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Characteristics of the boundary layer thermal structure at a coastal region of Adélie Land, East Antarctica

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Abstract: The boundary layer thermal structure, observed through Doppler sodar, at Dumont d'Urville, has been analysed. Typical echograms of the spiky layers, wavy layers and thermal plumes, except for the eroding inversion, have been observed. The annual distribution of these thermal structures is presented. The spiky layers are observed to coincide with strong winds (mainly katabatic) flowing from the inner continent sector, 90°–180°. The upper boundary of the spiky layers is correlated to the wind direction; the maximum depths (more than 400 m) are confined to 60° wide span centred at 135°. The predominant waves and the spiky layers, tend to occur alternately in accordance with the relative dominance of the katabatic flow intensity and the stability conditions. The sodar signatures of these structures are examined in relation to the onset and dissipation time, duration and the seasonal distribution. Both waves and spiky layers occur at any hour of the day; their maximum occurrence is in winter months. The persistence of the waves varies from a couple of hours to a couple of days while the spiky layers can occur for periods even longer than 3–4 days. The characteristics of these phenomena are associated with the diurnal radiational cycle and the temperature contrast in proximity to the coast.

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Key words: Antarctica, boundary layer, inversion, katabatic winds, sodar, spiky layer

Introduction

Climatological studies of the flows and the thermal structures in harsh environments, e.g. polar regions, high mountains and oceans, have been under investigation for a long time. In this context Antarctic regions have been a particular focus of attention with various kinds of experimental campaigns. Adélie Land in East Antarctica is of special interest because the well developed katabatic winds blow almost all the year with velocities often greater than 50 m s^{-1}, although no special topographic features have been conclusively demonstrated to exist. Since the severe weather conditions constrain most human activities and scientific experiments, the problem of forecasting the initiation, intensity and duration of the stronger katabatic winds has become increasingly important. Experiments and studies have been focused on understanding the katabatic winds regime which contributes, together with the wind waves, to the breaking and dispersion of the sea ice which in turn has a bearing on the general circulation and climate of the planet (Wendler *et al.* 1983). The IAGO (Interaction Atmosphere-Glace-Ocean) experiment (Poggi *et al.* 1983) was set up at this site for a better description and understanding of the conditions under which the katabatic winds originate, develop and interact with the rest of the planetary boundary layer and the free atmosphere.

The local circulations, arising from horizontal surface temperature gradient near the coastline when the ocean is ice free and the blowing snow densities are more than few grams per cubic metre, play a significant role in shaping the katabatic winds (Pettré *et al.* 1993) and modifying the katabatic force (Kodama *et al.* 1985). In this context, any change in the meteorological parameters at local or synoptic scale has a direct influence on the Atmospheric Boundary Layer (ABL) thermal structure. Therefore, the studies of the evolution and the characteristics of the boundary layer thermal structures, in relation to the prevailing wind regime and their seasonal dependence, are important to understand the processes that regulate the interaction between local katabatic winds and the ocean. These studies at Dumont d' Urville are also interesting because the area is a divergence zone and the intensive katabatic winds are thus not expected to occur (Periad & Pettré 1993).

Acoustic sounder capabilities to monitor the Planetary Boundary Layer (PBL) thermal structures in the Antarctic regions have been exploited by several researchers (Neff & Hall 1976, Culf 1989) to study the turbulence and the waves in a stably stratified atmospheric boundary layer. In pursuit of the same objectives a 3-axis Doppler acoustic sounder was deployed at the French base of Dumont d'Urville and operated continuously from January 1993 to January 1995. The experimental details, the system configuration, the reliability of the sodar measurements and some preliminary results have been reported by Argentini *et al.* (1996). In this paper we present further analysis of the 1993 data with two main objectives:

a) to examine the statistical occurrence of the various thermal structures in relation to the prevailing wind characteristics, and

b) to check if the sodar signatures of the dynamics of ABL thermal structures can be used as an indicator to 'nowcast' the onset, development, and decay of the katabatic winds.

Topography and climatological aspects of Dumont d'Urville

The sodar site (140°00'30"E, 66°39'45"S) is at the French station Dumont d'Urville on a small island 5 km from the coastline, in Adélie Land, East Antarctica (Fig. 1), at an elevation of about 50 m a.s.l. The island has a steep slope near the coast, so that the wind field at the low levels is modified by the local topography (Argentini *et al.* 1996). A sparse distribution of buildings and small rocks characterize the site. The ground is normally covered with snow throughout the year except during the summer months when some areas become clear of snow. The seasonal classification is well marked and separated by short inter seasons.

a) winter, April/May to October

b) summer, November to March

c) autumn, March to April, and

d) spring, four ten day periods, two in October and two in November (40 days spread over October to November).

Analysis of the meteorological data (Periad & Pettré 1993) shows that the continent has a warming trend of 0.26° per

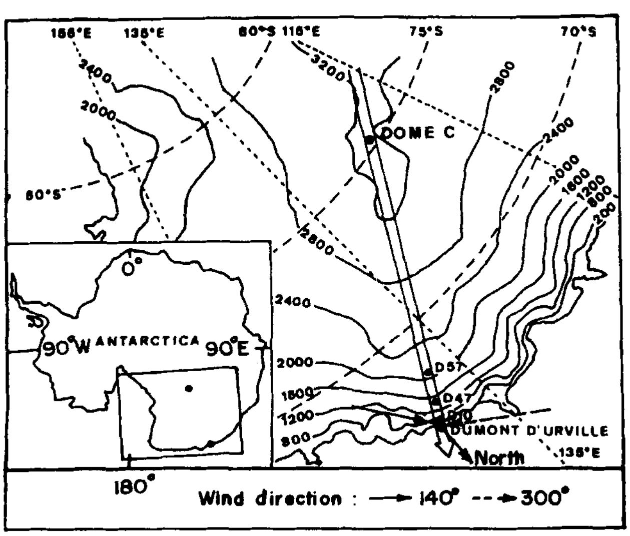

Fig. 1. Topographic map showing the location of Dumont d'Urville and the location of the AWS D-10, D-47, D-55 and Dome C.

