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Geoscientific Model Development Discussions

Interactive comment on "AerChemMIP: Quantifying the effects of chemistry and aerosols in CMIP6" *by* William J. Collins et al.

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This manuscript will serve as a key reference for those participating in AerChemMIP, a formal CMIP6 activity, which is expected to feed into the next IPCC report. The science goals of this MIP are to address the impact of aerosols and chemically-reactive gases on climate resulting from (1) historical anthropogenic emissions, (2) future policies on climate, air quality and land use, (3) climate feedbacks on natural emissions. AerChemMIP will also address uncertainties associated with anthropogenic emissions. The manuscript lays out the specific simulations needed to address these scientific goals, with a prioritization of which simulations are most critical to ensuring the success of AerChemMIP in achieving these goals.

We wish to thank reviewer 2 for taking the time to make valuable comments on

the AerChemMIP description.

General comments. Overall the paper is well-written, though the final two sections need some editing to help a less-initiated reader parse the jargon as it seems to assume the reader is immersed in all the details of many MIPs past and present. The tables usefully organize the key information that a modeling center needs to decide which experiments they wish to perform.

We will follow the reviewer's suggestion to reduce the jargon in the final two sections.

Based on the tiered rankings in the Tables, it seems that some of the science questions listed in the abstract are higher priority than others and it would be useful to indicate that there are goals that AerChemMIP will certainly achieve, and then others that will be possible to achieve if the modeling community responds with a sufficient set of Tier 2 and 3 experiments. It's important then to provide a strong motivation for answering these questions, and the current phrasing of both questions 3 and 4 could be improved unless the authors feel these are best posed as requiring a yes/no answer? Maybe something like, 'How important are climate feedbacks occurring through changes in natural emissions relative to anthropogenic perturbations of the climate system' ? For Question 3, what aspects of uncertainty are addressed (historical?); isn't the scenario approach of CMIP/IPCC designed to span a range of uncertainty in anthropogenic emissions?

We will rephrase question 4 as suggested by the reviewer. Question 3 will become "How can uncertainties in historical NTCF emissions be mapped onto pre-industrial to present-day changes?" Regarding the tiers, we will add: "We have arranged the experiments into 3 tiers to reflect their priority. Tier 1 experiments are those necessary to answer science questions 1 and 2 in terms of overall impacts of NTCFs and reactive well-mixed gases. Tier 2 experiments will answer question 4 and provide further detail on questions 1 and 2 by separating the ef-

fects of aerosol and ozone precursors. Tier 3 experiments contribute to question 3 and provide additional detail and speciation."

We realise that the 10% perturbations would have imposed extra work on the modelling groups. We have instead added extra single species simulations in section 3.3 in order to cover the main NTCFs. These simulations are also necessary to characterise the individual ERFs fully. This will generate sufficient data to answer the question whilst limiting the computational requests. This section will now read: "The primary focus of this question is to understand the sensitivity of present-day ERF to uncertainties in estimates of the historical NTCF emissions. Indeed, while all proposed simulations rely on the usage of a central estimate, it is clear that there is a range of emission estimates (as discussed in Granier et al., 2011; Smith et al., 2011; Bond et al., 2013) that needs to be considered. While this uncertainty will clearly be region, sector and species dependent, it would be unrealistic to explore the full spectrum of variations. For that purpose, we will make use of the perturbations (pre-industrial to present-day) simulations. This is likely to provide an upper bound on the impact of uncertainties. Results from the simulations can be directly compared to the simulations in section 3.1 and analysed for differences in radiative forcing as well as air quality and overall atmospheric composition. Inter-model differences will document their varying sensitivities to emissions."

While Section 5 is devoted to discussing overlap with other MIPs, it might make it easier for readers and for modeling groups to prioritize their overall contributions to the many CMIP6 MIPs if some of this discussion could be incorporated into the Tables. For instance, it could be noted in a different color or in footnotes which simulations are identical to those requested by other MIPs. Alternatively, the authors may wish to create a new Table based on the information in Section 5 that allows readers to quickly identify simulations from this MIP that overlap with other MIPs. If a group can only perform a limited number of Tier 2 or 3 experiments, they may wish to prioritize

simulations that address multiple MIPs and this would ease their task of identifying those simulations, at least for AerChemMIP.

Notes identifying simulations that overlap with other MIPs will be added to the table captions.

Similarly, it'd be useful to have a table explaining which DECK experiments or simulations from other MIPs are required for participation in AerChemMIP.

The DECK requirements are already described in section 3. The required simulations from other MIPS are already listed in the experiment tables. We will highlight these in the table captions.

