EGU2020-12565

Assimilation and Combination of SMAP-enhanced and SMAP/Sentinel-1A/B soil moisture estimates with land surface models

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1 Abstract

Prediction of water-related natural disasters such as droughts, floods, wildfires, landslides, and dust outbreaks on a regional-scale can benefit from the high-spatial-resolution soil moisture (SM) data of both satellite and modeled products. The reason is that the amount of surface SM controls in the partitioning of outgoing energy fluxes into latent and sensible heat fluxes. Recently, NASA's SMAP mission has been implemented, in order to provide 3-km and 1-km SM data from a combination of SMAP and Sentinel-1A/B observations along with 9- and 36-km SM data retrieved from an L-band radiometer brightness temperature (TB). The 3-km and 1-km SM products were produced by combining the Sentinel-1A/B C-band radar backscatter and SMAP radiometer TB observations.

In this present study, we conducted three analyses: 1) SMAP/Sentinel-1A/B 1-km (SS1), 3-km (SS3), and SMAP-enhanced 9-km (SE9) products were validated against in-situ SM data using conventional and triple collocation analysis (TCA), 2) SS1, SS3, and SE9 were combined with a Noah-Multiparameterization version 3.6 (NoahMP36) land surface model (LSM) using the maximize-R method, and 3) SS1 (A.M.), SS1 (A.M. and P.M.), and disaggregated-SE9 (1-km; SE1) were assimilated into NoahMP36 using an Ensemble Kalman filter (EnKF). The evapotranspiration (ET) output from NoahMP36 were validated against flux tower ET data.

When SMAP and NoahMP36 were combined, the R-values for SS1, SS3, and SE9 SM data were improved. When SS1 (A.M.) and SS1 (A.M.&P.M.) were assimilated, some pixels' ET data bias were reduced in comparison with open loop (OL) run. These results indicate the potential uses of SMAP/Sentinel data for improving regional-scale SM estimates and for creating further applications of LSMs with improved accuracy.

2 Problem Statement

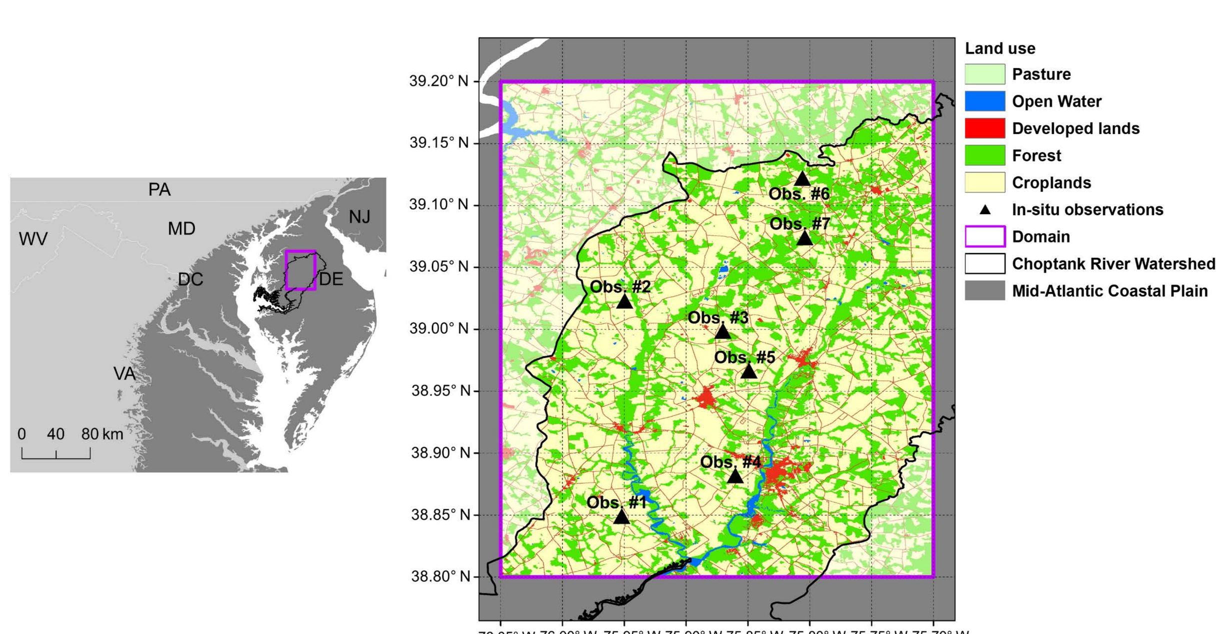
1) **Coverage of satellite-based SM observations is not spatially or temporally continuous.**
2) **Soil moisture in LSMs would be affected by the model's parameters and formulations, as well as by errors in the meteorological forcing variables.**
3) **Description of the fundamental processes that control the terrestrial hydrologic cycle across both time and space domains is limited**

