THE DISTRIBUTION OF MEAN ANNUAL TEMPERATURES IN THE ANTARCTIC PENINSULA

By JOHN M. REYNOLDS

ABSTRACT. Altitudinal lapse rates derived from multiple regression analyses of temperatures from two different climatic regimes, *viz* maritime on the west of the Antarctic Peninsula and pseudo-continental on the east, are identical (–0.57 °C/100 m) over the altitude range from sea-level to 1 050 m. Latitudinal lapse rates for the western (–0.77 °C/degree latitude) and east coast (–0.85 °C/degree latitude) regions are very similar, especially when compared with latitudinal lapse rates from other parts of the Antarctic. A latitudinal lapse rate deduced for Drake Passage to the north of the Antarctic Peninsula is very similar to that obtained for the western region. Despite the apparent uniformity of lapse rates over the peninsula the mean annual air temperatures at sea-level differ by 6°C, the east being colder than the west. This climatic contrast is related to a topographic effect caused by the Antarctic Peninsula. The divide between the two climatic regimes lies parallel to the topographic axis of the peninsula but offset to the east and at an altitude around 1 000 m above sea-level.

Mean annual air temperatures adjusted to sea-level have been used to derive a map of isotherms for the Antarctic Peninsula. With this information, suitable sites for the recovery of ice cores can be chosen in order to further climatic research as part of the Glaciology of the Antarctic Peninsula (GAP) programme.

Larsen, George VI and Prince Gustav Channel ice shelves have mean annual air temperatures in the range of –6°C to –10°C. These three ice shelves undergo considerable surface melting which results in the formation of extensive melt-lakes during the summer.

All ice shelves in the Antarctic Peninsula lie to the south and east of the –4°C mean annual isotherm.

THE principal objective of the Glaciology of the Antarctic Peninsula (GAP) programme is to establish a climatic record for the area from ice-core research (Swithinbank, 1974). In order to choose the most appropriate sites for deep ice drilling, a study of the present climatic regimes of the peninsula was required. It is well known that in glaciers where there is no warming caused by the refreezing of melt-water, a temperature measured at a depth of 10 m is within 1°C of the mean annual surface air temperature (Loewe, 1956, 1970). Thus, by studying measurements of 10-m ice temperatures over the peninsula our knowledge of the climate of the region could be extended from the limited area covered by meteorological stations. Martin and Peel (1978) have reported ice temperatures for the Antarctic Peninsula but here 10-m ice temperatures are analysed together with surface air temperatures measured at manned bases.

BACKGROUND

The Antarctic Peninsula is a physical barrier to tropospheric circulation (Schwerdtfeger, 1970; Schwerdtfeger and Amaturo, 1979). Depressions from the Bellingshausen Sea affect the western and central areas of the peninsula (Kyle and Schwerdtfeger, 1974). Cold air masses moving westwards across the Weddell Sea influence the eastern low-lying regions (Schwerdtfeger, 1974, 1975, 1979). The net effect of these two weather regimes is to produce a maritime climate in the western and central region (hereafter referred to as the western region) and a colder pseudo-continental climate in the east coast region (Schwerdtfeger, 1975; Martin and Peel, 1978). Martin and Peel (1978) showed that it was both climatically and statistically justifiable to divide the peninsula temperature data into western and east coast regions. This subdivision has also been demonstrated from oxygen isotope studies of 10-m ice cores by Peel and Clausen (in press) and from ecological studies by Holdgate [1964]. Data from the east coast region are therefore treated separately from those of the western region.

Paterson (1969, p. 173) states that the temperature at a depth of 10 m in a glacier approximates to the mean annual air temperature at the surface only in regions where "the *maximum* air temperature is less than 0°C". In areas where melting does occur, the refreezing of melt-water generates sufficient heat to warm the firn to a temperature greater than the mean annual air temperature (Loewe, 1956; Müller, 1976; Paterson, 1969; Paterson and Clarke, 1978). Martin and Peel (1978), in their study of 10-m ice temperatures from the Antarctic Peninsula, tried to avoid situations affected by such warming by restricting their analysis to ice

temperatures lower than –5°C. It is known, however, that Fossil Bluff (lat. 71°20'S, long. 68° 17'W) in the Antarctic Peninsula, has a mean annual air temperature of about –11°C (Pearce, 1963; Sanderson, 1978) and an average annual temperature variation of 11°C (from monthly mean temperatures; Sanderson, 1978). During the year, air temperatures reach 0°C and occasionally exceed this value. In January 1962, for example, the air temperature at Fossil Bluff rarely fell below –1.1°C, and, even in August, temperatures reached a maximum of 0°C (Pearce, 1963). As 10-m ice temperatures higher than –11°C are likely to have been affected by the refreezing of melt-water this analysis is restricted to ice temperatures equal to, or less than, –11°C. In areas other than the Antarctic Peninsula, the mean annual air temperature below which melting does not occur is likely to be different. For Mizuho plateau, eastern Antarctic (lat. 73°S, long. 45°E), for example, the critical temperature is about –21°C (Satow, 1978, fig. 6).

One set of temperatures was measured not in a borehole but down a bridged crevasse (E. W. Wolff, pers. comm.). Wolff found that air temperatures within the crevasse were the same at depths of both 10 m and 20 m and concluded that these temperatures were a measure of the mean annual air temperature at the surface.

Most 10-m ice temperatures have been measured within the last 15 years. Meteorological data acquired over a similar period up to 1980 have been used in the temperature analysis. This has been necessary because it is known that the mean annual air temperatures over the peninsula have increased by about 2°C between 1947 and 1970 (Limbert, 1974). A similar warming has also been reported for the Ross Ice Shelf area (Thomas, 1976). It is notable that the mean annual air temperatures in the Antarctic Peninsula have been decreasing since 1970 (from meteorological data; D. W. S. Limbert, pers. comm.). At Faraday (lat. 65°15'S, long. 64°17'W), for example, between 1971 and 1978 the mean annual air temperature decreased by 3.5°C and the trend is still continuing (D. W. S. Limbert, pers. comm.). If the data were available it would be better if a temporal regression were to be incorporated into the statistical analysis. As this is not feasible at present, I have restricted the data to those acquired between 1965 and 1980 in an attempt to reduce errors resulting from long-term variations in mean annual air temperatures.

