

# Estimation of soil and vegetation heat fluxes using the two-layer model and radiometric temperatures for partial canopy cover

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## Introduction

In the recent years, studies on estimation of surface heat and water vapor fluxes from sparsely vegetated surfaces have been reported frequently. The two-layer model proposed by Shuttleworth and Wallace (1985) and revised by Shuttleworth and Gurney (1990) (below demoted by S-W model) is the most successful and widely discussed model because it gives an adequate physical representation of heat and vapor transfers in complex surfaces. However, the use of S-W model is limited for its requirement of component temperatures to solve the equation set, which are still not available from the regular observation and retrieval of the most space-borne remote sensors. In this work, an alternative way of using S-W model with radiometric temperature was proposed, and validated.

## Methodology

Considering the difference between component (soil and foliage) temperatures (CTD) are caused mainly by the difference in water availability for evaporation and transpiration, which can be indicated by wetness of the surface layer and root layer of soil, respectively, we proposed assumptions of the CTD at dry point, wet point, and transition point corresponding to different conditions of water availability. The definitions of dry point and wet point are similar as those in SEBS (Su, 2002), and differ in processing soil and foliage components individually. The transition point occurs when surface layer is dry and root layer is still wet, which is understandable and predictable in natural vegetation because the drying-off process after a rainfall or irrigation event starts from the surface.

The state variables at the three points can be derived based on the assumptions and the S-W model, such as aerodynamic temperature, CTD, and soil and foliage temperature. And then radiometric surface temperature can be simulated using a directional thermal radiation transfer model. Comparing between the measured radiometric surface temperature and the simulated ones can tell us the overall status of soil wetness of the system. On the other hand, the sensible and latent heat fluxes of the soil and foliage can be calculated by the aid of a simple assumption.

## Data

Two sets of *in-situ* data were used for validation: data from the 'Quantitative Remote Sensing theory and application for Land Surface Parameters (QRSLS)' project at Shunyi, Beijing, 2001, and The 'Watershed Airborne Telemetry Experiment Research (WATER)' project in the Heihe River Basin, 2008. The surface type is winter wheat at Beijing site, and maize at Heihe site, respectively. The following data were collected and used in this study: heat fluxes data obtained by Bowen-ratio or eddy-correlation systems; surface temperature measured by TIR radiometer; component temperatures (soil and foliage) measured by thermal-couple instrument; meteorology data including air temperature, air pressure, vapor pressure, wind speed, net radiation; canopy structure data including leaf area index (LAI), canopy height and leaf width; soil moisture at surface and different layers in depth.

## Results

The simulated CTD, component temperatures, aerodynamic temperature, and radiometric surface temperature at the three hypothesis states of soil moisture showed that the assumptions of the method are

reasonable. The highest CTD appears at the transition point, which is predictable because soil evaporation is water-limited and transpiration is still energy-limited. Simulated component temperatures, aerodynamic temperature, and radiometric surface temperature increase from wet to dry limit. Calculated component heat fluxes at the three points agree with the basic idea of different soil water limit at surface layer and root layer.

Estimated component heat fluxes using radiometric surface temperature give acceptable result, from which we can obtain information about soil wetness at surface layer and root layer. For the 3 sites at Shunyi experiment, the overall difference of soil wetness can be reflected from the estimated soil evaporation and crop transpiration. The estimated canopy total sensible and latent heat fluxes agree very well with the field observation of turbulent heat fluxes, which in turn proves that the calculation of component heat fluxes is acceptable.

### **Conclusion and discussion**

Two-layer energy balance model has been validated and approved at many references. However, its application in remote sensing is still of problem because of short of data. In this study, assumption of several extreme states of soil wetness at surface layer and root layer was used to derive component temperatures at these wetness states, and surface temperature was simulated using a thermal radiation transfer model. The observed surface temperature then can be used to calculate component heat fluxes. The error of this method mainly comes from the following factors: 1) the definition and calculation of the transition point; 2) the directional thermal radiation transfer model; 3) allocation of net radiation between soil surface and foliage.

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