Estimating SM combined with LSMs would provide a better understanding of the role of hydrometeorological factors in extreme events.

3 Study areas

3-1. In-situ SM networks

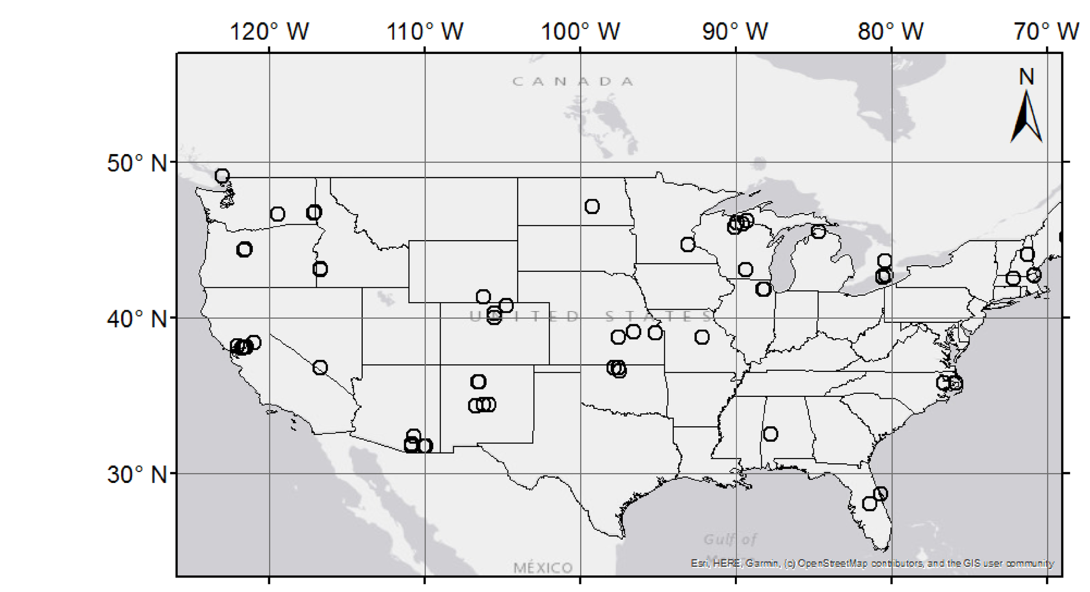
Choptank River watershed, U.S.A Kim et al. (2020)



- As a benchmark watershed, the Choptank River watershed has been extensively monitored and studied by the USDA-Agricultural Research Service (ARS) in the Conservation Effects Assessment Project as well as within the Long-term Agroecosystem Research network (LTAR)

3-2 AmeriFlux network

Contiguous United States and Canada



- 81 locations were selected based on the number of SS1 data.
- ET data were masked out based on BASE measurement height information, quality flag, and number of data. **https://ameriflux.lbl.gov**

