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Recent Variations of North Atlantic Sea Surface Temperatures (SST) and the "Type-Tendencies" of the Atmospheric Circulation

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The thermal state of the northern part of the North Atlantic sea surface may be taken as fairly well represented by the results of the observational system of the 9 Ocean Weather Stations (abbr. OWS). For their distribution see Fig. 1.
From the grand total of about 380.000 SST measurements made by the OWS's during the last 15 years (1951-1965) it comes out that this recent period is characterized by a distinct cooling trend. Running 5-year means for the collective of the 9 OWS's clearly show this cooling phenomenon (Fig. 2, after Rodewald, 1966).

The development of SST depends on many factors (Laevastu, 1960), but one of the primary questions may be that on the special pattern of the atmospheric circulation, because the air circulation includes other factors influencing SST, such as air temperatures, cloudiness, storm frequency, wind effect on ocean currents, etc. The general pattern of the atmospheric circulation during the cooling 10-year period 1956-65 may be represented in the form of mean pressure anomalies over the North Atlantic (Fig. 3). These are to be read like high and low pressure systems superposed to the normal pressure distribution, and with the vector "anomaly winds" going around them. Fig. 3 shows that the cyclonic activity was above-normal in middle latitudes of the ocean, to the south of the normal Icelandic Low. On the other hand, there was a strengthening of the Greenland High, accompanied by northeasterly anomaly winds over the Northwest Atlantic.

The year of coldest surface waters during the period 1956-65 was that of 1963, if we consider the collection of the 9 OWS's. The air circulation of this year is represented by Fig. 4. The type of pressure anomalies during 1963 comes out to be similar to that of the whole 10-year period, but more pronounced. A southerly belt of cyclonic activity extends between the sea off the USA east coast and Spain, while there is a high pressure tendency in subpolar regions.

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These pictures underline what the author said some years before concerning the North Atlantic decade 1951-60 (Rodewald, 1963): "The decadal development seems to support the idea that an expanding polar vortex over the ocean is accompanied by a cooling of the sea surface on a spatial average, especially so in middle latitudes."

The recent SST development, however, was not uniform in the different sea areas, and also not in the different months of the year. Table 1 gives for the various OWS's (A, B, C, etc.) and for the 12 months the amount of warming (+) or cooling (-) which occurred from the 5-year period 1951-55 to the 5-year period 1961-65, expressed in hundredths of degree C. In each column the arrangement is from the highest positive value to the highest negative one.

Table ___: Change of mean sea surface temperatures at the Ocean Weather Stations from the 5-year period 1951-55 to the 5-year period 1961-65 (hundredth °C)

DEC		JAN		FEB		MAR		APR		MAY	
A	+102	A	+80	A	+76	A	+116	A	+136	A	+102
M	+28	M	+40	M	+60	M	+44	M	+54	I	+38
I	+2	B	+36	B	+50	I	+40	I	+46	M	+30
C	-26	I	+32	I	+22	B	-12	B	+6	K	-6
B	-34	J	-6	J	-6	J	-12	J	-6	C	-54
J	-44	C	-10	K	-30	E	-14	C	-14	E	-58
K	-48	K	-30	C	-44	K	-42	K	-38	J	-70
D	-82	E	-70	E	-84	C	-88	E	-88	B	-82
E	-86	D	-136	D	-188	D	-230	D	-168	D	-172
Mean	-21		-7		-16		-22		-8		-30

JUN		JUL		AUG		SEP		OCT		NOV	
E	+68	A	-8	A	+32	D	+2	A	+52	M	+36
M	+26	M	-14	E	-14	M	±0	M	+36	A	+18
A	+18	I	-36	M	-16	A	-16	I	+12	I	-20
B	-20	J	-50	I	-44	I	-38	C	-24	B	-42
I	-20	B	-50	J	-58	K	-38	K	-36	J	-56
J	-66	E	-52	K	-58	J	-44	J	-42	C	-60
C	-88	C	-74	B	-68	B	-72	E	-50	K	-70
K	-88	K	-108	D	-140	C	-92	B	-88	E	-82
D	-226	D	-210	C	-142	E	-100	D	-94	D	-116
Mean	-44		-67		-56		-44		-26		-44

The great majority of months show OWS A in the top place of Table 1 and OWS D in the bottom place of it. That means: in general, the Irminger Sea is the region of maximum warming during the last 10 years, while the region about halfway between Newfoundland and the Azores is that of maximum cooling, this cooling being generally much more pronounced than the subpolar warming.

The warming - or least cooling - is mostly confined to the OWS's A, M, I which represent the areas to the west, south and east of Iceland. The more extensive area of stronger cooling is around OWS D, including Stations C, E and even K near Southwest Europe. Seasonally, there is more cooling and less warming during the 6-month period June-November than during the period December-May. Fig. 5 illustrates the seasonal SST development for the Northeast Atlantic area of predominant warming (OWS's A, M, I), for the remaining larger area of cooling (OWS's B, C, D, E, K, J), and for the whole area represented by the OWS's. In general, the cooling tendency was more pronounced during the warmer half of the year than during winter and early spring.

An even more regular annual variation results, when the monthly SST means for the 5-year period 1961-65 are compared with the SST normals of the OWS's compiled 15 years ago (Rodewald, 1952). This is shown by Fig. 6 for the same areas as have been taken for Fig. 5. In the Northeast (OWS's A, M, I), the positive SST anomaly has its maximum (+1.1°) in March (scattering Febr. - March) its minimum (+0.2°) in September (scattering August - October). This annual variation of the SST anomalies is nearly contrary to the annual variation of the SST itself, so that the annual range of SST is decreased by this type of seasonal anomaly distribution.

For the remaining North Atlantic region the annual variation of SST anomalies shows the minimum in May (-0.5°), the maximum in December (+0.3°), but there exists a greater scattering in the time of extremes between the various OWS's. The fact that the greatest cooling and negative anomaly occurred in the warmer season of main radiation input, could indicate an effect of increased cloudiness, but it could also be due to increased windiness and other factors.

It is worth mentioning that the recent SST cooling trend took place also along the Canadian and USA east coast, as may be seen from some ICNAF papers, Spec. Publ. No. 6, Section H (1965). At St. Andrews, N.B., the cooling from(1951-55) to (1961-65) was of the same amount (-1.4°) as at OWS D, the seasonal distribution showing the maximum decrease in July (-2.1°) and the minimum decrease in December (-1.0°).

For the rest, it may be taken from the trend curves of the OWS's B, C, D adjoining the ICNAF area (Fig. 7-9) that the cooling trend has stopped or reversed recently - raising uncertainty about the future development. The rewarming is greatest at OWS B from what it appears that it was spread from the warmed Irminger Sea, in consequence of the intensified circulation (see Fig. 2 and 3).

With regard to the fact that the SST variations and anomalies were by far not uniform seasonally, it is interesting to note that the atmospheric circulation also showed great seasonal differences in its anomalies. In the 5-year period 1961-65, for instance, strong positive pressure anomalies prevailed in the northern regions between Baffin-Land and Norway during the 5-month period November-March, whereas pressure was below-normal in middle and subtropical latitudes of the North Atlantic. Contrary to this "type-tendency" of the winter months, negative pressure anomalies prevailed in the northern regions during the 7-month period April - October. Tables 2 and 3 demonstrate the effect on the pressure difference between the Azores High and the Icelandic Low along a central meridian of the North Atlantic.

