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Global Carbon Budget 2024

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1. Abstract

Accurate assessment of anthropogenic carbon dioxide (CO_2) emissions and their redistribution among the atmosphere, ocean, and terrestrial biosphere in a changing climate is critical to better understand the global carbon cycle, support the development of climate policies, and project future climate change. Here we describe and synthesise datasets and methodologies to quantify the five major components of the global carbon budget and their uncertainties. Fossil CO_2 emissions (E_{FOS}) are based on energy statistics and cement production data, while emissions from land-use change (E_{LUC}) are based on land-use and land-use change data and bookkeeping models. Atmospheric CO_2 concentration is measured directly, and its growth rate (G_{ATM}) is computed from the annual changes in concentration. The ocean CO_2 sink (S_{OCEAN}) is estimated with global ocean biogeochemistry models and observation-based *f*CO_2-products. The terrestrial CO_2 sink (S_{LAND}) is estimated with dynamic global vegetation models. Additional lines of evidence on land and ocean sinks are provided by atmospheric inversions, atmospheric oxygen measurements and Earth System Models. The sum of all sources and sinks results in the carbon budget imbalance (B_{IM}), a measure of imperfect data and incomplete understanding of the contemporary carbon cycle. All uncertainties are reported as $\pm 1\sigma$.

For the year 2023, E_{FOS} increased by 1.3% relative to 2022, with fossil emissions at 10.1 ± 0.5 GtC yr^{-1} (10.3 ± 0.5 GtC yr^{-1} when the cement carbonation sink is not included), E_{LUC} was 1.0 ± 0.7 GtC yr^{-1}, for a total anthropogenic CO_2 emission (including the cement carbonation sink) of 11.1 ± 0.9 GtC yr^{-1} (40.6 ± 3.2 GtCO_2 yr^{-1}). Also, for 2023, G_{ATM} was 5.9 ± 0.2 GtC yr^{-1} (2.79 ± 0.1 ppm yr^{-1}), S_{OCEAN} was 2.9 ± 0.4 GtC yr^{-1} and S_{LAND} was 2.3 ± 1.0 GtC yr^{-1}, with a near zero B_{IM} (-0.02 GtC yr^{-1}). The global atmospheric CO_2 concentration averaged over 2023 reached 419.3 ± 0.1 ppm. Preliminary data for 2024, suggest an increase in E_{FOS} relative to 2023 of +0.8% (-0.3% to 1.9%) globally, and atmospheric CO_2 concentration increased by 2.8 ppm reaching 422.5 ppm, 52% above pre-industrial level (around 278 ppm in 1750). Overall, the mean and trend in the components of the global carbon budget are consistently estimated over the period 1959-2023, with a near-zero overall budget imbalance, although discrepancies of up to around 1 GtC yr^{-1} persist for the representation of annual to semi-decadal variability in CO_2 fluxes. Comparison of estimates from multiple approaches and observations shows: (1) a persistent large uncertainty in the estimate of land-use changes emissions, (2) a low agreement between the different methods on the magnitude of the land CO_2 flux in the northern extra-tropics, and (3) a discrepancy between the different methods on the mean ocean sink.

This living data update documents changes in methods and datasets applied to this most-recent global carbon budget as well as evolving community understanding of the global carbon cycle. The data presented in this work are available at https://doi.org/10.18160/GCP-2024 (Friedlingstein et al., 2024).

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2. Executive Summary

Global fossil CO_2 emissions (including cement carbonation) are expected to further increase in 2024 by 0.8%. The 2023 emission increase was 0.14 GtC yr^{-1} (0.5 $GtCO_2$ yr^{-1}) relative to 2022, bringing 2023 fossil CO_2 emissions to 10.1 ± 0.5 GtC yr^{-1} (36.8 ± 1.8 $GtCO_2$ yr^{-1}). Preliminary estimates based on data available suggest fossil CO_2 emissions to increase further in 2024, by 0.8% relative to 2023 (-0.3% to 1.9%), bringing emissions to 10.2 GtC yr^{-1} (37.4 $GtCO_2$ yr^{-1}).[1]

Emissions from coal, oil and gas in 2024 are expected to be slightly above their 2023 levels (by 0.2%, 0.9% and 2.4% respectively). Regionally, fossil emissions in 2024 are expected to decrease by 3.8% in the European Union reaching 0.7 GtC (2.4 $GtCO_2$), and by 0.6% in the United States (1.3 GtC, 4.9 $GtCO_2$). Emissions in China are expected to increase in 2024 by 0.2%, reaching 3.3 GtC, (12.0 $GtCO_2$). Fossil emissions are also expected to increase by 4.6% in India (0.9 GtC, 3.2 $GtCO_2$) and by 1.1% for the rest of the world (4.0 GtC, 14.5 $GtCO_2$) in 2024. Emissions from international aviation and shipping (IAS) are also expected to increase by 7.8% (0.3 GtC, 1.2 $GtCO_2$) in 2024.

Fossil CO_2 emissions decreased significantly in 22 countries with significantly growing economies during the decade 2014-2023. Altogether, these 22 countries contribute about 2.2 GtC yr^{-1} (8.1 $GtCO_2$) fossil fuel CO_2 emissions over the last decade, representing about 23% of world CO_2 fossil emissions.

Global CO_2 emissions from land-use, land-use change, and forestry (LULUCF) averaged 1.1 ± 0.7 GtC yr^{-1} (4.1 ± 2.6 $GtCO_2$ yr^{-1}) for the 2014-2023 period with a similar preliminary projection for 2024 of 1.1 ± 0.7 GtC yr^{-1} (4.2 ± 2.6 $GtCO_2$ yr^{-1}). Since the late-1990s, emissions from LULUCF show a statistically significant decrease at a rate of around 0.2 GtC per decade. Emissions from deforestation, the main driver of global gross sources, remain high at around 1.7 GtC yr^{-1} over the 2014-2023 period, highlighting the strong potential of halting deforestation for emissions reductions. Sequestration of 1.2 GtC yr^{-1} through re-/afforestation and forestry offsets two third of the deforestation emissions. Further, smaller emissions are due to other land-use transitions and peat drainage and peat fire. The highest emitters during 2014-2023 in descending order were Brazil, Indonesia, and the Democratic Republic of the Congo, with these 3 countries contributing more than half of global land-use CO_2 emissions.

Total anthropogenic emissions (fossil and LULUCF, including the carbonation sink) were 11.1 GtC yr^{-1} (40.6 $GtCO_2$ yr-1) in 2023, with a marginally higher preliminary estimate of 11.3 GtC yr^{-1} (41.6 $GtCO_2$ yr^{-1}) for 2024. Total anthropogenic emissions have been stable over the last decade (zero growth rate over the 2014-2023 period), much slower than over the previous decade (2004-2013) with an average growth rate of 2.0% yr^{-1}.

The remaining carbon budget for a 50% likelihood to limit global warming to 1.5°C, 1.7°C and 2°C above the 1850-1900 level has respectively been reduced to 65 GtC (235 $GtCO_2$), 160 GtC (585 $GtCO_2$) and 305

[1] All 2024 growth rates use a leap year adjustment that corrects for the extra day in 2024.

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GtC (1110 GtCO_2) from the beginning of 2025, equivalent to around 6, 14 and 27 years, assuming 2024 emissions levels.

The concentration of CO_2 in the atmosphere is set to reach 422.5 ppm in 2024, 52% above pre-industrial levels. The atmospheric CO_2 growth was 5.2 ± 0.02 GtC yr^{-1} (2.5 ppm) during the decade 2014-2023 (48% of total CO_2 emissions) with a preliminary 2024 growth rate estimate of around 5.9 GtC (2.8 ppm).

The ocean CO_2 sink has been stagnant since 2016 after rapid growth during 2002-2016, largely in response to large inter-annual climate variability. The ocean CO_2 sink was 2.9 ± 0.4 GtC yr^{-1} during the decade 2014-2023 (26% of total CO_2 emissions). A slightly higher value of 3.0 GtC yr^{-1} is preliminarily estimated for 2024, which marks an increase in the sink since 2023 due to the prevailing El Niño and neutral conditions in 2024.

The land CO_2 sink continued to increase during the 2014-2023 period primarily in response to increased atmospheric CO_2, albeit with large interannual variability. The land CO_2 sink was 3.2 ± 0.9 GtC yr^{-1} during the 2014-2023 decade (30% of total CO_2 emissions). The land sink in 2023 was 2.3 ± 1 GtC yr^{-1}, 1.6 GtC lower than in 2022, and the lowest estimate since 2015. This reduced sink is primarily driven by a response of tropical land ecosystems to the onset of the 2023-2024 El Niño event, combined with large wildfires in Canada in 2023. The preliminary 2024 estimate is around 3.2 GtC yr^{-1}, similar to the decadal average, consistent with a land sink emerging from the El Niño state.

So far in 2024, global fire CO_2 emissions have been 11-32% higher than the 2014-2023 average due to high fire activity in both North and South America, reaching 1.6-2.2 GtC during January-September. In Canada, emissions through September were 0.2-0.3 GtC yr^{-1}, down from 0.5-0.8 GtC yr^{-1} in 2023 but still more than twice the 2014-2023 average. In Brazil, fires through September emitted 0.2-0.3 GtC yr^{-1}, 91-118% above the 2014-2023 average due to intense drought. These fire emissions estimates should not be directly compared with the land use emissions or the land sink, because they represent a gross carbon flux to the atmosphere and do not account for post-fire recovery or distinguish between natural, climate-driven, and land-use-related fires.

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1 Introduction

The concentration of carbon dioxide (CO_2) in the atmosphere has increased from approximately 278 parts per million (ppm) in 1750 (Gulev et al., 2021), the beginning of the Industrial Era, to 419.3 ± 0.1 ppm in 2023 (Lan et al., 2024; Figure 1). The atmospheric CO_2 increase above pre-industrial levels was, initially, primarily caused by the release of carbon to the atmosphere from deforestation and other land-use change activities (Canadell et al., 2021). While emissions from fossil fuels started before the Industrial Era, they became the dominant source of anthropogenic emissions to the atmosphere from around 1950 and their relative share has continued to increase until present. Anthropogenic emissions occur on top of an active natural carbon cycle that circulates carbon between the reservoirs of the atmosphere, ocean, and terrestrial biosphere on time scales from sub-daily to millennial, while exchanges with geologic reservoirs occur on longer timescales (Archer et al., 2009).

The global carbon budget (GCB) presented here refers to the mean, variations, and trends in the perturbation of CO_2 in the environment, referenced to the beginning of the Industrial Era (defined here as 1750). This paper describes the components of the global carbon cycle over the historical period with a stronger focus on the recent period (since 1958, onset of robust atmospheric CO_2 measurements), the last decade (2014-2023), the last year (2023) and the current year (2024). Finally, it provides cumulative emissions from fossil fuels and land-use change since the year 1750, and since the year 1850 (the reference year for historical simulations in IPCC AR6) (Eyring et al., 2016).

We quantify the input of CO_2 to the atmosphere by emissions from human activities, the growth rate of atmospheric CO_2 concentration, and the resulting changes in the storage of carbon in the land and ocean reservoirs in response to increasing atmospheric CO_2 levels, climate change and variability, and other anthropogenic and natural changes (Figure 2). An understanding of this perturbation budget over time and the underlying variability and trends of the natural carbon cycle is necessary to understand the response of natural sinks to changes in climate, CO_2 and land-use change drivers, and to quantify emissions compatible with a given climate stabilisation target.

The components of the CO_2 budget that are reported annually in this paper include separate and independent estimates for the CO_2 emissions from (1) fossil fuel combustion and oxidation from all energy and industrial processes; also including cement production and carbonation (E_{FOS}; GtC yr^{-1}) and (2) the emissions resulting from deliberate human activities on land, including those leading to land-use change (E_{LUC}; GtC yr^{-1}); and their partitioning among (3) the growth rate of atmospheric CO_2 concentration (G_{ATM}; GtC yr^{-1}), and the uptake of CO_2 (the 'CO_2 sinks') in (4) the ocean (S_{OCEAN}; GtC yr^{-1}) and (5) on land (S_{LAND}; GtC yr^{-1}). The CO_2 sinks as defined here conceptually include the response of the land (including inland waters and estuaries) and ocean (including coastal and marginal seas) to elevated CO_2 and changes in climate and other environmental conditions, although in practice not all processes are fully accounted for (see Section 2.10). Global emissions and their partitioning among the atmosphere, ocean and land are in balance in the real world. Due to the combination of imperfect spatial and/or temporal data coverage, errors in each estimate, and smaller terms not

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Deleted: (the pre-industrial period), included in our budget estimate (discussed in Section 2.10), the independent estimates (1) to (5) above do not necessarily add up to zero. We hence estimate a budget imbalance (B_{IM}), which is a measure of the mismatch between the estimated emissions and the estimated changes in the atmosphere, land and ocean, as follows:

$$B_{IM} = E_{FOS} + E_{LUC} - (G_{ATM} + S_{OCEAN} + S_{LAND}) \quad (1)$$

G_{ATM} is usually reported in ppm yr^{-1}, which we convert to units of carbon mass per year, GtC yr^{-1}, using 1 ppm = 2.124 GtC (Ballantyne et al., 2012; Table 1). Units of gigatonnes of CO_2 (or billion tonnes of CO_2) used in policy are equal to 3.664 multiplied by the value in units of GtC.

We also assess a set of additional lines of evidence derived from global atmospheric inversion system results (Section 2.7), observed changes in oxygen concentration (Section 2.8) and Earth System Models (ESMs) simulations (Section 2.9), all of these methods closing the global carbon balance (zero B_{IM}).

We further quantify E_{FOS} and E_{LUC} by country, including both territorial and consumption-based accounting for E_{FOS} (see Section 2), and discuss missing terms from sources other than the combustion of fossil fuels (see Section 2.10, Supplement S1 and S2). We also assess carbon dioxide removal (CDR) (see Sect. 2.2 and 2.3). Land-based CDR is significant, but already accounted for in E_{LUC} in equation (1) (Sect 3.2.2). Other CDR methods, not based on vegetation, are currently several orders of magnitude smaller than the other components of the budget (Sect. 3.3), hence these are not included in equation (1), or in the global carbon budget tables or figures (with the exception of Figure 2 where CDR is shown primarily for illustrative purpose).

The global CO_2 budget has been assessed by the Intergovernmental Panel on Climate Change (IPCC) in all assessment reports (Prentice et al., 2001; Schimel et al., 1995; Watson et al., 1990; Denman et al., 2007; Ciais et al., 2013; Canadell et al., 2021), and by others (e.g. Ballantyne et al., 2012). The Global Carbon Project (GCP, www.globalcarbonproject.org, last access: 28 October 2024) has coordinated this cooperative community effort for the annual publication of global carbon budgets for the year 2005 (Raupach et al., 2007; including fossil emissions only), year 2006 (Canadell et al., 2007), year 2007 (GCP, 2008), year 2008 (Le Quéré et al., 2009), year 2009 (Friedlingstein et al., 2010), year 2010 (Peters et al., 2012a), year 2012 (Le Quéré et al., 2013; Peters et al., 2013), year 2013 (Le Quéré et al., 2014), year 2014 (Le Quéré et al., 2015a; Friedlingstein et al., 2014), year 2015 (Jackson et al., 2016; Le Quéré et al., 2015b), year 2016 (Le Quéré et al., 2016), year 2017 (Le Quéré et al., 2018a; Peters et al., 2017a), year 2018 (Le Quéré et al., 2018b; Jackson et al., 2018), year 2019 (Friedlingstein et al., 2019; Jackson et al., 2019; Peters et al., 2020), year 2020 (Friedlingstein et al., 2020; Le Quéré et al., 2021), year 2021 (Friedlingstein et al., 2022a; Jackson et al., 2022), year 2022 (Friedlingstein et al., 2022b), and most recently the year 2023 (Friedlingstein et al., 2023). Each of these papers updated previous estimates with the latest available information for the entire time series.

We adopt a range of ±1 standard deviation (σ) to report the uncertainties in our global estimates, representing a likelihood of 68% that the true value will be within the provided range if the errors have a gaussian distribution, and no bias is assumed. This choice reflects the difficulty of characterising the uncertainty in the CO_2 fluxes between the atmosphere and the ocean and land reservoirs individually, particularly on an annual basis, as well

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as the difficulty of updating the CO_2 emissions from land-use change. A likelihood of 68% provides an indication of our current capability to quantify each term and its uncertainty given the available information. The uncertainties reported here combine statistical analysis of the underlying data, assessments of uncertainties in the generation of the datasets, and expert judgement of the likelihood of results lying outside this range. The limitations of current information are discussed in the paper and have been examined in detail elsewhere (Ballantyne et al., 2015; Zscheischler et al., 2017). We also use a qualitative assessment of confidence level to characterise the annual estimates from each term based on the type, amount, quality, and consistency of the different lines of evidence as defined by the IPCC (Stocker et al., 2013).

This paper provides a detailed description of the datasets and methodology used to compute the global carbon budget estimates for the industrial period, from 1750 to 2024, and in more detail for the period since 1959. This paper is updated every year using the format of 'living data' to keep a record of budget versions and the changes in new data, revision of data, and changes in methodology that lead to changes in estimates of the carbon budget. Additional materials associated with the release of each new version will be posted at the Global Carbon Project (GCP) website (http://www.globalcarbonproject.org/carbonbudget, last access: 28 October 2024), with fossil fuel emissions also available through the Global Carbon Atlas (http://www.globalcarbonatlas.org, last access: 28 October 2024). All underlying data used to produce the budget can also be found at https://globalcarbonbudget.org/ (last access: 28 October 2024). With this approach, we aim to provide the highest transparency and traceability in the reporting of CO_2, the key driver of climate change.

2 Methods

Multiple organisations and research groups around the world generated the original measurements and data used to complete the global carbon budget. The effort presented here is thus mainly one of synthesis, where results from individual groups are collated, analysed, and evaluated for consistency. We facilitate access to original data with the understanding that primary datasets will be referenced in future work (see Table 2 for how to cite the datasets, and Section on data availability). Descriptions of the measurements, models, and methodologies follow below, with more detailed descriptions of each component provided as Supplementary Information (S1 to S5).

This is the 19th version of the global carbon budget and the 13th revised version in the format of a living data update in Earth System Science Data. It builds on the latest published global carbon budget of Friedlingstein et al. (2023). The main changes this year are: the inclusion of (1) data to year 2023 and a projection for the global carbon budget for year 2024; and (2) an estimate of the 2024 projection of fossil emissions from Carbon Monitor. Other methodological differences between recent annual carbon budgets (2020 to 2024) are summarised in Table 3 and previous changes since 2006 are provided in Table S9.

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2.1 Fossil CO_2 emissions (E_{FOS})

2.1.1 Historical period 1850-2023

The estimates of global and national fossil CO_2 emissions (E_{FOS}) include the oxidation of fossil fuels through both combustion (e.g., transport, heating) and chemical oxidation (e.g. carbon anode decomposition in aluminium refining) activities, and the decomposition of carbonates in industrial processes (e.g. the production of cement). We also include CO_2 uptake from the cement carbonation process. Several emissions sources are not estimated or not fully covered: coverage of emissions from lime production are not global, and decomposition of carbonates in glass and ceramic production are included only for the "Annex 1" countries of the United Nations Framework Convention on Climate Change (UNFCCC) for lack of activity data. These omissions are considered to be minor. Short-cycle carbon emissions - for example from combustion of biomass - are not included here but are accounted for in the CO_2 emissions from land use (see Section 2.2).

Our estimates of fossil CO_2 emissions rely on data collection by many other parties. Our goal is to produce the best estimate of this flux, and we therefore use a prioritisation framework to combine data from different sources that have used different methods, while being careful to avoid double counting and undercounting of emissions sources. The CDIAC-FF emissions dataset, derived largely from UN energy data, forms the foundation, and we extend emissions to 2023 using energy growth rates reported by the Energy Institute (a dataset formerly produced by BP). We then proceed to replace estimates using data from what we consider to be superior sources, for example Annex 1 countries' official submissions to the UNFCCC. All data points are potentially subject to revision, not just the latest year. For full details see Andrew and Peters (2024).

Other estimates of global fossil CO_2 emissions exist, and these are compared by Andrew (2020a). The most common reason for differences in estimates of global fossil CO_2 emissions is a difference in which emissions sources are included in the datasets. Datasets such as those published by the Energy Institute, the US Energy Information Administration, and the International Energy Agency's 'CO_2 emissions from fuel combustion' are all generally limited to emissions from combustion of fossil fuels. In contrast, datasets such as PRIMAP-hist, CEDS, EDGAR, and GCP's dataset aim to include all sources of fossil CO_2 emissions. See Andrew (2020a) for detailed comparisons and discussion.

Cement absorbs CO_2 from the atmosphere over its lifetime, a process known as 'cement carbonation'. We estimate this CO_2 sink, from 1931 onwards, as the average of two studies in the literature (Cao et al., 2020; Guo et al., 2021). Both studies use the same model, developed by Xi et al. (2016), with different parameterisations and input data, with the estimate of Guo and colleagues being a revision of Xi et al. (2016). The trends of the two studies are very similar. Since carbonation is a function of both current and previous cement production, we extend these estimates to 2023 by using the growth rate derived from the smoothed cement emissions (10-year smoothing) fitted to the carbonation data. In the present budget, we always include the cement carbonation carbon sink in the fossil CO_2 emission component (E_{FOS}).

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We use the Kaya Identity for a simple decomposition of CO_2 emissions into the key drivers (Raupach et al., 2007). While there are variations (Peters et al., 2017a), we focus here on a decomposition of CO_2 emissions into population, GDP per person, energy use per GDP, and CO_2 emissions per energy. Multiplying these individual components together returns the CO_2 emissions. Using the decomposition, it is possible to attribute the change in CO_2 emissions to the change in each of the drivers. This method gives a first-order understanding of what causes CO_2 emissions to change each year.

2.1.2 2024 projection

We provide a projection of global fossil CO_2 emissions in 2024 by combining separate projections for China, USA, EU, India, and for all other countries combined. The methods are different for each of these. For China we combine monthly fossil fuel production data from the National Bureau of Statistics and trade data from the Customs Administration, giving us partial data for the growth rates to date of natural gas, petroleum, and cement, and of the apparent consumption itself for raw coal. We then use a regression model to project full-year emissions based on historical observations. For the USA our projection is taken directly from the Energy Information Administration's (EIA) Short-Term Energy Outlook (EIA, 2024), combined with the year-to-date growth rate of cement clinker production. For the EU we use monthly energy data from Eurostat to derive estimates of monthly CO_2 emissions through July, with coal emissions extended through September using a statistical relationship with reported electricity generation from coal and other factors. For natural gas we use Holt-Winters to project the last four months of the year. EU emissions from oil are derived using the EIA's projection of oil consumption for Europe. EU cement emissions are based on available year-to-date data from three of the largest producers, Germany, Poland, and Spain. India's projected emissions are derived from estimates through August (July for coal) using the methods of Andrew (2020b) and extrapolated assuming seasonal patterns from before 2019. Emissions from international transportation (bunkers) are estimated separately for aviation and shipping. Changes in aviation emissions are derived primarily from OECD monthly estimates, extrapolated using the growth rates of global flight miles from Airportia, and then the final months are projected assuming normal patterns from previous years. Changes in shipping emissions are derived from OECD monthly estimates for global shipping. Emissions for the rest of the world are derived for coal and cement using projected growth in economic production from the IMF (2023) combined with extrapolated changes in emissions intensity of economic production; for oil using a global constraint from EIA; and for natural gas using a global constraint from IEA. More details on the E_{FOS} methodology and its 2024 projection can be found in Supplement S.1.

For the first time this year, we cross check our 2024 projection with a 2024 projection from Carbon Monitor. Carbon Monitor is an open access dataset (https://carbonmonitor.org/) of daily emissions constructed using hourly to daily proxy data (e.g., electricity consumption, travel patterns, etc) instead of energy use data. Available Carbon Monitor estimated emissions from January to August are combined to a new projection for September to December to give a full year 2024 estimate. The September to December projections are estimated by leveraging seasonal patterns from 2019-2023 daily CO_2 emission data from Carbon Monitor. A regression model is applied separately for individual countries to obtain their respective 4-month forecast. First, the

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seasonality component for each month is assessed based on daily average emissions from 2019 to 2023, excluding 2020 due to the COVID-19 pandemic. Then, a linear regression model is constructed using the calculated seasonal components and the daily average emissions for the months from January to August 2024. The resulting model is used to project carbon emissions for the remaining months of 2024. The uncertainty range is calculated by using historical monthly variance of seasonal components.

2.2 CO_2 emissions from land-use, land-use change and forestry (E_{LUC})

2.2.1 Historical period 1850-2023

The net CO_2 flux from land-use, land-use change and forestry (E_{LUC}, called land-use change emissions in the rest of the text) includes CO_2 fluxes from deforestation, afforestation, logging and forest degradation (including harvest activity), shifting cultivation (cycle of cutting forest for agriculture, then abandoning), regrowth of forests (following wood harvest or agriculture abandonment), peat burning, and peat drainage.

Four bookkeeping approaches (updated estimates each of BLUE (Hansis et al., 2015), OSCAR (Gasser et al., 2020), and H&C2023 (Houghton and Castanho, 2023), and new estimates of LUCE (Qin et al. 2024) were used to quantify gross emissions and gross removals and the resulting net E_{LUC}. Emissions from peat burning and peat drainage are added from external datasets, peat drainage being averaged from three spatially explicit independent datasets (see Supplement S.2.1). Uncertainty estimates were derived from the Dynamic Global Vegetation Models (DGVMs) ensemble for the time period prior to 1960, and using for the recent decades an uncertainty range of ±0.7 GtC yr^{-1}, which is a semi-quantitative measure for annual and decadal emissions and reflects our best value judgement that there is at least 68% chance (±1σ) that the true land-use change emission lies within the given range, for the range of processes considered here.

The GCB E_{LUC} estimates follow the CO_2 flux definition of global carbon cycle models and differ from IPCC definitions adopted in National GHG Inventories (NGHGI) for reporting under the UNFCCC. The latter typically include terrestrial fluxes occurring on all land that countries define as managed, following the IPCC managed land proxy approach (Grassi et al., 2018). This partly includes fluxes due to environmental change (e.g. atmospheric CO_2 increase), which are part of S_{LAND} in our definition. As a result, global emission estimates are smaller for NGHGI than for the global carbon budget definition (Grassi et al., 2023). The same is the case for the Food Agriculture Organization (FAO) estimates of carbon fluxes on forest land, which include both anthropogenic and natural fluxes on managed land (Tubiello et al., 2021). We translate the GCB and NGHGI definitions to each other, to provide a comparison of the anthropogenic carbon budget as reported in GCB to the official country reporting to the UNFCCC convention. We further compare these estimates with the net atmosphere-to-land flux from atmospheric inversion systems (see Section 2.7), averaged over managed land only.

E_{LUC} contains a range of fluxes that are related to Carbon Dioxide Removal (CDR). CDR is defined as the set of anthropogenic activities that remove CO_2 from the atmosphere, additional to the Earth's natural processes, and store it in durable form, such as in forest biomass and soils, long-lived products, or in geological or ocean

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reservoirs. Here, we quantify vegetation-based CDR that is implicitly or explicitly captured by land-use fluxes (CDR not based on vegetation is discussed in Section 2.3; IPCC, 2023). We quantify re/afforestation from the four bookkeeping estimates by separating forest regrowth in shifting cultivation cycles from permanent increases in forest cover (see Supplement S.2.1). The latter count as CDR, but it should be noted that the permanence of the storage under climate risks such as fire is increasingly questioned. Other CDR activities contained in E_{LUC} include the transfer of carbon to harvested wood products (HWP), bioenergy with carbon capture and storage (BECCS); and biochar production. Note that the different bookkeeping models represent HWP with varying details concerning product usage and their lifetimes. Bookkeeping and TRENDY models currently only represent BECCS and biochar with regard to the CO_2 removal through photosynthesis, but do not account for the durable storage. HWP, BECCS, and biochar are typically counted as CDR when the transfer to the durable storage site occurs and not when the CO_2 is removed from the atmosphere, which complicates a direct comparison to the GCB approach to quantify annual fluxes to and from the atmosphere. Estimates for CDR through HWP, BECCS, and biochar are thus not indicated in this budget, but can be found elsewhere (see Section 3.2.2).

2.2.2 2024 Projection

We project the 2024 land-use emissions for BLUE, H&C2023, OSCAR, and LUCE based on their E_{LUC} estimates for 2023 and adding the change in carbon emissions from peat fires and tropical deforestation and degradation fires (2024 emissions relative to 2023 emissions) estimated using active fire data (MCD14ML; Giglio et al., 2016). Peat drainage is assumed to be unaltered as it has low interannual variability. More details on the E_{LUC} methodology can be found in Supplement S.2.

2.3 Carbon Dioxide Removal (CDR) not based on vegetation

While some CDR involves CO_2 fluxes via land-use and is included in E_{LUC}, (such as afforestation, biochar, HWP, and BECCS) other CDR occurs through fluxes of CO_2 directly from the air to the geosphere. The majority of this derives from enhanced weathering through the application of crushed rock to soils, with a smaller contribution from Direct Air Carbon Capture and Storage (DACCS). We use data from the State of CDR Report (Smith et al., 2024), which compiles and harmonises reported removal rates from a combination of existing databases, surveys and novel research. Currently there are no internationally agreed methods for reporting these types of CDR, meaning estimates are based on self-disclosure by projects following their own protocols. As such, the fractional uncertainty on these numbers should be viewed as substantial, and they are liable to change in future years as protocols are harmonised and improved.

2.4 Growth rate in atmospheric CO_2 concentration (G_{ATM})

2.4.1 Historical period 1850-2023

The rate of growth of the atmospheric CO_2 concentration is provided for years 1959-2023 by the US National Oceanic and Atmospheric Administration Global Monitoring Laboratory (NOAA/GML; Lan et al., 2024),

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Deleted: CDR not based on terrestrial vegetation currently relies on enhanced rock weathering and Direct Air Carbon Capture and Storage (DACCS) projects. The majority of this (58%) derives from a single project: Climeworks' Orca DACCS plant based in Hellisheidi, Iceland. The remainder is generated by 13 small-scale projects including, for example, 500 tons of carbon dioxide sequestered through the spreading of crushed olivine on agricultural areas by Eion Carbon. We use data from the State of CDR Report (Smith et al., 2023), which quantifies all currently deployed CDR methods, including the land-use related activities already covered by Section 2.2. The State of CDR Report (Smith et al., 2023) combines estimates of carbon storage in managed land derived from NGHGI data with project-by-project storage rates obtained through 20 extant CDR databases and registries (status as of mid-year 2022) by Powis et al. (2023). They assessed the data quality on existing CDR projects to be poor, suffering from fragmentation, different reporting standards, limited geographical coverage, and inclusion of a number of pilot plants with uncertain lifespans. As a consequence, these numbers could change substantially from year-to-year in the near-term. ¶
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which includes recent revisions to the calibration scale of atmospheric CO_2 measurements (WMO-CO2-X2019; Hall et al., 2021). For the 1959-1979 period, the global growth rate is based on measurements of atmospheric CO_2 concentration averaged from the Mauna Loa and South Pole stations, as observed by the CO_2 Program at Scripps Institution of Oceanography (Keeling et al., 1976). For the 1980-2021 time period, the global growth rate is based on the average of multiple stations selected from the marine boundary layer sites with well-mixed background air (Ballantyne et al., 2012), after fitting a smooth curve through the data for each station as a function of time, and averaging by latitude band (Masarie and Tans, 1995). The annual growth rate is estimated by Lan et al. (2024) from atmospheric CO_2 concentration by taking the average of the most recent December-January months corrected for the average seasonal cycle and subtracting this same average one year earlier. The growth rate in units of ppm yr^{-1} is converted to units of GtC yr^{-1} by multiplying by a factor of 2.124 GtC per ppm, assuming instantaneous mixing of CO_2 throughout the atmosphere (Ballantyne et al., 2012; Table 1).

The uncertainty around the atmospheric growth rate is due to four main factors. First, the long-term reproducibility of reference gas standards (around 0.03 ppm for 1σ from the 1980s; Lan et al., 2024). Second, small unexplained systematic analytical errors that may have a duration of several months to two years come and go. They have been simulated by randomising both the duration and the magnitude (determined from the existing evidence) in a Monte Carlo procedure. Third, the network composition of the marine boundary layer with some sites coming or going, gaps in the time series at each site, etc (Lan et al., 2024). The latter uncertainty was estimated by NOAA/GML with a Monte Carlo method by constructing 100 "alternative" networks (Masarie and Tans, 1995; NOAA/GML, 2019). The second and third uncertainties, summed in quadrature, add up to 0.085 ppm on average (Lan et al., 2024). Fourth, the uncertainty associated with using the average CO_2 concentration from a surface network to approximate the true atmospheric average CO_2 concentration (mass-weighted, in 3 dimensions) as needed to assess the total atmospheric CO_2 burden. In reality, CO_2 variations measured at the stations will not exactly track changes in total atmospheric burden, with offsets in magnitude and phasing due to vertical and horizontal mixing. This effect must be very small on decadal and longer time scales, when the atmosphere can be considered well mixed. The CO2 increase in the stratosphere lags the increase (meaning lower concentrations) that we observe in the marine boundary layer, while the continental boundary layer (where most of the emissions take place) leads the marine boundary layer with higher concentrations. These effects nearly cancel each other. In addition, the growth rate is nearly the same everywhere (Ballantyne et al., 2012). We therefore maintain an uncertainty around the annual growth rate based on the multiple stations dataset ranges between 0.11 and 0.72 GtC yr^{-1}, with a mean of 0.61 GtC yr^{-1} for 1959-1979 and 0.17 GtC yr^{-1} for 1980-2023, when a larger set of stations were available as provided by Lan et al. (2024). We estimate the uncertainty of the decadal averaged growth rate after 1980 at 0.02 GtC yr^{-1} based on the calibration and the annual growth rate uncertainty but stretched over a 10-year interval. For years prior to 1980, we estimate the decadal averaged uncertainty to be 0.07 GtC yr^{-1} based on a factor proportional to the annual uncertainty prior and after 1980 (0.02 * [0.61/0.17] GtC yr^{-1}).

We assign a high confidence to the annual estimates of G_{ATM} because they are based on direct measurements from multiple and consistent instruments and stations distributed around the world (Ballantyne et al., 2012; Hall et al., 2021).

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To estimate the total carbon accumulated in the atmosphere since 1750 or 1850, we use an atmospheric CO_2 concentration of 278.3 ± 3 ppm or 285.1 ± 3 ppm, respectively (Gulev et al., 2021). For the construction of the cumulative budget shown in Figure 3, we use the fitted estimates of CO_2 concentration from Joos and Spahni (2008) to estimate the annual atmospheric growth rate using the conversion factors shown in Table 1. The uncertainty of ±3 ppm (converted to $\pm 1\sigma$) is taken directly from the IPCC's AR5 assessment (Ciais et al., 2013). Typical uncertainties in the growth rate in atmospheric CO_2 concentration from ice core data are equivalent to ±0.1-0.15 GtC yr^{-1} as evaluated from the Law Dome data (Etheridge et al., 1996) for individual 20-year intervals over the period from 1850 to 1960 (Bruno and Joos, 1997).

2.4.2 2024 projection

We provide an assessment of G_{ATM} for 2024 as the average of two methods. The GCB regression method models monthly global-average atmospheric CO_2 concentrations and derives the increment and annual average from these. The model uses lagged observations of concentration (Lan et al., 2024): both a 12-month lag, and the lowest lag that will allow model prediction to produce an estimate for the following January, recalling that the G_{ATM} increment is derived from December/January pairs. The largest driver of interannual changes is the ENSO signal (Betts et al., 2016), so the monthly ENSO 3.4 index (Huang et al., 2023) is included in the model. Given the natural lag between sea-surface temperatures and effects on the biosphere, and in turn effects on globally mixed atmospheric CO_2 concentration, a lagged ENSO index is used, and we use both a 5-month and a 6-month lag. The combination of the two lagged ENSO values helps reduce possible effects of noise in a single month. To help characterise the seasonal variation, we add month as a categorical variable. Finally, we flag the period affected by the Pinatubo eruption (August 1991 - November 1993) as a categorical variable. Note that while emissions of CO_2 are the largest driver of the trend in atmospheric CO_2 concentration, our goal here is to predict divergence from that trend. Because changes in emissions from year to year are relatively minor in comparison to total emissions, this has little effect on the variation of concentration from the trend line. Even the relatively large drop in emissions in 2020 due to the COVID-19 pandemic does not cause any problems for the model.

We also use the multi-model mean and uncertainty of the 2024 G_{ATM} estimated by the ESMs prediction system (see Section 2.9). We then take the average of the GCB regression and ESMs G_{ATM} estimates, with their respective uncertainty combined quadratically.

Similarly, the projection of the 2024 global average CO_2 concentration (in ppm), is calculated as the average of the estimates from the two methods. For the GCB regression method, it is the annual average of global concentration over the 12 months of 2024; for the ESMs, it is the observed global average CO_2 concentration for 2023 plus the annual increase in 2024 of the global average CO_2 concentration predicted by the ESMs multi-model mean.

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2.5 Ocean CO_2 sink

2.5.1 Historical period 1850-2023

The reported estimate of the global ocean anthropogenic CO_2 sink S_{OCEAN} is derived as the average of two estimates. The first estimate is derived as the mean over an ensemble of ten global ocean biogeochemistry models (GOBMs, Table 4 and Table S2). The second estimate is obtained as the mean over an ensemble of eight surface ocean fCO_2-observation-based data-products (Table 4 and Table S3). A ninth fCO_2-product (UExP-FFN-U) is shown but is not included in the ensemble average as it differs from the other products by adjusting the flux to a cool, salty ocean surface skin. In previous editions of the GCB, this product was following the Watson et al. (2020) method but has been updated following the method of Dong et al. (2022, see Supplement S.3.1 for a discussion). The GOBMs simulate both the natural and anthropogenic CO_2 cycles in the ocean. They constrain the anthropogenic air-sea CO_2 flux (the dominant component of S_{OCEAN}) by the transport of carbon into the ocean interior, which is also the controlling factor of present-day ocean carbon uptake in the real world. They cover the full globe and all seasons and were evaluated against surface ocean carbon observations, suggesting they are suitable to estimate the annual ocean carbon sink (Hauck et al., 2020). The fCO_2-products are tightly linked to observations of fCO_2 (fugacity of CO_2, which equals pCO_2 corrected for the non-ideal behaviour of the gas; Pfeil et al., 2013), which carry imprints of temporal and spatial variability, but are also sensitive to uncertainties in gas-exchange parameterizations and data-sparsity (Fay et al., 2021, Gloege et al., 2021, Hauck et al., 2023a). Their asset is the assessment of the mean spatial pattern of variability and its seasonality (Hauck et al., 2020, Gloege et al. 2021, Hauck et al., 2023a). To benchmark trends derived from the fCO_2-products, we additionally performed a model subsampling exercise following Hauck et al. (2023a, see section S3). In addition, two diagnostic ocean models are used to estimate S_{OCEAN} over the industrial era (1781-1958).

The global fCO_2-based flux estimates were adjusted to remove the pre-industrial ocean source of CO_2 to the atmosphere of 0.65 ± 0.3 GtC yr^{-1} from river input to the ocean (Regnier et al., 2022), to satisfy our definition of S_{OCEAN} (Hauck et al., 2020). The river flux adjustment was distributed over the latitudinal bands using the regional distribution of Lacroix et al. (2020; North: 0.14 GtC yr^{-1}, Tropics: 0.42 GtC yr^{-1}, South: 0.09 GtC yr^{-1}). Acknowledging that this distribution is based on only one model, the advantage is that a gridded field is available, and the river flux adjustment can be calculated for the three latitudinal bands and the RECCAP regions (REgional Carbon Cycle Assessment and Processes (RECCAP2; Ciais et al., 2020, Poulter et al., 2022, DeVries et al., 2023). This dataset suggests that more of the riverine outgassing is located in the tropics than in the Southern Ocean and is thus opposed to the previously used dataset of Aumont et al. (2001). Accordingly, the regional distribution is associated with a major uncertainty in addition to the large uncertainty around the global estimate (Crisp et al., 2022; Gruber et al., 2023). Anthropogenic perturbations of river carbon and nutrient transport to the ocean are not considered (see Section 2.10 and Supplement S.6.3).

We derive S_{OCEAN} from GOBMs by using a simulation (sim A) with historical forcing of climate and atmospheric CO_2 from GCB (Section 2.4), accounting for model biases and drift from a control simulation (sim B) with constant atmospheric CO_2 and normal year climate forcing. A third simulation (sim C) with historical

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atmospheric CO_2 increase and normal year climate forcing is used to attribute the ocean sink to CO_2 (sim C minus sim B) and climate (sim A minus sim C) effects. A fourth simulation (sim D; historical climate forcing and constant atmospheric CO_2) is used to compare the change in anthropogenic carbon inventory in the interior ocean (sim A minus sim D) to the observational estimate of Gruber et al. (2019) with the same flux components (steady state and non-steady state anthropogenic carbon flux). The fCO_2-products are adjusted with respect to their original publications to represent the full ice-free ocean area, including coastal zones and marginal seas, when the area coverage is below 99%. This is done by either area filling following Fay et al. (2021) or a simple scaling approach. GOBMs and fCO_2-products fall within the observational constraints over the 1990s (2.2 ± 0.7 GtC yr^{-1}, Ciais et al., 2013) before and after applying adjustments.

SOCEAN is calculated as the average of the GOBM ensemble mean and the fCO_2-product ensemble mean from 1990 onwards. Prior to 1990, it is calculated as the GOBM ensemble mean plus half of the offset between GOBMs and fCO_2-products ensemble means over 1990-2001.

We assign an uncertainty of ± 0.4 GtC yr^{-1} to the ocean sink based on a combination of random (ensemble standard deviation) and systematic uncertainties (GOBMs bias in anthropogenic carbon accumulation, previously reported uncertainties in fCO_2-products; see Supplement S.3.4). While this approach is consistent within the GCB, an independent uncertainty assessment of the fCO_2-products alone suggests a somewhat larger uncertainty of up to 0.7 GtC yr^{-1} (Ford et al. 2024, accepted). We assess a medium confidence level to the annual ocean CO_2 sink and its uncertainty because it is based on multiple lines of evidence, it is consistent with ocean interior carbon estimates (Gruber et al., 2019, see Section 3.6.5) and the interannual variability in the GOBMs and data-based estimates is largely consistent and can be explained by climate variability. We refrain from assigning a high confidence because of the deviation between the GOBM and fCO_2-product trends between around 2002 and 2020. More details on the SOCEAN methodology can be found in Supplement S.3.

2.5.2 2024 Projection

The ocean CO_2 sink forecast for the year 2024 is based on the annual historical time-series and our estimated 2024 atmospheric CO_2 concentration (Lan et al 2024), the historical and our estimated 2024 annual global fossil fuel emissions from this year's carbon budget, and the spring (March, April, May) Oceanic Niño Index (ONI) (NCEP, 2024). Using a non-linear regression approach, i.e., a feed-forward neural network, atmospheric CO_2, ONI, and the fossil fuel emissions are used as training data to best match the annual ocean CO_2 sink (i.e. combined SOCEAN estimate from GOBMs and data products) from 1959 through 2023 from this year's carbon budget. Using this relationship, the 2024 SOCEAN can then be estimated from the projected 2024 input data using the non-linear relationship established during the network training. To avoid overfitting, the neural network was trained with a variable number of hidden neurons (varying between 2-5) and 20% of the randomly selected training data were withheld for independent internal testing. Based on the best output performance (tested using the 20% withheld input data), the best performing number of neurons was selected. In a second step, we trained the network 10 times using the best number of neurons identified in step 1 and different sets of randomly selected training data. The mean of the 10 trainings is considered our best forecast, whereas the standard

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deviation of the 10 ensembles provides a first order estimate of the forecast uncertainty. This uncertainty is then combined with the S_{OCEAN} uncertainty (0.4 GtC yr^{-1}) to estimate the overall uncertainty of the 2024 projection. As an additional line of evidence, we also assess the 2024 atmosphere-ocean carbon flux from the ESM prediction system (see Section 2.9).

2.6 Land CO_2 sink

2.6.1 Historical Period 1850-2023

The terrestrial land sink (S_{LAND}) is thought to be due to the combined effects of rising atmospheric CO_2, increasing N inputs, and climate change, on plant growth and terrestrial carbon storage. S_{LAND} does not include land sinks directly resulting from land-use and land-use change (e.g., regrowth of vegetation) as these are part of the land-use flux (E_{LUC}), although system boundaries make it difficult to attribute exactly CO_2 fluxes on land between S_{LAND} and E_{LUC} (Erb et al., 2013).

S_{LAND} is estimated from the multi-model mean of 20 DGVMs (Table 4 and Table S1). DGVMs simulations include all climate variability and CO_2 effects over land. In addition to the carbon cycle represented in all DGVMs, 14 models also account for the nitrogen cycle and hence can include the effect of N inputs on S_{LAND}. The DGVMs estimate of S_{LAND} does not include the export of carbon to aquatic systems or its historical perturbation, which is discussed in Supplement S.6.3. DGVMs need to meet several criteria to be included in this assessment. In addition, we use the International Land Model Benchmarking system (ILAMB; Collier et al., 2018) for the DGVMs evaluation (see Supplement S.4.2), with an additional comparison of DGVMs with a data-informed, Bayesian model-data fusion framework (CARDAMOM) (Bloom and Williams, 2015; Bloom et al., 2016). The uncertainty on S_{LAND} is taken from the DGVMs standard deviation. More details on the S_{LAND} methodology can be found in Supplement S.4.

2.6.2 2024 Projection

Like for the ocean forecast, the land CO_2 sink (S_{LAND}) forecast for the year 2024 is based on the annual historical (Lan et al., 2024) and our estimated 2024 atmospheric CO_2 concentration, historical and our estimated 2024 annual global fossil fuel emissions from this year's carbon budget, and the summer (June, July, August) ONI (NCEP, 2024). All training data are again used to best match S_{LAND} from 1959 through 2023 from this year's carbon budget using a feed-forward neural network. To avoid overfitting, the neural network was trained with a variable number of hidden neurons (varying between 2-15), larger than for S_{OCEAN} prediction due to the stronger land carbon interannual variability. As done for S_{OCEAN}, a pre-training selects the optimal number of hidden neurons based on 20% withheld input data, and in a second step, an ensemble of 10 forecasts is produced to provide the mean forecast plus uncertainty. This uncertainty is then combined with the S_{LAND} uncertainty for 2023 (1.0 GtC yr^{-1}) to estimate the overall uncertainty of the 2024 projection.

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2.7 Atmospheric inversion estimate

The world-wide network of in-situ atmospheric measurements and satellite derived atmospheric CO_2 column (xCO_2) observations put a strong constraint on changes in the atmospheric abundance of CO_2. This is true globally (hence our large confidence in G_{ATM}), but also in regions with sufficient observational density found mostly in the extra-tropics. This allows atmospheric inversion methods to constrain the magnitude and location of the combined total surface CO_2 fluxes from all sources, including fossil and land-use change emissions and land and ocean CO_2 fluxes. The inversions assume E_{FOS} to be well known, and they solve for the spatial and temporal distribution of land and ocean fluxes from the residual gradients of CO_2 between stations that are not explained by fossil fuel emissions. By design, such systems thus close the carbon balance (B_{IM} = 0) and thus provide an additional perspective on the independent estimates of the ocean and land fluxes.

This year's release includes fourteen inversion systems that are described in Table S4. Each system is rooted in Bayesian inversion principles but uses different methodologies. These differences concern the selection of atmospheric CO_2 data or xCO_2, and the choice of a-priori fluxes to refine. They also differ in spatial and temporal resolution, assumed correlation structures, and mathematical approach of the models (see references in Table S4 for details). Importantly, the systems use a variety of transport models, which was demonstrated to be a driving factor behind differences in atmospheric inversion-based flux estimates, and specifically their distribution across latitudinal bands (Gaubert et al., 2019; Schuh et al., 2019). Eight inversion systems used surface observations from the global measurement network (Schuldt et al., 2023, 2024). Six inversion systems (CAMS-FT24r1, CMS-flux, GONGGA, COLA, GCASv2, NTFVAR) used satellite xCO_2 retrievals from GOSAT and/or OCO-2, scaled to the WMO 2019 calibration scale, of which three inversions this year (CMS-Flux, COLA, NTFVAR) used these xCO2 datasets in addition to the in-situ observational CO_2 mole fraction records.

The original products delivered by the inverse modellers were modified to facilitate the comparison to the other elements of the budget, specifically on two accounts: (1) global total fossil fuel emissions including cement carbonation CO_2 uptake, and (2) riverine CO_2 transport. We note that with these adjustments the inverse results no longer represent the net atmosphere-surface exchange over land/ocean areas as sensed by atmospheric observations. Instead, for land, they become the net uptake of CO_2 by vegetation and soils that is not exported by fluvial systems, similar to the DGVMs estimates. For oceans, they become the net uptake of anthropogenic CO_2, similar to the GOBMs estimates.

The inversion systems prescribe global fossil fuel emissions based on e.g. the GCP's Gridded Fossil Emissions Dataset versions 2024.0 (GCP-GridFED; Jones et al., 2024a), which are updates to GCP-GridFEDv2021 presented by Jones et al. (2021b). GCP-GridFEDv2024.0 scales gridded estimates of CO_2 emissions from EDGARv4.3.2 (Janssens-Maenhout et al., 2019) within national territories to match national emissions estimates provided by the GCB for the years 1959-2023, which were compiled following the methodology described in Section 2.1. Small differences between the systems due to for instance regridding to the transport model resolution, or use of different fossil fuel emissions than GCP-GridFEDv2024.0, are adjusted in the

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latitudinal partitioning we present, to ensure agreement with the estimate of E_{FOS} in this budget. We also note that the ocean fluxes used as prior by 8 out of 14 inversions are part of the suite of the ocean process model or fCO_2-products listed in Section 2.5. Although these fluxes are further adjusted by the atmospheric inversions (except for Jena CarboScope), it makes the inversion estimates of the ocean fluxes not completely independent of S_{OCEAN} assessed here.

To facilitate comparisons to the independent S_{OCEAN} and S_{LAND}, we used the same adjustments for transport and outgassing of carbon transported from land to ocean, as done for the observation-based estimates of S_{OCEAN} (see Supplement S.3).

The atmospheric inversions are evaluated using vertical profiles of atmospheric CO_2 concentrations (Figure S5). More than 30 aircraft programs over the globe, either regular programs or repeated surveys over at least 9 months (except for SH programs), have been used to assess system performance (with space-time observational coverage sparse in the SH and tropics, and denser in NH mid-latitudes; Table S8). The fourteen systems are compared to the independent aircraft CO_2 measurements between 2 and 7 km above sea level between 2001 and 2023. Results are shown in Figure S5 and discussed in Supplement S.5.2.

With a relatively small ensemble of systems that cover at least one full decade (N=10), and which moreover share some a-priori fluxes used with one another, or with the process-based models, it is difficult to justify using their mean and standard deviation as a metric for uncertainty across the ensemble. We therefore report their full range (min-max) without their mean. More details on the atmospheric inversion methodology can be found in Supplement S.5.

2.8 Atmospheric oxygen based estimate

Long-term atmospheric O_2 and CO_2 observations allow estimation of the global ocean and land carbon sinks, due to the coupling of O_2 and CO_2 with distinct exchange ratios for fossil fuel emissions and land uptake, and uncoupled O_2 and CO_2 ocean exchange (Keeling and Manning, 2014). The global ocean and net land carbon sinks were calculated following methods and constants used in Keeling and Manning (2014) but modified to also include the effective O_2 source from metal refining (Battle et al., 2023). For the exchange ratio of the net land sink at value of 1.05 is used, following Resplandy et al. (2019). For fossil fuels, the following values are used: gas: 1.95 (+/-) 0.04, liquid: 1.44, (+/-) 0.03, solid: 1.17 (+/-) 0.03, cement: 0 (+/-) 0, gas flaring: 1.98 (+/-) 0.07 (Keeling, 1988). Atmospheric O_2 is observed as $\delta(O_2/N_2)$ and combined with CO_2 mole fraction observations into Atmospheric Potential Oxygen (APO, Stephens et al., 1998). The APO observations from 1990 to 2024 were taken from a weighted average of flask records from three stations in the Scripps O_2 program network (Alert, Canada (ALT), La Jolla, California (LJO), and Cape Grim, Australia (CGO), weighted per Keeling and Manning (2014). Observed CO_2 was taken from the globally averaged marine surface annual mean growth rate from the NOAA/GML Global Greenhouse Gas Reference Network (Lan et al., 2024). The O_2 source from ocean warming is based on ocean heat content from updated data from NOAA/NCEI (Levitus et al., 2012). The effective O_2 source from metal refining is based on production data from Bray (2020), Flanagan (2021), and Tuck (2022). Uncertainty was determined through a Monte Carlo approach with 20,000 iterations, using

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uncertainties prescribed in Keeling and Manning (2014), including observational uncertainties from Keeling et al. (2007) and autoregressive errors in fossil fuel emissions (Ballantyne et al., 2015). The reported uncertainty is 1 standard deviation of the ensemble. The difference between the atmospheric O_2 estimate for GCB2023 is due to a revision to the Scripps O_2 program CO_2 data. As for the atmospheric inversions, the O_2 based estimates also closes the carbon balance (B_{IM} = 0) by design and provides another independent estimate of the ocean and land fluxes. Note that the O_2 method requires a correction for global air-sea O_2 flux, which has the largest uncertainty at annual time scales, but which is still non negligible for decadal estimates (Nevison et al., 2008).

2.9 Earth System Models estimate

Reconstructions and predictions from decadal prediction systems based on Earth system models (ESMs) provide a novel line of evidence in assessing the atmosphere-land and atmosphere-ocean carbon fluxes in the past decades and predicting their changes for the current year. The decadal prediction systems based on ESMs used here consist of three sets of simulations: (i) uninitialized freely evolving historical simulations (1850-2014); (ii) assimilation reconstruction incorporating observational data into the model (1960-2023); (iii) initialised prediction simulations for the 1981-2024 period, starting every year from initial states obtained from the above assimilation simulations. The assimilations are designed to reconstruct the actual evolution of the Earth system by assimilating essential fields from data products. The assimilations' states, which are expected to be close to observations, are used to start the initialised prediction simulations used for the current year (2024) global carbon budget. Similar initialised prediction simulations starting every year (Nov. 1st or Jan. 1st) over the 1981-2023 period (i.e., hindcasts) are also performed for predictive skill quantification and for bias correction. More details on the illustration of a decadal prediction system based on an ESM can refer to Figure 1 of Li et al. (2023).

By assimilating physical atmospheric and oceanic data products into the ESMs, the models are able to reproduce the historical variations of the atmosphere-sea CO_2 fluxes, atmosphere-land CO_2 fluxes, and atmospheric CO_2 growth rate (Li et al., 2016, 2019; Lovenduski et al., 2019a,b; Ilyina et al., 2021; Li et al., 2023). Furthermore, the ESM-based predictions have proven their skill in predicting the air-sea CO_2 fluxes for up to 6 years, the air-land CO_2 fluxes and atmospheric CO_2 growth for 2 years (Lovenduski et al., 2019a,b; Ilyina et al., 2021; Li et al., 2023). The reconstructions from the fully coupled model simulations ensure a closed budget within the Earth system, i.e., no budget imbalance term.

Five ESMs, i.e., CanESM5 (Swart et al., 2019; Sospedra-Alfonso et al., 2021), EC-Earth3-CC (Döscher et al. 2021; Bilbao et al., 2021; Bernardello et al., 2024), IPSL-CM6A-CO2-LR (Boucher et al., 2020), MIROC-ES2L (Watanabe et al., 2020), and MPI-ESM1-2-LR (Mauritsen et al., 2019; Li et al., 2023), have performed the set of prediction simulations. Each ESM uses a different assimilation method and combination of data products incorporated in the system, more details on the models configuration can be found in Table 4 and Supplementary Table S5. The ESMs use external forcings from the Coupled Model Intercomparison Project Phase 6 (CMIP6) historical (1960-2014) plus SSP2-4.5 baseline and CovidMIP two-year blip scenario (2015-2024) (Eyring et al., 2016; Lamboll et al., 2021). The CO_2 emissions forcing from 2015-2024 are substituted by GCB-GridFED

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(v2024.0, Jones et al., 2024a) to provide a consistent CO_2 forcing. Reconstructions of atmosphere-ocean CO_2 fluxes (S_{OCEAN}) and atmosphere-land CO_2 fluxes (S_{LAND}-E_{LUC}) for the time period from 1960-2023 are assessed here. Predictions of the atmosphere-ocean CO_2 flux, atmosphere-land CO_2 flux, and atmospheric CO_2 growth for 2024 are calculated based on the predictions at a lead time of 1 year. The predictions are bias corrected using the 1985-2014 climatology mean of GCB2022 (Friedlingstein et al., 2022), more details on methods can be found in Boer et al. (2016) and Li et al. (2023). The ensemble size of initialized prediction simulations is 10, and the ensemble mean for each individual model is used here. The ESMs are used here to support the assessment of S_{OCEAN} and net atmosphere-land CO_2 flux (S_{LAND} - E_{LUC}) over the 1960-2023 period, and to provide an estimate of the 2024 projection of G_{ATM}.

2.10 Processes not included in the global carbon budget

The contribution of anthropogenic CO and CH_4 to the global carbon budget is not fully accounted for in Eq. (1) and is described in Supplement S.6.1. The contributions to CO_2 emissions of decomposition of carbonates not accounted for is described in Supplement S.6.2. The contribution of anthropogenic changes in river fluxes is conceptually included in Eq. (1) in S_{OCEAN} and in S_{LAND}, but it is not represented in the process models used to quantify these fluxes. This effect is discussed in Supplement S.6.3. Similarly, the loss of additional sink capacity from reduced forest cover is missing in the combination of approaches used here to estimate both land fluxes (E_{LUC} and S_{LAND}) and its potential effect is discussed and quantified in Supplement S.6.4.

3 Results

For each component of the global carbon budget, we present results for three different time periods: the full historical period, from 1850 to 2023, the decades in which we have atmospheric concentration records from Mauna Loa (1960-2023), a specific focus on last year (2023), and the projection for the current year (2024). Subsequently, we assess the estimates of the budget components of the last decades against the top-down constraints from inverse modelling of atmospheric observations, the land/ocean partitioning derived from the atmospheric O_2 measurements, and the budget components estimates from the ESMs assimilation simulations. Atmospheric inversions further allow for an assessment of the budget components with a regional breakdown of land and ocean sinks.

3.1 Fossil CO_2 Emissions

3.1.1 Historical period 1850-2023

Cumulative fossil CO_2 emissions for 1850-2023 were 490 ± 25 GtC, including the cement carbonation sink (Figure 3, Table 8, with all cumulative numbers rounded to the nearest 5GtC). In this period, 46% of global fossil CO_2 emissions came from coal, 35% from oil, 15% from natural gas, 3% from decomposition of carbonates, and 1% from flaring. In 1850, the UK stood for 62% of global fossil CO_2 emissions. In 1893 the combined cumulative emissions of the current members of the European Union reached and subsequently surpassed the level of the UK. Since 1917 US cumulative emissions have been the largest. Over the entire

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period 1850-2023, US cumulative emissions amounted to 120GtC (24% of world total), the EU's to 80 GtC (16%), China's to 75 GtC (15%), and India's to 15 GtC (3%).

In addition to the estimates of fossil CO_2 emissions that we provide here (see Section 2.1), there are three global datasets with long time series that include all sources of fossil CO_2 emissions: CDIAC-FF (Hefner and Marland, 2024), CEDS version 2024_07_08 (Hoesly et al., 2024) and PRIMAP-hist version 2.6 (Gütschow et al., 2016; Gütschow et al., 2024), although these datasets are not entirely independent from each other (Andrew, 2020a). CEDS has cumulative emissions over 1750-2022 at 480 GtC, CDIAC-FF has 481 GtC, GCP 484 GtC, PRIMAP-hist CR 490 GtC, and PRIMAP-hist TR 492 GtC. CDIAC-FF excludes emissions from lime production. CEDS estimates higher emissions from international shipping in recent years, while PRIMAP-hist has higher fugitive emissions than the other datasets. However, in general these four datasets are in relative agreement as to total historical global emissions of fossil CO_2.

3.1.2 Recent period 1960-2023

Global fossil CO_2 emissions, E_{FOS} (including the cement carbonation sink), have increased every decade from an average of 3.0 ± 0.2 GtC yr^{-1} for the decade of the 1960s to an average of 9.7 ± 0.5 GtC yr^{-1} during 2014-2023 (Table 7, Figure 2 and Figure 5). The growth rate in these emissions decreased between the 1960s and the 1990s, from 4.3% yr^{-1} in the 1960s (1960-1969), 3.2% yr^{-1} in the 1970s (1970-1979), 1.6% yr^{-1} in the 1980s (1980-1989), to 1.0% yr^{-1} in the 1990s (1990-1999). After this period, the growth rate began increasing again in the 2000s at an average growth rate of 2.8% yr^{-1}, decreasing to 0.6% yr^{-1} for the last decade (2014-2023). China's emissions increased by +1.9% yr^{-1} on average over the last 10 years dominating the global trend, and India's emissions increased by +3.6% yr^{-1}, while emissions decreased in EU27 by 2.1% yr^{-1}, and in the USA by 1.2% yr^{-1}. Figure 6 illustrates the spatial distribution of fossil fuel emissions for the 2014-2023 period.

E_{FOS} reported here includes the uptake of CO_2 by cement via carbonation which has increased with increasing stocks of cement products, from an average of 20 MtC yr^{-1} (0.02 GtC yr^{-1}) in the 1960s to an average of 200MtC yr^{-1} (0.2 GtC yr^{-1}) during 2014-2023 (Figure 5).

3.1.3 Final year 2023

Global fossil CO_2 emissions were slightly higher, 1.4%, in 2023 than in 2022, with an increase of 0.14 GtC to reach 10.1 ± 0.5 GtC (including the 0.21 GtC cement carbonation sink) in 2023 (Figure 5), distributed among coal (41%), oil (32%), natural gas (21%), cement (4%), flaring (<1%), and others (<1%). Compared to 2022, the 2023 emissions from coal, oil, and gas increased by 1.4%, 2.5%, and 0.1% respectively, while emissions from cement decreased by 2%. All annual growth rates presented are adjusted for the leap year, unless stated otherwise.

In 2023, the largest absolute contributions to global fossil CO_2 emissions were from China (31%), the USA (13%), India (8%), and the EU27 (7%). These four regions account for 59% of global fossil CO_2 emissions, while the rest of the world contributed 41%, including international aviation and marine bunker fuels (3% of the

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total). Growth rates for these countries from 2022 to 2023 were 4.9% (China), -3.3% (USA), -8.4% (EU27), and 8.2% (India), with +0.7% for the rest of the world, including international aviation and marine bunker fuels (+9.5%). The per-capita fossil CO_2 emissions in 2023 were 1.3 tC $person^{-1}$ yr^{-1} for the globe, and were 3.9 (USA), 2.3 (China), 1.5 (EU27) and 0.6 (India) tC $person^{-1}$ yr^{-1} for the four highest emitters (Figure 5).

3.1.4 Year 2024 Projection

Globally, we estimate that global fossil CO_2 emissions (including cement carbonation, -0.21 GtC) will grow by 0.8% in 2024 (-0.3% to +1.9%) to 10.2 GtC (37.4 $GtCO_2$), an historical record high[2]. Carbon Monitor projects a similar 2024 increase of 0.6% (-0.7% to 1.9%). GCB estimates of changes in 2024 emissions per fuel types, relative to 2023, are projected to be 0.2% (range -1.0% to 1.4%) for coal, +0.9% (range 0.0% to 1.8%) for oil, +2.4% (range 1.1% to 3.8%) for natural gas, and -2.8% (range -4.7% to -0.9%) for cement.

For China, projected fossil emissions in 2024 are expected to increase slightly by 0.2% (range -1.6% to 2.0%) compared with 2023 emissions, bringing 2023 emissions for China around 3.3 GtC yr^{-1} (12.0 $GtCO_2$ yr^{-1}). In comparison, the Carbon Monitor estimate projects a 2024 decrease of 0.8% (range -3.8% to 1.9%). Our projected changes by fuel for China are +0.3% for coal, -0.8% for oil, +8%.0 natural gas, and -8.1% for cement.

For the USA, using the Energy Information Administration (EIA) emissions projection for 2024 combined with cement clinker data from USGS, we project a decrease of 0.6% (range -2.9% to 1.7%) compared to 2023, bringing USA 2023 emissions to around 1.3 GtC yr^{-1} (4.9 $GtCO_2$ yr^{-1}). Carbon Monitor projects a 2024 increase in USA emissions of 1.2% (-1.0% to 3.5%). Our projected changes by fuel are -3.5% for coal, -0.7% for oil, +1.0% for natural gas, and -5.8% for cement.

For the European Union, our projection for 2024 is for a decrease of 3.8% (range -6.2% to -1.4%) relative to 2023, with 2024 emissions around 0.7 GtC yr^{-1} (2.4 $GtCO_2$ yr^{-1}). The Carbon Monitor projection for the EU27 is slightly lower than GCB with a decrease of 5.5% (-9.2% to -1.9%). Our projected changes by fuel are -15.8% for coal, +0.2% for oil, -1.3% for natural gas, and -3.5% for cement.

For India, our projection for 2024 is an increase of 4.6% (range of 3.0% to 6.1%) over 2023, with 2024 emissions around 0.9 GtC yr^{-1} (3.2 $GtCO_2$ yr^{-1}). The Carbon Monitor projection for India is an increase of 5.5% (1.9% to 9.1%). Our projected changes by fuel are +4.5% for coal, +3.6% for oil, +11.8% for natural gas, and +4.0% for cement.

International aviation and shipping are projected to increase by 7.8% in 2024, with international aviation projected to be up 14% over 2023, continuing to recover from pandemic lows, and international shipping projected to rise by 3%. The Carbon Monitor projects international aviation and shipping to increase by 3.3% in 2024.

[2] Growth rates in this section use a leap year adjustment that corrects for the extra day in 2024.

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For the rest of the world, the expected change for 2024 is an increase of 1.1% (range -1.0% to 3.3%) with 2024 emissions around 4.0 GtC yr^{-1} (14.5 $GtCO_2$ yr^{-1}), similar to the Carbon Monitor projection of 1.1% (range -0.1% to 2.3%). The fuel-specific projected 2024 growth rates for the rest of the world are: +0.5% for coal, +0.5% for oil, +2.2% for natural gas, +2.0% for cement.

For traceability, Table S6 provides a comparison of annual projections from GCB since 2015 with the actual emissions assessed in the subsequent GCB annual report.

3.2 Emissions from Land Use Change

3.2.1 Historical period 1850-2023

Cumulative CO_2 emissions from land-use change (E_{LUC}) for 1850-2023 were 225 ± 65 GtC (Table 8; Figure 3; Figure 16). The cumulative emissions from E_{LUC} show a large spread among individual estimates of 150 GtC (H&C2023), 205 GtC (OSCAR), 250 GtC (LUCE) and 285 GtC (BLUE) for the four bookkeeping models and a similar wide estimate of 250 ± 85 GtC for the DGVMs (all cumulative numbers are rounded to the nearest 5 GtC). Vegetation biomass observations provide independent constraints on the E_{LUC} estimates (Li et al., 2017). Over the 1901-2012 period, the GCB bookkeeping models cumulative E_{LUC} amounts to 165 GtC [105 to 210 GtC], similar to the observation-based estimate of 155 ± 50 GtC (Li et al., 2017).

3.2.2 Recent period 1960-2023

In contrast to growing fossil emissions, CO_2 emissions from land-use, land-use change, and forestry remained relatively constant (around 1.5 GtC yr^{-1}) over the 1960-1999 period. Since then, they have shown a statistically significant decrease of about 0.2 GtC per decade, reaching 1.1 ± 0.7 GtC yr^{-1} for the 2014-2023 period (Table 7), but with significant spread, from 0.8 to 1.3 GtC yr^{-1} across the four bookkeeping models (Table 5, Figure 7). Different from the bookkeeping average, the DGVMs average grows slightly larger over the 1980-2010 period and shows no sign of decreasing emissions in the recent decades, apart from in the most recent decade (Table 5, Figure 7). This is, however, expected as DGVM-based estimates include the loss of additional sink capacity, which grows with time, while the bookkeeping estimates do not (Supplement S.6.4).

We separate net E_{LUC} into five component fluxes to gain further insight into the drivers of net emissions: deforestation, forest (re-)growth, wood harvest and other forest management, peat drainage and peat fires, and all other transitions (Figure 7c; supplemental Sec. S.2.1). We further decompose the deforestation and the forest (re-)growth term into contributions from shifting cultivation vs permanent forest cover changes (Figure 7d). Averaged over the 2014-2023 period and over the four bookkeeping estimates, fluxes from deforestation amount to 1.7 [1.4 to 2.3] GtC yr^{-1} (Table 5), of which 1.0 [0.8, 1.1] GtC yr^{-1} are from permanent deforestation. Fluxes from forest (re-)growth amount to -1.2 [-1.5, -0.9] GtC yr^{-1} (Table 5), of which -0.5 [-0.7, -0.3] GtC yr^{-1} are from re/afforestation and the remainder from forest regrowth in shifting cultivation cycles. Emissions from wood harvest and other forest management (0.3 [0.0, 0.6] GtC yr^{-1}), peat drainage and peat fires (0.2 [0.2, 0.3] GtC yr^{-1}) and the net flux from other transitions (0.1 [0.0, 0.1] GtC yr^{-1}) are substantially less important globally (Table

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5). However, the small net flux from wood harvest and other forest management contains substantial gross fluxes that largely compensate each other (see Figure S8): 1.4 [0.9, 2.0] GtC yr^{-1} emissions result from the decomposition of slash and the decay of wood products and -1.1 [-1.4, -0.8] GtC yr^{-1} removals result from regrowth after wood harvesting.

The split into component fluxes clarifies the potentials for emission reduction and carbon dioxide removal: the emissions from permanent deforestation - the largest of our component fluxes - could be halted (largely) without compromising carbon uptake by forests, contributing substantially to emissions reduction. By contrast, reducing wood harvesting would have limited potential to reduce emissions as it would be associated with less forest regrowth; removals and emissions cannot be decoupled here on long timescales. A similar conclusion applies to removals and emissions from shifting cultivation, which we have therefore separated out. Carbon Dioxide Removal (CDR) in forests could instead be increased by permanently increasing the forest cover through re/afforestation. Our estimate of about -0.5 GtC yr^{-1} removed on average each year during 2014-2023 by re/afforestation is similar to independent estimates that were derived from NGHGIs for CDR in managed forests (through re/afforestation plus forest management) for 2013-2022 (-0.5 GtC yr^{-1}, Pongratz et al., 2024). Re/afforestation constitutes the vast majority of all current CDR (Pongratz et al., 2024). Though they cannot be compared directly to annual fluxes from the atmosphere, CDR through transfers between non-atmospheric reservoirs such as in durable HWPs, biochar, or BECCS comprise much smaller amounts of carbon. 218 MtC yr^{-1} have been estimated to be transferred to HWPs, averaged over 2013-2022. The net flux of HWPs, considering the re-release of CO_2 through their decay, amounts to 91 MtC yr^{-1} over that period (Pongratz et al., 2024). Note that some double-counting between the CDR through HWPs and the CDR through re/afforestation exists if the HWPs are derived from newly forested areas. BECCS projects have been estimated to store 0.1 MtC yr^{-1} in geological projects worldwide in 2023, biochar projects 0.2 MtC yr^{-1} (Pongratz et al., 2024). "Blue carbon", i.e. coastal wetland management such as restoration of mangrove forests, saltmarshes and seagrass meadows, though at the interface of land and ocean carbon fluxes, are counted towards the land-use sector as well. Currently, bookkeeping models do not include blue carbon; however, current CDR deployment in coastal wetlands is small globally, less than 0.003MtC yr^{-1} (Powis et al., 2023).

The statistically significant decrease in E_{LUC} since the late-1990s, including the larger drop within the most recent decade, is due to the combination of decreasing emissions from deforestation (in particular permanent deforestation) and increasing removals from forest regrowth (with those from re/afforestation stagnating globally in the last decade). Emissions in 2014-2023 are 28% lower than in the late-1990s (1995-2004) and 20% lower than in 2004-2013. The steep drop in E_{LUC} after 2015 is due to the combined effect from a peak in peat fire emissions in 2015 and a long-term decline in deforestation emissions in many countries over the 2010-2020 period with largest declines in the Democratic Republic of the Congo, Brazil, China, and Indonesia. Since the processes behind gross removals, foremost forest regrowth and soil recovery, are all slow, while gross emissions include a large instantaneous component, short-term changes in land-use dynamics, such as a temporary decrease in deforestation, influences gross emissions dynamics more than gross removals dynamics, which rather are a response to longer-term dynamics. Component fluxes often differ more across the four bookkeeping estimates than the net flux, which is expected due to different process representation; in particular, the treatment

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of shifting cultivation, which increases both gross emissions and removals, differs across models, but also net and gross wood harvest fluxes show high uncertainty. By contrast, models agree relatively well for emissions from permanent deforestation.

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Overall, highest land-use emissions occur in the tropical regions of all three continents. The top three emitters (both cumulatively 1959-2023 and on average over 2014-2023) are Brazil (in particular the Amazon Arc of Deforestation), Indonesia and the Democratic Republic of the Congo, with these 3 countries contributing 0.7 GtC yr^{-1} or 60% of the global net land-use emissions (average over 2014-2023) (Figure 6b, Figure 7b). This is related to massive expansion of cropland, particularly in the last few decades in Latin America, Southeast Asia, and sub-Saharan Africa (Hong et al., 2021), to a substantial part for export of agricultural products (Pendrill et al., 2019). Emission intensity is high in many tropical countries, particularly of Southeast Asia, due to high rates of land conversion in regions of carbon-dense and often still pristine, undegraded natural forests (Hong et al., 2021). Emissions are further increased by peat fires in equatorial Asia (GFED4s, van der Werf et al., 2017). Our estimates of high ELUC in China has been revised down since the 1980s as compared to GCB2023 related to the update of the land-use forcing, which is now based on the cropland dataset by Yu et al. (2022) (see Supplement S.2.2), which suggests lower cropland expansion and thus less deforestation than the previous datasets assumed. Uptake due to land-use change occurs in several regions of the world (Figure 6b) particularly because of re/afforestation. Highest CDR in the last decade is seen in China, where our estimates show an even larger uptake since 2010 compared to GCB2023 related to the updated land-use forcing, in the EU27, partly related to expanding forest area as a consequence of the forest transition in the 19^{th} and 20^{th} century and subsequent regrowth of forest (Mather 2001; McGrath et al., 2015), and in the U.S. Substantial uptake through re/afforestation also exists in other regions such as Brazil, Myanmar or Russia, where, however, emissions from deforestation and other land-use changes dominate the net flux.

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While the mentioned patterns are robust and supported by independent literature, we acknowledge that model spread is substantially larger on regional than global levels, as has been shown for bookkeeping models (Bastos et al., 2021) as well as DGVMs (Obermeier et al., 2021). Assessments for individual regions are being performed as part of REgional Carbon Cycle Assessment and Processes (RECCAP2; Ciais et al., 2020, Poulter et al., 2022) or already exist for selected regions (e.g., for Europe by Petrescu et al., 2020, for Brazil by Rosan et al., 2021, for 8 selected countries/regions in comparison to inventory data by Schwingshackl et al., 2022). The revisions since GCB2023 reflect such uncertainties: The integration of a fourth bookkeeping model alters our estimates, though only to a limited extent given that the new model LUCE lies in between the other three models for the global ELUC estimates. Larger changes are obvious at regional level due to the revisions of the land-use forcing with a general update to more recent FAO input for agricultural areas and wood harvest, new MapBiomas input for Brazil and Indonesia and the updated cropland dataset in China.

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The NGHGI data under the LULUCF sector and the LULUCF estimates from FAOSTAT differ from the global models' definition of E_{LUC} (see Section 2.2.1). In the NGHGI reporting, the natural fluxes (S_{LAND}) are counted towards E_{LUC} when they occur on managed land (Grassi et al., 2018). To compare our results to the NGHGI approach, we perform a translation of our E_{LUC} estimates by adding S_{LAND} in managed forest from the DGVMs

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simulations (following the methodology described in Grassi et al., 2023) to the bookkeeping E_{LUC} estimate (see Supplement S.2.3). For the 2014-2023 period, we estimate that 1.8 GtC yr^{-1} of S_{LAND} occurred in managed forests. Adding this sink to E_{LUC} changes E_{LUC} from being a source of 1.1 GtC yr^{-1} to a sink of 0.7 GtC yr^{-1}, very similar to the NGHGI estimate that yields a sink of 0.8 GtC yr^{-1} (Figure 8, Table S10). We further apply a mask of managed land to the net atmosphere-to-land flux estimate from atmospheric inversions to obtain inverse estimates that are comparable to the NGHGI estimates and to the translated E_{LUC} estimates from bookkeeping models (see Supplement S.2.3). The inversion-based net flux in managed land indicates a sink of 0.7 GtC yr^{-1} for 2014-2023, which agrees very well with the NGHGI and the translated E_{LUC} estimates (Figure 8, Table S10). Additionally, the interannual variability of the inversion estimates and the translated E_{LUC} estimates show a remarkable agreement (Pearson correlation of 0.81 in 2000-2023), which supports the suggested translation approach.

The translation approach has been shown to be generally applicable also at the country-level (Grassi et al., 2023; Schwingshackl et al., 2022). Country-level analysis suggests, e.g., that the bookkeeping method estimates higher deforestation emissions than the national report in Indonesia, but less CO_2 removal by afforestation than the national report in China. The fraction of the natural CO_2 sinks that the NGHGI estimates include differs substantially across countries, related to varying proportions of managed vs total forest areas (Schwingshackl et al., 2022). By comparing E_{LUC} and NGHGI on the basis of the component fluxes used above, we find that our estimates reproduce very closely the NGHGI estimates for emissions from permanent deforestation, peat emissions, and other transitions (Figure 8), although a difference in sign for the latter (small source in bookkeeping estimates, small sink in NGHGI) creates a notable difference between NGHGI and bookkeeping estimates. Fluxes due to forest (re-)growth & other forest management, that is, (re-)growth from re/afforestation plus the net flux from wood harvesting and other forest management and emissions and removals in shifting cultivation cycles, constitute a large sink in the NGHGI (-1.9 GtC yr^{-1} averaged over 2014-2023), since they also include S_{LAND} in managed forests. Summing up the bookkeeping estimates of (re-)growth from re/afforestation, the net flux from wood harvesting and other forest management, and the emissions and removals in shifting cultivation cycles, and adding S_{LAND} in managed forests yields a flux of -2.0 GtC yr^{-1} (averaged over 2014-2023), which compares well with the NGHGI estimate. Though estimates between NGHGI, FAOSTAT and the translated budget estimates still differ in value and need further analysis, the approach suggested by Grassi et al. (2023), which we adopt here, provides a feasible way to relate the global models' and NGHGI approach to each other and thus link the anthropogenic carbon budget estimates of land CO_2 fluxes directly to the Global Stocktake, as part of the UNFCCC Paris Agreement.

3.2.3 Final year 2023

The global CO_2 emissions from land-use change are estimated as 1.0 ± 0.7 GtC in 2023, similar to the 2022 estimate. However, confidence in the annual change remains low. Despite El Niño conditions, which in general lead to more fires in deforestation areas, peat fire emissions in Indonesia remained below average (GFED4.1s; updated from van der Werf et al., 2017). In South America, emissions from tropical deforestation and

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degradation fires have been about average, as effects of the El Niño in the Amazon, such as droughts, are not expected before 2024.

3.2.4 Year 2024 Projection

In Southeast Asia, peat fire emissions have further dropped (from 27 Tg C in 2023 to 1 Tg C in 2024 through October 17 2024; GFED4.1s, van der Werf et al., 2017), as have tropical deforestation and degradation fires (from 33 Tg C to 6 Tg C) as the El Niño conditions ceased. By contrast, emissions from tropical deforestation and degradation fires in South America have risen from 121 Tg C in 2023 to 324 Tg C in 2024 up until October 17, as the impacts of the El Niño unfold, in particular drought conditions since 2023. The 2024 South American fire emissions are among the highest values in the record, which started in 1997. Part of the increase is due to elevated fire activity in the wetlands of the Pantanal. Disentangling the degree to which interannual variability in rainfall patterns and stronger environmental protection measures in both Indonesia after their 2015 high fire season and in Brazil after the change in government play a role in fire trends is an important research topic. Cumulative 2024 fire emission estimates through October 17 2024 are 422 Tg C for global deforestation and degradation fires and 1 Tg C for peatland fires in Southeast Asia.

Based on these estimates, we expect E_{LUC} emissions of around 1.1 GtC (4.2 $GtCO_2$) in 2024, slightly above the 2023 level. Note that although our extrapolation includes tropical deforestation and degradation fires, the degradation attributable to selective logging, edge-effects or fragmentation is not captured. Further, deforestation and fires in deforestation zones may become more disconnected, partly due to changes in legislation in some regions. For example, Van Wees et al. (2021) found that the contribution from fires to forest loss decreased in the Amazon and in Indonesia over the period of 2003-2018.

3.3 CDR not based on vegetation

Besides the CDR through land use (Sec. 3.2), the atmosphere to geosphere flux of carbon resulting from carbon dioxide removal (CDR) activity in 2023 is estimated at 0.011 MtC/yr. This results primarily from 0.009 MtC/yr of enhanced weathering projects and 0.001 MtC/yr of DACCS. While it represents a growth of 200% in the anthropogenic sink, from the 0.0036 MtC/yr estimate in 2022, it remains about a million times smaller than current fossil CO_2 emissions.

3.4 Total anthropogenic emissions

Cumulative anthropogenic CO_2 emissions (fossil and land use) for 1850-2023 totalled 710 ± 70 GtC (2605 ± 260 $GtCO_2$), of which 70% (500 GtC) occurred since 1960 and 34% (240 GtC) since 2000 (Table 7 and 8). Total anthropogenic emissions more than doubled over the last 60 years, from 4.6 ± 0.7 GtC yr^{-1} for the decade of the 1960s to an average of 10.8 ± 0.9 GtC yr^{-1} during 2014-2023, and reaching 11 ± 0.9 GtC (40.5 ± 3.2 $GtCO_2$) in 2023. However, total anthropogenic CO_2 emissions have been stable over the last decade (zero growth rate over the 2014-2023 period), much slower than the 2.0% growth rate over the previous decade (2004-2013).

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During the historical period 1850-2023, 31% of historical emissions were from land use change and 69% from fossil emissions. However, fossil emissions have grown significantly since 1960 while land use changes have not, and consequently the contributions of land use change to total anthropogenic emissions were smaller during recent periods, 18% during the period 1960-2023 and down to 10% over the last decade (2014-2023).

For 2024, we project global total anthropogenic CO_2 emissions from fossil and land use changes to be around 11.3 GtC (41.6 $GtCO_2$), 2% above the 2023 level. All values here include the cement carbonation sink (currently about 0.2 GtC yr^{-1}).

3.5 Atmospheric CO_2

3.5.1 Historical period 1850-2023

Atmospheric CO_2 concentration was approximately 278 parts per million (ppm) in 1750, reaching 300 ppm in the late 1900s, 350 ppm in the late 1980s, and reaching 419.31 ± 0.1 ppm in 2023 (Lan et al., 2024; Figure 1). The mass of carbon in the atmosphere increased by 51% from 590 GtC in 1750 to 890 GtC in 2023. Current CO_2 concentrations in the atmosphere are unprecedented in the last 2 million years and the current rate of atmospheric CO_2 increase is at least 10 times faster than at any other time during the last 800,000 years (Canadell et al., 2021).

3.5.2 Recent period 1960-2023

The growth rate in atmospheric CO_2 level increased from 1.7 ± 0.07 GtC yr^{-1} in the 1960s to 5.2 ± 0.02 GtC yr^{-1} during 2014-2023 with important decadal variations (Table 7, Figure 3 and Figure 4). During the last decade (2014-2023), the growth rate in atmospheric CO_2 concentration continued to increase, albeit with large interannual variability (Figure 4).

The airborne fraction (AF) is defined as the ratio of atmospheric CO_2 growth rate to total anthropogenic emissions:

$$AF = G_{ATM} / (E_{FOS} + E_{LUC}) \qquad (2)$$

It provides a diagnostic of the relative strength of the land and ocean carbon sinks in removing part of the anthropogenic CO_2 perturbation. The evolution of AF over the last 60 years shows no significant trend, remaining at around 44%, albeit showing a large interannual and decadal variability driven by the year-to-year variability in G_{ATM} (Figure 10). The observed stability of the airborne fraction over the 1960-2023 period indicates that the ocean and land CO_2 sinks have been increasing in pace with the total anthropogenic emissions over that period, removing on average about 56% of the emissions (see Sections 3.6.2 and 3.7.2).

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3.5.3 Final year 2023

The growth rate in atmospheric CO_2 concentration was 5.9 ± 0.2 GtC (2.79 ± 0.08 ppm) in 2023 (Figure 4; Lan et al., 2024), well above the 2022 growth rate (4.6 ± 0.2 GtC) or the 2014-2023 average (5.2 ± 0.02 GtC), as to be expected during an El Niño year. The 2023 atmospheric CO_2 growth rate was the 4th largest over the 1959-2023 atmospheric observational record, closely following 2015, 2016 and 1998, all strong El Niño years.