Analysis

This analysis assumes that there is no warming of the ice through the refreezing of melt-water and that the principal factors controlling annual temperatures are latitude (L, degrees south) and altitude (A, metres). Martin and Peel (1978) discussed Antarctic Peninsula ice surface temperatures which were linearly correlated with latitude and altitude. The same approach was adopted here and the data were analysed by multiple regression using an expression for temperature (T) of the form,

$$T = aL + bA + c, \qquad (1)$$

where a, b and c are multiple regression coefficients. It is more convenient to relate the expression to a datum taken as lat. 70°S and mean sea-level. Equation (1) then becomes,

$$T_c = a(L-70) + bA + t,$$

where t is the mean annual air temperature for lat. 70°S at sea-level as determined by the regression analysis, and T_c is the calculated mean annual air temperature.

The data used in the analysis are listed in the Appendix. The expressions derived for western and east coast regions (suffices w and e, respectively) with their correlation coefficient (R) are

$$T_{cw} = (-0.77(L-70) - 0.00615A - 8.09) \quad °C; \; R = 0.98 \qquad (2)$$

$$T_{ce} = (-0.85(L-70) - 0.00568A - 14.08) \quad °C; \; R = 0.96. \qquad (3)$$

The regression coefficients *a* and *b* represent the rate at which temperature changes with latitude and altitude and are referred to as the latitudinal (°C/degree latitude) and altitudinal (°C/100 m) lapse rates respectively (Table I). Lapse rates from elsewhere in Antarctica have been included in Table I for comparison. The standard deviation of calculated mean annual air temperatures (T_c) from those observed (T_o) is 1.1°C for the western region and 0.6°C for the east coast region.

Altitude–Temperature

In order to discuss the data with respect to altitude the observed temperatures (T_o) have been normalized to lat. 70°S using the equation

$$T_{oN} = (T_o - a(L-70)) \qquad °C \tag{4}$$

Table I. Altitudinal and latitudinal lapse rates for the Antarctic

Altitudinal lapse rate (°C/100 m)	*Altitudinal range* (m)	*Geographical area*	*Source of data*
−0.8 [a]	0–1 000	Mizuho plateau	Satow (1978)
−1.3 [a]	1 000–3 000	Mizuho plateau	Satow (1978)
>−2.0 [a]	3 000–3 800	Mizuho plateau	Satow (1978)
−0.55 [a]	500–2 000	Dronning Maud Land	Schytt (1960)
−0.82 [a]	0–2 400	West Antarctica	Shimizu (1964)
−0.9 [a]	0–1 200	Wilkes Land	Mellor (1961)
−1.05 [a]	0–2 000	Dronning Maud Land	Mellor (1961)
−1.27 [a]	2 000–3 300	Dronning Maud Land	Mellor (1961)
−4.6 [a]	3 000–3 550	Dronning Maud Land	Mellor (1961)
−0.86 [a]	0–1 000	MacRobertson Land	Mellor (1960)
−1.05 [a]	1 000–2 000	MacRobertson Land	Mellor (1960)
−1.27 [a]	2 000–2 700	MacRobertson Land	Mellor (1960)
−0.9 [e]	0–1 800	Halley	Peel (1976)
−0.74 [b]	0–2 000	Terre Adélie	Loewe (1956)
−0.682±0.23	0–2 150	Antarctic Peninsula	Martin & Peel (1978)
−0.615	0–2 150	west Antarctic Peninsula	This paper
−0.570	0–1 060	west Antarctic Peninsula	This paper
−0.568	0–1 060	east Antarctic Peninsula	This paper
Latitudinal lapse rate (°C/deg. lat.)	*Latitude range* (deg. lat. S)	*Geographical area*	*Source of data*
−0.81 [b,d]	30°–71°	30°E–60°E, Indian Ocean	Satow (1978)
−2.95 [b]	66°45′–69°15′	Terre Adélie	Loewe (1956)
−0.76±0.11 [b]	50°–69°	Drake Passage	Pepper (1954)
−0.5 [c]	74°–83°	West Antarctica	Shimizu (1964)
−1.7 [c]	83°–90°	West Antarctica	Shimizu (1964)
0.0 [c]	78°–85°	Ross Ice Shelf	Shimizu (1964)
−1.6 [d]	72°30′–79°	Mizuho plateau	Satow (1978)
−2.0 [e]	76°06′–78°36′	Halley	Peel (1976)
−0.84±0.009	64°–76°	Antarctic Peninsula	Martin & Peel (1978)
−1.17 [d]	66°45′–69°15′	Terry Adélie	Loewe (1956)
−0.89 [f]	65°–75°	Dronning Maud, Wilkes, MacRobertson Lands	Mellor (1961)
−1.1 [c]	73°–90°	West Antarctica	Shimizu (1964)
−0.68	30°–60°	Sea-level global air temps	Lamb (1977)
−0.65	30°–60°	Surface sea temperatures	Lamb (1977)
−0.77	64°–74°	west Antarctic Peninsula	This paper
−0.85	64°–76°	east Antarctic Peninsula	This paper

[a] uncorrected for latitude.
[b] derived using multiple regression analysis on published data; lapse rate not previously published.
[c] assumed altitudinal lapse rate of −0.65°C/100 m.
[d] assumed dry adiabatic lapse rate of −0.986°C/100 m.
[e] assumed latitudinal lapse rate of −2.0°C/deg. lat.
[f] averaged value with different altitudinal lapse rates for each area.

where a is the appropriate multiple regression coefficient. The normalized temperatures (T_{oN}) are presented in Fig. 1. Over the same altitude range (sea-level to 1 060 m) the altitudinal lapse rate for east coast and western regions is the same (–0.57 °C/100 m). There is only a slight increase in the western region lapse rate when data over the full altitude range (up to 2 140 m) are considered. Because the western region lapse rate applies up to 2 140 m (to the topographic axis) and the east coast region lapse rate, which is virtually the same as that of the western region, applies up to around 1 000 m, the climatic divide must be bounded by the topographic axis to the west and approximately by the 1 000 m contour to the east.

