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Atmospheric Measurement Techniques Discussions

Interactive comment on "Correlated observation error models for assimilating all-sky infrared radiances" *by* Alan J. Geer

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Overall this was an excellent paper, a joy to read, and of significant practical value as well to operational NWP centers. The concepts presented will be applicable to other sets of channels and other instruments as well.

The reviewer's positive and helpful comments are much appreciated.

1.1 *One relevant issue that I would like to see discussed is that of the sample eigenvalue spectrum of the observation error covariance matrix vs. the true eigenvalue spectrum. The expectation value of the largest eigenvalue is always overestimated by the sample eigenvalue, and the smallest is always underestimated. This provides additional justification for raising the value of the smallest sample eigenvalues. (This issue*

is discussed on a paper you reference, Campbell et al. 2017, which references Ledoit and Wolf, 2004)

It is an interesting point that sample eigenvalues are more dispersed than those of the true covariance matrix, as explained by Ledoit Wolf (2004). However the severity of the problem decreases as $\frac{p}{n}$ decreases. Here, p is the number of variables and n the number of observations. In the current work p is 7, for the 7 IASI channels, and n is always substantially greater than 10,000. Hence the number of samples may be sufficient to minimise this problem from a purely statistical point of view. A point raised by other reviewers may be equally or more important here: is it really appropriate to use the same covariance matrix globally, across different seasons, across different model versions? It might be particularly the trailing eigenvectors that would vary in different conditions.

Mansuscript change: This point will be added to the discussion of eigenvector and eigenvalue stability at the end of section 3.2, with reference to Campbell et al. (2017) and Ledoit and Wolf (2004)

1.2 *Instead of the Desroziers method, which estimates R as the outer product of the departures and the obs minus analysis, this paper uses the outer production of the departures with themselves, which yields $HBH^T + R$. Because HBH^T is small compared to R, especially in all-sky assimilation, this is justified; however, I would like to see a more quantitative estimate of the size of R relative to HBH^T. One advantage is that for monitored observations, some operational DA systems do not routinely produce obs minus analysis, which is an obstacle to the Desroziers calculation of R, but not to the calculation of $HBH^T + R$.*

A justification for HBH^T being significantly smaller than R is already made in a few ways in the introduction to the manuscript, based on prior work. On P2L32, reference is made to Geer and Bauer (2011) whose tuning exercise suggested that all error in cloudy skies could be assigned to R, and to Harnisch et al. (2016) who showed ensemble estimates of HBH^T around a third the size of $HBH^T + R$ estimated from the background departures. Further, as described in the introduction it has not been possible to provide similar estimates of HBH^T from ECMWF's ensemble of data assimilations, because the recorded estimates appear to be affected by a bug that has not yet been solved. I would ask that further quantification of HBH^T and R be left to future work, as it will be a major exercise both technically and scientifically. Nevertheless this would be an important area on which to make progress

Manuscript change: The manuscript already justifies qualitatively that HBH^T is significantly smaller than R in all-sky conditions. It is agreed there is need to document this quantitatively, but it will be left for future work

Some minor comments:

1.3 *P14, L20: Campbell et al. 2017 has an extensive discussion of trailing eigenvalues and condition number, so would be appropriate to include as a reference.*

Manuscript change: This citation will be added as requested at P14L20, and it will also now be covered in section 4.1 where the adjustment of eigenvalues in Weston et al. (2014) and Bormann et al. (2016) have been explained in more depth, but not as yet the Campbell et al. (2017) adjustments.

1.4 *P27, L15 Please provide a reference for the background fit to observations diagnostic presented here, and comments on how it compares to traditional forecast scores.*

Unfortunately there is no good reference for these background fit diagnostics, but they are widely used at ECMWF and increasingly in studies by other NWP centres. However the point is well taken that they are used with little introduction in the current manuscript.

Manuscript change: Text will be added to describe the widespread use of such diagnostics, to justify them as an easy way of verifying the short-range forecast against observations, making use of diagnostics already generated from the DA process. These are now used in preference to short-range verification against analysis (whether the

experiment's own or from other analyses) because of the substantial error correlations between the forecast and analysis at short range, as demonstrated in e.g. Geer and Bauer (2010); Geer et al. (2010). Further, it will be pointed out that the change in the analysis fit should be used with care as a measure of analysis quality, as the observational reference is not independent of the analysis, but at least in this work the changes in analysis fits are consistent with the changes in background fits, where the reference observations are independent of the forecast.

1.5 *P29, L11-12 Clarify how the blue curve is better than the orange curve*

Admittedly the effect of switching on VarQC is small, but there is significant impact in the background fits to ATMS channels 18, 19 and 20.

Manuscript change: Text will be added to clarify this, and the effect of VarQC will be more clearly signposted as minor both here and in the conclusion.

1.6 *P30 L15*. They did not have to increase all evals; they chose to.

Manuscript change: "Have to" will be changed to "Chose to"

The remainder of my comments relate exclusively to the figures:

1.7 *Fig 3. As noted in the text, eigenvectors are only unique up to sign, so the ones in this figure with the opposite sense should be multiplied by -1 and plotted, so as not to falsely draw the eye to a difference that is not real. Also the subfigures should be laid out differently to allow for larger size. A zero line would also be helpful.*

This figure is intended to occupy one column of the two-column A4 format used by AMT for final publication. It will appear slightly larger in that format when printed, and I believe of sufficient size to distinguish the different lines, but please let me know if that is not good enough.

Manuscript change: A zero line will be added and eigenvectors that differ only by sign will be replotted as suggested.

1.8 *Figs. 5-9, 16, 17, 21 Could use thicker lies to help differentiate the line color.*

Manuscript change: I will experiment with thicker lines in these plots; this was a comment from one of the other reviewers too.

1.9 *Fig. 10. White should not be used to correspond both to a zero value and to unassimilated. Use e.g. gray over the Antarctic, Sahara, etc.*

Manuscript change: I worked out how to get cross-hatching on these plots for the companion paper, so I will add that to Fig. 10 and Fig. 11 to distinguish areas where no data is used (such as over Antarctica).

1.10 *Fig 11. Colorbar does not need to extend to -2; -1 looks sufficient.*

I will experiment if the scale range can be shrunk. However there are values up to around +1.6 in panel f, and it is necessary to have a symmetric contour range to retain blue colours for negative and red for positive. So it might be possible to reduce it as far as -1.5 to +1.5, but that requires further experimentation.

Manuscript change: The colorbar will be reduced in range if at all possible.

References not in the original manuscript

Geer, Alan J. and Peter Bauer, "Enhanced use of all-sky microwave observations sensitive to water vapour, cloud and precipitation.", ECMWF Technical Memorandum 620 (2010)

Geer, Alan J., Peter Bauer, and Philippe Lopez. "Direct 4D-Var assimilation of all-sky radiances. Part II: Assessment." Quarterly Journal of the Royal Meteorological Society 136, no. 652 (2010): 1886-1905.

Ledoit, Olivier, and Michael Wolf. "A well-conditioned estimator for large-dimensional covariance matrices." Journal of multivariate analysis 88, no. 2 (2004): 365-411.

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