3.5.4 Year 2024 Projection

The 2024 growth in atmospheric CO_2 concentration (G_{ATM}) is projected to be about 5.9 GtC (2.76 ppm), still high, which is common for the year after a strong El Niño year. This is the average of the GCB regression method (5.6 GtC, 2.64 ppm) and ESMs the multi-model mean (6.1 GtC, 2.88 ppm). The 2024 atmospheric CO_2 concentration, averaged over the year, is expected to reach the level of 422.5 ppm, 52% over the pre-industrial level.

3.6 Ocean Sink

3.6.1 Historical period 1850-2023

Cumulated since 1850, the ocean sink adds up to 185 ± 35 GtC, with more than two thirds of this amount (130 ± 25 GtC) being taken up by the global ocean since 1960. Over the historical period, the ocean sink increased in pace with the anthropogenic emissions exponential increase (Figure 3). Since 1850, the ocean has removed 26% of total anthropogenic emissions.

3.6.2 Recent period 1960-2023

The ocean CO_2 sink increased from 1.2 ± 0.4 GtC yr^{-1} in the 1960s to 2.9 ± 0.4 GtC yr^{-1} during 2014-2023 (Table 7), with interannual variations of the order of a few tenths of GtC yr^{-1} (Figure 4, Figure 11). The ocean-borne fraction ($S_{OCEAN}/(E_{FOS}+E_{LUC})$) has been remarkably constant around 25% on average (Figure 10c), with variations around this mean illustrating the decadal variability of the ocean carbon sink. So far, there is no indication of a decrease in the ocean-borne fraction from 1960 to 2022. The increase of the ocean sink is primarily driven by the increased atmospheric CO_2 concentration, with the strongest CO_2 induced signal in the North Atlantic and the Southern Ocean (Figure 12a). The effect of climate change is much weaker, reducing the ocean sink globally by 0.17 ± 0.05 GtC yr^{-1} (-5.9% of S_{OCEAN}) during 2014-2023 (all models simulate a weakening of the ocean sink by climate change, range -3.4 to -10.7%), and does not show clear spatial patterns across the GOBMs ensemble (Figure 12b). This is the combined effect of change and variability in all atmospheric forcing fields, previously attributed to wind and temperature changes (LeQuéré et al., 2010, Bunsen et al., 2024). The effect of warming is smaller than expected from offline calculation due to a stabilising feedback from limited exchange between surface and deep waters (Bunsen et al., 2024).

The global net air-sea CO_2 flux is a residual of large natural and anthropogenic CO_2 fluxes into and out of the ocean with distinct regional and seasonal variations (Figure 6 and S1). Natural fluxes dominate on regional

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scales, but largely cancel out when integrated globally (Gruber et al., 2009). Mid-latitudes in all basins and the high-latitude North Atlantic dominate the ocean CO_2 uptake where low temperatures and high wind speeds facilitate CO_2 uptake at the surface (Takahashi et al., 2009). In these regions, formation of mode, intermediate and deep-water masses transport anthropogenic carbon into the ocean interior, thus allowing for continued CO_2 uptake at the surface. Outgassing of natural CO_2 occurs mostly in the tropics, especially in the equatorial upwelling region, and to a lesser extent in the North Pacific and polar Southern Ocean, mirroring a well-established understanding of regional patterns of air-sea CO_2 exchange (e.g., Takahashi et al., 2009, Gruber et al., 2009). These patterns are also noticeable in the Surface Ocean CO_2 Atlas (SOCAT) dataset, where an ocean fCO_2 value above the atmospheric level indicates outgassing (Figure S1). This map further illustrates the data-sparsity in the Indian Ocean and the southern hemisphere in general.

The largest variability in the ocean sink occurs on decadal time-scales (Figure 11). The ensemble means of GOBMs and fCO_2-products show the same patterns of decadal variability, although with a larger amplitude of variability in the fCO_2-products than in the GOBMs. The ocean sink stagnated in the 1990s and strengthened between the early 2000s and the mid-2010s (Figure 11; Le Quéré et al., 2007; Landschützer et al., 2015, 2016; DeVries et al., 2017; Hauck et al., 2020; McKinley et al., 2020, Gruber et al., 2023). More recently, the sink seems to have entered a phase of stagnation since 2016, largely in response to large inter-annual climate variability. Different explanations have been proposed for the decadal variability in the 1990s and 2000s, ranging from the ocean's response to changes in atmospheric wind systems (e.g., Le Quéré et al., 2007, Keppler and Landschützer, 2019), including variations in upper ocean overturning circulation (DeVries et al., 2017) to the eruption of Mount Pinatubo in the 1990s (McKinley et al., 2020). The main origin of the decadal variability is a matter of debate with a number of studies initially pointing to the Southern Ocean (see review in Canadell et al., 2021), but also contributions from the North Atlantic and North Pacific (Landschützer et al., 2016, DeVries et al., 2019), or a global signal (McKinley et al., 2020) were proposed.

On top of the decadal variability, interannual variability of the ocean carbon sink is driven by climate variability with a first-order effect from a stronger ocean sink during large El Niño events (e.g., 1997-1998) (Figure 11; Rödenbeck et al., 2014, Hauck et al., 2020; McKinley et al. 2017) leading to a reduction in CO_2 outgassing from the Tropical Pacific. During 2010-2016, the ocean CO_2 sink appears to have intensified in line with the expected increase from atmospheric CO_2 (McKinley et al., 2020). This effect is similar in the fCO_2-products (Figure 11, ocean sink 2016 minus 2010, GOBMs: +0.42 ± 0.11 GtC yr^{-1}, fCO_2-products: +0.44 GtC yr^{-1}, range 0.18 to 0.72 GtC yr^{-1}). The reduction of -0.18 GtC yr^{-1} (range: -0.41 to -0.03 GtC yr^{-1}) in the ocean CO_2 sink in 2017 is consistent with the return to normal conditions after the El Niño in 2015/16, which caused an enhanced sink in previous years. After an increasing S_{OCEAN} in 2018 and 2019, the GOBM and fCO_2-product ensemble means suggest a decrease of S_{OCEAN}, related to the triple La Niña event 2020-2022, followed by a rebound in 2023 linked to the onset of an El Niño event.

Although all individual GOBMs and fCO_2-products fall within the observational constraint, the ensemble means of GOBMs, and fCO_2-products (adjusted for the riverine flux) show a mean offset increasing from 0.31 GtC yr^{-1} in the 1990s to 0.49 GtC yr^{-1} in the decade 2014-2023 and a slightly lower offset of 0.3 GtC yr^{-1} in 2023. In this

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version of the GCB, the SOCEAN positive trend diverges over time by a factor of 1.4 since 2002 (GOBMs: 0.25 ± 0.04 GtC yr^{-1} per decade, *f*CO_2-products: 0.35 GtC yr^{-1} per decade [0.17 to 0.79 GtC yr^{-1} per decade], SOCEAN: 0.30 GtC yr^{-1} per decade), but the uncertainty ranges overlap. This divergence is smaller than reported in previous GCB versions, because of the updated lower sink estimates by the *f*CO_2-products for recent years. This also leads to agreement on the trend since 2010 (GOBMs: 0.18 ± 0.06 GtC yr^{-1} per decade, *f*CO_2-products: 0.18 GtC yr^{-1} per decade [-0.36 to 0.73 GtC yr^{-1} per decade] SOCEAN: 0.18 GtC yr^{-1} per decade). A hybrid approach recently constrained the trend 2000-2022 to 0.42 ± 0.06 GtC yr^{-1} decade^{-1} (Mayot et al., 2024), which aligns with the updated trends of SOCEAN (0.39 GtCyr^{-1} decade^{-1}) and of the *f*CO_2-products (0.45 [0.28,0.84] GtCyr^{-1} decade^{-1}), while the GOBMs result in a lower trend (0.32 ± 0.04 GtC yr^{-1} per decade) over the same period.

In the current dataset, the discrepancy between the two types of estimates stems from a persistently larger SOCEAN in the *f*CO_2-products in the northern extra-tropics since around 2002 and an intermittently larger SOCEAN in the southern extra-tropics in the period 2008-2020 (Figure 14). Note that the discrepancy in the mean flux, which was located in the Southern Ocean in GCB 2022 and earlier, was reduced due to the choice of the regional river flux adjustment (Lacroix et al., 2020 instead of Aumont et al., 2001). This comes at the expense of a discrepancy in the mean SOCEAN of about 0.2 GtC yr^{-1} in the tropics. Likely explanations for the discrepancy in the trends and decadal variability in the high-latitudes are data sparsity and uneven data distribution (Bushinsky et al., 2019, Gloege et al., 2021, Hauck et al., 2023a, Mayot et al., 2024). In particular, two *f*CO_2-products were shown to overestimate the Southern Ocean CO_2 flux trend by 50 and 130% based on current sampling in a model subsampling experiment (Hauck et al., 2023a) and the largest trends in the *f*CO_2-products occurred in a data void region in the North Pacific (Mayot et al., 2024). In this respect it is highly worrisome that the coverage of *f*CO_2 observations continues to decline (Dong et al 2024), and is now down to that of the early 2000s (Fig. 11). Another likely contributor to the discrepancy between GOBMs and *f*CO_2-products are model biases (as indicated by the comparison with Mayot et al., 2024, by the large model spread in the South, Figure 14, and the larger model-data *f*CO_2 mismatch, Figure S2).

The reported SOCEAN estimate from GOBMs and *f*CO_2-products is 2.2 ± 0.4 GtC yr^{-1} over the period 1994 to 2007, which is in agreement with the ocean interior estimate of 2.2 ± 0.4 GtC yr^{-1}, which accounts for the climate effect on the natural CO_2 flux of −0.4 ± 0.24 GtC yr^{-1} (Gruber et al., 2019) to match the definition of SOCEAN used here (Hauck et al., 2020). This comparison depends critically on the estimate of the climate effect on the natural CO_2 flux, which is smaller from the GOBMs (-0.1 GtC yr^{-1}) than in Gruber et al. (2019). Uncertainties of these two estimates would also overlap when using the GOBM estimate of the climate effect on the natural CO_2 flux. Similarly, the SOCEAN estimates integrated over the decades 1994-2004 (21.5 GtC yr^{-1}) and 2004-2014 (25.6 GtC yr^{-1}) agree with the interior ocean-based estimates of Müller et al. (2023; 21.4 ± 2.8 and 26.5 ± 1.3 GtC yr^{-1}), but depend critically on assumptions of the climate effect on natural carbon, which in turn, are based on the *f*CO_2-products in Müller et al. (2023).

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In previous GCB releases, the ocean sink 1959-1989 was only estimated by GOBMs due to the absence of *f*CO_2 observations. Now, the first data-based estimates extending back to 1957/58 are becoming available (Jena-MLS, Rödenbeck et al., 2022, LDEO-HPD, Bennington et al., 2022; Gloege et al., 2022). These are based on a multi-linear regression of *p*CO_2 with environmental predictors (Rödenbeck et al., 2022) or on model-data *p*CO_2 misfits and their relation to environmental predictors (Bennington et al., 2022). The Jena-MLS and LDEO-HPD estimates fall well within the range of GOBM estimates and have a correlation of 0.99 and 0.98 respectively with SOCEAN for the period 1959-2022 (and 0.98 and 0.97 for the 1959-1989 period). They agree well on the mean SOCEAN estimate since 1977 with a slightly higher amplitude of variability (Figure 10). Until 1976, Jena-MLS and LDEO-HPD are respectively abo ... [63]

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3.6.3 Final year 2023

The estimated ocean CO_2 sink is 2.9 ± 0.4 GtC for 2023. This is a small increase of 0.16 GtC compared to 2022, in line with the expected sink strengthening from the 2023 El Niño conditions. GOBM and fCO_2-product ensemble mean estimates consistently result in an S_{OCEAN} increase in 2023 (GOBMs: 0.17 ±0.15 GtC, fCO_2-products: 0.14 [-0.04,0.30] GtC). Eight GOBMs and six fCO_2-products show an increase in S_{OCEAN}, while only two GOBMs and two fCO_2-products show a minor decrease in S_{OCEAN} of less than 0.05 GtC (Figure 11). The fCO_2-products have a larger uncertainty at the end of the reconstructed time series, potentially linked to uncertainties related to fewer available observations in the final year and the shift from La Niña to El Niño (see e.g. Watson et al. 2020, Pérez et al 2024). Specifically, the fCO_2-products' estimate of the last year is regularly adjusted in the following release owing to the tail effect and an incrementally increasing data availability. While the monthly grid cells covered may have a lag of only about a year (Figure 11 inset), the values within grid cells may change with 1-5 years lag (see absolute number of observations plotted in previous GCB releases), potentially resulting in annual changes in the flux magnitude from fCO_2-products.

3.6.4 Year 2024 Projection

Using a feed-forward neural network method (see Section 2.5.2) we project an ocean sink of 3.0 GtC for 2024, only 0.1 GtC higher than for the year 2023, consistent with El Niño to neutral conditions in 2024. The set of ESMs predictions support this estimate with a 2024 ocean sink of around 3.0 [2.9, 3.1] GtC.

3.6.5 Evaluation of Ocean Models and fCO_2-products

The process-based model evaluation draws a generally positive picture with GOBMs scattered around the observational values for Southern Ocean sea-surface salinity, Southern Ocean stratification index and surface ocean Revelle factor (Section S3.3 and Table S11). However, the Atlantic Meridional Overturning Circulation at 26°N is underestimated by 8 out of 10 GOBMs and overestimated by one GOBM. It is planned to derive skill scores for the GOBMs in future releases based on these metrics.

The model simulations allow to separate the anthropogenic carbon component (steady state and non-steady state, sim D - sim A) and to compare the model flux and DIC inventory change directly to the interior ocean estimate of Gruber et al. (2019) without further assumptions (Table S11). The GOBMs ensemble average of anthropogenic carbon inventory changes 1994-2007 amounts to 2.4 GtC yr^{-1} and is thus lower than the 2.6 ± 0.3 GtC yr^{-1} estimated by Gruber et al. (2019) although within the uncertainty. Only three models fall within the range reported by Gruber et al. (2019). This suggests that the majority of the GOBMs underestimate anthropogenic carbon uptake by 10-20% and some models even more. Comparison to the decadal estimates of anthropogenic carbon accumulation (Müller et al., 2023) are close to the interior ocean data based estimate for the decade 2004-2014 (GOBMs sim D minus sim A, 24.7 ± 3.6 GtC yr^{-1}, Müller et al. 27.3 ± 2.5 GtC yr^{-1}), but do not reproduce the supposedly higher anthropogenic carbon accumulation in the earlier period 1994-2004 (GOBMs sim D minus sim A, 21.1 ± 3.0 GtC yr^{-1}, Müller et al. 29.3 ± 2.5 GtC yr^{-1}). Analysis of Earth System Models indicate that an underestimation by about 10% may be due to biases in ocean carbon transport and

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mixing from the surface mixed layer to the ocean interior (Goris et al., 2018, Terhaar et al., 2021, Bourgeois et al., 2022, Terhaar et al., 2022), biases in the chemical buffer capacity (Revelle factor) of the ocean (Vaittinada Ayar et al., 2022; Terhaar et al., 2022) and partly due to a late starting date of the simulations (mirrored in atmospheric CO_2 chosen for the preindustrial control simulation, Table S2, Bronselaer et al., 2017, Terhaar et al., 2022; 2024). Interestingly, and in contrast to the uncertainties in the surface CO_2 flux, we find the largest mismatch in interior ocean carbon accumulation in the tropics, with smaller contributions from the north and the south. The large discrepancy in accumulation in the tropics highlights the role of interior ocean carbon redistribution for those inventories (Khatiwala et al., 2009, DeVries et al., 2023).

The evaluation of the ocean estimates with the *f*CO_2 observations from the SOCAT v2024 dataset for the period 1990-2023 shows an RMSE from annually detrended data of 0.2 to 2.4 µatm for the eight *f*CO_2-products over the globe (Figure S2). The GOBMs RMSEs are larger and range from 2.7 to 4.9 µatm. The RMSEs are generally larger at high latitudes compared to the tropics, for both the *f*CO_2-products and the GOBMs. The *f*CO_2-products have RMSEs of 0.3 to 2.9 µatm in the Tropics, 0.6 to 2.4 µatm in the North, and 0.8 to 2.4 µatm in the South. Note that the *f*CO_2-products are based on the SOCAT v2024 database, hence SOCAT is not an independent dataset for the evaluation of the *f*CO_2-products. The GOBMs RMSEs are more spread across regions, ranging from 2.4 to 3.9 µatm in the tropics, 2.8 to 5.9 µatm in the North, and 2.7 to 6.0 µatm in the South. The higher RMSEs occur in regions with stronger climate variability, such as the northern and southern high latitudes (poleward of the subtropical gyres). Additionally, this year we evaluate the trends derived from a subset of *f*CO_2-products by subsampling four GOBMs used in Friedlingstein et al. (2023; covering the period up to the year 2022) following the approach of Hauck et al. (2023a) and evaluating the air-sea CO_2 flux trend for the 2001-2021 period, i.e. the period of strong divergence in the air-sea CO_2 exchange excluding the final year to remove the tail effect, against trend biases identified by the GOBM reconstruction. The results indicate a relationship between reconstruction bias and strength of the decadal trends (see Figure S3), indicating a tendency of the *f*CO_2-products ensemble to overestimate the air-sea CO_2 flux trends in agreement with a recent study by Mayot et al. (2024).

3.7 Land Sink

3.7.1 Historical period 1850-2023

Cumulated since 1850, the terrestrial CO_2 sink amounts to 220 ± 60 GtC, 31% of total anthropogenic emissions. As for the ocean, more than two thirds of this amount (150 ± 40 GtC) have been taken up by terrestrial ecosystems since 1960. Over the historical period, the sink increased in pace with the anthropogenic emissions increase (Figure 3).

3.7.2 Recent period 1960-2023

The terrestrial CO_2 sink S_{LAND} increased from 1.2 ± 0.5 GtC yr^{-1} in the 1960s to 3.2 ± 0.9 GtC yr^{-1} during 2014-2023, with important interannual variations of up to 2 GtC yr^{-1} generally showing a decreased land sink during El Niño events (Figure 9), responsible for the corresponding enhanced growth rate in atmospheric CO_2

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concentration. The larger land CO_2 sink during 2014-2023 compared to the 1960s is reproduced by all the DGVMs in response to the increase in both atmospheric CO_2, nitrogen deposition, and the changes in climate, and is consistent with the residual estimated from the other budget terms (E_{FOS}+E_{LUC}-G_{ATM}-S_{OCEAN}, Table 5).

Over the period 1960 to present the increase in the global terrestrial CO_2 sink is largely attributed to the CO_2 fertilisation effect (Prentice et al., 2001, Piao et al., 2009, Schimel et al., 2015) and increased nitrogen deposition (Huntzinger et al., 2017, O'Sullivan et al., 2019), directly stimulating plant photosynthesis and increased plant water use in water limited systems, with a small negative contribution of climate change (Figure 12). There is a range of evidence to support a positive terrestrial carbon sink in response to increasing atmospheric CO_2, albeit with uncertain magnitude (Walker et al., 2021). As expected from theory, the greatest CO_2 effect is simulated in the tropical forest regions, associated with warm temperatures and long growing seasons (Hickler et al., 2008) (Figure 12a). However, evidence from tropical intact forest plots indicate an overall decline in the land sink across Amazonia (1985-2011), attributed to enhanced mortality offsetting productivity gains (Brienen et al., 2015, Hubau et al., 2020). During 2014-2023 the land sink is positive in all regions (Figure 6) with the exception of eastern Brazil, Bolivia, northern Venezuela, Southwest USA, central Europe and Central Asia, North and South Africa, and eastern Australia, where the negative effects of climate variability and change (i.e. reduced rainfall and/or increased temperature) counterbalance CO_2 effects. This is clearly visible on Figure 12 where the effects of CO_2 (Figure 12a) and climate (Figure 12b) as simulated by the DGVMs are isolated. The negative effect of climate can be seen across the globe, and is particularly strong in most of South America, Central America, Southwest US, Central Europe, western Sahel, southern Africa, Southeast Asia and southern China, and eastern Australia (Figure 12b). Globally, over the 2014-2023 period, climate change reduces the land sink by 0.87 ± 0.56 GtC yr^{-1} (27% of S_{LAND}).

Most DGVMs have similar S_{LAND} averaged over 2014-2023, and 14/20 models fall within the 1σ range of the residual land sink [1.8-3.7 GtC yr^{-1}] (see Table 5), and all models but one are within the 2σ range [0.8-4.6 GtC yr^{-1}]. The ED model is an outlier, with a land sink estimate of 5.1 GtC yr^{-1} for the 2014-2023 period, driven by a strong CO_2 fertilisation effect (6.3 GtC yr^{-1} in the CO_2 only (S1) simulation). There are no direct global observations of the land sink (S_{LAND}), or the CO_2 fertilisation effect, and so we are not yet in a position to rule out models based on component fluxes if their net land sink (S_{LAND}-E_{LUC}) is within the observational uncertainty provided by atmospheric inversions or O_2 measurements (Table 5). Furthermore, DGVMs were compared against a model-data fusion based analysis of the land carbon cycle (CARDAMOM) (Bloom and Williams, 2015; Bloom et al., 2016). Results suggest good correspondence between approaches at the interannual timescales, but divergence in the recent trend in S_{LAND} with CARDAMOM simulating a stronger trend than the DGVM multi-model mean (Figure 9).

Since 2020 the globe has experienced La Niña conditions which would be expected to lead to an increased land carbon sink. This 3-year long period of La Niña conditions came to an end by the second half of 2023 and transitioned to an El Niño which lasted until mid-2024. A clear transition from maximum to a minimum in the global land sink is evident in S_{LAND}, from 2022 to 2023 and we find that a El Niño- driven decrease in tropical land sink is offset by a smaller increase in the high latitude land sink. In the past years several regions

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experienced record-setting fire events (see also section 3.8.3). While global burned area has declined over the past decades mostly due to declining fire activity in savannas (Andela et al., 2017), forest fire emissions are rising and have the potential to counter the negative fire trend in savannas (Zheng et al., 2021). Noteworthy extreme fire events include the 2019-2020 Black Summer event in Australia (emissions of roughly 0.2 GtC; van der Velde et al., 2021), Siberia in 2021, where emissions approached 0.4 GtC or three times the 1997-2020 average according to GFED4s, and Canada in 2023 (Byrne et al., 2024). While other regions, including Western US and Mediterranean Europe, also experienced intense fire seasons in 2021 their emissions are substantially lower.

Despite these regional negative effects of climate change on S_{LAND}, the efficiency of land to remove anthropogenic CO_2 emissions has remained broadly constant over the last six decades, with a land-borne fraction (S_{LAND}/(E_{FOS}+E_{LUC})) of around 30% (Figure 10b).

3.7.3 Final year 2023

The terrestrial CO_2 sink from the DGVMs ensemble S_{LAND} was 2.3 ± 1.0 GtC in 2023, 41% below the 2022 La Niña induced strong sink of 3.9 ± 1.0 GtC, and also below the 2014-2023 average of 3.2 ± 0.9 GtC yr^{-1} (Figure 4, Table 7). We estimate that the 2023 land sink was the lowest since 2015. The severe reduction in the land sink in 2023 is likely driven by the El Niño conditions, leading to a 58% reduction in S_{LAND} in the tropics (30N-30S) from 2.8 GtC in 2022 to 1.2 GtC in 2023. This is combined with intense wildfires in Canada that led to a significant CO_2 source (see also Section 3.8.3). We note that the S_{LAND} DGVMs estimate for 2023 of 2.3 ± 1.0 GtC is very similar to the 2.2 ± 1.0 GtC yr^{-1} estimate from the residual sink from the global budget (E_{FOS}+E_{LUC}-G_{ATM}-S_{OCEAN}, Table 5).

3.7.4 Year 2024 Projection

Using a feed-forward neural network method we project a land sink of 3.2 GtC for 2024, 0.9 GtC larger than the 2023 estimate. As for the ocean sink, we attribute this to the transition from the El Niño conditions in 2023 to a neutral state. The ESMs do not provide an additional estimate of S_{LAND} as they only simulate the net atmosphere-land carbon flux (S_{LAND}-E_{LUC}).

3.7.5 Land Models Evaluation

The evaluation of the DGVMs shows generally higher agreement across models for runoff, and to a lesser extent for GPP, and ecosystem respiration. These conclusions are supported by a more comprehensive analysis of DGVM performance in comparison with benchmark data (Sitch et al., 2024). A relative comparison of DGVM performance (Figure S4) suggests several DGVMs (CABLE-POP, CLASSIC, OCN, ORCHIDEE) may outperform others at multiple carbon and water cycle benchmarks. However, results from Seiler et al., 2022, also show how DGVM differences are often of similar magnitude compared with the range across observational datasets. All models score high enough over the metrics tests to support their use here. There are a few

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anomalously low scores for individual metrics from a single model, and these can direct the effort to improve models for use in future budgets.

3.8 Partitioning the carbon sinks

3.8.1 Global sinks and spread of estimates

In the period 2014-2023, the bottom-up view of global net ocean and land carbon sinks provided by the GCB, S_{OCEAN} for the ocean and S_{LAND} – E_{LUC} for the land, agrees closely with the top-down global carbon sinks delivered by the atmospheric inversions. This is shown in Figure 13, which visualises the individual decadal mean atmosphere-land and atmosphere-ocean fluxes from each, along with the constraints on their sum offered by the global fossil CO_2 emissions flux minus the atmospheric growth rate (E_{FOS} – G_{ATM}, 4.4 ± 0.5 Gt C yr^{-1}, Table 7, shown as diagonal line on Figure 13). The GCB estimate for net atmosphere-to-surface flux (S_{OCEAN} + S_{LAND} - E_{LUC}) during 2014-2023 is 4.9 ± 1.2 Gt C yr^{-1} (Table 7), with the difference to the diagonal representing the budget imbalance (B_{IM}) of 0.4 GtC yr^{-1} discussed in Section 3.9. By virtue of the inversion methodology, the atmospheric inversions estimate of the net atmosphere-to-surface flux during 2014-2023 is 4.5 Gt C yr^{-1}, with a < 0.1 GtC yr^{-1} imbalance, and thus scatter across the diagonal, with inverse models trading land for ocean fluxes in their solution. The independent constraint on the net atmosphere-to-surface flux based on atmospheric O_2 by design also closes the balance and is 4.5 ± 0.9 GtC yr^{-1} over the 2014-2023 period (orange symbol on Figure 13), while the ESMs estimate for the net atmosphere-to-surface flux over that period average to 4.7 [3.0, 5.8] GtC yr^{-1} (Tables 5 and 6).

The distributions based on the individual models and fCO2-products reveal substantial spread but converge near the decadal means quoted in Tables 5 to 7. Sink estimates for S_{OCEAN} and from inverse systems are mostly non-Gaussian, while the ensemble of DGVMs appears more normally distributed justifying the use of a multi-model mean and standard deviation for their errors in the budget. Noteworthy is that the tails of the distributions provided by the land and ocean bottom-up estimates would not agree with the global constraint provided by the fossil fuel emissions and the observed atmospheric CO_2 growth rate. This illustrates the power of the atmospheric joint constraint from G_{ATM} and the global CO_2 observation network it derives from.

3.8.1.1 Net atmosphere-to-land flux

The GCB estimate of the net atmosphere-to-land flux (S_{LAND} – E_{LUC}), calculated as the difference between S_{LAND} from the DGVMs and E_{LUC} from the bookkeeping models, amounts to a 2.1 ± 1.1 GtC yr^{-1} sink during 2014-2023 (Table 5). Estimates of net atmosphere-to-land flux (S_{LAND} – E_{LUC}) from the DGVMs alone (1.7 ± 0.6 GtC yr^{-1}, Table 5, green symbol on Figure 13) are slightly lower, although within the uncertainty of the GCB estimate and also within uncertainty of the global carbon budget constraint (E_{FOS} – G_{ATM} – S_{OCEAN}, 1.6 ± 0.6 GtC yr^{-1}; Table 7). Also, for 2014-2023, the inversions estimate the net atmosphere-to-land flux is a 1.4 [0.3, 2.2] GtC yr^{-1} sink, slightly lower than the mean of the DGVMs estimates (purple versus grey symbols on Figure 13). The independent constraint based on atmospheric O_2 is even lower, 1.0 ± 0.8 GtC yr^{-1} (orange symbol in Figure 13), although its large uncertainty overlaps with the uncertainty range from other approaches. Last, the ESMs

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estimate for the net atmosphere-to-land flux during 2014-2023 is a 2.2 [0.3, 3.6] GtC yr^{-1} sink, more consistent with the GCB estimates of S_{LAND} – E_{LUC} (Figure 14 top row).

As discussed in Section 3.5.3, the atmospheric growth rate of CO_2 was very high in 2023, 5.9 GtC (2.79 ppm) the 4th largest on record. Both DGVMs and inversions assign this large CO_2 growth rate to a severe decrease of the net atmosphere to land flux, and in particular in the tropics (Figure 14). DGVMs simulate a 2023 global the net atmosphere-to-land flux of 1.1 GtC yr^{-1}, a 55% decline relative to the 2.4 GtC yr^{-1} sink in 2022, primarily driven by the severe reduction in S_{LAND} (-41%, see Section 3.7.3). The tropics (30N-30S) are recording a dramatic decrease in the net atmosphere-to-land flux from 1.5 GtC yr^{-1} in 2022 to 0.1 GtC yr^{-1} in 2023. The atmospheric inversion shows a similar story with the global net atmosphere-to-land flux declining from 2.6 GtC yr^{-1} in 2022 to 0.9 GtC yr^{-1} in 2023 (-64%), with the tropics turning from a 1.0 GtC yr^{-1} sink in 2022 to a 0.4 GtC yr^{-1} source in 2023. Our results are broadly consistent with the Ke et al. (2024) study which reported a global atmosphere-to-land flux of 0.4 ± 0.2 GtC yr^{-1} in 2023.

In addition to the large decline of the tropical land uptake, the northern extra tropics experienced warmer than average conditions, in particular in the summer over North America and North Eurasia. In Canada alone, 2023 led to enhanced CO_2 release due to fires of 0.5-0.8 GtC yr^{-1} (see Section 3.8.3). The atmospheric inversions do simulate a slight reduction of the atmosphere-to-land flux in the northern extra-tropics (north of 30°N) , from 1.6 GtC yr^{-1} in 2022 to 1.4 GtC yr^{-1} in 2023, while the DGVM fail to capture this pattern, with a simulated northern extra-tropics net atmosphere-to-land flux larger in 2023 than in 2022 (1.0 vs 0.7 GtC yr^{-1}).

3.8.1.2 Net atmosphere-to-ocean flux

For the 2014-2023 period, the GOBMs (2.6 ± 0.4 GtC yr^{-1}) produce a lower estimate for S_{OCEAN} than the fCO_2-products with 3.1 [2.9, 3.7] GtC yr^{-1}, which shows up in Figure 13 as separate peaks in the distribution from the GOBMs (dark blue symbols) and from the fCO_2-products (light blue symbols). Atmospheric inversions (3.1 [2.4, 4.1] GtC yr^{-1}) suggest an ocean uptake more in line with the fCO_2-products for the recent decade (Table 7) , although the inversions range includes both the GOBMs and fCO_2-products estimates (Figure 14 top row) and the inversions are not fully independent as 6 out of 10 inversions covering the last decade use fCO_2-products as ocean priors and one uses a GOBM (Table S4) . The independent constraint based on atmospheric O_2 (3.4 ± 0.5 GtC yr^{-1}) is at the high end of the distribution of the other methods. However, as mentioned in section 2.8, the O_2 method requires a correction for global air-sea O_2 flux, which induces a non-negligible uncertainty on the decadal estimates (about 0.5 GtC yr^{-1}). The large growth in the ocean carbon sink from O_2 is compatible with the GOBMs and fCO_2-products estimates when accounting for their uncertainty ranges. Lastly, the ESMs estimate, 2.5 [2.2, 2.8] GtC yr^{-1}, suggest a moderate ocean carbon sink, comparable to the GOBMs estimate with regard to mean and spread. We caution that the riverine transport of carbon taken up on land and outgassing from the ocean, accounted for here, is a substantial (0.65 ± 0.3 GtC yr^{-1}) and uncertain term (Crisp et al., 2022; Gruber et al., 2023; DeVries et al., 2023) that separates the GOBMs, ESMs and oxygen-based estimates on the one hand from the fCO_2-products and atmospheric inversions on the other hand.

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3.8.2 Regional partitioning

Figure 14 shows the latitudinal partitioning of the global atmosphere-to-ocean (S_{OCEAN}), atmosphere-to-land (S_{LAND} – E_{LUC}), and their sum (S_{OCEAN} + S_{LAND} – E_{LUC}) according to the estimates from GOBMs and ocean fCO$_2$-products (S_{OCEAN}), DGVMs (S_{LAND} – E_{LUC}), and from atmospheric inversions (S_{OCEAN} and S_{LAND} – E_{LUC}).

3.8.2.1 North

Despite being one of the most densely observed and studied regions of our globe, annual mean carbon sink estimates in the northern extra-tropics (north of 30°N) continue to differ. The atmospheric inversions suggest an atmosphere-to-surface sink (S_{OCEAN}+ S_{LAND} – E_{LUC}) for 2014-2023 of 2.6 [2.0 to 3.4] GtC yr^{-1}, which is slightly higher than the process models' estimate of 2.2 ± 0.4 GtC yr^{-1} (Figure 14). The GOBMs (1.2 ± 0.2 GtC yr^{-1}), fCO$_2$-products (1.4 [1.3-1.5] GtC yr^{-1}), and inversion systems (1.2 [0.9 to 1.4] GtC yr^{-1}) produce largely consistent estimates of the ocean sink. However, the larger flux in the fCO$_2$-products may be related to data sparsity (Mayot et al., 2024). Thus, the difference mainly arises from the net land flux (S_{LAND} – E_{LUC}) estimate, which is 1.0 ± 0.4 GtC yr^{-1} in the DGVMs compared to 1.5 [0.6 to 2.3] GtC yr^{-1} in the atmospheric inversions (Figure 14, second row).

Discrepancies in the northern land fluxes conforms with persistent issues surrounding the quantification of the drivers of the global net land CO$_2$ flux (Arneth et al., 2017; Huntzinger et al., 2017; O'Sullivan et al., 2022) and the distribution of atmosphere-to-land fluxes between the tropics and high northern latitudes (Baccini et al., 2017; Schimel et al., 2015; Stephens et al., 2007; Ciais et al., 2019; Gaubert et al., 2019).

In the northern extra-tropics, the process models, inversions, and fCO$_2$-products consistently suggest that most of the interannual variability stems from the land (Figure 14). Inversions generally agree on the magnitude of interannual variations (IAV) over land, more so than DGVMs (0.29-0.32 vs 0.14-0.63 GtC yr^{-1}, averaged over 1990-2023).

3.8.2.2 Tropics

In the tropics (30°S-30°N), both the atmospheric inversions and process models estimate a net carbon balance (S_{OCEAN} + S_{LAND} - E_{LUC}) that is relatively close to neutral over the past decade (inversions: 0.3 [-0.4, 0.9] GtC yr^{-1}, process models: 0.6±0.6 GtC yr^{-1}). The GOBMs (-0.03 ± 0.3 GtC yr^{-1}), fCO$_2$-products (0.3 [0.1, 0.6] GtC yr^{-1}), and inversion systems (0.3 [-0.1, 0.8] GtC yr^{-1}) indicate a neutral to positive tropical ocean flux (see Figure S1 for spatial patterns). DGVMs indicate a net land sink (S_{LAND} - E_{LUC}) of 0.6 ±0.4 GtC yr^{-1}, whereas the inversion systems indicate a neutral net land flux although with large model spread (-0.0 [-0.9, 0.8] GtC yr^{-1}, (Figure 14, third row).

The tropical lands are the origin of most of the atmospheric CO$_2$ interannual variability (Ahlström et al., 2015), consistently among the process models and inversions (Figure 14). The interannual variability in the tropics is similar among the ocean fCO$_2$-products (0.06-0.16 GtC yr^{-1}) and the GOBMs (0.07-0.16 GtC yr^{-1}, Figure S2). The DGVMs and inversions indicate that atmosphere-to-land CO$_2$ fluxes are more variable than atmosphere-to-

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ocean CO_2 fluxes in the tropics, with interannual variability of 0.37 to 1.33 and 0.86-0.96 GtC yr^{-1} for DGVMs and inversions, respectively.

3.8.2.3 South

In the southern extra-tropics (south of 30°S), the atmospheric inversions suggest a net atmosphere-to-surface sink (S_{OCEAN}+S_{LAND}-E_{LUC}) for 2014-2023 of 1.5 [1.2, 1.9] GtC yr^{-1}, identical to the process models' estimate of 1.5 ± 0.4 GtC yr^{-1} (Figure 14). An approximately neutral net land flux (S_{LAND}-E_{LUC}) for the southern extra-tropics is estimated by both the DGVMs (0.05 ± 0.1 GtC yr^{-1}) and the inversion systems (-0.03 [-0.11, 0.08] GtC yr^{-1}). This means nearly all carbon uptake is due to oceanic sinks south of 30°S. The Southern Ocean flux in the fCO_2-products (1.5[1.3, 1.7 GtC] yr^{-1}) and inversion estimates (1.6 [1.2, 1.9] GtCyr-1) is marginally higher than in the GOBMs (1.4 ± 0.4 GtC yr^{-1}) (Figure 14, bottom row). This agreement is subject to the choice of the river flux adjustment (Lacroix et al., 2020, Hauck et al., 2023b). Nevertheless, the time-series of atmospheric inversions and fCO_2-products diverge from the GOBMs. A substantial overestimation of the trends in the fCO_2-products could be explained by sparse and unevenly distributed observations, especially in wintertime (Figure S1; Hauck et al., 2023a; Gloege et al., 2021). Model biases may contribute as well, with biases in mode water formation, stratification, and the chemical buffer capacity known to play a role in Earth System Models (Terhaar et al., 2021, Bourgeois et al., 2022, Terhaar et al., 2022).

The interannual variability in the southern extra-tropics is low because of the dominance of ocean areas with low variability compared to land areas. The split between land (S_{LAND}-E_{LUC}) and ocean (S_{OCEAN}) shows a substantial contribution to variability in the south coming from the land, with no consistency between the DGVMs and the inversions or among inversions. This is expected due to the difficulty of separating exactly the land and oceanic fluxes when viewed from atmospheric observations alone. The S_{OCEAN} interannual variability was found to be higher in the fCO_2-products (0.04-0.20 GtC yr^{-1}) compared to GOBMs (0.04 to 0.06 GtC yr^{-1}) in 1990-2023 (Figure S2). Inversions give an interannual variability of 0.10 to 0.13 GtC yr^{-1}. Model subsampling experiments recently illustrated that fCO_2-products may overestimate decadal variability in the Southern Ocean carbon sink by 30% and the trend since 2000 by 50-130% due to data sparsity, based on one and two fCO_2-products with strong variability (Gloege et al., 2021, Hauck et al., 2023a). The trend benchmark test using the method of Hauck et al., (2023a) and a subset of 6 fCO_2-products confirms the sensitivity of the decadal trends in fCO_2-products to reconstruction biases, particularly in the Southern Ocean, indicating an overestimation of the ensemble mean trend. However, we also find compensating positive biases in the ensemble so that the ensemble mean bias is smaller than the bias from some individual fCO_2-products.

3.8.2.4 RECCAP2 regions

Aligning with the RECCAP-2 initiative (Ciais et al., 2022; Poulter et al., 2022; DeVries et al., 2023), we provide a breakdown of this GCB paper estimate of the E_{LUC}, S_{LAND}, Net land (S_{LAND} - E_{LUC}), and S_{OCEAN} fluxes over the 10 land, and 5 ocean RECCAP-2 regions, averaged over the period 2014-2023 (Figure 15). The DGVMs and inversions suggest a positive net land sink in all regions, except for South America and Africa,

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where the inversions indicate a small net source of respectively -0.1 [-0.8, 0.3] GtC yr^{-1} and -0.3 [-0.7, -0.1] GtC yr^{-1}, compared to a small sink of 0.1±0.3 GtC yr^{-1} and 0.3±0.1 GtC yr^{-1} for the DGVMs. However, for South America, there is substantial uncertainty in both products (ensembles span zero). For the DGVMs, this is driven by uncertainty in both S_{LAND} (0.5±0.4 GtC yr^{-1}) and E_{LUC} (0.4±0.2 GtC yr^{-1}). The bookkeeping models also suggest an E_{LUC} source of around 0.4 GtC yr^{-1} in South America and Africa, in line with the DGVMs estimates. Bookkeeping models and DGVMs similarly estimate a source of 0.3-0.4 GtC yr^{-1} in Southeast Asia, with DGVMs suggesting a small net land sink (0.1±0.1 GtC yr^{-1}). This is similar to the inversion mean estimate of a 0.1 [-0.3,0.8] GtC yr^{-1} sink, although the inversion spread is substantial. The inversions suggest the largest net land sinks are located in North America (0.5 [-0.1,1.0] GtC yr^{-1}), Russia (0.6 [0.1,0.9] GtC yr^{-1}), and East Asia (0.4 [-0.2,1.3] GtC yr^{-1}). This agrees well with the DGVMs in North America (0.4±0.1 GtC yr^{-1}), which indicate a large natural land sink (S_{LAND}) of 0.6±0.2 GtC yr^{-1}, being slightly reduced by land-use related carbon losses (0.2±0.1 GtC yr^{-1}). The DGVMs suggest a smaller net land sink in Russia compared to inversions (0.3±0.2 GtC yr^{-1}), and a similar net sink in East Asia (0.2±0.1 GtC yr^{-1}).

There is generally a higher level of agreement in the estimates of regional S_{OCEAN} between the different data streams (GOBMs, *f*CO_2-products and atmospheric inversions) on decadal scale, compared to the agreement between the different land flux estimates. All data streams agree that the largest contribution to S_{OCEAN} stems from the Southern Ocean due to a combination of high flux density and large surface area, but with important contributions also from the Atlantic (high flux density) and Pacific (large area) basins. In the Southern Ocean, GOBMs suggest a sink of 1.0±0.3 GtC yr^{-1}, in line with the *f*CO_2-products (1.0 [0.8,1.3] GtC yr^{-1}) and atmospheric inversions (1.0 [0.7,1.4] GtC yr^{-1}). There is similar agreement in the Pacific ocean, with GOBMs, *f*CO_2-products, and atmospheric inversions indicating a sink of 0.6±0.2 GtC yr^{-1}, 0.7 [0.6,1.0] GtC yr^{-1}, and 0.6 [0.1,1.0] GtC yr^{-1}, respectively. However, in the Atlantic ocean, GOBMs simulate a sink of 0.5±0.1 GtC yr^{-1}, noticeably lower than both the *f*CO_2-products (0.8 [0.7,1.0] GtC yr^{-1}) and atmospheric inversions (0.7 [0.4,1.1] GtC yr^{-1}). It is important to note the *f*CO_2-products and atmospheric inversions have a substantial and uncertain river flux adjustment in the Atlantic ocean (0.3 GtC yr^{-1}) that also leads to a mean offset between GOBMs and *f*CO_2-products/inversions in the latitude band of the tropics (Figure 14). The Indian Ocean due its smaller size and the Arctic Ocean due to its size and sea-ice cover that prevents air-sea gas-exchange are responsible for smaller but non negligible S_{OCEAN} fluxes (Indian Ocean: (0.3 [0.2,0.3] GtC yr^{-1}, 0.3 [0.3,0.4] GtC yr^{-1}, and 0.4 [0.3,0.6] GtC yr^{-1} for GOBMs, *f*CO_2-products, and atmospheric inversions, respectively, and Arctic Ocean: (0.1 [0.1,0.1] GtC yr^{-1}, 0.2 [0.1,0.2] GtC yr^{-1}, and 0.1 [0.1,0.2] GtC yr^{-1} for GOBMs, *f*CO_2-products, and atmospheric inversions, respectively). Note that the S_{OCEAN} numbers presented here deviate from numbers reported in RECCAP-2 where the net air-sea CO_2 flux is reported (i.e. without river flux adjustment for *f*CO_2-products and inversions, and with river flux adjustment subtracted from GOBMs in most chapters, or comparing unadjusted datasets with discussion of uncertain regional riverine fluxes as major uncertainty, e.g. Sarma et al., 2023, DeVries et al., 2023).

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3.8.2.5 Tropical vs northern land uptake

A continuing conundrum is the partitioning of the global atmosphere-land flux between the northern hemisphere land and the tropical land (Stephens et al., 2017; Pan et al., 2011; Gaubert et al., 2019). It is of importance because each region has its own history of land-use change, climate drivers, and impact of increasing atmospheric CO_2 and nitrogen deposition. Quantifying the magnitude of each sink is a prerequisite to understanding how each individual driver impacts the tropical and mid/high-latitude carbon balance.

We define the North-South (N-S) difference as net atmosphere-land flux north of 30°N minus the net atmosphere-land flux south of 30°N. For the inversions, the N-S difference is 1.50 [0.05,3.0] GtC yr^{-1} across this year's inversion ensemble. An apparent clustering of six satellite-driven solutions towards a common NH land sink noted in GCB2023 is no longer clear.

In the ensemble of DGVMs the N-S difference is 0.4 ± 0.5 GtC yr^{-1}, a much narrower range than the one from atmospheric inversions. Only three out of twenty DGVMs have a N-S difference larger than 1.0 GtC yr^{-1}, compared to half of the inversion systems simulating a difference at least this large. The smaller spread across DGVMs than across inversions is to be expected as there is no correlation between Northern and Tropical land sinks in the DGVMs as opposed to the inversions where the sum of the two regions being well-constrained by atmospheric observations leads to an anti-correlation between these two regions. This atmospheric N-S gradient could be used as an additional way to evaluate tropical and NH uptake in DGVMs, if their fluxes were combined with multiple transport models. Vice versa, the much smaller spread in the N-S difference between the DGVMs could help to scrutinise the inverse systems further. For example, a large northern land sink and a tropical land source in an inversion would suggest a large sensitivity to CO_2 fertilisation (the dominant factor driving the land sinks) for Northern ecosystems, which would be not mirrored by tropical ecosystems. Such a combination could be hard to reconcile with the process understanding gained from the DGVM ensembles and independent measurements (e.g. Free Air CO_2 Enrichment experiments).

3.8.3 Fire Emissions in 2024

Fire emissions so far in 2024 have been above the average of recent decades, chiefly due to synchronous large emissions fluxes from North and South America. Figure S9 shows global and regional emissions estimates for the period 1st Jan-30th September in each year 2003-2024. Estimates derive from two global fire emissions products: the global fire emissions database (GFED, version 4.1s; van der Werf et al., 2017), and the global fire assimilation system (GFAS, operated by the Copernicus Atmosphere Service; Kaiser et al., 2012). The two products estimate that global emissions from fires were 1.6-2.2 GtC yr^{-1} during January-September 2024. These estimates are 11-32% above the 2014-2023 average for the same months (1.5-1.7 GtC yr^{-1}). In the GFED4.1s product, the year-to-date emissions in 2024 were highest since 2003, exceeding even the large emissions estimate of 2023, whereas the GFAS product showed lower emissions in 2024 than in 2023 and six other years since 2003.

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The pattern of high fire emissions from Canada in 2023, which were record-breaking (Jones et al., 2024b, Byrne et al., 2024), continued into 2024. In January-September 2024, emissions from Canada (0.2-0.3 GtC yr-1) were half as great as in the same months of 2023 (0.5-0.8 GtC yr^{-1}) but still 2.1-2.3 times the average of January-September periods in 2014-2023 (and 4-6 times greater than the average of those months in 2003-2022 [excluding the record-breaking year in 2023]; Figure S9). The continued anomaly in Canada propagated to the northern hemisphere, where emissions of 0.5-0.6 GtC yr^{-1} were 26-44% above the average of 2014-2023.

In January-September 2024, fire emissions from South America (0.4-0.6 GtC yr^{-1}) were 94-164% above the average of January-September periods in 2014-2023, marking 2024 out as a year with synchronous high fire emissions across the Americas. Emissions from Brazil in January-September 2024 (0.2-0.3 GtC yr^{-1}) were 91-118% above the average of January-September periods of 2014-2023 and were at a level not seen since the major drought year of 2010 (Figure S9; Aragão et al., 2018, Silva Junior et al., 2019). In 2023, deforestation fire activity in the Brazilian Amazon was below the average levels recorded in national recording systems and attributed to renewed environmental policy implementation, however the fall in Amazon deforestation fire activity was largely offset by above-average wildfires related to historic drought (Mataveli et al. 2024). According to the National Center for Monitoring and Early Warning of Natural Disasters (CEMADEN), drought conditions continued into 2024 and the current drought is the most intense and widespread Brazil has experienced since records began in 1950 (CEMADEN, 2024), prompting large wildfires anomalies across the Amazon, Cerrado and Pantanal regions (INPE, 2024).

Emissions anomalies in Africa strongly influence global totals because the continent typically contributed 41-47% of global fire emissions during 2014–2023 (average of January-September periods). GFAS suggests that fire emissions in Africa through September 2024 (0.6 GtC yr^{-1}) were slightly below the average of 2014-2023, whereas GFED4.1s suggests that fire emissions through September 2024 were slightly above the average of 2014-2023 (0.8 GtC yr^{-1}).

Tropical fire emissions through September 2024 (1.1-1.6 GtC yr^{-1}) accounted for 69-74% of the global total emissions, which is close to the average of the 2014-2023 period (1.1-1.2 GtC yr^{-1}; 72-75%). This marks a return to a more typical distribution of fire emissions between the tropics and extratropics after the tropical contribution fell to just 55-59% during January-September 2023 (Figure S9).

We caution that the fire emissions fluxes presented here should not be compared directly with other fluxes of the budget (e.g. S_{LAND} or E_{LUC}) due to incompatibilities between the observable fire emission fluxes and what is quantified in the S_{LAND} and E_{LUC} components of the budget. The fire emission estimates from global fire products relate to all fire types that can be observed in Earth Observations (Giglio et al., 2018; Randerson et al., 2012; Kaiser et al., 2012), including (i) fires occurring as part of natural disturbance-recovery cycles that would also have occurred in the pre-industrial period (Yue et al., 2016; Keeley and Pausas, 2019; Zou et al., 2019), (ii) fires occurring above and beyond natural disturbance-recovery cycle due to changes in climate, CO_2 and N fertilisation and to an increased frequency of extreme drought and heatwave events (Abatzoglou et al., 2019; Jones et al., 2022; Zheng et al., 2021; Burton et al., 2024), and (iii) fires occurring in relation to land use and land use change, such as deforestation fires and agricultural fires (van der Werf et al., 2010; Magi et al., 2012).

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While the fire emission fluxes presented above point towards a highly unusual Northern Hemisphere fire season so far in 2023, we…

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In the context of the global carbon budget, only the portion of fire emissions associated with (ii) should be included in the S_{LAND} component, and fire emissions associated with (iii) should already be accounted for in the E_{LUC} component. Emissions associated with (i) should not be included in the global carbon budget. It is not currently possible to derive specific estimates for fluxes (i), (ii), and (iii) using global fire emission products such as GFED or GFAS. In addition, the fire emissions estimates from global fire emissions products represent a gross flux of carbon to the atmosphere, whereas the S_{LAND} component of the budget is a net flux that should also include post-fire recovery fluxes. Even if emissions from fires of type (ii) could be separated from those of type (i), these fluxes may be partially or wholly offset in subsequent years by post-fire fluxes as vegetation recovers, sequestering carbon from the atmosphere to the terrestrial biosphere (Yue et al., 2016; Jones et al., 2024c). Increases in forest fire emissions and severity (emissions per unit area) from globally during the past two decades have highlighted the increasing potential for fire emissions fluxes to outweigh post-fire recovery fluxes, though long-term monitoring of vegetation recovery is required to quantify the net effect on terrestrial C storage (Jones et al., 2024c).

3.9 Closing the Global Carbon Cycle

3.9.1 Partitioning of Cumulative Emissions and Sink Fluxes

Emissions during the period 1850-2023 amounted to 710 ± 70 GtC and were partitioned among the atmosphere (285 ± 5 GtC; 40%), ocean (185 ± 35 GtC; 26%), and land (220 ± 60 GtC; 32%). The cumulative land sink is almost equal to the cumulative land-use emissions (225 ± 65 GtC), making the global land nearly neutral over the whole 1850-2023 period (Figure 3).

The use of nearly independent estimates for the individual terms of the global carbon budget shows a cumulative budget imbalance of 25 GtC (3% of total emissions) during 1850-2023 (Figure 3, Table 8), which, if correct, suggests that emissions could be slightly too high by the same proportion or that the combined land and ocean sinks are slightly underestimated (by about 6%), although these are well within the uncertainty range of each component of the budget. Nevertheless, part of the imbalance could originate from the estimation of significant increase in E_{FOS} and E_{LUC} between the mid 1920s and the mid 1960s which is unmatched by a similar growth in atmospheric CO_2 concentration as recorded in ice cores (Figure 3). However, the known loss of additional sink capacity of 30-40 GtC (over the 1850-2020 period) due to reduced forest cover has not been accounted for in our method and would exacerbate the budget imbalance (see Section 2.10 and Supplement S.6.4).

For the more recent 1960-2023 period where direct atmospheric CO_2 measurements are available, total emissions (E_{FOS} + E_{LUC}) amounted to 500 ± 50 GtC, of which 410 ± 20 GtC (82%) were caused by fossil CO_2 emissions, and 90 ± 45 GtC (18%) by land-use change (Table 8). The total emissions were partitioned among the atmosphere (220 ± 5 GtC; 45%), ocean (130 ± 26 GtC; 25%), and the land (150 ± 40 GtC; 30%), with a near zero (<1 GtC) unattributed budget imbalance. All components except land-use change emissions have significantly grown since 1960, with important interannual variability in the growth rate in atmospheric CO_2 concentration and in the land CO_2 sink (Figure 4), and some decadal variability in all terms (Table 7). Differences with previous budget releases are documented in Figure S6.

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The global carbon budget averaged over the last decade (2014-2023) is shown in Figure 2, Figure 16 (right panel) and Table 7. For this period, 90% of the total emissions (E_{FOS} + E_{LUC}) were from fossil CO_2 emissions (E_{FOS}), and 10% from land-use change (E_{LUC}). The total emissions were partitioned among the atmosphere (48%), ocean (26%) and land (30%), with a small negative budget imbalance (~4%, 0.4 GtC yr^{-1}). For single years, the budget imbalance can be larger (Figure 4). For 2023, the combination of our estimated sources (11.1 ± 0.9 GtC yr^{-1}) and sinks (11.1 ± 0.9 GtC yr^{-1}) leads to a B_{IM} of -0.02 GtC, suggesting a near perfect closure of the global carbon budget.

3.9.2 Trend and Variability in the Carbon Budget Imbalance

The carbon budget imbalance (B_{IM}; Eq. 1, Figure 4) quantifies the mismatch between the estimated total emissions and the estimated changes in the atmosphere, land, and ocean reservoirs. The budget imbalance from 1960 to 2023 is very small (0.5 GtC over the period, i.e. <0.01 GtC yr^{-1} on average) and shows no trend over the full time series (Figure 4e). The process models (GOBMs and DGVMs) and fCO_2-products have been selected to match observational constraints in the 1990s, but no further constraints have been applied to their representation of trend and variability. Therefore, the near-zero mean and trend in the budget imbalance is seen as evidence of a coherent community understanding of the emissions and their partitioning on those time scales (Figure 4). However, the budget imbalance shows substantial variability of the order of ±1 GtC yr^{-1}, particularly over semi-decadal time scales, although most of the variability is within the uncertainty of the estimates. The positive carbon imbalance during the 1960s, and early 1990s, indicates that either the emissions were overestimated, or the sinks were underestimated during these periods. The reverse is true for the 1970s, and to a lesser extent for the 1980s and 2014-2023 period (Figure 4, Table 7).

We cannot attribute the cause of the variability in the budget imbalance with our analysis, we only note that the budget imbalance is unlikely to be explained by errors or biases in the emissions alone because of its large semi-decadal variability component, a variability that is atypical of emissions and has not changed in the past 60 years despite a near tripling in emissions (Figure 4). Errors in S_{LAND} and S_{OCEAN} are more likely to be the main cause for the budget imbalance, especially on interannual to semi-decadal timescales. For example, underestimation of the S_{LAND} by DGVMs has been reported following the eruption of Mount Pinatubo in 1991 possibly due to missing responses to changes in diffuse radiation (Mercado et al., 2009). Although since GCB2021 we accounted for aerosol effects on solar radiation quantity and quality (diffuse vs direct), most DGVMs only used the former as input (i.e., total solar radiation) (Table S1). Thus, the ensemble mean may not capture the full effects of volcanic eruptions, i.e. associated with high light scattering sulphate aerosols, on the land carbon sink (O'Sullivan et al., 2021). DGVMs are suspected to overestimate the land sink in response to the wet decade of the 1970s (Sitch et al., 2008). Quasi-decadal variability in the ocean sink has also been reported, with all methods agreeing on a smaller than expected ocean CO_2 sink in the 1990s and a larger than expected sink in the 2000s (Figure 11; Landschützer et al., 2016, DeVries et al., 2019, Hauck et al., 2020, McKinley et al., 2020, Gruber et al., 2023) and the climate-driven variability could be substantial but is not well constrained (DeVries et al., 2023, Müller et al., 2023). Errors in sink estimates could also be driven by errors in the climatic forcing data, particularly precipitation for S_{LAND} and wind for S_{OCEAN}. Also, the B_{IM} shows substantial departure from

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zero on yearly time scales (Figure 4e), highlighting unresolved variability of the carbon cycle, likely in the land sink (S_{LAND}), given its large year to year variability (Figure 4d and 9).

Both the budget imbalance (B_{IM}, Table 7) and the residual land sink from the global budget (E_{FOS}+E_{LUC}-G_{ATM}-S_{OCEAN}, Table 5) include an error term due to the inconsistencies that arises from combining E_{LUC} from bookkeeping models with S_{LAND} from DGVMs, most notably the loss of additional sink capacity (see Section 2.10 and Supplement S.6.4). Other differences include a better accounting of land use changes practices and processes in bookkeeping models than in DGVMs, or the bookkeeping models error of having present-day observed carbon densities fixed in the past. That the budget imbalance shows no clear trend towards larger values over time is an indication that these inconsistencies probably play a minor role compared to other errors in S_{LAND} or S_{OCEAN}.

Although the budget imbalance is near zero for the recent decades, it could be due to a compensation of errors. We cannot exclude an overestimation of CO_2 emissions, particularly from land-use change, given their large uncertainty, as has been suggested elsewhere (Piao et al., 2018), and/or an underestimate of the sinks. A larger DGVM estimate of the atmosphere-land CO_2 flux (S_{LAND}-E_{LUC}) over the extra-tropics would reconcile model results with inversion estimates for fluxes in the total land during the past decade (Figure 14; Table 5). Likewise, a larger S_{OCEAN} is also possible given the higher estimates from the fCO_2-products, inversions and oxygen based estimates (see Section 3.6.2, Figure 11 and Figure 14), the underestimation of interior ocean anthropogenic carbon accumulation in the GOBMs (Section 3.6.5, Müller et al., 2023), known biases of ocean models (e.g., Terhaar et al., 2022; 2024), the role of potential temperature bias and skin effects in fCO_2-products (Watson et al., 2020; Dong et al., 2022; Bellenger et al., 2023, Figure 11) and regionally larger estimates based e.g. on eddy covariance measurements and aircraft data (Dong et al., 2024a; Long et al., 2021; Jin et al., 2024). More integrated use of observations in the Global Carbon Budget, either on their own or for further constraining model results, should help resolve some of the budget imbalance (Peters et al., 2017a).

4 Tracking progress towards mitigation targets

The average growth in global fossil CO_2 emissions peaked at nearly +3% per year during the 2000s, driven by the rapid growth in emissions in China. In the last decade, however, the global growth rate has slowly declined, reaching a low +0.6% per year over 2014-2023. While this slowdown in global fossil CO_2 emissions growth is welcome, global fossil CO_2 emissions continue to grow, far from the rapid emission decreases needed to be consistent with the temperature goals of the Paris Agreement.

Since the 1990s, the average growth rate of fossil CO_2 emissions has continuously declined across the group of developed countries of the Organisation for Economic Co-operation and Development (OECD), with emissions peaking in around 2005 and declining at 1.4% yr^{-1} in the decade 2014-2023, compared to a decline of 0.9% yr^{-1} during the 2004-2013 period (Table 9). In the decade 2014-2023, territorial fossil CO_2 emissions decreased significantly (at the 95% confidence level) in 22 countries/economies whose economies grew significantly (also at the 95% confidence level): Belgium, Czechia, Denmark, Estonia, Finland, France, Germany, Jordan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, South Korea, Romania, Slovenia, Somalia, Spain,

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Sweden, Switzerland, United Kingdom, USA (updated from Le Quéré et al., 2019). Altogether, these 22 countries emitted 2.2 GtC yr^{-1} (8.1 $GtCO_2$ yr^{-1}) on average over the last decade, about 23% of world CO_2 fossil emissions. For comparison, 18 countries showed a significant decrease in territorial fossil CO_2 emissions over the previous decade (2004-2013).

Decomposing emission changes into the components of growth, a Kaya decomposition, helps give an initial understanding of the drivers of the changes (Peters et al., 2017b). The reduction in growth in global fossil CO_2 emissions in the last decade is due to slightly weaker economic growth, accelerating declines in CO_2 emissions per unit energy, and sustained declines in energy per unit GDP (Figure 17). These trends are a supposition of the trends at the national level. Fossil CO_2 emission declines in the USA and the EU27 are primarily driven by slightly weaker economic growth since the Global Financial Crisis (GFC) in 2008/2009, sustained declines in energy per GDP, and sustained declines in CO_2 emissions per unit energy with a slight acceleration in the USA in the last decade. In contrast, fossil CO_2 emissions continue to grow in non-OECD countries, although the growth rate has slowed from 4.9% yr^{-1} during the 2004-2013 decade to 1.8% yr^{-1} in the last decade (Table 9). Representing 47% of non-OECD emissions in 2023, a large part of this slowdown is due to China, which has seen emissions growth decline from 7.5% yr^{-1} in the 2004-2013 decade to 1.9% yr^{-1} in the last decade. Excluding China, non-OECD emissions grew at 3% yr^{-1} in the 2004-2013 decade compared to 1.7% yr^{-1} in the last decade. China has had weaker economic growth in the 2000s compared to the 2010s, and the rate of reduction in the energy intensity of economic production has weakened significantly since 2015 with accelerating declines in CO_2 emissions per unit energy (Figure 17). India has had strong economic growth that is not offset by declines in energy per GDP or declines in CO_2 emissions per unit energy, driving up fossil CO_2 emissions. Despite the high deployment of renewables in some countries (e.g., China, India), fossil energy sources continue to grow to meet growing energy demand (Le Quéré et al., 2019). In the rest of the world, economic growth has slowed considerably in the last decade, but is only partly offset by declines in energy or carbon intensity, leading to growing emissions.

Globally, fossil CO_2 emissions growth is slowing, and this is due in part to the emergence of climate policy (Eskander and Fankhauser 2020; Le Quere et al 2019) and technological change, which is leading to a shift from coal to gas and growth in renewable energies, and reduced expansion of coal capacity. At the aggregated global level, decarbonisation shows a strong and growing signal in the last decade, with smaller contributions from lower economic growth and declines in energy per GDP (Figure 17). Altogether, global fossil CO_2 emissions are still growing (average of 0.6% per year over the 2014-2023 decade), far from the reductions needed to meet the ambitious climate goals of the UNFCCC Paris agreement.

Last, we update the remaining carbon budget (RCB) based on two studies, the IPCC AR6 (Canadell et al., 2021) and the revision of the IPCC AR6 estimates (Forster et al., 2024, Lamboll et al., 2023). We update the RCB assessed by the IPCC AR6 (Canadell et al., 2021), accounting for the 2020 to 2024 estimated emissions from fossil fuel combustion (E_{FOS}) and land use changes (E_{LUC}). From January 2025, the IPCC AR6 RCB (50% likelihood) for limiting global warming to 1.5°C, 1.7°C and 2°C is estimated to amount to 85, 180, and 315 GtC (305, 655, 1155 $GtCO_2$). The Forster et al. (2024) study proposed a significantly lower RCB than IPCC AR6,

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with the largest reduction being due to an update of the climate emulator (MAGICC) used to estimate the warming contribution of non-CO_2 agents, and to the warming (i.e. emissions) that occurred over the 2020-2023 period. We update the Forster et al., budget accounting for the 2024 estimated emissions from fossil fuel combustion (E_{FOS}) and land use changes (E_{LUC}). From January 2025, the Forster et al., (2024) RCB (50% likelihood) for limiting global warming to 1.5°C, 1.7°C and 2°C is estimated to amount to 45, 140, and 290 GtC (160, 510, 1060 $GtCO_2$), significantly smaller than the updated IPCC AR6 estimate. Both the original IPCC AR6 and Forster et al. (2024) estimates include the Earth System uncertainty on the climate response to cumulative CO_2 emissions, which is reflected through the percent likelihood of exceeding the given temperature threshold, an additional uncertainty of 220$GtCO_2$ due to alternative non-CO_2 emission scenarios, and other sources of uncertainties (see Canadell et al., 2021). The two sets of estimates overlap when considering all uncertainties. The IPCC AR6 estimates have the advantage of a consensus building approach, while the Forster et al. (2024) estimates include significant update estimates but without the backing of the IPCC yet.

Here, we take the average of our 2024 update of both IPCC AR6 and Forster et al. (2024) estimates, giving a remaining carbon (50% likelihood) for limiting global warming to 1.5°C, 1.7°C and 2°C of respectively 65, 160, and 305 GtC (235, 585, 1110 $GtCO_2$) starting from January 2025. We emphasise the large uncertainties, particularly when close to the global warming limit of 1.5°C. These 1.5°C, 1.7°C and 2°C remaining carbon budgets correspond respectively to about 6, 14 and 27 years from the beginning of 2025, at the 2024 level of total anthropogenic CO_2 emissions. Reaching net-zero CO_2 emissions by 2050 entails cutting total anthropogenic CO_2 emissions by about 0.4 GtC (1.6 $GtCO_2$), 3.9% of 2024 emissions, each year on average, comparable to the decrease in E_{FOS} observed in 2020 during the COVID-19 pandemic. However, this would lead to cumulative emissions over 2025-2050 of 145 GtC (530 $GtCO_2$), well above the remaining carbon budget of 65 GtC to limit global warming to 1.5°C, but still within the remaining budget of 160 GtC to limit warming to 1.7°C (in phase with the "well below 2°C" ambition of the Paris Agreement). Even reaching net zero CO_2 globally by 2040, which would require annual emissions cuts of 0.7 GtC (2.5 $GtCO_2$) on average, would still exceed the remaining carbon budget, with 90 GtC (325 $GtCO_2$) cumulative emissions over 2025-2040, unless the global emissions trajectory becomes net negative (i.e. more anthropogenic CO_2 sinks than emissions) after 2040.

5 Discussion

Each year when the global carbon budget is published, each flux component is updated for all previous years to consider corrections that are the result of further scrutiny and verification of the underlying data in the primary input datasets. Annual estimates may be updated with improvements in data quality and timeliness (e.g., to eliminate the need for extrapolation of forcing data such as land-use). Of all terms in the global budget, only the fossil CO_2 emissions and the growth rate in atmospheric CO_2 concentration are based primarily on empirical inputs supporting annual estimates in this carbon budget. The carbon budget imbalance, yet an imperfect measure, provides a strong indication of the limitations in observations, in understanding and representing processes in models, and/or in the integration of the carbon budget components.

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The persistent unexplained variability in the carbon budget imbalance limits our ability to verify reported emissions (Peters et al., 2017a) and suggests we do not yet have a complete understanding of the underlying carbon cycle dynamics on annual to decadal timescales. Resolving most of this unexplained variability should be possible through different and complementary approaches. First, as intended with our annual updates, the imbalance as an error term should be reduced by improvements of individual components of the global carbon budget that follow from improving the underlying data and statistics and by improving the models through the resolution of some of the key uncertainties detailed in Table 10. Second, additional clues to the origin and processes responsible for the variability in the budget imbalance could be obtained through a closer scrutiny of carbon variability in light of other Earth system data (e.g., heat balance, water balance), and the use of a wider range of biogeochemical observations to better understand the land-ocean partitioning of the carbon imbalance such as the constraint from atmospheric oxygen included this year. Finally, additional information could also be obtained through better inclusion of process knowledge at the regional level, and through the introduction of inferred fluxes such as those based on satellite xCO_2 retrievals. The limit of the resolution of the carbon budget imbalance is yet unclear, but most certainly not yet reached given the possibilities for improvements that lie ahead.

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Estimates of global fossil CO_2 emissions from different datasets are in relatively good agreement when the different system boundaries of these datasets are considered (Andrew, 2020a). But while estimates of E_{FOS} are derived from reported activity data requiring much fewer complex transformations than some other components of the budget, uncertainties remain, and one reason for the apparently low variation between datasets is precisely the reliance on the same underlying reported energy data. The budget excludes some sources of fossil CO_2 emissions, which available evidence suggests are relatively small (<1%). We have added emissions from lime production in China and the US, but these are still absent in most other non-Annex I countries, and before 1990 in other Annex I countries.

Estimates of E_{LUC} suffer from a range of intertwined issues, including the poor quality of historical land-cover and land-use change maps, the rudimentary representation of management processes in most models, and the confusion in methodologies and boundary conditions used across methods (e.g., Arneth et al., 2017; Pongratz et al., 2014, see also Supplement S.6.4 on the loss of sink capacity; Bastos et al., 2021). Uncertainties in current and historical carbon stocks in soils and vegetation also add uncertainty in the E_{LUC} estimates. Unless a major effort to resolve these issues is made, little progress is expected in the resolution of E_{LUC}. This is particularly concerning given the growing importance of E_{LUC} for climate mitigation strategies, and the large issues in the quantification of the cumulative emissions over the historical period that arise from large uncertainties in E_{LUC}.

By adding the DGVMs estimates of CO_2 fluxes due to environmental change from countries' managed forest areas (part of S_{LAND} in this budget) to the budget E_{LUC} estimate, we successfully reconciled the large gap between our E_{LUC} estimate and the land use flux from NGHGIs using the approach described in Grassi et al. (2021) for future scenarios and in Grassi et al. (2023) using data from the Global Carbon Budget 2021. The updated data presented here can be used as potential adjustment in the policy context, e.g., to help assess the collective countries' progress towards the goal of the Paris Agreement and avoiding double-accounting for the sink in managed forests. In the absence of this adjustment, collective progress would hence appear better than it is (Grassi et al., 2021). The application of this adjustment is also recommended in the UNFCCC Synthesis report for the first Global Stocktake (UNFCCC, 2022) whenever a comparison between LULUCF fluxes reported by countries and the global emission estimates of the IPCC is conducted. However, this adjustment should be seen as a short-term and pragmatic fix based on existing data, rather than a definitive solution to bridge the differences between global models and national inventories. Additional steps are needed to understand and reconcile the remaining differences, some of which are relevant at the country level (Grassi, et al., 2023, Schwingshackl, et al., 2022).

The comparison of GOBMs, fCO_2-products, and inversions highlights substantial discrepancy in the temporal evolution of SOCEAN in the Southern Ocean and northern high-latitudes (Figure 14, Hauck et al., 2023a) and in the mean SOCEAN in the tropics. A large part of the uncertainty in the mean fluxes stems from the regional distribution of the river flux adjustment term. The current distribution simulates the largest share of the outgassing to occur in the tropics (Lacroix et al., 2020). The long-standing sparse data coverage of fCO_2 observations in the Southern compared to the Northern Hemisphere (e.g., Takahashi et al., 2009) continues to exist (Bakker et al., 2016, 2024, Figure S1) and to lead to substantially higher uncertainty in the SOCEAN estimate for the Southern Hemisphere (Watson et al., 2020, Gloege et al., 2021, Hauck et al., 2023a). This discrepancy, which also hampers model improvement, points to the need for increased high-quality fCO_2 observations especially in the Southern Ocean. At the same time, model uncertainty is illustrated by the large spread of individual GOBM estimates (indicated by shading in Figure 14) and highlights the need for model improvement. The issue of diverging trends in SOCEAN from different methods is smaller this year as the trend in the fCO_2-products was revised downwards with the data available in this GCB release, but remains a matter of concern. Recent and on-going work suggests that the fCO_2-products may overestimate the trend (Hauck et al., 2023a, Supplement section S3.4), though the full fCO_2-product ensemble remains to be tested. A data-constrained model approach suggests that the GOBMs underestimate the amplitude of decadal variability, but that the fCO_2-products overestimate the trend (Mayot et al., 2024). At the same time, evidence is accumulating that GOBMs likely underestimate the mean flux (Section 3.6.2, Terhaar et al., 2022, DeVries et al., 2023, Müller et al., 2023, Dong et al., 2024). The independent constraint from atmospheric oxygen measurements gives a larger sink for the past decade and a steeper trend. However, the estimate is consistent within uncertainties with SOCEAN, with the relatively larger ocean sink in the fCO_2-products and some of the GOBMs. The assessment of the net land-atmosphere exchange from DGVMs and atmospheric inversions also shows substantial discrepancy, particularly for the estimate of the net land flux over the northern extra-tropic. This discrepancy highlights the difficulty to quantify complex processes (CO_2 fertilisation, nitrogen deposition and fertilisers, climate change and variability, land management, etc.) that collectively determine the net land CO_2 flux. Resolving the differences in the Northern Hemisphere land sink will require the consideration and inclusion of larger volumes of observations.

We provide metrics for the evaluation of the ocean and land models and the atmospheric inversions (Figures S2 to S4, Table S11). These metrics expand the use of observations in the global carbon budget, helping 1) to support improvements in the ocean and land carbon models that produce the sink estimates, and 2) to constrain

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the representation of key underlying processes in the models and to allocate the regional partitioning of the CO_2 fluxes. The introduction of process-based metrics targeted to evaluate the simulation of S_{OCEAN} in the ocean biogeochemistry models is an important addition to the evaluation based on ocean carbon observations. This is an initial step towards the introduction of a broader range of observations and more stringent model evaluation that we hope will support continued improvements in the annual estimates of the global carbon budget.

We assessed before that a sustained decrease of –1% in global emissions could be detected at the 66% likelihood level after a decade only (Peters et al., 2017a). Similarly, a change in behaviour of the land and/or ocean carbon sink would take as long to detect, and much longer if it emerges more slowly. To continue reducing the carbon imbalance on annual to decadal time scales, regionalising the carbon budget, and integrating multiple variables are powerful ways to shorten the detection limit and ensure the research community can rapidly identify issues of concern in the evolution of the global carbon cycle under the current rapid and unprecedented changing environmental conditions.

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6 Conclusions

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The estimation of global CO_2 emissions and sinks is a major effort by the carbon cycle research community that requires a careful compilation and synthesis of measurements, statistical estimates, and model results. The delivery of an annual carbon budget serves two purposes. First, there is a large demand for up-to-date information on the state of the anthropogenic perturbation of the climate system and its underpinning causes. A broad stakeholder community relies on the datasets associated with the annual carbon budget including scientists, policy makers, businesses, journalists, and non-governmental organisations engaged in adapting to and mitigating human-driven climate change. Second, over the last decades we have seen unprecedented changes in the human and biophysical environments (e.g., changes in the growth of fossil fuel emissions, impact of COVID-19 pandemic, Earth's warming, and strength of the carbon sinks), which call for frequent assessments of the state of the planet, a better quantification of the causes of changes in the contemporary global carbon cycle, and an improved capacity to anticipate its evolution in the future. Building this scientific understanding to meet the extraordinary climate mitigation challenge requires frequent, robust, transparent, and traceable datasets and methods that can be scrutinised and replicated. This paper via 'living data' helps to keep track of new budget updates.

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7 Data availability

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The data presented here are made available in the belief that their wide dissemination will lead to greater understanding and new scientific insights of how the carbon cycle works, how humans are altering it, and how we can mitigate the resulting human-driven climate change. Full contact details and information on how to cite the data shown here are given at the top of each page in the accompanying database and summarised in Table 2.

The accompanying database includes three Excel files organised in the following spreadsheets:

File Global_Carbon_Budget_2024v1.0.xlsx includes the following:

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1. Summary
2. The global carbon budget (1959-2023);
3. The historical global carbon budget (1750-2023);
4. Global CO_2 emissions from fossil fuels and cement production by fuel type, and the per-capita emissions (1850-2023);
5. CO_2 emissions from land-use change from the individual bookkeeping models (1959-2023);
6. Ocean CO_2 sink from the individual global ocean biogeochemistry models and fCO_2-products (1959-2023);
7. Terrestrial CO_2 sink from the individual DGVMs (1959-2023);
8. Cement carbonation CO_2 sink (1959-2023).

File National_Fossil_Carbon_Emissions_2024v1.0.xlsx includes the following:

1. Summary
2. Territorial country CO_2 emissions from fossil fuels and cement production (1850-2023);
3. Consumption country CO_2 emissions from fossil fuels and cement production and emissions transfer from the international trade of goods and services (1990-2020) using CDIAC/UNFCCC data as reference;
4. Emissions transfers (Consumption minus territorial emissions; 1990-2020);
5. Country definitions.

File National_LandUseChange_Carbon_Emissions_2024v1.0.xlsx includes the following:

1. Summary
2. Territorial country CO_2 emissions from Land Use Change (1850-2023) from three bookkeeping models;

All three spreadsheets are published by the Integrated Carbon Observation System (ICOS) Carbon Portal and are available at https://doi.org/10.18160/GCP-2024 (Friedlingstein et al., 2024). National emissions data are also available on Zenodo (Andrew and Peters, 2024), from the Global Carbon Atlas (http://www.globalcarbonatlas.org/, last access: 28 October 2024) and from Our World in Data (https://ourworldindata.org/co2-emissions, last access: 28 October 2024).

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Author contributions

PF, MO, MWJ, RMA, JH, PL, CLQ, HL, ITL, AO, GPP, WP, JP, CS, and SSi designed the study, conducted the analysis, and wrote the paper with input from JGC, PCi and RBJ. RMA, GPP and JIK produced the fossil CO_2 emissions and their uncertainties and analysed the emissions data. MH and GMa provided fossil fuel emission data. JP, TGa, ZQ, and CS provided the bookkeeping land-use change emissions with synthesis by JP and CS. SSm provided the estimates of non-vegetation CDR fluxes. LB, MC, ÖG, NG, TI, TJ, LR, JS, RS, and HTs provided an update of the global ocean biogeochemical models; LMD, ARF, DJF, MG, LG, YI, AJ, CR, AR, JZ, and PC provided an update of the ocean *f*CO2-data products, with synthesis on both streams by JH, PL and NMa. SRA, NRB, MB, CFB, HCB, KC, KE, WE, RAF, TGk, SKL, NL, NMe, NMM, SN, LO, TO, DP, AJS, ST, BT, CN, and RW provided ocean fCO_2 measurements for the year 2023, with synthesis by AO and TS. AA, VA, PCa, THC, JD, CDR, AF, JHe, AKJ, EK, JK, PCM, LM, TN, MO, QS, HTi, XYa, WY, XYu, and SZ provided an update of the Dynamic Global Vegetation Models, with synthesis by SSi and MO. HL, RSA, QT, and ET provided estimates of land and ocean sinks from Earth System Models, as well as a projection of the atmospheric growth rate for 2024. NC, FC, ARJ, FJ, ZJ, JL, SM, YN, PIP, CR, DY, and NZ provided an updated atmospheric inversion, WP, FC, and ITL developed the protocol and produced the synthesis and evaluation of the atmospheric inversions. RMA provided projections of the 2024 fossil emissions and atmospheric CO2 growth rate. PL provided the predictions of the 2024 ocean and land sinks. LPC, GCH, KKG, TMR, GRvdW, WX, and ZY provided forcing data for land-use change. FT and GG provided data for the land-use change NGHGI harmonisation. RFK provided key atmospheric CO2 data. EJM and RFK provided the atmospheric oxygen constraint on surface net carbon sinks. MWJ provided the historical atmospheric CO2 concentration and growth rate. MO and NB produced the aerosol diffuse radiative forcing for the DGVMs. IH provided the climate forcing data for the DGVMs. PCM provided the evaluation of the DGVMs. MWJ provided the emissions prior for use in the inversion systems. XD provided seasonal emissions data for most recent years for the emission prior. PF, MO and MWJ coordinated the effort, revised all figures, tables, text and numbers to ensure the update was clear from the 2023 edition and in line with the globalcarbonatlas.org.

Competing interests.

At least one of the (co-)authors is a member of the editorial board of Earth System Science Data

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References

Andela, N., Morton, D. C., Giglio, L., Chen, Y., van der Werf, G. R., Kasibhatla, P. S., DeFries, R. S., Collatz, G. J., Hantson, S., Kloster, S., Bachelet, D., Forrest, M., Lasslop, G., Li, F., Mangeon, S., Melton, J. R., Yue, C., and Randerson, J. T.: A human-driven decline in global burned area, Science, 356, 1356–1362, https://doi.org/10.1126/science.aal4108, 2017.

Andrew, R. M.: A comparison of estimates of global carbon dioxide emissions from fossil carbon sources, Earth Syst. Sci. Data, 12, 1437–1465, https://doi.org/10.5194/essd-12-1437-2020, 2020a.

Andrew, R. M.: Timely estimates of India's annual and monthly fossil CO2 emissions, Earth Syst. Sci. Data, 12, 2411–2421, https://doi.org/10.5194/essd-12-2411-2020, 2020b.

Andrew, R. M. and Peters, G. P.: The Global Carbon Project's fossil CO2 emissions dataset (2024v17), Zenodo [dataset], https://doi.org/10.5281/zenodo.13981696, 2024.

Aragão, L. E. O. C., Anderson, L. O., Fonseca, M. G., Rosan, T. M., Vedovato, L. B., Wagner, F. H., Silva, C. V. J., Silva Junior, C. H. L., Arai, E., Aguiar, A. P., Barlow, J., Berenguer, E., Deeter, M. N., Domingues, L. G., Gatti, L., Gloor, M., Malhi, Y., Marengo, J. A., Miller, J. B., Phillips, O. L., and Saatchi, S.: 21st Century drought-related fires counteract the decline of Amazon deforestation carbon emissions, Nat Commun, 9, 536, https://doi.org/10.1038/s41467-017-02771-y, 2018.

Archer, D., Eby, M., Brovkin, V., Ridgwell, A., Cao, L., Mikolajewicz, U., Caldeira, K., Matsumoto, K., Munhoven, G., Montenegro, A., and Tokos, K.: Atmospheric Lifetime of Fossil Fuel Carbon Dioxide, Annu. Rev. Earth Planet. Sci., 37, 117–134, https://doi.org/10.1146/annurev.earth.031208.100206, 2009.

Arneth, A., Sitch, S., Pongratz, J., Stocker, B. D., Ciais, P., Poulter, B., Bayer, A. D., Bondeau, A., Calle, L., Chini, L. P., Gasser, T., Fader, M., Friedlingstein, P., Kato, E., Li, W., Lindeskog, M., Nabel, J. E. M. S., Pugh, T. A. M., Robertson, E., Viovy, N., Yue, C., and Zaehle, S.: Historical carbon dioxide emissions caused by land-use changes are possibly larger than assumed, Nature Geosci, 10, 79–84, https://doi.org/10.1038/ngeo2882, 2017.

Asaadi, A., Arora, V. K., Melton, J. R., and Bartlett, P.: An improved parameterization of leaf area index (LAI) seasonality in the Canadian Land Surface Scheme (CLASS) and Canadian Terrestrial Ecosystem Model (CTEM) modelling framework, 15, 6885–6907, https://doi.org/10.5194/bg-15-6885-2018, 2018.

Aumont, O., Orr, J. C., Monfray, P., Ludwig, W., Amiotte-Suchet, P., and Probst, J.-L.: Riverine-driven interhemispheric transport of carbon, Global Biogeochem. Cycles, 15, 393–405, https://doi.org/10.1029/1999GB001238, 2001.

Aumont, O., Ethé, C., Tagliabue, A., Bopp, L., and Gehlen, M.: PISCES-v2: an ocean biogeochemical model for carbon and ecosystem studies, 8, 2465–2513, https://doi.org/10.5194/gmd-8-2465-2015, 2015.

Baccini, A., Walker, W., Carvalho, L., Farina, M., Sulla-Menashe, D., and Houghton, R. A.: Tropical forests are a net carbon source based on aboveground measurements of gain and loss, Science, 358, 230–234, https://doi.org/10.1126/science.aam5962, 2017.

Bakker, D. C. E., Pfeil, B., Landa, C. S., Metzl, N., O'Brien, K. M., Olsen, A., Smith, K., Cosca, C., Harasawa, S., Jones, S. D., Nakaoka, S., Nojiri, Y., Schuster, U., Steinhoff, T., Sweeney, C., Takahashi, T., Tilbrook, B., Wada, C., Wanninkhof, R., Alin, S. R., Balestrini, C. F., Barbero, L., Bates, N. R., Bianchi, A. A., Bonou, F., Boutin, J., Bozec, Y., Burger, E. F., Cai,

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Deleted: Angelsen, A. and Kaimowitz, D.: Rethinking the Causes of Deforestation: Lessons from Economic Models, World Bank…

Deleted: Obs., 14, 73–98, https://doi.org/10.1093/wbro/14.1.73, 1999.¶

W.-J., Castle, R. D., Chen, L., Chierici, M., Currie, K., Evans, W., Featherstone, C., Feely, R. A., Fransson, A., Goyet, C., Greenwood, N., Gregor, L., Hankin, S., Hardman-Mountford, N. J., Harlay, J., Hauck, J., Hoppema, M., Humphreys, M. P., Hunt, C. W., Huss, B., Ibánhez, J. S. P., Johannessen, T., Keeling, R., Kitidis, V., Körtzinger, A., Kozyr, A., Krasakopoulou, E., Kuwata, A., Landschützer, P., Lauvset, S. K., Lefèvre, N., Lo Monaco, C., Manke, A., Mathis, J. T., Merlivat, L., Millero, F. J., Monteiro, P. M. S., Munro, D. R., Murata, A., Newberger, T., Omar, A. M., Ono, T., Paterson, K., Pearce, D., Pierrot, D., Robbins, L. L., Saito, S., Salisbury, J., Schlitzer, R., Schneider, B., Schweitzer, R., Sieger, R., Skjelvan, I., Sullivan, K. F., Sutherland, S. C., Sutton, A. J., Tadokoro, K., Telszewski, M., Tuma, M., van Heuven, S. M. A. C., Vandemark, D., Ward, B., Watson, A. J., and Xu, S.: A multi-decade record of high-quality CO2 data in version 3 of the Surface Ocean CO2 Atlas (SOCAT), Earth Syst. Sci. Data, 8, 383–413, https://doi.org/10.5194/essd-8-383-2016, 2016.

