CHAPTER 9 TRACKING TROPICAL CYCLONES

** Not Completed*

9.1 Introduction

Since weather maps were first prepared the centre of a tropical cyclone has been taken as the point of lowest pressure. However, this point is not unique as a centre and is convenient only when charts are analysed in terms of pressure. If wind velocity and streamlines are used in the analysis an instantaneous centre of rotation relative to the earth is identified. Furthermore, if the component of motion due to movement of tropical cyclone as a system is removed from each of the wind observations, then, trajectories relative to the storm itself are obtained. These relative trajectories (See Fig. 5.3.1) define the system centre of rotation i.e. the vorticity centre. The relative importance of these different centres in the tracking context depends on which methods of observation and analysis are used. For example, wind observations define the instantaneous centre, pressure observations define the pressure centre and single radar and satellite images usually define the system or vorticity centre. This latter circumstance arises because clouds and rain are determined by the field of divergence which is unaffected by a superimposed uniform translation. Of course, the individual clouds on satellite pictures and the rain areas seen by radar are affected by both the storm rotation and translation and if followed in time they also determine the instantaneous centre of rotation. The greatly improved accuracy now attainable in fixing the centre of tropical cyclones by aircraft reconnaissance, satellite and radar often high lights the displacement of the different centres. An appreciation of the magnitudes involved is essential for good tracking of cyclone motion. On certain assumptions the relative positions of the three centres can be calculated.

If the air near the centre of a cyclone is assumed to rotate as a solid disc about the storm centre point O (Fig. 9.1.1) with uniform angular velocity ω_o and if the system moves in a straight line with velocity V then Shaw (1918) showed that the instantaneous centre of rotation moves to a point O_i to the left of the storm centre (Northern Hemisphere) such that

$$OO_i = \frac{V}{\omega_o} \qquad (9.1)$$

If the gradient wind equation is applied to this system the barometric centre O_b is found between O and O_i at a distance

$$OO_b = \frac{V f}{\omega_o (f + \omega_o)} = \frac{f}{f + \omega_o} \cdot OO_i \qquad (9.2)$$

where f is the Coriolis parameter.
The distance between the instantaneous centre O_i and the barometric centre O_b is, by subtraction

$$O_iO_b = \frac{V}{\omega_o} \left(1 - \frac{f}{f + \omega_o}\right) \qquad (9.3)$$

The three centres should therefore move further apart as the speed of translation of a cyclone increases or as the wind speeds determining ω_o decrease. The greatest displacement of the centres in a typhoon would be expected to be found in high latitudes, after recurvature, when speeds of translation of about 20 m/s occur and wind speeds are often decreasing.

Hatakeyama et al (1954) plotted the over-sea trajectories of radar rain echoes in typhoon Lorna on 18 September 1954. The echo movements defined an instantaneous centre of rotation O_i about 90 km to the left of the storm centre O as determined by the relative trajectories. The latter were obtained by removing the storm's motion (ENE at 18 m/s) from the echo motion. Putting OO_i equal to 90 km and V = 18 m/s in eqn (9.1), yields a value of 20×10^{-5} per second for ω_o. Noting that at 30^oN, $f = 8 \times 10^{-5}$ per second then eqn (9.2) can be used to calculate that the displacement of the barometric centre OO_b would be about $0.29 \times OO_i$ or 26 km, a value which was found to accord with the observations. The use of land station wind reports to determine trajectories yielded a greater displacement of about 50 km. Misalignment of the three centres in a tropical cyclone in the tropics will not in general be as great as in the example quoted. A typhoon of intensity similar to that of Lorna, moving westward at 6 m/s at 20^oN, would have its instantaneous centre O_i displaced about 30 km south of the vorticity centre O. The barometric centre would be about 6 km south of O. Somewhat larger displacements may be found over land. The wind circulation in typhoon Lucy 1965 can be seen to be displaced about 28 km to the west in the photograph from the Mt. Fuji radar shown in Fig. 10.33. The calm or light-wind area

Table 9.1. Displacement of the instantaneous centre of rotation from the vorticity centre.

