

- CHAPTER 13 INTENSITY CHANGES AND SYNOPTIC EFFECTS OF TROPICAL CYCLONES**
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** Not Completed*

3 13.2 Rapid deepening

One of the worries of a forecaster responsible for protecting navigators or communities from the ravages of typhoons, is that a nearby and relatively harmless tropical depression may, quite quickly, become a fully fledged typhoon with potential for causing widespread damage and loss of life. This situation is not rare. In addition, about six times a year, on average, existing typhoons over the Pacific to the east of Taiwan and the Philippines and over the China Sea rapidly deepen by 30 mb or more in 24 hours.

The South China Coast is frequently in the path of intensifying tropical storms or depressions; this comes about because all tropical cyclones are weakened as they cross the mountains of Luzon (2000 m high) and it is only after reaching the warm waters of the South China Sea that they regain or develop typhoon intensity. In addition, some typhoons - such as 'Mary' in June 1960 and 'Alice' in May 1961 - develop in a South China Sea trough and change from tropical depression to typhoon intensity in a few hours. Exceptionally rapid intensification is commonly known as "explosive deepening" and is arbitrarily defined by the forecasters at Guam as a rate of deepening of 30 mb/24 h or more. Although rapid deepening can take place anywhere when all environmental conditions strongly favour development it is, of course, most frequent in areas climatologically favourable for the formation of deep typhoons.

Figure 13.1 shows the frequency distribution of the maximum deepening over 24 hours for each of 255 typhoons. A maximum rate of 15 mb/24 h is seen to be most common whereas, over half of the typhoons deepened more quickly than 23 mb/24 h.

The segment of tracks along which typhoons underwent explosive deepening during the period 1956 - 1971 are shown in Fig. 13.2. There were 308 typhoons in the sixteen years but the necessary measurements of minimum central pressure were available for only 255. Of these, 37% (95 storms) experienced rapid deepening (≥ 30 mb/24 h) at least once in their lives and of these 93% deepened before recurvature while on a heading between 250° and 330° ; the two exceptions have been labelled 1 and 2 in Fig. 13.2. The areas where the 95 typhoons began rapid deepening are shown in Fig. 13.3 which should be compared with Fig. which shows where deep typhoons are most frequent.

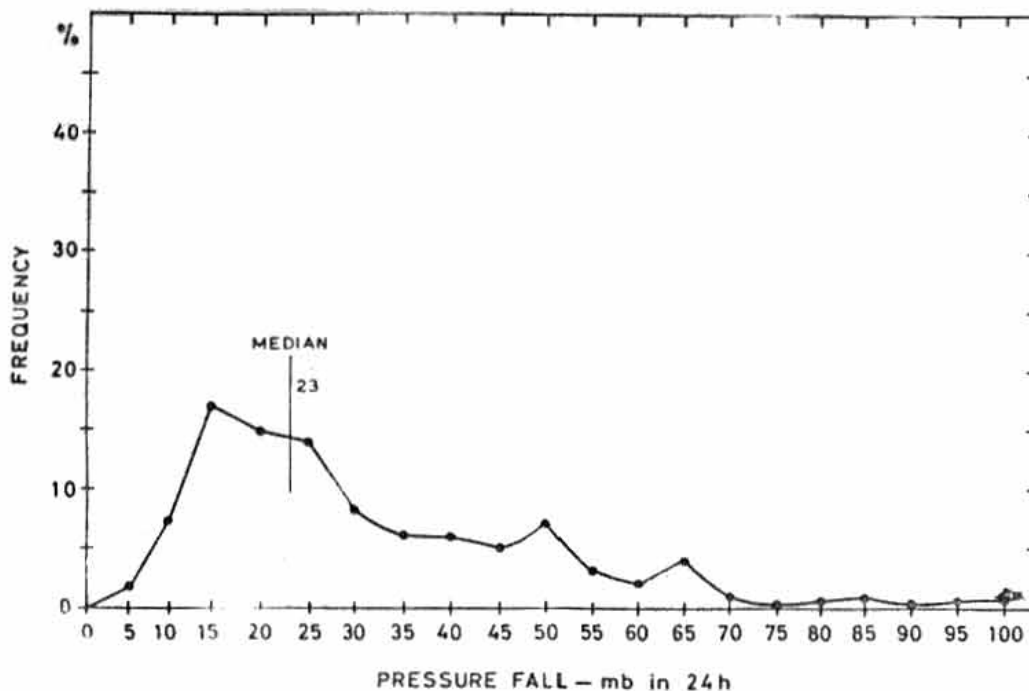


Fig. 13.1 The frequency distribution of maximum deepening in 24 hours observed in 255 typhoons during the period 1956-1971. (Adapted from JTWC Ann. Rep. 1971)

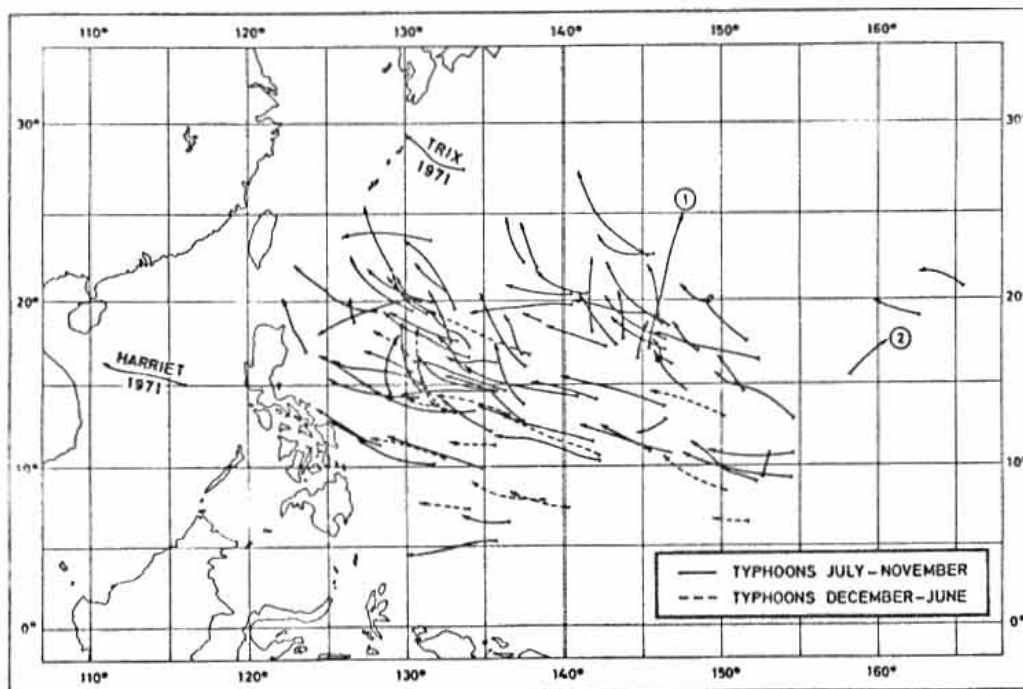


Fig. 13.2 Segments of the tracks of 95 typhoons during the 24 h in which they deepened by 30 mb or more during the years 1956 - 1971. (Adapted from JTWC Ann. Rep. 1971)

