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Interactive comment on "Assessing the CAM5 physics suite in the WRF-Chem model: implementation, evaluation, and resolution sensitivity" *by* P.-L. Ma et al.

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Response to comments from Reviewer #2

The authors made a laudable effort to implement the CAM5 physical parameterization package, including deep and shallow convections, turbulence scheme, aerosols, cloud microphysics, and cloud fraction into the WRF-Chem. They made this physics package available to the community as an option in the WRF-Chem. This reviewer appreciates the large amount of work that has been accomplished.

Reply: We thank the reviewer for the positive comments.

The paper describes the implementation of the porting of the physics packages, its evaluation relative to CAM5 and against field campaign data in April 2008, the resolution sensitivity of the simulations, and comparison with a standard version of the WRF-MESO. While the paper presented many valuable results, this reviewer has two major concerns that need to be addressed for the paper to be formally accepted for publication.

Reply: We address the reviewer's comments point-by-point below.

Major comments:

First, the title and the abstract of the paper gave people the false impression that the WRF-Chem with the CAM5 physics package has been evaluated. What the paper actually evaluated was for a very special case at high latitude in cold season about aerosols where synoptic-scale atmospheric transport dominates but the convection schemes and the boundary scheme likely play very minor roles. It is difficult to judge from this paper whether the porting of the convection schemes is working as expected. It would be ideal if the authors can include a convective case. If not, the title and the abstract of the paper should be revised to clearly state the limitations of the paper.

Reply: The scope of this paper is to provide the documentation summarizing the implementation of the CAM5 physics package in WRF-Chem, with a first evaluation of the model for this testbed case. Note that our domain covers almost the entire North Pacific Ocean, which is much larger than most regional atmospheric chemistry domains. The first paragraph of Section 4 provides the rationale for selecting this particular period/region as the testbed case for this paper. We have revised the title of this paper to "Assessing the CAM5 physics suite in the WRF-Chem model: implementation, resolution sensitivity, and a first evaluation for high latitude springtime regime" to better describe the scope of this paper. We have also included sentences in the abstract and the last paragraph of the concluding remarks section calling for future studies to test the CAM5 physics suite for different climate regimes.

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We provide this modeling tool for the community to use for exploring different aspects of the climate system for regions and seasons of interest and other papers already have begun being published that highlight this tool in other regions. For example, Lim et al. (2014) specifically focuses on how aerosols affect the deep convections using the CAM5 physics package. Their domain covers East Asia with the southern boundary at about 15°N. Gustafson et al. (2013) explores the cloud processes over the continental US using this code package as well. There are on-going projects in our group as well as the user community that uses the code package to investigate other regions, including China, Central America, the stratocumulus regime, the Southern Ocean, and the entire North Hemisphere.

The CAM5 deep and shallow convection schemes calculate the convective cloud fraction (which is used for radiative transfer calculation) and the condensate amount detrained from convections. The focused domain in Section 5 encompasses the Pacific storm track, where convection is an important process. The frequency of occurrence for convective clouds is found to decrease slightly with increasing resolution, from 20.7% for the 160 km simulation to 17.6% for the 10 km simulation, contributing to 4.1% and 2.6% of the total cloud fraction, respectively. This analysis demonstrates that the convection schemes operate as expected. We have revised the text to include this new analysis.

The CAM5 turbulence scheme operates to vertically mix tracers (except for aerosols which are mixed in the microphysics scheme via explicit treatment). The Turbulent Kinetic Energy (TKE) is used to calculate the subgrid vertical velocity, which is used for cloud (both ice and liquid) nucleation calculation. In this paper, we have evaluated the cloud condensate amounts and their statistics, and the resolution dependence of subgrid vertical velocity will be documented in another study (personal communication with K. Zhang).

Gustafson, W. I., Jr., P.-L. Ma, H. Xiao, B. Singh, P. J. Rasch, and J. D. Fast (2013), The Separate Physics and Dynamics Experiment (SPADE) framework for determining resolution awareness: A case study of microphysics, J. Geophys. Res. Atmos., 118, 9258–9276, doi:10.1002/jgrd.50711.

Lim, K.-S. S., J. Fan, L. R. Leung, P.-L. Ma, B. Singh, C. Zhao, Y. Zhang, G. Zhang, and X. Song(2014), Investigation of aerosol indirect effects using a cumulus microphysics parameterization in a regional climate model, J. Geophys. Res. Atmos., 119, doi:10.1002/2013JD020958.

My second major concern is about the lack of physical explanations on the resolution sensitivities or model differences. I understand this may be hard, but more efforts should be made to make the paper more interesting. For example, Figs. 4a and 4b showed clear resolution dependence of cloud liquid and cloud ice. The paper just mentioned the liquid "bias is reduced with increasing resolution". It did not mention that the ice path bias is increased with increasing resolution. It did not discuss the possible physical causes. Some explanation is necessary. Likewise, the large difference in the black carbon vertical profile between CAM5 and WRF-160km in Fig.6 and possible causes should be noted. The very large difference of aerosol concentrations between WRF_10km and models all other resolutions in Fig. 9 should be discussed.

