

SEBAL based regional-scale evapotranspiration estimation: A case study in the North China Plain

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ABSTRACT: The Surface Energy Balance Algorithm for Land (SEBAL) is applied in this paper to three Moderate-resolution Imaging Spectroradiometer (MODIS) scenes of 2004 and 2005 to assess the regional-scale evapotranspiration in the North China Plain. After a brief review of the SEBAL, the daily evapotranspiration over the North China Plain was analyzed, based on a preliminary comparison performed between the derived actual evapotranspiration and limited in-situ point measurement data. It was shown that the SEBAL is a convenient way to retrieve regional-scale evapotranspiration over a large area; however, due to the lower resolution images used, as well as the limited ground truth data in this study, result validation is not satisfactory. In this regard, a spatially well-distributed in-situ network of evapotranspiration or surface heat flux observations, as well as the high resolution images over study area, is needed for validate purpose in the future work.

1 INTRODUCTION

Evapotranspiration (ET) is one of the most significant components of water exchange over the land-atmosphere interface. Recently, remote sensing techniques for evapotranspiration estimation have developed rapidly. From satellite observation, it is possible to obtain consistent and frequent spectral reflectance and emittance radiation data of the land surface at a basin scale, so it is possible to estimate the regional evapotranspiration rate by combining remotely sensing data with solar radiation observation data based on a surface energy balance model. In the past decades, considerable efforts have been made in deriving appropriate models to counter this challenge (Norman et al., 1995; Bastiaanssen et al. 1998a,b; Su 2002). The Surface Energy Balance Algorithm for Land (SEBAL) was developed to parameterize the energy balance and surface fluxes based on spectral satellite measurements. After its establishment, a lot of field validations have been completed in different areas, especially in arid and semi-arid areas. In this paper, experiments were carried out in Hebei Plain over the winter of 2004 and spring of 2005 to compare the SEBAL based evapotranspiration with in-situ observations. The results are believed to be great importance, not merely in terms of estimating actual evapotranspiration, but also the ways in which the newly developed model can be used for other related purposes.

2 METHODOLOGY

The remote sensing based evapotranspiration estimation is based on the Conservation of Energy Principle. All the energy involved in the soil-vegetation-atmosphere interface comes from solar radiation, then expressed as several forms, which can be given as Energy Balance Equation (EBE),

$$R_n = G + H + LE \quad (1)$$

where R_n = net radiation; G = soil heat flux; H = sensible heat flux and LE = latent heat flux, which can be expressed as a height of water, i.e. evapotranspiration.

The R_n is estimated using basic radiation laws with shortwave incoming radiation, air temperature, relative humidity and remotely sensed surface albedo and emissivity as input, which can be formulated as,

$$R_n = (1 - \alpha)R_{swd} + \varepsilon \cdot R_{lwd} - \varepsilon \cdot \sigma \cdot T_0^4 \quad (2)$$

where α = albedo; R_{swd} = downward solar radiation; R_{lwd} = downward long wave radiation; ε = emissivity of the surface; σ = Stefan-Boltzmann constant; and T_0 = surface temperature.

In SEBAL, the soil heat flux G is empirically estimated using a function by Bastiaanssen based on

albedo, surface temperature and Normalized Difference Vegetation Index (NDVI):

$$\frac{G}{R_n} = \frac{(T_0 - 273.15)}{100\alpha} (0.32\alpha + 0.61\alpha^2)(1 - 0.98NDVI^4) \quad (3)$$

The sensible heat flux H is the flow of energy through air as a result of the temperature gradient,

$$H = \rho_a C_p \frac{T_0 - T_a}{r_{ah}} \quad (4)$$

where ρ_a = density of the moist air; C_p = air specific heat at constant pressure; and r_{ah} = aerodynamic resistance to heat transport between the reference and the surface. In SEBAL, the surface temperature difference is based on the extreme pixels of the images called dry pixel and wet pixel,

$$T_0 - T_a = dt = a + b \times T_0 \quad (5)$$

where “a” and “b” are constants and once they are determined for each and every pixel, “dt” is expressed using the surface temperature. The selection of wet pixel and dry pixel is done based on the temperature-albedo and the NDVI-albedo relationship in a particular image. After the selection of dry pixel and wet pixel, the constants “a” and “b” as well as the term “ r_{ah} ” are calculated by using sets of equations interactively.

After all these terms are determined, the ratio of latent energy to the available energy ($R_n - G$) is defined as the evaporative fraction (Λ):

$$\Lambda_{inst} = \frac{LE}{R_n - G} = \frac{R_n - G - H}{R_n - G} \quad (6)$$

Because the evaporative fraction remains (fairly) constant during daytime, and the daily average soil heat flux equals zero, the daily evapotranspiration (ET_{24}) is expressed as,

$$ET_{24} = \frac{\Lambda_{inst} \times R_{n,24}}{2.47} \quad (7)$$

where $R_{n,24}$ = daily net radiation, expressed in $\text{MJm}^{-2} \text{day}^{-1}$.

