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Observation of Energy Fluxes and Micrometeorological Environment Variables

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Simulation study of evapotranspiration needs observation data of the corresponding land and environmental. Using models, hourly variation or even more rapidly evapotranspiration variation can be simulated. The simulation results should be verified and compared with observation data, to modify and improve the models reliability.

The rapid variation of latent and sensible heat flux can be provided, most directly, using Eddy–correlation system. Beside this method of mesurement, it is also important to measure standard atmosperic variables such as temperature, humidity, and wind velocity, and also solar radiation as the source of energy. These data can be used to evaluate the evapotranspiration using indirect methods of Penman–Monteith and Bowen ratio.

The observation was conducted at Kyushu University Experimental Farm during summer and early of autumn year 2003. The land conditions chosen for this research were grass field, bare field and paddy field. Observation results show the differences of environmental variables and energy fluxes on each land condition.

INTRODUCTION

Observation of energy fluxes on different land conditions is important to provide reliable data for simulation study. The observation included the direct measurement of energy fluxes, using net radiometer, Eddy–Correlation System (ECS) and ground heat plate. Eddy–Correlation method consists of determining turbulent fluxes of water vapor, momentum, sensible heat or any other mixtures from covariance (Brutsaert, 1982), and could provide most direct measurement of latent and sensible heat flux.

Beside of obtaining latent heat flux from ECS, standard indirect methods for estimating ebapotranspiration were also used, which are Bowen ratio and Penman–Monteith equation. Measurements of standard atmospheric variables such as air temperature, humidity and wind velocity were also conducted to obtain the required data.

The purpose of this observation is to collect data required in simulation study of evapotranspiration on different land condition. The data will be used for verification and parameterization of the model. In this paper the results of the observation is presented.

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OBSERVATION

The observation was conducted at Kyushu University Experimental Farm, Kasuya–machi, Fukuoka. Energy fluxes and environmental parameters were measured on three different land condition of grass, bare and paddy. The height of grass was about 1–1.5 m. The height of paddy from the soil surface was about 70 cm and the soil surface was covered with 5 cm depth of water. The measurements were conducted during the summer, August 12–25 and in the early of autumn, November 1–10, year 2003.

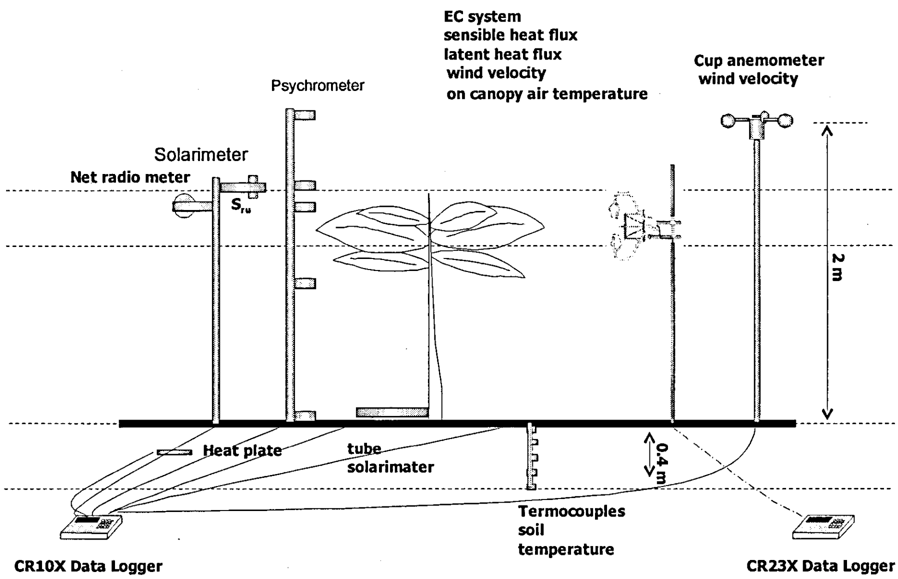

Fig. 1. Experiment setting.

Measurement of latent and sensible heat flux was done using Eddy–Correlation System (ECS). The ECS consists of fine wire thermocouple, 3 dimensional sonic anemometer and krypton hygrometer. Basically these instrument measures air temperature using fine wire thermocouple T_{fw}, sonic temperature T_s, wind velocity in 3 direction (u_x, u_y and u_z) and water vapor. The data were then obtained by a data logger with ECS program installed in it. These basic data and its fluctuation were analyzed and used to calculate latent and sensible heat fluxes (E and H) .

