CHAPTER III - SUMMARY OF TROPICAL CYCLONES

1. WESTERN NORTH PACIFIC TROPICAL CYCLONES

During 1981, the western North Pacific experienced the third consecutive year of below normal tropical cyclone activity. Twenty-nine tropical cylones occurred in 1981, one more than the previous two years but three less than the annual average. Only one significant tropical cyclone failed to develop beyond the tropical depression (TD) stage and 11 tropical storms (TS) failed to reach typhoon intensity. Of the 16 tropical cyclones that developed to typhoon (TY) intensity, only two reached the 130 kt (67 m/sec) intensity necessary to be classified as super typhoons (ST). Tropical cyclones reaching tropical storm intensity or greater are assigned names in alphabetical order from a list of alternating male/female names found in CINCPACINST 3140.1P. Table 3-1 provides a summary of key statistics for western North Pacific cyclones. Each tropical cyclone's maximum surface winds (MAX SFC WND), in knots, and minimum observed sea level pressure (MIN OBS SLP), in millibars, were obtained from best estimates based on all available data. The distance travelled, in nautical miles, was calculated from the JTWC official best track (see Annex A).

Tables 3-2 through 3-5 provide further information on the monthly distribution of tropical cyclones and statistics on Tropical Cyclone Formation Alerts and Warnings.

TABLE 3-1 WESTERN NORTH PACIFIC

1981 SIGNIFICANT TROPICAL CYCLONES

CYCLONE	TYPE	NAME	PERIOD OF WARNING	CALENDAR DAYS OF WARNING	MAX SFC WIND(KT)	MIN OBS SLP	NUMBER OF WARNINGS	DISTANCE TRAVELLED(NM)
01	TY	FREDA	12 MAR-17 MAR	6	100	940	22	1912
02	TS	GERALD	15 APR-19 APR	5	60	982	18	1659
03	TS	HOLLY	29 APR-07 MAY	9	45	997	31	1711
04	TY	IKE	09 JUN-14 JUN	6	65	967	21	1386
05	TY	JUNE	17 JUN-22 JUN	6	75	965	22	1569
06	TY	KELLY	30 JUN-04 JUL	5	75	966	20	1159
07	TS	LYNN	02 JUL-07 JUL	6	55	983	18	1992
08	TS	MAURY	18 JUL-20 JUL	3	55	990	9	741
09	TS	NINA	22 JUL-23 JUL	2	35	995	4	120
10	TY	OGDEN	27 JUL-01 AUG	6	65	975	20	1542
11	TD	TD-11	31 JUL-02 AUG	3	20	994	7	161
12	TS	PHYLLIS	03 AUG-04 AUG	2	45	978	7	318
13	TS	ROY	03 AUG-09 AUG	7	50	986	20	838
14	TS	SUSAN	08 AUG-13 AUG	6	60	975	19	1180
15	TY	THAD	16 AUG-23 AUG	8	85	965	29	1928
16	TS	VANESSA	17 AUG-19 AUG	3	55	983	8	1299
17	TS	WARREN	18 AUG-20 AUG	3	45	991	10	497
18	TY	AGNES	26 AUG-03 SEP	9	95	947	31	1717
19	TY	BILL	03 SEP-07 SEP	5	85	959	17	1583
20	TY	CLARA	17 SEP-22 SEP	8	120	924	29	2129
21	TY	DOYLE	20 SEP-23 SEP	4	80	964	14	2301
22	STY	ELSIE	23 SEP-02 OCT	8	150	893	33	2447
23	TS	FABIAN	13 OCT-14 OCT	2	45	990	6	1479
24	TY	GAY	14 OCT-23 OCT	10	95	947	35	3390
25	TY	HAZEN	14 NOV-23 NOV	10	100	956	37	2956
26	STY	IRMA	19 NOV-27 NOV	9	135	902	34	2732
27	TS	JEFF	23 NOV-26 NOV	4	35	999	14	1754
28	TY	KIT	11 DEC-21 DEC	11	115	924	40	1902
29	TY	LEE	23 DEC-29 DEC	7	95	948	24	1710
			1981 TOTALS	144*				

* OVERLAPPING DAYS INCLUDED ONLY ONCE IN SUM.

TABLE 3-2

1981 SIGNIFICANT TROPICAL CYCLONE STATISTICS

WESTERN NORTH PACIFIC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	(1959-80) AVERAGE
TROPICAL DEPRESSIONS	0	0	0	0	0	0	1	0	0	0	0	0	1	4.8
TROPICAL STORMS	0	0	0	2	0	0	3	5	0	1	1	0	12	10.0
TYPHOONS	0	0	1	0	0	3	1	2	4	1	2	2	(14) 16	17.7
ALL CYCLONES	0	0	1	2	0	3	5	7	4	2	3	2	29	32.3
(1959-80) AVERAGE	.6	.4	.6	.9	1.5	2.0	5.2	6.5	6.0	4.7	2.6	1.4	32.3	1959-1982 31.9

FORMATION ALERTS

28 of 29 Formation Alert Events developed into Tropical Cyclones. Tropical Cyclone Formation Alerts were issued for all but 1 significant tropical cyclones that developed during 1981.

WARNINGS

Number of warning days: 144

Number of warning days with 2 cyclones: 23

Number of warning days with 3 or more cyclones: 3

TABLE 3-3

FREQUENCY OF TYPHOONS BY MONTH AND YEAR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
AVERAGE (1945-58)	0.4	0.1	0.3	0.4	0.7	1.1	2.0	2.9	3.2	2.4	2.0	0.9	16.3
1959	0	0	0	1	0	0	1	5	3	3	2	2	17
1960	0	0	0	1	0	2	2	8	0	4	1	1	19
1961	0	0	1	0	2	1	3	3	5	3	1	1	20
1962	0	0	0	1	2	0	5	7	2	4	3	0	24
1963	0	0	0	1	1	2	3	3	3	4	0	2	19
1964	0	0	0	0	2	2	6	3	5	3	4	1	26
1965	1	0	0	1	2	2	4	3	5	2	1	0	21
1966	0	0	0	1	2	1	3	6	4	2	0	1	20
1967	0	0	1	1	0	1	3	4	4	3	3	0	20
1968	0	0	0	1	1	1	1	4	3	5	4	0	20
1969	1	0	0	1	0	0	2	3	2	3	1	0	13
1970	0	1	0	0	0	1	0	4	2	3	1	0	12
1971	0	0	0	3	1	2	6	3	5	3	1	0	24
1972	1	0	0	0	1	1	4	4	3	4	2	2	22
1973	0	0	0	0	0	0	4	2	2	4	0	0	12
1974	0	0	0	0	1	2	1	2	3	4	2	0	14
1975	1	0	0	0	0	0	1	3	4	3	2	0	15
1976	1	0	0	1	2	2	2	1	4	1	1	0	15
1977	0	0	0	0	0	0	3	0	2	3	2	1	11
1978	0	0	0	1	0	0	3	2	4	3	2	0	15
1979	1	0	1	1	0	0	2	2	3	2	1	1	14
1980	0	0	0	0	2	0	3	2	5	2	1	0	15
1981	0	0	1	0	0	2	2	2	4	1	2	2	16
AVERAGE (1959-81)	.3	0.04	.2	.7	.8	1.0	2.8	3.3	3.3	3.0	1.6	.6	17.6

TABLE 3-4

FREQUENCY OF TROPICAL STORMS AND TYPHOONS BY MONTH AND YEAR

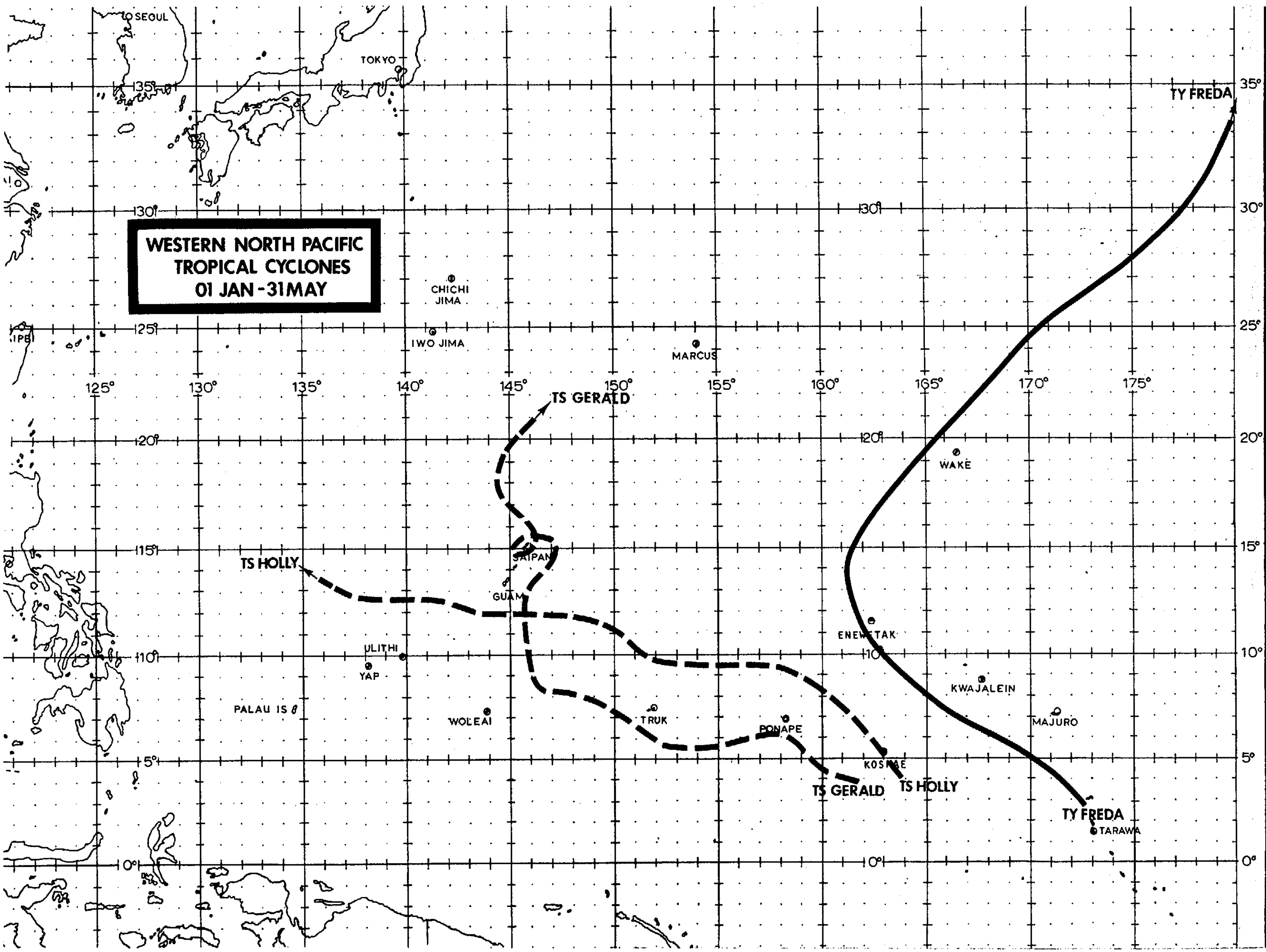
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
AVERAGE (1945-58)	0.4	0.1	0.4	0.5	0.8	1.3	3.0	3.9	4.1	3.3	2.7	1.1	21.6
1959	0	1	1	1	0	0	3	6	6	4	2	2	26
1960	0	0	0	1	1	3	3	10	3	4	1	1	27
1961	1	1	1	1	3	2	5	4	6	5	1	1	31
1962	0	1	0	1	2	0	6	7	3	5	3	2	30
1963	0	0	0	1	1	3	4	3	5	5	0	3	25
1964	0	0	0	0	2	2	7	9	7	6	6	1	40
1965	2	2	1	1	2	3	5	6	7	2	2	1	34
1966	0	0	0	1	2	1	5	8	7	3	2	1	30
1967	1	0	2	1	1	1	6	8	7	4	3	1	35
1968	0	0	0	1	1	1	3	8	3	6	4	0	27
1969	1	0	1	1	0	0	3	4	3	3	2	1	19
1970	0	1	0	0	0	2	2	6	4	5	4	0	24
1971	1	0	1	3	4	2	8	4	6	4	2	0	35
1972	1	0	0	0	1	3	6	5	4	5	2	3	30
1973	0	0	0	0	0	0	7	5	2	4	3	0	21
1974	1	0	1	1	1	4	4	5	5	4	4	2	32
1975	1	0	0	0	0	0	2	4	5	5	3	0	20
1976	1	1	0	2	2	2	4	4	5	1	1	2	25
1977	0	0	1	0	0	1	4	1	5	4	2	1	19
1978	1	0	0	1	0	3	4	7	5	4	3	0	28
1979	1	0	1	1	1	0	4	2	7	3	2	2	24
1980	0	0	0	1	4	1	4	2	6	4	1	1	24
1981	0	0	1	2	0	2	5	7	4	2	3	2	28
AVERAGE (1959-81)	.5	.3	.5	.9	1.2	1.6	4.5	5.4	5.0	4.0	2.4	1.2	27.6

TABLE 3-5

FORMATION ALERT SUMMARY

WESTERN NORTH PACIFIC

YEAR	NUMBER OF ALERT SYSTEMS	ALERT SYSTEMS WHICH BECAME NUMBERED TROPICAL CYCLONES	TOTAL NUMBERED TROPICAL CYCLONES	DEVELOPMENT RATE
1972	41	29	32	71%
1973	26	22	23	85%
1974	35	30	36	86%
1975	34	25	25	74%
1976	34	25	25	74%
1977	26	20	21	77%
1978	32	27	32	84%
1979	27	23	28	85%
1980	37	28	28	76%
1981	29	28	29	97%


WESTERN NORTH PACIFIC
TROPICAL CYCLONES
01 JAN - 31MAY
SEOUL
TOKYO
CHICHI JIMA
IWO JIMA
MARCUS
WAKE
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
KOSRAE
ENEWETAK
KWAJALEIN
MAJURO
TARAWA
TS GERALD
TS GERALD
TS HOLLY
TS HOLLY
TY FREDA
TY FREDA
125°
130°
135°
140°
145°
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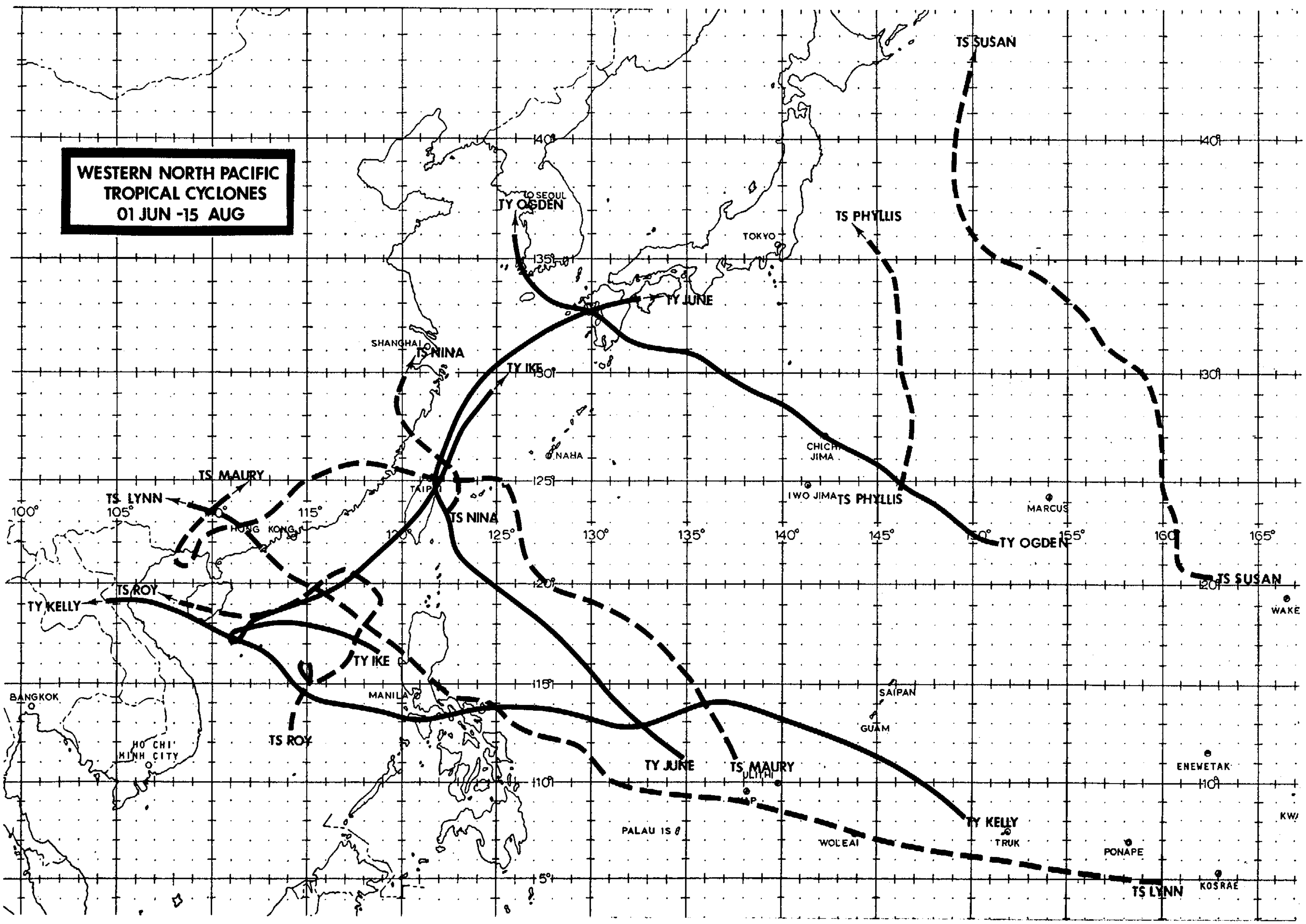
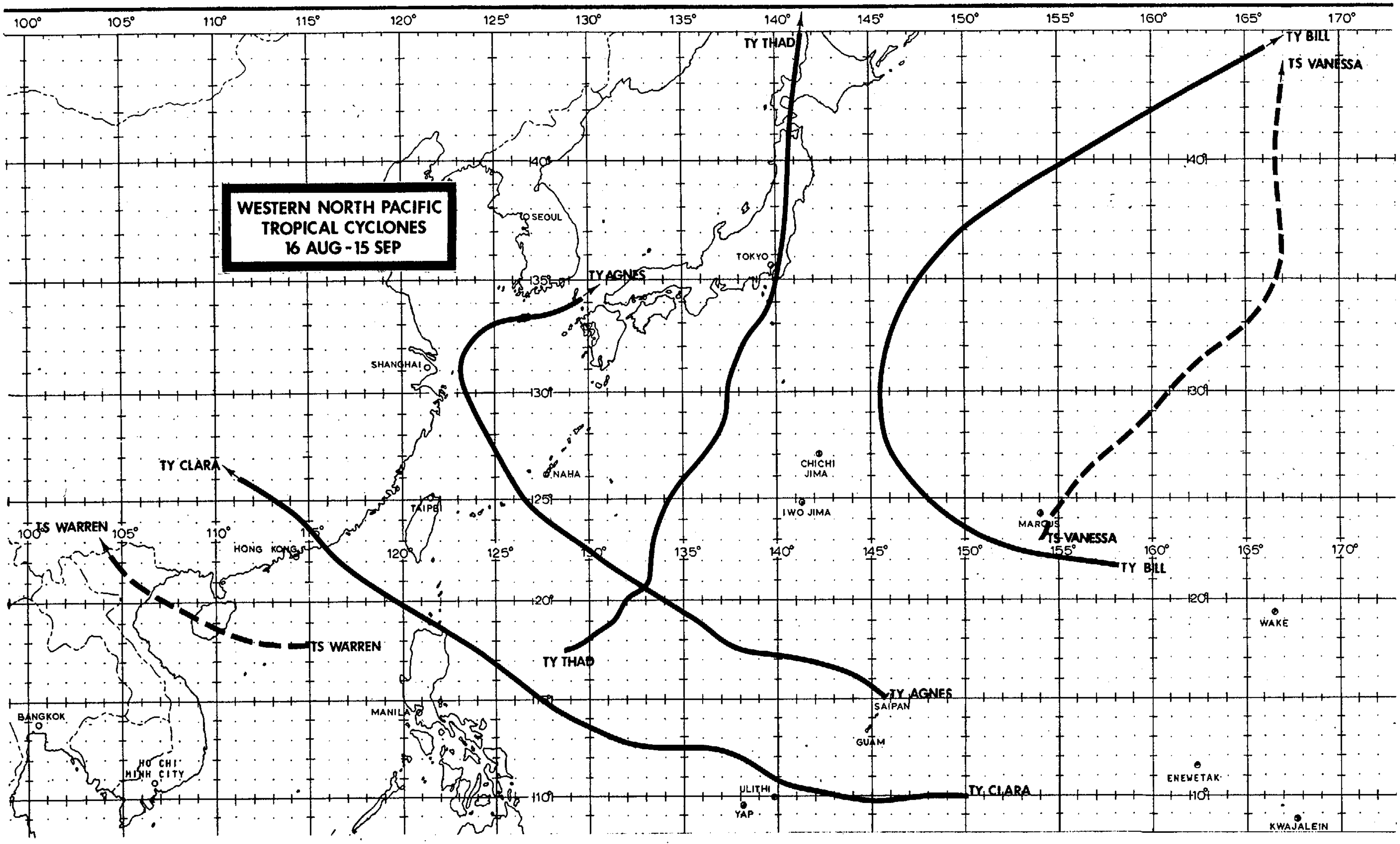
20°
15°
10°
5°
0°



WESTERN NORTH PACIFIC
TROPICAL CYCLONES
01 JUN -15 AUG
TS SUSAN
TS PHYLLIS
TY OGDEN
TY JUNE
TS NINA
TY IKE
TS MAURY
TS LYNN
TS ROY
TY KELLY
SHANGHAI
TOKYO
TO SEOUL
NAHA
CHICHI JIMA
IWO JIMA
MARCUS
WAKE
HONG KONG
TAIPEI
MANILA
BANGKOK
HO CHI MINH CITY
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
ENEWETAK
KOSRAE
100°
105°
115°
120°
125°
130°
135°
140°
145°
150°
155°
160°
165°
40°
35°
30°
25°
20°
15°
10°
5°


WESTERN NORTH PACIFIC
TROPICAL CYCLONES
16 AUG - 15 SEP
TY THAD
TY BILL
TS VANESSA
TY AGNES
TY CLARA
TS WARREN
SEOUL
TOKYO
SHANGHAI
NAHA
CHICHI JIMA
IWO JIMA
TAIPEI
HONG KONG
MARCUS
WAKE
SAIPAN
GUAM
MANILA
BANGKOK
HO CHI MINH CITY
ULITHI
YAP
ENEWETAK
KWAJALEIN
100°
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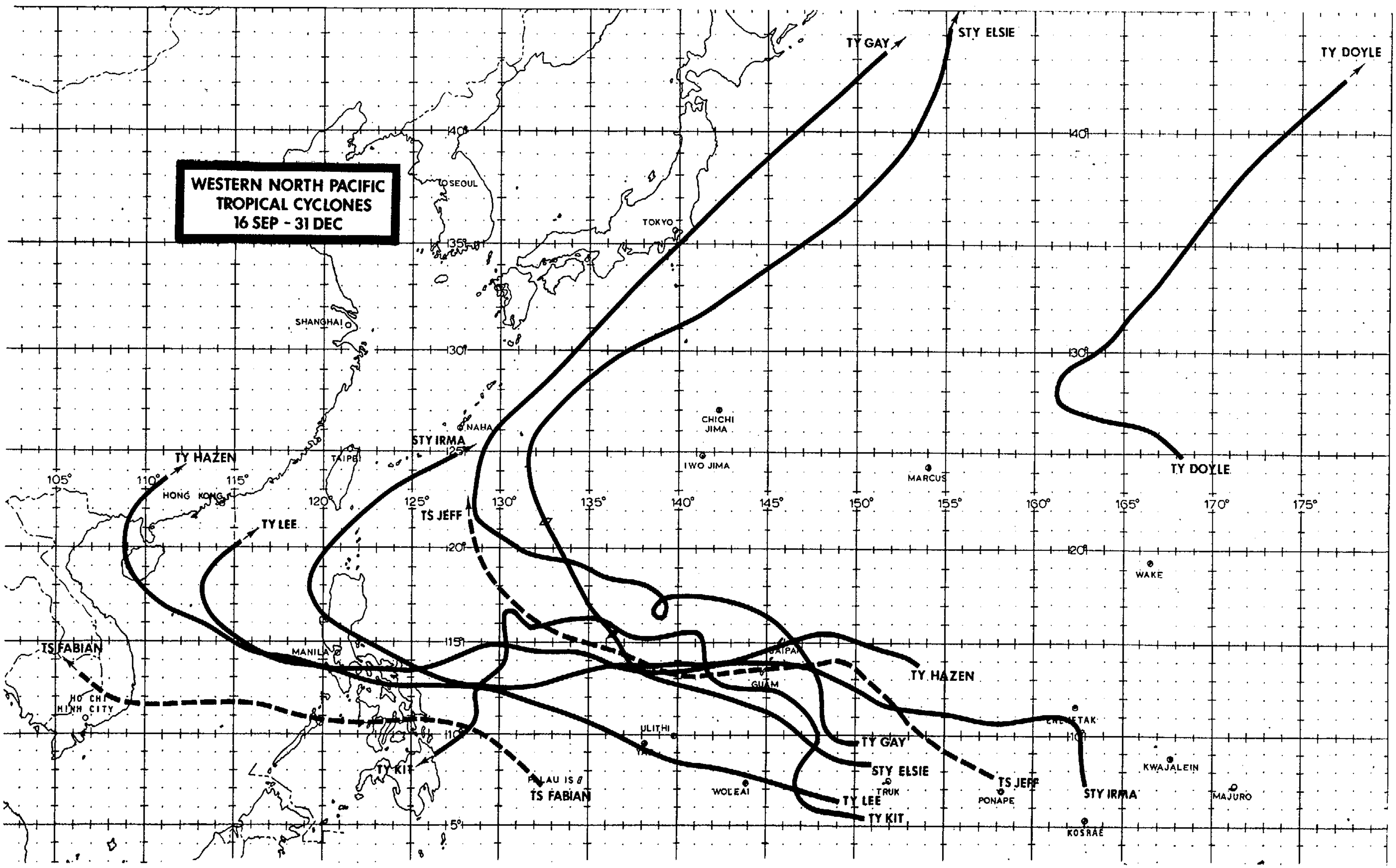
115°
120°
125°
130°
135°
140°
145°
150°
155°
160°
165°
170°


WESTERN NORTH PACIFIC
TROPICAL CYCLONES
16 SEP - 31 DEC
TY GAY
STY ELSIE
TY DOYLE
STY IRMA
TY HAZEN
TY LEE
TS JEFF
TS FABIAN
TY KIT
SEOUL
TOKYO
SHANGHAI
NAHA
TAIPEI
HONG KONG
MANILA
HO CHI MINH CITY
CHICHI JIMA
IWO JIMA
MARCUS
WAKE
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MAJURO
PALAU IS
105°
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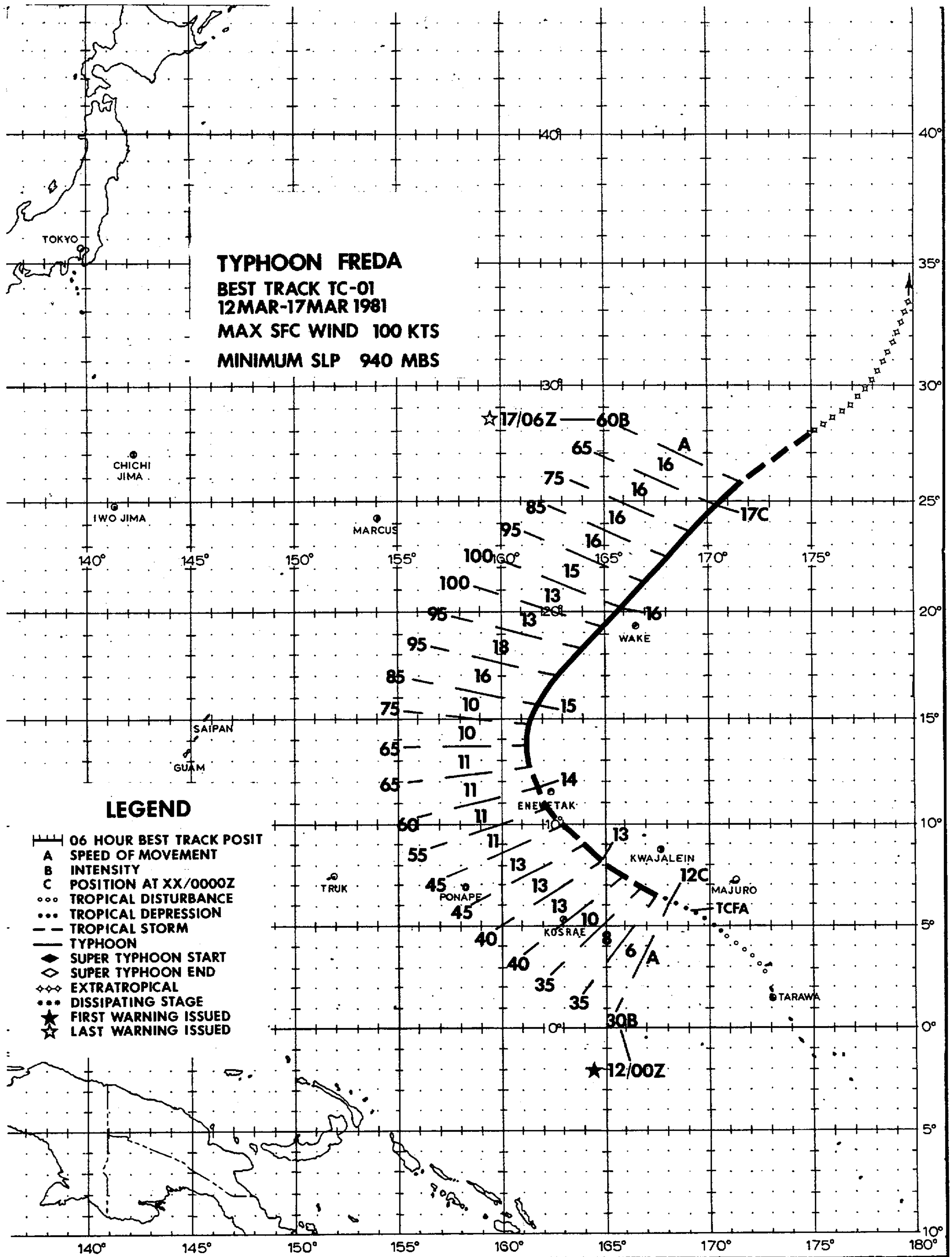
30°
35°
40°


TYPHOON FREDA
BEST TRACK TC-01
12MAR-17MAR 1981
MAX SFC WIND 100 KTS
MINIMUM SLP 940 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
17/06Z
60B
12/00Z
30B
17C
12C
TCFA
TOKYO
CHICHI JIMA
IWO JIMA
MARCUS
SAIPAN
GUAM
WAKE
ENEWETAK
KWAJALEIN
MAJURO
TRUK
PONAPE
KOSRAE
TARAWA
140°
145°
150°
155°
160°
165°
170°
175°
180°
40°
35°
30°
25°
20°
15°
10°
5°
0°

Typhoon Freda, the first tropical cyclone of 1981 and only the fourth typhoon since 1959 to occur in March, developed very slowly within the near-equatorial trough that shifted briefly north of the equator in early March.

Remaining quasi-stationary near the Gilbert Islands just north of the equator for nearly three days, the disturbance finally began to move northwestward and developed slowly as it reached higher latitudes. Although the upper-level synoptic pattern with strong unidirectional southeast flow (Fig. 3-01-1) was unfavorable for development, noticeable improvement in the satellite signature led to the issuance of a Tropical Cyclone Formation Alert at 111900Z. The first warning on TD 01 was issued six hours later as the disturbance approached the southern Marshall Islands when synoptic reports and satellite imagery indicated further development.

Beginning with the first warning, JTWC forecasts were consistent in predicting recurvature west of Enewetak Atoll. This track was based on an apparent break in the mid-tropospheric subtropical ridge along 160E between the mid-Pacific high and a large high pressure cell over the Philippine Islands. This break was later confirmed by valuable synoptic data received from reconnaissance aircraft flying to and from the developing cyclone.

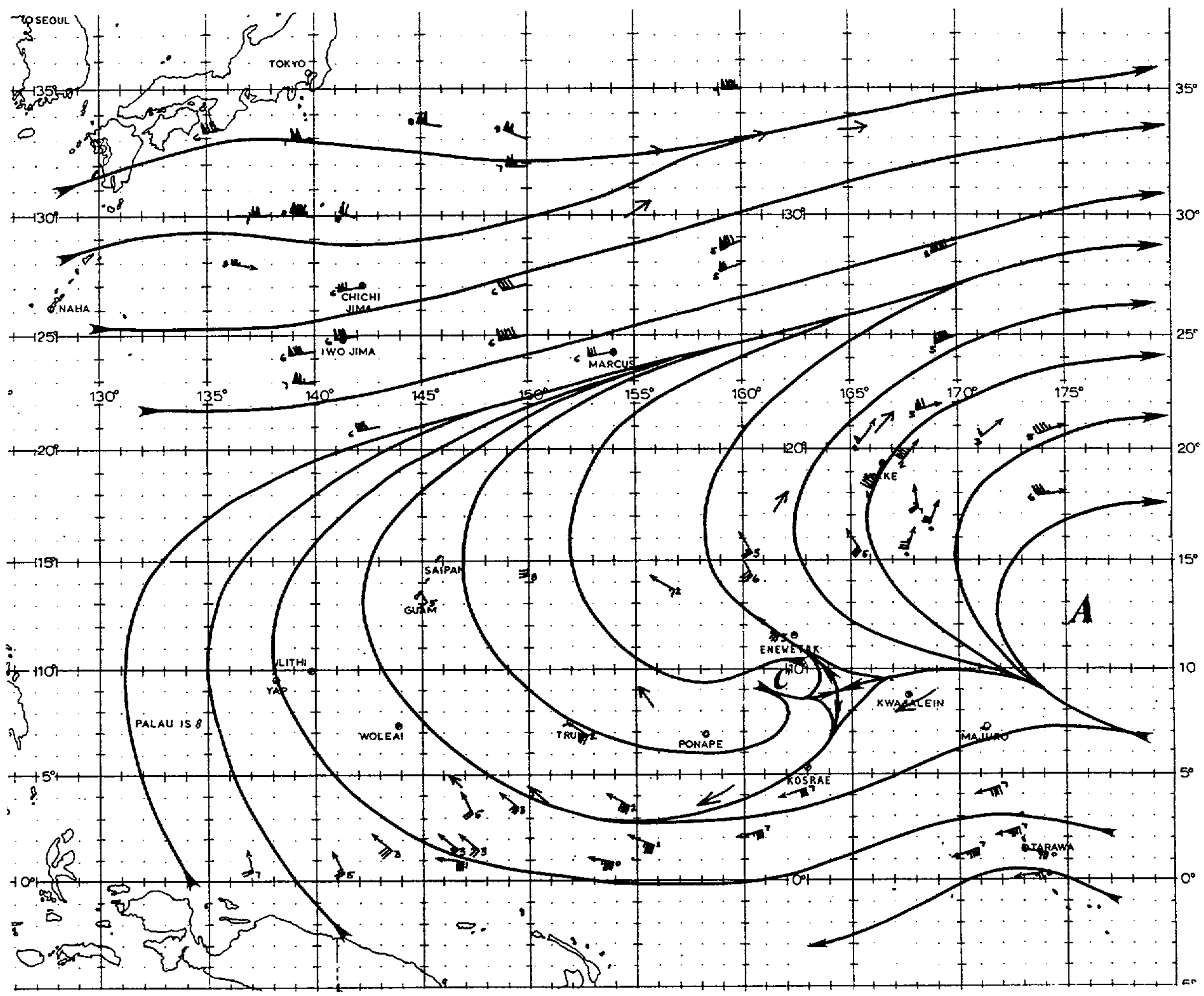


FIGURE 3-01-1. 200-mb streamline analysis at 131200Z. At this time, the flow pattern was still primarily associated with the mid-Pacific ridge with little indication of large-scale outflow over Freda at this level. Wind data are a combination of RAOBS, AIREPS, and satellite derived winds (←—\ ) and blow-off wind directions (←—). Wind speeds are in knots.

The strong southeasterly flow aloft resulted in considerable vertical tilt during Freda's northwest track. The 700-mb center was consistently observed 15 to 25 nm (28 to 46 km) north-northwest of the surface center. This poor vertical alignment combined with the absence of strong upper-level outflow channels resulted in her extremely slow intensification. This proved fortunate for Enewetak Atoll which lay directly in Freda's path. Freda passed 15 nm (28 km) west of the Atoll with 55 kt (28 m/sec) sustained winds, considerably less than normal for a disturbance that had developed to tropical storm intensity 48 hours earlier. Although no synoptic observations or damage reports were received from Enewetak, the situation could have been far more disastrous.

In contrast to the extremely slow development during the first three days of her existence, Freda intensified rapidly once north of the ridge axis and in a more favorable upper-level environment (Fig. 3-01-2). Contact with the southwest-

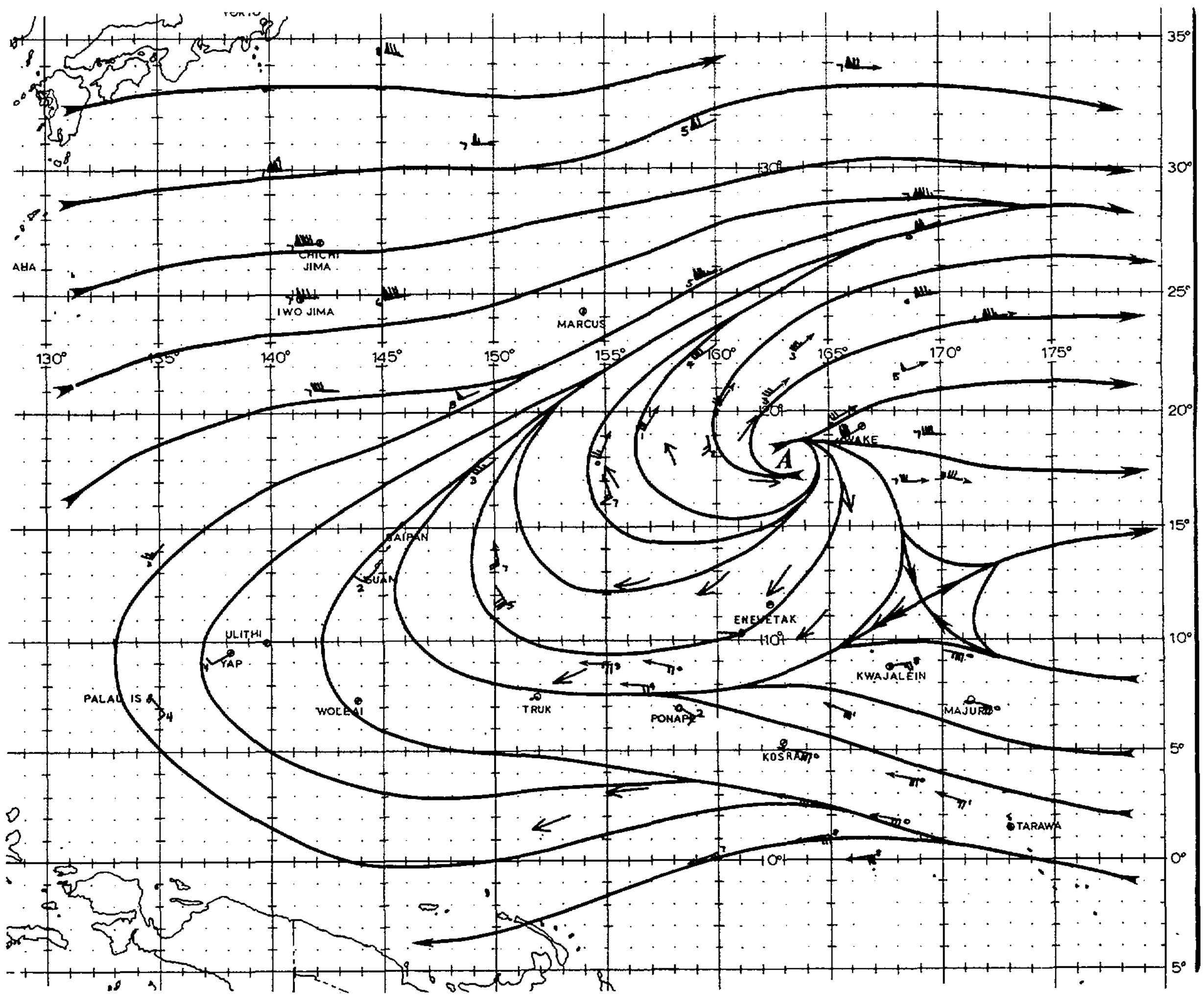


FIGURE 3-01-2. 200-mb streamline analysis at 150000Z depicting a dramatic change in the upper-level flow pattern with the outflow over Freda now the primary feature. The westerly jet has dipped as far south as 25N providing a vigorous outflow channel to the northeast for Freda. Wind data are a combination of RAOBS, AIREPS, and satellite derived winds (←―\ ) and blow-off wind directions (←―). Wind speeds are in knots.

erly jet north of her provided a vigorous outflow channel to the north. With multiple outflow channels to the environmental flow, Freda intensified from 65 kt (33 m/sec) to 100 kt (51 m/sec) and deepened from 975 mb to 940 mb within 30 hours (Fig. 3-01-3).

Unlike Enewetak, Freda was at her maximum intensity of 100 kt (51 m/sec) when she passed within 65 nm (120 km) of Wake Island. Wake reported maximum sustained winds of 50 kt (26 m/sec) with gusts to 75 kt (39 m/sec) at 152300Z. Damage to the island's runway and support equipment was extensive, caused primarily by the high surf, estimated to be over 20 feet, generated by Freda's close passage.

As Freda moved further north and approached the core of the jetstream, the strong mid-latitude westerlies responsible for her rapid intensification also caused her eventual weakening. Forty-eight hours after reaching maximum intensity, Freda's convection was sheared off and the low-level circulation moved quickly northward and was absorbed into a developing extratropical low pressure system.

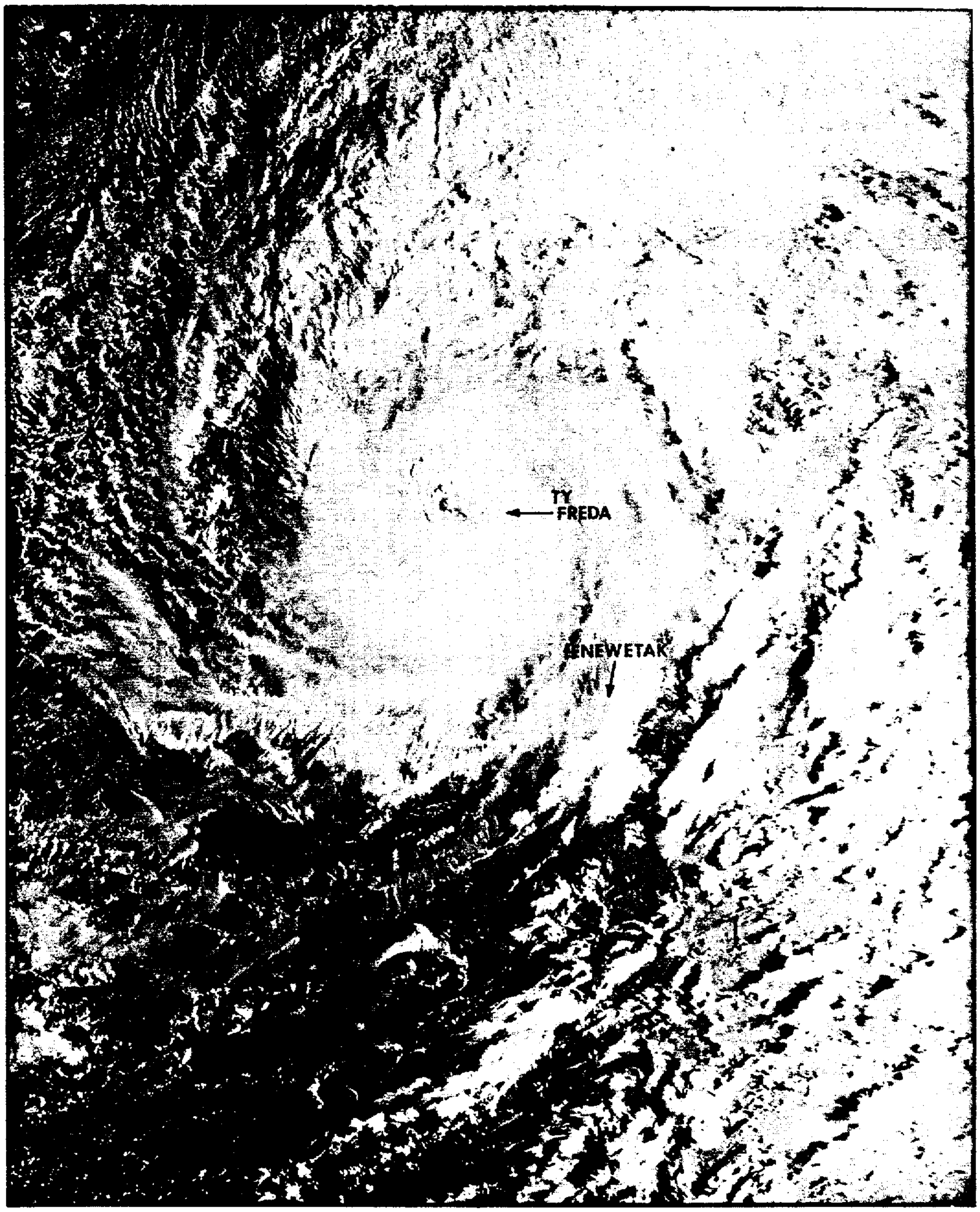
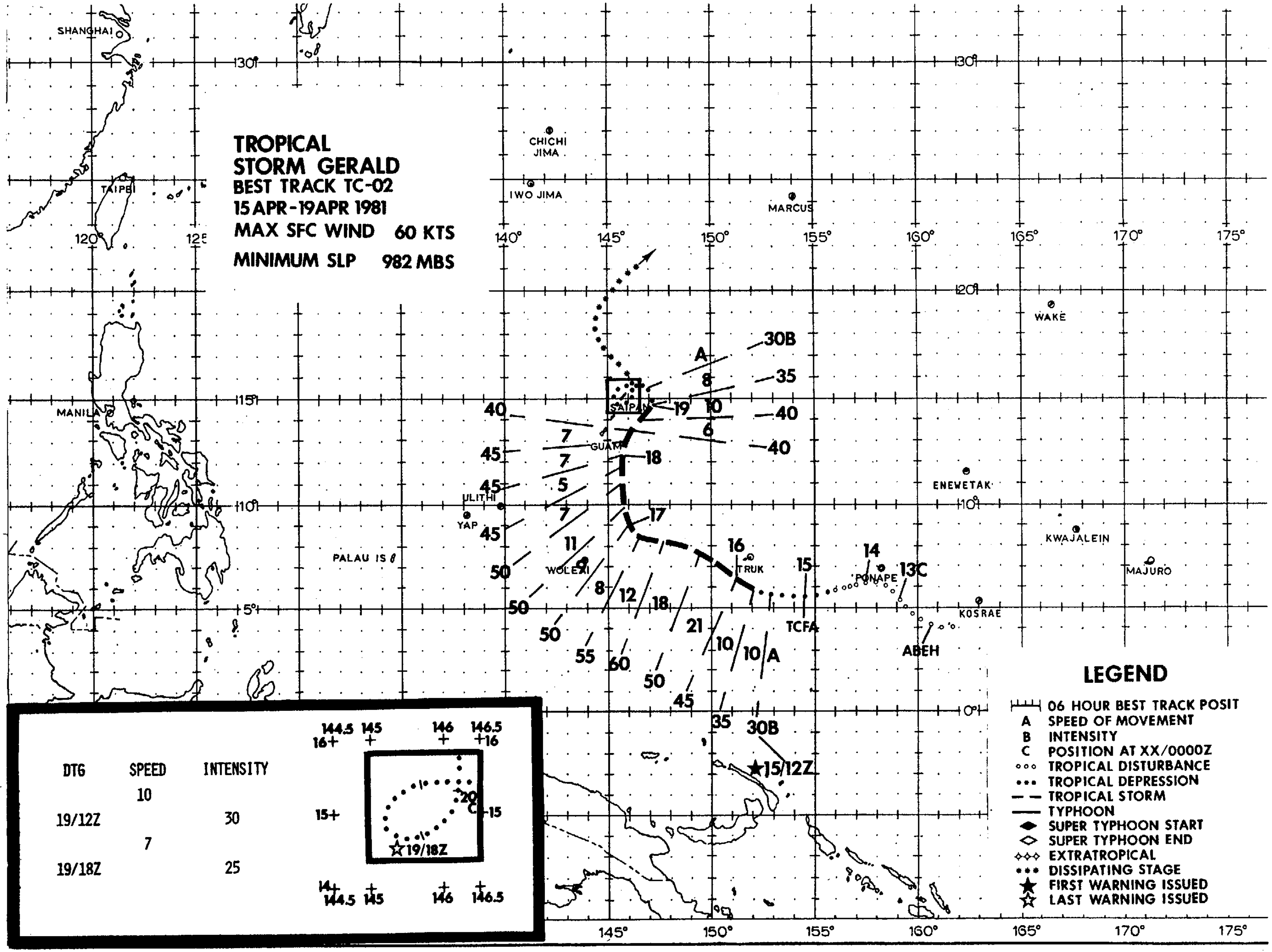


FIGURE 3-01-3. Typhoon Freda at 80-kt (41 m/sec) intensity 390 nm (722 km) southwest of Wake Island, 14 March 1981, 2120Z. (NOAA 6 visual imagery)


TROPICAL
STORM GERALD
BEST TRACK TC-02
15 APR-19 APR 1981
MAX SFC WIND 60 KTS
MINIMUM SLP 982 MBS
SHANGHAI
TAIPEI
MANILA
CHICHI JIMA
IWO JIMA
MARCUS
WAKE
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
KOSRAE
ENEWETAK
KWAJALEIN
MAJURO
TCFA
ABEH
15/12Z
30°
20°
15°
10°
5°
0°
120°
125
140°
145°
150°
155°
160°
165°
170°
175°
DTG
SPEED
INTENSITY
10
19/12Z
30
7
19/18Z
25
19/18Z
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED

A developing mid- to uppper-level circulation southeast of Ponape became evident on satellite imagery on 12 April. At this time, the cirrus outflow pattern was extensive and the cloud system displayed good curvature. A surface circulation, however, was not apparent until the 15th following further significant improvement of the satellite signature. A Tropical Cyclone Formation Alert was issued, vice a warning, at 150000Z because island stations in the vicinity of the circulation reported that the minimum sea-level pressure was a still relatively high 1009 mb. Eight hours later a reconnaissance aircraft observed a very tight surface circulation with maximum winds of 30 kt (15m/sec) and a minimum sea-level pressure of 1000 mb. Based on this new information, the first warning on Tropical Depression 02 was issued at 151200Z.

Several factors influenced JTWC to forecast that Gerald would reach typhoon strength. First, upper-level wind analyses showed an extensive upper-level outflow pattern assocated with Gerald. An anticyclone was located near the system's center and outflow was unrestricted and extended well into the Southern Hemisphere. Second, low-level cross-equatorial inflow became fully established by the 15th. Third, reconnaissance aircraft reported 700-mb center temperatures of 21°C. This observation was 11° higher than the environment and higher than temperatures normally observed in a tropical cyclone at Gerald's stage of development. The high amount of latent heat was being released, which usually indicates impending intensification.

The reason that Gerald did not develop as forecast appears to be rooted in a radical change which occurred in the upper-level flow pattern. As previously mentioned, Gerald began with a well-defined upper-level anticyclone that afforded excellent outflow channels in all directions. Steady intensification did occur until 170000Z when a synoptic-scale upper-level anticyclone began developing east of Gerald near 10N 155E. This anticyclone continued to intensify and increase in areal extent as it shifted slowly to the southeast. Gerald's outflow channel to the east became restricted as the south and southeasterly shearing winds aloft increased in strength. As a result, Gerald began weakening as he passed about 70 nm (130 km) to the east of Guam at 180900Z. The Island received between 3 - 5 inches of rain. Andersen Air Force Base reported a minimum sea-level pressure of 1005.7 mb and a maximum wind of 49 kt (25 m/sec) in gusts.

After passing Guam, Gerald's convection continued to shear off to the northeast as the exposed low-level circulation center (Fig. 3-02-1) meandered northwestward where it was eventually absorbed by an extratropical trough moving eastward across the Pacific.

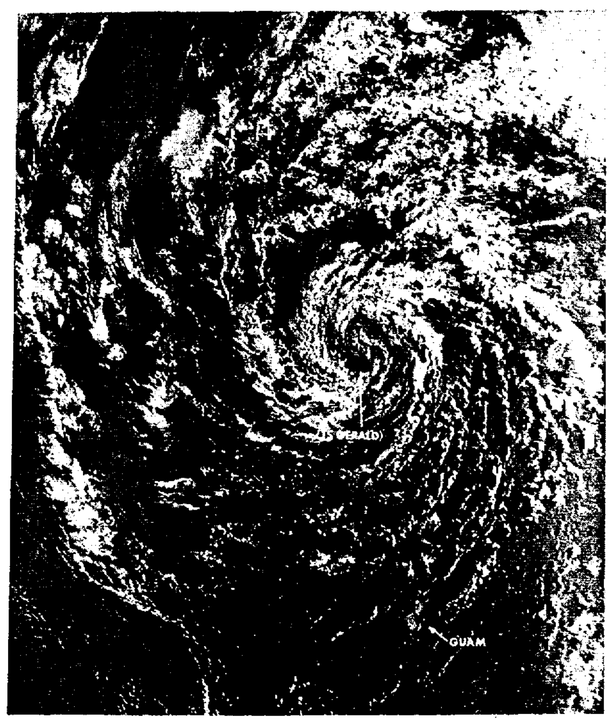


FIGURE 3-02-1. Tropical Storm Gerald as an exposed low-level circulation center north of Guam, 20 April 1981, 2228Z. (NOAA 6 visual imagery)

JTWC's better than average forecasting of Gerald's track was due in no small part to the extensive 500-mb synoptic track data provided by the 54th Weather Reconnaissance Squadron. Figures 3-02-2 through 3-03-5 show the evolution that occurred in the mid-level steering flow as indicated by aircraft data.

