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Validation and trend analysis of ECV soil moisture data on cropland in North China Plain during 1981–2010

Sisi Wang[a,b], Xingguo Mo[a,*], Suxia Liu[a], Zhonghui Lin[a], Shi Hu[a]

[a] Key Laboratory of Water Cycle and Related Land surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

[b] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

Global time series of the Essential Climate Variable (ECV) soil mositure (SM) is being developed from passive and active satellite microwave sensors at a coarse spatial resolution with Climate Change Initiative program funded by European Space Agency. This study aims to validate the reliability of ECV SM dataset, and attempts are made to analyze SM trends in cropland. Firstly, *in-situ* SM measurements during crop growing seasons from 1992 to 2010 for 228 stations across China and 21 stations over cropland of North China Plain (NCP) were employed to validate ECV SM product. Then, the spatiotemporal variations of ECV SM were analyzed during growing period of winter wheat (April–June) and summer maize (July–September) from 1981 to 2010 in NCP. Finally, the possible relationship between SM, precipitation, evapotranspiration and NDVI were explored. Results showed that ECV SM could generally capture the seasonal SM dynamics. The average triple collocation random error of ECV SM in China was 0.052 $m^3\ m^{-3}$ while the error in cropland ranged from 0.003 to 0.156 $m^3\ m^{-3}$. The averaged Spearman correlation coefficient between ECV SM and all *in-situ* observations was 0.42 ($p < 0.01$) in China and 0.43 ($p < 0.01$) for cropland over NCP. Spatially, ECV SM was decreasing in most areas during wheat season, whereas the trends of ECV SM were positive in south and negative in north during maize season in NCP, being consistent with the precipitation fluctuation. Overall, ECV SM is potentially suitable for trend analysis in NCP and its validations and analysis will be helpful for further enhancement of the ECV SM product.

1. Introduction

Soil moisture (SM) is one of the most important variables in water cycle linking with energy exchange and mass transport between land surface and atmosphere. It plays an essential role to control the vegetation growth through biogeochemical and biogeophysical processes such as evapotranspiration (ET), runoff, infiltration, regional carbon and nitrogen cycles (Grayson et al., 1997; Li and Rodell, 2013; Orth and Seneviratne, 2013). Meanwhile, the spatiotemporal pattern of SM is closely related to the seasonal variation of precipitation, transpiration and land use type (Mahmood and Hubbard, 2003; Savva et al., 2013). Thus, accurate measurement of SM and monitoring its conditions are of great importance for agricultural industry and water resource management.

The high variability of SM stimulates a number of studies to explore the mechanism of spatiotemporal patterns of SM at regional scale (Cho and Choi, 2014; Qiu et al., 2014; Qiu et al., 2001). Remote sensing technology, especially microwave sensors, has been used for monitoring the spatiotemporal pattern of SM widely (Choi, 2012; Juglea et al., 2010; Liu et al., 2012; Rebel et al., 2012; Wagner et al., 2006). And many global SM products have been retrieved with different remote sensing sensors, such as Advanced SCATterometer (ASCAT) (Figa-Saldaña et al., 2002), Advanced microwave scanning radiometer-earth observing system (AMSR-E) sensors (Jackson et al., 2010) and multi-satellite surface SM dataset (SM–MW) (Dorigo et al., 2012). Generally, the reliabilities of these SM products are assessed by comparing them with ground measurements or/and model simulations (Albergel et al., 2013; Brocca et al., 2011; Qiu et al., 2013). However, the application of these products is limited due to insufficient validation in different regions, and it is necessary to carry out more validation over different climate zones.

* Corresponding author. Fax: +86 010 64889307.
E-mail addresses: wangss.13b@igsnrr.ac.cn (S. Wang), moxg@igsnrr.ac.cn (X. Mo), liusx@igsnrr.ac.cn (S. Liu), linzh@igsnrr.ac.cn (Z. Lin), hus.08b@igsnrr.ac.cn (S. Hu).

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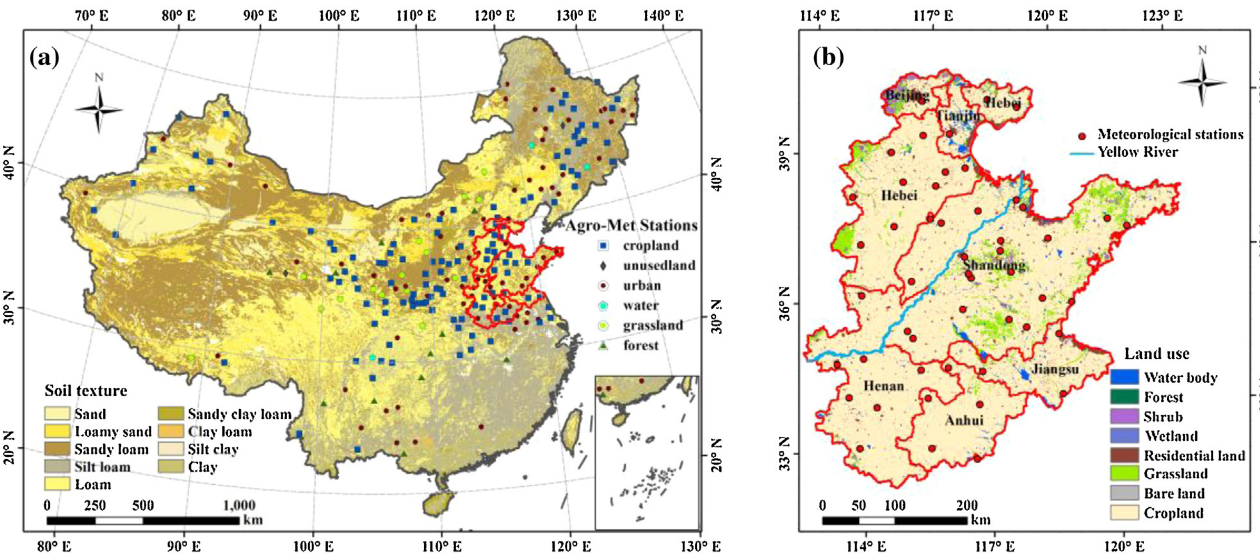

