ET Estimation of Agricultural Lands in Pietermaritzburg, South Africa using Satellite Images.

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Abstract

Evapotranspiration (*ET*) is one of the most important parameters in agricultural water management. The aim of this research is to estimate actual evapotranspiration using satellite imagery, by ET Index approach in Pietermaritzburg, South Africa, to monitor the agricultural water management in the area. Another aspect of this study is to test the performance and the applicability of the ET Index approach, as this is the first application of the approach closely to a southern hemisphere. NDVI and *ET* related information were derived using the combination of local weather data and the seven clear-sky Landsat 8 imagery for year 2015. The data availability of Landsat 8 implied some limitations of time-series monitoring of agricultural practice of this area in 2015, especially in summer season, due to the cloud availability. This problem might be avoided by more careful selection of study area. The derived preliminary *ET* estimation results reported in this paper seemed rational, and will be more carefully evaluated in future considering weather conditions and the land uses.

Keywords: Evapotranspiration, ET Index, ET Actual, NDVI, Surface Temperature, Satellite Image, Remote Sensing.

1. Introduction

This paper presents an ongoing progress in evapotranspiration (*ET*) estimation using Landsat satellite imagery, for Pietermaritzburg, KwaZulu-Natal, South Africa, using Evapotranspiration Index (ET_{index}) estimation approach which was recently developed by Tasumi et al. (2016a, b) for the Japan's Global Change Observation Mission (GCOM). Application of the algorithm to South Africa's agricultural region will be the first application of the algorithm closely to a southern hemisphere, and will provide valuable information of accuracy and applicability of the algorithm. The ET_{index} is defined as the actual evapotranspiration (ET_{act}) normalized by using a weather-based parameter referred to as "reference evapotranspiration" (ET_o), as shown in the following equation:

$$ET_{index} = \frac{ET_{act}}{ET_o} \tag{1}$$

where, ET_o is defined by the Food and Agricultural Organization of the United Nations (Allen et al., 1998), as the "*ET* from the hypothetical, adequately watered, extensive grass reference surface with crop height of 12 cm, surface resistance of 70 sm^{-1}, and an albedo of 0.23". ET_o is calculated using near-surface weather data (solar radiation, air temperature, humidity, and wind speed). The definition of ET_{index} given in equation 1 is equivalent to "crop coefficient", which is a popular term in irrigation water management. As shown in the equation 1, ET_{index} is convertible to ET_{act}, using ET_o.

ET_{index} is estimated primarily using satellite-observed surface temperature, assuming that a wet surface takes lower surface temperature than a dry surface, if other conditions are similar. The ET_{index} estimation equation is given in the following;

$$ET_{index} = C_{adj} \frac{T_s(dry) - T_s(act)}{T_s(dry) - T_s(wet)} \tag{2}$$

where, $T_s(act)$ is the instantaneous actual surface temperature from satellite thermal observation (°C), and $T_s(wet)$ and $T_s(dry)$ are the hypothetical wet surface temperature and the dry surface temperature (°C), which are the instantaneous surface temperature when the surface is expected to have zero sensible heat flux and zero latent heat flux, respectively. The constant C_{adj} is an adjustment factor employed in the algorithm. In the equation 2, $T_s(wet)$ and $T_s(dry)$ are the key to estimate ET_{index}. $T_s(wet)$ is estimated by solar radiation, and $T_s(dry)$ is estimated by solar radiation plus wind speed. See Tasumi et al. (2016a) for more details for the estimation algorithm,

The final goals of this research are, (1) to successfully provide a series of ET_{index} and ET_{act} images of Pietermaritzburg area for year 2015, and, (2) to use the information for analyzing and evaluating water resources management in agricultural fields around Pietermaritzburg. So far, we finished the initial processing of ET_{index} calculation for clear-sky Landsat images. Next step is to evaluate accuracy of the output, and then to interpolate data for in-between the clear-sky images.

2. Methodology

2-1. Study Area

Study area is Pietermaritzburg, KwaZulu-Natal province of South Africa, where is located around 29° 37' 0" South and 30° 23' 0" East. Since the area is located in southern hemisphere, the seasons are opposite to those in Japan - spring is from September to November, summer is from December to February, autumn is from March to May, and winter is from June to August. According to the ground survey and interviews conducted during November 2015, the major crop in this area is rain-fed sugar cane, cultivated twice a year. A typical cultivation schedule is that first (i.e. spring) cultivation starts around October and harvest by the end of December. The second (i.e. summer) cultivation starts January and harvest at around June. In year 2015, the harvest of spring cultivation had delayed due to water shortage during the cultivation season. Sugar cane plantation is conducted as monoculture and they typically keep planting sugar cane for several years using the same fields. Besides the sugar cane, some rain-fed or irrigated maize and wheat fields are also available. The dominant soil in this area is the mixture of silty and clay.

