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Improving of the AMSR-E/NASA soil moisture product in global scale using in-situ soil moisture measurements and fractional vegetation cover datasets

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ABSTRACT

The AMSR-E/NASA (Advanced Microwave Scanning Radiometer-Earth Observing System/National Aeronautics and Space Administration) daily global-scale soil moisture (SM) product, spanning from 2002 to 2011 with a spatial resolution of 25 km, was provided by the NASA National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC). However, the AMSR-E/NASA SM product exhibited limited sensitivity in capturing intra- and inter-annual variability of SM across many regions. Investigation revealed that inaccurate parameter values (A_0 and A_1) in the AMSR-E/NASA SM retrieval algorithm were pivotal in causing this issue. This study sought to improve the global-scale AMSR-E/NASA SM product. Parameter values (A_0 and A_1) were recalibrated using the 13 in-situ observation networks (totaling 192 sites), and their relationships with fractional vegetation cover (FVC) across four land cover types (sparse vegetation, grassland, cropland, and forest) were analyzed. Inversion models for A_0 and A_1 parameters tailored to each land cover type were constructed, utilizing a global FVC dataset. Subsequently, the improved AMSR-E/NASA SM product was generated employing the refined algorithm proposed by Xie et al. (2019). Evaluation of the product against SM measurements from the 6 in-situ observation networks indicated strong agreement, particularly evident in sparse vegetation areas where a linear relationship between A0 (or A1) parameter values and FVC was observed (e.g., A_1=-0.61×FVC+1.21 and A_0=-0.20×FVC+0.012). Conversely, non-linear relationships were prominent in grassland/cropland/forest areas (e.g., A_1 =69.04×(FVC)^2-28.49×FVC+5.67 for grass). Furthermore, the improved global-scale AMSR-E/NASA SM product demonstrated superior performance compared to AMSR-E/JAXA (Japan Aerospace Exploration Agency) and AMSR-E/LPRM (Land Parameter Retrieval Model) SM products, exhibiting lower Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) values (i.e., 0.026 cm^3/cm^3 and 0.032 cm^3/cm^3, respectively).

METHODS

AMSR-E/NASA soil moisture retrieval algorithm analysis. The original AMSR-E/NASA SM product inversion algorithm is a multi-frequency, multi-polarization method. The coefficients were determined by using a simplified radiative transfer equation to simulate the minimum difference between the brightness temperature and the AMSR-E satellite sensor observations. In 2003, Njoku et al. developed a linear method for retrieving SM from AMSR-E satellite observations (Njoku et al., 2003). The SM product inversion algorithm uses MPDI value and empirical coefficient to invert SM. The formula is as follows:

$$SM^t - SM^{dry} = a_0 \cdot g^* + a_1 \cdot \left(MPDI^t_{10.7} - MPDI^{dry}_{10.7}\right) \cdot exp(a_2 \cdot g^*)$$

$$MPDI_{10.7} = \left(T_{B(10.7V)} - T_{B(10.7H)}\right) / \left(T_{B(10.7V)} + T_{B(10.7H)}\right)$$

$$g^* = \beta_0 + \beta_1 \cdot ln(MPDI^*_{10.7})$$

Where, t represents the time in days; SM^t is SM with time; SM^{dry} is the minimum SM value (default is 0.05 cm^3/cm^3); $MPDI^t_{10.7}$ is the MPDI value of 10.7 GHz on day t; $MPDI^*_{10.7}$ is the annual minimum MPDI value under dry soil conditions. g^* is the baseline parameter, estimated by $MPDI^*_{10.7}$ (minimum MPDI at the monthly scale), which can be interpreted as equivalent vegetation water content (kg/m^2). V and H indicate vertical and horizontal polarization; a_0, a_1, a_2, β_0 and β_1 are empirical coefficients. In order to retrieve SM, the a_0, a_1, a_2, β_0 and β_1 parameter values need to be obtained. Jackson et al. determined the a_0, a_1, a_2, β_0 and β_1 parameters in 2012 by taking AMSR-E observations from Chad, Sudan, and the Central African Republic, where surface SM is low, and assuming an average SM of 0.1 cm^3/cm^3, thus the a_0, a_1, a_2, β_0 and β_1 parameters are determined.

