Estimation of latent and sensible heat flux through similarity theory in semi-arid conditions

Belén Martí[3,1], Daniel Martínez-Villagrasa[1], Jeremy Price[2], Joan Cuxart[1]

FIRST LIAISE CONFERENCE AND DETERMINING EVAPOTRANSPIRATION CROSSCUT WORKSHOP

Lleida 27-29 March 2023

1 Universitat de les Illes Balears, Palma, Spain
2 UKMO, Cardington, United Kingdom
3 CNRM, CNRS/Météo-France, Toulouse, France

Context

- Turbulent fluxes and flux-gradient relationships
- Estimated fluxes through Monin Obukhov Similarity Theory (MOST)
- Measurements in complex terrain near the ground
- Comparison of estimated and observed fluxes

  for two databases

  ECUIB and Els Plans: H and LE

Conclusions

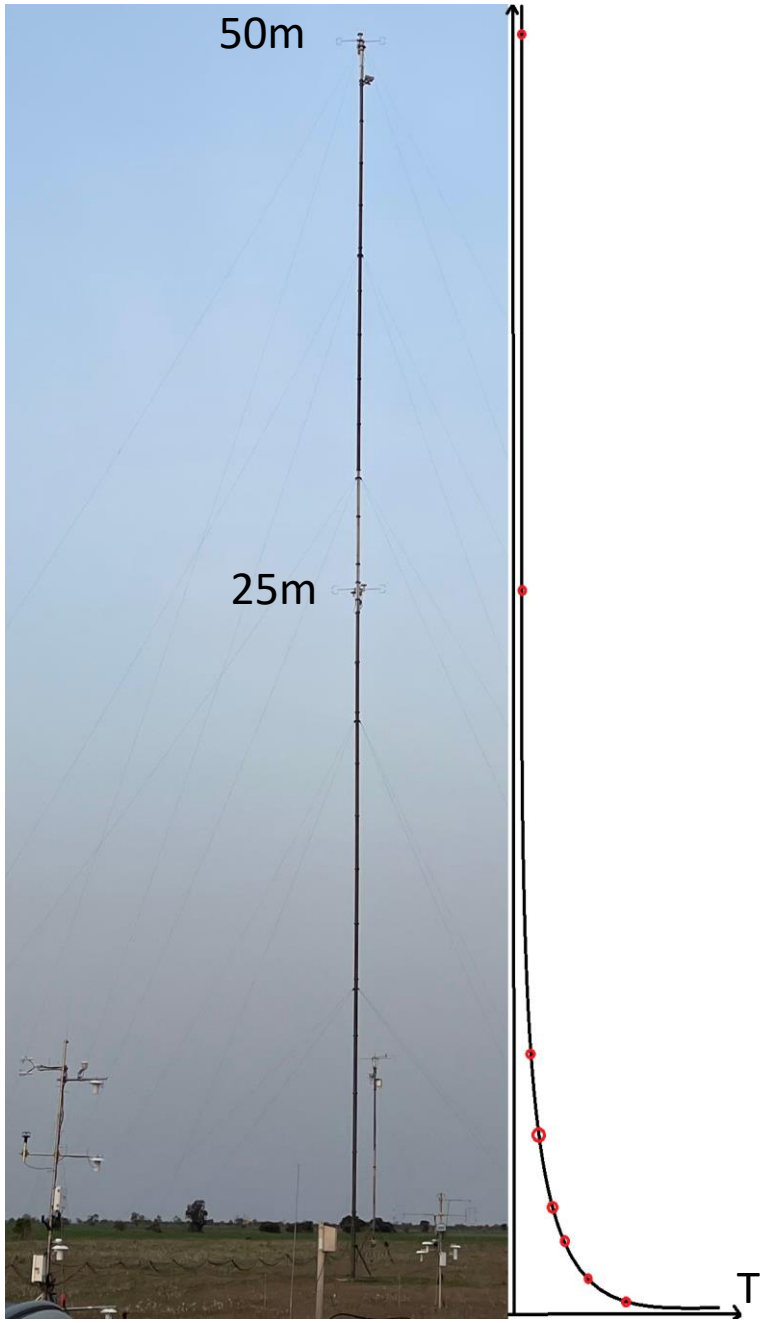
Objectives

- Evaluate if MOST relationships in moderately complex terrain are suitable to estimate turbulent fluxes near the ground.

- Characterize the behaviour of the stability functions of sensible and latent heat flux and suggest a suitable expression.

- Show the relationship of the stability functions of sensible and latent heat flux, are they equal?

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



Flux-gradient relationships

High frequency measurements (EC)

Fluxes

Flux-gradient approximation

Sensible heat

$$\overline{w'\theta'} = \frac{H}{\rho C_p} = -K_h \frac{\partial \theta}{\partial z}$$

