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Synoptic features of the severe winter 1986 at *Arctowski* Station, King George Island, West Antarctica

ABSTRACT: Over the South American sector of the Antarctic Ocean intensive cyclonal activity occurred in turn with meridional circulation, which was a more common feature of winter 1986 than it usually is. At the *Arctowski* Station strong temperature oscillations were observed during the austral winter from May to October. In the end of July the lowest temperature of this winter, −32.3°C, was recorded. In the first half of the winter an easterly air flow prevailed and in the second part — the westerly one. Winds were strong and gusty. The highest speed reached 74 ms^{-1}. Snowfalls were abundant; depth of snow exceeded 100 cm.

Key words: Antarctica, synoptic climatology, air temperature.

Introduction

Pressure field analysis of the South American sector of the Antarctic Ocean allows to distinguish two main tracks of low pressure centers, which in a differentiated manner influence the direction of air flow and weather conditions over the South Shetland Islands (Fig. 1).

One of them, splitting into two branches is directing the lows coming from the South Pacific Ocean into the latitudes between 50 and 55 S, through the Drake Passage towards southeast (track 1 in Fig. 1). Low pressure centers moving along this track pass north of the South Shetland Islands. The other track (track 2 in Fig. 1) leads the lows through higher latitudes, between 65 and 70 S, from over the Bellingshausen Sea, across the Antarctic Peninsula towards east or northeast. The centers moving along each of these tracks result over the South Shetland Islands in different weather, especially as to the wind directions and air temperature.

When an active low is moving from over the Drake Passage towards the South Shetland Islands, it generates over this region an air flow from east and southeast *i.e.* from over the cool basin of the ice-covered Weddell Sea. The weather at the station is then usually frosty, with snowfalls and light variable wind (Fig. 2). Often enough the persisting activity of low pressure

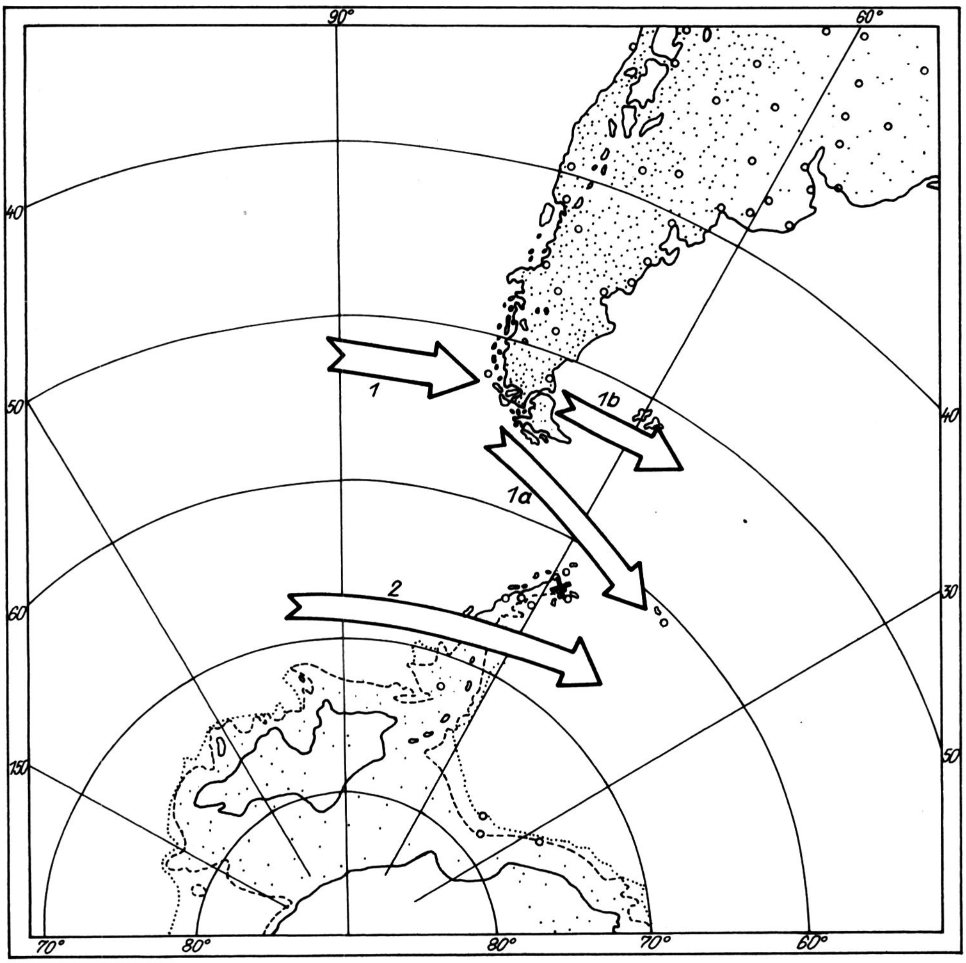


Fig. 1. Tracks of low pressure centers in the region of Antarctic Peninsula in winter 1986 1 — northern track leading low pressure centers through the Drake Passage eastwards and southeastwards; 2 — the southern, more subpolar track forms the route along which low pressure systems move from over the Bellingshausen Sea across the Antarctic Peninsula towards east or east-northeast; X — *Arctowski* Station

