Continuous measurement of evaporation and energy balance components in the field

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1. Introduction

In order to quantify the energy balance at the soil-atmosphere interface, reliable estimate of evaporation is required. The process of evaporation is a function of soil physical parameters such as moisture, vapor pressure, temperature gradient, radiation and air-turbulence. Due to the involvement of these complex processes it has been a challenge to accurately estimate evaporation and subsequently the latent heat flux. This paper describes a technique in evaluating continuously, the rate of heat fluxes at the bare soil-atmosphere interface using the 'open chamber system'[1)].

2. The open chamber system

Figure 1 schematically illustrates the open chamber system used for continuous measurement of evaporation from bare soil surfaces. As a detailed description of the chamber system and its accuracy in measuring evaporation are presented in Aluwihare et al.[1)], only a brief explanation is given here. The evaporation measuring equipment is based on the idea, that when an air stream is injected into the chamber, the vapor flux from the soil surface to the chamber increases absolute humidity of the extracted air. The evaporation rate is calculated in the following manner,

$$E = Q(\beta_{out} - \beta_{in})/\rho A \tag{1}$$

where, E is the evaporation rate, Q is the volumetric flow rate of the air in the chamber system, β_{out} and β_{in} are the absolute humidity of the air after and before passing through the chamber respectively. The uniqueness in this chamber is that it is completely open at its inlet. At a given time, temperature and relative humidity at the inlet and outlet, flow rate through the system and net radiation data are directly recorded with a data logger connected to a computer, which gives the evaporation rate and net radiation flux in return. The accuracy of the chamber under no rainfall conditions was found to be high enough to rely on its evaporation measurements[1)].

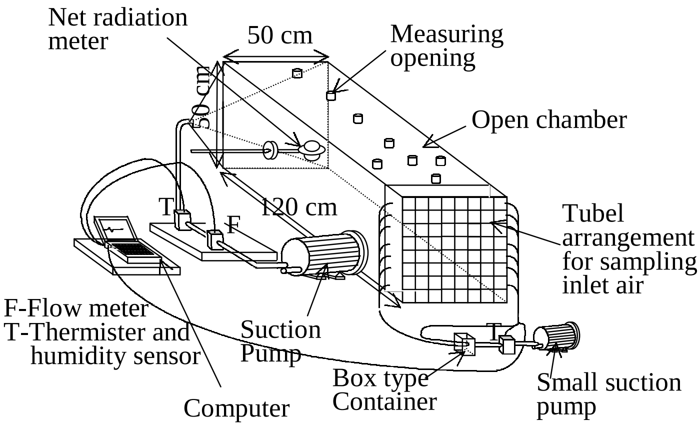

Fig.1 Schematic illustration of the open chamber system for measuring evaporation

3. Determination of the surface energy balance

The energy balance at the land surface is given by,

$$R_n = LE + G + H \tag{2}$$

where R_{net} is the net radiation, LE and H are the latent and sensible heat fluxes respectively and G is the soil heat flux. The latent heat of vaporization is found by the following relation[2)];

$$L = \left(\frac{R_d T_s^2}{0.622 e_s^*} \right) \frac{de_s^*}{dT} \tag{3}$$

where L is the latent heat of vaporization, T_s is the temperature of the evaporating surface, e_s^* is the saturated vapor pressure at T_s and de_s^*/dT is the rate of change of the saturated vapor pressure with respect to T. The latent heat flux is obtained by multiplying the evaporation rate measured by the equipment with the latent heat of vaporization at each time. If the soil heat flux can be determined by heat flux plate measurements, the sensible heat can be obtained as the residual of equation (2).
The latent heat flux can also be expressed as;

$$LE = \frac{\rho C_p}{\gamma} \left(\frac{e_s^* - e_a}{r_s + r_{av}} \right) \tag{4}$$

where ρC_p is the volumetric specific heat of air, γ is the psychrometric constant, e_a is the vapor pressure of air at a reference

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level and r_s and r_{av} are surface resistance and aerodynamic resistance for vapor respectively. Assuming aerodynamic resistance for water vapor and sensible heat transport from the surface upward to some reference level are same, the surface resistance to evaporation can be estimated with a known aerodynamic resistance.

3. Field measurements

Field measurements were carried out in an open, bare field in the premises of Saitama University from 21st March 2001. The soil can be described as silty sand, with a dry density of 1.32g/m^3, specific gravity of 2.73 and porosity of 48%. The selected experimental plot was well wetted by a rainfall occurred 2 days before the experiment was started. Eight thermistors were installed just beneath the soil surface in measuring soil surface temperatures and two heat flux plates were kept under the topsoil layer, in facilitating soil heat flux measurements. The open chamber was placed on the selected field and measurements were started for a period of four days of fair, sunny weather conditions. The results are presented from day 2 of the experiment, as a technical error resulted in misreading the data collected on day 1.

