Diurnal wind variations in Antarctica

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(Manuscript received 19 November 1971. Communicated by Professor R. C. Sutcliffe)

SUMMARY

For the three Antarctic ice shelf stations considered (Norway Station, Maudheim, and Halley Bay) it is shown that from spring to autumn a systematic diurnal variation of the mean vector wind at the surface exists. Different factors that may be responsible for this variation are discussed. The results seem to agree well with the assumption that in areas far from the ice front (the seaward edge of the ice shelf) the main cause is the larger net gain of momentum in the lowest layers during the middle of the day, while closer to the ice front there is an additional effect of the varying contrast between the air temperature over the sea and over the ice shelf.

1. INTRODUCTION

For several Antarctic stations the mean surface wind speed during the period from spring to autumn shows a systematic diurnal change. Some stations have a maximum mean wind speed in the late night or early morning, while for other stations the maximum occurs during the middle of the day.

The morning maximum is typical for stations that are influenced by katabatic winds, which reach their greatest intensity about the time when the temperature over the ice slopes is lowest. The noon maximum, on the other hand, may presumably be explained in the same way as the corresponding feature of the wind variation in lower latitudes, as caused by a maximal influence of the higher, faster moving layers at the time of the day when the turbulent exchange is strongest, and (or) to a maximal temperature contrast between neighbouring surfaces, with different thermal properties (usually a land- and sea-breeze effect).

It is the aim of the present paper to discuss briefly, on the basis of observations from Antarctic stations, factors that may be responsible for a diurnal change of wind speed as well as wind direction. In order to simplify the problem in some measure, we have chosen stations situated on extensive ice shelves, where orographic influences, if any, should be insignificant. Adequate data (mean vector winds) were available for three stations of this kind, viz. Norway Station (70°30'S, 02°32'W, period: April 1957 - December 1959), Maudheim (71°03'S, 10°56'W, period: April 1950 - January 1952), and Halley Bay (75°31'S, 26°37'W, period: January 1957 - December 1958). For the two former stations data were available from the Norwegian Polar Institute in Oslo, while for the latter station data were obtained from MacDowall, Ellis and Limbert (1964) and Limbert (1965). The surface wind considered here is recorded by instruments at or near the 10 m level.

The distance from Norway Station to the ice front (the seaward edge of the ice shelf) is about 30 km, while for the two other stations the corresponding distances are only about one tenth of this.

2. OBSERVATIONAL RESULTS

For the three stations considered the main bulk of the wind observations is concentrated in comparatively few, adjacent direction sectors. At all stations easterly winds are predominant, with a secondary frequency maximum for southerly, or south-western winds. It seems justified to assume, therefore, that the mean vector wind for the individual observation hours will give a sufficiently realistic picture of the diurnal wind variation.

Fig. 1 shows for each station mean vector winds for two seasons, which we call here, for the sake of convenience, the summer and winter season, and also the end points of the corresponding mean vectors for the individual observation hours, while Fig. 2 represents, for the summer season, the deviation of these latter mean vectors from their mutual mean. For the sake of simplicity these different vectors are in the following sometimes referred to as 'the diurnal wind'. It appears that the length of the seasons is not the same for the three stations: For Halley Bay and Maudheim the mean vector winds were computed already for the combination of months specified in Fig. 1. Regarding Norway Station, data for the individual months were available. As a
Figure 1. Seasonal mean vector winds and the end-points of the corresponding mean vectors for the individual observation hours. The numbers 1, 2, 3, ... refer to the observation hours 23:00 hr, 02:00 hr, 05:00 hr, ... LMT in the case of Norway Station, 23:30 hr, 02:30 hr, 05:30 hr, ... LMT in the case of Maudheim, and 22:02 hr, 01:02 hr, 04:02 hr, ... LMT in the case of Halley Bay (cf. Fig. 2).
Figure 2. Deviation of the mean vector winds for the individual observation hours (L.M.T.) from their mutual mean.
systematic diurnal variation was clearly in evidence only for the months October–February, it was natural to define that period as the 'summer season' for this station.

We note from Fig. 1 that for all stations the diurnal variation is greater and more systematic in summer than in winter. During the former season the end-points of the difference vectors given in Fig. 2 turn quite nicely in an anticlockwise direction as the day proceeds, their magnitude varying between about 25 and 75 cm s\(^{-1}\).

3. DISCUSSION

In the following we consider different factors that may be supposed to contribute to the observed diurnal wind variation:

(a) **Sampling fluctuations**

We first mention the obvious fact that the observed diurnal march of the wind is to some extent 'haphazard'. The amount of data is modest considering the small systematic changes we try to trace here, and the much greater wind changes connected to variations in the large-scale pressure pattern. However, the much larger and more systematic diurnal course for the summer season than for the winter season strongly suggests that the 'haphazard' element cannot be dominating.