2-2. Data used and the method of analysis

There are two primary data involved in this research; local weather data of Pietermaritzburg, and Landsat 8 satellite images data. The local weather data was provided by World Meteorological Organization (WMO) via NOAA Satellite and Information Service. There was only one weather station around Pietermaritzburg found from the WMO database that contains data for year 2015. The 16-years historical weather data from year 2000 to 2015 was analyzed for understanding the recent climatic trend in this area, although only weather data for year 2015 were directly used with satellite image processing. The weather data includes air temperature, due point temperature, wind speed, and precipitation. Obtained raw weather data were quality checked, and data for lacking days were filled primarily by linear interpolation. ET_o was calculated using the weather data according Allen et al. (1998). Solar radiation data was not available, and the Hargreaves approach using daily maximum and minimum air temperature to estimate the impact of solar radiation was adopted for ET_o calculation according the recommendation of Allen et al. (1998).

Fig. 1 shows monthly mean air temperature in 2015. The hottest month was December (25 ^oC) and the coolest months was June and July (15 ^oC). Monthly precipitation record in year 2015 is shown in Fig. 2. The rainy season is in summer to early autumn during December to March. The annual precipitation in year 2015 was 536 mm. The calculated ET_o was the highest in December (5.5 mm/day in monthly average) and the lowest in June (1.8 mm/day in monthly average).

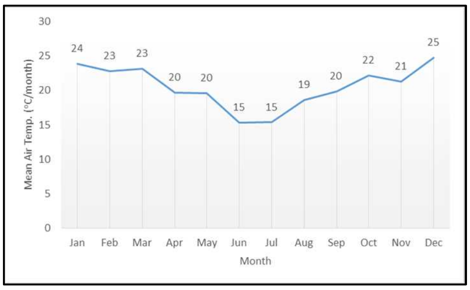


Fig. 1. Monthly Mean Air Temperature in 2015

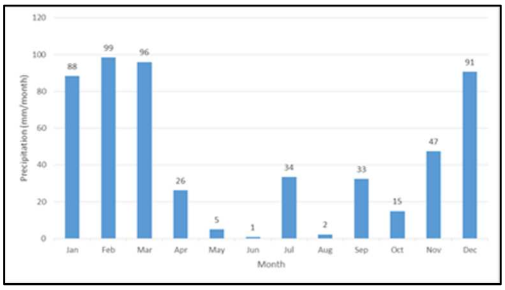


Fig. 2. Monthly Precipitation in 2015

In this study, crop growing status was evaluated by Normalized Difference Vegetation Index (NDVI) and the field water status was evaluated by ET_{index} and ET_{act}. In 2015, in total 22 Landsat 8 images (Path 168, Row 080-081) were available. The 22 images were composed by 9 cloud-free (i.e. cloud-cover less than 10%) images, 7 partial cloud-covered (i.e. cloud cover 10-50%) images, and 6 cloudy (i.e. cloud-cover more than 50%) images. ET_{index} and ET_{act} cannot be estimated for cloud-covered pixel, where surface temperature information is not available. The cloud-free image dates were; 3/10, 4/11, 5/13, 5/29, 7/16, 8/17, 10/4, 10/20, and 11/5. The partial-cloud image dates were; 1/5, 1/21, 6/14, 6/30, 9/2, 12/7, and 12/23. The cloudy image dates were; 2/6, 2/22, 3/26, 4/27, 9/18, and 11/21. Table 1 summarizes the image availability in year 2015. Unfortunately, no clear-sky image was found in summer in year 2015, which makes a good time-series observation of sugar cane cultivation difficult, although some agricultural fields can be kept observing in summer.

Table 1. Seasons in South Africa and the availability of Landsat 8 image in year 2015; ○ = cloud-free image; △= partial cloud-covered image; ×= cloudy image

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Summer		Autumn			Winter			Spring			Summer
△△	××	○×	○×	○○	△△	○	○	△×	○○	○×	△△

3. Results and Discussions

Calculated NDVI in April 11 and November 5, 2015 are shown in Figs. 3 and 4 respectively. Calculated ET_{index} for the respective image dates are shown in Figs. 5 and 6, and the *ET* are shown in Figs. 7 and 8. April 11 image indicates a good amount of vegetation over the wide area, having NDVI values around 0.5 to 0.7, and November 5 image shows much less vegetation. Distribution of ET_{index} agrees well with the distribution of the NDVI. ET_{index} is closely related to soil moisture (Tasumi and Kimura, 2013), so Figs. 5 and 6 indicates that April 11 was wetter than November 5. ET_{act} (Figs. 7 and 8) is the product of ET_{index} (relates to soil-water availability) and ET_o (relates to the energy availability to evaporate water plus aerodynamic vapor transfer condition). ET_{act} is small in April 11, although ET_{index} is relatively high, because of the small ET_o values in the mid-April. The results shown in Figs. 3 to 8 are intermediate results of calculation. In future, these results must be evaluated more carefully, by coupling with weather data and the land uses.

