Dear GMD editor,

We thank the two reviewers for their valuable suggestions. This GMDD manuscript has been revised accordingly. Point to point responses to the reviewers' comments are given below.

To comply with GMD code and data policy, we have created GSI and CRTM archives at Zenodo with corresponding doi and the section of 'Code and Data Availability' has been updated. The comment from the exec. Editor regarding github repository has been addressed.

The CRTM team has discussed a new releasing and versioning system for aerosol optical tables, but has yet to make a decision. We revised the text: "With the expansion of the aerosol schemes, a new releasing and versioning system for optical tables is essential and currently under discussion. ". (line 129-130). The comment from the topical editor during initial review is also addressed.

Two new figures and several citations are added. These revisions are in response to the comments from the two reviewers (see below).

We look forward to the decision of the editor office.

Thanks and Regards,

Sarah Lu

Comments from Reviewer #1

We thank the reviewer#1 for the valuable suggestions and constructing comments. This GMDD manuscript has been modified accordingly. Point-to-point response to the reviewer's comments is given below.

Dear Authors,

Thank you for your well-written and interesting manuscript. This topic of aerosol-aware DA is a frontier of development in data assimilation and this paper represents an important milestone in that development.

I have minor recommendations for clarity and completeness to make this manuscript more helpful to readers and eliminate some ambiguity in your descriptions. I did not identify any technical changes needed in the work you describe.

- I recognize that CRTM is well-described in other publications, but I think it is still appropriate to add some more text describing how the aerosol and RT modules interact. CRTM is a "fast radiative transfer model," which means that certain computations are done ahead using a more complete analytical model, with solutions stored in lookup tables used by CRTM. What aspects of the RT are solved via lookup tables and which ones are solved analytically is important information for understanding how this system reacts to the additional information about scattering and absorbing particles.

  The 2nd paragraph in Section 2.2 CRTM aerosol module has been revised. The following text is added (line 118-124): Absorption by atmospheric trace gases, such as water vapor and carbon dioxide, is parameterized using the Optical Depth in Absorber Space (ODAS) and the Optical Depth in Pressure Space (ODPS) algorithms (Chen et al., 2012), which are based on rigorous line-by-line calculations from the Line-By-Line Radiative Transfer Model (LBLRTM, Clough et al., 1992). Scattering and absorption by aerosols are calculated based on pre-computed lookup tables containing aerosol optical properties, including extinction coefficient, single-scattering albedo, asymmetry factor, and phase function coefficients. Operationally, given aerosol types, radius, concentration and ambient relative humidity, CRTM generates aerosol optical profiles that the radiative transfer solver requires for multi-scattering simulations and radiance calculations.

- Line 58-60: aerosol-aware DA is complicated to describe, because the model prior has high and low biases without aerosol information and different high and low biases when aerosol information is included. This part needs to be looked over carefully, especially the part about "leads to a warmer atmospheric analysis" needs a more complete description that reduces ambiguity about the referenced experiment and results.

  This paragraph has been revised by providing a more complete description of referenced experiments (line 55-62) and the results (line 65-67).

  Figure 2 and discussion in Lines 217-222: This part of the description seemed rushed and incomplete. There is plenty of room to expand this figure to show, for instance, the relationship between dust loading and differences in innovations.

Figure 2 in the previous version contains global BT differences and OMFs differences over the trans -Atlantic region. This figure has been revised to BT differences, OMFs for CTL, OMFs from AER, and OMFs differences over the trans-Atlantic region (Figure 3). We also add a new figure (Figure 4) showing the OMFs differences versus dust loading. The discussions on these 2 figures are also extended (line 237-250).

- Line 70: "In section 2.3,… given here." => "In section 2.3,… is given."

  Revised. "is given here" changed to "is given." (line 77). We also revise line 196 ('given here' changed to 'given').

- Line 96: "may degrade the data usage" It is not clear what this means.

  This phrase is clarified. Line 105: 'degrade the data usage' changed to 'fluctuate the amount of observations assimilated'

- Line 140: "optical properties… are"

  Corrected. "is" changed to "are". (line 157)

- Line 292: "include, but not" => "include, but are not"

  Corrected. "efforts include, but not limited to" changed to "efforts include, but are not limited to" (line 363)

Comments from Reviewer #2

We thank the reviewer#2 for the valuable suggestions and constructing comments. This GMDD manuscript has been modified accordingly. Point-to-point response to the reviewer's comments is given below.

This is a well-written manuscript on the important topic of assimilation of aerosol-affected infrared radiances. The manuscript describes key model developments and highlights the ability of aerosol-aware radiance assimilation to improve forecast performance. I recommend minor revisions to improve some of the analysis and discussion points in the manuscript.