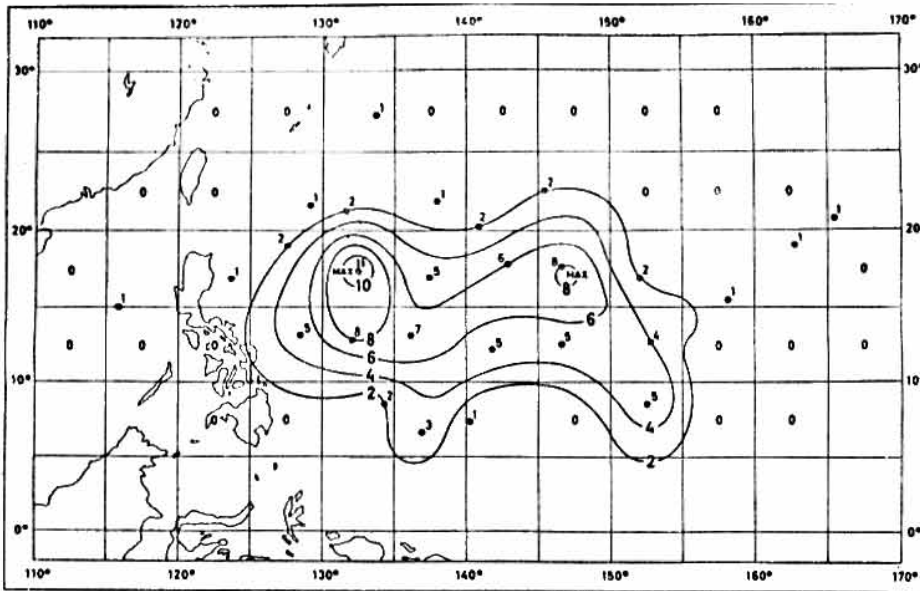


Fig. 13.3 The number of occasions on which typhoons began to deepen by 30 mb or more in 24 h, in each five degree square, during the period 1956 - 1971. The number is plotted beside the centroid of the points of initial deepening in each square. (Adapted from JTWC Ann. Rep. 1971)

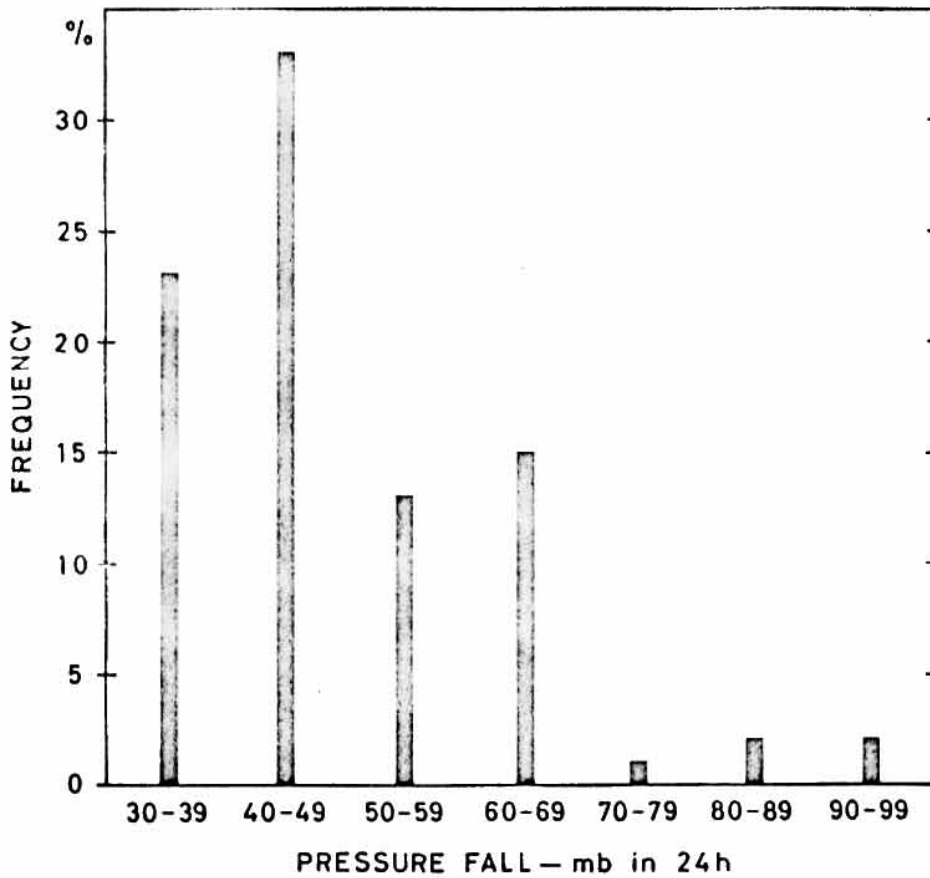


Fig. 13.4 The frequency distribution of the maximum rates of deepening over 24 h in the 95 typhoons which deepened by 30 mb or more in 24 h during the period 1956 - 1971. (Adapted from JTWC Ann. Rep. 1971)

In 91% of the cases, deepening began at or after the time at which the storm attained typhoon intensity (about knots on Guam's criteria) and 75% began to deepen within 36 hours of this time.

Of the 95 storms which exhibited explosive deepening the onset occurred most frequently (37%) when the central pressure was in the range 970-979 mb. 81% of the sample began rapid deepening when the central pressure was between 960 and 989 mb. The most frequent rate of fall was 40- mb/24 h as shown in Fig. 13.4. Falls of more than 30 mb in 6 h (5 mb/h) were observed in 4% of the 95 typhoons which exhibited rapid deepening and 2% of the whole sample. The true incidence of such rapid deepening over 6 h may differ somewhat from these figures because adequate observations were available from only 65 typhoons.

The greatest 24-hour fall of central pressure on record occurred in typhoon "Irma" 1971 and is illustrated in Fig. 4.14. The central pressure fell 95 mb in 24 h on the 11th November exceeding the previous record in typhoon "Ida" 1958 (Sect. 4.6). Typhoon "Irma" began to deepen when its central pressure was 980 mb and it moved under the 200 mb anticyclone shown in Fig. 15.5 - a situation which strongly favours deepening.

Although rather more than 95 cases are required to establish with confidence the seasonal variation of rapid deepening, it is nevertheless clear from Table 13.1 that most of the cases (71%) occur in the months July to November with the monthly peak occurring in September which is also the month most favourable for the formation of deep typhoons. The greatest proportion of typhoons exhibiting rapid deepening occurs in November (52%). It is of interest to note that mean streamlines at 200 mb (Fig.) first show an anticyclonic cell east of Taiwan in September and that this cell progressively intensifies and moves south-eastward to be off Luzon by November. Anticyclones at 200 mb favour the intensification of typhoons which move beneath them.

