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Short communication

# Combining the ensemble mean and bias correction approaches to reduce the uncertainty in hillslope-scale soil moisture simulation

Kaihua Liao, Xiaoming Lai, Zhiwen Zhou, Qing Zhu*

*Key Laboratory of Watershed Geographic Sciences, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China*

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ABSTRACT

The ROSETTA model has routinely been applied to predict the soil hydraulic properties for simulating the water flow at the hillslope scale. However, the uncertainties in water flow simulations are substantial due to the soil heterogeneity and ROSETTA model structure. In order to reduce these uncertainties, this study used the HYDRUS-2D and ensemble mean to simulate soil moisture based on the outputs of all candidate models. In addition, the bias correction techniques (including linear bias correction (LBC) and cumulative distribution function (CDF) matching) were also applied to improve the prediction of soil moisture. A total of 320 days of observed soil moisture data at two depths (10 and 30 cm) in the upper and lower slope positions were adopted to evaluate the performances of different bias correction methods results showed that the uncertainty in hillslope-scale soil moisture simulation due to the ROSETTA model structure was more important than that due to the soil heterogeneity. The CDF matching-based nonlinear bias correction approach was generally better than the LBC in reducing the uncertainty in soil moisture simulation. Combining the ensemble mean and CDF matching was a viable approach to improve the accuracy of the numerical model for simulating the hillslope-scale soil moisture variations.



## 1. Introduction

Soil moisture is a major component of the hydrologic cycle, controlling processes of runoff, infiltration and evapotranspiration at the hillslope scale (Pachepsky et al., 2003). Numerical simulation has often been applied to predict hillslope soil moisture variations in previous studies (e.g., Hopp and McDonnell, 2009; Noh et al., 2015; Dusek and Vogel, 2016). Modeling of soil water flow requires soil hydraulic properties (e.g., water retention characteristics and saturated hydraulic conductivity) which are difficult to measure. Alternatively, these parameters are often estimated from more easily measurable basic soil properties (e.g., texture and bulk density) using pedotransfer functions (PTFs) (Saxton et al., 1986). The most commonly used PTF is the ROSETTA model, which is developed by neural networks (Schaap et al., 1998). Although the ROSETTA has obvious advantages, uncertainties associated with the ROSETTA-estimated parameters and their effects on modeling results are substantial due to the soil heterogeneity and ROSETTA model structure (Deng et al., 2009; Chirico et al., 2010). In order to reduce these uncertainties, the combination of the ensemble mean and bias correction approaches has often been applied in previous studies (Liu et al., 2011; Cichota et al., 2013; Liao et al., 2014; Lee and Im, 2015).

The ensemble technique is based on a combination of the outputs of all candidate models using simple average method. However, the ensemble mean method was highly inaccurate due to the systematic model biases (Guber et al., 2009). Linear bias correction (LBC) is a simple method that provides a proportional shifting effect to the ensemble forecasts and brings the mean and variability of the predicted values closer to that of the observations. Kharin and Zwiers (2002) applied the LBC in climate prediction. They found that the LBC can improve predictive skill and reduce the climate noise by ensemble averaging. Liao et al. (2015) observed that the LBC was a suitable approach for improving the accuracy and reliability of the ensemble PTFs. In addition, nonlinear bias correction (NBC) has also been developed for hydrological simulations. Matching with cumulative distribution functions (CDF) of the values of the ensemble mean and the observations is a classical NBC technique. Reichle and Koster (2004) have demonstrated that on a global scale, the bias between the satellite-based mean near-surface soil moisture contents and modeling results was reduced by 80% using the CDF matching technique. Jana et al. (2008) also found that the CDF matching had better performance than the LBC in predicting soil water content across different spatial extents. However, little research was conducted to compare different bias correction techniques in reducing the uncertainties associated with the ROSETTA-based parameter estimation for hillslope-scale soil moisture modeling (e.g., De Lannoy et al., 2007; Kumar et al., 2012).

* Corresponding author.
*E-mail address:* qzhu@niglas.ac.cn (Q. Zhu).

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Based on this background, a two-dimensional physically based model (HYDRUS-2D) was used to simulate soil moisture variations along a hillslope. Soil hydraulic properties were derived from soil texture and bulk density by using the ROSETTA. The uncertainties in the ROSETTA-estimated parameters due to the soil heterogeneity and ROSETTA model structure were quantified and compared. The ensemble mean and bias corrections techniques were then used to combine all possible model outputs. We particularly focus on the comparison of different bias corrections in improving soil moisture prediction.