4 Data sets

	Product name	Variable	Spatial resolution (degree)	Abbreviation
Satellite	SMAP-Enhanced	SM	0.09	SE9
	SMAP/Sentinel-1A/B	SM	0.03	SS3
	SMAP/Sentinel-1A/B	SM	0.01	SS1
	Disaggregated SMAP-Enhanced	SM	0.01	SE1
	GPM	P	0.1	GPM
	MODIS	NDVI	0.01	NDVI
LSM	NoahMP3.6	SM	0.09	N9
	NoahMP3.6	SM	0.03	N3
	NoahMP3.6	SM	0.01	N1
Forcing	NLDAS-2	-	0.1	-
	MERRA-2	-	0.5 (lat) by 5/8 (lon)	-
In-situ	USDA	SM		-
		P	N/A	-
	AmeriFlux	ET		-

5 Methodology

5-1. TCA

Gruber et al. (2016)

$$SNR_{SM_{SAT}[\mathrm{dB}]} = \frac{10\log\left(\mathrm{cov}(\mathrm{SM}_{SAT},\mathrm{SM}_{MOD})\cdot\mathrm{cov}(\mathrm{SM}_{SAT},\mathrm{SM}_{REF})\right)}{\mathrm{cov}(\mathrm{SM}_{SAT},\mathrm{SM}_{MOD})\cdot\mathrm{var}(\mathrm{SM}_{SAT})}$$

$$TC-based\ R^2 = \frac{1}{1+\dfrac{1}{SNR}}$$

where SM_{SAT} indicate SM data from SMAP or SMAP/Sentinel, SM_{MOD} indicate SM data from model, and SM_{REF} indicate SM data from ground observations.

5-2. Maximize R

Kim et al. (2015)

The combined SM data (i.e., NS9, NS3, and NS1) were calculated by applying a weighting factor (w) with a normalized range of 0–1 as follows:

$$SM_{NSx} = w \times SM_{MOD} + (1-w)\times SM_{SAT}\ (x = 9, 3, or\ 1)$$

$$w = \frac{R_{\mathrm{SM}_{SAT}\cdot\mathrm{SM}_{REF}} - R_{\mathrm{SM}_{SAT}\cdot\mathrm{SM}_{MOD}} \times R_{\mathrm{SM}_{MOD}\cdot\mathrm{SM}_{REF}}}{R_{\mathrm{SM}_{MOD}\cdot\mathrm{SM}_{REF}} - R_{\mathrm{SM}_{SAT}\cdot\mathrm{SM}_{MOD}} \times R_{\mathrm{SM}_{SAT}\cdot\mathrm{SM}_{REF}} + R_{\mathrm{SM}_{SAT}\cdot\mathrm{SM}_{REF}} - R_{\mathrm{SM}_{SAT}\cdot\mathrm{SM}_{MOD}} \times R_{\mathrm{SM}_{MOD}\cdot\mathrm{SM}_{REF}}}$$

5-3. Data assimilation

► SS1 (A.M.), SS1 (A.M.&P.M.), and SE1 were assimilated into NoahMP36 (2016 ~ 2019) using EnKF in the Land Information System (Sujay et al., 2006).

► Parameters for perturbations to meteorological forcings and soil moisture prognostic model variables in the data assimilation integrations can be found in Peters-Lidard et al. (2011).