decade. The diurnal variation of the air temperature shows that the maximum occurs between 12:00–15:00 LT, while the minimum occurs between 24:00–06:00 LT. Frequent strong winds (10–12 m s^{-1}), from the continent (140°), following the direction of the katabatic winds, begin about two months before the autumn, in February, and continue until the end of May to July. However, the strongest mean winds as well as the lower temperatures are observed at the end of the autumn. Relatively weak mean wind speeds (8–9.5 m s^{-1}) are observed from October to January. Anticyclonic conditions prevail during the summer and winter while cyclonic conditions are concentrated in the inter seasons. On the average, during January and July, Dumont d' Urville is in a region of high geopotential (Schwerdtfeger 1984). The lower values of pressure temperature and strong winds are observed during the inter seasons.

Data and instrumentation

The Doppler sodar was operated continuously from January 1993 to January 1995 except for few days when short interruptions were required for the system checks. The present study is confined to the data from 1 February 1993 to 31 December 1993. The sodar is a monostatic three-axis Doppler system with 1.2 m diameter antennas emitting every 6 s at the acoustic frequencies centred at 1750–2000–2250 Hz (Argentini *et al.* 1992, Argentini & Mastrantonio 1994). Two of the antennas are tilted at an angle of 20° away from the vertical, the third antenna is directed vertically. The vertical resolution of the system is 27 m while the pulse repetition rate allows the recording of echoes in the range 40–1000 m. For each channel, the facsimile records: the instantaneous profile of radial wind velocity, the echo intensities, the vertical profiles of the averaged horizontal and vertical wind components. Argentini *et al.* (1996) have analysed the performance of the instrument and checked the reliability of the wind measurements. They have showed that most of the time measurements are available up to 900 m with a wind speed exceeding 15 m s^{-1}. A bias, increasing with the wind speed, was noticed in the vertical velocity below 200 m due to influence of the local topography. This bias was evaluated and a formula for the correction of the measurements in the lower layers was proposed. Hourly data from the continuous sodar echograms of the ABL thermal structures and 10-minutes averaged horizontal and vertical wind profiles have been analysed and are presented below.

Characteristics of the Antarctic ABL thermal structures

All types of commonly known thermal structures of the ABL have been observed at Dumont d'Urville (Fig. 2a, d). The schematic representation of the diurnal occurrence of these structures (Fig. 3), illustrates a ground based layer with flat top (representing statically stable laminar ABL) associated

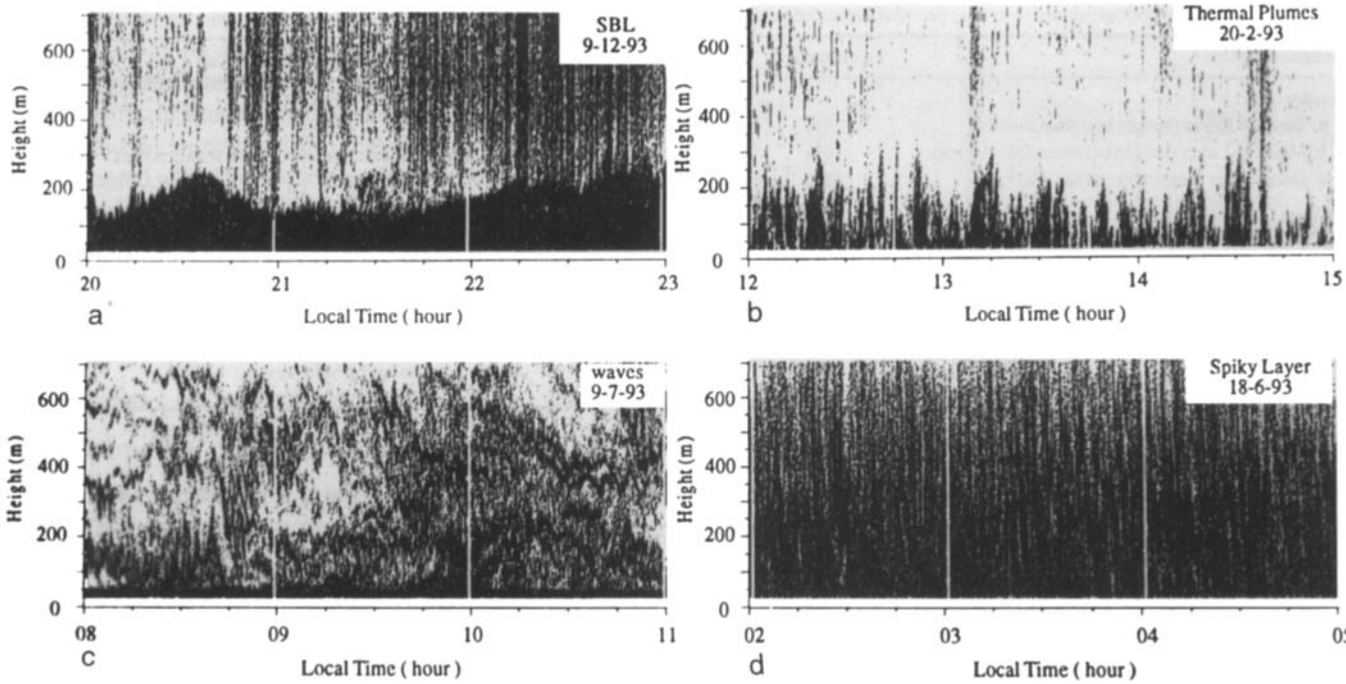

Fig. 2. Sodar echograms of ABL thermal structures observed at Dumount d'Urville: **a**. ground based layer with flat/short spiky top, **b**. thermal plumes, **c**. oscillating layers (waves), **d**. spiky layer (katabatic flow).

