Convective Mixing Layer Height During The Summer At Dome C, Antarctica

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Introduction
In the ADCLIMAT (Atmospheric Boundary Layer Climate) project framework, high temporal and spatial resolution mixing layer height (MH) 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. MH determinations were complemented with turbulent fluxes measurement by a sonic anemometer. The project focused on the characterization of the Atmospheric Boundary layer (ABL) through acoustic remote sensing observations, and on the verification of boundary layer parameterizations.

Instrumentation and methods
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 et 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.

The MH was estimated applying the technique originally proposed by Beegich and Weil (1993) to the range corrected sodar signal (RCS). Under convective conditions (Fig. 4a), the MH is determined as the height at which an elevated secondary maximum occurs, i.e. in correspondence of the onset of strong turbulence at the capping inversion. Under stable conditions (Fig. 4b), the MH 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 on the shape of the RCS profile. The procedures are summarized in Tab. 1.

Mixing layer evolution
At Dome C the mixing layer behaviour shows a daily cycle similar to that observed at mid-latitudes. The MH is comprised in the first 50 m during the night, and from 0600 SLT gradually increase until about 1300 LST, when a maximum ranging between 75 and 250 m is reached and maintained for ~2 hours (Fig. 5). At the occurrence of a certain value at each hour).

Gryning-Batchvarova model: the role of subsidence
The MH evolution can be described (Batchvarova et al., 1994) by the GB-model:

\[
\text{MH} = \text{MH}_{\text{in}}(1-\exp(-\alpha_{\text{MB}} b))
\]

This equation can easily be solved, for periods in which the kinematic heat flux is always positive, fixing an initial MH value (30), retrieving a daily y value from the radiosounding at about 2000 LST, and keeping fixed the external parameter \(w_s\) (0.04 m/s).

Since \(w_s\) has a clearly diurnal behavior, the major discrepancies between modeled and SLM-sodar determined MH are found in the second part of the day (Fig. 7), when the driving (\(\frac{\theta'}{w'}\)) shows a typical decreasing trend (King et al., 2006).

To investigate the dependence of MH 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 these, leading to a linear relationship of \(w_s\) (as function of time) that was used to retrieve the \(w_s\)-dependent MH values from the second dataset.

Results are shown in Fig. 7 and summarized in Tab. 2. The introduction of a variable \(w_s\) leads to a more accurate approximation, with a significantly higher (47%) Index of Agreement (IoA).

Diagnostic relation
The relevant processes to consider for the convective ABL development and evolution are the exchange of heat between the land surface and the atmosphere, the background static stability, and the buoyancy effect, represented by \(\frac{\theta'}{w'}\), and the buoyancy parameter \(\beta = g/f\), respectively. The friction velocity, usually considered in stable cases, can be neglected in convective conditions (Obukhov, 1968).

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

\[
\text{MH} = a\left(\frac{\theta'}{w'}\right)^{b-1} \text{e}^{-c_b/M\text{H}}
\]

where \(a\) is a coefficient to be determined.

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 parameters represent 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).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fixed (w_s)</th>
<th>Variable (w_s)</th>
<th>Diagnostic relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAE</td>
<td>0.41</td>
<td>0.29</td>
<td>0.53</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.49</td>
<td>0.30</td>
<td>0.62</td>
</tr>
<tr>
<td>FB</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>IoA</td>
<td>0.15</td>
<td>0.29</td>
<td>0.33</td>
</tr>
</tbody>
</table>

For the GBmodel, the first subset was used to retrieve a \(a\) (Fig. 7a), the other to validate the proposed equation (Fig. 7b). Since the model does not take into account the effect of subsidence, the two datasets were further reduced keeping only the data prior the maximum daily value of \(\frac{\theta'}{w'}\). Results are summarized in Tab. 2: despite its simplicity, the model is in good agreement with the observed data, supporting the use of a limited number of variables to characterize the convective growth.

References

Fig. 1 – Map of Antarctica
Fig. 2 – SLM-sodar.
Fig. 3 – SLM-sodar.
Fig. 4 – MH determined by sodar profiles under convective (a) and stable conditions (b).
Fig. 5 – 24 hours distribution of MH estimated by SLM-sodar.
Fig. 6 – Scatter plot of MH vs \(\frac{\theta'}{w'}\), and 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).
Fig. 7 – Plans of the observed MH versus the dimensional group (a), and of the MH values estimated by equation (2) versus the experimental ones (b).
Fig. 8 – Comparison of MH estimated by SLM-sodar and GB model with \(w_s\) fixed for the day (black line) and with \(w_s\) variable (plotted from eq. 2, green dots).
Tab. 1 – Scheme for MH estimation
Tab. 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 parameters represent 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).