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Parameterization of Numerical Energy Balance Model Using Surface Temperature Data to Estimate Evapotranspiration of Different Land Condition at Cidanau Watershed

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Two layer resistance models which were developed based on multi layer resistance model had been developed and widely applied by many scientists to evaluate the evapotraspiration of the vegetated surface. A two–layer crop resistance model was parameterized to be used for estimating evapotranspiration of paddy field and the surrounding environment in Cidanau watershed, Indonesia.

The model was parameterized by using surface temperature acquired by observation during clear day. The surface temperature resulted from the simulation were compared by the observation data. The parameters in the model were altered, until the simulation result agreed with the observation. By using the modified model, simulation was conducted to estimate evapotranspiration of different surface conditions.

INTRODUCTION

Evapotranspiration from natural surface can be calculated using the models based on electrical resistance that was originally devised by Waggoner (1968). This model had also been developed and improved by Waggoner *et al.* (1969) and Lhomme (1988). Numerical models of surface energy balance were developed by Myrup (1969), which was used to analyze urban heat island phenomenon, and Gutman and Torrance (1975) who analyzed the effect of urban climate to future heat addition and surface roughness. Combining the similar technique with two–layer resistance model, Nakano and Cho (1985) presented the evaluation of plant canopy effect on thermal environment modification. Analyzing thermal environment of the various surface conditions, Nakano and Kuroda (1989), has applied the energy balance model and obtained the energy fluxes of heat flux (H), ground heat flux (G) and the energy for evapotranpiration latent heat flux (λE).

The evaluation of evapotranspiration in a wide area can be troublesome because of the difficulties of acquiring the data of each point of the location. The development of remote sensing technology had overcome this problem. The remote sensing data, i.e. using satellite, are widely used in order to estimate evapotranspiration, such as presented by Sequin and Itier (1983), and Dibella *et al.* (2000). This method reduces the difficulty

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of observing parameters required to estimate the evapotranspiration and leads to more accurate result especially in large area. In the other hands it is not possible to obtain continuous remote sensing data required for estimating variation evapotranspiration of a day lenght, for example, hourly variation. Combining the data observed by remote sensing and the model, more informative results of the estimation can be expected

Before the model can be applied, parameterization is required. This step is very important that most of the time laboratory experiments or field observations are needed. The parameterization then can be performed by alteration of parameters value. The simplest way is by comparing the data resulted from calculation and from the field observation or experiments. In this paper we will discuss the model's formulation, the parameterization and the estimation of evapotranspiration of different land conditions in Cidanau watershed Indonesia.

THE SIMULATION MODEL

The model of energy balance used in this study consists of numerical model of boundary layer transport, radiation exchange and heat exchange calculation. This model is applied to calculate boundary layer properties of potential temperature (θ), specific humidity (q), wind velocity (u) and soil temperature (T). The two–layer resistance model was used to represent vegetation interaction with the atmosphere, when the surface is covered by vegetation.

The energy balance equation for the surface of the earth can be written as,

$$R_n = \lambda E + H + G \tag{1}$$

Where R_n is the net radiation flux, λE is latent heat, H is sensible flux and G is ground heat flux. Here the heat stored by plant and the energy used for photosyntesis are ignored.

Boundary layer transport equations

Wind velocity u, potential θ temperature and specific humidity q in horizontal direction are assumed to be uniform and only changes in vertical direction, neglecting the convection part; the equations are simply arranged as follow

$$\frac{\partial u}{\partial t} = \frac{\partial}{\partial z}\left(K_m \frac{\partial u}{\partial z}\right) \tag{2}$$

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K_h \frac{\partial \theta}{\partial z}\right) \tag{3}$$

$$\frac{\partial q}{\partial t} = \frac{\partial}{\partial z}\left(K_v \frac{\partial q}{\partial z}\right) \tag{4}$$

K_m, K_h, K_v are momentum, thermal and vapor turbulent diffusivity, in which $K_m = K_h = K_v = K$ that can be obtain from the following equation.

$$K = \kappa (z-d) u^* / \phi (z/L) \tag{5}$$

Here, κ is Karman constant, d is displacement height, u^* is friction velocity, ϕ is air stability function. Monin–Obkov length L is the atmosphere stability function's index and given as

$$L=(\rho_a c_p(T_a+273.16)u^3)/gkQ \tag{6}$$

where T_a is air temperature (°C), Q is sensible heat flux, ρ_a is air density and c_p is specific heat of air. The value of L indicates unstable condition ($L<0$) and stable condition ($L>0$). The change of ground temperature is expressed as

$$\frac{\partial T}{\partial t}=\frac{\partial}{\partial z}\left(K_s\frac{\partial T}{\partial z}\right) \tag{7}$$

with T is temperature, and K_s is soil thermal conductivity.

