ESSD 2023-306 – Answers to reviewer 1:

I read this document with great interest. Generally the data look useful and credible. However, it seems the authors did not think thoroughly how to present the data. During reading, things sometimes remain unclear. In some instances, clarification came later (e.g. on the used scaling of emissions). Sometimes, things remained unclear (e.g. short cycle co2 emissions).

For the rest, I include an annotated PDF, which contains my remarks.

Answer: We thank the reviewer for his/her comments. We have taken into account all the comments of the reviewer, and we think the paper presents the data in a clearer way now.

There is one issue with the NOx emissions. As far as I am aware, "normal" units are in mass NO2. Now, the authors use mass NO, which might lead to confusion. This is maybe an issue to check with the other inventories, although this information is normally difficult to find! (at least the authors mention the unit now clearly).

There is no consensus on the mass of NO_x: many groups working on air quality issues use NO_x as NO_2, many groups working on climate and chemistry-climate issues use NO_x as NO, and other groups working on natural sources as well as inverse studies often use NO_x as N. In the paper, we have used the standard unit used in the emissions database of the GEIA (Global Emissions InitiAtive) international project, i.e. the ECCAD database mentioned in the paper, where the standard unit is NO_x as NO. In order to make the use of this unit clearer, we have indicated in the figures and table captions: NO_x as NO instead of NO_x-NO.

<u>Answers to the annotated PDF:</u> Note that the lines indicated in the answer correspond to the annotated PDF provided by the reviewer

- Line 26: the words “emitted at the surface” have been removed, as the paper also describes the vertical distribution of the emissions from aircraft.
- Line 67: “make on-line evaluation of the emissions”. This text which was not very clear has been removed.
- Lines 73 and 74: we have removed the full section indicating why the CAMS-GLOB-ANT dataset does not provide the emissions of PMs, as there is no need to single out these two species, as mentioned by Reviewer 2. This section indicated a few papers that have also evaluated the CAMS-GLOB-ANT emissions in atmospheric models: the corresponding sentences have been now included at the end of Section 5.
- Line 107: In order to make the paper clearer, we now just mention in the description of the EDGAR and CEDS emissions the list of species included in the CAMS-GLOB-ANT. The species not included in CAMS-GLOB-ANT (such as PMs, SO_4 and ash) are not mentioned anymore.
- Line 143: EDGAR version 5 does not provide weekly or daily profiles, just monthly temporal profiles.

- Line 148: the figure caption has been changed as suggested by the reviewer, and it now indicates that it shows the temporal weights for the residential sector.
- Lines 162 and 166: the text was unclear and there was repetition in what Table S1 indicates. The text has been rewritten, and now indicates clearly the correspondence between the CAMS-GLOB-ANT, EDGAR and CEDS sectors.
- Line 188: we indicate now that Figure 2 shows the relative change in the emissions between 2013 and 2019, 2014 and 2019, 2015 and 2019. The figure caption has also been changed to indicate that relative changes are plotted.
- Line 190: we rephrased the definition of the quantity we called the "growth factor" and it is now indicated that this factor is dimensionless
- Line 214: as indicated above, the abstract does not mention anymore that the paper is about surface emissions
- Line 215: as mentioned in lines 240-247, the CAMS-GLOB-ANT dataset does not include the impact of the Covid lockdowns on the emissions in 2020. The users of the CAMS-GLOB-ANT can implement the CONFORM adjustment factors to take into account the impact of the COVID pandemic on the emissions.
- Lines 257: as for other emission datasets (EDGAR, CEDS, HTAP, ECLIPSE, etc.), no recommendation is given on the vertical profiles of emissions, except for the aircraft emissions.
- Lines 327 and 329: SO2 has been changed into SO_2
- Line 361: CH4 has been changed to CH_4, and the word "emissions" has been added after CH_4.
- Line 389: CH4 and NH3 have been changed to CH_4 and NH_3
- Lines 456: SO2 has been changed into SO_2
- Line 485: the division between the short cycle and excluding the short cycle emissions is now better explained at the beginning of Section 3.1, with the following sentence: "CO_2 (divided into short organic cycle (released by combusting biofuels, agricultural waste burning or field burning) and excluding the short cycle),…"
- Comments on the tables: as indicated at the beginning of the answers to Reviewer 1, we have changed the figures and table captions from "NO_x-NO" to "NO_x as NO".
- Line 746: the values of the totals for the region for 2000 and 2023 have been added, and the values of the percentages are now shown in the figure.

