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SEASONAL VARIATIONS IN THE WATER TEMPERATURE AND SALINITY NEAR SOUTH GEORGIA 1925 - 1937

G.E.R. DEACON

REPORT NO. 49

1977

NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE OF OCEANOGRAPHIC SCIENCES

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Antarctic whaling was concentrated near South Georgia and the South Shetlands till, in the early 1930's, floating factories were able to operate far from land. Most of the South Georgia whales were taken from the same general area NE of the island, but there were some differences from month to month and year to year. The whales seemed to arrive in batches, with one species, sex, or growth-stage predominating. Some schools arrived as others were leaving. The numbers of whales seemed to be related to the abundance of krill on which they feed, and this to the currents, particularly to a cold inflow of water from the Weddell Sea which bends round the eastern end of the island and dominates the water conditions NE of the island. The warmer water to the west of the island, more influenced by the drift from the Bellingshausen Sea through the Drake Passage, seemed less productive. The Discovery Investigations included plans for oceanographic surveys round the island to gain the relevant environmental information.

South Georgia is a mountainous island about 100 miles long, much indented with bays and fjords, and nowhere more than 15-20 miles wide. It lies about 800 miles ENE of Cape Horn, and some 250 miles inside the Antarctic convergence. A general account of its situation in relation to the main features of temperature and salinity distribution is given in the Discovery Reports (Deacon 1933 and 1937). The surface layer is well mixed: at 45 stations round the island in spring (November 1930) the temperature difference between 0 m and 50 m averaged 0.16°C, the maximum being 0.70°C and the minimum (at 3 stations) 0.00°C. In summer (January - February 1930) the difference at 57 stations averaged 0.55°C with a maximum of 1.90°C, and minimum 0.00°C at 2 stations. Within this range the surface temperature could change sharply from day to day in response to changes in wind and weather. To smooth out some of the difficulties it seems reasonable to base a first investigation on the more slowly changing 0 m to 50 m averages of temperature and salinity.

Another difficulty arises because practical problems sometimes prevented adequate and uniform coverage of the area. One of the most comprehensive surveys, that of 1929-30, is illustrated in Figure 1. Some of the others, especially after the spread of whaling in 1931, are less representative, tending to favour some sectors at the expense of others. To lessen the possibility of such bias the whole region was divided into sub-areas, each of which takes a full part in the final average if it has any observations at all. The numbers in

Figure 1 are the 0m to 50m mean temperatures. They are contoured at 0.5°C intervals, and the positions of the isotherms in this one particular survey are used to define the sub-areas A, B, C, D, and E for all the surveys. It seems to be a reasonable artifice, because the isotherms in all the surveys followed much the same pattern, though the actual temperature range varied from month to month and year to year.

The surveys are listed in Table 1 at the end of the paper. The station numbers are those under which they appear in full in the Station Lists, Discovery Reports, Volumes 1 (1929), III (1930), IV (1932), XXI (1941), XXII (1942), and XXIV (1944). Those with the prefix WS were made by the RRS William Scoresby, and the others by the Discovery in 1925-27, and afterwards by her successor the Discovery II. The 0 m to 50 m averages at all the stations are listed in Table II, stations less than 10 miles from the coast have been omitted because they are likely to be abnormally affected by increased mixing in shallow soundings, and by water and ice draining from the land. The area covered is 52°S to 56°S between 33°W and 41°W.

Seasonal Changes

A first examination of the figures in Table II shows that there is a seasonal temperature change of 4 or 5°C between winter and summer. There is also a clear indication that some years are warmer than others. To make a closer investigation a curve was fitted to all the sub-area averages listed in Table II; even if there was only one observation in a particular sub-area, it was used, as a makeshift, to represent the sub-area. In fitting the curve I was helped by Dr. M. J. Fasham who found that a third-order polynomial gave the best fit. It is shown in Figure 2. The sub area averages are marked by asterisks and the corresponding values of the polynomial by crosses. The ordinates are the 0 m to 50 m temperatures and the abscissae are days, starting with the earliest available data on 25 August, and continuing through the southern summer to the approach of winter in May. The curve shows an almost linear rise between October and February. The maximum occurs near the middle of March. There are not enough winter observations to be sure about the minimum, but there is some indication that it may occur in September. The total temperature range from September to March was 3.51°C, from -0.85°C to 2.66°C. During the same years, 1925-1937, the minimum monthly mean of air temperature at Grytviken in Cumberland Bay, near the middle of the NE coast, was lowest in June 5 times, in August 6

times in September twice. Its mean range was 6.2°C, from -1.5°C in August, to 4.7°C in February.

An early attempt to study seasonal change was based on a series of temperature and salinity observations between the surface and 75 m at a point 4 miles inside Cumberland Bay, from November 1930 to March 1931. (Discovery Reports, Vol. IV, 1931, pp. 222-229). A smooth curve through the 0 m - 50 m averages reached a maximum of 1.8°C early in March, but as will be seen later, 1930-1931 was a cold summer, and the offshore temperatures were not much warmer. There is also the possibility that the inshore temperatures were influenced by water and ice draining from the large glaciers close by.

The average 0 m - 50 m salinities listed in Table II seem to vary more from year to year than season to season, when plotted against the days of the year as in Figure 3. They only give some indication of an overall trend towards lower salinity in summer, as must be expected from the effects of ice melting. The year 1927-28 is known to have been exceptional : an abnormal number of icebergs was reported, including one 70 miles long lying between South Georgia and the Falkland Islands. Leaving out the figures for 1927-28 the correlation with time was found to be just significant at the 5 per cent level, and the mean change was $S = 0.000526T + 33.96‰$. This is the straight line drawn in Figure 3. The curved line is that for seasonal temperature change taken from Figure 2, on the same time scale, but with reversed temperature scale to give a rough indication of lower salinity in summer.

Annual Variations

The two main reasons for the scatter about the mean line in Figure 1 are the separate plotting of sub-areas which always have a temperature difference of 1°C to 2°C between A and E, and overall variations of temperature from year to year. The annual changes have been separated from the seasonal changes by using the deviation of each observation from the mean curve of seasonal change. They are listed in column 6 of Table III and plotted, each sub-area separately, in Figure 4. Observations falling between August in one year and May of the next are grouped together e.g. in 1928-29. When a sub-area has been studied twice in one year a mean of the two values is plotted. Deviations of annual air

temperature, averaged from August to the following May, from the overall average for August to May over the 12 years covered by the study, are also plotted. They are based on the monthly means reported at Grytviken, some 5 miles inside Cumberland Bay, near the middle of the NE coast, published in World Weather Records, 1921-30, and 1931-40, by H. H. Clayton and the Smithsonian Institution. The changes in water temperature (0 m to 50 m average) from year to year show similar trends in each sub-area, and the differences between the cooler and warmer sub-areas A and B range from 0.8°C in 1934-35 to 1.9°C in 1929-30. The annual changes in the deviation of mean air temperature from the 12-year average are remarkably similar to those of mean water temperature. The similarity is more obvious in Figure 5 which combines the sub-areas. It must be remembered that the figures are deviations from a mean for 1925-26 to 1936-37, and that the air temperatures were measured at the shore station at Grytviken. The actual mean of air temperature over the 12-year period was 2.1°C and that of the offshore water (0m - 50 m average) was 0.03°C.

Statistically the data are quite inadequate, but the general coherence between the sub-areas and the mean air temperature seems to justify some acceptance. They agree quite well with deviations of surface temperature from the mean worked out by Mackintosh (1972) on the basis of two well-sampled points north and east of the island. They show at least that there are warm years like 1929-30 and 1936-37, and cold years like 1927-28 and 1930-31, and that there was an overall trend to warmer climate, half a degree or so, over the 12 years, 1925-37. They fit in with the idea that 'warm' years were 'fin whale years' at South Georgia, and 'cold' years were 'blue whale years' (Harmer, 1931; Kemp and Bennett, 1932). The International Whaling statistics show that the ratios of fin to blue whales in the catches at South Georgia were 7.0 and 8.9 in 1929-30 and 1936-37, and only 0.6 and 1.3 in 1927-28 and 1930-31. The explanation given by Harmer was that blue whales concentrate earlier and closer to the ice edge, and in a cold year the ice edge is likely to be nearer South Georgia. It has since been demonstrated (Marr, 1962) that the Weddell Sea outflow is of overriding importance to the spreading of krill, and it might now be a argued that a cold year at South Georgia means a stronger spread of krill as well as of cold water. Some confirmation of this idea is given in the note and Figure by Mr. Arthur Baker at the end of this report. The annual changes in temperature show general agreement with what we know of the annual variations of ice coverage farther south (Mackintosh, 1972,

Fig. 3), but there are not sufficient ice observations for close comparison.