Available synoptic data, although sparse, suggested that the subtropical mid-tropospheric ridge was weak north of the developing Gerald. Thus, the initial forecast track called for recurvature well to the west of Guam. Aircraft data on the 15th defined a small anticyclone north of Guam (Fig. 3-02-2) which supported the subsequent forecast of passage southwest of Guam before recurvature. Because this was the first time this cell had been analyzed, there was no way to determine if the cell was moving or quasi-stationary. The 500-mb data 24 hours later (Fig. 3-02-3) showed that the major break in the ridge still existed to the west of Guam; thus, recurva-

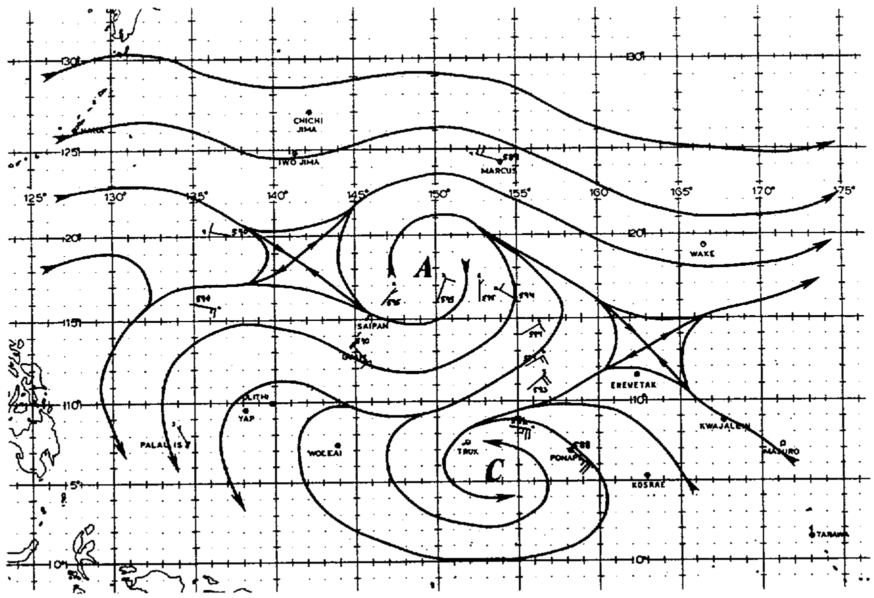


FIGURE 3-02-2. The 151200Z April 1981 500 mb streamline analysis. Wind data are a combination of RAOBS, AIREPS, and satellite derived winds (←—\ ). Wind speeds are in knots.

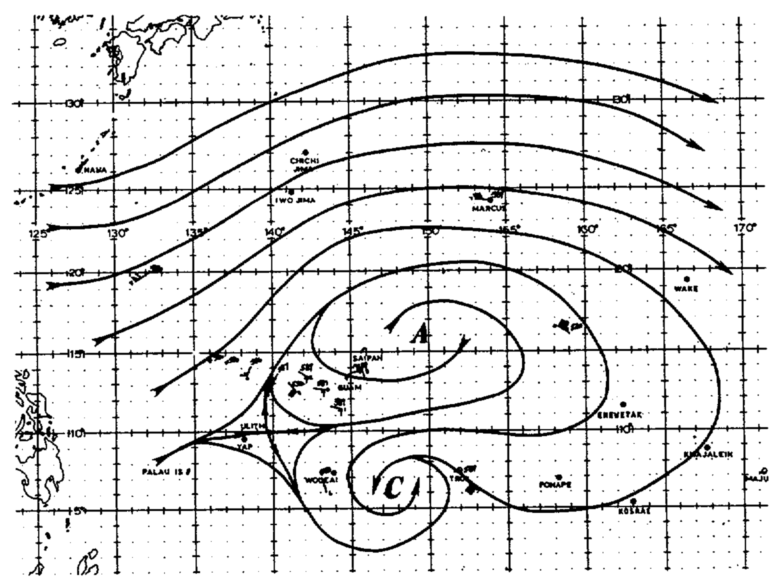


FIGURE 3-02-3. The 161200Z April 1981 500-mb streamline analysis. Wind data are a combination of RAOBS, AIREPS, and satellite derived winds (←—\ ). Wind speeds are in knots.

ture west of Guam still appeared to be the best forecast. By 171200Z, however, it became apparent that the anticyclone north of Guam had shifted farther to the east, allowing the break in the ridge to re-orient itself north of Guam (Fig. 3-02-4). At that time, the forecast track was altered to call for passage east of Guam, and, indeed, post-analysis shows that Gerald had actually begun to follow a more northward track about 12 hours earlier. The mid-level analysis at 181200Z, which combines both 400 and 500-mb aircraft data, shows Gerald's mid-level circulation being absorbed by the long wave trough (Fig. 3-02-5).

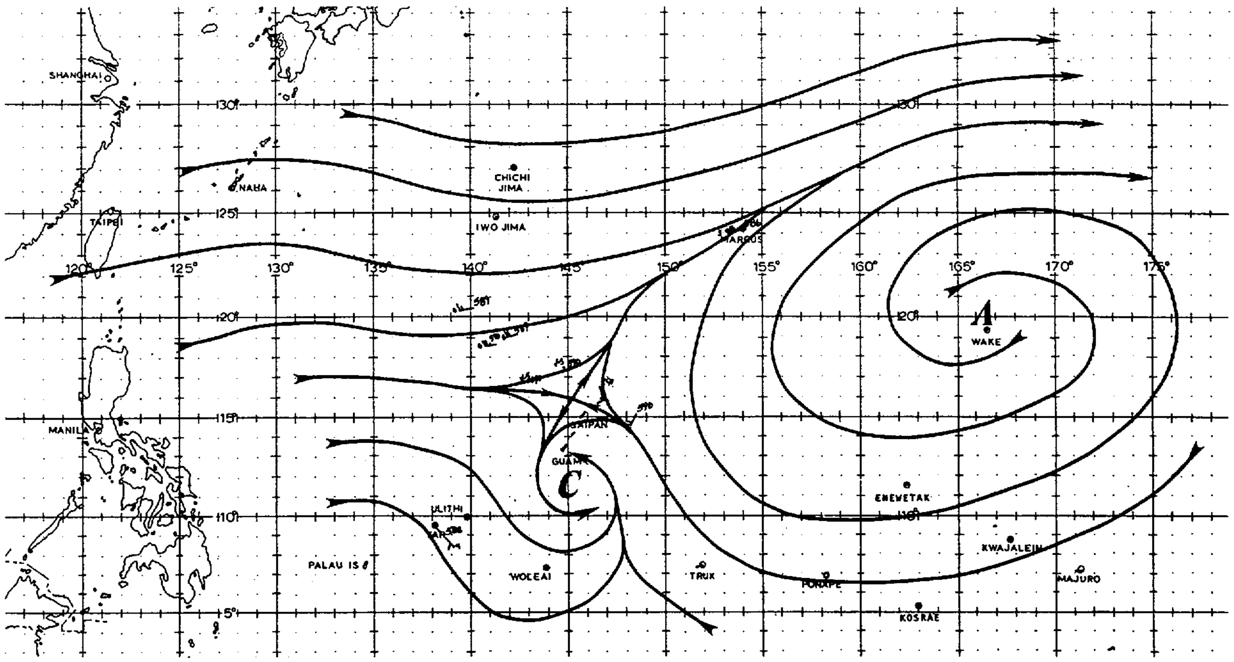


FIGURE 3-02-4. The 171200Z April 1981 500-mb streamline analysis. Wind data are a combination of RAOBS, AIREPS, and satellite derived winds (◄──). Wind speeds are in knots.

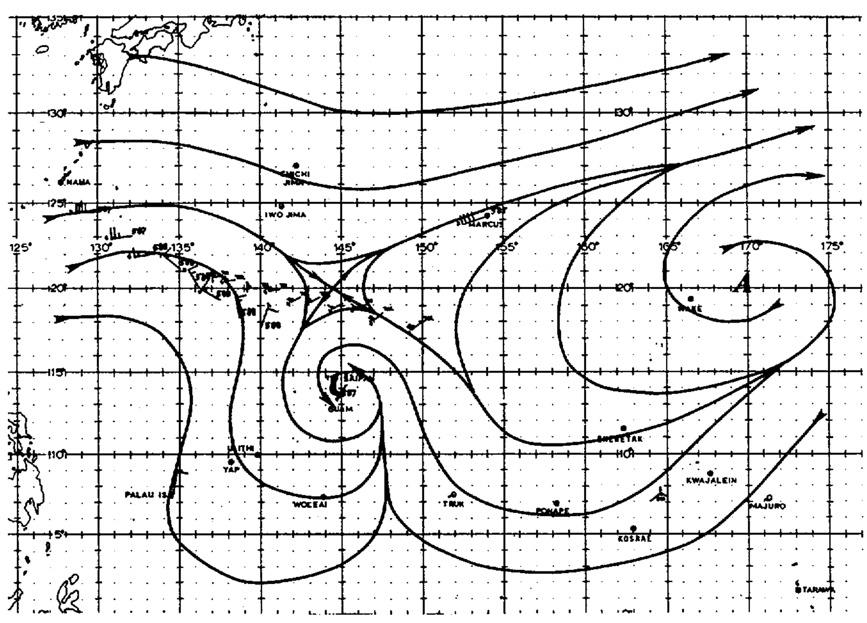
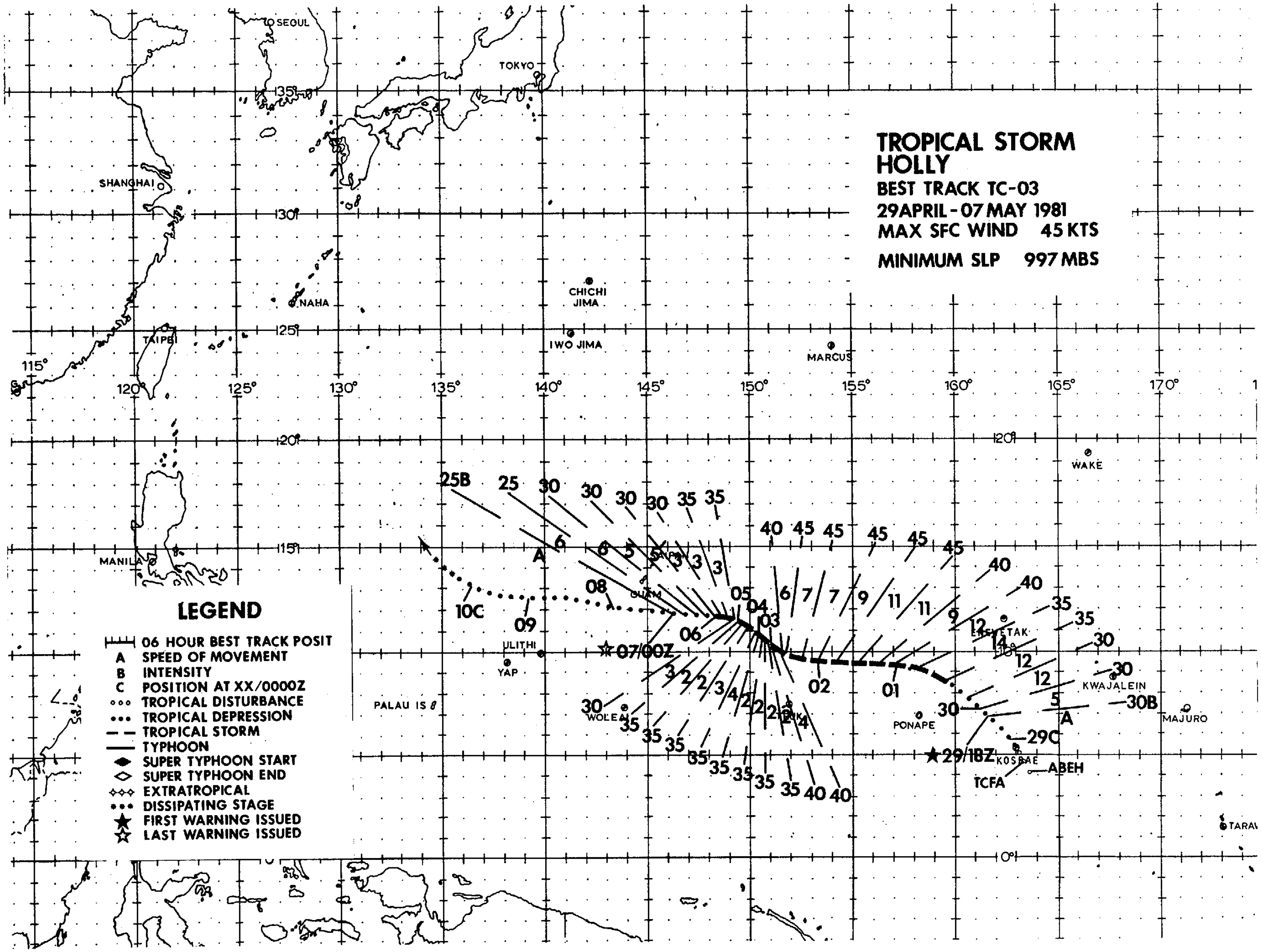


FIGURE 3-02-5. The 181200Z April 1981 mid-level streamline analysis based on 400- and 500-mb aircraft reconnaissance data.


TROPICAL STORM
HOLLY
BEST TRACK TC-03
29APRIL-07MAY 1981
MAX SFC WIND 45 KTS
MINIMUM SLP 997 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
SEOUL
TOKYO
SHANGHAI
NAHA
CHICHI JIMA
IWO JIMA
MARCUS
TAIPEI
MANILA
WAKE
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
PONAPE
KOSRAE
KWAJALEIN
MAJURO
TARAWA
ENIWETAK
TRUK
07/00Z
29/18Z
TCFA
ABEH
25B
30B
29C
10C
115°
120°
125°
130°
135°
140°
145°
150°
155°
160°
165°
170°
35
30
25
20
15
10

Development of Tropical Storm Holly followed a ten-day period of relative calm in the tropical northwest Pacific Ocean. Holly was interesting in several ways during her lifetime. Southern Hemisphere interaction, intensity fluctuations, weak mid-level steering flow, and strong upper-level shear will be discussed in relation to Holly's development and dissipation.

The source for the initial energy impulse in the development of TD-03 is an interesting point for speculation. A review of satellite imagery back to 21 April showed that varying amounts of convection existed almost continuously in the region of 5.0N from 160.0E to 165.0E from 211200Z to 260000Z. Satellite data suggest that this convection was related to a fairly active convective region just south of the equator (5.0-10.0S, 160.0E-175.0W). By 230000Z, satellite imagery showed that the southern hemisphere tropical system was interacting vigorously with a rather strong mid-latitude system. At the same time, the northern hemisphere convection increased. Although again weaker, some curvature in the convective pattern was noted by 250000Z, and a weak, broad low-level circulation developed by 251200Z near 4.0N 169.0E. This circulation was not analyzed consistently prior to Holly's formation. Sparsity of data and weakness of the circulation may have prevented detection of the circulation in synoptic data. Undisturbed easterlies existed in the area prior to development of the low-level circulation center. The surface/gradient level analysis showed cross-equatorial interaction, and with the evidence from satellite data, it appears that TD-03 was initiated through interaction with a southern hemisphere system.

The initial satellite alert by Det 1, 1WW on the disturbance which produced Holly was issued at 260000Z. Continued improvement of the convective signature led to issuance of a Tropical Cyclone Formation Alert 280255Z. At 290153Z, the first reconnaissance aircraft investigative mission was flown into TD-03. TD-03 was well defined at this time, and the circulation was closed easily at the surface and 1500-ft (457 m) level. The extrapolated central pressure was 1003 mb, while the maximum observed surface wind was 25 kt (13 m/sec). By 282106Z, the circulation was also evident on satellite imagery as an exposed low-level circulation (Fig. 3-03-1). A Dvorak satellite intensity analysis showed a weakening trend for the past 24 hours and forecast the trend to continue.

Early fluctuations in the satellite-derived intensity analysis produced the first interesting characteristic associated with TD-03. By 300000Z, a steady trend toward intensification was established. By 010300Z May 1981, both aircraft and satellite data suggested possible development of a banding-type eye. It certainly appeared that Holly was on the verge of becoming a major tropical cyclone; however, during the next 24 hours, Holly's satellite signature again weakened. A maximum intensity of 45 kt (23 m/sec) was reached at 011200Z and was maintained for 24 hours before the final weakening trend started (Fig. 3-03-2). From this point, Holly gradually weakened although there were continued fluctuations in the amount and intensity of convection.

Figure 3-03-1. Exposed low-level circulation of TD 03 approximately 5 hours prior to aircraft investigative mission, 28 April 1981, 2106Z. (NOAA 6 visual imagery)

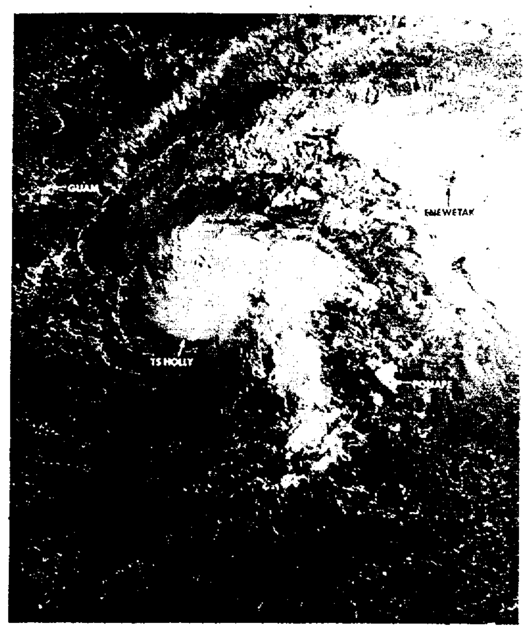


Figure 3-03-2. Tropical Storm Holly during the period of maximum intensity, 1 May 1981, 1238Z. (NOAA 6 visual imagery)

A second interesting characteristic associated with Holly was her extremely slow movement. From 300000Z through 020000Z, Holly averaged a forward speed of 11 kt (20 km/hr); from 020000Z through 030000Z, the average speed was 6 kt (11 km/hr); and from 030000Z through 060000Z, Holly's average speed was slightly less than 3 kt (6 km/hr). Due to sparseness of data, it is impossible to state with complete certainty why Holly slowed so dramatically. The surface/gradient level and 500 mb analysis, however, offer possible explanations. At the surface/gradient level, Holly's path was across the main stream of the northeast trade regime. The stream was significantly stronger on the north side of Holly, and this "crosswind" apparently helped in the retardation of forward speed as far as the lower tropospheric steering was concerned. When Holly finally began to accelerate, the trade winds were deflected more easterly and more toward a direction parallel to Holly (Fig. 3-03-3).

The second possible explanation for the sudden deceleration and extremely slow movement lies in the mid-troposphere. Wind analyses at 500 mb consistently showed weak steering surrounding the cyclone's environment. The weak flow was due in part to a cut-off low which was located near 30N and between 155E and 165E during the period of Holly's slow movement. The gradient between this cut-off low and the ridge placed major wind currents well northeast and northwest of Holly's 500 mb cyclone. This gradient slackened just north of Holly and winds that were not considered storm induced generally were 10 kt (5 m/s) or less. This was clearly evidenced by reconnaissance tracks flown

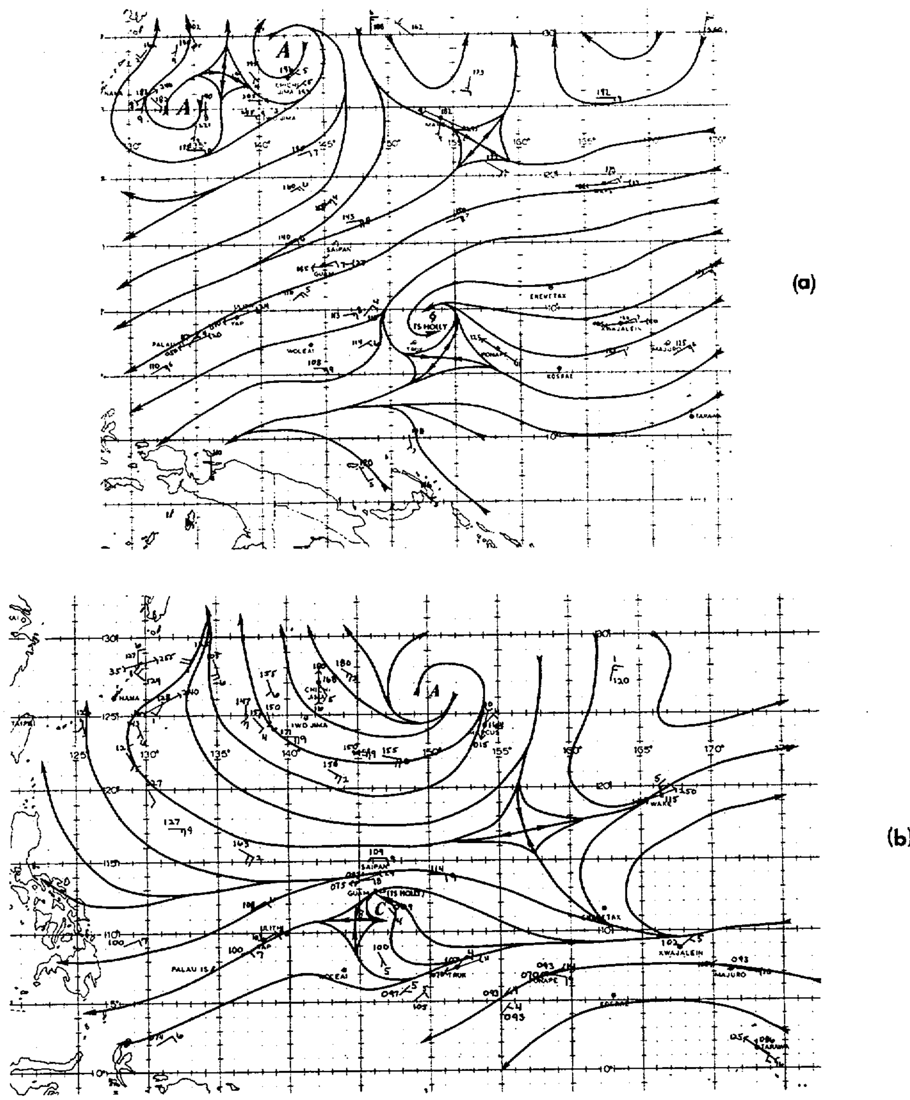


Figure 3-03-3. Surface (——\\)/gradient (←—⊣) level analyses: (a) at 020000Z which was typical during Holly's period of slow movement and (b) at 070000Z showing the pattern as Holly began to accelerate. Winds are in knots.

north of Holly. Furthermore, these same analyses showed Holly remained south of the ridge in the weak easterly current. A break in the ridge never occurred in suitable position to allow Holly any other possibility (Fig. 3-03-4).

The final interesting characteristic was Holly's failure to develop a significant outflow pattern. At 010000Z and again at 040900Z, Holly appeared to be developing a good outflow channel to the northeast. On each occasion, however, the outflow was not maintained and a southwest outflow channel never developed. The 200 mb wind pattern was fairly strong throughout Holly's lifetime with a large amplitude ridge anchored off the Asian coast. The position of this ridge forced additional pressure on the preexisting southwesterly subtropical jet which had been lying just west of Holly. Convergence of the two upper level wind streams induced a 40 to 60 kt (21-31 m/s) wind maximum just northwest of Holly's upper level center (Fig. 3-03-5). This persistent feature eroded Holly's convective organization and 062125Z satellite imagery showed a totally exposed low level circulation with the formerly associated convective 50 nm (93 km) east of the center. Once this shearing took place, Holly eventually spun down and dissipated over open tropical water.

Tropical Storm Holly never reached typhoon strength as originally expected. The intensity fluctuations, weak mid-level steering, and shearing flow at both low- and upper-tropospheric levels all contributed to Holly's eventual demise.

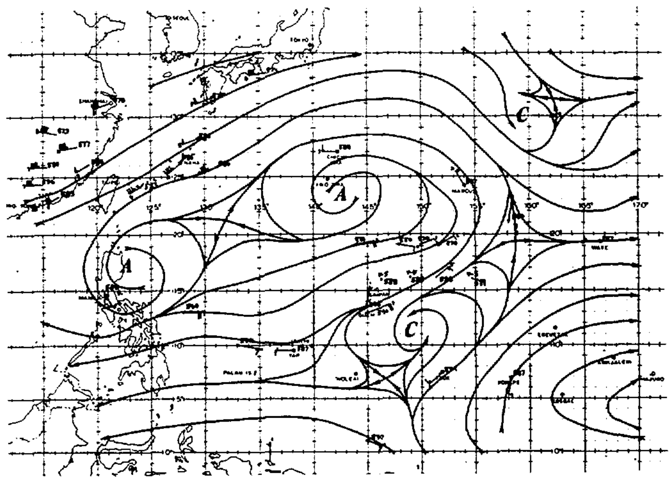


Figure 3-03-4. 500 mb streamline analysis at 051200Z. This analysis was typical of the pattern existing during Holly's lifetime. Wind data are a combination of RAOBS, RECON, and satellite-derived winds (←). Wind speeds are in knots.

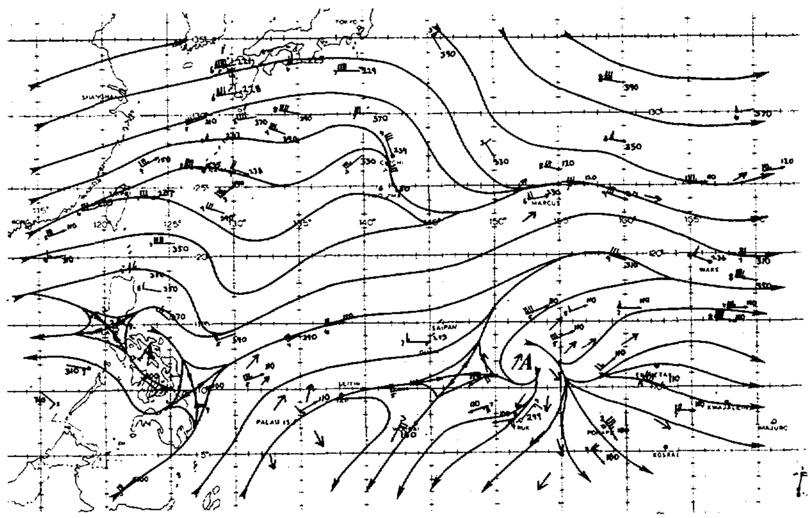
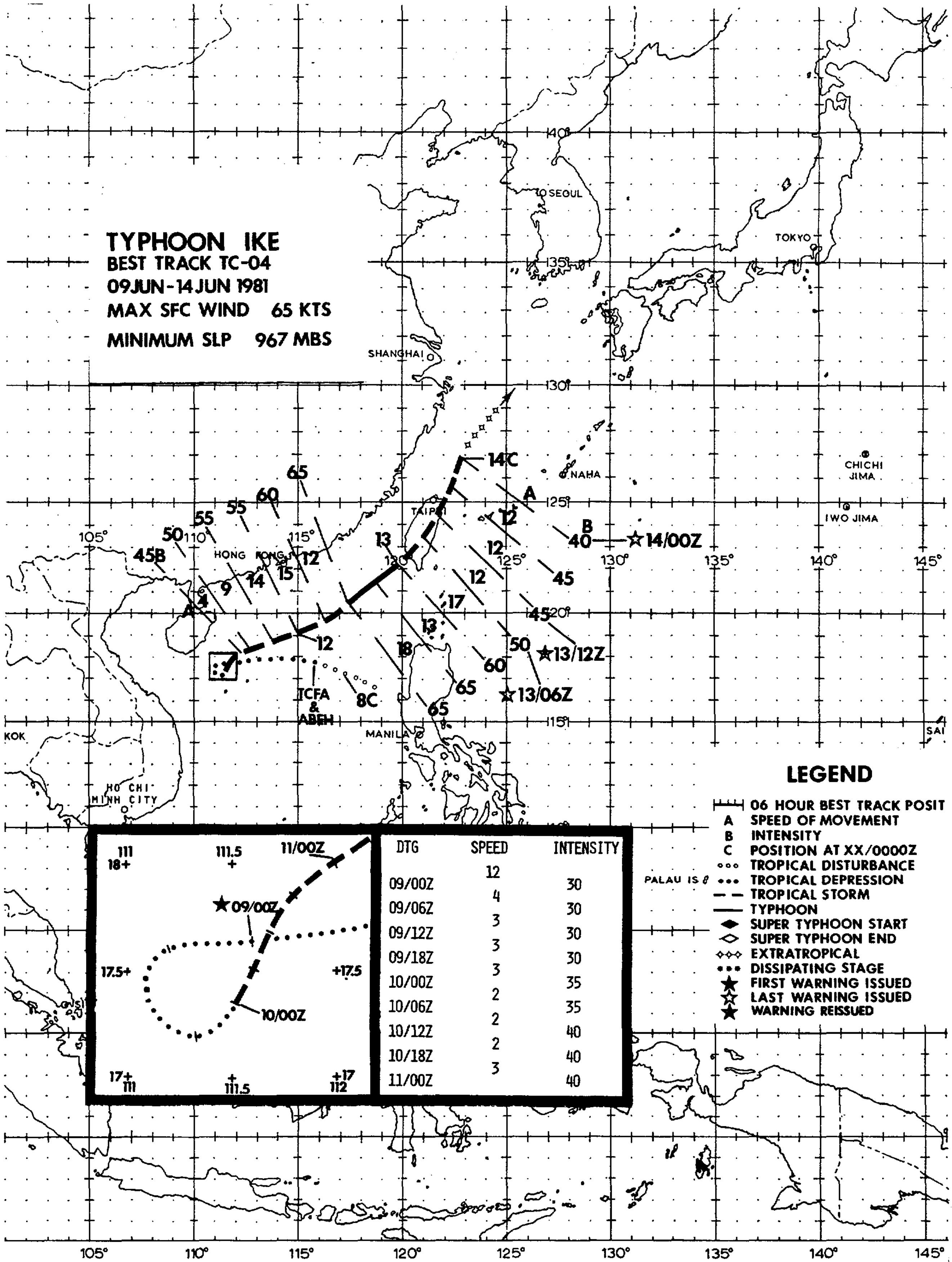


Figure 3-03-5. 200 mb streamline analysis at 031200Z. Wind data are a combination of RAOBS, AIREPS, and satellite-derived winds (←) and blow-off wind directions (←). Wind speeds are in knots.



DTG	SPEED	INTENSITY
09/00Z	12	30
09/06Z	4	30
09/12Z	3	30
09/18Z	3	30
10/00Z	3	35
10/06Z	2	35
10/12Z	2	40
10/18Z	2	40
11/00Z	3	40

Typhoon Ike was one of several recent examples of tropical cyclone development over the South China Sea during the end of the monsoonal transition season. Several characteristic features have often been observed by JTWC forecastors. Both in the tropical cyclogenesis and during the lifetime of the system as a tropical storm and typhoon, These include:

1) The system becomes initially evident on satellite imagery as a mid-tropospheric monsoonal depression with fluctuating associated convection.

2) The system is often initially slow to develop a closed surface circulation, despite persistent associated convection.

3) The system is also slow to intensify, even after evidence of surface development.

4) The system frequently maintains a broad asymmetrical wind distribution throughout its life cycle.

5) The system is usually short-lived, with repeated interactions with nearby land masses.

Ike was typical of this pattern and displayed all the above characteristics during his development. The first evidence that Ike may develop occurred on June 8th, as the 080000Z surface analysis indicated relatively lower surface pressures just west of the Philippine Islands. Based on this data, and satellite imagery which indicated continued convective support, a Tropical Cyclone Formation Alert (TCFA) was issued at 080600Z.

Ike had a difficult time persisting as a tropical cyclone as steady upper-level shear displaced Ike's 700 mb center as much as 60 nm (111 km) southwest of the surface circulation. Finally, on 9 June, Ike moved into an area of decreased shear aloft, which allowed vertical alignment to intensify the system. The first warning was issued at 090000Z and Ike reached tropical storm intensity at 100000Z (Figure 3-04-1). In the meantime, a mid-latitude, mid-tropospheric trough over Asia continued propagating eastward, and Ike accelerated to the northeast, steered by the increasingly strong southwesterly flow. Intensification continued during the acceleration process.

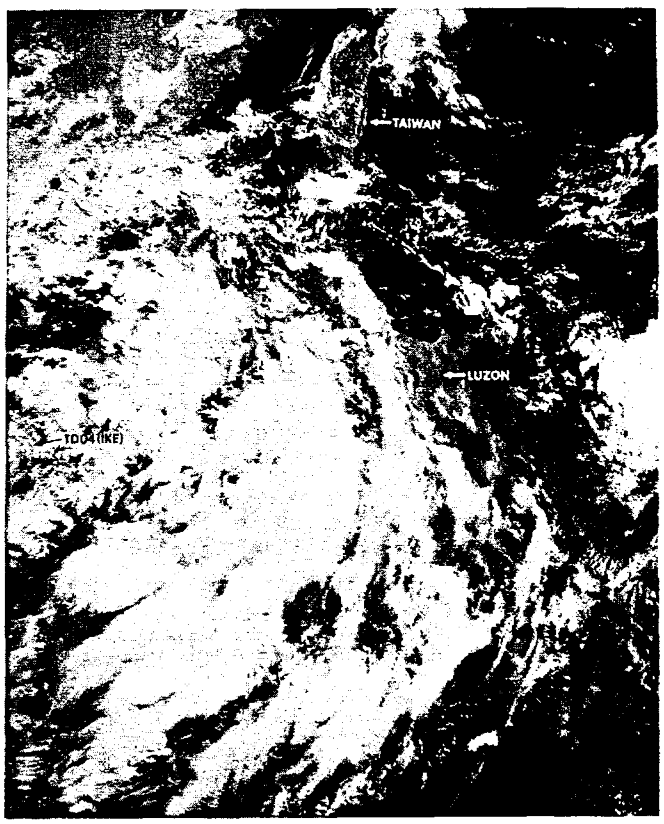


Figure 3-04-1. Tropical Depression 04 as it began to develop and consolidate its associated convection while over the South China Sea, 9 June 1981, 2336Z (NOAA 6 visual imagery).

Only one aircraft reconnaissance mission was able to penetrate Ike due to geographical and political constraints. This aircraft fixed Ike near the storm's peak intensity just prior to landfall over Taiwan. The crew reported that Ike's minimum sea-level pressure had decreased to 967 mb, 700 mb winds of over 60 kts (111 km/hr) were measured, and aircraft radar indicated partial eyewall formation. Based on the above data, it was concluded in post-analysis that Ike reached minimal typhoon intensity near this time. Less than 12 hours later, Ike moved ashore over southwestern Taiwan.

Ike weakened significantly while traversing Taiwan but emerged over open water north of Taipei around 131500Z with a small, persistent knot of central convection. This area of convection dissipated as Ike became an extratropical low at 140000Z (Figure 3-04-2).

Subsequent press releases reported minor damage over Taiwan due to heavy rains and flooding which accompanied Ike. Eight storm-related fatalities were reported, four from Taiwan and four from the Philippine Islands.

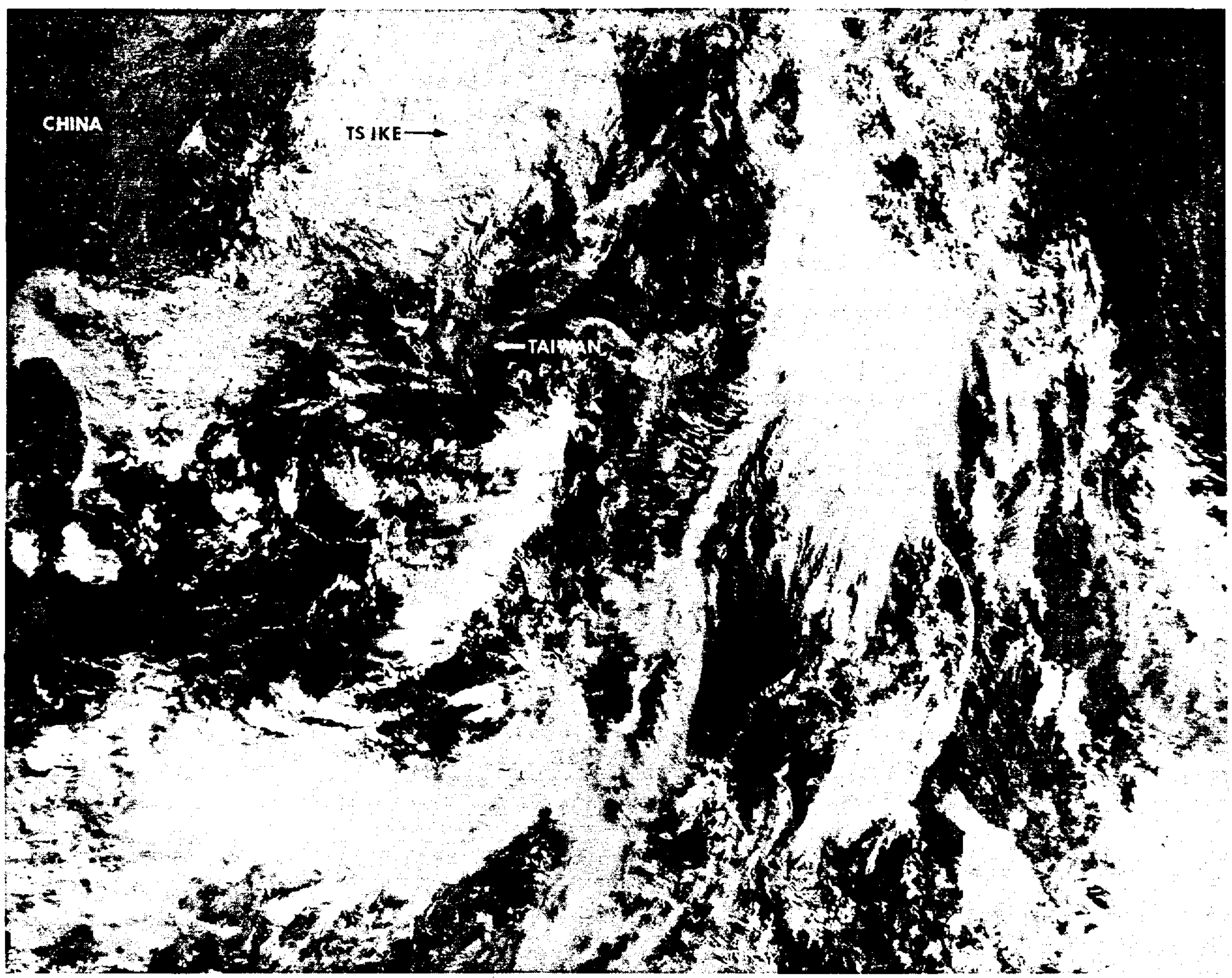


Figure 3-04-2. Tropical Storm Ike as a partially exposed low-level circulation as he began extratropical transition, 13 June 2245Z (NOAA 6 visual imagery).

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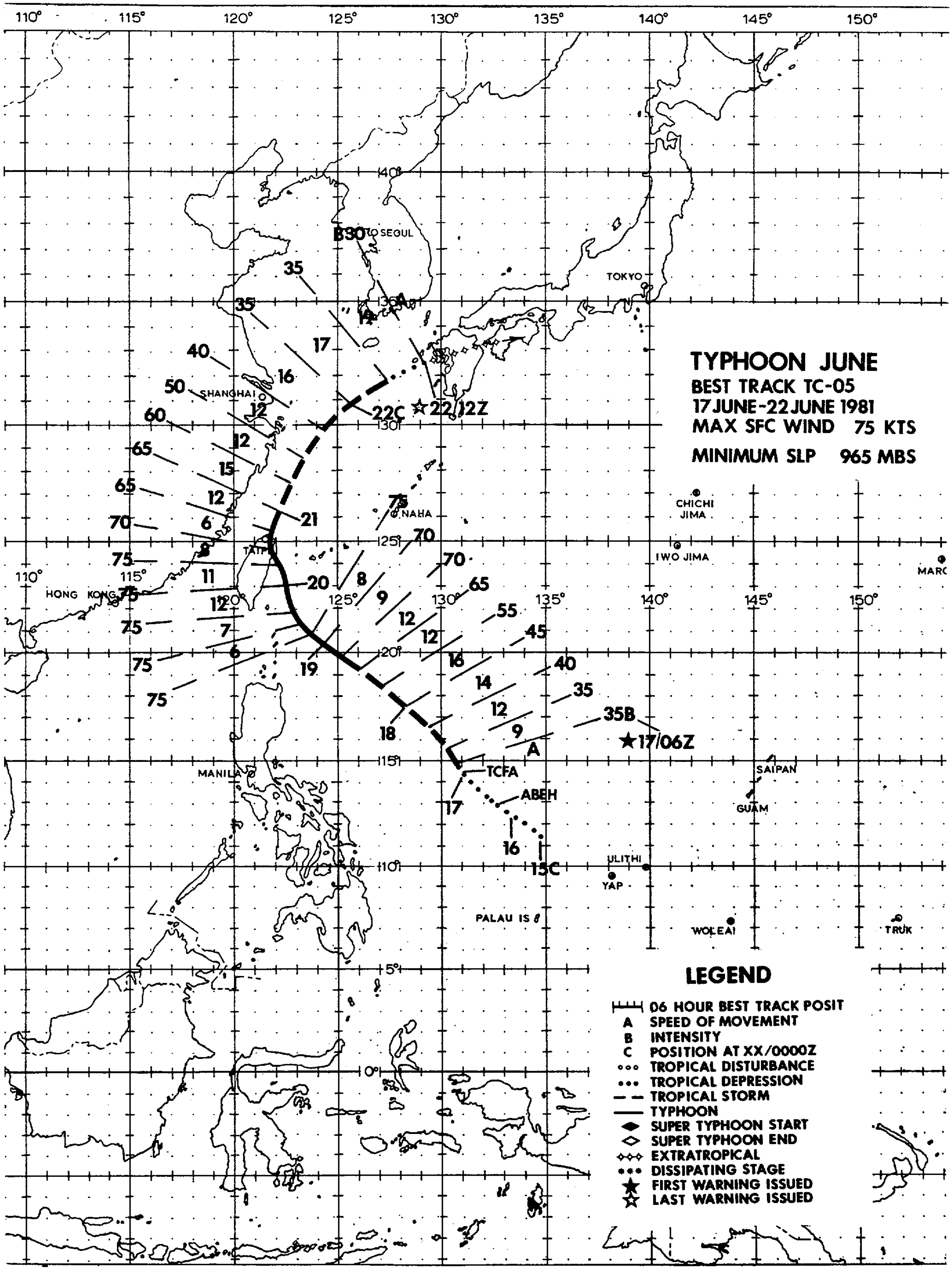


TYPHOON JUNE
BEST TRACK TC-05
17 JUNE-22 JUNE 1981
MAX SFC WIND 75 KTS
MINIMUM SLP 965 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
SEOUL
TOKYO
SHANGHAI
TAIPEI
HONG KONG
MANILA
NAHA
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
TCFA
ABEH
★17/06Z
☆22/12Z

The process for genesis of tropical cyclones through interaction with a tropical upper tropospheric trough (TUTT), (Sadler, 1976), was evident during the early development stages of Typhoon June. A TUTT was established over the Philippine Sea early in June leading to the generation of a tropical disturbance over the Palau Islands.

On the 13th of June a cell within the TUTT was observed on satellite imagery northeast of the disturbance resulting in improved organization of the disturbance as the TUTT cell tracked westward. Surface synoptic reports indicated no pre-existing circulation on the surface associated with this disturbance. The general flow pattern was converging in the area of the disturbance, then continuing northwestward into Typhoon Ike.

By the 15th the TUTT cell was northwest of the disturbed area and the potential for development of a tropical cyclone was greatly improved. The area of disturbance was optimally positioned with respect to the TUTT cell, i.e. under an upper level divergent area which served initially as an outflow mechanism. Nevertheless, progress in the development of the cyclone was very slow. Aircraft reconnaissance on the 15th indicated that a weak circulation was located 200 nm north of the Palau Islands.

Late on the 16th satellite data indicated an outflow center was beginning to form which prompted JTWC to issue a formation alert at 170100Z. The disturbance then developed its outflow aloft and banding features were evident on satellite imagery of 170600Z. At that same time aircraft reconnaissance also found that the disturbance had tropical storm strength winds. Subsequently, the first warning on Tropical Storm June was issued.

A 500 mb anticyclone was positioned over the Ryuku Islands with the ridge axis extending over much of China at the time the first warning was issued. The anti-cyclone remained virtually stationary as June tracked northwestward toward Taiwan. During the first 24 hours after the initial warning June did accelerate, but slowed again to her original speed the following 24 hours. The area in which the acceleration occurred was practically void of wind data at the 500 mb level and therefore no suitable explanation can be made for this occurrence.

It is interesting to note that the TUTT cell which helped form June moved ahead of her along a parallel track until she hit Taiwan. June maintained a position southeast of the TUTT cell throughout this period. Further, June intensified to a maximum of 75 kt (39 m/s) while tracking behind the TUTT cell. Satellite imagery at 191029Z (Fig. 3-05-1) showed Typhoon June at her maximum intensity.

FIGURE 3-05-1. *Satellite imagery at 191029Z of Typhoon June after attaining a maximum intensity of 75 kt (39 m/sec). (NOAA 6 infrared imagery)*

June hit Taiwan with winds of 75 kt (39 m/sec). Radar observations at Hua-Lien (WMO 47918) provided essential information to JTWC when June began to deviate from a northward direction toward a point 40 nm (74 km) southeast of Taipei. Figure 3-05-2 is a picture of the radar presentation taken at Hua-Lien at 0500Z on the 20th (photograph courtesy of the Central Weather Bureau, Taipei, Taiwan), when June had an intensity of 75 kt (39 m/sec) 9 hours before landfall.

June was forecast to recurve in all but two warnings. The initial reason for recurvature was based on a 500 mb trough that was expected to move over Eastern China, with the anticyclone over the Ryuku Islands moving eastward. As June neared Taiwan it was apparent that these forecast upper air movements had not taken place. June's forecast track was then changed, for two warnings, to reflect the strength of the anticyclone north of her and indicating a more westward track with landfall over China.

Another reason for the change in the forecast track was the lack of a large cirrus plume extending to the northeastward from June. Typically, several hours, or days, in advance of the event, a cirrus plume is seen to extend northwestward from a tropical cyclone that will soon recurve. The plume generally extends far downstream in the direction of the upper level winds, which greatly influence the direction and speed of the tropical cyclone after recurvature. June did not exhibit a cirrus plume either before or after recurvature.

Later upper air data indicated that a new anticyclone formed over China at 500 mb with a resultant weakening in the ridge between the anticyclones over China and the Ryukyu Islands. Recurvature was again forecast because of this change at 500 mb.

June began to weaken gradually after recurvature. The 500 mb anticyclone that had formed over China and allowed June to recurve, moved southward as a trough approached China's coast. As June neared Japan, she began to interact with a weak frontal system extending southwestward and entrain cold air supplied by the trough. At 1200Z on the 22nd the final warning was issued on June as she became extratropical before tracking over Kyushu.

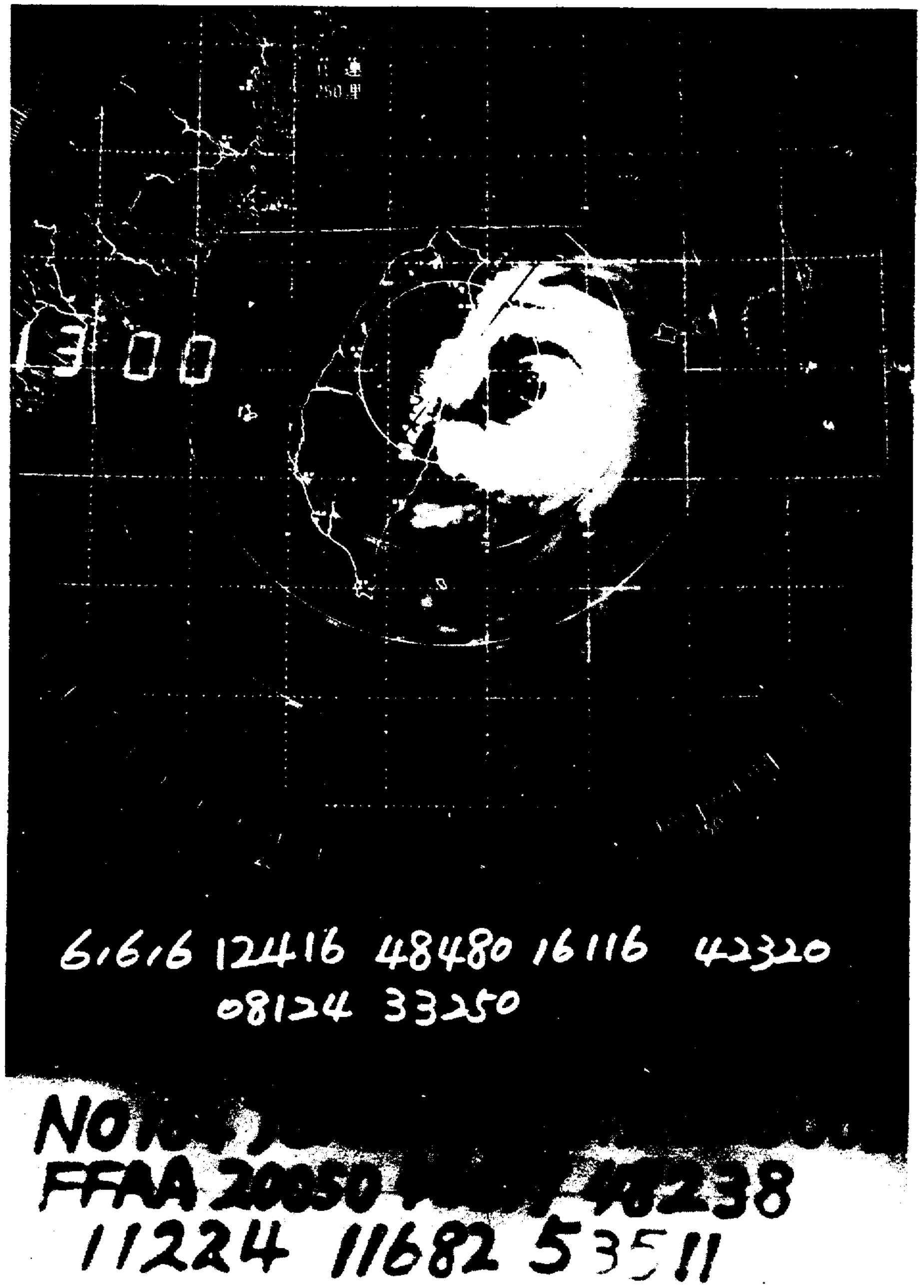
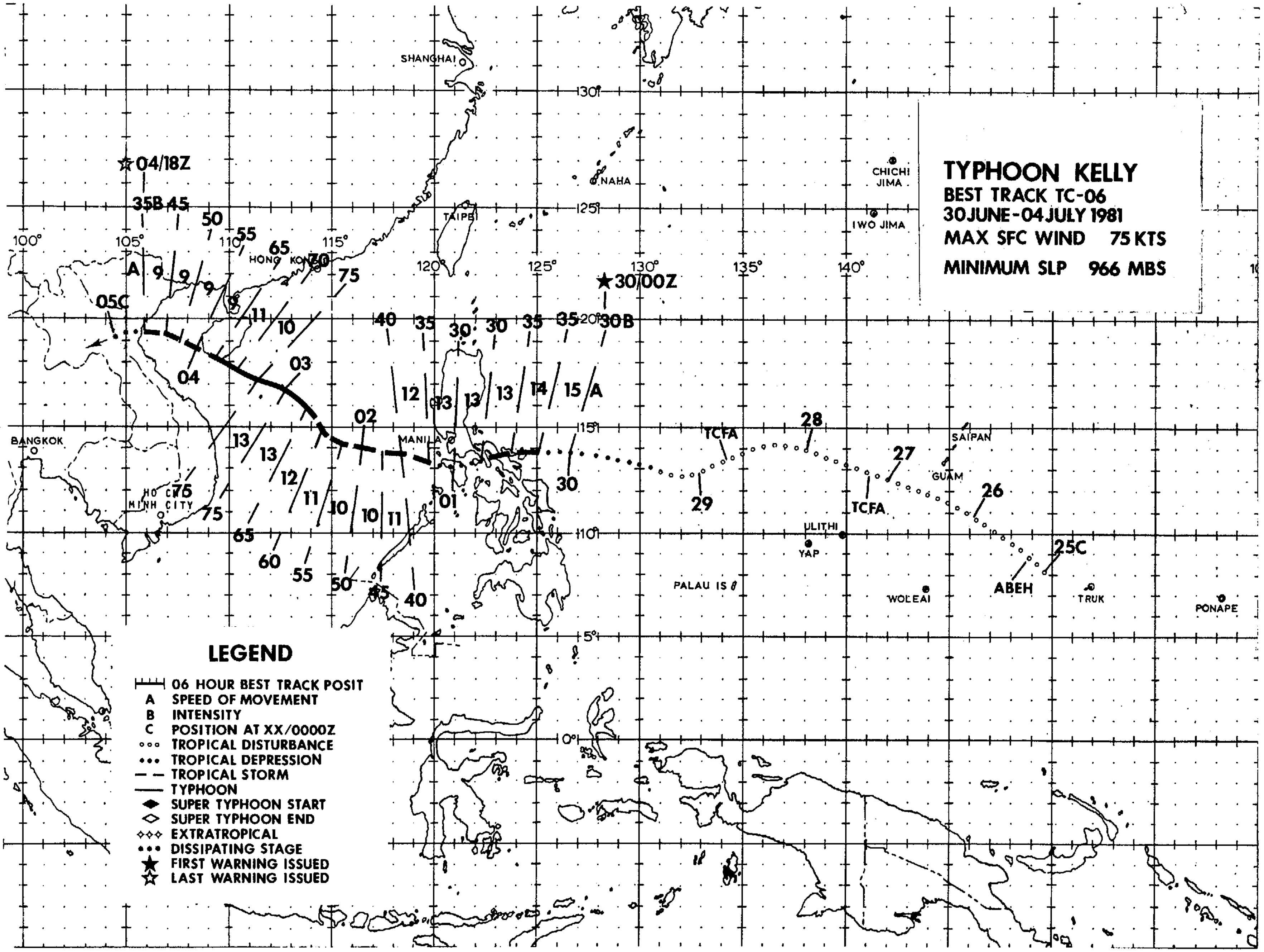


FIGURE 3-05-2. *Typhoon June as seen by radar at Hua-Lien, 20 June 1981, 0500Z. (Photograph courtesy of the Central Weather Bureau, Taipei, Taiwan.)*



TYPHOON KELLY
BEST TRACK TC-06
30 JUNE-04 JULY 1981
MAX SFC WIND 75 KTS
MINIMUM SLP 966 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
04/18Z
30/00Z
TCFA
ABEH
SHANGHAI
NAHA
TAIPEI
HONG KONG
MANILA
BANGKOK
HO CHI MINH CITY
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE

The disturbance which became Typhoon Kelly was first detected by satellite imagery on 25 June northwest of Truk Atoll (WMO 91334). During the four-day period which followed, three tropical cyclone formation alerts were issued. This period was marked by often impressive organization on satellite imagery with little or no evidence of a surface circulation center. However, with synoptic data at 291200Z, it became increasingly evident that a surface center had established itself and at 300000Z, the first warning was issued on Tropical Depression 06.

