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A COMPARISON BETWEEN HURRICANE-FREE AND HURRICANE-PRODUCING YEARS IN THE SOUTHWEST PACIFIC

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Abstract

A hurricane index, taking into account both intensity and number of disturbances, is applied to hurricanes and severe storms occurring in the tropical Southwest Pacific during each of the hurricane seasons 1946/47 to 1971/72 inclusive. An apparent relationship between this hurricane index and the combined effects of sea-surface temperature, vorticity and vertical shear properties of the broad scale flow is found.

Introduction

The 1971/72 hurricane season in the tropical Southwest Pacific was one of the most active in recent times. There were no fewer than ten severe storms and hurricanes compared with only one severe storm (no hurricanes) for the 1970/71 season.

Various authors have attempted to account for such marked variations in hurricane activity. Thus Namias (1968) investigating the causes of the small number of Atlantic hurricanes in 1968 studied height and temperature anomaly fields of the 700 mb surface and also anomalies of the sea-surface temperature. Gray (1968) in a global study of the origin of tropical storms demonstrated the importance of low values of vertical wind shear in development. More recently Carlson (1969, 1971) has shown an apparent relationship between sea-surface temperature and the development of African disturbances into tropical storms as they progress eastwards over the tropical Atlantic.

The present work attempts to relate the level of hurricane activity each season in the tropical Southwest Pacific to mean sea-surface temperatures and the vorticity and vertical shear field of the corresponding broadscale tropospheric circulation. It would be desirable to include also an analysis of the vertical temperature gradient of the water underlying the sea-surface but these data are not routinely available. Perlroth (1969) suggested that this temperature gradient may be more important than the sea-surface temperature itself for development. When tropical storm development occurs in warm surface waters in a strong vertical temperature gradient zone, the mechanical mixing of the surface waters caused by wind action results in a marked cooling of the surface waters, tending to inhibit further development (Jordan, 1963; Leipper, 1967; Leipper and Volgenau, 1972). On the other hand, a weak vertical temperature gradient tends to enhance further development.

Bjerknes (1972) in a study of the feedback effects of ocean temperature variations upon the atmosphere noted an apparent biennial oscillation of the sea-surface temperature at Canton Island during the period 1962-67. An attempt to determine whether oscillations of this kind are related to hurricane development is one objective of the present paper.

The Concept of Hurricane Index

All hurricanes and severe tropical storms (maximum sustained winds equal to or greater than 50 knots) from 1947 to 1972 (inclusive) observed in the tropical Southwest Pacific between lat. 10°S-25°S and long. 150°E-150°W are examined (Fig. 1). The hurricane season usually extends from November to April, and the 1947 season for example is taken as November 1946-April 1947. On the very rare occasions when hurricanes or severe storms occur outside these months, the hurricane year would be taken to extend from August to July.

In pre-satellite days many disturbances must have passed undetected unless they came close to land stations or ships. The present daily coverage of the tropics by satellite cloud photographs ensures detection of storms but the estimates of maximum winds are still subject to some error (Hubert and Timchalk, 1969).

Disturbances with madimum sustained winds less than 50 kt have been excluded as we are concerned only with the occurrence of hurricanes and severe storms. All data in this work were obtained from the routine synoptic streamline and isotach charts prepared either by the Nandi Meteorological Office or by the National Weather Forecasting Centre, Wellington, and from the Annual Climatological Summaries for the tropical Southwest Pacific area.

As a measure of the degree of hurricane activity a hurricane index, H, is introduced. Defined by the relation:

$$H = \Sigma V^2 \times 10^{-3}$$

where V is the strength in knots of the maximum sustained wind of each individual disturbance, the summation being carried over all storms in a given period. This somewhat arbitrary definition gives an approximate measure of the kinetic energy of the storms. The kinetic energy of systems with maximum sustained winds less than 50 kt, neglected in this study, is comparatively small.

Ideally not only the diameter of the storm but also the time it remains in the area under discussion should be considered. However, this cannot be found and the assumption is made that irrespective of the size, the maximum winds of each storm occur at the same radius (about 50 km) from

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Table 1. Maximum Sustained Winds, V (knots x 10^{-1}) of Individual Disturbances and Yearly Hurricane Indices ($H = \Sigma V^2 \times 10^{-3}$)
(Storms < 50 knots excluded)

	V (x10^{-1})							
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Other months	H (Nov-Apr)
1947			5					2.5
48				7				4.9
49		10		5				12.5
50				5	5,7			9.9
51				10	5			12.5
52		8	12					20.8
53					6			3.6
54			5,7					7.4
55			8,6		7			14.9
56		5	7	7	7	5		19.7
57	5		5	7,7	5			14.8
58			10		6	5		16.1
59		10	7	7	8			26.2
60		7	10	6	7	7		28.3
61				7	10,5,5			19.9
62				7,7,6				13.4
63				5	5,9	5		15.6
64	6	6	8	5	5,6		6(Sep)	22.2 25.8(yr)
65	5	7,7	6	12				30.3
66			8,6	5,5				15.0
67	5	5	7		6	7		18.4
68	6	8	7	7,5	(10)*			32.3 (22.3)*
69		9	5	8		6,5		23.1
70				7,6,5	8	6		21.0
71					6			3.6
72		5,6	8	8,6	6,7,6	6	6(Jun)	38.2 41.8(yr)
Means								
Monthly	0.6	2.7	4.0	4.7	4.2	1.2		
Yearly(H)								17.2 17.5(yr)

* This cyclone developed south of normal development area, i.e. south of 15°S.

the centre and that each storm remains in the area under discussion (essentially in the tropical area depicted in Fig. 1) for the same length of time.

