Response to reviewer #2

General Comments:

This manuscript analyses the impact of assimilating LAI and soil moisture data from remote sensing (separately) on the water and carbon fluxes simulated by a land surface model (Noah-MP) and how drought categorization is affected as a result. The impact of irrigated areas is also included in the analysis through a simple irrigation module. This is a very relevant topic as early drought warning can help implement mitigation measures to reduce adverse impacts. Irrigation is often not included in LSMs, and its inclusion here is valuable in bringing focus to the difficulties encountered in its inclusion in models, in particular in data scarce regions.

The work is well written and the evidence is clearly and convincingly presented.

Response: We thank the reviewer for the encouraging comments on our study and please see our responses in detail below.

Specific Comments/Questions:

1. There is no description of the downscaling of the SMAP/upscaling of the MODIS LAI data. A discussion on the spatial resolution of the datasets is also missing: what could be its impact relative to 1. the model grid and 2. the landscape fragmentation (in particular size of irrigated areas)?

Response: In this study, we use bilinear interpolation for spatial disaggregation and averaging for upscaling methods to regrid SMAP L3_E soil moisture product at 9 km and the MODIS LAI datasets at 500 m to 0.05° in model space, respectively. We agree that the differences in spatial resolution in the input and assimilated datasets may affect the model performance and its capability to capture fine scale variabilities. For instance, some of the irrigated areas are sparsely distributed and may not be reasonably represented by a 0.05° grid. The model resolution could go finer to 1 km along with the support of the input datasets at comparable spatial scales, however, that might not be necessary for SSM-DA as the resolution for the SMAP L3_E product is only 9 km. Therefore, we think the choice of 5 km is reasonable to capture major signals for water-energy-carbon cycle in response to data assimilation and irrigation. The sensitivity studies regarding the spatial resolution at which DA is performed could be an interesting point to explore but is beyond the scope of this study. We now added this information of downscaling/upscaling of the assimilated datasets in line 117 and lines 137-138.

2. The parameterization of the irrigated areas and module deserves more discussion: what could be the impact of the uncertainty of the global datasets used? How about irrigation amounts which assume reaching of field capacity? I also do not see a mention of matching the irrigated areas to the land use map, were irrigated areas only applied to pixels identified as cropped/partially cropped?

Response: These are great questions, and we address each one in turn.

1) what could be the impact of the uncertainty of the global datasets used?

The uncertainty coming from global irrigation maps can impact spatially where irrigation may be realistically located and in relation to uncertainties from methods in deriving the landcover types, since many of the datasets are derived independently from each other and sometimes with different training datasets. We accept that uncertainty is inherent in all modeling studies, even at fine resolutions given local observational data, and that is why we had compared and combined the most common spatial attributes found in the irrigation and landcover maps, to reduce such uncertainties. We also addressed a similar question from Reviewer 1 -- question #3, which we hope helps further address your question here.

2) How about irrigation amounts which assume reaching of field capacity?

The assumption of bringing irrigation to field capacity has been evaluated for CONUS, which has yielded good results, but it may inherit some uncertainties when being applied to Morocco. We do lack in situ data to optimize our irrigation parameter settings. Also, utilizing other datasets, such as a finer scale soil moisture product to inform irrigation timing and targeted soil moisture conditions, would be helpful.

3) I also do not see a mention of matching the irrigated areas to the land use map, were irrigated areas only applied to pixels identified as cropped/partially cropped?

To address your final question, we want to mention that we do match irrigated areas with certain landcover types from the land use map, mainly the cropland and grassland classes. This comparison has an initial check implemented when deriving the composited irrigation map and processed through LDT, and then again when the irrigation is applied in LIS, following the method outlined in Ozdogan et al. (2010). We now updated the text in the revised manuscript in lines 164-166 with the following statement: "Note that to avoid potential mismatch between the land cover type and irrigation fraction, an initial check has been implemented in both LDT and LIS to constrain irrigation within certain land cover types mainly the cropland and grassland classes."

3. There is a brief mention of loss of information due to the rescaling of the soil moisture product to the model climatology but I think this deserves further discussion. What is the impact of rescaling the SSM to a model run which does not include irrigation? In particular when there is also an attempt to use the SSM to improve the irrigation run. A comparison of the SMAP cdf over an irrigated vs. non-irrigated pixel would be an interesting starting point.

Response: We thank the reviewer for bringing up this question. We acknowledge that scaling soil moisture product to the model climatology in absence of irrigation representation may lose information especially for places where SMAP can detect irrigation signal. These issues may all limit the efficiency of data assimilation and have been acknowledged and discussed in prior studies (Kumar et al., 2015; Nearing et al., 2018). In our SSM-DA and SSM-DA$_{irr}$ experiments, the SMAP L3_E product is scaled to the climatology of OL and OL$_{irr}$ respectively to provide an overview of the model performance in scaling and assimilating soil moisture with/without irrigation representation. We also notice that the situation could be the opposite – that irrigation is represented in the model but was not detectable by SMAP. And it is challenging to come to a conclusion as both the irrigation parameterization in the model and the SMAP product are subject to errors in terms of capturing irrigation timing and frequency. Lacking of in situ observations for model calibration poses further challenges to improve the irrigation parameterization and the nature of sparsely located irrigation farms for the study region limits the benefit of SMAP in detecting irrigation signals for Morocco due to its relatively coarse spatial resolution. We now populate the discussion by listing possible reasons contributing to the failure of utilizing soil moisture data assimilation in improving modeling performance for this case study in section 4 lines 532-534.

4. Was a simultaneous assimilation of LAI and SSM tested? If not, why not? Do you see any potential for the inclusion of both to improve the results?

Response: We thank the reviewer for bringing up this question. In fact, joint SSM and LAI assimilation is initially planned for this study and we've tried various experiments attempting to find values from digesting the SMAP soil moisture information but unfortunately, we didn't see any encouraging messages from joint DA for the Morocco domain likely because the information utilization in the current SSM-DA setup is suboptimal and in areas such as this where irrigation and agricultural practices dominate, significant revisions to the SSM-DA strategy is required. But we do agree that potentially there are regions that can benefit from joint SSM and LAI DA.

Technical Comments

l.268: ‘for the’ should be removed (or rephrase sentence, unclear)

Response: The sentence is now rephrased as “Statistical skill metrics include the Pearson’s correlation (R) and anomaly correlation (anomaly R) coefficients based on monthly time series with 95% significance tested using Fisher’s z transform test…”

l.300: ‘with the percent change over 20%’ is awkward. Suggestion: ‘with a relative improvement of over 20%’

Response: Modified.

458-460: I assume the higher LAI leads to increased transpiration. The sentence structure implies the opposite effect. Add ‘for LAI-DA’ for clarity at the end of the sentence.

Response: Modified.

References

Kumar, S. V., Peters-Lidard, C. D., Santanello, J. A., Reichle, R. H., Draper, C. S., Koster, R. D., Nearing, G. and Jasinski, M. F.: Evaluating the utility of satellite soil moisture retrievals over irrigated areas and the ability of land data assimilation methods to correct for unmodeled processes, Hydrol. Earth Syst. Sci., 19(11), 4463–4478, doi:10.5194/hess-19-4463-2015, 2015.

Nearing, G., Yatheendradas, S., Crow, W., Zhan, X., Liu, J. and Chen, F.: The efficiency of data assimilation, Water Resour. Res., 54(9), 6374–6392, 2018.