The successful launch of NOAA 7 in June 1981 afforded JTWC the opportunity to receive local afternoon surveillance from a high resolution polar-orbiting satellite platform. At 250447Z, while NOAA 7 was in its 17th orbit, a disturbance was located just northwest of Truk. During the next two days, satellite imagery showed a continued developing trend. The 270424Z visual imagery from NOAA 7, yielded a Dvorak intensity classification of T2.5 (2.5 is equivalent to 35 kt or 18 m/sec in the classification system). Based on the later data, a Tropical Cyclone Formation Alert was issued at 270800Z for an area north of Ulithi Atoll (WMO 91203). However, during the 16 hours which followed, satellite imagery showed a rapid weakening of the disturbance, and at 280000Z the formation alert was cancelled.

Figure 3-06-1 shows a composite surface streamline analysis of 0000Z data from 25 to 28 June. There was very little evidence of a discernible low-level center near the disturbance which had been observed on satellite imagery during this period. However, the composite analysis does suggest a weak, but pre-existing, low-level center located well west of Ulithi.

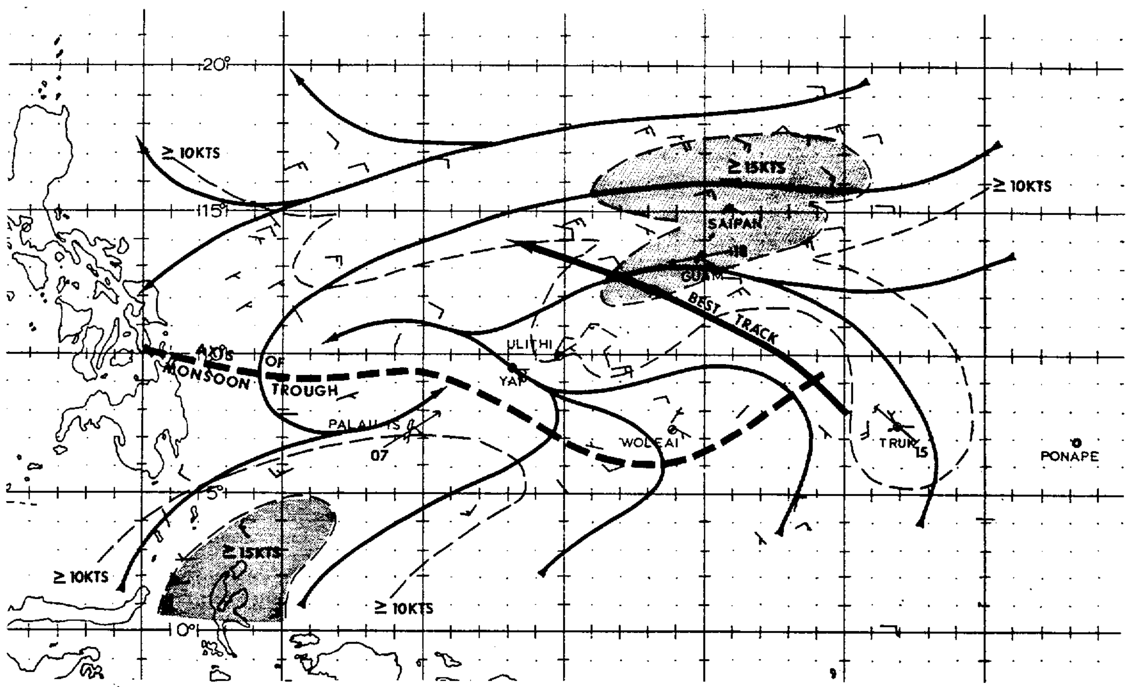


Figure 3-06-1. A composite streamline analysis from surface reports received for 0000Z from 25 to 28 June. During this period, the disturbance which became Kelly moved westward through the Philippine Sea. A lack of organized low-level inflow into the disturbance delayed its development until reaching the area west of 135 east longitude, where a possible pre-existing low-level circulation pattern induced Kelly's subsequent development.

At 281200Z, satellite imagery once again showed an area of increased convection, this time centered near 14N 135E. The 281200Z synoptic reports and subsequent satellite imagery showed improved organization, thus at 282000Z, a Tropical Cyclone Formation Alert was reissued. Figure 3-06-2 is a NOAA 6 image of the disturbance near the time the formation alert was issued. During the following 28 hours, further development was evident and the alert was repositioned. At 292241Z, a Dvorak intensity classification of T2.5 was provided by the Det 1, 1WW Nimitz Hill, Guam, and the first warning on TD-06 followed at 300000Z.

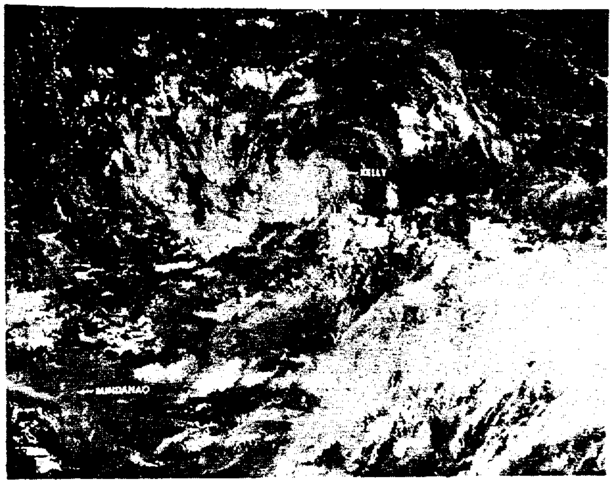


Figure 3-06-2. A weak cloud system center was seen redeveloping on this satellite imagery for 282304Z June. (NOAA 6 visual imagery)

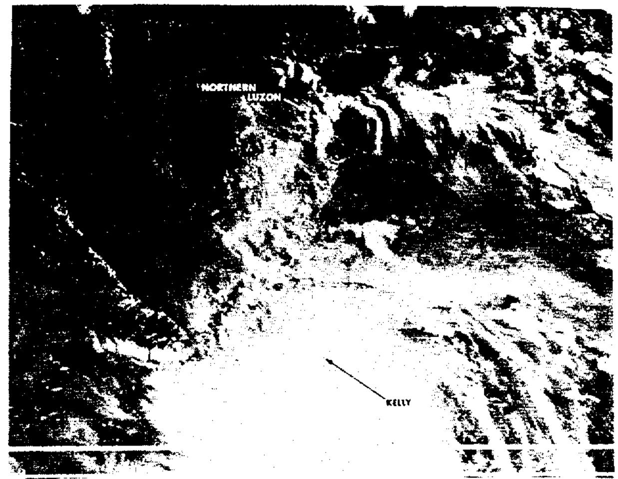


Figure 3-06-3. A weakened Kelly (TD-06) moving through the central Philippines (302359Z June). Although Kelly had lost some of his earlier intensity, the release of energy in heavy precipitation caused extensive flooding and human suffering which cannot be correlated to observed surface winds and pressures. (NOAA 6 visual imagery)

Synoptic observations from reporting stations along the southeastern coast of Luzon and Catanduanes Island (WMO 98447) indicated that TD-06 made landfall at, or near, tropical storm strength, at 301200Z. Thus, at that time TD-06 was upgraded to Tropical Storm Kelly. As Kelly tracked over the central Philippines, the low-level circulation pattern became distrupted and the observed wind speeds lessened, so that by 310000Z, Kelly was downgraded to TD-06. TD-06 tracked directly over Mindoro Island and despite having lost some of its earlier intensity, the combined effects of heavy rains, flooding and mudslides left thousands homeless and nearly 200 dead, Figure 3-06-3 shows TD-06 (Kelly) over Mindoro Island.

Within hours after TD-06 moved into the South China Sea, it regained its low-level circulation pattern and resumed its interrupted intensification trend. At 011800Z, TD-06 was upgraded to Tropical Storm Kelly. (In post-analysis, Kelly first attained tropical storm strength at 300600Z, was downgraded at 301800Z and was upgraded at 010600Z. This is fairly typical of post-storm analysis since the supporting synoptic data are received at JTWC after the warning has been issued for the synoptic hour; thus, the upgrading and downgrading usually follow on the next warning).

From the first warning on TD-06, an eventual track towards the north was anticipated once the system entered the South China Sea. The 500 mb pattern over Asia was fairly weak and the numerical model forecast series indicated a rather deep trough moving into the region. As Kelly approached the South China Sea, the 010000Z 500 mb hand-analysis (Fig. 3-06-4) showed Kelly in a favorable location for movement to the north. What followed in the first 24 hours, however, was a virtually westward track. Figure 3-06-5 shows the 500 mb pattern just 12 hours later (011200Z). In reconstructing the situation it is evident that the northward current moving around Kelly's eastern periphery actually aided in building the ridge to the north, such that the ridge line kept moving west with Kelly. Eventually this process abated and near 021200Z, Kelly began moving towards the

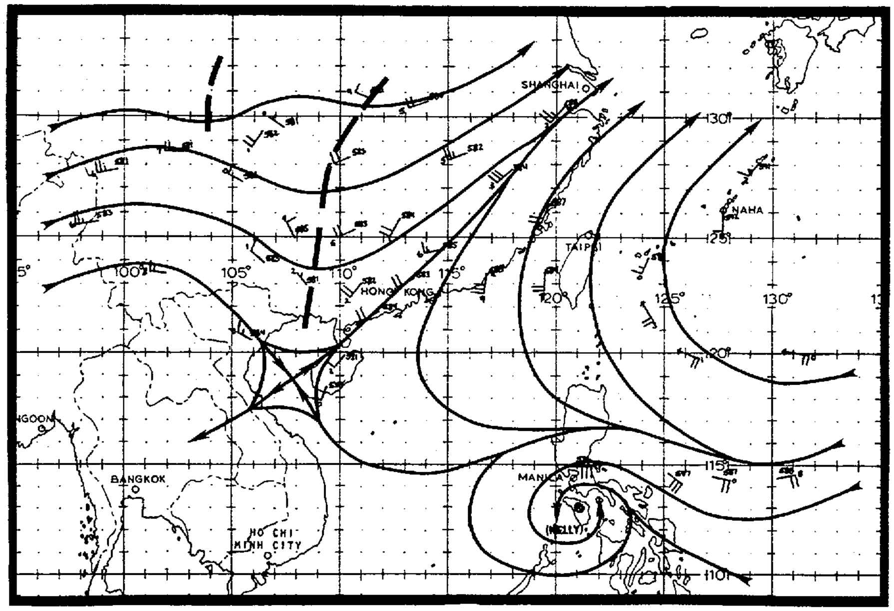


Figure 3-06-4. At 010000Z, a short wave trough is evident extending southward into the Gulf of Tonkin and a southerly flow is well established north of Kelly westward to the trough. Analyzed wind data are a combination of rawinsonde and aircraft reports at the 500 mb level.

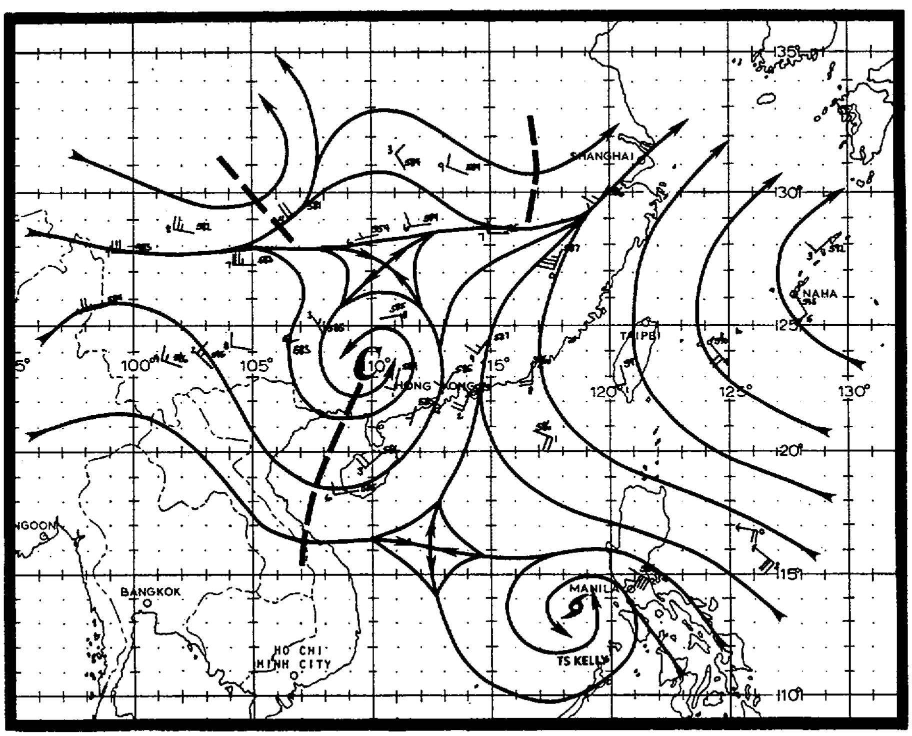


Figure 3-06-5. By 011200Z, the 500 mb analysis shows a fracturing of the short wave northwest of Kelly. Height rises of 20 to 30 meters are common throughout the region. This 12 hour change is striking, however subsequent forecasts continued to forecast eventual northward movement (see Figure 3-06-6).

northwest. Figure 3-06-6 depicts the official JTWC forecasts for Kelly. Note, the persistent trend in virtually every warning issued of Kelly having an increasing northward movement.

At 020000Z (in post-analysis, 021800Z), while moving to the northwest, Kelly was upgraded to typhoon strength. The 030300Z surface observation from the Paracel Islands (WMO 59981) indicated a windshift to southeasterly winds of 74 kt (38 m/sec) and a sea level pressure of 970.8 mb. It was during this period that Kelly is assumed to have reached his maximum intensity of 75 kt (39 m/sec). Subsequent satellite imagery indicated weakening convection with cirrus occasionally masking the eye. By 031800Z, Kelly had reached the southeastern portion of Hai-nan Island and the eye was no longer evident on satellite imagery. After skirting along its southern coastline, Kelly moved away from Hai-nan and lost much of his strength, resulting in downgrading to tropical storm strength at 040000Z. From Hai-nan to the coast of Vietnam, surface reports were sparse but there is little doubt that Kelly no longer had the low-level winds which were evidenced the preceding day. Interestingly, at 040629Z (Fig. 3-06-7), Kelly briefly displayed a large ragged eye which was observed to be opening to the west at 040900Z. There remains a possibility that Kelly may have regained some strength in the Gulf of Tonkin. However, if Kelly did, it must have been short-lived because hourly reports from Vietnam never indicated any significant or well-organized winds prior to, or after, landfall, which occurred about 100 nm (185 km) south of Hanoi at 041800Z. The last satellite fix received for the remnants of Kelly was at 050000Z, positioned along the Vietnam-Laos border.

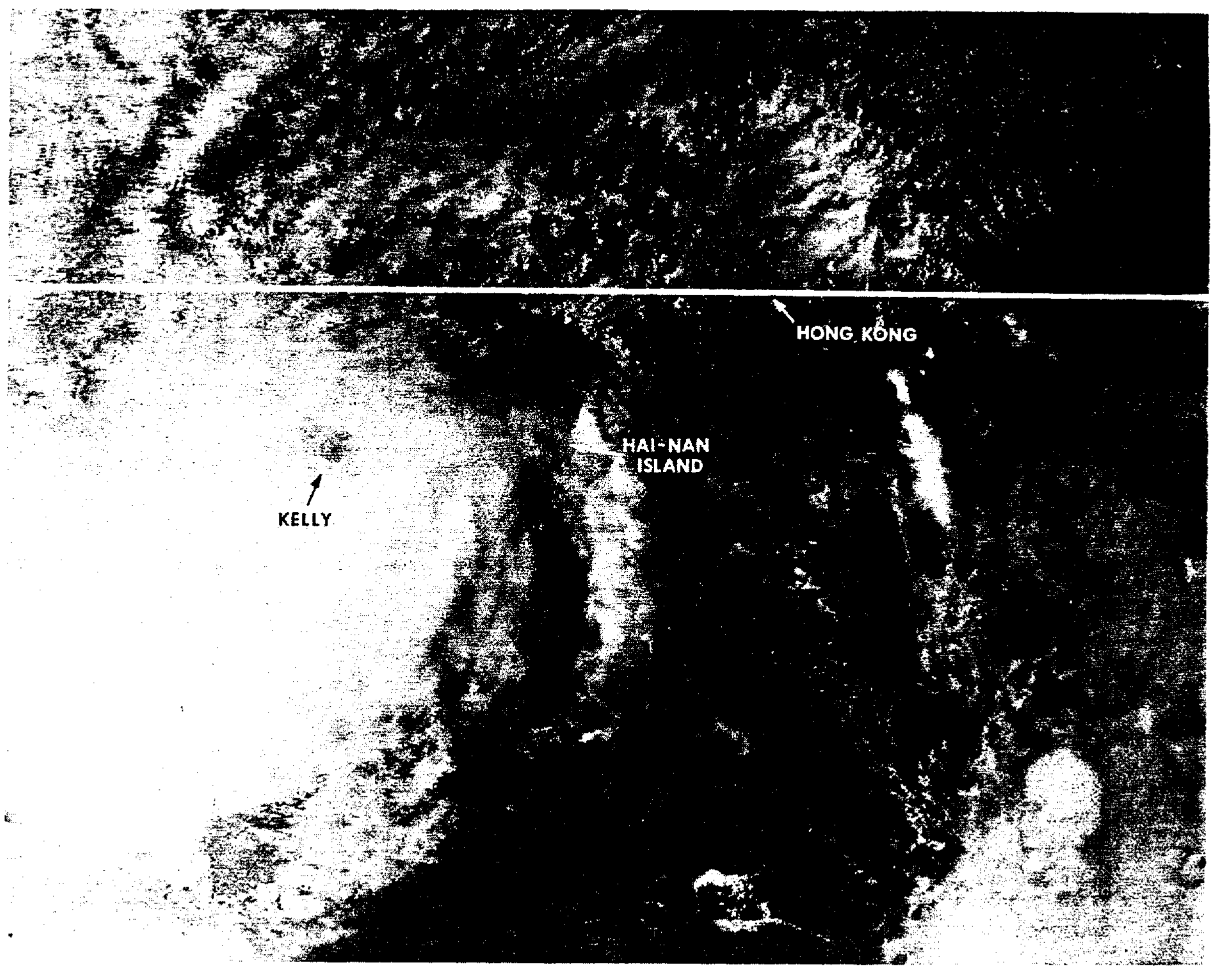


Figure 3-06-7. A ragged eye is apparent on 040629Z July satellite imagery as Kelly moves westward in the Gulf of Tonkin. This eye feature was short-lived and observed winds did not increase during this phase. (NOAA 7 visual imagery)

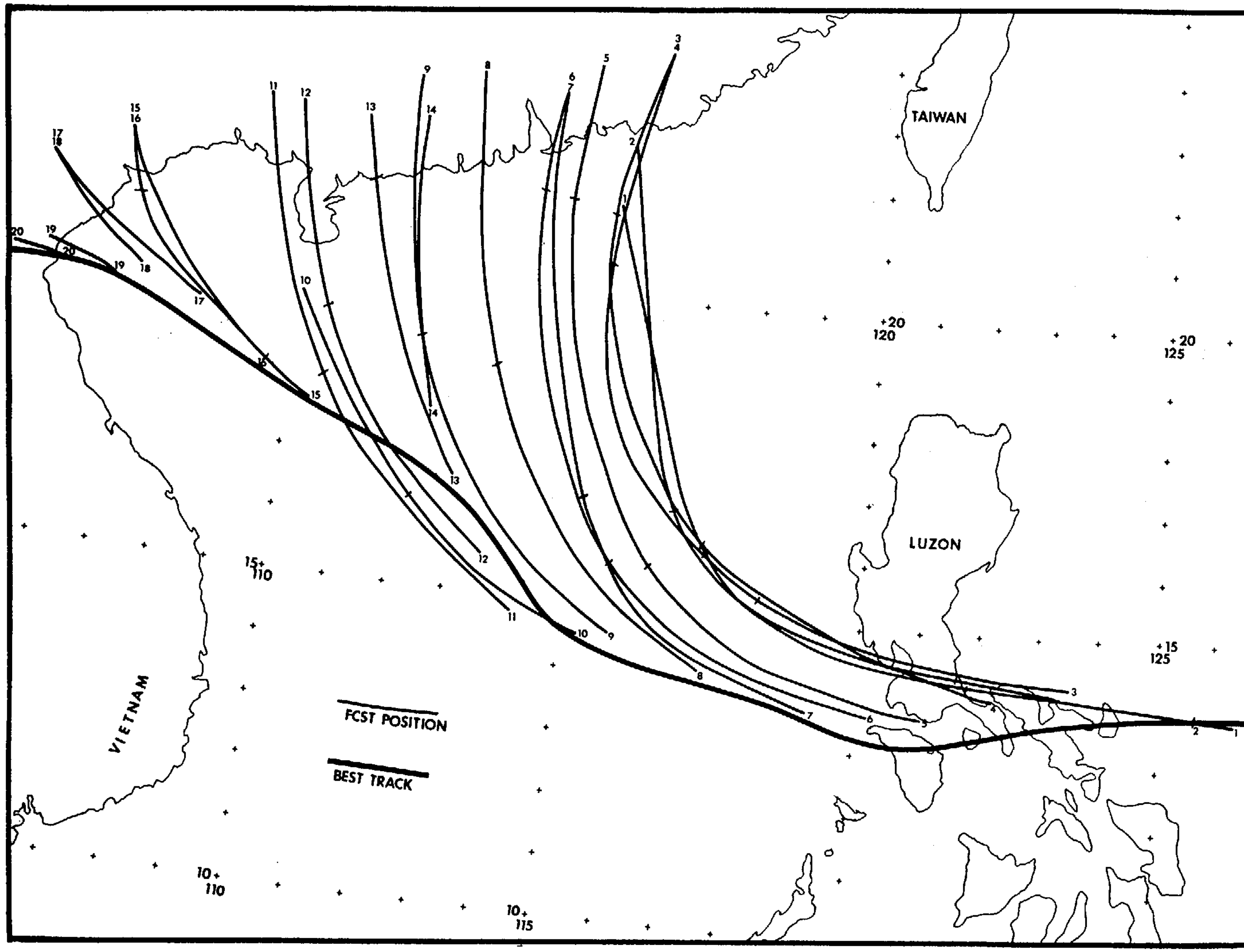
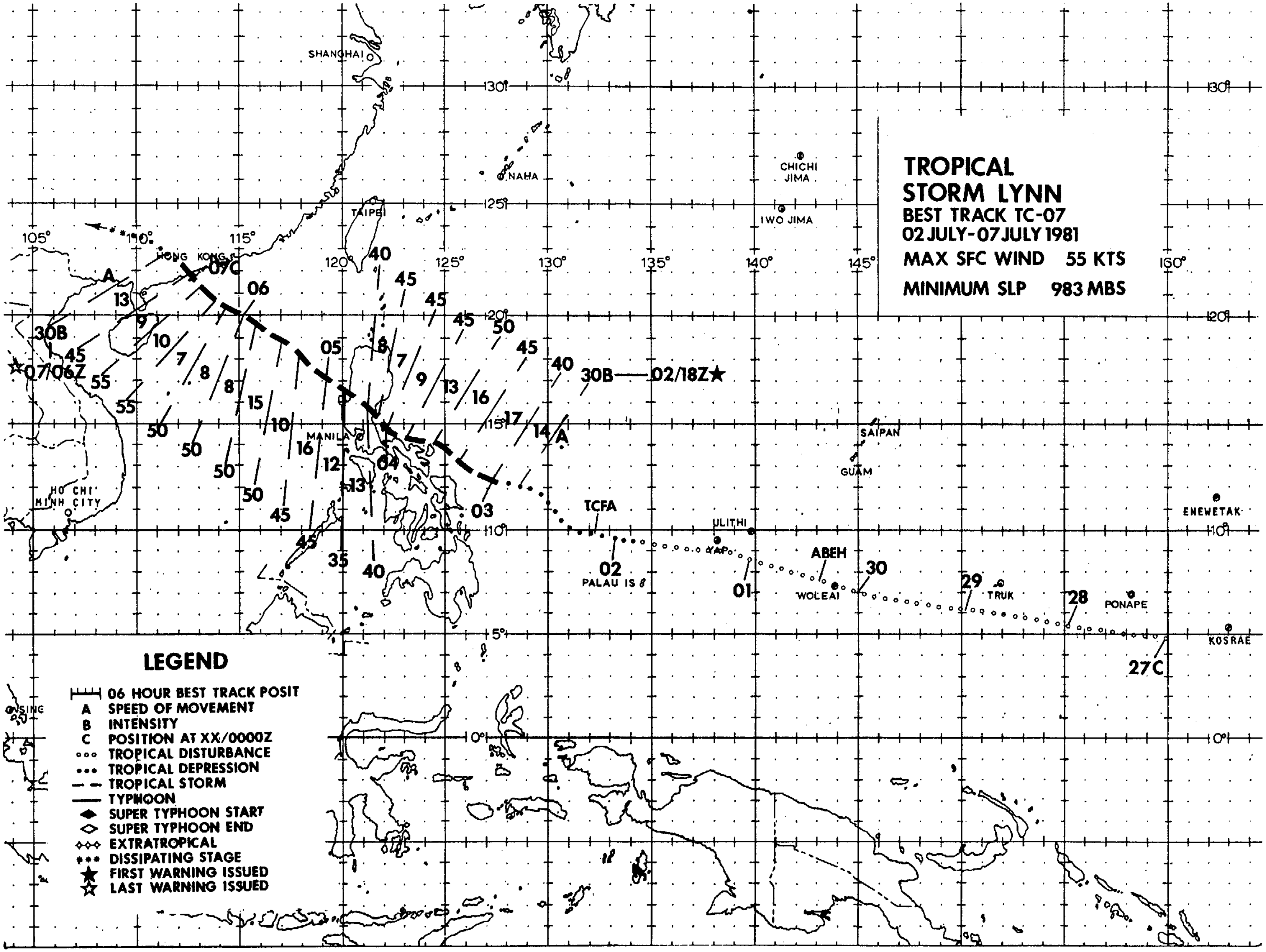


Figure 3-06-6. Official JTWC forecasts versus the final best track for Kelly. Note the obvious inclination to forecast a northward movement throughout Kelly's warning period.


TROPICAL
STORM LYNN
BEST TRACK TC-07
02 JULY-07 JULY 1981
MAX SFC WIND 55 KTS
MINIMUM SLP 983 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
SHANGHAI
NAHA
CHICHI JIMA
IWO JIMA
TAIPEI
HONG KONG
MANILA
HO CHI MINH CITY
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
KOSRAE
ENEWETAK
TCFA
ABEH
30B——02/18Z
07/06Z
07C
27C

Following on the heels of Typhoon Kelly, Tropical Storm Lynn was the second storm in three days to devastate the Philippine Islands. Packing winds of 45-50 kt (23-26 m/sec), Lynn's 30 hour track across the northern Philippine Islands brought torrential rains and accompanying mud slides leaving 18 persons dead and some tens of thousands homeless.

Lynn was first detected on satellite imagery at 270000Z as an area of enhanced convection just south of Ponape. This area was part of a weak equatorial trough that extended from Ponape northwestward to just southwest of Guam, where a second active convection area existed that later became Typhoon Kelly. A broad scale upper level divergent pattern existed over the entire region south of a Tropical Upper Tropospheric Trough (TUTT) located near 15N 160E.

During the next several days both disturbances tracked westward under the influence of the mid-to-lower-tropospheric westerly current south of the subtropical ridge. While the disturbance near Guam eventually intensified to Tropical Storm Kelly, the disturbance near Ponape continued to show marked variations in its convective activity, due in part to the degree of vertical wind shear that existed over the disturbance. Although synoptic data indicated a 1010 mb surface low as early as 291200Z, an analysis of 200 mb satellite-derived winds between 270000Z June and 020000Z July indicated that the north-south flow across the disturbance varied from as little as 10 kt (5 m/sec) to as great as 35 kt (18 m/sec). This large shearing effect appeared to prevent any significant development of the disturbance during this period.

By 020000Z the upper trough had extended westward to a position just to the northeast of Kelly in the South China Sea and a TUTT cell observed near 20N 128E finally blocked the strong shearing pattern (Fig. 3-07-1). A Tropical Cyclone Formation Alert (TCFA) was issued at 020300Z when an upper-level anticyclone could finally be identified over the disturbance. Development was still expected to continue slowly since satellite imagery did not indicate a strong central convective region. Aircraft reconnaissance at 020530Z could only detect a weakly organized 1005 mb circulation pattern.

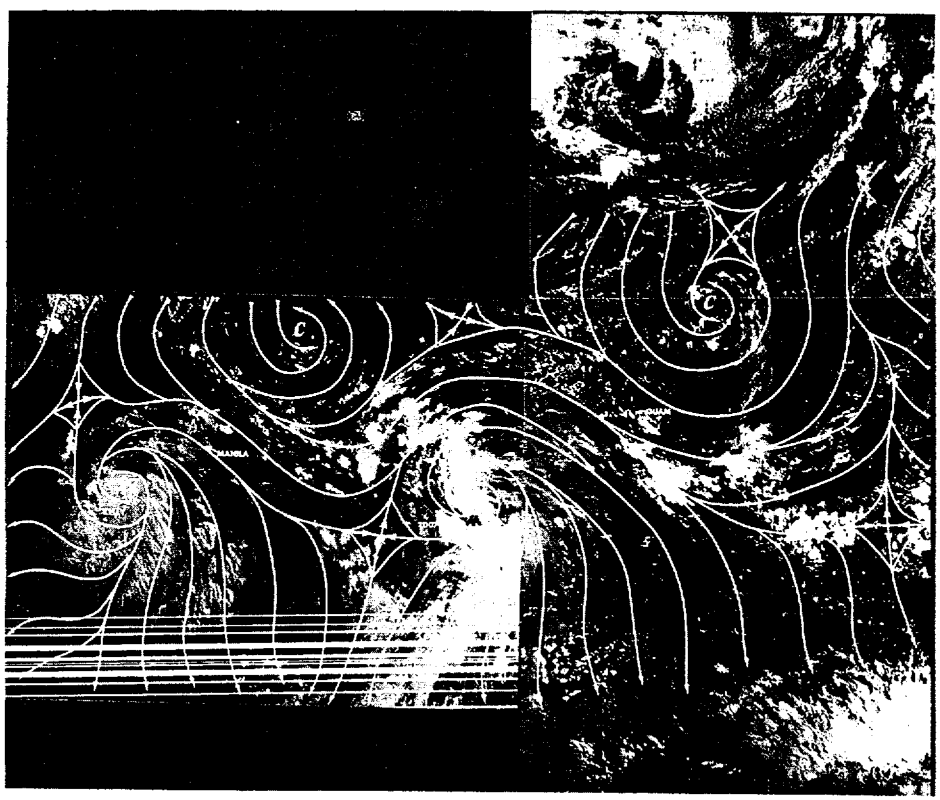


Figure 3-07-1. 020000Z July 1981, 200 mb streamline analysis superimposed on satellite pictures at 012155Z and 012336Z. This figure depicts the TUTT cells in relationship to the developing storms Kelly and Lynn. (NOAA 6 visual imagery)

By 021800Z satellite imagery indicated a much improved central convective region and the first warning was issued. Seven hours later at 030100Z aircraft reconnaissance found that Lynn had already reached tropical storm strength with 40 kt (21 m/sec) surface winds and a minimum sea level pressure of 998 mb.

As Lynn skirted the northern edge of the eastern Philippine Islands, she abruptly slowed from 16 to 7 kt (30-13 km/hr). This was partially due to the disruption of Lynn's circulation pattern over the mountainous terrain of the Philippines and the slight northern retreat of the 500 mb high which temporarily slackened the steering flow across the storm. Also during this time, a large influx of moisture from the South China Sea caused a massive build-up a tropical depression, with an intensity of 30 kts (15 m/sec) and a central pressure of 997 mb, and the final warning was issued.

of cloudiness along Lynn's southern periphery which, in turn, caused Lynn's circular convective pattern to become distorted. This made it very difficult to locate Lynn with satellite imagery. It was not until 040600Z, when a strong central dense overcast (CDO) had developed (Arnold, 1974) just east of Luzon, that Lynn could again be tracked reliably. Figure 3-07-2 shows Tropical Storm Lynn and her CDO just after she made landfall near Baler, Luzon (WMO 98333).

With the formation of the CDO, Lynn appeared to have gained back some of the organization that she had prior to reaching the Philippines. This seems to have enabled the storm to be more easily advected in the steering flow as Lynn quickly increased her speed to 13 kt (24 km/hr).

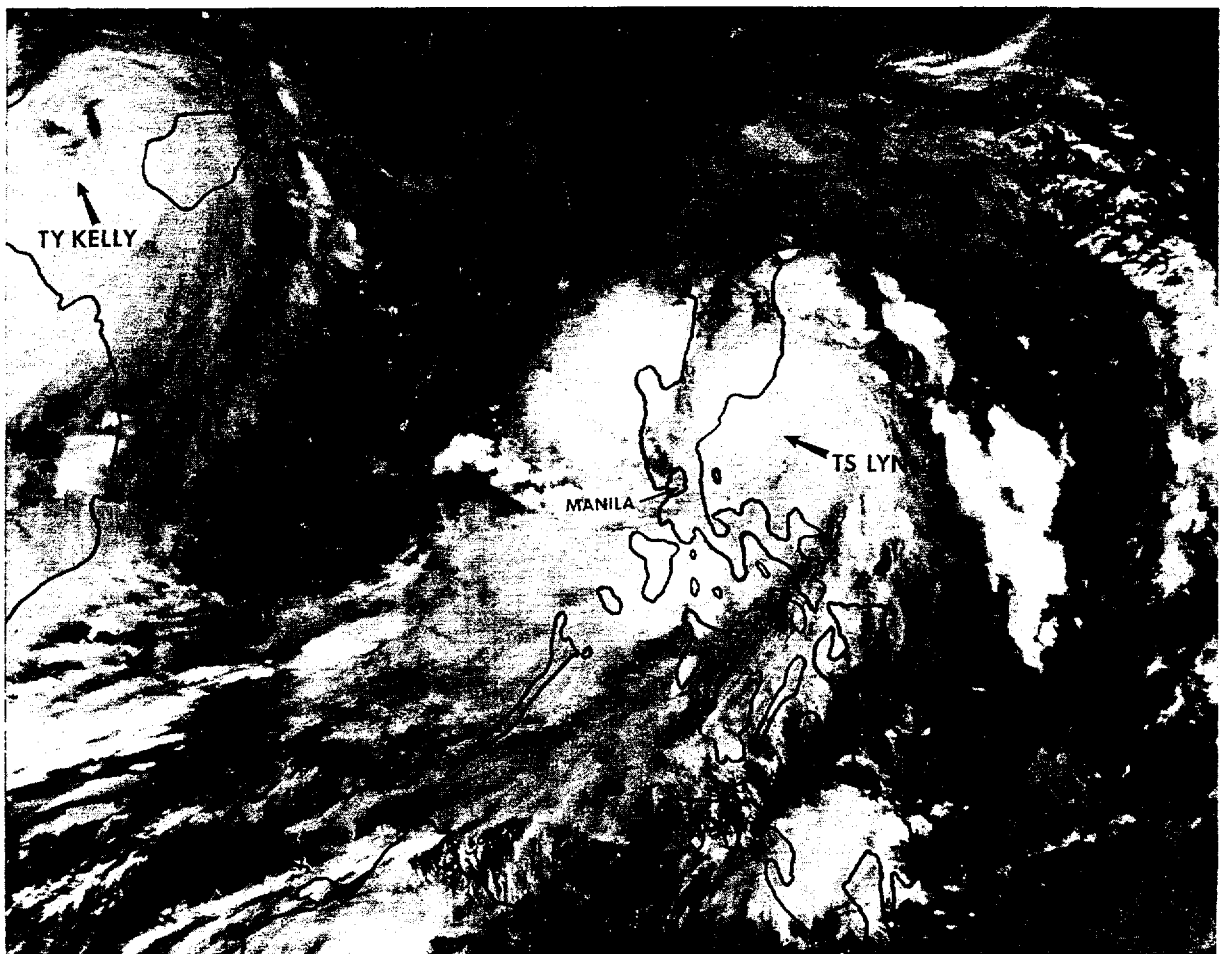


Figure 3-07-2. Tropical Storm Lynn just after reaching the coast of Luzon at 4 July 1981, 1129Z. Note Lynn's strong central convective area as well as the deep layer of cloudiness along her southern periphery. Typhoon Kelly can be seen approaching the coast of Vietnam. (NOAA 6 infrared imagery)

With her speed increased, Lynn lost little of her intensity while crossing the island of Luzon in less than six hours. From Luzon, Lynn followed a fairly climatological northwest track across the South China Sea. JTWC had very little trouble predicting her direction of movement as the 500 mb high over Asia was now 100 m higher than it had been a week prior with Typhoon Kelly.

Like Kelly before her, Lynn was predicted to become a minimum strength typhoon once she reached the central South China Sea. However, with the increase in strength of the Asiatic high, the flow at 200 mb also increased. By 051200Z, Lynn had reached a position just north of where Kelly obtained typhoon strength. As can be seen in Figure 3-07-3, Lynn's outflow was restricted in her northwest quadrant as 70 kt (36 m/sec) easterlies were observed only 420 nm (778 km) north of the storm. It was not until just prior to making landfall on the south China coast that the easterly winds north of the storm abated to only 20 kt (10 m/sec) and satellite imagery indicated that Lynn's outflow had improved. By this time there was little room for much intensificantion.

Lynn finally made landfall near Shang-Chuan-Tao, China (WMO 59673) at 062200Z 90 nm (167 km) west-southwest of Hong Kong. Maximum sustained surface winds at landfall were estimated to be near 55 kt (28 m/sec) with a central pressure of 983 mb.

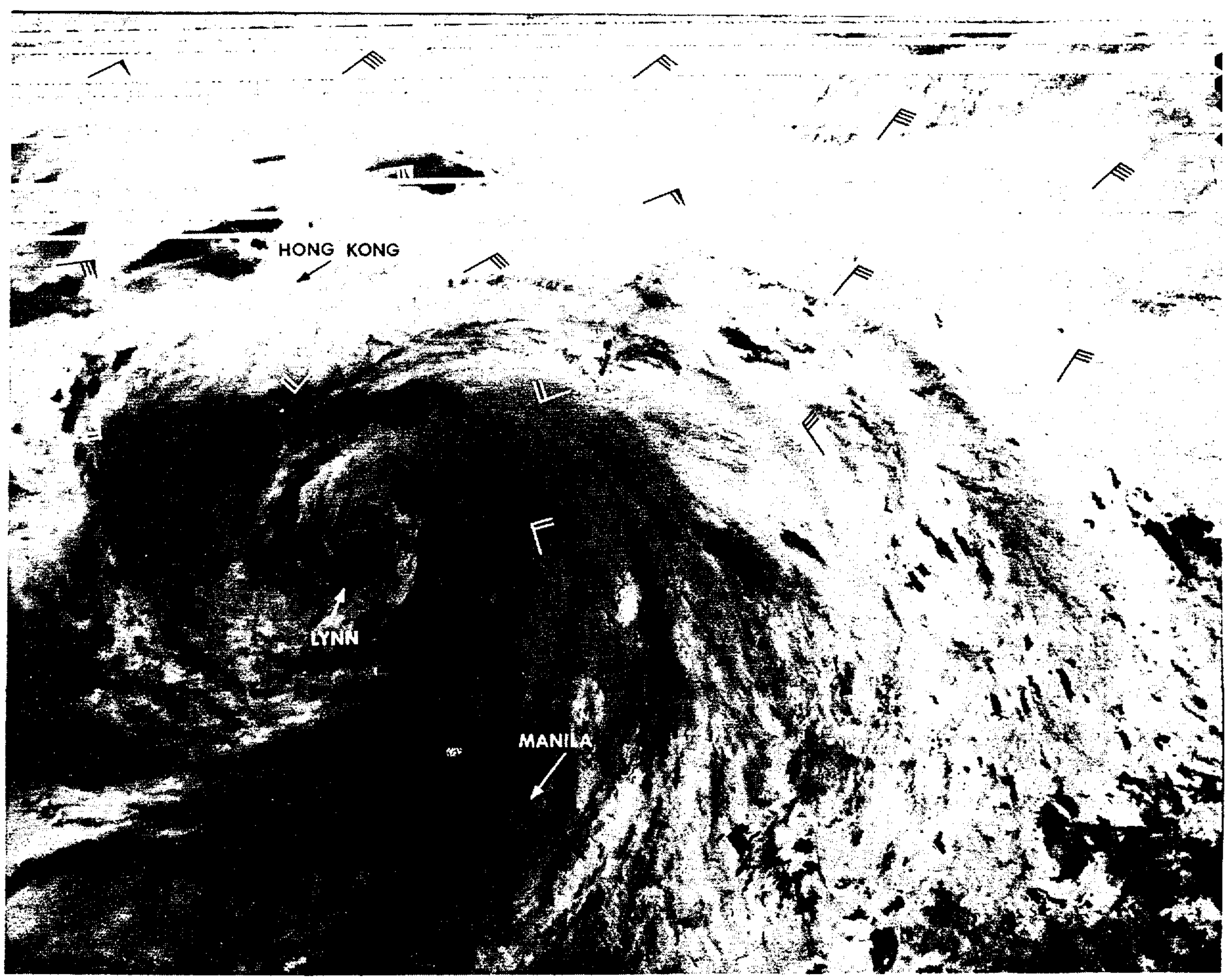
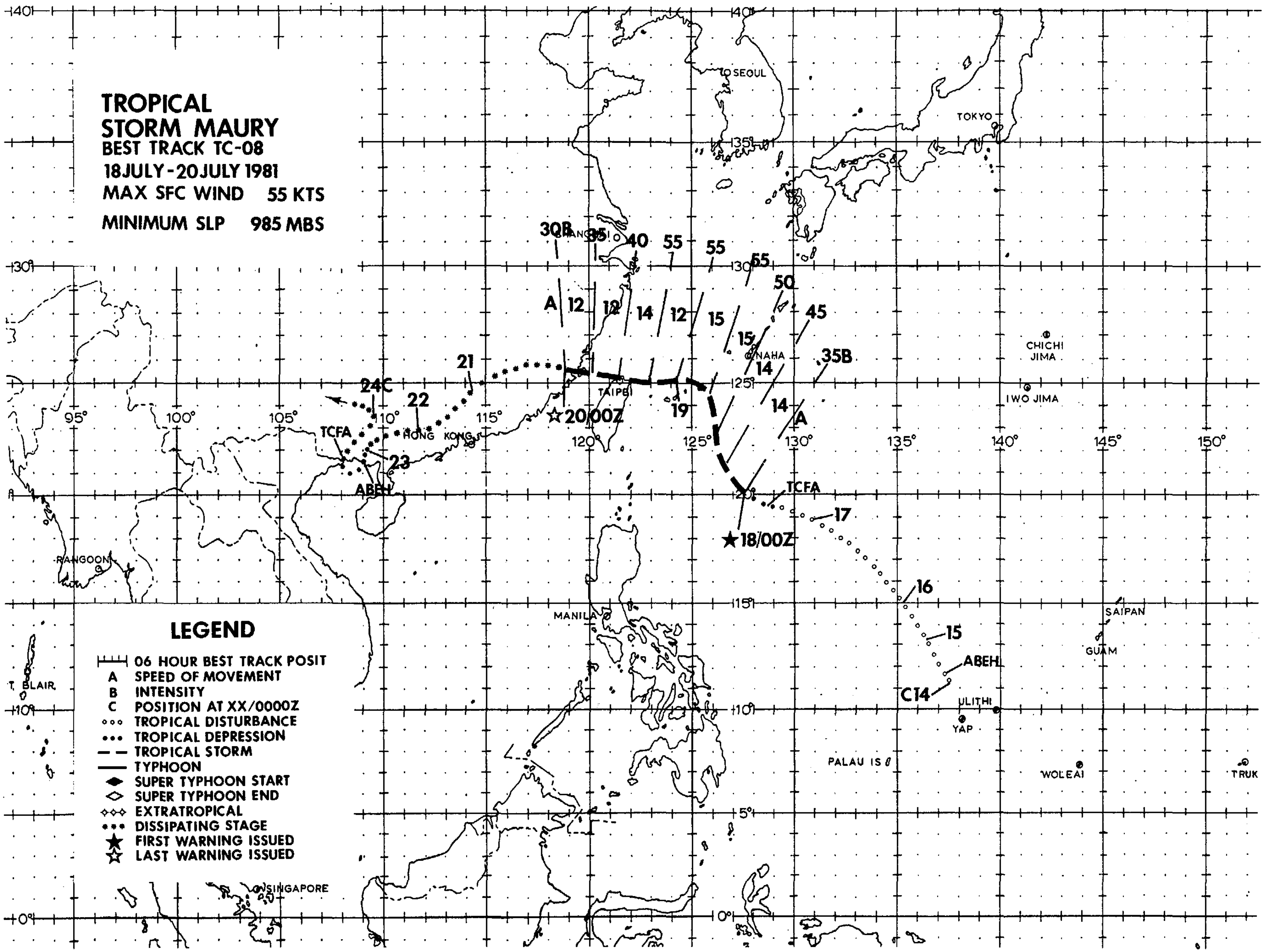


Figure 3-07-3. Tropical Storm Lynn in the South China Sea at 5 July, 1106Z. Strong upper-level flow north of the storm has restricted Lynn's outflow in her northwest quadrant. Wind barbs represent aircraft and rawinsonde reports near the 200 mb level at 051200Z. (NOAA 6 infrared imagery)


TROPICAL
STORM MAURY
BEST TRACK TC-08
18 JULY - 20 JULY 1981
MAX SFC WIND 55 KTS
MINIMUM SLP 985 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
SEOUL
TOKYO
TAIPEI
NAHA
HONG KONG
MANILA
RANGOON
T. BLAIR
SINGAPORE
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
TCFA
ABEH
30B
35
40
55
55
55
50
45
35B
A
12
12
14
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14
A
21
22
23
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16
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C14
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★18/00Z
95°
100°
105°
110°
115°
120°
125°
130°
135°
140°
145°
150°
40°
35°
30°
25°
20°
15°
10°
5°
0°

At 0000Z on 14 July, satellite imagery revealed what was to become Tropical Storm Maury within a convective area near 11N 137E, about 110 nm (204 km) north-northwest of the island of Yap (WMO 91413). Southwesterly low-level flow moved the disturbance at 05 kt (09 km/hr) during the initial 48 hour period. A 500 mb ridge influenced the system thereafter and accelerated it to 14 kt (26 km/hr) by 170000Z. A mid-level circulation was identified on 161200Z satellite imagery and could also be analyzed on the 500 mb charts. The disturbance slowed and moved west-northwest under the influence of the 500 mb ridge located to the northeast while south-southwesterly monsoonal flow continued near the surface.

A Tropical Cyclone Formation Alert was issued at 171600Z when synoptic data indicated winds associated with the disturbance, then located near 20N 128E, had reached 25 kts (13 m/sec). Pressures within the disturbance and the surrounding environment were 1003 mb.

The first warning on Tropical Storm Maury was issued at 180000Z based on several ship reports in the area at 171800Z. Once the disturbance became enhanced by the monsoonal flow, and the central pressure dropped to 999 mb, the system began rapid movement; once again being totally steered by the 500 mb flow.

Aircraft reconnaissance of the storm shortly after the first warning found the 700 mb center displaced to the north-northeast of the surface center by 50 nm (93 km), indicating the storm was tilted in that direction. Figure 3-08-1 depicts the exposed low level circulation, near 21N 128E, to the southwest of the main convection. The exposed low level circulation and displaced convection gave the appearance that Maury was moving to the northwest of his previous positions. The vertical alignment of the system eventually improved and the entire system moved northward under the influence of the 500 mb ridge, as Figure 3-08-2 indicates. The 181816Z position was near 24N 127E.

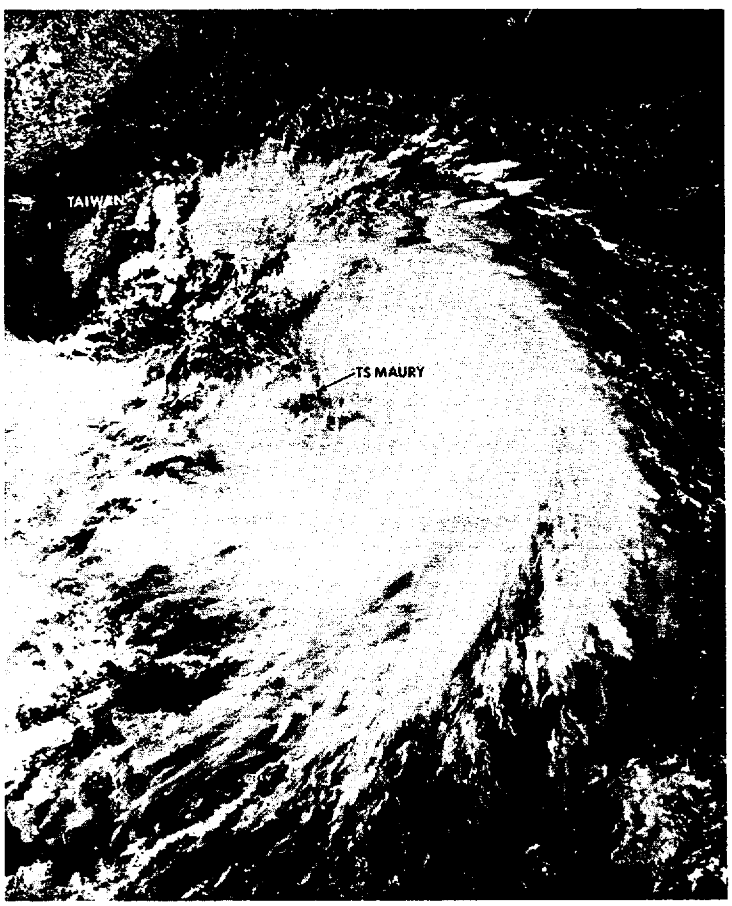


FIGURE 3-08-1. Tropical Storm Maury at 35 kts (18 m/sec) intensity, 18 July 1981, 0513Z. Maury's low-level center was exposed to the southwest of the main convection. (NOAA 7 visual imagery)

FIGURE 3-08-2. Tropical Storm Maury at 55 kts (28 m/sec) intensity, 18 July 1981, 1816Z. This imagery showed Maury had moved north during the preceding six hours instead of the forecasted northwestward movement. (NOAA 7 infrared imagery)

Following this northward movement, the system was forecast to track to the northwest, toward China, as indicated by steering aids from Fleet Numerical Oceanography Center, Montery, California. An apparent weak ridge over China turned out to be much stronger than originally believed and Maury was diverted toward Taiwan, as shown in Figure 3-08-3, when the position was analyzed to be 25.5N 124E. Aircraft reconnaissance of the storm at 190543Z found the 700 mb center continued to be displaced from the surface position, but now by 45 nm (83 km) to the west-southwest. This precession of the 700 mb center and erratic motion of the surface center presented a great deal of difficulty in forecasting the movement of the storm.

The Storm center made landfall on the northern tip of Taiwan at approximately 191000Z. Maury caused heavy flooding in the northern and central portions of Taiwan, leaving 27 dead and many others missing or injured. The flooding was the worst of this year in Taipei City, according to Taiwan press reports.

Maury then moved into the Formosa Strait, still maintaining tropical storm strength, but the intensity was now reduced to 35 kts (18 m/sec) following its interaction with the orographic features of Taiwan. Maury made its second landfall approximately 30 nm (56 km) south-southwest of Fu-chou, China, at 192100Z. Three hours later, at 200000Z, Maury was downgraded to

The remanents of Maury did not completely dissipate over China as expected, but continued inland and began tracking towards the southwest, eventually re-emerging in the Gulf of Tonkin. The remanents were identified as being over water based upon synoptic data at 230600Z, at which time the system was again discussed in the Significant Tropical Weather Advisory. The convective activity lagged behind the surface circulation until the surface circulation moved into the Gulf of Tonkin. A Tropical Cyclone Formation Alert was issued at 231200Z; synoptic data indicated the low level system had recurved northward to make final landfall, approximately 30 nm (56 km) southwest of Yin-chou, while the convective activity continued to move to the southwest. The remanents of the surface circulation then followed orographic features inland and could no longer be distinguished after 241200Z. The convective activity went over land south of Nam Dinh, Vietnam at 240000Z. These cells finally dissipated in the mountains of Laos at 241200Z.

