A diagnostic relation to estimate the mixing layer height under convective conditions

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Introduction

In the *ABLCLIMAT (Atmospheric Boundary Layer Climate)* project framework, high temporal and spatial resolution mixing layer height (h) measurements were performed with a surface-layer minisodar (SLM-sodar) at the French-Italian station of Concordia (**Fig. 1**), on the Antarctic plateau, during the summer 2011-2012. Determinations of h were complemented with turbulent fluxes measurement by a sonic anemometer. The poster focuses on the convective cases only. Stable cases are analysed in *Comparison of the mixing layer heights estimated by sodar and simple parametrizations at Dome C, Antarctica* (poster Z73).

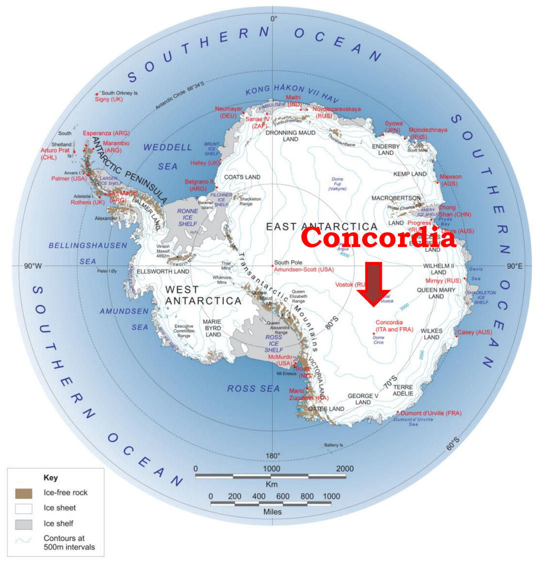

Fig. 1 - Map of Antarctica.

Instrumentation and methods

Fig. 2 – Sonic anemometer.

The sonic anemometer (**Fig. 2**) by Metek was operated at a sample frequency of 10 Hz. The raw data were analysed using the eddy covariance technique, in order to derive the turbulent fluxes over a period of 10 minutes.

The custom made SLM-sodar (**Fig. 3**) was specifically developed to investigate surface and boundary layer turbulent phenomena (*Argentini at al.*,2012), and to monitor the mixing layer height in both convective and stable conditions. During the summer period, the maximum potential instrument range was 360 m, with a lowest observation height and a vertical resolution of about 8 m.

Fig. 3 – SLM sodar.

Table 1 – Scheme for h estimation

ABL regime	Shape of the RCS	Applied method
Stable ABL	Continuous decrease with height	Maximum RCS curvature
	Elevated maximum in RCS	RCS first derivative minimum
Convective ABL	Secondary maximum in RCS	Height of the maximum

The h was estimated applying the technique originally proposed by *Beyrich and Weill* (1993) to the range corrected sodar signal (RCS). Under convective conditions (**Fig. 4a**), the h is determined as the height at which an elevated secondary maximum occurs, i.e. in correspondence of the zone of strong turbulence at the capping inversion. Under stable conditions (**Fig. 4b**), the h is determined either from the minimum of the first derivative, or from the maximum curvature of the RCS, depending on the stage of the ABL evolution and the shape of the RCS profile. The procedures are summarized in **Tab. 1**.

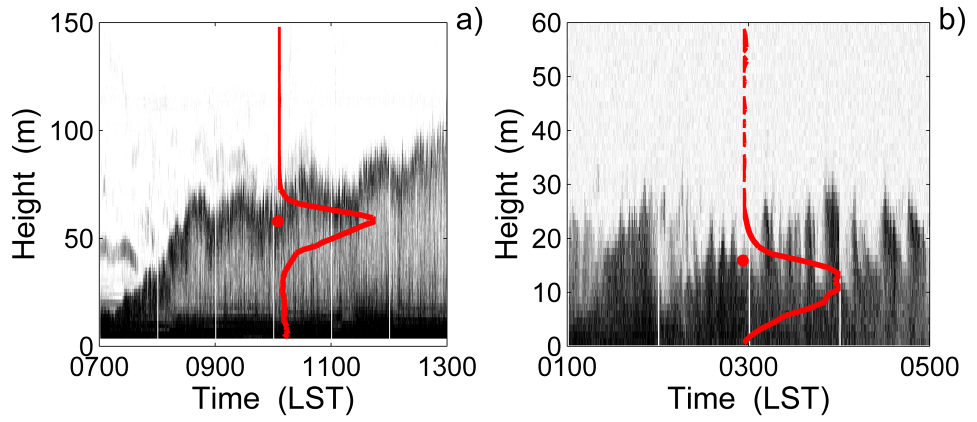

Fig. 4 – Determination of h by sodar profiles under convective (a) and stable conditions (b).

