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CYCLONICITY ESTIMATES IN THE SOUTHWEST PACIFIC FROM SATELLITE PHOTOGRAPHS

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CYCLONICITY ESTIMATES IN THE SOUTHWEST PACIFIC FROM SATELLITE PHOTOGRAPHS

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Abstract

Cloud vortices appearing in satellite pictures of the southwest Pacific region over a twelve-month period were tracked, and cyclonicity estimates made on the assumption that each vortex represented a surface cyclone. These estimates are compared with two others derived from conventional surface analyses. All three estimates confirm a local maximum of cyclonicity in the northern Tasman Sea, and there is evidence that surface analyses made in data-scarce regions, without the aid of satellite pictures, tend to underestimate the number of cyclone centres actually present.

1. Introduction

During the past decade at least two comprehensive studies have been published dealing with the frequency and distribution of southern hemisphere cyclones. One is in the form of a series of articles by Taljaard and van Loon (1962) and Taljaard (1963, 1964, 1965) containing maps of cyclone centres during the IGY period from July 1957 to December 1958; while positions are given once daily - at 1200 GMT - tracks have not normally been shown. The second study, by Karelsky (1961), made use of analysed maps of the Australia region for the 15-year period 1946-1960 to locate cyclone centres twice daily (1100 and 2300 GMT) and construct cyclone tracks from which it was possible to calculate a quantity called 'cyclonicity'. Karelsky defines 'cyclonicity' as "the time in hours during which cyclone centres occupy a given 5-degree square during a particular period of time (say, a week, month or season, etc.)".

Satellite pictures of the southwest Pacific region have been used here to identify and track vortical cloud patterns for a twelve-month period. These vortices were of two types, (i) frontal vortices in which one or more frontal cloud bands spiral into the centre of the vortex, and (ii) vorticity centres in which the central part of the system consists of an area of enhanced cumulus which may, or may not, exhibit spiral banding.[1]

1 Additional information on the subject of cloud vortices can be found in "Application of Meteorological Satellite Data in Analyses and Forecasting". ESSA Tech. Pub. NESC 51. Washington; U.S. Dept. Commerce Pub. by R.K. Anderson et al. 1969.

A frontal vortex seen in satellite pictures will be accompanied by a surface cyclone in almost every case, and often the two centres can be expected to lie within 200 miles of one another (Widger, 1964a). Cyclogenesis in association with a frontal cloud band can produce a circulation which begins at low levels and which later extends through to the higher levels of the troposphere; Widger (1964b) indicates that since a cloud vortex will not normally become visible in satellite pictures until a circulation develops at about 500mb, the early stages of this type of cyclogenesis will not be accompanied by a frontal cloud vortex.

A project FAMOS report (1966) states that vorticity centres seen in satellite pictures are "usually best represented at the surface in the form of sharp cyclonic curvature of the isobars". While the more prominent and active cloud patterns associated with vorticity centres (such as comma-shaped cloud patterns termed 'PVA max') will be accompanied by surface low pressure centres (Anderson, (1969), the case of the smaller and less active cloud patterns is obscure, as was revealed during discussions at the WMO Inter-regional Seminar on Interpretation of Satellite Data in Melbourne (1968). Despite these uncertainties, there would appear to be an approximate one-to-one relationship between cloud vortices and surface lows.

In the southwest Pacific region, values of cyclonicity for a twelve-month period have been calculated on the assumption that each cloud vortex represents a surface cyclone. These cyclonicity values have then been compared with those derived from data on surface cyclones published by Karelsky, and by Taljaard and van Loon.

2. Data

Satellite pictures received by direct readout in Wellington for the 12-month period ending in May 1970 were used to construct mosaics of cloud distribution, from which the cloud vortices were identified and tracked. ESSA 8, a sun-synchronous satellite, provided a mosaic of the southwest Pacific - Tasman Sea region once daily at about 0900 hours local time. A second sun-synchronous satellite, ITOS 1, joined ESSA 8 for the last three and a half months of the period and provided an additional mosaic at about 1600 hours daily.

3. Method

The southern limit of the cloud mosaic varied seasonally; in summer data were regularly available to 60°S, but in winter the northward movement of the terminator zone restricted useful observations to the area north of 45°S.

Karelsky considered that his values of cyclonicity were reliable only near the Australia-New Zealand region, and Fig. 1 shows where these reliable values overlap the area from which satellite data were available. Taljaard and van Loon presented information on cyclone centres for the whole southern hemisphere. In the present report comparisons will be made of twelve-month cyclonicity values (by definition these will be "the time in hours during which cyclone centres occupy a given 5-degree square during a twelve-month period.") Initially these comparisons will be over the area from 30°S to 45°S between 155°E and 175°W, this being the area common to all three data sources (Fig. 1).

