Review Responses for: A global anthropogenic emission inventory of atmospheric pollutants from sector- and fuel-specific sources (1970–2017): An application of the Community Emissions Data System (CEDS)" *by* Erin E. McDuffie et al.

We thank both Reviewers for their comments, which have helped improve the quality and clarity of our manuscript describing the CEDS$_{GBD-MAPS}$ dataset. We have responded to each comment below. The original comments are in black, our responses are in blue and the changes to the manuscript text are in *blue italics*. Overall, the dataset remains unchanged, but we have added two additional supplemental figures and 1 supplemental table to address reviewer-specific concerns. All other manuscript changes are related to clarifying the CEDS methodology or descriptions of the final dataset. Changes were made to maintain a similar manuscript length, while providing improved clarity, context, and interpretation of major features. Line numbers in our responses below correspond to the re-submitted (non-tracked) version of the manuscript.

Anonymous Referee #1

McDuffie et al. Describe an update to the global emission inventory of atmospheric pollutants from the Community Emissions data System (CEDS). The updated dataset improves upon the earlier release of the CEDS inventory by adding additional emission sectors, separating emissions by fuel type, extending the timeseries to 2017, and updating the regional inventories used to "calibrate" the emissions corresponding regional sections of the global domain. The new CEDS inventory is currently the most up to date global emission inventory available to the community that is based on reported data. This fact, along with the new features provided with this data release, should make the inventory very attractive to global atmospheric chemistry modellers.
The manuscript describing the dataset is generally organised and written well. A lot of detail goes into such emission inventories, and the authors have found a good balance between including information in the manuscript, the supplement, and as references to other work. As well as describing the methodology of constructing the inventory, the resulting dataset itself is also presented and described, as well as compared to other global inventories, including the previous version of the CEDS inventory. Uncertainties are also discussed.
My only major comment on the manuscript concerns the calibration procedure. It is obviously a strength of the CEDS approach that regional emissions are scaled using detailed regional inventories where they are available. In this way, more detailed local information can be incorporated than would typically be the case for completely globally consistent inventories such as EDGAR or GAINS.

We thank this reviewer for their thoughtful comments and concerns. First, we note that per the suggestion of Reviewer #2, we have changed the terminology throughout the manuscript to now describe the original 'calibration' procedure as the 'scaling' procedure. We agree with Reviewer #2 that the term 'calibration' implies too great a level of certainty and accuracy in the regional and global inventories.

What is not clear to this reviewer is the necessity of also scaling the "default emission estimates" calculated in "Step 1" of the CEDS workflow to "existing, authoritative" global inventories (such as EDGAR and GAINS). Given the general uncertainties in emission inventories, would it not be valuable to have an additional semi-independent global inventory in addition to these two established inventories? Of course, a lot of the information used in constructing the CEDS inventory is shared with, or derived from the other global inventories, so a completely independent emissions inventory would be very difficult to compile.

The Reviewer is correct that regardless of default emission scaling, information from both EDGAR and GAINS global inventories are used to develop the CEDS$_{GBD-MAPS}$ (and core CEDS) inventory. The original aim of CEDS was not to generate a completely new independent inventory, but to use a consistent and reproducible methodology, while also leveraging information from regional and country-specific inventories to generate historical emission time series with consistent sectoral and fuel-type definitions across all years and all world countries. EDGAR already exists as a consistent, global inventory developed using consistent assumptions, so we do not need to re-invent that work.

This reviewer would however like to see some more discussion of why it is necessary to calibrate the total CEDS emissions using other global inventories.

Section 2.1 describes how the default CEDS combustions source emissions are estimated using a combination of energy consumption data from the International Energy Agency and Emission Factors from other inventories such as GAINS and the US NEI. The GAINS EFs are only available for more aggregate regions, whereas the EDGAR inventory has country-specific emission estimates for all countries. Scaling to the EDGAR inventory is therefore meant to better account for country-specific information in the CEDS combustion emission estimates in locations where country-specific information was not available for the default estimates. We do note however that for countries that are later scaled to other regional inventories (shown in Fig. 2), the initial scaling to the EDGAR inventory should have a limited effect on the final emission values. We have added the following text to the main manuscript to clarify this point.

Line 310– *For example, global CEDS$_{GBD-MAPS}$ combustion source emissions of NO$_x$, total NMVOCs, CO, and NH$_3$ are first scaled to EDGAR v4.3.2 country-level emissions as a means to incorporate additional country-specific information relative to default estimates derived using more regionally-aggregate EFs from GAINS.*

Related to this point, it would also be very interesting to know the size of the "scaling factors" which are applied in "Step 2" to calibrate the CEDS default emissions with the other global inventories. These numbers to not appear to be presented in the manuscript or the supplement.

Scaling factor limits are set following the original CEDS protocol so that these factors do not exceed the range of 1/100 to 100. For a select number of sectors and countries, these limits are extended to 1/1000 to 1000 to ensure better agreement between the final CESD$_{GBD-MAPS}$ emission totals and the regional inventories, as was described in Section S2.3.2. To clarify, we have added the following sentence to the Supplement.

Supplement - Line 170 - *Following original CEDS protocols, scaling factors are limited to values between 0.01 and 100, with select inventories and sectors expanded to a range of 0.001 and 1000, as described in Supplemental Section S2.3.2. As discussed in Hoesly et al. (2018), particularly small or large scaling factors may result for multiple reasons, including default CEDS estimates that are drastically different than regional emissions or imprecise mapping between CEDS and regional emission sectors.*

At the Reviewer's request, we have additionally provided a supplemental table of example scaling factors for a sub-set of African countries and years (Table S4). As stated in the main text, small and large scaling factors may result from largely different emission estimates in the default inventory relative to the regional inventories and/or imperfect mapping between the CEDS and regional inventory sectors.

Supplement - Line 169: *Example scaling factors for select years and countries in Africa, as a function of scaling sector are provided in Table S4. Data are included for illustrative purposes only.*

Table S4. Example BC scaling factors for select DICE-Africa countries and years.

