ACCUMULATION AND TEMPERATURE MEASUREMENTS ON THE JAMES ROSS ISLAND ICE CAP, ANTARCTIC PENINSULA, ANTARCTICA

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ABSTRACT. Basic glaciological measurements from the James Ross Island ice cap are presented, including mean annual accumulation and firn temperature. In addition to the well-known radioactivity levels of January 1955 and 1965 in Antarctic snow, two new radioactivity levels corresponding to January 1969 and January 1974 are used in determining the accumulation values. The measurements reveal certain climatic features of this ice cap.

INTRODUCTION

James Ross Island (lat. 64°S., long. 58°W.) is located off the northern end of the Antarctic Peninsula. The island itself has a diameter of about 50 km, and it is completely covered by an ice cap with a central elevation of 1690 m and an estimated thickness of about 300 m (Aristarain, 1980).

In four successive field programs conducted during summer seasons 1976–78–79 and 1981, 17 shallow cores (with depths ranging from 8 to 31 m) were drilled in the central part of the island (Fig. 1), working from a base camp sited at Dalinger Dome.

Snow sampling was accompanied by other routine measurements: topographical surveys, elevations, 10 m depth snow temperatures, and sample densities.

The ice cores were analysed for global beta radioactivity. These results were used to determine the mean annual accumulation for each location.

EXPERIMENTAL CONDITIONS

The elevation determined for Dalinger Dome (1640 m) is the final result of a large number of barometric surveys conducted between this location and Vice Commodore Marambio Station, located about 50 km away.

From other simultaneous barometric surveys, we have determined the relative elevations of the other stations on James Ross Island with respect to Dalinger Dome.

The *in-situ* temperature measurements were made in 10–14 m depth bore holes either using a conventional thermometer or, more often, a set of calibrated thermistors (absolute accuracy: ±0.1°C). Two temperature profiles, covering the first 20 m were measured during one summer (Fig. 2), enabling us to calculate the vertical gradient of the in-depth temperature around the 10 m depth level, and to correct all the temperatures to 10 m depth (Table I).

The radio-isotopes were extracted from the snow samples using ion-exchange filters (Delmas and Pourchet, 1977) and then measured with our low-level beta-counting equipment (Pinglot and Pourchet, 1979).

DATING

Over the last 30 years, atmospheric thermonuclear tests have injected great amounts of artificial radio-isotopes into the stratosphere. They have since been deposited in the
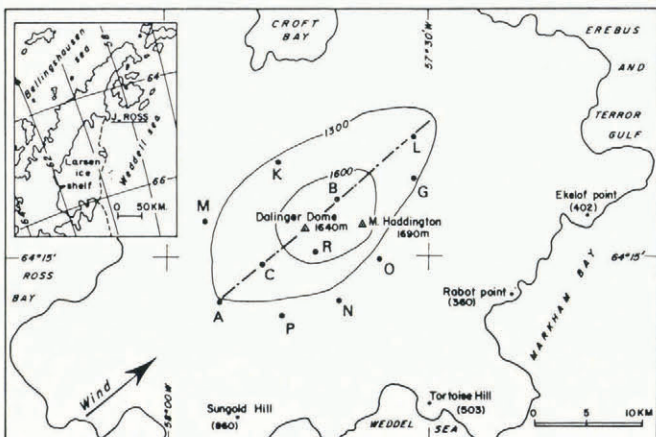

Fig. 1. Map of James Ross Island (British Antarctic Survey, 1974) showing sampling stations.
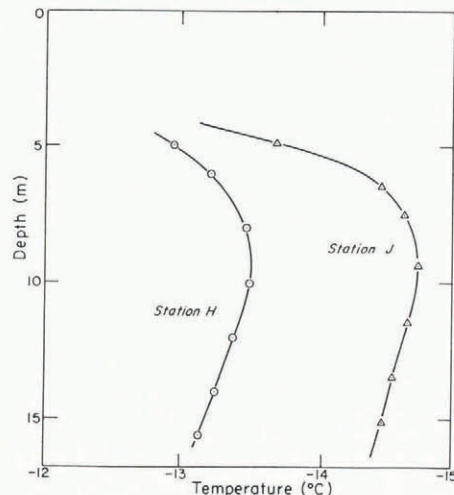

Fig. 2. Snow temperature versus depth for stations H and J. These measurements were made during the summer season.

snow, giving rise to radioactivity levels currently used to date the corresponding snow layers.