Karelsky's published cyclonicity values are for three-month seasons and can readily be changed to 12-month values. Taljaard and van Loon gave few cyclone tracks, but did locate the position of all cyclone centres once daily (1200 GMT); from these data it is possible to estimate the 12-month cyclonicity (Cy) by counting the number of cyclone centres (N) found in each 5-degree square over the 18-month period of their study, reducing this to a 12-month count, and by making the assumption that on average each centre spends twentyfour hours (from 0000 to 2400 GMT within the 5-degree square in which it appears at 1200 GMT; the following relationship can be derived

$$Cy = (N \cdot 2/3 \cdot 24) \text{ hours.}$$

Karelsky's figures have the advantage of being averages for a long (15-year) period, smoothing out fluctuations in cyclonic activity due to periodic changes in the planetary circulation pattern; however they do, along with Taljaard and van Loon's values, suffer from subjective analyses made over large areas devoid of routine surface observations. Taljaard and van Loon, using the 18-month period of the IGY, were able to take advantage of the better-than-usual - but still inadequate - observational network available at this time. Satellite data provide cloud mosaics in which there are no data-blank areas, and cloud vortices are identified with equal reliability over the whole mosaic.

4. Results

Figure 2 shows 12-month cyclonicity values from the three data sources. Small islands supplying routine surface observations have been circled, and it is seen that Karelsky's cyclonicity is unusually small in places remote from routine observations in the south and east of the region, yet elsewhere his values are much closer to those derived from the data of Taljaard and van Loon. This is taken to indicate that in the analysed maps used by Karelsky, cyclone centres were avoided unless necessitated by nearby observations. These dubiously low values are, however, outside the region to be used for the initial comparisons, viz 30°S to 45°S between 155°E and 175°W. Within this region cyclonicity has been averaged over 5-degree latitude bands and 5-degree longitude bands (Table 1) to reduce irregularities introduced by the short periods used by Taljaard and van Loon, and by the author.

The very good agreement between the values of Karelsky

Table 1. Twelve-month cyclonicity for individual 5-degree squares, averaged over 5-degree latitude and longitude bands, for the region between 30°S and 45°S from 155°E to 175°W. Cyclonicity values have been derived from data published by (a) Karelsky, and (b) Taljaard and van Loon, and from (c) satellite mosaics.

	Longitude belt 155°E - 175°W			Latitude belt 30°S - 45°S					
	Latitude bands			Longitude bands					
	30-35°S	35-40°S	40-45°S	155-160°E	160-165°E	165-170°E	170-175°E	175-180°	180 175°W
a	190	229	168	242	228	216	198	139	134
b	192	200	176	192	256	256	160	123	144
c	118	139	51	80	121	113	107	102	89

Average over the whole area: (a) 194, (b) 189, (c) 100.

and Taljaard and van Loon shows that in the 18-month period of the IGY, cyclonicity differed little from the 15-year average (1946-1960). Cyclonicity estimated from cloud vortices is little more than half that of the other two sources, suggesting that there should be about twice as many surface cyclones as there are cloud vortices; however from practical experience such a relationship seems unlikely and a closer parity between the two would be expected.

Investigation of the 12-month period used for tracking cloud vortices showed that the mean surface pressure was above normal in the New Zealand region, with the greatest anomaly (+ 2mb) occurring between 40°S and 45°S from 165°E to 175°W (Fig. 3); this is precisely the area where cyclonicity from cloud vortex data is unusually small (Fig. 2). Such low values of cyclonicity can be attributed to a minimum of cyclonic activity (and hence cloud vortices) in this region, which must have been influenced by anticyclones more intense and/or more numerous than is usually the case. Omitting these very low values of cyclonicity, a corrected estimate from cloud data becomes about 120 compared to some 190 hours from the other two sources. However since there is a positive pressure anomaly of one millibar or more over the whole New Zealand region, even this estimate of 120 hours is likely to be too low. Tentatively it is suggested that surface cyclones could outnumber cloud vortices by up to one-third.

Karelsky, Taljaard and van Loon, and to a lesser degree the present satellite study indicate that the northern Tasman Sea (30°S to 40°S between 155°E and 170°E) has greater cyclonicity than the area immediately to the south and east (Table 1).

Comparisons can be made between the values of Taljaard and van Loon and the satellite data over a larger area extending out to 155°W in the Pacific and to 60°S. Table 2 lists the average cyclonicity over 5-degree latitude and longitude bands for this enlarged area.

Taljaard and van Loon's figures indicate little

Table 2. Twelve-month cyclonicity for individual 5-degree squares, averaged over 5-degree latitude and longitude bands, for the area between 30°S and 60°S from 155°E to 155°W. Cyclonicity values have been derived from (a) data published by Taljaard and van Loon, and (b) satellite data.

(i) Longitude belt 155°E to 155°W

Latitude bands

	30-35°S	35-40°S	40-45°S	45-50°S	50-55°S	55-60°S
a	166	164	148	175	156	180
b	88	122	62	42	45	44

(ii) Latitude belt 30°S to 60°S

Longitude bands

	155-160°E	160-165°E	165-170°E	170-175°E	175-180°	180-175°W	175-170°W	170-165°W	165-160°W	160-155°W
a	192	256	256	160	123	144	139	85	133	165
b	80	121	113	107	102	89	78	91	72	93

variation of cyclonicity with latitude. The reason for the low values between 40°S and 45°S in the satellite data has already been discussed, while the low values south of 45°S are the result of sampling periods shorter than twelve months due to lack of illumination in winter; in these higher latitudes the cyclonicity listed in Table 2 can be converted to an approximate true 12-month value by multiplying by a factor which increases with latitude. Since the values in Table 2 are approximately equal, this confirms the known increase in cyclonic activity poleward in middle latitudes. The absence of such an increase in Taljaard and van Loon's figures is probably due to over-simplification of the basic analyses in data-scarce regions, when one large cyclone is drawn to fit isolated observations although often a complex system of several smaller cyclones would be more realistic.