Net solar radiation R_N was measured using net radiometer, place over the ground surface. Two solarimeters of the same type were put in opposite direction, to measure shortwave upward S_{ru} and downward S_{rd} radiation. A tube–type solarimeter was used to measure downward shortwave S_{rg} arriving at the soil surface below the plant canopy. Heat plate was placed in the soil near the surface to measure ground heat flux (G).

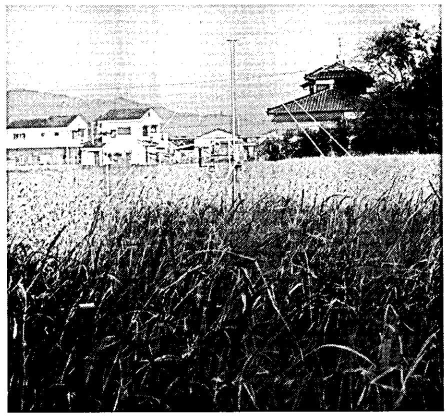

Fig. 2. Measurement with Eddy Correlation System.

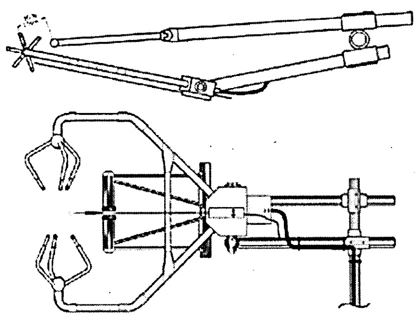

Fig. 3. Eddy Correlation System.

Psychrometer with pairs of dry bulb and wet bulb thermocouple was set at the field to obtained temperatures required in calculating vapor pressure. The thermocouple used for this observation is a copper–constant type. Measurement results of two level height is presented, which are at the soil surface and at 2 m above the soil surface. The vapor pressure e_a indirectly obtained from these dry and wet bulb air temperature using the following equation which commonly written :

$$e_a = e_s\,(T_w) - \gamma(T_a - T_w) \tag{1}$$

Here e_s (T_w) is saturation vapor pressure at wet bulb temperature T_w, T_a is dry bulb temperature and γ is psychrometric constant.

Wind velocity obtained using cup–type anemometer. Soil temperature was measured for different depths. The soil temperatures measurements was done using thermocouple placed in the soil at 0, 10, 20, 30 and 40 cm depth, and using button–type of temperature

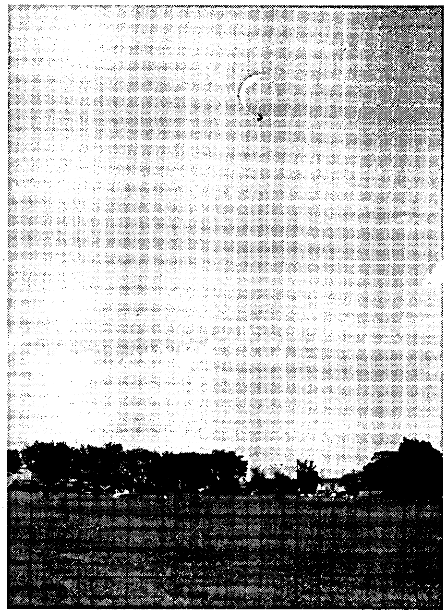

Fig. 4. Measurement using balloon.

sensors, placed at 0, 25, 50 and 100 cm depth. Leaf parameter was simply measured by placing 3 parallel thermocouple pairs on leaves. The result is respectively an average leaf temperature.

A helium balloon was needed to lift instruments and sensors to measure air temperature, humidity and wind velocity in the higher position. Three kinds of instruments were used to obtain these data. Button–type of temperature sensors were put on the wind velocity sensor cable hanging from the balloon, every 10 meter. They were used to obtain temperature profile of the air from the surface to the balloon during airborne.

PREDICTION OF MISSING DATA USING ARTIFICIAL NEURAL NETWORK (ANN)

During the observation, problems occurred and caused missing data in the measurements. This is because of the unchecked empty water tank of wet bulb thermocouple, which lead to the sensed temperature was the same as which was measured by dry bulb thermocouple, and also a set of sensors were incidentally disconnected. One of the missing data is wet bulb temperature measured at 2 m T_{w5} above the soil surface. This data is very important since it is necessary for calculation of vapor pressure at 2 m, which is needed for calculation of evapotranspiration using Penman–Monteith Equations and Bowen Ratio method.