In Antarctica, the two levels most often used as a chronological base are January 1955 (Picciotto and Wilgain, 1963) and January 1965 (Crozaz, 1969).

For all the 15 stations involved in radio-isotope measurements (Table I), the snow cores were continuously divided into a large number of 10 cm samples to ensure an accurate temporal resolution. This has allowed us to distinguish the austral summer radioactivity references, as artificial radio-isotopes arrive in Antarctica during this season of the year (Lambert and others, 1977).

Each detailed radioactivity profile has been smoothed to assist in interpreting the general trends of the curves. Moreover, the accuracy of the measurements is lower for samples corresponding to depths of weak specific radio-activity, i.e. for depths between the surface and January 1965.

DALINGER DOME STATIONS

At station D (Fig. 3), Aristarain and others (1986) have determined each single summer season since 1955 using both artificial radioactivity and stable-isotope stratigraphy. Located at the center of our study area, this station represents an excellent reference location for accumulation determinations. On the radioactivity profile, the peak corresponding to January 1955 (marked 1 in Figure 3) is poorly defined and does not offer a clear reference level. We have observed this same phenomenon at many coastal stations, questioning its general acceptance as a key chronological indicator.

The 1965 radioactivity peak (marked 2 in Figure 3) is well marked, lasting 5 years and showing an increase in radioactivity as early as January 1965, a maximum in January 1966, and then a continuous decrease over 3 years. This depletion is due to the draining of the stratospheric reservoir during the nuclear moratorium extending from December 1962 to May 1966 (Pourchet and others, 1983). This decrease ceased with the commencement of further atmospheric thermonuclear tests by China in June 1967 and by France in July 1968. Due to delay in the radio-isotope transport, the next increase in the radioactivity of Antarctic snow occurs in January 1969 (marked 3 in Figure 3).

Such a phenomenon also occurs in January 1974 (marked 4 in Figure 3). On the smoothed curve, these last

TABLE I. ALTITUDE, TEMPERATURE, AND ACCUMULATION FOR 17 STATIONS ON THE JAMES ROSS ISLAND ICE CAP

Station		Altitude (m)	10 m temp. (°C) and depth of measurement (m)	Date of drilling	Depth (cm) of beta horizons and cumulative density (Mg m⁻³)				Mean accumulation (g cm⁻² a⁻¹) Beta radioactivity			Snow stake
					Jan 1955	Jan 1965	Jan 1969	Jan 1974	1955–65	Since 1965	Since 1969 or 1974[2]	Average 2 years
Dalinger Dome	D		−14.3 (14 m)	Mar 1979	2142 (0.539)	1500 (0.533)	1180 (0.518)	650 (0.487)	35.5	57.1	61.1	47.0
	J	1640	−14.7 (11 m)	Mar 1981		1777 (0.544)	1410 (0.529)	927 (0.504)		60.4	62.1	
	154			Mar 1981	2420 (0.568)	1759 (0.544)			41.8	59.8		
	A	1310	−13.1 (14 m)	Jan 1979				860 (0.503)			86.5	
	M	1280	−12.7 (10 m)	Mar 1981				711 (0.490)			49.8	
	N	1240	−11.8 (12 m)	Mar 1981				880 (0.501)			63.0	
	O	1190	−11.3 (12 m)	Mar 1981			1110 (0.514)	540 (0.474)			47.5	
Mount Haddington	H1		−12.9 (10 m)	Jan 1976	575 (0.512)	268 (0.500)			14.0	12.2		
	F	1690	−13.4 (14 m)	Mar 1979	757 (0.518)	385 (0.500)			20.0	13.7		
	H		−13.5 (12 m)	Apr 1981								14.6[1]
	L	1375		Mar 1981		633 (0.522)	393 (0.498)			20.6		
	G	1350 (estimated)	−11.3 (14 m)	Mar 1979	1030 (0.550)	705 (0.528)	500 (0.510)	325 (0.489)	19.4	26.6	25.5	10.8
	C	1460	−13.8 (14 m)	Apr 1979				750 (0.484)			72.6	62.3
	P	1220	−11.2 (12 m)	Apr 1981				813 (0.496)			57.6	
	K	1330	−12.2 (12 m)	Mar 1981			1137 (0.515)	446 (0.464)			48.8	
	R	1610	−14.1 (11 m)	Apr 1981			1018 (0.549)				46.6	
	B	1630 (estimated)	−14.2 (10 m)	Dec 1977	985 (0.498)	620 (0.468)				37.7	32.2	