ESSD 2023-306 – Answers to reviewer 2:

We thank the reviewer for his/her comments. We have taken into account all the comments of the reviewer and improved the description of the dataset.

Answers to the annotated PDF: Note that the lines indicated in the answer correspond to the annotated PDF provided by the reviewer

- Line 23: “agriculture” has been replaced by “agricultural”

- Line 26: the words “emitted at the surface” have been removed, as the paper also describes the vertical distribution of the emissions from aircraft.

- Line 32: a sentence has been added concerning the analysis of the emissions data, i.e. : “Depending on the species and regions, good agreements as well as significant differences are highlighted, which can be further explained through an analysis for different sectors as shown in the figures in the supplement.”

- Line 36: the word “surface” has been removed, to account for the fact that the paper also describes the emissions from aircraft

- Line 38: the words “at the surface of the Earth” have been removed and the word “generated” has been replaced by “emitted”

- Line 44: as several references are detailed in Section 2, we have changed the words “as presented in Section 2” by “as detailed in Section 2. The words “surface inventories” have been replaced by “emission inventories”.

- Line 58: the word “gaseous” has been added

- Line 57: the words “with constant updates” which are too vague have been removed.

- Line 59: the sentence has been replaced by “None of the currently publicly available inventories such as the ones described in Section 2 and in Granier et al. (2023) provide the emissions required by the CAMS modeling system”.

- Line 60: in order to indicate the period required for the CAMS reanalysis, we have indicated in line 54 that the CAMS reanalysis starts in year 2003. In line 60, we have also replaced “CAMS modeling system” by “CAMS forecasts and reanalysis”. We added “for the reanalysis” after the words “too short period”.

- Line 63: we have changed the words “for the most recent years” into “for real-time forecasts”

- Line 63: we have changed “by the models” into “by the CAMS and other chemistry-climate models”, as the CAMS emissions are currently used by several other global and regional models.

- Line 69: as also mentioned by Reviewer 1, these sentences section have been deleted. They explain why some species are not considered in the dataset, and are not really meaningful in the paper.

- Line 79: we have indicated that the version of the emissions described in the paper is version 5. We will only indicate that this is version 5.3 of the dataset in the access to the data. As an information to the reviewer and also mentioned in the metadata in the ECCAD database, versions 5.1 and 5.2 use former version of the ship emissions.

- Line 94: in order to indicate that we have used the gridded emissions from EDGAR version 5, the word “gridded” has been added in line 93. We have also removed the words “national totals” in line 94, as well as the mention to the emissions of PMs.

- Line 107: when the development of the CAMS emissions started, the CEDS were only available at a 0.5x0.5 degree resolution. This is why we have used the CEDS emissions at that resolution.

- Line 114: the CAMS-GLOB-SHIP emissions are based on near-real-time data, using the AIS (Automatic Identification System) data: with AIS information, the exact location of ships is known, together with many more and accurate information than in the CEDS ship emissions.

