Reply to anonymous referee #1

Overview

The paper gives a model description and presents the evaluation results of the aerosol forecast of the GEFS-Aerosols v1 system. This system is a newly developed aerosol module coupled on-line to NOAA's FV3 Global Forecast System (FV3GFS) by means of the National Unified Operational Prediction Capability (NUOPC). The evaluation results are compared against the performance of the previous NGAC v2 aerosol forecast system showing a clear improvement in many aspects of the aerosol forecast.
Reply: We really appreciate the reviewer's very helpful comments and suggestions. The paper has been revised throughout based on all the general and specific comments listed by the reviewers, including the text, figures, references, etc.

General remarks

The paper inter-compares several aerosol model/analysis products (ICAP, GEOS5, MERRA, NGAC) with the GFES Aerosol forecast results. However, there is no stringent approach to the choice of these data sets for the different aspects. This makes the paper appear somewhat convoluted and too long. I recommend focusing on the forecast by GEFS-Aerosols v1 and its predecessor NGAC v2 only throughout the paper. These two data sets should be evaluated against observations and observation-based re-analysis data sets such as MERRA. The evaluation results of the two systems should be intercompared for all the discussed topics. If the authors still which to include other forecast or model data sets (ICAP, GEOS5) they need to describe these modelling systems in such a way that the identified differences in the evaluation against observations and observation-based reanalyses can be explained. There is little value in pointing out that GFES Aerosol is higher or lower than ICAP or GEOS5 without saying which one is better, i.e. closer to the observations.
Reply: We thank the reviewer's very good suggestion. We have removed the evaluation using GEOS-5. We keep the ICAP analysis data for evaluation because the MARRA-2 reanalysis data is not real-time, which has ~1-2 month time lag with respect to real-time. While in our real-time or operational forecast, the ICAP analysis is able to provide synchronous comparison. Before choosing the ICAP analysis data, we have done some evaluation with other observation (satellite and ANERONET observation), including the correlation and RMSE between ICAP and AERONET (see Table 1 some descriptions in Section 4), it obviously that the ICAP analysis has the highest correlation and smallest RMSE with respect to AERONET. It suggests that the ICAP analysis is quite close to the observation and is good to use it as the global evaluation data when MERRA-2 is not available in the real-time or operational forecast. We have emphasized it in the Section 2.2.

The paper remains too in explaining the reasons for the difference in the evaluation results between GEFS-Aerosols v1 and NGAC v2. It should be stated more clearly what aspects (emissions, removal processes, aerosol conversion, resolution, transport etc.) is assumed to be the reason for the mainly improved performance of the newer system. Further, I strongly recommend adding a table that summaries the communalities and differences between GEFS-Aerosols v1 and NGAC v2 as the reader is not made familiar with the configuration of NGAC v2.
Reply: We thank the reviewer's comments. As we introduced in Section 1 and Section 2.2.3, the NGACv2 is the previous global aerosol forecast system in NCEP. The major differences between

GEFS-Aerosols model and NGACv2 is not only the chemical model part, the atmospheric/weather model is completely different. NGACv2 is implemented into the NOAA Environmental Modeling System (NEMS) global spectral model (GSM), which has been developed at NCEP to implement the standalone global forecast system (GFS) in the NEMS framework in 2006 (Black et al., 2007, 2009). While GEFS-Aerosols is implemented into the global Finite-Volume cubed-sphere dynamical core (FV3) developed by GFDL within the physical scheme of GFSv15. There are a lot of differences in these two atmospheric models, including dynamical core, resolution, physics and microphysics, land surface model, etc. It is hard to exactly quantify the where the improvement may come from. In addition, the evaluation of the NGAC v2 model has been published in (Wang et al., 2018 and Bhattacharjee et al., 2018), which is not the scope of current paper. The comparisons between GEFS-Aerosols and NGACv2 in this study are only the evidence to show the improvement for replacement.
Taking the very good suggestions from the reviewer, we have added a table to summarize the comparison of model configurations between GEFS-Aerosols v1 and NGACv2 in Table 2, the NGACv2 information is from Wang et al., 2018.

