Subsidence role in convective boundary-layer development

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Index

- Scientific context – why the atmospheric boundary-layer height is important ?

- Convective boundary-layer evolution in undisturbed conditions, as retrieved by acoustic remote sensing measurements at DOME C, Antarctica

- Subsidence role in a widely-used prognostic model

- A new and simpler diagnostic formulation. What and how many parameters are really needed? Are we still missing something?

Scientific context

1. Air quality
   ABL height defines the maximum dispersion volume of pollutants

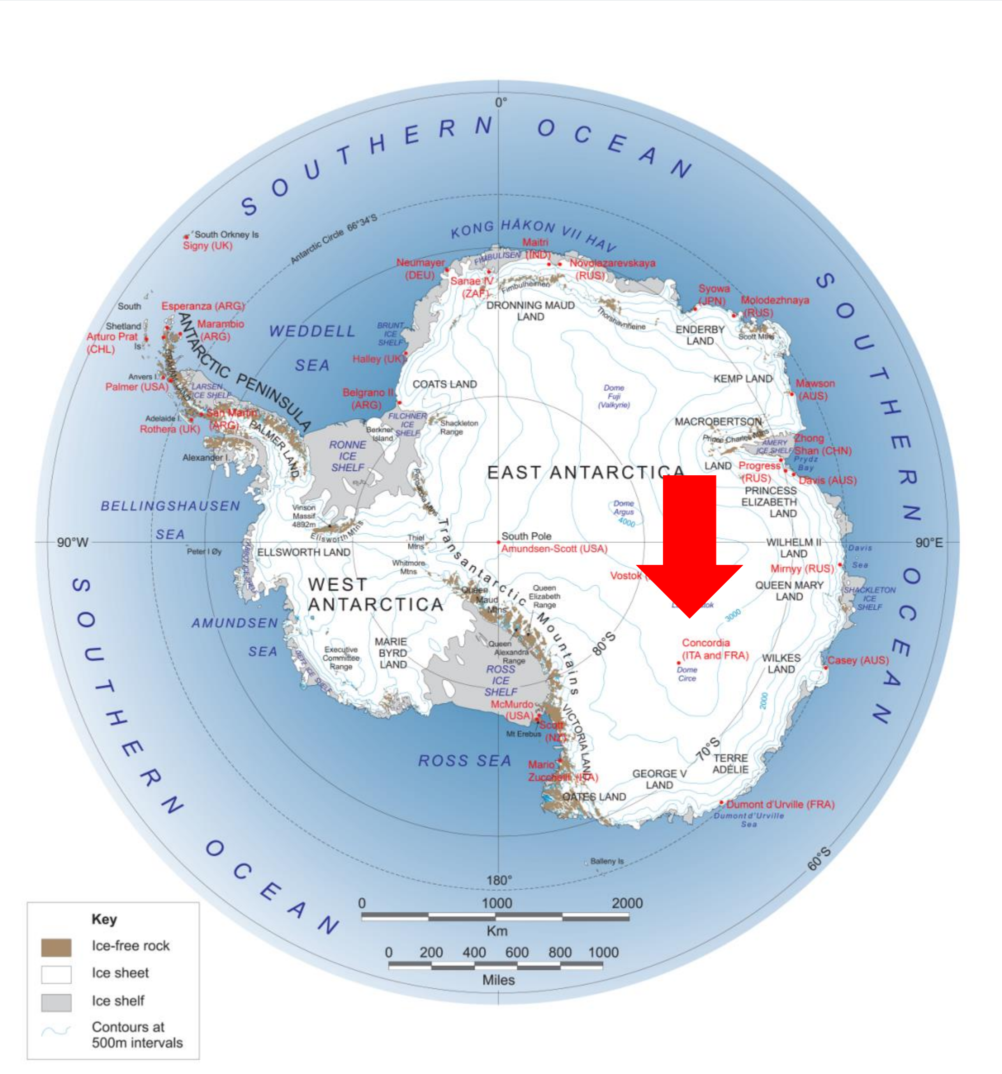
2. Climate model sensitivity
   large ensamble of more than 57,000 runs, www.climateprediction.net

   a. Entrainment rate (top-down, counter-gradient turbulent flux at ABL height) is associated with 30% of the variation seen in climate sensitivity (global mean temperature to a doubling of CO_2, Knight et al. 2007)

   b. The ABL mass budget leads to a direct proportionality between the ABL height and the entrainment rate (Medeiros et al., 2005)

   c. Subsidence is the large-scale, mean vertical motion at the ABL top, capable of affecting its height. Are we able to measure that?