Radiation exchange

In simulation models of plant growth, the absorption of radiation by leaves of a canopy is a major factor governing photosynthesis and transpiration. In this study the canopy is assumed to be homogenous in a horizontal plane. The measured incoming radiation must be distributed over direct and diffuse radiation. Absorption of direct radiation is written

$$I(z)=(1\text{-}a_0)I_0\exp[-\beta(\mathrm{LAI}(H)\text{–}\mathrm{LAI}(z))] \tag{8}$$

where, $I(z)$ is amount of direct downward shortwave radiation at the height z inside plants layer, I_0 is amount of direct radiation above the canopy surface, a_0 is the albedo of plant body opposing direct radiation, LAI(z) is leaf area index measured from soil surface, β is the extinction coefficient due to sun altitude changes, the canopy geometrical gap architecture is assumed spherical. The scattering rate caused by leaf reflection and transmission is assumed as 0.3, as used in Table 1. The ratio of diffused radiation and total radiation is presented as follows

Table 1. The Proportion of diffuse radiation and the extinction coefficients for the spherical leaf angle distribution with sun altitude (after Goudriaan, 1977)

FactorInclination of sun (degree)	5	15	25	35	45	65	85	90
Diffuse/Total	1.00	0.32	0.22	0.18	0.16	0.15	0.13	0.13
Extinction Coefficients (scattering coefficient=0.3)	9.00	5.01	1.03	0.64	0.59	0.50	0.46	0.46

These values are assumed to be uniform for all direction. The absorption by plants canopy is expressed using the same equation as Eq.8 with the extinction coefficient of 0.684. Then, with I_s represents amount of diffused radiation above the plant canopy, total amount of shortwave radiation absorbed by plant S_l is given as

$$S_l=(1\text{-}a_g)I_0[1\text{–}\exp(-\beta\ \mathrm{LAI}(H))]+(1\text{-}a_s)I_s[1\text{–}\exp(\text{–}0.684\ \mathrm{LAI}(H))] \tag{9}$$

Where a_s is the albedo of plants body opposing diffused radiation. Also, total shortwave radiation absorbed by soil S_g is obtained by using the following equation

$$S_g=(1-a_g)[(1-a_0)I_0\exp(-\beta\,\mathrm{LAI}(H))+(1-a_s)I_s\exp(-0.684\,\mathrm{LAI}(H))] \tag{10}$$

With a_g is the soil surface albedo. The shortwave radiation above the canopy is equal to the total of S_l and S_g. Figure 1 shows this relation.

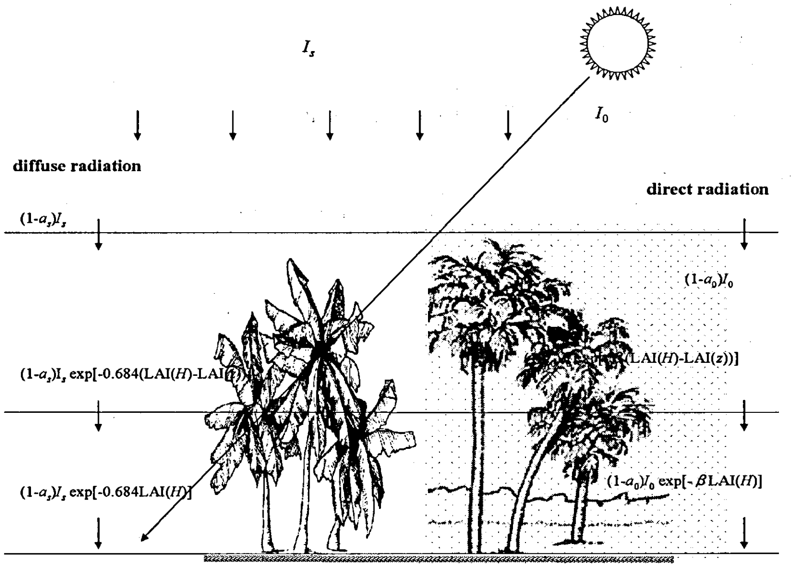

Fig. 1. Extinction and absorption of shortwave radiation.

