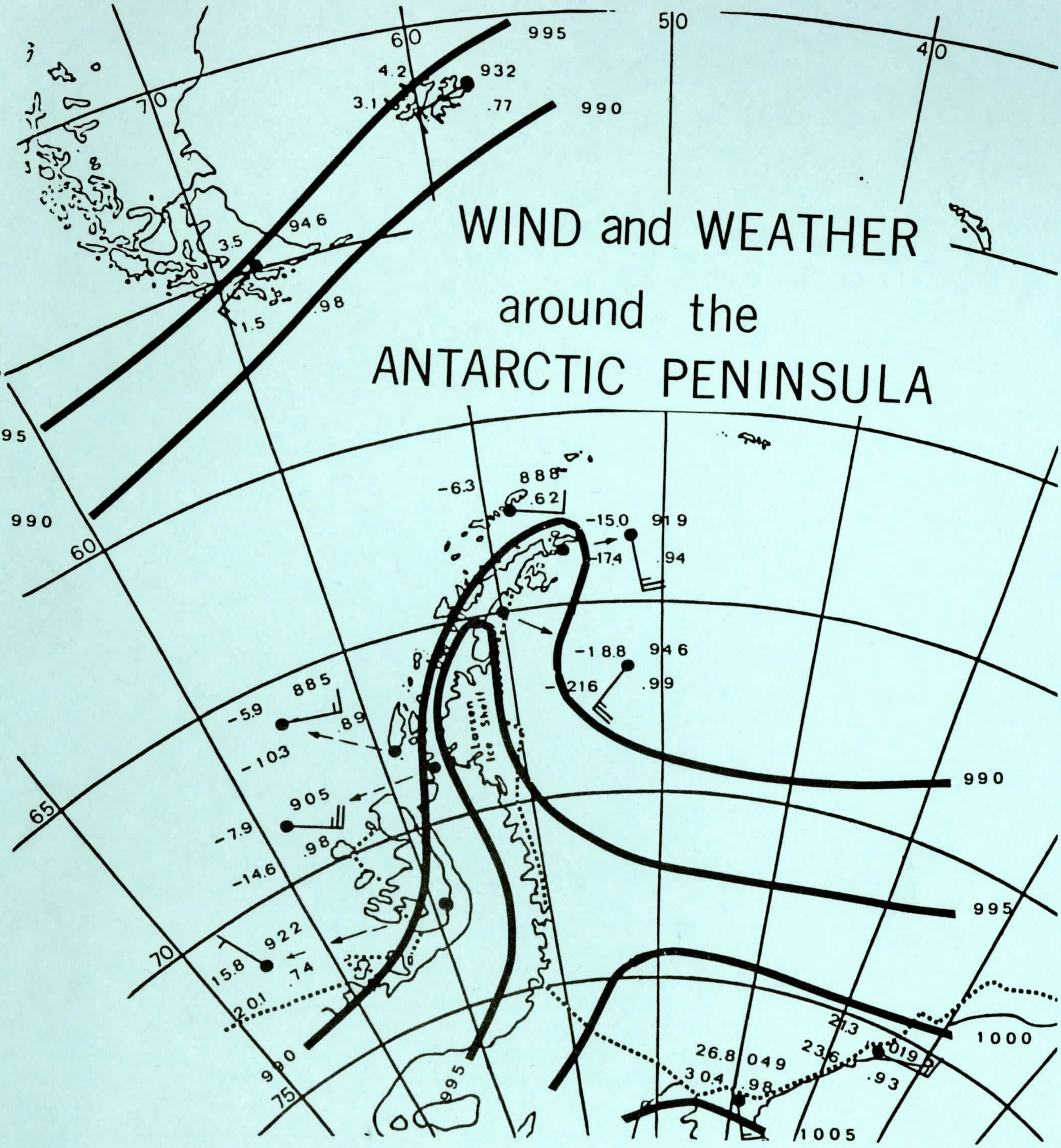
WIND and WEATHER around the ANTARCTIC PENINSULA



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*) Research funded by Grant DPP77-04506
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of Meteorology, U.W., January 1978-79.

Wind and weather around the Antarctic Peninsula

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Abstract: The surface wind field and related weather conditions along the coasts of the Antarctic Peninsula are strongly influenced by the area's topography and the peculiar flow characteristics of very stable air over such a terrain. In the first place, the present study shows and explains the persistent barrier winds along the east side of the Peninsula, which have often been misinterpreted in synoptic analyses, and the close relationship between these barrier winds and the occurrence of foehn storms over Marguerite Bay (on the west side). Proof of a theory developed some years ago can now be given, based on the simultaneous observations made by Ronne's Antarctic Expedition 1947/48 on both sides and on the plateau of the Peninsula, and on one year (1968) of three-hourly observations by the Argentine stations on the east side and the British stations on the west side. The barrier winds not only make the northwestern Weddell Sea a comparatively cold area; they also drive large masses of ice toward lower latitudes, thus influencing the climate of a wide region. Chapter 5 gives a discussion of the wind and weather development on both sides of the Peninsula when strong cyclones advance eastward south of 68° S. These relatively rare cases, important for their effect on the ice cover of the eastern Bellingshausen and the western Weddell Sea, appear to be characteristic for the spring season; during that time, the subpolar westerlies extend farther south than in the rest of the year. Chapter 6 deals with the surface wind fields and pressure gradients along the west side of the Peninsula, the pronounced terrain-effect on the stormy SW edge of Adelaide Island, and the protected location of Argentine Islands. A reprint of the paper "The effect of the Antarctic Peninsula on the temperature regime of the Weddell Sea" (MWR 103 (1), 1975) is appended.

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The map on the cover is explained on page 20.

1. Introduction

In the polar regions much more than in lower latitudes, the surface wind determines the overall conditions of life and work. It also is decisive for the drift of ice. The meteorological evidence clearly shows the formidable, fast changing forces of nature, unchained in the lowest layers of the atmosphere, where explorers work, ships navigate, and airplanes land and take off. Other weather elements, such as visibility, cloudiness, and precipitation are important too, but are better understood (and more frequently described, Pepper 1954, Burdecki 1957, Schwerdtfeger et al. 1959) than the vagaries of the surface wind. Therefore, the main purpose of the study is to give some insight into the characteristics and causes of the wind around the Antarctic Peninsula. At present, the practical interest might be focussed mostly on the conditions in the more benign part of the year. However, for the planning of activities extended into the harsher months, which is to be expected in the near future, it appears advisable to look at the severe conditions of the months September and October, and the fast deterioration in fall. Also in cases of emergency, wind and weather even in the worst part of the year command practical importance.

From a different point of view, our results will support Lettau's (1971) proposition that the Antarctic atmosphere can well serve as a "test tube for meteorological theories". Naturally, this aspect of the present study makes the wind conditions prevailing during the colder part of the year particularly interesting. Theories can be tested only against real, reliable observations. Due to the rugged terrain and the pronounced static stability of the boundary-layer air masses, the simple rules of synoptic meteorology regarding the pressure to wind-field relationships are often inadequate to explain the observed winds and to forecast the coming ones. In many cases the lack of weather observations off-shore leaves it in doubt by how much the wind might change a few tens of kilometers seaward. Near the bases of steep mountains, the winds can be: barrier winds with the air moving essentially parallel to the ranges, katabatic winds of the Foehn as well as the Borá type, near calm due to shelter effects in spite of the presence of a sizeable horizontal pressure gradient, or stormy winds due to funnel effects of gaps between mountains or islands. At some places even at a distance of a hundred kilometer or more from such a gap, wind speed and direction can be modified by an inertial flow effect so strong that no relationship to the larger scale synoptic pressure field remains apparent.

An example of a day with several of these phenomena, which combine to make a conventional analysis almost meaningless, is shown in Fig. 1.1. A synoptician who is not familiar with, or gives no attention to, the area's topography and the peculiar flow characteristics of very stable air in such terrain, might decide upon a simple solution to the problem: disregard a few wind and pressure data which do not seem to fit, and put a large low pressure system over the central Weddell Sea. Later, when examining the data and his analyses of 12 to 24 hours before and after reference time, he would find strange discontinuities; worse still, his forecasts for specific regions or locations would be prone to become disasters. And the same would happen if he were to rely on forecasts of the sea level pressure field produced by computer with a grid scale as is presently in use, and to interpret them in the conventional manner.

When automatic weather stations will be deployed in the near future, the forecaster's job will be somewhat alleviated. Meteorological satellite information will also help, though the most important weather element of the coastal regions of the Antarctic, the surface wind, cannot be observed directly, and can be deduced from other information only if the theory of the phenomena is well understood. The observational facts presented in this study should also have a sobering effect on those theoreticians, not too well familiar with a forecaster's real world, who promised in 1965, at the start of the planning for GARP, reliable daily weather forecasts two weeks ahead for any place on Earth (CMNCCIC 1966, Roberts 1966, White 1967). For places at or near the Antarctic Peninsula and many others in the polar regions, 24 hours would be a more realistic goal.

The sharp contrast between the wind, temperature, and ice conditions of the two sides of the Antarctic Peninsula has been well known for many years. Reliable meteorological evidence for the surprisingly harsh climate of the northwestern corner of the Weddell Sea*) was one of

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*) The name Weddell Sea is here understood to apply to the water body south of a line from Joinville Island (63°S, 55°W) to Cape Norvegia (71°S,12°W).

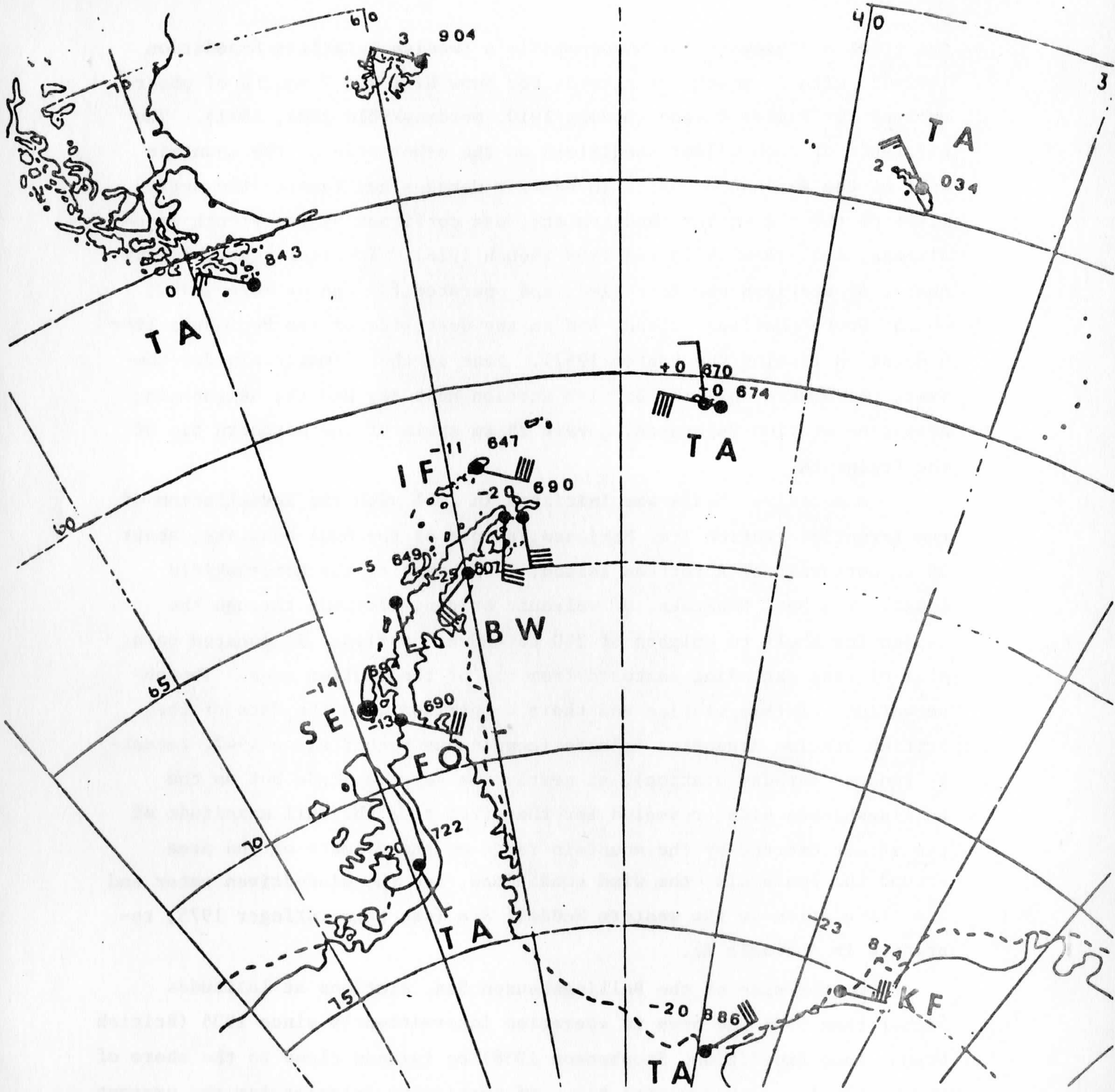

Fig. 1.1: An analyst's nightmare.
Synoptic observations for 12z, 18 July 1968

BW = Barrier winds

FO = Foehn

IF = Inertial flow effect

KF = Katabatic flow

SE = Shelter effect

TA = other terrain-affected flow.

the great achievements of Nordenskjöld's Swedish Antarctic Expedition 1902-03, with 20 months of records for Snow Hill and 7 months of observations for Paulet Island (Bodman 1910, Nordenskjöld 1904, 1911). The existence of much milder conditions on the other side of the mountain wall of the Peninsula, which in earlier decades had favored the activities of the old whalers and sealers, was confirmed by two French expeditions, 1904 (Rey 1911) and 1909 (Rouch 1914). In later years, a fair number of stations was installed, and operated for one or more years, on the South Shetland Islands and on the west side of the Peninsula (for a detailed listing see Venter 1957). East of the climatic divide, however, there were only the British station Hope Bay and the neighboring Argentine station Esperanza, barely 25 km south of the northern tip of the Peninsula.

A decisive change was initiated in 1961 with the installation of the Argentine station Tte. Matienzo, at one of the Seal Nunataks, about 30 km northwest of Robertson Island, 40 km east of the Nordenskjöld Coast. The Seal Nunataks, of volcanic origin, protrude through the Larsen Ice Shelf to heights of 200 to 400 m. Matienzo is located on a spit of land extending eastward from one of the smaller ones. The observations of this station and their comparison with the data of the British station Argentine Islands (continuous record since 1947, recently renamed Faraday station), at nearly the same latitude but on the Bellingshausen side, revealed for the first time the full magnitude of the effect exerted by the mountain range on the climate of the area around the Peninsula, the wind conditions, and the wind-driven water and ice circulation in the western Weddell Sea (see Schwerdtfeger 1975, reprinted in Appendix A).

On the side of the Bellingshausen Sea, stations at latitudes higher than 65°S had been in operation intermittently since 1936 (British Graham Land Expedition, Stephenson 1938) on islands close to the shore of the Peninsula, in Marguerite Bay. Of particular interest for the present study are the U.S. Antarctic Service Expedition 1940-41 and the Ronne Antarctic Research Expedition 1947-48; the former because it included, in addition to the main station on Stonington Island, the first-ever mountain station in the Antarctic (Dorsey 1945), located on the Plateau east of Stonington Island at 1637 m above sea level, November and December 1940. The Ronne Expedition, in turn, maintained stations not only on Stonington Island (1 year) and on the Plateau at 1768 m (September-November 1947), but also a third station on the other side of the mountains at Cape Keeler (see Fig. 1.2), in October and November 1947. Up to the time of this writing, 1978, these two months are the only time in which synoptic observations have been made at fixed places on both sides of the Peninsula, south of 65°S. That series of observations, as short as it is, proves to be valuable for the understanding, and hence the forecasting, of the wind conditions along the east side of the Peninsula. It contains better proof of the ideas regarding the nature of that wind regime than could be offered three years ago when the daily data of Ronne's stations were not yet available to the author of Appendix A.

A major part of the meteorological information on which the following study is based, is for March through December of 1968 and the first two months of 1969. This period was chosen because it includes the time in which the detailed publication of the synoptic observations of the British stations in the Antarctic (B.A.M.S. 1965-69) contains the reports of the stations Stonington Island in Marguerite Bay, and Fossil Bluff about 360 km farther south (see Pearce 1963, Wagner 1972), and because prior to February 23, 1968, the daily observations at the key-station, Matienzo, had been taken only between 08 and 20 hr local time.

Names, including abbreviations used in the text and maps, and coordinates of all stations mentioned in the following chapters are listed in Table 1. All wind data are given in knots, all temperatures in °C. Greenwich Meridian Time is conventionally indicated by the small letter z.

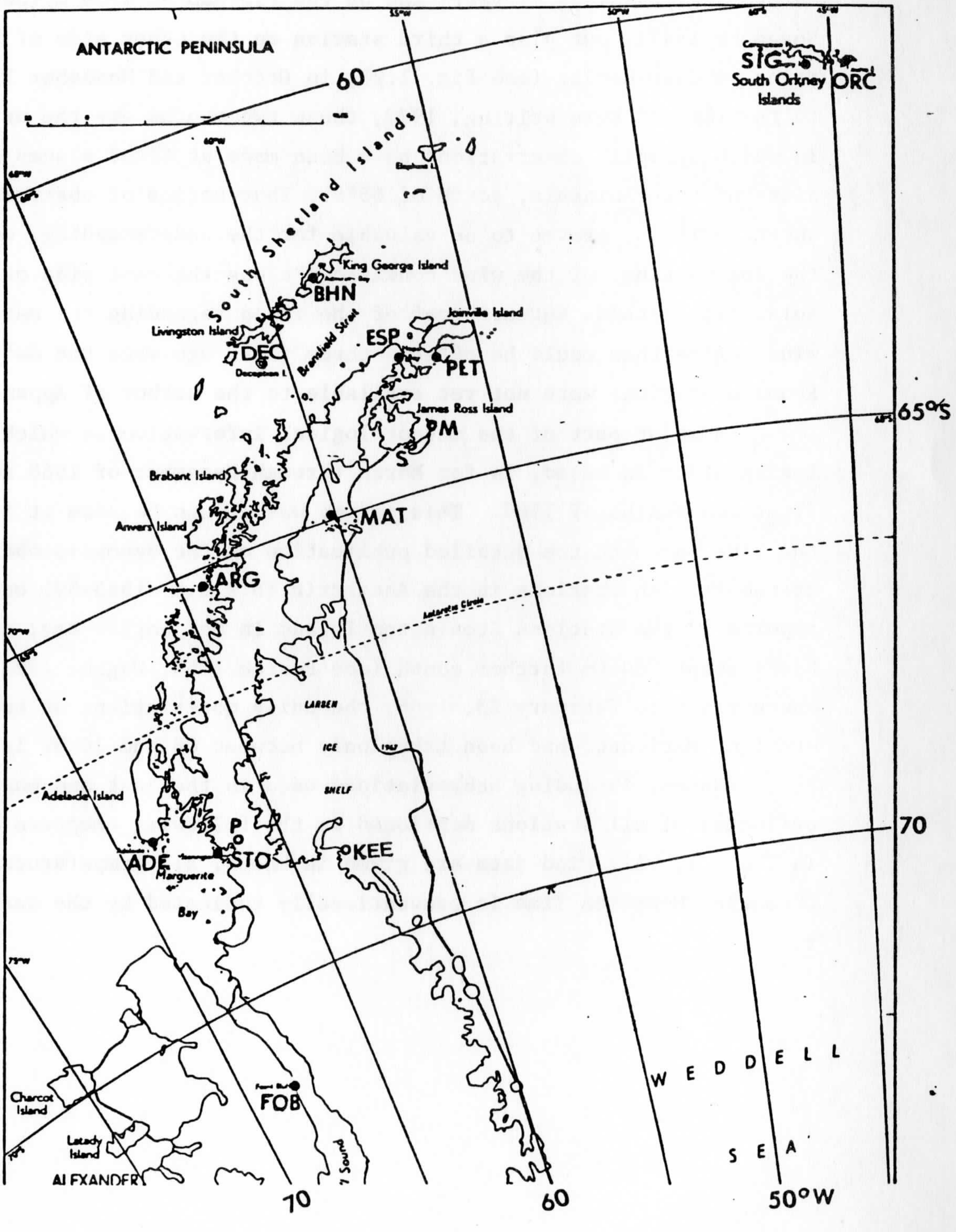

Fig. 1.2 : The Antarctic Peninsula.