The year to year variations in salinity are plotted in Figure 6. In an attempt to lessen the possible effect of seasonal changes the data have been increased according to the equation $S = 0.000526T + 33.96‰$ derived from Figure 3. The sub-area averages are plotted separately and the way they hang together gives some confirmation to the idea that overall changes, from year to year, go beyond overall seasonal trends. There are too few measurements of rainfall and ice coverage to judge their possible effect, though the low salinities of 1927-28, like the low temperatures, were almost certainly due to the presence of an abnormal number of icebergs. There is a general indication of a small upward trend in salinity during the 12-year period 1925 to 1937. The line showing changes in average salinity in Figure 6 has been added to Figure 5 for comparison with the temperature changes. It is the upper salinity line in Figure 5. To show that corrections for probable seasonal change, based on Figure 3, have not fabricated the pattern, the lower salinity line in Figure 5 is based on simple averages of the sub-area salinities listed in Table III. The truth may be somewhere between the two.

The small overall increase of both temperature and salinity between 1925 and 1937 might indicate that some kind of balance between northern and southern influences had advanced slightly southwards.

There is perhaps sufficient outcome from this first examination to suggest that more systematic and detailed study might be worthwhile. Perhaps changes at different depths might be compared, and the apparent correlation between water and air temperature changes might justify further use of the more generally available air-temperature data.

Annual variation in Krill catches by A. de C. Baker

During the same surveys which provided the temperature and salinity data around South Georgia, a large number of hauls were made with 1 m stramin nets to study the distribution of the macroplankton. The numbers of krill taken in these nets have been examined in a rough and ready manner to see if there is any obvious correlation between the annual variation in temperature and the abundance of krill.

The nets were fished in two ways, either horizontally near the surface (N100H) or obliquely from a depth of approximately 100 m to the surface (N100B). The success with which these two types of haul catch krill is different and in order to make them more comparable a factor has to be applied. The best factors to use have been discussed in detail by Marr (1962) and Mackintosh (1973),and their conclusions have been followed here except that no allowance has been made for the ability of the nets to catch small krill better than large krill, so that all N100B catches were multiplied by 4 and then corrected to the same length of tow as the N100H, i. e. 30 mins.

While catches from the same overall area used for the temperature data have been included, no allowance has been made for the numbers of hauls taken in the region to the south -west of South Georgia, which is known to be poor in krill when compared to the north-east of South Georgia. This may well have had a considerable effect.

Table IV shows, for each year, the total number of krill taken, the mean catch per haul, and the difference from the overall mean catch for the period 1925-37. It will be seen that in two years there are no data readily available and that the number of hauls in each year is very variable. In 1933-34 only one of the ten hauls used was positive and thus the calculated mean has little significance. The very patchy nature of krill distribution means that many of the hauls caught nothing but that periodically very large catches were made. This means that any more sophisticated treatment of the data is hardly worthwhile.

In spite of these various shortcomings it will be seen from Figure 7 that in the particularly cold years 1927-28 and 1930-31 the krill catches were considerably higher than the overall mean, and in the warm year 1936-37 considerably lower. The correlation does not hold good for 1928-29, which was also fairly cold, but the krill catch was well below the mean. However, the correlations that do appear tend to confirm the larger numbers of krill in Weddell Sea water (Marr, 1962) and provide a sensible link between the water temperature and the whole distributions.

REFERENCES

Clowes, A. J., 1938. Phosphate and silicate in the Southern Ocean. Discovery Reports, Vol. XIX, pp. 1-120.

Deacon, G. E. R., 1933. A general account of the hydrology of the South Atlantic Ocean. Discovery Reports, Vol. VII, pp. 171-238.

Deacon, G. E. R., 1937. The hydrology of the Southern Ocean. Discovery Reports, Vol. XV, pp. 1-124.

Harmer, S. F., 1931. Southern Whaling. Proc. Linn. Soc. London, Session 142, pp. 85-163.

Kemp, S. W., and Bennett, A. G., 1932. On the Distribution and Movements of Whales on the South Georgia and South Shetland Whaling Grounds. Discovery Reports, Vol. VI, pp. 165-190.

Mackintosh, N. A., 1972. Life Cycle of Antarctic Krill in relation to Ice and Water Conditions. Discovery Reports, Vol. XXXVI, pp. 1-94.

Mackintosh, N. A., 1973. Distribution of post-larval krill in the Antarctic. Discovery Reports, Vol. XXXVI, pp. 95-156.

Marr, J. W. S., 1962. The Natural History and Geography of the Antarctic krill. (Euphausia superba, Dana). Discovery Reports, Vol. XXXII, pp. 33-464.

Swithinbank, C., McClain, P., and Little, P., 1977. Drift tracks of Antarctic icebergs. Polar Record, Vol. 18, pp. 495-501.

APPENDIX

Annual Variations of Air Temperature, 1925-75

To get some idea of changes since 1925-37, the deviations of mean annual (August-May) air temperature at Grytviken from the (August-May) mean for 1925-37 have been plotted up to 1975 in Figure 8. It shows continued variations like those of 1925-37, and a continued upward trend. Recent warm years, such as 1956-57 and 1973-74, are warmer than those of 1925-37, and recent cold years are not so cold as those of 1925-37. The overall warming is about 1 °C in 50 years. Dr. M. J. Fasham has made a power spectrum analysis of the air temperature deviations. He finds a peak significant at 10 per cent level between 0.3 and 0.4 cycles a year.

The recent air temperatures were supplied by the British Antarctic Survey.

TABLE I

The South Georgia Survey

Season	Months	No. of stations	Station Numbers	
1925-26	February	15	13-41	NE of Cumberland Bay only
1926-27	Dec-Jan	50	124-139, WS18-61	
1926-27	May	5	WS110-114	NE of Cumberland Bay only
1927-28	Feb-Mar	24	WS144-190	
1928-29	Aug-Oct	24	WS257-295	No data SW of the island
1928-29	Dec-Jan	34	WS321-365	" "
1928-29	April	10	WS417-426	Only SW of the island
1929-30	Jan-Feb	57	300-358	
1930-31	November	45	480-525	
1930-31	Jan-Mar	10	WS532-575	Only N of the island
1931-32	December	20	769-791	
1932-33	December	12	1059-1079	
1932-33	February	9	1127-1136	Only N and E of the island
1933-34	Nov-Dec	11	1199-1210	No data SW of the island
1934-35	Aug-Sept	11	1394-1405	" "
1934-35	Jan-Feb	11	1497-1508	" "
1936-37	October	11	1839-1854	
1936-37	March	10	1978-1988	

TABLE II

The 0 - 50 m average temperatures and salinities at stations round South Georgia. The subdivisions A to E refer to those limited by the 2.0°, 2.5°, 3.0° and 3.5°C isotherms in figure 1.

Season	Area	Station No.	Temp °C	Salinity ‰	Date	Averages		
1925-26 March	B	17	2.59	33.75	4.3	2.59	33.78	4.3
	C	14	2.98	33.80	4.3			
		15	2.58	33.70	4.3			
		16	2.69	33.79	4.3			
		19	2.80	33.76	4.3			
		20	2.98	33.80	4.3			
		21	2.82	33.79	4.3			
		31	2.96	33.81	17.3			
		41	2.39	33.84	28.3	2.77	33.78	9.3
1926-27 November to January	B	137	0.68	33.84	22.12			
		138	0.56	33.85	22.12			
		139	0.67	33.87	23.12			
		151	0.93	33.83	16.1			
		WS 22	0.01	33.86	30.11			
		WS 38	0.80	33.82	23.12	0.61	33.85	23.12
	C	124	1.33	33.79	18.12			
		125	1.18	33.83	19.12			
		127	1.02	33.79	19.12			
		131	1.26	33.84	20.12			
		132	0.78	33.88	20.12			
		133	0.49	33.81	21.12			
		136	0.96	33.88	23.12			
		147	0.88	33.81	19.1			
		WS 19	0.15	33.83	27.11			
		WS 20	0.35	33.83	28.11			
		WS 21	0.08	33.86	28.11			
		WS 28	0.69	33.85	19.12			
		WS 29	1.35	33.80	19.12			
		WS 35	0.59	33.83	22.12			
		WS 36	0.62	33.78	22.12			
		WS 37	0.89	33.85	22.12			
		WS 39	1.28	33.87	23.12			
		WS 40	1.22	33.77	7.1			
		WS 44	1.49	33.76	8.1			
		WS 61	1.50	33.86	18.1	0.91	33.83	21.12