Table 13.1

Monthly variation of the number of typhoons which deepened by 30 mb or more in 24 hours (1956-1971)

	Total No. Typhoons	Number Deepening		Total No. Typhoons	Number Deepening
Jan	5	1 (Kit 1972)	July	46	10
Feb	1	0	Aug	65	18
Mar	3	1	Sept	56	23
Apr	14	4	Oct	45	12
May	15	1	Nov	25	15
Jun	19	6	Dec	10	4

Total number of typhoons	308
Number with sufficient information	255
Number deepening by \geq 30 mb/24 h	95

(After JTWC Ann. Rept. 1971)

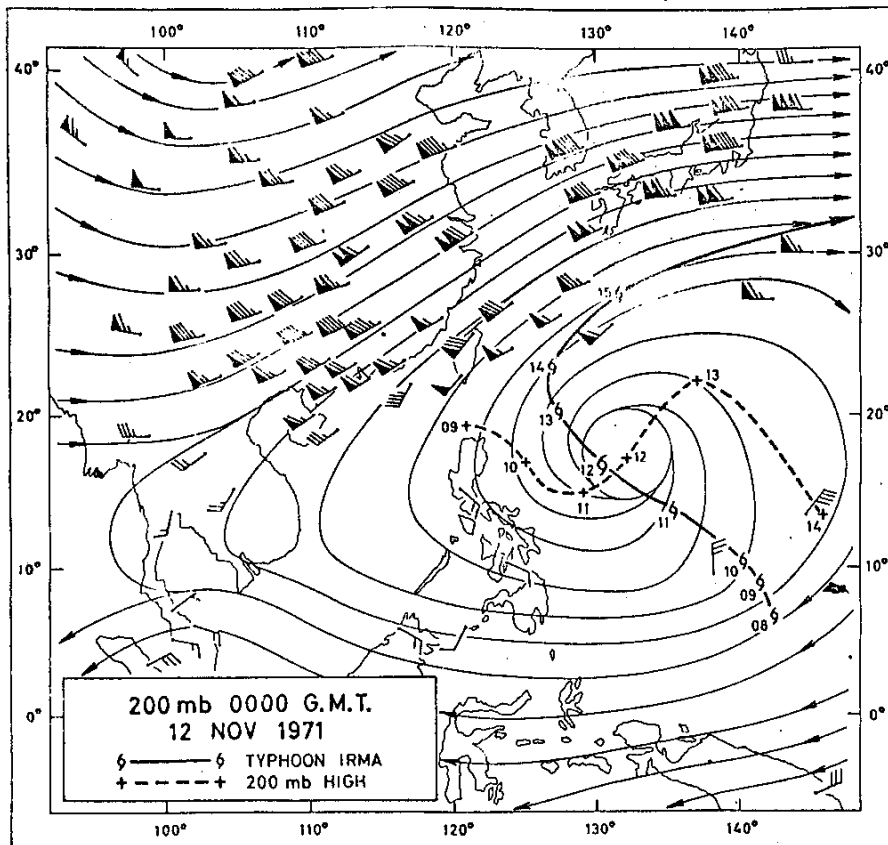


Fig. 13.5 The 200 mb chart for 12th November 1971 also showing the tracks of typhoon "Irma" and the centre of the anticyclone at 200 mb. The tracks cross between the 11th and 12th of November during the rapid deepening of the typhoon.

Development of frontal characteristics

After a tropical cyclone has recurved and moved sufficiently far northward to be well embedded in a baroclinic zone in the west wind belt a new energy source becomes available to maintain the circulation. This situation often results in the regeneration of the tropical cyclone and its simultaneous transformation into a frontal depression, an event which is quite common around Japan in the late typhoon season when outbreaks of polar air start to penetrate southward. Such transformed tropical cyclones give rise to some of the deepest winter depressions over the north Pacific and the north Atlantic (See Fig.). For example, Takeuchi (1954) showed that typhoon Ruth 1951 deepened by 26 mb in 24 hours around latitude 40°N.

In the early stages of transformation typhoons and hurricanes carry some tropical air along with them and retain tropical characteristics in their central region for a period, the length of which depends on the storm velocity. Snellman (1961) showed that if "cold" air was within 500 km of a storm centre after recurvature then slowly moving storms tended to decay rapidly while fast moving storms lost intensity much more slowly. By constructing low-level trajectories and relative streamlines he showed that the colder air cannot penetrate to the central regions of fast moving storms for 24 h or more after recurvature, thus delaying their decay. Such rejuvenated tropical cyclones, retaining some tropical characteristics, may survive as intense storms for several days so that transformed hurricanes may reach the west coast of Europe as far north as Iceland while in the Pacific transformed typhoons can reach the Bering Sea and Alaska. Palmén and Newton (1969) called such storms "quasi-tropical" and pointed to the one over the British Isles on 6th September 1966 which originated as hurricane Faith in the Caribbean ten days earlier. They consider that the 500 mb temperature over England of -6 to -8°C on this occasion indicated the tropical origin of the associated warm-air mass. A satellite photograph of a deep Atlantic depression which originated as hurricane Louis 1966 is shown in Fig.4.4 and discussed in Sect. 4.9.1.

Sawyer (1964) presented a radar photograph taken on board the Ocean Weather Ship "Weather Reporter", showing vestigial spiral bands (Fig. 13.) at the centre of an occluded depression (956.7 mb) near



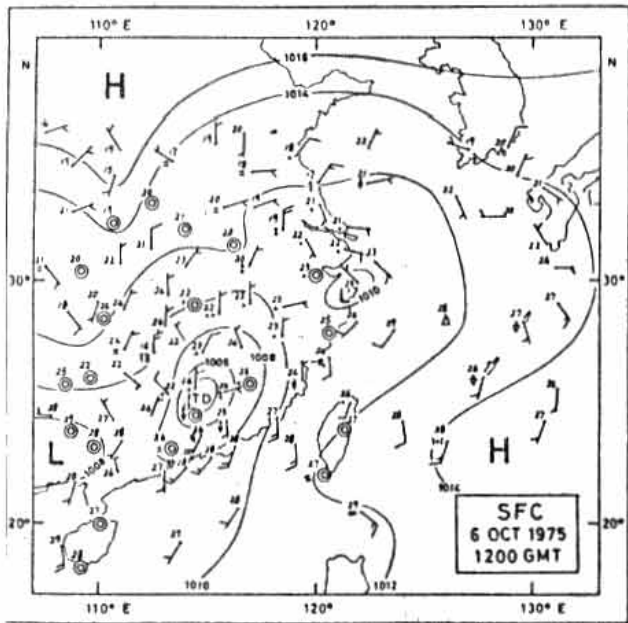
Fig. 13.1 Radar photograph of spiral rainbands in an occluded depression as seen on board the "Weather Reporter". The radius of the display is 75 n miles and the direction of north is towards the top of photograph (Photograph by R.H. Brass).

62°N 32.7°W at 1100 GMT on the 14th October 1963. This depression originated as a tropical cyclone which had moved northwards east of Bermuda three days earlier. The winds around the centre, as observed on the ship, were between 25 and 45 knots. It is not possible to prove that the spiral bands were directly related to the tropical origin of the storm but this seems likely in view of the high speed of the storm centre - approximately 30 kn - and the known persistence of the circulation and other tropical characteristics of these storms.