		Typhoon Lucy 1965	*Subtropical Cyclone* 211930 GMT	222030 GMT	231230 GMT	Typhoon Lorna 1954
V	m/s	4.5	6.7	5.2	5.2	18
Max. wind v_{max}	m/s	23	26	15	7.7	25
Ratio V/v_{max}		0.20	0.26	0.35	0.68	0.72
Displacement	km	28	37	55	74	90

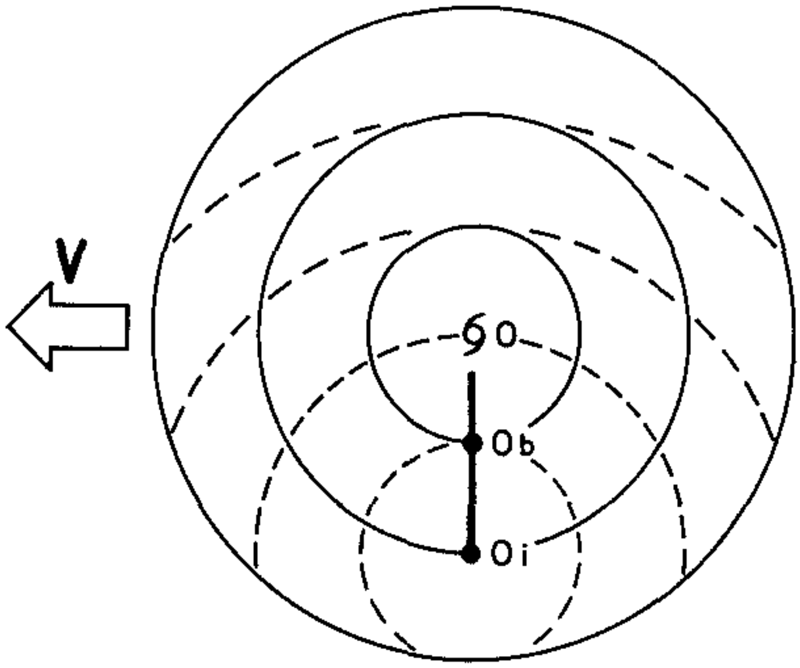

Fig. 9.1 (1). All portions of a disc (full lines) rotating cyclonically, in the Northern Hemisphere, about the centre O and being translated with velocity V will rotate (dashed lines) about an instantaneous centre O_i. In an atmospheric vortex the location of the minimum pressure shifts from O to a point O_b between O and O_i.

is associated with a smooth sea surface which does not return radar energy. The typhoon was moving north at 4.5 m/s with maximum wind speeds of about 23 m/s and an eye diameter of 55 km.

The technique of determinating the instantaneous centre of rotation O_i from successive radar images of a storm can sometimes be applied to successive satellite images from geostationary satellites. Fig. 9.1.2 from Lushine (1978) shows spiral cumulus bands with tops near 2.5 km in a subtropical cyclone moving westward to the northeast of Puerto Rico. The centre of the storm system or vorticity centre is at O. The movement of clouds between 1830 and 2000 GMT relative to the earth is depicted by wind arrows in Fig. 9.1.3. The instantaneous centre of rotation so determined and marked by an X is about 74 km to the left of O and in agreement with that found by reconnaissance aircraft. Since the displacement of the instantaneous centre is given by V/ω_o and since ω_o depends mainly on the speed of the wind in the inner regions of the storm the displacement will be greater as the ratio of V to the maximum wind speed increases. There are two special cases. Firstly, when V is everywhere greater than the storm wind speeds there will be no closed centre of circulation. This is often seen at upper levels when a recurved, weakening typhoon penetrates into the strong westerlies. Secondly, when the storm is stationary all three centres coincide.

Table 9.1 has been prepared from the data given by Lushine (1978) and Hatakeyama et al (1954) and from Fig. 10.33. It indicates that the displacement of the instantaneous centre of rotation from the cyclone's vorticity centre is approximately proportional to the ratio of the speed of translation V to the maximum sustained wind speeds V_{max} for ratios less than 0.35. To a first approximation the displacement is given by 140 times the ratio. For increasing ratios above 0.35 the displacement does not increase as fast as would be required by direct proportionality.

