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A comparison of two downscaling procedures to increase the spatial resolution of mapping actual evapotranspiration

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ABSTRACT

This research addressed the effects of downscaling cokriging Land Surface Temperature (LST) on estimation of Actual Evapotranspiration (AET) from remote sensing images. Two procedures were followed. We first applied downscaling cokriging to a coarse resolution LST product of MODIS at 1000 m. With its outcome, daily AET of a medium spatial resolution (250 m) was obtained using the Surface Energy Balance System (SEBS). Second, we downscaled a coarse AET map to medium spatial resolution (250 m). For both procedures, the 250 m resolution MODIS NDVI product was used as a co-variable. Validation was carried out using Landsat 8 images, from which LST was derived from the thermal bands. The two procedures were applied to an agricultural area with a traditional irrigation network in Iran. We obtained an average LST value of 305.8 K as compared to a downscaled LST value of 307.0 K. Reference AET estimated with SEBS using Landsat 8 data was equal to 5.756 mm day^{-1}, as compared with a downscaled AET value of 5.571 mm day^{-1}. The RMSE between reference AET and downscaled AET was equal to 1.26 mm day^{-1} ($r = 0.49$) and between reference and downscaled LST to 3.67 K ($r = 0.48$). The study showed that AET values obtained with the two downscaling procedures were similar to each other, but that AET showed a higher spatial variability if obtained with downscaled LST. We concluded that LST had a large effect on producing AET maps from Remote Sensing (RS) images, and that downscaling cokriging was helpful to provide daily AET maps at medium spatial resolution.

1. Introduction

Precision irrigation as a component of Precision Agriculture (PA) aims at supporting decision makers and farm managers with suggestions and recommendations to meet Crop Water Requirement (CWR) and hence to improve water productivity. It provides a management strategy from multiple sources to optimize crop production, dealing with variation at diverse levels of detail (Pierce and Nowak, 1999). Irrigation Water Requirement (IWR) is particularly challenging if water scarcity prevails. Efficient use of water is needed to provide optimal yields and contribute positively to issues of water scarcity and food security. Use of Remote Sensing (RS) technology in irrigation management applications provides an opportunity for farmers and decision makers to manage their farms by maximizing the cost-benefit ratio in terms of field variation as compared to traditional techniques (Brisco et al., 2014). RS technology acquires data from physical processes that are taking place on the Earth in a variety of types, and at various spatio-temporal resolutions. Satellite products are commonly divided into coarse (low), medium and fine (high) spatial resolution images. Many coarse and medium spatial resolution images of a high temporal resolution are publicly available and accessible to potential users, whereas high spatial resolution images have a too low temporal resolution or are only commercially available. In addition, such images commonly miss several of the required spectral bands, e.g. the middle infrared and thermal bands, thus limiting their applicability in modeling of natural processes like EvapoTranspiration (ET). PA requires detailed information on processes that are taking place on small segments of individual farms, hence requiring high spatial resolution products. In short, high spatial and temporal resolution images are required to provide ET maps that are useful for CWR and IWR to support irrigation management (Ha et al., 2012a) at the farm level.

Producing daily ET maps of a high spatial resolution has been a challenge as only coarse resolution thermal bands from satellite sensors are operationally available at the required temporal resolution (Ha et al., 2012b). Downscaling methods are potentially useful

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to increase the spatial resolution of ET maps and thermal bands of various satellite sensors.

Obtaining ET information is a key component in estimating the water balance in soil, vegetation and surface energy (Yang et al., 2006). It simultaneously comprises water evaporation by means of land and water surfaces and transpiration from vegetation (Gowda et al., 2007); (Allen et al., 1998). Two types of ET are distinguished: AET is the actual elimination of water from the vegetated area and the soil and potential ET (PET) is the capability of the atmosphere to remove water from the surface as consequence of evaporation and transpiration process if crop is severe water shortage.

Several methods exist to estimate ET. First, ET can be measured within the field. To do so, field measurements can be used in the eddy covariance technique (EC), the Bowen ratio-energy balance (BREB), or soil water balance techniques, such as surface renewal (SR) or lysimeter methods (Ha et al., 2012a). Second, ET can be spatially estimated by means of the surface energy balance, which combines information from different sources, such as RS images, ground meteorological data. This study considers ET as a spatial variable and hence it is important to know its spatial distribution at diverse spatial scales. The distribution is likely to also change in time. Field-based techniques are based upon point-based measurements and hence can only partly provide this distribution for a large area. RS-based ET models estimate ET from the field scale to the regional scale (Gowda et al., 2007) at different spatial and temporal resolutions. In this context, several models have been developed such as METRIC (Allen et al., 2007; Gowda et al., 2007), the Surface Energy Balance Algorithm for Land (SEBAL); (Bastiaanssen, 2000), the Simplified Surface energy Balance (SSEBS) (Senay et al., 2007), and the Surface Energy Balance System (SEBS) (Su, 2002). All these models require data from the thermal bands of satellite sensors. Daily ET maps estimated from available and accessible RS data are too coarse to be used in precision farm management, as the pixel sizes are commonly too large to well present spatial variability within individual fields, thus causing substantial errors (Braswell et al., 2003). Such errors are therefore caused by pixels that have diverse land cover and various vegetation types, roughness conditions and soil moisture contents (Kustas, 2004). Clearly, there is a gap between available and needed spatial and temporal scales (Wu and Li, 2009) for optimal water allocation in an irrigation network. Recently, high spatial resolution images provide a tool to identify more accurate detail and variation in space, whereas high temporal resolution images help us to understand variation of ET across time at different field scales.