6 Results and Discussion

6-1. TC result

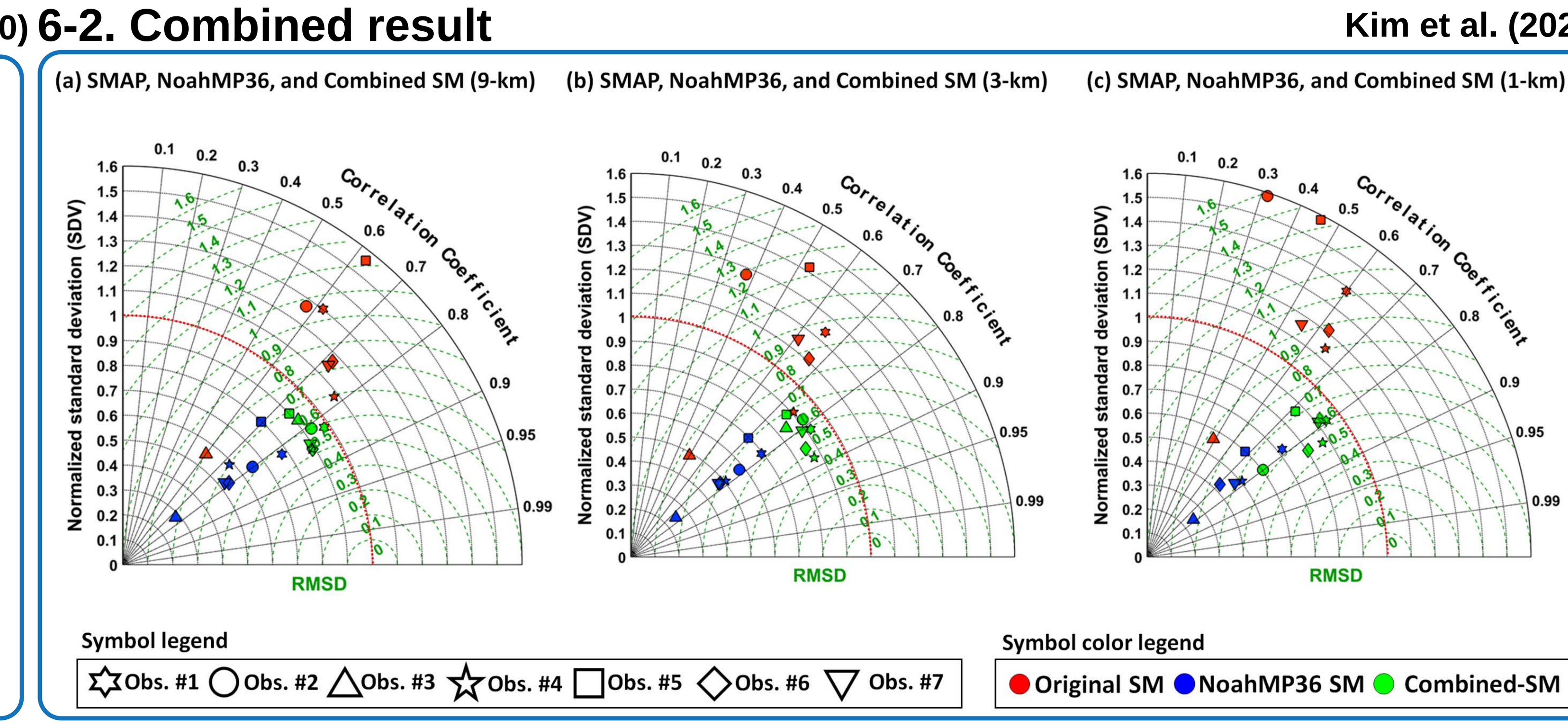
Kim et al. (2020)

TC-based R for SS1, SS3, and SE9

Obs. #	SE9	SS3	SS1
1	0.702	0.684	0.648
2	0.647	0.454	-
3	0.688	0.636	0.603
4	0.786	-	-
5	0.738	0.588	0.507
6	0.722	-	-
7	0.738	0.639	0.616
Median	0.722	0.636	0.610

6-2. Combined result

Kim et al. (2020)



