

Prognosis of the Road surface condition in Korea using Surface Energy Balance theory

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Abstract

The prognostic model for the prediction of the road surface temperature is developed using the surface energy balance theory, which includes detailed micro-meteorological physics. This model is adequately adjusted to the microclimatology of Korea and is able to represent as accurately as possible the detailed each surface energy budget. To verify the performance, the model is run for 2000/2001 winter periods, using the measurements of one German road weather monitoring site, and the results are compared with that of EBM(Energy Balance Model) which is currently operated by DWD(German Weather Service). The simulated results by both models are very similar to each other and have a good match with the observed data.

1. Introduction

The road surface condition such as the freezing temperature is mainly determined by the road surface temperature, which is to be considered with various micro-meteorological parameters. Topographic features can also affect a thermally driven road conditions, either directly, by causing changes in the wind direction (Atkinson, 1981) or indirectly, by inducing significant variations in the road surface temperature. But under the condition of the wide flat road or bridge an impact of topographical features on the road condition is not significant. Except for the topographical perturbations, the road-air energy budget exchange has also been found to affect significantly the

local ground heat budget and thus the surface temperature distribution (Segal et al., 1989; Betchtold, 1991).

It is evident that the reliable prediction of the road surface temperature for determining the freezing temperature, requires a powerful calculating tool that is able to represent as accurately as possible the detailed each surface energy budget and thus to reproduce temporal variation of the road surface temperature more realistically.

The prognostic model for the prediction of the road surface temperature is developed based on the surface energy balance model which was improved by Atmospheric Boundary Layer Lab, SNU (Park, 1994), under the co-work of Korea Meteorological Administration(KMA) and Humanopia Corp. This model also tend to calculate the several micro-meteorological variables, such as sensible heat flux, latent heat flux, ground heat flux, wind stress and friction temperature.

2. Model description

2.1 Surface Fluxes

The turbulent scales, such as friction velocity u_* and friction temperature θ_* , are usually computed iteratively starting from neutral values. However, this method is computationally time consuming. An analytical approach is suggested by Garratt(1992) with the use of the bulk Richardson number Ri_b and by Park(1994) in his surface parameterization.

The bulk transfer relation for surface fluxes is given by

$$u_*^2 = C_{DN} \cdot f_M (Ri_b) \cdot u_a^2$$

$$u_* \theta_* = C_{HN} \cdot f_H (Ri_b) \cdot (\theta_a - \theta_g) \cdot u_a$$

where C_{DN} and C_{HN} are, respectively drag coefficients for momentum and heat in neutral stability, f stability parameter that is the function of the bulk Richardson number for momentum and heat and sub-string a and g represent each air and ground level.

2.2 Road surface temperature and Subsurface temperature

The prognostic equations for the road surface temperature T_g and subsurface temperature T_2

are obtained from the force restore method proposed by Bhumralkar(1975) and Blackadar(1976). That is,

$$\frac{\partial T_g}{\partial t} = C_T G_0 - \frac{2\pi}{\tau} (T_g - T_2)$$

$$\frac{\partial T_2}{\partial t} = \frac{1}{\tau} (T_g - T_2)$$

where C_T is the road thermal coefficient, G_0 the heat storage rate and τ the time scale as 24 hours. The coefficient C_T is given by,

$$C_T = \left[\frac{(1-\sigma_f)}{C_g} + \frac{\sigma_f}{C_v} \right]^{-1}$$

where C_g and C_v are respectively thermal coefficient of soil and vegetation system. C_v is assumed to be $10^{-3} \text{ J}^{-1} \text{ m}^2 \text{ K}$ (Noilhan and Planton(1989)). For no vegetation system, (e.g. $\sigma_f = 0$), the coefficient C_T equals to C_g .

Thermal coefficient of soil system C_g depends on both the soil texture and soil moisture. This is estimated by,

$$C_g = 2 \left(\frac{\kappa}{\nu C} \right)^{\frac{1}{2}}$$

The thermal conductivity ν and volumetric heat capacity C vary with the volumetric moisture contents W_g and matric potential ψ . That is,

$$\nu = \begin{cases} 419 \exp[-\log|\psi| + 2.7], & \text{If } \log|\psi| < 5.1 \\ 0.171, & \text{If } \log|\psi| > 5.1 \end{cases}$$

where ψ is in unit cm(McCumber, 1980 ; Pielke, 1984) and the matric potential is,

$$\psi = \psi_{sat} \left(\frac{W_{sat}}{W_g} \right)^b$$

where ψ_{sat} is the saturated moisture potential, W_{sat} the saturated volumetric moisture contents and b the slope of retention curve on logarithmic graph.

The volumetric heat capacity C is expressed by the density of the road soil, the specific heat and the soil moisture contents.

