EVALUATION OF THE SIMILARITY FUNCTIONS Φ_m AND Φ_h FOR THE STABLE ATMOSPHERIC BOUNDARY LAYER: RANGE OF VALIDITY.

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1. INTRODUCTION

- Turbulent transfer is one of the most important processes in the Atmospheric Boundary Layer (ABL), showing many difficulties in stable situations (SBL): non stationary conditions, presence of internal gravity waves, intermittency, decoupling from the surface fluxes, etc.
- The Monin-Obukhov (M-O) Theory is a suitable framework for presenting micrometeorological data, as well as for extrapolating and predicting certain micrometeorological information where direct measurements are not available.
- In order to describe the surface fluxes, which is a key parameter in the atmospheric and dispersion models, the universal similarity functions ϕ_m and ϕ_h for non dimensional wind and temperature profiles must be determined [1].
- Some commonly used linear universal functions can be not valid for moderate to strong stability, leading to important errors in the evaluation of surface fluxes. What is the range of validity?

2. DATA

- In the period 10-28 September 1998, the Stable Atmospheric Boundary Layer Experiment in Spain (SABLES98) took place at the Research Centre for the Lower Atmosphere (CIBA), see Figure 1, in the Northern Spanish Plateau (Valladolid) [2].
- The data used in this study comprise 7 consecutive nights (from 18:00 GMT to 06:00 GMT) ranging from the 14-15 to 20-21 night (this is the so called S-period). The synoptic conditions was controlled by a High pressure system which produces light winds mainly from NE-E direction (Figure 2).
- Different instruments (3 sonic & 5 cup anemometers, 14 thermocouples, 3 wind vanes, etc) were deployed on a 100 m high tower. 5 minutes means have been used to evaluate all the parameters in this study.
- The evolution of wind speed, wind direction, Richardson number (Ri) and turbulent kinetic energy (TKE) is shown in Figure 3.

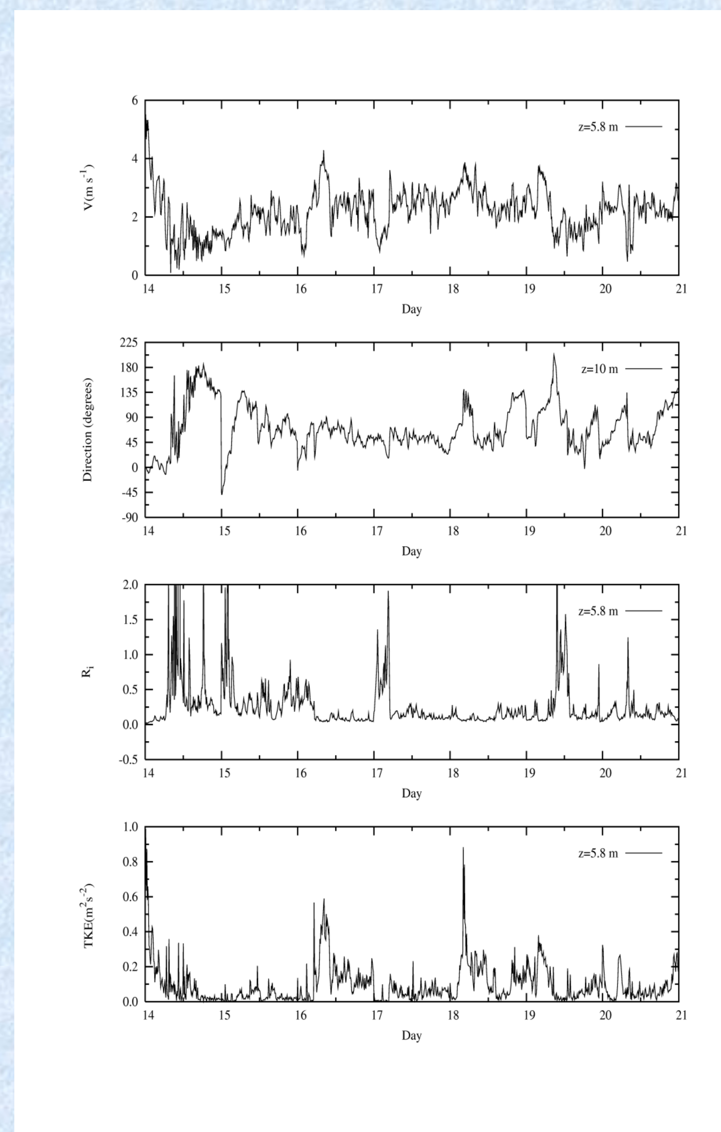

Figure 3: Evolution of wind speed and direction, Richardson number and TKE for all the S period.