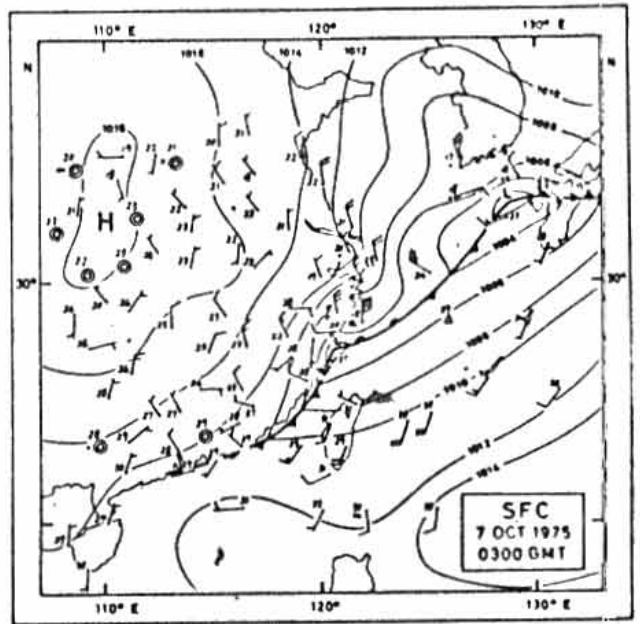
From the foregoing it will be clear that in the early stages of becoming frontal, typhoons may be regenerated while retaining for a time their size, circular symmetry and other tropical attributes.

It is not necessary for typhoons to remain over the sea to become transformed. Tropical cyclone remnants have travelled thousands of kilometres over land with little or no associated surface circulation only to become regenerated as a frontal cyclone on encountering a baroclinic zone. Sometimes the remnant regenerates as a tropical storm on regaining warm waters. In Fig. 13a typhoon Doris is seen over China having crossed the coast just west of St. John's Island about 190 km west of Hong Kong (track shown in Fig. 13c) at 1800 GMT on the 5th October 1975 at which time the surface central pressure was less than 976 mb and the winds in excess of 25 m/s. Much damage was caused in Canton where squalls of hurricane force were experienced. Fig. 13a shows that in less than 12 hours the wind velocities were down to a few metres per second and directed towards the low pressure centre (1003 mb) while the diameter of the 1004 mb isobar had shrunk from about 550 km on crossing the coast to 200 km or so. Winds of 25 m/s re-appeared as soon as the low reached the coast, reintensified and developed fronts (Fig. 13b). This change took place to the east of a wave in the westerlies (Fig. 13c,d) associated with a southward surge of polar. Such redevelopment at a coast can be disastrous, if not forecast, since small coastal vessels are easily distressed by sudden sustained winds of near hurricane force.

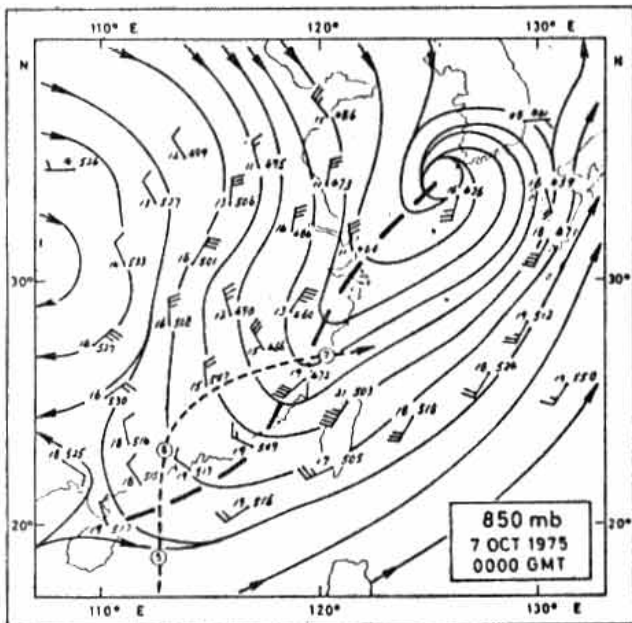
Table 13. has been constructed by observing when and where fronts were first shown in the circulation of decaying named tropical cyclones (i.e. typhoons and tropical storms) in the weather maps published



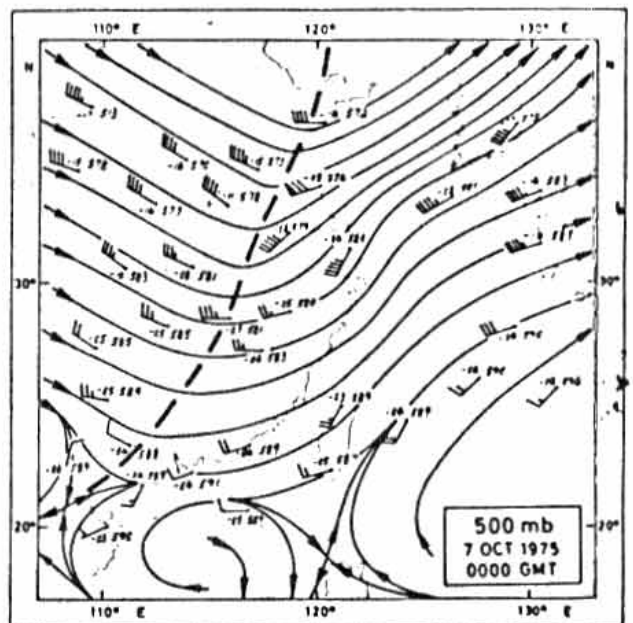
a



b



c



d

Fig. 13 . The track of typhoon Doris 1975 is shown in (c) the remnant over China is shown in (a) while (b) shows its regeneration as a frontal depression on regaining the sea. Relevant upper air charts are shown at (c) and (d).

Table 13.2 The average number of ^{named} tropical cyclones (T.C.) which became frontal during the period 1966-1975 and the average position at which this first occurred.

	JAN	FEB	MAR	APL	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Average No. of T.C.*	0.6	0.2	0.4	0.9	0.9	1.8	4.4	6.4	5.4	4.8	3.1	0.7	29.6
Average No. of T.C. to become frontal cyclones	0.2	0.1	0.3	0.4	0.4	0.4	0.7	1.9	2.6	2.0	0.9	0.1	10.0
% becoming frontal	33	50	75	44	44	22	16	30	48	42	29	14	34
Average Latitude °N	16.5	21.8	22.3	27.0	26.1	30.0	35.5	38.4	35.5	32.1	32.1	19.0	28.0
Average Longitude °E	148.0	127.2	146.9	133.8	142.0	135.5	136.6	140.3	145.0	149.4	146.0	145.5	141.7
Average No. becoming extratropical with mean diameter 7,110 km	0	0	0	0	0	0.1	0.1	0.2	0.2	0.5	0.1	0	1.2

* Area bounded by 0°- 45°N, 100°-160°E.

by the Japanese Meteorological Agency. During the early stages of the transformation from tropical cyclone to extratropical cyclone, the fronts are often ill-defined and the decision as to whether or not to mark them on a weather chart is to some extent subjective. Nevertheless, Table 13. should give a good indication of the incidence of these transformations in the North Pacific. It will be seen that in the ten years 1966 to 1975 an annual average of 10 or approximately 30% of all tropical cyclones became frontal although the annual number varied from one in 1973 to fifteen in 1968. On a monthly basis the Table shows that the event occurs most frequently in October (2 p.a. on average) but that March storms are the ones most likely to become extratropical (75%).