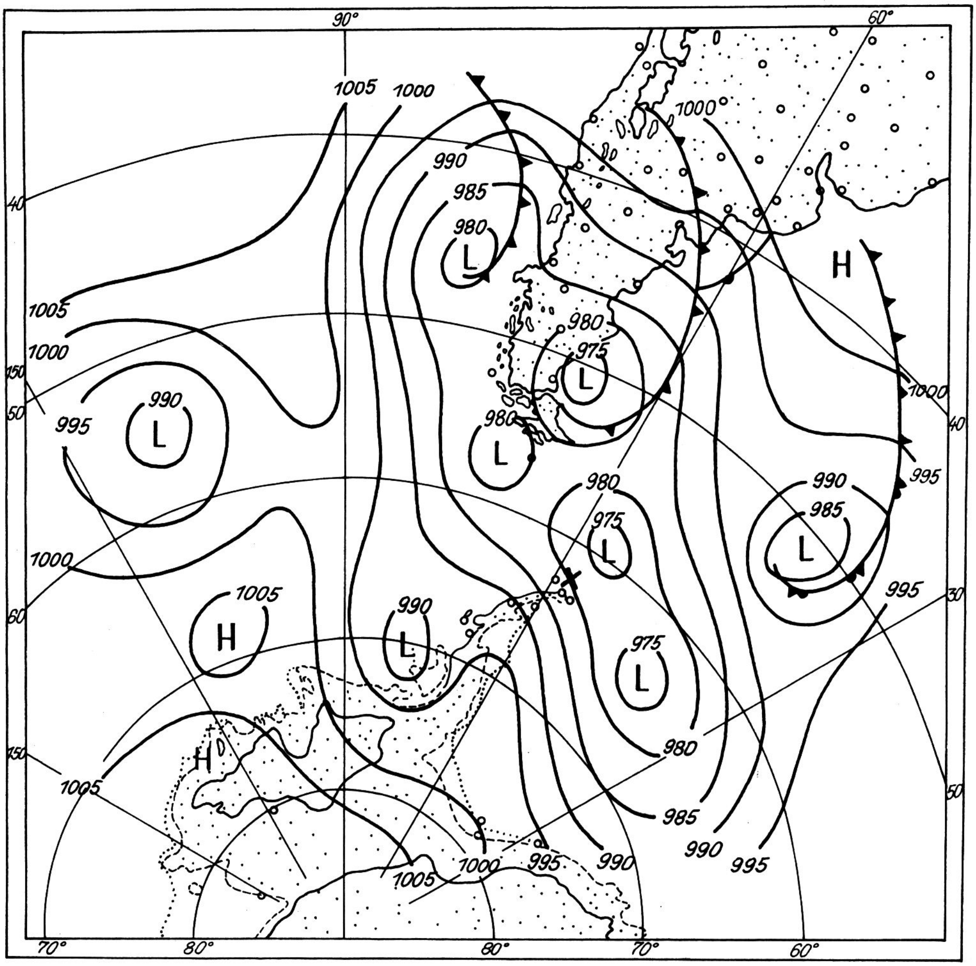


Fig. 2. Pressure pattern on May 27, 1986, 12 UTC (Universal Time Co-ordinated). Family of lows moving along the northern track through the Drake Passage towards south-eaast, caused an intrusion of frosty air from over the Antarctic Continent into the area of Antarctic Peninsula and South Shetland Islands. Such was the beginning of the severe winter 1986 in this region. X — *Arctowski* Station

centers moving along this track, a high pressure ridge from over the Antarctic continent is developing northwards covering the South Shetland Islands. Sometimes this high pressure ridge develops into a weak anticyclone (Fig. 3), giving as an effect low wind speeds and very low air temperatures. Such pressure pattern is favorable for the most frosty spells on the archipelago; they however do not last long.

When low pressure centers develop along the southern track, the South Shetland Islands remain in the warm sector of moving lows. The latter is usually the zone with great pressure gradient, thus the invasion of warmer air is especially intensive (Fig. 4). Therefore usually higher temperatures occur, including thawing conditions, with strong winds from northerly to northwesterly, and westerly to southwesterly directions. At the *Arctowski* Station winds connected with these low pressure centers are an especially