Over the thirty degree wide middle latitude band (30°S-60°S) Taljaard and van Loon show that cyclonicity over the Tasman Sea is about twice that over New Zealand and the Pacific out to 155°W (Table 2). The satellite data confirm this decrease in cyclonicity eastwards but show it to be less marked than in surface data.

The average time (t) taken by cyclones to traverse particular 5-degree squares can be calculated from the cyclonicity (Cy) provided the number of individual cyclone centres (n) is known, since $Cy = nxt$. Figure 4 shows the average traverse times calculated by Karelsky and those derived from cloud vortices. Table 3, averaging these times over 5-degree latitude bands reveals: (i) a decrease in traverse time with increasing latitude, and (ii) traverse times of cloud vortices that are some two hours less than those obtained for surface cyclones.

There is a decrease in the east-west dimension of

Table 3. The time (in hours) taken by individual cyclones and cloud vortices to traverse particular 5-degree squares, averaged over 5-degree latitude bands, for the area between 30°S and 60°S from 155°E to 155°W. (a) derived from Karelsky's data, and (b) derived from satellite pictures.

Latitude bands	Longitude belt 155°E to 175°W (a)	Longitude belt 155°E to 175°W (b)	155°E to 155°W (b)
30 - 35°S	14	12	13
35 - 40°S	13	11	10
40 - 45°S	11	9	9
45 - 50°S	9	7	7
50 - 55°S	8	6	6
55 - 60°S	-	5	6

5-degree squares with increasing latitude while the north-south dimension remains constant; however the rate of decrease is less than the rate of decrease of traverse times, consequently the mean displacement rates of both surface cyclones and cloud vortices increases with latitude (at least as far as 55°S). The consistency with which cloud vortex traverse times exceed, by about two hours, estimates for surface cyclones is surprising; however this effect could also be due to the simplified surface analyses in data-scarce regions where one large cyclone is drawn although a system of several smaller centres often exists. The traverse time of the large cyclone represents that of the centre of gravity of the several smaller centres; each of the smaller centres is probably rotating cyclonically about this centre of gravity. Thus the smaller centres (marked by cloud vortices) will move faster than their centre of gravity (analysed as the centre of a large surface cyclone).

It was possible to study in greater detail the motions of the two types of cloud vortex appearing in satellite pictures. Examples of the tracks of the two types of vortex are given in Fig. 5 (frontal vortex) and Fig. 6 (vorticity centre). During the length of time vortices were within the field of observation, about three quarters of both types of vortex moved on nearly straight paths (defined arbitrarily as those paths in which tangents drawn to the path at all points did not differ in orientation by more than thirty degrees). Of the remaining quarter, cyclonically curved paths were more frequent than anticyclonically curved; by a ratio of about two to one for frontal vortices and by ten to one for vorticity centres.

Table 4 lists the number of individual centres travelling along mean paths of given direction, along with their average speed. The predominance of eastward and southeastward motion is marked for both vortex types; in addition vorticity centres move a little faster than frontal vortices irrespective of direction of movement. Occasionally both types of vortex were observed to attain speeds of 50 to 60 kt.

Table 4. The number of cloud vortices found to move in given mean directions (a); and the average speed in knots of each group (b).

	Mean direction towards which cloud vortex moves									
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	Other	Total
Frontal vortex											
a	2	2	7	8	39	25	21	5	5	2	116
b	-	-	18	20	25	25	25	17	9	-	22.5
Vorticity centre											
a	1	2	10	11	39	17	5	2	-	1	88
b	-	-	22	26	26	26	18	-	-	-	25

Considering the relationship between the different vortex types and the long wave atmospheric motion, it is usual for frontal vortices to be located from near the long wave trough axis to the next ridge axis downstream, with a resultant tendency for such vortices to be steered to the east or southeast by the general motion in the troposphere; such a motion has already been found in Table 4. On the other hand, since vorticity centres are associated with cyclonic vorticity advection in the neighbourhood of short wave troughs lying between the long wave trough and the next long wave ridge upstream, such vorticity centres should be steered eastwards and moreover there will be a greater likelihood for them to move more northeastwards than is the case with frontal vortices. This effect too is supported by Table 4 which shows that while 65 to 70% of both types of vortex move to the east or southeast (at mean speed 25 kt), 24% of vorticity centres move eastnortheast or northeast at a mean speed of 24 kt, but only 13% of frontal vortices move in that direction at a mean speed of 19 kt.

5. Conclusions

Cloud vortices of two types (frontal vortices and vorticity centres) appearing in twelve month's satellite pictures of the southwest Pacific were tracked and, on the assumption that they represented surface cyclones, their frequency and distribution were compared with longer period estimates made by Taljaard and van Loon (18-month period) and Karelsky (15-year period) based on conventional analyses of surface observations. Karelsky's concept of cyclonicity was used in the comparison, from which the following results were obtained.

