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Stand-alone uncertainty characterization of GLEAM, GLDAS and MOD16 evapotranspiration products using an extended triple collocation approach

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ABSTRACT

An optimal use of the global scale actual evapotranspiration (AET) products for various hydro-meteorological applications requires a systematic characterization of their uncertainties. This study presents the first application of an extended triple collocation (TC) approach to provide mutually uncorrelated absolute and relative error structure among three readily available AET (MOD16, GLEAM, and GLDAS) products on the point and spatial scale within the extent of Asia. The physical evaluation results of GLEAM, GLDAS and MOD16 exhibited reasonable accuracy compared to the in-situ AET with mean Index of Agreement > 0.71, 0.59 and 0.58, respectively, thereby yielding Root Mean Square Error between ~4–13 mm/8 day over nine AsiaFlux sites representing forest, rice paddy, and grassland biomes. Theoretical uncertainty assessment of four AET dataset combinations revealed that an average ~1.5–5.5 mm/8 day random error was contributed from in-situ AET, thereby reducing the accuracy of other datasets. GLEAM performed consistently better with least absolute and relative uncertainties over forest compared with rice paddy and grassland surfaces where GLDAS had almost similar errors as those obtained from GLEAM, while MOD16 showed high uncertainties over all vegetation conditions. Interestingly, all four datasets had large relative uncertainties (> 25%) for low vegetation compared to the errors of tall canopies. A spatially merged product generated from the least uncertainties showed better agreement in order of GLDAS > GLEAM > MOD16 over 47%, 42% and 11% of the study area. Overall, the application of extended TC approach on the quality of three AET products is a step forward to develop the merged near real-time accurate AET dataset by processing of theoretical and systematic uncertainties in the current AET algorithms.

1. Introduction

Evapotranspiration (ET) is a nexus of energy, water, and the carbon cycle (Yang et al., 2016) which provides the interactions between climatic and hydrological processes to address the changes among plant-land-atmosphere conditions (Miralles et al., 2016). Actual evapotranspiration (AET) is defined as the loss of water from the surface of the Earth to the atmosphere, and it is typically linked with evaporation from the soil surface and plant transpiration in its natural environment under limited water conditions (Brutsaert and Chen, 1996). Availability of accurate and reliable AET information is a prerequisite for many hydro-meteorological applications such as water resource management, irrigation scheduling, crop yield estimation, and drought predictions (Liaqat et al., 2015; Baik and Choi, 2015). However, the involvement of sensitive climate feedback, heterogeneous land surfaces and environmental conditions, and their variability in space and time usually cause small to large-scale quantitative and qualitative uncertainties in the AET quantification (Ferguson et al., 2010; Long et al., 2014).

Despite of the above quantification and uncertainty challenges, the local field scale AET datasets generated through conventional ground-based techniques such as, scintillometers, weighing lysimeters, Bowen ratio, and eddy covariance based FLUXNET systems are usually considered as true representations of AET at a point scale, inspite of their own measurement errors and scaling issues (Park et al., 2017a,b; Sugita et al., 2017; Velpuri et al., 2013; Baik and Choi, 2015). Continuous efforts have been made in last few decades to produce multi-year global AET datasets by combining conventional methods with recent advancements in satellite remote sensing technologies (Rodell et al., 2004; Miralles et al., 2011a; Ghilain and Arboleda, 2011; Zhang et al., 2010;

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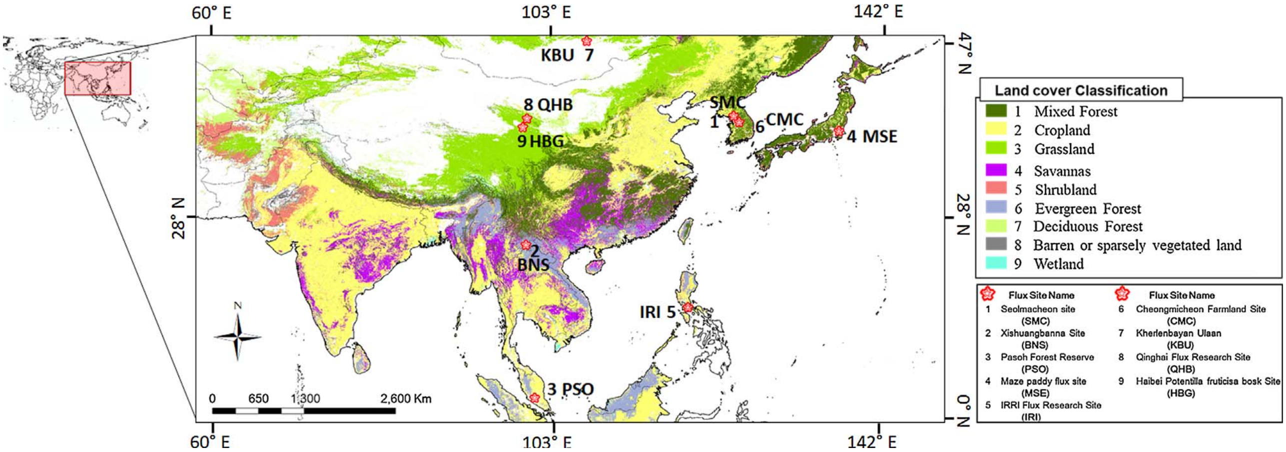

Fig. 1. Major geographical regions of study area with land cover information are portrayed, spatial distribution of flux tower sites are represented with red stars. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Onogi et al., 2007; Mu et al., 2007, 2011). These datasets have been generated considering the widespread application of the surface energy budget, land surface models, and empirical as well as semi-empirical approaches through the use of satellite imagery and observation based meteorological forcing (Landeras et al., 2008; Miralles et al., 2011a).

