Computers and Electronics in Agriculture 75 (2011) 278–287

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Soil moisture estimation from inverse modeling using multiple criteria functions

Sujittra Charoenhirunyingyos [a,*], Kiyoshi Honda [a], Daroonwan Kamthonkiat [b], Amor V.M. Ines [c]

[a] School of Engineering and Technology, Remote Sensing and Geographic Information Systems, Asian Institute of Technology, Bangkok, Thailand
[b] Department of Geography, Faculty of Liberal Arts, Thammasat University, Bangkok, Thailand
[c] International Research Institute for Climate and Society, The Earth Institute at Columbia University, Palisades, NY, USA

ARTICLE INFO

Article history:
Received 9 April 2010
Received in revised form 3 December 2010
Accepted 7 December 2010

Keywords:
Soil moisture
Soil hydraulic parameters
Inverse modeling
Remote sensing
Optimization

ABSTRACT

Soil hydraulic parameters are essential inputs to agricultural and hydrologic models for simulating soil moisture. These parameters however are difficult to obtain especially when the application is aimed at the regional scale. Laboratory and field methods have been used for quantifying soil hydraulic parameters but they are proved to be laborious and expensive. An emerging alternative of estimating soil hydraulic parameters is soil moisture model inversion using remote sensing (RS) data. Although soil hydraulic parameters could not be derived directly from remote sensing, they could be quantified by the inverse modeling of RS data. In this study, we conducted a multi-criteria inverse modeling approach to estimate the rootzone soil hydraulic parameters in a rainfed rice field at depths 3, 12, 28 and 60 cm, respectively. The conditioning data used in the inverse modeling are leaf area index (LAI) and actual evapotranspiration (ET_a) from satellite imageries, and soil moisture (SM) data from in situ measurements. The performances of all the model inversion experiments were evaluated against observed soil moisture in the field, and measured LAI during the growing season. The results showed that using remotely sensed LAI and ET_a in the inverse modeling provided a good matching between observed and simulated soil moisture down to 28 cm depth from the soil surface. With the addition of soil moisture information from the site, the model inversion significantly improved the soil moisture simulation up to a depth of 60 cm.

1. Introduction

Accurate knowledge of the state of soil moisture (spatial and temporal) is essential for a wide range of applications in agriculture and water management. Rootzone soil moisture can be used as an index in early warning systems (for flood or drought), and in the prediction of crop yields. But despite this importance, rootzone soil moisture is not always available for immediate applications in the field. Recent advances in remote sensing (microwave) allowed the measurements of soil moisture at a few centimeters from the soil surface (Jackson et al., 1995; Njoku et al., 2003). Although microwave remote sensing overcomes the interference of clouds, the resulting soil moisture data are still at low spatial resolution (25–60 km) and particularly limiting when applied in areas with high surface roughness and lush vegetations (Srivastava et al., 2003). To improve the utility of such soil moisture data, they have to be downscaled at the appropriate resolution and translated into soil moisture at deeper depths.

An emerging approach to estimate rootzone soil moisture is by integrating moderate to higher resolution remote sensing data e.g., vegetation indices with a Soil–Vegetation–Atmosphere–Transfer (SVAT) model using inverse modeling (e.g., Ines et al., 2006; Olioso et al., 2005). Soil moisture models require input parameters that describe vegetation and soil properties for simulating soil moisture, and inverse modeling can be used to incorporate measured data (remotely sensed or in situ) into the dynamic model to estimate these input parameters, e.g., soil hydraulic parameters, which in turn be used to simulate rootzone soil moisture in forward modeling.

A number of studies have been made to estimate soil parameters using remote sensing to simulate soil moisture (Ragab, 1995; Walker et al., 2001a,b). Several studies optimized soil parameters using soil moisture and soil temperature information (Enthekabi et al., 1994; Gupta et al., 1999; Hogue et al., 2005; Liu et al., 2005). Feddes et al. (1993a,b) used evapotranspiration (ET) and surface soil moisture to derive effective soil hydraulic parameters of the rootzone in a hypothetical watershed. Jhorar et al. (2002, 2004) also used evapotranspiration to inversely identify effective soil hydraulic parameters in a hypothetical soil profile. Ines and Mohanty (2008) used near-surface soil moisture from field measurements for quantifying effective soil hydraulic parameters of the rootzone. It is evident that information contents from soil moisture and evapotranspiration can be exploited to infer on soil hydraulic properties indirectly.

In this study, we conducted an inverse modeling experiments to estimate soil hydraulic parameters in a rainfed rice field in Ubon

* Corresponding author.
E-mail address: sujittra_geo@hotmail.com (S. Charoenhirunyingyos).