[1] 5 years at H.
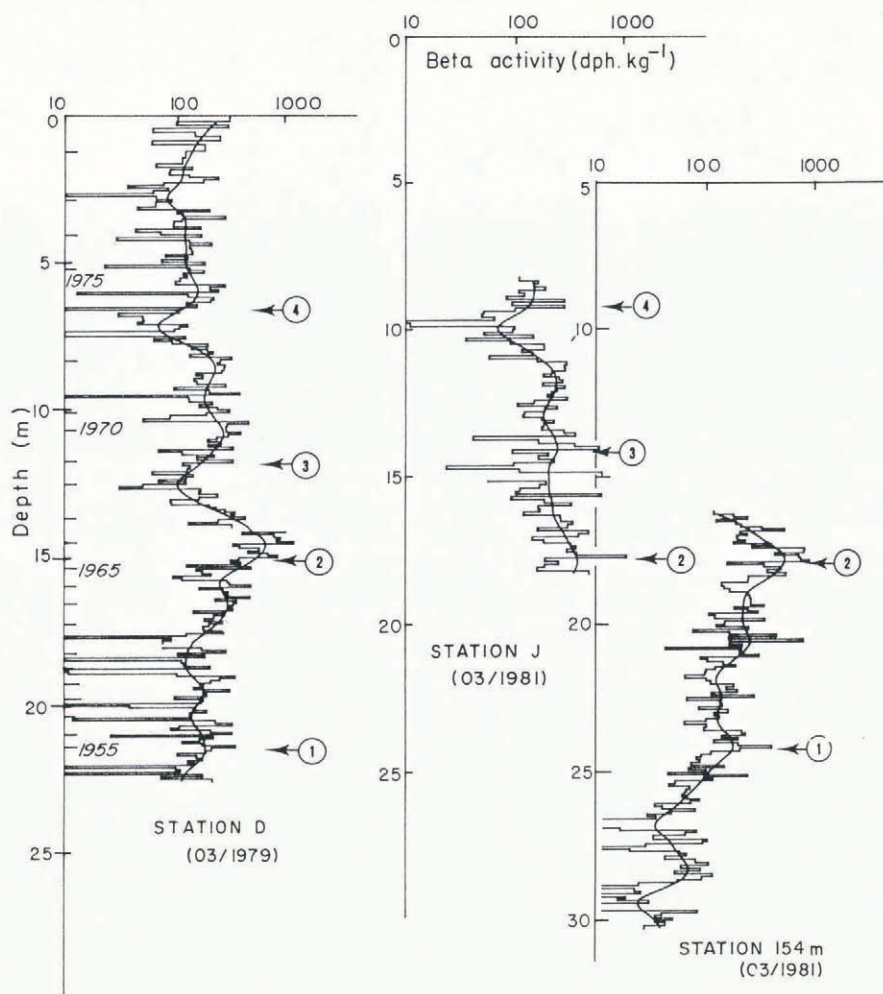[2] Determined for the greatest lapse of time.

