Typhoon Structure as Revealed by Aircraft Reconnaissance. Part II: Structural Variability

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ABSTRACT

This is the second of two papers on the structure of northwest Pacific tropical cyclones as revealed by U.S. Air Force aircraft reconnaissance. This paper describes the varying structure of the tropical cyclone's outer-radius wind profile in relation to its inner-core intensity or minimum sea level pressure (MSLP) and eye-size characteristics. We explore this inner- to outer-radius structural relationship and its variability for the full range of cyclone central pressures, eye diameters, outer-core (1°–2.5° radius) wind strengths, and for radial extent of 15 m s^{-1} (30 kt) and 25 m s^{-1} (50 kt) surface winds.

Results show that outer-radius wind strength and inner-core intensity can vary greatly and that there is only a weak relationship between these parameters. However, if information is available on whether an eye-wall cloud exists and what the size of the eye is, then a significant reduction in the wide variance between MSLP and outer wind radius is observed.

1. Introduction

Understanding the differences in wind velocity between one segment of the tropical cyclone's radial profile of wind and the other segments is important to both forecasters and researchers. Given the central pressure and eye-wall characteristics of a tropical cyclone as measured by a reconnaissance aircraft, can one make reasonably accurate estimates of the cyclone's associated outer-core wind strength and radial extent of 15 and 25 m s^{-1} surface winds? Similarly, if the cyclone's central pressure drops and its eye-wall size changes, what does this imply with regard to changes in the outer wind profile?

Part I of this paper (Weatherford and Gray 1985; hereafter Part I) gave aircraft reconnaissance derived average information on the characteristics of these radial wind profile relationships. Eye characteristics were not discussed. This paper portrays more individual cyclone analysis and discusses the relationship between Minimum Sea-Level Pressure (MSLP) and the Outer-Core wind Strength (OCS) for different eye-wall sizes. These inner- to outer-core wind variations appear to depend upon the way the cyclone has developed, the stage of its life cycle, the characteristics of its inner-core convection, its eye size, and other features.

2. Minimum sea level pressure (MSLP) versus outer-core wind strength (OCS)

Figure 1 compares tropical cyclone Minimum Sea-Level Pressure (MSLP) versus mean (1 to 2.5°) OCS. This figure illustrates the great wind profile variability which can occur between individual cyclones and between different time periods of the same cyclone. Note that there is apparently less scatter in this relationship in tropical storms than in typhoons. For intense cyclones only a weak relationship exists. For example, typhoons with an MSLP of approximately 960 mb exhibited 700 mb outer-core wind strengths ranging between 10 and 30 m s^{-1}, a three-fold difference in speed and an order of magnitude difference in kinetic energy. The most intense cyclone was Supertyphoon Wynne (MSLP of 890 mb) with an average OCS of only 17 m s^{-1}. By contrast, Typhoon Vernon had a MSLP of 940 mb but a mean OCS of 35 m s^{-1}. The outer-core region kinetic energy of Vernon was approximately four times greater than Wynne's outer-core kinetic energy, despite Vernon's 50 mb higher MSLP.

This large variability between MSLP and OCS among cyclones indicates that one cannot infer a total wind profile knowing the central pressure, for example, or the area of storm surge warning. It also brings up theoretical questions concerning why and how such variability occurs.

Individual cyclones can undergo distinctly different changes in their MSLP and OCS ratio. Figure 2 depicts four examples. Typhoon Betty increased its inner-core intensity while building its outer-core wind strength. After peak intensity, OCS receded along with intensity. If all cyclones followed the example of Typhoon Betty, forecasting a cyclone's OCS would be possible simply from knowledge of its MSLP. But Betty is not typical. Supertyphoon Wynne exhibited a very different MSLP to OCS relationship. Once Wynne attained typhoon intensity, its central pressure dropped sharply without a change in its OCS. However, as Wynne's

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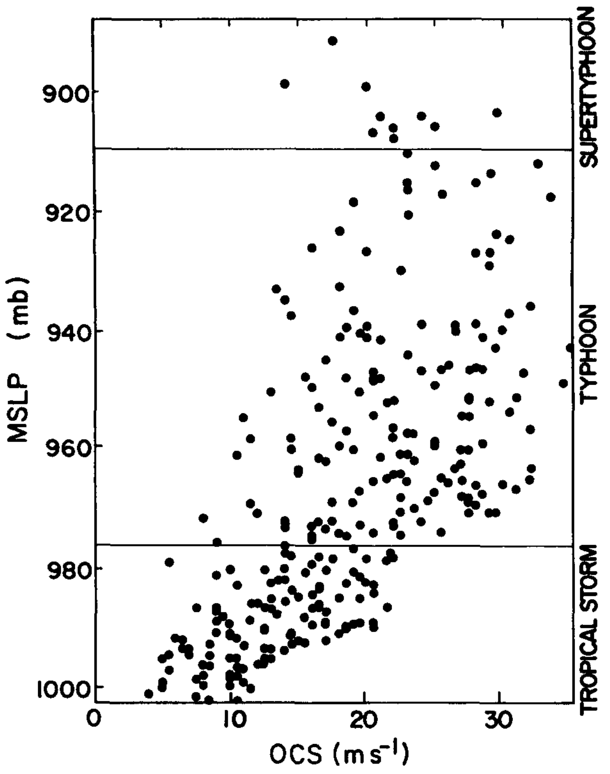


FIG. 1. Scatter diagram of cyclone minimum sea-level pressure (MSLP) vs outer-core wind strength (OCS).

MSLP began to fill (9–11 October), its OCS, instead of also decreasing, continued to increase. MSLP and OCS underwent opposite and apparently independent changes. Wynne then proceeded to fill for 2½ days while maintaining a constancy in OCS. Typhoon Nelson intensified and then later filled without ever exhibiting a significant change in OCS. Lastly, note how Typhoon Kit began its life cycle with nearly its highest OCS. A gradual weakening of outer winds then occurred as central pressure first increased and then decreased.

There are cyclones which exhibit distinct periods when their outer-core (1°–2½° radius) winds increase but their central pressures remain much the same. Figure 3 shows examples of some of these cases. There are also other distinct periods in the life cycle of cyclones when they undergo central pressure change with little or no outer-core wind strength (OCS) change as seen in Fig. 4.

Plotting 12-h incremental changes in MSLP and OCS for a random sample of cases (see Fig. 5) shows no correlation between such changes. When one analyzes such changes over a time period of a few days or more, characteristic life cycle changes in this relationship often occur. A follow-on study by Weatherford (1988) will give information on typical differences in this MSLP versus OCS relationship during different life cycle stages of the tropical cyclone. A cyclone in the intensifying stage has a distinctly greater ratio of MSLP to OCS than does a cyclone of the same central pressure but in a filling stage. Therefore, although inner-core intensity changes are observed to occur rather independently of outer-core strength changes over short time periods of 12-h, there is a better statistical relationship between MSLP and OCS when one takes into account the particular life cycle of a tropical cyclone, ie., intensifying or filling stage, etc. In the intensification stage, the ratio of MSLP to OCS is greater than in the filling stage.

Cyclone intensity versus mean radii for 15 m s^{-1} (R-15 or 30 kt) and 25 m s^{-1} (R-25 or 50 kt) surface winds exhibited a similar large scatter (see Figs. 6 and 7). This is to be expected given the previous weak relationship of MSLP to OCS. This is in agreement with Merrill's (1984) finding of only a very weak relationship exists (~0.3 correlation) between tropical cyclone size (or mean radius of outer-closed isobar) and cyclone intensity.

Figure 8 depicts individual case, 12-h changes in MSLP versus 12-h changes in the mean radius of 25 m s^{-1} (50 kt) surface winds. Note the large variability of values. No detectable relationship is observed. A similar variability was also found for the mean radius of 15 m s^{-1} (30 kt) surface winds.

