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Varying applicability of four different satellite-derived soil moisture products to global gridded crop model evaluation

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ABSTRACT

Satellite-derived daily surface soil moisture products have been increasingly available, but their applicability to global gridded crop model (GGCM) evaluation is unclear. This study compares four different soil moisture products with the flux tower site observation at 18 cropland sites across the world where either of maize, soybean, rice and wheat is grown. These products include the first and second versions of Climate Change Initiative Soil Moisture (CCISM-1 and CCISM-2) datasets distributed by the European Space Agency and two different AMSR-E (Advanced Microwave Scanning Radiometer–Earth Observing System)-derived soil moisture datasets, separately provided by the Japan Aerospace Exploration Agency (AMSRE-J) and U.S. National Aeronautics and Space Administration (AMSRE-N). The comparison demonstrates varying reliability of these products in representing major characteristics of temporal pattern of cropland soil moisture by product and crop. Possible reasons for the varying reliability include the differences in sensors, algorithms, bands and criteria used when estimating soil moisture. Both the CCISM-1 and CCISM-2 products appear the most reliable for soybean- and wheat-growing area. However, the percentage of valid data of these products is always lower than other products due to relatively strict criteria when merging data derived from multiple sources, although the CCISM-2 product has much more data with valid retrievals than the CCISM-1 product. The reliability of the AMSRE-J product is the highest for maize- and rice-growing areas and comparable to or slightly lower than the CCISM products for soybean- and wheat-growing areas. The AMSRE-N is the least reliable in most location-crop combinations. The reliability of the products for rice-growing area is far lower than that of other upland crops likely due to the extensive use of irrigation and patch distribution of rice paddy in the area examined here. We conclude that the CCISM-1, CCISM-2 and AMSRE-J products are applicable to GGCM evaluation, while the AMSRE-N product is not. However, we encourage users to integrate these products with in situ soil moisture data especially when GGCMs simulations for rice are evaluated.

1. Introduction

Global gridded crop models (GGCMs, Rosenzweig et al., 2014; Elliott et al., 2015) are emerging tools that simulate growth and yield of a specific crop over global cropland. Given global climate change, globalization of food trade, and the increasing importance of food imports to maintain national food balance in many countries, GGCMs are expected to provide sound basis for climate adaptation strategies for global crop production systems. For such purpose, it is crucial to assess the reliability of GGCMs-simulated agro-ecosystems dynamics, such as crop–soil interactions, as well

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as crop yield through a comparison with observation. Soil moisture is a key environmental driver because of its strong influence on crop yield in rainfed cropping systems (Kucharik and Ramankutty, 2005; Hawkins et al., 2013; Iizumi et al., 2013). However, long-term soil moisture observation covering a large spatial domain is seldom available. This situation hinders GGCMs from intensive evaluation and further improvement.

Satellite-derived soil moisture products have benefited from ongoing improvements in the instrument and retrieval algorithm. Currently, some global soil moisture products have become available, such as the ASCAT (Advanced Scatterometer, Naeimi et al., 2009; Wagner et al., 1999), AMSR-E (Advanced Microwave Scanning Radiometer–Earth Observing System) provided by JAXA (Japan Aerospace Exploration Agency, Koike et al., 2004; Fujii et al., 2009), NASA (U.S. National Aeronautics and Space Administration, Njoku and Chan, 2006) and VUA-NASA (Vrije Universiteit Amsterdam in collaboration with NASA, Owe et al., 2008), AMSR-2 (Koike et al., 2004; Fujii et al., 2009), WindSat (Li et al., 2010), SMOS (Soil Moisture and Ocean Salinity, Kerr et al., 2012) and CCISM (Climate Change Initiative Soil Moisture, Wagner et al., 2012; Liu et al., 2011, 2012) products. The availability of in situ observation to validate the products has also significantly increased (Dorigo et al., 2011). A number of studies have performed intercomparison with in situ observation of soil moisture to evaluate the quality of the products generated by different sensors and algorithms (Brocca et al., 2011; Dorigo et al., 2015; Jackson et al., 2010). However, the applicability for crop-related area is relatively unknown. Therefore, it is necessarily to know which product is more suitable for individual crop types as a parameter into crop-specific GGCMs.

