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Hydrology and Earth System Sciences
Discussions

Interactive comment on "The Influence of Assimilating Leaf Area Index in a Land Surface Model on Global Water Fluxes and Storages" by Xinxuan Zhang et al.

Anonymous Referee #1
Received and published: 11 November 2019

The authors would like to thank the reviewer for their time, effort, and detailed comments. All suggestions were incorporated into the manuscript and explained in this response to reviewer document. We also thoroughly proofread and revised the whole manuscript.

General comments

The authors aim to assess to what extent the Noah-MP model can be optimized through the assimilation of leaf area index (LAI) observations at global scale. By utilizing two observing system simulation experiments (OSSEs) and the EnKF algorithm, the efficiency of assimilating LAI and model performance for water related variables are discussed. At first in my opinion this manuscript needs to be proofread/revised carefully for academic writing.

We would like to thank the reviewer. We have carefully proofread the revised manuscript.

Something that I do not understand is that the authors use the simulated LAI from the nature run as the 'truth' instead of observations. If nature run can achieve the "truth", why did the authors conduct assimilation based on different conditions (wet or dry)?

We chose to use an Observing System Simulation Experiment (OSSE) to quantify the potential impact of LAI assimilation on water variables simulated by the Noah-MP model while the forcing precipitation is affected by severe biases.

The forcing precipitation is usually provided by either reanalysis or satellite products. Such products are often affected by large biases (and random errors), which consequently affect the accuracy of the modeled variables. The question we want to answer here is: When the forcing precipitation is biased, is LAI data assimilation able to improve the model estimates? A real case study would certainly be of interest but in-situ observations (taken as reference) would also be affected by uncertainty, making it difficult to draw meaningful conclusions regarding the methodology itself. The proposed OSSE should serve as a feasibility test to quantify the potential of the proposed framework.

In an OSSE, i) the nature run (NR) intends to mimic the true input (including *unbiased* precipitation), LAI, and all water variables, ii) the open-loop run (OL) adds biases to the forcing precipitation (i.e., double or half the original value) to mimic the error in the precipitation product which will also produce biased model outputs of LAI and water variables; iii) the data assimilation (DA) run applies LAI DA to the OL run. We named the model run with double precipitation as wet

condition, and named the run with half precipitation as dry condition to describe the wet/dry bias that these two runs represent.

We modified the manuscript to clarify the OSSE design in section 2.2:

"*First, the Noah-MP model is spun-up for a 10-year period (2001-2010) to ensure a physically realistic state of equilibrium. Second, the model is run for a 29-month period (January 2011 – May 2013) to conduct the Nature Run (NR) with the same configuration as the spin-up one. By definition, an OSSE is a controlled experiment that does not assimilate any real observation. Instead, it treats all the model outputs from NR as the "true" condition. Thus, the output LAI from NR is considered as the "truth", which is then perturbed via a simple additive error model to produce the synthetic observations to be assimilated into the DA runs. The spin-up run and NR are forced by the original MERRA-2 precipitation data. Third, two Open Loop (OL) runs (no DA) are conducted for the same 29-month period under two conditions: i) "extremely dry" condition (the model is forced by halving the MERRA-2 precipitation data; OL-dry), and ii) "extremely wet" condition (the model is forced by doubling the MERRA-2 precipitation; OL-wet). The biased forcing precipitation data in OL is to mimic the precipitation biases that are very common in current precipitation reanalysis and satellite products (e.g., Ghatak et al. 2018; Yoon et al. 2019). The two DA runs are then conducted under the same conditions (DA-dry and DA-wet) using a one-dimensional EnKF assimilation algorithm which is a built-in DA method in LIS ……*"

Other important comment is that why did the authors use the precipitation which are extremely biased instead of using a more precise precipitation forcing. Furthermore, did the authors run the assimilation experiment using the MERRA-2 precipitation instead of halving or doubling the value?

The 10-year spin-up run and the nature run are forced by the original MERRA-2 precipitation data. The OL and DA runs are forced by a perturbed (i.e., biased) version of the MERRA-2 precipitation. As described above, the OSSE uses this input in the OL and DA runs to mimic common biases in currently available precipitation products.

In conclusion, the manuscript in its current form suffers from several issues that prevent it to be published as is. In my opinion the paper still worth to be published after addressing all these issues, and a major revision is asked.

Specific comments

1. P3L56-57: As far as I know, LSMs not only couple with dynamic vegetation models, but also involve some dynamic vegetation modules. So the statement is not appropriate.

We changed "*dynamic vegetation model*" to "*dynamic vegetation module*" in the manuscript.