- Line 121: the back casting of the ship emissions before AIS data were available is based on many different data, which would be too long to detail in the paper. Information can be for example found in the 2nd IMO greenhouse gas study (https://www.imo.org/en/OurWork/Environment/Pages/Second-IMO-GHG-Study-2009.aspx).
  For example, the percentage change per year that was used for the size of ships is the following: Ropax vessels: 1.25%/yr; RoRos, Vehicle carriers: 1.25%/yr; General cargo ships, Bulk cargo ships: 0.4%/yr; Containerships, refrigerated cargo ships: 1.2%/yr; Chemical tankers, Crude oil tankers, LPG tankers, Oil Product tankers: 2%/yr; Small passenger ships, Ferryboats, high speed craft: 0.3%/yr; Cruise ships: 0.3%/yr; Fishing vessels: 0.3%/yr; Other ship classes: 0% /year
  For the fuel consumption changes, the following percentages were used: Ropax vessels: -2.2%/yr; RoRos, Vehicle carriers: -2.2%/yr; General cargo ships, Bulk cargo ships: -1.7%/yr; Containerships, refrigerated cargo ships: -2.2%/yr; Chemical tankers, Crude oil tankers, LPG tankers, Oil Product tankers: -1.9%/yr; Other ship classes: -1.3% /year
  If requested by the reviewer, these values could be put in a table in the supplement of the paper, though the focus of the paper is not on ship emissions.

  We have rewritten the current sentence in the paper as: “The earlier years, 2000-2013, have been back casted based on 2016 activity data and using scaling factors taking into

account for fleet size growth, the lower energy efficiency and smaller ship size in previous years"

- Line 130: a reference has been added for the ECAs zone, from the International Maritime Organization, which is: "as defined by the International Maritime Organization (https://www.imo.org/en/OurWork/Environment/Pages/Emission-Control-Areas-(ECAs)-designated-under-regulation-13-of-MARPOL-Annex-VI-(NOx-emission-control).aspx, last access December 2023)"
  The sentence has been rewritten as: "A global Sulphur cap (limit on the sulphur content in the fuel oil used on board ships) became effective in Jan 1st 2020, which decreased SO_x and PM emissions, but the ECAs regions, which implement those rules several years before 2020 were unaffected by the cap" to make clearer that some regions implemented a sulfur cap before the rule was mandatory at the global scale.

- Lines 133-134: these lines have been removed

- Line 137: the sentence has been modified and the mentioned daily and weekly temporal profiles have been removed. The sentence is now: "the monthly temporal profiles used in CAMS-GLOB-ANT are available on the ECCAD database"

- Line 143: the CAMS-GLOB-TEMPO temporal profiles are used, as they are based on more recent data than used in the EDGAR temporal profiles. Furthermore, the CAMS-GLOB-TEMPO account for meteorological conditions and sociodemographic factors, which is not the case for the EDGAR temporal profiles.

- Line 155: as indicated in the paper, the CAMS-GLOB-ANT emissions cover the 2000-2023 period, so no temporal profiles before 2000 have to be taken into account.

- Line 159: as mentioned above, we now use only the terminology version 5 for the CAMS-GLOB-ANT emissions, to avoid confusion.

- Line 160: there are 35 species in the dataset, 10 main species and 25 speciated VOCs. The difference between the two CO2 species is now better explained with "CO_2 (divided into short organic cycle (released by combusting biofuels, agricultural waste burning or field burning) and excluding the short cycle)".

- Line 162 and line 164: the sentence referring to the EDGAR sectors has been modified and is now: "The sectors used in CAMS-GLOB-ANT are detailed in Table S1, and the corresponding sectors in the EDGARv5 and CEDS inventories are shown as well in this table".

- Line 164: the reference to the 2000-2023 period has been removed, as it is explained in other parts of the paper.

- Line 174: as mentioned above, the CEDS emissions at 0.1x0.1 degree were available after the CAMS-GLOB-ANT emissions were developed. Therefore, er chose to use the

EDGAR emissions as a basis for the CAMS-GLOB-ANT inventory. We have also better specified that the emissions are needed until the end of the year 2023, so that they can be used for global forecasts.

- Line 184: we have now specified that we are calculating the relative change in the emissions for each of the three periods, 2013-2019, 2014-2019 and 2015-2019, in order to determine which data will be used as a basis for the extrapolation.

- Line 191: we have now better indicated below the equation that tf and ti are 2019 and 2014, respectively

- Line 195: the word "correspondent" has been replaced by the word "equivalent"

- Line 198, the acronym of the sector was not very clear. The sentence has been changed to: "For the sector "road transportation with resuspension" the same growth factor as for the road transportation sector is used."

