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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Emulating IPCC AR4 atmosphere-ocean and carbon cycle models for projecting global-mean, hemispheric and land/ocean temperatures: MAGICC 6.0" *by* M. Meinshausen et al.

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Response to Anonymous Referee 2

General remark (same for both reviewers):

First of all, an important general note: We are fully aware that this response comes very late, beyond the standard turnaround times for ACP. Nevertheless, we believe that this comprehensive model documentation and application is of considerable interest for future applications of MAGICC, which is why we would like to ask the editors and reviewers to accept our sincere apologies for this lateness. In the course of the two years, the described model parameterisations have been shown to be robust in the multiple model applications that followed our first draft manuscript. Thus, no changes had to be made to the substantive part of the model description.

There are, however, three major revisions that we have implemented:

a) We followed the recommendation of reviewer 3, and split up the paper into two, a “model description and calibration” paper (Part I) and an “application” paper (Part II).
b) We have updated the application examples. We noted previously the potential future use of MAGICC for forthcoming intercomparison exercises. MAGICC has indeed been used to assist in the design of the RCP pathways that will be the basis for model simulations under CMIP5. We have therefore included the use of MAGICC in the RCP process as one additional application example in Part II.
c) We have now included a section (Section 6.2 in Part I) on possible alternative explanations for increases in the effective climate sensitivity over time – following the suggestion of reviewer 2.

We believe that we have been able to address all reviewers’ comments, as detailed below. We are truly thankful for the time spent by both reviewers, and for their insightful comments that have helped to improve the paper(s).

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Reviewers comments are provided in italics, our responses in normal font.

REVIEW COMMENT: General comments: The full documentation of the updated MAGICC 6.0 model is important since this model will likely be relied on in future IPCC assessments to interpolate and extrapolate results obtained from more complex atmosphere-ocean general circulation models (AOGCMs) and earth system models (ESMs, e.g., AOGCMs coupled to carbon cycle models) to cover a wider range of emission scenarios. MAGICC has been modified in a number of ways to account more realistically for processes represented in ESMs. These improvements enable MAGICC to better emulate the time-evolving global-mean, hemispheric and land/ocean temperatures and well as carbon fluxes and reservoirs simulated by the CMIP3 and C4MIP models. These days one can only rarely find full documentation of any model in the published literature, so this article is a welcome addition, even though most readers will find it rather dense. As far as planning for future model intercomparisons, it is clear from this article that there is considerable value in obtaining more accurate estimates of radiative forcing from the AOGCMs, in order that better estimates of climate sensitivity can be obtained.

Reply: As the reviewer notes, in CMIP5 and future intercomparison exercises, more comprehensive forcing information would be highly desirable, not only to assist in the calibration of simple models, but also to improve our understanding of key components of ESM/AOGCM temperature projections. The importance of this is further emphasized in our revised papers.

REVIEW COMMENT: Specific Comments: Three options for tuning MAGICC to emulate the AOGCM results are provided, starting with one that adjusts only three parameters. Although tuning the additional parameters as specified in the second and third options improves the emulation for a few of the models, in others there is

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only marginal improvement. Given the large uncertainties in the forcing pointed out by the authors, one wonders whether the discrepancies found in the simply tuned case might be explainable by other factors. One such factor might be the recently discussed "tropospheric adjustment" (Gregory and Webb, 2008, cited by the authors), which accounts for fast tropospheric responses to forcing that are seemingly unrelated to the slower changes of temperature governed primarily by the ocean surface layers. In a subsequent article (published after submission of the article under review here), Williams, Ingram, and Gregory (2008; J. Clim., doi:10.1175/2008JCLI2371.1) suggest that "much of the apparent variation in effective climate sensitivity identified in previous studies is actually due to the comparatively fast forcing adjustment." Thus, a redefinition of the forcing may mean that at least two of the additional parameters would not need to be adjusted, since they only were considered to account for apparent changes in climate sensitivity. This highlights the importance of obtaining accurate estimates of properly adjusted radiative forcing.

Reply: This is indeed a vital point and it will be worthwhile to investigate this alternative approach in more depth in the future. However, at this stage, there are various complications that make switching to a framework of ‘effective radiative forcings’, and ‘constant climate feedbacks’ difficult. For example, there is only a very limited set of idealized instantaneous forcing experiments available. Thus, it would be impossible at this stage to estimate the fast forcing adjustments for the majority of CMIP3 AOGCMs. For the decadal forcing adjustments investigated by Williams, Ingram and Gregory, the constant feedback parameter as well as the effective forcing could be estimated using a simple regression of R onto T. However, under such a framework, the emulation skill under scenarios with changing forcings might be compromised, as highlighted by the discussion of forcing adjustment function G by Williams et al. In order to address the reviewer’s comment, we have inserted a new subsection on this issue into our manuscript, reproduced here below:

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Forcing adjustments as an alternative approach to time-variable climate sensitivitiy

This subsection discusses a potential alternative approach to explain and emulate phenomena currently represented by time-varying climate sensitivities. A number of recent studies suggest that there are relatively fast forcing adjustments following an increase in CO2 forcing (Andrews and Forster 2008; Gregory and Webb 2008; Williams et al. 2008; Doutriaux-Boucher et al. 2009). Time-varying sensitivities might therefore be considered "an artefact of using conventional forcings" (Williams et al. 2008).

