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Geoscientific Model Development Discussions

Interactive comment on "Adding Four Dimensional Data Assimilation by Analysis Nudging to the Model for Prediction Across Scales – Atmosphere (Version 4.0)" *by* Orren Russell Bullock Jr. et al.

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Comment: 1) As the focus of the manuscript is nudging as a DA method, the authors should extend the introduction section with the focus being more on nudging and less on air quality.

Response: We have extended the introduction to better describe the utility of nudging versus other data assimilation methods for the diagnostic purposes of this work. We are not really advancing the science of nudging but only extending its use to the MPAS

modeling platform. Therefore, we did not believe a full review of the development of nudging techniques was appropriate or necessary. The discussion regarding air quality modeling and the problems associated with the use of differing models and grid nesting for global-scale assessment is intended to explain the motivation for our use of MPAS. As can be seen in the first comment from Reviewer #1, there is some concern in the air-quality modeling community that our work is intended to create a replacement for CMAQ, which it is not.

Comment: 2) The implementation of the nudging algorithm and the setup of the experiment is well documented in the manuscript. However, there are some issues with the experiment setup which in my opinion are important to discuss: a) The observations assimilated into the model state are synthetic observations generated from NCEP analysis fields. As the implementation does work as expected, the nudged simulations closely resemble the input data. However, one major advantage of the nudging algorithm is to allow for a free simulation [of] the atmospheric processes corresponding to the model physics while being (temporally) constraint to the observations (or the target field in this case). With respect to the experiment design, the authors should add more discussion (and probably analysis) on this aspect. The experiment without PBL assimilation seems to be a natural starting point for this.

Response: We interpret this comment to say we should try to reduce or eliminate nudging between the times when target data are available to investigate the model's ability to provide a free simulation of atmospheric processes when guidance is lacking. The halting or gradual ramping down of analysis nudging has been applied elsewhere for the purposes of initializing prognostic simulations. However, this work has a necessary focus on diagnostic simulation. If we have misinterpreted this comment, we welcome clarification from the reviewer.

Comment: b) The setup of the experiment is based on the truth being represented by the target field. The synthetic observations are drawn from this field in a homogeneous and dense fashion. With this setup, it is not difficult to achieve an accordance of the

model with the target and the result will not strongly depend on the nudging coefficient(s). However, in reality, observations of the truth are heterogeneous, sparse and rare. Therefore, finding a reasonable and balanced setup which produces sound estimates of the atmospheric states is much harder especially with respect to the temporal availability of observations. Do the authors intend to do such experiments/simulations in the future? The authors should also provide results of sensitivity experiments with respect to the nudging coefficient.

Response: We agree that with analysis nudging it is easy to achieve an accordance of the model with the target fields by simply increasing the nudging coefficient. We also understand that nudging based on observational data (a.k.a., "obs nudging") is more difficult due to the heterogeneous and sparse nature of the observations, but that it also can provide additional accuracy with respect to the true state of the atmosphere. We intend to develop a method for "obs nudging" in MPAS-A, but that is beyond the scope of this initial effort.

Regarding sensitivity experiments with respect to the nudging coefficient, we had already conducted those using one-tenth, one-fifth and one-half nudging strength for all nudged variables. However, including those results here would result in an exceedingly long paper. We hope to submit a follow-on paper showing those sensitivity results in detail once this paper has demonstrated a proper facility for analysis nudging in MPAS-A.

Comment: 3) The authors should provide plots containing information on the analysis increments from the nudging with respect to its spatial and temporal variability.

Response: We have developed a new plot showing the temporal variation of simulated and target Ït' values and the nudging term for Ït' at layer 28 positioned over Research Triangle Park, NC (our laboratory location) during January 2013. That plot, which is Fig. 4 in the revised manuscript, shows a rather strong perturbation of Ït' near 0000 UTC on 18 January 2013. We also developed spatial plots, one focused on North

America to show detail, and a second showing the entire global domain for layer 28 at 0000 UTC on 18 January 2013. These spatial plots have been added as Fig. 5 of the revised manuscript. A short discussion of the results shown in Figs. 4 and 5 is included in the main text.

Comment: Page 2 Line 17: Please provide a reference for the Voronoi mesh.

Response: We have added a reference to Du, Q., V. Faber and M. Gunzburger (1999) Centroidal Voronoi Tessellations: Applications and Algorithms. SIAM Review Vol. 41, No. 4, pp.637-676.

Comment: Page 2 Line 23: Is the mesh really unstructured?

Response: No, on second thought it is not, and we thank the reviewer for pointing out the error in our original terminology. We now describe the mesh accurately as a centroidal Voronoi tessellation.

Comment: Page 6 Line 4: "show" instead of "shows"

Response: This correction has been made.

Comment: Page 7 Line 3: I am not able to comprehend what the authors want to say with this sentence.

Response: The sentence contained a typographical error where the word "if" should have been "of". We trust this correction will allow a proper comprehension.

Comment: Page 8 Line 29: It would rather say "are larger" instead of "are much larger"

Response: This correction has been made.

Comment: Page 9 Line 11: "RMSE" instead of "RMSA"

Response: This correction has been made.

Comment: Page 10 Line 2: "than" instead of "that"

Response: This correction has been made.

Comment: Discussion on Figures 10 to 13: The shape of the bottom and top diagram differ mostly by amplitude. Does this behavior arise from the fact that a majority of observations is coming from the CONUS region? Please elaborate on this.

Response: Yes, the CONUS region does have a high density of observations compared to the rest of the globe. This spatial concentration of observations probably does explain the temporal correlation of the bottom and top diagrams. However, finer model resolution over the CONUS and regional variation in the quality of observations complicate the matter. We were not able to draw firm conclusions as to why the line deflections are so similar for temperature and humidity (previously Figs. 10-13, now Figs. 12-15), but not so much for wind speed (previously Figs. 14-15, now Figs. 16-17). But we agree that this behavior needs to be mentioned and have included some discussion on the matter at the top on page 7 in the revised manuscript.

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