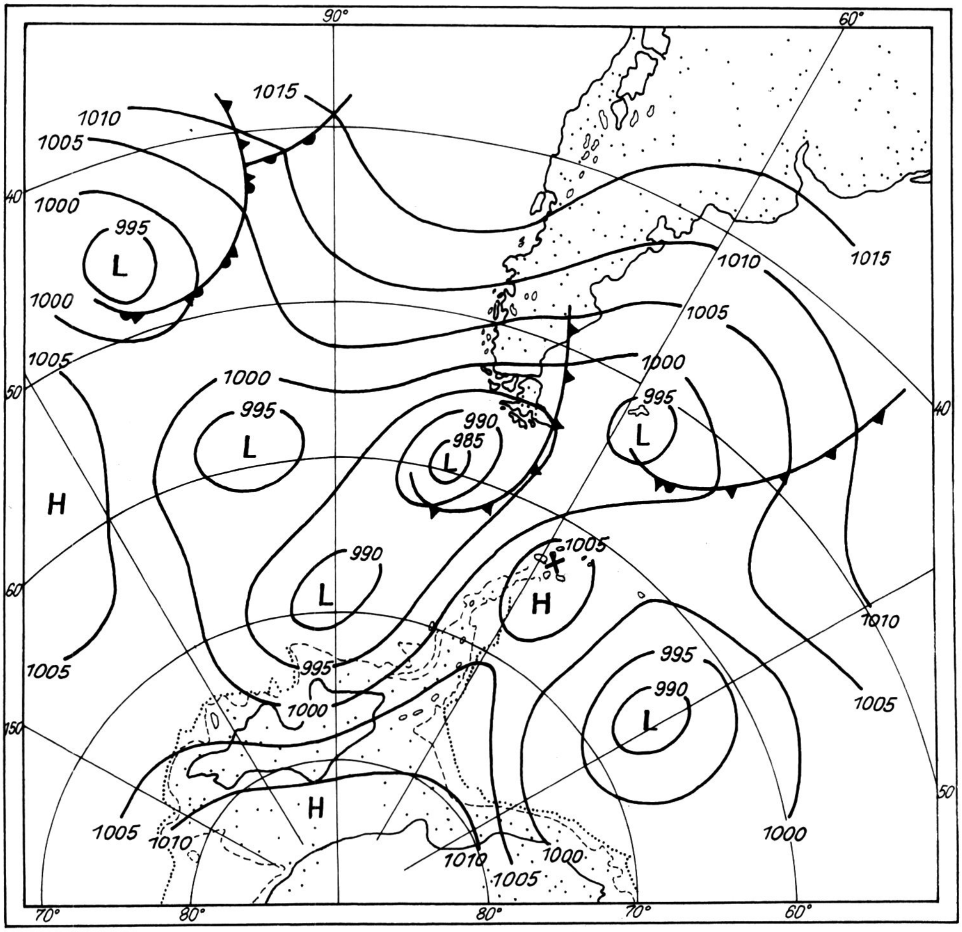


Fig. 3. Pressure pattern on 23 July, 1986, 12 UTC. Ridge of high pressure from over the Antarctic Continent developed in an independent though weak anticyclone with the center over the South Shetland Islands. Frosty air from over the central part of the Weddell Sea remained over the archipelago. July 23 was the frostiest day in winter 1986 at the *Arctowski* Station

importunate phenomenon due to their gustiness. It is caused by air streams entering the station after having crossed the island crest and the nearby hills, where they receive strongly turbulent structure and violent gustiness (Kowalski 1985, Skrzypczak and Wielbińska 1988).