Maximum sustained winds (kt x 10^{-1}) of individual disturbances and seasonal hurricane indices for the years 1947 to 1972 are tabulated in Table 1. Yearly values of H are also plotted graphically in Fig. 2 and display some suggestion of a 3 to 5 year periodicity.

The general trend in hurricane index during the 26-year period is probably due to the improvements in the observational coverage and technique. For this reason the pre-satellite years are excluded from the discussion in the later part of this paper.

Table 2 shows the number of storms observed each month in the 26 year period with maximum winds at least equal to given speeds. The mean frequency of occurrence is also given and in Fig. 2 the values are plotted on log paper and a straight line fitted. We may conclude that hurricanes (64 kt and above) occur in the Southwest Pacific on the average about twice a year. Severe hurricanes of 100 kt or more occur about once every three years. These figures are in general agreement with those given by Gabites (1956) for earlier years.

Analysis of Sea-Surface Temperature, T

In order to investigate the relation between hurricane occurrence and the temperature of the tropical oceans, sea-surface temperatures were analysed over an area bounded by the equator and latitude 30°S between longitudes 150°E and 150°W. The mean values of all sea-temperatures obtained from 6-hourly synoptic ship reports in each 5-degree square for a number of Januaries were used. (January was chosen since it lies in the middle of the hurricane season.)

Mean profiles of sea-surface temperature, T, averaged along 5-degree wide zonal strips from 150°E to 150°W are shown in Fig. 4(b) for the Januaries of 1965, 1969, 1970, and 1971. It is seen that the temperature for 1971, a hurricane-free year, is colder than for the remaining hurricane-producing years in the region equatorward of latitude 15°S, i.e. in the development latitudes.

Analysis of Intensification Potential, I

Following Gray (1968 , 1970), intensification potential, I, may be defined by the relation:

$$I = \frac{\overline{\zeta_r}}{|S_z|}$$

where $\overline{\zeta_r}$ is mean relative vorticity at sea-level and $|S_z|$ is mean tropospheric vertical wind shear. I is calculated for each 5-degree square using finite differences to obtain $\overline{\zeta_r}$

According to Gray (1970) and Williams (1970), "75-80% of the relative vorticity is determined by the shear of the zonal wind. Portrayals of zonal wind shear are usually adequate for relative vorticity determination." Thus to simplify the computations only the zonal components of $\bar{\zeta}_r$ and $|S_z|$ were considered. The latter was calculated directly from the 1000 mb and 200 mb data, neglecting the intermediate levels.

Mean monthly intensification potential for each 5-degree square was then given by

$$I = \frac{\text{Relative vorticity of mean monthly zonal 1000mb wind}}{|\bar{u}_2 - \bar{u}_{10}|}$$

where $\bar{u}_2$, $\bar{u}_{10}$ are the mean monthly zonal components of the winds at 200 mb and 1000 mb respectively. Values of I obtained in this way are about one order of magnitude smaller than those obtained for individual disturbances (Ward, 1971) in the main cyclone development area. I is taken to be zero in any 5-degree square where $\bar{\zeta}_r$ is zero or positive (i.e. anticyclonic).

Mean profiles of I averaged along 5-degree wide zonal strips from 150°E to 150°W are shown in Fig. 4(a) for the Januaries of 1965, 1969, 1970 and 1971.

In the rest of the discussion only the 10°S-15°S zonal strip is dealt with (Fig. 1). The highest values of I occur in this strip which corresponds with the latitude zone of main storm development discussed by Gabites (1956) and Gray (1968). Seasonal values of I were obtained in this way from the mean monthly values averaged for the whole season.

Seasonal variations of intensification potential, I, and sea-surface temperature, T, averaged along the 10°S-15°S zone for the years 1962-1972 are shown in Fig. 2, where they may be compared with corresponding values of hurricane index, H. November/December mean values of T are used in preference to the total hurricane season (November/April). The November/December temperatures are considered because the ocean is normally relatively undisturbed at this time of year before possible storms have had a chance to significantly cool the sea surface (see e.g. Leipper and Volgenau, 1972). A pilot study of sea-surface temperatures for later in the season suggested that this cooling effect could be quite significant following cyclone activity.

The biennial oscillation in the sea temperature found by Bjerknes (1972) at Canton Island for the hurricane seasons 1963 to 1968 (inclusive) had an amplitude of about 2°C. The variations found here are much smaller. However, using only data in the 150°W-180° half of the zone, a biennial oscillation of T about 1°C in range is obtained for the 1963/67 period and slightly larger amplitude when the square 10°-15°S, 170°-175°W (i.e. nearest Canton Island) is used (Fig. 6(b)).

After 1967 the oscillation broke down.

The accuracy of the observations of sea-surface temperature from ships is not known and it is difficult to make an estimate of the standard error. Further, while the density of reports in the western half of the $10^{\circ}S-15^{\circ}S$ zone is on the average 17 observations per 5-degree square for each November/December period, in the eastern half there are only 6 observations per 5-degree square.

The Ratio H/I

The ratio H/I is found to vary from year to year as shown in Fig. 2. (H and I here cover the November/April period).

