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Interactive comment on "3D-Var versus Optimal Interpolation for Aerosol Assimilation: a Case Study over the Contiguous United States" *by* Youhua Tang et al.

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Thank you for your detailed comments, which highlighted some important technique details. We changed this manuscript and make it easy to understand.

Section 2.1 – page 3, lines 13 to 16 and 23 to 24. There are two queries I have here about the OI set up that I believe are related. (i) The first is that I'm not clear how the background uncertainties have been formulated. I've also looked at the referenced paper but still have questions and so I think that a brief but slightly more comprehensive description would be useful here. As far as I can tell from the referenced paper, the background uncertainties have been made using a free running model and comparing

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to the observations. If I look at Figure 2 from that paper then this only gives values at observation locations. Is this correct? Generally B is formulated to give uncertainty values across the whole of the model domain not just at point locations, so why is this not done in this case?

It is true that the background error covariance matrix B needs to be formulated to give uncertainty values across the whole model domain. The dynamic uncertainty used in Tang et al. (2015) is applied to the locations in which surface PM2.5 monitoring stations exist, while all other areas use 80

You also mention the diurnal variations – does this mean you use a different B matrix for the different assimilation cycles? This also only addresses the diagonal variances or uncertainties of the B matrix and not the cross correlations and this is my second question.

Yes, the variances of the B matrix will change for different assimilation cycles over the monitoring stations. However, the cross correlations are only modeled as a function of separation distance, which has no diurnal variation (see equation 3 of Chai et al. 2017, http://onlinelibrary.wiley.com/doi/10.1002/2016JD026295/full). The corresponding clarification was added in the manuscript.

(ii) You mention that the OI adjustment is made in each 11x11 grid horizontally and it's effect expands up to the PBL. This would normally be done through the B matrix, is this the case here? If so is it a cut-off Gaussian that has been used for the horizontal correlations, or a uniform distribution? Similarly for the vertical correlations – you state that the surface PM2.5 OI increment is applied from the surface to the height of the PBL. Is this done after an increment is calculated by OI or through the formulation of the B matrix? Is it a constant adjustment at each model level or does it taper as you reach the PBL? If so how does it taper? All this is relevant because you attribute the differences in the schemes largely to this formulation of the B matrix.

It is a cut-off Gaussian-like B matrix in the horizontal directions, but uniform distribution for the adjusting ratio in the vertical direction up until the PBL (or whole column for AOD). At each grid point, an increment is calculated using OI formulation and the adjustment ratio is applied to all levels below the PBL (or whole column for AOD). No tapering is applied here.

Section 2.1 – page 4, lines 1 to 4. Again this question addresses the B matrix but now for the GSI scheme. The referenced paper was informative and from this I understand that the horizontal and vertical correlations that make up the B matrix are Gaussian (and again it might be worth mentioning that here) and I assume the GSI package has been used to create these? Although it talks about optimisation in the referenced paper, I couldn't find anything to suggest these length-scales should be the same across the domain. Are the background errors and length scales the same across the domain in this case? It is unclear from the description given whether these plots are a single point representation or not. I also wasn't totally clear what is being used as the control variable for the AOD. Is it just ASO4J? You also mention that other aerosol species have proportional model or background errors. Were these just computed for interest or do they also feed in to the modelled AOD?

Yes, B matrix is Gaussian here, which is generated from a GSI utility, called GEN_BE. You can find more detail about the tool (Descombes, et al, 2015, and http://www.dtcenter.org/com-GSI/users.v3.5/docs/presentations/2014_tutorial/Auligne_GSI_Tutorial2014.pdf).
Yes, the background errors and length scales used in this study are same across the domain for each control variable, and only have vertical variations. In AOD assimilation, the 54 control variables are listed in Table 1 (CMAQ 5.1 aerosol species, left column), and ASO4J is just one of them. We changed the "proportional" to "similar" to avoid from misunderstanding. Each aerosol species in AOD assimilation actually has its own background error and length scales. They are similar in term of B's vertical variation in the same aerosol size mode, but their standard deviations have magnitude difference due to their different atmospheric abundance. We added the clarification in

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manuscript.

Section 2.2 – page 5, lines 17-40. The final issue that I really struggled to understand was how the CMAQ forecast model and the GSI data assimilation method actually interact. Perhaps a schematic attached to this section would be more informative, as it's clearly quite a complex process. Are the species given in the forecast by CMAQ, translated to the variables required by the CRTM's GOCART aerosol as stated in Table 1, then run through the forward model calculation to give AOD, assimilated by GSI and an increment returned for each of the GOCART species? How is this increment divided back in to the CMAQ variables? Once this is done I assume that CMAQ is used to forecast the species on to the next assimilation time? Is the B matrix you describe also a plug in to the GSI? Is the resolution the same for both models? If a figure could be created that shows this process it would add a lot to the understanding of this section We add the schematic diagram, changed the literature and make it easy to understand. The GSI AOD assimilation actually uses the 54 CMAQ species, not the GOCART species. The concentrations of 54 species are feed into GSI and also gotten their each increment out from GSI. We only use GOCART's lookup table in CRTM to convert each CMAQ species' mass concentration to each aerosol optical properties etc which are needed for the AOD assimilation. Table 1 is used for the AOD conversion only. So, there is no species concentration re-distribution or model resolution issue, as all of them are native.

Section 3.1 – page 7. How do you distinguish the effect of assimilating AOD from the effect of the PM2.5 measurements? Are three different experiments run (one with just PM2.5, one with AOD and one with both)? Given that the GSI method solves a cost function, I'm not clear how you distinguish the effects from two different observation types in one experiment. For the OI, as far as I understand an increment is given by the AOD and PM2.5 observations separately, although this needs to be described/clarified in further detail (see my question 1 above), and so I can potentially envisage how this could be done with one experiment. However, this needs to be made clear.

Yes, we had three experiments to showing the effect, one with just PM2.5, one with AOD and one with both. You are right, and it is not easy to treat two different observation types in existing GSI in one step. For 18Z GSI assimilation, the assimilation was actually made in two steps: first is the GSI AOD assimilation, and surface PM2.5 assimilation was made upon the AOD assimilation adjustment. We added this content in the manuscript.

Abstract – page 1, line 26. I think perhaps 'background error uncertainties and the horizontal/vertical length-scales of the covariances' would be a more accurate description.
Changed. Thank you

Figure 1. Are these errors and length-scales static quantities used across the domain or for one specific point.

They are used across the domain. We added clarification.

3. Figure 4 is in the wrong order. 4. Page 9, line 14 - 'assimilation for the elevated layers blow PBL.'. Should be below. 5. Page 9, line 10 - 'steeper' not 'steepen'

Changed. Thank you

Thank you again for your comments

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