Estimation of Evapotranspiration in Mongolian Grassland using Remotely Sensed and Ground data

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Abstract: Evapotranspiration estimations are essential for monitoring drought, wild land fire risk etc. In this study, a surface energy balance method, which combines meteorological observations with spectral data derived from remote sensing measurements, was used to estimate the regional evapotranspiration in the Mongolia, a large arid and semi-arid region with heterogeneous surface conditions. The Surface Energy Balance method has been applied to Landsat+ETM and NOAA-AVHRR sensors for the estimation of evapotranspiration in the grassland of Mongolia. As a result, a daily evapotranspiration map of Mongolia was produced.

Keywords: Evapotranspiration; Surface energy balance; Remote sensing

1. Introduction

Evapotranspiration (ET) as part of the hydrological cycle is affected by a multitude of process at the interface between soil, vegetation and atmosphere. A number of models for ET estimation have been presented since then. These models, including empirical models, semi-empirical models and physical models, have increased the precision of ET estimation (Brutsert 1979). Over the past 20 years, remotely sensed data have been used widely to estimate ET.

The purpose of this study is to estimate regional ET for large arid and semi-arid region with heterogeneous surface condition in the Mongolia. This method is based on the Surface Energy Balance and Normalized Difference Vegetation Index (NDVI) and surface parameters. In addition, these parameters will be derived from sensor data from the AVHRR and LANSAT+ETM satellites.

2. Materials and method

1) Study Area

In this study includes grassland-steppe area of Dundgobi province in Mongolia. The area covers arid and semi-arid region between the latitudes of $44^0 00'$N and $46^0 00'$N and the longitudes $103^0 00'$E and $109^0 00'$E. Annual mean precipitation is about 150-250 mm and 85-90 percent of the annual precipitation falls as rain during the summer of which 50-60% in July and August.

2) Satellite Sensors

NOAA-AVHRR: The National Oceanic and Atmospheric Administration (NOAA) of the USA operates the series of NOAA satellites which each carry the Advanced Very High Resolution Radiometer (AVHRR) sensor. The first operational NOAA satellite (NOAA-6) was launched in 1979. This was followed by a series of additional NOAA satellites with the latest launch being NOAA-16 in September 2000. The AVHRR sensor is a five or six channel (depending on the model) scanner, sensing the visible, near infrared, and thermal infrared portions of the electromagnetic spectrum. It provides global on board collection of data over a 2399 km swath. The sensor orbits the earth 14 times each day from an altitude of 833 km.

LANDSAT-ETM+ : The newest in this series of remote sensing satellites is Landsat 7. Launched on 15 April 1999, Landsat 7 has the new Enhanced Thematic Mapper Plus (ETM+) sensor. This sensor has the same 7 spectral bands as its predecessor, TM, but has an added panchromatic band with 15-metre resolution and a higher resolution thermal band of 60 metres. The ETM+ sensor also has a five percent absolute radiometric calibration.

3) Method

The regional ET estimation method has many sub – models. These include evapotranspiration and instantaneous regional ET model.

Evaporation and transpiration models

A relationship between ET and temperature is derived from the energy balance equation:

$$LE = R_n - H - G \qquad (1)$$

Where Rn is the net radiation, H is the sensible heat flux, G is the soil heat flux, and LE is the latent heat flux (W/m^2). LE corresponds to the amount of water evaporated per unit area (ET) expressed in energy units (Dibella et al.2000).

Net radiation

Usually, net radiation can be estimated by:

$$R_n = (1-\alpha)R_s + \varepsilon\delta(\varepsilon_a T_a{}^4 - T_s^4) \qquad (2)$$

Where *R*s is the incoming short-wave solar radiation, α the surface short-wave albedo, ε the surface emissivity, δ the Stefan–Boltzman constant, and ea the effective atmospheric emissivity, with (Brutsaert, 1975)

$$\varepsilon_\alpha = 1.24\left(\frac{e_a}{T_a}\right)^{1/7} \qquad (3)$$

Where e_α is the atmospheric vapour pressure.

The surface emissivity is calculated as a weighted average between bare soil and vegetation, such that Where ε_v is the emissivity of vegetation assumed to be 0.95, ε_s, the emissivity of bare soil assumed to be

$$\begin{aligned} \varepsilon &= \varepsilon_v f_v + \varepsilon_s (1 - f_v) \\ \varepsilon_v &\approx 0.95 \qquad (4) \\ \varepsilon_s &\approx 0.85 \end{aligned}$$

0.85 and *f*v the fractional vegetation cover.

The *f*, vegetation coverage in a pixel, is yielded by a relationship between *f* and NDVI (Gutman 1998):

$$f = \frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \qquad (5)$$

Where NDVImax and NDVImin are the maximum and minimum NDVI in a whole growth of vegetation.

Soil heat flux

The soil heat flux can be empirically estimated using the net radiation and ***LAI*** or a satellite derived vegetation index, such as the normalised difference vegetation index**,** ***NDVI.*** Here we have adopted the Moran et al. (1989) model as:

$$G = R_n\left[0.58\exp(-2.13NDVI)\right] \qquad (6)$$

Where *NDVI*=(*NIR_RED*)/(*NIR*+*RED*), and *NIR* and *RED* are the near-infrared and red reflectances, respectively.

Sensible heat flux

The sensible heat flux can be written as:

$$H = \rho C_p (T_s - T_a)/r_a \qquad (7)$$

Where ρC_p *is* the thermal capacity of the atmosphere, (r_a) aerodynamic resistance and (T_a) is the air temperature at the reference height where meteorological measurements are available. The temperature at ET surface (T_s) can be derived from a remotely sensed radiometric surface temperature.