In an attempt to relate these variations to the sea-surface temperature, H/I is plotted against the mean November/December values of T (Fig. 5(a)). The straight line fitted to the plotted values was,

$$H/I = 20 (T - 27.6)$$

If the analysis is restricted to disturbances developing within 2 degrees on either side of the $10^{\circ}-15^{\circ}S$ latitude zone it is found that the correlation coefficient between H and the quantity 20(T-27.6)I is 0.95, (see Figs 5(b) and 6(a). This result suggests that most of the observed hurricane development is accounted for by the combined effect of sea-surface temperature excess (T-27.6) and the vorticity/vertical shear parameter (I), and that in any given hurricane season, no hurricanes will occur if the mean November/December values of T are $\leqslant 27.6^{\circ}C$. Further, no significant hurricane or storm activity is likely any season for values of T $< 28.0^{\circ}C$ provided monthly values of I are low. It should be stressed that these values of T apply to the $10^{\circ}-15^{\circ}S$ zonal strip. H is then given by the approximate relation:

$$H = 20(T - 27.6) I + 1.5$$

Because of the short period of observations since the availability of satellite pictures it has not been possible to test this relation on an independent set of data.

Conclusion

The results suggest that most hurricane development is accounted for by the combined effect of the vorticity and vertical shear properties of the broadscale flow and by sea-surface temperature. However, the accuracy of the observations, particularly sea-surface temperature, is probably not high. An apparent periodicity was found in some of the parameters studied.

There appears to be some suggestion of a quasi-4 year cycle in hurricane activity, and sea-surface temperature measurements made in November and December may give some indication of the hurricane activity for the remainder of the season.

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Table 2. Monthly totals of storms with maximum winds at least equal to given values during the 26-year period, 1947-1972 and corresponding mean frequencies.

Max. sustained wind (kt)	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	All months	Frequency (storms/year)
≥ 50	5	13	19	26	24	9	98*	3.8*
≥ 60	2	10	15	18	17	5	69*	2.7*
≥ 70	0	8	12	14	10	2	46	1.8
≥ 80	0	5	7	4	5	0	21	0.81
≥ 90	0	3	3	2	3	0	11	0.42
≥100	0	2	3	2	2	0	9	0.35