- Line 208: the quantity we call "growth factor" which is use for the extrapolation of the emissions is based only on the CEDS emissions. It assumes that the CEDS emissions have been validated with model or satellite studies.

- The aircraft emissions were developed before version 5 of CAMS-GLOB-ANT emissions were developed. Even if aircraft emissions from CEDS are now available, they are not mentioned in the McDuffie et al. (2020) and the O'Rourke (2021) articles and dataset. We have rephrased the text as: "We have developed the aircraft emissions on the basis of the CEDS aircraft emission data described in Hoesly et al. (2018).", so that the users know that we used the data from this Hoesly et al. paper.

- Line 218: we have removed the sentence "These dates were chosen because the trends are stable after 2011, except for the year 2020, as indicated in Section 4", as it could be confusing to the reader.

- Line 220: as indicated in the paper, the emissions after 2019 (or 2014 for aircraft) are all based on extrapolations, using the "growth factors" determined in section 3.2. Therefore, the extrapolation is done for the full year 2023, even if no information is yet available on activity data for the past 3-4 years.

- Line 223: the speciation used for the aircraft emissions is based on the paper used for the speciation of the surface VOCs emissions. This choice was done for consistency on the categories of the speciated VOCs. The corresponding sentences are now: "To be consistent with the VOCs speciation of the surface anthropogenic emissions, the emissions of speciated VOCs emissions from aircraft in CAMS-GLOB-AIR are based on the speciation described by Huang et al. (2017) for different emission sectors. We calculated the ratios of the emissions of each individual VOCs to the total NMVOCs species for each of these two altitude levels (landing/taking off and cruise altitudes) in the EDGAR dataset, at a 0.1x0.1degree horizontal resolution."

- Line 230: Table S2 has been changed to Table S3

- Line 235: “the most recent years” has been changed to 2023

- Line 237: the references to versions 5.1 and 5.2 of the emissions have been removed, in order to avoid confusion with obsolete versions.

- Line 244: “in” has been replaced by “by”.

- Line 249: the list of species has been removed, as it is given earlier.

- Line 264: the following words have been added at the end of the sentence: “these changes depend strongly on the regions and sectors, as discussed further in the following sections”.

- Line 267: we have added the words: “and four groups of sectors” as proposed.

- Line 268: we have changed the years in Table S4 and S5 to 2023 instead of 2021 and we have reported the numbers for 2023 in these tables.

- Line 307: the word “ammonia” is not used anymore, NH_3 is used everywhere

- Line 335: the space has been added

- Line 346: the word “changer” has been removed

- Line 361: we have changed the sentence concerning the CH4 emissions in the USA to: “The stability in the CH_4 emissions is related to constant oil and gas operations, as well as from livestock agriculture practices (fugitive and manure/enteric fermentation emissions in the EDGAR emissions).

- Line 365: as a reference, we added the following words: “these standards are described in details in the website of the US EPA (Environmental Protection Agency, https://www.epa.gov/air-emissions-inventories, last access: December 2023).”

- Line 389: some numbers have been added and the sentence is now: “From 2000 to 2012, the emissions of all species (except NH3) increased by 20% to 50% for most pollutants, and even 90% for NO_x.”

- Line 415: two references giving information on the emissions reduction plans implemented in the 2010s have been added, Kurokawa and Ohara, ACP, 2020 (already cited in the paper) and Zheng et al., ACP, 2018.

- Line 435: the decrease in the emissions of CO in India after 2015 is shown in the CEDS emissions dataset, and one reference has been added, i.e. Joshi et al, Chemosphere, 2023.

- Lines 451 and 452: the spelling mistakes and subscript have been corrected.

- Line 480: the CAMS-GLOB-AIR dataset is described in section 3.3. The reason why the acronym of this dataset is not CAMS-GLOB-ANT is due to the fact that the aircraft emissions are given as 3-dimensional fields. In the ECCAD database, we could not keep the same acronym for 2-D and 3-D fields.

- Line 485: the word "short-cycle" has been replaced by "short organic cycle" to be consistent with the rest of the paper.