Station names and coordinates are given in Table 1.1.

Table 1. List of meteorological stations mentioned in the text or maps.

a) Operating in 1968/69

Abbreviation	Name	Lat.	Long.	Elevation
BEL	BELGRANO *)	77^{46} S	38^{11} W	37 m
HAB	HALLEY BAY *)	75^{31}	26^{48}	30
FOB	FOSSIL BLUFF	71^{20}	68^{17}	68
STO	STONINGTON ISL.	68^{11}	67^{01}	9
ADE	ADELAIDE ISL.	67^{46}	68^{56}	26
ARG	ARGENTINE ISL.	65^{15}	64^{16}	11
MAT	MATIENZO	64^{58}	60^{04}	25
PET	PETREL	63^{28}	56^{17}	18
ESP	ESPERANZA	63^{24}	56^{59}	7
BHN	BELLINGSHAUSEN	62^{12}	58^{58}	16
ORC	ORCADAS	60^{44}	44^{44}	5
SIG	SIGNY ISL.	60^{43}	45^{36}	22
-	DIEGO RAMIREZ *)	56^{15}	70^{15}	--
-	STANLEY *)	51^{42}	57^{52}	53

*) shown in Fig. 1.1.

b) in 1947

KEE	CAPE KEELER	68^{51}	63^{13}	23 m
STO	STONINGTON ISL.	68^{11}	67^{01}	9
P	PLATEAU	68^{06}	66^{24}	1768

c) in other years

S	SNOW HILL (1902-03)	64^{22}	57^{00}	13 m
-	PAULET ISLAND (1903)	63^{35}	55^{50}	--
M	MARAMBIO (since 1973)	64^{14}	56^{43}	198
-	HORSESHOE ISLAND (1955-60)	67^{49}	67^{17}	--
-	HOPE BAY (1945-48, 52-60)	63^{24}	56^{59}	10
-	CAPE PEMBROKE (before 1940)	51^{41}	57^{42}	21
DEC	DECEPTION ISLAND (1945-67)	62^{59}	60^{34}	8
ROT	ROTHERA (since 1977)	67^{34}	68^{07}	15

2. The wind regime on the east side of the Antarctic Peninsula

> "With southerly winds the cold is rushing in; thundering like cannon-fire, the gusts of the storm hit the rocky cliffs." C.J. Skottberg, on Paulet Island, 1903*)

The single most remarkable feature of weather and climate in the area of the western Weddell Sea is the predominance of strong surface winds parallel to the narrow, tall mountain range of the Peninsula.**) They carry cold air toward lower latitudes, as southerly winds south of, say, 67°S, turning into southwesterlies farther north. These winds are of particular interest not only because of their effect on the temperature regime east of the Peninsula and farther northeastward in the southern Atlantic Ocean. They must also exert a profound effect on the motion of sea ice and bergs and the water masses of the Weddell Sea.

Two quite different types of synoptic-meteorological situations (sea level pressure fields, etc.) can produce that kind of winds. One type shows an intense cyclone over the central Weddell Sea. The other is characterized by a broad, not necessarily fast, east to west flow of stable cold air in the lowest 500 to 1000 m layer of the atmosphere over the central and/or southern Weddell Sea toward a 1500 to 2000 m high barrier, the Antarctic Peninsula. Such conditions result in a piling-up of the cold air on the east flank of the mountains, a process that leads to the formation of a narrow high pressure ridge over the Peninsula mainly east of the crest, an eastward directed isobaric temperature ascendant, and thus a deflection of the originally westward current of air to the right, along the mountain wall. The pressure effect was first discussed by Simpson (1919) with reference to the winds over the western Ross Sea, and later by Malberg (1967) in a more general form. A different approach to the theory of such winds is described in Appendix A; they may be called "barrier winds".

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*) 63.6°S, 55.8°W; between E and SW, no other island shields Paulet from the onslaught of the Weddell Sea winds (Bodman 1910, Lief. 3, p. 7 and 11).

**) For a lively description of the northern part of this mountain wall see Herbert (1968).

As will be seen below, the relative frequency of the occurrence of cold southerly or (farther north) southwesterly surface winds on the east side of the mountains is quite high. In contrast, the presence of an intense cyclone over the central Weddell Sea is a much less frequent and less persistent event, as studies of series of satellite pictures (Kachelhoffer 1976, Komro 1978) have shown. This is confirmed by much earlier evidence; i.e. the observations made on board the DEUTSCHLAND in 1912 and the ENDURANCE in 1915 during their drifts through the central Weddell Sea, see Table 2.1. Note in particular that in all months the average monthly windspeed is less than 14 knots, and south of 70°S it is less than 11 knots. In later years, the pressure variations in the southern half of the Weddell Sea during two weeks of December 1954 were briefly described by Capurro (1955), based on observations on board the Argentine icebreaker GEN. SAN MARTIN; only weak, eastward progressing pressure systems are mentioned. And in the last two weeks of February and first week of March 1977 the U.S.C.G. icebreaker BURTON ISLAND crossed the Weddell Sea from 64°S/53°W to Vashel Bay and back, along the ice fields (6 to 8 octas) covering the western Weddell Sea (Franceschini 1977, U.S. Navy Fleet Weather Facility Suitland 1977). The 52 six-hourly observations made between 65 and 77°S indicate sea level pressure values varying from 977 to 998 mb, temperatures from -6 to +1°C, maximum windspeed 30, mean speed 15.2, resultant wind 6.4 knots from the east (084°).

All this supports the notion that a large percentage of the total number of cold southwesterlies recorded at Matienzo must be of the second type, barrier-winds. Historical synoptic weather maps, like the well known IGY series (Weather Bureau of South Africa 1960) and the first years of the daily southern hemisphere analyses of the Australian Bureau of Meteorology, cannot be used as evidence because the analysts, unaware of the barrier-wind phenomenon, have often put a big low pressure system into the data-void central Weddell Sea when the only two available weather stations, Esperanza in the northwest corner and the about 1800 km distant Halley Bay station on the east side, reported strong southwesterly and easterly (katabatic!) winds, respectively.

The inappropriate location of the existing meteorological stations and the lack of direct observations from the Weddell Sea itself, a lack

Table 2.1: <u>Drift of DEUTSCHLAND 1912 and ENDURANCE 1915, surface wind statistics.</u>

(Under "Lat." and "Long.", the average positions for the respective month and ship are given. Data from Meinardus 1936.)

Month	Ship	Lat.	Long.	D_R	V_R(knots)	$\bar{V}$(knots)	q
MARCH	D	73.2°S	34.2°W	159°	6.8	10.5	.64
	E	76.7	37.1	127	2.3	9.5	.24
APRIL	D	72.3	39.5	113	3.1	10.7	.28
	E	76.0	40.4	122	1.9	6.4	.29
MAY	D	71.9	42.4	177	3.1	10.3	.30
	E	75.2	43.6	145	2.7	6.6	.41
JUNE	D	70.6	43.2	215	3.9	9.3	.41
	E	74.4	46.3	191	2.1	5.1	.43
JULY	D	69.1	44.4	214	6.2	12.0	.51
	E	73.6	48.4	215	5.6	9.1	.62
AUG.	D	66.2	43.4	231	7.0	10.9	.64
	E	70.8	49.5	196	5.6	7.6	.75
SEPT.	D	65.6	40.1	309	6.4	13.4	.47
	E	69.7	50.6	101	1.4	6.2	.21
OCT.	D	64.9	37.2	245	3.3	13.2	.25
	E	69.2	51.1	109	1.2	9.1	.16
NOV.	D	63.9	37.0	187	4.3	12.6	.34
	E	68.6	52.3	172	2.7	7.8	.34

D_R = direction of the vector-average of all wind observations,
V_R = magnitude of the vector-average of a-1 wind observations,
$\bar{V}$ = average wind speed,
q = $V_R/\bar{V}$ = directional constancy of the winds.

that cannot be fully compensated by satellite pictures, make it sometimes impossible to unequivocally distinguish between cyclonic winds and true barrier winds. There can also be synoptic situations in which the wind along the northern part of the Peninsula's eastside should be classified as of cyclonic origin while along the southern part it is clearly a barrier wind. These are the reasons why the two types will be combined for statistical purposes (as in Table 2.3) into one class: "cold winds from directions between S and W". The infrequent cyclonic winds do not need special explanation. The importance of the true barrier winds will be shown in the following pages.

A type of wind statistics, generally used for climatological considerations, is shown for the station Matienzo in Table 2.2. The essential information is given by the following parameters: a) the values called D_R and V_R, the direction and magnitude of the vector-average of all wind observations made every three or (in earlier years) every six hours; b) the average wind speed $\bar{V}$; and c) the ratio $q = V_R/\bar{V}$, called here the "directional constancy", which can vary between 0 (the vector average of the winds in the period considered is zero) and 1 (all winds have the same direction). It is of interest to note that these parameters can also be applied to much shorter time intervals than those used in climatology, in order to characterize the wind conditions during certain typical weather situations which may persist for several days. Several examples will be given in later sections of this study.

Nevertheless, for a meaningful description of the wind and weather conditions of places like Matienzo, such statistics have a serious shortcoming. The simple reason is that in one and the same month there may be SW-winds which temporarily can turn into W-winds, with temperatures of -20 to -30°, as well as W-winds, varying between WSW to NW, with temperatures above the freezing point. In the first case, we quite obviously deal with barrier winds or winds reacting to the presence of a low pressure system, both of which carry cold surface air from higher latitudes toward the station. In the second case, we have foehn winds which with sinking motion bring air from higher elevations down to the station level. Examination of the three-hourly wind and temperature data for a twelve months period indicates that a clear distinction between these

Table 2.2: Resultant surface winds at Matienzo, computed from statistics of the Argentine Serv. Met. Nac. for the period January 1962 through September 1967. n = number of observations, other notations explained in the text. Speed in knots.

Month	D_R	V_R	$\bar{V}$	q	calms	n
JAN.	207°	3.9	6.0	.65	38%	713
FEB.	220	7.4	9.3	.78	28	619
MAR.	228	7.6	10.5	.72	35	682
APR.	219	6.2	8.9	.69	36	690
MAY	227	11.9	13.6	.87	35	713
JUNE	225	7.6	9.5	.80	39	660
JULY	238	7.4	9.9	.75	37	744
AUG.	237	7.4	9.9	.75	38	744
SEP.	241	8.5	11.7	.74	33	718
OCT.	236	8.4	11.1	.75	31	620
NOV.	221	5.8	9.1	.63	30	600
DEC.	215	4.7	6.8	.67	31	620
ANN.	228	7.2	9.7	.73	34	8123

Note the high frequency of calms, a feature not found by the Deutschland and the Endurance, in the central Weddell Sea. Counting only observations with any motion of the air, the average "wind" speed at MAT would be about 50% higher than the values given in column $\bar{V}$.

two different classes of winds can easily be made in most cases, provided only winds with speeds greater than 10 knots are taken into account. In the few instances of borderline conditions, the change of temperature in the last three hours was used as criterion: temperature decrease = barrier winds, increase = foehn-type winds.

The restriction to cases with wind speeds greater than 10 knots not only helps with the separation of foehn-affected winds from barrier winds. It also makes the following frequency values more applicable to considerations of wind stress and inherent effects on ice; the weaker winds have less directional constancy, and exert only negligible stresses.

Table 2.3 contains the results. It divides the entire twelve months period into parts of unequal length because the seasonal variations can thus be shown much more clearly. In the western Weddell Sea region, for most years, the month of February brings several cases of strong cold air advection from the south (see Bodman 1910, Schwerdtfeger and Komro 1978). For the 12 year temperature record of MAT (1962-72 and 75) the average decrease from January to February amounts to 3.9°, while for the same period at ARG it is only 0.1°C. The February data have therefore been combined with the conventional three southern fall months. The two months September and October are the only ones with the frequency of the foehn-type winds comparable to that of the barrier-winds. Although it can be stated categorically only for 1968, it fits into general climatological experience: in those two months the anticyclonic cell over the southwestern South Atlantic extends farther south than in the rest of the year, so that the troughline between mid-latitude westerlies and polar easterlies in the Peninsula-area frequently lies south of 65°S; see also chapter 5, particularly Fig. 5.4.

Besides the number and relative frequency of observations in each of the five "classes" of winds, the average and the maximum duration of uninterrupted periods with winds of the respective class has also been determined. Naturally, the duration of moderate to strong winds with constant direction is a decisive factor for their effect on the motion of ice masses. The average wind speed has been computed only for the four classes with speeds > 10 knots. The average temperature deviations of each class from the multi-annual seasonal mean values are given in

Table 2.3: Characteristics of different classes of surface winds at Matienzo, from 2920 three-hourly observations for the twelve months from March 1968 to February 1969.

Explanation of the columns:

n = number of observations of the respective class of winds.

$\bar{D}$ = average duration (hours) of uninterrupted sequences of each class.

D_{max} = maximum duration (hours) of uninterrupted sequences of each class.

% = percentage of all observations.

% > 10 = percentage of the observations with speeds > 10 knots.

$\bar{V}$ = mean speed of the respective class (> 10).

$\overline{\Delta T}$ = average (weighted) deviation of the class-temperature from the respective seasonal ten-year mean values.

a) Febr. 69 and March, April, May 68; 951 obs.

Class of winds	n	$\bar{D}$(hours)	D_{max}(hours)	%	%>10	$\bar{V}$(knots)	$\overline{\Delta T}$(°C)
S to W, >10, cold barrier winds	450	24	123	47	93	26	- 2
W to NNW, > 10 warm, foehn-affected	17	17	30	2	4	25	+15
N to ENE, > 10	10	5	9	1	2	13	- 2
E to SSE, > 10	5	4	6	<1	1	14	+ 8
all winds ≤ 10 + calms	469	23	87	50	--	--	- 3
	951						

b) June, July, August 68; 746 obs.

Class of winds	n	$\bar{D}$(hours)	D_{max}(hours)	%	%>10	$\bar{V}$(knots)	$\overline{\Delta T}$(°C)
S to W, >10, cold barrier winds	248	15	69	33	83	33	- 2
W to NNW, > 10 warm, foehn-affected	37	9	18	5	13	29	+18
N to ENE, >10	9	3	6	1	3	17	+ 2
E to SSE, >10	5	4	6	1	2	18	+ 4
all winds $\leq$ 10 + calms	448	23	90	60	--	--	- 2
	747						

c) September and October 68; 486 obs.

Class of winds	n	$\bar{D}$(hours)	D_{max}(hours)	%	%>10	$\bar{V}$(knots)	$\overline{\Delta T}$(°C)
S to W, >10, cold barrier winds	154	18	72	32	51	28	- 4
W to NNW, >10 warm, foehn-affected	124	14	45	25	40	32	+14
N to ENE, >10	23	5	12	5	8	21	+ 5
E to SSE, >10	2	3	3	1	1	13	+ 8
all winds $\leq$ 10 + calms	183	12	33	38	--	--	- 1
	486						

d) November and December 68, January 69; 736 obs.

Class of winds	n	$\bar{D}$(hours)	D_{max}(hours)	%	%>10	$\bar{V}$(knots)	$\overline{\Delta T}$(°C)
S to W, >10, cold barrier winds	283	19	114	39	77	24	- 1
W to NNW, >10 warm, foehn-affected	20	8	24	3	5	24	+ 7
N to ENE, >10	64	10	33	8	15	14	+ 1
E to SSE, > 10	11	5	9	1	3	12	- 0
all winds $\leq$ 10 + calms	358	16	87	49	--	--	+ 1
	736						

the last column. These deviations have been computed as average differences from monthly mean temperatures, combined to one seasonal deviation value by taking into account the number of cases per month and class. Such a procedure entails, of course, that the $\overline{\Delta T}$ values in Table 2.3 must be small for the frequently observed wind classes, and can be large only for the less frequent ones.

Altogether, the following information can be gained from Table 2.3:

a) A clear distinction is possible between barrier-winds and foehn-affected winds.

b) Only these two classes of winds occur with sufficient frequency, duration, and strength to have a major effect on the drift of ice.

c) Alternation of these two wind classes, frequently found in spring, appears to be most favorable for the transport of ice toward lower latitudes; the foehn winds driving the ice away from the edge of the Larsen Ice Shelf (see NASA 1971, Sissala 1972, Kyle and Schwerdtfeger 1974, Colvill 1977), and the barrier winds forcing it northward. The importance of such an interaction of wind systems for the formation and transport of sea ice has been emphasized by Gordon and Taylor (1975).

d) The fall season (including February!), with its frequent and persistent barrier-winds and relatively rare occurrence of foehn winds, seems to present optimum conditions for the accumulation of ice in the northwest corner of the Weddell Sea.

Since the minimum of 11 knots (close to the annual median value) chosen to distinguish the "important" winds from the insignificant ones, is a rather modest value, the frequency of occurrence of the different types of winds has also been determined for higher speed limits. The results, summarized for the entire 12 month period, are given in Table 2.4. The proportion of the cold SW-winds remains essentially the same. Foehn winds achieve more importance with increasing minimum speed, at the expense of the winds from the other two quadrants.

In this context, comparable observations for the cold season at Nordenskjöld's station Snow Hill (160 km NE of Matienzo, 20 km SW of the present station Marambio) in 1902 and 1903 are of interest. For the eight months, March to October, hourly values of wind and temperature are available for both years - (Bodman 1910). There are 88 days in which the 24 hour average of wind speed (measured at 2 m above surface, 4 m above sea level) was >30 knots and the direction from SW. Table 2.5 gives the mean speed and mean temperature of these days. It shows that the air masses moving north and northeast along the eastern slopes of the Peninsula have temperatures which correspond to much higher latitudes, that is, to the southern regions of the Weddell Sea. The two longest periods of consecutive days with barrier winds >30 knots are also listed. Both cases belong to the year 1902 which must have been a year of particularly severe weather conditions, with 54 of the 88 days defined above.

It is obvious that the stress exerted by such surface winds is the main force which drives ice and cold water masses from the northwestern Weddell Sea into the W to E circumpolar current of the southern ocean. In recent years, this can directly be seen in the weekly ice maps of the U.S. Navy's Fleet Weather Facility (1971-present). The climatic effect is remarkable, as proven for instance, by the W to E temperature decrease from Tierra de Fuego to South Georgia, about 4°C on the annual average. For more data and interpretation see Fletcher (1969), Van Loon (1972), and Schwerdtfeger (1978).

Table 2.4: Winds at Matienzo: annual total number and relative frequency of four different classes of winds, for three minimum speed limits. March 1968 to February 1969, (total number of all three-hourly observations: 2920).

Wind speed	>10	>20	>30 knots
Total number of observations	1461	827	488
S to W, cold barrier winds	78	79	77%
W to NNW, warm, foehn-affected	14	20	22%
N to ENE	6.5	1	1%
E to SSE	1.5	0.1	0%

Table 2.5: Strong, cold barrier winds at Snow Hill in 1902 and 1903, March to October. Average wind speed and temperature for 88 days, each of them with a 24-hour average wind speed > 30 knots.

