Reply to reviewer #4 comments on "Improving the characterization of initial condition for ensemble streamflow prediction using data assimilation"

We would like to thank the reviewer for the feedback on our manuscript. These comments motivated us to improve the explanation of representativeness of the SNOTEL stations and fix a few errors/confusing statements. The revised manuscript gives a more detailed explanation of SNOTEL representativeness with respect to elevation.

Reviewer Summary:

This paper is following a long series of papers on ensemble DA techniques and their applications by the author(s) from 2005 onwards. There are no advances in the PF technique itself. However, it is applied in a very important area from operational perspectives. Too often we have seen the "death valley" that lies between researchers' delicately designed experiments and the operational environment. This study sets up an example of bridging the gap between research and operations, by applying a wellknow technique in research community into the operational ESP at multiple operational basins for the first time. The necessity of ensemble initialization of ESP has been long recognized by RFCs and the OHD, but not explored yet. Overall, the paper well fits into the scope of this special issue. On top of comments/suggestions from other reviewers, I have only several minor comments mostly for clarification purpose.

Comment:

I would suggest the authors list the (# of) SNOTEL sties used in assimilation experiments at each basin (Table 1). In the same table, the authors may also want to list how many tiers (elevation bands) of each basin (I guess not all of them are three-tiered?) to support the discussions on the representation of different bands by SNOTEL sites in the result section.

Reply:

There is only one SNOTEL site used for each elevation band. This is clarified on page 7212 lines 4-5 by changing "Each SNOTEL site is chosen as the observation of a given model elevation band..." to "A single SNOTEL site is chosen as the observation for a given model elevation band...". With this clarification, it will only be necessary to list the number of elevation bands in each basin.

Comment:

From Fig. 2, the statement "This figure shows that the middle elevation band is well represented in terms of elevation" (P7212, L8-9) seems not evident. To reach that conclusion, each band for each basin should be highlighted, along with the DEM overlap. Thus, the corresponding results need to be revisited. Actually, many SNOTEL sites are located in the top band of basins in general.

Reply:

We believe that explaining the elevation difference between the observation points and that elevation bands of the basins is much easier to understand through a chart showing the elevation difference between model elevation band and SNOTEL observation than through a hill-shade with many dividing lines (elevation bands) and points (SNOTEL stations). The figure becomes quite cluttered and difficult to understand. Further, this figure has been clarified as requested by another reviewer in addition to adding an entirely new figure to clarify the definition of the middle elevation band in this study (please refer to the revised manuscript or response to reviewer #2). The figure now shows the mean difference between SNOTEL and the model elevation in addition to the mean absolute difference between SNOTEL and the model elevation. This shows that the observation chosen for the upper elevation band is typically at a lower elevation than the model but the observation for the lower elevation band is typically at a higher elevation than the model. We agree that SNOTEL sites tend to be at the highest elevations of large basins but this study examines only the headwater basins determined by the NWS. Within these basins, the middle elevation band tends to be much closer in elevation to its respective SNOTEL observation site than the upper and lower elevation bands.

Comment:

P7213, L19, are SNOW17 parameters updated in this study? If yes, which ones?

Reply:

Thanks for noticing this error. There are no parameters estimated to keep the models consistent with those used operationally. Only states are updated. This has been revised.

Comment:

Equation (2), the author should specify how areal SWE (which is assimilated to the SNOW17 via the PF) is produced from point observations. In addition, how is the observation error is defined? For a specific basin, is it consistent for each year? Is it consistent for different basins?

Reply:

It was not attempted to change the SNOTEL from point observations to areal SWE. The description of SNOTEL (end of section 2.4) was modified to explain that a normally distributed error with a standard deviation equal to 25% of the observed SWE is added to account for differences between SNOTEL SWE observations and true areal averaged SWE. This 25% is kept constant across all basins and the whole year to keep the experiment more straightforward.

Comment:

SWE is assimilated to update snow water storage. Except for that, are there any other SNOW17 states also updated?

Reply:

In the PF with SIR algorithm, ensemble members, which include an entire state vector, are resampled and not individual states. This means that all states are updated though only the observation of SWE is used.

Comment:

P7215, L17-26, please be more specific about “sequential state estimation experiment”, how is that set up? Why “a sufficient number of time-steps” is required here? Given that the major difference between ESP-DA and ESP is initialization, it worth presenting how the ensemble states are generated for at least one test basin for demonstration purposes.

Reply:

“sequential state estimation experiment” referred to the use of data assimilation to create the initial states. Line 19 on page 7215 has been changed to “ESP-DA implements data assimilation to estimate the initial states” to make this more clear. Also, a “sufficient number of time-steps” is required for data assimilation similar to how the spin-up requires a certain time-period to reach accurate values. An explanation was added to the following sentence in the manuscript.