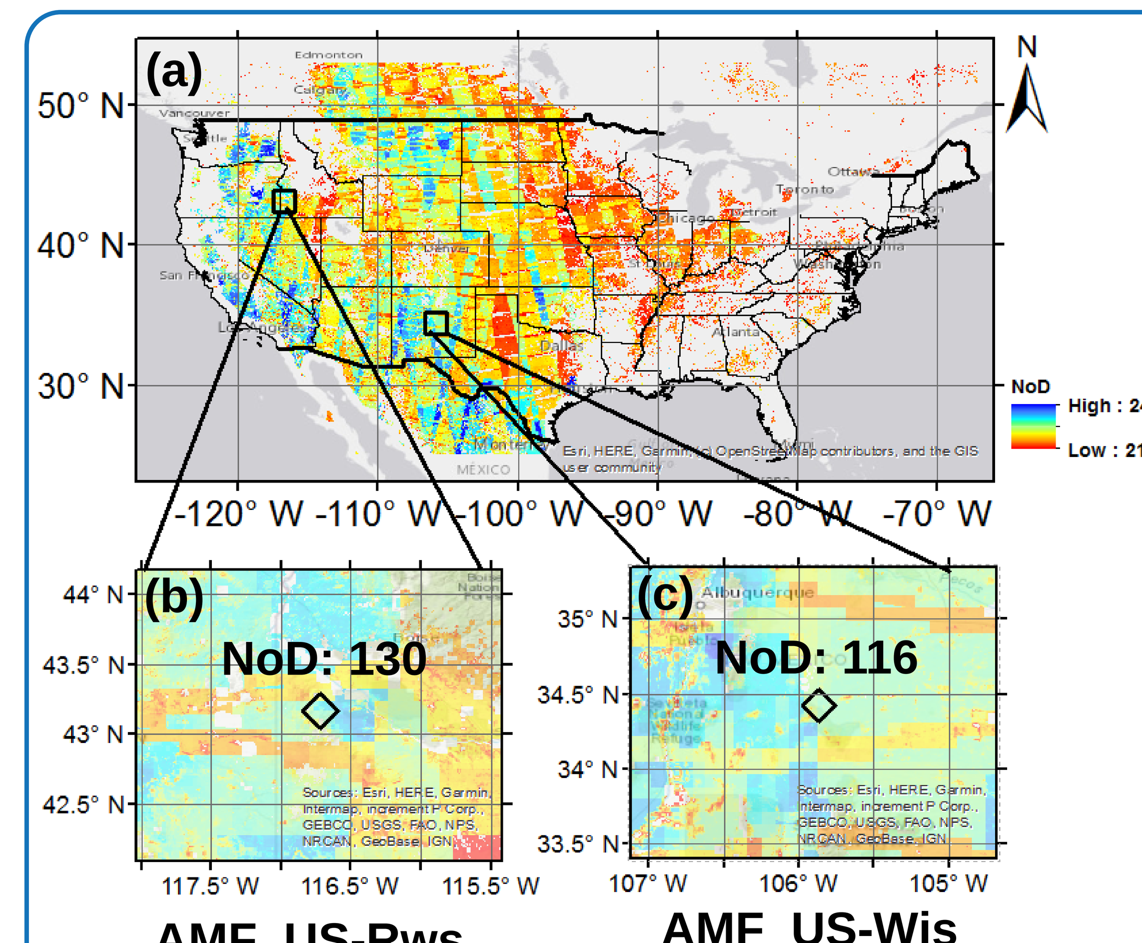
►(6-1) For SMAP 9-km data, the TC-based R values showed better performance than the other two products—the medians of the TC-based R values were 0.722, 0.636, and 0.610 for SMAP-9-km, SMAP/Sentinel-3-km, and SMAP/Sentinel-1-km, respectively.

►(6-2) The variability from combined products is similar to or a bit lower than that of in-situ SM data alone. Additionally, the combined products always produce a higher R-value than the individual parent products.