Table 13.1 also shows that the average latitude at which a typhoon becomes a frontal depression rises from 16.5°N in January to a maximum of 38.4°N in August; the annual average is 28.0°N. These mean monthly latitudes are mostly about eight degrees north of the Pacific ridge at 500 mb as shown in Fig. . The distance is slightly greater in October (10°) and November (11°) and considerably less (about 2°) in January and December. There is no systematic variation in the longitude at which tropical cyclones become frontal; the monthly average remained in the range from 127°E to 150°E.

In more detailed studies Sekioka (1956, 1957, 1959) has shown that of 21 typhoons moving over Japan and the Sea of Japan, 18 had a complex structure with some frontal characteristics, the remaining 3 did not change their structure. It is noteworthy that the three typhoons which retained their tropical characteristics at this relatively high latitude occurred in July when the Asia continent is at its warmest and baroclinic conditions associated with outbreaks of polar air are weak or non-existent.

~~It is of interest to record that~~ Very occasionally the transformation can proceed in the reverse direction that is, a tropical cyclone may form from an extratropical cyclone. Pope (1968) has presented a well documented case of such a process. An extratropical cyclone which formed off the east coast of Florida on a cold front near 28°N 74°W on 6 February 1968 moved north at about 20 kn and occluded. When it crossed the warmer waters (24°C) of the Gulf Stream the Cape Hatteras radar (35.3°N 75.5°W) showed the development of an eye and spiral bands and a reconnaissance aircraft observed a warm core structure. These tropical characteristics disappeared again as the centre moved further north over colder (< 21°C) waters.

About 12% of transformed typhoons became major extratropical cyclones with mean diameters in excess of 1110 km. These major storms occur most frequently in October when about 5% of all transformed typhoons reach this size. However, this corresponds to only one such storm every other October, on average. The frequency of occurrence in August and September is about half that in October and a few large storms occur in June, July and November but none were observed in the months December to May ~~during the period (1966-1975). (Table 13.1)~~ .

13.1.1 Mechanism of the transformation

There are three main ways in which tropical cyclones most frequently acquire extratropical characteristics. Firstly, they may move onto a pre-existing cold front, secondly they may approach a pre-existing extratropical cyclone through its warm sector and merge with its cyclonic circulation and, thirdly, they may move into a baroclinic zone and develop their own fronts. There are, of course, variations on the three main methods and case studies show that the details of individual transformations are usually complex. During the period 1966-75, 72% of transformations were associated with cold fronts, 21% were due to typhoons merging with existing extratropical cyclones only 7% were associated with frontogenesis.

A well studied example of the regeneration of a tropical cyclone and its simultaneous transformation into a very severe extratropical cyclone over land was hurricane Hazel 1954 (Hughes et al 1955, Palmen 1958). In this case the hurricane moved onto a cold front ahead of a major outbreak of cold air over the eastern United States on the 15th October 1954 (Fig. 13.). The cold-air outbreak was accompanied by a deep trough in the westerlies at 300 mb and the transformation took place below the upper-level divergence region ahead of the trough axis. Similar upper-air conditions prevailed over China in the case of the deepening of typhoon Doris shown in Fig. 13.

Sekioka (1970) considers that it is not usually the typhoon itself which is transformed into a frontal depression but rather that the typhoon induces the formation of a new cyclonic circulation on a pre-existing cold front which has penetrated the typhoon's outer circulation. A complex system is thereby formed consisting of a typhoon vortex and a new extratropical vortex; the latter intensifies and soon becomes dominant while the former eventually dissipates. A similar sequence occurred in the transformation of hurricane Hazel, the cross in the diagram for 1830 GCT indicates where the induced vortex developed.

An occasion when a typhoon combined with a pre-existing extratropical cyclone occurred on the 22nd August 1969 in typhoon Cora and has been described by Mantano & Sekioka (1971) and is illustrated in Fig. 13.

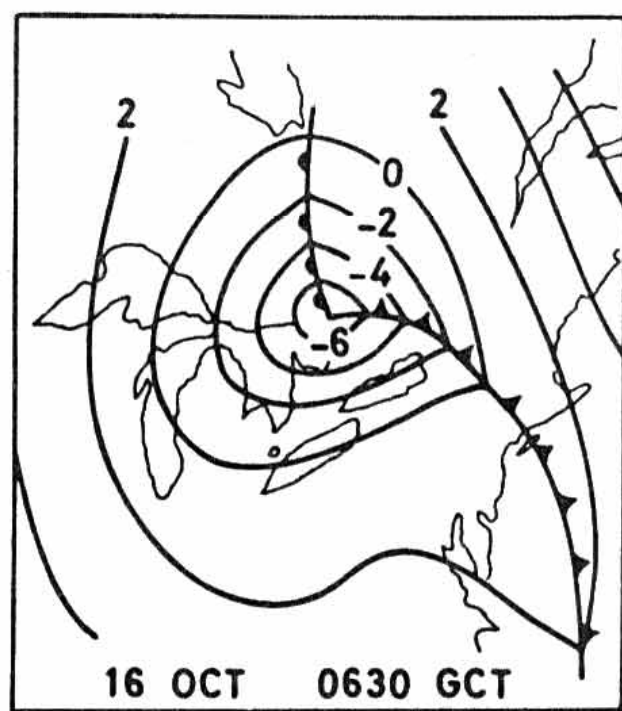
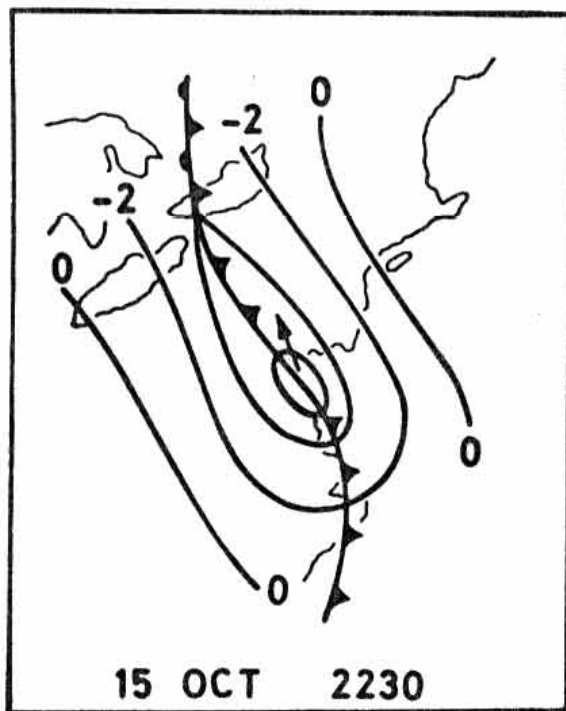
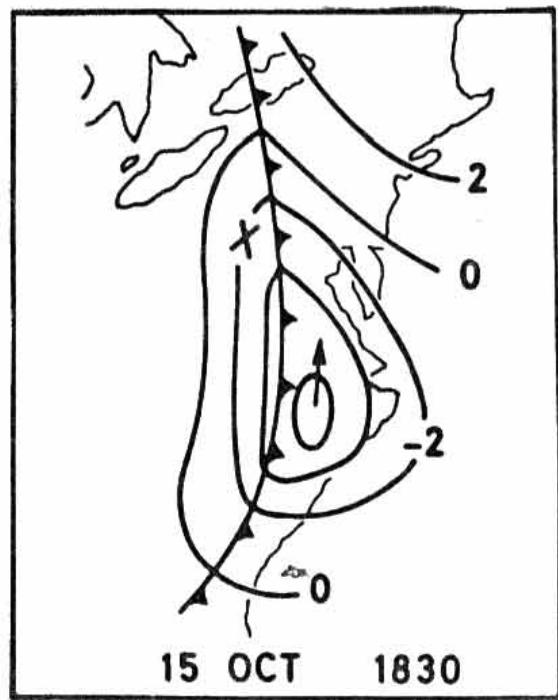
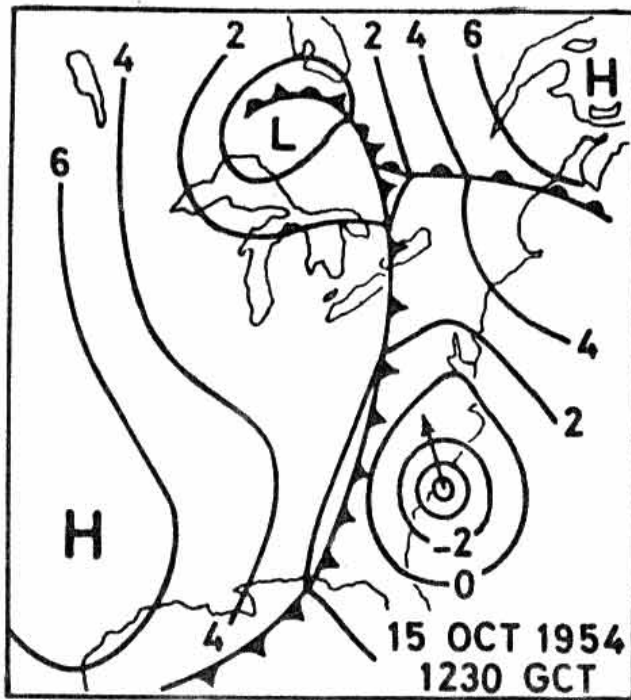