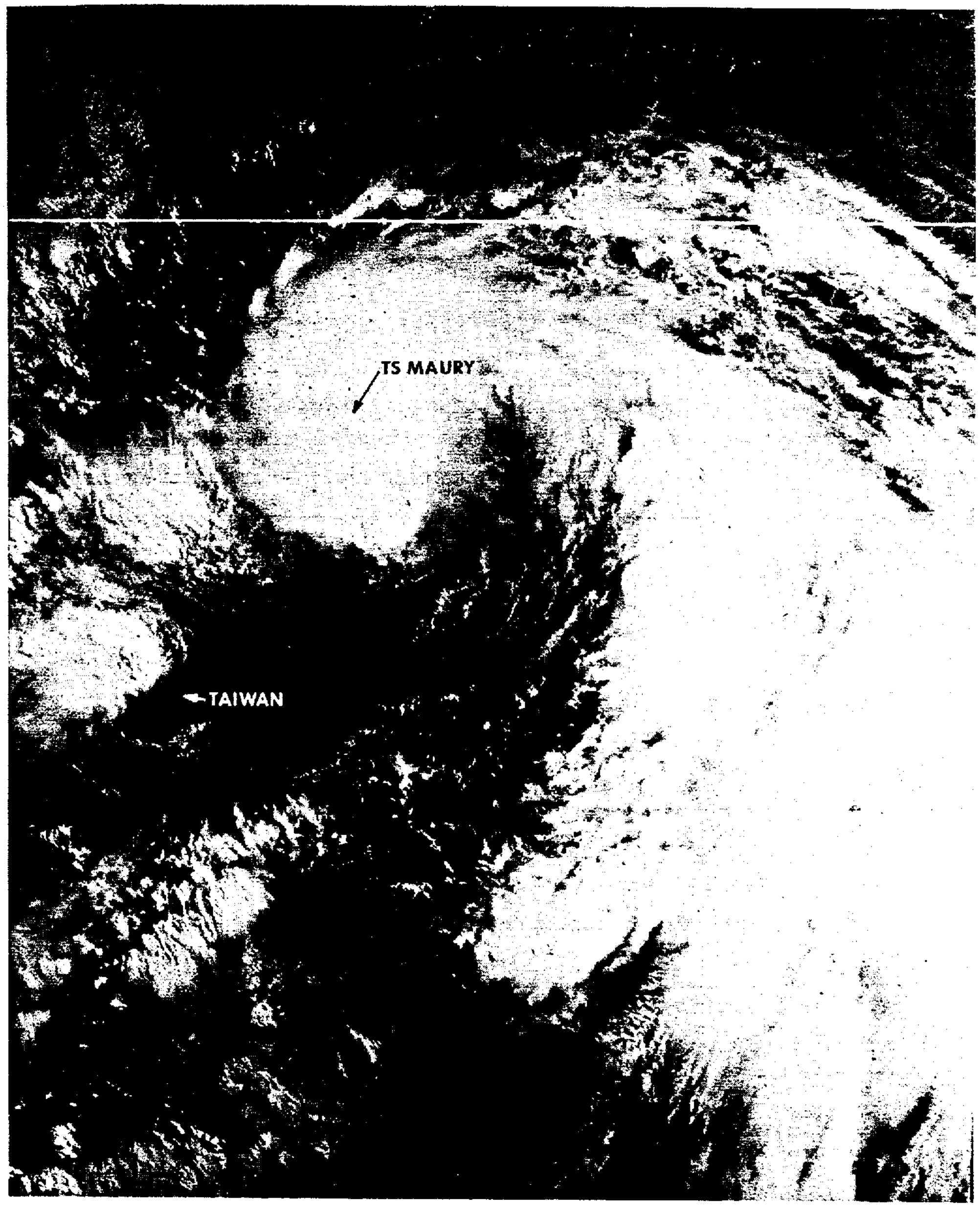
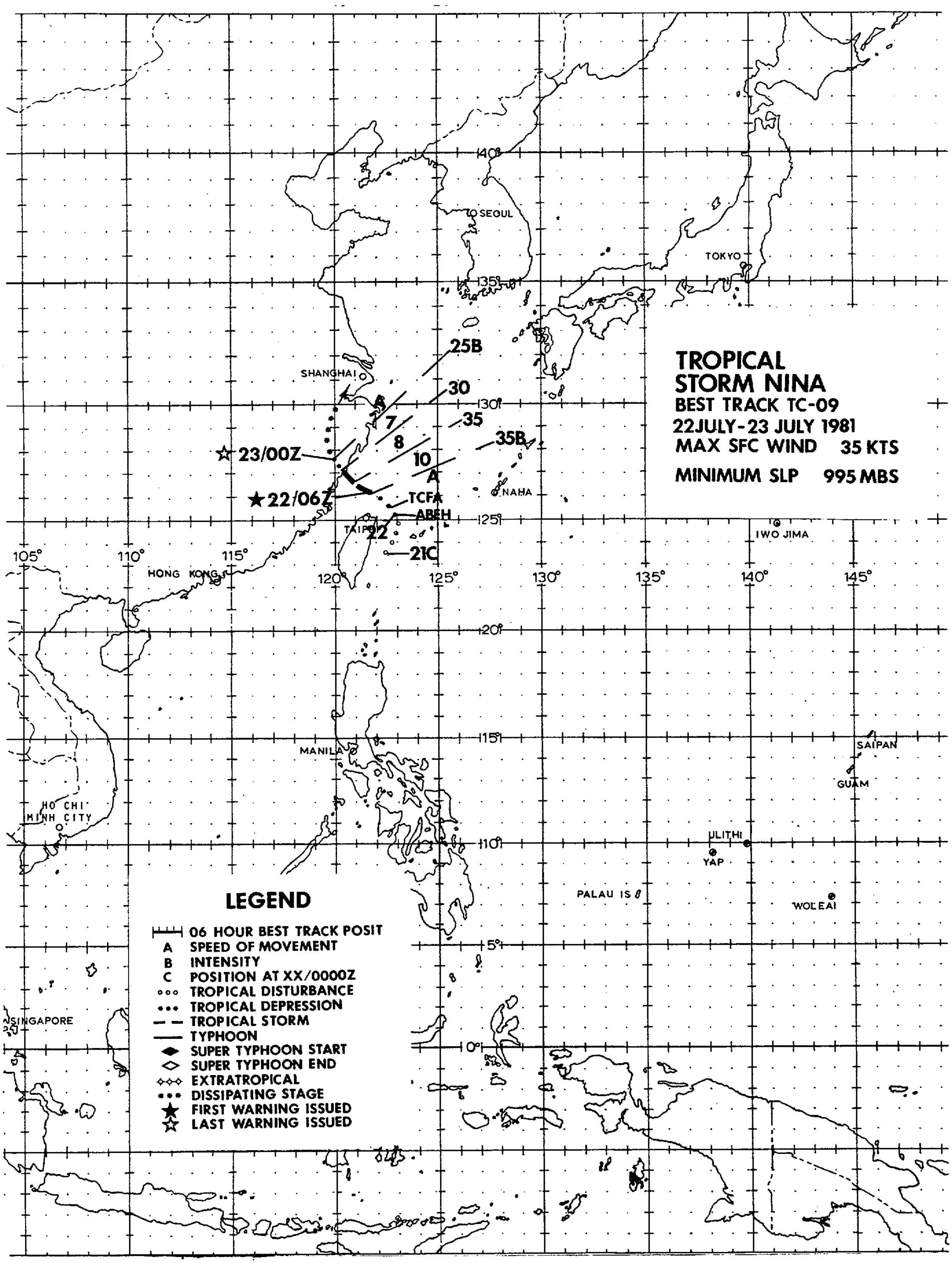


FIGURE 3-08-3. Tropical Storm Maury showed westward movement at the time of this imagery, 18 July 1981, 2305Z. Maury 10 hours before making landfall at the northern tip of Taiwan. (NOAA 6 visual imagery)

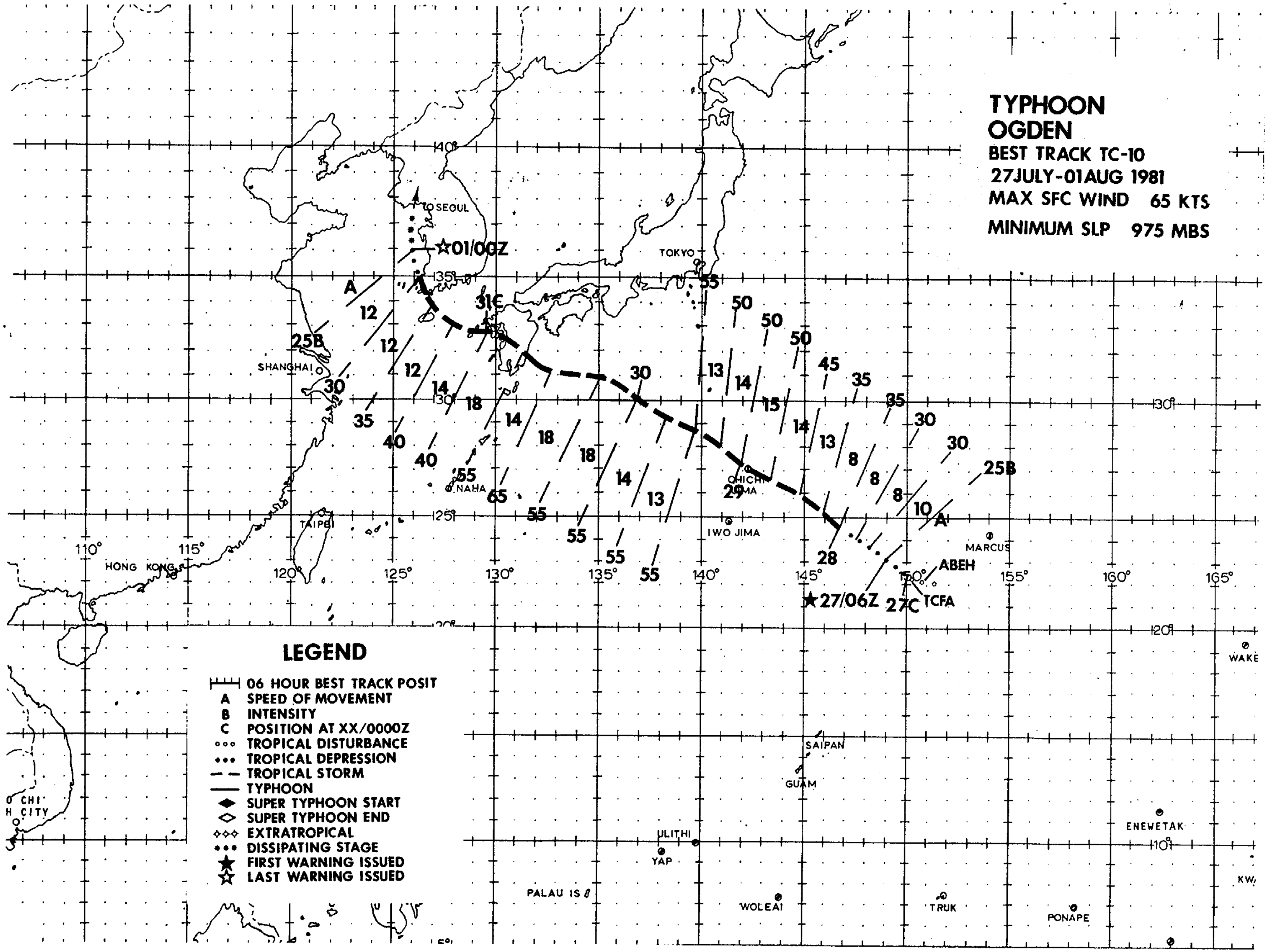

TROPICAL
STORM NINA
BEST TRACK TC-09
22JULY-23 JULY 1981
MAX SFC WIND 35 KTS
MINIMUM SLP 995 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
23/00Z
22/06Z
25B
30
35
35B
7
8
10
TCFA
ABEH
22
21C
SEOUL
TOKYO
SHANGHAI
NAHA
TAIPEI
IWO JIMA
HONG KONG
MANILA
SAIPAN
GUAM
HO CHI MINH CITY
ULITHI
YAP
PALAU IS
WOLEAI
SINGAPORE
105°
110°
115°
120°
125°
130°
135°
140°
145°

Tropical Storm Nina eventually formed from a leeside surface low in the wake of Tropical Storm Maury (08). The disturbance was first detected on 210000Z July synoptic charts near 24N 122E; to the east of Taiwan. The disturbance moved within the monsoonal flow from the southwest until the vertical development became entrained into the westward flow around a mid-level anticyclone to the east.

When the system began to drift northwestward around the northern tip of Taiwan, a Significant Tropical Weather Advisory was issued at 220003Z. The Tropical Cyclone Formation Alert was then transmitted at 220100Z when synoptic data indicated a surface circulation was located near 25N 123E. The first warning on Tropical Depression 09 was subsequently issued at 220600Z.

Nina maintained a northwest track throughout the warning period. Initially moving at 12 kts (22 km/hr) as it rounded Taiwan, the storm slowed as it approached land. Nina had weakened to tropical depression strength when landfall was made at 221800Z, 30 nm (56 km) northwest of Hsia-p'u, China. The final warning was issued at 230000Z, when the system was 35 nm (65 km) inland and orographic effects were rapidly dissipating the system.

Nina started out as an exposed low-level circulation with convective activity to the east. During the warning process this tropical cyclone was not forecast to reach tropical storm strength; however, in post-analysis Nina was upgraded to tropical storm strength for the initial 12 hour period. A 35 kt (18 m/sec) ship report originally considered suspect was later verified by several other ship reports of similar wind speed, but not in time to be included on the second warning.

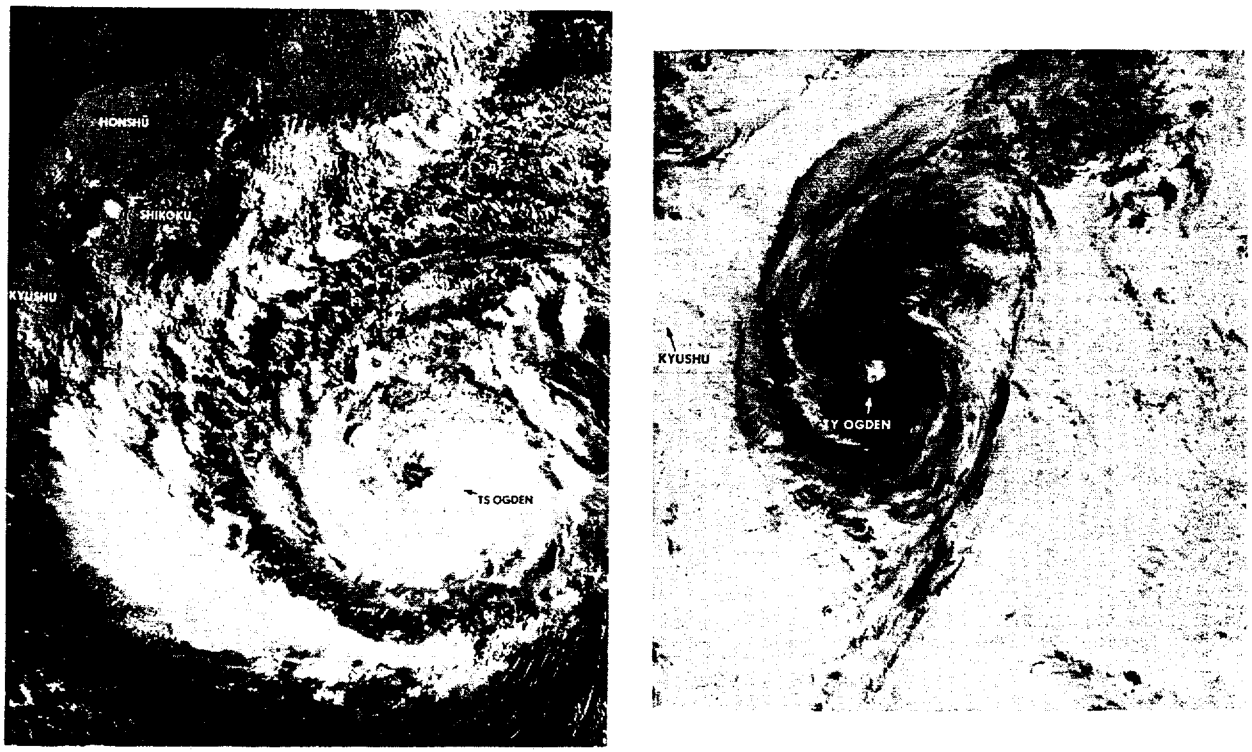

TYPHOON
OGDEN
BEST TRACK TC-10
27JULY-01AUG 1981
MAX SFC WIND 65 KTS
MINIMUM SLP 975 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
SEOUL
01/00Z
TOKYO
31C
SHANGHAI
NAHA
TAIPEI
HONG KONG
IWO JIMA
CHICHI JIMA
MARCUS
ABEH
TCFA
27/06Z
27C
WAKE
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
ENEWETAK
25B
A

Typhoon Ogden developed near 23N 151E when a circulation formed under a pre-existing convective area. Development of this circulation triggered TCFA issuance at 262200Z Aug 81, however, the area had been convectively active during the previous forty-eight hours. Once the circulation formed, very gradual intensification followed. A well-behaved storm track ensued that posed no significant forecast problems.

The initial warning on TD 10 (270600Z) carried a gradually recurving track to the east of Japan. This forecast was based on the apparent existence of a break in the 500 mb ridge to the northwest and the approach of an apparently significant trough in the westerlies. Forecast aids were in disagreement on the forecast track. Climatology and the current synoptic situation influenced the choice of the recurve track over a northwest to westerly straight track. Three warnings were issued with the recurve forecast before a change to straight northwest movement was decided upon. The change was precipitated by two things; synoptic data showed the approaching trough was not as strong as anticipated, and the ridge to the north was building westward ahead of TD 10. No further changes in track were required as TD 10 responded well to the steering currents on the south side of the ridge.

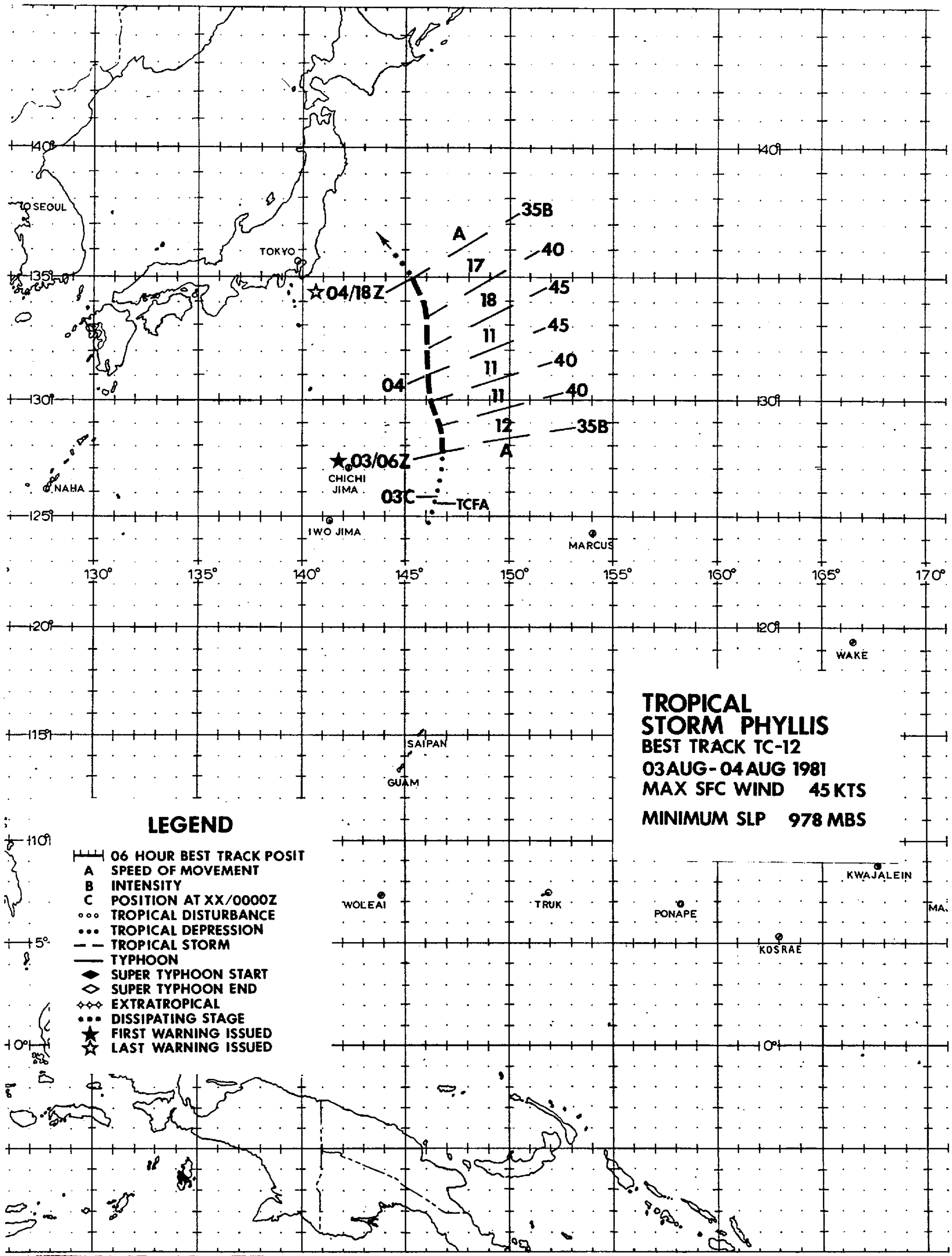
Favorable outflow conditions were never established for TD 10 and this perhaps explains the very gradual intensification. Twenty-four hours after TD 10 formed, tropical storm strength was reached, however, it took another sixty hours for then Tropical Storm Ogden to reach its maximum intensity of 65 kt (33 m/s) thus becoming a minimal typhoon (Fig. 3-10-1). Ogden was upgraded to typhoon in post-analysis based on a combination of aircraft and land synoptic data.

Ogden crossed southern Kyushu between 301600Z and 302100Z and weakened significantly. Ogden still possessed tropical storm strength winds when it emerged into the East China Sea. Weakening continued as Ogden headed northwest toward Cheju-Do Island and the Korean Peninsula. Succumbing to upper and mid-level shear, Ogden finally dissipated as a significant tropical cyclone over the Yellow Sea along the west coast of Korea.



(a) (b)

FIGURE 3-10-1. a) Tropical Storm Ogden at 292259Z approximately twelve hours prior to reaching typhoon strength. Intensity at this time was 55 kt (28 m/s). (NOAA 6 visual imagery) b) Typhoon Ogden at 300957Z near the time of maximum intensity, 65 kt (33 m/s). (NOAA 6 infrared imagery)



SEOUL
TOKYO
NAHA
CHICHI JIMA
IWO JIMA
MARCUS
WAKE
SAIPAN
GUAM
WOLEAI
TRUK
PONAPE
KOSRAE
KWAJALEIN
35B
A
40
17
04/18Z
45
18
45
11
40
11
04
40
11
35B
12
A
03/06Z
03C
TCFA
TROPICAL STORM PHYLLIS
BEST TRACK TC-12
03 AUG - 04 AUG 1981
MAX SFC WIND 45 KTS
MINIMUM SLP 978 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED

The genesis of TD-11 and Tropical Storm Phyllis were associated with one synoptic feature, but the extent of development of each was significantly different. The systems are being discussed together to contrast their early development and thereby come to some understanding as to the inability of TD-11 to mature into a significant tropical cyclone. A brief discussion of Tropical Storm Phyllis will then follow.

On 30 July a monsoon trough developed that extended from the Northern Marianas Islands southwestward toward the Palau Islands. Two surface circulations were embedded at opposite ends of the trough. A mid-level cyclonic circulation was located over the northeastern portion of the trough while upper-level data had been indicating the presence of an anticyclone over the area.

Development of a significant tropical cyclone was potentially high because of the vertical relationship of the upper level anticyclone to the mid-level and surface circulation centers. Consequently, a formation alert was issued at 310300Z for the Northern Marianas area. During the ensuing nine hours, satellite imagery showed evidence of strong upper-level outflow and ship data near the circulation center reported pressures of 997mb; thus JTWC issued the first warning on TD-11 (Fig. 3-11-1).

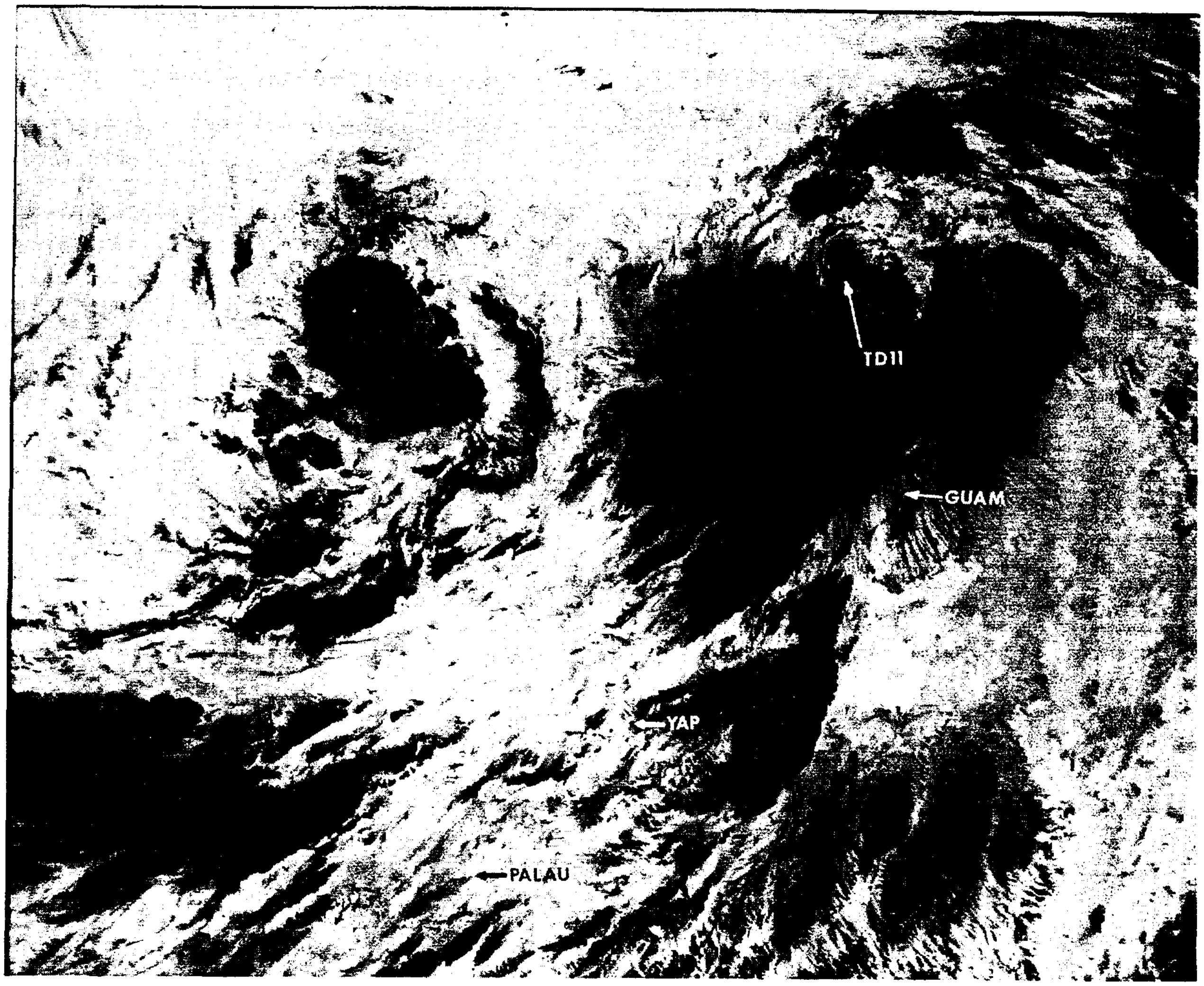


FIGURE 3-11-1. TD-11 early in its development on 30 July 1981, 2236Z. (NOAA 6 infrared imagery)

A decrease in the upper level organization was evident on satellite imagery as the anticyclone receded slowly northeastward. Although the mid and upper level features that helped form TD-11 were still present, by 1 August they appeared to be displaced from the vertical axis of the depression. TD-11 was tracking northeastward at a slower rate than the upper level anticyclone and eventually encountered upper level wind shear caused by the anticyclone which disassociated from TD-11 on the 2nd of August and moved well to the northeast. The final warning on TD-11 was issued at 020000Z.

Aircraft reconnaissance observations on the 1st of August (Fig. 3-11-2) revealed TD-11 was not as well organized as when the first warning was issued. A circulation center was evident at 1500 ft. but the surface winds were indicative of only an elongated trough extending from TD-11 to the second circulation north of the Palau Islands. Throughout the trough in general, surface pressures were low with weak pressure gradients, thus accounting for the weak wind field about TD-11 whose central pressure could have supported much higher winds had it not been embedded in the trough.

While attention had been focused on TD-11, another surface circulation, located in the eastern-most portion of the monsoon trough continued to persist. The upper-level anticyclone was now providing the outflow mechanism required for further development. A formation alert was issued at 022300Z for the area northeast of the Marianas Islands. By 030600Z aircraft and satellite reconnaissance provided evidence that the circulation had already attained tropical storm intensity and the first warning on Phyllis was subsequently issued at that time.

The two features most directly respons-

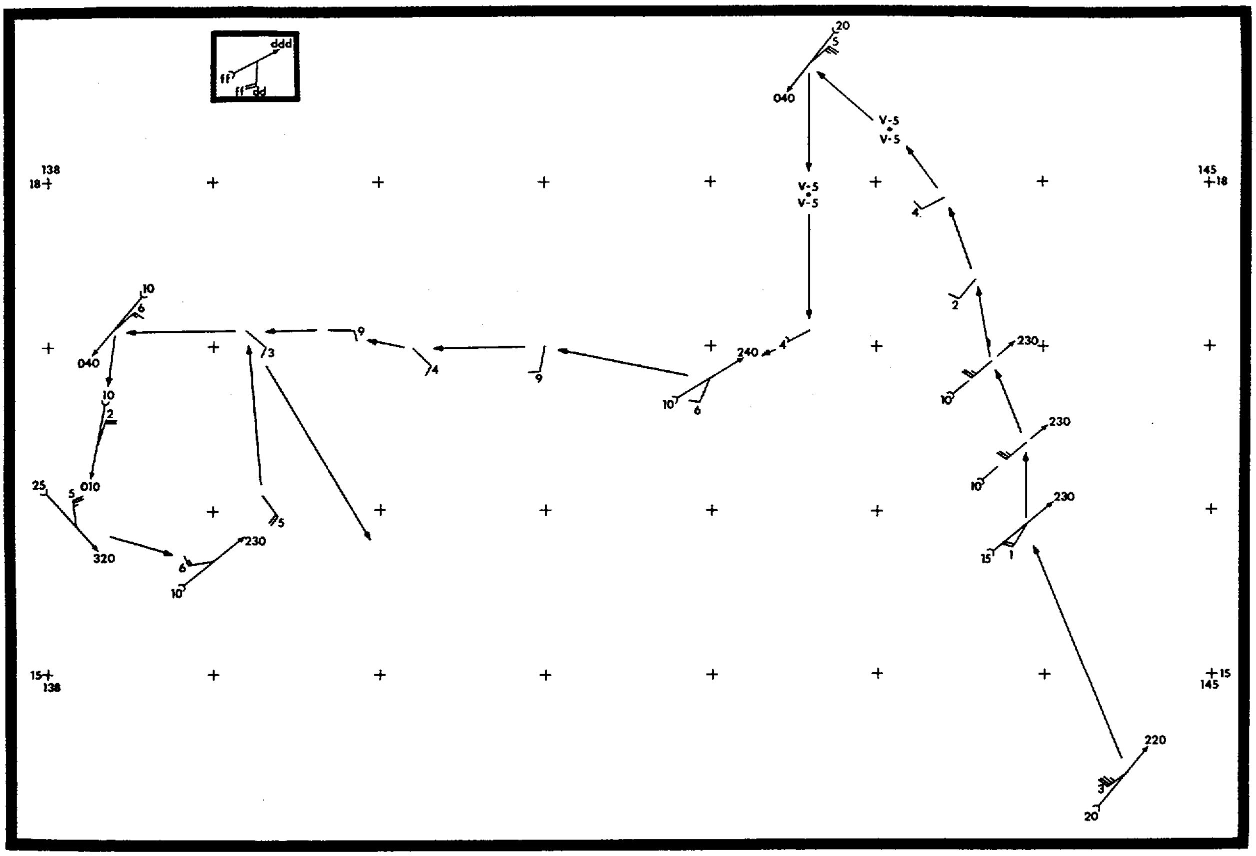


FIGURE 3-11-2. Plot of aircraft reconnaissance data at the 1500 ft. level and surface of TD-11 on the 1st of August.

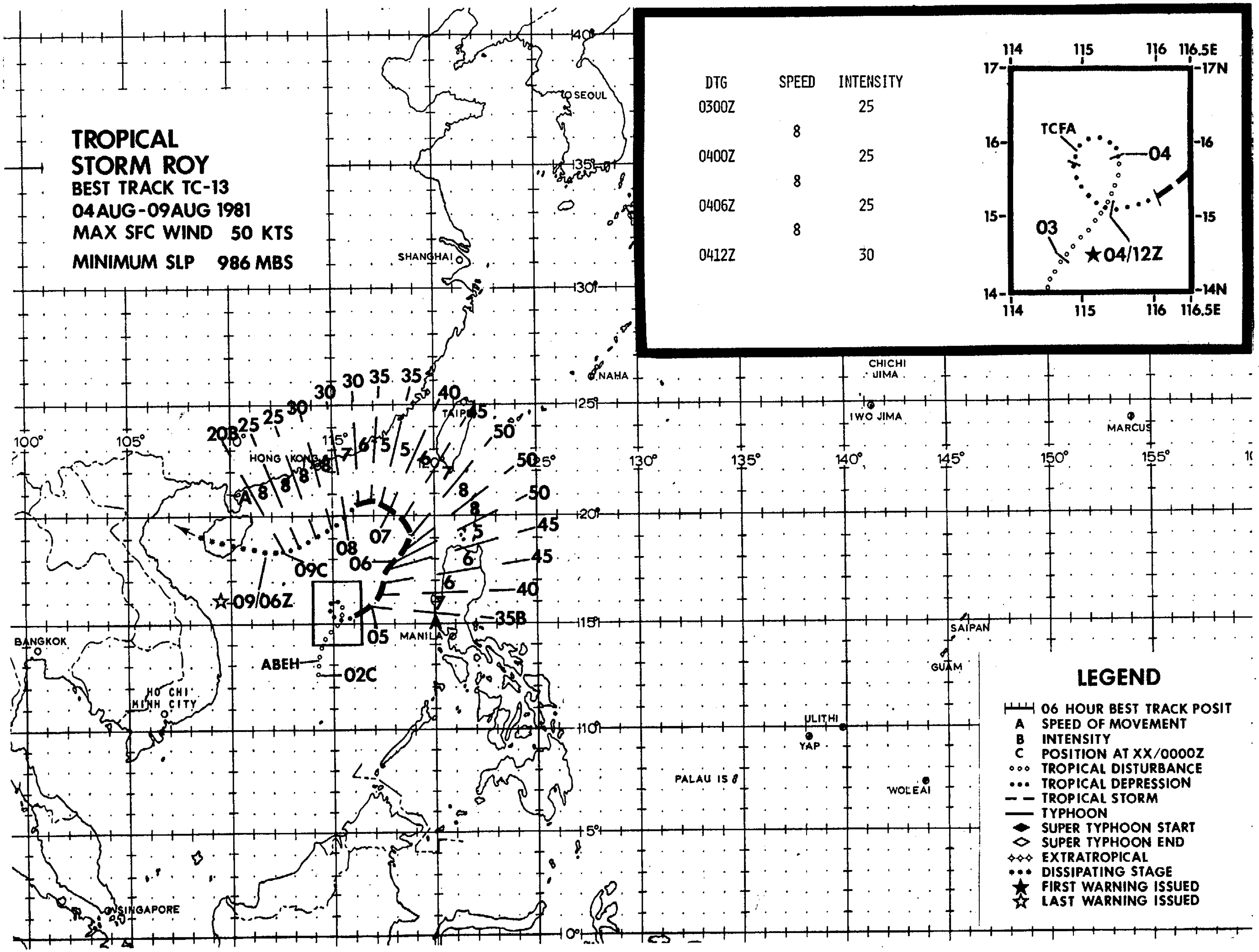
ible for the lack of development of TD-11 and the intensification to Tropical Storm Phyllis were the location of the upper-level anticyclone and the elongation of the monsoon trough as the anticyclone moved northeastward. Initially both circulations were favorably positioned under the upper level anticyclone. The intensification of TD-11 was retarded because the monsoon trough elongated, thereby restricting strong surface inflow from the east. Further, TD-11 did not have the advantage of a strong mid-level steering current and was thus unable to maintain its favorable position with respect to the upper level anticyclone. This resulted in an increased vertical wind shear and eventual dissipation.

Phyllis, on the other hand, was able to maintain a favorable position with respect to the anticyclone aloft. Located within the monsoon trough and exposed to strong surface inflow in three quadrants, Phyllis was able to mature into a significant tropical cyclone.

Phyllis initially tracked northward at 11 kt (20 km/hr) and intensified slowly. An interesting feature in the vertical structure of Phyllis after she attained tropical storm intensity was that the convection was mostly limited to the eastern periphery of her circulation center, (Fig. 3-12-1). Typically, this is suggestive of the cyclone having a tilted vertical axis.

The convective activity decreased as Phyllis advanced northward toward colder water and encountered increased vertical wind shear. By 041800Z Phyllis began to weaken rapidly and the final warning was issued. The remnants of Phyllis continued to track northwestward and later merged with an extratropical low pressure system off the east coast of Japan.

FIGURE 3-12-1. The exposed low level circulation center of Phyllis on 3 August 1981, 0410Z. The convective activity is limited to the east of her center of circulation. (NOAA 7 visual imagery)



TROPICAL
STORM ROY
BEST TRACK TC-13
04 AUG-09 AUG 1981
MAX SFC WIND 50 KTS
MINIMUM SLP 986 MBS
DTG SPEED INTENSITY
0300Z 25
8
0400Z 25
8
0406Z 25
8
0412Z 30
114 115 116 116.5E
17 17N
16 16
15 15
14 14N
TCFA
04
03
★04/12Z
SEOUL
SHANGHAI
NAHA
CHICHI JIMA
IWO JIMA
MARCUS
TAIPEI
HONG KONG
MANILA
BANGKOK
HO CHI MINH CITY
SINGAPORE
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
ABEH
02C
05
06
07
08
09C
☆09/06Z
20B
35B
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED

Tropical Storm Roy was spawned in the warm water east of Vietnam during the first few days of August. On 2 August, a low-level circulation center became evident from synoptic reports in the region. For the next two days, the disturbance tracked slowly northward and on 4 August, it acquired a noticeable central convective feature. At 040515Z, a tropical cyclone formation alert was issued and in the 13 hours which followed, the disturbance was upgraded to Tropical Depression 13 (041200Z) and Tropical Storm Roy (041800Z). Figure 3-13-01 shows the disturbance on infrared satellite imagery at the time the decision to upgrade to warning status was made.

For the next 36 hours, Roy slowly intensified and reached a peak intensity of 50 kt (26 m/sec) on 6 August. During this period of intensification, the upper level features associated with Roy began to move west of the surface center, under the influence of a moderate mid- and upper-tropospheric shearing current. Figure 3-13-02 shows Roy's low-level center emerging from the main convective feature. From 6 August to Roy's eventual dissipation on 9 August, the system existed as an exposed low-level center with most of the convection displaced well west of the low-level center.

Roy's track through the South China Sea was difficult to fully anticipate. From the beginning, Roy was expected to track slowly towards the north-northeast then turn to a more northwesterly heading. However, in the initial stages, Roy moved steadily northeastward. Roy's movement appeared to be related to the combined effects of the low-level monsoon flow east of Roy's center and the general alignment with a mid-tropospheric trough which extended southwest from Tropical Storm Phyllis. On 6 August, however, the mid-tropospheric trough closed-off northeast of Roy and the system gradually turned towards the west in response to the resetablishment of the Asian high pressure ridge over southern China. Eventually, Roy weakened as a significant tropical cyclone in the northwestern South China Sea prior to crossing Hai-nan.

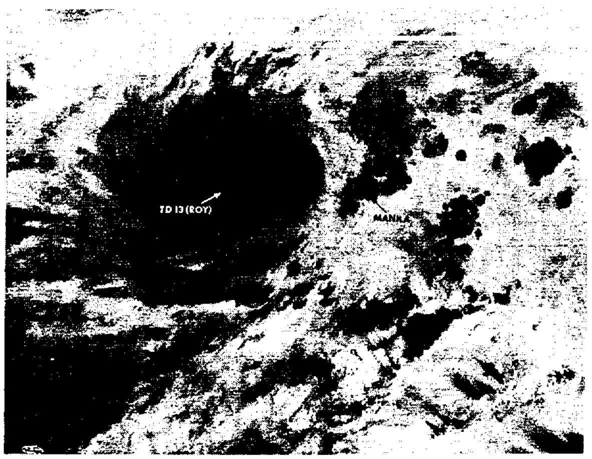


FIGURE 03-13-1. NOAA 6 IR 041124Z AUG 81
The central convective features over the developing Tropical Storm Roy. Based on this imagery (041124Z Aug 81) and some synoptic ship reports in the vicinity, the decision to issue tropical cyclone warnings was made. (NOAA 6 infrared imagery)

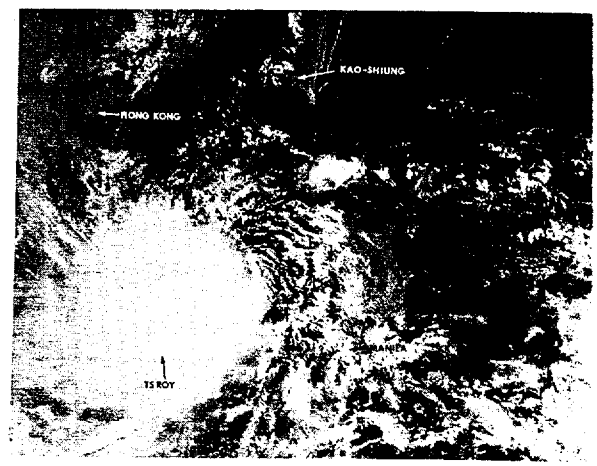
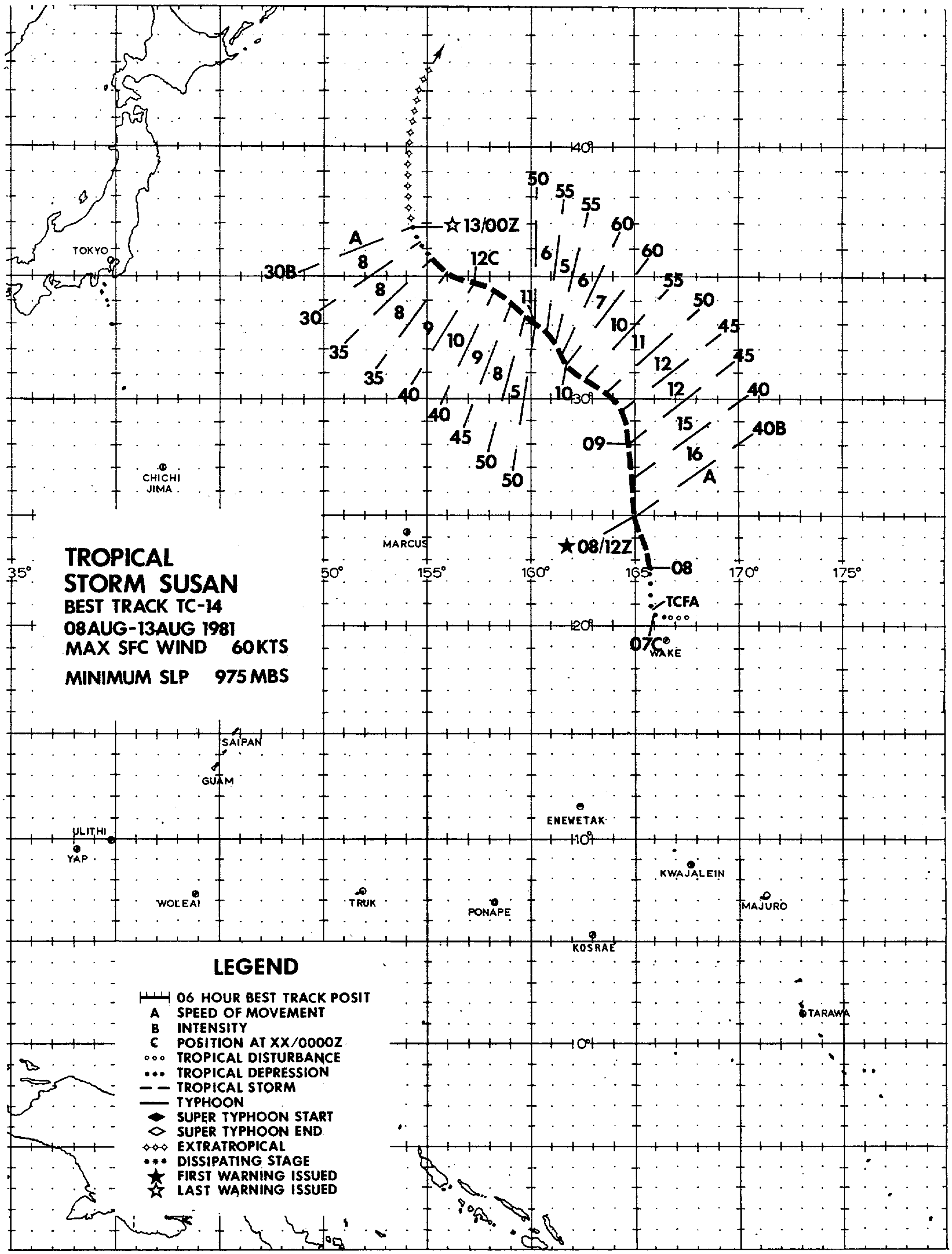


FIGURE 03-13-2. NOAA 6 VIS 052340Z AUG 81
Visual satellite imagery for the first time shows Roy as a partially exposed low-level circulation center. (052340Z Aug 81) During the 24 hours which followed, Roy would become fully exposed and would begin a gradual weakening trend. (NOAA 6 visual imagery)


TROPICAL
STORM SUSAN
BEST TRACK TC-14
08AUG-13AUG 1981
MAX SFC WIND 60KTS
MINIMUM SLP 975 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
13/00Z
12C
30B
09
08/12Z
08
TCFA
07C
40B
TOKYO
CHICHI JIMA
MARCUS
WAKE
SAIPAN
GUAM
ULITHI
YAP
WOLEAI
TRUK
PONAPE
ENEWETAK
KWAJALEIN
MAJURO
KOSRAE
TARAWA
40°
30°
20°
10°
150°
155°
160°
165°
170°
175°

During the week (27 July-3 August) prior to the formation of Tropical Storm Susan, the monsoon trough had been well established in the West Pacific along 20N. When Tropical Storm Phyllis developed near 26N 147E on 3 August and subsequently moved north, the prevailing low-level southwest flow south of 20N diverged into two channels; one continued north moving with Phyllis, while the other pushed further east to help establish a weak trough in the vicinity of Wake Island (WMO 91245). Tropical Storm Susan formed in this weak trough.

The disturbance that was to become Tropical Storm Susan first appeared on satellite imagery at 062136Z as an exposed low-level circulation approximately 60 nm (111 km) north of Wake Island (Fig. 03-14-1). At the time, the separation of the convection from the surface circulation, due to vertical shear, suggested that only a weak disturbance existed in the area. During the early morning hours prior to this visual satellite sighting, Wake Island had been reporting heavy rainfall with southwest winds as high as 45 kt (23 m/sec); however, it was felt that these reports were more representative of the strong convection in the area than of the exposed surface circulation. When Wake's winds subsided during the next several hours to only 15 kt (8 m/sec), and there was little apparent movement of the circulation center, it was deemed unnecessary to immediately issue a warning of this disturbance. Instead at 0703192Z, a Tropical Cyclone Formation Alert (TCFA) was issued with the expectation that, providing the strong upper level flow across the region subsided, enough convection would develop around the surface circulation for a significant tropical cyclone to form.

During the next 24 hours little changed in the synoptic situation. Althougn new convection had begun to develop approximately 100 to 150 nm (185 to 278 km) to the north and east of the exposed low-level circulation, 200 mb satellite-derived winds over the region still indicated strong 40 kt (21 m/sec) flow from the north. When the 080015Z aircraft investigative mission could find only 20 kt (10 m/sec) winds in possibly "one of several circulations in the area"[1] (992 mb sea level pressure), it was decided to reissue the formation alert. However by 081200Z, the convection on the periphery of the surface low appeared to have strengthened while satellite imagery indicated that the strong vertical shear had weakened enough for an upper level anticyclone to develop; consequently, the first warning on Tropical Storm Susan was issued.

Initially, Susan tracked north along a trough induced by convection left behind from the passage of Tropical Storm Phyllis a week earlier. Once she reached 30N 164E at 091200Z, Susan did not recurve as originally forecast but turned toward the northwest in response to an approaching weak cold front. It was during this stage that Susan reached her greatest intensity of 60 kt (31 m/sec) (Fig. 3-14-2). By 101800Z the approaching frontal system weakened enough so that Susan no longer responded to its presence. However, cool dry air from the remnants of this front appeared to entrain into the circulation center and by 111200Z very little convection remained. Susan next turned toward the west-northwest in response to a new frontal system coming off Japan (also increasing its convective activity). This time, however, the frontal system did not weaken before reaching Susan; and by 130000Z Tropical Storm Susan had become completely entrained into the front and quickly made the transition into an extratropical system.

Figure 3-14-1. The initial stages of Tropical Storm Susan just north of Wake Island at 6 August 2136Z. (NOAA 6 visual imagery)

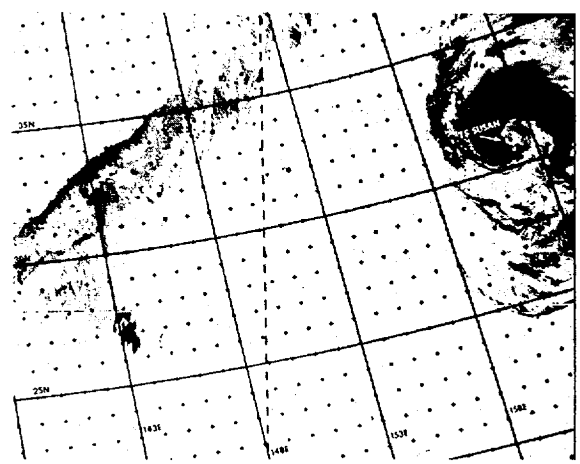
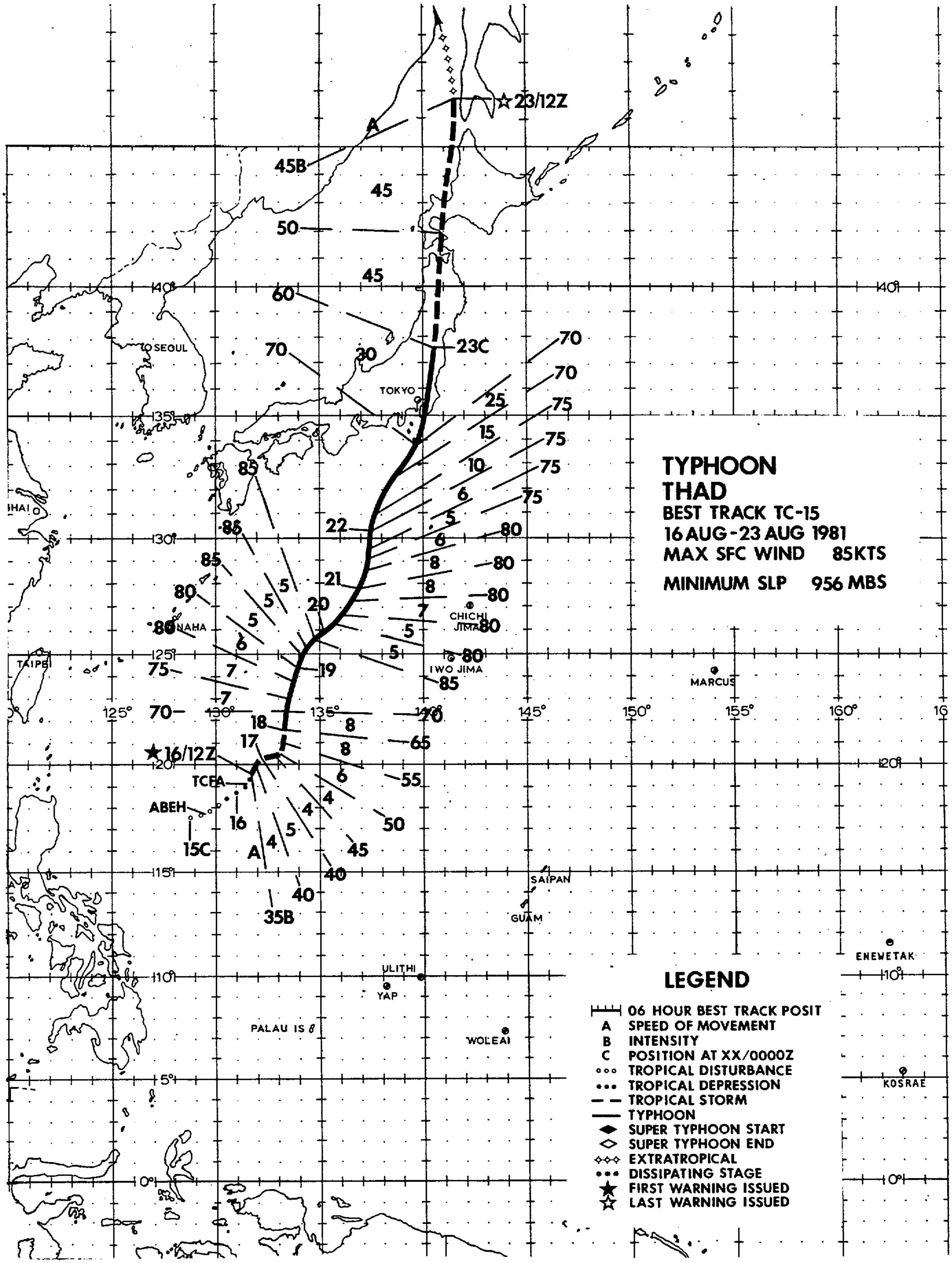


Figure 3-14-2. Tropical Storm Susan just prior to peak intensity on 9 August 2208Z. Note how the convection is displaced from the circulation center. A weak cold front can be seen approaching from the northwest. (NOAA 6 infrared imagery)

[1]RANDOLPH A. FIX, 1 Lt, USAF: Aerial Reconnaissance Weather Officer (ARWO).