Month	M	A	M	J	J	A	S	O	
Number of such days	17	10	7	11	13	11	10	9	
Mean wind speed	37	34	41	35	38	41	37	36	knots
Mean temperature	-13.8	-18.6	-22.7	-24.3	-24.3	-24.6	-21.0	-18.1	°C

Longest periods of consecutive days with cold SW winds > 30 knots:

1 - 7 June 1902: $\bar{V} = 39$ knots, $\bar{T} = -25.6$, $\bar{T}_{max} = -23.8$, $\bar{T}_{min} = -27.1$ °C;
15 - 21 July 1902: 41 - 25.6 -23.0 -28.1

3. Two examples

a) An extended period of barrier winds

The first eight days of May, 1968, present a good example of barrier winds. This time interval has been chosen mainly because there can be no doubt, in spite of the lack of data from the Weddell Sea proper, that a broad stream from the east carried cold, stable air masses across the mostly ice-covered Sea toward the Antarctic Peninsula. That is proved by the fact that the eight day average sea level pressure difference between 77.8°S (Station BEL) and 60.7°S (ORC) amounts to 25 mb, the individual values varying between 15 and 35 mb. A 25 mb difference over the distance of 1900 km corresponds to a value of 15 knots (at density 1.3) for the component of the geostrophic wind from 085°. The winds at MAT are not exceptionally strong in that period; only on two of the eight days does the speed rise to the relatively modest value of 43 knots. However, the directional constancy of the winds is almost total (see Table 3.1), and that is so not only at the key-station MAT, but also at the other stations to the northeast and, more important, at station STO at 68°S on the <u>other</u> side of the mountains.

The high persistence of the wind direction makes it meteorologically meaningful to draw an "average synoptic" map for the entire eight day period, shown in Fig. 3.1. Though the pressure field farther to the W of the Peninsula remains unknown, an unavoidable conclusion is that a narrow high pressure ridge exists east of the crestline of the mountain range. That is exactly what must be found when cold stable air, moving westward from the central Weddell Sea, is piling up on the eastern flanks, as explained in Appendix A. Such a situation also favors the occurrence of katabatic winds on the lee-side of the mountains.

Pressure and wind measurements at station ESP require explanation. This station is well known for the terrain-induced strength of its southwesterly winds, and the theory of the barrier winds suggests that their speed should be greatest close to the steep slopes of mountain ranges. Nevertheless, some reservations regarding the functioning of the anemograph are inescapable when one sees that the observational record, handwritten and signed by the observer, indicates a wind speed of 204 km/h (= 110 knots), not more and not less, for seven consecutive 3-hourly

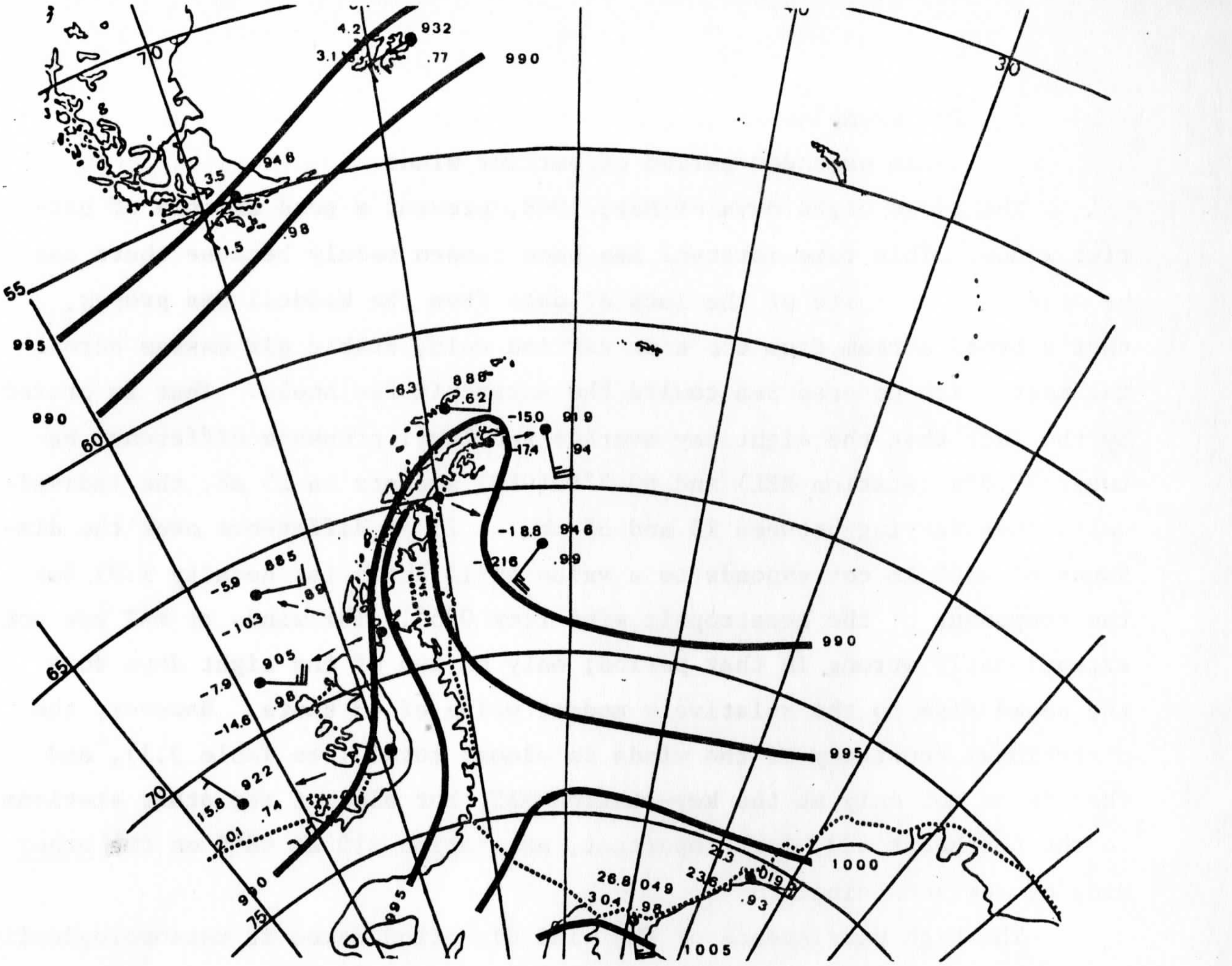

Fig. 3.1: Mean surface winds, temperatures, and sea level pressure conditions during an extended period of barrier winds on the east side of the Peninsula, 1968 May 1 - 8. Data are plotted only for those stations and isobars drawn only for those areas where the directional constancy of the surface winds was high. For each station: $\bar{T}$ at upper left, $\bar{T}_d$ at lower left, $\bar{p}_o$ at upper right, constancy q at low right; the wind arrows in conventional form indicate the vector average of the surface winds.

Note the extremely high constancy of the winds (q) at MAT, STO, and BEL; for May 3 - 8, it is very high also at PET and BHN.

Table 3.1: Average meteorological parameters for the period 1968 May 1 00z through May 8 12z; the asterisk marks stations with averages only for the last six days, after arrival of the cold air. Questionable values are put in parentheses, see text.

	p_o(mb)	T(°C)	T_d(°C)	D_R	V_R(km)	$\bar{V}$(km)	q
a) Stations to the east and north of the Peninsula							
MAT	994.6	-18.8	-21.6	226°	23.7	23.9	.99
ESP*	(989.7)	-15.0	-16.9	227	(75.8)	(84.3)	.90
PET*	994.6	-15.4	-17.8	176	33.6	35.8	.94
BHN*	992.2	- 8.6	-11.5	122	16.9	17.6	.96
b) Stations on the west side							
STO	990.5	- 7.9	-14.6	111	28.6	29.1	.98
ADE	998.5	- 5.9	-10.3	092	11.3	12.8	.89
ARG	998.4	- 4.4	- 8.6	091	3.1	6.8	.46
c) Stations south of 70°S							
BEL	1004.9	-26.8	-30.4	164	22.1	22.6	.98
HAB	1001.9	-21.3	-23.6	089	11.7	12.5	.93
FOB	992.2	-15.8	-20.1	324	3.4	4.6	.74
d) Upper air data for ARG							
ARG	850	-12.0	-17.7	164	2.4	10.5	.23
ARG	700	-21.8	-27.6	235	3.6	12.0	.30
ARG	500	-36.6	-43.1	225	7.3	16.0	.46

observations on May 4, and for 19 consecutive observations May 6 to 8. The visual observations of "blowing snow[2]" (ww = 39) leave no doubt about the character of the weather, but also make it understandable that the wind measurements must have been somehow impaired. As far as the pressure is concerned, all through 1968 ESP reports sea level pressure values about 4 mb lower than station PET, only 40 km to the east, whose pressure data generally are well compatible with those of MAT and BHN. And for the observations in which ESP reported SW-wind $\geq$ 100 knots, its pressure is 6 to 8 mb lower than at PET. (If the winds were geotriptic*), the difference would have the opposite sign and be much smaller.) Obviously, at least at one of the two stations the measurements are not giving the static pressure, and the wind-effect on the in-house pressure is probably stronger at ESP than at the other station.

The observations of the station BHN for the last six days offer a good example of the stream field in the Bransfield Strait when cold air moves with great speed northward through the Antarctic Sound. The barrier effect on the sea level pressure field cannot extend into the area north of the tip of the Peninsula, and the horizontal pressure gradient must change abruptly; in fact, it often weakens. When that is the case, the trajectory of the cold air shows the characteristics of inertial flow (see Parish 1978, Parish and Schwerdtfeger 1978). This explains the strong easterly component of the winds and, compared with ARG and ADE, the low temperature and moisture values at BHN, which had first been pointed out as characteristic for stations at the south side of the South Shetland Islands by Robin (1949).

During the eight days of barrier winds on the east side of the Peninsula, the sea level pressure at ARG, on the west side, was on the average about 6 mb lower than at MAT. The surface winds at ARG remained at speeds less than 15 knots with a slight prevalence of easterlies, but only for a few hours of May 4 was there a clear indication of a foehn effect, the relative humidity temporarily decreasing to 50%. In contrast

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*) geotriptic wind = wind in the boundary-layer when pressure gradient-, Coriolis-, and friction-forces are in equilibrium.

at STO, some 350 km farther south and very close to the steep west side slopes of the Peninsula, strong foehn winds persisted for the entire eight day period; the east side - west side pressure difference at 68°S can only be estimated from Fig. 3.1; it should be somewhat greater than at 65°S. It appears that there is a close correlation between the barrier winds along the Peninsula's east side and the easterly foehn winds at STO. This relationship will be analysed in the following chapter.

b) A foehn storm at Matienzo

Fig. 3.2 shows the interesting case of 20 July 1968. A day (the 18th) with pressure at Matienzo 10 to 15 mb higher than on the west side of the mountains and with the typical cold southwesterly winds was followed by a day with decreasing winds, later calms, clear sky, and the E-W pressure gradient reversing. The first half of the 20th brought a very weak northerly flow with increasing temperatures, until at 17 z (13 hs local time) a westerly storm broke through to the surface with a spectacular rise of temperature, from -23° at 15 z to +1 at 18 z; only three-hourly readings and extreme values are available. The minimum on the 19th between 18 and 22 z was -38.2°, the maximum 24 hours later, +2.2°. The storm at MAT persisted for 16 hours, followed by a short period of weak northerlies and almost 24 hours of calms, until the "normal" pattern, cold and strong southwesterlies, imposed itself again.

Temperature increases of 24° in three hours, or 40° in 24 hours, are certainly rare events anywhere, but not unique. A similar case on the east-coast of Greenland at 75°N was described by Schatz (1951).

On the other side of the mountains, at the station Argentine Islands, the surface winds remained weak to moderate all the five days shown in Fig. 3.2; in the three-hourly synoptic observations, no speeds of more than 17 knots appeared. During the foehn event at MAT, ARG reported moderate winds from the NW-sector, interrupted around midnight by weak northeasterlies. However, the sea level pressure difference ARG-ADE (mean latitude 66.5°S) amounts to 15 mb, corresponding to the geostrophic wind component of 50 knots from the WNW. Furthermore, the sounding of ARG made at 12 z, only a few hours before the foehn event at MAT, shows that at only a few hundred meters above the surface a much stronger wind must have been blowing toward the mountain range,

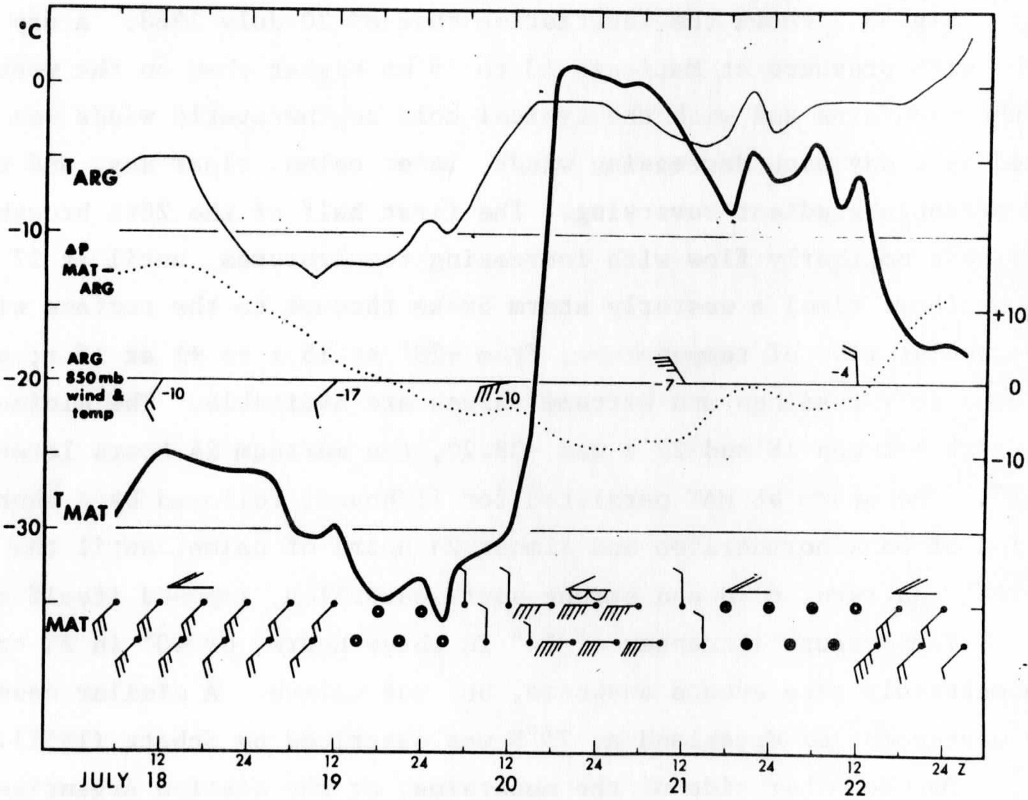

Fig. 3.2: Foehn storm at Matienzo, 20/21 July 1968.

see Fig. 3.3. Indeed, all available data strongly suggest that air from the lower layers above ARG passed across the mountains and reached the station MAT in a true katabatic motion on the lee side. The humidity measurements near the surface at MAT for the first 12 hours of the storm indicated a mixing ratio of 2.6 gram/kg. In the 12 z sounding at ARG, the same value belonged to the layer 200 to 400 m above sea level. Since routine measurements of the moisture content of the air at temperatures near and below the freezing point can generally not claim a high degree of exactness, it is worthwhile to note that the time series of the potential temperature values given in Table 3.2 supports the above conclusion regarding the level of origin of the foehn air. During the foehn storm the potential temperature at MAT was only 2° higher than the surface value at ARG, about 8° lower than the value which the sounding indicates for the level of the crest height.

At the station ESP, 230 km northeast of MAT and 25 km south of the northern tip of the Peninsula, the foehn event appeared in a form similar to that at MAT, with winds from 260° but speeds not more than 33 knots. It began about three hours earlier than at MAT with a temperature increase from -16 to 0°, reached a maximum of +2° and persisted for nearly 23 hours. The relative humidity during the foehn at ESP as well as at MAT varied between 55 and 65%, well compatible with the conditions on the other side of the mountains, though quite high in comparison to well known foehn events at the foot of the Andes or the Rocky Mountains. Some examples of foehn storms at ESP (Hope Bay) were already given by Pepper (1954).

The development was somewhat different at PET, 40 km east of ESP. Also at that station there was a pronounced temperature increase from -25° to -8° (at the time the foehn began at ESP) and later to -3°, but the surface winds which removed the shallow layer of cold air were mostly from the north; the relative humidity remained much higher than at the other two places. Without any upper wind measurement on the east side of the Peninsula, a further analysis is not possible.

Table 2.4 in chapter 2 indicates how often typical foehn winds have been observed at MAT in the twelve months period March 1968 to February 1969. It must be noted that at the latitude of MAT, 65°S, the frequency of occurrence of strong westerly or northwesterly winds in the free atmosphere, above the crest-height of the Peninsula, is much greater.

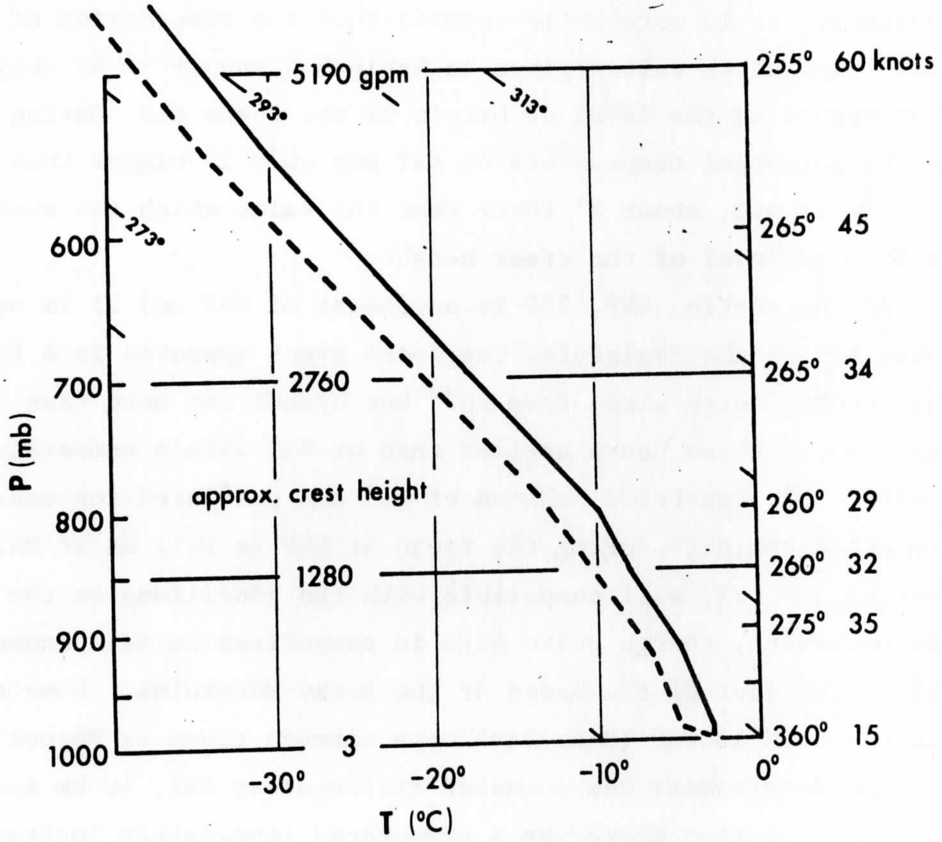

Fig. 3.3: Results of the sounding made at Argentine Islands, 12 z 20 July 1968, a few hours before the foehn storm at Matienzo on the other side of the Peninsula. Solid line = temperature; dashed line = dewpoint temp.

Table 3.2: Potential temperature (°K) of the air near the surface on both sides of the mountains, and for Argentine Islands at the 850 and 700 mb levels.

		MATIENZO		ARGENTINE ISLANDS		
Date and time		surface		surface	850 mb	700 mb
July 18.	12 z	250°		271°	276°	280°
19.	00	248		263		
	12	245		262	268	275
20.	00	240		264		
	12	244		270	276	279
	15	250		272		
	18	273	foehn	272		
	21	274		272		
21.	00	274		272		
	06	273		271		
	12	270		272	279	286
22.	00	268		272		
	12	268		273	282	290
23.	00	255		275		

However, on many days with such upper-level winds the sea level pressure field on the east side of the mountains does not force the cold air in the lowest few hundred meters to move away from the mountains.