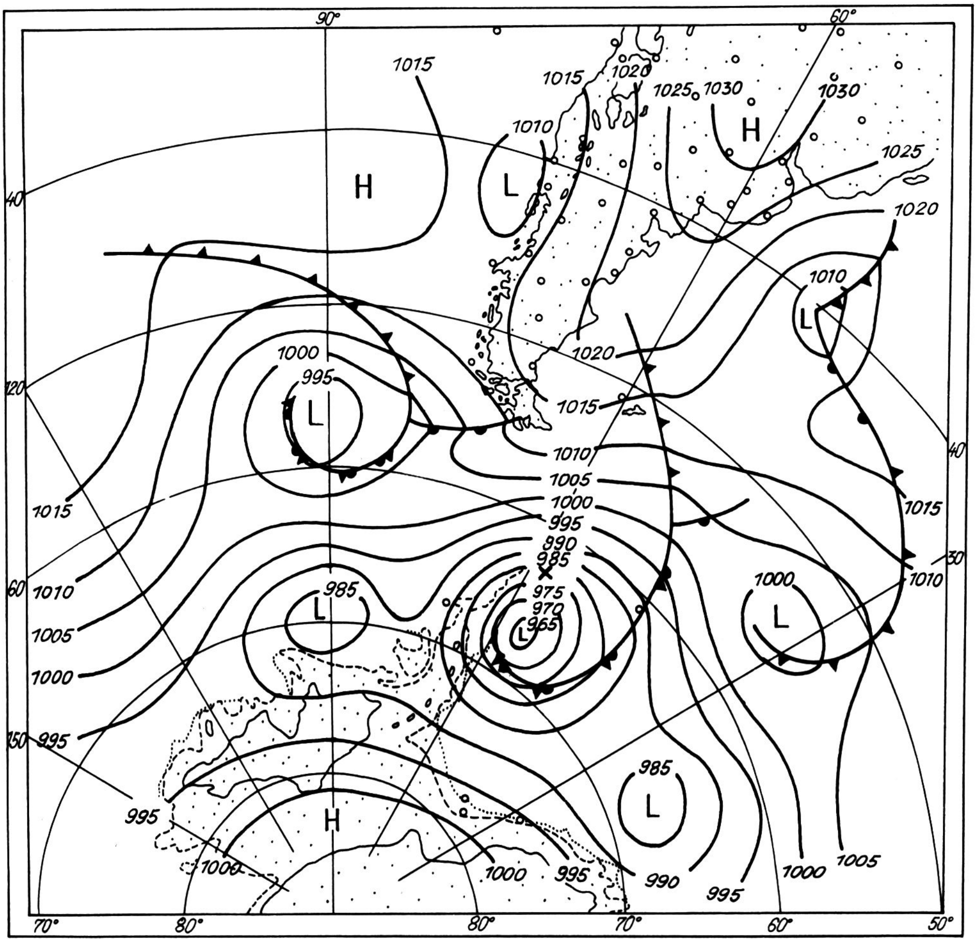
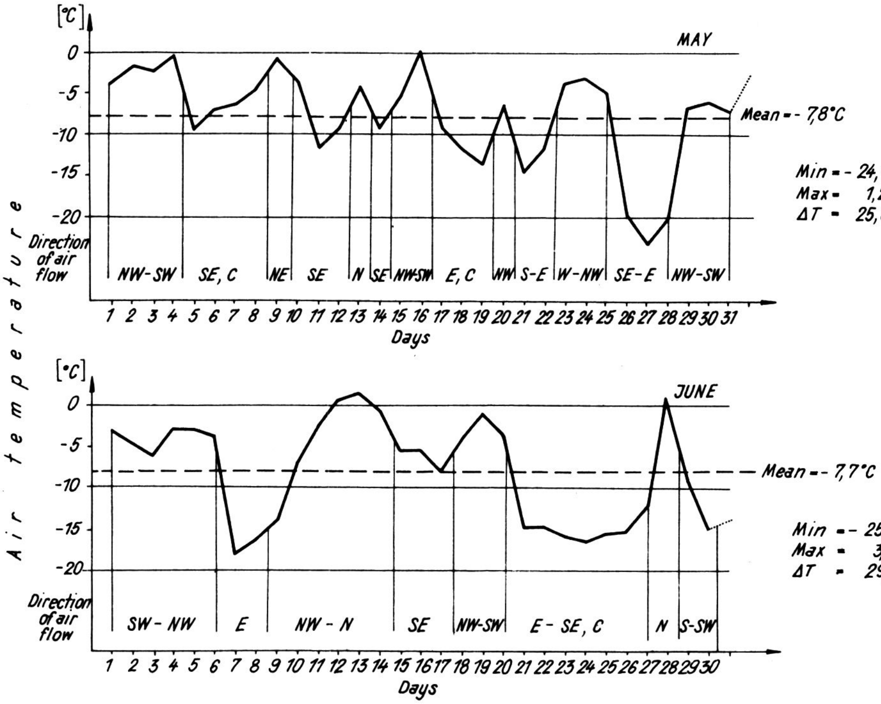
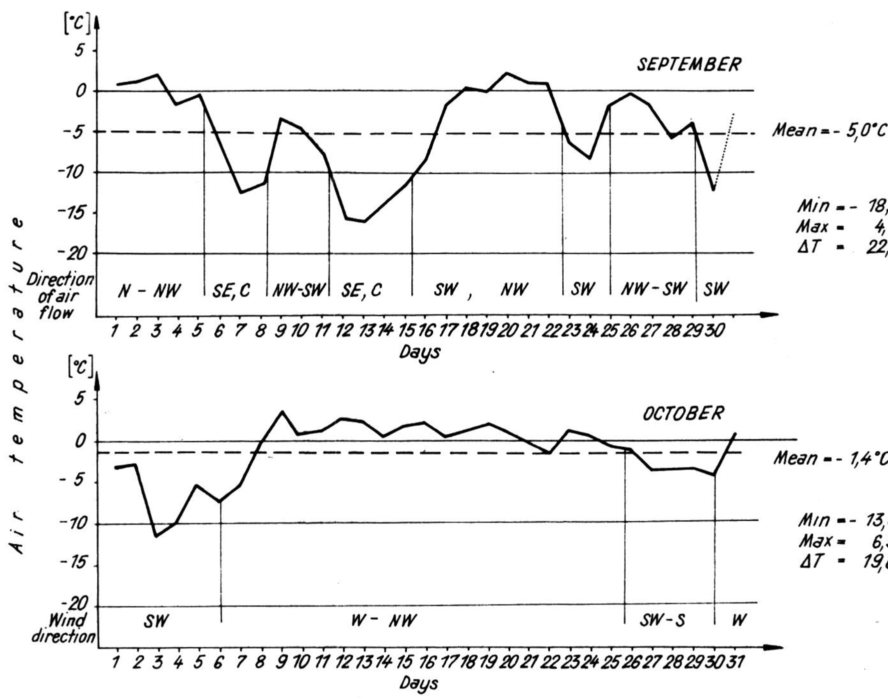


Fig. 4. Pressure pattern on September 4, 1986, 12 UTC. South Shetland Islands stayed for nearly a fortnight in an intense zonal air flow. Main trough of low pressure was oriented along the southern, subpolar track of moving cyclones. One of these cyclones was as deep as 950 hPa in the center. Passage of this low over the South Shetland Islands caused the strongest and gustiest winds during this winter at the *Arctowski* Station. The air coming onto the station from over the open ocean (from west-northwest) was comparatively warm. X — *Arctowski* Station

Thermal conditions in winter 1986

Alternate influence of the typical for this winter and described above pressure pattern found its reflection mainly in thermal conditions and in character of wind speed and structure. Variation of air temperature observed at the station this winter showed much more rapid changes than during


[°C]
MAY
Mean = - 7,8°C
Min = - 24,4°C (28)
Max = 1,2°C (4)
ΔT = 25,6°C
Direction of air flow
NW-SW
SE, C
NE
SE
N
SE
NW-SW
E, C
NW
S-E
W-NW
SE-E
NW-SW
Days
JUNE
Mean = - 7,7°C
Min = - 25,4°C (30)
Max = 3,8°C (28)
ΔT = 29,2°C
SW-NW
E
NW-N
SE
NW-SW
E-SE, C
N
S-SW
Air temperature