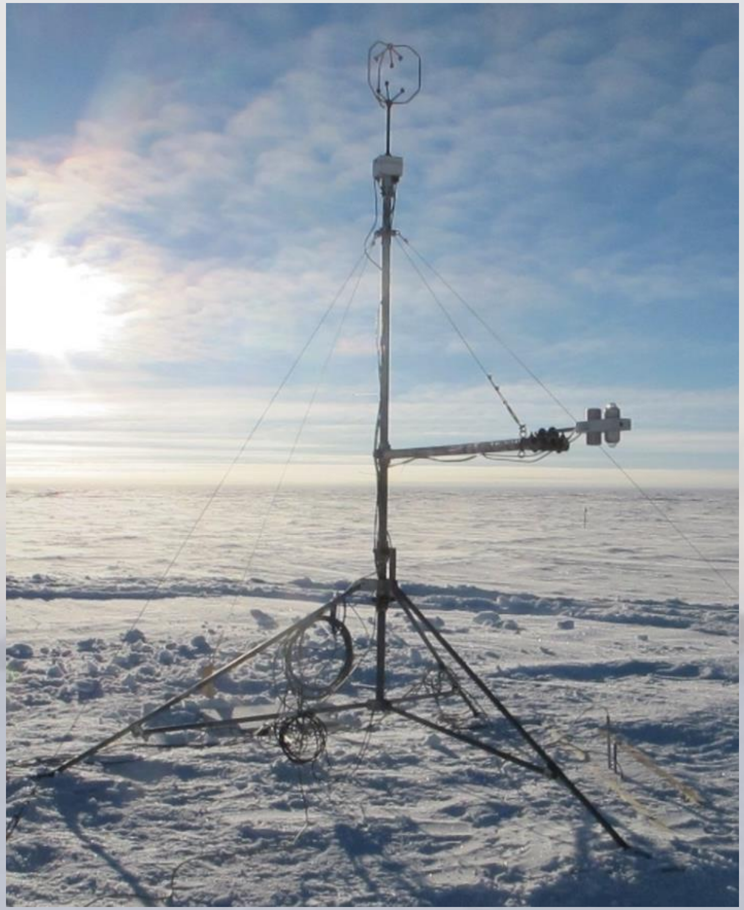
Experimental site



Concordia Base, Dome C, Antarctica

- In summer, the ABL evolution is similar to that observed at mid-latitudes
- Horizontal homogeneity for approximately 1200 km
- No orographic, human or environmental forcing
- Very stable meteorological conditions (most of the time)