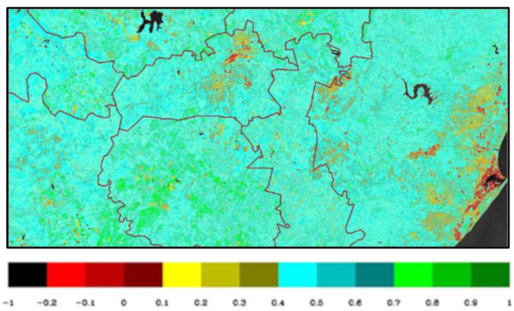


Fig. 3. NDVI April 11, 2015

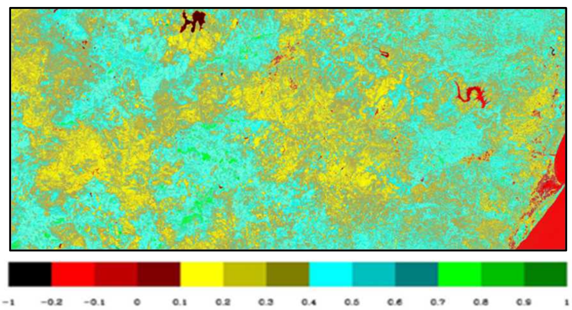


Fig. 4. NDVI Nov 5, 2015

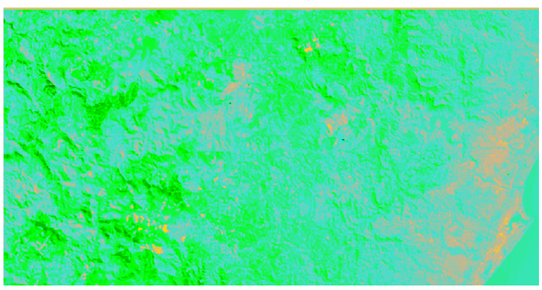
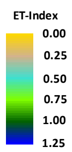


Fig. 5. ET Index April 11, 2015



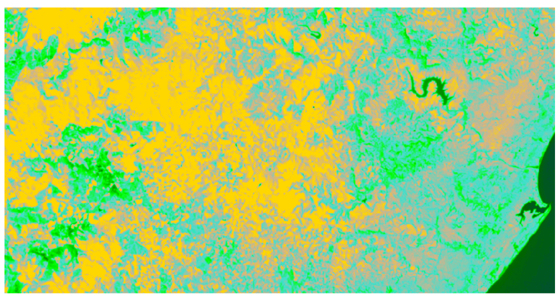


Fig. 6. ET Index Nov 5, 2015

Fig. 7. ET Actual April 11, 2015

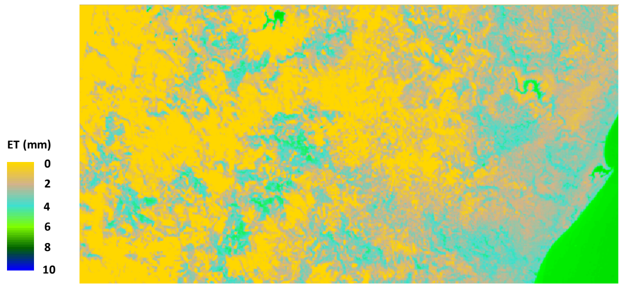


Fig. 8. ET Actual Nov 5, 2015

3. Conclusions

Weather data and Landsat 8 satellite data were collected and investigated to monitor the agricultural water management in Pietermaritzburg, South Africa. NDVI and *ET* related information have derived using the available satellite images. Weather data were successfully obtained. Data availability of Landsat image in 2015 was limited in summer, which prevents us from time-series observation of agricultural fields in summer time. Future investigation includes a more precise selection of study area where has less chance of clouds in summer, or, select study area from where the two Landsat passes overlaps. Preliminary evaluation of estimated results of ET_{index} and ET_{act} seem rational. The results will be more carefully evaluated in future, by coupling with weather data and the land uses, to derive valuable information regarding the performance of the *ET* estimation algorithm in an agricultural region in southern hemisphere.

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