The downward long wave radiation is not only composed by atmospheric radiation but also almost all part of long wave radiation emmited from soil surface and plant canopy. Since the leaf surface long wave radiation dispersion rate is considered as 0, extinction coefficient become 0.891. Therefore, with the presence of plant canopy, long wave radiation absorption L_l is obtained using the following equation.

$$L_l=[\,\varepsilon_l(L_{\mathrm{sky}}+L_e)-2L_p][1-\exp(-0.81\,\mathrm{LAI}(H))] \tag{11}$$

Where, ε_l is leaf long wave radiation emissivity, L_{sky}, L_e and L_p are long wave radiation emitted from atmosphere, soil surface and leaf surface. Mean while soil surfaces long wave radiation absorption L_g is written as

$$L_g=-L_e+\,\varepsilon_g L_{\mathrm{sky}}\exp(-0.81\mathrm{LAI}(H))+\,\varepsilon_g L_p[1-\exp(-0.81\mathrm{LAI}(H))] \tag{12}$$

Figure 2 shows the relation of long wave radiation extiction and absorption. The obtained value of radiation budget above plant cover surface is proper to the sum of S_l, S_g, L_l and L_g.

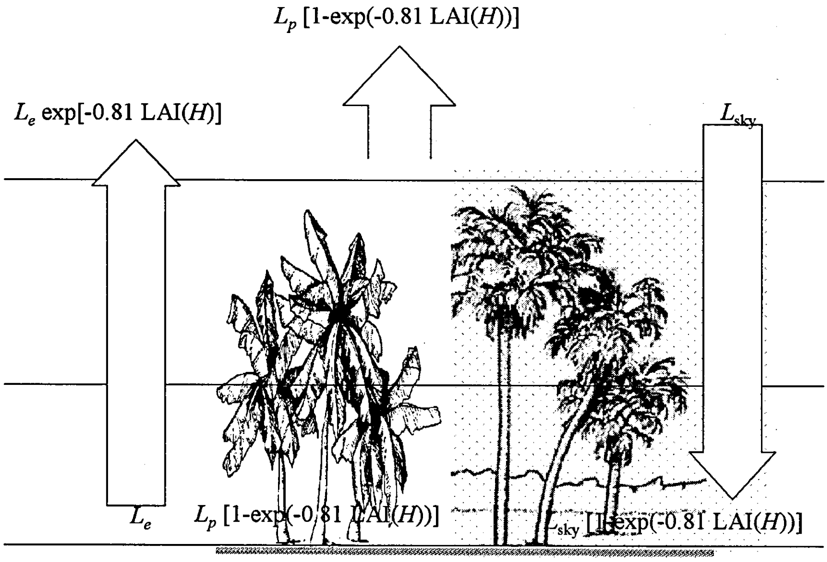

Fig. 2. Extinction and absorption of long wave radiation.

Heat exchange

Energy fluxes on vegetated surface was calculated using two layers resistance model. This model treats plant canopy as a single big leaf with a certain height. This model is depicted in Fig. 3.