Country (ISO)	Scaling Sector	Scaling Fuel	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
ago	residential	biomass	0.332	0.338	0.344	0.350	0.355	0.361	0.367	0.373	0.373	0.373
ago	residential	light oil	0.340	0.311	0.282	0.252	0.223	0.194	0.165	0.136	0.136	0.136
ago	road_ transport	gas_ diesel	0.307	0.293	0.278	0.264	0.250	0.235	0.221	0.207	0.207	0.207
nam	residential	biomass	0.297	0.320	0.342	0.364	0.386	0.409	0.431	0.453	0.453	0.453
nam	residential	light oil	44.71	44.72	44.72	44.72	44.73	44.73	44.73	44.74	44.74	44.74
nam	road_ transport	gas_ diesel	0.274	0.260	0.247	0.234	0.220	0.207	0.194	0.180	0.180	0.180

I also have one minor, and one extremely minor comment.
The minor comment relates to data availability. It is great that the CEDS inventory as well as the code is made available to the public. But what about the input data which are necessary for the CEDS code to run? While the data sources do all appear to be well referenced, it would be nice to see some comment in Section 5 on how freely available the input data sets are. This would of course influence the feasibility of other groups being able to reproduce the CEDS emissions using the CEDS code.

We have added the following sentence to section 5.
Line 858: *To run the CEDS system, users are required to first purchase the proprietary energy consumption data from the IEA (World Energy Statistics; https://www.iea.org/subscribe-to-data-services/world-energy-balances-and-statistics). The IEA is updated annually and provides the most comprehensive global energy statistics available to-date. All additional input data are available on the CEDS GitHub repository.*

The extremely minor comment relates to the presence or absence of seasonal cycles in the gridded emission data. While it seems clear that the gridded CEDS data do include a seasonal cycle, in two places (lines 250 and 790), these data are referred to as "annual" fluxes, implying strongly that they are annual averages. Perhaps this should be corrected to something like "seasonal cycles of annual . . . fluxes".

We have replaced the incorrect use of 'annual fluxes' on original lines 250 and 790 with 'monthly fluxes'. The seasonal profiles are primarily from the ECLIPSE project as mentioned in Section 2.1.

Line 257 - *Final products from the CEDS$_{GBD-MAPS}$ system include total annual emissions from 1970 - 2017 for each country, as well as monthly global gridded (0.5°×0.5°) emission fluxes…*

Line 862 - *Final products from the CEDS$_{GBD-MAPS}$ system include total annual emissions for each country as well as monthly global gridded (0.5°×0.5°) emission fluxes for the years 1970 – 2017.*

Reviewer #2 – Hugo Denier van der Gon

The paper describes an interesting new global emission Inventory (CEDSGBD-MAPS) for atmospheric pollutants (1970 – 2017) based on the so-called mosaic approach based on the Community Emissions Data System (CEDS). The paper is generally well-written and deserves to be published but I do have several concerns where I would ask for adjustment or further explanation. A problem with emission inventory papers is that one tries to describe a complete set for all pollutants, all source sectors, all countries and many years. It is impossible to write a paper on this that documents, explains & discusses all and is still readable. Choices have to be made. The intention of my review is not to be a dictate. Part of my comments will relate to choices made and I do not demand that all answers to my comments find their way into the paper. If the authors have good reasons for not adjusting something, they can explain themselves.

We thank the Reviewer for their thoughtful and detailed comments. We recognize the Reviewer's expertise and experience in this field and have addressed their comments accordingly. The changes and additions described below have greatly improved the quality and clarity of this manuscript.

The mosaic approach is not new and was previously successfully applied for example in the framework of HTAP by Janssens-maenhout et al (2015). This is an often used mosaic inventory. The approach by Janssens-maenhout et al differs from the approach taken in this paper and I think this should be briefly discussed in the introduction. Also to make clear that mosaic inventories are becoming a more frequently followed approach.

We have made adjustments to sentences in the Introduction and Methods sections to provide further context on the use of the 'mosaic' development strategy.

Line 95 - *In contrast to EDGAR and GAINS, the CEDS system implements an increasingly utilized mosaic approach, which, in this case, incorporates activity and emission input data from other sources such as EDGAR, GAINS, and regional/national-level inventories to produce global emissions that are both historically consistent and reflective of contemporary country-level estimates (Hoesly et al., 2018).*

Line 202 - *As described in Hoesly et al. (2018), CEDS uses a "mosaic" scaling approach to retain detailed fuel- and sector-specific information across different inventories, while maintaining consistent methodology over space and time. The development and use of mosaic inventories has been recently increasing as they provide a means to utilize detailed local emissions, while harmonizing this information across large regional or global scales (Li et al., 2017;Janssens-Maenhout et al., 2015). The CEDS approach, however, differs from previous mosaic inventories, such as that developed for the HTAP project (Janssens-Maenhout et al., 2015), as local and regional inventories in CEDS$_{GBD-MAPS}$ are used to scale sectoral emissions at the national-level, rather than merging together spatially distributed gridded estimates.*

A more fundamental problem is the term "calibration inventory" that is coined in the paper. Calibration is the comparison of measurement values delivered by a device under test (or a system) with those of a calibration standard of known accuracy. However, I think it is fair to say that the authors don't know the accuracy of their calibration inventories. They motivate that regional or national inventories may include more national/regional knowledge and are therefore more accurate. This was also the motivation for e.g. the earlier HTAP_v2.2 mosaic inventory. It may well be true (and this reviewer firmly believes in the usefulness of mosaic inventories) but a) we don't know for sure if the regional inventory is really better and b) we don't know how accurate exactly. Good enough for calibration? In my opinion the term calibration adds too much certainty to a more empirical and intuitive solution for an operational problem. It reads well but in reality it is more fitting or scaling than calibrating. In e.g. line 213 is also stated that scaling factors are calculated in the calibration procedure . Apparently scaling is seen as calibrating. Should the authors really think that calibration is still the best terminology some additional clarification/disclaimer is needed to avoid "whitewashing" of something still uncertain (scaling) by calling it certain (calibrating). [see also the confusion created in line 360-365 between scaling and calibration and the remark that BC / OC are not scaled due to large uncertainties in EDGAR – but how well do you know that other inventories are much less uncertain?]