Fig. 3. Beta-radioactivity versus depth for our reference station. The indices correspond to the radioactivity levels used to date the entire set of stations.
1, January 1955; 2, January 1965; 3, January 1969; 4, January 1974.
The isotope-stratigraphy dates are given for station D.

two events (marked 3 and 4 in Figure 3) are clearly defined, the slope of these somewhat lower peaks being greater than the slope of the moratorium decreasing curve, after the January 1965 peak. These events thus provide two further well-defined chronological levels.

We have also plotted (Fig. 3) the profiles for stations J and "154", located 290 m from station D. These profiles present general trends which are similar to those of station D, indicating a uniform stratigraphic pattern throughout the Dalinger Dome area.

For station B (Aristarain and Delmas, 1981), dating by use of the beta radioactivity curve alone is difficult. A tentative interpretation led to defining the 1965 and 1969 levels.

Stations A, M, N, and O

For these stations (Fig. 4), we observed similar overall trends as well as close mean values for the radioactivity at the different known levels. Although the minimum of the curve established for the period before the 1974 secondary peak is sometimes less marked than at station D (stations O and N), the maximum value for this peak is especially uniform: 282 dph kg^{-1} for station D, and 243, 300, 260, and 285 dph kg^{-1} for stations A, M, N, and O, respectively.

Stations F, G, H, and L

The general trend of the beta-radioactivity curves is very similar for these four stations (Fig. 5). The measured accumulation is low. Stations H and F are very close to Mount Haddington, the highest point on James Ross Island (1690 m). For these locations, the low accumulation value has been confirmed by stake measurements.

Moreover, the radioactivity level corresponding to January 1955 (marked 1 in Figure 5), while not as high as in central Antarctic stations such as Dome C (Petit and others, 1982) or South Pole (Pourchet and others, 1983), is still well marked.

The main feature leading to these similarities with the radioactivity curves from the East Antarctic plateau is the low accumulation rate and it is independent of a coastal or continental location, for stations F, G, H, and L.

Stations C, P, K, and R

This set of curves (Fig. 6) shows a poorer fit with respect to the Dalinger Dome curve than those of the preceding locations. However, we can confirm that the January 1965 level (marked 2 in Figure 6) is never reached, due to the shallow depth of the drilling; and at least one of the more recent levels, i.e. either January 1969 (marked 3 in Figure 6) or January 1974 (marked 4 in Figure 6), shows up reasonably well in each case. For station C, the accumulation value deduced from the radioactivity profile has been confirmed by stake measurements.

INTERPRETATION

1. The snow-accumulation rates relate to that part of the island with an altitude greater than 1190 m. Over this area, the firn temperature is sufficiently below 0 °C that there is no major percolation, even though ice layers of several centimeters in thickness can be seen in cores at certain low-altitude stations.

The mean accumulation at different sites, as a function of their distance from point A (orthogonal
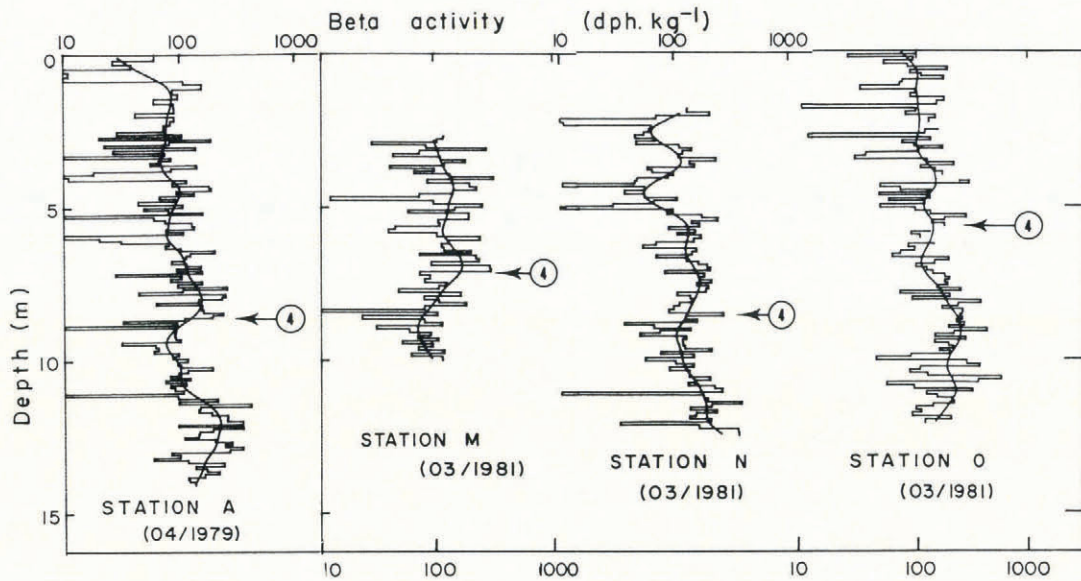
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Beta activity (dph. kg⁻¹)