Table 2: Mean pressure difference along 30°West between 35°N and 65°N

	Normal diff.	Mean diff. 1961-65		% of Normal
Annual mean	15.5 mbar	14.5 mbar	=	93.6 %
Mean (Nov.-March)	20.4 "	13.2 "	=	64.7 %
Mean (Apr.-Oct.)	12.0 "	15.4 "	=	128.3 %

Table 3: Departure (mbar) from the normal mean pressure difference along 30°W between 35°N and 65°N during the 5-year period 1961-65

APR	MAY	JUN	JUL	AUG	SEP	OCT
+3.5	+3.4	+4.6	-1.3	+1.1	+4.9	+7.3

NOV	DEC	JAN	FEB	MAR
-6.6	-9.3	-6.6	-8.3	-5.1

Mean (APR-OCT) +3.4; Mean (NOV-MAR) -7.2 mbar

The meridional pressure difference is an indicator for the vector mean speed of west winds between subtropical and subpolar latitudes. This westerly component was sharply below-normal during the cold season (Nov.-March) 1961-65, and it was well above-normal during the warmer season of this 5-year period. By this way, the normal annual variation of the vector mean speed of westerlies was smoothed in the period 1961-65. The seasonal distribution of SST anomalies, on the whole, corresponds to such a differential "type-tendency" of the atmospheric circulation.

A special phenomenon - and problem too - was the outstanding persistence of the type of atmospheric circulation during several months of the 10-year period 1956-65. The high degree of "type-tendency" may be shown for the months of March and October.

Figures 10 and 11 illustrate the mean circulation during March for the 5-year periods 1956-60 and 1961-65. During both periods the Icelandic Low shows a pronounced displacement and extension to the south, with a belt of strong "southern westerlies" in subtropical latitudes.

In order to express numerically the similarity of the two periods, field correlation has been computed for the gridpoints of the overlapping areas:

15° - 40°N, 0 - 20°W, 10°- 30°W, etc.
40° - 60°N, 0 - 30°W, 15° - 45°W, etc.
60° - 85°N, 0 - 40°W, 20° - 60°W, etc.

The result is shown by Fig. 12 in which correlation coefficients have been entered near the centre of the respective fields, underlined values being statistically significant. It comes out that the persistence of the March anomaly type from (1956-60) to (1961-65) is mostly far greater than by chance.

The month of October is an example for another type of atmospheric circulation: The Icelandic Low is greatly intensified nearly in its normal position, with strong "northern westerlies" blowing around its southern semicircle (Fig. 13 and 14). Also in this case the persistence is well developed (Fig. 15).

Over extended areas the sign (+ or -) frequency of the monthly pressure anomalies was 80 - 90 % for the 10 months of March and October, 1956-65.

Table 4: Geostrophic windfield of the pressure anomalies for the 10 year-period 1956-65; months of March (M) and October (O).
D = Direction of the "anomaly wind" in degrees
F = Speed of the "anomaly wind" in knots

		65°N		60°N		55°N		50°N		45°N	
		D	F	D	F	D	F	D	F	D	F
10°W	M	163	2.0	150	9.2	147	10.2	160	7.9	201	6.7
	O	212	6.0	237	7.9	243	4.2	237	1.5	73	3.1
20°W	M	130	6.8	122	10.0	139	7.9	171	6.0	219	6.9
	O	177	3.7	227	9.9	235	7.4	238	4.3	141	2.1
30°W	M	102	6.8	74	7.4	93	7.0	102	2.4	235	4.7
	O	67	5.3	222	8.1	238	9.6	235	5.3	184	2.8
40°W	M	47	7.6	63	8.8	55	9.6	37	6.6	352	4.0
	O	54	10.1	356	3.2	267	8.8	259	6.2	239	3.5
50°W	M	47	6.4	53	7.1	35	8.8	41	6.2	31	6.1
	O	31	4.6	3	7.1	323	5.6	295	2.9	216	1.0
60°W	M	50	3.6	38	6.0	50	9.0	53	7.5	26	5.6
	O	6	2.5	338	3.9	327	5.1	19	1.4	77	2.8

Table 4 shows the computed "anomaly winds" for the northern part of the North Atlantic for the two months March and October during the 10-year period 1956-65. The grid point data for the latitudes 65° - 45°N, longitudes 10 - 60°W clearly demonstrate the different mean wind systems of March and October which are superposed to the normal wind systems of the respective months.

Actual anomaly winds will have about 0.65 of the geostrophic wind speed (and an angle of inclination of about 13° with regard to isallobars). Even with such a reduction, they appear to be sufficiently strong for exe ting their influence which, in the Northwest Atlantic, would consist in a strengthening of both the warm Irminger Current and the cold Polar Current during the 10-year period 1956-65.

The SST anomalies in their space-time distribution certainly are correlated more or less to the atmospheric circulation anomalies, and the SST trend phenomena seem to be due not least to circulation "type tendencies which are predominant for a longer time. But from what are these tendencies and their quasi-persistence, if not from the sea ? There should exist some sort of feed-back, since the atmosphere may be assumed to have no memory in itself for more than half a month. This is an unsolved but important problem, and any attempt to predict future SST developments will depend to a great part on its solution.

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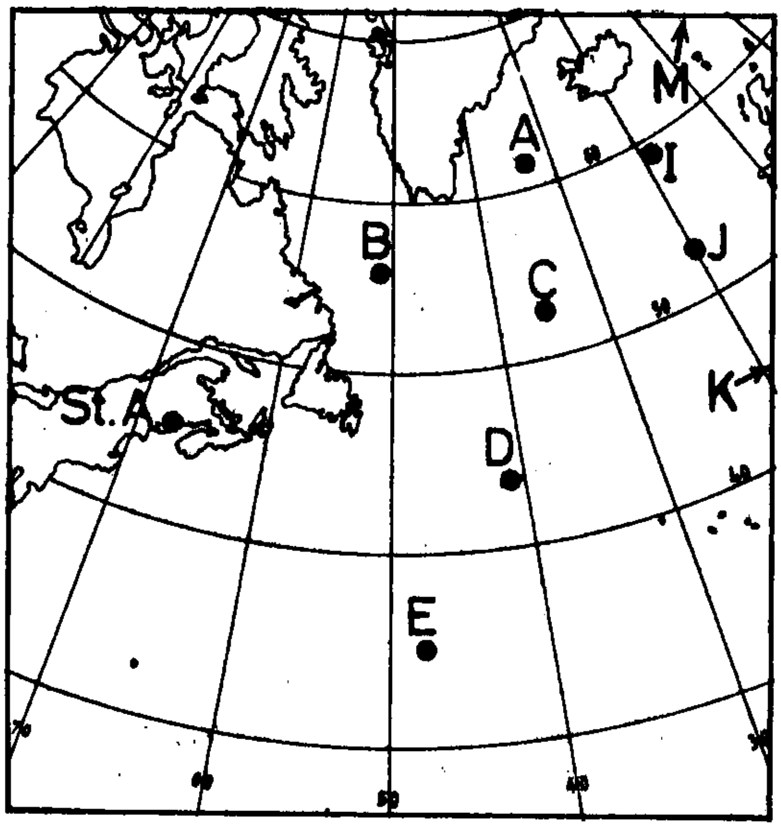

Fig. 1 Distribution of the Ocean Weather Stations. Positions M = 66°N, 2°E; K = 45°N, 16°W. St. A. = St. Andrews,N.B.