with radiational cooling of the ground and accumulation of a descending air mass due to the drainage winds. Such layers are manifestations of strong inversion conditions and are characterized by increase of potential temperature with height. Stratified layers/waves under statically stable conditions are often triggered during transition from laminar to turbulent ABL due to a sudden transfer of momentum (Schubert 1977) associated with the presence of wind shear at the interface of the laminar layer or the presence of vortex rolls (Offen & Kline 1975).

However, increased intensity of the wind speed causes mechanical mixing within the stable ABL and leads to spiky layer characteristics. Crease *et al.* (1977) have observed that spiky layers correspond to regions of marked wind shear responsible for mechanical turbulence in the steep temperature gradient and considered these layers to represent regions of strong mixing under stable atmospheric conditions. Singal *et al.* (1986) have shown that the depth of spiky layers is associated with the intensity of the surface winds. Vertical mixing in the stable layer reduces the magnitude of the temperature gradient and thereby weakens the prevailing stability.

The morning transition, from stable to unstable ABL, due to the solar heating of the ground, is normally seen as a rising layer (eroding inversion) with thermal plumes beneath it. However, such events were not seen during our observations.

Thermal plumes, characterizing well mixed ABL (free convection) and normally seen during sunshine hours, have been observed during the summer months. Towards evening, under calm and clear weather conditions, ABL gradually

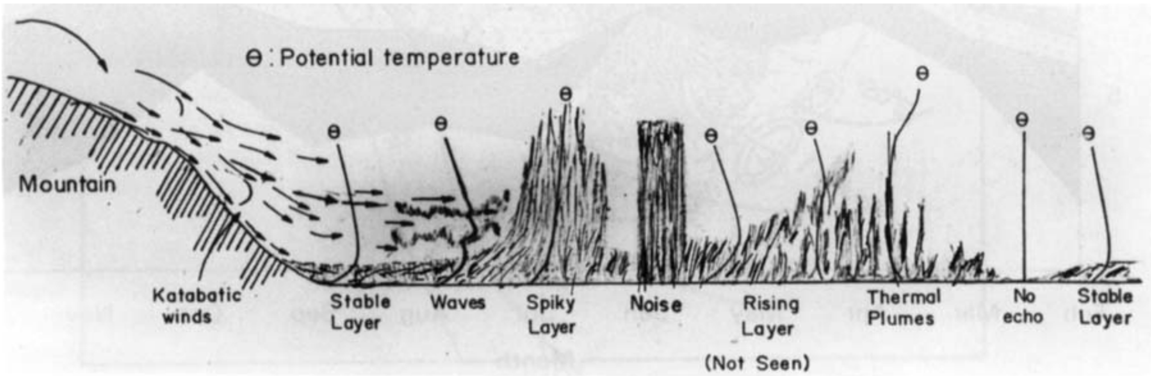

Fig. 3. Schematic representation of the various thermal structures observed during the period February to December 1993 at Dumont d' Urville.

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Table I. Frequency of occurrence of various thermal structures at Dumont d' Urville during February to December 1993.

Thermal structure	Occurrence %	Remarks (associated meteorological condition)
1. Spiky Layer:		
a. Narrow Layer (height less than 300 m)	27%	
b. Medium Layer (height between 300–400 m)	10%	Mechanical mixing in the stable layer due to strong winds
c. Deep Layer (height more than 400 m)	15%	
2. Waves	17.5%	Shear in the stable boundary layer
3. Dark echoes (noise)	17.5%	Very strong winds
4. Stable layer	10%	Strong inversion conditions
5. Thermal plumes	2.5%	Free convection
6. No echoes	0.5%	Neutral boundary layer (no turbulence)

transforms from statically unstable to stable PBL as solar radiation ceases and radiational cooling of the ground begins. During this transition period, ABL normally passes through a short-lived statically neutral atmosphere which is so lacking in turbulence to cause no sodar echo returns. Such events, have been observed over Antarctica.

Under conditions of excessively strong winds, the wind induced acoustic noise masks the sodar signals and dark unintelligible echoes, (called noise), appear on the sodar echograms.

As these structures relate to different meteorological conditions, the frequency of their occurrence have been examined (Table I). Spiky layers of different depth predominate most of the time (about 52%) while the noisy echograms due to very strong winds and the waves have a frequency of 17.5%. Monthly distribution, with respect to the total occurrence, is shown in Fig. 4. The maximum occurrence of the spiky layers (which depict mechanical mixing or the forced convection) was observed from April to June and in October, i.e. during the season change, at the beginning and at the end of the winter. Since more frequent and strong winds, mainly katabatics, were observed during the season change period, it is inferred that spiky layer characteristics are associated with strong katabatic winds. Therefore, for further analysis of the spiky layers, into deep layer (DL) with depth greater than 400 m, medium layer (ML) between 300–400 m and narrow layer (NL) with depth less than 300 m, depending upon the height traced in sodar echograms has been done. This classification is based on the similarity observed in the shape of the wind profile in addition to the visual inspection of the echogram. In terms of occurrence the NL predominate most of the time (about 27%), followed by