* Includes one September storm of 60 knots
and one June storm of 60 knots

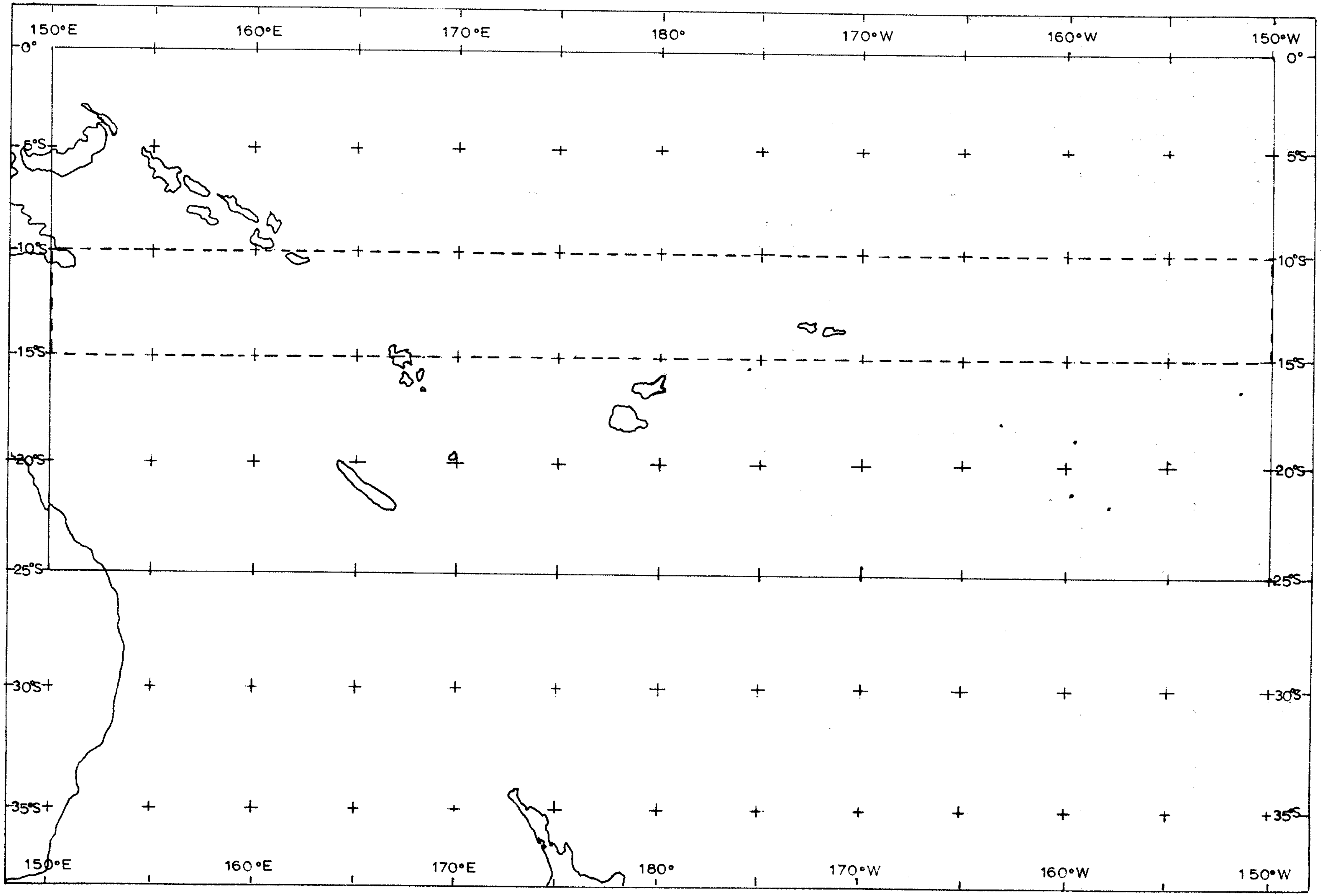
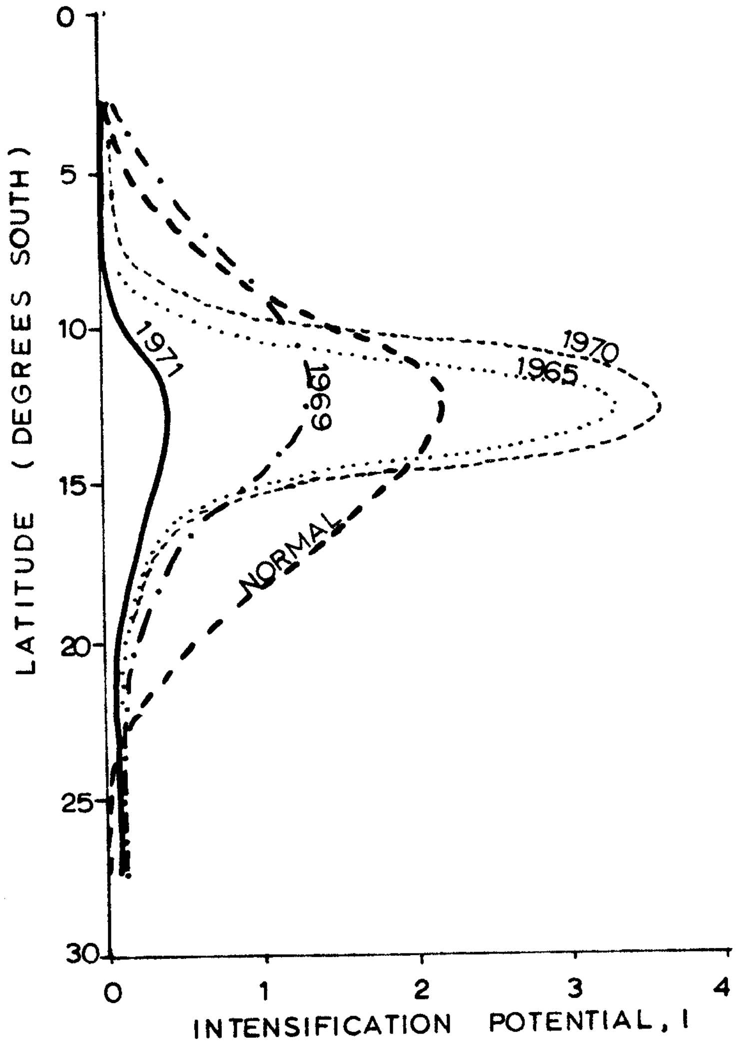
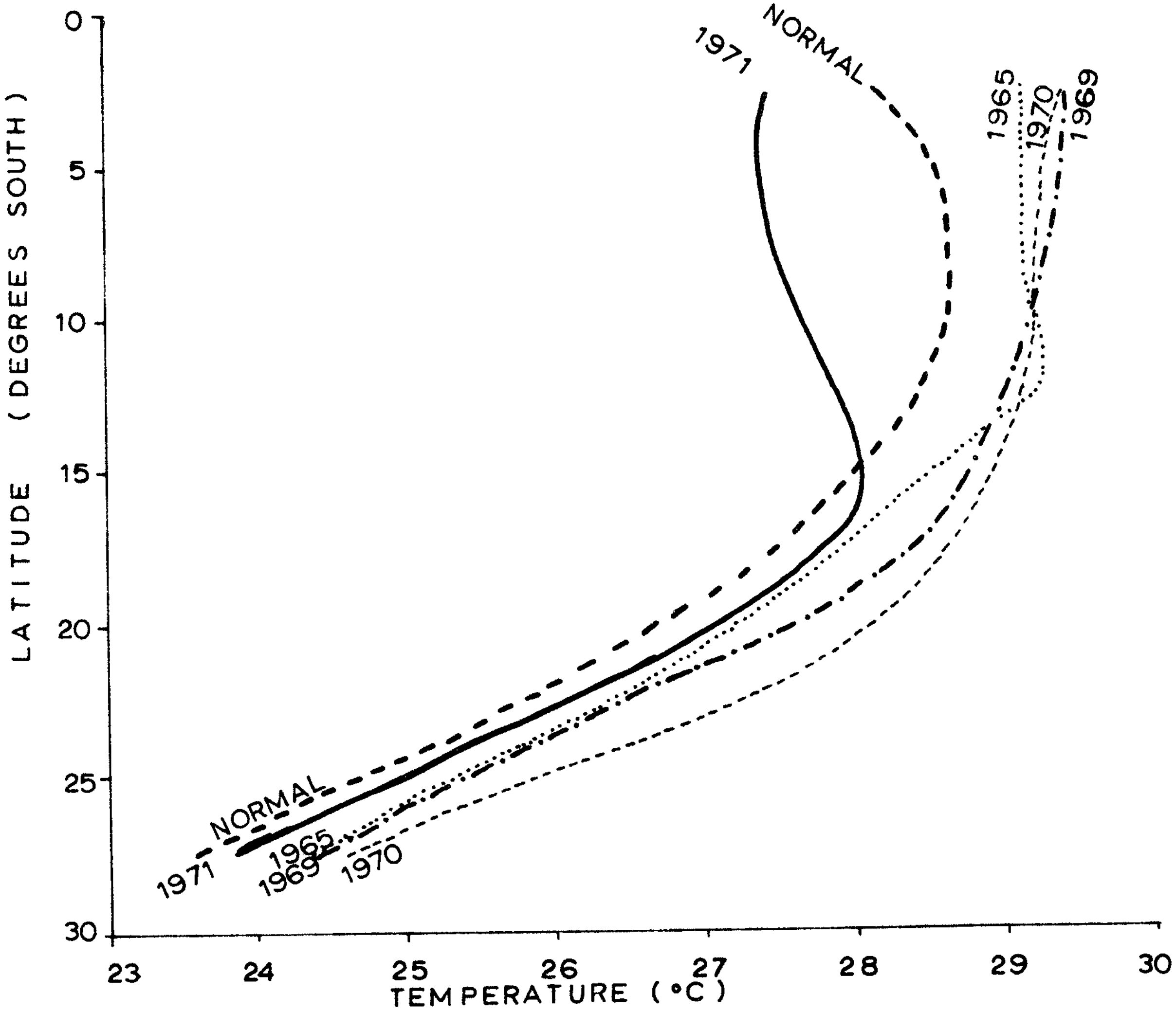