Season	Area	Station No.	Temp °C	Salinity ‰	Date	Averages		
contd.	D	128	0.88	33.84	19.12			
		129	1.12	33.84	19.12			
		135	1.53	33.81	21.12			
		WS 26	1.21	33.82	18.12			
		WS 30	1.33	33.85	20.12			
		WS 33	1.35	33.78	21.12			
		WS 34	0.98	33.84	21.12			
		WS 42	2.03	33.76	7.1			
		WS 43	1.55	33.76	8.1			
		WS 45	1.99	33.79	8.1			
		WS 48	1.79	33.80	9.1			
		WS 52	1.10	33.86	10.1			
		WS 54	1.00	33.86	12.1			
		WS 63	2.39	33.72	21.1	1.44	33.81	31.12
	E	WS 49	2.14	33.80	9.1			
		WS 50	2.05	33.83	9.1			
		WS 55	1.94	33.83	9.1	2.04	33.82	9.1
1926-27	B	WS111	0.46	33.87	26.5			
May	C	WS110	0.94	33.77	26.5			
		WS112	0.93	33.78	27.5			
		WS114	0.90	33.70	28.5	0.92	33.75	27.5
1927-28	A	WS175	1.41	33.55	7.3			
February to March	B	WS149	0.94	33.51	22.2			
		WS171	2.08	33.65	6.3			
		WS173	2.25	33.71	7.3			
		WS182	2.62	33.76	8.3	1.97	33.66	4.3
	C	WS145	2.13	33.58	19.2			
		WS146	1.24	33.46	19.2			
		WS151	0.98	33.46	22.2			
		WS158	2.94	33.56	27.2			
		WS160	2.29	33.53	27.2			
		WS163	1.71	33.65	29.2			
		WS164	2.06	33.63	29.2			
		WS180	2.46	33.52	7.3	1.98	33.55	26.2
	D	WS156	2.29	33.53	26.2			
		WS165	2.21	33.59	1.3			
		WS166	2.15	33.67	1.3			
		WS178	2.45	33.50	7.3			
		WS179	2.46	33.50	7.3	2.31	33.56	3.3

Season	Area	Station No.	Temp°C	Salinity ‰	Date	Averages		
contd.	E	WS167	2.46	33.71	1.3			
		WS190	2.34	33.62	10.3	2.40	33.67	6.3
1928-29	A	WS284	-1.50	33.80	18.9			
August to October	B	WS261	-1.75	33.86	28.8			
		WS282	-1.32	33.78	17.9	-1.55	33.82	8.9
	C	WS258	-0.84	33.96	27.8			
		WS259	-1.03	33.95	28.8			
		WS263	-1.70	33.87	28.8			
		WS266	-0.80	33.89	29.8			
		WS268	-1.09	33.90	29.8			
		WS276	-0.58	33.87	4.9			
		WS280	-0.98	33.88	17.9			
		WS293	-1.00	33.81	3.10			
		WS295	-1.12	33.83	4.10	-1.02	33.88	8.9
	D	WS270	-0.74	33.86	30.8			
		WS274	-0.96	33.87	4.9			
		WS275	-0.98	33.87	4.9			
		WS289	-1.12	33.75	1.10			
		WS291	-1.12	33.75	2.10			
		WS292	-1.05	33.77	3.10	-0.99	33.81	17.9
1928-29 December to January	A	WS353	0.46	33.72	12.1			
		WS354	0.38	33.73	12.1			
		WS355	0.07	33.80	13.1			
		WS356	0.30	33.82	13.1	0.30	33.77	12.1
	B	WS332	0.52	33.78	28.12			
		WS351	0.71	33.79	11.1			
		WS352	0.59	33.78	12.1			
		WS363	1.16	33.82	14.1			
		WS365	1.25	33.88	14.1	0.85	33.81	10.1
	C	WS322	0.78	33.81	17.12			
		WS329	1.04	33.79	27.12			
		WS330	0.60	33.83	27.12			
		WS334	0.41	33.78	30.12			
		WS339	1.25	33.80	8.1			
		WS342	1.40	33.77	8.1			
		WS343	1.49	33.78	9.1			
		WS344	1.42	33.77	9.1			
		WS345	0.83	33.81	9.1			
		WS347	0.97	33.77	9.1			
		WS349	0.96	33.84	11.1	1.04	33.79	7.1

Season	Area	Station No.	Temp°C	Salinity ‰	Date	Averages		
contd.	C	WS350	0.99	33.80	11.1			
		WS357	1.02	33.79	13.1			
		WS358	1.15	33.78	14.1			
		WS359	1.27	33.76	14.1			
		WS361	1.04	33.82	14.1	1.04	33.79	7.1
	D	WS323	0.84	33.78	21.12			
		WS325	0.83	33.79	21.12			
		WS326	1.19	33.80	31.12			
		WS340	1.38	33.79	8.1			
		WS341	1.18	33.78	8.1	1.08	33.79	30.12
1928-29 April	C	WS419	2.21	33.76	11.4			
	D	WS418	2.33	33.78	11.4			
		WS421	2.12	33.74	14.4			
		WS422	2.10	33.73	14.4			
		WS425	2.73	33.88	15.4			
		WS426	2.30	33.87	15.4	2.32	33.80	14.4
	E	WS423	2.16	33.75	14.4			
		WS424	2.08	33.77	14.4	2.12	33.76	14.4
1929-30 January to February	A	355	2.00	33.87	10.2			
		356	1.89	33.88	10.2	1.95	33.88	10.2
	B	312	2.23	33.88	25.1			
		313	2.30	33.86	25.1			
		342	2.18	33.83	7.2			
		343	2.21	33.83	7.2			
		344	2.27	33.81	8.2			
		353	2.38	33.82	9.2			
		354	2.31	33.87	9.2	2.27	33.85	4.2
	C	300	2.72	33.85	20.1			
		301	2.68	33.84	21.1			
		302	2.67	33.84	21.1			
		303	2.81	33.84	21.1			
		304	2.91	33.83	21.1			
		309	2.70	33.77	24.1			
		310	2.98	33.78	24.1			
		311	2.72	33.75	24.1			
		315	2.65	33.78	29.1			
		317	2.66	33.84	29.1			
		318	2.65	33.85	29.1			
		324	2.89	33.87	1.2			
		333	2.99	33.91	3.2			

Season	Area	Station No.	Temp°C	Salinity ‰	Date	Averages
contd.	C	334	2.84	33.89	4.2	
		335	2.77	33.82	5.2	
		336	2.77	33.83	5.2	
		337	2.67	33.89	5.2	
		345	2.72	33.86	8.2	
		346	2.76	33.85	8.2	
		352	2.90	33.87	9.2	2.77 33.84 30.1
	D	305	3.08	33.78	22.1	
		306	3.07	33.78	22.1	
		307	3.06	33.77	22.1	
		319	3.23	33.85	30.1	
		323	3.29	33.82	31.1	
		325	3.28	33.89	1.2	
		327	3.24	33.84	2.2	
		331	3.33	33.87	2.2	
		332	3.00	33.89	3.2	
		338	3.11	33.86	5.2	
		339	3.32	33.85	5.2	
		341	3.31	33.83	6.2	
		347	3.08	33.76	8.2	
		349	2.97	33.81	8.2	
		351	3.55	33.75	9.2	
		357	3.24	33.83	10.2	
		358	3.51	33.83	11.2	3.22 33.82 2.2
	E	320	3.74	33.80	30.1	
		321	3.78	33.82	31.1	
		322	3.57	33.81	31.1	
		326	3.35	33.86	2.2	3.61 33.82 31.1
1930-31 November to December	A	503	-1.21	33.90	23.11	
		504	-1.39	33.90	23.11	
		508	-0.99	33.78	24.11	-1.20 33.86 23.11
	B	496	-1.13	33.91	19.11	
		502	-0.87	33.83	22.11	
		505	-0.76	33.90	23.11	
		506	-0.62	33.91	23.11	
		509	-0.86	33.82	24.11	
		510	-0.89	33.87	25.11	
		514	-0.52	33.89	26.11	
		515	-0.39	33.88	26.11	
		516	-0.51	33.91	26.11	-0.73 33.88 24.11
	C	483	-0.47	34.03	14.11	
		492	-0.45	33.96	18.11	

