Surface flux-gradient estimations at two sites with Monin Obukhov similarity theory

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1) The Stations

Two fully equipped surface energy budget stations provide turbulent fluxes in a semi-arid environment.

a) Els Plans: The site is in a non-cultivated parcel, with dry vegetation almost all year and no irrigation. One year data-set is analysed (Fig 1a).
It belongs to the Land surface Interactions with the atmosphere over the Iberian Semi-arid Environment (LIAISE) Campaign carried at Lleida in Catalunya, north west of the Iberian Peninsula:
-Short Operational Period (SOP): 15th-30th July
-Long Operational Period (LOP): April-Sept 2021

b) ECUIB: This site is located at the UIB Campus in a semi-arid environment at Mallorca. Two year data-set is analysed (Fig 1c)

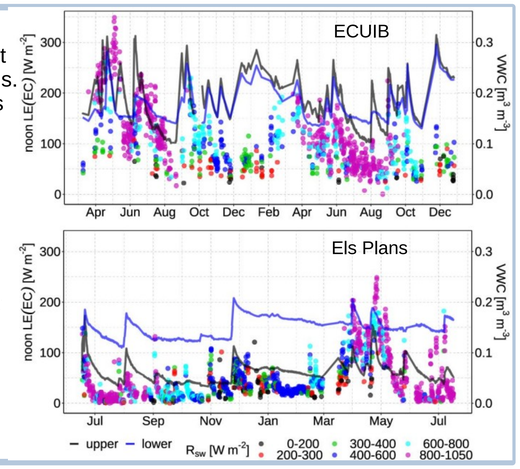
Fig 1a : Site of Els Plans

Fig 1b : Satellite image of the Mediterranean sea, marked the locations of the sites of Els Plans and the ECUIB

Fig 1c) ECUIB site

The ECUIB site is normally humid except for the summer months. High latent heat fluxes (LE) need high radiation fluxes and sufficient soil water content.
Els Plans is a much drier site, which lasts the whole year.

Fig 2 : Series of latent heat flux and volumetric water content (VWC) at two levels. In color the incident solar radiation.



2) Estimation of sensible and latent heat fluxes

- Vertical gradient close to the ground with two levels of temperature and humidity, one level of wind
- Estimation of sensible heat flux (H) and latent heat flux (LE) (Fig. 3) using Monin Obukhov's similarity theory (MOST) through an iterative method, eqs. (1) and (2).

$$\bar{\theta}(z_2)-\bar{\theta}(z_1)=-\frac{H}{\kappa u_*}\frac{1}{\rho c_p}\left[\ln(z_2/z_1)-\Psi_h(z_2/L)+\Psi_h(z_1/L)\right] \quad (1)$$

$$\bar{q}(z_2)-\bar{q}(z_1)=-\frac{LE}{\kappa u_*}\frac{1}{\rho L_v}\left[\ln(z_2/z_1)-\Psi_q(z_2/L)+\Psi_q(z_1/L)\right] \quad (2)$$

$$L=-\frac{u_*^3}{\kappa\frac{g}{\theta_v}\frac{H}{\rho c_p}} \qquad u_*=\left\{(\overline{u'w'})^2+(\overline{v'w'})^2\right\}^{1/4} \qquad Bo=\frac{H}{LE}$$

$$\phi_h=\alpha(1-\beta z/L)^{-1/2} \qquad \Psi_h(z/L)=(1-\alpha)\ln(z/L)+2\alpha\ln\left(\frac{1+y}{2}\right) \qquad y=\alpha(1-\beta z/L)^{1/2}$$

θ : temperature, q : humidity, ρ : density,
κ=0.4 : von karman constant, u* : friction velocity
L : Obukhov's Length, Ψ : integrated similarity function
Bo : Bowen ratio , Φ : Similarity function,
α, β : Businger et al. (1971) coeficients adapted by Högstrom(1996)

- Marti et al. (2022) found that sensible heat fluxes with high radiation and high soil water content were overestimated.
- For H, fluxes with Bo<1 are overestimated except when VWC is low.
- For LE : Most fluxes are overestimated, they are stratified by Bowen ratio

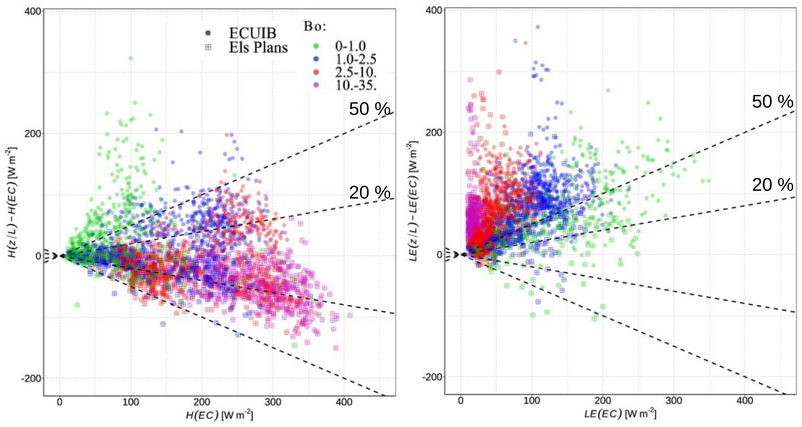


Fig. 3 : Estimated flux minus observed flux against observed flux. Dots correspond to the ECUIB site, squares correspond to Els Plans site. Color is the Bowen ratio. a) For the sensible heat flux. b) For the latent heat flux