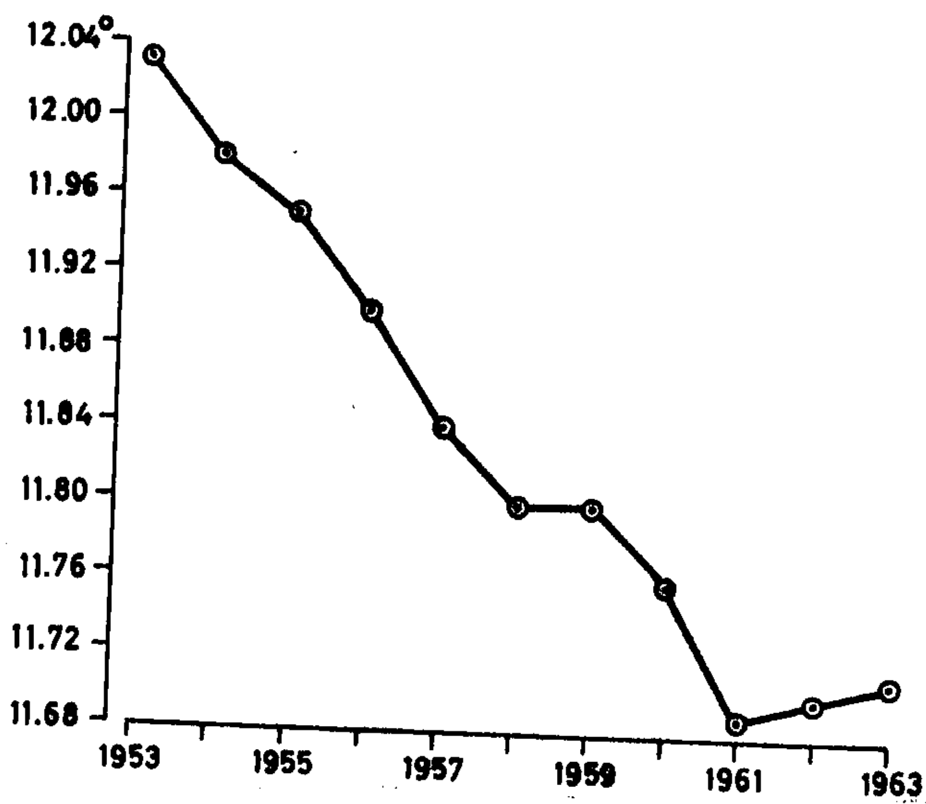

Fig. 2 Running 5-year means of SST for the collective of the 9 OWS's. Year numbers indicate the central year of the 5-year period (1953 = 1951-55).

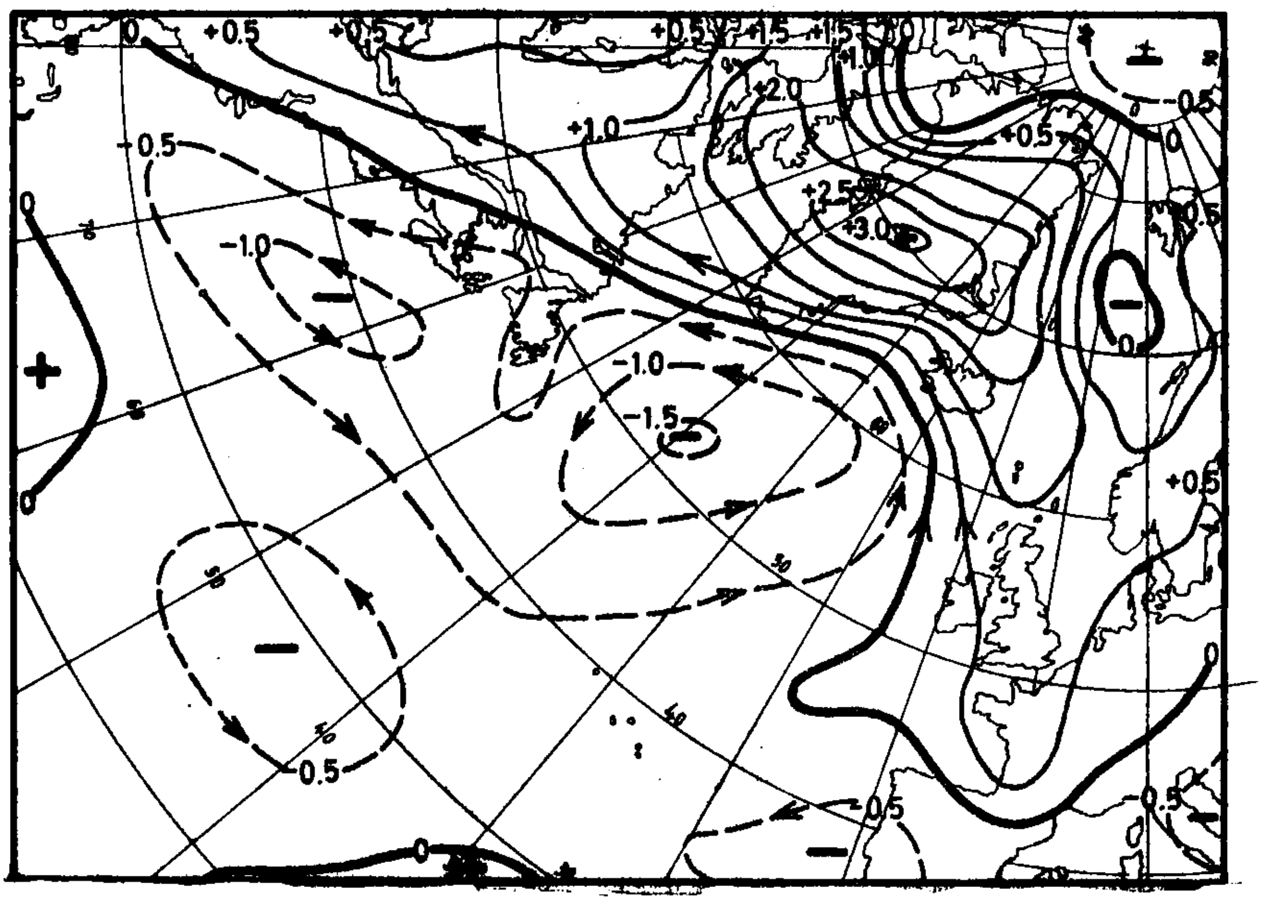

Fig. 3 Mean pressure deviation (mbar) from normal for the 10-year period 1956-65. Normal period 1900-1939. Arrows indicate the sense of anomaly circulation.

