3. SUMMARY OF WESTERN NORTH PACIFIC AND NORTH INDIAN OCEAN TROPICAL CYCLONES

3.1 WESTERN NORTH PACIFIC OCEAN TROPICAL CYCLONES

For the western North Pacific (WNP), 1995 included five super typhoons, 10 lesser typhoons, 11 tropical storms and eight tropical depressions (Table 3-1). The calendar-year total of 34 significant tropical cyclones[1] (TCs) in the WNP was three above the long-term (36-year) average. The year's total of 26 TCs of at least tropical storm intensity was two below the long-term average (Figure 3-1).

[1]Postanalysis indicated that Tropical Depression 33W was the regeneration of Tropical Depression 32W, and the two best tracks were combined as one.

Table 3-1 WESTERN NORTH PACIFIC SIGNIFICANT TROPICAL CYCLONES FOR 1995

Tropical Cyclone		Period of Warning	NUMBER OF WARNINGS ISSUED	Estimated Maximum Surface Winds KT	M/SEC	Estimated MSLP (MB)
01W	TD	08 JAN	3	30	15	1000
02W	TS CHUCK	28 MAY - 01 JUN	12	35	18	1002
03W	TS DEANNA	01 JUN - 09 JUN	30	45	23	991
04W	TS ELI	04 JUN - 08 JUN	13	40	21	994
05W	TY FAYE	16 JUL - 24 JUL	36	105	54	938
06W	TS UNNAMED	26 JUL - 29 JUL	10	35	18	996
07W	TY GARY	29 JUL - 31 JUL	12	65	33	976
08W	TY HELEN	07 AUG - 12 AUG	23	70	36	972
09W	TS IRVING	17 AUG - 20 AUG	15	60	31	980
10W	TS JANIS	21 AUG - 26 AUG	22	55	28	984
11W	TD	22 AUG - 23 AUG	2	25	13	1002
12W	STY KENT	26 AUG - 01 SEP	24	140	72	898
13W	TY LOIS	26 AUG - 30 AUG	18	65	33	976
14W	TY MARK	30 AUG - 02 SEP	15	95	49	949
15W	TS NINA	02 SEP - 07 SEP	20	45	23	991
16W	TD	09 SEP - 11 SEP	4	30	15	1000
17W	STY OSCAR	11 SEP - 18 SEP	26	140	72	898
18W	TY POLLY	14 SEP - 21 SEP	31	90	46	954
19W	STY RYAN	15 SEP - 24 SEP	36	130	67	910
20W	TY SIBYL	28 SEP - 03 OCT	24	95	49	949
21W	TD	28 SEP - 29 SEP	3	25	13	1002
22W	TD	01 OCT - 02 OCT	6	30	15	1000
23W	TD	05 OCT - 06 OCT	2	25	13	1002
24W	TY TED	09 OCT - 13 OCT	19	70	36	962
25W	TS VAL	09 OCT - 14 OCT	19	45	23	991
26W	STY WARD	16 OCT - 22 OCT	25	140	72	898
27W	TY YVETTE	23 OCT - 26 OCT	14	65	33	976
28W	TY ZACK	25 OCT - 01 NOV	31	120	62	922
29W	STY ANGELA	25 OCT - 06 NOV	49	155	80	879
30W	TS BRIAN	01 NOV - 04 NOV	13	50	26	987
31W	TS COLLEEN	12 NOV - 13 NOV	5	35	18	996
32W	TD 32 & 33	02 DEC - 04 DEC	6	30	15	1000
34W	TD	08-11 DEC/13-14 DEC	11	30	15	1000
35W	TS DAN	26 DEC - 31 DEC	20	55	28	984

The year of 1995 was the first since 1988 during which the number of TCs of at least tropical-storm intensity was below normal. Likewise, the total of 15 typhoons was below the long-term average of 18. Since 1959, twelve years (1969, 1970, 1973-1980, 1983, and 1988) have had 15 or less typhoons (Table 3-2). Most of the years with a low number of typhoons occurred during an eight-year run from 1973-1980. Despite the low number of typhoons during 1995, the year's total of five super typhoons was one above average (Figure 3-2).

Twenty-nine of the 34 significant TCs in the WNP during 1995 originated in the low-level monsoon trough or near-equatorial trough.

Table 3-2 DISTRIBUTION OF WESTERN NORTH PACIFIC TROPICAL CYCLONES FOR 1959 - 1995

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1959	0	1	1	1	0	1	3	8	9	3	2	2	31
	000	010	010	100	000	001	111	512	423	210	200	200	17 7 7
1960	1	0	1	1	1	3	3	9	5	4	1	1	30
	001	000	001	100	010	210	210	810	041	400	100	100	19 8 3
1961	1	1	1	1	4	6	5	7	6	7	2	1	42
	010	010	100	010	211	114	320	313	510	322	101	100	20 11 11
1962	0	1	0	1	3	0	8	8	7	5	4	2	39
	000	010	000	100	201	000	512	701	313	311	301	020	24 6 9
1963	0	0	1	1	0	4	5	4	4	6	0	3	28
	000	000	001	100	000	310	311	301	220	510	000	210	19 6 3
1964	0	0	0	0	3	2	8	8	8	7	6	2	44
	000	000	000	000	201	200	611	350	521	331	420	101	26 13 5
1965	2	2	1	1	2	4	6	7	9	3	2	1	40
	110	020	010	100	101	310	411	322	531	201	110	010	21 13 6
1966	0	0	0	1	2	1	4	9	10	4	5	2	38
	000	000	000	100	200	100	310	531	532	112	122	101	20 10 8
1967	1	0	2	1	1	1	8	10	8	4	4	1	41
	010	000	110	100	010	100	332	343	530	211	400	010	20 15 6
1968	0	1	0	1	0	4	3	8	4	6	4	0	31
	000	001	000	100	000	202	120	341	400	510	400	000	20 7 4
1969	1	0	1	1	0	0	3	3	6	5	2	1	23
	100	000	010	100	000	000	210	210	204	410	110	010	13 6 4
1970	0	1	0	0	0	2	3	7	4	6	4	0	27
	000	100	000	000	000	110	021	421	220	321	130	000	12 12 3
1971	1	0	1	2	5	2	8	5	7	4	2	0	37
	010	000	010	200	230	200	620	311	511	310	110	000	24 11 2
1972	1	0	1	0	0	4	5	5	6	5	2	3	32
	100	000	001	000	000	220	410	320	411	410	200	210	22 8 2
1973	0	0	0	0	0	0	7	6	3	4	3	0	23
	000	000	000	000	000	000	430	231	201	400	030	000	12 9 2
1974	1	0	1	1	1	4	5	7	5	4	4	2	35
	010	000	010	010	100	121	230	232	320	400	220	020	15 17 3
1975	1	0	0	1	0	0	1	6	5	6	3	2	25
	100	000	000	001	000	000	010	411	410	321	210	002	14 6 5
1976	1	1	0	2	2	2	4	4	5	0	2	2	25
	100	010	000	110	200	200	220	130	410	000	110	020	14 11 0
1977	0	0	1	0	1	1	4	2	5	4	2	1	21
	000	000	010	000	001	010	301	020	230	310	200	100	11 8 2
1978	1	0	0	1	0	3	4	8	4	7	4	0	32
	010	000	000	100	000	030	310	341	310	412	121	000	15 13 4
1979	1	0	1	1	2	0	5	4	6	3	2	3	28
	100	000	100	100	011	000	221	202	330	210	110	111	14 9 5
1980	0	0	1	1	4	1	5	3	7	4	1	1	28
	000	000	001	010	220	010	311	201	511	220	100	010	15 9 4
1981	0	0	1	1	1	2	5	8	4	2	3	2	29
	000	000	100	010	010	200	230	251	400	110	210	200	16 12 1
1982	0	0	3	0	1	3	4	5	6	4	1	1	28
	000	000	210	000	100	120	220	500	321	301	100	100	19 7 2
1983	0	0	0	0	0	1	3	6	3	5	5	2	25
	000	000	000	000	000	010	300	231	111	320	320	020	12 11 2

TABLE CONTINUED ON TOP OF NEXT PAGE

Table 3-2 (CONTINUED FROM PREVIOUS PAGE)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1984	0	0	0	0	0	2	5	7	4	8	3	1	30
	000	000	000	000	000	020	410	232	130	521	300	100	16 11 3
1985	2	0	0	0	1	3	1	7	5	5	1	2	27
	020	000	000	000	100	201	100	520	320	410	010	110	17 9 1
1986	0	1	0	1	2	2	2	5	2	5	4	3	27
	000	100	000	100	110	110	200	410	200	320	220	210	19 8 0
1987	1	0	0	1	0	2	4	4	7	2	3	1	25
	100	000	000	010	000	110	400	310	511	200	120	100	18 6 1
1988	1	0	0	0	1	3	2	5	8	4	2	1	27
	100	000	000	000	100	111	110	230	260	400	200	010	14 12 1
1989	1	0	0	1	2	2	6	8	4	6	3	2	35
	010	000	000	100	200	110	231	332	220	600	300	101	21 10 4
1990	1	0	0	1	2	4	4	5	5	5	4	1	31
	100	000	000	010	110	211	220	500	410	230	310	100	21 9 1
1991	0	0	2	1	1	1	4	8	6	3	6	0	32
	000	000	110	010	100	100	400	332	420	300	330	000	20 10 2
1992	1	1	0	0	0	3	4	8	5	6	5	0	33
	100	010	000	000	000	210	220	440	410	510	311	000	21 11 1
1993	0	0	2	2	1	2	5	8	5	6	4	3	38
	000	000	011	002	010	101	320	611	410	321	112	300	21 9 8
1994	1	0	1	0	2	2	9	9	8	7	0	2	41
	001	000	100	000	101	020	342	630	440	511	000	110	21 15 5
1995	1	0	0	0	1	2	3	7	7	8	2	3	34
	001	000	000	000	010	020	210	421	412	512	020	012	15 11 8
(1959-1995)													
MEAN	0.6	0.3	0.6	0.8	1.3	2.2	4.7	6.6	5.9	4.9	3.0	1.5	32.3
CASES	22	10	23	27	46	79	168	238	212	177	107	54	1129

The criteria used in Table 3-2 are as follows:
1) If a tropical cyclone was first warned on during the last two days of a particular month and continued into the next month for longer than two days, then that system was attributed to the second month.
2) If a tropical cyclone was warned on prior to the last two days of a month, it was attributed to the first month, regardless of how long the system lasted.
3) If a tropical cyclone began on the last day of the month and ended on the first day of the next month, that system was attributed to the first month. However, if a tropical cyclone began on the last day of the month and continued into the next month for only two days, then it was attributed to the second month.

TABLE 3-2 LEGEND

Total for the month/year → 34
Typhoons → 15
Tropical Storms → 11
Tropical Depressions → 8

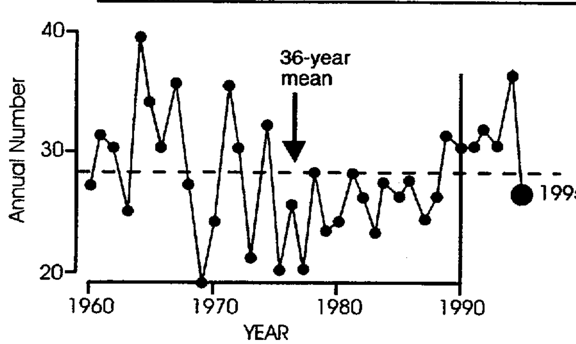


Figure 3-1 Tropical cyclones of tropical storm or greater intensity in the western North Pacific (1960-1995).

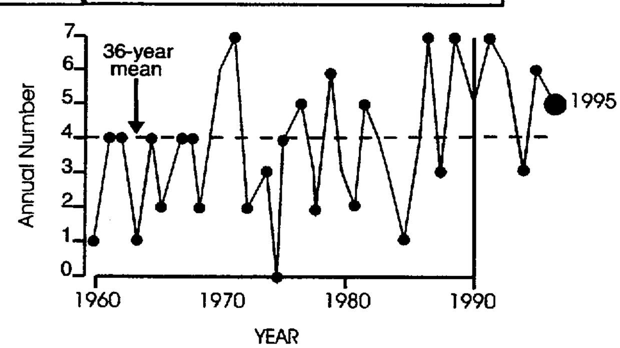


Figure 3-2 Number of western North Pacific super typhoons (1960-1995).

Three — Typhoon Mark (14W), Tropical Depression 22W, and Tropical Storm Brian (30W) — formed at relatively high latitude in association with cold-core cyclonic vortices in the tropical upper tropospheric trough (TUTT). Small-sized Tropical Depression 11W formed from a mesoscale convective system (MCS) that was located to the north of Tropical Storm Janis (10W), and Tropical Storm Colleen (31W) formed from a subtropical cyclone near the

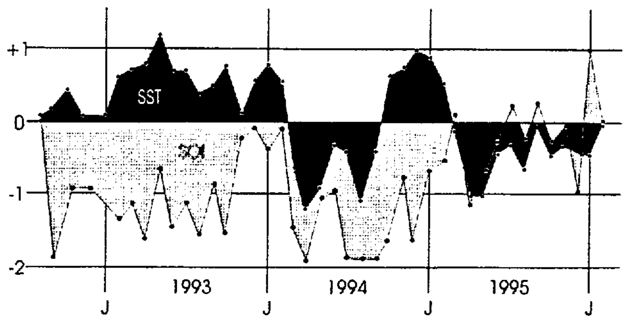


Figure 3-3 Anomalies from the monthly mean for eastern equatorial Pacific Ocean sea surface temperature (black) in degrees Celsius and the Southern Oscillation Index (SOI) (shaded) for the period 1993 through 1995. (Adapted from Climate Prediction Center 1995).

international date line. There were two TCs in the WNP during 1995 that originated east of the international date line — Tropical Depression 01W and Tropical Storm Colleen (31W) — which became significant TCs when they entered the JTWC's area of responsibility. Historically, about one significant TC per year named by the Central Pacific Hurricane Center (CPHC) or the National Hurricane Center (NHC) moves into the WNP.

This year marked the end of a prolonged period of the warm phase of the El Niño/Southern Oscillation (ENSO). Large-scale atmospheric and oceanic circulation anomalies indicative of the warm phase of ENSO (e.g., consistently warmer than normal sea surface temperature (SST) over much of the eastern equatorial Pacific, a strongly negative Southern Oscillation Index (SOI), and a penetration of monsoon westerlies in the WNP far to the east of normal), rapidly returned to near normal, or even reversed during the first half of 1995. By July of 1995, the SST along the equator in the central and eastern Pacific had become colder than normal (Figure 3-3), the SOI had risen to near zero (Figure 3-3), and low-level easterly wind anomalies replaced westerly wind anomalies in the low latitudes of the WNP (Figures 3-4 and 3-5). Based on these Pacific basin SST patterns and the distribution of wind and surface pressure in the tropics of the Pacific

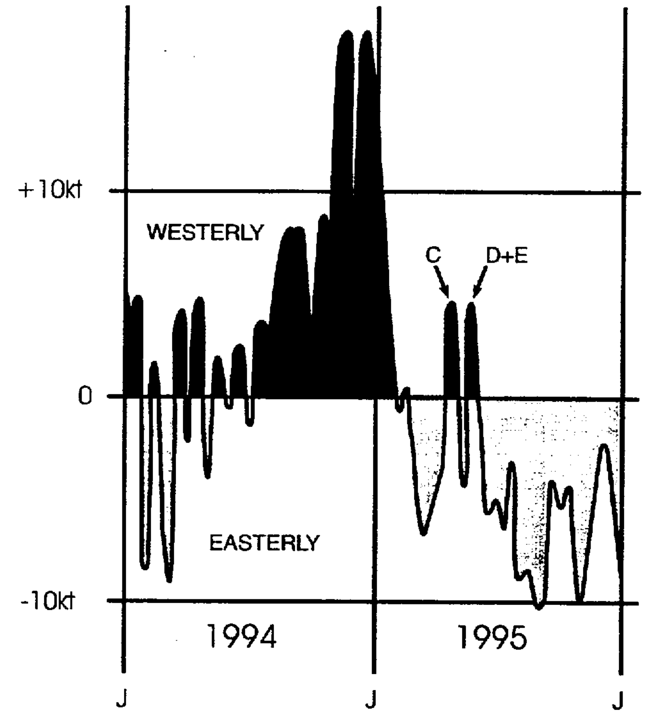


Figure 3-4 Time series of the daily low-level wind along the equator at 150°E during 1994 and 1995. Westerly winds are black, easterlies are shaded. The C indicates the time of formation of Chuck (02W), and the D and E indicates the time of formation of Deanna (03W) and Eli (04W). The winds were adapted from the Climate Prediction Center (1994, 1995).

basin, the U.S. Climate Analysis Center (along with other international meteorological centers) officially declared that the warm phase of ENSO was over. In some respects (e.g., the cooling of the equatorial sea surface, and the anomalously strong low-level easterly winds in the low latitudes of the WNP) the climatic anomalies of the Pacific basin during most of 1995 were consistent with those expected during a cold phase of ENSO, sometimes referred to as La Niña, or El Viejo.

During the first few months of 1995, when ENSO-related low-level westerly winds still dominated equatorial latitudes of the WNP, the year's first two significant TCs — Tropical Depression 01W in January and Chuck (02W) in April — formed at a low latitude (5° N) and east of 160° E. During most of May, a very weak monsoon trough stretched across Micronesia, but no significant TCs formed in it

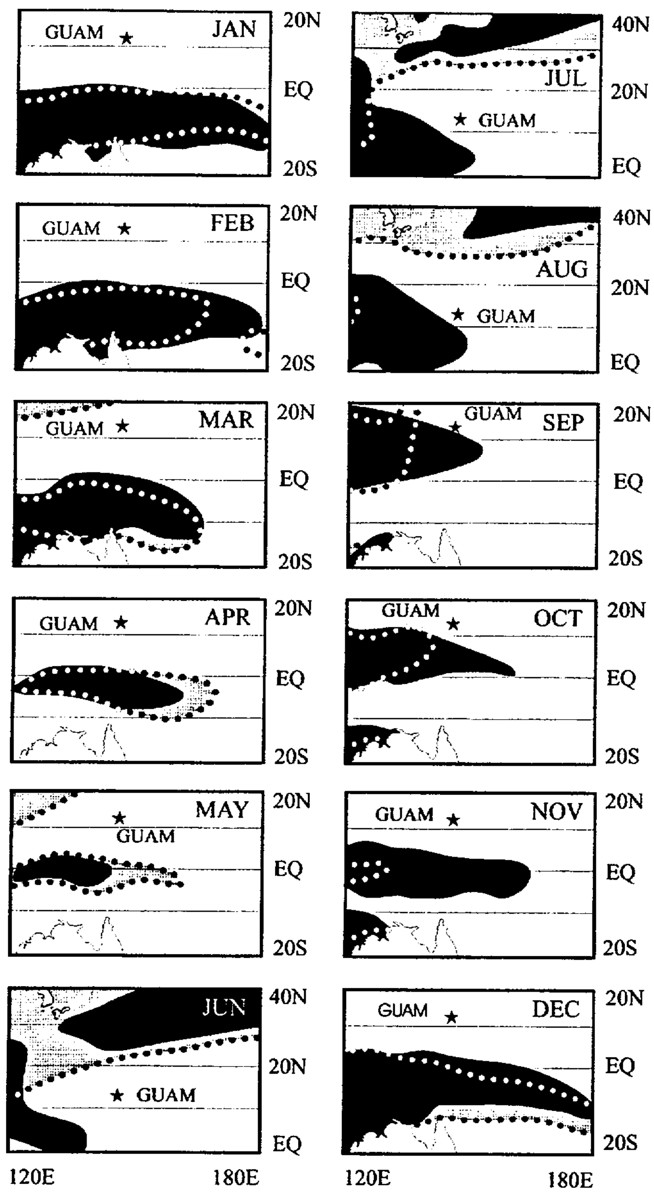


Figure 3-5 Comparison between climatological (black) and analyzed (shaded) mean monthly winds with a westerly component for the western North Pacific in 1995. For June, July, and August the area of coverage is shifted northward to include the subtropics of the North Pacific. For reference, the star indicates the location of Guam. The outline of Australia appears in the lower left of each panel except for June, July, and August where the Korean Peninsula and Japan appear in the upper left. The climatology is adapted from Sadler et al. (1987). The 1995 monthly mean winds were adapted from the Climate Prediction Center (1995) and the Australian Bureau of Meteorology (1995).

until very late in the month when two relatively small and weak TCs — Deanna (03W) and Eli (04W) — developed. As they moved northward during early June, the weak monsoon trough across Micronesia was replaced by low-level easterlies, and southwesterly winds became restricted to the South China Sea, within a narrow band south of the mei-yu trough (Figures 3-5 and 3-6a).

The annual mean genesis location (Figure 3-7a) was west of normal — the first such occurrence since 1990. The annual mean genesis location of tropical cyclones that form in the WNP is highly dependent upon the status of ENSO, and tends to be to the east of normal during El Niño years and west of normal during La Niña years. During 1995, six TCs formed east of 160°E (Figure 3-7b), but most formed in the Philippine Sea (west of 140°E) and eight formed in the South China Sea, resulting in a westward displacement of the annual mean genesis location.

The low-level wind of the tropical Pacific in 1995 was dominated by easterly flow. As a consequence, the summer monsoon circulation of the WNP was weak — in stark contrast to the very active summer monsoon of 1994. During June, July and August of 1995, low-level easterly wind flow was unusually persistent in the low latitudes of the WNP (Figure 3-8a), and the normal southwest monsoon of the Philippine Sea (Figure 3-6b) (with its episodic extensions further eastward) was replaced by mean monthly easterly flow. Also, during these months, the axis of the low-level subtropical ridge was displaced approximately 5° equatorward of normal. Corresponding anomalies in the upper troposphere consisted of westerly wind anomalies over the low latitudes of the WNP (Figure 3-8b). Low-level easterly anomalies coupled with upper tropospheric westerly anomalies resulted in strong westerly shear over the deep tropics of the WNP. This may be related to the large number of weak and poorly defined TCs during much of the year (Figure 3-9). The synoptic

(a)

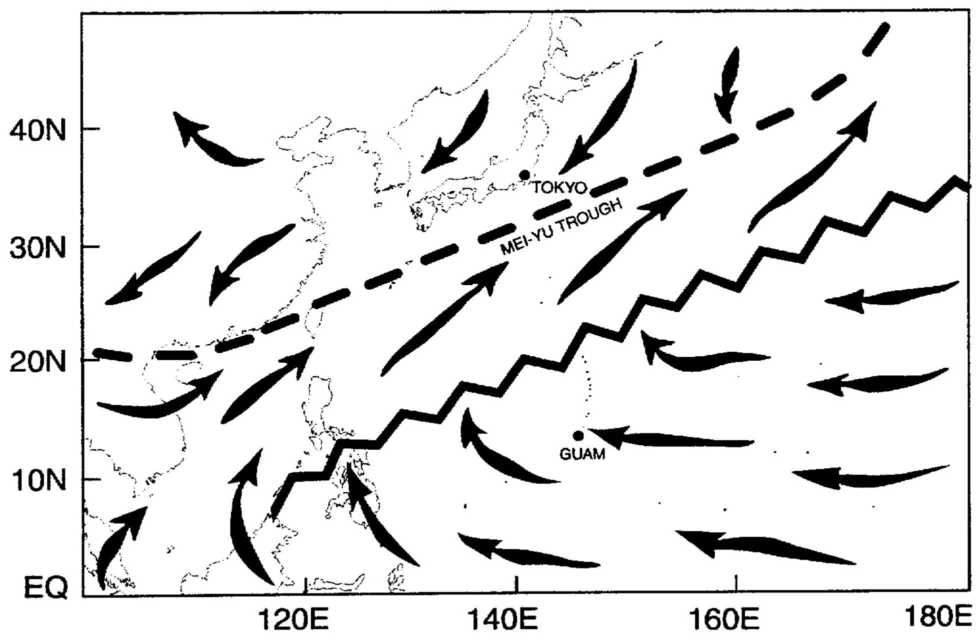


Figure 3-6a The low-level circulation during the summer in the tropics of the western North Pacific. Schematic example of the low-level circulation associated with dominant easterly flow in low latitudes and southwesterlies restricted to the South China Sea and to the south of the mei-yu trough.

(b)

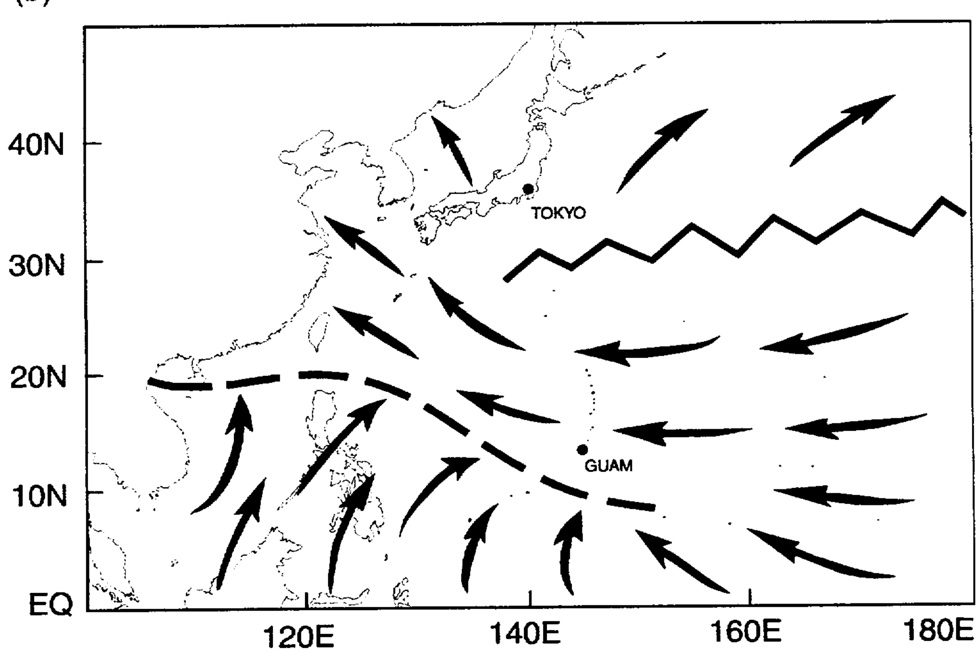


Figure 3-6b The low-level circulation during the summer in the tropics of the western North Pacific - the long-term average. Bold zig-zag lines indicate ridge axes, and bold dashed lines indicate trough axes. Arrows indicate low-level wind direction.

(c)

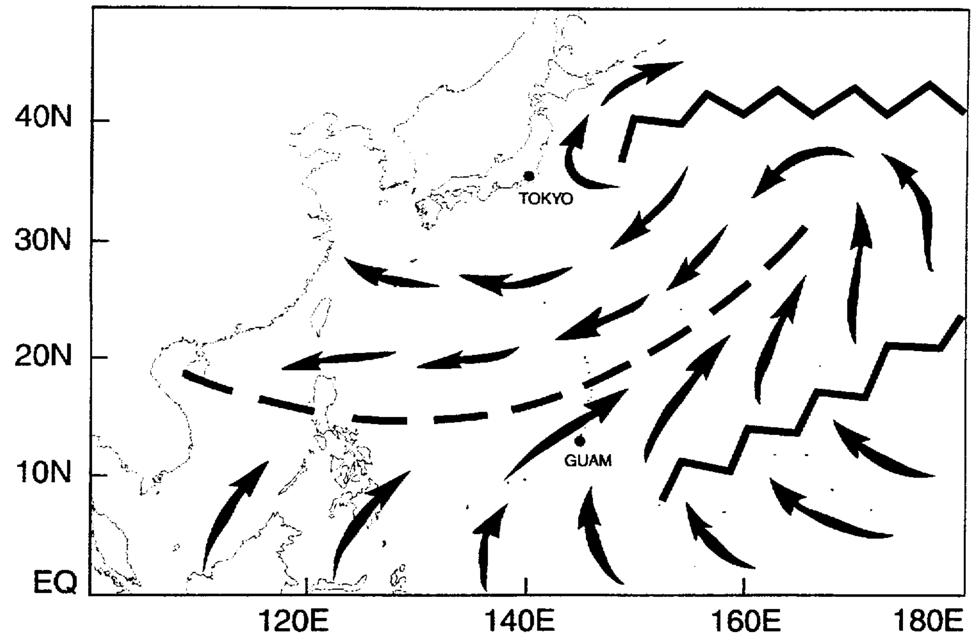


Figure 3-6c The low-level circulation during the summer in the tropics of the western North Pacific. A schematic example of the low-level circulation associated with a reverse-oriented monsoon trough.

(d)

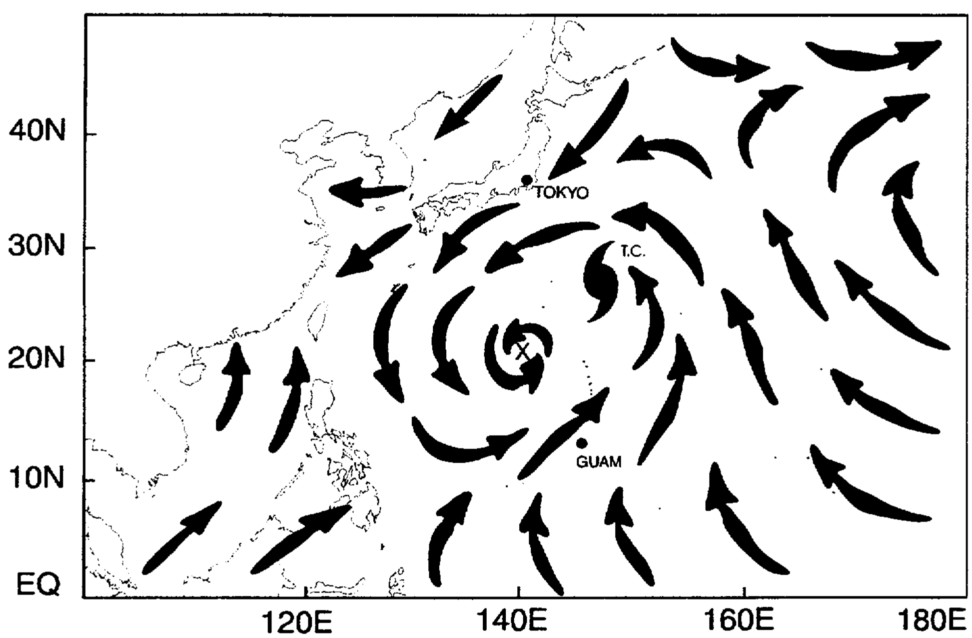


Figure 3-6d The low-level circulation during the summer in the tropics of the western North Pacific. A schematic example of the low-level circulation associated with a monsoon gyre ("x" = gyre center, a tropical cyclone is shown within the circulation of the gyre).

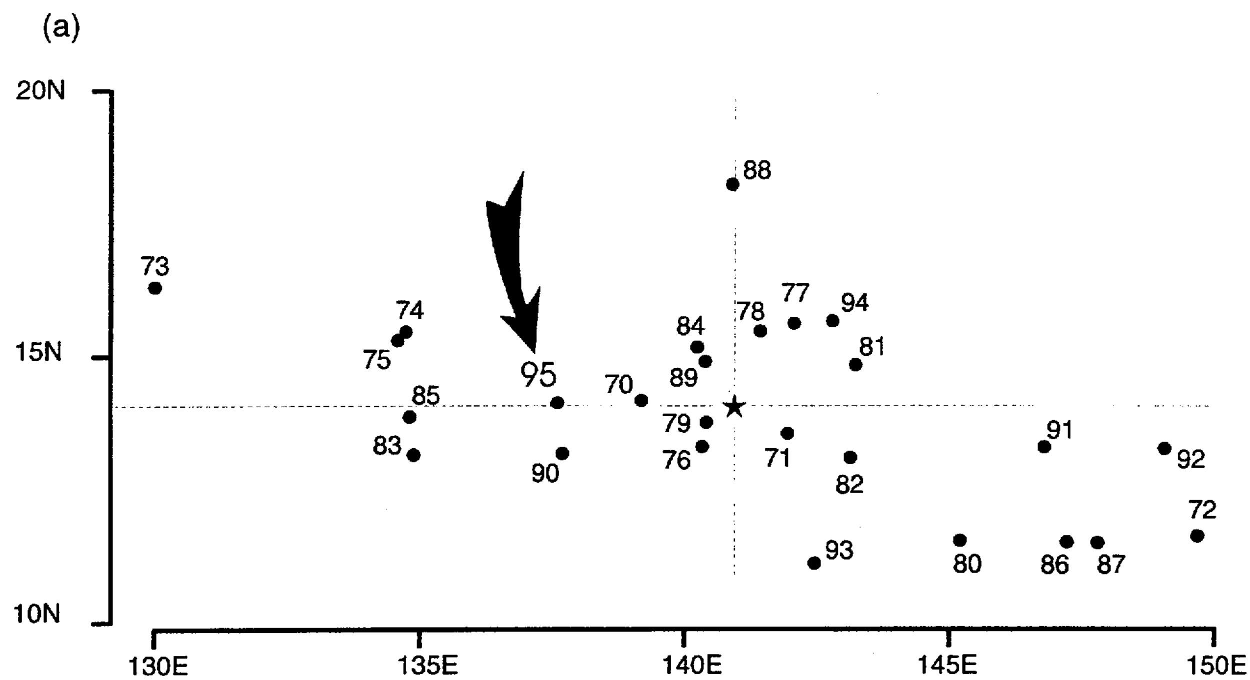


Figure 3-7a Mean annual genesis locations for the period 1970-1995. 1995's location is indicated by the arrow. The star lies at the intersection of the 26-year average latitude and longitude of genesis. For statistical purposes, genesis is defined as the first 25 kt (13 m/sec) intensity on the best track.

regime that dominated most of the middle and latter half of 1995 featured low-level winds with an easterly component that converged at low-latitude, while westerly winds aloft carried the cirrus generated by mesoscale convective systems (MCSs) eastward. Throughout Micronesia, MCSs grew and decayed at the 12-18 hour mesoscale life cycle along the convergence zone and in association with TUTT cells. With few exceptions, tropical cyclone formation was confined to the South China Sea and the Philippine Sea from May through the end of the year. Only two relatively active monsoon episodes were noted during 1995: a reverse-oriented monsoon trough (e.g., Figure 3-c) formed during mid-September and a large monsoon gyre (e.g., Figure 3-6d) formed during mid-October. Neither of these events brought exceptionally strong southwesterly monsoon winds into the tropical WNP, but each did briefly shift the southwest monsoon eastward.

During mid-September, a reverse-oriented monsoon trough formed. Its axis stretched from the South China Sea eastward across Luzon and the Philippine Sea, and then northeastward to the northeast of Guam. This episode of a reverse-oriented monsoon trough saw the simultaneous development of three TCs along its axis — Oscar (17W), Polly (18W), and Ryan (19W). When the monsoon trough axis acquires a reverse orientation, TCs along it tend to move on north-oriented tracks. An unusual type of north-oriented track — the "S" track — is almost always associated with reverse orientation of the monsoon trough axis (Lander 1996). Consistent with Lander's findings, Polly and Ryan moved on unusual north-oriented "S"-shaped tracks. After Oscar, Polly and Ryan recurved into the mid-latitudes during the latter half of September, easterly winds returned to most of the WNP basin.

In the mean, during October, the axis of the monsoon trough extended across Luzon and into the Philippine Sea to the southwest of Guam. This is where it remained for most of the month with one major exception: during

(b)

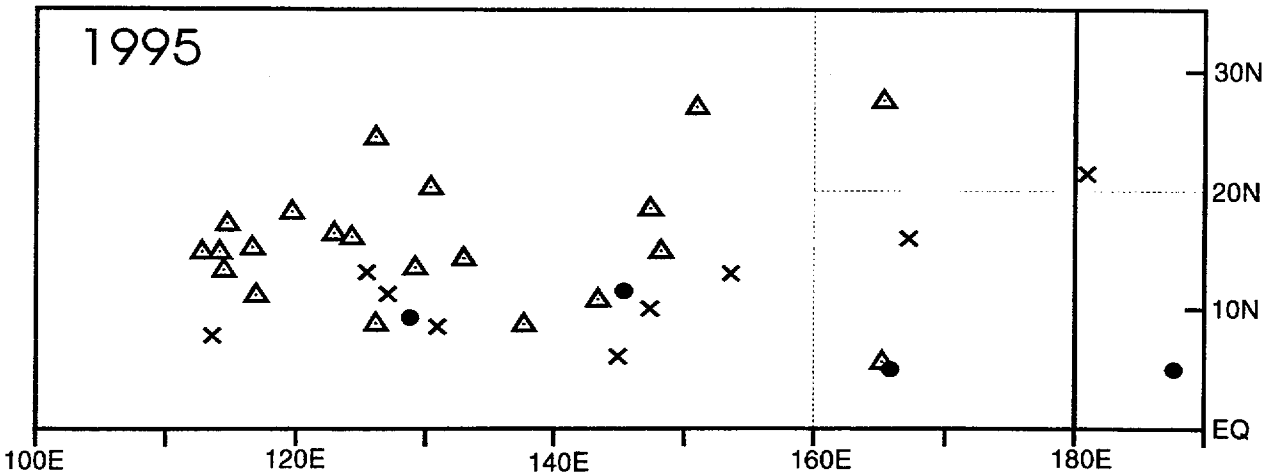


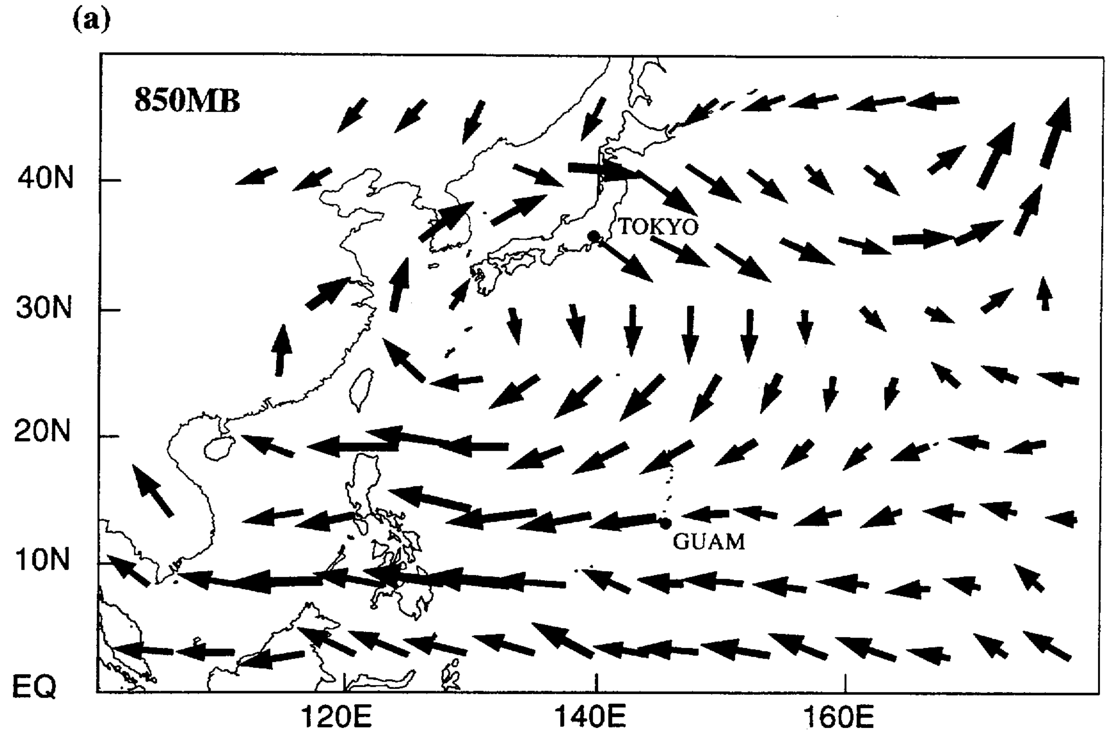
Figure 3-7b Point of formation of significant tropical cyclones in 1995 as indicated by the initial intensity of 25 kt (13 m/sec) on the best track. The symbols indicate: solid dots = 01 January to 15 July; open triangles = 16 July to 15 October; and, X = 16 October to 31 December.

mid-October a large monsoon gyre formed in the Philippine Sea. Tropical Storm Val (25W) interacted with this monsoon gyre. After the monsoon gyre dissipated in the latter half of October, the monsoon trough axis became re-established across the Philippine Sea from Luzon to the southwest of Guam. During the latter half of October, all TCs, except the TUTT-related Brian (30W), formed near, or west, of Guam.

During November 1995, easterly winds returned to the entire deep tropics of the WNP. In what is normally the month of farthest eastward extension of monsoonal westerly winds at low latitudes, the winds along the equator during November 1995 were easterly from the international date line to the Philippines. Tropical cyclone formation during November was restricted to the South China Sea and near the Philippines, with the exception of Colleen (31W) which developed from a cut-off low at relatively high latitude near the international date line. Easterly wind anomalies continued during December, and only one named tropical cyclone — Dan (35W) — formed near the Philippines.

The tracks of the tropical cyclones which formed in the WNP during 1995 indicate a high number of TCs (eight) in the South China Sea, and several (six) with very short tracks. Of the 34 TCs: seven (20%) were straight moving, six (18%) were recurvers, five (15%) moved on north-oriented tracks, and sixteen (47%) were designated as "other" (Table 3-3). Of the five TCs which moved on north-oriented tracks during 1995, two underwent "S" motion. Eight of the sixteen "other" storms remained in or near the South China Sea. Two of the five tropical cyclones which moved on north-oriented tracks occurred in association with September's episode of reverse orientation of the monsoon trough.

An illustration of all the tropical cyclone activity in the western North Pacific and North Indian Oceans is provided in Figure 3-10. Table 3-4 includes: a climatology of typhoons, and tropical storms and typhoons for the WNP for the period 1945-1959 and 1960-1995; and a summary of warning days. Table 3-5 is a summary of the TCFA's for the WNP for 1976-1995. Composite best tracks for the WNP tropical cyclones are provided for the periods: 01 January to 01 September (Figure 3-11), 21 August to 14 October (Figure 3-12), and 05



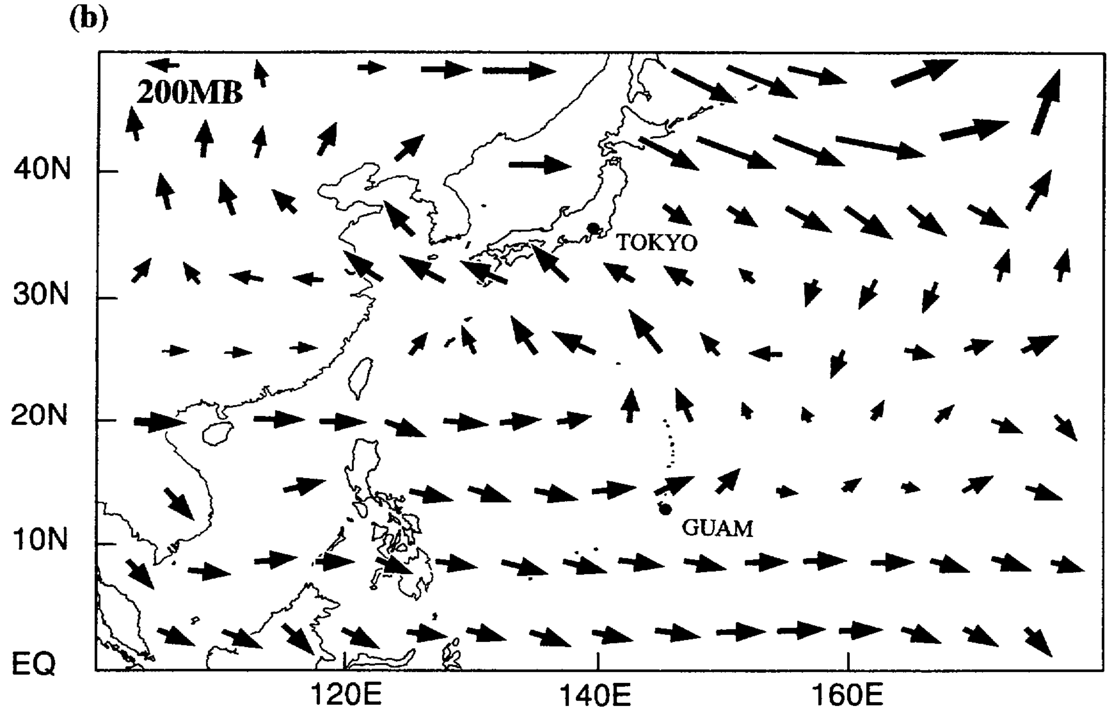


Figure 3-8a,b August wind anomalies: (a) 850 mb, and (b) 200 mb. Arrows indicate wind direction and arrow lenth is proportional to wind speed. In (a) the longest arrows indicate wind anomalies of approximately 10 kt (5 m/sec); in (b) the longest arrows indicate wind anomalies of approximately 30 kt (15 m/sec). The low-lattitude westerly wind anomalies at 200 mb and the low-lattitude easterly wind anomalies at 850 mb are both approximately 10 kt (5 m/sec) — the dicrepency of arrow length is due to the fact that the 200 mb arrows are scaled approximately one-third the length of the 850 mb wind arrows. The locations of Guam and Tokyo are indicated (wind anomalies are adapted from the Climate Prediction Center 1995).

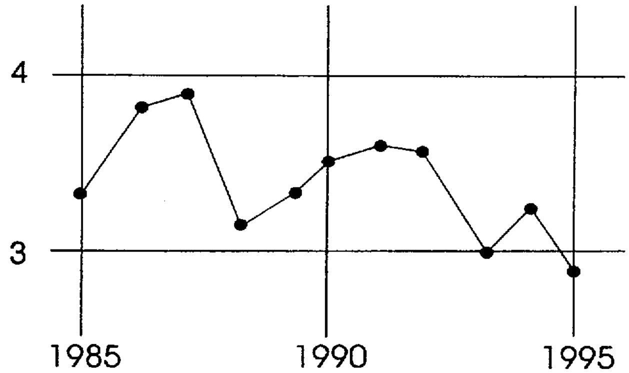


Figure 3-9 Average annual intensity of all tropical cyclones for each year from 1985 to 1995. Intensity units are based upon the following categories: 1 = 25-44 kt; 2 = 45-63 kt; 3 = 64-80 kt; 4 = 81-95 kt; 5 = 96-115 kt; 6 = 116-135 kt; and, 7 = > 135 kt. Categories 3 through 7 are indentical to Categories 1 through 5 on the Saffir-Simpson Hurricane Scale (Simpson 1974).

October to 31 December (Figure 3-13).

The year that saw the end of prolonged El Niño conditions, 1995 can be summarized as a year with a weak monsoon, many weak and poorly defined tropical cyclones, and a westward shift of the formation region of tropical cyclones in the WNP.

3.1.1 MONTHLY ACTIVITY SUMMARY

JANUARY

Tropical Depression 01W occurred in January in the near-equatorial trough. January TCs are most properly considered to be late-season storms, born in atmospheric conditions that evolved during November and December of the previous calendar year.

FEBRUARY

The month with the lowest average number of TCs in the WNP is February. In keeping with climatology, there were no significant TCs in the WNP basin during February 1995.

MARCH

Climatology shows a small increase (over February) in the number of tropical cyclones in the WNP during March. TCs occurring during March are related to the status of ENSO and during El Niño years there tends to be an increased number of early season (March through June) TCs. Consistent with the demise of El Niño conditions during 1995, there were no significant TCs in the WNP basin during March.

APRIL

One TC — **Chuck (02W)** — was active during April. The tropical disturbance from which this first named tropical cyclone of 1995 developed formed in the Marshall Islands at the end of the month. Chuck was a named TC for only two days and peaked at 35 kt (18 m/sec).

MAY

During the first week of May, the remnants of Chuck drifted toward the Mariana Islands bringing Guam about one-quarter of its rainfall for the month of May. The tropical disturbances that became Deanna (03W) and Eli (04W) formed in a weak monsoon trough that stretched across Micronesia during late May. They did not become named TCs until early June.

JUNE

Deanna (03W) was a relatively weak TC that crossed the central Philippines on 02 June. It stalled in the South China Sea for about two days, and then accelerated toward the northeast as it came under the steering influence of strong southwesterly flow to the south of the axis of the mei-yu trough. Deanna merged with the mei-yu cloud band as it moved rapidly northeastward through the Ryukyu island chain. **Eli (04W)**, also a weak tropical cyclone, passed very close to Guam on 04 June. The system turned northward, and dissipated over open water southeast of Japan.

JULY

July 1995 was a relatively quiet month in the WNP with only three named TCs active during the month. Forming at mid-month, **Faye (05W)** was the first TC of 1995 to become a typhoon. Reaching typhoon intensity on 19 July, Faye tied the record for the latest date for the occurrence of a typhoon in the WNP. Moving on a north-oriented track through the East China Sea, Faye made landfall on the southern coast of Korea, and was one of the most intense TC to strike the Korean peninsula in many years.

In postanalysis, Tropical Depression 06W (TD 06W) was upgraded to **Tropical Storm 06W** based upon scatterometer data from the European Space Agency's remote sensing (ERS-1) satellite. These data indicated that an area of 35 kt (18 m/sec) wind speed accompanied TD 06W as it moved northward just off the east coast of Luzon on 28 July. Tropical Storm 06W merged with Tropical Storm Gary (07W) during a time when both of these TCs were embedded within the circulation of a larger monsoon depression, and while both were affected by the island of Luzon.

Gary (07W) merged with Tropical Storm 06W during a time when both of these TCs were embedded within the circulation of a large monsoon depression near the island of Luzon. Forming in the South China Sea, Gary made landfall in southeastern China very close to the city of Shantou. Based upon ship reports received in the Weekly Tropical Cyclone Summaries compiled by Mr. Jack Beven of the National Hurricane Center, and upon delayed reports of typhoon intensity wind speeds experienced in the city of Shantou, Gary was upgraded from a tropical storm to a typhoon in post-analysis.

AUGUST

The pace of TC formation picked up during August with a total of seven significant TCs active during the month. Originating near Guam during the first week of August, the tropical disturbance that became **Helen (08W)** was slow to develop, taking six days to reach tropical storm intensity. Helen skirted northern Luzon and reached a peak intensity of 70 kt (36 m/sec) just before making landfall east of Hong Kong. Helen was upgraded to typhoon intensity in postanalysis based on data obtained from Hong Kong. A week later, **Irving (09W)** formed in the South China Sea. Irving was very small, and isolated in an otherwise relatively cloud-free region of the South China Sea, it maintained a very small CDO under which microwave imagery indicated the presence of an eye.

During the middle of August, a weak monsoon trough extended into the Philippine Sea. Forming in this monsoon trough, **Janis (10W)** moved northwestward and merged with **Tropical Depression 11W** (TD 11W formed in association with a TUTT-induced area of convection to the north of Janis). In an unusual case of TC merger, the larger Janis lost much of its deep convection and became less organized as it merged with the smaller TD 11W. Subsequent to the merger, all deep convection was lost, but later regenerated as the system moved northward east of Shanghai. Moving eastward across the Yellow Sea, Janis made landfall in central Korea near Seoul. Heavy rain and winds associated with Janis had a significant impact on South Korea.

As Janis was undergoing recurvature, two tropical disturbances formed in the monsoon trough simultaneously: **Kent (12W)** in the Philippine Sea, and **Lois (13W)** in the South China Sea. Kent was the first of five super typhoons to occur in 1995. It rapidly intensified as it approached the Luzon Strait. Basco, Batan Island (WMO 98135), which was briefly in the northern part of Kent's eye, observed a peak wind gust of 140 kt, and a minimum sea-level pressure of 928 mb. Hourly radar images from Kaohsiung, Taiwan showed concentric eyewalls that persisted for at least 22 hours. Kent continued on a west-northwest track and made landfall in China, just east of Hong Kong. Lois became a typhoon as it was passing over the southern end of Hainan Island in the South China Sea and later made landfall in northern Vietnam. Lois was one of an unusually large number of TCs (eight) that formed in the South China Sea during 1995.

At the end of August, **Mark (14W)** formed at a relatively high latitude. Mark was a small sized TC that moved northeastward for most of its track. It did not reach peak intensity until the first day of September.

SEPTEMBER

September was more active than August , with a total of nine significant TCs: eight that formed during the month and one — Mark — that was still active from August. On the first day of the month, Mark was moving in excess of 20 kt (37 km/hr) toward the polar front. While passing over increasingly cooler sea surface temperatures, it acquired a well-defined eye and reached a peak estimated intensity of 95 kt (49m/sec) as it tracked northeastward from 35°N to 37°N.

During the first week of September, two relatively weak TCs— **Nina (15W)** and **Tropical Depression 16W** (TD 16W) — formed in a weak monsoon trough, crossed the Philippines, and entered the South China Sea. Nina ultimately made landfall in Southern China. TD 16W made landfall in Vietnam, and survived its passage across Southeast Asia and entered the Bay of Bengal, where it regenerated and became **Tropical Cyclone 01B**.

During mid September, the first of two relatively active monsoon episodes during 1995 occurred. A reverse-oriented monsoon trough (Lander 1996) formed, its axis stretching from the South China Sea eastward across Luzon and the Philippine Sea, and then northeastward to the northeast of Guam. This episode of a reverse-oriented monsoon trough saw the simultaneous development of three TCs along its axis — Oscar (17W), Polly (18W), and Ryan (19W).

Oscar (17W) became a very large TC. It also became very intense, reaching a peak intensity of 140 kt (72 m/sec). Oscar posed a serious threat to Tokyo and the southeastern coast of Japan, however, it recurved enough eastward to give only a glancing blow to extreme southeastern Honshu; the eye remained offshore as it passed about 100 nm (185 km) southeast of Tokyo. Oscar's rapid speed of translation — in excess of 40 kt (75 km/hr) — helped to spare Japan the full effects of the typhoon's highest winds. Nevertheless, heavy rain and high winds were responsible for loss of life and some minor damage in Japan.

Like many other tropical cyclones that form within (or move into) a reverse-oriented monsoon trough, **Polly (18W)** underwent unusual motion: an "S"-shaped track. Polly reached peak intensity of 90 kt (46 m/sec) before it turned to the north-northeast on the final leg of its "S" track. The extratropical remains of Polly, possessing a well-defined low-level circulation, moved across the international date line on 24 September.

Ryan (19W) was the first TC on JTWC's records to both form and attain super typhoon intensity within the South China Sea. As was also the case with Polly (18W), Ryan moved on an "S"-shaped track. Ryan passed through the southern islands of the Ryukyu chain, and made landfall in southwestern Japan. On 22 September, Ryan passed near the Taiwanese island of Lanyu (WMO 46762) where a peak wind gust of 166 kt (85.3 m/sec) tied the strongest wind gust ever recorded in a typhoon. The other event occurred at Miyako Jima (WMO 47927) in September 1966 near the eye of Typhoon Cora.

After the reverse-oriented monsoon trough of mid-September migrated out of the tropics, a near-equatorial trough was re-established across Micronesia during the final week of September. **Sibyl (20W)** and **Tropical Depression 21W** (TD 21W) formed in this trough. Sibyl reached its peak intensity of 95 kt (49 m/sec) as it crossed the Visayan Islands. Later, it tracked over metro-Manila and entered the South China Sea, where it slowly weakened before making landfall east of the Luichow peninsula in southern China. The tropical disturbance that became TD 21W crossed the Philippines on 25 September, and on 28 September, as this tropical disturbance neared the coast of Vietnam, the deep convection consolidated near the low-level circulation center, and it became TD 21W. The system made landfall on the coast of Vietnam and dissipated.

An unusual TC — **Tropical Depression 22W** (TD 22W) — formed at the end of the month and continued into October. TD 22W formed at a relatively high latitude (30°N) near the international date line. It was a very small TC — the smallest TC in the WNP warned on by the JTWC during 1995.

OCTOBER

October was a month of above normal TC activity in the WNP basin: eight TCs formed during the month and two — TD 22W and Sibyl (20W) — formed in September, but were active until 04 October. The first TC that formed during October was **Tropical Depression 23W** (TD 23W). The tropical disturbance that became TD 23W originated over the Philippines and briefly became a tropical depression with maximum winds of 25 kt (13 m/sec) as it moved westward over the South China Sea. **Ted (24W)** developed east of the Philippines in the near-equatorial trough. After moving through the islands of the central Philippines as a tropical disturbance, Ted became a typhoon in the South China Sea when south of Hainan Island. As Ted passed into the Gulf of Tonkin, a gust of 111 kt (55 m/sec) was observed at the top (100 m above sea level) of an oil rig. Ted eventually dissipated over the mountains of southern China.

In the mean, during October, the axis of the monsoon trough extended across Luzon and into the Philippine Sea to the southwest of Guam. This is where it remained for most of the month with one major exception: during mid-October a large monsoon gyre formed in the Philippine Sea. **Tropical Storm Val (25W)** interacted with this monsoon gyre: Val orbited from the eastern side of the gyre to its northern side. Eventually, all of Val's deep convection was sheared away, and it merged with the monsoon gyre. The merged vortex drifted to the west-southwest and slowly dissipated. After the monsoon gyre dissipated in the latter half of October, the monsoon trough axis became re-established across the Philippine Sea from Luzon to the southwest of Guam. During the latter half of October, all TCs — Ward (26W), Yvette (27W), Zack (28W), and Angela (29W) — except the TUTT-related Brian (30W), formed near, or west, of Guam.

The fourth of five super typhoons during 1995, **Ward (26W)** formed as a small TC east of Guam. Moving rather quickly at 17 kt (32 km/hr) toward the west, Ward passed between the islands of Rota and Saipan, or about 70 nm (130 km) to the north of Guam, during the night of 17 October. While approaching its point of recurvature, Ward also intensified, and attained its peak intensity of 140 kt (72 m/sec).

Yvette (27W) was one of seven TCs during 1995 that passed over the Philippines with an intensity of 35 kt (18 m/sec) or greater. Like many other TCs during 1995, Yvette did not develop significantly until it had tracked westward, to near the Philippines where it finally became a tropical storm. After crossing the Philippines, Yvette moved westward over the South China Sea where it reached typhoon intensity just before making landfall along the coast of Vietnam.

Originating from a tropical disturbance in the eastern Caroline Islands, **Zack (28W)** did not significantly intensify for nearly six days. As was the case with Sibyl (20W), Zack intensified as it crossed the Visayan Islands. But, unlike Sibyl (which weakened over the South China Sea after crossing the Philippines), Zack intensified significantly, peaking at an intensity of 120 kt (62 m/sec).

Angela (29W) was the most intense typhoon of 1995, and it was the most intense typhoon to hit the Philippines since Typhoon Joan (1970). First striking southern Luzon, it moved westward and crossed the metro-Manila area. More than 600 people perished in the Philippines as a result of Angela. At its various stages of development, Angela followed Typhoon Zack (28W) nearly 4000 nm (7400 km) across the western North Pacific. Like many of the 1995 tropical cyclones, Angela was slow to develop, but ultimately, it became one of the most intense typhoons of the decade when it peaked at an intensity of 155 kt (80 m/sec).

During the final days of October, **Brian (30W)** formed in direct association with a TUTT cell. Typical of such TCs, Brian was small and embedded in the easterly wind flow on the southwestern quadrant of the low-level subtropical high. It recurved and became absorbed into the cloud band of an advancing cold front.

NOVEMBER

Easterly wind anomalies related to La Niña dominated the tropics of the WNP during November and, as a consequence, November was very quiet. As November began, Brian was recurving, and only one tropical cyclone — Colleen (31W) — formed during the month. On the final day of the month, a tropical disturbance that would become Tropical Depression 32W formed near the Philippines.

Colleen (31W) developed in an unusual manner for a TC in the WNP. The disturbance that became Colleen was a cut-off low that formed in the subtropics to the northwest of Hawaii — a classic "Kona" low. Drifting toward the southwest, the "Kona" low crossed the international date line into JTWC's area of responsibility, where it acquired persistent central convection and became a tropical storm. Colleen was a tropical storm for only six hours, and dissipated after a short life about 420 nm (800 km) east-southeast of Wake Island.

DECEMBER

Three significant TCs formed in the WNP during December — Tropical Depression 32/33W, Tropical Depression 34W, and Tropical Storm Dan. The tropical disturbance that became **Tropical Depression 32W** (TD 32W) formed near the Philippines on the last day of November. As it drifted toward the central Philippines on 02 December, it intensified and was upgraded by the JTWC to TD 32W. Deep convection moving northward along a shear line was originally thought to be TD 32W. After this convection dissipated, a new area of persistent deep convection formed over the central Philippines and it was, at the time, upgraded to Tropical Depression 33W. TD 33W dissipated as it moved westward toward the South China Sea. Postanalysis indicated that TD 33W was the regeneration of Tropical Depression 32W, and the two best tracks were combined as one.

On 07 December, satellite imagery and synoptic data showed that a low-level circulation center was associated with an area of persistent deep convection northwest of Borneo. Based on ship reports indicating wind speeds of 30 kt (15 m/sec) near the low-level circulation center, this system was upgraded to **Tropical Depression 34W** (TD 34W). Wind speeds of 40 kt (21 m/sec) were occurring throughout much of the South China Sea to the north of TD 34W as a manifestation of a surge in the northeast monsoon. TD 34W formed from processes that produce TC twins during times of enhanced equatorial westerly winds (Lander 1990) and it was the Northern Hemisphere twin to Tropical Cyclone Frank (03S) in the Southern Hemisphere. TD 34W dissipated over water near 7°N 109°E.

Dan (35W) was the last significant TC to occur in the WNP during 1995. Like many other TCs during 1995, Dan did not develop until it had tracked westward to near the Philippines. During December 1995, strong tradewinds dominated the tropics of the WNP. A persistent tradewind convergence zone developed along 5°N, extending from 170°W to 140°E. Several tropical disturbances formed in the convergence zone and moved across the southern islands of Micronesia. These disturbances, coupled with the penetration of shear lines into low latitudes, produced heavier than normal rainfall across Guam and the Northern Mariana Islands. One of these disturbances became Dan. Dan reached a peak intensity of 55 kt (28 m/sec), and early on 30 December, it began to accelerate toward the northeast. Moving to the northeast in excess of 30 kt (55 km/hr), the last TC warning of 1995 was issued on Dan, valid at 310600Z, when the system transitioned into an extratropical low.

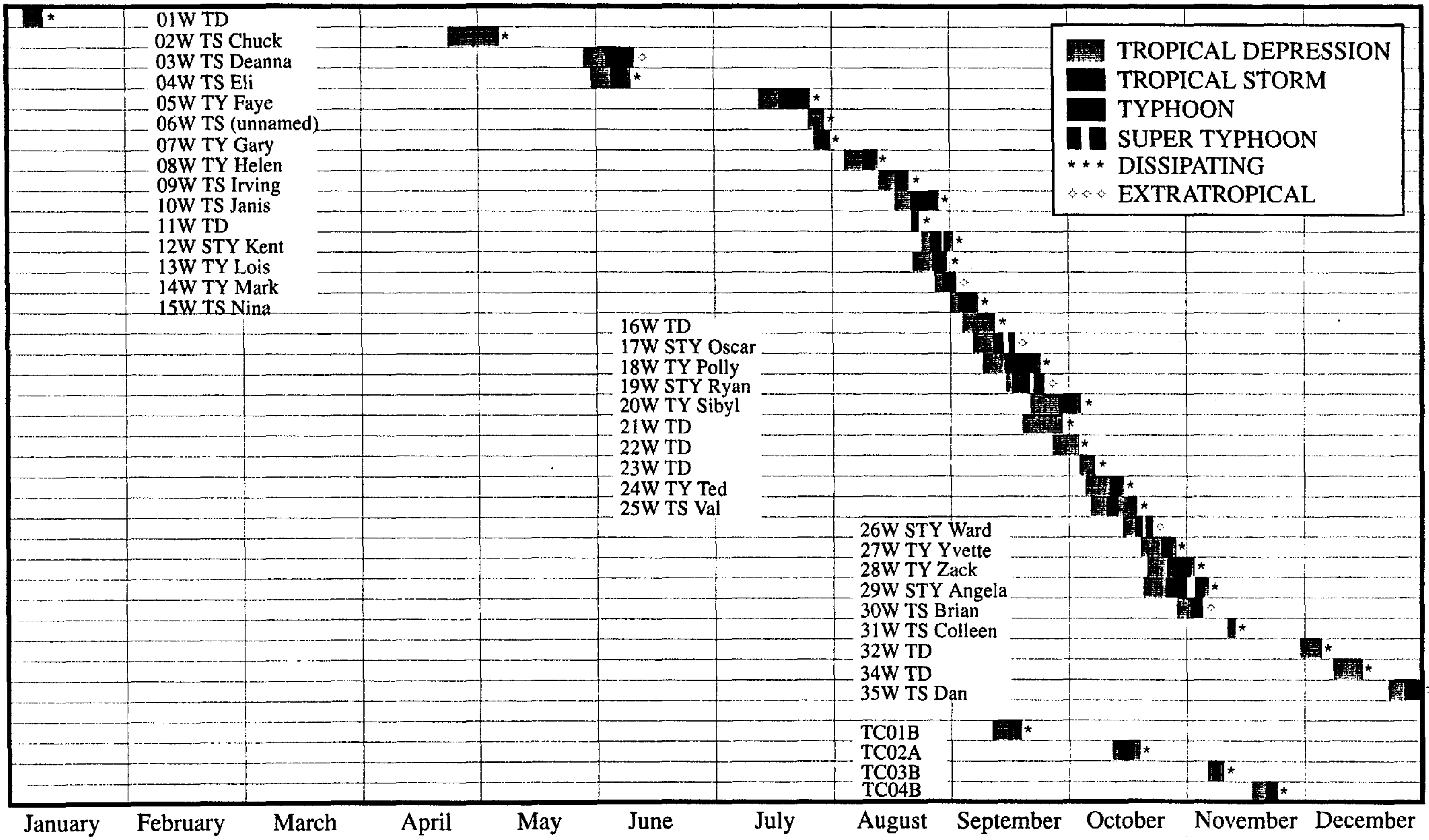


Figure 3-10 Chronology of western North Pacific and North Indian Ocean tropical cyclones for 1995.

Table 3-3 Individual 1978-1995 tropical cyclone (TC) track types. The observed track classes are defined as straight moving (SM), Recurving (R), North-oriented (NO), "S"-track (S), and OTHER. Further subdivisions of the OTHER category are indicated by icons: SCS = TC remained in or near South China Sea for its whole life; A = TC formed over open Pacific and died over water after a short track; B= TC made many loops and meanders but made little overall forward progress; C = TC formed in Mei-yu cloud band and tracked rapidly to the northeast; D = TC formed in the lee of Taiwan during conditions of monsoonal southerwesterly flow and tracked northward then westward around the top of Taiwan to make landfall on the China coast. Note: the subdivisions within the OTHER category are not mutually exclusive: for example, a South China Sea TC (SCS) might also have looped and meandered (B).

YEAR	SM	R	NO	"S"	OTHER	SCS	A	B	C	D
1978	5	10	9	1	7	4	3	-	-	-
1979	10	12	2	-	4	2	1	1	1	-
1980	10	7	5	1	6	5	1	1	-	-
1981	11	7	4	1	6	2	2	1	-	1
1982	9	5	6	1	7	3	1	2	2	-
1983	11	5	4	-	4	4	-	1	-	-
1984	6	5	7	4	8	5	3	1	-	-
1985	7	3	3	6	8	5	2	1	-	-
1986	9	12	2	-	3	1	1	1	1	-
1987	8	2	9	-	5	2	3	-	-	-
1988	9	4	7	1	5	2	-	1	2	1
1989	15	5	5	4	6	3	3	-	-	-
1990	8	11	1	4	7	5	1	-	-	1
1991	11	14	2	-	4	3	1	1	-	-
1992	8	11	5	4	4	3	1	2	-	-
1993	15	10	4	-	8	2	6	-	-	-
1994	15	5	6	8	5	4	1	-	-	-
1995	7	6	3	2	16	8	6	2	-	-
Total:	174	134	84	37	113	61	36	15	6	3
Avg:	9.7	7.4	4.7	2.0	6.3	3.4	2.0	0.8	0.3	0.2

Table 3-4 WESTERN NORTH PACIFIC TROPICAL CYCLONES

TYPHOONS

(1945 - 1959)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.3	0.1	0.3	0.4	0.7	1.0	2.9	3.1	3.3	2.4	2.0	0.9	16.4
CASES	5	1	4	6	10	15	29	46	49	36	30	14	245

(1960 - 1995)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.3	0.1	0.2	0.4	0.7	1.1	2.8	3.5	3.4	3.4	1.7	0.7	18.3
CASES	10	2	8	15	25	38	98	122	120	118	61	24	641

TROPICAL STORMS AND TYPHOONS

(1945 - 1959)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.4	0.1	0.5	0.5	0.8	1.6	2.9	4.0	4.2	3.3	2.7	1.2	22.2
CASES	6	2	7	8	11	22	44	60	64	49	41	18	332

(1960 - 1995)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.5	0.3	0.5	0.6	1.1	1.9	4.3	5.7	5.2	4.5	2.7	1.7	28.7
CASES	19	9	17	22	39	67	152	201	182	156	94	44	1004

Table 3-5 TROPICAL CYCLONE FORMATION ALERTS FOR THE WESTERN NORTH PACIFIC OCEAN FOR 1976-1995

YEAR	INITIAL TCFAS	TROPICAL CYCLONES WITH TCFAS	TOTAL TROPICAL CYCLONES	PROBABILITY OF TCFA WITHOUT WARNING*	PROBABILITY OF TCFA BEFORE WARNING
1976	34	25	25	26%	100%
1977	26	20	21	23%	95%
1978	32	27	32	16%	84%
1979	27	23	28	15%	82%
1980	37	28	28	24%	100%
1981	29	28	29	3%	96%
1982	36	26	28	28%	93%
1983	31	25	25	19%	100%
1984	37	30	30	19%	100%
1985	39	26	27	33%	96%
1986	38	27	27	29%	100%
1987	31	24	25	23%	96%
1988	33	26	27	21%	96%
1989	51	32	35	37%	91%
1990	33	30	31	9%	97%
1991	37	29	31	22%	94%
1992	36	32	32	20%	100%
1993	50	35	38	30%	92%
1994	50	40	40	20%	100%
1995	54	33	34	19%	97%
(1976-1995)					
MEAN:	35	26	28	22%	95%
TOTALS:	691	526	533		

* Percentage of initial TCFA's not followed by warnings.

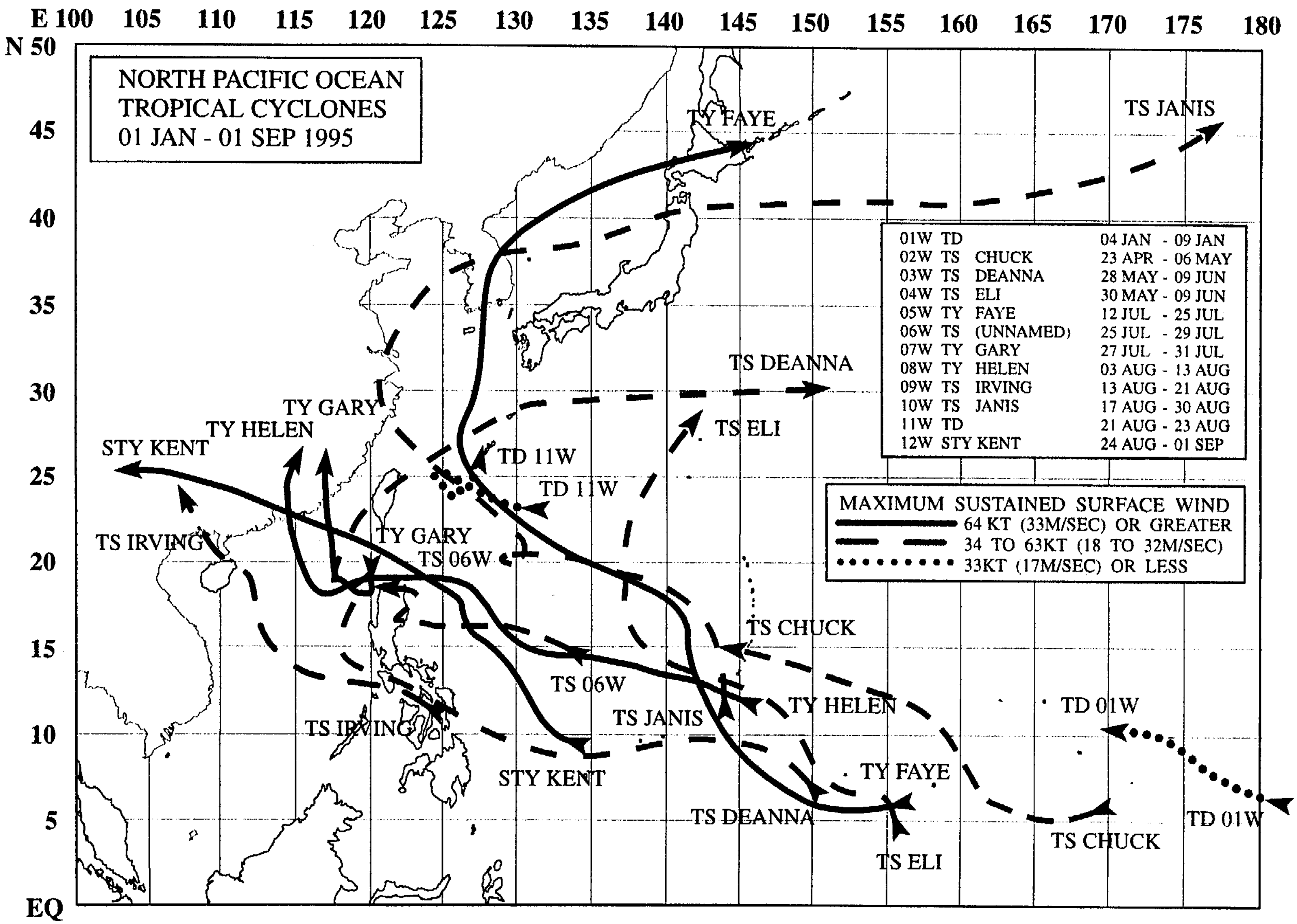


Figure 3-11 Composite best tracks for the North West Pacific Ocean tropical cyclones for the period 01 January to 01 September 1995.

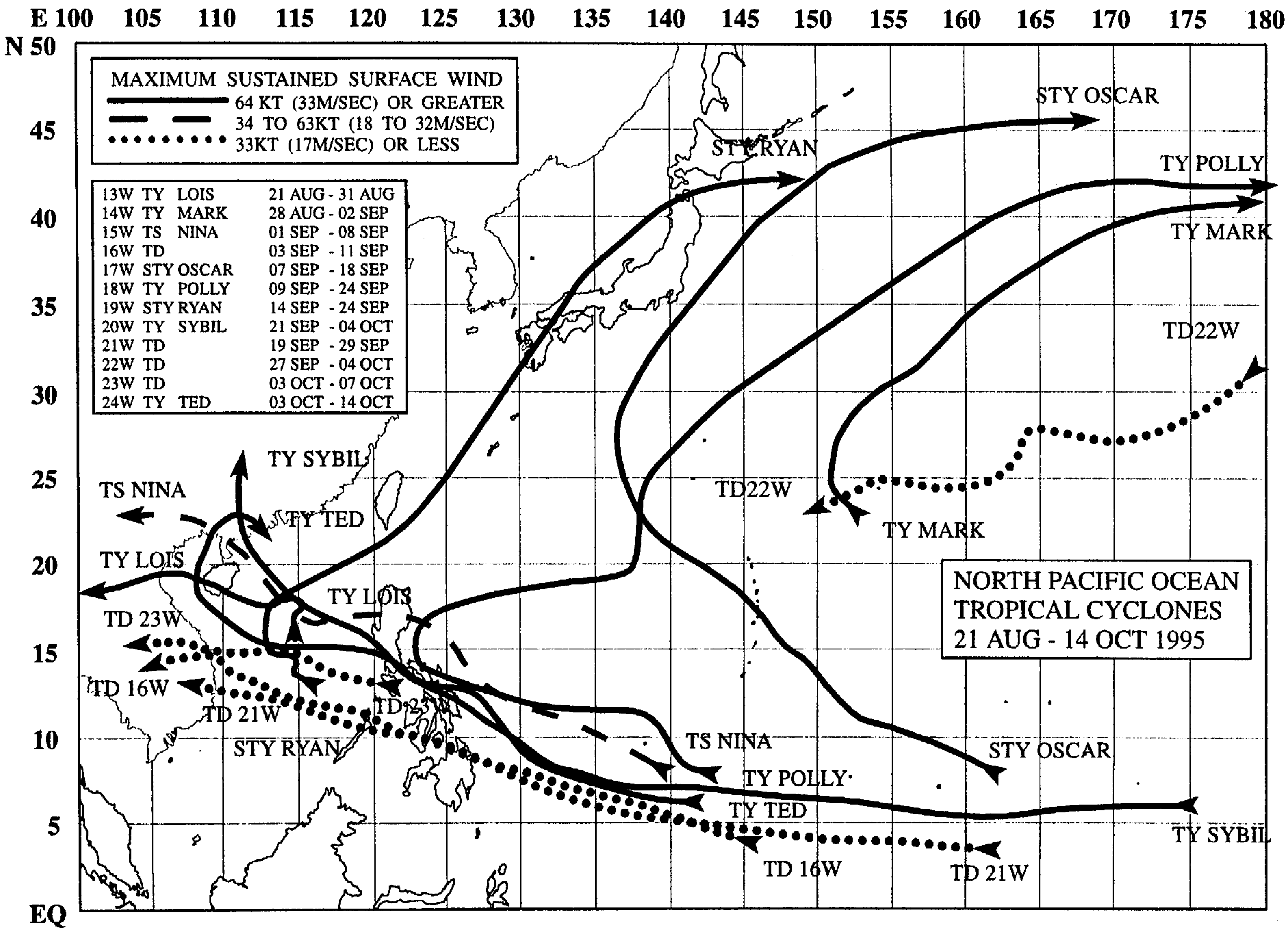


Figure 3-12 Composite best tracks for the North West Pacific Ocean tropical cyclones for the period 21 August to 14 September 1995.

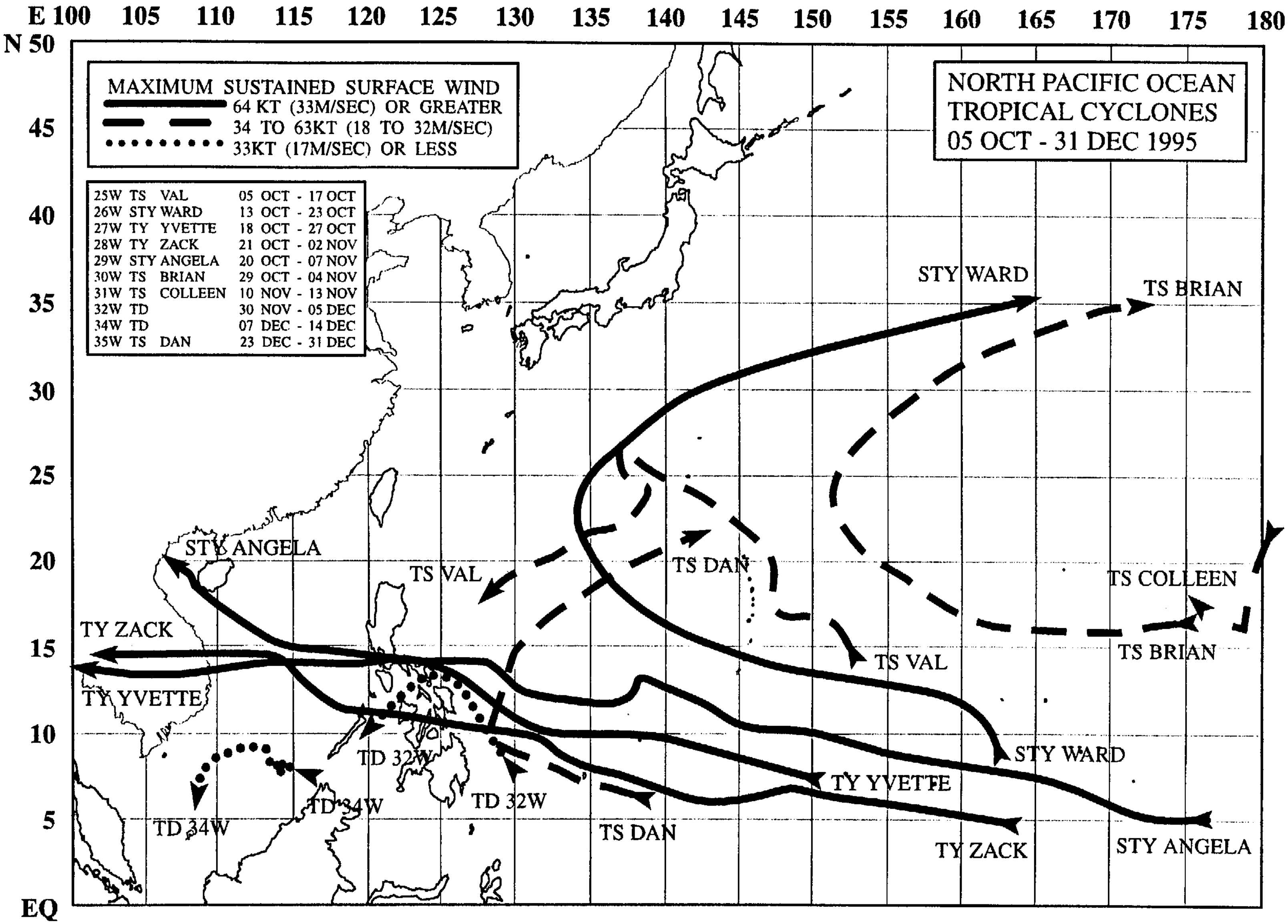
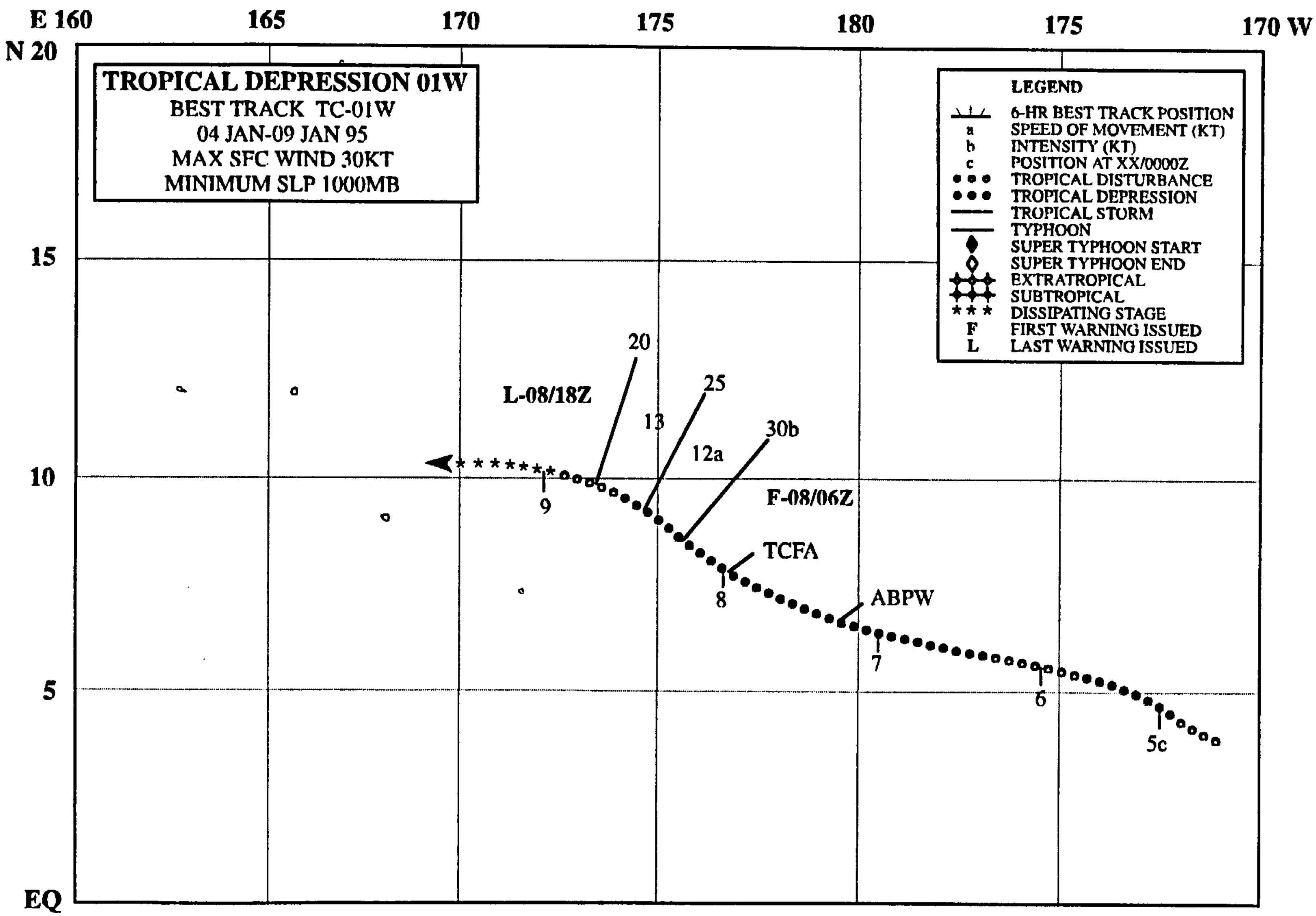


Figure 3-13 Composite best tracks for the North West Pacific Ocean tropical cyclones for the period 05 October to 31 December 1995.


E 160
165
170
175
180
175
170 W
N 20
15
10
5
EQ
TROPICAL DEPRESSION 01W
BEST TRACK TC-01W
04 JAN-09 JAN 95
MAX SFC WIND 30KT
MINIMUM SLP 1000MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-08/18Z
20
25
13
12a
30b
F-08/06Z
TCFA
ABPW
9
8
7
6
5c

TROPICAL DEPRESSION 01W

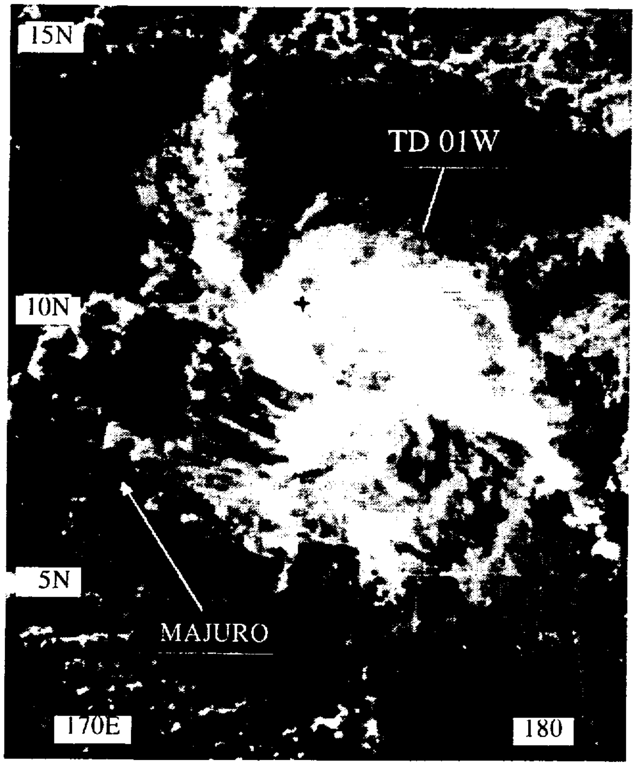


Figure 3-01-1 Tropical Depression 01W shortly before the time of the first warning (080331Z January visible GMS imagery).

I. HIGHLIGHTS

The first significant tropical cyclone of 1995 in the western North Pacific, Tropical Depression 01W formed east of the international date line, moved westward, and dissipated in the Marshall Islands after only a brief life span. This tropical depression formed at the eastern reaches of the near-equatorial trough of the Northern Hemisphere at a time when the axis of this trough had extended far to the east of its typical climatological position — a large scale circulation anomaly associated with the warm phase of El Niño/Southern Oscillation (ENSO) conditions in the tropical Pacific.

II. TRACK AND INTENSITY

The tropical disturbance that became Tropical Depression 01W was first detected east of the international date line, and was first mentioned on the 040600Z January Significant Tropical Weather Advisory as a low-level cyclonic circulation that was a Northern Hemisphere twin to another cyclonic circulation that was located in the Southern Hemisphere. This Advisory stated:

"[an] area of convection . . . is now located near 10°S 180°. . . . A flare up of convection is [located] on the northern side of the low-level circulation. A "twin" low-level circulation exists in the Northern Hemisphere near 5°N 175°W and the two may be enhancing each other . . ."