(1) Having regard to the unusually low level of cyclonic activity in the New Zealand region during the period of the satellite study, it is tentatively assumed that surface cyclones outnumber cloud vortices by up to one-third.

(2) Cloud vortices confirm that there is greater cyclonicity in the Tasman Sea than in the region over New Zealand and the adjacent Pacific Ocean out to at least 155°W; however this eastward decrease is less marked than in the studies based on conventional surface analyses.

(3) The southward increase in cyclonic activity in middle latitudes of the southern hemisphere is confirmed from the satellite study, and the increase is more marked than indicated by conventional surface analyses.

(4) The marked differences found in the higher latitudes between cyclonicity values from cloud vortex observations and the conventional surface analyses can be attributed to the tendency to assume a single cyclone centre in data blank regions when in fact a more complex system of several smaller centres is often nearer reality. Such an

analysis bias can also explain the fact that cloud vortices move faster than surface cyclones tracked from conventional analysis.

(5) The average speed of movement of the two types of cloud vortex was between 20 and 25 kt (the range being from zero to 60 kt), with vorticity centres tending to move a little faster than frontal vortices.

(6) More vorticity centres move east-northeast and northeast (24%) than do frontal vortices (13%).

6. References

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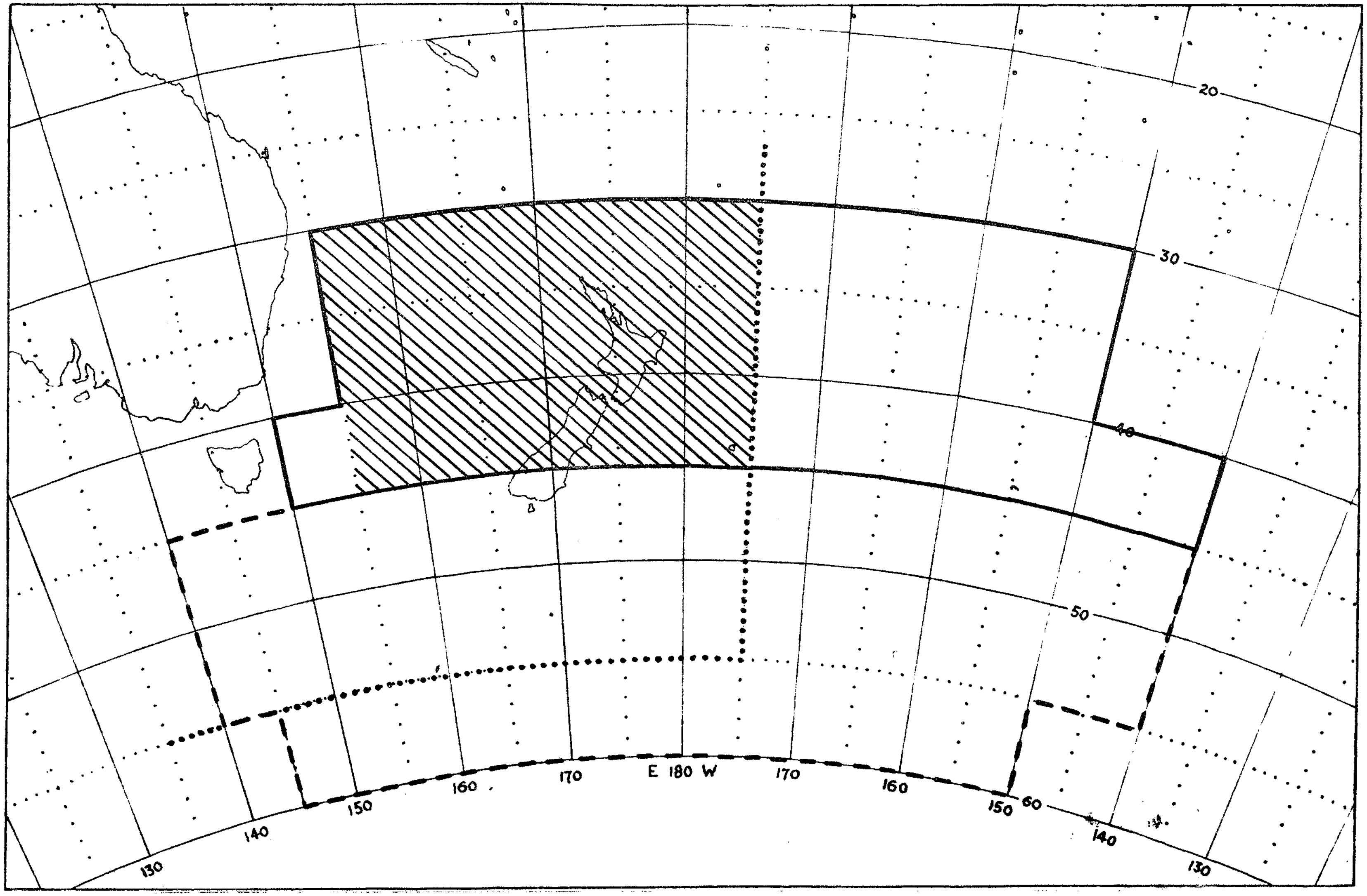

Fig. 1. Satellite-viewed cloud data were available daily throughout the 12-month period from the area within the solid line, the southern boundary of which (45S) lies near the winter position of the terminator zone. In summer this terminator moves far to the south and the dashed line shows the boundary of the additional area from which cloud data were obtained over a period shorter than twelve months. The dotted line is the boundary of overlapping data presented by Karelsky, and considered by him to be representative. Cyclonicity from three different sources was compared over the hatched area.