These tenuous relationships between MSLP and OCS, R-15, or R-25 perhaps imply a decoupling influence between a cyclone's central pressure and its adjacent outer radius circulation. Changes in the inner-core intensity appear at times to occur almost independently of outer radius wind changes.

a. OCS versus mean radius of 15 and 25 m s^{-1} surface winds

Away from the inner-core, the wind profiles show more distinctive relationships. Figure 9 shows that a strong relationship exists between OCS (1°–2.5° radius mean wind) and mean radius of 15 m s^{-1} surface winds (correlation of 0.9). This relationship allows outer-core wind strength to be estimated given the average radial extent of 15 m s^{-1} surface winds (18 m s^{-1} flight-level winds) or vice versa. The least-squares best fit relationship between OCS and mean radius of 15 m s^{-1} surface winds is

$$\text{OCS (m s}^{-1}\text{)} = 7.54 + .05(\text{R-15 km}). \quad \text{(1a)}$$

For example, a measured mean radius of 15 m s^{-1} surface winds of about 3.8° implies a mean OCS of 28 m s^{-1} ± about 5 m s^{-1}. The larger the radius of 15 m s^{-1}, the larger the spread in the OCS.

b. Farthest radial extent of 15 and 25 m s^{-1} surface winds along individual flight legs

All calculations presented so far have been a four-quadrant average (or a mean of 2 quadrants beyond

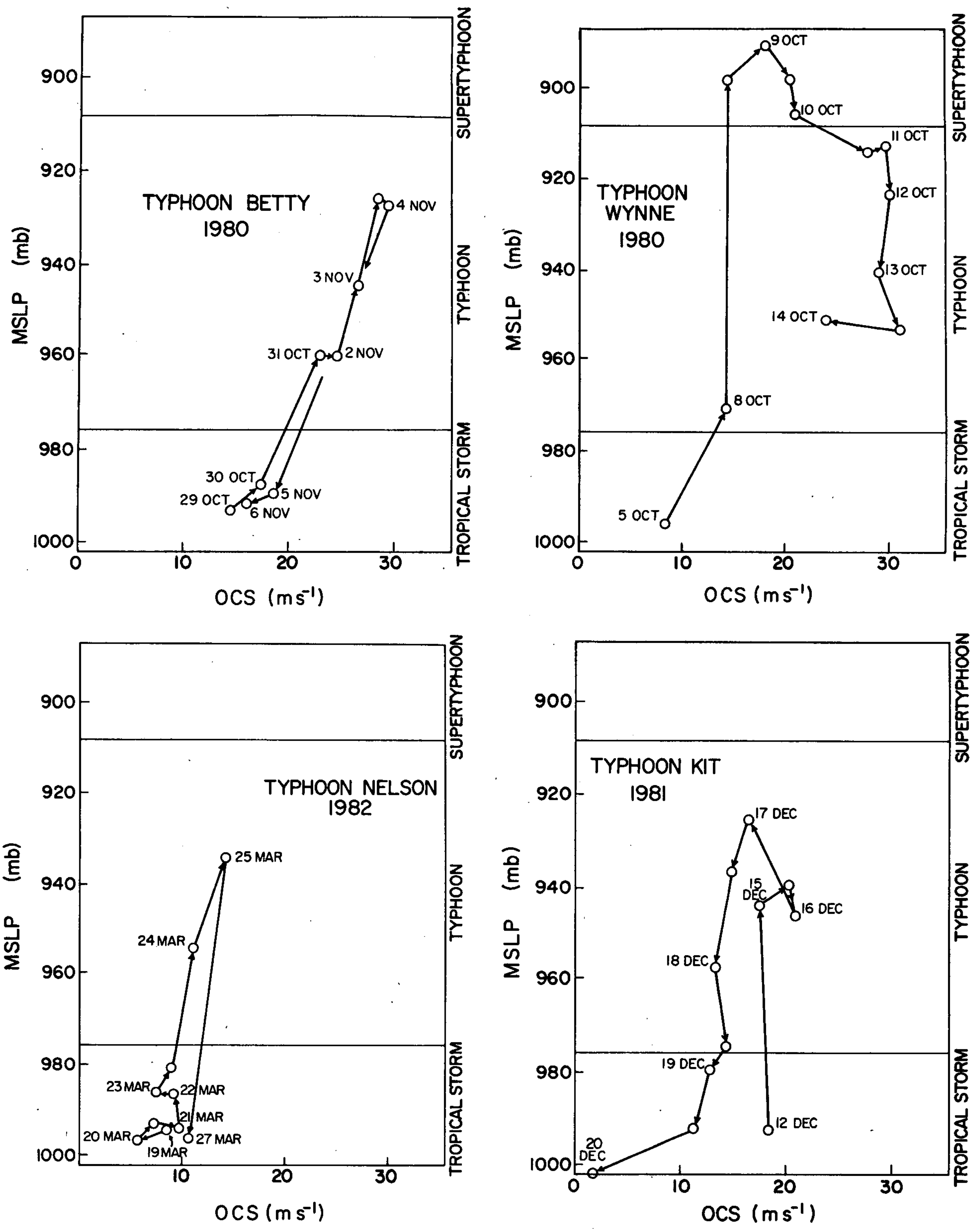


FIG. 2. MSLP vs OCS followed through the life cycles of Typhoons Betty, Wynne, Nelson and Kit.

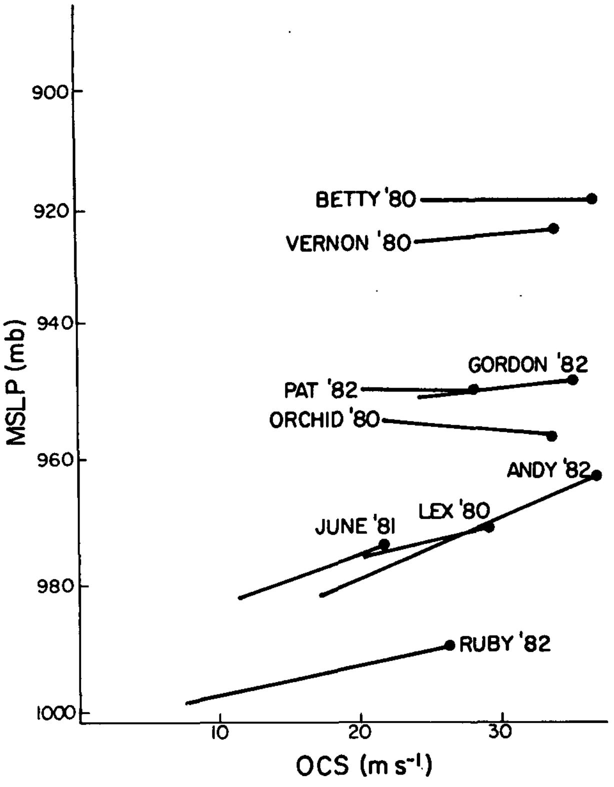


FIG. 3. MSLP vs OCS for cyclones undergoing an increase without appreciable MSLP change. Dot denotes the end of the period.