Fig. 4. *Beta-radioactivity versus depth for stations A, M, N, and O.*
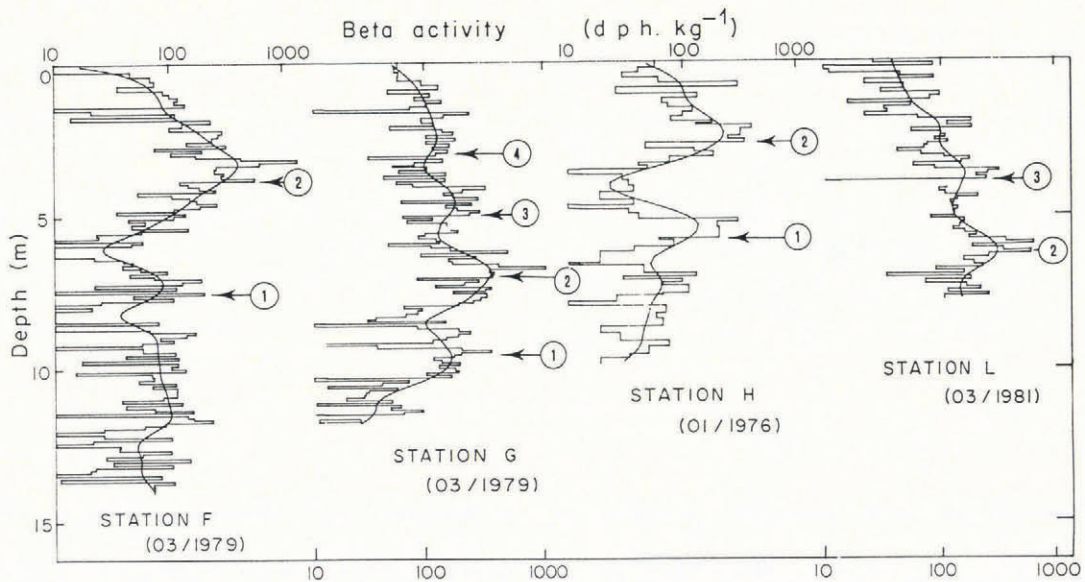
Beta activity (d p h. kg⁻¹)

Fig. 5. *Beta-radioactivity versus depth for stations F, G, H, and L.*

projection along the AL axis), fits a straight line (correlation coefficient = 0.95, excluding Mount Haddington). Over a distance of less than 20 km, the mean accumulation rates decrease by a factor of 4 (Fig. 7). Only the summit dome of the ice cap deviates significantly from this average straight line and shows a major accumulation deficit which can be accounted for by the intense wind erosion occurring at this particular site where accumulation variations of 1–7 from one year to another were detected (Aristarain, 1980). Our measurements appear to indicate that the geographic distribution of accumulation values is influenced by the south-westerly winds. The atmospheric disturbances carried by these winds likely condense rapidly when they reach the ice cap.