Turbulent Eddy diffusivities

Latent heat

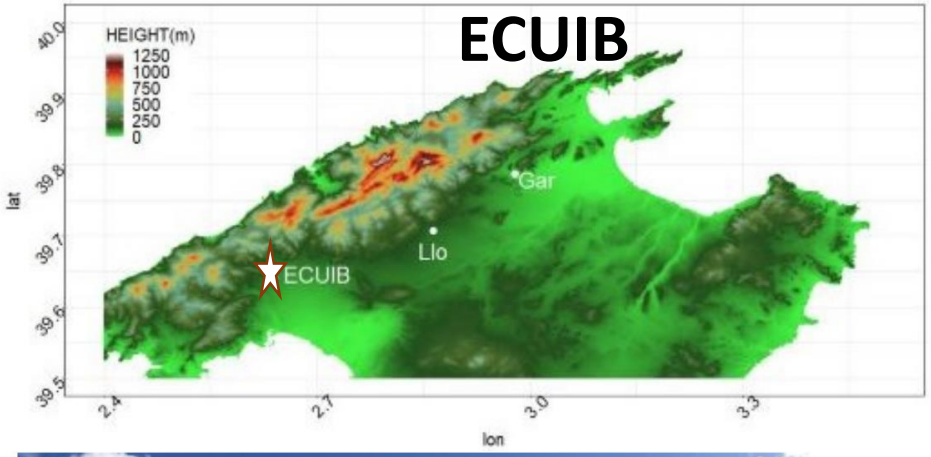
$$\overline{w'q'} = \frac{LE}{\rho L_v} = -K_q \frac{\partial q}{\partial z}$$

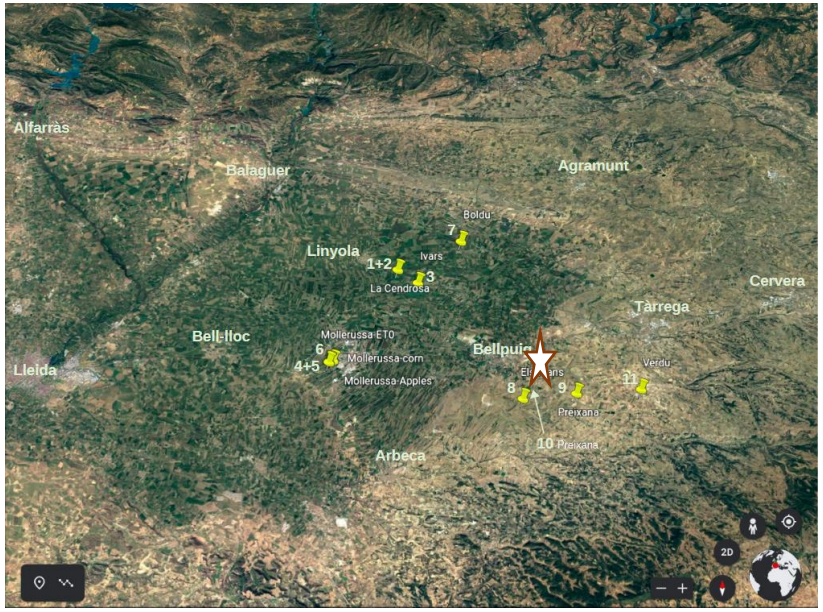
Monin Obukhov's Similarity theory (MOST)

$$\frac{H}{\rho c_p} = -\frac{\kappa u_* z}{\phi_h} \frac{\partial \bar{\theta}}{\partial z}$$