Artificial Neural Network (ANN) was used to estimate the missing data. ANN has been widely used in biosystem and meteorological fields such as for estimation of

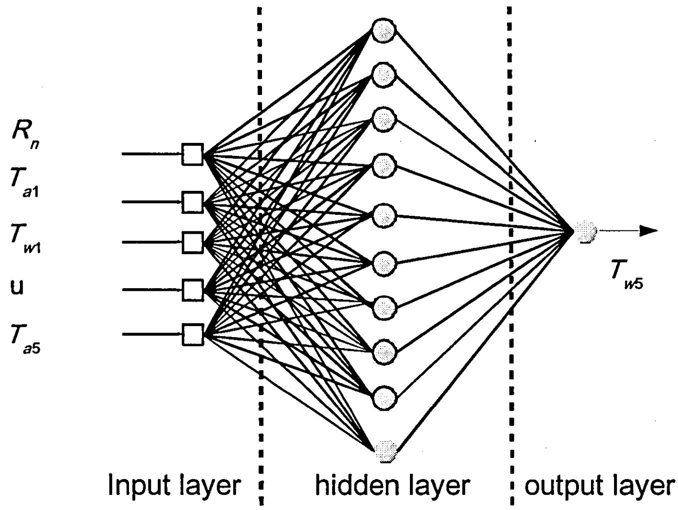

Fig. 5. Artificial Neural Network for estimation of missing wet bulb temperature.

photosynthetically active radiation (PAR) (López *et al.*, 2001), daily solar radiation (Elizondo *et al*, 1994) and potential evaporation (Tahir, 1998). This system has proven its capability to make estimation of unknown parameters, such as weather, when there was uncertainty and the related model was not available.

Estimation of T_{w5} during the day when it was not measured was done using ANN, having inputs of net radiation, wind velocity, air temperature (dry bulb T_{a1} and wt bulb T_{w1}) at the soil surface and air temperature at 2 m T_{a5}. A feed forward ANN was constructed and trained using available data, and then used to give output of T_{w5}. The input layer of the ANN consists of 5 neurons, the hidden layer was constructed by 10 neurons, and the output layer only has a single neuron (Fig. 5). This ANN was trained with learning rate of 0.01.

EVAPOTRANSPIRATION ESTIMATION USING BOWEN RATIO METHOD AND PENMAN-MONTEITH EQUATION

Bowen ratio method is one of the indirect standard applications to calculate the energy budget. This method requires R_N. Bowen ratio β can be written as:

$$\beta = \gamma \frac{(T_2 - T_1)}{(e_2 - e_1)} \tag{2}$$

where T_1 and T_2 are air temperatures; e_1 and e_2 are vapor pressure at T_1 and T_2. Using energy balance, E can be obtained

$$E=R_N\text{-G}/(\beta+1) \tag{3}$$

and

$$H=\beta E \tag{4}$$

The FAO standard Penman–Monteith equation (Allen, 1998) to calculate E takes into account R_N, G, vapor pressure deficit (e_s-e_a), aerodynamic resistance r_a and bulk surface resistance r_s is written as follow:

$$E=\frac{\Delta(R_N-G)+\rho_a c_p \dfrac{(e_s-e_a)}{r_a}}{\Delta+\gamma\left(1+\dfrac{r_s}{r_a}\right)} \tag{5}$$

where ρ_a is the mean air density at constant pressure, c_p is the specific heat of the air and Δ is the slope of the saturation vapor pressure temperature relationship. These methods of calculating evapotranspiration were used to estimate E from observation data, to be compared to those acquired from Eddy–Correlation system.