Science questions/issues

Line 112: "The optical tables from other aerosol models are not finalized yet"; It would benefit readers to know what other optical tables are in development. Can you mention at least one of them here?

The sentence is changed to "There are ongoing and planned CRTM development efforts to incorporate more aerosol optical tables (such as the Community Multiscale Air Quality model, CMAQ). With the expansion of the aerosol schemes, a new releasing and versioning system for optical tables is essential and currently under discussion. This article, however, discusses mainly the GOCART model, which is the default aerosol scheme in the CRTM version 2." (line 128-131)

Note that the statement regarding version number is to respond to the editor's comment.

Line 195-198: According to Gelaro et al. (2017), MERRA-2 includes infrared radiance assimilation of IASI in an aerosol-blind configuration. As a result, should we expect any significant differences in the meteorological fields (e.g., temperature) between MERRA-2 and the baseline GSI experiment? Can you provide information on the possible magnitude of systematic biases in dusty regions of the MERRA-2 reanalyses?

Presume the baseline GSI experiment, mentioned in the reviewer's comment, is the aerosol-blind, cycled experiment using GDAS. Both GEOS-ADAS and MERRA-2 by GSFC are aerosol-blind cycled runs (using GSI/CRTM for analysis and GOES-5 for forward model). GDAS, on the other hand, uses GSI/CRTM for analysis and GFS for forward model. We don't anticipate significant aerosol-induced differences between GDAS and MERRA-2 (or GEOS-ADAS).

We do anticipate that there could be some differences between aerosol-aware GDAS versus aerosol-blind MERRA-2. To quantify systematic errors associated with not constraining aerosol transmittance effects, cycled experiments with aerosol-blind versus aerosol-aware configuration over a longer time period will be needed.

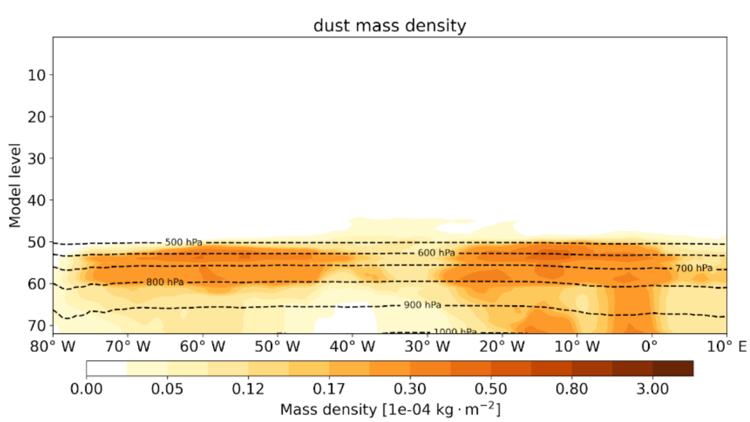
Our previous study (Wei et al 2021) shows 0.3-0.5K warmer SST and 0.15K warmer lower atmosphere over the dust-laden region. While we hesitate to draw any conclusion on the anticipated differences, the manuscript is revised to provide more information on the temperature differences (see line 65-67).

Lines 199 – 206: More explanation on Fig. 1b is recommended. This map shows dust dominating in almost all areas of IASI coverage. I understand this is the active dust season with long-range transport, but could MERRA-2 be overestimating the global dust coverage, which would impact the results in Fig. 1a? For instance, there are some areas of carbon aerosols mostly over eastern Siberia, but I would expect a more extensive area of carbon dominated aerosols across Siberia.