For the five months June to October 1968, the frequency and duration of foehn storms at station ESP have been compared with the values of MAT. The differences are not significant. South of 65°S latitude, where the number of days with strong westerly flow on the west side of the Peninsula is smaller, foehn storms on the east side of the mountains must be expected to be less frequent; but there is clear evidence that they occur occasionally (NASA 1971, Sissala et al. 1972, Gloersen et al. 1973, Kyle and Schwerdtfeger 1974).

4. Barrier and foehn winds between 68 and 69°S

a) Data for 1968/69

Easterly winds above the boundary-layer over the western Weddell Sea, at least up to the crest height of the Peninsula, are a necessary condition for the maintenance of foehn winds down the west flanks of the mountains, because the total area of the so-called plateau, north of 69°S, is much too small to serve as source region for katabatic winds persisting through several days. As has been shown in the previous sections and in Appendix A, easterly winds over the central Weddell Sea also are a prerequisite for the maintenance of barrier winds along the Peninsula's east side. A close relationship between the two wind systems is therefore to be expected.

There are, of course, other conditions also to be fulfilled for a true foehn storm to descend to the islands in Marguerite Bay. This makes it understandable that in the twelve months March 1968 to February 1969 only 15% of all observations at STO indicate strong easterly winds, while the frequency of barrier winds on the mountains' east side are much greater. More details are given in Table 4.1. Exceptions are found mostly in the relatively quiet months, November to January. It appears that with the weaker pressure gradients and the smaller stability of the air in the boundary layer over the Weddell Sea, typical for that time of the year, the general conditions do not favor an extension of the barrier winds over a distance of 300 km or more, in the south to north direction.

b) Two months in 1947

It is evident that synoptic observations on both sides of the mountains are needed to find out more about the relationship between barrier winds along the east flanks and foehn winds at Stonington Island. Fortunately, a few such observations exist.

In the years 1947 and 48, the Ronne Antarctic Research Expedition maintained a meteorological station for 12 months at Stonington Island, for three months (September to November 1947) on the Plateau 25 km east of Stonington at 1768 m above sea level, and for two months (October and November 1947) at Cape Keeler (KEE) on the east side of the Peninsula (see Table 1.1 and Fig. 1.2).

Table 4.1: Frequency and mean temperature of southwesterly barrier winds observed at Matienzo in all cases in which Stonington reported strong easterly winds ($\geq$ 28 knots).

S = number of observations of winds $\geq$ 28 knots from the E-sector at Stonington,

M = number of simultaneous observations of cold southwesterlies at Matienzo,

$\bar{V}(M)$ = mean speed of cases M (knots),

$\bar{T}(M)$ = mean temperature of cases M,

$\Delta T(M)$ = deviation of $\bar{T}(M)$ from 10 year average temperature,

E = exceptions = number of simultaneous observations of other winds or calms at Matienzo,

$\bar{V}(E)$ = mean speed of these cases (knots).

Period	S	M	$\bar{V}(M)$	$\bar{T}(M)$	$\Delta T(M)$	E	$\bar{V}(E)$
Febr. 69 and March 68	22	22	28	-10°	-4°	0	—
April and May 68	35	31	21	-22	-4	4	4
June - August 68	22	21	25	-24	-3	1	0
Sept. and Oct.	11	10	25	-14	-2	1	0
Nov. 68 - Jan. 69	16	7	14	- 6	-3	9	7
Total	106	91	≈ 86%				
Total minus summer	90	84	≈ 93%				

Only 00 and 12 z observations are available for Stonington; eleven days missing.

Climatological summaries for the three stations have been published by the U.S. Navy (Peterson 1948), but the synoptic data have received little attention. The twice daily (00 and 12 GMT) observations and some additional notes of the observers contain valuable information about the character and origin of the strong katabatic winds which are an important phenomenon in Marguerite Bay, particularly in the vicinity of the steep rising mountains to the east, and about the simultaneous conditions on the eastern foot of the mountains as well as on the plateau. Even though the typical foehn events appear more frequently and with greater force in late fall and winter, the two months October and November include a fair sample of interesting cases.

The synoptic observations of all cases show quite clearly that during a foehn storm in Marguerite Bay the atmospheric pressure (at sea level) is considerably greater on the east side than on the west side of the mountains. Of the ten cases of strongest easterly winds at Stonington Island (>30 knots at about 3 m above ground), nine had a pressure difference Δp (KEE - STO) > 10 mb, and in the tenth case the difference was 8 mb. Even allowing for possible dynamic effects of strong and gusty winds on the pressure inside a station building, the average for the ten cases (13 mb, $\sigma_m = 1.1$ mb) is large enough to support the above statement. Looking inversely at situations with particularly strong pressure differences, Table 4.2a gives the average values of wind and temperature for all 13 cases in which Δp(KEE-STO) > 10 mb, and for ten cases with Δp between 6 and 10 mb.

In all the 13 cases summarized in Table 4.2a, the lapse rate of temperature between the Plateau at 1768 m and Stonington Island at 9 m is very nearly the dry-adiabatic one, so that the mean temperature of that atmospheric layer can easily be determined. Since the horizontal distance between the two stations is only 25 km, the pressure at Plateau can be computed with appreciable exactness. A similar computation for the eastern side of the mountains is a little more problematic because the exact temperature profile between Plateau and Cape Keeler is not known and the distance between the two places is much larger (155 km). Still, there is no doubt that the air on the east side is considerably colder and hence the sea level pressure must be greater than on the warmer west side. Assuming

Table 4.2: Average surface wind and temperature values in cases with a large positive pressure difference east side minus west side of the Antarctic Peninsula at 68.5°S. Symbols:

n = number of cases (observations at 00 or 12 z).

D_R and V_R = direction and speed (knots) of the resultant wind (vector average of the wind).

$\bar{V}$ = mean wind speed (knots).

q = directional constancy of the wind, defined as $V_R/\bar{V}$; the possible maximum is $q = 1$ = all individual winds have the same direction.

$\bar{T}$ and $\sigma(T)$ = mean temperature at station level and standard deviation (°C).

$\bar{\Theta}$ = mean potential temperature (°K).

$\bar{p}$ = mean pressure at sea level for STO and KEE.

	a) $\Delta p(\mathrm{KEE} - \mathrm{STO}) > 10$ mb; $n = 13$.			b) $6 \text{ mb} < \Delta p(\mathrm{KEE} - \mathrm{STO}) \leq 10$ mb; $n = 10$.		
	STO (9 m)	PLA (1768 m)	KEE (23 m)	STO	PLA	KEE
D_R	108°	051°	165°	087°	020°	179°
V_R	32	18	13	13	10	10
$\bar{V}$	33	19	15	15	12	11
q	.97	.97	.86	.90	.82	.89
$\bar{T}$	-3.9	-21.1	-14.6	-1.7	-16.7	-14.1
$\sigma(T)$	3.6	4.9	3.5	4.3	5.9	3.0
$\bar{\Theta}$	272	272	260	273	275	260
$\bar{p}$	969.4	769 *)	982.3	978.7	784 *)	986.0

*) Computed for station level, as described in text

temperature profiles characteristic for Weddell Sea air masses as suggested by kite soundings made during the drift of the DEUTSCHLAND in 1912 (Barkow 1913, Schwerdtfeger Appendix A) and Halley Bay soundings on days with west winds (see Table 4.3), i.e. a cold layer in the lowest 500 to 1000 m and warmer air above, one obtains a sea level pressure at the foot of the mountains east of Plateau between 976 and 978 mb. For the 13 cases to which this consideration applies, the mean pressure at Cape Keeler, 85 km farther south, is 982 mb. This entails the presence of a N-ward directed pressure gradient (higher pressure to the south), that is, a geostrophic wind from the east-sector, as the observations of Plateau confirm.

From these facts evolves a clear picture of a stream-field, as described in Appendix A: Winds with an east to west component over the Weddell Sea carry stable air masses toward the mountain wall of the Peninsula. The cold air of the lowest layers piles up along the eastern slopes, and the wind in the lower layers is deflected into a S to N direction, parallel to the mountain wall. In most cases this cold air does not reach the crest of the mountains. That is evident from the pronounced difference in potential temperature between Cape Keeler and the Plateau. Even a saturation - adiabatic rise of the air near the surface on the east side would not make much of a difference; it would lead to a temperature at the height of the Plateau of 262°K instead of 260° for a dry-adiabatic rise, to be compared with the 272°K determined for that station. In such situations, the weather along the east side of the Peninsula is characterized by overcast sky, often light snowfall, and drifting or blowing snow whenever the strength of the surface winds is sufficient.

The weather conditions are quite different on the west side of the mountains: The typical phenomenon is a foehn storm which carries air from about crest height down into Marguerite Bay, as the potential temperature values for Plateau and Stonington as well as the descriptions quoted in section 4c suggest. Note also the extremely high values of the directional constancy (q) of the wind in Table 4.2a and b. The moisture measurements at the two stations are probably not precise enough to justify a detailed analysis. For all 23 cases with Δp(KEE-STO) > 6 mb combined, the relative humidity decreases from 78% (close to saturation with respect to ice) at

Table 4.3: Some upper air data for Halley Bay. In columns A,B, and C: average monthly temperature and height values for the lower troposphere at HALLEY BAY, for all soundings 1968-74 (January and February 1971 missing). In columns D and E: average monthly temperature differences 850 mb level - surface; in D for all soundings 1968-74, in E for the 142 soundings of a 36 month period, October 65 to September 68, in which the surface winds were from the WSW sector (225-270°).

Column	A	B		C		D	E
Level	surface	850 mb		700 mb		Temp. differences 850 mb-surface	
MONTH	$\bar{T}$(°C)	$\bar{T}$	$\bar{H}$(gpm)	$\bar{T}$	H	all soundings	with WSW winds
JAN.	- 4.7	- 9.9	1229	-17.9	2718	-5.2	-6.1
FEB.	- 9.9	-12.4	1183	-18.9	2648	-2.5	-5.1
MAR.	-15.4	-14.1	1146	-20.3	2602	1.3	-0.5
APR.	-19.8	-15.8	1153	-21.4	2602	4.0	4.9
MAY	-23.7	-17.4	1153	-23.6	2590	6.3	9.1
JUNE	-27.7	-20.4	1140	-25.3	2565	7.3	10.2
JULY	-31.7	-21.7	1118	-25.8	2540	10.0	9.3
AUG.	-29.7	-20.6	1127	-25.0	2554	9.1	8.2
SEP.	-24.6	-20.3	1097	-24.5	2525	4.3	5.5
OCT.	-18.5	-16.4	1131	-21.8	2574	2.1	1.8
NOV.	-11.1	-13.6	1156	-20.3	2613	-2.5	-2.0
DEC.	- 5.0	-10.3	1210	-17.5	2684	-5.3	-5.0
Total number of soundings		2404		2404		2404	142

Plateau to 64% at Stonington, which corresponds to an increase of the specific humidity from .7 to 1.8 gram/kg. That could be attributed, at least in part, to the evaporation of blowing snow which is reported in most cases.

There is one case among the 13 summarized in Table 4.2a, 28 October 1947, in which the above mentioned conditions for the development of a foehn storm appear to be met, but nothing happens at Stonington Island itself. The pressure difference KEE-STO is 11 mb, KEE reports -14° with winds SSE 37 knots, PLA -13° with E 24, and STO +3°, but an E-wind of only 4 knots. The observer writes: "Snow falling off the plateau in the east.....Looks like someone is shoveling pile after pile of snow off the fringe. The splash is deflected by NE-Glacier." It may be that the non-development of a full grown foehn storm in this case is due to a lack of time; 12 hours before and after the critical time, Δp(KEE-STO) was less than 2 mb.

c) Examples of foehn storms in Marguerite Bay*)

A lively description of the weather development at Stonington Island, on 2 October 1947, was given by one of the observers, on the back of the daily data sheet, as follows:

"Morning was clear, cold, calm, and --- except for one-third cirrostratus in the East --- cloudless. Slight wisps of drifting snow were visible on the Plateau fringes about 20 miles eastward. These wisps grew gradually during the morning, and by late afternoon clouds of drifting snow were seen over the escarpment 3 miles eastward. Drifting snow was also seen falling down the upper half of Figure Four Mountain (now called Roman Four Promontory, 68° 13' S, 66° 56' W) one mile eastward. At 17 GCT the avalanche of drifting snow arrived and winds, temperature, and dew point suddenly rose. Drifts were also seen near the Debenham Islands six miles northward. Middle clouds appeared from the North and rapidly covered the sky over 9/10ths during the afternoon. The freshly fallen snow of last night in the drifts made a very strange sight shooting off the precipice of NE Glacier."

In this case, whose data are shown in Table 4.4a, it is quite obvious that the air near the surface of the Larsen Ice Shelf (on the Weddell Sea side)

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*) see also Pepper, 1954.

Table 4.4: Observational data in two cases of foehn winds at Stonington Island, Marguerite Bay; a) 2-4 October, b) 5-6 November 1947. For Stonington, simultaneous data in upper line for the American, in lower line for the British station.

T = temperature (°C); Θ = potential temperature (°K); U = relative humidity;
N = total cloudiness (tenths); D = wind direction; F = wind speed (knots);
ΔP = sea level pressure difference KEE-STO

a)	STONINGTON, 9 m						PLATEAU, 1768 m						CAPE KEELER, 23 m					KEE-STO
	T	Θ	U	N	D	F	T	Θ	U	N	D	F	T	Θ	N	D	F	ΔP (mb)
Oct. 2 00 z	-14 -14	260	72 84	4 4	WNW NW	12 11	-13	280	80	x	NW	16	-28	248	0	C	0	-8
2 12	-21 -21	253	87 100	2 1	E SE	5 1	-20	272	46	4	ENE	1	-16	258	1	C	0	1
3 00	- 6 - 7	270	45 --	x 10	ESE ESE	45* 36	-21	272	68	x	ENE	19	-16	258	8	S	13	19
3 12	- 4 - 7	272	56 --	9 9	ESE ESE	35 36	-23	271	78	9	NE	16	-18	257	10	SW	11	14
4 00	- 3 - 4	273	64 --	x 6	ESE NE	3 6	-19	274	44	x	NW	2	-19	257	10	SW	5	4

* = max. wind speed at Am. station, 23^{30} z: 63 knots.

b)	T	Θ	U	N	D	F	T	Θ	U	N	D	F	T	Θ	N	D	F	ΔP
Nov. 5 00 z	-1 -1	273	70 69	x 10	ESE SE	12 15	-16	276	88	10	NE	9	-6	268	9	C	0	4
5 12	-2 -2	273	86 91	10 10	ESE SE	33 21	-17	276	86	10	NE	16	-6	268	9	C	0	11
5 18	-3 -4	273	75 97	2 9	ESE E	30 16*	-19	274	86	9	NE	26	-7	268	9	SSE	12	12
6 00	-6 -6	270	73 97	4 10	ESE SE	39 41	-22	271	84	9	NE	30	-8	267	9	SSE	18	13
6 12	-6 -4	270	94 97	10 10	WNW E	2 3	-15	277	90	9	W	17	-8	267	8	SSE	15	2

* = max. wind speed at Am. station, 19 z : 64 knots.

has no chance to be lifted to the height of the Peninsula's plateau. The potential temperature at KEE is 14 degrees lower than at PLA.

Five weeks later, when the air over the Weddell Sea is already considerably warmer, different conditions prevail (see Table 4.4b). The temperature difference KEE minus PLA corresponds to the saturation-adiabatic lapse rate, while the difference STO-PLA lies between the saturation-adiabatic and the dry-adiabatic rate. It is possible that the air from near the Larsen Ice Shelf has reached the plateau and moved on downward to Marguerite Bay. It is also possible that the cold air mass over the Weddell Sea had a greater vertical extent and steeper lapse rate than in many other cases. Since no soundings have been made, it cannot be decided which of the two alternatives gives the correct interpretation.

As a third example, Fig. 4.1 shows the march of temperature at Stonington, Cape Keeler (both from thermograph records), and at the Plateau, and sea level pressure at the two first named stations in a case of three days of continuously strong east winds at Stonington Island, October 10 - 12, 1947. Since so little is known about the weather on the east side of the Peninsula south of 65°S, it might be of interest to quote verbatim Cape Keeler station's observer referring to the days 12 - 15 October 1947:

"The 23 z report was made from notes and the records of the thermograph and barograph. As from 18 z of the 12th to 18 z of the 15th the station was weathering in from a severe storm of drifting snow. Although I have no way of proving it, I am sure considerable snow itself fell from the observations I made, one in particular: soft wet snow is not a usual product of drifting snow storms.

The instrument shelter was completely snowed under upon inspection the 13th at 15 z. It took over 5 feet of digging to retrieve barograph, psychrometer, and alcohol thermometer. All were in good order. I noted the snow gauge read only 3" at this time and the wind was due South about 30 m.p.h.

On the 14th at 15 z the snow gauge still read only 3", wind South 12 - 20 m.p.h., and at 17 z a small blue hole opened up to the North, making Cape Joerge and Cape Keeler visible. There were high sheep-fleecy Cirrus, thick Altostratus middle clouds, and below was still drifting snow and Stratus.

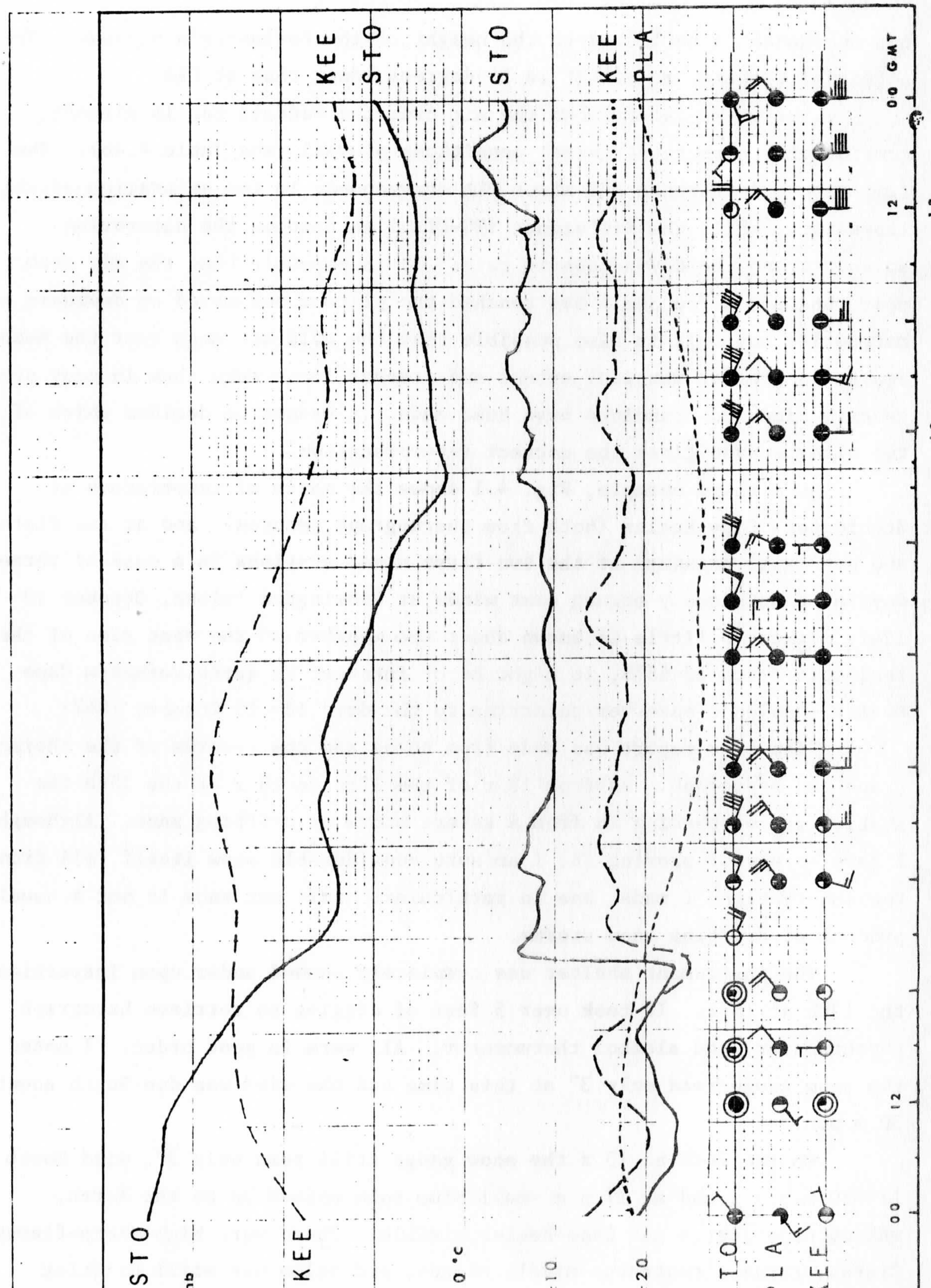

Fig. 4.1. Three days of strong easterlies at Stonington Island, October 1947.