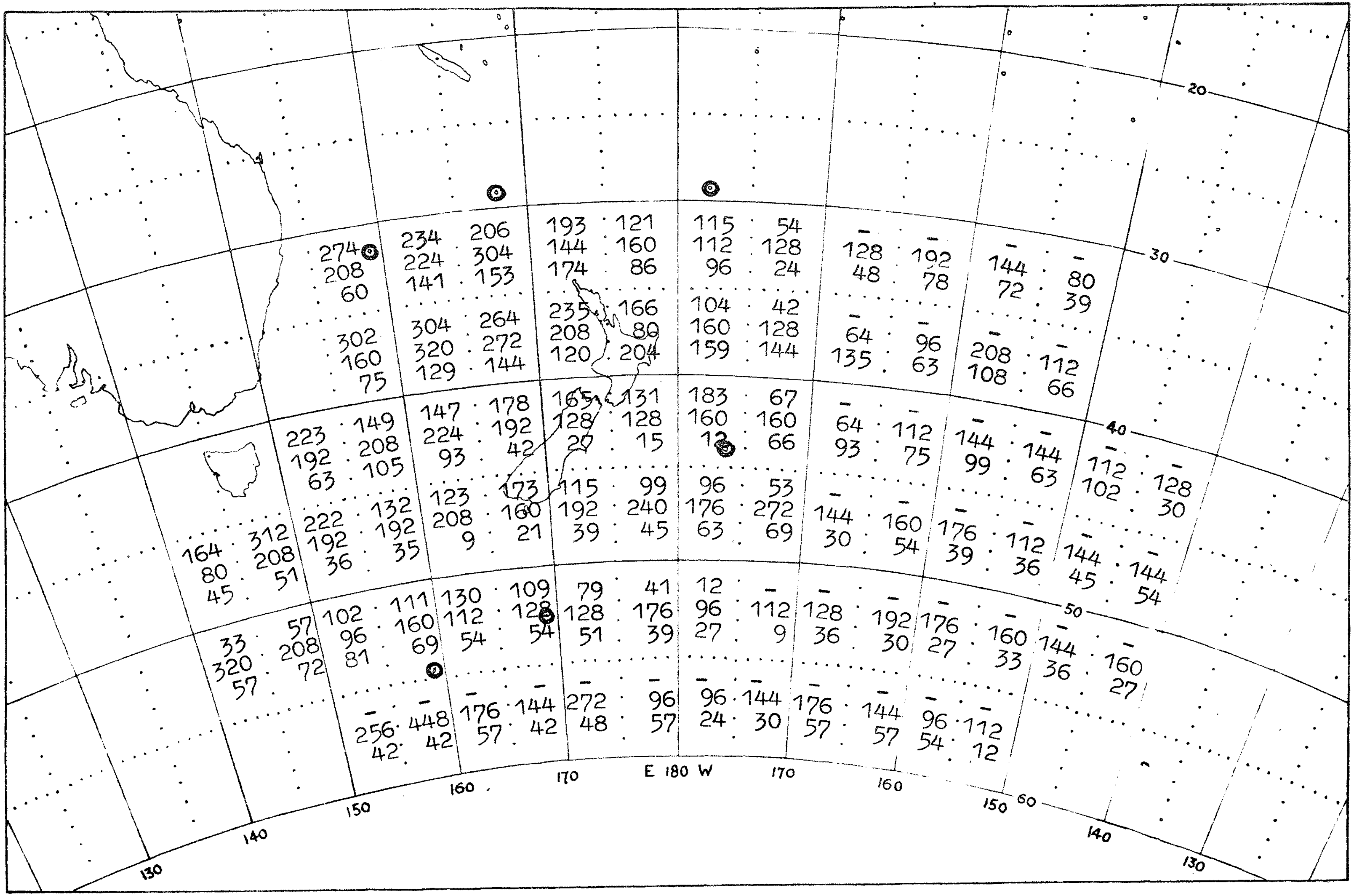

Fig.2. Twelve-month cyclonicity values for 5-degree squares. The three vertically listed figures for each square are derived from different sources, viz. top - Karelsky; middle - Taljaard and van Loon; and bottom - satellite data. Small islands supplying conventional weather observations have been shown circled.