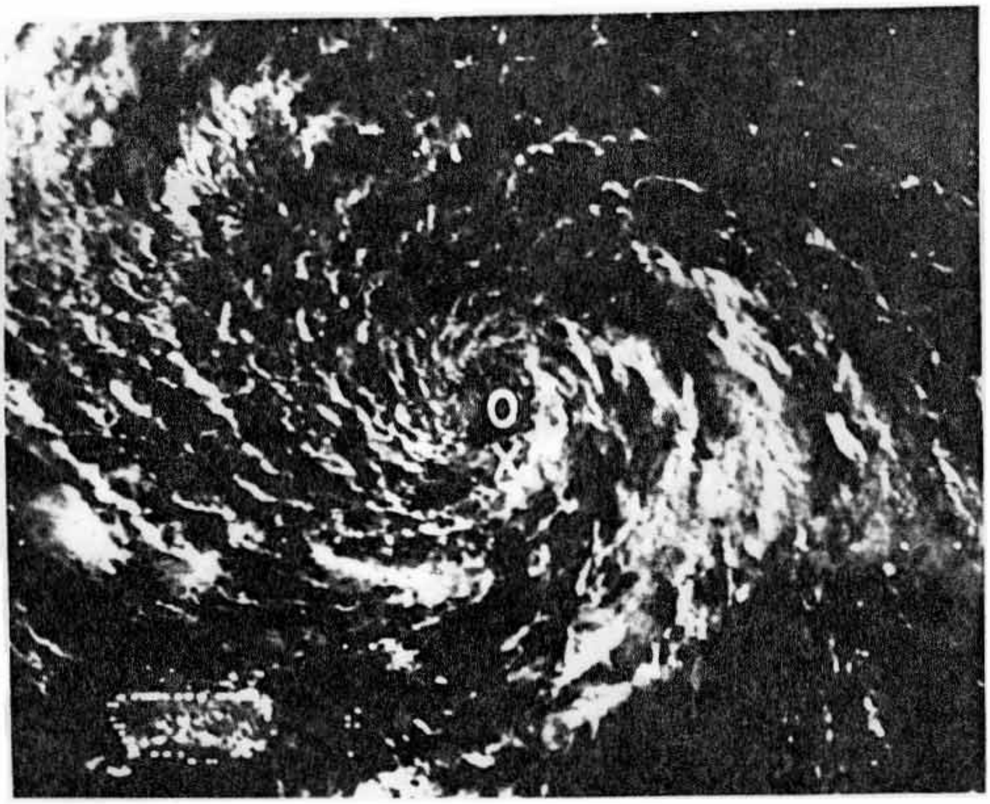

Fig. 9.1(2) A subtropical cyclones in the Atlantic, just northeast of Puerto Rico moving westward at 5 m/s at 2030 GMT on 22 January 1978 with maximum winds of 15 m/s. The centre of the system is at O. Reconnaissance flights found the wind centre at X. (From Lushine 1978)

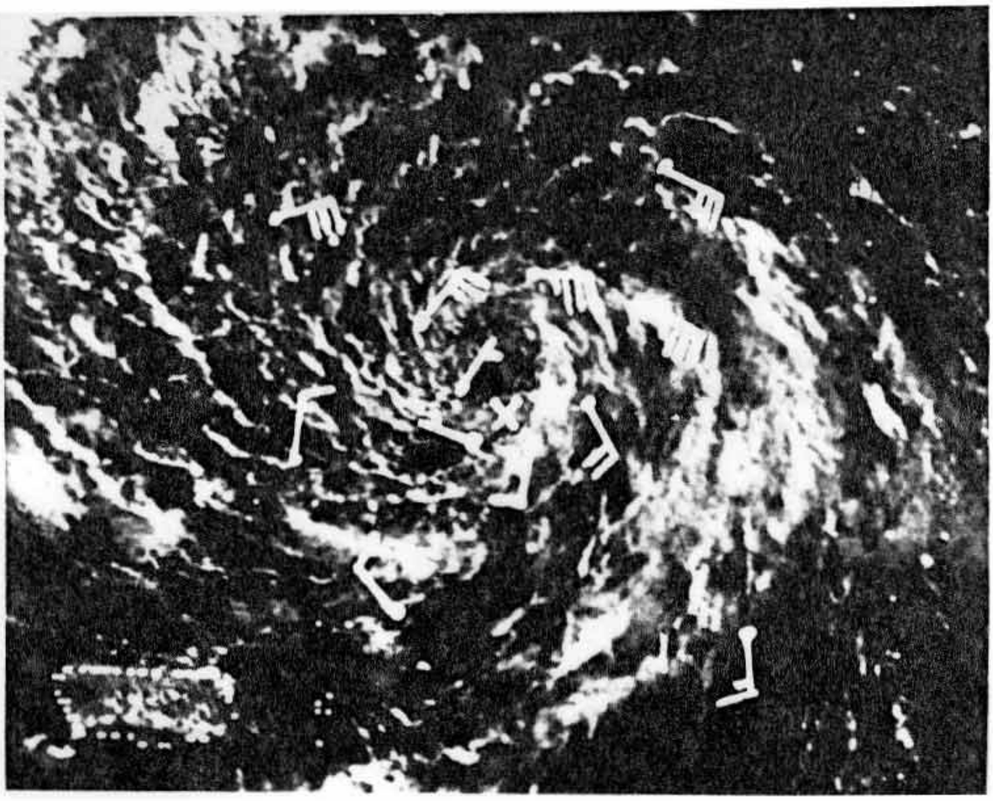

Fig. 9.1(3) Winds derived from the motion of clouds between 1830 and 2000 GMT are here superimposed on the photogroph in Fig. 9.1.2. The instantaneous centre of rotation X agrees with that found by aircraft reconnaissance. (From Lushine 1978)

