gmdd-7-C2642–C2644,-2014, Development of the GEOS-5 Atmospheric General Circulation Model: Evolution from MERRA to MERRA2.

Response to Reviewers

Reviewer 2

In this manuscript the authors disentangle the development from one version of an atmospheric model to the next. This is something that is not often done, but the resulting information is useful for both users of the model and derived products, as well as for developers of other models that can find inspiration in their work. To be complete, I would add some tabulated global means of fluxes, precipitation, cloud cover/liquid/ice, etc. for the various runs.

We thank the reviewer for the recognition that the sort of "disentangling" of model development is rarely done but quite useful. We have added a summary table of global values of precipitation, column cloud water and ice, and surface turbulent and radiative fluxes.

My main problem with reading the manuscript is that the authors take their new model as a starting point, and then back-track towards the old model. This is confusing because as the reader you naturally think forwards and not backwards, i.e. the effect of improving ocean surface roughness is this and that. Another general issue is the figures which need improvement. I provide several suggestions below.

We recognize that it would have been interesting and perhaps even more intuitive for some readers if we had written the manuscript presenting the experimental results from the "oldest model" to the "newest". We believe, however, that the sequencing through the results of the experiments as presented is valid as well, as the main point is to identify the differences between any set of two experimental results and attribute them to a specific change in the model physics. In addition, the task of re-ordering the presentation of experiments entails a fundamental rewrite of all of the results sections of the manuscript and a regeneration of almost all the figures. We will therefore retain the ordering of the manuscript.

The figures that needed improvement were modified, and the captions were corrected.

Comments:

Section 3.3 got fairly confusing, partly because of the back-tracking issue, partly because the authors seem to define heat-flux positive upwards (which is fairly uncommon). If anything the Louis-scheme is among the more diffusive, which is also seen by the fact that the model hardly visits the very stable regime. Thereby sentences such as "indicating less sensible heating when using the Louis scheme", if not incorrect, become fairly difficult to comprehend.

Some additional text has been added to this section to make more clear which turbulence models are used in experiments 2 and 3. The Louis (1979) scheme was used in the MERRA AGCM for the surface layer turbulent fluxes only, and was replaced in the MERRA2 AGCM with the Helfand and Schubert (1995) similarity theory based scheme for surface layer turbulent fluxes. The change in parameterizations, therefore, being evaluated in this section, is due only to the change in the algorithm for the surface layer turbulence (the bottom model level only, the constant flux layer). In addition, the fundamental differences between the two schemes are the choice of stable layer similarity functions and the implementation of the laminar viscous sublayer. This has now been elaborated in the text. The turbulent diffusion above the surface layer is modeled in ALL versions of GEOS-5 with a combination of the Lock scheme and the Louis and Geleyn (1982) scheme.

The sign convention for turbulent surface fluxes (positive upward) is the convention for atmospheric budgets and modeling and so was chosen for this study. Modeling studies (Donner et al., 2011; Pope et al., 2000; Neale et al., 2013 for example) and observational studies (Shie et al., 2009) also use this sign convention.

Our results indicate that of the two surface layer schemes discussed here, the sensible heat flux simulated when using the Helfand Monin-Obukhov scheme is generally higher, as shown in figure 6.

Section 3.5 is also difficult to comprehend for the uninitiated. I would suggest to add a better description of the parameterization, and to use a different figure to display the effects. The annual cycle of the zero-wind contour is not something that the most readers will be familiar looking at.

The time series of the zero-wind contour of the zonal wind, either at 60S or averaged from 50S to 70S, is used in many studies to examine the timing of the breakup of the southern hemisphere stratospheric jet. Some studies that present the timing of the jet breakup in this manner are Eyring et al. (2006) and Garfinkel et al (2013).

It may be worthwhile to contrast the strategy to limit convection at higher resolutions with alternative strategies to enhance the parameterized convection to avoid explicit convection (e.g. Bechtold et al. 2008, QJRMS, their equation 3).

Some discussion of other strategies to change the parameterized convection with resolution has been added to section 4. This includes the Bechtold et al. (2008) approach as well as the approach of Arakawa and Wu (2012).

The figures are all plotted using the rainbow colour scale, which is an unfortunate choice for a number of reasons elaborated here: http://www.climate-labbook.ac.uk/2014/end-of-the-rainbow/.

