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Boundary layer convective-like activity at Dome Concordia, Antarctica

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Summary. — The paper presents the micro-meteorological field experiment carried out at the plateau station of Dome Concordia (3300 m a.s.l.) during the Antarctic summer of 1997. The experiment dealt with the study of the trends of boundary layer features and the characteristics of the surface energy and momentum exchanges. A monostatic Doppler sodar, fast-response sensors and radiometers were used for this study. The experiment was part of a program that aims to assess the role of the continental polar regions in shaping the surface circulation over Antarctica. In spite of the markedly stable conditions found throughout the investigated period, some convective-like activity was detected during the warmer hours of the day.

PACS 93.30.Sq – Polar regions.
PACS 47.27.Nz – Boundary layer and shear turbulence.
PACS 47.27.Te – Convection and heat transfer.

1. – Introduction

The annual radiative balance of the Antarctic continent is negative and, therefore, the air layer close to the surface is cooled for the most part of the year [1-3]. Strong inversion conditions are subsequently persistent sustaining the presence of gravitational flows downslope which are called katabatic winds [4-8].

Several studies have been conducted in the Antarctic region to investigate the relationships between surface energy balances and katabatic winds occurrence [7, 9-11] but very few studies have been conducted over the Antarctic Plateau to characterise the structure of the planetary boundary layer (PBL) and the surface energy partition [3, 9, 12, 13].

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The aim of the present study is to show a peculiar behaviour of the planetary boundary layer and the surface layer patterns in a plateau area (Dome Concordia station), in order to obtain information on the energy and radiation partition in the interior of the Antarctic continent, and on the height, evolution and structure of the PBL during daytime.

2. – Description of the site, experimental set-up and data analysis

Located on the high polar plateau Dome C is one of the coldest places on Earth. Both its altitude (3300 m) and its location near the pole (latitude 74°06′06″ S, longitude 123°20′74″ E) ensure cold summers (December and January with permanent sunlight and a temperature between −20 and −40°C) and even colder winters (April to September with permanent darkness and a temperature ranging between −40 and −80°C). The experiment started on January 20 1997, and the measurements were carried on without any significant interruption (except for system check-up and a few power shut downs) until February 2, 1997.

A mini-sodar antenna was located about 30 m south of the laboratory (an ISO10 container) while the anemometric and the radiometer stations were about 60 m west of the laboratory. The container itself was located about 150 m from the main camp to avoid noise due to the experimental and logistics activities. The antenna's parameters were chosen to allow a sounding between 12 and 400 m with a vertical resolution of about 13 m.

A radiometer mod. CNR-1 (Kipp and Zonen) was used for the determination of the radiation budget. The instrument was capable to measure separately the short- and long-wave radiation of incoming and outgoing components to derive the net radiation at the surface. The radiometric data were recorded by a CR10-ET data-logger (Campbell) every minute, averaged every 10 minutes and then stored in a Campbell SM192 memory module.

A sonic anemometer mod. USA-1 (Metek) was used in a station for turbulence and heat flux measurements. It was aligned to the north with a precision of 10 degrees. The sonic anemometer height above the ground was 3.4 meters to avoid ground influence and located in a flat zone with little or no obstruction nearby. The vertical alignment of the sonic anemometer was ensured by two optical levels able to guarantee a precision of 1°. The raw data were collected by a MeteoFlux computer system performing real-time measurements.

3. – Results and discussion

3˙1. *Micrometeorological parameters*. – The analysis of the wind speed recorded during the observation period (fig. 1) shows the 120°–300° sector as the main prevailing sector of wind origin. The S-W direction corresponds to the main flow pattern (peaked at about 200° - 240°) that Parish [14] calculated for the winds coming from the interior of the continent.

The site was prevalently influenced by light winds (about 2.5 ms^{-1}) which exceeded 5 ms^{-1} in a few cases only (fig. 2).

As far as temperature is concerned the sonic temperature given by the anemometer was recorded during the experiment (fig. 3); the very low humidity content of the atmospheric surface layer of the site can support the approximation that sonic temperature should differ from air temperature by only a few tens of degree up to one degree [15-17]. The temperature range was −46°C and −26°C.