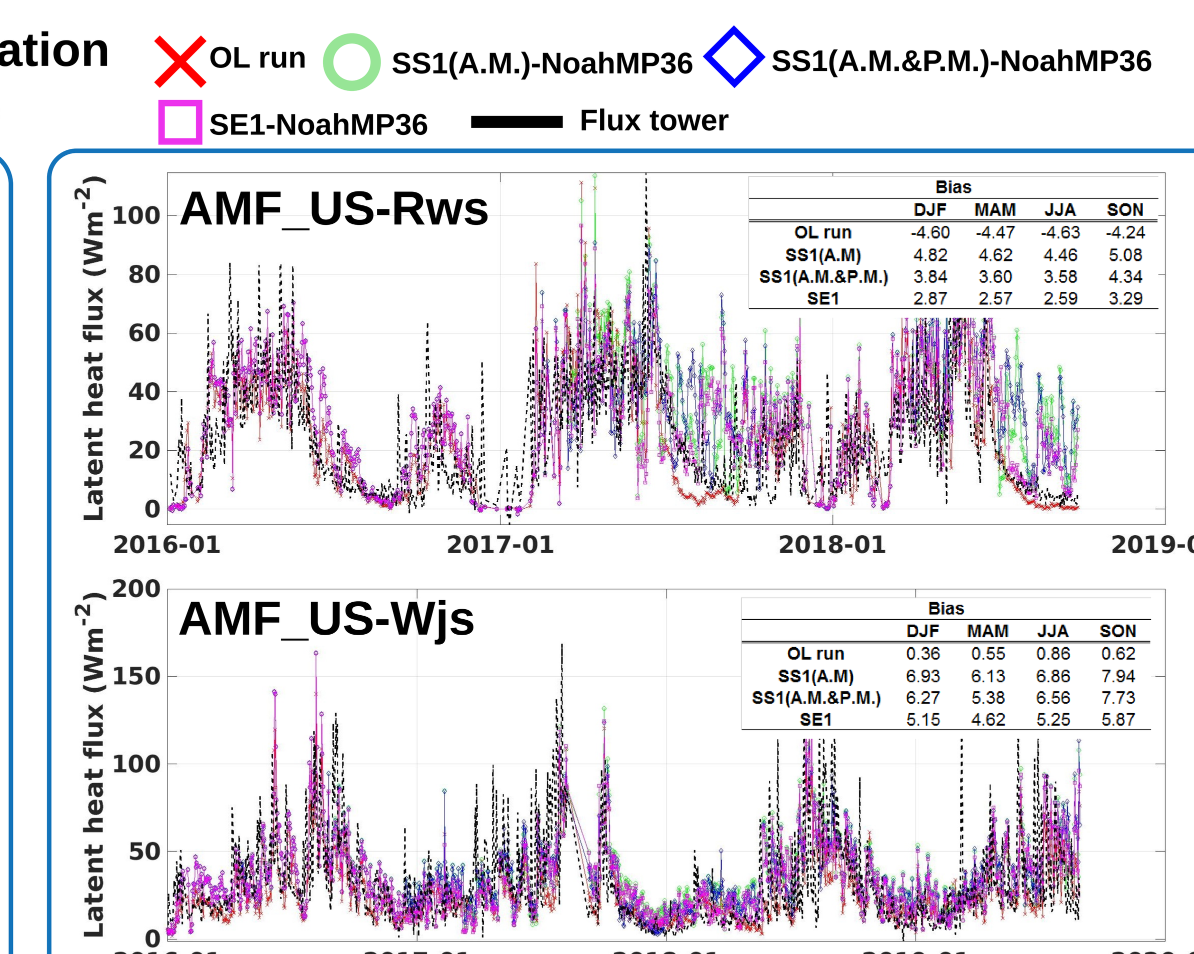
► SMAP and SMAP/Sentinel products can be utilized to improve the temporal pattern of fine SM spatial resolutions estimated from LSMs.

6-3. SS1 (A.M), SS1 (A.M/P.M.), and SE1 SM assimilation

Number of quality-controlled SS/SE data used (2016-2019)



► (a) Number of SS1 data that passed the quality control process. (b) The location of AMF_US-Rws site. (c) The location of AMF_US-Wjs.



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7 Conclusion

Through this study, we have shown a potential application of SMAP/Sentinel SM data to improve the estimation of SM from models. By combining SS1, SS3, and SE9 data, we were able to improve the quality of SM data. Furthermore, by assimilating SS1 into NoahMP3.6, we were able to reduce bias in ET at some points. In a future study, we will conduct similar analyses of all AmeriFlux points, and we will also spatially compare assimilated ET data with other spatial ET data sources.

Acknowledgement

Hyunglok Kim acknowledges funding from the Future Investigators in NASA Earth and Space Science and Technology (FINESST) (Award #: 80NSSC19K1337) and the UVA ESE Bicentennial Fellowship. We gratefully acknowledge funding from the NASA Terrestrial Hydrology Program (Program Manager Dr. Jared Entin, Grant # NNX12AP75G). Hyunglok Kim is particularly grateful to Dr. Sangchul Lee and Dr. Michael Cosh for their assistance.