3) Similarity functions

The similarity functions for temperature and humidity are assumed to be equal $\phi_h=\phi_q$ under homogeneous and stationary conditions.
New coefficients are adjusted using the data of the two sites.

$$\phi_h=\frac{\kappa z u_*}{H/\rho Cp}\frac{\Delta\bar{\theta}}{\Delta z} \qquad \phi_q=\frac{\kappa z u_*}{LE/\rho Lv}\frac{\Delta\bar{q}}{\Delta z}$$

H: Two different functions are identified, for Bo < 1 (wet) and Bo > 1 (dry)
LE: Three different functions are identified Bo<2.5: $\phi_h=\phi_q$
2.5<Bo<10: The higher Bo the more separate of reference line
Bo> 10: arid regime needs an extra separation to be properly estimated

Possible reasons for departure are :
- active roles of temperature and water vapour
- ground sources and sinks due to vegetation
- advective conditions

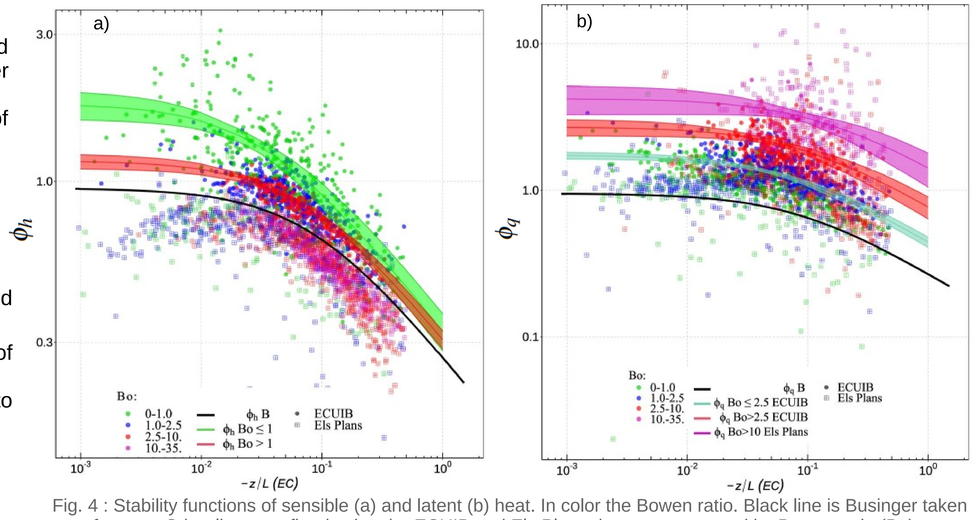


Fig. 4 : Stability functions of sensible (a) and latent (b) heat. In color the Bowen ratio. Black line is Businger taken as reference. Other lines are fitted using the ECUIB and Els Plans datasets separated by Bowen ratio (Bo).

4) The Lewis number

$$Lw=\frac{K_h}{K_q}=\frac{\phi_q}{\phi_h}$$

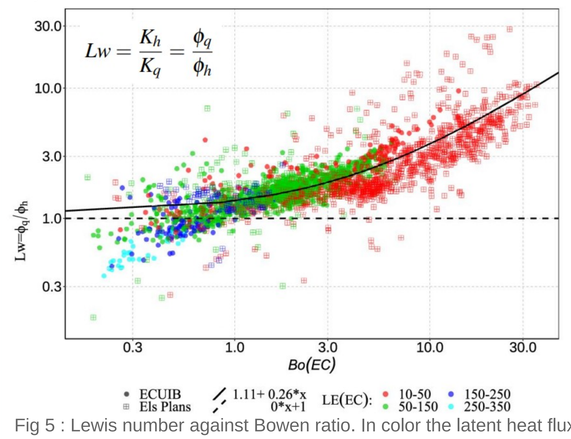


Fig 5 : Lewis number against Bowen ratio. In color the latent heat flux.

- The Lewis number at the two sites depends on Bo instead of having a value equal to one
- Diffusivity of heat and humidity are not equal
- Low values of Rtq are observed at the ECUIB
- The relative transport efficiency is dependent on the correlation of T and q with two behaviours separated by Bo<1

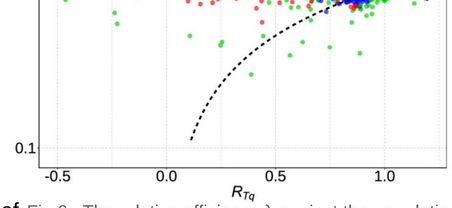


Fig 6 : The relative efficiency λ against the correlation coefficient of temperature and humidity R_{tq}. In color the Bowen ratio Bo for the ECUIB site. The solid line corresponds to the dry value 1/λ of Bink and Meesters (1997) and the dashed line to the wet value λ

$$\lambda=\frac{R_{wT}}{R_{wq}} \qquad R_{Tq}=\overline{T'q'}/(\sigma_T\sigma_q)$$

Conclusions

- Analysis of Els Plans with a very dry non-irrigated soil and the ECUIB with mostly humid semi-arid conditions.
- Assessment of MOST for ECUIB and Els Plans shows different behaviour shown as new curves are dependent on the value Bowen ratio.
- Lewis number is shown to be different to one and the relative efficiency depends on the correlation of Tq.
- Impact of the dependence of the Bowen ratio could inform changes in the atmosphere contribution of H and LE in land surface models.
- Eddy-covariance only measurements of the ECUIB show the Bowen ratio dependence.

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