TYPHOON
THAD
BEST TRACK TC-15
16 AUG - 23 AUG 1981
MAX SFC WIND 85KTS
MINIMUM SLP 956 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
23/12Z
16/12Z
SEOUL
TOKYO
NAHA
TAIPEI
CHICHI JIMA
IWO JIMA
MARCUS
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
ENEWETAK
KOSRAE
TCFA
ABEH
45B
35B
23C
15C

The monsoon trough was particularly active in mid-August, and within the 48 hour period beginning 16 August three tropical cyclones were spawned. Typhoon Thad, the first of the three, was initially evident on 10 August when surface synoptic data indicated a weak circulation was embedded in the trough near 18N 130E. The circulation was first cited in the Significant Tropical Weather Advisory on 15 August when satellite imagery indicated limited outflow had developed above the surface circulation. The outflow was initially the result of a 200 mb ridge that had built westward over the surface trough. Continued improvement in the outflow prompted the issuance of a Tropical Cyclone Formation Alert at 151800Z. Aircraft reconnaissance data, which located the circulation near 19N 132E, provided the basis for the alert area being moved northeast and reissued at 160530Z. Analysis of 160000Z 200 mb synoptic data showed that an anticyclone had developed in the ridge over the circulation, enhancing the outflow pattern necessary for further intensification of the disturbance.

Satellite imagery eventually indicated better organization of the system, thus the first warning on TD-15 was issued at 161200Z. TD-15 was initially forecast to move slowly northward then accelerate to the northwest as it came under the influence of easterly winds south of the 500 mb ridge. By 170600Z both aircraft and satellite data showed Thad's movement was to the northeast in response to a weakness in a 500 mb ridge which had developed over Japan (Fig. 3-15-1). Forecasts of this 500 mb feature maintained the weakness over Japan and the forecast track for Thad was adjusted from northwestward to northward to reflect the new steering pattern. Recurvature was expected east of Japan.

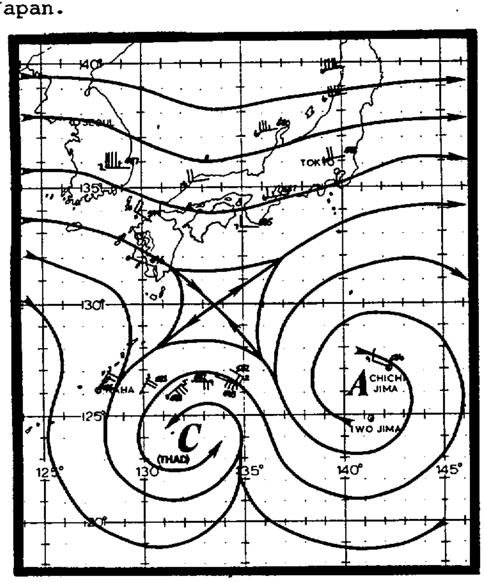


Figure 3-15-1. 500 mb streamline analysis for 181200Z showing the major synoptic features upon which the recurvature forecast was based. Wind data are a combination of rawinsonde and aircraft reconnaissance data. Wind speeds are in knots.

By 180000Z Thad had reached typhoon strength and developed a ragged eye that remained for 80 hours (Fig. 3-15-2).

As Thad neared 30N, analysis of 500 mb data established the likelihood that Thad would interact with a progressing long wave trough just south of Japan, where recurvature and subsequent acceleration were expected. Post-analysis has revealed several deficiencies in that conclusion: the trough did move eastward over the Sea of Japan late on 21 July; a rapidly building ridge east of Thad caused the trough to stall northwest of Thad; coincident with the stalling long wave, a weak short wave moved through the trough and caused a rapid, unforecast, deepening. The entire trough system generated 500 mb height drops of up to 100 meters in 12 hours. This rapid deepening, combined with high pressure in the ridge to the east, established an intense 500 mb pressure gradient over eastern Japan with resultant wind speeds as high as 65 kt (120 km/hr). Thad tracked northward under the influence of the 500 mb flow, was entrained into this area of high winds early on 22 August and accelerated very rapidly to the north over eastern Japan, rather than taking the expected recurvature path. Thad's speed of advance accelerated from 10 kt (19 km/hr) at 220000Z to 45 kt (83 km/hr) by 230000Z.

Post analysis has shown Thad started a very rapid extratropical transition near 32N that continued as the system accelerated along the eastern side of the trough. The rapid acceleration, and an associated rapid entrainment of cool dry air, completed the transition by 231200Z, at which time satellite imagery indicated Thad had merged with the trough over the Tatar Strait and was no longer discernible as a tropical entity.

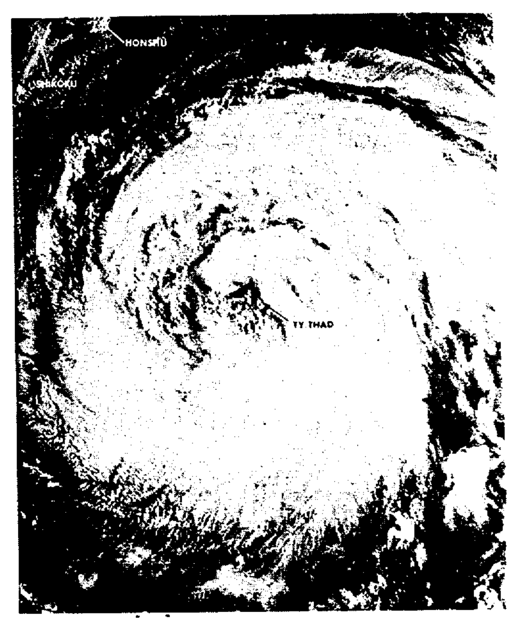
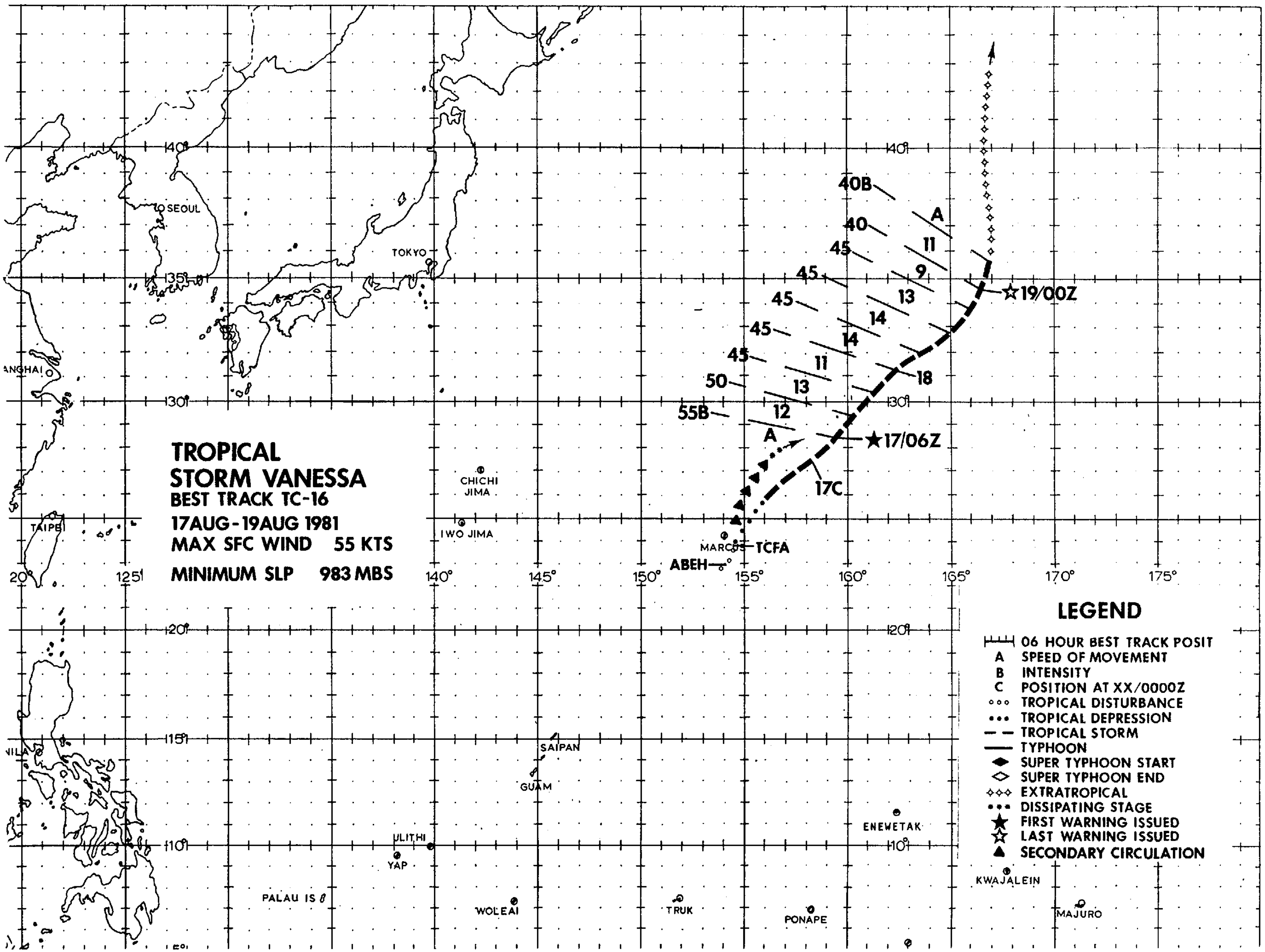


Figure 3-15-2. Visual satellite imagery from 202259Z Aug 81 showing Thad at 80 knots (41 m/sec) intensity, with ragged eye. (NOAA 6 visual imagery)



TROPICAL STORM VANESSA
BEST TRACK TC-16
17AUG-19AUG 1981
MAX SFC WIND 55 KTS
MINIMUM SLP 983 MBS
SEOUL
TOKYO
SHANGHAI
TAIPEI
CHICHI JIMA
IWO JIMA
MARCUS
TCFA
ABEH
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
ENEWETAK
KWAJALEIN
MAJURO
17/06Z
19/00Z
17C
40B
40
45
45
45
45
45
50
55B
A
A
11
9
13
14
14
11
13
12
18
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
SECONDARY CIRCULATION

Tropical Storm Vanessa developed approximately 60 nm (111 km) south of Marcus Island (WMO #47991) during a period of enhanced convective activity within the monsoon trough. Despite diurnal fluctuations, the increased convective activity was evident on the satellite imagery of 12 August and continued to increase over the next several days. Furthermore, surface synoptic data and satellite data confirmed the merger of the monsoon trough with a pre-existing north-south oriented trough near 170E that had been in evidence since 7 August. This second trough was particularly intense due to prior passage of Tropical Storm Susan (14). Weak circulations and minor disturbances were detected along the entire length of the merged troughs and investigative missions were flown to several of them. The first disturbance to intensify significantly produced Typhoon Thad (15), while 18 hours later (170600Z) the first warning was issued on Tropical Storm Vanessa (Fig. 3-16-1).

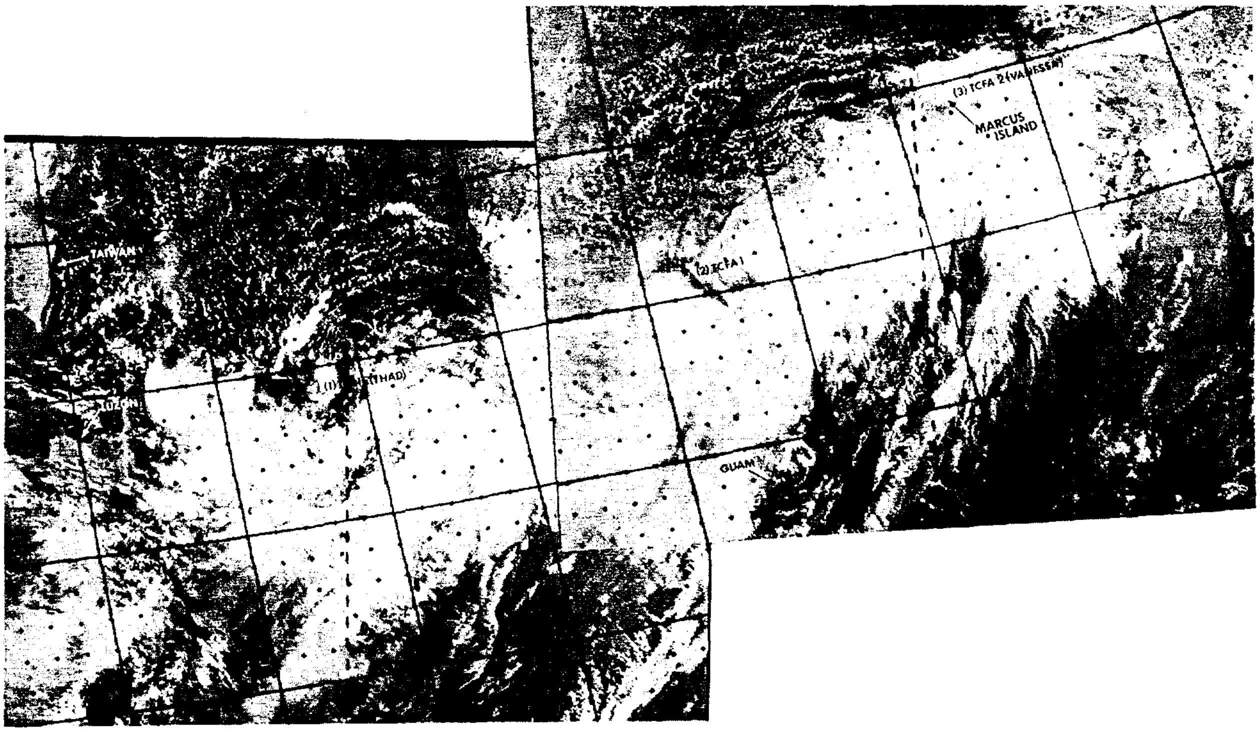


FIGURE 3-16-1a: Active monsoon trough as it appeared prior to development of Tropical Storm Vanessa. (1) TD-15(Thad), (2) initial TCFA and (3) area where TD-16(Vanessa) developed. Photo is mosaic using consecutive NOAA 6 passes for 152131Z and 152312Z, Aug 1981. (NOAA 6 visual imagery)

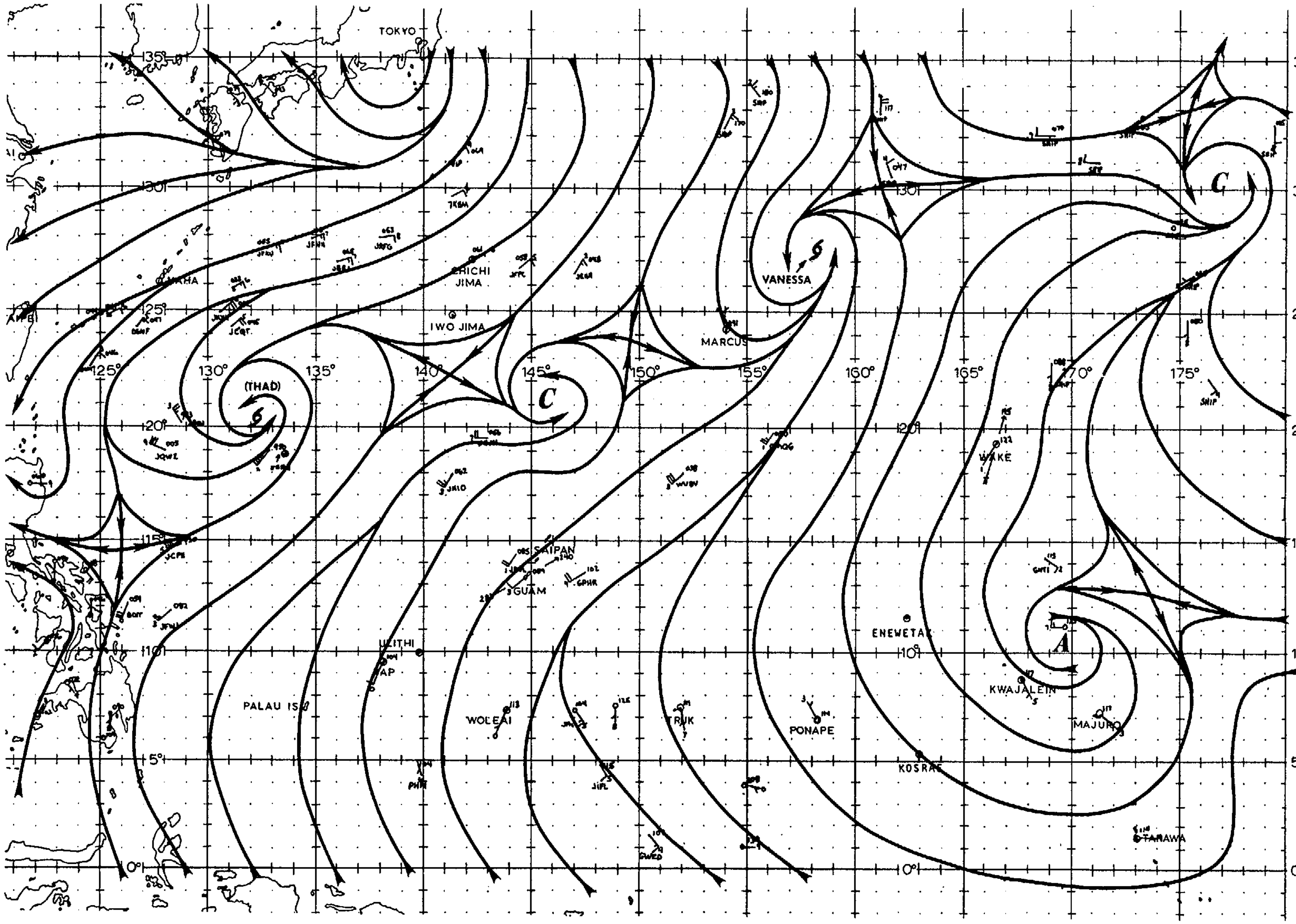


FIGURE 3-16-1b: The 170000Z, Aug 1981 surface (⟵┐)/gradient-level (ddd ⟵ ff) wind data and streamline analysis depicting the monsoon trough. Wind speeds are in knots.

An initial Tropical Cyclone Formation Alert (TCFA) was issued at 150525Z for a circulation near 20N 149E which, in the ensuing 24 hours, weakened. This TCFA was superseded by a second TCFA at 160617Z for a circulation near 24N 155E. Re-analysis of all available satellite data for the period shows that the circulations were separate entities and were related only because they developed within the same trough. Furthermore, re-analysis also reveals that there was a primary and a secondary circulation present when the second TCFA was issued. The primary circulation was totally obscured by dense overcast and was not initially apparent. Initial satellite fixes were based on the partially exposed secondary circulation. In actuality, the primary circulation was located approximately 60 nm (111 km) to the south of the satellite fixes (Fig. 3-16-2). The troublesome secondary circulation was no longer discernible after approximately 12 hours and satellite analysts were able to locate the primary circulation.

Enhanced convection and the intense trough were the key low level features contributing to the genesis of Vanessa. Two other contributory features were a mid-tropospheric trough and an upper level anticyclone, both of which were in positions favorable for tropical cyclone development.

The mid-tropospheric trough approximated the position of the surface trough. Several circulations were embedded within this trough, including one over the surface position where Vanessa formed. In the upper troposphere, an anticyclone had existed over the area since 15 August. Vanessa, therefore, possessed the vertical alignment of a mature tropical cyclone from her inception. (Similar conditions existed during the formation of Tropical Storm Phyllis (12)).

It is interesting to note that although Vanessa was vertically aligned, little further development took place after Vanessa was completely free of the surface trough. Two factors probably contributed to non-development:

a. Initially, Vanessa had outflow to the southwest and the northeast. The wind currents exiting the Asian landmass split with the major current being diverted north of the ridge while the weaker current passed south. This weaker southern current was not sufficiently strong enough to maintain the northeast outflow channel and no other outlets were available to connect Vanessa to the westerlies. Thus, only southwest outflow was maintained.

b. In addition to the loss of an outflow channel, Vanessa's northeastward progression was blocked by strong ridging associated with a large 500 mb anticyclone over the Marshall Islands. The ridge forced Vanessa to steer due north. Since Vanessa initially formed at a rather high latitude subsequent northward movement brought her rapidly into contact with upper level shearing currents.

By 190000Z, Vanessa was devoid of convection and the extratropical transition was completed. The completely exposed low level circulation continued to be visible on the satellite imagery for sometime as it continued to track north and eventually merged with a mid-latitude system near 40N 165E. It was finally no longer discernible as a separate entity by 210000Z.

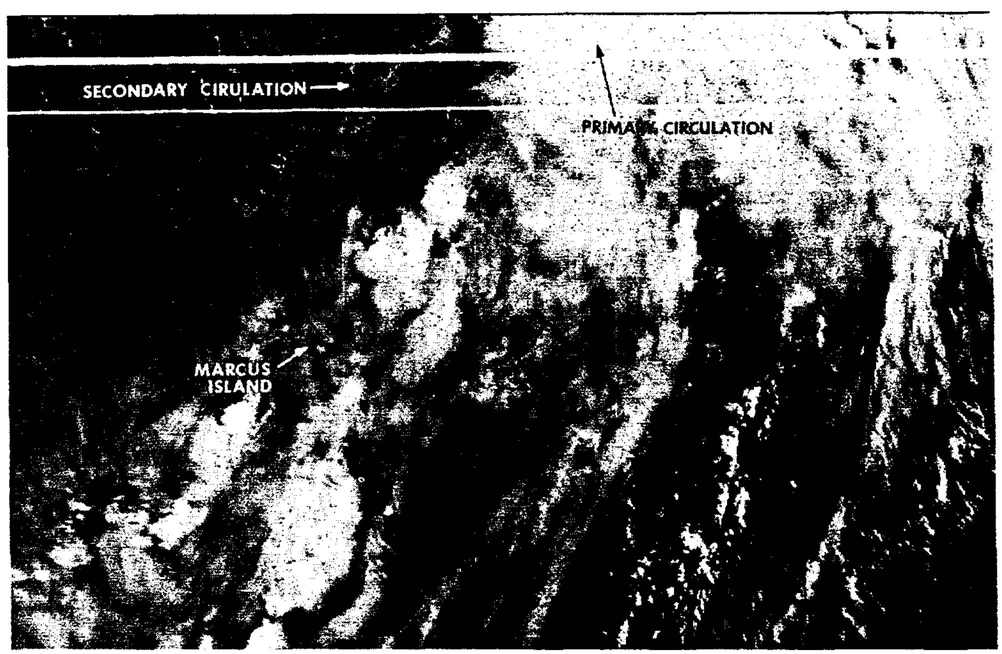
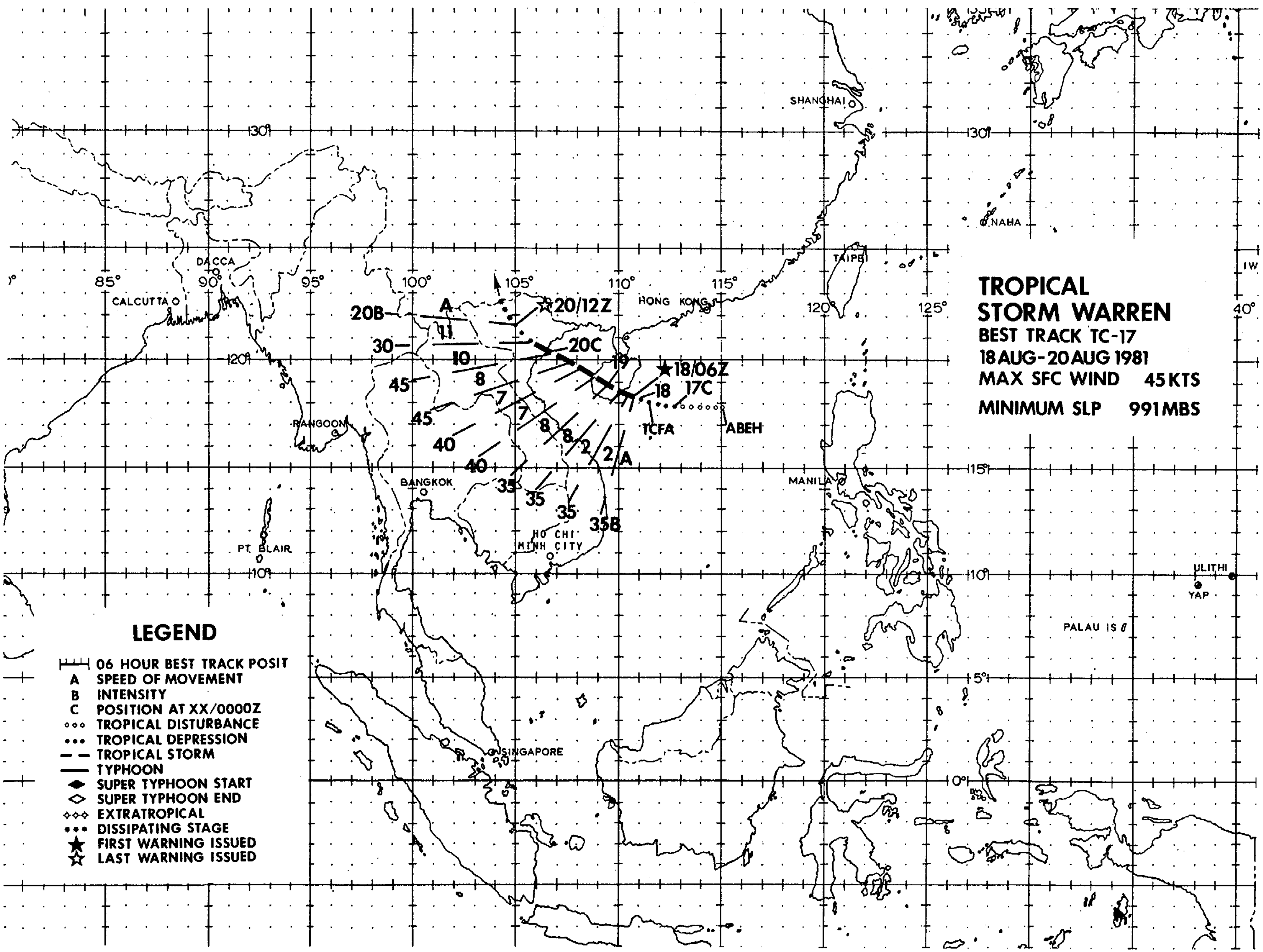


FIGURE 3-16-2. Satellite imagery for 162108Z, Aug 81 showing the exposed secondary circulation and the convective area associated with the developing TD-16 (Vanessa). (NOAA 6 visual imagery)


TROPICAL
STORM WARREN
BEST TRACK TC-17
18 AUG-20 AUG 1981
MAX SFC WIND 45 KTS
MINIMUM SLP 991 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
20/12Z
20C
18/06Z
17C
19
18
TCFA
ABEH
20B
30
45
45
40
40
35
35
35
35B
11
10
8
7
7
8
8
2
2
A
A
SHANGHAI
NAHA
TAIPEI
HONG KONG
DACCA
CALCUTTA
RANGOON
BANGKOK
HO CHI MINH CITY
PT. BLAIR
MANILA
SINGAPORE
ULITHI
YAP
PALAU IS
85°
90°
95°
100°
105°
110°
115°
120°
125°
30°
20°
15°
10°
5°
0°

The disturbance that eventually became Warren developed within a monsoon trough that extended across the South China Sea on the 14th of August. Strong vertical wind shear, caused by northeasterly flow at the 200 mb level, inhibited development of the circulation for the next three days. By the 17th of August the 200 mb wind field weakened, allowing upper level features to develop, surface pressures dropped below 1000 mb, and convective activity south of the disturbance center increased. Consequently a Tropical Cyclone Formation Alert was issued at 171500Z.

The system was initially tracking westward at 05 kt (9 km/hr) under the influence of mid-level easterlies generated by a stationary 500 mb anticyclone positioned over Southeast China. This anticyclone persisted throughout Warren's life cycle and its intensity changes were responsible for the variable speed of movement (between 2 kt (4 km/hr) and 5 kt (9 km/hr)) seen prior to the storm striking Hai-nan Island.

By 180600Z satellite imagery showed that Warren had developed an upper level outflow center and the first tropical storm warning was issued. Most of the convective activity was located south of the surface center as were the maximum surface winds. Synoptic and satellite data also indicated that Warren's vertical axis was tilted southward as he tracked over Hai-nan.

After passing over Hai-nan, Warren emerged into the Gulf of Tonkin. Warren continued to show indications of increased organization and intensification as he tracked over the warm water in the Gulf of Tonkin. At 1800Z on the 19th Warren reached his maximum intensity of 45 kt (23 m/sec) while over the Gulf (Fig. 3-17-1), a typical occurrence for most tropical cyclones that move into the Gulf of Tonkin. During the summer months the gulf water becomes extremely warm and thus provides excellent source of energy for transiting tropical cyclones.

Warren made landfall near Nam Dinh, Vietnam, on the 20th of August and weakened rapidly. The final warning on Warren was issued at 1200Z on the 20th as it began to dissipate over Vietnam.

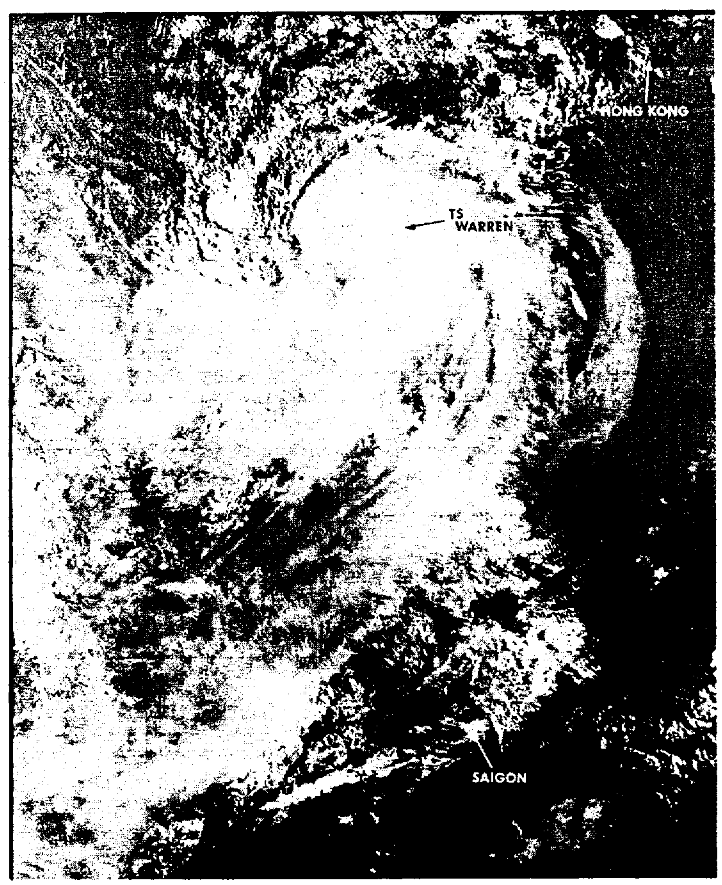
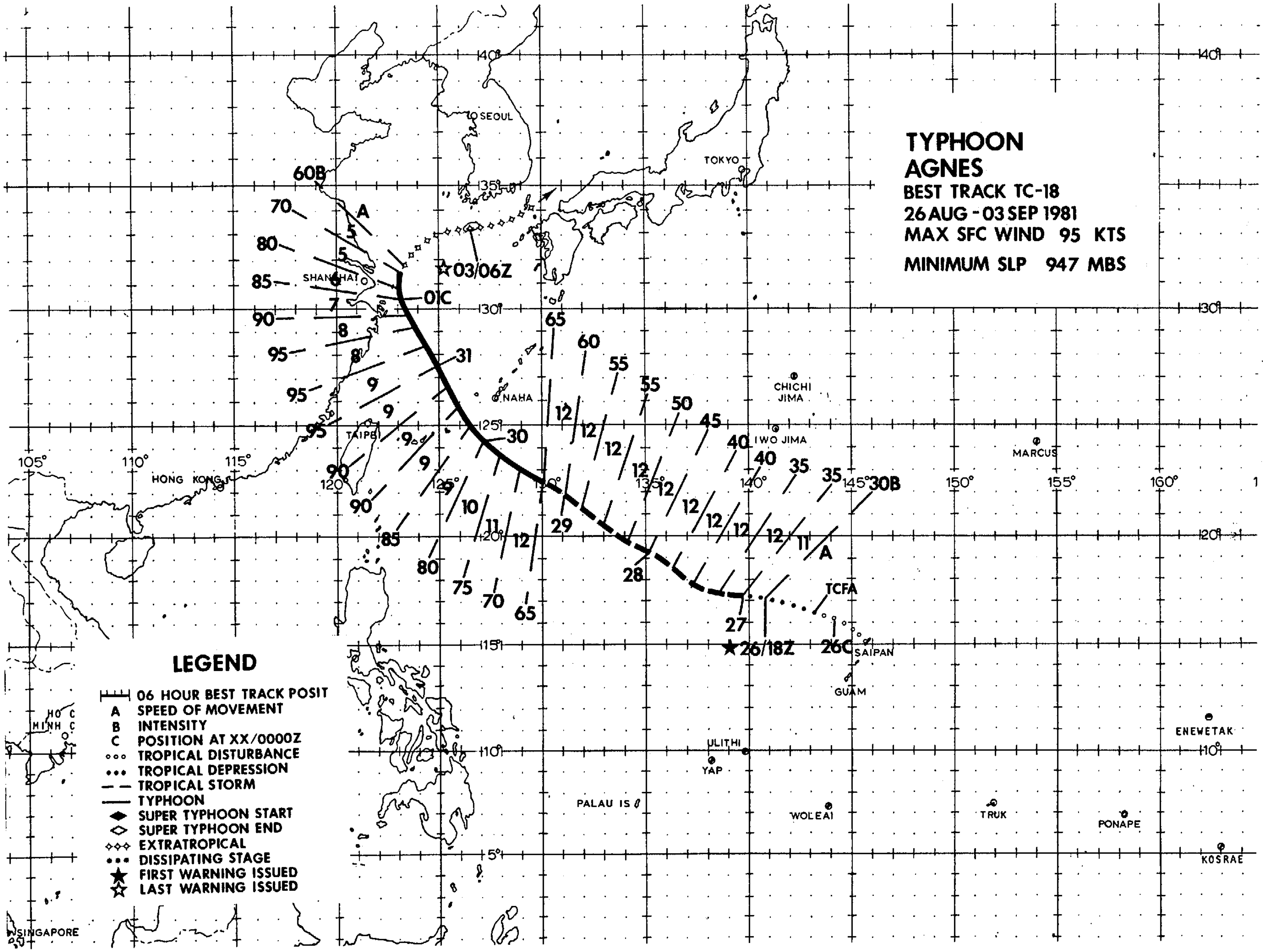


FIGURE 3-17-1. Tropical Storm Warren with maximum surface winds of 45 kt (23 m/sec) prior to landfall of 20 August, 0102Z. (NOAA 6 visual imagery)



TYPHOON
AGNES
BEST TRACK TC-18
26 AUG - 03 SEP 1981
MAX SFC WIND 95 KTS
MINIMUM SLP 947 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
SEOUL
TOKYO
SHANGHAI
NAHA
TAIPEI
HONG KONG
CHICHI JIMA
IWO JIMA
MARCUS
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
ENEWETAK
KOSRAE
HO CHI MINH C
SINGAPORE
03/06Z
01C
31
30
29
28
27
26/18Z
26C
TCFA
60B
30B

In mid-August, after several weeks of active cyclogenesis near Wake Island (WMO 91366) which spawned Tropical Storm Susan (14) and Vanessa (16), an upper-level ridge built over the latitudes north of the Marshall Islands and further activity was suppressed for several days. At 230000Z, satellite and upper-level wind reports showed evidence of an upper-level trough building westward from the dateline and during the next 36 hours, a well-defined Tropical Upper Tropospheric Trough (TUTT) cyclone developed in the vicinity of Wake Island. This upper cyclone induced an area of extensive, but yet unorganized, convection southwest of the TUTT cyclone. Gradually, as the convective area moved westward, a weak upper-level anticyclone became evident northeast of Guam. Concurrently, at 251200Z, the mid-tropospheric winds reported from Guam became northerly, and 12 hours later, shifted to southeasterly as the system moved just north of Guam. On 26 August, while a reconnaissance aircraft conducted the initial investigation of the developing system, the 260000Z synoptic data indicated a possible low-level center approximately 150 nm (278 km) northwest of Guam. Based on these data, a Tropical Cyclone Formation Alert was issued at 260500Z and, at 260807Z, the investigating aircraft located a 1006 mb surface center 215 nm (398 km) northwest of Guam. During the subsequent period, satellite imagery showed improving convective organization and, at 261800Z, the first warning was issued for Tropical Depression 18. (Figure 3-18-1 shows TD-18 shortly after the first warning was issued).

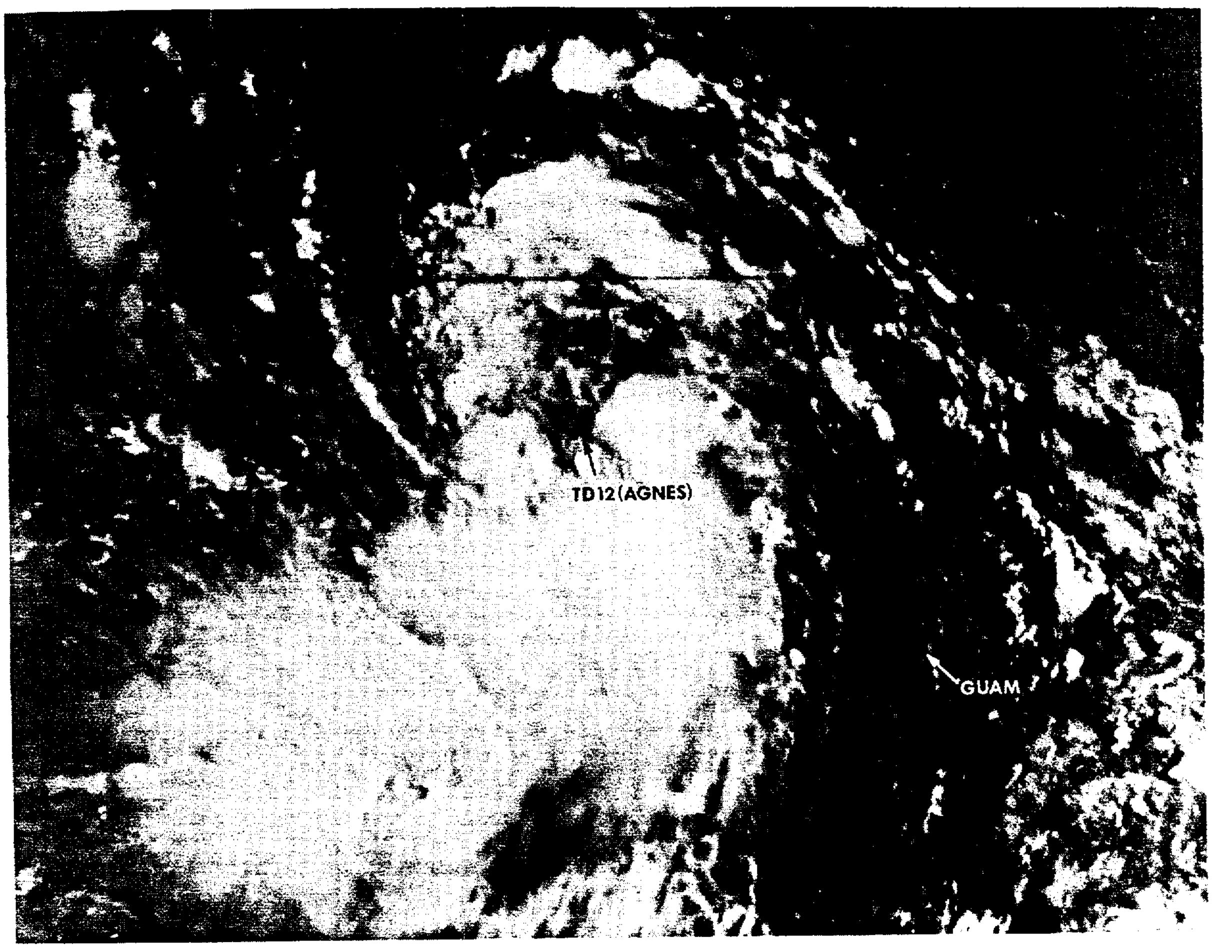


Figure 3-18-1. Tropical Depression 16 at 262221Z AUG located 360 nm (667 km) west-northwest of Guam. This imagery shows a partially exposed low-level circulation on the north side of an extensive area of convection. (NOAA 6 visual imagery)

At 270600Z, TD-18 was upgraded to Tropical Storm Agnes when aircraft reconnaissance data showed a 994 mb sea level pressure at the center and measured winds of 46 kt (24 m/sec) at flight level (1500 ft (472 m)). The first three warnings on Agnes (TD-18) forecast a westward trajectory toward the Bashi Channel, south of Taiwan. However, by 271200Z, the analyses and numerical prognostic series indicated that the 500 mb ridge north of Agnes had not built, and would not build as far west as originally thought. Thus, the forecast track was changed to a more northwestward direction toward Okinawa. While moving toward the west-northwest and intensifying along climatological norms, Agnes was upgraded to a typhoon on the 290000Z warning. At 300600Z, Agnes passed 90 nm (167 km) southwest of Okinawa and then began a turn toward the north along the western periphery of the subtropical ridge. (Figure 3-18-2 shows Agnes south of Okinawa with maximum winds of 85 kt (44 m/sec) and intensifying). At 310000Z, 170 nm (315 km) northwest of Okinawa, Agnes reached a peak intensity of 95 kt (49 m/sec) which was maintained for 12 hours then, after 311200Z, all available data indicated that Agnes had begun a weakening trend.

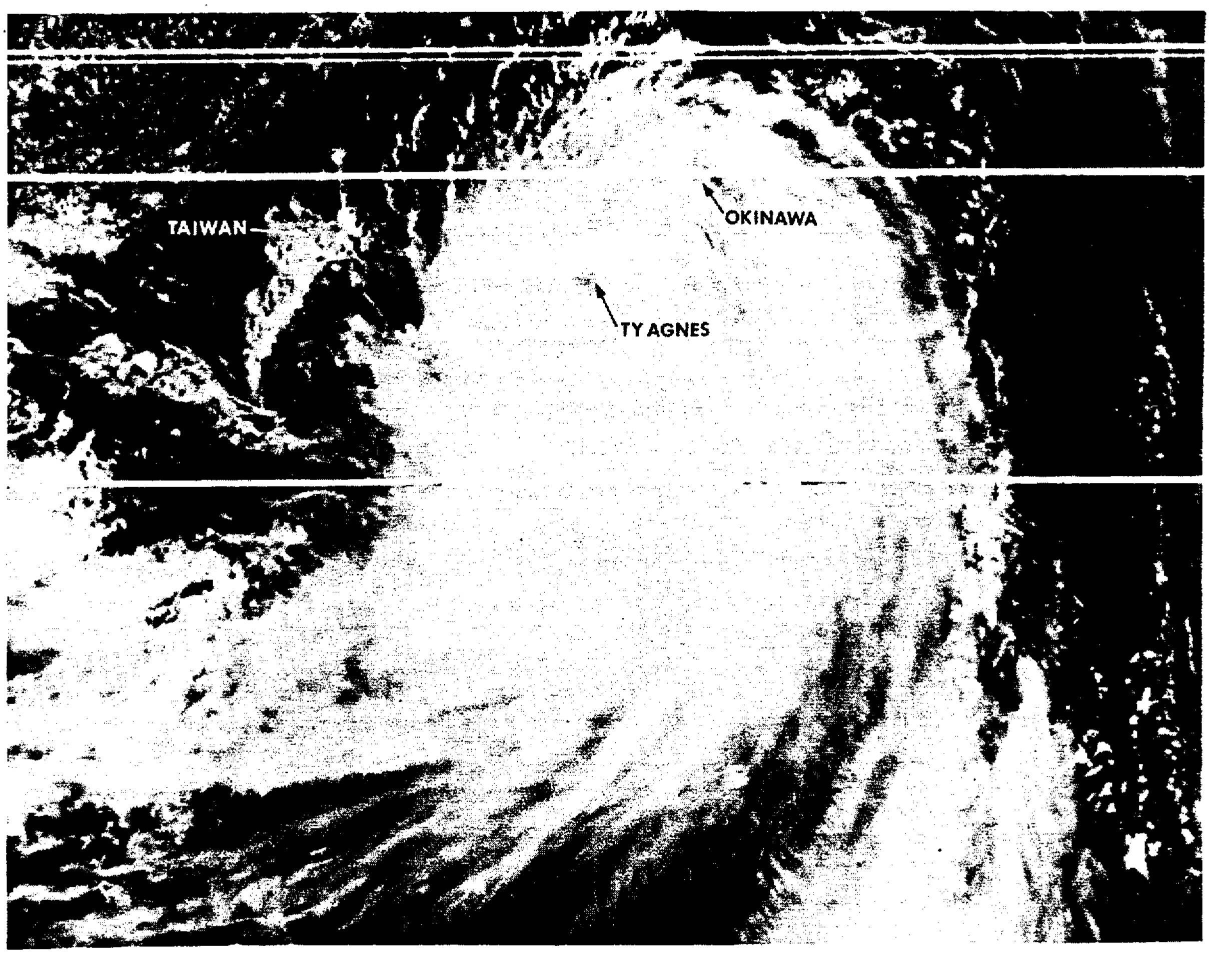


Figure 3-18-2. Typhoon Agnes (200548Z AUG), located just south of Okinawa, with maximum winds of 85 kt (44 m/sec) and approaching her maximum intensity of 95 kt (49 m/sec). Agnes had developed a large banding eye which later imagery and aircraft data would show as a much more compact central feature. (NOAA 7 visual imagery)

Prior to 020600Z September, the forecast scenario had anticipated Agnes would interact with a mid-latitude trough south of Korea and then accelerate northeastward. However, as Agnes moved north of 30N, there was no evidence of the anticipated acceleration; instead, there was increasing evidence that Agnes was losing much of her deep-layered convection and a premature extra-tropical transition was underway. (Figure 3-18-3 shows the 010000Z September 200 mb and 500 mb streamline pattern near Agnes). As Figure 3-18-3 indicates, there were significant opposing mid- and upper-level currents over Agnes and by 01C900Z, satellite imagery showed the last evidence of an upper-level circulation pattern over Agnes. In post-analysis it was determined that Agnes had lost much of her tropical characteristics by 011800Z. However, since there were no aircraft or synoptic data close to Agnes to confirm this apparent transition, warnings were maintained until 030600Z at which time synoptic data from Jeju-Do (WMO 47184) confirmed Agnes' character and that the threat as a significant tropical cyclone to Korea and Japan had passed. Although the system remained well south of Korea until 3 September, much of the southern portion of South Korea was being inundated with the heaviest recorded rainfalls in this century, up to 28 inches (approximately 71 cm). This adverse weather preceded the low-level center as the heavy rains and thunderstorms were sheared northeastward over Korea. Because most of the earlier forecasts had predicted Agnes moving over this region by this time, much of the potential damage from these rains may have been averted by the precautions taken well before the heavy rainfalls and flooding began. Finally, as a relatively weak wind system, the extratropical remains of Agnes passed through the Korea Straits and into the Sea of Japan on 3 and 4 September without any known reports of significant wind or sea damage in the region.

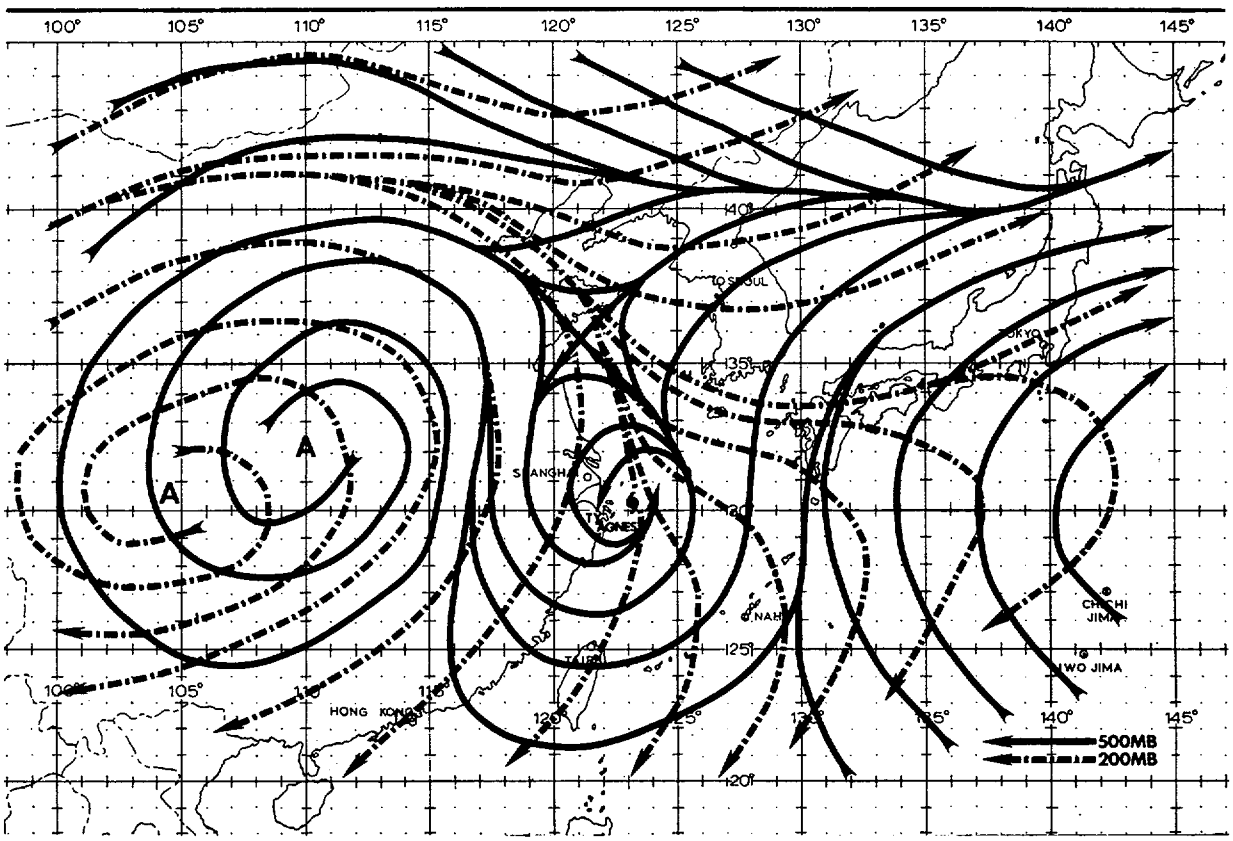
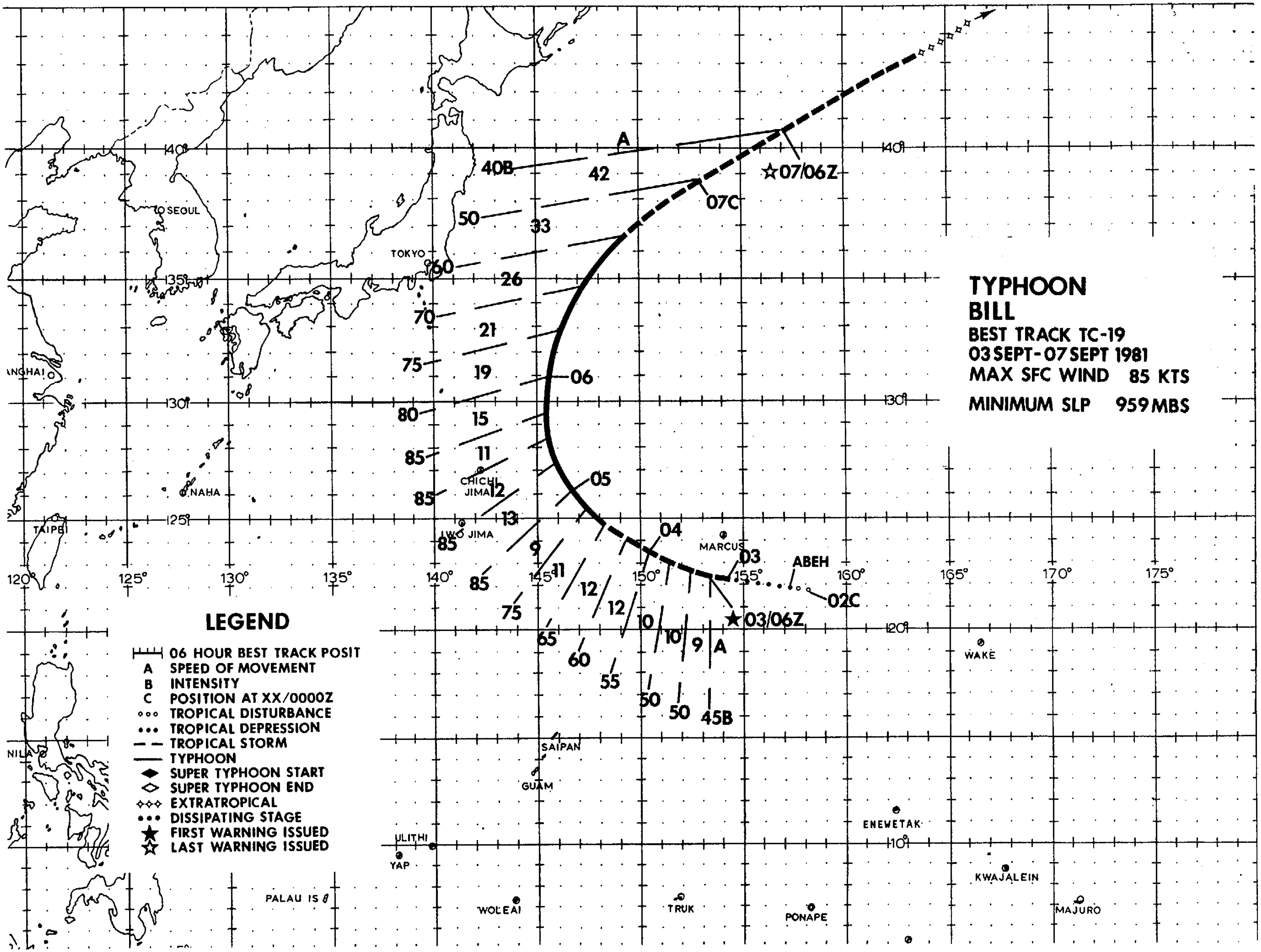


Figure 3-18-3. At 010000Z SEP, Typhoon Agnes was located near 30.2N 123.2E with maximum winds of 85 kt (44 m/sec). However, a strong 200 mb flow of 40 to 50 kt (21 to 31 m/sec) was evident over the 500 mb circulation. This pattern, already underway for 24 hours, continued for the next 36 hours during which Agnes lost her tropical characteristics and weakened to a weak extratropical cyclone.