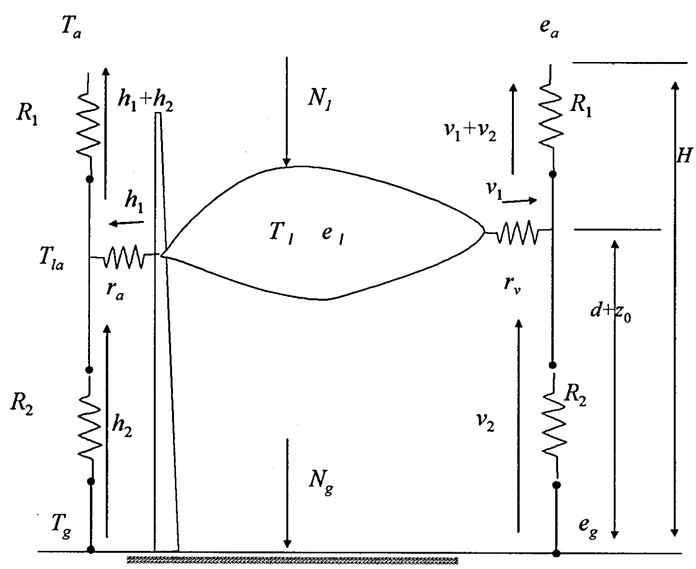

Fig. 3. Two layer resistance model.

The sensible and latent heat transfer is arranged imitating electrical resistance model, and described by the following equations.

$$T_l - T_a = [R_1(h_1+h_2) + r_a h_1] / c_p \rho \tag{13}$$
$$T_g - T_l = [R_2 h_2 + r_a h_1] / c_p \rho \tag{14}$$
$$T_l - T_a + [e_s(T_a) - e_a] / \Delta = [R_1 (v_1+v_2) + r_v v_1] \gamma / c_p \rho \Delta \tag{15}$$
$$T_g - T_l - [e_s(T_g) - e_g] / \Delta = [R_2 v_2 + r_v v_1] \gamma / c_p \rho \Delta \tag{16}$$
$$N_l = h_1 + v_1 \tag{17}$$
$$N_g = h_2 + v_2 + G \tag{18}$$

Here, T_a, T_l and T_g are air, leaf and soil surface temperature; $e_s(T_a)$ and $e_s(T_g)$ are saturation vapor pressure at T_a and T_g; e_a and e_g are the vapor pressure above the canopy and at the soil surface; h_1, h_2, v_1 and v_2 are sensible and latent heat transmitted from leaf surface and soil surface; R_1 and R_2 are resistances of the canopy's layers, r_a is leaf resistance, r_v is latent heat transfer resistance, γ is humidity constant, c_p and ρ are the air specific heat capacity and density, and Δ is the gradient of saturation vapor pressure's curve. The value of T_l , G, h_1, h_2, v_1 and v_2 have to be determined. The air temperature within the canopy layer T_{la} is simply determined by using the following equation.

$$T_{la} = T_l - h_1 r_a / c_p \rho \tag{19}$$

The acquired air temperature is the air temperature of the model that possesses the resembled functions in the actual heat exchange occur in a canopy.

Leaf surface boundary resistance r_a is determined using the next equation, involving leaf effective width W and average wind velocity u_{av}.

$$r_a = 1.8 \sqrt{\frac{W}{u_{av}}} \tag{20}$$

The resistance occurs in latent heat transfer is obtained with taking into account the evaporation resistance r_s, known as stomata resistance, and $r_v = r_a + r_s$. Stomatal resistance r_s is influenced by environmental condition, especially it is strongly affected by solar radiation and soil moisture.

The distribution of wind velocity inside plant canopy can be determined by using momentum exchange equation and in general is expressed by a simple exponential equation.

$$u(z) = u_H \exp[-\alpha (1 - z/H)] \tag{21}$$

In this equation, u_H is wind speed at the height the leaf heat of H, α is attenuation coefficient which is settled by leaf size, slope and gap density.

The diffusion coefficient K is expressed,

$$K(z) = K_H \exp[-\alpha (1 - z/H)] \tag{22}$$

where K_H is the diffusion occurs above plant cover surface. The transfer resistance between two compartments of heights of 0-z_l and z_l -H, are :

$$R_1 = \frac{-H\{1 - \exp[-\alpha (z_1/H - 1)]\}}{K_H \alpha} \tag{23}$$

$$R_2 = \frac{-H\{\exp(\alpha)[\exp(-\alpha z_1/H)]-1\}}{K_H \alpha} \tag{24}$$

Near the soil surface below the canopy, molecules are diffusing properly to the viscosity at the bottom layer. Following Linacre (1972), this layer resistance Rs is presented as,

$$R_s = \sqrt{\frac{\delta_s v}{u_s}} / D_a \tag{25}$$

with δ_s is the average height of soil grain, ν is the viscosity coefficient, u_s is the wind velocity at soil surface ($=u_H \exp(-\alpha)$), D_a is the transport coefficient of air molecule. Equation 24 then is included in Eq. 23 and termed as R_2.

