Study on Thermal energy budget in the Mongolian plateau using satellite data

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1. Introduction

Our ultimate goal is estimation of albedo and thermal energy budget of an experimental field of ADEOS-II/AMSR around Mandalgovi in Mongolia using satellite data such as ADEOS-II/GLI or LANDSAT/ETM+. Using this result, we would like to study the relationship between measurements of soil moisture and the thermal energy budget, and between the net primary production of vegetation and the thermal energy budget, in the next step.

Satellite measurements of the radiation at wavelengths from $8\mu m$ to $12\mu m$ provide information on the ground surface temperature. The ground surface temperature at satellite pass-over time can be estimated from the ground surface radiant energy. In the case of Landsat/ETM+, the surface temperature at 11 a.m. local time can be estimated every 16 days.

Ground surface temperature changes periodically day by day. Therefore we studied a method of estimating the radiant energy from the ground surface per day using satellite measurements of brightness temperature.

In this study, we studied the thermal energy budget using this method with LANDSAT/ETM+ data.

2. Data used in this study

We used satellite data and weather data in this study. For satellite data, LANDSAT/ETM+ data measured on June 12 was used. The results of land cover mapping [1] obtained from LANDSAT/EMT+ image around the experimental site were also used. For weather data, automatic weather station (AWS) data was used. AWS was installed in June 2000 as ADEOS-II/AMSR soil moisture validation project. The following items were measured at AWS: air temperature, brightness temperature of the ground surface, wind speed and direction, precipitation, net radiant energy, soil moisture and so on. The values of solar irradiance at Mandalgovi were provided by Prof. Takamura, Chiba University.

3. Estimation method of the surface radiant energy integrated over one day using satellite data.

The estimation method [2] of the surface radiant energy in a day is described briefly in this chapter. The time difference between maximal solar irradiance and maximal surface temperatures was defined as the phase difference. The radiant energy from the surface and solar irradiance showed a linear relationship, when the phases of them were synchronized. It follows that the radiant energy from the surface and air can be approximated by the equations as follows,

$$\sigma T_g^4(t-\delta) = \alpha_i \times S(t) + \beta_i(\tau), \qquad (1)$$

where T_g is ground surface temperature, σ is the Stefan-Boltzmann constant, $S(t)$ is solar irradiance (W/m^2) at time t ($= 0 \sim 24$ hours)in a day, and i means each ground type, δ is the phase difference, and τ is a day ($\tau = 1 \sim 365$ days) in a year. The slope α_i and the intercept β_i should be determined for each ground type i. We can know σT_g^4 from satellite measurements at satellite pass-over time, and we assume that the value of $\beta_i(\tau)$ is approximately the same as the minimal radiant energy from air. From this assumption, the intercept $\beta_i(\tau)$ can be calculated using AWS data.

4. Thermal energy balance on the ground surface

Thermal energy balance on the ground surface is shown in Figure 1. Ground surface with albedo (A) absorbs solar irradiance (S) and downward radiant energy ($F_\downarrow$) from atmosphere. The absorbed energy was used for the ground radiant energy σT_s^4, where T_s is the ground surface temperature, σ is the Stefan-Boltzmann constant, and the ground conductive heat flux (G), the sensible heat flux (H) and the latent heat flux (L). The thermal energy balance on the ground surface is as follows:

$$(1 - A)S + \epsilon F_{\downarrow} = \epsilon \sigma T_s^4 + G + H + L. \quad (2)$$

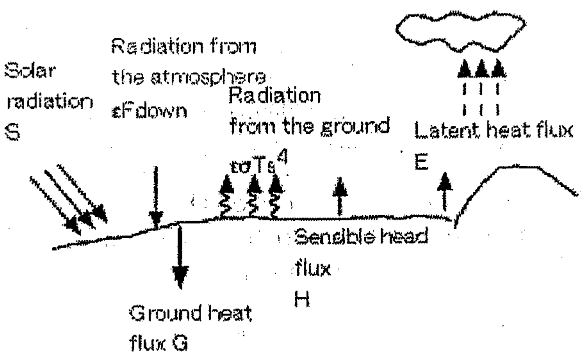

Figure 1: Thermal energy balance on ground surface.