Season	Area	Station No.	Temp°C	Salinity ‰	Date	Averages		
contd.	C	495	-0.96	33.91	19.11			
		498	-0.68	33.91	21.11			
		499	-0.61	33.91	21.11			
		500	-0.80	33.92	21.11			
		501	-0.99	33.88	22.11			
		507	-0.73	33.91	23.11			
		511	-0.91	33.87	25.11			
		519	-0.25	33.92	27.11			
		520	-0.55	33.89	28.11			
		521	-0.76	33.86	28.11			
		522	-0.28	33.89	28.11			
		523	-0.30	33.88	29.11	-0.62	33.91	23.11
	D	482	-0.59	33.96	14.11			
		485	-0.68	33.94	16.11			
		486	-0.47	33.97	16.11			
		487	-0.47	33.94	16.11			
		488	-0.47	33.96	17.11			
		489	-0.83	33.90	17.11			
		490	-0.72	33.89	17.11			
		493	-0.31	33.96	19.11			
		494	-0.88	33.96	19.11			
		512	-0.67	33.87	25.11			
		518	-0.21	33.93	27.11			
		524	-0.10	33.87	29.11			
		525	0.20	33.87	29.11	-0.48	33.92	20.11
	E	478	0.20	33.93	13.11			
		479	-0.67	33.91	13.11			
		480	-0.71	33.90	13.11			
		481	-0.59	33.98	14.11			
		491	-0.62	33.96	17.11	-0.48	33.94	14.11
1930-31 January to March	C	WS532	1.20	33.85	23.1			
		WS534	1.52	33.87	10.1	1.36	33.86	17.1
	D	WS568	1.84	33.87	6.3			
		WS569	2.39	33.78	6.3			
		WS572	2.03	33.91	24.3			
		WS573	2.10	33.83	25.3			
		WS574	2.18	33.83	26.3			
		WS575	2.76	33.82	26.3	2.22	33.84	19.3
	E	WS570	2.26	33.83	8.3			
1931-32 December	A	780	0.22	34.00	19.12			

Season	Area	Station No.	Temp °C	Salinity ‰	Date	Averages
contd.	B	781	0.52	34.08	20.12	
	C	769	0.58	33.97	12.12	
		771	1.83	34.00	15.12	
		773	1.47	34.04	16.12	
		774	1.23	34.00	16.12	
		782	0.74	33.99	20.12	1.17 34.00 16.12
	D	772	1.24	34.04	15.12	
		779	0.76	34.07	19.12	
		784	1.41	33.90	20.12	
		785	1.12	33.94	21.12	
		791	1.12	34.00	22.12	1.13 33.99 19.12
	E	786	1.43	33.91	21.12	
		788	1.34	33.85	21.12	
		789	1.05	33.91	21.12	
		790	1.18	33.97	22.12	1.25 33.91 21.12
1932-33 December	A	1076	0.95	33.95	13.12	
	B	1077	1.01	33.93	14.12	
	C	1061	1.39	33.95	10.12	
		1062	1.21	33.94	11.12	
		1078	1.27	33.94	14.12	1.29 33.94 12.12
	D	1059	1.03	33.90	10.12	
		1060	1.10	33.95	10.12	
		1070	1.53	33.95	12.12	1.22 33.93 11.12
	E	1067	1.80	33.95	12.12	
		1068	1.31	33.94	12.12	
		1069	1.39	33.94	12.12	1.50 33.94 12.12
1932-33 February	A	1131	1.58	33.97	24.2	
	B	1132	2.31	33.91	24.2	
	C	1127	2.84	33.89	23.2	
		1128	2.85	33.90	23.2	
		1130	2.50	33.75	23.2	
		1133	2.68	33.87	25.2	
		1136	2.40	33.90	1.3	2.65 33.86 24.2
	D	1129	3.03	33.82	23.2	

Season	Area	Station No.	Temp °C	Salinity ‰	Date	Averages
1933-34 November to December	A	1203	-0.09	33.90	28.11	
	B	1204	0.00	33.95	28.11	
	C	1200	1.03	34.02	27.11	
		1205	0.47	33.97	28.11	0.75 34.00 28.11
	D	1199	0.77	33.98	27.11	
		1201	1.20	34.05	27.11	
		1202	1.05	33.97	27.11	
		1206	0.62	33.90	28.11	
		1208	0.74	33.96	4.12	0.88 33.97 29.11
	E	1209	0.94	33.97	4.12	
		1210	0.72	33.96	4.12	0.83 33.97 4.12
1934-35 August to September	A	1394	-1.10	34.06	25.8	
	B	1395	-0.69	33.99	25.8	
	C	1396	-0.30	33.99	26.8	
		1401	-0.32	34.01	2.9	
		1402	-0.46	34.02	2.9	-0.36 34.01 31.8
	D	1397	-0.33	33.93	26.8	
		1399	-0.39	33.93	1.9	
		1400	-0.39	33.99	1.9	-0.37 33.95 30.8
	E	1403	-0.01	33.98	2.9	
		1404	-0.32	33.95	3.9	
		1405	0.23	33.96	3.9	-0.03 33.96 3.9
1934-35 January to February	A	1508	2.15	34.01	8.2	
	B	1505	2.11	33.97	7.2	
	C	1501	2.44	33.95	5.2	
		1502	2.45	33.95	5.2	
		1506	2.30	33.96	7.2	2.40 33.95 6.2
	D	1499	2.19	33.87	27.1	
		1503	2.38	33.97	5.2	
		1504	2.41	33.85	5.2	
		1507	2.36	33.79	7.2	2.34 33.87 3.2
	E	1497	2.48	33.93	27.1	

Season	Area	Station No.	Temp °C	Salinity ‰	Date	Averages		
contd.	E	1498	2.33	33.89	27.1	2.41	33.91	27.1
1936-37 October to November	A	1839	-1.25	34.14	13.10			
	B	1840	-0.16	34.06	14.10			
	C	1841	-0.02	34.07	14.10			
		1846	0.30	33.99	20.10			
		1847	0.09	34.02	21.10	0.12	34.03	18.10
	D	1842	-0.05	34.05	14.10			
		1844	0.01	33.98	20.10			
		1845	0.52	33.97	20.10			
		1851	0.17	33.96	23.10	0.16	33.99	19.10
	E	1850	0.27	33.96	22.10			
		1854	1.48	33.93	3.11	0.88	33.95	28.10
1936-37 March	A	1988	2.74	34.05	9.3			
	B	1987	3.40	33.97	9.3			
	C	1981	3.61	33.95	4.3			
		1982	3.35	33.97	4.3			
		1984	3.34	33.90	5.3			
		1986	3.31	33.86	9.3	3.40	33.92	5.3
	D	1980	3.33	33.93	4.3			
		1983	3.75	33.95	5.3	3.54	33.94	5.3
	E	1978	3.82	33.99	3.3			
		1979	3.40	33.96	3.3	3.61	33.98	3.3

TABLE III

Sub-area Averages

Day - after 25 August	Temp °C	Salinity ‰	Region	Estimated temperature	Deviation	Year
0	-1.10	34.06	A	-0.64	-0.46	34-35
0	-0.69	33.99	B	-0.64	-0.05	34-35
5	-0.37	33.95	D	-0.72	0.35	34-35
6	-0.36	34.01	C	-0.74	0.38	34-35
9	-0.03	33.96	E	-0.78	0.75	34-35
14	-1.55	33.82	B	-0.83	-0.72	28-29
14	-1.02	33.88	C	-0.83	-0.19	28-29
23	-0.99	33.81	D	-0.87	-0.12	28-29
24	-1.50	33.80	A	-0.87	-0.63	28-29
49	-1.25	34.14	A	-0.70	-0.55	36-37
50	-0.16	34.06	B	-0.69	0.53	36-37
54	0.12	34.03	C	-0.63	0.75	36-37
55	0.16	33.99	D	-0.61	0.77	36-37
64	0.88	33.95	E	-0.44	1.32	36-37
81	-0.48	33.94	E	-0.05	-0.43	30-31
87	-0.48	33.92	D	0.11	-0.59	30-31
90	-0.62	33.91	C	0.19	-0.81	30-31
90	-1.20	33.86	A	0.19	-1.39	30-31
91	-0.73	33.88	B	0.22	-0.95	30-31
95	-0.09	33.90	A	0.33	-0.42	33-34
95	0.00	33.95	B	0.33	-0.33	33-34
95	0.75	34.00	C	0.33	0.42	33-34
96	0.88	33.97	D	0.36	0.52	33-34
101	0.83	33.97	E	0.50	0.33	33-34
108	1.22	33.93	D	0.70	0.52	32-33
109	1.50	33.94	E	0.73	0.77	32-33
109	1.29	33.94	C	0.73	0.56	32-33
110	0.95	33.95	A	0.76	0.19	32-33
111	1.01	33.93	B	0.79	0.22	32-33
113	1.17	34.00	C	0.85	0.32	31-32
116	1.13	33.99	D	0.94	0.19	31-32
116	0.22	34.00	A	0.94	-0.72	31-32
117	0.52	34.08	B	0.97	-0.45	31-32
118	1.25	33.91	E	1.00	0.25	31-32
118	0.91	33.83	C	1.00	-0.09	26-27
127	0.61	33.85	B	1.06	-0.45	26-27
127	1.08	33.79	D	1.27	-0.19	28-29
128	1.44	33.81	D	1.30	0.14	26-27
135	1.04	33.79	C	1.50	-0.46	28-29
137	2.04	33.82	E	1.55	0.49	26-27
138	0.85	33.81	B	1.58	-0.73	28-29