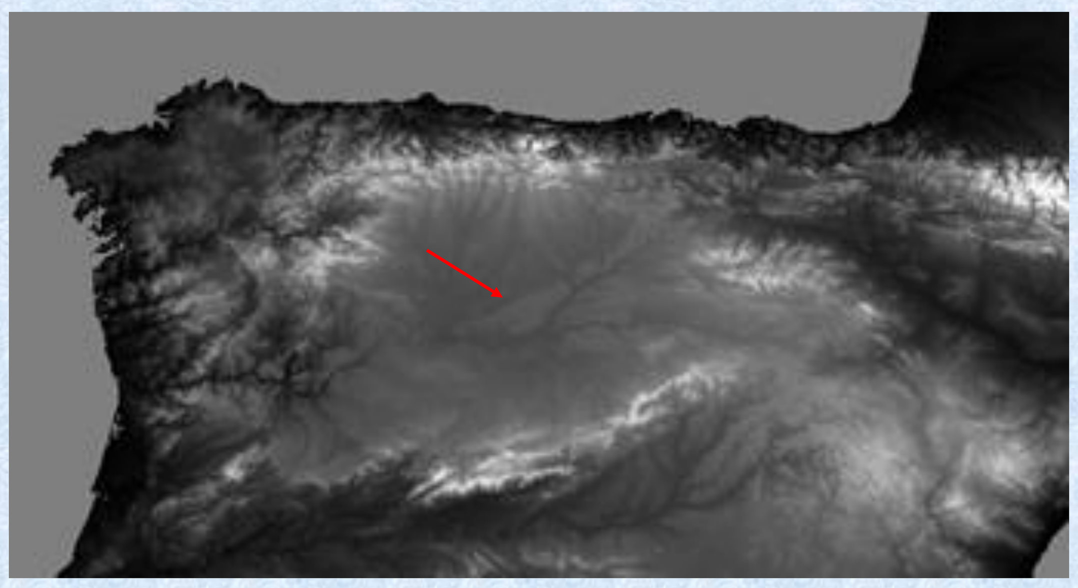

Figure 1: Location of the CIBA in the Iberian Peninsula

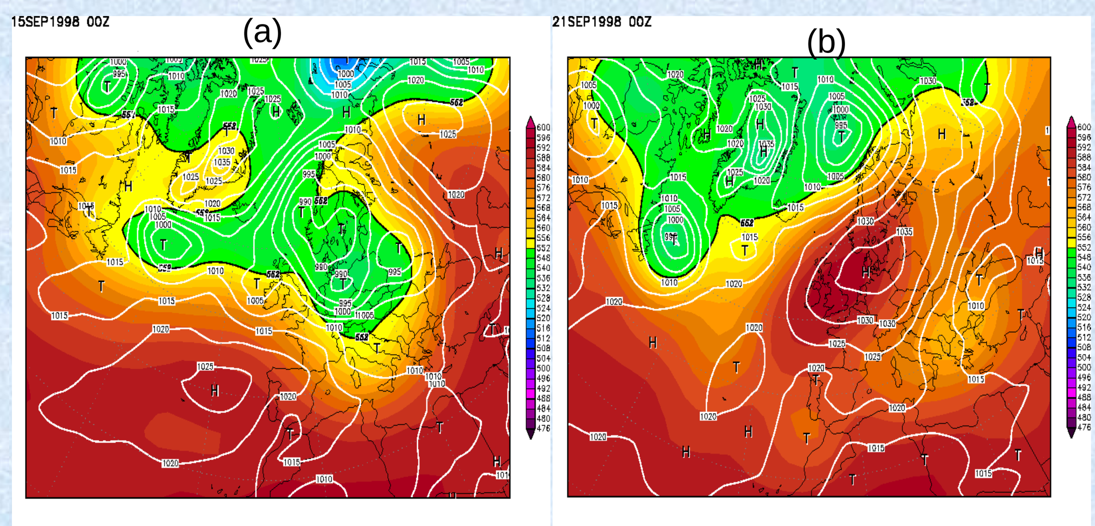

Figure 2: Synoptic conditions (pressure at surface level and geopotential height at 500 hPa) for a) the first night and b) the last night of the S period. NCEP Reanalysis.

