

This paper presents a technical overview of the models and simulations that contribute to the Chemistry-Climate Model Initiative (CCMI). In particular, the authors highlight changes and improvements to the models since CCMVal-2.

This paper contains a vast array of useful information that I anticipate will be widely used as a point of reference by many in the chemistry-climate modeling community. I recommend publication after my comments below have been addressed.

General comments

1. Firstly, I suggest some structural changes - mainly in Section 3 and related Tables - to enhance readability. A few points:

(a) Why is Section 2 standalone? Why not use this as an introduction in Section 3, (since both sections describe model details)? Then, the paper would be neatly partitioned into sections describing model details (Sect. 2), simulations (Sect. 3) and forcings (Sect. 4).

(b) I do not find the ordering sensible of Sect. 3 sensible. It is currently difficult for a reader to quickly obtain information about any particular aspect of the models. How about ordering such that similar subsections appear close together, especially since there are so many of them. For example, consider the ordering below (but feel free to make changes around this general idea):

-Grid and numerical methods: general model makeup, model resolution, advection, timestepping and calendars, horizontal diffusion

-Dynamical and physical processes: QBO, gravity wave drag, physical parameterizations, cloud microphysics

-Chemistry, aerosols, radiation: trop chemistry, strat chemistry, heterogeneous chemistry, PSCs, trop aerosols, volcanic effects, photolysis, SW, LW, solar forcing

-Coupling / other boundary conditions: ocean surface / ocean coupling, land surface

(c) The tables in the Supplement should more or less follow the above order. Consider also adding an explicit sentence at the beginning of each subsection that references the appropriate supplemental table e.g. 'Table Sx shows ...'.

(d) Similarly, in Section 4, I would re-order such that the simulations in which one set of boundary conditions is kept fixed (fGHG, fODS, fEMIS, fCH4, fN2O) appear together, as do the simulations in which time-varying perturbations are applied (C1-Emis, C2-RCP, C2-GeoMIP, C1-SSI, C2-SolarTrend).

2. My second general point is to include more detail throughout the paper. This includes, but is not limited to, my questions in the Specific comments below. This also applies to Table captions (including expansion of abbreviations); the reader cannot be expected to reference the CCMVal-2 report. Finally, this applies to Appendix A e.g. no details on the chemical species or mechanisms is not provided for most models; I understand that this is might be a tough task given the large number of different modeling groups involved. On that note, I do commend the authors on well documenting the changes in each model since CCMVal-2.

Specific comments

I organize the following points primarily by section, and page/line number where necessary:

(3.1) General model make-up:

-I'm not entirely sure about the point of this subsection. Much of it could be neatly partitioned elsewhere. Perhaps just include some general comments on the components/coupling in the models and retain the text on familial relationships.

-First few lines are repeated in Section 3.12 (Ocean Forcing). Could remove details here and reference that section.

-P3 L20: 'the impact of ozone depletion on surface climate is represented consistently': a bit unclear. Consider making a broader statement (first): 'surface

climate is able to respond to changes in atmospheric composition, some of which may be considered climate feedbacks', or simply make the point that climate feedbacks are self-consistently incorporated.

-P3 L28: would make sense to include grid details with model resolution (Sect. 3.2).

(3.2) Model resolution:

P4 L9: from Table 3, it looks like CNRM-CM5-3 and TOMCAT also do not completely cover the stratosphere (I'm defining a stratopause at ~50km, 1hPa).

(3.3) QBO:

-P4 L15: '...which means the QBO may not require explicit forcing to occur in the models, or it may be absent': I don't understand this sentence. Please clarify.

-Mention which models do not have a QBO at all and which (few!) internally generate a QBO either in the text or tables.

(3.4) Volcanic effects:

-Clean up slightly: highlight, in turn, which (or how many) models include (a) online volcanic aerosols, (b) impose offline aerosols (heating rates) and (c) do not have any representation of radiative effects from volcanic aerosols. This will correspond much better with Table S4.

(3.5) Advection:

-Expand on the 'different settings for hydrological and chemical tracers' in the MetUM models or add reference.

(3.8) Tropospheric aerosols:

-Combine this section with Sect. 3.21.

-Would it be worth mentioning the main tropospheric aerosol species / heterogeneous reactions included in the models?

(3.9) Stratospheric chemistry

-P5 L28: 'to lump all': is it really all, or most?

-Reference for how Cl source gases are lumped?

-Are Br source gases also lumped in some cases?

-P5 L30: reference for the recommendation for Br species?