In this study, the applicability of four products is evaluated by comparing with the soil moisture observation obtained from flux tower networks in cropland across the world. Four products include two AMSR-E-derived soil moisture products, separately provided by the JAXA (AMSRE-J) and NASA (AMSRE-N) using different retrieval algorithms, and the CCISM version 1 (CCISM-1) and version 2 (CCISM-2) products. Recently, the updated version of the soil moisture product has been released by the ESA (European Space Agency). The CCISM-2 product has great improvements than the former version, e.g. improved gap filling, new data attributes, and a revision of processing algorithms and merging procedures (Zeng et al., 2015). The differences in the reliability across products and crops (maize, rice, wheat and soybean) were compared, including the CCISM-1 product. Products other than the AMSR-E- and CCISM-related products were not used because of the shortage of available in situ data in cropland during their operational period. Also, we noted the potentials and limitations of these soil moisture products for use in GGCMs evaluation at the end of this article.

2. Data and methods

2.1. Satellite-derived soil moisture products

Four daily soil moisture products were used for this study: the AMSRE-J level 3 product, the AMSRE-N level 3 product and the CCISM-1 and CCISM-2 products. The AMSRE-N product with a cylindrical 25-km grid was re-projected to 0.25-degree Lambert Azimuthal Equal Area projection on the World Geodetic System spheroid of 1984 (WGS84) using the bicubic interpolation method to match the spatial resolution and projection of the AMSRE-J and CCISM products. The main characteristics of the products are summarized in Table 1.

The retrieval algorithms used for estimating soil moisture are based on the same theoretical framework but with varying assumptions and parameterizations across the products. Both the AMSRE-J and AMSRE-N products are solely based on the AMSR-E sensor on-board Aqua satellite (Table 1). The AMSR-E sensor provides data of passive microwave brightness temperatures at six different bands (6.9, 10.7, 18.7, 23.8, 36.5 and 89.0 GHz) in horizontal and vertical polarizations, with daily ascending (13:30 LST) and descending (01:30 LST) in a sun synchronized orbit, over a swath width of 1445 km. Such products are available from June 2002 to October 2011. The spatial resolution of the AMSR-E sensor depends on bands and ranges from 5.4 km for 89.0 GHz to 56 km for 6.9 GHz. In general, especially for passive microwave, bands with lower frequency (e.g., 6.9 GHz or C-band) are sensitive to soil moisture on one hand, but strongly affected by radio frequency interference on the other hand (Castro et al., 2012). To avoid radio frequency interference, the AMSRE-J and AMSRE-N products use the relatively low-frequency band of 10.7 GHz (X-band) and higher.

As shown in Table 1, a main difference between the AMSRE-J and AMSRE-N products can be seen in their combination of bands used and their algorithms for estimating soil moisture. The AMSRE-J product uses the band of 36.5 GHz (Ka-band), instead of 18.7 GHz (Ku-band) used in the AMSRE-N product, although both products commonly use the band of 10.7 GHz (X-band). As for the soil moisture estimation algorithms, there are a number of differences between the AMSRE-J and AMSRE-N products, although users cannot ascertain which part of the algorithms is the most influential to soil moisture estimates. However, a relatively large difference can be found, for instance, in the way of using multiple data sources. On one hand, the AMSRE-J product use the sub-grid level information on vegetation coverage derived from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor to count for the heterogeneity of land surface condition within a 0.25° grid cell in addition to data from the AMSR-E sensor (Fujii et al., 2009). On the other hand, although many efforts to remove noises due to the vegetation and atmosphere are made (Njoku and Chan, 2006), the AMSRE-N product is solely based on the information derived from the single sensor (the AMSR-E). For both the AMSRE-J and AMSRE-N products, two different products, one is based on data from the descending orbit (nighttime overpass) and the other is based on data from ascending orbit (daytime overpass), are available. However, in this study, the products based on the descending orbit are used to conduct a consistent intercomparison with the CCISM-1 and CCISM-2 products because a substantial portion of valid data of these CCISM products are based on data from descending orbit.

The major difference of these CCISM products relative to the AMSRE-J and AMSRE-N products is the use of more data

Table 1
General description of four different satellite-derived soil moisture products.

	Soil moisture product			
	AMSRE-J	AMSRE-N	CCISM	
Sensor	AMSR-E	AMSR-E	AMSR-E/SCAT	AMSR-E/ASCAT
Duration	2002–2011	2002–2011	2002–2006	2007–2011
Bands used for soil moisture	10.7/36.5 GHz	10.7/18.7 GHz	5.3/6.9/10.7/18.7/36.5 GHz	
Spatial resolution	0.25°	25 km	0.25°	
Distributor	JAXA	NASA	ESA	
Reference	Fujii et al. (2009)	Njoku and Chan (2006)	Wagner et al. (2012), Liu et al. (2011, 2012)	