[°C]
SEPTEMBER
Mean = - 5,0°C
Min = - 18,5°C (8)
Max = 4,1°C (3)
ΔT = 22,6°C
Direction of air flow
N-NW
SE, C
NW-SW
SE, C
SW, NW
SW
NW-SW
SW
Days
OCTOBER
Mean = - 1,4°C
Min = - 13,3°C (3)
Max = 6,3°C (9)
ΔT = 19,6°C
Wind direction
SW
W-NW
SW-S
W
Air temperature

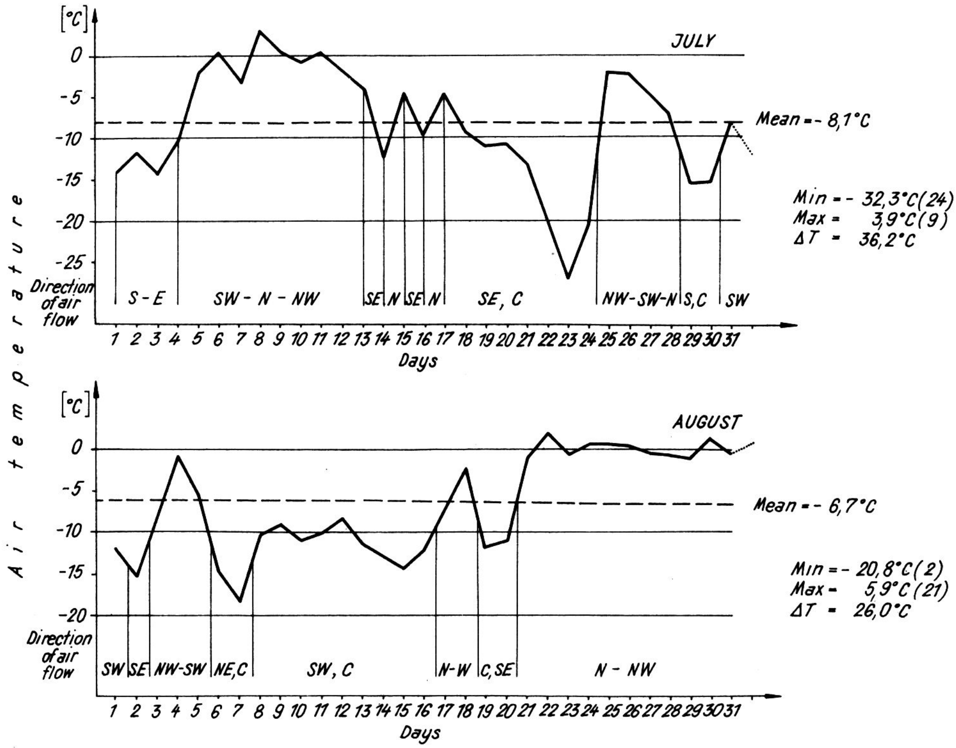


Fig. 5. Variation of mean daily air temperatures and the prevailing direction of air flow during cold and warmer spells at the *Arctowski* Station in winter 1986

previous winters. It was characterized by a great variability in time and by great amplitudes, both interdiurnal and from month to month. Some cases have been observed, when the mean daily air temperature dropped or raised rapidly, nearly by 20°C as it was the case from May 25 to 26, and from July 23 to 24 (Fig. 5). The same figure shows some other examples of markant though minor changes, as for instance the temperature fall from June 6 to 7 and from 20 to 21, the rise from May 28 to 29, and others. During the whole winter such rapid changes were observed often enough: frosty weather was abruptly followed by thaw or vice versa. The changes set in a time not very much longer than half-day and some of them occurred in barely some minutes, as for instance on May 25 (Fig. 6). It was due to a sharp change in direction of air flow over the archipelago, in a low pressure system which developed over the Weddell Sea. One of its centers over the South Shetland Islands steered over them at first a mild air from the nothwest, and when the center of the low slowly moved east, the frosty air stream from south--southeast struck the islands and persisted for several days. It was a true beginning of the severe winter that year.

Similar strong daily temperature oscillations were observed during the whole period from May to October, though towards the end of the season they were much smaller than in midwinter and comparable with oscillations in previous winters. Consequently to the interdiurnal oscillations, the monthly temperature amplitudes of the first half of the winter season were also considerable. To give an idea of an extent of thermal oscillations during this winter, frequencies of daily and monthly amplitudes and frequencies of interdiurnal differences of mean daily temperatures are presented (Table 1).

Table 1

Daily amplitudes of air temperature (a), values of monthly amplitudes (b) and interdiurnal changes of mean daily temperature (c) at the *Arctowski* Station in winter 1986

	Winter 1986:	May	Jun	Jul	Aug	Sep	Oct
a)	Magnitude of amplitudes, °C	Daily amplitudes of air temperature, number of days					
	≥ 5°C	18	22	28	23	17	13
	≥ 10°C	7	8	8	16	8	1
	15 C	4	3	6	2	·	·
b)		Values of monthly amplitude of air temperature, °C					
		25.6	29.2	36.2	26.0	22.6	19.6
c)	Magnitude of interdiurnal changes, °C	Interdiurnal changes of mean daily temperature, number of cases					
	≥ 5°C	9	7	11	8	8	2
	≥ 10°C	3	3	1	·	·	·
	≥ 15°C	1	·	1	·	·	·

Such big discrepancy and rapidity of thermal changes were the effect of intensive cyclonal activity occurring in turn w meridional circulation, which was, more often than usually, observed this year over the South American sector of the Antarctic Ocean. As mentioned above, the region of the Antarctic Peninsula was during the winter 1986 influenced by both the lows coming from over the Drake Passage and the lows advancing along the southern track. This diversity of pressure systems resulted in a variety of air masses: from mild, warm and wet air of maritime origin to frosty and dry continental air masses coming with southerly and easterly winds. Their interaction caused rapid temperature changes described above, being not a very common phenomenon in this region, where usually conditions of marine climate prevail.