3 DATA AND STUDY AREA

3.1 Description of the study area

The study area, the North China Plain, is located in northeastern China between $114^{\circ}15'E$ – $117^{\circ}45'E$ and $36^{\circ}N$ – $39^{\circ}40'N$ (Figure 1). It is one of the largest agricultural areas in China and also one of the most densely populated regions in the world. Groundwater is one of the most important natural resources in this area, which provides drinking water to urban and

rural communities, supports irrigation, and maintains ecosystems. Agriculture is the largest consumer in this area and a total of about 79% of water pumped from the aquifers is used for irrigation (Wang et al., 2005). Due to traditional irrigation performance, a lot of water has been wasted. In this regard, a thorough understanding of water exchange over the land-atmosphere interface is needed to determine crop water use and to guide irrigation practices.

3.2 Description of satellite data

Three sets of Moderate-resolution Imaging Spectroradiometer (MODIS) products for the North China Plain have been used (Table 1). These include surface reflectance products MOD09 and surface temperature/emissivity products MOD11. All the necessary bio-physical parameters for SEBAL were derived from these visible bands and thermal bands products, including emissivity, albedo, and vegetation index (NDVI) as well as surface temperature.

3.3 Meteorological data

Standard meteorological observations required for SEBAL include wind speed, air temperature, surface pressure, humidity and radiation. The Chinese National Meteorological Center (NMC) operates several meteorological stations in the Hebei Plain collecting data on a daily basis. The dataset available from these stations include relative humidity, wind speed, air temperature at a 2 m height, actual vapour pressure and sunshine hours.

3.4 Lysimeter observations

The remotely sensed actual evapotranspiration is validated against ground truth ET observations derived from lysimeter observations, installed at the Luancheng Agro-Ecosystem Station (LAES) near Shijiazhuang. To keep the same plant densities and uniform plant growth inside and outside of the lysimeter, the same agronomic practices were carried out. Crops in the lysimeter were managed according to the local agricultural recommendations, and the irrigation methods were referenced to those used locally (Liu, & Wang, 1999).

4 RESULTS AND DISCUSSIONS

4.1 Comparison SEBAL results to field measurements

The weighing lysimeter installed in LAES has a surface area of 3 m^2 ($2 \text{ m} \times 1.5 \text{ m}$) and a depth of 2.5 m. Unfortunately, this field size is too small to be compared with the MODIS products pixel size, which is about 1 km^2 ($1000 \text{ m} \times 1000 \text{ m}$). Due to the high inten-

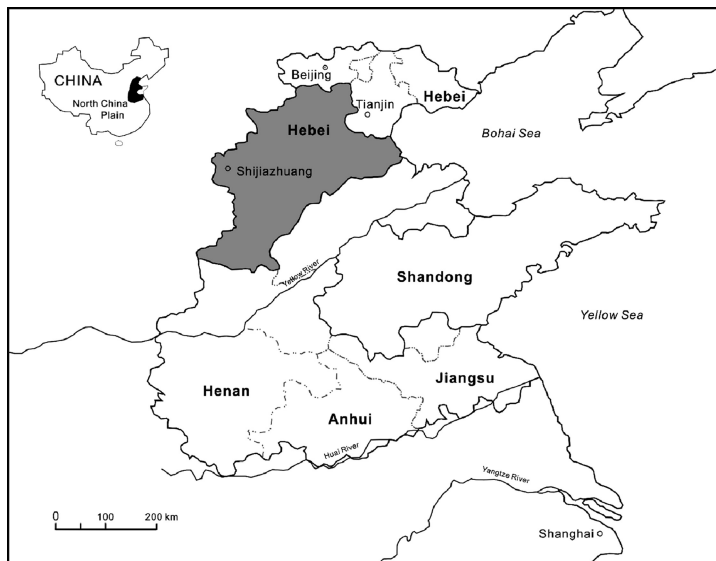


Figure 1. Location map of the study area.

sity distribution of small villages in the study area, the land cover types included in one pixel are not only the crop land, but also the rural area, so the integrated ET value weighting these different land covers in one pixel is highly dependent. Figure 2 shows the comparison between SEBAL daily evapotranspiration and in-situ lysimeter observations. There is a good agreement of ET between these two approaches on 17 Nov, 2004 with a reasonable error about 16.8%. However, the big errors were apparent for the other two days, especially on 25 Mar. 2005, and the SEBAL modeled error was 48.7%. In this regard, the lower resolution satellite images are not suitable to validate related surface energy balance model for actual evapotranspiration purposes, and further work should be based on high resolution satellite observations.

4.2 Evaporative fraction

The histograms of SEBAL evaporative fraction in the study area are shown in Figure 3. One peak represents the homogeneous land cover in the study area.

