Interactive comment on "Comparative evaluation of the impact of WRF/NMM and WRF/ARW meteorology on CMAQ simulations for PM2:5 and its related precursors during the 2006 TexAQS/GoMACCS study" by S. Yu et al.

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We thank the anonymous referee #1 for the constructive and helpful comments, the incorporation of which has led to a substantially improved manuscript.

Reviewer #1(Comments):

Major comments:
General comments In view of the large spread between air-quality model predictions the influence of meteorology is of scientific as well as practical interest. This may also be understood in terms of online coupled meteorology and air-quality models or in terms of ensemble predictions of air-quality. Allthough the subject is of general importance the article still needs some revision before publication (see specific comments below). The main issue regarding the discussion paper is that the title suggests that the impact of two meteorological drivers (with different dynamical cores) on the predictions of the modeling systems will be considered, but in practice the authors focus more on the similarities between the model systems. In particular there is only little explicit interpretation of the results in terms of differences in meteorological drivers.

We thank the reviewer for the overall positive assessment of the manuscript. More interpretations of the results in terms of differences in meteorological drivers have been added in particular, in response to the specific comments as detailed below.

Specific comments
The title of the article suggests that the differences between model system (WRF/NMM-VMAQ and WRF/ARW-CMAQ) predictions will be explicitly interpreted in terms of differences in the dynamical cores of the model systems. This is however, not the case and it may be suggested to either include more discussion of the results or change the title.

Thanks a lot. Again, more interpretations of the results in terms of differences in meteorological drivers have been added in the revised manuscript when we address your later comments as you suggested.

The description of the model systems provided in the article is not sufficient to facilitate interpretation of the results in terms of differences of the model systems. In particular the main differences between the NMM and ARW dynamical cores is not explained and the model configurations (domain, resolution etc.) are also not properly explained. It should not be neccessary to consult a reference for basic features which are of importance in the interpretation (comparison of model system predictions) of the results.

We agree with the reviewer that the addition of few more pertinent details on the NMM and ARW versions of WRF would be useful for interested readers. Following the reviewer's suggestion, the following additional details have been included in the revised manuscript "These two dynamic cores cannot be merged because each dynamic core corresponds to a set of dynamic solvers that operates on a particular grid projection, grid staggering and vertical coordinate (Skamarock, 2005). As summarized by Skamarock (2005), operational results indicated that the significant differences between these two dynamic core forecasts are more the result of different physics but not dynamical core designs. The NMM core is a fully compressible hydrostatic NWP (Numerical Weather Prediction) model using mass based vertical coordinate, which has been extended to include the non-hydrostatic motions (Janjić, 2003), whereas the ARW core is a fully compressible, Eulerian nonhydrostatic model with a run-time hydrostatic option available. The NMM core uses a terrain-following hybrid (sigma-pressure) vertical coordinate and Arakawa E-grid staggering for horizontal grid, whereas the ARW core uses a terrain-following hydrostatic-pressure vertical coordinate with vertical grid stretching permitted and Arakawa C-grid staggering for horizontal grid. As summarized in Yu et al. (2011), the physics package of the NMM (ARW) includes the Betts-Miller-Janjic (Kain-Fritsch (KF2)) convective mixing scheme, Mellor-Yamada-Janjic (Asymmetric Convective Model (ACM2)) planetary boundary layer (PBL) scheme, Lacis-Hansen (Dudhia) shortwave and Fels-Schwartzkopf (RRTM) longwave radiation scheme, Ferrier (Thompson) cloud microphysics, and NOAH (Pleim-Xiu (PX)) land-surface scheme. In this study, both WRF-ARW and WRF-NMM are employed to provide meteorological fields for CMAQ (the notations ARW-CMAQ and NMM-CMAQ will be used hereafter to represent these two configurations). NMM-CMAQ uses the lowest 22 layered vertical grid structure of the 60 hybrid layers in WRF-NMM meteorological fields directly without vertical interpolation through the use of a common vertical coordinate system. On the other hand, the WRF-ARW model has been employed to generate meteorological fields for CMAQ because the WRF-ARW meteorological model is compatible with CMAQ like MM5 before. For the NMM-CMAQ run, the results from the target forecast period (0400 UTC to next day's 0300 UTC) based on the 1200 UTC NMM-CMAQ simulation cycle over the domain of the continental United States (see Figure 1a of Yu et al. (2011)) are used, whereas the ARW-CMAQ model with 34 vertical layers was applied over a domain encompassing the eastern United States (see Figure 1b of Yu et al. (2011)) and was run from the beginning to end with first three days as model spin-up over the whole period.