TYPHOON
BILL
BEST TRACK TC-19
03 SEPT - 07 SEPT 1981
MAX SFC WIND 85 KTS
MINIMUM SLP 959 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
07/06Z
07C
06
05
04
03
02C
03/06Z
ABEH
SEOUL
TOKYO
NAHA
TAIPEI
CHICHI JIMA
IWO JIMA
MARCUS
SAIPAN
GUAM
WAKE
ENEWETAK
KWAJALEIN
MAJURO
PONAPE
TRUK
WOLEAI
YAP
ULITHI
PALAU IS

Without the benefit of satellite data Typhoon Bill may have gone undetected since the initial disturbance formed 295 nm (546 km) east-southeast of Marcus Island (WMO 47991) and only came within 120 nm (222 km) of that island at 0600Z on 3 September. The disturbance was never discernible in the synoptic data observations from Marcus Island.

Bill remained a compact system throughout its duration. Figures 3-19-1 thru 3-19-4 illustrate the life cycle of Bill from a time near the first warning until its final hours.

The steering for Bill was provided by the flow around the mid-tropospheric sub-tropical anticyclone to the east. Speed of advance (SOA) forecasts were particularly good during the period of Bill's recurvature and eventual extratropical transition when Bill gradually entrained into the mid-latitude mid- and upper-level westerlies. Using a method developed by Burroughs and Brand (1973), operational SOA forecasts were extremely close to the post-storm analysis values.

Unlike larger storms which tend to create their own environment and move sub-tropical systems out of their way, Bill reacted to the environment and maintained a tight gradient between himself and the anticyclone until he was north of 28N at 051200Z, where weakening began. Once this occurred, the maximum observed wind speeds correlated quite well with the wind/pressure relationship of Atkinson and Holliday until extratropical transition occurred.

First detected at 010000Z September, Bill's convection covered a small area, approximately 150 nm (278 km) in diameter, and had an associated small mid-level cyclonic circulation. This mid-level system slowly built down to the surface and then deepened rapidly. Environmental pressures were generally near 1009 mb; however, aircraft reconnaissance at 030807Z found a 993 mb central pressure and winds of 70 kt (36 m/sec) northeast of the center. The Atkinson and Holliday (1977) wind/pressure relationship indicates that a 993 mb central pressure would support a mean maximum wind of 45 kt (23 m/sec). The higher wind speed in Bill was the result of an extremely tight pressure gradient between the storm and a subtropical ridge to the northeast.

FIGURE 3-19-1. Tropical Storm Bill at 50 kt (26 m/sec) intensity, 3 September 1981, 1605Z. This imagery shows that Bill was a compact system in the early stages. (NOAA 7 infrared imagery)

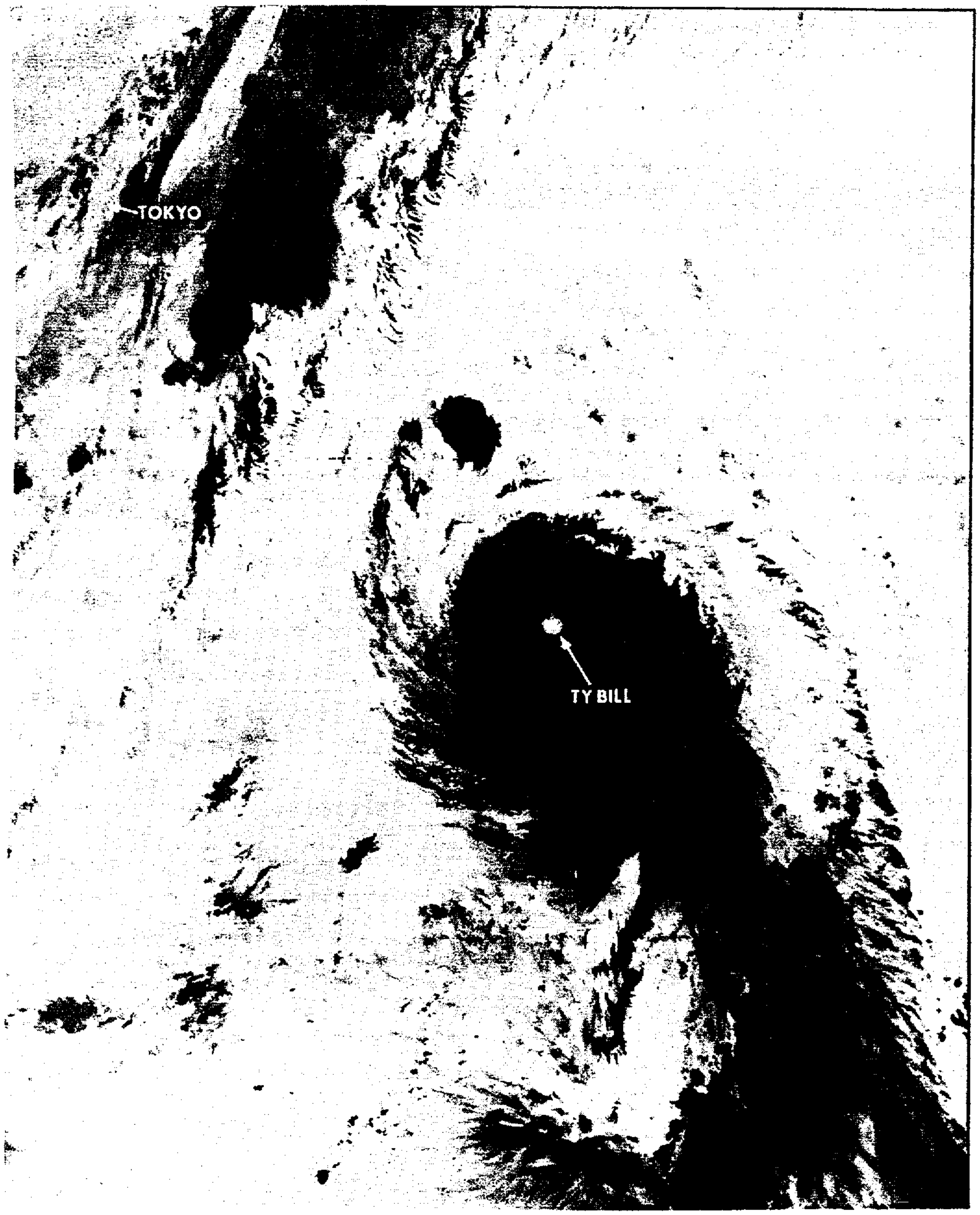


FIGURE 3-19-2. Typhoon Bill at 85 kt (44 m/sec) intensity, 5 September 1981, 1724Z. This imagery shows Bill at peak intensity has remained a compact system. (NOAA 7 infrared imagery)

FIGURE 3-19-3. Typhoon Bill at 75 kt (39 m/sec) intensity, 6 September 1981, 0428Z. Here Bill is beginning to entrain cold air from the frontal system to the north. (NOAA 7 visual imagery)

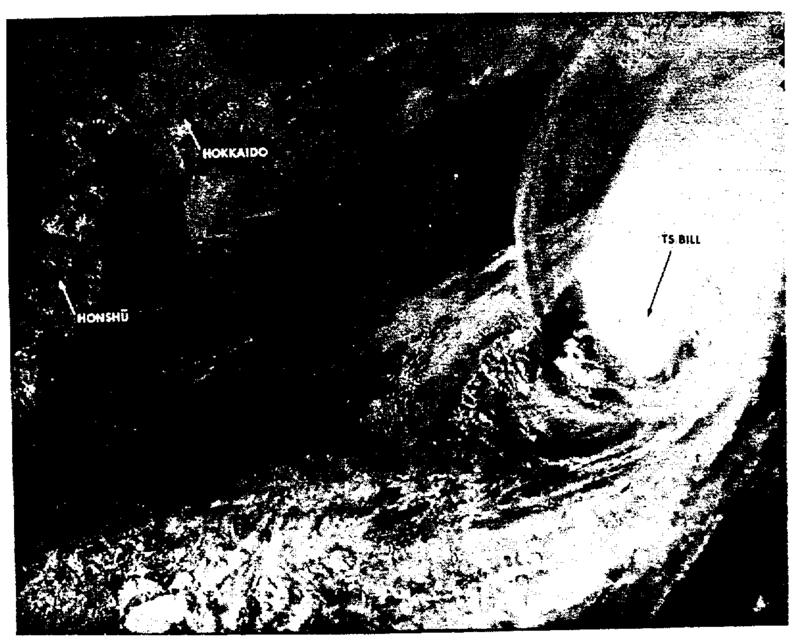
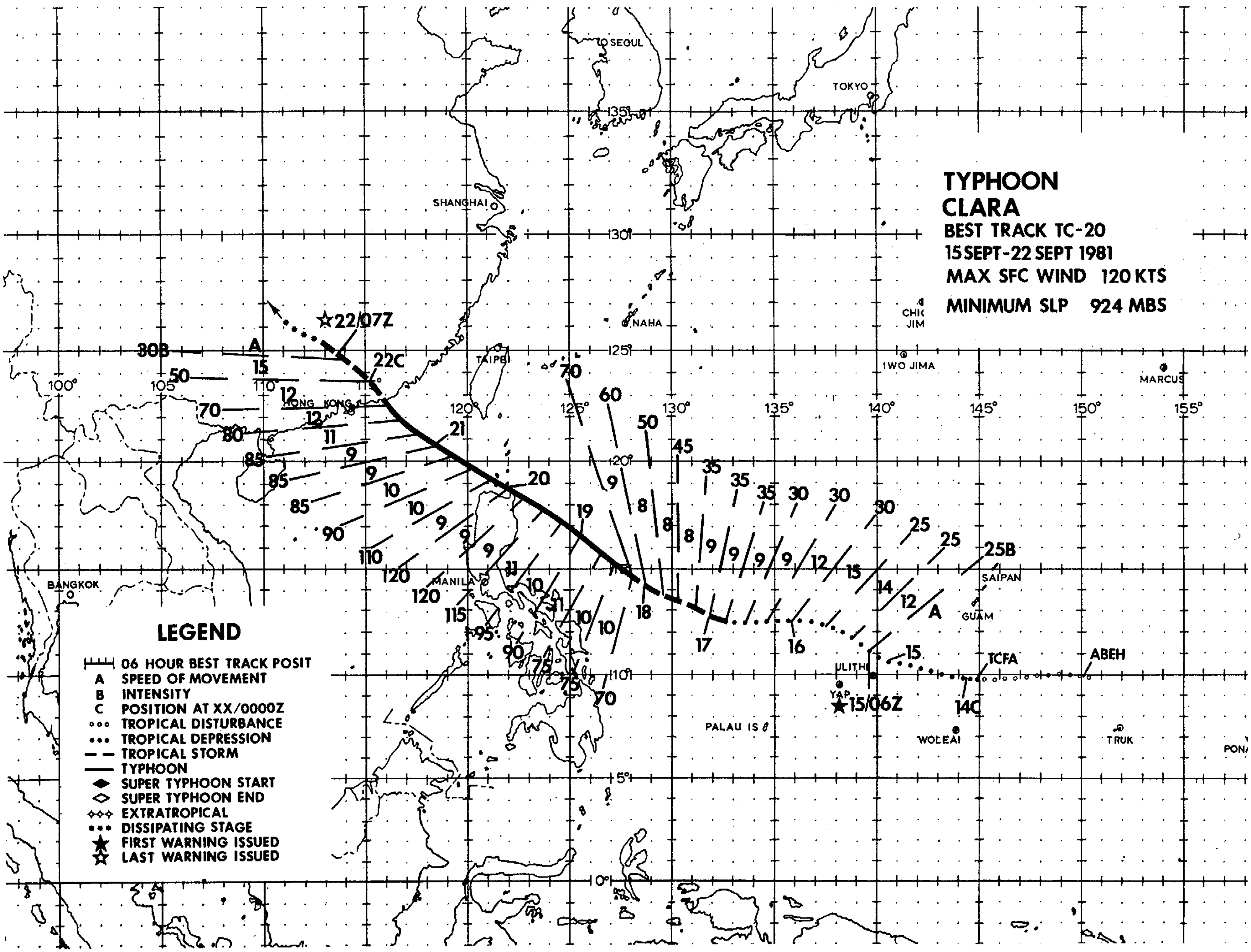


FIGURE 3-19-4. Tropical Storm Bill at 40 kt (20 m/sec) intensity, 7 September 1981, 0416Z. This imagery shows Bill just prior to the issuance of the last warning and the extratropical transitioning is almost complete. (NOAA 7 visual imagery)


TYPHOON
CLARA
BEST TRACK TC-20
15 SEPT-22 SEPT 1981
MAX SFC WIND 120 KTS
MINIMUM SLP 924 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
SEOUL
TOKYO
SHANGHAI
NAHA
TAIPEI
HONG KONG
MANILA
BANGKOK
IWO JIMA
MARCUS
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
TCFA
ABEH
22/07Z
15/06Z
22C
14C
30B
25B

Clara was first detected on satellite imagery at 1600Z, 11 September near Ponape as an area of concentrated convection embedded within the monsoon trough. No development was noted during the next two days as the disturbance tracked westward at 9 kt (16 km/hr).

A Tropical Upper Tropospheric Trough (TUTT) had been evident on the satellite imagery and was analyzed from synoptic data on the 200 mb streamline analysis northwest of Guam for several days. This feature had induced a large area of upper level divergence in the vicinity of the disturbance while some troughing and vertical wind shear were induced by a second TUTT cell analyzed to the northeast of the disturbance. The relative position of the disturbance to the upper level feature prevented significant development by restricting available outflow channels.

As Clara continued westward and moved past the trough axis it became apparent that the potential for significant development would increase as it moved into the upper level divergent area induced by the TUTT northwest of Guam. Satellite imagery at 131800Z showed increased convection and organization while synoptic reports indicated surface winds of 15 kt (8 m/sec) near the center of the convection. As a result a Tropical Cyclone Formation Alert (TCFA) was issued at 131935Z.

During the next 24 hours Clara remained under the upper level trough and further development was not evident based on satellite imagery during 13-14 September. However, near the end of the initial 24 hour period, convection flared up and the disturbance began moving west of the trough so the TCFA was re-issued at 141923Z.

After passing about 210 nm (389 km) south of Guam, slow but steady intensification took place as a 200 mb anticyclone became evident over the disturbance based on streamline analysis on 15 September. The first warning was issued at 150600Z with a straight westerly forecast track based on the 500 mb steering flow induced by a mid-tropospheric ridge north of Clara. Clara continued to track west-northwest and attained tropical storm intensity by 161800Z.

The warnings issued between 15 and 18 September continued to forecast Clara to take a westward track to eventually cross Luzon while, in fact, Clara was moving west-northwest. The forecast reasoning appeared sound based upon synoptic analyses that depicted a large sub-tropical ridge to the north of Taiwan, producing a strong easterly 500 mb steering flow over Clara. However, streamline analysis of the 500 mb chart on the 18th showed a weakness in the ridge west of Taiwan with a second anticyclone over southeast China. As a result of this new analysis, future forecast tracks steered Clara towards the break in the ridge with eventual recurvature west of Taiwan in response to the deepening trough moving into southeast China.

Figure 3-20-1. Typhoon Clara at 0521Z, 19 September 1981, at 115 kt (58 m/sec), 16 hours before crossing the northern tip of Luzon. (NOAA 7 visual imagery)

During this same period Clara had intensified rapidly as she attained her maximum surface winds of 120 kt (60 m/sec) six hours prior to crossing the northern tip of Luzon at 192200Z (Figures 3-20-1 and 3-20-2). Upon entering the South China Sea it became apparent that Clara was not going to recurve because the anticyclone over southeast China had moved northeast displacing the weakness west of Taiwan and preventing recurvature to the north. Clara responded to these changes and remained on a northwest track making landfall 140 nm (259 km) east-northeast of Hong Kong at 212000Z. After making landfall Clara dissipated rapidly as she accelerated inland into hilly terrain.

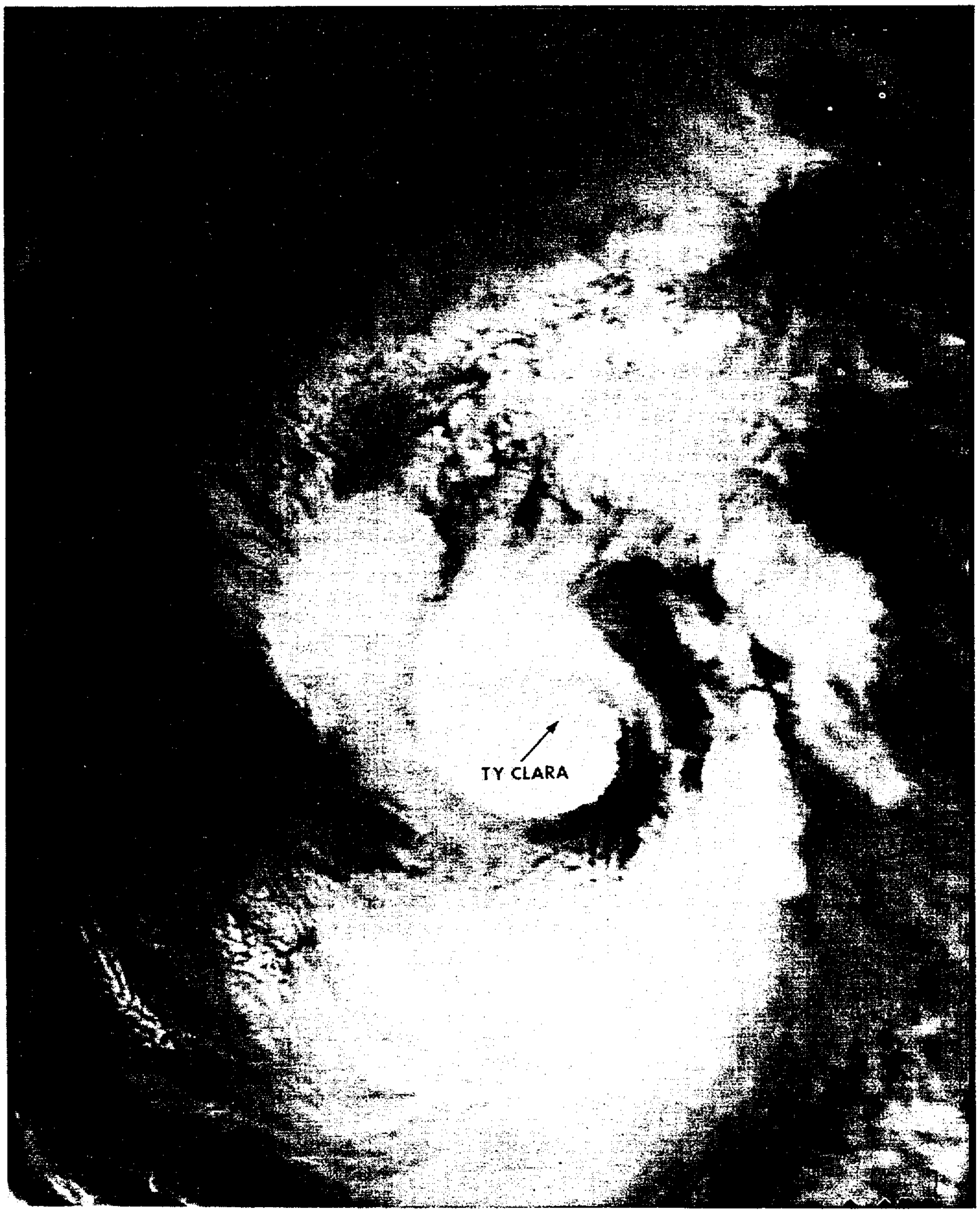


Figure 3-20-2. Typhoon Clara at 1937Z, 20 September 1981, at 85 kt (43 m/sec), about 24 hours after crossing the northern tip of Luzon and approximately 360 nm (667 km) northwest of Manila. (NOAA 7 infrared imagery)

Clara was a devastating storm as she crossed northern Luzon causing widespread damage and loss of life in eight northern Luzon provinces. Torrential rains caused floods which left thousands homeless and caused extensive damage to property and crops. A Philippine Navy destroyer and a cargo ship sank 330 nm (661 km) north of Manila leaving 68 persons missing (Fig. 3-20-3).

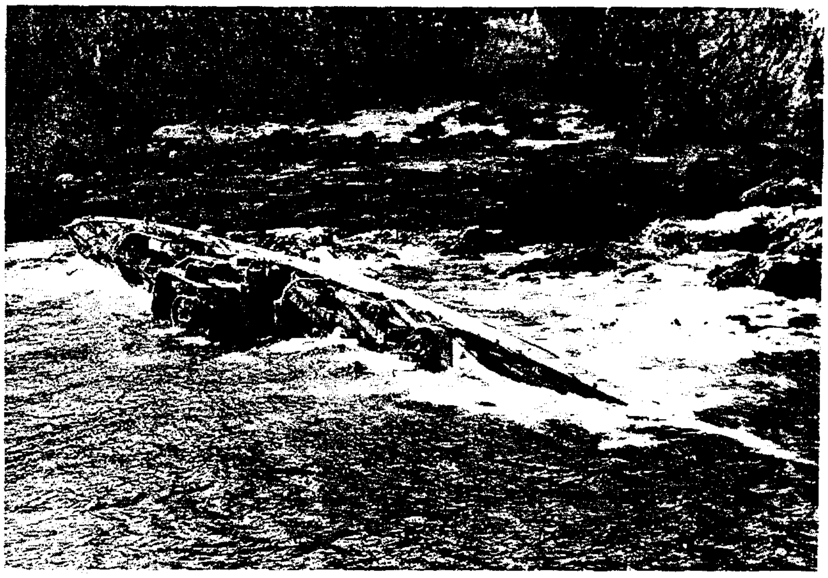
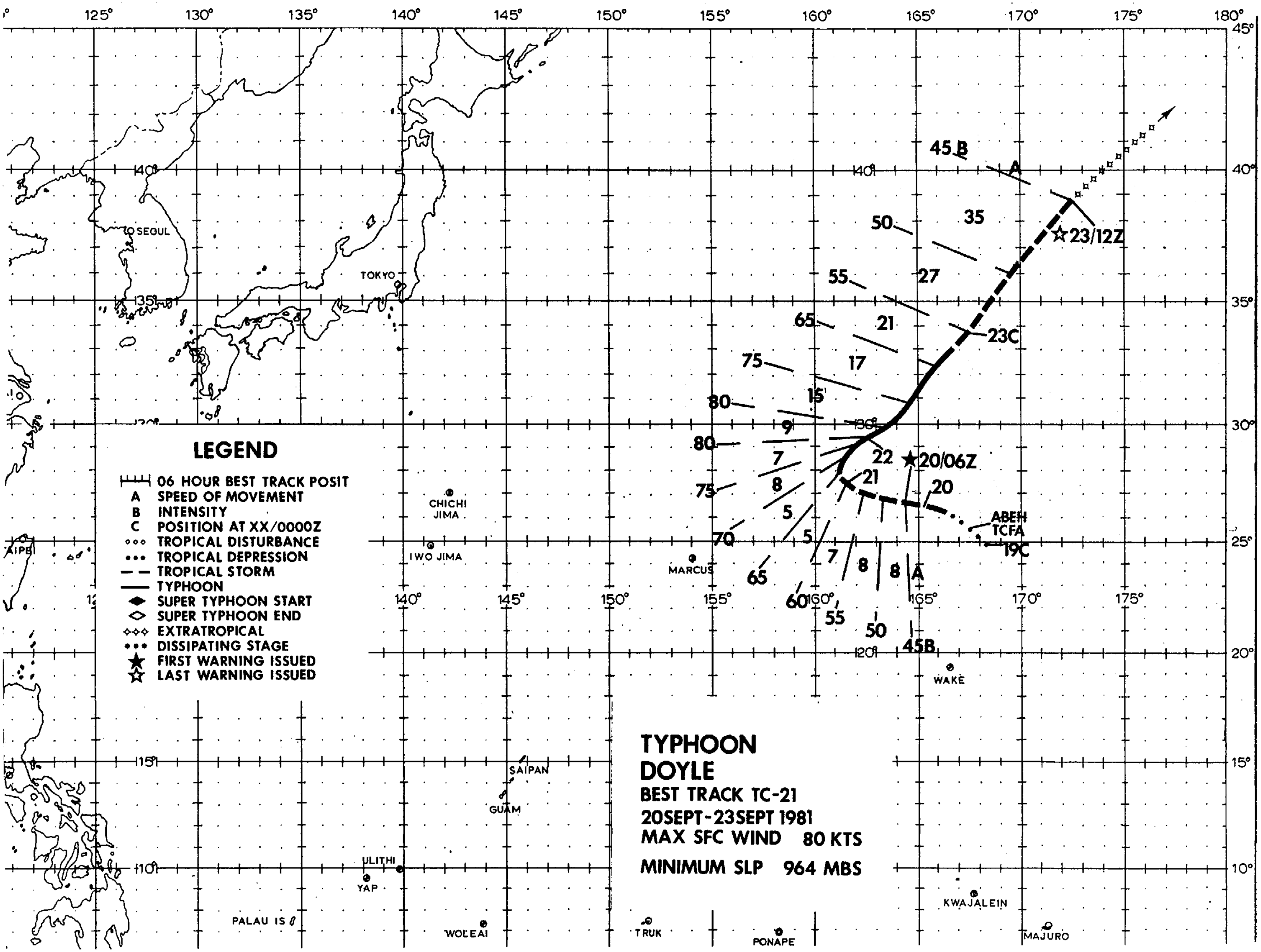


Figure 3-20-3. U. S. Navy personnel are seen on board the Philippine Navy Destroyer Datu Kalantigaw during recovery operations. The destroyer was forced aground on Calagan Island by Typhoon Clara. (U. S. Navy Photo by PH2 P. B. Soutar)


LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TYPHOON
DOYLE
BEST TRACK TC-21
20SEPT-23SEPT 1981
MAX SFC WIND 80 KTS
MINIMUM SLP 964 MBS
SEOUL
TOKYO
CHICHI JIMA
IWO JIMA
MARCUS
WAKE
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
KWAJALEIN
MAJURO
ABEH
TCFA
20/06Z
23/12Z
23C
19C
20
21
22
45B
45 B
50
55
60
65
70
75
80
35
27
17
15
9
7
8
5
125°
130°
135°
140°
145°
150°
155°
160°
165°
170°
175°
180°
45°
40°
35°
30°
25°
20°
15°
10°

Typhoon Doyle was the second midget storm of the 1981 season and followed (Typhoon Bill (19), the first of the midget storms) by less than three weeks. Doyle and Bill were very similar in size, intensity and track. Doyle was also unusual in that all of the warnings were based on satellite imagery analysis.

Doyle was first detected as an apparent mid-to-upper-level disturbance early on 18 September near 25N 178E. The disturbance built down to the surface as it drifted westward at 8 kt (15 km/hr). A Tropical Cyclone Formation Alert was issued at 190600Z when low-level cumulus banding became apparent on satellite imagery. The first warning was issued at 200600Z based upon Dvorak analysis of visual satellite data which indicated that Tropical Storm Doyle had an estimated intensity of 35 kt (18 m/sec).

Doyle initially tracked west-northwest then recurved around a mid-tropospheric anticyclone. As Doyle recurved he became entrained in strong westerlies and accelerated rapidly northeastward. Doyle then started to weaken over the cooler waters north of 30N, finally losing tropical characteristics near 39N 172E when the system merged with an existing front. Typhoon Doyle was never larger than 180 nm (333 km) in diameter, even though the maximum intensity was 80 kt (41 m/sec) (Fig. 3-21-1).

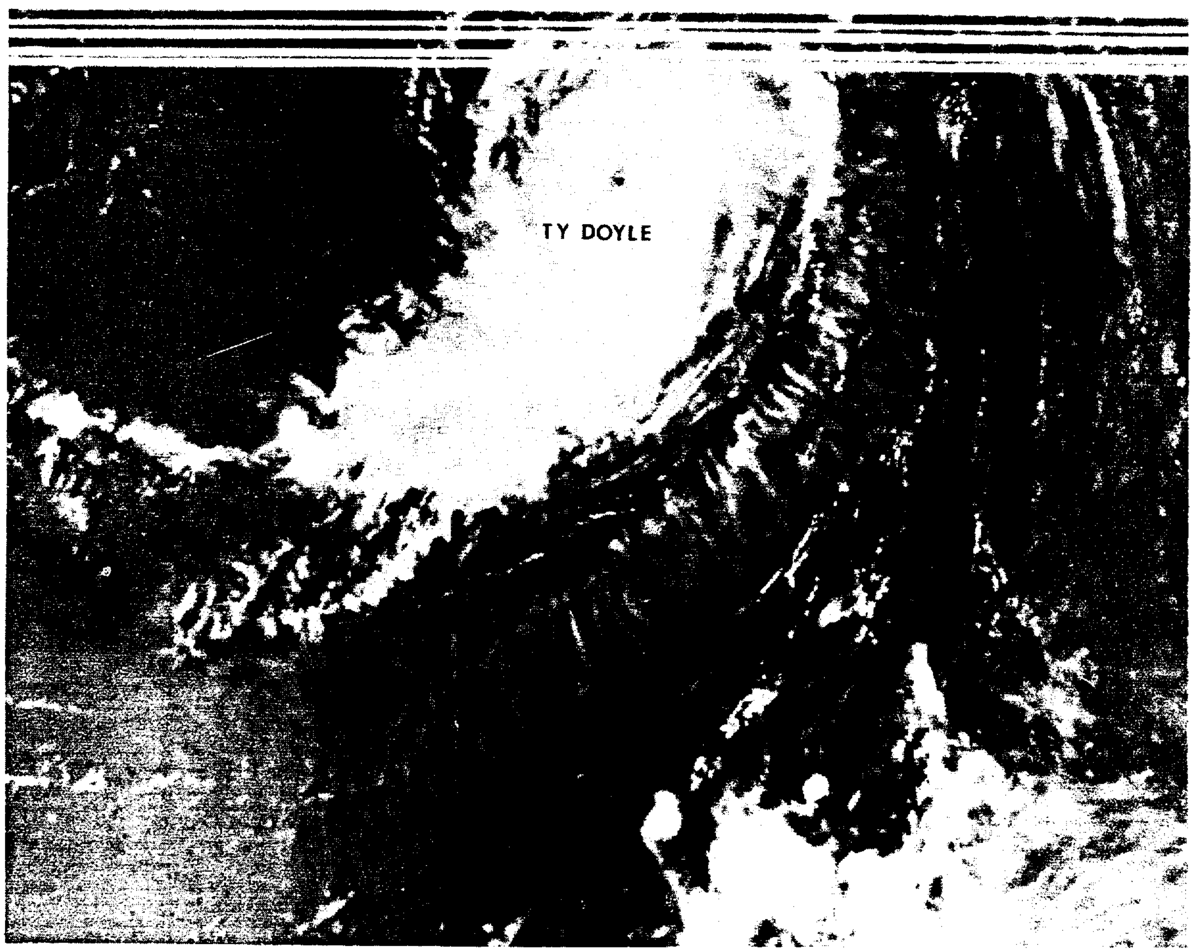
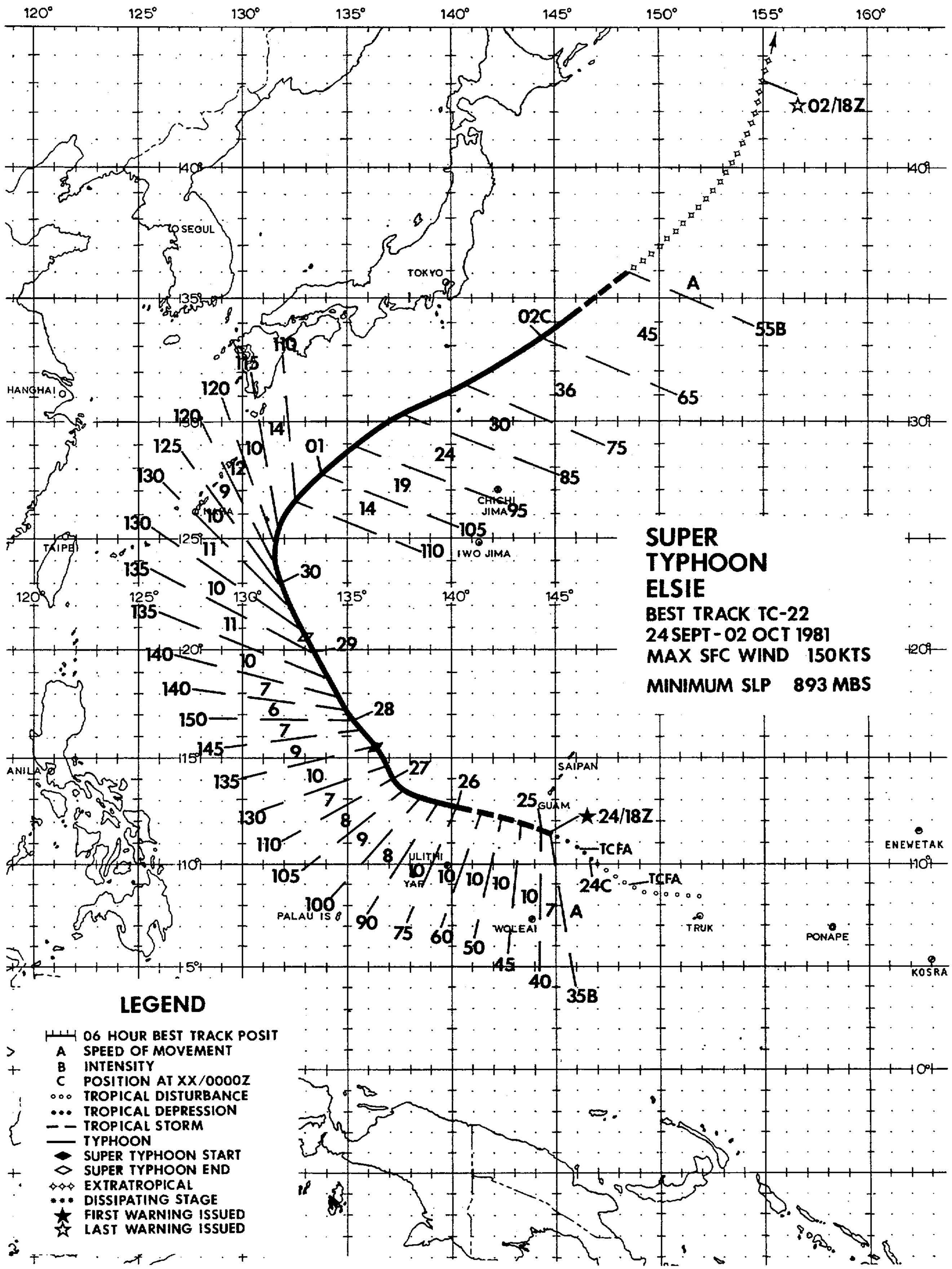


Figure 3-21-1. Doyle's compact size is graphically illustrated in this 210317Z satellite data. Note the well developed eye. At this time, Doyle was approximately 400 nm (741 km) northeast of Marcus Island. (NOAA 6 visual imagery)


SUPER
TYPHOON
ELSIE
BEST TRACK TC-22
24 SEPT - 02 OCT 1981
MAX SFC WIND 150KTS
MINIMUM SLP 893 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
02/18Z
24/18Z
TCFA
SEOUL
TOKYO
HANGHAI
TAIPEI
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
ENEWETAK
KOSRA

Following the northward progression of Typhoons Clara (20) and Doyle (21), the near equatorial trough became very weak and diffuse with very few areas of concentrated convection during 19 and 20 September 1981. By 210600Z two areas of significant convection, one near 10N 170E and the other near 5N 155E, signaled the re-establishment of substantial activity. The signal, however, appeared to be false, as convection along the trough dropped dramatically during the subsequent twenty-four hours. One small convective area, approximately one degree in diameter, remained near 8N 150E at 220600Z and surface/gradient level wind data at 220000Z identified a weak but well defined associated circulation. At 230700Z an initial Tropical Cyclone Formation Alert (TCFA) was issued for this convective area following further definition of the disturbance by satellite data which showed a fairly well organized upper-level anticyclone (ULAC) located above the low-level circulation. This action was taken despite the failure of aircraft reconnaissance to find anything significant. A second TCFA was issued at 240700Z, following a more successful aircraft reconnaissance mission which did locate the low-level circulation. Continued improvement of the satellite image, supported by the aircraft findings, culminated in the issuance of the first warning on TD-22 at 241800Z.

In retrospect, Elsie (Fig. 3-22-1) was a very well behaved cyclone. The major pro-

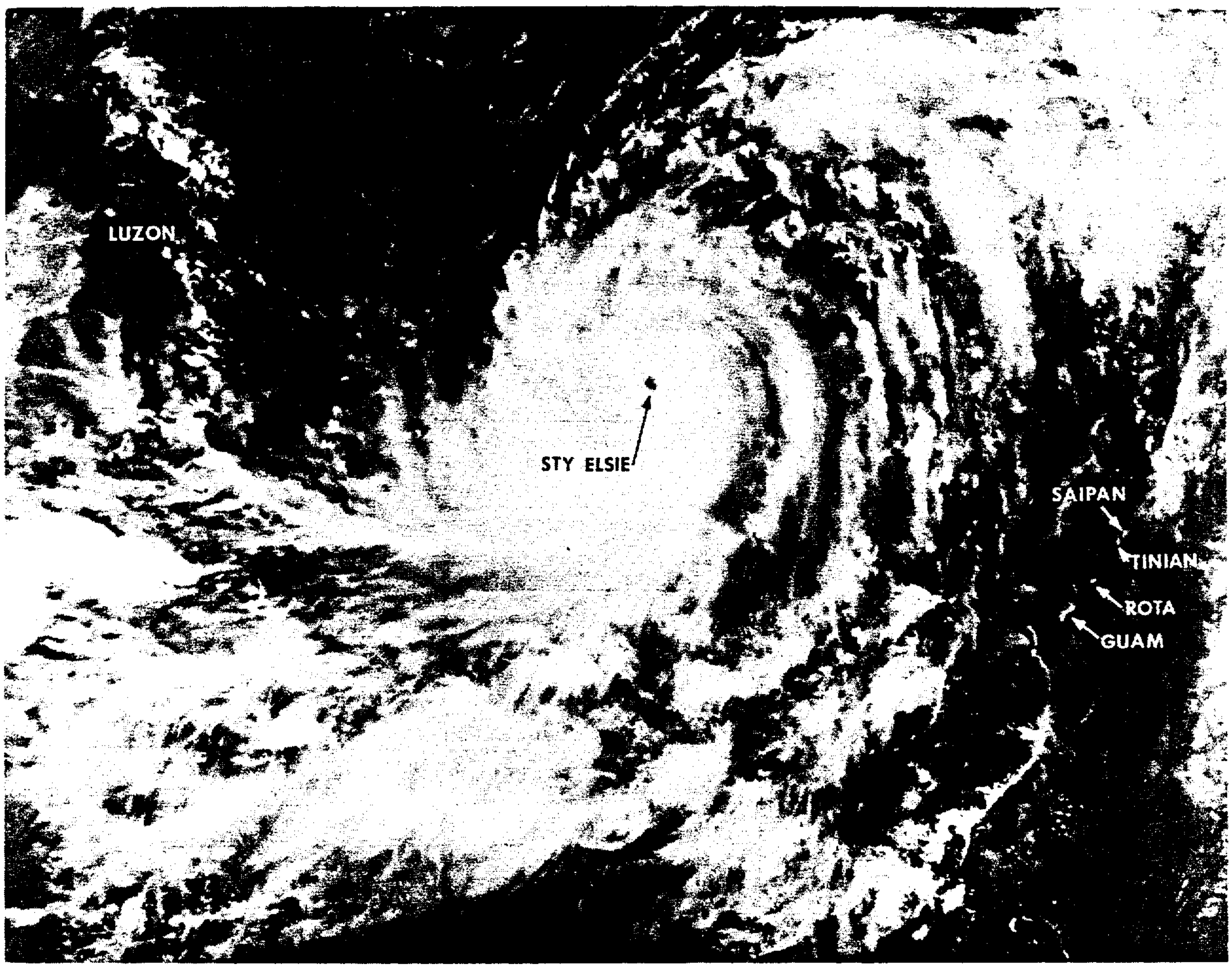


Figure 3-22-1. This 280520Z satellite photo shows Super Typhoon Elsie just after reaching a peak intensity of 150 kt (77 m/sec). At this time Elsie was located 615 nm (1139 km) west-northwest of Guam. (NOAA 7 visual imagery)

blem faced by JTWC was one of timing the significant segments (Fig. 3-22-2) of Elsie's track, each of which represents a different response to the surrounding environment. The approach of this discussion will be to evaluate each segment of the track, the apparent forecast reasoning at the time, and the performance of the one way interactive tropical cyclone model (OTCM) in predicting progression into the next segment.

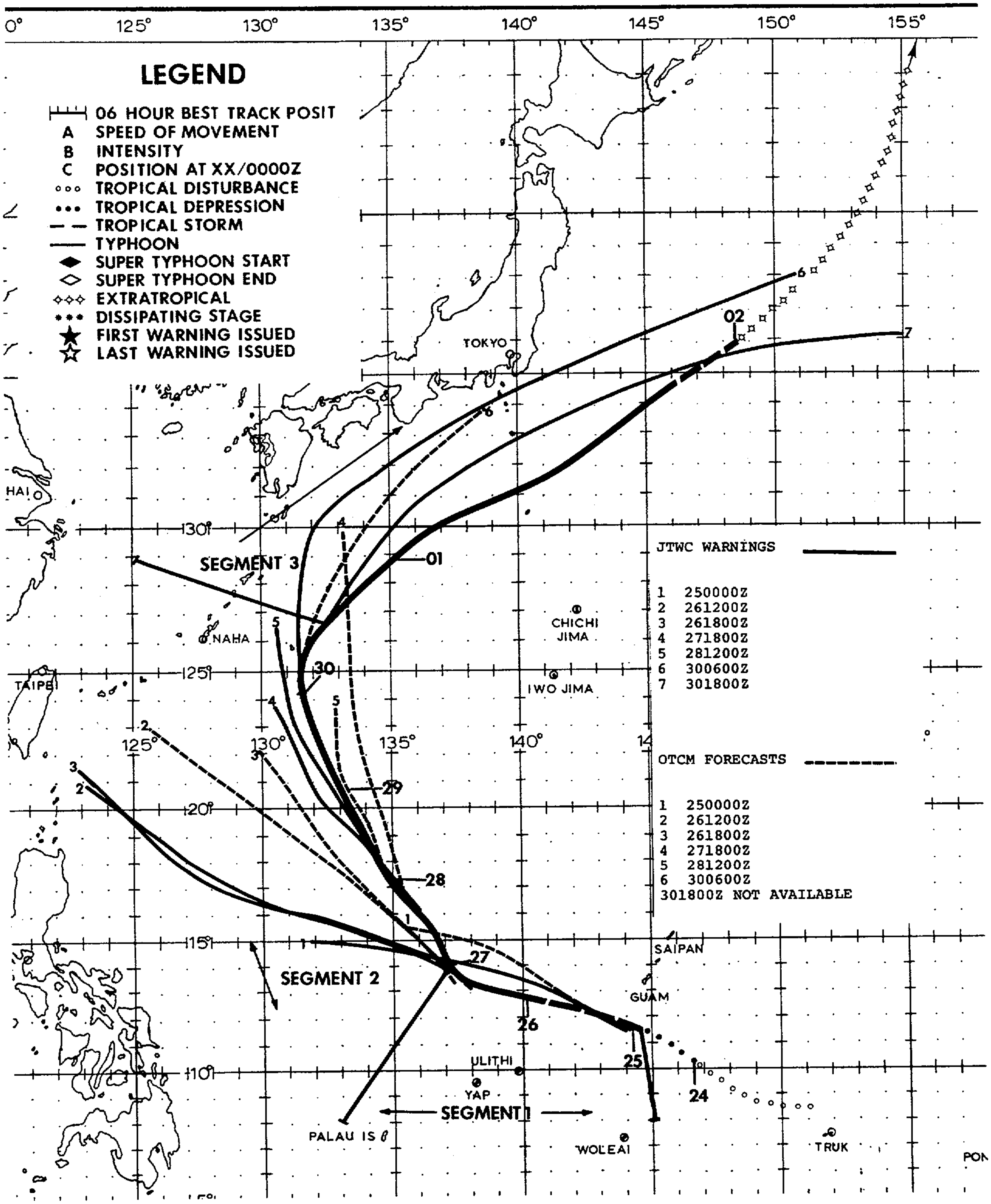


Figure 3-22-2. Elsie's best track overlayed with JTWC and OTCM forecasts. Forecasts illustrated here bracket significant changes in Elsie's direction of movement.

Segment #1 (241800Z - 261800Z Sep 81): During this period, which begins with the issuance of the first warning, the JTWC 500 mb analysis placed the subtropical ridge axis between 20N and 23N with no breaks along Elsie's predicted track. Analysis from Fleet Numerical Oceanography Center (FNOC) agreed on the placement of major 500 mb synoptic scale features. FNOC's 500 mb forecast built the ridge and the resultant OTCM predicted a west-northwest track. JTWC continued this forecast trend through warning No. 9, issued at 261800Z.

Prognostic reasoning bulletins were calling for an eventual shift toward a more northward track, however timing was the big factor. JTWC's analysis showed the building of the ridge; aircraft reconnaissance tracks north of Elsie continued to yield support to the JTWC forecast. FNOC's forecast did predict movement of a major 500 mb trough eastward over Japan. Height falls associated with this trough showed up on JTWC analysis at 260000Z, coincident with the appearance of a break in the ridge near 20N 135E, a position northwest of Elsie's 500 mb cyclone. The break was most likely induced by the trough to the north and the presence of Elsie to the south of the ridge.

Interestingly, the OTCM made its first change in track at 261200Z by suggesting a more northwestward track. By 261800Z the OTCM had definitely locked into a northwest track, however, it was not until warning No. 13, at 271800Z, that JTWC's warnings relinquished west-northwest movement for the more northwestward track shown by the OTCM.

Segment #2 (270000Z - 301200Z): FNOC and JTWC analysis of 500 mb data, and support from aircraft reconnaissance, continued to confirm the break in the ridge, which was fostered by the deep trough over Japan and Elsie's enlarging 500 mb circulation. Responding to this induced trough, Elsie began to track north-northwest for a period of 48 hours. JTWC forecasts through this segment of Elsie's life not only predicted the movement trend well but also predicted transition into the next segment of Elsie's track, the recurve.

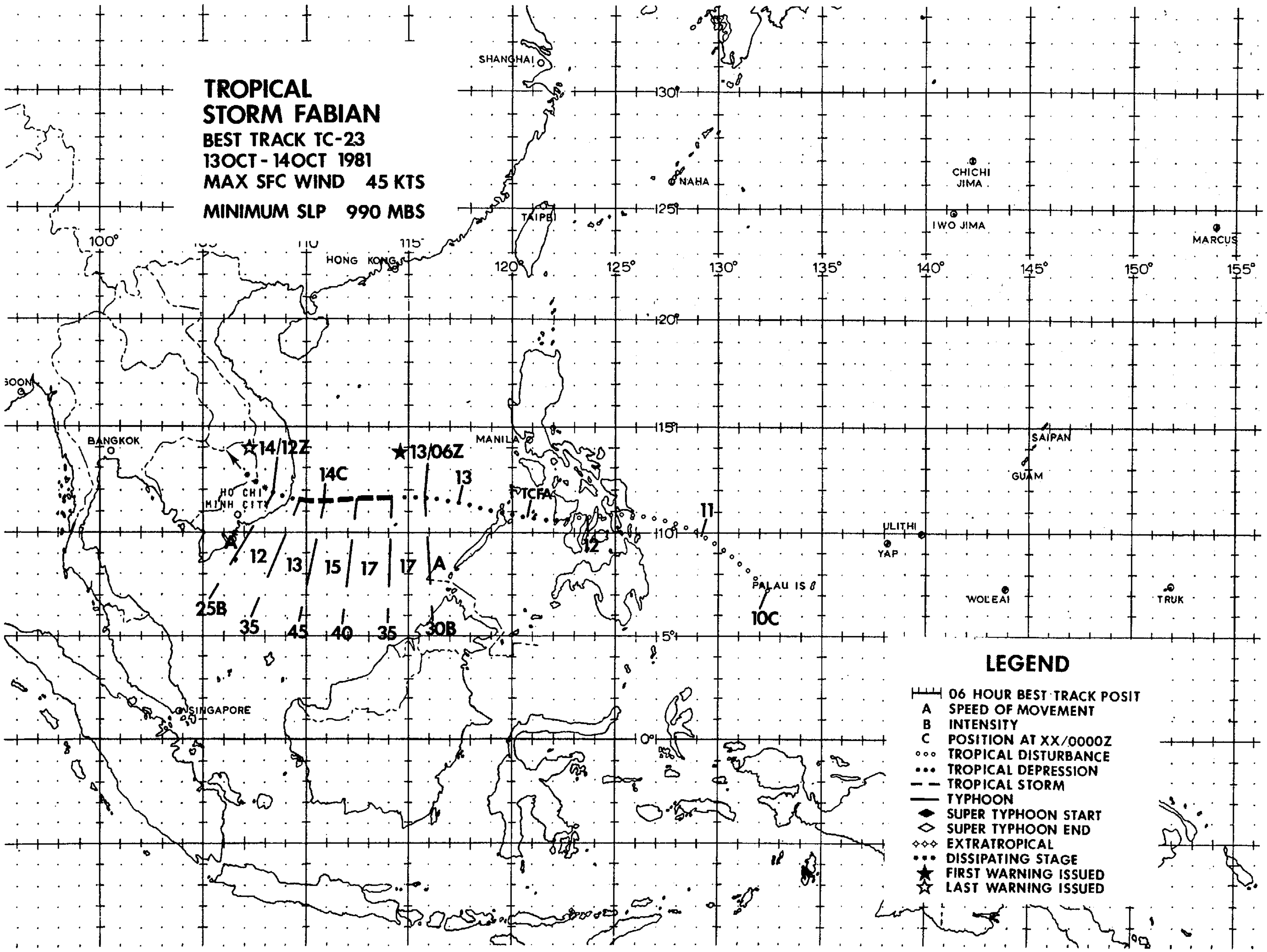
Warning No. 16, issued at 281200Z, represented the first warning that truly fits the segment 2 profile and predicted the change of track to segment 3. FNOC analysis and forecasts, as well as the JTWC analysis, defined the synoptic pattern extremely well, such that the JTWC forecasts were very consistent in their call for recurvature. Post-analysis has shown that in anticipating a recurve, JTWC's forecasts were conservative when compared with the OTCM and the actual storm best track. The conservatism of JTWC was based on the belief that the weak 500 mb winds (15-20 kt (8-10 m/sec)) south of Japan would allow Elsie to penetrate further north before encountering westerlies sufficiently strong enough to cause deflection northeastward. FNOC forecasts also showed no major trough movement at 500 mb that might lend support to any other forecast track. In fact, FNOC forecasts generally favored development of a zonal flow over Southern Japan. OTCM forecasts also drove Elsie northward toward Japan.

FNOC forecasts of a trough moving eastward off Asia did not indicate deepening, thus the most representative forecast was toward Japan. However, significant deepening did occur; the OTCM forecast for 300600Z Sep (Warning No. 23) was the initial indicator of this influence on the forecast track. JTWC's forecasts had predicted the recurve all along, but now began to converge on a tighter recurve pattern and finally stablized, by warning No. 25, at 301800Z Sep.

Segment #3 (301800Z - 020500Z Oct 81): This portion of the storm track began with Elsie accelerating rapidly northeastward and ended with extratropical transition. The FNOC forecasts, once they picked up the trough, deepened it significantly, as analyses at JTWC and FNOC eventually bore out. Elsie accelerated up the leading edge of the trough and by 020600Z had transitioned into an extratropical system. It is instructive to note that not until warning No. 30, issued at 020000Z, did JTWC make its final track change and forecast the disturbance to move north-northeast, up the back of the ridge. The OTCM had predicted this track some twelve hours earlier at 011200Z.

JTWC warnings up to warning No. 30 continued with the northeast track thus sending the system through the ridge. The JTWC warnings that continued to forecast eastward movement did have sound basis, since Elsie's movement as indicated from satellite and aircraft data continued to be northeast. This movement also placed Elsie within a steering regime that, based upon 500 mb analysis and forecast, should have kept Elsie moving northeast. The problem was the result of sound forecast logic based upon a faulty prognostic chart series. The 500 mb forecast series failed to adequately handle an advancing trough and the rapid building of the ridge ahead of Elsie. Once these forecasts began to reflect the changes, the JTWC forecaster was faced with making a decision based upon two significantly different 500 mb patterns. The first was the consistency of the longer established forecast trend, with its near zonal pattern, and the second was the rather abrupt change to this pattern which was first suggested in the 36 hour 500 mb forecasts valid at 021200Z. The apparent radical change in 500 mb steering caused by the sudden deepening of the trough and amplification of the ridge was not "bought" by the Typhoon Duty Officer, the OTCM did however "buy" the change by 011200Z. This final track predicted by the OTCM was followed by Elsie through her extratropical transition and subsequent merger with mid-latitude, migrating systems.

The OTCM handled the final segment of Elsie's life quite well just as it did with the earlier stages. In summary, this single case study indicates that for this particular cyclone, the OTCM appeared to "sense" the environmental changes to which Elsie responded from 12-24 hours prior to them being reflected in the JTWC forecast.


TROPICAL
STORM FABIAN
BEST TRACK TC-23
13OCT - 14OCT 1981
MAX SFC WIND 45 KTS
MINIMUM SLP 990 MBS
SHANGHAI
NAHA
CHICHI
JIMA
TAIPEI
IWO JIMA
MARCUS
HONG KONG
100°
110
115
120°
125°
130°
135°
140°
145°
150°
155°
130
125
20
15
10
5
0
BANGKOK
MANILA
SAIPAN
GUAM
HO CHI
MINH CITY
☆14/12Z
★13/06Z
14C
13
TCFA
11
12
ULITHI
YAP
PALAU IS
10C
WOLEAI
TRUK
12
13
15
17
17
A
25B
35
45
40
35
30B
SINGAPORE
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED

On 6 October, satellite imagery indicated an area of active, but unorganized, convection northeast of the Palau Islands. During the 5 days that followed, the convective system moved westward and remained unorganized until just prior to making landfall on Samar Island. As it tracked over Samar, Cebu, Negros and Panay Islands, the disturbance lost much of what little convective organization it did have, however during this period, the affected central Philippine Islands reported torrential rainfall and flooding, although surface reports showed virtually no low-level wind circulation. When the disturbance entered the Sulu and South China Seas, it once again showed signs of reorganizing and at 121100Z, a Tropical Cyclone Formation Alert was issued.