2. Section 2.2: Why do you use the precipitation forcing data which are strongly biased.

In the OSSE study, we use biased precipitation data in OL and DA runs to mimic precipitation biases that are very common in current precipitation reanalysis and satellite products (e.g., Ghatak et al. 2018, Yoon et al. 2019. These two references have been added to text in section 2.2:

- *Ghatak, D., Zaitchik, B., Kumar, S., Matin, M. A., Bajracharya, B., Hain, C., & Anderson, M. (2018). Influence of Precipitation Forcing Uncertainty on Hydrological Simulations with the NASA South Asia Land Data Assimilation System. Hydrology, 5(4), 57. https://doi.org/10.3390/hydrology5040057*
- *Yoon, Y., Kumar, S. V., Forman, B. A., Zaitchik, B. F., Kwon, Y., Qian, Y., Rupper, S., Maggioni, V., Houser, P., Kirschbaum, D., Richey, A., Arendt, A., Mocko, D., Jacob, J., Bhanja, S., & Mukherjee, A. (2019). Evaluating the Uncertainty of Terrestrial Water Budget Components Over High Mountain Asia. Frontiers in Earth Science, 7. https://doi.org/10.3389/feart.2019.00120*

3. Why did you choose the LAI simulations from the nature run as the "truth" instead of using the LAI observations? As you have described the reasons from P9L171 to L172, there are many other LAI products without missing data which can be used for assimilation.

By definition, an OSSE is a controlled experiment that does not assimilate any real observation. Instead, it treats all the model output from the nature run as the "true" condition. The LAI from the nature run is also considered as the true. We then perturbed it with a simple additive error model to produce synthetic observations to be assimilated into the model (DA run). Some explanation was added in section 2.2:

"*Second, the model is run for a 29-month period (January 2011 – May 2013) to conduct the Nature Run (NR) with the same configuration as the spin-up one. By definition, an OSSE is a controlled experiment that does not assimilate any real observation. Instead, it treats all the model outputs from NR as the "true" condition. Thus, the output LAI from NR is considered as the "truth", which is then perturbed via a simple additive error model to produce the synthetic observations to be assimilated into the DA runs. The spin-up run and NR are forced by the original MERRA-2 precipitation data."*

4. Did you evaluate the LAI or other variables from the natural run by using remote sensing LAI datasets or other kinds of observations?

As mentioned above, The LAI from the nature run is considered as the truth in the OSSE framework. The same LAI is perturbed with a simple additive error model to produce synthetic observations of LAI that are assimilated in the DA experiment. The LAI from OL or DA run is evaluated against the synthetic LAI observation from the nature run.

5. P9L178-P9L184: How did you determine the values of multiplicative perturbations (such as, the shortwave radiation and precipitation with a mean of 1 and standard deviations of 0.3 and 0.5, the standard deviation for longwave radiation of 50 W/m2, the standard deviation for LAI of 0.1)?

The forcing data perturbation applied here used the same perturbations as found in the literature:

- *Kumar, S. V., Peters-Lidard, C. D., Mocko, D., Reichle, R., Liu, Y., Arsenault, K. R., Xia, Y., Ek, M., Riggs, G., Livneh, B. and Cosh, M.: Assimilation of remotely sensed soil moisture and snow depth retrievals for drought estimation, J. Hydrometeorol., 15, 2446-2469, https://doi.org/10.1175/JHM-D-13-0132.1, 2014.*
- *Kumar, S. V., Jasinski, M., Mocko, D. M., Rodell, M., Borak, J., Li, B., Beaudoing, H. K. and Peters-Lidard, C. D.: NCA-LDAS land analysis: Development and performance of a*

multisensor, multivariate land data assimilation system for the National Climate Assessment, J. Hydrometeorol., 20, 1571-1593, https://doi.org/10.1175/JHM-D-17-0125.1, 2019.

- *Kumar, S. V., Mocko, D. M., Wang, S., Peters-Lidard, C. D. and Borak, J.: Assimilation of remotely sensed Leaf Area Index into the Noah-MP land surface model: Impacts on water and carbon fluxes and states over the Continental US, J. Hydrometeorol., 20, 1359-1377, https://doi.org/10.1175/JHM-D-18-0237.1, 2019.*

6. Have the evaluation and error metrics been used in former studies? If so, please list at least one references.

The equation for the Normalized Information Contribution (NIC) index is similar to the NIC used by Kumar et al. 2016. We added this reference to the text:

Kumar, S.V., Zaitchik, B.F., Peters-Lidard, C.D., Rodell, M., Reichle, R., Li, B., Jasinski, M., Mocko, D., Getirana, A., De Lannoy, G. and Cosh, M.H.: Assimilation of gridded GRACE terrestrial water storage estimates in the North American Land Data Assimilation System, J. Hydrometeorol., 17, 1951-1972, https://doi.org/10.1175/JHM-D-15-0157.1, 2016

7. How did you determine the initial conditions?

Initial conditions are obtained by a 10-year spin-up run. The spin-up run is described in the second paragraph of section 2.2.