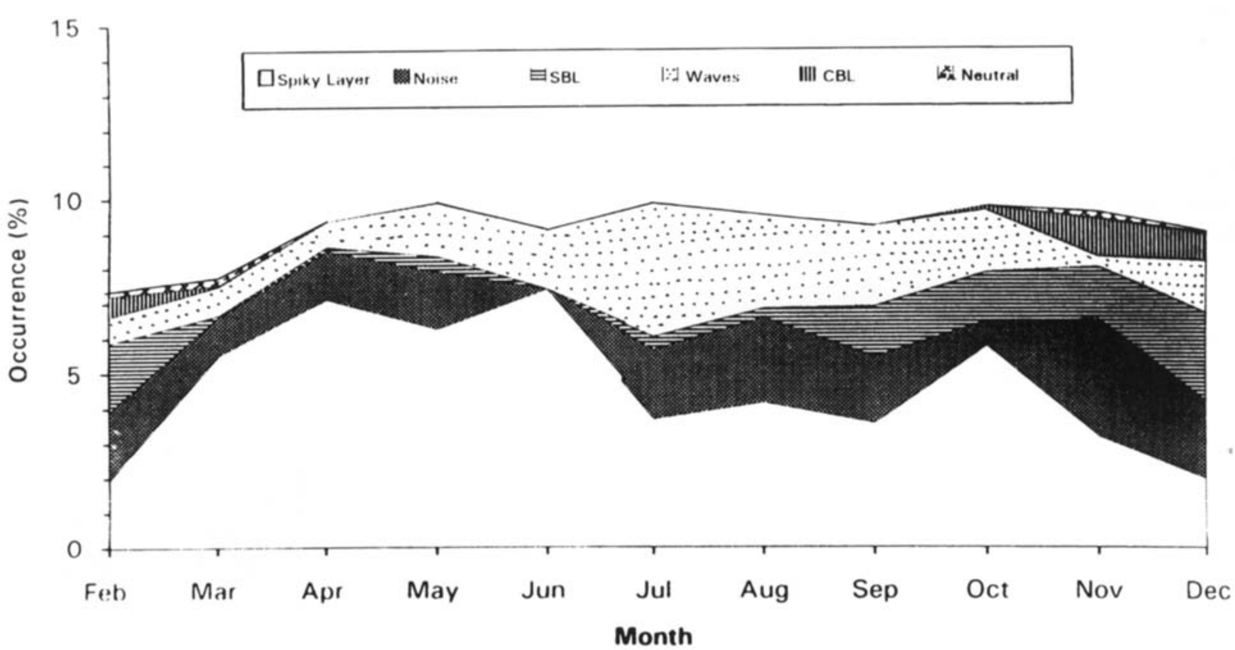

Fig. 4. Monthly patterns of the occurrence of the various thermal structures observed at Dumont d'Urville (February to December 1993).

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DL (about 15%) and ML (10%) as shown in Fig. 3. The noise, generally due to the occurrence of strong winds, is more or less equally distributed throughout the year. The stable layers with nearly flat or short spikes top, the thermal plumes and the neutral conditions prevailed during the summer season which was associated with fair weather anticyclonic conditions and large sunshine fraction (Periad & Pettré 1993). Waves were observed mainly during the midwinter month of July, wherein Dumont d'Urville is a region of high geopotential (Schwerdtfeger 1984).

Characteristics of the katabatic winds

Sodar signatures of the katabatic wind

Recent studies by Argentini *et al.* (1995), of the wind direction statistics at Dumont d'Urville have shown that 80% of the time, wind direction lies in the angular sector 90°–180°. Both land breeze and gravity driven flows blow from this sector, the expected direction for the katabatic flow lying close to 120°–140°. To examine the correlation of spiky layer characteristics in relation to the katabatic winds, we have analysed the histograms of the wind direction (in 30° wide sectors) relating to spiky layers with different depth. Fig. 5 shows that the occurrence of the spiky layers is mainly

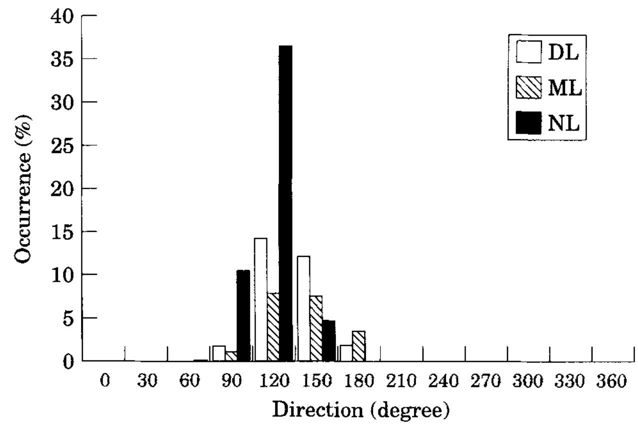

Fig. 5. Distribution of spiky layers of different depth (DL, ML and NL) for different angular sectors (February to December 1993).