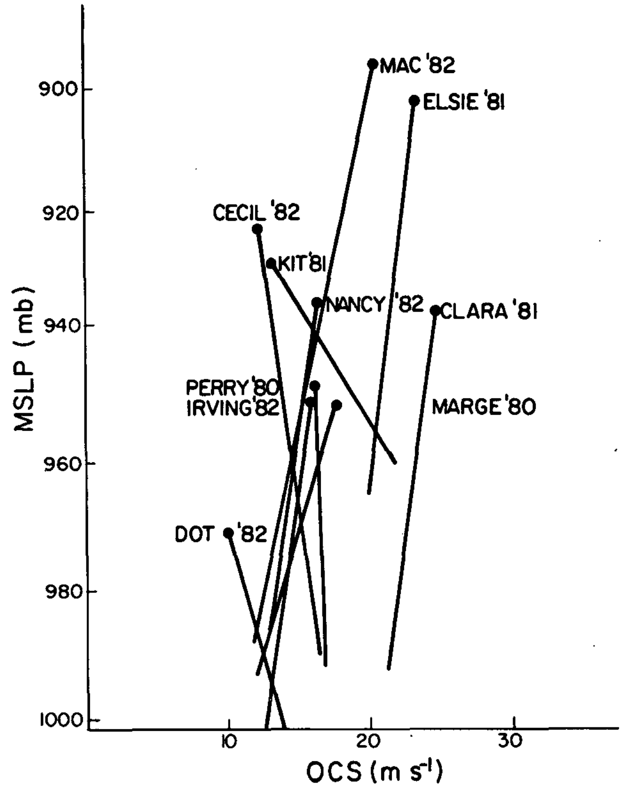


FIG. 4. MSLP vs OCS for cyclones experiencing primarily MSLP change. Dot denotes the end of the period.

2½° radius) in cyclone relative motion (or MOT coordinates). The forecaster is usually more interested in the radial extent of high winds in a particular quadrant in the natural (NAT) coordinate system. Therefore, the farthest radial extent of 15 or 25 m s^{-1} surface winds along any radial leg in the fixed or (NAT) coordinate system was determined. Figures 10 and 11 indicate how the farthest radial extent of 15 and 25 m s^{-1} surface winds (or 700 mb, 18 and 30 m s^{-1} wind, respectively) in any quadrant is related to MSLP. As expected, a wide scatter is present. The relationship is generally weak. Correlations are −0.48 (15 m s^{-1}) and −0.34 (25 m s^{-1}). The MSLP thus explains only about 10% to 25% of the variance in farthest outward radial extent of 15 and 25 m s^{-1} surface winds along any quadrant. On average, the farthest radial extent of 15 m s^{-1} (30 kt) surface winds on the strongest quadrant was about 100 km (~50 n mi) greater than for the four-quadrant average. For the 25 m s^{-1} (50 kt) surface winds this difference between the individual NAT and the MOT four quadrant average was about 50 km (~25 n mi).

While MSLP and farthest radial extent of 15 and 25 m s^{-1} surface winds along any flight leg are not well related, OCS is much better related to the farthest extent of 15 and 25 m s^{-1} surface winds (see Figs. 12 and 13). This is to be expected.

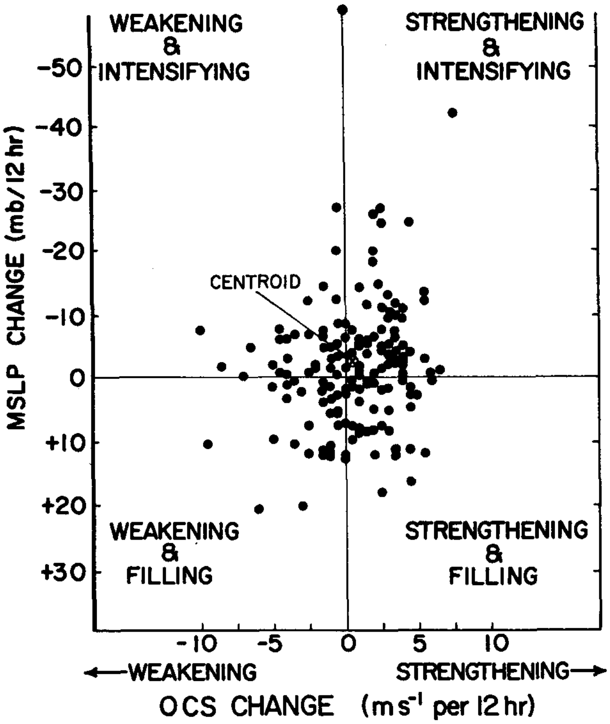


FIG. 5. Scatter diagram of 12-h MSLP vs 12-h change in OCS.

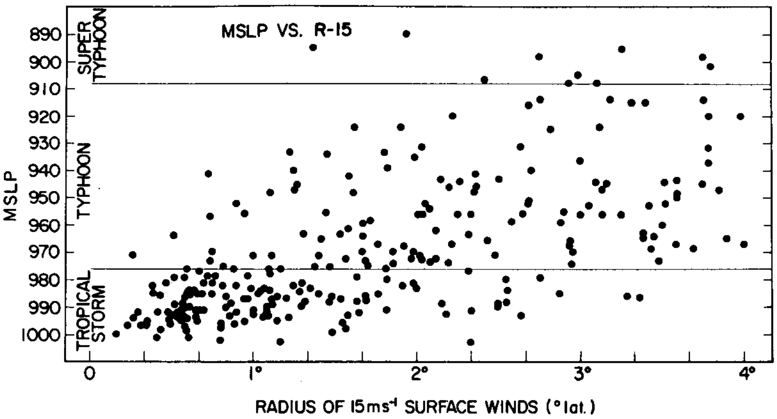


FIG. 6. Scatter diagram of MSLP vs mean radius of 15 m s^{-1} surface wind speeds.

Although satisfactory relationships between OCS and R-15 and R-25 are found, the large variability between MSLP and OCS implies that there is a wide range in radial extent of strong wind, irrespective of the core strength. Section 3 discusses how this variability is reduced if one takes into account knowledge of the cyclone's eye characteristics.

3. The association of the TC's eye size with its outer-radius wind profile

One goal of this research was to provide the forecaster with an improved way to estimate the strength of a cyclone's outer wind circulation from reconnaissance measured inner-core information. This is particularly relevant in the Atlantic where reconnaissance flights do not extend beyond 1°–1.2° radius.

The data presented so far have shown that the skill of estimating the outer-wind profile solely from information of the MSLP is quite low, especially for the intense cyclones. We will show, however, that when one uses MSLP in combination with eye-wall information, a substantially better relationship is obtained.

Air Force reconnaissance measuring procedures dictated that an eye-wall cloud was reported only when a circular, inner-cloud feature was observed on 3-cm radar to subtend at least half a circle around the cyclone's center. Following normal procedures, the eye-wall size is determined from the cyclone's center to the beginning of the eye-wall convection. It was required that the eye-wall's convection be distinct from the adjacent spiralling convective bands. There were typically two formal eye-wall reports on each flight mission. As this study is not involved with the hourly changes in eye characteristics, eye radii were averaged for each flight mission. Since eye reports were about 3 h apart, this lent a degree of short-term conservatism to the eye measurement. Figure 14 is a scatter diagram showing the distribution of the eye-wall size to MSLP. One can see that eyes frequently occur in tropical storms as well as typhoons. In this sample, 24% of all tropical storms exhibited an eye-wall cloud. Note also that both the

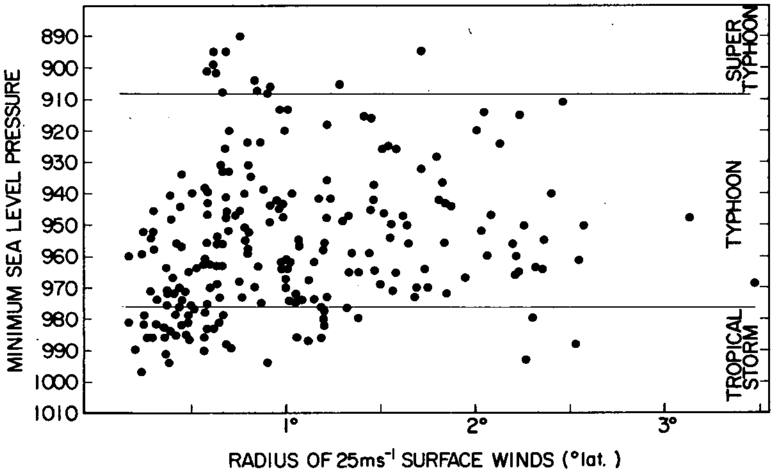


FIG. 7. Scatter diagram of MSLP vs mean radius of 25 m s^{-1} surface wind speeds.