8. The discussion section should include the discussion of the results in the context of other papers dealing with the same of similar subjects.

We added some discussion of past work on similar subjects:

"*Overall the improvement of water variables through LAI assimilation is not remarkable enough to compensate the model degradation caused by the biased precipitation forcing data. Previous studies (Pauwels et al. 2007; Sabater et al. 2007; Barbu et al. 2011; Fairbairn et al. 2017) have tested the performance of the joint assimilation of LAI and soil moisture over regional domains and showed promising results. However, no experiment was performed at the global scale. Future work could investigate a multi-variate data assimilation system that concurrently merges both LAI and soil moisture (or TWS) observations globally.*"

9. A more in-depth analysis of the results is necessary. In this paper the authors only talk about the statistical characteristic variables (such as the NCRMSE, NIC, etc) of LAI and water related variables. Why not focus on the LAI and water related variables themselves?

Sections 3.1 and 3.2 have been modified to add more analyses. Time series of global averaged LAI and water variables (Figure 3 in the manuscript, please check below) were also added to the manuscript to provide more information on the actual variables (rather than anomalies). The discussion section (3.3) was also modified to provide more in-depth interpretation of the results.

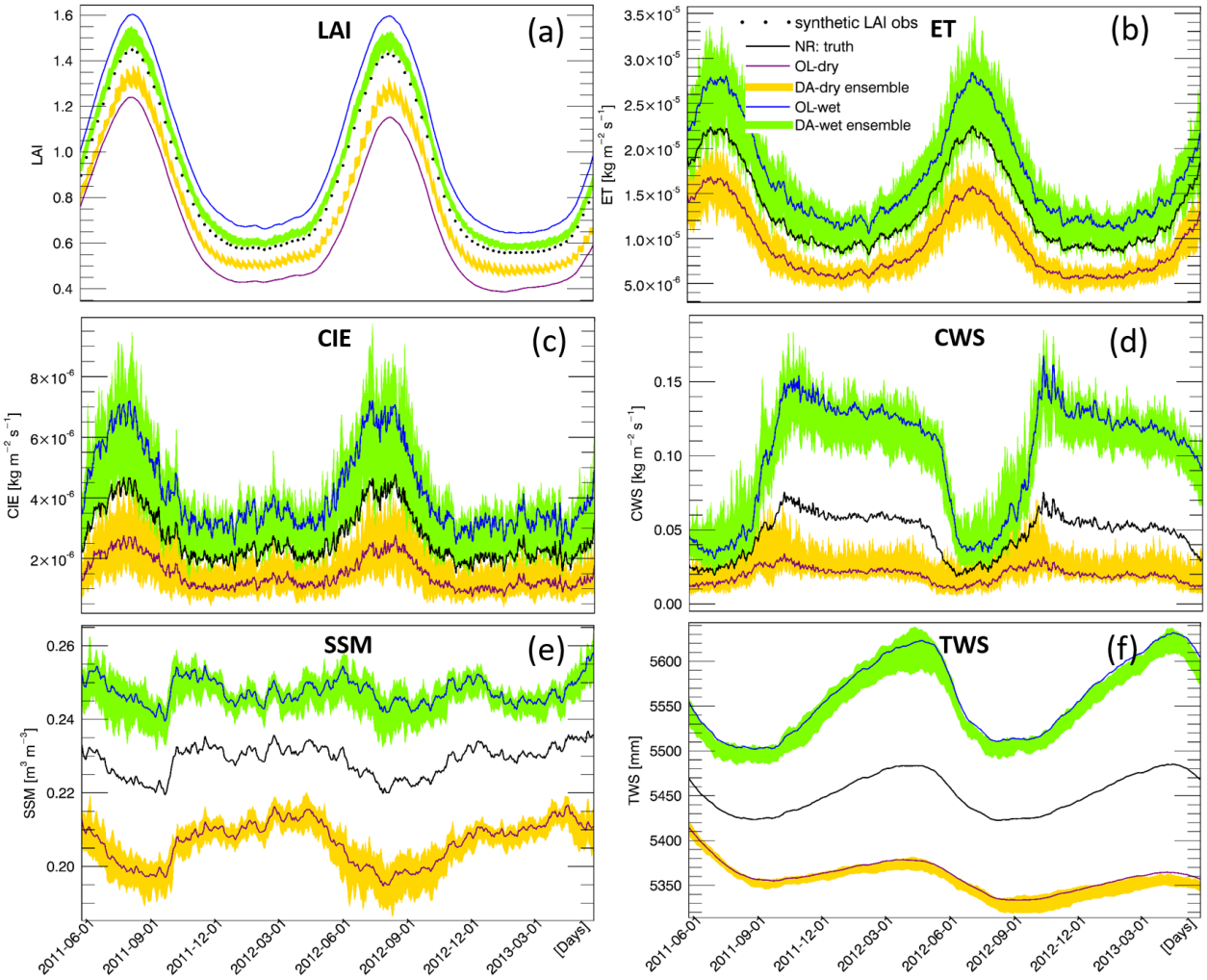


Figure 3. Global averaged daily values of LAI and five water variables (2011-06-01 to 2013-05-30).

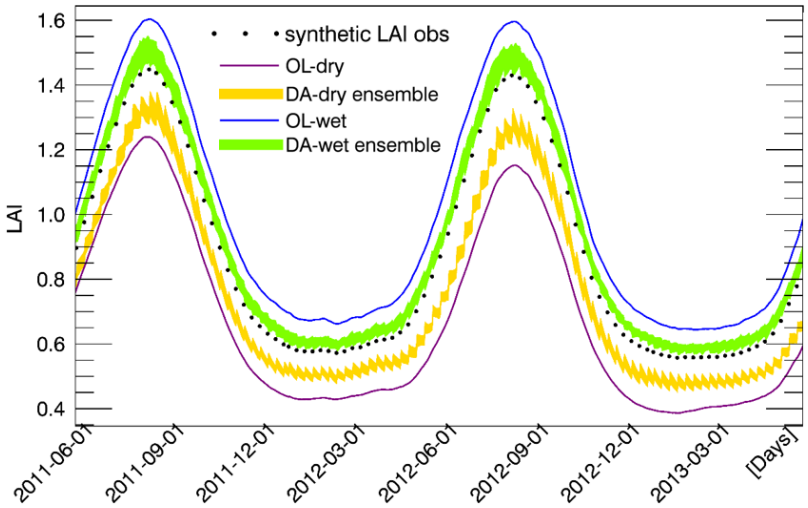
10. Why only perturb the meteorological forcing and not the initial conditions and/or model parameters?

We perturbed precipitation and radiation forcings because deemed dominant in water variable simulated by land surface models. Perturbing initial condition and model parameters is certainly an option that could be investigated in future studies. This recommendation has been added to the conclusion section.