Gryning-Batchvarova model: the role of subsidence

The h evolution can be described (*Batchvarova and Gryning*, 1994) by the GBmodel:

$$\left\{\left(\frac{h^2}{(1+2A)h-2BkL}\right)+\frac{Cu_*^2T}{\gamma g[(1+A)h-BkL]}\right\}\left(\frac{dh}{dt}-w_s\right)=\frac{\overline{(w'\theta')}_s}{\gamma}$$

k: von−Karman constant
g: gravitational acceleration
γ: free atmosphere lapse rate
w_s: opposite of the subsidence velocity
L: Obukhov lenght
T: near−surface temperature
A, B, C: constants

This equation can easily be solved, for periods in which the kinematic heat flux is always positive, fixing an initial h value (30 m), retrieving a daily γ value from the radiosounding at about 2000 LST, **and keeping fixed the external parameter w_s (0.04 ms^{-1}).**

Since w_s has a clearly diurnal behavior, the major discrepancies between modeled and SLM-sodar determined h are found in the second part of the day, when the driving $\overline{(w'\theta')}_s$ shows a typical decreasing trend (*King at al.*,2006).

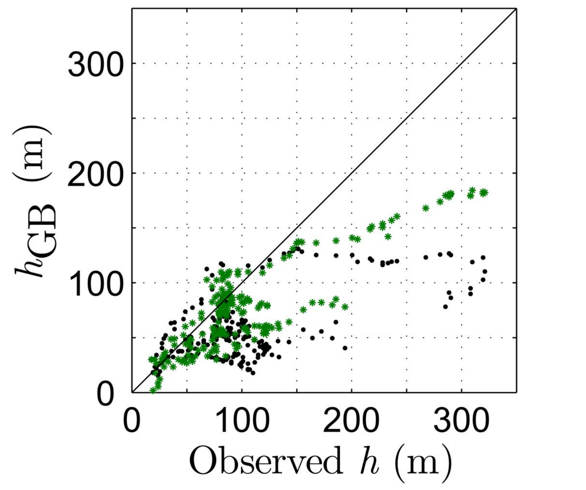

Fig. 5 – Comparison of h derived by SLM-sodar and GBmodel with w_s fixed (black dots) and variable (green dots) w_s.

To investigate the dependence of h on w_s variation, the entire dataset was divided into two subsets. The w_s values were retrieved applying the GB model to one of them, leading to a linear relationship of w_s (as function of time) that was used to retrieve the w_s-dependent h values from the second dataset. Results are shown in **Fig. 5** and summarized in **Tab. 2**.

The introduction of a variable w_s leads to more accurate predictions, with a significantly higher (~47%) Index of Agreement (IoA).

It's worth to note that the model still tends to slightly underestimate the h values (Fractional Bias of 0.29).

The GBmodel requires the knowledge of parameters provided by measurement non routinely available. To overcome this issue, when the mechanical turbulence is weak the simple encroachment model (EM),

$$\frac{dh}{dt}=\frac{\overline{(w'\theta')}_s}{\gamma\, h},$$

is the simplest way to calculate h.

As reported in **Tab. 2**, despite the good agreement (IoA = 0.72), the EM tends to heavily overestimate h (FB = -0.53), and the other statistical parameters are appreciably higher than those of the Gbmodel. Thus, a more accurate simple model needs to be developed.

Table 2 – Performance of the GBmodel with a fixed (second column) and variable (third column) value of w_s, and of the diagnostic relation (fourth column). The parameter represents the mean absolute error (mae), the root mean square error (rmse), the Fractional Bias (FB, varying between -2 and 2) and the Index of Agreement (IoA).

Parameter	Fixed w_s	Variable w_s	EM	Diagnostic relation
mae	41	33	79	33
rmse	69	49	92	47
FB	0.53	0.29	-0.53	0.19
IoA	0.57	0.84	0.72	0.76

A new diagnostic relation

The relevant processes to be considered for the convective ABL development and evolution are the exchange of heat between the land surface and the atmosphere $\overline{(w'\theta')}_s$, the background static stability γ, and the buoyancy effect $\beta = g/T$. The friction velocity, usually considered in stable cases, can be neglected in convective condition. To take into account the ABL history, the instantaneous kinematic heat flux cab be substituted with a history scale defined as:

$$Q=\frac{1}{t_m-t_s}\int_{t_s}^{t_m}\overline{(w'\theta')}_s^{1/2}\,dt$$

where t_m is the measure time, and t_s starts when $\overline{(w'\theta')}_s$ become positive; the difference $t_m - t_s$ must not exceed the mixing-layer evolution time scale, $\tau_{ML} = h(dh/dt) \approx 5$ hours.