Fig. 1 Chart showing boundaries enclosing storm occurrence area in this study (solid lines) and 5-degree zonal strip used for measuring Intensification Potential, I and Sea-Surface Temperature, T (dashed lines)



<u>Fig. 4(a)</u> Latitudinal variation of I. (January)



<u>Fig. 4(b)</u> Latitudinal variation of sea surface temperature T (January)

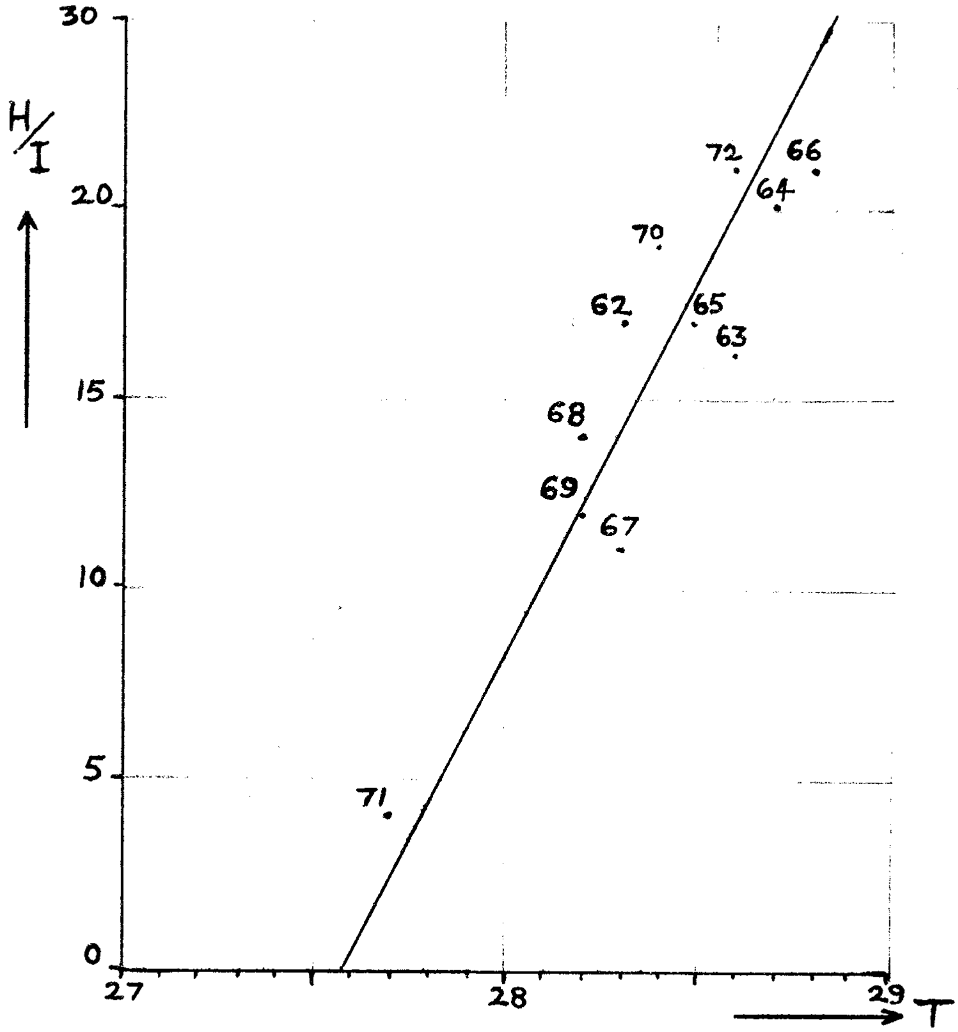


Fig. 5(a)

$$H/I \doteqdot 20\,(T - 27.6)$$

(Only disturbances developing within 2 degs. of 10-15S lat. zone considered)