RESULTS

Spatiotemporal variations of AMSR-E soil moisture products. By comparing the global AMSR-E/JAXA and AMSR-E/LPRM SM products with the AMSR-E/NASA SM products on August 1, 2010 (Figure. 2 and 3)

Parameter optimization of AMSR-E/NASA soil moisture retrieval algorithm. Based on the four land cover types of farmlands, grassland, forest area and sparse vegetation area, the relationship between A_0 and A_1 parameter values of the four land cover types and the monthly minimum MPDI data of 10.7GHz and vegetation coverage was analyzed respectively (Figure 4).

Evaluation for the improved AMSR-E/NASA SM product. Long-term measured data of six sites (Widgiewa site of OZNET observation network, Cullingral site of SASMAS observation network, NST_09 site of Maqu observation network, HYDROL-NET_PERUGIA observation network site, ARAPAHO_RIDGE on the SNOTEL network and Edinburg_17_NNE on the USCRN network) located in five typical land cover types, namely irrigated farmland, forest/grassland mixed, grassland, forest area and raon-fed farmland, were selected for comparison and analysis with the improved AMSR-E, AMSR-E/NASA, AMSR-E/JAXA, AMSR-E/LPRM SM products (Figure 5 and Table 5).

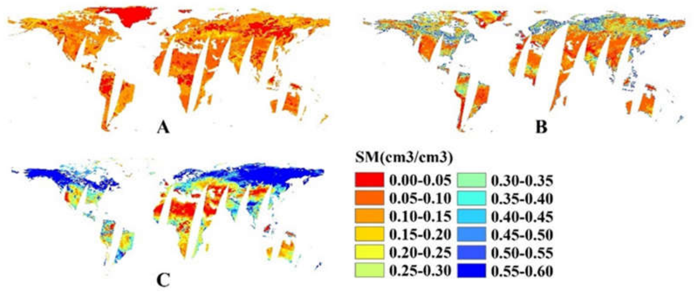

Figure 2.Spatial distribution patterns of AMSR-E (A: NASA; B: JAXA; C: LPRM) SM products.

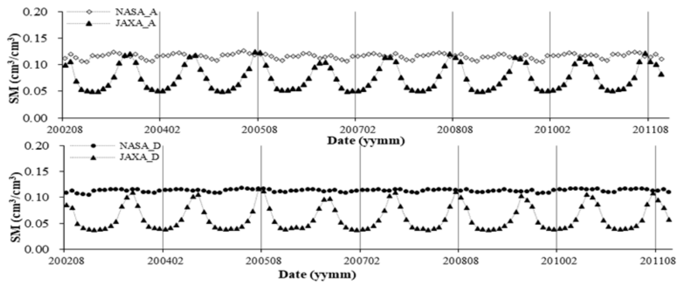

Figure 3. Daily GCF during 2011~2018 of global SMOS, FY3-B, ASCAT, ESA-CCI, SMAP, 1st and 2nd merged SSM (2015~2018 only).

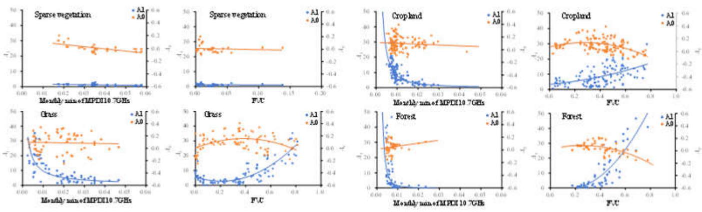

Figure 4. Scatter plots between A_1 (or A_0) values and monthly min of MPDI in 10.7GHz data (or fractional vegetation coverage).