I noted the snow gauge was full of snow, an accumulation of over 10" of water in the past 24 hours, as I had emptied it the previous day. I do not know how much is drift and how much is fallen, but it was of the soft wet variety. The wind was quite high during the night of the 14th. Wednesday the 15th: Moderate combined storm of falling and drifting snow. South wind gives a still overcast day. At 18 z of this day, I will resume normal observations."

d) Winds and temperatures on days with low pressure on the east side

It must be noted that the monthly averages of the pressure on both sides of the Antarctic Peninsula at about 68°S are very nearly the same, though the mean temperatures differ considerably:

	STONINGTON ISL.		CAPE KEELER	
October 1947	980.8 mb	- 7.5°	981.1 mb	- 17.9°
November 1947	979.9	- 3.1	979.4	- 8.3 .

Since up to now we have discussed only events with much higher pressure on the east side than on the west side, it is necessary to ask what might happen when the opposite is true. The answer: in the majority of all cases, not much! , at least in the two months for which observations exist. Table 4.5 summarizes the essential parameters. It shows that there is no such uniformity of the winds at STO and KEE as exists in the previously described cases of foehn wind on the west side. With higher pressure over Marguerite Bay, the speed and the directional constancy of the winds, q, are much smaller and the lapse rate of temperature between Plateau and Cape Keeler is in most cases far from the adiabatic one.

In fact, there is only one in the series of 122 observations (00 and 12 z) taken at Cape Keeler in the two months October and November which can be interpreted as a moderate case of foehn winds, 12 z 3 Nov. 47, with the following data:

	STO	PLA	KEE
wind	SE 3	WNW 16	WSW 24 knots
temperature	- 7.7	- 18.9	- 1.7°
sea level pressure	989.6	--	978.0 mb

Table 4.5: Average surface wind and temperature values in cases with a large negative pressure difference east side minus west side of the Antarctic Peninsula at 68.5 °S in October and November 1947. Symbols as in Table 4.2.

$\Delta p(\text{KEE} - \text{STO}) < -6$ mb ; $n = 27$

	STO (9m)	PLA (1768m)	KEE (23m)
D_R	316°	264°	325°
V_R	2	11	6
$\bar{V}$	5	13	10
q	.44	.81	.61
$\bar{T}$	-10.2	-18.3	-12.7
$\sigma(T)$	8.9	4.6	8.6
$\bar{\Theta}$	264	273	262
$\bar{p}$	987.6	–	977.4

According to the observer's notes, strong winds from the west sector persisted for eight hours, the highest speed being not more than 32 knots.

The different reaction of the lower layers of the troposphere to the occurrence of strong positive and negative zonal pressure differences, in spite of favorable wind directions at crest height (see D_R, V_R, and q at Plateau in Tables 4.2 and 4.5) in both groups of cases, may be due to the different temperature regimes and therefore be found also in other parts of the year. In the majority of all days, the air near the surface on the east side is 10 to 15° colder than on the west side; only in the three summer months November to January, may the difference be closer to 5°. Downslope motion of potentially warmer, less dense air will reach the surface layer on the east side only when there is a strong horizontal pressure gradient so directed that it forces the cold air in the boundary layer away from the mountains. That can be the case when an intense cyclonic vortex moves into the southwestern Weddell Sea; a possible, but certainly not a frequent situation. This statement will be corroborated in chapter 5.

In this context, another case (15 November 1947) with NW winds at Cape Keeler "steady in the 50's (knots), gusts to 63", may be of interest. On that day, the temperature difference KEE - PLA amounted to less than 9°, and the temperature at KEE decreased by 6° during the storm. Therefore, it can hardly be understood as a case of katabatic winds. The strong NW-wind is more likely due to an intense cyclone passing eastward, as the W-wind at crest height suggests, at a latitude south of, say, 70°S.

It is obvious that wind and weather statistics for a period of only two months cannot give a representative picture, and could be misleading if one would try to generalize the results. Still, for the west coast of the Weddell Sea south of 65°S two months is all we have. Therefore, the following frequency values of observed wind directions and respective temperatures may be of interest. They refer to those 37 observations (00 to 12 GMT) of a total of 122 made at KEE, in which the wind speed was 10 knots or more:

Wind from sector	Number of obs.	Mean temperature
SE - S	20	- 13.6°
SSW - WSW	3	- 12.4
W - NW	7	- 6.7
NNW - NNE	7	- 12.1
NE - ESE	0	----

That may lead to the tentative conclusion that, even if fully developed foehn winds are rare events, some downslope motion can be the cause of the considerably above average temperatures of air reaching the station from the W - NW sector.

5. Eastward progressing cyclones south of 68°S

As mentioned in the introduction, one of the reasons the year 1968 was chosen for the major part of the present study is that during almost the entire year daily observations have been made at Fossil Bluff (FOB, 71° 20' S, 510 km due south of the station Adelaide Island (ADE)). From the three-hourly pressure values of these two stations some information can be deduced regarding the frequency and intensity of the deep cyclones which occasionally advance from the Bellingshausen Sea east- or southeastward into the Weddell Sea area south of 68°S.

There are two particularly interesting aspects about these sometimes quite formidable storms: in the first place the effect on the sea ice on both sides of the Peninsula south of said latitude and sometimes extending northward to about 64° S; and secondly, the effect on the synoptic development produced by the transport of relatively warm and moist air masses toward the southwest corner of the Weddell Sea and the adjacent steeply rising slopes of the continent. Both effects can best be explained by means of the example of September 12 to 14, shown in Figs. 5.1 and 5.2.

As long as a pronounced positive pressure difference ADE - FOB persists, the vector representing the stress exerted by the surface winds on the ice must have a large west to east component. A difference of 10 mb corresponds to an average geostrophic wind component of 28 knots (assumed air density 1.27 kg m^{-3}, mean latitude 70°) across the 400 km line between the two stations. The resulting stress is directed on-shore on the Bellingshausen side, essentially into Marguerite Bay (see Fig. 1.2) where the ice conditions*) must deteriorate, depending, of course, also on the duration of the westerly windstorm. In the example of Figs. 5.1 and 5.2 the duration is only about 36 hours, with a brief interruption in the afternoon of the 13th. Some other cases are of much longer duration; see Fig. 5.3.

The wind stress over the Larsen Ice Shelf acts in the off-shore direction, and is capable of producing leads or polynyas along the rim of the shelf. In recent years, the latter phenomenon has been well documented

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*) regarding the ice conditions in Marguerite Bay prior to 1962 see Heap (1964), for the years 1951-1961 a detailed study by De La Canal (1963), and for the favorable years 1970-75 Schwerdtfeger (1976).

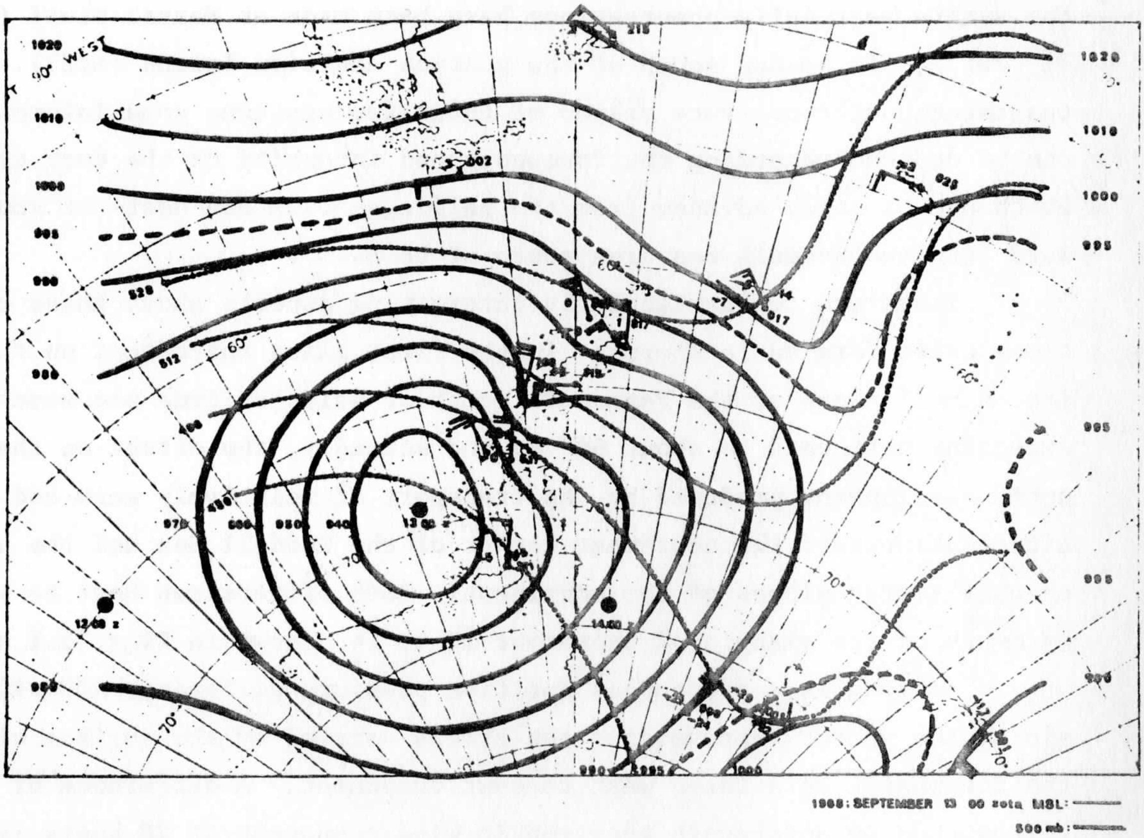


Fig. 5.1: Example of a cyclone over the southeastern Bellingshausen Sea, 00z 13 September 1968, with central pressure about 935 mb. Black dots indicate the estimated location of the cyclone at 00z, 12, 13 and 14 September. Heavy lines: sea level isobars. Dotted lines: contourlines of the 500 mb surface, in geopotential decameters.

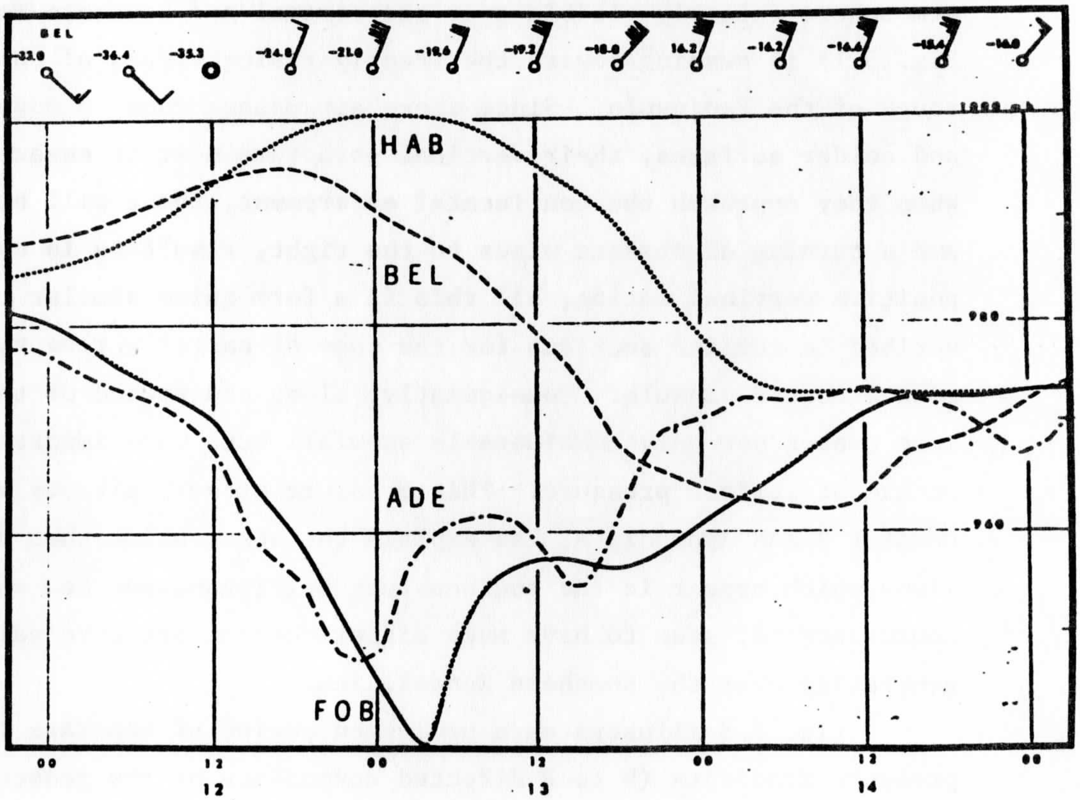


Fig. 5.2: Barograms of the four stations FOB, ADE, HAB, and BEL for 12 - 14 September 1968. In the upper part, wind and temperature at BEL.

by satellite pictures (Sissala et al. 1972, Gloersen 1973, Kyle and Schwerdtfeger 1974, Colvill 1977). Indeed, this kind of synoptic situation appears to be the only one that can initiate major temporary changes in the ice cover of the western Weddell Sea.

The second remarkable effect, initiated when a southeastward progressing intense cyclone reaches the southeast corner of the Bellingshausen Sea, is brought about by the fact that the broad stream of relatively warm and moist air masses in the lowest few thousand meters of the atmosphere (clearly visible over the central and southern Weddell Sea in Fig. 5.1) is heading toward the steeply rising slopes of the continent south of the Peninsula. Since these air masses come to move over colder and colder surfaces, their vertical structure must be essentially stable. When they approach the continental escarpment, there will be "damming-up" and a turning of surface winds to the right, resulting in convergence and positive vertical motion, all this in a form quite similar to that described in earlier sections for the case of easterly flow toward the mountainous Peninsula. Consequently, along and upwind of the slopes one must expect not only considerable snowfall but, more important, an increase of surface pressure. This pressure effect, already mentioned in Chapter 2 and Appendix A, can explain the observation that deep depressions which appear in the southeastern Bellingshausen Sea and advance southeastward, seem to have much higher central pressure values when regenerating over the southern Weddell Sea.

Fig. 5.3 illustrates a prolonged period of moderate to strong N-S pressure gradients (W to E directed components of the geostrophic wind) which extend southward to 70° S or more. It is the case of longest duration found in the data for 1968. When the surface winds blow from the W or NW and, as is generally the case, the temperature decreases poleward, it is evident that winds from the west-quadrant predominate in the free atmosphere (above the boundary-layer) and increase with height. Under such conditions tropospheric pressure systems tend to move eastward, and a N to S pressure gradient will prevail also on the east side of the Peninsula, though the magnitude may differ.

The barogram of ARG (65.3°S) has been included in Fig. 5.3 to show the meridional pressure gradient over a wider distance (800 km). The

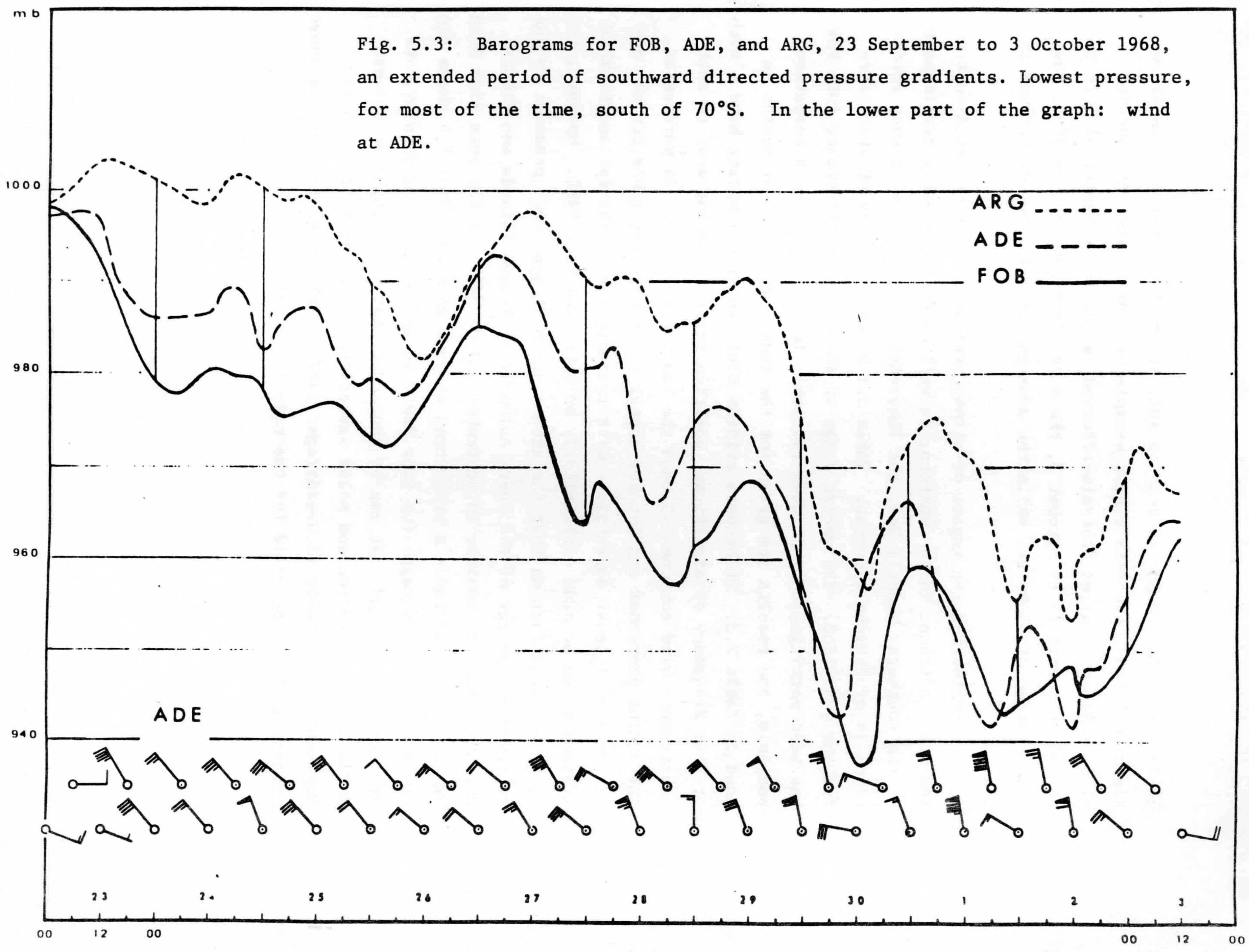


Fig. 5.3: Barograms for FOB, ADE, and ARG, 23 September to 3 October 1968, an extended period of southward directed pressure gradients. Lowest pressure, for most of the time, south of 70°S. In the lower part of the graph: wind at ADE.

series of surface winds of station ADE, at the SW corner of mountainous Adelaide Island, presents a good example of what in the introduction (Fig. 1.2) were called "terrain-affected" winds (see chapter 6). In the period September 23 to October 3, the winds from NNW, 340 or 350°, have a mean speed of 55 knots, while the average for all other directions is 23.