The evaluation of the forecast consists mainly of the comparisons with respect to observations and analyses of total or speciated AOD. It is an omission of the paper that routine surface PM observations are not included in the evaluation. PM 2.5 observation data sets are widely available, and the forecast of surface PM should be a main objective of any state-of-the-art aerosol forecasting system.
Reply: We thank the reviewer's suggestion. As the first paper to introduce the operational GEFS-Aerosols, it can not include all the evaluations, especially the $PM_{2.5}$, which need more detailed analysis related to local availability of observation data, emission, topography, and weather. We have the other groups working on evaluating different aspect of the model performance, including the surface $PM_{2.5}$ for GEFS-Aerosols prediction with more detailed validation against the Open-AQ $PM_{2.5}$. They are preparing the drafts and will submit them as separate papers soon.

Bhattacharjee, P. S. ; Zhang, L.; Baker, B.; Pan, L., Mountuoro,R., Grell, G. and McQueen, J : Evaluation of Aerosol optical depth forecast and surface PM2.5 from NOAA's Global Aerosol Forecast Model (GEFS-Aerosols), 2022, to be submitted.

Jeong, G.-R., B. Baker, P. C. Campbell, R. Saylor, and Partha Bhattacharjee, Daniel Tong, and Youhua Tang: Updating Anthropogenic Emissions in NOAA's Global Ensemble Forecast System with Aerosols (GEFS-Aerosols): Application of a Bias-Scaling Method. 2022, to be submitted.

The paper shows detailed comparisons against speciated AOD (BC, OC, SO4/SO2). However, the speciated AOD are model results, i.e. not provided by observation instruments, which mainly observe/retrieve total AOD. Even data assimilation of these observations for the re-analysis (MERRA) is no guarantee that the speciation of the reanalysis is better than the modelled speciation. Therefore, the evaluation with total AOD observations (AERONET) should be given a much larger emphasis in the paper. It is urgently recommended to also include the biases or RMSE (and not only the correlation) against AERONET observations in the paper. At the same time, the applied optimisations of the AOD calculation to account for aerosol species (Nitrates, SOA) not modelled by GEFS-Aerosols needs to be better explained.

Reply: We completely agree with reviewer's comment that the speciated AOD from either MERRA-2 or GEOS-5 has model dependency, and it may not be accurate enough, especially both MERRA-2 and GEOS-5 include data assimilation. As the reviewer's suggestions, we have added the RMSE for AERONET in Table 1, and also calculate the RMSE for Figure 5 in the revised manuscript, and corresponding descriptions in Section 4.2, and 4.3. We have also explained the AOD calculation to account for the absence other aerosols in GOCART aerosol scheme in Section 2.1.3.

The paper also includes and evaluation with flight campaign data (ATOM-1). While this is an interesting aspect of the scientific verification, it seems inconsistent that this section includes a discussion of the impact of spatial resolution which is not discussed before and which is not very large. In the interest of keeping the paper short, I would omit the resolution discussions.
Reply: We thank the reviewer's suggestions. We have removed the discussion of C96 resolution in Section 5.

Finally, the paper requires more clarification of the implied benefits of aerosol – weather feedbacks and the relation of this aerosol-aware forecast as part of the NWP ensemble of the NOAA Environmental Modeling System. It remains unclear what benefits were achieved by including the aerosol ensemble member. If no results can be presented as part of the paper, this should be stated more clearly (also in the title) and less emphasis should be given on weather-composition feedbacks as part of the introduction.
Reply: We thank the reviewer's comments. Currently, the aerosol (from the chemical model) feedback on the atmospheric model has not yet been included, which is next step in our plan. We have clarified that in Section 1:" There is not aerosol feedback on the atmospheric model of GEFS, and the aerosols are not in any way interactive with the radiation and clouds". Also, in the Global Ensemble Forecast System, there is no aerosol ensemble member, the ensemble members are with respective to the weather model for separate forecasts. The GEFS-Aerosols is only using one of the same weather model as other GEFS members but includes the prognostic aerosols. We have described and clarified it in Section 2.1.1 as: "The GEFS is a weather forecast modeling system made up of 31 separate forecasts, or ensemble members, which have the same horizontal (~25 km) and vertical resolution (64 layers from the surface to 0.2 hPa). The GEFS-Aerosols is only using one of the same weather model as other GEFS members but includes the prognostic aerosols. It is about 2.5 times computational cost when include the aerosol component in the forecast. In the operation, there is no execution time since the it only performs 120 hours forecast with aerosol component, while other members without aerosol component would perform 384 hours forecast. The NCEP started the GEFS to address the nature of uncertainty in weather observations that are used to initialize weather forecast models and uncertainties in model representation of atmospheric dynamics and physics. The aerosol component coupled with FV3GFS v15 has been merged into the GEFS, as a single ensemble member named GEFS-Aerosols, for real-time and retrospective forecast that preceded operational implementation, which occurred in September 2020."