Somewhere it would help to articulate the rationale for the Tier categorizations. For instance, why is N2O lower priority than CH4 in Table 2?

N2O is lower priority since its chemical effects are less important than for methane. We will revise the Tier categorisations as follows: "We have arranged the experiments into 3 tiers to reflect their priority. Tier 1 experiments are those necessary to answer science questions 1 and 2 in terms of overall impacts of NTCFs and reactive well-mixed gases. Tier 2 experiments will answer question 4 and provide further detail on questions 1 and 2 by separating the effects of aerosol and ozone precursors. Tier 3 experiments contribute to question 3 and provide additional detail and speciation."

Specific comments.

P2 L5-7. The definition of NTCF given here doesn't seem to align with that from IPCC AR5 WG1 Chapter 8 Box 8.2, which explicitly includes methane as a major motivation for using NTCF versus short-lived climate forcers. It's important to note that methane falls in both WMGG and NTCF categories, at least as defined in the last IPCC report. If the authors are revising this definition, it's important to explain this, particularly as several of the authors were lead authors on this recent IPCC chapter. But on P5 L40,

NTCF emissions include methane.

We will modify the text to include methane.

P3 L5-7, "The knowledge base used to manage air pollution to date must be updated. . .". This seems reversed to me, and in any case the phrasing could be improved. Isn't it rather that air pollution policies are driving major changes in NTCFs and we need to be sure we understand the global atmospheric composition and climate impacts from implementing these policies? With the exception of methane, it's hard to imagine that climate policies are going to have a bigger effect on NTCFs than healthmotivated air pollution policies. Or maybe the authors are simply trying to make point here that the CMIP6 scenarios will be more relevant for air quality planning than the CMIP5 RCPs?

We will revise this text: "CMIP6 will provide comprehensive information on the future large-scale evolution of atmospheric composition thus updating the knowledge base used to manage air pollution."

P3 17-20. "Undiscovered feedback processes. . .' It's not clear what this means. Will AerChemMIP discover these processes?

We will delete the word "Undiscovered"

P4 L15-16. How do we know that the climate forcing from stratospheric ozone is improved?

This will be rephrased: "This has led to substantial improvements in the representation of climate forcing by stratospheric ozone in climate models since the AR4."

P5 Section 2.1. Are the historical emissions going to be the same as what was used in CMIP5?

No. CMIP6 will use an updated historical emission dataset, see https://pcmdi.llnl.gov/projects/input4mips/ and

http://www.globalchange.umd.edu/ceds/ceds-cmip6-data/.

P5 L 28-30 vs L32-33 seem like contradictory statements?

We will improve the text to remove the contradiction: "A detectable regional response to inhomogeneous climate forcing concerns the Southern hemisphere summertime surface circulation changes and is induced by the Antarctic ozone hole as an indirect response to stratospheric ozone depletion from increasing halocarbons. These changes have been argued to lead to changes in the subtropical jet position, rainfall patterns, ocean circulation, and possibly sea-ice cover (Arblaster and Meehl, 2006; McLandress et al., 2011; Polvani et al, 2011). The relative role of these ozone-induced changes for observed Southern hemisphere summertime climate compared to other anthropogenic forcings and natural variability is not fully resolved by the scientific community with some contradictory studies in particular for the Antarctic sea-ice response (WMO, 2014). Hence there is a need for a multiâĂŘmodel ensemble of simulations that resolve stratospheric chemistry to isolate the role of stratospheric ozone depletion."

P6 L5 How do these SSP emission scenarios for air pollution compare with those used from IIASA in the ECLIPSE project (e.g., Stohl et al., Evaluating the climate and air quality impacts of short-lived pollutants, ACP, 2015)?

This discussion will be moved to section 3.2: "The medium strength of pollution control corresponds to following current legislation (CLE) until 2030 and progressing three-quarters of the way towards maximum technically feasible reduction (MTFR) thereafter. Strong pollution control exceeds CLE and progresses ultimately towards MTFR. The rate of progress is different for high, medium and low income countries. Weak pollution controls assume delays to the implementation of CLE and make less progress towards MTFR than the medium scenario. For more details see Rao et al. (2016)."

P6 L12. Please elaborate on what is meant by 'mixed results'.

We will remove the comment on "mixed results"

P6 L14. What are the statistically significant differences between? (2015 versus 2055 or between SSP3-7.0 and SSP3-7.0 with maximum feasible reductions applied?)

This referred to increasing the number of ensemble members, but we will remove this sentence as it is not relevant to section 2.2.

Section 2.3. How will artificially increasing present-day emissions help with quantifying uncertainty? Isn't there more uncertainty associated with the time-evolution of emission changes (i.e., when BC emissions versus SO2 emissions peak)? This question and approach to answering it should be elaborated on.