Bakker, Dorothee C. E.; Alin, Simone R.; Bates, Nicholas; Becker, Meike; Gkritzalis, Thanos; Jones, Steve D.; Kozyr, Alex; Lauvset, Siv K.; Metzl, Nicolas; Nakaoka, Shin-ichiro; O'Brien, Kevin M.; Olsen, Are; Pierrot, Denis; Steinhoff, Tobias; Sutton, Adrienne J.; Takao, Shintaro; Tilbrook, Bronte; Wada, Chisato; Wanninkhof, Rik; Akl, John; Arbilla, Lisandro A.; Arruda, Ricardo; Azetsu-Scott, Kumiko; Barbero, Leticia; Beatty, Cory M.; Berghoff, Carla F.; Bittig, Henry C.; Burger, Eugene F.; Campbell, Katie; Cardin, Vanessa; Collins, Andrew; Coppola, Laurent; Cronin, Margot; Cross, Jessica N.; Currie, Kim I.; Emerson, Steven R.; Enright, Matt P.; Enyo, Kazutaka; Evans, Wiley; Feely, Richard A.; Flohr, Anita; Gehrung, Martina; Glockzin, Michael; González-Dávila, Melchor; Hamnca, Siyabulela; Hartman, Sue; Howden, Stephan D.; Kam, Kitty; Kamb, Linus; Körtzinger, Arne; Kosugi, Naohiro; Lefèvre, Nathalie; Lo Monaco, Claire; Macovei, Vlad A.; Maenner Jones, Stacy; Manalang, Dana; Martz, Todd R.; Mdokwana, Baxolele; Monacci, Natalie M.; Monteiro, Pedro M. S.; Mordy, Calvin; Morell, Julio M.; Murata, Akihiko; Neill, Craig; Noh, Jae-Hoon; Nojiri, Yukihiro; Ohman, Mark; Olivier, Léa; Ono, Tsuneo; Petersen, Wilhelm; Plueddemann, Albert J.; Prytherch, John; Rehder, Gregor; Rutgersson, Anna; Santana-Casiano, J. Magdalena; Schlitzer, Reiner; Send, Uwe; Skjelvan, Ingunn; Sullivan, Kevin F.; T'Jampens, Michiel; Tadokoro, Kazuaki; Telszewski, Maciej; Theetaert, Hannelore; Tsanwani, Mutshutshu; Vandemark, Douglas; van Ooijen, Erik; Veccia, Martín H.; Voynova, Yoana G.; Wang, Hongjie; Weller, Robert A.; Woosley, Ryan J.: Surface Ocean CO2 Atlas Database Version 2024 (SOCATv2024) (NCEI Accession 0293257). NOAA National Centers for Environmental Information, https://doi.org/10.25921/9wpn-th28, last access: 28 October 2024, 2024.

Ballantyne, A. P., Alden, C. B., Miller, J. B., Tans, P. P., and White, J. W. C.: Increase in observed net carbon dioxide uptake by land and oceans during the past 50 years, Nature, 488, 70–72, https://doi.org/10.1038/nature11299, 2012.

Ballantyne, A. P., Andres, R., Houghton, R., Stocker, B. D., Wanninkhof, R., Anderegg, W., Cooper, L. A., DeGrandpre, M., Tans, P. P., Miller, J. B., Alden, C., and White, J. W. C.: Audit of the global carbon budget: estimate errors and their impact on uptake uncertainty, Biogeosciences, 12, 2565–2584, https://doi.org/10.5194/bg-12-2565-2015, 2015.

Bastos, A., Hartung, K., Nützel, T. B., Nabel, J. E. M. S., Houghton, R. A., and Pongratz, J.: Comparison of uncertainties in land-use change fluxes from bookkeeping model parameterisation, 12, 745–762, https://doi.org/10.5194/esd-12-745-2021, 2021.

Battle, M. O., Raynor, R., Kesler, S., and Keeling, R.: Technical Note: The impact of industrial activity on the amount of atmospheric O2, Atmospheric Chem. Phys. Discuss., 1–17, https://doi.org/10.5194/acp-2022-765, 2023.

Bellenger, H., Bopp, L., Ethé, C., Ho, D., Duvel, J. P., Flavoni, S., Guez, L., Kataoka, T., Perrot, X., Parc, L., and Watanabe, M.: Sensitivity of the Global Ocean Carbon Sink to the Ocean Skin in a Climate Model, J. Geophys. Res. Oceans, 128, e2022JC019479, https://doi.org/10.1029/2022JC019479, 2023.

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Deleted: . Dataset.

Deleted: r7xa-bt92, 2023

Deleted: Beckman, J. and Countryman, A. M.: The Importance of Agriculture in the Economy: Impacts from COVID-19, Am. J. Agr. Econ., 103, 1595–1611, https://doi.org/10.1111/ajae.12212, 2021.

Formatted: Space Before: 0 pt, After: 0 pt

Formatted: Normal

Bennington, V., Gloege, L., and McKinley, G. A.: Variability in the Global Ocean Carbon Sink From 1959 to 2020 by Correcting Models with Observations, Geophys. Res. Lett., 49, e2022GL098632, https://doi.org/10.1029/2022GL098632, 2022.

Bernardello, R., Sicardi, V., Lapin, V., Ortega, P., Ruprich-Robert, Y., Tourigny, E. and Ferrer, E.: Ocean biogeochemical reconstructions to estimate historical ocean CO_2 uptake. Earth System Dynamics, 15(5), pp.1255-1275, https://doi.org/10.5194/esd-15-1255-2024, 2024.

Berthet, S., Séférian, R., Bricaud, C., Chevallier, M., Voldoire, A., and Ethé, C.: Evaluation of an Online Grid-Coarsening Algorithm in a Global Eddy-Admitting Ocean Biogeochemical Model, J. Adv. Model Earth Sy., 11, 1759–1783, https://doi.org/10.1029/2019MS001644, 2019.

Betts, R. A., Jones, C. D., Knight, J. R., Keeling, R. F., and Kennedy, J. J.: El Niño and a record CO_2 rise, Nat. Clim. Change, 6, 806–810, https://doi.org/10.1038/nclimate3063, 2016.

Bilbao, R., Wild, S., Ortega, P., Acosta-Navarro, J., Arsouze, T., Bretonnière, P.A., Caron, L.P., Castrillo, M., Cruz-García, R., Cvijanovic, I. and Doblas-Reyes, F.J.: Assessment of a full-field initialised decadal climate prediction system with the CMIP6 version of EC-Earth. Earth System Dynamics Discussions, 2020, pp.1-30, https://doi.org/10.5194/esd-12-173-2021, 2020.

Bloom, A. A. and Williams, M.: Constraining ecosystem carbon dynamics in a data-limited world: integrating ecological "common sense" in a model–data fusion framework, Biogeosciences, 12, 1299–1315, https://doi.org/10.5194/bg-12-1299-2015, 2015.

Bloom, A. A., Exbrayat, J.-F., van der Velde, I. R., Feng, L., and Williams, M.: The decadal state of the terrestrial carbon cycle: Global retrievals of terrestrial carbon allocation, pools, and residence times, Proc. Natl. Acad. Sci., 113, 1285–1290, https://doi.org/10.1073/pnas.1515160113, 2016.

Boer, G. J., Smith, D. M., Cassou, C., Doblas-Reyes, F., Danabasoglu, G., Kirtman, B., Kushnir, Y., Kimoto, M., Meehl, G. A., Msadek, R., Mueller, W. A., Taylor, K. E., Zwiers, F., Rixen, M., Ruprich-Robert, Y., and Eade, R.: The Decadal Climate Prediction Project (DCPP) contribution to CMIP6, Geosci. Model Dev., 9, 3751–3777, https://doi.org/10.5194/gmd-9-3751-2016, 2016.

Boucher, O., Servonnat, J., Albright, A. L., Aumont, O., Balkanski, Y., Bastrikov, V., Bekki, S., Bonnet, R., Bony, S., Bopp, L., Braconnot, P., Brockmann, P., Cadule, P., Caubel, A., Cheruy, F., Codron, F., Cozic, A., Cugnet, D., D'Andrea, F., Davini, P., de Lavergne, C., Denvil, S., Deshayes, J., Devilliers, M., Ducharne, A., Dufresne, J.-L., Dupont, E., Éthé, C., Fairhead, L., Falletti, L., Flavoni, S., Foujols, M.-A., Gardoll, S., Gastineau, G., Ghattas, J., Grandpeix, J.-Y., Guenet, B., Guez, E., Lionel, Guilyardi, E., Guimberteau, M., Hauglustaine, D., Hourdin, F., Idelkadi, A., Joussaume, S., Kageyama, M., Khodri, M., Krinner, G., Lebas, N., Levavasseur, G., Lévy, C., Li, L., Lott, F., Lurton, T., Luyssaert, S., Madec, G., Madeleine, J.-B., Maignan, F., Marchand, M., Marti, O., Mellul, L., Meurdesoif, Y., Mignot, J., Musat, I., Ottlé, C., Peylin, P., Planton, Y., Polcher, J., Rio, C., Rochetin, N., Rousset, C., Sepulchre, P., Sima, A., Swingedouw, D., Thiéblemont, R., Traore, A. K., Vancoppenolle, M., Vial, J., Vialard, J., Viovy, N., and Vuichard, N.: Presentation and Evaluation of the IPSL-CM6A-LR Climate Model, J. Adv. Model. Earth Syst., 12, e2019MS002010, https://doi.org/10.1029/2019MS002010, 2020.

Bourgeois, T., Goris, N., Schwinger, J., and Tjiputra, J. F.: Stratification constrains future heat and carbon uptake in the Southern Ocean between 30°S and 55°S, Nat. Commun., 13, 340, https://doi.org/10.1038/s41467-022-27979-5, 2022.

Bray, E.: 2017 Minerals Yearbook: Aluminum [Advance Release], Tech. rep., U.S. Geological Survey, https://d9-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/atoms/files/myb1-2017-alumi.pdf, 2020.

Brienen, R. J. W., Caldwell, L., Duchesne, L., Voelker, S., Barichivich, J., Baliva, M., Ceccantini, G., Di Filippo, A., Helama, S., Locosselli, G. M., Lopez, L., Piovesan, G., Schöngart, J., Villalba, R., and Gloor, E.: Forest carbon sink neutralized by pervasive growth-lifespan trade-offs, Nat. Commun., 11, 4241, https://doi.org/10.1038/s41467-020-17966-z, 2020.

Brienen, R. J. W., Phillips, O. L., Feldpausch, T. R., Gloor, E., Baker, T. R., Lloyd, J., Lopez-Gonzalez, G., Monteagudo-Mendoza, A., Malhi, Y., Lewis, S. L., Vásquez Martinez, R., Alexiades, M., Álvarez Dávila, E., Alvarez-Loayza, P., Andrade, A., Aragão, L. E. O. C., Araujo-Murakami, A., Arets, E. J. M. M., Arroyo, L., Aymard C., G. A., Bánki, O. S., Baraloto, C., Barroso, J., Bonal, D., Boot, R. G. A., Camargo, J. L. C., Castilho, C. V., Chama, V., Chao, K. J., Chave, J., Comiskey, J. A., Cornejo Valverde, F., da Costa, L., de Oliveira, E. A., Di Fiore, A., Erwin, T. L., Fauset, S., Forsthofer, M., Galbraith, D. R., Grahame, E. S., Groot, N., Hérault, B., Higuchi, N., Honorio Coronado, E. N., Keeling, H., Killeen, T. J., Laurance, W. F., Laurance, S., Licona, J., Magnussen, W. E., Marimon, B. S., Marimon-Junior, B. H., Mendoza, C., Neill, D. A., Nogueira, E. M., Núñez, P., Pallqui Camacho, N. C., Parada, A., Pardo-Molina, G., Peacock, J., Peña-Claros, M., Pickavance, G. C., Pitman, N. C. A., Poorter, L., Prieto, A., Quesada, C. A., Ramírez, F., Ramírez-Angulo, H., Restrepo, Z., Roopsind, A., Rudas, A., Salomão, R. P., Schwarz, M., Silva, N., Silva-Espejo, J. E., Silveira, M., Stropp, J., Talbot, J., ter Steege, H., Teran-Aguilar, J., Terborgh, J., Thomas-Caesar, R., Toledo, M., Torello-Raventos, M., Umetsu, R. K., van der Heijden, G. M. F., van der Hout, P., Guimarães Vieira, I. C., Vieira, S. A., Vilanova, E., Vos, V. A., and Zagt, R. J.: Long-term decline of the Amazon carbon sink, 519, 344–348, https://doi.org/10.1038/nature14283, 2015.

Bronselaer, B., Winton, M., Russell, J., Sabine, C. L., and Khatiwala, S.: Agreement of CMIP5 Simulated and Observed Ocean Anthropogenic CO2 Uptake, Geophys. Res. Lett., 44, 12,298-12,305, https://doi.org/10.1002/2017GL074435, 2017.

Bruno, M. and Joos, F.: Terrestrial carbon storage during the past 200 years: A Monte Carlo Analysis of CO 2 data from ice core and atmospheric measurements, Global Biogeochem. Cycles, 11, 111–124, https://doi.org/10.1029/96GB03611, 1997.

Burrows, S. M., Maltrud, M., Yang, X., Zhu, Q., Jeffery, N., Shi, X., Ricciuto, D., Wang, S., Bisht, G., Tang, J., Wolfe, J., Harrop, B. E., Singh, B., Brent, L., Baldwin, S., Zhou, T., Cameron-Smith, P., Keen, N., Collier, N., Xu, M., Hunke, E. C., Elliott, S. M., Turner, A. K., Li, H., Wang, H., Golaz, J.-C., Bond-Lamberty, B., Hoffman, F. M., Riley, W. J., Thornton, P. E., Calvin, K., and Leung, L. R.: The DOE E3SM v1.1 Biogeochemistry Configuration: Description and Simulated Ecosystem-Climate Responses to Historical Changes in Forcing, J. Adv. Model. Earth Syst., 12, e2019MS001766, https://doi.org/10.1029/2019MS001766, 2020.

Bunsen, F., Nissen, C., and Hauck, J.: The Impact of Recent Climate Change on the Global Ocean Carbon Sink. Geophysical Research Letters, 51(4), e2023GL107030, https://doi.org/10.1029/2023GL107030, 2024.

Burton, C., Betts, R., Cardoso, M., Feldpausch, T. R., Harper, A., Jones, C. D., Kelley, D. I., Robertson, E., and Wiltshire, A.: Representation of fire, land-use change and vegetation dynamics in the Joint UK Land Environment Simulator vn4.9 (JULES), Geosci. Model Dev., 12, 179–193, https://doi.org/10.5194/gmd-12-179-2019, 2019.

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Formatted: Normal

Burton, C., Lampe, S., Kelley, D. I., Thiery, W., Hantson, S., Christidis, N., Gudmundsson, L., Forrest, M., Burke, E., Chang, J., Huang, H., Ito, A., Kou-Giesbrecht, S., Lasslop, G., Li, W., Nieradzik, L., Li, F., Chen, Y., Randerson, J., Reyer, C. P. O., and Mengel, M.: Global burned area increasingly explained by climate change, Nature Climate Change, https://doi.org/10.1038/s41558-024-02140-w, 2024.

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Deleted: *under review*

Deleted: 21203/rs.3.rs-3168150/v1, 2023.

Bushinsky, S. M., Landschützer, P., Rödenbeck, C., Gray, A. R., Baker, D., Mazloff, M. R., Resplandy, L., Johnson, K. S., and Sarmiento, J. L.: Reassessing Southern Ocean Air-Sea CO 2 Flux Estimates With the Addition of Biogeochemical Float Observations, Global Biogeochem. Cycles, 33, 1370–1388, https://doi.org/10.1029/2019GB006176, 2019.

Byrne, B., Liu, J., Bowman, K.W., Pascolini-Campbell, M., Chatterjee, A., Pandey, S., Miyazaki, K., van der Werf, G.R., Wunch, D., Wennberg, P.O., Roehl, C.M., and Sinha, S.: Carbon emissions from the 2023 Canadian wildfires. Nature, 633, 835–839, https://doi.org/10.1038/s41586-024-07878-z, 2024.

Canadell, J. G., Le Quere, C., Raupach, M. R., Field, C. B., Buitenhuis, E. T., Ciais, P., Conway, T. J., Gillett, N. P., Houghton, R. A., and Marland, G.: Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks, Proceedings of the National Academy of Sciences, 104, 18866–18870, https://doi.org/10.1073/pnas.0702737104, 2007.

Canadell, J. G., Monteiro, P. M. S., Costa, M. H., Cotrim da Cunha, L., Cox, P. M., Eliseev, A. V., Henson, S., Ishii, M., Jaccard, S., Koven, C., Lohila, A., Patra, P. K., Piao, S., Rogelj, J., Syampungani, S., Zaehle, S., and Zickfeld, K.: Global Carbon and other Biogeochemical Cycles and Feedbacks. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 673–816, https://doi.org/10.1017/9781009157896.007., 2021.

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Cao, Z., Myers, R. J., Lupton, R. C., Duan, H., Sacchi, R., Zhou, N., Reed Miller, T., Cullen, J. M., Ge, Q., and Liu, G.: The sponge effect and carbon emission mitigation potentials of the global cement cycle, Nat Commun, 11, 3777, https://doi.org/10.1038/s41467-020-17583-w, 2020.

Centro Nacional de Monitoramento e Alertas de Desastres Naturais (CEMADEN): Monitoramento de secas e impactos no Brasil - Agosto 2024, available at: https://www.gov.br/cemaden/pt-br/assuntos/monitoramento/monitoramento-de-seca-para-o-brasil/monitoramento-de-secas-e-impactos-no-brasil-agosto-2024, last access: 28 October 2024.

Céspedes, J., Sylvester, J. M., Pérez-Marulanda, L., Paz-Garcia, P., Reymondin, L., Khodadadi, M., Tello, J. J., and Castro-Nunez, A.: Has global deforestation accelerated due to the COVID-19 pandemic?, J. For. Res., 34, 1153–1165, https://doi.org/10.1007/s11676-022-01561-7, 2023.

Chandra, N., Patra, P. K., Niwa, Y., Ito, A., Iida, Y., Goto, D., Morimoto, S., Kondo, M., Takigawa, M., Hajima, T., and Watanabe, M.: Estimated regional CO2 flux and uncertainty based on an ensemble of atmospheric CO2 inversions, Atmospheric Chem. Phys., 22, 9215–9243, https://doi.org/10.5194/acp-22-9215-2022, 2022.

Chatfield, C.: The Holt-Winters Forecasting Procedure, J. Roy. Stat. Soc. C., 27, 264–279, https://doi.org/10.2307/2347162, 1978.

Chau, T. T. T., Gehlen, M., and Chevallier, F.: A seamless ensemble-based reconstruction of surface ocean pCO_2 and air–sea CO_2 fluxes over the global coastal and open oceans, Biogeosciences, 19, 1087–1109, https://doi.org/10.5194/bg-19-1087-2022, 2022.

Chevallier, F., Fisher, M., Peylin, P., Serrar, S., Bousquet, P., Bréon, F.-M., Chédin, A., and Ciais, P.: Inferring CO 2 sources and sinks from satellite observations: Method and application to TOVS data, J. Geophys. Res., 110, D24309, https://doi.org/10.1029/2005JD006390, 2005.

Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J. G., Chhabra, A., DeFries, R., Galloway, J., Heimann, M., Jones, C., Le Quéré, C., Myneni, R., Piao, S., Thornton, P., Willem, J., Friedlingstein, P., and Munhoven, G.: Carbon and Other Biogeochemical Cycles, in Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, https://doi.org/10.1017/CBO9781107415324.015, 2013.

Ciais, P., Tan, J., Wang, X., Roedenbeck, C., Chevallier, F., Piao, S.-L., Moriarty, R., Broquet, G., Le Quéré, C., Canadell, J. G., Peng, S., Poulter, B., Liu, Z., and Tans, P.: Five decades of northern land carbon uptake revealed by the interhemispheric CO2 gradient, Nature, 568, 221–225, https://doi.org/10.1038/s41586-019-1078-6, 2019.

Ciais, P., Bastos, A., Chevallier, F., Lauerwald, R., Poulter, B., Canadell, P., Hugelius, G., Jackson, R. B., Jain, A., Jones, M., Kondo, M., Luijkx, I. T., Patra, P. K., Peters, W., Pongratz, J., Petrescu, A. M. R., Piao, S., Qiu, C., Von Randow, C., Regnier, P., Saunois, M., Scholes, R., Shvidenko, A., Tian, H., Yang, H., Wang, X., and Zheng, B.: Definitions and methods to estimate regional land carbon fluxes for the second phase of the REgional Carbon Cycle Assessment and Processes Project (RECCAP-2), Geosci. Model Dev., 15, 1289–1316, https://doi.org/10.5194/gmd-15-1289-2022, 2022.

Collier, N., Hoffman, F. M., Lawrence, D. M., Keppel-Aleks, G., Koven, C. D., Riley, W. J., Mu, M., and Randerson, J. T.: The International Land Model Benchmarking (ILAMB) System: Design, Theory, and Implementation, J. Adv. Model. Earth Syst., 10, 2731–2754, https://doi.org/10.1029/2018MS001354, 2018.

Cox, P. M., Pearson, D., Booth, B. B., Friedlingstein, P., Huntingford, C., Jones, C. D., and Luke, C. M.: Sensitivity of tropical carbon to climate change constrained by carbon dioxide variability, Nature, 494, 341–344, https://doi.org/10.1038/nature11882, 2013.

De Kauwe, M. G., Medlyn, B. E., Zaehle, S., Walker, A. P., Dietze, M. C., Wang, Y.-P., Luo, Y., Jain, A. K., El-Masri, B., Hickler, T., Wårlind, D., Weng, E., Parton, W. J., Thornton, P. E., Wang, S., Prentice, I. C., Asao, S., Smith, B., McCarthy, H. R., Iversen, C. M., Hanson, P. J., Warren, J. M., Oren, R., and Norby, R. J.: Where does the carbon go? A model–data intercomparison of vegetation carbon allocation and turnover processes at two temperate forest free-air CO2 enrichment sites, New Phytol., 203, 883–899, https://doi.org/10.1111/nph.12847, 2014.

Delire, C., Séférian, R., Decharme, B., Alkama, R., Calvet, J.-C., Carrer, D., Gibelin, A.-L., Joetzjer, E., Morel, X., Rocher, M., and Tzanos, D.: The Global Land Carbon Cycle Simulated With ISBA-CTRIP: Improvements Over the Last Decade, J. Adv. Model. Earth Syst., 12, e2019MS001886, https://doi.org/10.1029/2019MS001886, 2020.

Denman, K. L., Brasseur, G., Chidthaisong, A., Ciais, P., Cox, P. M., Dickinson, R. E., Hauglustaine, D., Heinze, C., Holland, E., Jacob, D., Lohmann, U., Ramachandran, S., Leite da Silva Dias, P., Wofsy, S. C., and Zhang, X.: Couplings Between Changes in the Climate System and Biogeochemistry, in: Climate Change 2007: The Physical Science Basis.

Formatted: Normal

Deleted: .

Deleted: :

Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor, M. M. B., Miller, H. L., and Chen, Z. L., Cambridge University Press, Cambridge, UK and New York, USA, 499–587, ISBN: 9780521705967, 2007.

Denvil-Sommer, A., Gehlen, M., and Vrac, M.: Observation system simulation experiments in the Atlantic Ocean for enhanced surface ocean pCO2 reconstructions, Ocean Sci., 17, 1011–1030, https://doi.org/10.5194/os-17-1011-2021, 2021.

DeVries, T., Holzer, M., and Primeau, F.: Recent increase in oceanic carbon uptake driven by weaker upper-ocean overturning, Nature, 542, 215–218, https://doi.org/10.1038/nature21068, 2017.

DeVries, T., Quéré, C. L., Andrews, O., Berthet, S., Hauck, J., Ilyina, T., Landschützer, P., Lenton, A., Lima, I. D., Nowicki, M., Schwinger, J., and Séférian, R.: Decadal trends in the ocean carbon sink, PNAS, 116, 11646–11651, https://doi.org/10.1073/pnas.1900371116, 2019.

DeVries, T., Yamamoto, K., Wanninkhof, R., Gruber, N., Hauck, J., Müller, J. D., Bopp, L., Carroll, D., Carter, B., Chau, T.-T.-T., Doney, S. C., Gehlen, M., Gloege, L., Gregor, L., Henson, S., Kim, J. H., Iida, Y., Ilyina, T., Landschützer, P., Le Quéré, C., Munro, D., Nissen, C., Patara, L., Pérez, F. F., Resplandy, L., Rodgers, K. B., Schwinger, J., Séférian, R., Sicardi, V., Terhaar, J., Triñanes, J., Tsujino, H., Watson, A., Yasunaka, S., and Zeng, J.: Magnitude, trends, and variability of the global ocean carbon sink from 1985-2018, Glob. Biogeochem. Cycles, n/a, e2023GB007780, https://doi.org/10.1029/2023GB007780, 2023.

Döscher, R., Acosta, M., Alessandri, A., Anthoni, P., Arneth, A., Arsouze, T., Bergmann, T., Bernadello, R., Bousetta, S., Caron, L.P. and Carver, G.: The EC-earth3 Earth system model for the climate model intercomparison project 6. Geoscientific Model Development Discussions, 2021, pp.1-90, https://doi.org/10.5194/gmd-15-2973-2022, 2021.

Forster, P. M., Smith, C., Walsh, T., Lamb, W. F., Lamboll, R., Hall, B., Hauser, M., Ribes, A., Rosen, D., Gillett, N. P., Palmer, M. D., Rogelj, J., von Schuckmann, K., Trewin, B., Allen, M., Andrew, R., Betts, R. A., Borger, A., Boyer, T., Broersma, J. A., Buontempo, C., Burgess, S., Cagnazzo, C., Cheng, L., Friedlingstein, P., Gettelman, A., Gütschow, J., Ishii, M., Jenkins, S., Lan, X., Morice, C., Mühle, J., Kadow, C., Kennedy, J., Killick, R. E., Krummel, P. B., Minx, J. C., Myhre, G., Naik, V., Peters, G. P., Pirani, A., Pongratz, J., Schleussner, C.-F., Seneviratne, S. I., Szopa, S., Thorne, P., Kovilakam, M. V. M., Majamäki, E., Jalkanen, J.-P., van Marle, M., Hoesly, R. M., Rohde, R., Schumacher, D., van der Werf, G., Vose, R., Zickfeld, K., Zhang, X., Masson-Delmotte, V., and Zhai, P.: Indicators of Global Climate Change 2023: annual update of key indicators of the state of the climate system and human influence, Earth Syst. Sci. Data, 16, 2625–2658, https://doi.org/10.5194/essd-16-2625-2024, 2024.

Doney, S. C., Lima, I., Feely, R. A., Glover, D. M., Lindsay, K., Mahowald, N., Moore, J. K., and Wanninkhof, R.: Mechanisms governing interannual variability in upper-ocean inorganic carbon system and air–sea CO2 fluxes: Physical climate and atmospheric dust, Deep Sea Research Part II: Topical Studies in Oceanography, 56, 640–655, https://doi.org/10.1016/j.dsr2.2008.12.006, 2009.

Dong, Y., Bakker, D. C. E., Bell, T. G., Huang, B., Landschützer, P., Liss, P. S., and Yang, M.: Update on the Temperature Corrections of Global Air-Sea CO2 Flux Estimates, Glob. Biogeochem. Cycles, 36, e2022GB007360, https://doi.org/10.1029/2022GB007360, 2022.

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Dong, Y., Bakker, D. C. E., Bell, T. G., Yang, M., Landschützer, P., Hauck, J., Rödenbeck, C., Kitidis, V., Bushinsky, S. M., and Liss, P. S. (2024). Direct observational evidence of strong CO_2 uptake in the Southern Ocean. Science Advances, 10(30), eadn5781, https://doi.org/10.1126/sciadv.adn5781, 2024a.

Dong, Y., Bakker, D. C. E., and Landschützer, P.: Accuracy of ocean CO_2 uptake estimates at a risk by a reduction in the data collection. Geophysical Research Letters, 51, e2024GL108502, https://doi.org/10.1029/2024GL108502, 2024b.

Dorgeist, L., Schwingshackl, C., Bultan, S., and Pongratz, J.: A consistent budgeting of terrestrial carbon fluxes. Nature Communications, 15(1), 7426, https://doi.org/10.1038/s41467-024-51126-x, 2024.

Dou, X., Wang, Y., Ciais, P., Chevallier, F., Davis, S. J., Crippa, M., Janssens-Maenhout, G., Guizzardi, D., Solazzo, E., Yan, F., Huo, D., Zheng, B., Zhu, B., Cui, D., Ke, P., Sun, T., Wang, H., Zhang, Q., Gentine, P., Deng, Z., and Liu, Z.: Near-real-time global gridded daily CO_2 emissions, The Innovation, 3, 100182, https://doi.org/10.1016/j.xinn.2021.100182, 2022.

Edson, J. B., Jampana, V., Weller, R. A., Bigorre, S. P., Plueddemann, A. J., Fairall, C. W., Miller, S. D., Mahrt, L., Vickers, D., and Hersbach, H.: On the Exchange of Momentum over the Open Ocean, J. Phys. Oceanogr., 43, 1589–1610, https://doi.org/10.1175/JPO-D-12-0173.1, 2013.

EIA. Short-Term Energy Outlook: September 2023. U.S. Energy Information Administration [dataset]. Available at: http://www.eia.gov/forecasts/steo/outlook.cfm, last access: 28 October 2024, 2023.

Embury, O., Merchant, C.J., Good, S.A., Rayner, N.A., Høyer, J.L., Atkinson, C., Block, T., Alerskans, E., Pearson, K.J., Worsfold, M. and McCarroll, N. and Donlon, C.: Satellite-based time-series of sea-surface temperature since 1980 for climate applications. Scientific Data, 11(1), 326, https://doi.org/10.1038/s41597-024-03147-w, 2024.

Erb, K.-H., Kastner, T., Luyssaert, S., Houghton, R. A., Kuemmerle, T., Olofsson, P., and Haberl, H.: Bias in the attribution of forest carbon sinks, Nature Clim Change, 3, 854–856, https://doi.org/10.1038/nclimate2004, 2013.

Erb, K.-H., Kastner, T., Plutzar, C., Bais, A. L. S., Carvalhais, N., Fetzel, T., Gingrich, S., Haberl, H., Lauk, C., Niedertscheider, M., Pongratz, J., Thurner, M., and Luyssaert, S.: Unexpectedly large impact of forest management and grazing on global vegetation biomass, Nature, 553, 73–76, https://doi.org/10.1038/nature25138, 2018.

Eskander, S. M. S. U. and Fankhauser, S.: Reduction in greenhouse gas emissions from national climate legislation, Nat. Clim. Chang., 10, 750–756, https://doi.org/10.1038/s41558-020-0831-z, 2020.

Etheridge, D. M., Steele, L. P., Langenfelds, R. L., Francey, R. J., Barnola, J.-M., and Morgan, V. I.: Natural and anthropogenic changes in atmospheric CO_2 over the last 1000 years from air in Antarctic ice and firn, J. Geophys. Res., 101, 4115–4128, https://doi.org/10.1029/95JD03410, 1996.

Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., and Taylor, K. E.: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, Geosci. Model Dev., 9, 1937–1958, https://doi.org/10.5194/gmd-9-1937-2016, 2016.

FAO, Food and Agriculture Organization of the United Nations (FAO): Impact of the Ukraine-Russia conflict on global food security and related matters under the mandate of the Food and Agriculture Organization of the United Nations (FAO),

Formatted: Normal

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Hundred and Seventieth Session of the Council, https://www.fao.org/3/nj164en/nj164en.pdf, last access: 28 October 2024, 2023.

Fay, A. R., Gregor, L., Landschützer, P., McKinley, G. A., Gruber, N., Gehlen, M., Iida, Y., Laruelle, G. G., Rödenbeck, C., Roobaert, A., and Zeng, J.: SeaFlux: harmonization of air–sea CO2 fluxes from surface pCO2 data products using a standardized approach, Earth System Science Data, 13, 4693–4710, https://doi.org/10.5194/essd-13-4693-2021, 2021.

Feng, L., Palmer, P. I., Bösch, H., and Dance, S.: Estimating surface CO2 fluxes from space-borne CO2 dry air mole fraction observations using an ensemble Kalman Filter, Atmospheric Chem. Phys., 9, 2619–2633, https://doi.org/10.5194/acp-9-2619-2009, 2009.

Feng, L., Palmer, P. I., Parker, R. J., Deutscher, N. M., Feist, D. G., Kivi, R., Morino, I., and Sussmann, R.: Estimates of European uptake of CO2 inferred from GOSAT XCO2 retrievals: sensitivity to measurement bias inside and outside Europe, Atmos. Chem. Phys., 16, 1289–1302, https://doi.org/10.5194/acp-16-1289-2016, 2016.

Flanagan, D.: 2017 Minerals Yearbook: Copper [Advance Release], Tech. rep., U.S. Geological Survey, https://pubs.usgs.gov/myb/vol1/2017/myb1-2017-copper.pdf, 2021.

Ford, D., Blannin, J., Watts, J., Watson, A., Landschützer, P., Jersild, A. and Shutler, J.: A comprehensive analysis of air-sea CO2 flux uncertainties constructed from surface ocean data products, Global Biogeochemical Cycles, accepted, 2024.

Friedlingstein, P., Houghton, R. A., Marland, G., Hackler, J., Boden, T. A., Conway, T. J., Canadell, J. G., Raupach, M. R., Ciais, P., and Le Quéré, C.: Update on CO2 emissions, Nature Geosci, 3, 811–812, https://doi.org/10.1038/ngeo1022, 2010.

Friedlingstein, P., Andrew, R. M., Rogelj, J., Peters, G. P., Canadell, J. G., Knutti, R., Luderer, G., Raupach, M. R., Schaeffer, M., van Vuuren, D. P., and Le Quéré, C.: Persistent growth of CO2 emissions and implications for reaching climate targets, Nature Geosci, 7, 709–715, https://doi.org/10.1038/ngeo2248, 2014.

Friedlingstein, P., Jones, M. W., O'Sullivan, M., Andrew, R. M., Hauck, J., Peters, G. P., Peters, W., Pongratz, J., Sitch, S., Le Quéré, C., Bakker, D. C. E., Canadell, J. G., Ciais, P., Jackson, R. B., Anthoni, P., Barbero, L., Bastos, A., Bastrikov, V., Becker, M., Bopp, L., Buitenhuis, E., Chandra, N., Chevallier, F., Chini, L. P., Currie, K. I., Feely, R. A., Gehlen, M., Gilfillan, D., Gkritzalis, T., Goll, D. S., Gruber, N., Gutekunst, S., Harris, I., Haverd, V., Houghton, R. A., Hurtt, G., Ilyina, T., Jain, A. K., Joetzjer, E., Kaplan, J. O., Kato, E., Klein Goldewijk, K., Korsbakken, J. I., Landschützer, P., Lauvset, S. K., Lefèvre, N., Lenton, A., Lienert, S., Lombardozzi, D., Marland, G., McGuire, P. C., Melton, J. R., Metzl, N., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S.-I., Neill, C., Omar, A. M., Ono, T., Peregon, A., Pierrot, D., Poulter, B., Rehder, G., Resplandy, L., Robertson, E., Rödenbeck, C., Séférian, R., Schwinger, J., Smith, N., Tans, P. P., Tian, H., Tilbrook, B., Tubiello, F. N., van der Werf, G. R., Wiltshire, A. J., and Zaehle, S.: Global Carbon Budget 2019, Earth Syst. Sci. Data, 11, 1783–1838, https://doi.org/10.5194/essd-11-1783-2019, 2019.

Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Hauck, J., Olsen, A., Peters, G. P., Peters, W., Pongratz, J., Sitch, S., Le Quéré, C., Canadell, J. G., Ciais, P., Jackson, R. B., Alin, S., Aragão, L. E. O. C., Arneth, A., Arora, V., Bates, N. R., Becker, M., Benoit-Cattin, A., Bittig, H. C., Bopp, L., Bultan, S., Chandra, N., Chevallier, F., Chini, L. P., Evans, W., Florentie, L., Forster, P. M., Gasser, T., Gehlen, M., Gilfillan, D., Gkritzalis, T., Gregor, L., Gruber, N., Harris, I., Hartung, K., Haverd, V., Houghton, R. A., Ilyina, T., Jain, A. K., Joetzjer, E., Kadono, K., Kato, E., Kitidis, V., Korsbakken, J. I., Landschützer, P., Lefèvre, N., Lenton, A., Lienert, S., Liu, Z., Lombardozzi, D., Marland, G., Metzl, N., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S.-I., Niwa, Y., O'Brien, K., Ono, T., Palmer, P. I., Pierrot, D., Poulter, B., Resplandy, L.,

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Robertson, E., Rödenbeck, C., Schwinger, J., Séférian, R., Skjelvan, I., Smith, A. J. P., Sutton, A. J., Tanhua, T., Tans, P. P., Tian, H., Tilbrook, B., van der Werf, G., Vuichard, N., Walker, A. P., Wanninkhof, R., Watson, A. J., Willis, D., Wiltshire, A. J., Yuan, W., Yue, X., and Zaehle, S.: Global Carbon Budget 2020, Earth Syst. Sci. Data, 12, 3269–3340, https://doi.org/10.5194/essd-12-3269-2020, 2020.

Friedlingstein, P., Jones, M. W., O'Sullivan, M., Andrew, R. M., Bakker, D. C. E., Hauck, J., Le Quéré, C., Peters, G. P., Peters, W., Pongratz, J., Sitch, S., Canadell, J. G., Ciais, P., Jackson, R. B., Alin, S. R., Anthoni, P., Bates, N. R., Becker, M., Bellouin, N., Bopp, L., Chau, T. T. T., Chevallier, F., Chini, L. P., Cronin, M., Currie, K. I., Decharme, B., Djeutchouang, L. M., Dou, X., Evans, W., Feely, R. A., Feng, L., Gasser, T., Gilfillan, D., Gkritzalis, T., Grassi, G., Gregor, L., Gruber, N., Gürses, Ö., Harris, I., Houghton, R. A., Hurtt, G. C., Iida, Y., Ilyina, T., Luijkx, I. T., Jain, A., Jones, S. D., Kato, E., Kennedy, D., Klein Goldewijk, K., Knauer, J., Korsbakken, J. I., Körtzinger, A., Landschützer, P., Lauvset, S. K., Lefèvre, N., Lienert, S., Liu, J., Marland, G., McGuire, P. C., Melton, J. R., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S.-I., Niwa, Y., Ono, T., Pierrot, D., Poulter, B., Rehder, G., Resplandy, L., Robertson, E., Rödenbeck, C., Rosan, T. M., Schwinger, J., Schwingshackl, C., Séférian, R., Sutton, A. J., Sweeney, C., Tanhua, T., Tans, P. P., Tian, H., Tilbrook, B., Tubiello, F., van der Werf, G. R., Vuichard, N., Wada, C., Wanninkhof, R., Watson, A. J., Willis, D., Wiltshire, A. J., Yuan, W., Yue, C., Yue, X., Zaehle, S., and Zeng, J.: Global Carbon Budget 2021, Earth Syst. Sci. Data, 14, 1917–2005, https://doi.org/10.5194/essd-14-1917-2022, 2022a.

Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Gregor, L., Hauck, J., Le Quéré, C., Luijkx, I. T., Olsen, A., Peters, G. P., Peters, W., Pongratz, J., Schwingshackl, C., Sitch, S., Canadell, J. G., Ciais, P., Jackson, R. B., Alin, S. R., Alkama, R., Arneth, A., Arora, V. K., Bates, N. R., Becker, M., Bellouin, N., Bittig, H. C., Bopp, L., Chevallier, F., Chini, L. P., Cronin, M., Evans, W., Falk, S., Feely, R. A., Gasser, T., Gehlen, M., Gkritzalis, T., Gloege, L., Grassi, G., Gruber, N., Gürses, Ö., Harris, I., Hefner, M., Houghton, R. A., Hurtt, G. C., Iida, Y., Ilyina, T., Jain, A. K., Jersild, A., Kadono, K., Kato, E., Kennedy, D., Klein Goldewijk, K., Knauer, J., Korsbakken, J. I., Landschützer, P., Lefèvre, N., Lindsay, K., Liu, J., Liu, Z., Marland, G., Mayot, N., McGrath, M. J., Metzl, N., Monacci, N. M., Munro, D. R., Nakaoka, S., Niwa, Y., O'Brien, K., Ono, T., Palmer, P. I., Pan, N., Pierrot, D., Pocock, K., Poulter, B., Resplandy, L., Robertson, E., Rödenbeck, C., Rodriguez, C., Rosan, T. M., Schwinger, J., Séférian, R., Shutler, J. D., Skjelvan, I., Steinhoff, T., Sun, Q., Sutton, A. J., Sweeney, C., Takao, S., Tanhua, T., Tans, P. P., Tian, X., Tian, H., Tilbrook, B., Tsujino, H., Tubiello, F., van der Werf, G. R., Walker, A. P., Wanninkhof, R., Whitehead, C., Willstrand Wranne, A., Wright, R., Yuan, W., Yue, C., Yue, X., Zaehle, S., Zeng, J., and Zheng, B.: Global Carbon Budget 2022, Earth Syst. Sci. Data, 14, 4811–4900, https://doi.org/10.5194/essd-14-4811-2022, 2022b.

Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Bakker, D. C. E., Hauck, J., Landschützer, P., Le Quéré, C., Luijkx, I. T., Peters, G. P., Peters, W., Pongratz, J., Schwingshackl, C., Sitch, S., Canadell, J. G., Ciais, P., Jackson, R. B., Alin, S. R., Anthoni, P., Barbero, L., Bates, N. R., Becker, M., Bellouin, N., Decharme, B., Bopp, L., Brasika, I. B. M., Cadule, P., Chamberlain, M. A., Chandra, N., Chau, T.-T.-T., Chevallier, F., Chini, L. P., Cronin, M., Dou, X., Enyo, K., Evans, W., Falk, S., Feely, R. A., Feng, L., Ford, D. J., Gasser, T., Ghattas, J., Gkritzalis, T., Grassi, G., Gregor, L., Gruber, N., Gürses, Ö., Harris, I., Hefner, M., Heinke, J., Houghton, R. A., Hurtt, G. C., Iida, Y., Ilyina, T., Jacobson, A. R., Jain, A. K., Jarníková, T., Jersild, A., Jiang, F., Jin, Z., Joos, F., Kato, E., Keeling, R. F., Kennedy, D., Klein Goldewijk, K., Knauer, J., Korsbakken, J. I., Körtzinger, A., Lan, X., Lefèvre, N., Li, H., Liu, J., Liu, Z., Ma, L., Marland, G., Mayot, N., McGuire, P. C., McKinley, G. A., Meyer, G., Morgan, E. J., Munro, D. R., Nakaoka, S., Niwa, Y., O'Brien, K. M., Olsen, A., Omar, A. M., Ono, T., Paulsen, M., Pierrot, D., Pocock, K., Poulter, B., Powis, C. M., Rehder, G., Resplandy, L., Robertson, E., Rödenbeck, C., Rosan, T. M., Schwinger, J., Séférian, R., Smallman, T. L., Smith, S. M., Sospedra-Alfonso, R., Sun, Q., Sutton, A. J., Sweeney, C., Takao, S., Tans, P. P., Tian, H., Tilbrook, B., Tsujino, H., Tubiello, F., van der Werf, G. R., van

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Ooijen, E., Wanninkhof, R., Watanabe, M., Wimart-Rousseau, C., Yang, D., Yang, X., Yuan, W., Yue, X., Zaehle, S., Zeng, J., and Zheng, B.: Global Carbon Budget 2023, Earth Syst. Sci. Data, 15, 5301–5369, https://doi.org/10.5194/essd-15-5301-2023, 2023.

Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Hauck, J., Landschützer, P., Le Quéré, C., Li, H., Luijkx, I. T., Olsen, A., Peters, G. P., Peters, W., Pongratz, J., Schwingshackl, C., Sitch, S., Canadell, J. G., Ciais, P., Jackson, R. B., Alin, S. R., Arneth, A., Arora, V., Bates, N. R., Becker, M., Bellouin, N., Berghoff, C. F., Bittig, H. C., Bopp, L., Cadule, P., Campbell, K., Chamberlain, M. A., Chandra, N., Chevallier, F., Chini, L. P., Colligan, T., Decayeux, J., Djeutchouang, L. M., Dou, X., Duran Rojas, C., Enyo, K., Evans, W., Fay, A. R., Feely, R. A., Ford, D. J., Foster, A., Gasser, T., Gehlen, M., Gkritzalis, T., Grassi, G., Gregor, L., Gruber, N., Gürses, Ö., Harris, I., Hefner, M., Heinke, J., Hurtt, G. C., Iida, Y., Ilyina, T., Jacobson, A. R., Jain, A. K., Jarníková, T., Jersild, A., Jiang, F., Jin, Z., Kato, E., Keeling, R. F., Klein Goldewijk, K., Knauer, J., Korsbakken, J. I., Lauvset, S. K., Lefèvre, N., Liu, Z., Liu, J., Ma, L., Maksyutov, S., Marland, G., Mayot, N., McGuire, P. C., Metzl, N., Monacci, N. M., Morgan, E. J., Nakaoka, S., Neill, C., Niwa, Y., Nützel, T., Olivier, L., Ono, T., Palmer, P. I., Pierrot, D., Qin, Z., Resplandy, L., Roobaert, A., Rosan, T. M., Rödenbeck, C., Schwinger, J., Smallman, T. L., Smith, S. M., Sospedra-Alfonso, R., Steinhoff, T., Sun, Q., Sutton, A. J., Séférian, R., Takao, S., Tatebe, H., Tian, H., Tilbrook, B., Torres, O., Tourigny, E., Tsujino, H., Tubiello, F., van der Werf, G., Wanninkhof, R., Wang, X., Yang, D., Yang, X., Yu, Z., Yuan, W., Yue, X., Zaehle, S., Zeng, N., Zeng, J.: Supplemental data of the Global Carbon Budget 2024, ICOS-ERIC Carbon Portal, https://doi.org/10.18160/GCP-2024, 2024.

Ganzenmüller, R., Bultan, S., Winkler, K., Fuchs, R., Zabel, F., and Pongratz, J.: Land-use change emissions based on high-resolution activity data substantially lower than previously estimated, Environ. Res. Lett., 17, 064050, https://doi.org/10.1088/1748-9326/ac70d8, 2022.

Gasser, T., Crepin, L., Quilcaille, Y., Houghton, R. A., Ciais, P., and Obersteiner, M.: Historical CO2 emissions from land use and land cover change and their uncertainty, Biogeosciences, 17, 4075–4101, https://doi.org/10.5194/bg-17-4075-2020, 2020.

Gaubert, B., Stephens, B. B., Basu, S., Chevallier, F., Deng, F., Kort, E. A., Patra, P. K., Peters, W., Rödenbeck, C., Saeki, T., Schimel, D., Van der Laan-Luijkx, I., Wofsy, S., and Yin, Y.: Global atmospheric CO2 inverse models converging on neutral tropical land exchange, but disagreeing on fossil fuel and atmospheric growth rate, Biogeosciences, 16, 117–134, https://doi.org/10.5194/bg-16-117-2019, 2019.

GCP: The Global Carbon Budget 2007, available at: http://www. globalcarbonproject.org/carbonbudget/archive.htm, last access: 28 October 2024, 2007.

Giglio, L., Schroeder, W., and Justice, C. O.: The collection 6 MODIS active fire detection algorithm and fire products, Remote Sensing of Environment, 178, 31–41, https://doi.org/10.1016/j.rse.2016.02.054, 2016.

Gloege, L., McKinley, G. A., Landschützer, P., Fay, A. R., Frölicher, T. L., Fyfe, J. C., Ilyina, T., Jones, S., Lovenduski, N. S., Rodgers, K. B., Schlunegger, S., and Takano, Y.: Quantifying Errors in Observationally Based Estimates of Ocean Carbon Sink Variability, Global Biogeochem. Cy., 35, e2020GB006788, https://doi.org/10.1029/2020GB006788, 2021.

Gloege, L., Yan, M., Zheng, T., and McKinley, G. A.: Improved Quantification of Ocean Carbon Uptake by Using Machine Learning to Merge Global Models and pCO2 Data, J. Adv. Model. Earth Syst., 14, e2021MS002620, https://doi.org/10.1029/2021MS002620, 2022.

Deleted: 9 November 2023

Golar, G., Malik, A., Muis, H., Herman, A., Nurudin, N., and Lukman, L.: The social-economic impact of COVID-19 pandemic: implications for potential forest degradation, Heliyon, 6, e05354, https://doi.org/10.1016/j.heliyon.2020.e05354, 2020.

Goris, N., Tjiputra, J. F., Olsen, A., Schwinger, J., Lauvset, S. K., and Jeansson, E.: Constraining Projection-Based Estimates of the Future North Atlantic Carbon Uptake, J. Clim., 31, 3959–3978, https://doi.org/10.1175/JCLI-D-17-0564.1, 2018.

Grassi, G., House, J., Kurz, W. A., Cescatti, A., Houghton, R. A., Peters, G. P., Sanz, M. J., Viñas, R. A., Alkama, R., Arneth, A., Bondeau, A., Dentener, F., Fader, M., Federici, S., Friedlingstein, P., Jain, A. K., Kato, E., Koven, C. D., Lee, D., Nabel, J. E. M. S., Nassikas, A. A., Perugini, L., Rossi, S., Sitch, S., Viovy, N., Wiltshire, A., and Zaehle, S.: Reconciling global-model estimates and country reporting of anthropogenic forest CO2 sinks, Nature Clim Change, 8, 914–920, https://doi.org/10.1038/s41558-018-0283-x, 2018.

Grassi, G., Stehfest, E., Rogelj, J., van Vuuren, D., Cescatti, A., House, J., Nabuurs, G.-J., Rossi, S., Alkama, R., Viñas, R. A., Calvin, K., Ceccherini, G., Federici, S., Fujimori, S., Gusti, M., Hasegawa, T., Havlik, P., Humpenöder, F., Korosuo, A., Perugini, L., Tubiello, F. N., and Popp, A.: Critical adjustment of land mitigation pathways for assessing countries' climate progress, Nat. Clim. Chang., 11, 425–434, https://doi.org/10.1038/s41558-021-01033-6, 2021.

Grassi, G., Schwingshackl, C., Gasser, T., Houghton, R. A., Sitch, S., Canadell, J. G., Cescatti, A., Ciais, P., Federici, S., Friedlingstein, P., Kurz, W. A., Sanz Sanchez, M. J., Abad Viñas, R., Alkama, R., Bultan, S., Ceccherini, G., Falk, S., Kato, E., Kennedy, D., Knauer, J., Korosuo, A., Melo, J., McGrath, M. J., Nabel, J. E. M. S., Poulter, B., Romanovskaya, A. A., Rossi, S., Tian, H., Walker, A. P., Yuan, W., Yue, X., and Pongratz, J.: Harmonising the land-use flux estimates of global models and national inventories for 2000–2020, Earth Syst. Sci. Data, 15, 1093–1114, https://doi.org/10.5194/essd-15-1093-2023, 2023.

Gregor, L., Lebehot, A. D., Kok, S., and Scheel Monteiro, P. M.: A comparative assessment of the uncertainties of global surface ocean CO< sub> 2</sub> estimates using a machine-learning ensemble (CSIR-ML6 version 2019a)–have we hit the wall?. Geoscientific Model Development, 12(12), 5113-5136, https://doi.org/10.5194/gmd-12-5113-2019, 2019.

Gregor, L., Shutler, J., and Gruber, N.: High-resolution variability of the ocean carbon sink. Global Biogeochemical Cycles, 38(8), e2024GB008127, https://doi.org/10.1029/2024GB008127, 2024.

Gruber, N., Bakker, D. C. E., DeVries, T., Gregor, L., Hauck, J., Landschützer, P., McKinley, G. A., and Müller, J. D.: Trends and variability in the ocean carbon sink, Nat. Rev. Earth Environ., 4, 119–134, https://doi.org/10.1038/s43017-022-00381-x, 2023.

Gruber, N., Clement, D., Carter, B. R., Feely, R. A., van Heuven, S., Hoppema, M., Ishii, M., Key, R. M., Kozyr, A., Lauvset, S. K., Lo Monaco, C., Mathis, J. T., Murata, A., Olsen, A., Perez, F. F., Sabine, C. L., Tanhua, T., and Wanninkhof, R.: The oceanic sink for anthropogenic CO2 from 1994 to 2007, 363, 1193–1199, https://doi.org/10.1126/science.aau5153, 2019.

Guan, D., Liu, Z., Geng, Y., Lindner, S., and Hubacek, K.: The gigatonne gap in China's carbon dioxide inventories, Nature Clim Change, 2, 672–675, https://doi.org/10.1038/nclimate1560, 2012.

Gulev, S. K., Thorne, P. W., Ahn, J., Dentener, F. J., Domingues, C. M., Gerland, S., Gong, D. S., Kaufman, S., Nnamchi, H. C., Quaas, J., Rivera, J. A., Sathyendranath, S., Smith, S. L., Trewin, B., von Shuckmann, K., and Vose, R. S.: Changing

Formatted: Normal

Deleted: .

Deleted: Gruber, N.: OceanSODA-ETHZ: a global gridded data set…

Deleted: carbonate system for seasonal to decadal studies of ocean acidification, 13, 777–808

Deleted: essd-13-777-2021, 2021

State of the Climate System. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R. and Zhou, B. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 287–422, https://doi.org/10.1017/9781009157896.004, 2021.

Guo, R., Wang, J., Bing, L., Tong, D., Ciais, P., Davis, S. J., Andrew, R. M., Xi, F., and Liu, Z.: Global CO2 uptake by cement from 1930 to 2019, 13, 1791–1805, https://doi.org/10.5194/essd-13-1791-2021, 2021.

Gürses, Ö., Oziel, L., Karakuş, O., Sidorenko, D., Völker, C., Ye, Y., Zeising, M., Butzin, M., and Hauck, J.: Ocean biogeochemistry in the coupled ocean–sea ice–biogeochemistry model FESOM2.1–REcoM3, Geosci. Model Dev., 16, 4883–4936, https://doi.org/10.5194/gmd-16-4883-2023, 2023.

Gütschow, J., Jeffery, M. L., Gieseke, R., Gebel, R., Stevens, D., Krapp, M., and Rocha, M.: The PRIMAP-hist national historical emissions time series, 8, 571–603, https://doi.org/10.5194/essd-8-571-2016, 2016.

Gütschow, J., Busch, D. and Pflüger, M.: The PRIMAP-hist national historical emissions time series (1750-2023) v2.6, Zenodo [dataset], https://doi.org/10.5281/zenodo.13752654, 2023.

Hall, B. D., Crotwell, A. M., Kitzis, D. R., Mefford, T., Miller, B. R., Schibig, M. F., and Tans, P. P.: Revision of the World Meteorological Organization Global Atmosphere Watch (WMO/GAW) CO2 calibration scale, 14, 3015–3032, https://doi.org/10.5194/amt-14-3015-2021, 2021.

Hansis, E., Davis, S. J., and Pongratz, J.: Relevance of methodological choices for accounting of land use change carbon fluxes, Global Biogeochem. Cycles, 29, 1230–1246, https://doi.org/10.1002/2014GB004997, 2015.

Hauck, J., Nissen, C., Landschützer, P., Rödenbeck, C., Bushinsky, S., and Olsen, A.: Sparse observations induce large biases in estimates of the global ocean CO2 sink: an ocean model subsampling experiment, Philos. Trans. R. Soc. Math. Phys. Eng. Sci., 381, 20220063, https://doi.org/10.1098/rsta.2022.0063, 2023a.

Hauck, J., Gregor, L., Nissen, C., Patara, L., Hague, M., Mongwe, P., Bushinsky, S., Doney, S. C., Gruber, N., Le Quéré, C., Manizza, M., Mazloff, M., Monteiro, P. M. S., and Terhaar, J.: The Southern Ocean Carbon Cycle 1985–2018: Mean, Seasonal Cycle, Trends, and Storage. Global Biogeochemical Cycles, 37(11), e2023GB007848, https://doi.org/10.1029/2023GB007848, 2023b.

Hauck, J., Zeising, M., Le Quéré, C., Gruber, N., Bakker, D. C. E., Bopp, L., Chau, T. T. T., Gürses, Ö., Ilyina, T., Landschützer, P., Lenton, A., Resplandy, L., Rödenbeck, C., Schwinger, J., and Séférian, R.: Consistency and Challenges in the Ocean Carbon Sink Estimate for the Global Carbon Budget, Front. Mar. Sci., 7, 571720, https://doi.org/10.3389/fmars.2020.571720, 2020.

Haverd, V., Smith, B., Nieradzik, L., Briggs, P. R., Woodgate, W., Trudinger, C. M., Canadell, J. G., and Cuntz, M.: A new version of the CABLE land surface model (Subversion revision r4601) incorporating land use and land cover change, woody vegetation demography, and a novel optimisation-based approach to plant coordination of photosynthesis, Geosci. Model Dev., 11, 2995–3026, https://doi.org/10.5194/gmd-11-2995-2018, 2018.

Formatted: Normal

Deleted: :

Deleted: . (2023):

Deleted: v2.4.2

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Formatted: English (UK)

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Formatted: English (UK)

Heinke, J., Rolinski, S., and Müller, C.: Modelling the role of livestock grazing in C and N cycling in grasslands with LPJmL5.0-grazing, Geosci. Model Dev., 16, 2455–2475, https://doi.org/10.5194/gmd-16-2455-2023, 2023.

Hefner, M., Marland, G., Boden, T., Andres, R.: Global, Regional, and National Fossil-Fuel CO2 Emissions: 1751-2020 CDIAC-FF [dataset], available at: https://energy.appstate.edu/cdiac-appstate/data-products, last access: 28 October 2024, 2023.

Hefner, M; Marland G; (2023): Global, Regional, and National Fossil-Fuel CO2 Emissions: 1751-2020 CDIAC-FF, Research Institute for Environment, Energy, and Economics, Appalachian State University, https://rieee.appstate.edu/projects-programs/cdiac

Hickler, T., Smith, B., Prentice, I. C., Mjöfors, K., Miller, P., Arneth, A., and Sykes, M. T.: CO2 fertilization in temperate FACE experiments not representative of boreal and tropical forests, Glob. Change Biol., 14, 1531–1542, https://doi.org/10.1111/j.1365-2486.2008.01598.x, 2008.

Hoesly, R. M., Smith, S. J., Feng, L., Klimont, Z., Janssens-Maenhout, G., Pitkanen, T., Seibert, J. J., Vu, L., Andres, R. J., Bolt, R. M., Bond, T. C., Dawidowski, L., Kholod, N., Kurokawa, J., Li, M., Liu, L., Lu, Z., Moura, M. C. P., O'Rourke, P. R., and Zhang, Q.: Historical (1750–2014) anthropogenic emissions of reactive gases and aerosols from the Community Emissions Data System (CEDS), Geosci. Model Dev., 11, 369–408, https://doi.org/10.5194/gmd-11-369-2018, 2018.

Hoesly, R., Smith, S. J., Prime, N., Ahsan, H., Suchyta, H., O'Rourke, P., Crippa, M., Klimont, Z., Guizzardi, D., Behrendt, J., Feng, L., Harkins, C., McDonald, B., Mott, A., McDuffie, A., Nicholson, M. and Wang, S.: CEDS v_2024_07_08 Release Emission Data, Zenodo [dataset], https://doi.org/10.5281/zenodo.12803196, 2024.

Hong, C., Burney, J. A., Pongratz, J., Nabel, J. E. M. S., Mueller, N. D., Jackson, R. B., and Davis, S. J.: Global and regional drivers of land-use emissions in 1961–2017, Nature, 589, 554–561, https://doi.org/10.1038/s41586-020-03138-y, 2021.

Holding, T., Ashton, I. G., Shutler, J. D., Land, P. E., Nightingale, P. D., Rees, A. P., Brown, I., Piolle, J.-F., Kock, A., Bange, H. W., Woolf, D. K., Goddijn-Murphy, L., Pereira, R., Paul, F., Girard-Ardhuin, F., Chapron, B., Rehder, G., Ardhuin, F., and Donlon, C. J.: The FluxEngine air–sea gas flux toolbox: simplified interface and extensions for in situ analyses and multiple sparingly soluble gases, Ocean Sci., 15, 1707–1728, https://doi.org/10.5194/os-15-1707-2019, 2019.

Houghton, R. A. and Castanho, A.: Annual emissions of carbon from land use, land-use change, and forestry from 1850 to 2020, Earth Syst. Sci. Data, 15, 2025–2054, https://doi.org/10.5194/essd-15-2025-2023, 2023.

Houghton, R. A., House, J. I., Pongratz, J., van der Werf, G. R., DeFries, R. S., Hansen, M. C., Le Quéré, C., and Ramankutty, N.: Carbon emissions from land use and land-cover change, Biogeosciences, 9, 5125–5142, https://doi.org/10.5194/bg-9-5125-2012, 2012.

Huang, B., Thorne, P. W., Banzon, V. F., Boyer, T., Chepurin, G., Lawrimore, J. H., Menne, M. J., Smith, T. M., Vose, R. S., and Zhang, H.-M.: NOAA Extended Reconstructed Sea Surface Temperature (ERSST), Version 5, https://doi.org/10.7289/V5T72FNM, 2017.

Hubau, W., Lewis, S.L., Phillips, O.L., Affum-Baffoe, K., Beeckman, H., Cuní-Sanchez, A., Daniels, A.K., Ewango, C.E.N., Fauset, S., Mukinzi, J.M., Sheil, D., Sonké, B., Sullivan, M.J.P., Sunderland, T.C.H., Taedoumg, H., Thomas, S.C., White, L.J.T., Abernethy, K.A., Adu-Bredu, S., Amani, C.A., Baker, T.R., Banin, L.F., Baya, F., Begne, S.K., Bennett, A.C.,

Formatted: Normal

Deleted: 9 November 2023

Formatted: Normal

Benedet, F., Bitariho, R., Bocko, Y.E., Boeckx, P., Boundja, P., Brienen, R.J.W., Brncic, T., Chezeaux, E., Chuyong, G.B., Clark, C.J., Collins, M., Comiskey, J.A., Coomes, D.A., Dargie, G.C., de Haulleville, T., Kamdem, M.N.D., Doucet, J.-L., Esquivel-Muelbert, A., Feldpausch, T.R., Fofanah, A., Foli, E.G., Gilpin, M., Gloor, E., Gonmadje, C., Gourlet-Fleury, S., Hall, J.S., Hamilton, A.C., Harris, D.J., Hart, T.B., Hockemba, M.B.N., Hladik, A., Ifo, S.A., Jeffery, K.J., Jucker, T., Yakusu, E.K., Kearsley, E., Kenfack, D., Koch, A., Leal, M.E., Levesley, A., Lindsell, J.A., Lisingo, J., Lopez-Gonzalez, G., Lovett, J.C., Makana, J.-R., Malhi, Y., Marshall, A.R., Martin, J., Martin, E.H., Mbayu, F.M., Medjibe, V.P., Mihindou, V., Mitchard, E.T.A., Moore, S., Munishi, P.K.T., Bengone, N.N., Ojo, L., Ondo, F.E., Peh, K.S.-H., Pickavance, G.C., Poulsen, A.D., Poulsen, J.R., Qie, L., Reitsma, J., Rovero, F., Swaine, M.D., Talbot, J., Taplin, J., Taylor, D.M., Thomas, D.W., Toirambe, B., Mukendi, J.T., Tuagben, D., Umunay, P.M., van der Heijden, G.M.F., Verbeeck, H., Vleminckx, J., Willcock, S., Wöll, H., Woods, J.T., Zemagho, L.: Asynchronous carbon sink saturation in African and Amazonian tropical forests, Nature, 579, 80–87, https://doi.org/10.1038/s41586-020-2035-0, 2020.

Humphrey, V., Zscheischler, J., Ciais, P., Gudmundsson, L., Sitch, S., and Seneviratne, S. I.: Sensitivity of atmospheric CO2 growth rate to observed changes in terrestrial water storage, Nature, 560, 628–631, https://doi.org/10.1038/s41586-018-0424-4, 2018.

Humphrey, V., Berg, A., Ciais, P., Gentine, P., Jung, M., Reichstein, M., Seneviratne, S. I., and Frankenberg, C.: Soil moisture–atmosphere feedback dominates land carbon uptake variability, Nature, 592, 65–69, https://doi.org/10.1038/s41586-021-03325-5, 2021.

Huntzinger, D. N., Michalak, A. M., Schwalm, C., Ciais, P., King, A. W., Fang, Y., Schaefer, K., Wei, Y., Cook, R. B., Fisher, J. B., Hayes, D., Huang, M., Ito, A., Jain, A. K., Lei, H., Lu, C., Maignan, F., Mao, J., Parazoo, N., Peng, S., Poulter, B., Ricciuto, D., Shi, X., Tian, H., Wang, W., Zeng, N., and Zhao, F.: Uncertainty in the response of terrestrial carbon sink to environmental drivers undermines carbon-climate feedback predictions, Sci Rep, 7, 4765, https://doi.org/10.1038/s41598-017-03818-2, 2017.

Iida, Y., Takatani, Y., Kojima, A., and Ishii, M.: Global trends of ocean CO2 sink and ocean acidification: an observation-based reconstruction of surface ocean inorganic carbon variables, J Oceanogr, 77, 323–358, https://doi.org/10.1007/s10872-020-00571-5, 2021.

Ilyina, T., Li, H., Spring, A., Müller, W. A., Bopp, L., Chikamoto, M. O., Danabasoglu, G., Dobrynin, M., Dunne, J., Fransner, F., Friedlingstein, P., Lee, W., Lovenduski, N. S., Merryfield, W. j., Mignot, J., Park, J. y., Séférian, R., Sospedra-Alfonso, R., Watanabe, M., and Yeager, S.: Predictable Variations of the Carbon Sinks and Atmospheric CO2 Growth in a Multi-Model Framework, Geophys. Res. Lett., 48, e2020GL090695, https://doi.org/10.1029/2020GL090695, 2021.

IMF: International Monetary Fund: World Economic Outlook, available at: http://www.imf.org, last access: 28 October 2024, 2023.

Deleted: 9 November 2023

Instituto Nacional de Pesquisas Espaciais (INPE): Portal TerraBrasilis, available at: http://terrabrasilis.dpi.inpe.br/en/home-page/, last access: 28 October 2024.

IPCC: Annex II: Glossary [Möller, V, J.B.R. Matthews, R. van Diemen, C. Méndez, S. Semenov, J.S. Fuglestvedt, A. Reisinger (eds.)]. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)], in:

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Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Möller, V, J.B.R. Matthews, R. van Diemen, C. Méndez, S. Semenov, J.S. Fuglestvedt, A. Reisinger (eds.)], Cambridge University Press, Cambridge, UK and New York, NY, 2897–2930, https://doi.org/10.1017/9781009325844.029, 2023.

Ito, A. and Inatomi, M.: Use of a process-based model for assessing the methane budgets of global terrestrial ecosystems and evaluation of uncertainty, 9, 759–773, https://doi.org/10.5194/bg-9-759-2012, 2012.

Jackson, R. B., Canadell, J. G., Le Quéré, C., Andrew, R. M., Korsbakken, J. I., Peters, G. P., and Nakicenovic, N.: Reaching peak emissions, Nature Clim Change, 6, 7–10, https://doi.org/10.1038/nclimate2892, 2016.

Jackson, R. B., Le Quéré, C., Andrew, R. M., Canadell, J. G., Korsbakken, J. I., Liu, Z., Peters, G. P., and Zheng, B.: Global energy growth is outpacing decarbonization, Environ. Res. Lett., 13, 120401, https://doi.org/10.1088/1748-9326/aaf303, 2018.

Jackson, R. B., Friedlingstein, P., Andrew, R. M., Canadell, J. G., Le Quéré, C., and Peters, G. P.: Persistent fossil fuel growth threatens the Paris Agreement and planetary health, Environ. Res. Lett., 14, 121001, https://doi.org/10.1088/1748-9326/ab57b3, 2019.

Jackson, R. B., Friedlingstein, P., Quéré, C. L., Abernethy, S., Andrew, R. M., Canadell, J. G., Ciais, P., Davis, S. J., Deng, Z., Liu, Z., Korsbakken, J. I., and Peters, G. P.: Global fossil carbon emissions rebound near pre-COVID-19 levels, Environ. Res. Lett., 17, 031001, https://doi.org/10.1088/1748-9326/ac55b6, 2022.

Jacobson, A. R., Schuldt, K. N., Tans, P., Andrews, A., Miller, J. B., Oda, T., Basu, S., Mund, J., Weir, B., Ott, L., Aalto, T., Abshire, J. B., Aikin, K., Aoki, S., Apadula, F., Arnold, S., Baier, B., Bartyzel, J., Beyersdorf, A., Biermann, T., Biraud, S. C., Boenisch, H., Brailsford, G., Brand, W. A., Chen, G., Chen, H., Chmura, L., Clark, S., Colomb, A., Commane, R., Conil, S., Couret, C., Cox, A., Cristofanelli, P., Cuevas, E., Curcoll, R., Daube, B., Davis, K. J., De Wekker, S., Della Coletta, J., Delmotte, M., DiGangi, E., DiGangi, J. P., di Sarra, A. G., Dlugokencky, E., Elkins, J. W., Emmenegger, L., Fang, S., Fischer, M. L., Forster, G., Frumau, A., Galkowski, M., Gatti, L. V., Gehrlein, T., Gerbig, C., Gheusi, F., Gloor, E., Gomez-Trueba, V., Goto, D., Griffis, T., Hammer, S., Hanson, C., Haszpra, L., Hatakka, J., Heimann, M., Heliasz, M., Hensen, A., Hermansen, O., Hintsa, E., Holst, J., Ivakhov, V., Jaffe, D. A., Jordan, A., Joubert, W., Karion, A., Kawa, S. R., Kazan, V., Keeling, R. F., Keronen, P., Kneuer, T., Kolari, P., Komínková, K., Kort, E., Kozlova, E., Krummel, P., Kubistin, D., Labuschagne, C., Lam, D. H. Y., Lan, X., Langenfelds, R. L., Laurent, O., Laurila, T., Lauvaux, T., Lavric, J., Law, B. E., Lee, J., Lee, O. S. M., Lehner, I., Lehtinen, K., Leppert, R., Leskinen, A., Leuenberger, M., Levin, I., Levula, J., Lin, J., Lindauer, M., Loh, Z., Lopez, M., Luijkx, I. T., Lunder, C. R., Machida, T., Mammarella, I., Manca, G., Manning, A., Manning, A., Marek, M. V., Martin, M. Y., Matsueda, H., McKain, K., Meijer, H., Meinhardt, F., Merchant, L., Mihalopoulos, N., Miles, N. L., Miller, C. E., Mitchell, L., Mölder, M., Montzka, S., Moore, F., Moossen, H., Morgan, E., Morgui, J.-A., Morimoto, S., Müller-Williams, J., Munger, J. W., Munro, D., Myhre, C. L., Nakaoka, S.-I., Necki, J., Newman, S., Nichol, S., Niwa, Y., Obersteiner, F., O'Doherty, S., Paplawsky, B., Peischl, J., Peltola, O., Piacentino, S., Pichon, J.-M., Pickers, P., Piper, S., Pitt, J., Plass-Dülmer, C., Platt, S. M., Prinzivalli, S., Ramonet, M., Ramos, R., Reyes-Sanchez, E., Richardson, S. J., Riris, H., Rivas, P. P., Ryerson, T., Saito, K., Sargent, M., Sasakawa, M., Scheeren, B., Schuck, T., Schumacher, M., Seifert, T., Sha, M. K., Shepson, P., Shook, M., Sloop, C. D., Smith, P., Stanley, K., Steinbacher, M., Stephens, B., Sweeney, C., Thoning, K., Timas, H., Torn, M., Tørseth, K., Trisolino, P., Turnbull, J., van den Bulk, P., van Dinther, D., Vermeulen, A., Viner, B., Vitkova, G., Walker, S., Watson, A., Wofsy, S. C., Worsey, J.,

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Worthy, D., Young, D., Zaehle, S., Zahn, A., and Zimnoch, M.: CarbonTracker CT2022, NOAA GML [dataset], https://doi.org/10.25925/Z1GJ-3254, 2023a.

Jacobson, A. R., Schuldt, K. N., Tans, P., Andrews, A., Miller, J. B., Oda, T., Basu, S., Mund, J., Weir, B., Ott, L., Aalto, T., Abshire, J. B., Aikin, K., Aoki, S., Apadula, F., Arnold, S., Baier, B., Bartyzel, J., Beyersdorf, A., Biermann, T., Biraud, S. C., Boenisch, H., Brailsford, G., Brand, W. A., Chen, G., Chen, H., Chmura, L., Clark, S., Colomb, A., Commane, R., Conil, S., Couret, C., Cox, A., Cristofanelli, P., Cuevas, E., Curcoll, R., Daube, B., Davis, K. J., De Wekker, S., Della Coletta, J., Delmotte, M., DiGangi, E., DiGangi, J. P., di Sarra, A. G., Dlugokencky, E., Elkins, J. W., Emmenegger, L., Fang, S., Fischer, M. L., Forster, G., Frumau, A., Galkowski, M., Gatti, L. V., Gehrlein, T., Gerbig, C., Gheusi, F., Gloor, E., Gomez-Trueba, V., Goto, D., Griffis, T., Hammer, S., Hanson, C., Haszpra, L., Hatakka, J., Heimann, M., Heliasz, M., Hensen, A., Hermansen, O., Hintsa, E., Holst, J., Ivakhov, V., Jaffe, D. A., Jordan, A., Joubert, W., Karion, A., Kawa, S. R., Kazan, V., Keeling, R. F., Keronen, P., Kneuer, T., Kolari, P., Komínková, K., Kort, E., Kozlova, E., Krummel, P., Kubistin, D., Labuschagne, C., Lam, D. H. Y., Lan, X., Langenfelds, R. L., Laurent, O., Laurila, T., Lauvaux, T., Lavric, J., Law, B. E., Lee, J., Lee, O. S. M., Lehner, I., Lehtinen, K., Leppert, R., Leskinen, A., Leuenberger, M., Levin, I., Levula, J., Lin, J., Lindauer, M., Loh, Z., Lopez, M., Luijkx, I. T., Lunder, C. R., Machida, T., Mammarella, I., Manca, G., Manning, A., Manning, A., Marek, M. V., Martin, M. Y., Matsueda, H., McKain, K., Meijer, H., Meinhardt, F., Merchant, L., Mihalopoulos, N., Miles, N. L., Miller, C. E., Mitchell, L., Mölder, M., Montzka, S., Moore, F., Moossen, H., Morgan, E., Morgui, J.-A., Morimoto, S., Müller-Williams, J., Munger, J. W., Munro, D., Myhre, C. L., Nakaoka, S.-I., Necki, J., Newman, S., Nichol, S., Niwa, Y., Obersteiner, F., O'Doherty, S., Paplawsky, B., Peischl, J., Peltola, O., Piacentino, S., Pichon, J.-M., Pickers, P., Piper, S., Pitt, J., Plass-Dülmer, C., Platt, S. M., Prinzivalli, S., Ramonet, M., Ramos, R., Reyes-Sanchez, E., Richardson, S. J., Riris, H., Rivas, P. P., Ryerson, T., Saito, K., Sargent, M., Sasakawa, M., Scheeren, B., Schuck, T., Schumacher, M., Seifert, T., Sha, M. K., Shepson, P., Shook, M., Sloop, C. D., Smith, P., Stanley, K., Steinbacher, M., Stephens, B., Sweeney, C., Thoning, K., Timas, H., Torn, M., Tørseth, K., Trisolino, P., Turnbull, J., van den Bulk, P., van Dinther, D., Vermeulen, A., Viner, B., Vitkova, G., Walker, S., Watson, A., Wofsy, S. C., Worsey, J., Worthy, D., Young, D., Zaehle, S., Zahn, A., and Zimnoch, M.: CarbonTracker CT-NRT.v2023-3, NOAA GML [dataset], https://doi.org/10.25925/7TAF-J322, 2023b.

Jain, P., Barber, Q. E., Taylor, S. W., Whitman, E., Castellanos Acuna, D., Boulanger, Y., Chavardès, R. D., Chen, J., Englefield, P., Flannigan, M., Girardin, M. P., Hanes, C. C., Little, J., Morrison, K., Skakun, R. S., Thompson, D. K., Wang, X., Parisien, M.-A.: Drivers and Impacts of the Record-Breaking 2023 Wildfire Season in Canada. Nature Communications, 15(1), p.6764, https://doi.org/10.1038/s41467-024-51154-7, 2024.

Janssens-Maenhout, G., Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Dentener, F., Bergamaschi, P., Pagliari, V., Olivier, J. G. J., Peters, J. A. H. W., van Aardenne, J. A., Monni, S., Doering, U., Petrescu, A. M. R., Solazzo, E., and Oreggioni, G. D.: EDGAR v4.3.2 Global Atlas of the three major greenhouse gas emissions for the period 1970–2012, Earth Syst. Sci. Data, 11, 959–1002, https://doi.org/10.5194/essd-11-959-2019, 2019.

Jean-Michel, L., Eric, G., Romain, B.-B., Gilles, G., Angélique, M., Marie, D., Clément, B., Mathieu, H., Olivier, L. G., Charly, R., Tony, C., Charles-Emmanuel, T., Florent, G., Giovanni, R., Mounir, B., Yann, D., and Pierre-Yves, L. T.: The Copernicus Global 1/12° Oceanic and Sea Ice GLORYS12 Reanalysis, Front. Earth Sci., 9, 2021.

Jiang, F., Ju, W., He, W., Wu, M., Wang, H., Wang, J., Jia, M., Feng, S., Zhang, L., and Chen, J. M.: A 10-year global monthly averaged terrestrial net ecosystem exchange dataset inferred from the ACOS GOSAT v9 XCO2 retrievals (GCAS2021), Earth Syst. Sci. Data, 14, 3013–3037, https://doi.org/10.5194/essd-14-3013-2022, 2022.

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Deleted: Kateřina

Deleted: et al.: CarbonTracker CT-NRT.v2023-3,

Jiang, F., Wang, H., Chen, J. M., Ju, W., Tian, X., Feng, S., Li, G., Chen, Z., Zhang, S., Lu, X., Liu, J., Wang, H., Wang, J., He, W., and Wu, M.: Regional CO_2 fluxes from 2010 to 2015 inferred from GOSAT XCO_2 retrievals using a new version of the Global Carbon Assimilation System, Atmospheric Chem. Phys., 21, 1963–1985, https://doi.org/10.5194/acp-21-1963-2021, 2021.

Jin, Y., Keeling, R. F., Stephens, B. B., Long, M. C., Patra, P. K., Rödenbeck, C., Morgan, E. J., Kort, E. A., and Sweeney, C.: Improved atmospheric constraints on Southern Ocean CO 2 exchange. Proceedings of the National Academy of Sciences, 121(6), e2309333121, https://doi.org/10.1073/pnas.2309333121, 2024.

Jin, Z., Wang, T., Zhang, H., Wang, Y., Ding, J., and Tian, X.: Constraint of satellite CO_2 retrieval on the global carbon cycle from a Chinese atmospheric inversion system, Sci. China Earth Sci., 66, 609–618, https://doi.org/10.1007/s11430-022-1036-7, 2023.

Joos, F. and Spahni, R.: Rates of change in natural and anthropogenic radiative forcing over the past 20,000 years, Proceedings of the National Academy of Sciences, 105, 1425–1430, https://doi.org/10.1073/pnas.0707386105, 2008.

Jones, C. D., Hickman, J. E., Rumbold, S. T., Walton, J., Lamboll, R. D., Skeie, R. B., Fiedler, S., Forster, P. M., Rogelj, J., Abe, M., Botzet, M., Calvin, K., Cassou, C., Cole, J. N. S., Davini, P., Deushi, M., Dix, M., Fyfe, J. C., Gillett, N. P., Ilyina, T., Kawamiya, M., Kelley, M., Kharin, S., Koshiro, T., Li, H., Mackallah, C., Müller, W. A., Nabat, P., van Noije, T., Nolan, P., Ohgaito, R., Olivié, D., Oshima, N., Parodi, J., Reerink, T. J., Ren, L., Romanou, A., Séférian, R., Tang, Y., Timmreck, C., Tjiputra, J., Tourigny, E., Tsigaridis, K., Wang, H., Wu, M., Wyser, K., Yang, S., Yang, Y., and Ziehn, T.: The Climate Response to Emissions Reductions Due to COVID-19: Initial Results From CovidMIP, Geophys. Res. Lett., 48, e2020GL091883, https://doi.org/10.1029/2020GL091883, 2021a.

Jones, M. W., Abatzoglou, J. T., Veraverbeke, S., Andela, N., Lasslop, G., Forkel, M., Smith, A. J. P., Burton, C., Betts, R. A., van der Werf, G. R., Sitch, S., Canadell, J. G., Santín, C., Kolden, C., Doerr, S. H., and Le Quéré, C.: Global and Regional Trends and Drivers of Fire Under Climate Change, Rev. Geophys., 60, e2020RG000726, https://doi.org/10.1029/2020RG000726, 2022.

Jones, M. W., Andrew, R. M., Peters, G. P., Janssens-Maenhout, G., De-Gol, A. J., Ciais, P., Patra, P. K., Chevallier, F., and Le Quéré, C.: Gridded fossil CO_2 emissions and related O_2 combustion consistent with national inventories 1959–2018, Sci Data, 8, 2, https://doi.org/10.1038/s41597-020-00779-6, 2021b.

Jones, M. W., Andrew, R. M., Peters, G. P., Janssens-Maenhout, G., De-Gol, A. J., Dou, X., Liu, Z., Pickers, P., Ciais, P., Patra, P. K., Chevallier, F., and Le Quéré, C.: Gridded fossil CO_2 emissions and related O_2 combustion consistent with national inventories, Zenodo [dataset], https://doi.org/10.5281/zenodo.13909046, 2024a.

Jones, M. W., Kelley, D. I., Burton, C. A., Di Giuseppe, F., Barbosa, M. L. F., Brambleby, E., Hartley, A. J., Lombardi, A., Mataveli, G., McNorton, J. R., Spuler, F. R., Wessel, J. B., Abatzoglou, J. T., Anderson, L. O., Andela, N., Archibald, S., Armenteras, D., Burke, E., Carmenta, R., Chuvieco, E., Clarke, H., Doerr, S. H., Fernandes, P. M., Giglio, L., Hamilton, D. S., Hantson, S., Harris, S., Jain, P., Kolden, C. A., Kurvits, T., Lampe, S., Meier, S., New, S., Parrington, M., Perron, M. M. G., Qu, Y., Ribeiro, N. S., Saharjo, B. H., San-Miguel-Ayanz, J., Shuman, J. K., Tanpipat, V., van der Werf, G. R., Veraverbeke, S., and Xanthopoulos, G.: State of Wildfires 2023–2024, Earth System Science Data, 16, 3601–3685, https://doi.org/10.5194/essd-16-3601-2024, 2024b.

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Jones, M.W., Veraverbeke, S., Andela, N., Doerr, S.H., Kolden, C., Mataveli, G., Pettinari, M.L., Le Quéré, C., Rosan, T.M., van der Werf, G.R. and van Wees, D.: Global rise in forest fire emissions linked to climate change in the extratropics. Science, 386(6719), p.eadl5889, 2024c.

Jung, M., Reichstein, M., Schwalm, C. R., Huntingford, C., Sitch, S., Ahlström, A., Arneth, A., Camps-Valls, G., Ciais, P., Friedlingstein, P., Gans, F., Ichii, K., Jain, A. K., Kato, E., Papale, D., Poulter, B., Raduly, B., Rödenbeck, C., Tramontana, G., Viovy, N., Wang, Y.-P., Weber, U., Zaehle, S., and Zeng, N.: Compensatory water effects link yearly global land CO2 sink changes to temperature, Nature, 541, 516–520, https://doi.org/10.1038/nature20780, 2017.

Kaiser, J. W., Heil, A., Andreae, M. O., Benedetti, A., Chubarova, N., Jones, L., Morcrette, J.-J., Razinger, M., Schultz, M. G., Suttie, M., and van der Werf, G. R.: Biomass burning emissions estimated with a global fire assimilation system based on observed fire radiative power, Biogeosciences, 9, 527–554, https://doi.org/10.5194/bg-9-527-2012, 2012.

Kato, E., Kinoshita, T., Ito, A., Kawamiya, M., and Yamagata, Y.: Evaluation of spatially explicit emission scenario of land-use change and biomass burning using a process-based biogeochemical model, J. Land Use Sci., 8, 104–122, https://doi.org/10.1080/1747423X.2011.628705, 2013.