Given the fact that both models use different map projections and grid staggering, it is difficult to make the WRF-ARW grid coverage identical to the WRF-NMM coverage. Several steps are taken to ensure that both the models are set up as consistently as possible so that the comparison of the two models is meaningful. First, the meteorological fields of ARW were padded by 5 cells in both x and y directions around the original meteorological domain when the meteorological fields were processed using Meteorology-Chemistry Interface Program (MCIP) to create the CMAQ-ready files. This helps match the larger NMM domain and smaller ARW domain sizes, and is able to use the emission data from the NMM-CMAQ forecast model. Second, the point source emissions were redistributed to the 34 layers according to the ARW meteorological fields on the basis of those from the NMM-CMAQ model. In addition, the ARW-CMAQ uses the same area sources such as the mobile and biogenic sources as those in NMM-CMAQ. Therefore, the total emission budgets for both models are the same. In both ARW-CMAQ and NMM-CMAQ, the lateral boundary conditions are horizontally constant and

are specified by continental ''clean'' profile for O_3 and other trace gases; the vertical variations are based on climatology (Byun and Schere, 2006). For both models, the thickness of layer 1 is about 38 m and the vertical coordinate system resolves the atmosphere between the surface and 50 hPa although each model uses different number of vertical levels. ''

Referring back to the title the conclusion should contain at least one valid bullet regarding the differences (or no differences) between the model systems, i.e the impact of WRF/NMM and WRF/ARW meteorology on the CMAQ pm2.5 simulations.

Thanks a lot for your suggestion. We agree with you. Actually, in our conclusion we mentioned that the daily domain mean $PM_{2.5}$ concentrations for the ARW-CMAQ are consistently about 17% higher than those for the NNM-CMAQ during the 2006 TexAQS/GoMACCS period although both models performed much better at the urban sites than at the rural sites, with greater underpredictions at the rural sites. To address your concern, last paragraph in the conclusion has been rewritten and the following sentences have been added in the conclusion of the revised manuscript "Given the fact that WRF-ARW and WRF-NMM use different dynamic cores which correspond to different sets of dynamic solvers that operates on a particular grid projection, grid staggering and vertical coordinate, it is not surprising that ARW-CMAQ and NMM-CMAQ showed some different as well as some similar model performances for $PM_{2.5}$, its chemical components and its related precursors, depending on the species and networks, as shown in this study. Since the significant differences between these two dynamic core meteorological forecasts are more the result of different physics but not dynamical core designs as summarized by Skamarock (2005), differences in the physics packages for WRF-ARW and WRF-NMM mainly cause the differences in ARW-CMAQ and NMM-CMAQ model performance as expected. ".

The comparison with measurement data is vital in this article and a discussion of the the quality of the measurements should be included.

The measurements used in the study are either from routine networks or specialized field campaigns; in each case detailed documentations of data quality are available either along with the data or in associated references. However, to address the reviewer's concern, the following sentence "The overview of data quality and the principal findings from the 2006 TexAQS/GoMACCS field experiment is given by Parrish et al. (2009)" and a reference "Parrish, D. D., D. T. Allen, T. S. Bates, M. Estes, F. C. Fehsenfeld, G. Feingold, R. Ferrare, R. M. Hardesty, J. F. Meagher, J. W. Nielsen-Gammon, R. B. Pierce, T. B. Ryerson, J. H. Seinfeld, and E. J. Williams: Overview of the Second Texas Air Quality Study (TexAQS II) and the Gulf of Mexico Atmospheric Composition and Climate Study (GoMACCS). *J. Geophys. Res*., 114, D00F13, doi:10.1029/2009JD011842,2009" have been added in the revised manuscript.