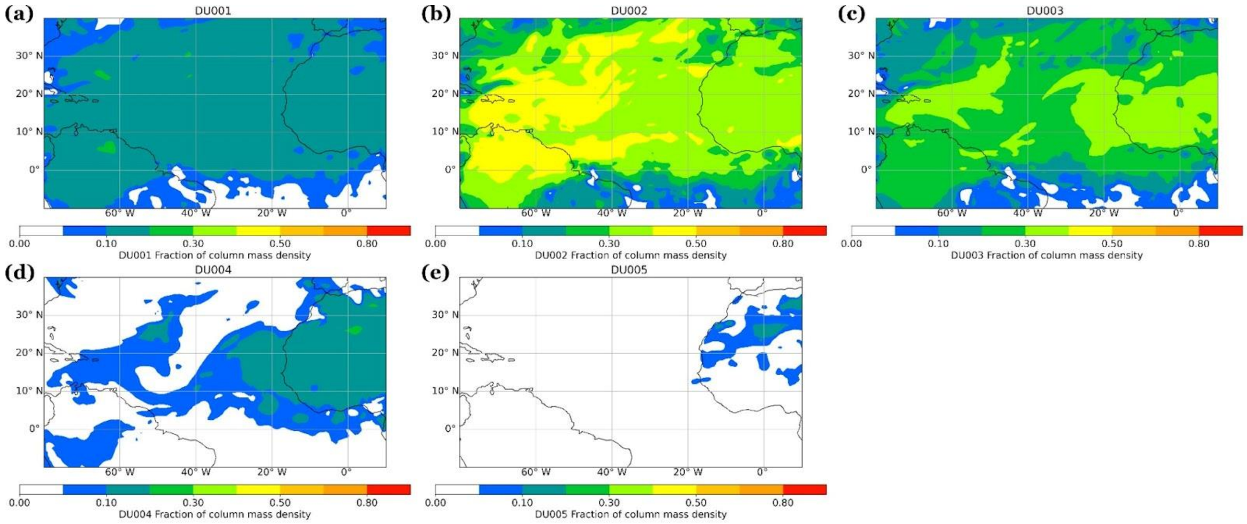
We add a new figure (Figure 1) showing dust, sea salt, carbonaceous, and sulfate loading. A new paragraph is added (line 220-231) to describe Figure 1 and address MERRA-2 high biased on dust at high-latitude region.

Lines 228 – 232: A more detailed explanation of Fig. 3 is strongly recommended. Additional panels showing dust column mass density (in addition to total aerosol column density) and dust effective radius would be helpful to the analysis and readers. How are dust sizes varying in the dust contaminated areas and influencing the AER-CTL TEMP differences? Dust size should be analyzed and discussed here, as it is an important factor when accounting for aerosol-affected satellite radiances. Also, why are the much cooler BTs in the AER experiment over western Africa (Fig. 2a) leading to only a minimal warming signal at 900 hPa? I was expecting to see significant warmer temperatures in AER compared to CTL at 900 hPa in this area. Less important, what is causing the significant AER-CTL temperature differences over the Southern Ocean and Antarctica?

After adding two figures (Figure 1 and 4), the Figure 3 mentioned here is now Figure 5. The discussions on Figure 5 are extended (line 285-300) to address the reviewer's comments. Dust off of west Africa is carried by the SAL and the aloft air mass (see top panel below) is changed toward more fine particles (see bottom panel below). The present study, however, is focused on documenting the CRTM aerosol option. The GSI experiments conducted in the present study demonstrate the aerosol impact, but further study will be needed to characterize and quantify the response of the GSI analysis to aerosol-affected BT calculations.



Meridional mean of dust aerosol mass density over region (10S-40N and 80W-10E) on 12Z June 22, 2020.



Fraction of total column mass density for bin 1 to 5 dust aerosols from MERRA-2 on 12Z June 22, 2020.

Line 242: What are the specifics of this fully cycled experiment (e.g., cycling frequency and assimilation window)?

The specifics of this fully cycled experiments, including model version, resolution, initialization, cycling frequency and assimilation window) are described in line 307-311.

Line 243: "aerosol-affected satellite radiances are taken into account"; Were infrared radiances from all satellites in GDAS considered? A short list of some key satellites considered in these experiments would be helpful.

A list of satellite IT sensors is given in section 2.1 (line 92-97).

Line 263: Can you explain the poorer results over the Southern Hemisphere? Simply due to less aerosol loading?

We suspect the cloud contamination and mixture of sea salt and aged sulfate/smoke aerosols (line 334-335). However, further study will be needed to understand the poorer results.

Lines 263 – 265: A map of mean total aerosol column mass (or for the different aerosol species) for the period of interest or perhaps a table of aerosol column masses for the different regions would be helpful here.

We add a new figure (Figure 1) showing column mass density for dust and other aerosols.

Technical corrections

Line 232: missing "K" after "0.5° to 1°"

Corrected. See Line 290.

Line 262 – 263: “The RMSE scorecards … while neutral or degradation over the Southern Hemisphere (20° S – 80° S)”, sentence structure needs improvement

Revised to “The RMSE scorecards show the forecast improvements in the wind, temperature and height fields throughout the troposphere over the Tropics (20° S – 20°N) and at upper level over the Northern Hemisphere (20° N – 80° N). For the Southern hemisphere (20º S – 80º S), however, there is neutral or degradation in the forecasts, which is likely due to cloud contamination and mixture of sea salt and aged smoke/sulfate aerosols“ (line 332-334).

Line 270, Figure 5 caption: replace “means” with “mean”

Corrected. (Line 341-342)