Considering the impact of strong meridional pressure gradients on the ice conditions in the western, as well as on the weather development in the southern Weddell Sea, the frequency of occurrence of such conditions is of obvious interest. Table 5.1 shows the relevant statistics for the year 1968. The entire range of the pressure difference ADE - FOB has been partitioned into seven classes. In order to make a comparison possible, the results are given for the same combination of months as used in Table 2.3. It becomes evident that winter and spring have a much greater frequency of significant positive values (meaning west to east geostrophic wind components) than the rest of the year. In particular, the months September and October appear to be most favorable for the occurrence of intense depressions with trajectories in the far south. That statement can be made categorically only for the year 1968. However, the climatological fact is that the annual march of sea level pressure in the southwestern sector of the South Atlantic (Falkland Islands and Tierra del Fuego) has its maximum in September and October, at the same time when in the higher latitudes a pronounced minimum appears. Fig. 5.4 shows the 40 year monthly averages for Cape Pembroke and neighboring Stanley, and for Horseshoe Island. It can be concluded that the troughline between midlatitude westerlies and polar easterlies lies farthest south in September and October (Schwerdtfeger 1967). This suggests that the above statement should be valid for the majority of all years.

Fig. 5.4

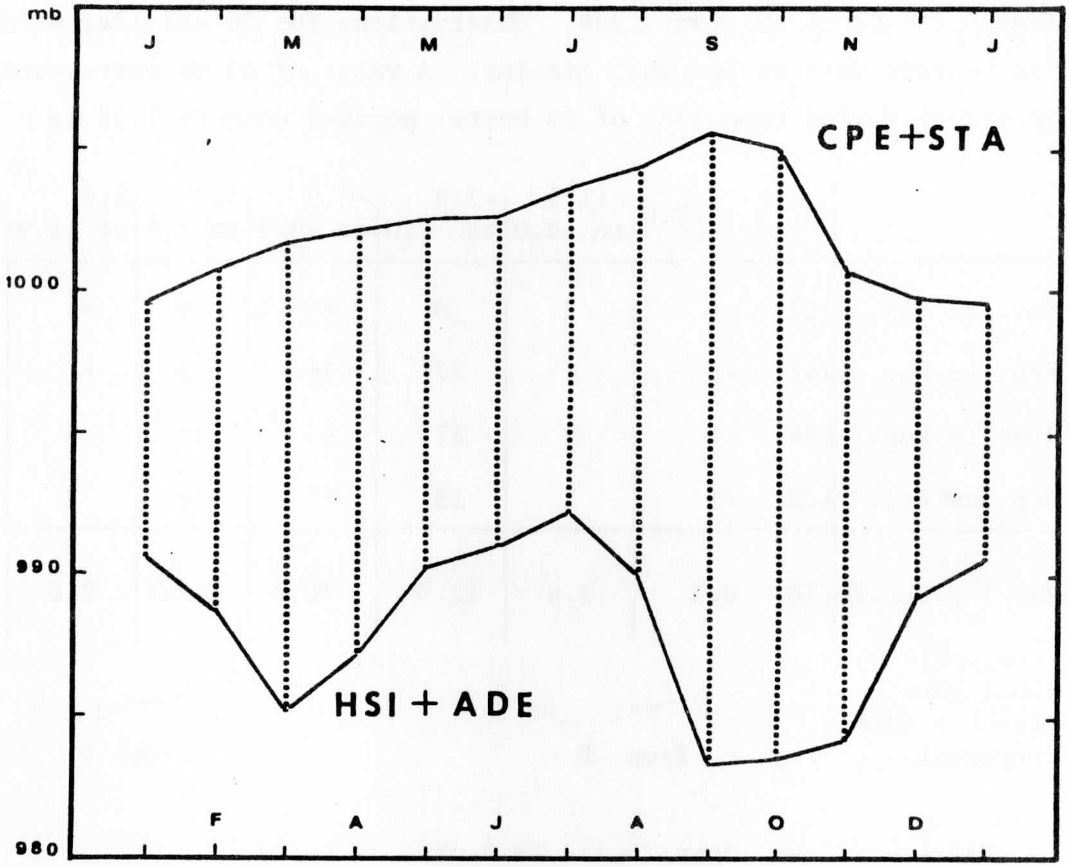


Fig. 5.4: Average monthly mean pressure at Falkland Islands (Cape Pembroke and Stanley, 40 years) and northern Marguerite Bay (Adelaide and Horseshoe Islands, 18 years), about 52 and 68°S, respectively. The semi-annual variation of pressure over the Antarctic and the spring maximum over the southern South Atlantic combine to make the difference largest in September and October.

Table 5.1: Relative frequency (%) of the magnitude of the sea level pressure difference between Adelaide Island and Fossil Bluff (distance 400 km), in four sections of the year 1968. Observations for 00 and 12a; data for the last eleven days of December missing. A value of 10 mb corresponds to a geostrophic wind component of 28 knots; assumed density 1.27 kg m^{-3}.

	n	≤ - 12.0	-11.9 to -8.0	-7.9 to -4.0	-3.9 to +3.9	4.0 to 7.9	8.0 to 11.9	≥ 12.0	mb
Nov. to Jan.	162	-	2	8	80	9	<1	-	%
Feb. to May	242	-	1	17	76	5	<1	-	%
June to Aug.	184	<1	2	12	64	16	5	<1	%
Sep. and Oct.	122	<1	1	10	52	26	7	4	%
Jan. 1 to Dec. 20	710	0.3	1.4	12.3	70.2	12.4	2.6	0.8	
zonal geostrophic wind component		from E				from W			

Extreme values June 26 : - 19.5 mb ≈ 55 knots

Sept. 28 : + 16.9 mb ≈ 47 knots

6. Terrain effects at the west side of the Antarctic Peninsula

a) Northern half of Marguerite Bay

In the introduction, the possibility was mentioned that at sea, not more than a few kilometers from the coast, the winds can differ drastically from those observed at a coastal station. That is true not only for the strong off-shore winds which dominate the surface wind regime along the major part of the Antarctic continent's coast. It is also found in the neighborhood of the Peninsula when broad streams of air move toward the mountainous land. As far as the barrier winds along the east coast are concerned, the paper reprinted in Appendix A contains the explanation. Another type of terrain effect, one for which the pronounced static stability of the boundary-layer is a contributing but not a decisive factor, can be seen in the wind records of the British station on Adelaide Island, in operation 1962-1975. The station is located at the SW tip of the island which extends 144 km from SSW to NNE, with a width of less than 50 km (see Fig. 6.1); the main mountain range has crest heights between 1500 and 2800 m (Bryan 1965). As a consequence of such topographic conditions, the winds, in particular the strong winds, show a directional distribution which could never be found on the open sea. As Fig. 6.2a indicates for the winter half of 1968, winds from 350° are by far the most frequent ones in two classes of speed, >20 and >30 knots. About 14% of the total time (April to September, 1968), the winds at ADE are >30 knots and from the narrow sector 335 to 005°. Nothing remotely comparable occurs in the eleven other 30° sectors of the wind rose. The decline in frequency of strong winds and in the average speed of all winds from 350° to 010° is spectacular.

The overall wind pattern of ADE as shown in Fig. 6.2a) can be understood as the combined effect of several factors:

a) The frequent presence of relatively low sea-level pressure over the Bellingshausen Sea, where in latitudes north of 68° S the average ice cover is considerably less than over the Weddell Sea, particularly in fall and spring.

b) The appearance of a moderate form of barrier effect which steers air masses approaching the Peninsula from the W to the right, toward SE and S. Since pronounced static stability (temperature in the boundary-layer increasing with height) is a requirement for the development of strong

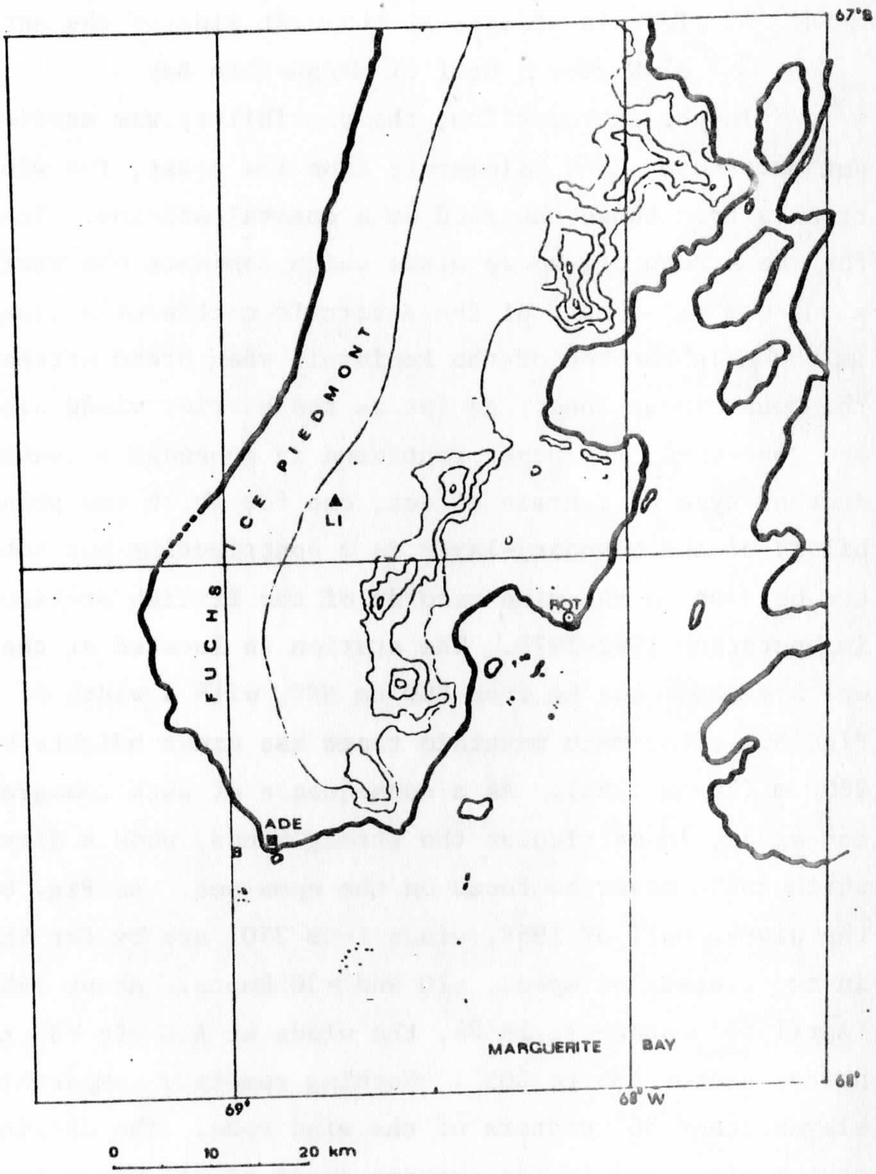


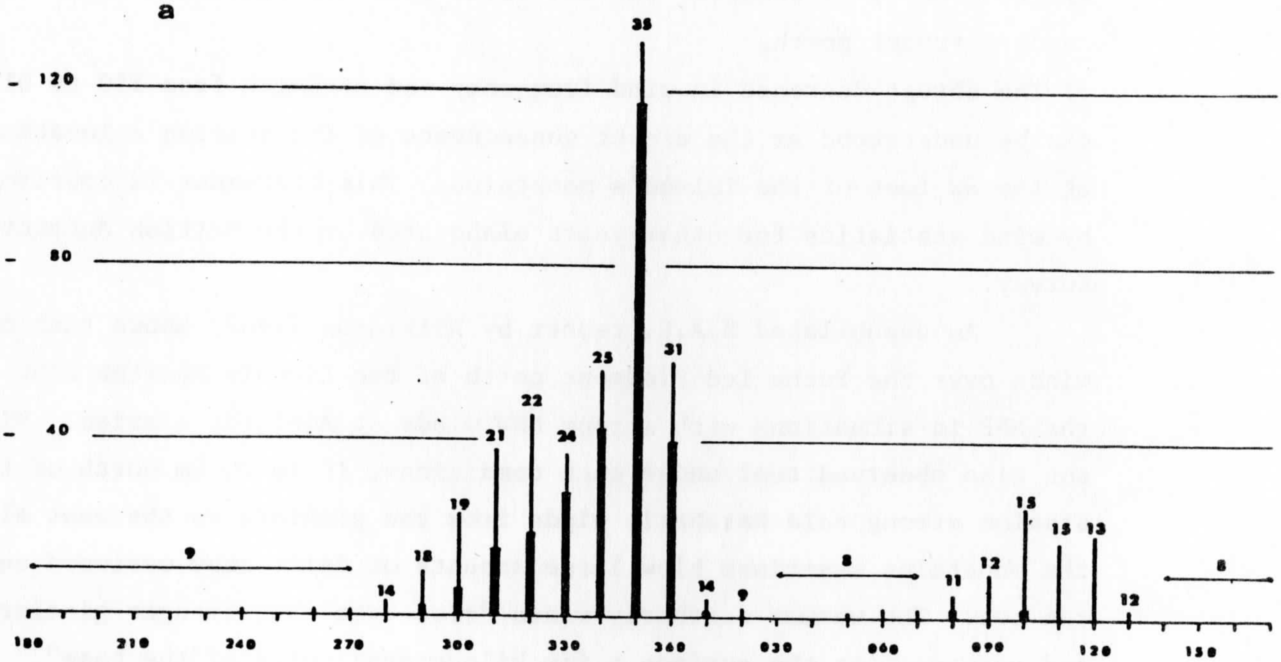
Fig. 6.1: Outline of Adelaide Island south of 67°S, and adjacent land and islands to the west. The thin lines, drawn only for Adelaide Island, are contour lines of 500, 1000, 1500, and 2000 m above sea level.

ADE = Adelaide station (88958, 1961-76).

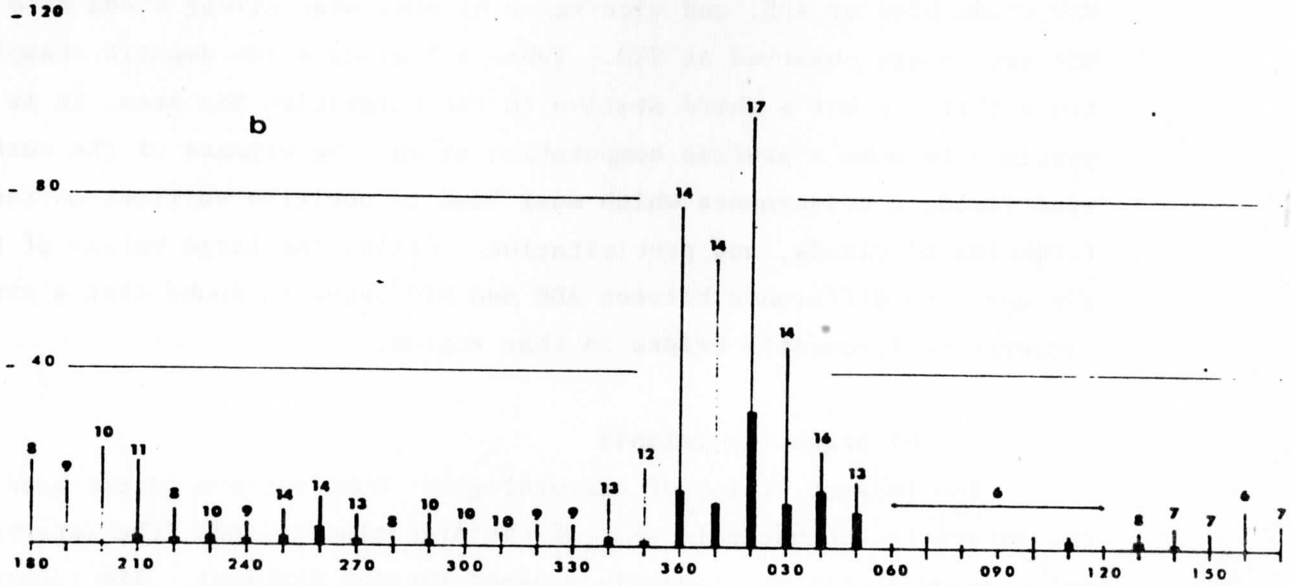
ROT = The new station Rothera (89062, since 1977, 67°34'S, 68°07'W, 15 m).

LI = Lincoln Nunatak, mentioned in the text.

Fig. 6.2



a) Station ADE, 1961-76, located at SW corner of Adelaide Island: Frequencies of winds >20 and >30 knots per direction, April to September 1968. Total number of three-hourly observations: 1456. Heavy vertical line: frequency of speeds >30 knots; from base-line of the graph to top of thin line the same for >20 knots. Above each vertical column: average speed for all observations with direction as indicated below.



b) Station ARG: the same as above, but for frequency classes ≥10 and ≥20 knots. Total number of observations: 1462.

barrier winds, it must be assumed to be particularly efficient in the winter months, or whenever the ice cover over the Bellingshausen Sea extends farthest north.

c) The abrupt decrease in wind frequency and strength from 350 to 010° can be understood as the direct consequence of the station's location at the SW foot of the island's mountains. This statement is confirmed by wind statistics for other years elaborated by the British Antarctic Survey.

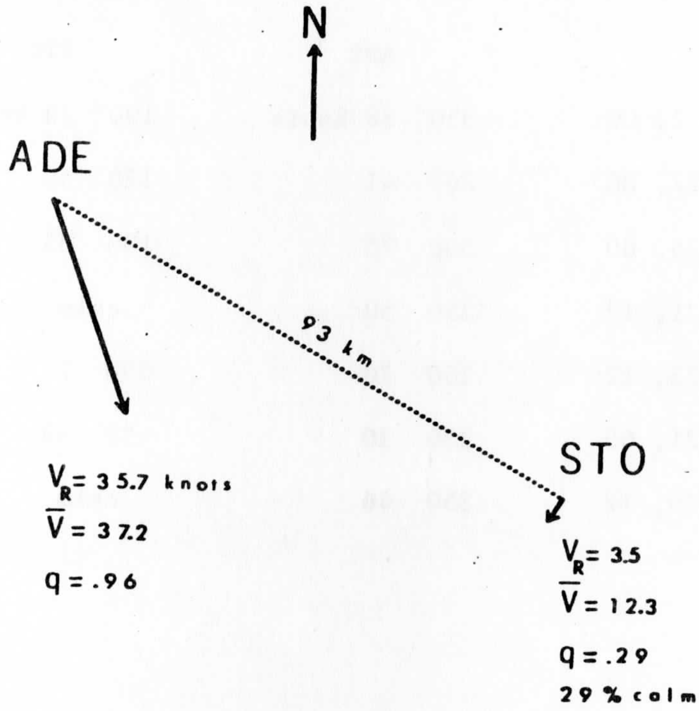
An unpublished B.A.S. report by Wilkinson (1967) shows that the winds over the Fuchs Ice Piedmont north of the Lincoln Nunatak blow from the NNE in situations with strong NNW winds at Adelaide station. Wilkinson also observed that under such conditions, 10 to 20 km north of the station strong cold katabatic winds from the glaciers on the west side of the mountains sometimes blow large amounts of drift snow westward out to the sea. The warmer northerly winds "rise over the stronger glacier winds and reappear [at the surface a few kilometers] north of the base".

Another interesting feature in the northern part of Marguerite Bay is the discrepancy between winds at the SW-corner of Adelaide Island and those observed at Stonington Island, where either calm conditions or strong easterlies, often of the foehn type, are most frequently observed. By means of resultant wind vectors and their directional constancy q, Fig. 6.3 shows what happens at STO, only 93 km to the ESE, when strong NNW winds blow at ADE, and vice versa at ADE, when strong winds from the ESE sector are observed at STO. Table 6.1 gives a few drastic examples. Since there is not a third station in the Marguerite Bay area, it is not possible to make a precise computation of the convergence of the surface wind field, a convergence which must lead to positive vertical motion, formation of clouds, and precipitation. Still, the large values of the average wind difference between ADE and STO leave no doubt that a strong convergence frequently exists in that region.