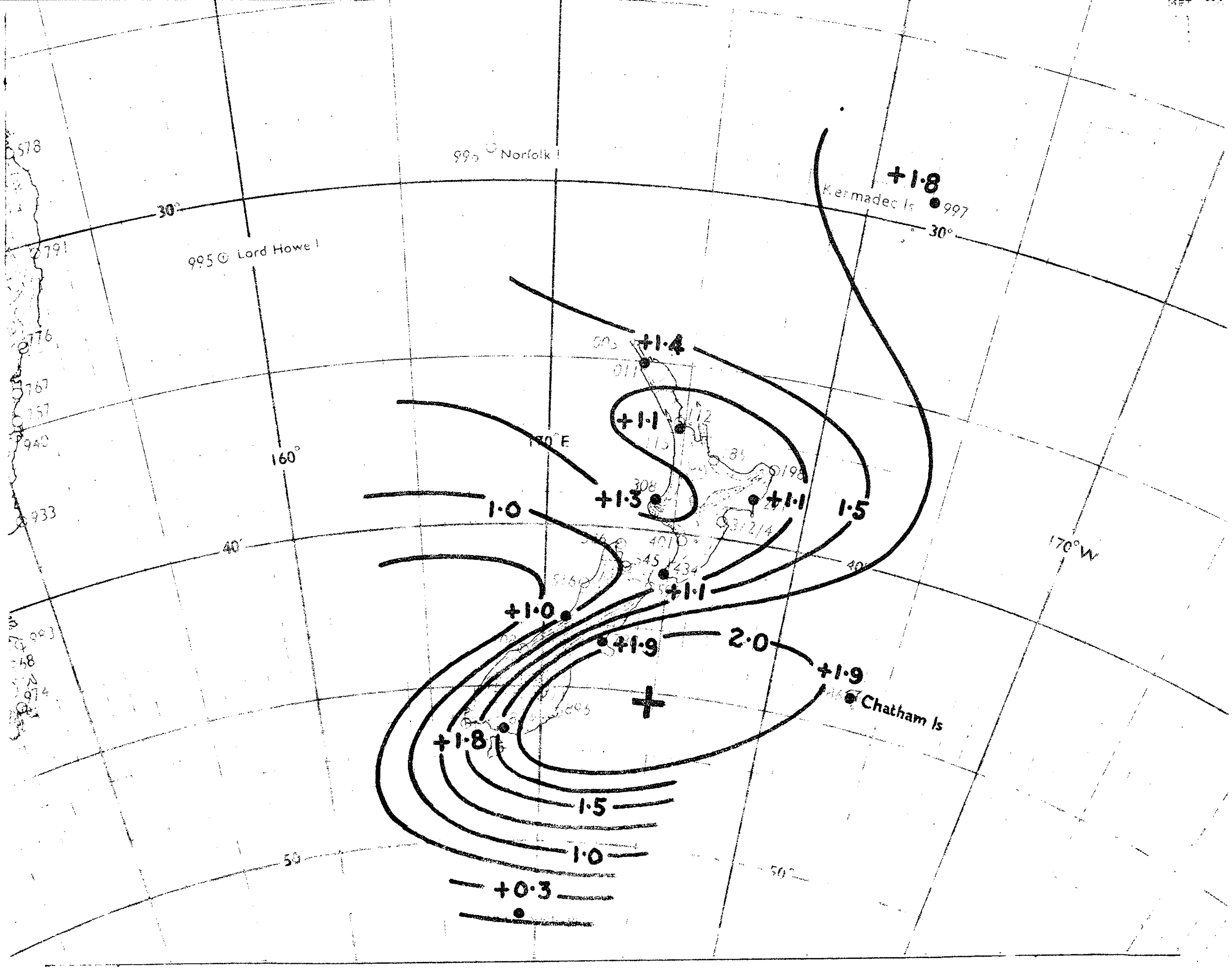

Fig.3. Twelve-month sea level pressure anomaly chart for the period June 1969 to May 1970. Anomalies shown in millibars. A positive anomaly of at least two millibars occurrs between the South Island and Chatham Islands.

