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Global Soil Moisture Data Fusion by Triple Collocation Analysis from 2011 to 2018

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ABSTRACT

Global surface soil moisture (SSM) products with higher accuracy are needed urgently for agricultural water resource management, environment, and climate analysis applications such as the global climate change monitoring, drought monitoring and vegetation growth monitoring. Temporal and spatial sampling by the space-borne instruments designed to retrieve SSM is limited by the orbit of the satellite and by the operation of the sensor system. This constraints the generation of global, daily SSM data products. To obtain a global SSM product with higher coverage and accuracy this study integrated five SSM products with good performance in global coverage and accuracy, i.e., the SSM retrievals from the data acquired by the Soil Moisture and Ocean Salinity (SMOS), Advanced Scatterometer (ASCAT), FengYun 3-B (FY3-B), ESA-CCI and Soil Moisture Active and Passive mission (SMAP). These five SSM data products were retrieved using different algorithms, but they were combined to produce a (2011~2018) time-series of daily global SSM by applying the TCA and Linear Weight Fusion (LWF). First, we merged the global SMOS, FY3-B, and ASCAT SSM products from 2011 till 2018 using the TCA-based LWF algorithm. Then, the first merged SSM product, ESA-CCI, and SMAP SSM products were 2nd merged using the same fusion method but for the period 2015~2018. The Global Daily-scale Soil Moisture Fusion Dataset (GDSMFD) with 25km spatial resolution (2011~2018) was produced. Finally, we used five metrics to evaluate and compare the SMOS, FY3-B, ASCAT, ESA-CCI, SMAP, the GDSMFD SSM products against in-situ soil moisture measurements at the sites of ten observation networks, which belong to the International Soil Moisture Network (ISMN). Results indicated that the GDSMFD was consistent with in-situ soil moisture measurements, the minimum of root mean square error values of GDSMFD was only 0.036 cm^3/cm^3. Moreover, the GDSMFD had a good global coverage with mean Global Coverage Fraction (GCF) of 0.672 and the maximum GCF of 0.837. GDSMFD performed well in accuracy and global coverage fraction, making it valuable in applications to the global climate change monitoring, drought monitoring and hydrological monitoring. GDSMFD product was released at the National Tibetan Plateau Data Center.