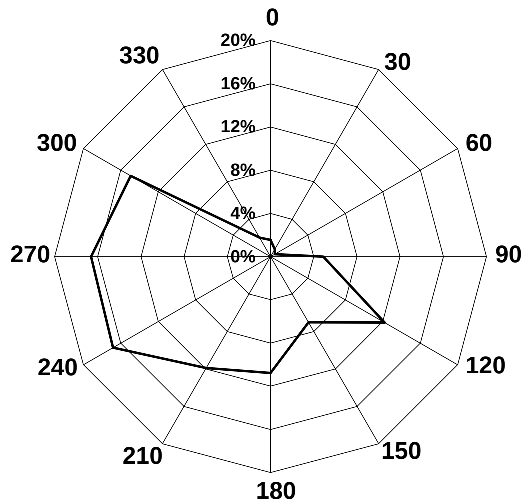

Fig. 1. – Wind rose recorded during the experiment.

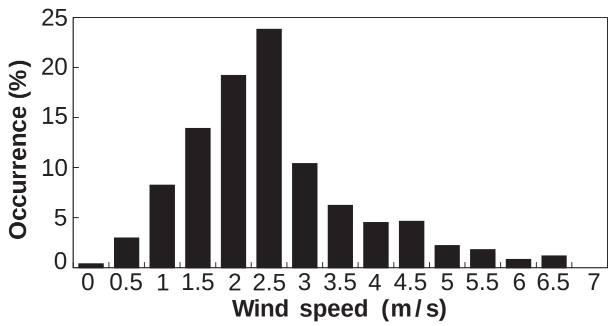

Fig. 2. – Wind speed occurrences for the whole measurement period.

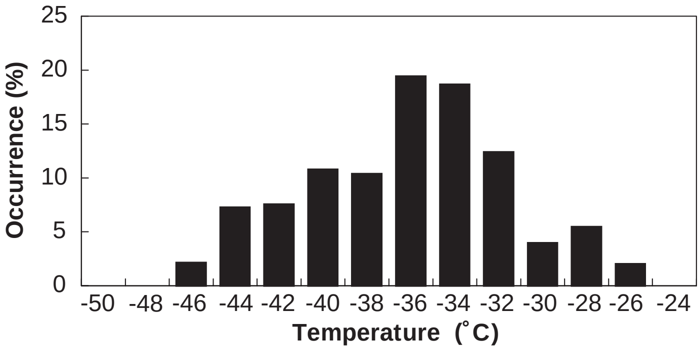

Fig. 3. – Sonic temperature occurrences for the whole measurement period.

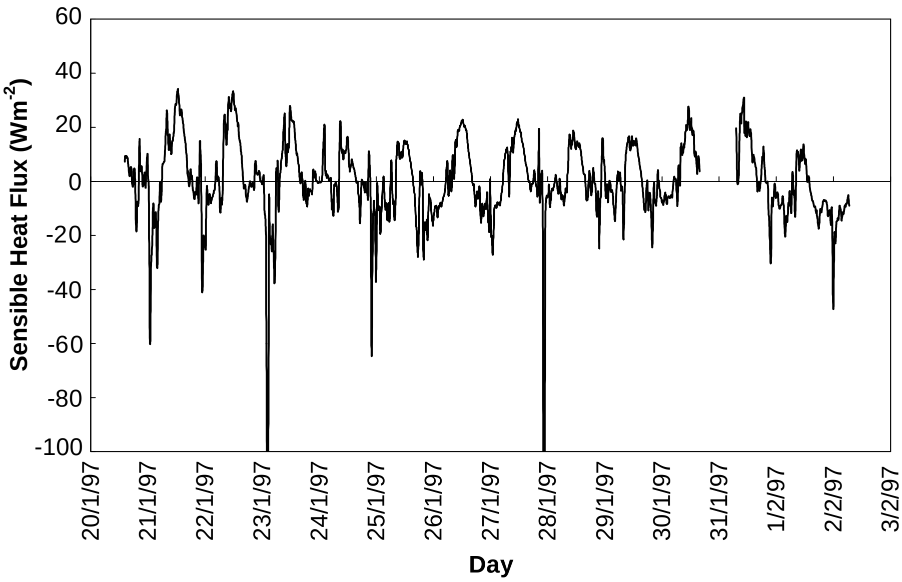

Fig. 4. – Trend of the sensible heat flux for the whole measurement period.

