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Evaluation of Landsat and MODIS imagery fusion for high-resolution evapotranspiration mapping over large agricultural area

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ABSTRACT

Regarding to severe droughts and increasing shortages in water resources, in particular in the Middle East, evapotranspiration estimation is essential for irrigation management in agricultural lands. Evapotranspiration mapping is currently possible in a suitable spatial resolution from Landsat imagery; however, these data do not allow to obtain an optimal temporal resolution, required in agriculture management. In other hand, Modis imagery provide a dense temporal resolution, with however a deficiency in spatial resolution. In this study, we evaluated the fusion of 16-dayily Landsat and daily Modis imageries in order to obtain a sufficient spatio-temporal resolution for evapotranspiration mapping required in water management over agricultural areas. The image fusion is applied on the six-month Landsat and Modis images over large sugarcane farms in south-western Iran. The Spatial and Temporal Adaptive Reflectance Fusion Model (STARFM) are applied on the images. The evapotranspiration estimations are based on two algorithms: SEBAL and METRIC. The point extracted results are highly consistent with the evapotranspiration product from Modis in terms of temporal resolution. As well as, the Kappa index indicates on an acceptable accuracy in spatial resolution of estimations. Due to the smoothness of the region, no significant differences between SEBAL and METRIC estimations are resulted.

1. Introduction

Since the last half-century, remote sensing facilities have provided effective capabilities in evapotranspiration estimation and mapping over agricultural areas. The evapotranspiration estimations is required irrigation management particularly during the crop growing season. Different methods are developed to estimate reference and actual evapotranspiration, which are demonstrated in several research and applications.

Evapotranspiration is a principal contribution of energy and water balances. It is one of the most complex components of hydrological balance.

Field measuring of evapotranspiration is costly and time consuming., and thus, limited to local scales. However, satellite data has made possible estimating evapotranspiration in large-scale fields without requiring the calculation of complex hydrologic processes.

Although high temporal resolution instruments, such as Moderate Resolution Imaging Spectroradiometer (MODIS) and the Advanced Very High-Resolution Radiometer (AVHRR) sensors, provide temporally dense data, the coarse spatial resolution of these sensors make them inefficient to quantify evapotranspiration of vegetation covers at fine scales.

Over the past two decades, the most well-known algorithms that have been considered in this regard are Surface Energy Equilibrium Algorithms (SEBAL) and Mapping Evapotranspiration at high Resolution with Internalized Calibration (METRIC). These models are based on energy balance and spatial distribution of energy.

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2. Material

2.1. Study area

Iran, is a predominantly warm and dry country, where about 93 percent of renewable water is consumed by agricultural activities. This issue eventually led to the severe loss of underground water in most of plains in country, particularly in the south. Sugarcane farms in Khuzestan province (Figure 1) include large areas locateing around rivers of 'previously' large discharges. In the result of severe decrease in rivers discharges in recent years, irrigation of sugarcane farms become more and more challengus.

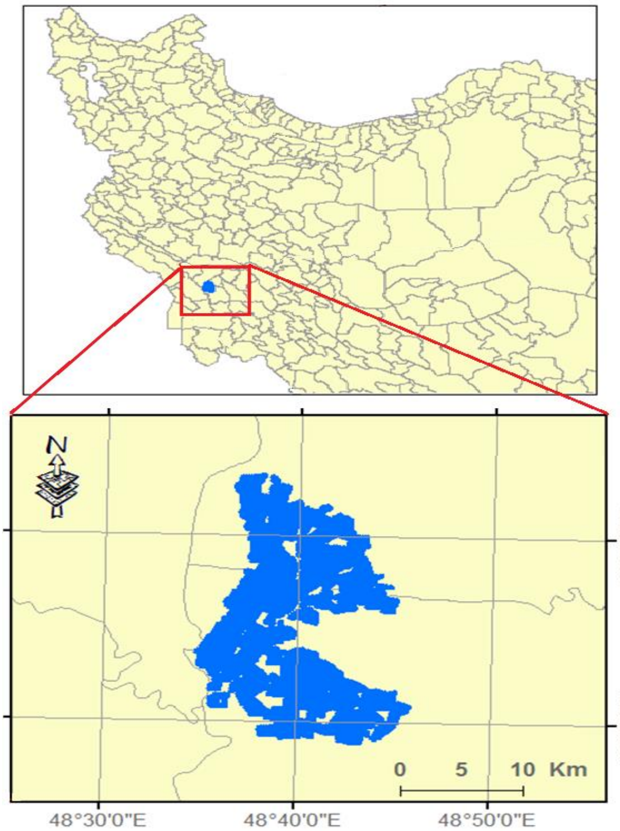

Figure 1. The study area

2.2. Data

The reflectance and thermal bands of MODIS/Terra at 500 meters resolution are obtained from lpdaac (USGS).

11 Landsat-8 images, dated from the late 2019 to the middle of 2020, are obtained from Alaska Satellite Facility (ASF) data center. A set of postprocessing are applied to mask cloud, cloud shadow, snow and outliers. Beside the imagery, subsidiary dare needed to calculate evapotranspiration include: digital elevation model and land cover map.