We appreciate this comment and in retrospect, agree that the term 'calibration' provides too much weight to the accuracy of the regional inventories. While the accuracies of some regional inventories have been quantified (e.g., Venkataraman et al., 2018), we agree that the term 'calibration' is not appropriate in this context. We have changed all instances and variations of the term 'calibration' to 'scaling' throughout the main text, supplement, and figure and table captions. Similarly, the 'calibration inventories' are changed to 'scaling inventories'. These changes are now also in better alignment with the original CEDS description in Hoesly et al. (2018).

An advantage of the mosaic approach is the inclusion of more locally / nationally representative inventories in the global emission map. A disadvantage is that the emissions from different regions become apples and oranges. Obviously still the same species but the underlying choices are no longer necessary the same. It would be interesting for some of the more uncertain species like CO, NMVOC or BC to show a plot comparing some implied emission factors for certain source sectors for e.g. Africa, India, China, Former Soviet Union. What is the range in these implied EFs and based on expert judgement of the authors do these ranges seem plausible? This may be used to flag some of the pollutant / source sector / region combinations that may deserve further investigation in the future? It could also be connected to the paragraph starting at line 300.

We have added Figure S2 to the Supplement to provide an illustration of the time series of implied emission factors for each compound for the top 15 emitting countries. The panels in this figure show the implied emission factors (units of g g^{-1}) for the fuel and sector combinations that

dominantly contribute to emissions of each compound. For example, NO_x emissions are predominately from the combustion of oil and natural gas in the road-transport sector. We have used this figure to support several sections of our manuscript including the Methods and uncertainties discussion and have added the following sections to the main text.

Line 229 - *Figure S2 provides a time series of implied emission factors after the scaling procedure for select sector- and fuel- combinations that dominant emissions of each compound in the top 15 emitting countries.*

Line 336 - *Figure S2 shows that after scaling, the implied emission factors of CO from oil and gas combustion in the on-road transport sector for four African countries range from 0.19-0.28 g g^{-1}, slightly smaller than the range of 0.029 - 0.380 g g^{-1} used in the DICE-Africa inventory.*

Line 345 - *After scaling, the implied EFs for residential biofuel emissions of OC are ~0.001-0.002 g g^{-1} in three African countries (Figure S2), within the range of EFs of 0.0007 – 0.003 g g^{-1} implemented in the DICE-Africa inventory.*

Line 354 - *Figure S2 shows that the implied emission factor for NO_x emissions from oil & gas combustion in the on-road transport sector in India is ~0.015 g g^{-1} in 2015, which falls within the range of values of 0.0026 – 0.046 g g^{-1} used for various vehicles and fuel type in Venkataraman et al. (2018).*

Line 359 - *For SO_2, Figure S2 shows that the implied EF for coal combustion in the energy sector is ~0.004 g g^{-1}, slightly lower than the range of 0.0049 – 0.0073 g g^{-1} used for the SMoG-India inventory.*

Line 761 - *In addition to uncertainties in the scaling inventory emissions, uncertainties are also introduced by the CEDS$_{GBD-MAPS}$ scaling procedure. Uncertainties arise when mapping sectoral and fuel (when available) specific emissions between inventories (as discussed previously), as well as in the application of the calculated scaling factors outside the range of available scaling inventory years. For example, the implied CO EFs in Figure S2 highlight one case in China where the EFs for oil and gas combustion in the on-road transport sector peak in 1999 at a value over three times larger than EFs in all other top emitting countries. For China specifically, the calculated scaling factors for the year 2010 (earliest scaling inventory year) are applied to emissions from all years prior, which was calculated as a value of ~1.58 for the on-road transport sector. The implied EF of ~1.8 g g^{-1} for this sector in 2003 (Figure S2) suggests that the SF from 2010 may not be representative of emissions during this earlier time period. We do note, however, that the 1999 peak in total CO emissions in China (Figure S9) is driven by the IEA energy data and is consistent with the CEDS$_{Hoesly}$ inventory (Hoesly et al., 2018). In contrast, EFs from this sector in China after the year 2010 agree with the magnitude and trends found in other countries, further indicating that the scaling factors*

are most appropriate for years with overlapping inventory data. Other similar examples include coal energy emissions of SO_2 in Thailand (Figure S2). In this case, the REAS scaling inventory spans the years 2000 – 2008. The default EFs for the energy sector, however, independently decrease between 1997 and 2001. As a result, when the implied EF of 3.3 for the year 200 is applied to all historical energy emissions, the implied EFs prior to 1997 become an order of magnitude larger than those in nearly all other top emitting countries (Figure S2). Overall, the applicability of the scaling factors to emissions in years outside the available scaling inventory years remain uncertain due to real historical changes in activity, fuel-use, and emissions mitigation strategies. These uncertainties, however, vary by compound and sector as, for example, there are no similar peaks in on-road emissions for compounds other than CO in China.

