Evapotranspiration estimation using remote sensing data

D. SINGH*, I. HERLIN, J. P. BERROIR, S. BOUZIDI and F. LAHOCHE

Institute National de Recherche en Informatique et Automatique,
Domaine de Voluceau, B.P., 105, Rocquencourt, 78153 Le Chesnay Cedex, France

e mail: dharmendrasing@yahoo.com

ABSTRACT. Evapotranspiration (ET) is a critical hydrological link between the earth surface and the atmosphere. It is therefore important point of issues involving many aspects of climate, climate change, and ecosystem response. It is well known that ET is the process responsible for the transfer of the moisture from soil and vegetated surface to the atmosphere. Changes in ET are likely to have large impacts on terrestrial vegetation. Since the distribution and abundance of plant communities are controlled to a large extent by the quantity and seasonality of moisture. If the changes in water balance are significant, major shifts in vegetative patterns and condition are a likely result of climate change. Equally changes in ET are likely to impact atmospheric composition of greenhouse gases, and climate, as the hydrological cycle increases in intensity with warming. Therefore, in this paper, it is attempted to estimate the ET over vegetative and bare field using National Oceanic and Atmospheric Administration (NOAA)/ Advanced Very High Resolution Radiometer (AVHRR) data at coarse spatial resolution of 1.1 km as a function of Normalized Difference Vegetation Index (NDVI) and with semi-empirical approach.  For this purpose, a model has been proposed to estimate the ET over vegetative and bare field. The dependence of ET on NDVI-Surface temperature has been checked by multiple regression analysis and quite good percentage of dependence of ET on NDVI-Surface temperature has been observed. This type of estimation will be helpful for climate modeler, climatologists, ecosystem modeler and regional planer.

Key words – Evapotranspiration, Surface temperature, Normalized difference vegetation index, Radiometer, Remote sensing.

1. Introduction

Apart from the precipitation the most significant component of the hydrologic and climatic budget is evapotranspiration (ET). ET varies regionally and seasonally; during a drought it varies according to weather and wind conditions. Because of these variabilities, water managers who are responsible for planning and adjudicating the distribution of water resources need to have a thorough understanding of the evapotranspiration process and knowledge about the spatial temporal rates of ET.

ET is a process where water evaporating from the ground and transpiration by the plants. It is also the way by which water vapor re-enters the atmosphere. It occurs when radiant energy from the sun heats water causing the water molecules become so active that same of them rise
into the atmosphere as vapor. Transpiration occurs when plants take water through the roots and release it through the leaves, a process that can clean water by removing contaminants and pollution. The seasonal trend of ET within given climate region follows the seasonal trend of solar radiation and air temperature. Minimum ET rates generally occur during the coldest month in the year and maximum rates, which generally coincide with the summer season, when water may be in short supply, also depend on the availability of soil moisture and plant moisture. ET is one of the most important climate parameter. It is also a key variable in the circulation of soil water balance, the detection of water stress or soil water availability. In fact, NDVI may be a useful indicator of soil moisture, it seems worthwhile to examine NDVI in relation to soil moisture availability. In fact, NDVI may be a useful indicator for ET. The paper is divided in five sections. In which section 2 presents the theoretical approach to estimate the ET using NOAA/AVHRR data. Section 3 describes the methodology and available data. The results and discussions are presented in section 4 followed by conclusions.

2. Theoretical approach to estimate the ET

2.1. Semi empirical approach

From the energy balance equation, the application of a single layer model to the convective heat exchange yields the following equation (Jackson et al., 1977)

\[ \text{ET}_a - R_{net}^* = \beta (T_{air} - T_{soil}) \alpha \]  

(1)

Where \( \text{ET}_a \) is the actual evapotranspiration expressed in millimeter per day of water, \( R_{net}^* = R_n / L \) is net radiation expressed in millimeter per day of water, \( L \) is the latent heat flux, \( (T_{air} - T_{soil}) \) is the temperature difference between air and crop surface, the daily values are denoted by subscripts “\( d \)”, \( \beta \) is the semi-empirical coefficients whose value is given by (Hurtado et al., 1995)

\[ \beta = \left( \frac{R_{net}}{R_{n}} \right) \frac{\rho C_p}{L(r_a + r_o)} \]  

(2)

where, \( \rho \) is the air density (kg m\(^{-3}\)), \( C_p \) is the specific heat of air at constant pressure (J kg\(^{-1}\) K\(^{-1}\)), and \( r_a \) and \( r_o \) are the aerodynamic and crop resistance respectively (sm\(^{-1}\)). The average value over the growing season of the crop is denoted by symbol \( \langle \text{ } \rangle \).