The regional ET model

The actual 24h ET can be estimated from instantaneous latent heat fluxes with (Brutsaert and Sugita 1992; Crago, 1996):

$$ET_{24} = EFxR_{n24}(\mathrm{Wm}^{-2}) \qquad (8)$$

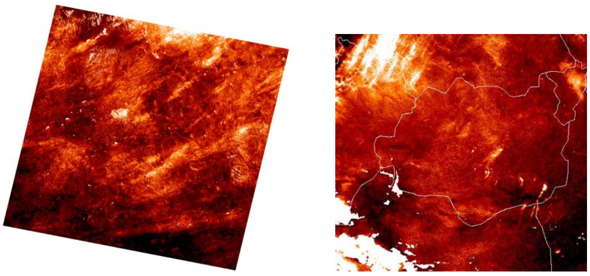
Where ET_{24} is the 24h actual evaporation, R_{n24} is the 24h net radiation and EF is the instantaneous evaporative fraction (Shuttleworth et al. 1989) calculated as:

$$EF = \frac{\lambda E}{R_n - G_0} \qquad (9)$$

Where H is the instantaneous sensible heat flux, R_n the instantaneous net radiation and G_0 the instantaneous soil heat flux.

LANDSAT-ETM+	**NOAA-AVHRR**
10.August, 1999	**20.April, 2003**
Projection: UTM	**Projection: ACEA**

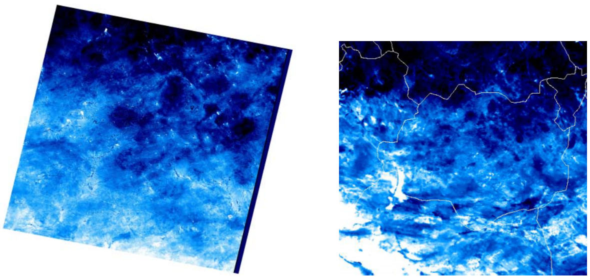
1. Land Surface Temperature



(a) (b)

Figure 1. Surface temperature maps in degrees Celsius calculated (left. a) from Landsat-7 and (right. b) from NOAA-AVHRR of the grassland –steppe in the Mandalgobi region estimated with the SEBAL parameterisation. The dark colour shows high and light is low surface temperature.

2. Evaporative Fraction

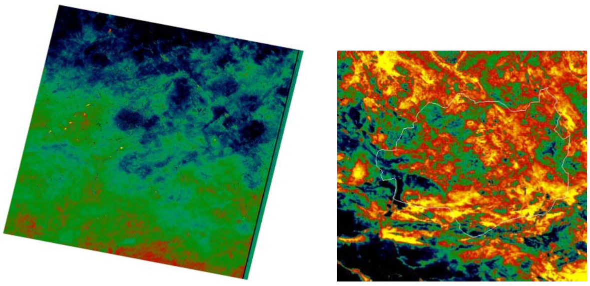


(a) (b)

Figure 2. Evaporative fraction maps of the grassland –steppe in the Mandalgobi region estimated with the

SEBAL parameterisation. The dark blue colour shows high and light blue is low evaporative fractions value.

3. Evapotranspiration rate



(a) (b)

Fig. 3. The satellite-based calculation with the SEBAL parameterisation of the evapotranspiration rates in W m^{-2}, (left. a) from Landsat-7 and (right, b) from NOAA-AVHRR of the grassland –steppe in the Mandalgobi region. The dark blue colour shows high

3. Results

The main output of SEBAL is the partitioning of energy balance, and can be visualized as the actual over the potential ET mentioned as the evaporative fraction.

Fig.1 presents the results of the land surface temperature in degrees Celsius calculations obtained from the satellite imagery and to situate the two study dates (10.August, 1999 and 20.April, 2003). Fig. 1(a) shows the results of land surface temperature using Landsat-ETM+ data ranged between 20-45 degree Celsius, and Fig. 1(b) using NOAA-AVHRR imagery land surface temperature ranged between 5-25 degrees Celsius.

Fig. 2 presents the results of the evaporative fraction. The evaporative fraction, EF, is computed from instantaneous surface energy balance at the moment of satellite overpass for each pixel ranged from Lansat-ETM+ (a) between 0.13-0.40, from NOAA-AVHRR ranged between 0.26-0.38.

Fig. 3 shows the results of evapotranspiration rates calculated using Landsat-ETM+ (a) and NOAA-AVHRR (b) satellite data. The evapotranspiration rates estimates obtained by Landsat-ETM+ (a) imagery was in the range of 70-300 W m^{-2} .on 10.August, 1999.

The eavpotranspiration rates high in the northern part than southern part of the Mandalgoi region. Because southern part of the Mandalgobi is more dry and sparsely vegetated. The evapotranspiration rates estimates obtained by NOAA-AVHRR imagery in the of 74-200 W m^{-2}. on 20.April, 2003. The eavpotranspiration rates high in the some of the southern part of the Mandalgoi region related with rainfall. In the 2003 spring in the Gobi region of Mongolia has more rainfall compare with other years.

4. Conclusions

The SEBAL methodology has been applied with Landsat ETM+ and NOAA-AVHRR images covering the grassland-steppe of Mandalgobi in Mongolia on 10.August, 1999. The evaporative fraction is a promising indicator to express energy partitioning and is directly related to the soil moisture conditions. It is a suitable indicator for crop water stress and may be considered as an alternative for actual/potential evapotranspiration as it avoids the intricate definitions related to potential evapotranspiration. Moreover, this study has demonstrated that it can be determined successfully from satellites. SEBAL can and has been applied for crops, pastures, forests, natural vegetation, bare soil, desert and open water bodies, and this makes it possible to study consumptive use of noncrops.

5. REFERENCE

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