Reply: Figure 4a shows that the liquid water content bias decreases with increasing resolution, and Figure 4b shows that the ice water content bias is insensitive to resolution. A possible explanation for the increase of cloud liquid water content with increasing resolution is that the moisture convergence is larger in the high-resolution simulation, resulting in higher production of liquid condensates. This discussion has been included in the manuscript. Further diagnostics is needed to identify the responsible physical mechanisms, but it is out of the scope of this paper and should be documented in a separate paper.

The difference between CAM5 and WRF-160km can be explained by the differences between the two models, e.g., their dynamical cores, time steps, etc. We have performed a sensitivity test (not shown) and found that the difference in the simulated clouds and aerosols between these two model simulations can be greatly reduced by setting the CAM5 time step (30 minute) to a smaller time step (5 minute) that is closer to WRF's time step (1 minute). The model dependence on time step is currently under investigation (personal communication with P. Caldwell, H. Wan, and K. Zhang) and should be addressed in a separate paper.

One possible explanation for the much larger aerosol burden than the other simulations is the much lower cloud susceptibility as shown in Figure 10. Lower cloud susceptibility leads to weaker scavenging, which results in larger aerosol burdens and higher long-range transport of aerosols.

We have revised the text accordingly to include these discussions.

Other comments: In the WRF-CAM5, how does the radiation code treat the fractional cloud cover? (Page 9, L26) Same as in CAM5?

Reply: As discussed in Section 2, the default version of WRF without the full CAM5 physics suite has a slightly different version of the Rapid Radiative Transfer Model for general circulation models (RRTMG) that uses a very simple cloud fraction scheme and requires cloud condensate amount, number concentration, and effective radius of droplets from moist physics. When the CAM5 microphysics scheme is selected, the total cloud fraction (the combination of stratiform and convective cloud fraction) is computed and used in the radiative transfer calculation by overwriting the standard WRF cloud fraction values calculated in the radiative transfer interface routine.

In Fig.5a and 5b, why are the differences between CAM5 and WRF-160 km in BC and OM so large?

Reply: As mentioned above, the difference in the simulated clouds and aerosols between these two model simulations can be greatly reduced by setting the CAM5 time step (30 minute) to a smaller time step (5 minute) that is closer to WRF's time step (1 minute).

Page 19, L14, "..high BC concentration that starts around 20 April, and about one to three orders of magnitude when the episode starts (Fig. 7b)". The episode mentioned is not clear in Fig. 7b.

Reply: In Figure 7b, we use a log scale to show the time evolution of observed and simulated BC, because the observed BC is at least 3 orders of magnitude larger than model simulations. In the figure, around April 20 the observed BC increases from about 70 ng/m3 to 500 ng/m3, and the model simulations also increase from about 0.1 to 50 ng/m3, representing a high BC concentration episode. We have revised the text to describe the episode.

Page 20, L22, and Fig. 9, why wasn't CAM5 included in the comparison?

Reply: Figure 9 and 10 are dedicated to evaluate the resolution dependence of the model. Hence, including CAM5 (which uses a different dynamical core, time step, etc.) in these two figures are not appropriate for resolution-dependence analysis. Furthermore, CAM5 uses the fixed latitude-longitude grid; the actual grid spacing changes with latitude (in this domain dx varies from about 240 km to about 45 km), which makes a true grid scale dependence comparison difficult.

Page 20, L26-28, this sentence is not clear.

Reply: We have revised the sentence: "One possible explanation is that the resolution-dependent cloud-free pathways are more frequent over ocean than land in the simulations. Hence, the impact of the cloud-free pathways (where aerosols are not subject to cloud processing) is greatest for aerosols produced over ocean."

Page 21, L13, and Fig. 10, why wasn't CAM5 included in the comparison?

Reply: Please see our response above.

Section 6. Is the one month of April 2008 still used in the free simulation of CAM5? Is CAM5 initialized?

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Reply: Please refer to page 6173, line 3-6: “The offline CAM5 simulation was started on January 1, 2008. Water vapor, condensate, and aerosol fields were allowed to spin up for 3 months, and simulation results from April 1 to May 1, 2008 were analyzed and used for initial and boundary conditions for regional downscaling modeling.”

Page 24, L28-29: “Figure 15 shows..WRF_CAM5 ... much more realistic... than ..WRF_MESO..” This is not obvious to the reviewer. The same comment is true for Figure 17 (Page 25, L24). A more objective measure should be used.

Reply: We stated that the WRF_CAM5 simulations produce much more realistic frequency of occurrence of liquid cloud in Page 6180, line 26-28. The values of frequency of occurrence are given in the figure. For clarity, we have revised the sentence to “... much more realistic frequency of occurrence of liquid cloud..., compared with ARM observations at Barrow.” In Figure 17, WRF_CAM5 shows better agreements with the observations in terms of both frequency of occurrence and the monthly averaged ice water content, which are given in Figure 17. We have revised the sentence to include the metric used. Note that in the concluding remarks section we acknowledge that this is based on one testbed base and other WRF parameterization combinations are likely to behave differently. Further studies focus on different climate regimes are needed to understand the general behavior of the CAM5 physics suite compared with other parameterization suites.

Interactive comment on Geosci. Model Dev. Discuss., 6, 6157, 2013.