Databases: ECUIB and Els Plans

11-14UTC
ECUIB: 22 months (2020-2021)
Els Plans: 13 months

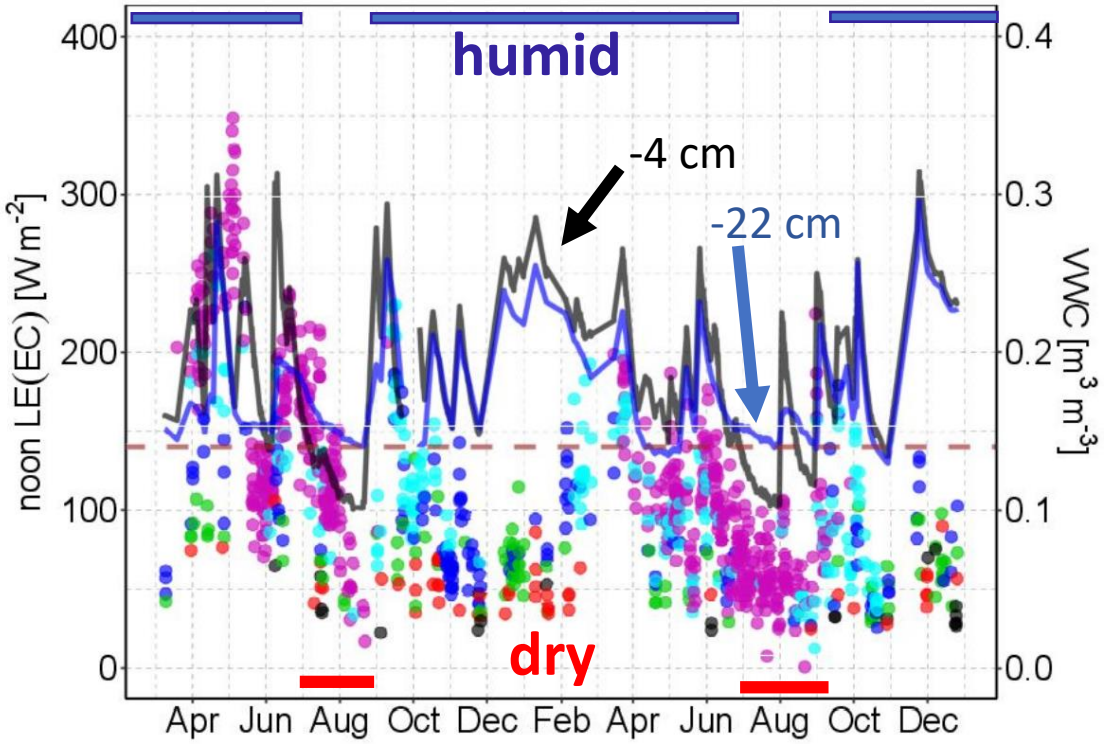




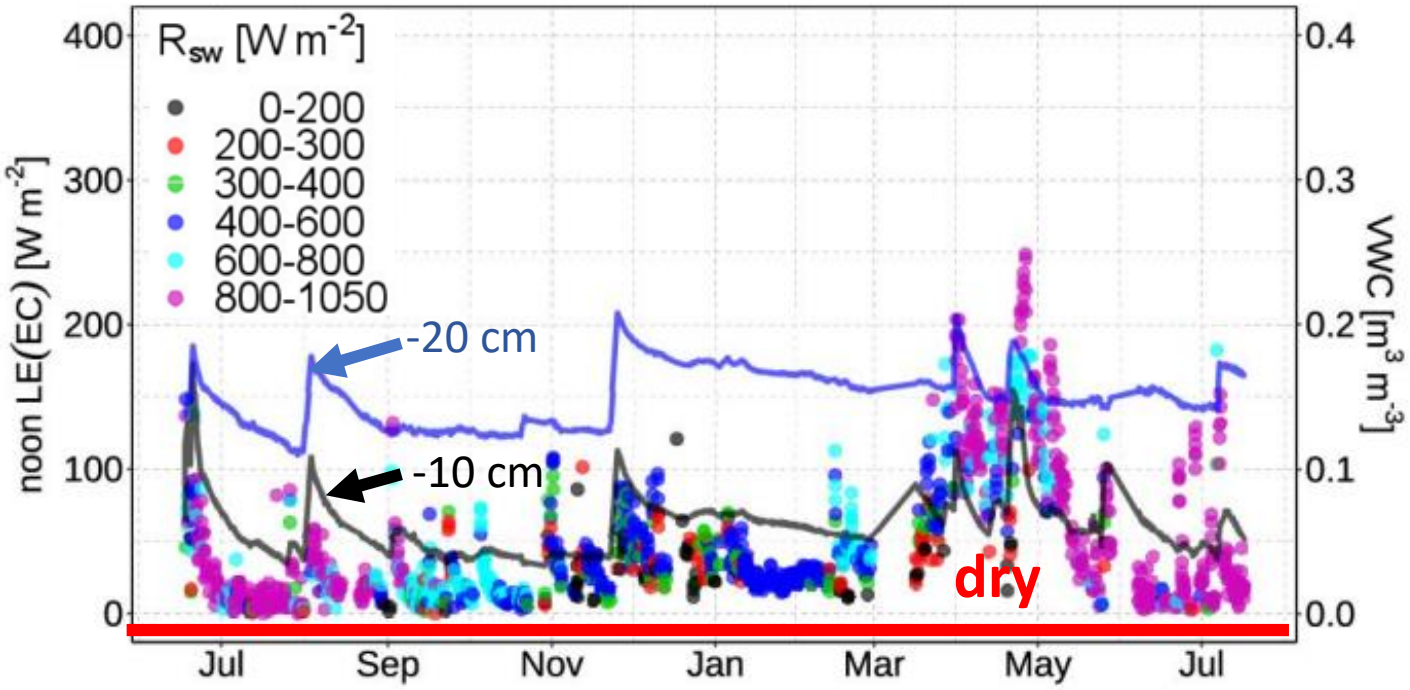
Els Plans

VWC and LE flux at ECUIB and Els Plans

ECUIB



Els Plans



Sensible heat flux

$$\bar{\theta}(z_{\theta_2}) - \bar{\theta}(z_{\theta_1}) = \frac{H}{\rho C_p \kappa}\left[\ln(z_{\theta_2}/z_{\theta_1}) - \Psi_h\left(z_{\theta_2}/L\right) + \Psi_h\left(z_{\theta_1}/L\right)\right],$$