METHODS

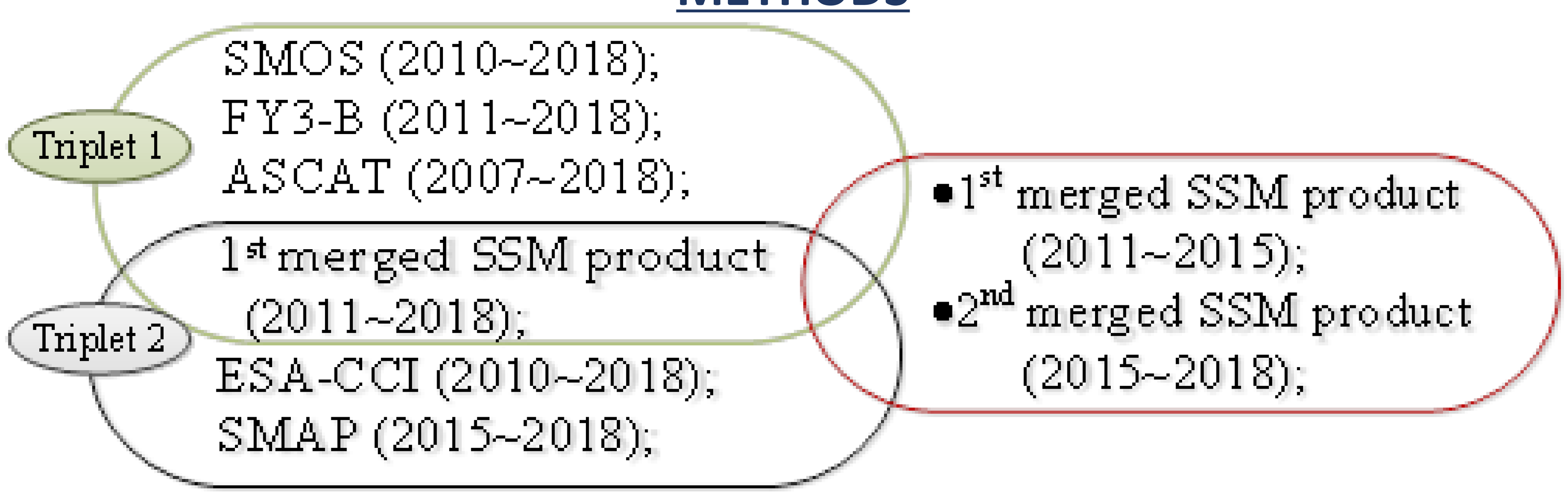


Figure.1 Overview of the two-triplet merging approach from global-scale original SSM products (SMOS, FY3-B, ASCAT, ESA-CCI and SMAP) to final merged SSM products (1st and 2nd merged SSM products)

Triple Collocation Analysis (TCA). At present the TCA method is one of the most widely used evaluation methods for satellite SSM products in the absence of in-situ soil moisture measurement data 55. The evaluation of errors in satellite SSM data products using TCA is based on three assumptions: a) soil moisture retrievals are linearly related to the true soil moisture value; b) the errors on each SSM retrieval are uncorrelated with the true soil moisture; and c) errors within each selected triplet of SSM retrievals are uncorrelated with each other. The main equation of TCA as:

$$\begin{cases}\sigma_{\varepsilon1}^2\\ \sigma_{\varepsilon2}^2\\ \sigma_{\varepsilon3}^2\end{cases} = \begin{bmatrix} Q_{11}-\frac{Q_{12}Q_{13}}{Q_{23}} \\ Q_{22}-\frac{Q_{12}Q_{23}}{Q_{13}} \\ Q_{33}-\frac{Q_{23}Q_{13}}{Q_{12}}\end{bmatrix} \qquad (1)$$

There are six unique terms (Q_{11}, $Q_{12}=Q_{21}$, $Q_{13}=Q_{31}$, Q22, $Q_{23}=Q_{32}$, Q_{33}) in the 3×3 covariance matrix. The error variance values on the three independent surface soil moisture products in each triplet ($\sigma_{\varepsilon1}^2, \sigma_{\varepsilon2}^2, \sigma_{\varepsilon3}^2$).

The linear weight fusion (LWF) method. The key in the LWF method is to estimate the weight value of each pixel of each SSM product. When the soil moisture values of three surface soil moisture products in 1st or 2nd step of the merging procedure are available, the weight values of three SSM products (w_1, w_2, w_3) can be calculated by using the estimated error variance values on three SSM products :

$$\begin{cases}w_1\\ w_2\\ w_3\end{cases} = \begin{cases}\frac{1/\sigma_{\varepsilon1}^2}{1/\sigma_{\varepsilon1}^2+1/\sigma_{\varepsilon2}^2+1/\sigma_{\varepsilon3}^2}\\ \frac{1/\sigma_{\varepsilon2}^2}{1/\sigma_{\varepsilon1}^2+1/\sigma_{\varepsilon2}^2+1/\sigma_{\varepsilon3}^2}\\ \frac{1/\sigma_{\varepsilon3}^2}{1/\sigma_{\varepsilon1}^2+1/\sigma_{\varepsilon2}^2+1/\sigma_{\varepsilon3}^2}\end{cases},\ w_1+w_2+w_3=1 \ (2)$$

RESULTS

Global-scale weight comparison. The global-scale weight distribution maps of SMOS, FY3-B, ASCAT, ESA-CCI, and SMAP SSM products are compared and shown in Figure.2.

Global-scale comparison of SSM products. We compared the spatial distribution of global SMOS, FY3-B, ASCAT, ESA-CCI, SMAP, the 1st and 2nd merged SSM products on August 1, 2015 (Figure.3 and 4).

