A New Heat Pulse Sensor for Measuring Soil Profile Evaporation

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Problem and Objective

- Water evaporation from near-surface soil is a key component of the hydrological process in soil-plant-atmosphere system, yet few technologies are available for measuring soil profile evaporation in situ.
- Recently a 3-needle heat-pulse probe has been proved to be a promising tool for continuously monitoring water evaporation from soil (Heitman et al., 2008). Due to its limited measuring volume, however, several these heat-pulse sensors have to be installed at different depths to complete the evaporation measurement at a given site. This brings about the challenge to install the individual sensors accurately at specific depths, which is essential for the success of the technique. Furthermore, additional sensors are required to record soil temperatures at the topmost layers.
- In this study, a multi-needle heat-pulse sensor is designed to overcome the above difficulties. The ability of the sensor for monitoring the dynamics of soil temperature, thermal properties, and evaporation in the 0-5 cm soil layer was investigated.

Materials and Methods

- **The sensor**. The new probe has seven thermocouple needles, and four heater needles each enclosing a heater wire and a thermocouple (**Fig. 1**). The top three needles are spaced 1-mm apart, and the remaining needles are spaced 6-mm apart.
- **The procedures**. The experiment was conducted in a sandy loam soil at the China Agricultural University. The sand, clay, and organic content of the soil is 79.8%, 12.3%, and 0.18%, respectively. The sensor was inserted into the soil horizontally with the top-most needle located 1 mm below the soil surface. After a rainfall event, heat-pulse measurement was conducted consecutively on the four heater needles in a 4-hour interval.
- **Calculations**. The heat balance equation for a soil layer between depths 1 and 2 is (Gardner and Hanks, 1966):

$$(H_1 - H_2) - \Delta S = LE \qquad (1)$$

where H_1 and H_2 are the inflow and out flow sensible heat fluxes (W m^{-2}) at depth 1 and 2, respectively, ΔS is the change in heat storage in the soil layer (W m^{-2}), L (J m^{-3}) is the latent heat of water vaporization; and E is the evaporation rate (m s^{-1}). H can be determined by the Fourier's law,

$$H = -\lambda dT/dz \qquad (2)$$

where λ is soil thermal conductivity (W m^{-1} ^{o}C^{-1}), and dT/dz is the temperature gradient (^{o}C m^{-1}).

The change in soil heat storage ΔS is estimated from the soil temperature measurements and volumetric heat capacity (C, J m^{-3} ^{o}C^{-1}) :

$$\Delta S = \sum_{i=1}^{n} C_{i,j-1} \frac{T_{i,j} - T_{i,j-1}}{t_j - t_{j-1}} (z_i - z_{j-1}) \qquad (3)$$

where *z* (m) is soil depth and the subscripts *i* and *j* indicate soil depth layers and time steps, respectively.

Finally soil evaporation in a given layer is estimated from:

$$E = \frac{(H_1 - H_2) - \Delta S}{L} \qquad (4)$$

Acknowledgement

This work is funded by the Basic Research Development Program of China (973 Program, 2009CB118607).

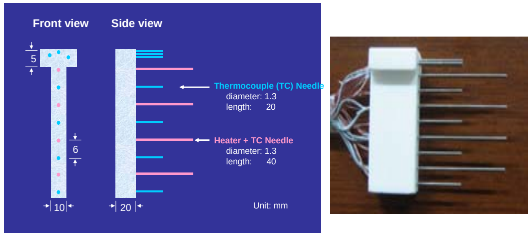

Fig. 1 Schematic view (a) and the actual body (b) of the multi-needle heat-pulse probe for measuring soil profile evaporation.

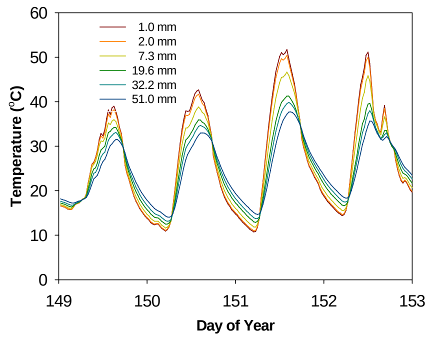

Fig. 2. Soil temperature dynamics at different depths from day 149 to day 153, 2009.

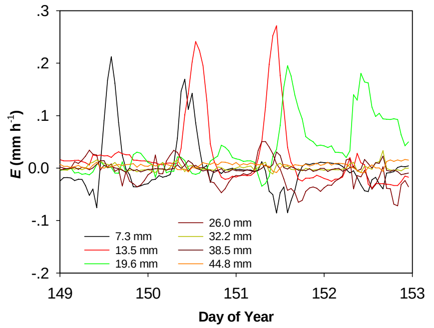

Fig. 4. Measured evaporation rate at different soil depths in a drying period from day 149 to day 153, 2009.

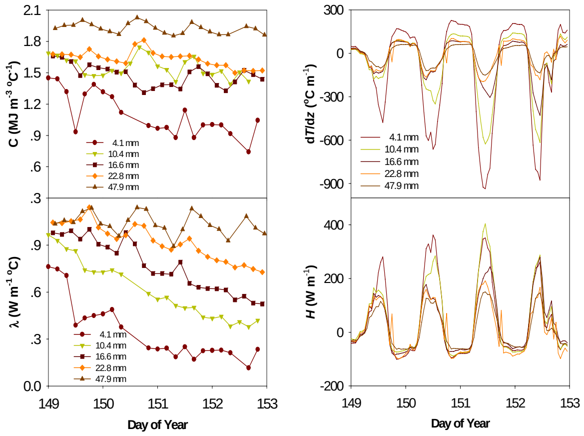

Fig. 3. Temporal changes of the soil volumetric heat capacity (*C*), thermal conductivity (λ), temperature gradient (d*T*/dz), and soil heat flux density (*H*) during the evaporation process from day 149 to day 153, 2009.

Results and Conclusions

- The accuracy of soil temperature data affects the reliability of the calculated sensible heat flux density and heat storage. **Figure 2** shows that the multi-needle heat-pulse probe captured the diurnal dynamics in soil temperature, even at the top 1-2 mm layers.
- When the soil was dried from day 149 to day 153, volumetric heat capacity *C* and thermal conductivity λ near soil surface decreased continuously, but near surface temperature gradient and sensible heat flux increased to a maximum at day 151 and then decreased (**Fig. 3**), indicating that the new heat-pulse probe is able to provide the dynamic information of soil thermal properties and sensible heat flux. At soil depths greater than 30 mm, soil thermal properties did not change significantly.
- Immediately after irrigation, evaporation occurred near soil surface (7.3 mm), advanced to the 13.5 mm depth in two days, and to the 19.6 mm in three days (**Fig. 4**). No apparent evaporation was noticed at soil depth greater than 30 mm. Thus the new sensor is able to quantify the soil layer and magnitude of evaporation rate.
- Further work is undergoing to compare the evaporation data from the multi-needle heat-pulse probe against the measurements from other techniques.

References

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