Day - after 25 August	Temp °C	Salinity ‰	Region	Estimated temperature	Deviation	Year
139	0.30	33.77	A	1.61	-1.31	28-29
144	1.36	33.86	C	1.75	-0.50	30-31
154	2.41	33.91	E	1.99	0.42	34-35
158	2.77	33.84	C	2.09	0.68	29-30
159	3.61	33.82	E	2.11	1.50	29-30
161	3.22	33.82	D	2.15	1.07	29-30
162	2.34	33.87	D	2.18	0.16	34-35
163	2.27	33.85	B	2.20	0.07	29-30
165	2.40	33.95	C	2.24	0.16	34-35
166	2.11	33.97	B	2.26	-0.15	34-35
167	2.15	34.01	A	2.28	-0.13	34-35
169	1.95	33.88	A	2.32	-0.37	29-30
182	3.03	33.82	D	2.52	0.51	32-33
183	2.65	33.86	C	2.54	0.12	32-33
183	2.31	33.91	B	2.54	-0.23	32-33
183	1.58	33.97	A	2.54	-0.96	32-33
185	1.98	33.55	C	2.56	-0.58	27-28
190	2.31	33.56	D	2.61	-0.30	27-28
190	3.61	33.98	E	2.61	1.00	36-37
191	1.97	33.66	B	2.62	-0.65	27-28
191	2.59	33.78	B	2.62	-0.03	25-26
192	3.40	33.92	C	2.62	0.78	36-37
192	3.54	33.94	D	2.62	0.92	36-37
193	2.40	33.67	E	2.63	-0.23	27-28
194	1.41	33.55	A	2.64	-1.23	27-28
195	2.26	33.83	E	2.64	-0.38	30-31
196	2.77	33.78	C	2.65	0.12	25-26
196	3.40	33.97	B	2.65	0.75	36-37
196	2.74	34.05	A	2.65	0.09	36-37
206	2.22	33.84	D	2.67	-0.45	30-31
229	2.21	33.76	C	2.44	-0.23	28-29
231	2.32	33.80	D	2.40	-0.08	28-29
232	2.12	33.77	E	2.38	-0.26	28-29
274	0.46	33.87	B	0.61	-0.15	26-27
275	0.92	33.75	C	0.54	0.38	26-27

TABLE IV

Catches of Krill (Euphausia superba)

in 1925 - 1937

	Total Krill catch	No. Samples	Mean Catch	Variation from overall mean
1925-26	3,229	8	404	-1475
1926-27	50,195	17	2,953	+1074
1927-28	195,086	46	4,241	+2362
1928-29	94,746	90	1,053	- 826
1929-30	75,205	60	1,253	- 626
1930-31	182,700	46	3,972	+2093
1931-32	5,124	18	285	-1594
1932-33	-	-	-	-
1933-34	2,208	10	221	-1658 *
1934-35	21,258	18	1,181	- 698
1935-36	-	-	-	-
1936-37	1,753	23	76	-1803

* based on one positive catch only

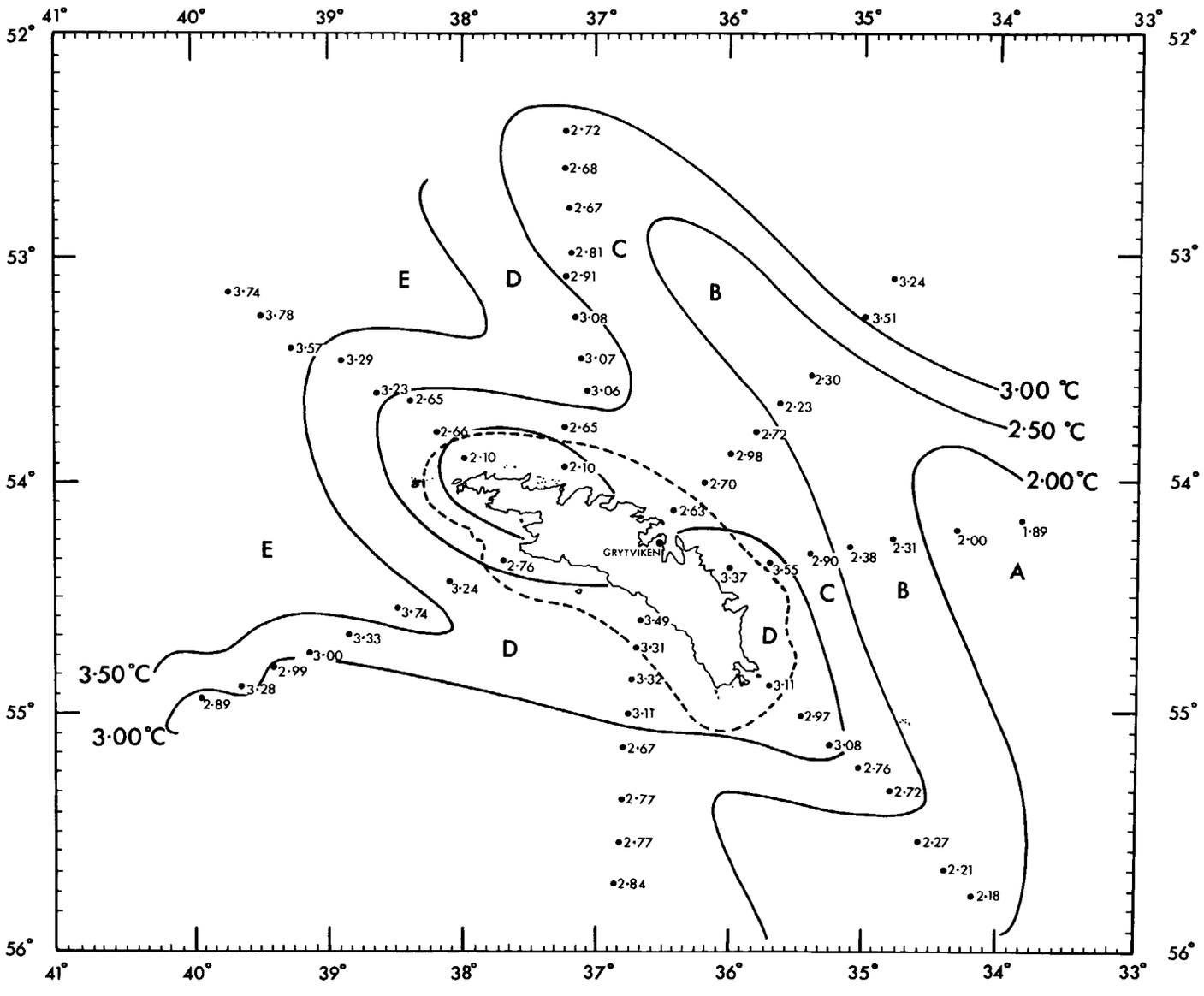

Fig. 1 Water temperature averaged from the surface to a depth of 50 m during an oceanographical survey of South Georgia in January to February 1930. The isotherms, drawn at 0.5°C intervals, are used as the limits of sub-areas A, B, C, D and E for all the surveys.