Moreover, this particular accumulation distribution would appear to be the reason why we found no relationship between its values and the firn temperatures, as has been observed for other Antarctic regions (Young and others, 1982).

At sites D and G, the comparison of the mean accumulation rates since 1965 are about 50% and 40%, respectively, greater than those for the period 1955–65,

which agrees with the increase in Antarctic precipitation as pointed out by Pourchet and others (1983).

2. Field measurements have shown that the firn temperature at a depth of 10 m is close to the mean annual temperature at the surface for values greater than about −35°C in areas where there is no substantial surface melting (Loewe, 1970).

In the case of surface snow melt, the heat of refreezing can lead to considerable differences (several deg) between the mean temperatures at the surface and in the firn (Paterson, 1981). This accounts for the higher temperature (≈1°C) of the firn at Mount Haddington with respect to Dalinger Dome (Fig. 2), in spite of its higher altitude (50 m). A relatively high degree of snow melt has in fact been found on the summit dome (Aristarain, 1980). This situation must also exist to some extent at lower stations, since layers of ice were sometimes found.

We can now estimate the altitudinal lapse-rate (deg/100 m) on James Ross Island, using our measurements of altitude and temperature. The gradient found is −0.58 deg/100 m (correlation coefficient = 0.85 when considering, in Table I, the 1981 temperature values for
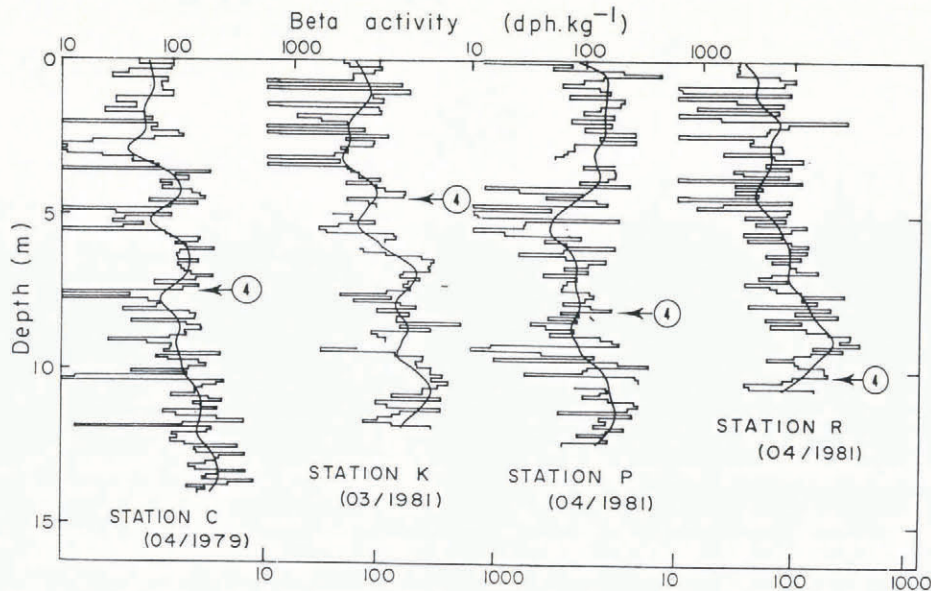
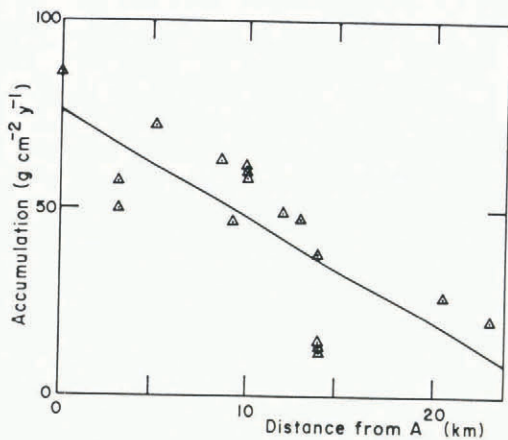Fig. 6. *Beta-radioactivity versus depth for stations C, K, P, and R.*