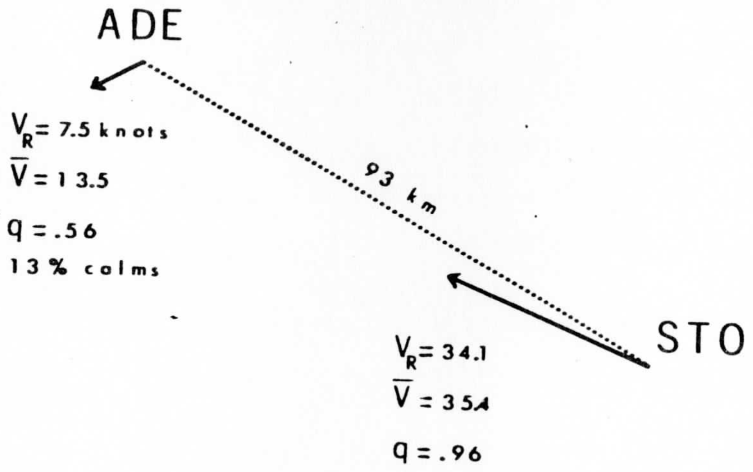
b) Argentine Islands

The longest series of meteorological observations in the area of the Antarctic Peninsula is that of the Argentine Islands (the meteorological station itself was recently renamed Faraday Station). Its record is uninterrupted since February 1947. The site and its surroundings were

Fig. 6.3: Wind changes between Adelaide and Stonington Island; distance: 93 km. April through September 1968, 00 and 12 z; total number of observations available for STO: 333.



a) Resultant wind at ADE for all 77 observations of winds >20 knots from 300-360°, and for simultaneous observations at STO. Average wind difference between ADE and STO: 27 knots.



b) Resultant wind at STO for all 77 observations of winds >20 knots from 080-130°, and for simultaneous observations at ADE. Average wind difference between STO and ADE: 30 knots.

The equality of the number of observations in a) and b) is accidental.

Table 6.1: Some cases of extremely large differences between simultaneous wind observations of ADE and STO, winter half of 1968.

	ADE	STO
June 2, 00z	350° 38 knots	190° 20 knots
June 27, 00	360 41	120 40
July 16, 00	300 25	100 35
July 21, 12	350 50	calm
July 23, 12	350 70	090 22
Aug. 21, 00	330 30	130 55
Sept. 20, 12	350 46	calm

described by Pepper (1954), and later changes by Sadler (1968). Naturally, the surface and upper air observations are of great importance for climatologists as well as synopticians. However, the protected location of the station makes the correct interpretation of the surface winds highly problematic (Schwerdtfeger 1959). The frequency of moderate and strong winds and the mean speed of all winds, both per direction, are shown for the winter half of 1968 in Fig. 6.2b). In the summer, the prevalence of weak winds is greater still. Note the remarkable contrast between stations ARG and ADE. In Fig. 6.2b) the vertical columns refer to the wind classes >10 and >20 knots, while those in Fig. 6.2a) for ADE refer to >20 and >30.

In fact, the surface winds at ARG are often so weak, variable, or in apparent disagreement with the sea level pressure field, that synopticians tend to disregard them entirely. Still, for winds of more than 10 knots, recorded in a 37% of all observations April to September 1968, there is already a remarkable prevalence of winds from the 360 to 050° sector, and for speeds >20 knots, 85 of a total of 107 occurrences belong to that sector. It therefore appears worthwhile to investigate the relationship between strong horizontal pressure gradients and the surface wind at ARG.

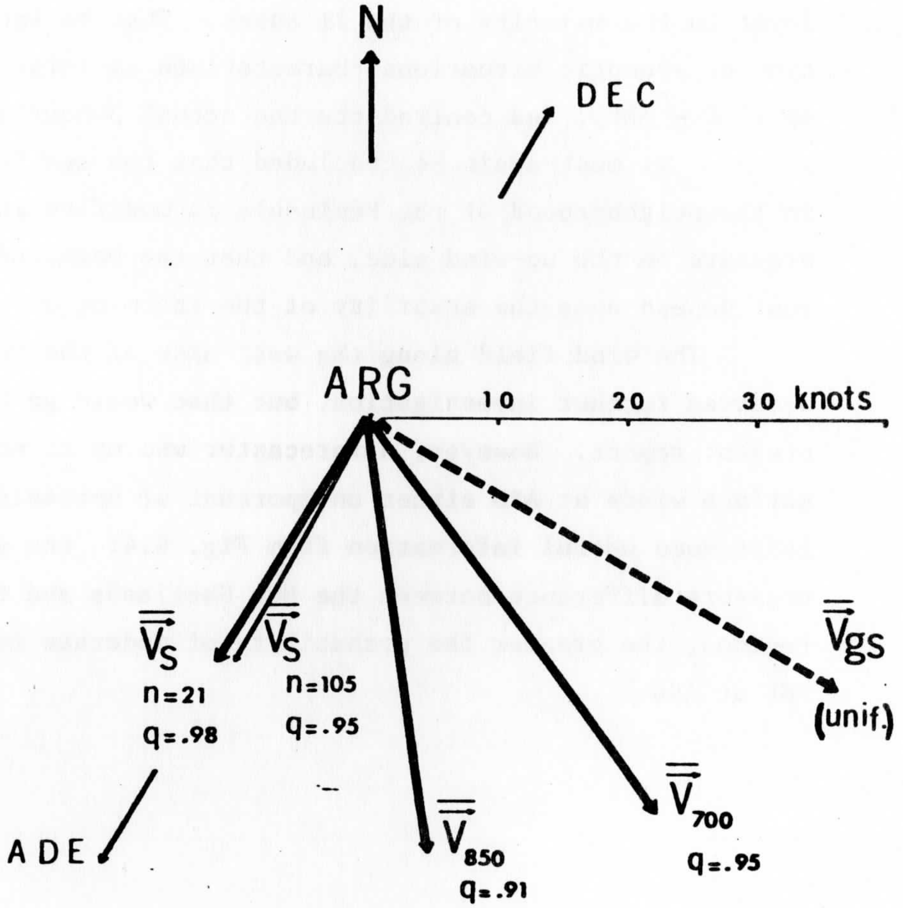
Since there are no synoptic observations available for the Bellingshausen Sea, only one component of the horizontal pressure gradient force can be determined with reasonable certainty, that is, between Deception Island (DEC) and the station ADE, 658 km to the SSW. Station ARG lies very close to the great circle through DEC and ADE, 350 km NNE of the latter. When the pressure difference between two stations and hence the geostrophic wind component in the direction perpendicular to the great circle trough both is very great, then it is highly probable that the second (in our case unknown) component is comparatively small. Otherwise, the magnitude of the geostrophic wind vector would become unreasonably large. This logical consideration is based, however, on the assumption that the pressure field between the two end-stations is uniform and not disturbed by mountainous terrain in between. The importance of that reservation will be shown in the following.

From all 3-hourly observations of the three winter half years 1965, 66, and 67, only those cases in which the pressure difference DEC - ADE amounted to 20 mb or more have been selected. For the winter of 1968, used in other parts of this report, the necessary data for Deception were not available because Nature discontinued the three meteorological stations on that island in December 1967 (Polar Record, 1968; Baker 1968). The average pressure difference for the 105 selected cases is 23.7 mb, corresponding to a geostrophic wind component of 42 knots, at a mean density of 1.27 kg/m^3. The direction of this component, from 300°, may be considered as the most probable direction of the average geostrophic wind vector for a uniform, undisturbed pressure field between DEC and ADE. The vector average and the directional constancy of the simultaneous surface wind values at ARG have been computed. The result, shown in Fig. 6.4, is that the resultant wind is almost exactly at a 90° angle to the direction of the above defined mean geostrophic wind. It is obvious that the resultant surface wind vector at ARG cannot be explained as due to an equilibrium state between a uniform DEC to ADE pressure gradient, Coriolis, and frictional forces. It must rather be concluded that the fast flow of air toward the mountain wall of the Peninsula leads to a modification of the horizontal pressure field, a deflection of the streamlines to the right hand side, and thus to ageostrophic wind components. This type of flow is an analog to the barrier winds on the east side of the Peninsula, discussed in earlier chapters and the Appendix, but different insofar as the static stability of the boundary layer of the air masses on the west side of the Peninsula is much smaller, and the speed of their motion (in the selected cases) much greater, than on the east side.

Some proof can be offered for the effect of the flow toward the mountains on the sea level pressure field. For that purpose, the average difference has been determined between the pressure values at ARG computed by linear interpolation between DEC and ADE, and the actually observed pressure values of ARG, for all 105 cases. That average difference amounts to 3.5 mb ($\sigma = 2.3$ mb), and increases to 6.3 mb ($\sigma = 2.1$ mb) for those 12 cases in which the surface temperature at ARG was 5° or more below the average temperature for the 105 cases.

Further proof can be gained from the upper air soundings at ARG. There are 21 days with Δp (DEC - ADE) $\geq$ 20 mb on which a sounding was made within ± 6 hours of the reference time. The vector wind averages at surface, 850 and 700 mb for these 21 cases are also shown in Fig. 6.4. There is an obvious discrepancy between the directions of $\vec{V}_{850}$ which is based

Fig. 6.4



Resultant wind at ARG when Δp(DEC - ADE) ≥ 20.0 mb.
Direction DEC to ADE = 030 to 210°; distance 658 km.

$\overline{\Delta p}$ for 105 cases (April-Sept. 1965-67) = 23.7 mb ≈ $\overline{|\vec{V}_{gs}|}$ = 42 knots at density $\bar{\rho}$ = 1.27.

$\overline{\Delta p}$ for 21 cases with upper winds (same period) = 23.8 mb.

$\overline{\vec{V}}_s$ = resultant surface wind;

$\overline{\vec{V}}_{gs}$ = geostrophic wind at sea level in uniform, undisturbed pressure field;

$\overline{\vec{V}}_{850}$ and $\overline{\vec{V}}_{700}$ = resultant winds at 850 and 700 mb level, respectively;

n = number of cases;

q = directional constancy of the winds.

on observations, and $\vec{\bar{V}}_{gs}$ which is derived under the assumption of an uniform, undisturbed pressure field between DEC and ADE. The turning of the geostrophic wind from 300° at the surface to 352° at 850 mb would imply the existence of strong cold-advection in the surface to 850 mb layer in the majority of the 21 cases. That is incompatible with the type of synoptic situations characterized by large positive values of Δp (DEC - ADE), and contradicts the actual 3-hourly temperature records of ARG. It must again be concluded that the sea level pressure field in the neighborhood of the Peninsula is modified in the sense of higher pressure on the up-wind side, and that the magnitude of this modification must depend upon the stability of the incoming air masses and their speed.

The wind field along the west side of the Peninsula certainly deserves further investigation, but that would go beyond the scope of the present report. However, a forecaster who up to now has considered the surface winds at ARG either unimportant or unpredictable, can derive at least some useful information from Fig. 6.4: the greater the positive pressure difference between the New Shetlands and the Adelaide Island regions, the greater the probability of moderate to strong winds from the NNE at ARG.

7. Acknowledgments

Copies of the synoptic observations of the Argentine Antarctic stations used in this study were made available by the Servicio Meteorológico de la Armada, República Argentina. Mr. D.W.S. Limbert, British Antarctic Survey, helped with valuable information regarding the British stations. Copies of the original records of the American Expeditions of 1940/41 and 1947/48 were obtained through Mr. G. Pagano of the Center for Polar and Scientific Archives, Washington, D.C. The first-named author's work was supported by the National Science Foundation, Grant DPP77-04506. All this generous help is gratefully acknowledged.

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APPENDIX

Reprinted from MONTHLY WEATHER REVIEW, Vol. 103, No. 1, January 1975, pp. 45–51
American Meteorological Society
Printed in U. S. A.

The Effect of the Antarctic Peninsula on the Temperature Regime of the Weddell Sea

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(Manuscript received 1 August 1974)

ABSTRACT

Theoretical considerations as well as observational evidence lead to the conclusion that the frequent, strong, southerly and southwesterly surface winds along the east coast of the Antarctic Peninsula do *not* necessarily indicate the presence of a low-pressure system in the central Weddell Sea. Such winds can, and frequently do, develop when cold air masses with a pronounced surface inversion move westward over the ice-covered sea and find their way blocked by the mountains of the Peninsula. Consequently, much colder air is found east of the mountain than on their west side. For the six months of fall and winter, the average west–east surface temperature difference amounts to 12°C at 65°S. The feedback mechanisms between the surface winds in the western and northern Weddell Sea, the resulting drift of ice, and the temperature regime of the entire Weddell Sea area are examined.

1. Introduction

The combination of two distinct climatic characteristics is instrumental in making the Weddell Sea a highly efficient source region of ice and cold water. First, the region of the Weddell Sea is the coldest part of the entire coastal belt of the Antarctic continent. Second, along the east side of the Antarctic Peninsula there exists a surface wind regime which favors a strong drift of ice masses toward lower latitudes. It therefore appears appropriate to ask how such a particular temperature regime and the related surface layer circulation pattern originate, how they are maintained, and how the feedback mechanism between low temperatures and the wide extension of the ice cover really operates.

Over the Weddell Sea south of about 70°S, surface winds with an east-to-west component prevail (Taljaard *et al.*, 1969; van Loon *et al.*, 1971); between 70° and 65°, easterly and westerly flow components are of approximately equal frequency; farther north, westerly winds predominate. On its west and northwest side, the Weddell Sea is confined by the Antarctic Peninsula, a high, narrow mountain ridge which projects from the west-Antarctic mainland north and then northeastward up to 63°S (see Fig. 1), that is, to a much lower latitude than any other Antarctic land mass. In this aspect the Weddell Sea differs essentially from the Ross Sea, whose western confinement ends at about 71°S. Hence, the mountain ridge of the Antarctic Peninsula much more than any other northward extension of the continent presents a formidable obstacle to air masses advancing from the east or southeast; indeed, it must act almost as a limiting solid wall to the extremely stable air masses which normally are found in the lowest 1000 m over the ice-covered Weddell Sea during most of the year. When a west- or northwestward directed flow approaches this wall, it is deflected to the north and northeast, advecting colder air from higher latitudes and exerting the stress which drives the ice toward lower latitudes and into the eastward current of the subpolar South Atlantic.

2. The low temperatures of the Weddell Sea area

Better than any lengthy explanations, Table 1 gives a clear picture of the comparably severe temperature regime of the Weddell Sea area. SANAE-station, at 2.4°W, is here included in the Weddell Sea group because its temperature regime is essentially affected by the pack-ice belt originating farther to the west, as will be shown later. The only high latitude station near sea level with a noticeably lower mean annual temperature than that of any Weddell Sea station is Little America (78.6 to 78.2°S); its record of seven years of operation (1911, 1929, 1934, 1940, 1956–58) gives $\bar{T} = -25.5°C$[1]). The low temperatures of Matienzo and Snow Hill are of particular interest. Matienzo is a station of the Argentine Air Force, in operation since 1962; Snow Hill is the historic place where Nordenskjöld's Swedish South Polar Expedition was forced to stay for almost two years, 1902–03 (Nordenskjöld, 1911). Its meteorological observations have been elaborated and published in full detail by Bodman (1910).

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[1] The mean monthly temperatures May–November and the annual average given for this station by Schwerdtfeger (1970) are erroneous.

TABLE 1. Average annual temperatures at stations in the Weddell Sea sector and other parts of the coastal belt of Antarctica in comparable latitutes (n = number of years of record).

Weddell Sea sector				Other parts of the coastal belt			
Station	Lat.	T	n	Station	Lat.	T	n
Belgrano	78.0	−22.2	16				
				McMurdo	77.9	−17.3	17
Halley Bay	75.5	−18.8	17				
Sanae	70.5	−17.4	16	Hallett	72.3	−15.3	8
Matienzo	65.0	−12.1	11	Argentine Islands	65.3	− 5.2	27
Snow Hill	64.4	−11.5	2	Melchior	64.3	− 3.7	14
Hope Bay	63.4	− 6.2	16	Deception	63.0	− 2.8	23
Orcadas	60.7	− 4.3	69	Bellingsh.	62.2	− 2.8	6
S. Georgia	54.3	1.8	68	Macquarie	54.5	4.7	25

The very strong, very cold SSW winds at Snow Hill were far beyond anything Nordenskjöld's people had expected to find this side of the polar circle. At first, Bodman thought that it was a specific local effect in combination with an exceptional year which produced the harsh conditions at Snow Hill; the winter of 1902 was indeed worse than 1903. At the end of the second winter at Snow Hill, Nordenskjöld travelled SSW along the coast up to 66°S, and found essentially the same wind and weather conditions as Bodman observed at the main base. However, it took more than 60 years until, after the installation of Matienzo, it became completely evident that the observations of Snow Hill very well represent the climatic characteristics of the east coast of the Antarctic Peninsula. How far south this region of strong southerly flow extends, is unknown as of today. The southwest corner of the Weddell Sea still remains one of the most inaccessible, meteorologically unexplored regions of the world. There is only one short record of wind and temperature observations for Cape Keller (68.9°S, 63.2°W, 20 m); it was obtained by a group of Ronne's Expedition in October and November of 1947 after a traverse across the mountains from Stonington Island on the west side of the Peninsula (Peterson, 1948). The results have been summarized by Schwerdtfeger *et al.* (1959, p. 195, Table 62). The most frequent and strongest winds were from the south; the mean temperature (all observations) was 6°C lower than it was in the same period at Stonington Island. It is important to note that at the latitude of Cape Keeler where the mountains of the Peninsula extend from south to north, the prevailing strong surface winds are from the south. Farther north where the mountain range turns toward northeast, these winds also turn, blowing predominantly from the southwest.

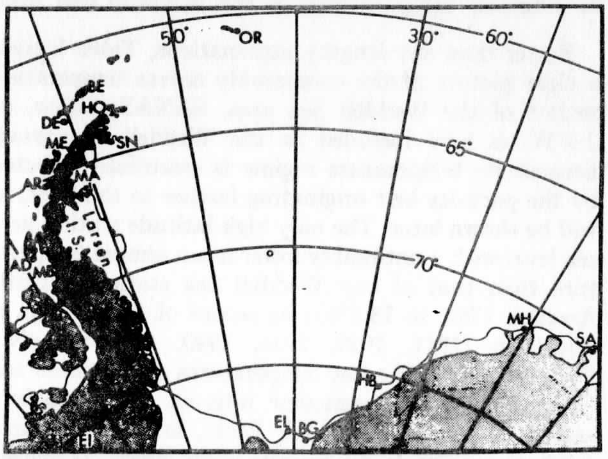

FIG. 1. Antarctic Peninsula and Weddell Sea area. Stations mentioned in the text: AD = Adelaide Island; AR = Argentine Islands; ME = Melchior; DE = Deception Island; BE = Bellingshausen; MA = Matienzo; SN = Snow Hill; HO = Hope Bay/Bahía Esperanza; OR = Orcadas; SA = SANAE; HB = Halley Bay; BG = Belgrano. The small circle in the midst of the Weddell Sea indicates the average position May–July 1912 of Filchner's ship *Deutschland* drifting in the ice.