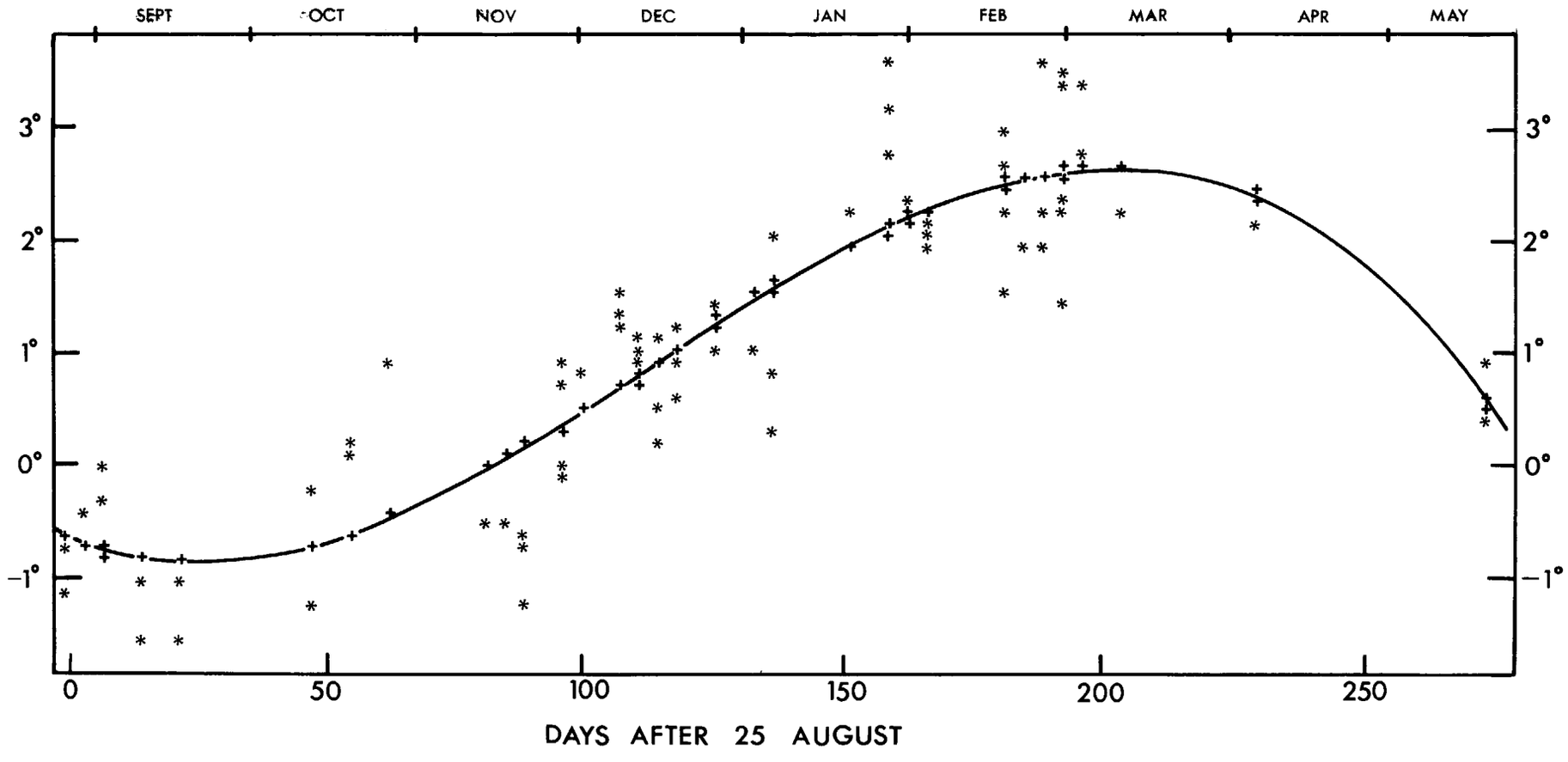

Fig. 2 Seasonal temperature change (0 m to 50 m) round South Georgia. The averages of sub-areas are marked by asterisks and the computed values of a fitted 3rd order polynomial curve by crosses.

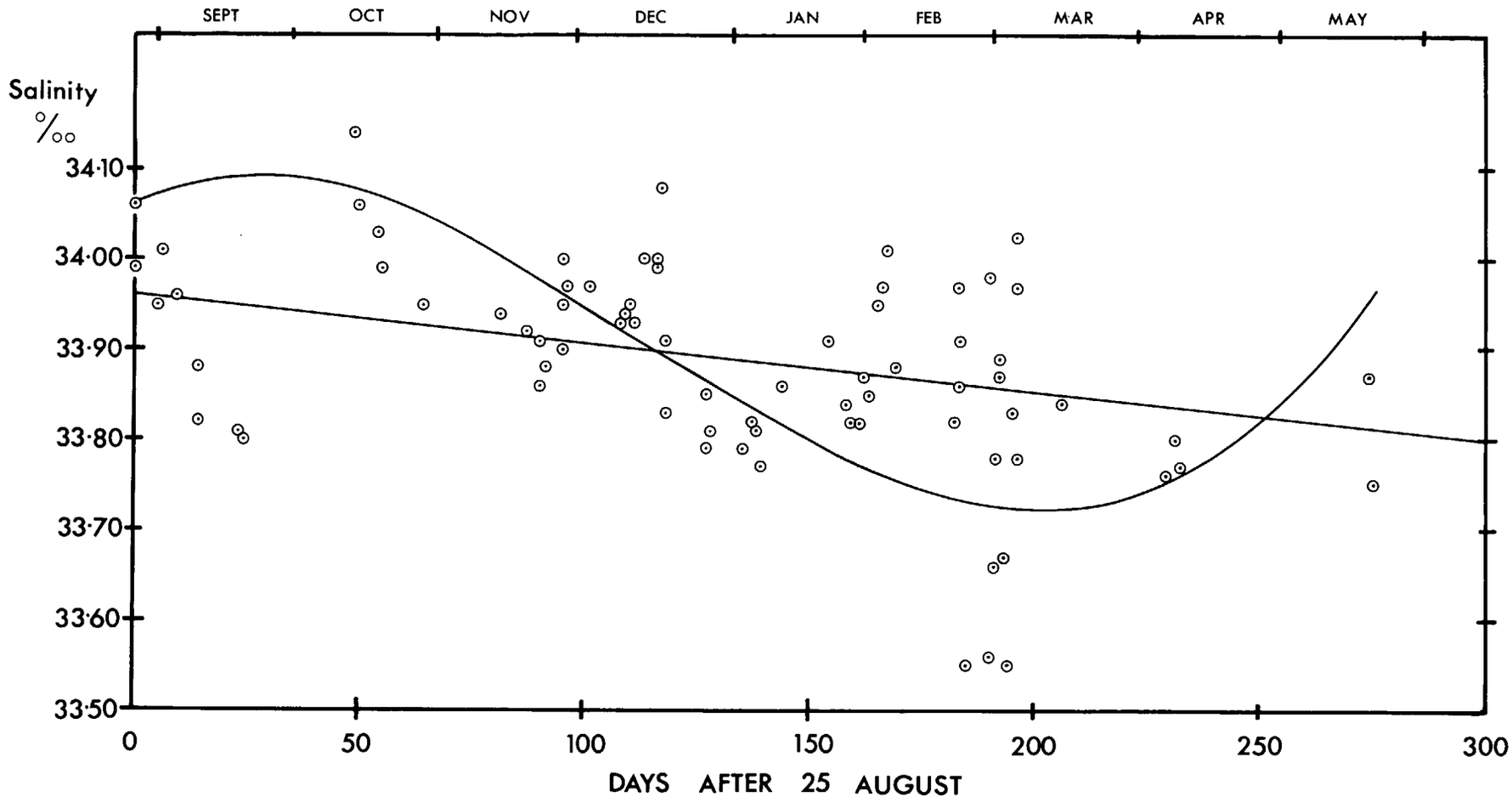

Fig. 3 Seasonal salinity change (0 m to 50 m) round South Georgia. The averages of sub-areas are marked by dots. The straight line is the equation $S = 0.000526T + 33.96‰$. The curved line is the seasonal temperature change from Figure 2 with the temperature scale reversed to show a rough match between high temperatures and low salinities.