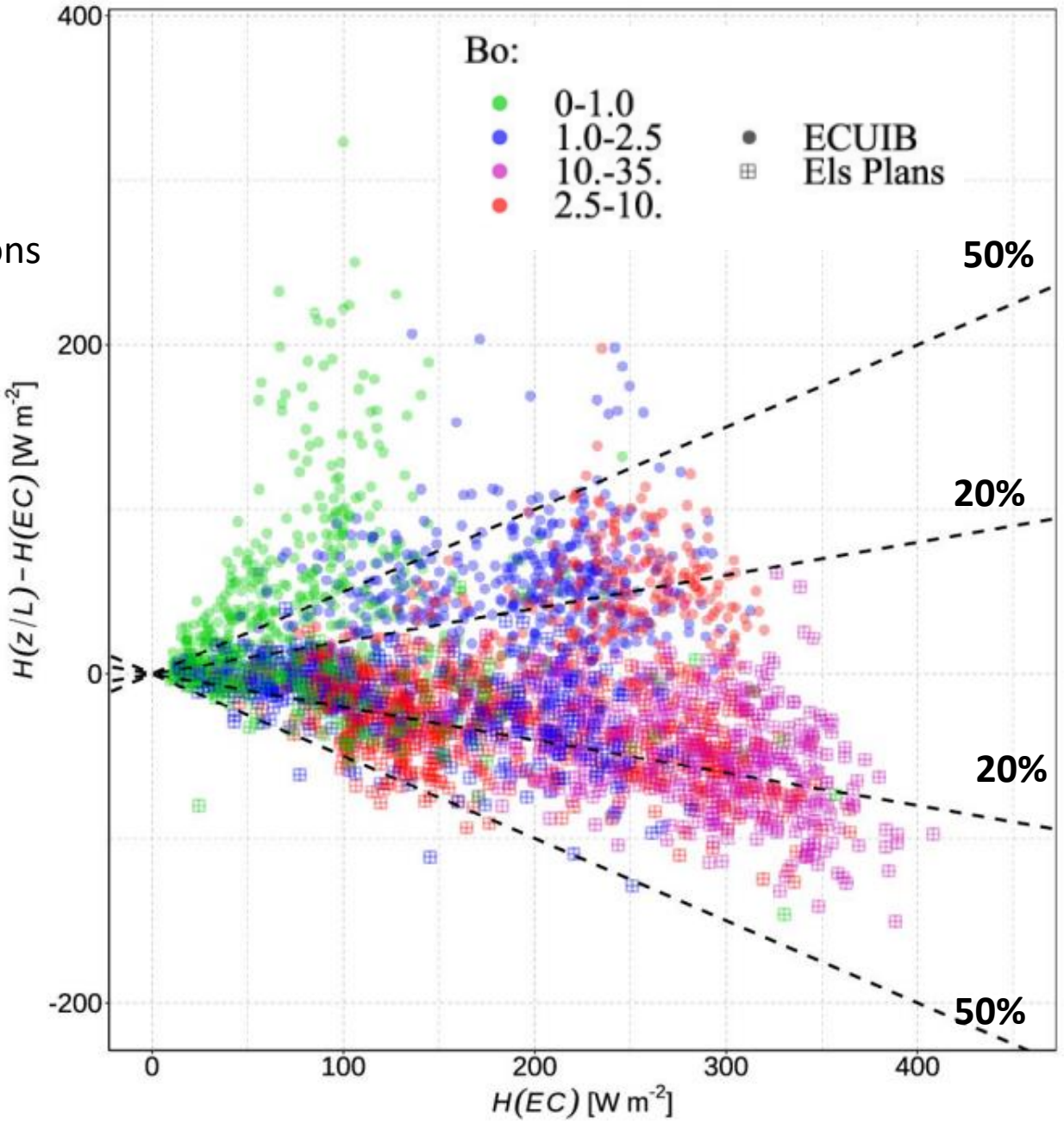
Businger (1971) functions

- *Discussion of the results is made through relative error*

$$\Delta\chi/\chi \equiv (\chi(z/L) - \chi(\mathrm{EC}))/\chi(\mathrm{EC})$$

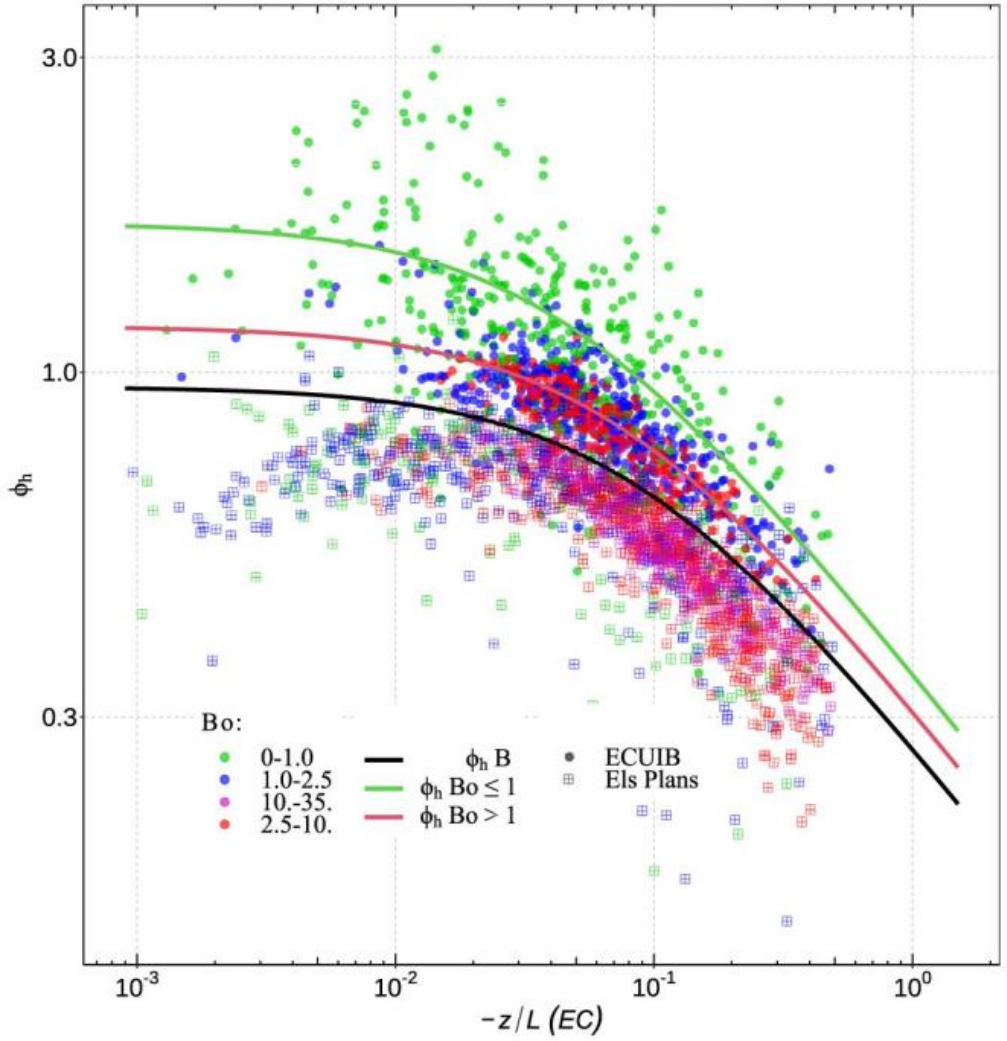
- $\chi(z/L) \equiv$ estimated value ; $\chi(EC) \equiv$ observed value
- We set two thresholds: 20% and 50% of relative error