Supplemental Line 202 - *To illustrate the outcome of the scaling procedure, implied emission factors for the top 15 emitting countries are additionally shown in Figure S2 for the select fuel-types and sectors that dominantly contribute to global emission of each compound. Various anomalies in the implied EFs can arise from multiple sources of uncertainty, including the underlying activity data or application of scaling factors outside the available scaling inventory years, as is the case with the on-road CO emission factor for China in 1999. These uncertainties are discussed further in Section 4.2 in the main text.*
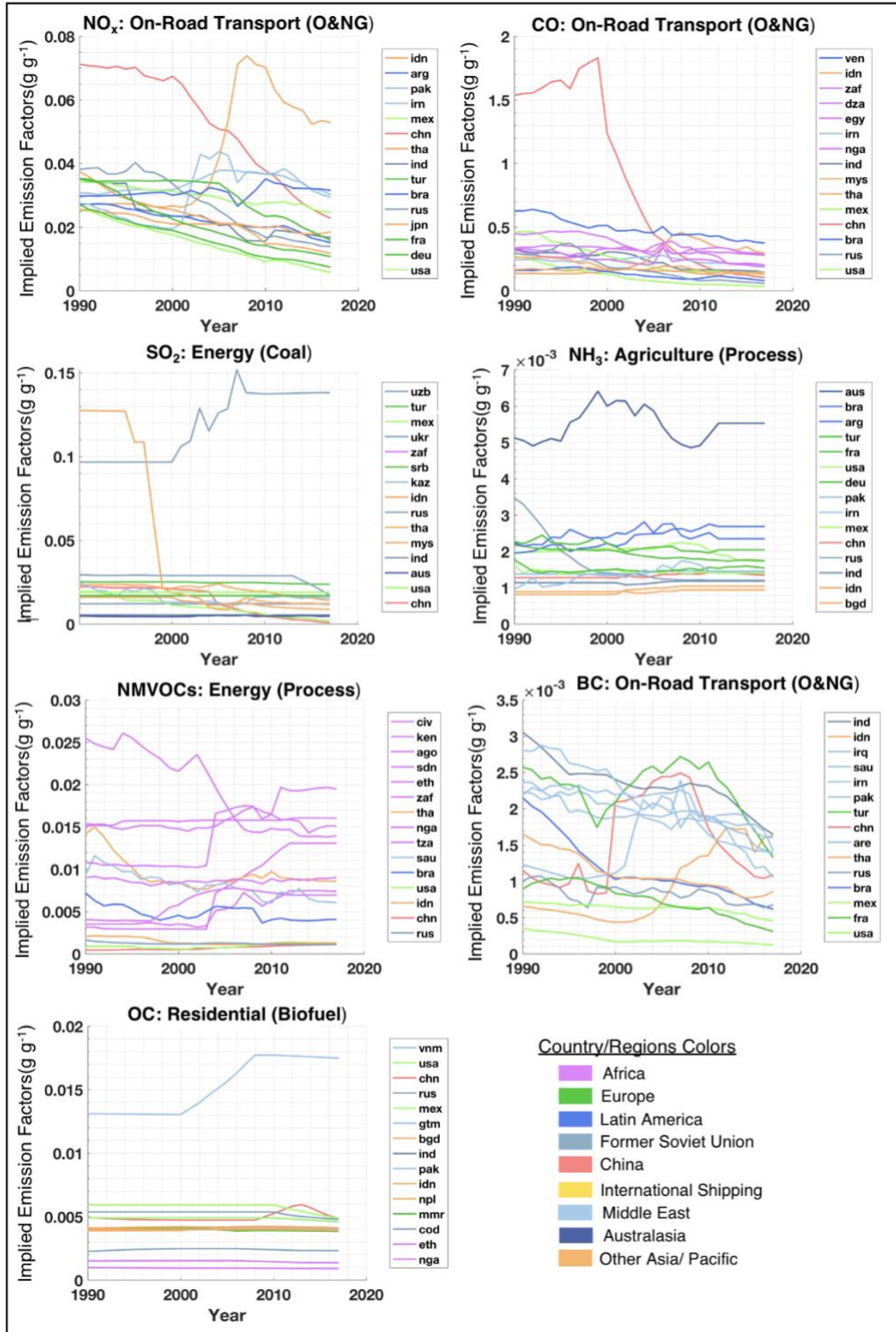
Figure S2. Time-series of implied (post-scaling) emission factors for select fuel and sector combinations that dominantly contribute to global emissions of each compounds. NOx, CO, and BC: oil & natural gas combustion in the on-road transport sector, SO₂: coal combustion in the energy sector, NH₃: agricultural emissions, NMVOCs: process-level energy sources, and OC: residential biofuel combustion. Time series are shown for the top 15 emitting countries, listed by their ISO codes to the right of each panel. Time series are colored by the region of each country.

From the methods section it was not clear to me where the shipping emissions come from. Are these based on AIS data or taken from EDGAR? Or another approach? Like with the regional inventories there may be ways to "scale/calibrate" these in recent years by using AIS based inventories. Was this considered?

We had not originally included an explicit description for international shipping emissions as these were not changed relative to the CEDS$_{Hoesly}$ inventory. To clarify the source of these emissions, we have added the following description to the Methods section.

Line 192 - For International Shipping, IEA activity data is supplemented with consumption data and EFs from the International Maritime Organization (IMO), as described in Hoesly et al. (2018) and its supplement.

The region "Other Asia/Pacific/Middle East region". This I find non-informative and I invite the authors to think of a solution possibly by breaking it up. The mix of countries (see Table S8 - e.g. Australia, Mongolia, Yemen, Saudi Arabia, Korea, New Zealand, Pakistan, Indonesia etc.) is such that any discussion of the trends for this group in the paper is pointless. Also graphs of such a group in my opinion do not add any information.

In an attempt to simplify the line plots and maintain consistency with Hoesly et al. (2018), we chose to aggregate many of the countries that were not central to the discussion in our manuscript (i.e., those countries that were not largely updated relative to the CEDS$_{Hoesly}$ inventory). To provide a more meaningful discussion, we have now broken the 'Other Asia / Pacific/ Middle East region into the Australasia, Middle East, and Other Asia / Pacific regions. The new definitions are in Table S9. We have also updated Fig 8 accordingly, as well as SI Fig's S10 and S17-S20. The following sections of text have been updated as well.

Line 441 - Time series of regional contributions to global emissions in Fig. 8 additionally show that 50% of global 2017 NO$_x$ emissions are from the combined Other Asia/Pacific region (Table S9) (13 Tg), China (24 Tg), International Shipping (25 Tg).

Line 450 - Fig. 8 shows that in 2017, China is the dominant source of global CO (144 Tg, 27% of global total), SO$_2$ (12 Tg, 15% of global total), NH$_3$ (12 Tg, 20% of global total), OC (2.7 TgC, 20% of global total), and BC (1.4 TgC, 24% of global total). In contrast, Africa is the dominant source of global NMVOCs in 2017 (48 TgC, 27% of global total) and International Shipping is the dominant source of global NO$_x$ emissions (25 Tg, 20% of global total).

Line 466 - Despite, however, continued reductions in these regions, global emissions of CO slightly increase between 2002 and 2012 due to simultaneous increases among the energy, industry, and residential sectors in China, India, Africa, and the Other Asia/Pacific region (Fig. S9-S12).