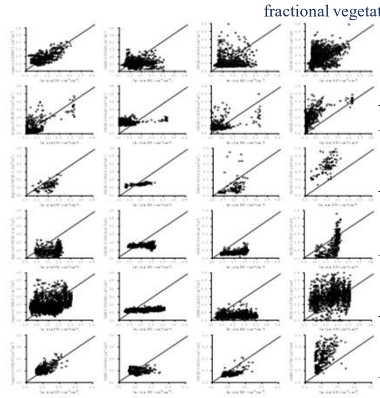

Figure 5. Scatter plots of AMSR-E SM products and in-situ SM measurements in Widgiewa site of OZNET (A), Cullingral site of SASMAS (B), NST_09 site of Maqu (C), HYDROL-NET_PERUGIA site (D), ARAPAHO_RIDGE site of SNOTEL (E) and Edinburg_17_NNE site of USCRN (F)

Table 5. MAE (cm^{3}cm^{-3}), RMSE (cm^{3}cm^{-3}), ubRMSE (cm^{3}cm^{-3}), Bias (cm^{3}cm^{-3}) and R values of AMSR-E SM products against in-situ SM measurements

Ob. Networks (Site: Land cover type)	Metrics	Improved AMSR-E	AMSRE/ NASA	AMSRE/ JAXA	AMSR-E/ LPRM
OZNET (Widgiewa: Irrigated cropland)	MAE	**0.055**	0.057	0.059	0.070
	RMSE	**0.067**	0.077	0.084	0.092
	Bias	0.034	**-0.011**	-0.014	0.053
	R	**0.689**	0.305	0.376	0.580
	ubRMSE	**0.058**	0.076	0.083	0.075
SASMAS (Cullingral: Mixing of forest/grass)	MAE	**0.048**	0.105	0.064	0.146
	RMSE	**0.070**	0.116	0.085	0.165
	Bias	**0.015**	0.080	0.032	0.144
	R	**0.704**	0.293	0.517	0.675
	ubRMSE	**0.068**	0.085	0.078	0.081
MAQU (NST_09: Grass)	MAE	0.073	**0.061**	0.070	0.214
	RMSE	0.084	**0.069**	0.093	0.229
	Bias	-0.068	**-0.001**	-0.051	0.214
	R	0.536	**0.710**	0.455	0.559
	ubRMSE	**0.050**	0.069	0.078	0.082
HYDROL-NET_PERUGIA (Grass)	MAE	0.139	**0.086**	0.154	0.115
	RMSE	0.155	**0.099**	0.167	0.134
	Bias	-0.134	**-0.068**	-0.154	-0.099
	R	0.210	**0.047**	0.425	0.706
	ubRMSE	0.077	0.073	**0.064**	0.090
SNOTEL (ARAPAHO_RIDGE: Forest)	MAE	**0.093**	0.114	0.138	0.117
	RMSE	**0.098**	0.138	0.172	0.125
	Bias	**0.008**	-0.099	-0.137	0.065
	R	**0.329**	0.298	0.198	0.227
	ubRMSE	**0.097**	0.096	0.103	0.129
USCRN (Edinburg_17_NNE: Rainfed cropland)	MAE	**0.026**	0.031	0.032	0.110
	RMSE	**0.032**	0.041	0.042	0.133
	Bias	0.011	**-0.007**	-0.029	0.109
	R	**0.630**	0.125	0.587	0.496
	ubRMSE	**0.030**	0.040	0.030	0.076

CONCLUSIONS

The main conclusions of this study are as follows:

1. The spatial and temporal distribution of AMSR-E/NASA, AMSE-E/JAXA and AMSR-E/LPRM SM products are significantly different. In particular, AMSR-E/NASA SM product values have small changes in time and space, and narrow inter-annual and inter-annual dynamic ranges, which can hardly reflect the characteristics of inter-annual and seasonal changes of SM.
2. Globally, A_0 and A_1 parameter values are not constant, but change with vegetation change, and there is an obvious nonlinear correlation between them and vegetation coverage. A_0 and A_1 parameter values vary from 0 to 35 and from -0.2 to 0.4, respectively. Compared with AMSR-E/NASA SM products, the improved AMSR-E SM products have a wider spatiotemporal variation range and are more consistent with the spatial distribution pattern of vegetation coverage.
3. The improved AMSR-E, AMSR-E/NASA, AMSR-E/JAXA and AMSR-E/LPRM SM products were evaluated using the measured data of 6 observation network sites. The results showed that the improved AMSR-E had better performance and was more consistent with the measured SM data. Compared with the AMSR-E/NASA SM products, the improved AMSR-E had a wider dynamic variation range and could better reflect the characteristics of annual and interannual variation of SM value.

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