RESULTS AND DISCUSSION

The fluxes measurements resulted interesting energy fluxes composition on each surface condition. The energy fluxes composition on each field is different (Fig. 6). In this figure ground heat flux G was extracted from net radiation R_N, and latent heat flux LE

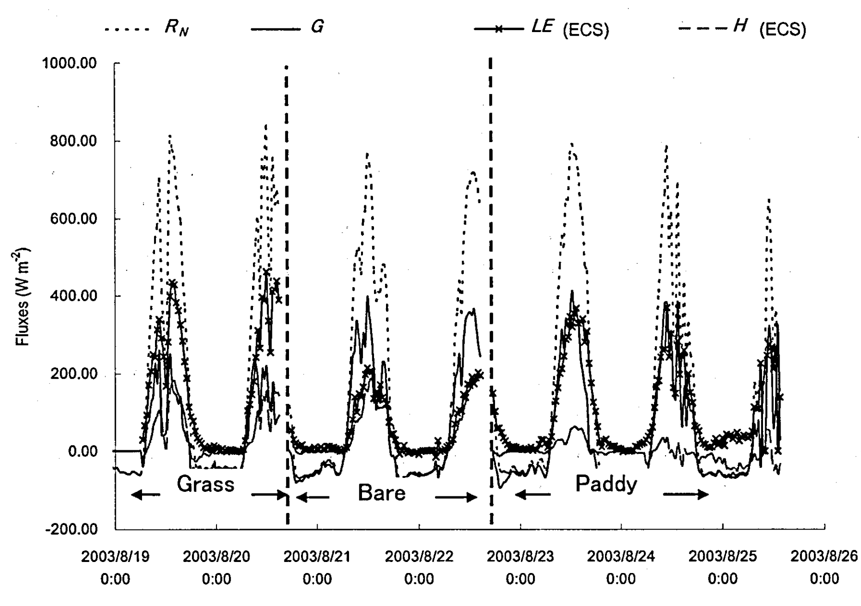

Fig. 6. Observed energy fluxes.

and sensible heat flux H from ECS.

On grass and paddy fields, the largest part of energy was used for evapotranspiration, indicated by the large value of LE. The grass field released small amount of H, this is a common behavior of vegetated surface, where evaporation was the dominant means of dissipating the daytime radiative surplus as shown in textbook such as Oke (2001). The similar condition also occurred on paddy fields portion of LE and H. Bare field on the other hand release less LE and dissipated large portion of energy as G.

Air temperature at soil surface on grass field and bare field are almost always higher than at 2 m height. The opposite condition happened on paddy field. This can be seen in Fig. 7.

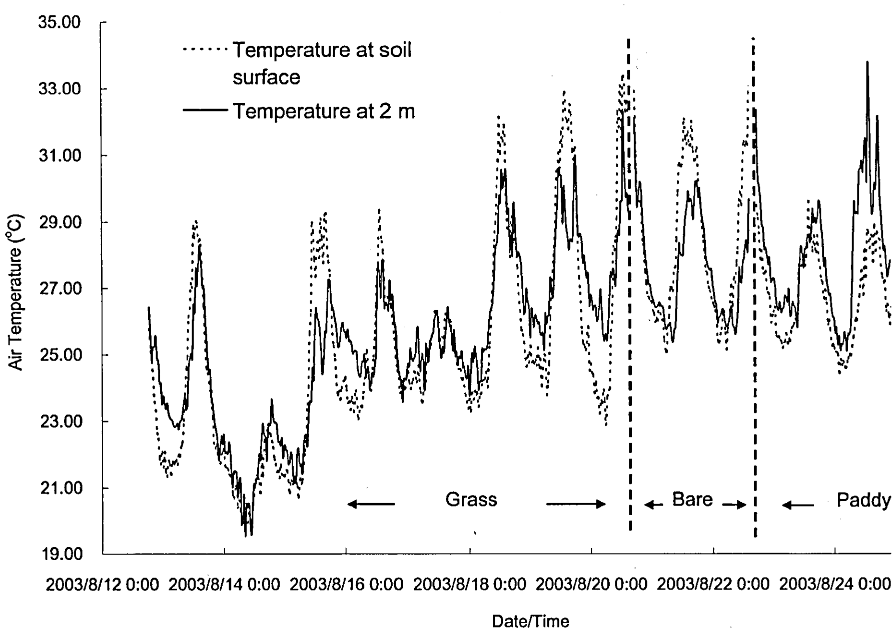

Fig. 7. Air temperature.

The results of wet bulb temperature estimation using ANN is shown in Fig. 8. The temperature from ANN (T_{w5NN}) is fluctuating following its corresponding observation data T_{w5}, but somehow it seems to follow the fluctuating behavior of the dry temperature T_{a5} as one of inputs for the ANN. This results has not yet been analyzed further, but hopefully this system can be useful if more training of this ANN is conducted.

