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Interactive comment on "Variational data assimilation with superparameterization" *by* I. Grooms and Y. Lee

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Thanks to both the referees for their time and effort in reviewing the manuscript, which we believe have led to an improved version. In addition to the changes made in response to the referee comments, listed below, we added a citation to recent work of Y Lee and AJ Majda on multiscale filtering at the beginning of section 3.

Response to Referee #1

General Comments:

- *"I have a hard time seeing the figure axis labels. At least in the version I received, the axis labels and numbers are very small and can't be read."*

We have increased the font size on the axis labels in both figures.

- *"I wonder if the title could be a bit misleading. Not to detract from the excellent work that you've done, but perhaps you would consider changing to e.g. 'A framework for variational data assimilation with superparameterization' since you are not applying to a full NWP/climate SP model yet."*

  This is an excellent suggestion, and we have revised the title.

- *"I think you should consider changing the order of the sections so you introduce the model first and then describe the data assimilation, followed by the experiments. The way it reads now it goes from data assimilation to model and back to data assimilation. Reading your results I found myself having to flick back to the beginning having moved on to thinking about the model that you've developed."*

  We seriously considered the ordering suggested, but prefer the current one. The main emphasis of the paper is the framework for data assimilation, not the new model that plays a supporting role, and placing the model in section 2 could overemphasize it at the expense of the framework.

Specific Comments:

- *"P516 L22: I wonder if you should just state at this point that it is periodic between large scale grid points. Although that quickly becomes clear it would save confusing a reader new to this topic."*

  The sentence has been changed to read "The small scale variables exist on local periodic domains so that the small scale variables at each coarse grid point are disconnected from those at surrounding coarse grid points, and the small scale variables have zero average across the periodic directions." It can be hard to describe the SP multiscale grid, and we hope the above is an improvement.

- *"P517 L6: You say mean of u computed from SP variables but later say that it is zero?"*

  We added the clarification: "Although the true small scale variables u' can in principle have nonzero statistical mean, the small scale SP variables $\tilde{u}$ always have zero mean because their average over the local periodic domains is always zero by definition."

- *"P517 L13: Could you comment on why you chose to interpolate the co-variances, rather than the small scale variable itself?"*

  This is a good place to point out that we interpolate the co-variances rather than the variables, and we added the sentence "We also assume that the statistics of the small scale variables vary on large scales and can therefore be smoothly interpolated from the coarse grid points, where small scale SP statistics are available, to the locations of the observations."

- *"P518 Ls20-21: Perhaps state here whether or not the periodic domain is centered on coarse grid points?"*

  We added the following sentences at the beginning of section 2 to help clarify the nature of the multiscale SP grid: "Each location in the small scale periodic domains doesn't correspond to a different location in the real physical domain. Instead, all points in a given periodic domain are best thought of as existing at one physical location: the associated coarse grid point." As a result, the small scale periodic domains can't really be 'centered' or 'off-center.'

- *"P522 L16: can you state what the index i refers to here?"*

  We added the phrase "and the index i, which is periodic $Y_{i+JK} = Y_i$, is analogous to spatial location on a latitude circle, similar to the original L96 model"

- *"P523 L44: Should Y_N in fact by $N(Y)$ or $N_Y(N)$?"*

  We have corrected this typo.

- *"P526 L15: This opening sentence is a bit wordy and could be shortened to just e.g. 'In this section we describe data assimilation experiments in both regimes of the test model using the 3D-Var framework from Sect. 2.'. Start a new paragraph after the opening sentence."*

  We have made the suggested change.

Response to Referee #2

"I would find the results more convincing if their filter using SP were compared to standard techniques for the full true model (an ensemble filter would be feasible in this situation), rather than just comparing with the observations and the climatology."

Standard techniques are certainly possible in this model, but this comparison could be misleading. The main point of our paper is not that SP models with our new assimilation framework are more efficient or otherwise better than standard models with a standard assimilation framework, as would be suggested by making such a comparison. Instead, we are simply demonstrating how to use our new framework in the context of a simple test model, and comparing to climatology (though somewhat of a weak comparison) serves to demonstrate that the combination "works." Our new framework provides the only practical way to use existing SP models in a data assimilation context.

"Page 518: In what sense is 'the assumption that they are uncorrelated [is] reasonable"? Could the authors elaborate on this?"

We re-arranged the ordering of the sentences following equation (5) so that we could insert the following discussion:

> ...the assumption that they are uncorrelated is reasonable within the context of an SP model where the small scale variables have zero mean. The joint probability distribution of large and small scale variables can be factored into the large scale marginal and the small scale conditional distributions $p(\overline{u}, u') = p_M(\overline{u})p_C(u'|\overline{u})$. The cross-covariance between large and small scale variables is $\int\int(\overline{u} - \overline{\mu})u'^T p_M(\overline{u})p_C(u'|\overline{u})d\overline{u}du' = \int(\overline{u} - \overline{\mu})p_M(\overline{u})\left[\int u'^T p_C(u'|\overline{u})du'\right]d\overline{u} = \mathbf{0}$ where the term in square brackets is zero because the small scale variables are assumed to have zero mean regardless of the state of the large scale variables.

"pages 527/528: On page 527 the climatological mean value of X_k is 3.8 and 3.6, and on page 528 it is 0.57 and 0.53, respectively."

We have clarified that the values 0.57 and 0.53 are the climatological pattern correlations, not the climatological means.

"The figure labels should be increased."

The figure labels have been increased.