Kawasaki, T., Hasumi, H., and Tanaka, Y.: Role of tide-induced vertical mixing in the deep Pacific Ocean circulation, J. Oceanogr., 77, 173–184, https://doi.org/10.1007/s10872-020-00584-0, 2021.

Ke, P., Ciais, P., Sitch, S., Li, W., Bastos, A., Liu, Z., Xu, Y., Gui, X., Bian, J., Goll, D. S., Xi, Y., Li, W., O'Sullivan, M., Goncalves de Souza, J., Friedlingstein, P., Chevallier, F.: Low latency carbon budget analysis reveals a large decline of the land carbon sink in 2023. National Science Review, p.nwae367, https://doi.org/10.1093/nsr/nwae367, 2024.

Keeley, J. E. and Pausas, J. G.: Distinguishing disturbance from perturbations in fire-prone ecosystems, Int. J. Wildland Fire, 28, 282–287, https://doi.org/10.1071/WF18203, 2019.

Keeling, C. D., Bacastow, R. B., Bainbridge, A. E., Ekdahl, C. A., Guenther, P. R., Waterman, L. S., and Chin, J. F. S.: Atmospheric carbon dioxide variations at Mauna Loa Observatory, Hawaii, Tellus A., 28, 538–551, https://doi.org/10.1111/j.2153-3490.1976.tb00701.x, 1976.

Keeling R.F.: Development of an Interferometric Oxygen Analyzer for Precise Measurement of the Atmospheric O2 Mole Fraction, PhD thesis, Harvard University, Cambridge, Massachusetts, available at: https://bluemoon.ucsd.edu/publications/ralph/34_PhDthesis.pdf, last access: 28 October 2024, 1988.

Keeling, R. F., Manning, A. C., Paplawsky, W. J., and Cox, A. C.: On the long-term stability of reference gases for atmospheric O2/N2 and CO2 measurements, Tellus B Chem. Phys. Meteorol., 59, 3–14, https://doi.org/10.1111/j.1600-0889.2006.00196.x, 2007.

Keeling, R. F. and Manning, A. C.: 5.15 - Studies of Recent Changes in Atmospheric O2 Content, in: Treatise on Geochemistry (Second Edition), edited by: Holland, H. D. and Turekian, K. K., Elsevier, Oxford, 385–404, https://doi.org/10.1016/B978-0-08-095975-7.00420-4, 2014.

Keppler, L. and Landschützer, P.: Regional Wind Variability Modulates the Southern Ocean Carbon Sink, Sci Rep, 9, 7384, https://doi.org/10.1038/s41598-019-43826-y, 2019.

Formatted: Normal

Khatiwala, S., Primeau, F., and Hall, T.: Reconstruction of the history of anthropogenic CO2 concentrations in the ocean, Nature, 462, 346–349, https://doi.org/10.1038/nature08526, 2009.

Khatiwala, S., Tanhua, T., Mikaloff Fletcher, S., Gerber, M., Doney, S. C., Graven, H. D., Gruber, N., McKinley, G. A., Murata, A., Ríos, A. F., and Sabine, C. L.: Global ocean storage of anthropogenic carbon, Biogeosciences, 10, 2169–2191, https://doi.org/10.5194/bg-10-2169-2013, 2013.

Kong, Y., Zheng, B., Zhang, Q., and He, K.: Global and regional carbon budget for 2015–2020 inferred from OCO-2 based on an ensemble Kalman filter coupled with GEOS-Chem, Atmospheric Chem. Phys., 22, 10769–10788, https://doi.org/10.5194/acp-22-10769-2022, 2022.

Korsbakken, J. I., Peters, G. P., and Andrew, R. M.: Uncertainties around reductions in China's coal use and CO2 emissions, Nature Clim Change, 6, 687–690, https://doi.org/10.1038/nclimate2963, 2016.

Krinner, G., Viovy, N., de Noblet-Ducoudré, N., Ogée, J., Polcher, J., Friedlingstein, P., Ciais, P., Sitch, S., and Prentice, I. C.: A dynamic global vegetation model for studies of the coupled atmosphere-biosphere system: DVGM for coupled climate studies, Global Biogeochem. Cycles, 19, GB1015, https://doi.org/10.1029/2003GB002199, 2005.

Lacroix, F., Ilyina, T., and Hartmann, J.: Oceanic CO2 outgassing and biological production hotspots induced by pre-industrial river loads of nutrients and carbon in a global modeling approach, Biogeosciences, 17, 55–88, https://doi.org/10.5194/bg-17-55-2020, 2020.

Lacroix, F., Ilyina, T., Mathis, M., Laruelle, G. G., and Regnier, P.: Historical increases in land-derived nutrient inputs may alleviate effects of a changing physical climate on the oceanic carbon cycle, Glob Change Biol, 27, 5491–5513, https://doi.org/10.1111/gcb.15822, 2021.

Lamboll, R. D., Nicholls, Z. R. J., Smith, C. J., Kikstra, J. S., Byers, E., and Rogelj, J.: Assessing the size and uncertainty of remaining carbon budgets, Nat. Clim. Change, https://doi.org/10.1038/s41558-023-01848-5, 2023.

Lamboll, R. D., Jones, C. D., Skeie, R. B., Fiedler, S., Samset, B. H., Gillett, N. P., Rogelj, J., Forster, P. M., 2021: Modifying emissions scenario projections to account for the effects of COVID-19: protocol for CovidMIP, Geosci. Model Dev., 14, 3683–3695, https://doi.org/10.5194/gmd-14-3683-2021, 2021.

Lan, X., Tans, P. and K.W. Thoning: Trends in globally-averaged CO2 determined from NOAA Global Monitoring Laboratory measurements, Version 2024-09. National Oceanic and Atmospheric Administration, Global Monitoring Laboratory (NOAA/GML) [dataset], available at: https://gml.noaa.gov/ccgg/trends/global.html, last access: 28 October 2024, 2024.

Landschützer, P., Gruber, N., Haumann, F. A., Rödenbeck, C., Bakker, D. C. E., van Heuven, S., Hoppema, M., Metzl, N., Sweeney, C., Takahashi, T., Tilbrook, B., and Wanninkhof, R.: The reinvigoration of the Southern Ocean carbon sink, Science, 349, 1221–1224, https://doi.org/10.1126/science.aab2620, 2015.

Landschützer, P., Gruber, N., and Bakker, D. C. E.: Decadal variations and trends of the global ocean carbon sink: decadal air-sea CO2 flux variability, Global Biogeochem. Cycles, 30, 1396–1417, https://doi.org/10.1002/2015GB005359, 2016.

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Lapola, D. M., Pinho, P., Barlow, J., Aragão, L. E. O. C., Berenguer, E., Carmenta, R., Liddy, H. M., Seixas, H., Silva, C. V. J., Silva-Junior, C. H. L., Alencar, A. A. C., Anderson, L. O., Armenteras, D., Brovkin, V., Calders, K., Chambers, J., Chini, L., Costa, M. H., Faria, B. L., Fearnside, P. M., Ferreira, J., Gatti, L., Gutierrez-Velez, V. H., Han, Z., Hibbard, K., Koven, C., Lawrence, P., Pongratz, J., Portela, B. T. T., Rounsevell, M., Ruane, A. C., Schaldach, R., da Silva, S. S., von Randow, C., Walker, W. S.: The drivers and impacts of Amazon forest degradation. Science, 379(6630), p.eabp8622, https://doi.org/10.1126/science.abp8622, 2023.

Law, R. M., Ziehn, T., Matear, R. J., Lenton, A., Chamberlain, M. A., Stevens, L. E., Wang, Y.-P., Srbinovsky, J., Bi, D., Yan, H., and Vohralik, P. F.: The carbon cycle in the Australian Community Climate and Earth System Simulator (ACCESS-ESM1) – Part 1: Model description and pre-industrial simulation, Geosci. Model Dev., 10, 2567–2590, https://doi.org/10.5194/gmd-10-2567-2017, 2017.

Lawrence, D. M., Fisher, R. A., Koven, C. D., Oleson, K. W., Swenson, S. C., Bonan, G., Collier, N., Ghimire, B., van Kampenhout, L., Kennedy, D., Kluzek, E., Lawrence, P. J., Li, F., Li, H., Lombardozzi, D., Riley, W. J., Sacks, W. J., Shi, M., Vertenstein, M., Wieder, W. R., Xu, C., Ali, A. A., Badger, A. M., Bisht, G., van den Broeke, M., Brunke, M. A., Burns, S. P., Buzan, J., Clark, M., Craig, A., Dahlin, K., Drewniak, B., Fisher, J. B., Flanner, M., Fox, A. M., Gentine, P., Hoffman, F., Keppel-Aleks, G., Knox, R., Kumar, S., Lenaerts, J., Leung, L. R., Lipscomb, W. H., Lu, Y., Pandey, A., Pelletier, J. D., Perket, J., Randerson, J. T., Ricciuto, D. M., Sanderson, B. M., Slater, A., Subin, Z. M., Tang, J., Thomas, R. Q., Val Martin, M., and Zeng, X.: The Community Land Model Version 5: Description of New Features, Benchmarking, and Impact of Forcing Uncertainty, J. Adv. Model Earth, Sy., 11, 4245–4287, https://doi.org/10.1029/2018MS001583, 2019.

Le Quéré, C., Rödenbeck, C., Buitenhuis, E. T., Conway, T. J., Langenfelds, R., Gomez, A., Labuschagne, C., Ramonet, M., Nakazawa, T., Metzl, N., Gillett, N., and Heimann, M.: Saturation of the Southern Ocean CO2 Sink Due to Recent Climate Change, Science, 316, 1735–1738, https://doi.org/10.1126/science.1136188, 2007.

Le Quéré, C., Raupach, M. R., Canadell, J. G., Marland, G., Bopp, L., Ciais, P., Conway, T. J., Doney, S. C., Feely, R. A., Foster, P., Friedlingstein, P., Gurney, K., Houghton, R. A., House, J. I., Huntingford, C., Levy, P. E., Lomas, M. R., Majkut, J., Metzl, N., Ometto, J. P., Peters, G. P., Prentice, I. C., Randerson, J. T., Running, S. W., Sarmiento, J. L., Schuster, U., Sitch, S., Takahashi, T., Viovy, N., van der Werf, G. R., and Woodward, F. I.: Trends in the sources and sinks of carbon dioxide, Nature Geosci, 2, 831–836, https://doi.org/10.1038/ngeo689, 2009.

Le Quéré, C., Andres, R. J., Boden, T., Conway, T., Houghton, R. A., House, J. I., Marland, G., Peters, G. P., van der Werf, G. R., Ahlström, A., Andrew, R. M., Bopp, L., Canadell, J. G., Ciais, P., Doney, S. C., Enright, C., Friedlingstein, P., Huntingford, C., Jain, A. K., Jourdain, C., Kato, E., Keeling, R. F., Klein Goldewijk, K., Levis, S., Levy, P., Lomas, M., Poulter, B., Raupach, M. R., Schwinger, J., Sitch, S., Stocker, B. D., Viovy, N., Zaehle, S., and Zeng, N.: The global carbon budget 1959–2011, Earth Syst. Sci. Data, 5, 165–185, https://doi.org/10.5194/essd-5-165-2013, 2013.

Le Quéré, C., Peters, G. P., Andres, R. J., Andrew, R. M., Boden, T. A., Ciais, P., Friedlingstein, P., Houghton, R. A., Marland, G., Moriarty, R., Sitch, S., Tans, P., Arneth, A., Arvanitis, A., Bakker, D. C. E., Bopp, L., Canadell, J. G., Chini, L. P., Doney, S. C., Harper, A., Harris, I., House, J. I., Jain, A. K., Jones, S. D., Kato, E., Keeling, R. F., Klein Goldewijk, K., Körtzinger, A., Koven, C., Lefèvre, N., Maignan, F., Omar, A., Ono, T., Park, G.-H., Pfeil, B., Poulter, B., Raupach, M. R., Regnier, P., Rödenbeck, C., Saito, S., Schwinger, J., Segschneider, J., Stocker, B. D., Takahashi, T., Tilbrook, B., van Heuven, S., Viovy, N., Wanninkhof, R., Wiltshire, A., and Zaehle, S.: Global carbon budget 2013, Earth Syst. Sci. Data, 6, 235–263, https://doi.org/10.5194/essd-6-235-2014, 2014.

Formatted: Normal

Le Quéré, C., Moriarty, R., Andrew, R. M., Peters, G. P., Ciais, P., Friedlingstein, P., Jones, S. D., Sitch, S., Tans, P., Arneth, A., Boden, T. A., Bopp, L., Bozec, Y., Canadell, J. G., Chini, L. P., Chevallier, F., Cosca, C. E., Harris, I., Hoppema, M., Houghton, R. A., House, J. I., Jain, A. K., Johannessen, T., Kato, E., Keeling, R. F., Kitidis, V., Klein Goldewijk, K., Koven, C., Landa, C. S., Landschützer, P., Lenton, A., Lima, I. D., Marland, G., Mathis, J. T., Metzl, N., Nojiri, Y., Olsen, A., Ono, T., Peng, S., Peters, W., Pfeil, B., Poulter, B., Raupach, M. R., Regnier, P., Rödenbeck, C., Saito, S., Salisbury, J. E., Schuster, U., Schwinger, J., Séférian, R., Segschneider, J., Steinhoff, T., Stocker, B. D., Sutton, A. J., Takahashi, T., Tilbrook, B., van der Werf, G. R., Viovy, N., Wang, Y.-P., Wanninkhof, R., Wiltshire, A., and Zeng, N.: Global carbon budget 2014, Earth Syst. Sci. Data, 7, 47–85, https://doi.org/10.5194/essd-7-47-2015, 2015a.

Le Quéré, C., Moriarty, R., Andrew, R. M., Canadell, J. G., Sitch, S., Korsbakken, J. I., Friedlingstein, P., Peters, G. P., Andres, R. J., Boden, T. A., Houghton, R. A., House, J. I., Keeling, R. F., Tans, P., Arneth, A., Bakker, D. C. E., Barbero, L., Bopp, L., Chang, J., Chevallier, F., Chini, L. P., Ciais, P., Fader, M., Feely, R. A., Gkritzalis, T., Harris, I., Hauck, J., Ilyina, T., Jain, A. K., Kato, E., Kitidis, V., Klein Goldewijk, K., Koven, C., Landschützer, P., Lauvset, S. K., Lefèvre, N., Lenton, A., Lima, I. D., Metzl, N., Millero, F., Munro, D. R., Murata, A., Nabel, J. E. M. S., Nakaoka, S., Nojiri, Y., O'Brien, K., Olsen, A., Ono, T., Pérez, F. F., Pfeil, B., Pierrot, D., Poulter, B., Rehder, G., Rödenbeck, C., Saito, S., Schuster, U., Schwinger, J., Séférian, R., Steinhoff, T., Stocker, B. D., Sutton, A. J., Takahashi, T., Tilbrook, B., van der Laan-Luijkx, I. T., van der Werf, G. R., van Heuven, S., Vandemark, D., Viovy, N., Wiltshire, A., Zaehle, S., and Zeng, N.: Global Carbon Budget 2015, Earth Syst. Sci. Data, 7, 349–396, https://doi.org/10.5194/essd-7-349-2015, 2015b.

Le Quéré, C., Andrew, R. M., Canadell, J. G., Sitch, S., Korsbakken, J. I., Peters, G. P., Manning, A. C., Boden, T. A., Tans, P. P., Houghton, R. A., Keeling, R. F., Alin, S., Andrews, O. D., Anthoni, P., Barbero, L., Bopp, L., Chevallier, F., Chini, L. P., Ciais, P., Currie, K., Delire, C., Doney, S. C., Friedlingstein, P., Gkritzalis, T., Harris, I., Hauck, J., Haverd, V., Hoppema, M., Klein Goldewijk, K., Jain, A. K., Kato, E., Körtzinger, A., Landschützer, P., Lefèvre, N., Lenton, A., Lienert, S., Lombardozzi, D., Melton, J. R., Metzl, N., Millero, F., Monteiro, P. M. S., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S., O'Brien, K., Olsen, A., Omar, A. M., Ono, T., Pierrot, D., Poulter, B., Rödenbeck, C., Salisbury, J., Schuster, U., Schwinger, J., Séférian, R., Skjelvan, I., Stocker, B. D., Sutton, A. J., Takahashi, T., Tian, H., Tilbrook, B., van der Laan-Luijkx, I. T., van der Werf, G. R., Viovy, N., Walker, A. P., Wiltshire, A. J., and Zaehle, S.: Global Carbon Budget 2016, Earth Syst. Sci. Data, 8, 605–649, https://doi.org/10.5194/essd-8-605-2016, 2016.

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Pongratz, J., Manning, A. C., Korsbakken, J. I., Peters, G. P., Canadell, J. G., Jackson, R. B., Boden, T. A., Tans, P. P., Andrews, O. D., Arora, V. K., Bakker, D. C. E., Barbero, L., Becker, M., Betts, R. A., Bopp, L., Chevallier, F., Chini, L. P., Ciais, P., Cosca, C. E., Cross, J., Currie, K., Gasser, T., Harris, I., Hauck, J., Haverd, V., Houghton, R. A., Hunt, C. W., Hurtt, G., Ilyina, T., Jain, A. K., Kato, E., Kautz, M., Keeling, R. F., Klein Goldewijk, K., Körtzinger, A., Landschützer, P., Lefèvre, N., Lenton, A., Lienert, S., Lima, I., Lombardozzi, D., Metzl, N., Millero, F., Monteiro, P. M. S., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S., Nojiri, Y., Padin, X. A., Peregon, A., Pfeil, B., Pierrot, D., Poulter, B., Rehder, G., Reimer, J., Rödenbeck, C., Schwinger, J., Séférian, R., Skjelvan, I., Stocker, B. D., Tian, H., Tilbrook, B., Tubiello, F. N., van der Laan-Luijkx, I. T., van der Werf, G. R., van Heuven, S., Viovy, N., Vuichard, N., Walker, A. P., Watson, A. J., Wiltshire, A. J., Zaehle, S., and Zhu, D.: Global Carbon Budget 2017, Earth Syst. Sci. Data, 10, 405–448, https://doi.org/10.5194/essd-10-405-2018, 2018a.

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Hauck, J., Pongratz, J., Pickers, P. A., Korsbakken, J. I., Peters, G. P., Canadell, J. G., Arneth, A., Arora, V. K., Barbero, L., Bastos, A., Bopp, L., Chevallier, F., Chini, L. P., Ciais, P., Doney, S. C., Gkritzalis, T., Goll, D. S., Harris, I., Haverd, V., Hoffman, F. M., Hoppema, M., Houghton, R. A., Hurtt, G., Ilyina, T., Jain, A. K., Johannessen, T., Jones, C. D., Kato, E., Keeling, R. F., Klein Goldewijk, K., Landschützer, P., Lefèvre, N.,

Formatted: Normal

Lienert, S., Liu, Z., Lombardozzi, D., Metzl, N., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S., Neill, C., Olsen, A., Ono, T., Patra, P., Peregon, A., Peters, W., Peylin, P., Pfeil, B., Pierrot, D., Poulter, B., Rehder, G., Resplandy, L., Robertson, E., Rocher, M., Rödenbeck, C., Schuster, U., Schwinger, J., Séférian, R., Skjelvan, I., Steinhoff, T., Sutton, A., Tans, P. P., Tian, H., Tilbrook, B., Tubiello, F. N., van der Laan-Luijkx, I. T., van der Werf, G. R., Viovy, N., Walker, A. P., Wiltshire, A. J., Wright, R., Zaehle, S., and Zheng, B.: Global Carbon Budget 2018, Earth Syst. Sci. Data, 10, 2141–2194, https://doi.org/10.5194/essd-10-2141-2018, 2018b.

Le Quéré, C., Korsbakken, J. I., Wilson, C., Tosun, J., Andrew, R., Andres, R. J., Canadell, J. G., Jordan, A., Peters, G. P., and van Vuuren, D. P.: Drivers of declining CO2 emissions in 18 developed economies, Nat. Clim. Chang., 9, 213–217, https://doi.org/10.1038/s41558-019-0419-7, 2019.

Le Quéré, C., Peters, G. P., Friedlingstein, P., Andrew, R. M., Canadell, J. G., Davis, S. J., Jackson, R. B., and Jones, M. W.: Fossil CO2 emissions in the post-COVID-19 era, Nat. Clim. Chang., 11, 197–199, https://doi.org/10.1038/s41558-021-01001-0, 2021.

Levitus, S., Antonov, J. I., Boyer, T. P., Baranova, O. K., Garcia, H. E., Locarnini, R. A., Mishonov, A. V., Reagan, J. R., Seidov, D., Yarosh, E. S., and Zweng, M. M.: World ocean heat content and thermosteric sea level change (0–2000 m), 1955–2010, Geophys. Res. Lett., 39, https://doi.org/10.1029/2012GL051106, 2012.

Li, H., Ilyina, T., Müller, W. A., and Sienz, F.: Decadal predictions of the North Atlantic CO2 uptake, Nat. Commun., 7, 11076, https://doi.org/10.1038/ncomms11076, 2016.

Li, H., Ilyina, T., Müller, W. A., and Landschützer, P.: Predicting the variable ocean carbon sink, Sci. Adv., 5, eaav6471, https://doi.org/10.1126/sciadv.aav6471, 2019.

Li, H., Ilyina, T., Loughran, T., Spring, A., and Pongratz, J.: Reconstructions and predictions of the global carbon budget with an emission-driven Earth system model, Earth Syst. Dyn., 14, 101–119, https://doi.org/10.5194/esd-14-101-2023, 2023.

Li, W., Ciais, P., Peng, S., Yue, C., Wang, Y., Thurner, M., Saatchi, S. S., Arneth, A., Avitabile, V., Carvalhais, N., Harper, A. B., Kato, E., Koven, C., Liu, Y. Y., Nabel, J. E. M. S., Pan, Y., Pongratz, J., Poulter, B., Pugh, T. A. M., Santoro, M., Sitch, S., Stocker, B. D., Viovy, N., Wiltshire, A., Yousefpour, R., and Zaehle, S.: Land-use and land-cover change carbon emissions between 1901 and 2012 constrained by biomass observations, Biogeosciences, 14, 5053–5067, https://doi.org/10.5194/bg-14-5053-2017, 2017.

Liao, E., Resplandy, L., Liu, J., and Bowman, K. W.: Amplification of the Ocean Carbon Sink During El Niños: Role of Poleward Ekman Transport and Influence on Atmospheric CO2, Global Biogeochem. Cy., 34, e2020GB006574, https://doi.org/10.1029/2020GB006574, 2020.

Lienert, S. and Joos, F.: A Bayesian ensemble data assimilation to constrain model parameters and land-use carbon emissions, Biogeosciences, 15, 2909–2930, https://doi.org/10.5194/bg-15-2909-2018, 2018.

Liu, J., Baskaran, L., Bowman, K., Schimel, D., Bloom, A. A., Parazoo, N. C., Oda, T., Carroll, D., Menemenlis, D., Joiner, J., Commane, R., Daube, B., Gatti, L. V., McKain, K., Miller, J., Stephens, B. B., Sweeney, C., and Wofsy, S.: Carbon Monitoring System Flux Net Biosphere Exchange 2020 (CMS-Flux NBE 2020), 13, 299–330, https://doi.org/10.5194/essd-13-299-2021, 2021.

Formatted: Normal

Liu, Z., Guan, D., Wei, W., Davis, S. J., Ciais, P., Bai, J., Peng, S., Zhang, Q., Hubacek, K., Marland, G., Andres, R. J., Crawford-Brown, D., Lin, J., Zhao, H., Hong, C., Boden, T. A., Feng, K., Peters, G. P., Xi, F., Liu, J., Li, Y., Zhao, Y., Zeng, N., and He, K.: Reduced carbon emission estimates from fossil fuel combustion and cement production in China, Nature, 524, 335–338, https://doi.org/10.1038/nature14677, 2015.

Liu, Z., Zeng, N., Liu, Y., Kalnay, E., Asrar, G., Wu, B., Cai, Q., Liu, D., and Han, P.: Improving the joint estimation of CO2 and surface carbon fluxes using a constrained ensemble Kalman filter in COLA (v1.0), Geosci. Model Dev., 15, 5511–5528, https://doi.org/10.5194/gmd-15-5511-2022, 2022.

Long, M. C., Stephens, B. B., McKain, K., Sweeney, C., Keeling, R. F., Kort, E. A., Morgan, E. J., Bent, J. D., Chandra, N., Chevallier, F., Commane, R., Daube, B. C., Krummel, P. B., Loh, Z., Luijkx, I. T., Munro, D., Patra, P., Peters, W., Ramonet, M., Rödenbeck, C., Stavert, A., Tans, P., Wofsy, S. C.: Strong Southern Ocean carbon uptake evident in airborne observations. Science, 374(6572), 1275–1280, https://doi.org/10.1126/science.abi4355, 2021.

Lovenduski, N. S., Bonan, G. B., Yeager, S. G., Lindsay, K., and Lombardozzi, D. L.: High predictability of terrestrial carbon fluxes from an initialized decadal prediction system, Environ. Res. Lett., 14, 124074, https://doi.org/10.1088/1748-9326/ab5c55, 2019a.

Lovenduski, N. S., Yeager, S. G., Lindsay, K., and Long, M. C.: Predicting near-term variability in ocean carbon uptake, Earth Syst. Dyn., 10, 45–57, https://doi.org/10.5194/esd-10-45-2019, 2019b.

Lutz, F., Herzfeld, T., Heinke, J., Rolinski, S., Schaphoff, S., von Bloh, W., Stoorvogel, J. J., and Müller, C.: Simulating the effect of tillage practices with the global ecosystem model LPJmL (version 5.0-tillage), Geosci. Model Dev., 12, 2419–2440, https://doi.org/10.5194/gmd-12-2419-2019, 2019.

Ma, L., Hurtt, G., Ott, L., Sahajpal, R., Fisk, J., Lamb, R., Tang, H., Flanagan, S., Chini, L., Chatterjee, A., and Sullivan, J.: Global evaluation of the Ecosystem Demography model (ED v3.0), Geosci. Model Dev., 15, 1971–1994, https://doi.org/10.5194/gmd-15-1971-2022, 2022.

Magi, B. I., Rabin, S., Shevliakova, E., and Pacala, S.: Separating agricultural and non-agricultural fire seasonality at regional scales, Biogeosciences, 9, 3003–3012, https://doi.org/10.5194/bg-9-3003-2012, 2012.

Maksyutov, S., Oda, T., Saito, M., Janardanan, R., Belikov, D., Kaiser, J. W., Zhuravlev, R., Ganshin, A., Valsala, V. K., Andrews, A., Chmura, L., Dlugokencky, E., Haszpra, L., Langenfelds, R. L., Machida, T., Nakazawa, T., Ramonet, M., Sweeney, C., and Worthy, D.: Technical note: A high-resolution inverse modelling technique for estimating surface CO2 fluxes based on the NIES-TM–FLEXPART coupled transport model and its adjoint, Atmos. Chem. Phys., 21, 1245–1266, https://doi.org/10.5194/acp-21-1245-2021, 2021.

Masarie, K. A. and Tans, P. P.: Extension and integration of atmospheric carbon dioxide data into a globally consistent measurement record, J. Geophys. Res., 100, 11593, https://doi.org/10.1029/95JD00859, 1995.

Mataveli, G., Jones, M.W., Carmenta, R., Sanchez, A., Dutra, D.J., Chaves, M., de Oliveira, G., Anderson, L.O. and Aragão, L.E.: Deforestation falls but rise of wildfires continues degrading Brazilian Amazon forests. Global Change Biology, 30(2), p.e17202, https://doi.org/10.1111/gcb.17202, 2024.

Formatted: Normal

Mather, A. S.: The transition from deforestation to reforestation in Europe, in: Agricultural technologies and tropical deforestation (eds. Angelsen, A.; Kaimowitz, D.), CABI in association with centre for international Forestry Research, 35–52, 2001.

Mauritsen, T., Bader, J., Becker, T., Behrens, J., Bittner, M., Brokopf, R., Brovkin, V., Claussen, M., Crueger, T., Esch, M., Fast, I., Fiedler, S., Fläschner, D., Gayler, V., Giorgetta, M., Goll, D. S., Haak, H., Hagemann, S., Hedemann, C., Hohenegger, C., Ilyina, T., Jahns, T., Jimenéz-de-la-Cuesta, D., Jungclaus, J., Kleinen, T., Kloster, S., Kracher, D., Kinne, S., Kleberg, D., Lasslop, G., Kornblueh, L., Marotzke, J., Matei, D., Meraner, K., Mikolajewicz, U., Modali, K., Möbis, B., Müller, W. A., Nabel, J. E. M. S., Nam, C. C. W., Notz, D., Nyawira, S.-S., Paulsen, H., Peters, K., Pincus, R., Pohlmann, H., Pongratz, J., Popp, M., Raddatz, T. J., Rast, S., Redler, R., Reick, C. H., Rohrschneider, T., Schemann, V., Schmidt, H., Schnur, R., Schulzweida, U., Six, K. D., Stein, L., Stemmler, I., Stevens, B., von Storch, J.-S., Tian, F., Voigt, A., Vrese, P., Wieners, K.-H., Wilkenskjeld, S., Winkler, A., and Roeckner, E.: Developments in the MPI-M Earth System Model version 1.2 (MPI-ESM1.2) and Its Response to Increasing CO2, J. Adv. Model Earth Sy., 11, 998–1038, https://doi.org/10.1029/2018MS001400, 2019.

Mayot, N., Buitenhuis, E. T., Wright, R. M., Hauck, J., Bakker, D. C. E., and Le Quéré, C.: Constraining the trend in the ocean CO2 sink during 2000–2022. Nat Commun 15, 8429, https://doi.org/10.1038/s41467-024-52641-7, 2024.

McGrath, M. J., Luyssaert, S., Meyfroidt, P., Kaplan, J. O., Bürgi, M., Chen, Y., Erb, K., Gimmi, U., McInerney, D., Naudts, K., Otto, J., Pasztor, F., Ryder, J., Schelhaas, M.-J., and Valade, A.: Reconstructing European forest management from 1600 to 2010, 12, 4291–4316, https://doi.org/10.5194/bg-12-4291-2015, 2015.

McKinley, G. A., Fay, A. R., Eddebbar, Y. A., Gloege, L., and Lovenduski, N. S.: External Forcing Explains Recent Decadal Variability of the Ocean Carbon Sink, AGU Advances, 1, e2019AV000149, https://doi.org/10.1029/2019AV000149, 2020.

McKinley, G. A., Fay, A. R., Lovenduski, N. S., and Pilcher, D. J.: Natural Variability and Anthropogenic Trends in the Ocean Carbon Sink, Annu. Rev. Mar. Sci., 9, 125–150, https://doi.org/10.1146/annurev-marine-010816-060529, 2017.

Meiyappan, P., Jain, A. K., and House, J. I.: Increased influence of nitrogen limitation on CO 2 emissions from future land use and land use change, Global Biogeochem. Cycles, 29, 1524–1548, https://doi.org/10.1002/2015GB005086, 2015.

Melton, J. R., Arora, V. K., Wisernig-Cojoc, E., Seiler, C., Fortier, M., Chan, E., and Teckentrup, L.: CLASSIC v1.0: the open-source community successor to the Canadian Land Surface Scheme (CLASS) and the Canadian Terrestrial Ecosystem Model (CTEM) – Part 1: Model framework and site-level performance, Geosci. Model Dev., 13, 2825–2850, https://doi.org/10.5194/gmd-13-2825-2020, 2020.

Mercado, L. M., Bellouin, N., Sitch, S., Boucher, O., Huntingford, C., Wild, M., and Cox, P. M.: Impact of changes in diffuse radiation on the global land carbon sink, Nature, 458, 1014–1017, https://doi.org/10.1038/nature07949, 2009.

Merchant, C. J., Embury, O., Bulgin, C. E., Block, T., Corlett, G. K., Fiedler, E., Good, S. A., Mittaz, J., Rayner, N. A., Berry, D., Eastwood, S., Taylor, M., Tsushima, Y., Waterfall, A., Wilson, R., and Donlon, C.: Satellite-based time-series of sea-surface temperature since 1981 for climate applications, Sci. Data, 6, 223, https://doi.org/10.1038/s41597-019-0236-x, 2019.

Moorcroft, P. R., Hurtt, G. C., and Pacala, S. W.: A Method for Scaling Vegetation Dynamics: The Ecosystem Demography Model (ed), Ecol. Monogr., 71, 557–586, https://doi.org/10.1890/0012-9615(2001)071[0557:AMFSVD]2.0.CO;2, 2001.

Müller, J. D., Gruber, N., Carter, B., Feely, R., Ishii, M., Lange, N., Lauvset, S. K., Murata, A., Olsen, A., Pérez, F. F., Sabine, C., Tanhua, T., Wanninkhof, R., and Zhu, D.: Decadal Trends in the Oceanic Storage of Anthropogenic Carbon From 1994 to 2014, AGU Adv., 4, e2023AV000875, https://doi.org/10.1029/2023AV000875, 2023.

Nayagam, L., Maksyutov, S., Oda, T., Janardanan, R., Trisolino, P., Zeng J., Kaiser, J.W. and Matsunaga, T.: A top-down estimation of subnational CO2 budget using a global high-resolution inverse model with data from regional surface networks, Environ. Res. Lett., 19, 0140312024, https://doi.org/10.1088/1748-9326/ad0f74, 2024.

NCEP: National Centers for Environmental Prediction. ONI Index. Cold & Warm Episodes by Season [dataset], available at: https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php, last access: 28 October 2024, 2023.

Nevison, C.D., Mahowald, N.M., Doney, S.C., Lima, I.D. and Cassar, N.:. Impact of variable air-sea O 2 and CO 2 fluxes on atmospheric potential oxygen (APO) and land-ocean carbon sink partitioning. Biogeosciences, 5(3), pp.875-889, https://doi.org/10.5194/bg-5-875-2008, 2008.

Niu, G.-Y., Yang, Z.-L., Mitchell, K. E., Chen, F., Ek, M. B., Barlage, M., Kumar, A., Manning, K., Niyogi, D., Rosero, E., Tewari, M., and Xia, Y.: The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements, J. Geophys. Res. Atmospheres, 116, https://doi.org/10.1029/2010JD015139, 2011.

Niwa, Y., Ishijima, K., Ito, A., and Iida, Y.: Toward a long-term atmospheric CO2 inversion for elucidating natural carbon fluxes: technical notes of NISMON-CO2 v2021.1, Prog. Earth Planet Sci., 9, 42, https://doi.org/10.1186/s40645-022-00502-6, 2022.

Niwa, Y., Langenfelds, R., Krummel, P., Loh, Zoe, Worthy, Doug, Hatakka, Juha, Aalto, Tuula, Ramonet, Michel, Delmotte, Marc, Schmidt, Martina, Gheusi, Francois, Mihalopoulos, N., Morgui, J.A., Andrews, Arlyn, Dlugokencky, Ed, Lee, John, Sweeney, Colm, Thoning, Kirk, Tans, Pieter, De Wekker, Stephan, Fischer, Marc L., Jaffe, Dan, McKain, Kathryn, Viner, Brian, Miller, John B., Karion, Anna, Miller, Charles, Sloop, Christopher D., Saito, Kazuyuki, Aoki, Shuji, Morimoto, Shinji, Goto, Daisuke, Steinbacher, Martin, Myhre, Cathrine Lund, Hermanssen, Ove, Stephens, Britton, Keeling, Ralph, Afshar, Sara, Paplawsky, Bill, Cox, Adam, Walker, Stephen, Schuldt, Kenneth, Mukai, Hitoshi, Machida, Toshinobu, Sasakawa, Motoki, Nomura, Shohei, Ito, Akihiko, Iida, Yosuke, and Jones, Matthew W.: Long-term global CO2 fluxes estimated by NICAM-based Inverse Simulation for Monitoring CO2 (NISMON-CO2) (ver.2022.1), National Institute for Environmental Studies Japan [dataset], https://doi.org/10.17595/20201127.001, 2020.

Obermeier, W. A., Nabel, J. E. M. S., Loughran, T., Hartung, K., Bastos, A., Havermann, F., Anthoni, P., Arneth, A., Goll, D. S., Lienert, S., Lombardozzi, D., Luyssaert, S., McGuire, P. C., Melton, J. R., Poulter, B., Sitch, S., Sullivan, M. O., Tian, H., Walker, A. P., Wiltshire, A. J., Zaehle, S., and Pongratz, J.: Modelled land use and land cover change emissions – a spatio-temporal comparison of different approaches, 12, 635–670, https://doi.org/10.5194/esd-12-635-2021, 2021.

O'Rourke, P. R., Smith, S. J., Mott, A., Ahsan, H., McDuffie, E. E., Crippa, M., Klimont, Z., McDonald, B., Wang, S., Nicholson, M. B., Feng, L., and Hoesly, R. M.: CEDS v_2021_04_21 Release Emission Data, Zenodo [dataset], https://doi.org/10.5281/zenodo.4741285, 2021.

Formatted: Normal

Moved up [16]: M.,

Deleted: Nakano, H., Tsujino, H., Hirabara,

Deleted: Yasuda

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Deleted: Yamanaka, G.: Uptake mechanism

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Moved (insertion) [12]

Deleted: , J. Oceanogr., 67, 765–783

Deleted: 1007/s10872-011-0075-7, 2011

Deleted: ,

Deleted: 9 November 2023

Formatted: Normal

O'Sullivan, M., Zhang, Y., Bellouin, N., Harris, I., Mercado, L. M., Sitch, S., Ciais, P., and Friedlingstein, P.: Aerosol–light interactions reduce the carbon budget imbalance, Environ. Res. Lett., 16, 124072, https://doi.org/10.1088/1748-9326/ac3b77, 2021.

O'Sullivan, M., Friedlingstein, P., Sitch, S., Anthoni, P., Arneth, A., Arora, V. K., Bastrikov, V., Delire, C., Goll, D. S., Jain, A., Kato, E., Kennedy, D., Knauer, J., Lienert, S., Lombardozzi, D., McGuire, P. C., Melton, J. R., Nabel, J. E. M. S., Pongratz, J., Poulter, B., Séférian, R., Tian, H., Vuichard, N., Walker, A. P., Yuan, W., Yue, X., and Zaehle, S.: Process-oriented analysis of dominant sources of uncertainty in the land carbon sink, Nat. Commun., 13, 4781, https://doi.org/10.1038/s41467-022-32416-8, 2022.

O'Sullivan, M., Spracklen, D. V., Batterman, S. A., Arnold, S. R., Gloor, M., and Buermann, W.: Have Synergies Between Nitrogen Deposition and Atmospheric CO2 Driven the Recent Enhancement of the Terrestrial Carbon Sink?, Glob. Biogeochem. Cycles, 33, 163–180, https://doi.org/10.1029/2018GB005922, 2019.

Palmer, P. I., Feng, L., Baker, D., Chevallier, F., Bösch, H., and Somkuti, P.: Net carbon emissions from African biosphere dominate pan-tropical atmospheric CO2 signal, Nat Commun, 10, 3344, https://doi.org/10.1038/s41467-019-11097-w, 2019.

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S. L., Canadell, J. G., Ciais, P., Jackson, R. B., Pacala, S. W., McGuire, A. D., Piao, S., Rautiainen, A., Sitch, S., and Hayes, D.: A Large and Persistent Carbon Sink in the World's Forests, Science, 333, 988–993, https://doi.org/10.1126/science.1201609, 2011.

Pendrill, F., Persson, U. M., Godar, J., Kastner, T., Moran, D., Schmidt, S., and Wood, R.: Agricultural and forestry trade drives large share of tropical deforestation emissions, Global Environmental Change, 56, 1–10, https://doi.org/10.1016/j.gloenvcha.2019.03.002, 2019.

Pérez, F. F., Becker, M., Goris, N., Gehlen, M., López-Mozos, M., Tjiputra, J., Olsen, A., Müller, J. D., Huertas, I. E., Chau, T. T. T., Cainzos, V., Velo, A., Benard, G., Hauck, J., Gruber, N., and Wanninkhof, R.: An Assessment of CO 2 Storage and Sea-Air Fluxes for the Atlantic Ocean and Mediterranean Sea Between 1985 and 2018. Global Biogeochemical Cycles, 38(4), e2023GB007862, https://doi.org/10.1029/2023GB007862, 2024.

Peters, G. P., Minx, J. C., Weber, C. L., and Edenhofer, O.: Growth in emission transfers via international trade from 1990 to 2008, Proceedings of the National Academy of Sciences, 108, 8903–8908, https://doi.org/10.1073/pnas.1006388108, 2011a.

Peters, G. P., Marland, G., Le Quéré, C., Boden, T., Canadell, J. G., and Raupach, M. R.: Rapid growth in CO2 emissions after the 2008–2009 global financial crisis, Nature Clim Change, 2, 2–4, https://doi.org/10.1038/nclimate1332, 2012a.

Peters, G. P., Andrew, R. M., Boden, T., Canadell, J. G., Ciais, P., Le Quéré, C., Marland, G., Raupach, M. R., and Wilson, C.: The challenge to keep global warming below 2 °C, Nature Clim Change, 3, 4–6, https://doi.org/10.1038/nclimate1783, 2013.

Peters, G. P., Le Quéré, C., Andrew, R. M., Canadell, J. G., Friedlingstein, P., Ilyina, T., Jackson, R. B., Joos, F., Korsbakken, J. I., McKinley, G. A., Sitch, S., and Tans, P.: Towards real-time verification of CO2 emissions, Nature Clim Change, 7, 848–850, https://doi.org/10.1038/s41558-017-0013-9, 2017a.

Deleted: 2017

Peters, G. P., Andrew, R. M., Canadell, J. G., Fuss, S., Jackson, R. B., Korsbakken, J. I., Le Quéré, C. and Nakicenovic, N.: Key indicators to track current progress and future ambition of the Paris Agreement, 7, 118–122, https://doi.org/10.1038/nclimate3202, 2017b.

Peters, G. P., Andrew, R. M., Canadell, J. G., Friedlingstein, P., Jackson, R. B., Korsbakken, J. I., Le Quéré, C., and Peregon, A.: Carbon dioxide emissions continue to grow amidst slowly emerging climate policies, Nat. Clim. Chang., 10, 3–6, https://doi.org/10.1038/s41558-019-0659-6, 2020.

Peters, W., Miller, J. B., Whitaker, J., Denning, A. S., Hirsch, A., Krol, M. C., Zupanski, D., Bruhwiler, L., and Tans, P. P.: An ensemble data assimilation system to estimate CO2 surface fluxes from atmospheric trace gas observations, J. Geophys. Res. Atmospheres, 110, https://doi.org/10.1029/2005JD006157, 2005.

Petrescu, A. M. R., Peters, G. P., Janssens-Maenhout, G., Ciais, P., Tubiello, F. N., Grassi, G., Nabuurs, G.-J., Leip, A., Carmona-Garcia, G., Winiwarter, W., Höglund-Isaksson, L., Günther, D., Solazzo, E., Kiesow, A., Bastos, A., Pongratz, J., Nabel, J. E. M. S., Conchedda, G., Pilli, R., Andrew, R. M., Schelhaas, M.-J., and Dolman, A. J.: European anthropogenic AFOLU greenhouse gas emissions: a review and benchmark data, Earth Syst. Sci. Data, 12, 961–1001, https://doi.org/10.5194/essd-12-961-2020, 2020.

Pfeil, B., Olsen, A., Bakker, D. C. E., Hankin, S., Koyuk, H., Kozyr, A., Malczyk, J., Manke, A., Metzl, N., Sabine, C. L., Akl, J., Alin, S. R., Bates, N., Bellerby, R. G. J., Borges, A., Boutin, J., Brown, P. J., Cai, W.-J., Chavez, F. P., Chen, A., Cosca, C., Fassbender, A. J., Feely, R. A., González-Dávila, M., Goyet, C., Hales, B., Hardman-Mountford, N., Heinze, C., Hood, M., Hoppema, M., Hunt, C. W., Hydes, D., Ishii, M., Johannessen, T., Jones, S. D., Key, R. M., Körtzinger, A., Landschützer, P., Lauvset, S. K., Lefèvre, N., Lenton, A., Lourantou, A., Merlivat, L., Midorikawa, T., Mintrop, L., Miyazaki, C., Murata, A., Nakadate, A., Nakano, Y., Nakaoka, S., Nojiri, Y., Omar, A. M., Padin, X. A., Park, G.-H., Paterson, K., Perez, F. F., Pierrot, D., Poisson, A., Ríos, A. F., Santana-Casiano, J. M., Salisbury, J., Sarma, V. V. S. S., Schlitzer, R., Schneider, B., Schuster, U., Sieger, R., Skjelvan, I., Steinhoff, T., Suzuki, T., Takahashi, T., Tedesco, K., Telszewski, M., Thomas, H., Tilbrook, B., Tjiputra, J., Vandemark, D., Veness, T., Wanninkhof, R., Watson, A. J., Weiss, R., Wong, C. S., and Yoshikawa-Inoue, H.: A uniform, quality controlled Surface Ocean CO2 Atlas (SOCAT), Earth Syst. Sci. Data, 5, 125–143, https://doi.org/10.5194/essd-5-125-2013, 2013.

Piao, S., Ciais, P., Friedlingstein, P., de Noblet-Ducoudré, N., Cadule, P., Viovy, N., and Wang, T.: Spatiotemporal patterns of terrestrial carbon cycle during the 20th century, Global Biogeochem. Cy., 23, GB4026, https://doi.org/10.1029/2008GB003339, 2009.

Piao, S., Huang, M., Liu, Z., Wang, X., Ciais, P., Canadell, J. G., Wang, K., Bastos, A., Friedlingstein, P., Houghton, R. A., Le Quéré, C., Liu, Y., Myneni, R. B., Peng, S., Pongratz, J., Sitch, S., Yan, T., Wang, Y., Zhu, Z., Wu, D., and Wang, T.: Lower land-use emissions responsible for increased net land carbon sink during the slow warming period, Nature Geosci, 11, 739–743, https://doi.org/10.1038/s41561-018-0204-7, 2018.

Pongratz, J., Reick, C. H., Houghton, R. A., and House, J. I.: Terminology as a key uncertainty in net land use and land cover change carbon flux estimates, Earth Syst. Dynam., 5, 177–195, https://doi.org/10.5194/esd-5-177-2014, 2014.

Pongratz, J., Smith, S. M., Schwingshackl, C., Dayathilake, L., Gasser, T., Grassi, G. and Pilli, R.: Chapter 7: Current levels of CDR. in The State of Carbon Dioxide Removal 2024 – 2nd Edition, https://doi.org/10.17605/OSF.IOZXSKB, 2024.

Formatted: Normal

Deleted: Peters W, Woude Avd, Luijkx I, Joetzjer E, Lafont S, Loubet B, Herig-Coimbra P, Loustau D, Koren G, Ciais P, Ramonet M, Xu Y, Bastos A, Sitch S, Kneuer T, Kubistin D, De Kok R, Botía S. Temperature extremes of 2022 reduced carbon uptake by forests in Europe. doi:10.21203/rs.3.rs-2841861/v1. PPR:PPR653515, 2023.¶

Formatted: Normal

Poulter, B., Bastos, A., Canadell, J., Ciais, P., Gruber, N., Hauck, J., Jackson, R., Ishii, M., Müller, J., Patra, P., and Tian, H.: Inventorying Earth's Land and Ocean Greenhouse Gases, Eos, 103, https://doi.org/10.1029/2022EO179084, 2022.

Poulter, B., Frank, D. C., Hodson, E. L., and Zimmermann, N. E.: Impacts of land cover and climate data selection on understanding terrestrial carbon dynamics and the CO2 airborne fraction, Biogeosciences, 8, 2027–2036, https://doi.org/10.5194/bg-8-2027-2011, 2011.

Poulter, B., Freeborn, P. H., Jolly, W. M., and Varner, J. M.: COVID-19 lockdowns drive decline in active fires in southeastern United States, PNAS, 118, e2105666118, https://doi.org/10.1073/pnas.2105666118, 2021.

Powis, C. M., Smith, S. M., Minx, J. C., and Gasser, T.: Quantifying global carbon dioxide removal deployment, Environ. Res. Lett., 18, 024022, https://doi.org/10.1088/1748-9326/acb450, 2023.

Prentice, I. C., Farquhar, G. D., Fasham, M. J. R., Goulden, M. L., Heimann, M., Jaramillo, V. J., Kheshgi, H. S., Le Quéré, C., Scholes, R. J., and Wallace, D. W. R.: The Carbon Cycle and Atmospheric Carbon Dioxide, in Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K., and Johnson, C. A., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 183–237, ISBN: 978-0521014953, 2001.

Price, J. T. and Warren, R.: Literature Review of the Potential of "Blue Carbon" Activities to Reduce Emissions, available at: https://avoid-net-uk.cc.ic.ac.uk/wp-content/uploads/delightful-downloads/2016/03/Literature-review-of-the-potential-of-blue-carbon-activities-to-reduce-emissions-AVOID2-WPE2.pdf, last access: 28 October 2024, 2016.

Deleted: 9 November 2023

Qin, Y., Xiao, X., Wigneron, J.-P., Ciais, P., Brandt, M., Fan, L., Li, X., Crowell, S., Wu, X., Doughty, R., Zhang, Y., Liu, F., Sitch, S., and Moore, B.: Carbon loss from forest degradation exceeds that from deforestation in the Brazilian Amazon, Nat. Clim. Chang., 11, 442–448, https://doi.org/10.1038/s41558-021-01026-5, 2021.

Qin, Z., Zhu, Y., Canadell, J.G., Chen, M., Li, T., Mishra, U. and Yuan, W.: Global spatially explicit carbon emissions from land-use change over the past six decades (1961–2020). One Earth, 7(5), pp.835-847, https://doi.org/10.1016/j.oneear.2024.04.002, 2024.

Randerson, J. T., Chen, Y., van der Werf, G. R., Rogers, B. M., and Morton, D. C.: Global burned area and biomass burning emissions from small fires: BURNED AREA FROM SMALL FIRES, J. Geophys. Res. Biogeosciences, 117, n/a-n/a, https://doi.org/10.1029/2012JG002128, 2012.

Raupach, M. R., Marland, G., Ciais, P., Le Quere, C., Canadell, J. G., Klepper, G., and Field, C. B.: Global and regional drivers of accelerating CO2 emissions, Proceedings of the National Academy of Sciences, 104, 10288–10293, https://doi.org/10.1073/pnas.0700609104, 2007.

Regnier, P., Resplandy, L., Najjar, R. G., and Ciais, P.: The land-to-ocean loops of the global carbon cycle, Nature, 603, 401–410, https://doi.org/10.1038/s41586-021-04339-9, 2022.

Reick, C. H., Gayler, V., Goll, D., Hagemann, S., Heidkamp, M., Nabel, J. E. M. S., Raddatz, T., Roeckner, E., Schnur, R., 110 and Wilkenskjeld, S.: JSBACH 3 – The land component of the MPI Earth System Model: documentation of version 3.2, available at: https://doi.org/10.17617/2.3279802, 2021.

Remaud, M., Chevallier, F., Cozic, A., Lin, X., and Bousquet, P.: On the impact of recent developments of the LMDz atmospheric general circulation model on the simulation of CO2 transport, 11, 4489, https://doi.org/10.5194/gmd-11-4489-2018, 2018.

Resplandy, L., Keeling, R. F., Rödenbeck, C., Stephens, B. B., Khatiwala, S., Rodgers, K. B., Long, M. C., Bopp, L., and Tans, P. P.: Revision of global carbon fluxes based on a reassessment of oceanic and riverine carbon transport, Nature Geosci, 11, 504–509, https://doi.org/10.1038/s41561-018-0151-3, 2018.

Resplandy, L., Keeling, R. F., Eddebbar, Y., Brooks, M., Wang, R., Bopp, L., Long, M. C., Dunne, J. P., Koeve, W., and Oschlies, A.: Quantification of ocean heat uptake from changes in atmospheric O2 and CO2 composition, Scientific Reports, 9, 20244, https://doi.org/10.1038/s41598-019-56490-z, 2019.

Rodenbeck, C., Houweling, S., Gloor, M., and Heimann, M.: CO2 flux history 1982–2001 inferred from atmospheric data using a global inversion of atmospheric transport, Atmos Chem Phys, 3, 1919–1964, 2003.

Rödenbeck, C., Bakker, D. C. E., Metzl, N., Olsen, A., Sabine, C., Cassar, N., Reum, F., Keeling, R. F., and Heimann, M.: Interannual sea–air CO2 flux variability from an observation-driven ocean mixed-layer scheme, 11, 4599–4613, https://doi.org/10.5194/bg-11-4599-2014, 2014.

Rödenbeck, C., Zaehle, S., Keeling, R., and Heimann, M.: History of El Niño impacts on the global carbon cycle 1957–2017: a quantification from atmospheric CO2 data, 373, 20170303, https://doi.org/10.1098/rstb.2017.0303, 2018.

Rödenbeck, C., DeVries, T., Hauck, J., Le Quéré, C., and Keeling, R. F.: Data-based estimates of interannual sea–air CO2 flux variations 1957–2020 and their relation to environmental drivers, Biogeosciences, 19, 2627–2652, https://doi.org/10.5194/bg-19-2627-2022, 2022.

Rosan, T. M., Klein Goldewijk, K., Ganzenmüller, R., O'Sullivan, M., Pongratz, J., Mercado, L. M., Aragao, L. E. O. C., Heinrich, V., Randow, C. V., Wiltshire, A., Tubiello, F. N., Bastos, A., Friedlingstein, P., and Sitch, S.: A multi-data assessment of land use and land cover emissions from Brazil during 2000–2019, Environ. Res. Lett., 16, 074004, https://doi.org/10.1088/1748-9326/ac08c3, 2021.

Sakamoto, K., H. Nakano, S. Urakawa, T. Toyoda, Y. Kawakami, H. Tsujino, G. Yamanaka, 2023: Reference manual for the Meteorological Research Institute Community Ocean Model version 5 (MRI.COMv5), Technical Reports of the Meteorological Research Institute, No.87, https://doi.org/10.11483/mritechrepo.87.

Sarma, V. V. S. S., Sridevi, B., Metzl, N., Patra, P. K., Lachkar, Z., Chakraborty, K., Goyet, C., Levy, M., Mehari, M., and Chandra, N.: Air-Sea Fluxes of CO2 in the Indian Ocean Between 1985 and 2018: A Synthesis Based on Observation-Based Surface CO2, Hindcast and Atmospheric Inversion Models, Glob. Biogeochem. Cycles, 37, e2023GB007694, https://doi.org/10.1029/2023GB007694, 2023.

Schaphoff, S., von Bloh, W., Rammig, A., Thonicke, K., Biemans, H., Forkel, M., Gerten, D., Heinke, J., Jägermeyr, J., Knauer, J., Langerwisch, F., Lucht, W., Müller, C., Rolinski, S., and Waha, K.: LPJmL4 – a dynamic global vegetation model with managed land – Part 1: Model description, Geosci. Model Dev., 11, 1343–1375, https://doi.org/10.5194/gmd-11-1343-2018, 2018.

Formatted: Normal

Schimel, D., Alves, D., Enting, I. G., Heimann, M., Joos, F., Raynaud, D., Wigley, T., Prater, M., Derwent, R., Ehhalt, D., Fraser, P., Sanhueza, E., Zhou, X., Jonas, P., Charlson, R., Rodhe, H., Sadasivan, S., Shine, K. P., Fouquart, Y., Ramaswamy, V., Solomon, S., Srinivasan, J., Albritton, D., Derwent, R., Isaksen, I., Lal, M., and Wuebbles, D.: Radiative Forcing of Climate Change, in: Climate Change 1995: The Science of Climate Change, Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J. T., Meira Rilho, L. G., Callander, B. A., Harris, N., Kattenberg, A., and Maskell, K. (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, ISBN: 978-0521559621, 1995.

Schimel, D., Stephens, B. B., and Fisher, J. B.: Effect of increasing CO 2 on the terrestrial carbon cycle, Proc Natl Acad Sci USA, 112, 436–441, https://doi.org/10.1073/pnas.1407302112, 2015.

Schuh, A. E., Jacobson, A. R., Basu, S., Weir, B., Baker, D., Bowman, K., Chevallier, F., Crowell, S., Davis, K. J., Deng, F., Denning, S., Feng, L., Jones, D., Liu, J., and Palmer, P. I.: Quantifying the Impact of Atmospheric Transport Uncertainty on CO 2 Surface Flux Estimates, Global Biogeochem. Cycles, 33, 484–500, https://doi.org/10.1029/2018GB006086, 2019.

Schuldt, K. N., Mund, J., Aalto, T., Abshire, J. B., Aikin, K., Allen, G., Andrews, A., Apadula, F., Arnold, S., Baier, B., Bakwin, P., Bartyzel, J., Bentz, G., Bergamaschi, P., Beyersdorf, A., Biermann, T., Biraud, S. C., Blanc, P.-E., Boenisch, H., Bowling, D., Brailsford, G., Brand, W. A., Brunner, D., Bui, T. P., Bäni, L., Calzolari, F., Chang, C. S., Chen, H., Chen, G., Chmura, L., Clark, S., Climadat, S., Colomb, A., Commane, R., Conen, F., Conil, S., Couret, C., Cristofanelli, P., Cuevas, E., Curcoll, R., Daube, B., Davis, K. J., De Mazière, M., De Wekker, S., Dean-Day, J. M., Della Coletta, J., Delmotte, M., Di Iorio, T., DiGangi, E., DiGangi, J. P., Elkins, J. W., Elsasser, M., Emmenegger, L., Fang, S., Fischer, M. L., Forster, G., France, J., Frumau, A., Fuente-Lastra, M., Galkowski, M., Gatti, L. V., Gehrlein, T., Gerbig, C., Gheusi, F., Gloor, E., Goto, D., Griffis, T., Hammer, S., Hanisco, T. F., Hanson, C., Haszpra, L., Hatakka, J., Heimann, M., Heliasz, M., Heltai, D., Henne, S., Hensen, A., Hermans, C., Hermansen, O., Hintsa, E., Hoheisel, A., Holst, J., Iraci, L. T., Ivakhov, V., Jaffe, D. A., Jordan, A., Joubert, W., Karion, A., Kawa, S. R., Kazan, V., Keeling, R. F., Keronen, P., Kim, J., Klausen, J., Kneuer, T., Kolari, P., Kominkova, K., Kort, E., Kozlova, E., Krummel, P. B., Kubistin, D., Kulawik, S. S., Kumps, N., Labuschagne, C., Lam, D. H., Lan, X., Langenfelds, R. L., Lanza, A., Laurent, O., Laurila, T., Lauvaux, T., Lavric, J., Law, B. E., Lee, J., Lehner, I., Lehtinen, K., Leppert, R., Leskinen, A., Leuenberger, M., Leung, W. H., Levin, I., Levula, J., Lin, J., Lindauer, M., Lindroth, A., Loh, Z. M., Lopez, M., Lunder, C. R., Löfvenius, M. O., Machida, T., Mammarella, I., Manca, G., Manning, A., Manning, A., Marek, M. V., Marklund, P., Marrero, J. E., Martin, D., Martin, M. Y., Martins, G. A., Matsueda, H., McKain, K., Meijer, H., Meinhardt, F., Merchant, L., Metzger, J.-M., Mihalopoulos, N., Miles, N. L., Miller, J. B., Miller, C. E., Mitchell, L., Monteiro, V., Montzka, S., Moore, F., Moossen, H., Morgan, E., Morgui, J.-A., Morimoto, S., Munger, J. W., Munro, D., Mutuku, M., Myhre, C. L., Mölder, M., Müller-Williams, J., Necki, J., Newman, S., Nichol, S., Nisbet, E., Niwa, Y., Njiru, D. M., Noe, S. M., Nojiri, Y., O'Doherty, S., Obersteiner, F., Paplawsky, B., Parworth, C. L., Peischl, J., Peltola, O., Peters, W., Philippon, C., Piacentino, S., Pichon, J. M., Pickers, P., Piper, S., Pitt, J., Plass-Dülmer, C., Platt, S. M., Prinzivalli, S., Ramonet, M., Ramos, R., Reyes-Sanchez, E., Richardson, S. J., Rigouleau, L.-J., Riris, H., Rivas, P. P., Rothe, M., Roulet, Y.-A., Ryerson, T., Ryoo, J.-M., Sargent, M., Sasakawa, M., Scheeren, B., Schmidt, M., Schuck, T., Schumacher, M., Seibel, J., Seifert, T., Sha, M. K., Shepson, P., Shook, M., Sloop, C. D., Smith, P. D., Spain, G., St. Clair, J. M., Steger, D., Steinbacher, M., Stephens, B., Sweeney, C., Sørensen, L. L., Taipale, R., Takatsuji, S., Tans, P., Thoning, K., Timas, H., Torn, M., Trisolino, P., Turnbull, J., Vermeulen, A., Viner, B., Vitkova, G., Walker, S., Watson, A., Weiss, R., Weyrauch, D., Wofsy, S. C., Worsey, J., Worthy, D., Xueref-Remy, I., Yates, E. L., Young, D., Yver-Kwok, C., Zaehle, S., Zahn, A., Zellweger, C., Zimnoch, M., de Souza, R. A., di Sarra, A. G., van Dinther, D., and van den Bulk, P. (2023) Multi-laboratory compilation of atmospheric carbon dioxide data for the period 1957-2022;

Formatted: Normal

obspack_co2_1_GLOBALVIEWplus_v9.0_2023-09-09; NOAA Earth System Research Laboratory, Global Monitoring Laboratory, http://doi.org/10.25925/20230801.

Schuldt, K. N., Jacobson, A. R., Aalto, T., Andrews, A., Apadula, F., Arnold, S., Bakwin, P., Bartyzel, J., Bergamaschi, P., Biermann, T., Biraud, S. C., Blanc, P.-E., Bäni, L., Calzolari, F., Chen, H., Chmura, L., Colomb, A., Condori, L., Conen, F., Conil, S., Couret, C., Cristofanelli, P., Cuevas, E., De Mazière, M., De Wekker, S., Della Coletta, J., Delmotte, M., Di Iorio, T., Elsasser, M., Emmenegger, L., Fischer, M. L., Forster, G., Frumau, A., Fuente-Lastra, M., Galkowski, M., Gheusi, F., Hammer, S., Hatakka, J., Heliasz, M., Heltai, D., Hensen, A., Hermans, C., Hermansen, O., Hoheisel, A., Holst, J., Jaffe, D. A., Karion, A., Kazan, V., Keronen, P., Kneuer, T., Kolari, P., Kominkova, K., Krummel, P. B., Kubistin, D., Kumps, N., Lan, X., Langenfelds, R. L., Lanza, A., Laurent, O., Laurila, T., Lee, J., Lehner, I., Lehtinen, K., Leskinen, A., Leuenberger, M., Levin, I., Levula, J., Lindauer, M., Lindroth, A., Loh, Z. M., Lopez, M., Lunder, C. R., Löfvenius, M. O., Mammarella, I., Manca, G., Manning, A., Manning, A., Marek, M. V., Marklund, P., McKain, K., Meijer, H., Meinhardt, F., Metzger, J.-M., Miller, C. E., Miller, J. B., Myhre, C. L., Mölder, M., Müller-Williams, J., Necki, J., O'Doherty, S., Peltola, O., Philippon, C., Piacentino, S., Pichon, J. M., Pickers, P., Pitt, J., Plass-Dülmer, C., Platt, S. M., Ramonet, M., Ramos, R., Reyes-Sanchez, E., Rigouleau, L.-J., Rivas, P. P., Roulet, Y.-A., Scheeren, B., Schmidt, M., Schumacher, M., Sha, M. K., Sloop, C. D., Smith, P. D., Steger, D., Steinbacher, M., Sweeney, C., Sørensen, L. L., Taipale, R., Tans, P., Thoning, K., Trisolino, P., Turnbull, J., Vermeulen, A., Viner, B., Vitkova, G., Weyrauch, D., Worthy, D., Xueref-Remy, I., Young, D., Yver-Kwok, C., Zimnoch, M., di Sarra, A. G., van Dinther, D., and van den Bulk, P. (2024) Multi-laboratory compilation of atmospheric carbon dioxide data for the period 2023-2024; obspack_co2_1_NRT_v9.2_2024-03-25; NOAA Earth System Research Laboratory, Global Monitoring Laboratory, http://doi.org/10.25925/20240215.

Schwinger, J., Goris, N., Tjiputra, J. F., Kriest, I., Bentsen, M., Bethke, I., Ilicak, M., Assmann, K. M., and Heinze, C.: Evaluation of NorESM-OC (versions 1 and 1.2), the ocean carbon-cycle stand-alone configuration of the Norwegian Earth System Model (NorESM1), Geosci. Model Dev., 9, 2589–2622, https://doi.org/10.5194/gmd-9-2589-2016, 2016.

Schwingshackl, C., Obermeier, W. A., Bultan, S., Grassi, G., Canadell, J. G., Friedlingstein, P., Gasser, T., Houghton, R. A., Kurz, W. A., Sitch, S., and Pongratz, J.: Differences in land-based mitigation estimates reconciled by separating natural and land-use CO2 fluxes at the country level, One Earth, 5, 1367–1376, https://doi.org/10.1016/j.oneear.2022.11.009, 2022.

Séférian, R., Nabat, P., Michou, M., Saint-Martin, D., Voldoire, A., Colin, J., Decharme, B., Delire, C., Berthet, S., Chevallier, M., Sénési, S., Franchisteguy, L., Vial, J., Mallet, M., Joetzjer, E., Geoffroy, O., Guérémy, J.-F., Moine, M.-P., Msadek, R., Ribes, A., Rocher, M., Roehrig, R., Salas-y-Mélia, D., Sanchez, E., Terray, L., Valcke, S., Waldman, R., Aumont, O., Bopp, L., Deshayes, J., Éthé, C., and Madec, G.: Evaluation of CNRM Earth System Model, CNRM-ESM2-1: Role of Earth System Processes in Present-Day and Future Climate, Journal of Advances in Modeling Earth Systems, 11, 4182–4227, https://doi.org/10.1029/2019MS001791, 2019.

Seiler, C., Melton, J. R., Arora, V. K., Sitch, S., Friedlingstein, P., Anthoni, P., Goll, D., Jain, A. K., Joetzjer, E., Lienert, S., Lombardozzi, D., Luyssaert, S., Nabel, J. E. M. S., Tian, H., Vuichard, N., Walker, A. P., Yuan, W., and Zaehle, S.: Are Terrestrial Biosphere Models Fit for Simulating the Global Land Carbon Sink?, J. Adv. Model. Earth Syst., 14, e2021MS002946, https://doi.org/10.1029/2021MS002946, 2022.

Sellar, A. A., Jones, C. G., Mulcahy, J. P., Tang, Y., Yool, A., Wiltshire, A., O’Connor, F. M., Stringer, M., Hill, R., Palmieri, J., Woodward, S., Mora, L., Kuhlbrodt, T., Rumbold, S. T., Kelley, D. I., Ellis, R., Johnson, C. E., Walton, J., Abraham, N. L., Andrews, M. B., Andrews, T., Archibald, A. T., Berthou, S., Burke, E., Blockley, E., Carslaw, K., Dalvi, M., Edwards, J., Folberth, G. A., Gedney, N., Griffiths, P. T., Harper, A. B., Hendry, M. A., Hewitt, A. J., Johnson, B., Jones, A., Jones, C. D., Keeble, J., Liddicoat, S., Morgenstern, O., Parker, R. J., Predoi, V., Robertson, E., Siahaan, A., Smith, R. S., Swaminathan, R., Woodhouse, M. T., Zeng, G., and Zerroukat, M.: UKESM1: Description and Evaluation of the U.K. Earth System Model, J. Adv. Model. Earth Syst., 11, 4513–4558, https://doi.org/10.1029/2019MS001739, 2019.

Shu, S., Jain, A. K., Koven, C. D., and Mishra, U.: Estimation of Permafrost SOC Stock and Turnover Time Using a Land Surface Model With Vertical Heterogeneity of Permafrost Soils, Global Biogeochem. Cy., 34, e2020GB006585, https://doi.org/10.1029/2020GB006585, 2020.

Shutler, J. D., Land, P. E., Piolle, J.-F., Woolf, D. K., Goddijn-Murphy, L., Paul, F., Girard-Ardhuin, F., Chapron, B., and Donlon, C. J.: FluxEngine: A Flexible Processing System for Calculating Atmosphere–Ocean Carbon Dioxide Gas Fluxes and Climatologies, J. Atmospheric Ocean. Technol., 33, 741–756, https://doi.org/10.1175/JTECH-D-14-00204.1, 2016.

Silva Junior, C.H., Anderson, L.O., Silva, A.L., Almeida, C.T., Dalagnol, R., Pletsch, M.A., Penha, T.V., Paloschi, R.A. and Aragão, L.E.: Fire responses to the 2010 and 2015/2016 Amazonian droughts. Frontiers in Earth Science, 7, p.97, https://doi.org/10.3389/feart.2019.00097, 2019.

Sitch, S., Huntingford, C., Gedney, N., Levy, P. E., Lomas, M., Piao, S. L., Betts, R., Ciais, P., Cox, P., Friedlingstein, P., Jones, C. D., Prentice, I. C., and Woodward, F. I.: Evaluation of the terrestrial carbon cycle, future plant geography and climate-carbon cycle feedbacks using five Dynamic Global Vegetation Models (DGVMs): Uncertainty In Land Carbon Cycle Feedbacks, Glob. Change Biol., 14, 2015–2039, https://doi.org/10.1111/j.1365-2486.2008.01626.x, 2008.

Sitch, S., O'Sullivan, M., Robertson, E., Friedlingstein, P., Albergel, C., Anthoni, P., Arneth, A., Arora, V. K., Bastos, A., Bastrikov, V., Bellouin, N., Canadell, J. G., Chini, L., Ciais, P., Falk, S., Harris, I., Hurtt, G., Ito, A., Jain, A. K., Jones, M. W., Joos, F., Kato, E., Kennedy, D., Klein Goldewijk, K., Kluzek, E., Knauer, J., Lawrence, P. J., Lombardozzi, D., Melton, J. R., Nabel, J. E. M. S., Pan, N., Peylin, P., Pongratz, J., Poulter, B., Rosan, T. M., Sun, Q., Tian, H., Walker, A. P., Weber, U., Yuan, W., Yue, X., Zaehle, S.: Trends and Drivers of Terrestrial Sources and Sinks of Carbon Dioxide: An Overview of the TRENDY Project, Global Biogeochemical Cycles, 38(7), e2024GB008102, https://doi.org/10.1029/2024GB008102, 2024.

Smallman, T. L., Milodowski, D. T., Neto, E. S., Koren, G., Ometto, J., and Williams, M.: Parameter uncertainty dominates C-cycle forecast errors over most of Brazil for the 21st century, Earth Syst. Dyn., 12, 1191–1237, https://doi.org/10.5194/esd-12-1191-2021, 2021.

Smith, B., Wårlind, D., Arneth, A., Hickler, T., Leadley, P., Siltberg, J., and Zaehle, S.: Implications of incorporating N cycling and N limitations on primary production in an individual-based dynamic vegetation model, Biogeosciences, 11, 2027–2054, https://doi.org/10.5194/bg-11-2027-2014, 2014.

Smith, S. M., Geden, O., Gidden, M. J., Lamb, W. F., Nemet, G. F., Minx, J. C., Buck, H., Burke, J., Cox, E., Edwards, M. R., Fuss, S., Johnstone, I., Müller-Hansen, F., Pongratz, J., Probst, B. S., Roe, S., Schenuit, F., Schulte, I., and Vaughan, N. E. The State of Carbon Dioxide Removal 2024 - 2nd Edition, http://dx.doi.org/10.17605/OSF.IO/F85QJ, 2024.

Sospedra-Alfonso, R., Merryfield, W. J., Boer, G. J., Kharin, V. V., Lee, W.-S., Seiler, C., and Christian, J. R.: Decadal climate predictions with the Canadian Earth System Model version 5 (CanESM5), Geosci. Model Dev., 14, 6863–6891, https://doi.org/10.5194/gmd-14-6863-2021, 2021.

Formatted: Normal

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Formatted: Normal

Stephens, B. B., Gurney, K. R., Tans, P. P., Sweeney, C., Peters, W., Bruhwiler, L., Ciais, P., Ramonet, M., Bousquet, P., Nakazawa, T., Aoki, S., Machida, T., Inoue, G., Vinnichenko, N., Lloyd, J., Jordan, A., Heimann, M., Shibistova, O., Langenfelds, R. L., Steele, L. P., Francey, R. J., and Denning, A. S.: Weak Northern and Strong Tropical Land Carbon Uptake from Vertical Profiles of Atmospheric CO2, Science, 316, 1732–1735, https://doi.org/10.1126/science.1137004, 2007.

Stephens, B. B., Keeling, R. F., Heimann, M., Six, K. D., Murnane, R., and Caldeira, K.: Testing global ocean carbon cycle models using measurements of atmospheric O2 and CO2 concentration, Glob. Biogeochem. Cycles, 12, 213–230, https://doi.org/10.1029/97GB03500, 1998.

Stocker, T., Qin, D., and Platner, G.-K.: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Intergovernmental Panel on Climate Change (eds.)], Cambridge University Press, Cambridge, ISBN: 9789291691388, 2013.\

Swart, N. C., Cole, J. N. S., Kharin, V. V., Lazare, M., Scinocca, J. F., Gillett, N. P., Anstey, J., Arora, V., Christian, J. R., Hanna, S., Jiao, Y., Lee, W. G., Majaess, F., Saenko, O. A., Seiler, C., Seinen, C., Shao, A., Sigmond, M., Solheim, L., von Salzen, K., Yang, D., and Winter, B.: The Canadian Earth System Model version 5 (CanESM5.0.3), Geosci. Model Dev., 12, 4823–4873, https://doi.org/10.5194/gmd-12-4823-2019, 2019.

SX Coal: Monthly coal consumption estimates, http://www.sxcoal.com/, last access: 28 October 2024, 2022.

Deleted: 9 November 2023

Takahashi, T., Sutherland, S. C., Wanninkhof, R., Sweeney, C., Feely, R. A., Chipman, D. W., Hales, B., Friederich, G., Chavez, F., Sabine, C., Watson, A., Bakker, D. C. E., Schuster, U., Metzl, N., Yoshikawa-Inoue, H., Ishii, M., Midorikawa, T., Nojiri, Y., Körtzinger, A., Steinhoff, T., Hoppema, M., Olafsson, J., Arnarson, T. S., Tilbrook, B., Johannessen, T., Olsen, A., Bellerby, R., Wong, C. S., Delille, B., Bates, N. R., and de Baar, H. J. W.: Climatological mean and decadal change in surface ocean pCO2, and net sea–air CO2 flux over the global oceans, Deep Sea Research Part II: Topical Studies in Oceanography, 56, 554–577, https://doi.org/10.1016/j.dsr2.2008.12.009, 2009.

Terhaar, J., Frölicher, T. L., and Joos, F.: Southern Ocean anthropogenic carbon sink constrained by sea surface salinity, Sci. Adv., 7, eabd5964, https://doi.org/10.1126/sciadv.abd5964, 2021.

Terhaar, J., Frölicher, T. L., and Joos, F.: Observation-constrained estimates of the global ocean carbon sink from Earth system models, Biogeosciences, 19, 4431–4457, https://doi.org/10.5194/bg-19-4431-2022, 2022.

Terhaar, J., Goris, N., Müller, J. D., DeVries, T., Gruber, N., Hauck, J., Perez, F. F., and Séférian, R.: Assessment of Global Ocean Biogeochemistry Models for Ocean Carbon Sink Estimates in RECCAP2 and Recommendations for Future Studies. Journal of Advances in Modeling Earth Systems, 16(3), e2023MS003840, https://doi.org/10.1029/2023MS003840, 2024.

Tian, H., Xu, X., Lu, C., Liu, M., Ren, W., Chen, G., Melillo, J., and Liu, J.: Net exchanges of CO2, CH4, and N2O between China's terrestrial ecosystems and the atmosphere and their contributions to global climate warming, J. Geophys. Res. Biogeosciences, 116, G02011, https://doi.org/10.1029/2010JG001393, 2011.

Tian, H., Chen, G., Lu, C., Xu, X., Hayes, D. J., Ren, W., Pan, S., Huntzinger, D. N., and Wofsy, S. C.: North American terrestrial CO2 uptake largely offset by CH4 and N2O emissions: toward a full accounting of the greenhouse gas budget, Climatic Change, 129, 413–426, https://doi.org/10.1007/s10584-014-1072-9, 2015.

Tsujino, H., Nakano, H., Sakamoto, K., Urakawa, L.S., Toyama, K., Kosugi, N., Kitamura, Y., Ishii, M., Nishikawa, S., Nishikawa, H., Sugiyama, T., and Ishikawa, Y.: Impact of increased horizontal resolution of an ocean model on carbon circulation in the North Pacific Ocean. Journal of Advances in Modeling Earth Systems, 16, e2023MS003720, https://doi.org/10.1029/2023MS003720, 2024.

Tubiello, F. N., Conchedda, G., Wanner, N., Federici, S., Rossi, S., and Grassi, G.: Carbon emissions and removals from forests: new estimates, 1990–2020, Earth Syst. Sci. Data, 13, 1681–1691, https://doi.org/10.5194/essd-13-1681-2021, 2021.

Tuck, C.: 2022 Mineral Commodity Summary: Iron Ore, Tech. rep., U.S. Geological Survey, https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-iron-ore.pdf, 2022.

UNFCCC: Synthesis report for the technical assessment component of the first global stocktake, available at: https://unfccc.int/documents/461466, last access: 28 October 2024, 2022.

Vale, M. M., Berenguer, E., Argollo de Menezes, M., Viveiros de Castro, E. B., Pugliese de Siqueira, L., and Portela, R. de C. Q.: The COVID-19 pandemic as an opportunity to weaken environmental protection in Brazil, Biological Conservation, 255, 108994, https://doi.org/10.1016/j.biocon.2021.108994, 2021.

van der Laan-Luijkx, I. T., van der Velde, I. R., van der Veen, E., Tsuruta, A., Stanislawska, K., Babenhauserheide, A., Zhang, H. F., Liu, Y., He, W., Chen, H., Masarie, K. A., Krol, M. C., and Peters, W.: The CarbonTracker Data Assimilation Shell (CTDAS) v1.0: implementation and global carbon balance 2001–2015, Geosci. Model Dev., 10, 2785–2800, https://doi.org/10.5194/gmd-10-2785-2017, 2017.

van der Velde, I. R., van der Werf, G. R., Houweling, S., Maasakkers, J. D., Borsdorff, T., Landgraf, J., Tol, P., van Kempen, T. A., van Hees, R., Hoogeveen, R., Veefkind, J. P., and Aben, I.: Vast CO2 release from Australian fires in 2019–2020 constrained by satellite, Nature, 597, 366–369, https://doi.org/10.1038/s41586-021-03712-y, 2021.

van der Werf, G. R., Randerson, J. T., Giglio, L., Collatz, G. J., Mu, M., Kasibhatla, P. S., Morton, D. C., DeFries, R. S., Jin, Y., and van Leeuwen, T. T.: Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997–2009), Atmospheric Chem. Phys., 10, 11707–11735, https://doi.org/10.5194/acp-10-11707-2010, 2010.

van der Werf, G. R., Randerson, J. T., Giglio, L., van Leeuwen, T. T., Chen, Y., Rogers, B. M., Mu, M., van Marle, M. J. E., Morton, D. C., Collatz, G. J., Yokelson, R. J., and Kasibhatla, P. S.: Global fire emissions estimates during 1997–2016, Earth Syst. Sci. Data, 9, 697–720, https://doi.org/10.5194/essd-9-697-2017, 2017.

van Wees, D., van der Werf, G. R., Randerson, J. T., Andela, N., Chen, Y., and Morton, D. C.: The role of fire in global forest loss dynamics, Glob. Change Biol., 27, 2377–2391, https://doi.org/10.1111/gcb.15591, 2021.

von Bloh, W., Schaphoff, S., Müller, C., Rolinski, S., Waha, K., and Zaehle, S.: Implementing the nitrogen cycle into the dynamic global vegetation, hydrology, and crop growth model LPJmL (version 5.0), Geosci. Model Dev., 11, 2789–2812, https://doi.org/10.5194/gmd-11-2789-2018, 2018.

Vaittinada Ayar, P., Bopp, L., Christian, J. R., Ilyina, T., Krasting, J. P., Séférian, R., Tsujino, H., Watanabe, M., Yool, A., and Tjiputra, J.: Contrasting projections of the ENSO-driven CO2 flux variability in the equatorial Pacific under high-warming scenario, Earth Syst. Dynam., 13, 1097–1118, https://doi.org/10.5194/esd-13-1097-2022, 2022.

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Deleted: Urakawa, L. S.,

Deleted: Yamanaka,

Deleted: and Toyoda, T.: The sensitivity of a depth-coordinate model to diapycnal mixing induced by practical implementations of the isopycnal tracer diffusion scheme, Ocean Model., 154, 101693, https://doi.org/10.1016/j.ocemod.2020.101693, 2020.¶

Formatted: Normal

Vuichard, N., Messina, P., Luyssaert, S., Guenet, B., Zaehle, S., Ghattas, J., Bastrikov, V., and Peylin, P.: Accounting for carbon and nitrogen interactions in the global terrestrial ecosystem model ORCHIDEE (trunk version, rev 4999): multi-scale evaluation of gross primary production, Geosci. Model Dev., 12, 4751–4779, https://doi.org/10.5194/gmd-12-4751-2019, 2019.

Walker, A. P., Quaife, T., Bodegom, P. M., De Kauwe, M. G., Keenan, T. F., Joiner, J., Lomas, M. R., MacBean, N., Xu, C., Yang, X., and Woodward, F. I.: The impact of alternative trait-scaling hypotheses for the maximum photosynthetic carboxylation rate (V cmax) on global gross primary production, New Phytol., 215, 1370–1386, https://doi.org/10.1111/nph.14623, 2017.

Walker, A. P., De Kauwe, M. G., Bastos, A., Belmecheri, S., Georgiou, K., Keeling, R. F., McMahon, S. M., Medlyn, B. E., Moore, D. J. P., Norby, R. J., Zaehle, S., Anderson-Teixeira, K. J., Battipaglia, G., Brienen, R. J. W., Cabugao, K. G., Cailleret, M., Campbell, E., Canadell, J. G., Ciais, P., Craig, M. E., Ellsworth, D. S., Farquhar, G. D., Fatichi, S., Fisher, J. B., Frank, D. C., Graven, H., Gu, L., Haverd, V., Heilman, K., Heimann, M., Hungate, B. A., Iversen, C. M., Joos, F., Jiang, M., Keenan, T. F., Knauer, J., Körner, C., Leshyk, V. O., Leuzinger, S., Liu, Y., MacBean, N., Malhi, Y., McVicar, T. R., Penuelas, J., Pongratz, J., Powell, A. S., Riutta, T., Sabot, M. E. B., Schleucher, J., Sitch, S., Smith, W. K., Sulman, B., Taylor, B., Terrer, C., Torn, M. S., Treseder, K. K., Trugman, A. T., Trumbore, S. E., van Mantgem, P. J., Voelker, S. L., Whelan, M. E., and Zuidema, P. A.: Integrating the evidence for a terrestrial carbon sink caused by increasing atmospheric CO2, New Phytol., 229, 2413–2445, https://doi.org/10.1111/nph.16866, 2021.

Watanabe, M., Tatebe, H., Koyama, H., Hajima, T., Watanabe, M., and Kawamiya, M.: Importance of El Niño reproducibility for reconstructing historical CO2 flux variations in the equatorial Pacific, Ocean Sci., 16, 1431–1442, https://doi.org/10.5194/os-16-1431-2020, 2020.

Watson, A. J., Schuster, U., Shutler, J. D., Holding, T., Ashton, I. G. C., Landschützer, P., Woolf, D. K., and Goddijn-Murphy, L.: Revised estimates of ocean-atmosphere CO2 flux are consistent with ocean carbon inventory, Nat Commun, 11, 4422, https://doi.org/10.1038/s41467-020-18203-3, 2020.

Watson, R. T., Rohde, H., Oeschger, H., and Siegenthaler, U.: Greenhouse Gases and Aerosols, in: Climate Change: The IPCC Scientific Assessment. Intergovernmental Panel on Climate Change (IPCC), edited by: Houghton, J. T., Jenkins, G. J., and Ephraums, J. J., Cambridge University Press, Cambridge, ISBN: 978-0521403603, 1990.

Wenzel, S., Cox, P. M., Eyring, V., and Friedlingstein, P.: Projected land photosynthesis constrained by changes in the seasonal cycle of atmospheric CO2, Nature, 538, 499–501, https://doi.org/10.1038/nature19772, 2016.

Wilkenskjeld, S., Kloster, S., Pongratz, J., Raddatz, T., and Reick, C. H.: Comparing the influence of net and gross anthropogenic land-use and land-cover changes on the carbon cycle in the MPI-ESM, Biogeosciences, 11, 4817–4828, https://doi.org/10.5194/bg-11-4817-2014, 2014.

Wiltshire, A. J., Burke, E. J., Chadburn, S. E., Jones, C. D., Cox, P. M., Davies-Barnard, T., Friedlingstein, P., Harper, A. B., Liddicoat, S., Sitch, S., and Zaehle, S.: JULES-CN: a coupled terrestrial carbon–nitrogen scheme (JULES vn5.1), 14, 2161–2186, https://doi.org/10.5194/gmd-14-2161-2021, 2021.

Winkler, K., Yang, H., Ganzenmüller, R., Fuchs, R., Ceccherini, G., Duveiller, G., Grassi, G., Pongratz, J., Bastos, A., Shvidenko, A., Araza, A., Herold, M., Wigneron, J.-P., and Ciais, P.: Changes in land use and management led to a decline

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in Eastern Europe's terrestrial carbon sink, Commun. Earth Environ., 4, 1–14, https://doi.org/10.1038/s43247-023-00893-4, 2023.