Care should be taken when comparing lapse rates from different authors (Table I) because it is the exception rather than the rule to take into account latitudinal variations of temperature. For example, Loewe (1956, p 663), in discussing his altitudinal lapse rate for Terre Adélie, (lat. 67°S, long. 140°E), states that "only a small fraction of the [observed] decrease [in temperature as one ascends the ice sheet] can be attributed to the increase in latitude". The following equation has been derived by multiple regression using data from Loewe (1956, table V):

$$T_c = (-2.95(L-70)-0.0074A-21.78) \quad °C.$$

This enables Loewe's observed temperatures to be calculated to within ±0.2°C. Loewe's data therefore show that the altitudinal lapse rate is –0.74°C/100 m and the latitudinal lapse rate is –2.95°C/degree latitude. As a matter of convenience, and in order to compare lapse rates with

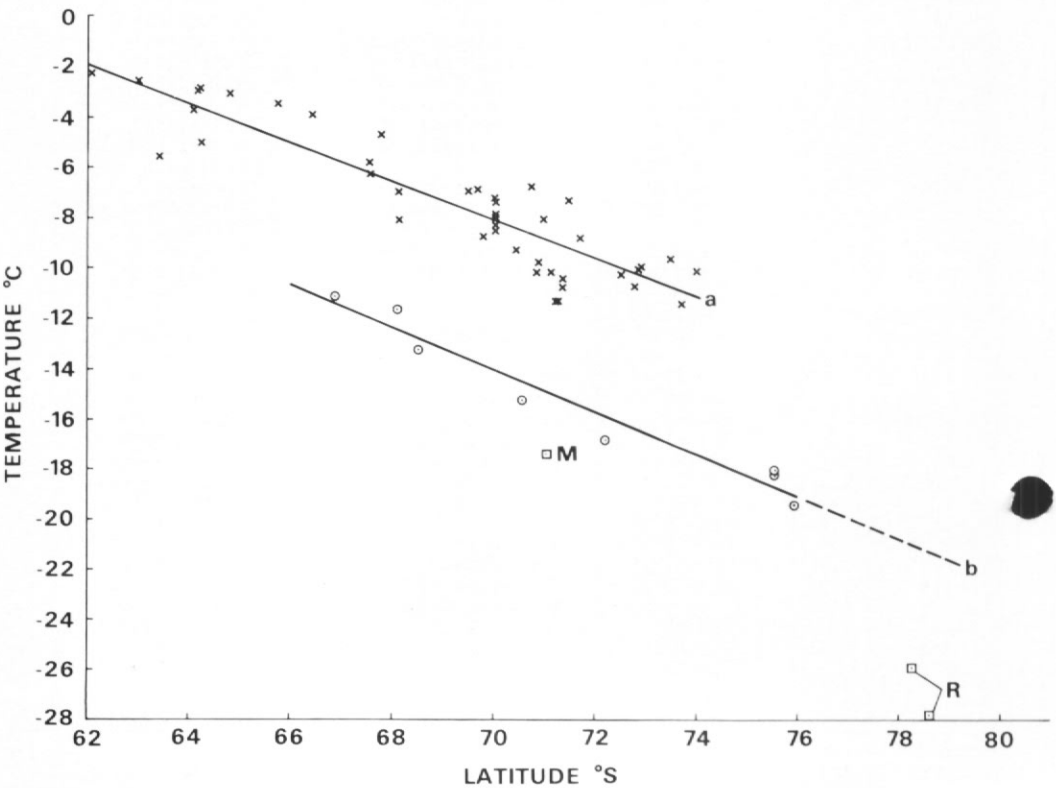

Fig. 1. Temperatures from western (a; ×) and east coast (b; ⊙) regions normalized to lat. 70°S. The solid lines represent temperatures (T_c) calculated from the multiple regression analysis. M: Maudheim; R: Rutford Ice Stream.

those from Satow (1978), Loewe's data (Loewe, 1956) have been normalized to sea-level using the dry adiabatic lapse rate (–0.986 °C/100 m). The equation thus obtained,

$$T_c = (-1.17(L-70)-0.00986A-15.23) \quad °C$$

yields temperatures within ±0.7 °C of the observed values. If the lower altitudinal lapse rate is more realistic, it may suggest that there is a moderating influence upon the climate, perhaps related to the depressions which approach Terre Adélie from west Australia (Shimizu, 1964) and to the effect of temperature inversions (D. A. Peel, pers. comm.).

Ten-metre ice temperatures from Maudheim and Rutford Ice Stream have been normalized using Equations (4) and (5) with east coast lapse rates and included in Figs 1–3 to contrast with temperatures from the Antarctic Peninsula. Both Maudheim and Rutford Ice Stream are situated at the boundary of the area considered in the statistical analysis in this paper: Maudheim is on the limits of the Weddell Sea, and Rutford Ice Stream is at the southernmost part of the Antarctic Peninsula. It is clear from Figs 1–3, that these two areas have different temperature regimes from either western or east coast regions and therefore different normalization parameters, as yet unknown. In trying to differentiate between various factors related to mean annual air temperatures, the effect of continentality (distance from the coast) has been neglected. The further inland one goes, the greater the effect of continentality becomes (Mellor, 1961; Satow, 1978). It is possible, therefore, that because of their greater degrees of continentality, temperatures at Maudheim and on Rutford Ice Stream are lower than elsewhere in the Antarctic Peninsula and Weddell Sea region. Rutford Ice Stream, for example, is at least 420 km from the sea and is furthest inland of the observations used. It is also adjacent to the Ellsworth Mountains which include the highest peaks in Antarctica and which may have a large effect on the local climate.