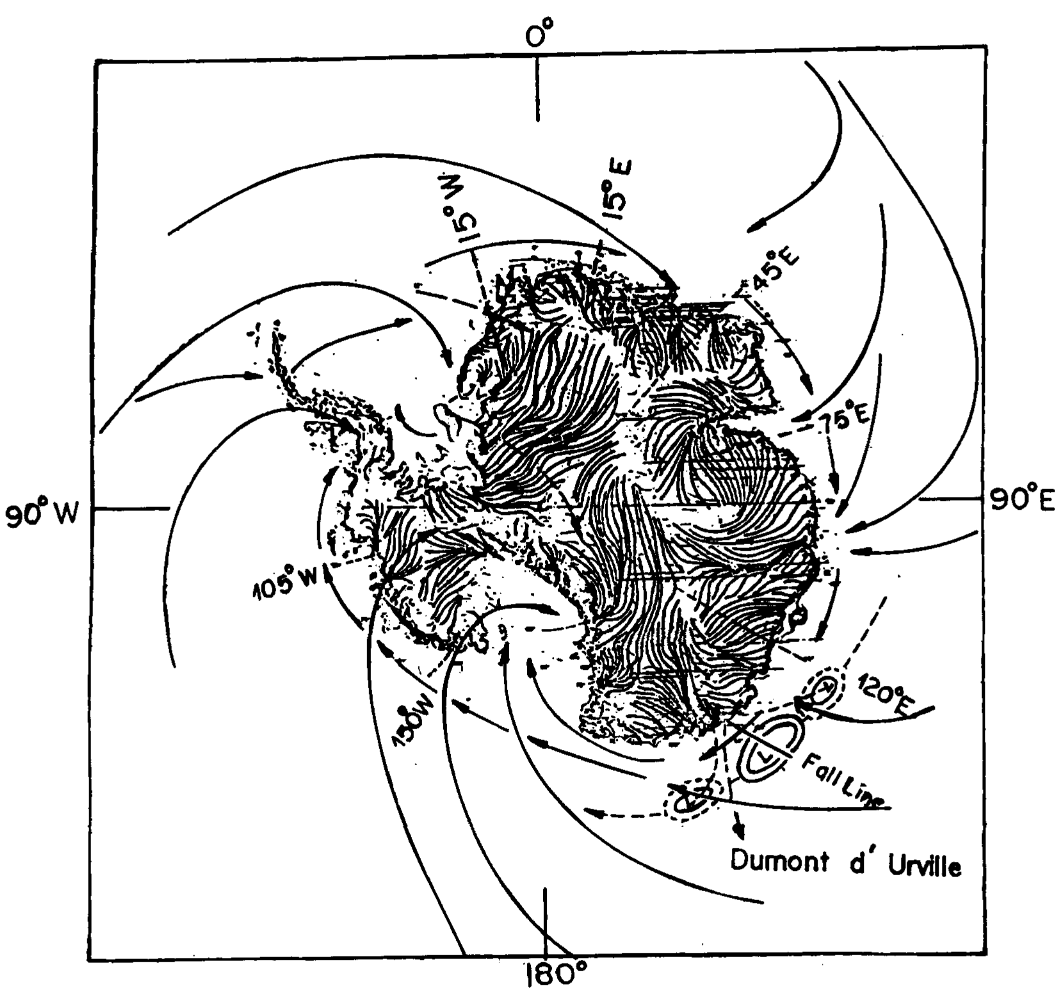

Fig. 6. Schematic diagram showing cycloning tracks (curved arrows) and hypothetical passage of a low pressure system (L) causing modifications of drainage flow intensity in relation to the normal fall lines (dark lines).

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confined to the wind sector 90°–180°. The depth of the spiky layers can be attributed to the strength of the mechanical mixing which is determined by the wind intensity (Singal *et al.* 1986). Thus, the statistical analysis of the spiky layers depth in relation to the wind speed and direction is of practical significance in identifying the main factors for the occurrence of the strong katabatic wind regime at Dumont d'Urville. In this context, the maximum occurrence of the NL is seen to be associated with the winds centred at 120° whilst the DL include an equal additional contribution of winds from the adjoining wind sector at 150° (Fig. 5). The increasing depth (from NL to DL) with a broadening of the wind channel suggests that passages of the low pressure troughs over the coastal margin of Adélie Land (Fig. 6) not only modulate the intensity of the gravity driven katabatic flow but also interact with the topography to cause convergence of winds from a wider wind sector (120°–150°). The increasing wind speeds contribute to vertical mixing of the warmer air from the upper layers into the lower layers (analogous to the entrainment process during free convection) which in turn reduce the ABL stability. The reduced thermal stability conditions allow further favourable conditions for vertical mixing and thereby deepen the spiky layer. The stronger katabatic wind events have been observed (Parish *et al.* 1993) to be associated with warmer temperatures and lower pressures over the coastal margin with a predominantly easterly flow above the katabatic layer. However, Parish (1981) proposed that the primary cause of persistent strong katabatics in Adélie Land is due to the anomalously large supply of cold air set up by converging air currents in the continental interior.

ML is largely confined to the same wind sector as DL (120°–150°) and the frequency distribution looks similar although with a small shift towards the 150° sector. Again the broadening of the frequency distribution may be due to the combined effect of horizontal temperature and pressure gradients and to the location of the low pressure troughs.

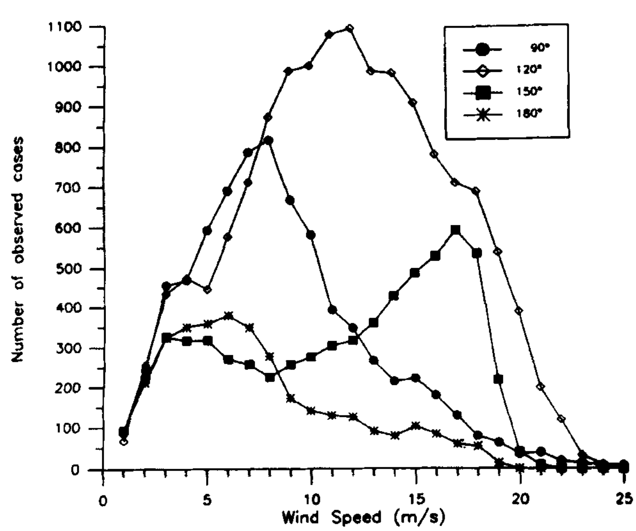

Fig. 7. Distribution of the wind speed for 30° wide angular sectors centred at 90°, 120°, 150° and 180°.