During the next few days, the tropical disturbance in the Northern Hemisphere moved westward, crossed the international date line and entered the western North Pacific basin. As this tropical disturbance approached the Marshall Island group in the early morning hours of 08 January, a major flare-up of a very cold topped mesoscale convective system (MCS) occurred near the low-level circulation center, and this event, coupled with a twenty-four hour pressure fall of 2 mb at Majuro (WMO 91366), prompted the JTWC to issue a Tropical Cyclone Formation Alert at 072300Z. During the day on 08 January, the deep convection of the MCS collapsed, leaving behind well-defined cyclonically curved low-level cloud lines accompanying a curved band of deep convection on the northern side of the low-level circulation center (Figure 3-01-1). Based upon these improvements in organization, the first warning valid at 080600Z January on Tropical Depression 01W was issued.

Synoptic data from the Marshall Islands at 081200Z January, indicated that Tropical Depression 01W was not well developed at the surface. The Prognostic Reasoning message that accompanied the 081200Z warning included commentary on the implications of the synoptic reports in the Marshall Islands:

"Tropical Depression 01W . . . is weak, with the primary cyclonic circulation existing in the midlevels of the troposphere. Synoptic reports from the eastern Marshall Islands do not yet support a well defined low-level vortex. . . ."

When the first-light visual satellite imagery and synoptic data on the morning of 09 January did not show evidence of a low-level circulation center, the 081800Z warning on Tropical Depression 01W was amended at 082153Z to become the final warning.

III. DISCUSSION

Tropical Depression 01W formed in a low-level wind pattern associated with the twin-trough pattern that is commonly observed during the simultaneous occurrence of tropical cyclones on both sides of the equator (Figure 3-01-2). The twin near-equatorial troughs and the equatorial low-level westerly winds associated with Tropical Depression 01W and its accompanying unnamed southern twin, were located well to the east of their typical climatological position. Beginning in October of 1994 and extending into January of 1995, low-level westerly winds had persisted to the east of the international date line at low latitudes. This eastward push of monsoonal westerlies was associated with a warm phase (i.e., El Niño conditions) of the ENSO that had dominated the climate of the Pacific basin for all of 1994. El Niño continued to affect the large-scale wind flow of the tropical Pacific during early 1995, but it later waned, and easterly winds began to dominate the low-level flow in the deep tropics of the western North Pacific basin for much of the rest of 1995.

IV. IMPACT

No reports of significant damage or fatalities were received.

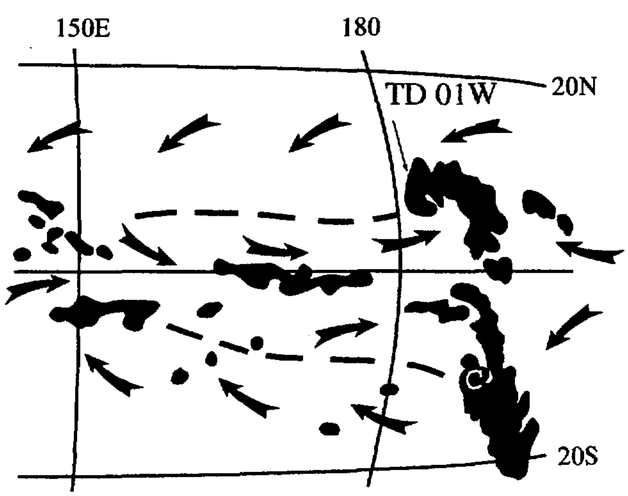
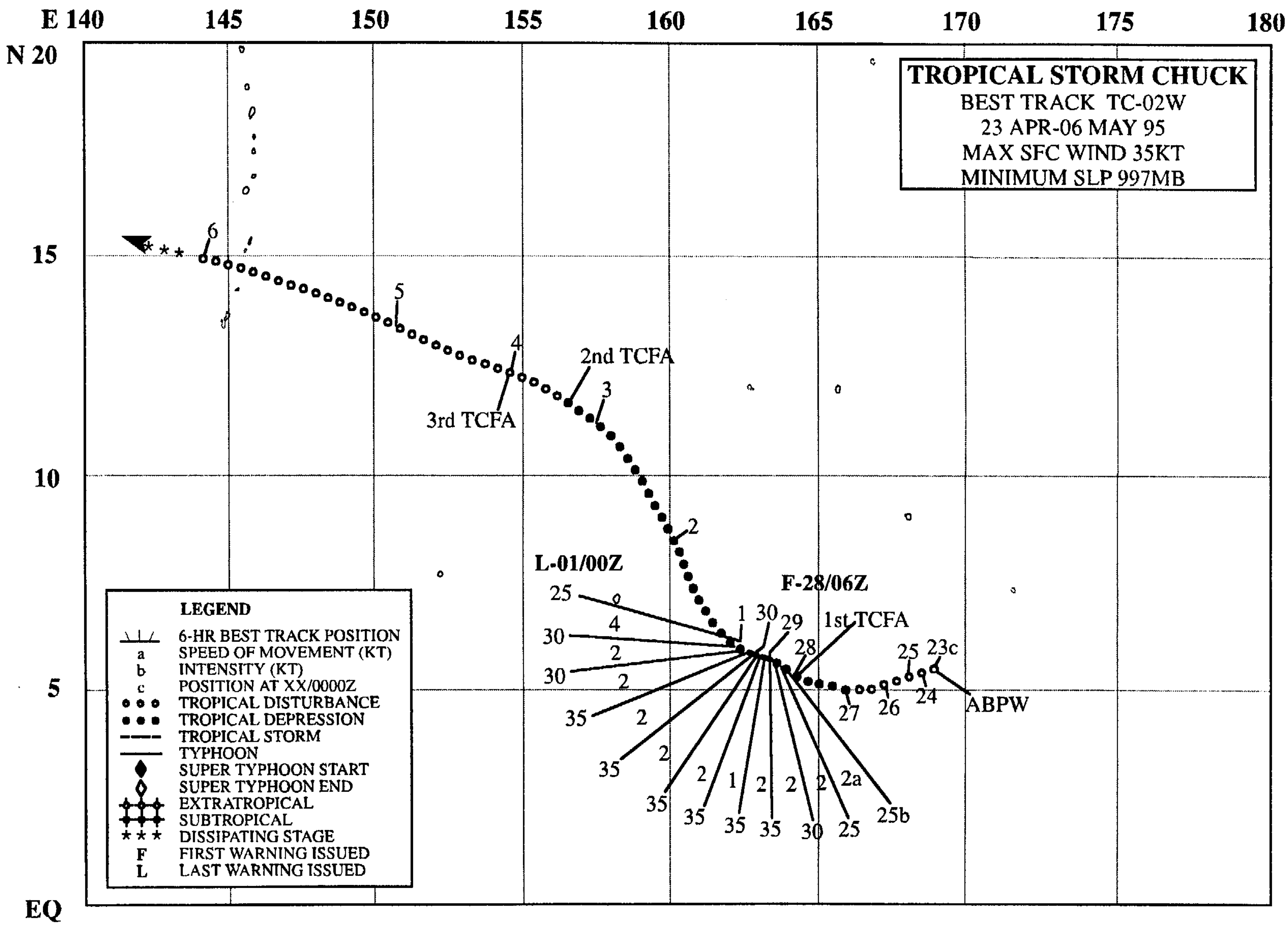


Figure 3-01-2 Cloud silhouettes based on the 070231Z January infrared GMS imagery show patterns typical of the distribution of deep convection within the twin-trough pattern of the low-level monsoon flow. The low-level winds are indicated by arrows, the trough axes by large dashed lines, and the twin cyclones are located in the cloudiness at the eastern ends of the trough axes.



TROPICAL STORM CHUCK
BEST TRACK TC-02W
23 APR-06 MAY 95
MAX SFC WIND 35KT
MINIMUM SLP 997MB
E 140
145
150
155
160
165
170
175
180
N 20
15
10
5
EQ
2nd TCFA
3rd TCFA
1st TCFA
L-01/00Z
F-28/06Z
ABPW
LEGEND
6-HR BEST TRACK POSITION
SPEED OF MOVEMENT (KT)
INTENSITY (KT)
POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED

TROPICAL STORM CHUCK (02W)

I. HIGHLIGHTS

After Tropical Depression 01W dissipated in January, tropical cyclone activity was confined to the Southern Hemisphere until Tropical Storm Chuck (02W) formed in the Northern Hemisphere during late April. The first named tropical cyclone of 1995 in the western North Pacific basin, Chuck formed in a near-equatorial trough in the Marshall Islands. Chuck was a named tropical cyclone for only two days and peaked at 35 kt (18 m/sec) (Figure 3-02-1). While slowly dissipating, the remnants of Chuck drifted toward the Mariana Islands bringing Guam about one quarter of its rainfall for the month of May, a dry season month.

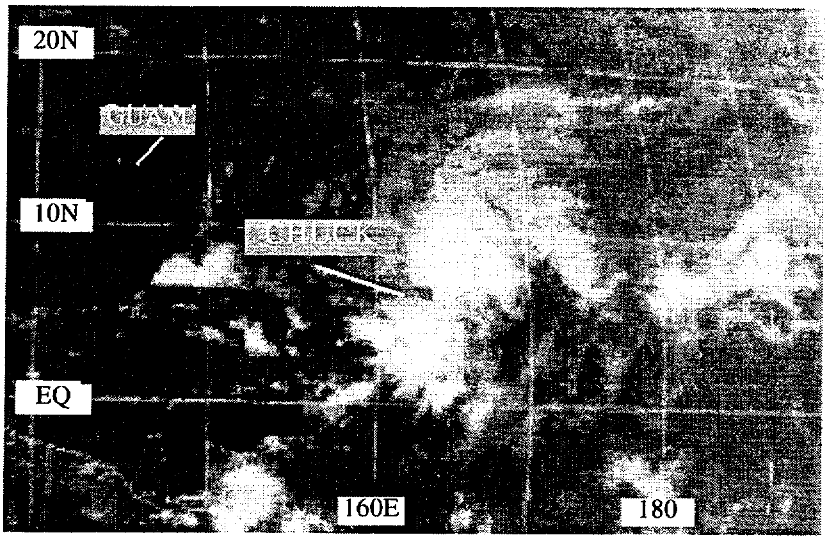


Figure 3-02-1 Tropical Storm Chuck (02W) at peak intensity (291833Z April visible GMS imagery).

II. TRACK AND INTENSITY

Beginning on or about 20 April, low-level westerly monsoonal winds became established along the equator between about 150°E to 170°E. Twin near-equatorial troughs bounded these low-level westerlies, and twin (i.e., one north, and the other south, of the equator) low-level cyclonic circulations persisted equatorward of 10° at about 170°E (e.g., see Figure 3-02-2). This synoptic pattern persisted for several days, and at 230600Z April, an area of deep convection associated with a weak low-level circulation located near 6°N 168°E was first mentioned on JTWC's Significant Tropical Weather Advisory. For several more days, this tropical disturbance drifted slowly westward, and did not show any signs of intensification. On 28 April, satellite data and synoptic reports indicated that the system was intensifying, and a Tropical Cyclone Formation Alert (TCFA) was issued at 272200Z. Remarks on this TCFA included:

"The tropical disturbance near Kosrae in the Marshall Islands has gradually become better organized over the past 24 hours. Synoptic data from Kosrae and the NOAA vessel 'Discoverer' now indicate that a well-defined circulation is present at the surface. The Discoverer reported light winds near the center of the disturbance, but 25 kt [13 m/sec] west-southwesterly sustained winds south of the center . . ."

Based upon these reports and synoptic reports from other ships and islands in the area, and indications on satellite imagery of increased organization of the deep convection, the tropical disturbance near

Kosrae was upgraded to Tropical Depression 02W at 280600Z April. Eighteen hours later, with improved organization observed in satellite imagery, Tropical Depression 02W was upgraded to Tropical Storm Chuck at 290000Z.

At 291200Z, satellite imagery indicated that Chuck was being affected by westerly vertical wind shear, and the low-level circulation center became displaced to the west of the deep convection. The intensity remained at 35 kt (18 m/sec) until 301200Z April, when Chuck was downgraded to a tropical depression. The downgrade to tropical depression was based upon the loss of clear indications from synoptic reports of the existence of a well-defined low-level circulation center, and on evidence from satellite imagery that the deep convection had become displaced even further to the east-northeast of the estimated low-level center position. At 010000Z May, Tropical Depression 02W (Chuck) was completely sheared, with the deep convection displaced 135 nm (250 km) to the east of the very weak low-level circulation center, and a final warning was issued.

For the next six days the remnants of Chuck drifted west northwestward toward the Mariana Islands. At 030600Z, a second TCFA was issued when low-level cloud lines better defined the remnants of Chuck on satellite imagery. The deep convection, however was still displaced well to the east of the low-level circulation center. A third TCFA was issued at 040130Z May in order to adjust the coordinates of the alert area to account for a more westward motion of the tropical disturbance. At 042230Z, the TCFA was cancelled when satellite imagery indicated that the weak low-level circulation center had become further displaced from the deep convection. The remnants of Chuck drifted westward and passed to the north of Guam on 06 May.

III. DISCUSSION

Chuck was the last tropical cyclone to form in the western North Pacific in association with low-level monsoonal winds that were displaced well eastward of normal in association with a waning El Niño event. After Chuck, which first attained an estimated intensity of 25 kt (13 m/sec) at 166°E, no significant tropical cyclones in the western North Pacific basin of monsoon origin would form east of 160°E. Three tropical cyclones — Tropical Depression 22W, Tropical Storm Brian and Tropical Storm Colleen formed east of 160°E, but these were not of monsoon origin.

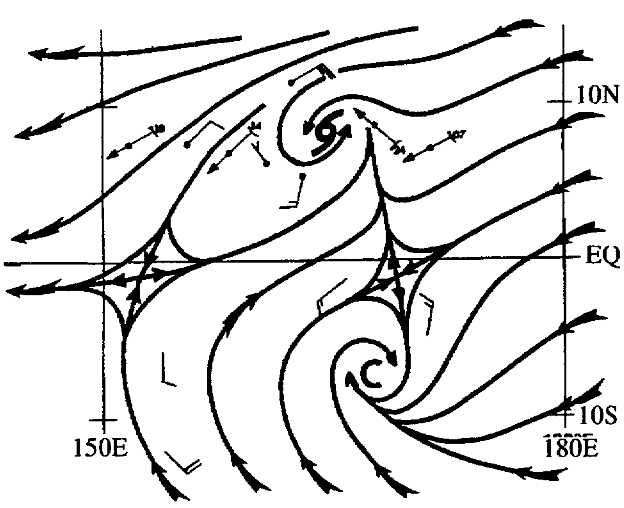
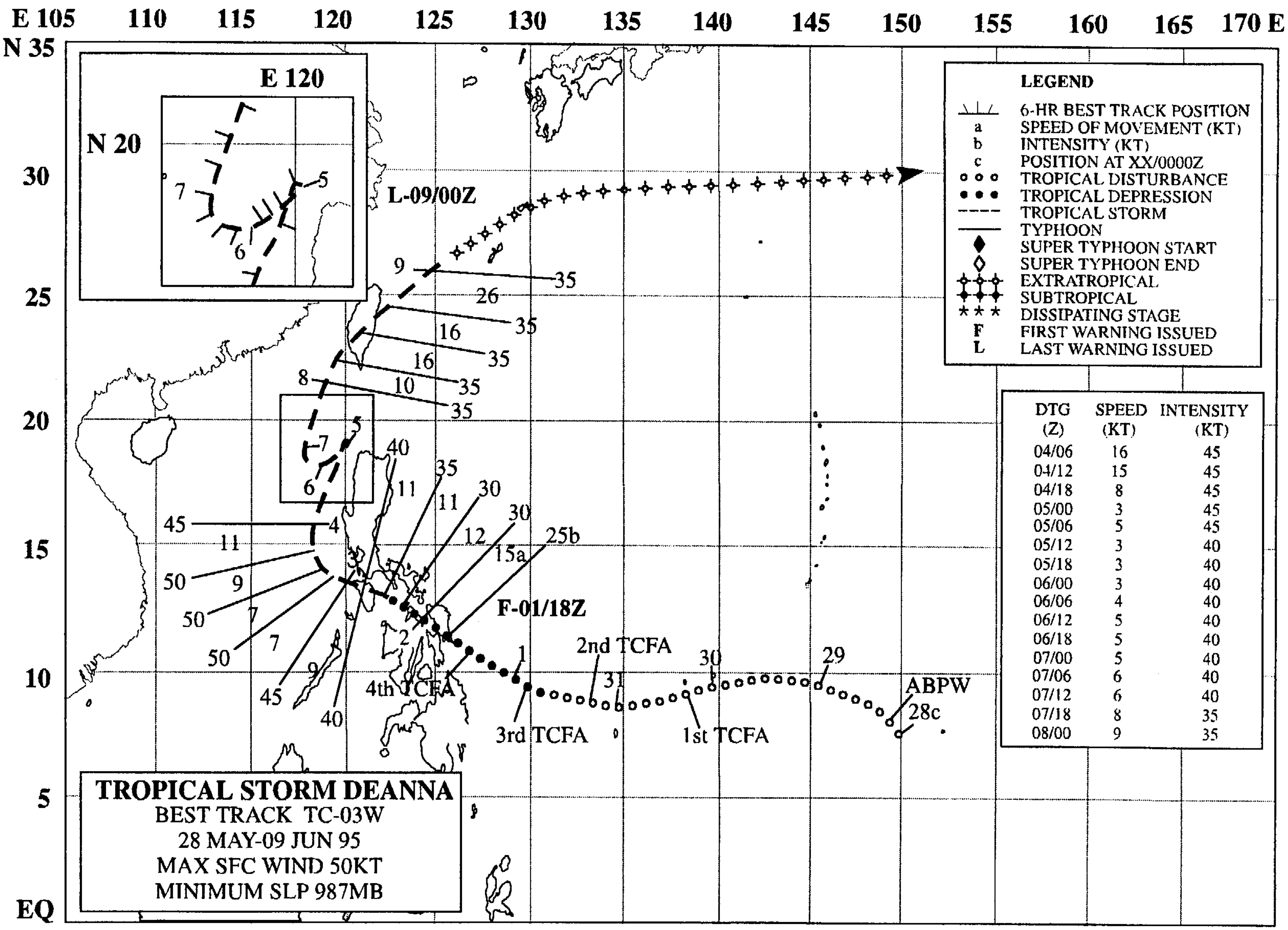


Figure 3-02-2 Surface/gradient streamline analysis for 290000Z April shows Tropical Storm Chuck (02W) and a twin cyclonic circulation to the south. Gradient wind reports are indicated by arrows and surface winds by wind barbs. All reports are in knots.

IV. IMPACT

The passage of Chuck (and later, its remnants) across much of Micronesia did not result in any known incidences of significant damage or injury. On the positive side, the remnants of Chuck contributed some much needed dry season rainfall to some of the Mariana Islands. On the islands of Guam and Rota, 25% (1.5 inches) of May's rainfall occurred during a 24 hour period as the remnants of Chuck neared and passed north of these islands.



DTG (Z)	SPEED (KT)	INTENSITY (KT)
04/06	16	45
04/12	15	45
04/18	8	45
05/00	3	45
05/06	5	45
05/12	3	40
05/18	3	40
06/00	3	40
06/06	4	40
06/12	5	40
06/18	5	40
07/00	5	40
07/06	6	40
07/12	6	40
07/18	8	35
08/00	9	35

TROPICAL STORM DEANNA (03W)

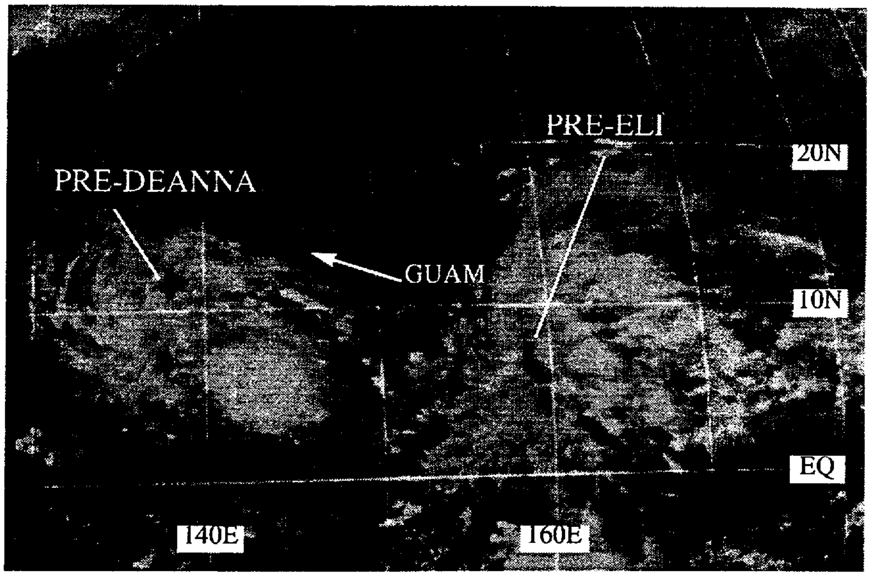


Figure 3-03-1 The tropical disturbances that became Deanna (03W) and Eli (04W) are found along a weak monsoon trough that stretched across Micronesia during late May (301332Z May infrared GMS imagery).

I. HIGHLIGHTS

Tropical Storm Deanna formed in a weak monsoon trough that stretched across Micronesia during late May. Deanna was a relatively weak tropical cyclone that crossed the central Philippines, stalled in the South China Sea for about two days, and then accelerated toward the northeast as it came under the steering influence of strong southwesterly flow to the south of the axis of the mei-yu trough. Deanna merged with the mei-yu cloud band as it moved rapidly northeastward through the Ryukyu island chain.

II. TRACK AND INTENSITY

During the last week of May, there were two tropical disturbances located along a weak monsoon trough that stretched east-west across Micronesia (Figure 3-03-1). The westernmost of the two became Deanna (03W), while the easternmost became Eli (04W). The tropical disturbance that became Deanna was first mentioned on the 280600Z May Significant Tropical Weather Advisory when satellite and synoptic data indicated that a weak low-level cyclonic circulation center had formed in an extensive area of persistent deep convection in the Caroline Islands. Over the next three days, this disturbance moved westward, just south of 10°N, and passed 240 nm (445 km) south of Guam on the evening of 29 May. During the daylight hours of 30 May, satellite imagery indicated that a broad area of persistent convection was consolidating near the island of Yap. Based upon the imagery, and lowered sea-level pressure at Yap (WMO 91413), a Tropical Cyclone Formation Alert (TCFA) was issued at 300730Z May. The tropical disturbance continued moving westward toward the central Philippines, however, on 31 May, it appeared that it had become less organized, and thus the TCFA was cancelled at 310600Z May. Reasons cited for cancellation of the TCFA included:

"... Satellite imagery and synoptic data from Yap and Koror indicate that the tropical disturbance east of Mindanao has a weak cyclonic circulation near the surface. Winds and pressure trends at Yap and Koror do not indicate that a tropical cyclone is developing at the present time. The disturbance appears to be primarily a mid-level feature with active unorganized convection. The long-term outlook favors very slow intensification. ..."

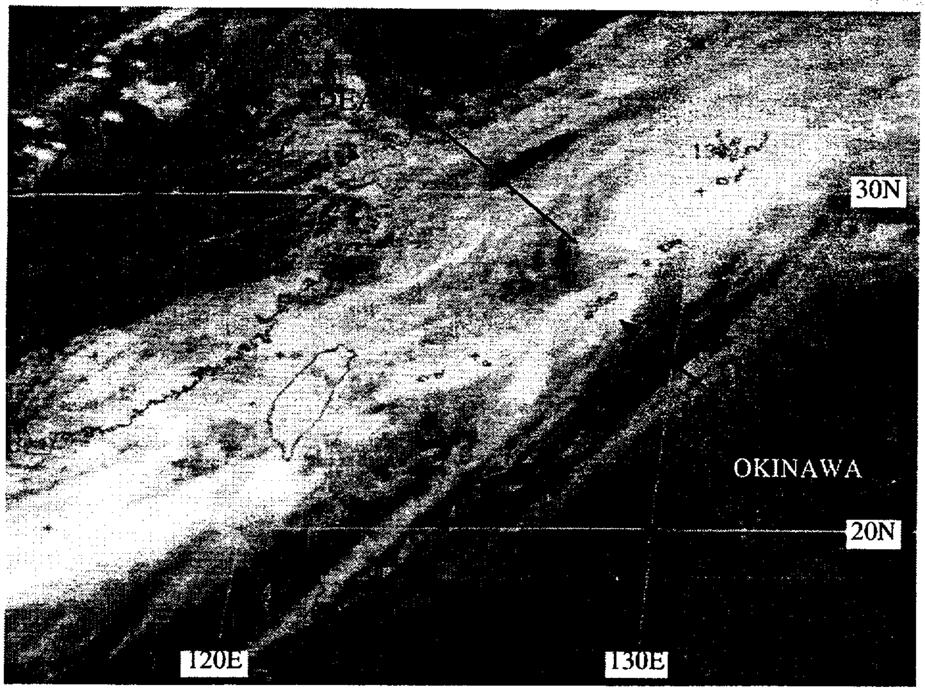


Figure 3-03-2 Absorbed into the mei-yu cloud band, the remnants of Deanna race northeastward (090424Z June visible GMS imagery.)

As the system approached Mindanao, satellite imagery and synoptic data once again indicated that intensification was taking place. A TCFA was issued at 312200Z May. The tropical disturbance now began to track toward the islands of the central Philippines. Evidence of further intensification was lacking, but further development was considered possible, so another TCFA was issued at 011500Z June. Shortly thereafter, satellite imagery showed an increase in the amount of deep convection near the estimated position of the low-level circulation center, and the JTWC issued the first warning on Tropical Depression 03W valid at 011800Z June.

Tropical Depression 03W moved rapidly through the islands of the central Philippines. Tropical Depression 03W was upgraded to Tropical Storm Deanna at 021200Z June based on satellite intensity estimates and synoptic data.

On 03 June, Deanna entered the South China Sea where it slowed and turned toward the north. It is here also, while southwest of Luzon, that Deanna reached its peak intensity of 50 kt (26 m/sec). Subsequently, a slight weakening occurred as Deanna moved slowly northward. On 05 June, Deanna stalled northwest of Luzon, and began a very slow drift back toward the southwest. At this time, northeasterly vertical shear caused the low-level circulation center to become partially exposed on the northeastern side of the deep convection. On 07 June, Deanna resumed a slow north-northeastward movement toward Taiwan. On 08 June, Deanna began to increase its speed of translation as it neared Taiwan. The low-level circulation center became fully exposed and the system was downgraded to tropical depression intensity at 080000Z. (In postanalysis, however, it was determined that Deanna retained tropical storm intensity through 09 June based on a 49-kt 925-mb report from Kadena (WMO 47931) at 290000Z and later a 35-kt surface wind from the buoy (WMO 21004) near 29°N, 135°E at 091800Z). On 09 June, Deanna was absorbed into the mei-yu cloud band, (Figure 3-03-2), although it retained a distinct circulation center. The final warning was issued at 090000Z June when it was deemed that the rapidly moving low pressure system along the mei-yu cloud band (that had been Deanna) had become extratropical. The remnants of Deanna retained gale force winds for 18 hours following the final warning.

III. DISCUSSION

NEXRAD observed wind profile as pre-Deanna passed south of Guam

On the evening of 29 May, the tropical disturbance that became Deanna passed 240 nm (445 km) south of Guam. At this time, Guam was experiencing heavy showers and gusty easterly winds. The vertical wind profile over Guam at this time (obtained from Guam's NEXRAD) (Figure 3-03-3) shows three characteristics that are typical of the vertical wind profiles obtained within the vicinity of tropical cyclones:

1) A peak wind velocity in the lowest levels of the troposphere (2000 to 5000 ft).

2) A relatively deep unidirectional wind flow— in this case, deep easterly — through at least 35,000 ft.

3) Evidence of upper-level outflow (winds directed away from the tropical cyclone) restricted to 40,000 feet and higher.

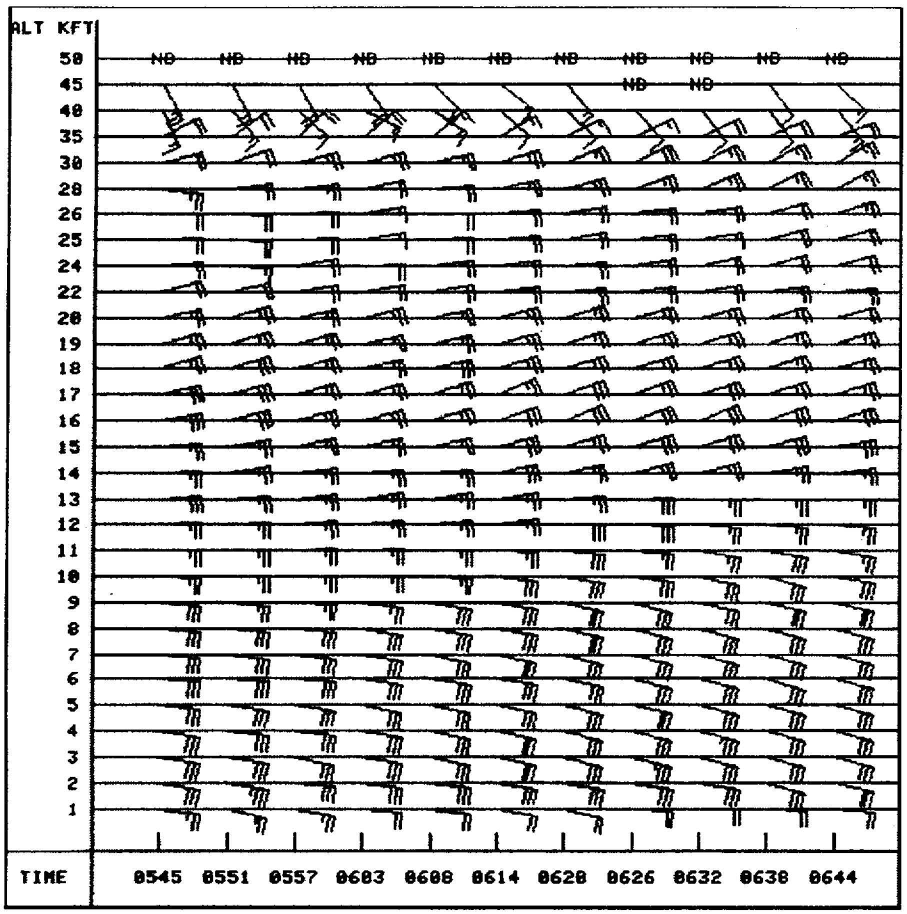
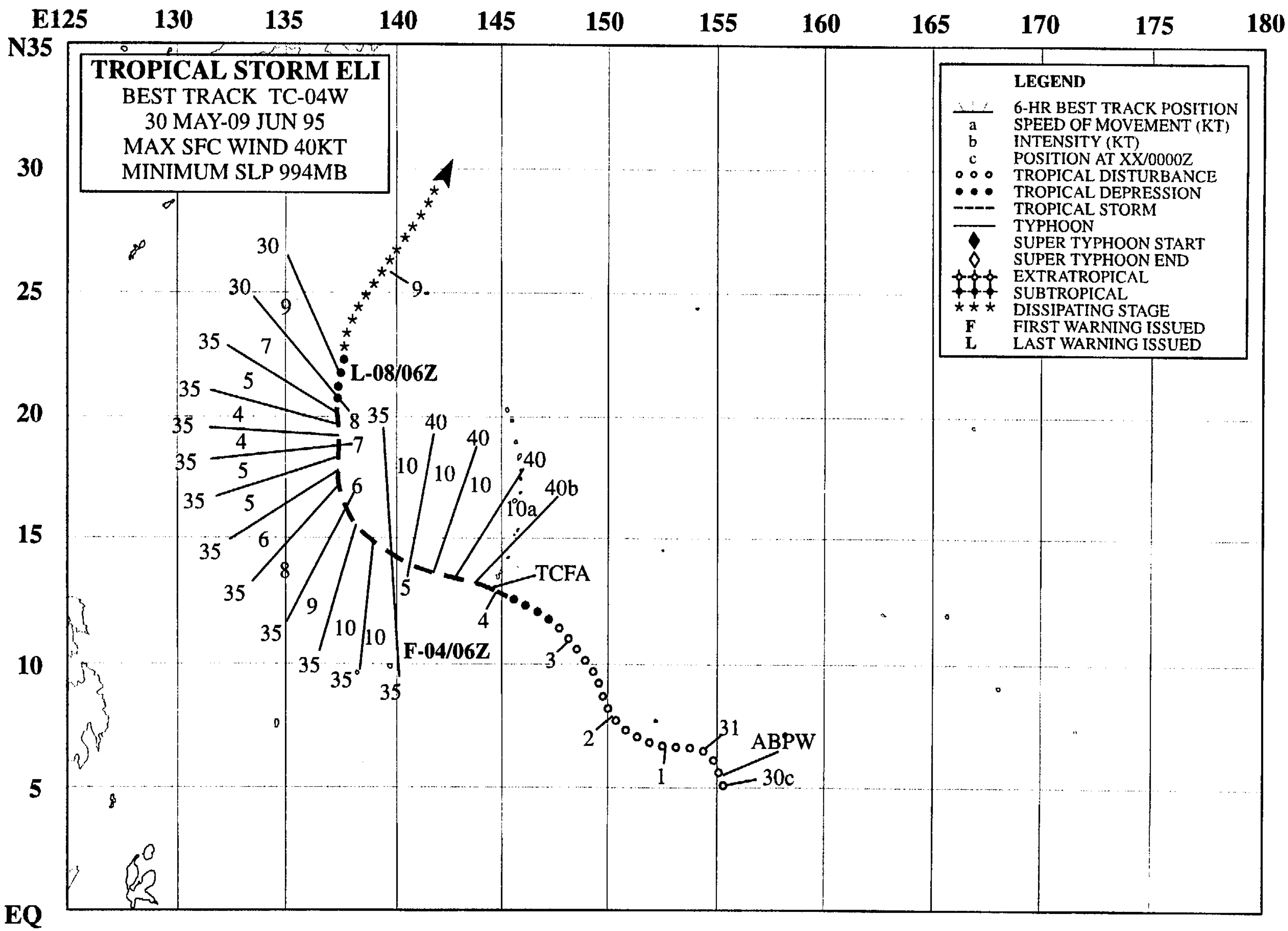


Figure 3-03-3 Vertical wind profile over Guam from the NEXRAD for the period 290545Z to 290644Z May reflects the passage of Deanna to the south.

IV. IMPACT

Heavy rains associated with Tropical Storm Deanna caused mudslides near Mayon Volcano, located in southeastern Luzon. These mudslides buried 140 homes; it is not known if there were any associated injuries or deaths. No additional reports of damage or injuries were received.


TROPICAL STORM ELI
BEST TRACK TC-04W
30 MAY-09 JUN 95
MAX SFC WIND 40KT
MINIMUM SLP 994MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E125
130
135
140
145
150
155
160
165
170
175
180
N35
30
25
20
15
10
5
EQ
L-08/06Z
F-04/06Z
TCFA
ABPW
30c
31
10a
40b

TROPICAL STORM ELI (04W)

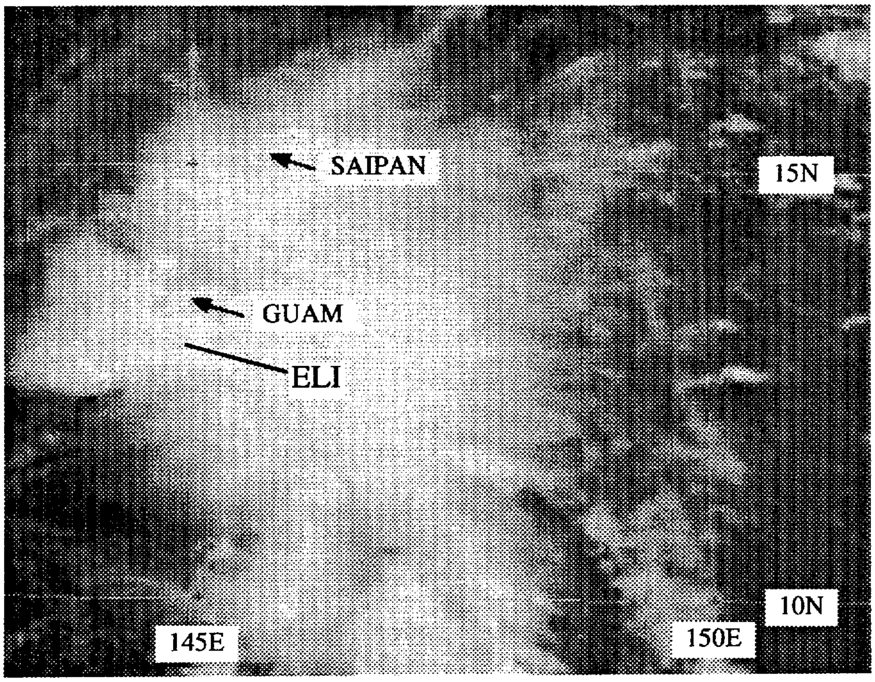


Figure 3-04-1 Eli at minimal tropical storm intensity passes south of Guam (032331Z June visible GMS imagery).

I. HIGHLIGHTS

Forming in a weak monsoon trough that stretched across Micronesia during late May, Eli was a relatively weak tropical cyclone that passed very close to Guam, turned northward, and then dissipated over open water southeast of Japan. While passing south of Guam on 04 June, Eli came within range of Guam's NEXRAD (see discussion section).

II. TRACK AND INTENSITY

During the last week of May, two tropical disturbances formed in a weak monsoon trough that stretched east-west across Micronesia (see Figure 3-03-1 of Deanna's summary). The westernmost of the two became Deanna (03W), while the easternmost became Eli (04W). The Significant Tropical Weather Advisory was reissued at 300800Z May to included the tropical disturbance that became Eli. Comments on this advisory included:

". . . A broad area of convection has persisted for 24 hours near 6°N 160°E. This broad area of convection, around 900 nm [1700 km] in diameter, is the third in a series of circulation areas associated with the establishment of the first monsoon trough of the '95 WNP season. This area is expected to continue to organize and develop over the next 72 hours. . . ."

This tropical disturbance continued moving northwestward through the Caroline Islands toward Guam. On the morning of 04 June, satellite imagery, Doppler radar (NEXRAD), and synoptic data from Guam, indicated that this disturbance had intensified. At 040230Z June, a Tropical Cyclone Formation Alert was issued, followed by the first warning on Tropical Depression 04W at 040600Z June. Based upon 34-kt wind observations received after the fact from Guam's commercial port, it was determined in postanalysis that Tropical Depression 04W had reached tropical storm intensity as it passed south of Guam on 04 June (Figure 3-04-1). In real time, Tropical Depression 04W was not upgraded to Tropical Storm Eli until 070000Z, when satellite intensity estimates increased to tropical storm intensity. Earlier satellite intensity estimates remained at tropical depression intensity due to the appearance of westerly wind shear aloft on the cloud system and a lack of organized low-level cloud lines to define a circulation center.

At 080300Z June, Tropical Storm Eli was downgraded to a tropical depression in response to satellite imagery that indicated increasing northerly wind shear on the system. The final warning was issued shortly thereafter, at 080600Z, when satellite imagery indicated that the organization of the system had further deteriorated. In postanalysis, the intensity was held at 30 kt (15 m/sec) through 090000Z based on synoptic data.

III. DISCUSSION

NEXRAD observations of Eli as it passed south of Guam

On the morning of 04 June, the tropical disturbance that became Eli passed 30 nm (55 km) south of Guam. During the day, the wind speeds on Guam increased as the sea-level pressure fell. Position and intensity estimates made from satellite imagery did not agree with the synoptic reports from Guam. The location of the low-level circulation center as diagnosed from satellite and as determined from NEXRAD products differed by 90 nm (170 km). Guam's NEXRAD provided crucial information that allowed for a more accurate estimate of position of the low-level circulation center. The curved paths of the rainfall on the NEXRAD three-hour precipitation product (Figure 3-04-2) implied a circulation center was located near the heaviest band of rain located about 30 nm south southwest of Guam. In fact, for a few hours (centered at 040000Z), the NEXRAD generated alerts on mesocyclones forming near the downstream end of the curved rain band.

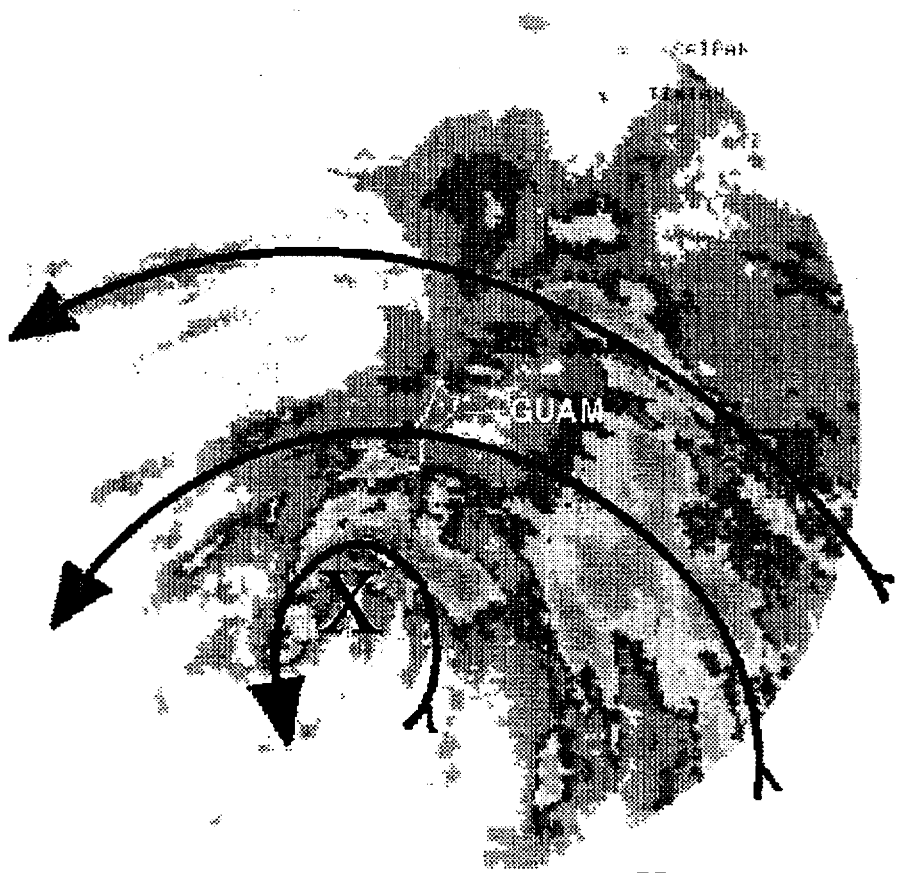


Figure 3-04-2 NEXRAD three-hour integrated rainfall total ending at 040100Z June. Shaded regions depicting the total rainfall over a three-hour period exhibit curved paths that imply a center about 30 nm southwest of Guam. The NEXRAD was producing mesocyclone alerts at the location marked with an "X".

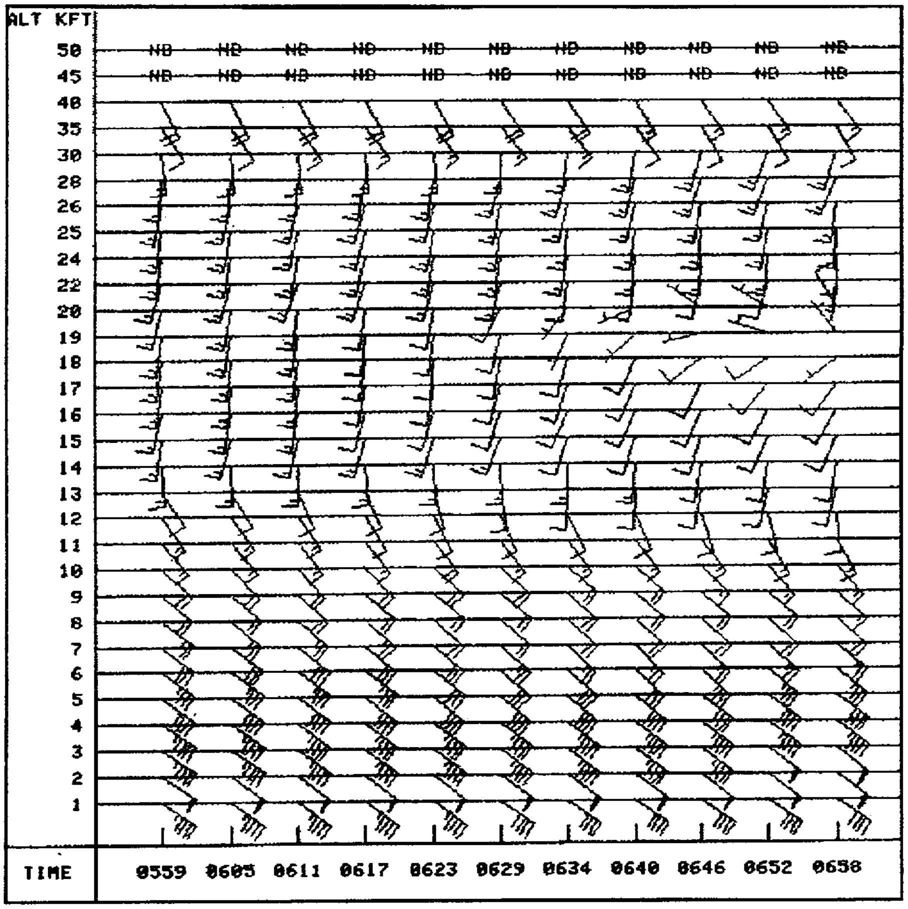


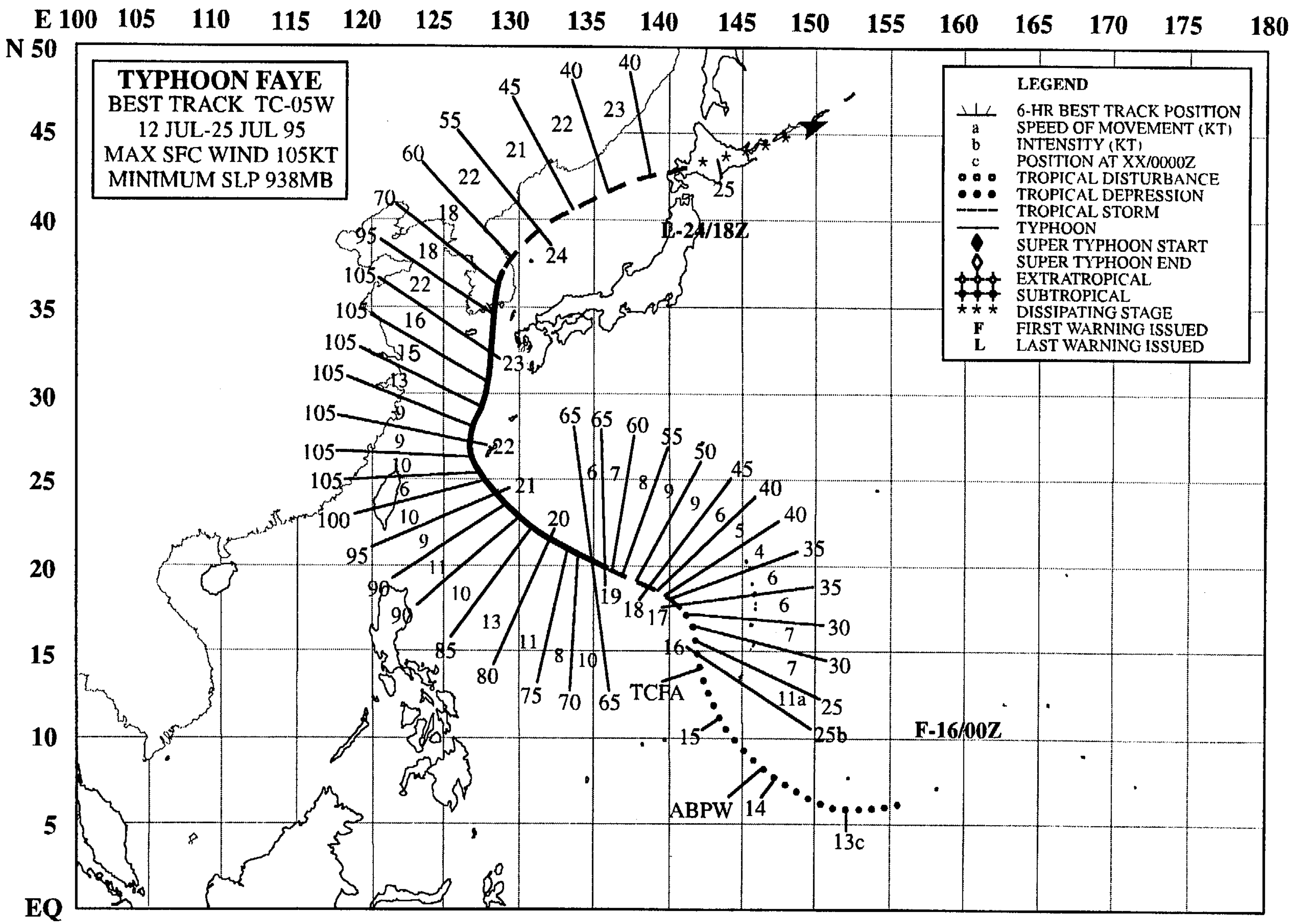
Figure 3-04-3 NEXRAD velocity azimuth display wind profile for the period 040559Z to 040658Z June shows the maximum winds associated with Eli are located at 2,000 to 3,000 feet.

The NEXRAD vertical wind profiles over Guam during the afternoon of 04 June (Figure 3-04-3) showed a peak wind velocity in the lowest levels (2,000 to 3,000 feet) of the troposphere. The 50-kt winds at 2,000 feet were reflected in a peak wind gust to 48 kt (25 m/sec) at Guam's commercial port.

In addition, the synoptic reports and information from Guam's NEXRAD suggest that Eli's wind distribution most probably featured a large asymmetry, with highest winds on the northeastern side and a very small region of light westerly wind close to the small low-level cyclonic vortex located at the western edge of the primary rain band.

IV. IMPACT

The two to three inches of rain that fell on Guam in association with Eli comprised roughly one-third of the total precipitation on Guam during an otherwise relatively dry month of June. No reports of damage or injuries were received.


TYPHOON FAYE
BEST TRACK TC-05W
12 JUL-25 JUL 95
MAX SFC WIND 105KT
MINIMUM SLP 938MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-24/18Z
F-16/00Z
TCFA
ABPW
E 100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
N 50
45
40
35
30
25
20
15
10
5
EQ

TYPHOON FAYE (05W)

I. HIGHLIGHTS

Faye (05W) was the first tropical cyclone of 1995 to become a typhoon. Reaching typhoon intensity on 19 July, Faye tied the record for the latest date for the occurrence of a typhoon in the western North Pacific. Moving on a north-oriented track through the East China Sea, Faye made landfall on the southern coast of Korea, and was one of the most intense tropical cyclones to strike the Korean peninsula in many years.

II. TRACK AND INTENSITY

During the first week of July, most of the deep convection in the tropics of the western North Pacific was located near the Philippines and over the South China Sea. Throughout Micronesia, amounts of deep convection were relatively low, the low-level winds were predominantly from the east, and the upper-level winds were predominantly from the west (creating a zone of high vertical wind shear within which isolated mesoscale convective systems grew and decayed). Toward the end of the second week of July, an area of persistent deep convection was located in the Caroline Islands. On 14 July, synoptic data indicated that a low-level circulation center accompanying this area of deep convection was located about 300 nm (550 km) south-southeast of Guam, prompting its first mention on the 140600Z July Significant Tropical Weather Advisory. During the next 24 hours, this weak low-level circulation turned toward the north-northwest and passed about 180 nm (330 km) to the west of Guam. Late on 15 July, satellite imagery and radar data from Guam indicated that the organization of the system was improving. A Tropical Cyclone Formation Alert was issued at 151730Z.

On the morning of 16 July, visible satellite imagery indicated that the system had a well-defined low-level circulation center associated with its small area of deep convection. This prompted the JTWC to issue the first warning on Tropical Depression 05W, valid at 160000Z. Despite numerical guidance (i.e., NOGAPS) that indicated that the system would not deepen, the relatively small-sized tropical cyclone continued to intensify and, on the warning valid at 170600Z, Tropical Depression 05W was upgraded to Tropical Storm Faye. In keeping with indications of northeasterly shear on the system, and with NOGAPS not indicating deepening, Faye was not forecast to reach typhoon intensity.

Faye continued to intensify as it moved northwestward toward Okinawa. It was upgraded to a typhoon on the warning valid at 191200Z. After passing to the southwest of Okinawa on 21 July, Faye turned to the north and intensified. It reached its peak intensity of 105 kt (54 m/sec) at 211200Z as it was moving northward (Figure 3-05-1). Now on a north-oriented track, Faye maintained its intensity of 105 kt (54 m/sec) for the next 36 hours. It began to weaken after 230000Z, while accelerating toward Korea. Shortly after 230600Z, Faye made landfall on the south coast of Korea with an intensity of 95 kt (49 m/sec) (Figure 3-05-2). Weakening rapidly over the Korean peninsula, Faye was downgraded to a tropical storm on the warning valid at 240000Z after it had recurved and entered the Sea of Japan. In postanalysis it was downgraded to a tropical storm about nine hours earlier, while it was over the mountains of Korea. Moving rapidly across the Sea of Japan, Faye continued to weaken, and the final warning was issued, valid at 241800Z, shortly before it made landfall on the west coast of Hokkaido.

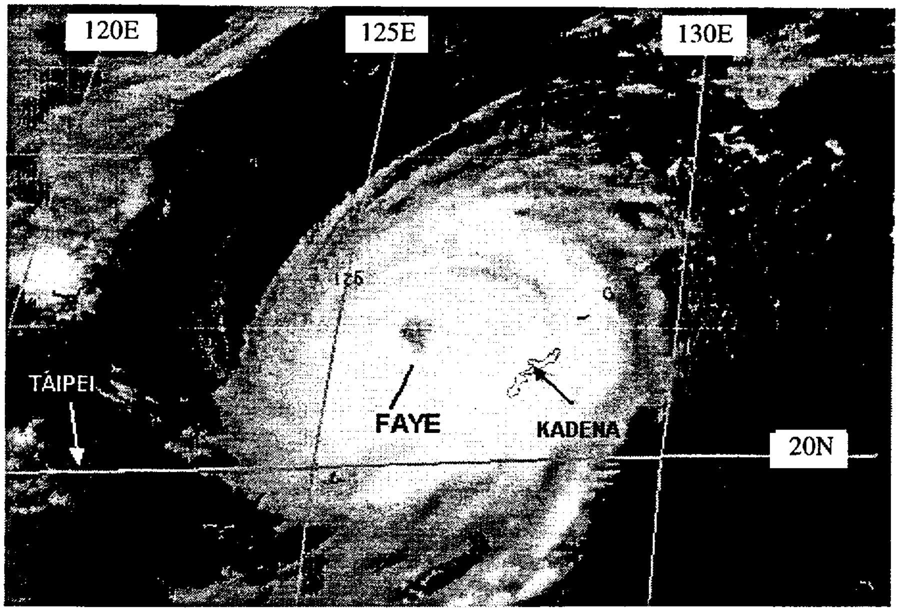


Figure 3-05-1 Faye at peak intensity of 105 kt (54 m/sec) (212331Z July visible GMS imagery).

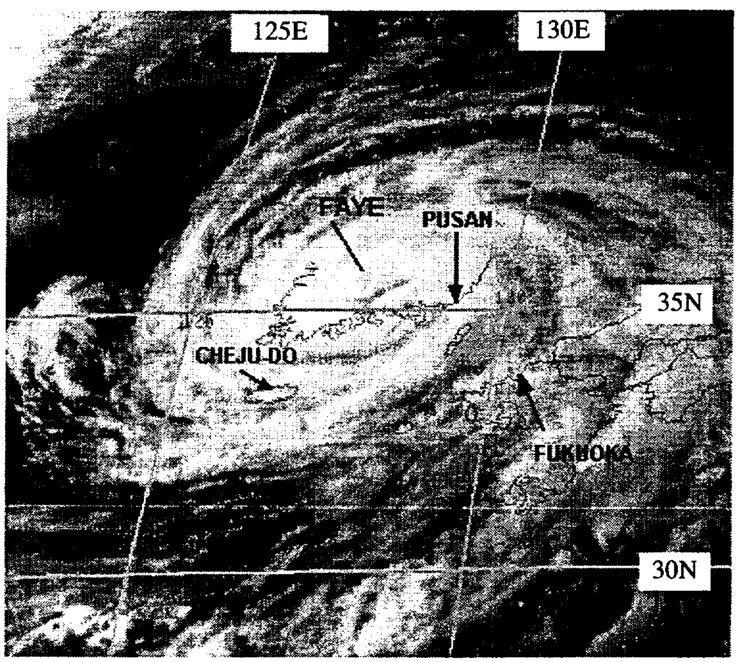


Figure 3-05-2 Faye makes landfall on the southern coast of Korea (230831Z July visible GMS imagery).

III. DISCUSSION

a. *A late date for the first typhoon*

Faye became a typhoon on 19 July, tying the latest date in the year for a tropical cyclone to become a typhoon in the western North Pacific. In the 37-year period 1959-1995, only one other year — 1977 — had such a late date of record for the first tropical cyclone of typhoon intensity. Other years during which the first typhoon intensity was recorded in July (but before 19 July) include 1973 (07 July), 1983 (11 July), and 1984 (02 July). Note: the latest occurrence of typhoon intensity during what might be considered the most active part of the year in the western North Pacific was 01 August 1975, not counting the occurrence of a typhoon during January of that year.

b. *Forecast performance*

The JTWC's mean track forecast errors for Faye (91 nm, 194 nm, and 348 nm at 24, 48, and 72 hours respectively) were close to their long-term averages. During the period 21 through 23 July, however, Faye underwent a synoptic-scale meander along its north-oriented track that led to track forecasts with some large errors. By 220000Z, Faye had passed to the west of Okinawa and began to head to the north-northeast. At 221200Z it appeared that Faye had begun its recurvature to the northeast, and a significant track change was forecast, bringing Faye along an accelerating recurve trajectory that skirted along the southeastern coast of Japan (Figure 3-05-3). This was in sharp contrast to earlier track forecasts that had Faye tracking northward toward the coast of southern Korea. Soon after 221200Z, Faye's track began to shift back to a more northward direction, and the next warning, valid at 221800Z indicated that Faye would pass approximately 35 nm (65 km) to the east of Pusan, Korea — the 24-hour forecast position on this warning was nearly 240 nm (450 km) to the northwest of the 24-hour forecast position given on the previous warning. Faye's meandering track caused the JTWC to incur some large forecast errors.

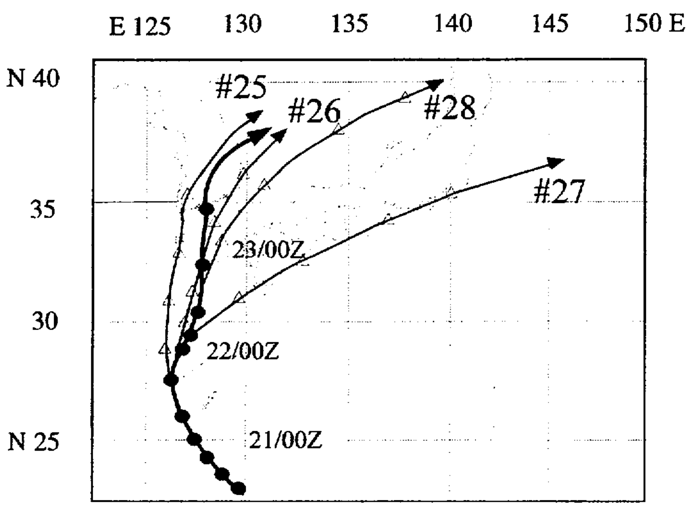


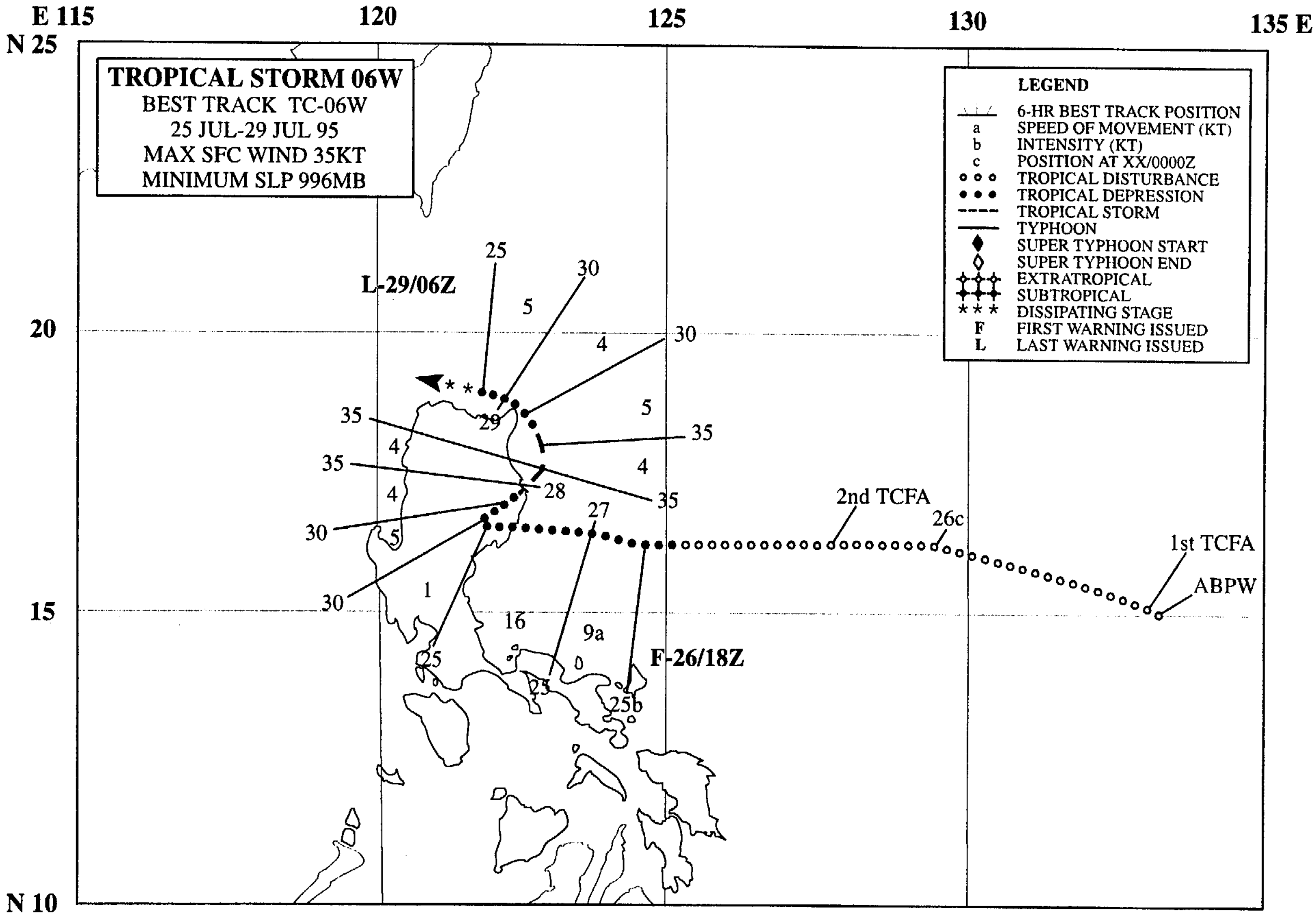
Figure 3-05-3 A synoptic-scale meander in Faye's track prompts dramatic changes in the forecast track. The final best track is indicated by the thick black line that connects large black dots at six hour intervals. The thin lines connecting the open triangles indicate the forecast track of the indicated warning. Open triangles are at 12-hour intervals.

IV. IMPACT

As Faye approached Okinawa, aircraft from Kadena Air Force Base were evacuated to Guam and other locations. Kadena reported gales and gusts over 50 kt throughout the evening of 21 July as Faye passed about 120 nm (220 km) to the southwest.

On the afternoon of 23 July, the USNS Wilkes (an oceanographic survey ship operated by the Commander, Military Sealift Command for the Commander, Naval Meteorology and Oceanography Command) was overtaken by Typhoon Faye, and probably experienced eye passage. During its encounter with Faye, the Wilkes reported winds of 70-80 kt (36-41 m/sec) and a minimum sea level pressure of 965 mb. At approximately 230530Z July, the master of Wilkes judged that the ship was in the eye of Faye. Damage to the Wilkes caused by Typhoon Faye included: broken wires, lights, and chemical containers; numerous holes in the deck; crane cradle torn loose; VHF and INMARSAT antennae damaged; salt water contamination of oil in all deck machinery; and damage to scientific equipment stowed on weather decks. Personnel casualties were limited to only one minor head laceration.

In the East China Sea, the cargo ship Far East Beauty sank with two Chinese crewmen reported dead and three others missing. In Korea, Faye was described as the worst typhoon to hit the Korean peninsula in 37 years. It capsized dozens of small boats, overturned cars, uprooted trees, and disrupted train service. At least 14 people were reported killed and 21 others were missing. Nine people died and three were missing after high surf swept a bus off of a coastal highway. The 140,000-ton tanker Sea Prince ran aground and leaked oil into the sea around Yochon, one of many small islands off the coast of Yosu on the southern tip of South Korea. In southern Japan, the typhoon disrupted air travel and caused power outages, but no injuries or deaths were reported. U.S. military bases in South Korea and Japan reported no significant damage.


TROPICAL STORM 06W
BEST TRACK TC-06W
25 JUL-29 JUL 95
MAX SFC WIND 35KT
MINIMUM SLP 996MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 115
120
125
130
135 E
N 25
20
15
N 10
L-29/06Z
F-26/18Z
2nd TCFA
1st TCFA
ABPW
26c
9a
25b

TROPICAL STORM 06W

I. HIGHLIGHTS

In postanalysis, Tropical Depression 06W was upgraded to tropical storm intensity based upon scatterometer data from the European Space Agency's remote sensing (ERS-1) satellite. These data indicated that an area of 35 kt (18 m/sec) wind speed accompanied Tropical Depression 06W as it moved northward just off the east coast of Luzon on 28 July. Conventional visible and infrared satellite imagery also supported the post-event upgrade. Tropical Storm 06W merged withTropical Storm Gary (07W) during a time when both of these tropical cyclones were embedded within the circulation of a larger monsoon depression, and while both were affected by the island of Luzon.

II. TRACK AND INTENSITY

The tropical disturbance that became Tropical Storm 06W began as a large area of disturbed weather near the Mariana Islands. This tropical disturbance was first mentioned on the 230600Z July Significant Tropical Weather Advisory. Moving westward as a large weak monsoon depression, the convection in this tropical disturbance expanded as it approached the Philippines. On 25 July, a smaller area of deep convection, within the confines of the larger monsoon depression, became focused near a poorly defined low-level circulation center. A Tropical Cyclone Formation Alert (TCFA) was issued at 250800Z July based upon expectations that this area of deep convection would continue to develop and become a significant tropical cyclone within 24 hours. When the system failed to intensify, a second TCFA was issued at 260800Z. The first warning on 06W, valid at 261800Z, was issued by JTWC when the amount of deep convection increased and lines of deep convective cloud began to exhibit increased cyclonic curvature.

On 27 July, 06W moved ashore on the east coast of the island of Luzon. At this time, the synoptic situation became more complex, as the larger scale circulation of the monsoon depression, within which 06W was embedded, began to be affected by the island of Luzon. In addition to Tropical Storm 06W, there was evidence that a second circulation was forming in the South China Sea just off the northwest corner of Luzon. This second circulation became Typhoon Gary (07W). In response to a surge in the southwest monsoon, coupled with an interaction with the developing Gary (07W), 06W stalled over land on the eastern side of Luzon, and then moved northeastward back over water.

As visible satellite imagery became available on the morning of 28 July, it indicated that the low-level circulation center of Tropical Storm 06W had moved back over water east of Luzon. At 280000Z, JTWC relocated the center of 06W. During the daylight hours of 28 July, the well-defined, exposed, low-level circulation center of 06W (Figure 3-06-1) moved northward, over water, east of Luzon (it was at this time that scatterometer winds obtained from the ERS-1 satellite indicated that the wind speeds associated with 06W had reached tropical storm intensity — see the discussion section for more details). For several hours, later in the day, a circular area of deep convection developed in association with the low-level circulation center (Figure 3-06-2). During the night of 28 July, and into the morning of 29 July, the convection associated with 06W moved on a cyclonically curved track around the northeastern coast of Luzon, and was absorbed into cloud bands associated with the developing Gary (07W). The Prognostic Reasoning Message accompanying the 290000Z July warning stated:

". . . 06W is becoming more disorganized as the circulation to the west of Luzon (Tropical Depression 07W) becomes more dominant. Synoptic data around Luzon also shows the western circulation [TD 07W] affecting most of the monsoon flow over this region. However, synoptic data . . . still

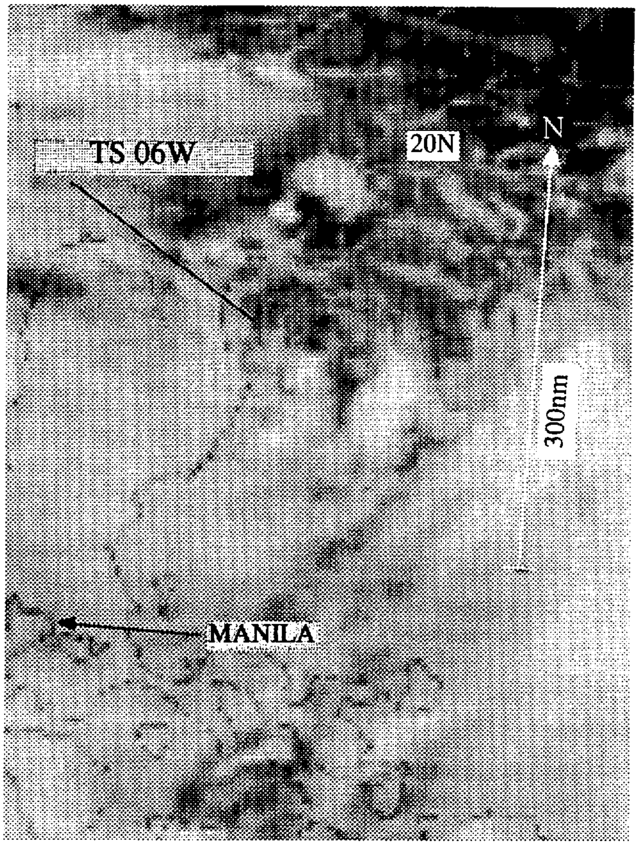


Figure 3-06-1 The well-defined and tightly wrapped low-level cloud lines of the exposed circulation of Tropical Storm 06W are seen just east of Luzon (280031Z July visible GMS imagery).

support a 999 mb circulation just north of the island of Luzon. . . ."

The final warning on Tropical Storm 06W was issued at 290600Z when, according to remarks on the warning:

". . . Latest satellite and synoptic data reveal that the surface circulation that was once ....06W has become completely entrained into the large circulation of TD 07W . . ."

III. DISCUSSION

TD 06W— an unnamed tropical storm

While 06W was moving northward, over water east of Luzon on 28 July (see Figures 3-06-1 and 3-06-2), the scatterometer aboard the ERS-1 spacecraft obtained a pass directly over the circulation center (Figure 3-06-3). Wind speeds of 35 kt (18 m/sec) were indicated by the scatterometer in the vicinity of 06W. In postanalysis, these scatterometer-derived wind speeds, and also synoptic data supporting an estimated central sea-level pressure of 996 mb, were used to upgrade the estimated peak intensity of 06W to 35 kt (18 m/sec). Figure 3-06-3 is a classic example of the wind direction algorithm used to process the scatterometer data failing on its first guess. This resulted in all the wind directions being plotted 180° out of phase — e.g. the wind field that curves anticyclonically is in reality cyclonically curved.

Over the past several years, the JTWC has been receiving and evaluating unconventional sources of remotely sensed marine wind speeds (e.g., the scatterometer-derived winds, and the SSM/I wind speeds). These scatterometer winds, from JTWC's perspective, are sufficiently accurate to be a useful tool in diagnosing the structure of the low-level wind field within and near tropical cyclones.

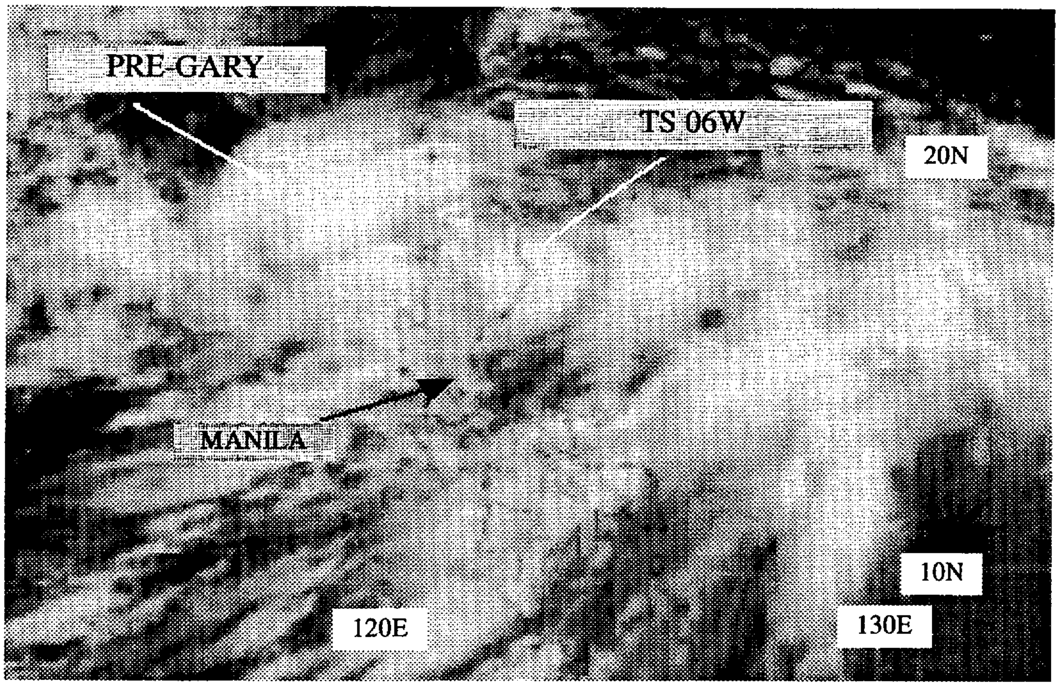


Figure 3-06-2 Deep convection has formed at the center of Tropical Storm 06W. Gary (07W) can be seen forming northwest of Luzon (280424Z July visible GMS imagery).

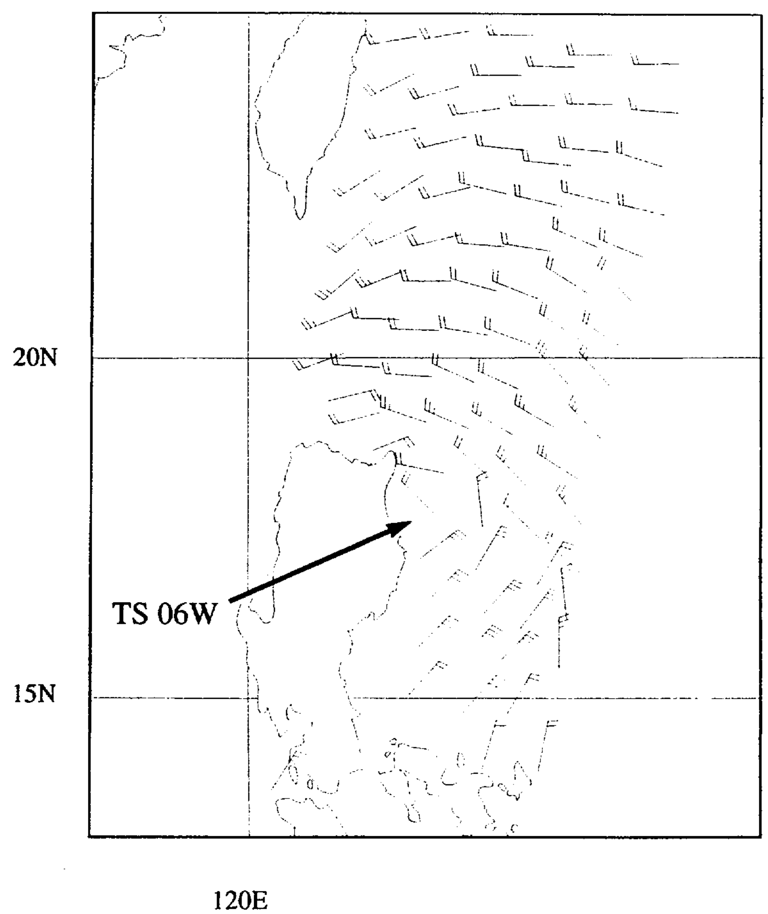
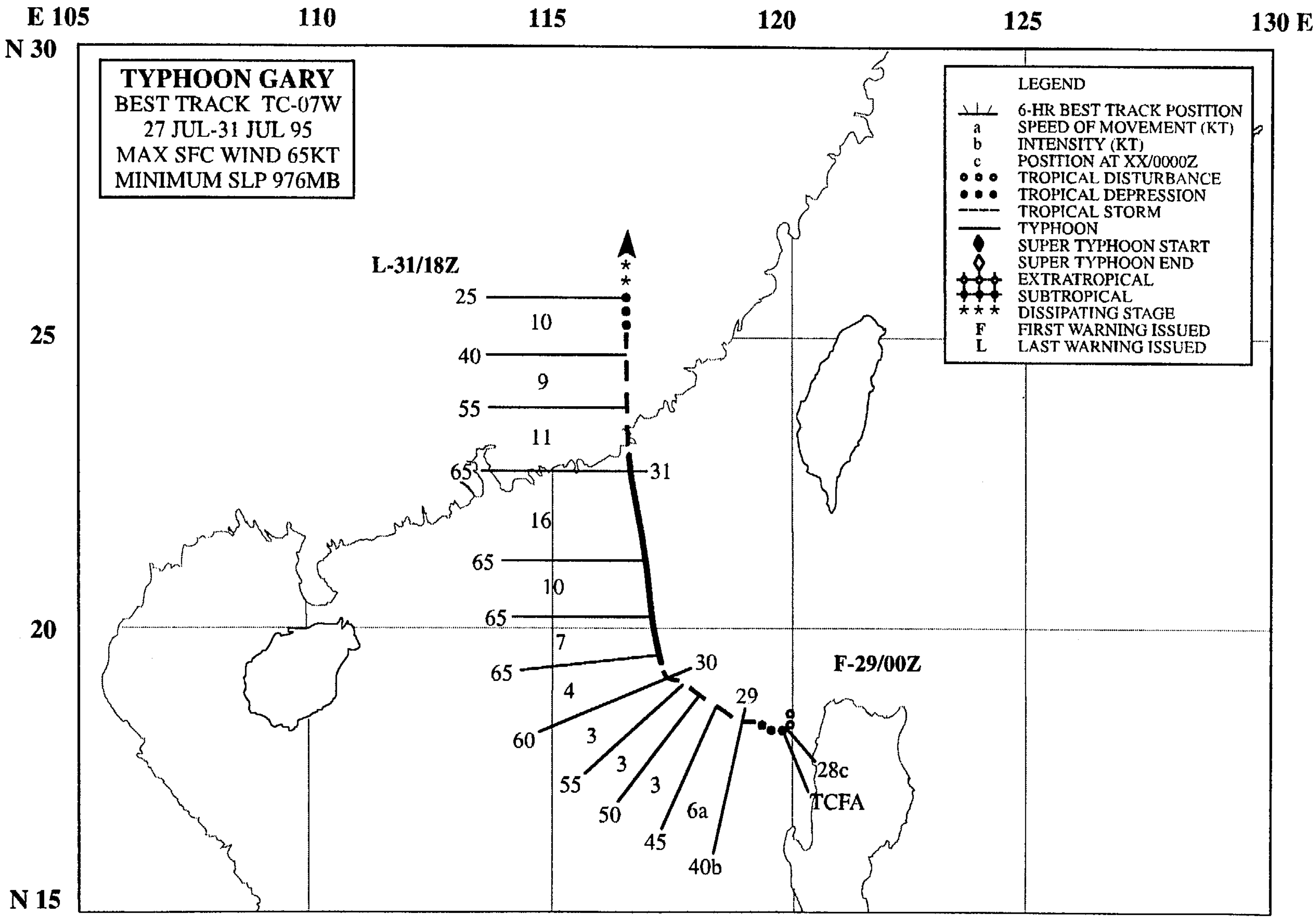


Figure 3-06-3 Scatterometer-derived wind speeds in a swath that passed over 06W (280214Z July ERS-1 scatterometer-derived marine surface wind speeds). The 35-kt (18-m/sec) wind speeds define the center of TS 06W. (The wind direction algorithm's first guess resulted in all the wind directions being 180 degrees in error).

IV. IMPACT

No reports of damage or injuries were received.



TYPHOON GARY
BEST TRACK TC-07W
27 JUL-31 JUL 95
MAX SFC WIND 65KT
MINIMUM SLP 976MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 105
110
115
120
125
130 E
N 30
25
20
N 15
L-31/18Z
F-29/00Z
25
10
40
9
55
11
65
31
16
65
10
65
7
65
30
4
60
3
55
3
50
3
45
6a
29
40b
28c
TCFA

TYPHOON GARY (07W)

I. HIGHLIGHTS

Gary (07W) merged with Tropical Storm 06W during a time when both of these tropical cyclones were embedded within the circulation of a large monsoon depression near the island of Luzon (see also the summary of Tropical Storm 06W). Gary made landfall in southeastern China very close to the city of Shantou. Based upon ship reports received in a delayed mode on the Weekly Tropical Cyclone Summaries compiled by Mr. Jack Beven of the National Hurricane Center, and upon delayed reports of typhoon intensity wind speeds experienced in the city of Shantou that accompanied severe damage to a newly constructed sea wall, Gary was upgraded from a tropical storm to a typhoon in post-analysis.

II. TRACK AND INTENSITY

During the last week of July, a monsoon depression moved westward over the Philippine Islands. There were multiple low-level circulation centers in this monsoon depression — one of these became Tropical Storm 06W, and another became Typhoon Gary (07W).

As early as 270600Z July, when Tropical Depression 06W was making landfall on the island of Luzon, it was noted in the remarks section of JTWC's second warning for Tropical Depression 06W that a secondary circulation may be forming off the west coast of Luzon. On 28 July, as Tropical Storm 06W moved northward just east of Luzon, a Tropical Cyclone Formation Alert was issued at 280230Z July indicating the possibility of further development of the circulation west of Luzon. The Prognostic Reasoning Message that accompanied the 281200Z July warning on 06W included the following synoptic discussion:

"... Infrared satellite imagery shows a broad region of convection that extends from 112°E to 135°E. Synoptic data indicate there are two distinct circulations in this region of convection ... 06W is a well-defined [low-level circulation center] ... just east of Luzon with minimum sea-level pressure estimated at 996 mb.... The second circulation evident in this broad region of convection is west of the island of Luzon, and the possibility exists for this area to also develop into a significant tropical cyclone ..."

On the morning of 29 July, satellite imagery indicated that the circulation west of Luzon had become more organized. It was upgraded to Tropical Depression 07W at 290000Z. At 290600Z, Tropical Storm 06W was entrained into the circulation of Tropical Depression 07W — the final warning was thus issued on 06W, and 07W continued to move slowly westward in the South China Sea. At 291200Z, Tropical Depression 07W was upgraded to Tropical Storm Gary. The Prognostic Reasoning Message accompanying this warning included the following synoptic discussion:

"... Tropical Depression 07W has intensified and has been upgraded to Tropical Storm Gary. Gary is tracking slowly to the north-northwest in the South China Sea. Satellite imagery indicates that the system has become more organized [and has absorbed] the remnants of former Tropical Depression 06W... Intensity estimates are based upon a combination of satellite analysis and ... a 40 kt [21 m/sec] ship observation near the system center. ..."

On 30 July, Gary accelerated northward and intensified. Shortly before 310600Z July, Gary made landfall near the city of Shantou in southeastern China (Figure 3-07-1). In real time, the peak intensity was estimated to be 60 kt (31 m/sec), however, in postanalysis, it was determined that Gary most prob-

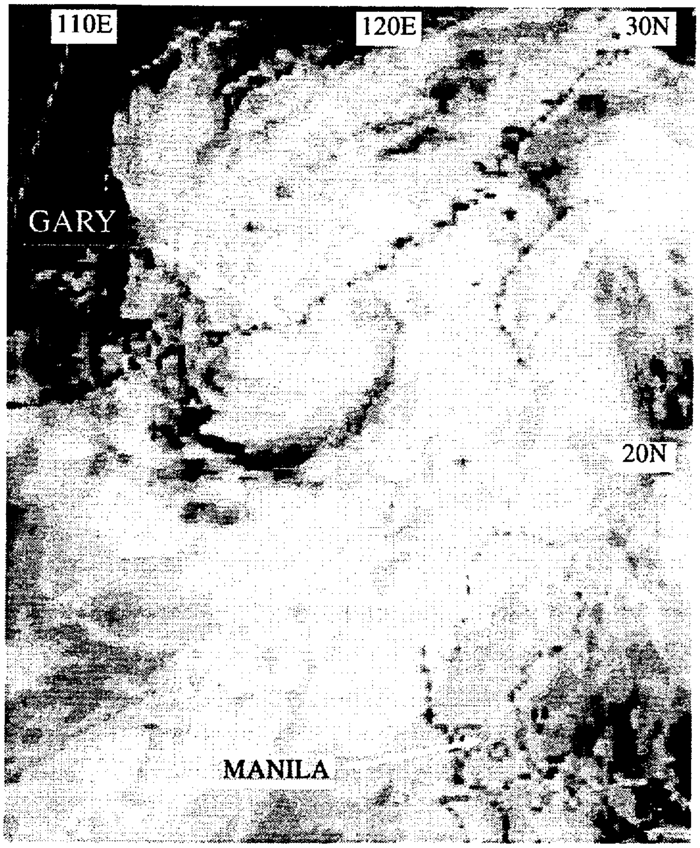


Figure 3-07-1 Gary becomes a typhoon shortly before making landfall near the city of Shantou (302331Z July visible GMS imagery).

ably became a typhoon a day earlier at 300600Z. Gary was well inland in southeastern China when JTWC issued the final warning valid at 311800Z July.

III. DISCUSSION

Island effects

The complex behavior of Tropical Storm 06W and the developing Gary (07W) while they were near the island of Luzon presented a unique forecasting challenge. Initially, as Tropical Storm 06W approached the Philippines, it was thought that it would pass across the islands into the South China Sea, and then intensify. When it stalled over Luzon, and a second circulation appeared to be forming off of the northwest coast of Luzon, it became unclear which circulation would dominate, or whether two would form and undergo a binary interaction.

A case can be made that TD 07W developed from a lee side low that formed off the northwest coast of Luzon as the center of the monsoon depression moved across the central Philippines. Another interesting feature to note is the binary interaction — at close range, and ending in merger — that 06W and 07W underwent for approximately 30 hours (Figure 3-06-2a,b). The after the fact upgrade to typhoon intensity at 300600Z was based on a 62 kt (32 m/sec) ship report that appeared in Mr. Jack Beven's Weekly Tropical Cyclone Summary #208. Gary appeared to have maintained minimal typhoon intensity until making landfall near Shantou a day later.

IV. IMPACT

A newly constructed sea wall was seriously damaged as Gary made landfall near the city of Shantou along the southeastern coast of China. No other reports of significant damage or serious injuries were received.