3. METHODOLOGY

•The non-dimensional forms of wind and temperature gradients are defined as:

$$\phi_m(\zeta) = \frac{kz}{u_*}\frac{\partial u}{\partial z} \qquad (1)$$

$$\phi_h(\zeta) = \frac{kz}{\theta_*}\frac{\partial \theta}{\partial z} \qquad (2)$$

where u and θ are respectively mean wind speed and potential temperature, k the von Karman constant, z height, u_* friction velocity (related to turbulent momentum flux) and θ_* a scale temperature related to turbulent heat flux:

$$u_* = \left[(-\overline{u'w'})^2 + (-\overline{v'w'})^2\right]^{1/4} \qquad (3)$$

$$\theta_* = \left[\frac{\overline{w'\theta'}}{-u_*}\right] \qquad (4)$$

•For each 5 minutes block of data $u(z)$ and $\theta(z)$ profiles are obtained from fitting a log-linear curve to the data

[$u(z)$= a + bz + c log(z); $\theta(z)$ = a' + b'z + c' log(z)].

•Then vertical gradients are evaluated for any height (5.8, 13.5 and 32 m). With these gradients and u_* and θ_*, ϕ_m and ϕ_h are directly obtained for the three heights.
•The Monin-Obukhov length is defined as:

$$L = \frac{u_*^2}{k(g/T_0)\theta_*} \qquad (5)$$

where T_0 is a reference temperature (near the surface) and g is the acceleration due to gravity.
•The M-O Theory established that ϕ_m and ϕ_h are functions of the stability parameter $\zeta = z/L$.

$$\phi_m = 1 + \beta_1 \zeta \qquad (6)$$

$$\phi_h = \alpha + \beta_2 \zeta \qquad (7)$$

•Once ϕ_m and ϕ_h and z are evaluated (for a wide range of stability $0 < \zeta < 50$) their relationship is studied, functional forms are obtained and compared with those widely used in the literature.

4. RESULTS

- According to [3] it is considered weak stability for $\zeta \leq 0.1$, moderate stability for $0.1 < \zeta \leq 1$ and strong stability for $\zeta > 1$.
- In order to aid interpretation and to improve convergence of statistics, results can be grouped into different intervals of the stability parameter (ζ), evaluating the standard deviation (shown as error bars in the figures).

Reference	k	β_1	α	β_2
Businger et al. (1971)				
Original	0.35	4.7	0.74	4.7
Modified (Högström, 1996)	0.40	6	0.95	7.99
Dyer (1974)				
Original	0.41	5.0	1	5
Modified (Högström, 1996)	0.40	4.8	0.95	4.5
Zilitinkevich & Chailikov (1968)				
Original	0.43	9.9	1	9.9
Modified (Högström, 1996)	0.40	9.4	0.95	8.93
Webb (1970) Original	0.41	5.2	1	5.2
Modified (Högström, 1996)	0.40	4.2	0.95	7.03
Hicks (1976)				
Original	0.41	5.0	1	5

Table I: Original functions $\phi_m=1+\beta_1\zeta$ y $\phi_h=\alpha+\beta_2\zeta$ for different authors in stable conditions, and their modified forms (Högström, 1996) considering a value of k (Von Karman constant) of 0.4

ϕ_m (nondimensional gradient of wind):

- ϕ_m increases with stability (ζ) although this increasing is not uniform for all the stability range: for $\zeta < 1$ (weak to moderate stability), the obtained similarity function is similar to that proposed by [4] and other authors [5], see Table I. For stronger stability ($\zeta > 1$) ϕ_m calculated are below the functions found in the literature. If these functions are used ϕ_m is overestimated (Figure 4 and 5).
- For stronger stability ($\zeta > 1$) the theory of *z*-less stratification [6] must be used as fluxes are decoupling from surface, and z has no influence on turbulence in higher levels, being more intermittent. ϕ_m is not controlled by stability (Figure 5).
- The data are more scattered when *z* is increased, due to the increasing stability and intermittency with height (Figure 6).