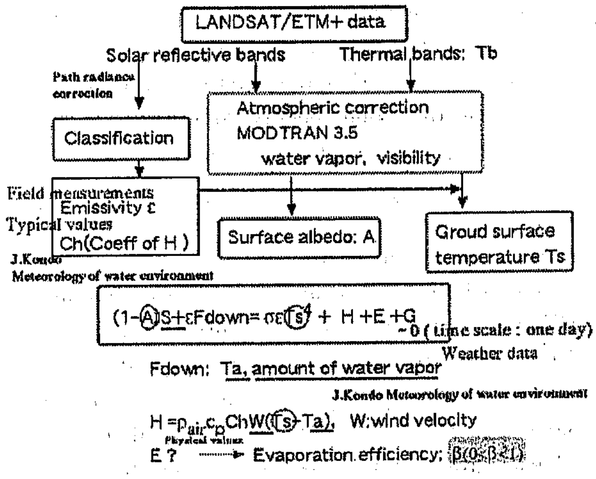

Figure 2: Analysis flow

5. Analysis flow

In this study, we would initially like to estimate ground surface albedo and ground surface temperature measured by satellite. Then, we will estimate the absorbed energy on the ground and each term on the right side of Equation 2.

The analysis flow is shown in Figure 2. Reflective and radiant thermal energy measured by LANDSAT/ETM+ were corrected for atmospheric effects using MODTRAN 3.5 with a water vapor profile of atmosphere and visibility. Spectral solar irradiance on the surface is also simulated by MODTRAN 3.5.

Ground types	$C_h W$ (m/s)
soil	$0.0027+0.0031W_{1m}$
grass (height about 0.1m)	$0.02+0.0045W_{1.5m}$
grass (height about 1m)	$0.006W_{1.5m}$
a column (a diameter about 0.5m)	$0.001+0.003W_{1.5m}$

Table 1: The values of sensible heat transfer coefficients used in this study.

Using spectral reflectance on the ground and spectral solar irradiance data, surface albedo was estimated. Ground surface temperature was calculated using the corrected brightness temperature and the emissivity which was determined for each land cover. From satellite data, surface albedo (A) and surface temperature (T_s) was estimated.

To calculate each term in Equation 2, we should determine the absorbed energy in the ground. The solar energy absorbed by the ground surface can be estimated from the albedo and the value of solar irradiance measurements on the ground. The downward radiation from atmosphere is estimated by the empirical method [3] using air temperature and the amount of water vapor as shown in the following formula,

$$F_{\downarrow} = (0.74 + 0.19x + 0.07x^2)\sigma T_a^4, \quad (3)$$

$$x = \log_{10} w_{top}, \quad (4)$$

where T_a is average air temperature, w_{top} is a total amount of effective water vapor. Sensible heat flux is estimated by the following formula.

$$H = \rho_{air} C_p C_h W (T_s - T_a), \quad (5)$$

where ρ_{air} and C_p is the density and heat capacity of air, respectively. These are physical constants, and C_h is the sensible heat transfer coefficient. The values of C_h are used as typical values [4] and summarized in Table 1.

In this analysis, the time scale is one day. Since we assume that the ground conductive heat can be negligible. All terms of Equation 2 can be estimated except for latent heat flux. The latent heat flux can be calculated from Equation 2. To check this analysis, the evaporation efficiency was calculated. That value should range from 0. to 1.

6. Results and Discussion

Land cover type		Albedo	Incoming		Outgoing			
			(1-A)Solar	Ldown	$\epsilon\sigma T_s^4$	H	E	β
	%		MJ/m²day	MJ/m²day	MJ/m²day	MJ/m²day	MJ/m²day	
Pond	2.3	0.238±0.070	21.46±1.84	25.81	34.72±1.11	-0.15±0.12	19.08±1.22	20.6±5.9
Marsh	0.2	0.202±0.070	22.17±0.76	25.81	36.38±0.54	8.01±3.33	9.26±3.87	0.10±0.06
Shrub	56.1	0.227±0.018	21.48±0.52	25.81	36.90±0.49	7.88±2.32	8.87±2.81	0.11±0.05
Long-type grass	0.5	0.252±0.010	20.78±0.28	25.81	37.02±0.32	4.89±1.52	11.74±1.84	0.16±0.03
Short-type grass	34.9	0.236±0.010	21.25±0.49	25.81	36.91±0.50	11.25±3.05	5.48±3.55	0.05±0.04
Whitish Soil	0.4	0.333±0.018	18.54±0.69	25.81	34.76±0.64	5.04±1.96	13.85±2.60	0.28±0.10
Soil	8.1	0.253±0.027	20.76±0.76	25.81	37.16±0.54	4.11±1.55	12.38±2.09	0.26±0.07

Table 2: The average values of each energy term in Equation 2 for each land cover type.

The analysis result of surface albedo, absorbed solar irradiance, radiant energy from ground surface, sensible heat flux, latent heat flux and evaporation efficiency are shown in Figure 3 to Figure 8. A rough comparison of these results with soil moisture measurements on the grid the pattern of the soil moisture is similar to the image of albedo.

