THE EFFECTS OF SOIL MOISTURE ON THE ENERGY BALANCE AT THE BARE SOIL SURFACE*

By Soo-Jin HWANG**

(Manuscript received 31 August, 1995)

ABSTRACT

A knowledge of soil surface thermal properties and an understanding of the interaction between the air and soil surface layer are crucial to improve the performance of current numerical weather forecasting model.

When solar radiation reaches the soil surface, this energy flux is redistributed in the sensible heat flux, latent heat flux, soil heat flux, and long wave radiative energy flux by which the energy balance is maintained.

The relative magnitude of each of these redistributed energy balance components is deeply influenced by the soil surface conditions. For example, the soil surface albedo, the canopy density, and the soil thermal properties such as the soil thermal conductivity or diffusivity are all affected by the soil moisture regime.

In order to study the redistribution of solar energy and energy balance at the soil surface which is affected by the soil thermal properties, field observations were carried out and numerical experiments were conducted by solving the partial differential equation for heat conduction. The field observations took place at the Environmental Research Center of Tsukuba University, Japan during July to August 1982 and July to August 1983.

The results can be summarized as follows;

(1) Soil moisture is evaporated extensively to the atmosphere from the soil surface layer during the daytime, and it is restored from the lower part of soil layer during the nighttime hours. This periodic phenomenon is repeated every day during the drying stage of the soil.

(2) It was found that for the purpose of the numerical experiments the distribution of soil moisture can be assumed to take a logarithmic form as follows.

$\theta_{w(z,t)} = V_1(t)\log(z) + V_2(t)$

(3) The vertical gradient of soil temperature in the upper most part of the soil layer becomes gradually steeper in response to the drying process of the soil as the soil moisture becomes depleted. On the other hand, the soil thermal conductivity decreases as the soil moisture decreases. Therefore, on the whole the value of ratio G_0/S_n (soil heat flux at surface / net short wave radiation) may either increase or decrease, depending on the relative importance of the temperature gradient and of the thermal conductivity. Actually, it can usually be assumed that the soil heat flux density is relatively constant, because the high value of the soil temperature gradient and the low thermal conductivity tend to balance each other.

(4) The ratio of the sensible heat flux to net short wave radiation is somewhat small, and it increases little

* A dissertation submitted to the Dectoral program in Geoscience, the University of Tsukuba in partial fulfillment of the requirements for the degree of Dector of Philosophy (Science)

**Department of Earth Science, Pusan National University, Jangjeun-Dong Geumjeung-Ku, Pusan, 609−735 KOREA

with decreasing soil water content.

(5) The ratio of the net radiation to the short wave radiation decreases with decreasing soil moisture. This means that the net radiation at the soil surface is deeply influenced by the variation of soil moisture.

(6) A decrease in soil moisture results in an increase of the surface soil temperature and soil surface albedo. As a result, the ratio of net long wave radiation and the net short wave radiation L_n/S_n has a negative correlation with the soil moisture.

(7) The ratio of the latent and sensible heat fluxes has a positive correlation with soil moisture.

(8) The parameter Hr has a negative correlation with the soil moisture. In other words, the ratio of the radiative energy term to the thermo-and aerodynamic heat energy term at the soil surface increases with decreasing soil moisture in the surface soil layer.

(9) The surface albedo of Kanto loam displays a step-like behavior. It has critical points of change from 0.2 to 0.1, between the volumetric soil water contents of 0.3 and 0.2 m^3m^{-3}, respectively.

(10) The results of numerical experiments with Kanto loam suggest that the soil thermal conductivity data of the Kimball (loam, porosity, 0.41) are more representative of the present situation than Kersten's (peat soil, porosity, 0.8).

From the above results, the following conclusions can be drown:

1) There is a low heat conducting layer in the upper most soil layer under dry conditions in the Kanto loam study area. This layer can be defined as a quasi insulated soil layer which is assumed to be developed from the soil surface to lower depth of 0.01 m, and is deepened with drying of soil moisture. The quasi insulated soil layer reveals following characteristics.

(1) The volumetric soil water content in the layer is as small as 0.1 to 0.2 m^3m^{-3}.

(2) The temperature of this layer can change rapidly with rates varying from 5 ℃ h^{-1} to 10 ℃ h^{-1}.

(3) The soil temperature gradient in the layer is usually very steep with typical values of 5×10^2 ℃ m^{-1} to 7×10^2 ℃ m^{-1}.

2) When the soil surface is moist, the incoming solar energy is mainly redistributed into the thermo-and aerodynamic heat flux terms, namely, sensible heat flux, latent heat flux, and soil heat flux. On the other hand, it is mainly transformed into the radiative heat flux when the soil is dry. When the volumetric soil water content at 0.01 m depth varies from about 0.35 m^3m^{-3} to 0.1 m^3m^{-3}, namely, from a wet to a dry state, each component of the energy balance typically varies as follows.

(1) The ratio of net radiation and net short wave radiation Rn/Sn decreases from 0.9 to 0.7.

(2) Both the ratio of sensible heat flux and net short wave radiation H/S_n, and the ratio of the soil heat flux and net short wave radiation G_0/S_n increase from 0.1 to 0.2.

(3) The ratio of latent heat flux and net short wave radiation lE/S_n decreases from 0.6 to 0.3.

(4) The ratio of net long wave radiation and net short wave radiation L_n/S_n increases from 0.1 to 0.3.

(5) The ratio of latent heat flux and sensible heat lE/H which indicates the inverse of the Bowen ratio decreases from 5 to 2.

(6) The parameter H_r which represents the ratio of radiative heat flux term to the thermo-and aerodynamic heat flux term increases from 0.1 to 0.5.

3) In the numerical experiment on soil temperature variation, the soil thermal conductivity and diffusivity are dealt with as functions of soil moisture, which varies with depth and time. The profile of soil moisture can be assumed to be a logarithmic function of depth, that is, the soil moisture increases logarithmically with depth from the soil surface.

The model' s output of soil temperature yields good agreement with the observational results. This confirms the presence of the quasi insulated soil layer in the upper most part of the soil.