The soil temperature variation at the soil surface and 40 cm height can be seen in Fig. 9. In this figure, the temperature variations of three different land conditions were presented. The highest temperature occurred on the surface of the bare soil, where the temperature at the surface is about three time the 40 cm depth's temperature. The temperature of grass field soil shows no big difference between the surface and 40 cm depth. The lowest soil temperature at the paddy field was possibly because it was covered by

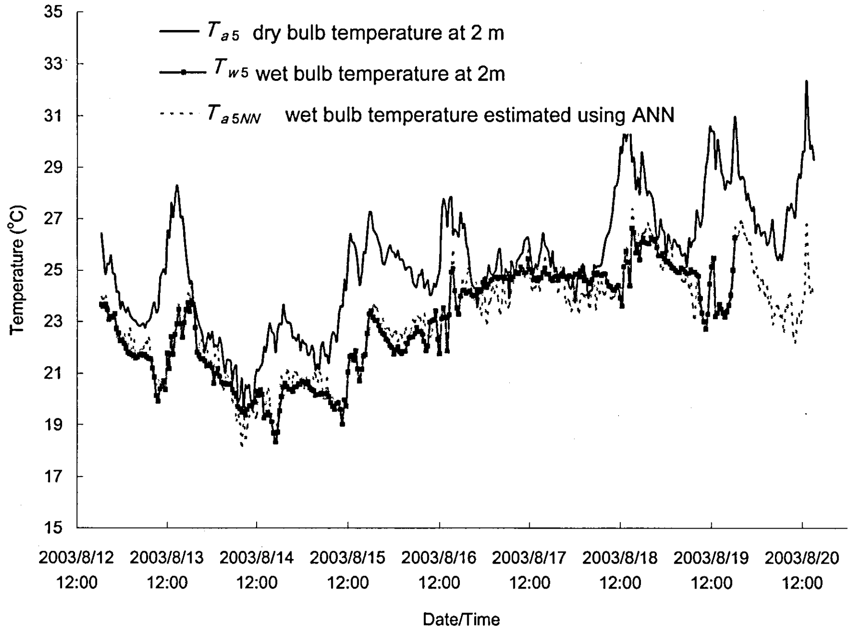

Fig. 8. Wet bulb temperature estimation using ANN.

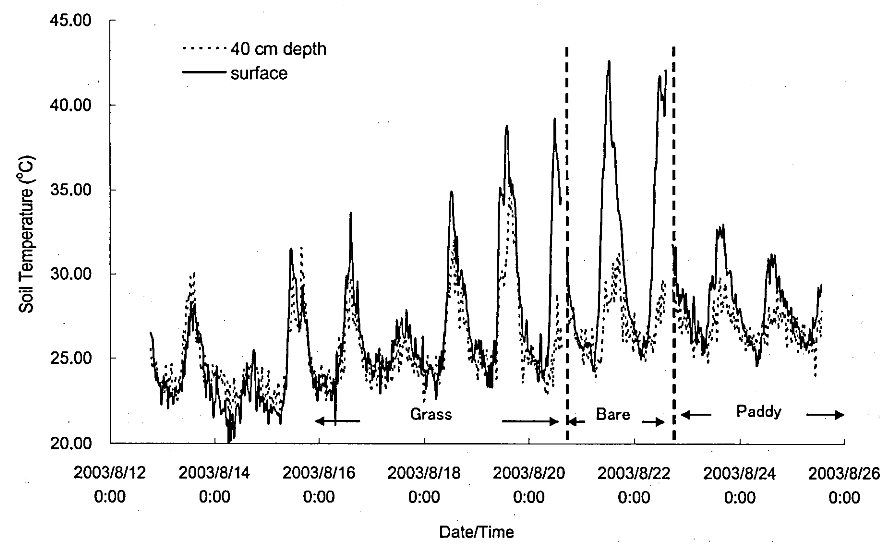

Fig. 9. Soil temperature of different surface condition.