Instruments

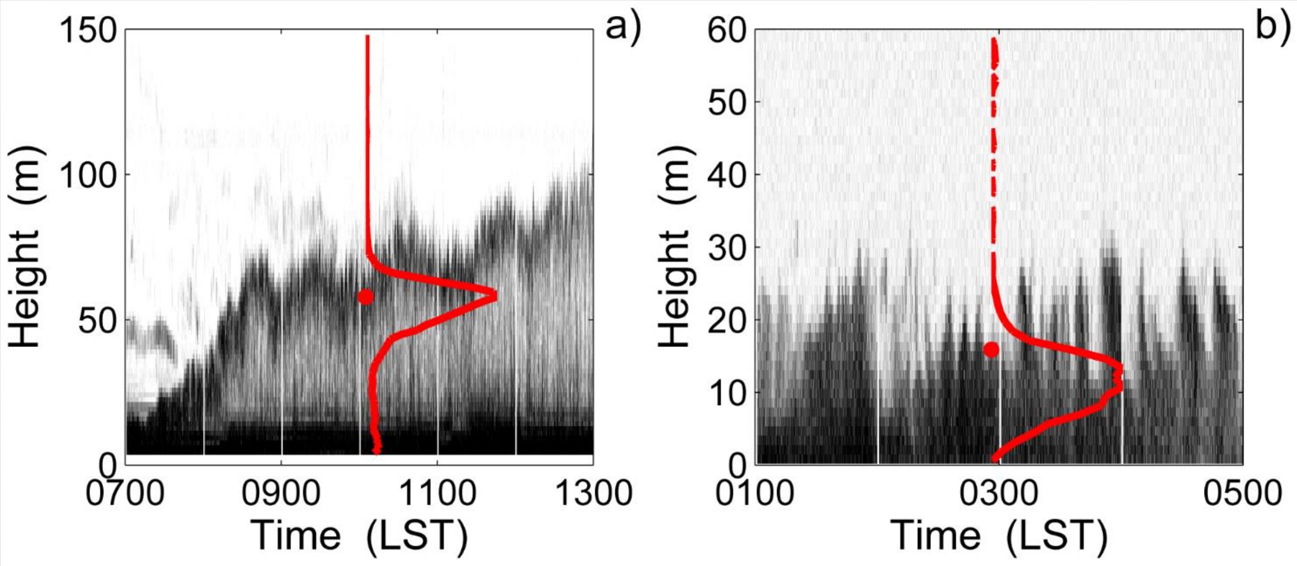


Metek ultrasonic anemometer (10 Hz)

- Friction velocity
- Virtual temperature
- Kinematic heat flux

Instruments

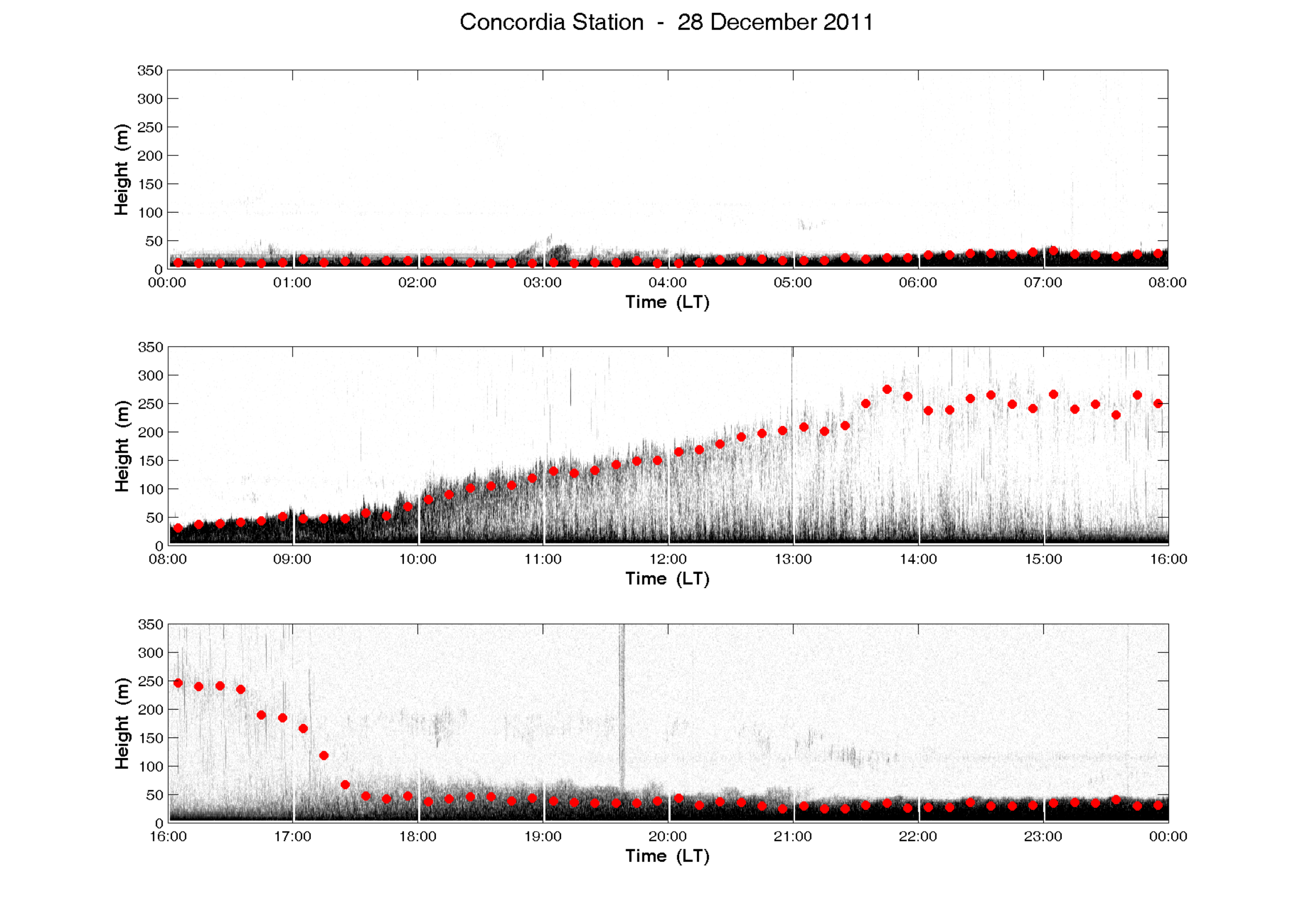
Specifically designed Doppler SODAR (2000 Hz)