We have examined the wind speed distribution (Fig. 7) within the wind sector (90°–180°) wherein lies the main gravity driven flow. The distribution can not be considered reliable for wind speeds greater than 20 m s^{-1} because of the background noise. Most of the time the wind sector centred at 120° is associated with wind speeds of about 12 m s^{-1}. The adjacent sectors (at 90° and 150°) tend to follow a similar velocity distribution but with pronounced peaks respectively at about 8 and 17 m s^{-1}. Since these two sectors are adjacent to the sector at 120°, we infer that the two peaks result from the interaction of the low pressure systems passing along the coastal periphery and the unperturbated gravity driven katabatic flow. This is because the modulation of the katabatic wind intensity will depend on the intensity and location of the low pressure system with respect to the normal fall line (Fig. 6). The schematic Fig. 6 is based on the time average near surface streamline of cold air drainage (Parish 1988) and cyclonic tracks in the Antarctic regime depicted by Alt *et al.* (1959).

Analysis of wind velocity by sector (Fig. 7) suggests that the locations of low pressure troughs causing development of the easterly winds in the upper layers (sector at 90°, being associated with the 8 m s^{-1} velocity peak) will act to retard the main flow intensity while the locations causing south-easterly winds (sector at 150°, being associated with the 17 m s^{-1} velocity peak) will enhance the katabatic flow intensity. Thus an NL will transform into a DL and tend to reverse in accordance with the intensity and orientation of synoptic pressure gradient forcings. Examining Figs 5 & 7, we can see that the occurrence of DL in the different wind sectors (Fig.5) is correlated with the relative occurrence of higher wind speed values. For the 8–16 m s^{-1} wind speed interval (Fig. 7), the maximum number of events are observed for the sector at 120°. Since this sector is associated with the direction of the main gravity driven flow and shows a pronounced peak for the occurrence of NL (Fig. 5), it indicates that NL is transformed into DL under the influence of the intensity modulation of the topo-dynamic flow.

The katabatic flow from the sector centred at 120° is associated with the maximum frequency of the wind speed reaching about 12 m s^{-1}, although events of the higher and lower velocities are also present. This value for the wind speed is in agreement with the results of the numerical model simulations by Parish *et al.* (1993) which have shown that, in the absence of any initial horizontal pressure gradient, the katabatic wind speed at the nearby AWS of D-10 (see Fig. 1 for its location) reaches a quasi-steady state of approximately 12 m s^{-1}. These results suggest that katabatic flow in the absence of additional synoptic forcing is reflected as NL through sodar signatures while the modulation of the katabatic flow intensity may be reflected as ML or DL depending upon the degree of the modulation introduced.

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Under negative modulation of the flow intensity the spiky character of the layer cease to exist, while the well known persistence of strong stability conditions over Antarctica are reflected by the appearance (on sodar echograms) of waves in the SBL. The model simulations have also shown (Parish *et al.* 1993) that the large scale winds associated with synoptic horizontal pressure field have a noticeable influence on the katabatic wind wind intensity although they do not produce a significant influence on wind direction. However, the presence of events of the greater or smaller wind speed in the katabatic flow from sector 120° (Fig. 7) together with the observation of DL occurring over a wider region of wind direction, reveal that the passing low pressure troughs may not only modulate the intensity of the gravity driven flow but may also affect the main flow lines. Our observations reveal that although katabatic winds from the broad angular sector 90° to 180° have been observed, stronger katabatic winds (as reflected by the occurrence of DL) are confined to the 120°–150° wind sector, leading to a mean wind direction of about 135°.

Keeping in view the consistency in our observation of mean wind direction for the strong katabatic winds (represented by spiky layers) and the climatological result for the persistence of strong katabatic winds direction, we can say that the spiky layers thermal structure at Dumont d'Urville may be taken as an indicator of the strong katabatic winds.

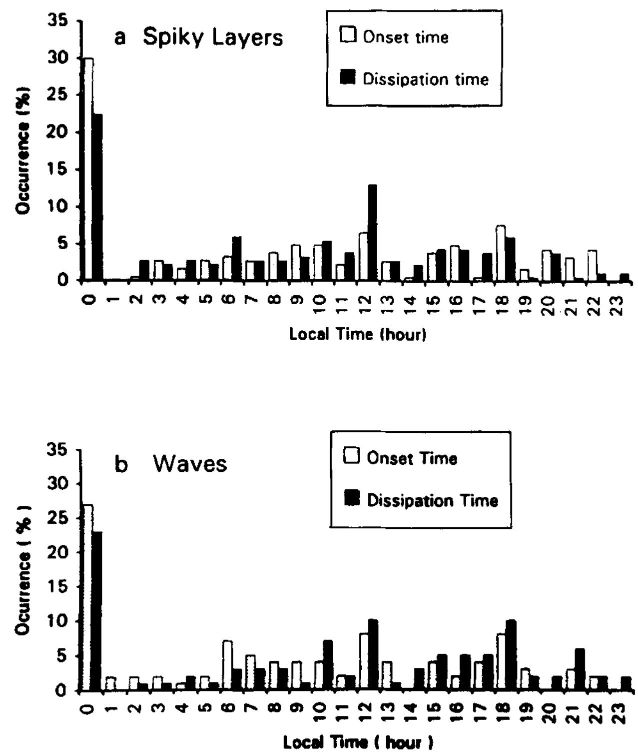

Fig. 8. Occurrence probability for the onset and dissipation time of **a.** katabatic winds and **b.** waves.