Latitude–Temperature

In order to discuss the observed data with respect to latitude the data have been normalized to sea-level using the equation

$$T_{\mathrm{oN}} = (T_{\mathrm{o}} - bA) \quad °C \qquad (5)$$

where b is the appropriate multiple regression coefficient. The normalized data are presented in Fig. 2. The latitudinal lapse rates for western and east coast regions are –0.77 and –0.85 °C/degree latitude, respectively. There is only a small difference between the two lapse rates, yet there is a 6 °C difference in sea-level temperatures (at lat. 70 °S) which demonstrates the contrast in climate between the two regions. A latitudinal lapse rate of –0.76 °C/degree latitude has been deduced from fig. 33 of Pepper (1954) for Drake Passage to the north of the peninsula. This lapse rate is very similar to that deduced from the present analysis, suggesting that the value of –0.77±0.01 °C/degree latitude can be considered to be valid over the latitude range 52° to 74 °S.

Most pseudo-continental lapse rates tend to be larger than maritime lapse rates: for example, –1.6 °C/degree latitude is estimated on Mizuho plateau (Satow, 1978, p. 67) and –1.17 °C/degree latitude is calculated for Loewe's data (Fig. 3). The temperature data have been normalized to sea-level in both cases by assuming the dry adiabatic lapse rate which, if too high, is likely to result in the latitudinal lapse rate being underestimated.

It is thought that latitudinal lapse rates reflect the effect of continentality. In Fig. 3, where lapse rates for the Antarctic Peninsula are compared with other regions of the Antarctic, the steeper lines indicate greater degrees of continentality. Lines *d* and *e* are profiles across the peninsula from the coast inland, whereas line *b* is drawn through data obtained from along the

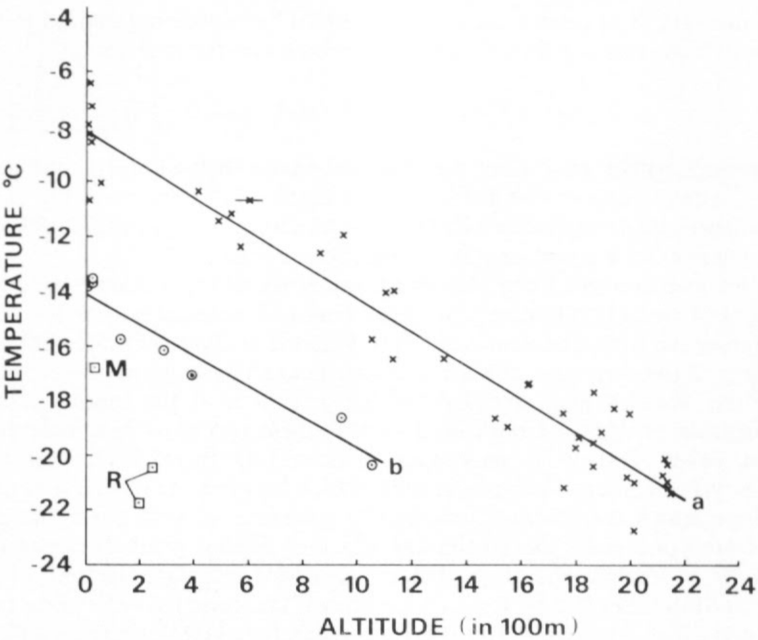

Fig. 2. Temperatures from western (a; ×) and east coast (b; ⊙) regions normalized to sea-level. The solid lines represent temperatures (T_c) calculated from the multiple regression analysis. M: Maudheim; R: Rutford Ice Stream.

east coast of the Antarctic Peninsula over a narrow altitude range and therefore line *b* can be considered to be a line of approximate isocontinentality.

The various lines cannot be extrapolated to higher latitudes because it would imply severe temperature discontinuities for the South Pole. As the latitude increases towards lat. 90°S the various lapse rates must converge.

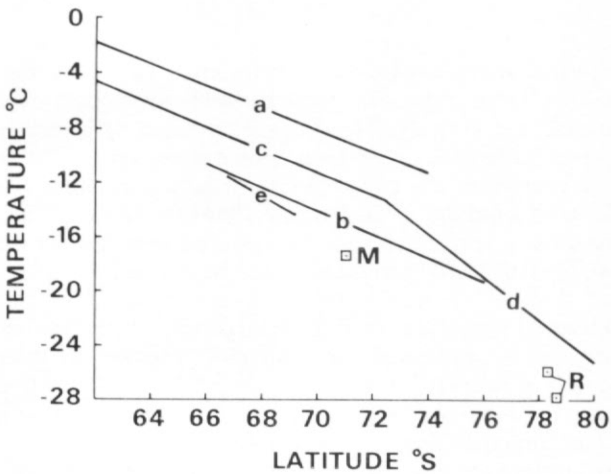

Fig. 3. The solid lines represent T_c for different parts of Antarctica. a: western and central Antarctic Peninsula; b: east coast Antarctic Peninsula; c: the line from lat. 30°S from sea-level measurements over the Indian Ocean from long. 30°E to 60°E (Satow, 1978); d: Mizuho plateau (Satow, 1978); e: data normalized assuming the dry adiabatic lapse rate for data from Loewe (1956) for Terre Adélie. M: Maudheim; R: Rutford Ice Stream.