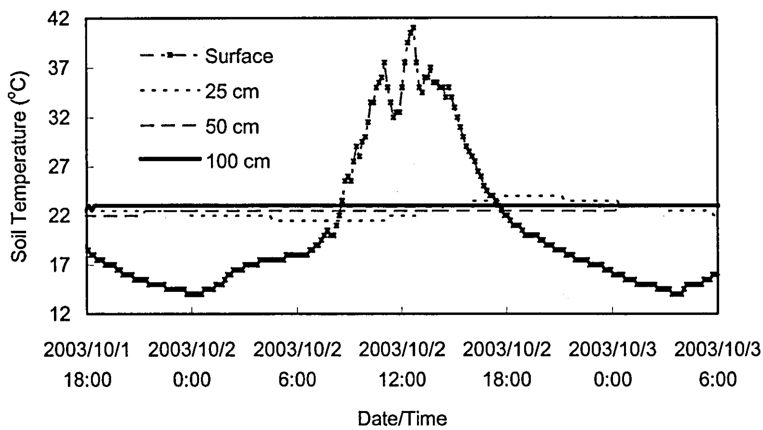

Fig. 10. Diurnal soil temperature variation in depth and time.

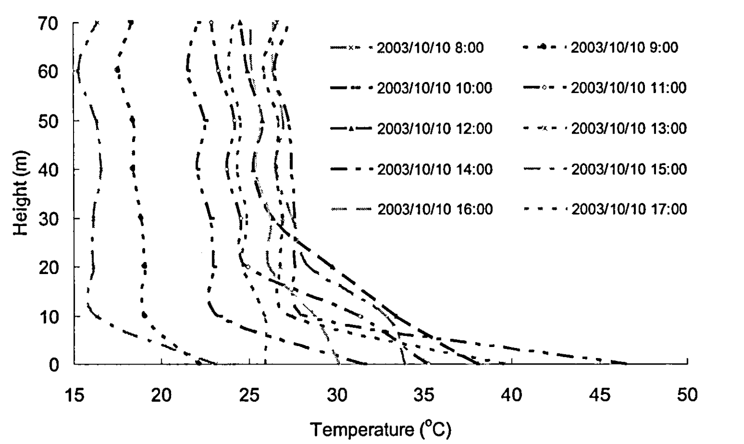

Fig. 11. Air temperature profile between heights 0–70 m from the surface.

water.

The diurnal variation of soil temperature in time and depth showed in Fig. 10 shows similarity to the hypothetical temperature variation, which follows sinusoidal fluctuation mentioned in Campbell (1998). The deeper the soil is the temperature varies less. In this figure, the soil temperature at the surface increases rapidly and reaches its peak at noon-time when the solar radiation is at its highest intensity. Compared to the surface, the temperature variation at deeper depth shows a time lag to reach its maximum and the deeper the soil is the lag is larger, as shown by temperature at 25 and 50 cm depth. The temperature at 1 m depth can be considered as steady at daily basis and it is proper for lower boundary layer in soil temperature exchange simulation.

Figure 11 shows the profile of air temperature distribution, obtained using sensors on

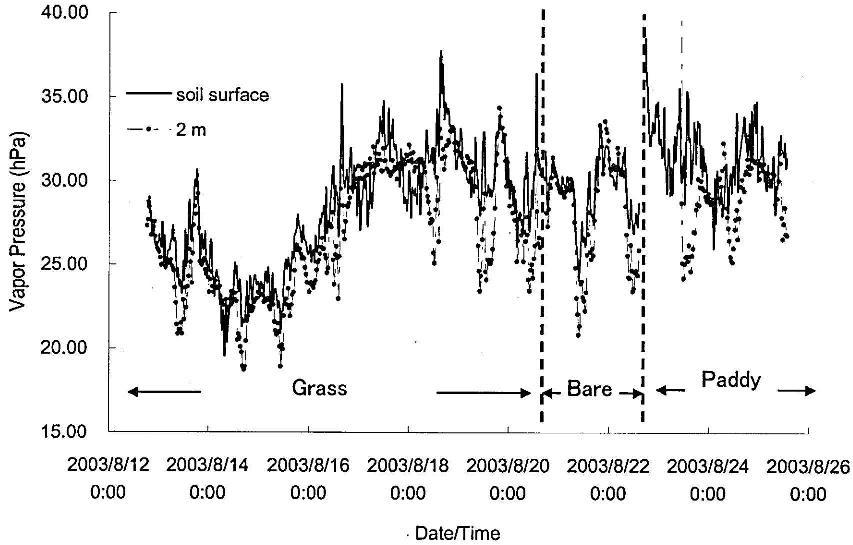

Fig. 12. Vapor pressure variation.