3˙2. *Surface flux analysis*. – The sensible heat flux shows (fig. 4) that the partitioned energy ranged from -60 Wm^{-2} up to 40 Wm^{-2}, with the exception of days 23 and 28 January when negative heat fluxes were observed (-125 and -200 Wm^{-2}). Such values are directly related to two episodes of exhaust gas from the power generator passing in

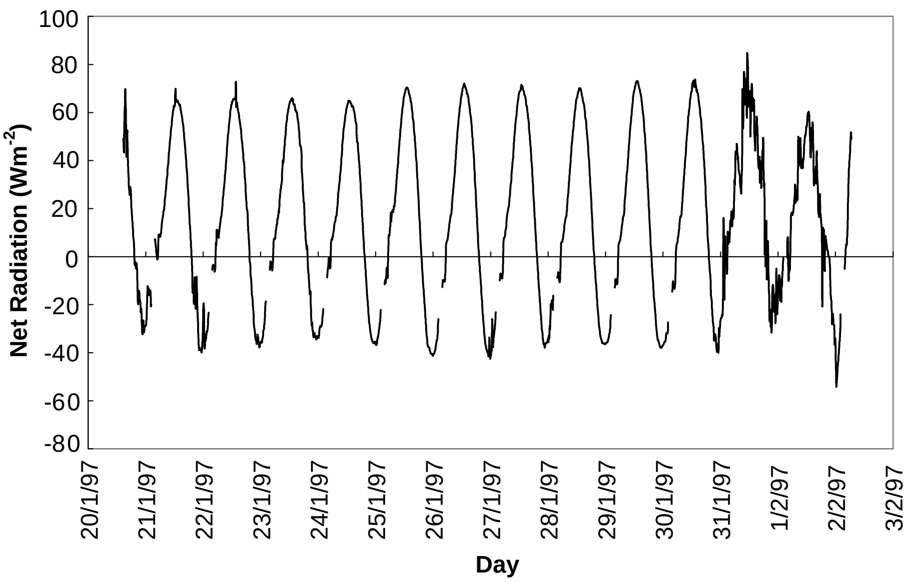

Fig. 5. – Net radiation trend for the whole measurement period.

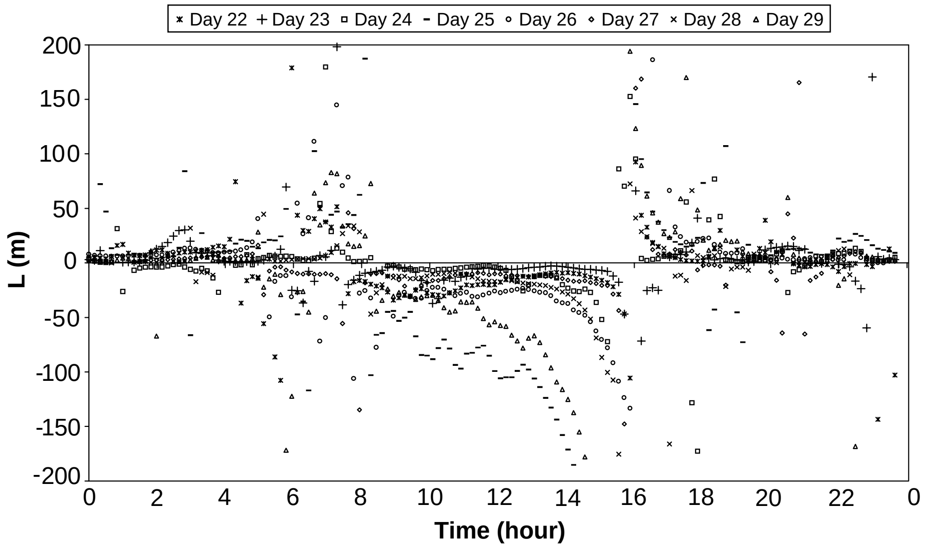

Fig. 6. – Diurnal behaviour of the Monin-Obhukov length for the period 21 January-29 January 1997; different symbols indicate different days.

the vicinity of the mast.

On the average, the sensible heat flux presents a daily pattern with positive values for half of the day and negative ones for the remaining half following the net radiation behaviour (fig. 5) which ranged from $-55\ \mathrm{Wm}^{-2}$ to $80\ \mathrm{Wm}^{-2}$. It can be concluded that, on the average, half of the maximum available energy at the surface was partitioned into sensible heat flux.