In geostatistics, scale is equivalent to the support size, and scale transfer means change of support. Support for RS images is equivalent to the pixel footprint. Support is the largest area for the property of interest that does not include its variation. Downscaling decreases the support size of the pixel area, thus increasing the spatial resolution of an image (Tang et al., 2015); this is also called disaggregation. Disaggregation methods are classified into two groups, traditional scale-based downscaling methods and image fusion methods (Ha et al., 2012a), both aiming to enhance spectral properties and spatial resolution of images. Downscaling methods convert a coarse spatial resolution image to a finer spatial resolution image using geostatistical models. They preserve the radiometric properties of the image. Image fusion, in contrast, uses two or more images (Aiazzi et al., 2002) to obtain both high spatial and spectral resolution images at the same time (Ha et al., 2012b). Early examples are downscaling the Landsat 7 thermal band using NDVI as a co-variable (Rodriguez-Galiano et al., 2012), and integrating super resolution mapping for ET estimation at the field scale using image fusion (Mahour et al., 2015). The basis for downscaling LST, however, is the inverse relationship between LST and NDVI as has been studied well in literature (e.g. Kustas et al., 2003). In this research geostatistical downscaling is used to increase the spatial resolution thermal band of RS images for PA purposes. Moreover, the SEBS model is used to estimate AET using satellite image data and weather information.

The objective of this research was to study the effect of downscaling LST using cokriging on estimation of AET applying SEBS. Medium resolution daily AET maps were generated to quantify the uncertainties encountered during downscaling.

2. Study area and data

Iran is a water scarce country with limited rainfall in a semi-arid region, being a relatively dry country with limited water resources. The study area is a part of an irrigation network located in a semi-arid region in the Qazvin province, in the North of Iran. Qazvin is near Tehran and suffers from water shortage in the agricultural sector. The Qazvin irrigation network contains two main lateral canals (L1 and L2) and is one of the oldest and most advanced systems in the country. The study area and its related network are used as a pilot area for this study. The irrigation network is located between 36°01′05″ to 36°13′09″N and 50°14′34″ to 50°29′31″E (Fig. 1), near the city of Qazvin and covers an area of approximately 400 km^2. The network structures and methods to determine CWR are old, causing substantial water loss, low water efficiency and poor crop productivity.

The irrigated area consists of fallow farms and a wide diversity of crop types such as wheat, corn, barley, canola, potato, sugar beet, lentil, pea, bean, tomato, orchard and grape garden (vineyard). The irrigation network is defined from the smallest level e.g., the field, to the largest level, e.g. the whole area. A field (parcel) is the unit with a single crop type, and each farm includes one or more fields. Fig. 1 illustrates the irrigation network with the canals L1 and L2 and the gates at the delivery points of water from the water utility system. Each gate supplies water to several farms, e.g. each farm is irrigated via a single gate.

2.1. Remote sensing imagery

The Moderate-resolution Imaging Spectroradiometer (MODIS) is an RS instrument installed in two Terra and Aqua satellites. It captures data at diverse spatial resolutions from 250 m to 1000 m for different bands. MODIS with two satellites is able to provide data every one or two days. In addition, it has several derived products such as the Land Surface Temperature (LST) and the Normalized Difference Vegetation Index (NDVI) to be used in this study. The more recent Landsat Data Continuity Mission (LDCM) has a sensor of a finer spatial resolution sensor in the thermal channels. Landsat 8 provides multispectral sensor images at 30 m spatial resolution, panchromatic sensor image at 15 m spatial resolution and two thermal channels of 30 m spatial resolution. Image data from Landsat 8 are available every 16 days.

In this study, three RS images were acquired: an LST (MOD11A2) and an NDVI (MOD13Q1) MODIS product, and a Landsat 8 satellite image (Fig. 2). The daily LST product has a 1000 m spatial resolution and the 16 days NDVI product has a 250 m spatial resolution. The LST product was collected on June 6, 2014 whereas the NDVI product was taken on June 10, 2014. The period covered by the NDVI product included the date of the LST product. The Landsat 8 image was taken on June 6, 2014 at 7:13 AM (GMT).

2.2. Meteorological data

Major input for the SEBS model are the local weather data that were available from the local Qazvin weather station on June 6,