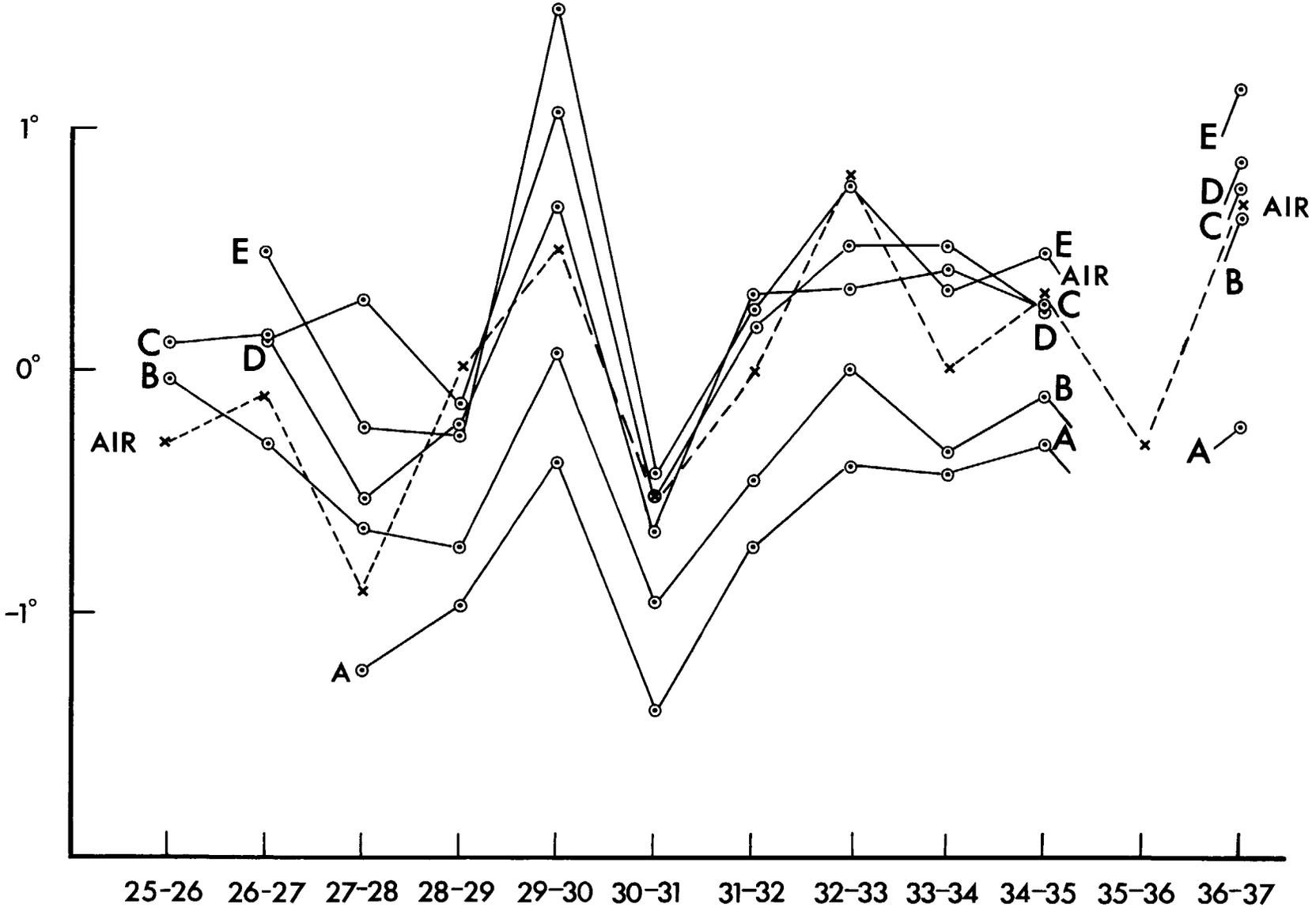

Fig. 4 Annual deviations of average, 0 m to 50 m, August - May, water temperatures of sub-areas A, B, C, D and E round South Georgia, and annual deviations of mean, surface, August - May, air temperature at Grytviken.

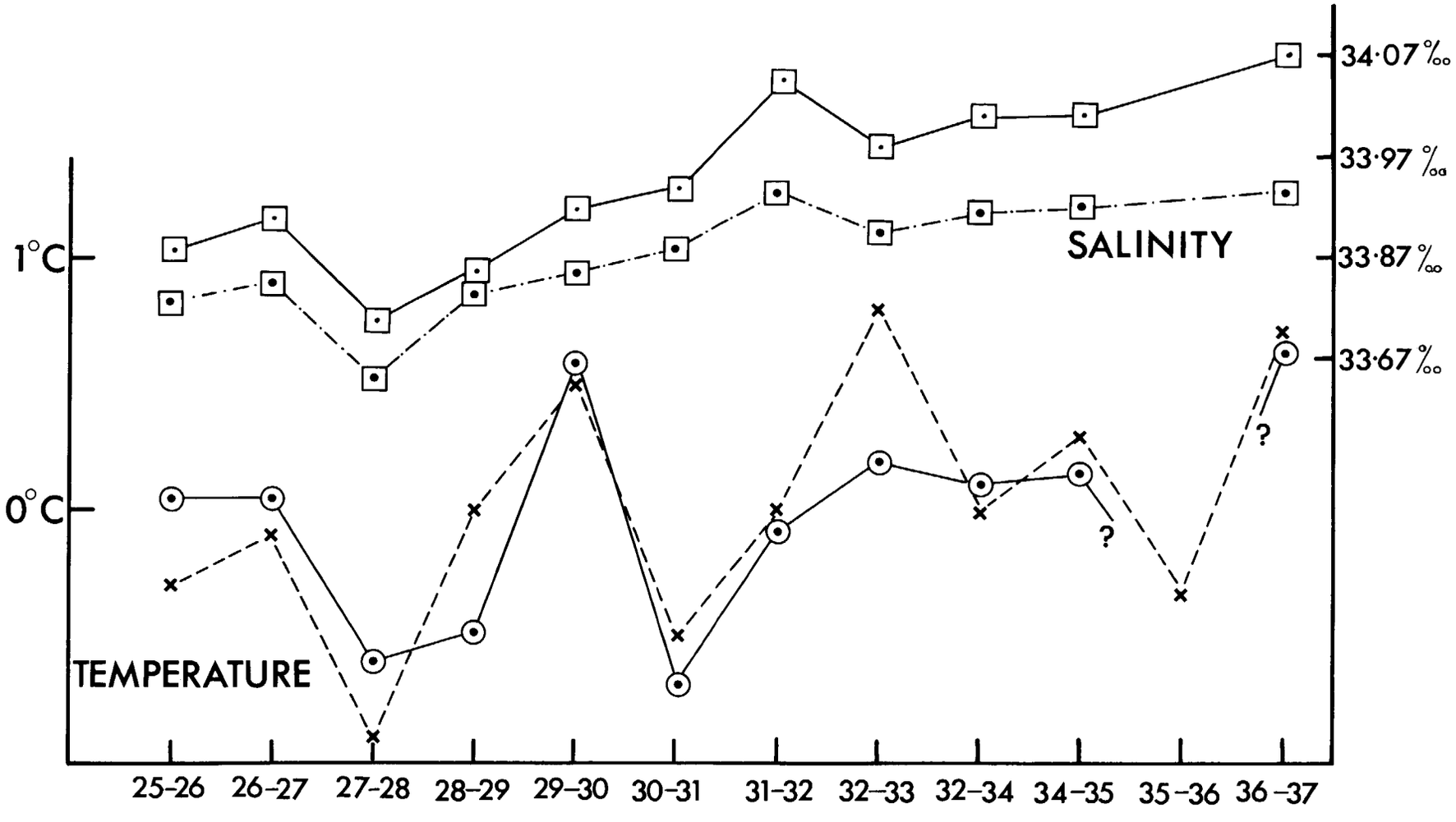

Fig. 5 Annual deviations of average, 0 m - 50 m, August - May, water temperatures round South Georgia (continuous line). Corresponding deviations of mean air temperature at Grytviken (dashed line). Annual variations of average, 0 m - 50 m, August - May, salinity : corrected for seasonal change, continuous line; not corrected, dash and dot line.