Specific comments:

Abstract:

L 11: no need to include references and mentioning of FIM-Chem in the abstract.

Reply: Revised.

L 22: Please mention the main reasons for the improvements in the abstract
Reply: Revised.

P 3 L 10 -22 : The discussion of the various feedbacks would only be justified if the paper reports about modified NWP results because of considering aerosol-weather feedback. This seems not the case and the text should be shortened substantially.
Reply: The aerosol feedback is an important part in NWP and it is planning in next step implementation, which need to be based on current model development and performance in AOD forecast. We have shortened and revised this part to better describe this motivation.

P 4 L 22: Here or elsewhere add the spatial resolution of the NRT GEFS-Aerosols v1 forecasts
Reply: Added.

P 5 L15: Please clarify how the emissions are added and how this is linked to the diffusion and convection tracer transport parameterizations.
Reply: Revised. The emissions are no added into the FV3 atmospheric model of the physical part, however, the emissions are added into the aerosol concentration in the chemical model. Then the chemical tracers are passed back to atmospheric model for transport and advection after the chemical related processes. In the physical part (GFS scheme) of the FV3 atmospheric model, all sub-grid scale transport and convective deposition is handled inside the atmospheric physics routines of simplified Arakawa–Schubert (SAS) scheme. All the chemical tracer related processes, such as emission, dry deposition, settling, large-scale wet deposition, chemical reactions are handled by the chemical model. We have clarified it Section 2.1.1 and Section 2.1.2.

P 5 L 17: Please expand on why wet deposition by large scale and convective precipitation is dealt with in different components.
Reply: We thank the reviewer brought up this important point. The most consistent way would be to have all wet deposition done inside the physics. This was easily possible for the convective parameterization. However, moving the large-scale wet deposition into the microphysics routine was at this point not an option, but it will be done at a later stage of our plan for future development. It is a non-trivial task to include wet scavenging and possibly aqueous phase chemistry in the explicit microphysics scheme. An additional complication may be that the microphysics parameterization might be switched with the next implementation.

P 5 L 17: Please comment in this section about the consistency of land use and other climatological surface fields (z0, vegetation type etc.) between the dynamical core and the aerosol model.
Reply: Revised in Section 2.1.2. All the Metrological fields (such as land use and other climatological surface fields (z0, vegetation type etc.) are imported from the FV3 atmospheric model to the chemical model to drive the aerosols components. So there is no inconsistency.

P 5 L 21: What is the motivation to include FIM-chem here?
Reply: Though the current atmospheric composition option in the GEFS-Aerosols model is based on the simple bulk aerosol modules from WRF-Chem, however WRF-Chem is a reginal model. While the first time to include the same aerosol component into global model is in FIM-Chem

model, which showed good performance. That is one the reasons we chose it for the global aerosol forecast of GEFS-Aerosols.

P 5 L 24: Please provide more details on the oxidant fields. Are these statistic climatologies or do they change in space and time because of advection. Is SO2 a tracer?
Reply: Provided in Section 2.1.2. The GOCART model background fields of prescribed OH, H_2O_2, and NO_3 have been replaced by the newer version of 2015 from the NASA GEOS Global Modeling Initiative (GMI) Chemical transport model (https://acd-ext.gsfc.nasa.gov/Projects/GEOSCCM/MERRA2GMI/). These are monthly mean data and these prescribed OH, H_2O_2, and NO_3 fields would not be transported and changed in space. They are provided to the calculation in chemical reactions for gaseous sulfur oxidations. They will not be passed back to FV3 for transport and advection, no loss and sink. Yes, SO2 is a transport chemical tracer in the model.

P 6 L 11: It is not clear from the text what the threshold values are based on … wind tunnel experiments ?
Reply: Revised. The threshold friction velocities are based on wind tunnel measurements done in both the laboratory and field (Gillette et al., 1980).

P 6 L 18: please add (BSM)
Reply: Added.

P 6 L24: What is a 3-year climatology?
Reply: Revised. The 3-year climatology refers to a monthly average over 3 observation years, in this case 2016, 2017 and 2018 as these were the latest full years at the time of model development. For example, January would be the average values of the BSM over January of 2016, 2017, and 2018.

P 6 L 25: This section describes more than the coupler – so consider renaming that section or introduce sub-sections.
Reply: Revised.

P 7: A reference to Fig 2a is missing in that section.
Reply: Added.