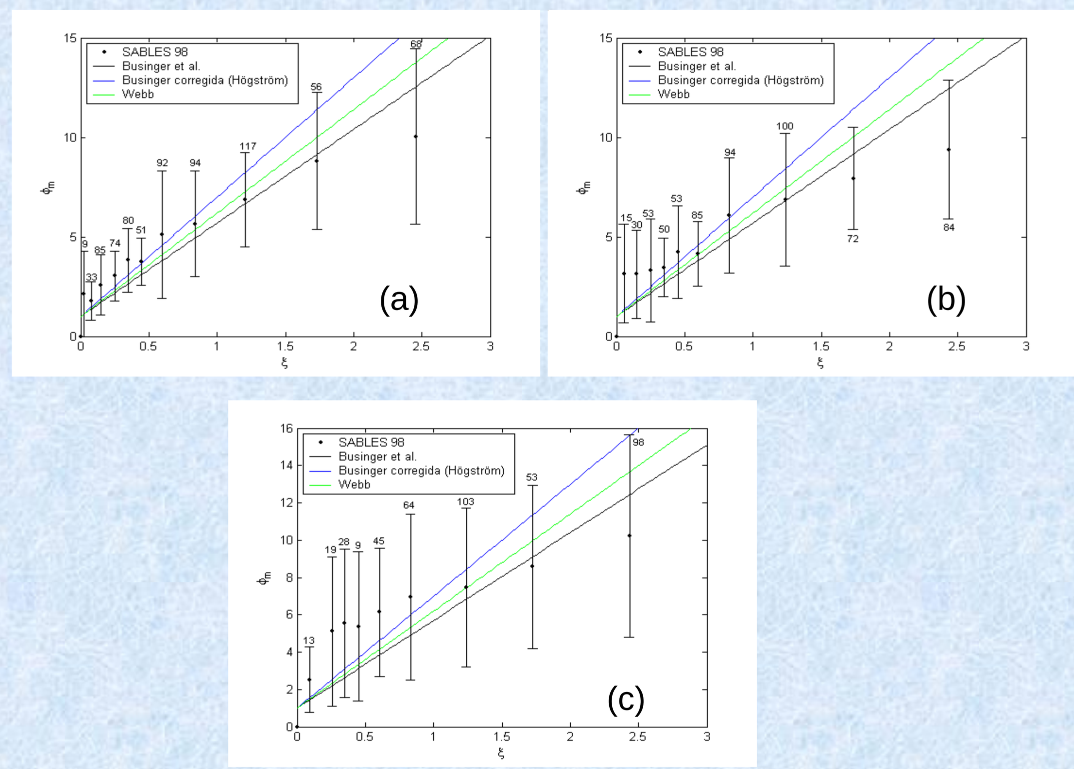

Figure 4: ϕ_m versus stability parameter grouping in intervals for $\zeta < 3$ for: a) 5.8 m, b) 13.5m and c) 32 m. Functions found by other authors are shown for comparison. Error bars indicate the standard deviation of the individual results contributing to the mean value in each stability bin. The number of samples in each stability bin is given over the upper bar.

