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Analysis of evaporative fraction diurnal behaviour

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Abstract

Experimental studies indicate that evaporative fraction (EF), the ratio between the latent heat flux and the available energy at the land surface, is a normalized diagnostic that is nearly constant during daytime under fair weather conditions (so-called daytime self-preservation). This study examines this observation and investigates contributions to the variability of EF due to environmental factors (air temperature, solar incoming radiation, wind velocity, soil water content or leaf area index). It is shown here that the phase difference between soil heat flux and net radiation needs to be characterized fully in application models that invoke EF daytime self-preservation. Further conditions under which the diurnally constant EF assumption can hold are also discussed.

Keywords: Evaporation; Evapotranspiration; Soil heat flux; Diurnal; Soil moisture

1. Introduction and motivation

Evapotranspiration (ET) is a flux linking water, energy and carbon cycles. Flux measurement networks (as FluxNet, EuroFlux, AmeriFlux) are only available in few tens of point locations around the Globe. They are costly both to install and maintain. Moreover there is a strong heterogeneity of the fluxes over the land surface because of the inherent physical diversity of the land and vegetation properties. Therefore, the locally measured fluxes cannot be representative of a whole region of interest, nor can they be used to produce mapped estimates.

The only currently available way to obtain ET mapping is to rely on remote sensing data that now have both nearly continuous spatial coverage and adequate temporal sampling using constellation of satellites or geostationary platforms. It is not possible to directly measure fluxes using satellite information. In fact the remotely sensed surface state measurements such as land surface temperature (LST) are only indirectly related to the state of the land surface and the corresponding heat fluxes.

Different remote sensing-based methods have been developed to estimate ET using either empirical or physically based methods (see Caparrini et al., 2004a,b for review). Physically based methods solve the energy budget at the land surface. Land surface temperature (LST) data are assimilated in models of surface energy balance. Often diurnal self-preservation of EF, which is defined as the ratio between the latent heat flux and the available energy at the land surface EF = $\lambda E/(R_n - G)$, is used to make the retrieval problem well-posed.

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The observation that EF is often constant during daytime is based on Shuttleworth et al. (1989), Nichols and Cuenca (1993) and Crago and Brutsaert (1996). They use in situ measurements of surface energy balance components to show that EF is almost constant during the daytime hours under clear skies. EF supposedly removes available energy diurnal cycle and isolates surface control (soil and plant resistance to moisture loss) on turbulent heat flux partitioning. These controls vary on approximately daily time-scales.

In an important study Lhomme and Elguero (1999) has shown that EF is not necessarily constant during daytime especially in non-fair weather conditions. This leads to ET estimation errors, in particular in the morning and late afternoon due to the typical parabolic shape of EF. The robustness of the self-preservation of EF and the range of its applicability under different environmental conditions is the rationale for this study. Lhomme and Elguero (1999) is the foundation for this study and the analysis here is intended to provide additional detail. Lhomme and Elguero (1999) and this study together should provide the basis to understand the daytime self-preservation of EF and assess the limitations of its application.

In order to better understand the diurnal behaviour of EF and its environmental dependencies it is important to have long-term field experiment data. In this paper we use a SVAT model in conjunction with micrometeorological data in order to assess the EF temporal behaviour under diverse meteorological conditions. The dual-source (soil and vegetation) SVAT model also allows the test of the influences of vegetation cover and soil moisture on EF daytime self-preservation. This model is also used to understand the possible phase shift between the different surface fluxes, which can lead to dramatic EF under/overestimation.

The field experiment data used in this study is first presented. The SVAT model outlined in Fig. 1 is described in Appendix A. Then, the diurnal course of EF is physically explained through SVAT modeling and its consistency with Lhomme and Elguero (1999) result is discussed. The partial soil moisture and vegetation cover influences on the EF diurnal shape is further analyzed. Finally, the temporal correlations between EF and the main environmental factors are discussed and a strategy for the refinement of ET estimation using both land surface temperature and EF daytime self-preservation is forwarded.

2. Field experiment data set

The SVAT model (see Fig. 1 and Appendix A) was calibrated and tested on two wheat parcels and one olive tree orchard during the 2002 and 2003 SUDMED project in the region of Marrakech, Morocco, described in further detail in Duchemin et al. (2006). The experiment area is a typical Mediterranean semi-arid region. This region is heterogeneous in terms of vegetation cover and climate both spatially and temporally. These conditions are particularly appropriate to test and apply SVAT models because of the sparse vegetation with strong phenological cycle, which permits variations in the contribution of soil and vegetation to the surface energy balance. The air temperature ranges from as low as 0 °C in the winter to 50 °C in the summer; LAI from 0 (sowing) to more than 5 before harvest.

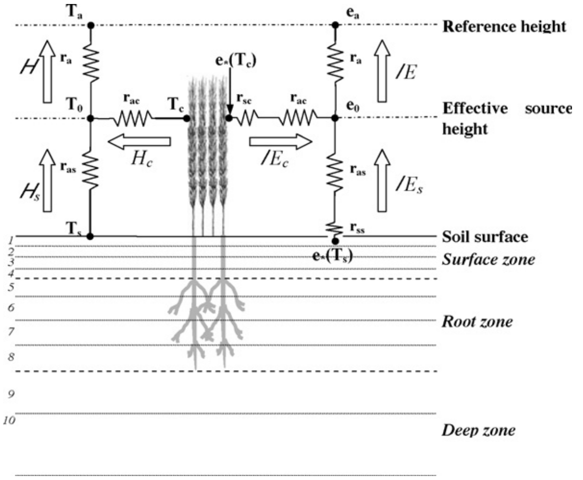

Fig. 1. Dual source (soil-canopy) resistance network. This model is coupled with a 10-layer diffusive soil model for heat and moisture transfer.

The study site is composed of sparse vegetation (varying with season) in which latent and sensible heat fluxes are of comparable magnitude. There are both bare soil and canopy contributions to turbulent fluxes. The specific study site, named R3, is located in an irrigated area in the Haouz plain surrounding Marrakech, where wheat is the main cultivated plant.

The R3 site is a 2800 ha area where irrigated wheat is cultivated, located 45 km East of Marrakech. Two fields were equipped with instrumentation, namely the 123rd (R3-B123 used in this study) and 130th (R3-B130) parcels. The parcels are cultivated with wheat. The sowing date is January 13 (day of year 13). The climate is characterized by a dry and warm period with very few precipitations events in Summer and Fall. Almost all of the annual precipitation occurs in Winter and Spring (see Fig. 2). The rainy period lasts 6 months from November to April and the cumulative precipitation is generally of the order of 250 mm per year. The site is