Isothermal Map of the Antarctic Peninsula

Fig. 4 is a map of the Antarctic Peninsula showing the positions of temperature measurements. The data have been normalized to sea-level using the altitudinal lapse rates in Equations (2) and (3) and contoured. In normalizing the data to sea-level a linear latitudinal relationship has already been assumed, and calculated mean annual temperatures at three latitudes are listed in Table II to provide a contrast with normalized temperatures in Fig. 4. Figure 4 emphasizes the anomalies between the simple statistical model and the observed temperatures. The fine detail of Fig. 4 may well be inaccurate because of localized climatic factors which have not been considered in the analysis and because the data have been collected over a period of years, but the overall temperature pattern should be realistic. Because of temporal variations in mean annual air temperature, the contours are only accurate to within 1 °C. As different thermal regimes have been derived for the western and east coast regions there must be a transitional area or discontinuity where they meet. From Fig. 4, the transitional zone seems to be to the east of the topographic axis of the peninsula. The parallelism of the isotherms in Fig. 4 to the topographic axis of the Antarctic Peninsula confirms that there is a major topographic effect on mean annual air temperatures. The surface mean annual isotherms are predominantly parallel to the western coast line of the peninsula, as are the surface sea-water isotherms in the Bellingshausen Sea and Drake Passage (Deacon, 1937; Pepper, 1954, p 80).

Three significant anomalies are apparent in Fig. 4. The first is associated with James Ross Island (lat. 64°09′S, long. 57°45′W). It appears that the higher temperatures in that part of the peninsula have been sufficient to restrict the growth of an ice shelf in the northern part of Prince Gustav Channel. In addition, a temperature inversion has been reported for the James Ross ice cap (Aristarain and Delmas, in press). The 10-m ice temperature measured at the summit of the island was 1.3 °C higher than at a site 128 m lower down. The positions at which these temperatures were measured lie within the postulated transitional climatic regime.

The second anomaly is associated with the area around Adelaide Island. North-east Marguerite Bay is colder by 2 °C than the west coast of Adelaide Island at the same latitude. This is reflected in the prolonged duration of sea ice in the fjords in that area. The sea ice normally breaks out of western Marguerite Bay much earlier in summer than it does in the north-east of the bay. This cold area is possibly a consequence of the mountains of Adelaide Island acting as a shield against the warmer weather moving in from the Bellingshausen Sea (Schwerdtfeger and Amaturo, 1979).

The third major anomaly is a warm basin found to the east of Alexander Island. There are two principal weather systems affecting the weather around Alexander Island and George VI Sound. Depressions from the eastern Pacific move south-eastwards from the Bellingshausen Sea and then southwards over Alexander Island and George VI Sound (Shimizu, 1964, p 49). Cold dry winds flow northwards from Ellsworth Land in the south and along George VI Sound (Schwerdtfeger, 1976). In 1949, Sir Vivian Fuchs found that in George VI Sound winds from the north were up to 9 °C warmer than winds from the south (Pepper, 1954). During a 10-month period at Fossil Bluff, 70% of winds were from the quadrant W to N, and 23% were from E to S (Pearce, 1963). This channelling of the weather along George VI Sound possibly contributes to

Table II. Mean annual sea-level air temperatures for the Antarctic Peninsula, derived from the statistical analysis

Latitude (°S)	*Calculated mean annual temperature* (°C) *Western region*	*East coast region*
65	−4.2	−9.8
70	−8.1	−14.1
75	−11.9	−18.3