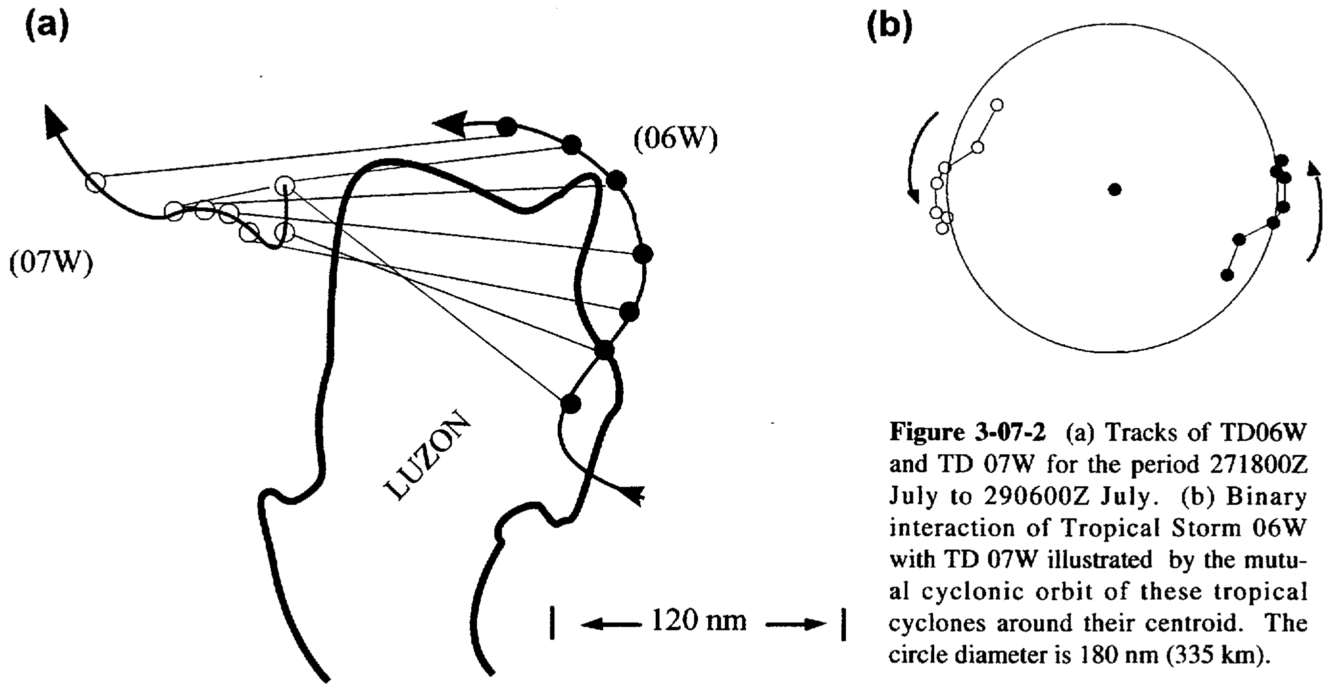
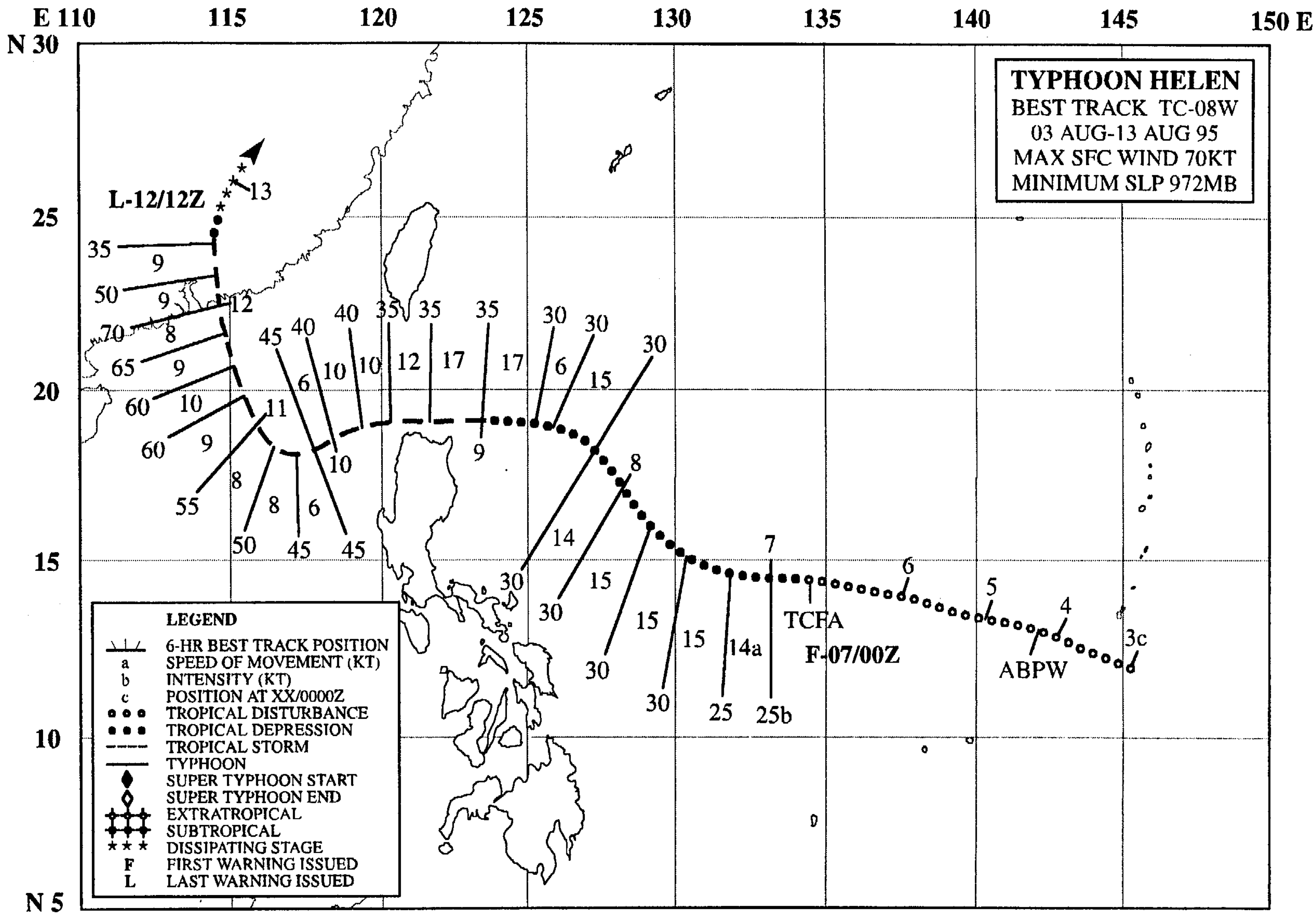


Figure 3-07-2 (a) Tracks of TD06W and TD 07W for the period 271800Z July to 290600Z July. (b) Binary interaction of Tropical Storm 06W with TD 07W illustrated by the mutual cyclonic orbit of these tropical cyclones around their centroid. The circle diameter is 180 nm (335 km).



TYPHOON HELEN
BEST TRACK TC-08W
03 AUG-13 AUG 95
MAX SFC WIND 70KT
MINIMUM SLP 972MB
E 110
115
120
125
130
135
140
145
150 E
N 30
25
20
15
10
N 5
L-12/12Z
F-07/00Z
TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TYPHOON HELEN (08W)

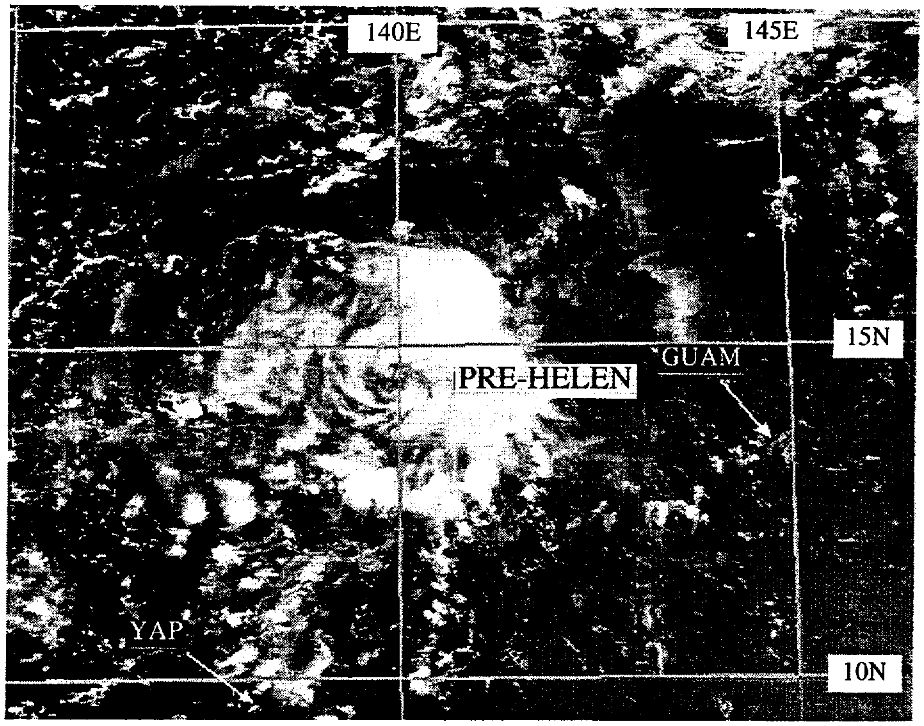


Figure 3-08-1 This vortical cloud pattern was observed about 300 nm (550 km) to the west of the region where, a day earlier, a large MCS had grown and collapsed. Appearing well-organized, it later dissipated, and new deep convection in the pre-Helen tropical disturbance developed further to the south and west (050131Z August visible GMS imagery).

I. HIGHLIGHTS

Helen (08W) was upgraded to typhoon intensity in postanalysis based on data obtained from the Royal Observatory Hong Kong. Originating near Guam, the tropical disturbance that became Helen was slow to develop, taking six days to reach tropical storm intensity. Helen skirted northern Luzon and, after moving into the South China Sea, dipped toward the west-southwest for a day prior to turning to the north-northwest and intensifying. Helen reached a peak intensity of 70 kt (36 m/sec) just before making landfall east of Hong Kong.

II. TRACK AND INTENSITY

Despite the persistent easterly low-level winds that dominated the western North Pacific through early August, a weak low-level cyclonic circulation developed to the south of Guam on 03 August. Scatterometer data from the ERS-1 satellite indicated that the surface circulation had an intensity of 15 kt (8 m/sec). For the next three days, the disturbance moved to the west-northwest and remained poorly organized. A large mesoscale convective system (MCS) that formed over Guam on 04 August, collapsed by the early morning of 05 August and left behind a well-defined, but short-lived, vortical cloud pattern (Figure 3-08-1). The vortical cloud pattern dissipated by the evening of 05 August, and one can not establish a direct link between it and the subsequent development of Helen (see the discussion section for more details on the generation of mid-tropospheric vortices by MCSs and their possible association with tropical cyclogenesis).

Organized convection began to persist by 06 August and a Tropical Cyclone Formation Alert was issued valid at 061830Z. The first warning on Tropical Depression 08W was issued, valid at 070000Z, as the tropical disturbance intensified. During the evening of 07 August, TD 08W turned to the northwest, as monsoon winds to its southwest strengthened and deepened. On 08 August, the tropical depression turned to the west in response to easterly wind flow south of the mid-tropospheric subtropical ridge. Based on intensity estimates made from satellite imagery, Tropical Depression 08W was upgraded to Tropical Storm Helen on the warning valid at 090000Z. On 09 August, Helen moved westward about 30 nm (55 km) north of Luzon. After the system cleared the northwest tip of Luzon and entered the South China Sea, it slowed and took a dip to the west-southwest for about 24 hours.

At approximately 101800Z, Helen turned abruptly to the north-northwest and accelerated to an average speed of 9 kt (17 km/hr). This turn was most probably due to the modification of the steering flow by the deepening southerly flow of a surging monsoon to the southwest of the tropical cyclone. Such sudden track changes that are caused by the interaction of a tropical cyclone with the monsoon flow are described by Carr and Elsberry (1994).

Helen intensified after turning to the north-northwest (Figure 3-08-2). During postanalysis, wind observations from Waglan Island (WMO 45007), which were obtained from the Royal Observatory in Hong Kong, revealed that Helen reached typhoon intensity before making landfall in southern China early on 12 August (for further details about the postanalysis upgrade of Helen to typhoon intensity see the discussion section). The JTWC issued the final warning valid at 121200Z as Helen dissipated over the mountains of southern China.

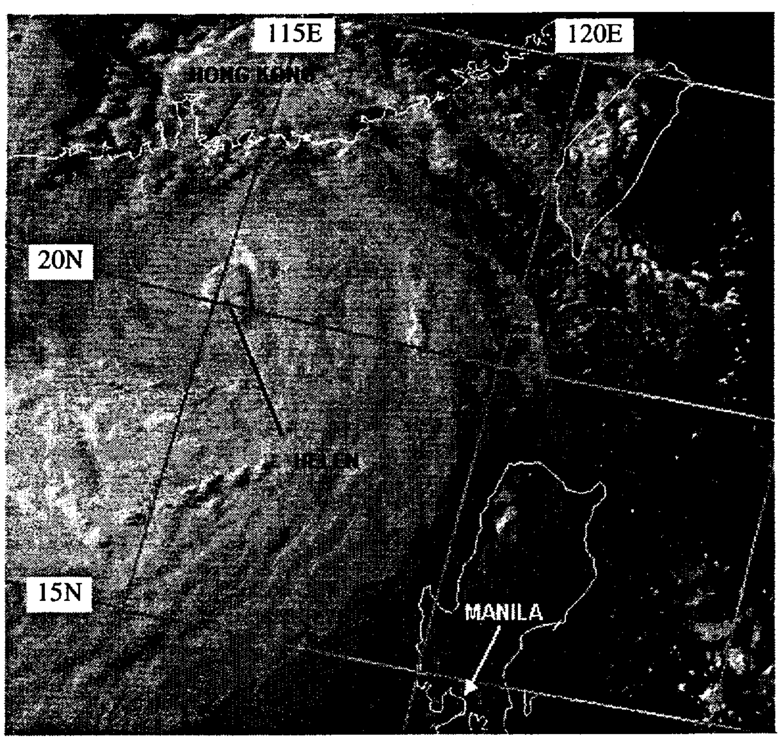


Figure 3-08-2 An intensifying Tropical Storm Helen is located about 150 nm (275 km) south of Hong Kong. The intensity is estimated to be 60 kt (31 m/sec) (110854Z August visible DMSP imagery).

III. DISCUSSION

a. *On the use of microwave imagery to modify the Dvorak intensity estimate*

Between 110000Z and 120000Z, most of the satellite intensity estimates for Helen made by applying Dvorak's techniques to visible (e.g., Figure 3-08-2) and infrared satellite imagery had a magnitude of T3.0 (45 kt) to T3.5 (55 kt), while analysts at the AFGWC assigned it a T4.0 (65 kt). The higher T number assigned to Helen by the AFGWC was based upon additional information about the structure of the tropical cyclone as revealed by microwave imagery. Able to see through the overlying cirrus with the microwave sensor, they noted a well-developed circular eye and wall cloud. Thus, the AFGWC analysts upped their intensity estimates by one-half a T number to arrive at the T4.0 estimate for the 111525Z and 120230Z DMSP satellite fixes. Confirmation of Helen's typhoon status was later obtained from wind observations at Waglan Island where one-minute average sustained winds were 65 kt (33 m/sec) at 111740Z. Seventy-five knot (39 m/sec) gusts were recorded at 111751Z and 120158Z. These winds were recorded on the west side of Helen while it was moving at 9 kt (17 km/hr) toward the north. Allowing for the speed of translation, the final best track intensity was adjusted to 70 kt (36 m/sec).

b. *JTWC forecast performance*

JTWC track forecasts for Helen were very good at the longer time periods. Average forecast errors were 122 nm (226 km), 172 nm (319 km), and 117 (217 km) for 24, 48, and 72 hours. While NOGAPS handled the transition from westward to northward motion in the South China Sea on 11 August quite well, it indicated the northward turn earlier than actually observed. According to Carr (personal communication), this is a common NOGAPS trait. JTWC intensity forecasts were also very good, with an average error of 10 kt (5 m/sec) or less at all forecast periods. The largest intensity forecast errors were produced during the 10 August period, where the intensity was under-forecast by as much as 30 kt (15 m/sec).

c. *Tropical cyclogenesis initiated by a mesoscale convective system*

A recent hypothesis concerning the mechanism of TC genesis is that TCs originate from a mid-level cyclonic vortex that is the product of a mesoscale convective system (MCS). Bartels and Maddox (1990) and Frank and Chen (1991) have provided theoretical and observational evidence that the formation of a mid-tropospheric mesoscale vortex is favored in the large stratiform-rain region of a mature MCS. It has been further proposed that the mid-level mesoscale cyclonic vortices formed via this mechanism can develop into tropical cyclones (e.g., Frank and Chen 1991; Zehr 1992; and Emanuel 1992). The problem lies in linking such mid-level mesoscale vortices to the generation of a surface circulation with organized deep convection. Zehr (1992) postulates a two-stage process whereby a mid-level mesoscale vortex generated by an MCS becomes a TC. In the first stage, a mature MCS creates a mid-level mesoscale vortex which persists after the MCS collapses. The second stage occurs when the remnant mid-level mesoscale vortex works its way to the surface and becomes the site for renewed deep convection resulting in the creation of a TC.

That mid-tropospheric mesoscale vortices are produced during the life cycle of both continental and maritime MCSs is beyond dispute. The results of the TCM-92 and TCM-93 field experiments (Mckinley and Elsberry 1993) and of the TEXMEX field experiment (Bister and Emanuel 1995) confirmed the generation of mid-level mesoscale vortices by tropical maritime MCSs. There remains some controversy as to how the mid-level vortex produced by MCS works its way into the low levels; although Zehr (1992), and Bister and Emanuel (1995), have shown convincing observational evidence that the mesoscale vortices created during the life cycle of an MCS have later become the site of TC development. In Helen's case, there is insufficient evidence to determine if the well-defined mesoscale vortex that appears in Figure 3-08-1 played a direct role in Helen's development. At best, the formation of this mesoscale vortex is a good example Stage One of Zehr's two-stage pathway to tropical cyclogenesis (i.e., the formation of a mid tropospheric mesoscale vortex by an MCS). However, since this well-defined mesoscale vortex dissipated, it is difficult to establish a direct link between it and Helen's subsequent development.

IV. IMPACT

Twenty-three deaths were reported by the Chinese media. In Hong Kong, one person was reported killed and two were reported missing. Although Waglan Island reported sustained (one-minute average) winds of 65 kt (33 m/sec) with gusts to 75 kt (39 m/sec) between 111740Z and 111751Z August (see Figure 3-08-3), winds were weaker over Hong Kong proper. Helen caused about 100 landslides and deposited about 24 inches (600 mm) of rain on Hong Kong during its four days of influence. Damage was slight as implied by a small number of insurance claims.

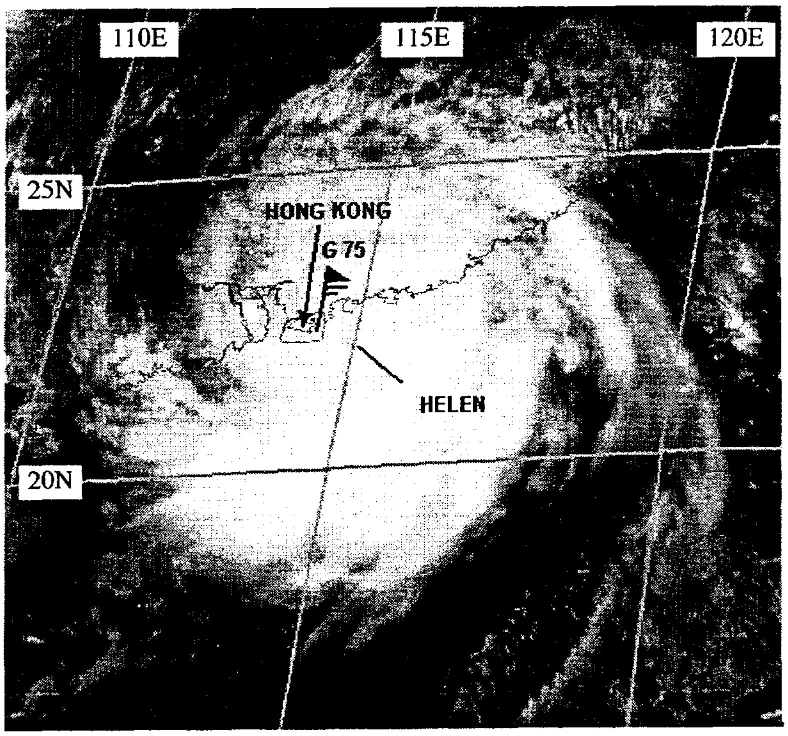
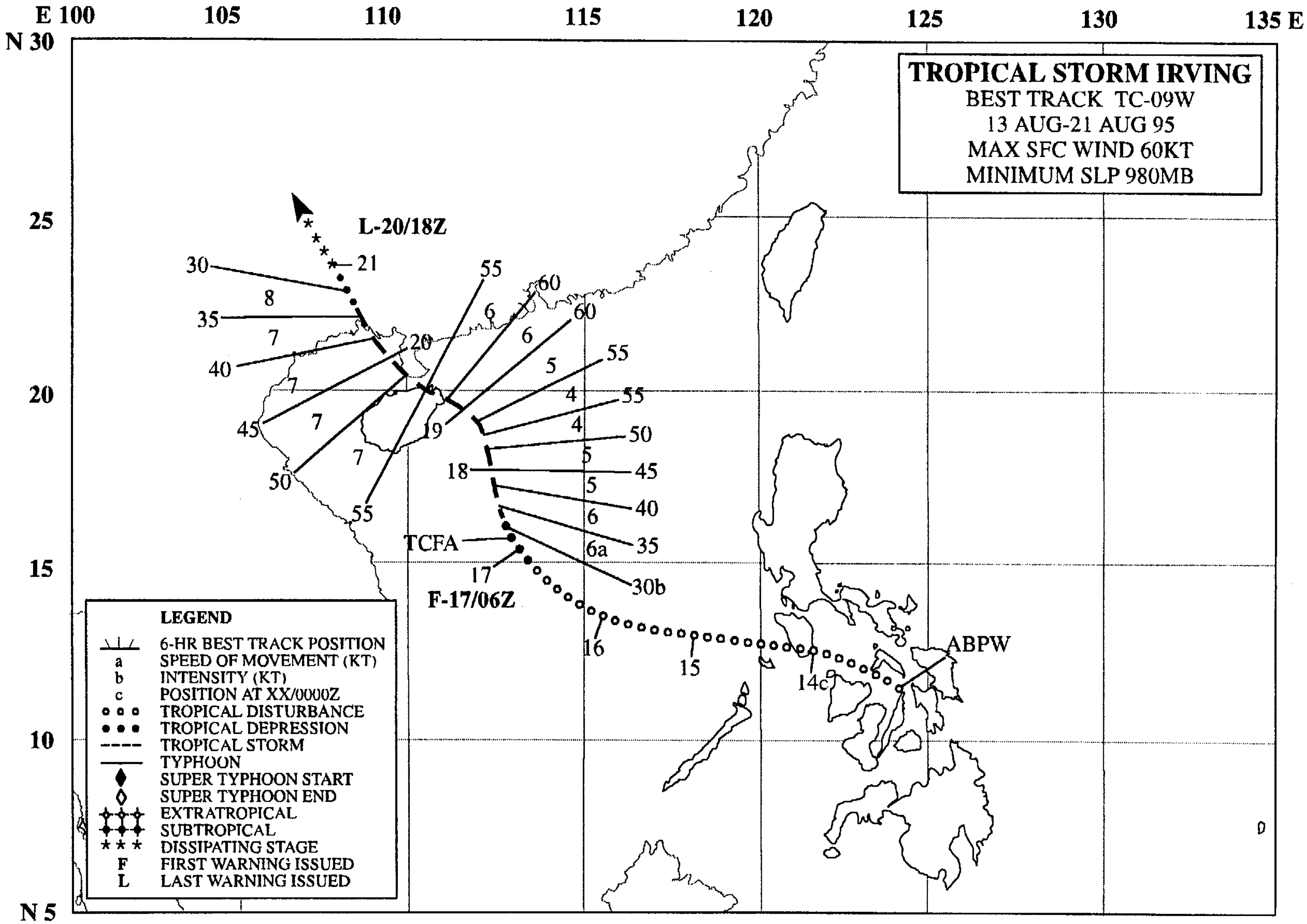


Figure 3-08-3 Typhoon Helen brushes by to the east of Waglan Island, Hong Kong (120131Z August visible GMS imagery). The 120000Z 65 kt (33 m/sec) one-minute averaged sustained wind and the peak 75 kt (39 m/sec) wind gust observed at Waglan Island are indicated (wind data courtesy of the Royal Observatory Hong Kong).


TROPICAL STORM IRVING
BEST TRACK TC-09W
13 AUG-21 AUG 95
MAX SFC WIND 60KT
MINIMUM SLP 980MB
E 100
105
110
115
120
125
130
135 E
N 30
25
20
15
10
N 5
L-20/18Z
F-17/06Z
TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
21
30
8
35
7
40
7
45
7
50
7
55
55
6
60
60
6
20
19
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5
55
4
50
4
45
5
18
5
40
5
35
6
30b
6a
17
16
15
14c

TROPICAL STORM IRVING (09W)

I. HIGHLIGHTS

The second of eight tropical cyclones to form in, or near, the South China Sea during 1995, Irving was very small. Isolated in an otherwise relatively cloud free region of the South China Sea, Irving maintained a very small CDO under which microwave imagery indicated the presence of an eye.

II. TRACK AND INTENSITY

As Tropical Storm Helen (08W) was moving inland over southern China, an area of deep convection associated with the monsoon trough consolidated near the central Philippines on 12 August. On 13 August, synoptic data indicated that a weak low-level circulation center accompanied this tropical disturbance, which was mentioned on the 130600Z August Significant Tropical Weather Advisory. For the next few days, the tropical disturbance moved slowly westward in the South China Sea and showed no signs of further intensification. Visible satellite imagery obtained at first light on the morning of 17 August revealed increased organization of the convective cloud lines, and JTWC issued a Tropical Cyclone Formation Alert at 170100Z. Later that afternoon, visible satellite imagery indicated a further increase in the definition of the low-level circulation center, and the JTWC issued the first warning on Tropical Depression 09W, valid at 170600Z. The deep convection of Tropical Depression 09W rapidly consolidated into a small area very close to the low-level circulation center while, at the same time, other areas of deep convection away from the low-level circulation center subsided. The formation of this small CDO led to the upgrade of Tropical Depression 09W to tropical storm intensity at 171200Z August.

As Irving moved northward toward Hainan Island, it retained its small CDO. Microwave imagery at 172121Z (Figure 3-09-1) indicated the presence of an eye. A visible image two hours later showed that the eye was obscured (Figure 3-09-2). The intensity estimates of Irving gradually increased (based on its persistent CDO, more

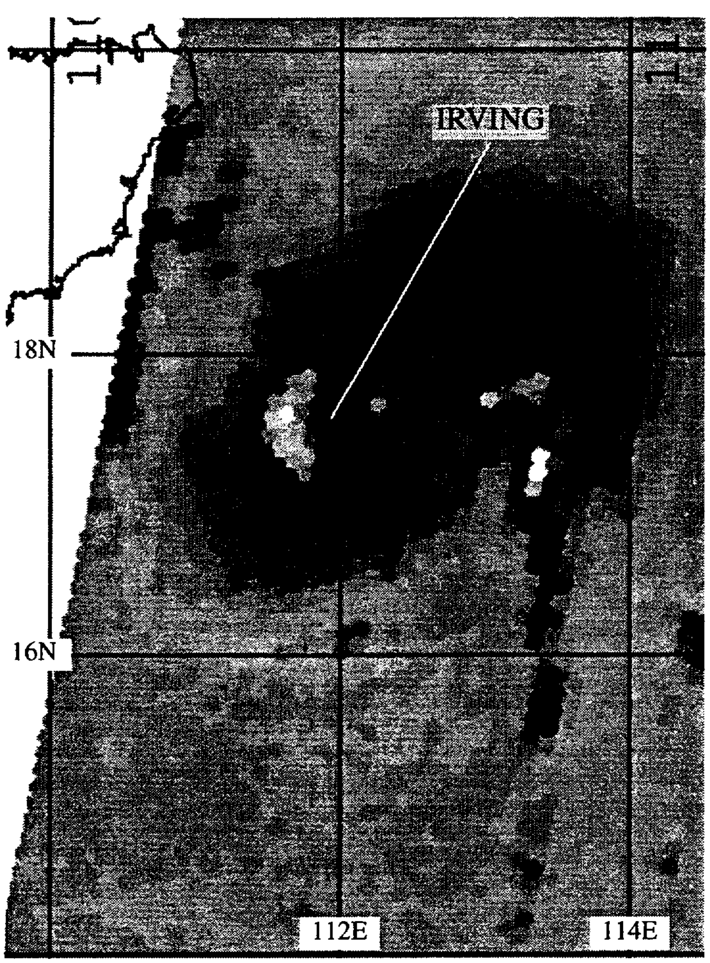


Figure 3-09-1 A small eye is revealed by microwave imagery under the dense cirrus overcast of Irving's small CDO (172121Z August SSM/I 85 GHz DMSP imagery).

tightly curved low-level cloud lines, and better organized cirrus outflow streamers), and at 190000Z it peaked at 60 kt (31 m/sec) (Figure 3-09-3). Moving northwestward, Irving grazed the northeastern tip of Hainan island, crossed the southern end of the Luichow peninsula, and moved inland into southern China near the city of Quinzhou on 20 August. The JTWC issued the final warning, valid at 201800Z August, as Irving dissipated over land.

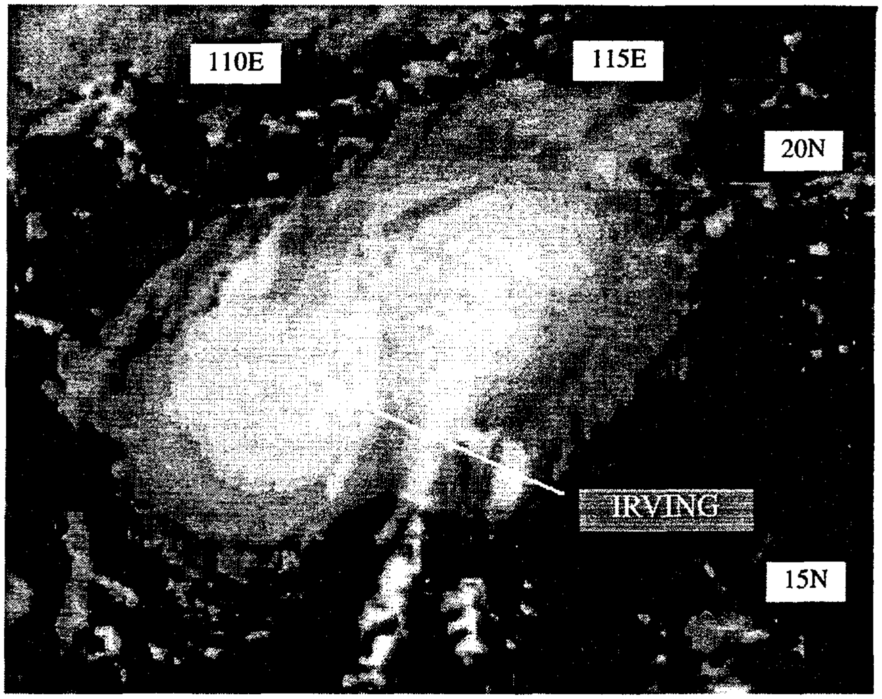


Figure 3-09-2 Cirrus overcast obscures the small eye that appears in Figure 3-09-1 (172331Z August visible GMS imagery).

III. DISCUSSION

a. *Tropical cyclone size: the "midget" tropical cyclone*

Tropical Storm Irving was one of the smallest tropical cyclones of 1995 — only Tropical Depression 22W was smaller. In fact, from the perspective of the size of Irving's satellite-observed cloud shield (including the CDO and curved cirrus outflow streamers), there are few tropical cyclones in recent years that have been as small. Since 1990, only Cecil (1990), Ellie (1991), Zelda (1991), and Ofelia (1993) have been of similar size.

Tropical cyclones of very small size have caught the attention of forecasters and researchers for many years. The terminology used to address very small tropical cyclones still has not been resolved. One of the first written studies of very small typhoons was by Arakawa (1952). Arakawa wrote of very small typhoons that had struck Japan by complete surprise. He called such typhoons, Mame-Taifu (literally, "bean" typhoon; figuratively "midget" typhoon). Dr. C.E. Palmer, one of the meteorologists working in the Marshall Islands during the years of atomic testing by the United States, corresponded with Arakawa on his (Palmer's) observations of very small storms of typhoon intensity occurring in the Marshalls. During September 1966, a reconnaissance flight passed through an extremely intense, but incredibly small hurricane (Inez) in the Caribbean. This hurricane was so small that two scientists working with the data from the flight into Inez (Hawkins and Rubsam 1967) proposed that such storms be called "micro-hurricanes". However, the preferred designation for very small tropical cyclones in the western North Pacific remains Arakawa's "midget".

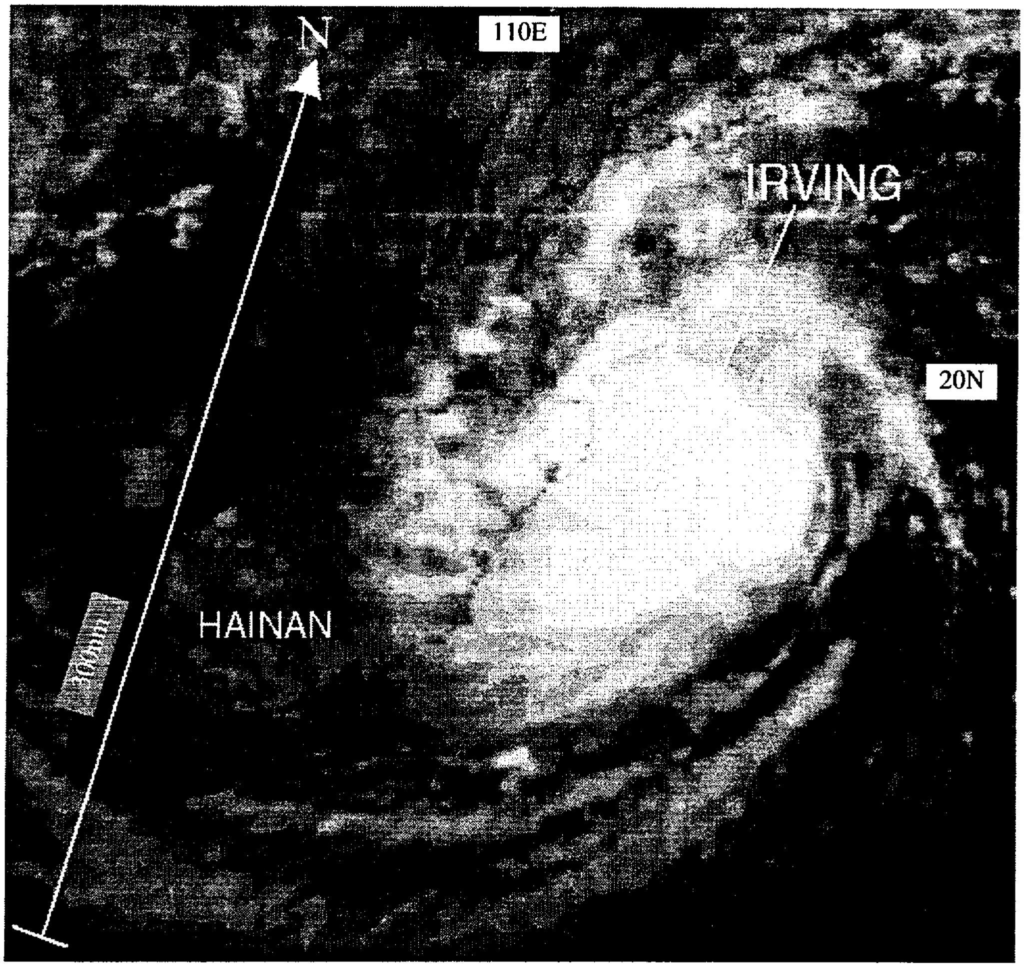


Figure 3-09-3 Tropical Storm Irving at its peak intensity of 60 kt (31 m/sec) (190231Z August visible GMS imagery).

Tropical cyclone size is a very difficult parameter to objectively measure. Brand (1972) classified a tropical cyclone as "very small" if the mean radius to the outer-most closed isobar (ROCI) was two degrees (120 nm, 222 km) of great circle arc (GCA) or smaller. Both the terms "very small" and the term "midget" are used on JTWC bulletins and in the research community, however, the term "midget" is nowhere officially defined (see Appendix A, where herein the size categories of tropical cyclones are: very small, small, average, large, and very large — and are based upon the ROCI). Determining the mean ROCI of tropical cyclones is difficult. This is especially true of tropical cyclones in the western North Pacific that are embedded within larger monsoonal low pressure areas, and where synoptic reports are sparse. After examining recent "midget" tropical cyclones, Guard and Lander (1995) suggest that the satellite cloud signature be used as the primary tool to identify "midget" tropical cyclones. Cloud features used to identify a midget tropical cyclone include:

(1) a CDO, or eyewall plus eye, that does not exceed 90 nm in diameter,

(2) no bands of deep convection more than 120 nm from the low-level center,

(3) a conspicuous lack of low-level cloud lines away from the cover of the central cirrus canopy,

(4) central convection that is often isolated in an otherwise relatively cloud free region,

(5) anticyclonically curved cirrus outflow streamers may be well-organized, but do not extend more than 180 nm from the central convection in any direction.

In addition to the aforementioned satellite-observed characteristics, a structural characteristic found by Lander and Guard (1996) to be typical of the midget tropical cyclone is a rapid drop-off of the wind from the radius of maximum wind outward.

Typical of many "midget" tropical cyclones, Irving lacked peripheral rainbands, and synoptic data indicated that the highest winds were concentrated extremely close to the center. In fact, while it was over the South China Sea, if it were not for detection by satellite, it is doubtful that this tropical cyclone would have ever been detected. Even with detection of Irving by satellite, its intensity was difficult to diagnose. The rapid, and early, formation of Irving's CDO — and its very small size — did not lend itself well to Dvorak enhanced infrared analysis, which requires that the intensity of a tropical cyclone must have become at least 55 kt (28 m/sec) 12 hours before the embedded center technique can be applied. Microwave imagery showing a cirrus covered eye embedded in Irving's small CDO was helpful in supporting the warning intensity of 60 kt (31 m/sec).

b. *Inability of numerical models to analyze and maintain midget tropical cyclones*

Because of their very small size, "midget" tropical cyclones tend not to be analyzed by numerical products. Further, a "midget" tropical cyclone tends to weaken in the forecast and lose its identity as a distinct vortex. These shortcomings of the dynamic guidance are reflected in the following excerpts from the Deputy Director's unofficial log during the development of Irving:

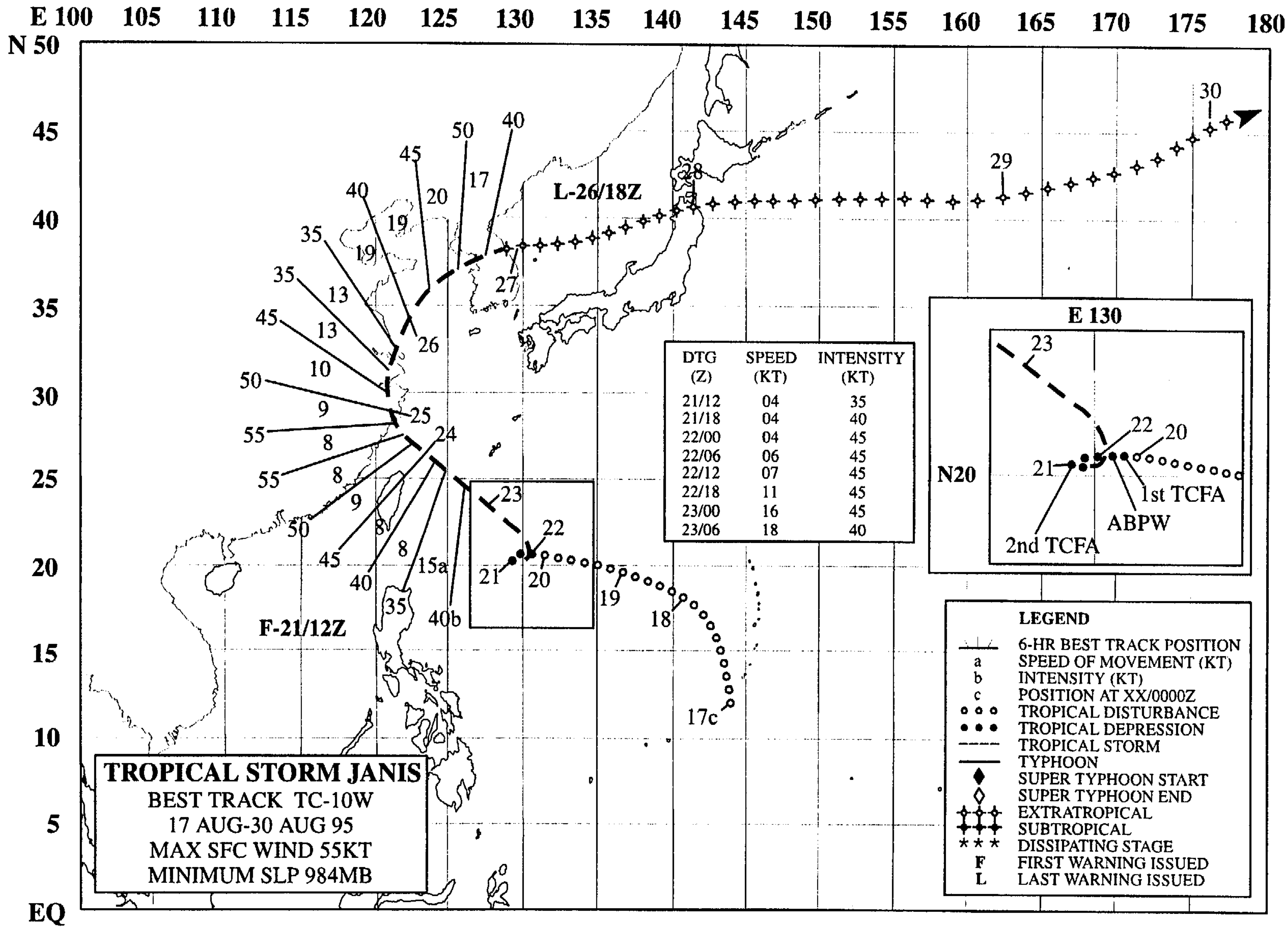
"... Warning # 01: 170900 ... [Irving] should continue to [intensify] in the forecast period. NOGAPS does not have the circulation. ..."

"... Warning # 02: 171500 ... Aids are confusing showing a scatter from west to north. NGPS has no vortex to track. ..."

"... Warning # 03: 172100 ... NOGAPS model progs are now in fairly good agreement. N to NNWward, slow. ... However it [NOGAPS] doesn't hold the circulation. NGPS therefore still having problems. ..."

IV. IMPACT

No reports of significant damage or injuries were received.


TROPICAL STORM JANIS
BEST TRACK TC-10W
17 AUG-30 AUG 95
MAX SFC WIND 55KT
MINIMUM SLP 984MB
F-21/12Z
L-26/18Z
DTG (Z) | SPEED (KT) | INTENSITY (KT)
21/12 04 35
21/18 04 40
22/00 04 45
22/06 06 45
22/12 07 45
22/18 11 45
23/00 16 45
23/06 18 40
E 130
N20
1st TCFA
ABPW
2nd TCFA
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL STORM JANIS (10W)

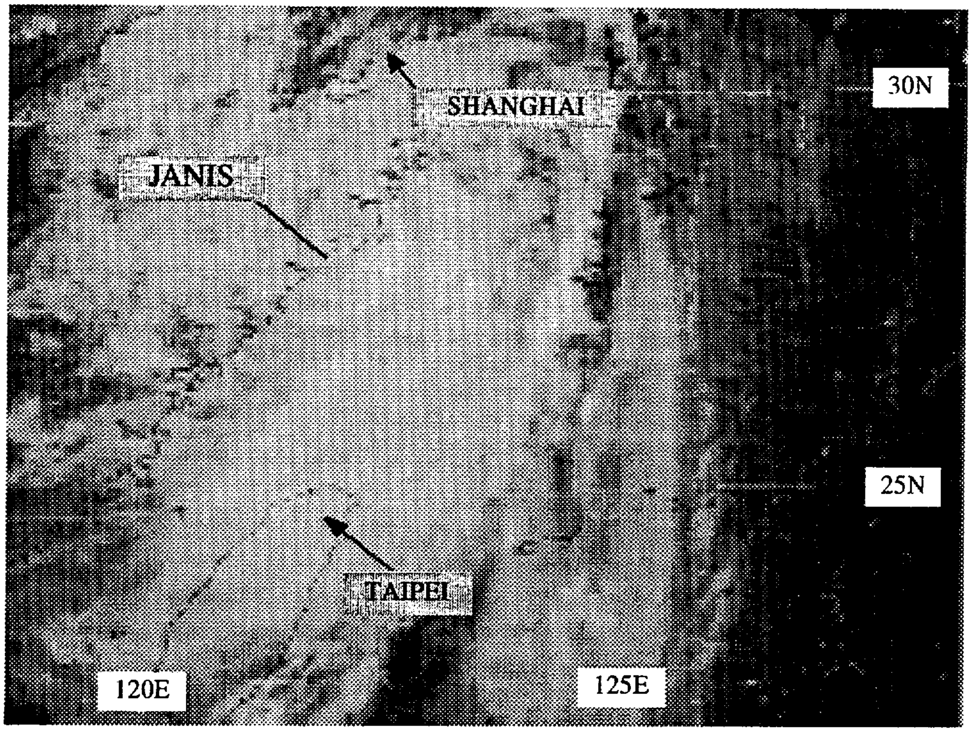


Figure 3-10-1 Janis makes landfall in eastern China shortly after attaining its peak intensity of 55 kt (28 m/sec) (250031Z August visible GMS imagery).

I. HIGHLIGHTS

Forming in a monsoon trough that extended from Asia into the Philippine Sea, Janis moved northwestward and merged with Tropical Depression 11W. In an unusual case of tropical cyclone merger, the larger Janis actually lost much of its deep convection and became less organized as it merged with the smaller Tropical Depression 11W. Subsequent to the merger, all deep convection was lost, but later regenerated as the system moved northward east of Shanghai (Figure 3-10-1). Moving eastward across the Yellow Sea, Janis made landfall in central Korea near Seoul. Heavy rain and winds associated with Janis had a significant impact on South Korea.

II. TRACK AND INTENSITY

During the second week of August, there was relatively little deep convection throughout the tropics of the western North Pacific. On or about 16 August, deep convection had increased across the Philippine Sea and eastward into Micronesia. Several clusters of enhanced convection were distributed along this cloud band in a complex association with a chain of TUTT cells to the north. The tropical disturbance that became Janis had a rather ambiguous start. The first mention of the tropical disturbance that most probably became Janis appeared on the 180600Z August Significant Tropical Weather Advisory. This tropical disturbance moved northwestward and slowly became better organized. The following excerpts from the Deputy Directors' unofficial log provide an insight into the techniques and thought processes used by JTWC forecasters to construct the sequence of warnings on Janis (note the use of concepts developed by Carr and Elsberry (1994) in their systematic approach to tropical cyclone forecasting):

"[Tropical Cyclone Formation Alert] TCFA #1 [issued at 200330Z August], circulation around 21N 132E, Broad area of deepening convection starting to show cyclonic turning."

"TCFA #2, [issued at 210300Z August] Two distinct circulation centers: 19N 133E and 20N 129E. Broad circulation, [it] remains unclear which of these will [develop]. BUT one of them will."

"Warning #01: 21/12Z: Dvorak 2.0 and synoptic obs of 20 and 25 knots about the circulation center near 20.4N 129.9E prompts this warning [on Tropical Depression 10W]. NOGAPS anal indicates model has fair to good initialization despite not having the circulation. 700 and 500 mb indicates slow westward motion through 24-36 hours followed by increasing northward motion out to 72 hours. Models indicate building of the ridge, already analyzed, to the SE of the circulation. Appears to be a classic N2 [see discussion of the Systematic Approach] and forecasting a north-oriented track after about 24 hours of slow westward drift, while consolidating. Intensification 1T/day. Everything looks favorable; in addition there is a TUTT cell to NW that should support outflow on NE quadrant of the TC."

"Warning #02: 21/18Z: [Upgraded to TS (JANIS) based on synoptic and satellite data. Still N2 forecasting very slow westward drift while system consolidates followed by northward acceleration at 36 - 48 hours."

"Warning #03: 22/00Z: NOGAPS 21/12Z continues to build ridge from south along east side of storm up to the [subtropical ridge]. Modifying the [subtropical ridge] in classic N2 and north-oriented motion. However the model does not build very strong [outer wind] asymmetries . . . as expected. This may be a factor of large TC actual size, but NOGAPS not hanging onto the vortex yet. Still forecasting for slow westward now for 12-24 hours, followed by acceleration to northward. Okinawa in danger. Intensification remains 1T/day. NOTE: [Mesoscale Convective Complex] developing about 350 nm NNW of Janis. This is [associated with] the TUTT cell, but may . . . support cyclogenesis. Issuing TCFA on it. Potentially 11W."

"Warning #05: 22/12Z: TS Janis has slowly moved back to the east as it undergoes binary interaction with TD 11W. Intensification is stalling but that should be temporary. Forecasting for slow ENEward motion followed by . . . NWward track thru period. This places Okinawa directly in the path of Janis."

"Warning #07: 23/00Z RELOCATED: Janis absorbed TD 11W but did not execute as long a ENEward track as forecasted. Janis is now tracking NWward at about 16 knots. NOGAPS no longer supports north-oriented pattern. NWward steering asymmetries are evident early in prog series and weaken thru 72 hours. Now forecasting for a more classic recurver scenario. NWward track thru 48 hours followed by recurvature towards Korea. Intensification should resume but current rate does not support 1T/day. Forecast TY by 25/00Z with 75 knots at 72 hours off the southern coast of Korea."

"Warning #09: 23/12Z: Janis is tracking Nward at 13 knots and intensifying slowly. NOGAPS fields do not clearly [indicate] the steering flow . . . 500 mb 20 knot, Nward asymmetries are evident thru 48 hours. By 72 hours only a small finger of 20 knot [wind extends] north towards the storm circulation. This could indicate northward motion and weakening, OR the storm could move over China and dissipate. Forecast is similar to previous: NWward out to 25/00Z followed by recurvature towards Korea. [However] losing confidence in this philosophy. System may go over land in China and dissipate."

On 25 August, Janis made landfall in eastern China near Wenzhou. Moving northward over land, the system weakened. Approximately six hours after passing near or over Shanghai, Janis turned to the northeast and moved into the Yellow Sea; its intensity had fallen to 35 kt (18 m/sec). Once over water again, Janis began to re-intensify as it turned more eastward and accelerated toward the Korean peninsula. Janis made landfall near Seoul at approximately 261500Z. Peak winds at the time of landfall were estimated to have been 50 kt (26 m/sec). The JTWC issued the final warning valid at 261800Z as Janis became extratropical while passing over the mountains of Korea. The system continued as an extratropical low — with gales — as it crossed the Sea of Japan.

III. DISCUSSION

a. *The "Systematic Approach" to tropical cyclone track forecasting*

As seen in some of the Deputy Director's log entries listed above, the rationale for the forecast is couched in terms of a forecast scheme developed by Carr and Elsberry (1994). Carr and Elsberry developed what they term "a systematic and integrated approach to tropical cyclone track forecasting" (hereafter referred to as the "Systematic Approach"). The "Systematic Approach" is intended to address some deficiencies in the current forecasting process. It employs two important knowledge bases: (1) a comprehensive set of conceptual models (Part I) to assist the forecaster in characterizing the tropical cyclone environment; and, (2) a compilation (Part II) of the traits and biases of the numerical tropical cyclone prediction models organized in accordance with the conceptual model knowledge base. The conceptual models developed in Part I relate tropical cyclone motion to tropical cyclone structure (both intensity and size); and, most importantly, to tropical cyclone/environment transformations, by which environmental patterns (and thus the attendant steering) may be significantly altered by the presence of the tropical cyclone.

The set of conceptual models is organized into three general groups that are further organized into two subsets based on scale: synoptic patterns (classifications of the large-scale environment surrounding the tropical cyclone based on the existence and orientation of various synoptic features such as cyclones, anticyclones, ridges, and troughs); and, synoptic regions (identification of smaller areas within the synoptic patterns where certain characteristic directions of environmental steering may be expected to occur).

JTWC forecasters have begun to use and evaluate Carr and Elsberry's "Systematic Approach". The comment, "modifying the [subtropical ridge] in classic N2 and north-oriented motion", that appeared in the log entry concerning Warning #3 is based upon use of the "Systematic Approach". The N2 pattern is a specific environmental flow pattern identified by Carr and Elsberry (Figure 3-10-2) that is associated with north-oriented motion. Carr and Elsberry's scheme is still in the process of development, but it is also being used by JTWC forecaster's even as the knowledge base is established and refined; thus, a

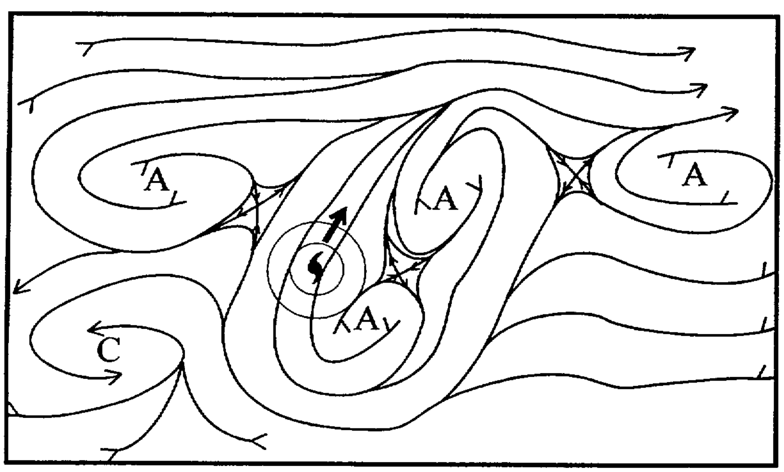


Figure 3-10-2 Schematic illustration of the wind flow at the 500-mb level in the synoptic pattern N2 that is favorable for north-oriented tropical cyclone motion. (Adapted from Carr and Elsberry, 1994).

healthy feedback between the JTWC and the research community has been established. The reader is referred to Carr and Elsberry (1994) for a complete treatment of the "Systematic Approach".

b. *Tropical cyclone merger*

Janis merged with Tropical Depression 11W. Tropical cyclone merger is one possible outcome of the mutual interaction of spatially proximate tropical cyclones. The interaction of two adjacent tropical cyclones is often referred to as the Fujiwhara effect after the pioneering laboratory and observational studies of Fujiwhara (1921, 1923, and 1931). Fujiwhara demonstrated that the relative motion of two adjacent cyclonic vortices was composed of cyclonic orbit around their centroid, coupled with a mutual attraction. The rate of orbit steadily increases as the vortices spiral inward toward one another and eventually the two vortices coalesce into one vortex located at the centroid (i.e., the geographical mid-point between the two tropical cyclones).

The observed behavior of two adjacent tropical cyclones usually differs from the classical Fujiwhara effect in several aspects. Prominent among these is the usual failure of tropical cyclones to merge. Because of these differences, the interaction between two tropical cyclones is usually called binary interaction. Lander and Holland (1993) developed a generalized model of binary interaction, and showed that the classical Fujiwhara model of converging cyclonic rotation about a centroid followed by merger is rarely observed. Rather, the most common outcome of binary interaction is a mutual cyclonic orbit of the centroid by each tropical cyclone at a fairly constant separation distance followed by a sudden escape wherein the mutual cyclonic orbit ceases and the tropical cyclones move apart.

Though less frequent, the merger of two tropical cyclones usually involves the destruction (i.e. loss of deep convection) of one member of the binary pair. The remnants of the destroyed tropical cyclone are

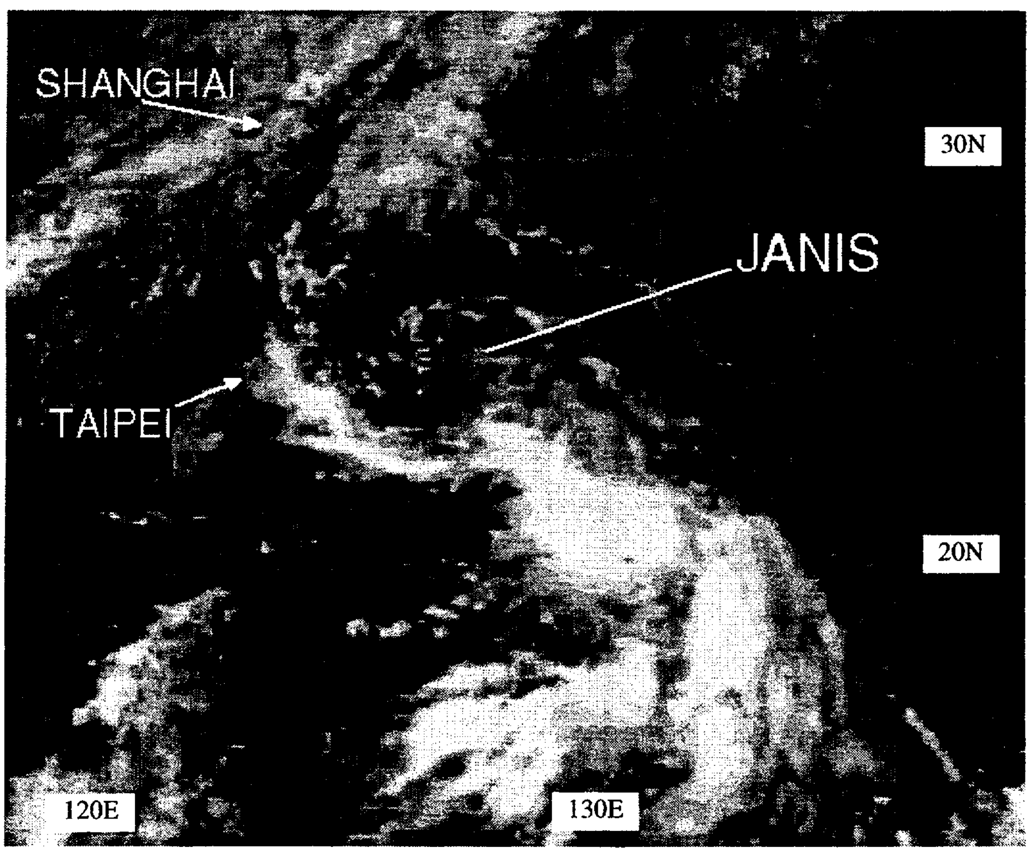


Figure 3-10-3 After Janis had absorbed the circulation of Tropical Depression 11W, the amount of deep convection near the center of the combined vortex decreased considerably (230231Z August visible GMS imagery).

then swept into the circulation of the remaining one. The merger of Janis with Tropical Depression 11W was somewhat unusual in that, as the merger was taking place, each system lost much of its deep convection, and in the case of the larger and better organized Janis, the deep convection also lost much of its organization. Ultimately, Tropical Depression 11W was absorbed into the larger circulation of Janis, but after the merger, most of the deep convection was lost in the combined vortex (Figure 3-10-3). Later, convection became reestablished near the low-level circulation center (Figure 3-10-4).

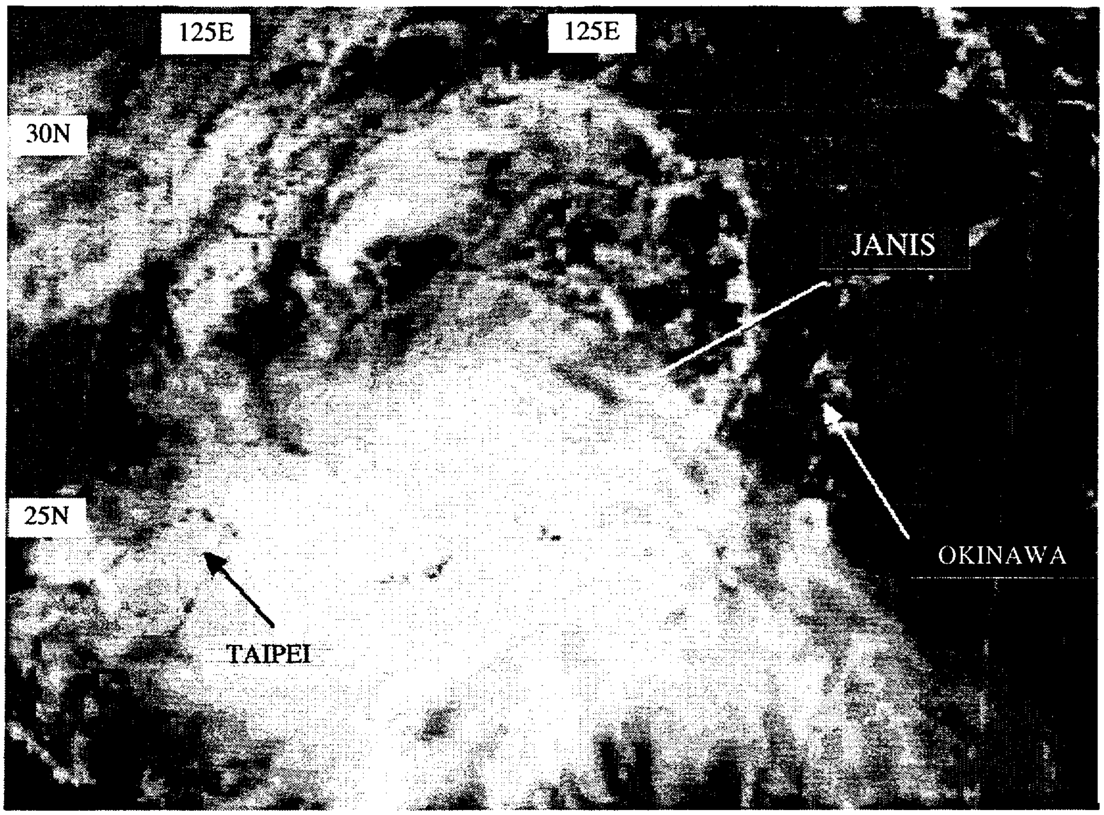


Figure 3-10-4 Deep convection became reestablished near the center of Janis approximately 24 hours after its merger with Tropical Depression 11W (232331Z August visible GMS imagery).

IV. IMPACT

After brushing past Shanghai, Janis turned eastward, crossed the Yellow Sea (Figure 3-10-5), and then made landfall in Korea just north of Seoul. At Osan Air Base, a wind gust of 52 kt (27 m/sec) broke the standing record of 51 kt (26 m/sec) recorded in 1968. The record wind, accompanied by heavy rain, forced the evacuation of two fighter squadrons, uprooted hundreds of trees, knocked down power lines, and left more than 65 buildings without power for more than 12 hours. Elsewhere in Korea, reports of 45 people dead and nine missing were received. Thirty of those killed were crushed by landslides. The rest died when they were swept away by strong currents in streams or struck by lightning. One person died when a train derailed on a bridge over a swollen river. Torrential rains associated with Janis left more than 22,000 people homeless and caused damage in South Korea totaling about $US 428.5 million, the largest rain related disaster in the nation's history. As Janis passed over northern Japan, wind gusts in the high 40s were recorded at many stations. No reports of significant damage or injuries were received from Japan.

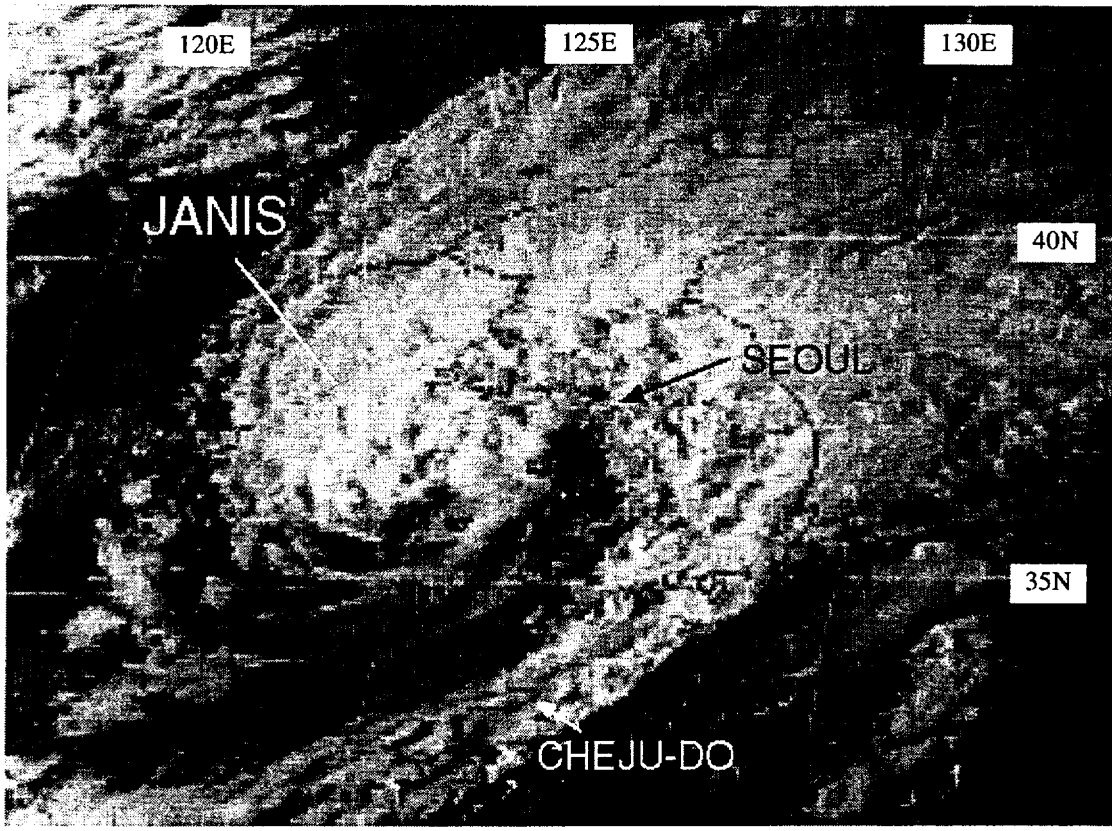
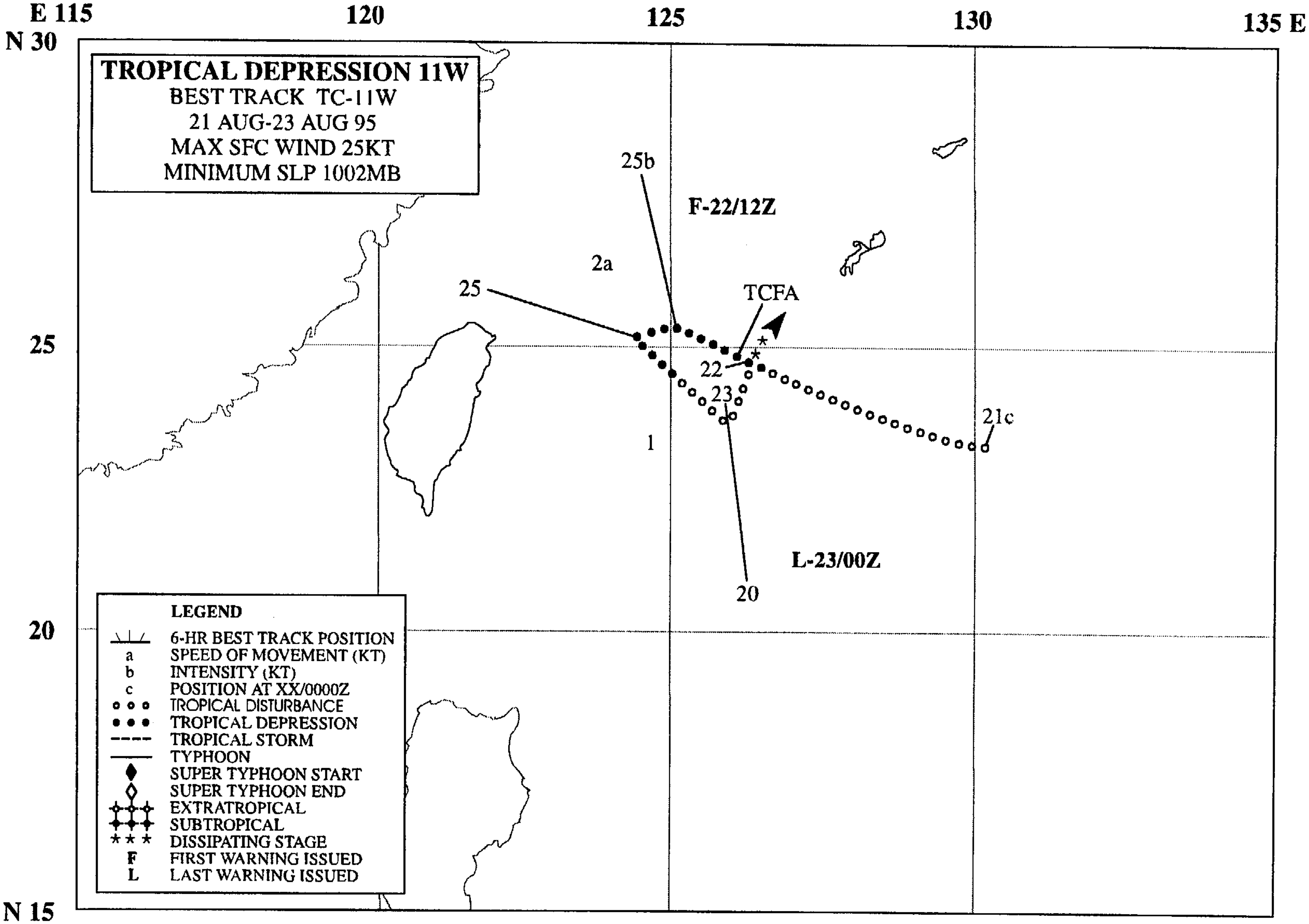


Figure 3-10-5 Janis closes in on the Korean peninsula (260831Z August visible GMS imagery).


TROPICAL DEPRESSION 11W
BEST TRACK TC-11W
21 AUG-23 AUG 95
MAX SFC WIND 25KT
MINIMUM SLP 1002MB
E 115
120
125
130
135 E
N 30
25
20
N 15
25b
F-22/12Z
2a
25
TCFA
22
23
1
21c
20
L-23/00Z
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL DEPRESSION (11W)

I. HIGHLIGHTS

Forming in association with a TUTT-induced area of convection to the north of Tropical Storm Janis (10W), Tropical Depression 11W eventually merged with Janis (see Janis' summary for more details on the merger).

II. TRACK AND INTENSITY

On August 20, an area of persistent deep convection became established to the north of the area of convection associated with the developing Janis (10W). This area of deep convection (pre-TD 11W) appeared to be directly related to a TUTT cell that had moved westward into the southern Ryukyu Islands. This area of persistent deep convection became better organized (e.g., cyclonically curved bands of deep convection, low-level cloud lines suggesting the formation of a low-level circulation center, and a wide band of anticyclonically curved cirrus outflow to the north) in satellite imagery (Figure 3-11-1). Synoptic data also indicated the formation of a low-level circulation center separate from, and to the north of, Janis. A Tropical Cyclone Formation Alert (TCFA) was issued on this area at 220330Z August.

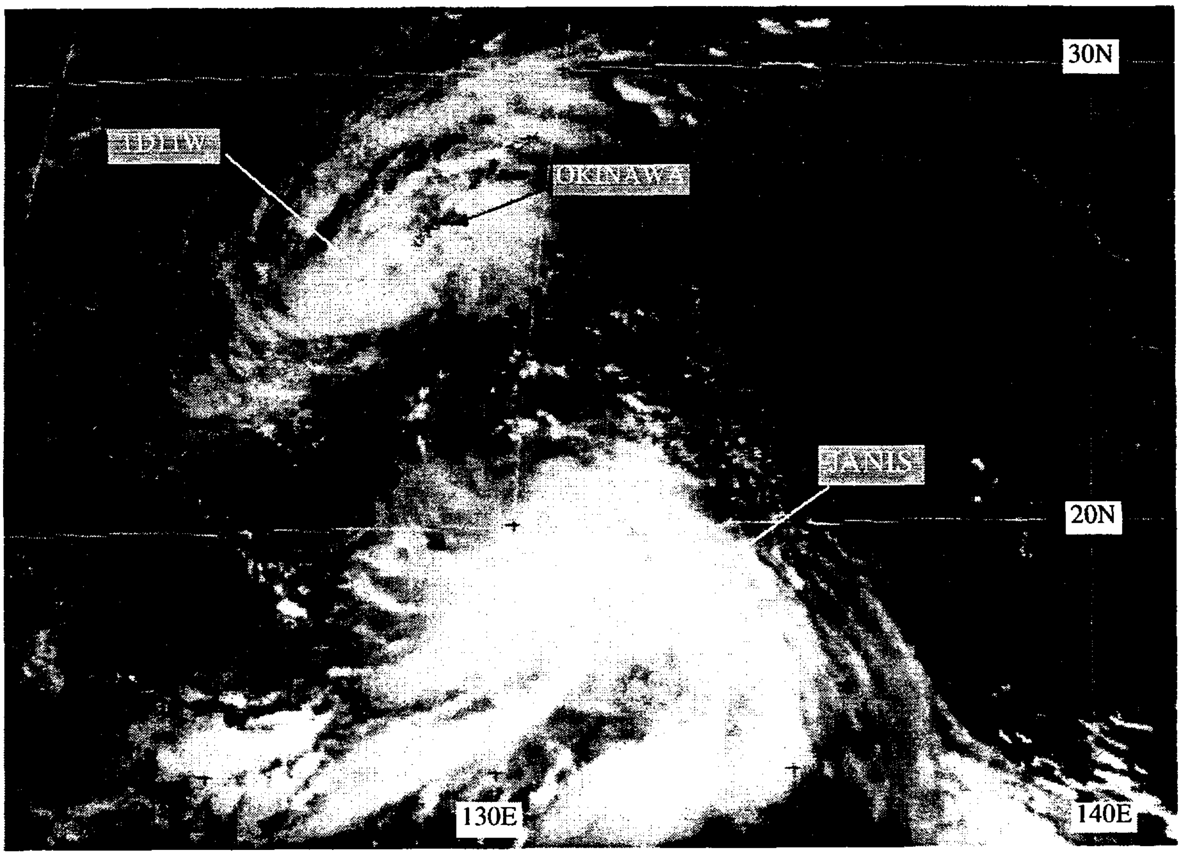


Figure 3-11-1 Tropical Depression 11W as it orbits Tropical Storm Janis (10W) in a binary interaction that will culminate in the merger of these two tropical cyclones (212331Z August visible GMS imagery).

From the beginning, the JTWC anticipated that this system would be absorbed into the larger circulation of Janis (10W). Remarks on the TCFA included:

". . . conditions are currently favorable for separate development of this system, re-absorption of this [system] into Janis (10W) is the favored scenario . . ."

Remarks on the Prognostic Reasoning message that accompanied the 221200Z warning on Janis (10W) included:

". . . there is some evidence of binary interaction [of Janis] with the tropical disturbance near Okinawa. This may cause Janis to remain stationary, or undergo erratic motion over the next 12-24 hours . . ."

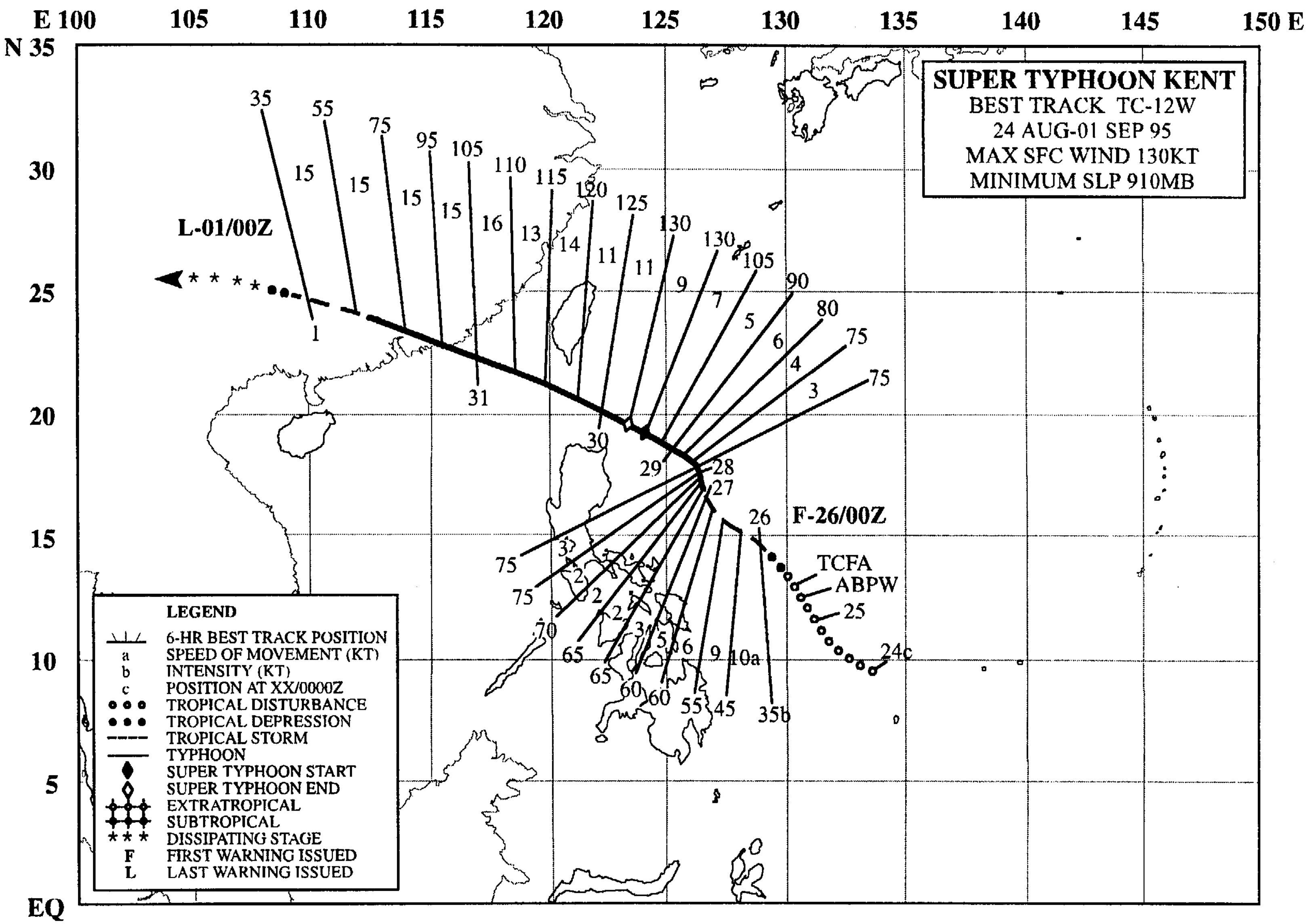
The first warning on Tropical Depression 11W was issued valid at 221200Z August based upon satellite imagery and synoptic data that clearly indicated that a separate low-level circulation center, possessing 25 kt (13 m/sec) maximum sustained wind, had formed in the southern Ryukyu Islands. During the subsequent 12 to 18 hours, Tropical Depression 11W executed a counter-clockwise loop, and its deep convection collapsed as it merged with the low-level circulation center of Janis. The JTWC issued the final warning valid at 230000Z for Tropical Depression 11W.

III. DISCUSSION

Tropical Depression 11W merged with Tropical Storm Janis (10W). For more details of the merger of these two tropical cyclones see the discussion section of Janis' narrative.

IV. IMPACT

No reports of significant damage or injuries were received.



SUPER TYPHOON KENT
BEST TRACK TC-12W
24 AUG-01 SEP 95
MAX SFC WIND 130KT
MINIMUM SLP 910MB
E 100
105
110
115
120
125
130
135
140
145
150 E
N 35
30
25
20
15
10
5
EQ
L-01/00Z
F-26/00Z
TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

SUPER TYPHOON KENT (12W)

I. HIGHLIGHTS

Kent was one of seven tropical cyclones and one of three typhoons to develop in August. It was also the first of five super typhoons to occur in 1995. Kent formed in the Philippine Sea and, after slow development, it rapidly intensified as it approached the Luzon Strait. Basco, Batan Island (WMO 98135), which was briefly in the northern part of Kent's eye, observed a peak wind gust of 140 kt, and a minimum sea-level pressure of 928 mb. Hourly radar images from Kaohsiung, Taiwan showed concentric eyewalls that persisted for at least 22 hours. Kent continued on a west-northwest track and made landfall in China, just east of Hong Kong.

II. TRACK AND INTENSITY

The tropical disturbance that became Kent was first mentioned on the 250600Z August Significant Tropical Weather Advisory when satellite imagery indicated increased organization in an area of deep convection, located north-northwest of Palau. Scatterometer data from the ERS-1 satellite (which was not available to the JTWC in real time) revealed that, 24 hours earlier, this disturbance was accompanied by a low-level cyclonic vortex with a maximum intensity of 15 kt (8 m/sec). The disturbance moved to the northwest, and its satellite signature continued to improve. A Tropical Cyclone Formation Alert was issued by the JTWC at 251130Z. At 260000Z, Dvorak intensity estimates reached 35 kt (18 m/sec) and the first warning on Tropical Storm Kent was issued, valid at 260000Z. The tropical cyclone intensified at a greater-than-normal rate (i.e., greater than one "T" number per day), and at 270600Z, Kent was upgraded to a typhoon. After becoming a typhoon, Kent's rate of intensification slowed, as did its speed of translation. During its 48-hour period (261800Z to 281800Z) of slow (5 kt, or less) forward motion, satellite imagery (Figure 3-12-1) revealed restricted outflow of the cirrus to the northwest of the system.

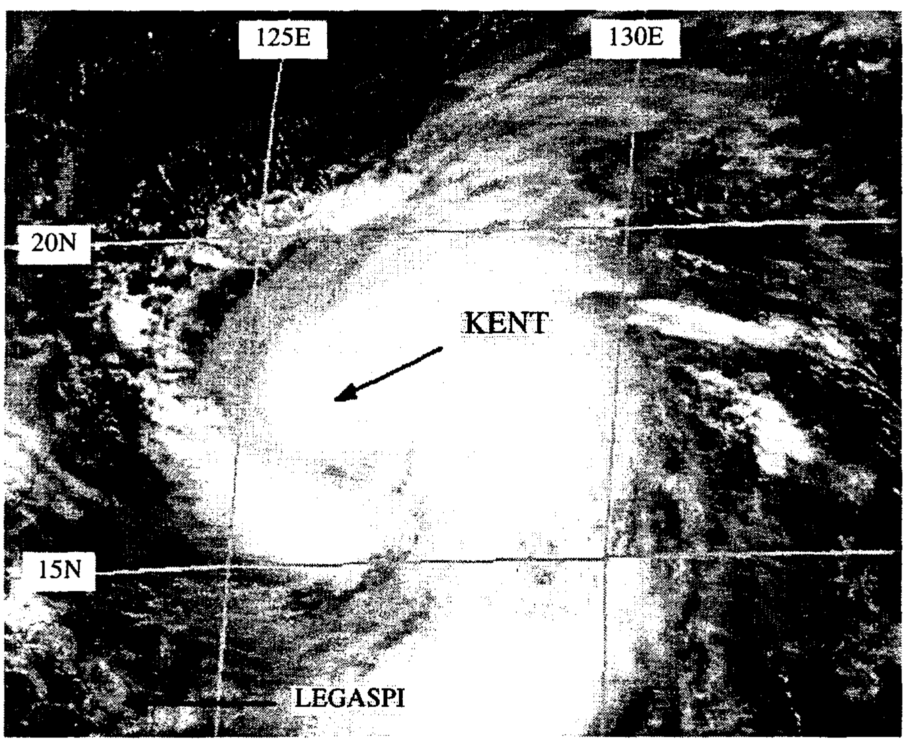


Figure 3-12-1 Kent with an intensity of 75 kt (39 m/sec) when 270 nm (510 km) east of Luzon (272331Z August visible GMS imagery).

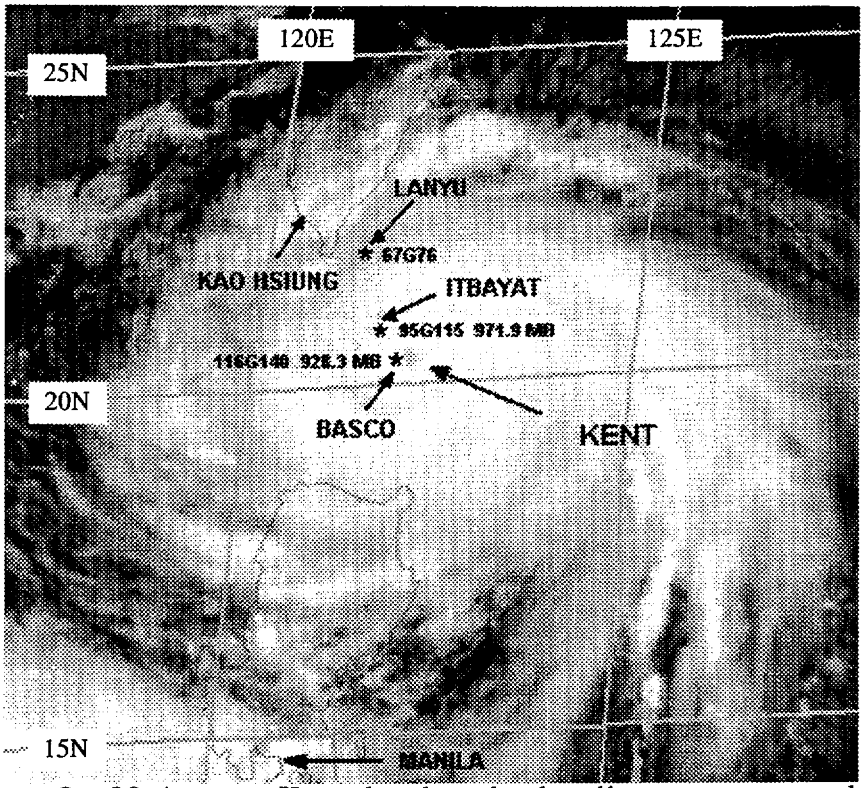


Figure 3-12-2 Kent nears Basco, with sustained winds estimated at 125 kt (64 m/sec). Maximum observed winds and minimum sea-level pressures are indicated for Basco and Itbayat Island during peak conditions (292331Z August visible GMS imagery).

On 28 August, Kent developed a banding-type eye, and remained at 75 kt (39 m/sec) intensity until 281800Z, when it began to intensify. Kent reached its peak intensity of 130 kt (67 m/sec) at 291200Z. At 300100Z, the center of Kent's eye passed south of Basco. Satellite imagery (Figure 3-12-2) and radar imagery (Figure 3-12-3a-h) are available for this time period. Kent's passage over Basco afforded an opportunity for ground validation of the satellite-derived intensity. Kent's intensity (satellite-derived and ground-truth), and its structure as revealed by radar during its passage over Basco, are described more fully in the discussion section.

On 30 August, Kent began to weaken slowly. At the same time, it began to accelerate on its west-northwest track toward the China mainland (Figure 3-12-4). Kent made landfall at 310700Z approximately 50 nm (95 km) northeast of central Hong Kong. The final warning was issued, valid at 010000Z September, as Kent dissipated while passing over the rugged terrain of south central China.

III. DISCUSSION

a. *The passage of Kent over Basco*

The passage of the eye of Kent just south of the Philippine meteorological station at Basco, Batan Island (WMO 98135), allowed for an excellent comparison between actual measured winds and the estimated winds given by the application of Dvorak's techniques to a very intense typhoon. At the time of the satellite image (292331Z) in Figure 3-12-2, Basco was entering the western wall cloud of the eye of Kent. The application of the digital Dvorak (DD) algorithm (see Oscar's (17W) summary for an in-depth discussion of the DD algorithm) to the 292331Z infrared image yielded an intensity estimate of T 6.1. This corresponds to a sustained 1-minute wind speed of 117 kt (60 m/sec) and a minimum sea-level pressure of 926 mb. The DD estimates of Kent's intensity during the six hours prior to its closest point of approach to Basco averaged approximately T6.5, which yields an equivalent 1-minute wind speed of approximately 130 kt (67 m/sec) and a minimum sea level pressure of 910 mb.