The corresponding Monin-Obukhov length (M-Ol) calculated for each day of measurements is reported in fig. 6. From the figure it is evident that in the central part of the day a convective-like activity at the surface seems to be present. A large scatter of the M-Ol is also present during the early morning hours but presents the almost complete absence of a clear trend.

3·3. *Sodar data analysis*. – As expected, very little thermal turbulence was observed during the field experiment. Figure 7 shows, as an example, the boundary layer evolution for day 29 January.

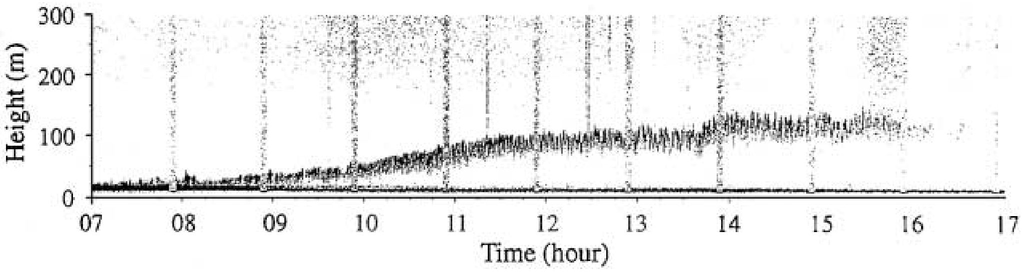

Fig. 7. – Sodar facsimile recording for day 29 January, 1997.

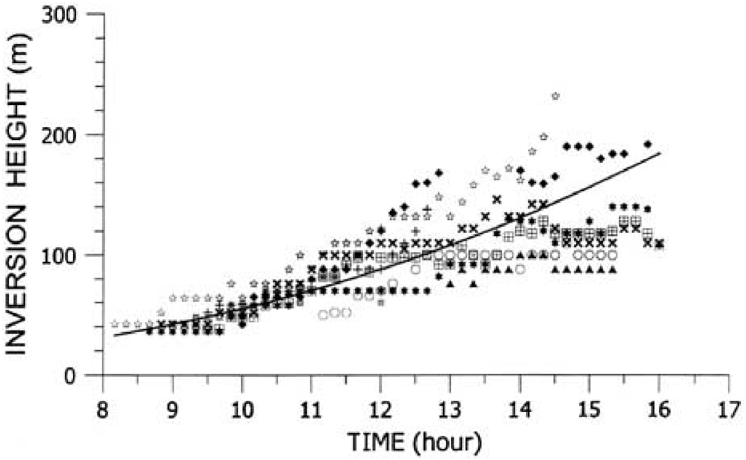

Fig. 8. – Boundary layer height estimated by the sodar facsimile recording; different symbols indicate different days.

A little convective activity was observed during the warmer hours of the day. In the facsimile record only the thermal turbulence at the capping inversion is evident. The thermals that usually appear in a facsimile record when convection takes place are not present because of the low-temperature fluctuations; however the harmonic analysis of the echo clearly displays the vertical movements associated to convective cells with positive velocities up to 1 ms^{-1}; in our case the descending part of the convection does not usually produce echoes intense enough to allow the retrieval of the Doppler information. Usually no echoes seem to be present before 07:00 ST and after 17:00 ST. If any thermal turbulent layer exists, it must be confined to the first 10–20 m, *i.e.* below the first sodar range gate. The observed behaviour of the PBL height is in agreement with the M-Ol trend.

The mixing height was estimated using sodar data represented on the fax by the line of intense echo due to the temperature and wind variations through the inversion layer [18-20]. Figure 8 shows the estimated boundary layer height for the whole experiment. The boundary layer height increases from about 20–30 m in the early morning up to 150 m during the warmer hours of the day.

4. – Conclusions

The presence of a sodar at the plateau station of Dome Concordia allowed the estimation of the boundary layer height. As the mini-sodar antenna was directed vertically an estimate of the vertical velocity was obtained that confirmed the presence of convective-like activity.

The simultaneous surface measurements performed at the site strongly support the findings obtained by sodar measurements. The occurrence of a positive sensible heat flux while M-Ol exhibits a minimum during the central part of the day can be interpreted as the development of convective activity produced by the partition of half of the available energy at the surface into an upward heat flux which leads to vertical air movements.

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