Some discussion of the meteorological performance of the NMM and ARW dynamical cores would be helpful in interpreting the model system predictions.

Agree. We actually did compare the modeled vertical temperature and water vapor with aircraft P-3 observations and presented it in Yu et al. (2011) paper. To address the reviewer's concern, the following sentences have been added in the revised manuscript "As shown in Yu et al. (2011), the mean temperature of the ARW model is slightly lower than that of the NMM model on the basis of P-3 measurements. This may be one of the reasons which cause different model performances of ARW-CMAQ and NMM-CMAQ for PM$_{2.5}$ and its related chemical composition."

Technical comments
The preparation of model data to be comparable with measured
profiles is not explained in enough detail (section).

Thanks a lot for your comments. To address the reviewer's concern, the following new sentences have been added in the revised manuscript "To compare the modeled (ARW-CMAQ, NMM-CMAQ) and observed vertical profiles, following Yu et al., (2011), the modeled results were extracted by matching the positions of the aircraft to the model grid indices (column, row and layer). The hourly resolved modeled outputs were also linearly interpolated to the corresponding observational times."

Too many abbreviations which are either not used or not defined (e.g HGB, DFW,CEM,NEI,VMT,P3)

Thanks a lot for your comments. HGB, DFW, CEM, NEI and VMT have been deleted and WP-3 has been used in the revised manuscript

The term "reasonably well" is used throughout the article to indicate some basic level of performance. It is, however,often unclear what is meant when the term is used, e.g. section 2.1, 3.3.1, 3.3.2; conclusion.

Thanks a lot. When we said "reasonably well", we mean that the model results are accepted on the basis of our current scientific ability, for example, the NMB value is less than 50%. To address the reviewer's concern, "reasonably" word has been deleted in the revised manuscript.

Include more details regarding the model system and configurations used (section 2.1)
Missing reference on p. 32035, second paragraph, line 4: ...CEM estimates of ...
CEM not defined

To address the reviewer's comments, the new reference "Department of Energy (DOE), Annual Energy Outlook 2006, DOE/EIA-0383, 2006" has been added and Continuous Emission Monitoring has been used in the revised manuscript. More details regarding the model system and configuration have been added in the revised manuscript as follows: "These two dynamic

cores cannot be merged because each dynamic core corresponds to a set of dynamic solvers that operates on a particular grid projection, grid staggering and vertical coordinate (Skamarock, 2005). As summarized by Skamarock (2005), operational results indicated that the significant differences between these two dynamic core forecasts are more the result of different physics but not dynamical core designs. The NMM core is a fully compressible hydrostatic NWP (Numerical Weather Prediction) model using mass based vertical coordinate, which has been extended to include the non-hydrostatic motions (Janjić, 2003), whereas the ARW core is a fully compressible, Eulerian nonhydrostatic model with a run-time hydrostatic option available. The NMM core uses a terrain-following hybrid (sigma-pressure) vertical coordinate and Arakawa E-grid staggering for horizontal grid, whereas the ARW core uses a terrain-following hydrostatic-pressure vertical coordinate with vertical grid stretching permitted and Arakawa C-grid staggering for horizontal grid. As summarized in Yu et al. (2011), the physics package of the NMM (ARW) includes the Betts-Miller-Janjic (Kain-Fritsch (KF2)) convective mixing scheme, Mellor-Yamada-Janjic (Asymmetric Convective Model (ACM2)) planetary boundary layer (PBL) scheme, Lacis-Hansen (Dudhia) shortwave and Fels-Schwartzkopf (RRTM) longwave radiation scheme, Ferrier (Thompson) cloud microphysics, and NOAH (Pleim-Xiu (PX)) land-surface scheme. In this study, both WRF-ARW and WRF-NMM are employed to provide meteorological fields for CMAQ (the notations ARW-CMAQ and NMM-CMAQ will be used hereafter to represent these two configurations). NMM-CMAQ uses the lowest 22 layered vertical grid structure of the 60 hybrid layers in WRF-NMM meteorological fields directly without vertical interpolation through the use of a common vertical coordinate system. On the other hand, the WRF-ARW model has been employed to generate meteorological fields for CMAQ because the WRF-ARW meteorological model is compatible with CMAQ like MM5 before. For the NMM-CMAQ run, the results from the target forecast period (0400 UTC to next day's 0300 UTC) based on the 1200 UTC NMM-CMAQ simulation cycle over the domain of the continental United States (see Figure 1a of Yu et al. (2011)) are used, whereas the ARW-CMAQ model with 34 vertical layers was applied over a domain encompassing the eastern United States (see Figure 1b of Yu et al. (2011)) and was run continuously over the whole period.