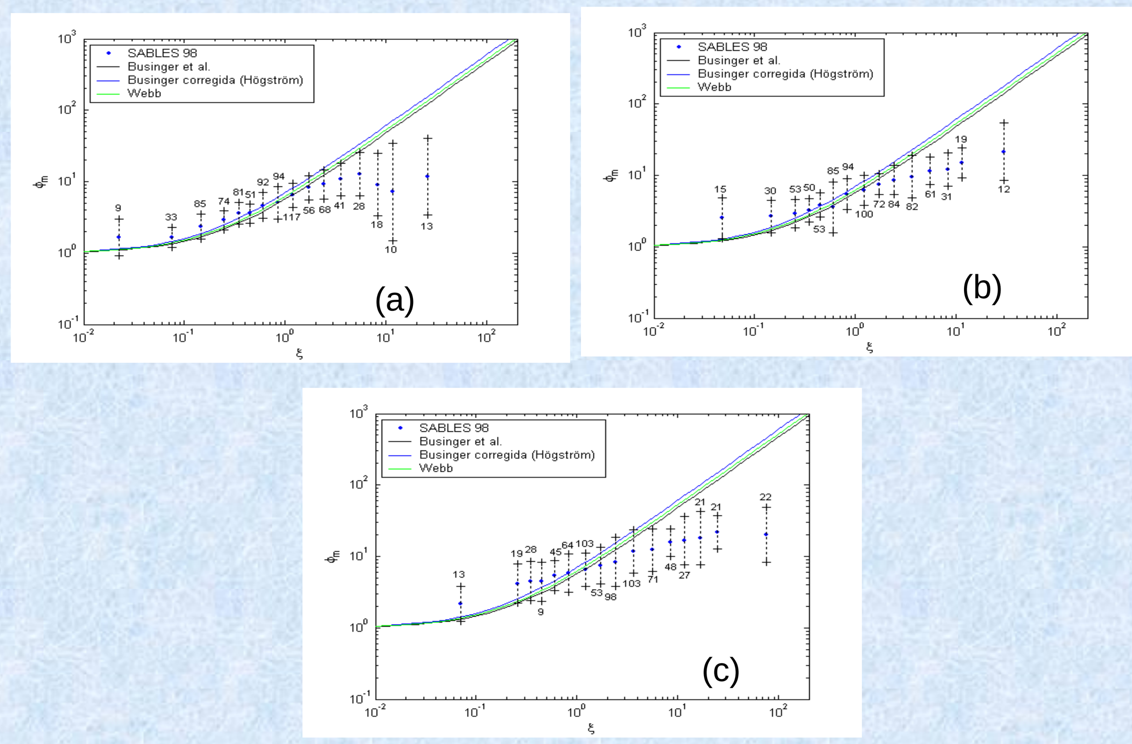

Figure 5: As Figure 4, but for all stability range and in Log-Log scale.