Part of the debate may be a terminology issue, i.e., defining what is a forcing and what is regarded as a feedback. For example, cloud effects follow tropospheric temperature and lapse rate adjustments, before noticeable changes are apparent in surface temperatures, and the question is: are these to be regarded as an indirect forcing effect or a feedback? Assuming that forcings and feedbacks could be freely redefined, then estimating a forcing value by regressing surface temperature changes against the top of the atmosphere radiative imbalance (Gregory et al. 2004) will, by construction, lead to a less time-variant diagnosed feedback parameter. However, a constant feedback that works well for medium to longer-time scales of forcing may come at the cost of not being able to emulate sufficiently well the first decades of climate response. In this respect, Williams, et al. (2008) propose a time-varying forcing adjustment function, G, to emulate the initial response more closely, if the feedback parameter is assumed constant. Thus, although having gained the advantage of a simplified representation for longer-term idealized stabilization scenarios, emulating the response to more realistic scenarios with changing forcings might be equally cumbersome. Given that these forcing adjustments seem to be highly model-dependent (see e.g. Table 2 in Williams et al. (2008)), the theoretical beauty of distinguishing between model-independent forcing and AOGCM-dependent feedback and inertia parameters is lost.

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Of practical importance is whether alternative parameterizations will lead to improved emulation skill. Parameterizations based on short-term forcing adjustments could, for example, have substantial advantages, if they strongly differ among forcing agents. Rather than taking into account efficacies of the conventional forcings (as this study does), one could take any fast semi-direct and indirect forcing adjustments explicitly into account. However, if time-varying climate sensitivities can be adequately calibrated in simpler models across a range of scenarios, then the emulation skill for the climate response would be no worse in comparison to an approach where fast forcing adjustments are taken into account, but with assumed constant climate sensitivity. In reality, both fast forcing adjustments and time-varying or climate-state dependent feedbacks will be at play and more research is needed to gain a better understanding of these phenomena.

Recently, Doutriaux-Boucher et al. (2009) pointed to an indirect forcing mechanism that is specific to CO2: namely, the physiological response to increased CO2 concentration by plants via stomatal conductance changes leading to a CO2 forcing enhancement of roughly 10%. This is because the resulting reduced evaporation over land areas (in their analysis) induces a reduction in low cloud cover, which then has the forcing effect. If this is found to be a robust effect, future versions of MAGICC will attempt to include it explicitly.

We anticipate that further studies into the fast and longer-term forcing adjustments will help to refine the optimal parameterizations required to emulate AOGCMs in the future.

REVIEW COMMENT: Technical corrections/suggestions: page 6164: "allows to a better" should read "allows a better" page 6231 (Acknowledgements): "B. Santers"

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should read "B. Santer". figures: several figures cannot be read unless they are zoomed in on (by a factor of 4). It would be nice if several of these were enlarged, so that when they are printed out normally, they would be clear.

Reply: We implemented these changes – However, some figures continue to contain detail, which we consider of value for the interested reader.

References:

Andrews, T. and P. M. Forster (2008). "CO2 forcing induces semi-direct effects with consequences for climate feedback interpretations." Geophysical Research Letters 35: L04802.
Doutriaux-Boucher, M., M. J. Webb, J. M. Gregory and O. Boucher (2009). "Carbon dioxide induced stomatal closure increases radiative forcing via a rapid reduction in low cloud." Geophysical Research Letters 36: L02703.
Gregory, J. M., W. J. Ingram, M. A. Palmer, G. S. Jones, P. A. Stott, R. B. Thorpe, J. A. Lowe, T. C. Johns and K. D. Williams (2004). "A new method for diagnosing radiative forcing and climate sensitivity." Geophysical Research Letters 31(3): -.
Gregory, J. M. and M. Webb (2008). "Tropospheric Adjustment induces a cloud component of CO2 forcing." Journal of Climate 21(1): 58-71.
Williams, K. D., W. J. Ingram and J. M. Gregory (2008). "Time variation of effective climate sensitivity in GCMs." Journal of Climate 21(19): 5076-5090.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 6153, 2008.