## 2. Materials and methods

### 2.1. Experimental data

This study was conducted on a hillslope (31°21′N, 119°03′E) in the western hilly region of Taihu Lake Basin, China (Fig. 1). The green tea (*Camellia sinensis* (L.) *O. Kuntze*) is dominant on the hillslope. The elevation of the hillslope ranges between 79 and 85 m, while the slope angle ranges between 8% and 21%. The slope length is about 65 m. The soil type is shallow lithosols according to the World Reference Base for Soil Resources (FAO/ISRIC/ISSS, 1998). Soils are described as sandy silt loam and silt loam textures with silt content generally larger than 60% according to the USDA classification. The depth to bedrock is less than 0.6 m. The bedrock is sedimentary (sandstone) with high water permeability. A 50-cm deep soil profile was excavated in the upper (8 m away from slope crest) and lower (8 m away from the foot of slope) slope positions, respectively (Fig. 1). The dead leaves were removed from the soil surface. For each profile, the low cost soil moisture sensor EC-5 (Decagon Devices Inc., Pullman WA, USA) was installed horizontally at depths of 10 and 30 cm. At the same time, an automatic weather station was installed for recording rainfall and air temperature. The profile was carefully backfilled after all devices were installed. All measurements were collected every 5 min. Measurements started on 1 Jan. 2013 (Day 0). We used 600 d of data. The Hargreaves method (Hargreaves and Samni, 1985) was applied to compute the crop reference evapotranspiration ($ET_0$) based on daily air temperature. A total of 76 undisturbed soil samples were taken at depths of 10 and 30 cm. These sampling sites were distributed evenly over the hillslope, with a spatial resolution of about 8 m (Lv et al., 2016). The contents of sand (0.05–2 mm), silt (0.002–0.05 mm) and clay (0–0.002 mm) particles were obtained by the pipette method. Bulk density was determined by oven-drying soil samples at 105 °C for 24 h.

### 2.2. Hillslope soil water movement model

The HYDRUS-2D model (Šimůnek et al., 1999) was employed to simulate water flow in hillslope soils rather than bedrock. The two-dimensional Richards equation can be formulated as:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}(K\frac{\partial h}{\partial x}) + \frac{\partial}{\partial z}(K\frac{\partial h}{\partial z}) + \frac{\partial K}{\partial z} + S \quad (1)$$

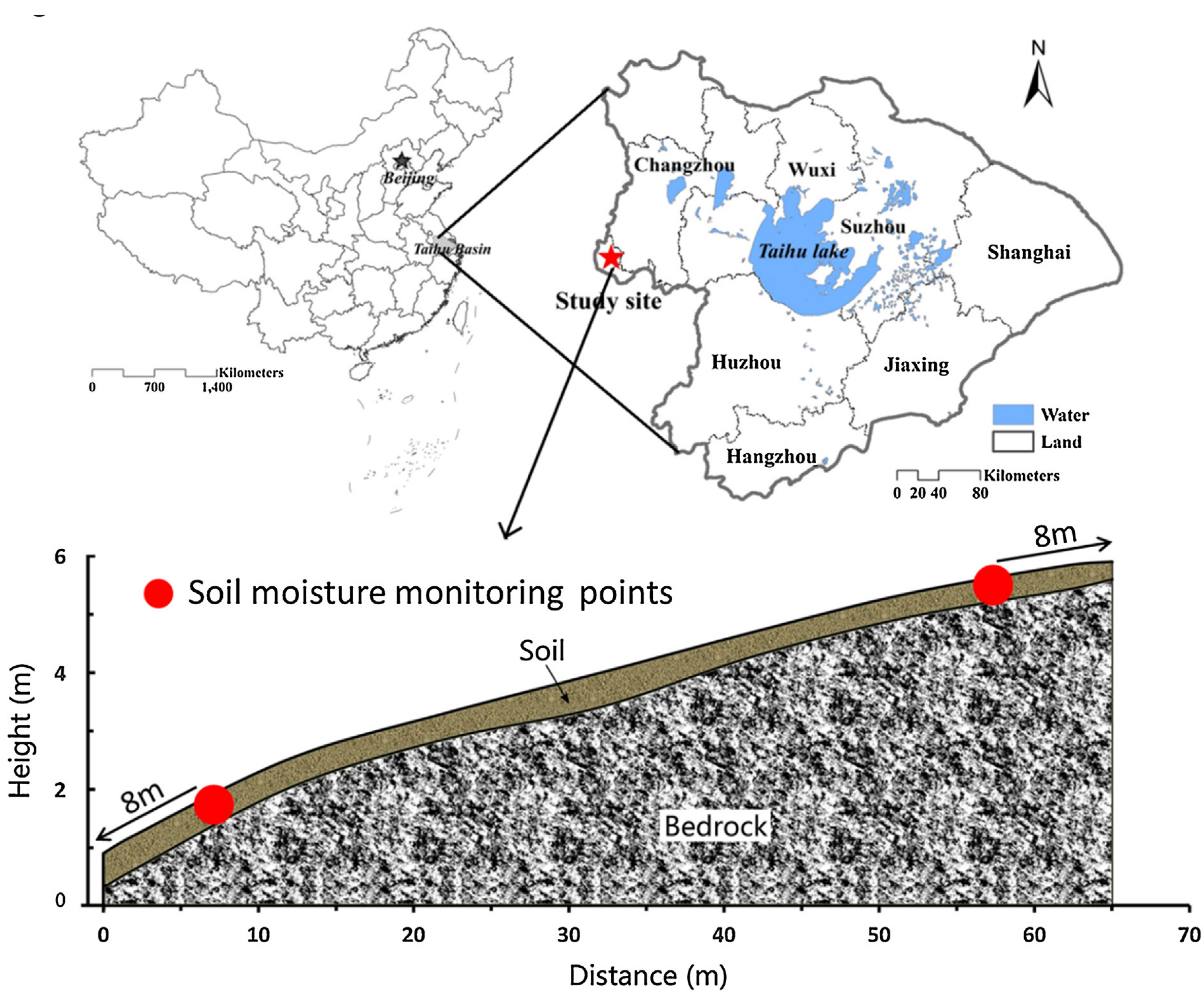


**Fig. 1.** Geographic location and topography of study hillslope. The type of bedrock is sedimentary rock.