

# ***Interactive comment on “Evaluating the strength of the land–atmosphere moisture feedback in earth system models using satellite observation” by P. A. Levine et al.***

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Received and published: 10 August 2016

We thank the Referee 2 for their supportive and thoughtful review. The reviewer presented a highly positive perspective on our analysis in their general comments, and provided several constructive criticisms in their specific comments. Below, we address the reviewer’s specific comments by quoting each comment in *italicized* font, providing our response in roman font, and quoting our proposed revisions as indented roman font.

*Page 4, line 16-17: “Until recently, studies using remote sensing data to look for evidence of land–atmosphere coupling relied on data products that provide information about surface soil moisture.” There are some exceptions and some remote-sensing*

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*products also estimate soil moisture in the whole root zone (for instance, I recall that Guillod et al. (2015) used such estimates).*

We re-read the Guillod et al. (2015) paper, and found that while they did account for root-zone soil moisture in their estimation of evaporative stress, this was done indirectly through a data-assimilated estimate. Their direct observations of soil moisture were of surface soil moisture in the top few cm of the soil column from AMSR-E. We plan to add the following explanation of this to the text in order to clarify the distinction between direct and indirect observations of root-zone soil moisture:

Consideration of root-zone soil moisture has been accomplished only indirectly via data-assimilated estimates (Guillod et al., 2015).

*Section 3.3: These results on the role of internal variability are interesting. Another source of discrepancy between a single model run and observations can be observational error combined with short record (e.g., Findell et al., 2015), which may artificially decrease the coupling found in observations. Together, this effect and internal variability probably tell us something about the data length required to robustly assess land-atmosphere coupling.*

This point is well taken, and plan to expand upon this point with an addition to our discussion section in which we acknowledge the relevance of Findell et al., 2015:

One important factor contributing toward stronger feedback metrics in models relative to observations is the effect of observational uncertainty combined with a relatively short time series. Adding error to one or more variables in a correlation analysis will reduce the correlation coefficient, and this degradation has been shown to be sensitive to the length of data sets used to establish metrics of land-atmosphere interactions (Findell et al., 2015). Given the relatively short time series available for the current analysis, the

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correlation coefficients from remote sensing data may be reduced due to observational uncertainty, unlike those derived from internally-consistent models. We obtained a qualitative estimate of the influence of observational uncertainty on derived feedback metrics by replacing the atmospheric remote sensing data with reanalysis data from ERA-Interim. We found that both sets of observationally based metrics were weaker than those from LENS and several other models, suggesting that some of the overestimated feedback metrics in models may not be fully explained by observational uncertainty.

This addition serves to strengthen the conclusion that the utility of our approach will increase as the satellite data record grows longer, and reinforces the importance of the GRACE follow-on mission in lengthening the time series of TWS anomalies. We plan to further modify our discussion section to emphasize this point as follows:

Furthermore, we acknowledge that observational error over an insufficiently long time series could reduce the apparent strength of correlations (Findell et al., 2015). Therefore, the utility of the feedback metrics will increase alongside the length of the time series available from remote sensing platforms. This emphasizes the importance of the GRACE follow-on mission (Flechtner et al., 2014) and the need for continuity in the record between missions.

*Page 8, line 24 and Page 11, line 5: Supplementary figures references could be more specific. I think that the first mention on page 8 refers to Fig. S3 while the second mention (page 11) refers to Figs. S1 and S2. The order of the supplementary figures could also be adapted so they are cited in sequence.*

We agree that the supplementary figures should be referenced more specifically, and plan to adapt the relevant sections on both Page 8 and Page 11 to address this. The

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first mention in page 8 is intended to refer to all three of the supplementary figures, so we plan to add additional text to refer specifically to what each of the supplementary figures show:

To extend our analysis to models that do not output an explicit TWS field, the accumulated residuals of precipitation, evapotranspiration, and total runoff (surface and subsurface) were compared with TWS in LENS (Figure S1). We also compared feedback metrics calculated from LENS using accumulated residuals with those calculated from the explicit TWS field (Figures S2 and S3).

This revision includes a change to the order of figures, so that the Taylor diagrams will become S1 (previously S3) and the histograms will become S2 and S3 (previously S1 and S2).

*Page 13, line 20-29: The authors write that overestimating ET would lead to excessive land-atmosphere coupling. This is a bit confusing: if the coupling is strongest in transitional regions between wet and dry climate, why would a too high ET in an already wet region lead to an increase in coupling? I agree that model errors with respect to the distribution of water between storage reservoirs can be an issue; however I do not think that this necessarily leads to stronger coupling, but maybe I am missing something here.*

We thank the reviewer for pointing out the need to clarify the basis of this argument. We plan to replace the paragraph in question with the following:

A set of possible explanations involves models overestimating the amount of water available for ET during the drawdown interval. The land surface influence on the atmosphere requires water to be a limiting factor to ET but not limiting enough to prevent it altogether. Under more moisture-limited

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conditions, a drawdown interval may experience multiple shorter time periods during which ET is inhibited due to insufficient water, and the terrestrial moisture state exerts no control over flux partitioning. These periods of insufficient moisture would tend to reduce the overall feedback strength integrated across the duration of the drawdown interval. Model shortcomings that make water too readily available for ET could reduce the amount of time spent in a periods of insufficient moisture during the drawdown interval, thereby unrealistically strengthening the longer-term feedback. We note that the opposite could take place under near-saturated conditions if a model overestimates the amount of time in which ET is energy-limited, but we would not expect these conditions to be as prevalent during the drawdown interval that was the time period of focus in our analysis.

## References cited in this response:

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Flechtner, F., Morton, P., Watkins, M. and Webb, F.: Status of the GRACE Follow-On Mission, in *Gravity, Geoid and Height Systems: Proceedings of the IAG Symposium*, edited by U. Marti, pp. 117–121, Springer International Publishing, 2014.

Guillod, B. P., Orlowsky, B., Miralles, D. G., Teuling, A. J. and Seneviratne, S. I.: Reconciling spatial and temporal soil moisture effects on afternoon rainfall, *Nat Commun.*, 6, doi:10.1038/ncomms7443, 2015.

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