- Line 486: the word "hydrocarbons" has been replaced by "volatile organic compounds" for consistency with the rest of the paper.

- Line 629: the unit of the global and regional (Tg/yr) totals have been added in the table captions.

- Line 699: the figure has been replaced by a new figure with larger fonts

- Line 703: the units are Tg/yr as indicated in the figure caption, but they don't represent the emissions of a specific com

- Line 709: the growth factors are defined in section 3.2, and this section includes Figure 5.

- Line 719: the answer is the same as the answer to line 220: "as indicated in the paper, the emissions after 2019 (or 2014 for aircraft) are all based on extrapolations, using the "growth factors" determined in section 3.2. Therefore, the extrapolation is done for the full year 2023, even if no information is yet available on activity data for the past 3-4 years."

Answers to Reviewer 3:

We thank the reviewer for his/her comments. We have taken into account all the comments of the reviewer, and we think the paper presents the data in a clearer way now.

Line 26 and 45: Rephrase "emitted at the surface". Currently, it suggests that aloft emissions (point sources, aircraft etc) are not necessary by omission.
Answer: the words "emitted at the surface" have been removed, as the paper also describes the vertical distribution of the emissions from aircraft.

Line 48: Might be worth referring to an overview paper of emission needs that talk about this (e.g, 10.1080/10962247.2019.1629363). Also, worth highlighting near-term top-down papers as another solution.
Answer: we have added a reference to the review published in 2023 by Granier at al., https://doi.org/10.1007/978-981-15-2760-9_5

Line 60: "most recent years" What level of fidelity is needed in the "most recent years"? Can you show that simple persistence from a previous year is not sufficient? Right now, this reads as an assumption that some readers may not yet have. Also, can you define the what is acceptable latency? Do you need this year now? One month lag? One year lag?
Answer: we have changed "most recent years" to "recent and current years". The CAMS/Copernicus forecasts are done for the present day, and the reanalyses also need emissions for the recent years. Activity data are generally available after a 2-4 years delay, and we have chosen to extrapolate the emissions to the current year, so that the forecasts models can use them as inputs for the forecasts simulations.

Lines 69-74: I think the omission of non BC/OC primary PM25 is not good. In my experience, some models go to extreme efforts to infer the non OC/EC primary PM25 emissions that are omitted from the model. For example, many models make gross assumptions about all OC having the same OC:OM ratio. Obviously, this ratio is specific to the emission activity generating it. What other species like crustal components? This paragraph is glossing over a need by saying that models deal with it.
Answer: At the suggestion of reviewer 1, we have removed the full section indicating why the CAMS-GLOB-ANT dataset does not provide the emissions of PMs, as there is no need to single out these two species, as also mentioned by Reviewer 2. Note that this section indicated a few papers that have also evaluated the CAMS-GLOB-ANT emissions in atmospheric models: the corresponding sentences have been now included at the end of Section 5. The development of the CAMS emissions is also dependent on users' requests. We will send the reviewer's remark to the CAMS/ECMWF management group, who might consider to add the emissions of PMs in future CAMS contracts.

Line 79: *Because EDGAR and CEDS are overlapping, it would be nice to put up front some comment about how they are both used. You make it clear later, but it isn't for quite some time.*
Answer: after the mention to the CEDS inventory, we have added the following words: "which are used for the extrapolation of the emissions to the most recent years," to indicate better that the EDGAR emissions are used as a basis and the CEDS emissions are used for the extrapolation.

Line 82: Is it true that this dataset does not include HTAP? If so, you should state why this was not a good starting place for CAMS.
Answer: The HTAP emissions are based on the EDGAR emissions, as for the CAMS emissions. A version of the CAMS emissions as a mosaic will be developed (in collaboration with the HTAP group at JRC) in 2024, and the discussions between the HTAP, EDGAR and CAMS emissions groups have started.