The objection to the rainbow color scale by the reviewer and by the authors of the climate lab book is noted. We do not find the shaded plots in this manuscript to be misleading, however, due to our use of the chosen color scale, as was suggested in the online article referenced by the reviewer.

Beware that acronyms must be defined.

The manuscript was re-read with this in mind. We believe that all acronyms are now defined (the acronym 'GEOS' was not defined in the original manuscript).

7576, 11 The term "nature run" is unspecific and not used later.

The term was removed.

7577, 27 I would avoid using hyphens, here and in most other places.

This line of text in the introduction does not contain hyphens. A hyphen was found on line 3 of this page (1-2 degree) and was removed. The hyphens in the following paragraphs used a line continuation markers, they were inserted by the GMDD typesetting.

7580, 17 'changes at a time'

The correct syntax, we believe, is "….one parameterization change at a time…". Later in the sentence we refer to "…small groups of parameterizations at a time…."

7584, 20, In my book a higher critical RH should give you less cloud fraction. If the model behaves differently then this is worth an explanation.

A higher RH crit results in two potentially competing effects. The requirement that the atmosphere must have a higher relative humidity before condensation can take place could indeed result in reduced cloud cover. The higher RH crit, however, also leaves behind an atmosphere with a higher relative humidity, which would be associated with increased cloud cover. One of these two effects may dominate, or they may cancel and the result would be no change in cloud cover. The results shown here demonstrate that the latter of these two effects is dominant in the GEOS-5 AGCM. It is not clear to the authors, however, precisely why the atmospheric relative humidity increases beyond the change in RH crit. We speculate that it may be related to the sequencing of the macro- and micro-physical processes in the moist parameterization combined with the enhanced rates of rain and condensate re-evaporation, leaving behind an atmosphere which is no longer in equilibrium with the specific RH crit (wetter in our case). These issues are typical of AGCM moist parameterizations, as can be seen in the complex sequencing described in Gettelman et al. (2015). Some text was added to the manuscript to explain this interplay.

7586, 13 What is SD?

SD was replaced with "standard deviation"

7588, 3 It is 'ERA-Interim' here and elsewhere.

This was corrected here and elsewhere

7589, 4 'severely'

Corrected

Table 2, What is Fortuna AGCM?

References to Fortuna AGCM have been removed from the captions for Tables 1 and 2.

Figure 1. It is odd that the data shown in panel a (up to 0.001) is not visible in the lower left part of panel b).

The original Figure 1b was from an experiment with the upper limit in place but without the change in the lower wind regime. Figure 1a was removed altogether, and a single scatter diagram is shown spanning the entire range of wind speeds, reflecting the change in the middle range and at high wind speeds.

Figure 2. Panels b and e show the same thing.

The figure was changed to show only one copy of the "observed" panel.

Figure 9, panels a and b are the same.

Panel b) was replaced, and now shows the results from experiment 4.

Figures 11-14 are too small to be readable in print.

The size of figures 11 and 14 was increased.

Figure 15, caption does not reflect the displayed quantity.

The caption was changed to reflect the display of the zero wind contour.

Figures 16-17, panels b, e and h can be deleted.

The two figures were combined, removing the rows of "model" and "observation" panels from both and showing only the differences between the model and verification at each resolution for each version of the model.

References:

A. Arakawa and C.-M. Wu, 2013: A Unified Representation of Deep Moist Convection in Numerical Modeling of the Atmosphere. Part I. *J. Atmos. Sci.*, **70**, 1977–1992. doi: http://dx.doi.org/10.1175/JAS-D-12-0330.1

Garfinkel, C., L. Oman, E. Barnes, D. Waugh, M. Hurwitz and A. Molod: Connections between the Spring Breakup of the Southern Hemisphere Polar Vortex, Stationary Waves, and Air–Sea Roughness. *J. Atmos. Sci*., **70**, 2137-2151. doi:10.1175/JAS-D-12-

0242.1

Gettelman, A., H. Morrison, S. Santos, P. Bogenschutz, and P. M. Caldwell, 2015: Advanced Two-Moment Bulk Microphysics for Global Models. Part II: Global Model Solutions and Aerosol–Cloud Interactions. *J. Climate*, **28**, 1288–1307. doi:http://dx.doi.org/10.1175/JCLI-D-14-00103.1

V. Eyring and co-authors, 2006: Assessment of temperature, trace species, and ozone in chemistry-climate model simulations of the recent past. *J. Geophys. Res.*, **111**, D22308, doi:10.1029/2006JD007327.