Woodward, F. I. and Lomas, M. R.: Vegetation dynamics – simulating responses to climatic change, Biol. Rev., 79, 643–670, https://doi.org/10.1017/S1464793103006419, 2004.

Wright, R. M., Le Quéré, C., Buitenhuis, E., Pitois, S., and Gibbons, M. J.: Role of jellyfish in the plankton ecosystem revealed using a global ocean biogeochemical model, 18, 1291–1320, https://doi.org/10.5194/bg-18-1291-2021, 2021.

Wunder, S., Kaimowitz, D., Jensen, S., and Feder, S.: Coronavirus, macroeconomy, and forests: What likely impacts?, For. Policy Econ., 131, 102536, https://doi.org/10.1016/j.forpol.2021.102536, 2021.

Xi, F., Davis, S. J., Ciais, P., Crawford-Brown, D., Guan, D., Pade, C., Shi, T., Syddall, M., Lv, J., Ji, L., Bing, L., Wang, J., Wei, W., Yang, K.-H., Lagerblad, B., Galan, I., Andrade, C., Zhang, Y., and Liu, Z.: Substantial global carbon uptake by cement carbonation, Nature Geosci, 9, 880–883, https://doi.org/10.1038/ngeo2840, 2016.

Xia, J., Chen, Y., Liang, S., Liu, D., and Yuan, W.: Global simulations of carbon allocation coefficients for deciduous vegetation types, Tellus B, 67, 28016, https://doi.org/10.3402/tellusb.v67.28016, 2015.

Yang, D., Liu, Y., Feng, L., Wang, J., Yao, L., Cai, Z., Zhu, S., Lu, N., and Lyu, D.: The First Global Carbon Dioxide Flux Map Derived from TanSat Measurements, Adv. Atmospheric Sci., 38, 1433–1443, https://doi.org/10.1007/s00376-021-1179-7, 2021.

Yang, X., Thornton, P., Ricciuto, D., Wang, Y., and Hoffman, F.: Global evaluation of terrestrial biogeochemistry in the Energy Exascale Earth System Model (E3SM) and the role of the phosphorus cycle in the historical terrestrial carbon balance, Biogeosciences, 20, 2813–2836, https://doi.org/10.5194/bg-20-2813-2023, 2023.

Yu, Z., Ciais, P., Piao, S., Houghton, R. A., Lu, C., Tian, H., Agathokleous, E., Kattel, G. R., Sitch, S., Goll, D., Yue, X., Walker, A., Friedlingstein, P., Jain, A. K., Liu, S., and Zhou, G.: Forest expansion dominates China's land carbon sink since 1980, Nat. Commun., 13, 5374, https://doi.org/10.1038/s41467-022-32961-2, 2022.

Yue, X. and Unger, N.: The Yale Interactive terrestrial Biosphere model version 1.0: description, evaluation and implementation into NASA GISS ModelE2, Geosci. Model Dev., 8, 2399–2417, https://doi.org/10.5194/gmd-8-2399-2015, 2015.

Yuan, W., Liu, D., Dong, W., Liu, S., Zhou, G., Yu, G., Zhao, T., Feng, J., Ma, Z., Chen, J., Chen, Y., Chen, S., Han, S., Huang, J., Li, L., Liu, H., Liu, S., Ma, M., Wang, Y., Xia, J., Xu, W., Zhang, Q., Zhao, X., and Zhao, L.: Multiyear precipitation reduction strongly decreases carbon uptake over northern China, J. Geophys. Res.-Biogeo., 119, 881–896, https://doi.org/10.1002/2014JG002608, 2014.

Yue, C., Ciais, P., Zhu, D., Wang, T., Peng, S. S., and Piao, S. L.: How have past fire disturbances contributed to the current carbon balance of boreal ecosystems?, Biogeosciences, 13, 675–690, https://doi.org/10.5194/bg-13-675-2016, 2016.

Zaehle, S. and Friend, A. D.: Carbon and nitrogen cycle dynamics in the O-CN land surface model: 1. Model description, site-scale evaluation, and sensitivity to parameter estimates: Site-scale evaluation of a C-N model, Global Biogeochem. Cycles, 24, GB1005, https://doi.org/10.1029/2009GB003521, 2010.

Zaehle, S., Ciais, P., Friend, A. D., and Prieur, V.: Carbon benefits of anthropogenic reactive nitrogen offset by nitrous oxide emissions, Nature Geosci, 4, 601–605, https://doi.org/10.1038/ngeo1207, 2011.

Zaehle, S., Medlyn, B. E., De Kauwe, M. G., Walker, A. P., Dietze, M. C., Hickler, T., Luo, Y., Wang, Y.-P., El-Masri, B., Thornton, P., Jain, A., Wang, S., Warlind, D., Weng, E., Parton, W., Iversen, C. M., Gallet-Budynek, A., McCarthy, H., Finzi, A., Hanson, P. J., Prentice, I. C., Oren, R., and Norby, R. J.: Evaluation of 11 terrestrial carbon–nitrogen cycle models against observations from two temperate Free-Air CO2 Enrichment studies, New Phytol., 202, 803–822, https://doi.org/10.1111/nph.12697, 2014.

Zeng, J., Iida, Y., Matsunaga, T., and Shirai, T.: Surface ocean CO2 concentration and air-sea flux estimate by machine learning with modelled variable trends, Front. Mar. Sci., 9, https://doi.org/10.3389/fmars.2022.989233, 2022.

Zheng, B., Ciais, P., Chevallier, F., Chuvieco, E., Chen, Y., and Yang, H.: Increasing forest fire emissions despite the decline in global burned area, Sci. Adv., 7, eabh2646, https://doi.org/10.1126/sciadv.abh2646, 2021.

Zou, Y., Wang, Y., Ke, Z., Tian, H., Yang, J., and Liu, Y.: Development of a REgion-Specific Ecosystem Feedback Fire (RESFire) Model in the Community Earth System Model, J. Adv. Model. Earth Syst., 11, 417–445, https://doi.org/10.1029/2018MS001368, 2019.

Zscheischler, J., Mahecha, M. D., Avitabile, V., Calle, L., Carvalhais, N., Ciais, P., Gans, F., Gruber, N., Hartmann, J., Herold, M., Ichii, K., Jung, M., Landschützer, P., Laruelle, G. G., Lauerwald, R., Papale, D., Peylin, P., Poulter, B., Ray, D., Regnier, P., Rödenbeck, C., Roman-Cuesta, R. M., Schwalm, C., Tramontana, G., Tyukavina, A., Valentini, R., van der Werf, G., West, T. O., Wolf, J. E., and Reichstein, M.: Reviews and syntheses: An empirical spatiotemporal description of the global surface–atmosphere carbon fluxes: opportunities and data limitations, Biogeosciences, 14, 3685–3703, https://doi.org/10.5194/bg-14-3685-2017, 2017.

Tables

Table 1. Factors used to convert carbon in various units (by convention, Unit 1 = Unit 2 × conversion).

Unit 1	Unit 2	Conversion	Source
GtC (gigatonnes of carbon)	ppm (parts per million) (a)	2.124 (b)	Ballantyne et al. (2012)
GtC (gigatonnes of carbon)	PgC (petagrams of carbon)	1	SI unit conversion
GtCO2 (gigatonnes of carbon dioxide)	GtC (gigatonnes of carbon)	3.664	44.01/12.011 in mass equivalent

(a) Measurements of atmospheric CO2 concentration have units of dry-air mole fraction. 'ppm' is an abbreviation for micromole/mol, dry air.

(b) The use of a factor of 2.124 assumes that all the atmosphere is well mixed within one year. In reality, only the troposphere is well mixed and the growth rate of CO2 concentration in the less well-mixed stratosphere is not measured by sites from the NOAA network. Using a factor of 2.124 makes the approximation that the growth rate of CO2 concentration in the stratosphere equals that of the troposphere on a yearly basis.

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Table 2. How to cite the individual components of the global carbon budget presented here.

Component	Primary reference
Global fossil CO2 emissions (EFOS), total and by fuel type	Andrew and Peters (2024)
National territorial fossil CO2 emissions (EFOS)	Hefner and Marland (2023), UNFCCC (2024)
National consumption-based fossil CO2 emissions (EFOS) by country (consumption)	Peters et al. (2011a) updated as described in this paper
Net land-use change flux (ELUC)	This paper (see Table 4 for individual model references).
Growth rate in atmospheric CO2 concentration (GATM)	Lan et al. (2024)
Ocean and land CO2 sinks (SOCEAN and SLAND)	This paper (see Table 4 for individual model and data products references).

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Table 3. Main methodological changes in the global carbon budget since 2020. Methodological changes introduced in one year are kept for the following years unless noted. Empty cells mean there were no methodological changes introduced that year. Table S9 lists methodological changes from the first global carbon budget publication up to 2019.

Publication year	Fossil fuel emissions		LUC emissions	Reservoirs			Other changes
	Global	Country (territorial)		Atmosphere	Ocean	Land	
2020							
Friedlingstein et al. (2020) GCB2020	Cement carbonation now included in the EFOS estimate, reducing EFOS by about 0.2GtC yr-1 for the last decade	India's emissions from Andrew (2020: India); Corrections to Netherland Antilles and Aruba and Soviet emissions before 1950 as per Andrew (2020: CO2); China's coal emissions in 2019 derived from official statistics, emissions now shown for EU27 instead of EU28. Projection for 2020 based on assessment of four approaches.	Average of three bookkeeping models; use of 17 DGVMs. Estimate of gross land use sources and sinks provided	Use of six atmospheric inversions	Based on nine models. River flux revised and partitioned NH, Tropics, SH	Based on 17 models	
2021	Projections are no longer an assessme	Official data included for a	ELUC estimate compared to the		Average of means of eight models	Current year prediction of SLAND	

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Friedlingstein et al. (2022a) GCB2021	nt of four approaches.	number of additional countries, new estimates for South Korea, added emissions from lime production in China.	estimates adopted in national GHG inventories		and means of seven data-products. Current year prediction of SOCEAN using a feed-forward neural network method	using a feed-forward neural network method	
2022 Friedlingstein et al. (2022) GCB2022			ELUC provided at country level. Revised components decomposition of ELUC fluxes. Revision of LUC maps for Brazil. New datasets for peat drainage.	Use of nine atmospheric inversions	Average of means of ten models and means of seven data-products	Based on 16 models. Revision of LUC maps for Brazil.	
2023 Friedlingstein et al. (2023) GCB2023			Refined components decomposition of ELUC. Revision of LUC maps for Indonesia. Use of updated peat drainage estimates.	Use of 14 atmospheric inversions. Additional use of 4 Earth System Models to estimate current year CO2	Additional use of 4 Earth System Models and atmospheric oxygen method to assess SOCEAN. Regional distribution of river flux adjustment revised.	Based on 20 models. Additional use of 4 Earth System Models and atmospheric oxygen method to assess the net atmosphere-land flux.	Inclusion of an estimate of Carbon Dioxide Removal
2024	Inclusion of 2024	Inclusion of 2024	Fourth bookkeepi	Use of 14 atmosphe	Use of 10 GOBMs, 8	Use of 20 DGVMs	

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This study	projections from Carbon Monitor	projections from Carbon Monitor for China, USA, EU27, India, and Rest of the World	ng estimate (LUCE). Update in land-use data (HYDE3.4) including revision of LUC maps for China. Updated definition of forest (re-)growth fluxes (consistent with 2nd State of CDR Report).	ric inversions models	fCO2-products. Added evaluation for fCO2-products.		

Table 4. References for the process models, bookkeeping models, ocean data products, and atmospheric inversions. All models and products are updated with new data to the end of year 2023.

Model/data name	**Reference**	**Change from Global Carbon Budget 2023 (Friedlingstein et al., 2023)**
Bookkeeping models for land-use change emissions		
BLUE	Hansis et al. (2015)	No change to model, but simulations performed with LUH2-GCB2024 forcing. Update in added peat drainage emissions.
H&C2023	Houghton and Castanho (2023)	No change to model. Data for years after last modelled year (2020) extrapolated based on anomalies in deforestation fires from GFED. Update in added peat drainage emissions.
OSCAR	Gasser et al. (2020)	No change to model, but land-use forcing changed to LUH2-GCB2024 and FRA2020 extrapolated to 2023. Constraining based on GCB2023 data for SLAND over 1960-2022. Update in added peat drainage emissions.
LUCE	Qin et al. (2024)	New model in GCB2024.
Dynamic global vegetation models		
CABLE-POP	Haverd et al. (2018)	Bug fix applied to land use change calculations enabling variable crop and pasture fractions; corrections to the pre-industrial primary forest fraction in Europe; minor parameter changes
CLASSIC	Melton et al. (2020), Asaadi et al. (2018)	Permeable soil depth reduced to 4 m ; 15 soil layers in the top 4 m permeable soil and 5 bed rock layers from 4 m to 62 m; saturated hydraulic conductivity decreases with depth in the permeable soil layers; transpiration occurs from a partially-wet canopy leaves. These changes yield better runoff seasonality and a more realistic partitioning of precipitation into runoff and evapotranspiration.
CLM6.0	Lawrence et al. (2019)	Updates to surface datasets; improvement of roughness length calculation; updates to snow optical properties and snow thermal conductivity; improved excess ice; improved simulation of burial of vegetation by snow; urban updates, including transient urban, urban properties, and air conditioning; improvements to biomass heat storage; tillage and residue removal; crop penology and planting dates; improvement to irrigation methods; PFT parameter update.

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DLEM	Tian et al. (2015), You et al. (2022)	Incorporate mechanistic representations of dynamic crop growth and development processes, such as crop-specific phenological development, carbon allocation, yield formation, and biological N fixation. Agricultural management practices such as N fertiliser use, irrigation, tillage, manure application, dynamic crop rotation, cover cropping, and genetic improvements are also included (You et al. 2022).
EDv3	Moorcroft et al. (2001), Ma et al. (2022)	Minor bug fixes, updated fire submodule
ELM	Yang et al.(2023), Burrows et al.(2020)	No change
IBIS	Xia et al. (2024)	Improved algorithm of leaf area index
iMAPLE	Yue et al. (2024)	The updated version of YIBs model with dynamic coupling between carbon and water cycles.
ISAM	Jain et al. (2013), Meiyappan et al. (2015), Shu et al. (2020)	Vertically resolved soil biogeochemistry (carbon and nitrogen) module, following Shu et al. (2020),
ISBA-CTRIP	Delire et al. (2020)	No change.
JSBACH	Mauritsen et al. (2019), Reick et al. (2021)	Minor bug fixes in post-processing
JULES-ES	Wiltshire et al. (2021), Sellar et al. (2019), Burton et al. (2019)	Minor bug fixes. (Using JULES v7.4)
LPJ-GUESS	Smith et al. (2014)	No change
LPJml	Schaphoff et al., 2018, von Bloh et al., 2018, Lutz et al., 2019 (tillage), Heinke et al., 2023 (livestock grazing)	No change
LPJwsl	Poulter et al. (2011) (d)	Minor bug fixes, weighting of fire carbon by GFED to simulate annual cycle
LPX-Bern	Lienert and Joos (2018)	No change.
OCN	Zaehle and Friend (2010), Zaehle et al. (2011)	No change
ORCHIDEEv3	Krinner et al. (2005), Zaehle and Friend (2010), Vuichard et al. (2019)	No change
SDGVM	Woodward and Lomas (2004), Walker et al. (2017)	Parameter adjustment for reducing evaporation from vegetation that intercepted precipitation, as well as other adjustments to the calculation of evapotranspiration; bug fix in output of monthly NEP, NBP, soilr, and rh; bug fix on cLeaf monthly output; further development on gross land-use transitions, tracking of carbon from wood & crop harvest, and tracking of primary & secondary vegetation.
VISIT	Ito and Inatomi (2012), Kato et al. (2013)	No change.

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Intermediate complexity land carbon cycle model		
CARDAMOM	Bloom et al. (2016), Smallman et al. (2021)	No change
Global ocean biogeochemistry models		
NEMO-PlankTOM12	Wright et all (2021)	Minor bug fixes, change to salinity restoring and restart file. New atmospheric CO2 input for simulations A and C.
NEMO4.2-PISCES (IPSL)	Aumont et al. (2015)	Switch to the new model version NEMO4.2-PISCES. Update following the new protocol (with 1750 preindustrial CO2 for spin-up). New atmospheric CO2 input for simulations A and C.
MICOM-HAMOCC (NorESM1-OCv1.2)	Schwinger et al. (2016)	No change in model set-up. New atmospheric CO2 file for simulations A and C. Corrected diagnostic output for pco2atm; diagnostic output for sfco2 and spco2 provided at the air-sea interface (not with respect to dry air at 1 atm).
MPIOM-HAMOCC6	Lacroix et al. Global Change Biology 2021	No change; only updated atmosphere CO2 input for A and C experiments and run 1948-2023.
NEMO3.6-PISCESv2-gas (CNRM)	Berthet et al. (2019) Séférian et al. (2019)	Updated simulations using 1750 preindustrial conditions instead of 1850. No change in model configuration. New atmospheric CO2 input for simulations A and C
FESOM2.1-REcoM3	Gürses et al. (2023)	Updated atmospheric CO2 for simulations A and C
MOM6-COBALT (Princeton)	Liao et al. (2020)	No change.
CESM-ETHZ	Doney et al. (2009)	Compared to the 2023 submission, the spinup was extended to 1422 years before 1750. Also, starting at 1751 the new atmospheric CO2 concentrations provided by GCB have been used for simulations A and C
MRI-ESM2-3	Tsujino et al. (2024), Sakamoto et al. (2023)	Iron circulation and its limitation on primary production are introduced. Updated atmospheric CO2 for simulations A and C
ACCESS (CSIRO)	Law et al. (2017)	No change in model set-up (since GCB2023). Updated atmospheric CO2 for simulations A and C
fCO2-products		
VLIZ-SOMFFN (former MPI-SOM-FFN)	Landschützer et al. (2016)	Time period 1982-2023; The estimate now coveres the full open ocean and coastal domain as well as the Arctic Ocean extension by merging 2 MLD proxies for year round full coverage. Additionally, in the SOM step, the Seaflux climatology is now used

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Jena-MLS	Rödenbeck et al. (2014) updated to Rödenbeck et al (2022)	Time period extended to 2023
CMEMS-LSCE-FFNNv2	Chau et al. (2022)	Time period now 1985-2023
UExP-FNN-U (previously Watson et al.)	Watson et al. (2020) and Ford et al. (accepted)	Updated CCI-SST to v3 (Embury et al. 2024), with cool bias with respect to global drifter observations corrected following recommendations in Dong et al. (2022). Updated SOM-FFN implementation to Python
NIES-ML3	Zeng et al. (2022)	Updated time period 1982-2023.
JMA-MLR	Iida et al. (2021)	Time period extended to 2023
OceanSODA-ETHZv2	Gregor et al. (2024)	Updated method following Gregor et al 2024 and time period extended to 2023
LDEO-HPD	Gloege et al. 2022 and Bennington et al. 2022	Timeperiod extended to 2023
CSIR-ML6	Gregor et al. (2019)	Time period 1982-2023.
Atmospheric inversions		
Jena CarboScope	Rödenbeck et al. (2018), Stephens et al. (2007)	Extension to end of year 2023. Slight change in station set. In the NBE-T inversion, removal of the relaxation term, instead, filtering out decadal variations from air temperature. Adding an additive correction to the result of the NBE-T inversion, to account for CO2 flux IAV not related to air temperature, based on 8 long atmospheric records available near-continuously since at least 1976. TM3 driven by ERA5 rather than NCEP
CAMS	Chevallier et al. (2005), Remaud et al. (2018)	Extension to year 2023. Increase of the 3D resolution with hexagonal prisms rather than rectangular parallelepipeds (3 times more 3D cells than the previous submission). Update of the prior fluxes.
CarbonTracker Europe (CTE)	van der Laan-Luijkx et al. (2017)	Extension to 2023, update of prior fluxes.
NISMON-CO2	Niwa et al. (2022), Niwa et al. (2017).	Extension to 2023, update of prior fluxes
CT-NOAA	Jacobson et al. (2023a), Jacobson et al. (2024), Byrne et al. (2023), Krol et al. (2005), Peiro et al. (2022)	Extended to 2023 using the CarbonTracker Near-Real Time release CT-NRT.v2024-1 (Jacobson et al. 2024)
CMS-Flux	Liu et al. (2021)	Extension to 2023, update of prior fluxes.
CAMS-Satellite	Chevallier et al. (2005), Remaud et al. (2018)	Extension to year 2023. Increase of the 3D resolution with hexagonal prisms rather than rectangular parallelepipeds (3 times more 3D cells than the previous submission). Update of the prior fluxes.

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GONGGA	Jin et al. (2023), Nassar et al. (2010)	Extension to 2023, update of prior fluxes.
COLA	Liu et al. (2022)	Extension to 2023, update of prior fluxes.
GCASv2	Jiang et al. (2021) & Emmons et al. (2010)	Extension to 2023, update of prior fluxes.
UoE in-situ	Feng et al. (2016) & Palmer et al. (2019)	Extension to 2023, update of prior fluxes.
IAPCAS	Yang et al. (2021) & Feng et al. (2016)	Extension to 2023, update of prior fluxes.
MIROC4-ACTM	Chandra et al. (2022) & Patra et al. (2018)	Extension to 2023, update of prior fluxes using only CASA and not VISIT. Less observation sites used in the assimilation (46 instead of 50).
NTFVAR	Nayagam et al. (2024) & Maksyutov et al. (2021)	New this year
Earth System Models		
CanESM5	Swart et al. (2019), Sospedra-Alfonso et al. (2021)	Reconstructions are extended to 1960-2023, and predictions are extended to 2024.
EC-Earth3-CC	Döscher et al. (2021), Bilbao et al. (2021), Bernardello et al. (2024)	New this year.
IPSL-CM6A-CO2-LR	Boucher et al. (2020)	Reconstructions are extended to 1960-2023, and predictions are extended to 2024. No change to model, the CMIP6 CovidMIP CO2 emissions after 2015 are used.
MIROC-ES2L	Watanabe et al. (2020)	Reconstructions are extended to 1960-2023, and predictions are extended to 2024. No change to model, the simulations were rerun including a long spinup.
MPI-ESM1-2-LR	Mauritsen et al. (2019), Li et al. (2023)	Reconstructions are extended to 1960-2023, and predictions are extended to 2024.

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Table 5. Comparison of results from the bookkeeping method and budget residuals with results from the DGVMs, as well as additional estimates from atmospheric oxygen, atmospheric inversions and Earth System Models (ESMs) for different periods, the last decade, and the last year available. All values are in GtCyr−1. See Figure 7 for explanation of the bookkeeping component fluxes. The DGVM uncertainties represent ±1σ of the decadal or annual (for 2023) estimates from the individual DGVMs: for the inverse systems the mean and range of available results is given. All values are rounded to the nearest 0.1 GtC and therefore columns do not necessarily add to zero.

Mean (GtC/yr)

		1960s	1970s	1980s	1990s	2000s	2014-2023	2023
Land-use change emissions (ELUC)	Bookkeeping (BK) Net flux (1a)	1.6±0.7	1.4±0.7	1.4±0.7	1.6±0.7	1.4±0.7	1.1±0.7	1±0.7
	BK - deforestation (total)	1.7 [1.3,2.2]	1.6 [1.2,2]	1.6 [1.3,1.9]	1.8 [1.6,2]	1.9 [1.6,2.2]	1.7 [1.4,2.3]	1.7 [1.3,2.3]
	BK - forest regrowth (total)	-0.8 [-1.1,-0.6]	-0.9 [-1.1,-0.7]	-0.9 [-1,-0.7]	-0.9 [-1.1,-0.8]	-1.1 [-1.2,-0.9]	-1.2 [-1.5,-0.9]	-1.2 [-1.5,-0.9]
	BK - other transitions	0.3 [0.3,0.4]	0.2 [0.2,0.3]	0.2 [0.1,0.3]	0.1 [0,0.2]	0.1 [0,0.1]	0.1 [0,0.1]	0 [0,0.1]
	BK - peat drainage & peat fires	0.2 [0.1,0.2]	0.2 [0.1,0.2]	0.2 [0.2,0.2]	0.3 [0.2,0.3]	0.2 [0.2,0.3]	0.2 [0.2,0.3]	0.2 [0.2,0.3]
	BK - wood harvest & forest management	0.2 [-0.2,0.6]	0.3 [-0.2,0.6]	0.3 [-0.2,0.7]	0.3 [-0.1,0.6]	0.3 [-0.1,0.6]	0.3 [0,0.6]	0.3 [0,0.7]
	DGVMs-net flux (1b)	1.5±0.5	1.5±0.5	1.5±0.5	1.7±0.5	1.7±0.6	1.5±0.6	1.2±0.7
Terrestrial sink (SLAND)	Residual sink from global budget (E_{FOS}+E_{LUC}(1a)-G_{ATM}-S_{OCEAN}) (2a)	1.7±0.8	1.9±0.8	1.6±0.9	2.6±0.9	2.8±0.9	2.7±0.9	2.3±1
	DGVMs (2b)	1.2±0.5	2±0.8	1.8±0.8	2.5±0.6	2.8±0.7	3.2±0.9	2.3±1
Net land fluxes (SLAND-ELUC)	GCB2024 Budget (2b-1a)	-0.4±0.9	0.5±1.1	0.4±1.1	0.9±0.9	1.4±1	2.1±1.1	1.3±1.2
	Atmospheric O_2	---	---	---	1.3±0.7	1±0.7	1±0.8	-
	DGVMs-net (2b-1b)	-0.3±0.5	0.5±0.7	0.3±0.6	0.8±0.4	1.1±0.4	1.7±0.6	1.1±0.8

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	1960s	1970s	1980s	1990s	2000s	2014-2023	2023
Inversions*	- [-,-]	- [-,-]	0.3 [0.3,0.4] (2)	0.9 [0.6,1.1] (3)	1.2 [0.6,1.5] (4)	1.4 [0.3,2.2] (10)	0.9 [-0.1-2.7] (14)
ESMs	0 [-0.7,0.5]	1.5 [1.2,2]	1 [0.5,1.4]	1.7 [1.2,2.4]	1.8 [0.4,2.7]	2.2 [0.3,3.6]	1.8 [-2.9-3.7]

*Estimates are adjusted for the pre-industrial influence of river fluxes, for the cement carbonation sink, and adjusted to common EFOS (Sect. 2.7). The ranges given include varying numbers (in parentheses) of inversions in each decade (Table A4)

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Table 6: Comparison of results for the ocean sink from the *f*CO2-products, from global ocean biogeochemistry models (GOBMs), the best estimate for GCB2024 as calculated from fCO2-products and GOBMs that is used in the budget Table 7, as well as additional estimates from atmospheric oxygen, atmospheric inversions and Earth System Models (ESMs) for different periods, the last decade, and the last year available. All values are in GtCyr−1. Uncertainties represent ±1σ of the estimates from the GOBMs (N>10) and range of ensemble members is given for ensembles with N<10 (*f*CO2-products, inversions, ESMs). The uncertainty of the GCB2024 budget estimate is based on expert judgement (Section 2 and Supplementary S1 to S4) and for oxygen it is the standard deviation of a Monte Carlo ensemble (Section 2.8).

Mean (GtC/yr)

Product	1960s	1970s	1980s	1990s	2000s	2014-2023	2023
fCO_2-products	---	---	---	2.3 [1.9,2.9]	2.5 [2.3,2.7]	3.1 [2.9,3.7]	3 [2.3,4]
GOBMs	1±0.2	1.3±0.3	1.8±0.3	2±0.3	2.2±0.3	2.6±0.4	2.7±0.4
GCB2024 Budget	1.2±0.4	1.5±0.4	1.9±0.4	2.1±0.4	2.3±0.4	2.9±0.4	2.9±0.4
Atmospheric O_2	---	---	---	2±0.5	2.8±0.4	3.4±0.5	-
Inversions	- [-,-]	- [-,-]	1.8 [1.8,1.9] (2)	2.3 [2.1,2.5] (3)	2.5 [2.3,3.1] (4)	3.1 [2.4,4.1] (10)	3 [1.8-4.1] (14)
ESMs	0.7 [0.	1 [0.	1.4 [0.7,1.7]	1.7 [1.1,2]	1.9 [1.5,2.2]	2.5 [2.2,2.8]	2.5 [2.

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Table 7: Decadal mean in the five components of the anthropogenic CO2 budget for different periods, and last year available. All values are in GtC yr-1, and uncertainties are reported as ±1σ. Fossil CO_2 emissions include cement carbonation. The table also shows the budget imbalance (B_{IM}), which provides a measure of the discrepancies among the nearly independent estimates. A positive imbalance means the emissions are overestimated and/or the sinks are too small. All values are rounded to the nearest 0.1 GtC and therefore columns do not necessarily add to zero.

Mean (GtC/yr)

		1960s	1970s	1980s	1990s	2000s	2014-2023	2023	2024 (Projection)
Total emissions (EFOS + ELUC)	Fossil CO2 emissions (EFOS) *	3±0.2	4.7±0.2	5.5±0.3	6.4±0.3	7.8±0.4	9.7±0.5	10.1±0.5	10.2±0.5
	Land-use change emissions (ELUC)	1.6±0.7	1.4±0.7	1.4±0.7	1.6±0.7	1.4±0.7	1.1±0.7	1±0.7	1.1±0.7
	Total emissions	4.6±0.7	6.1±0.7	6.9±0.8	7.9±0.8	9.2±0.8	10.8±0.9	11.1±0.9	11.3±0.9
Partitioning	Growth rate in atmos CO2 (GATM)	1.7±0.07	2.8±0.07	3.4±0.02	3.1±0.02	4±0.02	5.2±0.02	5.9±0.2	5.9±0.5
	Ocean sink (SOCEAN)	1.2±0.4	1.5±0.4	1.9±0.4	2.1±0.4	2.3±0.4	2.9±0.4	2.9±0.4	3±0.6
	Terrestrial sink (SLAND)	1.2±0.5	2±0.8	1.8±0.8	2.5±0.6	2.8±0.7	3.2±0.9	2.3±1	3.2±1.5
Budget Imbalance	BIM=EFOS+ELUC-(GATM+SOCE	0.5	-0.1	-0.2	0.1	0	-0.4	0	-0.7

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	1960s	1970s	1980s	1990s	2000s	2014-2023	2023	2024 (Projection)
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*Fossil emissions excluding the cement carbonation sink amount to 3±0.2 GtC/yr, 4.7±0.2 GtC/yr, 5.5±0.3 GtC/yr, 6.4±0.3 GtC/yr, 7.9±0.4 GtC/yr, and 9.9±0.5 GtC/yr for the decades 1960s to 2010s respectively and to 10.3±0.5 GtC/yr for 2023, and 10.4±0.5 GtC/yr for 2024.

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Table 8. Cumulative CO_2 for different time periods in gigatonnes of carbon (GtC). Fossil CO_2 emissions include cement carbonation. The budget imbalance (B_{IM}) provides a measure of the discrepancies among the nearly independent estimates. All values are rounded to the nearest 5 GtC and therefore columns do not necessarily add to zero. Uncertainties are reported as follows: E_{FOS} is 5% of cumulative emissions; E_{LUC} prior to 1959 is 1σ spread from the DGVMs, E_{LUC} post-1959 is 0.7*number of years (where 0.7 GtC/yr is the uncertainty on the annual E_{LUC} flux estimate); G_{ATM} uncertainty is held constant at 5 GtC for all time periods; S_{OCEAN} uncertainty is 20% of the cumulative sink (20% relates to the annual uncertainty of 0.4 GtC/yr, which is ~20% of the current ocean sink); and S_{LAND} is the 1σ spread from the DGVMs estimates.

		1750-2023	1850-2014	1850-2023	1960-2023	1850-2024
Emissions	Fossil CO2 emissions (EFOS)	490±25	400±20	490±25	410±20	500±25
	Land-use change emissions (ELUC)	255±75	215±60	225±65	90±45	225±65
	Total emissions	745±80	615±65	710±70	500±50	725±70
Partitioning	Growth rate in atmos CO2 (GATM)	305±5	235±5	285±5	220±5	290±5
	Ocean sink (SOCEAN)	195±40	160±30	185±35	130±25	185±35
	Terrestrial sink (SLAND)	245±65	190±55	220±60	150±40	225±60
Budget imbalance	BIM=EFOS+ELUC-(GATM+SOCEAN+SLAND)	0	30	25	0	20

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Table 9. Average annual growth rate in fossil CO_2 emissions over the most recent decade (2014-2023) and the previous decade (2004-2013). The data for the World include the cement carbonation sink. IAS are emissions from international aviation and shipping. Rest of the World is World minus China, USA, EU27, India and IAS.

	World	China	USA	EU27	India	OECD	Non-OECD	IAS	Rest of the World
2004-2013	2.4%	7.5%	-1.4%	-1.8%	6.4%	-0.9%	4.9%	2.6%	1.9%
2014-2023	0.6%	1.9%	-1.2%	-2.1%	3.6%	-1.4%	1.8%	-1.6%	0.4%

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Table 10. Major known sources of uncertainties in each component of the Global Carbon Budget, defined as input data or processes that have a demonstrated effect of at least ±0.3 GtC yr^{-1}.

Source of uncertainty	**Time scale (years)**	**Location**	**Evidence**
Fossil CO2 emissions (EFOS; Section 2.1)			
energy statistics	annual to decadal	global, but mainly China & major developing countries	(Korsbakken et al., 2016, Guan et al., 2012)
carbon content of coal	annual to decadal	global, but mainly China & major developing countries	(Liu et al., 2015)
system boundary	annual to decadal	all countries	(Andrew, 2020a)
Net land-use change flux (ELUC; section 2.2)			
land-cover and land-use change statistics	continuous	global; in particular tropics	(Houghton et al., 2012, Gasser et al., 2020, Ganzenmüller et al., 2022, Yu et al. 2022)
sub-grid-scale transitions	annual to decadal	global	(Wilkenskjeld et al., 2014, Bastos et al., 2021)
vegetation biomass	annual to decadal	global; in particular tropics	(Houghton et al., 2012, Bastos et al., 2021)
forest degradation (fire, selective logging)	annual to decadal	tropics; Amazon	(Aragão et al., 2018, Qin et al., 2021, Lapola et al., 2023)
wood and crop harvest	annual to decadal	global; SE Asia	(Arneth et al., 2017, Erb et al., 2018)
peat burning	multi-decadal trend	global	(van der Werf et al., 2010, 2017)
loss of additional sink capacity	multi-decadal trend	global	(Pongratz et al., 2014, Gasser et al., 2020; Obermeier et al., 2021; Dorgeist et al., 2024)
environmental effects	multi-decadal trend	global	(Gasser et al. 2020, Dorgeist et al., 2024)
Atmospheric growth rate (GATM; section 2.4) no demonstrated uncertainties larger than ±0.3 GtC yr-1 . The uncertainties in GATM have been estimated as ±0.2 GtC yr-1, although the conversion of the growth rate into a global annual flux assuming instantaneous mixing throughout the atmosphere introduces additional errors that have not yet been quantified.			
Ocean sink (SOCEAN; section 2.5)			

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sparsity in surface fCO2 observations	mean, decadal variability and trend	global, in particular southern hemisphere	(Gloege et al., 2021, Denvil-Sommer et al., 2021, Hauck et al., 2023a; Dong et al., 2024b)
riverine carbon outgassing and its anthropogenic perturbation	annual to decadal	global, in particular partitioning between Tropics and South	(Aumont et al., 2001, Lacroix et al., 2020, Crisp et al., 2022)
Models underestimate interior ocean anthropogenic carbon storage	annual to decadal	global	(Friedlingstein et al., 2022a, this study, DeVries et al., 2023, Müller et al., 2023)
near-surface temperature and salinity gradients	mean on all time-scales	global	(Watson et al., 2020, Dong et al., 2022, Bellenger et al., 2023, Dong et al., 2024a)
Land sink (SLAND; section 2.6)			
strength of CO2 fertilisation	multi-decadal trend	global	(Wenzel et al., 2016; Walker et al., 2021)
response to variability in temperature and rainfall	annual to decadal	global; in particular tropics	(Cox et al., 2013; Jung et al., 2017; Humphrey et al., 2018; 2021)
nutrient limitation and supply	annual to decadal	global	(Zaehle et al., 2014)
carbon allocation and tissue turnover rates	annual to decadal	global	(De Kauwe et al., 2014; O'Sullivan et al., 2022)
tree mortality	annual	global in particular tropics	(Hubau et al., 2021; Brienen et al., 2020)
response to diffuse radiation	annual	global	(Mercado et al., 2009; O'Sullivan et al., 2021)
estimation under constant pre-industrial land cover	multi-decadal trend	global	(Gasser et al. 2020, Dorgeist et al., 2024)

Figures and Captions

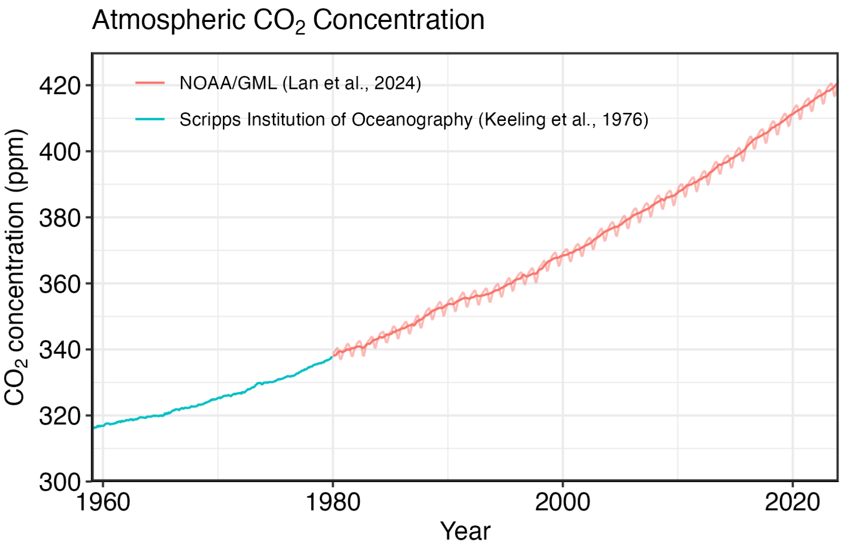

Figure 1. Surface average atmospheric CO_2 concentration (ppm). Since 1980, monthly data are from NOAA/GML (Lan et al., 2024) and are based on an average of direct atmospheric CO_2 measurements from multiple stations in the marine boundary layer (Masarie and Tans, 1995). The 1958-1979 monthly data are from the Scripps Institution of Oceanography, based on an average of direct atmospheric CO_2 measurements from the Mauna Loa and South Pole stations (Keeling et al., 1976). To account for the difference of mean CO_2 and seasonality between the NOAA/GML and the Scripps station networks used here, the Scripps surface average (from two stations) was de-seasonalised and adjusted to match the NOAA/GML surface average (from multiple stations) by adding the mean difference of 0.667 ppm, calculated here from overlapping data during 1980-2012.

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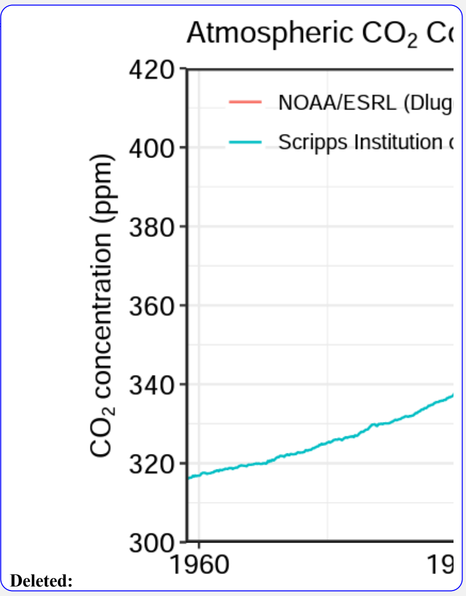

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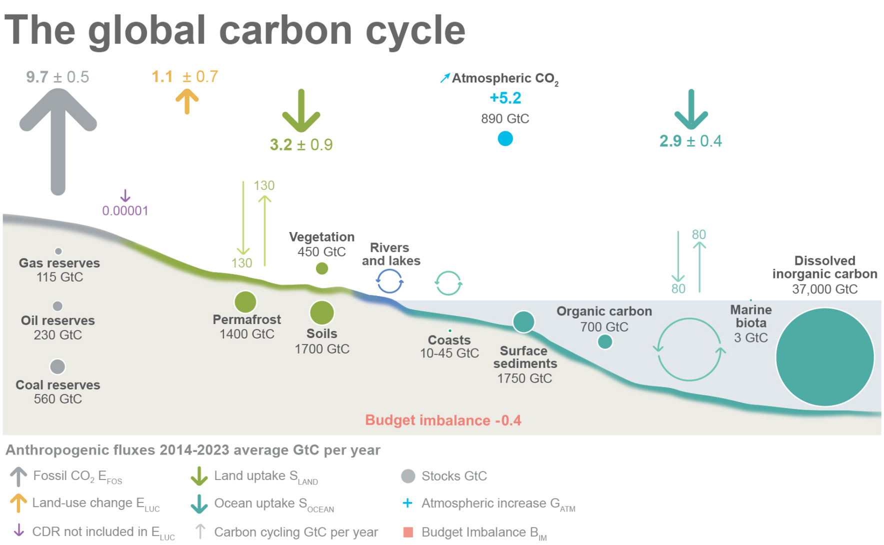

Figure 2. Schematic representation of the overall perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2014-2023. See legends for the corresponding arrows. Fluxes estimates and their 1 standard deviation uncertainty are as reported in Table 7. The CDR estimate is for the year 2023 only. The uncertainty in the atmospheric CO_2 growth rate is very small (±0.02 GtC yr^{-1}) and is neglected for the figure. The anthropogenic perturbation occurs on top of an active carbon cycle, with fluxes and stocks represented in the background and taken from Canadell et al. (2021) for all numbers, except for the carbon stocks in coasts which is from a literature review of coastal marine sediments (Price and Warren, 2016). Fluxes are in GtC yr^{-1} and reservoirs in GtC.

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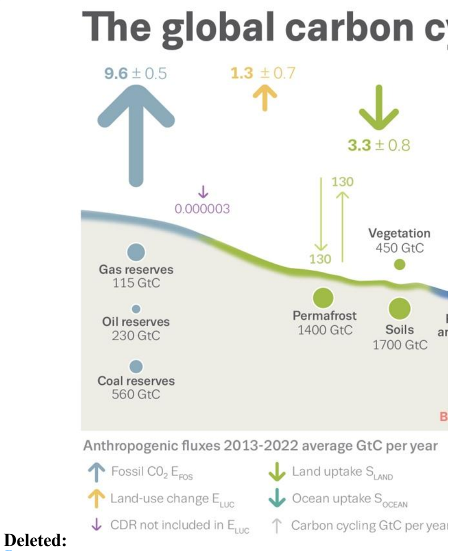

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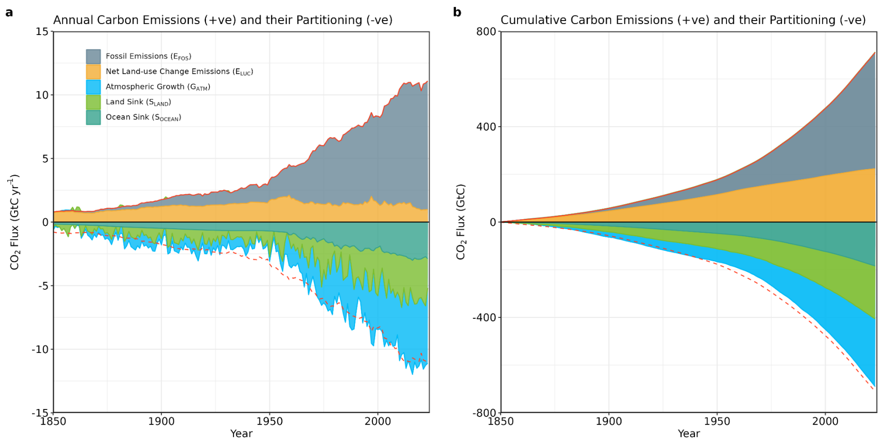

Figure 3. Combined components of the global carbon budget as a function of time, for fossil CO_2 emissions (E_{FOS}, including a small sink from cement carbonation; grey) and emissions from land-use change (E_{LUC}; brown), as well as their partitioning among the atmosphere (G_{ATM}; cyan), ocean (S_{OCEAN}; blue), and land (S_{LAND}; green). Panel (a) shows annual estimates of each flux (in GtC yr^{-1}) and panel (b) the cumulative flux (the sum of all prior annual fluxes, in GtC) since the year 1850. The partitioning is based on nearly independent estimates from observations (for G_{ATM}) and from process model ensembles constrained by data (for S_{OCEAN} and S_{LAND}) and does not exactly add up to the sum of the emissions, resulting in a budget imbalance (B_{IM}) which is represented by the difference between the bottom red line (mirroring total emissions) and the sum of carbon fluxes in the ocean, land, and atmosphere reservoirs. All data are in GtC yr^{-1} (panel a) and GtC (panel b). The E_{FOS} estimate is based on a mosaic of different datasets, and has an uncertainty of ±5% (±1σ). The E_{LUC} estimate is from four bookkeeping models (Table 4) with uncertainty of ±0.7 GtC yr^{-1}. The G_{ATM} estimates prior to 1959 are from Joos and Spahni (2008) with uncertainties equivalent to about ±0.1-0.15 GtC yr-1 and from Lan et al. (2024) since 1959 with uncertainties of about +-0.07 GtC yr^{-1} during 1959-1979 and ±0.02 GtC yr^{-1} since 1980. The S_{OCEAN} estimate is the average from Khatiwala et al. (2013) and DeVries (2014) with uncertainty of about ±30% prior to 1959, and the average of an ensemble of models and an ensemble of fCO_2-products (Table 4) with uncertainties of about ±0.4 GtC yr^{-1} since 1959. The S_{LAND} estimate is the average of an ensemble of models (Table 4) with uncertainties of about ±1 GtC yr^{-1}. See the text for more details of each component and their uncertainties.

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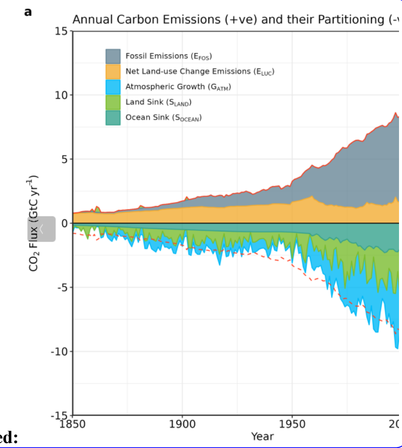

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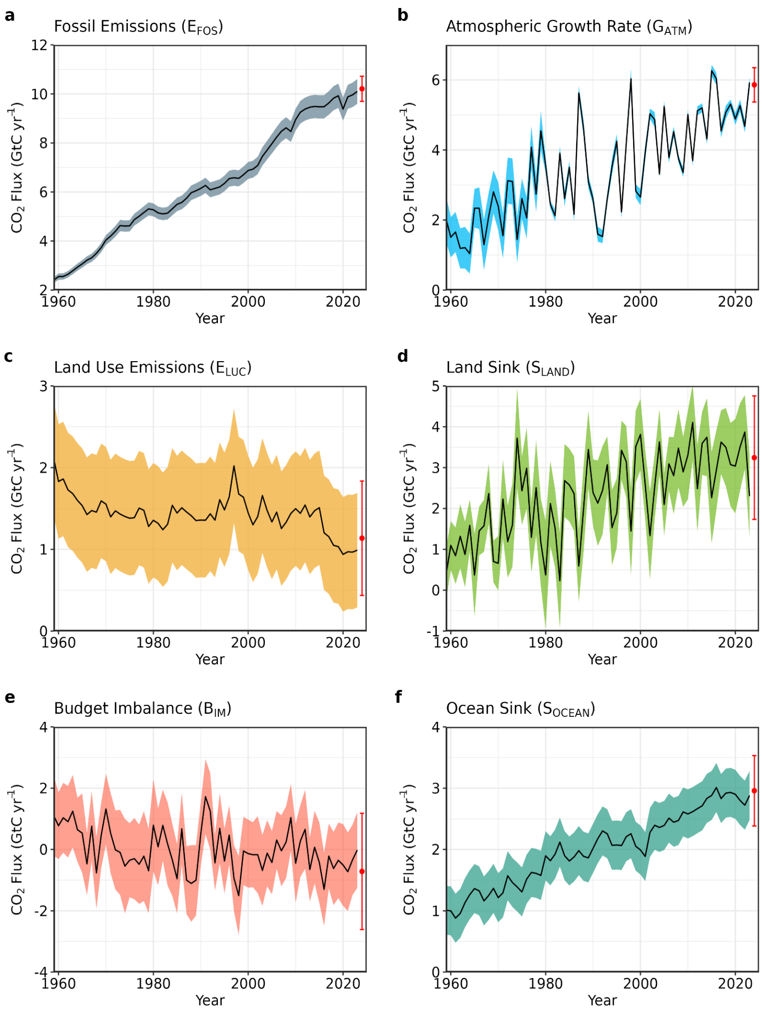

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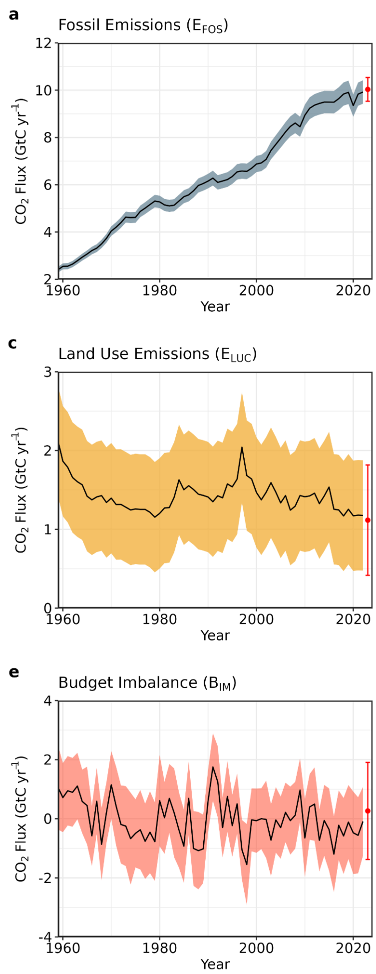

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Figure 4. Components of the global carbon budget and their uncertainties as a function of time, presented individually for (a) fossil CO_2, including cement carbonation emissions (E_{FOS}), (b) growth rate in atmospheric CO_2 concentration (G_{ATM}), (c) emissions from land-use change (E_{LUC}), (d) the land CO_2 sink (S_{LAND}), (e) the ocean CO_2 sink (S_{OCEAN}), (f) the budget imbalance (B_{IM}) that is not accounted for by the other terms. Positive values of S_{LAND} and S_{OCEAN} represent a flux from the atmosphere to land or the ocean. All data are in GtC yr^{-1} with the uncertainty bounds representing ±1 standard deviation in shaded colour. Data sources are as in Figure 3. The red dots indicate our projections for the year 2024 and the red error bars the uncertainty in the 2024 projections (see methods).

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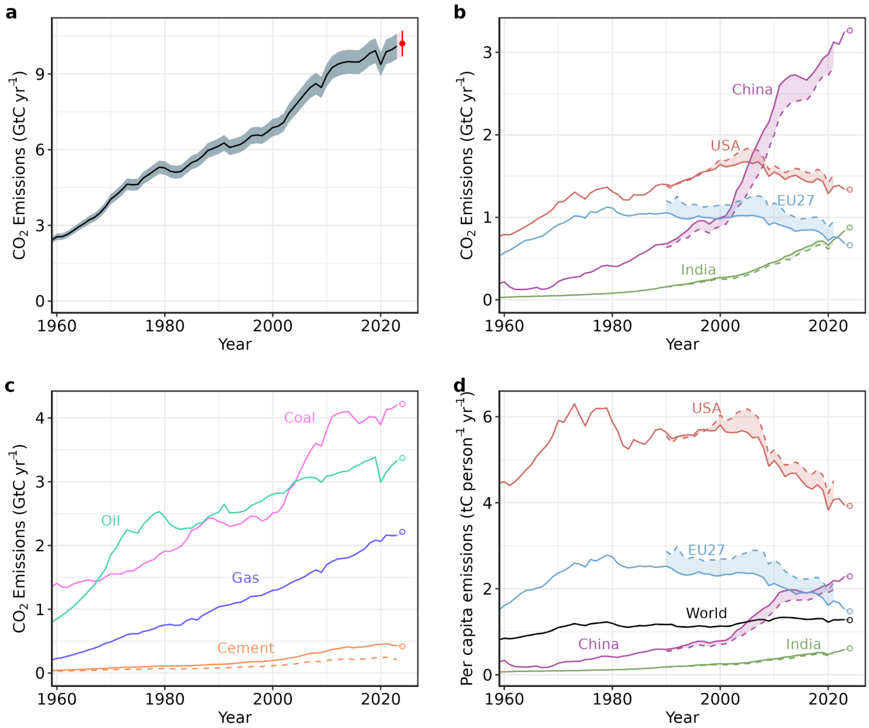

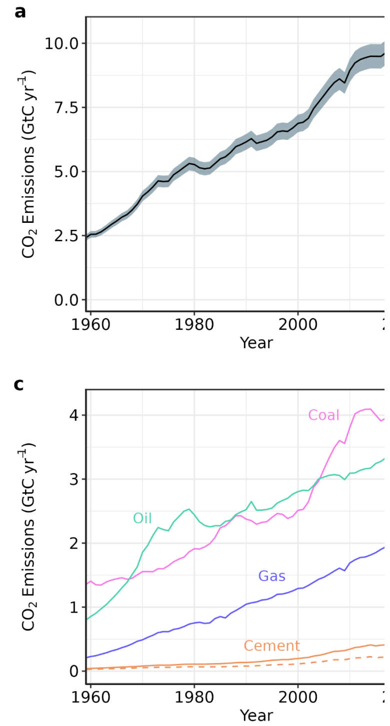

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Figure 5. Fossil CO_2 emissions for (a) the globe, including an uncertainty of ± 5% (grey shading) and a projection through the year 2024 (red dot and uncertainty range), (b) territorial (solid lines) and consumption (dashed lines) emissions for the top three country emitters (USA, China, India) and for the European Union (EU27), (c) global emissions by fuel type, including coal, oil, gas, and cement, and cement minus cement carbonation (dashed), and (d) per-capita emissions the world and for the large emitters as in panel (b). Territorial emissions are primarily from a draft update of Hefner and Marland (2023) except for national data for most Annex I countries for 1990-2022, which are reported to the UNFCCC as detailed in the text, as well as some improvements in individual countries, and extrapolated forward to 2023 using data from Energy Institute. Consumption-based emissions are updated from Peters et al. (2011a). See Section 2.1 and Supplement S.1 for details of the calculations and data sources.

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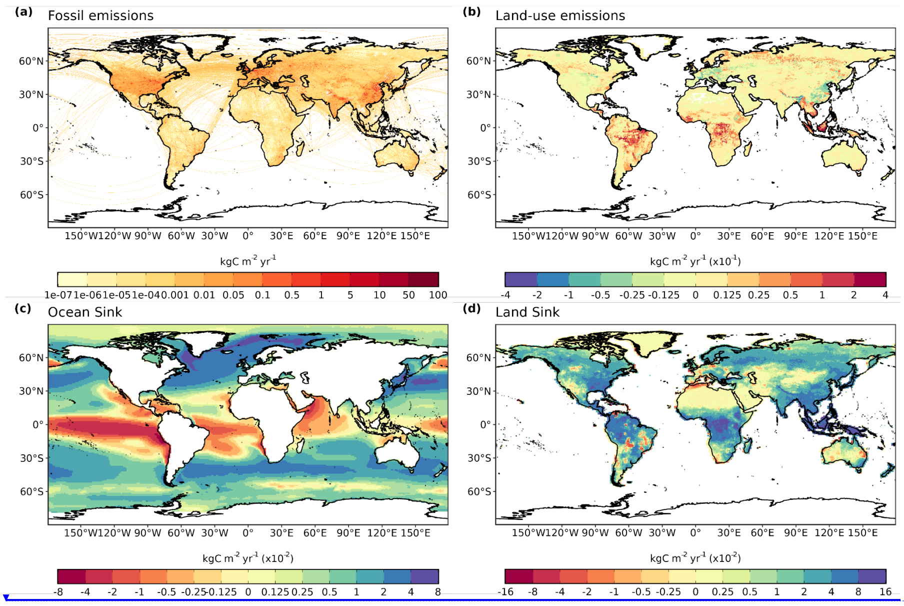

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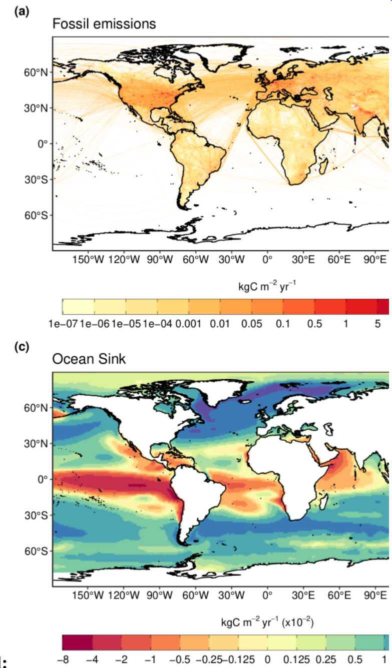

Figure 6. The 2014-2023 decadal mean components of the global carbon budget, presented for (a) fossil CO_2 emissions (E_{FOS}), (b) land-use change emissions (E_{LUC}), (c) the ocean CO_2 sink (S_{OCEAN}), and (d) the land CO_2 sink (S_{LAND}). Positive values for E_{FOS} and E_{LUC} represent a flux to the atmosphere, whereas positive values of S_{OCEAN} and S_{LAND} represent a flux from the atmosphere to the ocean or the land (carbon sink). In all panels, yellow/red colours represent a source (flux from the land/ocean to the atmosphere), green/blue colours represent a sink (flux from the atmosphere into the land/ocean). All units are in kgC m^{-2} yr^{-1}. Note the different scales in each panel. E_{FOS} data shown is from GCP-GridFEDv2024.0 and does not include cement carbonation. The E_{LUC} map shows the average E_{LUC} from the four bookkeeping models plus emissions from peat drainage and peat fires. BLUE and LUCE provide spatially explicit estimates at 0.25° resolution. Gridded E_{LUC} estimates for H&C2023 and OSCAR are derived by spatially distributing their national data based on the spatial patterns of BLUE gross fluxes in each country (see Schwingshackl et al., 2022, for more details about the methodology). S_{OCEAN} data shown is the average of GOBMs and fCO$_2$-products means, using GOBMs simulation A, no adjustment for bias and drift applied to the gridded fields (see Section 2.5). S_{LAND} data shown is the average of the DGVMs for simulation S2 (see Section 2.6).

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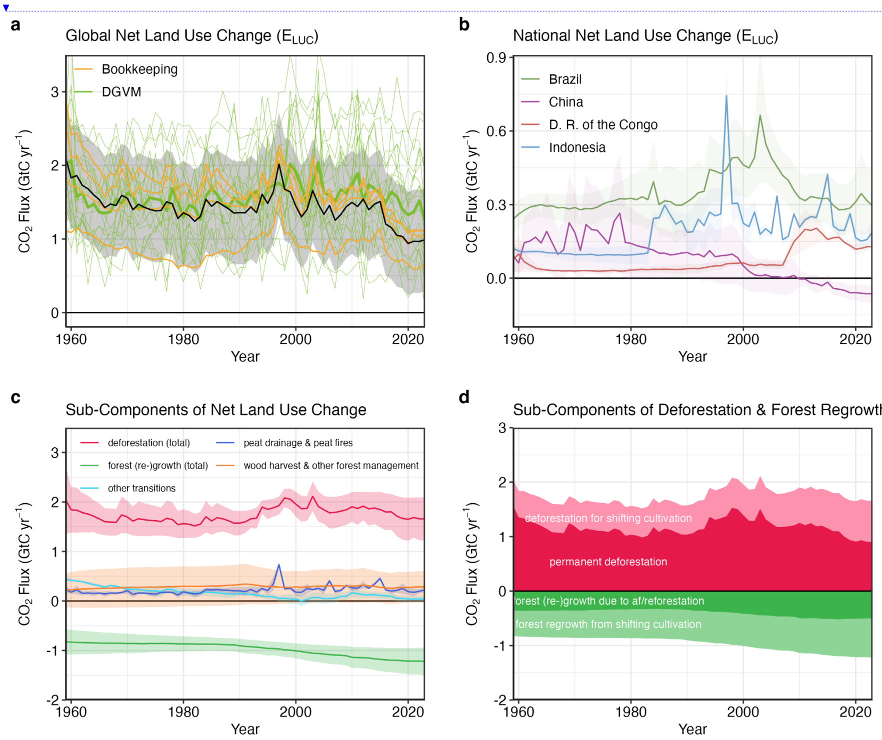

Figure 7. Net CO_2 exchanges between the atmosphere and the terrestrial biosphere related to land use change. (a) Net CO_2 emissions from land-use change (E_{LUC}) with estimates from the four bookkeeping models (yellow lines) and the budget estimate (black with ±1σ uncertainty), which is the average of the four bookkeeping models. Estimates from individual DGVMs (narrow green lines) and the DGVM ensemble mean (thick green line) are also shown. (b) Net CO_2 emissions from land-use change from the four countries with largest cumulative emissions since 1959. Values shown are the average of the four bookkeeping models, with shaded regions as ±1σ uncertainty. (c) Sub-components of E_{LUC}: (i) emissions from deforestation (including permanent deforestation and deforestation in shifting cultivation cycles), (ii) emissions from peat drainage & peat fires, (iii) removals from forest (re-)growth (including forest (re-)growth due to afforestation and reforestation and forest regrowth in shifting cultivation cycles), (iv) fluxes from wood harvest and other forest management (comprising slash and product decay following wood harvest, regrowth after wood harvest, and fire suppression), and (v) emissions and removals related to other land-use transitions. The sum of the five components is E_{LUC} shown in panel (a). (d) Sub-components of 'deforestation (total)' and of 'forest (re-)growth (total)': (i) deforestation in shifting cultivation cycles, (ii) permanent deforestation, (iii) forest (re-)growth due to afforestation and/or reforestation, and (iv) forest regrowth in shifting cultivation cycles.

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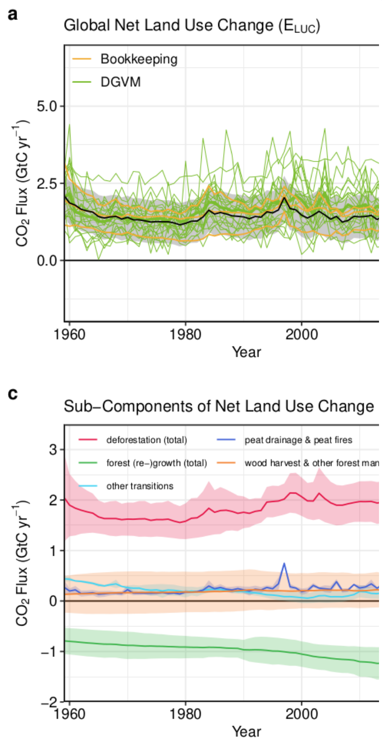

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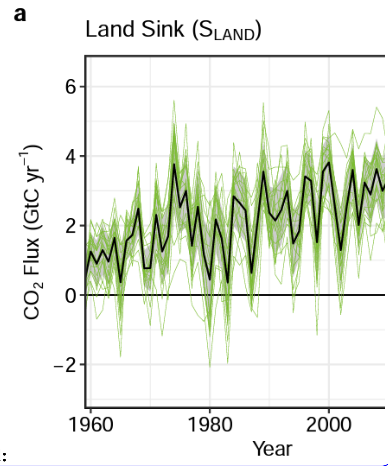

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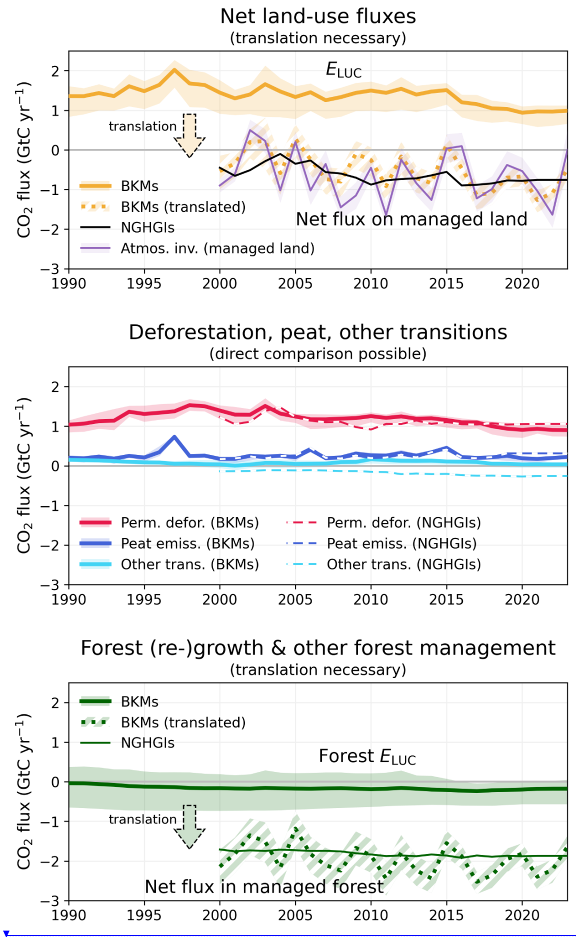

Figure 8. Comparison of land-use flux estimates from bookkeeping models (BKMs; following the GCB definition of E_{LUC}), national GHG inventories (NGHGIs; following IPCC guidelines and thus including all carbon fluxes on managed land), and atmospheric inversion systems (considering fluxes on managed land only). To compare BKM results with NGHGIs, a translation is necessary for some subcomponents. (a) Net land-use fluxes, for which a translation of BKMs is necessary, (b) subcomponents permanent deforestation, peat drainage & peat fires, and other transitions, which can be directly compared and (c) subcomponent forest (re-)growth & other forest management, for which a translation is necessary. The lines represent the mean of 4 BKMs and 14 atmospheric inversion estimates, respectively; Shaded areas denote the full range across BKM estimates and the standard deviation for atmospheric inversions, respectively. The subcomponent forest (re-)growth & other forest management includes removals from forest (re-)growth (permanent), emissions and removals from wood harvest & other forest management, and emissions and removals in shifting cultivation cycles. The translation of

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BKM estimates to NGHGI estimates in (a) and (c) is done by adding the natural land sink in managed forests to the BKM estimates (see also Table S10). The GCB definition of ELUC and the NGHGI definition of land-use fluxes are equally valid, each in its own context. For illustrative purposes we only show the translation of BKM estimates to the NGHGI definition.

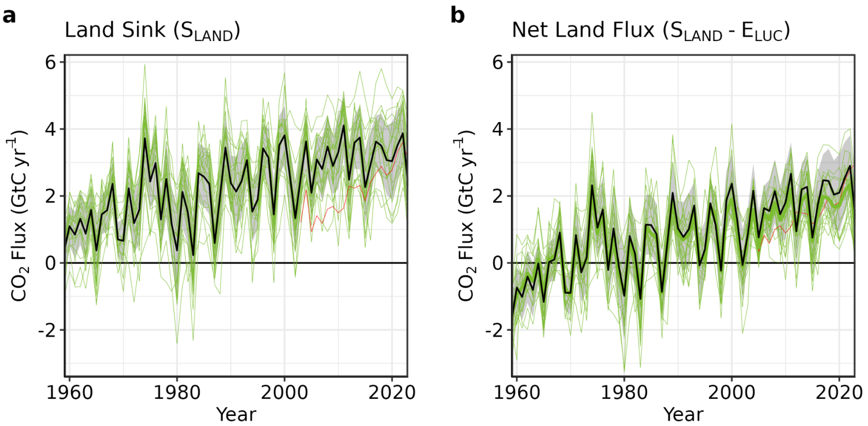

Figure 9. (a) The land CO_2 sink (S_{LAND}) estimated by individual DGVMs (green), and CARDAMOM (red), as well as the budget estimate (black with ±1σ uncertainty), which is the average of all DGVMs. (b) Net atmosphere-land CO_2 fluxes (S_{LAND} – E_{LUC}). The budget estimate of the net land flux (black with ±1σ uncertainty) combines the DGVM estimate of S_{LAND} from panel (a) with the bookkeeping estimate of E_{LUC} from Figure 7a. Uncertainties are similarly propagated in quadrature. DGVMs also provide estimates of E_{LUC} (see Figure 7a), which can be combined with their own estimates of the land sink. Hence panel (b) also includes an estimate for the net land flux for individual DGVMs (thin green lines) and their multi-model mean (thick green line).

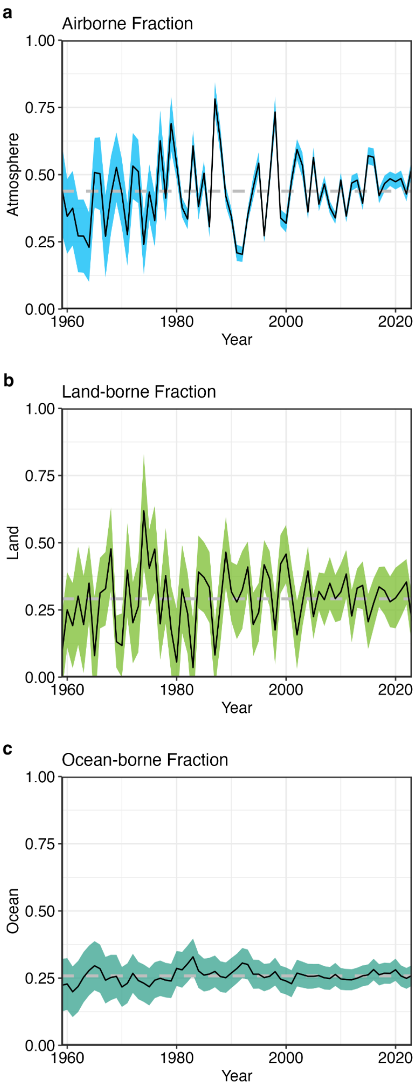

Figure 10. The partitioning of total anthropogenic CO_2 emissions (E_{FOS} + E_{LUC}) across (a) the atmosphere (airborne fraction), (b) land (land-borne fraction), and (c) ocean (ocean-borne fraction). Black lines represent the central estimate, and the coloured shading represents the uncertainty. The grey dashed lines represent the long-term average of the airborne (44%), land-borne (30%) and ocean-borne (25%) fractions during 1960-2023 (with a B_{IM} of 1%).

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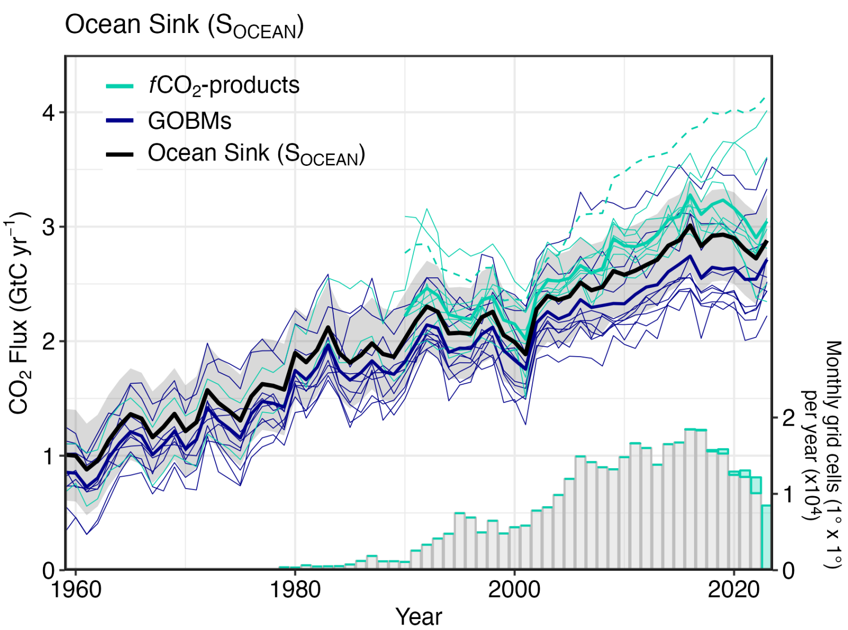

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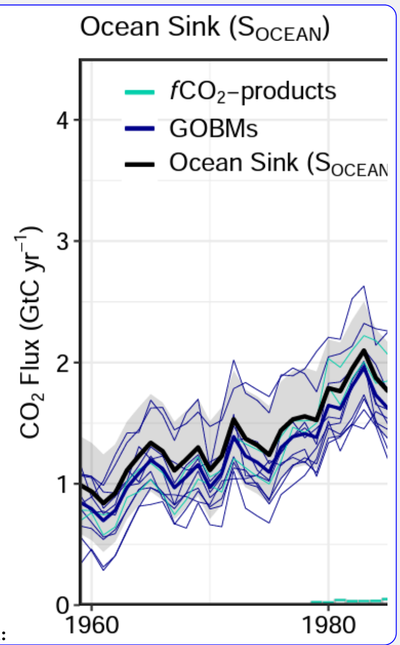

Figure 11. Comparison of the anthropogenic atmosphere-ocean CO_2 flux showing the budget values of S$_{OCEAN}$ (black; with the uncertainty in grey shading), individual ocean models (royal blue), and the ocean fCO$_2$-products (cyan; with UExP-FFN-U, previously Watson et al. (2020), in dashed line as not used for ensemble mean). Two fCO$_2$-products (Jena-MLS, LDEO-HPD) extend back to 1959. The fCO$_2$-products were adjusted for the pre-industrial ocean source of CO_2 from river input to the ocean, by subtracting a source of 0.65 GtC yr^{-1} to make them comparable to S$_{OCEAN}$ (see Section 2.5). Bar-plot in the lower right illustrates the number of monthly gridded values in the SOCAT v2024 database (Bakker et al., 2024). Grey bars indicate the number of grid cells in SOCAT v2023, and coloured bars indicate the newly added grid cells in v2024.

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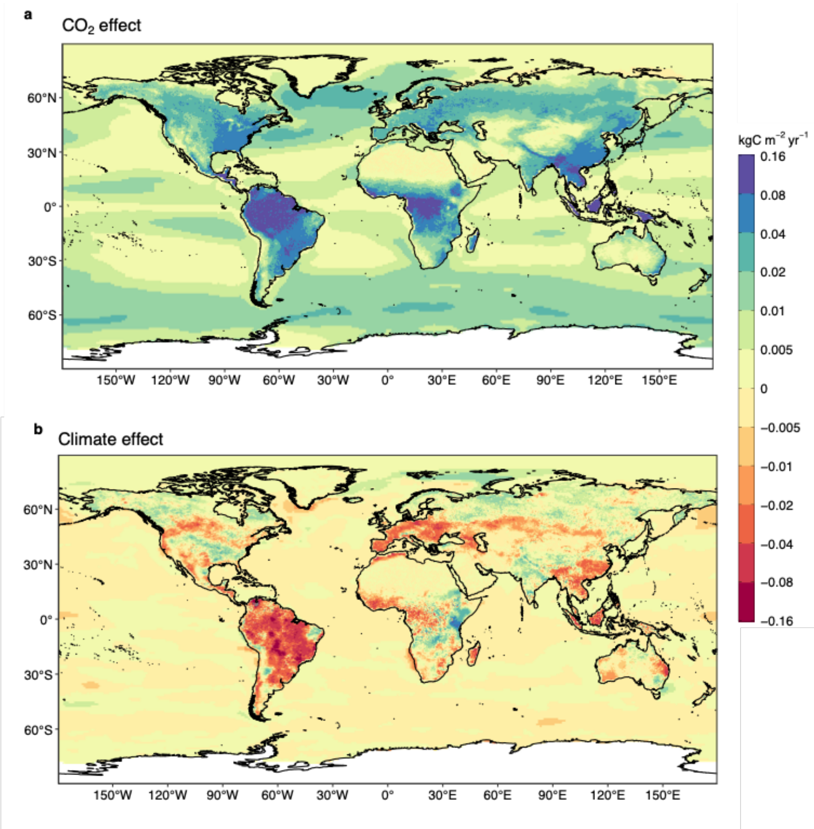

Figure 12. Attribution of the atmosphere-ocean (S_{OCEAN}) and atmosphere-land (S_{LAND}) CO_2 fluxes to (a) increasing atmospheric CO_2 concentrations and (b) changes in climate, averaged over the previous decade 2014-2023. All data shown is from the processed-based GOBMs and DGVMs. Note that the sum of ocean CO_2 and climate effects shown here will not equal the ocean sink shown in Figure 6, which includes the $f$$CO_2$-products. See Supplement S.3.2 and S.4.1 for attribution methodology. Units are in kgC m^{-2} yr^{-1} (note the non-linear colour scale). Positive values (blue) are CO_2 sinks, negative values (red) are CO_2 sources.

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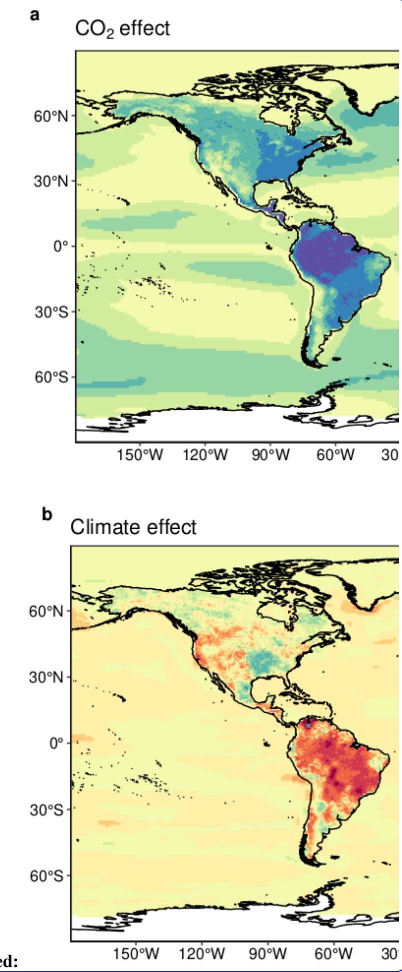

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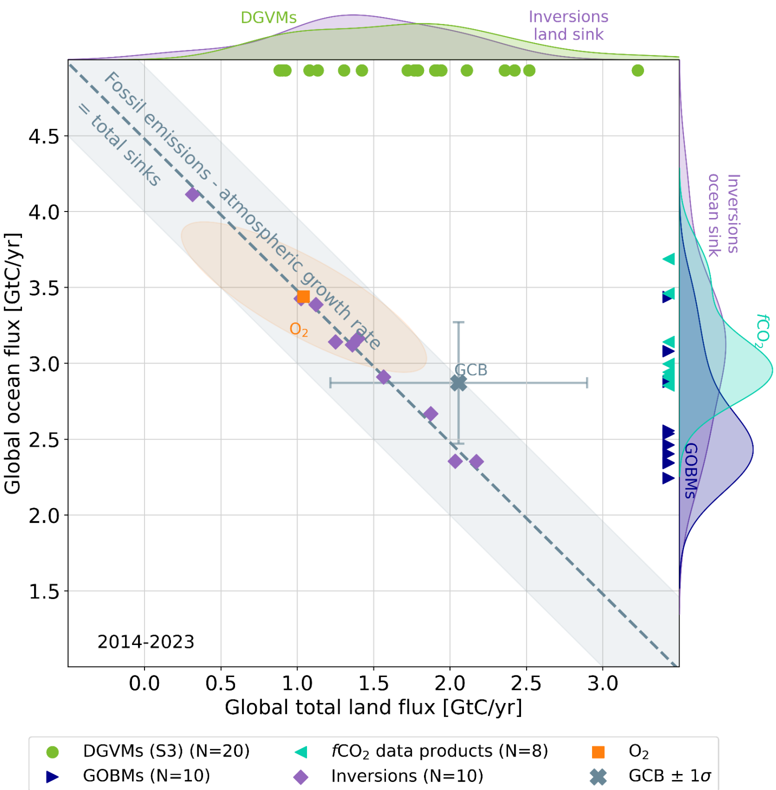

Figure 13. The 2014-2023 decadal mean global net atmosphere-ocean and atmosphere-land fluxes derived from the ocean models and fCO_2 products (y-axis, right and left pointing blue triangles respectively), and from the DGVMs (x-axis, green symbols), and the same fluxes estimated from the atmospheric inversions (purple symbols). The shaded distributions show the densities of the ensembles of individual estimates. The grey central cross is the mean (±1σ) of S_{OCEAN} and (S_{LAND} – E_{LUC}) as assessed in this budget. The grey diagonal line represents the constraint on the global land + ocean net flux, i.e. global fossil fuel emissions minus the atmospheric growth rate from this budget (E_{FOS} – G_{ATM}). The orange square represents the same global net atmosphere-ocean and atmosphere-land fluxes as estimated from the atmospheric O_2 constraint (the ellipse drawn around the central atmospheric O_2 estimate is a contour representing the 1σ uncertainty of the land and ocean fluxes as a joint probability distribution). Positive values are CO_2 sinks. Note that the inverse estimates have been scaled for a minor difference between E_{FOS} and GridFEDv2024.0 (Jones et al., 2024a).

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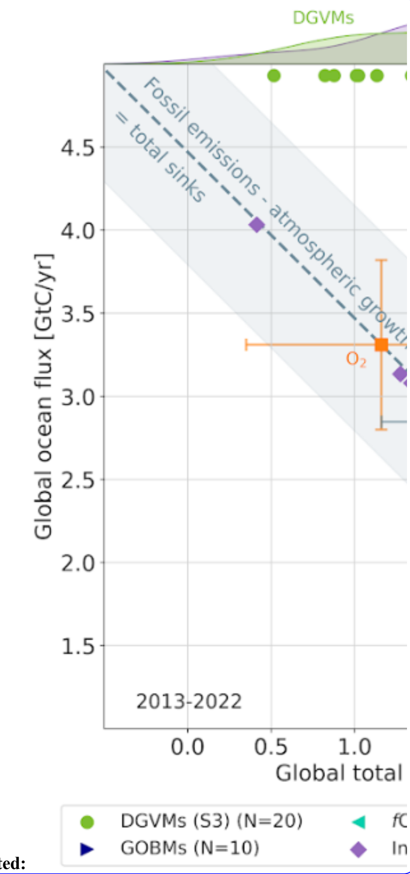

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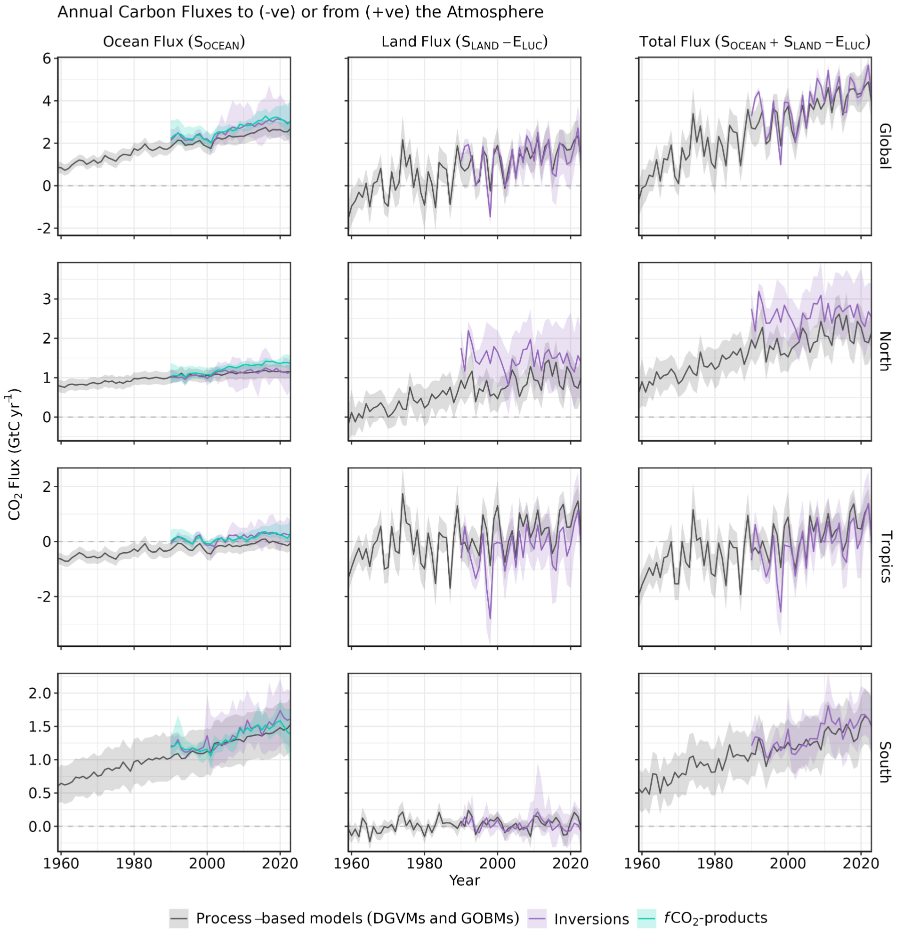

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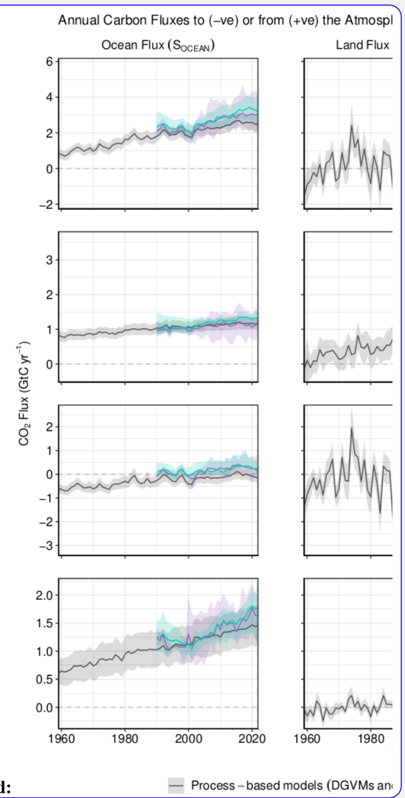

Figure 14. CO_2 fluxes between the atmosphere and the Earth's surface separated between land and oceans, globally and in three latitude bands. The ocean flux is S_{OCEAN} and the land flux is the net atmosphere-land fluxes from the DGVMs. The latitude bands are (top row) global, (2nd row) north (>30°N), (3rd row) tropics (30°S-30°N), and (bottom row) south (<30°S), and over ocean (left column), land (middle column), and total (right column). Estimates are shown for: process-based models (DGVMs for land, GOBMs for oceans); inversion systems (land and ocean); and *f*CO_2-products (ocean only). Positive values are CO_2 sinks. Mean estimates from the combination of the process models for the land and oceans are shown (black line) with ±1 σ of the model ensemble (grey shading). For the total uncertainty in the process-based estimate of the total sink, uncertainties are summed in quadrature. Mean estimates from the atmospheric inversions are shown (purple lines) with their full spread (purple shading). Mean estimates from the *f*CO_2-products are shown for the ocean domain (light blue

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lines) with full model spread (light blue shading). The global S_{OCEAN} (upper left) and the sum of S_{OCEAN} in all three regions represents the anthropogenic atmosphere-to-ocean flux based on the assumption that the preindustrial ocean sink was 0 GtC yr^{-1} when riverine fluxes are not considered. This assumption does not hold at the regional level, where preindustrial fluxes can be significantly different from zero. Hence, the regional panels for S_{OCEAN} represent a combination of natural and anthropogenic fluxes. Bias-correction and area-weighting were only applied to global S_{OCEAN}; hence the sum of the regions is slightly different from the global estimate (<0.07 GtC yr^{-1}).