Stomatal Resistance

Stomatal resistance of the plant should be taken into account in estimating latent heat flux transfer, beside boundary resistance or aerodynamic resistance as in the sensible heat flux transfer. In multi–layered resistance model, stomatal resistance is calculated for each layer, except the bottom layer which is the soil surface layer.

There is a general consensus among plant scientist about the stomatal resistance, that it is correlated with number of factors (Lynn and Carlson, 1990). These are the short–term changes in leaf water potential, significant soil drying, vapor pressure deficit, solar radiation, leaf temperature and ambient carbon dioxide. The relation between stomatal resistance and temperatures has been the subjects of previous researches (Smith *et al.* (1988), Shuttleworth and Gurney (1990), Lhomme and Monteny (2000)).

Stomatal resistance r_s were calculated taking into account the minimum stomatal resistance r_{min}, using the equation (Nakano and Cho, 1985)

$$r_s = r_{min} + b/[I + b/(r_c - r_{min})] \tag{26}$$

where, r_c is cuticle resistance and b is a constant. Since latent heat flux density changes depending on r_{min}, the sensible heat flux density will also be affected. The effects of changing the value of r_{min} is shown in Fig. 4. The plant surface temperature is increasing

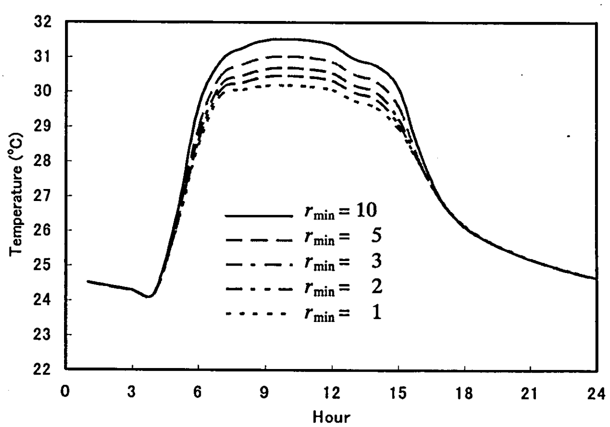

Fig. 4. The effect of changing r_{min} to the plant surface temperature.

when higher r_{min} occurs.

OBSERVATION

The observation was conducted to collect surface temperature and meteorological data of the location. Surface temperature was observed hourly under clear sky condition in the daytime, remotely measured with an infrared thermometer from a high spot.

The study area is mainly a wide paddy field (S 6° 11'49", E 105° 54'25") surrounding by trees, forest and hilly topography. The location is near to a swamp forest belongs to a natural reserve known as 'Rawa Dano' in Cidanau Watershed. From Fig. 5 the difference in surface temperature of different land condition is noticeable.

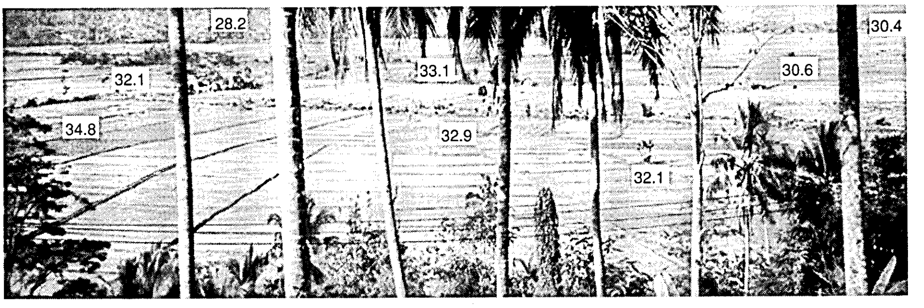

Fig. 5. Surface temperature distribution

RESULTS AND DISCUSSION

The simulation was conducted using the modified model using meteorological data of Cidanau watershed, for 4 land conditions. The calculation of energy fluxes over artificial surface was conducted using a simple surface energy balance model that is not discussed in this paper. The parameters used in this simulation are enlisted in Table 2. These parameters were cited from references (Nakano and Kuroda, 1989; Oke, 2001),