4.3 Actual evapotranspiration

Due to the variable irrigation performances in different places and a high spatial distribution of rainfall, the soil moisture in the root zone at different sites in the study area is highly variable. The spatial distribution patterns of ETa over Hebei Plain are shown on Figure 4. On 17 November 2004, high ET was indicated in the south-west of study area, at around 1.7 mm per

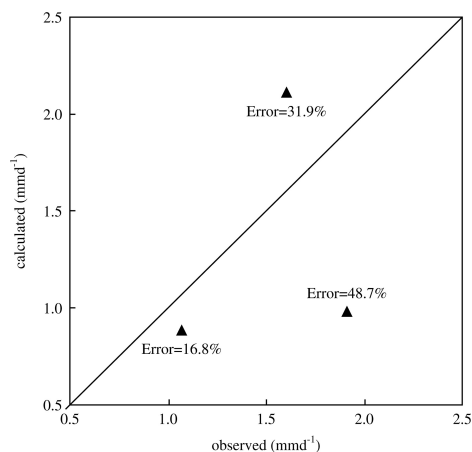


Figure 2. Validation of the SEBAL calculated evapotranspiration against the field lysimeter measurements, together with the 1:1 line.

day, and lower ET about only 0.20 mm per day was mainly located in the western Taihang Mountain foot plain. In early March, the highest ETa values, up to 3.6 mm per day, were found for the central plain, and in later March, a clear south-east to north-west ET gradient in the plain can be recognized. High ET values were located along the south-east boundary of the plain, with mean values more or less about 4.5 mm per day, which declined progressively to 0.15 mm per day towards the north-west boundary.

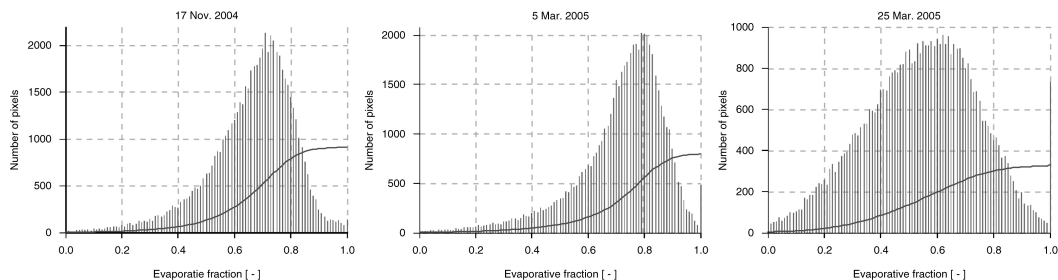


Figure 3. Evaporative fractions [-] estimated with SEBAL for MODIS products.

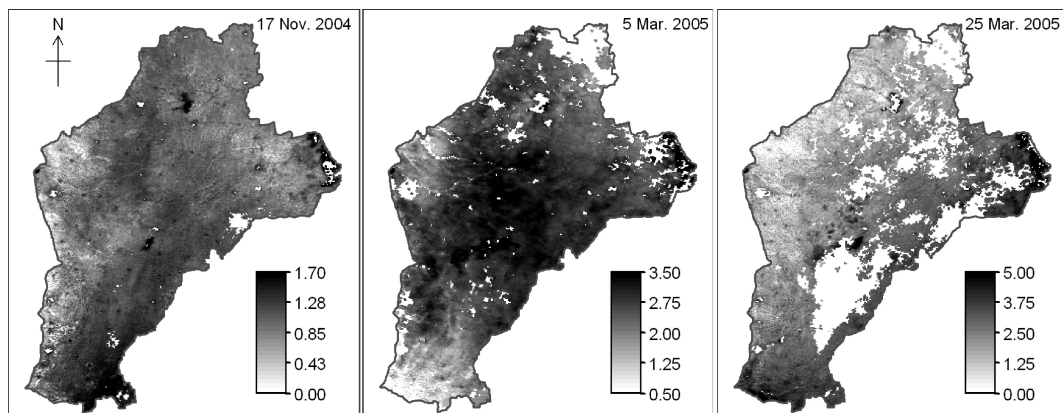


Figure 4. Daily evapotranspiration estimated with SEBAL for MODIS products (mm/day).

5 CONCLUSION

Evapotranspiration (ET) is one of the most significant components of water exchange over the land-atmosphere interface. Determination of ET over large scale plays important roles for basin-scale water resources evaluation and management, for example, groundwater recharge assessment, soil water dynamics, etc. MODIS products have been used in this paper to estimate daily evapotranspiration in the North China Plain based on the SEBAL model as well as meteorological observations. It can be seen that remote sensing techniques have obvious comparative advantages over traditional methods when dealing with water or energy exchanges over a large scale spatially and temporally, e.g. for estimating evapotranspiration. This methodology can be applied to regional water resources evaluation and management, irrigation performance assessment, as well as global climate change etc.. In this regard, further consideration should be addressed according to the fields where it is applied. SEBAL was developed to estimate the actual evapotranspiration spatially, based on remote sensing observations. It basically scales the latent heat fluxes to a wet and a dry limit within satellite images, which restricts its

application to areas with a large dynamic variability. In this regard, a spatially well-distributed in-situ network of evapotranspiration or surface heat flux observations over study area is needed for validation purposes.

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