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

Beyrich and Weill (1993)

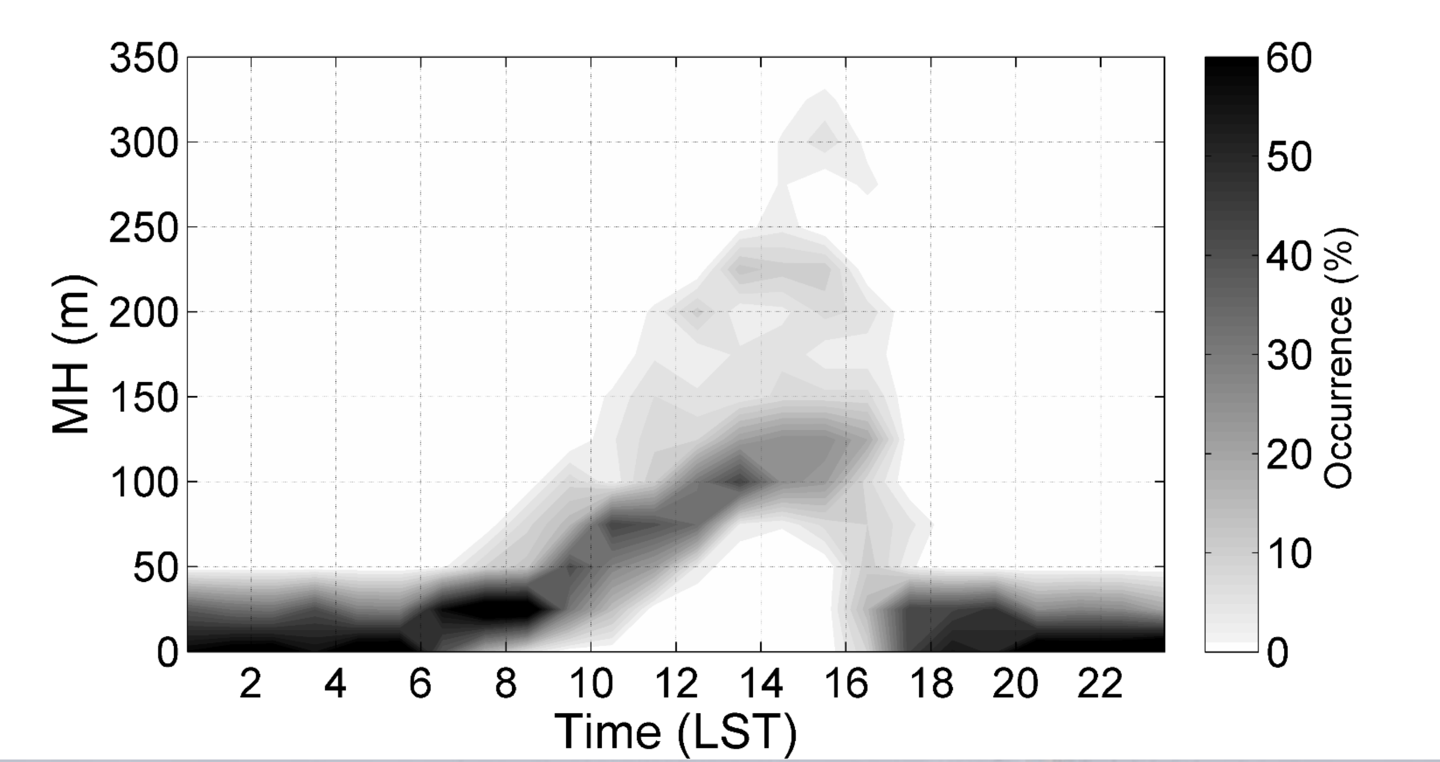
Instruments



ABL evolution – 12 days

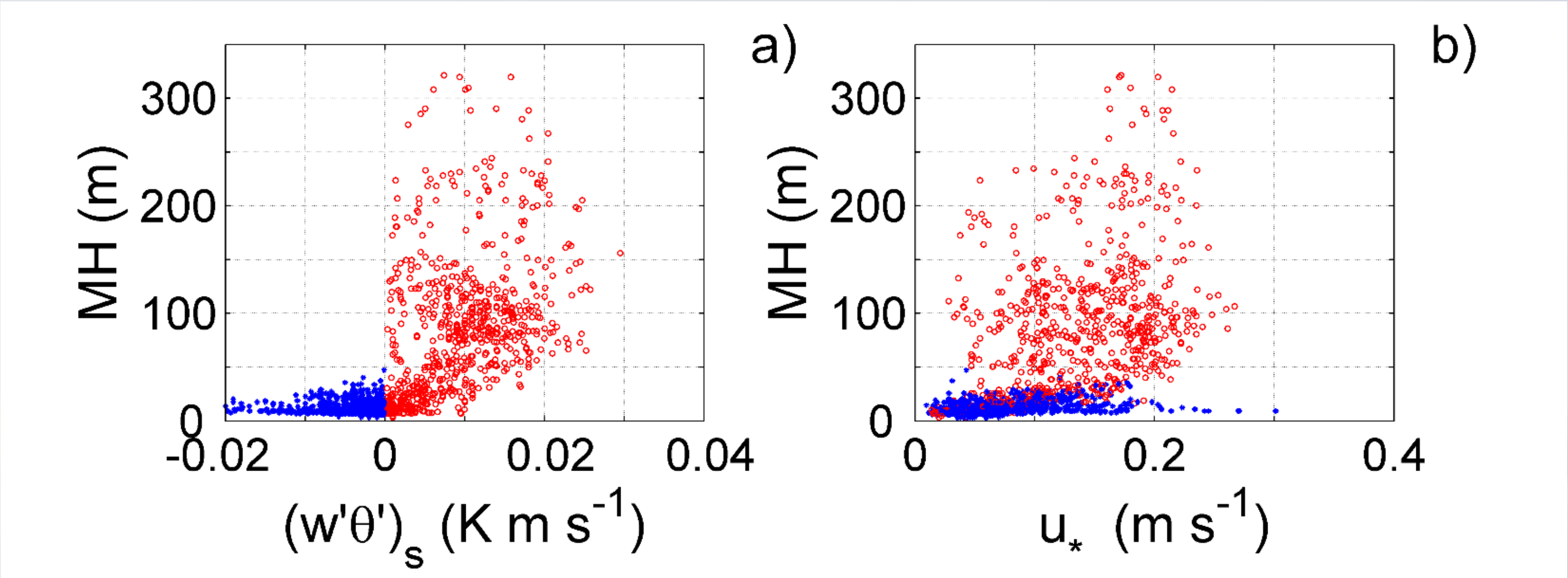
Main characteristics

- Expected diurnal cycle
- Stable MH below 50 m
- Convective MH up to 300 m
- Convection starts at 0600 LST
- Neutrality is reached at 1600 LST



KEY POINT After reaching is maximum value around noon (1300 LST), corresponding to the diurnal heat flux maximum, MH lasts without decreasing for approximately 2-3 hours

Key variables behaviour



Scatter plots of *h* determined from SODAR measurements and micrometeorological parameters $\overline{(w'\theta')}$ (**a**), and u^{*} (**b**) in both convective (*open red dots*) and stable cases (*blue dots*)

a) The scatter of red points is due to the fact that MH does not follow the afternoon decrease of $\overline{(w'\theta')}$

b) Mechanical turbulence appears to be negligible under convective conditions

Prognostic model

Batchvarova and Gryning (1994)