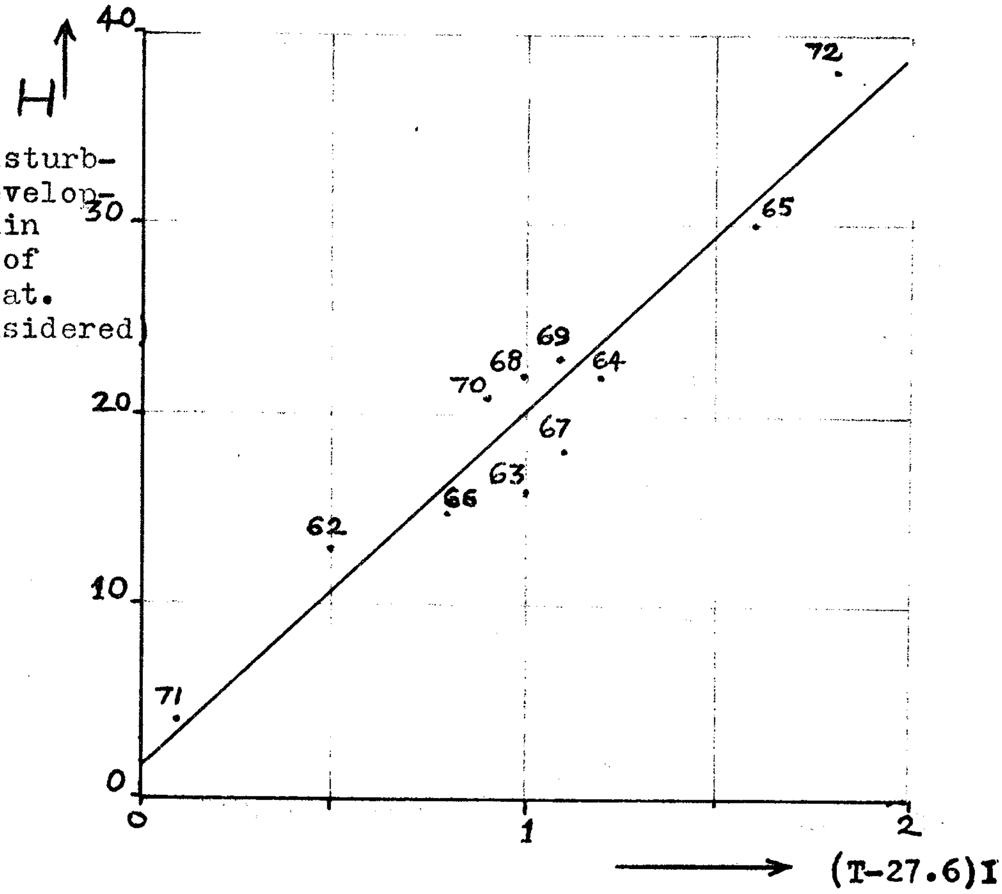


Fig. 5(b)