Lines 124-125, That seems inconsistent with the statement that activity is based on data from years 201-2018. COVID happened after the data. If it really is addressed, you'd need some clarity on the scope of the activity data to better match the statement.
Answer: some more details on the back casting of the ship emissions are now given in a new sentence: "The earlier years, 2000-2013, have been back casted based on 2016 activity data and using scaling factors taking into account for fleet size growth, the lower energy efficiency and smaller ship size in previous years: these factors take into account the lower. These scaling factors are applied separately for various shipping segments."
The detailed values used for the back casting are the following:
"For example, the percentage change per year that was used for the size of ships is the following: Ropax vessels: 1.25%/yr; RoRos, Vehicle carriers: 1.25%/yr; General cargo ships, Bulk cargo ships: 0.4%/yr; Containerships, refrigerated cargo ships: 1.2%/yr; Chemical tankers, Crude oil tankers, LPG tankers, Oil Product tankers: 2%/yr; Small passenger ships, Ferryboats, high speed craft: 0.3%/yr; Cruise ships: 0.3%/yr; Fishing vessels: 0.3%/yr; Other ship classes: 0% /year
For the fuel consumption changes, the following percentages were used: Ropax vessels: -2.2%/yr; RoRos, Vehicle carriers: -2.2%/yr; General cargo ships, Bulk cargo ships: -1.7%/yr; Containerships, refrigerated cargo ships: -2.2%/yr; Chemical tankers, Crude oil tankers, LPG tankers, Oil Product tankers: -1.9%/yr; Other ship classes: -1.3% /year
If requested by the reviewer, these values could be put in a table in the supplement of the paper, though the focus of the paper is not on ship emissions.

Lines: 136-138, You should remove "monthly" given that you have daily profiles. Maybe month-specific? Also, do you have diurnal profiles?
Answer: The sentence has been modified and the mentioned daily and weekly temporal profiles have been removed, as the CAMS-GLOB-ANT dataset is provided as monthly averages. The sentence is now: "the monthly temporal profiles used in CAMS-GLOB-ANT are available on the ECCAD database"

Line 138, Consider species separately? Or at sectoral level giving rise to variability in primary pollutants? Or sector-species specific?
Answer: the word "categories" has been changed to "sectors", in order to make it clearer that the temporal profiles are applied to the same sectors as the ones considered in the CAMS-GLOB-ANT emissions.

Line 155, Given that 2020 was the COVID year, this seems like a mistake. Why not use 2019?
Answer: even if the emissions have changed significantly in 2020, the temporal profiles did not change, compared to previous years.

Line 175-190: The methodology for geometric projections seems unnecessarily complex for the 2016-2019 period. Why not use the actual ratio change in CEDS for those years and then use the mean factor for future years (i.e, outside of both CEDS and EDGAR)?
Answer: the methodology we used has been tested in the previous CAMS-GLOB-ANT versions and compared with other methodologies such as the one proposed by the reviewer. After several tests using chemistry-transport models and observations of CO and NOx for the most recent years, we adopted the methodology described in the paper, as it gave the best results.

Line *199, Figure 3: caption "growth factor for the industry factor"? Maybe "growth factor for the industry sector"?*
Answer: the figure caption has been changed, and the word “sector” is now used.

Line 301, Seems weird that you left out NMVOC, but kept in BC. This is not consistent. I would also recommend adding NMVOC to the list of significant decrease ("CO, NOx, NMVOC, SO2, and BC have")changing "other species" to a "NH3 and OC".
Answer: we are not sure about what the reviewer indicates as “weird”. Line 301 refers to Figure 8. This figure includes NMVOCs, this species was not left out in the figure.
“other species” has been replaced by “NH3 and OC”.

Line 493-497, This seems like a small list. Perhaps expand on key other uncertainties.
Answer: The last sentence has been modified, and is now” “The current limitations of the inventory will be considered, such as the constant NMVOCs speciation after 2012 (following the EDGAR VOCs speciation), the inclusion of more up-to-date data for the extrapolations to the more recent years, the inclusion of the CONFORM adjustment factors for the Covid-19 lockdowns directly into the emission dataset and when possible the inclusion of regional information for the different species and sectors.”