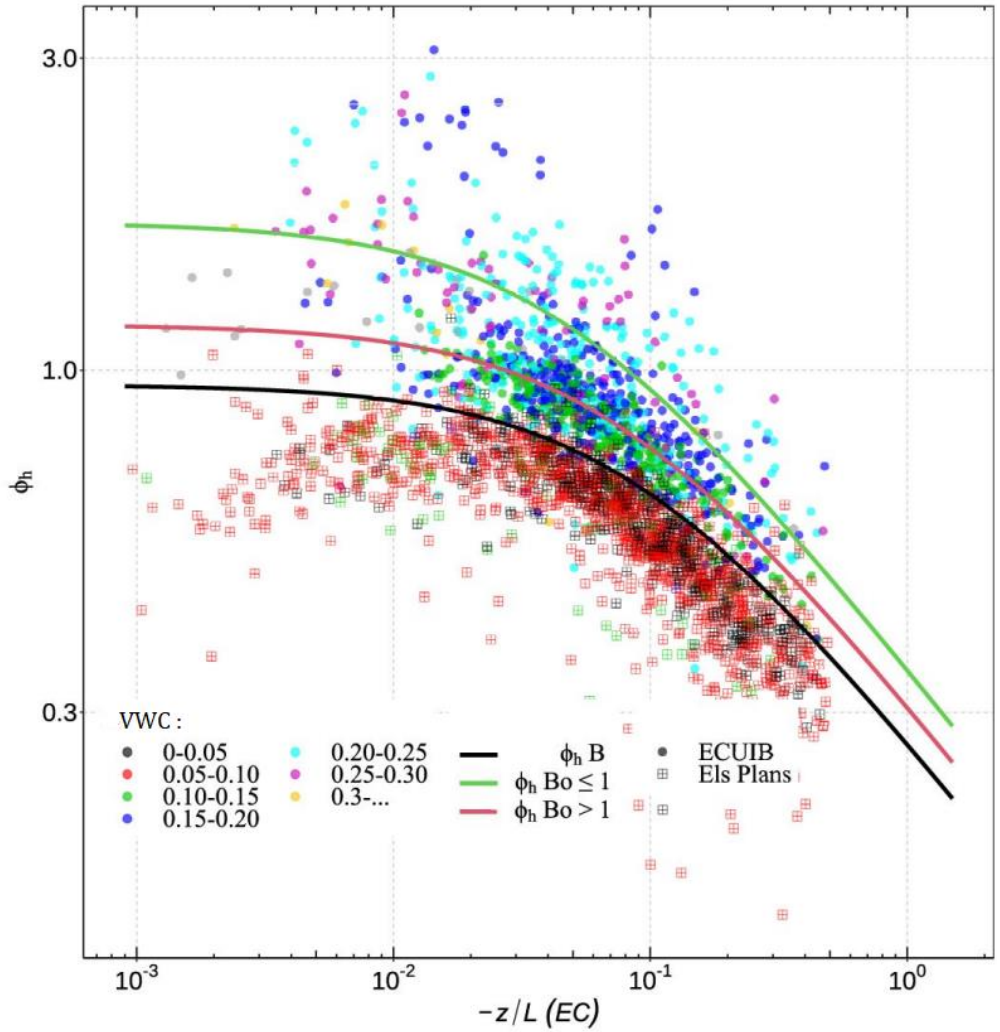
Tested at the ALEX campaign, estimation of H in daytime needs a new function when both solar radiation and soil water content are large (Marti et al. 2022, BLM)



Sensible heat flux

- Function of sensible heat flux stratifies by both water content of the ground and Bowen ratio