Table 2. Parameters used in the simulation

Parameter	Forest	Bare soil	Paddy field	Artificial
Minimum resistance r_{min} (s/m)	100	300	100	
Leaf Area Index LAI	8	0.5	3.7	
Thermal diffusivities of soil (m^2s^{-1} $\times 10^{-6}$)	0.2	0.4	0.27	0.38
Volumetric heat capacity of soil ($Jm^{-1}K^{-1}$ $\times 10^{6}$)	0.6	0.55	0.65	0.47
Soil water potential (bar)	−1	−1000	0	−10 (20%)
Albedo (%)	15	20	20	20
Roughness length (m)	1.04	0.02	0.09	0.06
Obstacle height (m)	8	0.2	0.7	0.1
Zero–plane displacement height (m)	5.04	0.13	0.44	0.02

meteorological data from local climate station, field measurement and assumption. The boundary condition of air temperature, air humidity, and wind velocity at the height 100 m and soil temperature are 30.7 °C, 0.017 g/g, 3.3 m/s and 31.7 °C.

Surface Temperature.

The estimated surface temperature of 4 different land use types are shown in Fig. 6. Due to lack of observation data, the surface temperature resulted from simulation can only be compared with the data which are available from 10:00 to 16:00. The temperature data was not continuously measured. Remote observation using an infrared thermometer was done on hourly basis, depended on the weather condition. The observation was conducted in the month of August year 2002.

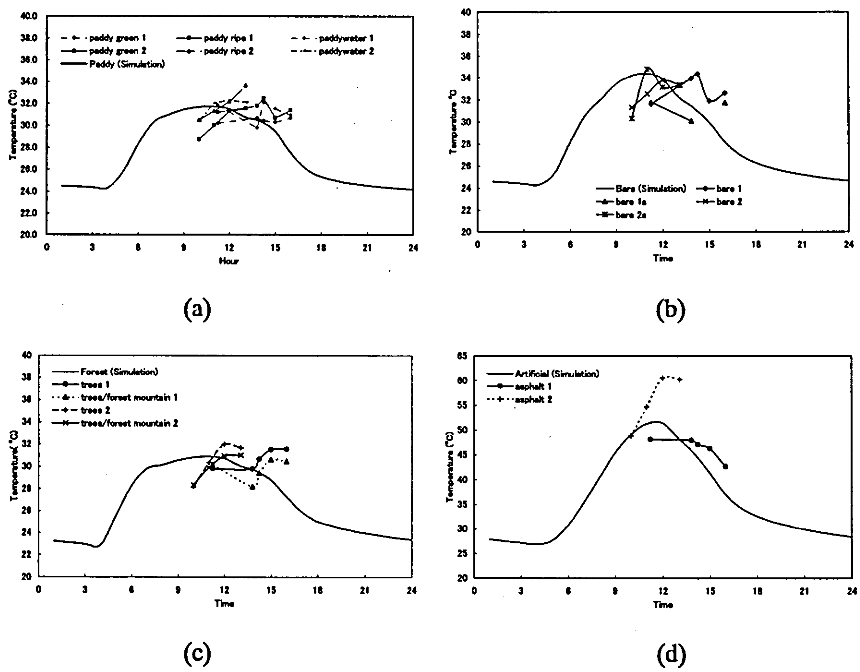

Fig. 6. Simulated and observed surface temperature of (a) paddy field, (b) bare soil, (c) forest (d) artificial surface (asphalt road).

The simulated temperature fluctuates within the range of the measured temperature data of 28 °C to 32 °C (forest), 28 °C to 34 °C (paddy field), 31 °C to 34 °C (bare soil) and 38 °C to 60 °C (asphalt). In the noon time, the simulation results seem to agree with the observation data, especially for paddy fields, forests and bare soils. But in the afternoon, the surface temperatures were underestimated.

The hourly variation of estimated surface temperature of four different land use types shows the effect of surface condition to its thermal environment. Under the same condition of meteorology, temperature of artificial surface (asphalt) reaches more than 50 °C, while the highest forest temperature only about 30 °C, following paddy field and bare soil.