Line 480 - *While China is the largest global contributor to SO_2 emissions between 1994 and 2017, these large regional reductions, coupled with increasing SO_2 emissions in the Other Asia/Pacific region, African countries, and India (Fig. 8), indicate that future global SO_2 emissions will increasingly reflect activities in these other rapidly growing regions.*

Line 488 - *While more stringent vehicle emission standards result in more than a factor of 2 decrease in on-road transportation NO_x emissions in North America and Europe between 1992 and 2017 (Fig. S7-S8), on-road transport emissions in China, India, and the Other Asia/Pacific region simultaneously experience between a factor of 1.3 to 2.8 increase (Fig. S9-S11).*

Line 493 - *Global NO_x emissions from the energy and industry sectors increase by up to a factor of 6 between 1970 and 2011 due to regional increases in China, India, the Other Asia/Pacific region, and African countries, with reductions between 2011 and 2017, again largely from reductions in China from stricter emissions control policies for coal fired power plants and coal use in industrial processes (Zheng et al., 2018;Liu et al., 2015).*

Line 503 - *Though emissions of BC and OC have a higher level of uncertainty relative to other compounds (Sect. 4), emissions from African countries and the Other Asia/Pacific region experience growth in BC and OC emissions from these sectors.*

Line 509 – *Similar to trends in SO_2 emissions, increasing trends in total OC and BC emissions from Africa, India, Latin America, the Middle East, and the Other Asia/Pacific region, coupled with large decreases in emissions from China, North America, and Europe (Fig. 8) indicate that global emissions will increasingly reflect activities in these rapidly growing regions.*

Line 518- *Similarly, global NH_3 emissions from the waste sector increase by 77% between 1970 and 2017, driven by increases in Latin America, the Other Asia/Pacific region, Africa, and India (Fig. S6-S12).*

Line 525 - *Emissions from China are the second largest global NMVOC source between 1996 and 2017 (Fig. 8), while the Other Asia/Pacific region is the third largest source between 1999 and 2017.*

Line 540 - *Figure S17, however, also shows that emissions from coal combustion are simultaneously increasing in India, the Other Asia/Pacific region, and Africa.*

Line 544 - *In contrast, biofuel emissions from all other regions remain relatively flat or increase between 1970 and 2017, though biofuel emissions of NMVOCs, CO, SO_2, and OC in India, as well as SO_2 emissions in North America both decrease between 2010 and 2017 (Fig. S18). In 2017, biofuel*

emissions of all compounds are dominated by emissions from either Africa (NO$_x$, SO$_2$, NH$_3$, NMVOC, BC) or India (OC).

Line 550 - In contrast to other combustion sectors and fuels, emissions of NO$_x$, CO, NMVOCs, BC, and OC from the combustion of liquid fuels and natural gas in China remain relatively flat or slightly decrease between 2010 and 2017. Dominant global regions vary by compound (Fig. S19) and include International Shipping (NOx, SO$_2$), Africa (OC), India (BC), North America (CO, NH$_3$), and the Other Asia/Pacific region (NMVOCs).

Line 559 - Dominant source regions in 2017 of these process level emissions include China (NO$_x$, CO, NH$_3$, BC, OC), India (SO$_2$), and African countries (NMVOCs) (Fig. S20).

Line 903 - Outside of international shipping, China is the largest regional source of global emissions of all compounds other than NMVOCs. As emissions in North America, Europe, and China continue to decrease, global emissions of NO$_x$, CO, SO$_2$, BC, and OC will increasingly reflect emissions in rapidly growing regions such as Africa, India, and countries throughout Asia, Latin America, and the Middle East. Lastly, in contrast to other compounds, global emissions of NMVOCs and NH$_3$ continuously increase over the entire time period. These increases are predominantly due to increases in agricultural NH$_3$ emissions in nearly all world regions, as well as NMVOCs from increased waste, energy sector, and solvent use emissions. In 2017, global emissions of these compounds have the largest regional contributions from India, China, and countries throughout Africa, Asia, and the Pacific.

Compliments to the authors for all the line plots, they are generally really good to read and intercompare and thereby also reveal some issues that appear unlikely to be correct. That does not mean they have to (or even can be) solved in the current paper. There are a few individual cases that draw attention and possibly merit more comments. I like to share them but it is also up to the authors to think about what they feel is justified. I am not advocating to make the paper very anecdotical by discussing every detail. Like the drop in OC emissions for Industry in Figure S6; the CO peak from road transport and SO2 peak for energy in fig S8 (the latter is discussed in the text) - My suspicion is that what such abrupt peaks or drops have in common is most likely a change in legislation or methodology that "on paper" has almost immediate effect but in reality is smeared out over a longer time. For example the car fleet cannot be changed in 1-2 years, cleaner fuels (like low sulphur) generally take years to be completely adopted. NMVOCs from the Energy sector appear a special case (Fig S5) with a very large contribution but little explanation is given other than that these are process emissions. NMVOCs in general draw some attention – e.g. in line 630 there is a discrepancy of possibly missing NMVOC emissions as CEDS has no agricultural NMVOC emission? And, for example Fig3 India NOx emissions – almost a factor 2 difference between 2 CEDS versions. It is commented on in the text but would it also imply it is better not to use the previous CEDS version because of these large deviations? The difference is too large for both to be equally

plausible. This also applies to the discussion in line 568 and onward. As both inventories come from the CEDS team it seems logical to express some advice on to what extend you believe the new inventory replaces the old one. (Like the EDGAR team would advise to use v5 and v3 or v4.)

The Reviewer has highlighted some of the notable features in the region, fuel, and sector-specific line plots in the main text and supplement. These features highlight additional uncertainties in the CEDS system that were not explicitly discussed in the original text: 1) uncertainties and discontinuities in the IEA energy consumption data, and 2) uncertainties in the methodology of the CEDS scaling procedure. To provide a further analysis of some of these features, we have added two paragraphs to the main text that discuss these additional sources of uncertainty. We have chosen to discuss the specific features that the Review has noted as these are some of the most striking and provide a means to illustrate how these sources of uncertainty can impact the final emission estimates. We have added/edited the following text.