The reviewer raises relevant issues, some of which are outside of the scope of AerChemMIP, which focuses on uncertainties related to atmospheric chemical processes. AerChemMIP results can then be used in future work to access the influence of time trends (e.g. Smith and Bond 2014, ACP, 14 537–549.). As noted elsewhere in this response, the 10% perturbation experiments have been replaced in order to reduce the modelling burden.

Section 2.4. It would help to provide more rationale for the selection of the 6 sensitivity simulations proposed. While marine biogenic aerosols are noted, only DMS (not organics) is considered. A large climate feedback is likely to be through methane from wetlands and yet that is not mentioned. What about feedbacks via N2O or halogens on stratospheric (and tropospheric) ozone? Maybe this is limited to what processes are typically included in current climate models, or some of these processes are addressed in other MIPs, but this should be stated.

We agree that methane and N2O feedbacks are important, but we do not need extra experiments to characterise these. As noted elsewhere, we will be able to diagnose any changes in, for example, natural methane emissions in the historical experiments due to feedbacks. We will add: "To do this it will be necessary to

quantify the climate response to the heterogeneous forcing patterns from naturally emitted short-lived species (the climate responses to WMGHGs are already covered in section 2.1)."

P7 L12-15 Include this point in the tables so it's very clear that the more complex configuration is always encouraged for AerChemMIP as opposed to preferring minimum configuration for inter-model consistency.

We will add this point in each table: "The "AER" suffix means that at least interactive aerosols are required, interactive chemistry should be active if available."

P7 L35. How realistic are these requests? Is it possible to further prioritize some of the Tier 1 into lower Tiers? How many years are needed for DECK + other MIP simulations needed for entry to AerChemMIP?

We will add the text "This includes 30 years for pre-industrial fixed SST control in common with RFMIP. In addition, models should have been run for the DECK experiments (501 years excluding control) and 3 ensembles of SSP3-7.0 for ScenarioMIP (41 years each)."

P8 L13-14. But does the net impact of NOx emissions depend on how it affects nitrate?

Yes it does. We will clarify this: "even though it will generate both ozone and nitrate aerosol in models."

P8 L20. Where is 'historical' defined?

We will clarify this: "which is a simulation from 1850 to 2014 with all forcings applied (Eyring et al. 2016)"

P9 L8-11. Confusing. Is this assuming everyone is also participating in DAMIP? Explaining this in the tables, or with a new table, would help here.

No, we are just explaining that AerChemMIP does not address responses to homogeneous forcing. Modelling groups are free to choose whether or not they

wish to participate in DAMIP hist-GHG. We will clarify this: "The ERF pattern from these simulations is expected to be relatively homogeneous, although their chemical effects on ozone and secondary aerosols may be less so therefore AerChemMIP does not include any experiments to derive the climate responses to methane or nitrous oxide forcing. The climate response to homogeneous forcing is quantified in Detection and Attribution Model Intercomparison Project (DAMIP) from the hist-GHG simulation (as historical, but only the WMGHG forcings evolve)."

We will also clarify this in section 5: "AerChemMIP is self-contained in so far as the questions posed can be answered by running only the experiments listed here, the DECK and historical. For a full analysis of the past and future climate-composition interactions (including unreactive greenhouse gases) in the CMIP6 chemistry climate models we recommend that as many as possible of the tier 1 simulations of RFMIP (Pincus et al., 2016), DAMIP (Gillett et al. 2016), ScenarioMIP (O'Neill et al., 2016), C4MIP (Jones et al. 2016) and LUMIP (Lawrence et al., 2016) are run with the AER CHEM model configuration and with AerChemMIP diagnostics."

P9 L20 explain the 7.0 next to SSP3. Will this paper be updated to reflect the ongoing discussions with ScenarioMIP? Otherwise should be sure to encourage readers to check the AerChemMIP website.

We will clarify the reference scenario: "we choose the reference scenario to be SSP3-7.0 "Regional Rivalry" without climate policy (7.0 Wm-2 at 2100), (Fujimori et al. 2016)" and will explain that the AIM group are generating the perturbation scenario. "The perturbation experiment to this within AerChemMIP will be generated by the AIM group using the same socio-economic scenario as in Fujimori et al. (2016), but with "Strong" levels of air quality control measures SSP3-7.0-lowNTCF"

P10 L5-6. What exactly is being compared from the previous coupled model simulations with the magnitudes and patterns of ERF?

We will clarify this: "Comparison between the magnitudes and patterns of ERF with surface temperature and precipitation from the previous coupled model simulations will allow quantification of the efficacy of the NTCFs to affect climate."