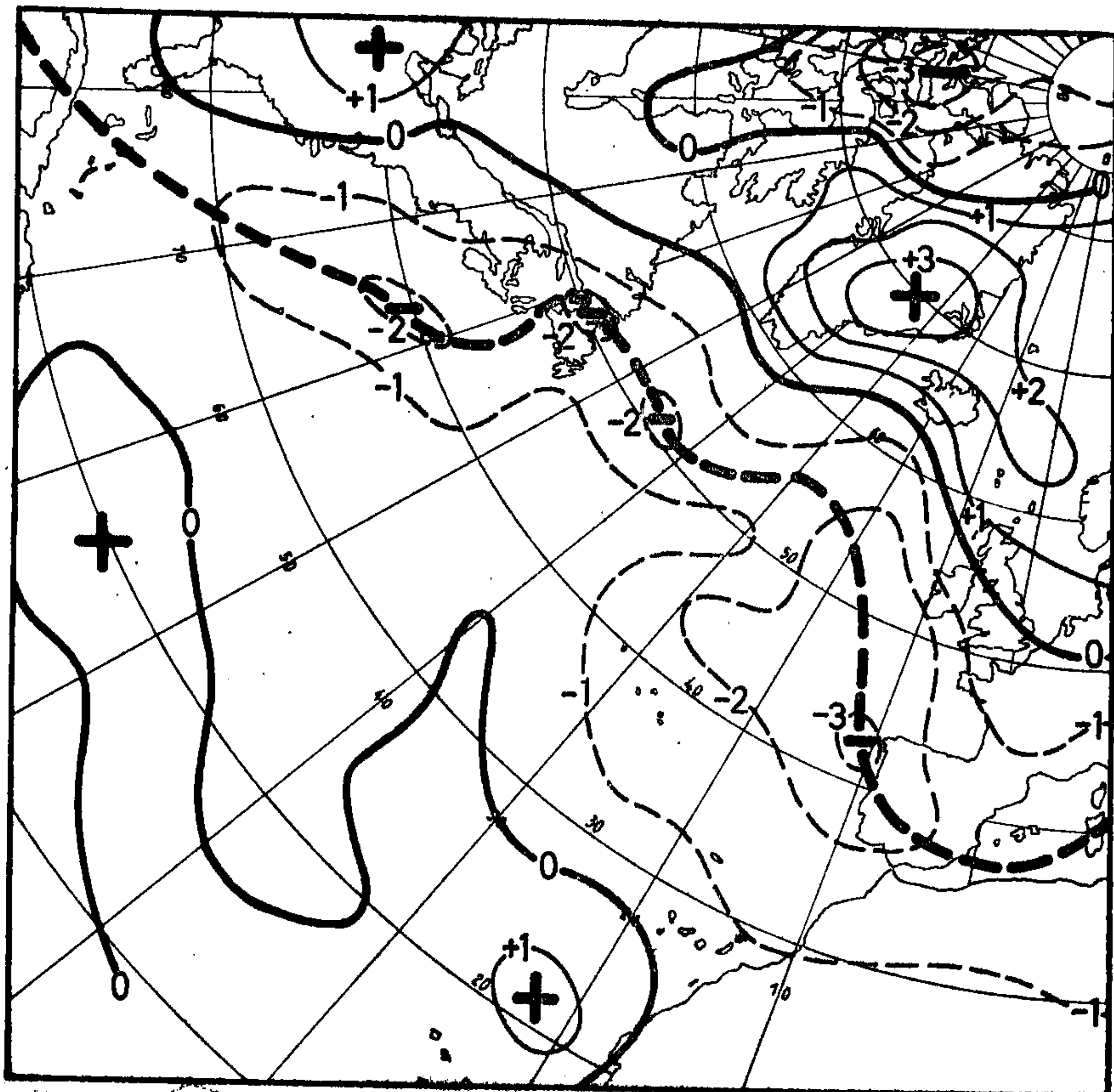

Fig. 4 Mean pressure deviation (mbar) from normal for the year 1963. The thick dashed line marks the axis of above-normal cyclonic activity.

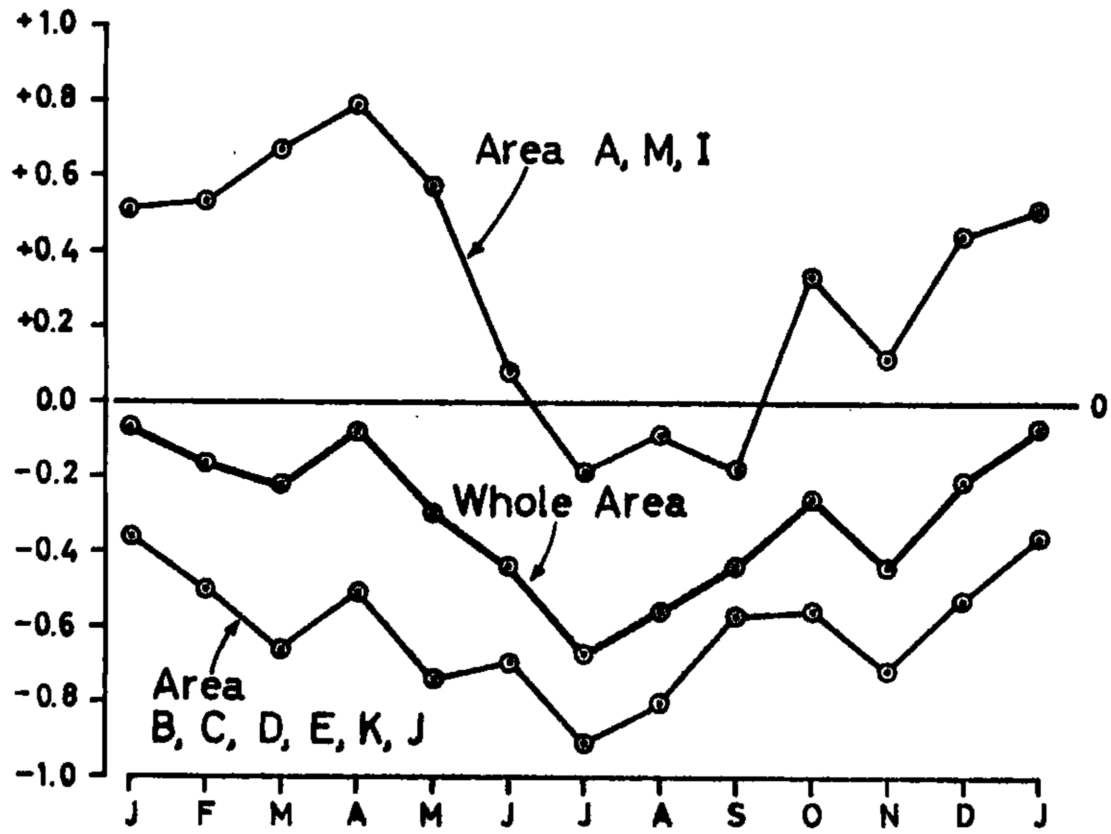

Fig. 5 Change of mean SST from the period 1951-55 to the period 1961-65 for the area of OWS's and for two sub-areas.