As it traversed the South China Sea, the disturbance continued to develop although available surface observations showed small pressure falls near the system. Reconnaissance aircraft at 130600Z reported a 1002 mb center pressure and a closed circulation, prompting the first warning for Tropical Depression 23. Subsequent satellite imagery showed continued convective organization and at 131200Z, TD-23 was upgraded to Tropical Storm Fabian. The storm continued to intensify during the next 12 hours, reaching a maximum intensity of 45 kt (23 m/sec) at 140000Z. Figure 3-23-1 shows Fabian while at maximum intensity and 9 hours prior to making landfall just south of Cam Ranh Bay, Vietnam. As Fabian moved into Vietnam, surface winds weakened rapidly and by 15 October, the system could no longer be detected from synoptic reports or on satellite imagery.

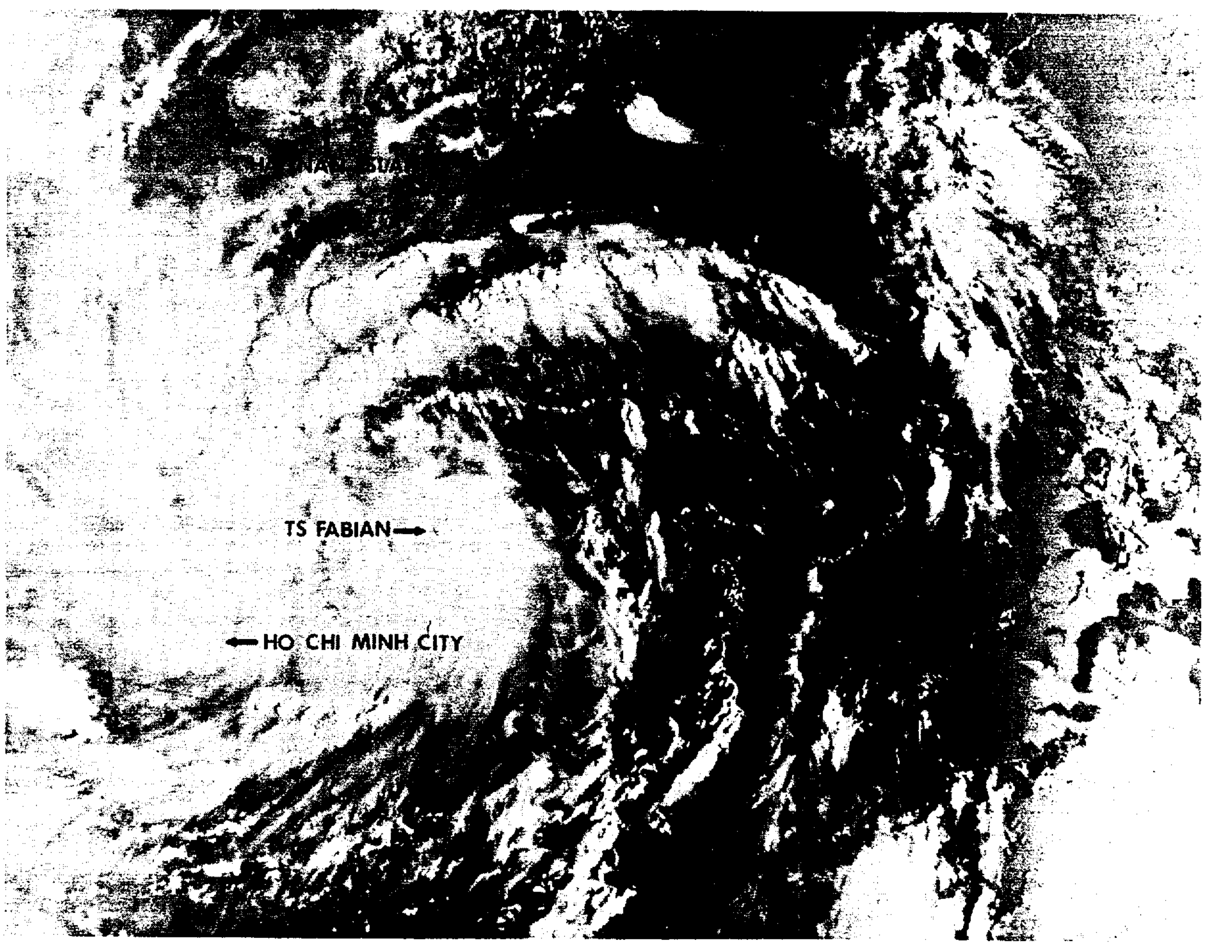
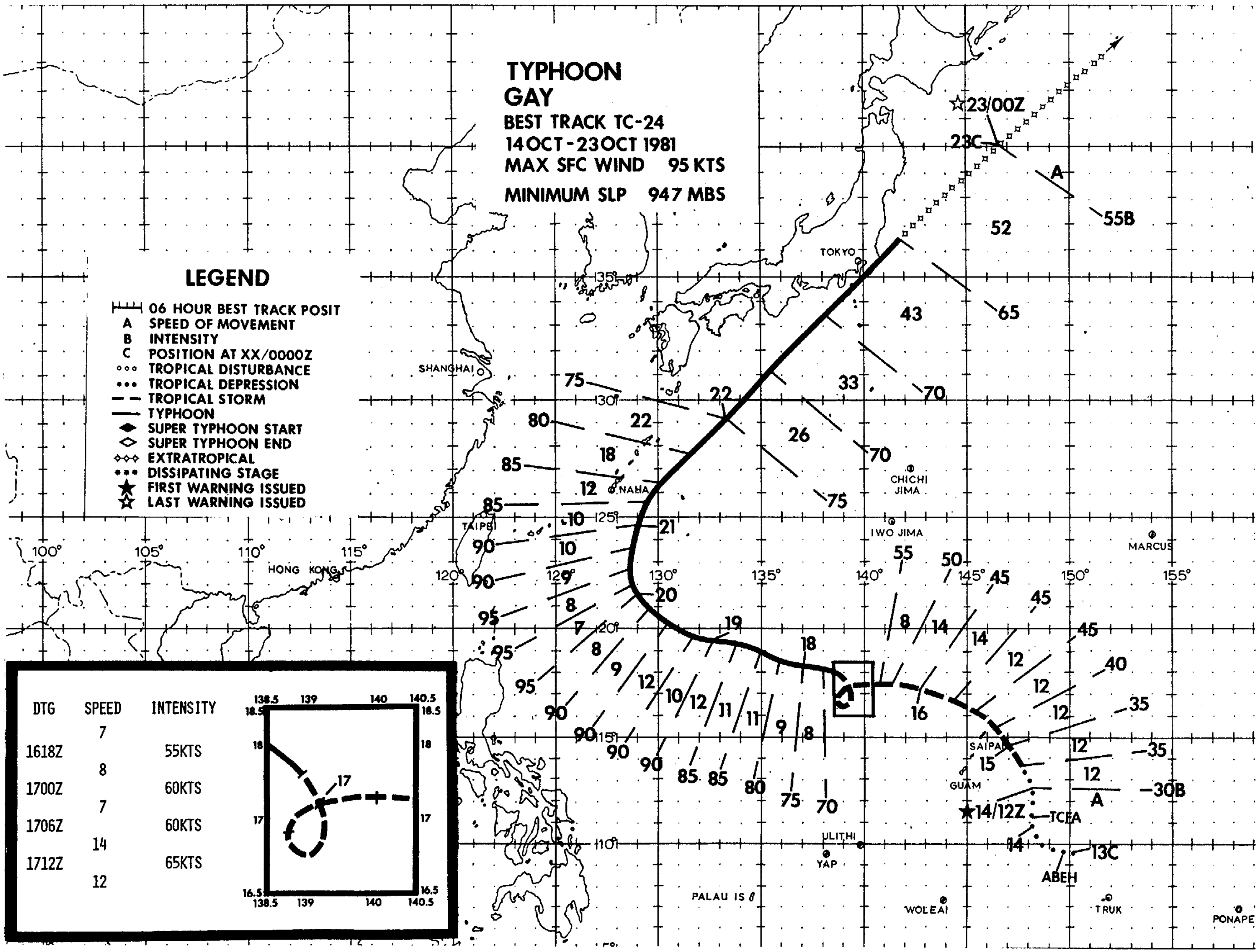


Figure 3-23-1. Four days after initial detection, Tropical Storm Fabian is located 100 nm (185 km) east of Cam Ranh Bay, Vietnam, at a peak intensity of 45 kt (23 m/sec) on this 140005Z December satellite image. (NOAA 6 visual imagery)


TYPHOON
GAY
BEST TRACK TC-24
14 OCT - 23 OCT 1981
MAX SFC WIND 95 KTS
MINIMUM SLP 947 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
DTG
SPEED
INTENSITY
1618Z 55KTS
1700Z 60KTS
1706Z 60KTS
1712Z 65KTS
7
8
7
14
12
SHANGHAI
TAIPEI
HONG KONG
NAHA
TOKYO
CHICHI JIMA
IWO JIMA
MARCUS
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
23/00Z
14/12Z
TCFA
ABEH
100°
105°
110°
115°
120°
125°
130°
135°
140°
145°
150°
155°

Typhoon Gay was a harbinger of good tidings for the island of Okinawa, providing 5.89 inches (14.96 cm) of rain as she passed some 95 nm (176 km) to the southeast. Locked in a severe drought, Okinawa residents had been suffering under strict water rationing.

From its inception within an abnormally large convective area Gay was far from a straight forward system. Early satellite fixes were very unreliable, resulting in the vectoring of aircraft reconnaissance to the wrong portion of the convective area. Post-analysis has shown the actual "center" of the developing system was far to the west-southwest of where it was believed to be. Figure 3-24-1 shows the system shortly after initial warning.

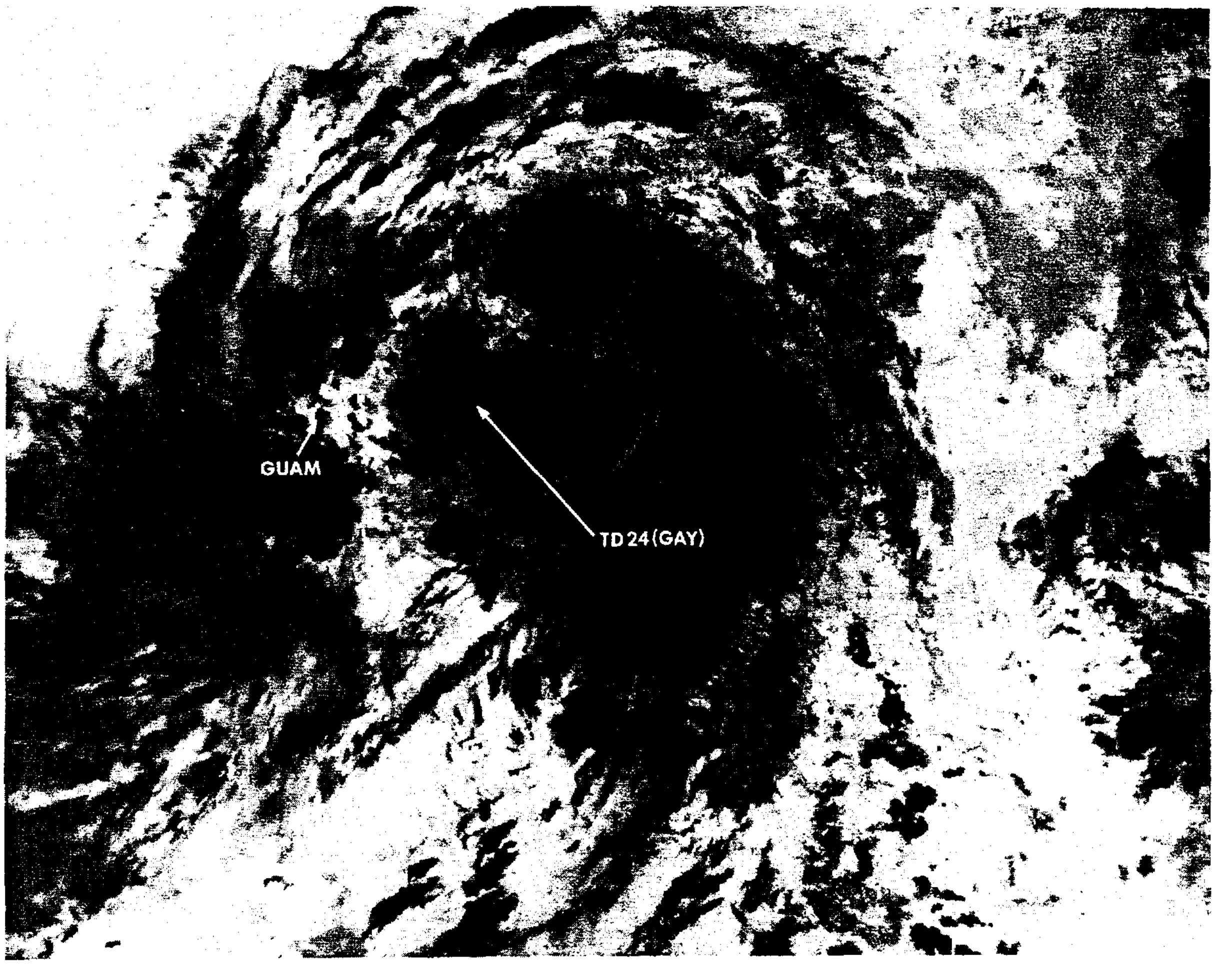


Figure 3-24-1. Tropical Depression 24 (Gay), 14 October 1981, 1614Z. At this time the initial warning with winds of 30 kt (15 m/sec) had been issued. The system was quickly upgraded to tropical storm status. The circulation center was approximately 100 nm (185 km) east of Guam. (NOAA 7 infrared imagery)

As Gay became better organized she became somewhat more predictable, with a forecast for a generally westward track and for an eventual recurvature around the west side of the prevailing mid-tropospheric anticyclone. Figure 3-24-2 shows Gay during a period when she took the slight southwest jog and loop shown on the best track in response to an eastward building anticyclone upstream from Gay's location.

Typhoon Gay remained a fickle system until reaching maximum intensity (Fig. 3-24-3) when a large eye finally developed. Until this time, the center of Gay was characterized by an unusually large area of light and variable winds, further contributing to the problems of accurate location.

Figure 3-24-2. Tropical Storm Gay, 17 October 1981, 0503Z when she began the slight southwestward movement and eventually looped. (NOAA 7 visual imagery)

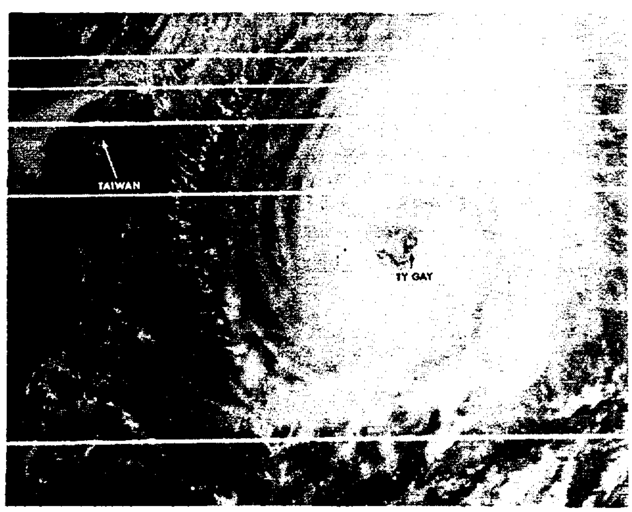


Figure 3-24-3. Typhoon Gay, 20 October 1981, 0610Z at maximum intensity of 95 kt (49 m/sec), located approximately 420 nm (778 km) east-southeast of Taiwan. (NOAA 7 visual imagery)

Following recurvature and passage to the east of Okinawa (Fig. 3-24-4), Gay continued around the western side of the mid-Pacific anticyclone and accelerated toward Japan. Eventually passing within 30 nm (56 km) of Tokyo, Gay brought extensive rainfall to the central regions of Japan. Yokosuka Naval Facility reported peak gusts of 60 kt (31 m/sec) and 9.38 inches (23.8 cm) of rain over the 24 hour period of Gay's passage.

A low pressure system north of Japan rapidly drew Gay northward and quickly initiated an extratropical transition with Gay merging completely with the existing low center.

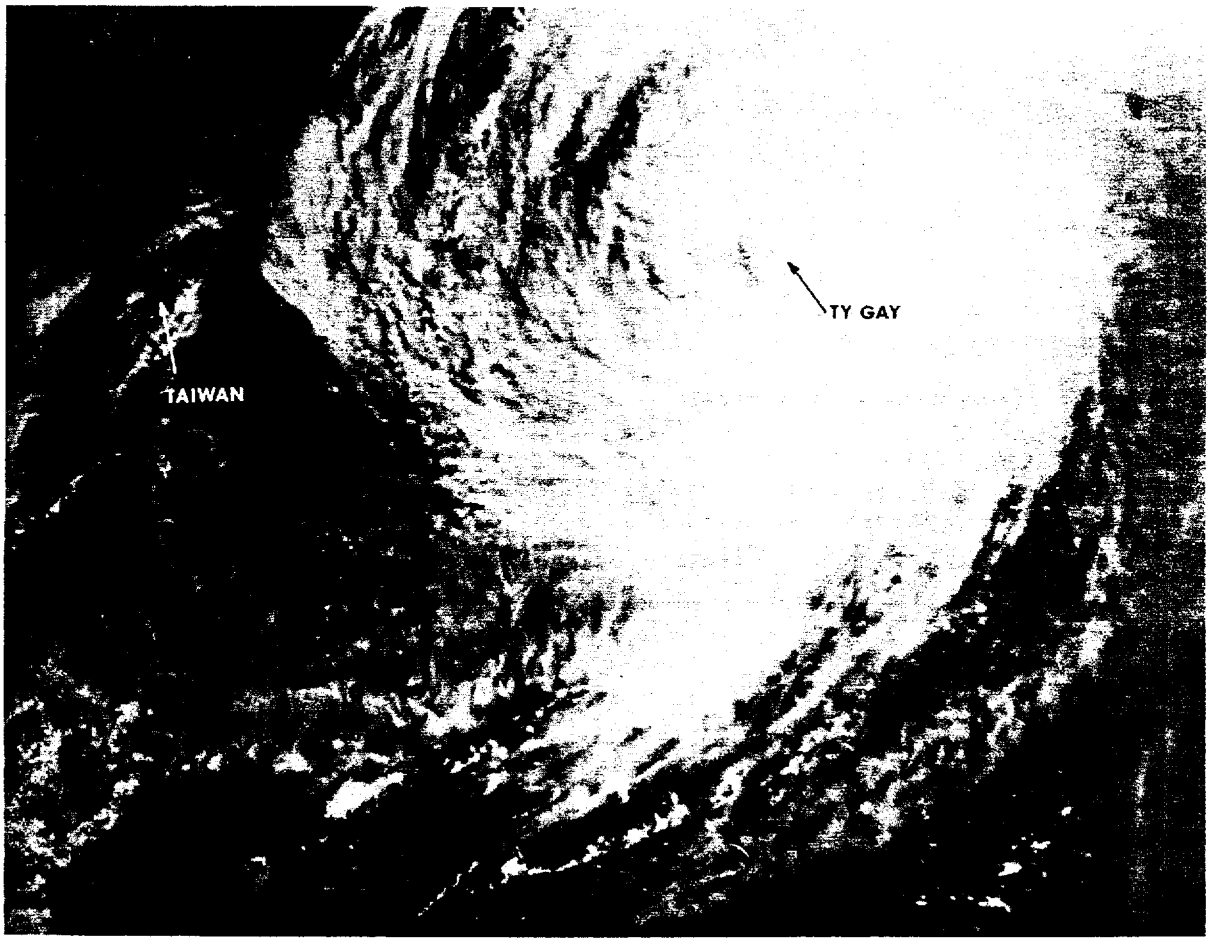
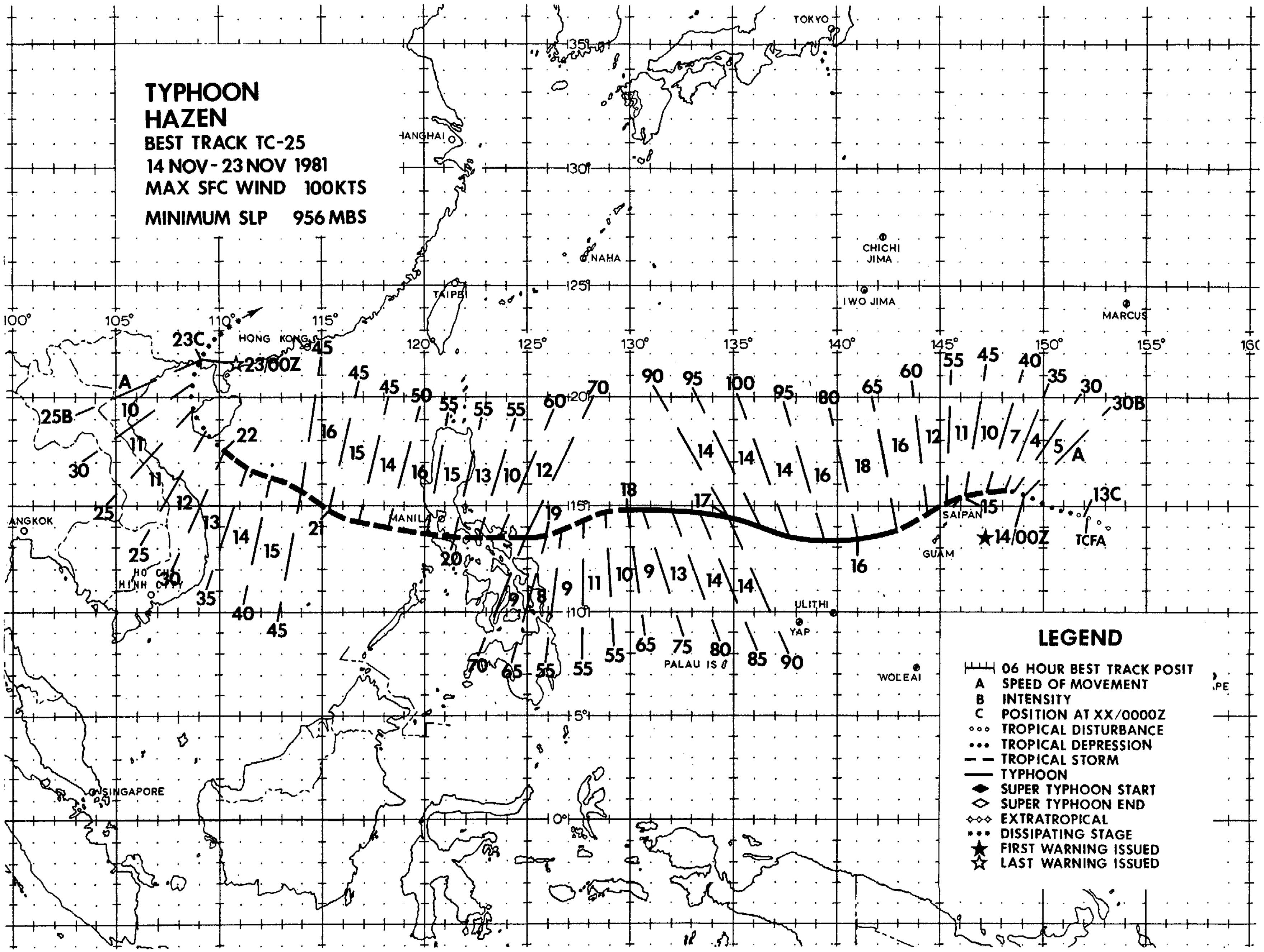


Figure 3-24-4. Typhoon Gay, 21 October 1981, 0559Z breaking the drought on Okinawa; center location is some 120 nm (185 km) east-southeast of the island. (NOAA 7 visual imagery)


TYPHOON
HAZEN
BEST TRACK TC-25
14 NOV - 23 NOV 1981
MAX SFC WIND 100KTS
MINIMUM SLP 956 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TOKYO
SHANGHAI
NAHA
CHICHI JIMA
IWO JIMA
MARCUS
TAIPEI
HONG KONG
MANILA
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
BANGKOK
HO CHI MINH CITY
SINGAPORE
14/00Z
23/00Z
TCFA

Following two weeks with no tropical cyclone activity in the northwest Pacific, a disturbance associated with enhanced convection began to develop in an elongated trough east of Guam. At 122347Z, November a Tropical Cyclone Formation Alert (TCFA) was issued as the system's circulation pattern improved and an increase in convection was evident from satellite imagery.

Aircraft reconnaissance on 13 November was not able to close off a circulation, but the convective features and the satellite signature remained strong, so the TCFA was reissued. Aircraft reconnaissance data at 140000Z found a closed circulation with maximum surface winds of 35 kt (18 m/sec), thus the disturbance became Tropical Depression 25, with the first warning being issued at 140200Z. Aircraft reconnaissance later that evening reported the surface pressure had dropped to 990 mb, prompting upgrading to Tropical Storm Hazen with estimated maximum winds of 40 kt (20 m/sec). Satellite imagery at this time showed the development of an intense, 150 nm (278 km) diameter, convective mass.

Forecasts during the early stages of Hazen's rapid development predicted movement to the west-northwest at 7 kt (13 km/hr) in response to weak steering flow in the mid-troposphere. Hazen was expected to become entrained into a frontal boundary associated with a strong mid-latitude low pressure system east of Japan. However, this did not occur; the front weakened and moved to the east. A mid-tropospheric ridge began building behind the front, causing Hazen to take a westward jog and eventually forcing a southwest track as the ridge intensified north of the storm.

Tropical Storm Hazen's southwestward path took it over the northern tip of Saipan between 150300Z and 150600Z (Fig. 3-25-1). Maximum sustained winds of 35 kt (17 m/sec) with gusts to 62 kt (31 m/sec) were reported by the Saipan weather office. Minor structural damage and many downed trees and power lines were reported.

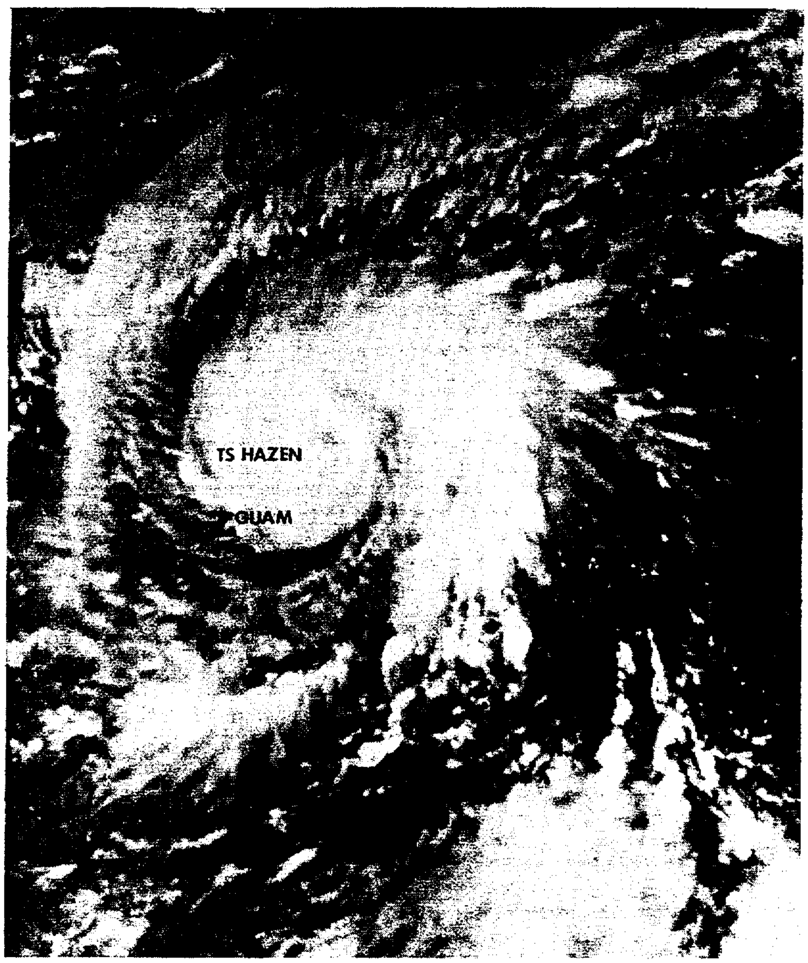


Figure 3-25-1. Tropical Storm Hazen at 55 kt (28 m/sec) intensity 110 nm (204 km) northeast of Guam shortly after crossing Saipan, 150430Z November. (NOAA 7 visual imagery)

Hazen then passed 60 nm (111 km) north of Guam at 151200Z and began a more westerly movement. Winds near the center were estimated to be 55 kt (28 m/sec) at this time but only the weaker southern quadrants passed over Guam, where winds of 15 kt (8 m/sec) were reported with some heavy showers. These synoptic reports provided verification that Hazen was a very compact storm with winds of over 30 kt (15 m/sec) extending no more than 30 nm (56 km) from the center.

Hazen was upgraded to typhoon strength at 151800Z, 3 hours before aircraft reconnaissance reported surface pressures of 957 mb and estimated surface winds of 90 kt (45 m/sec). After passing Guam, Hazen rapidly intensified to his maximum intensity of 100 kt (50 m/sec) as it followed the more westward track. Early on 17 November Hazen began to interact with a mid-latitude trough and was drawn northwestward into an area of increased vertical wind shear. Hazen weakened as the upper-level outflow channels to the north diminished. As the trough passed to the east, Hazen resumed westerly movement and reintensified (Fig. 3-25-2).

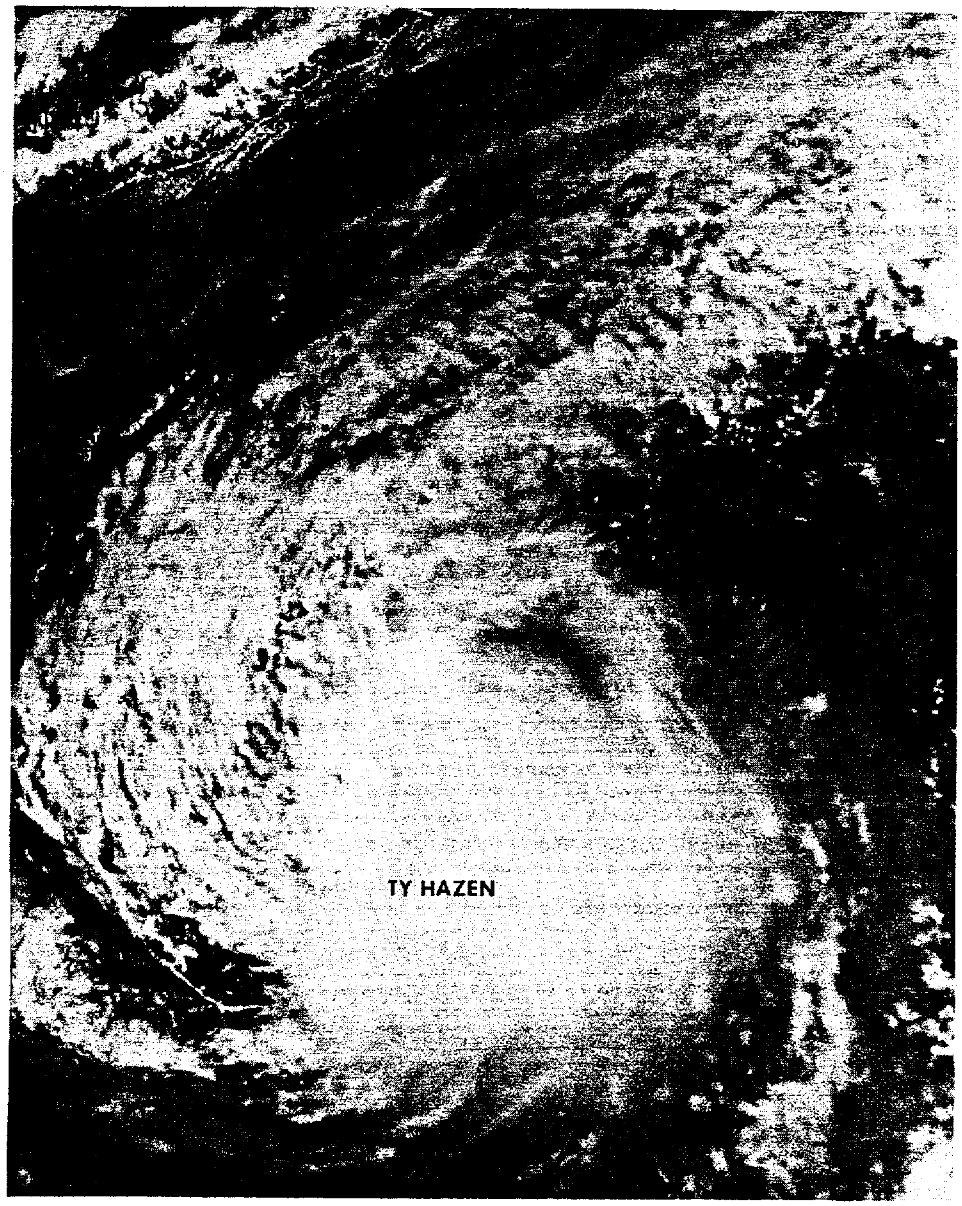


Figure 3-25-2. Typhoon Hazen at 85 kt (43/sec) intensity 640 nm (1185 km) west of Guam. Hazen is seen here interacting with the trough that eventually weakened Hazen to tropical storm strength, 170549Z November. (NOAA 7 visual imagery)

As Hazen approached the Philippines a slow weakening occurred as part of his circulation was interrupted by the mountainous terrain of the islands south of Luzon. Hazen passed just south of Catanduanes Island (WMO 98447) at 191200Z (Fig. 3-25-3) and entered the South China Sea 18 hours later. Highest recorded winds were 65 kt (33 m/sec) at Catanduanes Island. As Hazen entered the South China Sea no intensification occurred over the warm water due in part to the severe interactions between the low-level circulation and the mountainous terrain of southern Luzon; the loss of strength just could not be overcome. Hazen continued to weaken as he tracked toward Hanoi guided by a weakness in the 500 mb ridge that was evident upon the 211200Z streamline analysis. Hazen continued to move toward the weakness, eventually making landfall 150 nm (278 km) east-northeast of Hanoi and then dissipated over the hilly terrain of southeast China.

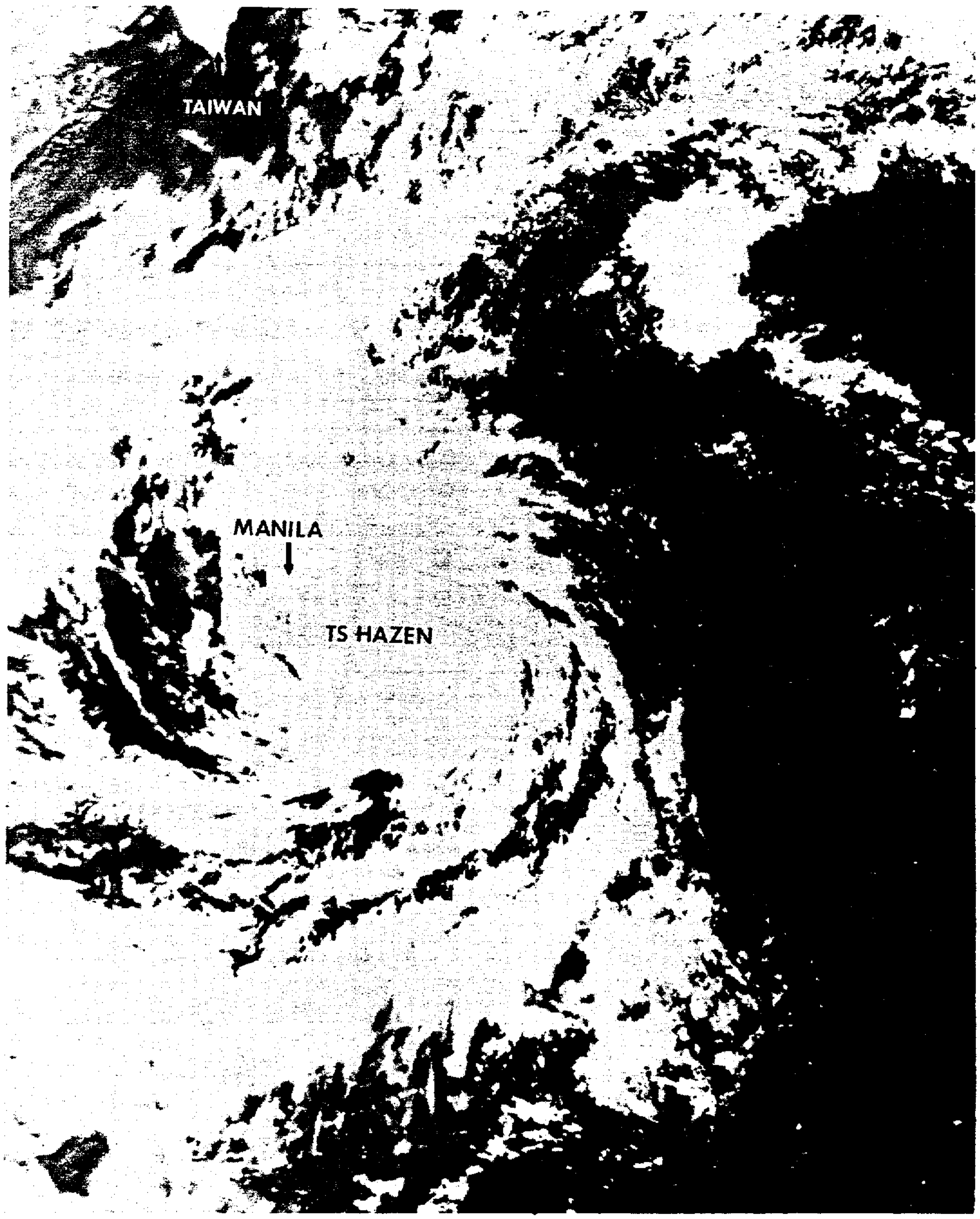
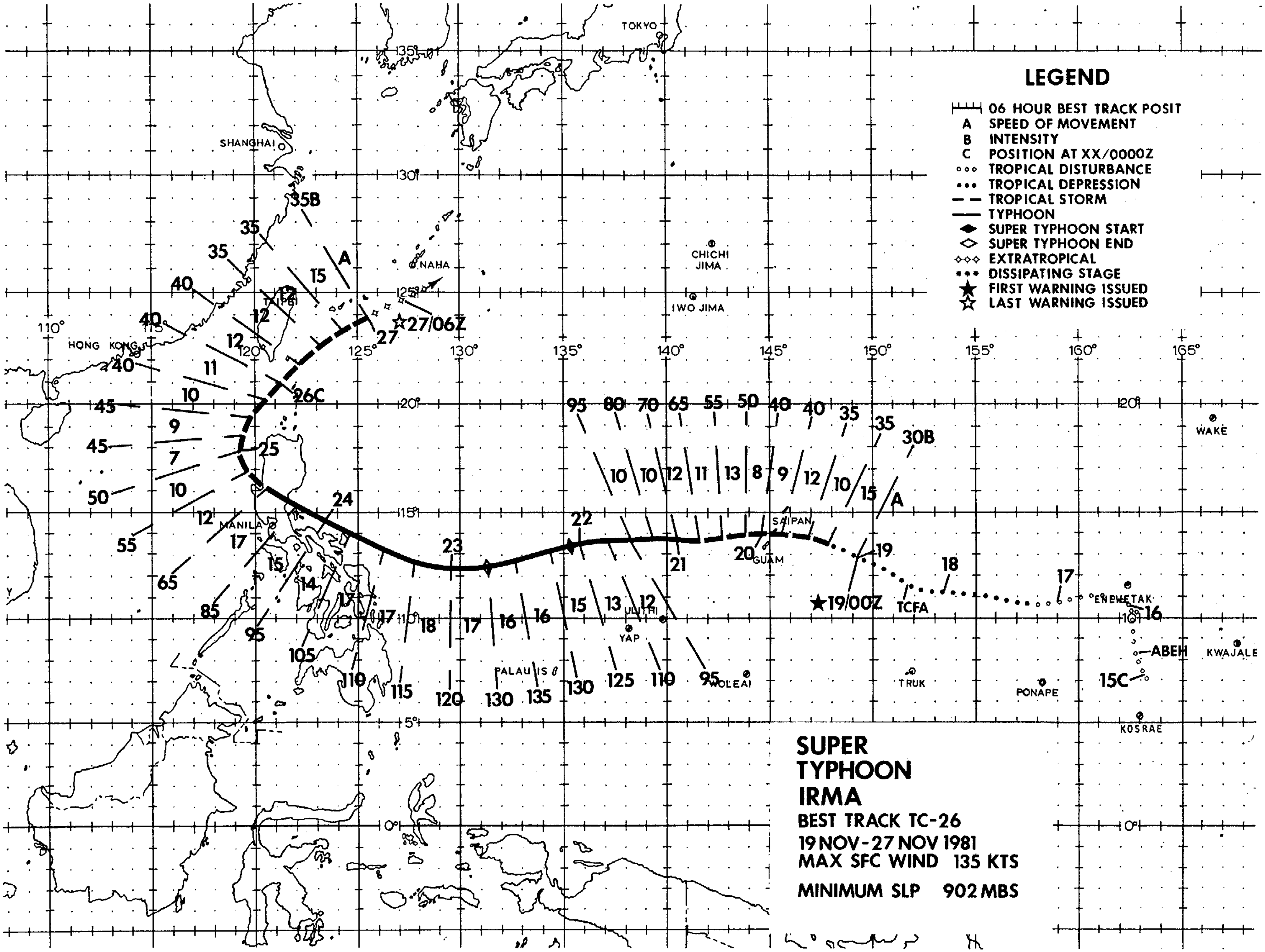


Figure 3-25-3. Tropical Storm Hazen at 55 kt (23 m/sec) 125 nm (232 km) southeast of Manila while moving south of Luzon, 191801Z November. (NOAA 7 infrared imagery)


SUPER
TYPHOON
IRMA
BEST TRACK TC-26
19 NOV - 27 NOV 1981
MAX SFC WIND 135 KTS
MINIMUM SLP 902 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TOKYO
SHANGHAI
NAHA
CHICHI JIMA
IWO JIMA
TAIPEI
HONG KONG
MANILA
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
ENEWETAK
ABEH
KWAJALE
KOSRAE
WAKE
★19/00Z
TCFA
☆27/06Z
26C
30B
35B
15C

Super Typhoon Irma was the second of three tropical cyclones (Hazen(25), Irma (26), and Jeff(27)) to form in an active equatorial trough between 150E to 170E near 10N during the middle weeks of November. Reaching a maximum intensity of 135 kt (69 m/sec) and a minimum sea-level pressure of 902 mb, Irma was the strongest of the three storms, and fortunately, also the best "behaved" and the easiest to forecast.

When the area of enhanced convection that eventually became Typhoon Hazen formed near 10N 165E on 10 November, a zone of strong convective activity, located between 8N and 10N, stretched eastward from 165E to 150W. During the following week, westward propagating cloud clusters, as referenced in Ruprecht and Gray (1976) supported by convergence in the low-level easterly flow plus a strong upper-level divergent pattern, could be seen forming and dissipating along the entire zone. Throughout the period neither the data-sparse regions east of 170E, nor the satellite data, suggested the existence of a low-level circulation. Synoptic data along the western periphery of the zone, between 160E and 170E, did indicate the possibility of several minor troughs, or small circulations, propagating from the east. Similar synoptic situations existed for each of the three systems, i.e. Hazen, Irma, and Jeff; there was also a fourth circulation, detected on 12 November near 10N 161E. This latter system quickly dissipated because of the immediate proximity of the developing Hazen, a stronger cyclone.

The convective disturbance that spawned Super Typhoon Irma was first mentioned in the Significant Tropical Weather Advisory Bulletin (ABEH PGTW) on 15 November. Synoptic data indicated a circulation east of Ponape (WMO 91348) at 7N 163E and satellite imagery showed that a westward moving cloud cluster in the area beginning to develop an upper-level anticyclone. However, as the system moved north and then west during the ensuing three days, the convection fluctuated, then weakened greatly. A large clear subsidence region which extended 600 nm (1111 km) eastward from Typhoon Hazen seemed to hinder any further development (as it did for the 12 November circulation). However, by 181200Z Hazen had moved far enough to the west for the convection to once again increase in intensity as well as organization. A Tropical Cyclone Formation Alert (TCFA) was issued at 181641Z (Fig. 3-26-1). The following morning, an aircraft investigative mission found a central sea-level pressure of 1003 mb with 30 kt (15 m/sec) winds and the first warning was issued on Tropical Depression 26 at 190000Z.

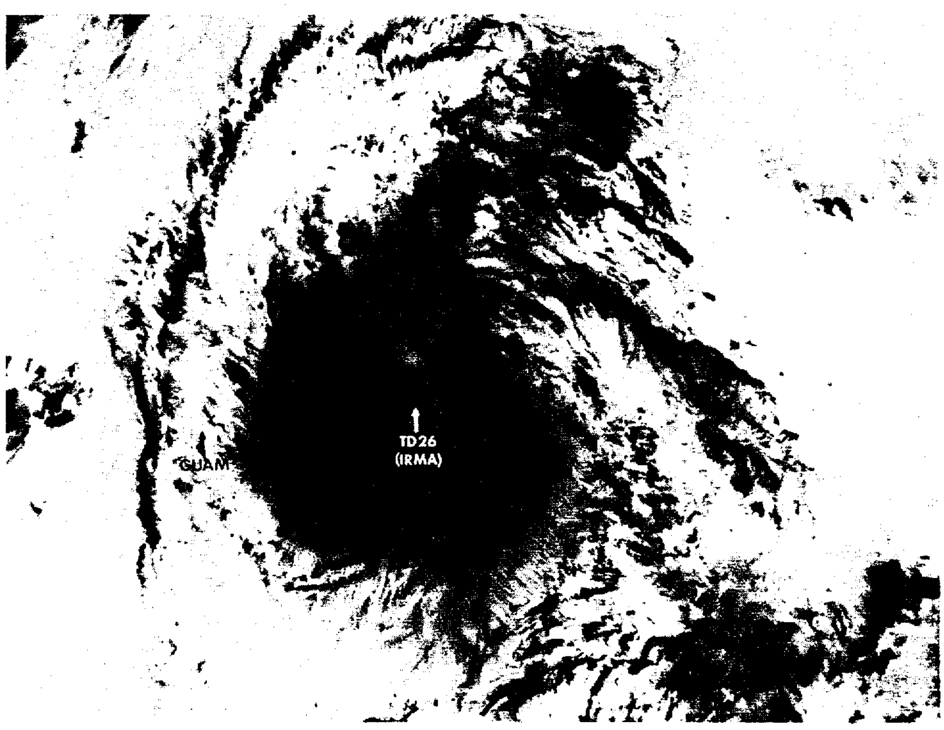


FIGURE 3-26-1. Tropical Depression 26 approximately 300 nm (556 km) east of Guam just prior to the first warning. Note the good outflow pattern developing with this system, 18 November, 2156Z. (NOAA 6 infrared imagery)

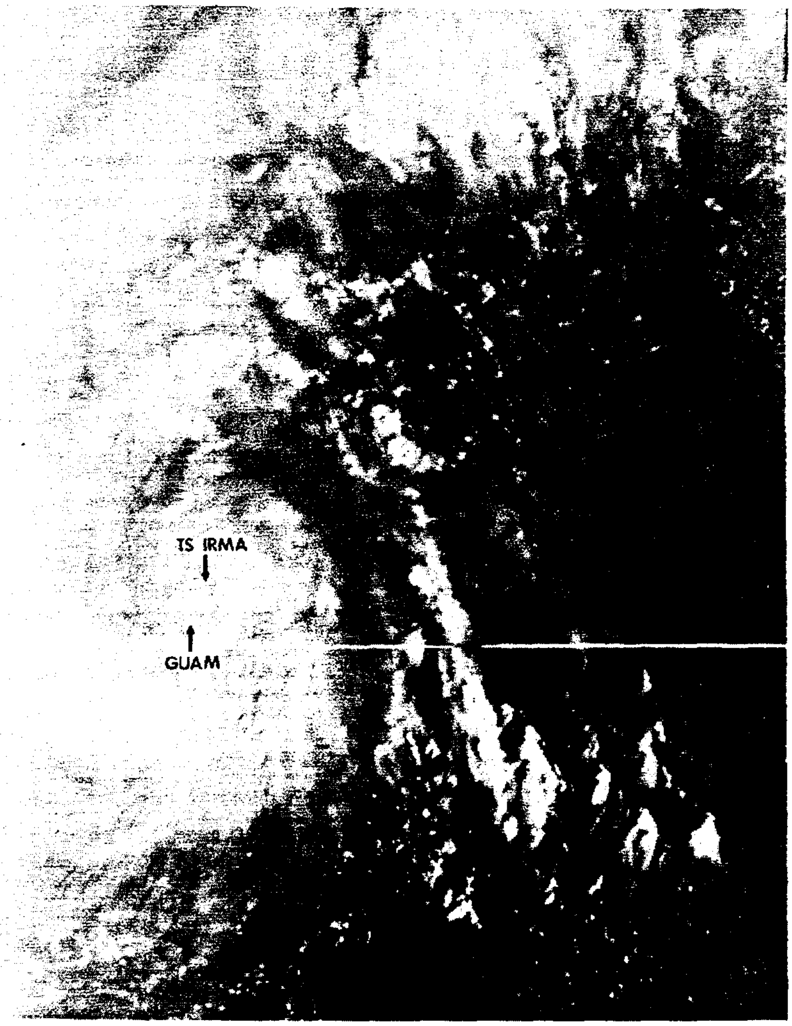


FIGURE 3-26-2. Tropical Storm Irma near its closest approach to Guam, 19 November, 2132Z. The extension of clouds just north of Irma are associated with a frontal system which was also near its closest approach to Guam. (NOAA 6 visual imagery)

Tropical Storm Irma passed just north of Guam at 182230Z (Fig. 3-26-2). Fortunately, at this time, the storm was intensifying very slowly and the strongest winds were away from Guam, in the northeast quadrant. In fact, Guam did not receive its strongest winds until nearly 8 hours later (29 kt (15 m/sec), with gusts to 43 kt (22 m/sec), at the Naval Air Station, Agana) when the storm began to deepen west of Guam.

Based upon the experience gained from Typhoon Hazen, JTWC's initial forecast tracks ignored the temptation to forecast an early recurvature into an advancing front just north of Guam. Although westerly winds north of 20N were in excess of 60 kt (31 m/sec) and 80 kt (41 m/sec) at 500 mb and 200 mb, respectively, it was deemed, that as in the case for Hazen, the strongest westerly winds associated with the front would pass too quickly to affect the storm. Furthermore, it was predicted that the strong northerly low-level flow beyond the front would force the storm back on a more westerly or southwesterly track. (JTWC's forecast errors for Super Typhoon Irma of 76, 118, and 141 nm (141, 219, and 261 km) for 24, 48, and 72 hours, respectively, were excellent - nearly half the long-term mean).

When the frontal system passed Irma and moved off to the east, the ridge at 500 mb built to the north and west of the storm. This ridge persisted along 18N throughout Irma's track towards the Philippines. Although the ridge was quite narrow and elongated, it appeared to shelter Irma from the effects of the strong westerly flow north of 20N. JTWC was able to monitor the strength of this ridge with the aid of several 500 mb synoptic tracks flown by the 54th Weather Reconnaissance Squadron (Fig. 3-26-3).

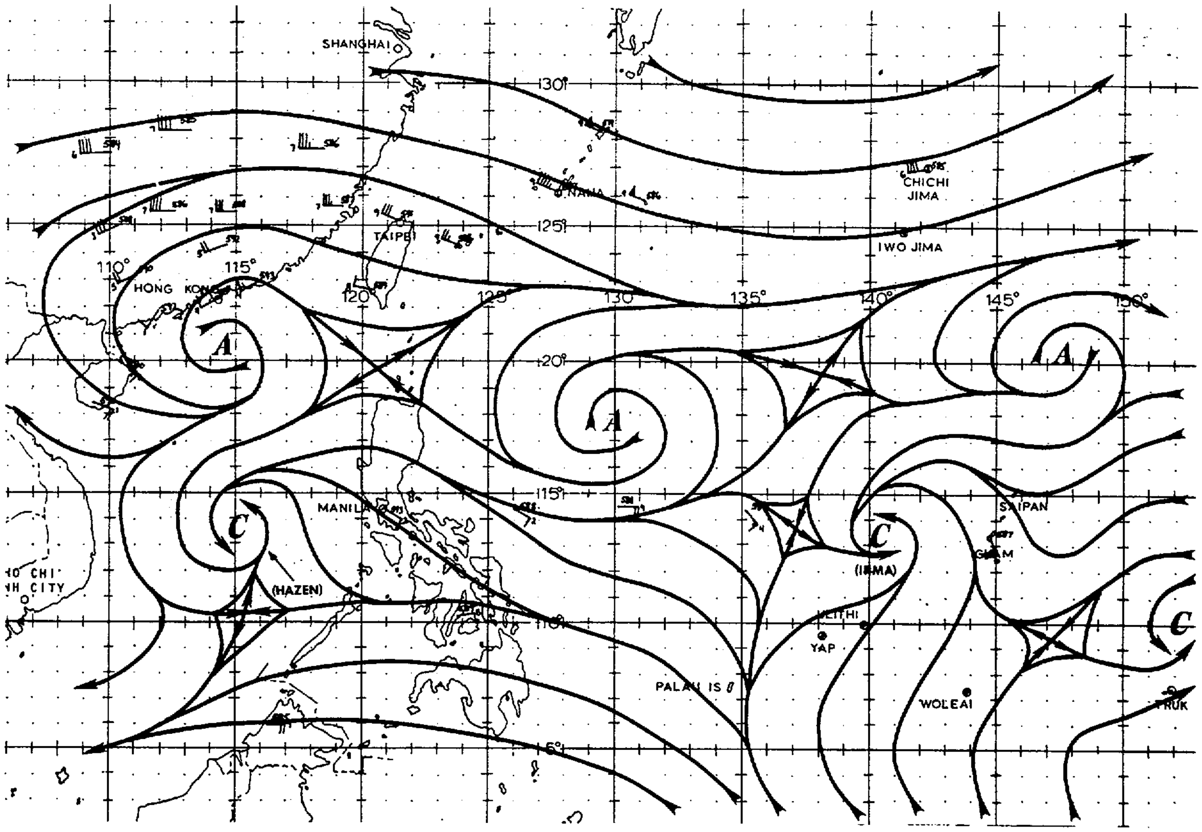


FIGURE 3-26-3. The 210000Z November 500 mb streamline analysis. Wind speeds are in knots. Data taken along 14N are a JTWC requested 500 mb synoptic track.

