Title: A three-dimensional variational data assimilation system for aerosol optical properties based on WRF-Chem: design, development, and application of assimilating Himawari-8 aerosol observations
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General Comments:

The authors developed a new capability of assimilating aerosol optical properties, including AOD, aerosol mass concentration, and aerosol backscatter data, using a 3DVAR method. The analysis system was developed to work with the MOSAIC chemistry option inside the WRF-Chem model. They used one severe air pollution episode that occurred in North China during November 23-29, 2018, to demonstrate the new development. Only the AOD data from Himawari-8 were assimilated. Two numerical experiments were conducted, and their forecasts were initialized by different aerosol data. One used aerosol analysis after 24-h data cycling of AOD assimilation (called Assimilation) and the other one used aerosol data from the previous 24-h forecast (called Control). Results are compared with different observations, including AOD from Himawari-8, Terra MODIS, and AERONET and surface PM2.5 concentration, and are statistically evaluated using the correlation coefficient, RMSE, and mean bias. The assimilation of AOD can improve aerosol forecasts for about 24 h.

The new development of assimilating aerosol optical properties should be encouraged. In particular, the development of assimilating more optical properties, such as backscatter data, can be useful, though no data assimilation experiments have been tested, except for AOD. The authors provide a lot of details on their analysis system development, which is great but could be also too tedious, depending on the background of readers. Nevertheless, the documentation of the system development will certainly be appreciated by some readers. I have a few comments to further improve the manuscript.

Major comments:

- Using a constant observational error covariance of 0.06 seems not very convincing. For AOD of 1.8, the error is only 3.3%. Is this realistic? The observational error plays an important role in the DA analysis. Some justification for using this value is needed.

- More detailed information in numerical experiment design is needed. Is AOD DA performed every hour whenever AOD data are available? Does the forecast last for 24 h only? For each 24-h DA cycle, are the meteorological data in the first guess from FNL or from data at the end of the previous cycle? Similarly, for each forecast starting at 0300 UCT, while aerosols are taken from the analysis after a 24-h DA cycle for the Analysis run and from the previous 24-h forecast for the Control run, are meteorological conditions taken from FNL?

- The development of assimilating optical properties was built on the framework of Li et al. (2013). The authors should discuss major differences between the two analysis systems and major differences in the conclusions of the two studies.

- The improvement of aerosol forecasts only lasts for 24 hours in this study. Although Li et al. (2013) also showed a similar result, this seems a little bit short in terms of forecast length. Some studies have shown the benefit of assimilating AOD data in longer aerosol forecasts (48 h), such as Benedetti, et al. 2019 and Choi et al. 2020. Could it be due to, for example, no assimilation of meteorological data, the quality of AOD data, the assimilation method, the study location, etc.? The authors should compare their results with others' or make some comments about this issue (24 h versus 48 h).

  Benedetti, A., Di Giuseppe, F., Jones, L., Peuch, V.-H., Rémy, S., and Zhang, X.: The value of satellite observations in the analysis and short-range prediction of Asian dust, Atmos. Chem. Phys., 19, 987–998, https://doi.org/10.5194/acp-19-987-2019, 2019.

  Choi, Y., Chen, S.-H., Huang, C.-C.,Earl, K., Chen, C.-Y., Schwartz, C. S., &Matsui, T. (2020). Evaluating theimpact of assimilating aerosol opticaldepth observations on dust forecastsover North Africa and the East Atlanticusing diff erent data assimilation meth-ods. Journal of Advances in ModelingEarth Systems, 12, e2019MS001890

- **Minor comments:**
  1. Line 65. "… monitoring, for instance, China has…" should be ""… monitoring. For instance, China has…"
  2. Line 74. "… detailed aerosol profiles (Kaufman et al., 2002), …" Kaufman et al., 2002 used AOT and aerosol index for their study. Both are vertically integrated data and thus do not provide vertical profile information.
  3. Line 98. What does the "control variable scheme" mean? DA methods usually need control variables. Do you mean "...PM10, which is used as a control variable?"
  4. Lines 120-122. I believe that ECMWF uses a 4DVAR method to assimilate AOD and it is an online approach. Check out Benedetti et al. 2019 paper listed above.
  5. Lines 236-237. "…observation errors associated with AOD retrievals are determined by measuring instruments…" It is probably more than just the instrument itself, but also the retrieval algorithm and surface emissivity, to name a few.
  6. Line 261. Define BEGS.
  7. Lines 440 and 442. The data reduction used in this study is not a thinning procedure but a superobbing procedure.
  8. Line 457. Add "AOT" in front of assimilation.
  9. Line 569. "… with negative increments marked in blue." Improve the color shading in Figure 6c. Make warm and cold colors for positive and negative values, respectively. The current plot mixes red and blue colors for positive values, while it uses blue shading for negative values. This is confusing. A similar problem is seen in Figure 9c.

10. Line 594. "… BIAS increase…" This statement sounds like that the assimilation of AOD data makes the result worse, but it is not true. Need to rewrite this. The same for line 663.

11. Try to use words consistently throughout the paper, such as "cost function" versus "objective function", "AOD" versus "AOT", "Control" versus "control" experiment, and "Assimilation" versus "assimilation" experiment.