Local Surface Ground Temperature based on Energy Balance Model with the use of GRID/GIS, Remote Sensed and Meteorological Station Data

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Abstract: The purpose of the study is to produce the surface ground temperature diagnostically using surface EBM with the use of GRID model in Geographic Information Systems (GIS). Certain characteristics have been analyzed for local slope effect, coastal effect and influence of high orographic aspect on the surface ground temperature. We present discussions on the meteorological responsibility for their temperature. The derived surface ground temperatures can be provided for comparison with those from satellite-based observation.
Keywords: ground temperature, EBM, GRID/GIS

1. Introduction

To simulate surface temperature, surface energy balance model (EBM) with GRID/GIS is used. Most surface EBMs are usually based on the assumption that the surface in the modeling area is homogeneous in radiative, thermal and geometrical properties (Bornstein, 1986; Oke, 1987).

In this study, surface inhomogeneity over southeastern part of Korean peninsula are considered in estimation of the absorbed surface solar radiation in terms of the illumination angle, depending on topographical aspect and slope in GRID. For sensible, latent heat fluxes and long-wave radiative flux in EBM, the common surface ground temperature should be evaluated. The model surface area types such as hilly area, partially vegetated area, and bare soil surface should be divided into small, homogeneous area so that the equations have to be applied for each homogeneous facet. In this study, we attempt to provide the small homogeneous grid with the use of GRID structure in GIS that Lin Wu(1996) proposed.

The results of our study show the changes in the surface ground temperature due to local ground aspect and slope effect. We also present discussions on the meteorological responsibility for their temperature. The derived surface ground temperatures will be compared with those of satellite-based observation.

2. Energy Balance Equation

Energy Balance Model consists of the radiative and turbulent fluxes terms as the following:

$$\mathbf{Q^* = K^* + L^* = Q_H + Q_L + Q_G.} \qquad (1)$$

The net radiation (**Q***) of the sum of the net short-wave radiation (**K***) and net long-wave radiation (**L***) is balanced by three surface fluxes: sensible($\mathbf{Q_H}$), latent($\mathbf{Q_L}$) and ground heat flux($\mathbf{Q_G}$).

To produce the surface ground temperature diagnostically using EBM, all components except the short-wave radiation term were expressed by a function of the surface temperature(**Ts**) in this study.

1) Short-wave radiation

The net short-wave radiation (**K***) is the balance between the incoming short-wave radiation (**K↓**) and the reflected short-wave radiation (**K↑**). The short-wave radiation is expressed by direct solar radiation (**S**) and diffuse solar radiation (**D**).

$$\mathbf{K^* = K\downarrow \;\; K\uparrow} = (1 \;\; \acute{a})\mathbf{K\downarrow} = (1 \;\; \acute{a})(\mathbf{S}+\mathbf{D}) \qquad (2)$$

Direct solar radiation (**S**) is calculated as following

$$\mathbf{S = So\ cos\,□} \qquad (3)$$

$$\mathbf{cos\,□ = cos\ddot{o}\,cosZ + sin\ddot{o}\,sinZ\,cos(\grave{U}_{sl} \;\; \grave{U}_{s})} \qquad (4)$$

In the equations above, **So** is direct radiation at normal incidences, and □ is illumination angle, which is a parameter determined by slope angle(**ö**), slope azimuth ($\grave{U}_{sl}$), zenith angle (**Z**) and solar azimuth ($\grave{U}_{s}$). Slope angle and slope azimuth angle are calculated by terrain information in GRID supplied from GIS.

2) Long-wave radiation

The net long-wave radiation (**L***) is determined by the absorbed incoming long-wave ($æ_{ong}$**L↓**) radiation and outgoing long-wave radiation (**L↑**).

$$\mathbf{L^* = æ_{ong}L\downarrow \;\; L\uparrow} \qquad (5)$$

$$æ_{ong} = {}^{a}s = 1.009 + 0.047\,ln(\mathrm{NDVI}) \qquad (6)$$

$$\mathbf{L\uparrow} = ó^{a}\,sTs^{4}\;,\quad \mathbf{L\downarrow} = ó^{a}\,aTa^{4} \qquad (7)$$

$${}^{a}a = 0.67 + 0.05(e_a)^{1/2} \qquad (8)$$

where $æ_{ong}$ is the absorptivity of long-wave radiation, and it is set to be same as emissivity of surface (ε_s) as a function of vegetation index (NDVI) according to Kirchhoff's law (Van de Griend and Owe, 1993). The upward and downward long-wave radiation in eq (5) were determined by the Stefan-Boltzman's law.

3) Surface fluxes : sensible , latent , ground heat flux

The surface heat fluxes from sensible, latent and ground heat flux, which are balanced by net radiation energy, are expressed by a function of surface temperature as following

$$Q_H = \rho_a C_p C_{dh} u(T_s - T_a) \qquad (9)$$

$$Q_L = Q_H/\beta \qquad (10)$$

$$Q_G = K_G(T_s - T_g)/d \qquad (11)$$

The sensible heat flux, Q_H is calculated as a function of the temperature difference between the surface and the adjacent air and wind speed and specified surface variables. And, latent heat flux, Q_L is estimated using of Bowen ratio approach (Oke, 1987). The ground heat flux, Q_G is determined by the subsurface temperature gradient and thermal conductivity of the surface.

3. Retrieval of Surface Temperature

Surface temperature, **Ts** is obtained by interactive numerical approach (Fig. 1).