(b) **Orographic and katabatic effects**

Due to the site of the stations these effects are, as previously mentioned, supposed to be negligible. The distances to the slopes of the inland ice sheet are several tenths of kilometres.

(c) **Diurnal pressure oscillations**

This phenomenon involves a diurnal change, however small, of the wind, and we shall describe briefly some results of an attempt to trace such effects. At a certain time of the year a pressure oscillation of this kind is supposed to give a small additional wind that is dependent on the time of the day only, and not on the direction of the main wind. Consequently, the hourly vector mean winds should be applicable as a basis of our investigation. The amplitudes and phases referred to in the following are found by means of an harmonic analysis of three-hourly mean values of the air pressure and of the vector components of the diurnal wind for the individual stations and seasons considered.

For all stations the calculated amplitude of the 24-hourly pressure wave (order of magnitude 0.1 mb) is greater for the winter than for the summer season, which in itself indicates that this phenomenon cannot have any great influence on the diurnal wind. This is further verified by the fact that there is no clear evidence of a connection between the phases of this pressure variation on the one hand, and the phases of the corresponding variation of the east- and north-components of the diurnal wind on the other. This applies both to the summer and winter season. As is well known, the 12-hourly pressure oscillation is of a far more systematic character than the 24-hourly oscillation. Thus the geographical variation of the phase as well as the amplitude shows certain regular features, and it has been possible to derive an approximate expression for the variation with latitude and longitude of the amplitude and phase of the semi-diurnal wave. This has been made by Simpson (1918) and others. Introducing Simpson's expression in a perturbation equation Stolov (1955) has, after some simplifying assumptions, calculated the corresponding periodic variation of the surface wind. If the time (LMT) of the first daily maxima of the east- and north-component of Stolov's 'tidal winds' for the stations considered here are denoted \(t(E)\) and \(t(N)\) respectively, we find that the maximum of the semi-diurnal harmonic constituent of the observed diurnal wind in four out of six cases occur in the interval

\[ t(E) \pm 2 \text{ hr} \]

as far as the east-component is concerned, and, also, in four out of six cases in the interval

\[ t(N) \pm 2 \text{ hr} \]

as far as the north-component is concerned. The a priori probability that this result is purely accidental, is not very great (1 per cent). However, taking into account the fact that the time intervals (± 2 hr) are chosen a posteriori, by studying a graphical representation of the different components in an harmonic dial, the conclusive value of our result is considerably reduced. It should, however, encourage further investigations on this point, preferably by means of longer observation series. The magnitude of Stolov's tidal wind in the considered area, about 50 cm s\(^{-1}\), is some five to ten times greater than the values found for the 12-hourly wind variation when analysing the observed data. This may to some extent be due to the simplifying assumptions
introduced when computing the tidal wind field (i.e. frictionless atmosphere) and the fact that Simpson's expression generally gives much too large values of the pressure amplitude in high latitudes (Hisdal, Amble and Schumacher 1956).

Concerning the 8-hourly period, there are some indications of a connection between the phase of the east-component of the wind and that of the 8-hourly pressure oscillation, while for the north-component there seems to be no such connection. The computed amplitude of the wind for the 8-hourly period is very small, however, generally well below 10 cm s$^{-1}$.

On the basis of the above considerations it seems safe to conclude that compared with the observed diurnal wind change in the summer season, the influences on the wind of the 24-, 12- or 8-hourly pressure oscillations are slight, and that for the stations (or latitudes) in question a greater observation material is necessary to obtain conclusive information as to these influences. It is not unlikely that in particular the influence of the 12-hourly pressure oscillation may be partly responsible for the observed irregularities in the dominating 24-hourly wind variation.

(d) Diurnal variations of friction and of the surface geostrophic wind

The two last effects to be considered, viz. a diurnal change of (i) the eddy viscosity and of (ii) the horizontal temperature-pressure field, are difficult to separate, especially since they may give rise to a diurnal course of the wind of much the same form. We will here confine ourselves to some tentative considerations.

The frequently observed noon maximum of the surface wind speed is generally explained as due to maximal vertical mixing during the middle of the day. Although the details of the connection between a changing eddy flux of momentum and the wind are still not fully understood, the observational basis is fairly well established. Thus it is generally found that the end-point of the wind vector, because of this effect, describes in the course of the day a closed curve resembling more or less an ellipse, whose major axis cuts the curve near the points representing the time of maximum and minimum surface air temperature (or strictly, the time of minimum and maximum stability of the surface layer).