Diurnal characteristics

The continental periphery is prone to the maximum cyclonic activity associated with the sea level trough (Schwerdtfeger 1984). The development or passage of a cyclonic system induces changes in the surface pressure and thereby modifies the horizontal pressure gradients as well as the wind field. Eventually it will change the mixing level within the stable ABL which in turn is likely to be reflected as a change in spiky layer depth. Thus, diurnal variations in the spiky layer characteristics, with reference to the diurnal pressure changes and to the forcing due to the horizontal pressure gradient, may be an important key to understand the role of the cyclonic fronts in shaping the katabatic wind regime. The sodar signatures of the spiky layers (NL, ML and DL are treated collectively) have been analysed, from hourly data, to study the onset/dissipation time, the duration and the probable period of occurrence of the strong katabatic winds.

Figure 8a, shows that the onset and the dissipation of the katabatic winds may occur at any hour but their maximum occurrence is observed around midnight when the near surface temperature may be a minimum (Periad & Pettré 1993). The dissipation shows a secondary maximum around noon when the surface temperature has a maximum. Similar patterns are observed for the onset and dissipation of the waves (Fig. 8b). It is important to note that in the case of the waves these secondary peaks in onset and dissipation are observed at 6, 12, 18 and 24 LT, corresponding with the probable period for the transition of stability (6 and 18 h) or the maximum of temperature contrast (at midnight and noon) between land and sea surface. The horizontal temperature gradient will act to enhance the katabatic wind intensity for the onset of the spiky layers at midnight while it will oppose the same at noon due to conditions in favour of the land and sea breeze respectively. The primary peak in dissipation, at midnight, may be attributed to the persistence of relatively stronger stability (in the absence of external forcing) due to the radiative cooling rather than to the topo-dynamic forcings. A closer look at the Fig. 8 reveals that the secondary peaks (at periodic interval of 6 h) for the onset of the waves are correlated with the peaks in dissipation for the spiky layers, reflecting the alternation of waves and spiky layers. This suggests that the appearance or disappearance of waves or spiky layers (under katabatic wind directions) is determined by the relative dominance of stability and the turbulent forcings associated with the katabatic wind regime. This supports the suggestions (Periard & Pettré 1993) that the local thermal effects associated with the diurnal radiational cycle play a significant role in shaping the katabatic wind regime at Dumont d'Urville. Nevertheless large scale perturbations may modify the pressure field in this region, and can easily destroy such balancing tendencies to either produce or eliminate a well developed katabatic flow.

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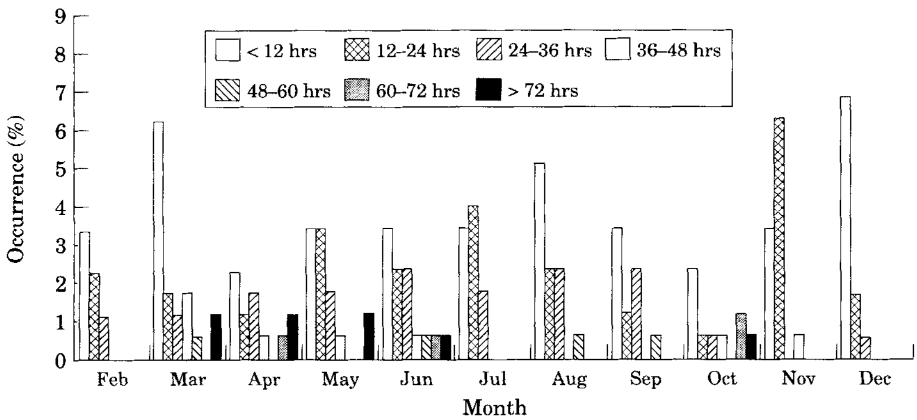

Fig. 9. Occurrence frequency of katabatic winds of different duration during different months of the year.

Seasonal characteristics

Katabatic winds with a duration less than 24 hours are more or less evenly distributed throughout the year while events longer than three days mainly occur before the winter, from March to June, and in October (Fig. 9). During non-summer months, when a more persistent ice cover is present over the ocean, the local temperature contrasts are strongly reduced and consequently, the katabatic winds respond more directly to the radiative cooling of the sloping ice terrain. The wind speeds are also high in this period; such factors offer the conditions for the prolonged persistence of the spiky layers. Moreover, the mass flux imparted by the persisting drainage flow tends to increase the surface pressure near the coast and decrease it over the plateau. This would lead to the existence of a secondary circulation, throughout much of the troposphere, associated with a component of the horizontal pressure gradient that opposes the intensity of katabatic winds. This argument supports our observation of the sharp decrease in the occurrence of spiky layers (Fig. 10) in July when Dumont d'Urville is a region of high geopotential. Figure 10 also shows that the katabatic winds with intensities sufficient to generate a spiky layer can be seen throughout the year. The NL and ML have a maximum occurrence in the change of season period, in autumn (March) until the beginning of the winter (May), while the DL (strong katabatic winds) has the maximum pronounced occurrence in June. It is interesting to note that this happens just prior to the period (July) associated with nearly minimum occurrence of the spiky layers (Fig. 10) and the maximum occurrence of the waves (Fig. 11) which reflect the development of strong stability conditions during this period.

A similar study concerning the monthly occurrence of the waves (Fig. 11) shows that about 80% of the waves activity is confined to the winter (May–October) season with the maximum occurrence in July. The lower frequencies have been observed in the summer months (November–April) with the exception of December with a secondary maximum that is about twice that of the other summer months. The secondary maximum during December may be associated with the inland penetration of the sea breeze or marine layer. In May, with the winter approaching , the frequency of the waves starts progressively increasing, reflecting the development of a progressive increase in stability. After having achieved the maximum in the midwinter, the wave frequency gradually decreases to a minimum at the beginning of the summer in November. The two seasonal maxima for waves are observed during the periods (July and December) that are associated with periods of high geopotential (Periad & Pettré 1993). The data for the month of January were unfortunately not available to assess the correlation with the secondary maximum observed in December.