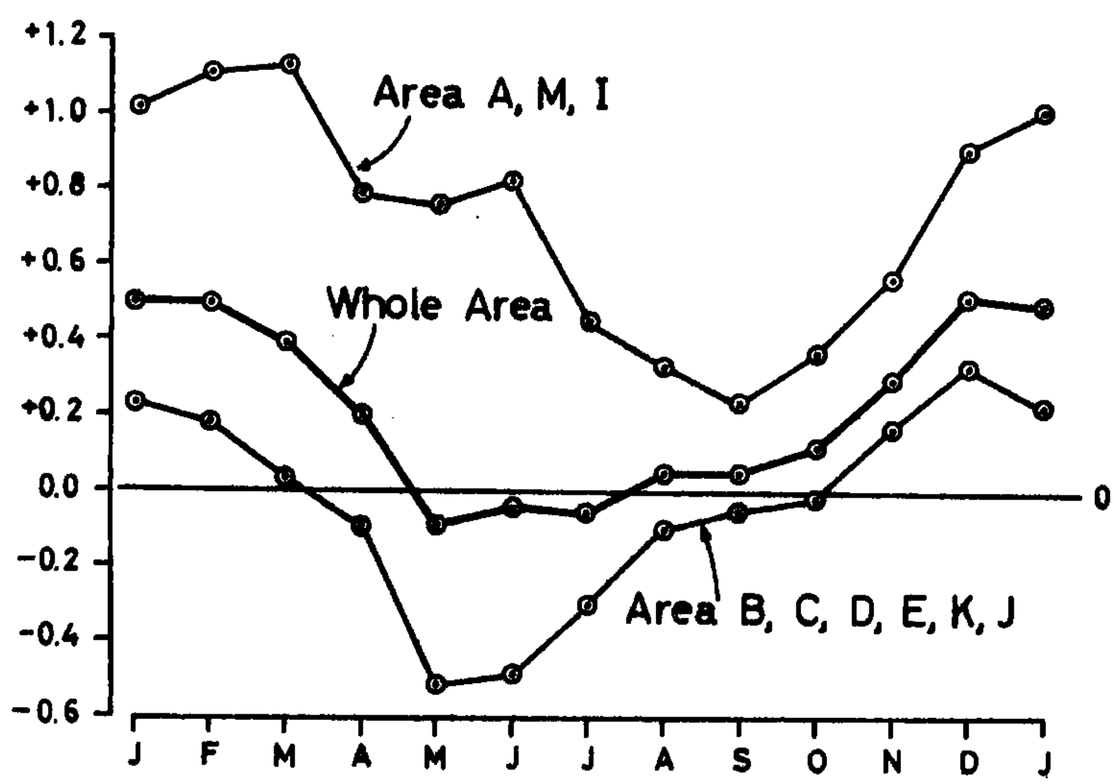

Fig. 6 Departure from normal SST during the period 1961-65 for the area of OWS's and for two subareas.

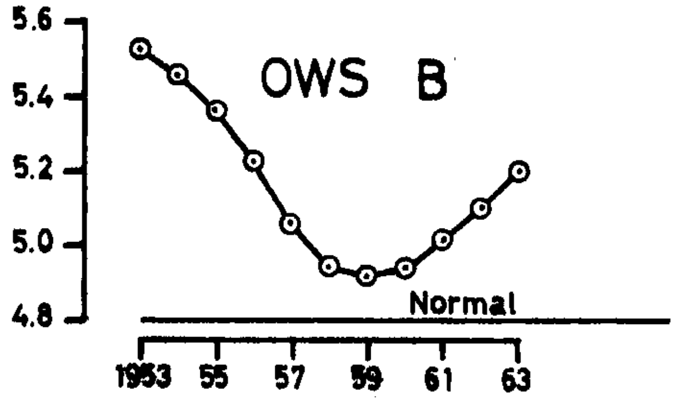

Fig. 7 SST running 5-year means for OWS B (1953 = period 1951-55)

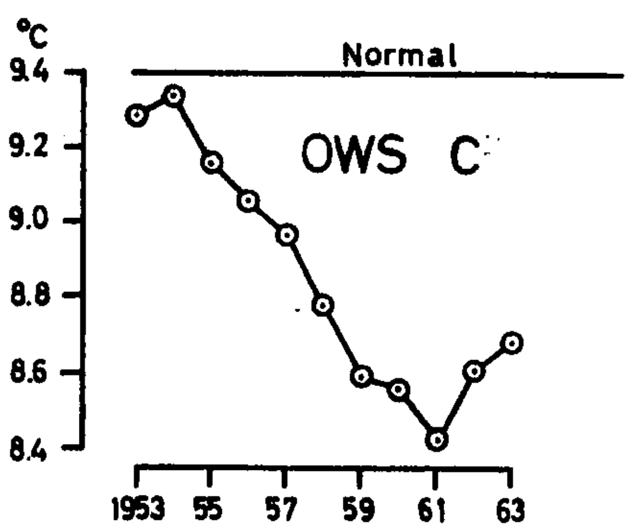

Fig. 8 SST running 5-year means for OWS C
(1953 = period 1951-55).

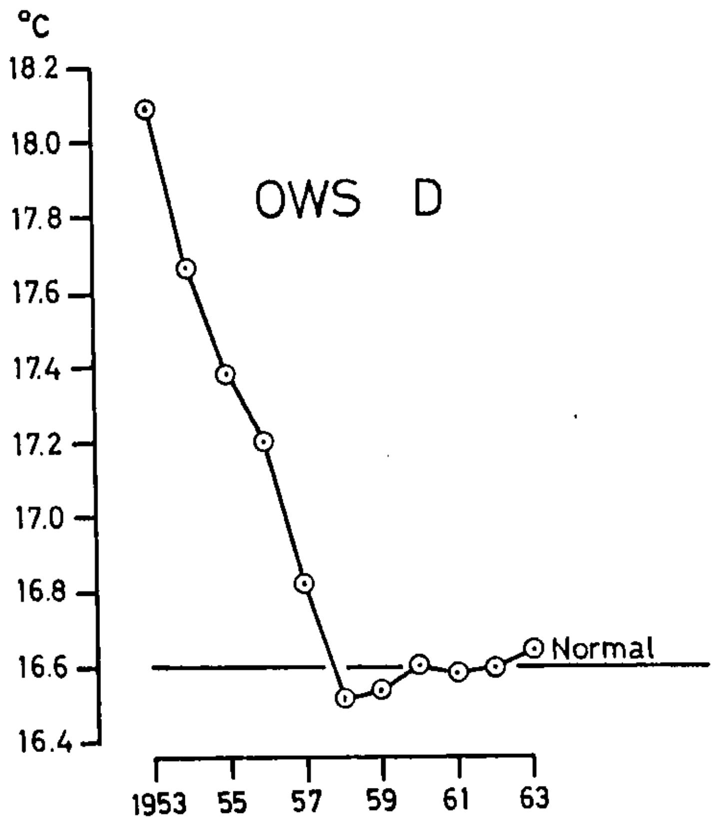

Fig. 9 SST running 5-year means for OWS D (1953 = period 1951-55).

