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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Estimating Sahelian and East African soil moisture using the Normalized Difference Vegetation Index" *by* A. McNally et al.

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Thank you for your comments. We hope that we clarify some points below and look forward to improving the revised manuscript to reflect these points.

1. It is well known that soil moisture impacts and is impacted by vegetation activity, but the linear model somehow implies that NDVI is the explanatory variable for soil moisture. This would be appropriate when trying to capture, e.g., the effect of leaf ïňĆushing and shedding on soil moisture within a drought deciduous ecosystem or crop emergence and harvest in an agricultural system. While clearly any variable can be regressed against any other, I wonder how the proposed approach is superior to others, maybe still based on regressions, but with a more solid physical motivation. . ..

the authors should make a stronger case on why the proposed approach is superior to existing others.

RESPONSE: We agree that soil moisture is impacted by vegetation. We initially explored the potential need to capture is aspect of the system. However, given the point to pixel comparisons we were unable to resolve this level of detail. It is possible that the soil-vegetation feedbacks, and point-scale inter-annual variability could be captured if, for example we were using field measurements of NDVI from a hand-held spectrometer where measurements were taken at the soil moisture sites. While this experimental design would be interesting for a more eco-hydrology oriented analysis this paper is motivated by agricultural drought monitoring for the Famine Early Warning Systems Network (FEWS NET). Using NDVI as an indicator of moisture independent from rainfall is well supported by the literature and FEWS NET currently uses NDVI a qualitative indicator (predictor) of the soil moisture deficits that define agricultural droughts. Our more application driven approach still benefits from representing soil moisture as the intermediary between satellite-derived rainfall and vegetation greenness because we are now able to compare these two drought-monitoring data products in commensurate units and phase and investigate how assumptions in our rainfall and NDVI driven models influence the interpretation of these two data products for drought monitoring.

We will be clearer in our introduction/motivation to support our use of NDVI as an explanatory variable for soil moisture. We will also give some more details in the methods section about our initial model fitting attempts when we were discovering what level of detail (re: physical mechanisms) our data is able to resolve.

2. The currently presented comparison of the soil moisture estimates obtained with API and NDVI does not clarify if and under which circumstances the NDVI estimate works better that the API one. The only clear conclusion is that the NDVI estimate (and the API one) are not expected to "match with the point soil moisture observations" (p. 7977), nor they capture the interannual variability (p. 7981). RESPONSE: We do show in the validation with the Mpala, Kenya observations that the NDVI-estimated soil

moisture with parameters calibrated in Niger is superior to the API. While this was an important result which highlighted the benefits of using NDVI to represent plant available water our goal was not necessarily to outperform rainfall based estimates of soil moisture. As with previous comment we will more clearly outline our motivation in the introduction. The main points will be that (1) both rainfall and NDVI are currently used for monitoring moisture conditions associated with agricultural drought (i.e. soil moisture deficits, plant water requirement satisfaction). We are able to model soil moisture with rainfall using a variety of models (e.g. statistical, water balance, water & energy balance land surface models). However, without a way to estimate soil moisture from NDVI we are restricted to qualitative comparisons that assume vegetation greenness is an indicator of plant available water. The goal here was to develop an NDVI-derived estimate of soil moisture (single input, three parameter) and compare it to an analogous rainfall-derived estimate of soil moisture (API: single input, three parameter).

Regarding the second point that the only clear conclusions were mismatch with point observations and lack of inter-annual variability: We accept responsibility for not being clear with the take-home messages and we will refine our presentation to reflect the following points: (1) We did find that when we aggregated to the country-crop zones (Section 9 Comparison with WRSI and yields) our NDVI-derived soil moisture estimates did capture inter-annual variability as measured by the Water Requirement Satisfaction Index (WRSI) and FAO millet yields, as shown in 'Table 1. Rank correlations.' Thus, our estimates of soil moisture derived from NDVI represent regional moisture conditions, and this scale is relevant for agricultural drought monitoring. (2) Discussion of strength and weaknesses of using rainfall driven 'supply side' model of soil moisture versus NDVI-derived 'demand side' estimates of soil moisture: The API can be thought of as a 'supply side model'. It relies on rainfall inputs and its parameters represent how the soil dries, which will be a function of drainage (soil type and slope) and evapotranspiration rates (related to aspect, average time between storm events and atmospheric moisture demand). In the Kenya validation, we found NDVI estimates to be superior to API estimates. When we re-calibrated the API to local, Mpala soil moisture observa-

tions it was able to represent the observed soil moisture reasonably well. In summary, the API's parameters represent aspects of the system which are relatively local characteristics, which will limit the robustness of our single calibration approach across a heterogeneous landscape. The NDVI model, on the other hand, can be thought of as a 'demand side model', where plants are responding to whatever soil moisture is available. Thus, the parameters in this model represent the lag between peak soil moisture storage and peak vegetation greenness. This lag can vary over space, but has been shown to be relatively consistent: NDVI is highly correlated with the current and two previous months of rainfall for regions where annual rainfall is between 200-1200mm (Nicholson et al. 1990).

3. I wonder why the data have not been used in a different fashion, dividing the available years in two subsets (and exploring different partitioning) and using the ïňĄrst one for calibration, the second one for validation, and repeating the same exercise for each location. This would allow better assessing the robustness of the obtained coefïňĄcient against year, soil and vegetation types, and local climate. RESPONSE: In our analysis we tried many different combinations of model fitting and validation, like what you have described above. We were not able to find significant differences between the Mali and Niger sites, probably due to their similar characteristics (grassy vegetation, sandy soils, 300-500mm of rainfall per year). And, we only had one year of data available at the Mpala Kenya site, where environmental conditions, like elevation, rainfall regime may lead to some interesting patterns in the data. We should have been clearer when explaining our methods and intermediate results. We will better describe when we conducted local calibrations and discuss the difference, or lack thereof, between the different sites.

4. First, its inability to capture the inter-annual variability and the effect of different rainfall patterns significantly hampers the effectiveness of such a tool as an early warning index.

RESPONSE: In Table 1 and Figure 8 we did show that the NDVI-derived soil moisture was more well correlated with yield than the Water Requirement Satisfaction Index (WRSI), which is an index calculated from a water balance model and used operationally by the Famine Early Warning Systems Network. We have found similar results in other Sahelian countries (e.g. Mali, Burkina Faso) as well. Including a larger sample will make the potential utility of the NDVI-derived soil moisture more convincing. We will more clearly explain the strengths of this model and how it compares to the performance of operational drought monitoring products. 5. Second, if soil water availability for agricultural purposes is the goal, then more attention should be devoted to i) the model performances during the main growing season, ii) the applicability of the approach to crops (at least as a discussion on the expected differences between savanna and the staple crops in the region). RESPONSE: We will do a better job in our presentation explaining how these results are relevant for agricultural purposes. Figure 8, which compares the different soil moisture metrics to yields, for example is restricting the analysis to a July-August average for each year. These months were chosen because they are the time of peak water demand for millet crops. This may not have been clearly stated in the text and should be included in the figure caption. In general we will improve our introduction/motivation to highlight that the data products (satellite rainfall and NDVI), and metrics that we use (e.g. millet yields, water requirement satisfaction index) are already a part of operation drought monitoring. We will more clearly explain how our results help the drought monitoring community by enhancing their ability to interpret familiar data products and models.

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