Line 676 - ***4.2.1 Uncertainties in Activity Data***
As discussed in Section 2.1, CEDS default emissions from combustion sources are largely informed by fuel consumption data from the IEA 2019 World Energy Statistics Product (IEA, 2019). While this database provides energy consumption data as a function of detailed source sector and fuel-type for most countries, the IEA data is uncertain and includes breaks in time-series data that can lead to abrupt changes in the CEDS$_{GBD-MAPS}$ emissions for select sectors, fuels, and countries. For example, Fig. S6 shows an order of magnitude decrease (0.1 TgC) in OC industrial emissions from North America between 1992 and 1993, which is driven by a break in IEA biofuel consumption data for the non-specified manufacturing industry sector (CEDS sector: 1A2g_Ind-Comb-other) in the United States. While the magnitude of this particular change is negligible on the global scale, this is not the case for all sectors. For example, as noted in Section S4, a known issue in the IEA data in China in the energy sector causes peaks in the associated NO_x and SO_2 CEDS$_{GBD-MAPS}$ emissions in 2004. These peak emissions may be over-estimated by up to 4 and 10 Tg, respectively, which is large enough to impact historical trends in both regional (Figure 8: NO_x and SO_2) and global (Figures6-7: SO_2) emissions. These point to areas where improvements could be made to the underlying driver data in future work.

Line 761 - *In addition to uncertainties in the scaling inventory emissions, uncertainties are also introduced by the CEDS$_{GBD-MAPS}$ scaling procedure. Uncertainties arise when mapping sectoral and fuel (when available) specific emissions between inventories (as discussed previously), as well as in the application of the calculated scaling factors outside the range of available scaling inventory years. For example, the implied CO EFs in Figure S2 highlight one case in China where the EFs for oil and gas combustion in the on-road transport sector peak in 1999 at a value over three times larger than EFs in all other top emitting countries. For China specifically, the calculated scaling factors for the year 2010 (earliest scaling inventory year) are applied to emissions from all years prior, which was calculated as a value of ~1.58 for the on-road transport sector. The implied EF of ~1.8 g g^{-1} for*

this sector in 2003 (Figure S2) suggests that the SF from 2010 may not be representative of emissions during this earlier time period. We do note, however, that the 1999 peak in total CO emissions in China (Figure S9) is driven by the IEA energy data and is consistent with the CEDS$_{Hoesly}$ inventory (Hoesly et al., 2018). In contrast, EFs from this sector in China after the year 2010 agree with the magnitude and trends found in other countries, further indicating that the scaling factors are most appropriate for years with overlapping inventory data. Other similar examples include coal energy emissions of SO$_2$ in Thailand (Figure S2). In this case, the REAS scaling inventory spans the years 2000 – 2008. The default EFs for the energy sector, however, independently decrease between 1997 and 2001. As a result, when the implied EF of 3.3 for the year 2000 is applied to all historical energy emissions, the implied EFs prior to 1997 become an order of magnitude larger than those in nearly all other top emitting countries (Figure S2). Overall, the applicability of the scaling factors to emissions in years outside the available scaling inventory years remain uncertain due to real historical changes in activity, fuel-use, and emissions mitigation strategies. These uncertainties, however, vary by compound and sector as, for example, there are no similar peaks in on-road emissions for compounds other than CO in China.

To answer the Reviewers other specific comments/questions, the CEDS$_{GBD-MAPS}$ inventory does not include agricultural emissions of NMVOCs, nor do the EDGAR or GAINS inventories. In the original Fig. S22, it appeared that the GAINS inventory included AGR NMVOC emissions and that the CEDS inventory did not. There was an error in the color scale of this figure that was displaying GAINS NMVOC solvent emissions as those from the AGR sector. This color scale has been corrected in the new Fig. S24.
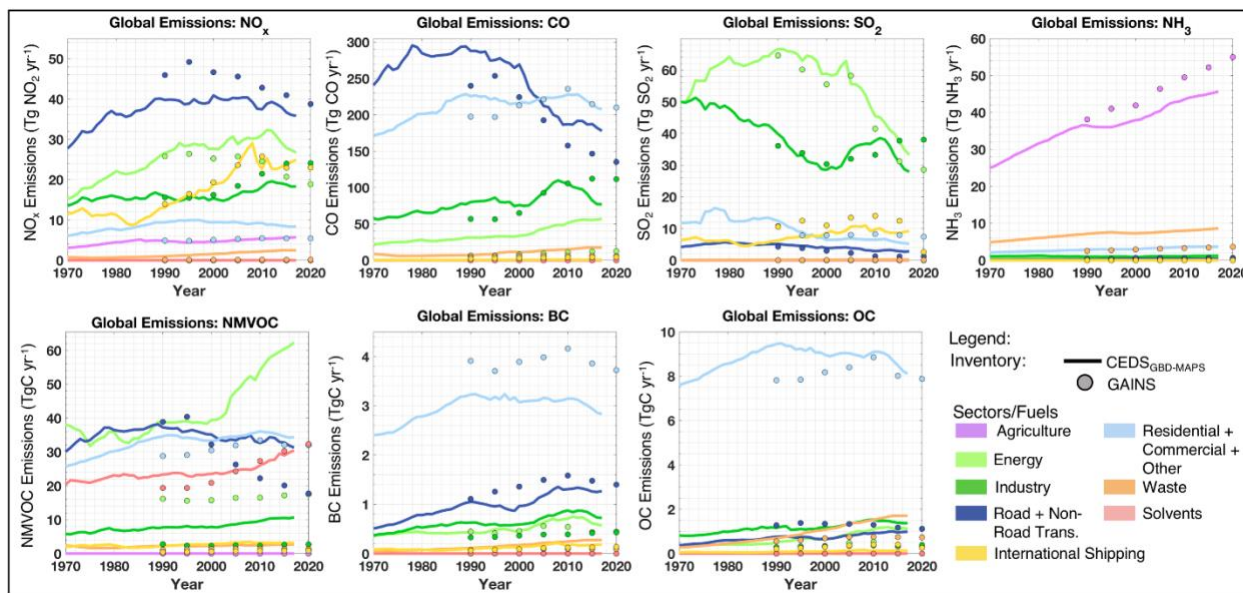

Figure S24.

The increase in energy NMVOC emissions noted by the Reviewer is largely associated with large increases in the Fugitive solid fuels sector in Africa between 2003 and 2017 in the EDGAR v4.3.2 inventory. As these emissions are assigned to the 'process' fuel-type in CEDS$_{GBD-MAPS}$, these emissions are taken directly from the EDGAR inventory. For instance, NMVOC emissions from this sector in EDGAR increased by nearly a factor of 5 in Nigeria during this time period. The source of the increase in this sector has been clarified on the following lines.