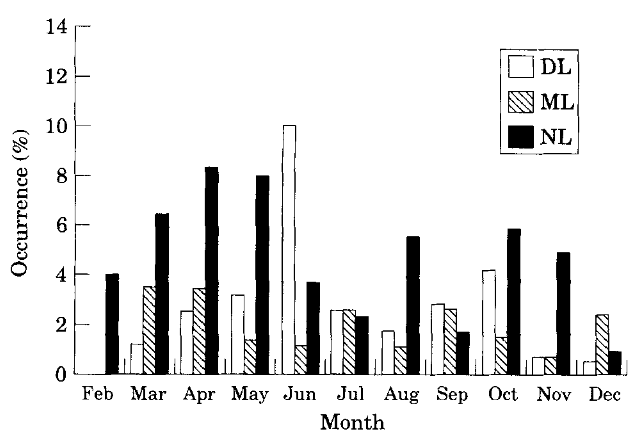

Fig. 10. Occurrence distribution of spiky layers of different depths (DL, ML, NL) during different months of the year.

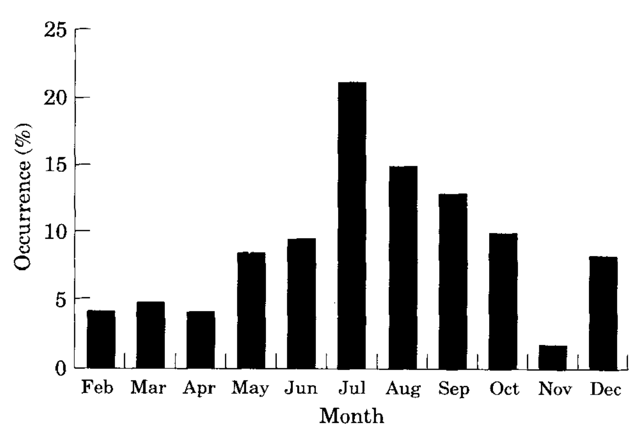

Fig. 11. Occurrence distribution of waves during different months.

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The distribution of waves in relation to the prevailing wind direction at 66 m (Fig. 12) shows that about 85% of the wave activity is confined between 90°–270° with a percentage that is almost equally distributed in all the wind sectors around 180°. Although a considerable portion of the waves relate to the same sector as that of the spiky layers, the occurrence of the waves increases as we move from East to South. These sectors are associated with the lower wind speeds (Fig. 6) suggesting that the waves tend to occur under low winds, a condition for the persistence of strong stability.

The spiky layers and the waves have been observed (Figs 5 & 12) several times from the same angular sector and these are associated, respectively, with high and low wind conditions. This is in support of the proposals (Parish *et al.* 1993) that the modulation of katabatic wind intensity due the passage of the cyclones appears to cause a minimal directional change in the near surface wind direction, and the overwhelming influence is that of the topography.

Further, the maximum occurrence of the waves and the spiky layer, being confined to the winter (a period known for the persistence of stability conditions and the katabatic winds) convey that under conditions of strong stability and/or the absence of synoptic forcing the interaction between the katabatic flow and the accumulated cold air is not strong enough to create a spiky layer thermal structure. In such a situation, the drainage winds are reflected as stably stratified shear instabilities.

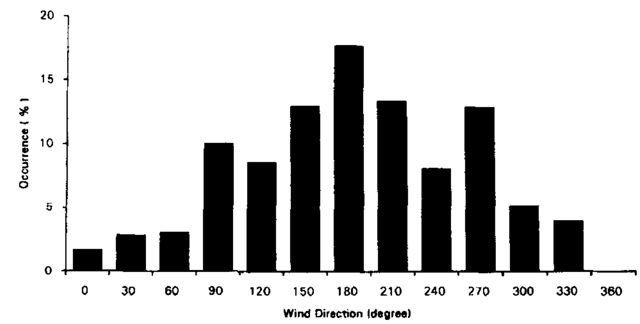

Fig. 12. Occurrence frequency of the waves in relation to different wind directions.

Conclusions

Our analysis of the ABL thermal structure at Dumont d'Urville supports the idea that the local thermal effects associated with the diurnal radiation cycle and temperature contrast over the coast play a significant role in shaping the katabatic wind regime. The strong katabatic winds are responsible in part for the build up an adverse environment of high geopotential which furthers its own continuance. The persistence of the strong katabatic winds and the strong stability conditions are reflected, respectively, in the presence of the spiky layer and the wavy layer thermal structures on sodar echograms. These are the two most predominantly occurring thermal structures which tend to occur alternately on a time scale of few hours to few days depending upon the local meteorological factors: the trends in the diurnal cycle, the cloud cover, the snow cover, the sunshine factor, the movement of the oceanic frontal systems and the temperature contrast over the coastal vicinity.

Diurnal variation characteristics of the spiky layers can be used as an indicator to 'nowcast' the onset, development and decay of strong katabatic winds.

The wind direction is important in determing the intensity of the katabatic winds which in turn is reflected as a change in the spiky layer depth. The strong katabatic winds, producing spiky layers higher than 400 m, are associated with the modulation of the katabatic wind intensity due to the contribution of the south-easterly winds centred at 135°. The maximum occurrence of the strong katabatic flow as well long lasting episodes are observed during the interseasons.

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