Hydrol. Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/hess-2017-680-AC1, 2018

Hydrology and Earth System Sciences
Discussions

Interactive comment on "Global Downscaling of Remotely-Sensed Soil Moisture using Neural Networks" *by* Seyed Hamed Alemohammad et al.

Seyed Hamed Alemohammad et al.

sha2128@columbia.edu

Received and published: 20 May 2018

We thank Referee #1 for their positive comments. We respond to the general comments and specific points in the following.

General Comments:

The manuscript presents a new global soil moisture product provided at an unprecedented spatial resolution of 2.25 km. It is built from a neural network (NN) and data comprised of SMAP 36 km resolution level 3 soil moisture, an enhanced soil moisture product derived from 36 km SMAP observations and posted on a 9 km resolution grid (Chan et al. 2017) and MODIS NDVI data aggregated at various resolutions between 2.25 and 45 km. The authors have also tested the

inclusion of a topographic index at the target downscaling resolution. The approach is evaluated by analyzing global soil moisture maps and by comparing downscaled soil moisture estimates against in situ data from the international soil moisture network (ISMN).

A global soil moisture product at 2.25 km resolution is of high interest to the hydrological and Earth system science community. I also find that the comparison of the NN method with simpler methods (linear interpolation, and the null-hypothesis i.e. no disaggregation) is quite positive as well. In fact, my comments mainly concern the underlying assumptions of the approach (comments #1 and 2) and the evaluation of the downscaled data set (#3).

1) On the use of the 9 km resolution soil moisture product. The basis for the proposed approach is to calibrate a relationship between 36 km (SPL3SMP) and 9 km (SPL3SMP_E) resolution soil moisture products, and then to apply it at 9 km resolution to derive the 2.25 km soil moisture. The point is that the actual spatial resolution of SPM3SMP_E (the so-called "9 km resolution product") is 33 km while it is resampled at 9 km resolution (Chan et al. 2017). The 33 km resolution is so close to the original 36 km resolution SMAP level 3 data that one may wonder how a relationship derived from 36 and 33 km resolution data can be valid between 9 km and 2.25 km resolutions. At the very least, I recommend a sensitive analysis to assess the impact on the results of a coarser spatial resolution (33 km instead of 9 km) for training.

Response/Action: *We agree with the difference between native resolution and grid spacing of the SPM3SMP_E product. Indeed, we have included this in the product description (Section 2.1) of the original submission. However, the methodology to generate gridded brightness temperature (TB) (and subsequently soil moisture) from the original observations of the SMAP antenna is different in the 36km and 9km product. The 9km product applies the Backus-Gilbert (BG) optimal interpolation technique to the oversampled radiometer measurements to* *estimate TB at each point, which is the center of each 9km pixel. Meanwhile, the native resolution of the data which is the spatial extent projected on earth surface by the 3-dB beamwidth of the radiometer is very close to the 36km product.*

Contrary to this approach, the SMAP 36km product uses the antenna pattern information to estimate TB from the original radiometer measurements, and does not take into account the oversampling effect. This results in a coarser grid resolution data.

Unfortunately, we cannot conduct a sensitivity analysis since the main assumption is that the downscaling has the same scaling ratio during training and retrieval (from 36km to 9km, and from 9km to 2.25km). Moreover, the enhanced soil moisture product is already on a 9km grid. If we wanted to upscale that to 33km it would add uncertainty to the sensitivity analysis (there is no soil moisture product from SMAP on 33km grid).

In this study, we made the assumption that the scaling relationship from the 36km product to the 9km product can be used to estimate soil moisture at 2.25km. We have independently validated the soil moisture estimates at the 2.25km scale; therefore, we believe this is a valid assumption and unfortunately there is no other way to directly test this assumption. We now explicitly emphasize that this is a required assumption to build our product.

2) The NN is trained and run using NDVI data as auxiliary information about the sub- pixel soil moisture variability. Some limitations related to the soil moisture-NDVI relationship are mentioned in the conclusion (such as presence of vegetation, saturation effects). However, I think that the discussion should be deepened. It is true that NDVI and topography are variables available at global scale, but they are not the only factors explaining the soil moisture variability. In addition, the soil moisture-NDVI relationship established at the monthly time scale (phenological time scale) may not be valid at the daily time scale, at which SMAP observes the Earth and the observed surface soil moisture evolves. For clarity, the assump-

tions underlying the implementation of the NN using NDVI data should be better highlighted in the manuscript.

Response/Action: *We agree with the referee on the limitations of the NDVI – SM relationship. The assumption we make in using NDVI as an auxiliary information to predict variability of soil moisture is that within a neighborhood of a specific pixel NDVI of that pixel 'relative' to the NDVI of the neighboring pixels is an indicator of the wetness or dryness of that pixel with respect to its neighboring pixels. This is different than using the 'absolute' value of NDVI for soil moisture prediction.*

However, to clarify this point, we will add the following paragraph in the conclusion section:

"In this study, we use the relative value of NDVI (in a given pixel with respect to the neighboring pixels) as an auxiliary information to predict spatial variability of soil moisture in each coarse-scale pixel. While the relationship between soil moisture and NDVI at phenological time scales may not be valid at the temporal scale of SMAP observations (couple of days), our assumption builds on the relative value of NDVI within a small region and not the absolute value. Therefore, it is reasonable to use NDVI as a predictor in this case"