-Besides halogen chemistry, can you briefly describe the differences/commonalities in stratospheric chemistry between the models? E.g. how is CH₄ oxidized to stratospheric water vapor in the models?

-How is stratospheric chemistry represented for the models that do not cover the full vertical extent of the stratosphere?

(3.11) Strat/trop heterogeneous chemistry

-Provide more details of SO₂ → SO₃ oxidation (e.g. is it with interactive or offline oxidant fields?).

(3.15) Cloud microphysics

-P8 L10: Add reference(s) to first sentence.

(3.15) and (3.16)

-Little detail provided on cloud and land surface schemes - elaborate if practical.

(3.17) PSCs

-For the non-expert, elaborate on what is calculated assuming 'thermodynamic equilibrium'. Can mention formation of NAT/ice PSCs, and how these differ between models.

-It would make sense for this section to be near Sect. 3.11 (heterogeneous chemistry)

(3.22) Ocean coupling

- This section should be combined with Sect. 3.12 (ocean surface forcing) or appear close to it.
- Mention also the sea ice modules / boundary conditions here.

(3.23) Solar forcing

- In cases where SW radiation and photolysis are not handled consistently, what are the radiation schemes for photolysis? For these photolysis schemes, can we assume the effects of the 11-yr solar cycle are not included?

(4) CCM simulations

- P10 L15: 'Forcings are discussed briefly...' -> 'The specific forcings imposed are discussed briefly...'
- P10 L18-20: This sentence is very unclear and should probably be separated into at least 3 sentences. Do you mean that ODS concentrations (or EESC), rather than emissions, peak around yr 2000? Which 'industrial emissions' do you mean? Separate the discussion of GHGs from ODSs and the other 'emissions' that are referred to. Should this sentence be in the Forcings section?
- P10 L22: clarify that SD stands for "specified dynamics".
- P10 L22: differences in dynamics between nudged and free-running models are not necessarily due to inherent dynamical biases in the model; they could also be due to the greater presence of internal variability in the free-running case.
- P11 L3: which emissions?
- P11 L5: I'm confused as to the exact forcings imposed here: GHGs? SSTs and sea ice for models not coupled to an ocean? ODSs (including those that are not GHGs)? NOx? NMHCs?
- P11 L9: 'sea surface' -> 'sea surface and sea ice'.
- P11 L11: only surface emissions, or also 3D emissions (e.g. aircraft NOx)?
- P11 L15: clarify that SSI stands for Spectral Solar Irradiance.

(5) Forcings

- P12 L1-2: clarify that N2O and CH4 boundary conditions refer to surface mass mixing ratios.
- P13 L9: add reference.
- P13 L14: 'cause NOx emissions to peak and then decline' - clarify that this is only an assumption for the future.
- P13 L26: reference for MEGAN model
- P13 L19-30: which dataset(s) is/are used for historic emissions in which biogenic emissions are not interactively computed?
- P14 L10: reference appropriate table
- P15 L1-15: much of this information is provided in Sect. 3.21. Instead of repetition, talk here about the time series of aerosol precursor emissions (e.g. the projected reduction in future aerosol emissions over certain regions as with ozone precursors).

Tables

- Table 2: Is it possible to list (alongside the model names) the versions used for CCMVal-2, and, where relevant, the name of the ESM? Right now, there is little consistency.
- Table 4: caption: state that the numbers in the table stand for (I'm guessing) the number of ensemble members.
- Table 5 and 6: why are some numbers in bold and in brackets? What does L39 stand for?
- Table S2 caption: clarify that the numbers represent number of grid boxes.
- Table S5 caption: expand on abbreviations used in the table e.g. SL = semi-lagrangian etc.
- Table S5: for CESM models, CAM4 describes the atmospheric component but not the transport scheme (is it SL? please check.)
- Table S26: would make sense to keep this next to Table S5.

All tables: please try to find more references for each model (e.g. for the aerosol schemes in Table S4).

Appendices

-P22 L22-24: The two first sentences are already mentioned in the previous paragraph.

-P23 L15: citation for Wesely scheme.

-P25 L29: why are two of the simulations in bold?

-P26 L24: elaborate.

Technical comments

-P4 L12: misspelled 'oscillation'

-P5 L18: 'included' -> 'include'

-P5 L27: 'Unified Model' -> 'MetUM' for consistency

-P9 L2: Remove comma after 'table S17'

-P10 L8: 'increasing' -> 'increasingly'

-P19 L13: "Earth'" -> "Earth's"

-P24 L18: 'CTM be' -> 'CTM can be'

-Table S3 caption: 'CCM name' -> 'model name'