Line 347 - *Total CEDS$_{GBD-MAPS}$ emissions of NMVOCs are larger, primarily due to increased contributions from solvent use and the energy sector associated with changes in the EDGAR v4.3.2 inventory, while total emissions of CO, SO$_2$, and NH$_3$ are relatively consistent between the two CEDS versions.*

Line 524 - *Increases in energy sector emissions after 2003 are largely driven by increases in fugitive emissions from select African countries, including Nigeria, Kenya, and Angola, and Mozambique.*

For NO$_x$ emissions in India, the original Fig. 3 shows that CEDS$_{GBD-MAPS}$ emissions are reduced by ~40%, due largely to road emissions. This sector is particularly uncertain in India due to uncertainties in the vehicle fleet. As discussed in Section 2, however, the road emissions in India are scaled to match the recent SMoG-India inventory. As previously discussed in Section 2.2, major difference between the two CEDS inventories for this sector are due to differences in the employed emission factors. We have added additional discussion that note that the scaled implied emission factors are within the range used for the road transport sector in the SMoG-India inventory, further suggesting that the large decrease in road emissions in India are resulting from the smaller NOx emissions factor. As the CEDS$_{GBD-MAPS}$ inventory presented in this manuscript was developed for the GBD-MAPS project (and not an updated release of the core CEDS system) we have discussed the differences between the two inventories in this manuscript, but refrain from making more specific recommendations. We have clarified this point in the Methods section.

Line 159 - *The CEDS$_{GBD-MAPS}$ inventory is developed for the GBD-MAPS project and is not an updated release of the core CEDS emissions inventory.*

Line 648 – "decreasing uncertainties": Here I do not by definition agree. If for example the (more uncertain) emissions from Africa and India become dominant and e.g. the more certain emissions from the US & EU go down, than the overall uncertainty might also increase in future years.

The reviewer raises a good point and we have updated the relevant text accordingly.

Line 695- *While improvements in data collection and reporting standards may decrease the uncertainty in some underlying sources overtime, the most recent years of CEDS$_{GBD-MAPS}$ emissions are still subject to high levels of uncertainty. For instance, the degree of local and national*

compliance with control measures is often variable or unknown (e.g., Wang et al., 2015;Zheng et al., 2018), recent activity and regional emissions data are often updated as new information becomes available, and emissions in generally more uncertain regions, including India and Africa are becoming an increasingly large fraction of global totals. Additionally, from a methodological standpoint, default CEDS emissions after 2010 also currently rely on the projection of emission factors from the GAINS EMF30 data release for sectors and countries where contemporary regional scaling inventories are not available.

A good assessment of uncertainty from a mosaic inventory is very challenging and simply stating that the uncertainty is similar to the other inventories (e.g. line 655) is an unsatisfactory answer. Moreover, there may also be considerable uncertainty in the spatial distribution. The authors, however, announce that in the near future a more robust uncertainty analysis is planned. And a much longer paper would not be helpful for the community. So separating this is an acceptable solution.

As this Reviewer points out, it is challenging to quantify uncertainties in emission estimates, especially for those derived using a mosaic approach. Core CEDS system uncertainties have been previously described in Hoesly et al. (2018), and a more robust uncertainty analysis is planned for an upcoming release of the core CEDS system, as mentioned on line 788. We have provided a summary of the sources of uncertainties in this inventory, including uncertainties in global bottom up inventories (Section 4.2.2), regional-level inventories (including the reported uncertainties in the few studies where they were reported) (Section 4.2.3), sectoral and fuel contributions (Section 4.2.4), as well as those in the gridded emission files (Section 4.2.5). We have also added two additional paragraphs to the uncertainties section as well as an addition supplemental figure of implied emission factors in order to provide a further discussion and analysis of inventory uncertainties.

Additional suggestions for final discussion: Recently Huneeus et al. (2020) published an evaluation of emission inventories for South America which included EDGSAR, ECLIPSE and CEDS. It would be interesting to comment on how the new inventory presented here would have an impact on SA estimates and compares to the CEDS version used in that paper?

In Section 2, we highlight the major updates implemented in this work relative to the previous CEDS$_{Hoesly}$ inventory. These updates will result in differences at the global level (discussed explicitly in Section 4.1.1), regional level (discussed for China, India, and Africa in Sections 2.2-2.3 and throughout Section 4), and in the gridded emission products. From a global perspective, we discuss on line 615 about how differences reflect the different activity data and scaling inventories. Per the Reviewer's question/comment, the updated CEDS emissions in Latin American countries will therefore largely reflect the changes between the EDGARv4.3.1 (used to derived CEDS$_{Hoesly}$) and EDGARv4.3.2 (used for CEDS$_{GBD-MAPS}$), except for in Argentina (see Fig. 2). The Reviewer, however,

has highlighted an important point that we had not provided a comparison to the previous CEDS_Hoesly inventory across all regions. Therefore, we have added Figure S22 to the supplement to highlight the regional inventory differences. Based on this figure, the CEDS_GBD-MAPS emissions in Latin America are slightly lower than CEDS_Hoesly, which would indicate a slight improvement in the agreement with other inventories shown for select Latin American countries in Figure 4 of Huneeus et al. (2020).

We have added the following text to the end of Section 4.1.1: Comparison to CEDS_Hoesly Inventory.

