Review of *"Optimized Stochastic Representation of Soil States Model Uncertainty of WRF (v4.2) in the Ensemble Data Assimilation System"* – Manuscript gmd-2023-28 by S. Lim, S. K. Park, and C. Cassardo

Summary:

This study applies an additive stochastic perturbation scheme to soil temperature and moisture (separately) in the topsoil layer of the Noah LSM in the WRF model as a means to improve background error covariances in an ensemble data assimilation system. The micro-genetic algorithm is used to calculate "optimized" amplitude, time, and length scales for different configurations of the perturbation scheme. If the perturbation scheme is working correctly (see MC1), there is some modest indication that it could act as a supplement to other perturbation schemes in the DA cycle (e.g., SPPT, SPP, etc.), since its effect on atmospheric variability is limited when applied in isolation.

There are numerous instances of unclear, incorrect, or otherwise awkward wording that need to be corrected at this stage. Additionally, there are several major questions about the application of both the SPSS and micro-GA that should be addressed before this manuscript can be accepted for publication. Further discussion of the results presented here in the context of other methods for representing land surface uncertainty (see SC2) would be helpful.

Recommendation:

Major revisions

Major Comments:

1. Figure 3 and Equation 7 do not appear to correspond to the same operation. In Equation 7, the updated state variable is computed as the sum of the random forcing and the original variable. Since the random forcing is small compared to the variables themselves, the differences between panels (7a and 7c) and (7d and 7f) are small, as expected. However, plotted values appear to be larger nearly everywhere in the "Updated" panels (except, for example, near 25N,120E in panel 7f) despite the negative values of the random forcing field. Is this supposed to be the case, if so why? Or, is this a minor figure error (e.g., panels plotted at the wrong time)? Or, is there a larger systematic error in the application of the random forcing scheme?

2. At several points in the manuscript (e.g., Line 373), it is mentioned that the optimized perturbation length scale is related to incoming solar radiation and the spatial scale of soil texture variability, depending on time of day. It might be helpful to provide some support for this (e.g., a map of different land use categories or soil textures as a "Fig. 2b"?). If an experiment were conducted in which the soil texture/land use distribution was artificially made uniform, would the length scale of the nighttime perturbations be more similar to the daytime length scale?

3. Were the optimal perturbation parameters derived over only the two 6-hour periods listed on Lines 226–228? Would using additional periods to optimize these parameters (perhaps averaging over multiple optimization values) improve or degrade performance? Related to this, is it possible to calculate the percent increase in computational time that

optimizing the perturbation parameters adds to the DA process, since re-optimizing the parameters in the cycling system is suggested on Lines 301–302 (of course, this will vary depending on a user's specific model/resource configuration)?

4. There are numerous language and grammar errors that should be revised for clarity and precision. While most of these issues are not severe enough to detract from understanding the research presented in the manuscript, they do interrupt the reader's experience. The manuscript should be thoroughly reviewed for grammar and scientific language, many of these issues are identified in the "technical comments" section.

Specific Comments:

1. Line 52: Replace "the less" with "reduced," however, neither choice seems consistent with the discussion of stochastic representations of model uncertainty in this paragraph, since these schemes improve (increase) ensemble spread. Please clarify.

2. Lines 53–58; 61: The sentence starting on line 54 "For example…" could be removed, since the focus of the present study is on soil state perturbations. It would also help to elaborate (in 1–3 sentences) on some of the relevant references included in these lines to show how soil state uncertainty has been represented in recent literature and forecast systems, beyond the already mentioned sensible and latent heat fluxes.

3. Line 85: Please revise the non-scientific text "and so on." Consider changing the in-text list of variables calculated by the Noah LSM to a table.

4. Line 127: The description of the decorrelation time scale is somewhat unclear. As it is written, "determine how long the perturbed errors will be sustained," implies that the perturbations will be held fixed for the duration of the decorrelation time. It may be more clear to say something like, "determine how quickly perturbations evolve in time"

5. Figure 3: Please add a date/time to the caption or figure panels.

6. Line 147–148: Please add a citation in the sentence that begins with "A previous study…"

7. Line 224: First use of OSTP and OSMP acronyms. Please define these in the text.

8. Line 244–246: Please define acronyms when they first appear in the text (STP1, STP2, SMP1, SMP2).

9. Table 1, Lines 161–162, and Line 231:
    a. Please add relevant references (e.g., "previous studies" on line 161) and further discussion to how these ranges were defined.
    b. The numbers of candidate values (Line 231) do not need to be in exponential form. 64, 64, and 16 provides better clarity to the reader.

c. Table 1 indicates that a decorrelation time of 0s was included in the tested ranges – would perturbations with this time scale simply behave as temporally uncorrelated noise?

10. Line 274–283 and Figure 6: There is no time and date information in the caption for Figure 6. Are these means and spreads averaged over the entire experimental forecast period (for all 6-hour background forecasts)? Or are they for a single 6 hour forecast? Line 277 refers to "a 6 hour forecast." Please clarify this both in the text and in the figure caption/labels.