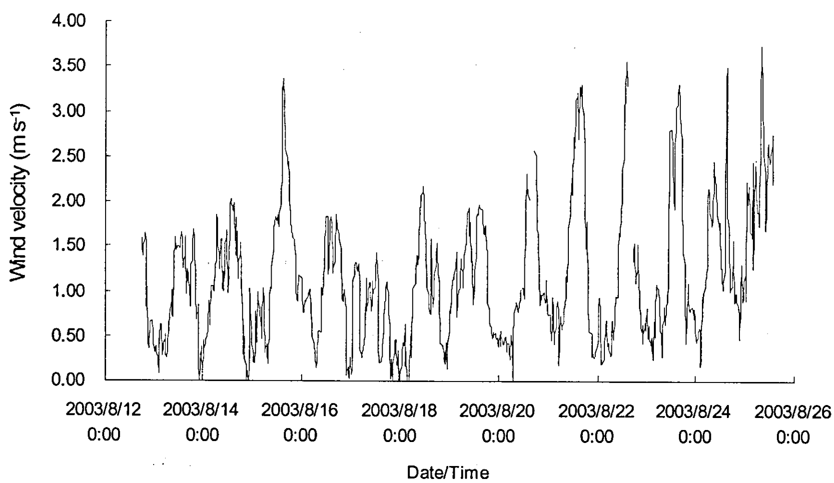

Fig. 13. Wind velocity variation.

a cord hanging from the balloon at 70 m height, every 10 m down to the soil surface. The highest air temperature in noontime was at the surface. The air temperature from the top down to 30 m was uniform, and increasing at the height below 30 m.

Vapor pressure variation is generally higher and fluctuates more rapidly near the soil surface, especially on the grass and paddy fields (Fig. 12). On a bare soil, the vapor pres-

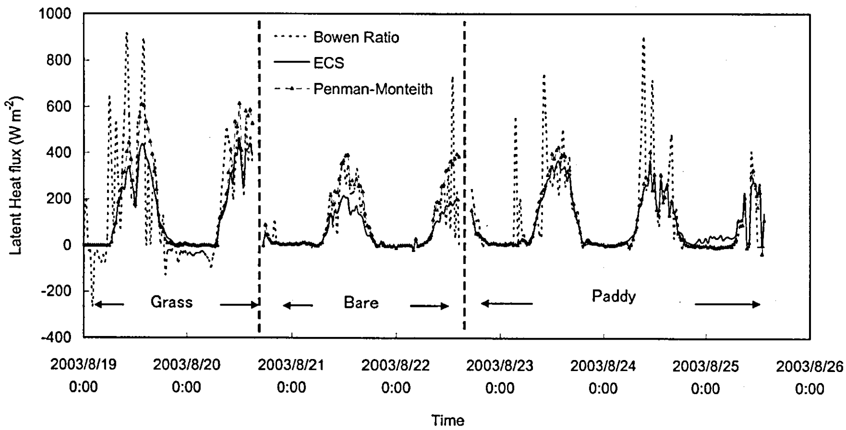

Fig. 14. Latent heat flux.

sure at the surface and 2 m seems to have the same value. In the other hand, the difference is obvious on paddy field, which is also having its soil surface covered by water. The similar with paddy field, the vapor pressure also differs on grass fields. These are understandable as there were vegetation covers and water, which modified the air humidity.

The variation of wind velocity during the observation is presented in Fig. 13. Figure 14 shows latent heat fluxes observed by ECS, indirectly obtained using Penman–Monteith equation and Bowen ratio method. In most case in this result Penman–Monteith calculated latent heat flux fits the ECS measurements results better than Bowen ratio method.

CONCLUSION

The observation of energy fluxes and micrometeorological environment variables had been conducted to provide data required for simulation study. The results give a clear understanding of the effect of surface condition to its environment. This can be seen through the differences of energy fluxes composition, temperature and vapor pressure presented in this paper.

The air temperature above 30 meter is considerably uniform, and the variation is increasing below this height. Soil temperature variation in depth and times shows that the temperature at 1 m depth is steady and good for lower boundary layer in soil temperature simulation. The use of ANN to estimate missing data seems to be reliable with proper training and enough data, and can give solution for estimation with limited inputs. Penman–Monteith method gives estimation results the fits the ECS measurement results better than Bowen ratio method.

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