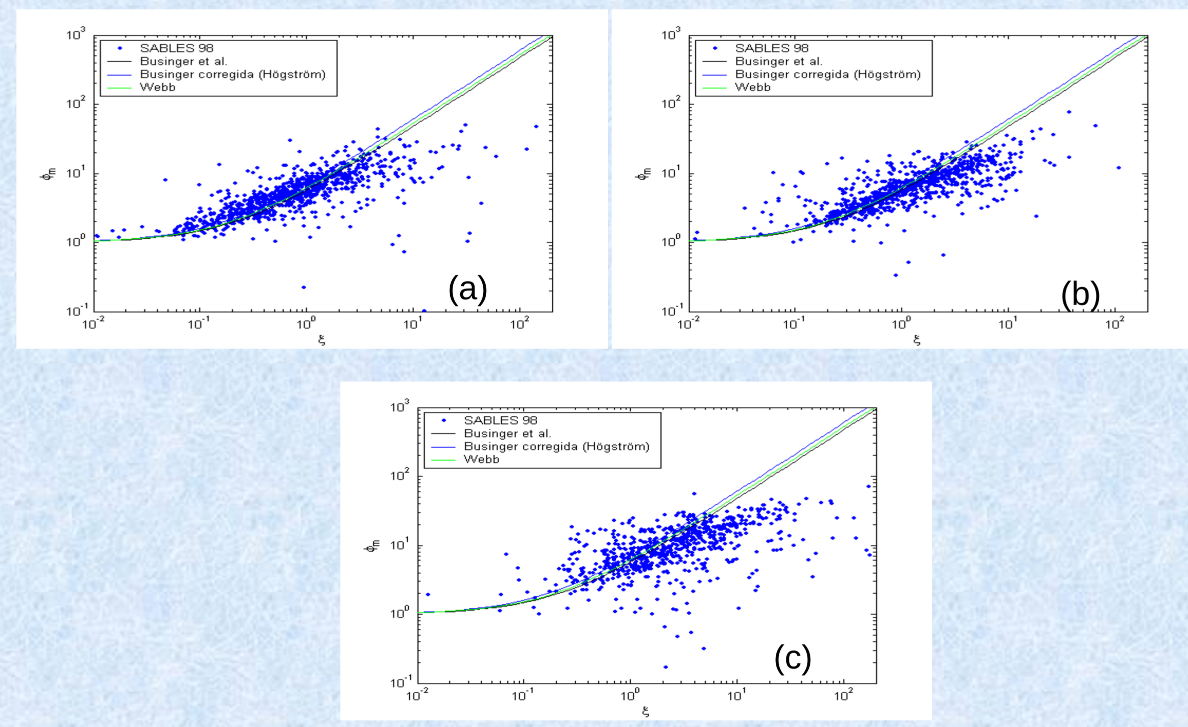

Figure 6: ϕ_m versus stability parameter for all the values calculated at : a) 5.8 m, b) 13.5m and c) 32 m.

ϕ_h (nondimensional gradient of temperature):

• ϕ_h presents much more dispersion that ϕ_m and the dependence on stability (ζ) is not so clear (Figures 7 and 8).
• For the lowest level (5.8 m) and for $0.1 < \zeta < 1$ the results are similar to other found in the literature.
• For stronger stability, the z-less result is again found, ϕ_h is no dependent on stability and a level off is obtained.
• For weak stability ($\zeta < 0.1$) ϕ_h shows quite unexpected values, especially for the higher levels. This could be related to the interaction of turbulence with internal waves, which gives low values of ζ (produced by prompt mixing) in a overall context of stable stratification, as it is the case of this S period.