Lengths of cold and warmer spells were not the same: strong frosts persisted shorter, only for two to five days. A 7-day frosty period in June is an exception. The length of warm spells was more differentiated: from one day thaw to 9 days of warm period in the first half of August and another fortnight of warm air advection at the turn of August and September. Each of the winter months had short thawing periods too, from a single thaw day in May to 5 thaw days in August, when the maximum temperature reached

Table 2

Monthly mean and extreme air temperatures, minimum temperature near the ground (grass minimum) and number of days with mean daily temperature above or below definite treshold values at the *Arctowski* Station in winter 1986

Winter 1986:	May	Jun	Jul	Aug	Sep	Oct
Temperature characteristics	°C					
Absol. monthly maximum temperature	1.0	3.8	3.9	5.2	4.1	6.1
Mean monthly temperature	−7.8	−7.7	−8.1	−6.7	−5.1	−1.4
Absol. monthly minimum temperature	−24.4	−25.4	−32.3	−20.8	−18.5	−13.3
Absolute monthly minimum temperature near the ground	−28.2	−29.1	−37.2	−23.0	−23.0	−14.0
Mean daily air temperature	Number of days					
≥ 5°C	·	·	·	·	·	·
≥ 0°C	1	3	4	5	7	15
≤ −10°C	8	11	13	13	7	1
≤ −15°C	3	6	5	2	2	·
≤ −20°C	2	·	3	·	·	·

5.2 C (Table 2). Thermal character of this winter, however, depended on the peculiarity of cold spells. Nearly every three days, and from June to August even nearly every second day, mean daily temperature was below 10 C. In May there were two days with mean daily temperature lower than 20 C and in June even three days. The coldest day of the winter was July 23, with daily mean temperature as low as 26.8 C and daily minimum equal to 32.3 C. Minimum temperature near the ground dropped on that day to 37.8 C (Table 2).

Synoptic features of thermally marked periods in winter 1986

Synoptic backgrounds of the thermal conditions were especially interesting with reference to the two cold spells, May 25 to 28 and July 19 to 24, and to the warm period from August 21 to September 4. They are to be considered more thoroughly.

The temperature fall at the end of May (Figs 5 and 6) accompanied by strong southeasterly winds was due to the passage of three successive lows moving east from over the Drake Passage. During their activity very cold air masses from over the Weddell Sea invaded the region of the South Shetland Islands (Fig. 2). Easterly direction of prevailing strong winds forced the drift of ice floes and ice fields into the Bransfield Strait and into the Admiralty Bay. In result of described air and water circulation, weak tides, low air and water temperatures, fast ice formed over wide areas arouned the South Shetland Islands. Low temperatures which followed in June accompanied by abundant snowfalls, led to further growth of ice cover, so that thickness of ice exceeded

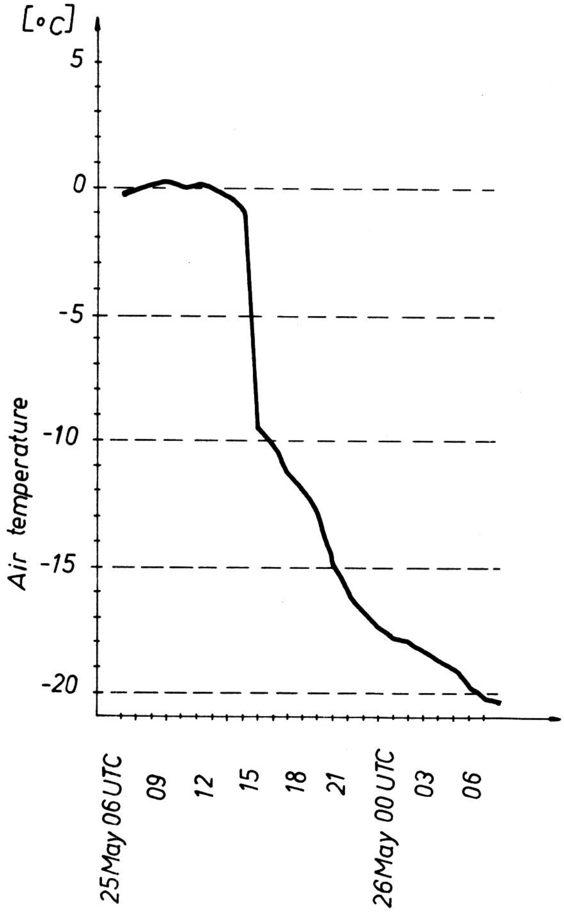


Fig. 6. Example of rapid temperature fall connected with change of wind direction at the *Arctowski* Station on May 25, 1986, 14—15 UTC (Universal Time Co-ordinated)

1 m and reached 3 m in some favorable places. Thickness of fast ice in the Admiralty Bay could be estimated when the ice cover was disintegrating into separate floes at the end of winter.