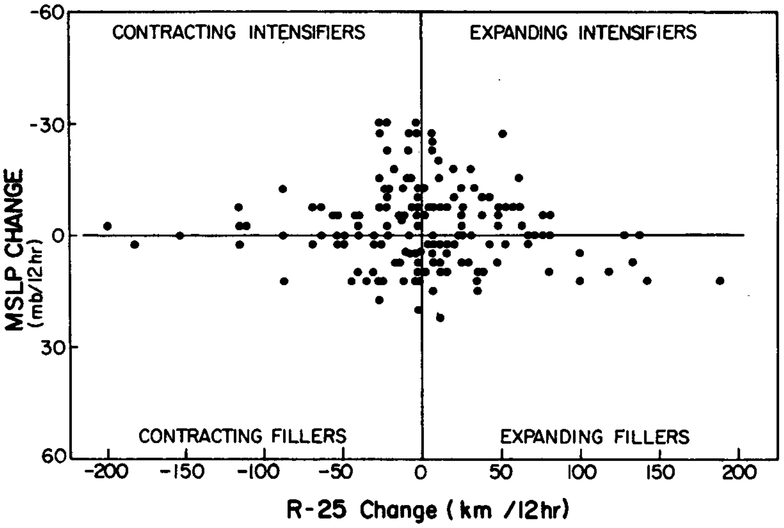


FIG. 8. Twelve-hour MSLP (in mb) change vs 12-h change in mean radius of 25 m s^{-1} surface winds.

weaker tropical storm and intense supertyphoon can have small eyes. There is not much of a correlation between the size of an eye and MSLP. Sheets (1971) has also shown that there is not much of a correlation between eye size and MSLP in Atlantic hurricanes.

Figure 15 portrays the average eye size and the standard deviation of eye size as a function of MSLP. Note that on a statistical basis the more intense a cyclone, generally, the smaller will be its eye size. But a wide variability can occur in individual cases. Notice that weak intensity cyclones can also have small eye sizes. Although very few cyclones of tropical storm intensity form eyes early, those that do, tended to form small ones while cyclones forming eyes later tend to form larger ones. This gives the false impression of an early stage expansion of the eye. One needs to interpret Fig. 15 in conjunction with Fig. 16.

There is a systematic difference in the percent of eye reports for intensifying and filling cyclones of identical MSLP. Figure 16 shows that intensifying cyclones have a significantly higher percent of reported eyes than do filling cyclones of similar MSLP. This is especially the situation for the weaker intensity systems. Note that there are almost twice as many reported eyes for intensifying as there is for filling cyclones of identical MSLP for cyclones with central pressures greater than 960 m. This supports the hypothesis that the concentration of inner-core convection is more of a feature of the intensification process. Cyclone inner-core intensification typically precedes outer-core wind increase (Weatherford, 1988). Similarly, inner-core filling typically precedes outer-core weakening. These relationships are being studied currently and will be reported in a future paper by the first author.

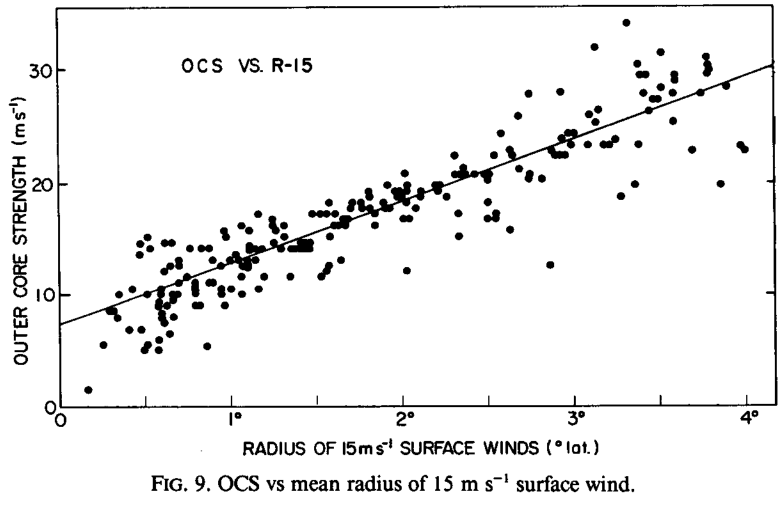


FIG. 9. OCS vs mean radius of 15 m s^{-1} surface wind.

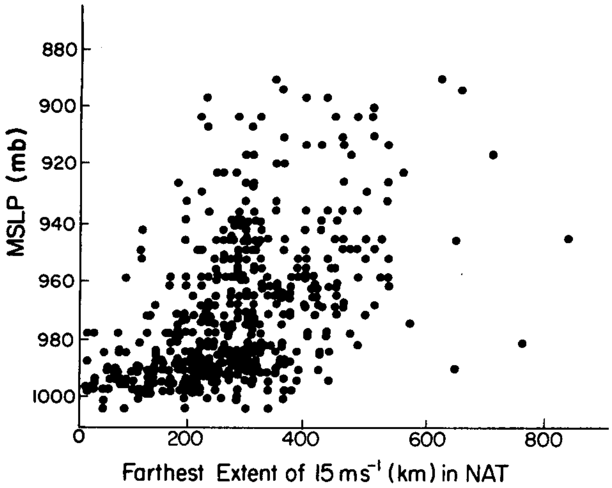


FIG. 10. MSLP vs the farthest reported 15 m s^{-1} wind speed for any radial leg (not averaged) for the case where motion of the cyclone center has not been subtracted out (NAT coordinate).

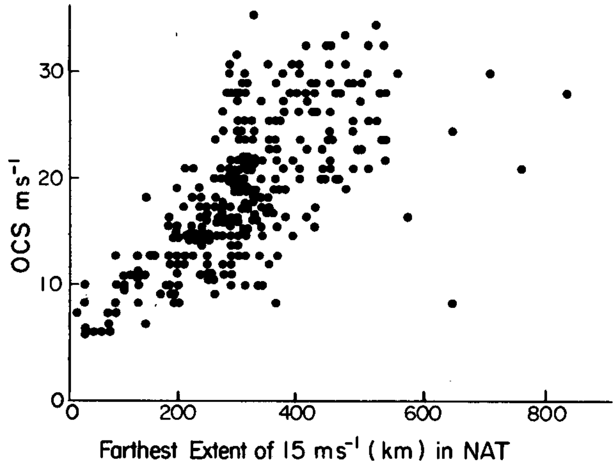


FIG. 12. The OCS vs farthest extent of 15 m s^{-1} surface wind measured in NAT coordinates (cyclone motion not subtracted out).

a. Eye-size classes

In order to better relate a cyclone's eye size to its adjoining outer-radius wind profile, eye size was classified into the various size groups of small, medium, and large. A fourth class, having many typhoons, represents the situation when no eye was observed. Table 1 defines eye classes. The small eye class (eye radius < 15 km) comprised 15% of the data sample. Typhoon Dinah exhibited the smallest inner-eye size of 4 km radius. The medium sized, eye-wall class (16–30 km radius) comprises one-quarter of the sample. The average size of this medium eye class was 22 km. Finally, the large sized eye-wall class (radius > 30 km) made up only 8% of the flight missions. Typhoon Thad had the largest eye of 120 km. Figure 17 shows the distribution of eye sizes. A quite broad range of eye sizes were observed.