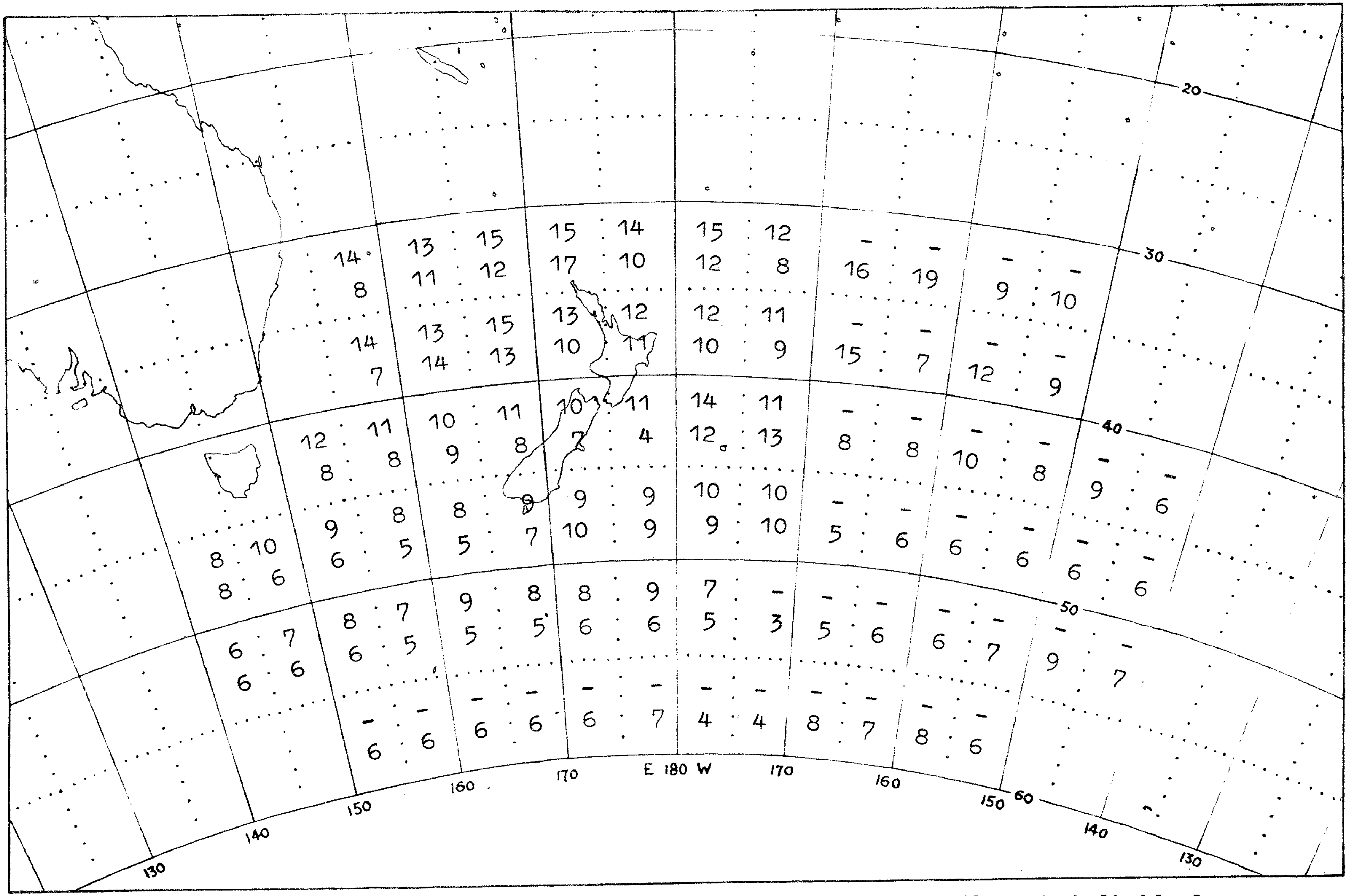

Fig.4. Average traverse times (in hours) for centres passing through individual 5-degree squares. Two vertically listed values for each square are:- top - surface cyclones from Karelsky, and bottom - cloud vortices from satellite data.