The average value of each energy for each ground type is summarized in Table 2. The average value of albedo for the whole area is 0.23 and vegetated area is around 0.24, for soil area 0.25, and for whitish soil area containing salt 0.33. The average value of evaporation efficiency is less than 0.3. These did not appear to be bad results roughly speaking. In detail, however the average value of evaporation efficiency for the pond is 20.6, which is too high. We consider that the assumption that the ground conducive heat flux for the pond is negligible causes this results. The average value of the evaporation efficiency for the whole area is 0.11. The average value for shrub is 0.16 and that of short grass is 0.05. For soil, the value is slightly greater than that for vegetated area. For soil area, dry soil and wet soil around the pond are mixed. We consider that these should be separately analyzed in the next step.

7. Conclusion

We studied the thermal energy budget in an experimental area in Mongolia. Using Landsat/ETM+ data measured on June 21, the ground surface albedo and ground surface temperature were estimated. Using the results and weather data, we estimated absorbed energy on the ground, radiative energy from the surface, and sensible heat flux. Latent heat flux was calculated from the energy balance equation on the ground and estimated energy fluxes. To check this analysis, we calculated the evaporation efficiency which should range from 0. to 1.

The average value of evaporation efficiency for the whole area except for pond is 0.11. This results was reasonable. A rough comparison of the showing images with soil moisture measurements on the grid shows that the pattern of the soil moisture is similar to the image of albedo.

Acknowledgments

Landsat/ETM+ data were provided by U.S. Geological Survey's (USGS). Solar irradiance data observed as Skynet project were provided by Prof. Takamura, Chiba University. Data of water vapor profiles of atmosphere were provided by Institude of Meteorology and Hydrology, Ministry of Nature and Environment, in Mongolia. This study was supported by NASDA as AMSR project and GLI project.

References

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Figure 3: Ground surface albedo

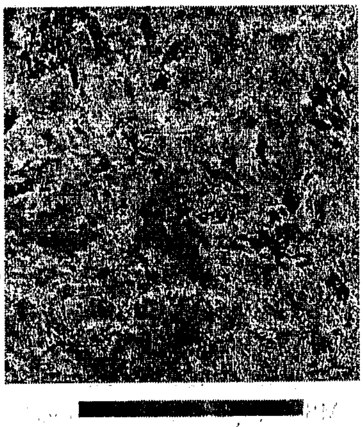

Figure 4: Absorbed solar irradiance

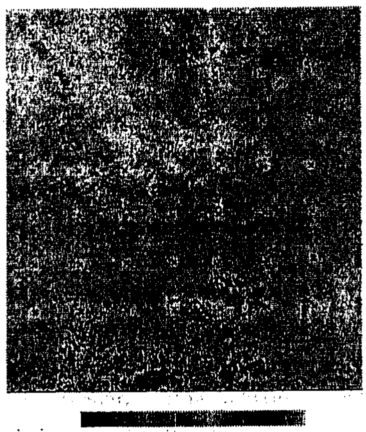

Figure 5: Radiant energy from ground surface

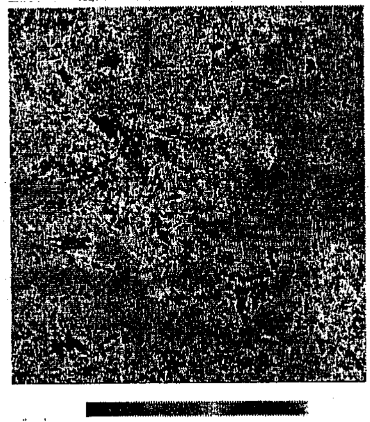

Figure 6: Sensible heat flux

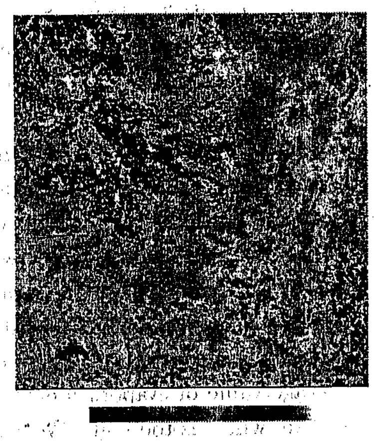

Figure 7: Latent heat flux

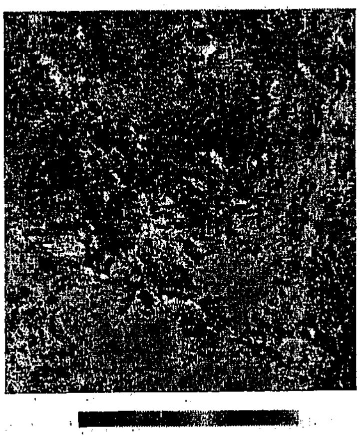

Figure 8: Evaporation efficiency