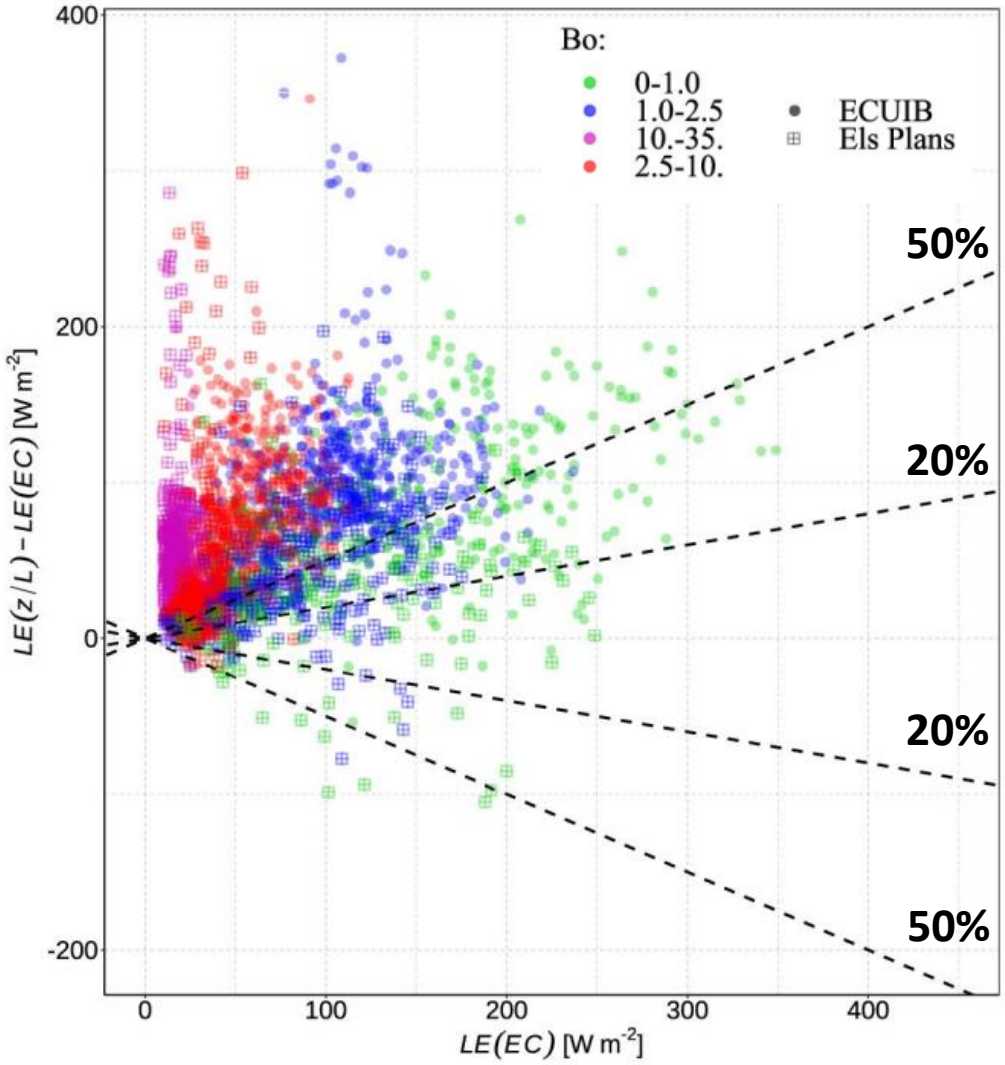


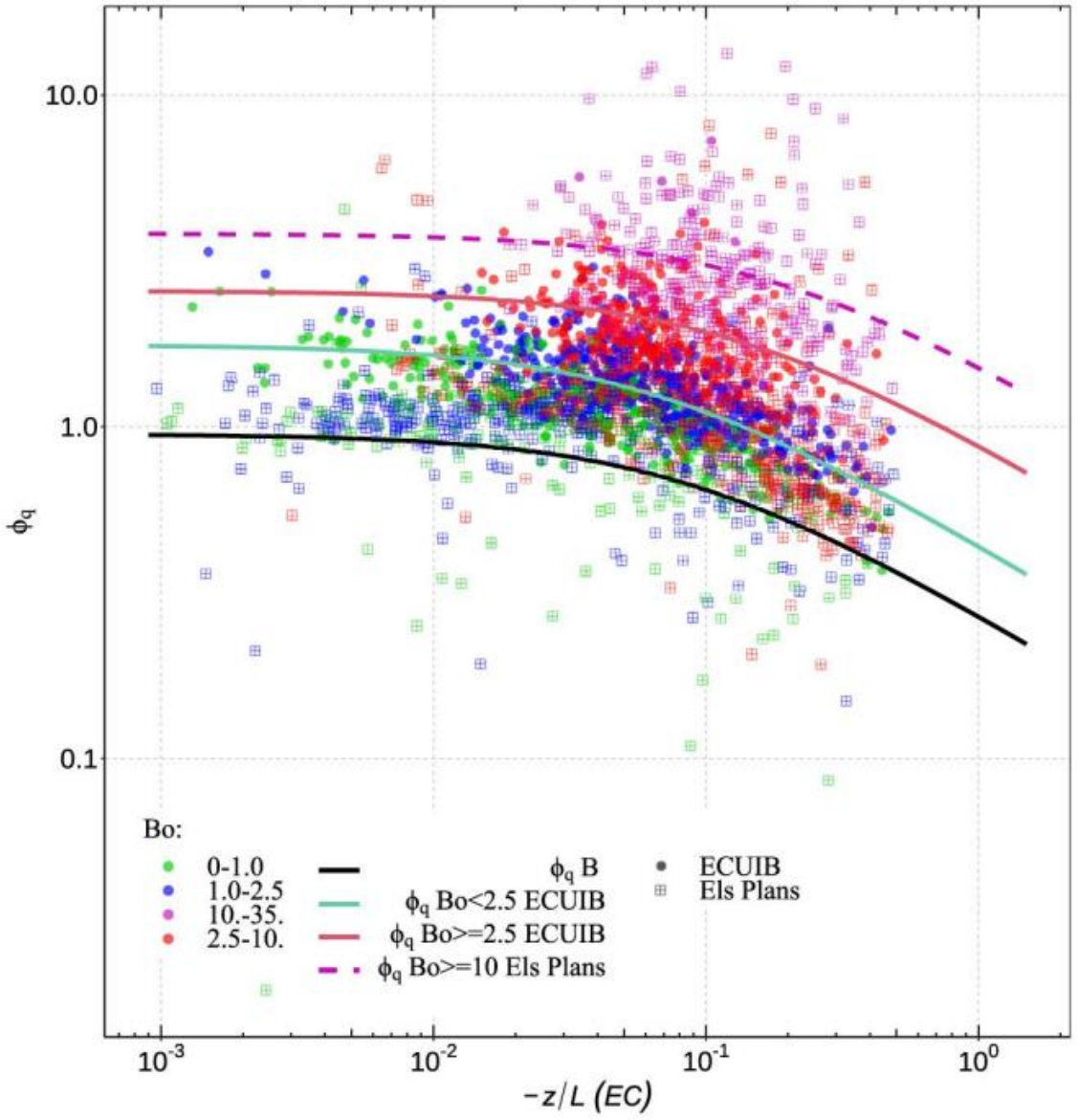


Latent heat flux

$$\bar{q}(z_{q_2}) - \bar{q}(z_{q_1}) = \frac{LE}{\rho L_v \kappa} \left[\ln(z_{q_2}/z_{q_1}) - \Psi_q(z_{q_2}/L) + \Psi_q(z_{q_1}/L) \right],$$