Fig. 7. *Accumulation versus distance from station A (orthogonal projection along AL axis).*
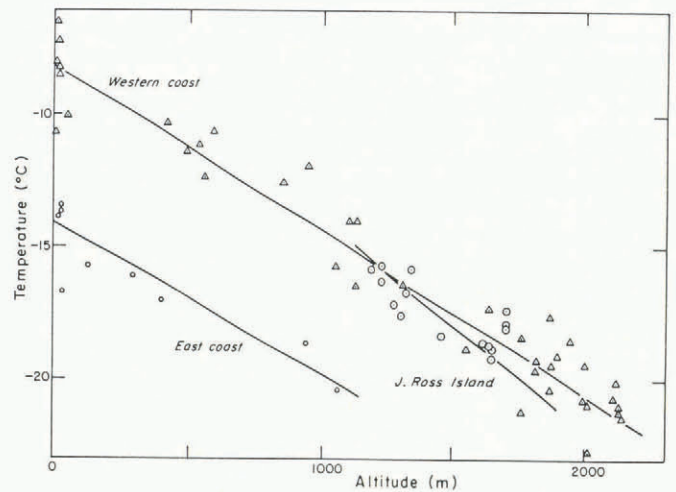

Fig. 8. *Regression of 10 m temperature versus altitude, normalized to lat. 70°S.*

Dalinger Dome and Mount Haddington). This value is in good agreement with the value calculated by Reynolds (1981): −0.57 deg/100 m for the Antarctic Peninsula.

The western and eastern regions of the Antarctic Peninsula have very different climatic characteristics, with maritime and continental regimes, respectively (Schwerdtfeger, 1970; Martin and Peel, 1978).

Figure 8 shows temperature versus altitude normalized to lat. 70°S. for each region, as obtained by Reynolds (1981), with the points representing our stations on James Ross Island. We used the normalization coefficient given by Reynolds (1981) for the western part of the Antarctic Peninsula: −0.77 deg/degree of latitude; the use of the coefficient for the eastern part of the Antarctic Peninsula (−0.85 deg/degree of latitude) would shift these points by −0.45 deg. In both cases, Figure 8 shows the predominantly western climatic character on the upper part of the James Ross Island ice cap, even though it is located on the eastern side of the Antarctic Peninsula. This fact, which agrees with the west coast change in temperature regime after 1970 (Schwerdtfeger, 1976), and the isotope trend at James Ross Island (Aristarain and Delmas, 1981) may be due to the influence of the prevailing westerly winds north of about lat. 65°S., as reported by Schwerdfeger (1975). However, the strong winds from the south (south-west in the north of the Antarctic Peninsula), characteristic of the eastern climatic regime (Schwerdtfeger, 1975) and

which affect James Ross Island and appear to dominate the distribution of accumulation on the ice cap, demonstrate the existence of a component of this regime. The isotope study carried out on Dalinger Dome supports this finding (Aristarain and others, 1986).

CONCLUSIONS

The snow accumulation has been deduced from well-known radioactivity peaks, including the 1969 and 1974 peaks as new Antarctic Peninsula references. The snow-accumulation rates at 12 sites, located between 1190 and 1690 m in altitude on the James Ross Island ice cap, have provided an indication of the intensity and geographic distribution of precipitation on this part of the ice cap.

Firn temperatures at the different sites have enabled the estimation of the altitudinal lapse-rate for the study area. This gradient agrees well with that measured for the Antarctic Peninsula as a whole (Reynolds, 1981).

The temperatures at the various stations considered (after correction to lat. 70°S.) confirm a predominantly western climatic character for the upper part of the ice cap in spite of its location to the east of the Antarctic Peninsula. However, the south-westerly winds, which appear to dominate the geographic distribution of precipitation, demonstrate the existence of an eastern climatic component.

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