11. Line 305; 316; 323–324: There are several occasions where the impact of the tuning parameters on ensemble spread is discussed. On Lines 305 and 323-324, a smaller length scale with a longer timescale increases ensemble spread. On line 316, a larger length scale and larger amplitude scale yield a larger spread. To improve clarity and reduce confusion, it may be better to simply omit the length scale on these lines, since its influence appears to be secondary to the configuration of the time and amplitude scales [which is consistent with SPPT experiments by both Bouttier et al. (2012) and Lupo et al. (2020)].

12. Line 318–319: The sentence starting with "Because…" is unclear and should be revised.
    a. "…it indirectly changed the temperature…" Does this refer to SPSS indirectly modifying the air temperature? Please clarify.
    b. "…soil temperature perturbing…" This should probably be "soil temperature perturbation," Please revise.

13. Line 320: Please clarify "underestimated temperature." In the present phrasing, it is unclear if this refers to underestimated temperature spread or a cold bias.

14. Line 327–333: The first and last sentences of this paragraph imply that the number of observations assimilated (or discarded) could be shown here. Elsewhere in the paragraph, the wording seems more related to the ensemble spread including the observed value at station 31873 (Fig. 10). Please consider making a more clear distinction between the uses of "including more observations" in this paragraph. If possible, consider also computing and showing the number of assimilated observations here.

15. Figure 10: Could the shaded areas in Fig. 10 be made partially transparent? This may be helpful at times when the CTRL spread is similar to the STP1 and STP2 spread (e.g., between 20180800212–2018080512 in Fig. 10b.)

16. Line 369–379: It could be worth mentioning here that the amplitude scale of the daytime soil temperature perturbations is an order of magnitude larger than the night time perturbations, which could be a reason why the daytime-only perturbations more effectively propagated to the atmospheric variables. In its current form, the text here focuses more heavily on the length scale and time scale parameters.

17. Line 374: Please rephrase “classified as a mesoscale convection system.” The length scale and soil moisture itself is not an MCS, but may be similar in scale. If there are indeed mesoscale convective systems active in the domain at the time of the optimization cycle, it would be helpful to see these on a map, since the optimization appears to be only over a single 6-hour period (e.g., perhaps as a Fig. 2b or 2c).

Technical comments:

1. Line 8: Word “respectively” isn’t necessary here. This could be a good place in the abstract to specify that soil temperature and soil moisture are perturbed in separate experiments, though, since this is not stated clearly in the abstract.

2. Line 29: Remove unnecessary “The” starting the sentence.

3. Line 32: Replace “out” with “outside”

4. Line 36–38: This sentence would probably be more clear if the colon on line 37 was removed. Either make this into two separate sentences or combine to remove the colon.

5. Line 49: “This…representations” number inconsistency. Please revise.

6. Equations 4 and 5: Are the vertical bars ‘|’ used here to group terms? If so, it is a little confusing when first reading these equations since they look like operators. Consider removing or replacing the vertical bars.

7. Line 113: “resolve the” doesn’t seem like the most correct word choice here. “represent” may be more clear.

8. Line 124: “depend on the characteristics being applied” is unclear. Please revise.

9. Lines 129–131: This short paragraph could be merged with the previous one.

10. Line 210: “widely used in the mesoscale model” is somewhat awkward phrasing. Consider revising to “widely used in mesoscale modelling”

11. Line 211–212: “is” “are” number inconsistency, please revise.

12. Line 215: “,…the interpolation uncertainties” – “the” is unnecessary, please remove. Also consider rephrasing to “interpolation uncertainties are avoided”

13. Line 219: “It included…” – Pronoun “It” is inconsistent in number with the antecedent “observations” or “data” in the previous sentence. Consider revision to “These observations included…”

14. Line 221: Unnecessary “The” starting the sentence. Consider revision to “Satellite radiances were…”

15. Line 229: “i.e.,” is more appropriate here than “e.g.,”. Please revise.

16. Line 230: Parenthetical “e.g.,” is probably unnecessary and can be reworded. Consider revision to “a potential solution of RF tuning parameters”

17. Line 277: Missing space after period between “…(Fig. 6).For temperature…”

18. Line 296–308: Numerous instances of awkward or confusing wording, or typos in this paragraph that should be revised.
    a. Line 298: Revise phrasing “it went…”
    b. Line 300: Revise phrasing “when happened underestimated…”
    c. Line 301: Revise phrasing “it is recommended optimizing…”
    d. Line 303: “necessary” should be “necessity”
    e. Line 306–307: Remove “As for the” and “, they”
    f. Line 308: Revise phrasing “weakly decreased RMSE” to “a small RMSE reduction”

19. Line 330: Replace word “tried.”

20. Line 337: Add missing words “of the” after most.

21. Line 379: Replace “strengthened” with “increased”

22. Line 381: “As further studies” is awkward phrasing. Consider revising to “in future research”

References:

Bouttier, F., B. Vié, O. Nuissier, and L. Raynaud, 2012: Impact of Stochastic Physics in a Convection-Permitting Ensemble. *Mon. Wea. Rev.*, **140,** 3706–3721, https://doi.org/10.1175/MWR-D-12-00031.1.

Lupo, K. M., R. D. Torn, and S. Yang, 2020: Evaluation of Stochastic Perturbed Parameterization Tendencies on Convective-Permitting Ensemble Forecasts of Heavy Rainfall Events in New York and Taiwan. *Wea. Forecasting,* **35,** 5–24, https://doi.org/10.1175/WAF-D-19-0064.1.