Line 609 - *Similar to the total global emissions, changes between the two CEDS versions for the national-level and 0.5°×0.5° gridded products will also result from updates to the energy consumption data, scaling inventories (Section 2.2-2.3) and spatial distribution proxies from EDGARv4.3.2 (Section 2.1). Time series of differences between the CEDS_Hoesly and CEDS_GBD-MAPS inventories for 11 world regions are shown for each compound in Fig. S22. In recent years, Figure S22 shows that CEDS_GBD-MAPS emissions are generally lower in each region, with the greatest differences in Africa, India and China. The relative changes in Africa and India are discussed previously in Section 2. For China, the CEDS_GBD-MAPS emissions are generally lower than the CEDS_Hoesly estimates after the year 2010 as a result of the updated scaling inventory. Regional differences between inventories are also greater for OC and BC emissions relative to other compounds due to the added scaling procedure discussed in Section 2. Differences in spatial distributions are not discussed here as changes represent differences in the spatial proxies, which are largely from updates to the EDGAR inventory.*
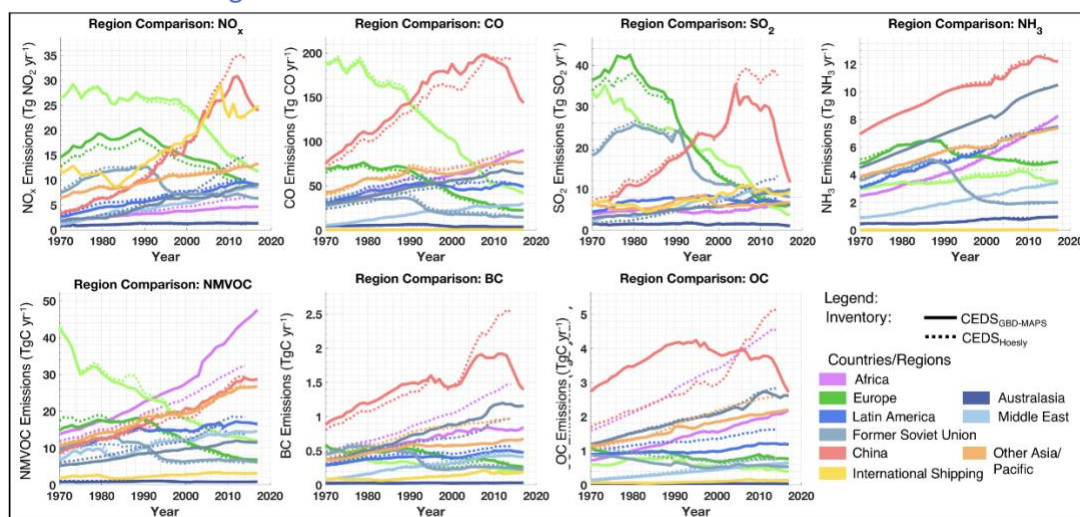
We have added Figure S22.

Figure S22. *Comparison of CEDS_Hoesly and CEDS_GBD-MAPS emissions as a function of 11 world regions.*

SI Line 385 - *Figures S21 and S22 compare CEDS_GBD-MAPS and CEDS_Hoesly emissions.*

Small editorial remarks

Line 42 – from "waste" combustion (otherwise strange to have carb aerosol from waste.)

To keep consistent terminology throughout the text, we have changed to '*the waste sector*'.
Line 39 - *Dominant sources of global CO emissions in 2017 include on-road transportation and residential biofuel combustion. Dominant global sources of carbonaceous aerosol in 2017 include residential biofuel combustion, on-road transportation (BC only), as well as emissions from the waste sector.*

Line 78 – as inputs to solve for? Not clear to me, maybe reformulate slightly?

Updated as follows.
Line 76 - *For example, spatially gridded emission inventories are used as inputs in general circulation/climate (GCM) and chemical transport models (CTM), which are used to predict the evolution of atmospheric constituents over space and time.*

Line 108 – "emission" reduction of coal-fired etc.

Changed

Line 181 – explain the term "working sector"
This terminology is from Hoesly et al. (2018) and refers to the sub-sectors that are carried through the CEDS system calculations and later aggregated for the final reported CEDS sectors. This term was first used 4 lines prior and is now further defined there.

Line 176- *In Eq. (1), emissions are calculated using relevant activity (A) and emission factor (EF) data for each country (c) and year (y), as a function of 52 detailed working sectors (s) (sub-sectors used for intermediate steps in the CEDS system) and nine working fuel-types (f) (Table 2).*

Line 410 – you mean Section S4.

Changed

Line 481 Global emissions of NOx from waste "combustion".

Changed

Line 680 I don't see how satellites will aid in fuel-type recognition.

In this case, we were considering examples such as from McLinden et al. (2016), where top-down estimates from specific point sources could be identified and/or better quantified by incorporating satellite-derived estimates. We did not mean to say that satellite-retrievals will aid in identifying the fuel used by various point sources, but rather that they can aid in reducing the uncertainties for point sources where fuel-type is already known.

Line 684 "emissions" – should be "uncertainties"?

We have clarified this sentence.
Line 732- *The inventories with the largest impact on the CEDS$_{GBD-MAPS}$ emission uncertainties relative to the CEDS$_{Hoesly}$ inventory will be those from China from Zheng et al. (2018), the DICE-Africa emission inventory from Marais and Wiedinmyer (2016), and the SMoG-India inventory from Venkataraman et al. (2018).*

Line 786 – but not for the latest years? And these will not be scaled ("calibrated") so not consistent?

We clarified this sentence.
Line 854 - *These compounds were previously included through 2014 in the CEDS$_{Hoesly}$ inventory.*

Line 791 – it seems the reference of (McDuffie et al., 2020c) here and in the ref list is redundant because this sis the dataset connected to the present paper? So won't the reference to that data not be simply this paper instead of (McDuffie et al., 2020c).

Yes, the dataset is connected to the paper. However, the dataset is also publicly available at Zenodo, which has a unique data doi and is not directly tied to this manuscript. Therefore, the data doi (McDuffie t al., 2020c) is for the dataset. The description of the dataset is provided in this manuscript, which will have a unique doi. Having a data-specific doi will also allow for the creation of new doi's on Zenodo when there are future updates to the CEDS_GBD-MAPS dataset.

Line 836 in agricultural "NH3" emissions

Changed

Line 867 – what is fuel abatement?

Changed.

Line 936 - Due to the direct and secondary contribution of these reactive gases and carbonaceous aerosol to ambient air pollution, contemporary gridded and country-level emissions with both sector and fuel-type information can provide new insights necessary to motivate and develop effective strategies for emission reductions and air pollution mitigation around the world.

There is an error in Table S8 – Other Asia includes Montenegro and I assume Chinese Taipei is Taiwan?

Changed both (Table S8 now Table S9)

There is an error in Table S9 – in the column for EDGAR "solvent use" and "waste" are swapped.

Changed. (Table S9 now Table S10)

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