Studying Fig. 1 we find that Norway Station is the only station revealing a diurnal march that may be considered as typical of a 'frictional wind'. This agrees well with the fact that Norway Station is the only one of the three stations that has a well-defined noon maximum of the mean scalar wind speed and, furthermore, that this station is situated relatively far from the ice front, and thus from the region where the influence of a diurnal change of the 'land'-sea temperature contrast should be most strongly in evidence.

Accepting tentatively the view that the diurnal wind at Norway Station is mainly due to frictional effects, we have to suppose these effects to produce similar wind variations at the two other stations as well, but here presumably more strongly masked by changes caused by the diurnal course of the temperature contrast between the air over the sea and over the snow fields. It is tempting to try to estimate the part played by the latter influence by assuming that the variations caused by the changing frictional force are of the same form at all three stations. This is of course to be considered as a rather broad assumption, as it implies, among other things, that the diurnal changes of the stability conditions are the same, which is hardly likely to be true. The different lengths of the 'summer' seasons mean an additional complicating factor in this connection.

The frictional part of the wind variation is obtained by a certain adjustment of the observed diurnal course at Norway Station. A moderate smoothing of the observed angular speed of the frictional vector is obtained by fitting a sine function to the observed values. Furthermore, the end-points of the frictional vector are supposed to describe an ellipse in the course of the day. The axes of the ellipse and their orientation are determined by minimizing the following quantities: (i) the angular distance between the observed frictional vector and the corresponding vector turning with the smoothed angular speed, and (ii) the distance along the latter vector from the vector end-point to the ellipse. The fitting of the sine function as well as the ellipse is based on the method of least squares. In Fig. 3 (uppermost diagram) are entered the observed as well as the adjusted frictional vector. The adjusted vector is indicated by the end-points on the ellipse only.

In accordance with the assumption that the diurnal change of the frictional effect is nearly the same at the three stations, we may suppose the axes of the ellipse to form the same angles with the total mean vector wind at all stations, the length of the axes being proportional to the magnitude of this mean vector. The frictional vector for the different observations hours at Maudheim and Halley Bay is then easily found, and may be subtracted from the observed diurnal wind. The result is shown in Fig. 3 (lower part). Comparing this diagram with Fig. 2 we see that
Figure 3. Uppermost diagram: Assumed frictional wind vectors for Norway Station. Both observed and adjusted vectors. The adjusted vectors are indicated by their end points on the ellipse only. Lower part of the diagram: The diurnal wind at Maudheim and Halley Bay after a tentative correction for the frictional effect.
the new diurnal wind vectors are turned in an anticlockwise direction with respect to the observed ones, especially so for Maudheim. The magnitudes of the vectors are, as a whole, not very much altered. As indicated in the diagram, the main direction of the coastline (i.e. ice front) most close to the stations is roughly south-west/north-east both at Maudheim and at Halley Bay. It appears that the vectors point off-shore during the night and on-shore during the day, the directions at the time of maximum and minimum temperature (cf. Fig. 4) being to the left of the normal to the coastline. The diurnal variation of the vector component perpendicular to the main direction of the ice front is in fact quite similar to that of the air temperature at the two stations, as illustrated by Fig. 4. These features correspond well to the characteristics found when studying the land- and sea-breeze phenomenon in lower latitudes.

Comparison with a linear sea-breeze model (Defant 1950) gave some general, qualitative conformities. However, a further discussion on this point does not seem worth while, as a fair agreement between theory and observation cannot be expected in the present case. This is due not only to the relatively primitive model applied and the very broad assumptions leading to the

Figure 4. Solid lines: Diurnal variation of the on-shore component of the wind vectors in Fig. 3 (lower part). Broken lines: Diurnal variation of the surface air temperature ('screen temperature').
difference vectors in Fig. 3, but also to the irregular course of the coastline. It goes without saying that in the areas considered we do not imagine a land- and sea-breeze circulation that is reversed from day to night. The phenomenon may rather be compared to a small scale winter monsoonal system, where the appertaining isobaric – isosteric solenoidal field is subject to a weakening during day-time and reinforcement during the night, the direction of the circulation being unaltered.

4. CONCLUDING REMARKS

In the vicinity of the ice front the diurnal change of the surface wind over the Antarctic ice shelf may reasonably be supposed to be a combined effect of the diurnal variation of (i) the vertical exchange of momentum and of (ii) the contrast between the air temperature over the sea and over the ice shelf. The results presented here, based on some tentative assumptions, seem to agree well with this supposition.

It is hoped that the present discussion will help to stimulate interest in further investigations of the problem, based on more exhaustive observations, preferably also of the conditions at higher levels in the planetary boundary layer. It would of course be desirable as well to have sufficient information about the diurnal change of the eddy viscosity characteristics to allow a theoretical estimation of the corresponding variation of the frictional wind.

ACKNOWLEDGMENT

This paper is published by permission of the Director of the Norwegian Polar Institute.

REFERENCES

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