Fig. 13 Hurricane Hazel 1954 moving onto a cold front and inducing a new vortex to form at point "x" - see the 1830 GCT chart. Contours at the 1000 mb surface are shown at intervals of 200 ft.

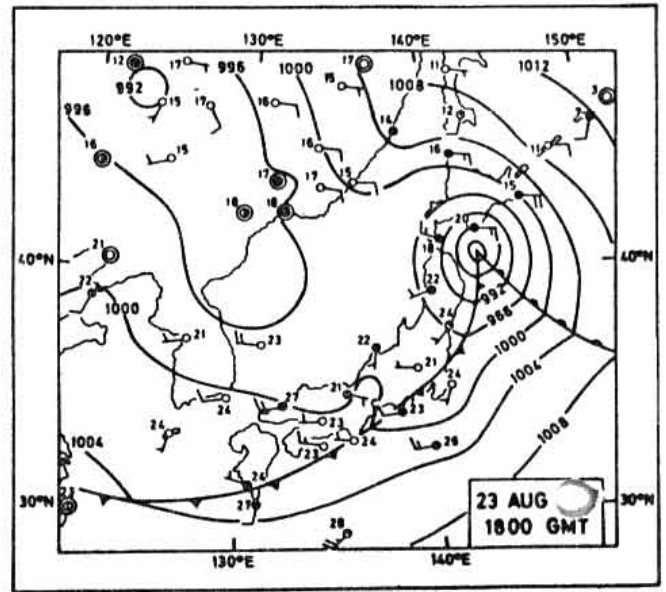
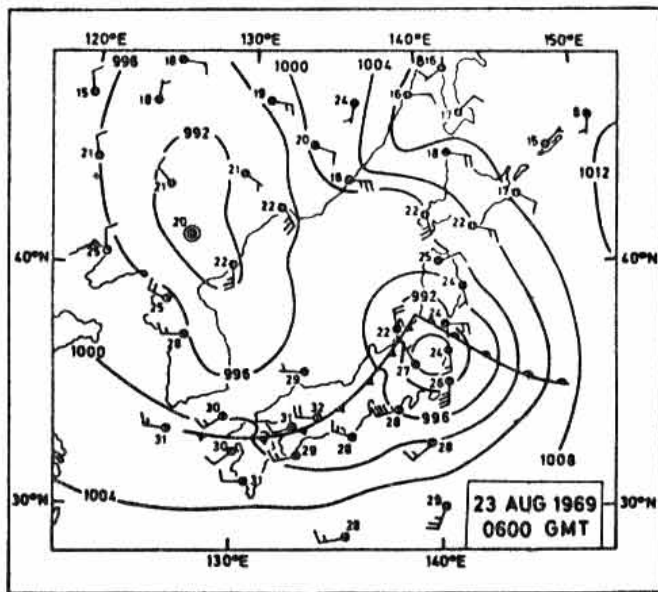
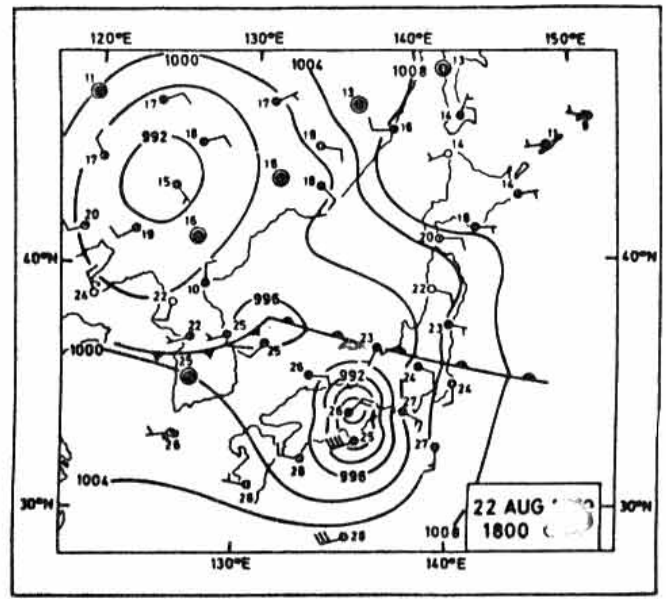
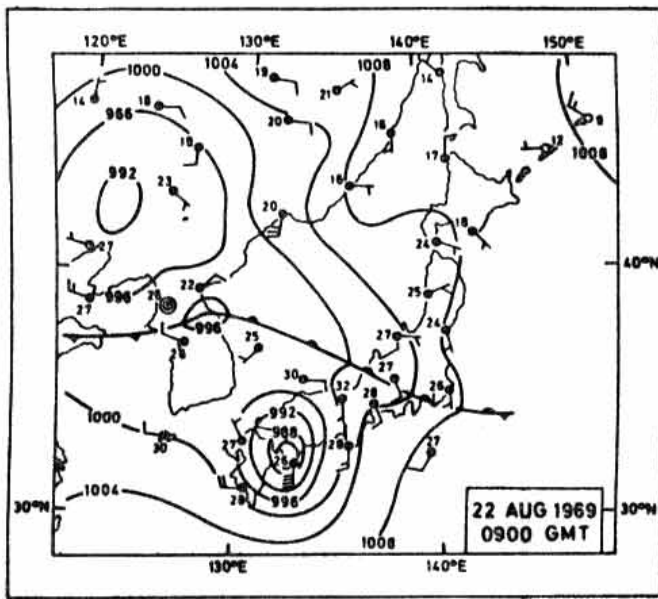