This variation presented in Fig. 7. Here, the effect of plant and vegetation existence to the thermal environment is obvious.

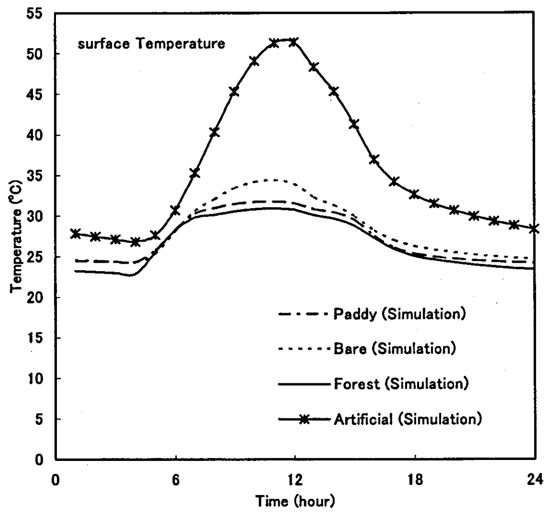

Fig. 7. Hourly variation of simulated surface temperature of four different land uses.

Sensible and Ground heat flux

The net radiation absorbed by the earth surface is dissipated into sensible heat flux, ground heat flux and latent heat flux. Sensible heat flux, when released, will cause the temperature of the environment above ground surface to increase. Ground heat flux in the other hand will be used for heating the soil.

Figure 8 shows the variation of sensible heat flux of each land use. Artificial surface releases very high amount sensible heat flux compared to the others. The forest has the role as the sink of heat energy. This is indicated by the negative sensible heat flux that causes the forest temperature is lower than its environment and. In Fig. 9, characteristic of artificial surface, in this case asphalt road, which has high ground flux, is clearly noticed.

Evapotranspiration

The component of energy balance used for evapontraspiration process is the latent heat flux. Each land use type has different condition of latent heat flux variation (Fig. 10). The latent heat flux of the artificial surface is zero, which means no evaporation occurs, and the whole of surface energy was used to increase the environmental temperature and the ground temperature. The evapotranspiration of bare soil is lower than paddy field. Paddy field usually has a shallow water surface above the soil surface and it contributes to the evapotransoiration. Figure 10 shows that evaporation occurs in four

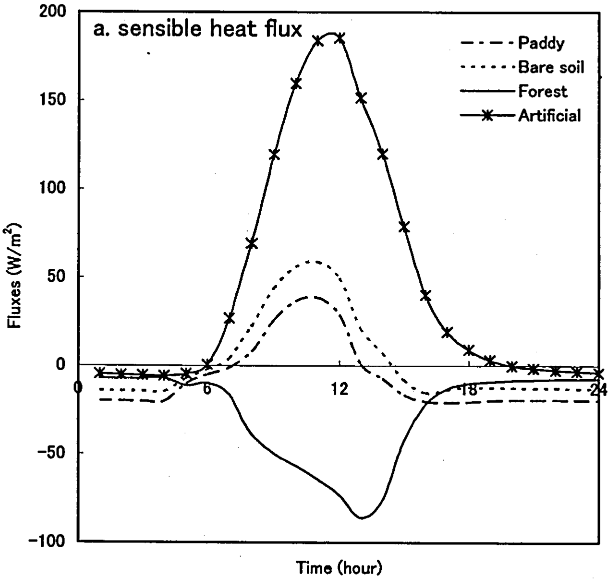

Fig. 8. Hourly variation of simulated sensible heat flux of four different land uses.