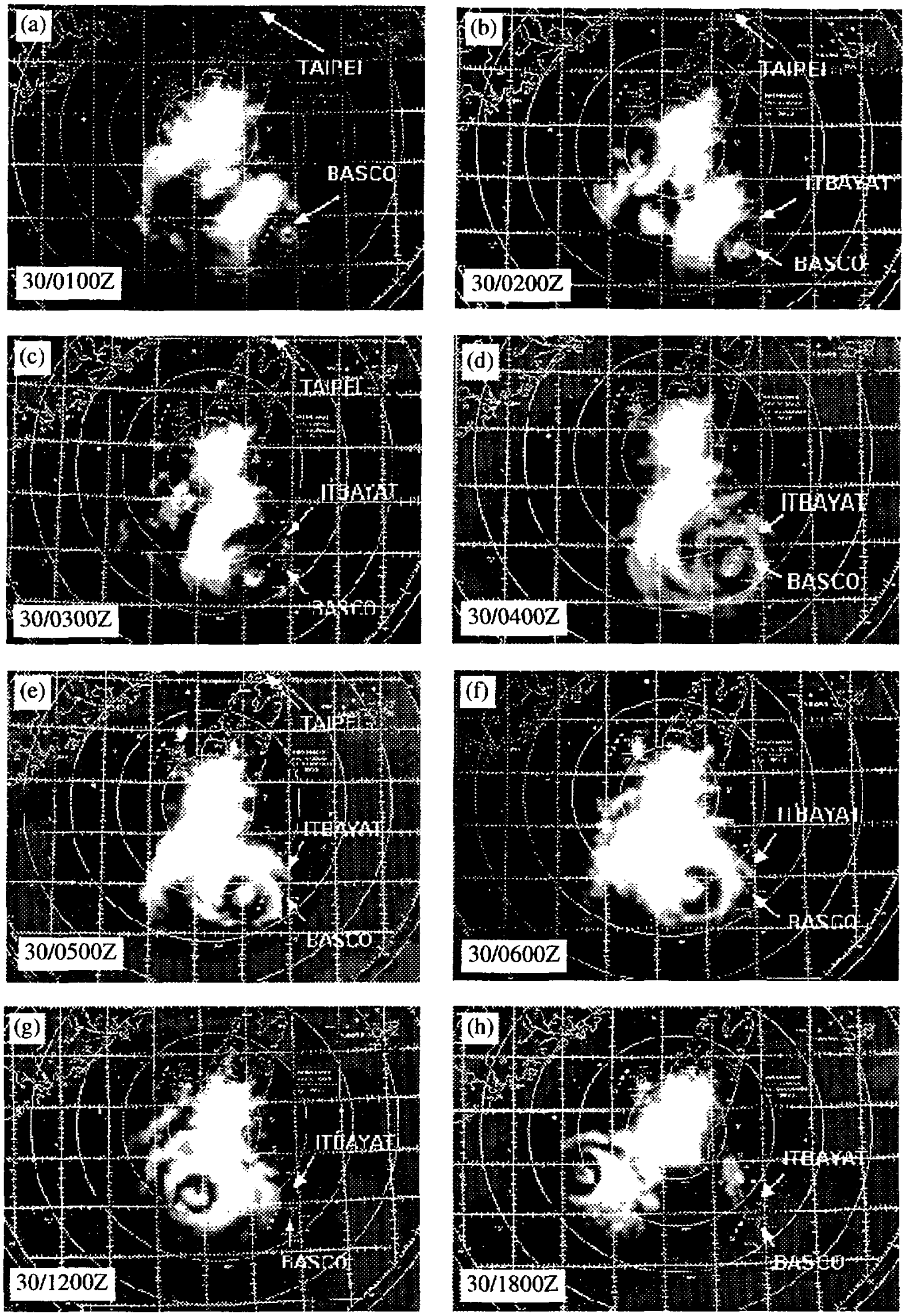


Figure 3-12-3 Radar images from the Kaohsiung radar show the concentric eye-walls of Kent. Images (a) through (f) are hourly, and (g) and (h) are 6-hourly. (Radar images courtesy of the Central Weather Bureau, Taiwan).

For the purposes of postanalysis, research, and development of a high-confidence tropical cyclone intensity data base at the University of Guam, several international meteorological agencies have generously provided landfall/eye passage maximum wind information to researchers there. For Kent, critical data were provided by the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), the Royal Observatory Hong Kong, and the Central Weather Bureau, Taiwan. These agencies report sustained winds as a 10-minute average, and when necessary for comparison with the JTWC, a conversion is made to the equivalent 1-minute sustained average. Critical wind and pressure data measured at various island locations that were affected by Kent have been superimposed on the satellite imagery of Figure 3-12-2. Table 3-12-1 summarizes the wind and pressure data recorded during Kent's passage over Basco.

The following conclusions can be drawn concerning Kent's passage over Basco: (1) the center of the eye may not have gone directly over Basco (the Kaohsiung radar images indicate that the center of the eye passed approximately 5 nm (10 km) south of Basco), but it did enter the northern edge of the eye given Basco's reported brief period (15 minutes) of lighter winds; (2) using the Atkinson/Holliday (A&H) wind-pressure relationship, the minimum sea-level pressure recorded at Basco of 928 mb corresponds to a sustained 1-minute wind speed of 114 kt (59 m/sec); (3) allowing for the fact the pressure in the exact center of the eye may have been approximately 10 mb lower (i.e., 918 mb), the corresponding sustained wind on the A&H scale would rise to 123 kt (63 m/sec); and, (4) the peak gust of 140 kt (72 m/sec) measured at Basco supports a sustained over-water 1-minute sustained wind of at least 115 kt (59 m/sec). The best-track indicates an intensity of 125 kt (64 m/sec) at 300000Z (and a gradual weakening trend) 50 minutes prior to Basco's peak gust and one hour prior to the minimum recorded sea-level pressure there. The peak wind and minimum sea-level pressure recorded at Basco are consistent with the intensity estimates from satellite imagery yielded by the DD algorithm.

b. *Radar depiction of Kent*

Radar images from Kaohsiung, Taiwan, (Figure 3-12-3a-h) indicated that Kent had concentric eye walls for at least 22 hours. Each hourly radar image from 300100Z to 302300Z (not all of these are shown in Figure 3-12-3a-h) shows an inner eyewall surrounded by an outer eyewall. The diameter of each eye appears to remain the same each hour, although the inner eye occasionally became open in one quadrant and the reflectivity appeared to fluctuate within the inner eyewall. The inner eye also appeared to wobble within the clear region separating the two eyewalls. The diameter of the inner eye was approximately 9 nm (17 km). The diameter of the outer eye fluctuated from 50-70 nm (93-130 km). There was no indication, however, that the inner eye disappeared or that as the outer eyewall shrank and replaced the inner eyewall (as in the eyewall replacement process described by Willoughby (1982, 1990)). A similar occurrence is discussed in the 1994 Annual Tropical Cyclone Report concerning Typhoon Gladys. In both cases, the inner and outer eye appeared to conserve their general characteristics for nearly a day.

IV. IMPACT

Damage at Basco (WMO 98135) was estimated at US$2 million, and at Itbayat (WMO 98132) US$50,000. Considerable flooding occurred on Luzon. In Pampanga province, 50 nm (95 km) north of Manila, 65,000 people were reported to have fled as heavy rains created mudflows from the slopes of Mount Pinatubo that buried entire communities. Five deaths were reported in Luzon. In southern China, Kent destroyed banana plantations and sunk many fishing boats. Thirty people were reported dead in Guangdong province, and 17 lost their lives in Hainan. Kent caused an estimated US$87 million in damage in China. Hong Kong was spared serious damage.

Table 3-12-1 Information about the eye passage of Super Typhoon Kent at Basco (WMO 98135). MWBE is the maximum sustained wind direction/speed/gust prior to eye passage; MWDE is the peak gust during eye passage; MSLP is the minimum sea-level pressure at eye passage; MWAE is the maximum sustained wind direction/speed/gust after eye passage. Sustained winds are one-minute averages. Time of occurrence is given below the meteorological information.

MWBE(kt)	MWDE(kt)	MSLP(mb)	MWAE(kt)
020/116/140	40	928.3	120/M/140
30/0050Z	30/0100Z	30/0100Z	30/0110Z

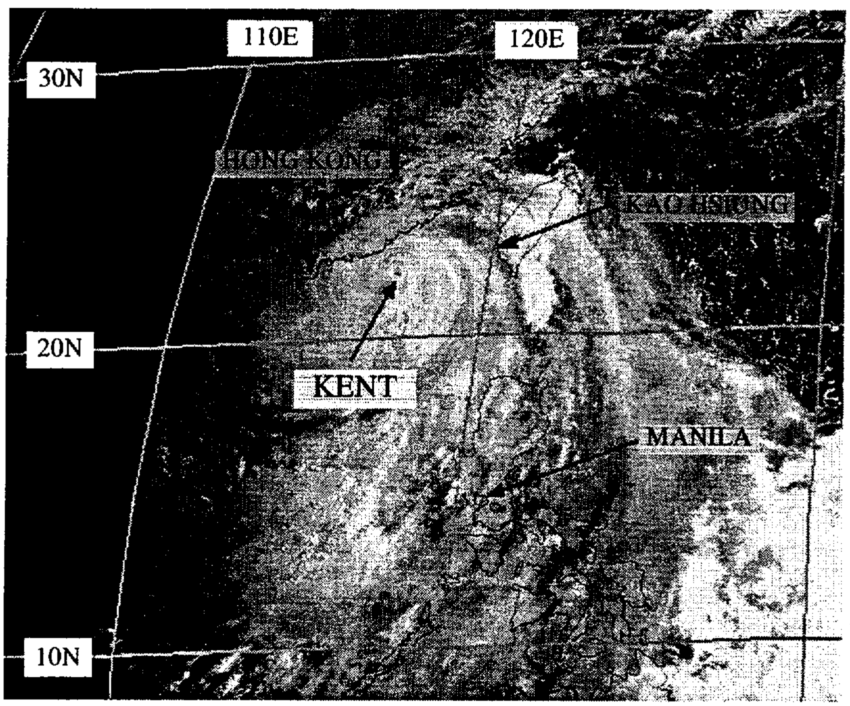
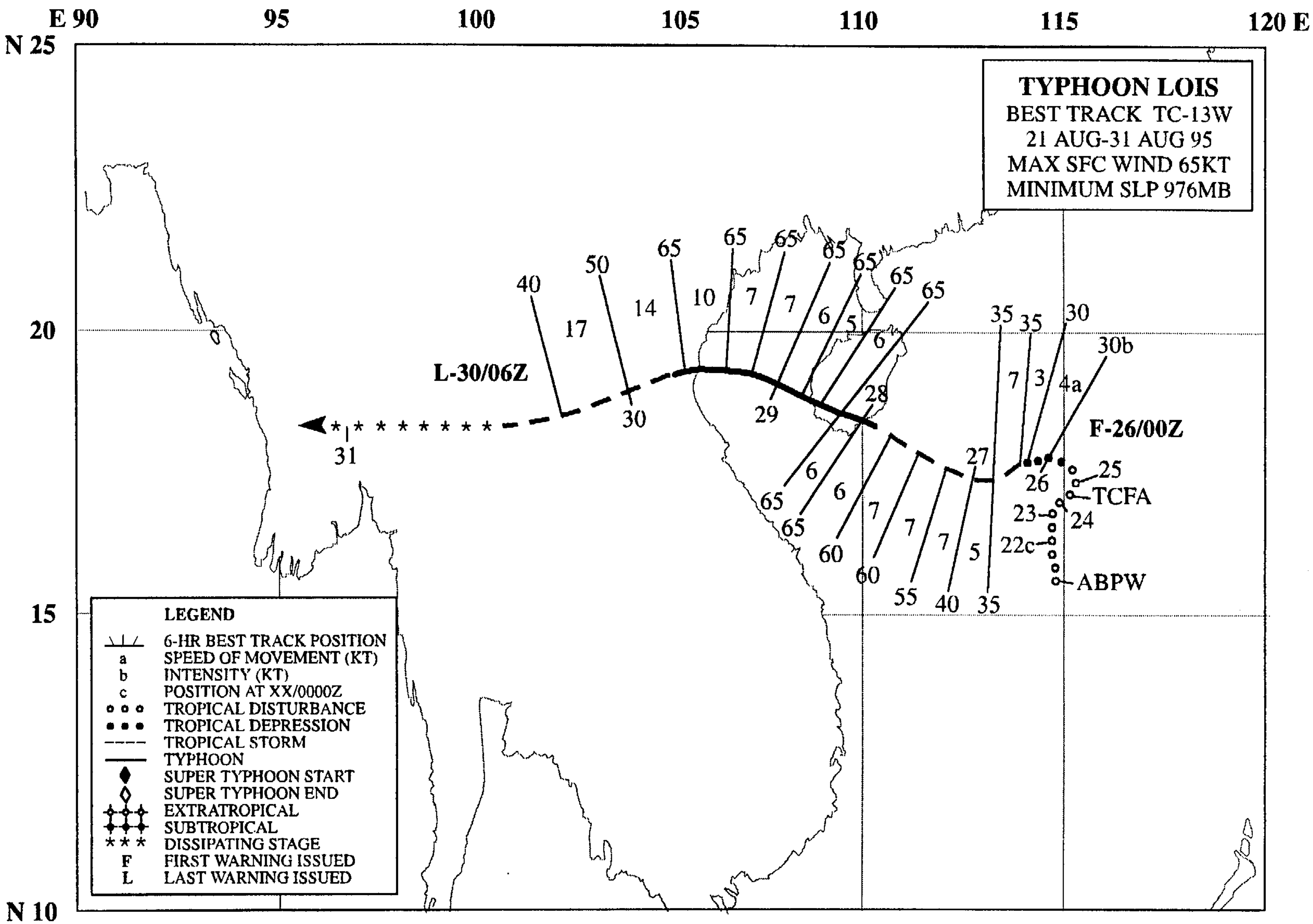


Figure 3-12-4 Kent with an intensity of 105 kt (54 m/sec) when located about 175 nm (325 km) east of Hong Kong (302231Z August visible GMS imagery).


TYPHOON LOIS
BEST TRACK TC-13W
21 AUG-31 AUG 95
MAX SFC WIND 65KT
MINIMUM SLP 976MB
E 90
95
100
105
110
115
120 E
N 25
20
15
N 10
L-30/06Z
F-26/00Z
TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TYPHOON LOIS (13W)

I. HIGHLIGHTS

As Typhoon Kent (12W) was developing east of the Philippines and Tropical Storm Janis (10W) was crossing the southwestern Ryukyu Islands, Lois formed in the South China Sea. This was one of only three occasions during 1995 that the JTWC was simultaneously warning on three tropical cyclones in the western North Pacific. Lois was one of an unusually large number of tropical cyclones that formed in the South China Sea during 1995.

II. TRACK AND INTENSITY

On 21 August, synoptic data indicated the presence of a weak cyclonic circulation center near 15°N 115°E that accompanied an area of deep convection. This tropical disturbance was first mentioned on the 210600Z August Significant Tropical Weather Advisory. For two days, the disturbance drifted slowly to the north, and its deep convection became better organized. Beginning on 23 August, the disturbance moved toward the northeast, possibly in response to a surge in the southwest monsoon that flowed past the pre-Lois disturbance northeastward to the circulation of Janis (10W). A Tropical Cyclone Formation Alert was issued at 240830Z when the system appeared to be improving in organization. On 25 August, the long fetch of southwesterly monsoon flow began to weaken between pre-Lois and Janis (10W) as the axis of the subtropical ridge began to build between these two systems (see the discussion section for a more detailed discussion of the effects of the monsoon flow on the motion of Lois). As the subtropical ridge strengthened to its north, the pre-Lois tropical disturbance responded with a slow counterclockwise turn to the west. Based upon intensity estimates of 25 kt (13 m/sec) made from satellite imagery, the first warning on Tropical Depression 13W was issued valid at 260000Z. The system was upgraded to tropical storm intensity twelve hours later. South of a strengthening subtropical ridge, Lois moved on a generally westward track. At 280000Z, Lois was upgraded to a typhoon, just as it touched the southern coastline of Hainan Island. Crossing the southern edge of Hainan Island, Lois passed close to the city of Yaxian (WMO 59948) where a minimum sea-level pressure of 981.9 mb was reported. Lois then spent a day crossing the Gulf of Tonkin (Figures 3-13-1 and 3-13-2), before moving ashore at 291600Z in a sparsely populated area of Vietnam. Bach Longvi, Vietnam (WMO 48839), reported a minimum sea-level pressure of 989.9 mb at 291800Z. Continuing westward, the system dissipated over the mountains of Laos, prompting the JTWC to issue the final warning, valid at 300600Z.

III. DISCUSSION

Influence of the southwest monsoon on tropical cyclone motion

Lois' northeastward motion during the period of its formation (23 through 24 August) was typical of that seen whenever a tropical cyclone is affected by deep southwesterly monsoonal winds that flow past that tropical cyclone to another tropical cyclone downstream. In the case of Lois, as Tropical Storm Janis (10W) crossed the region of Taiwan and the Ryukyu Islands, the southwest monsoon in the South China Sea extended to the north-northeast, linking with the circulation of Janis (10W) (Figure 3-13-3). A case can be made that the pre-Lois tropical disturbance moved northeastward in response to the monsoonal flow that had extended toward Janis (10W). By 26 August, Janis (10W) was recurving into midlatitudes, and a ridge became established between it and Lois that severed the northeastward extension

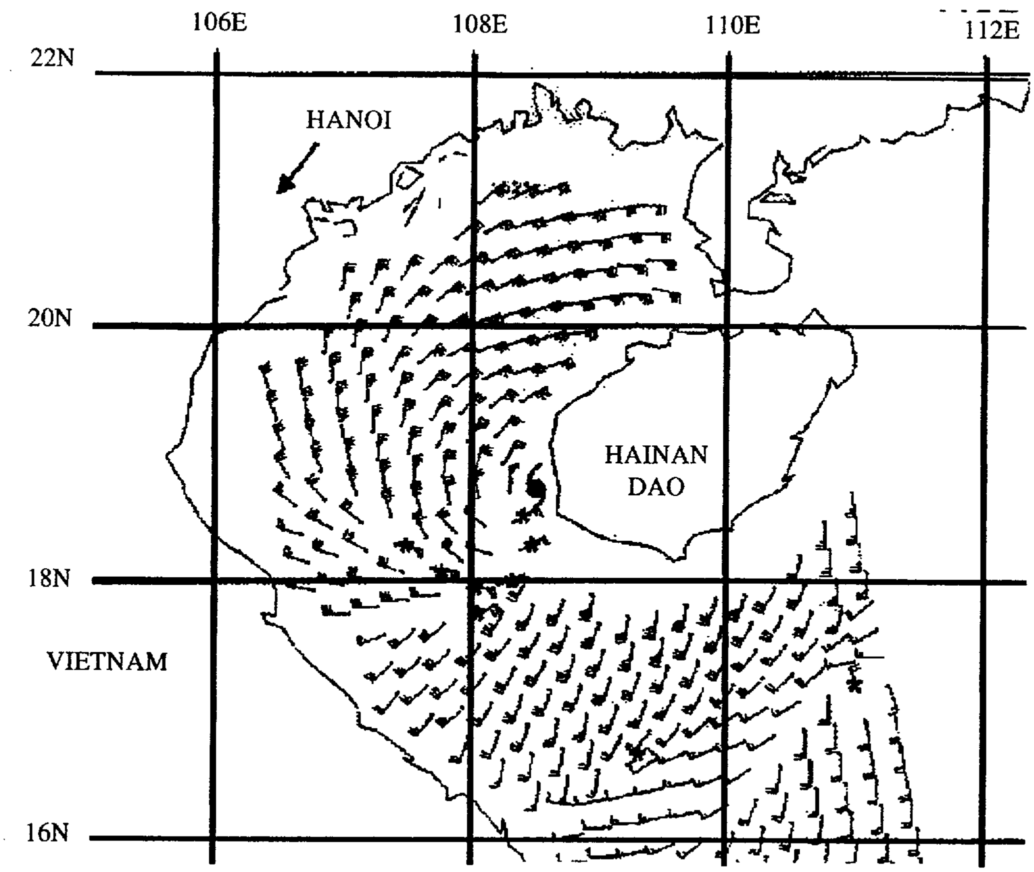


Figure 3-13-1 The surface wind field of Lois as it moves from Hainan Island into the Gulf of Tonkin as derived from the scatterometer aboard the ERS-1 spacecraft. Wind barbs that are 180 degrees in error are marked with an asterisk. Typhoon symbol marks the interpolated location of Lois (281500Z August ERS-1 scatterometer-derived marine surface winds).

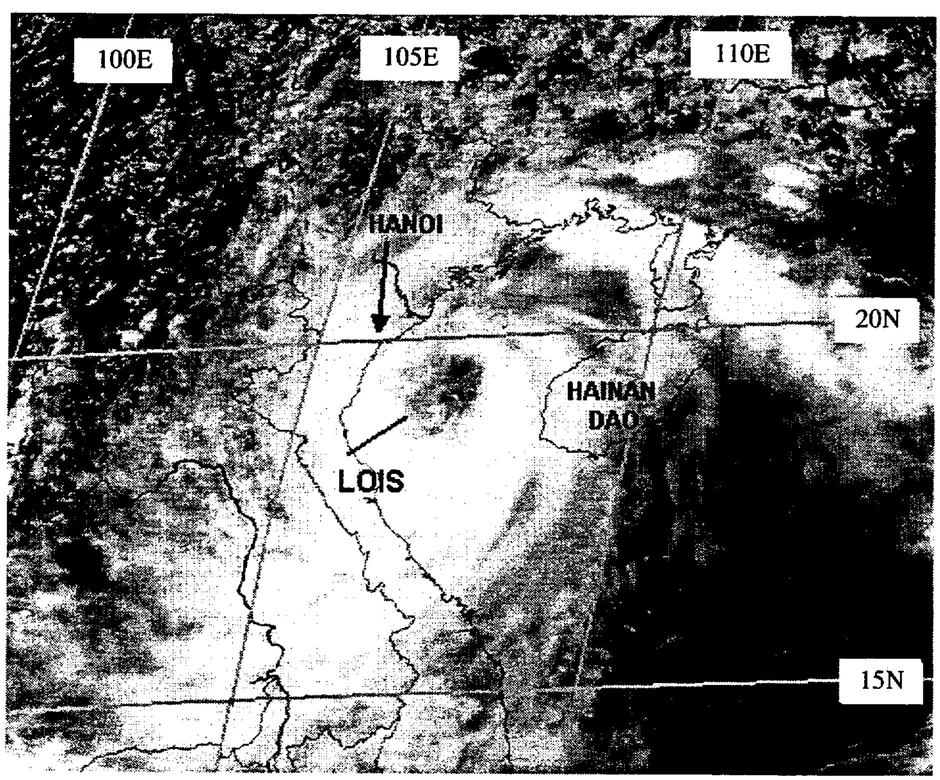


Figure 3-13-2 Typhoon Lois in the Gulf of Tonkin with a large 60 nm (110 km) diameter eye (290531Z August visible GMS imagery).

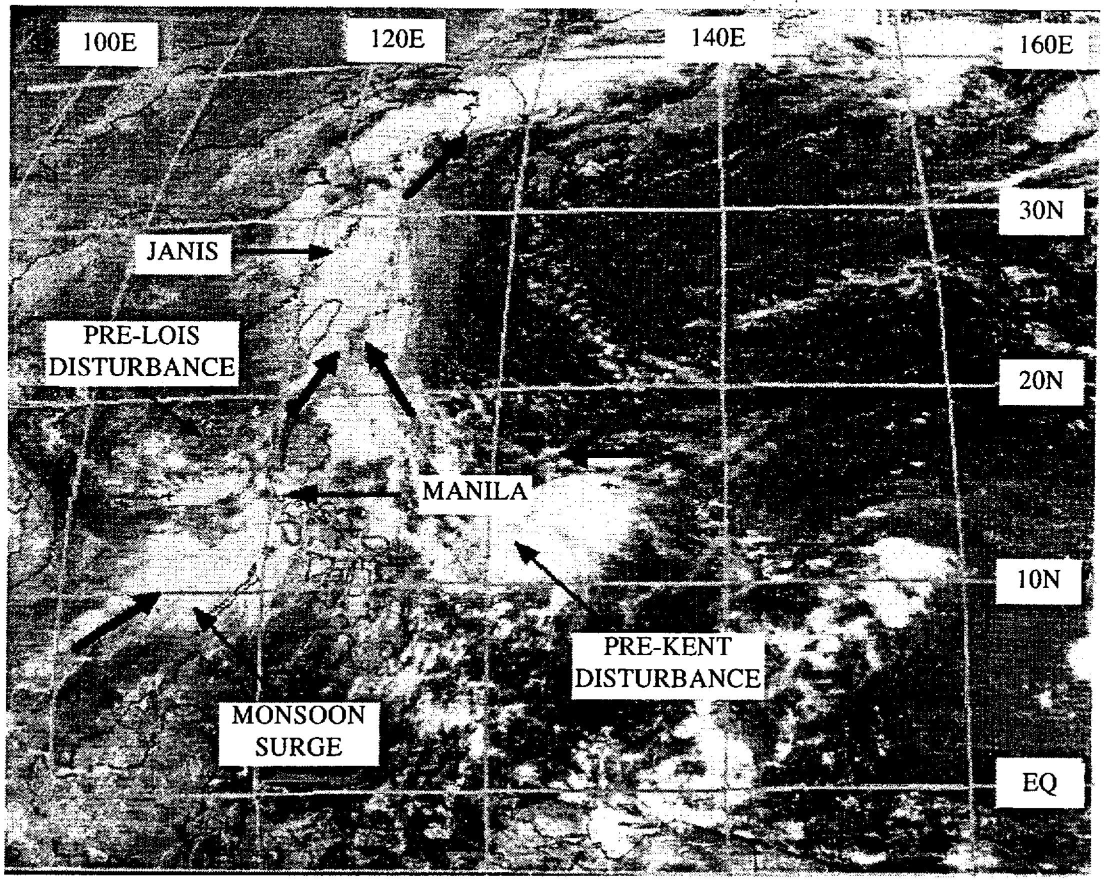
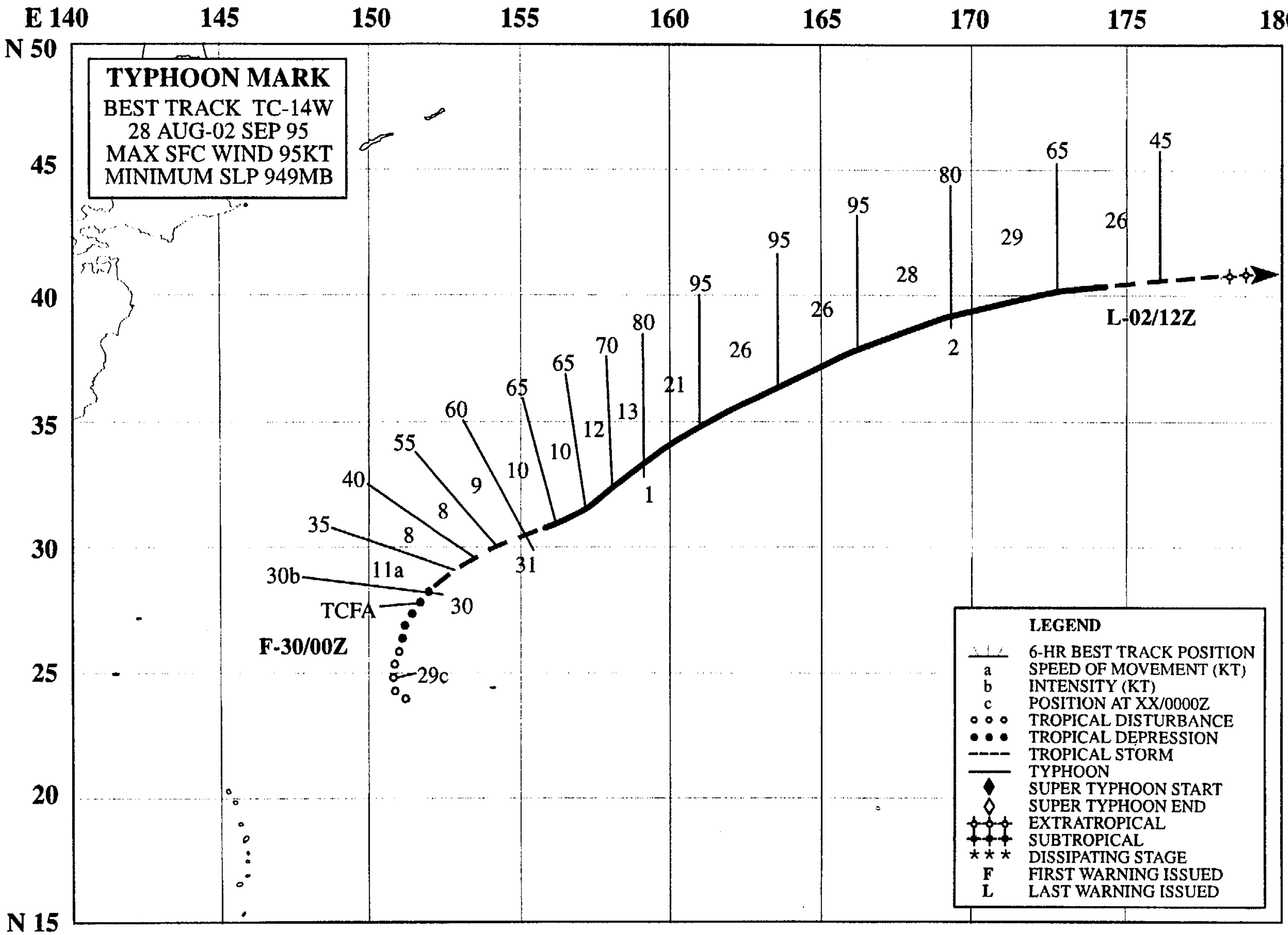


Figure 3-13-3 The southwest monsoon extends beyond the pre-Lois tropical disturbance and continues northeastward across the Philippines, then north-northeastward into Janis' circulation (242331Z August visible GMS imagery). Bold arrows depict the low-level wind flow. The locations of Janis (10W), pre-Kent (12W), and of pre-Lois are indicated.

of the southwest monsoon. In response to easterly flow south of the strengthening ridge, Lois turned toward the west.

IV. IMPACT

No reports of damage or injuries were received from China. In Vietnam, 45,000 acres of rice fields were reported flooded, with a total loss of the rice crop in nearly ten percent of the flooded acres. One hundred houses were destroyed and 2000 other homes were damaged in the province of Thanh Hoa, the hardest hit province. No reports of deaths or injuries in Vietnam were received at the JTWC.


TYPHOON MARK
BEST TRACK TC-14W
28 AUG-02 SEP 95
MAX SFC WIND 95KT
MINIMUM SLP 949MB
E 140
145
150
155
160
165
170
175
180
N 50
45
40
35
30
25
20
N 15
F-30/00Z
L-02/12Z
TCFA
29c
30b
30
31
1
2
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TYPHOON MARK (14W)

I. HIGHLIGHTS

Forming at a relatively high latitude, Mark was a very small sized tropical cyclone that moved northeastward for most of its track. While moving in excess of 20 kt (37 km/hr) toward the polar front, and while passing over increasingly cooler sea surface temperatures, Mark acquired a well-defined eye and reached a peak estimated intensity of 95 kt (49m/sec) as it tracked northeastward from 35°N to 37°N. The relatively high peak intensity attained by Mark was somewhat of a surprise, given the synoptic situation.

II. TRACK AND INTENSITY

The tropical disturbance that became Mark was first detected on the northeastern side of a westward moving TUTT cell. Visible satellite imagery obtained shortly after sunrise on 30 August showed cyclonically curved low-level cloud lines wrapping beneath an area of deep convection. This disturbance was located north-northwest of Minami Tori Shima in a data-poor region in the subtropics of the western North Pacific. Based upon the aforementioned indications on satellite imagery of the development of a low-level circulation center associated with this tropical disturbance, a Tropical Cyclone Formation Alert was issued at 292200Z August. Shortly thereafter, at 300000Z August, the first warning was issued. The prognostic reasoning message accompanying this first warning stated:

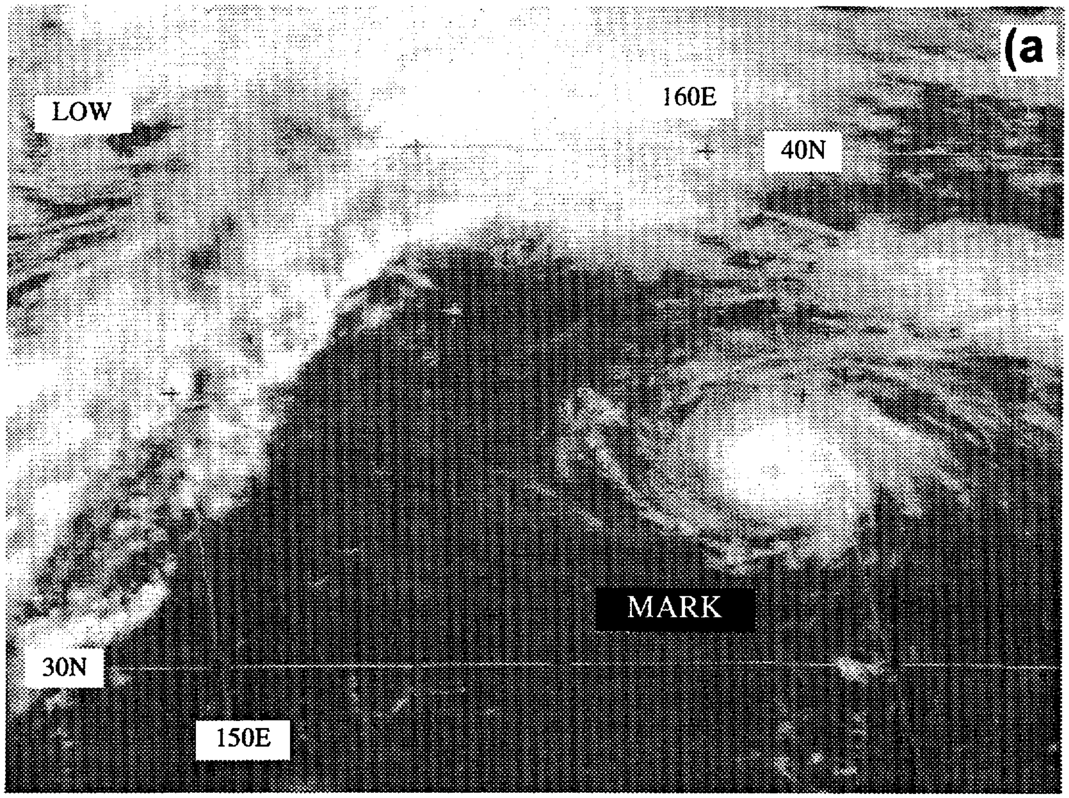
"Tropical Depression 14W has formed north of Minami Tori Shima . . . the initial disturbance was spawned from a tropical upper tropospheric trough (TUTT) cell . . . [deep] convection [has] developed rapidly over an 18 hour period."

Additional comments included:

"Due to the relatively high latitude at which 14W formed, and its proximity to the baroclinic zone to the northeast, 14W is not expected to intensify much past minimal tropical storm [intensity] before it undergoes extratropical transition."

Tropical depression 14W was upgraded to Tropical Storm Mark at 300600Z August based upon indications from satellite imagery of further intensification. Mark was already moving to the northeast at a relatively high latitude (approximately 30°N), and significant further intensification was not anticipated. On the evening of 31 August, a small ragged eye appeared within the small CDO, and Mark was upgraded to a Typhoon at 310600Z August. Mark was now north of 30°N and moving northeastward at 10 kt. A frontal system was approaching from the west, and JTWC forecasters expected Mark to accelerate, interact with the approaching front, and undergo extratropical transition within 36 to 48 hours.

During the subsequent 24 hours, Mark continued to move northeastward while remaining ahead of the approaching front. In a surprising structural evolution, during the morning of 01 September, the very small sized Typhoon Mark developed a small well-defined eye (Figure 3-14-1a,b). During the evening and night of 01 September, the cloud-top temperatures of the wall cloud surrounding Mark's well-defined eye cooled, and the estimated intensity peaked at 95 kt (49 m/sec) at 010600Z September. While Mark retained its peak intensity during the period 010600Z to 011800Z September, its speed of translation increased from 20 kt to 31 kt (37 to 57 km/hr). This rapid speed of translation delayed Mark's entrainment into the frontal system approaching from the west. On 02 September, the typhoon began to experience vertical wind shear from the west, and Mark was downgraded to a tropical storm late in the day. At 021200Z September, the JTWC issued the final warning on Tropical Storm Mark based upon its acquisition of extratropical characteristics.



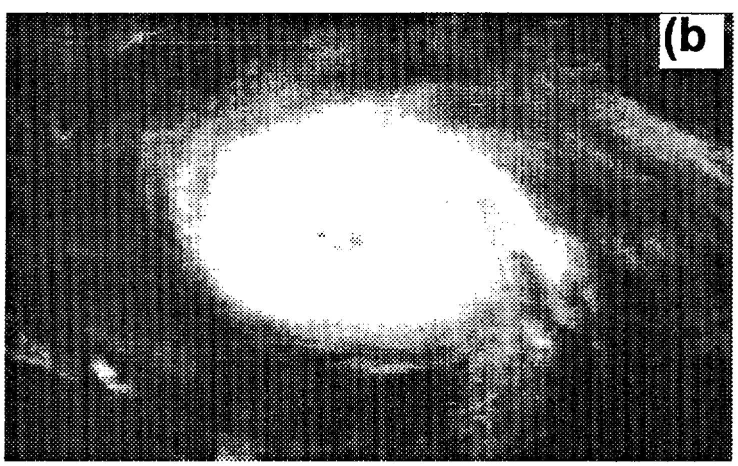


Figure 3-14-1 (a) Typhoon Mark intensifies as it moves rapidly northeastward in the warm sector of an approaching mid-latitude low-pressure system. (b) An expanded image of Typhoon Mark at the same picture time as in (a). (Both images are 010031Z September visible GMS imagery).

III. DISCUSSION

a. *Formation and development at high latitude*

Relatively few tropical cyclones (TCs) form in the western North Pacific poleward of 25°N — during the 21-year period 1970 to 1990 only twenty-four of 585 tropical cyclones (4%) that formed in the western North Pacific first attained 25 kt (12 m/sec) intensity at, or north, of 25°N. Mark first attained 25 kt intensity at 27°N. It became a tropical storm at 29°N, a typhoon at 31°N, and reached its peak intensity of 95 kt (49 m/sec) at 35°N. The sea surface temperature at the point where Mark's intensity peaked was approximately 24°C (Figure 3-14-2).

The synoptic conditions under which TCs form at very high latitude include:

1) formation in the mei-yu front,

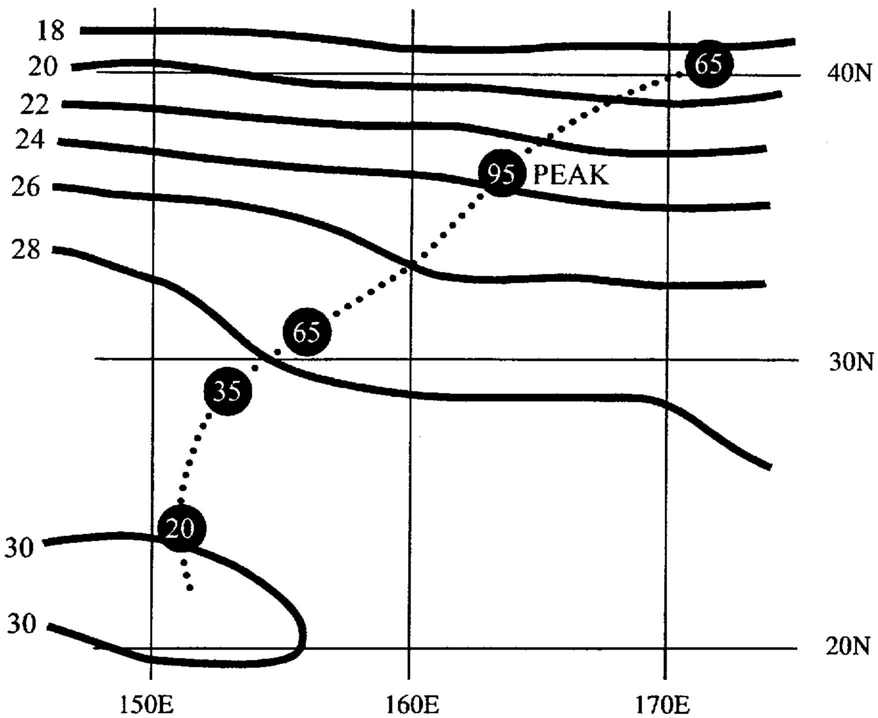


Figure 3-14-2 Selected threshold intensities (in kt) of Mark (white numbers within the black circles) along Mark's track (dotted line) superimposed on the NOGAPS sea surface temperature analysis (°C) of 02 September.

2) formation at the northeastern reaches of a reverse-oriented monsoon trough,
3) formation in association with a TUTT cell, and
4) formation at the base of a mid-latitude trough.

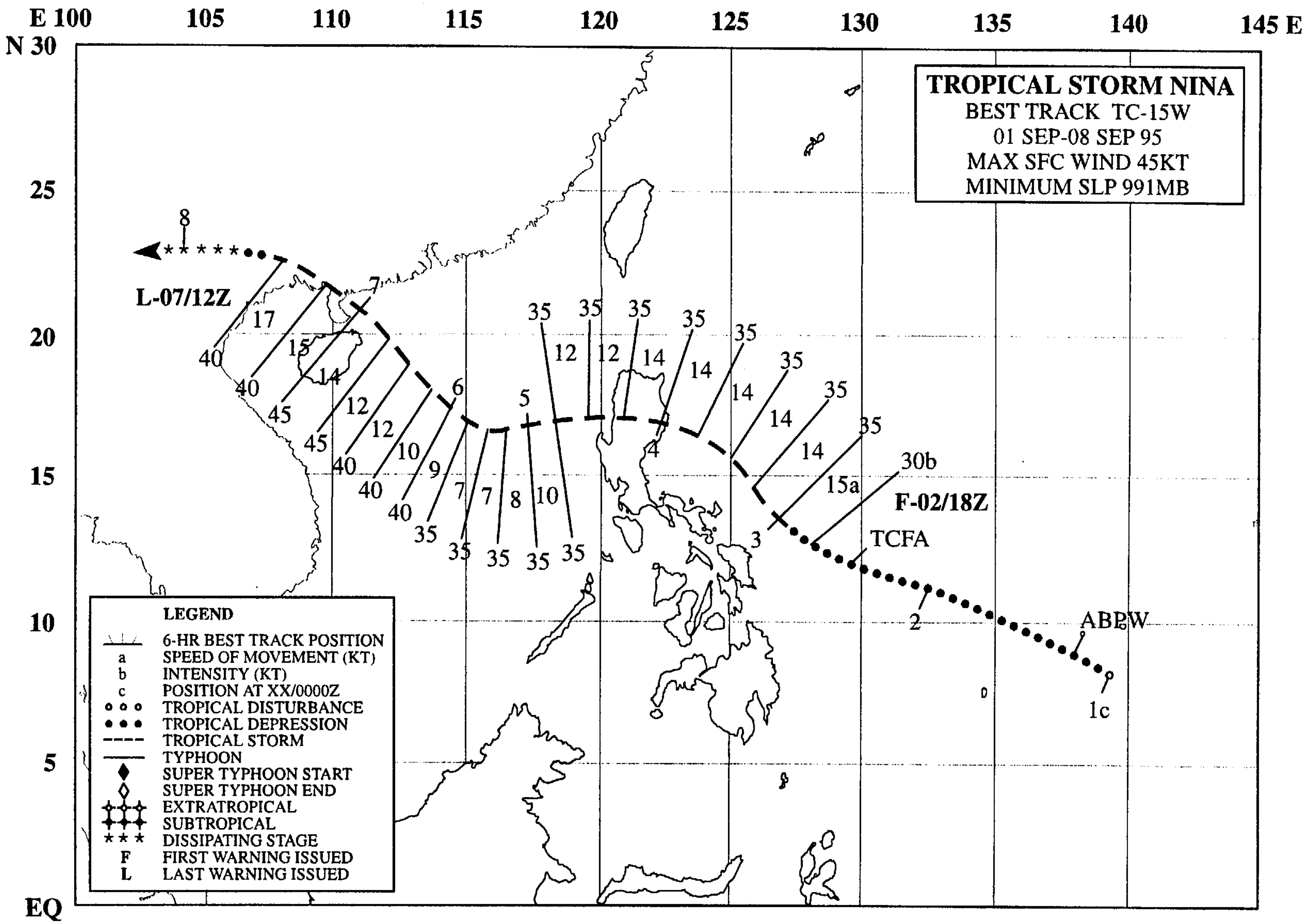
Mark formed in association with a TUTT cell. On 28 August, the tropical disturbance that became Mark was located in the northeastern quadrant of a TUTT cell that was centered at about 20°N over the Mariana Islands . The pre-Mark disturbance moved northward, intensified and approached the polar frontal boundary which then stretched east-west along approximately 35°N. Mark reached its peak intensity while traveling northeastward at a relatively high speed of translation, and while in the warm sector of an eastward moving mid-latitude low-pressure system (Figure 3-14-1a).

b. *Small size*

Like most TCs that form at high latitude in association with TUTT cells, Mark was a very small tropical cyclone. The diameter of its cloud shield was about 100 nm (185 km), and it encompassed a very small eye whose diameter fluctuated within a range from 5 (9 km) to 10 nm (18 km) on satellite imagery. As with many very small tropical cyclones, the intensity forecasts were quite poor: on the first eight warnings (issued at six-hour intervals from 300000Z August to 311800Z August), the 24-hour intensity was under-forecast by anywhere from 20 to 40 kt (21 m/sec); and, the 48-hour intensity was under-forecast by as much as 65 kt (33 m/sec).

IV. IMPACT

For its entire track, Mark remained far at sea, and no reports of significant damage were received.


TROPICAL STORM NINA
BEST TRACK TC-15W
01 SEP-08 SEP 95
MAX SFC WIND 45KT
MINIMUM SLP 991MB
E 100
105
110
115
120
125
130
135
140
145 E
N 30
25
20
15
10
5
EQ
L-07/12Z
F-02/18Z
TCFA
ABPW
1c
2
3
4
5
6
7
8
15a
30b
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL STORM NINA (15W)

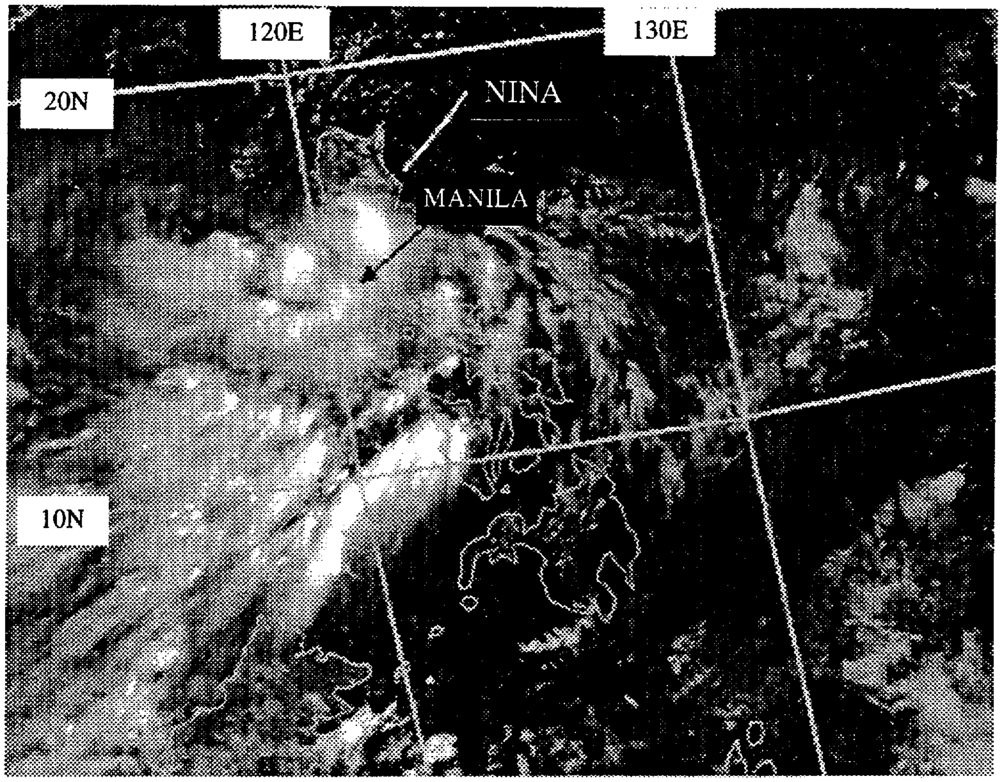


Figure 3-15-1 Tropical Storm Nina just after making landfall on eastern Luzon (040107Z September visible DMSP imagery).

I. HIGHLIGHTS

Nina was one of seven tropical cyclones during 1995 that passed over the Philippines with an intensity of 35 kt (18 m/sec) or greater. Reaching a peak intensity of only 45 kt (23 m/sec), it was one of several slow developing and low-intensity tropical cyclones — a signature characteristic of 1995.

II. TRACK AND INTENSITY

On the afternoon of 01 September, an area of deep convection was first mentioned on the Significant Tropical Weather Advisory, valid at 010600Z. This area, located approximately 400 nm (740 km) south-southwest of Guam, moved rapidly to the northwest. As the disturbance crossed the 130°E meridian, low-level southwesterly monsoon winds increased across the southern Philippines and merged with the disturbance. Based on an increase in the amount of deep convection and improvements in organization, the JTWC issued a Tropical Cyclone Formation Alert valid at 021630Z September. The first warning on Tropical Depression 15W followed, valid at 021800Z. Only six hours after the first warning, TD 15W was upgraded to Tropical Storm Nina.

Moving northwestward at 14 kt (26 km/hr), Nina made landfall on the east coast of Luzon shortly before 040000Z. Nina was poorly organized as it crossed Luzon (Figure 3-15-1), and though satellite intensity estimates indicated 35 kt (18 m/sec), no landfall wind reports were available from PAGASA that indicated more than 15 kt (8 m/sec). The lowest sea-level pressure recorded in the Philippines during Nina's passage was 1003 mb.

Nina slowly intensified once it entered the South China Sea. Under the influence of strong upper-level northeasterly flow, the system was sheared, with most of the deep convection located on the south side (Figure 3-15-2). On the morning of 06 September, Nina's movement changed from westward to northwestward. The system continued on a northwestward track until it made landfall at 070300Z on the Luichow peninsula in southern China. The peak intensity of 45 kt (23 m/sec) was attained eight hours before landfall. The final warning, valid at 071200Z, was issued by the JTWC as Nina dissipated near the China-Vietnam border.

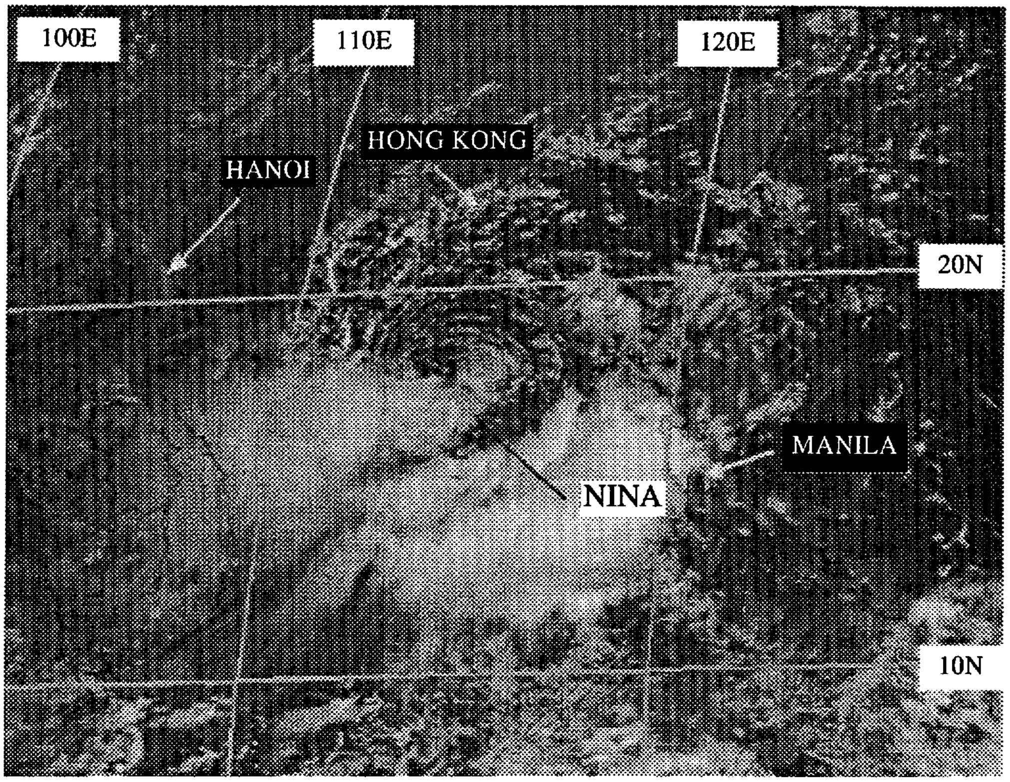


Figure 3-15-2 Thirty-six hours after exiting the Philippines, Tropical Storm Nina, with 40 kt (21 m/sec) one-minute sustained winds, is becoming better organized despite apparent manifestations of northeasterly shear (e.g., the low-level circulation center is partially exposed on the northeastern side of an area of deep convection) (052331Z September visible GMS imagery).

III. DISCUSSION

a. *Another low end tropical cyclone during 1995*

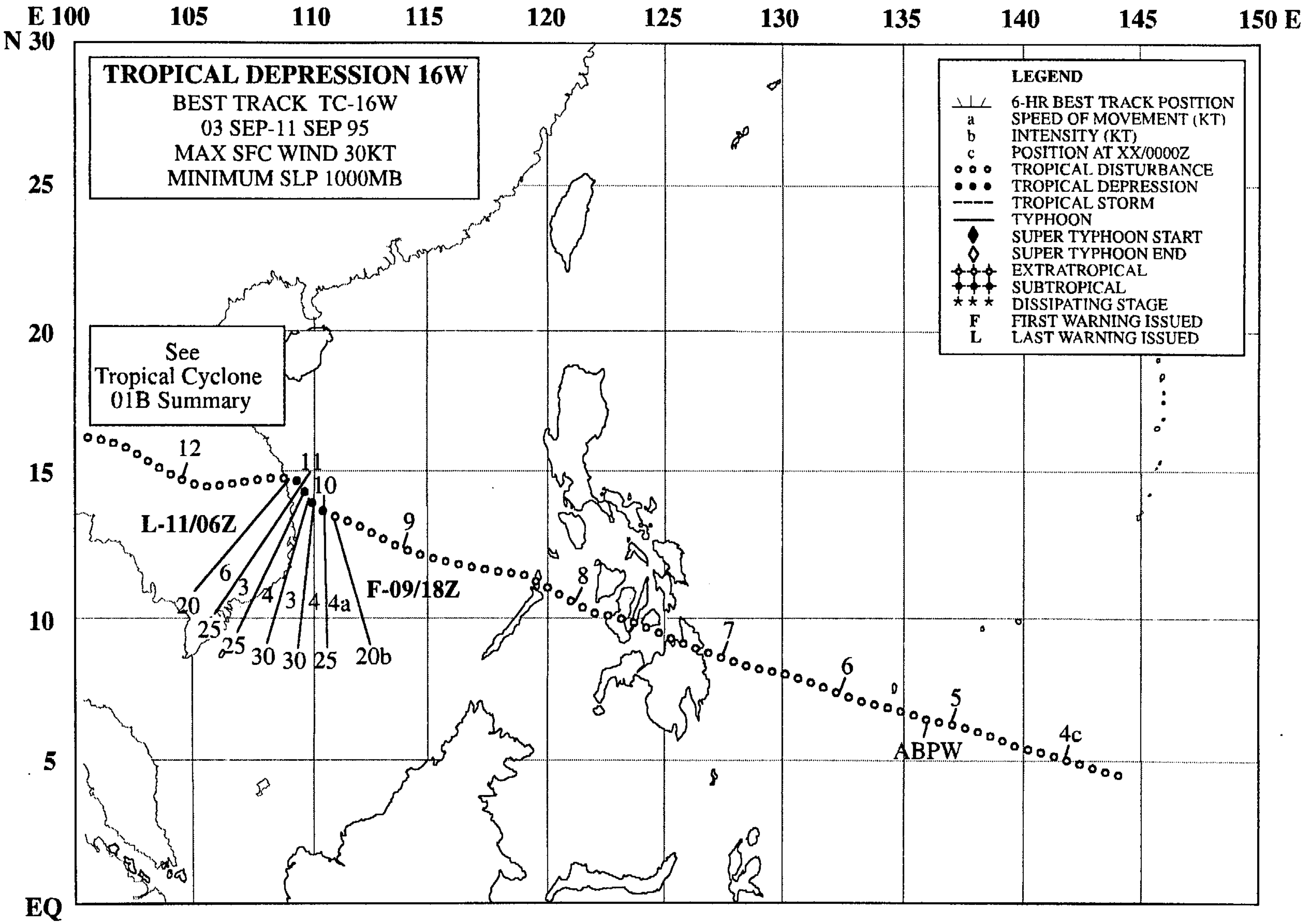
During 1995, a large proportion of the year's tropical cyclones were weak. Of the 34 significant tropical cyclones only 26 were tropical storms or typhoons, and eight never made it past tropical depression intensity. Of the 26 tropical cyclones that intensified beyond the tropical depression stage, 11 were tropical storms and 15 were typhoons. In all, 19 (56%) of the significant tropical cyclones of 1995 did not mature to become typhoons. The long term annual distribution of tropical cyclones in the western North Pacific stratified by intensity is: 18 typhoons, 10 tropical storms, and three tropical depressions. Thus, of the long-term annual average of 31 significant tropical cyclones in the western North Pacific, a total of 13 (42%) do not mature to become typhoons. The higher proportion of low-end tropical cyclones during 1995 is consistent with the persistent easterly wind flow at low latitudes, and the resulting westward shift of the leading edge of the monsoon trough and the westward shift of the mean genesis latitude.

b. *Dvorak T numbers too low*

From 06-08 September, the Dvorak T-number values were consistently 1.5 to 2.0 T-numbers too low for the observed maximum wind speeds. This result is typical when the Dvorak techniques are applied to tropical cyclones (such as Nina) that possess the characteristics of a monsoon depression. Many tropical cyclones that form in the western North Pacific start out as monsoon depressions. The lack of significant central deep convection within the light-wind core of the typical monsoon depression renders Dvorak's satellite intensity estimation techniques largely inapplicable. Many monsoon depressions that form in the western North Pacific develop peripheral gales before they acquire persistent central deep convection. Persistent central deep convection in the core of a monsoon depression marks its transition into a conventional tropical cyclone to which Dvorak's technique applies.

IV. IMPACT

In the Philippines, at least 50 people perished due to floods and mudslides. Several villages in the Pampanga Province (about 50 nm (95 km) north of Manila) were buried under lahars surging off the slopes of Mount Pinatubo. No reports of damage or injuries in China were received at the JTWC.


TROPICAL DEPRESSION 16W
BEST TRACK TC-16W
03 SEP-11 SEP 95
MAX SFC WIND 30KT
MINIMUM SLP 1000MB
See
Tropical Cyclone
01B Summary
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 100
105
110
115
120
125
130
135
140
145
150 E
N 30
25
20
15
10
5
EQ
L-11/06Z
F-09/18Z
ABPW
12
11
10
9
8
7
6
5
4c
4a
20b

TROPICAL DEPRESSION (16W)

I. HIGHLIGHTS

Tropical Depression 16W (TD 16W) followed three days behind Tropical Storm Nina (15W) on an almost parallel track, approximately 5 degrees latitude further to the south. Although their tracks were similar, TD 16W failed to develop into a significant tropical cyclone until just prior to making landfall on the Vietnam coast. The remains of TD 16W continued westward across Southeast Asia to form Tropical Cyclone 01B in the Bay of Bengal.

II. TRACK AND INTENSITY

The tropical disturbance that would eventually become Tropical Depression 16W (TD 16W) was first identified on satellite imagery as a large area of enhanced convection centered near 5°N 145°E on 03 September. Similar to other disturbances during this period, the system was slow to develop as it tracked slowly westward under persistent upper-level easterly shear. By 050600Z September, when it was first discussed on the Significant Tropical Weather Advisory, a well-defined low-level circulation still could not be readily identified on visual satellite imagery although it could be inferred from the gradient wind flow over Yap (WMO 91413) and Koror (WMO 91408). The disturbance continued to track westward for the next five days across the southern Philippine Islands and into the South China Sea with little sign of development. At 081200Z satellite imagery indicated the convective organization had improved and synoptic data indicated several 20-25 kt (10-13 m/sec) wind reports along the outer periphery of the convective area. During this time, however, the 200 mb analysis continued to show 25-35 kt (13-18 m/sec) easterly winds in the vicinity of the disturbance. The first warning for TD 16W was finally issued at 091800Z when scatterometer data from 091512Z and nearby ship reports indicated 25 kt (13 m/sec) winds near the circulation center. TD 16W reached a maximum intensity of 30 kt (15 m/sec) just prior to reaching the coast of Vietnam (Figure 3-16-1). The final warning for this system was issued at 110600Z after TD 16W had made landfall. The remains of TD 16W continued to move slowly

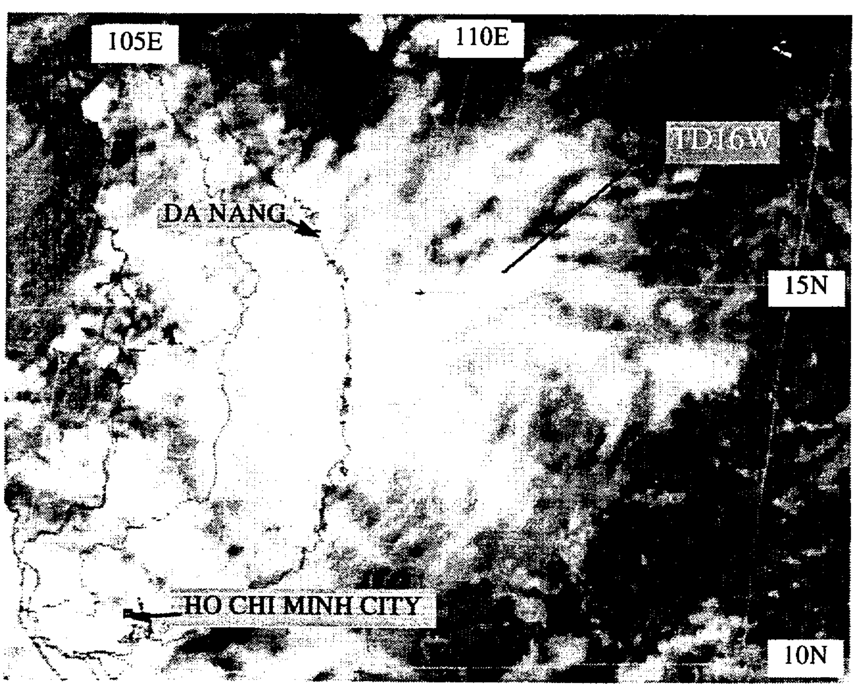


Figure 3-16-1 Tropical Depression 16W approaches the coast of Vietnam (100631Z September visible GMS imagery).

westward across Southeast Asia where it eventually became Tropical Cyclone 01B in the Bay of Bengal.

III. DISCUSSION

Eleven tropical cyclones formed in the western North Pacific during the nearly seven week period between 26 July and 10 September. Of these, eight formed in either the Philippine Sea or the South China Sea and were straight movers — presumably related to a strong dominant ridge (Figure 3-16-2) over the East China Sea and a monsoon flow that generally only extended as far east as the Philippine Islands. Typical of 1995, seven of the eight were relatively weak systems (one tropical depression, four tropical storms, and two minimal typhoons). TD 16W was the last of this series of weak systems.

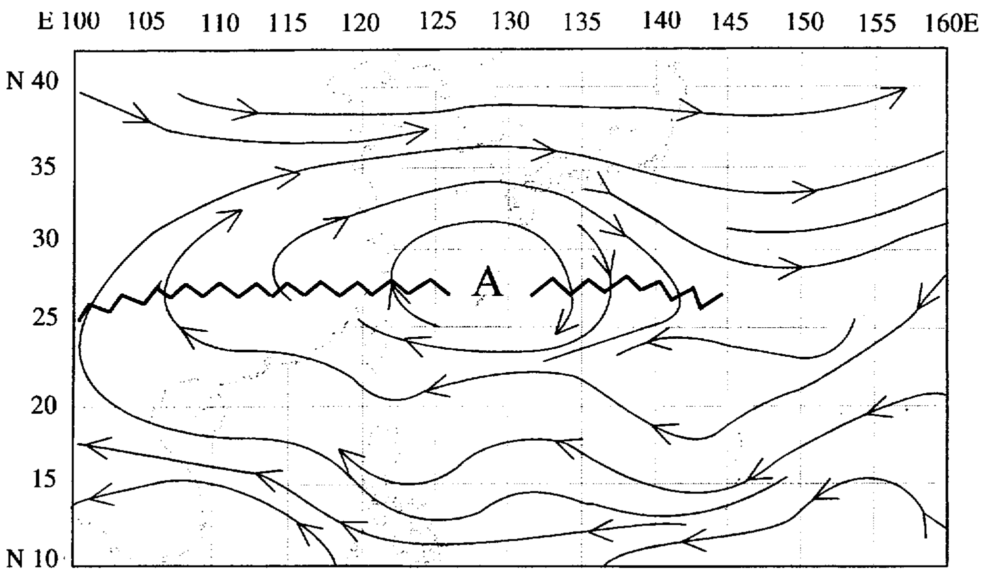


Figure 3-16-2 A strong subtropical ridge dominates the synoptic scale steering flow in the western North Pacific (091200Z September 500-mb NOGAPS streamline analysis).

Situated within the equatorial trough, the disturbance that was to become TD 16W fell under the influence of a strong upper-level ridge situated over the East China Sea and eastern China throughout most of its life. This dominant flow served to steer the cyclone on a mostly westward track under moderate to strong easterly shear. It was not until the disturbance moved into the South China Sea and under the influence of southwest monsoon flow, that development occurred. After TD 16W, the dominant ridge moved back into China (Figure 3-16-3) while the monsoon pushed east of the Philippines, and a series of more intense recurving tropical cyclones developed.

IV. IMPACT

No reports were received of significant damage or fatalities in Vietnam. However, news releases dated 07 September from the Mindanao Islands in the Philippines reported numerous homes damaged. The damage was initially attributed to a surprise eruption of a volcano. Later reports attributed the damage to mudslides from the collapse of a volcanic wall due to heavy rains in the area. Postanalysis shows that these heavy rains were probably associated with the disturbance that would eventually become TD 16W.

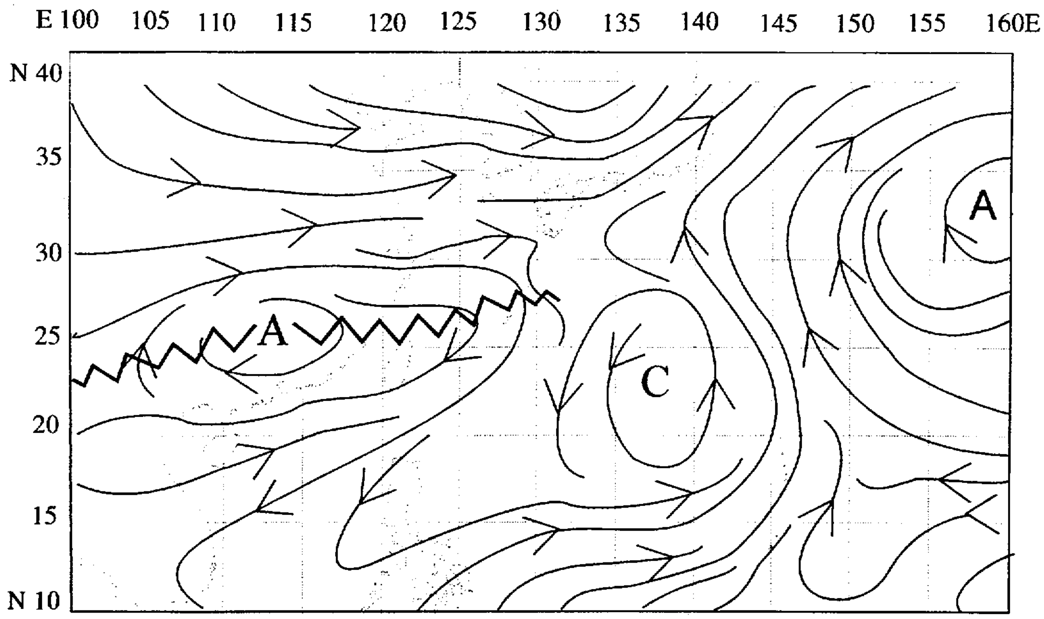
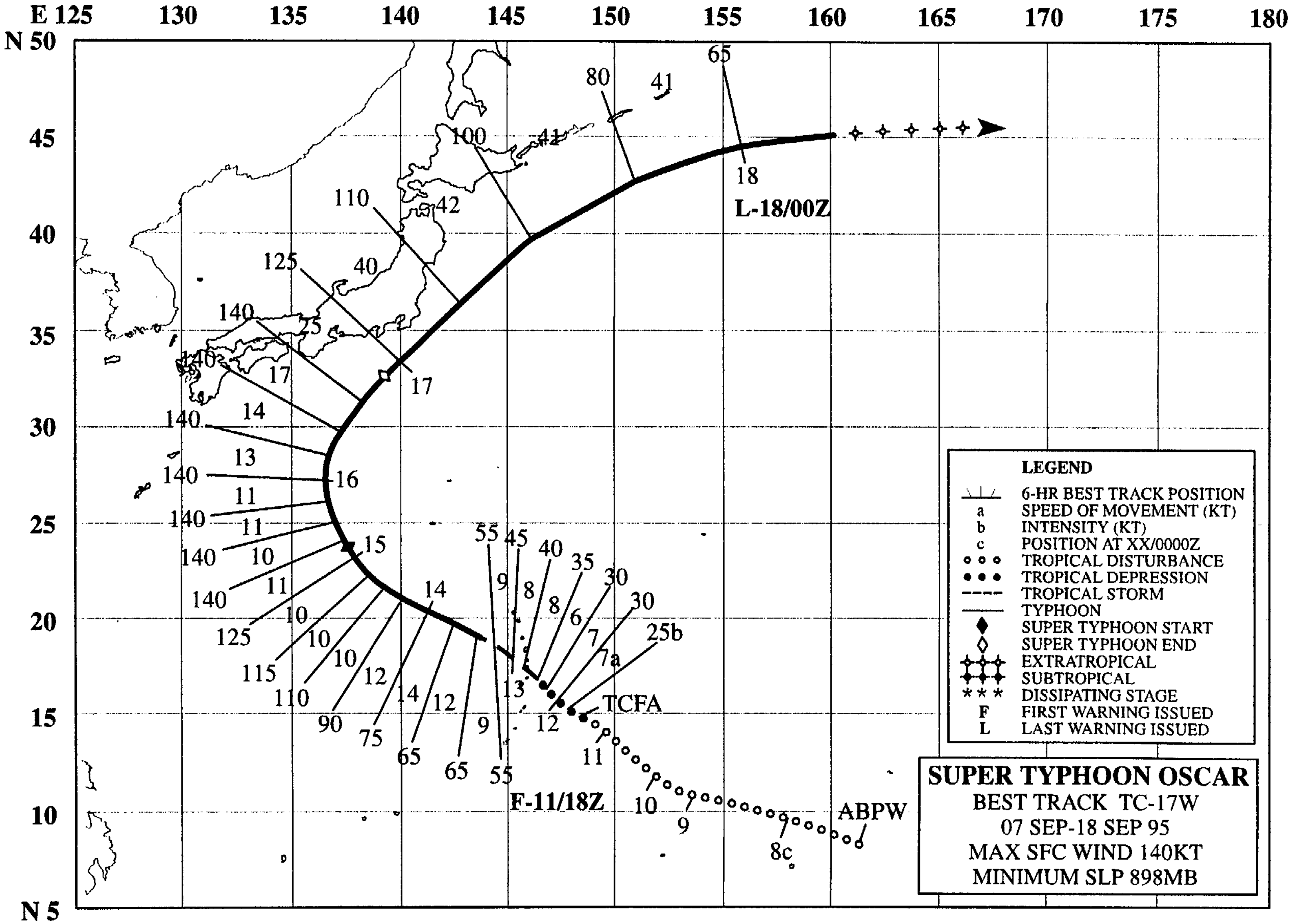


Figure 3-16-3 By mid-September, the subtropical ridge had receded westward into China, allowing a series of more intense recurving tropical cyclones to form (150000Z September 500-mb NOGAPS streamline analysis).


SUPER TYPHOON OSCAR
BEST TRACK TC-17W
07 SEP-18 SEP 95
MAX SFC WIND 140KT
MINIMUM SLP 898MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
F-11/18Z
L-18/00Z
TCFA
ABPW
E 125
130
135
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155
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N 5

SUPER TYPHOON OSCAR (17W)

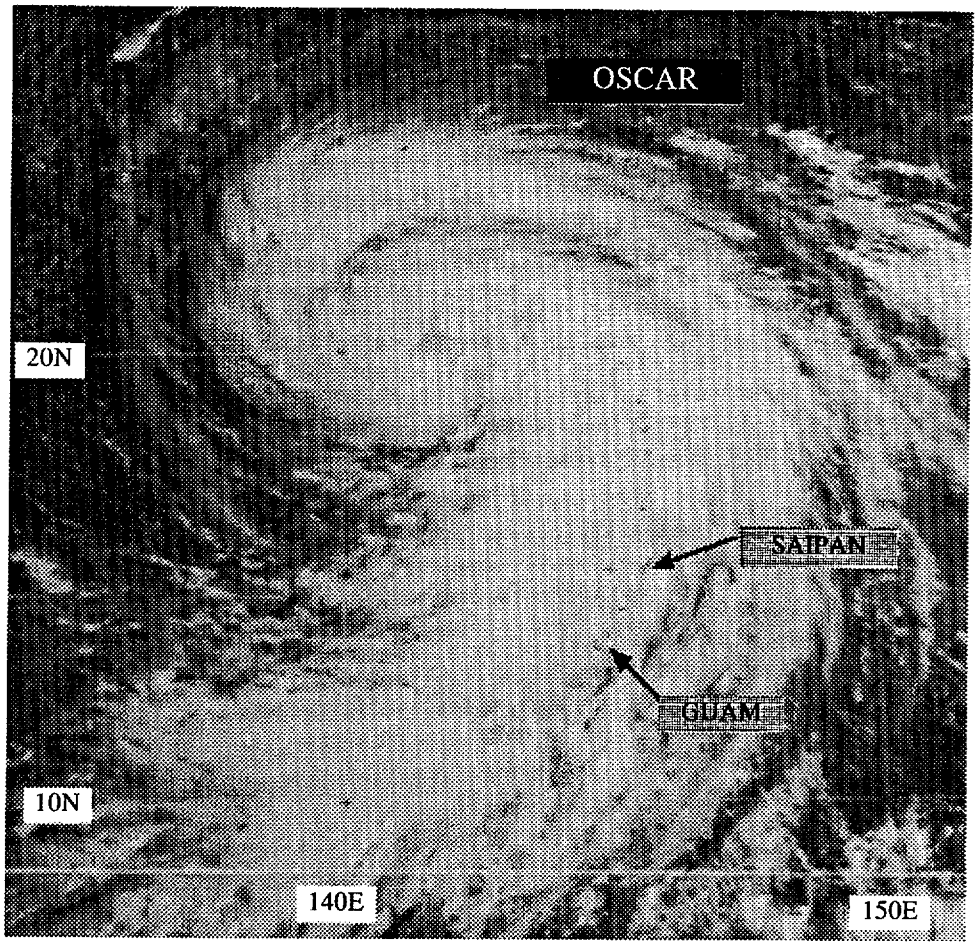


Figure 3-17-1 As Oscar becomes a typhoon, its cloud system covers a large area of the Pacific near the Mariana Islands (132131Z September visible GMS imagery).

I. HIGHLIGHTS

Forming at the eastern end of a monsoon trough which later became reverse-oriented, Oscar became a large tropical cyclone (Figure 3-17-1). Oscar also became a very intense tropical cyclone (Figure 3-17-2), reaching a peak intensity of 140 kt (72 m/sec). When the typhoon passed through the point of recurvature, it posed a serious threat to Tokyo and the southeastern coast of Japan. However, it turned far enough eastward to give only a glancing blow to extreme southeastern Honshu; the eye remained offshore as it passed about 100 nm (185 km) southeast of Tokyo. Oscar's rapid speed of translation — in excess of 40 kt (75 km/hr) — helped to spare Japan the full effects of the typhoon's highest winds. Nevertheless, heavy rain and high winds were responsible for loss of life, and some minor damage in Japan.

II. TRACK AND INTENSITY

Prior to the formation of Oscar, Tropical Storm Nina (15W) moved through the South China Sea. The southwest monsoon was well-established across the South China Sea, but extended only as far east as the Philippines. Elsewhere in the tropics, low-level winds were light, sea-level pressure was slightly above normal, and deep convection was scattered in disorganized clusters throughout Micronesia. Then, on 07 September, the amount of deep convection began to increase in a broad area bounded by the equator and 20°N from 140°E to 170°E. A tropical disturbance was first mentioned on the 070600Z September Significant Tropical Weather Advisory: synoptic data indicated that a weak low-level cyclonic circulation center accompanied an area of convection near 8°N 163°E. By 11 September, the monsoon trough axis had lifted northward and extended past Guam to about 150°E. For the first time during 1995, Guam experienced monsoonal low-level southwesterly wind. At the eastern reaches of this monsoon trough (about 200 nm northeast of Guam), deep convection began to organize around a low-level circulation center, prompting the JTWC to issue a Tropical Cyclone Formation Alert at 111430Z. The JTWC issued the first warning, valid at 111800Z on Tropical Depression 17W. This was based on increased amounts of deep convection, the improved organization of the lines of deep convection and the pattern of the cirrus outflow. The island of Guam lay under one of the bands of deep convection. Lowering sea-level pressure, heavy rains, and gusty westerly winds confirmed the development of Tropical Depression 17W.

During the next two days, Oscar intensified, becoming a tropical storm at 121200Z, a typhoon at 131200Z, and a super typhoon at 150600Z. Even more noteworthy than the fairly rapid intensification of Oscar was its large size (Figures 3-17-1 and 3-17-2) (see the discussion section for comments on Oscar's large size). Near its point of recurvature, Oscar's radius of gales reached outward to 335 nm (620 km).

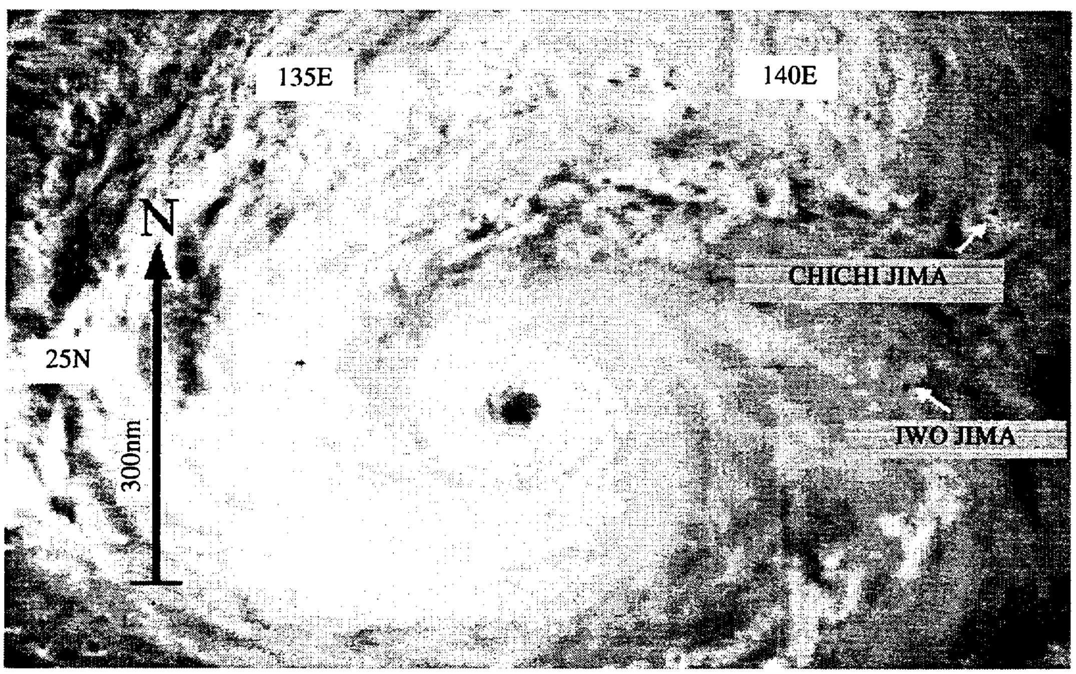


Figure 3-17-2 Oscar reaches its peak intensity of 140 kt (72 m/sec) (150730Z September visible GMS imagery).

Oscar reached its point of recurvature at 160000Z September when it was about 500 nm (925 km) southwest of Tokyo. At this point, forecast guidance and the synoptic situation suggested that Oscar would accelerate rapidly to the northeast and pass very close to Tokyo. During this very critical period, the JTWC forecasts were for landfall near Tokyo. Not until 170000Z did the official forecast take Oscar offshore about 90 nm (170 km) east-southeast of Tokyo. The following chronology of comments on JTWC warnings leading up to Oscar's closest point of approach (CPA) to Tokyo was extracted from the JTWC Deputy Director's unofficial electronic logbook:

"Warning #14 (15/0000Z): TY Oscar continues NWward 320 @ 09 knots. Forecasting super TY around 16/12Z. Track forecast follows the NO [north-oriented] pattern with slow turn NEward. This is the first forecast that makes landfall on Japan. Tokyo/Yokosuka around 17/06Z."

"Warning #19 (16/0600Z): STY Oscar's course has become more northward indicating the slow turn to the NEward track is occurring. (005@11 KTS). System will pass very close to Tokyo around 17/06. In fact, forecasting for landfall on Tokyo at 17/06Z."

"Warning #23 (17/0000Z): Oscar turned sharper to the right than forecasted. Now forecasting for about 60 nm's off the coast around 17/03Z."

"Warning #25 (17/1800Z): Tracking 046 @ 46 knots rapidly transitioning to ET [extratropical]." The final warning, valid at 180000Z, was issued by the JTWC when Oscar was deemed to have transitioned into a vigorous extratropical low moving rapidly eastward along 45°N.

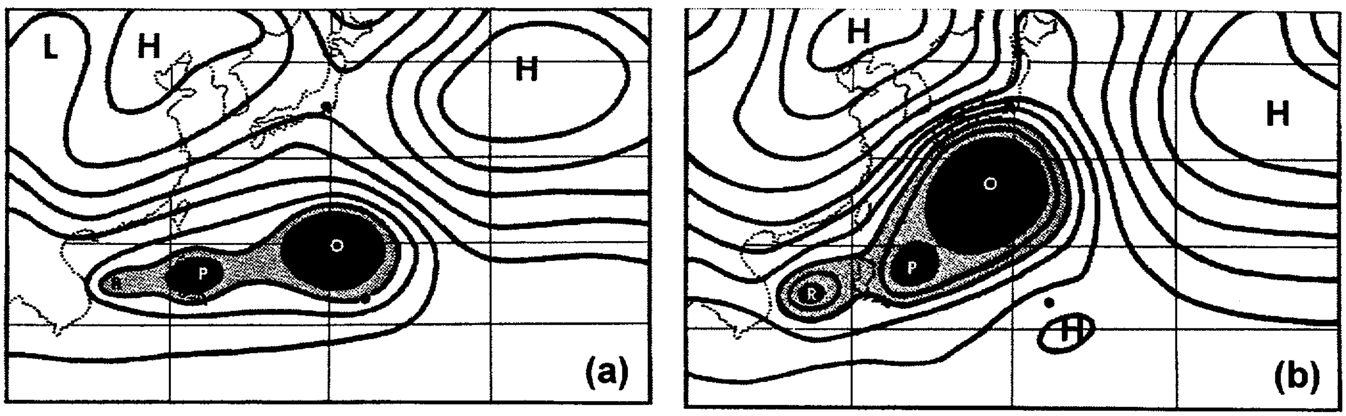


Figure 3-17-3 Sea-level pressure (SLP) analysis over the western North Pacific basin at 140000Z September (a), and 160000Z September (b). Three tropical cyclones — Oscar (O), Polly (18W) (P), and Ryan (19W) (R)— formed simultaneously along a reverse-oriented monsoon trough. Oscar's large size is indicated by its large average radius of outermost closed isobar which has a value of approximately 500 nm in (b). Solid lines are isobars at 2 mb intervals. In (a), the shaded region shows where SLP is lower than 1006 mb, the black areas are below 1004 mb. In (b), the shaded region shows where SLP is lower than 1006 mb, the black areas are below 1002 mb. The 1002 mb isobar in (b) is the outermost closed isobar of Oscar at that time.

III. DISCUSSION

a. *Development in a reverse-oriented monsoon trough.*

Oscar was the first of three tropical cyclones — the other two were Polly (18W) and Ryan (19W) — to develop along the axis of a reverse-oriented monsoon trough that stretched from the South China Sea east-northeastward into the Pacific Ocean north of Guam (Figure 3-17-3a). Oscar was the eastern-most tropical cyclone of the three. For a more detailed discussion of the reverse-oriented monsoon trough within which Oscar, Polly (18W) and Ryan (19W) developed, and its association with unusual motion of Polly and Ryan, see the discussion section in Polly's (18W) summary.

b. *Largest TC of 1995*

Super Typhoon Oscar was the largest tropical cyclone of 1995. Using the mean radius to the outermost closed isobar (ROCI) as a measure of Oscar's size, the system reached the threshold of the "very large" size category used by the JTWC (see Appendix A). At its largest, the mean ROCI was about 8° of great circle arc (GCA) (Figure 3-17-3b). Interestingly, the large expanse of cyclonically curved low-level wind flow surrounding Oscar, and the extensive amounts of cyclonically curved lines of low-level cumulus and deep convection surrounding Oscar (e.g., see Figure 3-17-2), extend significantly beyond the mean ROCI.

Tropical cyclone size is a very difficult parameter to objectively measure. Merrill (1984) classified a tropical cyclone as "small" if the mean ROCI was three degrees (180 nm, 335 km) GCA, or smaller; as "medium" if the mean ROCI was between three to five degrees GCA (180 nm to 300 nm ; 335 km to 555 km), and as "large" if the mean ROCI was greater than five degrees GCA (greater than 300 nm, 555 km). The Japan Meteorological Agency recognizes two additional size categories — "very small" and "ultra large" — that mesh neatly with Merrill's scheme (See Table 3-17-1). The definitions of size used herein (see Appendix A) have been adapted by a mesh of the JMA size categories with those of Merrill.

Table 3-17-1 Categories of tropical cyclone size based upon the average radius of the outermost closed isobar.

SIZE CATEGORY	RADIUS OF OUTERMOST CLOSED ISOBAR	
	(Degrees)	Nautical Miles
VERY SMALL	<2	<120
SMALL	2-3	120-180
AVERAGE	3-6	181-360
LARGE	6-8	361-480
VERY LARGE	>8	>480

c. *High speed of translation east of Japan*

While passing close to the eastern shores of the Japanese main island of Honshu, Oscar's speed of translation increased to values in excess of 40 kt (75 km/hr). The result of this rapid translation was a drastic reduction of the radial extent of high wind speeds to the left of Oscar's track, sparing Japan the full effects of Oscar's highest winds. A reasonable first approximation of the wind asymmetries in a tropical cyclone is to simply add the speed of translation to the vortex intensity on the right side — the so called dangerous semicircle — and to subtract the speed of translation from the vortex intensity on the left side, or weak semicircle. NEXRAD cross sections of tropical cyclones passing near Guam (see the discussion section of Super Typhoon Ward (25W)), and other composites of tropical cyclone wind structure show that this simple picture of tropical cyclone wind distribution is reasonable in the tropics. As tropical cyclones recurve into mid latitudes, it is not clear that the wind asymmetries are so simple. Indeed, the concepts of the "dangerous semicircle", where the vortex intensity is enhanced by the addition of translation, and the weak semicircle, where the vortex winds are reduced by the speed of translation are still valid to a large extent. However, as the case with Oscar shows, there are some fundamental properties of fast moving recurving tropical cyclones that need to be clarified.

There are insufficient data to allow one to accurately determine the wind distribution in Oscar as it sped past Japan, but one can analytically derive two possible wind distributions given two different interpretations of the warning intensity. If the intensity of a tropical cyclone is considered to be representative of the peak winds in the dangerous semicircle, one must subtract twice the translation speed from this wind in order to obtain the highest wind on the left side (given a uniform steering flow). In Oscar's case, if the peak winds were 120 kt on the right side of the storm, then, given its 40-kt translation speed, the peak winds on the left side could have been only 40 kt (i.e., 120 kt minus 80 kt). Mathematically, the shape of the isotachs surrounding a tropical cyclone with such a wind distribution will be bean-shaped (Figure 3-17-4). Given the warning radius of 50 kt winds of 220 nm (410 km) on the right side of Oscar, it is possible that 50 kt winds extended only 40 nm (75 km) to the left of Oscar's track in two lobes northwest and southwest of the center (Figure 3 -17-4).

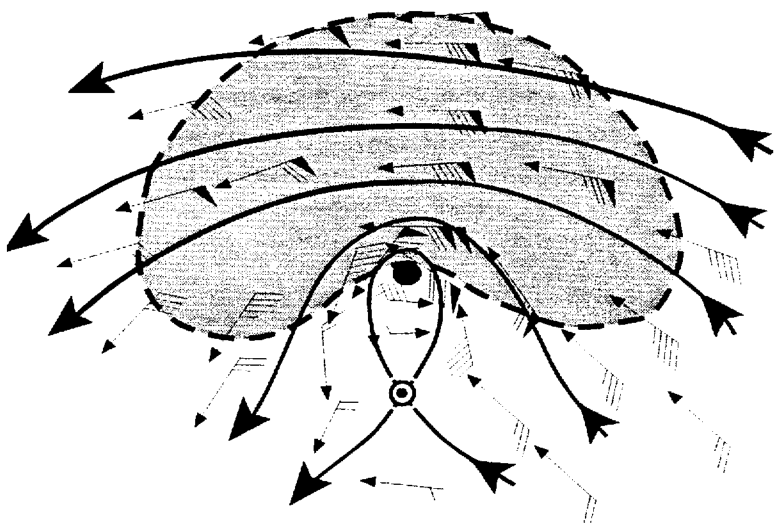


Figure 3-17-4 The analytical wind distribution for a tropical cyclone that is composed of an 80 kt symmetric vortex embedded in a 40 kt unidirectional steering flow. Large dot shows the cyclone center, solid lines are streamlines, and the dotted line shows the area of winds of 50 kt or greater.