The MODIS/Terra Net Evapotranspiration 8-Day L4 Global 500 m SIN Grid (Mod16A2 v006), which is the global evapotranspiration product from Modis, is used as an evaluation source. The MOD16A2 Version 6 Evapotranspiration product include 8-day composites, at 500-meter resolution. This data is based on the Penman-Monteith method. The inputs include vegetation property dynamics, albedo, and land cover derived from Modis bands, along with daily meteorological reanalysis data.

3. Method

Two kinds of processing applied on the data: 1) time series of synthesis images are generated from the specified Modis and Landsat images; then, 2) evapotranspiration are estimated for the three set of images.

3.1. Image fusion

In this study we employed the Spatial and Temporal Adaptive Reflectance Fusion Model (STARFM) to fuse two image series ordered based on time intervals. This methos functions based on Euclidean distance of spectral and temporal similarities between the reference and target pixel.

After proposing in 2006 by Gao et al., the STARFM algorithm is latterly developed and optimized by researchers; The STAARCH (The Spatial Temporal Adaptive Algorithm for mapping Reflectance Change) algorithm, for example, is also based on the STARFM algorithm. STARFM generates synthetic Landsat-like images from a spatially weighted difference of one reference Landsat- MODIS pair, and one (or more) MODIS scene(s) to be downscaled. The outliers are minimized using a moving averaged window.

3.2. Evapotranspiration estimation

The three main components for calculating evapotranspiration include: 1- soil heat flux, 2 - tangible heat flux, and, 3 - net radiation reached to the surface. Estimating the three components, the latent heat flux is obtained. The latent heat is amount of energy that is spent in evapotranspiration. Therefore, evapotranspiration is the equivalent height of water associated to the latent heat.

By subtracting the tangible and soil heat flux from net radiation flux, the latent heat, and thus, actual evapotranspiration is estimated for each pixel of the image at the instant of the satellite passage. Hourly evapotranspiration values are converted to daily evapotranspiration by considering the average daily net radiation.

METRIC differs with SEBAL method in employing reference in-situ measurements. In METRIC algorithm based on the area to be studied at least one high quality climatological station is required to calculate the reference ET. Climatological data for the exact time of satellite image acquisitions are obtained from the Ahwaz synaptic station, locating at 40 km distant form the study area.

4. Results

The main characteristics of the estimated evapotranspiration from synthetic images include: 1- For the corresponding pixels, the amplitudes stand between the values of Landsat and Modis images, with an approximated distance of 60% and 40% relative to Modis and Landsat respectively. 2- The best results belong to the inner areas of large parcels, far from the margins. A median filter would improve the accuracy of synthetic derived maps. And, 3- Generally, the similarity of estimations is higher in the areas of higher evapotranspiration than area of small evapotranspiration.

Generated evapotranspiration maps for three dates (12 January 2020; 29 January 2020 and 3 March 2020) are shown in Fig.1. Accordingly, the RMS between the synthetic derived estimations, and, both Landsat derived evapotranspirations and Modis evapotranspirations product (Mod16) are shown in Table 1. The RMSs with Mod16 are considerably lower than those with Landsat. It should be referred to the time smoothing of Mod16; which are composites over 8 days. Difference of results from SEBAL and METRIC algorithms are estimated between 4 and 6.2 percent. The small difference is because the area is flat, and is thus expected to be homogenous in terms of land surface temperatures. For the same reason the METRIC calculations are based on only one climatologic station.

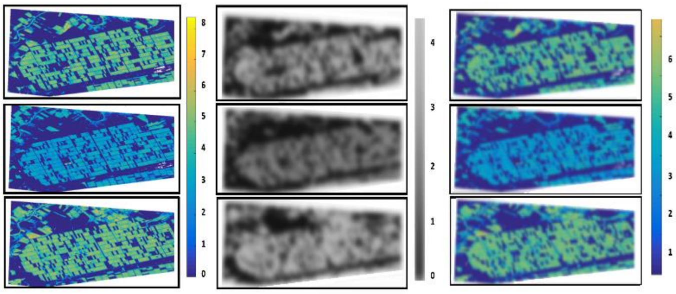

Figure 2. Estimated evapotranspiration from Landsat 8 (right column), from Modis (middle column), and from synthetic blended imaged (left column).

Table 1. The RMS between estimation from synthetic and Landsat images

Date	RMS (with Landsat)	RMS (with Mod16)	Difference % (Seb. & Met.)
Jan. 12	2.2	1.8	4
Jan. 29	2.7	2.2	6.2
Mar. 3	1.7	0.8	4.4

5. Conclusion

Fusion of high spatial resolution images such as Landsat with temporally dense images (as Modis) would allow to combine their strengths, and resolve their shortcomings. In the contest of increasing requirement to frequently and precisely estimating of evapotranspiration in arid and semiarid countries, such studies may play a vital role in water and agriculture managements in the national levels. Furthermore, the results are promising in order to assists developing precision agriculture. Evapotranspiration derived from blended images tend to be smoother than actual estimations; This should be due to averaging over large areas. Nevertheless, in vast homogenous vegetation cover such as large farms of single crops (e.g., sugarcane farms studied in the present study), the fusion method performs well enough. This method would also be effective in areas of frequent cloudy sky.

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