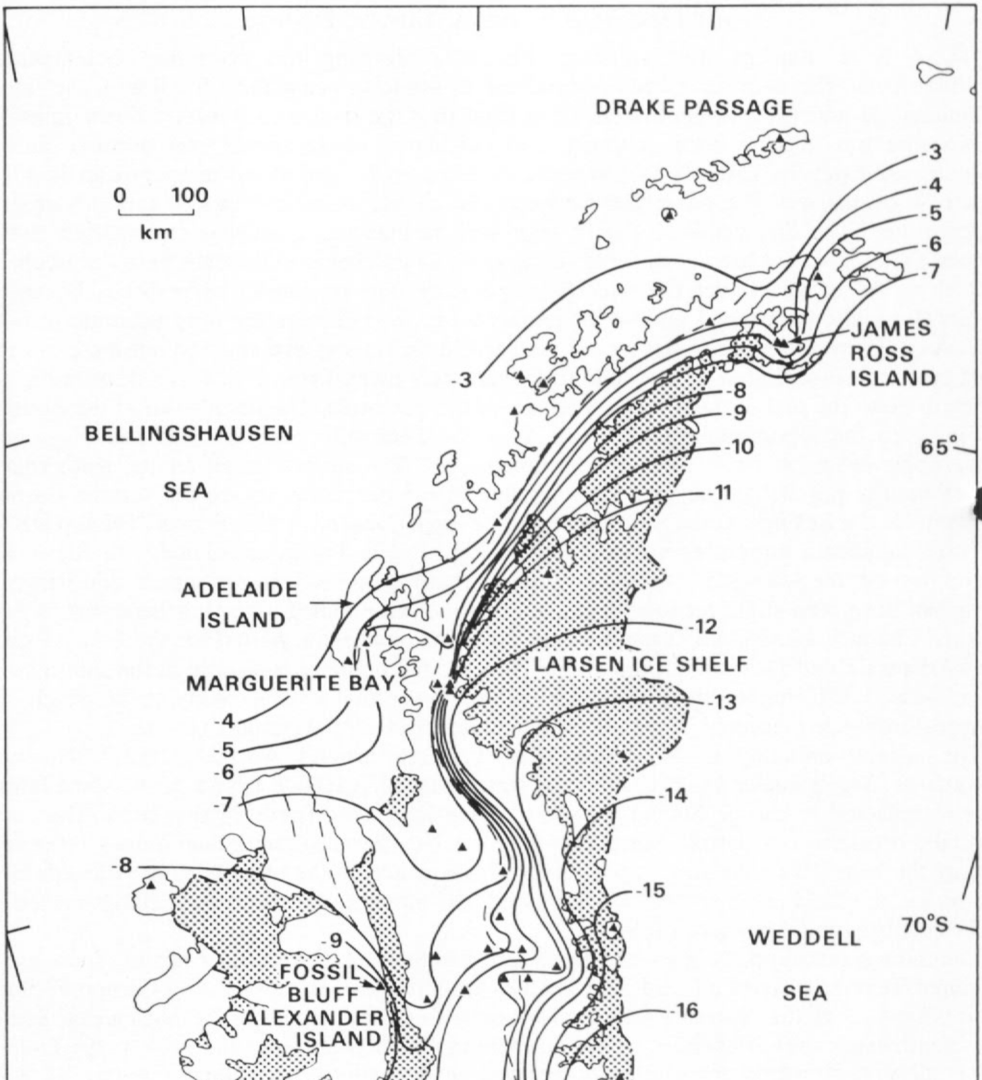

Fig. 4. Map of the Antarctic Peninsula with positions of temperature measurements (triangles). The temperatures have been normalized to sea-level. The isotherms are accurate to within 1°C. Ice shelves are shown stippled. The dashed lines mark the main topographic ridges where they exceed 1 500 m.

the relatively warm area to the east of Alexander Island. It is also known that the central part of George VI Sound (lat. 70° 15′ to 72° S) is in a precipitation shadow of Alexander Island (Bishop and Walton, in press; Pearson and Rose, 1981). Because precipitation shadows are normally associated with less cloudy skies, greater radiational warming occurs.

The central part of George VI Sound is also affected by melt-lakes during the summer (Sanderson, 1978; Wager, 1972). Larsen Ice Shelf, especially north of Jason Peninsula (Mason, 1950) and the ice shelf in the southern part of Prince Gustav Channel (Reece, 1950) also develop melt-lakes during the summer. Figure 4 shows that these three ice shelves have a similar range of mean annual air temperatures, −6°C to −10°C. This similarity may help to account for the presence of melt-lakes in these three different areas. It is of interest to note that the Amery Ice Shelf also develops surface melt-lakes (Mellor and McKinnon, 1960) and that it, too, has a mean annual air temperature of around −10°C (Mellor, 1961).

Calculated mean annual air temperatures have been compared with observed 10-m ice temperatures which are higher than −11°C (and therefore not used in this analysis) and which were listed by Martin and Peel (1978, table I). The observed temperatures are on average over 2°C higher than those calculated using Equation (2); only 3 out of 21 observed temperatures are lower (on average by only 0.55°C). In three instances the difference between observed and calculated temperatures exceeds 6°C which is far in excess of any temporal changes in mean annual air temperatures. Most of the differences can be attributed to the warming effect arising from the refreezing of melt-water.

From Fig. 4 it can be seen that all the ice shelves in the Antarctic Peninsula lie to the south and east of the −4°C mean annual isotherm.

Acknowledgements

I am grateful to E. W. Wolff and T. D. Fogg for their crevasse work, to D. W. S. Limbert for meteorological data from British Antarctic Survey bases in and around the Antarctic Peninsula, and to S. N. Stephenson for 10-m ice temperatures from Rutford Ice Stream. This paper has benefited from discussions with Drs J. G. Paren and D. A. Peel.

MS received 3 December 1980; accepted 4 March 1981

REFERENCES

Aristarain, A. J. *and* R. Delmas. In press. First glaciological studies on the James Ross Ice Cap (Antarctic Peninsula). *Journal of Glaciology*.

Bishop, J. F. *and* J. L. W. Walton. In press. Bottom melting under George VI Ice Shelf, Antarctica. *Journal of Glaciology*.

Deacon, G. E. R. 1937. The hydrology of the Southern Ocean. *Discovery Reports* **15**, 1–24.

Holdgate, M. W. [1964]. Terrestrial ecology in the maritime Antarctic. *In* Carrick, R. *and others, ed. Biologie antarctique. Paris, 2–8 septembre 1962. Comptes-rendus*. Paris, Hermann, 181–94.

[illegible]le, T. H. *and* W. Schwerdtfeger. 1974. Synoptic wind scale effects on the ice cover of the western Weddell Sea. *Antarctic Journal of the United States* **9**, No. 5, 212–13.

Lamb, H. H. 1977. *Climate, present, past and future*. Vol 2. *Climatic history and the future*, London, Methuen.

Limbert, D. W. S. 1974. Variations in the mean annual temperature for the Antarctic Peninsula, 1904–72. *Polar Record* **17**, No. 108, 303–06.

Loewe, F. 1956. Contributions to the glaciology of the Antarctic. *Journal of Glaciology* **2**, No. 19, 657–65.

———. 1970. Screen temperatures and 10 m temperatures. *Journal of Glaciology* **9**, No. 56, 263–68.

Martin, P. J. *and* D. A. Peel. 1978. The spatial distribution of 10 m temperatures in the Antarctic Peninsula. *Journal of Glaciology* **20**, No. 83, 311–17.

Mason, D. 1950. The Larsen Ice Shelf. *Journal of Glaciology* **1**, No. 8, 409–13.

Mellor, M. 1960. Temperature gradients in the Antarctic ice sheet. *Journal of Glaciology* **3**, No. 28, 773–82.

———. 1961. The Antarctic ice sheet. *United States Army Cold Regions Research and Engineering Laboratory*, 1-B1.

——— *and* G. McKinnon. 1960. The Amery Ice Shelf and its hinterland. *Polar Record* **10**, No. 64, 30–35.

Müller, F. 1976. On the thermal regime of a high-arctic glacier. *Journal of Glaciology* **16**, No. 74, 119–32.

Paren, J. G. 1979. Summer season glaciology 1978–79. (Unpublished British Antarctic Survey report No. S2/1978–79/R.)