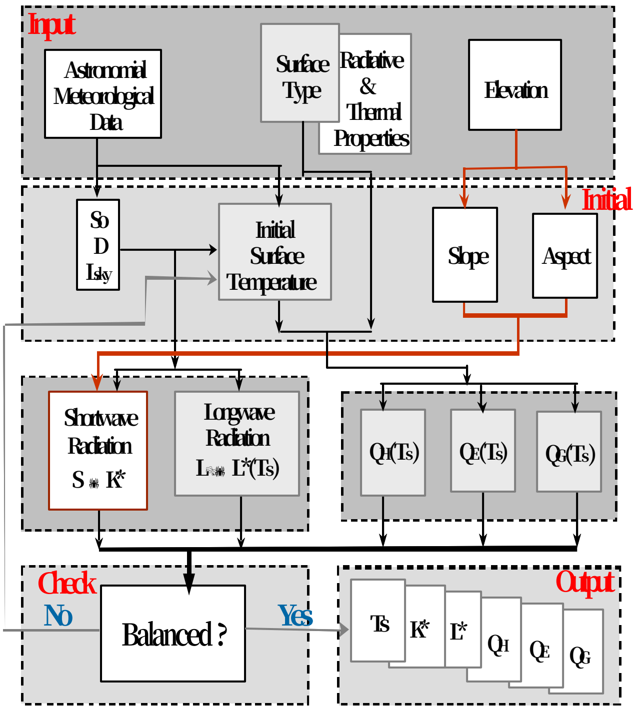

Fig. 1. Illustrative flow chart of the EBM and GRID in this study.

The processes begin with an initial **Ts** that is given from the input data. Each term is expressed as a function of **Ts.**

If net radiation energy and surface fluxes are not in balance, **Ts** is adjusted by a given interval and each function of **Ts** is recalculated. After every calculation, the interval is reduced by half. The process is repeated in the equation balances until the difference between radiative term and surface flux term falls within a given tolerance level (=0.01Wm^{2}).

4. Results and Discussions

The surface ground temperature is produced diagnostically using surface EBM with the use of GRID model in GIS. And, using of topographical aspect and slope in GRID, surface inhomogeneity over southeast part of Korean peninsula is considered to compute the absorbed surface solar radiation in terms of the illumination angle. We expect the model's ability to be enhanced to simulate the spatial variability of surface temperature and surface fluxes in heterogeneous area with the use of GRID/GIS.

Fig. 2 represents the incident direct solar radiation field (**So**) at normal surface and direct solar radiation (**S**) corrected by the illumination angle that considered topographic information. According as terrain information is supplied, we can confirm that spatial distribution of solar radiation is precisely obtained.

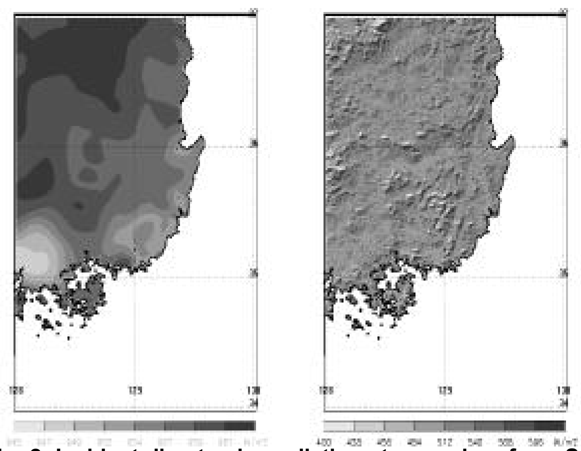

Fig. 2. Incident direct solar radiation at normal surface, So (left) and direct solar radiation corrected by illumination angle, S (right).

Fig. 3 shows the air temperature (**Ta**) field from AWS (Automatic Weather Station) data, which is given from input data of model. The initial surface temperature used in this study is **Ts** = **Ta** +4. The black square in the figure represents the observation point of AWS. Although the station of AWS data is densely distributed with interval of about 15km, horizontal distribution of surface variable is required to be much smaller scale feature due to complex topography.

Fig. 4 is the horizontal distribution of surface temperature, **Ts** simulated from our model (a) and retrieved from NOAA satellite (b). This result is diagnostically produced from surface EBM, which shows the changes in the surface temperature field due to high orographic aspect as well as local ground properties and slope effect. Also, we confirm surface temperature field from EBM would be very useful for comparing to that retrieved from NOAA satellite.

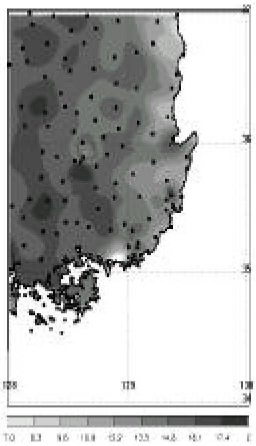

Fig. 3. Air temperature field from AWS data. It is given to input data of model and is used to initial surface temperature. The black square is the observation point of AWS.

(a) EBM (b) NOAA

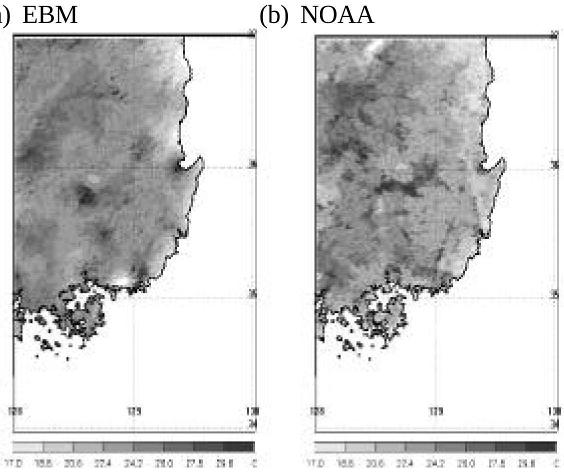

Fig. 4. Ts calculated by EBM and retrieved from NOAA satellite.

Acknowledgement

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