Note that 53% of all flight missions reported no eye-wall cloud. This is an observation of considerable note. Guam reconnaissance personnel over the years have often commented to the second author about the large number of tropical cyclones they flew into that did not

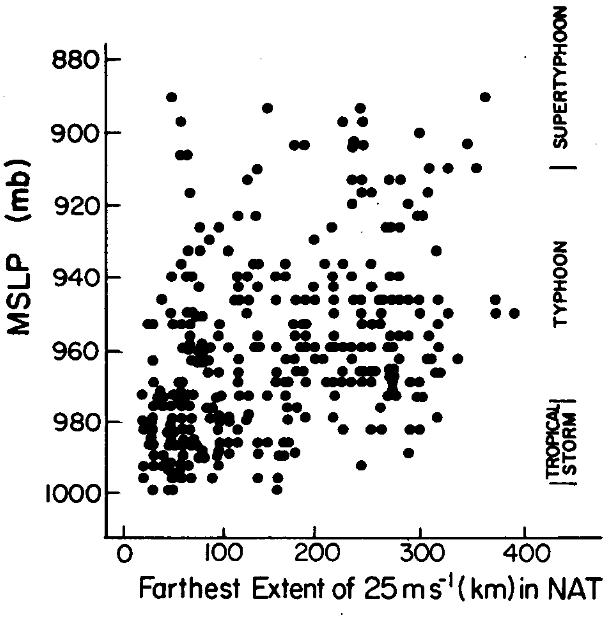


FIG. 11. MSLP vs the farthest reported 25 m s^{-1} wind speed for any quadrant for the case where the motion of the cyclone center was not subtracted (NAT coordinate).

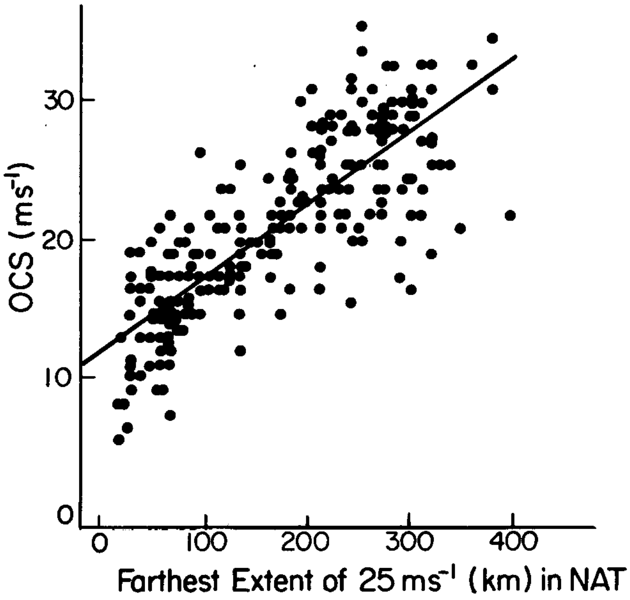


FIG. 13. OCS vs furthest extent of 25 m s^{-1} surface wind measured in NAT coordinates.

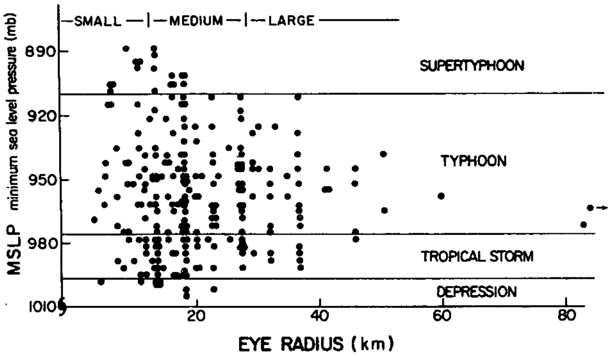


FIG. 14. Eye radius (in km) vs MSLP.

have eye-walls—particularly cyclones whose central pressure was higher than about 950–960 mb.

It appears that the northwest Pacific may have a somewhat higher percentage of cyclones without eyes than occurs in Atlantic cyclones of comparable MSLP. This may be related to the large number of Pacific cyclones which develop within the already established large-scale circulation of the monsoon trough. Twenty-nine percent of all missions into typhoons did not find an eye. The phenomenon of a typhoon without an eye-wall cloud has been well documented by Fett (1968) for the case of Typhoon Ethel.

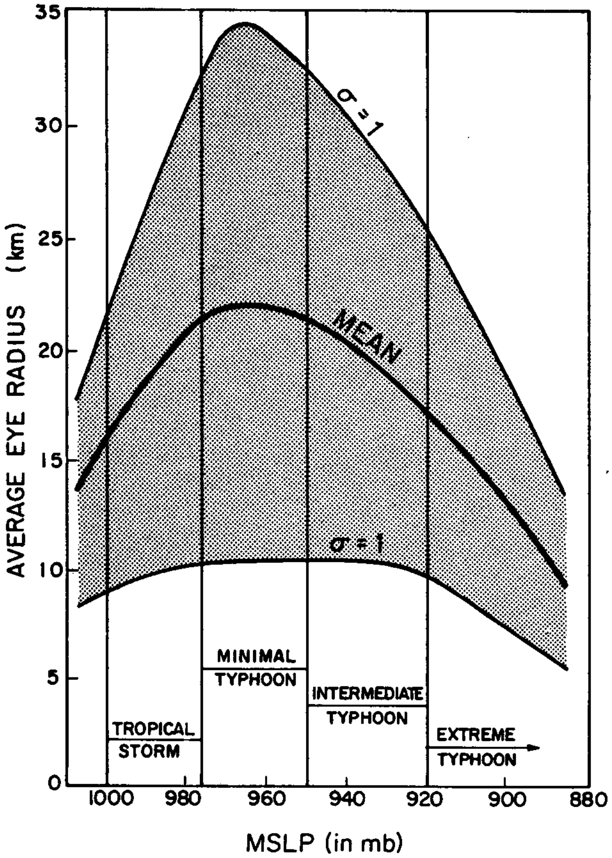


FIG. 15. Average eye size for a given MSLP with standard deviation

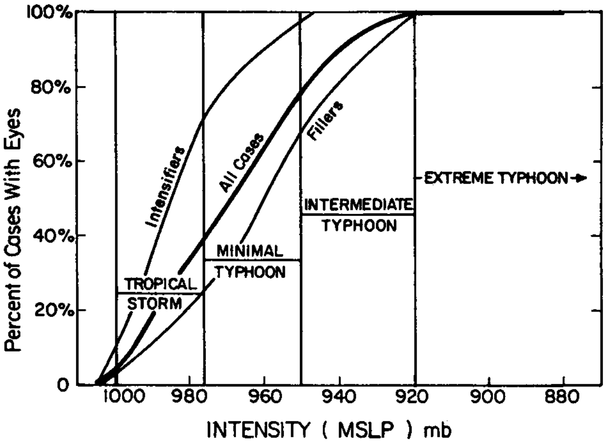


FIG. 16. Percentage probability that a cyclone will have an eye for a given MSLP. Relationship for intensifying and filling cyclones is also shown.

b. Relationship of eye size of MSLP and OCS

A better relationship between cyclones MSLP and OCS is obtained if one separates the data by eye-wall class. Figure 18 shows how an approximate straight line might be drawn to best represent this relationship for each eye-size class. Although there is still a very large scatter between individual observations, the scatter is significantly reduced by taking into consideration the size of the eye wall. Looking at just the small eye versus no eye cases, Fig. 19 gives a better portrayal of this association of MSLP and OCS given eye size. Cyclones with a specific MSLP will have a considerable greater OCS if they have no eye than if they have a small eye. Similarly, cyclones with a specified OCS > 10 m s^{-1} have a lower MSLP if they have a small eye than if they have no eye. The linear least-squares best fit relationships between cyclone OCS and MSLP for eye classes of NW Pacific is given as follows:

$$\text{small eye:} \quad \text{OCS} = 156 - 0.146\,(\text{MSLP}) \qquad (2a)$$

$$\text{medium eye:} \quad \text{OCS} = 183 - 0.171\,(\text{MSLP}) \qquad (2b)$$

$$\text{large eye:} \quad \text{OCS} = 260 - 0.248\,(\text{MSLP}) \qquad (2c)$$

$$\text{no eye:} \quad \text{OCS} = 401 - 0.391\,(\text{MSLP}) \qquad (2d)$$

TABLE 1. Classification of eyes by size.