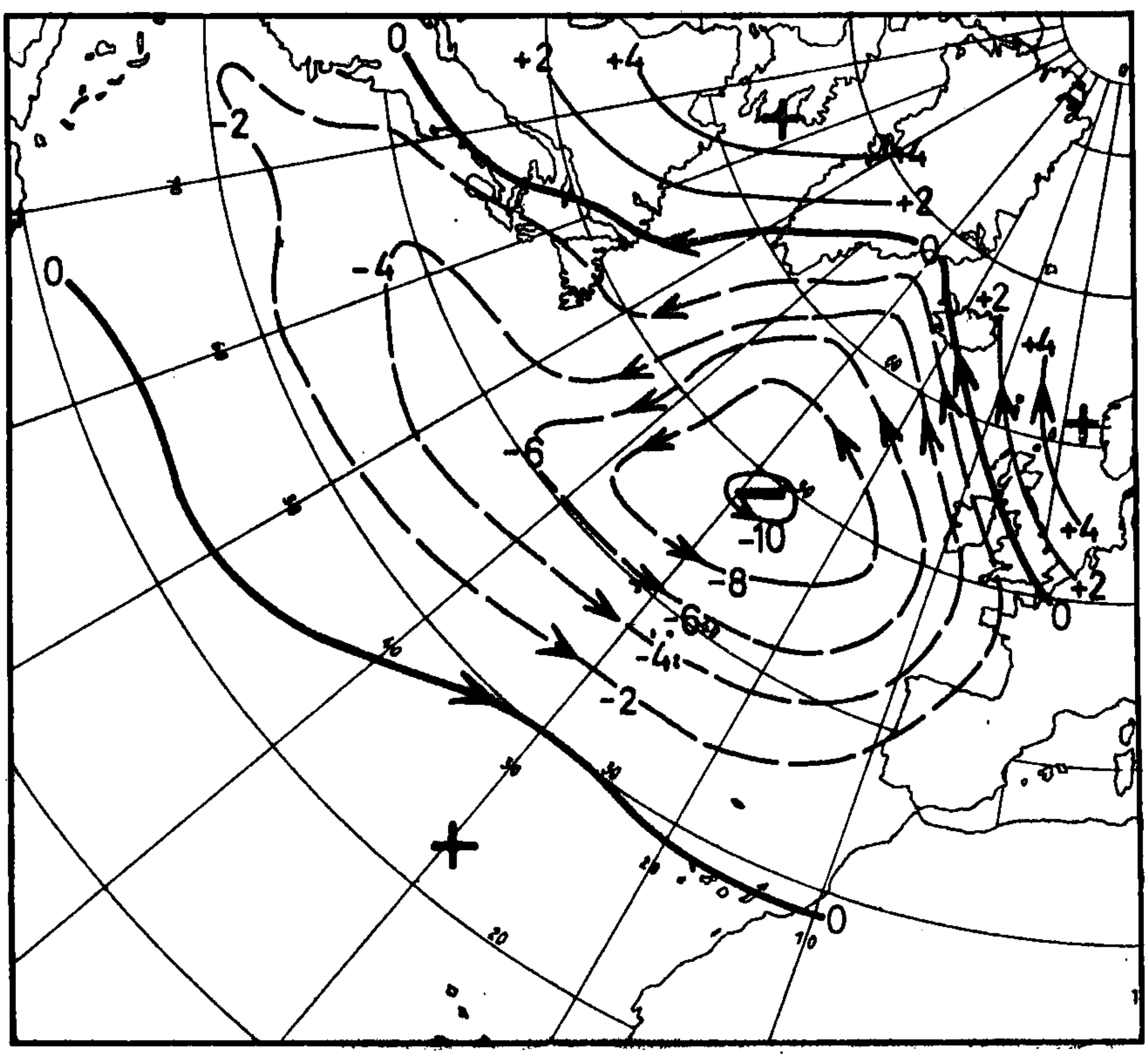

Fig. 10 Mean pressure deviation (mbar) from normal for the month of March during the period 1956-60

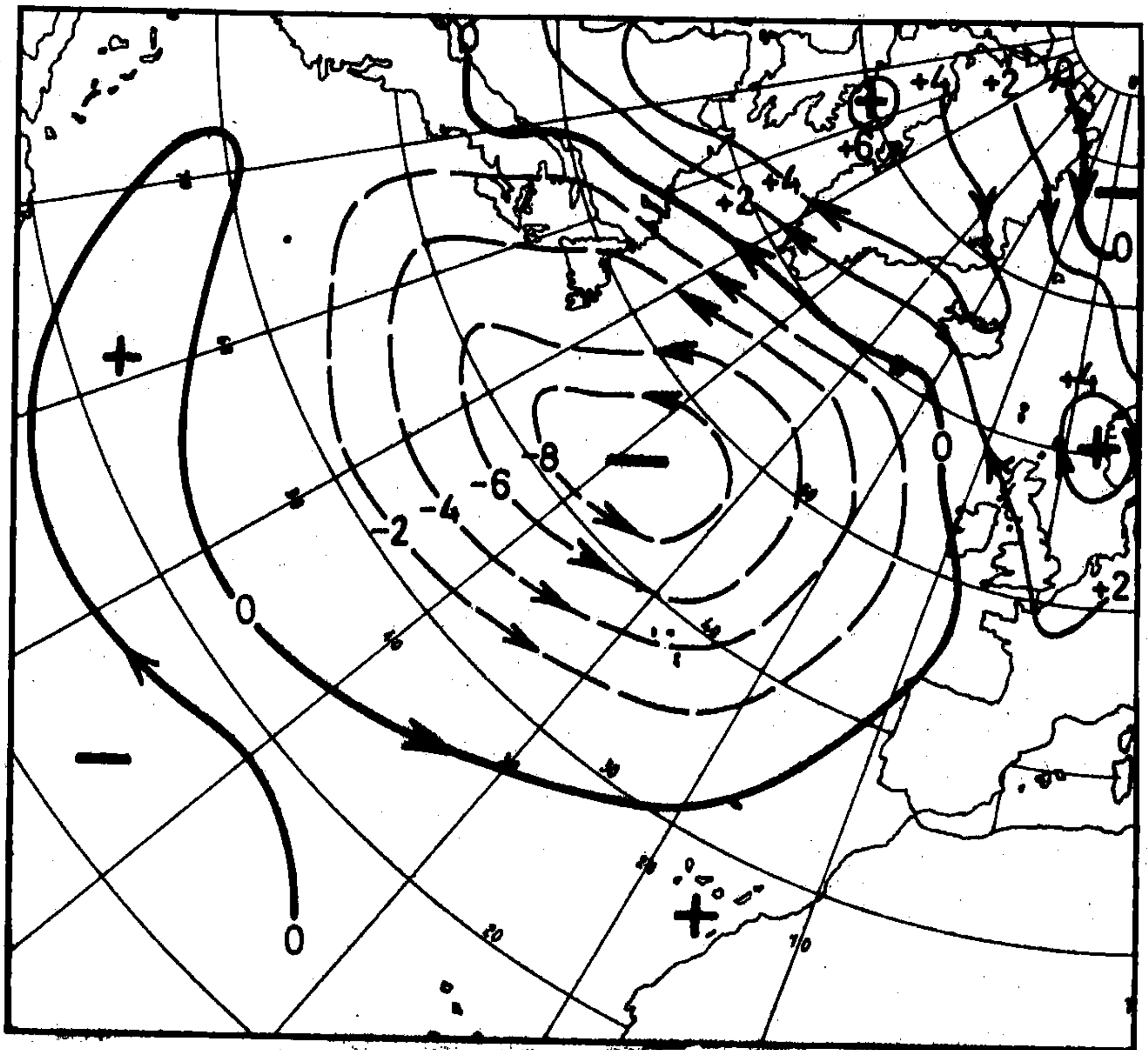

Fig. 11 Mean pressure deviation (mbar) from normal for the mcmth of March during the period 1961-65