PATERSON, W. S. B. 1969. *The physics of glaciers*. Oxford, Pergamon Press.

———. *and* G. K. C. CLARKE. 1978. Comparison of theoretical and observed temperature profiles in Devon Island ice cap, Canada. *Geophysical Journal of the Royal Astronomical Society* **55,** No. 3, 615–632.

PEARCE, C. J. 1963. Meteorological observations at Fossil Bluff, Alexander Island. *British Antarctic Survey Bulletin,* No. 1, 17–24.

PEARSON, M. R. *and* I. H. ROSE. 1981. The dynamics of George VI Ice Shelf. *British Antarctic Survey Bulletin,* No. 52.

PEEL, D. A. 1976. Snow accumulation, conductance and temperature inland from Halley Bay. *British Antarctic Survey Bulletin*, No. 43, 1–13.

———, *and* H. B. CLAUSEN. In press. Oxygen isotope and total beta radioactivity measurements on 10 m ice cores from the Antarctic Peninsula. *Journal of Glaciology*.

———. *and* E. W. WOLFF. 1980. Snow chemistry. *In* PEEL, D. A., *ed.* Summer season glaciology (1979/80). 20–28. (Unpublished British Antarctic Survey report No. S/1979–80/R.)

PEPPER, J. 1954. *The meteorology of the Falkland Islands and Dependencies, 1944–50*. London, Falkland Island Dependencies Survey.

REECE, A. 1950. The ice of Crown Prince Gustav Channel, Graham Land, Antarctica. *Journal of Glaciology* **1,** No. 8. 404–09.

SANDERSON, T. J. O. 1978. Thermal stresses near the surface of a glacier. *Journal of Glaciology* **20,** No. 83, 257–83.

SATOW, K. 1978. Distribution of 10 m snow temperatures in Mizuho Plateau. *In* ISHIDA, T., *ed. Glaciological studies in Mizuho Plateau, East Antarctica, 1969–1975*. Memoirs of National Institute of Polar Research, Special Issue No. 7, Tokyo, National Institute of Polar Research, 63–71.

SCHWERDTFEGER, W. 1970. The climate of the Antarctic. *In* ORVIG, S., *ed. Climates of the Polar Regions, World Survey of Climatology*, Vol. 14, Amsterdam, Elsevier, 253–355.

———. 1974. The Antarctic Peninsula and the temperature regime of the Weddell Sea. *Antarctic Journal of United States* **9,** No. 5, 213–14.

———. 1975. The effect of the Antarctic Peninsula on the temperature regime of the Weddell Sea. *Monthly Weather Review* **103,** No. 1, 45–51.

———. 1976. Annual temperature and ice condition changes in the Antarctic Peninsula area. *Antarctic Journal of the United States* **11,** No. 3, 152.

———. 1979. Discharge of Weddell Sea ice into the belt of mid-latitude westerlies. *Antarctic Journal of the United States* **14,** No. 5, 108–09.

———. *and* L. R. AMATURO. 1979. *Wind and weather around the Antarctic Peninsula*. University of Wisconsin, Department of Meteorology, research report.

SCHYTT, V. 1960. Snow and ice temperatures in Dronning Maud Land. *Norwegian–British–Swedish Antarctic Expedition 1949–1952. Scientific Results,* 4, D.

SHIMIZU, H. 1964. Glaciological studies in West Antarctica, 1960–1962. *In* MELLOR, M., *ed. Antarctic Snow and ice studies,* Washington, D. C., American Gerographical Union, 37–64. (Antarctic Research Series, Vol. 2.)

SWITHINBANK, C. W. M. 1974. An international glaciological programme for the Antarctic Peninsula: report of a meeting held in Cambridge, England, 27–30 April 1973. *Polar Record* **17,** No. 106, 86–98.

THOMAS, R. H. 1976. The distribution of 10 m ice temperatures on the Ross Ice Shelf. *Journal of Glaciology* **16,** No. 74. 111–17.

WAGER, A. C. 1972. Flooding of the ice shelf in George VI Sound. *British Antarctic Survey Bulletin,* No. 28, 71–74.