Comparison with in-situ measurements. We used the mean value of in-situ measurements within a satellite SSM pixel as the reference to evaluate the satellite SSM products. We compared the SMOS, FY3-B, ASCAT, ESA-CCI, SMAP, the 1st and 2nd merged SSM with in-situ soil moisture measurements from 2014 to 2018 (Figure.5)

To improve our validation study on GDSMFD product, we have expanded significantly the soil moisture reference data set used for this purpose. We used soil moisture retrievals based on the area-scale airborne radiometer observation by SCA-V (Single Channel Algorithm-Vertical polarization) soil moisture retrieval algorithm. Also, we used two global-scale merged soil moisture data, i.e. the NNsm and RSSSM data products based on the neural network fusion algorithm.

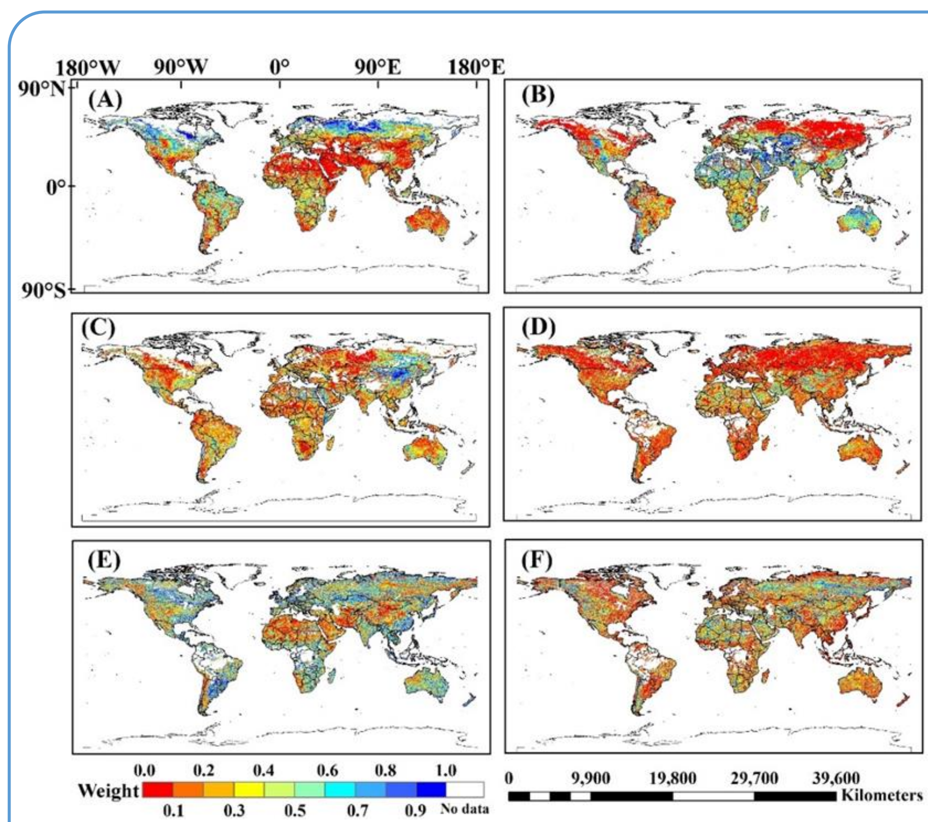


Figure 2 . Weight values of SMOS (A), FY3-B (B), ASCAT (C), the 1st merged SSM (D), ESA-CCI (E), and SMAP (F) SSM products based on TCA