Fig. 13. Typhoon Cora 1969 moved through the warm sector of an extratropical cyclone with which it merged. (After Matano & Sekioka 1971)

5

Frontogenesis within a typhoon circulation is not as frequent as the other two methods of transformation and I have seen no published case studies. However, the case of typhoon Trix 1971 illustrates the phenomenon. On the 1st September 1971 this typhoon moved northward into a baroclinic zone over Japan and came under the influence of the associated westerly winds which carried it away from Japan, towards the east, at 15 kn. On the same day fronts were indicated within the circulation in both the Japanese and Hong Kong weather maps. The Hong Kong map for 0000 GMT on that day and the almost simultaneous satellite photograph are shown in Figs. 13. and 13. respectively. The case is typical in so far as the cold front is relatively short and the warm front extends to the trailing cold front from the next depression to the eastward (Fig. 13.). Once again, there was a well marked trough in the upper-level westerlies to the west of the typhoon; this trough, at 300 mb, extended across Hokaido and Kyushu and as far south as Hong Kong. Cases of significant deepening during the transformation of typhoons are usually associated with the characteristic vorticity advection and associated divergence region ahead of upper-level, middle-latitude troughs, which assist in the eviction of air at these levels from the typhoon circulation. Hughes et al (1955) pointed out that it is sometimes possible to forecast the deepening and movement of these upper troughs which, in turn, can lead to the prediction of the intensification of any associated cyclones; the current, widespread availability of good computed forecast charts for the upper levels in temperate latitudes is of great assistance in this connection.

When a typhoon approaches a baroclinic zone and begins to take on extratropical characteristics its speed of progression is usually accelerated and considerable asymmetries can occur in the outer circulation. Colder air is advected southward to the west of the centre and the typhoon rapidly moves closer to well defined cyclones or anticyclones of higher latitudes which are themselves moving. These features can combine to give an impression, from observations at a station, of enhanced asymmetry. This is especially so in the case of ships having a component of motion opposite to that of the typhoon. For example, when the "Arctic Tokyo" crossed the track of typhoon Tess at latitude 46°N while en route from Alaska to Tokyo in

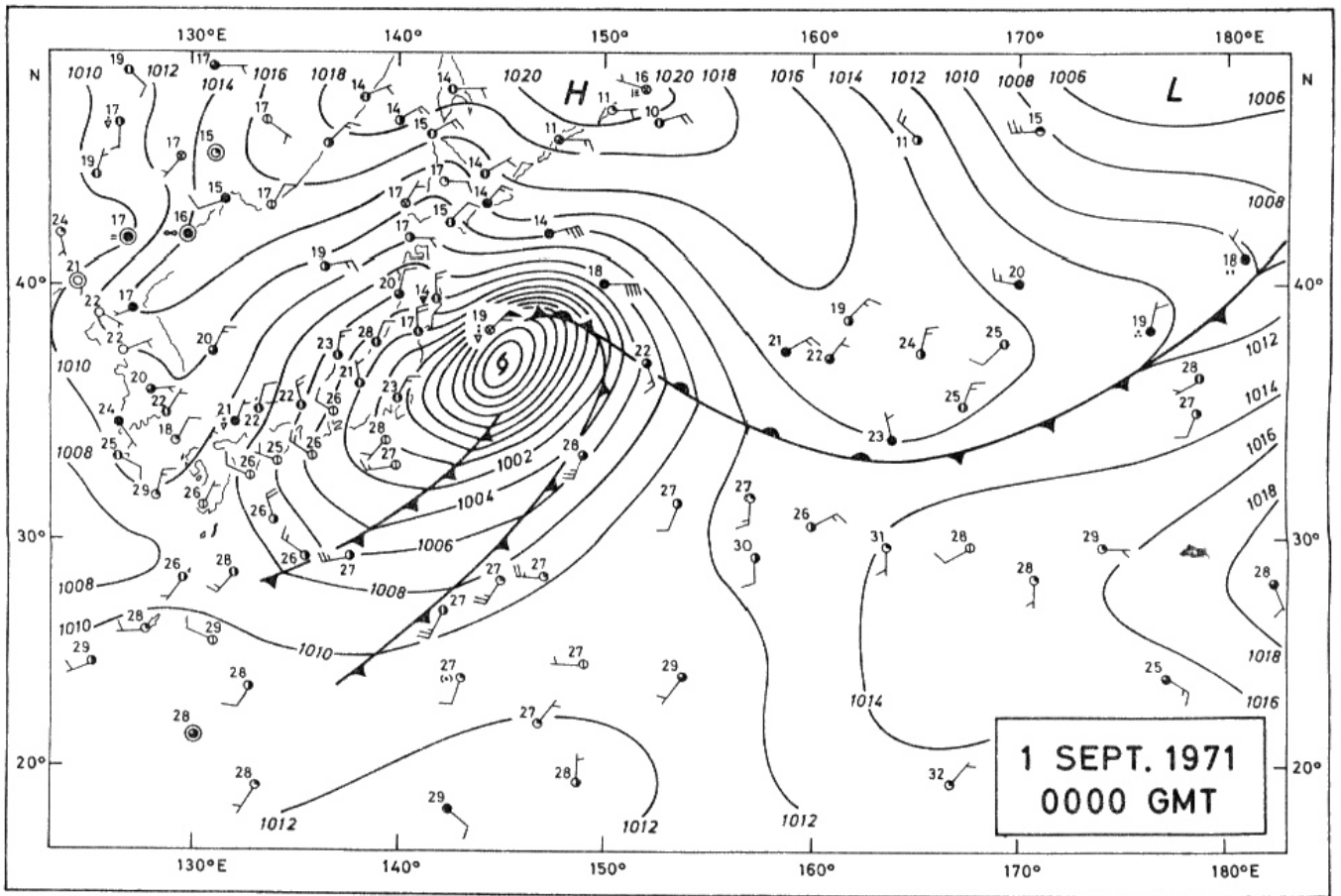


Fig. 13.9.1 The remnant of typhoon Trix with newly developed fronts.