Eye-class	Radius (km)	No. of cases	Percent of total
Small eye	4–15	79	15
Medium eye	16–30	122	24
Large eye	31–120	42	8
No eye		274	53

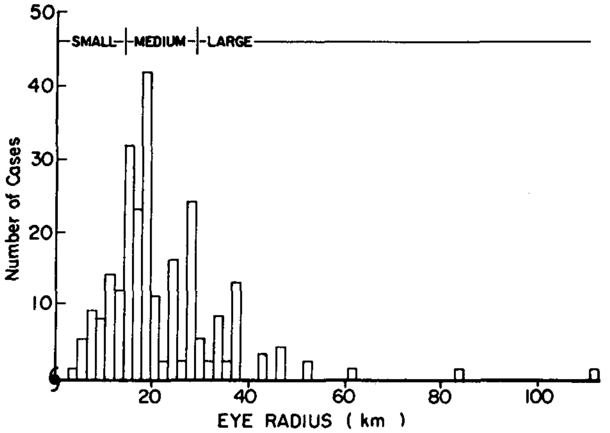


FIG. 17. Distribution of eye radius (km) with corresponding eye classes (above).

where

OCS strength measured in m s^{-1}

MSLP minimum sea-level pressure (mb)

For example, given a central pressure of 970 mb, the cyclone without an eye would have an average OCS of 22 m s^{-1}, while another cyclone with the same MSLP but with a small eye would have an average OCS of 14 m s^{-1}—40% less wind and 65% less kinetic energy or outer wind damage potential. The above relationships [Eq. (2a) to (2d)] would need some systematic MSLP modification for application in other tropical cyclone ocean basins.

In a similar vein, MSLP could be estimated from knowledge of eye size and OCS. Each eye size class exhibits characteristic outer radius wind properties. Table 2 shows average MSLP, average OCS, and mean radius 15 m s^{-1} surface winds for each eye-size class. Cyclones without an eye had, on average, a MSLP of 985 mb and an OCS of 34 m s^{-1}. The average cyclone with an eye had an MSLP of 956 mb regardless of whether the eye was small, medium or large. Note that the larger the eye, the greater the OCS and larger the radial extent of 15 m s^{-1} surface winds for an equivalent central pressure. The general characteristics of these relationships correlate to those obtained from gradient wind arguments.

Another characteristic of note is MSLP change (Table 2). The smaller the eye, the more rapidly the MSLP fluctuates. The cyclone with a small eye has an average MSLP fluctuation rate twice that of cyclones without an eye.

Although these general physical relationships have a large scatter which will make them unreliable in some individual cases, they are, nevertheless, important physical relationships for the forecaster and researcher to have a general grasp of.

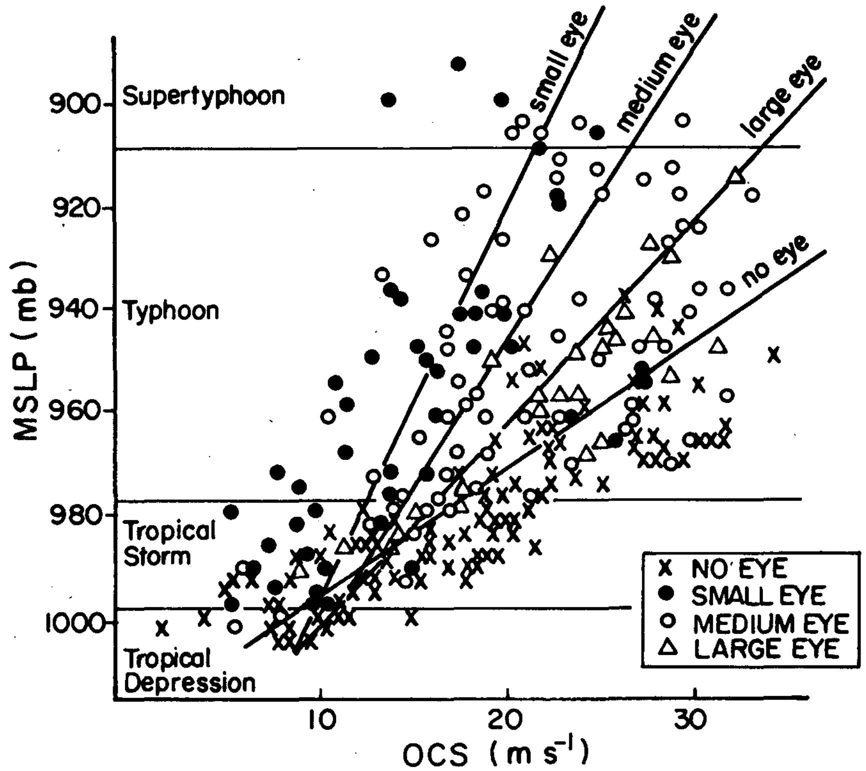


FIG. 18. The MSLP vs OCS by eye-size class as shown in Table 1.

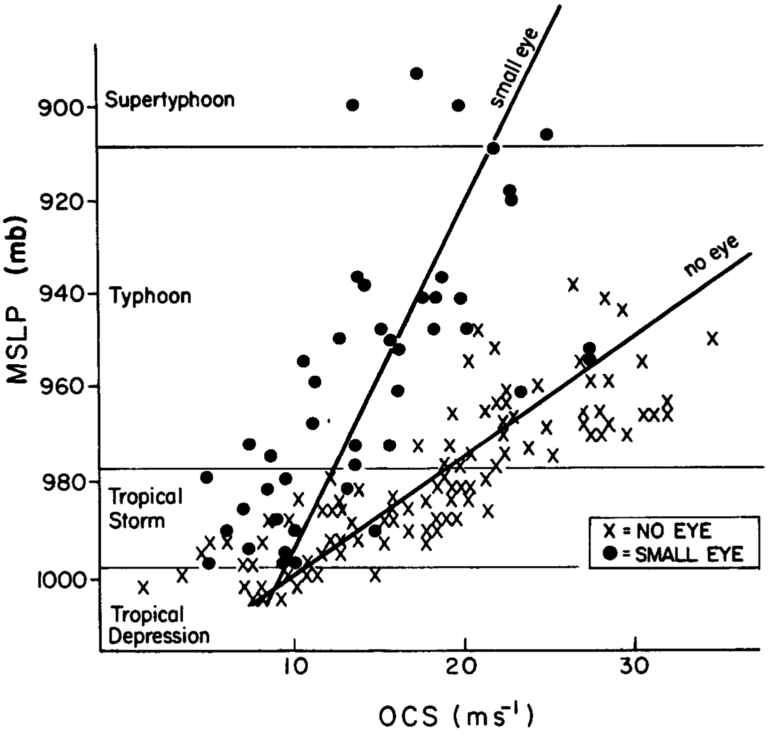


FIG. 19. The MSLP vs OCS for the small eye class (solid circles) and the no eye class (dashes).

c. Wind profiles stratified by eye size

The MSLP, eye size, OCS, and radius of 15 and 25 m s^{-1} surface winds are statistically related to each other. Figures 20a–d compare the wind profile out to 4° radius by cyclone MSLP and eye-size classes (information given on the upper right of each figure). Note that for cyclones of similar MSLP, outer radius wind strength is, on average, inversely related to eye size. These differences in outer radius circulation are quite a bit larger if one considers them in terms of kinetic energy. Average outer-core kinetic energy for cyclones without an eye is nearly twice as great as for cases of cyclones with identical MSLP but with small eyes. This has direct application to the areal extent of damaging winds and cyclone rainfall. Cyclones without eyes or with large eyes will typically produce more rain and have greater radial extent of damaging surface winds than other cyclones of similar MSLP but with medium or small eye sizes.