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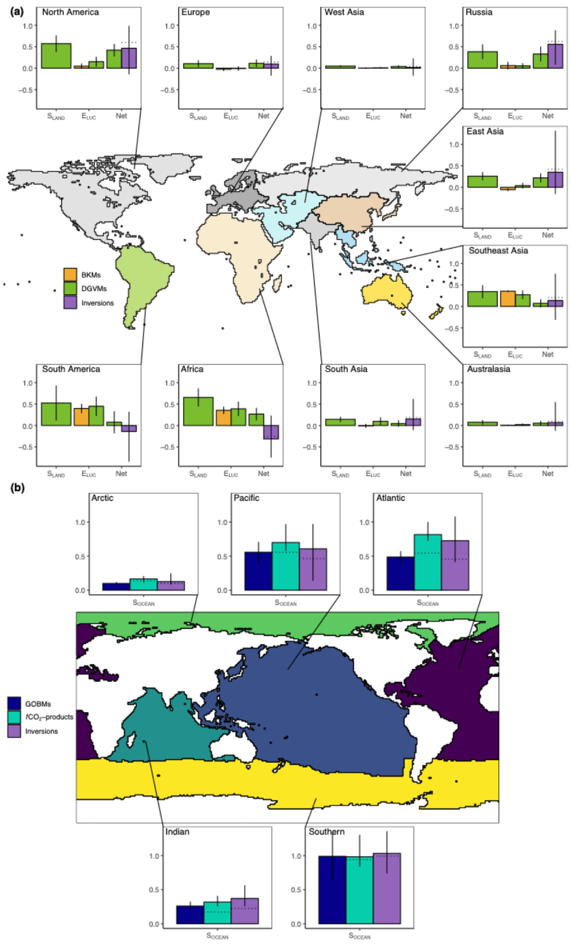

Figure 15. Decadal mean (a) land and (b) ocean fluxes for RECCAP-2 regions over 2014-2023. For land fluxes, S_{LAND} is estimated by the DGVMs (green bars), with the error bar as ±1σ spread among models. A positive S_{LAND} is a net transfer of carbon from the atmosphere to the land. E_{LUC} fluxes are shown for both DGVMs (green) and bookkeeping models (orange), again with the uncertainty calculated as the ±1σ spread. Note, a positive E_{LUC} flux indicates a loss of carbon from the land. The net land flux is shown for both DGVMs (green) and atmospheric inversions (purple), including the full model spread for inversions. The net ocean sink (S_{OCEAN}) is estimated by GOBMs (royal blue), fCO_2-products (cyan), and atmospheric inversions (purple). Uncertainty is estimated as the ±1σ spread for GOBMs, and the full model spread for the other two datasets. The dotted lines show the fCO_2-products and inversion results without river flux adjustment. Positive values are CO_2 sinks.

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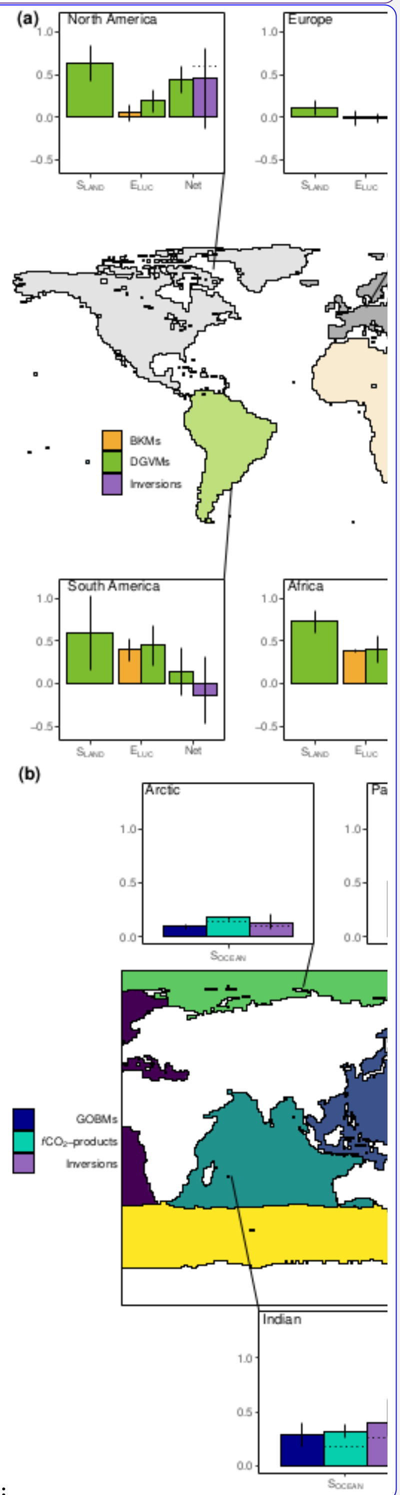

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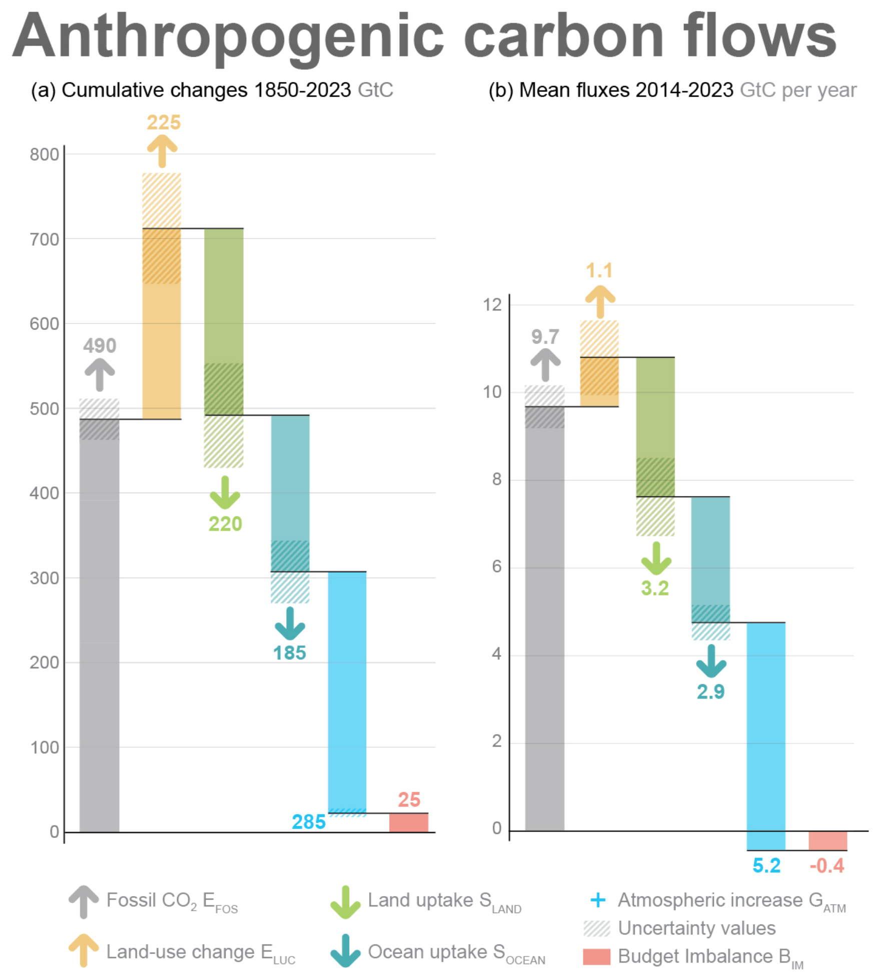

Figure 16. Cumulative changes over the 1850-2023 period (left) and average fluxes over the 2014-2023 period (right) for the anthropogenic perturbation of the global carbon cycle. See the caption of Figure 3 for key information and the methods in text for full details.

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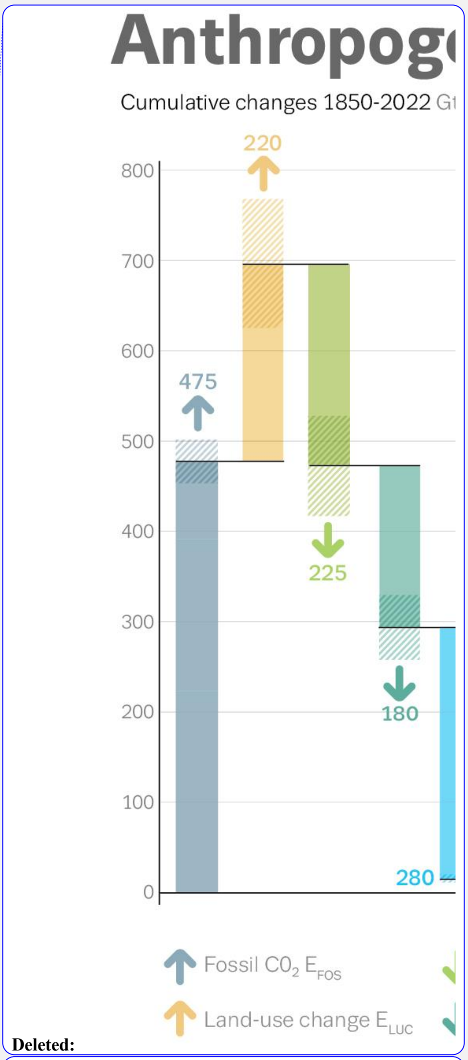

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Figure 17. Kaya decomposition of the main drivers of fossil CO_2 emissions, considering population, GDP per person, Energy per GDP, and CO_2 emissions per energy, for China (top left), USA (top right), EU27 (middle left), India (middle right), Rest of the World (bottom left), and World (bottom right). Black dots are the annual fossil CO_2 emissions growth rate, coloured bars are the contributions from the different drivers to this growth rate. A general trend is that population and GDP growth put upward pressure on emissions (positive values), while energy per GDP and, more recently, CO_2 emissions per energy put downward pressure on emissions (negative values). Both the COVID-19 induced drop during 2020 and the recovery in 2021 led to a stark contrast to previous years, with different drivers in each region.

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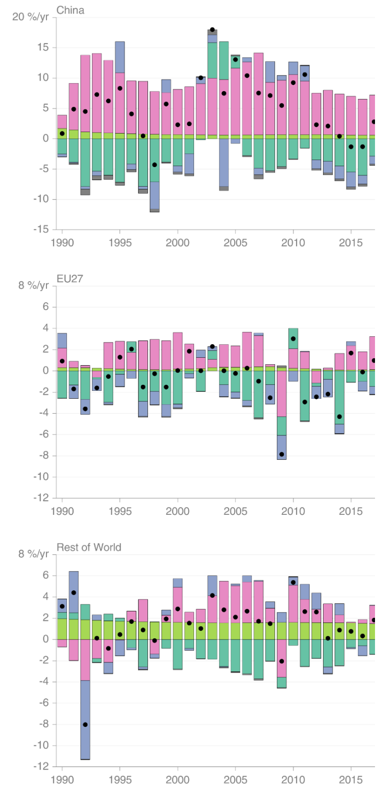

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	World	China	USA	EU27	India	OECD	Non-OECD	IAS	Rest of the World

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Global Carbon Budget 2024

Supplementary Information

S.1 Methodology Fossil Fuel CO_2 emissions (EFOS)

S.1.1 Cement carbonation

From the moment it is created, cement begins to absorb CO_2 from the atmosphere, a process known as 'cement carbonation'. We estimate this CO_2 sink, from 1931 onwards, as the average of two studies in the literature (Cao et al., 2020; Guo et al., 2021 extended by Huang et al., 2023). The Global Cement and Concrete Association reports a much lower carbonation rate, but this is based on the highly conservative assumption of 0% mortar (GCCA, 2021). Modelling cement carbonation requires estimation of a large number of parameters, including the different types of cement material in different countries, the lifetime of the structures before demolition, of cement waste after demolition, and the volumetric properties of structures, among others (Xi et al., 2016). Lifetime is an important parameter because demolition results in the exposure of new surfaces to the carbonation process. The main reasons for differences between the two studies appear to be the assumed lifetimes of cement structures and the geographic resolution, but the uncertainty bounds of the two studies overlap.

S.1.2 Emissions embodied in goods and services

CDIAC, UNFCCC, and BP national emission statistics 'include greenhouse gas emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction' (Rypdal et al., 2006), and are called territorial emission inventories. Consumption-based emission inventories allocate emissions to products that are consumed within a country, and are conceptually calculated as the territorial emissions minus the 'embodied' territorial emissions to produce exported products plus the emissions in other countries to produce imported products (Consumption = Territorial – Exports + Imports). Consumption-based emission attribution results (e.g. Davis and Caldeira, 2010) provide additional information to territorial-based emissions that can be used to understand emission drivers (Hertwich and Peters, 2009) and quantify emission transfers by the trade of products between countries (Peters et al., 2011a). The consumption-based emissions have the same global total, but reflect the trade-driven movement of emissions across the Earth's surface in response to human activities. We estimate consumption-based emissions from 1990-2020 by enumerating the global supply chain using a global model of the economic relationships between economic sectors within and between every country (Andrew and Peters, 2013; Peters et al., 2011b). Our analysis is based on the economic and trade data from the Global Trade and Analysis Project (GTAP; Narayanan et al., 2015), and we make detailed estimates for the years 1997 (GTAP version 5), 2001 (GTAP6), and 2004, 2007, 2011, and 2014 (GTAP10.0a), covering 57 sectors and 141 countries and regions. The detailed results are then extended into an annual time series from 1990 to the latest year of the Gross Domestic Product (GDP) data (2020 in this budget), using GDP data by expenditure in current exchange rate of US dollars (USD; from the UN National Accounts main Aggregates database; UN, 2022) and time series of trade data from GTAP (based on the methodology in Peters et al.,

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2011b). We estimate the sector-level CO_2 emissions using the GTAP data and methodology, add the flaring and cement emissions from our fossil CO_2 dataset, and then scale the national totals (excluding bunker fuels) to match the emission estimates from the carbon budget. We do not provide a separate uncertainty estimate for the consumption-based emissions, but based on model comparisons and sensitivity analysis, they are unlikely to be significantly different than for the territorial emission estimates (Peters et al., 2012b).

S.1.3 Uncertainty assessment for E_{FOS}

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We estimate the uncertainty of the global fossil CO2 emissions at ±5% (scaled down from the published ±10 % at ±2σ to the use of ±1σ bounds reported here; Andres et al., 2012). This is consistent with a more detailed analysis of uncertainty of ±8.4% at ±2σ (Andres et al., 2014) and at the high-end of the range of ±5-10% at ±2σ reported by (Ballantyne et al., 2015). This includes an assessment of uncertainties in the amounts of fuel consumed, the carbon and heat contents of fuels, and the combustion efficiency. While we consider a fixed uncertainty of ±5% for all years, the uncertainty as a percentage of emissions is growing with time because of the larger share of global emissions from emerging economies and developing countries (Marland et al., 2009). Generally, emissions from mature economies with good statistical processes have an uncertainty of only a few per cent (Marland, 2008), while emissions from strongly developing economies such as China have uncertainties of around ±10% (for ±1σ; Gregg et al., 2008; Andres et al., 2014). Uncertainties of emissions are likely to be mainly systematic errors related to underlying biases of energy statistics and to the accounting method used by each country.

S.1.4 Growth rate in emissions

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We report the annual growth rate in emissions for adjacent years (in percent per year) by calculating the difference between the two years and then normalising to the emissions in the first year: $(E_{FOS}(t_0+1)-E_{FOS}(t_0))/E_{FOS}(t_0)\times100\%$. We apply a leap-year adjustment where relevant to ensure valid interpretations of annual growth rates. This affects the growth rate by about 0.3% yr-1 (1/366) and causes calculated growth rates to go up approximately 0.3% if the first year is a leap year and down 0.3% if the second year is a leap year.

The relative growth rate of E_{FOS} over time periods of greater than one year can be rewritten using its logarithm equivalent as follows:

$$\frac{1}{E_{FOS}}\frac{dE_{FOS}}{dt}=\frac{d(lnE_{FOS})}{dt} \qquad (2)$$

Here we calculate relative growth rates in emissions for multi-year periods (e.g. a decade) by fitting a linear trend to $ln(E_{FOS})$ in Eq. (2), reported in percent per year.

S.1.5 Emissions projection for 2023

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To gain insight on emission trends for 2023, we provide an assessment of global fossil CO_2 emissions, E_{FOS}, by combining individual assessments of emissions for China, USA, the EU, and India (the four countries/regions with the largest emissions), and the rest of the world.

The methods are specific to each country or region, as described in detail below.

China: We use a regression between monthly data for each fossil fuel and cement, and annual data for consumption of fossil fuels / production of cement to project full-year growth in fossil fuel consumption and cement production. The monthly data for each product consists of the following:

- Coal: Production data from the National Bureau of Statistics (NBS), plus net imports from the China Customs Administration (i.e., gross supply of coal, not including inventory changes), adjusted using monthly production data for thermal electricity, crude steel, pig iron, coke and cement from NBS.
- Oil: Production data from NBS, plus net imports from the China Customs Administration (i.e., gross supply of oil, not including inventory changes)
- Natural gas: Same as for oil
- Cement: Production data from NBS

For oil, we use data for production and net imports of refined oil products rather than crude oil. This choice is made because refined products are one step closer to actual consumption, and because crude oil can be subject to large market-driven and strategic inventory changes that are not captured by available monthly data. Furthermore, refinery output in 2022 was atypically low through August of that year compared to the rest of the year, which results in very high growth figures for the 2023 data compared to what one can likely expect for the last four months of this year. The estimate has been adjusted down by 0.8 percentage points to account for this, corresponding to how much lower the ratio of January-August and September-December refinery output was in 2022 compared to the average for 2014-2022.

For each fuel and cement, we make a Bayesian linear regression between year-on-year cumulative growth in supply (production for cement) and full-year growth in consumption (production for cement) from annual consumption data. In the regression model, the growth rate in annual consumption (production for cement) is modelled as a regression parameter multiplied by the cumulative year-on-year growth rate from the monthly data through August of each year for past years (through 2022). We use broad Gaussian distributions centered around 1 as priors for the ratios between annual and through-August growth rates. We then use the posteriors for the growth rates together with cumulative monthly supply/production data through August of 2023 to produce a posterior predictive distribution for the full-year growth rate for fossil fuel consumption / cement production in 2023.

If the growth in supply/production through August were an unbiased estimate of the full-year growth in consumption/production, the posterior distribution for the ratio between the monthly and annual growth rates would be centered around 1. However, in practice the ratios are different from 1 (in most cases below 1). This is a result of various biasing factors such as uneven evolution in the first and second half of each year, inventory changes that are somewhat anti-correlated with production and net imports, differences in statistical coverage, and other factors that are not captured in the monthly data.

For fossil fuels, the mean of the posterior distribution is used as the central estimate for the growth rate in 2023, while the edges of a 68% credible interval (analogous to a 1-sigma confidence interval) are used for the upper and lower bounds.

USA: We use emissions estimated by the U.S. Energy Information Administration (EIA) in their Short-Term Energy Outlook (STEO) for emissions from fossil fuels to get both YTD and a full year projection (EIA, 2023). The STEO also includes a near-term forecast based on an energy forecasting model which is updated monthly (we use the November 2023 edition), and takes into account expected temperatures, household expenditures by fuel type, energy markets, policies, and other effects. We combine this with our estimate of emissions from cement production using the monthly U.S. cement clinker production data from USGS for January-August 2023, assuming changes in clinker production over the first part of the year apply throughout the year.

India: We use monthly emissions estimates for India updated from Andrew (2020b) through August-October 2023. These estimates are derived from many official monthly energy and other activity data sources to produce direct estimates of national CO_2 emissions, without the use of proxies. Emissions from coal are then extended to October using a regression relationship based on power generated from coal, coal dispatches by Coal India Ltd., the composite PMI, time, and days per month. For the last 3-5 months of the year, each series is extrapolated assuming typical (pre-2019) trends.

EU: We use a refinement to the methods presented by Andrew (2021), deriving emissions from monthly energy data reported by Eurostat. Some data gaps are filled using data from the Joint Organisations Data Initiative (JODI, 2022). Sub-annual cement and cement-clinker production data are limited, but data for Germany, Poland and Spain, the three largest producers, suggest a decline of over 8%. For fossil fuels this provides estimates through July-September, varying by fuel. We extend coal emissions through October using a regression model built from generation of power from hard coal, power from brown coal, and the number of working days in Germany, the biggest coal consumer in the EU. These are then extended through the end of the year assuming typical trends. We extend oil emissions by building a regression model between our monthly CO_2 estimates and oil consumption reported by the EIA for Europe in its Short-Term Energy Outlook (November edition), and then using this model with EIA's monthly forecasts. For natural gas, the strong seasonal signal allows the use of the bias-adjusted Holt-Winters exponential smoothing method (Chatfield, 1978), although this comes with larger uncertainty given the unusual energy situation in Europe in 2022-23.

Rest of the world: We use the close relationship between the growth in GDP and the growth in emissions (Raupach et al., 2007) to project emissions for the current year. This is based on a simplified Kaya Identity, whereby E_{FOS} (GtC yr^{-1}) is decomposed by the product of GDP (USD yr^{-1}) and the fossil fuel carbon intensity of the economy (I_{FOS}; GtC USD^{-1}) as follows:

$$E_{FOS} = GDP \times I_{FOS} \tag{3}$$

Taking a time derivative of Equation (3) and rearranging gives:

$$\frac{1}{E_{FOS}}\frac{dE_{FOS}}{dt} = \frac{1}{GDP}\frac{dGDP}{dt} + \frac{1}{I_{FOS}}\frac{dI_{FOS}}{dt} \tag{4}$$

where the left-hand term is the relative growth rate of E_{FOS}, and the right-hand terms are the relative growth rates of GDP and I_{FOS}, respectively, which can simply be added linearly to give the overall growth rate.

The I_{FOS} is based on GDP in constant PPP (Purchasing Power Parity) from the International Energy Agency (IEA) up to 2017 (IEA/OECD, 2019) and extended using the International Monetary Fund (IMF) growth rates through 2022 (IMF, 2023). Interannual variability in I_{FOS} is the largest source of uncertainty in the GDP-based emissions projections. We thus use the standard deviation of the annual IFOS for the period 2013-2022 as a measure of uncertainty, reflecting a ±1σ as in the rest of the carbon budget. For rest-of-world oil emissions growth, we use the global oil demand forecast published by the EIA less our projections for the other four regions, and estimate uncertainty as the maximum absolute difference over the period available for such forecasts using the specific monthly edition (e.g. August) compared to the first estimate based on more solid data in the following year (April).

Bunkers: Given the divergence in behaviour of international shipping from countries' emissions since the COVID-19 pandemic, we project international bunkers separately using sub-annual data on international aviation from the OECD (Clarke et al., 2022) and international shipping from MarineBenchmark and IMF (Cerdeiro et al., 2020).

World: The global total is the sum of each of the countries and regions.

S.2 Methodology CO_2 emissions from land-use, land-use change and forestry (E_{LUC})

The net CO_2 flux from land-use, land-use change and forestry (E_{LUC}, called land-use change emissions in the rest of the text) includes CO_2 fluxes from deforestation, afforestation, logging and forest degradation (including harvest activity), shifting cultivation (cycle of cutting forest for agriculture, then abandoning), regrowth of forests following wood harvest or abandonment of agriculture, peat burning, and peat drainage. Land-management activities are only partly included in our land-use change emissions estimates (Table S1). Some land-use change and land-management activities cause emissions of CO_2 to the atmosphere, while others remove CO_2 from the atmosphere. E_{LUC} is the net sum of emissions and removals due to all anthropogenic activities considered. Our annual estimates for 1960-2022 are provided as the average of results from four bookkeeping approaches (Supplement S.2.1 below): the Bookkeeping of Land Use Emissions model (BLUE; Hansis et al., 2015), the compact Earth system model OSCAR (Gasser et al., 2020), an estimate from Houghton and Castanho (2023; hereafter H&C2023), and the Land-Use Change Emissions model (LUCE; Qin et al., 2024). Peat emissions are added from external datasets (see Supplement S.2.1 below). BLUE and OSCAR are updated with new land-use forcing data covering the time period until 2023. All four data sets are extrapolated to provide a projection for 2024 (see Supplement S.2.5 below). In addition, we use results from Dynamic Global Vegetation Models (DGVMs; see Supplement S.2.2 and Table 4) to help quantify the uncertainty in E_{LUC} (Supplement S.2.4), and thus better characterise the robustness of annual estimates and trends. In this budget, we follow the scientific E_{LUC} definition as used by global carbon cycle models, which counts fluxes due to environmental changes on managed land towards S_{LAND}, as opposed to the national greenhouse gas inventories (NGHGIs) under the UNFCCC, most of which include them in E_{LUC} and thus often report smaller land-use emissions (Grassi et al., 2018; Petrescu et al., 2020). Following the methodology of Grassi et al. (2023), we provide harmonised estimates of the two approaches further below (see Supplement S.2.3).

S.2.1 Bookkeeping models

CO_2 emissions and removals from land-use change are calculated by four bookkeeping models. These are based on the original bookkeeping approach of Houghton (2003), which keeps track of the carbon stored in vegetation and soils before and after a land-use change event (transitions between various natural vegetation types,

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croplands, and pastures). Literature-based response curves describe the decay of vegetation and soil carbon, including carbon transfer to product pools of different lifetimes, as well as carbon uptake due to regrowth. In addition, the bookkeeping models represent long-term degradation of primary forest as lowered standing vegetation and soil carbon stocks in secondary forests, and include forest management practices such as wood harvests.

BLUE, LUCE and H&C2023 exclude the transient response of land ecosystems to changes in climate, atmospheric CO_2, and other environmental factors, and base the carbon densities of soil and vegetation on contemporary data from literature and inventory data. Since carbon densities thus remain fixed over time, the additional sink capacity that ecosystems provide in response to CO_2 fertilisation and some other environmental changes are not captured by these models (Pongratz et al., 2014). OSCAR includes this transient response, and it follows a theoretical framework (Gasser and Ciais, 2013) that allows separating bookkeeping land-use emissions and the loss of additional sink capacity. Only the former is included here, while the latter is discussed in Supplement S.6.4. The bookkeeping models differ in (1) computational units (spatially explicit treatment of land-use change at 0.25° resolution for BLUE and LUCE, country-level for H&C2023 and OSCAR), (2) processes represented (see Table S1), and (3) carbon densities assigned to vegetation and soils for different types of vegetation (literature-based for BLUE and H&C2023, calibrated to DGVMs for OSCAR, mainly literature-based but additionally considering the impact of land cohort age on secondary land carbon stocks for LUCE). A notable difference between models exists with respect to the treatment of shifting cultivation: H&C2023 assumes that forest loss—derived from the Global Forest Resources Assessment (FRA; FAO, 2020)—in excess of increases in cropland and pastures—derived from FAOSTAT (FAO, 2021)—represents an increase in shifting cultivation. If the excess loss of forests in a year is negative, it is assumed that shifting cultivation is returned to forest. Historical areas in shifting cultivation are defined taking into account country-based estimates of areas in fallow in 1980 (FAO/UNEP, 1981) and expert opinion (from Heinimann et al., 2017). In contrast, BLUE, OSCAR, and LUCE include subgrid-scale transitions between all vegetation types. Furthermore, H&C2023 assumes conversion of natural grasslands to pasture, while BLUE, OSCAR, and LUCE allocate pasture transitions proportionally to all natural vegetation that exists in a grid-cell. This is one reason for generally higher emissions in BLUE and OSCAR. In this GCB, we split CO_2 emissions into emissions from permanent deforestation and from deforestation for shifting cultivation. Similarly, we separate the forest (re-)growth estimates into (re-)growth from af/reforestation and from regrowth associated with shifting cultivation. This distinction is insightful with regard to the levers on the reduction of net emissions: as deforestation for shifting cultivation is only temporary, the associated CO_2 emissions cannot easily be avoided without compromising the CO_2 removals from regrowth in shifting cultivation cycles. By contrast, permanent deforestation is typically not directly related to af/reforestation. Stopping deforestation for permanent agricultural expansion and increasing the forest area provide two independent levers for net emissions reduction.

Bookkeeping models do not directly capture carbon emissions from the organic layers of drained peat soils nor from peat fires. Particularly the latter can create large emissions and interannual variability due to synergies of land-use and climate variability in equatorial Southeast Asia, especially during El-Niño events. We add peat fire emissions based on the Global Fire Emission Database (GFED4s; van der Werf et al., 2017) to the bookkeeping models' output. Peat fire emissions are calculated by multiplying the mass of dry matter emitted by peat fires with the C emission factor for peat fires indicated in the GFED4s database. Emissions from deforestation and

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degradation fires used for extrapolating the H&C2023 data beyond 2020 and to derive the 2023 projection of all three models (see below) are calculated analogously. The satellite-derived GFED4s estimates of peat fire emissions start in 1997. For the previous years, we follow the approach by Houghton and Nassikas (2017), which linearly ramps up from zero emissions in 1980 to 0.04 GtC yr^{-1} in 1996, reflecting the onset of major clearing of peatlands in equatorial Southeast Asia in the 1980s.

We further add estimates of peat drainage emissions, combining estimates from three spatially explicit datasets. We employ FAO peat drainage emissions 1990–2022 from croplands and grasslands (Conchedda and Tubiello, 2020; FAO, 2023), peat drainage emissions 1700–2010 from simulations with the DGVM ORCHIDEE-PEAT (Qiu et al., 2021), and peat drainage emissions 1701–2023 from simulations with the DGVM LPX-Bern v1.5 (Lienert and Joos, 2018; Müller and Joos, 2021), the latter applying the updated LUH2-GCB2024 forcing as also used by BLUE, OSCAR, LUCE, and the DGVMs. The LPX-Bern simulations started from a transient run over the last deglaciation (-20,050 to 1700 AD) following Müller and Joos (2020) and are forced by changes in climate, atmospheric CO_2, nitrogen deposition/input, and land-use changes. Simulations were done with and without prescribing land-use changes since 1700 AD. The difference between the simulations represents anthropogenic peat drainage emissions. To account for internal variability, we used the median peat drainage emissions from a 20-member ensemble. In LPX-Bern, peat carbon is stored in (i) active peatlands, (ii) former peatlands ("natural"), and (iii) former peatlands under anthropogenic use. We average the two CO_2 emission cases from Müller and Joos (2021), assuming that half the peat carbon is lost immediately to the atmosphere after transformation from active to former peatland, while the rest decays slowly, pending on local temperature and soil moisture. The LPX-Bern peat drainage emissions show a very high emission peak in Russia in 1959 followed by very low emissions in 1960. This peak can be attributed to an artefact in the HYDE3.4 dataset, which was corrected for Brazil and the Democratic Republic of the Congo in GCB2022 (Friedlingstein et al. 2022b) but remains for Russia where it strongly impacts the LPX-Bern peat drainage estimates in 1959 and 1960. To correct for this unrealistic peak, we replace the LPX-Bern peat drainage emissions in Russia in 1959 and 1960 by the average of the estimates in 1958 and 1961. FAO data are extrapolated to 1850-2023 by keeping the post-2020 emissions constant at 2020 levels and by linearly increasing tropical peat drainage emissions between 1980 and 1990 starting from 0 GtC yr^{-1} in 1980 (consistent with H&N2017's assumption, Houghton and Nassikas, 2017), and by keeping pre-1990 emissions from the often old drained areas of the extra-tropics constant at 1990 emission levels. ORCHIDEE-PEAT data are extrapolated to 2011-2023 by replicating the average emissions in 2000-2010 (pers. comm. C. Qiu). Further, ORCHIDEE-PEAT only provides peat drainage emissions north of 30°N, and thus we fill the regions south of 30°N by the average peat drainage emissions from FAO and LPX-Bern. The final peat drainage emissions are calculated as the average of the estimates from the three different peat drainage datasets. The net E_{LUC} values indicated in the manuscript are the sum of E_{LUC} estimates from bookkeeping models, peat fire emissions, and peat drainage emissions.

The four bookkeeping estimates used in this study differ with respect to the land-use change data used to drive the models. H&C2023 base their estimates directly on the Forest Resource Assessment (FRA) of FAO, which provides statistics on forest-area change and management at intervals of five years currently updated until 2020 (FAO, 2020). The data is based on country reporting to FAO and may include remote-sensing information in more recent assessments. Changes in land use other than forests are based on annual, national changes in cropland and pasture areas reported by FAO (FAO, 2021). BLUE and LUCE use the harmonised land-use

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change data LUH2-GCB2024 covering the period 850-2023 (an update to the previously released LUH2 v2h dataset; Hurtt et al., 2017; Hurtt et al., 2020), which was also used as input to the DGVMs (Supplement S.2.2). LUH2-GCB2024 provides land-use change data at 0.25° spatial resolution based on the FAO data (as described in Supplement S.2.2) as well as the HYDE3.4 dataset (Klein Goldewijk et al., 2017a, 2017b), considering subgrid-scale transitions between primary forest, secondary forest, primary non-forest, secondary non-forest, cropland, pasture, rangeland, and urban land (Hurtt et al., 2020; Chini et al., 2021). LUH2-GCB2024 provides a distinction between rangelands and pasture, based on inputs from HYDE. Rangeland establishment in forests is assumed to transform forests to grasslands, rangeland establishment in non-forest primary vegetation degrades primary to secondary vegetation, and rangeland establishment in non-forest secondary vegetation has no effect (e.g., browsing on shrubland) (Ma et al., 2020). This case distinction is implemented in BLUE based on a forest mask provided with LUH2-GCB2021. OSCAR was run with both LUH2-GCB2024 and FAO/FRA, where the drivers of the latter were linearly extrapolated to 2023 using their 2015-2020 trends. The best-guess OSCAR estimate used in our study is a combination of results for LUH2-GCB2024 and FAO/FRA land-use data and a large number of perturbed parameter simulations weighted against a constraint (the cumulative S_{LAND} over 1960-2022 of last year's GCB). As the record of H&C2023 ends in 2020, we extend it up to 2023 by adding the yearly anomalies of the emissions from tropical deforestation and degradation fires from GFED4s between 2020 and 2022 to the model's estimate for 2020 (emissions from peat fires and peat drainage are added to all models later in the process).

The annual E_{LUC} from 1850 onwards is calculated as the average of the estimates from BLUE, H&C2023, OSCAR, and LUCE. For the cumulative numbers starting in 1750, emission estimates between 1750-1850 are added based on the average of four earlier publications (30 ± 20 GtC 1750-1850, rounded to nearest 5; Le Quéré et al., 2016).

We provide a split of net E_{LUC} into component fluxes to better identify reasons for divergence between bookkeeping estimates and to give more insight into the drivers of net E_{LUC}. This split distinguishes between emissions from deforestation (including due to shifting cultivation), removals from forest (re-)growth (including regrowth in shifting cultivation cycles), fluxes from wood harvest and other forest management (i.e., emissions in forests from slash decay and emissions from product decay following wood harvesting, removals from regrowth after wood harvesting, and fire suppression), emissions from peat drainage and peat fires, and emissions and removals associated with all other land-use transitions. Additionally, we split deforestation emissions into emissions from permanent deforestation and emissions from deforestation in shifting cultivation cycles, and we split removals from forest (re-)growth into forest (re-)growth due to af/reforestation and forest regrowth in shifting cultivation cycles. This split helps to identify the emission reductions that would be achievable by halting permanent deforestation, and the removals that are caused by permanently increasing the forest cover through re/afforestation. Forest (re-)growth due to af/reforestation is calculated using a slightly updated method compared to GCB2023, now following the method used to calculate CDR due to re/afforestation in the 2nd State of CDR Report (Pongratz et al., 2024). E_{LUC} data are provided as global sums, as spatially explicit estimates at 0.25° spatial resolution (i.e., the native LUH2 resolution), and for 199 countries (based on the list of UNFCCC parties). Spatially explicit E_{LUC} estimates for BLUE and LUCE are directly available at 0.25°. For OSCAR and H&C2023, the country-level estimates were scaled to 0.25° based on the patterns of gross emissions and gross removals in BLUE (see Schwingshackl et al. 2022 for more details about

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the methodology). The gridded net E_{LUC} estimates of BLUE, LUCE, OSCAR, and H&C2023 are averaged, and the gridded estimates of peat drainage emissions (average of FAO, LPX-Bern, and ORCHIDEE-PEAT) and of peat fire emissions (from GFED4s) are added. Country-level estimates for the gridded datasets (BLUE, LUCE, LPX-Bern, ORCHIDEE-PEAT, GFED4s) are calculated based on a country map from Eurostat (Eurostat, 2024), which was remapped to 0.25°. In case multiple countries are present in a 0.25° grid cell, the E_{LUC} estimates are allocated proportional to each country's land fraction in that grid cell.

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S.2.2 Dynamic Global Vegetation Models (DGVMs)

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Land-use change CO_2 emissions are also estimated by an ensemble of 20 DGVMs. The DGVMs account for deforestation and regrowth, the most important components of E_{LUC}, but they do not represent all processes resulting directly from human activities on land (Table S1). All DGVMs represent processes of vegetation growth and mortality, as well as decomposition of dead organic matter associated with natural cycles, and include the vegetation and soil carbon response to increasing atmospheric CO_2 concentration, to climate variability and to climate change. Most models explicitly simulate the coupling of carbon and nitrogen cycles and account for atmospheric N deposition and N fertilisers (Table S1). The DGVMs are independent from the other budget terms except for their use of atmospheric CO_2 concentration to calculate the fertilisation effect of CO_2 on plant photosynthesis.

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All DGVMs use the LUH2-GCB2024 dataset as input, which includes the HYDE cropland/grazing land dataset (Klein Goldewijk et al., 2017a, 2017b), and some additional information on land-use transitions, land-use management activities and wood harvest. This includes annual, quarter-degree (regridded from 5 minute resolution), fractional data on cropland and pasture from HYDE3.4.

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DGVMs that do not simulate subgrid-scale transitions (i.e., those estimating net land-use emissions; see Table S1) used the HYDE information on agricultural area change. For all countries, with the exception of Brazil, the Democratic Republic of the Congo, Indonesia, and China these data are based on the available annual FAO statistics of change in agricultural land area available from 1961 up to and including 2017. The FAO retrospectively revised their reporting for the Democratic Republic of the Congo, which was newly available until 2020 as reported in GCB2022. In addition to FAO country-level statistics, the HYDE3.4 cropland/grazing land dataset is constrained spatially based on multi-year satellite land cover maps from ESA CCI LC (see below). The extension of HYDE beyond the years that were directly informed by data was done as part of the LUH2 methodology this year and was a simple extension of the previous 5-year trend. The actual years for this extension varied by country since some countries were based on FAO data (2021), some used the China data (2019), and some used MapBiomas data (Brazil and Indonesia, 2022). This methodology is not appropriate for countries that have experienced recent rapid changes in the rate of land-use change, e.g. Brazil which has experienced a recent upturn in deforestation. For Brazil and Indonesia we replace FAO state-level data for cropland and grazing land in HYDE by those from the satellite-based land cover dataset MapBiomas (collection 7) for 1985-2022 (Brazil) (Souza et al. 2020) and 2000-2022 (Indonesia). ESA-CCI is used to spatially disaggregate as described below. The pre-1985 period is scaled with the per capita numbers from 1985 from MapBiomas, so this transition is smooth.

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HYDE uses satellite imagery from ESA-CCI from 1992-2018 for more detailed yearly allocation of cropland and grazing land, with the ESA area data scaled to match the FAO annual totals at country-level. The original 300 metre spatial resolution data from ESA was aggregated to a 5 arc minute resolution according to the classification scheme as described in Klein Goldewijk et al. (2017a).

DGVMs that simulate subgrid-scale transitions (i.e., those estimating gross land-use emissions; see Table S1) use more detailed land use transition and wood harvest information from the LUH2-GCB2024 data set. LUH2-GCB2024 is an update of the comprehensive harmonised land-use data set (Hurtt et al., 2020), that includes fractional data on primary and secondary forest vegetation, as well as all underlying transitions between land-use states (850-2023; Hurtt et al., 2011, 2017, 2020; Chini et al., 2021; Table S1). This data set consists of 0.25° fractional areas of land-use states and all transitions between those states, including a new wood harvest reconstruction, new representation of shifting cultivation, crop rotations, management information including irrigation and fertiliser application. The land-use states include five different crop types in addition to splitting grazing land into managed pasture and rangeland. Wood harvest patterns are constrained with Landsat-based tree cover loss data (Hansen et al. 2013). Updates of LUH2-GCB2024 over last year's version (LUH2-GCB2023) are using the most recent HYDE release. HYDE4.3 is based on new FAO inputs for years 1961-2021, new MapBiomas inputs for Brazil (for years 1985-2022) and Indonesia (for years 2000-2022) and new cropland data for China from Yu et al. 2022 (for years 1900-2019).

We use updated FAO wood harvest data for all dataset years from 1961 to 2022, and linearly extended to the year 2023. The HYDE3.4 population data is also used to extend the wood harvest time series back in time. Other wood harvest inputs (for years prior to 1961) remain the same in LUH2. These updates in the land-use forcing are shown in Figure S7 in comparison to LUH2-GCB2022 and LUH2-GCB2023. DGVMs implement land-use change in different ways (e.g. an increased cropland fraction in a grid cell can either be at the expense of grassland, shrubs, or forest, the latter resulting in deforestation; land cover fractions of the non-agricultural land differ between models). Similarly, model-specific assumptions are applied to convert deforested biomass or deforested area, and other forest product pools into carbon, and different choices are made regarding the allocation of rangelands as natural vegetation or pastures.

The difference between two DGVMs simulations (see Supplement S.4.1 below), one forced with historical changes in land-use and a second one with time-invariant pre-industrial land cover and pre-industrial wood harvest rates, allows quantification of the dynamic evolution of vegetation biomass and soil carbon pools in response to land-use change in each model (E_{LUC}). Using the difference between these two DGVM simulations to diagnose E_{LUC} means the DGVM estimate includes the loss of additional sink capacity (around 0.4 ± 0.3 GtC yr-1; see Section 2.10 and Supplement S.6.4), while the bookkeeping model estimate does not.

As a criterion for inclusion in this carbon budget, we only retain models that simulate a positive E_{LUC} during the 1990s, as assessed in the IPCC AR4 (Denman et al., 2007) and AR5 (Ciais et al., 2013). All DGVMs met this criterion.

S.2.3 Translation between NGHGIs and E_{LUC}

Land-use emissions estimates from bookkeeping models and from national GHG Inventories (NGHGIs) show a large gap (see Figure 8 and Table S10). This gap is due to different approaches for calculating "anthropogenic"

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CO_2 fluxes related to land-use change and land management (Grassi et al. 2018). Land sinks due to environmental change on managed lands are treated as non-anthropogenic in the global carbon budget, while they are generally considered as anthropogenic in NGHGIs (“indirect anthropogenic fluxes”; Eggleston et al., 2006). Building on previous studies (Grassi et al. 2021), we implement an approach that adds the DGVM estimates of CO_2 fluxes due to environmental change from managed forest areas (part of S_{LAND}) to the E_{LUC} estimate from bookkeeping models. This sum is expected to be conceptually more comparable to NGHGI estimates than E_{LUC}.

E_{LUC} data are taken from bookkeeping models, in line with the global carbon budget approach. To determine S_{LAND} in managed forest, the following steps were taken: Spatially gridded data of “natural” forest NBP (S_{LAND} i.e., including carbon fluxes due to environmental change and excluding land use change fluxes) were obtained from DGVMs using S2 runs from the TRENDY v13 dataset. Results were first masked with a forest map that is based on tree cover data from Hansen et al. (2013). To perform the conversion “tree” cover to “forest” cover, we exclude gridcells with less than 20% tree cover and isolated pixels with maximum connectivity less than 0.5 ha following the FAO definition of forest. Forest NBP is then further masked with a map of “intact” forest for the year 2013, i.e. forest areas characterised by no remotely detected signs of human activity (Potapov et al. 2017). This way, we obtained S_{LAND} in “intact” and “non-intact” forest areas, which previous studies (Grassi et al. 2021) indicated to be a good proxy, respectively, for “unmanaged” and “managed” forest areas in the NGHGI. Note that only a subset of models had forest NBP at grid cell level. For the other DGVMs, when a grid cell had forest, all the NBP in that grid cell was allocated to forest. Since S2 simulations use pre-industrial forest cover masks that are at least 20% larger than today’s forest (Hurtt et al. 2020), we corrected this NBP by a ratio between observed (based on Hansen et al. 2013) and prescribed (from DGVMs) forest cover. This ratio is calculated for each individual DGVM that provides information on prescribed forest cover, and a common ratio (median ratio of this subset of models) is used. The details of the method used are explained in a GitHub repository (Alkama, 2022).

LULUCF data from NGHGIs are from Grassi et al. (2023), updated up to August 2024. While Annex I countries report a complete time series 1990-2021, gap-filling was applied for Non-Annex I countries through linear interpolation between two points and/or through extrapolation backward (till 2000) and forward (till 2021) using the single closest available data. For all countries, the estimates of the years 2022 and 2023 are assumed to be equal to those of 2021. The managed forest area, used to filter SLAND data from DGVMs to derive the natural land sink in managed forests, accounts for temporal dynamics from 2000 to 2023. This data includes all CO_2 fluxes from land considered managed, which in principle encompasses all land uses (forest land, cropland, grassland, wetlands, settlements, and other land), changes among them, emissions from organic soils (i.e., from peat drainage) and from fires. In practice, although almost all Annex I countries report all land uses, many non-Annex I countries report only on deforestation and forest land, and only few countries report on other land uses. In most cases, NGHGIs include most of the natural response to recent environmental change because they use direct observations (e.g., national forest inventories) that do not allow separating direct and indirect anthropogenic effects (Eggleston et al., 2006).

Last, we also used the gridded data of net land flux from 14 atmospheric inversion systems (Table S4) to get an additional estimate of land-use fluxes in managed land. We applied a correction for riverine transport (see Supplement S.5.1.) and multiplied the resulting values with the fraction of managed land in each grid cell for

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each inversion. For this purpose, we used masks of managed land from Grassi et al. (2023) available for the years 1994, 2002, 2010, and 2016. We linearly interpolated the masks in time and replicated the 2016 mask in the years 2017-2023. Subsequently, we applied another correction for lateral transport due to international wood and crop trade (data from Deng et al. 2024). The obtained values are summed globally and compared to the NGHGI estimates and the translated E_{LUC} estimates.

Figure 8 and Table S10 shows the resulting translation of global carbon cycle models' land flux definitions to that of the NGHGI (discussed in Section 3.2.2). For comparison we also show LULUCF estimates from FAOSTAT (FAO, 2024), which include emissions from net forest conversion and fluxes on forest land (Tubiello et al., 2021) as well as CO_2 emissions from peat drainage and peat fires. Forest land stock change data for 2021-2023 are carried forward from the 2020 estimates. The FAO data shows global emissions of 0.30 GtC yr^{-1} averaged over 2014-2023, in contrast to the removals of -0.76 GtC yr^{-1} estimated by the gap-filled NGHGI data. Most of this difference is attributable to different scopes: a focus on carbon fluxes for the NGHGI and a focus on land-use area and biomass estimates for FAO. In particular, the NGHGI data includes a larger forest sink for non-Annex 1 countries resulting from a more complete coverage of non-biomass carbon pools and non-forest land uses. NGHGI and FAO data also differ in terms of underlying data on forest land (Grassi et al., 2022).

S.2.4 Uncertainty assessment for E_{LUC}

Differences between the bookkeeping models and DGVMs originate from three main sources: different methodologies, which among others lead to inclusion of the loss of additional sink capacity in DGVMs (see Supplement S.6.4), different underlying land-use/land cover datasets, and different processes represented (Table S1). We examine both the results from DGVMs and from the bookkeeping method and use the resulting variations as a way to characterise the uncertainty in E_{LUC}.

Despite the existing differences, the E_{LUC} estimate from the DGVM multi-model mean is consistent with the average of the emissions from the bookkeeping models (Table 5). However, there are large differences among individual DGVMs (standard deviation at 0.6 GtC yr^{-1}; Table 5), between the bookkeeping estimates (standard deviation at 0.3 GtC yr^{-1} for cumulative emissions in 1850-2022), and between the H&C2023 model and its previous model version H&N2017 (average difference 1850-2015 of 0.2 GtC yr^{-1}; see Table 1 in Houghton and Castanho, 2023). A factorial analysis of differences between BLUE and H&N2017 (the precursor of H&C2023) attributed them particularly to differences in carbon densities between primary and secondary vegetation (Bastos et al., 2021). Earlier studies additionally showed the relevance of the different land-use forcing as applied (in updated versions) also in the current study (Gasser et al., 2020). Ganzenmüller et al. (2022) showed that E_{LUC} estimates with BLUE are substantially smaller when the model is driven by a new high-resolution land-use dataset (HILDA+). They identified shifting cultivation and the way it is implemented in LUH2 as a main reason for this divergence. They further showed that a higher spatial resolution reduces the estimates of both gross emissions and gross removals because successive transitions are not adequately represented at coarser resolution, which has the effect that—despite capturing the same extent of transition areas—overall less area remains pristine at the coarser compared to the higher resolution.

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The uncertainty in E_{LUC} of ±0.7 GtC yr^{-1} reflects our best value judgement that there is at least 68% chance (±1σ) that the true land-use change emissions lie within the given range, for the range of processes considered here. Prior to the year 1959, the uncertainty in E_{LUC} is taken from the standard deviation of the DGVMs. We assign low confidence to the annual estimates of E_{LUC} because of the inconsistencies among estimates and because of the difficulties to quantify some of the processes with DGVMs.

S.2.5 Land-use emissions projection for 2024

We project the 2024 land-use emissions for BLUE, H&C2023, OSCAR, and LUCE based on their E_{LUC} estimates for 2023 and on the interannual variability of peat fires and tropical deforestation and degradation fires as estimated using active fire data (MCD14ML; Giglio et al., 2016). The latter scales almost linearly with GFED emissions estimates over large areas (van der Werf et al., 2017), and thus allows for tracking fire emissions in deforestation and tropical peat zones in near-real time. Peat drainage is assumed to be unaltered, as it has low interannual variability. We project the 2024 land-use emissions for BLUE, H&C2023, OSCAR, and LUCE based on their E_{LUC} estimates for 2023 and add the change in carbon emissions from peat fires and tropical deforestation and degradation fires (2024 emissions relative to 2023 emissions) from GFED4s. The GFED4s estimates for 2024 are as of October 17.

S.3 Methodology Ocean CO2 sink

S.3.1 Observation-based estimates

We primarily use the observational constraints assessed by IPCC of a mean ocean CO_2 sink of 2.2 ± 0.7 GtC yr^{-1} for the 1990s (90% confidence interval; Ciais et al., 2013) to verify that the GOBMs provide a realistic assessment of S_{OCEAN}. This is based on indirect observations with seven different methodologies and their uncertainties, and further using three of these methods that are deemed most reliable for the assessment of this quantity (Denman et al., 2007; Ciais et al., 2013). The observation-based estimates use the ocean/land CO_2 sink partitioning from observed atmospheric CO_2 and O_2/N_2 concentration trends (Manning and Keeling, 2006; Keeling and Manning, 2014), an oceanic inversion method constrained by ocean biogeochemistry data (Mikaloff Fletcher et al., 2006), and a method based on penetration time scale for chlorofluorocarbons (McNeil et al., 2003). The IPCC estimate of 2.2 GtC yr^{-1} for the 1990s is consistent with a range of methods (Wanninkhof et al., 2013). We refrain from using the IPCC estimates for the 2000s (2.3 ± 0.7 GtC yr^{-1}), and the period 2002-2011 (2.4 ± 0.7 GtC yr^{-1}, Ciais et al., 2013) as these are based on trends derived mainly from models and one data-product (Ciais et al., 2013). Additional constraints summarised in AR6 (Canadell et al., 2021) are the interior ocean anthropogenic carbon change (Gruber et al., 2019) and ocean sink estimate from atmospheric CO_2 and O_2/N_2 (Tohjima et al., 2019) which are used for model evaluation and discussion, respectively.

We also use nine estimates of the ocean CO_2 sink and its variability based on surface ocean fCO_2 maps obtained by the interpolation of surface ocean fCO_2 measurements. Seven of the methods cover a period from 1990 onwards due to severe restriction in data availability prior to 1990 (Figure 11), whereas two span the time period from 1957 and 1959 onwards. These estimates differ in many respects: they use different maps of surface fCO_2,

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different atmospheric CO_2 concentrations, wind products and different gas-exchange formulations as specified in Table S3. We refer to them as fCO_2-products. The measurements underlying the surface fCO_2 maps are from the Surface Ocean CO_2 Atlas version 2024 (SOCAT v2024; Bakker et al., 2024), which is an update of version 3 (Bakker et al., 2016) and the subsequent annual updates used in previous versions of the global carbon budget. SOCAT v2024 has an additional 3.0 million fCO_2 measurements with an estimated accuracy of better than 5 µatm relative to v2023. Of these, 2 million are from 2023 in a total of 210 data sets (Table S7), while the largest addition from earlier years is from 2022 with 64 data sets new to SOCAT. For the 2023 data, there are a total of 178 data sets with measurements in the Northern hemisphere, while there are only 52 with data from the Southern hemisphere. For the Southern Ocean, there are only 11 data sets from 2023 in the subpolar zone and further south (defined as south of 45°S), and only one from Austral winter (June-August). The coverage of SOCAT observations in 2023 is only about 50% of that in 2016 (Fig. 11), with large reductions in sampling in both the Northern (from 391 to 178 data sets) as well as Southern hemisphere (from 109 to 52 data sets). This reduction cannot be explained only in terms of lags in data submission. The quality control criteria used for SOCATv2024 are described in Lauvset et al. (2018).

. Each of the data-based estimates uses a different method to map the SOCAT v2024 data to the global ocean. The methods include a data-driven diagnostic method combined with a multi linear regression approach to extend back to 1957 (Rödenbeck et al., 2022; referred to here as Jena-MLS), four neural network models (Landschützer et al., 2014; referred to as VLIZ-SOMFFN; Chau et al., 2022; Copernicus Marine Environment Monitoring Service, referred to here as CMEMS-LSCE-FFNN; Zeng et al., 2022; referred to as NIES-ML3; Gregor et al. 2019, referred to as CSIR-ML6), one cluster regression approach (Gregor et al., 2024; referred to as OceanSODA-ETHZv2), a multi-linear regression method (Iida et al., 2021; referred to as JMA-MLR), and one method that relates the fCO_2 misfit between GOBMs and SOCAT to environmental predictors using the extreme gradient boosting method extending back to 1959 (Gloege et al., 2022).. The ensemble mean of the fCO_2-based flux estimates is calculated from these eight mapping methods. Further, we show the flux estimate of the UExP-FNN-U method (Watson et al., 2020; Ford et al., accepted) who also use a neural network model to map fCO_2 data to the globe, but resulting in a substantially larger ocean sink estimate, owing to a number of adjustments they applied to the surface ocean fCO_2 data. Concretely, these authors adjusted the SOCAT fCO_2 downward to account for differences in temperature between the depth of the ship intake and the relevant depth right near the surface, and included a further adjustment to account for the cool surface skin temperature effect. In Friedlingstein et al. 2023, the UExP-FNN-U product correction was applied illustrating that this temperature adjustment leads to an upward correction of the ocean carbon sink, up to 0.9 GtC yr^{-1}, that, if correct, should be applied to all fCO_2-based flux estimates. This year, the updated UExP-FFN-U method applies a smaller adjustment as proposed by Dong et al. (2022), who illustrate a smaller correction effect of 0.6 GtC yr^{-1}. The impact of the cool skin effect on air-sea CO_2 flux is based on established understanding of temperature gradients (as discussed by Goddijn-Murphy et al., 2015 and Woolf et al., 2016), and laboratory observations (Jähne and Haussecker, 1998; Jähne, 2019), but in situ field observational evidence is lacking (Dong et al., 2022). The UExP-FNN-U method is thus, similar to the UExP-FNN-U flux estimate in previous editions, not included in the ensemble mean of the fCO_2-based flux estimates. This choice will be re-evaluated in upcoming budgets based on further lines of evidence.

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Typically, *f*CO_2-products do not cover the entire ocean due to missing coastal oceans and sea ice cover. The CO_2 flux from each *f*CO_2-based product is already at or above 99% coverage (either due to complete coverage or a posteriori filling) of the ice-free ocean surface area in several products this year (UExP-FNN-U, JMA-MLR, VLIZ-SOMFFN, Jena-MLS, OceanSODA-ETHZv2), . The products that remained below 99% coverage of the ice-free ocean (CMEMS-LSCE-FFNN, NIES-ML3, UExP-FNN-U, CSIR-ML6) were scaled by the following procedure:

Since v2022 of the GCB we now scale fluxes globally and regionally (North, Tropics, South) to match the ice-free area (using the HadISST sea surface temperature and sea ice cover; Rayner et al., 2003):

$$FCO_2^{reg-scaled} = \frac{A_{(1-ice)}^{region}}{A_{FCO_2}^{region}} \cdot FCO_2^{region}$$

In the equation, *A* represents area, (1 – ice) represents the ice free ocean, A_{FCO2}^{region} represents the coverage of the *f*CO_2-product for a region, and FCO_2^{region} is the integrated flux for a region.

We further use results from two diagnostic ocean models, Khatiwala et al. (2013) and DeVries (2014), to estimate the anthropogenic carbon accumulated in the ocean prior to 1959. The two approaches assume constant ocean circulation and biological fluxes, with S_{OCEAN} estimated as a response in the change in atmospheric CO_2 concentration calibrated to observations. The uncertainty in cumulative uptake of ±20 GtC (converted to ±1σ) is taken directly from the IPCC's review of the literature (Rhein et al., 2013), or about ±30% for the annual values (Khatiwala et al., 2009).

S.3.2 Global Ocean Biogeochemistry Models (GOBMs)

The ocean CO_2 sink for 1959-2023 is estimated using ten GOBMs (Table S2). The GOBMs represent the physical, chemical, and biological processes that influence the surface ocean concentration of CO_2 and thus the air-sea CO_2 flux. The GOBMs are forced by meteorological reanalysis and atmospheric CO_2 concentration data available for the entire time period. They mostly differ in the source of the atmospheric forcing data (meteorological reanalysis), spin up strategies, and in their horizontal and vertical resolutions (Table S2). All GOBMs except one (CESM-ETHZ) do not include the effects of anthropogenic changes in nutrient supply (Duce et al., 2008). They also do not include the perturbation associated with changes in riverine organic carbon (see Section 2.10 and Supplement S.6.3).

Four sets of simulations were performed with each of the GOBMs. Simulation A applied historical changes in climate and atmospheric CO_2 concentration. Simulation B is a control simulation with constant atmospheric forcing (normal year or repeated year forcing) and constant pre-industrial atmospheric CO_2 concentration. Simulation C is forced with historical changes in atmospheric CO_2 concentration, but repeated year or normal year atmospheric climate forcing. Simulation D is forced by historical changes in climate and constant pre-industrial atmospheric CO_2 concentration.

The atmospheric CO_2 forcing file was updated in GCB2024 to ensure consistency with the atmospheric CO_2 growth rate reported in the GCB. Since January 1980, we use the CO_2 global growth rate reported by NOAA/GML (Lan et al., 2024). In the period March 1958-December 1979, we use bias-adjusted values of the global growth rate based on measurements of atmospheric CO_2 made by the Scripps Institution of

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Oceanography at the Mauna Loa Observatory, Hawaii (Keeling et al., 1976; full period of coverage 1758-2024). Bias adjustment of the Scripps data was performed in three sequential stages as follows:

- First, to correct for differences in the mean atmospheric concentration of CO_2 at Mauna Loa versus the globally averaged value, a constant of -0.231 ppm was added to all Scripps data to improve alignment of the "CO_2[trend]" values from the Scripps data with the "CO_2[trend]" values from the global NOAA data. The value of -0.231 ppm is the mean offset of "CO_2[trend]" at Mauna Loa from the global "CO_2[trend]" value during 1980-2000.
- Second, to correct for differences in the seasonality of atmospheric CO_2 concentrations at Mauna Loa versus globally, we shifted monthly anomalies between CO_2 concentration data and "trend" values backward in time by one month in the Scripps data. This specifically corrects for the fact that peaks/troughs in the climatology of "CO_2[monthly_observation] - CO_2[trend]" at Mauna Loa occur 1 month earlier than peaks/troughs in the climatology of "CO_2[monthly_observation] - CO_2[trend]" in the global data from NOAA. A one-month shift to the Scripps data was found to optimally align the climatologies of "CO_2[monthly_observation] - CO_2[trend]" in the Scripps and global data.
- Third, to correct for the greater amplitude of seasonal anomalies at Mauna Loa from Scripps than the global data from NOAA, we apply a monthly multiplier that dampens the magnitude of monthly anomalies from "trend" values in the Scripps data. The monthly multiplier reduces values of "CO_2[monthly_observation] - CO_2[trend]" in the Scripps data to more closely match values of "CO_2[monthly_observation] - CO_2[trend]" in the NOAA global data.

For the period Jan 1750 to February 1958, we use bias-adjusted values of the global growth rate based on measurements of atmospheric CO_2 from air trapped in ice at Law Dome (Joos and Spahni, 2008; full period of coverage 1750-2004). Bias adjustments were made to improve alignment with the post-1980 time series of data from Scripps and NOAA, and were performed in two sequential stages as follows:

- First, a constant of 0.973 was added to all data from Law Dome to improve alignment with the Scripps data (which had already been bias-corrected as described above). The constant of 0.973 is the mean offset of CO_2 annual values (annual mean in the case of the Scripps data) in the period 1958-1979.
- Second, the climatology of "CO_2[monthly_observation] - CO_2[trend]" from the period 1958-2000 was superimposed on the data from Law Dome (note that the 1958-2000 data includes both Scripps and NOAA data, combined as described above). To achieve this, a spline interpolation was fitted to downscale annual observations from CO_2 concentration from Law Dome to monthly values of "CO_2[trend]" and the climatological seasonality of "CO_2[monthly_observation] - CO_2[trend]" from 1958-2000) was then added to the interpolated values of "CO_2[trend]".

To derive S_{OCEAN} from the model simulations, we subtracted the slope of a linear fit to the annual time series of the control simulation B from the annual time series of simulation A. Assuming that drift and bias are the same in simulations A and B, we thereby correct for any model drift. Further, this difference also removes the natural steady state flux (assumed to be 0 GtC yr^{-1} globally without rivers), which is often a major source of biases. Note, however, that Gürses et al. (2023) questioned the assumption of comparable bias and drift in simulations A and B as they compared two versions of FESOM-REcoM, and found a very similar air-sea CO_2 flux in

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simulation A despite a different bias as derived from simulation B. This approach works for all model set-ups, including IPSL, where simulation B was forced with variable historical climate changes (looping over a 10-year forcing). This approach assures that the interannual variability is not removed from IPSL simulation A. The absolute correction for bias and drift per model in the 1990s varied between <0.01 GtC yr^{-1} and 0.31 GtC yr^{-1}, with five models having positive biases, four having negative biases and one model having essentially no bias (NorESM). The MPI model uses riverine input and therefore simulates outgassing in simulation B. By subtracting a linear fit of simulation B, also the ocean carbon sink of the MPI model follows the definition of Socean. This correction increases the model mean ocean carbon sink by 0.07 GtC yr^{-1} in the 1990s. The ocean models cover 99% to 101% of the total ocean area, so that area-scaling is not necessary.

S.3.3 GOBM evaluation

The ocean CO_2 sink for all GOBMs and the ensemble mean falls within 90% confidence of the observed range, or 1.5 to 2.9 GtC yr^{-1} for the 1990s (Ciais et al., 2013) before and after applying adjustments. The GOBMs and fCO_2-products have been further evaluated using the fugacity of sea surface CO_2 (fCO_2) from the SOCAT v2024 database (Bakker et al., 2016, 2024). We focused this evaluation on the root mean squared error (RMSE) between observed and modelled fCO_2 and on a measure of the amplitude of the interannual variability of the flux (modified after Rödenbeck et al., 2015). The RMSE is calculated from detrended, annually and regionally averaged time series of fCO_2 calculated from GOBMs and fCO_2-products subsampled to SOCAT sampling points to measure the misfit between large-scale signals (Hauck et al., 2020). To this end, we apply the following steps: (i) subsample data points for where there are observations (GOBMs/fCO_2-products as well as SOCAT), (ii) average spatially, (iii) calculate annual mean, (iv) detrend both time-series (GOBMs/fCO_2-products as well as SOCAT), (v) calculate RMSE. We use a mask based on the minimum area coverage of the fCO_2-products. This ensures a fair comparison over equal areas. The amplitude of the Socean interannual variability (A-IAV) is calculated as the temporal standard deviation of the detrended annual CO_2 flux time series after area-scaling (Rödenbeck et al., 2015, Hauck et al., 2020). These metrics are chosen because RMSE is the most direct measure of data-model mismatch and the A-IAV is a direct measure of the variability of Socean on interannual timescales. We apply these metrics globally and by latitude bands. Results are shown in Figure S2 and discussed in Section 3.6.5.

In addition to the interior ocean anthropogenic carbon accumulation (Section 3.6.5) and SOCAT fCO_2, we evaluate the models with process-based metrics that were previously related to ocean carbon uptake. These are the Atlantic Meridional Overturning Circulation (Goris et al., 2018, Terhaar et al., 2022, Terhaar et al., in review), the Southern Ocean sea surface salinity (Terhaar et al., 2021, 2022, 2024, Hauck et al., 2023b), the Southern Ocean stratification index (Bourgeois et al., 2022) and the surface ocean Revelle factor (Terhaar et al., 2022, 2024).

We follow the methodology of previous studies wherever possible, particularly the RECCAP model evaluation chapter (Terhaar et al. 2024). The Atlantic Meridional Overturning Circulation from the GOBMs is here defined as the maximum of the Atlantic meridional overturning streamfunction at 26°N. This is compared to data from

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the RAPID array at 26°N (Moat et al., 2024). An uncertainty of 0.9 Sv was reported in McCarthy et al. (2015). We use the years 2005-2022, which are all complete calendar years available from the RAPID data set, and report the temporal standard deviation over that period.

The Southern Ocean sea surface salinity is reported for the subpolar seasonally stratified biome (SPSS) and for the area covering both the SPSS and subtropical seasonally stratified (STSS) biomes. Biome definitions are taken from Fay and McKinley (2014, as provided for the RECCAP2 project). The sea surface salinity was first used as an emergent constraint for the Southern Ocean CO_2 uptake with Earth System Models (Terhaar et al. 2021, 2022) using the interfrontal salinity between the polar and subtropical fronts with dynamic fronts. As the GOBMs are forced with reanalysis data, the fronts do not vary as much as in the ESMs, and thus the use of fixed biomes is justified (Hauck et al., 2023b, Terhaar et al., 2024). We use the time period 2005-2022 for consistency with the AMOC metric. The observational sea surface salinity values are calculated from the EN4 data set (Good et al., 2013; using the objective analyses – Gouretski and Reseghetti (2010) XBT corrections and Gouretski and Cheng (2020) MBT corrections) with the aid of the Fay and McKinley (2014) mask.

The Southern Ocean stratification index is a simplified version of the metric used in Bourgeois et al. (2022). It is defined as the difference between in situ density at the surface and at 1000 m depth in the latitudinal band of 30°S to 55°S. Each model provider calculated this metric based on their native model mesh. We use again the period of 2005-2022 for consistency with the AMOC metric. The same metric was calculated from the EN4 data set mentioned above (Good et al., 2013).

Finally, the global surface ocean Revelle factor is reported. Monthly 1°x1° gridded fields were provided by the modelling groups, based on standard carbonate chemistry routines (e.g., mocsy, Orr & Epitalon, 2015; PyCO2SYS, Humphreys et al., 2022a,b). The observational metrics come from two sources, firstly the gridded GLODAP data set v2.2016 (Lauvset et al., 2016), which is a climatology centered around the year 2002. For comparison with GLODAP, the models were subsampled to GLODAP data coverage and to a comparable time window also centred around 2002 (1997-2007). Secondly, the OceanSODA v2024 data set (Gregor and Gruber, 2020, updated) was used, which has all input data available to calculate the surface ocean Revelle factor. OceanSODA covers a slightly smaller surface area (~96 % of GLODAP), but provides data until 2021. The period 2005-2021 was used due to data availability and the models were subsampled to the same spatial and temporal coverage.

For this release, only the comparison of the metrics between GOBMs and observational data sets is presented, whereas it is foreseen to translate this comparison into a quantitative benchmarking comparable to the iLAMB benchmarking for the DGVMs and the corresponding iOMB framework (Ogunro et al., 2018). In a next step, model weighting can be applied based on the benchmarking (e.g., Brunner et al., 2020).

S3.4 *f*CO_2-product trend benchmarking

In addition to the air-sea CO2 flux estimates, *f*CO_2-product providers reconstructed the sea surface *f*CO_2 of a set of 4 GOBM´s, namely CESM-ETHZ, FESOM2.1REcoM, MRI-ESM2 and IPSL, that were submitted to the

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GCB2023 (Friedlingstein et al. 2023) following the approach of Hauck et al. (2023). A total of 6 fCO_2-products conducted the benchmark test (VLIZ-SOMFFN, NIES-ML3, Jena-MLS, CSIR-ML6, OceanSODA-ETHZv2 and JMA-MLR). The GOBM´s serve as known truth and are subsampled according to the real world observation tracks. The fCO_2-products then reconstruct the true model field, based on the subsampled information provided. We then compare trends for the period 2001-2021, i.e. the period where we see the divergence between fCO_2-products and models, removing the final year to avoid the tail effect. The trends of the individual fCO_2-products from the GCB24 were then plotted against the mean of the trend reconstruction bias (evaluated against the known truth GOBM trends) of the 4 GOBM. This is shown in Figure S3. The figure illustrates the tendency that fCO_2-products with negative biases in the fCO_2 reconstruction show the strongest air-sea CO_2 flux trends and vice versa for the fCO2 products with positive biases. Overall, the ensemble of 6 fCO2 methods shows a tendency to underestimate the fCO_2 trend from the GOBMs (with a mean bias across 6 fCO_2-products and 4 model reconstructions of 0.25 µatm/decade) and thus an inferred tendency to overestimate the air-sea CO_2 flux trend (mean across 6 fCO_2-products of 0.50±0.13 PgC yr^{-1} decade^{-1}), however, due to compensating negative and positive fCO_2 biases, the ensemble mean trend bias is smaller than suggested from previous studies focusing on one or two fCO_2-products only (see e.g. Gloege et al. 2021, Hauck et al. 2023). The inferred global trend of 0.43±0.13 PgC yr-1 decade-1 that intercepts with the 0 bias line closely corresponds to a recent estimate by Mayot et al. 2024 of 0.42±0.06 PgC yr-1 decade-1 (period 2000-2022) in the mean, although with a substantially larger uncertainty and different time period. The evidence basis, thus, remains low due to the small sample size of fCO2-products (n=6) and reconstructed GOBMs (n=4), thus a more detailed analysis is required to better constrain fCO2-product trends.

S3.4 Uncertainty assessment for S_{OCEAN}

We quantify the 1-σ uncertainty around the mean ocean sink of anthropogenic CO_2 by assessing random and systematic uncertainties for the GOBMs and fCO_2-products. The random uncertainties are taken from the ensemble standard deviation (0.3 GtC yr^{-1} for GOBMs, 0.3 GtC yr^{-1} for fCO_2-products). We derive the GOBMs systematic uncertainty by the deviation of the DIC inventory change 1994-2007 from the Gruber et al. (2019) estimate (0.4 GtC yr^{-1}) and suggest these are related to physical transport (mixing, advection) into the ocean interior. For the fCO_2-products, we consider systematic uncertainties stemming from uncertainty in fCO_2 observations (0.2 GtC yr^{-1}, Takahashi et al., 2009; Wanninkhof et al., 2013), gas-transfer velocity (0.2 GtC yr^{-1}, Ho et al., 2011; Wanninkhof et al., 2013; Roobaert et al., 2018), wind product (0.1 GtC yr^{-1}, Fay et al., 2021), river flux adjustment (0.3 GtC yr^{-1}, Regnier et al., 2022, formally 2-σ uncertainty), and fCO_2 mapping (0.2 GtC yr^{-1}, Landschützer et al., 2014). Combining these uncertainties as their squared sums, we assign an uncertainty of ± 0.5 GtC yr^{-1} to the GOBMs ensemble mean and an uncertainty of ± 0.6 GtC yr^{-1} to the fCO_2-product ensemble mean, which is smaller than a recent estimate by Ford et al. (2024), who estimate an uncertainty of ±0.7 GtC yr-1 based on propagating different sources of uncertainty in fCO_2-products. Here, the uncertainties are propagated as $\sigma(S_{OCEAN}) = (1/2^2 * 0.5^2 + 1/2^2 * 0.6^2)^{1/2}$ GtC yr^{-1} and result in an ± 0.4 GtC yr^{-1} uncertainty around the best estimate of S_{OCEAN}.

We examine the consistency between the variability of the GOBMs and the fCO_2-products to assess confidence in S_{OCEAN}. The interannual variability of the ocean fluxes (quantified as A-IAV, the standard deviation after

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detrending, Figure S2) of the eight fCO_2-products plus the UExP-FNN-U product (Watson et al., 2020; Ford et al., accepted) for 1990-2023, ranges from 0.08 to 0.37 GtC yr^{-1} with the lower estimates by the three ensemble methods (NIES-ML3, CMEMS-LSCE-FFNN, OS-ETHZ-GRaCER). The inter-annual variability in the GOBMs ranges between 0.10 and 0.20 GtC yr^{-1}, hence there is overlap with the A-IAV estimates of the fCO_2-products.

Individual estimates (both GOBMs and fCO_2products) generally produce a higher ocean CO_2 sink during strong El Niño events. There is emerging agreement between GOBMs and fCO_2-products on the patterns of decadal variability of S_{OCEAN} with a global stagnation in the 1990s, an extra-tropical strengthening in the 2000s (McKinley et al., 2020, Hauck et al., 2020). More recently, a fast growth of the sink is simulated by both methods between 2001 and 2016, and a stagnation period since then. A stagnation or even decline of S_{OCEAN} occurred during the triple La Niña years 2020-2023. The central estimates of the annual flux from the GOBMs and the fCO_2-products have a correlation r of 0.98 (1990-2023). The agreement between the models and the fCO_2products reflects some consistency in their representation of underlying variability since there is little overlap in their methodology or use of observations.

S.4 Methodology Land CO_2 sink

S.4.1 DGVM simulations

The DGVMs model runs were forced by either the merged monthly Climate Research Unit (CRU) and 6 hourly Japanese 55-year Reanalysis (JRA-55) data set or by the monthly CRU data set, both providing observation-based temperature, precipitation, and incoming surface radiation on a 0.5°x0.5° grid and updated to 2023 (Harris et al., 2014, 2020). The combination of CRU monthly data with 6 hourly forcing from JRA-55 (Kobayashi et al., 2015) is performed with methodology used in previous years (Viovy, 2016) adapted to the specifics of the JRA-55 data.

Introduced in GCB2021 (Friedlingstein et al., 2022a), incoming short-wave radiation fields take into account aerosol impacts and the division of total radiation into direct and diffuse components as summarised below.

The diffuse fraction dataset offers 6-hourly distributions of the diffuse fraction of surface shortwave fluxes over the period 1901-2023. Radiative transfer calculations are based on monthly-averaged distributions of tropospheric and stratospheric aerosol optical depth, and 6-hourly distributions of cloud fraction. Methods follow those described in the Methods section of Mercado et al. (2009), but with updated input datasets.

The time series of speciated tropospheric aerosol optical depth is taken from the historical and RCP8.5 simulations by the HadGEM2-ES climate model (Bellouin et al., 2011). To correct for biases in HadGEM2-ES, tropospheric aerosol optical depths are scaled over the whole period to match the global and monthly averages obtained over the period 2003-2020 by the CAMS Reanalysis of atmospheric composition (Inness et al., 2019), which assimilates satellite retrievals of aerosol optical depth.

The time series of stratospheric aerosol optical depth is taken from the by Sato et al. (1993) climatology, which has been updated to 2012. Years 2013-2020 are assumed to be background years so replicate the background year 2010. That assumption is supported by the Global Space-based Stratospheric Aerosol Climatology time series (1979-2016; Thomason et al., 2018). The time series of cloud fraction is obtained by scaling the 6-hourly distributions simulated in the Japanese Reanalysis (Kobayashi et al., 2015) to match the monthly-averaged cloud

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cover in the CRU TS v4.06 dataset (Harris et al., 2020). Surface radiative fluxes account for aerosol-radiation interactions from both tropospheric and stratospheric aerosols, and for aerosol-cloud interactions from tropospheric aerosols, except mineral dust. Tropospheric aerosols are also assumed to exert interactions with clouds. The radiative effects of those aerosol-cloud interactions are assumed to scale with the radiative effects of aerosol-radiation interactions of tropospheric aerosols, using regional scaling factors derived from HadGEM2-ES. Diffuse fraction is assumed to be 1 in cloudy sky. Atmospheric constituents other than aerosols and clouds are set to a constant standard mid-latitude summer atmosphere, but their variations do not affect the diffuse fraction of surface shortwave fluxes.

In addition to the climate forcing, the DGVMs forcing also include the global atmospheric CO_2 time series, same as for the GOBMs and described in Section S.3.2 (Lan et al. (2023), the gridded land cover changes (see Supplement S.2.2), and the gridded nitrogen deposition and fertilisers (see Table S1 for specific models details). Four simulations were performed with each of the DGVMs. Simulation 0 (S0) is a control simulation which uses fixed pre-industrial (year 1700) atmospheric CO2 concentrations, cycles early 20th century (1901-1920) climate and applies a time-invariant pre-industrial land cover distribution and pre-industrial wood harvest rates. Simulation 1 (S1) differs from S0 by applying historical changes in atmospheric CO2 concentration and N inputs. Simulation 2 (S2) applies historical changes in atmospheric CO_2 concentration, N inputs, and climate, while applying time-invariant pre-industrial land cover distribution and pre-industrial wood harvest rates. Simulation 3 (S3) applies historical changes in atmospheric CO_2 concentration, N inputs, climate, and land cover distribution and wood harvest rates.

S2 is used to estimate the land sink component of the global carbon budget (S_{LAND}). S3 is used to estimate the total land flux but is not used in the global carbon budget. We further separate S_{LAND} into contributions from CO_2 (=S1-S0) and climate (=S2-S1+S0).

S.4.2 DGVM evaluation

We apply three criteria for minimum DGVMs realism by including only those DGVMs with (1) steady state after spin up, (2) global net land flux (S_{LAND} – E_{LUC}) that is an atmosphere-to-land carbon flux over the 1990s ranging between -0.3 and 2.3 GtC yr^{-1}, within 90% confidence of constraints by global atmospheric and oceanic observations (Keeling and Manning, 2014; Wanninkhof et al., 2013), and (3) global E_{LUC} that is a carbon source to the atmosphere over the 1990s, as already mentioned in Supplement S.2.2. All DGVMs meet these three criteria.

In addition, the DGVMs results are also evaluated using the International Land Model Benchmarking system (ILAMB; Collier et al., 2018). This evaluation is provided here to document, encourage and support model improvements through time. ILAMB variables cover key processes that are relevant for the quantification of S_{LAND} and resulting aggregated outcomes (see Figure S4 for the results and for the list of observed databases). Results are shown in Figure S4 and briefly discussed in Section 3.7.5.

The International LAnd Model Benchmarking (ILAMB) system (Collier et al. 2018; version 2.7.2 (2024): https://github.com/rubisco-sfa/ILAMB/releases/tag/v2.7.2) was used to compare the 21 models (20 DGVMs and CARDAMOM) to observational benchmarks for a number of different variables related to the land surface: gross primary productivity (GPP), leaf area index (LAI), ecosystem respiration, soil carbon, evapotranspiration,

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runoff, burned areas, fire CO_2 emissions, and soil respiration), either for the entire global land surface or for the different RECCAP regions. Furthermore, relationships between selected pairs of variables can be visualised with ILAMB. Each row for each variable in Figs. S4 is clickable in the full website version https://gws-access.jasmin.ac.uk/public/landsurf_rdg/pmcguire/ILAMB_output/TRENDYv13_latest/) and gives access to geographic plots for such quantities as bias relative to observational benchmark, temporal RMSE from the observational benchmark, and difference in max month from the observational benchmark. The full website version also gives a spatial Taylor diagram for all the models, as well as time series comparisons of the regional mean time-series and the regional mean annual cycle. The Biomass variable was not included this year, due to a mismatch between the TRENDY *cVeg* variable (above-ground and below-ground biomass, for all PFTs) and two of the previously-used observational benchmark datasets for biomass (Saatchi et al., 2011 and Thurner et al., 2014), which are both only for forests and for above-ground biomass.

In the ILAMB setup for TRENDYv13, we have added three more variables (annual-averaged Burned Area, Fire Emissions, and Soil Respiration) and we have modified the Koven visualisation slightly for the Soil Carbon variable. All four of these changes have been put into a category of variables that we call 'Ecosystem and Carbon Cycle Extended'. Two of the models (EDv3 and SDGVM) compute burned area either on a national level or without considering arid non-vegetated lands, as the model biases for burned area for these two models are rather high in the world's deserts, compared to the GFED4.1S observational benchmark until the year 2016. However, in the case of SDGVM, the positive burned-area bias in the deserts is not apparent in the fire emissions variable. The Soil Respiration variable has been added only for those models that provided the *soilr* model output, which is calculated as the sum of heterotrophic respiration and root respiration. For the soil respiration variable, three observational benchmarks were selected (Tang et al. 2019, 2020, Raich et al. 2002 and Hashimoto et al. 2015) from the data sets contrasted by Hashimoto et al. (2023). The Koven analysis of the Soil Carbon turnover time is part of the standard setup in ILAMB version 2.7.2, but we put it into the Extended category largely since it seems to be missing proper application of an aridity mask for all of the models, unlike for the Observational Benchmark. We also added a model-fit curve to the Koven analysis, for better visualisation by allowing the comparison to the benchmark-fit curve. The TRENDYv13 version of the updated ILAMB version 2.7.2 GitHub code fork/branch is available at: https://github.com/mcguirepatr/ILAMB/tree/master

S.4.3 Uncertainty assessment for S_{LAND}

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For the uncertainty for S_{LAND}, we use the standard deviation of the annual CO_2 sink across the DGVMs, averaging to about ± 0.6 GtC yr^{-1} for the period 1959 to 2021. We attach a medium confidence level to the annual land CO_2 sink and its uncertainty because the estimates from the residual budget and averaged DGVMs match well within their respective uncertainties (Table 5).

S.5 Methodology Atmospheric Inversions

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S.5.1 Inversion System Simulations

Fourteen atmospheric inversions (details of each in Table S4) were used to infer the spatio-temporal distribution of the CO_2 flux exchanged between the atmosphere and the land or oceans. These inversions are based on

Bayesian inversion principles with prior information on fluxes and their uncertainties. They use very similar sets of surface measurements of CO_2 time series (or subsets thereof) from various flask and in situ networks. Six inversion systems used satellite xCO_2 retrievals from GOSAT and/or OCO-2, of which two systems used a combination of satellite and surface observations.

Each inversion system uses different methodologies and input data but is rooted in Bayesian inversion principles. These differences mainly concern the selection of atmospheric CO_2 data and prior fluxes, as well as the spatial resolution, assumed correlation structures, and mathematical approach of the models. Each system uses a different transport model, which was demonstrated to be a driving factor behind differences in atmospheric inversion-based flux estimates, and specifically their distribution across latitudinal bands (Gaubert et al., 2019; Schuh et al., 2019).