P10 L7. What are the different groups of NTCFs?

We will clarify that these are "emissions (aerosols, ozone precursors, black carbon)"

P10 L8-9. Methane isn't Tier 1 – why?

The ERF of the methane change will approximately scale with concentration, and so could be derived from histSST-piCH4 or piClim-CH4. The ssp370SST-lowCH4 simulation will however provide extra information on non-linearities and the air quality benefits from methane mitigation under the SSP3-7.0 scenario.

P10 L13. How is land use affecting NTCFs? Do these models have their NTCF emissions tied to specific land-use categories imposed in the model? How would this work for groups using MEGAN driven by present-day base emission capacity maps?

We will clarify this: ". . . **for models which include interactive schemes for emission and deposition. Not all models will model all these processes interactively."**

General question on Section 3.2.2 versus 3.3. What is the difference between ERF simulations and prescribed SSTs? Can these terms be used interchangeably?

We will refer to the quantities in section 3.2.1 (and 3.1.2) as "transient ERFs" to distinguish them from the ERFs in section 3.3. We will also add text to section 3.3: "These simulations differ from the transient ERF simulations in 3.1.2 in that they use pre-industrial SSTs and maintain the same emissions (or concentrations) for 30 years. They therefore give a more accurate representation of

the pre-industrial to present ERF than would be obtained from portions of the transient historical ERF simulations."

P11 L9-11. How good is the assumption of the same climate response to ERF from any species?

The feedback parameters calculated here (in W/m2/K) don't make any assumptions about the climate response to ERF. How these parameters are then subsequently used would depend on assumptions made, but that is moving out of the scope of this paper.

Section 4 is clearly written assuming the reader has some knowledge to parse all the jargon and may benefit from re-organization. It might help to include a table translating 'Mon3d', 'Mon2d', etc. What is 'MonDay2d' – typo? It gets even worse in Section 4.1

We will rewrite this section avoiding jargon and using the recently agreed CMIP6 nomenclature

P12 L5-6. What is COSP simulator data? Similarly, the long section 4.2 might be possible to shorten by moving information there to an appropriate table.

We will add text to explain what the COSP simulator is: "To facilitate the exploitation of A Train satellite data in numerical models, a system has been developed that allows simulation of the signal that CloudSat/CALIPSO would see in a model-generated world. It is a flexible tool to simulate active instruments in models (climate, forecast, cloud-resolving)."

P12 L35-38 seems to jump from talking about quantifying natural emissions to anthropogenic. Aren't separate diagnostics needed for natural versus anthropogenic? Please clarify.

This was trying to explain that we would ask for total and anthropogenic emissions (from which we could calculate natural). The anthropogenic emissions are specified by CMIP6, so we will modify these sentences to say that we ask for

total emissions and assume anthropogenic emissions are as CMIP6.

P14 L9. What are these new transport tracers? Define them in a table or a separate section to call attention to modelers that they may need to add some new development to participate in some of the science for this MIP?

We will add a link to the definition of these tracers: "In addition, two artificial transport tracers will help to track changes in tropospheric transport between hemispheres (aoa_nh and nh_50; see definitions in the CCMI-1 data request at http://blogs.reading.ac.uk/ccmi/data-requests-and-formats/)."

P14 L9 and L15-16 repeat requests for loss rates of methane, CO, N2O.

Thank you. This repetition will be removed.

P15 L26-30. Why can't the DAMIP and AerChemMIP requests be the same to reduce the number of requests to modeling groups?

The only overlap is between hist-piAer (AerChemMIP) and hist-aer (DAMIP). The DAMIP protocols will not work for interactive ozone chemistry. For historically evolving NTCF and ODS runs the chemistry will need to see historically evolving methane and N2O concentrations in order to reproduce the historical ozone evolution, whereas in DAMIP these are fixed to PI levels. The stratospheric temperature differences between PI and present would also mean the DAMIP setup would fail to reproduce the present day stratospheric ozone when running their hist-stratO3 experiment with interactive chemistry.

P16 L20 what is 1pctco2 / abrupt4co2?

This will be explained: "...the DECK 1% yr-1 CO2 (1pctco2) or 4$\times$CO2 (abrupt4co2) simulations..."

Figure 1. Not sure the figure adds much beyond what is in the Table, and it's hard to read. Consider converting to a regular table.

We will convert this to a regular table.

Figure 2. This implies that the net impact of air quality controls are to lower surface temperature, but wouldn't reductions in aerosols actually warm in the near term? Is warming from aerosol reductions being offset by substantial methane controls here?

This schematic originally assumed methane controls as well, but it will be redrawn to show a warming from aerosol mitigation.

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