9.3 Aircraft Reconnaissance

On 15 July 1973 I flew into the eye of the developing typhoon Dot in a twin engined Islander aircraft of the Royal Hong Kong Auxiliary Air Force. Whilst in the eye at 1 500 m above the sea we were joined by a USAF reconnaissance Hercules (WC-130) flying at 3 000 m. The eye was not well formed and the centre was determined mostly by the sea state. The Islander reported the centre at 0300 GMT as being at 18°N 113.6°E. The Hercules reported 17.9°N 113.6°E. Coming in from the north the Islander found maximum easterly winds of 23 m/s, whereas the Hercules found maximum winds of 25 m/s on the south side of the storm (JTWC Ann. Rep. 1973). This occasion was most probably the first time that reconnaissance aircraft from different air forces had shared the air space within the eye of a tropical cyclone.

When within range of land-based radar reconnaissance aircraft can be observed making their fix. A radar time-lapse film of typhoon Shirley 1968 taken at the Royal Observatory Hong Kong showed a USAF reconnaissance Hercules entering the eye by flying between rainbands on the southeast side of the centre and orbiting several times to locate the minimum-pressure centre. The radar return from this aircraft is visible in Fig. 9.3(1) when the centre of the typhoon was some 120 km SSE of Hong Kong. ~~Some~~ three penetrations intervals of approximately six hours were filmed. Observations from the last fix at 0845 GMT on 21 August 1968 are compared with those made at Hong Kong stations in Table 9.3(1). The agreement is good, the aircraft surface winds are here seen to be 1.11 times the Waglan 10-min mean winds indicating that they refer to an averaging time between 30 s and 1 min. The flight level winds are close to the 10-min average wind speeds in this case.

A Hercules (WC-130) of the 54th Weather Reconnaissance Squadron with six crewmen on board crashed into the South China Sea, km to the south of Hong Kong while tracking typhoon Bess on 12 October 1974. Crash position indicators and crushions were subsequently located but none of the crew members or the aircraft were subsequently found. The aircraft had been tracked on the Royal Observatory Hong Kong's weather until its disappearance. As a token to the memory of the aircrew lost on this flight the name "Bess" was dropped from the list of names used for tropical cyclones in the following years (sect).

Table 9.3(1) Comparison of aircraft and conventional observations as Typhoon Shirley (1968) crossed Hong Kong

	Time	Min. Pressure	Surface Wind			700 mb Observations				Eye Diameter
			A/c	Waglan Island 10-min	Waglan Island Gust	Wind	Ht.	TT	T_dT_d	
	GMT	mb	m/s	m/s	m/s	m/s	m	°C	°C	km
Aircraft	0845	964	41	-	-	36	2801	18	14	93
Waglan Island	1000	966	-	37	60	-	2831*	15	13	98+

* From 1015 GMT ascent

+From radar (Fig. 9.3(1))