The period of strong frosts on July 19—24 was (otherwise than that in May) connected with a high pressure system. A weak anticyclonic center had formed over the South Shetland Islands, connecting a high pressure ridge from over the Antarctic Peninsula with another ridge from over the southern South Atlantic. This system of high pressure was maintained for some days by intensive cyclonal motion in two large neighboring depressions: over the Bellingshausen Sea and over the Weddell Sea. The circulation in the latter depression steered a cold air flow in the region of the South Shetland Islands. The following windless weather in anticyclonic conditions over the islands (only calm or light easterly winds) was favorable to backradiation and thus to further cooling of the air. In this cold spell the already mentioned minimum temperature of this winter was recorded on July 24. It was equal to 32.3 C and was the lowest value ever observed during the past ten years of station activity. The air was very dry. specific humidity being scarce 0.3 g kg^{-1}. In the air as dry as that. without possibility of thawing or snow subsidence. on the surface of thick snow cover the fresh fallen snow was very airly. This caused an accident of Chilean helicopter when landing at the *Arctowski* Station. The pressure pattern which caused the lowest temperature at the station this winter is presented in Fig. 3.

The period characteristic for a warm air advection lasting for 16 days which occurred at the turn of August and September. was connected with intensive cyclonal activity along the subpolar track. A broad belt of persisting zonal cirulation spread far south and covered the archipelago. Almost during the whole time strong and gusty northerly and westerly winds prevailed. bringing warm and moist air from over the open ocean (Fig. 4). These conditions of westerly air flow lasting for over a fortnight were interrupted by a very deep low with pressure below 955 hPa in the center over the Weddell Sea. While passing the station it gave hurricane-like wind speeds. reaching 74 m s^{-1} in gusts. These speeds were recorded by the anemometer mounted on the *Arctowski* Station light tower. Winds generated by passage of this cycles produced the first fractures in fast ice in the Bransfield Strait and in the Admiralty Bay. where the fast ice had persisted since the beginning of May. This active low effected in intrusion of cold air from the areas south of the Antarctic Peninsula into the wide cyclonal circulation system. Consequently. the air masses moving around the large depression were markedly cooler than in the previously dominating westerly air flow. Calm weather which followed afterwards. was favorable for further cooling of the air and for a comeback of winter.

Relations between direction and character of wind and air temperature

Both the type of variation of air temperature and character of wind speed at the station depend on the direction of air stream over the island. Air flow from southerly and easterly directions (S to NE) is usually laminar. and the directions from the sector north to southwest result in eddy and turbulent winds. This feature of air flow dependent on direction is of local origin. It is caused by orography of the island and by location of the station. But there exists also a regional reason which influences the thermal character of winds from definite directions: southerly and easterly winds (the laminar ones) bring usually cool air of antarctic origin whereas northerly to southwesterly winds (those of turbulent and gusty character which they gained by moving over the rocky island) bring usually warm air from over the open ocean. In winter 1986 this feature could be also easily confirmed. Table 3 presents the time of duration (in number of days) of prevailing winds from

Table 3

Number of days with predominance of definite directions of air flow and mean wind speed from these directions the *Arctowski* Station in winter 1986

Month	Prevailing direction of air flow				Mean monthly wind speed, ms^{-1}	Maximum wind speed in gusts, ms^{-1}	Number of days with gusts exceeding 20 ms^{-1}
	SW–N (210°C — 360°C)		NE–S (60°C – 150°C)				
	Number of days	Mean wind speed, ms^{-1}	Number of days	Mean wind speed, ms^{-1}			
May	16	6.1	15	5.5	5.8	38	8
Jun	16	6.4	14	3.7	5.4	37	13
Jul	18	6.6	13	3.4	5.2	44	15
Aug	24	8.6	7	2.8	7.3	42	19
Sep	23	8.8	7	3.2	7.5	74	22
Oct	29	7.6	2	2.0	7.2	38	20

Table 4

Precipitation amount and depth of snow at the *Arctowski* Station in winter 1986

Months	May	Jun	Jul	Aug	Sep	Oct
Precipitation amount, mm	21.7	77.9	50.7	32.1	31.7	27.6
Mean depth of snow, cm	31	58	90	79	77	45
Maximum depth of snow, cm	50	102	112	89	86	76

the directions defined above. The first winter month reveal a marked share of winds from the "cold" sector (NE–E–SE). Their speeds are comparatively lower. In the second part of winter the invasion of warmer air from the west (*i.e.* the share of winds from N, NW, W and SW) increased, accompanied by increase in wind velocities and gustiness. Conformity between lower temperatures and the northeasterly to southeasterly air flow, and between higher temperatures and the northerly to southwesterly air flow is evident when considering the figure 5: cold spells are usually accompanied by winds with the easterly component and often calm weather (the symbol C) whereas the warmer periods — by northerly and westerly directions.