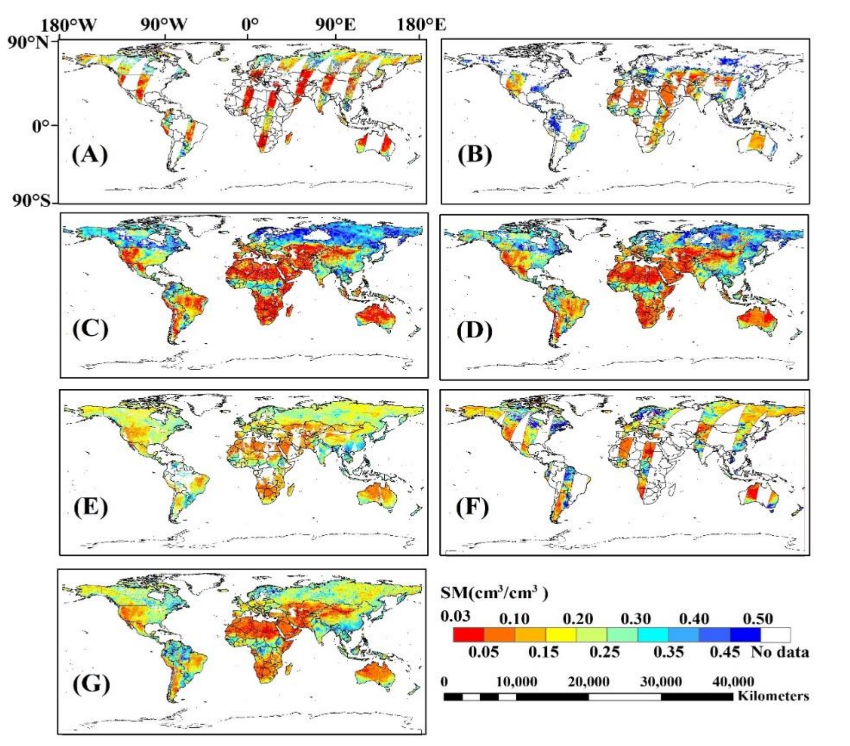


Figure 3 . Global SSM data products on August 1st, 2015: SMOS (A), FY3-B (B), ASCAT (C), 1st merged SSM (D), ESA-CCI (E), SMAP (F) and 2nd merged SSM (G)

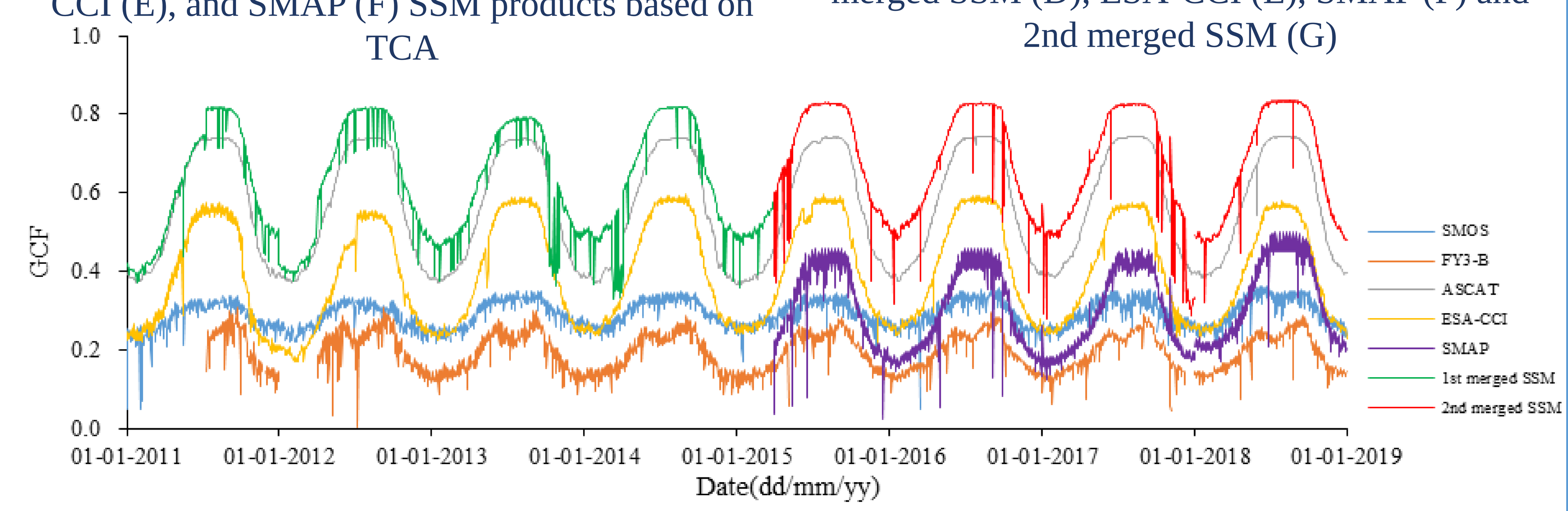
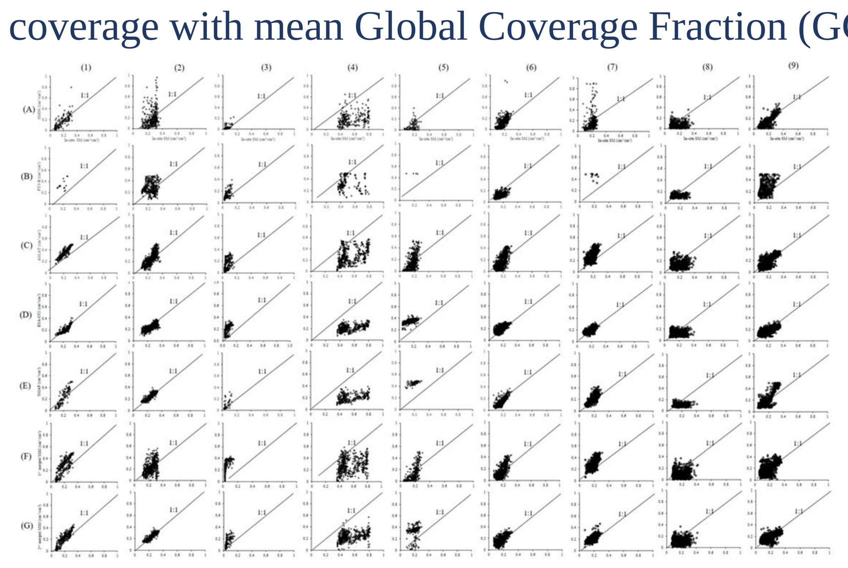