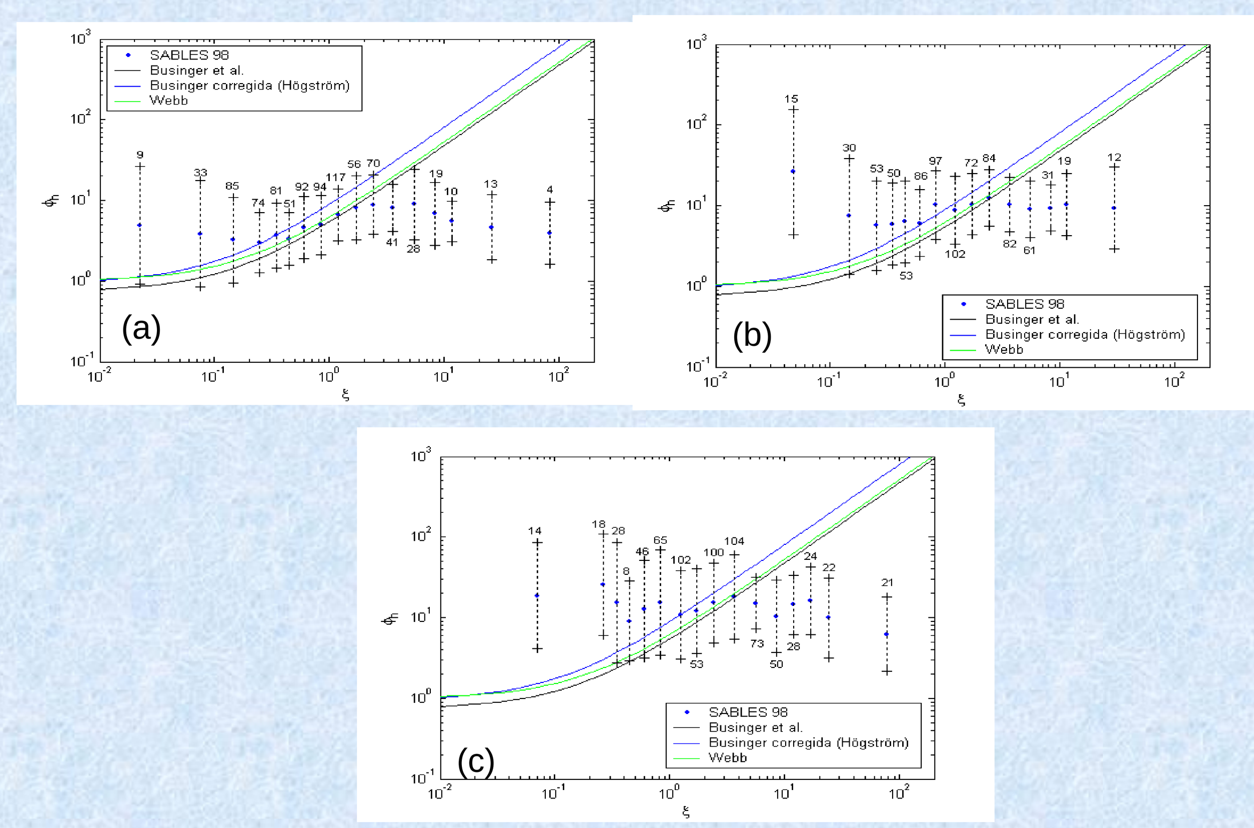

Figure 8: ϕ_h versus stability parameter grouping in intervals for all the ζ for: a) 5.8 m, b) 13.5 m and c) 32 m.

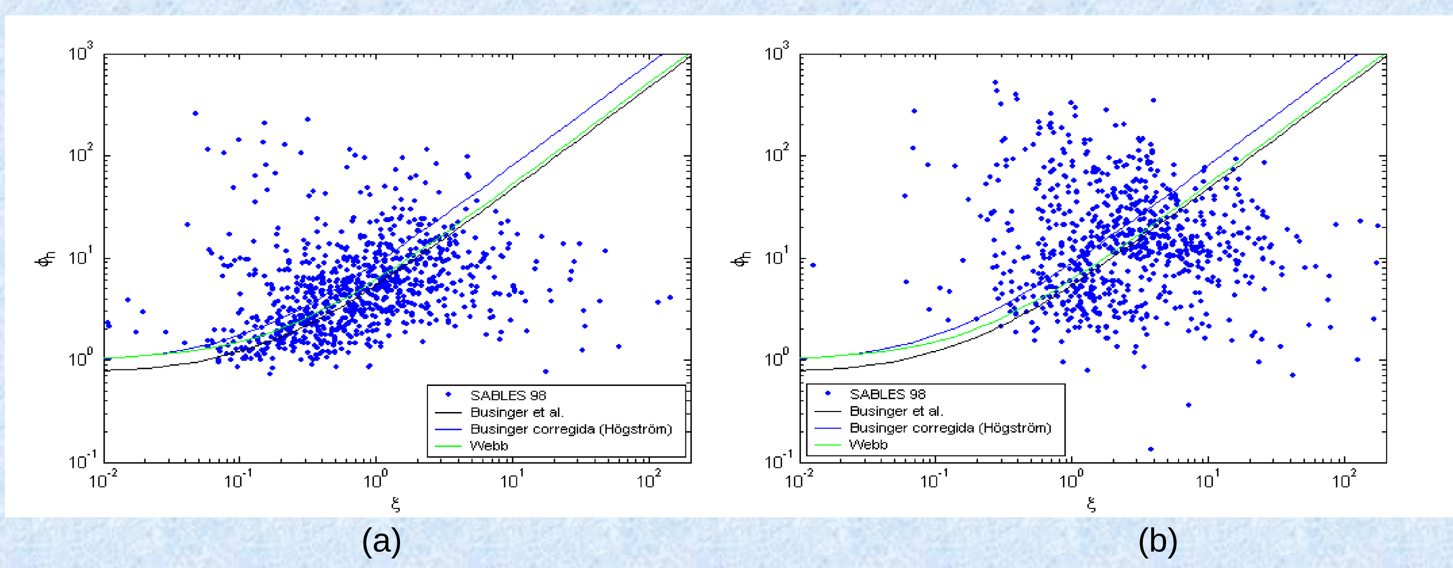

Figure 7: ϕ_h versus stability parameter for all the values calculated at : a) 5.8 m and b) 32 m.

5. CONCLUSIONS

• Most of the universal similarity functions found in the literature can not be valid when the stable conditions are in the range of strong stability.

•The use of the usual similarity functions for $\zeta>1$ can produce overestimation of the true values and give big errors in the atmospheric and dispersion models where this information is used to characterize the turbulent fluxes and other turbulent parameters evaluated from ϕ_m and ϕ_h values.

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