The ground heat flux G_0 can be calculated by the surface energy budget conservation theory. That is,

$$G_0 = R_N - H_0 - \lambda E_0$$

where H_0 is the sensible heat flux that is the function of friction velocity and friction temperature, λE_0 the latent heat flux and R_N the net radiation flux.

2.3 Latent heat flux and evaporation

For the latent heat flux, the calculation of both the soil moisture contents and the evaporation amount is required and is usually estimated through the bucket method or the force restore method. The main shortcoming of the bucket method is that evaporation does not respond rapidly to short period occurrence of precipitation. So in our model, the force restore method (Noilhan and Platon, 1989) is used for two layer as like the calculation of the road surface temperature base on the Penman-Monteith equation set (Monteith, 1981).

This equation set is very complex and long, so in this paper is omitted for the paper margin.

3. Verification of Model

Korea Meteorological Administration (KMA) and Humanopia Corp. are working on the development of a road weather prediction model as part of the road Weather Information System (RoWIS), under the cooperation with the German Weather Service (DWD) from 2001. To verify the developed model, we compare the model run with the measurement of one German road-weather monitoring site, as well as with the calculation of EBM (Energy Balance Model), which is currently operated by DWD.

DWD's EBM calculates the energy transfer through 21 subsurface mediums and classifies 160 types of the climatology for road condition. And 5 types of the other road characteristics is considered. We carry out the simulation for L857 region (Hanau) of Germany by using both DWD's EBM and the developed model with same initial conditions and same period (from November 2000 to March 2001). To compare each other results, the forecasted road surface temperature by both models and the

observed one is shown(**Figure 1**) for the period of December 2000.

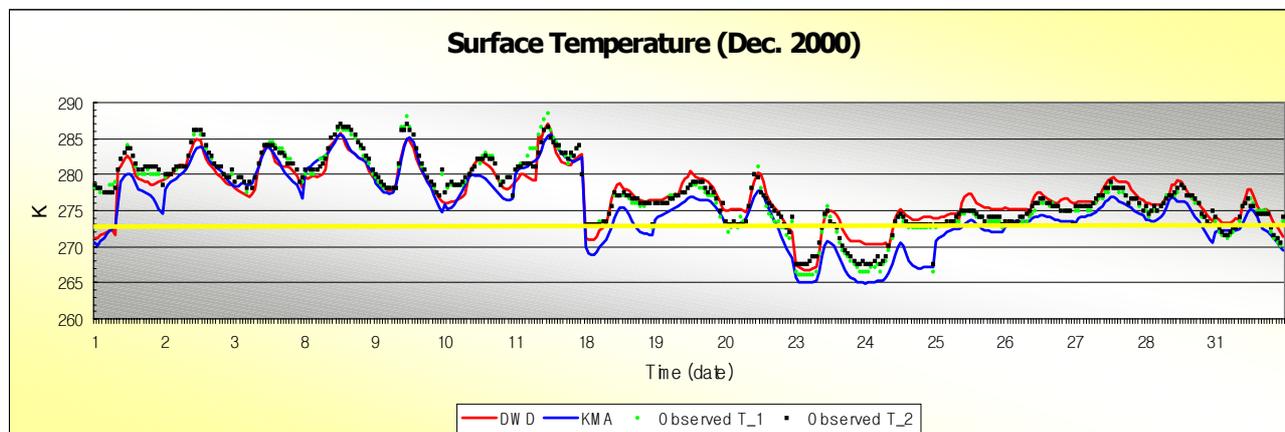


Figure 1. Calculated road surface temperature by using the both model and Observed data

The simulated results by using both model are very similar each other and have a good match with the observed one. But the forecasted road surface temperature by using the developed model is about 1 K ~ 2 K lower than that by using DWD's EBM. To find the cause of the under-estimation of the developed model's one, we checked the calculated several flux amount but here is not shown. Especially we could find that when the heat is transferred between the road surface and the subsurface layer, the response of the developed model(2-layer model) is occurred more quickly rather than that of DWD's EBM(multi-layer model). So, the minimum temperature is affected by the heat transfer rate.

4. Conclusion

The prognostic model for the prediction of the road surface temperature is developed using the surface energy balance theory, under the cooperation of Korea Meteorological Administration (KMA) and Humanopia Corp., which includes detailed micro-meteorological physics. And the developed model is run for 2000/2001 winter periods, using the measurements of one German road weather monitoring site(Hanau, L857), and the results are compared with that of EBM(Energy Balance Model) which is currently operated by DWD(German Weather Service). We show that the simulated results from both models are very similar to each other and have a good match with the observed data.

KMA and Humanopia Corp. are improving this model to have more accurate result on road surface temperature. If the sub-surface energy transfer processes are considered for multi-layer, we expect more accurate simulation would be produced.

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