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

Spin-up term: $\left(\frac{dh}{dt}-w_s\right)$

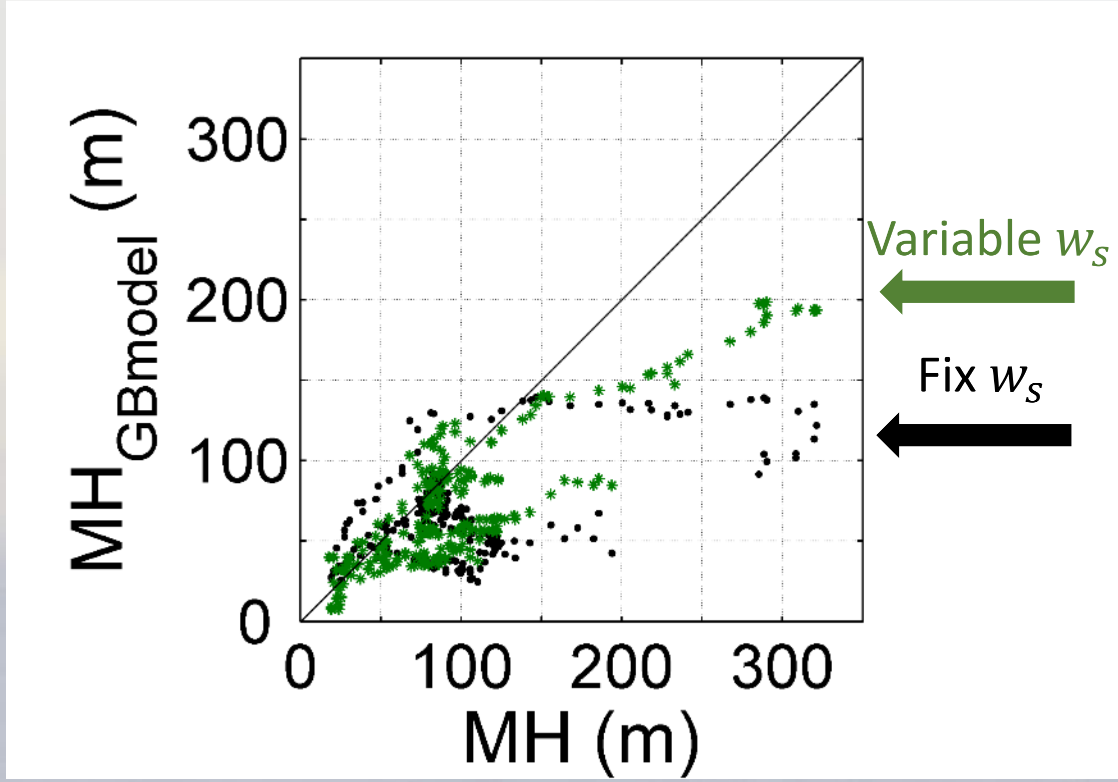
Mechanical and thermal turbulence contribution: the expression in braces $\{\ldots\}$

h	ABL height
k	von−Karman constant
A, B, C	empirical constants
T	reference temperature
L	Obukhov length
u_*	friction velocity
g	acceleration due to gravity
γ	free atmosphere lapse rate
$-w_s$	subsidence
$\left(\overline{w'\theta'}\right)_s$	surface heat flux

Initial conditions

h:	30 m
γ:	2000 LST
w_s:	0.04 ms^{-1}

Prognostic model



Measuring subsidence is a real challenge, but the diurnal behaviour of w_s can be estimated by splitting the dataset into two parts, and use one of them to retrieve it.

The introduction of a variable w_s leads to more accurate predictions, although the GM model still tends to slightly underestimate MH

Is it a real relevant variable, i.e. a parameter that should be considered, or it is acting as an additional free parameter that just improves the fit?

Diagnostic model

Relevant parameters

- Kinematic heat flux $\left(\overline{w'\theta'}\right)_s$
- Lapse rate γ
- Buoyancy $\beta = g/T$

Neglected paramteres

- Coriolis parameter
- Friction velocity

Memory effect

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

where t_m is the time at which the measurement are taken, and t_s that at which $\left(\overline{w'\theta'}\right)_s$ become positive

The difference $t_m - t_s$ has to be less than $\tau_{ML} = h(dh/dt) \approx 5$ ore