5.Results

Hourly average values of measured net radiation, soil heat flux, latent heat fluxes and calculated sensible heat fluxes for a period of 3 days are shown in Fig. 2. The actual latent heat flux is compared with the potential value calculated using Penman –Monteith equation, in Fig.3. The courses of hourly averaged surface and air temperatures are given in Fig.4. In Fig. 5 the derived surface resistances are plotted against the topsoil moisture.

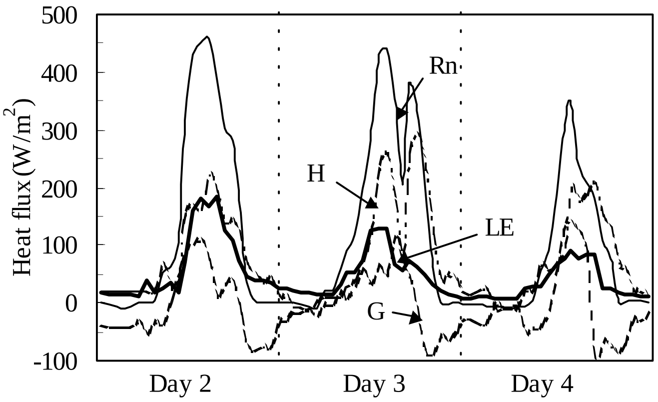

Fig. 2. Temporal variation of energy balance components

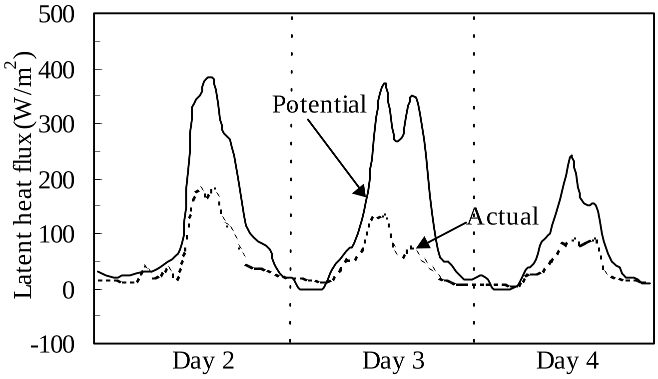

Fig.3. Temporal variations of actual and potential latent heat flux calculated using Penman-Montieth equation

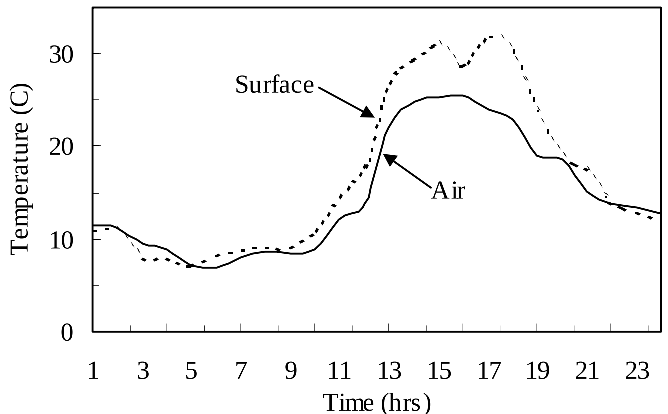

Fig. 4. Temporal variation of measured surface and air temperatures on Day 3 of the experiment

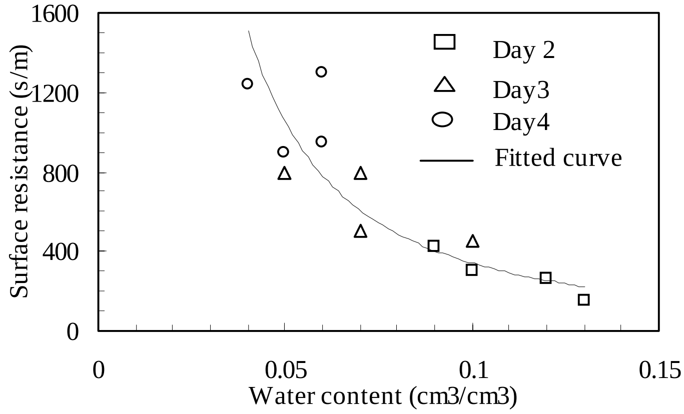

Fig. 5. Variation of soil surface resistance with top 0-1 cm soil moisture

6. Conclusions

The open chamber system can be used in continuous computing of both evaporation rate and energy balance components at the surface. Although there is a large difference between the potential and actual evaporation rates during daytime, the difference seems to be less during nighttime. The surface resistance can be well modeled as an exponential function of soil moisture in the top 0-1 cm on bare soil.

7. References

1) Aluwihare S. and Watanabe K., (2001): A new open chamber for measuring evaporation, Annual Journal of Hydraulic Engineering, JSCE, Vol.45
2) Brutsaert, W.(1982):Evaporation into the atmosphere, Kluwer Academic Publishers