APPENDIX

Data Used in the Multiple Regression Analysis

Western and central region

Latitude (°S)	*Longitude* (°W)	*Altitude* (m)	*Temperature* (°C) T_O	T_c	T_{ON}*	T_{ON}**	*Comments*	*Source of data*
64°05′	59°35′	1 806	−14.9	−14.65	−19.34	−3.69		Martin & Peel (1978)
64°13′	57°38′	1 628	−12.9	−13.66	−17.34	−2.89		Martin & Peel (1978)
66°25′	64°57′	1 937	−15.8	−17.25	−18.55	−3.89		Martin & Peel (1978)
67°32′	66°00′	1 750	−16.5	−16.96	−18.40	−5.74		Martin & Peel (1978)
68°07′	66°18′	1 315[e]	−15.0	−14.73	−16.44	−6.91		Martin & Peel (1978)
68°08′	65°54′	1 125[e]	−15.0	−13.57	−16.44	−8.08		Martin & Peel (1978)
69°30′	66°16′	860	−12.2	−13.00	−12.58	−6.91		Martin & Peel (1978)
69°40′	65°30′	1 994	−19.1	−20.10	−19.43	−6.84		Martin & Peel (1978)
69°47′	75°13′	565	−12.2	−11.40	−12.37	−8.73		Martin & Peel (1978)
70°01′	64°29′	2 131	−21.0	−21.21	−20.98	−7.89	Mt Charity depot	Martin & Peel (1978)
70°25′	64°32′	1 861	−20.7	−19.86	−20.38	−9.25		Martin & Peel (1978)
70°43′	63°09′	1 860	−18.2	−20.08	−17.65	−6.76		Martin & Peel (1978)
70°50′	64°27′	1 987	−21.4	−20.95	−20.76	−9.18		Martin & Peel (1978)
70°53′	64°57′	1 860	−20.2	−20.20	−19.52	−8.76		Martin & Peel (1978)
70°59′	66°15′	1 101	−14.8	−15.61	−14.05	−8.03		Martin & Peel (1978)
71°07′	62°20′	1 050	−16.59	−15.41	−15.73	−10.13		Martin & Peel (1978)
71°14′	63°22′	1 752	−22.1	−19.81	−21.16	−11.33		Martin & Peel (1978)
71°15′	64°30′	2 010	−23.67	−21.41	−22.71	−11.31		Martin & Peel (1978)
71°23′	65°30′	1 547	−20.0	−18.66	−18.94	−10.49		Martin & Peel (1978)
71°29′	66°58′	946	−13.1	−15.05	−11.96	−7.28		Martin & Peel (1978)
71°42′	64°05′	1 886	−20.4	−20.99	−19.09	−8.80		Martin & Peel (1978)
72°30′	72°50′	488	−13.3	−13.01	−11.38	−10.30		Martin & Peel (1978)
72°47′	64°30′	1 797	−21.8	−21.28	−19.67	−10.75		Martin & Peel (1978)
72°50′	75°00′	539	−13.32	−13.58	−11.15	−10.01		Martin & Peel (1978)
73°42′	64°47′	2 007	−23.8	−23.27	−20.96	−11.46		Martin & Peel (1978)
70°01′	64°29′	2 140	−21.6	−21.27	−21.40	−8.44	Mt Charity depot	Paren (1979)
70°01′	64°29′	2 131	−21.4	−21.21	−21.20	−8.29	C3	Paren (1979)
70°01′	64°29′	2 131	−20.5	−21.21	−20.30	−7.39	C5	Paren (1979)
70°01′	64°29′	2 122	−20.3	−21.16	−20.10	−7.25	C10	Paren (1979
70°01′	64°29′	2 113	−20.9	−21.10	−20.70	−7.91	C11	Paren (1979)
74°00′	70°45′	1 128	−17.05	−18.10	−13.98	−10.11	Gomez Nunatak	Peel & Wolff (1980)
72°53′	74°41′	410	−12.5	−12.82	−10.29	−9.98	Spaatz Island	Peel & Wolff (1980)
73°29′	70°08′	600±50	−13.3[A]	−14.45	−10.63	−9.61	Crevasse	E. W. Wolff (pc, 1980)
62°03′	58°24′	19	−2.4[A]	−2.10	−8.50	−2.28	Admiralty Bay '70/8	D. W. S. Limbert (pc, 1980)
62°59′	60°34′	8	−2.6[A]	−2.75	−7.99	−2.55	Deception Is. '70/8	D. W. S. Limbert (pc, 1980)
63°24′	56°59′	11	−5.59[A]	−3.09	−10.66	−5.52	Hope Bay, '70/8	D. W. S. Limbert (pc, 1980)
64°46′	64°05′	20[e]	−3.2[A]	−4.20	−7.22	−3.08	Palmer St. '74/80	*Ant. J. United States*
65°15′	64°16′	10	−3.54[A]	−4.51	−8.29	−3.48	Faraday, '70/78	D. W. S. Limbert (pc, 1980)
67°34′	68°08′	20[e]	−6.36[A]	−6.35	−8.23	−6.24	Rothera, '77/80	*Polar Record*
67°46′	68°55′	14	−4.7[A]	−6.47	−6.41	−4.61	Adelaide, '70/8	D. W. S. Limbert (pc, 1980)
71°20′	68°17′	55	−11.1[A]	−9.47	−10.06	−10.76	Fossil Bluff	Pearce (1963); Sanderson (1978)
64°13′	57°38′	1 620	−12.9	−13.62	−17.34	−2.94	James Ross Island	Aristarain & Delmas (ip)
64°13′	57°38′	1 500	−14.2	−12.88	−18.64	−4.98	James Ross Island	Aristarain & Delmas (ip)

[e] estimated; [A] Air temperatures; pc personal communication; ip in press; *Data normalized to 70°S; **Data normalized to mean sea-level.

East coast and Weddell Sea margin

Latitude (°S)	*Longitude* (°W)	*Altitude* (m)	*Temperature* (°C) T_O	T_c	T_{ON}*	T_{ON}**	*Comments*	*Source of data*
66°52′	63°08′	18	−11.2	−11.54	−13.85	−11.10		Martin & Peel (1978)
68°07′	66°06′	940[e]	−17.0	−17.84	−18.59	−11.66		Martin & Peel (1978)
68°32′	61°06′	290	−14.9	−14.49	−16.15	−13.25		Martin & Peel (1978)
70°35′	60°50′	396	−17.51	−16.83	−17.02	−15.26		Martin & Peel (1978)
72°13′	60°16′	130	−17.6	−16.70	−15.72	−16.86		Martin & Peel (1978)
75°31′	26°37′	29	−18.4	−18.93	−13.72	−18.24	Halley	Martin & Peel (1978)
75°31′	26°37′	29	−18.19[A]	−18.93	−13.50	−18.03	Halley, '70/80	D. W. S. Limbert (pc, 1980)
75°56′	84°15′	1 054	−25.4	−25.10	−20.38	−19.41	Siple Station	Paren (1979)
71°03′	10°56′	37	−17.61[x]	−15.18	−16.72	−17.40	Maudheim	Schytt (1960)
78°15′	83°24′	250	−27.4[x]	−22.49	−20.41	−25.98	Rutford Ice Stream	S. N. Stephenson (pc, 1980)
78°36′	82°26′	200	−29.0[x]	−22.51	−21.72	−27.86	Rutford Ice Stream	S. N. Stephenson (pc, 1980)

[e] estimated; [A] Air temperatures; [x] data recorded but not used in analysis;
pc personal communication; ip in press; *Data normalized to 70°S; **Data normalized to mean sea-level.