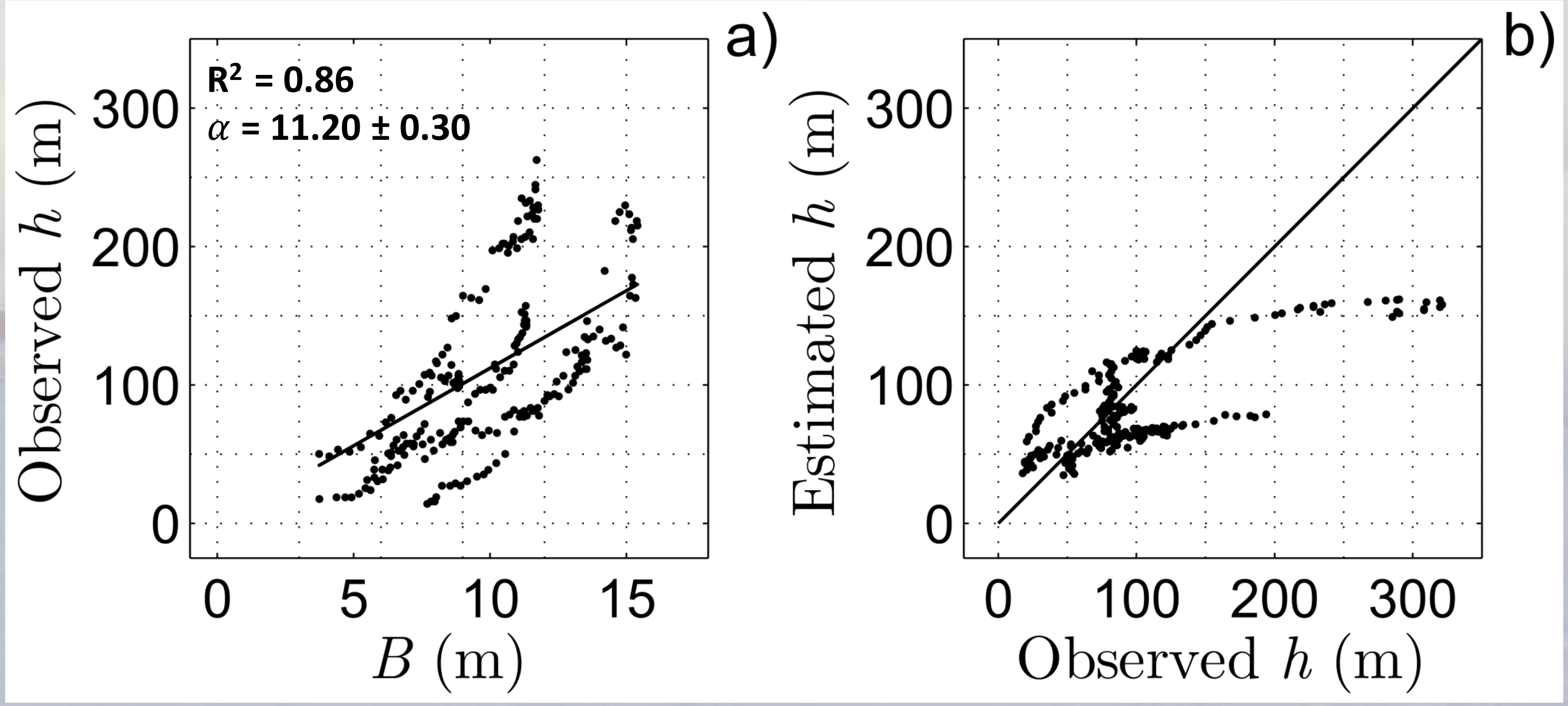
Quasi-steady state

- Convective turbulence scale $\tau_* = h/w_* \approx 10^2\ s$
- ABL evolution time scale $\tau_{ML} = h\left(\frac{dh}{dt}\right)^{-1} \approx 10^4\ s$

Diagnostic model

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

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



Confronto

Parameter	Fix w_s	Variable w_s	Diagnostic relation
mae	41	33	33
rmse	69	49	47
FB	0.53	0.29	0.19
IoA	0.57	0.84	0.76

Despite its simplicity, the diagnostic model is in good agreement with the observed data and its performance is comparable to that of the more sophisticated GB model.

Such a result, confirmed by further analysis performed with Tor Vergata data, support the use of a limited number of variable to characterise the convective ABL behaviour.