Fig. 1. (a) Geographical and soil texture map of China with the locations of the agro-meteorological (Agro-Met) stations. (b) Land use map of the North China Plain with the locations of the meteorological stations. Black and red solid lines are the national boundary and the provincial boundary, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The analysis of long time series data is helpful for identifying the trends of natural variables (Leroy et al., 2008; Santer et al., 2011). However, the time span of the remote sensing products is usually short, which limits our knowledge for clarifying the effect of human activities on the climatic variables. In order to generate a consistent long-term SM record, the Essential Climate Variable (ECV) SM product was supplied within the framework of the European Space Agency (ESA) Water Cycle Multi-mission Observation Strategy (WACMOS) and Climate Change Initiative (CCI) project by blending four passive and two active microwave satellite-based retrievals (Liu et al., 2012, 2011b) covering the period from 1979 to 2013 at the global scale with the spatial resolution of 0.25°. The ECV SM dataset was produced from sensors with different temporal and spatial resolution, center frequencies, band-width, radiometric accuracy, observation principle and calibration method (Albergel et al., 2013; Dorigo et al., 2012; Liu et al., 2012). Thus, the reliabilities and potential application of this product need to be analyzed and evaluated. By comparing with model predicted SM, Dorigo et al. (2012) found the most prominent trend patterns in ECV SM were line with the trends of modeled SM from GLDAS-Noah and ERA Interim, and GPCP precipitation. Pratola et al. (2014) recently indicated that ECV SM data were highly correlated with *in-situ* measurements with correlation coefficient $r > 0.6$ ($p < 0.025$). ECV SM in Sahelian region showed a good performance on inter-annual and intra-annual variations of SM and precipitation dynamics (Loew et al., 2013). So far as, there are still some limitations and uncertainties in the merged dataset (Dorigo et al., 2012, 2015; Liu et al., 2012), such as: (1) blending process of ECV SM slightly decreased the precision of the merged datasets with respect to the individual input datasets before blending; (2) given the lower quality and less-stable satellite instrumentation and the heterogeneity in ground samplings, the uncertainty of ECV SM increased in earlier periods; and (3) the ECV SM's retrieval algorithms were sensitive to topography, surface water, and vegetation.

Remotely sensed SM can only detect the water in upper few centimeters of the soil, while the water exchange usually happens in the deep soil layer. For example, roots which absorbed water for transpiration often grow in 0–150 cm or deeper soil layer. Normalized difference vegetation index (NDVI) as proxy of vegetation development should reflect potentially long-term changes in root-zone SM. Some studies found that the correlation between remotely sensed SM and NDVI was complicated (Dorigo et al., 2012). Liu et al. (2011a) stated that NDVI reacted more directly to changes in available water in crops than bushes and trees. As root-zone SM at large scale is onerous to obtain, remotely sensed SM is taken as a proxy. However, it is required to analyze the relationship between ECV SM and NDVI to determine whether ECV SM is suitable to study structural moisture changes in the root layer in cropland.

In this study, ECV SM dataset of 30 years (1981–2010) was verified with *in-situ* measurements and simulated time series from an ecohydrological (VIP) model, and used to detect the trend of SM in cropland over the North China Plain (NCP). More specifically, the purposes are:

(1) Validating the accuracy of ECV SM using *in-situ* SM measurements and model simulated SM by triple collocation method.
(2) Detecting and comparing the spatiotemporal variability, trends between the ECV SM and the model simulated SM in the growing seasons.
(3) Analyzing the correlations between ECV SM and NDVI to reveal SM effect on vegetation growth.

2. Materials and methods

2.1. Study area

NCP is located in the eastern part of China, extending from latitude 32°00′N to 40°24′N and longitude 112°48′E to 122°45′E (Fig. 1) with an area of 33×10^4 km^2 and average elevation of 50 m above sea level. It is one of the most important granaries of the country. The region has a typical temperate and monsoonal climate with annual mean air temperature of 8–15°C. The annual precipitation (PPT) distributes non-evenly among seasons ranging from 500 to 1000 mm and more than 70% of PPT events occur in summer during the maize growing season. Both temperature and PPT decrease gradually from southeast to northwest. The prevailing double-cropping system is winter wheat (*Triticum aestivum L.*) and summer maize (*Zea mays L.*). Due to insufficient PPT in spring, the supplemental irrigation for winter wheat is required to obtain optimum yield. NCP suffers from serious water shortage and environmen-