"*Future research should focus on alternative methods to run the DA system in a more optimal way, such as updating other related model states while assimilating LAI observations, perturbing the model initial condition and model parameters, and/or assimilating actual satellite-based LAI observations (e.g., MODIS, GLASS) at the global scale to verify the efficiency of the proposed vegetation DA framework.*"

11. How sensitive is LAI with respect to the meteorological forcing?

LAI is very sensitive to the forcing precipitation data. The figure below shows time series of global averaged LAI. LAIs simulated with biased precipitation data (OL-wet or OL-dry) are either larger or smaller than the nature run LAI.



Technical corrections

1. P2L27-L28: Can you illustrate which land surface model you use here? And the same to P2L38, P5L104, and so on.

We added "Noah-MP" to these three sentences.

2. P2L28-L29: Remove "the" from the phrase of "at the global scale", and the same to P5L100, P5L100, P22L361, and so on.

"the" was removed from "at the global scale" phrases.

3. P3L44: Do not need to leave two blank spaces here.

This has been fixed.

4. P3L46: It's not appropriate to use "between" among vegetation, precipitation, and soil moisture.

"between" was changed to "among".

5. P3L51: The related references cited here are not enough to illustrate the phenomenon that "these land surface processes and feedbacks have been examined through numerical modeling experiments". List more .....

More references have been listed: "*Foley et al. 1996; Kim and Wang 2007; Druel et al. 2019*"

6. P3L54: You needn't capitalizes the first letter for leaf area index.

This was fixed.

7. P4L67: "the Moderate Resolution Imaging Spectroradiometer" has been abbreviated to "MODIS" before.

This was removed.

8. P4L88-P5L90: Please refine this sentence.

The sentence was rewritten as *"Some water budget variables were improved through the assimilation procedure. The improvement is remarkable in agricultural areas because the assimilation added harvesting information to the model."*

9. P5L95: Change "model simulated LAI" to "simulated LAI".
Removed.

10. P5L97: Please refine the statement of "focused on small regions".
Changed to "*…… and most of them are small region studies*".