We can also use equation (1) in semi-empirical ways for computing the ET, as, (Jackson et al., 1977)

\[ \text{ET} = A + B (T_{surface} - T_{air}) \]  

(3)

Where, \( A \) and \( B \) are empirical coefficients, \( T_{surface} \) can be estimated from data given by satellite channels, and \( T_{air} \) can only be obtained with meteorological stations.

2.2. Land surface temperature by satellite data

At a coarse scale (1.1 km) land surface temperature (\( T_{surface} \)) is directly obtained from the NOAA/AVHRR thermal channels (channel 4 and 5) using split window method (Price, 1984)

\[ T_{surface} = T_4 + a^* (T_4 - T_5) + b \]  

(4)

Parameters \( a \) and \( b \) are adopted to the test site using field measurements collected in Mkomazi, South Africa (Lahoche et al., 2000)

\[ T_{surface} = T_4 - 5.23^* (T_4 - T_5) + 30.73 \]  

(5)

Equation (3) and (5) allow the computation of ET on NOAA acquisition area.
Nevertheless, due to the coarse resolution of this sensor (1.1 km), it is not possible to characterize ET behavior according to land cover. In fact, each pixel contains more than one land cover type. So, individual ET temporal profiles to the different land cover types, have to be computed.

This can be obtained by applying equation (3) for each date \( t \) and each land cover type \( j \)

\[
\text{ET}_j(t) = A + B \left[ (T_{\text{surface}})_j(t) - (T_{\text{air}})_j(t) \right]
\]

Where \( (T_{\text{surface}})_j(t) \) is the individual surface temperature for land cover \( j \) at date \( t \).

2.3. Estimation of ET by NDVI as modulating factor

To assess the ET over various land covers, we have proposed a model in which we used NDVI as modulating factor. The normalized difference vegetation index (NDVI) is defined as

\[
\text{NDVI} = \frac{R_2 - R_1}{R_2 + R_1}
\]

where \( R_1 \) and \( R_2 \) are the reflectance in channel 1 and 2 in NOAA/AVHRR.

To account for the fractional crop coverage contribution to total evapotranspiration \((\text{ET})_T\), NDVI may be used as modulating factor. When interpreting NDVI as a modulating parameter of the function vegetation cover, \((\text{ET})_v\), which is often regarded as simple additive measure

\[
(\text{ET})_T = (\text{NDVI}_n) (\text{ET})_v + (1 - \text{NDVI}_n) (\text{ET})_s
\]

where \( \text{NDVI}_n \) is the normalized NDVI

\[
\text{NDVI}_n = (\text{NDVI} - \text{NDVI}_{\text{soil}})/(\text{NDVI}_{\text{veg}} - \text{NDVI}_{\text{soil}})
\]

Here, NDVI is referred to the pixel for which \( (\text{ET})_T \) is computed.

If, we have more than one type of land cover in one pixel then, we can write eq. (8) as

\[
(\text{ET})_T = \sum_{i=1}^{N} (\text{NDVI}_n)_i (\text{ET})_i + \left[ 1 - \sum_{i=1}^{N} (\text{NDVI}_n)_i \right] (\text{ET})_s
\]

where \( i \) is the type of land cover and \( N \) is the number of type of land cover in one NOAA/AVHRR pixel. Using least square method, we have solved the eqn. (10) for neighboring pixels and get the values of ET over various land cover and soil.

2.4. Individual temporal profiles

For calculating the NDVI, we must know the individual profiles (i.e., reflectance in channel 1 and 2 for each land cover). So, in this section, we have to explain how to infer individual temporal profiles from NOAA/AVHRR acquisitions by modeling the information.
contained with in a pixel. On the small test area, the land
cover classification gives proportion \( \alpha_j \) of land cover \( j \)
within each NOAA pixel \( i \). For calculation of individual
reflectance of each land cover in one pixel, here, we
assumed a linear mixture model for reflectance in visible
(channel 1) and near infrared (channel 2) channel
(Bouzidi, 1998)

\[
R_k^i = \sum_{j=1}^{N} \alpha_{ij} R_j^k
\]  

(11)

Where, \( k \) is the number of channel (either 1 or 2), \( R_j \)
is the reflectance of NOAA pixel \( i \), \( R_j \) is the reflectance
of land cover \( j \), \( \alpha_{ij} \) is the proportion of land cover \( j \) in
the pixel \( i \), \( N \) is the number of land cover. On the same
learning area, knowing proportions \( \alpha_j \) is, the inversion of
the linear mixture model (eqn.11) gives individual
reflectance \( R_j^k \).