$$H = 20\,(T - 27.6)\,I + 1.5$$

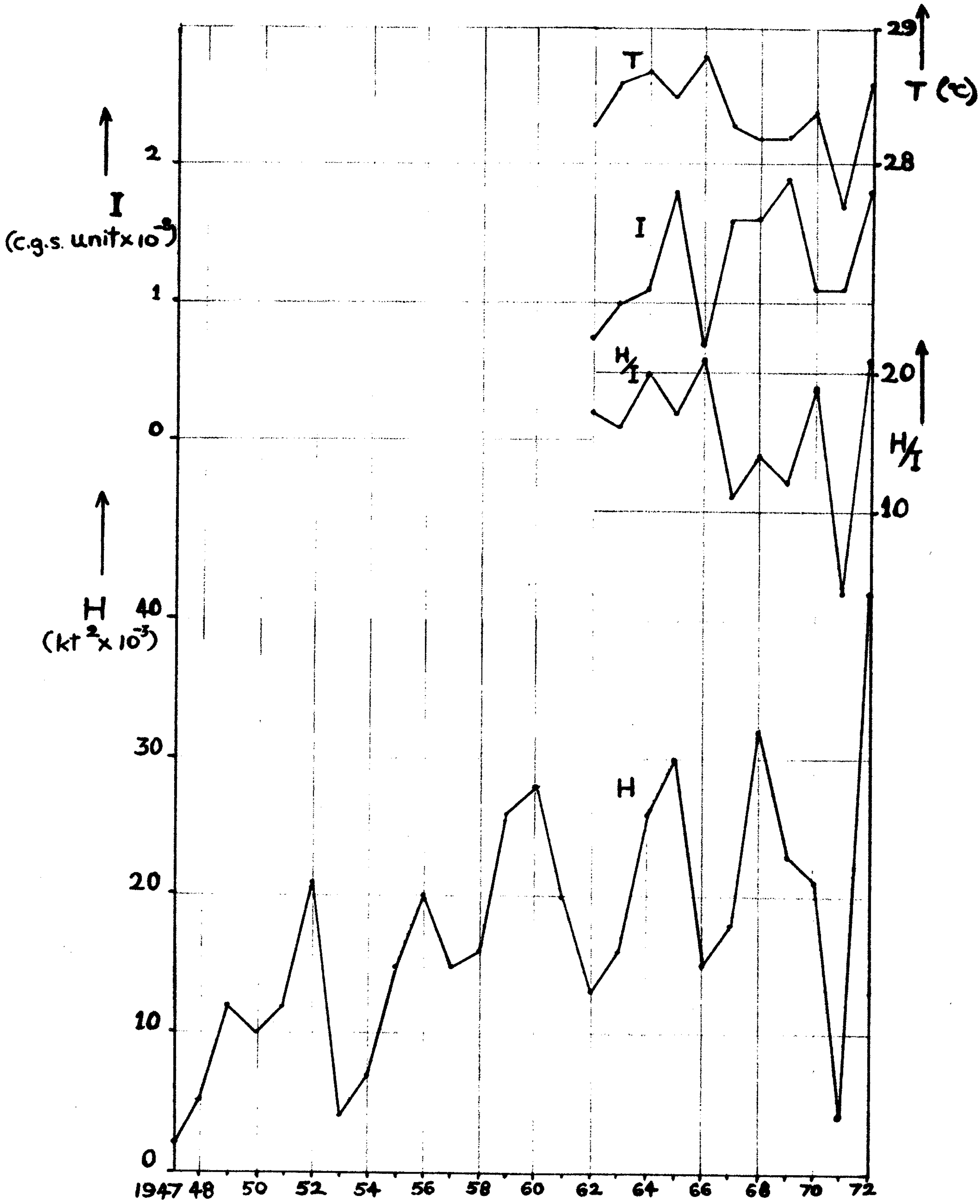


Fig. 2

Yearly variation of H, I, H/I and T.