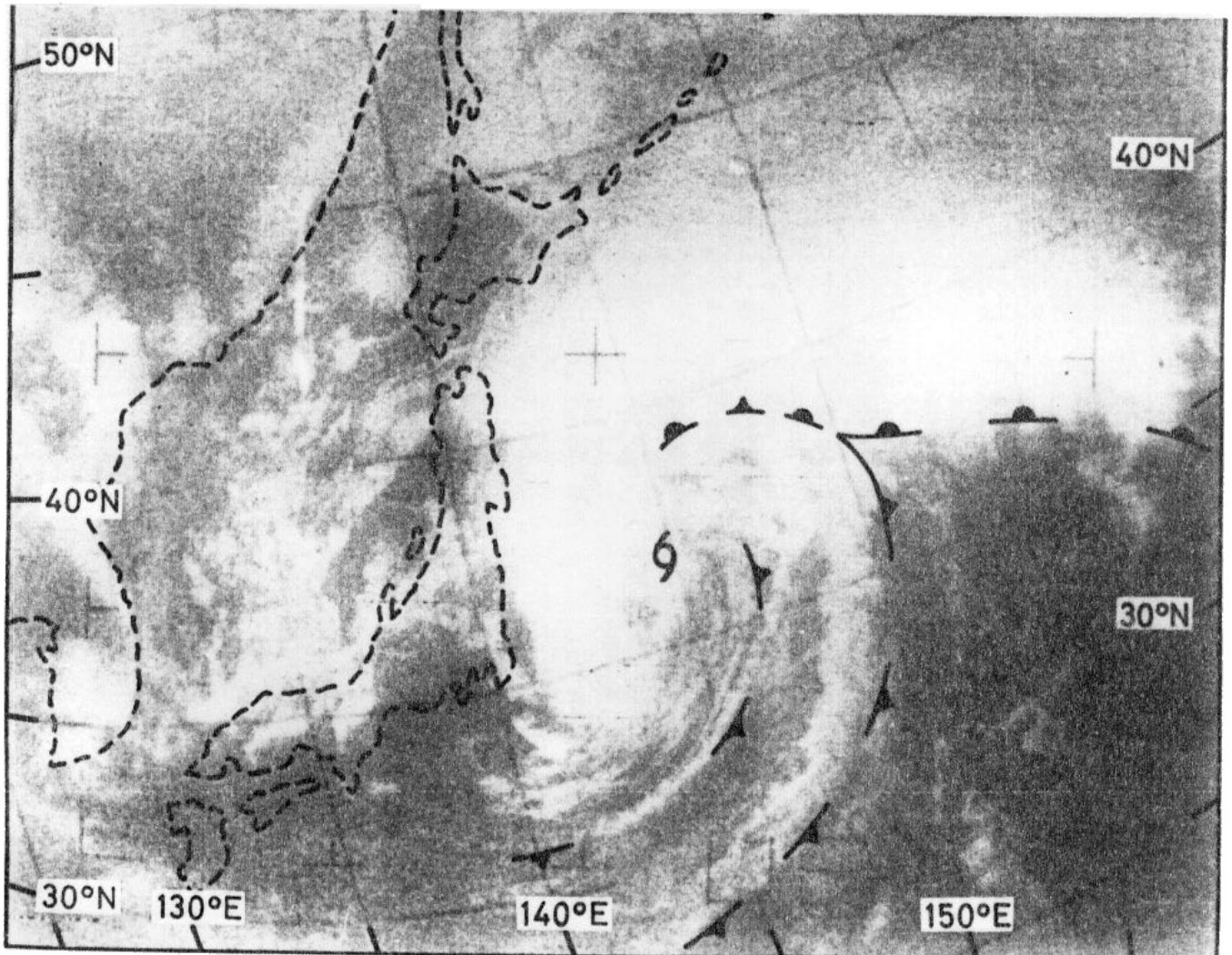


Fig. 13.9.2 ESSA 8 satellite picture of the situation in Fig. 13 as received at Hong Kong at 0030 GMT on 1st September, 1971.

September 1975, the barograph trace shown in Fig. 13. was obtained. This trace gives the impression that the environment on one side of the typhoon was some 30 mb higher in pressure than on the other. In fact the ship was near the centre of the Aleutian High 1850 km northeast of Tess at 091200Z whereas it was 1445 km southwest of the typhoon and a long way from the anticyclone at 111200Z.

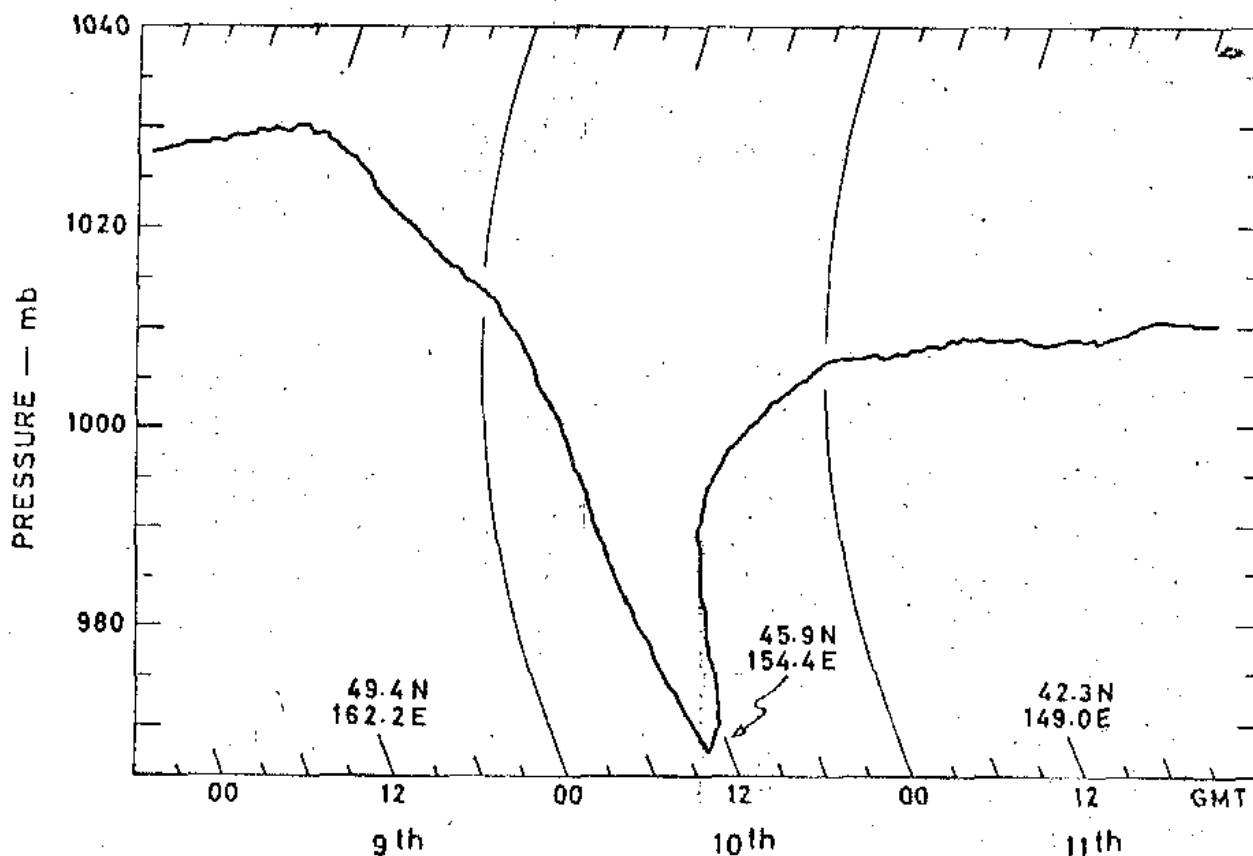


Fig. 13.9 3. The barograph trace from the "Artic Tokyo" which crossed the path of typhoon Tess, in September 1975, as it was becoming extratropical.

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