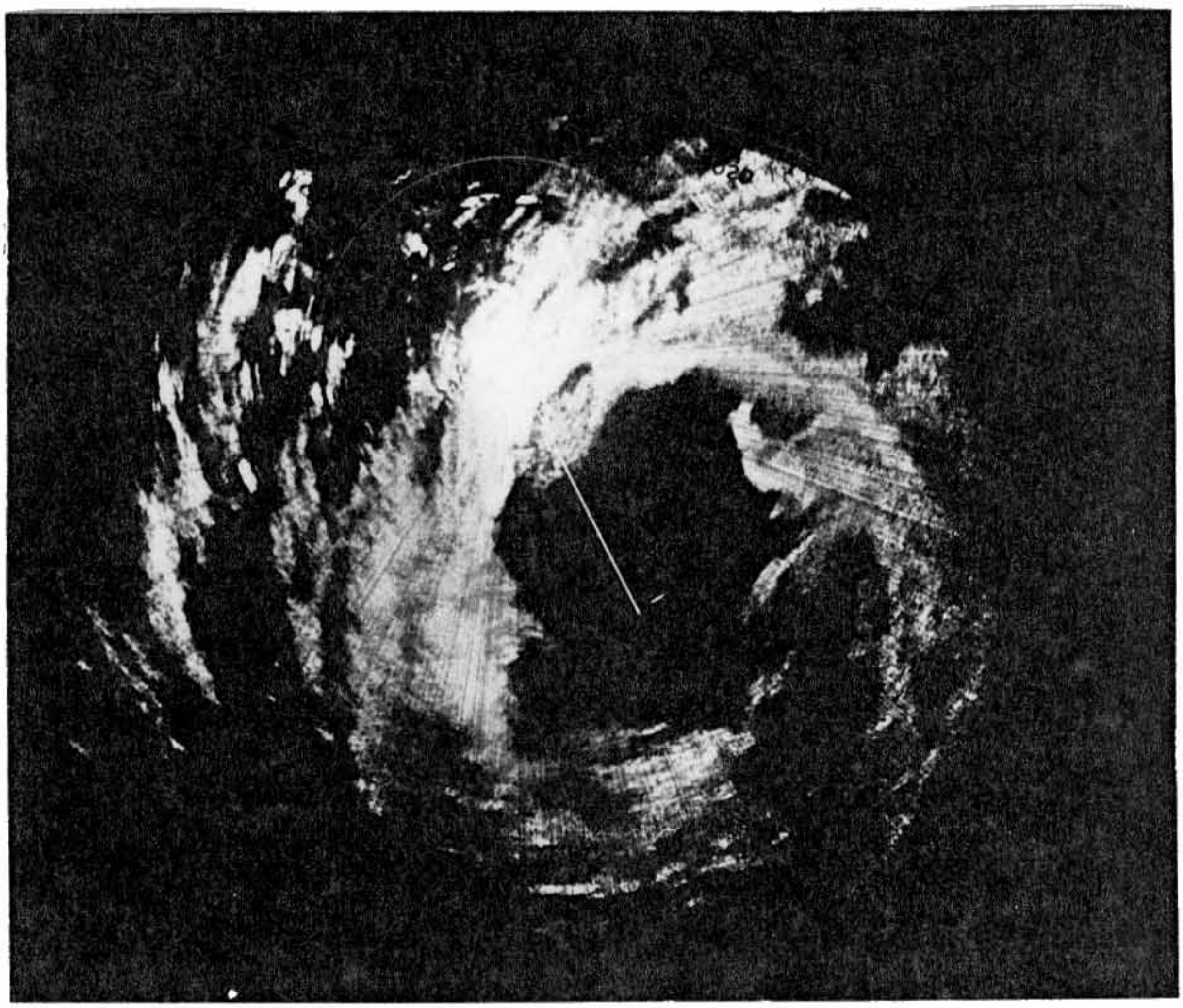

Fig. 9.3.(1) The radar return from a U.S. Air Force reconnaissance Hercules (WC-130) in the eye of typhoon Shirley can be seen just to the right of the distance marker 120 km SE of the Hong Kong radar. The time was 0530 GMT on 21 August 1968. The radar beam was elevated 1.5° above the horizonal. Range rings are at intervals of 74 km.