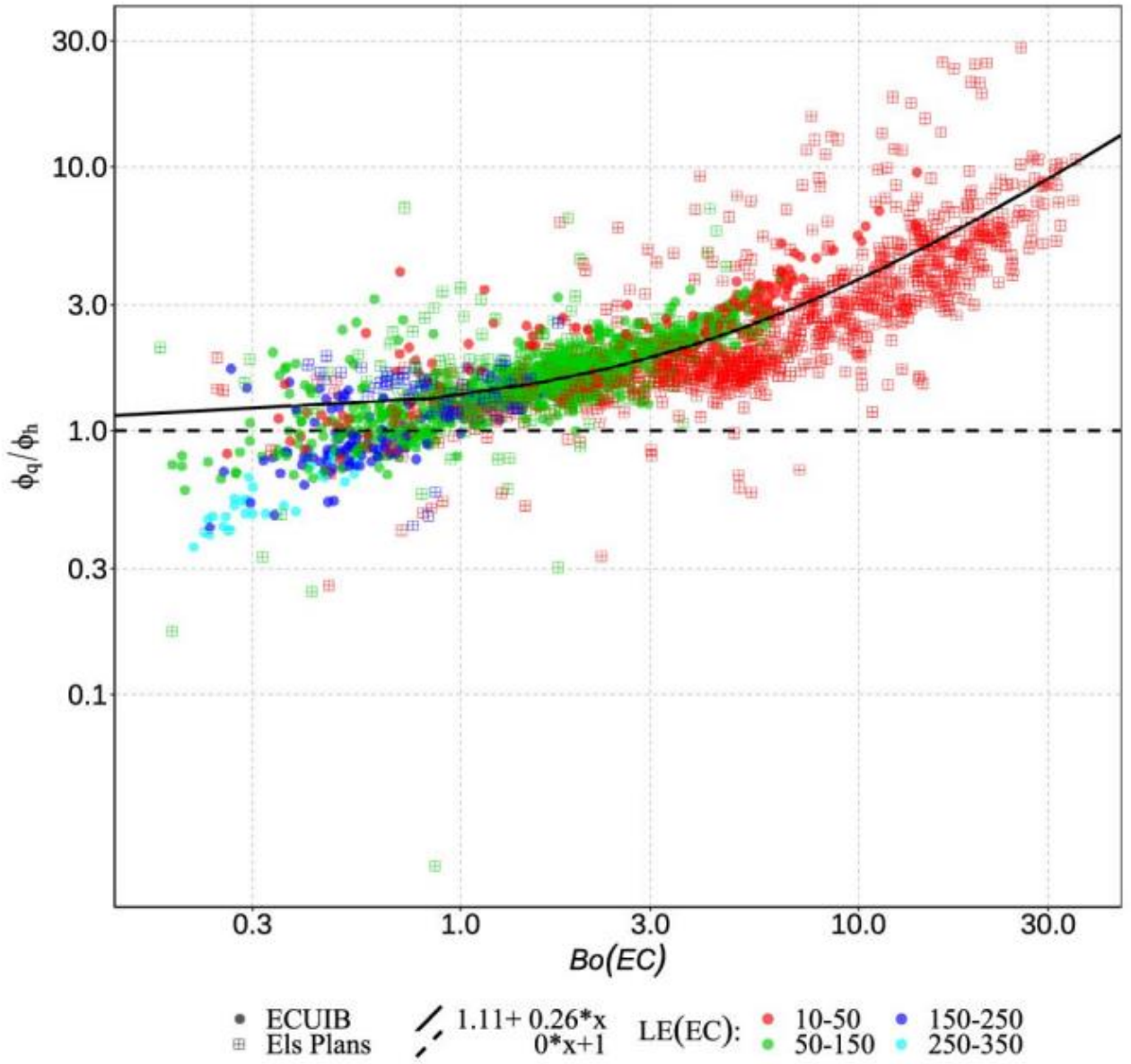
- Function of humidity stratifies by bowen ratio
- No one line can represent all variability





Lewis number

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



Conclusions

- For H: the Businger line describes well most cases, those with Bo<1 need a new function.
- For LE: New functions dependant on Bo are necessary. The larger the Bo is the farther from Businger they are. Between databases, ECUIB functions provide reasonable results for Els Plans.

- The functions for temperature and humidity can be used within a 50% accuracy

- The Lewis number increases with the Bowen ratio and separates from the Lw=1 starting at Bo>1, coinciding with the use of new different functions for H and LE

Acknowledgements

- FPI-CAIB (FPI/2165/2018) grant of the Vicepresidència i Conselleria d'Innovació, Recerca i Turisme del Govern de les Illes Balears and the Fons Social Europeu.
- ERA NET PLUS NEWA (PCIN-2014-016-C07-01 and PCIN-2016-091)
- Grants of the Spanish Government CGL2015-65627-C3-1-R (that includes Regional Funds FEDER)
- This work has been partially sponsored by the *Comunitat Autonoma de les Illes Balears* through the *Direcció General de Política Universitaria i Recerca with funds from the Tourist Stay Tax Law ITS 2017-006 (PRD2018/67)*
- This work is part of the research project RTI2018-098693-B-C31 funded by MCIN/AEI/10.13039/501100011033 and by ERDF A way of making Europe.