3) Evaluation of the NN output: Line 22 page 9: "NN is appropriately explaining the spatial variability of soil moisture using NDVI as ancillary data". Line 14 page 13: "our evaluation shows that the downscaling algorithm has high accuracy in terms of temporal correlation, anomaly correlation and ubRMSE when compared to in situ soil moisture estimates from ISMN". It is difficult to assess the quality of the downscaled soil moisture at fine scale using global maps. Global maps convey the message that the high-resolution product is global, but some fine scale assessment is missing. Evaluation of the results over focus (perhaps instrumented) areas would be very useful. Regarding the temporal aspect, validation using 2-year averages does not allow for assessing the relevance of soil

moisture-NDVI relationships at the temporal scale of SMAP observations/surface soil moisture dynamics. In addition, I do not think that the comparison with in situ measurements shows "that the downscaling algorithm has high accuracy". I would soften this point of view as results are very similar for all products (from 2.25 km to 36 km, see Figure 8). Even though the downscaling method does not degrade low resolution information, the improvement is hard to detect. The authors mention that "accuracy is better than or equal to the SMAP 9 km soil moisture estimates". I take them at their word, but from Figure 8 it seems that the original 36 km product be more accurate at several stations. More explanations are needed to clarify the improvement provided at 2.25 km and at which temporal scale.

Response/Action: *We agree with referee's comment that conducting evaluations over focus regions would be informative. We will add this to the revised manuscript. The goal of the comparison with in-situ observations is to assess temporal accuracy of the downscaled product. Since the input data to the soil moisture estimates at 2.25km is the 9km product, we did not expect to get significantly higher temporal accuracy with respect to the 9km product. The value of the 2.25km product is an enhanced spatial resolution, while having the same temporal accuracy. We will revise the statements in the result section, as highlighted by the referee, to clarify this.*

Specific Comments:

a) I may have missed something but the two statements re-written below look contradictory: - Page 9, line 11: "Moreover, the latitudinal average plots (on the right side of each panel of Figure 5) show that at higher spatial resolutions there is more spatial heterogeneity. The latitudinal average for the 36 km product is much smoother than the 2.25 km one." - page 9, line 18 : "For comparison, we also calculate CV for the 9km soil moisture estimates from SMAP at the 36km

grid (Figure 6 bottom panel). The two panels in Figure 6 have different range of CV which is expected given the difference in their spatial scales." Since aggregation tends to reduce variabilities, one would expect an increase in the spatial variability at higher spatial resolution. However, the CV is divided by about 5 at 9 km resolution compared to the CV at 36 km resolution. Could the authors comment on their seemingly opposite findings ?

Response/Action: *Indeed, these two statements are not contradictory. The first one referring to Figure 5 is based on the fact that at higher spatial resolution we are seeing more variability. Mainly, the latitudinal plots capture the smaller changes in soil moisture that were not observable with the coarse resolution product.*

On the other hand, the CV plots in Figure 6 show the variability of soil moisture within a 9km pixel and within a 36km pixel. Within a 9km pixel the variability of soil moisture is smaller than that of a 36km pixel, since the surface is less heterogeneous (this is true for a 9km pixel which is spatially within the 9km pixel). It is true that the 2.25km product should show more heterogeneity compared to the 9km product but this would be true if both 9km and 2.25km product variabilities are compared at the 36km scale. Currently, we are comparing variability of the 2.25km product within the 9km pixel, and variability of the 9km pixel within the 36km pixel. We will add the CV plot of the 2.25km product within each 36km pixel in the revised manuscript to better explain the spatial variability of soil moisture.

b) Line 13 page 2: "Some of them use linear relationships (i.e. projection) to define the impact of spatial heterogeneity using ancillary data, typically in combination with a radiative-transfer model to relate surface temperature and soil moisture (Colliander et al., 2017a; Merlin et al. 2005, 2008a, 2008b, 2008c)." I noted two errors in this sentence: 1) physical models that relate surface temperature and soil moisture are energy balance models (not radiative transfer models) and

2) the projection technique used in Merlin et al. 2005, 2008a does not implement linear relationships, but a non- linear energy balance model.

Response/Action: *We agree with the referee's comment, and will revise this section to correctly summarize the work done in the literature.*

c) Line 15 page 2: "A major issue is that surface temperature at finer spatial scales from satellites cannot be estimated under cloudy conditions". Agree and I would add another essential limitation that the surface temperature cannot be used as a signature of soil moisture in energy-limited conditions.

Response/Action: *We agree with this limitation, and will add it to the revised manuscript.*

d) Line 21 page 4: "we assume that the scaling relationship between 36 and 9 km soil moisture estimates is the same as the scaling relationship between 9 km and 2.25 km resolution. To the best of our knowledge, this is the first time that the assumption of similar scaling relationship is used to downscale soil moisture". I would like to mention that the same scaling relationship has already been used to downscale soil moisture from 40 km to 1 km and from 1 km and 100 m in Merline tal. 2009 and Merlinetal. 2013.

Merlin, O., Al Bitar, A., Walker, J. P., Kerr, Y. (2009). A sequential model for disaggregating near-surface soil moisture observations using multi-resolution thermal sensors. Remote Sensing of Environment, 113(10), 2275-2284.

Merlin, O., Escori- huela, M. J., Mayoral, M. A., Hagolle, O., Al Bitar, A., Kerr, Y. (2013). Self-calibrated evaporation-based disaggregation of SMOS soil moisture: An evaluation study at 3 km and 100 m resolution in Catalunya, Spain. Remote sensing of environment, 130, 25-38.

Response/Action: *We acknowledge new references provided by the referee.*

We will revise this statement and make appropriate citations to these papers in the revised manuscript.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2017-680, 2018.