The generalized relationship of air temperature and wind direction in winter 1986 is presented by a thermal rose (Fig. 7). Mean air temperature of these five coolest winter months was somewhat lower than −7°C. Temperatures averaged over the same time but accompanying particular wind di-

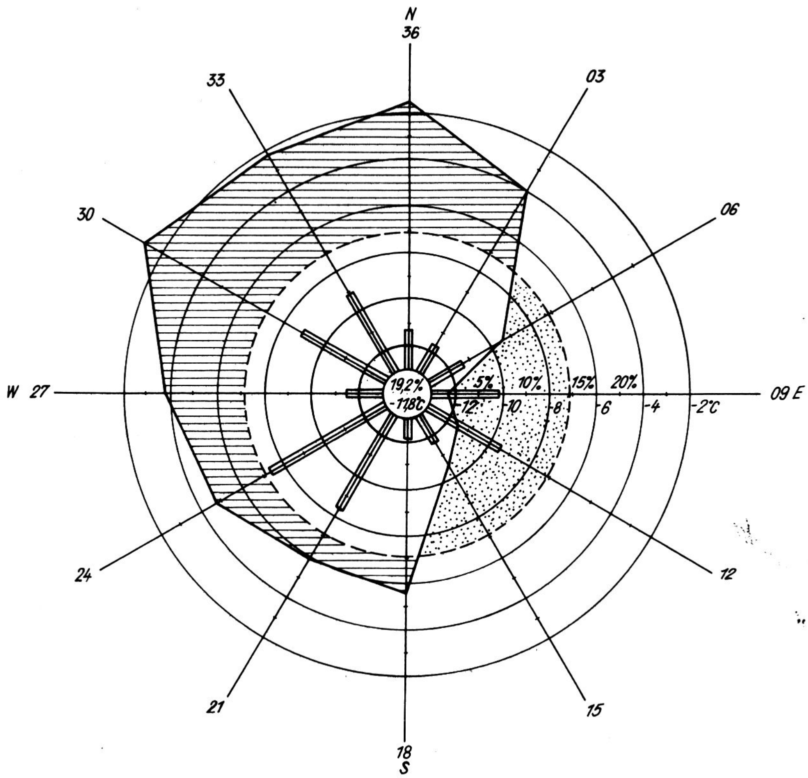


Fig. 7. Mean air temperatures accompanying definite wind directions (thermal wind rose) at the *Arctowski* Station in winter months (May—September) 1986. Temperature scale is given by the concentric circles. Dashed circle illustrates mean air temperature of the five coldest months (−7.9°C). Length of bars denotes frequency of wind directions (in %); figures in the center give frequency of calm weather and the mean value of co-occurring air temperatures (°C). Hatched area illustrates positive deviation of mean temperatures accompanying wind directions from the western warmer sector, the dotted area — negative deviation of mean temperatures accompanying air flow from the eastern cooler sector; both deviations are from the mean value of the winter

rections were greatly differentiated. Coolest air of the average temperature 13 C was transported by easterly winds (90 C), of a frequency slightly over 7 %. The west-northwesterly winds (300) were the warmest. The air they brought had an average temperature about 1 C and their frequency exceeded slightly 10 %.

Precipitation and snow depth

Abundant snowfalls formed an additional feature of the winter 1986. Precipitation amount in June equal to 77.9 mm was the highest monthly value recorded in winter during the nine past years of the station existence.

Thus snow depth was big, exceeding 100 cm in July and August (Table 4). Permanent snow cover was observed from April 30 till November 12.

Snowfall was usually accompanied by drifting snow and in many places, especially along buildings, snow-drift was deposited to a height of about 4 m and near the fuel-tank to 7 m. Both violent snow storms diminishing the visibility sometimes to less than 1 m and enormous heaps of deposited snow were specific features of the winter 1986 on the South Shetland Islands.

Final remarks

It must be kept in mind that the winter described was not an extreme, though a very cold one. Nevertheless, absolute minimum temperature at the *Arctowski* Station was in 1986 by 0.1 C lower than absolute minimum observed in 1954 on the nearby British station *Admiralty Bay* during thirteen years of its activity *i.e.* 1948—1960 (Dolgin and Petrov 1977, Schwerdtfeger 1984).

Among the winters 1978—1987 at the *Arctowski* Station three can be regarded as severe (in 1980, 1986 and 1987). From among the remaining seven, six were moderate and the winter 1985 can be regarded as a mild one.

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Streszczenie

Zima 1986 roku w rejonie Szetlandów Południowych należała pod względem warunków meteorologicznych i hydrologicznych do bardzo surowych (fig. 1—7, tab. 1—4). W pierwszych jej miesiącach, od maja do sierpnia, notowano bardzo niskie temperatury; już w maju średnia temperatura miesiąca wynosiła $-7,8$°C. Absolutna temperatura minimalna lipca wynosiła $-32,3$°C, a przy gruncie -37°C. Obydwie te wartości są najniższe w całym dotychczasowym dziesięcioletnim okresie funkcjonowania stacji. Cechą charakterystyczną były też bardzo duże wahania temperatury — od silnych mrozów do odwilży lub odwrotnie — w bardzo krótkim czasie. W kilku przypadkach skok średniej temperatury dobowej z dnia na dzień osiągnął 20°C.

Częste były obfite opady śnieżne i w ich konsekwencji duża grubość pokrywy śnieżnej, przekraczająca w lipcu i sierpniu 100 cm. Duże spadki temperatury i obfite opady śnieżne spowodowały pięciomiesięczny okres całkowitego zlodzenia grubą do około 3 m pokrywą lodową Zatoki Admiralicji i wód wokół Archipelagu Szetlandów Południowych.

W końcowych miesiącach zimy — wrześniu i październiku — przeważały okresy nieco cieplejsze i bardzo silne wiatry o prędkościach dochodzących w porywach do 74 ms^{-1} (4 września).