If the intensity of a tropical cyclone is considered to be the intensity of the symmetrical portion of the tropical cyclone wind field (i.e., the translation speed is not considered), then the isotachs are shaped as above, only now the peak wind in the dangerous semicircle of a 120 kt tropical cyclone is 160 kt (i.e., 120 kt plus 40 kt), and in the weak semicircle (i.e., to the left of the track) it is only 80 kt. Now, given the warning radius of 50 kt winds of 220 nm (410 km) on the right side of Oscar, wind speeds of 50 kt (26 m/sec) extend 60 nm (110 km) directly to the left of the track, and nearly 100 nm to the left of the track in two lobes to the northwest and southwest. The wind distribution of a tropical cyclone that is rapidly accelerating following recurvature, and that is becoming extratropical is certainly a topic worthy of further study. This topic is of interest especially since the Dvorak technique does not explicitly address translational effects on intensity and wind distribution.

d. *Time series of the "digital Dvorak" (DD) number*

One of the utilities installed in the MIDDAS satellite image processing equipment is an automated routine for computing Dvorak "T" numbers for tropical cyclones that possess eyes. The routine, developed by Zehr (personal communication), adapts the rules of the Dvorak technique as subjectively applied to enhanced infrared imagery (Dvorak 1984) in order to arrive at an objective T number, or "digital Dvorak" T number (hereafter referred to as DD numbers). Infrared imagery is available hourly from the GMS satellite, and hourly DD numbers were calculated for several of the typhoons of 1995 (including Oscar).

The DD numbers presented herein are experimental, and methods for incorporating them into operational practice are being explored. In some cases, the DD numbers differ substantially from the warning intensity and also from the subjectively determined T numbers obtained from application of Dvorak's technique. The output of the DD algorithm, when performed hourly, often undergoes rapid and large fluctuations. The fluctuations of the DD numbers may lay the ground work for future modifications to the current methods of estimating tropical cyclone intensity from satellite imagery. The discussion of the behavior of the time series of the DD numbers for Oscar, and for some of the other typhoons of 1995 (e.g., see the summaries of Polly (18W), Ryan (19W), Ward (26W), and Angela (29W)), is intended to highlight certain aspects of the DD time series that may prove to have important research and/or warning implications.

In Oscar's case, the DD numbers rise steadily from values in the low fives beginning at 141630Z

September to a peak in the mid-sevens within a period of a few hours either side of 151230Z September (Figure 3-17-5). Thereafter, the DD numbers fall quite steadily, and drop below T 4.0 after 0630Z on September 17. Compared with both the warning intensity, and the final best track intensity, one can see that the DD number and the warning intensity (converted to a T number) rise in tandem. As the DD numbers began to fall, the warning intensity did not reflect this fall, but remained consistently higher. Part of the reason for this is the requirement in Dvorak's scheme that the current intensity (i.e., real-time warning intensity) be held one T number higher than the diagnosed (or data) T number when that diagnosed T number is falling.

On a final note, notice that in the case of Oscar, the time series of the DD numbers is well-behaved: they steadily rise to a peak, and then steadily fall after the peak is reached. The hour- to-hour variation is within a few tenths of a T number, and few large fluctuations are noted. Also, the warning intensity and the DD numbers are consistent (as described in the previous paragraph). This is not always the case: for Super Typhoon Ryan (19W), there were large short-term variations, and the DD numbers were not consistent with the best track intensity (see the discussion section in Ryan's summary).

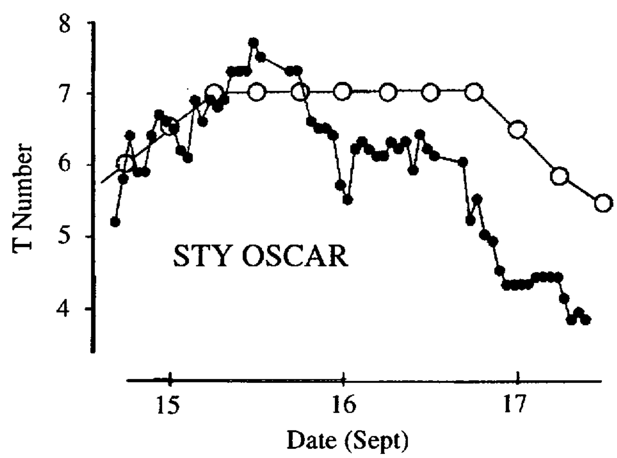
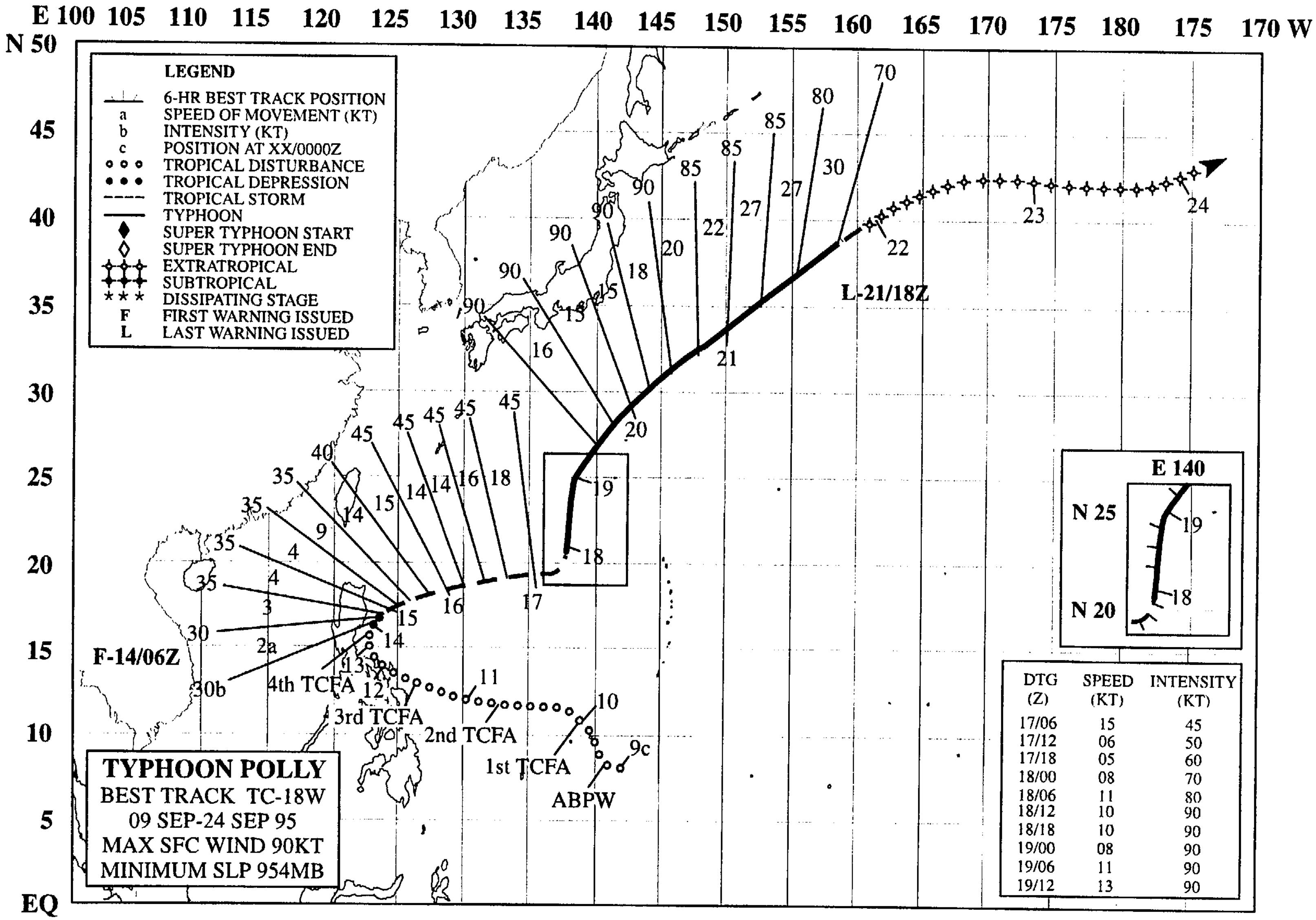


Figure 3-17-5 Hourly time series of the DD number obtained for Oscar during the period 141630Z September through 170930Z September (black dots), versus the final best track warning intensity (open circles).

IV. IMPACT

Sustained winds of typhoon intensity were recorded at exposed locations along the east coast of the Boso peninsula southeast of Tokyo. Winds at Narita airport and in the city of Tokyo did not exceed 50 kt (26 m/sec) sustained. The eye of Oscar passed near or over the island of Hachicho-Jima (WMO 47678) located about 90 nm (170 km) south of Tokyo; minimum sea-level pressure recorded was 938 mb.

Strong wind gusts and heavy rains associated with Oscar caused rail, air and ferry services to be suspended throughout the Kanto Plain. Press reports indicate that Oscar caused three deaths on land in Japan with six missing and feared dead in incidents at sea. Approximately 50 people were injured by falling debris (tiles blowing off roofs, and falling branches). Overall, only minor property damage was reported.



DTG (Z)	SPEED (KT)	INTENSITY (KT)
17/06	15	45
17/12	06	50
17/18	05	60
18/00	08	70
18/06	11	80
18/12	10	90
18/18	10	90
19/00	08	90
19/06	11	90
19/12	13	90

TYPHOON POLLY (18W)

I. HIGHLIGHTS

Polly developed in a reverse-oriented monsoon trough that extended from the South China Sea east-northeastward to just beyond Guam. Like many other tropical cyclones that form within, or move into, a reverse-oriented monsoon trough, Polly underwent unusual motion: an "S" shaped track. Two other tropical cyclones — Oscar (17W) and Ryan (19W) — also developed in this reverse-oriented monsoon trough; and, along with Polly, formed a SW-NE chain of tropical cyclones.

II. TRACK AND INTENSITY

The tropical disturbance that became Typhoon Polly can be traced back to a large area of deep convection centered south of Guam late on 08 September. It was first mentioned on the 090600Z Significant Tropical Weather Advisory when satellite imagery and synoptic data indicated the presence of a low-level cyclonic circulation center associated with this tropical disturbance. This disturbance moved westward for three days and then slowed as it neared Luzon. The first of four Tropical Cyclone Formation Alerts (TCFA) was issued on this disturbance at 100100Z as satellite imagery indicated improving organization of the system's deep convection and cirrus outflow, and synoptic data indicated that the sea level pressure near the center was falling. A second TCFA was issued at 102000Z when synoptic data indicated that the low-level circulation center had moved out of the area delineated by the first TCFA.

The pre-Polly tropical disturbance was slow to develop, as its deep convection failed to consolidate around a distinct center. Instead, the deep convection became more widespread and oriented east-west along the axis of the monsoon trough. Moving steadily westward, the low-level circulation center once again moved out of the area delineated by the TCFA, so a third TCFA was issued at 111330Z. The disturbance had shown little sign of further development, other than synoptic data that indicated that the central SLP had fallen to near 1004 mb. At 120600Z, the third TCFA was cancelled, as synoptic data indicated that the central sea level pressure had risen from 1004 mb to 1006 mb. At this time, the pre-Polly tropical disturbance had moved to a position just east of Luzon, where it had slowed and turned northward. A fourth TCFA was issued on this tropical disturbance at 132330Z, when satellite imagery indicated consolidation of deep convection near a low-level circulation center, and synoptic data indicated that the central SLP had fallen to 1000 mb. At this time, the large circulation of the developing Oscar (17W) was located about 1200 nm (2200 km) east-northeast of the pre-Polly tropical disturbance. Perhaps in response to deep monsoonal southwesterly flow south of the monsoon trough axis, the pre-Polly tropical disturbance began to move very slowly northeastward. The first warning on Tropical Depression 18W was issued at 140600Z when satellite imagery indicated a well-defined low-level circulation center accompanied by an area of persistent deep convection.

Polly was upgraded to a tropical storm at 141800Z as the amount of deep convection increased near the low-level circulation center, and the organization of the deep convection and cirrus outflow improved. With the very large Oscar to its northeast (Figure 3-18-1), Polly began to track east-northeastward. With little further intensification, Polly continued to move east-northeastward for approximately two days until late on 17 September when it made an abrupt turn to the north and began to intensify more rapidly. On the morning of 18 September, Polly was upgraded to a typhoon. Polly reached peak intensity of 90 kt (46 m/sec) at 181200Z (Figure 3-18-2). At 190000Z, Polly turned to the north-northeast on the final leg of its "S" track. With a remarkably stable satellite signature (i.e., a nearly con-

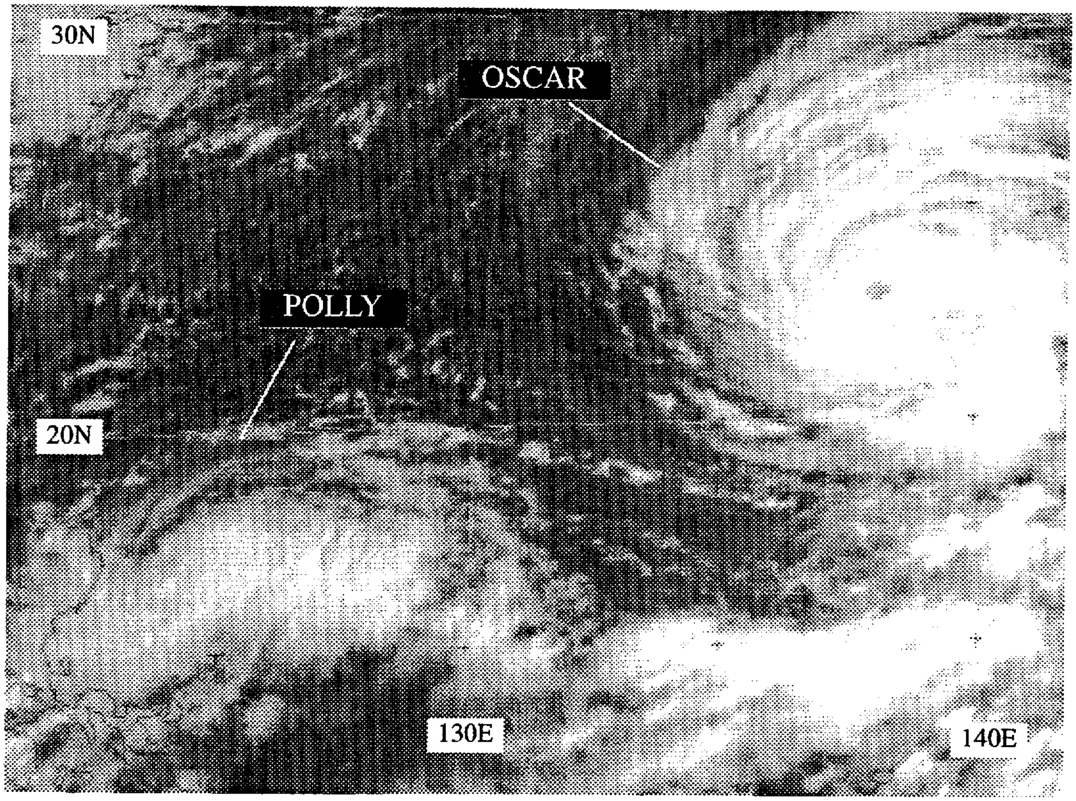


Figure 3-18-1 Polly's deep convection begins to consolidate around its low-level circulation center as it begins to move toward the east-northeast under the steering influence of southwesterly monsoonal flow and Oscar's large circulation (142331Z September visible GMS imagery).

stant Dvorak satellite intensity estimate of T 5.0), Polly's intensity remained at 90 kt (46 m/sec) for the 48-hour period 181200Z through 201200Z. After 201200Z, Polly increased its speed of translation to 30 kt (55 km/hr) as it moved northeastward into the mid latitudes. The final warning was issued on Polly, valid at 211800Z, when it appeared that it would become fully extratropical within six hours. The extratropical remains of Polly, possessing a well-defined low-level circulation, moved across the international date line on 24 September (Figure 3-18-3).

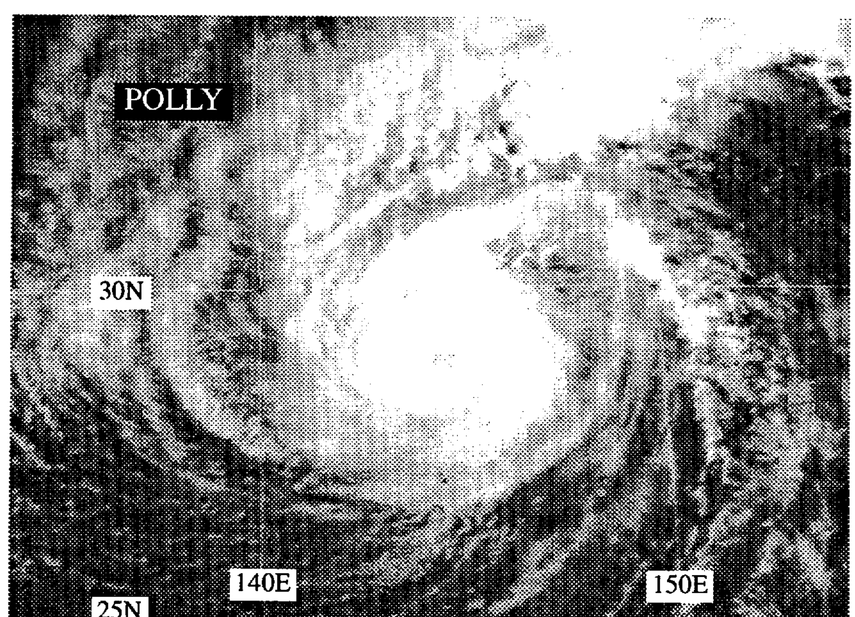


Figure 3-18-2 Polly at peak intensity of 90 kt (46 m/sec) (192224Z September visible GMS imagery).

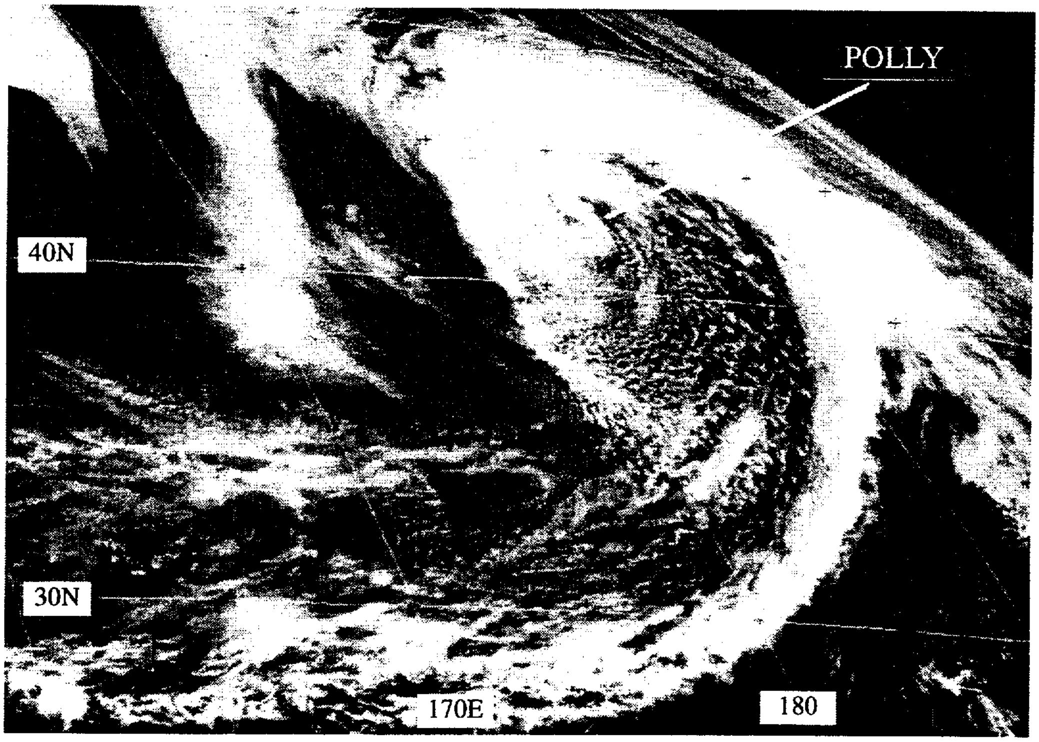


Figure 3-18-3 After the transition to an extratropical low, the well-defined low-level circulation — the remnants of Polly — crossed the international date line on a track towards the Gulf of Alaska (232331Z September visible GMS imagery).

III. DISCUSSION

a. *Unusual "S" motion*

During much of 1995 the low-level flow of the tropical Pacific was dominated by anomalous easterly low-level wind flow. As a consequence, the summer monsoon circulation of the western North Pacific was very weak. During June, July and August of 1995, low-level easterly wind flow dominated the low latitudes of the western North Pacific, and the normal southwest monsoon of the Philippine sea (with episodic extensions further eastward) was replaced by mean monthly easterly flow.

Only two relatively active monsoon episodes were noted during 1995: a reverse-oriented monsoon trough formed during mid-September and a large monsoon gyre formed during mid-October. The reverse-oriented monsoon trough of September stretched from the South China Sea eastward across Luzon and the Philippine Sea, and then northeastward to the northeast of Guam. This episode of reverse-oriented monsoon trough formation was associated with the simultaneous development of three tropical cyclones along the trough axis — Oscar (17W), Polly, and Ryan (19W).

When the monsoon trough axis acquires a reverse-orientation, TCs along it tend to move on north-oriented tracks. One unusual type of north-oriented track — the "S" track — is almost always associated with reverse orientation of the monsoon trough axis (Lander 1996). Consistent with Lander's findings, Polly and Ryan (19W) moved on unusual north-oriented "S"-shaped tracks.

Though not perfectly "S"-shaped, Polly's track nonetheless featured the requisite characteristics to be considered an example of "S" motion, as defined by Lander (1996). The "S" track — a specific variant of north-oriented motion — features eastward movement at low latitude, a later bend to the north or northwest, and then eventually northeastward motion as the system enters the mid-latitude westerlies. As was the case with Polly, a tropical cyclone undergoing "S" motion often intensifies after making its first bend to the north.

b. *Time series of Digital Dvorak (DD) numbers*

In Polly's case, there was a long period of time (181200Z to 210600Z) during which the warning intensity held steady at 85 to 90 kt (44 to 46 m/sec) — an intensity corresponding to a T 5.0 on Dvorak's scale. DD numbers were obtained during much of Polly's period of stable warning intensity. Unlike the DD number time series for Oscar (17W) (refer to the discussion section in Oscar's (17W) summary), the DD numbers for Polly showed a larger degree of short-term fluctuations (Figure 3-18-4). Nonetheless, the warning intensity represents an average value around which the DD numbers scatter. This is not the case with the next tropical cyclone — Ryan (19W) — in the three-TC (Polly, Oscar, Ryan) outbreak (refer to the discussion section in Ryan's summary).

IV. IMPACT

Polly affected the Volcano Islands where Iwo Jima reported a peak gust of 52 kt (27 m/sec) at 190424Z September, with nearby Chichi Jima reporting a minimum pressure of 987.8 mb at 1800Z the same day. Polly passed 130 nm (240 km) and 65 nm (120 km) to the northwest of these islands respectively. No reports of injuries or damage were received.

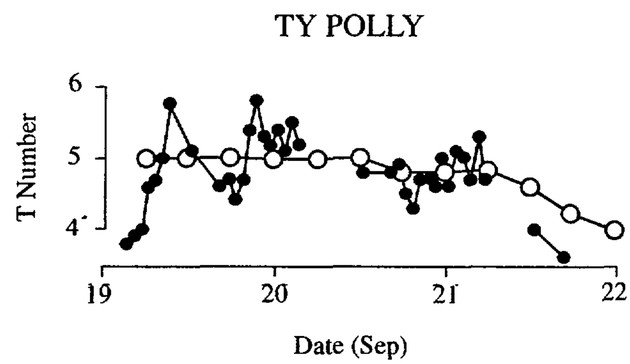
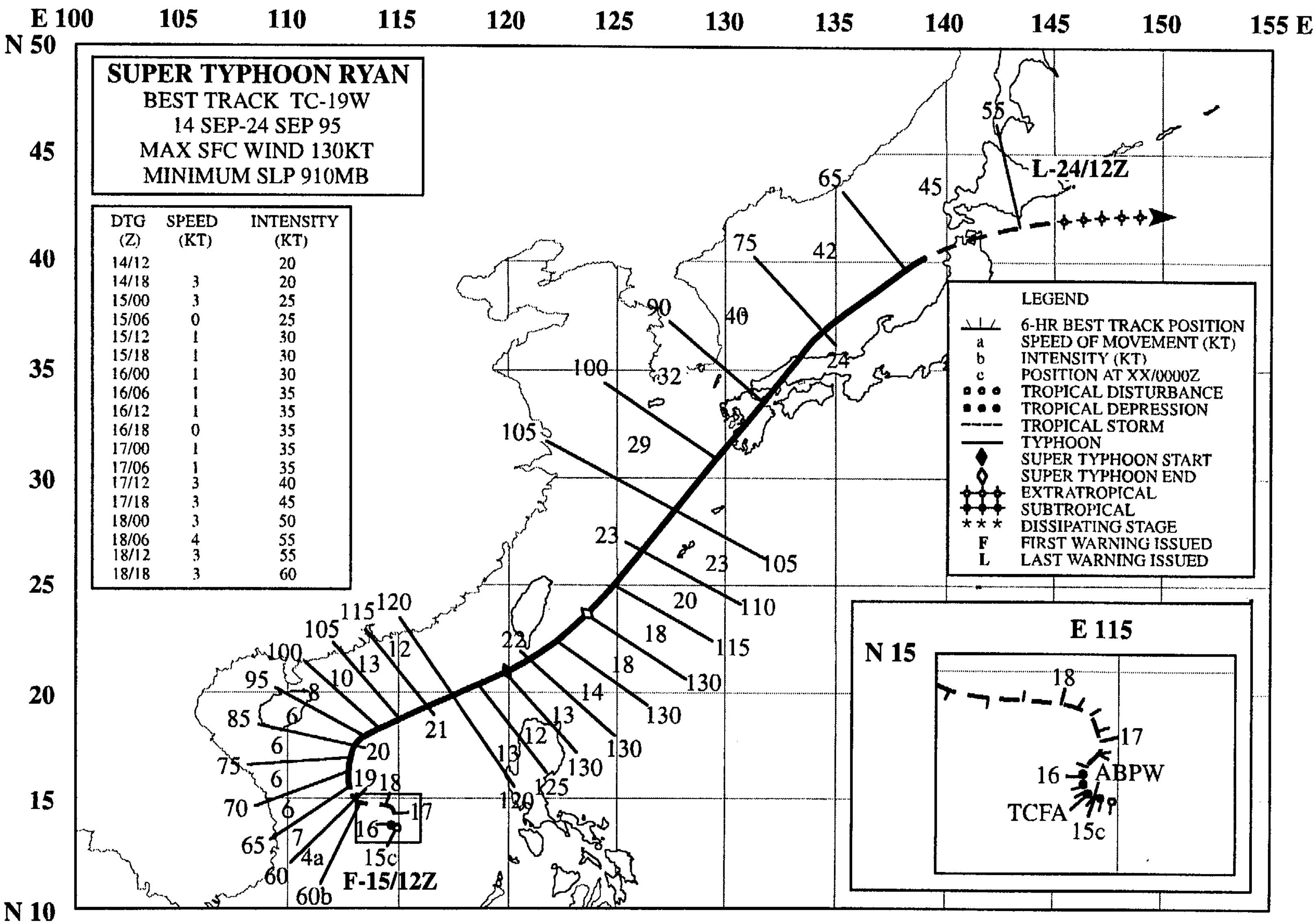


Figure 3-18-4 The hourly time series of the DD numbers obtained for Polly during the period 19 - 22 September (black dots), versus the final best track intensity (open circles). Ordinate labels are placed at 0000Z for the indicated date.



DTG (Z)	SPEED (KT)	INTENSITY (KT)
14/12		20
14/18	3	20
15/00	3	25
15/06	0	25
15/12	1	30
15/18	1	30
16/00	1	30
16/06	1	35
16/12	1	35
16/18	0	35
17/00	1	35
17/06	1	35
17/12	3	40
17/18	3	45
18/00	3	50
18/06	4	55
18/12	3	55
18/18	3	60

SUPER TYPHOON RYAN (19W)

I. HIGHLIGHTS

Ryan was the first tropical cyclone on JTWC's records to both form and attain super typhoon intensity within the South China Sea. Located along the axis of a reverse-oriented monsoon trough, Ryan underwent unusual motion: an "S"-shaped track. Two other tropical cyclones — Oscar (17W) and Polly (18W) — also developed in this reverse-oriented monsoon trough and, along with Ryan, formed a SW-NE chain of tropical cyclones. Estimates of Ryan's intensity based upon Digital Dvorak (DD) numbers exhibited some unusually large and rapid fluctuations. Ryan passed through the southern islands of the Ryukyu chain, and made landfall in southwestern Japan.

II. TRACK AND INTENSITY

On 13 September, the axis of the monsoon trough extended eastward from Southeast Asia across the South China Sea to Luzon, and from there, east-northeastward to Oscar (17W) in the northern Mariana Islands. Westward from Oscar (17W), and along the trough axis, lay the tropical disturbance that became Polly (18W) (then east of Luzon), and (in the South China Sea) the tropical disturbance that became Ryan. The pre-Ryan tropical disturbance was first mentioned on the 130600Z September Significant Tropical Weather Advisory based upon 24 hours of persistent deep convection associated with a weak low-level circulation center. Over the next two days, the sea-level pressure (SLP) slowly fell in the pre-Ryan tropical disturbance. At 151000Z September a Tropical Cyclone Formation Alert was issued based primarily on synoptic reports that indicated that the central SLP had fallen to 1002 mb within a well-defined low-level cyclonic circulation. The JTWC issued the first warning on Tropical Depression 19W valid at 151200Z.

Improvements in the organization of its deep convection resulted in an upgrade of Tropical Depression 19W to Tropical Storm Ryan at 160000Z. During the period 16 through 19 September, Ryan moved very slowly northward and then very slowly westward. After making a turn toward the north early on 19 September, Ryan was upgraded to a typhoon at 190600Z. On the morning of 20 September, the typhoon turned to the east-northeast, accelerated, and continued to intensify (Figure 3-19-1). Ryan attained its peak intensity of 130 kt (67 m/sec) at 211800Z as it swept around the southern tip of Taiwan, whereafter, it accelerated further, made a slight left turn, passed near (or over) Ishigaki Shima (WMO 47918) (see impact section), and then moved northeastward toward Japan.

Ryan made landfall on the Japanese island of Kyushu late on 23 September. Its landfall intensity was just under 100 kt (51 m/sec). After crossing Kyushu, Ryan tracked across the westernmost portion of the Japanese main island of Honshu and entered the Sea of Japan. Encountering strong deep layer westerly wind flow, Ryan weakened as it turned toward the east on the last leg of its "S" track, and passed over the northern tip of Honshu between 0600Z and 1200Z on 24 September. Under the influence of shear in the westerly wind flow at the higher latitudes, Ryan continued to weaken and began to transition to an extratropical cyclone. The final warning was issued valid at 240600Z.

III. DISCUSSION

a. *First super typhoon to form in the South China Sea*

Since the JTWC was established in 1959, there have been no super typhoons (130 kt (67 m/sec), or greater) in the South China Sea (although there have been super typhoons in the Philippine Sea that have moved into the South China Sea at lesser intensities). During the period 1945 to 1959, before the

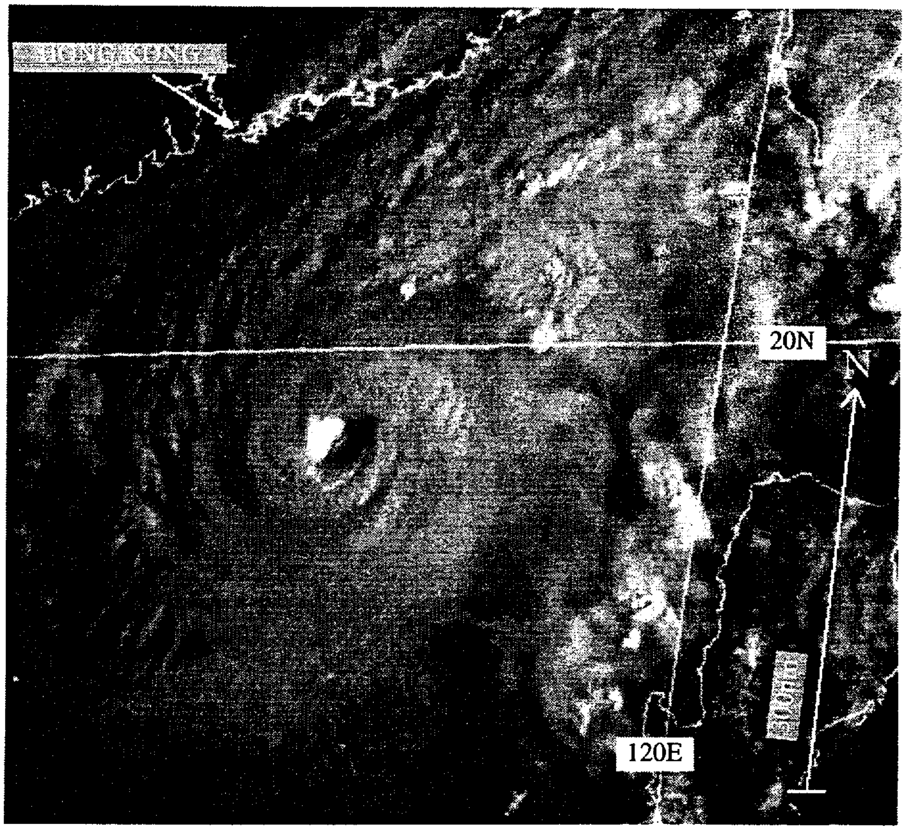


Figure 3-19-1 Ryan at 115 kt (59 m/sec) continues to intensify and will reach super typhoon intensity in 18 hours. The low sun angle in this image accentuates the cloud top topography (202332Z September visual GMS imagery).

JTWC was established, tropical cyclones in the western North Pacific were nonetheless reconnoitered by Air Force and Navy aircraft. During these years, two typhoons — Gloria (1952) and Betty (1953) — were reported to have attained super typhoon intensity after crossing the Philippines and while over the South China Sea. In the case of these two typhoons, it is difficult to assess the reliability of the reconnaissance reports of super typhoon intensity.

In the case of Gloria (1952) a Navy reconnaissance flight departed from Sangley Point at 222055Z December 1952, and made two eye fixes, one at 222309Z and the other at 230400Z. During the first pass through the eye, the crew estimated the maximum surface wind to be 110 kt (57 m/sec) in the northwest quadrant of the system accompanied by an estimated minimum sea-level pressure (SLP) in the eye of 982 mb. On the second pass through the eye, the maximum estimated surface wind was 130 kt (67 m/sec) in the southeastern quadrant accompanied by an estimated minimum SLP in the eye of 983 mb. The Atkinson/Holliday wind-pressure relationship (currently used as a baseline by the JTWC) requires a minimum SLP of 910 mb for a wind intensity of 130 kt (67 m/sec); conversely, a minimum SLP of 982 mb corresponds to a maximum wind speed of 55 kt (28 m/sec). In the case of Betty (1953), a Navy reconnaissance flight estimated the surface winds to be 130 kt (67 m/sec) in the left forward quadrant of the system. The lowest "observed" SLP (most probably obtained from a dropsonde) was 988.6 mb; however, owing to severe turbulence, the aircraft was unable to penetrate the eye.

Historical reconnaissance reports during the early years of record frequently have large mismatches between the minimum SLP and the associated maximum wind speed. Such large mismatches (as was the case with Gloria) render the data suspect. This is typical of historical reports during the early years of tropical cyclone reconnaissance.

Returning now to the case of Ryan, It must be noted that its super typhoon intensity was diagnosed from satellite using the techniques developed by Dvorak (1975, 1984), and one could raise questions as to the accuracy of its peak intensity estimate. Dvorak's techniques have been in use now for two decades, and for the most part, have been proven to be reasonable from coincident aircraft and land-falling "ground truth" measurements. There are occasional outliers from Dvorak intensity estimates, and examples have been pointed out in past Annual Tropical Cyclone Reports (e.g., see the summaries of Seth and John in the 1994 ATCR). Given that there may be a significant level of uncertainty of tropical cyclone intensity as estimated from satellite imagery, the least that can be said of Ryan is that during the past two decades of intensity estimation by satellite (accompanied by aircraft reconnaissance until 1987), no typhoon has ever been estimated to have attained super typhoon intensity while in the South China Sea.

b. *Ryan's north-oriented motion*

The north-oriented track was first recognized by the Japan Meteorological Agency (JMA) (1976). Lander (1996) further elaborated on the characteristics of north-oriented tracks. One particular type of north-oriented motion described by Lander was the "S" track. "S" motion is north-oriented motion of a TC that features eastward motion at low latitude, a later bend to the north or northwest, and then eventually northeastward motion as the TC enters the mid-latitude westerlies.

Twenty-five of 37 cases (68%) of observed "S" motion during the years 1978 through 1995 occurred when tropical cyclones undergoing "S" motion were located along the axis of a reverse-oriented monsoon trough. The "S" motion of Ryan — and also that of Polly (18W) — occurred when these tropical cyclones were located along the axis of a reverse-oriented monsoon trough. During 1995, the tracks of Ryan, and Polly (18W) were the only "S" tracks; and they comprised two of only five north-oriented tracks during the year (see Table 3-1).

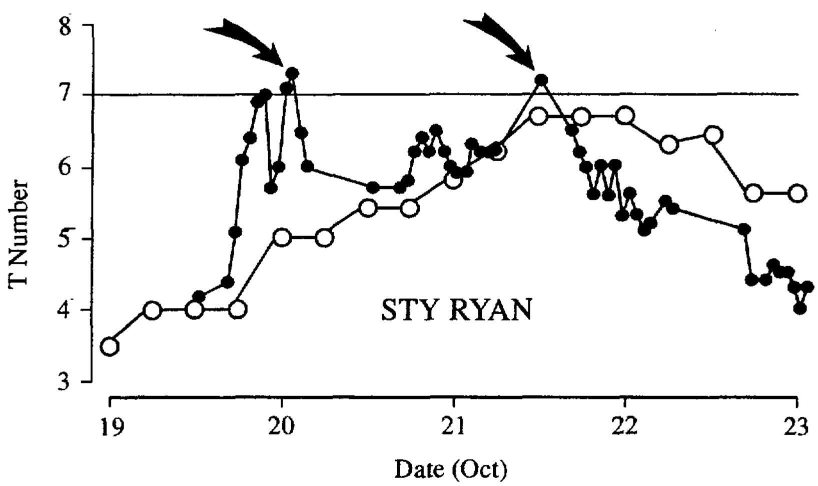


Figure 3-19-2 This comparison of the DD numbers (solid circles) and final best track intensity (open circles) converted to T-numbers for the period 19 to 23 September shows the variation between raw data and the final smoothed product for Ryan. Arrows indicate the two instances where the "digital" values exceeded T7.0.

c. *Rapid fluctuations in Ryan's DD numbers*

During 1995, detailed records of the hourly values of the DD numbers were tabulated for five typhoons: Oscar (17W), Polly (18W), Ryan, Ward (26W), and Angela (29W). (See the more detailed description of the DD numbers in Oscar's (17W) summary.) The time series of the hourly values of the DD numbers for Oscar (17W) was relatively stable, and was in good agreement with the JTWC warning intensity and the final best-track intensity. With Ryan, the time series of the hourly DD numbers underwent some large fluctuations (Figure 3-19-2) that were not in good agreement with the warning intensity or with the final best track intensity. The magnitude of Ryan's DD numbers exceeded T 7.0 — equivalent to an intensity of 140 kt (72 m/sec) maximum sustained wind speed — twice during its life (for maximum wind and minimum sea-level pressure equivalents to Dvorak's T numbers, see Table 2-2). The first DD of T 7.0 occurred at 192230Z, and reached T 7.3 at 200230Z (see Figure 3-19-3a) before falling back into values in the vicinity of T 6.0. The warning intensity at this time was 90 kt (46 m/sec), and the final best track intensity was 85 kt (44 m/sec) — this intensity is approximately T 5.0 on the Dvorak scale.

After the first DD peak of T 7.3 at 200230Z, the hourly time series of the DD fell back to within a few tenths of T 6.0 for a period of about 30 hours, after which the DD rose once again above T 7.0 at 211230Z (see Figure 3-19-3b). The warning intensity (and final best-track intensity) for Ryan reached a peak of 130 kt (67 m/sec) at this time (211200Z). An intensity of 130 kt lies between a T 6.5 and a T 7.0 on the Dvorak scale. The warning intensity and the DD were in close agreement at this time.

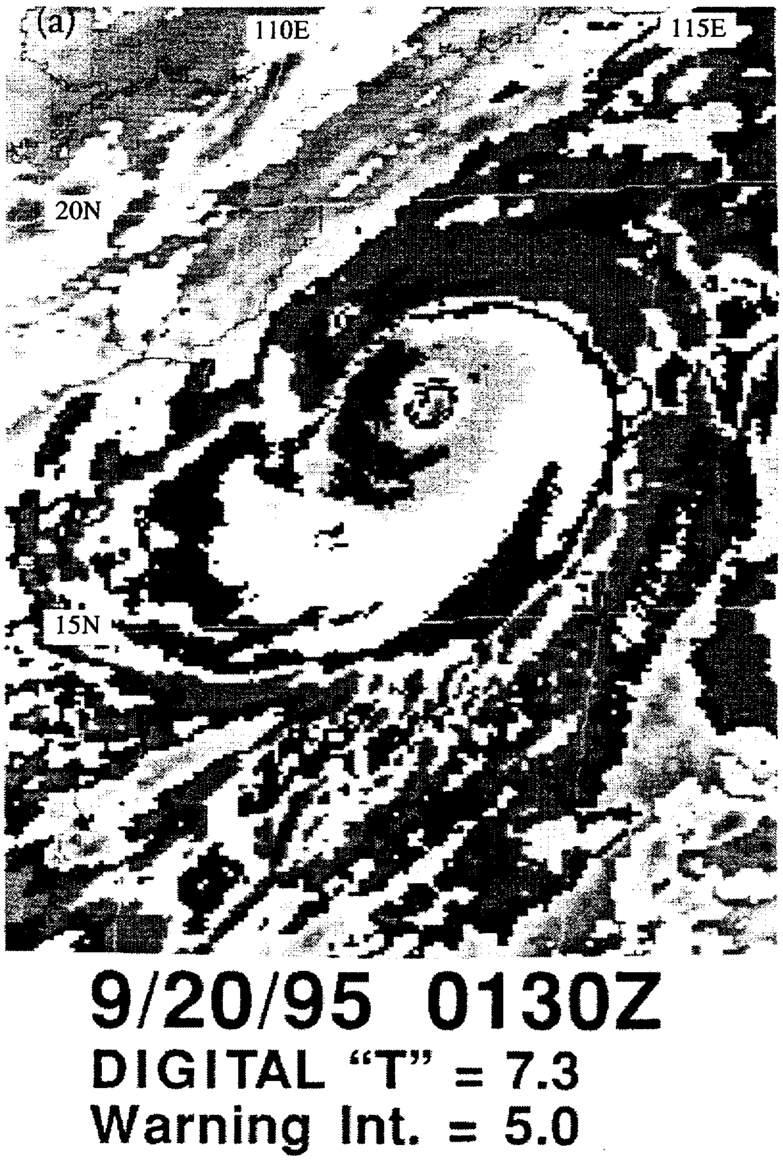
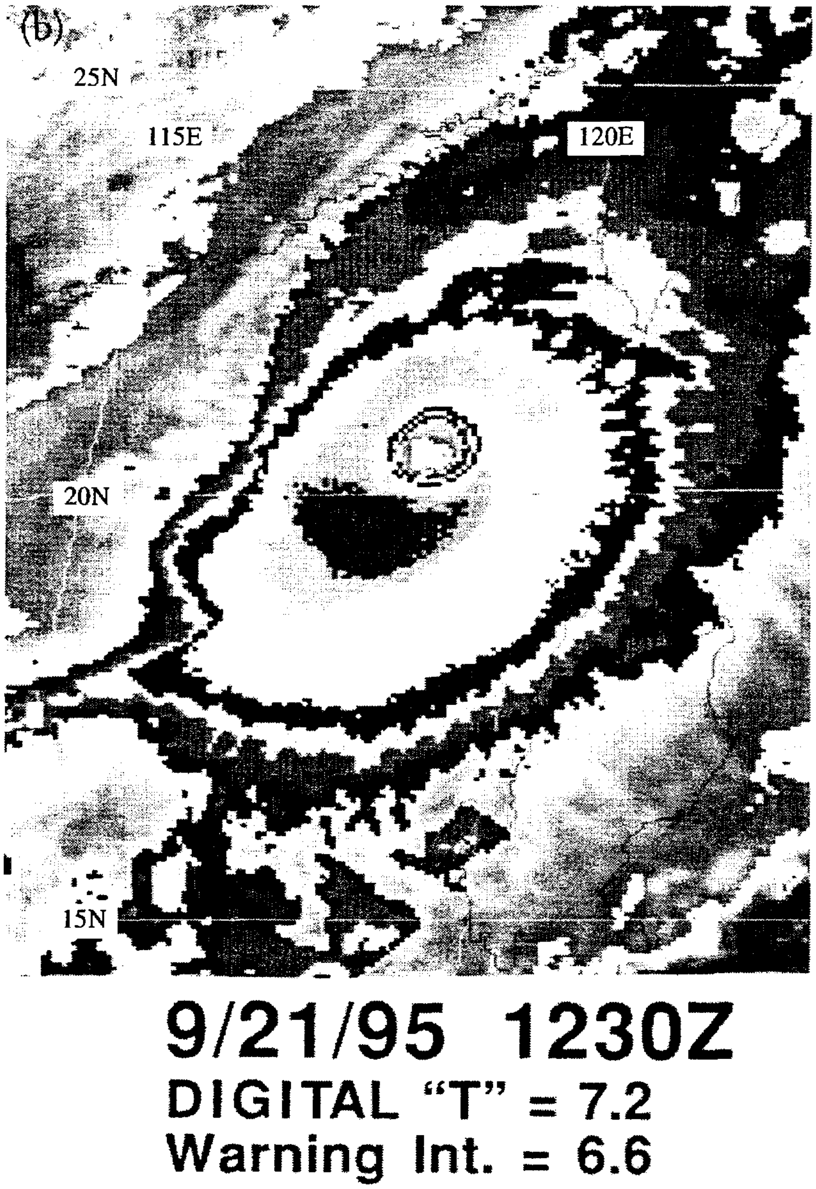


Figure 3-19-3 (a) Ryan reaches a DD number of 7.3 (200130Z September enhanced infrared GMS imagery).

That the warning intensity and best track intensity do not reflect the first rise of the DD to T 7.0 has several explanations. For one, the magnitude of the rise of 2.6 T numbers in five hours (from T 4.4 to T 7.0) exceeds the constraints allowed by Dvorak's technique. For another, given the large fluctuations of the intensity at this time (both up and down), the best-track intensity has been greatly smoothed. In the absence of ground-truth measurements, it will never be known if the intensity of Ryan was actually on the order of 140 kt (72 m/sec) at one, both, or neither of the places along its track where the DD exceeded T 7.0. If the DD numbers truly represented Ryan's intensity, there are two topics for further research: (1) how are the extremely rapid fluctuations of intensity, if they are genuine, to be incorporated into the warning? and, (2) how can the best-tracks, having had these rapid fluctuations removed, be used to study the processes governing what may prove to be real intensity fluctuations of the magnitude indicated by the DD numbers?

d. *Record tying wind gust*

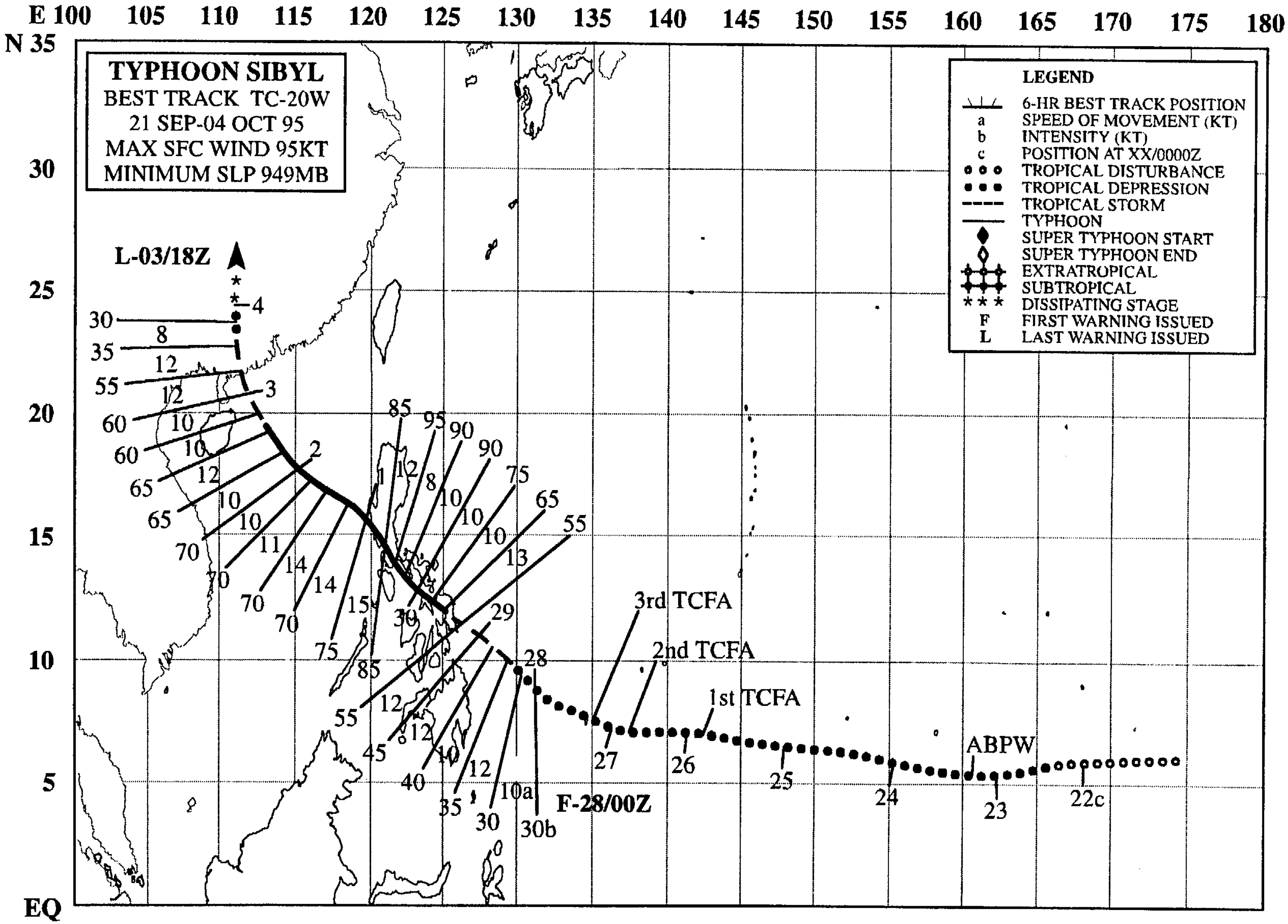
At 220300Z September, Ryan passed near the Taiwanese island of Lanyu (WMO 46762) where a peak wind gust of 166 kt (85.3 m/sec) tied the strongest wind gust ever recorded in a typhoon. The other event occurred at Miyako Jima (WMO 47927) in September 1966 near the eye of Typhoon Cora.



(b) Ryan's DD number once again is greater than 7.0 (211230Z September enhanced infrared GMS imagery).

IV. IMPACT

Ryan affected the Philippines, Taiwan, and Japan. In the northern Philippines, at least three fishermen died when high waves generated by Ryan overturned their boats. Nearly 2,500 people were forced to flee when high surf washed into homes along the coast of Ilocos Norte. A Philippine Navy ship, the Badjao, was reported adrift and listing badly in high seas, and members of the crew of 54 were being rescued. Reports concerning the ultimate fate of this ship were not received by the JTWC. In Taiwan, two people were reported to have died in typhoon-related incidents, and wind damage cut electricity to 4,500 households in the central and southern parts of the island. Rail and air traffic was disrupted. Taipei's financial markets, government offices and schools were closed for one day. In southwestern Japan, heavy rain flooded more than 950 homes and high winds cut off electrical power to about 17,400 homes. More than 1,500 buildings were damaged by heavy rain. Three people were hurt by flying glass in Kagoshima, and two people were injured by flying objects on the southern island of Okinawa. Domestic air and rail service was disrupted. The highest wind gust on the main islands of Japan was 90 kt (46 m/sec) recorded at Hiroshima. Earlier, as Ryan passed through the southern Ryukyu islands, a minimum sea-level pressure of 956.5 mb accompanied by a peak gust of 123 kt (63.5 m/sec) was observed on Ishigaki Shima (WMO 47918).


TYPHOON SIBYL
BEST TRACK TC-20W
21 SEP-04 OCT 95
MAX SFC WIND 95KT
MINIMUM SLP 949MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-03/18Z
F-28/00Z
3rd TCFA
2nd TCFA
1st TCFA
ABPW
E 100
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TYPHOON SIBYL (20W)

I. HIGHLIGHTS

Scatterometer data from the ERS-1 satellite played an important role in tracking Sibyl while the system was poorly organized. Sibyl reached its peak intensity of 95 kt (49 m/sec) as it crossed the Visayan islands. Later, it tracked over metro-Manila and entered the South China Sea, where it slowly weakened before making landfall east of the Luichow peninsula in southern China.

II. TRACK AND INTENSITY

The weak tropical disturbance that became Sibyl passed south of Majuro Atoll in the Marshall Islands late on 21 September and just south of Kosrae 24 hours later. Application of Dvorak's technique to the satellite imagery at 221130Z indicated that the system had developed sufficiently to be classified as a T 1.0 (equivalent to an intensity of 25 kt (13m/sec)). Based upon synoptic data and satellite intensity estimates, this tropical disturbance was first mentioned on the 230600Z Significant Tropical Weather Advisory. At 231200Z, the amount and organization of deep convection diminished, and no satellite classifications were made until 251700Z. Nevertheless, synoptic data and satellite imagery did indicate the continued westward movement of the poorly organized disturbance.

When the system began to develop, it did so at a very slow rate, and three Tropical Cyclone Formation Alerts were issued: the first at 252000Z, the second at 262000Z, and the third at 270600Z September. The latter was superseded when the JTWC issued the first warning on Tropical Depression 20W (TD 20W), valid at 280000Z. The slow development from the Marshall Islands to near 130°E is typical of La Niña (cold phase of ENSO) conditions as persistent low-level easterlies prevent the monsoon trough from extending into Micronesia.

Poorly organized convection created working best track problems. For example, from 271800Z until 281130Z, satellite fixes following the deep convection, indicated continued westward movement (the cluster of fixes shown in area A on Figure 3-20-1). However, the low-level wind circulation tracked to the northwest, which was confirmed by two ERS-1 scatterometer passes (note the location of these two fixes on Figure 3-20-1). The differences between the fixes placed within the center of the deep convec-

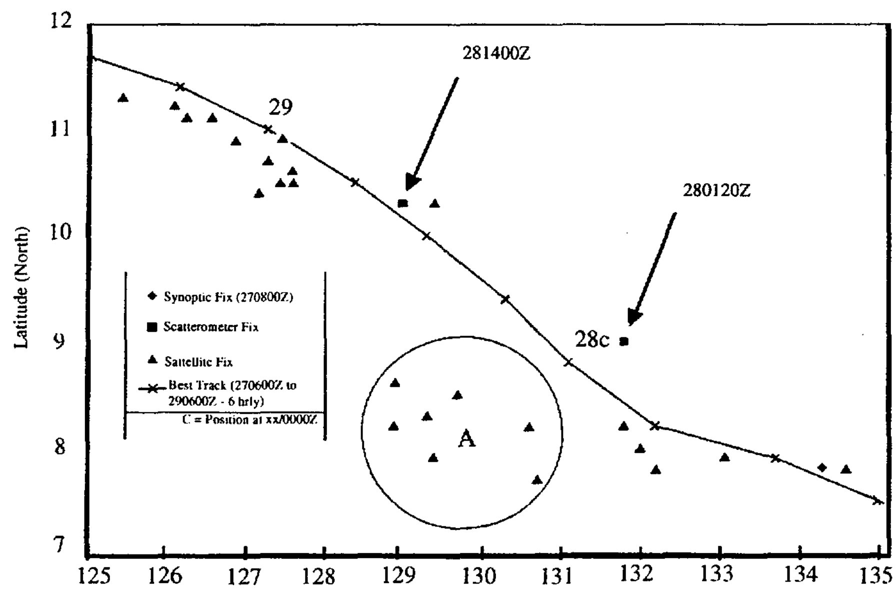


Figure 3-20-1. Display of weather satellite tropical cyclone fixes (triangles), ERS-1 scatterometer fixes (squares), a synoptic fix (diamond), and the best-track positions at 6-hour intervals for the pre-Sibyl tropical disturbance during the period 270600Z to 291200Z September. Note the cluster of satellite fixes in region A (enclosed by a circle) that are well south of the scatterometer fixes and the final best-track positions.

tion versus the wind center fixes based on the scatterometer data were as large as 120 nm (220 km). The 280120Z ERS-1 pass also showed that the system had intensified to 30 kt (15 m/sec) one-minute average (note: the scatterometer winds are considered to be representative of an eight-minute average 10-meter surface wind measurement). The scatterometer data from the ERS-1 pass at 281400Z indicated 35 kt (18 m/sec) maximum marine surface winds in the southeastern quadrant of a well-defined cyclonic circulation (Figure 3-20-2).

Based upon satellite intensity estimates, and scatterometer winds, TD 20W was upgraded to Tropical Storm Sibyl on the warning valid at 281800Z. Sibyl intensified as it neared the Philippines (Figure 3-20-3), and continued to intensify as it moved through the northern Visayan Islands. A minimum sea-level pressure of 977.9 mb was recorded at Tacloban (WMO 98550) at 290900Z. Sibyl attained typhoon intensity three hours later at 291200Z, and reached its peak intensity of 95 kt (49 m/sec) at 301200Z just before moving ashore in Luzon southeast of Manila (Figure 3-20-4). Possible mechanisms for intensification while crossing through an archipelago of high islands are outlined in the discussion section. Surface observations from the Philippines enabled the JTWC to make seven synoptic fixes that aided in tracking Sibyl.

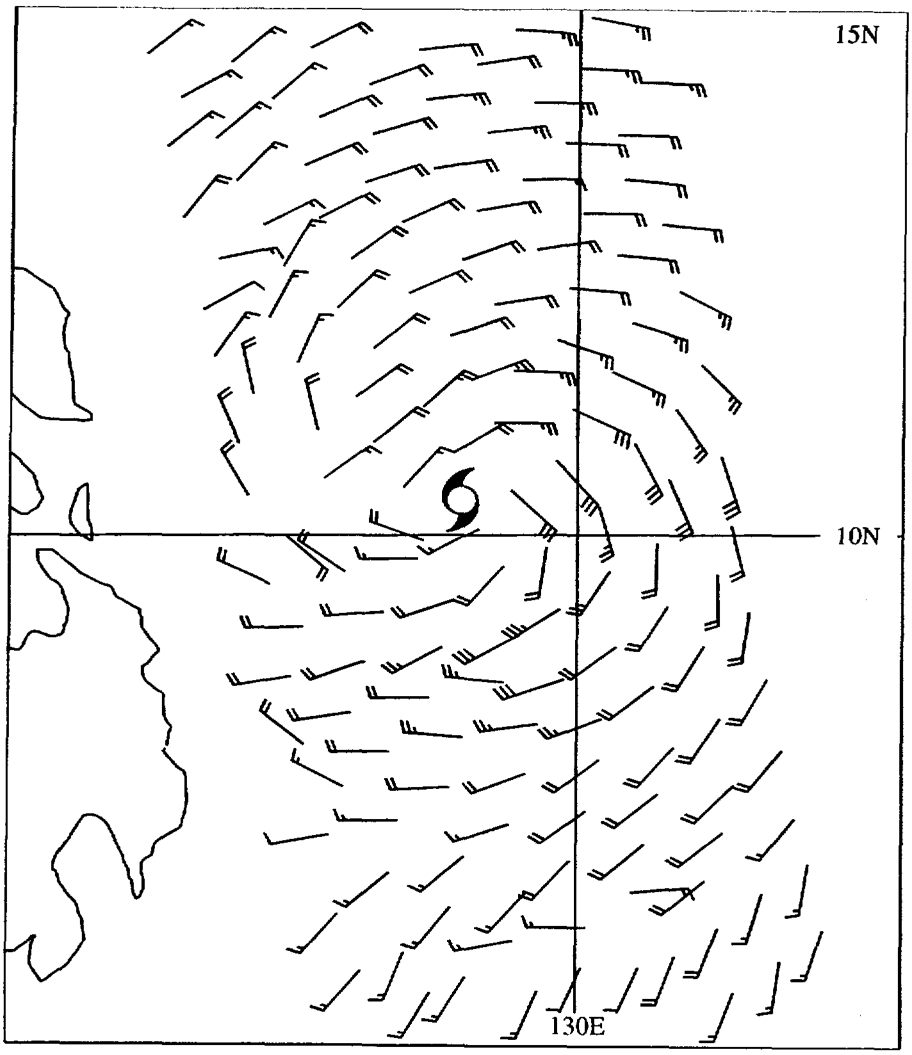


Figure 3-20-2 Scatterometer data from the ERS-1 spacecraft indicate that Sibyl has a well-defined cyclonic circulation in the low-level wind field and a maximum wind speed of 35 kt (17m/sec) (281400Z September ERS-1 scatterometer-derived marine surface winds).

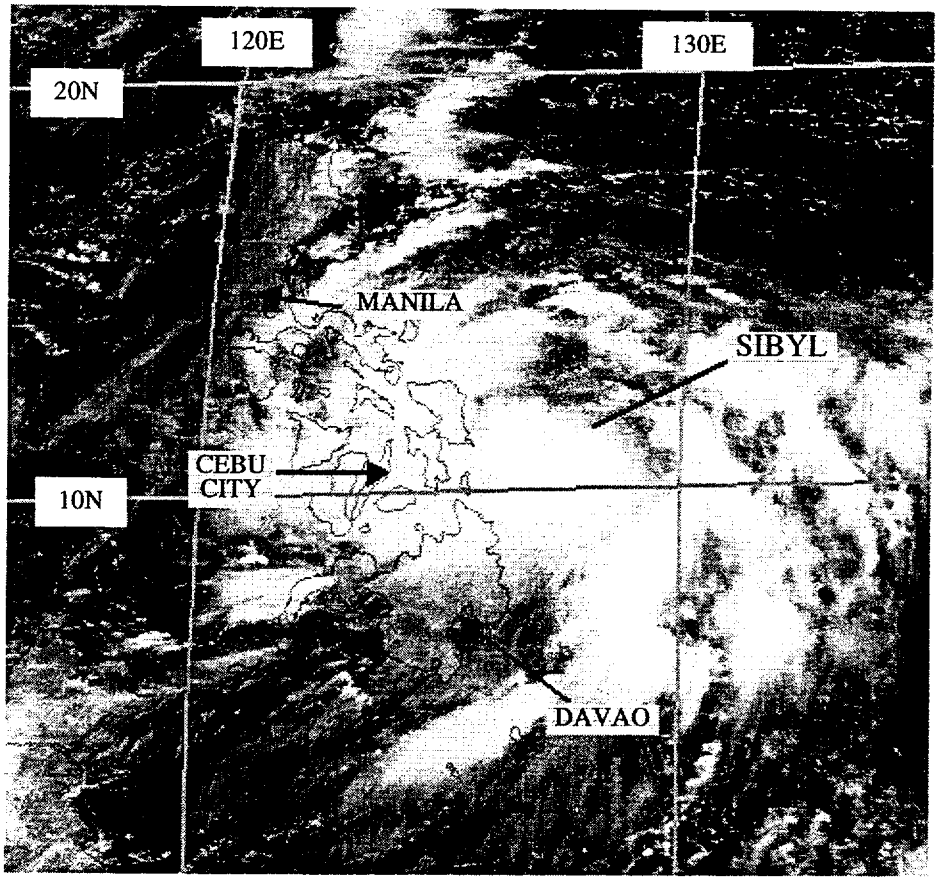


Figure 3-20-3 Sibyl approaches the Philippines with an intensity of 45 kt (23 m/sec) (290031Z September visible GMS imagery).

By 301800Z, Sibyl had crossed most of metropolitan Manila. Data received after-the-fact from the Philippine Atmospheric, Geophysical, and Astronomical Services (PAGASA) indicated that Sangley Point (WMO 98428) recorded maximum 10-minute sustained winds of 65 kt (33 m/sec) at 301655Z. This converts to 75 kt (39 m/sec) 1-minute sustained wind speed. The typhoon exited the Philippines at 010000Z October and entered the South China Sea. Weakening over water in the South China Sea , Sibyl was downgraded to a tropical storm on the warning valid at 021800Z October. Making a gradual turn to the north, Sibyl made landfall at 030400Z about 175 nm (325 km) west-southwest of Hong Kong, where Waglan Island (WMO 45007) measured maximum sustained winds of 58 kt (30 m/sec) (one-minute average) with a peak gust of 62 kt (32 m/sec). Surface synoptic reports in China near Sibyl indicated that the low-level circulation dissipated on the morning of 04 October. The JTWC issued the final warning on Sibyl valid at 031800Z October.

III. DISCUSSION

Intensification while crossing the Philippines

Although tropical cyclones usually weaken over land, those that cross through the Visayan region of the Philippines often intensify. The following discussion offers a hypothetical explanation of this phenomenon. The Visayan region of the Philippines is an archipelago of high islands with more of the area covered by water — very warm water — than by land. A tropical cyclone passing through this region may thus continue to derive energy through air-sea interaction. In addition, the mountainous islands of the archipelago and the southern part of Luzon (which forms a barrier on the northern side of the region) may act — through frictional effects and geographic barrier effects — to shrink the size of a tropical

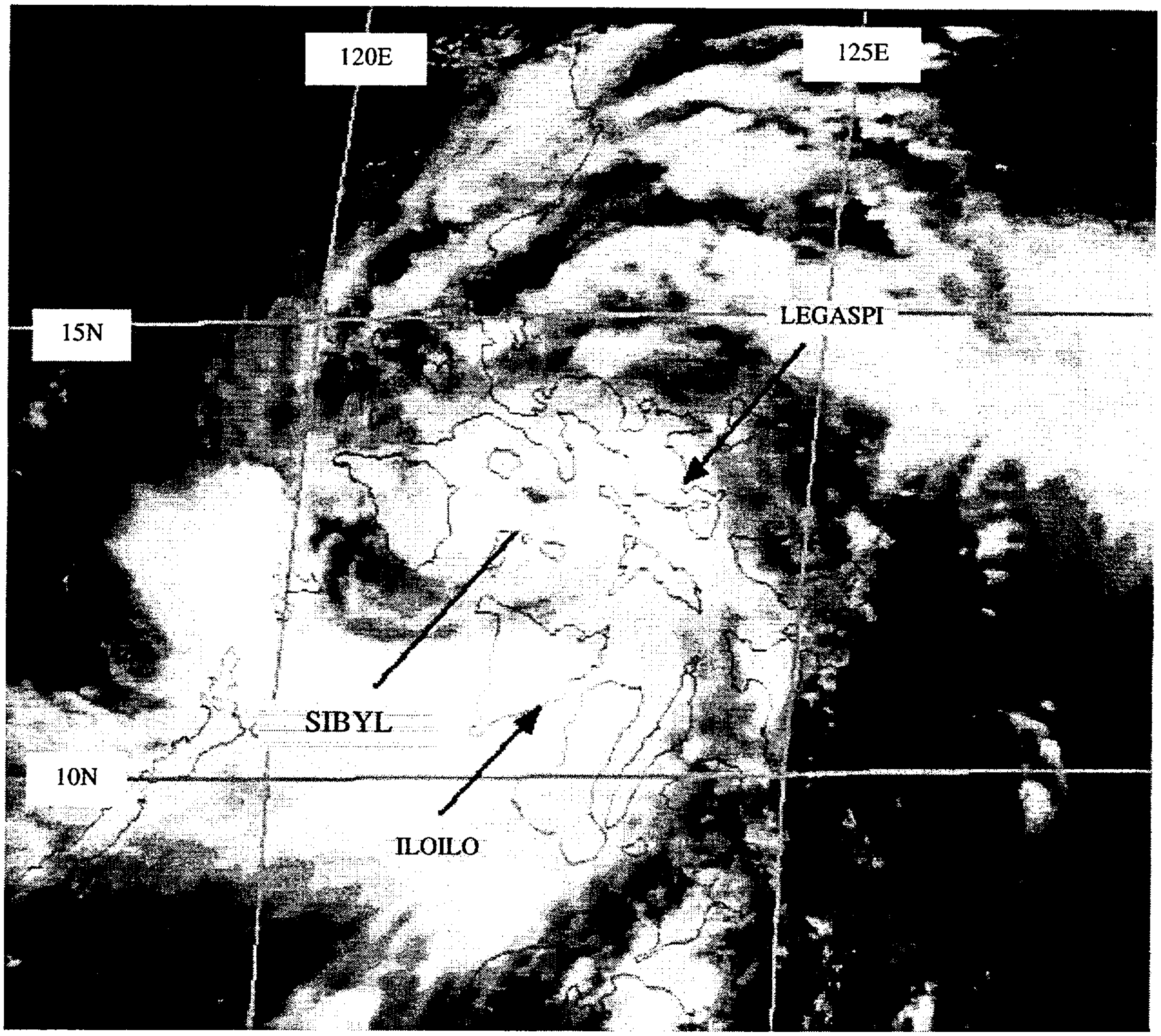
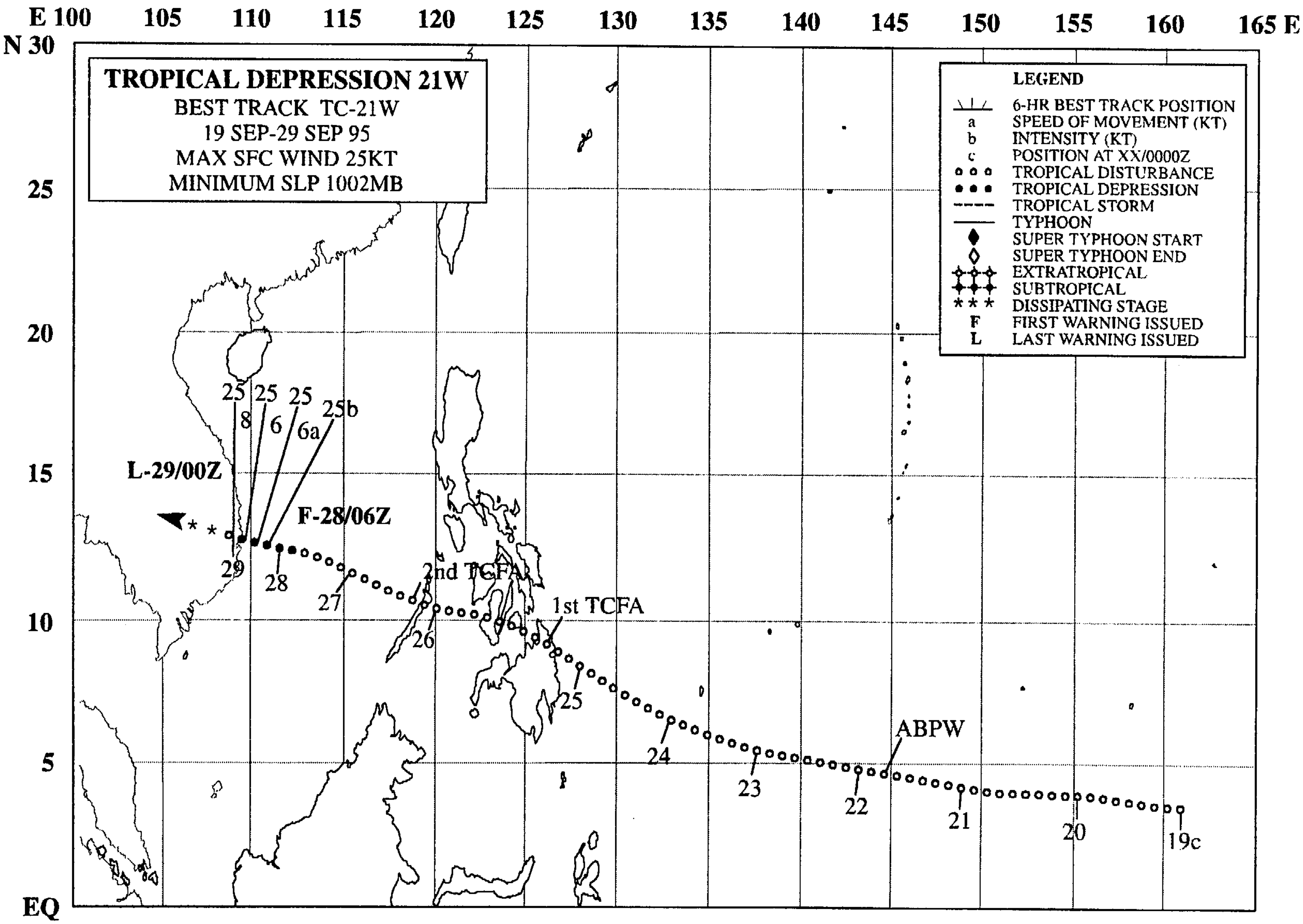


Figure 3-20-4. Typhoon Sibyl a few hours before reaching its peak intensity of 95 kt (49 m/sec) when located about 125 nm (230 km) southeast of Manila (300331Z September visible GMS imagery).

cyclone entering the region. Low-level cyclonic winds are forced to accelerate through channels between the land areas, enhancing the low-level convergence. As long as upper-level flow patterns are favorable for intensification, the increased low-level convergence will lead to greater convection, and, as the wind field shrinks, the vorticity may become more concentrated toward the core or the tropical cyclone. As a result, intensification proceeds as the tropical cyclone passes through the archipelago.

IV. IMPACT

In the Philippines, Sibyl's passage resulted in at least 108 deaths and left 100 people missing. Fifty of the deaths occurred in the town of Cabalantian (50 nm (95 km) north of Manila) from floods and 18-foot high lahars (mudflows) from the slopes of Mount Pinatubo. Storm-related torrential rains and associated landslides caused fatalities and destruction of property as far as 500 nm (925 km) south of Manila. In Manila, power was cut to thousands of people. Damage from Sibyl exceeded 1 billion pesos or US$38.5 million. No reports of damage were received from China.


TROPICAL DEPRESSION 21W
BEST TRACK TC-21W
19 SEP-29 SEP 95
MAX SFC WIND 25KT
MINIMUM SLP 1002MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 100
105
110
115
120
125
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135
140
145
150
155
160
165 E
N 30
25
20
15
10
5
EQ
L-29/00Z
F-28/06Z
25
8
25
6
25
6a
25b
29
28
27
26
2nd TCFA
1st TCFA
25
24
23
22
ABPW
21
20
19c

TROPICAL DEPRESSION (21W)

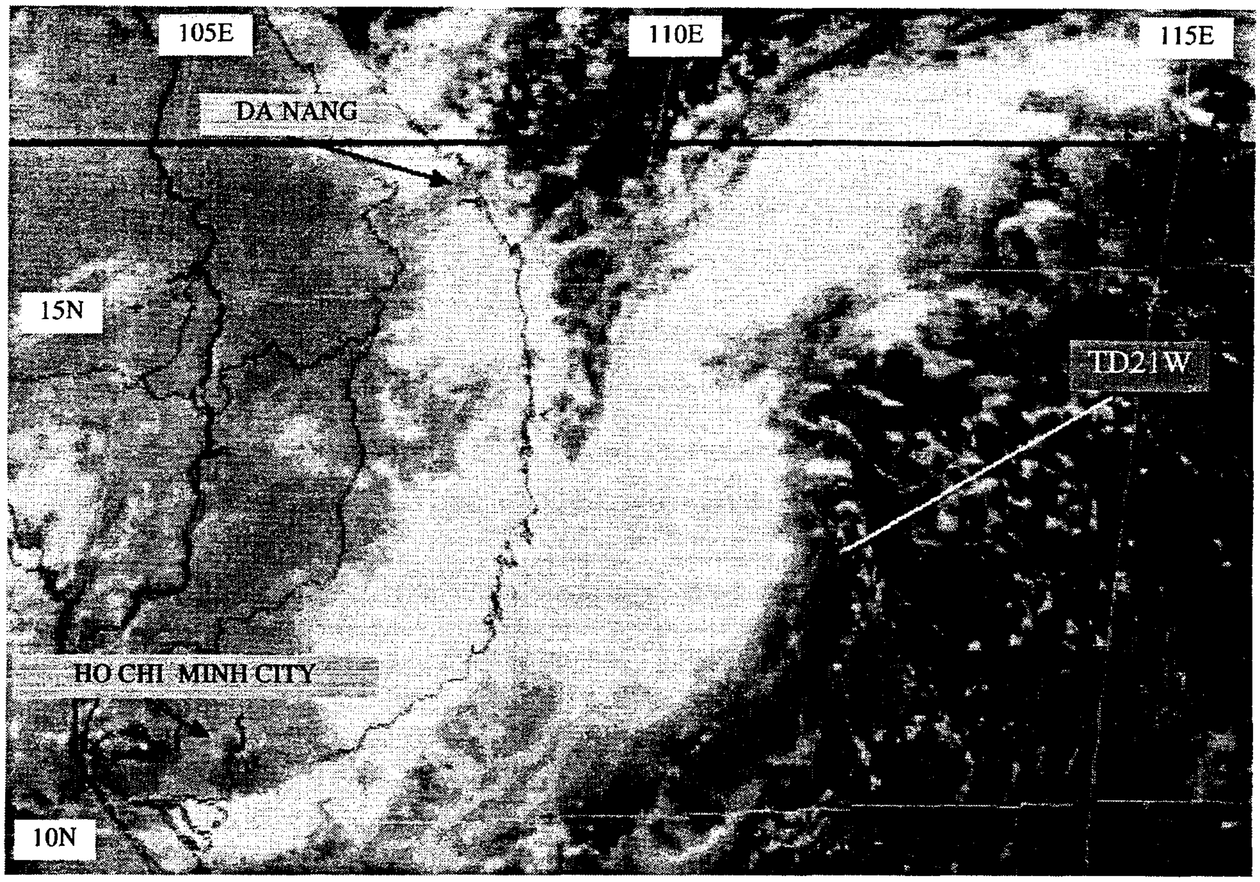
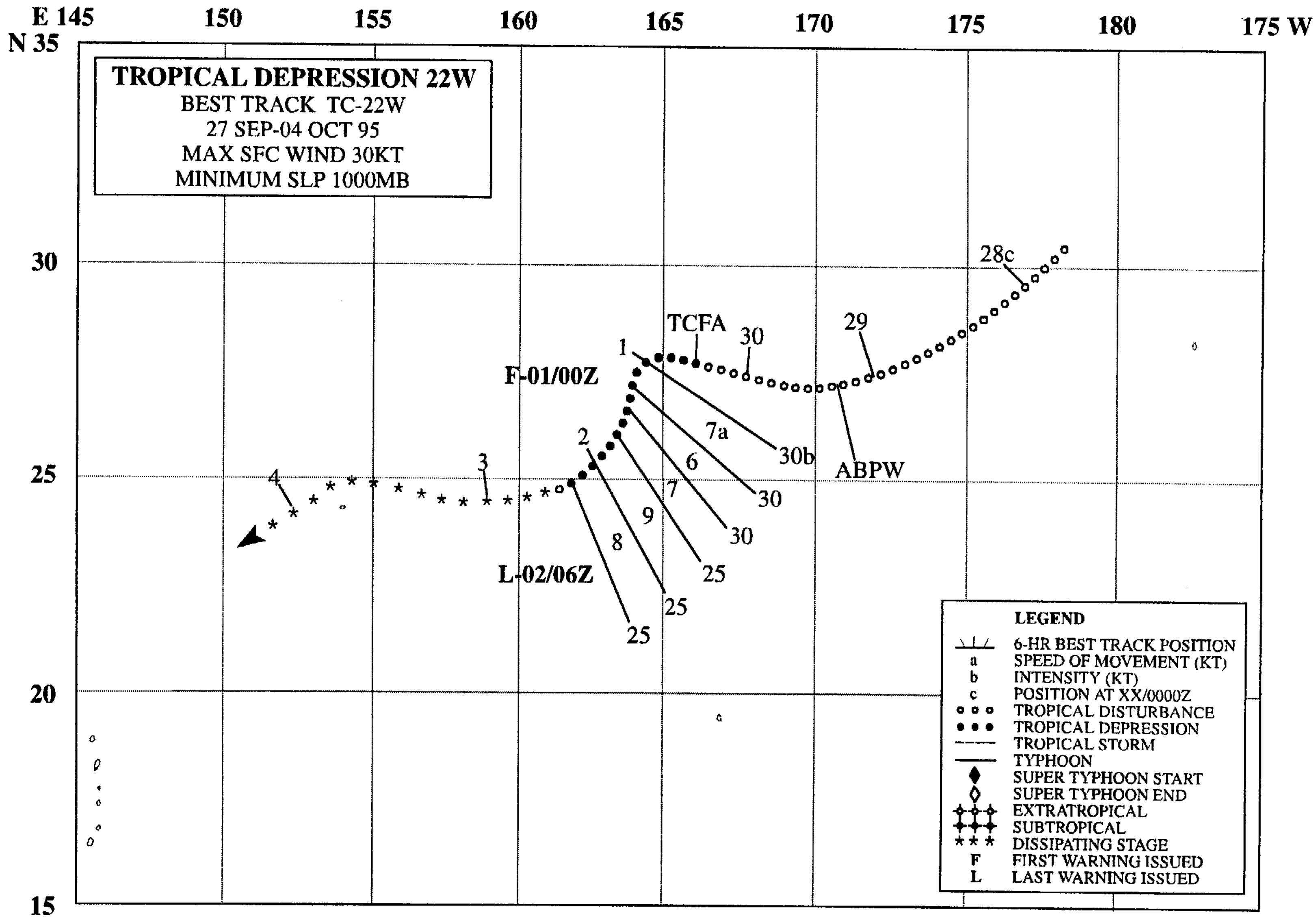


Figure 3-21-1 Tropical Depression 21W reaches its peak intensity of 25 kt (13 m/sec) as it approaches the coast of Vietnam (280231Z September visible GMS imagery).

During the last week of September, amounts of deep convection increased throughout Micronesia. This convection organized into an east-west chain of tropical disturbances. The disturbance that became Tropical Depression 21W was first mentioned on the 211800Z September Significant Tropical Weather Advisory when synoptic data indicated that a weak surface circulation accompanied an area of deep convection south of Chuuk. For three days, this tropical disturbance drifted westward toward the Philippines. On 25 September, satellite imagery indicated that the deep convection and low-level cloud lines accompanying this disturbance had become better organized, prompting the JTWC to issue a Tropical Cyclone Formation Alert (TCFA) at 250500Z. As the disturbance crossed the Philippines, it failed to intensify, and a second TCFA was issued at 260400Z in anticipation of intensification as it moved into the South China Sea. When the system failed to become better organized once in the South China Sea, the second TCFA was canceled at 262130Z. On 28 September, as this tropical disturbance neared the coast of Vietnam, the deep convection consolidated near the low-level circulation center, and its low-level cloud lines became better defined (Figure 3-21-1). The JTWC issued the first warning on Tropical Depression 21W, valid at 280600Z. The final warning was issued, valid at 290000Z, after the system made landfall on the coast of Vietnam and began to dissipate.



TROPICAL DEPRESSION 22W
BEST TRACK TC-22W
27 SEP-04 OCT 95
MAX SFC WIND 30KT
MINIMUM SLP 1000MB
E 145
150
155
160
165
170
175
180
175 W
N 35
30
25
20
15
TCFA
F-01/00Z
L-02/06Z
ABPW
28c
29
30
1
2
3
4
7a
30b
6
30
7
30
9
25
8
25
25
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL DEPRESSION (22W)

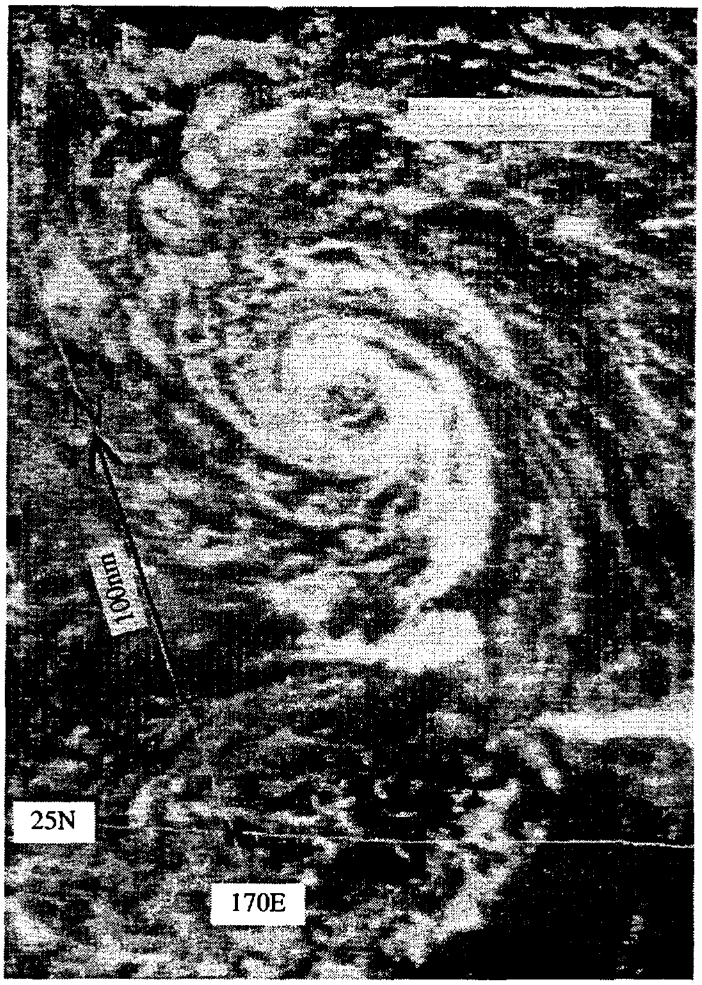


Figure 3-22-1 The low-level vortex that became TD 22W possesses cloud features that mimic those of a mature tropical cyclone: well-defined tightly coiled low-level cloud lines, and a "ring" of low and middle cloud surrounding a relatively cloud-free "eye" (290031Z September visible GMS imagery).

I. HIGHLIGHTS

Forming at a relatively high latitude (30°N) near the international date line, Tropical Depression 22W was a very small tropical cyclone — the smallest tropical cyclone in the western North Pacific warned on by the JTWC during 1995.

II. TRACK AND INTENSITY

On 24 September, a portion of a dissipating cold front (linked to an occluded low-pressure system south of the Aleutian Islands) pushed slowly southward across 30°N between 160° E and the international date line. An area of deep convection formed along this front near the international date line. This convection was most probably associated with an upper-tropospheric low that was in the process of becoming cut-off at approximately 35°N 175°E. On 28 September, a very small well-defined low-level cyclonic vortex formed to the northwest of this area of deep convection. On 29 September, the deep convection in the subtropics (25-30°N) near the international date line subsided, however the very small well-defined low-level vortex remained (Figure 3-22-1) and began to drift toward the west. This low-level vortex was first mentioned on the 290600Z Significant Tropical Weather Advisory. This advisory included the following remarks:

" . . . A low level circulation is indicated on visible satellite imagery [Figure 3-22-1] . . . Scatterometer data [Figure 3-22-2] indicate winds of 20 to 25 knots, however, almost no [deep] convection is associated with this system . . ."

For the next several days, this vortex drifted toward the west-southwest while embedded in the east-northeasterly flow south of the axis of the lower tropospheric subtropical ridge. During the night of 29 September, deep convection (on the scale of an individual large thunderstorm) developed near the low-level circulation center of this disturbance (Figure 3-22-3). This deep convection grew and decayed several times until the night of 30 September, when it became more extensive and persistent. Based upon this increase and persistence of deep convection, a Tropical Cyclone Formation Alert was issued at 301200Z. On the morning of 01 October, the amount and organization of the deep convection associated with this very small vortex increased (Figure 3-22-4), and the first warning, valid at 010000Z, on Tropical Depression 22W was issued. Central deep convection associated with TD 22W persisted for only about 24 hours. On 02 October, the deep convection began to shear away to the east (Figure 3-22-5), and by the afternoon of 02 October the deep convection was lost. As a result, the JTWC issued the final warning, valid at 020600Z on Tropical Depression 22W. Steadily weakening, the low-level vortex continued to track toward the west-southwest, and could be located in the low-cloud field through 04 October.