Once eye size is taken into account, it is evident that a more direct relationship between inner-core intensity and adjacent outer-core wind strength is obtained.

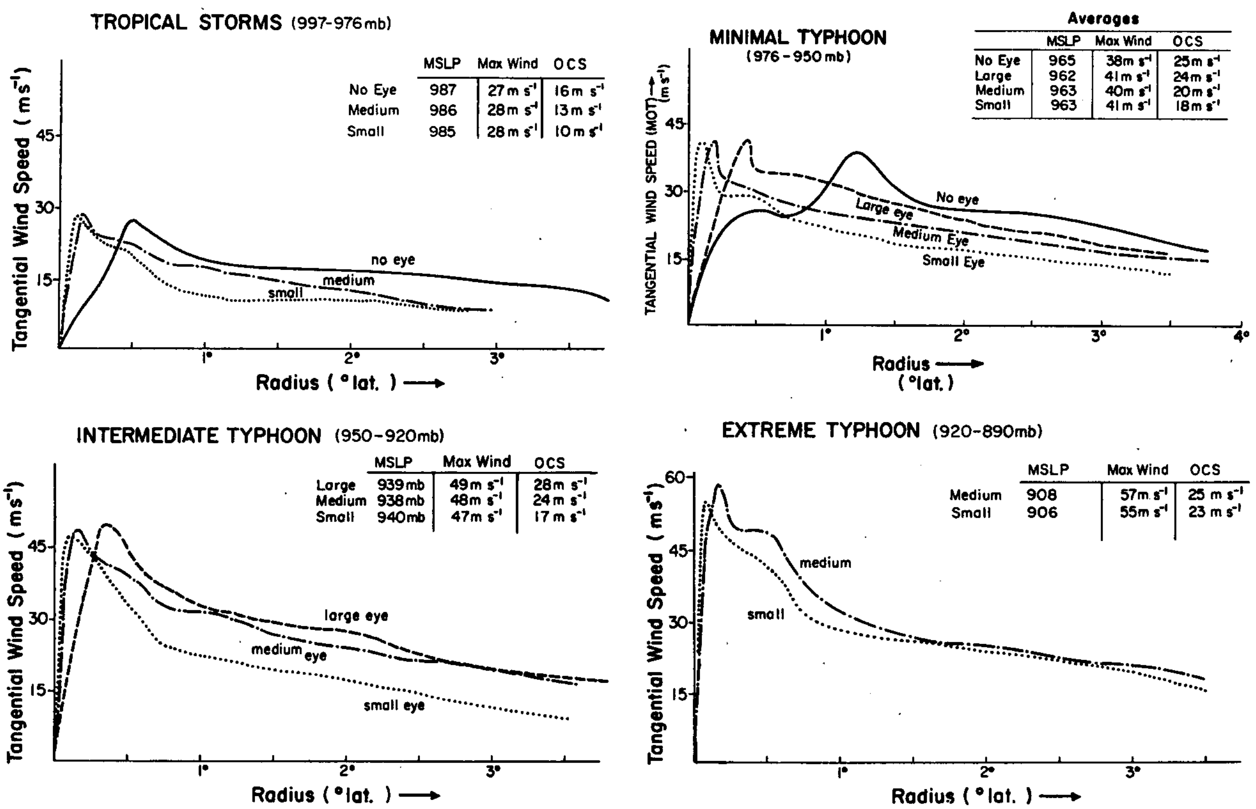
Figures 21a–d show that if one stratifies the cyclone by eye-wall class, then a better relationship between MSLP and OCS is obtained. Forecasters should try to combine knowledge of MSLP and eye size when they attempt to estimate outer radius wind strength.

Guam JTWC forecasters presently use Holland's 1980 wind/pressure scheme for estimates of radii of 15 and 25 m s^{-1} surface wind speeds, which does not take into account the size of the eye. It is obviously important, however, that consideration be given to eye size. Differences in R-15 between a minimal typhoon with a small eye and a minimal typhoon without an eye can be quite significant. These eye size differences can have an obvious impact upon the outer-radius wind forecast and wind damage potential.

These are, of course, average profiles. The forecaster must always be prepared for an individual cyclone

TABLE 2. Averages for the 1980–82 tropical cyclones which have been classified by the size of the eyewall. MSLP is minimum sea level pressure; OCS, outer-core strength; and R-15, the average extent of 15 m s^{-1} surface winds.

	Averages by eyewall radius			
Eye-class	MSLP (mb)	OCS (m s^{-1})	R-15 (km)	MSLP change (mb/12 hrs)
No eyewall	985	17	172	±5
◯ Large eye (>28 km)	987	24	268	±8
○ Medium eye (15–28 km)	956	20	216	±9
○ Small eye (<15 km)	954	17	165	±12



TROPICAL STORMS (997-976mb)

	MSLP	Max Wind	OCS
No Eye	987	27 m s^{-1}	16 m s^{-1}
Medium	986	28 m s^{-1}	13 m s^{-1}
Small	985	28 m s^{-1}	10 m s^{-1}

MINIMAL TYPHOON (976-950 mb)

Averages

	MSLP	Max Wind	OCS
No Eye	965	38 m s^{-1}	25 m s^{-1}
Large	962	41 m s^{-1}	24 m s^{-1}
Medium	963	40 m s^{-1}	20 m s^{-1}
Small	963	41 m s^{-1}	18 m s^{-1}