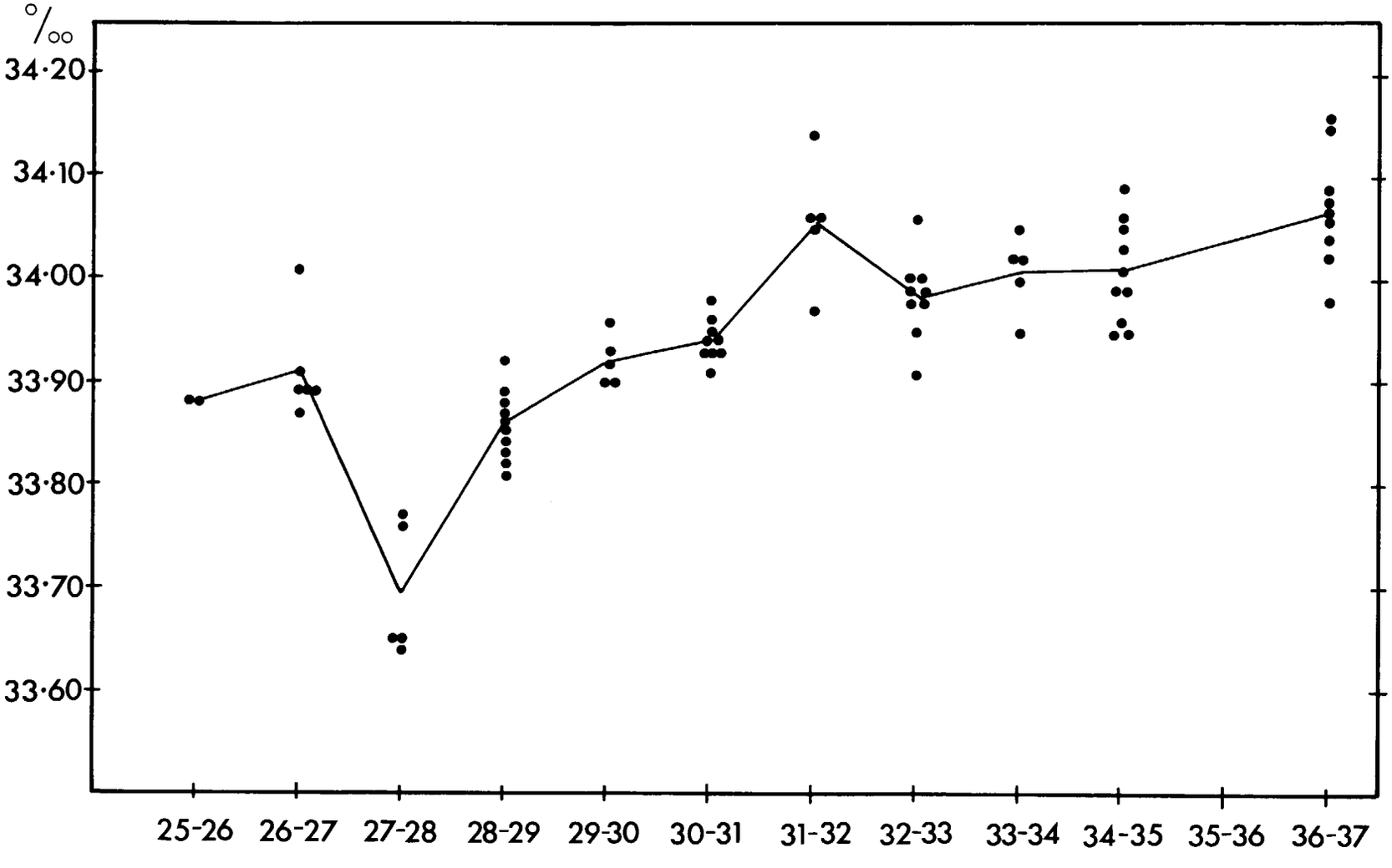

Fig. 6 Annual variations of average, 0 m - 50 m, August - May, salinity at sub-areas A, B, C, D and E, corrected for seasonal change.

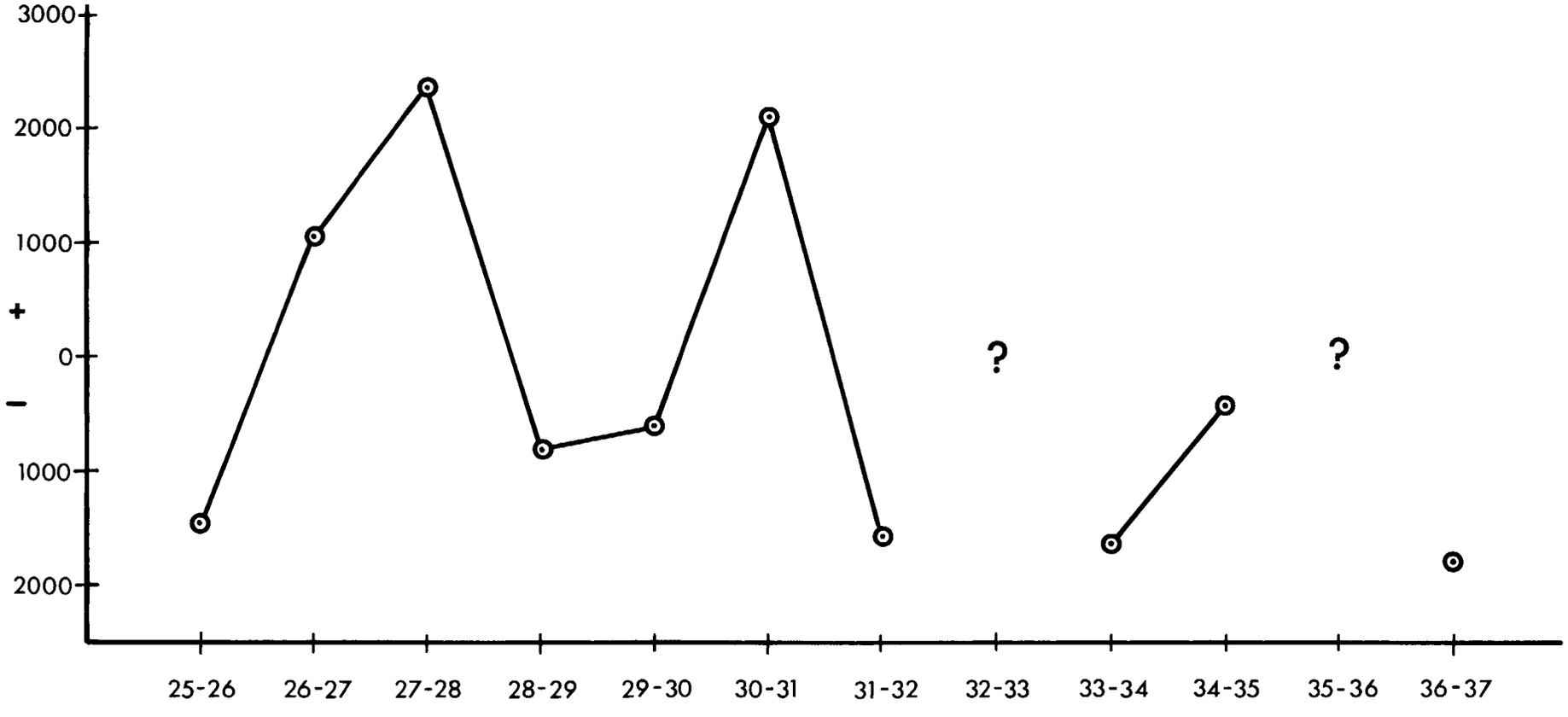

Fig. 7 Annual variation of krill catches from the overall mean for 1925-37.

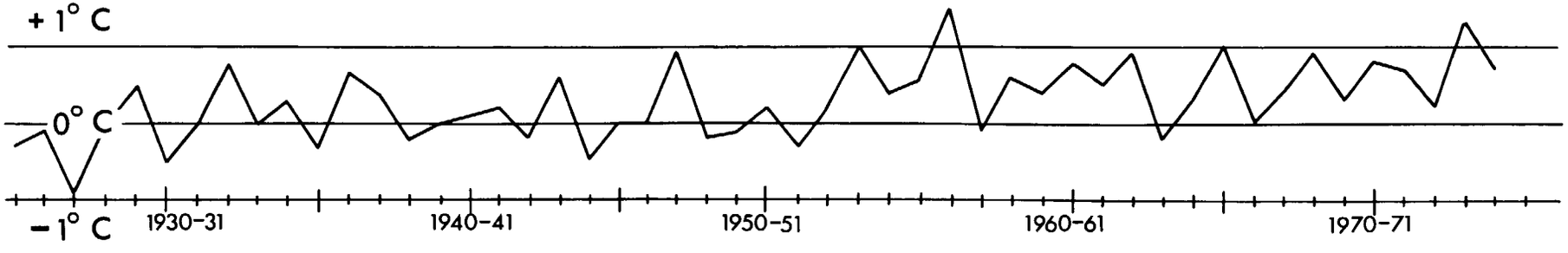

Fig. 8 Deviations of annual mean (August-May) air temperatures at Grytviken, South Georgia, from the mean (August-May) for 1925-37.