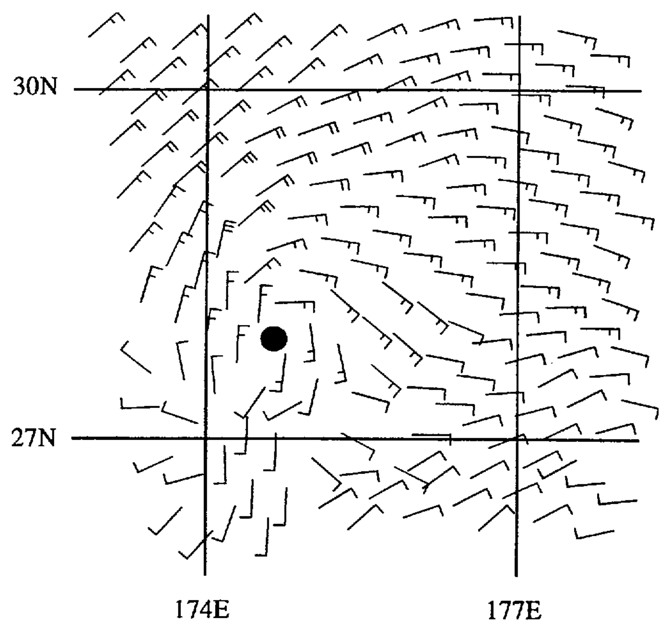


Figure 3-22-2 The surface wind field accompanying the low-level vortex (solid dot) that became TD 22W (281049Z September ERS-1 scatterometer-derived sur-

III. DISCUSSION

How small can a tropical cyclone be?

Tropical Depression 22W was a very small tropical cyclone — easily the smallest tropical cyclone of 1995, and perhaps about as small as a tropical cyclone can be. Although the processes governing the formation of the very small low-level circulation center that became TD 22W are uncertain, it is clear that this tiny vortex later acquired persistent central deep convection, and became a typical tropical cyclone except for its unusually small size. Before it acquired its central deep convection, the diameter of the region occupied by well-defined cyclonically curved lines of low-level clouds was approximately 180 nm (300 km). At one point, a ring of low and middle cloud (with perhaps some low-topped convection) (Figure 3-22-1) surrounded a relatively cloud-free "eye" whose diameter was 20 nm (35 km). Interestingly, the physical dimensions of these central features are typical for the analogous central features in much larger tropical cyclones. What seemed to contribute most to the apparent very small size of Tropical Depression 22W was the absence of peripheral bands of deep convection and extensive curved bands of outflow cirrus.

The very small size of Tropical Depression 22W leads one to ask a fundamental question: how small can a tropical cyclone be? The answer to this question is beyond the scope of this summary, however the nature of the formation and evolution of this tropical cyclone yield some information that may be relevant: (1) the size was established at the time of the genesis of its embryonic vortex, (2) the size was established before it acquired persistent central deep convection, and (3) the size remained unchanged during the brief 24-hour time span during which it possessed central deep convection. A final point to consider is that without remotely sensed imagery and scatterometry, it is doubtful that Tropical Depression 22W would ever have been detected.

IV. IMPACT

No reports of damage or injuries attributable to Tropical Depression 22W were received at the JTWC.

Figure 3-22-3 A lone thunderstorm casting a long shadow in the evening sunlight is the first deep convection to appear near the center of TD 22W (290531Z September visible GMS imagery).

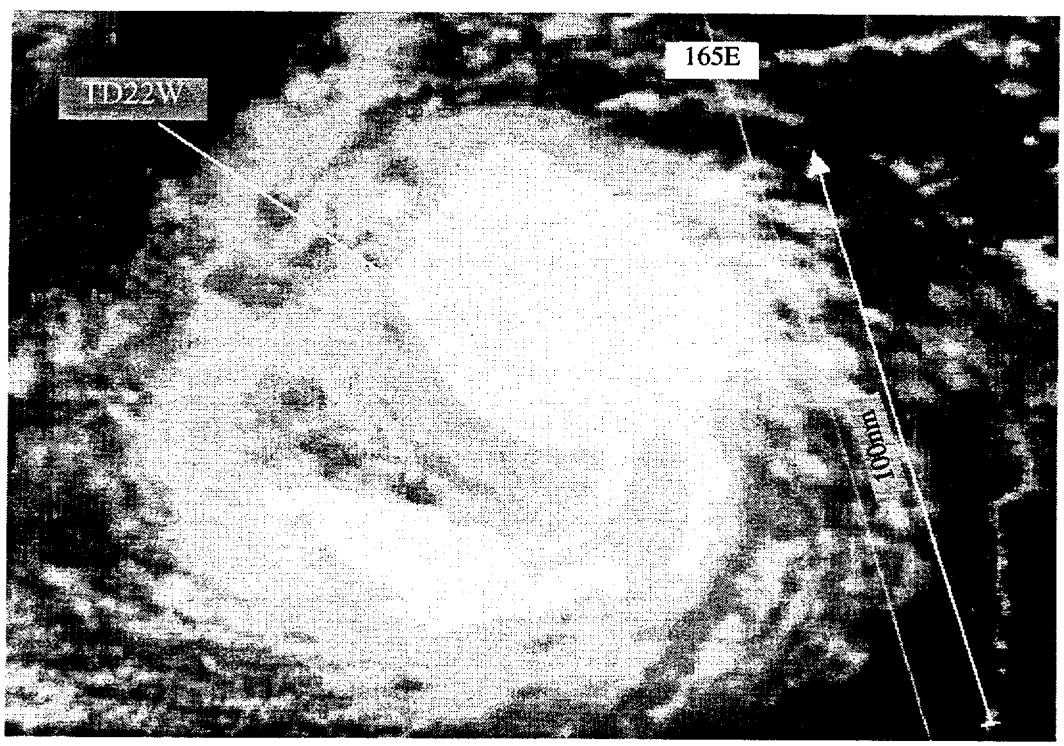


Figure 3-22-4 Deep convection associated with TD 22W reaches a maximum (010131Z October visible GMS imagery).

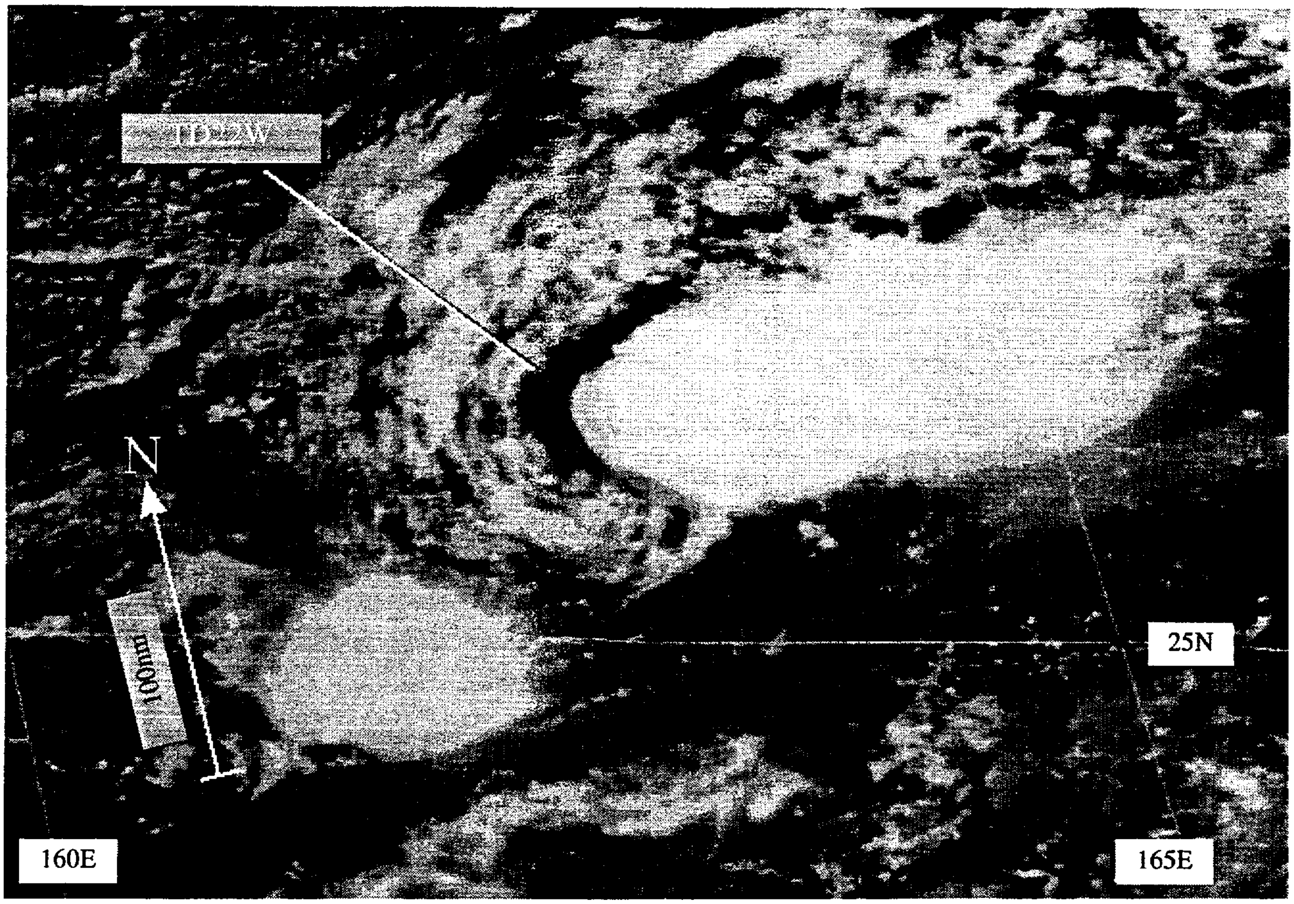
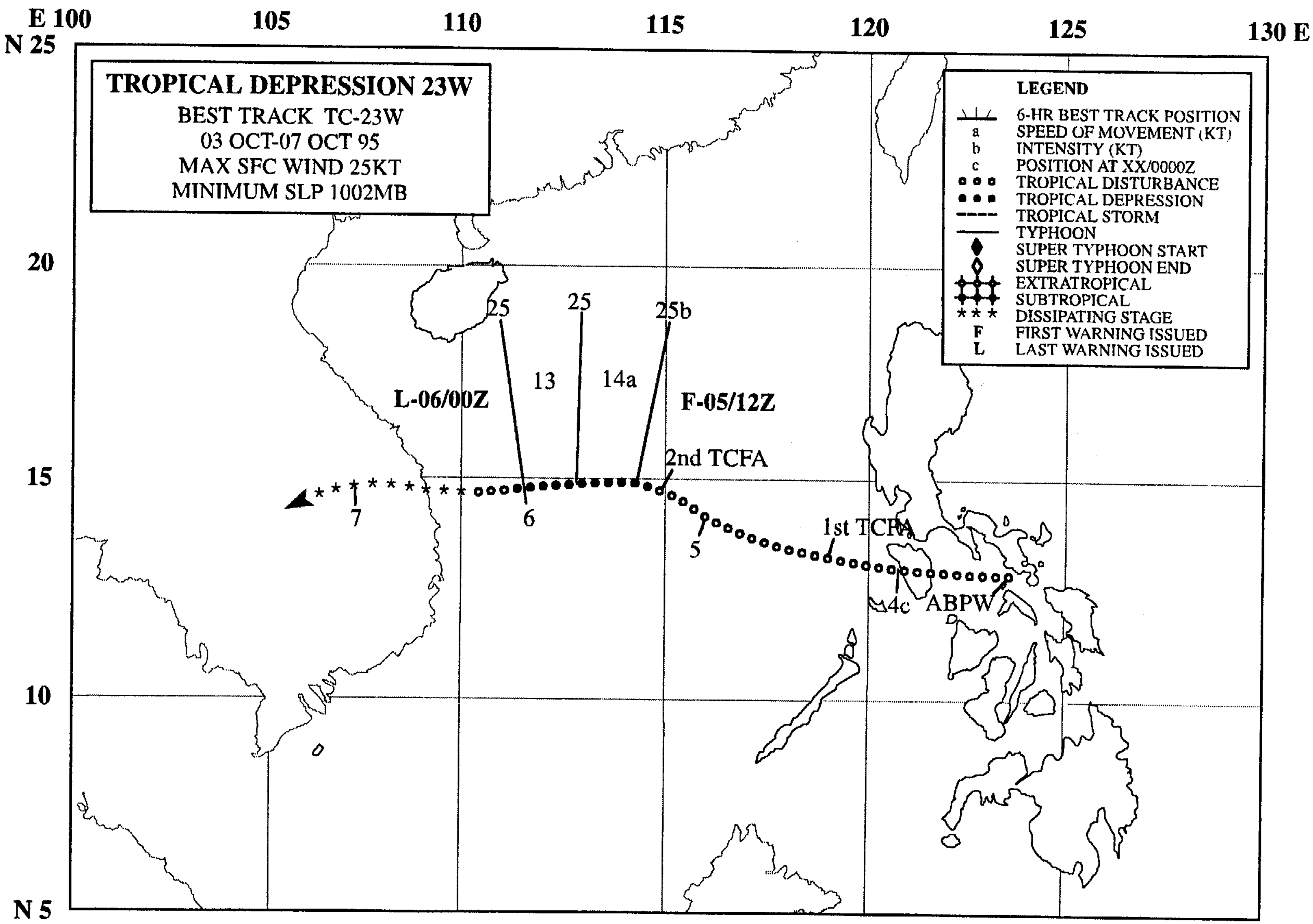


Figure 3-22-5 The central deep convection associated with TD 22W begins to encounter westerly vertical wind shear, and will shortly collapse (012131Z October visible GMS imagery).



E 100
105
110
115
120
125
130 E
N 25
20
15
10
N 5
TROPICAL DEPRESSION 23W
BEST TRACK TC-23W
03 OCT-07 OCT 95
MAX SFC WIND 25KT
MINIMUM SLP 1002MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
25
25
25b
13
14a
L-06/00Z
F-05/12Z
2nd TCFA
1st TCFA
7
6
5
4c
ABPW

TROPICAL DEPRESSION 23W

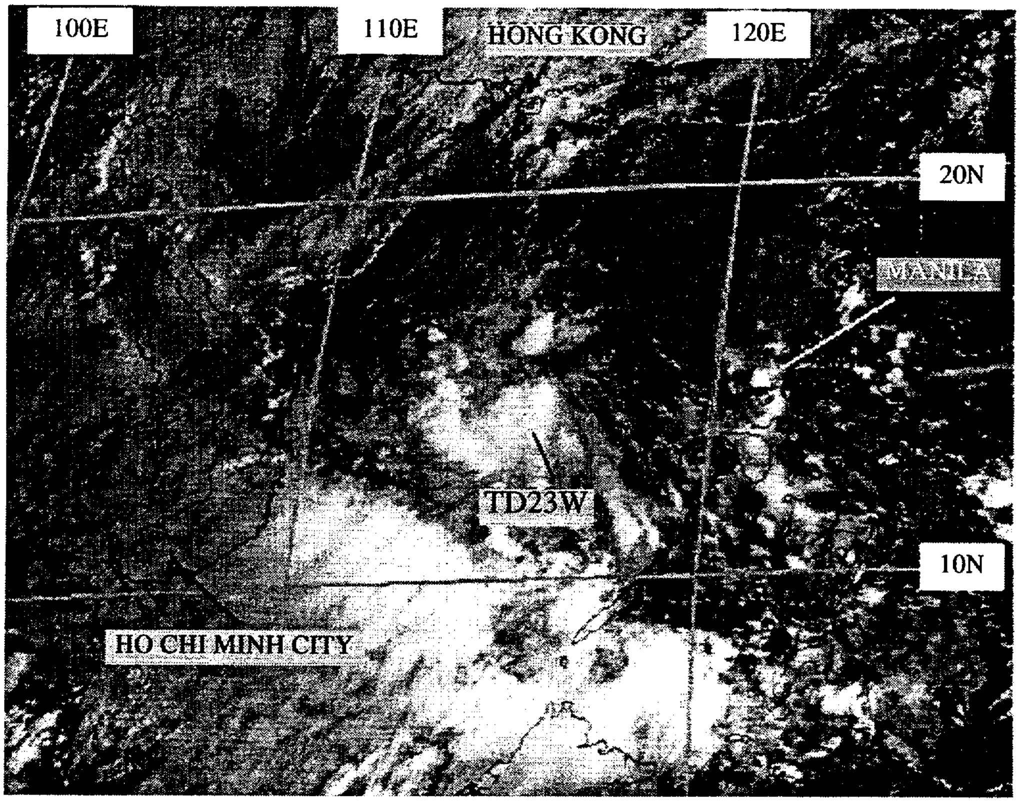
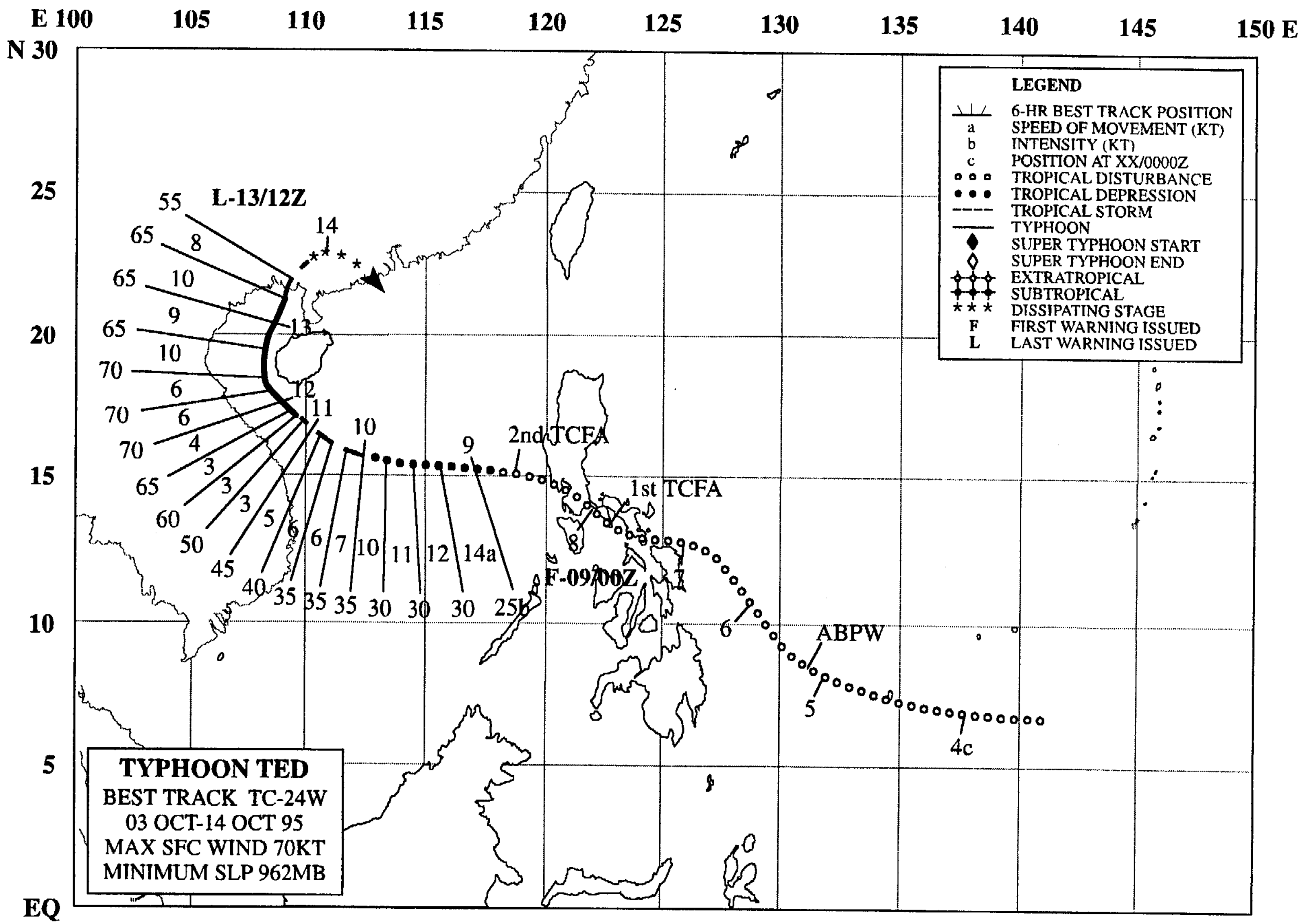


Figure 3-23-1 The tropical disturbance that became Tropical Depression 23W begins to consolidate its deep convection around its low-level circulation center (042331Z October visible GMS imagery).

While Tropical Storm Sibyl (20W) was making landfall in southern China, another tropical disturbance was crossing the central Philippines. Expecting that the environment would become more favorable for development of the tropical disturbance over the Philippines once Sibyl weakened over China (the outflow from Sibyl appeared to be creating northerly shear on this disturbance), the JTWC added it to the Significant Tropical Weather Advisory at 030600Z October. When this disturbance moved into the South China Sea, deep convection increased in areal coverage and organization, prompting the JTWC to issue a Tropical Cyclone Formation Alert (TCFA) at 040800Z. Moving westward in the South China Sea, the disturbance failed to intensify. An exposed low-level circulation center was revealed by visible satellite imagery during the daylight hours of 05 October (Figure 3-23-1). Although the maximum winds in the system were estimated to be only 15 to 20 kt (8 to 10 m/sec), the environment was considered favorable for development, so a second TCFA was issued at 050800Z. At 051200Z, synoptic data, and wind speeds derived from microwave imagery indicated that the wind speeds in the system had increased to 25 kt (13 m/sec). Based on these data, the first warning on Tropical Depression 23W (TD 23W) was issued, valid at 051200Z. TD 23W moved steadily westward toward the coast of Vietnam and, only twelve hours after the first warning, the final warning was issued at 060000Z when satellite imagery indicated weakening. The remnants of TD 23W moved inland over southeast Asia later that day and dissipated.


TYPHOON TED
BEST TRACK TC-24W
03 OCT-14 OCT 95
MAX SFC WIND 70KT
MINIMUM SLP 962MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 100
105
110
115
120
125
130
135
140
145
150 E
N 30
25
20
15
10
5
EQ
L-13/12Z
F-09/00Z
2nd TCFA
1st TCFA
ABPW
4c
14a
25b

TYPHOON TED (24W)

I. HIGHLIGHTS

Typhoon Ted developed east of the Philippines in the near-equatorial trough. After moving through the islands of the central Philippines as a tropical disturbance, Ted became a typhoon in the South China Sea when south of Hainan Island. As Ted passed into the Gulf of Tonkin, a gust of 111 kt (55 m/sec) was observed at the top (100 m above sea level) of an oil rig, and winds of typhoon force were estimated to have occurred at sea-level by crew members working at the base of the platform. Ted eventually dissipated over the mountains of southern China.

II. TRACK AND INTENSITY

The tropical disturbance that became Ted can be traced back to a flare-up of deep convection approximately 200 nm (370 km) south-southeast of Ulithi Atoll in the western Caroline Islands that occurred at 031200Z October along the axis of a weak near-equatorial trough. This disturbance was slow to develop and wasn't mentioned by the JTWC until the Significant Tropical Weather Advisory was reissued at 050300Z to include it. The first of two Tropical Cyclone Formation Alerts (TCFAs) was issued at 071800Z when the disturbance went ashore in southeastern Luzon near Legaspi. At this time, the upper-tropospheric flow pattern was deemed by forecasters to be favorable for intensification. The system, however, did not intensify as it passed over the many islands in the center of the Philippine archipelago. With the synoptic environment still appearing to favor intensification, a second TCFA was issued at 081800Z as the disturbance entered the South China Sea.

Based on an improved satellite signature and ship reports, the first warning was issued on Tropical Depression 24W (TD 24W), valid at 090000Z. Twenty-four hours later, satellite intensity estimates reached 35 kt (18 m/sec), and TD 24W was upgraded to Tropical Storm Ted on the warning valid at 100000Z. Thereafter, Ted moved westward and continued to intensify (Figure 3-24-1). On 11 October, Ted began to track more northwestward toward the Gulf of Tonkin, and started to intensify at a faster rate.

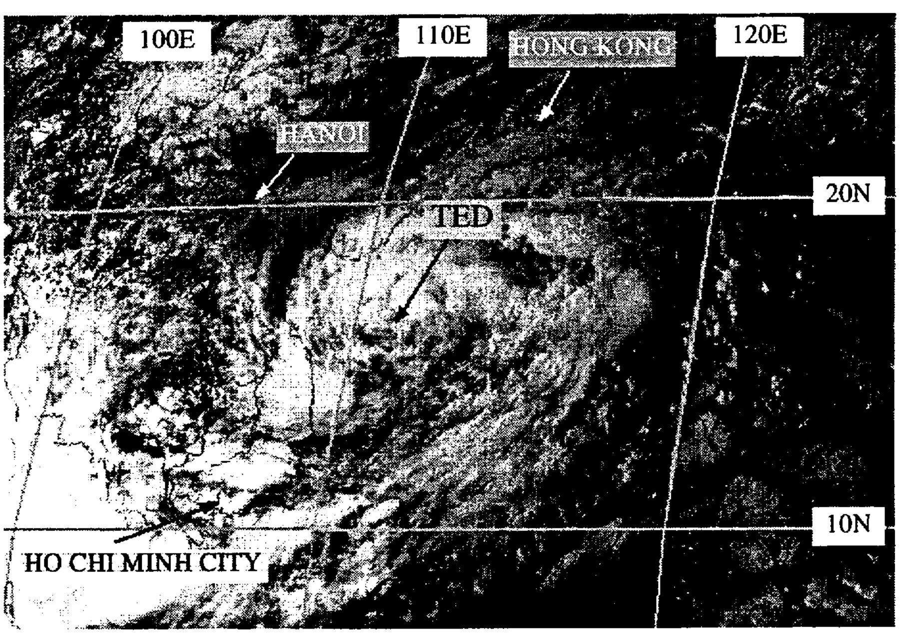


Figure 3-24-1 Ted begins to intensify as it nears Hainan Island (100831Z October visible GMS imagery).

Intensity estimates based upon the application of Dvorak's technique to satellite imagery did not provide an accurate picture of Ted's "true" intensity as determined from synoptic data. All warning intensities on 11 October were at least 20 kt (10 m/sec) too low, and all forecasts indicated a weakening trend. However, observations from an oil rig at approximately 120000Z (that were not received at the JTWC until 120600Z) indicated that Ted most probably reached typhoon intensity late on 11 October (see the discussion of Ted's intensity on 11 and 12 October in the next section).

Typhoon Ted reached its peak intensity of 75 kt (39 m/sec) at 120000Z and maintained this intensity for 18 hours. The typhoon continued to track around the west side of Hainan Island with its eye and eye wall remaining just offshore. Late on 12 October, Ted turned to the north-northeast and made landfall near Beihai in southern China as a minimal typhoon. It dissipated rapidly as it moved inland, and the final warning, valid at 131200Z, was issued.

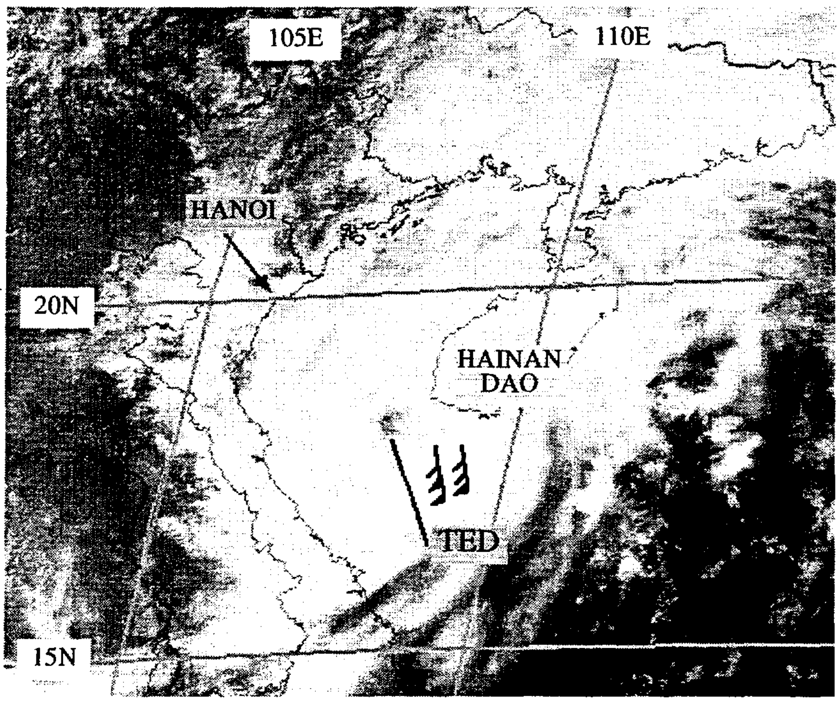


Figure 3-24-2 Typhoon Ted with the observed winds at an oil rig superimposed. The winds (observed at different times) are plotted relative to Ted's center, not the rig location (120331Z October visible GMS imagery). (Wind data courtesy of Nobel Denton Weather Services Ltd, London).

III. DISCUSSION

Typhoon intensity revealed by synoptic data

The peak wind information observed on an oil rig located at 17.9°N 109.7°E (south of Hainan Island) that was passed to the JTWC by Noble Denton Weather Services Ltd. of London, is a good illustration of discrepancies that can occur between surface observations of the winds in a tropical cyclone and the surface wind speed as estimated using currently available satellite techniques. Intensity values yielded by the application of Dvorak's techniques indicated an intensity of 45 kt (23 m/sec) as Ted approached Hainan Dao. Observations from the oil rig, however, indicated that the wind speeds were substantially higher. Wind gusts at the top of the 300 ft (100 m) platform reached a peak of 111 kt (57 m/sec) at 111930Z, while wind speeds near the surface were estimated to be at typhoon force at 120000Z (Figure 3-24-2). Using the reduction scheme for marine observations of Liu et al. (1979) and the gust factors of Atkinson (1974) or Krayer and Marshall (1992), the 111 kt gust at 300 feet yields an estimate of 75 kt (37 m/sec) for the one-minute sustained wind at a height of 10 meters. These synoptic reports were the basis for the upgrade of Ted to typhoon intensity. The graphic in Figure 3-24-3 shows the influence of synoptic ground truth data on both the warning and the final best track warning intensity.

IV. IMPACT

The disturbance that became Ted caused local flooding as it traversed the Philippines. No reports of damage or injuries in either the Philippines or in China were received at the JTWC.

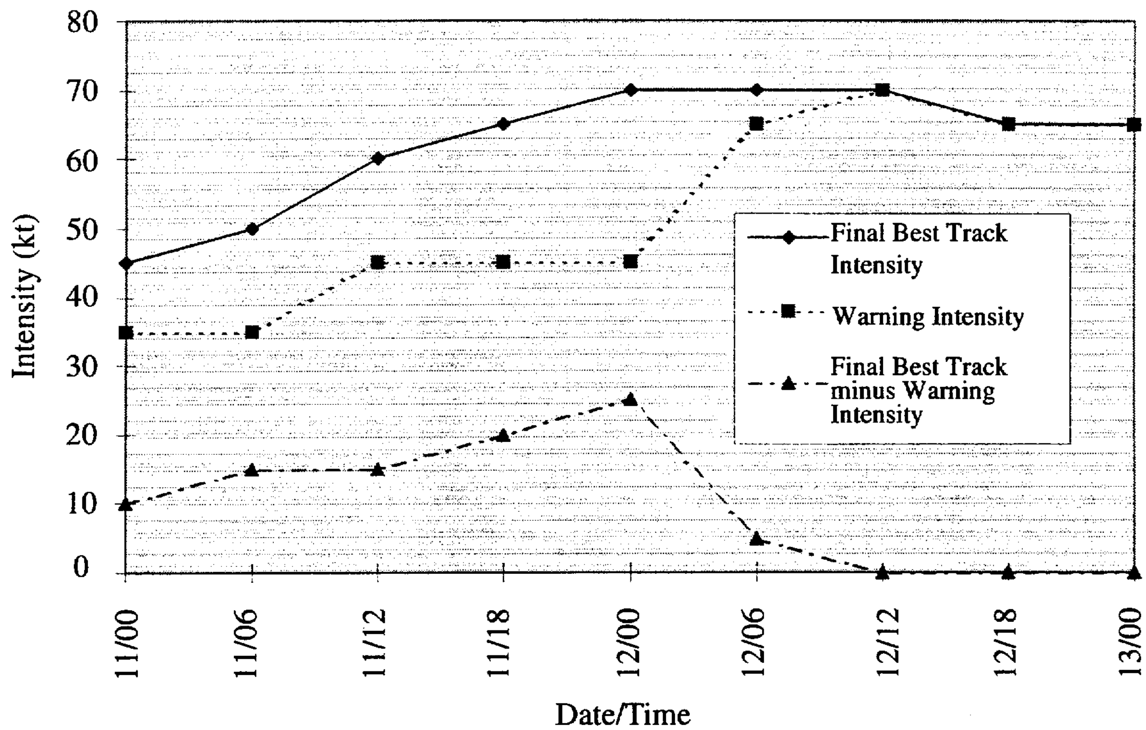
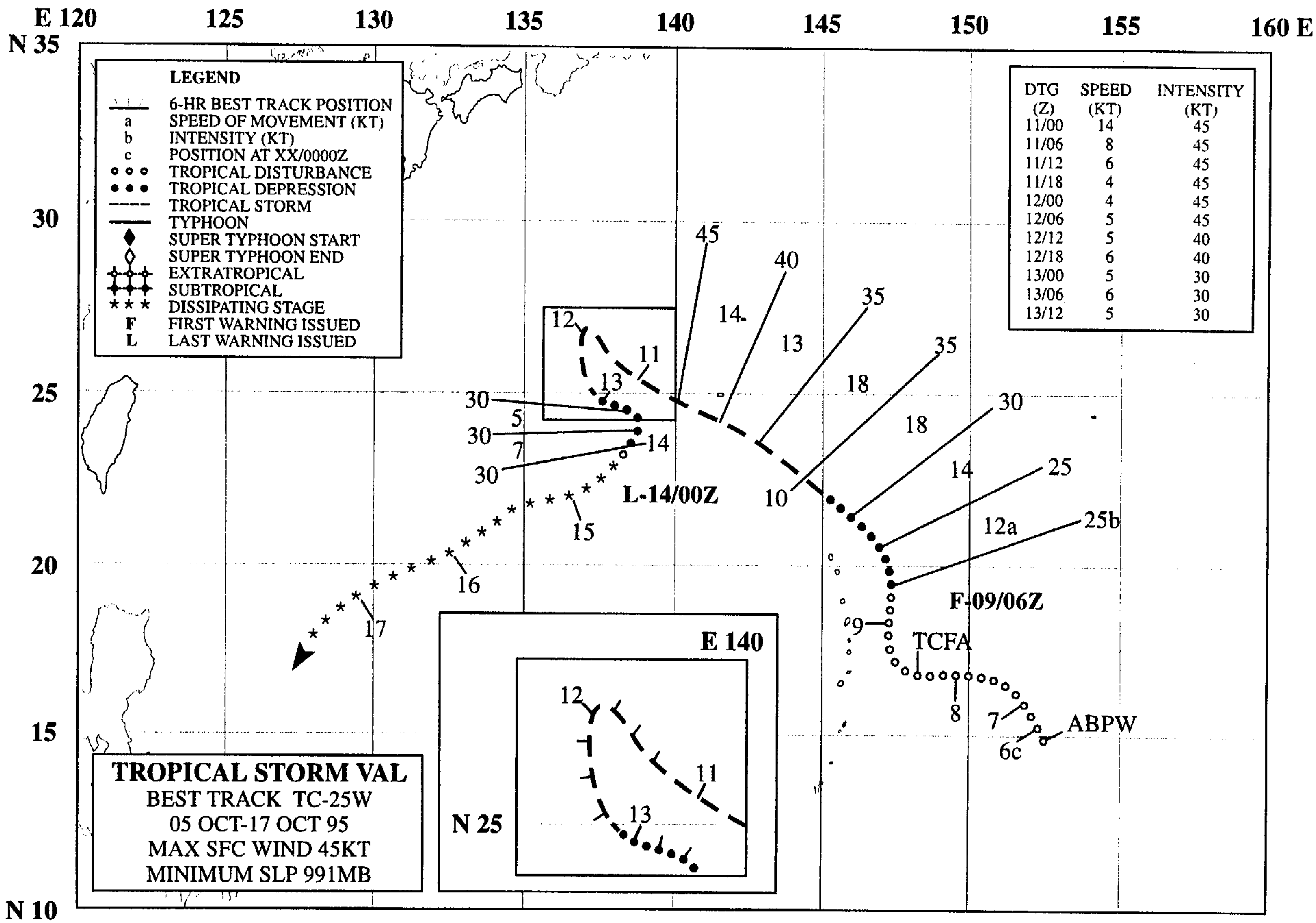


Figure 3-24-3 The influence of ground truth data at 120000Z (12/00Z) October on both the warning and final best track intensity.


E 120
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N 10
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
DTG (Z) | SPEED (KT) | INTENSITY (KT)
11/00 | 14 | 45
11/06 | 8 | 45
11/12 | 6 | 45
11/18 | 4 | 45
12/00 | 4 | 45
12/06 | 5 | 45
12/12 | 5 | 40
12/18 | 6 | 40
13/00 | 5 | 30
13/06 | 6 | 30
13/12 | 5 | 30
L-14/00Z
F-09/06Z
TCFA
ABPW
12a
25b
6c
E 140
N 25
TROPICAL STORM VAL
BEST TRACK TC-25W
05 OCT-17 OCT 95
MAX SFC WIND 45KT
MINIMUM SLP 991MB

TROPICAL STORM VAL (25W)

I. HIGHLIGHTS

Tropical Storm Val interacted with a monsoon gyre. This interaction coupled with the structural evolution of Val contributed to large track forecast errors.

II. TRACK AND INTENSITY

During the first week of October, an extensive area of deep convection and its associated cirrus debris stretched east-west from Southeast Asia to the Marshall Islands. This zone of maximum cloudiness, associated with a weak monsoon trough and a well-developed TUTT to its north, eventually produced two tropical disturbances that became named tropical cyclones: Typhoon Ted (24W), and Tropical Storm Val.

When Ted (24W) began to consolidate east of the Philippines, the zone of maximum cloudiness had moved northward, and stretched from the Philippines eastward past Guam. This band of deep convection was first mentioned on the 051800Z October Significant Tropical Weather Advisory. Val developed within this area of deep convection, but not until the large-scale low-level wind flow and the large scale pattern of deep convection became organized as a monsoon gyre.

At 080800Z October, a Tropical Cyclone Formation Alert (TCFA) was issued on this tropical disturbance. Remarks on this TCFA included:

". . . Satellite imagery and synoptic data indicate that a tropical disturbance located approximately 200 nm [370 km] northeast of Guam is becoming better organized. The area is located beneath an upper level anticyclone and outflow is being enhanced by the presence of an upper-level low (TUTT cell) to the northwest. . ."

During the daylight hours of 09 October, the tropical disturbance that became Val consolidated into a well-organized area of deep convection to the northeast of Guam. It was embedded in a larger band of deep convection that wrapped around the periphery of a monsoon gyre whose broad center was located north-northwest of Guam and about 450 nm (850 km) west-northwest of the pre-Val tropical disturbance (Figure 3-25-1). Turning northward, as it interacted with the circulation of the monsoon gyre, the tropical disturbance intensified and the JTWC issued the first warning valid at 090600Z October on Tropical Depression 25W.

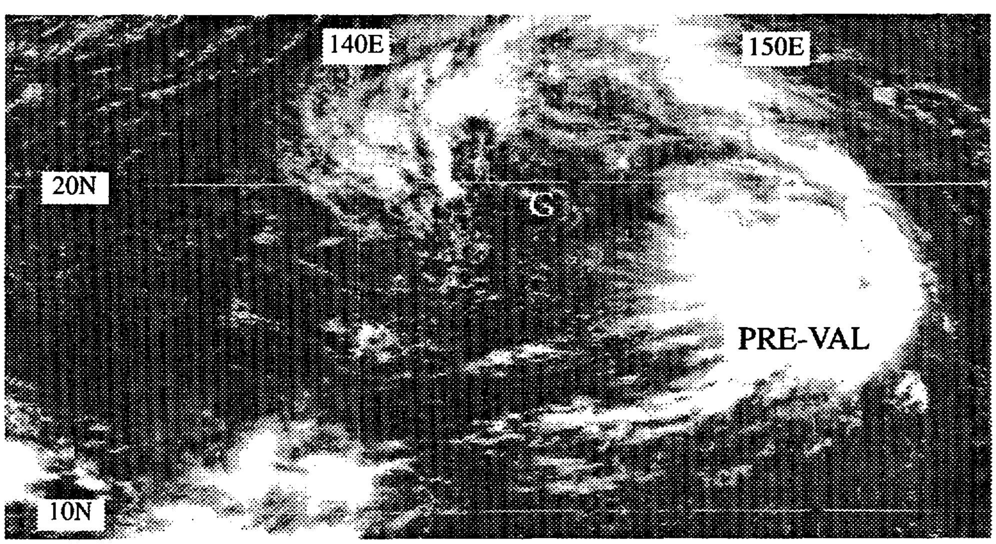


Figure 3-25-1 The tropical disturbance that became Val is located in the eastern side of the circulation of a monsoon gyre whose center is labeled "G" (090031Z October visible GMS imagery).

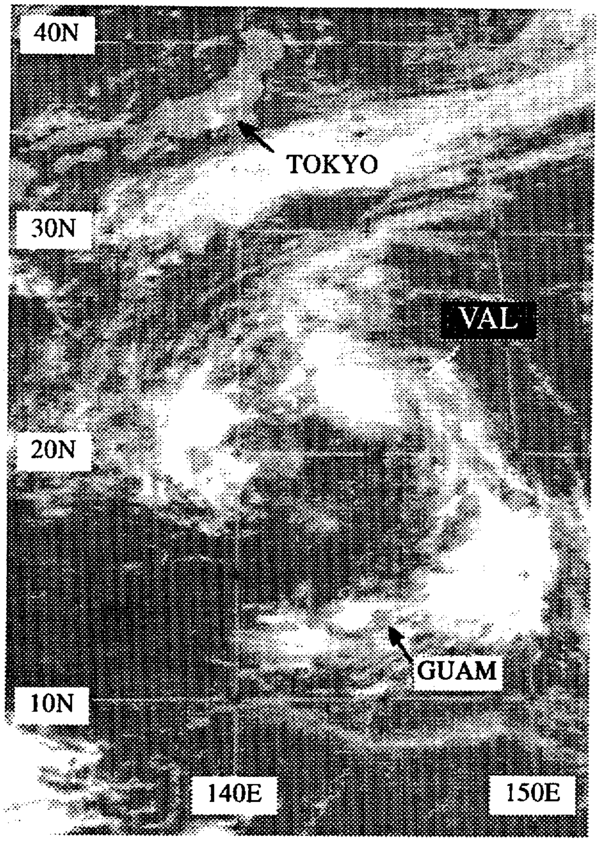


Figure 3-25-2 The CDO of Val is located to the northeast of the center of the monsoon gyre (100131Z October visible GMS imagery).

At 100000Z October, Tropical Depression 25W was upgraded to a tropical storm based upon persistent central deep convection (Figure 3-25-2). Remarks on this warning included:

"... Tropical Depression 25W has been upgraded to Tropical Storm Val ... Latest Satellite imagery indicates that Val is orbiting around a larger monsoon gyre. Our forecast is for these two systems to merge in the next 24 to 36 hours then move off to the west-northwest. ..."

By 11 October, Val had orbited from the eastern side of the gyre to its northern side (Figure 3-25-3). While located north of the center of the monsoon gyre, Val stalled and began to undergo vertical shearing from the west. On the morning of 12 October, visible satellite imagery (Figure 3-25-4) indicated that the low-level circulation center of Val was sheared to the west of the deep convection. Earlier during the previous night, the low-level circulation center was thought to have moved to the northeast under the deep convection, leading to a nearly 120 nm (225 km) relocation in the morning (a perfect example of the phenomenon known as the "sunrise surprise"). These diagnostic problems led to some very large forecast track errors (see discussion).

Eventually, all of the deep convection was sheared away, and Val merged with the monsoon gyre; the merged vortex drifted to the west-southwest and slowly dissipated. The final warning valid at 140000Z was issued when all deep convection was lost and only a low-level circulation center remained.

III. DISCUSSION

a. *Tropical cyclone interaction with a monsoon gyre*

A monsoon gyre is one of several patterns of the summer monsoon flow of the western North Pacific. As a monsoon gyre, the low-level circulation of the western North Pacific becomes organized as a large cyclonic vortex associated with a nearly circular 2500-km-wide depression in the contours of the sea-level pressure (e.g., see Figure 3-25-3). Typically, a cyclonically curved band of deep convection rims the southern through eastern periphery of this large vortex — in the case of the October 1995 monsoon gyre, the deep convection wrapped all the way around to the northwestern side of the gyre (see Figure 3-25-2). Also typical of a monsoon gyre is the formation of small or very small tropical cyclones in the peripheral cloud band of the gyre. Historically, most tropical cyclones that interact with a monsoon gyre undergo one of three possible fates (Figure 3-25-5): (1) the tropical cyclone orbits the gyre within the northeast quadrant of the gyre, and then escapes the influence of the gyre and recurves, (2) the tropical cyclone merges with the gyre and the two become one large circulation, and (3) the tropical cyclone, upon reaching the northern side of the gyre continues to move westward, or west-southwestward, in tandem with the gyre or between the gyre and an anticyclone to its northwest. In Val's case, it appeared that upon reaching the north side of the monsoon gyre, that it came very close to recurving. Instead, it stalled for two days, its convection was sheared away, and the remnant vortex merged with the gyre and then moved to the west-southwest and dissipated near the Philippines.

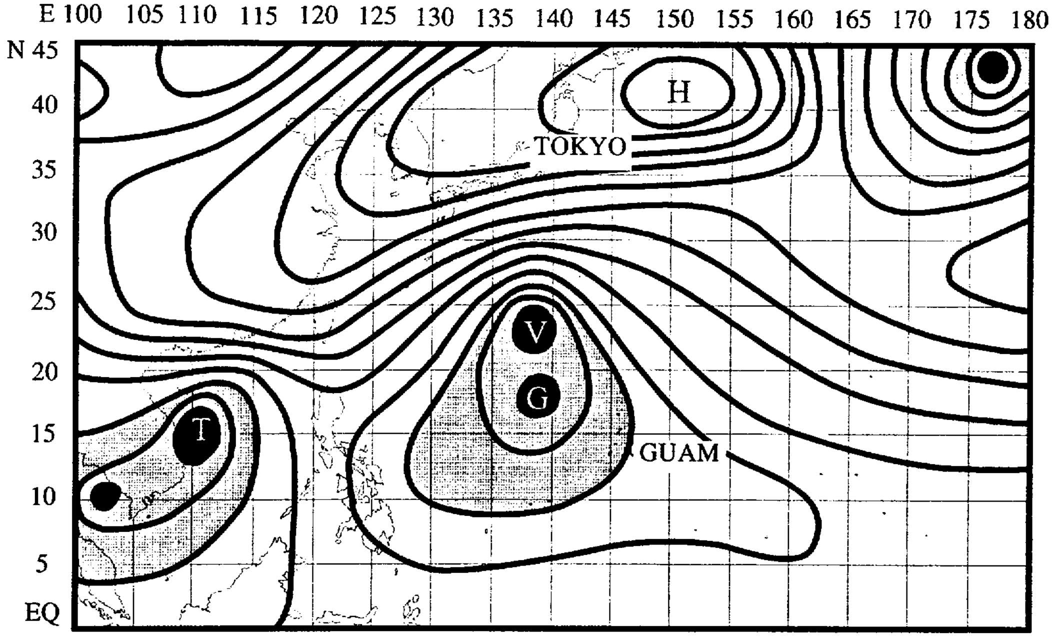


Figure 3-25-3 Contours of sea-level pressure (SLP) (at 2 mb intervals) at 110000Z October showing Val (V) located to the north of the center of the monsoon gyre (G). Another tropical cyclone — Ted (T) — is located in the South China Sea. Shaded region shows area where SLP is 1010 mb or lower; regions of SLP of 1006 mb or lower are black.

b. *Large track errors*

Val had large 48- and 72-hour track forecast errors (Figure 3-25-6). The four forecasts made between 110600Z and 120000Z each exceeded 1000 nm (1850 km) at 72 hours — the largest of these errors was 1386 nm (2550 km). The four forecasts made between 100600Z and 110000Z each exceeded 600 nm (1125 km) at 72 hours as a result of assuming that Val would continue to move steadily westward after rounding the northern side of the monsoon gyre. The largest of all the track forecast errors — those that occurred between 110600Z and 120000Z — resulted from an incorrect anticipation that Val would recurve.

Diagnostic errors during the night hours of 11 October contributed to the erroneous forecasts for Val to recurve. During the night hours of 11 October, the deep convection associated with the low-level circulation center of Val appeared to be moving northward. The satellite fix positions incorrectly followed the convection northward, while in reality, the deep convection was being sheared away from the low-level circulation center. By the first light of the morning of 12 October, the extent of the diagnostic errors became known. Based upon visible satellite imagery (Figure 3-25-4), the low-level circulation center of Val was repositioned approximately 120 nm to the west-southwest of the night infrared position estimate. Also contributing to the nighttime choice of recurvature were some dynamic model indications that Val would recurve.

In retrospect, it is possible that an SSM/I image of Val at 1110005Z October (Figure 3-25-7) could have been used to diagnose the sheared condition of Val, and that this information could have been used by the JTWC to reconsider its forecasts of recurvature before the morning visible satellite imagery revealed the diagnostic error.

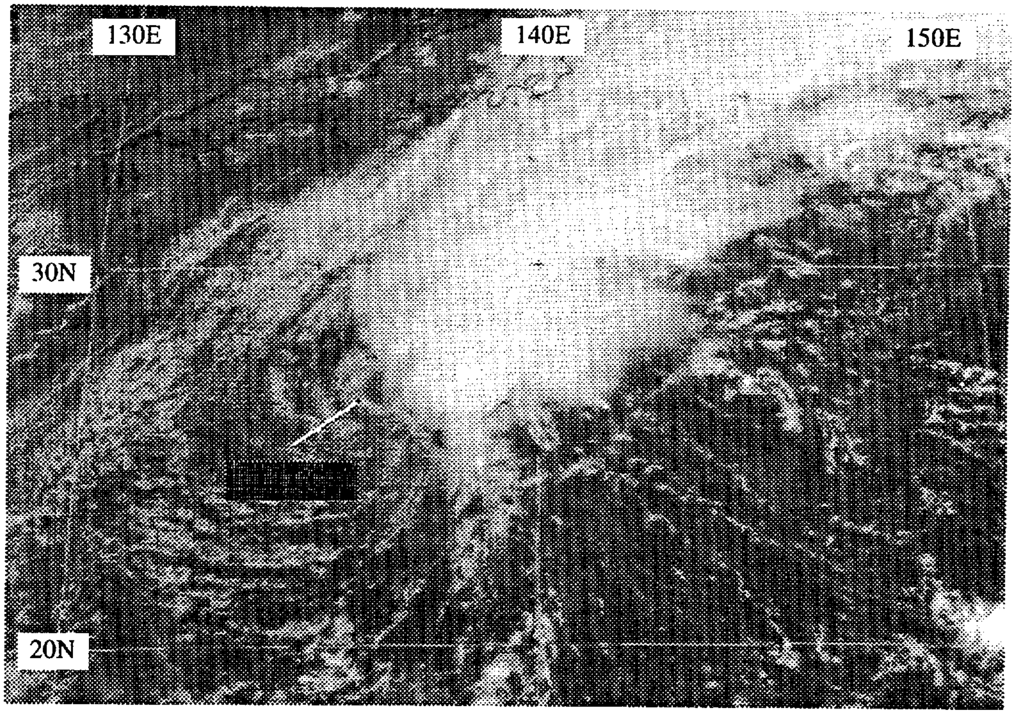


Figure 3-25-4 Val's low-level circulation center (marked LLCC) is located to the west of the deep convection (112224Z October visible GMS imagery).

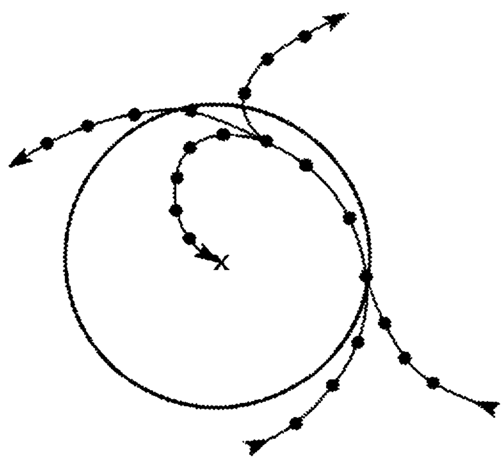


Figure 3-25-5 A schematic illustration of the typical interactions between a tropical cyclone and a monsoon gyre. The circle represents the outermost closed isobar of the monsoon gyre. Possible cyclone tracks are shown with respect to the center of the monsoon gyre.

IV. IMPACT

No reports of damage or injuries were received at the JTWC.

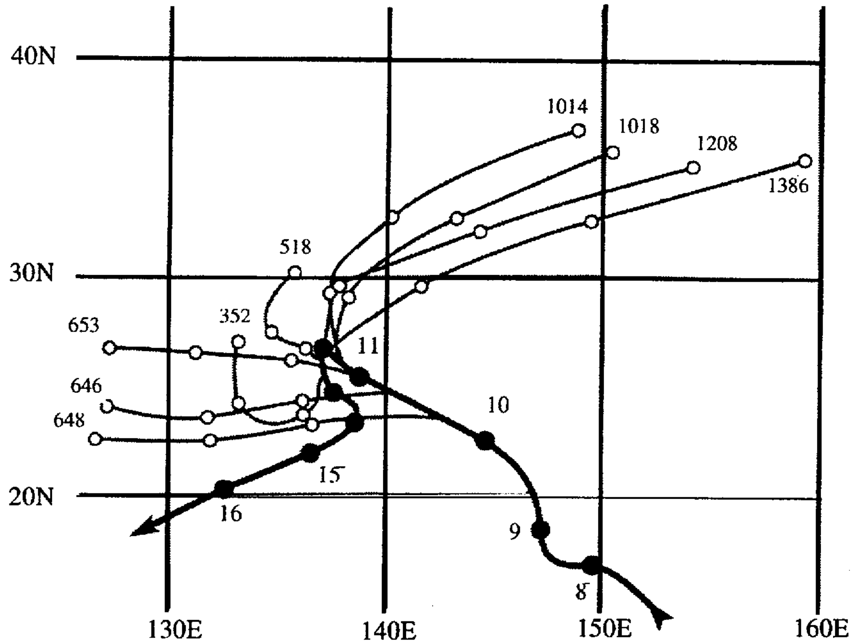


Figure 3-25-6 A schematic illustration of some selected track forecasts made by the JTWC for Val. The track of Val is indicated by the thick black line with black dots indicating the 0000Z positions of the indicated day. Small open circles connected by thin lines are selected JTWC track forecasts. Each track forecast has three open circles indicating the 24-, 48- and 72-hour forecast positions. The small numbers at the 72-hour forecast positions indicate the error associated with that forecast position (units are nm).

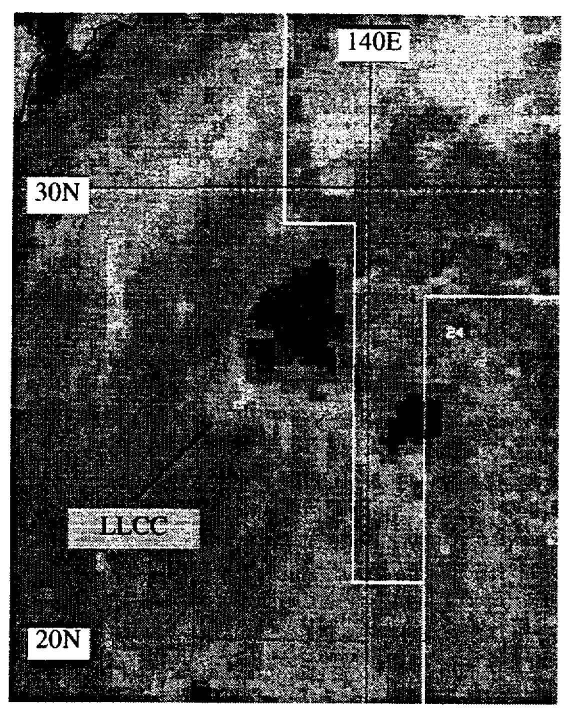
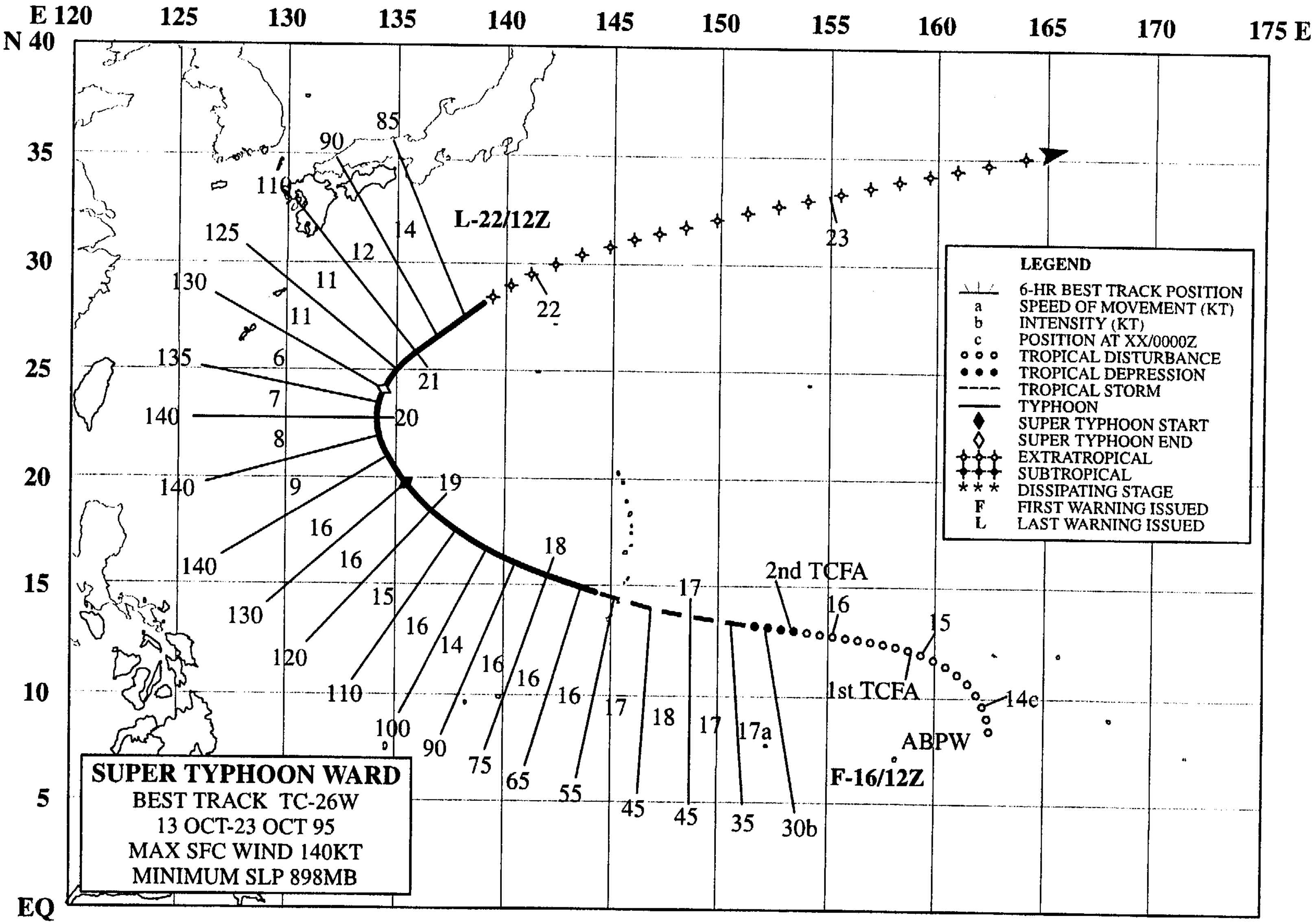


Figure 3-25-7 An 85 GHz (horizontally polarized) microwave image of Val showing that the deep convection is sheared to the northeast of the low-level circulation center (111005Z October SSM/I DMSP imagery).


SUPER TYPHOON WARD
BEST TRACK TC-26W
13 OCT-23 OCT 95
MAX SFC WIND 140KT
MINIMUM SLP 898MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-22/12Z
F-16/12Z
2nd TCFA
1st TCFA
ABPW
E 120
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SUPER TYPHOON WARD (26W)

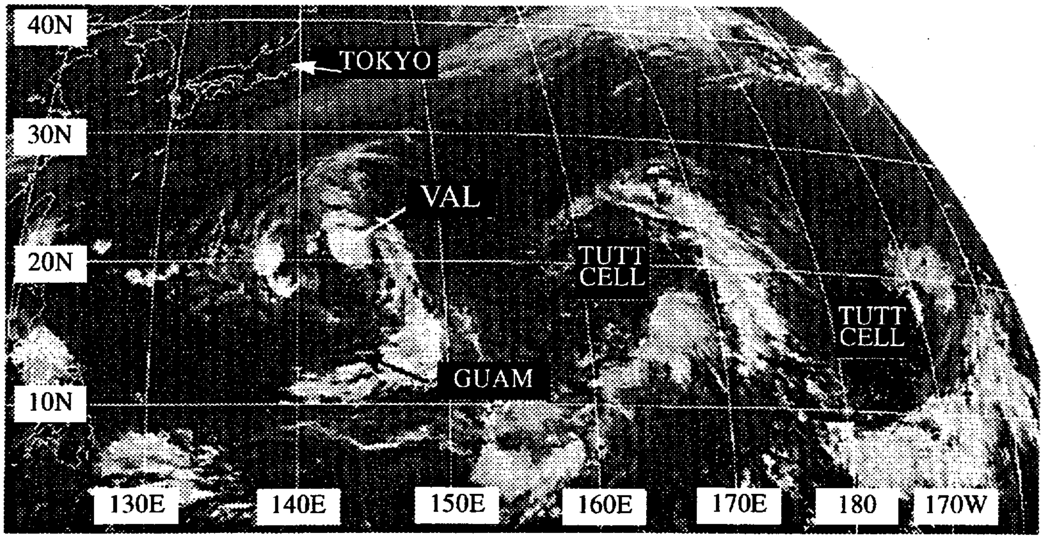


Figure 3-26-1 A chain of three atmospheric vortices with similar satellite signatures is spread across the tropics of the western Pacific: a monsoon gyre with an embedded tropical cyclone — Val (25W), and two TUTT cells centered at the indicated locations (100033Z October infrared GMS imagery).

I. HIGHLIGHTS

The fourth of five super typhoons during 1995, Ward formed as a small tropical cyclone east of Guam. Guam's NEXRAD provided a detailed look at the structure of this small tropical cyclone as it was intensifying and passing through the southern Mariana Islands. Ward's first visible eye was very small; it was later replaced by an average sized eye.

II. TRACK AND INTENSITY

The tropical disturbance that became Ward had it origins in the Marshall Islands where a nearly stationary area of deep convection associated with a chain of TUTT cells was present as early as 10 October (Figure 3-26-1). This area of convection remained poorly organized for the next few days, and was comprised of mesoscale convective systems that grew and decayed. On 14 October, this area of deep convection — located to the south of a well-defined TUTT cell — became more organized (e.g., a cyclonically curved band composed of mesoscale convective systems and anticyclonically curved streamers of outflow cirrus), prompting its first mention on the 131800Z October Significant Tropical Weather Advisory.

While moving westward in tandem with the TUTT cell to its north, the deep convection in this tropical disturbance began to consolidate around a well defined low-level circulation center. This prompted the JTWC to issue a Tropical Cyclone Formation Alert (TCFA) at 150130Z October. At 152330Z, the TCFA was canceled when amounts of deep convection near the center diminished. A second TCFA was issued soon thereafter at 160830Z when persistent deep convection once again consolidated near the low-level circulation center. The JTWC issued the first warning on Tropical Depression 26W valid at 161200Z when it became apparent in satellite imagery that the system was rapidly becoming better organized. By the morning of 17 October, satellite imagery indicated a significant improvement in the organization of TD 26W, and it was upgraded to Tropical Storm Ward at 170000Z. Moving rather quickly at 17 kt (32 km/hr) toward the west, Ward passed between the islands of Rota and Saipan, or about 70 nm (130 km) to the north of Guam, during the night of 17 October. At 171800Z, Ward was upgraded to a typhoon based upon a maximum inbound velocity of 81 kt (42 m/sec) at 7,000 ft above sea level as depicted by Guam's NEXRAD, and also as corroborated by satellite intensity estimates.

After becoming a typhoon, Ward began to track on a more northwestward direction. Moving towards a "break" (i.e., a col) along the axis of the mid-tropospheric subtropical ridge axis, Ward slowed, turned toward the north and reached its point of recurvature at 200000Z. While approaching its point of recurvature, Ward also intensified, and attained its peak intensity of 140 kt (72 m/sec) at 191200Z (Figure 3-26-2). After passing through the ridge axis, Ward turned sharply toward the northeast, accelerated, and

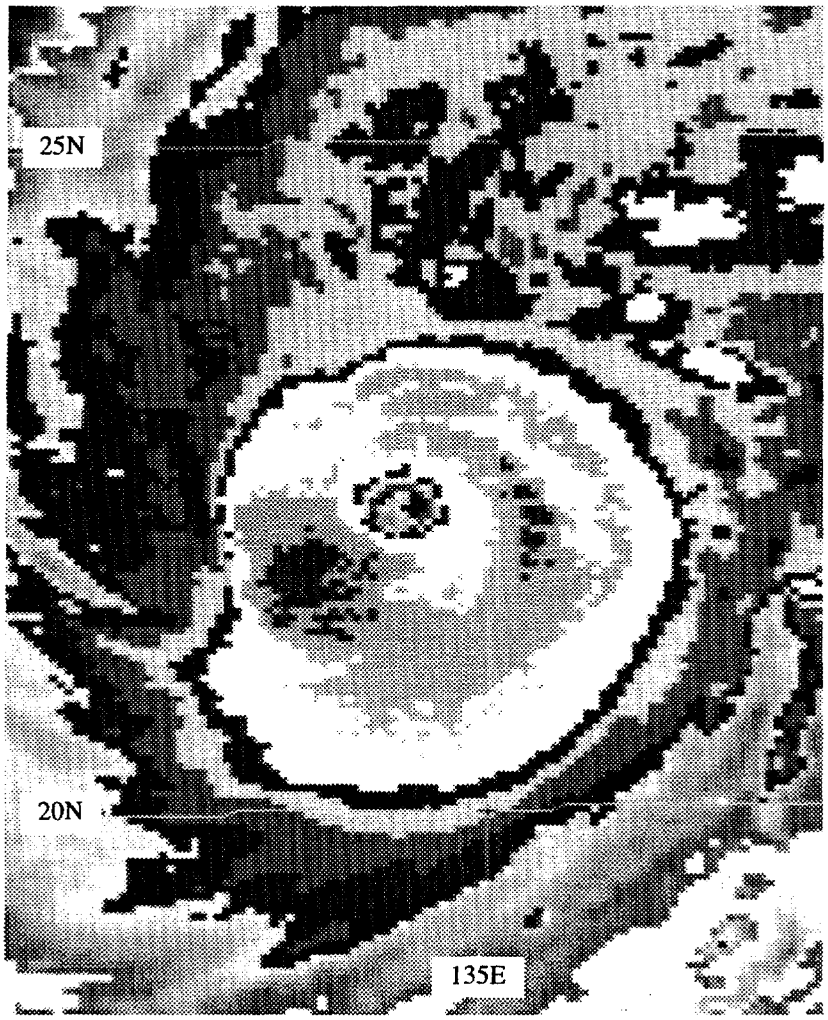


Figure 3-26-2 Ward at peak intensity of 140 kt (72 m/sec) (191931Z October enhanced infrared GMS imagery).

began to weaken as the vertical wind shear in the westerly wind flow north of the subtropical ridge sheared the system. At 220600Z, Ward was downgraded to a tropical storm as the low-level circulation became fully exposed to the southwest of its extensive shield of multi-layered middle and high cloud — a typical appearance of a tropical cyclone undergoing extratropical transition (Figure 3-26-3). Based upon the expected completion of its extratropical transition, the final warning was issued at 221200Z.

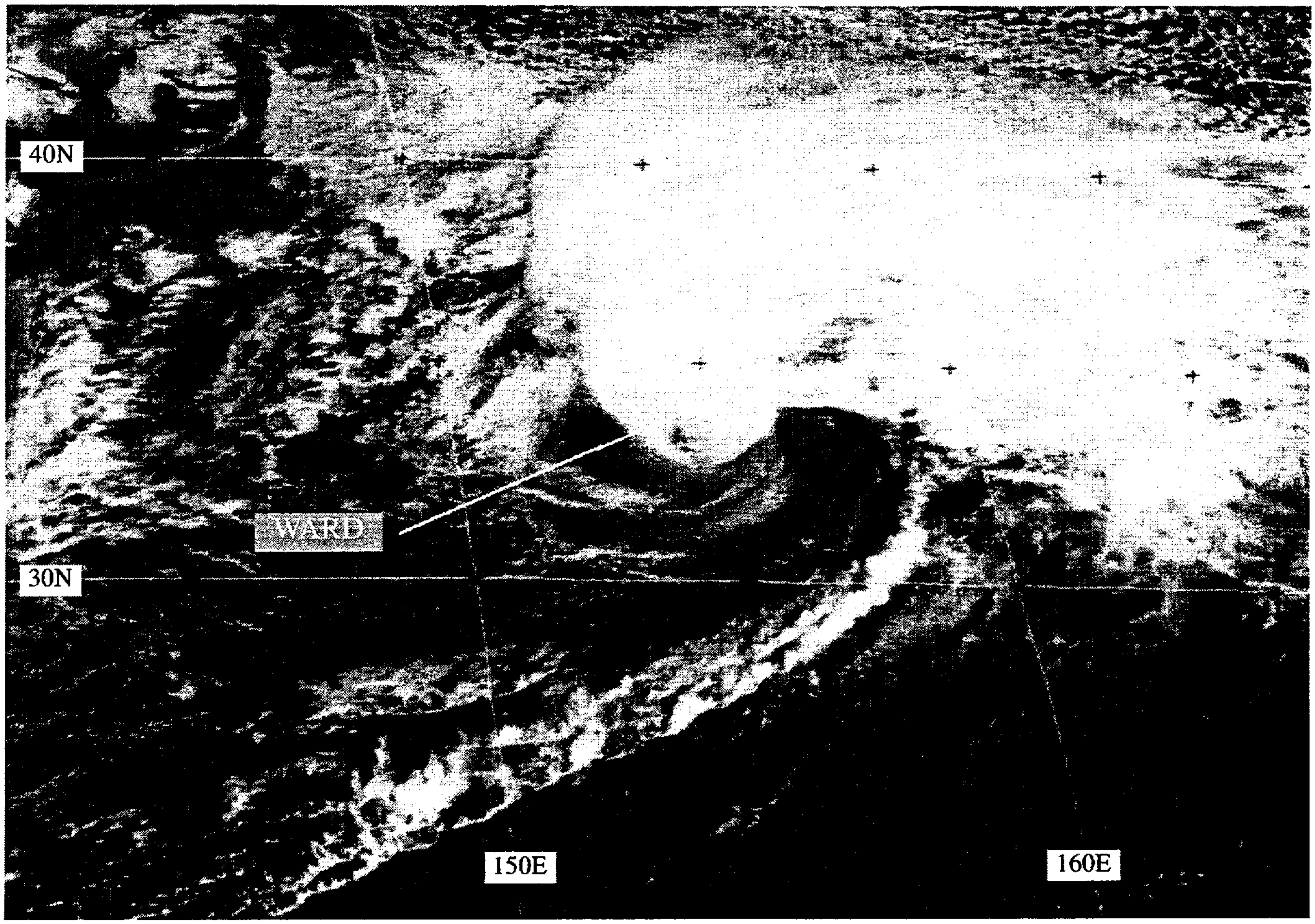


Figure 3-26-3 Ward's extratropical transition is nearly complete (222331Z October visible GMS imagery).

III. DISCUSSION

a. *A NEXRAD view of the early development of Ward*

During the night of 17 October, Ward passed between the islands of Rota and Saipan, or about 70 nm (130 km) to the north of Guam. This placed the small circulation of the intensifying Ward well within the range of Guam's NEXRAD. While within the 124-nm range of the NEXRAD Doppler capability, Ward moved toward the west-northwest at an average translational speed of 17 kt (32 km/hr) and intensified from 45 to 65 kt (23 to 33 m/sec). One aspect of Ward's structure that was well-depicted by the NEXRAD was the nature of the wind asymmetry. The wind asymmetry between the north side and the south side of Ward appeared to be primarily a result of Ward's translation speed. The effect of the translation was almost fully represented. At a translation speed of 17 kt, one would expect the difference in the wind speed between the north side and the south side of Ward to be twice the speed of translation, or approximately 35 kt. As Ward came within the Doppler range, about 120 nm (220 km) to the east-northeast of Guam, a maximum inbound wind of 50 kt (26 m/sec) was present on the north side at the lowest beam altitude of 16,000 ft. On the south side of Ward, the maximum outbound wind was 17 kt (9 m/sec) (also at 16,000 ft). The differential between the inbound and outbound wind was thus 33 kt, or very nearly what would be expected from a full accounting of the speed of translation. Later, as Ward moved due north of the NEXRAD (and thereby placing the asymmetry introduced by the speed of translation perpendicular to the radar), the inbound and outbound velocities became nearly equal at about 65 kt each way, and both at the lowest beam elevation of 7,000 ft.

This brings us to another structural characteristic of Ward's wind field as revealed by the NEXRAD: the maximum wind speed, whether inbound or outbound, always occurred at the lowest possible beam elevation. In this case, the lowest altitude of beam penetration was 7,000 ft when Ward was at its closest point of approach. That the highest winds in a TC should be at a low level is not a surprising finding, however, in some other TCs that have come even closer to Guam (e.g., Eli (04W) and Verne (1994)), the maximum winds near the center have been observed to occur at elevations as low as 2,000 feet; and again nearly always at the lowest possible viewing altitude of the NEXRAD. Such findings bring into question the conventional tactic of reducing aircraft reconnaissance flight-level wind speed (usually near 10,000 ft) by 80% to estimate the surface wind speed.

Ward was a small-sized tropical cyclone as it passed to the north of Guam. When due north of Guam, the distance between the maximum inbound and outbound winds was only 12 nm (22 km) at 7,000 ft. The diameter of gale-force winds was approximately 40 nm (75 km) at 7,000 ft. The speed of the westerly winds on Guam when Ward passed only 70 nm (130 km) to the north was only 10 kt (5 m/sec). The subsequent growth in size and the large increase of the intensity of this small vortex was a remarkable structural change.

Some additional general structural characteristics of tropical cyclones passing within the range of Guam's NEXRAD are: (1) the maximum wind speed is found at the lowest beam elevation in the most highly reflective and deepest convection, (2) over time scales on the order of tens of minutes, the wind speeds rise and fall as deep convective elements grow and decay, and (3) when deep convection grows in the eye wall, wind speeds increase throughout the depth of the troposphere and become more nearly constant with height (i.e., the deep convection appears to be accelerating the wind velocity, and also to be transporting the momentum to higher altitudes).

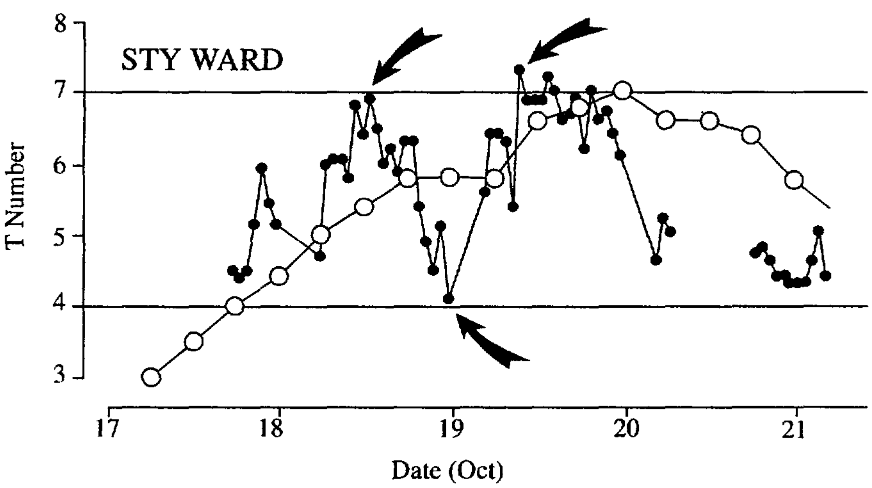


Figure 3-26-4 A time series of Ward's hourly "Digital" Dvorak (DD) intensity estimates (black dots). Also shown is the warning intensity (converted to a T number) (open circles). Arrows indicate two peaks and an intervening minimum in the DD time series.

b. *Evidence of two intensity peaks related to eye structure*

Ward was another of the year's tropical cyclones for which hourly values of the Digital Dvorak (DD) numbers (Figure 3-26-4) were tabulated during much of its life (see Oscar's (17W) summary for a description of the DD algorithm installed on the JTWC's MIDDAS satellite image processing equipment). The time series of Ward's DD (Figure 3-26-4) indicates two peaks of intensity near T 7.0 (equivalent to 140 kt): one near 181200Z and the other 24 hours later at 191200Z. Between these two peaks, the DD indicated that the intensity fell as low as T 4.0 (minimal typhoon intensity) at about 190000Z.

These two intensity peaks are closely related to the evolution of Ward's eye. After first becoming a typhoon, Ward's eye was extremely small (as seen by NEXRAD and later as it appeared on visible satellite imagery). After attaining its first intensity peak at 181200Z with a very small eye (Figure 3-26-5), the eye clouded over (resulting in lower intensity estimates) and then reappeared at a larger size when it attained its second peak intensity at 191200Z (Figure 3-26-2).

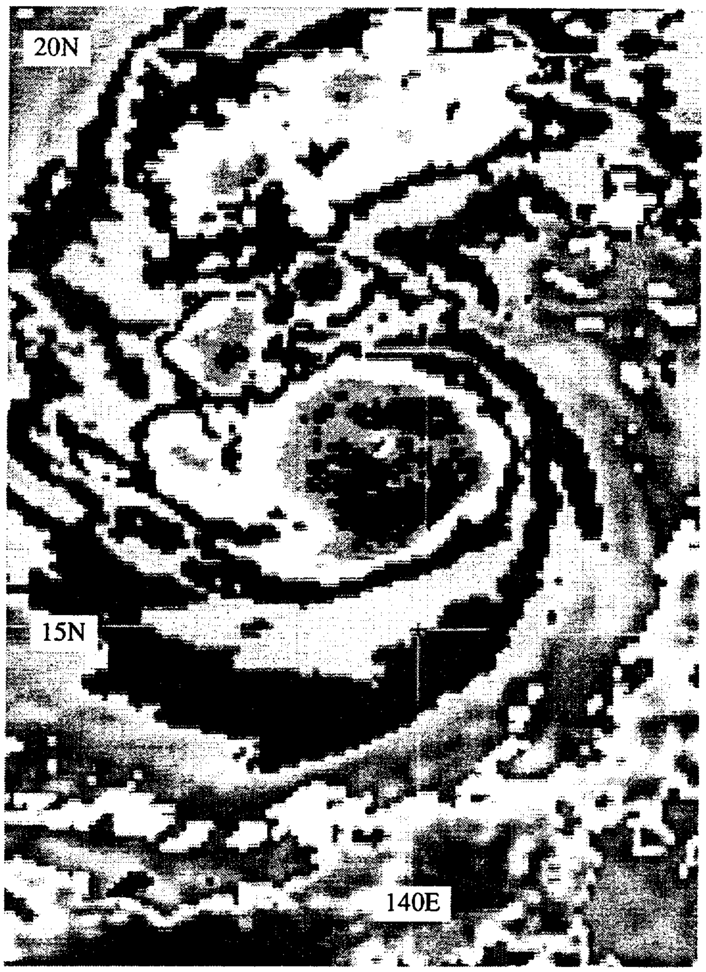
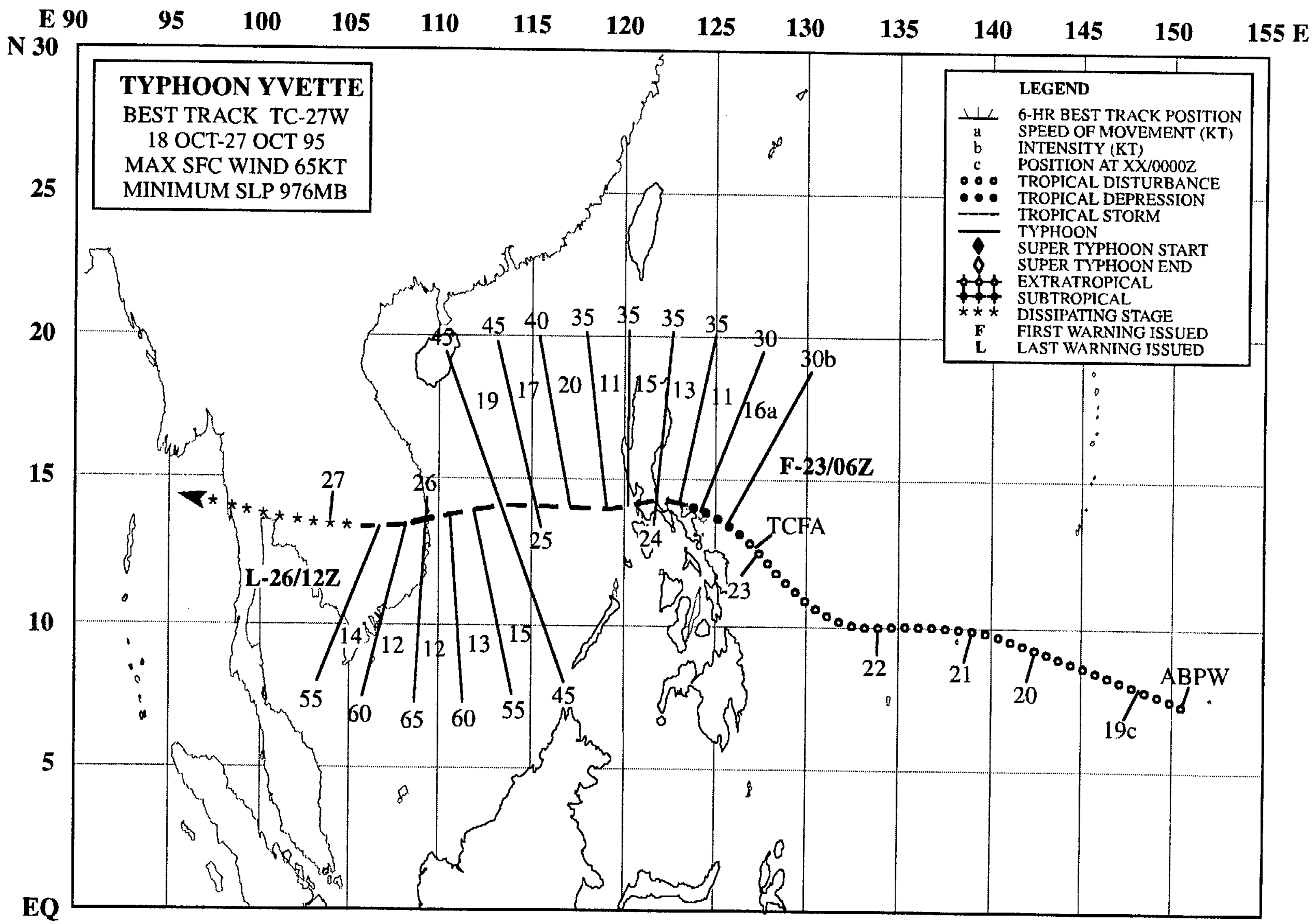


Figure 3-26-5 Ward possesses a very small eye at the time of the first peak on the DD time series (181031Z October enhanced infrared GMS imagery).

Similar to the case with Ryan (19W), the warning intensity and the final best-track intensity do not reflect the first peak of the DD (i.e., DD = 140 kt; final best-track = 100 kt). As the DD rose to its second peak, the warning and final best-track intensity rose to match it (i.e., DD = 140 kt; final best-track intensity = 140 kt). Once again, the DD has revealed extremely large and rapid fluctuations of intensity that were not reflected in the warning intensity or the final best-track intensity. In the absence of ground truth measurements, it is not possible to know in fine detail how Ward's intensity changed. In the case of Ward, there is a clear reason for the rapid changes in the DD intensity: the changes in Ward's eye characteristics. If the DD truly represented Ward's intensity, there are two sobering implications: (1) an extremely rapid increase of intensity occurred that was not reflected in the warning, and (2) the best-track data base, having had these rapid fluctuations removed, can not be used to study the processes governing what may prove to be real intensity fluctuations of the magnitude indicated by the DD.

IV. IMPACT

As Ward passed through the Mariana Islands it affected the islands of Rota, Tinian and Saipan. Heavy rain caused minor flooding on several Saipan streets. On Tinian, gusty winds and heavy rains caused a loss of electrical power to half of the island.


TYPHOON YVETTE
BEST TRACK TC-27W
18 OCT-27 OCT 95
MAX SFC WIND 65KT
MINIMUM SLP 976MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
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L LAST WARNING ISSUED
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TYPHOON YVETTE (27W)

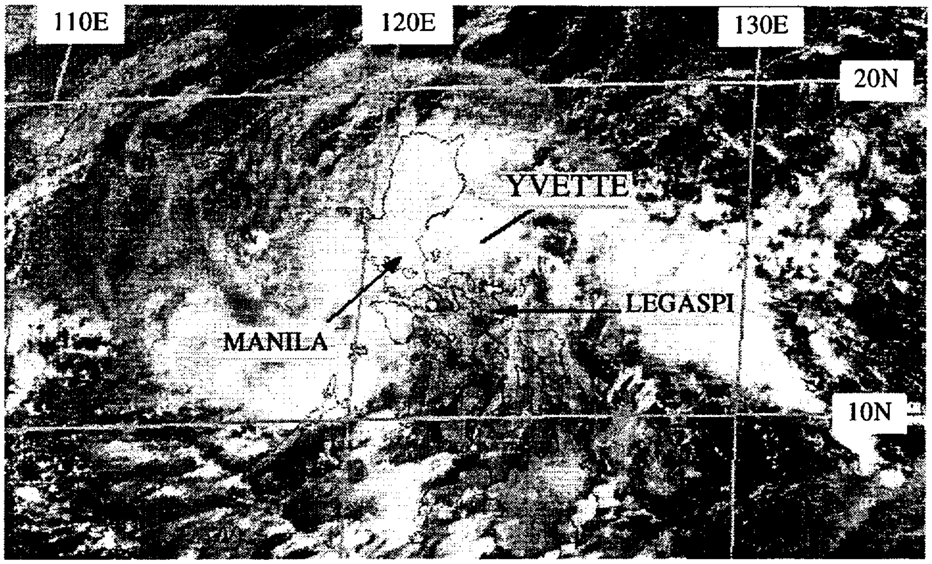


Figure 3-27-1 As the low-level circulation center of Yvette makes landfall on Luzon, bands of deep convection extend well to the east and west, giving Yvette an elongated appearance (232331Z October visible GMS imagery).

I. HIGHLIGHTS

Yvette was one of seven tropical cyclones during 1995 that passed over the Philippines with an intensity of 35 kt (18 m/sec) or greater. Like many other tropical cyclones during 1995, Yvette did not develop significantly until it had tracked westward to near the Philippines. While in the Philippine Sea, Yvette was difficult to track by satellite due to its poor organization.

II. TRACK AND INTENSITY

As Typhoon Ward was beginning its recurvature south of Japan, the tropical disturbance that became Yvette originated west of Chuuk in a weak near-equatorial trough. This disturbance was first mentioned on the 180900Z October Significant Tropical Weather Advisory when an area of deep convection had persisted for 12 hours in association with a weak low-level cyclonic circulation near Chuuk. For over three days, the disturbance moved westward without intensifying. On 23 October, as the disturbance approached the Philippines, satellite imagery indicated that the system had become better organized, and that northeasterly shear on the system was weakening. This prompted the JTWC to issue a Tropical Cyclone Formation Alert, valid at 230100Z. Rapid improvement in the organization of the system was subsequently noted in visible satellite imagery, and the JTWC issued the first warning on Tropical Depression 27W, valid at 230600Z. As Tropical Depression 27W was passing just north of Daet (located on southeastern Luzon), it appeared to be forming a CDO, and was upgraded to Tropical Storm Yvette on the warning valid at 231800Z. However, as Yvette began to cross Luzon, its development was arrested; its cloud bands became elongated in an east-west direction (Figure 3-27-1), and its intensity held steady at 35 kt (18 m/sec) until it entered the South China Sea. Moving westward over the South China Sea, Yvette began to slowly intensify, and reached typhoon intensity (Figure 3-27-2) just before making landfall along the coast of Vietnam at 260000Z. After making landfall, Yvette weakened over the mountains of Vietnam, and dissipated over Kampuchea. The final warning, valid at 261200Z, was issued as the weakening Yvette moved into Kampuchea.