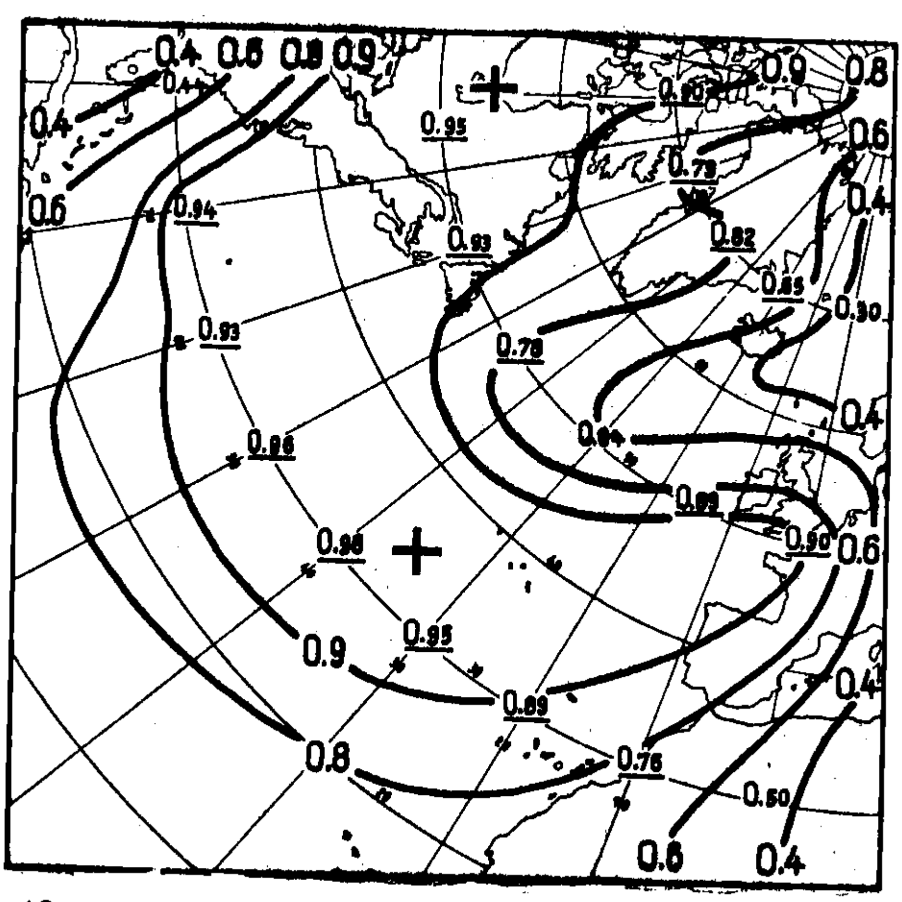

Fig. 12 Correlation between the March pressure anomalies of the periods (1956-60) and (1961-65)

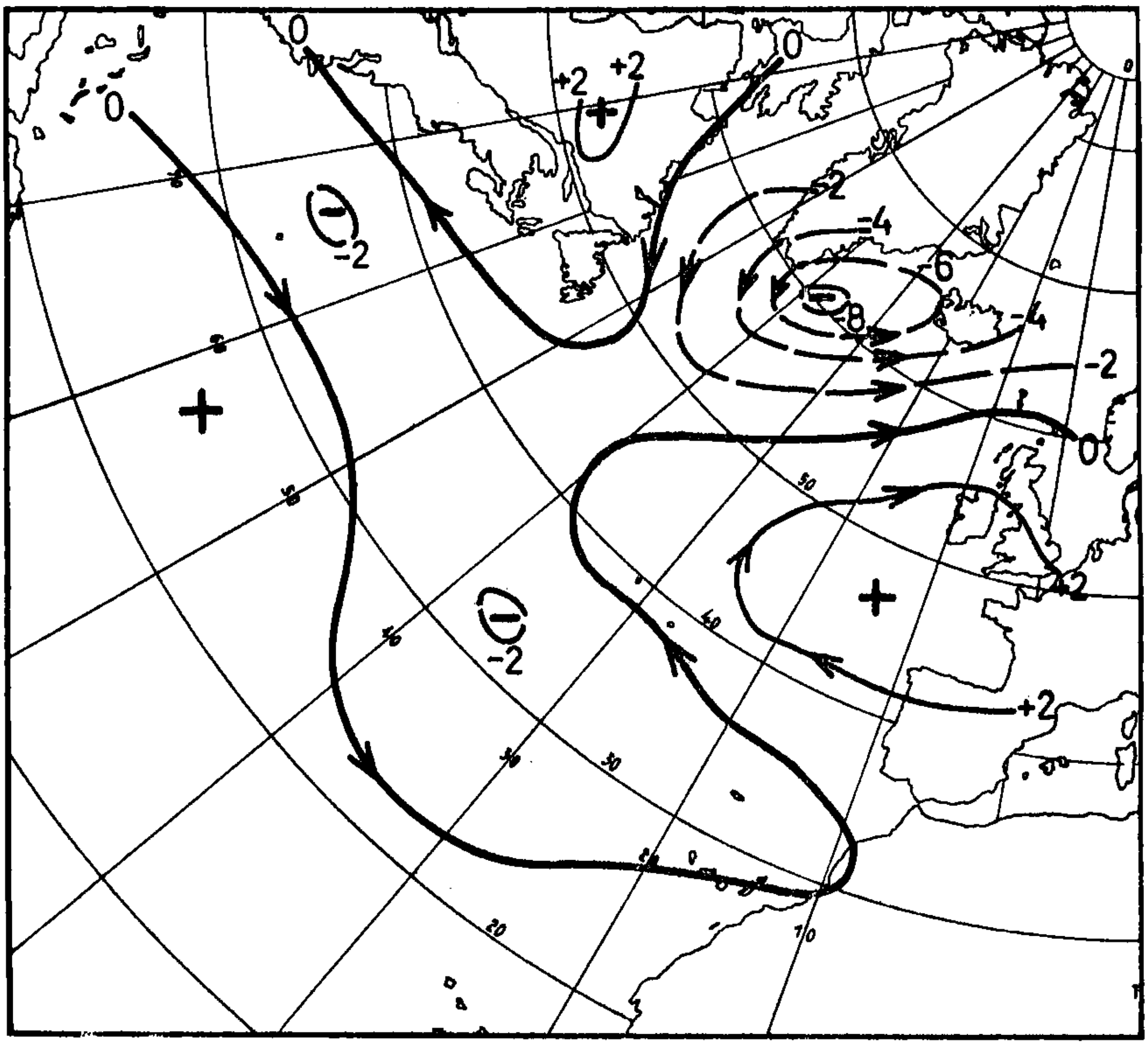

Fig. 13 Mean pressure deviation (mbar) from normal for the month of October during the period 1956-60