P 7 L 11: Please indicate the computational cost of the aerosol module in relation to the cost of the dynamical core.
Reply: Added in Section 2.1.3. In operation, the computational cost with aerosol component would take 129 mins for 120 hours forecast using 330 tasks. The atmospheric model without aerosol component run would take 168 mins for 384 hours forecast using 320 tasks. Therefore, the efficiency for the former is 120/(330x129)=2.82x10-e3 hour/mins, while the latter is 384/(320x168)=7.14e-3hour/min. It is about 2.53 times computational cost when include the chemical model in the forecast.

P 7 L 12: Please indicate the resolution of the 31 non-aerosol members and the resolution of the aerosol member. Are they the same? How does the potentially increased cost and execution time of the aerosol member impact the execution time of the ensemble as a whole?
Reply: The resolution of the 31 non-aerosols members and the aerosols member are the same. The aerosol member only performs 120 hours forecast, however, the non-aerosol members perform 384 hours forecast, so the no execution time issue because the aerosol member finishes the forecast before other non-aerosol members, so there is no execution time issue.

P 7 L 19: Fig 2b is not clear at all. The names of specific routines such as checkic is not of interest for the reader. Why is re-gridding needed if the aerosol module runs at the same resolution as the core? What are the meaning of the green and yellow boxes. How is Fig 2.b related to Fig 2.a.
Reply: All the red abbreviations (e.g. "checkgdas", "gfsgetic" ect.) are the names of the tasks in the xml file of global workflow (https://github.com/NOAA-EMC/global-workflow) to run the GEFS-Aerosols for operational forecast way, which are a uniform way in the operational system (not only for GEFS-Aerosols model forecast) and named by the global workflow designers. The black statements below the red abbreviations are the explanations. The regriding in the "regrid" step is not used to regrid the meteorological fields from atmospheric model to chemical model, it is not necessary to do that because they are in the same resolution. The "regrid" step is used to regrid the meteorological fields from GFS/GDAS data assimilation system (normally this data is at very high resolution, ~3km) as initial condition (ICs) input to drive the FV3GFS model. The yellow box includes the necessary steps for atmospheric model, while the green box includes the necessary steps for chemical model. We have modified the Fig. 2b to make it more clearly. Fig. 2a is the model coupled structure of GEFS-Aerosols. Fig. 2b shows the steps about how to run the GEFS-Aerosols in operational forecast system using global workflow, including all the tasks of preprocessing (prepare input data before model forecast) and postprocessing (process output data after model forecast), the whole processes are controlled by the global workflow shown as Fig. 2b. We have clarified it in Section 2.1.3.

P 7 L26: As the AOD evaluation is an important aspect of the paper, more detail (here or elsewhere) needs to be provided to understand the impact of the optimization of the AOD calculation on the evaluation results.
Reply: Revised as "The AOD is calculated in the post-processing part of the workflow, using a look-up table (LUT) of aerosol optical properties from NASA GOCART model (Colarco et al. 2010, Colarco et al. 2014), which was implemented in the Unified Post Processor (UPP, https://dtcenter.org/community-code/unified-post-processor-upp). It should be noted that the LUT reflects the impacts of a larger number of aerosol species in the atmosphere than the simple GOCART module treats. Also, considering the bulk aerosol scheme in GOCART, there is no size distribution for OC, BC and sulfate, the LUT may have uncertainties in the AOD calculation. Based on observational validation, some adjustments with factor of 2 have been applied in into LUT calculation to compensate the contributions for the absence of nitrate, ammonium and secondary organic aerosol (SOA) in GOCART."

P 7 L29: This section should be re-arranged to clarify in a better way what the reference data sets are (observations, re-analysis) and what the evaluated forecasts are (GEFS-Aerosols v1 and NGAC v2 and perhaps GEOS5 and ICAP)
Reply: We have re-arranged the section 2.2.

P 8 L 12: Please mention the number of stations and comment on the spatial coverage of the AERONET network.

Reply: Table 1 lists number of stations, their location in terms of latitude and longitude. The stations are selected based on years in service and geographic location near the aerosol source regions. Stations covered major aerosol sources: African Dust, Southern Africa and South America (major forest fire stations), mixed aerosol regimes (urban areas in Europe, Asia and N. America), high latitude stations (capture major transport of forest fires from Siberia and Canada). We have updated in Section 2.2.2.

P 8 L 19 / 27: Please comment on the uncertainty of the MODIS and VIIRS retrievals especially with respect to the differences over land and ocean.