11. P5L106-L107: Please define the abbreviation of all the water related variables when they first appear in this manuscript. Furthermore, "evapotranspiration" has been abbreviated to "ET" in P5L93.
The revised manuscript defined the abbreviation of all the water variables when they first appeared.

12. P5L110: Please specify which land surface model.
The title of section 2.1 was changed to "2.1. Land surface model (Noah-MP)".

13. P6L116-120: Please refine this sentence as it is too long.
The long sentence was divided into two sentences. "*Specifically, the prognostic vegetation growth combines a Ball-Berry photosynthesis-based stomatal resistance (Ball et al. 1987) with a dynamic vegetation model (Dickinson et al. 1998). The dynamic vegetation model calculates the carbon storages in various parts of the vegetation (leaf, stem, wood, and root) and the soil carbon pools.*"

14. P6L121: Please define "NASA".
Defined NASA as National Aeronautics and Space Administration.

15. P6L126: Keep the tense consistent.
Changed to "*The …….. (MERRA-2 ……) dataset serves as the meteorological forcings for Noah-MP.*"

16. P6L133-P7L138: Please define the abbreviation of all the water related variables when they first appear in this manuscript.
The revised manuscript defined the abbreviation of all the water variables when they first appeared.

17. P7L150: I am not sure whether the state of "a LAI EnKF" is appropriate.
Changed to "*the EnKF LAI assimilation*".

18. P7L153: The phase of "on a global scale" is not appropriate.
Changed to "*The proposed framework is evaluated by global scale experiments (Antarctica excluded) at the 0.625° × 0.5° spatial resolution of the MERRA-2 forcing dataset (Figure 1).*"

19. P10L188-L189: Keep the tense consistent.
The sentence was changed to "*Thus, all the DA simulations are run for 20 members.*"

20. P10L194-L195: The water related variables have been defined before, and you can use their acronyms.
The variable names were changed to their acronyms.

21. P10L203: What does i and N in Equation 1 mean?
This explanation was added to the manuscript: "*N is the total number of X values, and i represents the index of each X value.*"

22. P10L208: the word "O" in the denominator looks like "zero" in Equation 2.
The letter "*O*" in "*OL*" does look similar to "zero", though "zero" is thinner. Hope the readers won't get confused.

$$C = \frac{E_{DA} - E_{OL}}{0 - E_{OL}}$$

23. P11L209: There are two periods.
Removed.

24. P12L220-L222: As Figure 3 shows the GLOBAL averaged LAI anomalies, it is better to use the statement of month (or JJA and SON seasons) instead of winter/summer season.
Changed to "*Moreover, the seasonality of LAI anomalies is evident, showing larger variations in DJF and JJA than during the transition periods (MAM and SON).*"

25. P12L229: Please refine this sentence.
The sentence was rewritten as "*Moreover, the DA runs show lower NCRMSEs than the corresponding OL runs across the globe (Figure 4) especially over shrublands and grasslands (refer to Figure 1 for land covers).*"

26. P12L241: Remove "the". Furthermore, this sentence is a little too long in my opinion.
Changed "*In the summer*" to "*In JJA*".
The long sentence was divided into two short ones. "*In JJA, the vegetation leaves in the north hemisphere are fully developed and the plants can use stomatal closure to preserve water under water limited condition (dry condition). Thus, the NCRMSE of dry condition becomes smaller and does not show much difference from the wet condition.*"

27. P14L263: Please change the "has higher chance" into "is more likely to".
Modified.

28. P14L268-269: I think this is the first appearance that positively biased is wet condition (or negatively biased is dry condition), or maybe earlier, and this statement does not need to be repeated each time it appears in this paper (see P14L277, P16L296-L297, P21L337, P21L339).

Most of the repetitions were removed. We kept the “wet/dry” in the conclusion section in case some readers check the conclusion before going through the whole manuscript.

29. P15L282-L287: It is better to use the statement of month instead of season.
All the season names in the manuscript were substituted by month.

30. Please add the description for the Y-coordinate for Figure 7, 8 and 9.
The Y-axis titles are added to Figure 7, 8 and 9 in the revised manuscript.

31. P21L357: Please specify which land surface model.
This was added to manuscript: “*This study evaluates the efficiency of assimilating vegetation information (i.e., LAI synthetic observations) within a land surface model (Noah-MP 3.6) when the precipitation forcing data are strongly biased (either positively or negatively).*”