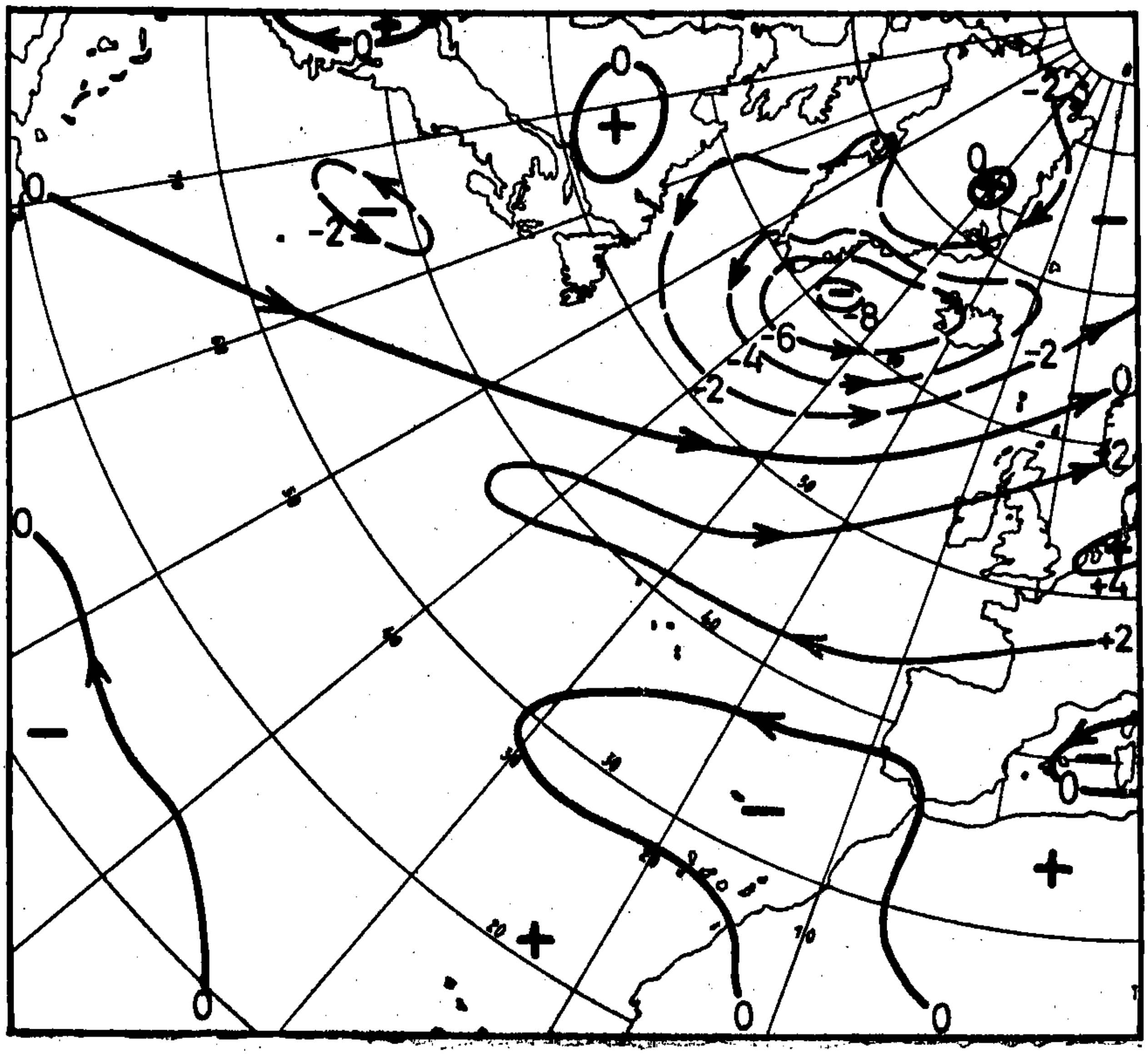

Fig. 14 Mean pressure deviation (mbar) from normal for the month of October during the period 1961-65

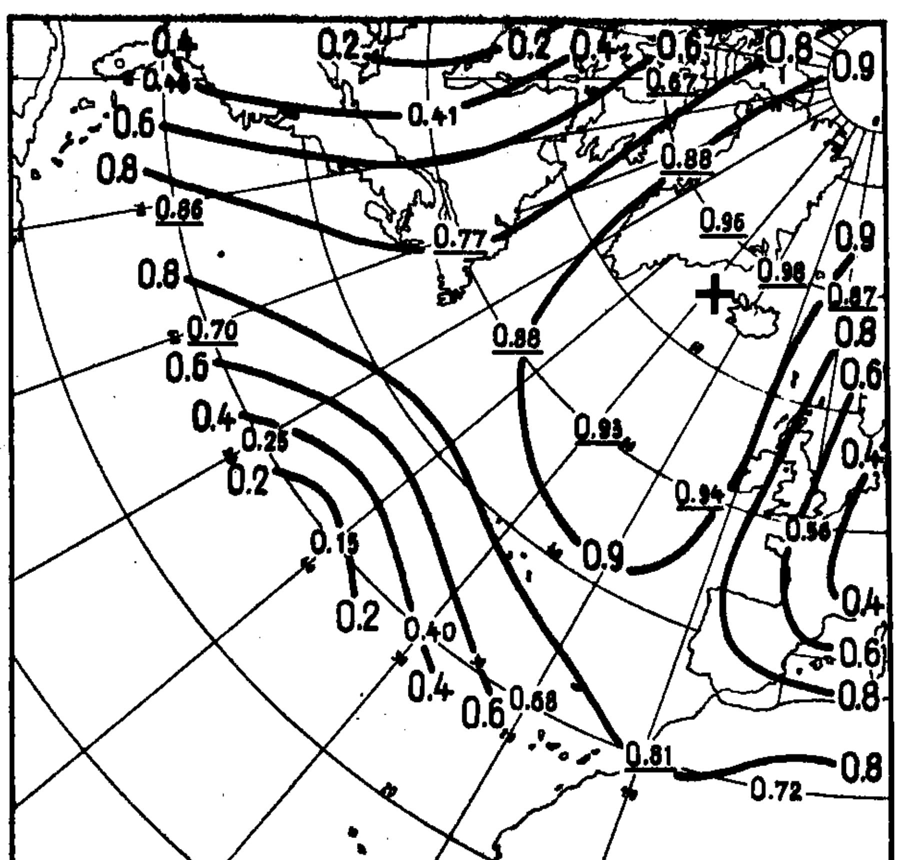

Fig. 15 Correlation between the October pressure anomalies of the periods (1956-60) and (1961-65)