Reply: Added. We have used Collection 6.1 MODIS AOD at 550nm, which has Expected Errors (EEs) of [± (0.05 + 15%AOD)] and [± (0.03 + 5%AOD)] for Dark Target retrievals at a 10-km resolution over land and ocean, respectively. The EEs are approximately [± (0.03+21%AOD] for 'arid' and [± (0.03+18%AOD)] for 'vegetated' path Deep Blue retrievals at a 10-km resolution over land (Levy et la., 2013).

P 8 L 32: Please clarify if data assimilation is applied in GEOS5 and how that data set relates to MERRA2.

Reply: According to the reviewer's comment in the general part, we have removed the evaluation using GEOS-5.

Yes. There is data assimilation applied in GEOS5. GEOS-5 Data Assimilation System (GEOS-5 DAS) integrates the GEOS-5 Atmospheric Global Climate Model (GEOS-5 AGCM) with the Gridpoint Statistical Interpolation (GSI) atmospheric analysis developed jointly with NOAA/NCEP/EMC.

P 9 L 8: The section on ATOM is very long compared to the other sections. Please consider shorten it to information relevant to the paper.

Reply: We have revised the ATOM-1 data descriptions and shorten it.

P 10 L 11: Please provide also numbers in the comparison of the CDES and HTAP 2 emission data. Please comment on the fact that the data represent different reference years and its impact of using the data for simulations in 2019.

Reply: We have added the quantified numbers of global total emission in the comparison of CEDS and HTAP 2 emissions in Fig. 3. We also added comments about the data represent different reference years and its impact of using the data for simulations in 2019.

P 11 L 9: The section 3.3 remains a bit anecdotic because only plots for selected days are shown. The paper could work without that section and it would just be enough to mention the selected biomass burning data set and injection option. If this section should remain it will require to quantify the mean aerosol biomass burning emissions for the period and to present an evaluation with independent data for the whole period. The comparison with other model and analysis data sets will require a discussion of the underlying vegetation fire data sets, in particular for NCAG v2, which does not seem to capture the fire events.

Reply: We thank the review's good suggestion. We have removed the fire emission comparison section 3.3 and Figure 4-5 in previous manusrcipt.

P 13 L 14: It is not possible to conclude from a map that the temporal variability was captured.
Reply: Revised.

P 13 L 21: Please provide the reasons for that underestimation by NGAC v2.
Reply: The NGAC v2 model is not the scope of this paper and project. We are not the major developers of the NGACv2 (more than 5 years ago) and hard to conclude the underpredicted reasons of NGACv2. It quires further studies and tons of sensitivity experiments to dig into the NGACv2 performance which is out of the current study of GEFS-Aerosols model development. We just got the NGACv2 history output data from NCEP for comparisons. More details about the NGAC v2 model performance and evaluation can be found in Wang et al., 2018 and Bhattacharjee et al., 2018.

P 13 L 22: Please clarify if the GEOS5 is a forecast or an analysis (data assimilation of AOD).
Reply: According to the reviewer's comment in the general part, we have removed the evaluation using GEOS-5. The reanalysis data of AOD are all use MERRA-2 now.

P 14 L 13: The comparison with AERONET AOD is more important for the reader than the inter-comparison of various modelled and analysis data sets. The section should therefore start best with the AERONET comparison.
Reply: We thank the reviewer's suggestion. We have revised this section and started with the AERONET comparison.

P 14 L 29: Please discuss the biases against AERONET and not only the correlations. Please add a figure for the biases (or RMSE) similar to Fig 10 for the correlation.
Reply: We have added a figure for the biases of RMSE similar to Fig.5 other than the correlation. We also add the RMSE values in Table 1.

P 15 L 11: Please motivate the choice of the selected stations. Why were no North-American or Siberian fire events selected?
Reply: Sites are selected based on the following two factors: 1) observation data availability for the duration of the study; 2) Sites that hold long records based on various previous studies.
In table 1 of the AERONENT sites, the Site 30 Tomsk is the only site located close to Siberian fire and only cover few days of our prediction periods. Also, there are few N. American sites (only Ft. Mcmurray, Bonanza creek, Missoula) that are close to major biomass burning areas, but not very good coverage of our prediction periods like other fire regions. We have added the motivation in Section 4.2.