0168-1699/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.compag.2010.12.004

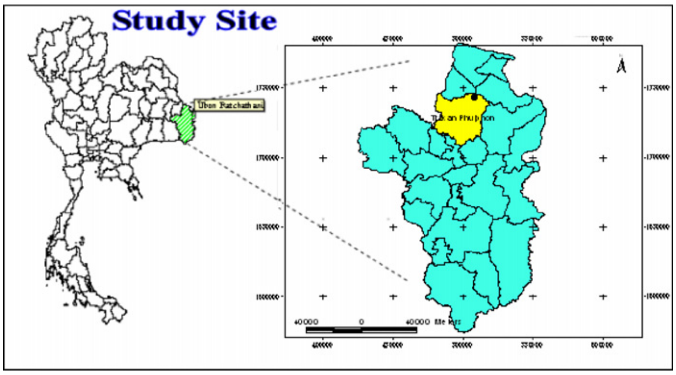

Fig. 1. Study site in Trakan Phutphon district, Ubon Ratchathani Province, Thailand.

Ratchathani, Thailand using remotely sensed data, actual evapotranspiration (ET_a) and leaf are index (LAI), and observed soil moisture (SM) in the field employing a multi-objective optimization.

2. Materials and methods

2.1. Study area and instrumentation

The study site is located in Trakan Phutphon District (15°42′22″N 105°00′21″E) in the upper part of Ubon Ratchathani Province in Northeastern Thailand (Fig. 1). Most of the farmers in the study site grow rice at one cropping per year because their rice fields are mostly rainfed. The cropping cycle starts at the beginning of the rainy season from late April to late May. One month later, rice seedlings are transplanted in the flooded fields at around late June. Rice from the paddy fields is usually harvested after the rainy season around late October to mid November.

A near real-time weather and flux observation station (Fig. 2) was set up in the paddy field with the support of the Thailand Research Fund (TRF). Data were collected from the station during the whole cropping season starting from the dry season in March 2007, when the field was bare and sparsely covered with grass. The harvesting period in the study area is around mid-November. After the rice growing season, the farmers let their fields fallow until rains start again from late May to June. The instruments used at the meteorological stations are shown in Fig. 2.

The sensors comprise of Davis General Weather Station (symbol 1) installed at 2 m above ground for recording temperature, humidity, rainfall, wind speed and solar radiation, and two Bowen ratio instruments (symbol 2) mounted at heights of 2 and 10 m. These Bowen instruments measure temperature and vapor pressure variations at 2 and 10 m above ground necessary to calculate the actual evapotranspiration (ET_a). The data from the different sensors are stored in a database, which can be accessed remotely through the Internet using a satellite link (receiver) installed in the site (symbol 3). The Internet service was provided by IPStar. Other sensors in the station include a Net Radiometer (symbol 4) set up at 2.5 m above ground for recording net radiation. Apart from the Davis instruments, there are other sets of wind speed sensors and rain counters (symbol 5) installed at 2 m and 10 m heights. The Sensor Control box that controls the whole system consists of a Linux Box (computer server) and Data Acquisition System (DAQs) from National Instruments (NI) set up to record the data (symbol 6). Underground soil moisture sensors have also been installed at 3, 12, 28 and 60 cm soil (symbol 7), these sensors measure the dielectric constant or permittivity by finding the rate of change of voltage in the soil, which can be translated to volumetric soil moisture contents.

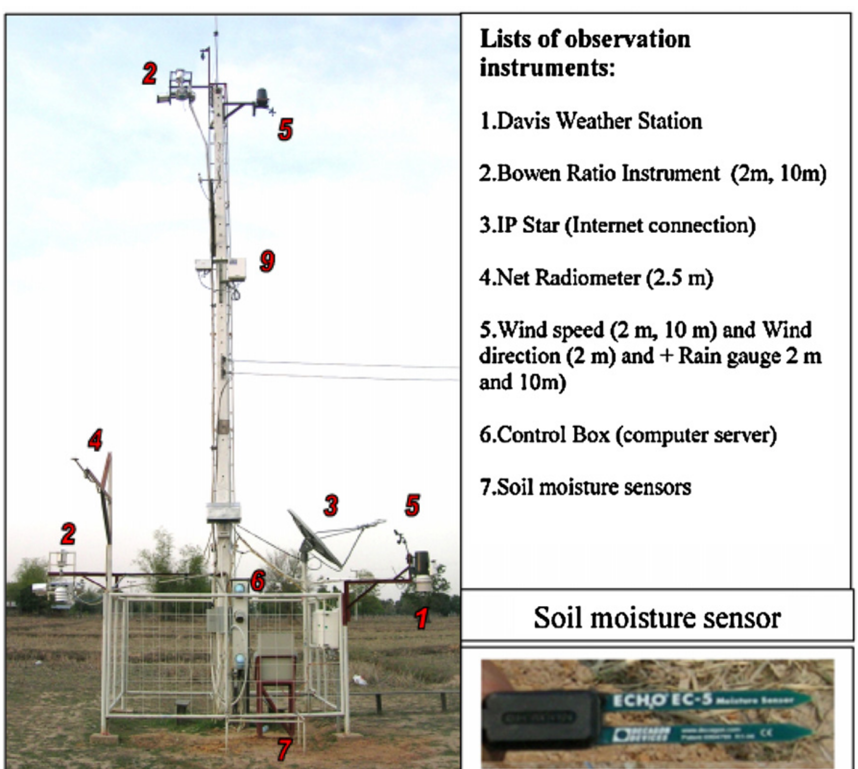

Fig. 2. Observation system.