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Estimating the bowen ratio from measurements taken at one height. A study over sprinkler irrigated rice

F. Castellvi (1), A. Martínez (2) , O. Pérez (3) and P. Perez (1)

1. Dpt. Medi Ambient i Cienciès del Sòl, Lleida 25198, Spain (f-castellvi@macs.udl.es, j.perez@macs.udl.es)
2. Dpto. Genética y Producción Vegetal (EEAD), Zaragoza , Spain (macoan@eead.csic.es
3. Unidad de Regadíos, Zaragoza, Spain. (operez@zaragob.es)

Knowledge of all components of the surface energy budget or the available net surface energy partitioning into scalar fluxes is crucial for climate understanding. This explains the active research involving the Bowen ratio carried out in different fields during decades. For instance, the flux-gradient relationship (K-theory) has been widely used for estimating the Bowen ratio from temperature and humidity profiles and firms, such as Csi, provide specific equipment for applying this technique. Recently, the Bowen ratio is desired for accurate micro-meteorological studies. Independent measurement of energy fluxes using the most modern sensors and accurate techniques are often not able to ensure the closure of the surface energy balance equation. Therefore, the Bowen ratio may be used for correcting fluxes and thus forcing the closure (Twin et al., 2000; Mauder et al., 2004).

We concern on estimating the Bowen ratio using one measurement height with the aim to avoid constraints associated with fetch requirements and set up tall towers or masts. Two methods were analysed; (1) Flux-variance method, based on surface layer Monin-Obukov Similarity Theory (MOST) (Stull, 1991; Kaimal and Finnigan, 1994); and (2) Surface Renewal (SR) analysis in conjunction with the scalar time traces, based on the scalar conservation equation (Paw U et al., 1995; Castellvi, 2004). The flux-variance method and SR analysis can be used for estimating surface scalar fluxes independently. However, we assume that the available net surface energy can be measured accurately. We note that; the expression for determining the Bowen ratio using the flux-variance method is exempt of ‘universal’ constants; for SR analysis, the

expression avoids determining the volume per unit area of the air parcel renewed.

The fact that variance of scalars are relatively constant with height above a canopy (within the roughness and inertial sub-layer) has important practical application for estimating the Bowen ratio through the flux-variance method. Moreover, Hill (1989) demonstrated that MOST assumes a perfect correlation coefficient between high frequency scalar fluctuations. Hence, a priori it is known if MOST backgrounds are hold during an experiment. This is crucial because turbulence may transport scalars, such as heat and humidity, with different efficiency. On the other hand for SR analysis, ramps-like patterns in the scalar traces are present within and above a canopy and are associated to the renewal of air parcels that are enriched (or depleted) of the scalar when they remained in contact with the sources (or sinks). Then, ramps reveal injections of flux of the scalar into the atmosphere.

Castellvi et al. (2004) demonstrated (experimental evidence for heat was shown) that the turbulent eddy diffusion depends on the ramp period. This issue indicates that dissimilarity in the renewal period of scalars implies that the flux-gradient similarity relationships are different. Hence, MOST assumes that ramp frequencies for any scalar must be the same. SR analysis requires determination of ramp frequencies. Therefore, it may operate when MOST does not hold.

An experiment was carried out in August over a homogeneous and dense canopy (sprinkler-irrigated rice (0.4 m tall in a plot of 100 m x 110 m), at flowering stage, at Montañana (Zaragoza county), in the river Ebro basin, NE of Spain). The climate is dry and windy. High frequency measurements (10 Hz) of three wind components, air temperature and water vapour density were taken at 1.4 m above the soil from August 27^{th} to 30^{th}, 2004.

The following results were obtained:

1. Whatever the stability conditions, MOST backgrounds did not hold during the experiment. The correlation coefficient between fluctuations of air temperature and water vapour density, R_{TW} , were different from 1.0 for most samples. The ramp frequencies for air temperature and vapour density were quite different.

2. A non-dimensional index defined as the square root of the ratio of ramp periods for water vapour density and temperature, did similar performance to R_{TW} for analysing when heat was more (less) efficiently transported than water vapour.

3. Bowen ratios determined using SR analysis performed excellent under unstable conditions and reasonable under stable conditions. As a consequence of (1),

Bowen ratios determined using the air temperature and specific humidity standard deviations performed poorly.

The experiment was carried out in summer during which the formation of a capping inversion over irrigated areas is typical. It is very common that latent heat flux exceeds the available net surface energy from afternoon up to sunrise. This issue induces displacement between sources of heat and water vapour that explains the poor performance obtained from the flux-variance method (turbulent efficiency on transporting heat and water vapour was different). Therefore, this experiment showed a case where MOST was limited but SR analysis was accurate in determining surface fluxes.