Among several global AET products (Rodell et al., 2004; Mu et al., 2007, 2011; Miralles et al., 2011a; Zhang et al., 2010; Ghilain and Arboleda, 2011; Onogi et al., 2007), very few qualify as datasets, which are widely available possess large coverage and find operational applications. Examples of such datasets include the MODerate resolution Imaging Spectroradiometer (MODIS) i.e., MOD16 AET (Mu et al., 2007, 2011) having eight-day, monthly, and yearly temporal and 1 km spatial resolution; Global Land Evaporation and Amsterdam Model (GLEAM) 25 km daily AET products (Martens et al., 2017; Miralles et al., 2011a,b); and Global Land Data Assimilation System (GLDAS) having 25 km AET products at 3 hourly and monthly temporal resolutions (Rodell et al., 2004). Moreover, MOD16, GLEAM, and GLDAS provide continuous AET datasets on a global scale which are based on Penman-Monteith, Priestley-Taylor, and land surface model approaches, respectively. All of these datasets are based on geophysical measurement systems such as models estimation, remote sensing and in-situ network forcing which are subject to various error sources that include the difference between in-situ measurements itself, sensor calibration and support scale, and underlying model assumptions and parametrization. Thus, the uncertainty analysis of these error sources is critical to characterize and use the above AET datasets with greater confidence in operational applications involving hydro-meteorological projections.

Currently, two types of error estimation techniques are available to investigate the accuracy of geophysical measurements. The first method involves measurments of the difference between modeled and in-situ datasets in terms of correlation, bias, and root mean square error (Majozi et al., 2017; Velpuri et al., 2013; Kim et al., 2012; Liu et al., 2016; Ramoelo et al., 2014; Li et al., 2014). This method is mostly used for calibration and validation purposes due to limited in-situ datasets availability (Jia et al., 2012). The second method employs the triple collocation (TC) error estimation technique (Stoffelen, 1998) that uses the statistical relationships to estimate the random error standard deviation for three collocated datasets of the same geophysical variable. At the same time, it does not consider any dataset which belongs to the perfectly observed system. This implies that the errors associated with target dataset are a true representation of uncertainty associated with that system, and this is mutually independent of the other two sources. Moreover, the mathematical simplicity of covariance based extended TC analysis is that the high-quality reference datasets are not really required. Instead the TC method directly estimates the Pearson's correlation coefficient between noisy and unknown reference datasets (McColl et al., 2014; Gruber et al., 2016). Therefore, TC has emerged as one of the most promising error estimation techniques for earth observations and hydrological applications due to its optimal utilization of an independent reference system. Although, this method has been widely used to map error structures of a number of geophysical variables including ocean, wind and wave data (Caires and Sterl, 2003), precipitation (Alemohammad et al., 2015), sea surface temperature (Gentemann, 2014), leaf area indices (Fang et al., 2012) and more specifically soil moisture (Kim et al., 2018; Gruber et al., 2016; Scipal et al., 2008; Su et al., 2014a,b), but, to best of our knowledge, it has not yet been considered for analyzing AET datasets.

Therefore, the main objective of this study is to examine the error structure of three independently available long-term AET (MOD16, GLEAM, and GLDAS) datasets over a 10-years duration (2000–2010) in Asia using new covariance based extended TC method. The accuracy of each AET dataset was first examined by comparing its results independently against nine different eddy covariance-based flux tower observations collected over a range of rice paddy, forest, and grassland ecosystems. The results of error structures obtained using the TC method were then interpreted to understand the uncertainties and usage of each AET dataset under their observed dynamics. Moreover, we have also examined the spatio-temporal variations of TC error structures corresponding to land use land cover types in order to choose a suitable AET product for different land surface ecosystems in the region. Overall, the analysis of error characteristics in this study represents a significant step towards the evaluation of multiple global AET products under different land use conditions, which may serve as a baseline for suitable data assimilation insights.

2. Study area and datasets

2.1. Study area

This study was conducted within the extent of Asia (Fig. 1) the Wolrd's largest and most populous continent with a heterogeneous land cover and fragile ecosystem. It was considered that the selected study region would likely experience accelerated hydrological cycles due to the recent increase in temperature and global warming effects (Zohaib et al., 2017; Liaqat and Choi, 2015; Byun et al., 2014). Recent modeling endeavors indicate that such warming effects would be prominent in the Tibetan plateau of the Himalayan highlands and arid regions of Asia (Sivakumar and Stefanski, 2011). Moreover, we selected nine flux tower sites within the domain of the AsiaFlux regional research network based on dominant vegetation types (Fig. 1 and Table 1), including mixed forest sites [Xishuangbanna (BNS), Pasoh (PSO), and Seolma (SMC)], rice paddy regions [Cheongmi (CMC), Mase paddy (MSE), and