3. Methodology/Available data

The studied area is the Mkomazi river catchment
located in South Africa. The available data are (1) a daily
NOAA/AVHRR sequence of month March 1999 with 5
channels, (2) A supervised land cover classification
derived from Landsat TM data (Fl gel 1998). After a
preprocessing of the NOAA/AVHRR data and matching
of NOAA and Landsat data (Berroir et al., 1998), a test
area is chosen for which we have simultaneously both
(i.e., ground truth and satellite) data. The split window
algorithm (eqn. 4), ET semi empirical model eqn. (6) are
calibrated using field measurements (Jackson et al., 1977
and Price, 1984). The process described in the section 2.4
is applied and individual temporal profiles of temperature
and NDVI are obtained. Results of surface temperature
over bare soil, bush land, agricultural field and grassland
are represented in Fig. 1.

4. Results and discussion

Temporal profiles of evapotranspiration are
computed using semi empirical model eqn. (6) and NDVI
as modulating factor model eqn. (10) for month
March 1999 of the test area Mkomazi in South Africa.
The estimated ET over various land covers has been
shown in Fig. 2, using NDVI as modulating factor. In
these figures, we can easily discriminate the ET values
over different land cover. If, we compare the ET over
different land cover in the month March, 1999, than it is
observed that the variation in ET during March is 2.1 to 6
mm/day over the bare soil, 2.2-5.1 mm/day over the
grassland, 3.4-5.8 mm/day for agricultural field, 2-6.5
mm/day for bushland and 1.2-7 mm/day over the forest.
The maximum variation or dynamic range in ET is found
over the forestland cover in the March 1999. This will
help to predict that which type of land cover is maximum
affecting ET as well as to the climate in the particular
season or month.
The ET estimated over the various land covers that by semi empirical method is compared with the NDVI as modulating factor method. The results are shown in the [Figs. (3-5)]. It is observed that ET computed by the semi-empirical approach over the agricultural field over estimates the ET computed by NDVI as modulating factor, while we observed the reverse thing over the grass field and bare field.

A multiple regression analysis has been carried out for observing the dependence of ET on NDVI and surface temperature. We found a significant relationship among the ET, NDVI and surface temperature ($T_s$) for the Mkomazi area. The coefficient of determination and standard error of estimate over various areas is given in Table 1. However, difference in land cover over the test site has some effect on the relationship between ET and NDVI- $T_s$ (Table 1). In the Mkomazi area, we found that the percentage of dependence of ET on NDVI and grass surface temperature is higher in comparison to the other land cover ($r^2=0.64$) and standard error of estimate is also less in comparison to other land cover. Although, the dependence of ET on NDVI and surface temperature depends upon a various factor (i.e., green biomass of crop/grass, wind speed, etc). The maximum value of coefficient of determination over the grassland has been

| Land Cover    | $r^2$ | SE  |
|---------------|-------|-----|
| Bare soil     | 0.50  | 0.65|
| Grass         | 0.64  | 0.48|
| Bushland      | 0.58  | 0.56|
| Agricultural field | 0.62  | 0.52|
observed. It may be due to the fact that the grass was dense and greener in the month March 1999, in comparison to other land cover. This type of analysis helps us to know the effect of each land cover on the climate as well as for hydrological modeling.

5. Conclusions

We have estimated the ET by two methods. Despite the some differences among all estimation of ET. The NDVI as modulating factor approach seems to be a good approach for estimating ET over various land covers at regional scale. This approach may be an important tool for solving the gap between local and regional monitoring of climate. ET over the grass field is highly dependent on the NDVI and surface temperature of the grass in comparison to the other land cover. The results presented strengthen the possibility of developing the most needed operation product, ET to monitor the climate and water balance.

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