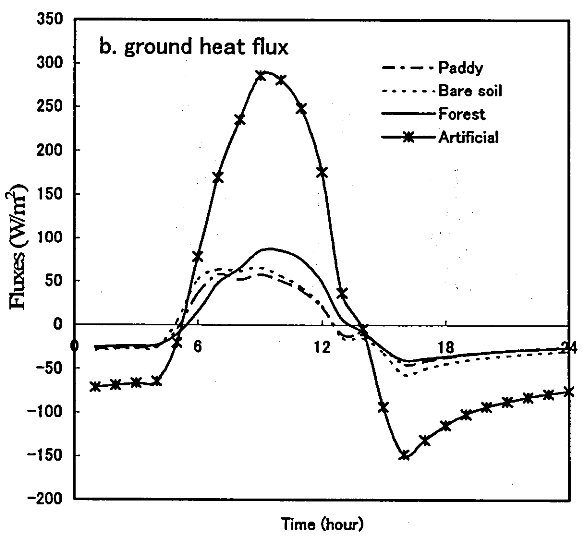

Fig. 9. Hourly variation of simulated ground heat flux of four different land uses.

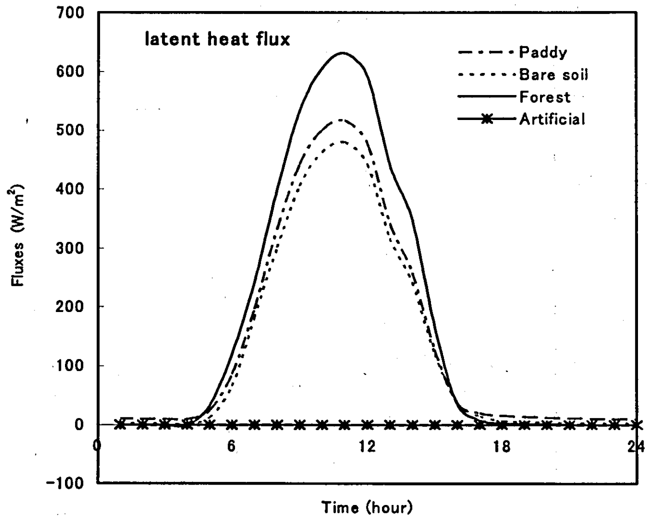

Fig. 10. Hourly variation of simulated latent heat flux of four different land uses.

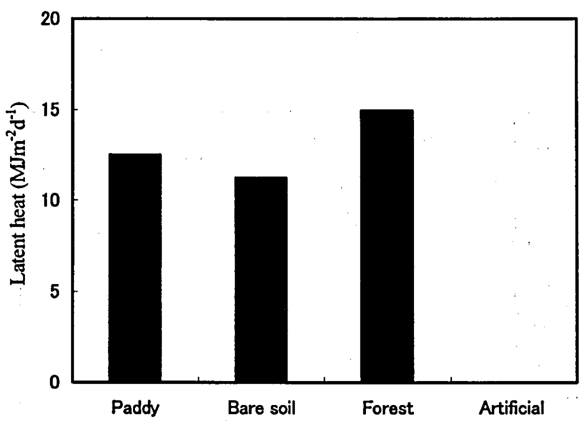

Fig. 11. Total latent heat.

different land uses are, in order from the largest, forest, paddy field, bare soil and artificial field. The total daily latent heat of every land use (Fig. 11) are 12.5 $MJm^{-2}d^{-1}$ (Paddy field), 11.2 $MJm^{-2}d^{-1}$ (Bare soil) and 15 $MJm^{-2}d^{-1}$ (Forest). These values are equal to 5, 4.5 and 6 mm of water.

CONCLUSION

A numerical model of energy balance had been parameterized and used for estimation of evapotranspiration in Cidanau watershed. The parameterization was done by altering parameters in the model while comparing the value of surface temperature from observation and the surface temperature resulted from simulation using the modified model. The simulated surface temperatures seem to be consistent with the observation for the mid–day, but underestimated in the afternoon.

The latent heat flux of the natural surfaces in order from the largest are: forest, paddy field and bare soil, with the total daily 12.5 $MJm^{-2}d^{-1}$ (Paddy field), 11.2 $MJm^{-2}d^{-1}$ (Bare soil) and 15 $MJm^{-2}d^{-1}$ (Forest). These simulated latent heat values are equal to 5, 4.5 and 6 mm of water evapotranspiration.

Further parameterizations are needed to improve the models. The requirement of better and more informative data can be fulfilled by conducting field observation and experiment. The introduction of more effective parameters setting technique is important to be sought, instead of relying on manual trial and error only. A comparative study between the present model and a well–known model is also expected to examine the model's reliability.

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