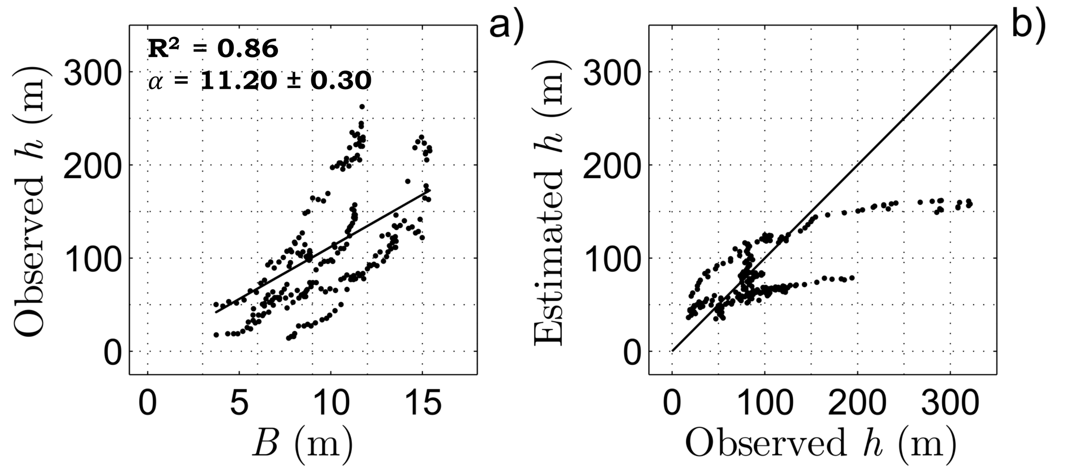

Fig. 6 – Plots of the measured h versus the dimensional group B (a), and of the h values estimated by equation (2) versus the experimental ones (b).

In the framework of the Buckingham Π theorem, the selected parameters lead to a single non-dimensional group, that can be re-written as:

$$h=\alpha\, Q\, \gamma^{-3/4}\beta^{-1/4}=\alpha B$$

where α is a coefficient to be determined. As for the GBmodel, the first subset was used to retrieve α (**Fig. 6a**), the other to validate the proposed equation (**Fig. 6b**).

Despite its simplicity, the model is in good agreement with the observed data. The results are summarized in Tab. 2, and published in Casasanta et al. (2014).

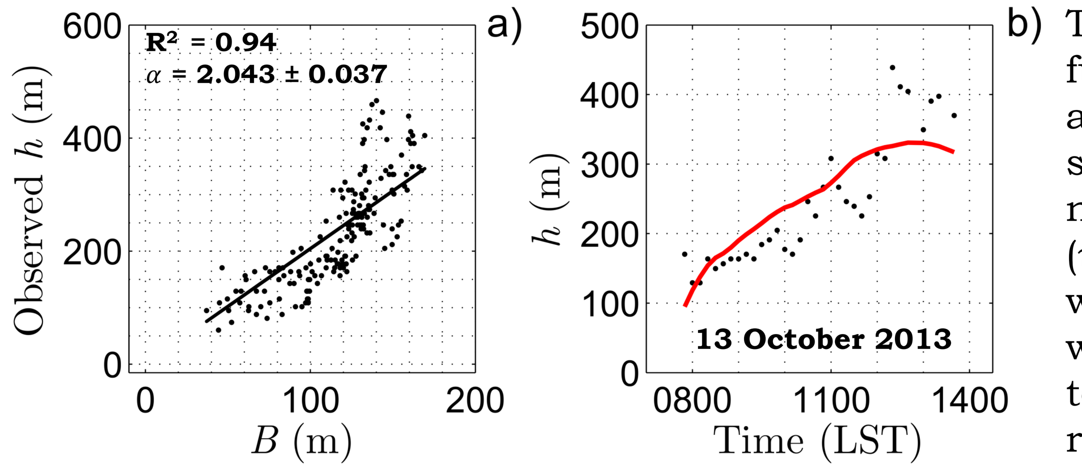

Fig. 7 – Plots of the measured h versus the dimensional group B (a), and of the estimated by h values versus the experimental ones (b).

The relation performance was further confirmed using sodar and anemometric data from the semi-rural site of Tor Vergata, near the polluted city of Rome ($\tau_{ML} \approx 4$ hours). Since only 5 days were available, the same dataset was used to both retrieve α and test the model. Results are reported in **Fig. 7**. The difference between the α coefficients at the two sites reflects the dependency on parameter not taken into account, such as, for instance, latitude and subsidence.

References

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