Most of the fourteen inversion systems prescribe similar global fossil fuel emissions for E_{FOS}; specifically, the GCP's Gridded Fossil Emissions Dataset version 2024.0 (GCP-GridFEDv2024.0; Jones et al., 2024), which is an update through 2023 of the first version of GCP-GridFED presented by Jones et al. (2021b) (Table S4). All GCP-GridFED versions scale gridded estimates of CO_2 emissions from EDGARv4.3.2 (Janssens-Maenhout et al., 2019) within national territories to match national emissions estimates provided by the GCP for the years 1959-2023, which are compiled following the methodology described in Supplement S.1. GCP-GridFEDv2024.0 adopts the seasonality of emissions (the monthly distribution of annual emissions) from the Carbon Monitor (Liu et al., 2020a,b; Dou et al., 2022) for Brazil, China, all EU27 countries, the United Kingdom, the USA and shipping and aviation bunker emissions. The seasonality present in Carbon Monitor is used directly for years 2019-2023, while for years 1959-2018 the average seasonality of 2019, and 2021 and 2022 are applied (avoiding the year 2020 during which emissions were most impacted by the COVID-19 pandemic). For all other countries, seasonality of emissions is taken from EDGAR (Janssens-Maenhout et al., 2019; Jones et al., 2023), with small annual correction to the seasonality present in 2010 based on heating or cooling degree days to account for the effects of inter-annual climate variability on the seasonality of emissions (Jones et al., 2021b).

Small remaining differences between regridding of the GridFED inputs, or the use of different fossil fuel emission priors are corrected for by scaling the resulting inverse fluxes to GridFEDv2024.0. The consistent use of E_{FOS} ensures a close alignment with the estimate of E_{FOS} used in this budget assessment, enhancing the comparability of the inversion-based estimate with the flux estimates deriving from DGVMs, GOBMs and *f*CO_2-based methods. The fossil fuel adjustment (including emissions from cement production and cement carbonation CO_2 sink) ensures that the estimated uptake of atmospheric CO_2 by the land and oceans was fully consistent within the inversion ensemble.

The land and ocean CO_2 fluxes from atmospheric inversions contain anthropogenic perturbation and natural pre-industrial CO_2 fluxes. On annual time scales, natural pre-industrial fluxes are primarily land CO_2 sinks and ocean CO_2 sources corresponding to carbon taken up on land, transported by rivers from land to ocean, and outgassed by the ocean. These pre-industrial land CO_2 sinks are thus compensated over the globe by ocean CO_2 sources corresponding to the outgassing of riverine carbon inputs to the ocean, using the exact same numbers and distribution as described for the oceans in Section 2.5. To facilitate the comparison, we adjusted the inverse estimates of the land and ocean fluxes per latitude band with these numbers to produce historical perturbation CO_2 fluxes from inversions.

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S.5.2 Inversion System Evaluation

All participating atmospheric inversions are checked for consistency with the annual global growth rate, as both are derived from the global surface network of atmospheric CO_2 observations. In this exercise, we use the conversion factor of 2.086 GtC/ppm to convert the inverted carbon fluxes to mole fractions, as suggested by Prather (2012). This number is specifically suited for the comparison to surface observations that do not respond uniformly, nor immediately, to each year's summed sources and sinks. This factor is therefore slightly smaller than the GCB conversion factor in Table 1 (2.142 GtC/ppm, Ballantyne et al., 2012). Overall, the inversions agree with the growth rate with biases between 0.0002-0.065 ppm yr^{-1} (0.0004-0.13 $GtCyr^{-1}$) for the period 2015-2023.

The atmospheric inversions are also evaluated using vertical profiles of atmospheric CO_2 concentrations (Figure S5). More than 30 aircraft programs over the globe, either regular programs or repeated surveys over at least 9 months (except on the SH), have been used in order to draw a robust picture of the system performance (with space-time data coverage irregular and denser in the 0-45°N latitude band; Table S8 and lower panel in Figure S4). The fourteen systems are compared to these independent aircraft CO_2 observations between 2 and 7 km above sea level between 2001 and 2023. Results are shown in Figure S5, where the inversions generally match the atmospheric mole fractions to within 0.7 ppm at all latitudes.

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S.6 Processes not included in the global carbon budget

S.6.1 Contribution of anthropogenic CO and CH_4 to the global carbon budget

Equation (1) includes only partly the net input of CO_2 to the atmosphere from the chemical oxidation of reactive carbon-containing gases from sources other than the combustion of fossil fuels, such as: (1) cement process emissions, since these do not come from combustion of fossil fuels, (2) the oxidation of fossil fuels, (3) the assumption of immediate oxidation of vented methane in oil production. However, it omits any other anthropogenic carbon-containing gases that are eventually oxidised in the atmosphere, forming a diffuse source of CO_2, such as anthropogenic emissions of CO and CH_4. An attempt is made in this section to estimate their magnitude and identify the sources of uncertainty. Anthropogenic CO emissions are from incomplete fossil fuel and biofuel burning and deforestation fires. The main anthropogenic emissions of fossil CH_4 that matter for the global (anthropogenic) carbon budget are the fugitive emissions of coal, oil and gas sectors (see below). These emissions of CO and CH_4 contribute a net addition of fossil carbon to the atmosphere.

In our estimate of E_{FOS} we assumed (Section 2.1.1) that all the fuel burned is emitted as CO_2, thus CO anthropogenic emissions associated with incomplete fossil fuel combustion and its atmospheric oxidation into CO_2 within a few months are already counted implicitly in E_{FOS} and should not be counted twice (same for E_{LUC} and anthropogenic CO emissions by deforestation fires). The diffuse atmospheric source of CO_2 deriving from anthropogenic emissions of fossil CH_4 is not included in E_{FOS}. In reality, the diffuse source of CO_2 from CH_4 oxidation contributes to the annual CO_2 growth. Emissions of fossil CH_4 represent 30% of total anthropogenic CH_4 emissions (Saunois et al. 2020; their top-down estimate is used because it is consistent with the observed CH_4 growth rate), that is 0.083 GtC yr^{-1} for the decade 2008-2017. Assuming steady state, an amount equal to this fossil CH_4 emission is all converted to CO_2 by OH oxidation, and thus explain 0.083 GtC yr^{-1} of the global CO_2 growth rate with an uncertainty range of 0.061 to 0.098 GtC yr^{-1} taken from the min-max of top-down estimates in Saunois et al. (2020). If this min-max range is assumed to be 2 σ because Saunois et al. (2020) did not account for the internal uncertainty of their min and max top-down estimates, it translates into a 1-σ uncertainty of 0.019 GtC yr^{-1}.

Other anthropogenic changes in the sources of CO and CH_4 from wildfires, vegetation biomass, wetlands, ruminants, or permafrost changes are similarly assumed to have a small effect on the CO_2 growth rate. The CH_4 and CO emissions and sinks are published and analysed separately in the Global Methane Budget and Global Carbon Monoxide Budget publications, which follow a similar approach to that presented here (Saunois et al., 2020; Zheng et al., 2019).

S.6.2 Contribution of other carbonates to CO_2 emissions

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Although we do account for cement carbonation (a carbon sink), the contribution of emissions of fossil carbonates (carbon sources) other than cement production is not systematically included in estimates of E_{FOS}, except for Annex I countries and lime production in China (Andrew and Peters, 2021). The missing processes include CO_2 emissions associated with the calcination of lime and limestone outside of cement production. Carbonates are also used in various industries, including in iron and steel manufacture and in agriculture. They are found naturally in some coals. CO_2 emissions from fossil carbonates other than cement not included in our dataset are estimated to amount to about 0.3% of E_{FOS} (estimated based on Crippa et al., 2019).

S.6.3 Anthropogenic carbon fluxes in the land-to-ocean aquatic continuum

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The approach used to determine the global carbon budget refers to the mean, variations, and trends in the perturbation of CO_2 in the atmosphere, referenced to the pre-industrial era. Carbon is continuously displaced from the land to the ocean through the land-ocean aquatic continuum (LOAC) comprising freshwaters, estuaries, and coastal areas (Bauer et al., 2013; Regnier et al., 2013). A substantial fraction of this lateral carbon flux is entirely 'natural' and is thus a steady state component of the pre-industrial carbon cycle. We account for this pre-industrial flux where appropriate in our study (see Supplement S.3). However, changes in environmental conditions and land-use change have caused an increase in the lateral transport of carbon into the LOAC – a perturbation that is relevant for the global carbon budget presented here.

The results of the analysis of Regnier et al. (2013) can be summarised in two points of relevance for the anthropogenic CO_2 budget. First, the anthropogenic perturbation of the LOAC has increased the organic carbon export from terrestrial ecosystems to the hydrosphere by as much as 1.0 ± 0.5 GtC yr^{-1} since pre-industrial times, mainly owing to enhanced carbon export from soils. Second, this exported anthropogenic carbon is partly respired through the LOAC, partly sequestered in sediments along the LOAC and to a lesser extent, transferred to the open ocean where it may accumulate or be outgassed. The increase in storage of land-derived organic carbon in the LOAC carbon reservoirs (burial) and in the open ocean combined is estimated by Regnier et al. (2013) at 0.65 ± 0.35GtC yr^{-1}. The inclusion of LOAC related anthropogenic CO_2 fluxes should affect estimates of S_{LAND} and S_{OCEAN} in Eq. (1) but does not affect the other terms. Representation of the anthropogenic perturbation of LOAC CO_2 fluxes is however not included in the GOBMs and DGVMs used in our global carbon budget analysis presented here.

S.6.4 Loss of additional land sink capacity

Historical land-cover change was dominated by transitions from vegetation types that can provide a large carbon sink per area unit (typically, forests) to others less efficient in removing CO_2 from the atmosphere (typically, croplands). The resultant decrease in land sink, called the 'loss of additional sink capacity', can be calculated as the difference between the actual land sink under changing land-cover and the counterfactual land sink under pre-industrial land-cover. This term is not accounted for in our global carbon budget estimate. Here, we provide a quantitative estimate of this term to be used in the discussion. Seven of the DGVMs used in Friedlingstein et al. (2019) performed additional simulations with and without land-use change under cycled pre-industrial environmental conditions. The resulting loss of additional sink capacity amounts to 0.9 ± 0.3 GtC yr^{-1} on average over 2009-2018 and 42 ± 16 GtC accumulated between 1850 and 2018 (Obermeier et al., 2021). OSCAR, emulating the behaviour of 11 DGVMs finds values of the loss of additional sink capacity of 0.7 ± 0.6 GtC yr^{-1} and 31 ± 23 GtC for the same time period (Gasser et al., 2020). Since the DGVM-based ELUC estimates are only used to quantify the uncertainty around the bookkeeping models' ELUC, we do not add the loss of additional sink capacity to the bookkeeping estimate.

Supplementary Tables

Table S1. Comparison of the processes included in the bookkeeping method and DGVMs in their estimates of ELUC and SLAND. See Table 4 for model references. All models include deforestation and forest regrow… after abandonment of agriculture (or from afforestation activities on agricultural land). Processes relevant for ELUC are only described for the DGVMs used with land-cover change in this study.

	Bookkeeping Models				DGVMs																				
	H&C2023	BLUE	OSCAR	LUCE	CABLE-POP	CLASSIC	CLM6.0	DLEM	EDv3	ELM	IBIS	iMAPLE	ISAM	ISBA-CTRIP	JSBACH	JULES-ES	LPJ-GUESS	LPJml	LPJwsl	LPX-Bern	OCNv2	ORCHIDEEv3	SDGVM	VISIT	CARD OM
Processes relevant for ELUC																									
Wood harvest and forest degradation (a)	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	no	yes	no	yes	no	yes	no	yes	no (d)	yes	yes	yes	yes	yes (P
Shifting cultivation / Subgrid scale transitions	yes (b)	yes	yes	yes	yes	no	yes	no	yes	yes	yes	no	no	no	yes	no	yes	no	yes	no (d)	no	no	yes	yes	no
Cropland harvest (removed, R, or added to litter, L)	yes (R) (j)	yes (R) (j)	yes (R)	yes (R) (j)	yes (R)	yes (L)	yes (R+L)	yes	yes (R+L)	yes (L)	yes (R)	yes (L)	yes	yes (R)	yes (R+L)	yes (R)	yes (R)	yes (R+L)	yes (L)	yes (R)	yes (R+L)	yes (R)	yes (R)	yse (R)	n
Peat fires	yes (k)	yes (k)	yes (k)	yes (k)	no	no	yes	no	no	no	no	no	no	yes	no	no	no	no	no	no	no	no	no	no	yes (
fire as a management tool	yes (j)	yes (j)	yes (h)	yes(j)	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	yes
N fertilisation	yes (j)	yes (j)	yes (h)	yes(j)	no	no	yes	yes	no	no	yes	no	yes	no	no	yes(i)	yes	yes	no	yes	yes	yes	no	no	no
tillage	yes (j)	yes (j)	yes (h)	yes(j)	no	yes (g)	yes	yes	no	no	no	no	no	no	no	no	yes	yes	no	no	no	yes (g)	no	no	no
irrigation	yes (j)	yes (j)	yes (h)	yes(j)	no	no	yes	yes	no	no	no	no	yes	no	no	no	yes	yes	no	no	no	no	no	no	nc
wetland drainage	yes (j)	yes (j)	yes (h)	yes(j)	no	no	no	no	no	no	no	no	yes	no	no	no	no	no	no	no	no	no	no	no	nc
erosion	yes (j)	yes (j)	yes (h)	yes(j)	no	no	no	yes	no	no	yes	no	no	no	no	no	no	no	no	no	no	no	no	yes	nc

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peat drainage	yes (k)	yes (k)	yes (k)	yes (k)	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no
Grazing and mowing Harvest (removed, R, or added to litter, L)	yes (R) (j)	yes (R) (j)	yes (R)	yes (r) (j)	yes (R)	no	no	no	yes (R+L)	no	yes	no	yes (R, L)	no	yes (L)	no	yes (R)	yes (R+L)	yes (L)	no	yes (R+L)	no	no	no
Processes also relevant for SLAND (in addition to CO2 fertilisation and climate)																								
ecosystem demography (ED) / vegetation competition (VC)					yes (ED), No (VC)		no	no	yes	no	yes ED, no VC	no		no	no	No ED, Yes VC	yes	no ED, yes VC	yes	no ED, yes VC	dynamional c		yes	no
Fire simulation and/or suppression	N.A.	N.A.	N.A.	N.A.	no	yes	yes	no	yes	yes	yes	no	no	yes	yes	yes	yes	yes	yes	yes	no	no	yes	yes
Carbon-nitrogen interactions, including N deposition	N.A.	N.A.	N.A.	N.A.	yes	no (f)	yes	yes	no	yes	yes	no (f)	yes	no	yes	yes	yes	yes	no	yes	yes	yes	yes (c)	no
Separate treatment of direct and diffuse solar radiation	N.A.	N.A	N.A	N.A	yes	no	yes	no	no	yes	yes	yes	no	no	no	yes	no	no	no	no	no	no	no	no

(a) Refers to the routine harvest of established managed forests rather than pools of harvested products.

(b) No back- and forth-transitions between vegetation types at the country-level, but if forest loss based on FRA exceeded agricultural expansion based on FAO, then this amount of area was cleared for cropland a the same amount of area of old croplands abandoned.

(c) Limited. Nitrogen uptake is simulated as a function of soil C, and Vcmax is an empirical function of canopy N. Does not consider N deposition.

(d) Available but not active.

(f) Although C-N cycle interactions are not represented, the model includes a parameterization of down-regulation of photosynthesis as CO2 increases to emulate nutrient constraints (Arora et al., 2009)

(g) Tillage is represented over croplands by increased soil carbon decomposition rate and reduced humification of litter to soil carbon.

(h) as far as the DGVMs that OSCAR is calibrated to include it

(i) perfect fertilisation assumed, i.e. crops are not nitrogen limited and the implied fertiliser diagnosed

(j) Process captured implicitly by use of observed carbon densities.

(k) Emissions added from external datasets.

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Table S2. Comparison of the processes and model set up for the Global Ocean Biogeochemistry Models for their estimates of SOCEAN. See Table 4 for model references.

	NEMO-PlankTOM12	NEMO4.2-PISCES (IPSL)	MICOM-HAMOCC (NorESM1-OCv1.2)	MPIOM-HAMOCC6	FESOM-2.1-REcoM3	NEMO3.6-PISCESv2-gas (CNRM)	MOM6-COBALT (Princeton)	CESM-ETHZ	MRI-ESM2-3	ACCESS (CSIRO)
Model specifics										
Physical ocean model	NEMOv3.6-ORCA2	NEMOv4.2 eORCA1L75	MICOM (NorESM1-OCv1.2)	MPIOM	FESOM-2.1	NEMOv3.6-GELATOv6-eORCA1L75	MOM6-SIS2	CESMv1.3 (ocean model based on POP2)	MRI.COMv5	MOM5
Biogeochemistry model	PlankTOM12	PISCESv2	HAMOCC (NorESM1-OCv1.2)	HAMOCC6	REcoM-3	PISCESv2-gas	COBALTv2	BEC (modified & extended)	NPZD+Fe	WOMBAT
Horizontal resolution	2° lon, 0.3 to 1.5° lat	1° lon, 0.3 to 1° lat	1° lon, 0.17 to 0.25 lat	1.5°	unstructured mesh, 20-120 km resolution (CORE mesh)	1° lon, 0.3 to 1° lat	0.5° lon, 0.25 to 0.5° lat	1.125° lon, 0.53° to 0.27° lat	1° lon, 0.3 to 0.5° lat	1°x1° with enhan... latitudinal resolu... in the tropics and ... lat Southern Oce...
Vertical resolution	31 levels	75 levels, 1m at the surface	51 isopycnic layers + 2 layers representing a bulk mixed layer	40 levels	46 levels, 10 m spacing in the top 100 m	75 levels, 1m at surface	75 levels hybrid coordinates, 2m at surface	60 levels	60 levels with 1-level bottom boundary layer	50 levels, 20 in t... 200m
Total ocean area on native grid (km2)	3.6080E+08	3.6360E+08	3.6006E+08	3.6598E+08	3.6435E+08	3.6270E+14	3.6111E+08	3.5926E+08	3.6094E+08	3.613...
Gas-exchange parameterization	Wanninkhof et al (1992)	Orr et al., 2017	Orr et al., 2017, but with a=0.337	Orr et al., 2017	Orr et al., 2017	Orr et al., 2017; Wanninkhof et al. 2014	Wanninkhof et al., 2014	Wanninkhof (1992, coefficient a scaled down to 0.31)	Orr et al., 2017	Wanninkhof et a... (1992)
CO2 chemistry routines	OCMIP2 (Orr et al. 2017)	mocsy	Following Dickson et al. 2007	Ilyina et al. (2013) adapted to comply with OMIP protocol (Orr et al., 2017)	mocsy	mocsy	mocsy	OCMIP2 (Orr et al. 2017)	mocsy	OCMIP2 (Orr et a... 2017)
River input (PgC/yr) (organic/inorganic DIC)	0.723 / -	0.9167 (0.2577 / 0.659)	0	0.77 / -	0 / 0	0.611 / -	~0.07 / ~0.15	0.33 / -	0 / 0	0/0
Net flux to sediment (PgC/yr) (organic/other)	0.723 / -	0.3969 (0.0855 / 0.3114)	around 0.54 / -	0.71/-	0 / 0	around 0.656 / -	~0.11 / ~0.07 (CaCO3)	0.21 / -	0 / 0	0/0
SPIN-UP procedure										
Initialisation of carbon chemistry	GLODAPv2 (preindustrial DIC)	GLODAPv2 (preindustrial DIC)	GLODAPv1 (preindustrial DIC)	initialization from previous simulation	GLODAPv2 (preindustrial DIC)	GLODAPv2	GLODAPv2 (Alkalinity, DIC). DIC corrected to 1959 level (simulation A and C) and to pre-industrial level (simulation B and	GLODAPv2 (preindustrial DIC)	GLODAPv2 (preindustrial DIC)	GLODAPv1 preindustrial DI...

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Preindustrial spin-up prior to 1850	spin-up 1750-1947	~300 yrs with xCO2=278ppm	1000 year spin up (prior to 1762)	~2000 years	189 years	long spin-up (> 1000 years) from 1750 fixed conditions	Other bgc tracers initialized from a GFDL-ESM2M spin-up (> 1000 years)	1422 years (329-1750) with xCO2 = 278	1661 years with xCO2 = 278	1000+ years
Atmospheric forcing fields and CO2										
Atmospheric forcing for (i) pre-industrial spin-up, (ii) spin-up 1850-1958 for simulation B, (iii) simulation B	looping ERA5 year 1990	looping first ten years (1958-1967) of JRA55-do-v1.4	CORE-I (normal year) forcing (i, ii, iii)	OMIP climatology (i), NCEP year 1957 (ii,iii)	JRA55-do v.1.4.0 repeated year 1961 (i, ii, iii)	JRA55-do-v1.5.0 full reanaylsis (i) cycling year 1958 (ii,iii)	GFDL-ESM2M internal forcing (i), JRA55-do-v1.5.0 repeat year 1959 (ii,iii)	(i) until 1750: JRA cycles 1958-2022 (ii, iii) after 1750: NYF (mean of 1958-2018 with 2001 anomalies)	JRA55-do v1.5.0 repeat year 1990/91 (i, ii, iii)	(i) 800+ years C spinup. 250 yea with JRA55-do a another 500 ye JRA55-do and 278ppm CO2, (and (iii) JRA55- 1990/1991 repe year forcing
Atmospheric CO2 for control spin-up 1850-1958 for simulation B, and for simulation B	constant 278ppm; converted to pCO2 temperature formulation (Sarmiento et al., 1992)	xCO2 of 278ppm converted to pCO2 with constant sea-level pressure and water vapour pressure	xCO2 of 278ppm, converted to pCO2 with sea-level pressure and water vapour pressure	xCO2 of 278ppm, no conversion to pCO2	xCO2 of 278ppm, converted to pCO2 with sea-level pressure and water vapour pressure	xCO2 of 278 ppm converted to pCO2 with constant sea-level pressure and water vapour pressure	xCO2 of 278ppm, converted to pCO2 with sea-level pressure and water vapour pressure	xCO2 = 278 ppm, converted to pCO2 with atmospheric pressure, and water vapour pressure	xCO2 of 278ppm, converted to pCO2 with water vapour and sea-level pressure (JRA55-do repeat year 1990/91)	xCO2 of 278p converted to p with sea-leve pressure
Atmospheric forcing for historical spin-up 1850-1958 for simulation A (i) and for simulation A (ii)	1750-1940: looping ERA5 year 1990; 1940-2023: ERA5	1750-1958 : first ten years (1958-1967) of JRA55-do-v1.4 , then full JRA55 reanalysis : JRA55-do-v1.4 then 1.5 for 2020-23 (ii)	CORE-I (normal year) forcing; from 1948 onwards NCEP-R1 with CORE-II corrections	NCEP 6 hourly cyclic forcing (10 years starting from 1948, i), 1948-2021: transient NCEP forcing	JRA55-do-v1.4.0 repeated year 1961 (i), transient JRA55-do-v1.4.0 (1958-2019), v1.5.0.1 (2020-2023 ii)	JRA55-do cycling year 1958 (i), JRA55-do-v1.5.0 (ii)	JRA55-do-v1.5 repeat year 1959 (i), v1.5.0 (1959-2019, v1.5.0.1b (2020), v1.5.0.1 (2021; ii)	(i): JRA55 version 1.5.0.1 repeat cycle 1958-2023 (ii) JRA55 1.5.0.1 1968-2023	1653-1957: repeated cycle JRA55-do v1.5.0 1958-2018 (i), v1.5.0 (1958-2018), v1.5.0.1 (2019-2023; ii)	(i) JRA55-do, 1990/1991 repe year forcing, (ii) JRA55-do v1.5 1958-2019, and v1.5.0.1 for 202 2023.
Atmospheric CO2 for historical spin-up 1850-1958 for simulation A (i) and simulation A (ii)	xCO2 provided by the GCB; converted to pCO2 temperature formulation (Sarmiento et al., 1992), monthly resolution (i, ii)	xCO2 as provided by the GCB, global mean, annual resolution, converted to pCO2 with sea-level pressure and water vapour pressure (i, ii)	xCO2 as provided by the GCB, converted to pCO2 with sea level pressure (taken from the atmopheric forcing) and water vapor correction (i, ii)	transient monthly xCO2 provided by GCB, no conversion (i, ii)	xCO2 as provided by the GCB, converted to pCO2 with sea-level pressure and water vapour pressure, global mean, monthly resolution (i, ii)	xCO2 as provided by the GCB, converted to pCO2 with constant sea-level pressure and water vapour pressure, global mean, yearly resolution (i, ii)	xCO2 at year 1959 level (315 ppm, i) and as provided by GCB (ii), both converted to pCO2 with sea-level pressure and water vapour pressure, global mean, yearly resolution	xCO2 as provided by the GCB in 2024 (from 1751 onward), converted to pCO2 with locally determined atm. pressure, and water vapour pressure (i, ii)	xCO2 as provided by GCB, converted to pCO2 with water vapour and sea-level pressure (i, ii).	xCO2 as provic the GCB, conve to pCO2 with level pressu

Table S3: Description of ocean *f*CO2-products used for assessment of SOCEAN. See Table 4 for references.

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	Jena-MLS	VLIZ-SOMFFN	CMEMS-LSCE-FFNN	UExP-FNN-U (previously Watson et al.)	NIES-ML3	JMA-MLR	OceanSODA-ETHZv2	LDEO HPD	CSIR-ML6
Method	Spatio-temporal interpolation (version oc_v2023). Spatio-temporal field of ocean-internal carbon sources/sinks is fit to the SOCATv2022 pCO2 data. Includes a multi-linear regression against environmental drivers to bridge data gaps,	A feed-forward neural network (FFN) determines non-linear relationship between SOCAT pCO2 measurements and environmental predictor data for 16 biogeochemical provinces (defined through a self-organizing map, SOM) and is used to fill the existing data gaps.	An ensemble of neural network models trained on 100 subsampled datasets from SOCAT and environmental predictors. The models are used to reconstruct sea surface fugacity of CO2 and convert to air-sea CO2 fluxes	A self organising map feed forward neural network (SOM-FNN) implementation using SOCATv2024 fCO2 database, corrected to the subskin temperature (ESA CCI v3 bias corrected to surface drifter data following recommendations in Dong et al. 2022) of the ocean as measured by satellites (Goddijn-Murphy et al. 2015). Flux calculation corrected for the cool and salty surface skin. Monthly skin temperature	The ensemble of a random forest, a gradient boost machine, and a feed forward neural network trained on SOCAT 2024 fCO2 and environmental predictor variables. The interannual trend of fCO2 was estimated first by the decadal trend of atmospheric CO2 and then corrected by a so-called leave-one-year-out validation method. The trend was used to normalize fCO2 to the mid year of 1982-2023 for model training. The monthly fCO2	Fields of total alkalinity (TA) were estimated by using a multiple linear regressions (MLR) method based on GLODAPv2.2023 and satellite observation data. SOCATv2024 fCO2 data were converted to dissolved inorganic carbon (DIC) with the TA. Fields of DIC were estimated by using a MLR method based on the DIC and satellite observation data	OceanSODA-ETHZv2 is a two-phase machine learning approach. In phase 1, we estimate the ΔfCO2 8-day seasonal cycle climatology with a Gradient Boosted Decision Tree which is used as a predictor in the next phase. In phase 2, we predict the non-thermal component of ΔfCO2 at a 8-day by 0.25° by 0.25° resolution with a two-layer fully-connected neural network using 35 ensemble members. The atmospheric CO2	Based on fCO2-misfit between observed fCO2 and 10 Global Carbon BudgetGOBMs. The eXtreme Gradient Boosting method links this misfit to environmental observations to reconstruct the model misfit across all space and time., which is then added back to the model-based fCO2 estimate. The final reconstruction of surface fCO2 is the average across the 10 reconstructions. A climatology of the misfits calculated for the years	An ensemble average of six machine-learning models, where each model is constructed with a two-step clustering-regression approach to determine a non-linear relationship between SOCAT fCO2 measurements and environmental proxy variables, and it used to fill the existing data gaps. The clustering step consists of two methods: the Mini-batch K-means clustering and the extended Fay and McKinley

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				calculated from ESA CCI v3 (Embury et al. 2024) with the cool skin difference calculated using NOAA COARE 3.5. Flux calculations completed using FluxEngine (Shutler et al., 2016; Holding et al., 2019).	maps were reconstructed using model prediction and the trend.		and non-thermal component are added back to the result.	2000-2023 is used as an offset for years prior to 1982 when no/limited envionmental observations are available to train the ML algorithm.	(2014) biomes. The regression step consists of three methods: Gradient Boosting Machine, Support Vector Regression and Feed-forward Neural Network.
Gas-exchange parameterization	Wanninkhof 1992. Transfer coefficient k scaled to match a global mean transfer rate of 16.5 cm/hr by (Naegler, 2009)	Wanninkhof 1992. Transfer coefficient k scaled to match a global mean transfer rate of 16.5 cm/hr	Wanninkhof 2014. Transfer coefficient k scaled to match a global mean transfer rate of 16.5 cm/hr (Naegler, 2009)	Nightingale et al 2000	Wanninkhof, 2014. Transfer coefficient k scaled to match a global mean transfer rate of 16.5 cm/hr in 1990-2019 (Fay et al., 2021)	Wanninkhof, 2014. Transfer coefficient k scaled to match a global mean transfer rate of 16.5 cm/hr (Naegler, 2009)	Wanninkhof 1992, averaged and scaled for three reanalysis wind data, to a global mean 16.5 cm/hr (after Naegler 2009; Fay & Gregor et al. 2021)	Wanninkhof 1992 parameterization. Transfer coefficient k scaled to match a global mean transfer rate of 16.5 cm/hr (Naegler, 2009)	Wanninkhof 1992 averaged and scaled for three reanalysis wind data, to a global mean 16.5 cm/hr (after Naegler 2009; Fay & Gregor et al. 2021)
Wind product	JMA55-do reanalysis	ERA 5	ERA5	CCMP3.1	ERA5	JRA3Q	ERA5	ERA5	ERA 5
Spatial resolution	2.5 degrees longitude x 2 degrees latitude	1x1 degree	0.25x0.25 degree regridded to 1x1 degree	1x1 degree	Regrid 0.25x0.25 degree monthly data to 1x1	1x1 degree	0.25x0.25 degree regridded to 1x1 degree	1x1 degree	1x1 degree

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Temporal resolution	daily	monthly	monthly	monthly	monthly	monthly	8-daily regridded to monthly	monthly	monthly
Atmospheric CO2	Spatially and temporally varying field based on atmospheric CO2 data from 169 stations (Jena CarboScope atmospheric inversion sEXTALL_v2021)	Spatially varying 1x1 degree atmospheric pCO2_wet calculated from the NOAA ESRL marine boundary layer xCO2 and NCEP sea level pressure with the moisture correction by Dickson et al 2007	Spatially and monthly varying fields of atmospheric pCO2 computed from CO2 mole fraction (CO2 atmospheric inversion from the Copernicus Atmosphere Monitoring Service), and atmospheric dry-air pressure which is derived from monthly surface pressure (ERA5) and water vapour pressure fitted by Weiss and Price 1980	Atmospheric fCO2 (wet) calculated from NOAA marine boundary layer XCO2(atm) and ERA5 sea level pressure, with pH2O calculated from Cooper et al. (1998). 2023 XCO2 marine boundary values were not available at submission so we used preliminary values, estimated from 2022 values and increase at Mauna Loa.	NOAA Greenhouse Gas Marine Boundary Layer Reference. https://gml.noaa.gov/ccgg/mbl/mbl.html	Atmospheric xCO2 fields of JMA-GSAM inversion model (Maki et al. 2010; Nakamura et al. 2015) were converted to pCO2 by using JRA3Q sea level pressure. 2023 xCO2 fields were not available at this stage, and we used Cape Grim and Mauna Loa xCO2 increments from 2022 to 2023 for the southern and northern hemispheres, respectively.	NOAA's marine boundary layer product for xCO2 is linearly interpolated onto a 0.25°x0.25° grid and resampled from weekly to 8-daily. xCO2 is multiplied by ERA5 mean sea level pressure, where the latter corrected for water vapour pressure using Dickson et al. (2007). These results are regridded to a monthly 1x1 degree pCO2atm.	NOAA's marine boundary layer (MBL) surface xCO2 product is linearly interpolated to a 1x1 degree monthly grid for years 1979-2023. Prior to 1979, calculating an offset between the MBL and Mauna Loa seasonal climatologic xCO2 values for a subset of common years (1979-1989) yields a mean seasonality difference which is then applied to the Mauna Load time series. Monthly 1x1 degree xCO2 is multiplied by	NOAA's marine boundary layer product for xCO2 is linearly interpolated onto a 1x1 degree grid and resampled from weekly to monthly. ERA5 mean sea level pressure is used, where the latter corrected for water vapour pressure using Dickson et al. (2007).

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								ERA5 mean sea level pressure, with the correction for water vapour pressure using Dickson et al. 2007, using ERA5 SST and EN4 SSS. FInally converted to fCO2 using ERA5 SST and SLP.	
Total ocean area on native grid (km2)	3.63E+08	3.63E+08	3.50E+08	3.61E+08	3.62E+08	3.19E+08	3.55E+08	3.586 E+8	3.63E+08
method to extend product to full global ocean coverage		Arctic and marginal seas added following Landschützer et al. (2020). No coastal cut.				Fay & Gregor et al. 2021	Coverage of the global ice free ocean (ice frac < 0.9)	Based on method in Fay & Gregor et al. 2021. Gaps were filled with monthly climatology (Landschützer et al. 2020) scaled for interannual variability based on the temporal evolution of this product for all years.	Method has near full coverage

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Table S4. Comparison of the inversion set up and input fields for the atmospheric inversions. Atmospheric inversions see the full CO2 fluxes, including the anthropogenic and pre-industrial fluxes. Hence they need to be adjusted for the pre-industrial flux of CO2 from the land to the ocean that is part of the natural carbon cycle before they can be compared with SOCEAN and SLAND from process models. See Table 4 for references.

Name	Jena CarboScope	Copernicus Atmosphere Monitoring Service (CAMS)	Carbon-Tracker Europe (CTE)	NISMON-CO2	CT-NOAA	CMS-Flux	Copernicus Atmosphere Monitoring Service (CAMS)	GONGGA	COLA	GCASv2	UoE	JAPCAS	MIROC-ACTM	NTFVAR
Version number	r76nbetEXToc_v2024E	v23r1	v2024	v2024.1	CT2022 + CT-NRT v2024-1	v2024	FT24r1	v2023	v2024	v2024	v2024	v2024	v2024	v2024
Flags														
Observations														
Atmospheric observations (a, b)	Flasks and hourly from various institutions (outliers removed by 2σ criterion)	Hourly resolution (well-mixed conditions) obspack GLOBALVIEWplus v9.0 and NRT_v9.3 and obspack_co2_466_GVeu_v9.2_20240502	Hourly resolution (well-mixed conditions) obspack GLOBALVIEWplus v8.0 and v9.0 and NRT_v9.2	Hourly resolution (well-mixed conditions) obspack GLOBALVIEWplus v9.0 and NRT_v9.3	Hourly resolution (well-mixed conditions) obspack GLOBALVIEWplus v7.0 and NRT_v9.2.	ACOS-GOSAT B9 and OCO-2 V11.1 and obspack GLOBALVIEWplus v9.1	OCO-2 ACOS retrievals from NASA, v11.1	OCO-2 v11r data that scaled to WMO 2019 standard	Hourly resolution (well-mixed conditions) obspack GLOBALVIEWplus v9.1 and NRT_v9.2. And OCO-2_b11.1_LNLG	ACOS v11 OCO-2 XCO2 retrievals, scaled to WMO 2019 standard	Hourly resolution (well-mixed conditions) obspack GLOBALVIEWplus v9.1 and NRT_v9.2	Hourly resolution (well-mixed conditions) obspack GLOBALVIEWplus v9.1 and NRT_v9.2	Hourly resolution (well-mixed conditions) obspack GLOBALVIEWplus v9.1 and NRT_v9.3 and JMA	Hourly resolution (well-mixed conditions) obspack GLOBALVIEWplus v9.1 and NRT_v9.2 and GOSAT XCO2 data NIES Level 2 product v02.97 and v03.05
Period covered	1976-2023	1979-2023	2001-2023	1990-2023	2000-2023	2010-2023	2015-2023	2015-2023	2015-2023	2015-2023	2001-2023	2001-2023	2001-2023	2010-2023
Prior fluxes														

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Biosphere and fires	Zero	ORCHIDEE, GFEDv4.1s	SiB4-MERRA and GFAS	VISIT and GFEDv4.1s	GFED-CASA and GFED_CMS(Climatology for the CT-NRT of CT2022 plus statistical flux anomaly model).	CARDAMOM	ORCHIDEE, GFEDv4.1s	ORCHIDEE-MICT and GFEDv4.1s	VEGAS + GFAS	BEPS	CASA v1.0, climatology after 2016 and GFED4.0	CASA v1.0, climatology after 2016 and GFED4.0	CASA-3h	Zeng et al. 2020 and GFAS
Ocean	CarboScope oc_v2024E	CMEMS-LSCE-FFNN 2024	CarboScope v2022 and v2023	JMA global ocean mapping (Iida et al., 2021)	Ocean inversion fluxes, Takahashi pCO2	ECCO-Darwin and MOM6	CMEMS-LSCE-FFNN 2023	Takahashi climatology	Jena OC-v2023	JMA Ocean CO2 Map v2023 (Global) and v2024 (regional)	Takahashi climatology	Takahashi climatology	Takahashi climatology	Zeng et al. 2014
Fossil fuels (c)	GridFED v2024.0	GridFED 2023.1 with an extrapolation to 2023-24 based on Carbonmonitor and NO2	GridFED 2023.1 and 2024.0	GridFED v2024.0	Miller/CT, and ODIAC/NASA	GridFED v2024.0	GridFED 2023.1 with an extrapolation to 2023-24based on Carbonmonitor and NO2	GridFED 2024.0	GridFEDv2023.1 and v2024.0	GridFEDv2024.0	GridFED 2024.0	GridFED 2024.0	GridFEDv2024.0	GridFEDv2024.0
Transport and optimization														
Transport model	TM3	LMDZ v6	TM5	NICAM-TM	TM5	GEOS-CHEM	LMDZ v6	GEOS-Chem v12.9.3	GEOS-CHEM v13.0.2	MOZART-4	GEOS-CHEM	GEOS-CHEM v12.5	MIROC-ACTM	NIES-TM-FLEXPART
Weather forcing	ERA	ECMWF	ECMWF	JRA55	ERA5	MERRA2	ECMWF	MERRA2	MERRA-2	GEOS5	MERRA	MERRA	JRA-55	ERA5(NIES-TM)/JRA-55(FLEXPART)
Horizontal Resolution	Global 3.83°x5°	global ~90 km in the horizontal	Global 3°x2°, Europe 1°x1°, North	glevel-5 (~223 km)	Global 3°x2°, North America	Global 4°x5°	global ~90 km in the horizontal	Global 2°x2.5°	2°×2.5°	2.5°×1.875°	Global 2°x2.5°	Global 4°x5°	2.8°×2.8°	NIES-TM 3.75x3.75°and FLEXPART

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Optimization	Conjugate gradient (re-ortho-normalization)	Variational	5-week ensemble Kalman smoother	Variational	12-week ensemble Kalman smoother	Variational	Variational	Nonlinear least squares four-dimensional variation (NLS-4DVar)	Ensemble Kalman Filter (LETKF with CEnKF/AAPO)	Ensemble Kalman filter	Ensemble Kalman filter	Ensemble Kalman filter	Bayesian inversion, similar to that of Rayner et al. (Tellus, 1999)	Variational, M1QN3

(a) Schuldt et al. 2023. Multi-laboratory compilation of atmospheric carbon dioxide data for the period 1957-2022; obspack_co2_1_GLOBALVIEWplus_v9.0_2023-09-09; NOAA Earth System Research Laboratory, Global Monitoring Laboratory. http://doi.org/10.25925/20230801

(b) Schuldt et al. 2024. Multi-laboratory compilation of atmospheric carbon dioxide data for the period 2023-2024; obspack_co2_1_NRT_v9.2_2024-03-25; NOAA Earth System Research Laboratory, Global Monitoring Laboratory. http://doi.org/10.25925/20240215

(c) GCP-GridFED v2024.0 and v2023.1 (Jones et al., 2024, 2023) are updates through the year 2023 of the GCP-GridFED dataset presented by Jones et al. (2021b).

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Table S5: Overview of the Earth System Models (ESMs) and the simulations.

Model	CanESM5	EC-Earth3-CC	IPSL-CM6A-CO2-LR	MIROC-ES2L	MPI-ESM1.2-LR
Resolution Atmosphere	T63, 49 hybrid levels up to 1hPa	T255, 91 levels	2.5°x1.25°, 79 levels	T42, 40 levels	T63, 47 levels
Resolution Ocean	1° refined meridionally to 1/3° near Equator, 45 levels	1°, 75 levels	1° (nominal), 75 levels	Tripolar (~1°), 62 levels	1.5°, 40 levels
Assimilation Atmosphere	ERA-Interim (Dee et al. 2011) from 1980 to 2018 and ERA5 (Hersbach et al. 2020) afterwards: full-field nudging of temperature, horizontal wind and specific humidity	ERA5 (Hersbach et al. 2020) full-field	None	3D full field wind and T of JRA55 (Kobayashi et al. 2015) with the simplified IAU (Tatebe et al. 2012)	ERA-40 (Uppala et al. 2005) before 1979 and ERA5 (Hersbach et al. 2020) from 1980: Vorticity, divergence, log(p), T; full field with nudging

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Assimilation Ocean	Nudging to 3D potential temperature and salinity from ORAS5 reanalysis (Zuo et al. 2019). Sea surface temperature relaxed to interpolated values from NOAA's OISSTv2 from Nov. 1981 to present, and NOAA's ERSSTv3 prior (Smith et al. 2008).	EN4 (Good et al. 2013) 3D nudging T and S with weaker nudging band around equator. SST and SSS restoring to ORAS5 (Zuo et al. 2019). Atmospheric forcing: DFS5.2 1958-1979 and ERA5 after 1980	Nudging towards SST (ERSSTv5) and SSS (EN4) using a restoring coefficient dependent on the mixed layer depth (Ortega et al. 2017)	3D full field T, S, and sea-ice concentration of an ocean objective analysis (Ishii and Kimoto 2009) with the simplified IAU (Tatebe et al. 2012)	EN4 (Good et al. 2013) 3D full field T and S with ensemble Kalmann filter (Brune et al. 2018)
Assimilation Land	Indirectly through response of CLASS-CTEM to the data-constrained coupled ESM	LPJ-GUESS forced offline with ERA5 1979-2020 after preindustrial spinup+transient up to 1979	None	None	Indirectly initialized by atmospheric and oceanic data assimilation within the fully coupled ESM
Ensemble Size	10	10	10	10	10
Period of reconstruction	1960-2023	1980-2023	1960-2023	1960-2023	1960-2023
Hindcasts and forecasts	1 year starting from Jan. 1st 1980-2024	14 months starting from Nov.1st 1980-2023	1 year starting from Jan. 1st 1981-2024	14 months starting from Nov. 1st 1980-2023	14 months starting from Nov.1st 1980-2023
External forcings	The Coupled Model Intercomparison Project Phase 6 (CMIP6) historical (1960-2014) plus SSP2-4.5 baseline and CovidMIP two year blip scenario (after 2015) (Eyring et al. 2016; Lamboll et al. 2021). The CO2 emissions forcing from 2015 onward are substituted by GCP-GridFED (Jones et al. 2021; 2023) for all the models except for IPSL-CM6A-CO2-LR. Note the difference in global integrated CO2 emissions between CMIP6 CovidMIP and GCP-GridFED in recent years is within the emission uncertainty.				

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References	Swart et al. 2019; Sospedra-Alfonso et al. 2021	Döscher et al. 2021; Bilbao et al., 2021; Bernardello et al., 2024	Boucher et al. 2020	Watanabe et al. 2020	Mauritsen et al. 2019; Li et al. 2023

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Table S6. Comparison of the projection with realised fossil CO2 emissions (EFOS). The 'Actual' values are first the estimate available using actual data, and the 'Projected' values refers to estimates made before the end of the year for each publication. Projections based on a different method from that described here during 2008-2014 are available in Le Quéré et al., (2016). All values are adjusted for leap years.

	World		China		USA		EU28 / EU27 (i)		India		Rest of World (ii)	
	Projected	Actual	Projected	Actual	Projected	Actual	Projected	Actual	Projected	Actual	Projected	Actual
2015 (a)	–0.6% (–1.6 to 0.5)	0.06%	–3.9% (–4.6 to –1.1)	–0.7%	–1.5% (–5.5 to 0.3)	–2.5%	–	–	–	–	1.2% (–0.2 to 2.6)	1.2%
2016 (b)	–0.2% (–1.0 to +1.8)	0.20%	–0.5% (–3.8 to +1.3)	–0.3%	–1.7% (–4.0 to +0.6)	–2.1%	–	–	–	–	1.0% (–0.4 to +2.5)	1.3%
2017 (c)	2.0% (+0.8 to +3.0)	1.6%	3.5% (+0.7 to +5.4)	1.5%	–0.4% (–2.7 to +1.0)	–0.5%	–	–	2.00% (+0.2 to +3.8)	3.9%	1.6% (0.0 to +3.2)	1.9%
2018 (d)	2.7% (+1.8 to +3.7)	2.1%	4.7% (+2.0 to +7.4)	2.3%	2.5% (+0.5 to +4.5)	2.8%	-0.7% (-2.6 to +1.3)	-2.1%	6.3% (+4.3 to +8.3)	8.0%	1.8% (+0.5 to +3.0)	1.7%
2019 (e)	0.5% (-0.3 to +1.4)	0.1%	2.6% (+0.7 to +4.4)	2.2%	-2.4% (-4.7 to -0.1)	-2.6%	-1.7% (-5.1% to +1.8%)	-4.3%	1.8% (-0.7 to +3.7)	1.0%	0.5% (-0.8 to +1.8)	0.5%
2020 (f)	-6.7%	-5.4%	-1.7%	1.4%	-12.2%	-10.6%	-11.3% (EU27)	-10.9%	-9.1%	-7.3%	-7.4%	-7.[illegible]%

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2021 (g)	4.8%	5.1%	4.3%	3.5%	6.8%	6.2%	6.3%	6.8%	11.2%	11.1%	3.2%	4.5%
	(4.2% to 5.4%)		(3.0% to 5.4%)		(6.6% to 7.0%)		(4.3% to 8.3%)		(10.7% to 11.7%)		(2.0% to 4.3%)	
2022 (h)	1.1%	0.9%	-1.5%	0.9%	1.6%	1.0%	-1.0%	-1.9%	5.6%	5.8%	2.5%	0.6%
	(0% to 1.7%)		(-3.0% to 0.1%)		(-0.9% to 4.1%)		(-2.9% to 1.0%)		(3.5% to 7.7%)		(0.1% to 2.3%)	
2023 (i)	1.1%	1.3%	4.0%	4.9%	-3.0%	-3.3%	-7.4%	-8.4%	8.2%	8.2%	0.4%	0.7%
	(0.0% to 2.1%)		(1.9% to 6.1%)		(-5% to -1%)		(-9.9% to -4.9%)		(6.7% to 9.7%)		(-1.4% to 2.3%)	
2024 (k)	0.8%		0.2%		-0.6%		-3.8%		4.6%		1.6%	
	(-0.3% to 1.9%)		(-1.6% to 2.0%)		(-2.9% to 1.7%)		(-6.2% to -1.4%)		(3.0% to 6.1%)		(-0.4% to 3.6%)	

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Table S7 Attribution of fCO2 measurements for the year 2023 included in SOCATv2024 (Bakker et al., 2016, 2024) to inform ocean fCO2-based data products.

Platform Name	Regions	No. of measurements	Principal Investigators	No. of datasets	Platform Type
Atlantic Explorer	North Atlantic, coastal	48,596	Bates, N. R.; Enright M.	20	Ship
Atlantic Sail	North Atlantic, coastal	16,770	Steinhoff, T.; Körtzinger, A.	3	Ship
Bell M. Shimada	North Pacific, Tropical Pacific, coastal	35,730	Alin, S.; Feely, R.	7	Ship
Cap San Lorenzo	Tropical Atlantic, coastal	18,343	Lefèvre, N.	1	Ship
CCE1_122W_33N	Coastal	1,426	Sutton, A.; Send, U.; Ohman, M.	1	Mooring
CCE2_121W_34N	Coastal	417	Sutton, A.; Send, U.; Ohman, M.	1	Mooring
Colibri	North Atlantic, coastal	24,528	Lefèvre, N.	3	Ship
Equinox	North Atlantic, Tropical Atlantic, coastal	19,612	Wanninkhof, R.; Pierrot, D.	12	Ship
F.G. Walton Smith	Coastal	3,831	Barbero L.; Pierrot, D.; Wanninkhof, R.	3	Ship
Finnmaid	Coastal	311,468	Rehder, G; Bittig, H. C.; Glockzin, M.	10	Ship
G.O. Sars	Arctic, North Atlantic, coastal	103,965	Skjelvan, I.	12	Ship
GAKOA_149W_60N	Coastal	470	Monacci, N.	1	Mooring
Gordon Gunter	North Atlantic, coastal	24,848	Wanninkhof, R.; Pierrot, D.	4	Ship
Henry B. Bigelow	Coastal	18,661	Wanninkhof, R.; Pierrot, D.	3	Ship
Heron Island	Coastal	1,322	Tilbrook, B.; van Ooijen E.	1	Mooring
Investigator	Southern Ocean	152,788	Tilbrook, B.; Akl, J.; Neill, C.	7	Ship
Kangaroo Island	Southern Ocean	378	Tilbrook, B.; van Ooijen E.	1	Mooring
KC_BUOY	Coastal	3,020	Evans, W.	1	Mooring
Keifu Maru II	North Pacific, Tropical Pacific, coastal	7,300	Enyo, K.	5	Ship
Maria Island	Southern Ocean	1,640	Tilbrook, B.; van Ooijen E.	1	Mooring
Marion Dufresne	Indian Ocean, Southern Ocean	5,662	Lo Monaco, C.; Metzl, N.	1	Ship
New Century 2	North Atlantic, North Pacific, Tropical Pacific, Southern Ocean, coastal	258,209	Nakaoka, S.-I.; Takao, S.	16	Ship
Papa_145W_50N	North Pacific	820	Sutton, A.; Cronin, M.; Emerson, S.	1	Mooring
Quadra Island Field Station	Coastal	78,466	Evans, W.	1	Mooring
R/V Belgica	Coastal	4,485	Theetaert, H.; Gkritzalis, T.	1	Ship
Roger Revelle	Tropical Pacific, Southern Ocean	37,941	Alin, S.; Woosley R.J.; Feely, R.; Martz T. R.	3	Ship

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Ryofu Maru III	North Pacific, Tropical Pacific, coastal	7,454	Enyo, K.	7	Ship
SA Agulhas II	Southern Ocean	7,123	Hamnca, S.; Tsanwani, M.; Monteiro, P. M. S.	1	Ship
Sea Explorer	Southern Ocean, Coastal, Tropical Atlantic, North Atlantic	69,377	Olivier, L.; Landschützer,P.	3	Ship
Seaspan Royal	Coastal	230,720	Evans, W.	6	Ship
Simon Stevin	Coastal	80,488	Gkritzalis, T.; Theetaert, H.; T'Jampens, M.	11	Ship
Soyo Maru	North Pacific, coastal	42,169	Ono, T.	2	Ship
Statsraad Lehmkuhl	North Atlantic, Tropical Atlantic, Southern Ocean, coastal	27,582	Becker, M.; Olsen, A.	2	Ship
Tangaroa	Southern Ocean	15,315	Currie, K. I.	3	Ship
TAO170W_0N	Tropical Pacific	2,091	Sutton, A.	1	Mooring
Thomas G. Thompson	North Pacific, Tropical Pacific, Southern Ocean, coastal	29,782	Alin, S.; Feely, R.	5	Ship
Trans Future 5	North Pacific, Tropical Pacific, Southern Ocean, coastal	159,856	Nakaoka, S.-I.; Takao, S.	14	Ship
Tukuma Arctica	North Atlantic, coastal	53,130	Becker, M.; Olsen, A.	17	Ship
Victor Angelescu	Southern Ocean	23,904	Berghoff C.; Arbilla L.; Veccia M.	3	Ship
Wakataka Maru	North Pacific, coastal	62,156	Tadokoro, K.; Ono, T.	5	Ship
WHOTS_158W_23N	Tropical Pacific	1,440	Sutton, A.; Weller, B.; Pluddemann, A.	1	Mooring

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Table S8. Aircraft measurement programs archived by Cooperative Global Atmospheric Data Integration Project (Schuldt et al. 2023 and 2024) that contribute to the evaluation of the atmospheric inversions (Figure S5).

Site code	Measurement program name in Obspack	Specific doi	Data providers
AAO	Airborne Aerosol Observatory, Bondville, Illinois		Sweeney, C.; Dlugokencky, E.J.
ABOVE	Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE)	https://doi.org/10.3334/ORNLDAAC/1404	Sweeney, C., J.B. Miller, A. Karion, S.J. Dinardo, and C.E. Miller. 2016. CARVE: L2 Atmospheric Gas Concentrations, Airborne Flasks, Alaska, 2012-2015. ORNL DAAC, Oak Ridge, Tennessee, USA
ACG	Alaska Coast Guard		Sweeney, C.; McKain, K.; Karion, A.; Dlugokencky, E.J.
ACT	Atmospheric Carbon and Transport - America		Sweeney, C.; Dlugokencky, E.J.; Baier, B; Montzka, S.; Davis, K.
AIRCORENOAA	NOAA AirCore		Colm Sweeney (NOAA) AND Bianca

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			Baier (NOAA)					
AJAX	Alpha Jet Atmospheric eXperiment (AJAX)		Emma L. Yates, Laura T. Iraci, Susan S. Kulawik, Ju-Mee Ryoo, Josette E. Marrero, Caroline L. Parworth, Thao Paul V. Bui, Cecilia S. Chang, Jonathan M. Dean-Day (NASA Ames Research Center), Jason M. St. Clair, Thomas F. Hanisco (Atmospheric Chemistry and Dynamics Laboratory, NASA Goddard Space Flight Center)					
ALF	Alta Floresta		Gatti, L.V.; Gloor, E.; Miller, J.B.;					
AOA	Aircraft Observation of Atmospheric trace gases by JMA							ghg_obs@met.kishou.go.jp
BGI	Bradgate, Iowa		Sweeney, C.; Dlugokencky, E.J.					
BNE	Beaver Crossing, Nebraska		Sweeney, C.; Dlugokencky, E.J.					
BRZ	Berezorechka, Russia		Sasakama, N.; Machida, T.					
CAR	Briggsdale, Colorado		Sweeney, C.; Dlugokencky, E.J.					
CMA	Cape May, New Jersey		Sweeney, C.; Dlugokencky, E.J.					
CON	CONTRAIL (Comprehensive Observation Network for TRace gases by AIrLiner)	http://dx.doi.org/10.17595/20180208.001	Machida, T.; Ishijima,					

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			K.; Niwa, Y.; Tsuboi, K.; Sawa, Y.; Matsueda, H.; Sasakawa, M.					
CRV	Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE)		Sweeney, C.; Karion, A.; Miller, J.B.; Miller, C.E.; Dlugokencky, E.J.					
DND	Dahlen, North Dakota		Sweeney, C.; Dlugokencky, E.J.					
ESP	Estevan Point, British Columbia		Sweeney, C.; Dlugokencky, E.J.					
ETL	East Trout Lake, Saskatchewan		Sweeney, C.; Dlugokencky, E.J.					
FWI	Fairchild, Wisconsin		Sweeney, C.; Dlugokencky, E.J.					
GSFC	NASA Goddard Space Flight Center Aircraft Campaign		Kawa, S.R.; Abshire, J.B.; Riris, H.					
HAA	Molokai Island, Hawaii		Sweeney, C.; Dlugokencky, E.J.					
HFM	Harvard University Aircraft Campaign		Wofsy, S.C.					
HIL	Homer, Illinois		Sweeney, C.; Dlugokencky, E.J.					
HIP	HIPPO (HIAPER Pole-to-Pole Observations)	https://doi.org/10.3334/CDIAC/HIPPO_010	Wofsy, S.C.; Stephens, B.B.; Elkins, J.W.; Hintsa, E.J.; Moore, F.					
IAGOS-CARIBIC							In-service Aircraft for a Global Observing System	Obersteiner, F.; Boenisch, H.; Gehrlein, T.; Zahn, A.; Schuck, T.
IAGOS-CORE	In-service Aircraft for a Global Observing System		Christoph Gerbig (Max-Planck-Institut für Biogeochemie, Jena)					
INX	INFLUX (Indianapolis Flux Experiment)		Sweeney, C.; Dlugokencky, E.J.; Shepson, P.B.; Turnbull, J.					
LEF	Park Falls, Wisconsin		Sweeney, C.; Dlugokencky, E.J.					
MAN	Manaus, Brazil		Miller, J.B.; Martins, G.A.; de Souza, R.A.F.					
NHA	Offshore Portsmouth, New Hampshire (Isles of Shoals)		Sweeney, C.; Dlugokencky, E.J.					
OIL	Oglesby, Illinois		Sweeney, C.; Dlugokencky, E.J.					
ORC	ORCAS (O2/N2 Ratio and CO2 Airborne Southern Ocean Study)	https://doi.org/10.5065/D6SB445X	Stephens, B.B, Sweeney, C., McKain, K., Kort, E.					
PFA	Poker Flat, Alaska		Sweeney, C.; Dlugokencky, E.J.					
RBA-B	Rio Branco		Gatti, L.V.; Gloor, E.; Miller, J.B.					
RTA	Rarotonga		Sweeney, C.; Dlugokencky, E.J.					

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SCA	Charleston, South Carolina		Sweeney, C.; Dlugokencky, E.J.
SGP	Southern Great Plains, Oklahoma		Sweeney, C.; Dlugokencky, E.J.; Biraud, S.
TAB	Tabatinga		Gatti, L.V.; Gloor, E.; Miller, J.B.
TGC	Offshore Corpus Christi, Texas		Sweeney, C.; Dlugokencky, E.J.
THD	Trinidad Head, California		Sweeney, C.; Dlugokencky, E.J.
UGD	Kajjansi Airfield, Kampala, Uganda		McKain, K; Sweeney, C
ULB	Ulaanbaatar, Mongolia		Sweeney, C.; Dlugokencky, E.J.
WBI	West Branch, Iowa		Sweeney, C.; Dlugokencky, E.J.

(a) Schuldt et al. 2023. Multi-laboratory compilation of atmospheric carbon dioxide data for the period 1957-2022; obspack_co2_1_GLOBALVIEWplus_v9.0_2023-09-09; NOAA Earth System Research Laboratory, Global Monitoring Laboratory. http://doi.org/10.25925/20230801

(b) Schuldt et al. 2024. Multi-laboratory compilation of atmospheric carbon dioxide data for the period 2023-2024; obspack_co2_1_NRT_v9.2_2024-03-25; NOAA Earth System Research Laboratory, Global Monitoring Laboratory. http://doi.org/10.25925/20240215

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a Raupach et al. (2007) ... [1238]

Table S9. Main methodological changes in the global carbon budget since first publication. Methodological changes introduced in one year are kept for the following years unless noted. Empty cells mean there were no methodological changes introduced that year.

Publication year	Fossil fuel emissions			LUC emissions	Reservoirs			Uncertainty & other changes
	Global	Country (territorial)	Country (consumption)		Atmosphere	Ocean	Land	
2006 (a)		Split in regions						
2007 (b)				ELUC based on FAO-FRA 2005; constant ELUC for 2006	1959-1979 data from Mauna Loa; data after 1980 from global average	Based on one ocean model tuned to reproduced observed 1990s sink		±1σ provided for all components
2008 (c)				Constant ELUC for 2007				
2009 (d)		Split between Annex B and non-Annex B	Results from an independent study discussed	Fire-based emission anomalies used for 2006-2008		Based on four ocean models normalised to observations with constant delta	First use of five DGVMs to compare with budget residual	
2010 (e)	Projection for current year based on GDP	Emissions for top emitters		ELUC updated with FAO-FRA 2010				

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2011 (f)			Split between Annex B and non-Annex B					
2012 (g)		129 countries from 1959	129 countries and regions from 1990-2010 based on GTAP8.0	ELUC for 1997-2011 includes interannual anomalies from fire-based emissions	All years from global average	Based on 5 ocean models normalised to observations with ratio	Ten DGVMs available for SLAND; First use of four models to compare with ELUC	
2013 (h)		250 countriesb	134 countries and regions 1990-2011 based on GTAP8.1, with detailed estimates for years 1997, 2001, 2004, and 2007	ELUC for 2012 estimated from 2001-2010 average		Based on six models compared with two data-products to year 2011	Coordinated DGVM experiments for SLAND and ELUC	Confidence levels; cumulative emissions; budget from 1750
2014 (i)	Three years of BP data	Three years of BP data	Extended to 2012 with updated GDP data	ELUC for 1997-2013 includes interannual anomalies from fire-based emissions		Based on seven models	Based on ten models	Inclusion of breakdow of the sinks in three latitude bands and comparison with three atmospheric inversions

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2015 (j)	Projection for current year based Jan-Aug data	National emissions from UNFCCC extended to 2014 also provided	Detailed estimates introduced for 2011 based on GTAP9			Based on eight models	Based on ten models with assessment of minimum realism	The decadal uncertainty for the DGVM ensemble mea now uses ±1σ of the decadal spread acros models
2016 (k)	Two years of BP data	Added three small countries; China's emissions from 1990 from BP data (this release only)		Preliminary ELUC using FRA-2015 shown for comparison; use of five DGVMs		Based on seven models	Based on fourteen models	Discussion of projection for full budget for current year
2017 (l)	Projection includes India-specific data			Average of two bookkeeping models; use of 12 DGVMs		Based on eight models that match the observed sink for the 1990s; no longer normalised	Based on 15 models that meet observation-based criteria (see Sect. 2.5)	Land multi-model average now used in main carbon budget with the carbon imbalance presente separately; new tabl of key uncertainties
2018 (m)	Revision in cement emissions; Projection includes EU-specific data	Aggregation of overseas territories into governing nations for total of 213		Average of two bookkeeping models; use of 16 DGVMs	Use of four atmospheric inversions	Based on seven models	Based on 16 models; revised atmospheric forcing from CRUNCEP to CRUJRA	Introduction of metric for evaluation of individual models usin observations

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		countries a						
2019 (n)	Global emissions calculated as sum of all countries plus bunkers, rather than taken directly from CDIAC.			Average of two bookkeeping models; use of 15 DGVMs	Use of three atmospheric inversions	Based on nine models	Based on 16 models	

a Raupach et al. (2007)

b Canadell et al. (2007)

c GCP (2008)

d Le Quéré et al. (2009)

e Friedlingstein et al. (2010)

f Peters et al. (2012a)

g Le Quéré et al. (2013), Peters et al. (2013)

h Le Quéré et al. (2014)

i Le Quéré et al. (2015a)

j Le Quéré et al. (2015b)

k Le Quéré et al. (2016)

l Le Quéré et al. (2018a)

m Le Quéré et al. (2018b)

n Friedlingstein et al. (2019)

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Table S10: Translation of global carbon cycle models' land flux definitions to the definition of the LULUCF net flux used by National GHG Inventory (NGHGI) reports to UNFCCC. Non-intact lands are used here as proxy for "managed lands" in the country reporting. NGHGIs are gap-filled (see Sec. C.2.3 for details). For comparison, we provide the net land flux on managed land from atmospheric inversions and FAOSTAT estimates. Units are GtC yr-1.

Carbon flux	Source	2004-2013	2014-2023
ELUC	Bookkeeping estimates from Table 5	1.41	1.13
SLAND total	DGVMs from Table 5	3.15	3.19
SLAND in non-intact forest	DGVMs	1.75	1.83
ELUC minus SLAND in non-intact forest	Bookkeeping ELUC & DGVM SLAND	-0.34	-0.70
LULUCF	NGHGIs	-0.57	-0.76
Net land flux on managed land	Atmospheric inversions	-0.80	-0.69
LULUCF	FAOSTAT	0.32	0.30

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Table S11 - Evaluation of global ocean biogeochemistry models based on comparison with observation-based interior ocean carbon accumulation and process-based evaluation metrics for Atlantic Meridional Overturning Circulation (AMOC), Southern Ocean sea surface salinity and surface ocean Revelle factor (following the RECCAP2 ocean model evaluation chapter, Terhaar et al., 2024) and Southern Ocean stratification index (Bourgeois et al., 2022). See supplementary text C3.3 for details of calculation and observational data sources. Note that AMOC from MOM6-Cobalt (Princeton) is only available between 2018 - 2022, which is the value reported here

		Global Ocean Biogeochemistry Models									
Metric	**Observations**	ACCESS (CSIRO)	CESM-ETHZ	FESOM2.1-REcoM	MOM6-Cobalt (Princeton)	MPIOM-HAMOCC6	MRI-ESM2-3	NEMO-PISCES (IPSL)	NEMO-PlankTOM12	NEMO3.6-PISCESv2-gas (CNRM)	NorESM-OC1.2
Interior ocean anthropogenic carbon accumulation in GtC yr⁻¹											
Global (1994-2007, Gruber et al., 2019)	33.8 ± 4.0	36.4	26.0	31.4	27.1	19.9	27.4	28.9	25.4	27.1	33.6
North (1994-2007, Gruber et al., 2019)	5.9	6.4	5.3	5.9	5.1	3.6	5.6	6.0	4.3	5.8	6.8
Tropics (1994-2007, Gruber et al., 2019)	17.5	15.0	8.7	13.3	11.5	9.1	12.5	12.8	12.5	12.5	13.7
South (1994-2007, Gruber et al., 2019)	10.4	15.0	12.0	12.3	10.6	7.2	9.4	10.1	8.6	8.8	12.9
Global (1994-2004, Müller et al., 2023)	29.3 ± 2.5	24.6	19.5	24.1	20.6	15.3	20.3	21.9	18.5	21.2	24.8
Global (2004-2014, Müller et al., 2023)	27.3 ± 2.5	31.4	22.5	27.4	24.2	18.5	23.8	25.0	22.4	23.8	28.5
Atlantic Meridional Overturning Circulation at 26°N, 2005-2022 in Sv (Moat et al., 2023)	*17.0 ± 1.3*	9.7	13.0	10.2	10.7	15.3	13.5	14.2	17.9	13.1	22.9
Southern Ocean sea surface salinity 2005-2022 in psu (Good et al., 2013)											
subpolar seasonally stratified biome (SPSS)	33.942	34.262	33.809	34.295	34.061	33.925	34.074	34.239	33.873	33.824	34.116
subpolar seasonally stratified and subtropical seasonally stratifed biomes (SPSS+STSS)	34.307	34.577	34.185	34.565	34.385	34.254	34.363	34.554	34.358	34.124	34.506
Southern Ocean stratification index 2005-2022, in kg m-3 (Bourgeois et al., 2022, Good et al., 2013)	5.88	5.45	5.97	5.68	6.13	5.97	6.03	5.60	5.06	6.18	5.76

Surface ocean Revelle factor											
1997-2007, unitless (GLODAPv2.2016, Lauvset et al., 2016)	10.44	10.61	10.33	10.65	10.34	10.72	10.60	10.65	10.49	10.77	10.58
2005-2021, unitless (OceanSODA_v2023, updated from Gregor and Gruber, 2021)	10.62	10.77	10.52	10.84	10.52	10.93	10.79	10.81	10.65	10.93	10.75

Supplementary Figures

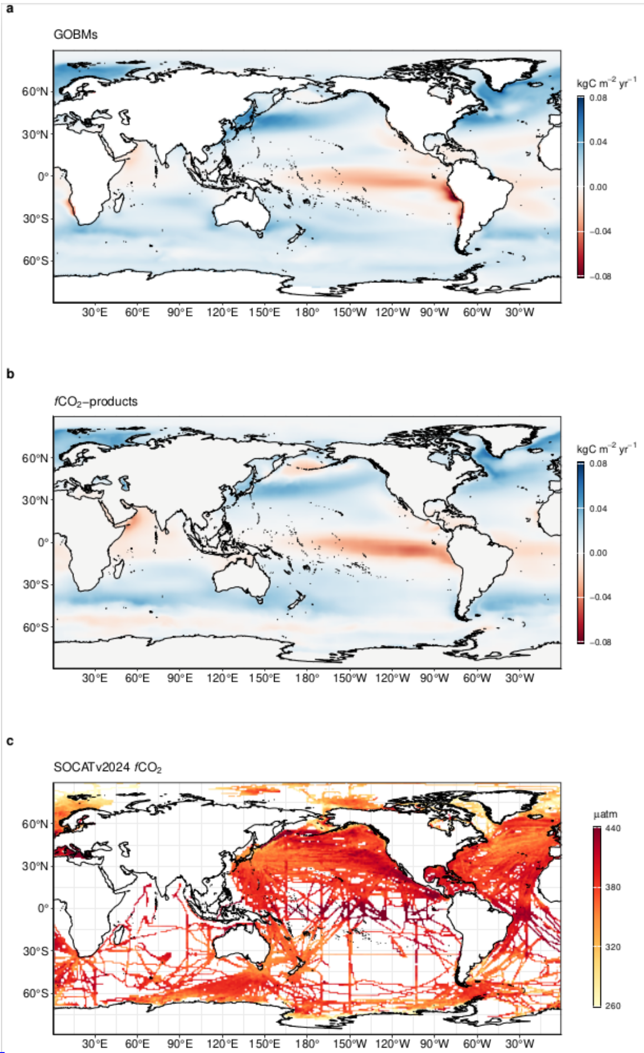
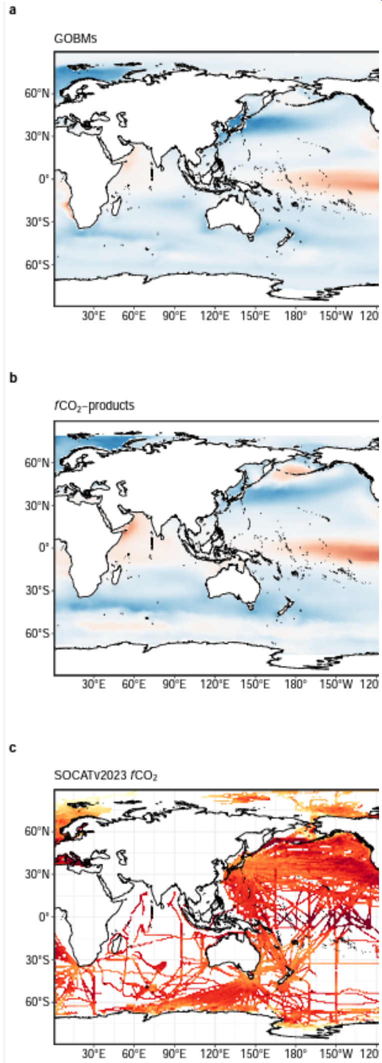


Figure S1. Ensemble mean air-sea CO_2 flux from a) global ocean biogeochemistry models and b) *f*CO_2 based data products, averaged over 2014-2023 period (kgC m^{-2} yr^{-1}). Positive numbers indicate a flux into the ocean. c) gridded SOCAT v2024 *f*CO_2 measurements, averaged over the 2014-2023 period (µatm). In (a) model simulation A is shown. The *f*CO_2-products represent the contemporary flux, i.e. including outgassing of riverine carbon, which is estimated to amount to 0.65 GtC yr^{-1} globally.



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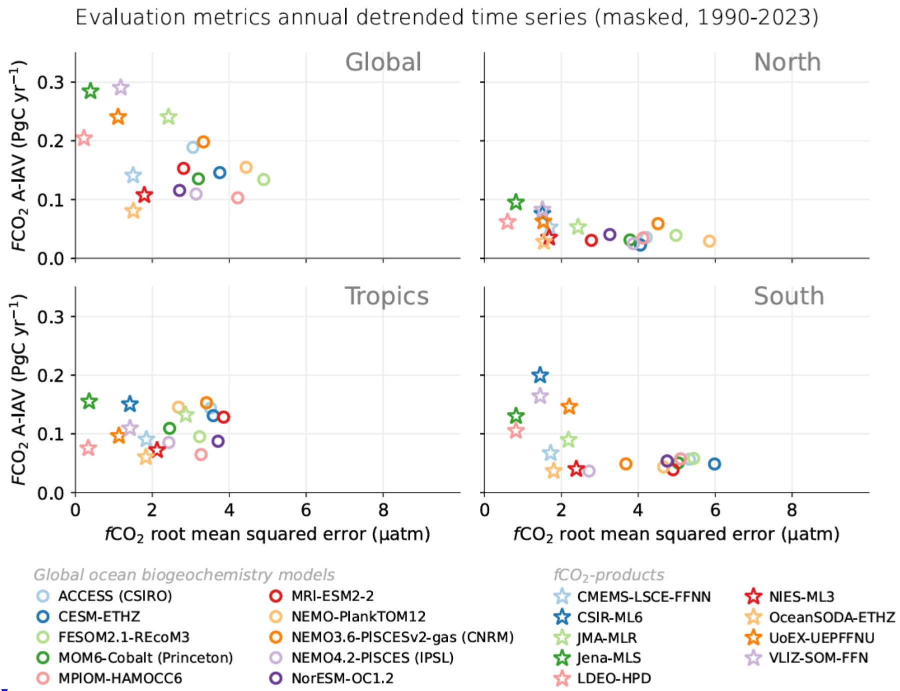
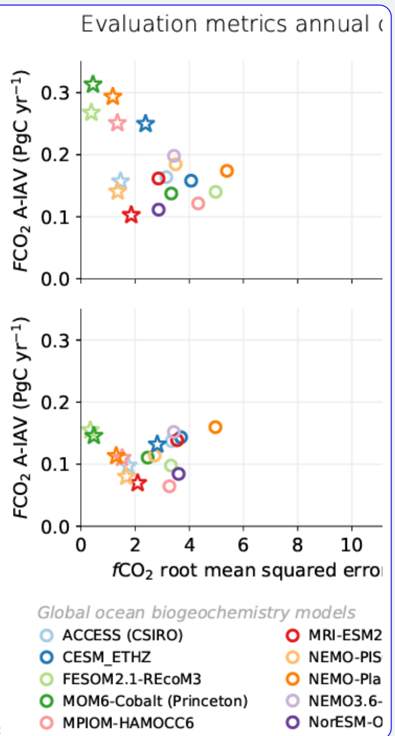


Figure S2. Evaluation of the GOBMs and *f*CO_2-products using the root mean squared error (RMSE) for the period 1990 to 2023, between the individual surface ocean fCO_2 mapping schemes and the SOCAT v2024 database. The y-axis shows the amplitude of the interannual variability of the air-sea CO_2 flux (A-IAV, taken as the standard deviation of the detrended annual time series). Results are presented for the globe, north (>30°N), tropics (30°S-30°N), and south (<30°S) for the GOBMs (see legend, circles) and for the *f*CO_2-based data products (star symbols). The *f*CO_2-products use the SOCAT database and therefore are not independent from the data (see Section 2.5.1).



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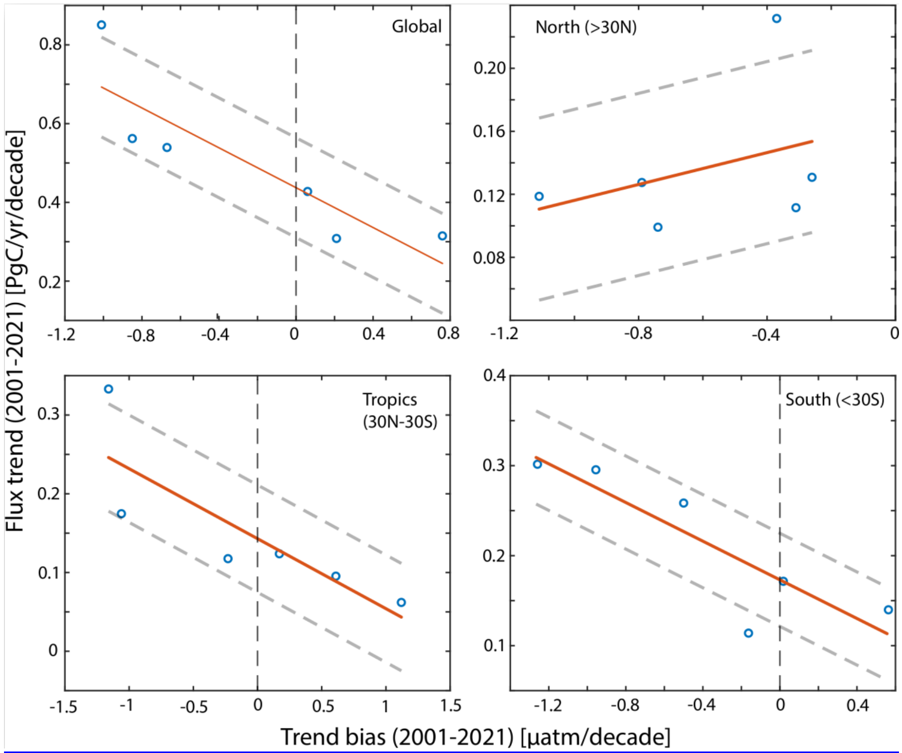

Figure S3. Trend evaluation of six from the eight fCO_2-products used for S_{OCEAN} (blue circles - CSIR-ML6, NIES-ML3, VLIZ-SOMFFN, OceanSODA-ETHZv2, JMA-MLR, Jena-MLS) . The x-axis represents the mean fCO_2 trend bias from a model subsampling exercise (following Hauck et al., 2023) using four of the GCB2023 GOBMs (CESM, FESOM-REcoM, IPSL and MRI-ESM). The y-axis represents the flux trend as submitted by the fCO_2 product to this study. Besides the northern hemisphere, where all of the six fCO_2-products overestimate the subsampled model trend, there is a clear relationship between the trend reconstruction bias and the flux trend (red line with grey dashed lines representing the 1 sigma uncertainty interval), indicating that flux trends are sensitive to the fCO_2-products ability to reconstruction biases.

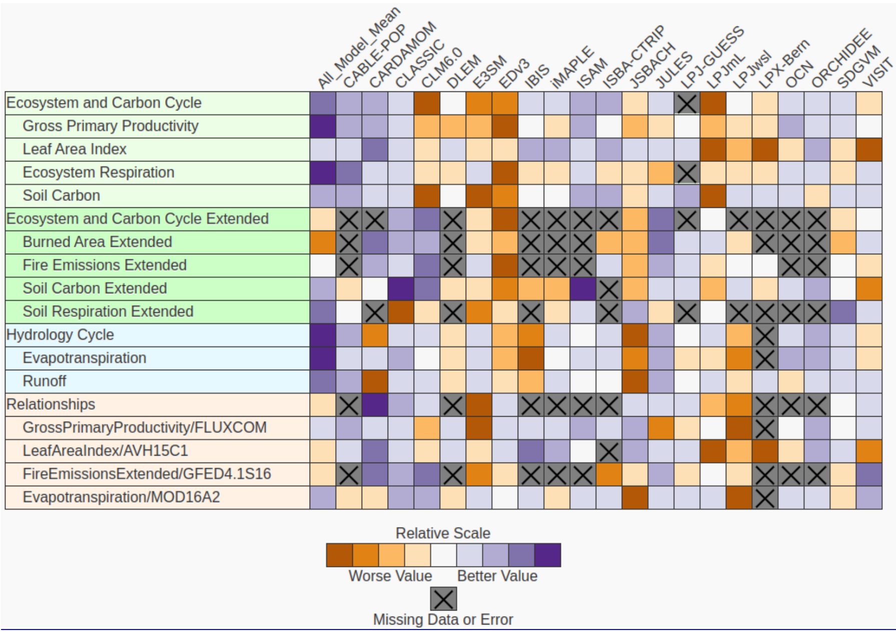

Figure S4. Evaluation of the DGVMs using the International Land Model Benchmarking system (ILAMB; Collier et al., 2018) Skill scores relative to other models. The benchmarking is done with observations for GPP and ecosystem respiration (Reichstein et al., 2007; Lasslop et al., 2010; Knauer et al., 2018; Jung et al., 2017; Tramontana et al., 2016; Alemohammad et al., 2017), leaf area index (Vermote, 2019; Claverie et al., 2016; De Kauwe et al., 2011; Myneni et al., 1997), soil carbon (Hugelius et al., 2013; Fischer et al., 2008), evapotranspiration (De Kauwe et al., 2011; Martens et al., 2017; Miralles et al., 2011; Mu et al., 2011), and runoff (Dai and Trenberth, 2002; Hobeichi et al., 2019; Hobeichi et al., 2020). Metrics include relationships between carbon cycle variables, precipitation (Adler et al., 2003) and temperature (Harris et al., 2014). For each model–observation comparison a series of error metrics are calculated, scores are then calculated as an exponential function of each error metric, and finally for each variable the multiple scores from different metrics and observational datasets are combined to give the overall variable scores. Overall variable scores increase from 0 to 1 with improvements in model performance. The set of error metrics vary with dataset and can include metrics based on the period mean, bias, root mean squared error, spatial distribution, interannual variability, and seasonal cycle. The relative skill score shown is a Z score, which indicates in units of standard deviation the model scores relative to the mean score for a given variable. Grey boxes represent missing model data.

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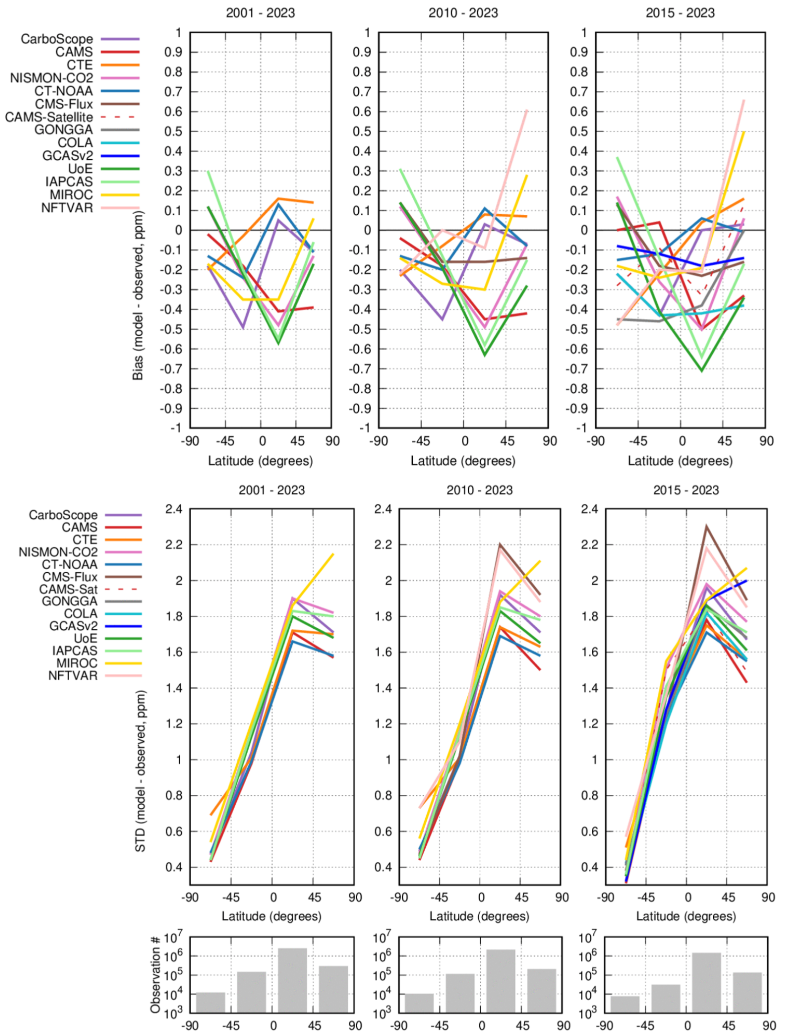
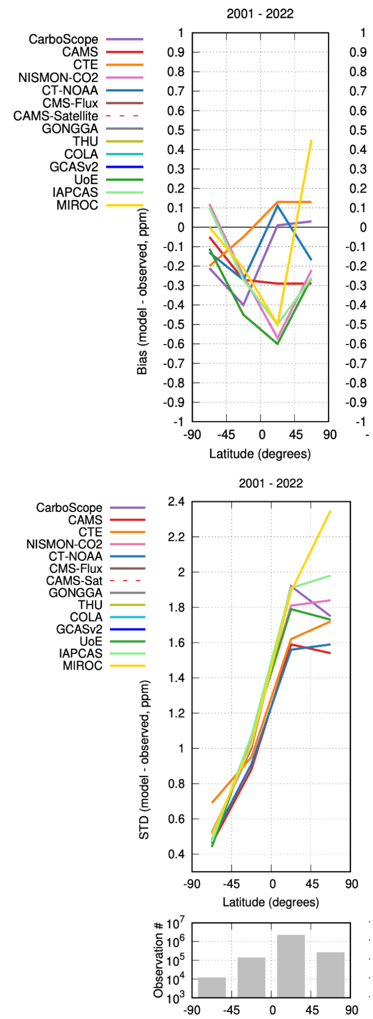


Figure S5. Evaluation of the atmospheric inversion products. The mean of the model minus observations is shown for four latitude bands in three periods: (first panel) 2001-2023, (second panel) 2010-2023, (third panel) 2015-2023. The 14 systems are compared to independent CO_2 observations from aircraft over many places of the world between 2 and 7 km above sea level. Aircraft measurements archived in the Cooperative Global Atmospheric Data Integration Project (Schuldt et al. 2023, Schuldt et al. 2024) from sites, campaigns or programs that have not been assimilated and cover at least 9 months (except for SH programs) between 2001 and 2023, have been used to compute the biases (top row) and their standard deviations (middle row) in four 45° latitude bins. Land and ocean data are used without distinction, and observation density varies strongly with latitude and time as seen on the lower panels.