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Similarity theory

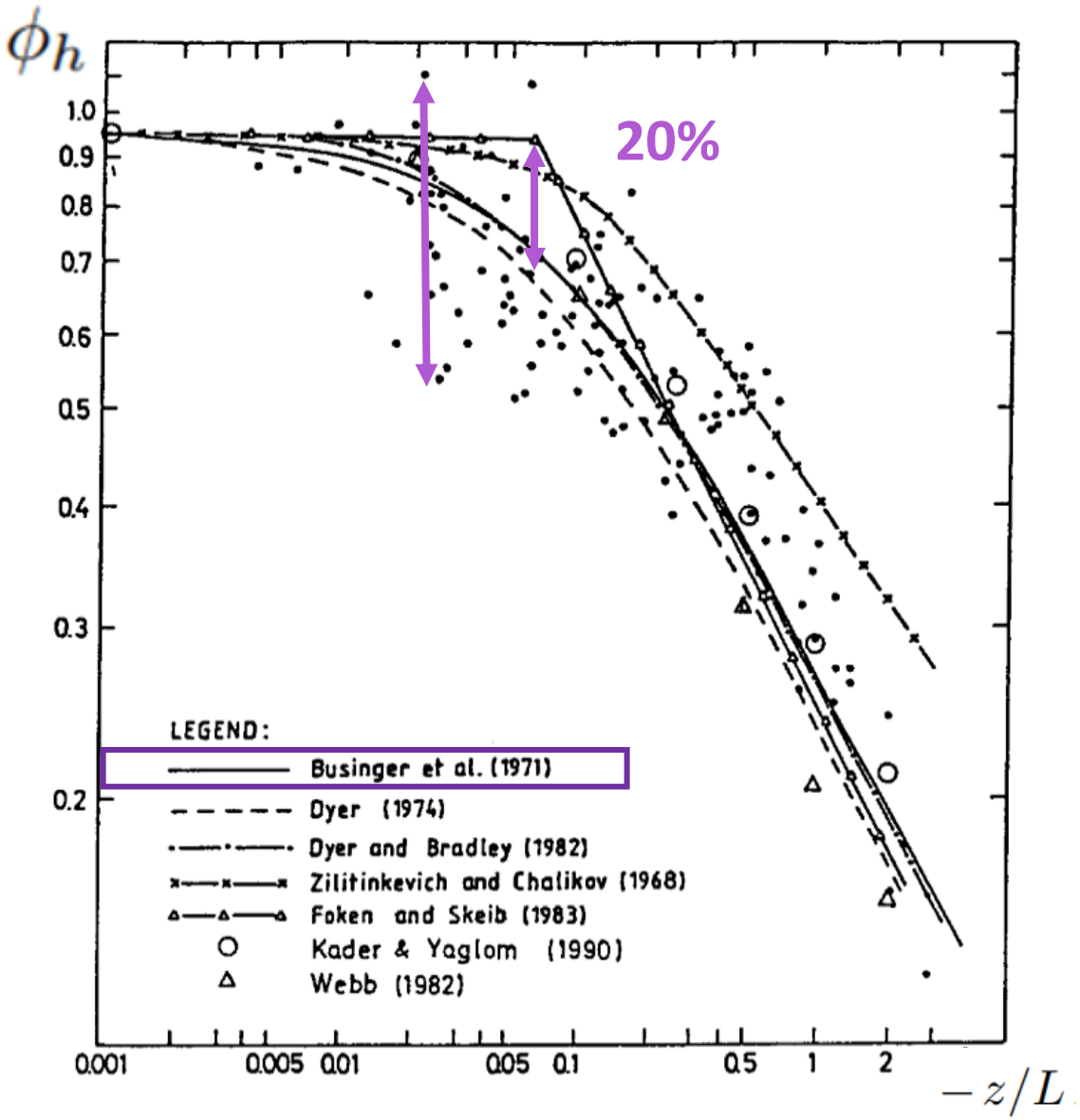
- Similarity theory fluxes: can be determined by a vertical gradient using the universal functions ϕ_m, ϕ_h, ϕ_q that depend on a stability parameter
- Universal functions have been fitted in several experimental campaigns, a lot of uncertainty remains in the estimations.
- Universal functions were developed using instrumented towers of over 30 m in flat terrain

Stability parameter: z/L

Obukhov's Length

$$L = -\frac{u_*^3}{\kappa \frac{g}{\theta} \overline{w'\theta'}}$$

Graphic: Högstrom (1996)



$$\phi_m^2 = \phi_h = \alpha(1-\beta z/L)^{-1/4}; \quad \text{for } z/L < 0$$

$$\phi_m = \phi_h = \alpha(1+\beta z/L); \quad \text{for } z/L > 0,$$

Observed turbulent fluxes

$$Rn + H + LE + G = Imb$$

- Parametrization of the fluxes is included in forecast models

$$\frac{\partial \bar{\theta}}{\partial t} = \cdots - \frac{\partial \overline{\omega'\theta'}}{\partial z}$$

$$\overline{\omega'\theta'} = -k\frac{\partial \bar{\theta}}{\partial z}$$

term of the energy balance equation		error in %	energy in W m^{-2}
latent heat flux (carefully corrected)	LE	5–20	20–50
sensible heat flux	H	10–20	15–30
net radiation	Rn	10–20	50–100
ground heat flux	G	50	25

Table: Foken (2008)