P 16 L 30: Why do you not include the ICAP data in the intercomparison in Fig 14 as you do in Fig 13 and before?
Reply: Figure 14 is the scattering figure which can be used to compare the model results with observation. Here the blue and orange dots are good enough to include the information compared with AERONET observation. If we include ICAP comparison, there need to have the other 2 colors dots and they would be overlapped by each other and hard to get better presentation. The

correlation and RMSE of ICAP with respect to AERONET observation have been added into Table1.

P 18 L 10: Please discuss the reasons for the poorer performance of NGAC v2.
Reply: As we answered above, the NGAC v2 model is not the scope of this paper and project. Though NGACv2 is the previous global aerosols forecast system at NCEP, it has been retired and replaced by GEFS-Aerosols in the NWS since September 2020. NGACv2 has been developed by different group of scientists who are not the major developers of GEFS-Aerosols. GEFS-Aerosols and NGACv2 are two different models both in the atmospheric and chemical part. We are not the major developers of the NGACv2 and hard to conclude the reasons to cause poor performance in NGACv2 without further studies. We only got the NGACv2 history data from NCEP for comparisons. More details about the NGAC v2 model performance and evaluation can be found in Wang et al., 2018 and Bhattacharjee et al., 2018.

P 18 L 23: Please provide the resolution in km here and before of the “native” grid.
Reply: Revised.

P 18 L 28: Which resolution was used for section 4?
Reply: C384, ~25km. Added.

P 19 L 22: Please comment what the impact of the resolution on the dust emissions are. Dust emissions are known to be resolution dependent because of the respective ustar thresholds.
Reply: Yes. The dust emission is sensitive to the meteorological fields, such as surface wind the friction velocity. From our experiment in Fig.17 and Fig.19 (in previous mansucript), the impact of dust emission does not have significantly resolution dependency, which means that these meteorological fields are quite similar in these two resolutions. We have added responding comments. But according to the reviewer’s suggestion in the general remarks, we have removed the discussion of C96 in the revised manuscript.

P 22 L 10: Volcanic eruptions have not been mentioned before. Please provide more details. On the other hand, one would expect that topics mentioned in the summary have been dealt with in the paper.
Reply: We have added the volcanic descriptions according to other reviewer’s comments as: “Meanwhile, it is also capable of handling volcanic eruptions, which can inject vast quantities of particulates into the atmosphere. While for the predicted results in the paper, we have not included the volcanic emission into the model for the June 2019 Raikoke eruption, it may partially impact on the underprediction over high northern latitude.”

P 22 L 27: Please also mention the biases against Aeronet AOD observations.
Reply: We have added the RMSE in Table 1 and corresponding discussion in Section 4 in the revised manuscript.

P 23 L 11: The paper only contains tests for different resolutions and not for different emissions in section 5.
Reply: Revised.

P 35 Fig 2: Consider introducing two separate Figures (2a = 2, 2b 3). The Fig 2b is not clear and a better caption is required.
Reply: Revised.

P 36 Fig 3: add the different reference years and global total (Tg) in the caption.
Reply: Revised. The global total (Tg) emissions have been added in Fig.3.

P 37 Fig 4: Please add the total in caption.
Reply: We have removed Fig.4 according to the reviewer's above suggestion.

P 39 Fig 6: "verified" is not the right word. You just show different plots/maps of AOD.
Reply: Revised it at "compared with"

P 40 Fig 7: Please add that you show the temporal mean of the day-1 forecasts etc.
Reply: Revised.

P 49 Fig 16: Why is NGAC not included in that Figure?
Reply: NGAC does have the OC output archived for 2016 ATOM-1 periods.

P 51 Fig 18: Please add the meaning of red and blue curve in caption.
Reply: Revised.

References:

Black, T., Juang, H. M. H., Yang, W. Y., and Iredell, M.: An ESMF framework for NCEP operational models, J3.1, in: 22nd Conference on Weather Analysis and Forecasting/18th Conference on Numerical Weather Prediction, Park City, UT, USA, 25–29 June 2007, American Meteorological Society, 2007.

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Wang, J., Bhattacharjee, P. S., Tallapragada, V., Lu, C.-H., Kondragunta, S., da Silva, A., Zhang, X., Chen, S.-P., Wei, S.-W., Darmenov, A. S., McQueen, J., Lee, P., Koner, P., and Harris, A.: The implementation of NEMS GFS Aerosol Component (NGAC) Version 2.0 for global multispecies forecasting at NOAA/NCEP – Part 1: Model descriptions, Geosci. Model Dev., 11, 2315–2332, https://doi.org/10.5194/gmd-11-2315-2018, 2018.