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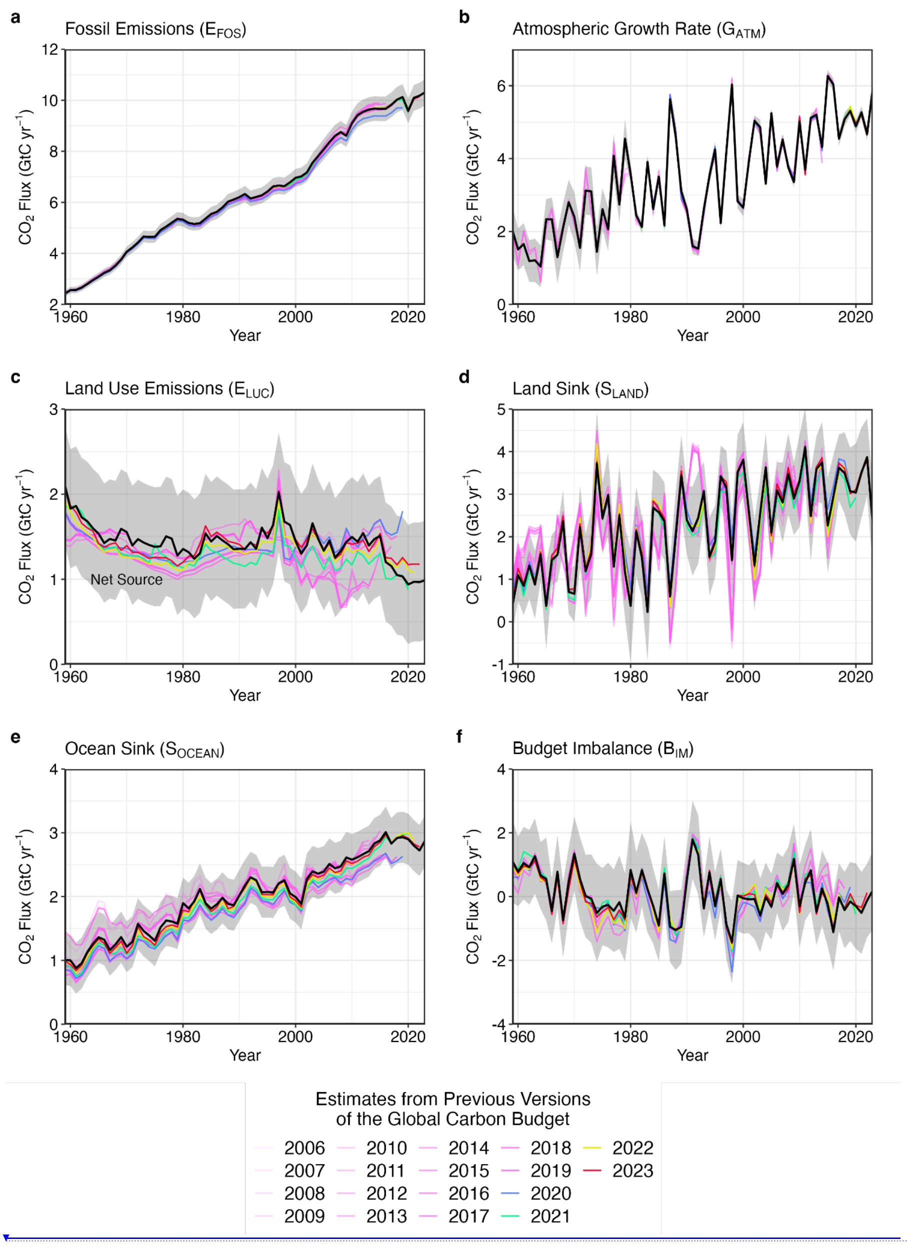

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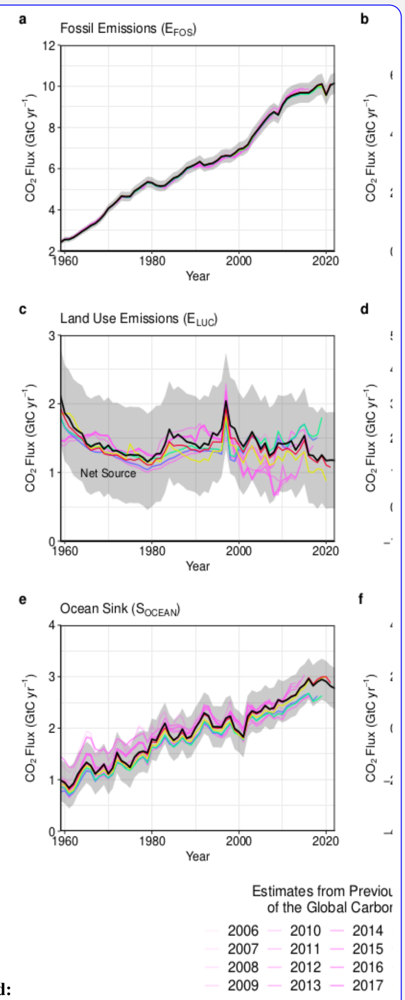

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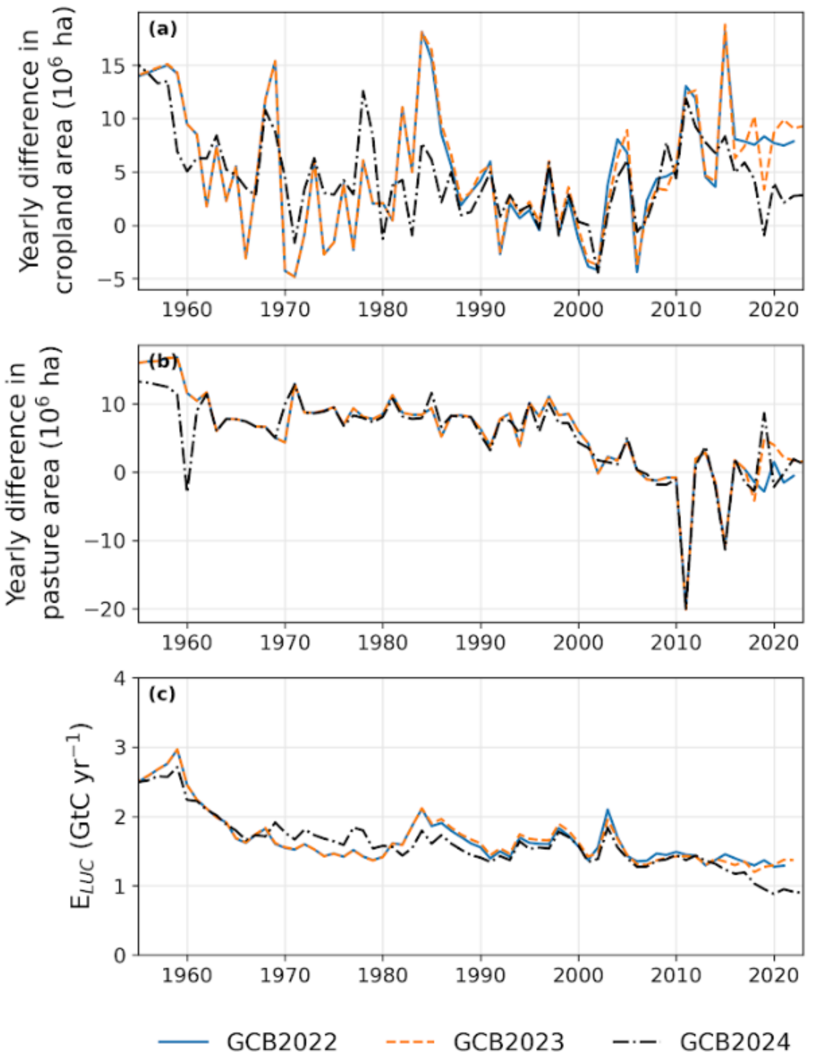
Figure S6. Comparison of the estimates of each component of the global carbon budget in this study (black line) with the estimates released annually by the GCP since 2006. Grey shading shows the uncertainty bounds representing ±1 standard deviation of the current global carbon budget, based on the uncertainty assessments described in Supplement S1 to S4. CO_2 emissions from (a) fossil CO_2 emissions excluding cement carbonation (E_{FOS}), and (b) land-use change (E_{LUC}), as well as their partitioning among (c) the atmosphere (G_{ATM}), (d) the land (S_{LAND}), and (e) the ocean (S_{OCEAN}). See legend for the corresponding years, and Tables 3 and A8 for description of changes in methodology. The budget year corresponds to the year when the budget was first released. All values are in GtC yr^{-1}.



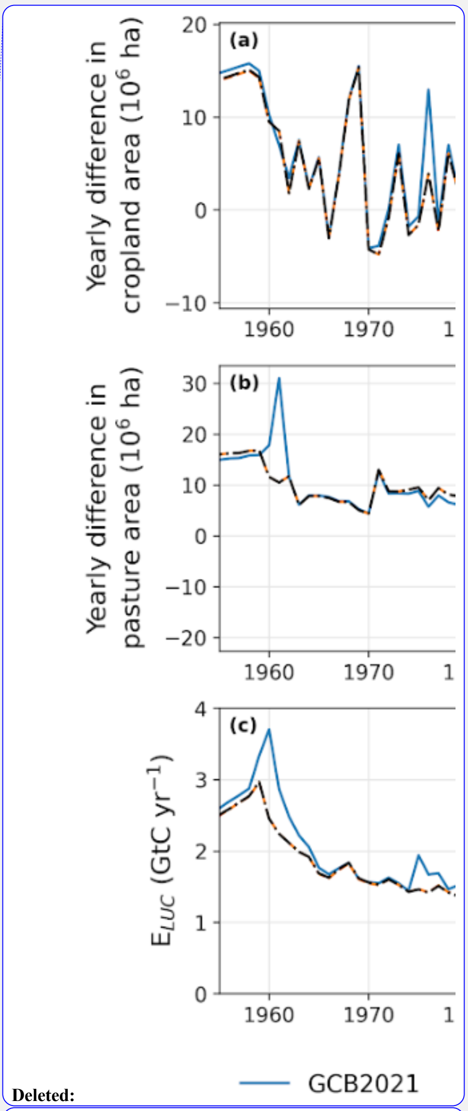


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Figure S7. Differences in the HYDE/LUH2 land-use forcing used for the global carbon budgets GCB2022 (Friedlingstein et al., 2022b), GCB2023 (Friedlingstein et al., 2023), and GCB2024 (this paper). Shown are

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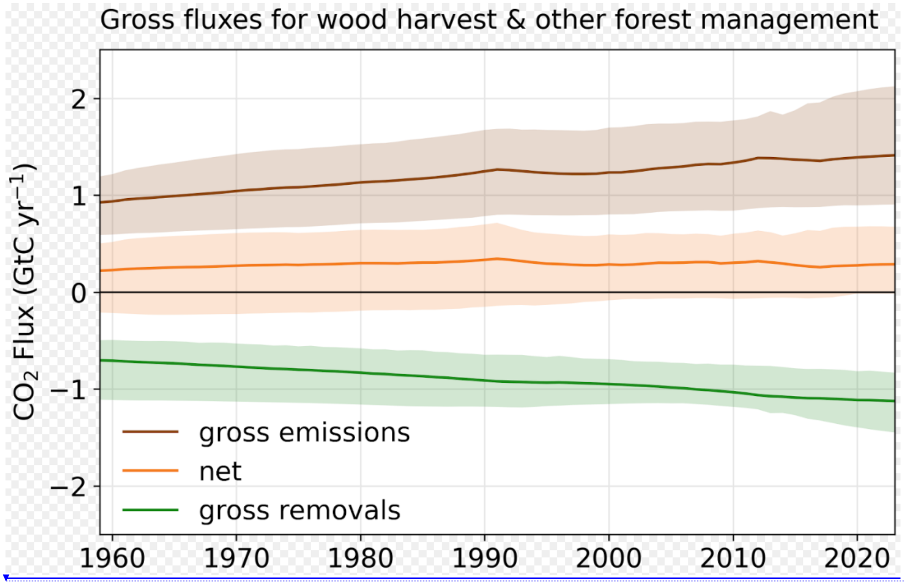
year-to-year changes in cropland area (top panel) and pasture area (middle panel). To illustrate the relevance of the update in the land-use forcing to the recent trends in E_{LUC}, the bottom panel shows the land-use emission estimate from the bookkeeping model BLUE (original model output, i.e., excluding emissions from peat fire and peat drainage).



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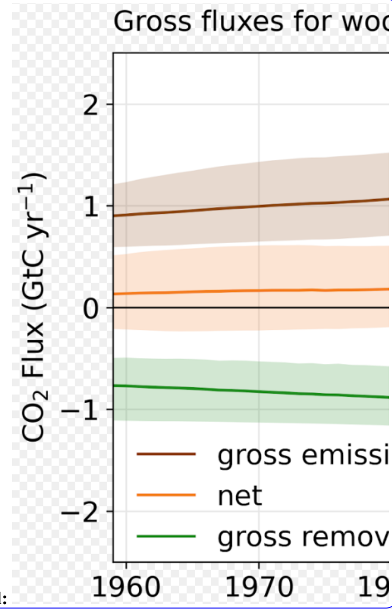

Figure S8: Split of net fluxes from wood harvest and other forest management into gross emissions and gross removals. Solid lines denote the average of the three bookkeeping models and shaded areas the full range (min-max) of the bookkeeping model estimates.

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Figure S9. Fire carbon emissions for the months January-September for each year 2003-2024 from two global fire emissions products. **(Top row)** Global emissions. **(Middle row)** Emissions for the northern hemisphere extratropics (>30° N), tropics (30° N-30° S) and southern extratropics (>30° S). **(Bottom row)** Emissions by RECCAP2 region. The Global Fire Assimilation System (GFAS; Di Giuseppe et al., 2018) **(left column)** and the Global Fire Emissions Database (GFED, version 4.1s; van der Werf et al., 2017) **(right column)** are among the most widely applied global fire emissions products based on satellite remote sensing of fire. GFED relies on the post-fire detection of burned areas combined with fuel consumption factors. GFAS relies on the detection of thermal energy release during active fires.

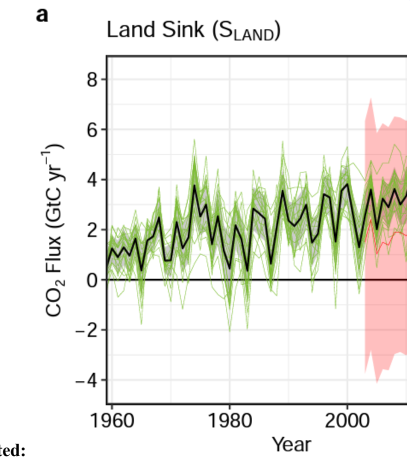

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Figure S8. As Figure 8 but with the inclusion of CARDAMOM) (a) The land CO_2 sink (S_{LAND}) estimated by individual DGVMs estimates (green), as well as the budget estimate (black with ±1σ uncertainty), which is the average of all DGVMs. (b) Total atmosphere-land CO_2 fluxes (S_{LAND} – E_{LUC}). Panel (b) also includes an estimate for the total land flux for individual DGVMs (thin green lines) and their multi-model mean (thick green line). The red line is the mean CARDAMOM result and uncertainty range in pink.

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References

Adler, R. F., Huffman, G. J., Chang, A., Ferraro, R., Xie, P.-P., Janowiak, J., Rudolf, B., Schneider, U., Curtis, S., Bolvin, D., Gruber, A., Susskind, J., Arkin, P., and Nelkin, E.: The Version-2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979–Present), J. Hydrometeor, 4, 1147–1167, https://doi.org/10.1175/1525-7541(2003)004<1147:TVGPCP>2.0.CO;2, 2003.

Alemohammad, S. H., Fang, B., Konings, A. G., Aires, F., Green, J. K., Kolassa, J., Miralles, D., Prigent, C., and Gentine, P.: Water, Energy, and Carbon with Artificial Neural Networks (WECANN): a statistically based estimate of global surface turbulent fluxes and gross primary productivity using solar-induced fluorescence, Biogeosciences, 14, 4101–4124, https://doi.org/10.5194/bg-14-4101-2017, 2017.

Alkama, R.: Land Carbon Budget: Intact and Non-Intact Forest NBP from TRENDY-v11 S2 simulations [code], available at: https://github.com/RamAlkama/LandCarbonBudget_IntactAndNonIntactForest, last access: 9 October 2024, 2022.

Amador-Jiménez, M., Millner, N., Palmer, C., Pennington, R. T., and Sileci, L.: The Unintended Impact of Colombia's Covid-19 Lockdown on Forest Fires, Environ Resource Econ, 76, 1081–1105, https://doi.org/10.1007/s10640-020-00501-5, 2020.

Amante, C. and Eakins, B. W.: ETOPO1 Global Relief Model converted to PanMap layer format, PANGAEA [dataset], https://doi.org/10.1594/PANGAEA.769615, 2009.

Andres, R. J., Boden, T. A., Bréon, F.-M., Ciais, P., Davis, S., Erickson, D., Gregg, J. S., Jacobson, A., Marland, G., Miller, J., Oda, T., Olivier, J. G. J., Raupach, M. R., Rayner, P., and Treanton, K.: A synthesis of carbon dioxide emissions from fossil-fuel combustion, Biogeosciences, 9, 1845–1871, https://doi.org/10.5194/bg-9-1845-2012, 2012.

Andres, R. J., Boden, T. A., and Higdon, D.: A new evaluation of the uncertainty associated with CDIAC estimates of fossil fuel carbon dioxide emission, Tellus B: Chemical and Physical Meteorology, 66, 23616, https://doi.org/10.3402/tellusb.v66.23616, 2014.

Andrew, R. M.: Towards near real-time, monthly fossil CO2 emissions estimates for the European Union with current-year projections, Atmos. Pollut. Res., 12, 12, 101229, https://doi.org/10.1016/j.apr.2021.101229, 2021.

Andrew, R. M. and Peters, G. P.: A multi-region input–output table based on the global trade analysis project database (GTAP-MRIO), Economic Systems Research, 25, 99–121, https://doi.org/10.1080/09535314.2012.761953, 2013.

Arora, V. K., Boer, G. J., Christian, J. R., Curry, C. L., Denman, K. L., Zahariev, K., Flato, G. M., Scinocca, J. F., Merryfield, W. J., and Lee, W. G.: The Effect of Terrestrial Photosynthesis Down Regulation on the Twentieth-Century Carbon Budget Simulated with the CCCma Earth System Model, 22, 6066–6088, https://doi.org/10.1175/2009JCLI3037.1, 2009.

Bauer, J. E., Cai, W.-J., Raymond, P. A., Bianchi, T. S., Hopkinson, C. S., and Regnier, P. A. G.: The changing carbon cycle of the coastal ocean, Nature, 504, 61–70, https://doi.org/10.1038/nature12857, 2013.

Beckman, J. and Countryman, A. M.: The Importance of Agriculture in the Economy: Impacts from COVID-19, Am. J. Agr. Econ., 103, 1595–1611, https://doi.org/10.1111/ajae.12212, 2021.

Bellouin, N., Rae, J., Jones, A., Johnson, C., Haywood, J., and Boucher, O.: Aerosol forcing in the Climate Model Intercomparison Project (CMIP5) simulations by HadGEM2-ES and the role of ammonium nitrate, J. Geophys. Res.-Atmos., 116, D20206, https://doi.org/10.1029/2011JD016074, 2011.

Bernardello, R., Sicardi, V., Lapin, V., Ortega, P., Ruprich-Robert, Y., Tourigny, E., and Ferrer, E.: Ocean biogeochemical reconstructions to estimate historical ocean CO2 uptake, Earth Syst. Dynam.,15, 1255–1275, https://doi.org/10.5194/esd-15-1255-2024, 2024.

Bethke, I., Wang, Y., Counillon, F., Keenlyside, N., Kimmritz, M., Fransner, F., ... & Eldevik, T.: NorCPM1 and its contribution to CMIP6 DCPP. Geoscientific Model Development, 14(11), 7073-7116, 2021.

Bilbao, R., S. Wild, P. Ortega et al. (2021). Assessment of a full-field initialised decadal climate prediction system with the CMIP6 version of EC-Earth. Earth Systems Dynamics, doi:10.5194/esd-2020-66. Broecker, W. S.: Ocean chemistry during glacial time, Geochimica et Cosmochimica Acta, 46, 1689–1705, https://doi.org/10.1016/0016-7037(82)90110-7, 1982.

Boucher O., Servonnat, J., Albright,A. L., Aumont, O., Balkanski, Y.,Bastrikov, V., et al.: Presentation and evaluation of the IPSL-CM6A-LRclimate model.Journal of Advances inModeling Earth Systems,12,e2019MS002010, 2020.

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Brune, S., A. Düsterhus, H. Pohlmann, W. A. Müller, and J. Baehr: Time dependency of the prediction skill for the north atlantic subpolar gyre in initialized decadal hindcasts. Climate dynamics, 51 (5), 1947–1970, 2018.

Brunner, L., Pendergrass, A. G., Lehner, F., Merrifield, A. L., Lorenz, R., and Knutti, R.: Reduced global warming from CMIP6 projections when weighting models by performance and independence, Earth Syst. Dynam., 11, 995–1012, https://doi.org/10.5194/esd-11-995-2020, 2020.

Cerdeiro, D.A., Komaromi, A., Liu, Y., Saeed, M.: World Seaborne Trade in Real Time: A Proof of Concept for Building AIS-based Nowcasts from Scratch. International Monetary Fund (IMF) WP/20/57, available at: https://www.imf.org/en/Publications/WP/Issues/2020/05/14/World-Seaborne-Trade-in-Real-Time-A-Proof-of-Concept-for-Building-AIS-based-Nowcasts-from-49393, last access: 9 October 2024, 2020.

Chatfield, C.: The Holt-Winters Forecasting Procedure, J. Roy. Stat. Soc. C., 27, 264–279, https://doi.org/10.2307/2347162, 1978.

Chini, L., Hurtt, G., Sahajpal, R., Frolking, S., Klein Goldewijk, K., Sitch, S., Ganzenmüller, R., Ma, L., Ott, L., Pongratz, J., and Poulter, B.: Land-use harmonization datasets for annual global carbon budgets, 13, 4175–4189, https://doi.org/10.5194/essd-13-4175-2021, 2021.

Clarke, D., Flachenecker, F., Guidetti, E., and Pionnier, P.-A.: CO2 Emissions from air transport: A near-real-time global database for policy analysis, Organization for Economic Co-operation and Development, Paris OECD Statistics Working Papers 2022/04, available at: https://doi.org/10.1787/ecc9f16b-en, last access: 9 October 2024, 2022.

Claverie, M., Matthews, J., Vermote, E., and Justice, C.: A 30+ Year AVHRR LAI and FAPAR Climate Data Record: Algorithm Description and Validation, Remote Sensing, 8, 263, https://doi.org/10.3390/rs8030263, 2016.

Conchedda, G. and Tubiello, F. N.: Drainage of organic soils and GHG emissions: Validation with country data, Biosphere – Biogeosciences, https://doi.org/10.5194/essd-2020-202, 2020.

Cooper, D. J., Watson, A. J., and Ling, R. D.: Variation of pCO2 along a North Atlantic shipping route (U.K. to the Caribbean): A year of automated observations, Marine Chemistry, 60, 147-164, 1998.

Crippa, M., Janssens-Maenhout, G., Guizzardi, D., Van Dingenen, R., and Dentener, F.: Contribution and uncertainty of sectorial and regional emissions to regional and global PM2.5 health impacts, 19, 5165–5186, https://doi.org/10.5194/acp-19-5165-2019, 2019.

Dai, A. and Trenberth, K. E.: Estimates of Freshwater Discharge from Continents: Latitudinal and Seasonal Variations, J. Hydrometeorol., 3, 660–687, https://doi.org/10.1175/1525-7541(2002)003<0660:EOFDFC>2.0.CO;2, 2002.

Davis, S. J. and Caldeira, K.: Consumption-based accounting of CO2 emissions, Proceedings of the National Academy of Sciences, 107, 5687–5692, https://doi.org/10.1073/pnas.0906974107, 2010.

De Kauwe, M. G., Disney, M. I., Quaife, T., Lewis, P., and Williams, M.: An assessment of the MODIS collection 5 leaf area index product for a region of mixed coniferous forest, Remote Sensing of Environment, 115, 767–780, https://doi.org/10.1016/j.rse.2010.11.004, 2011.

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., ... & Vitart, F.. The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. Quarterly Journal of the royal meteorological society, 137(656), 553-597, 2011.

Dickson, A. G., Sabine, C. L., and Christian, J. R.: Guide to best practices for ocean CO2 measurement. Sidney, British Columbia, North Pacific Marine Science Organization, 191pp. (PICES Special Publication 3; IOCCP Report 8). DOI: https://doi.org/10.25607/OBP-1342, 2007.

Dou, X., Wang, Y., Ciais, P., Chevallier, F., Davis, S. J., Crippa, M., Janssens-Maenhout, G., Guizzardi, D., Solazzo, E., Yan, F., Huo, D., Zheng, B., Zhu, B., Cui, D., Ke, P., Sun, T., Wang, H., Zhang, Q., Gentine, P., Deng, Z., and Liu, Z.: Near-real-time global gridded daily CO2 emissions, The Innovation, 3, 100182, https://doi.org/10.1016/j.xinn.2021.100182, 2022.

Döscher, R., Acosta, M., Alessandri, A., Anthoni, P., Arneth, A., Arsouze, T., ... & Zhang, Q.: The EC-earth3 Earth system model for the climate model intercomparison project 6. Geoscientific Model Development Discussions, 2021, 1-90. 2021.

Duce, R. A., LaRoche, J., Altieri, K., Arrigo, K. R., Baker, A. R., Capone, D. G., Cornell, S., Dentener, F., Galloway, J., Ganeshram, R. S., Geider, R. J., Jickells, T., Kuypers, M. M., Langlois, R., Liss, P. S., Liu, S. M., Middelburg, J. J., Moore, C. M., Nickovic, S., Oschlies, A., Pedersen, T., Prospero, J., Schlitzer, R., Seitzinger, S., Sorensen, L. L., Uematsu, M., Ulloa, O., Voss, M., Ward, B., and Zamora, L.: Impacts of Atmospheric Anthropogenic Nitrogen on the Open Ocean, Science, 320, 893–897, https://doi.org/10.1126/science.1150369, 2008.

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Eakins, B. W. and Sharman, G. F.: National Geophysical Data Center: Volumes of the World's Oceans from ETOPO1, available at: https://www.ngdc.noaa.gov/mgg/global/etopo1_ocean_volumes.html, last access: 9 October 2024, U.S. Department of Commerce, 2010.

Deleted: November 2023

Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T., and Tanabe, K.: Volume 4: Agriculture, forestry and land use. in: 2006 IPCC guidelines for national greenhouse gas inventories, available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html, last access: 9 October 2024, 2006.

Deleted: November 2023

Eurostat: Countries 2020, 1:1 million, available at: https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/countries, last access: 9 October 2024, 2024.

Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., and Taylor, K. E.: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, Geosci. Model Dev., 9, 1937–1958, https://doi.org/10.5194/gmd-9-1937-2016, 2016.

EIA: U.S. Energy Information Administration: Short-Term Energy Outlook, available at: http://www.eia.gov/forecasts/steo/outlook, last access: 9 October 2024, 2023.

Deleted: November

Deleted: , 2022

FAO: Global Forest Resources Assessment 2020: Main report, FAO, Rome, Italy, 184 pp., https://doi.org/10.4060/ca9825en, 2020.

FAO: FAO Statistical Database (FAOSTAT), domains Climate Change, available at: http://www.fao.org/faostat/en/#data/GT, last access: 9 October 2024, 2021.

Deleted: November 2023

FAO: FAOSTAT Climate Change: Agrifood systems emissions, Emissions from Drained, available at http://www.fao.org/faostat/en/#data/GV, last access: 9 October 2024, 2023.

FAO: FAO Statistical Database (FAOSTAT), domains Climate Change, available at: http://www.fao.org/faostat/en/#data/GT, last access: 9 October 2024, 2024.

FAO/UNEP: Food and Agriculture Organisation / United Nations Environment Programme: The state of food and agriculture 1981, available at: https://www.fao.org/3/ap661e/ap661e.pdf, last access: 9 October 2024, 1981.

Deleted: November 2023

Fay, A. R. and McKinley, G. A.: Global open-ocean biomes: mean and temporal variability, 6, 273–284, https://doi.org/10.5194/essd-6-273-2014, 2014.

Fischer, G., Nachtergaele, F., Prieler, S., van Velthuizen, H. T., Verelst, L., and Wiberg, D.: Global Agro-ecological Zones Assessment for Agriculture (GAEZ 2008). IIASA, Laxenburg, Austria and FAO, Rome, Italy, available at: https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/land-cover-data/ar/, last access: 9 October 2024, 2008.

Deleted: November 2023

Ford, D., Blannin, J., Watts, J., Watson, A., Landschützer, P., Jersild, A. and Shutler, J.: A comprehensive analysis of air-sea CO2 flux uncertainties constructed from surface ocean data products, Global Biogeochemical Cycles, accepted, 2024.

Gasser, T. and Ciais, P.: A theoretical framework for the net land-to-atmosphere CO2 flux and its implications in the definition of "emissions from land-use change", Earth Syst. Dynam., 4, 171–186, https://doi.org/10.5194/esd-4-171-2013, 2013.

GCCA. Concrete Future: The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete, available at: https://gccassociation.org/concretefuture/ , last access: 2 August 2022, 2021.

Goddijn-Murphy, L. M., Woolf, D. K., Land, P. E., Shutler, J. D., and Donlon, C.: The OceanFlux Greenhouse Gases methodology for deriving a sea surface climatology of CO2 fugacity in support of air–sea gas flux studies, 11, 519–541, https://doi.org/10.5194/os-11-519-2015, 2015.

Golar, G., Malik, A., Muis, H., Herman, A., Nurudin, N., and Lukman, L.: The social-economic impact of COVID-19 pandemic: implications for potential forest degradation, Heliyon, 6, e05354, https://doi.org/10.1016/j.heliyon.2020.e05354, 2020.

Good, S. A., Martin, M. J., and Rayner, N. A.: EN4: Quality controlled ocean temperature and salinity profiles and monthly objective analyses with uncertainty estimates, Journal of Geophysical Research: Oceans, 118, 6704–6716, https://doi.org/10.1002/2013JC009067, 2013.

Gouretski, V. and Cheng, L.: Correction for Systematic Errors in the Global Dataset of Temperature Profiles from Mechanical Bathythermographs, Journal of Atmospheric and Oceanic Technology, 37, 841–855, https://doi.org/10.1175/JTECH-D-19-0205.1, 2020.

Gouretski, V. and Reseghetti, F.: On depth and temperature biases in bathythermograph data: Development of a new correction scheme based on analysis of a global ocean database, Deep Sea Research Part I: Oceanographic Research Papers, 57, 812–833, https://doi.org/10.1016/j.dsr.2010.03.011, 2010.

Grassi, G., Conchedda, G., Federici, S., Abad Viñas, R., Korosuo, A., Melo, J., Rossi, S., Sandker, M., Somogyi, Z., and Tubiello, F. N.: Carbon fluxes from land 2000–2020: bringing clarity on countries' reporting, Biogeosciences and biodiversity, https://doi.org/10.5194/essd-2022-104, 2022.

Gregg, J. S., Andres, R. J., and Marland, G.: China: Emissions pattern of the world leader in CO 2 emissions from fossil fuel consumption and cement production, Geophys. Res. Lett., 35, L08806, https://doi.org/10.1029/2007GL032887, 2008.

Gürses, Ö., Oziel, L., Karakuş, O., Sidorenko, D., Völker, C., Ye, Y., Zeising, M., Butzin, M., and Hauck, J.: Ocean biogeochemistry in the coupled ocean–sea ice–biogeochemistry model FESOM2.1–REcoM3, Geoscientific Model Development, 16, 4883–4936, https://doi.org/10.5194/gmd-16-4883-2023, 2023.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., Thau, D., Stehman, S. V., Goetz, S. J., Loveland, T. R., Kommareddy, A., Egorov, A., Chini, L., Justice, C. O., and Townshend, J. R. G.: High-Resolution Global Maps of 21st-Century Forest Cover Change, Science, 342, 850–853, https://doi.org/10.1126/science.1244693, 2013.

Harris, I., Jones, P. D., Osborn, T. J., and Lister, D. H.: Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset, Int. J. Climatol., 34, 623–642, https://doi.org/10.1002/joc.3711, 2014.

Harris, I., Osborn, T. J., Jones, P., and Lister, D.: Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset, Sci Data, 7, 109, https://doi.org/10.1038/s41597-020-0453-3, 2020.

Hashimoto, S., Carvalhais, N., Ito, A., Migliavacca, M., Nishina, K. and Reichstein, M.: Global spatiotemporal distribution of soil respiration modeled using a global database. Biogeosciences, 12(13), pp.4121-4132, 2015.

Hashimoto, S., Ito, A. and Nishina, K.: Divergent data-driven estimates of global soil respiration. Communications Earth & Environment, 4(1), p.460, 2023.

Hefner, M., Marland, G., Boden, T., Andres, R.: Global, Regional, and National Fossil-Fuel CO2 Emissions: 1751-2020 CDIAC-FF, Appalachian Energy Centre [data set], available at: https://energy.appstate.edu/cdiac-appstate/data-products, last access: 9 October 2024, 2023.

Heinimann, A., Mertz, O., Frolking, S., Christensen, A. E., Hurni, K., Sedano, F., Chini, L. P., Sahajpal, R., Hansen, M., and Hurtt, G.: A global view of shifting cultivation: Recent, current, and future extent, PLOS ONE, 12, e0184479, https://doi.org/10.1371/journal.pone.0184479, 2017.

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., ... & Thépaut, J. N.: The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society, 146(730), 1999-2049, 2020.

Hertwich, E. G. and Peters, G. P.: Carbon Footprint of Nations: A Global, Trade-Linked Analysis, Environ. Sci. Technol., 43, 6414–6420, https://doi.org/10.1021/es803496a, 2009.

Ho, D. T., Wanninkhof, R., Schlosser, P., Ullman, D. S., Hebert, D., and Sullivan, K. F.: Toward a universal relationship between wind speed and gas exchange: Gas transfer velocities measured with 3He/SF6 during the Southern Ocean Gas Exchange Experiment, J. Geophys. Res.-Oceans, 116, C00F04, https://doi.org/10.1029/2010JC006854, 2011.

Hobeichi, S., Abramowitz, G., Evans, J., and Beck, H. E.: Linear Optimal Runoff Aggregate (LORA): a global gridded synthesis runoff product, Hydrol. Earth Syst. Sci., 23, 851–870, https://doi.org/10.5194/hess-23-851-2019, 2019.

Hobeichi, S., Abramowitz, G., and Evans, J.: Conserving Land–Atmosphere Synthesis Suite (CLASS), Journal of Climate, 33, 1821–1844, https://doi.org/10.1175/JCLI-D-19-0036.1, 2020.

Houghton, R. A.: Why are estimates of the terrestrial carbon balance so different?, Glob. Change Biol., 9, 500–509, https://doi.org/10.1046/j.1365-2486.2003.00620.x, 2003.

Houghton, R. A. and Nassikas, A. A.: Global and regional fluxes of carbon from land use and land cover change 1850-2015: Carbon Emissions From Land Use, Global Biogeochem. Cycles, 31, 456–472, https://doi.org/10.1002/2016GB005546, 2017.

Hauck, J., Gregor, L., Nissen, C., Patara, L., Hague, M., Mongwe, P., Bushinsky, S., Doney, S. C., Gruber, N., Le Quéré, C., Manizza, M., Mazloff, M., Monteiro, P. M. S., & Terhaar, J.: The Southern Ocean Carbon Cycle 1985–2018: Mean, Seasonal Cycle, Trends, and Storage. Global Biogeochemical Cycles, 37(11), e2023GB007848. https://doi.org/10.1029/2023GB007848, 2023b.

Huang, Z., Wang, J., Bing, L., Qiu, Y., Guo, R., Yu, Y., Ma, M., Niu, L., Tong, D., Andrew, R. M., Friedlingstein, P., Canadell, J. G., Xi, F., and Liu, Z.: Global carbon uptake of cement carbonation accounts 1930–2021, Earth Syst. Sci. Data, 15, 4947–4958, https://doi.org/10.5194/essd-15-4947-2023, 2023.

Hugelius, G., Bockheim, J. G., Camill, P., Elberling, B., Grosse, G., Harden, J. W., Johnson, K., Jorgenson, T., Koven, C. D., Kuhry, P., Michaelson, G., Mishra, U., Palmtag, J., Ping, C.-L., O'Donnell, J., Schirrmeister, L., Schuur, E. A. G., Sheng, Y., Smith, L. C., Strauss, J., and Yu, Z.: A new data set for estimating organic carbon storage to 3 m depth in soils of the northern circumpolar permafrost region, Earth Syst. Sci. Data, 5, 393–402, https://doi.org/10.5194/essd-5-393-2013, 2013.

Hurtt, G., Chini, L., Sahajpal, R., Frolking, S., Bodirsky, B. L., Calvin, K., Doelman, J., Fisk, J., Fujimori, S., Klein Goldewijk, K., Hasegawa, T., Havlik, P., Heinimann, A., Humpenöder, F., Jungclaus, J., Kaplan, J., Krisztin, T., Lawrence, D., Lawrence, P., Mertz, O., Pongratz, J., Popp, A., Riahi, K., Shevliakova, E., Stehfest, E., Thornton, P., van Vuuren, D., and Zhang, X.: input4MIPs.CMIP6.CMIP.UofMD.UofMD-landState-2-1-h, World Climate Research Programme [dataset], https://doi.org/10.22033/ESGF/input4MIPs.1127, 2017.

Hurtt, G. C., Chini, L. P., Frolking, S., Betts, R. A., Feddema, J., Fischer, G., Fisk, J. P., Hibbard, K., Houghton, R. A., Janetos, A., Jones, C. D., Kindermann, G., Kinoshita, T., Klein Goldewijk, K., Riahi, K., Shevliakova, E., Smith, S., Stehfest, E., Thomson, A., Thornton, P., van Vuuren, D. P., and Wang, Y. P.: Harmonization of land-use scenarios for the period 1500–2100: 600 years of global gridded annual land-use transitions, wood harvest, and resulting secondary lands, Climatic Change, 109, 117–161, https://doi.org/10.1007/s10584-011-0153-2, 2011.

Hurtt, G. C., Chini, L., Sahajpal, R., Frolking, S., Bodirsky, B. L., Calvin, K., Doelman, J. C., Fisk, J., Fujimori, S., Klein Goldewijk, K., Hasegawa, T., Havlik, P., Heinimann, A., Humpenöder, F., Jungclaus, J., Kaplan, J. O., Kennedy, J., Krisztin, T., Lawrence, D., Lawrence, P., Ma, L., Mertz, O., Pongratz, J., Popp, A., Poulter, B., Riahi, K., Shevliakova, E., Stehfest, E., Thornton, P., Tubiello, F. N., van Vuuren, D. P., and Zhang, X.: Harmonization of global land use change and management for the period 850–2100 (LUH2) for CMIP6, Geosci. Model Dev., 13, 5425–5464, https://doi.org/10.5194/gmd-13-5425-2020, 2020.

IEA/OECD: International Energy Agency/Organisation for Economic Cooperation and Development: CO2 emissions from fuel combustion, available at: https://webstore.iea.org/co2-emissions-from-fuel-combustion-2019-highlights, last access: 9 October 2024, 2019.

Deleted: November 2023

Iida, Y., Kojima, A., Takatani, Y., Nakano, T., Sugimoto, H., Midorikawa, T., and Ishii, M.: Trends in pCO2 and sea–air CO2 flux over the global open oceans for the last two decades, J Oceanogr, 71, 637–661, https://doi.org/10.1007/s10872-015-0306-4, 2015.

Ilyina, T., Six, K. D., Segschneider, J., Maier-Reimer, E., Li, H., and Núñez-Riboni, I.: Global ocean biogeochemistry model HAMOCC: Model architecture and performance as component of the MPI-Earth system model in different CMIP5 experimental realizations: The Model Hamocc within Mpi-Esm in Cmip5, J. Adv. Model. Earth Syst., 5, 287–315, https://doi.org/10.1029/2012MS000178, 2013.

Inness, A., Ades, M., Agustí-Panareda, A., Barré, J., Benedictow, A., Blechschmidt, A.-M., Dominguez, J. J., Engelen, R., Eskes, H., Flemming, J., Huijnen, V., Jones, L., Kipling, Z., Massart, S., Parrington, M., Peuch, V.-H., Razinger, M., Remy, S., Schulz, M., and Suttie, M.: The CAMS reanalysis of atmospheric composition, 19, 3515–3556, https://doi.org/10.5194/acp-19-3515-2019, 2019.

Ishii, M., and M., Kimoto: Reevaluation of historical ocean heat content variations with time-varying XBT and MBT depth bias corrections. Journal of Oceanography, 65(3), 287–299, 2009.

Jähne, B.: Air-Sea Gas Exchange, in: Encyclopedia of Ocean Sciences, Elsevier, 1–13, https://doi.org/10.1016/B978-0-12-409548-9.11613-6, 2019.

Jähne, B. and Haußecker, H.: Air-water gas exchange, Annu. Rev. Fluid Mech., 30, 443–468, https://doi.org/10.1146/annurev.fluid.30.1.443, 1998.

JODI: Joint Organisations Data Initiative, available at: https://www. jodidata.org, last access: 9 October 2024, 2022.

Deleted: November 2023

Jones, M.W., Andrew, R.M., Peters, G.P. et al., 2021: Gridded fossil CO2 emissions and related O2 combustion consistent with national inventories 1959–2018. Sci Data 8, 2. https://doi.org/10.1038/s41597-020-00779-6

Jones, M. W., Andrew, R. M., Peters, G. P., Janssens-Maenhout, G., De-Gol, A. J., Dou, X., Liu, Z., Pickers, P., Ciais, P., Patra, P. K., Chevallier, F., and Le Quéré, C.: Gridded fossil CO2 emissions and related O2 combustion consistent with national inventories 1959-2022, Zenodo [dataset], https://doi.org/10.5281/zenodo.8386803, 2023.

Jung, M., Reichstein, M., Schwalm, C. R., Huntingford, C., Sitch, S., Ahlström, A., Arneth, A., Camps-Valls, G., Ciais, P., Friedlingstein, P., Gans, F., Ichii, K., Jain, A. K., Kato, E., Papale, D., Poulter, B., Raduly, B., Rödenbeck, C., Tramontana, G., Viovy, N., Wang, Y.-P., Weber, U., Zaehle, S., and Zeng, N.: Compensatory water effects link yearly global land CO2 sink changes to temperature, Nature, 541, 516–520, https://doi.org/10.1038/nature20780, 2017.

Keeling, R. F. and Manning, A. C.: 5.15 - Studies of Recent Changes in Atmospheric O2 Content, in: Treatise on Geochemistry (Second Edition), edited by: Holland, H. D. and Turekian, K. K., Elsevier, Oxford, 385–404, https://doi.org/10.1016/B978-0-08-095975-7.00420-4, 2014.

Klein Goldewijk, K., Beusen, A., Doelman, J., and Stehfest, E.: Anthropogenic land use estimates for the Holocene – HYDE 3.2, Earth Syst. Sci. Data, 9, 927–953, https://doi.org/10.5194/essd-9-927-2017, 2017a.

Klein Goldewijk, K., Dekker, S. C., and van Zanden, J. L.: Per-capita estimations of long-term historical land use and the consequences for global change research, J. Land Use Sci., 12, 313–337, https://doi.org/10.1080/1747423X.2017.1354938, 2017b.

Knauer, J., Zaehle, S., Medlyn, B. E., Reichstein, M., Williams, C. A., Migliavacca, M., De Kauwe, M. G., Werner, C., Keitel, C., Kolari, P., Limousin, J., and Linderson, M.: Towards physiologically meaningful water-use efficiency estimates from eddy covariance data, Global Change Biology, 24, 694–710, https://doi.org/10.1111/gcb.13893, 2018.

Kobayashi, S., Ota, Y., Harada, Y., Ebita, A., Moriya, M., Onoda, H., Onogi, K., Kamahori, H., Kobayashi, C., Endo, H., Miyaoka, K., and Takahashi, K.: The JRA-55 Reanalysis: General Specifications and Basic Characteristics, Journal of the Meteorological Society of Japan, 93, 5–48, https://doi.org/10.2151/jmsj.2015-001, 2015.

Lamboll, R. D., Jones, C. D., Skeie, R. B., Fiedler, S., Samset, B. H., Gillett, N. P., Rogelj, J., Forster, P. M.: Modifying emissions scenario projections to account for the effects of COVID-19: protocol for CovidMIP, Geosci. Model Dev., 14, 3683–3695, https://doi.org/10.5194/gmd-14-3683-2021, 2021.

Landschützer, P., Gruber, N., Bakker, D. C. E., and Schuster, U.: Recent variability of the global ocean carbon sink, Global Biogeochem. Cycles, 28, 927–949, https://doi.org/10.1002/2014GB004853, 2014.

Landschützer, P., Laruelle, G. G., Roobaert, A., and Regnier, P.: A uniform pCO2 climatology combining open and coastal oceans, 12, 2537–2553, https://doi.org/10.5194/essd-12-2537-2020, 2020.

Lasslop, G., Reichstein, M., Papale, D., Richardson, A. D., Arneth, A., Barr, A., Stoy, P., and Wohlfahrt, G.: Separation of net ecosystem exchange into assimilation and respiration using a light response curve approach: critical issues and global evaluation: Separation of NEE into GPP and RECO, Glob. Change Biol., 16, 187–208, https://doi.org/10.1111/j.1365-2486.2009.02041.x, 2010.

Lauvset, S. K., Key, R. M., Olsen, A., van Heuven, S., Velo, A., Lin, X., Schirnick, C., Kozyr, A., Tanhua, T., Hoppema, M., Jutterström, S., Steinfeldt, R., Jeansson, E., Ishii, M., Perez, F. F., Suzuki, T., and Watelet, S.: A new global interior ocean mapped climatology: the 1° × 1° GLODAP version 2, Earth System Science Data, 8, 325–340, https://doi.org/10.5194/essd-8-325-2016, 2016.

Lauvset, S. K., Currie, K., Metzl, N., Nakaoka, S., Bakker, D., Sullivan, K., Sutton, A., O'Brien, K., and Olsen, A.: SOCAT quality control cookbook - for SOCAT version 7 and onwards, available at https://socat.info/wp-content/uploads/2020/12/2018_SOCAT_QC_Cookbook_final_with-v2021-contact-details.pdf, last access: 25 October 2024, 2018.

Li, H., Ilyina, T., Loughran, T., Spring, A., and Pongratz, J.: Reconstructions and predictions of the global carbon budget with an emission-driven Earth system model, Earth Syst. Dyn., 14, 101–119, https://doi.org/10.5194/esd-14-101-2023, 2023.

Liu, Z., Ciais, P., Deng, Z., Davis, S. J., Zheng, B., Wang, Y., Cui, D., Zhu, B., Dou, X., Ke, P., Sun, T., Guo, R., Zhong, H., Boucher, O., Bréon, F.-M., Lu, C., Guo, R., Xue, J., Boucher, E., Tanaka, K., and Chevallier, F.: Carbon Monitor, a near-real-time daily dataset of global CO2 emission from fossil fuel and cement production, Sci Data, 7, 392, https://doi.org/10.1038/s41597-020-00708-7, 2020a.

Liu, Z., Ciais, P., Deng, Z., Lei, R. Davis, S. J., Feng, S., Zheng, B., Cui, D., Dou, X., Zhu, B., Guo, R., Ke, P., Sun, T., Lu, C., He, P., Wang, Y., Yue, X., Wang, Y., Lei, Y., Zhou, H., Cai, Z., Wu, Y., Guo, R., Han, T., Xue, J., Boucher, O., Boucher, E., Chevallier, F., Tanaka, K., Wei, Y., Zhong, H., Kang, C., Zhang, N., Chen, B., Xi, F., Liu, M., Bréon, F.-M.,

Deleted: .,

Lu, Y., Zhang, Q., Guan, D., Gong, P., Kammen, D. M., He, K., and Schellnhuber, H. J.: Near-real-time monitoring of global CO2 emissions reveals the effects of the COVID-19 pandemic, Nat Commun, 11, 5172, https://doi.org/10.1038/s41467-020-18922-7, 2020b.

Ma, L., Hurtt, G. C., Chini, L. P., Sahajpal, R., Pongratz, J., Frolking, S., Stehfest, E., Klein Goldewijk, K., O'Leary, D., and Doelman, J. C.: Global rules for translating land-use change (LUH2) to land-cover change for CMIP6 using GLM2, Geosci. Model Dev., 13, 3203–3220, https://doi.org/10.5194/gmd-13-3203-2020, 2020.

Maki, T., Ikegami, M., Fujita, T., Hirahara, T., Yamada, K., Mori, K., Takeuchi, A., Tsutsumi, Y., Suda, K., and Conway, T. J.: New technique to analyse global distributions of CO2 concentrations and fluxes from non-processed observational data, Tellus B., 62, 797–809, https://doi.org/10.1111/j.1600-0889.2010.00488.x, 2010.

Manning, A. and Keeling, R. F.: Global oceanic and land biotic carbon sinks from the Scripps atmospheric oxygen flask sampling network, Tellus B Chem. Phys. Meteorol., 58, 95–116, https://doi.org/10.1111/j.1600-0889.2006.00175.x, 2006.

Marland, G.: Uncertainties in Accounting for CO 2 From Fossil Fuels, J. Indust. Ecol., 12, 136–139, https://doi.org/10.1111/j.1530-9290.2008.00014.x, 2008.

Marland, G., Hamal, K., and Jonas, M.: How Uncertain Are Estimates of CO2 Emissions?, J. Indust. Ecol., 13, 4–7, https://doi.org/10.1111/j.1530-9290.2009.00108.x, 2009.

Martens, B., Miralles, D. G., Lievens, H., Van Der Schalie, R., De Jeu, R. A. M., Fernández-Prieto, D., Beck, H. E., Dorigo, W. A., and Verhoest, N. E. C.: GLEAM v3: satellite-based land evaporation and root-zone soil moisture, Geosci. Model Dev., 10, 1903–1925, https://doi.org/10.5194/gmd-10-1903-2017, 2017.

Mauritsen, T. et al.: Developments in the MPI-M Earth System Model version 1.2 (MPI-ESM1. 2) and its response to increasing CO2. Journal of Advances in Modeling Earth Systems, 11 (4), 998–1038, 2019.

McNeil, B. I.: Anthropogenic CO2 Uptake by the Ocean Based on the Global Chlorofluorocarbon Data Set, Science, 299, 235–239, https://doi.org/10.1126/science.1077429, 2003.

Mikaloff Fletcher, S. E., Gruber, N., Jacobson, A. R., Doney, S. C., Dutkiewicz, S., Gerber, M., Follows, M., Joos, F., Lindsay, K., Menemenlis, D., Mouchet, A., Müller, S. A., and Sarmiento, J. L.: Inverse estimates of anthropogenic CO2 uptake, transport, and storage by the ocean, Glob. Biogeochem. Cycles, 20, GB2002, https://doi.org/10.1029/2005GB002530, 2006.

Miralles, D. G., Holmes, T. R. H., De Jeu, R. A. M., Gash, J. H., Meesters, A. G. C. A., and Dolman, A. J.: Global land-surface evaporation estimated from satellite-based observations, Hydrol. Earth Syst. Sci., 15, 453–469, https://doi.org/10.5194/hess-15-453-2011, 2011.

Moat B.I.; Smeed D.A.; Rayner D.; Johns W.E.; Smith, R.; Volkov, D.; Elipot S.; Petit T.; Kajtar J.; Baringer M. O.; and Collins, J.: Atlantic meridional overturning circulation observed by the RAPID-MOCHA-WBTS (RAPID-Meridional Overturning Circulation and Heatflux Array-Western Boundary Time Series) array at 26N from 2004 to 2023 (v2023.1), British Oceanographic Data Centre - Natural Environment Research Council, UK. doi: 10.5285/223b34a3-2dc5-c945-e063-7086abc0f274, 2024.

Mu, Q., Zhao, M., and Running, S. W.: Improvements to a MODIS global terrestrial evapotranspiration algorithm, Remote Sensing of Environment, 115, 1781–1800, https://doi.org/10.1016/j.rse.2011.02.019, 2011.

Müller, J. and Joos, F.: Global peatland area and carbon dynamics from the Last Glacial Maximum to the present – a process-based model investigation, Biogeosciences, 17, 5285–5308, https://doi.org/10.5194/bg-17-5285-2020, 2020.

Müller, J. and Joos, F.: Committed and projected future changes in global peatlands – continued transient model simulations since the Last Glacial Maximum, Biogeosciences, 18, 3657–3687, https://doi.org/10.5194/bg-18-3657-2021, 2021.

Myneni, R. B., Ramakrishna, R., Nemani, R., and Running, S. W.: Estimation of global leaf area index and absorbed par using radiative transfer models, IEEE Trans. Geosci. Remote Sensing, 35, 1380–1393, https://doi.org/10.1109/36.649788, 1997.

Naegler, T.: Reconciliation of excess 14C-constrained global CO2 piston velocity estimates, Tellus B., 61, 372–384, https://doi.org/10.1111/j.1600-0889.2008.00408.x, 2009.

Nakamura, T., Yamazaki, K., Iwamoto, K., Honda, M., Miyoshi, Y., Ogawa, Y., and Ukita, J.: A negative phase shift of the winter AO/NAO due to the recent Arctic sea-ice reduction in late autumn, J. Geophys. Res. Atmos., 120, 3209–3227, https://doi.org/10.1002/2014JD022848, 2015.

Narayanan, B., Aguiar, A., and McDougall, R.: Global Trade, Assistance, and Production: The GTAP 9 Data Base, Cent. Glob. Trade Anal. Purdue Univ., available at: https:// www.gtap.agecon.purdue.edu/databases/v9/default.asp, last access: 9 October 2024, 2015.

Deleted: November 2023

Nightingale, P. D., Liss, P. S., and Schlosser, P.: Measurements of air-sea gas transfer during an open ocean algal bloom, Geophys. Res. Lett., 27, 2117–2120, https://doi.org/10.1029/2000GL011541, 2000.

Orr, J. C., Najjar, R. G., Aumont, O., Bopp, L., Bullister, J. L., Danabasoglu, G., Doney, S. C., Dunne, J. P., Dutay, J.-C., Graven, H., Griffies, S. M., John, J. G., Joos, F., Levin, I., Lindsay, K., Matear, R. J., McKinley, G. A., Mouchet, A., Oschlies, A., Romanou, A., Schlitzer, R., Tagliabue, A., Tanhua, T., and Yool, A.: Biogeochemical protocols and diagnostics for the CMIP6 Ocean Model Intercomparison Project (OMIP), 10, 2169–2199, https://doi.org/10.5194/gmd-10-2169-2017, 2017.

Ortega, P., E. Guilyardi, D. Swingedouw, J. Mignot, and S. Nguyen: Reconstructing extreme amoc events through nudging of the ocean surface: a perfect model approach. Climate Dynamics, 49 (9), 3425–3441, 2017.

Peters, G. P., Andrew, R., and Lennox, J.: Constructing an environmentally-extended multi-regional input–output table using the GTAP database, Economic Systems Research, 23, 131–152, https://doi.org/10.1080/09535314.2011.563234, 2011b.

Peters, G. P., Davis, S. J., and Andrew, R.: A synthesis of carbon in international trade, Biogeosciences, 9, 3247–3276, https://doi.org/10.5194/bg-9-3247-2012, 2012b.

Pongratz, J., Smith, S. M., Schwingshackl, C., Dayathilake, L., Gasser, T., Grassi, G. and Pilli, R.: Chapter 7: Current levels of CDR. in The State of Carbon Dioxide Removal 2024 – 2nd Edition, https://doi.org/10.17605/OSF.IOZXSKB, 2024.

Potapov, P., Hansen, M. C., Laestadius, L., Turubanova, S., Yaroshenko, A., Thies, C., Smith, W., Zhuravleva, I., Komarova, A., Minnemeyer, S., and Esipova, E.: The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013, Sci. Adv., 3, e1600821, https://doi.org/10.1126/sciadv.1600821, 2017.

Poulter, B., Freeborn, P. H., Jolly, W. M., and Varner, J. M.: COVID-19 lockdowns drive decline in active fires in southeastern United States, PNAS, 118, e2105666118, https://doi.org/10.1073/pnas.2105666118, 2021.

Prather, M.: Interactive comment on “Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: a multi-model analysis” by F. Joos et al., Atmospheric Chem. Phys. Discuss., 12, C8465, 2012.

Qin, Z., Zhu, Y., Canadell, J.G., Chen, M., Li, T., Mishra, U. and Yuan, W.: Global spatially explicit carbon emissions from land-use change over the past six decades (1961–2020). One Earth, 7(5), pp.835-847, 2024.

Qiu, C., Ciais, P., Zhu, D., Guenet, B., Peng, S., Petrescu, A. M. R., Lauerwald, R., Makowski, D., Gallego-Sala, A. V., Charman, D. J., and Brewer, S. C.: Large historical carbon emissions from cultivated northern peatlands, Sci. Adv., 7, eabf1332, https://doi.org/10.1126/sciadv.abf1332, 2021.

Raich, J.W., Potter, C.S. and Bhagawati, D.: Interannual variability in global soil respiration, 1980–94. Global Change Biology, 8(8), pp.800-812, 2002.

Rayner, N. A., Parker, D. E., Horton, E. B., Folland, C. K., Alexander, L. V., Rowell, D. P., Kent, E. C., and Kaplan, A.: Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century, Journal of Geophysical Research: Atmospheres, 108, https://doi.org/10.1029/2002JD002670, 2003.

Rayner, P. J., Enting, I. G., Francey, R. J., and Langenfelds, R.: Reconstructing the recent carbon cycle from atmospheric CO2, δ13C and O2/N2 observations*, Tellus B, 51, 213–232, https://doi.org/10.1034/j.1600-0889.1999.t01-1-00008.x, 1999.

Regnier, P., Friedlingstein, P., Ciais, P., Mackenzie, F. T., Gruber, N., Janssens, I. A., Laruelle, G. G., Lauerwald, R., Luyssaert, S., Andersson, A. J., Arndt, S., Arnosti, C., Borges, A. V., Dale, A. W., Gallego-Sala, A., Goddéris, Y., Goossens, N., Hartmann, J., Heinze, C., Ilyina, T., Joos, F., LaRowe, D. E., Leifeld, J., Meysman, F. J. R., Munhoven, G., Raymond, P. A., Spahni, R., Suntharalingam, P., and Thullner, M.: Anthropogenic perturbation of the carbon fluxes from land to ocean, Nature Geosci, 6, 597–607, https://doi.org/10.1038/ngeo1830, 2013.

Reichstein, M., Papale, D., Valentini, R., Aubinet, M., Bernhofer, C., Knohl, A., Laurila, T., Lindroth, A., Moors, E., Pilegaard, K., and Seufert, G.: Determinants of terrestrial ecosystem carbon balance inferred from European eddy covariance flux sites, Geophys. Res. Lett., 34, L01402, https://doi.org/10.1029/2006GL027880, 2007.

Rhein, M., Rintoul, S. R., Aoki, S., Campos, E., Chambers, D., Feely, R. A., Gulev, S., Johnson, G. C., Josey, S. A., Kostianoy, A., Mauritzen, C., Roemmich, D., and Talley, L. D.: Observations: Ocean, in: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P. M. (eds.)], Cambridge University Press, 255–316, ISBN: 9781107057991, 2013.

Rödenbeck, C., Bakker, D. C. E., Gruber, N., Iida, Y., Jacobson, A. R., Jones, S., Landschützer, P., Metzl, N., Nakaoka, S., Olsen, A., Park, G.-H., Peylin, P., Rodgers, K. B., Sasse, T. P., Schuster, U., Shutler, J. D., Valsala, V., Wanninkhof, R., and Zeng, J.: Data-based estimates of the ocean carbon sink variability – first results of the Surface Ocean CO2 Mapping intercomparison (SOCOM), Biogeosciences, 12, 7251–7278, https://doi.org/10.5194/bg-12-7251-2015, 2015.

Roobaert, A., Laruelle, G. G., Landschützer, P., and Regnier, P.: Uncertainty in the global oceanic CO2 uptake induced by wind forcing: quantification and spatial analysis, 15, 1701–1720, https://doi.org/10.5194/bg-15-1701-2018, 2018.

Rypdal, K., Paciornik, N., Eggleston, S., Goodwin, J., Irving, W., Penman, J., and Woodfield, M.: Volume 1: Introduction to the 2006 Guidelines in: 2006 IPCC guidelines for national greenhouse gas inventories, available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol1.html, last access: 9 October 2024, 2006.

Saatchi, S. S., Harris, N. L., Brown, S., Lefsky, M., Mitchard, E. T. A., Salas, W., Zutta, B. R., Buermann, W., Lewis, S. L., Hagen, S., Petrova, S., White, L., Silman, M., and Morel, A.: Benchmark map of forest carbon stocks in tropical regions across three continents, Proceedings of the National Academy of Sciences, 108, 9899–9904, https://doi.org/10.1073/pnas.1019576108, 2011.

Sarmiento, J. L., Orr, J. C., and Siegenthaler, U.: A perturbation simulation of CO2 uptake in an ocean general circulation model, J. Geophys. Res.-Oceans., 97, 3621–3645, https://doi.org/10.1029/91JC02849, 1992.

Sato, M., Hansen, J. E., McCormick, M. P., and Pollack, J. B.: Stratospheric aerosol optical depths, 1850–1990, Geophys. Res.-Atmos., 98, 22987–22994, https://doi.org/10.1029/93JD02553, 1993.

Saunois, M., Stavert, A. R., Poulter, B., Bousquet, P., Canadell, J. G., Jackson, R. B., Raymond, P. A., Dlugokencky, E. J., Houweling, S., Patra, P. K., Ciais, P., Arora, V. K., Bastviken, D., Bergamaschi, P., Blake, D. R., Brailsford, G., Bruhwiler, L., Carlson, K. M., Carrol, M., Castaldi, S., Chandra, N., Crevoisier, C., Crill, P. M., Covey, K., Curry, C. L., Etiope, G., Frankenberg, C., Gedney, N., Hegglin, M. I., Höglund-Isaksson, L., Hugelius, G., Ishizawa, M., Ito, A., Janssens-Maenhout, G., Jensen, K. M., Joos, F., Kleinen, T., Krummel, P. B., Langenfelds, R. L., Laruelle, G. G., Liu, L., Machida, T., Maksyutov, S., McDonald, K. C., McNorton, J., Miller, P. A., Melton, J. R., Morino, I., Müller, J., Murguia-Flores, F., Naik, V., Niwa, Y., Noce, S., O'Doherty, S., Parker, R. J., Peng, C., Peng, S., Peters, G. P., Prigent, C., Prinn, R., Ramonet, M., Regnier, P., Riley, W. J., Rosentreter, J. A., Segers, A., Simpson, I. J., Shi, H., Smith, S. J., Steele, L. P., Thornton, B. F., Tian, H., Tohjima, Y., Tubiello, F. N., Tsuruta, A., Viovy, N., Voulgarakis, A., Weber, T. S., van Weele, M., van der Werf, G. R., Weiss, R. F., Worthy, D., Wunch, D., Yin, Y., Yoshida, Y., Zhang, W., Zhang, Z., Zhao, Y., Zheng, B., Zhu, Q., Zhu, Q., and Zhuang, Q.: The Global Methane Budget 2000–2017, Earth Syst. Sci. Data, 12, 1561–1623, https://doi.org/10.5194/essd-12-1561-2020, 2020.

Schuldt, K. N., Mund, J., Aalto, T., Abshire, J. B., Aikin, K., Allen, G., Andrews, A., Apadula, F., Arnold, S., Baier, B., Bakwin, P., Bartyzel, J., Bentz, G., Bergamaschi, P., Beyersdorf, A., Biermann, T., Biraud, S. C., Blanc, P.-E., Boenisch, H., Bowling, D., Brailsford, G., Brand, W. A., Brunner, D., Bui, T. P., Bäni, L., Calzolari, F., Chang, C. S., Chen, H., Chen, G., Chmura, L., Clark, S., Climadat, S., Colomb, A., Commane, R., Conen, F., Conil, S., Couret, C., Cristofanelli, P., Cuevas, E., Curcoll, R., Daube, B., Davis, K. J., De Mazière, M., De Wekker, S., Dean-Day, J. M., Della Coletta, J., Delmotte, M., Di Iorio, T., DiGangi, E., DiGangi, J. P., Elkins, J. W., Elsasser, M., Emmenegger, L., Fang, S., Fischer, M. L., Forster, G., France, J., Frumau, A., Fuente-Lastra, M., Galkowski, M., Gatti, L. V., Gehrlein, T., Gerbig, C., Gheusi, F., Gloor, E., Goto, D., Griffis, T., Hammer, S., Hanisco, T. F., Hanson, C., Haszpra, L., Hatakka, J., Heimann, M., Heliasz, M., Heltai, D., Henne, S., Hensen, A., Hermans, C., Hermansen, O., Hintsa, E., Hoheisel, A., Holst, J., Iraci, L. T., Ivakhov, V., Jaffe, D. A., Jordan, A., Joubert, W., Karion, A., Kawa, S. R., Kazan, V., Keeling, R. F., Keronen, P., Kim, J., Klausen, J., Kneuer, T., Kolari, P., Kominkova, K., Kort, E., Kozlova, E., Krummel, P. B., Kubistin, D., Kulawik, S. S., Kumps, N., Labuschagne, C., Lam, D. H., Lan, X., Langenfelds, R. L., Lanza, A., Laurent, O., Laurila, T., Lauvaux, T., Lavric, J., Law, B. E., Lee, J., Lehner, I., Lehtinen, K., Leppert, R., Leskinen, A., Leuenberger, M., Leung, W. H., Levin, I., Levula, J., Lin, J., Lindauer,

Deleted: November 2023

Deleted: Santoro, M. and Cartus, O.: ESA Biomass Climate Change Initiative (Biomass_cci): Global datasets of forest above-ground biomass for the years 2010, 2017 and 2018, v3, https://doi.org/10.5285/5F331C418E9F4935B8EB1B836F8A91B8, 2021.¶

Deleted: Kenneth…. N., John …und, Ingrid T. Luijkx, Tuula…., Aalto, James B….., Abshire, Ken…. B., Aikin, Arlyn…., Allen, G., Andrews, Shuji Aoki, Francesco…., Apadula, Bianca…., Arnold, S., Baier, Peter…., Bakwin, Jakub…., Bartyzel, Gilles…., Bentz, Peter…., Bergamaschi, Andreas…., Beyersdorf, Tobias…., Biermann, Sebastien C….., Biraud, Harald…. C., Blanc, P.-E., Boenisch, David…., Bowling, Gordon…., Brailsford, Willi A….., Brand, Huilin…. A., Brunner, D., Bui, T. P., Bäni, L., Calzolari, F., Chang, C. S., Chen, Gao…., Chen, Lukasz…., Chmura, Shane…., Clark, Sites…., Climadat, Aurelie…., Colomb, Roisin…., Commane, Sébastien…., Conen, F., Cedric…., Couret, Adam Cox, Paolo…., Cristofanelli, Emilio…., Cuevas, Roger…., Curcoll, Bruce…., Daube, Kenneth…., Davis, Martine…. J., De Mazière, Stephan…., De Wekker, Julian…., Dean-Day, J. M., Della Coletta, Marc…., Delmotte, Joshua P….., Di Iorio, T., DiGangi, Ed Dlugokencky, James W. …., DiGangi, J. P., Elkins, Lukas…. W., Elsasser, M., Emmenegger, Shuangxi…., Fang, Marc L….., Fischer, Grant…. L., Forster, Arnoud…., France, J., Frumau, Michal…., Fuente-Lastra, M., Galkowski, Luciana V….., Gatti, Torsten…. V., Gehrlein, Christoph…., Gerbig, Francois…., Gheusi, Emanuel…., Gloor, Vanessa Gomez-Trueba, Daisuke…., Goto, Tim…., Griffis, Samuel…., Hammer, Chad…., Hanisco, T. F., Hanson, László…., Haszpra, Juha…., Hatakka, Martin…., Heimann, Michal…., Heliasz, Daniela…., Heltai, Arjan…., Henne, S., Hensen, Hermanssen, Eric…., Hermans, C., Hermansen, O., Hintsa, Antje…., Hoheisel, Jutta…., Holst, Viktor…., Iraci, L. T., Ivakhov, Dan…., Jaffe, Armin…. A., Jordan, Warren…., Joubert, Anna…., Karion, Stephan R….., Kawa, Victor…. R., Kazan, Ralph…., Keeling, Petri…. F., Keronen, Jooil…., Kim, Tobias…., Klausen, J., Kneuer, Pasi…., Kolari, Katerina…., Kominkova, Eric…., Kort, Elena…., Kozlova, Paul…., Krummel, Dagmar…. B., Kubistin, Casper…., Kulawik, S. S., Kumps, N., Labuschagne, David H….., Lam, Xin…. H., Lan, Ray…., Langenfelds, Olivier…. L., Lanza, A., Laurent, Tuomas…., Laurila, Thomas…., Lauvaux, Jost…., Lavric, Bev…., Law, Olivia S….. E., Lee, John Lee, Irene…., Lehner, Kari…., Lehtinen, Reimo…., Leppert, Ari…., Leskinen, Markus…., Leuenberger, Ingeborg…., Leung, W. H., Levin, Janne…., Levula, John…., Lin, Matthias… ... [1394]

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M., Lindroth, A., Loh, Z. M., Lopez, M., Lunder, C. R., Löfvenius, M. O., Machida, T., Mammarella, I., Manca, G., Manning, A., Manning, A., Marek, M. V., Marklund, P., Marrero, J. E., Martin, D., Martin, M. Y., Martins, G. A., Matsueda, H., McKain, K., Meijer, H., Meinhardt, F., Merchant, L., Metzger, J.-M., Mihalopoulos, N., Miles, N. L., Miller, J. B., Miller, C. E., Mitchell, L., Monteiro, V., Montzka, S., Moore, F., Moossen, H., Morgan, E., Morgui, J.-A., Morimoto, S., Munger, J. W., Munro, D., Mutuku, M., Myhre, C. L., Mölder, M., Müller-Williams, J., Necki, J., Newman, S., Nichol, S., Nisbet, E., Niwa, Y., Njiru, D. M., Noe, S. M., Nojiri, Y., O'Doherty, S., Obersteiner, F., Paplawsky, B., Parworth, C. L., Peischl, J., Peltola, O., Peters, W., Philippon, C., Piacentino, S., Pichon, J. M., Pickers, P., Piper, S., Pitt, J., Plass-Dülmer, C., Platt, S. M., Prinzivalli, S., Ramonet, M., Ramos, R., Reyes-Sanchez, E., Richardson, S. J., Rigouleau, L.-J., Riris, H., Rivas, P. P., Rothe, M., Roulet, Y.-A., Ryerson, T., Ryoo, J.-M., Sargent, M., Sasakawa, M., Scheeren, B., Schmidt, M., Schuck, T., Schumacher, M., Seibel, J., Seifert, T., Sha, M. K., Shepson, P., Shook, M., Sloop, C. D., Smith, P. D., Spain, G., St. Clair, J. M., Steger, D., Steinbacher, M., Stephens, B., Sweeney, C., Sørensen, L. L., Taipale, R., Takatsuji, S., Tans, P., Thoning, K., Timas, H., Torn, M., Trisolino, P., Turnbull, J., Vermeulen, A., Viner, B., Vitkova, G., Walker, S., Watson, A., Weiss, R., Weyrauch, D., Wofsy, S. C., Worsey, J., Worthy, D., Xueref-Remy, I., Yates, E. L., Young, D., Yver-Kwok, C., Zaehle, S., Zahn, A., Zellweger, C., Zimnoch, M., de Souza, R. A., di Sarra, A. G., van Dinther, D., and van den Bulk, P. (2023) Multi-laboratory compilation of atmospheric carbon dioxide data for the period 1957-2022; obspack_co2_1_GLOBALVIEWplus_v9.0_2023-09-09; NOAA Earth System Research Laboratory, Global Monitoring Laboratory. http://doi.org/10.25925/20230801.

Schuldt, K. N., Jacobson, A. R., Aalto, T., Andrews, A., Apadula, F., Arnold, S., Bakwin, P., Bartyzel, J., Bergamaschi, P., Biermann, T., Biraud, S. C., Blanc, P.-E., Bäni, L., Calzolari, F., Chen, H., Chmura, L., Colomb, A., Condori, L., Conen, F., Conil, S., Couret, C., Cristofanelli, P., Cuevas, E., De Mazière, M., De Wekker, S., Della Coletta, J., Delmotte, M., Di Iorio, T., Elsasser, M., Emmenegger, L., Fischer, M. L., Forster, G., Frumau, A., Fuente-Lastra, M., Galkowski, M., Gheusi, F., Hammer, S., Hatakka, J., Heliasz, M., Heltai, D., Hensen, A., Hermans, C., Hermansen, O., Hoheisel, A., Holst, J., Jaffe, D. A., Karion, A., Kazan, V., Keronen, P., Kneuer, T., Kolari, P., Kominkova, K., Krummel, P. B., Kubistin, D., Kumps, N., Lan, X., Langenfelds, R. L., Lanza, A., Laurent, O., Laurila, T., Lee, J., Lehner, I., Lehtinen, K., Leskinen, A., Leuenberger, M., Levin, I., Levula, J., Lindauer, M., Lindroth, A., Loh, Z. M., Lopez, M., Lunder, C. R., Löfvenius, M. O., Mammarella, I., Manca, G., Manning, A., Manning, A., Marek, M. V., Marklund, P., McKain, K., Meijer, H., Meinhardt, F., Metzger, J.-M., Miller, C. E., Miller, J. B., Myhre, C. L., Mölder, M., Müller-Williams, J., Necki, J., O'Doherty, S., Peltola, O., Philippon, C., Piacentino, S., Pichon, J. M., Pickers, P., Pitt, J., Plass-Dülmer, C., Platt, S. M., Ramonet, M., Ramos, R., Reyes-Sanchez, E., Rigouleau, L.-J., Rivas, P. P., Roulet, Y.-A., Scheeren, B., Schmidt, M., Schumacher, M., Sha, M. K., Sloop, C. D., Smith, P. D., Steger, D., Steinbacher, M., Sweeney, C., Sørensen, L. L., Taipale, R., Tans, P., Thoning, K., Trisolino, P., Turnbull, J., Vermeulen, A., Viner, B., Vitkova, G., Weyrauch, D., Worthy, D., Xueref-Remy, I., Young, D., Yver-Kwok, C., Zimnoch, M., di Sarra, A. G., van Dinther, D., and van den Bulk, P. (2024) Multi-laboratory compilation of atmospheric carbon dioxide data for the period 2023-2024; obspack_co2_1_NRT_v9.2_2024-03-25; NOAA Earth System Research Laboratory, Global Monitoring Laboratory. http://doi.org/10.25925/20240215.

Smith, T. M., Reynolds, R. W., Peterson, T. C., & Lawrimore, J.: Improvements to NOAA's historical merged land–ocean surface temperature analysis (1880–2006). Journal of climate, 21(10), 2283-2296, 2008.

Sospedra-Alfonso, R., W. J. Merryfield, G. J. Boer, V. V. Kharin, W.-S. Lee, C. Seiler, and J. R. Christian: Decadal climate predictions with the canadian earth system model version 5 (canesm5). Geoscientific Model Development, 14 (11), 6863–6891, 2021.

Souza, C. M., Z. Shimbo, J., Rosa, M. R., Parente, L. L., A. Alencar, A., Rudorff, B. F. T., Hasenack, H., Matsumoto, M., G. Ferreira, L., Souza-Filho, P. W. M., de Oliveira, S. W., Rocha, W. F., Fonseca, A. V., Marques, C. B., Diniz, C. G., Costa, D., Monteiro, D., Rosa, E. R., Vélez-Martin, E., Weber, E. J., Lenti, F. E. B., Paternost, F. F., Pareyn, F. G. C., Siqueira, J. V., Viera, J. L., Neto, L. C. F., Saraiva, M. M., Sales, M. H., Salgado, M. P. G., Vasconcelos, R., Galano, S., Mesquita, V. V., and Azevedo, T.: Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine, Remote Sens., 12, 2735, https://doi.org/10.3390/rs12172735, 2020.

Deleted: Zoe…., Lindroth, A., Loh, Morgan…. M., Lopez, Chris R….., Lunder, Toshinobu…. R., Löfvenius, M. O., Machida, Ivan…., Mammarella, Giovanni…., Manca, Alistair…., Manning, Andrew…., Manning, Michal V….., Marek, Melissa Y….. V., Marklund, P., Marrero, J. E., Martin, D., Martin, Giordane A….. Y., Martins, Hidekazu…. A., Matsueda, Kathryn…., McKain, Harro…., Meijer, Frank…., Meinhardt, Lynne…., Merchant, N….., Metzger, J.-M., Mihalopoulos, Natasha…., Miles, John B….. L., Miller, Charles E….. B., Miller, Logan…. E., Mitchell, Stephen…., Monteiro, V., Montzka, Fred…., Moore, Heiko…., Moossen, Eric…., Morgan, Josep-Anton…., Morgui, Shinji….-A., Morimoto, Bill…., Munger, David…. W., Munro, Cathrine L….., Mutuku, M., Myhre, Meelis…. Mölder, Jennifer…., Müller-Williams, Jaroslaw…., Necki, Sally…., Newman, Sylvia…., Nichol, Yosuke…., Nisbet, E., Niwa, Simon O\'Doherty, Florian…., Njiru, D. M., Noe, S. M., Nojiri, Y., O'Doherty, S., Obersteiner, Bill…., Paplawsky, Jeff…., Parworth, C. L., Peischl, Olli…., Peltola, Salvatore…., Peters, W., Philippon, C., Piacentino, Jean M….., Pichon, Steve…. M., Pickers, P., Piper, Joseph…., Pitt, Christian…., Plass-Duelmer, Stephen M….ülmer, C., Platt, Steve…. M., Prinzivalli, Michel…., Ramonet, Ramon…., Ramos, Enrique…., Reyes-Sanchez, Scott…., Richardson, Haris…. J., Rigouleau, L.-J., Riris, Pedro P….., Rivas, Michael…. P., Rothe, Thomas…., Roulet, Y.-A., Ryerson, Kazuyuki Saito, Maryann…., Ryoo, J.-M., Sargent, Motoki…., Sasakawa, Bert…., Scheeren, Martina…., Schmidt, Tanja…., Schuck, Marcus…., Schumacher, Thomas…., Seibel, J., Seifert, Mahesh K….., Sha, Paul…. K., Shepson, Michael…., Shook, Christopher D….., Sloop, Paul…. D., Smith, Martin…. D., Spain, G., St. Clair, J. M., Steger, D., Steinbacher, Britton…., Stephens, Colm ... [1395]

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Swart, N. C. et al.: The Canadian Earth System Model version 5 (CanESM5. 0.3). Geoscientific Model Development, 12 (11), 4823–4873, 2019.

Tang, X., Fan, S., Zhang, W., Gao, S., Chen, G. and Shi, L.: Global variability in belowground autotrophic respiration in terrestrial ecosystems. Earth System Science Data, 11(4), pp.1839-1852, 2019.

Tang, X., Fan, S., Du, M., Zhang, W., Gao, S., Liu, S., Chen, G., Yu, Z. and Yang, W., 2020. Spatial and temporal patterns of global soil heterotrophic respiration in terrestrial ecosystems. Earth System Science Data, 12(2), pp.1037-1051.

Tatebe, H. et al.: The initialization of the MIROC climate models with hydrographic data assimilation for decadal prediction. Journal of Meteorological Society of Japan, 90A, 275–294, 2012.

Thomason, L. W., Ernest, N., Millán, L., Rieger, L., Bourassa, A., Vernier, J.-P., Manney, G., Luo, B., Arfeuille, F., and Peter, T.: A global space-based stratospheric aerosol climatology: 1979–2016, 10, 469–492, https://doi.org/10.5194/essd-10-469-2018, 2018.

Thurner, M., Beer, C., Santoro, M., Carvalhais, N., Wutzler, T., Schepaschenko, D., Shvidenko, A., Kompter, E., Ahrens, B., Levick, S. R., and Schmullius, C.: Carbon stock and density of northern boreal and temperate forests, Global Ecology and Biogeography, 23, 297–310, https://doi.org/10.1111/geb.12125, 2014.

Tohjima, Y., Mukai, H., Machida, T., Hoshina, Y., and Nakaoka, S.-I.: Global carbon budgets estimated from atmospheric O2/N2 and CO2 observations in the western Pacific region over a 15-year period, 19, 9269–9285, https://doi.org/10.5194/acp-19-9269-2019, 2019.

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Tramontana, G., Jung, M., Schwalm, C. R., Ichii, K., Camps-Valls, G., Ráduly, B., Reichstein, M., Arain, M. A., Cescatti, A., Kiely, G., Merbold, L., Serrano-Ortiz, P., Sickert, S., Wolf, S., and Papale, D.: Predicting carbon dioxide and energy fluxes across global FLUXNET sites withregression algorithms, Biogeosciences, 13, 4291–4313, https://doi.org/10.5194/bg-13-4291-2016, 2016.

UN: United Nations Statistics Division: National Accounts Main Aggregates Database, available at: http://unstats.un.org/unsd/snaama/Introduction.asp, last access: 9 October 2024, 2021.

Deleted: November 2023

Uppala, S. M., Kållberg, P. W., Simmons, A. J., Andrae, U., Bechtold, V. D. C., Fiorino, M., ... & Woollen, J.: The ERA-40 re-analysis. Quarterly Journal of the Royal Meteorological Society: A journal of the atmospheric sciences, applied meteorology and physical oceanography, 131(612), 2961-3012, 2005.

Vermote, E. and NOAA CDR Program: NOAA Climate Data Record (CDR) of AVHRR Leaf Area Index (LAI) and Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), Version 5, https://doi.org/10.7289/V5TT4P69, 2018.

Viovy, N.: CRUNCEP data set, available at: ftp://nacp.ornl.gov/synthesis/2009/frescati/temp/land_use_change/original/readme.htm, last access: 9 October 2024, 2016.

Deleted: November 2023

Wanninkhof, R.: Relationship between wind speed and gas exchange over the ocean, J. Geophys. Res.-Oceans., 97, 7373–7382, https://doi.org/10.1029/92JC00188, 1992.

Wanninkhof, R.: Relationship between wind speed and gas exchange over the ocean revisited, Limnol. Oceanogr. Methods., 12, 351–362, https://doi.org/10.4319/lom.2014.12.351, 2014.

Wanninkhof, R., Park, G.-H., Takahashi, T., Sweeney, C., Feely, R., Nojiri, Y., Gruber, N., Doney, S. C., McKinley, G. A., Lenton, A., Le Quéré, C., Heinze, C., Schwinger, J., Graven, H., and Khatiwala, S.: Global ocean carbon uptake: magnitude, variability and trends, Biogeosciences, 10, 1983–2000, https://doi.org/10.5194/bg-10-1983-2013, 2013.

Watanabe, M., H. Tatebe, H. Koyama, T. Hajima, M. Watanabe, and M. Kawamiya: Importance of El Niño reproducibility for reconstructing historical CO2 flux variations in the equatorial Pacific. Ocean Science, 16, 1431–1442, 2020.

Weiss, R. F. and Price, B. A.: Nitrous oxide solubility in water and seawater, Marine Chemistry, 8, 347–359, https://doi.org/10.1016/0304-4203(80)90024-9, 1980.

Woolf, D. K., P. E. Land, J. D. Shutler, L. M. Goddijn-Murphy, and C. J. Donlon: On the calculation of air-sea fluxes of CO2 in the presence of temperature and salinity gradients, J. Geophys. Res. Oceans, 121, 1229–1248, https://doi.org/10.1002/2015JC011427, 2016.

Xia, J., Chen, Y., Liang, S., Liu, D., and Yuan, W.: Global simulations of carbon allocation coefficients for deciduous vegetation types, Tellus B, 67, 28016, https://doi.org/10.3402/tellusb.v67.28016, 2015.

Zeng, J., Nojiri, Y., Landschützer, P., Telszewski, M., and Nakaoka, S.-I.: A global surface ocean fCO2 climatology based on a feed forward neural network, J. Atmos. Ocean. Tech., 31, 1838–1849, https://doi.org/10.1175/JTECH-D-13-00137.1, 2014.

Zeng J., Matsunaga T., Tan Z-H., Saigusa N., Shirai T., Tang Y., Peng S. and Fukuda Y.: Global terrestrial carbon fluxes of 1999–2019 estimated by upscaling eddy covariance data with a random forest, Sci. Data, 7, 1–11, https://doi.org/10.1038/s41597-020-00653-5, 2020.

Zheng, B., Chevallier, F., Yin, Y., Ciais, P., Fortems-Cheiney, A., Deeter, M. N., Parker, R. J., Wang, Y., Worden, H. M., and Zhao, Y.: Global atmospheric carbon monoxide budget 2000–2017 inferred from multi-species atmospheric inversions, Earth Syst. Sci. Data, 11, 1411–1436, https://doi.org/10.5194/essd-11-1411-2019, 2019.

Zuo, H., Balmaseda, M. A., Tietsche, S., Mogensen, K., & Mayer, M.: The ECMWF operational ensemble reanalysis–analysis system for ocean and sea ice: a description of the system and assessment. Ocean science, 15(3), 779-808, 2019.

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