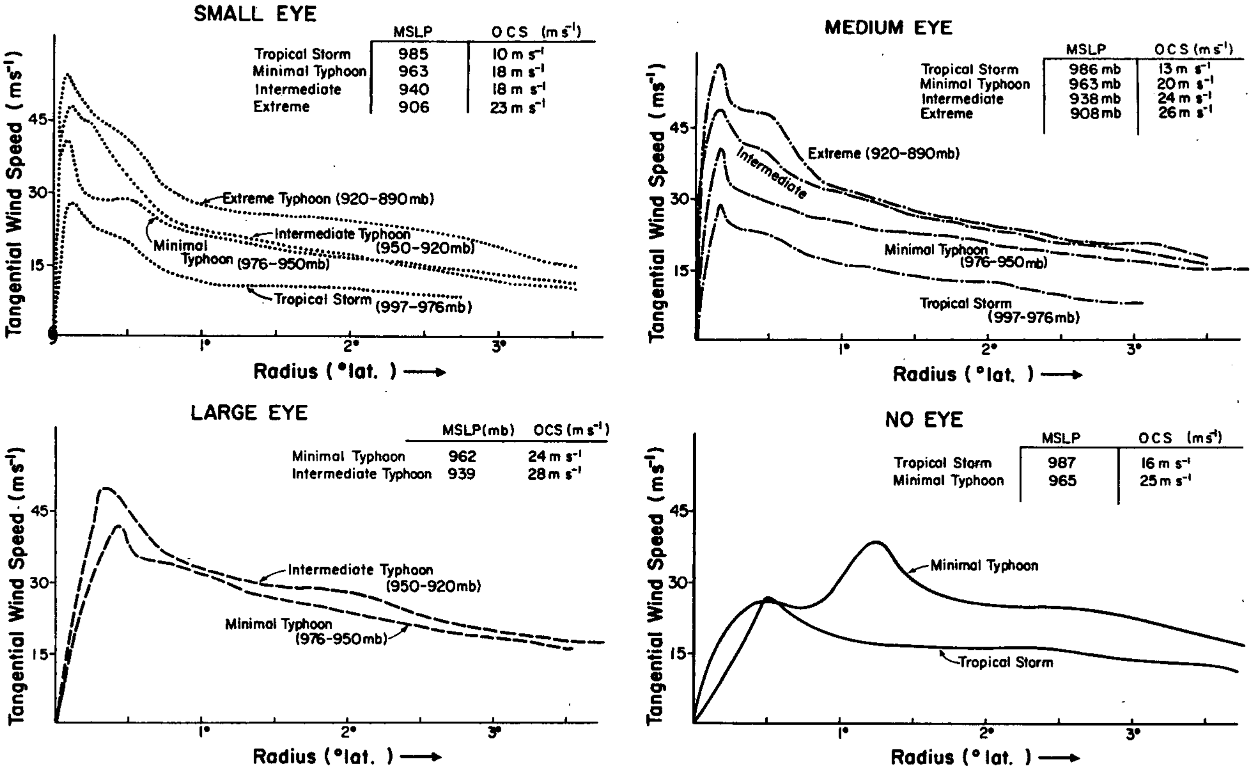
INTERMEDIATE TYPHOON (950-920mb)

	MSLP	Max Wind	OCS
Large	939 mb	49 m s^{-1}	28 m s^{-1}
Medium	938 mb	48 m s^{-1}	24 m s^{-1}
Small	940 mb	47 m s^{-1}	17 m s^{-1}

EXTREME TYPHOON (920-890mb)

	MSLP	Max Wind	OCS
Medium	908	57 m s^{-1}	25 m s^{-1}
Small	906	55 m s^{-1}	23 m s^{-1}

FIG. 20a–d. Average tangential wind profiles by eye-size class for the cyclone intensity class of (a) tropical storm, (b) minimal typhoon, (c) intermediate typhoon, and (d) extreme typhoon.



SMALL EYE

	MSLP	OCS (m s^{-1})
Tropical Storm	985	10 m s^{-1}
Minimal Typhoon	963	18 m s^{-1}
Intermediate	940	18 m s^{-1}
Extreme	906	23 m s^{-1}

MEDIUM EYE

	MSLP	OCS (m s^{-1})
Tropical Storm	986 mb	13 m s^{-1}
Minimal Typhoon	963 mb	20 m s^{-1}
Intermediate	938 mb	24 m s^{-1}
Extreme	908 mb	26 m s^{-1}

LARGE EYE

	MSLP(mb)	OCS (m s^{-1})
Minimal Typhoon	962	24 m s^{-1}
Intermediate Typhoon	939	28 m s^{-1}

NO EYE

	MSLP	OCS (m s^{-1})
Tropical Storm	987	16 m s^{-1}
Minimal Typhoon	965	25 m s^{-1}

FIG. 21a–d. Average tangential wind profiles by cyclone intensity class for cyclones with: (a) small eyes, (b) medium eyes, (c) large eyes, and (d) no eyes.

which shows a large deviation from these average conditions.

4. Discussion

This paper's analysis of many hundreds of northwest Pacific tropical cyclone outer wind profiles demonstrates the large variability which can exist for cyclones of similar central pressure. The common practice of classifying the intensity of a tropical cyclone by its maximum sustained wind speed or MSLP frequently can be misleading as to estimates of outer radius wind strength or of the radii of 15 and 25 m s^{-1} surface winds. There are tropical cyclones with small and very intense inner-core circulations but weak outer circulations. There are other tropical cyclones whose inner-core winds are weak but whose outer circulations are very strong. This has, of course, been generally known by the experienced forecaster, but never before has it been systematically well documented in a statistical sample of large data.

These large variations in inner and outer radius wind speed are also evident with respect to hourly and day-to-day time changes in the cyclone's radial profile of wind. When the winds of a TC increase or decrease, they seldom do so evenly. Winds at one radius may become stronger, while a simultaneous wind decrease or no change in wind occurs at another radius. Cyclones can experience a simultaneous inner-core filling and an outer-core wind strengthening or inner-core intensification with little or no change in OCS.

A cyclone's OCS is important in determining the cyclone's net rainfall and the radial extent of 15 m s^{-1} (30 kt) and 25 m s^{-1} (50 kt) surface winds. The strength of the outer-core winds likely also has an influence on a cyclone's surge potential.

Our project's recent-year research by Holland and Merrill (1984), Chen and Gray (1986), and Merrill (1988) is indicating that tropical cyclone intensity change is strongly related to the concentration of inner-core deep convection. This has also been previously discussed by Willoughby et al., (1982, 1984) for Atlantic hurricanes. Such a concentration appears to be frequently associated with the characteristics of the cyclone's upper tropospheric outflow. By contrast, the physical processes influencing cyclone OCS change appear to be more related to the character of the cyclone's surrounding lower tropospheric environmental flow conditions. Strong OCS does not depend much on inner-core concentration of deep convection. Changes in a cyclone's outer circulation are not nearly as rapid as changes near the center (the eye-wall cloud, the MSLP, and the maximum wind speed).

Without evidence to the contrary, many forecasters would likely assume that a cyclone's MSLP would be approximately related to the OCS and radii of 15 and 25 m s^{-1} surface winds. Although this is true in the broad climatological sense, there can be very wide variations in such an association for the individual cyclone at individual time periods.

A large variation in eye conditions exists among cyclones with comparable central pressure. By itself, the size of a TC's eye does not have much of an observable relationship with the cyclone's MSLP. A contracting eye size with time is, on average, associated with a decreasing MSLP as Jordan first noted (in 1961). Similarly, an expanding eye size is, on average, associated with a cyclone filling. Forecasters who do not have outer-core wind information probably can improve their outer-core wind estimates if they combine information on eye size and MSLP.

It is important that the forecaster try to understand the synoptic conditions that lead to the development of cyclones with small and intense inner-core circulations in contrast with those synoptic conditions that bring about cyclones with weaker inner cores but stronger outer circulations. If there is a very strong and broad monsoon trough in which the tropical cyclone has developed or into which it has moved, then the cyclone's outer-radius circulation will typically be stronger for its central pressure than it would be if it formed within a weak environmental circulation. This is particularly the case in the cyclone's development period to maximum intensity.

New research to be reported on later (Weatherford 1988), is showing that a cyclone's outer radial wind profile is weaker for intensifying versus filling vortices of the same central pressure. Other recent research is also showing that it may be possible to use the areal extent of a tropical cyclone's outer cloud shield as an estimate of the strength of the OCS. The broader a tropical cyclone's cloud shield, the generally broader and stronger will be the OCS for a specified surface pressure.

It is expected that these relationships which have been derived for the northwest Pacific Ocean are also generally valid for the other ocean basins with adjustment for different storm basin climatologies.

This data source has recently been expanded to include the years of 1983–86. New relationships with regard to cyclone motion also need to be analyzed. This reconnaissance information is now beginning to be utilized in conjunction with satellite and conventional weather map analyses in an attempt to see how much improvement in understanding and forecasting may be forthcoming through the combined information of these different data sources. There are many new physical relationships yet to be investigated with these reconnaissance data sets.

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