Given the fact that both models use different map projections and grid staggering, it is difficult to make the WRF-ARW grid coverage identical to the WRF-NMM coverage. Several steps are taken to ensure that both the models are set up as consistently as possible so that the

comparison of the two models is meaningful. First, the meteorological fields of ARW were padded by 5 cells in both x and y directions around the original meteorological domain when the meteorological fields were processed using Meteorology-Chemistry Interface Program (MCIP) to create the CMAQ-ready files. This helps match the larger NMM domain and smaller ARW domain sizes, and is able to use the emission data from the NMM-CMAQ forecast model. Second, the point source emissions were redistributed to the 34 layers according to the ARW meteorological fields on the basis of those from the NMM-CMAQ model. In addition, the ARW-CMAQ uses the same area sources such as the mobile and biogenic sources as those in NMM-CMAQ. Therefore, the total emission budgets for both models are the same. In both ARW-CMAQ and NMM-CMAQ, the lateral boundary conditions are horizontally constant and are specified by continental ''clean'' profile for O_3 and other trace gases; the vertical variations are based on climatology (Byun and Schere, 2006). For both models, the thickness of layer 1 is about 38 m and the vertical coordinate system resolves the atmosphere between the surface and 50 hPa although each model uses different number of vertical levels."

Unclear what is meant by running the model continously: no restarts or no "holes" in the simulation period or something else ? (section 2.1)

Thanks a lot for your comments. "run the model continuously" means that we run the simulation from the beginning to the end without stop. This is relative to the NMM-CMAQ simulations which can have different simulation cycles. To address the reviewer's concern, the following new sentence was used in the revised manuscript "…… was run from the beginning to end with first three days as model spin-up over the whole period".

Several references to "part 1" of this study; the title, however, there is no part 2 in the title of the current study . Include specific reference instead.

 "part 1" has been replaced by Yu et al. (2011) in the revised manuscript.

Unclear what is meant by "slightly consistent" (section 3.1)

It should be "consistently slight". The new sentence "….had consistently slight underestimations of $PM_{2.5}$…" has been used in the revised manuscript.

The term "OTHER" should have been defined when first used (section 3.2)

Thanks a lot for your comments. We said "Note that "OTHER" species in Figure 4 refers to unspecified anthropogenic mass which comes from the emission inventory of $PM_{2.5}$" to address the reviewer's concern, the new sentence ""OTHER" species refers to unspecified anthropogenic mass which comes from the emission inventory of $PM_{2.5}$" has been added to the caption of Figure 4 in the revised manuscript.

The terms "underestimated/overestimated vertically" is not clear (section 3.3.1)

"vertically" has been deleted and the following new sentence has been used in the revised manuscript "Figure 5 and Table 4 reveal that both models often overestimated NH_4^+ for all altitudes except at layer 1, whereas both models systematically underestimated the NH_3 for all altitudes."

No need to include an "extra" summary in the last paragraph of the conclusion

Agree. The paragraph has been deleted in the revised manuscript.