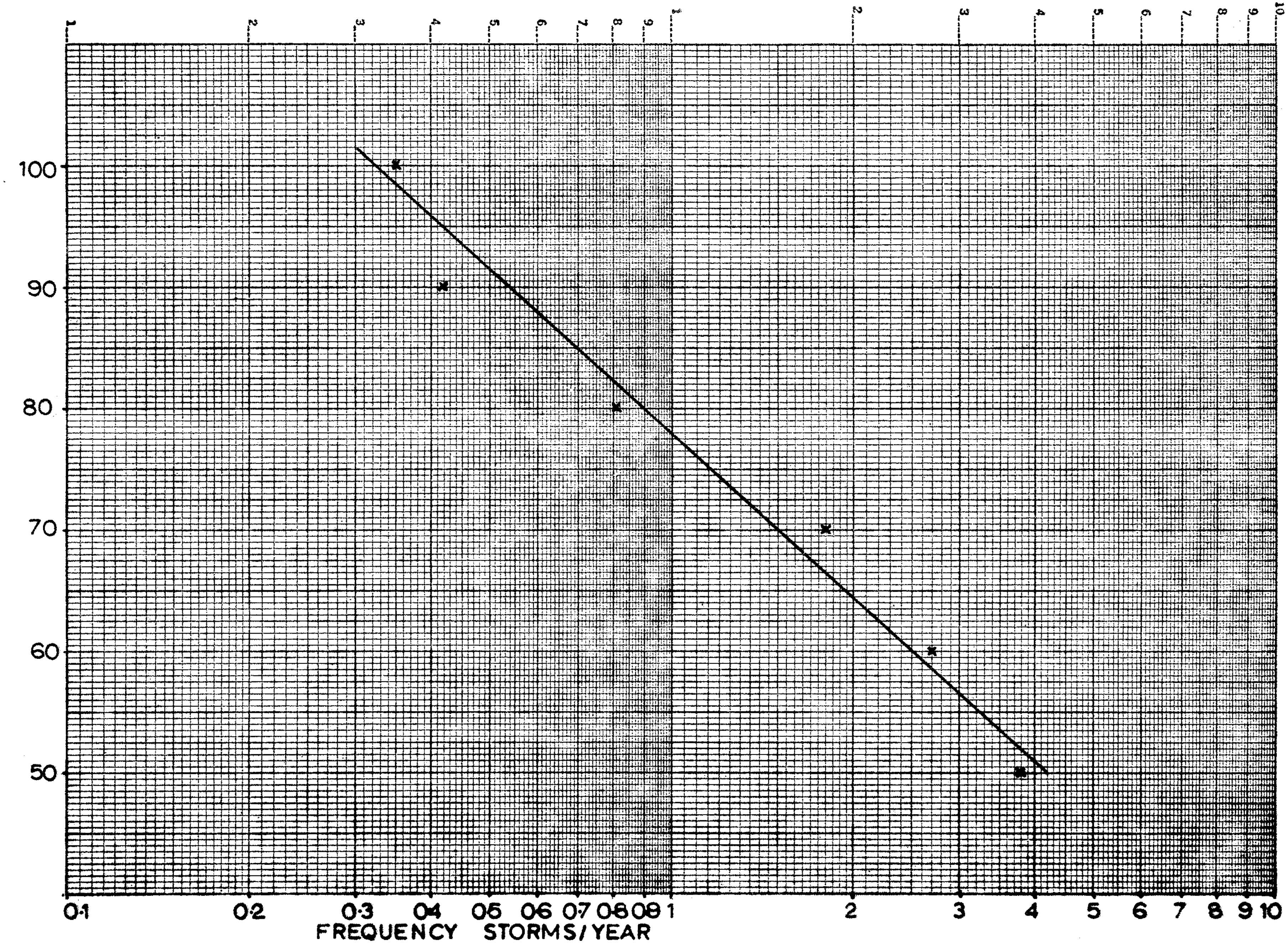


Fig. 3 Frequency of storms of given intensity

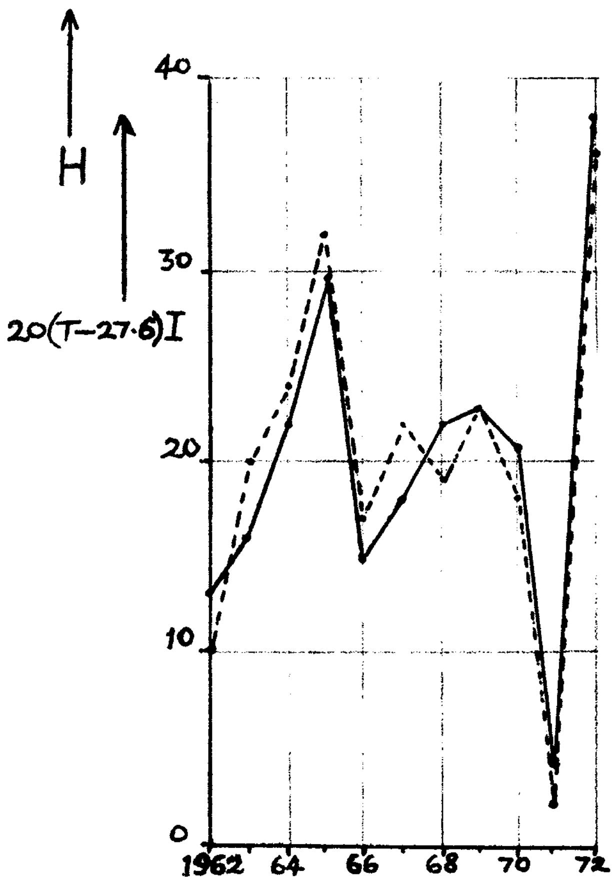


Fig. 6(a)

H ——— versus
20(T-27.6)I - - - - -

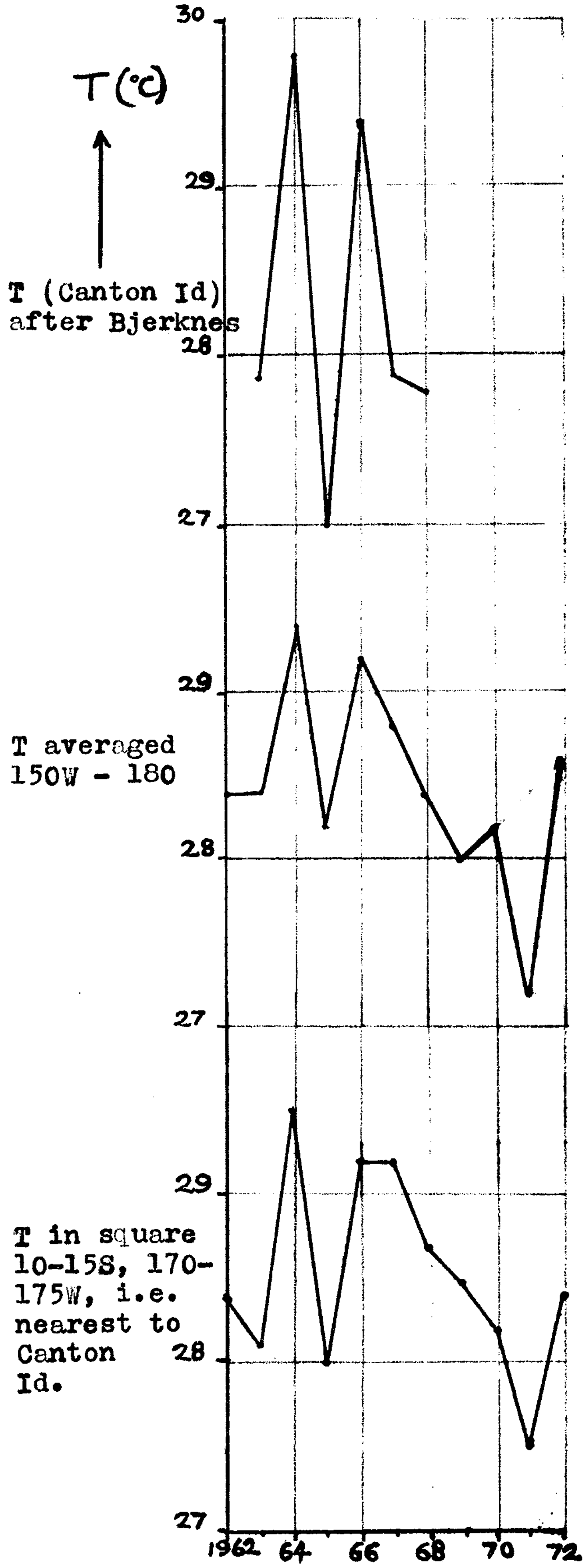


Fig. 6(b) Annual variations of T (Nov./Dec. mean).