Figure 2 shows the striking contrast between the two sides of the Antarctic Peninsula. The west coast has the mildest (and wettest) climate of the Antarctic. Adelaide station at 67.8°S has a slightly higher mean annual temperature than any coastal station at lower

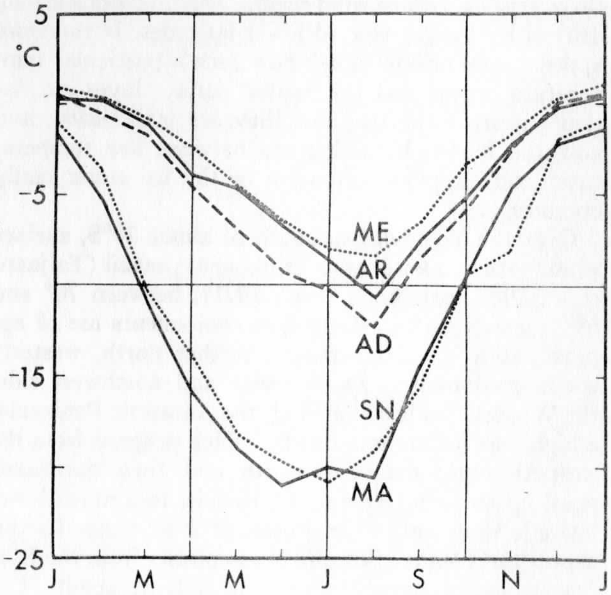

FIG. 2. Mean annual march of temperature at two stations (MA and SN) on the east coast, and at three stations on the west coast of the Antarctic Peninsula. Locations and abbreviations shown in Fig. 1.

TABLE 2. Surface wind Statistics, month of May, for stations west and east of the Antarctic Peninsula (speeds in m/s).

	West side			East side		
Station	AD	AR	ME	MA	SN	HO
Latitude (°S)	67.8	65.3	64.3	65.0	64.4	63.4
Longitude (°W)	68.9	64.3	63.0	60.0	57.0	57.0
Elevation (m)	25	11	8	32	12	10
Record used	1966–70	1966–70	1947–56	1962–67	1902–03	1945–48
Direction of resultant wind (°)	034	071	154	227	215	227
Magnitude of resultant wind	2.3	0.8	0.7	6.1	6.4	4.1
Mean wind speed	5.1	3.1	3.3	7.0	8.2	6.5
Directional constancy	0.45	0.25	0.20	0.87	0.78	0.63
Relative frequency of calms (%)	16	27	37	35	20	11
Mean speed of SW winds	*	*	*	13	15	10

* Not evaluated.

latitude in other sectors of the Antarctic. At Argentine Islands, winter months with mean temperatures below −15°C are found only seldom (1958 and 1959 were such years), when the ice cover of the Bellingshausen Sea extends exceptionally far north and northeast. About 200 km to the eastnortheast, on the east side of the climatic divide, Matienzo and Snow Hill are colder than many stations at considerably higher latitude, as Dumont D'Urville at 67.7°S with −11.0°C, or Novolazarevskaja at 70.8°S with −10.8°C.

Understandably, the surface wind regimes along the two flanks of the Peninsula also differ strongly. As will be shown in the following section, the damming-up of stable cold air, occurring whenever the low-level flow over the western Weddell Sea is directed toward the mountain wall of the Peninsula, decisively affects the atmospheric motion field near the surface east of the mountains and thus also the drift of the ice and water masses. Assessing the ice conditions of the Weddell Sea, Capurro (1955, p. 103) writes: "The maximum ice pressure takes place on the western side of the Weddell Sea where the ice set in motion by the action of the wind and the ocean currents is impeded in its free movement by the Antarctic Peninsula, developing therefore great ice pressures. Shackleton's 'Endurance' and Nordenskjöld's 'Antarctic' were destroyed on the western side of the Weddell Sea." Observational evidence regarding the surface winds is given in Table 2, indirectly also in Table 4. In Table 2, only data referring to the month of May have been compiled in order to keep the climatological statistics at the necessary minimum. The directional constancy of the surface winds at Matienzo and Snow Hill is remarkably high. The April, June, and July data are very similar. Slightly different general conditions exist in the later months of the cold season, when the subpolar low pressure trough (at sea level) frequently is located a few degrees of latitude farther south than in the rest of the year. It may be noted that the cold SW winds in the Matienzo region, which often are accompanied by heavy snowfall (Bodman, 1910), are definitely not of the katabatic type. Katabatic winds east of the Peninsula must always be relatively warm (foehn) winds, because the air masses at the level of the narrow mountain ridge have practically always a much higher potential temperature than the air at the Weddell Sea coast. This can be proved by the temperature soundings of the Argentine Islands station; see Table 3. In the winter months, the resultant wind at this station at 1200 m above sea level (850 mb) is from 340°, 2 m/s, constancy 0.25.

3. The damming up of stable cold air along the east coast of the Peninsula

Information regarding the vertical structure of the lowest thousand meters of the atmosphere over the central Weddell Sea during the winter months is available from the aerological ascents made during the drift of the "Deutschland" in 1912 (Barkow, 1913 and 1924). In the three months May–July, when the ship drifted in the ice from about 72.3°S, 40.8°W to 67.8°S, 45.3°W, 50 soundings were carried out, 39 by kite and 11 by captive balloon; 27 ascents reached at least the 1000-m

TABLE 3. Average temperature in the lower troposphere over Argentine Islands, month of May and winter half-year (April–September), 1955–63.

	May			April–September		
Pressure level (mb)	Height (m)	Temperature (°C)	Potential temperature (K)	Height (m)	Temperature (°C)	Potential temperature (K)
Sfc	11	−5.9	266	11	−8.7	263
900	749	−7.7	274	746	−9.2	273
850	1191	−9.3	277	1186	−10.9	275
700	2669	−17.1	284	2658	−17.8	283

level. The average temperatures as function of height are shown in Fig. 3. The maximum inversion recorded amounted to 19.5°C, 17 June 1912.

Whenever such stable cold air approaches the Peninsula from the east or southeast, it is dammed up along the mountains. A detailed analysis of the dynamics of the resulting flow pattern has been given by Schwerdtfeger (1974), with application to the peculiarities of the wind field north of the Brooks Range in northern Alaska. The following shorter version will refer to the conditions along the west coast of the Weddell Sea: as long as the motion of the air near the surface maintains a component toward the mountains, there must be adiabatic cooling of the rising air. In the late fall and winter months, no heat source is available as long as there is a closed ice cover over the western Weddell Sea. Since at the low temperatures of polar air masses the difference between dry- and saturation-adiabatic lapse rate is small, it becomes irrelevant whether condensation and ice crystal formation occurs or not. In either case, the air on the mountain slopes, a few hundred meters above sea level, must be considerably colder than the air at the same height above the Weddell Sea. It follows that there must be in the lowest layers of the atmosphere a horizontal temperature or thickness gradient directed toward the mountains, and thus a thermal wind $\mathbf{V}_t$ parallel to the mountains; the wind diagram in Fig. 4b shows its direction. When the wind at an upper level is calm, the geostrophic wind at the surface level $\mathbf{V}_{gs}$ is equal in magnitude, opposite in direction to the thermal wind of the layer between surface and upper level. In reality, of course, the wind above the inversion layer can have any speed and direction. For the formation of the typical Snow Hill-Matienzo wind phenomenon, weak upper winds are most favorable; in Fig. 4b, a moderate (in comparison to a strong thermal wind) geostrophic wind ($\mathbf{V}_{gh}$) from the east is assumed to exist above the inversion. The geostrophic wind at the surface level along the coast follows as $\mathbf{V}_{gs}=\mathbf{V}_{gh}-\mathbf{V}_t$. When the undisturbed surface layer flow over the wide Weddell Sea, $\mathbf{V}_{sA}$, is from the east-southeast (lower pressure to the north), it must experience a deflection toward the right when approaching the coast. This turning to the right implies the existence of an advective ageostrophic wind component $\mathbf{V}'$ pointing to the left from the wind difference vector $\mathbf{V}_t=(\mathbf{V}_{gh}-\mathbf{V}_{gs})$. The vector sum $\mathbf{V}_{gs}+\mathbf{V}'$ gives the wind vector at the surface level without friction, $\mathbf{V}$. Finally, the surface friction effect leads again to the deflection to the right so that a surface wind $\mathbf{V}_s$ from the southwest results. It is important to note that the strength of these winds is directly dependent upon the magnitude of the coast-parallel thermal wind, and that this thermal wind must develop whenever the general sea level pressure field over the Weddell Sea leads to a surface level flow toward the Peninsula. It thus becomes evident that the strong, cold southwesterly winds along the east side of the Peninsula can appear precisely when they would not be expected from the large-scale atmospheric circulation pattern. Of course, they can appear also when an intense baric depression lies over the central Weddell Sea. Therefore, the frequent, strong southwesterly surface winds observed at Hope Bay, Snow Hill, Matienzo,

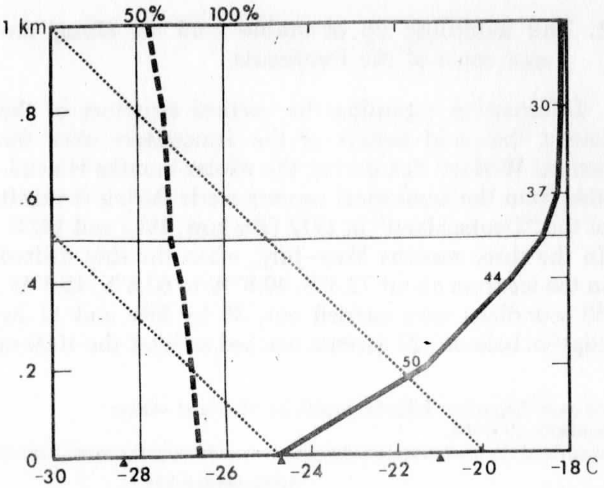

FIG. 3. Average temperature (solid line) and relative humidity (dashed) in the lowest 1000 m over the central Weddell Sea (70°S, 43°W), May–July 1912. The small numbers along the temperature line give the number of soundings reaching the respective height. The two thin, dotted diagonals are dry adiabats. The triangles at the bottom line mark the mean minimum, the mean, and the mean maximum temperature at 2 m above the ice, for all days of the three-months period. Data source: Barkow. 1924.

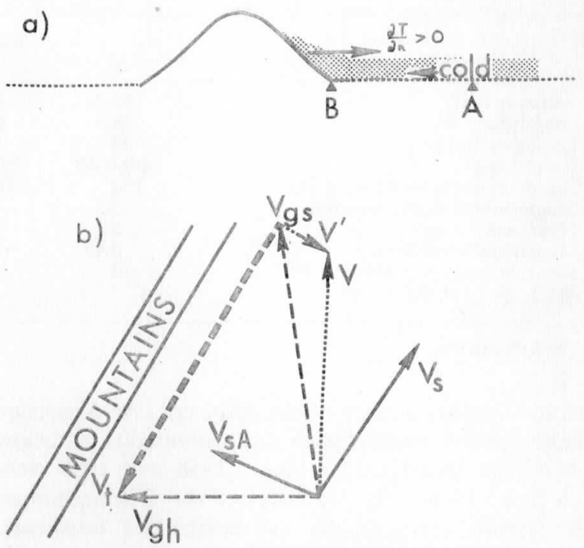

FIG. 4. Schematic illustration of the flow of very stable air (surface inversion) toward and along a mountain range. a) Stratification and horizontal temperature ascendant $\partial T/\partial n$. b) Wind vector diagram: $\mathbf{V}_{sA}$ represents the surface wind over the ice covered Weddell Sea not affected by the mountains. All other wind vectors refer to the coastal region, near point B, and are explained in the text.

TABLE 4. Average meridional sea-level pressure differences, and frequency of an east-to-west geostrophic flow component, over the western Weddell Sea (50°W), between 60 and 75°S, for months with strong temperature deviations from normal at Matienzo (65°S, 60°W). Data sources mentioned in the text.

		Six winter months ΔT < − 2.3°C	Five winter months ΔT > + 2.3°C	Southern Hemisphere Atlas* average (April–Sept.)
Average pressure	60–65°S	1.7	3.9	3.3
differences ΔP	65–70°S	0.1	3.0	1.3
(mb) at 50°W	70–75°S	−1.9	1.1	−1.4
Relative frequency (%)				
of an easterly	60–65°S	39	29	
component of	65–70°S	51	27	
the geostrophic	70–75°S	58	38	
wind at 50°W				
Number of analyzed maps		357	306	

* Taljaard *et al.* 1969.

and on traverses over the Larsen Ice Shelf are ambiguous with respect to the analysis of the sea-level pressure field. This is a serious dilemma which in past years has puzzled synopticians working in that area (Pepper, 1954; Burdecki, 1957).

Another way to look at the strong coast-parallel flow due to the damming-up of very stable cold air would be the following: One can compute the contribution of the air masses below the crest height of the mountains to the total sea-level pressure in the coastal belt and far away from it, with the assumption that the horizontal pressure field at a level above crest height remains essentially unaffected by the flow pattern in the lower layers, for instance, remains a straight westerly stream. In this case one would operate with pressure gradients instead of wind vectors. With reliable pressure data over sea and over the coast one could estimate the height up to which the damming-up of the stable cold air reaches, but such simultaneous pressure observations do not exist. Still, it has been found that relatively high sea-level pressure values of Matienzo do not appear to fit into a smooth isobar pattern suggested the by data of stations located to the west (Argentine Islands, Adelaide Island), north (Deception Island, Bellingshausen), and east-northeast (Orcadas) of the Peninsula. This apparent discrepancy can even be found in the monthly averages of sea-level pressure, in months with strong negative temperature deviations at Matienzo which are also months with frequent easterlies over the Weddell Sea (see Table 4).

4. Pressure gradients over the western Weddell Sea

The conclusion that strong and persistent southwesterly winds can appear along the east coast of the Peninsula *without* the presence of an intense cyclonic disturbance over the central Weddell Sea leads directly to the question whether such conditions occur frequently, or should be considered as exceptional. To answer it, use can be made of the fact that the low temperature averages of the winter months of the east side of the mountains are essentially due to the prevailing cold air advection from south and southwest. The thermal wind roses computed by Bodman (1910) leave no doubt about it; for instance, the mean temperature of the southwesterlies is 4°C lower than the mean at calm conditions, even in the season when insolation is negligible. Consequently, if the mountain effect contributes much to the cold temperature regime of the east side, a clear relationship should exist between the deviations from multi-annual temperature averages and the occurrence of easterly flow over the western Weddell Sea. The results of an examination of this relationship are shown in Table 4, which gives average meridional sea-level pressure gradients and frequencies of negative values of these gradients. Negative values indicate the presence of an easterly component of the geostrophic wind, that is, a flow component toward the mountains of the Peninsula. It becomes evident that in the months with strong negative temperature deviations at Matienzo the frequency of easterly winds over the western Weddell Sea is considerably larger than in the months with temperatures much above normal. We must conclude that the mountain effect on the flow of stable cold air masses decisively influences the temperature and wind regime on the east side of the Peninsula. The statistical evidence condensed in Table 4 is based on the observations of the winter half-years 1968–72 only. Although the temperature records of Matienzo are available since 1962, the twice-daily synoptic analyses of the Australian Bureau of Meteorology, which have been used to determine the pressure gradients along the 50°W meridian, did not permit a daily evaluation of the pressure field over the Weddell Sea in the earlier years. The increase of quality and quantity of satellite information usable for synoptic analysis is quite remarkable since about 1968.

Although this study is mainly concerned with the temperature and wind conditions over the Weddell Sea, a brief digression to the west side of the Antarctic Peninsula is necessary. Since it has been shown in Sections 3 and 4 that the air flow from the western Weddell Sea toward the mountains has a profound effect on the wind regime along the coast, the question must arise if there is a similar effect when westerly or northwesterly flow exists near the surface over the eastern part of the Bellingshausen Sea. The answer is yes, as the resultant surface winds from the NE at Argentine Islands and Adelaide Island (Table 2) indicate. Nevertheless, there is one essential difference. The long series of daily soundings at Argentine Islands shows that the vertical structure of the air in the lower troposphere over the eastern Bellingshausen Sea is much less stable than on the other side of the Peninsula (see Table 3 together with Fig. 2). This makes the thermal wind effect illustrated in Fig. 4 correspondingly weaker, a fact which explains the much smaller values of the magnitude of the resultant wind and the directional constancy of the winds found at the west side stations (Table 2).

5. Temperature and wind regime along the east coast of the Weddell Sea

The stress of the strong southwesterly winds which predominate along the east side of the Peninsula is the main driving force for the transport of pack ice northeastward. As the ice masses advance, they come more and more under the influence of the prevailing westerly winds, north of 65°S. This way, an area of frequent occurrence of large ice fields and correspondingly low surface water temperatures extends far toward the east, identifiable on maps of average ice cover downstream to the 0° meridian, at least. The decrease of the surface water temperature in the latitudinal belt between 60 and 65°S, eastward of about 60°W, is quite pronounced (U. S. Navy, 1965; USSR, 1966). For the air temperature near the surface, the eastward decrease of the annual averages at 60 and 65°S, summarized from the monthly data given by Taljaard *et al.* (1969), is shown in Table 5.

As a kind of "feedback," the existence of this area of cold surface waters has an effect on the temperature regime on the east and northeast flanks of the Weddell Sea, represented by the meteorological stations Halley Bay (75.5S) and SANAE (70.5S). Maritime air masses advected from lower latitudes in the "warm" east quadrant of low pressure systems must pass over the cold belt and are, therefore, losing more heat than comparable air masses at the same latitudes in other sectors of the Antarctic. This explains the relatively low mean temperatures in the northeastern and eastern Weddell Sea. In turn, the colder the air moving near the surface from the east across the Weddell Sea, the more favorable the conditions must be for the development of strong southwesterly winds on the Peninsula side.

There must be, of course, a damming-up effect of onshore moving air masses also on the east- and northeast-coast of the Weddell Sea. On this side, again, the participating air masses are less stable than along its western boundary so that the thermal wind effect, favoring northeasterly winds, becomes less pronounced. Nevertheless, the frequency of such winds a few hundred meters above sea level, as observed at Halley Bay, indicates that the damming-up of onshore winds is still an important feature. In the very lowest layer of the atmosphere along the coast of Coats Land, cold katabatic winds are the dominating flow pattern which produces the well-known open water lead along the coast. The conditions in this area are quite different from those along the Peninsula coast because east and southeast of the Weddell Sea the terrain rises steeply to the vast inland ice of the continent. In contrast, the mountains of the Antarctic Peninsula are only a very narrow wall, and at crest height air masses are advected from the west, whose potential temperature is considerably higher than that of the surface layer east of the mountains.

TABLE 5. Annual average surface air temperature along the parallels 60 and 65°S, between 110°W and 30°E.

Longitude	110°W	90°W	70°W	50°W	30°W	10°W	10°E	30°E
At 60°S	+2.2	+2.2	+2.6	−2.4	−3.9	−3.6	−3.3	−3.0C
At 65°S	−2.8	−2.7	−3.2	−8.6	−8.3	−7.5	−6.8	−6.4C

6. Conclusions

From the foregoing the following general picture emerges: The strong and frequent southwesterly surface winds in the eastern and northeastern part of the Weddell Sea are *not* necessarily an indication of the presence of a sea-level low pressure system in the central Weddell Sea; rather, these winds develop when stable air masses move westward over the ice-covered sea and find their way blocked by the mountainous Antarctic Peninsula. These prevailing southwesterly winds act as a "driving wheel" for the transport of ice masses northeastward. The outflow of ice opens fresh leads which again will soon freeze over; hence, the "freezing potential" in this region must be large. North of about 64°S where westerly winds are more frequent, the ice drift turns to the right, eastward. The result is a relatively cold sector of the southern ocean across which warmer maritime air from the north or northwest must flow before reaching the east coast of the Weddell Sea. Hence, weakened warm advection is responsible for the relatively low temperatures along the east coast (Halley Bay), while intensified cold advection determines the harsh temperature regime of the west coast (Matienzo, Snow Hill). Altogether, then, the presence of the mountainous Antarctic Peninsula with its effect on temperature and motion of the lower layers of the atmosphere is an important factor that contributes to make the Weddell Sea the main ice-producing area of the Southern Hemisphere.

Acknowledgments. Unpublished climatological data for Tte. Matienzo Station were kindly supplied by the Director General del Servicio Meteorológico Nacional, República Argentina, Buenos Aires, and microfilm copies of the daily Southern Hemisphere synoptic analysis were available from the Australian Bureau of Meteorology, Melbourne. Without such basic information the present study would not have been possible. The author's work has been supported by the National Science Foundation, Office of Polar Programs, through Grant GV-28810. All this generous help is gratefully acknowledged.

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