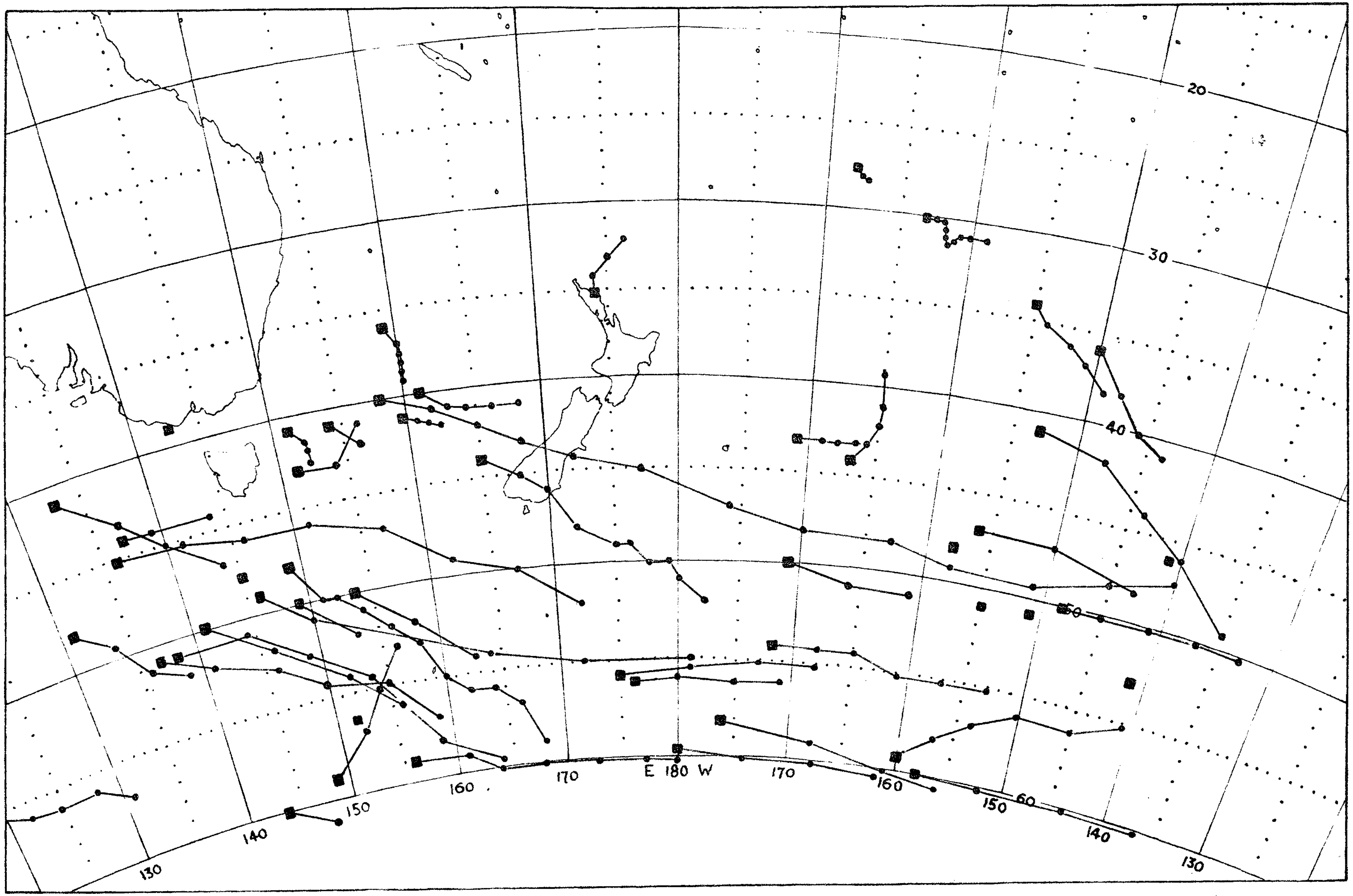

Fig.5. Tracks of frontal vortices for the three months December 1969 to February 1970. First sightings shown by squares with subsequent six-hourly positions given by dots.

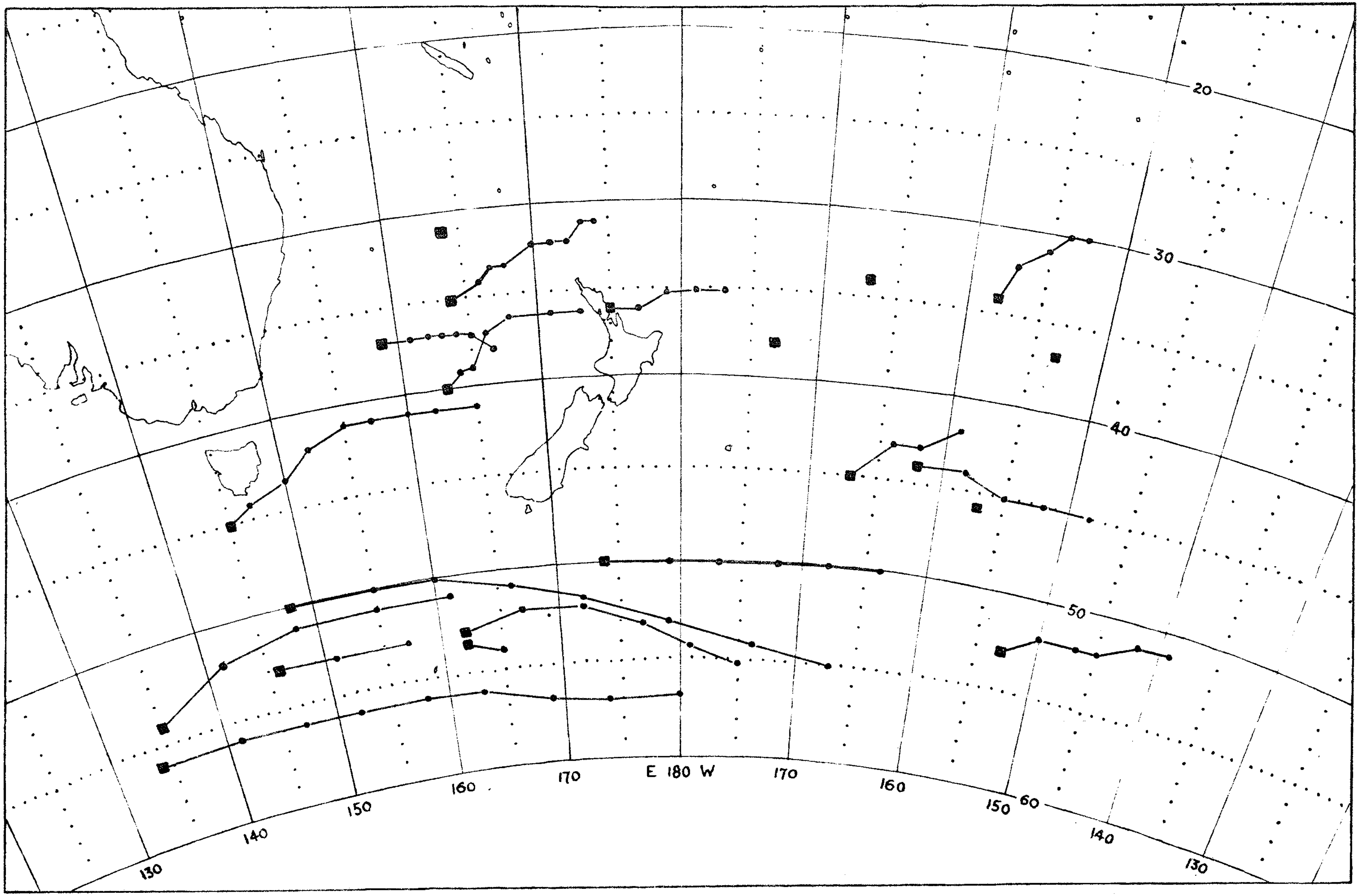

Fig.6. Tracks of vorticity centres for the three months September - November 1969. First sightings shown by squares with subsequent six-hourly positions given by dots.