III. DISCUSSION

Large positioning errors and poor guidance

Yvette was often difficult to track with satellite imagery. Average fix errors were 59 nm (109 km) as compared with the 1995 average of 29 nm (54 km). This, and the poor performance of the dynamic model guidance, led to larger than average track forecast errors. CLIPER forecasts were extremely poor, partly due to the initial position errors, and partly due to the fact that climatology favors recurvature for tropical cyclones in the South China Sea during October.

IV. IMPACT

No reports of damage or injuries were received.

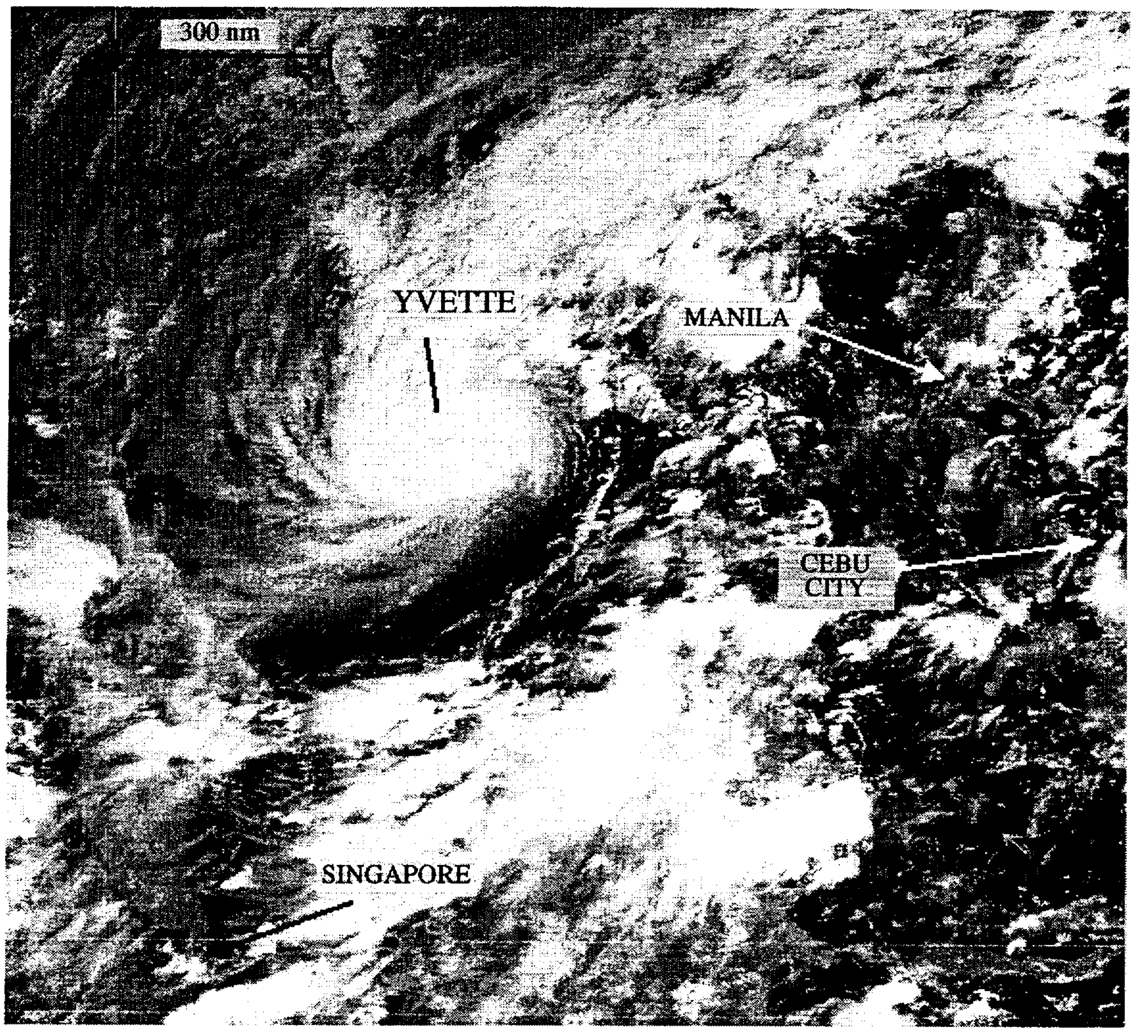
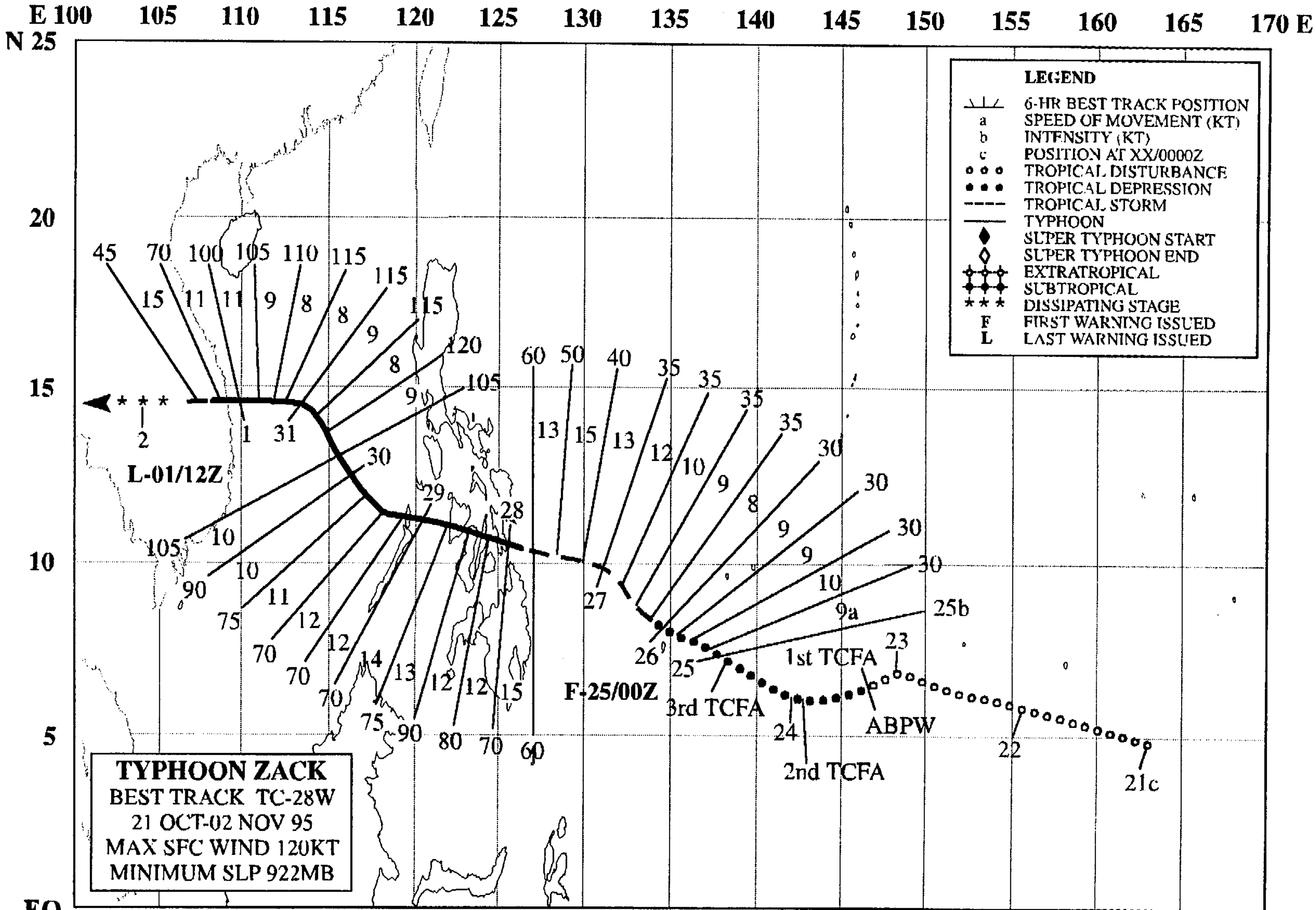


Figure 3-27-2 Yvette briefly attains typhoon intensity just as it makes landfall on the coast of Vietnam (260031Z October visible GMS imagery).



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LEGEND
6-HR BEST TRACK POSITION
SPEED OF MOVEMENT (KT)
INTENSITY (KT)
POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
L-01/12Z
F-25/00Z
1st TCFA
2nd TCFA
3rd TCFA
ABPW
21c
25b
9a
TYPHOON ZACK
BEST TRACK TC-28W
21 OCT-02 NOV 95
MAX SFC WIND 120KT
MINIMUM SLP 922MB

TYPHOON ZACK (28W)

I. HIGHLIGHTS

Originating from a tropical disturbance in the eastern Caroline Islands, Zack did not significantly intensify for nearly six days. As was the case with Sibyl (20W), Zack intensified as it crossed the Visayan islands. But, unlike Sibyl (which weakened over the South China Sea after crossing the Philippines), Zack intensified significantly, peaking at 120 kt (62 m/sec). Zack became one of that region's most intense tropical cyclones (see Ryan's summary for a discussion of very intense tropical cyclones in the South China Sea). Typhoon Zack, along with Super Typhoon Angela (29W) and Tropical Storm Brian (30W), comprised one of only three occasions during 1995 that the JTWC was simultaneously warning on three tropical cyclones in the western North Pacific. Zack made landfall in Vietnam with 100 kt (51 m/sec) maximum sustained winds. It left a path of death and destruction in both the Philippines and Vietnam.

II. TRACK AND INTENSITY

The tropical disturbance that became Zack was first detected on 21 October along the axis of the near-equatorial trough near Kosrae, and was first mentioned on the 230600Z Significant Tropical Weather Advisory. This poorly defined tropical disturbance appeared to have multiple wind circulation centers creating a difficult diagnostic situation. The circulation that became Zack was properly identified at 221200Z when amounts of deep convection increased and became focused around a single low-level circulation center. The tropical disturbance that became Zack, like so many others in 1995, was slow to develop. This slow rate of development contributed to the issuance of three Tropical Cyclone Formation Alerts: the first at 230600Z October, the second at 232030Z, and the third at 242030Z. The latter was superseded when the JTWC issued the first warning on Tropical Depression 28W, valid at 250000Z. The system was upgraded to Tropical Storm Zack 30 hours later on the warning valid at 260600Z.

Zack was difficult to track during the early stages of its development. On 25 October, position estimates of Zack's (then Tropical Depression 28W) low-level circulation center made from satellite imagery (Figure 3-28-1) incorrectly indicated that Zack was moving on a northwest track, vice the west-northwest track of the actual system that is shown in the final best track. As a result, positioning errors were as large as 140 nm (260 km) with respect to the final best track. In retrospect, the Japanese research ship, Tokai Maru (call sign: JBOA), passed just to the west of the low-level circulation center at 250600Z where it recorded a minimum sea-level pressure of 1002 mb. It wasn't until the first visible satellite imagery on the morning of 26 October that the satellite fixes began to track the low-level circulation center that was consistent with synoptic data (e.g., the surface and upper-air data from Koror). Forecasts during the period were heavily weighted toward climatology, and the tropical cyclone was forecast to move toward the central Philippines.

On the afternoon of 27 October, Zack began to intensify at a rate of 10 kt (5 m/sec) every 6 hours as it approached the Visayan Islands of the Philippines. Based upon satellite intensity estimates, Zack was upgraded to a typhoon on the warning valid at 280000Z. At 280200Z, Zack struck Leyte with sustained winds of 70 kt (36 m/sec). The Island capital of Tacloban (WMO 98550) recorded a peak gust of 81 kt (42 m/sec) and the Guian radar site on the island of Samar (WMO 98558) recorded a 1-minute sustained wind of 62 kt (32 m/sec) and a peak gust of 68 kt (35 m/sec). Zack continued to intensify as it crossed the Visayan Islands, reaching a peak intensity of 90 kt (46 m/sec) before striking the large mountainous

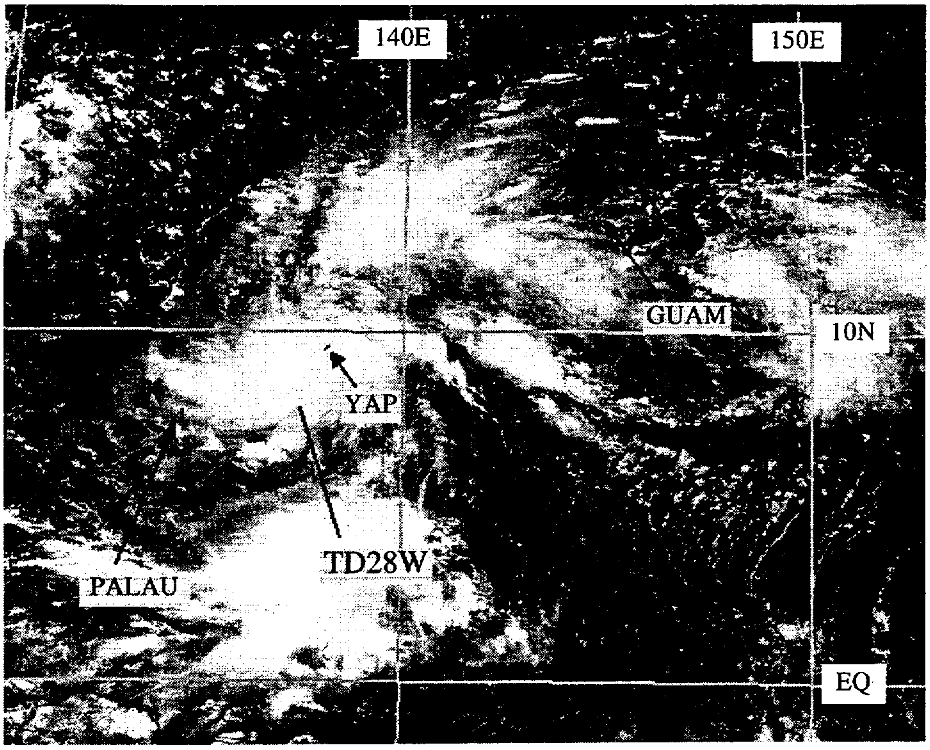


Figure 3-28-1 Tropical Depression 28W is located about 175 nm (325 km) east of Palau. The obvious knot of convection west of Yap was not co-located with the primary low-level circulation center. (250424Z October visible GMS imagery).

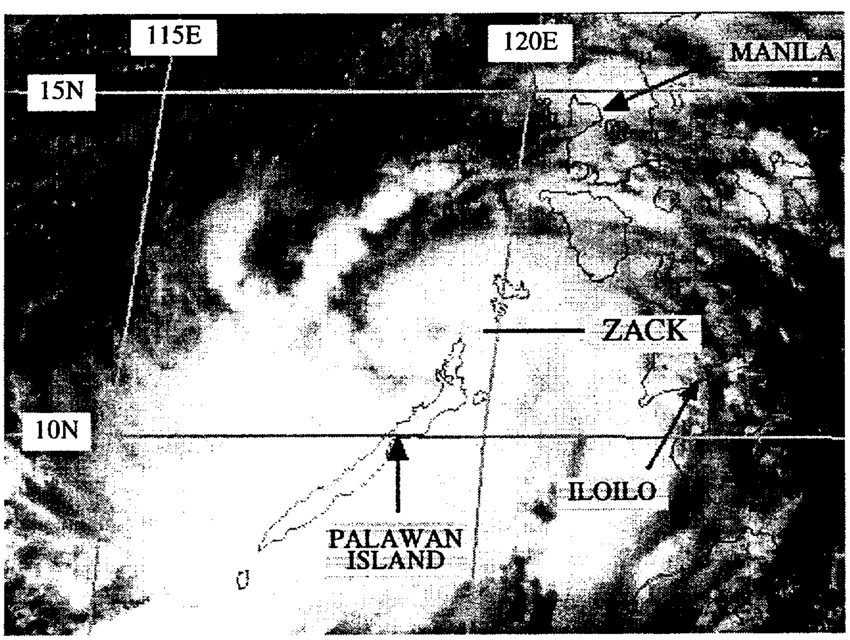


Figure 3-28-2 Typhoon Zack, at an intensity of 70 kt (36 m/sec) enters the South China Sea after passing by the northwest tip of Palawan Island (290531Z October visible GMS imagery).

island of Panay, after which the typhoon weakened (Figure 3-28-2). Both Cuyo Island (WMO 98630) and Iloilo (WMO 98637) measured sustained winds of 62 kt (32 m/sec) as Zack was crossing Panay. Possible mechanisms for intensification while crossing through an archipelago of high islands are outlined in the discussion section of Typhoon Sibyl's (20W) summary — Sibyl (20W) also intensified as it followed a path similar to Zack's through the central Philippines.

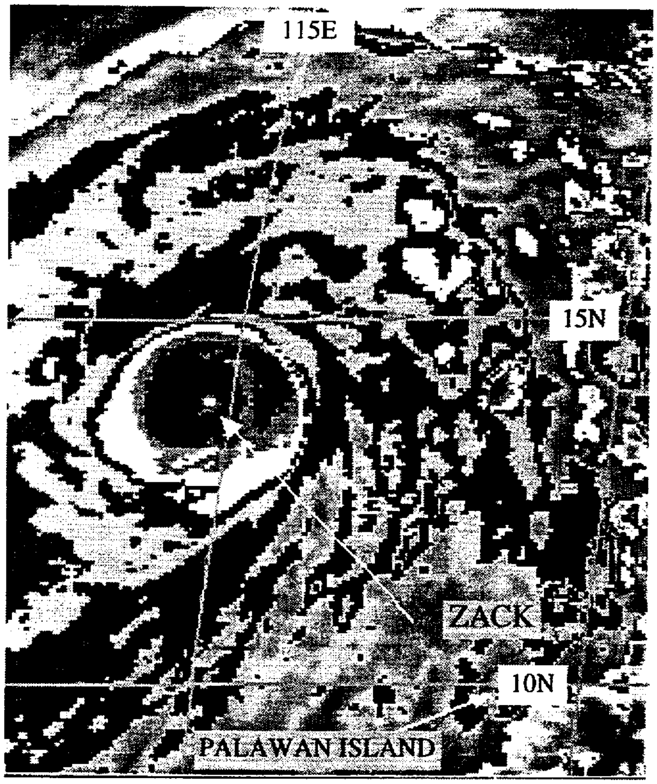


Figure 3-28-3 Typhoon Zack at peak intensity (301231Z October enhanced infrared GMS imagery).

After entering the South China Sea, Zack began to re-intensify. From 291800Z to 301200Z (a period of only 18 hours), Zack intensified 45 kt (23 m/sec) to its peak intensity of 120 kt (62 m/sec) (Figure 3-28-3). The associated rate of decrease of the estimated minimum sea-level pressure of 2.5 mb/hour meets the criterion for explosive deepening (see the discussion section). After peaking, Zack slowly weakened over water as it headed westward toward Vietnam. Zack made landfall in Vietnam at 010300Z November, about 70 nm (130 km) south of Da Nang. The final warning was issued, valid at 011200Z November, as the system entered the highlands of Laos. Complete dissipation occurred 18 hours later over Thailand.

III. DISCUSSION

a. *Intensification while passing over the central Philippines*

Zack, like Sibyl (20W), intensified while tracking across the central Philippines. For a discussion of the possible mechanisms for intensification while crossing through an archipelago of high islands, the reader is referred to the discussion section of Typhoon Sibyl's (20W) summary.

b. *Explosive deepening in the South China Sea*

Zack intensified 45 kt (23 m/sec) over an 18-hour span while over water in the South China Sea. This corresponds to a decrease of minimum sea-level pressure of 2.5 mb/hour which meets the criterion for explosive deepening as described by Dunnavan (1981). Zack reached a peak intensity of 120 kt (62 m/sec) at 301200Z (Figure 3-28-3). It is interesting to note that Zack appears to be totally isolated from its environment as the phase of explosive deepening began (Figure 3-28-4). In a study of the relationship between the cloud pattern and the intensification rate of tropical cyclones, Spratt (1990) found no significant differences in the average intensification rates of tropical cyclones whose cloud patterns resembled a "9", a "6", a two-tailed pattern (resembling the tropical cyclone symbol), or those (like Zack) that were circular.

IV. IMPACT

Zack caused considerable death, destruction, and agricultural losses in the Visayan Islands of the Philippines. Hardest hit of the Visayan Islands were Panay and Negros Occidental. There were over 110 deaths reported, of which 72 occurred in Negros Occidental, 18 in Cebu, and 20 in Iloilo. Flooded rivers and capsized boats claimed most of the victims. More than 30,000 homes were reported destroyed or damaged and preliminary estimates of agricultural losses amounted to US$2 million, primarily sugar cane. Bacolod, a city of 400,000, was without power for several days.

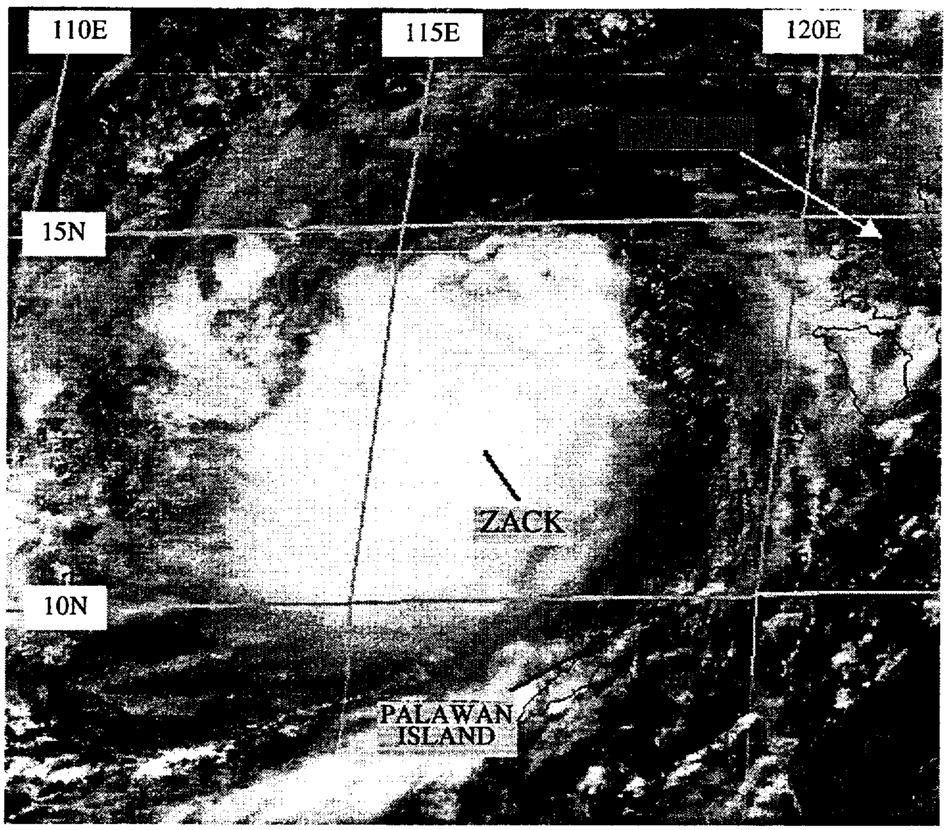
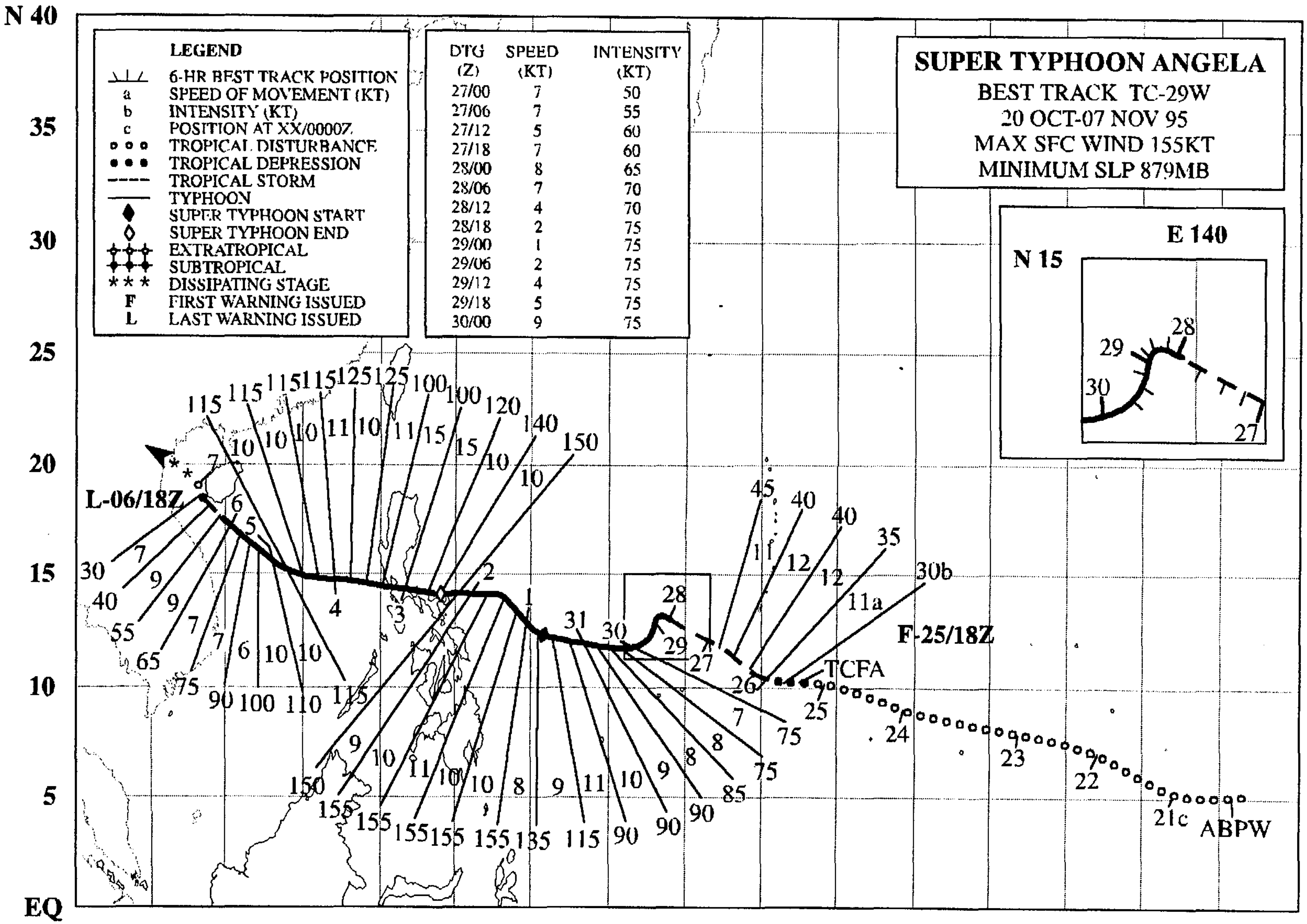


Figure 3-28-4 Zack is undergoing explosive deepening at the time of this picture (300031Z October visible GMS imagery). Note that the system appears to be isolated from its environment.



DTG (Z)	SPEED (KT)	INTENSITY (KT)
27/00	7	50
27/06	7	55
27/12	5	60
27/18	7	60
28/00	8	65
28/06	7	70
28/12	4	70
28/18	2	75
29/00	1	75
29/06	2	75
29/12	4	75
29/18	5	75
30/00	9	75

SUPER TYPHOON ANGELA (29W)

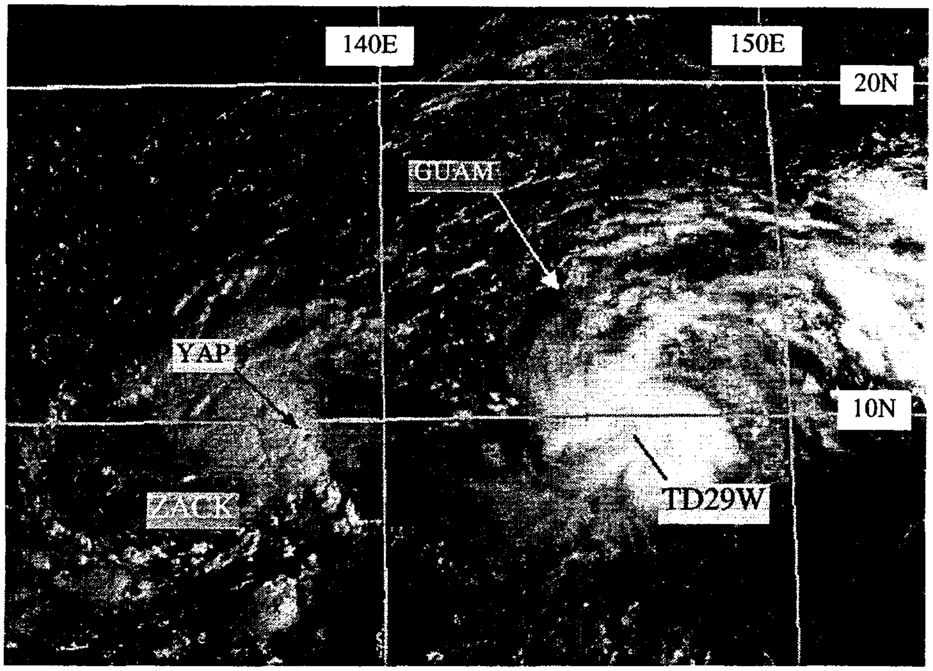


Figure 3-29-1 Tropical Depression 29W at an intensity of 30 kt (15 m/sec). Tropical Storm Zack (28W) is located about 480 nm (890 km) to its west (252131Z October visible GMS imagery).

I. HIGHLIGHTS

Angela was the most intense typhoon to hit the Philippines since Typhoon Joan (1970). First striking southern Luzon, it moved westward and crossed the metro-Manila area. More than 600 people perished in the Philippines as a result of Angela. Angela moved westward in tandem with Typhoon Zack (28W) nearly 4000 nm (7400 km) across the western North Pacific. Like many of the 1995 tropical cyclones, Angela was slow to develop, but ultimately, it became one of the most intense typhoons of the decade, peaking at an intensity of 155 kt (80 m/sec).

II. TRACK AND INTENSITY

In the third week of October, as Ward (26W) was recurving and heading towards its eventual transition into an extratropical cyclone southeast of Japan, the monsoon trough again became active along 10°N, from 130°E to east of the international date line. This trough spawned three tropical cyclones that at one time existed simultaneously: Yvette (27W) in the South China Sea, Angela to the south of Guam, and Zack (28W) in between the two and located northwest of Palau. The earliest stages of Angela can be traced to a tropical disturbance that formed in the Marshall Islands. This disturbance was first mentioned on the 200600Z October Significant Tropical Weather Advisory. It moved toward the west-northwest for more than five days — in tandem with the tropical disturbance that became Zack (28W) — before finally organizing into a tropical depression. A Tropical Cyclone Formation Alert was issued at 251230Z when the disturbance was located 240 nm (450 km) south-southeast of Guam. The system continued to organize during the night hours of 25 October, and the first warning on Tropical Depression 29W (TD 29W) was issued by the JTWC, valid at 251800Z (Figure 3-29-1). Twelve hours later, as the system passed about 145 nm (270 km) to the south of Guam and took a more northwestward course, it was upgraded to a tropical storm. During the next two days, Angela slowly intensified as its forward motion slowed to an average speed of 7 kt (13 km/hr). On the warning valid at 280000Z, Angela was upgraded to a typhoon. At 281200Z, the typhoon abruptly turned to the south-southwest (an unusual heading for a tropical cyclone). This erratic motion was at first difficult to detect due to the lack of a visible eye and frequently changing size, shape, and cloud-top temperatures of its central deep convection. During the 24-hour period of slow south-southwestward motion Angela maintained a 75 kt (39 m/sec) intensity (Figure 3-29-2).

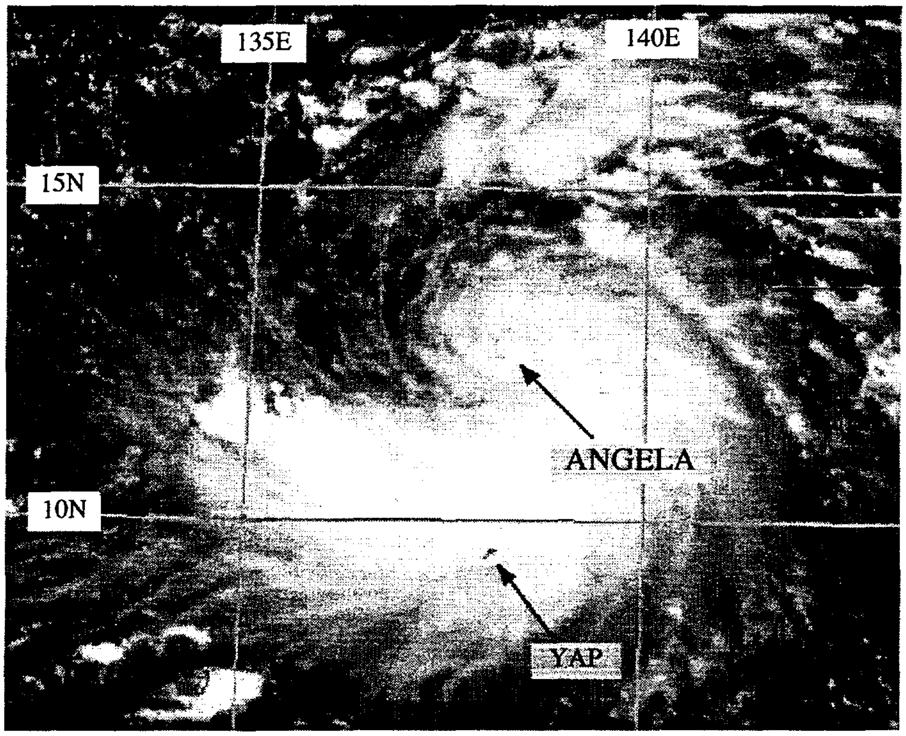


Figure 3-29-2 Typhoon Angela moves slowly south-southwestward as it passes north of Yap (290631Z October visible GMS imagery).

On the morning of 30 October, Angela turned back to the west and accelerated to an average speed of 9 kt (17 km/hr). During the afternoon, the typhoon began to slowly intensify. At 310600Z, with an intensity of 90 kt (46 m/sec), Angela began to rapidly intensify (Figure 3-29-3), and 18 hours later, it reached its maximum intensity of 155 kt (80 m/sec) (Figure 3-29-4). (A more in-depth description of Angela's rapid intensification process, including digital Dvorak (DD) intensity estimates, is found in the Discussion Section).

On the morning of 01 November, Angela moved to the northwest for 18 hours, before heading west along 14°N latitude. Angela maintained its peak intensity for 36 hours before striking the northern Bicol region of southern Luzon. During 31 October through 01 November, Angela passed to the north of a Navy drifting buoy (WMO 52523). The data recorded by this buoy (Figure 3-29-5) were important for defining the radius of 35 kt (18 m/sec) and 50 kt (26 m/sec) winds (see the discussion section). Also, landfall data obtained from PAGASA for postanalysis provided valuable information concerning Angela's peak winds as it approached and crossed Luzon.

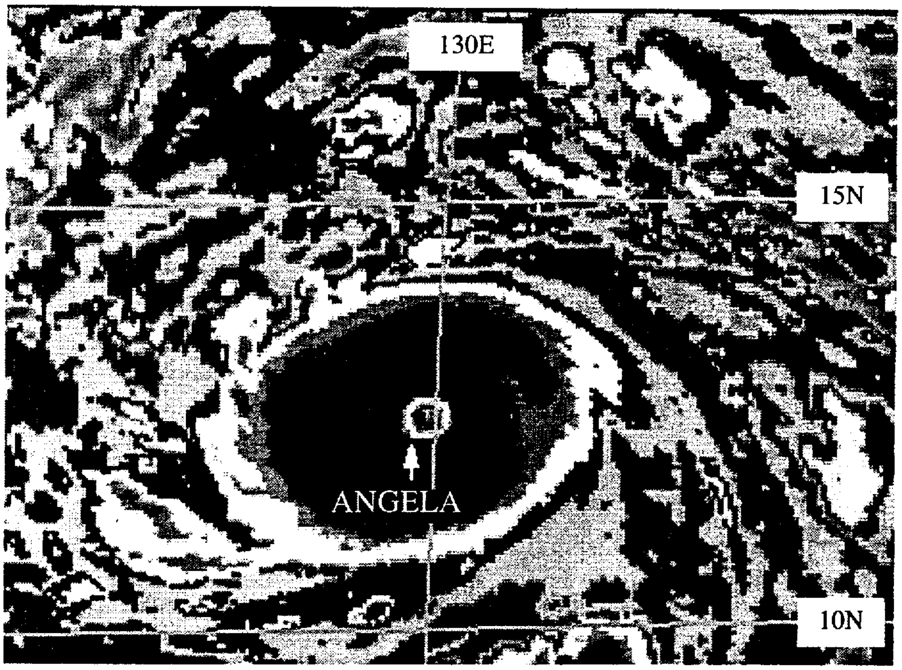


Figure 3-29-3 Angela undergoing explosive deepening. At the time of this picture, its intensity was 140 kt (72 m/sec). The typhoon is located about 420 nm (780 km) northwest of Palau and 50 nm (95 km) east of one of the Navy drifting buoys (312231Z October enhanced infrared GMS imagery).

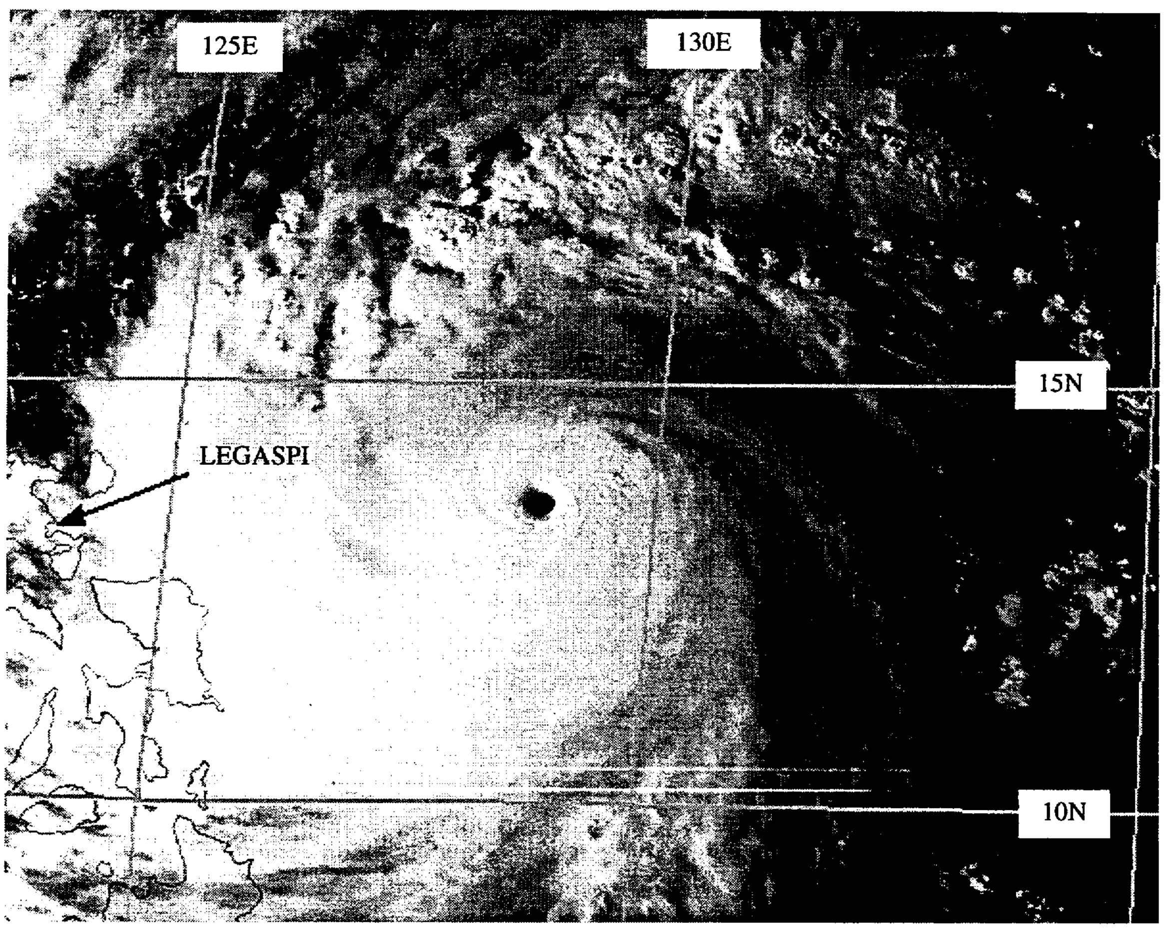


Figure 3-29-4 Angela at peak intensity of 155 kt (80 m/sec) (010731Z November visible GMS imagery).

At 030600Z November, Angela exited the Philippines into the South China Sea with 100 kt (51 m/sec) sustained winds. It re-intensified to a peak of 125 kt (64 m/sec) in the South China Sea, then slowly weakened as it turned to the northwest toward Hanoi (Figure 3-29-6). On the evening of 05 November, Angela weakened further as a result of strong vertical shear imposed on it by the northeast monsoon in the low levels and strong westerlies in the middle and upper levels. The following afternoon, the typhoon was downgraded to a tropical storm. The final warning, valid at 061800Z, was issued as the system dissipated over the Gulf of Tonkin.

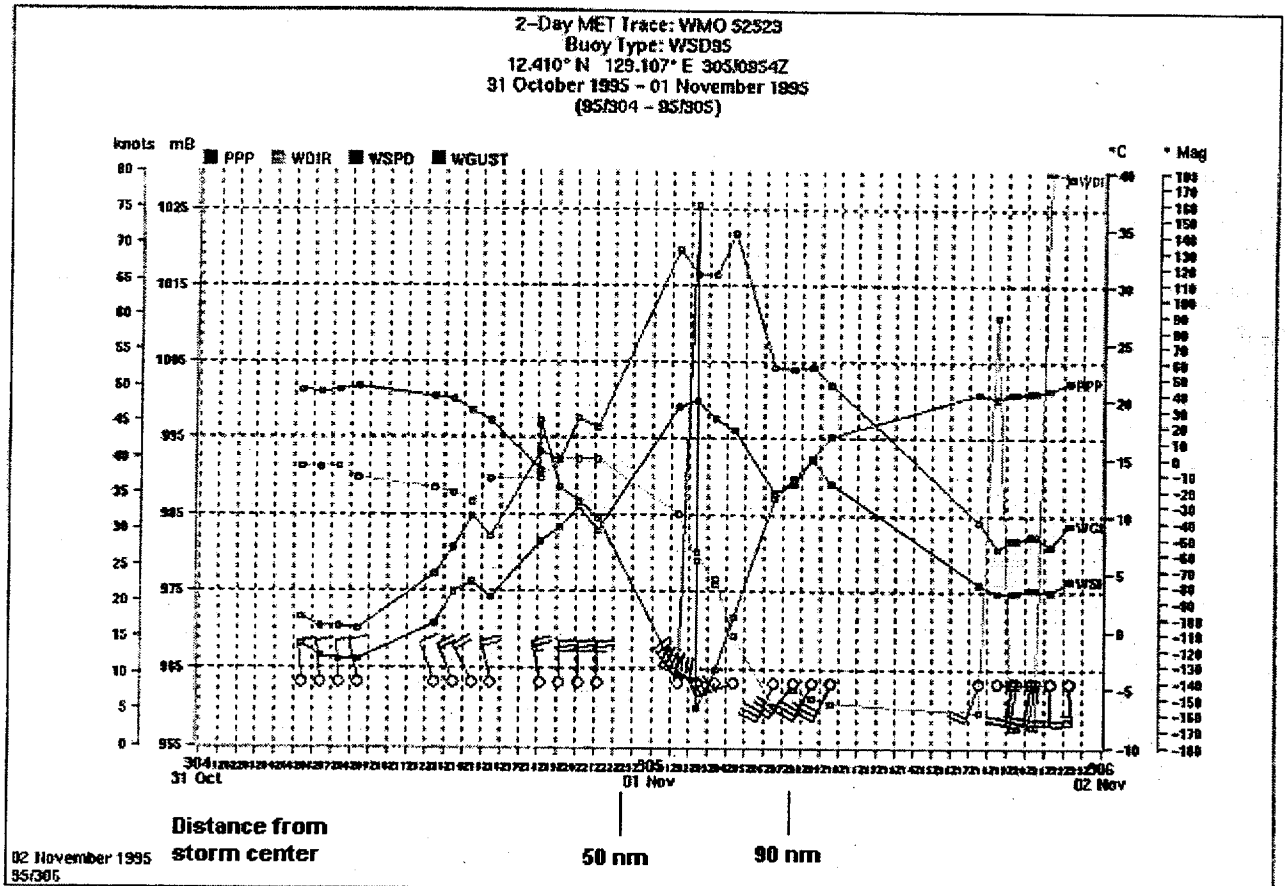


Figure 3-29-5 Two-day (31 October through 01 November) meteorogram from one of the Navy's drifting buoys, designated WMO 52523, as Angela passed by it. Sea-level pressure, 8-minute average wind speed, wind gusts, and wind direction are indicated.

III. DISCUSSION

a. *Erratic movement over the Philippine Sea*

On 28 October, Angela's west-northwestward movement abruptly stopped, and the system moved slowly to the south — about 90 nm (170 km) over 24 hours. By 300000Z, the typhoon had resumed a westward track at 8-10 kt (15-19 km/hr). The sudden change in motion was not predicted. It is hypothesized that Angela was forced to move southward by the building of a subsidence-induced anticyclone between it and Zack (28W). As Zack and Angela moved in tandem to the west, the clouds between the two tropical cyclones rapidly dissipated on 28 October, indicative of subsidence, when the separation distance between the two tropical cyclones was only 540 nm (1000 km). This clearing was very evident on 29 October as Angela was moving slowly southward.

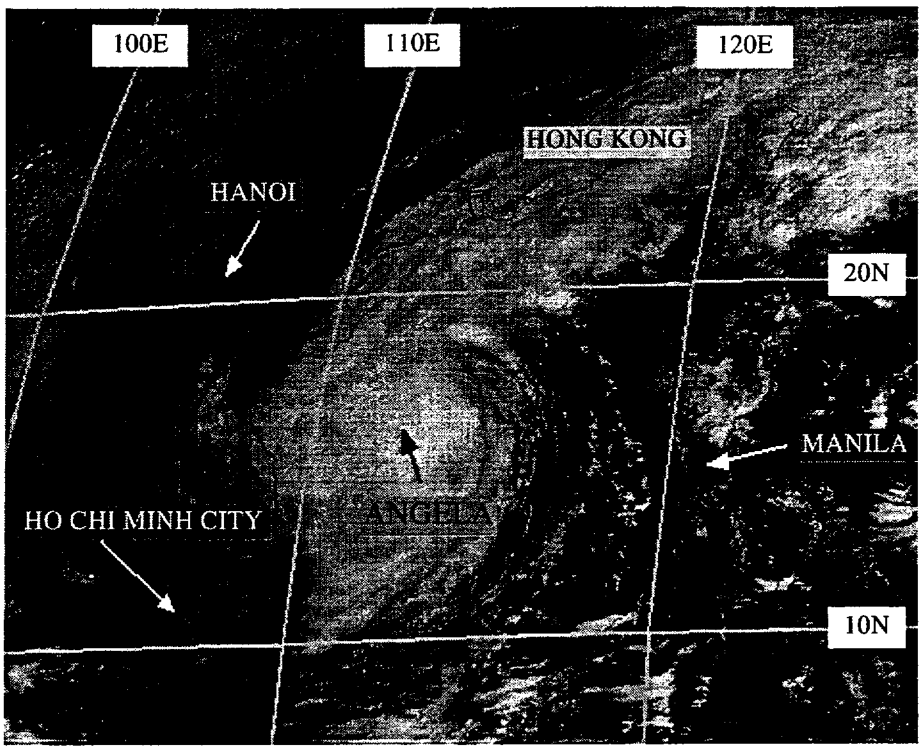


Figure 3-29-6 Angela in the South China Sea (050031Z November visible GMS imagery).

b. *Rapid intensification over the Philippine Sea*

On 31 October, after Angela's intensity had reached 90 kt (46 m/sec), it began to rapidly intensify (Holliday and Thompson 1979). Eighteen hours later, Angela's maximum sustained wind had increased to 155 kt (80 m/sec). The equivalent pressure fall over this eighteen-hour period was 71 mb, and the average rate of fall was 3.94 mb/hr. This meets the criterion for a special case of rapid intensification called explosive deepening (Dunnavan 1981), in which the pressure decrease must exceed 2.5 mb/hr for at least 12 hours. Of interest, satellite imagery does not reveal significant differences between Angela's environment and that of other tropical cyclones that intensify at much slower rates.

At approximately 010200Z November, the center of Angela passed 40 nm (75 km) to the northeast of the Navy's drifting buoy (WMO 52523). Data from this buoy (Figure 3-29-5) helped to define the distribution of 35 kt (18 m/sec) and 50 kt (26 m/sec) winds on the south side of Angela. They depict a small radius of 35 kt (18 m/sec) wind in the southwestern quadrant during the explosive deepening phase of Angela. A peak gust of 72 kt (37 m/sec) and a minimum sea-level pressure of 960 mb was recorded by the buoy.

c. *Measured winds and pressures as Angela crossed the Philippines*

As Angela approached the Philippines with 155 kt (80 m/sec) maximum sustained 1-minute winds, satellite intensity estimates began to indicate a weakening. Table 3-29-1 shows the T numbers, the current intensity (CI) numbers, DD numbers, and the intensity-based analysis of synoptic observations over the Philippines during the period 020000Z to 030300Z November (see also Figure 3-29-7). While still at peak intensity, Angela moved about 15 nm (28 km) north of the Catanduenas Island radar site (WMO 98446) and 40 nm (75 km) north of Virac, Catanduenas Island (WMO 98447). The radar site recorded gusts to 140 kt (72 m/sec) and Virac had gusts to 111 kt (57 m/sec). Since the radar site appeared to be in the southern eyewall, and the translation speed of Angela was toward the west at 10 kt (19 km/hr), a reasonable estimation of Angela's intensity when it passed to the north of Catanduenas at 021200Z (taking full account of the speed of translation and using a gust factor of 1.2) is 140 kt sustained 1-minute wind with gusts to 170 kt (72G87 m/sec).

Since Angela was not a small tropical cyclone, its wind and pressure would be expected to conform relatively well to the Atkinson and Holliday wind-pressure relationship, which gives a sustained 1-minute wind of 115 kt (59 m/sec) using the 926 mb minimum sea-level pressure recorded at Daet (WMO 98440) at 021900Z. Since the center of Angela's eye passed over Daet, this value — 115 kt with gusts to 140 kt (59G72 m/sec) — must be considered to be a reasonable estimate of Angela's intensity. The peak gust recorded at Daet was 135 kt (69 m/sec).

In the Metro-Manila area, wind and pressure measurements indicate that Angela's sustained winds had weakened to 80-90 kt (41-46 m/sec). The center of Angela appears to have passed near or over the Ninoy Aquino International Airport in Manila (WMO 98429) where a minimum sea-level pressure of 975.6 mb was recorded at 030230Z; the center of Angela also appears to have passed near or over Cubi Point (WMO 98426) where a minimum sea-level pressure of 976.3 mb was recorded at 030330Z.

IV. IMPACT

Angela caused considerable death, destruction, and agricultural losses in the Philippines. More than 600 people perished with and additional 100 reported missing. Over 96,000 homes were destroyed, and an estimated US$70 million in damage was inflicted on roads and bridges. Hardest hit was the northern Bicol region of southern Luzon (located approximately 100-150 nm (185-280 km) southeast of Manila). Catanduenas Island and the Metro-Manila area were also hard hit. There were at least 121 deaths in Calauag, Bicol, primarily from storm surge and a river that flooded when a dam burst. More than 100 perished in the neighboring village of Paracale, primarily from mudslides. Damage to agriculture exceeded US$18 million. Electrical power was lost by one-third of the country.

Table 3-29-1 Intensity Comparison for Angela

Date/time	Average#	CI#	DD#	Synoptic Analysis
020000Z	7.0	7.5	6.9	7.5
020300Z	7.0	7.5	6.9	7.5
020600Z	7.0	7.5	6.8	7.4
020900Z	7.0	7.5	6.3	7.2
021200Z	7.0	7.5	6.0	7.0
021500Z	6.5	7.5	5.5	6.6
021800Z	6.0	7.0	5.8	6.3
022100Z	6.0	7.0		5.8
030000Z	6.0	7.0		5.4
030300Z	6.0	7.0		4.6

Date/time	Intensity (kt)	Intensity (kt)	Intensity (kt)	Synoptic Analysis
020000Z	140	155	138	155
020300Z	140	155	138	155
020600Z	140	155	136	150
020900Z	140	155	124	145
021200Z	140	155	115	140
021500Z	127	155	102	130
021800Z	115	155	110	120
022100Z	115	140		110
030000Z	115	140		100
030300Z	115	140		80

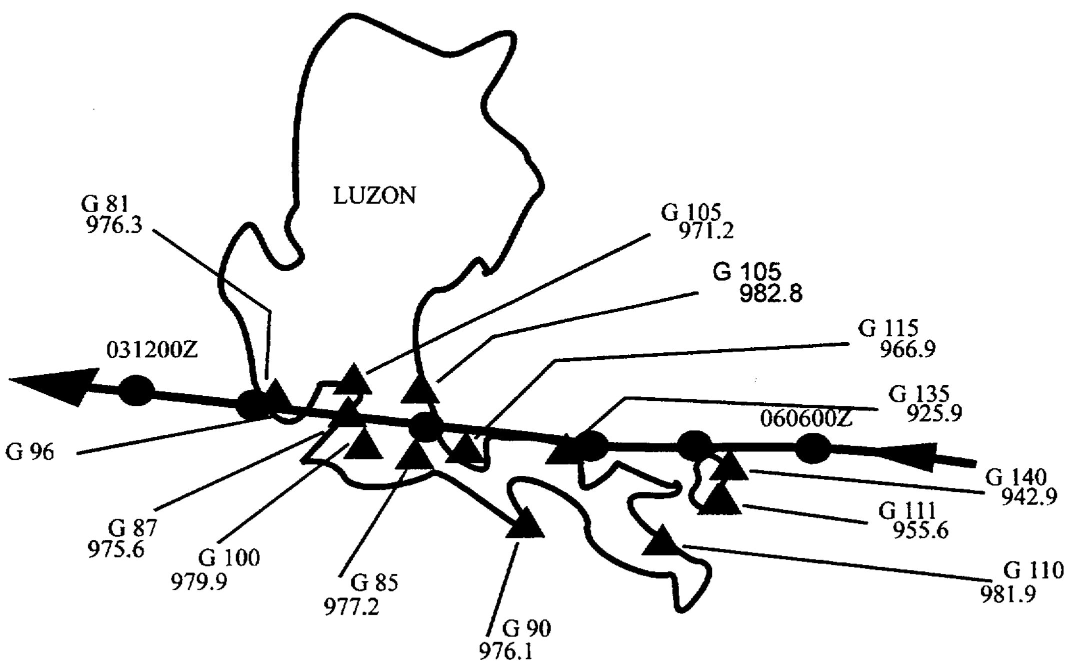
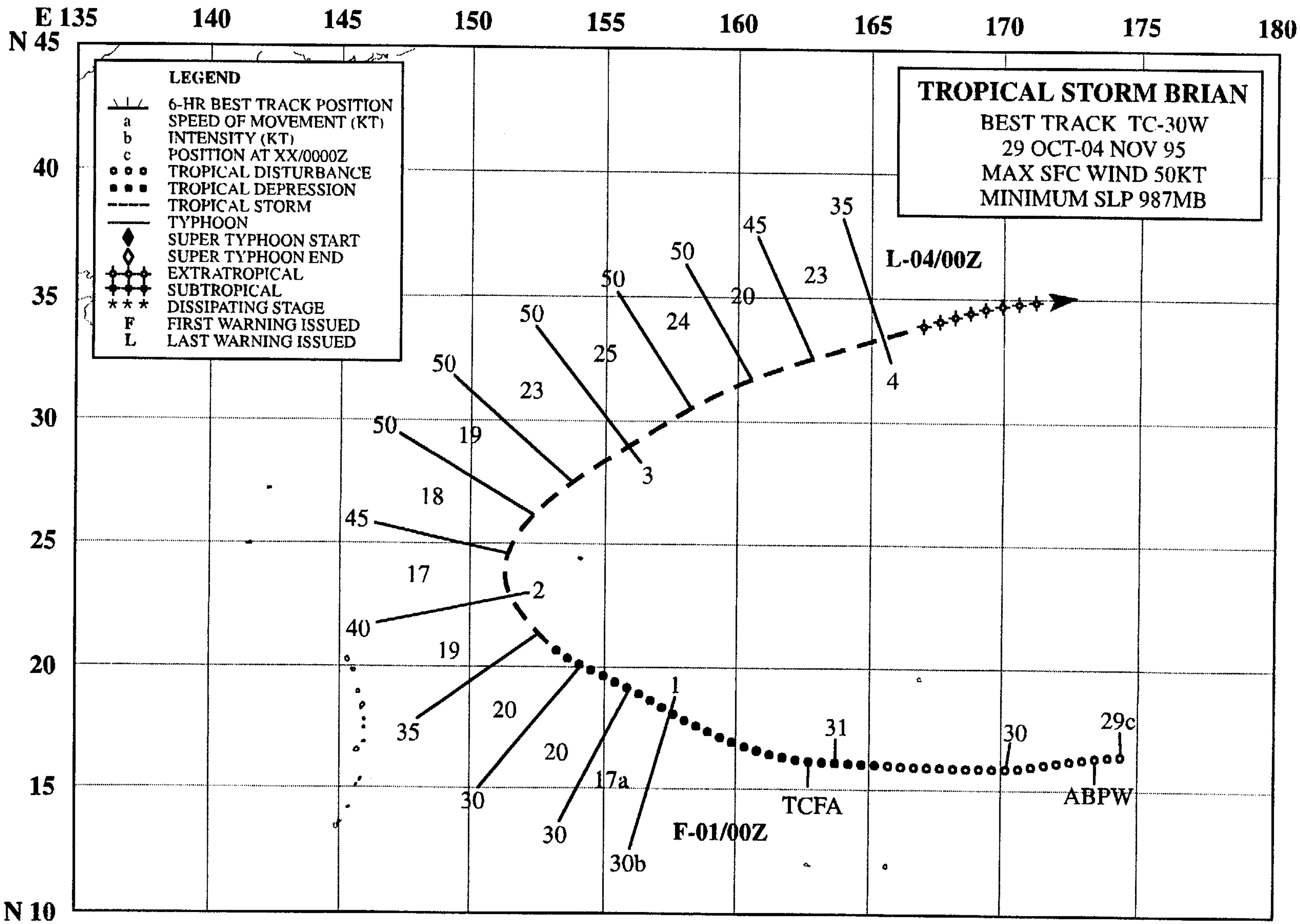


Figure 3-29-7 Peak wind gusts and minimum sea-level pressures recorded at selected observation sites (solid triangles) as Angela crossed the Philippines. Angela's 6-hourly best-track positions are indicated by the black dots connected by the solid line.



TROPICAL STORM BRIAN
BEST TRACK TC-30W
29 OCT-04 NOV 95
MAX SFC WIND 50KT
MINIMUM SLP 987MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 135
140
145
150
155
160
165
170
175
180
N 45
40
35
30
25
20
15
N 10
L-04/00Z
F-01/00Z
TCFA
ABPW
29c
30
31
1
30b
17a
2
3
4

TROPICAL STORM BRIAN (30W)

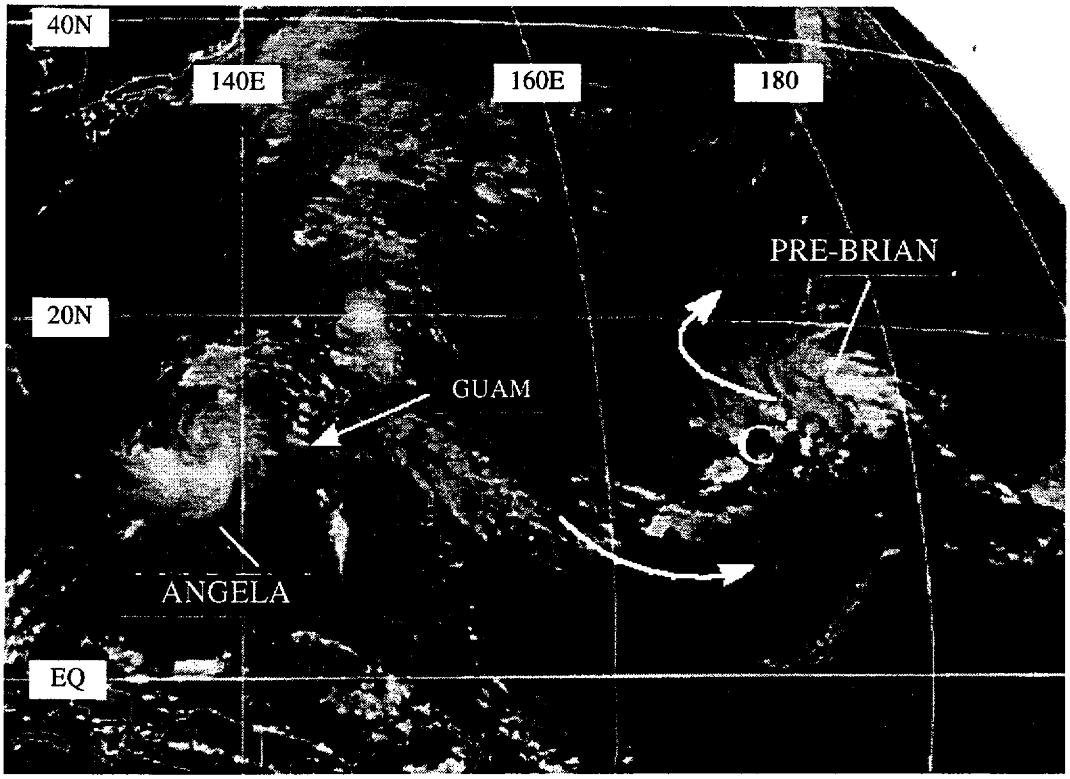


Figure 3-30-1 The indicated area of deep convection located to the northeast of a TUTT cell (labeled, C) that was the precursory tropical disturbance from which Brian developed (290633Z October Infrared GMS imagery).

I. HIGHLIGHTS

Brian formed in direct association with a TUTT cell. Typical of such tropical cyclones, Brian was small and embedded in the easterly wind flow on the southwestern flank of the low-level subtropical ridge. Prior to recurving and becoming absorbed into the cloud band of an advancing cold front, Brian's entire cloud system was isolated within a large relatively cloud-free region south of the polar front and to the north of the convection associated with the tradewind trough.

II. TRACK AND INTENSITY

Based upon over 48 hours of persistence, an area of deep convection that was located to the north of the Marshall Islands was first mentioned on the 290600Z October Significant Tropical Weather Advisory. This area of deep convection (Figure 3-30-1) was associated with a TUTT cell (Figure 3-30-2a,b). On 31 October, the deep convection consolidated to the northeast of the TUTT cell and became better organized (Figure 3-30-3), prompting the JTWC to issue a Tropical Cyclone Formation Alert at 310500Z. By the daylight hours of 01 November, visible satellite imagery indicated that the cloud system had become well-organized, and the first warning on Tropical Depression 30W, valid at 010000Z November, was issued.

In advance of an approaching frontal system (Figure 3-30-4), Tropical Depression 30W turned northward and intensified. It was upgraded to Tropical Storm Brian on the warning valid at 020600Z (post-analysis indicated that tropical storm intensity was reached 12 hours earlier at 011800Z). Brian was at its point of recurvature at this time, and subsequently began to accelerate to the northeast. It continued to intensify following recurvature reaching a peak intensity of 50 kt (26 m/sec) during the period

021200Z to 031200Z. As Brian moved northeast, the frontal system to its west was catching up with it. Overtaken by the frontal system on 04 November, Brian lost its deep convection and merged with the frontal cloud band. The final warning on Tropical Storm Brian was issued valid at 040000Z November when the weakening tropical cyclone began to merge with the frontal cloud band.

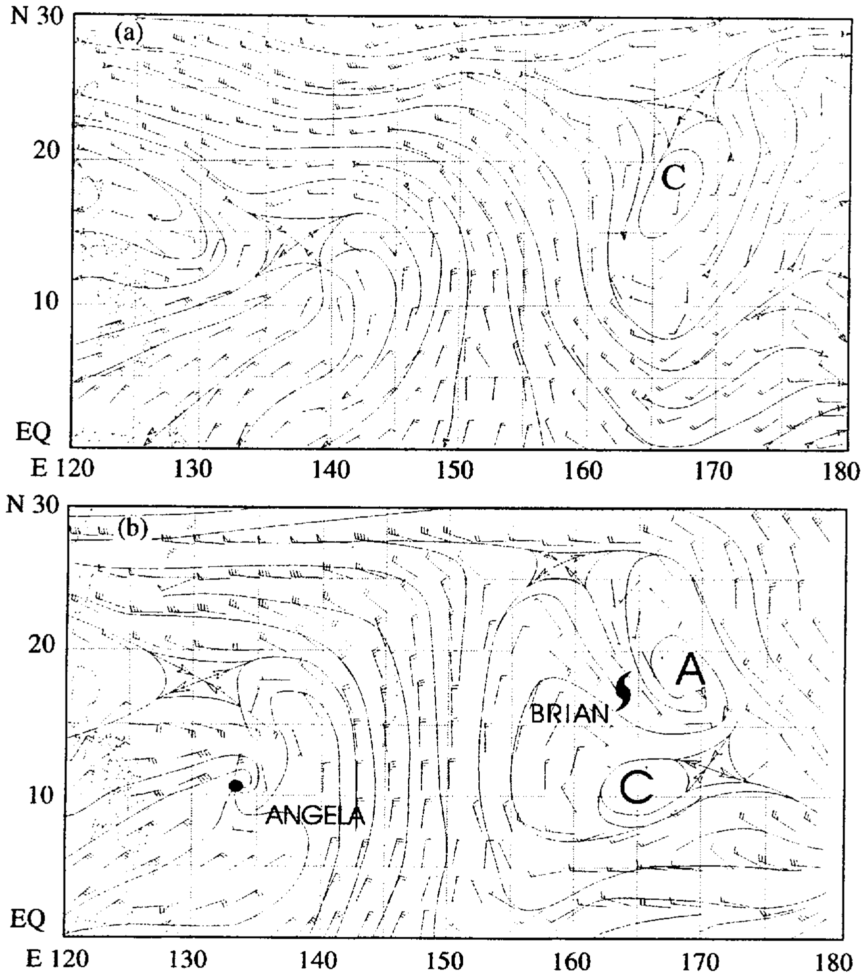


Figure 3-30-2 (a) A TUTT cell (labeled, C) is located north of the Marshall Islands (281200Z October NOGAPS 200-mb windbarbs and streamlines). (b) The TUTT cell (labeled, C) moved southward as diffluent and anticyclonically curved flow became established over the developing Brian (indicated by the tropical cyclone symbol). The center of an anticyclone is labeled, A. (310000Z October NOGAPS 200-mb windbarbs and streamlines).

III. DISCUSSION

Formation in direct association with a TUTT cell

A persistent feature of the upper-tropospheric flow over the tropics of the western North Pacific and North Atlantic oceans during the summer is the tropical upper tropospheric trough (TUTT) (Sadler 1975). In the western North Pacific, the axis of the TUTT overlies low-level easterly flow approximately mid-way between the axis of the subtropical ridge and the axis of the monsoon trough.

In synoptic analyses, the TUTT is commonly observed to consist of a chain of westward moving synoptic-scale cyclonic vortices called "TUTT cells" in the western North Pacific, and, "upper cold lows" in the Atlantic. The typical distribution of clouds associated with a TUTT cell features isolated cumulonimbi and/or small mesoscale convective systems in, or near, its core. Cloudiness to the south and east of a TUTT cell in the western North Pacific is often associated with the monsoon trough, and the TUTT cell (or a chain of TUTT cells) may affect the distribution of cloudiness along the axis of the trough and also of the cirrus outflow from the monsoon cloud band (e.g., see Figure 3-26-1 in Ward's summary).

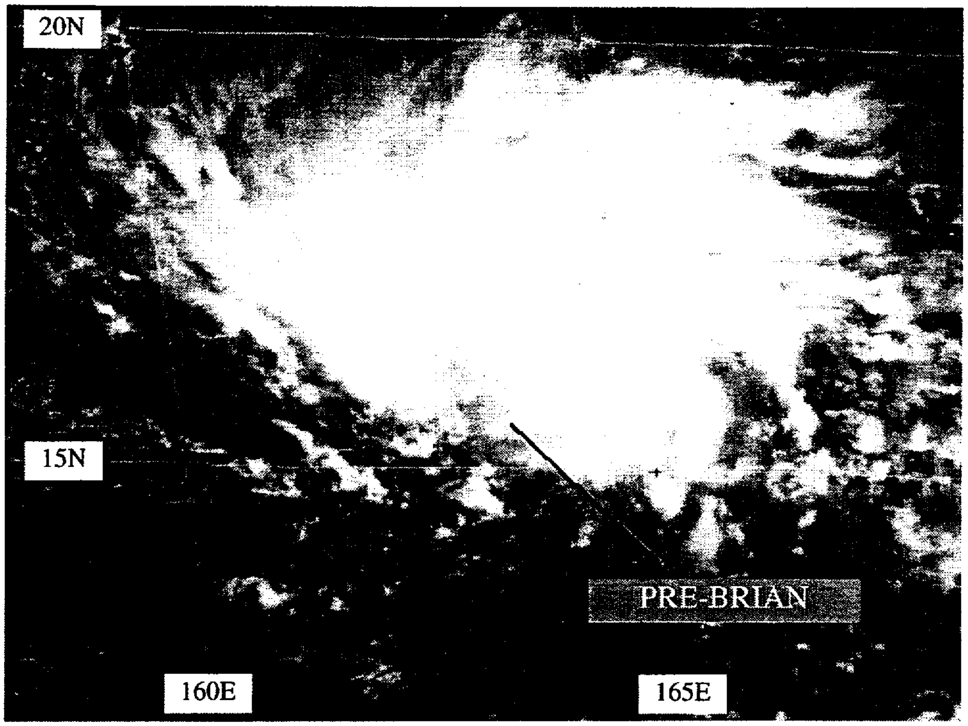


Figure 3-30-3 Cyclonically curved bands of deep convection associated with some poorly defined cyclonically curved low-level cloud lines indicated that the tropical disturbance that became Brian was intensifying (302331Z October visible GMS imagery).

Sadler (1967) proposed that the TUTT (with its embedded TUTT cells) was the primary source for disturbances (e.g., inverted troughs, isolated areas of deep convection, etc.) in the tradewind flow. Sadler (1967) also credits TUTT cells with the capacity to induce tropical cyclogenesis. TUTT-induced tropical cyclogenesis was envisioned by Sadler to be the result of the distal penetration of the TUTT cell's cyclonic circulation into the lower levels, thereby initiating deep convection which, through the release of latent heat, gradually converted the TUTT cell into a warm-core low (i.e., a tropical cyclone). In a later paper (Sadler 1976), the TUTT (and of TUTT cells within it) is hypothesized to contribute to the development of a tropical cyclone by providing an efficient outflow channel for the incipient tropical cyclone. In this scenario, the tropical cyclone is located to the south or southeast of the TUTT, or a TUTT cell.

In our investigations of the role of the TUTT — and in particular, TUTT cells — in tropical cyclone formation, we have observed a process whereby a small tropical cyclone forms (sometimes rapidly) under diffluent and anticyclonically curved flow to the east through north of the TUTT cell. This process is similar to Sadler's (1967) distal mechanism of TUTT cell-induced tropical cyclogenesis. Careful observation has shown that the isolated area of deep convection that forms a tropical cyclone near a TUTT cell, does so not directly in the core of the TUTT cell, but usually 200 to 400 km to the north or northeast of the circulation center of the TUTT cell. Brian was a good example of tropical cyclogenesis in direct association with a TUTT cell. Typical characteristics of direct TUTT-induced tropical cyclones include:

(1) rapid formation;
(2) small size;
(3) isolation in an easterly low-level flow regime;
(4) a relatively cloud free environment;

(5) a relatively high latitude of formation (i.e., near the latitude of the axis of the TUTT — usually at about 20-30°N); and,

(6) initial motion with a component south of west.

IV. IMPACT

No reports of damage or injuries attributable to Tropical Storm Brian were received at the JTWC.

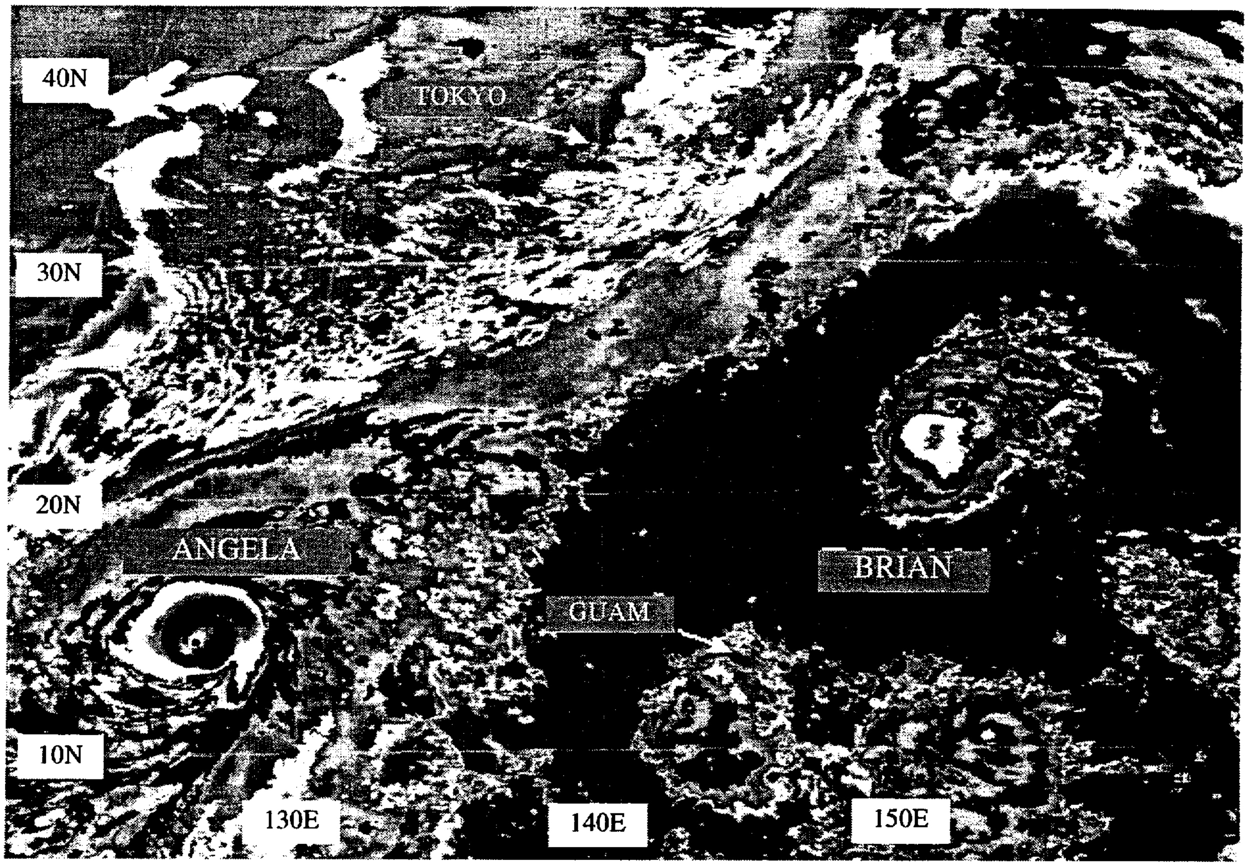
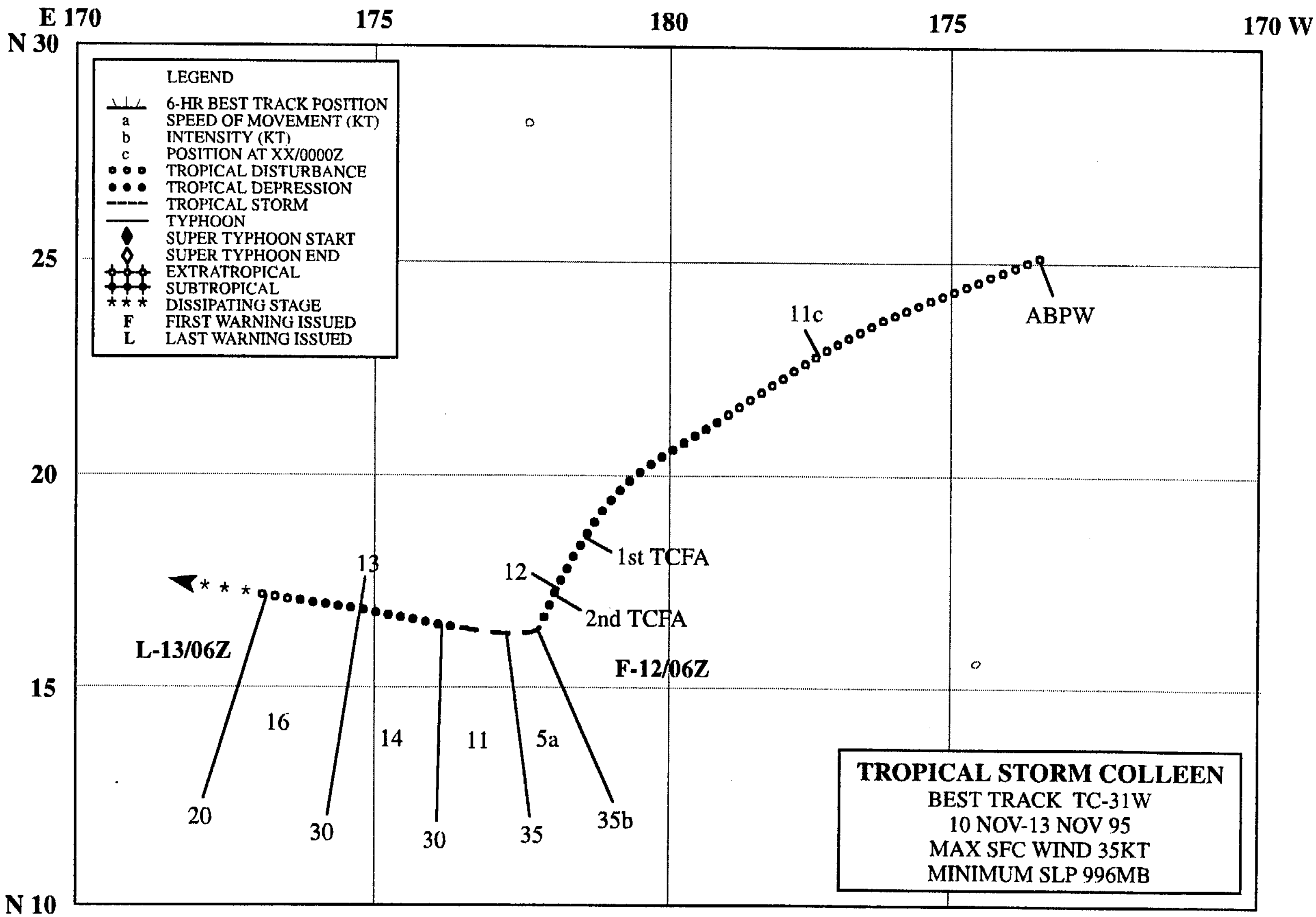


Figure 3-30-4 In advance of an approaching frontal system, Brian recurves and intensifies (012031Z November enhanced infrared GMS imagery).


E 170
175
180
175
170 W
N 30
25
20
15
N 10
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
11c
ABPW
1st TCFA
2nd TCFA
12
13
L-13/06Z
F-12/06Z
16
14
11
5a
20
30
30
35
35b
TROPICAL STORM COLLEEN
BEST TRACK TC-31W
10 NOV-13 NOV 95
MAX SFC WIND 35KT
MINIMUM SLP 996MB

TROPICAL STORM COLLEEN (31W)

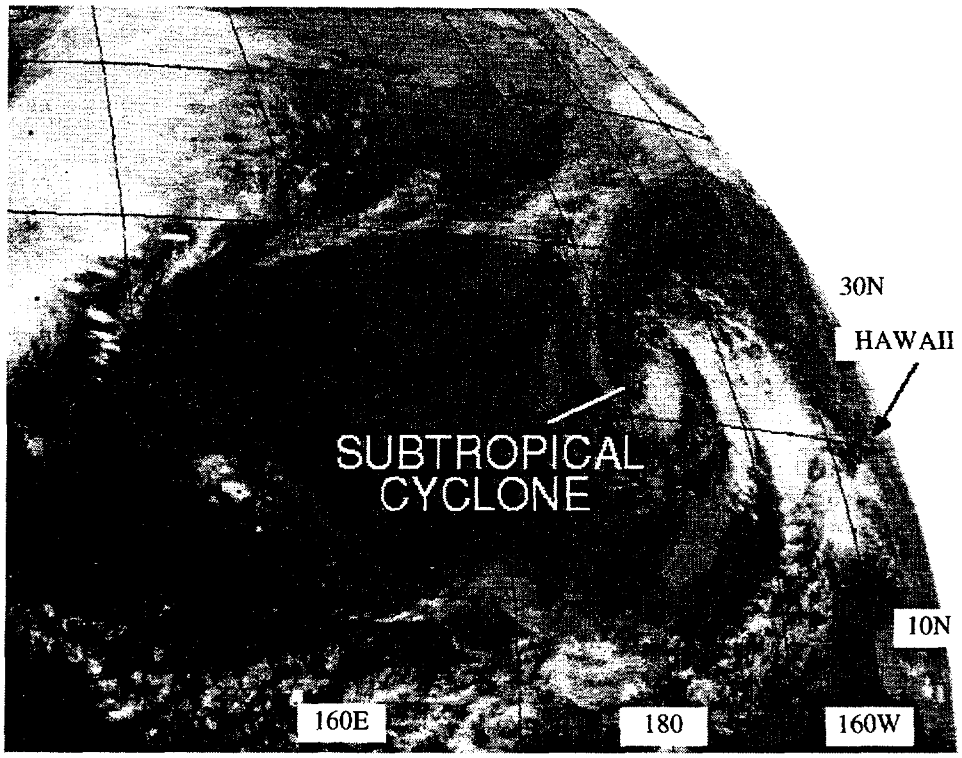


Figure 3-31-1 A "Kona" storm located to the west-northwest of Hawaii has just acquired central deep convection marking the beginning of its transition from a subtropical cyclone to a tropical cyclone (102332Z November infrared GMS imagery).

I. HIGHLIGHTS

Colleen developed in an unusual manner for a tropical cyclone in the western North Pacific. The disturbance that became Colleen was a cut-off low that formed in the subtropics to the northwest of Hawaii — a classic "Kona" low. Drifting toward the southwest, the "Kona" low crossed the international date line into JTWC's area of responsibility, where it acquired persistent central convection and became a tropical storm.

II. TRACK AND INTENSITY

On 09 November, a cold-core low pressure system became cut-off about 600 nm (1100 km) to the northwest of Hawaii. This system possessed the structural characteristics of a subtropical cyclone (Hebert and Poteat 1975). Such systems in the Hawaiian region are called "Kona" storms (Ramage 1971) in reference to their southwesterly winds that blow onshore in the normal leeward, or "Kona", sides of the islands.

After becoming cut-off to the northwest of Hawaii, the subtropical low (or "Kona" storm) that became Colleen began to drift toward the southwest, and on 11 November it crossed the international date line. Prior to crossing the international date line, the amount of deep convection began to increase near the low-level circulation center (Figure 3-31-1), prompting its first mention on the 110600Z Significant Tropical Weather Advisory. Remarks on this advisory included:

". . . A low-level circulation is located near 22°N 179°W. This area is associated with a subtropical low pressure system that has been moving southwest at 15 knots [28 km/hr] over the past 24 hours. Convection has increased, and is sheared to the east and south of the exposed low-level circulation . . ."

The system crossed the international date line at 110900Z. Shortly thereafter, based upon persistent convection near the low-level circulation center, and anticipation that the system would intensify, the first Tropical Cyclone Formation Alert (TCFA) was issued at 111930Z. A second TCFA was issued at 120100Z in order to reposition the alert area. Remarks on this second TCFA included:

". . . A low-level circulation associated with a subtropical low pressure system has continued drifting south-southwest, and is showing signs of developing into a tropical cyclone. Convection is forming closer to the center of the circulation, which is well defined in the low-level cloud lines. . . ."

During the daylight hours of 12 November, it was deemed by the JTWC that the subtropical low had become a tropical storm (Figure 3-31-2), and the first warning on Tropical Storm Colleen valid, at 120600Z was issued. Remarks on this first warning included:

". . . Tropical Storm Colleen (31W) has formed from a subtropical low pressure system located north-east of the Marshall Islands. Colleen has been diving southward over the past twelve hours, but is expected to assume a westward track within 12 to 24 hours . . ."

After becoming a tropical storm, Colleen did indeed assume a westward track. After turning toward the west, however, amounts of deep convection near the low-level circulation center decreased, most-probably as a result of increasing westerly wind shear on the system. By warning number 4 (valid at 130000Z), there was no organized deep convection associated with the system, however microwave imagery indicated that 30 kt (15 m/sec) sustained winds were still associated with the low-level circulation center. Tropical Storm Colleen was downgraded to a tropical depression at this time and, with continued weakening, the JTWC issued a final warning valid at 130600Z.

III. DISCUSSION

Subtropical cyclones, "Kona" storms, and tropical cyclones

Establishing the defining characteristics of a tropical cyclone is a challenging exercise. For purposes of public warning, the nature of tropical cyclones has been simplified to a stratification based upon intensity. In this simplified framework, the first stage toward the development of a tropical cyclone is the tropical disturbance. A tropical disturbance is a discrete system of apparently organized convection, generally 200 to 600 km in diameter, originating in the tropics or subtropics, having a non-frontal, migratory character and having maintained its identity for 12- to 24-hours (Elsberry, et al. 1987). The system may or may not be associated with a detectable perturbation of the low-level wind or pressure field. It is the basic generic designation which, upon acquiring a persistent low-level cyclonic wind field associated with an area of lowered sea-level pressure, becomes a tropical cyclone. In the United States, (TCs) are categorized by their intensity: (1) a tropical depression is a TC with maximum sustained one-minute mean surface winds (V1 Max) of less than 34 kt (17 m/sec); (2) a tropical storm is a TC with a V1 Max in the range of 34 to 63 kt (17 to 32 m/sec); (3) a hurricane (typhoon) is a TC with a V1 Max of 64 kt (33 m/sec) or more. In recent years, a fourth category — the super hurricane (typhoon) — has gained popular acceptance; it is a subset of the hurricane (typhoon) category with a V1 Max of 130 kt (67 m/sec) or greater.