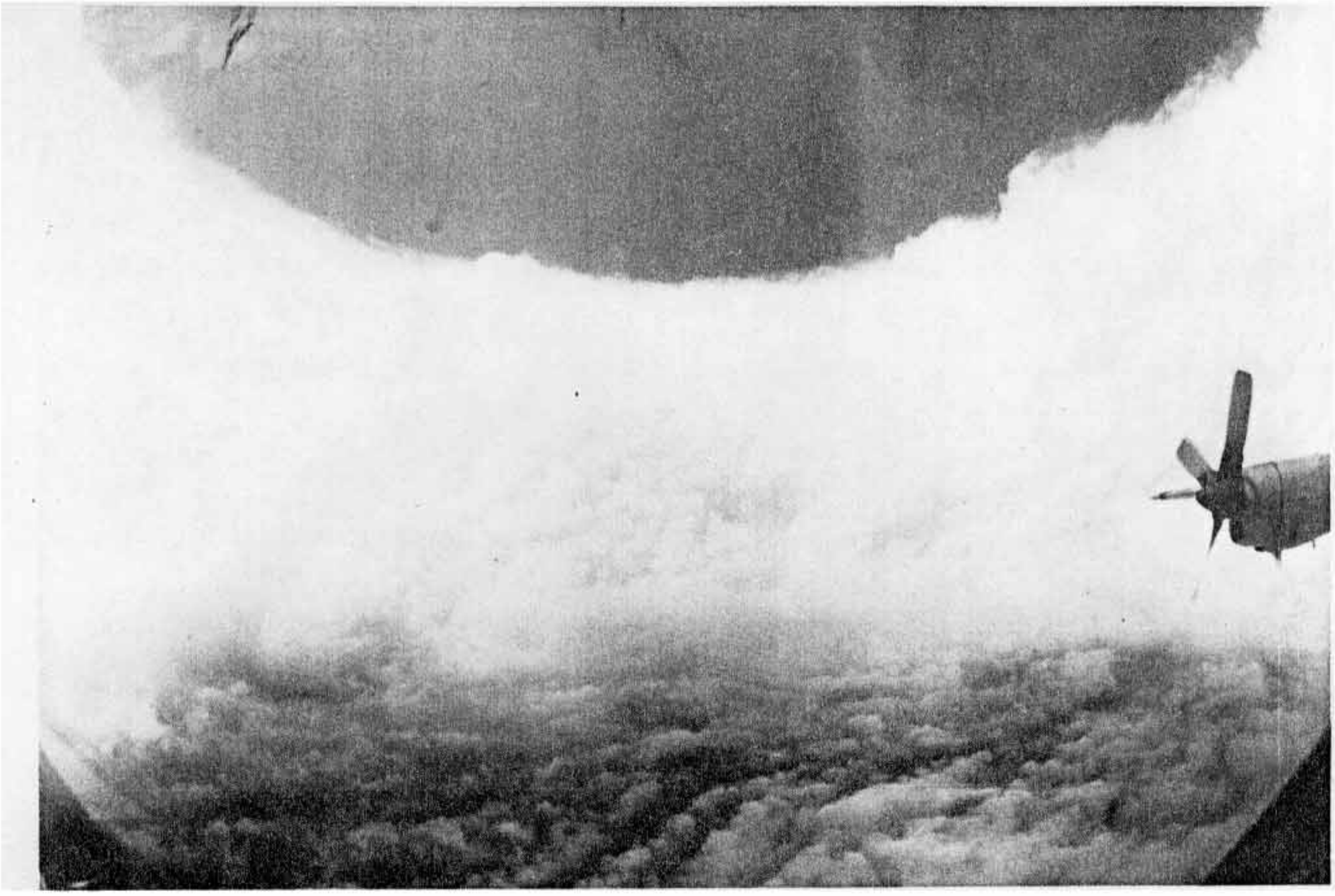

Fig. 9.3. (2) A Hercules (WC-130) reconnaissance aircraft in the eye of typhoon Sarah near noon on 10 October 1979 when the typhoon was located over the South China Sea near 11.7°N 116.4°E. The eye was 28 km in diameter and the minimum surface pressure was 929 mb. (Photograph by courtesy Robin Moyer).

" Everyone and every set of men who are pursuing the investigation of any great question, are apt to over-rate its importance;and perhaps I shall only excite a smile when I say, that the day will yet come when ships will be sent out to investigate the course of storms and hurricanes,......."

To Piddington, therefore, must go the credit for ~~being the~~ first ~~to~~ conceive the value of reconnoitring tropical cyclones. However, almost one hundred years passed before, in August 1937, a delegation of irate citizens turned up at the White House in Washington to get President Roosevelt's agreement to send Coast Guard cutters to reconnoitre hurricanes (Tannehill, 1955). The citizens were irate because they were dissatisfied with the warnings they had received. The trouble arose because ships no longer went near hurricanes, the good warnings received from the Weather Bureau enabled them to keep clear of the hurricane path. A result of this was that occasionally hurricanes were lost as they approached land because there were no ships near their centres to send weather reports. People living around the Gulf of Mexico and on the southeast seaboard wanted Coast Guard cutters to go out to find these storms and make observations. Legislation was passed to give the necessary authority but it was vetoed by President Roosevelt; his opinion had not changed when the delegation arrived at the White House. Admiral Waesche met the delegation and agreed to their proposal before being briefed on the President's views. The cutters were sent out a few times but, in the heavy seas, they were slow and unable to obtain information early enough for the preparation of warnings so, the procedure was abandoned. Routine reconnaissance of hurricanes by aircraft did not begin until 1944 in the Atlantic and 1945 in the Pacific.