Figure 4 . Daily GCF during 2011~2018 of global SMOS, FY3-B, ASCAT, ESA-CCI, SMAP, 1st and 2nd merged SSM (2015~2018 only)

In different areas, the weight values of SMOS, FY3-B, and ASCAT have a large spatial variability (Fig.2). There are some areas without data because of less sample points used in TCA calculation in triplet 1 or 2 and permanent snow, ice and water bodies. In general, SMOS and FY3-B are dominant SSM products in the first merging process. Comparing weight values of the 1st merged SSM product, ESA-CCI, and SMAP SSM, the weight values of ESA-CCI and SMAP are higher than that of the 1st merged SSM product. Missing values in the 2nd merged SSM product are significantly less than in SMOS, FY3-B, ASCAT, ESA-CCI, and SMAP SSM (Fig.3 and 4). Our fusion dataset has a good global coverage with mean Global Coverage Fraction (GCF) of 0.672 and the maximum GCF of 0.837.



Scatter plots of SSM retrievals: SMOS (A), FY3-B (B), ASCAT (C), ESA-CCI (D), SMAP (E), 1st merged (F) and 2nd merged (G) versus in-situ soil moisture measurements vs at: (1) CTP_SMTMN, (2) RSMN, (3) AMMA-CATCH and DAHRA, (4) BIEBRZA_S-1, (5) MySMNet, (6) REMEDHUS, (7) HOBE, (8) USCRN, (9) OZNET.

CONCLUSIONS

These results demonstrate there were clearly less missing soil moisture values in space in the merged SSM map. Our fusion dataset has a good global coverage with mean GCF of 0.672 and the maximum GCF of 0.837. The merged product had a higher accuracy when compared with in-situ soil moisture measurements in most sites. The minimum of root mean square error values was only 0.036 cm3/cm3 .In most areas the weight of ESA-CCI was dominant in the merged SSM data except in northern Africa where the weight values of SMAP were higher than ESA-CCI, and SMAP SSM was dominant. Quality of SSM products to be used for fusion is essential for generating merged SSM dataset with higher accuracy.

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