Dvorak (1975, 1984) developed a technique for estimating the intensity of tropical cyclones from satellite imagery. His technique is used worldwide. In the Dvorak classification technique, persistent deep convection must be located within 120 nm (220 km) of the low-level circulation center in order to initiate classification. The intensity of the tropical cyclone is determined by several properties of the deep convection (e.g., the proximity of the low-level circulation center to the deep convection, the size of the central dense overcast, the cloud-top temperatures and horizontal width of the eye wall cloud, the width and extent of peripheral banding features, etc.). The basic tropical cyclone pattern types identi-

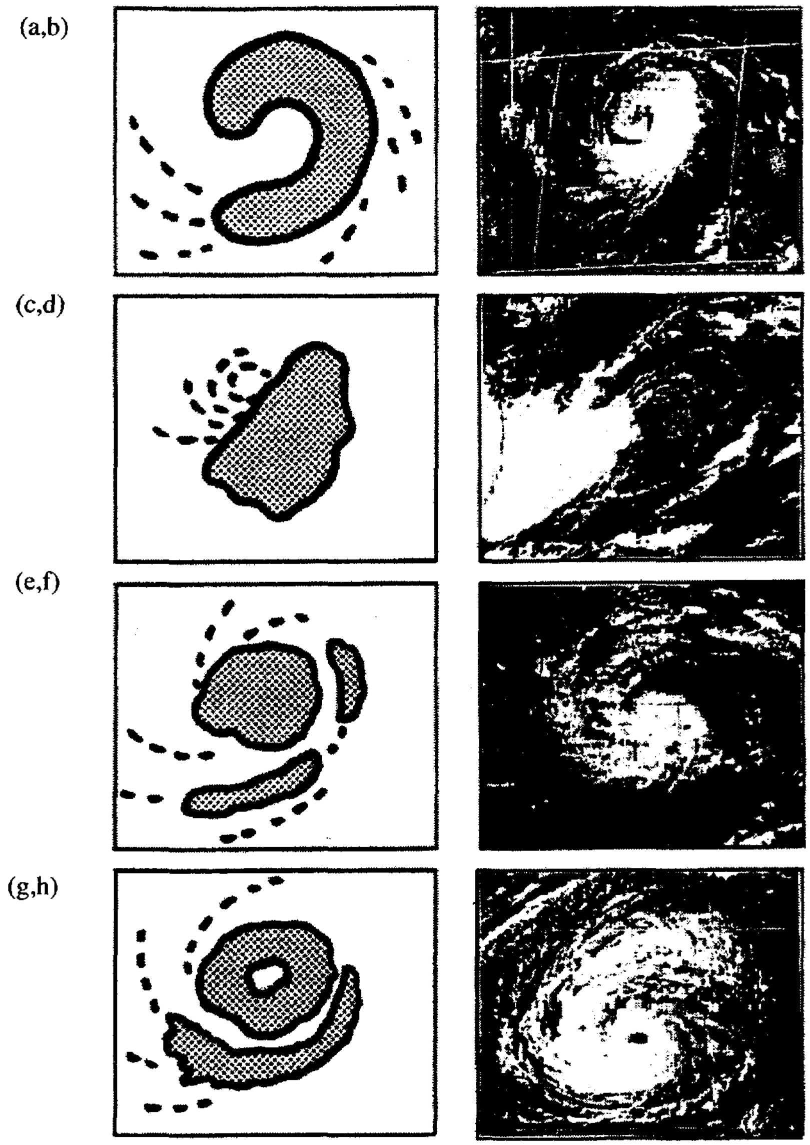


Figure 3-31-2 Schematic illustration (left column) and representative satellite imagery (right column) of Dvorak's (1975) basic tropical cyclone pattern types: (a,b) the "curved band" pattern; (c,d) the "shear" pattern; (e,f) the "central dense overcast" pattern; and, (g,h) the "eye" pattern.

fied by Dvorak are: (1) the "curved band" pattern (Figure 3-31-3a,b); (2) the "shear" pattern (Figure 3-31-3c,d); (3) the "central dense overcast", or "embedded center", pattern (Figure 3-31-3e,f); and, (4) the "eye" pattern (Figure 3-31-3g,h).

Some cyclones possess characteristics of both extra-tropical (ET) cyclones and tropical cyclones. For example, the subtropical cyclone (Hebert and Poteat 1975), the "Kona" storm (Ramage 1971), the arctic hurricane (Businger and Baik 1991), the monsoon depression (Ramage 1971, and JTWC 1993), and the monsoon gyre (Lander 1994, Carr and Elsberry 1994). These types of cyclones have caused diagnostic and forecast problems for decades. Further complicating things is the fact that transitions among some of the types are possible.

Because Dvorak's techniques are not applicable to subtropical (ST) cyclones, Hebert and Poteat (1975) (hereafter referred to as HP75) developed a satellite classification technique for ST cyclones. Their technique provides an intensity estimate (from satellite imagery) of ST cyclones, and provides guidelines for determining the cyclone type (i.e., tropical, ST or ET). The technique was designed so that the intensity estimate would intermesh with the Dvorak technique when the cyclone changed type.

For example, if a subtropical cyclone with an estimated intensity of ST 3.0 became a tropical cyclone, it would then be given a Dvorak "T" number of T 3.0.

HP75 identified three modes of origin for the ST cyclone: (1) high-level origin from an upper cold low; (2) low-level origin from a frontal wave; and (3) low-level origin east of an upper-level trough but not on a front. Determining when a ST cyclone becomes a TC is not clearly defined by HP75, but one of the criteria in Table 3-31-1 would seem to be the most definitive: the ST cyclone cannot have its center under central dense overcast. If it does, it should be classified as tropical.

Colleen developed when an upper cold low that cut-off to the northwest of Hawaii — a "Kona" storm — moved southwestward and acquired persistent central deep convection. "Kona" storms are primarily a feature of the winter weather of Hawaii. Occurring from about late October to mid-April, they rarely become tropical cyclones. The "Kona" storm that became Colleen is a good example of the transition of a subtropical cyclone to a tropical cyclone — a rare event in the North Pacific Ocean.

IV. IMPACT

No reports of damage or injuries attributable to Tropical Storm Colleen were received at the JTWC.

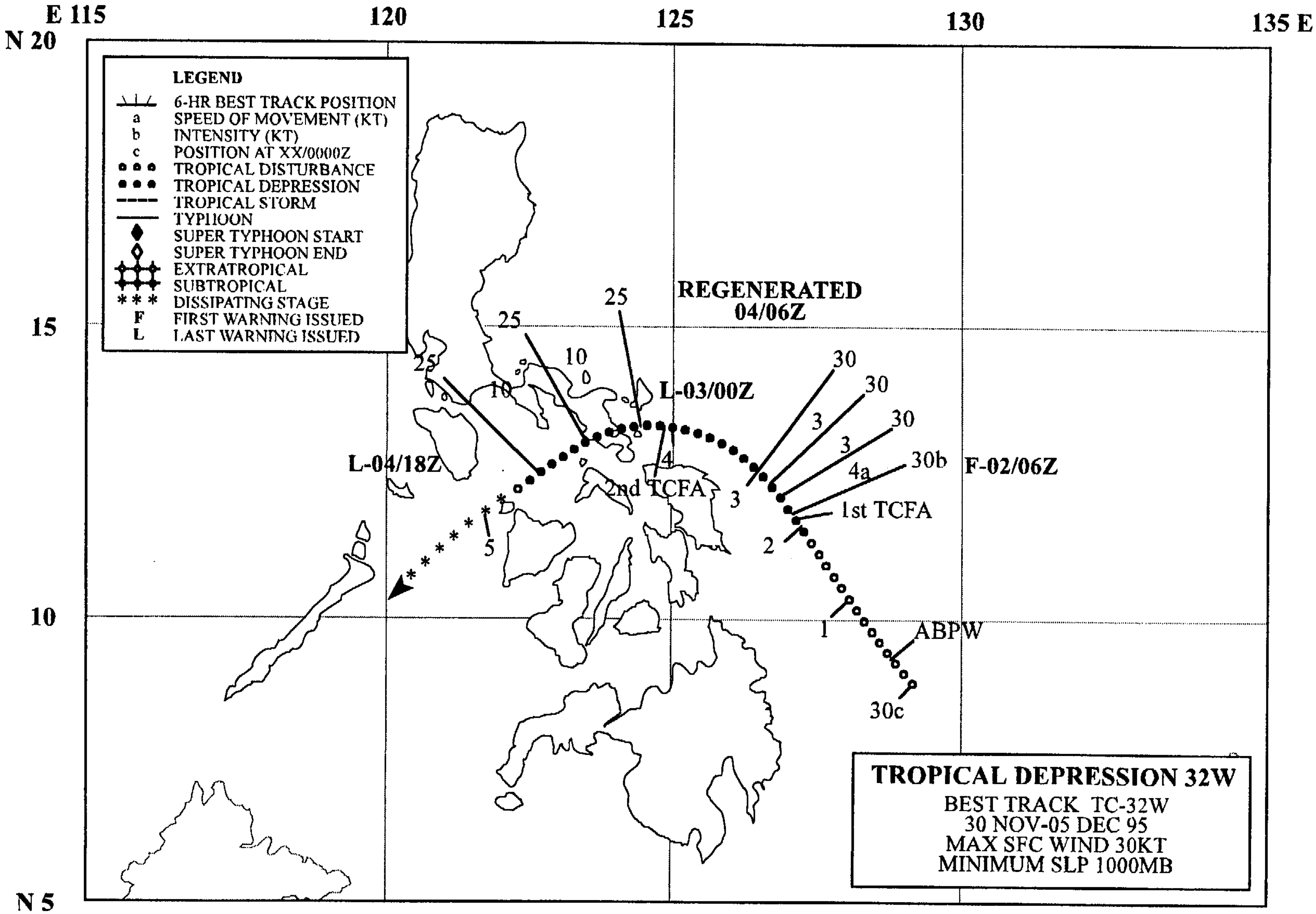
Table 3-31-1. Similarities and differences between the Dvorak technique for tropical cyclones and the technique of Hebert and Poteat (1975) for subtropical cyclones as adapted from Table 3 in HP75.

SIMILARITIES

(1) Uses convective overcast.
(2) Uses distance of the low-level circulation center from the convective overcast.
(3) The ST number features and associated intensities are selected to correspond to observed current intensity numbers so that ST numbers merge to Dvorak's T numbers when the system becomes tropical.

DIFFERENCES

(1) ST technique considers the environment in determining type.
(2) A subtropical cyclone cannot have its low-level circulation center under central dense overcast.
(3) The ST technique adds translation speed excess above 20 kt to cloud feature wind estimate.


E 115
120
125
130
135 E
N 20
15
10
N 5
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
REGENERATED
04/06Z
L-03/00Z
L-04/18Z
F-02/06Z
2nd TCFA
1st TCFA
ABPW
25
25
25
10
10
30
30
30
30b
30c
3
3
3
4a
4
2
1
5
TROPICAL DEPRESSION 32W
BEST TRACK TC-32W
30 NOV-05 DEC 95
MAX SFC WIND 30KT
MINIMUM SLP 1000MB

TROPICAL DEPRESSION 32W

I. HIGHLIGHTS

Tropical Depression 32W (TD 32W) was originally treated as two separate tropical cyclones by the JTWC — TD 32W and TD 33W. The decision to combine the two tropical cyclones was based on a rigorous postanalysis. It is the first time since 1989, when Tropical Storm Ken and Tropical Storm Lola were designated as Tropical Storm Ken-Lola, that two tropical cyclones that were warned on separately have been subsequently designated as a single tropical cyclone. The after-the-fact designation of TD 32W and TD 33W as one system (i.e., TD 32W) underscores the difficulty that occasionally occurs in warning on poorly organized tropical cyclones. TD 32W developed east of Mindanao, tracked across southeastern Luzon near Legaspi, and dissipated in the Sulu Sea.

II. TRACK AND INTENSITY

The origin of Tropical Depression 32W can be traced to a tropical disturbance that formed on 30 November about 150 nm (280 km) east of Mindanao. The disturbance was first mentioned on the 300600Z November Significant Tropical Weather Advisory. For two days, the low-level circulation center (located on the west side of a 150 nm wide area of deep convection) moved slowly to the north-northwest. On 02 December, the deep convection appeared on satellite imagery to have become better organized and a Tropical Cyclone Formation Alert was issued at 020430Z. The first warning on TD 32W was issued, valid at 020600Z based on a satellite-derived intensity of 30 kt (15 m/sec). A Navy drifting buoy (WMO 52523) — the same one that survived an earlier nearby passage of Angela (29W) — recorded sustained southwest winds of 30 kt (15 m/sec) at 020300Z (Figure 3-32-1). TD 32W was forecast to recurve to the northeast and intensify. As the deep convection moved northward, however, it moved into a deformation zone along the shearline and appeared to split into two parts: one part moved to the northeast and the other part moved to the west (see the Discussion Section). The final warning on TD 32W was issued, valid at 030000Z, as the area of deep convection that was moving to the northeast along the shearline dissipated. In Figure 3-32-1, the track a-b-c shows the original working best track of TD 32W.

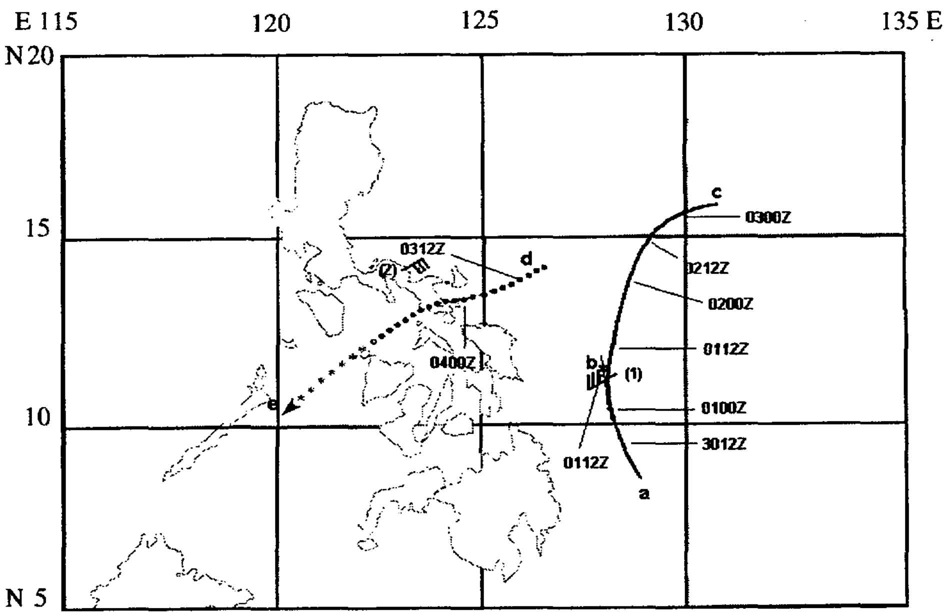


Figure 3-32-1 Working best track of the original TD 32W (indicated by the curved line labeled, a-b-c), and the working best track of the original TD 33W (indicated by the dotted line, d-e) are shown. Supporting synoptic observations shown are: (1) the wind from the Navy drifting buoy (WMO 52523) at 020300Z December, and (2) the wind observed at Daet (WMO 98440) at 040000Z December.

As convection associated with TD 32W dissipated, another area of deep convection was noted to its west and mentioned on the 030600Z December Significant Tropical Weather Advisory. A Tropical Cyclone Formation Alert was issued at 040030Z. The first warning on TD 33W was issued by the JTWC, valid at 040600Z. During the night of 04 December, the low-level circulation center of TD 33W (Figure 3-32-1) passed over the Bicol region of southern Luzon, where, earlier in the day, maximum sustained winds of 30 kt (15 m/sec) were observed at Daet (WMO 98440). The deep convection associated with the system decreased and the final warning was issued by the JTWC, as TD 33W moved into the northern Sulu Sea.

III. DISCUSSION

Rationale for combining TD 32W with TD 33W

Track a-b-c in Figure 3-32-1 was the working best track of the original TD 32W and track d-e was the working best track of the original TD 33W. Figure 3-32-2 illustrates the separation of convection into the two areas (labeled, x and y). Cloud system y (the area of deep convection that moved northeast along the shear line) was initially believed to contain a vertically coupled low-level cyclonic circulation (i.e., TD 32W). When cloud system x (the area of deep convection that moved to the west over the Philippines) showed signs of becoming better organized it was thought to be associated with a new low-level circulation center, and hence was warned on as TD 33W (Figure 3-32-3). A careful reexamination of synoptic data suggests that there was all along only one low-level circulation center throughout the period and that the motion of the masses of convection was not directly associated with the movement of the low-level circulation center.

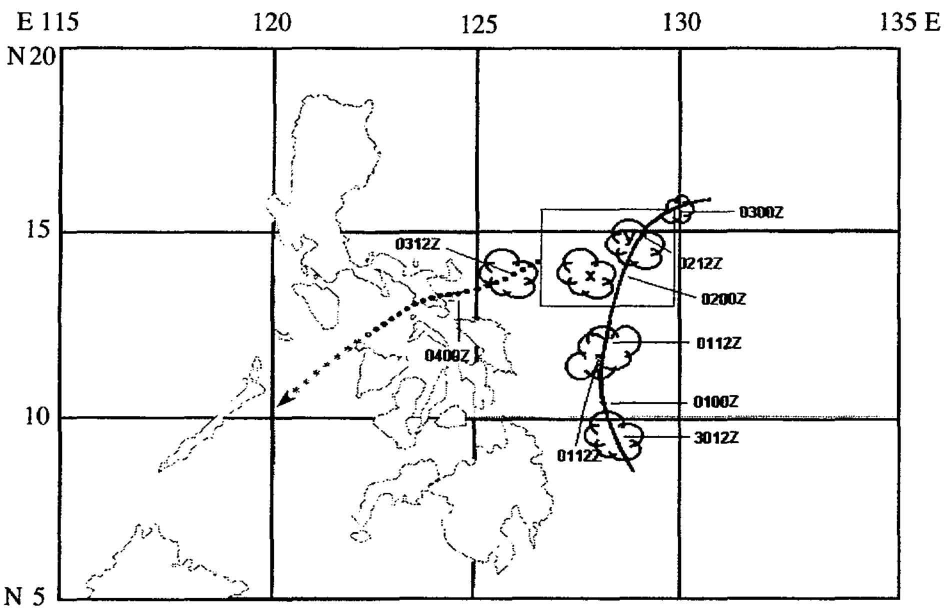


Figure 3-32-2 Schematic illustration of the movement and splitting of the mesoscale convective system (MCS) that was the original TD 32W into elements x and y. MCS "x" became TD 33W (working best track is indicated by the dotted line). MCS "y" was thought to have been associated with a recurving TD 32W (working best track is indicated by the solid line).

IV. IMPACT

At least 14 people were reported killed in floods and landslides in the Philippines. Twelve people were buried in a landslide that occurred at Viga, Catanduenas Island. The two others drowned in flooding at other villages of the Bicol region of southeastern Luzon.

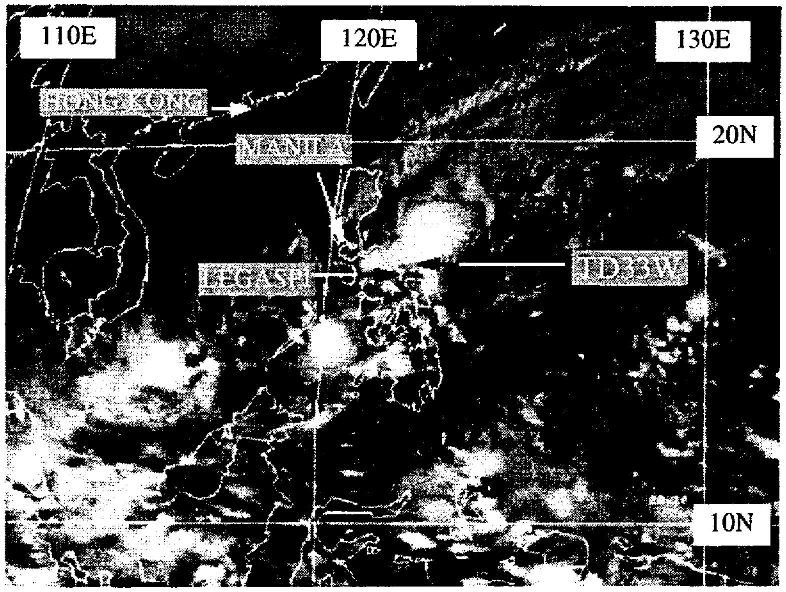
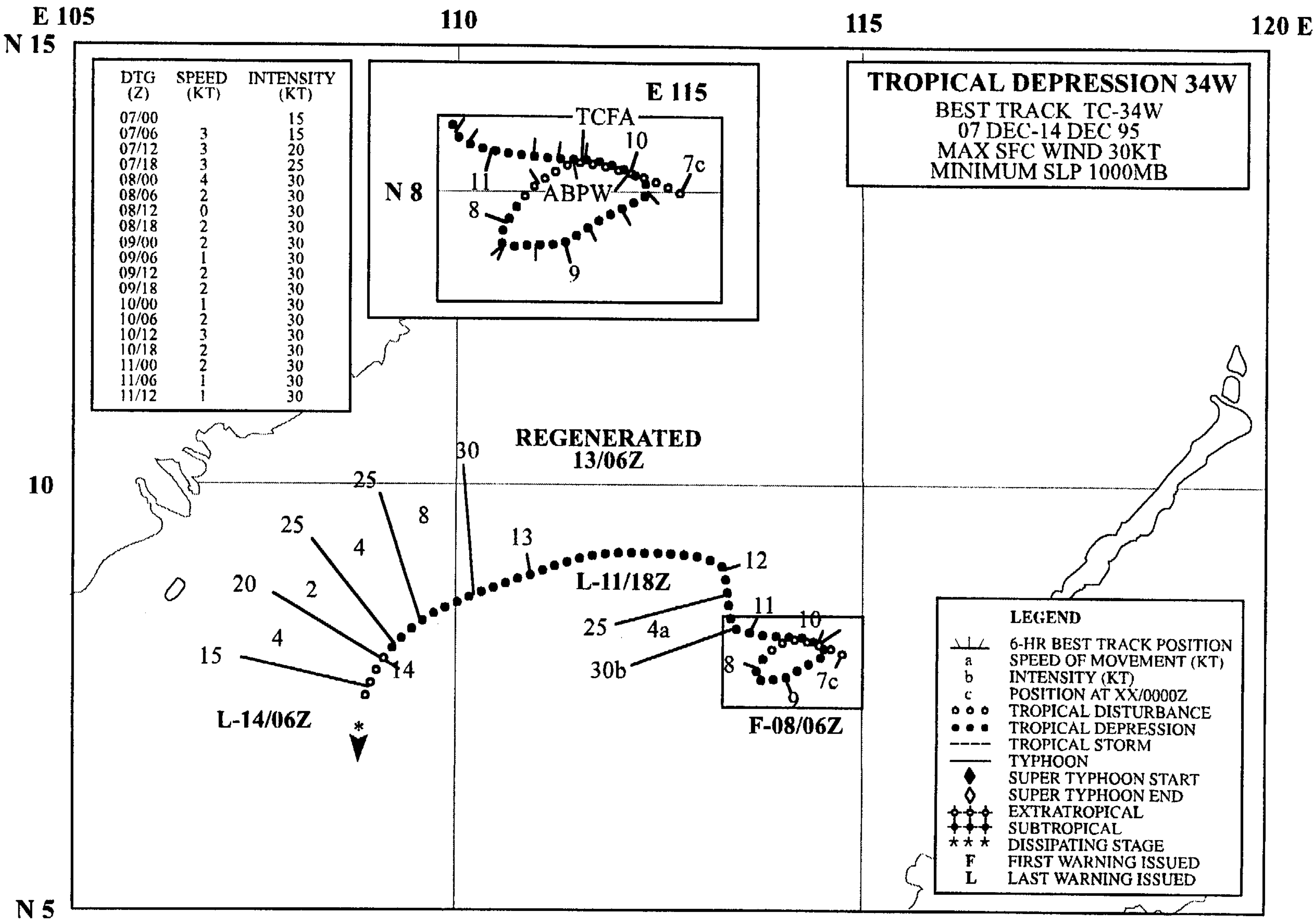


Figure 3-32-3 The deep convection associated with the original TD 33W (later combined with TD 32W) as it passes over southeastern Luzon near Legaspi (041233Z December infrared GMS imagery).



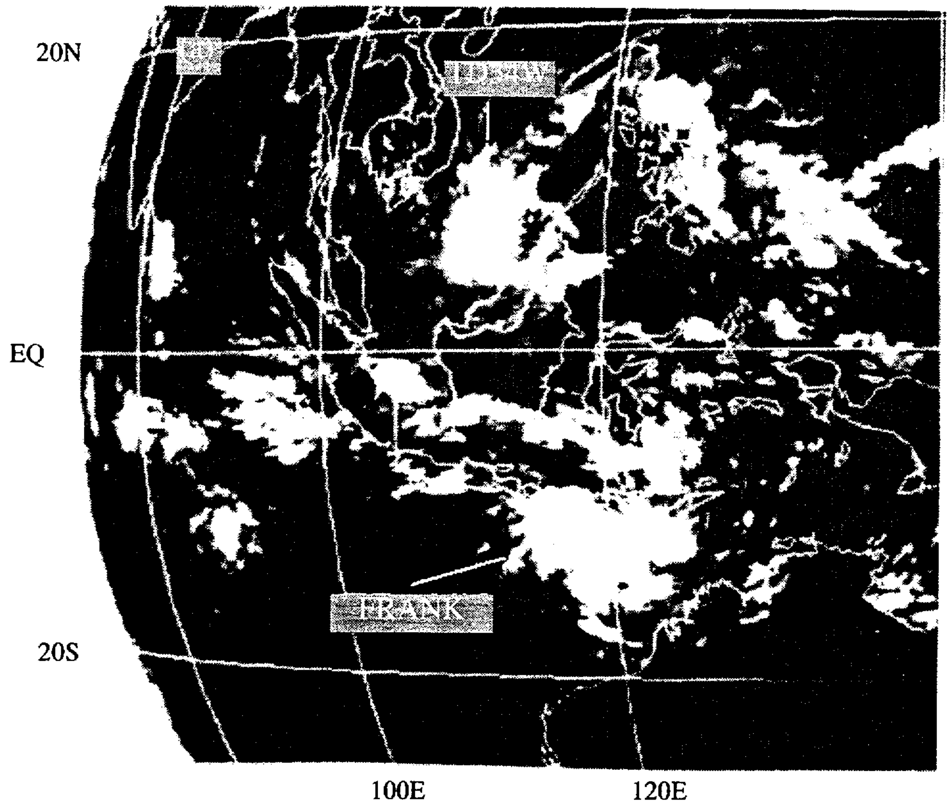
DTG (Z)	SPEED (KT)	INTENSITY (KT)
07/00		15
07/06	3	15
07/12	3	20
07/18	3	25
08/00	4	30
08/06	2	30
08/12	0	30
08/18	2	30
09/00	2	30
09/06	1	30
09/12	2	30
09/18	2	30
10/00	1	30
10/06	2	30
10/12	3	30
10/18	2	30
11/00	2	30
11/06	1	30
11/12	1	30

TROPICAL DEPRESSION 34W

Tropical Depression 34W was the second of three significant tropical cyclones that formed in the western North Pacific during December. It was first mentioned on the 070600Z December Significant Tropical Weather Advisory when satellite imagery and synoptic data showed that a low-level circulation center was associated with an area of persistent deep convection northwest of Borneo. As the deep convection became better organized, the JTWC issued a Tropical Cyclone Formation Alert, valid at 071130Z. Ship reports indicating wind speeds of 30 kt (15 m/sec) near the low-level circulation center prompted the JTWC to issue the first warning on Tropical Depression 34W, valid at 080600Z. Even higher wind speeds of 40 kt (21 m/sec) were occurring throughout much of the South China Sea to the north of TD 34W as a manifestation of a surge in the Northeast Monsoon.

Under normal conditions, a surge in the northeast monsoon flow of winter in the South China Sea accompanies a low-pressure system that becomes anchored off the northwest coast of Borneo — the so-called "Borneo low". Tropical cyclogenesis is not normally expected from a true Borneo low. In the case of TD 34W, however, the low-pressure area that formed to the northwest of Borneo was not a typical Borneo low, but rather, it formed from processes that produce tropical cyclone twins during times of enhanced equatorial westerly winds (Lander 1990). Tropical Depression 34W was the Northern Hemisphere twin to Tropical Cyclone Frank (03S) in the Southern Hemisphere (Figure 3-34-1a,b).

Whereas Frank (03S) recurved into northwestern Australia, TD 34W was constrained by the Northeast Monsoon to remain in the southern portion of the South China Sea for its entire life. For three days (08-11 December), the depression meandered in a small area about one degree of latitude square, centered near 8°N 114°E. During the night of 11 December, convection had subsided, and a "final" warning was issued, valid at 111800Z. The remnant low-level vortex drifted to the west during 12 December, and on 13 December, satellite imagery indicated that the system had regenerated, prompting the JTWC to reissue warnings commencing at 130600Z. The second final warning was issued by the JTWC, valid at 140600Z, as the system dissipated over water near 7°N 109°E.



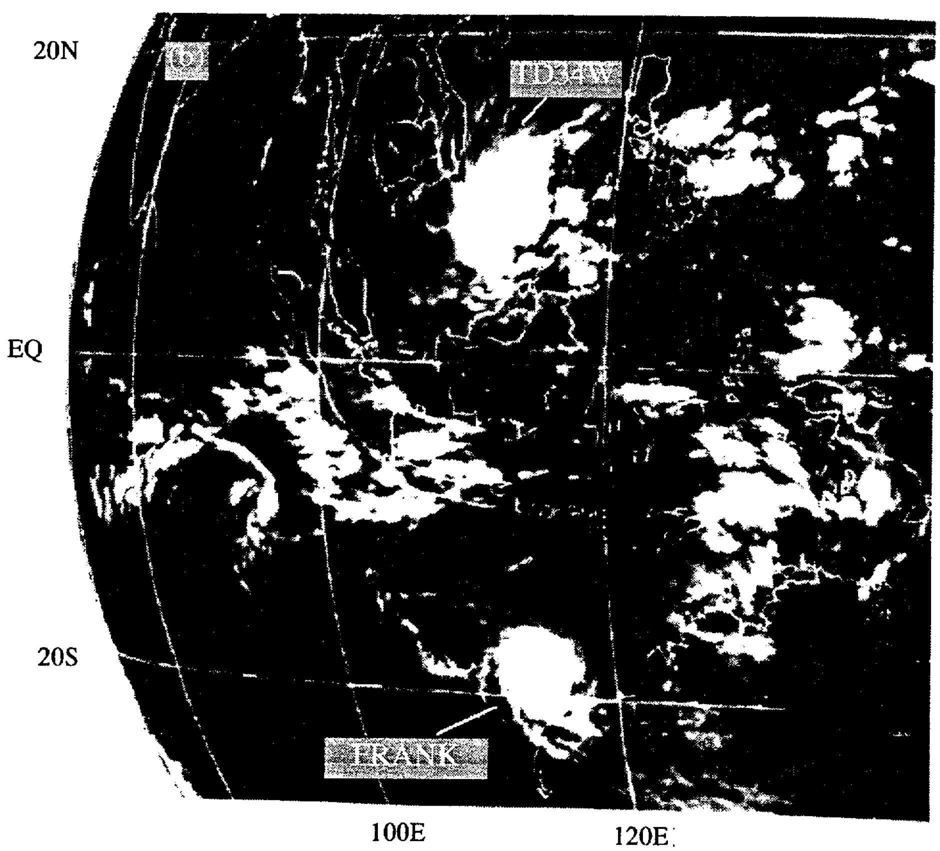
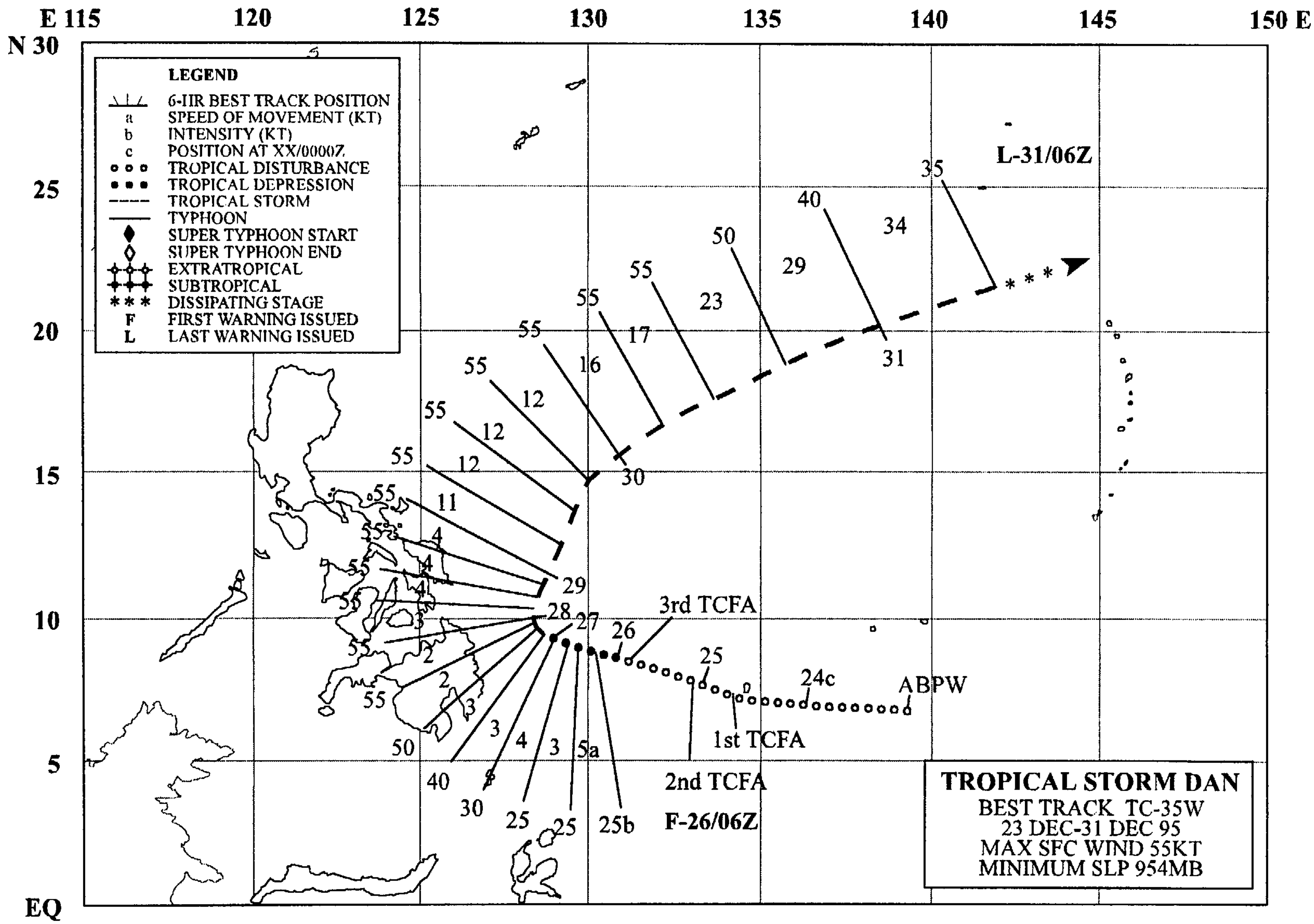


Figure 3-34-1 Tropical Depression 34W, and Tropical Cyclone Frank (03S) developed in tandem as tropical cyclone twins: (a) 070033Z December infrared GMS imagery, and (b) 100033Z December infrared GMS imagery).



E 115
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150 E
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25
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5
EQ
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-31/06Z
3rd TCFA
1st TCFA
2nd TCFA
ABPW
F-26/06Z
TROPICAL STORM DAN
BEST TRACK TC-35W
23 DEC-31 DEC 95
MAX SFC WIND 55KT
MINIMUM SLP 954MB

TROPICAL STORM DAN (35W)

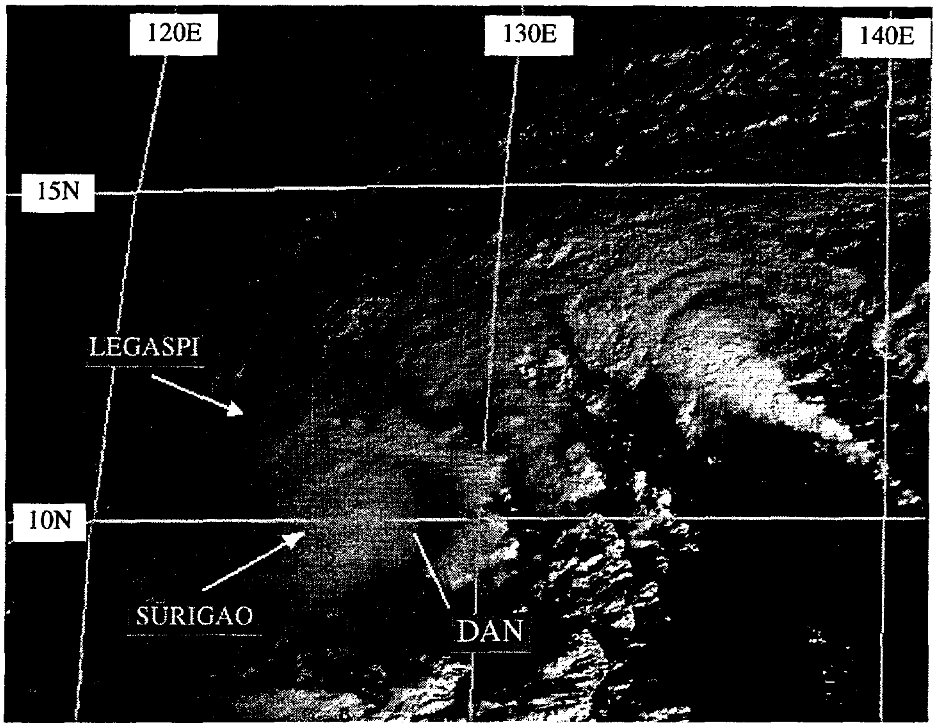


Figure 3-35-1 Tropical Storm Dan at peak intensity of 55 kt (28 m/sec). The low-level circulation center, located on the east side of the CDO, is obscured by dense cirrus (272331Z December visible GMS imagery).

I. HIGHLIGHTS

Dan was the last significant tropical cyclone to occur in the western North Pacific during 1995. Like many other tropical cyclones during 1995, Dan did not develop until it had tracked westward to near the Philippines. Tracking Dan by satellite was difficult because of its large cirrus canopy, obscuring its low-level circulation center. Microwave imagery from a DMSP satellite proved to be important in determining the location and structure of Dan.

II. TRACK AND INTENSITY

During December 1995, strong tradewinds dominated the tropics of the western North Pacific. A persistent tradewind convergence zone developed along 5°N, extending from 170°W to 140°E. Several tropical disturbances formed in the convergence zone and moved across the southern islands of Micronesia. These disturbances, coupled with the penetration of shear lines into low latitudes, produced heavier than normal rainfall across Guam and the Northern Mariana Islands. One of these disturbances, mentioned on the 230600Z December Significant Tropical Weather Advisory, became Tropical Storm Dan. The disturbance moved toward the west, but similar to the evolution of many other tropical cyclones during 1995 remained poorly organized until it moved west of 130°E. Between 241300Z and 260000Z, three Tropical Cyclone Formation Alerts were issued. On 26 December, the amount and organization of deep convection improved, prompting the JTWC to issue the first warning on Tropical Depression 35W (TD 35W), valid at 260600Z. With the development of persistent central deep convection, and extensive bands of deep convection to its north and east, satellite intensity estimates increased, and TD 35W was upgraded to Tropical Storm Dan on the 270600Z warning. Dan reached its peak intensity of 55 kt (28 m/sec) at 271800Z (Figure 3-35-1). At this time, Dan turned toward the north and maintained its 55 kt (28 m/sec) intensity for the next 60 hours (271800Z to 301200Z). Early on 30 December, Dan began to accelerate toward the northeast. The final warning was issued on Dan, valid at 310600Z, when the system transitioned into an extratropical low and was moving to the northeast in excess of 30 kt (55 km/hr).

III. DISCUSSION

a. *Large positioning errors*

Tracking Dan by satellite was difficult because of its large central dense overcast (CDO), which obscured the low-level circulation center. Dan's low-level circulation center was sheared to the east of the center of its large cirrus canopy, but the amount of shear was not easily determined until the night of 28 December when microwave imagery (Figure 3-35-2) showed the large extent of the shear. The difference between the low-level circulation center inferred from infrared satellite imagery and that revealed beneath the cirrus canopy by microwave imagery at nearly the same time was over 100 nm (185 km). Average fix errors were over 74 nm (137 km) as compared to 29 nm (54 km) for all of 1995. Most of the fixes with large errors were significantly west of the actual location of the low-level circulation center. The large errors of the fixes led to a large average initial position error of 44 nm (82 km), with individual errors as high as 95 nm (176 km). Also, the large positioning errors resulted in larger than normal forecast track errors, especially for forecast periods less than 36 hours.

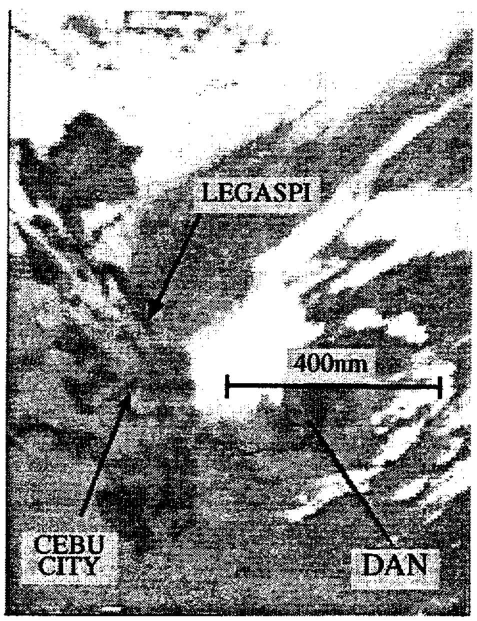


Figure 3-35-2 Microwave imagery acquired from the special sensor microwave/imager (SSM/I) reveals that the low-level circulation center of Dan is displaced to the southeast of the deep convection (281335Z December horizontally polarized 85 GHz microwave DMSP imagery). The low-level center was obscured by dense cirrus in conventional visible and infrared satellite imagery.

b. *Large wind asymmetries*

As Dan reached its closest point of approach to the Philippines and made its sharp turn to the north, a large area of gales formed in the Philippine Sea to Dan's north (Figure 3-35-3). Such large asymmetries are common when late-season tropical cyclones approach the Asian mainland where the sea-level pressure is very high. The high pressure over the Asian mainland is responsible for the northeast monsoon that occupies the South China Sea during the late fall and winter. Similar wind asymmetries were noted in the case of Tropical Depression 34W (see its summary).

IV. IMPACT

Dan caused heavy rain and high surf in northern and eastern Mindanao. Waves as high as 7 feet (2.1 m) destroyed some houses in Cagayan de Oro. Several thousand people in the region were evacuated because of high surf.

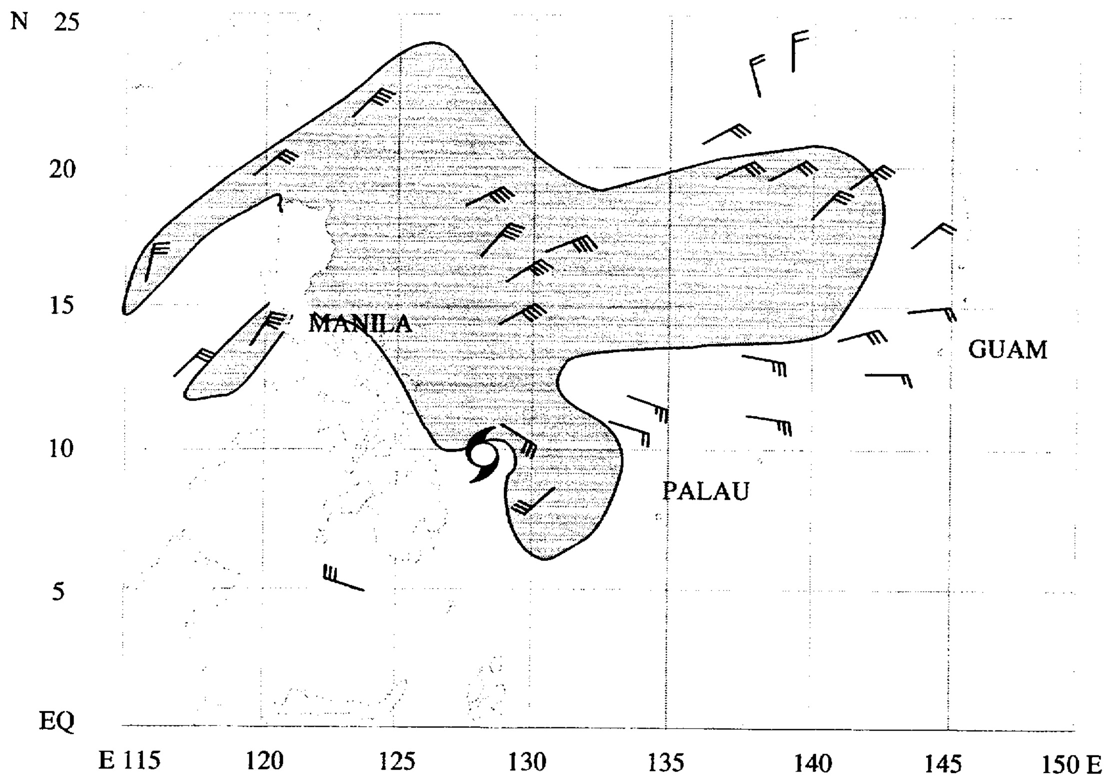


Figure 3-35-3 Ship reports and low-cloud velocities observed between 270600Z to 280000Z December reveal a large area of 30-40-kt (15-21-m/sec) winds (within the shaded area) to the north and northeast of Dan.

3.2 NORTH INDIAN OCEAN TROPICAL CYCLONES

In 1995, four significant tropical cyclones occurred in the North Indian Ocean. Three of these were in the Bay of Bengal and one in the Arabian Sea (Table 3-6). Spring and fall in the North Indian Ocean are periods of transition between major climatic controls, and the most favorable seasons for tropical cyclone activity. There is a tendency for the months of May and June to be less favored than the months of October, November and December (Table 3-7). The distribution in 1995, where all the tropical cyclones occurred in the fall, was unusual. For the 26-year record (1975-1995), this has only been noted in four years: 1980, 1981, 1983 and 1993.

The best track composite for 1995 is shown in Figure 3-14. The two most intense tropical cyclones were in November. They both recurved through the axis of the subtropical ridge.

Table 3-6 NORTH INDIAN OCEAN SIGNIFICANT TROPICAL CYCLONES FOR 1995

TROPICAL CYCLONE	PERIOD OF WARNING	NUMBER OF WARNINGS ISSUED	MAXIMUM SURFACE WINDS-KT (M/SEC)	ESTIMATED MSLP (MB)
01B	16 SEP - 17 SEP	4	45 (23)	991
02A	12 OCT - 17 OCT	22	50 (26)	987
03B	07 NOV - 09 NOV	11	70 (36)	972
04B	21 NOV - 25 NOV	17	105 (54)	938
	TOTAL	54		

The criteria used in Table 3-7 are as follows:

1. If a tropical cyclone was first warned on during the last two days of a particular month and continued into the next month for longer than two days, then that system was attributed to the second month.
2. If a tropical cyclone was warned on prior to the last two days of a month, it was attributed to the first month, regardless of how long the system lasted.
3. If a tropical cyclone began on the last day of the month and ended on the first day of the next month, that system was attributed to the first month. However, if a tropical cyclone began on the last day of the month and continued into the next month for only two days, then it was attributed to the second month.

TABLE 3-7LEGEND

Total for the month/year → 4

Typhoons → 2

Tropical Storms → 2

Tropical Depressions → 0

Table 3-7 DISTRIBUTION OF NORTH INDIAN OCEAN TROPICAL CYCLONES FOR 1975-1995

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1975	1	0	0	0	2	0	0	0	0	1	2	0	6
	010	000	000	000	200	000	000	000	000	100	020	000	3 3 0
1976	0	0	0	1	0	1	0	0	1	1	0	1	5
	000	000	000	010	000	010	000	000	010	010	000	010	0 5 0
1977	0	0	0	0	1	1	0	0	0	1	0	2	5
	000	000	000	000	010	010	000	000	000	010	000	110	1 4 0
1978	0	0	0	0	1	0	0	0	0	1	2	0	4
	000	000	000	000	010	000	000	000	000	010	200	000	2 2 0
1979	0	0	0	0	1	1	0	0	2	1	2	0	7
	000	000	000	000	100	010	000	000	011	010	011	000	1 4 2
1980	0	0	0	0	0	0	0	0	0	0	1	1	2
	000	000	000	000	000	000	000	000	000	000	010	010	0 2 0
1981	0	0	0	0	0	0	0	0	1	0	1	1	3
	000	000	000	000	000	000	000	000	010	000	100	100	2 1 0
1982	0	0	0	0	1	1	0	0	0	2	1	0	5
	000	000	000	000	100	010	000	000	000	020	100	000	2 3 0
1983	0	0	0	0	0	0	0	1	0	1	1	0	3
	000	000	000	000	000	000	000	010	000	010	010	000	0 3 0
1984	0	0	0	0	1	0	0	0	0	1	2	0	4
	000	000	000	000	010	000	000	000	000	010	200	000	2 2 0
1985	0	0	0	0	2	0	0	0	0	2	1	1	6
	000	000	000	000	020	000	000	000	000	020	010	010	0 6 0
1986	1	0	0	0	0	0	0	0	0	0	2	0	3
	010	000	000	000	000	000	000	000	000	000	020	000	0 3 0
1987	0	1	0	0	0	2	0	0	0	2	1	2	8
	000	010	000	000	000	020	000	000	000	020	010	020	0 8 0
1988	0	0	0	0	0	1	0	0	0	1	2	1	5
	000	000	000	000	000	010	000	000	000	010	110	010	1 4 0
1989	0	0	0	0	1	1	0	0	0	0	1	0	3
	000	000	000	000	010	010	000	000	000	000	100	000	1 2 0
1990	0	0	0	1	1	0	0	0	0	0	1	1	4
	000	000	000	001	100	000	000	000	000	000	001	010	1 1 2
1991	1	0	0	1	0	1	0	0	0	0	1	0	4
	010	000	000	100	000	010	000	000	000	000	010	000	1 3 0
1992	0	0	0	0	1	2	1	0	1	3	3	2	13
	000	000	000	000	100	020	010	000	001	021	210	020	3 8 2
1993	0	0	0	0	0	0	0	0	0	0	2	0	2
	000	000	000	000	000	000	000	000	000	000	200	000	2 0 0
1994	0	0	1	1	0	1	0	0	0	1	1	0	5
	000	000	010	100	000	010	000	000	000	010	010	000	1 4 0
1995	0	0	0	0	0	0	0	0	1	1	2	0	4
	000	000	000	000	000	000	000	000	010	010	200	000	2 2 0
(1975-1995)													
MEAN	0.2	0.1	0.1	0.2	0.6	0.6	0.1	0.1	0.3	0.9	1.4	0.6	4.8
CASES	3	1	1	4	12	12	1	1	6	19	29	12	101

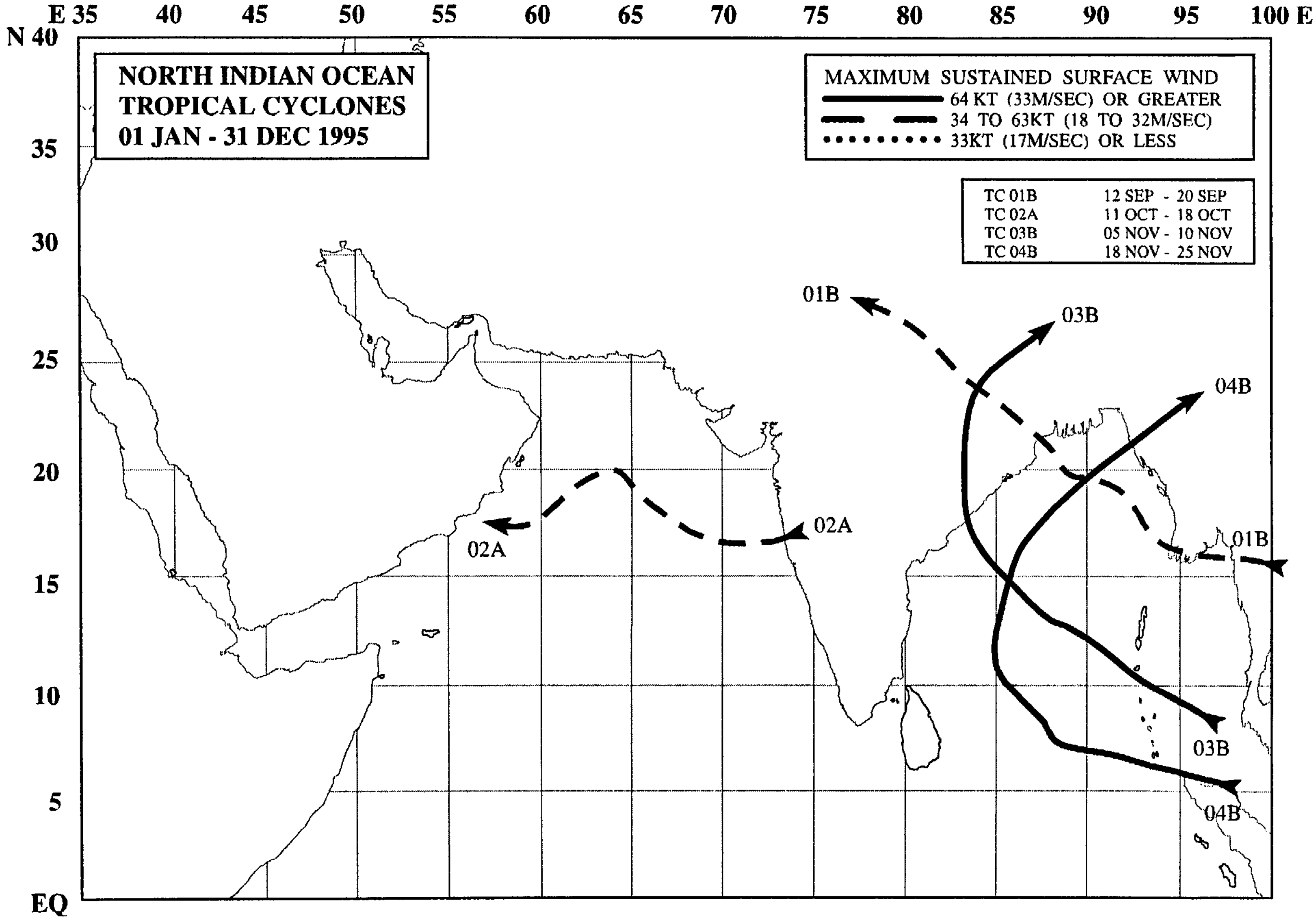
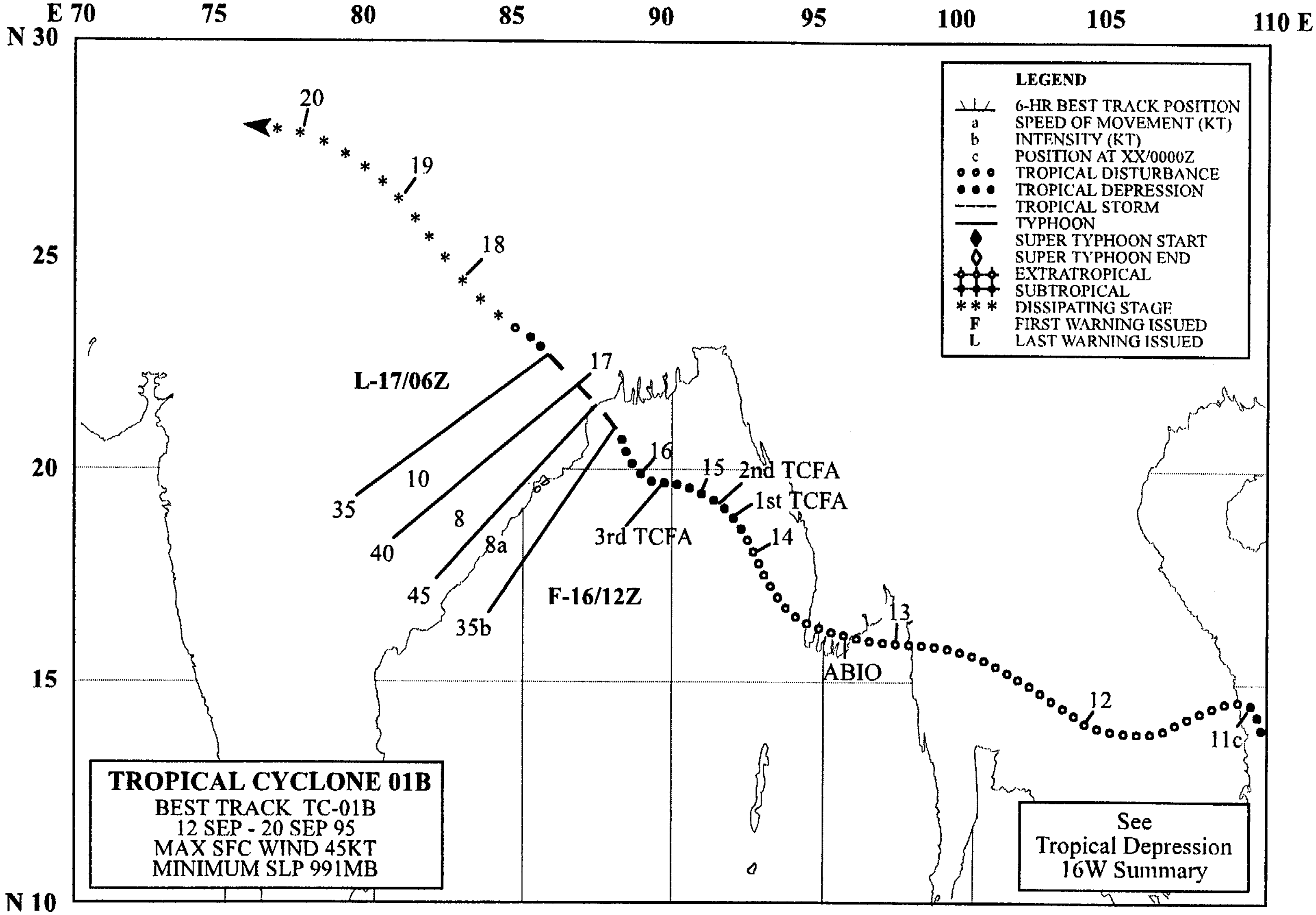


Figure 3-14 Composite of best tracks for North Indian Ocean tropical cyclones for 1995.


E 70
75
80
85
90
95
100
105
110 E
N 30
25
20
15
N 10
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
20
19
18
17
16
15
14
13
12
11c
L-17/06Z
F-16/12Z
2nd TCFA
1st TCFA
3rd TCFA
ABIO
35
10
40
8
45
8a
35b
TROPICAL CYCLONE 01B
BEST TRACK TC-01B
12 SEP - 20 SEP 95
MAX SFC WIND 45KT
MINIMUM SLP 991MB
See
Tropical Depression
16W Summary

TROPICAL CYCLONE 01B

I. HIGHLIGHTS

Forming in September, Tropical Cyclone 01B was the North Indian Ocean's (NIO's) first significant tropical cyclone of 1995. For the second time in the past three years, a significant tropical cyclone did not occur until the fall transition season. Since 1975 this has only happened six times, while climatologically one to two cyclones develop during the April-June spring transition season.

II. TRACK AND INTENSITY

Tropical Cyclone 01B (TC01B) developed from the remnant vortex of Tropical Depression 16W (TD16W), a western North Pacific system that tracked from the South China Sea and across Vietnam and Southeast Asia between 11-13 September. Convection and upper-level divergent winds had been observed over the Andaman Sea and Bay of Bengal over this period — an environment that supported further development once the low-level circulation moved into this area.

The potential for redevelopment was first discussed on the 130600Z September Significant Tropical Weather Advisory when the vortex entered the NIO. As convective activity increased, the first of three Tropical Cyclone Formation Alerts (TCFAs) was issued, valid 140900Z. Two more TCFAs followed, valid at 141600Z and 151600Z, respectively. The system moved slowly northwestward across the Bay of Bengal. The 151600Z TCFA stated, in part: "The cyclonic circulation ... has taken on the appearance of a large monsoon depression and has yet to consolidate...".

The first warning, valid at 161200Z, was issued on TC01B when satellite imagery indicated that convection had concentrated about the low-level circulation center and that the system was intensifying. Six hours later, TC01B peaked in intensity at 45 kt (23 m/sec) — just prior to making landfall on the Indian coast, south of Calcutta (Figure 3-01B-1). The JTWC issued the final warning, valid 170600Z, as the tropical cyclone tracked slowly northwestward. The remnants of TC01B continued to track slowly to the northwest for the next several days before finally dissipating near Delhi on 20 September.

III. IMPACT

No reports of fatalities or significant damage were received at the JTWC.

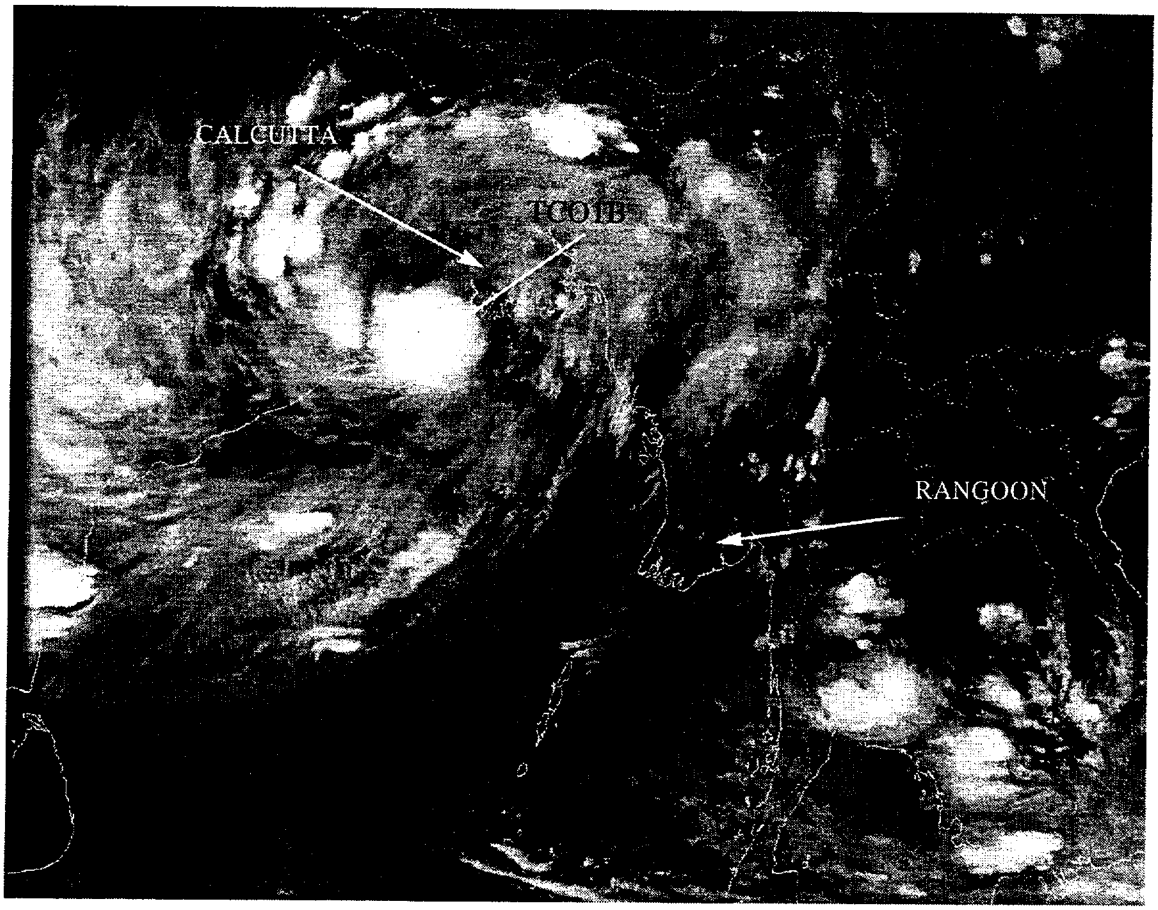
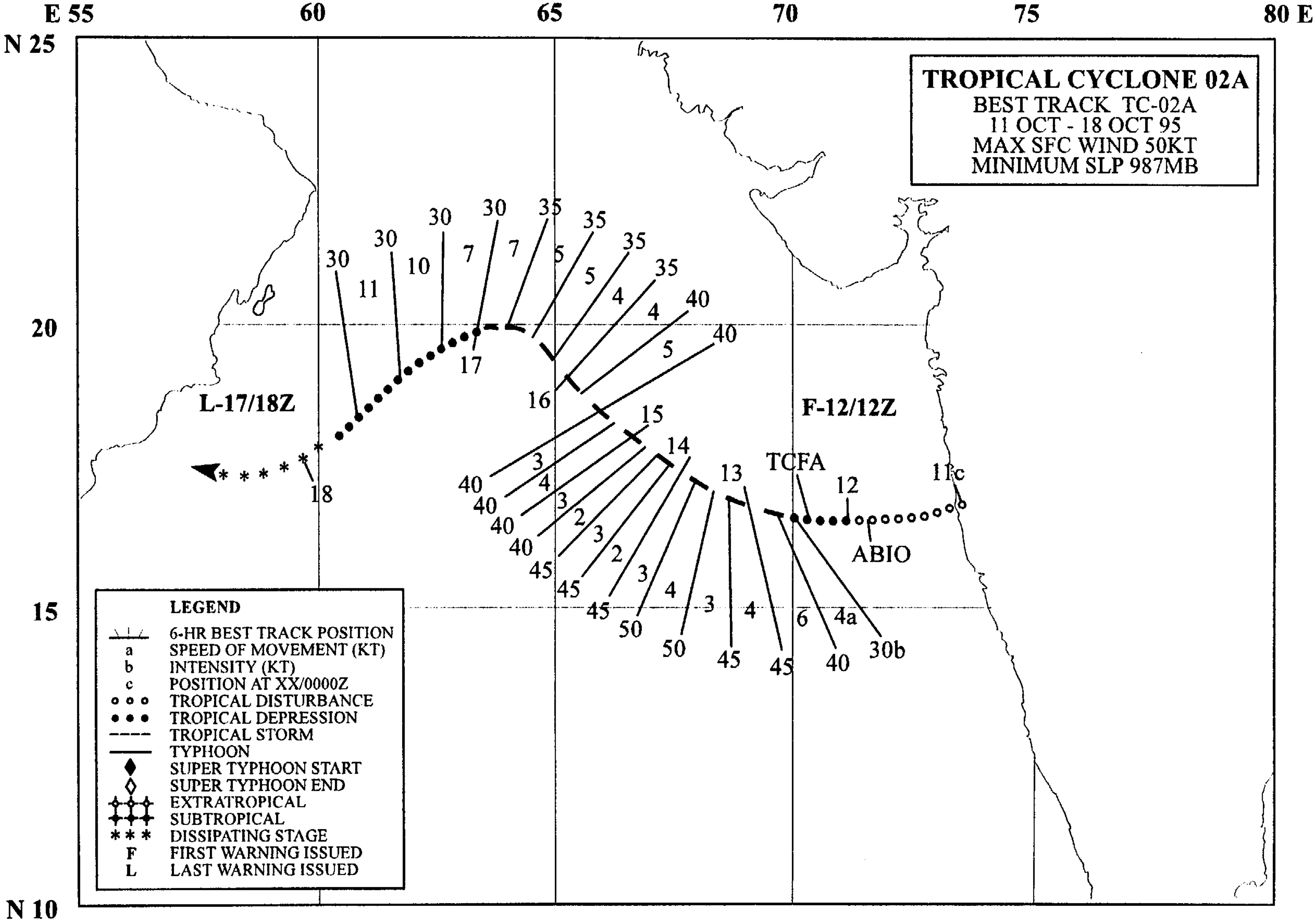


Figure 3-01B-1 Tropical Cyclone 01B at peak intensity of 45 kt (23 m/sec) (161406Z September infrared DMSP imagery).


TROPICAL CYCLONE 02A
BEST TRACK TC-02A
11 OCT - 18 OCT 95
MAX SFC WIND 50KT
MINIMUM SLP 987MB
E 55
60
65
70
75
80 E
N 25
20
15
N 10
L-17/18Z
F-12/12Z
TCFA
ABIO
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL CYCLONE 02A

The disturbance that became Tropical Cyclone 02A was first mentioned on the 111800Z October Significant Tropical Weather Advisory when a persistent surface circulation moved westward from India into the North Arabian Sea where it became better organized. When convective organization improved, a Tropical Cyclone Formation Alert was issued at 120500Z. The first warning followed, valid at 121200Z. The system moved west-northwestward and intensified for the next 36 hours, reaching a maximum intensity of 50 kt (26 m/sec) at 131200Z. The system began to weaken slowly thereafter, maintaining a generally northwestward track through 161200Z. Subjected to strong northeasterly vertical wind shear, the system continued to weaken. After the deep convection was sheared away, the low-level circulation center moved west and then southwest, and the system dissipated over water. The final warning was issued valid at 171800Z.

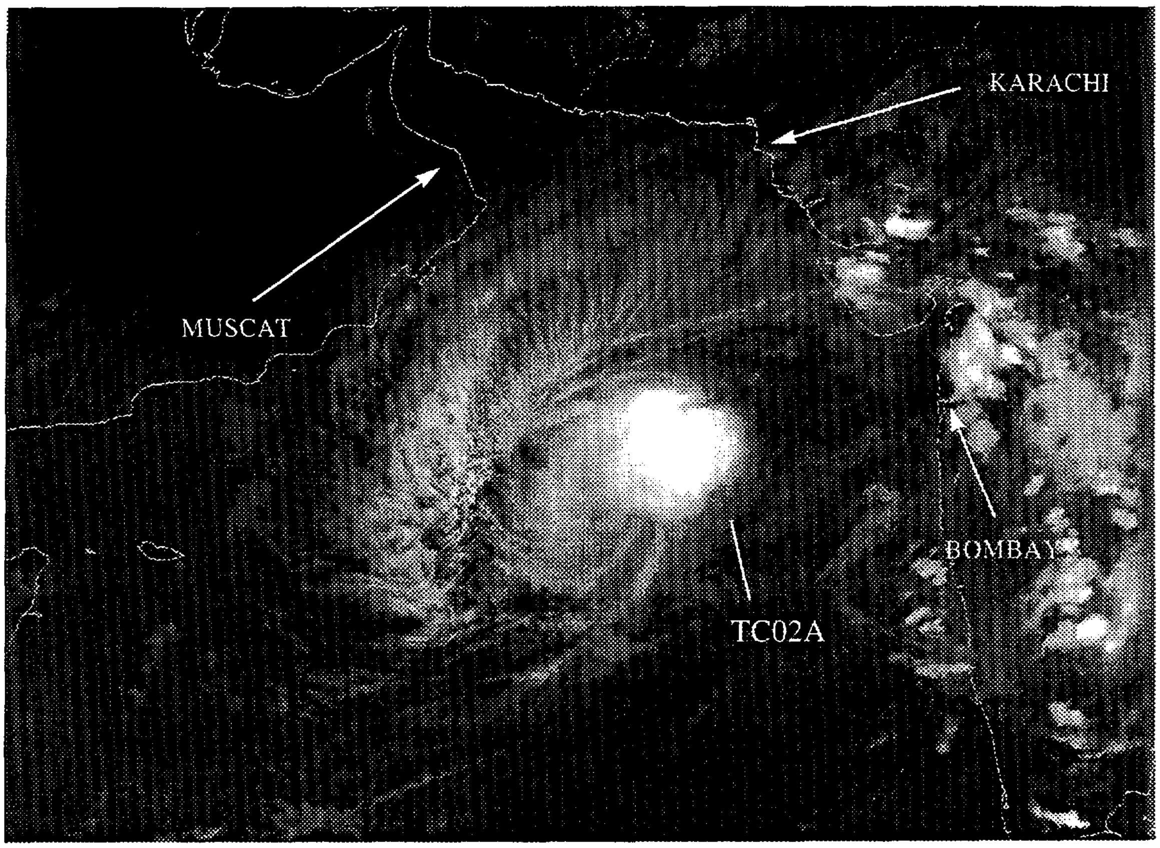
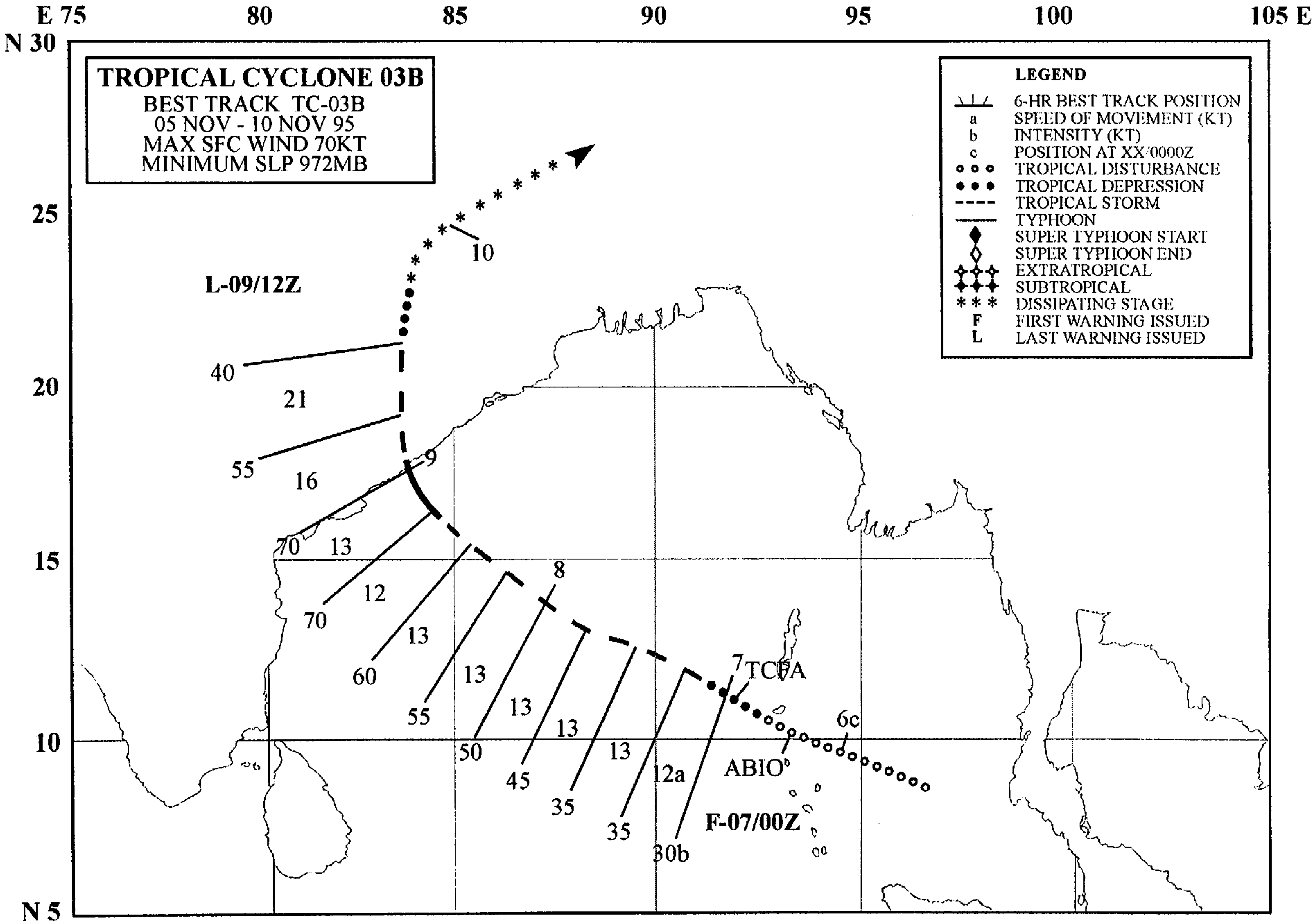


Figure 3-02A-1 Tropical Cyclone 02A at peak intensity of 50 kt (26 m/sec)(131216Z October infrared DMSP imagery).



E 75
80
85
90
95
100
105 E
N 30
25
20
15
10
N 5
TROPICAL CYCLONE 03B
BEST TRACK TC-03B
05 NOV - 10 NOV 95
MAX SFC WIND 70KT
MINIMUM SLP 972MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-09/12Z
10
40
21
55
9
16
70
13
70
12
60
13
55
13
50
8
13
45
13
35
13
35
12a
30b
7
TCFA
ABIO
6c
F-07/00Z

TROPICAL CYCLONE 03B

I. HIGHLIGHTS

Tropical Cyclone 03B originated as a tropical disturbance on 05 November and reached peak intensity just prior to landfall on the east coast of India on 09 November. Its remnants induced heavy snowfall as this moist tropical system ascended the steep slopes of the Himalayan Mountains.

II. TRACK AND INTENSITY

Persistent convection associated with a low-level circulation, an estimated minimum sea-level pressure of 1002 mb, and a surge in the monsoon westerlies led to the re-issuance of the Significant Tropical Weather Advisory for the Indian Ocean at 061230Z November to include the tropical disturbance which developed into Tropical Cyclone 03B. A Tropical Cyclone Formation Alert was issued on this system at 062100Z, and the initial warning, valid at 070000Z, followed. Warnings on Tropical Cyclone 03B commenced while the system was still a tropical depression, but it soon intensified to 35 kt. The tropical cyclone continued to intensify as it tracked northwestward toward India, reaching a maximum intensity of 70 kt (36 m/sec) around 081800Z (Figure 3-03B-01). Minimum sea-level pressure is estimated at 972 mb just before the system made landfall near the city of Vishakhapatnam, India, just after 090000Z November.

Tropical Cyclone 03B weakened to tropical storm intensity as it moved inland and tracked northward. The final warning was issued, valid at 091200Z. The remnants of Tropical Cyclone 03B continued northward, and then northeastward, and moved up the mountain slopes of Nepal, at which point the weak circulation could no longer be tracked with satellite imagery or synoptic observations.

III. IMPACT

Tropical Cyclone 03B brought a fair amount of precipitation and cloud cover across the Bay of Bengal and adjoining land areas, but no significant damage as a result of the cyclone's passage were received at the JTWC. Casualties and property damage remain unknown. Quite evident, however, was the impact the remnants of this cyclone had over the Himalayan Mountains. The moist tropical clouds ascended the slopes, bringing heavy snowfall. At least 62 people were killed in avalanches and landslides along the bases of the mountains along Nepal's Goyko Valley. An additional 418 people were reported rescued from the area by helicopter. Snow accumulation of over 6 feet in eastern Nepal was reported.

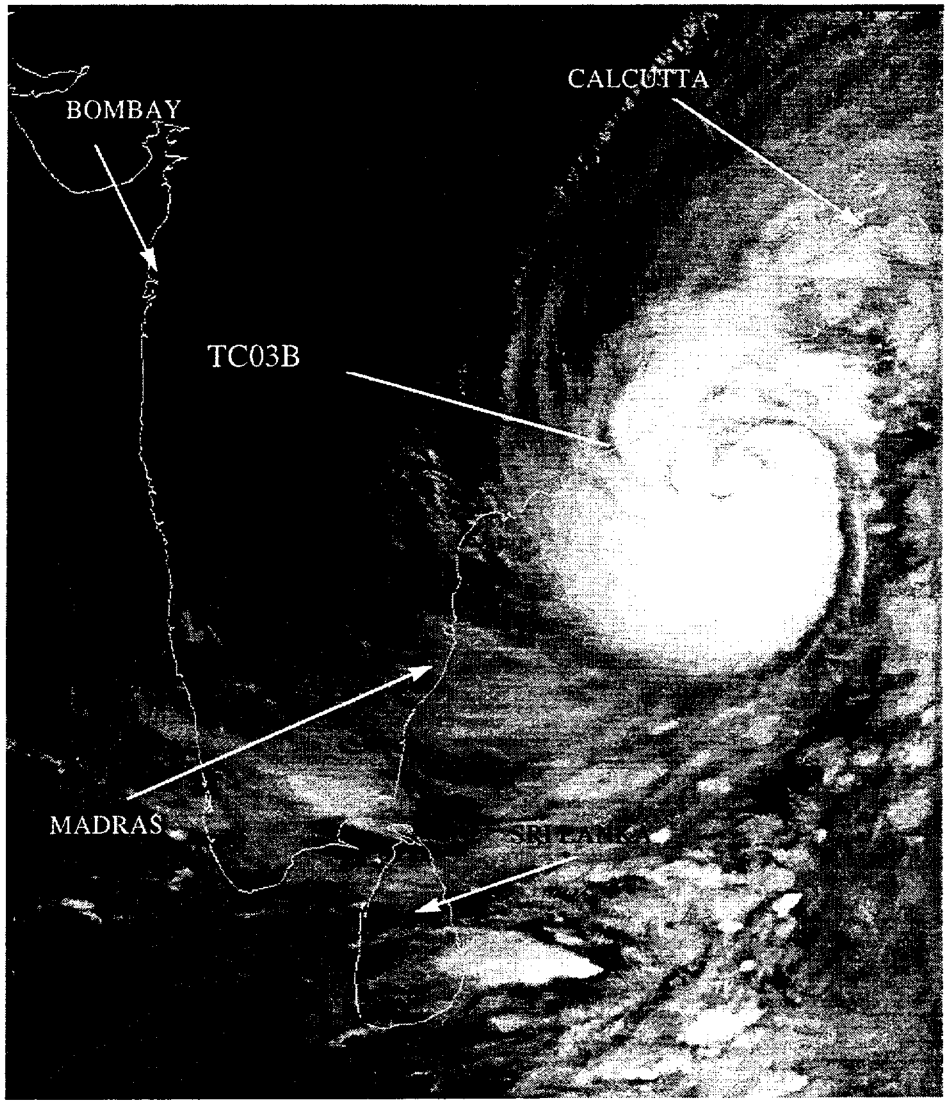
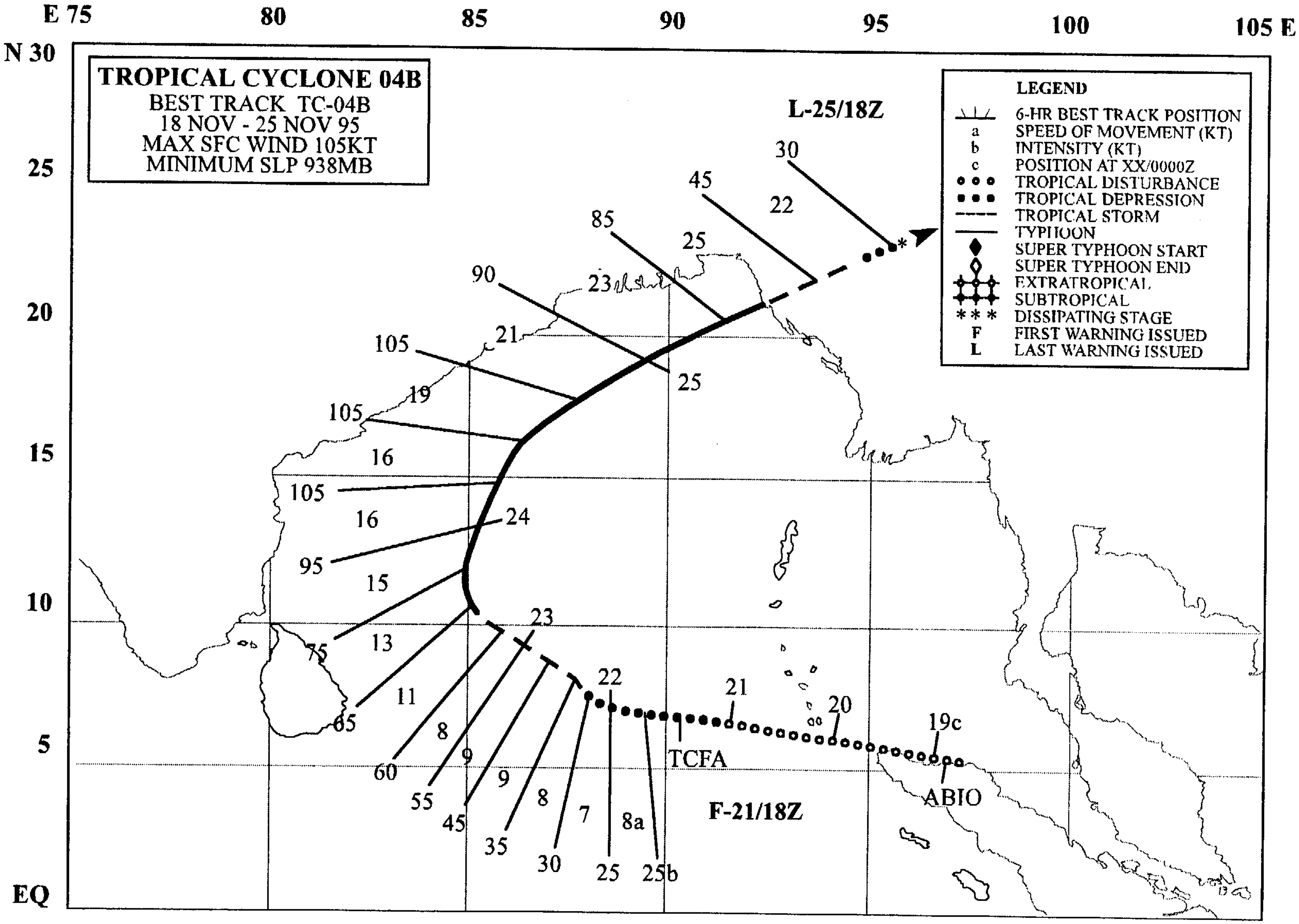


Figure 3-03B-1 Tropical Cyclone 03B heads for the coast of India with an intensity of 70 kt (36 m/sec) (081751Z November infrared DMSP imagery).


TROPICAL CYCLONE 04B
BEST TRACK TC-04B
18 NOV - 25 NOV 95
MAX SFC WIND 105KT
MINIMUM SLP 938MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-25/18Z
F-21/18Z
TCFA
ABIO
E 75
80
85
90
95
100
105 E
N 30
25
20
15
10
5
EQ

TROPICAL CYCLONE 04B

I. HIGHLIGHTS

Tropical Cyclone 04B was the most intense tropical cyclone in the North Indian Ocean during 1995. Its path was similar to Tropical Cyclone 02B of 1994, forming north of Sumatra, recurving, and making landfall near Cox's Bazar in Bangladesh.

II. TRACK AND INTENSITY

A flare up in the convection associated with the tropical disturbance that became Tropical Cyclone 04B was the reason for the reissuance of a Significant Tropical Weather Advisory at 182330Z November. A Tropical Cyclone Formation Alert was issued for the area of persistent convection at 211130Z, followed by a first warning, valid 211800Z. The tropical cyclone intensified rapidly, increasing two T-numbers a day from 220000Z [25 kt (13m/sec)] to 230000Z [55 kt (29 m/sec)], then one-and-a-half T-numbers a day from 230000Z to 240000Z [95 kt (49 m/sec)], reaching a maximum intensity of 105 kt (54 m/sec) by 240600Z. The 250600Z intensity prior to landfall was 85 kt (44 m/sec). The JTWC issued a final warning, valid at 251800Z, as Tropical Cyclone 04B's weakening low-level vortex dissipated over land.

III. IMPACT

Cox's Bazar reported 50 kt (26 m/sec) sustained winds and a 989.5 mb pressure at 250600Z — three hours before this cyclone swept across the coast. Press reports indicated nine people were killed and 300 were missing in the area. Monetary figures were not available for property damage incurred.

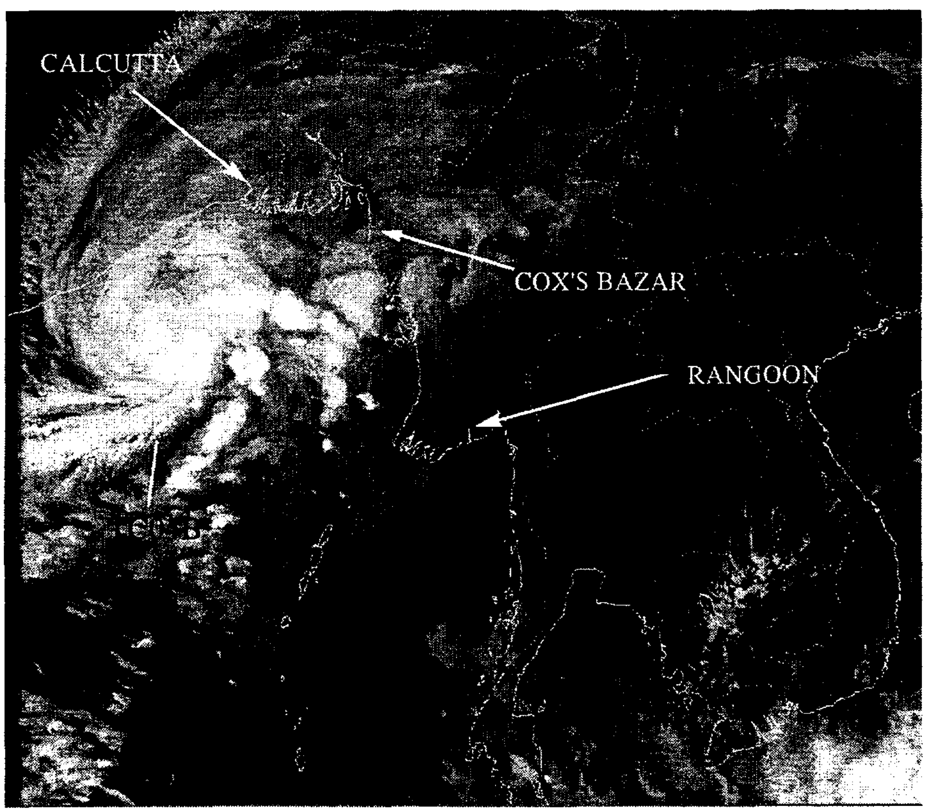


Figure 3-04B-1 The most intense cyclone in the North Indian Ocean in 1995, TC04B churns across the Bay of Bengal towards Bangladesh (241618Z November infrared DMSP imagery).