The 202254Z weather reconnaissance mission found that Irma's pressure had dropped to 968 mb with 68 kt (25 m/sec) surface winds (85 kt (44 m/sec), 700 mb flight level winds) and that a 40 nm (74 km) diameter eye had developed. (In post-analysis, Irma was upgraded to typhoon status at 201800Z). By 210900Z, aircraft data was applied to JTWC's empirically derived relationship between sea-level pressure and 700 mb equivalent potential temperature (Dunnavan, 1981) and suggested the potential for rapid deepening below 925 mb within the next 12 to 36 hours. Twenty-four hours later, the aircraft reconnaissance mission verified this prediction with a 905 mb minimum sea-level pressure, low enough to qualify Irma as a Super Typhoon (Fig. 3-24-4). It is interesting to note that during the time of Irma's greatest deepening, another cold front had passed approximately 500 nm (926 km) to the north. The 200 mb data indicated a 120 kt (62 m/sec) jet maximum, associated with this fast moving front, had passed just north of Irma (at 30N). This jet, along with a 50 kt (26 m/sec) easterly flow to the south of Irma supplied her with two excellent outflow channels. Irma remained at super typhoon strength for near 16 hours before slowly weakening as the western half of the circulation field began to interact with the outher edges of the Philippine Islands.

Although Irma steadily weakened before making landfall at 240900Z with 85 kt (44 m/sec) winds about 60 nm (111 km) northeast of Manila, she still caused widespread destruction (Fig. 3-26-5). Reports from the Philippines indicated more than 200 deaths with hundreds injured and a damage estimate as high as $9 million. This included the almost total destruction of 4 coastal towns in the province of Camarines Sur, 170 nm (315 km) southeast of Manila, due to 50 foot (15 m) storm surge waves and the capsizing of a ship in Manila Bay.

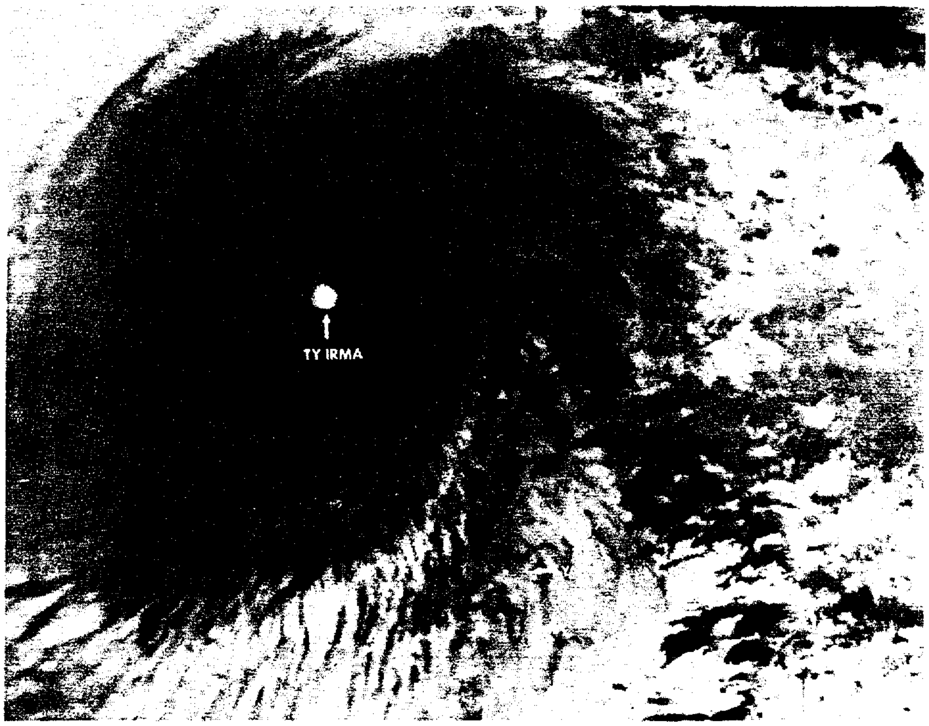


FIGURE 3-26-4. Super Typhoon Irma near maximum strength in the Philippine Sea, 22 November, 0450Z. Four hours later Irma's eye was described as an "... excellent stadium effect (with) layered clouds up to an overhead fishbowl...". (NOAA 7 infrared imagery)

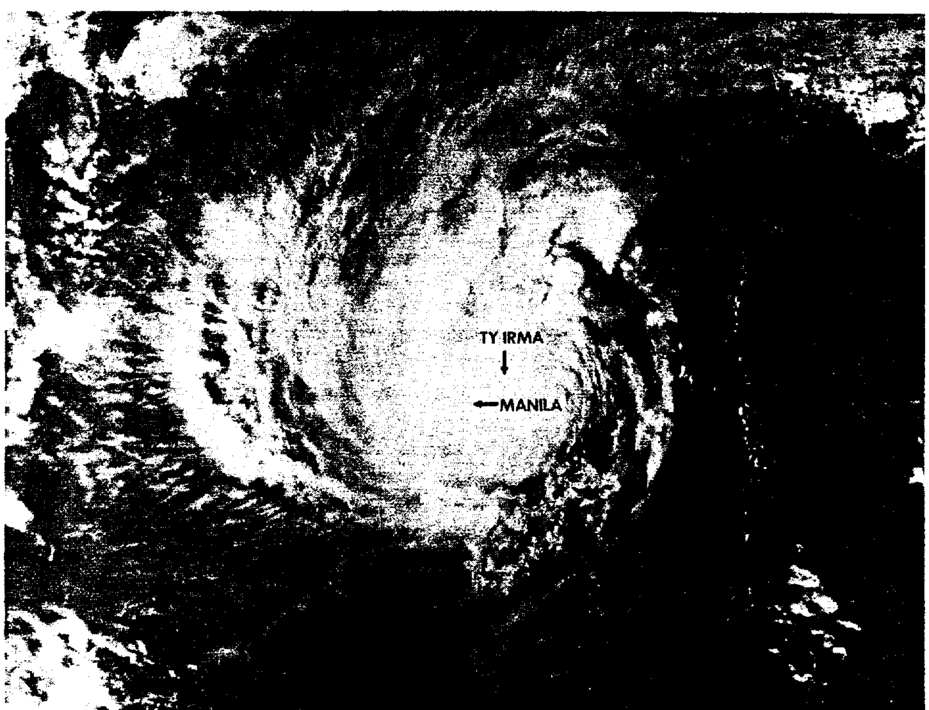
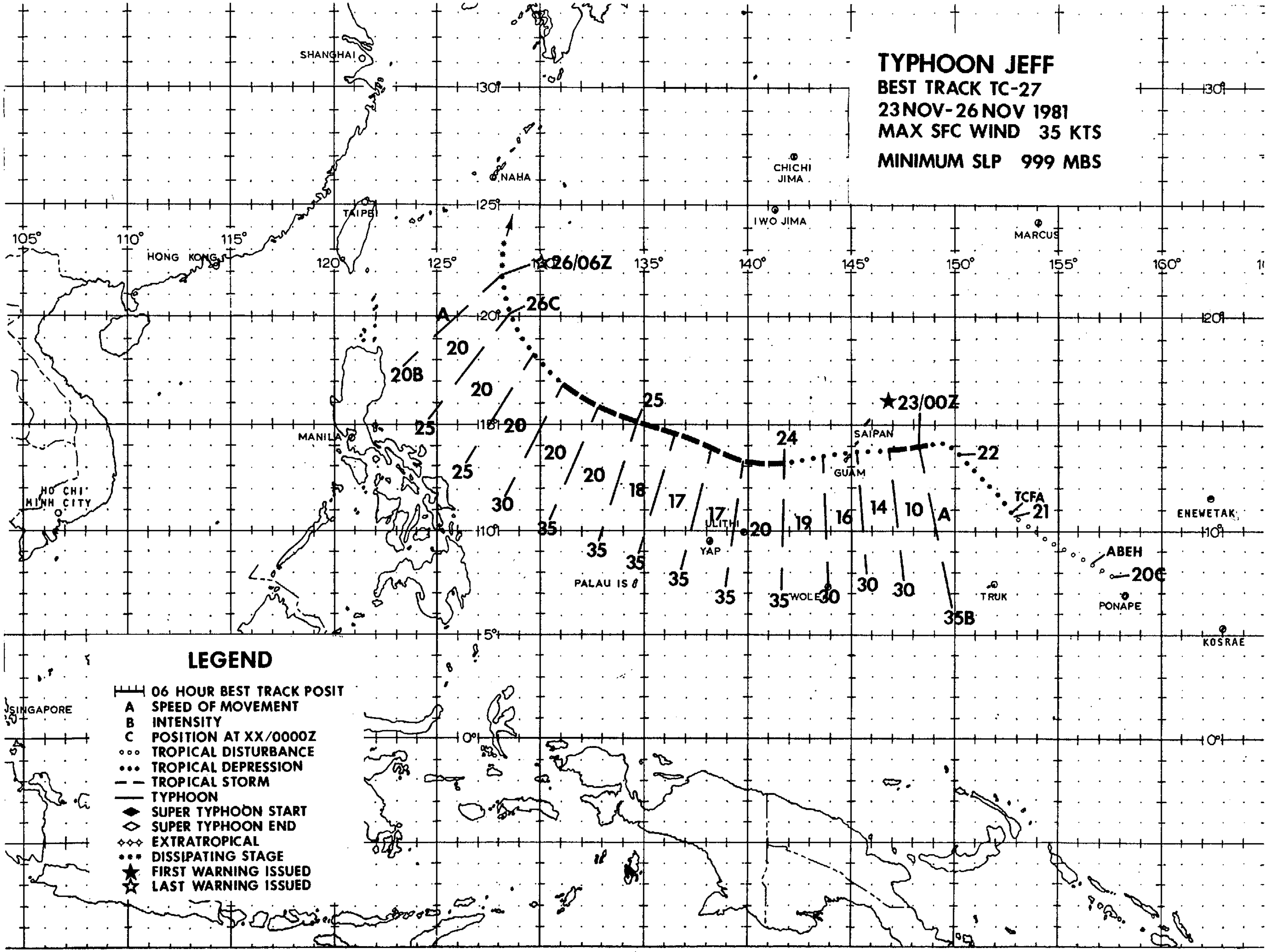


FIGURE 3-26-5. Typhoon Irma with 85 kt (44 m/sec) is only 65 nm (120 km) from Manila and three hours from reaching the coast of Luzon, 24 November, 0609Z. (NOAA 7 visual imagery)

As Irma approached the Philippines, JTWC correctly predicted that she would begin to move in a more northwesterly direction towards a break in the ridge just west of Luzon near 20N 118E. Synoptic data over Southeast Asia indicated the approach of a significant trough as evidenced by southwest winds of 70 kt (36 m/sec) at 500 mb and 80 kt (41 m/sec) at 200 mb occurring as far south as 20N. These indicators seemed to presage a situation that offered the best opportunity for Irma to recurve.

Irma lost her typhoon strength winds at 241200Z just before entering Lingayen Gulf and the South China Sea. Aircraft reconnaissance ten hours later found the storm moving north and poorly organized with strong convection and winds only on her north side. By 250900Z, Irma's upper-levels began to shear towards the northeast and Irma began to recurve into the Luzon Straits in advance of the trough moving off of Asia. Irma managed to linger on for another two days before finally becoming absorbed into a cold front at 270000Z just south of the Ryukyu Islands.


TYPHOON JEFF
BEST TRACK TC-27
23NOV-26NOV 1981
MAX SFC WIND 35 KTS
MINIMUM SLP 999 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
26/06Z
26C
23/00Z
TCFA
ABEH
20C
35B
20B
SHANGHAI
NAHA
CHICHI JIMA
IWO JIMA
TAIPEI
MARCUS
HONG KONG
MANILA
SAIPAN
GUAM
HO CHI MINH CITY
ENEWETAK
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
KOSRAE
SINGAPORE
105°
110°
115°
120°
125°
130°
135°
140°
145°
150°
155°
160°

Tropical Storm Jeff was first detected as a distinct surface circulation through synoptic data analysis on 18 November. Jeff developed from the second of two major disturbances that formed in the wake of Typhoon Hazen (25). The first disturbance, Super Typhoon Irma (26), was a determining factor in Jeff's development, intensity and track.

The first warning on Jeff was issued on 23 November. This was during the period that Irma dominated the wind fields of the western Pacific (21-25 Nov). Irma's strong low-level inflow was the major steering force in the early part of Jeff's life as he followed Irma across the Pacific (Fig. 3-27-1). Strong outflow from Irma created an upper-level east-west ridge that stretched across the western Pacific. Because of the expansiveness of the ridge and the small areal extent of Jeff's convection, he was prohibited from reaching favorable outflow channels.

Jeff, due mainly to a lack of upper-level support, never intensified beyond minimal tropical storm strength (Fig. 3-27-2). Jeff's initial movement, as a weak disturbance, was northwest towards Guam, following the low-level flow into Irma. Jeff reached tropical storm strength on 23 November, just after turning west towards Guam, eventually passing 15 nm (28 km) north of the island. Jeff's westward acceleration, just prior to reaching Guam resulted from a mid-tropospheric ridge that had built eastward from Taiwan. Maintaining an intensity between 30 and 35 kt (15 to 18 m/sec), Jeff continued westward until the forecast recurvature through a break in the ridge occurred near 130E. Jeff dissipated over water on 26 November due to increasing upper-level wind shear. The final warning was issued when aircraft reconnaissance could no longer discern a surface circulation.

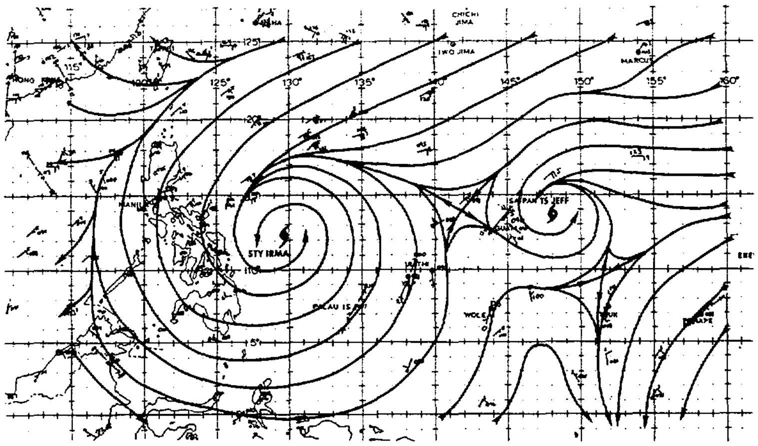


FIGURE 3-27-1. Surface (⟵┐)/gradient (⟵┤) level streamline analysis for 230000Z NOV showing the low-level flow into Super Typhoon Irma. This flow pattern acted as low-level steering for Jeff.

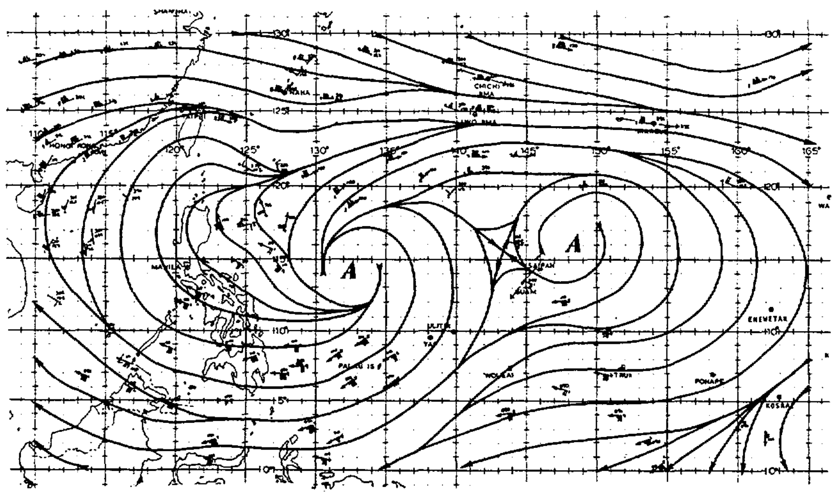
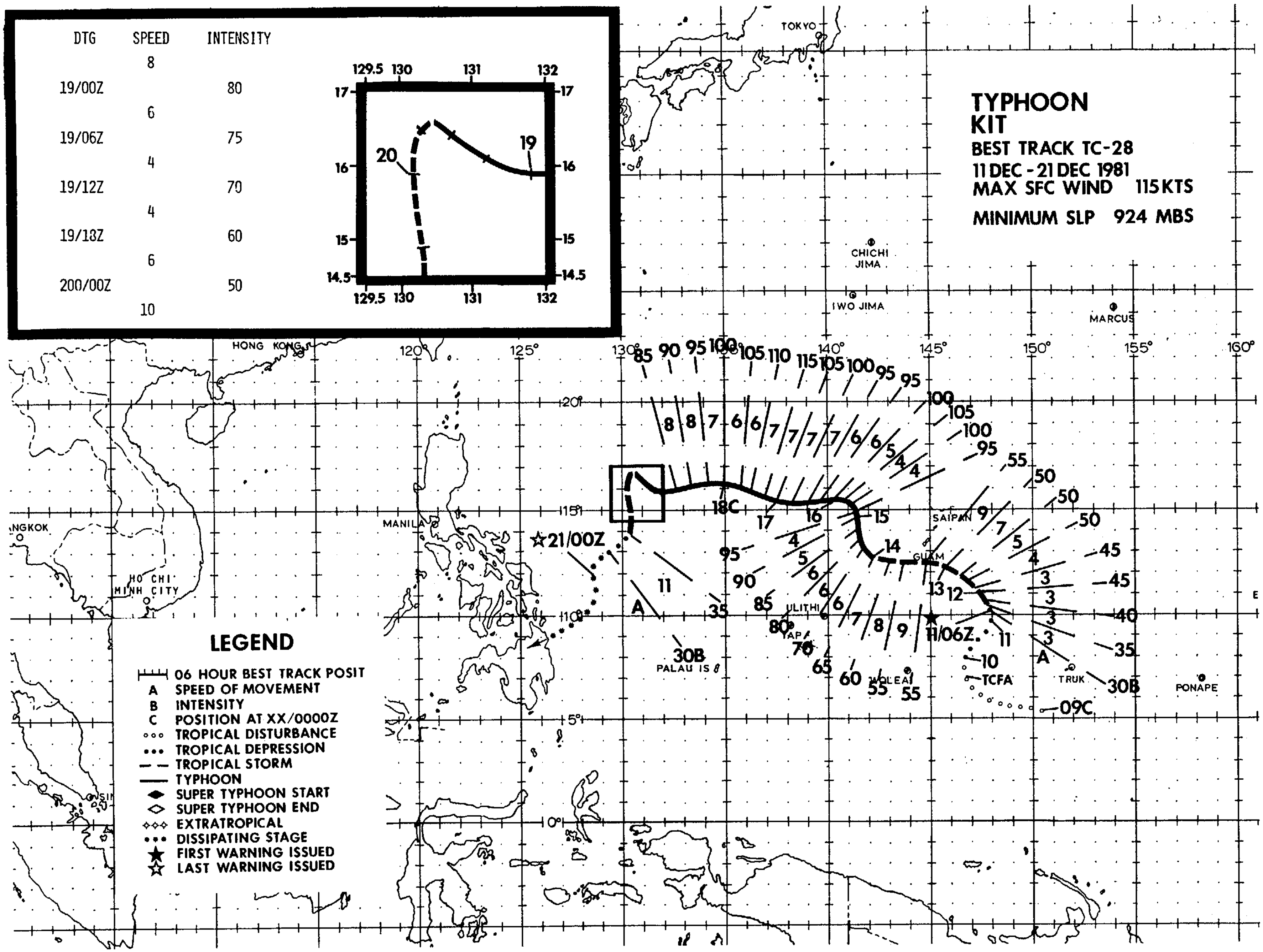


FIGURE 3-27-2. 200 mb streamline analysis at 221200Z November. Note the broad ridge across the western Pacific. Wind data are a combination rawinsonde, AIREPS, and satellite derived winds (⟵┐).


TYPHOON
KIT
BEST TRACK TC-28
11 DEC - 21 DEC 1981
MAX SFC WIND 115 KTS
MINIMUM SLP 924 MBS
DTG SPEED INTENSITY
8
19/00Z 80
6
19/06Z 75
4
19/12Z 70
4
19/18Z 60
6
200/00Z 50
10
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TOKYO
CHICHI JIMA
IWO JIMA
MARCUS
HONG KONG
MANILA
HO CHI MINH CITY
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
21/00Z
11/06Z
TCFA
09C
18C
30B

Typhoon Kit was unlike most December tropical cyclones in that it had a prolonged lifetime (40 warnings) and attained a maximum intensity well over 100 kt (51 m/sec). Kit's origin was not uncommon for late season tropical cyclones; during early December, the winter near-equatorial trough had established itself south of 10N as the tradewind easterlies merged with northeasterlies from higher latitudes placing the westernmost extension of the trough in the Philippine Sea. Eastward, lighter winds were observed turning cyclonically within the trough and, as early as 4 December, surface analyses suggested a possible low-level center developing southwest of Ponape (WMO 91348). On 7 December, the Significant Tropical Weather Advisory (ABEH PGTW) discussed an area of disturbed weather southwest of Truk Atoll (WMO 91334), but the associated convective pattern and observational data were not conducive to further action for another two days. At 091930Z, based primarily upon the improved convective organization as revealed on satellite imagery, the first of three Tropical Cyclone Formation Alerts was issued.

On 10 December, a reconnaissance aircraft conducted an investigation in the western periphery of the trough and the opportunity to close off a circulation center was lost. Satellite data (Fig. 3-28-1) and subsequent aircraft reports suggest that the center existed just east of the area investigated. At 101845Z, a formation alert was reissued for the same general area. Later satellite data and aircraft observations indicated that the center had moved northward, thus at 102325Z the third formation alert was issued. Reconnaissance aircraft finally closed off a circulation center near 10N 148E (110348Z) and at 110443Z, the first warning on Tropical Depression 28 was issued (Fig. 3-28-2). The 111200Z warning upgraded TD-28 to Tropical Storm Kit based on aircarft data (110723Z) which indicated tropical storm strength winds in all four quadrants.

Figure 3-28-1. Active convection surrounds a developing low-level center. During this period, a reconnaissance aircraft investigated the westernmost area but did not reach the convective center as depicted on satellite imagery, 100443Z December. (NOAA 7 visual imagery)

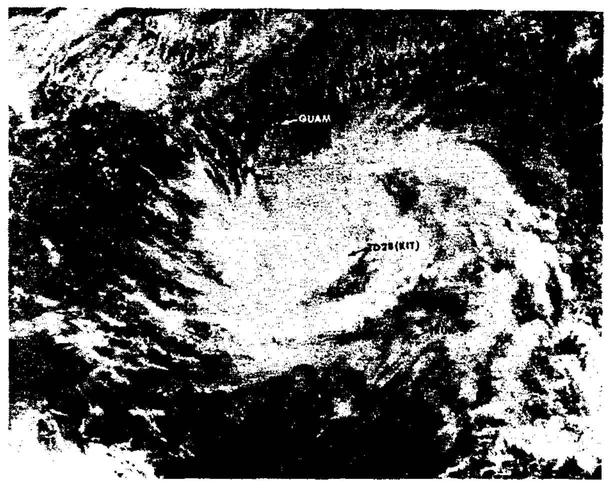


Figure 3-28-2. Tropical Depression 28 at the time of the first warning. Note the extended cirrus clouds on the western side. Strong upper-level easterlies would continue to exert considerable pressure on TD-28 (Kit) for another 2 1/2 days. Thus, most of the associated convection was displaced in the western two-thirds of the circulation, 110430Z December. (NOAA 7 visual imagery)

The initial warnings indicated that Kit would track slowly north-northwestward until approaching 12N then, as the system interacted with mid- and low-level easterlies, a more westward track was anticipated taking Kit just south of Guam. Although Kit maintained the forecast track, the speed of movement remained at or below 4 kt (7 km/hr) for the first 30 hours of warning status. Having not fully anticipated the exceptionally prolonged slow speed, all reconnaissance aircraft were evacuated to Clark AB after the 120849Z fix to avoid the expected destructive winds on Guam. As a result, warnings issued during the ensuing 25 hours were based entirely on satellite data. However, during this stage of development, Kit was not well-aligned in the vertical and the main convective mass was displaced to the west of the low-level center. Thus, nighttime infrared imagery had to be scrutinized for subtle details which could help locate the low-level center. Figure 3-28-3 is typical of the nighttime infrared imagery used to fix Kit during this period. Thanks to the efforts of satellite operations personnel from Detachment 1, 1WW, Nimitz Hill, Guam, the fixes received during this period were highly accurate (never more than 15 nm (28 km) from the final best track) and the warnings issued from this data followed Kit closely as she finally accelerated on a west-northwest track south of Guam.

Just after Kit passed south of Guam, reconnaissance aircraft indicated a central pressure of 992 mbs which revealed that no appreciable development had taken place during the 25 hour period between aircraft penetrations. However, during the two days that followed, Kit intensified and reached a peak of 105 kt (54 m/sec) before weakening slightly to 95 kt (49 m/sec) at 160600Z. Figure 3-28-4 shows Kit early in this intensification period. During this period of

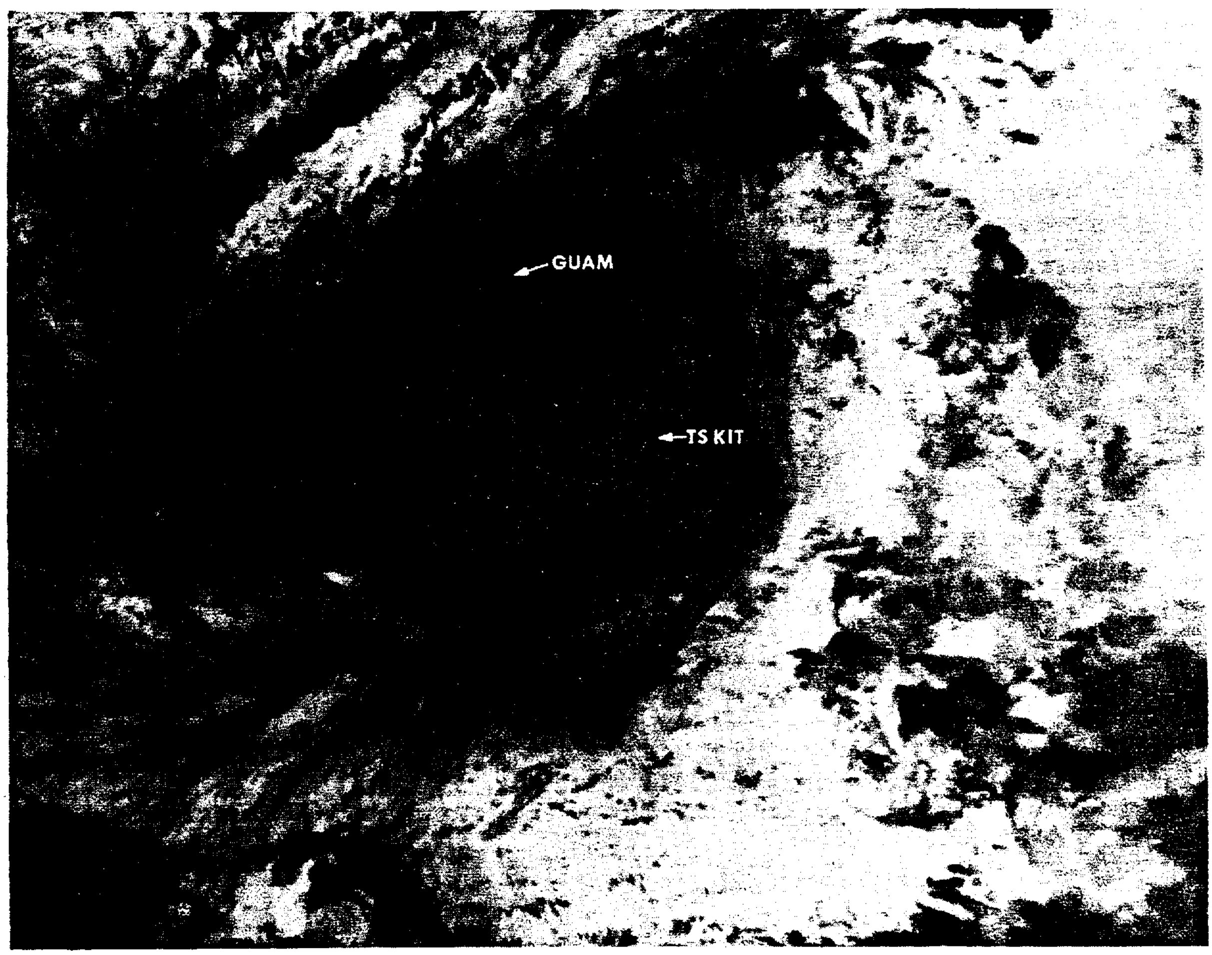


Figure 3-28-3. Infrared imagery which shows Tropical Storm Kit's large convective mass, however, the lighter grey shades on the eastern side show lower cloud features. Utilizing these data, Det 1, 1WW satellite analysts provided accurate fixes during a lengthy period without aircraft fixes, 121003Z December. (NOAA 6 infrared imagery)

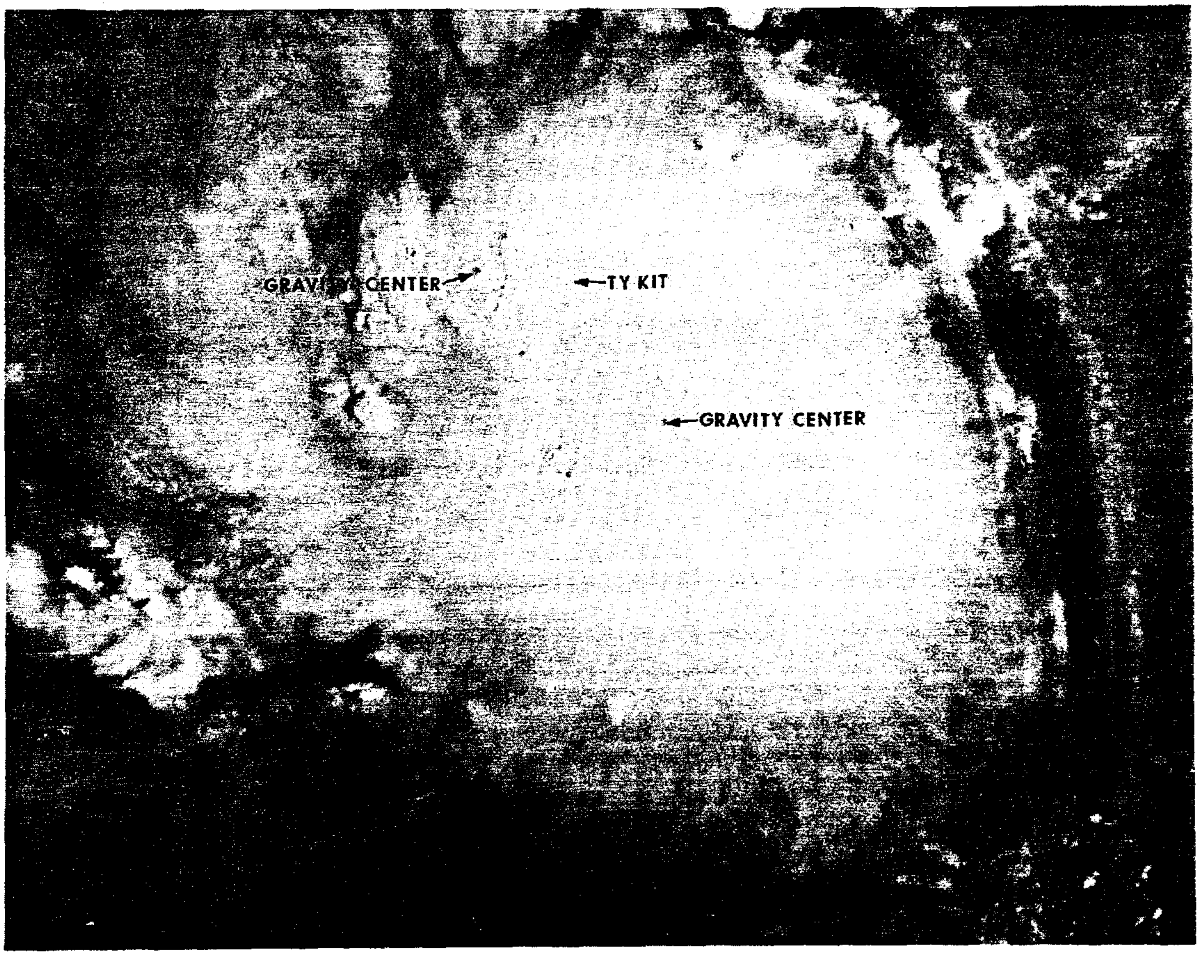


Figure 3-28-4. An intensifying Typhoon Kit, located 165 nm (306 km) west of Guam. Note the textured cloud pattern. Often referred to as gravity waves, these features are frequently seen in rapidly developing tropical cyclones prior to the development of an eye. About 14 hours later, Kit's eye was first detected, 132219Z December. (NOAA 6 visual imagery)

intensification, Kit turned sharply northward and once again slowed to a speed of movement of 4 kt (7 km/hr). Kit's northward movement presented JTWC forecasters with a major dilemma. From the very first warning, Kit was thought to be an eventual westward mover. The strength of the low-level northeast surge originating over Asia had previously dictated the tracks of Hazen (25), Irma (26) and Jeff (27). There had been no appreciable change in the mid-latitude wind regime since those tropical cyclones, thus, a similar scenario seemed very appropriate. But Kit's movement was seemingly in defiance to the synoptic situation. When the 142005Z reconnaissance aircraft data located Kit at 14.3N, the 141800Z warning was amended to show recurvature. However, at 150000Z, the synoptic data showed renewed strength in the northeast surge (Fig. 3-28-5) and accordingly, near 151200Z, Kit turned westward once again. At 161200Z the forecast that abandoned the concept of eventual recurvature was issued.

With hindsight it is fair to say that virtually all the ingredients were present to allow Kit to recurve, except one. The effect of the low-level flow could not be overcome, and despite the presence of a mid-latitude trough just north of Kit, there was a limit to her northward movement.

Following the resumption of a westerly track, Kit began to reintensify as she moved into a position that allowed strong upper-level westerlies to provide an excellent outflow channel to the northeast (Fig. 3-28-6). At 170830Z, a reconnaissance aircraft measured a 924 mb central pressure, or approximately 115 kt (59 m/sec) maximum winds based upon the Atkinson and Holliday (1977) pressure/intensity curve. During the next two days, as Kit began interacting with stronger mid-tropospheric westerlies, she steadily weakened and by 191800Z, had lost typhoon force winds. On 18 December, Kit

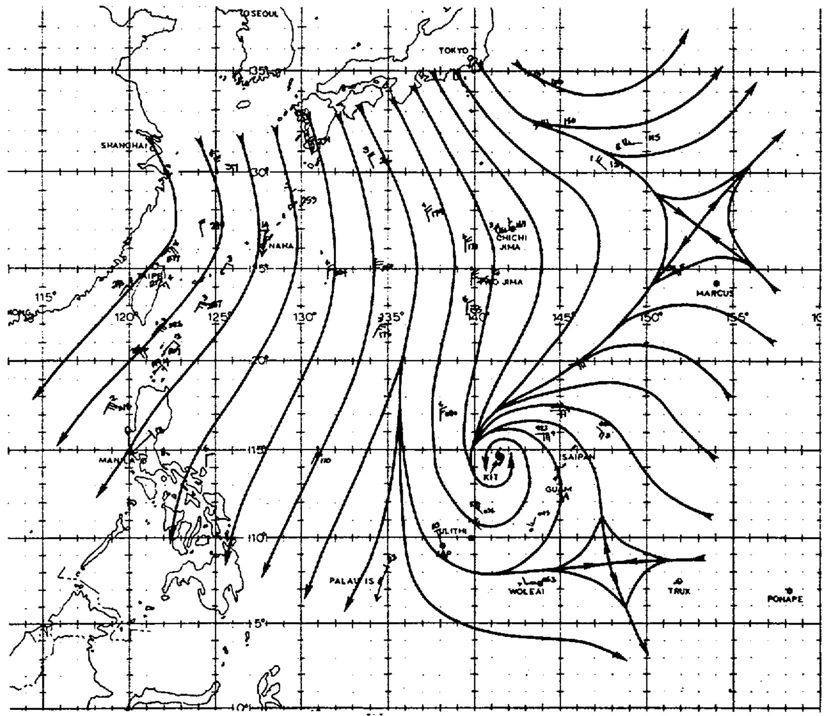


Figure 3-28-5. Surface and gradient level data at 150000Z December with streamline analysis showing a new surge of high pressure moving off of northeastern China. During the following 12 hour period, this surge effectively closed-off any potential for Kit to recurve and once again forced her on a westward track.

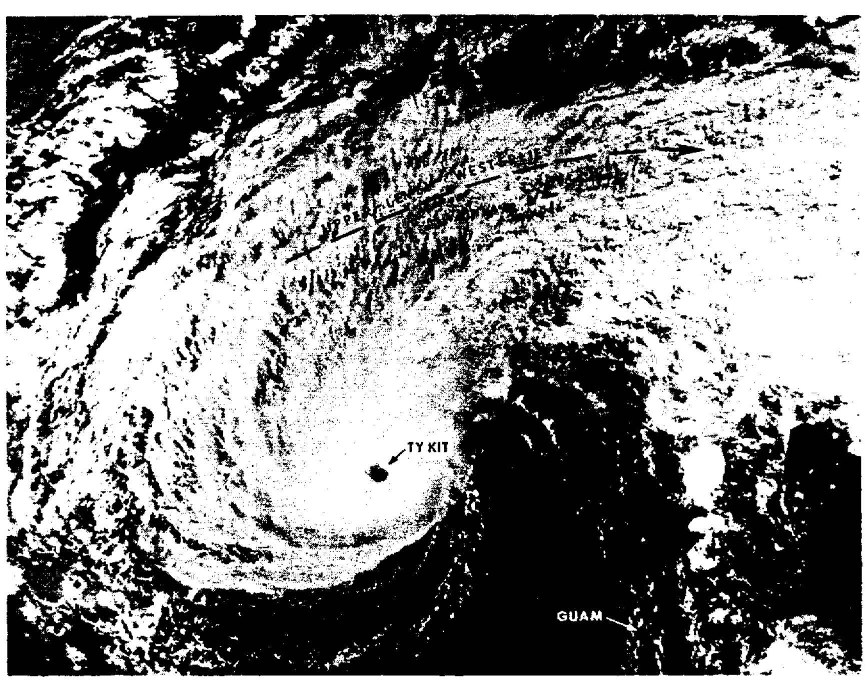


Figure 3-28-6. Typhoon Kit near peak intensity (115 kt (59 m/sec)). Virtually all of Kit's outflow is into the upper-level westerlies. This is the most common pattern for late season typhoons at higher latitudes, 170502Z December. (NOAA 7 visual imagery)

was once again in position where, because of the presence of a deepening trough over eastern China and a break in the northeast surge, she might again jog north and possibly recurve. Thus, from 180600Z to 191800Z, the forecasts showed an increasing tendency for a track toward recurvature near 125E. However, by 200000Z, it became obvious that Kit's low-level circulation had failed to link-up with the approaching shortwave trough and the track toward recurvature was once again abandoned. It was about this time, that aircraft and satellite data began showing Kit's low-level circulation center emerging on the southern edge of the main convective mass. Within hours, Kit's mid- and upper-level features weakened and began drifting northward into the shortwave trough. The low-level center, now fully exposed, turned southward under the influence of low-level northerlies which followed the shortwave trough off of China. At 200743Z, a reconnaissance aircraft located Kit's low-level center 110 nm (204 km) south of the 200000Z warning position. The 200743Z aircraft, as well as 200520Z satellite imagery (Fig. 3-28-7), showed Kit's entire circulation pattern enveloped in a heavy stratocumulus cloud deck. Later infrared imagery could not identify the circulation center, but at 202157Z, the final reconnaissance aircraft mission located a weak low-level center near 13N 129E. Downgraded to Tropical Depression 28 at 201800Z, the fortieth and final warning was issued at 210000Z. During the 36 hours which followed, a weak low-level center could be identified moving southwestward into Mindanao, Republic of the Philippines.

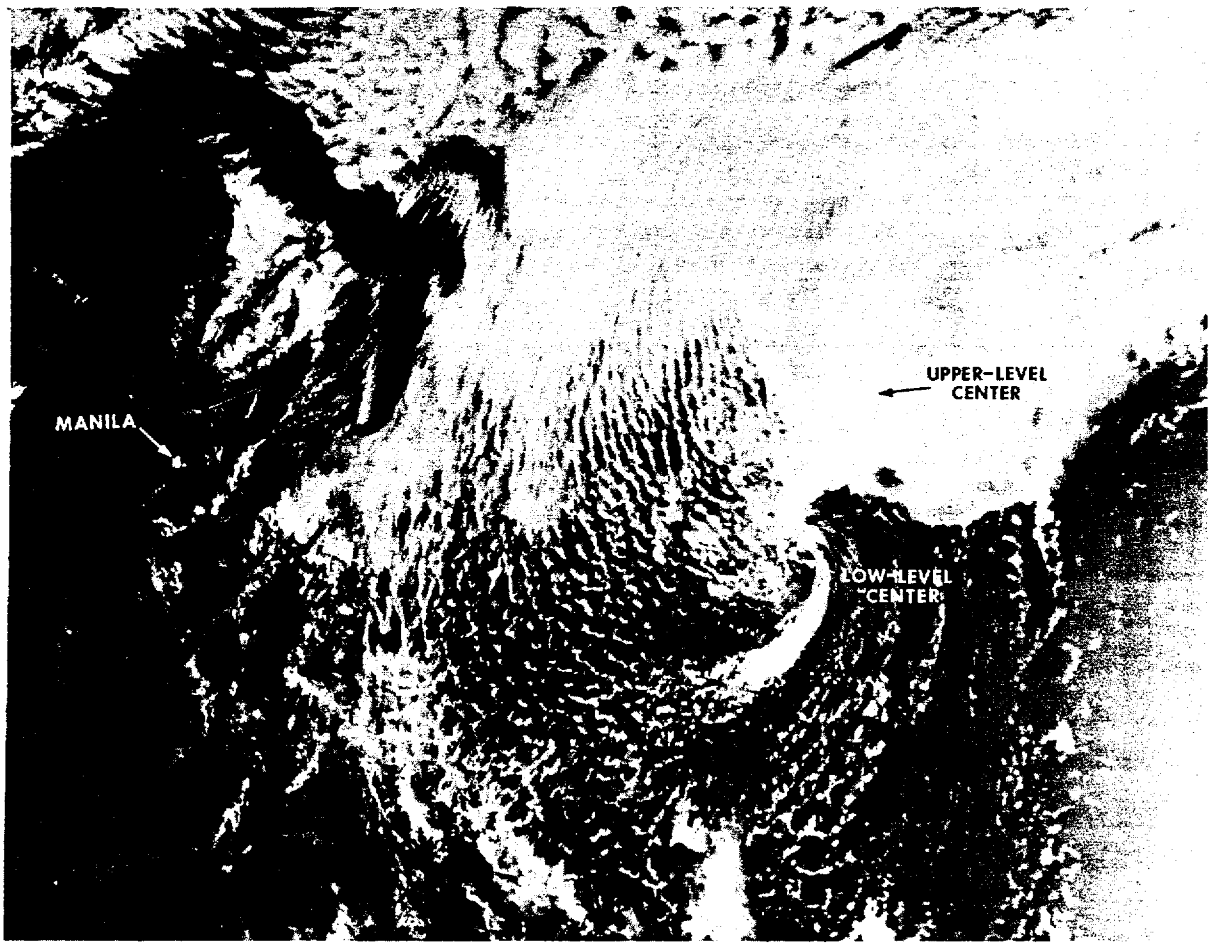
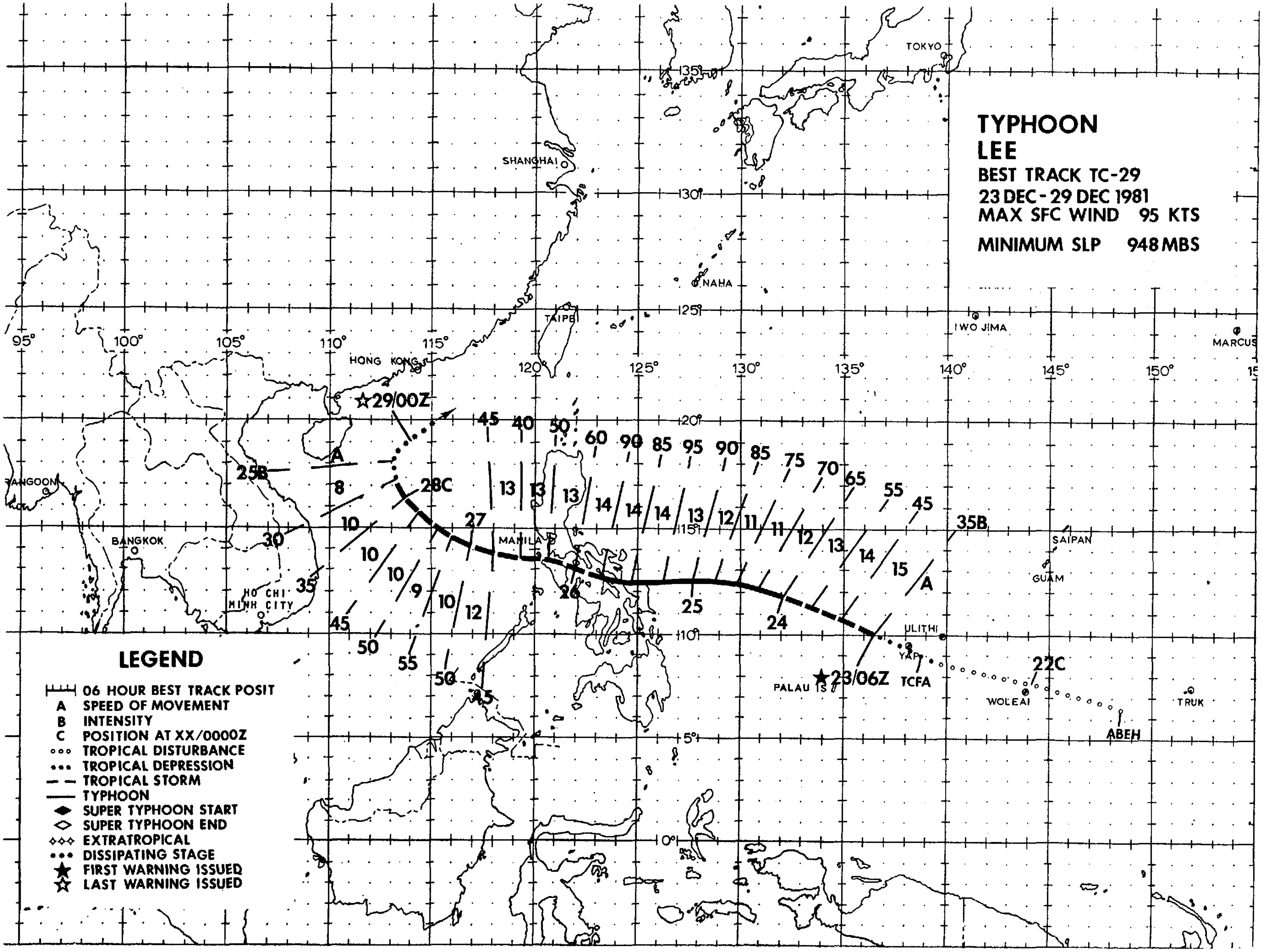


Figure 3-28-7. A weakening Tropical Storm Kit, with the low-level center moving southward while the remnants of her convection move northeastward into a shortwave trough. Note the hyper-extended circulation pattern. The low-level steering was literally stretching Kit southward with time, 200609Z December. (NOAA 7 visual imagery)



TYPHOON
LEE
BEST TRACK TC-29
23 DEC - 29 DEC 1981
MAX SFC WIND 95 KTS
MINIMUM SLP 948 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TOKYO
SHANGHAI
NAHA
TAIPEI
HONG KONG
MANILA
BANGKOK
HO CHI MINH CITY
RANGOON
IWO JIMA
MARCUS
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
ABEH
TCFA
29/00Z
23/06Z
95° 100° 105° 110° 115° 120° 125° 130° 135° 140° 145° 150°
5° 10° 15° 20° 25° 30° 35°

On 21 December, as Tropical Depression 28 (Kit) was dissipating in the western Philippine Sea, an area of convection began organizing west of Truk Atoll. Strong northerly winds, previously feeding into Kit, began moving toward the eastern Philippine Sea, thus closing the western end of the near-equatorial trough southwest of Guam. On 22 December, reconnaissance aircraft data indicated near-gale force tradewind easterlies had penetrated to 8N and to the south of the convective center. However, both the 220000Z 500 mb analysis and a portion of the 700 mb aircraft data indicated a mid-tropospheric trough was present southwest of Guam in a virtually convection-free region. A singular 700 mb height from the reconnaissance aircraft showed an extrapolated surface pressure of 1002 mb near 9N 143E. The aircraft reconnaissance mission was not able to thoroughly investigate this trough, thus it was not possible to determine whether or not a closed circulation had developed. By 221800Z, the convection had moved westward and was located close to the mid-tropospheric trough. At 222100Z, when Yap (WMO 91413) reported a 5 mb pressure fall in a 9 hour period, a Tropical Cyclone Formation Alert was issued for the developing system.

The first warning was issued for Tropical Depression 29 when reconnaissance aircraft data at 220503Z located a closed circulation; at 221200Z, because of increased convective organization and reports of stronger tradewinds north of the cyclone, TD-29 was upgraded to Tropical Storm Lee. During the first 24 hours in warning status, Lee moved west-northwestward in response to a mid-latitude shortwave trough moving off of Asia. Once this trough moved on, Lee turned toward the west into the Philippines. Lee intensified rapidly, reaching typhoon strength just 18 hours after initial warning and, subsequently, attaining a peak intensity of 95 kt (49 m/sec) within 48 hours. Figure 3-29-1 shows Lee during this intensification period. However, shortly after reaching maximum intensity, Lee began crossing the Philippines and a rapid weakening trend followed. Just 24 hours after

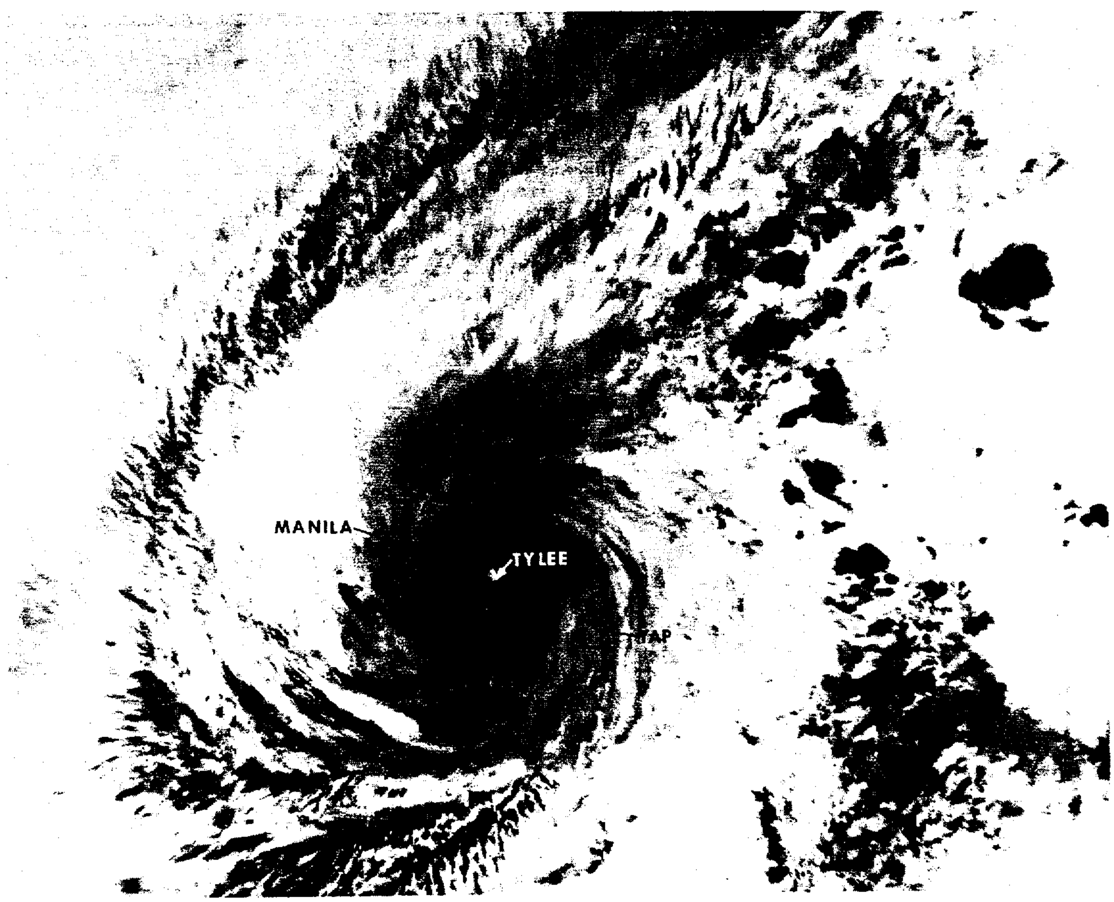


FIGURE 3-29-1. Typhoon Lee, now at 85 kt (44 m/sec), is intensifying rapidly while approaching the central Philippines. 12 hours later, aircraft data had Lee with a 948 mb surface pressure (95 kt (49 m/sec)), 241806Z December. (NOAA 7 infrared imagery)

reaching 95 kt (49 m/sec), Lee entered the South China Sea with an estimated intensity of 40 kt (21 m/sec).

The JTWC forecast tracks had accurately predicted a track between Mindoro and Luzon Islands, then into the South China Sea. Beyond this point, the track was much more difficult to forecast. The numerical prognostic fields were forecasting a deepening of a mid-latitude trough over central China and the subsequent development of a "Shanghai" low in the East China Sea. However, these same forecast fields were not weakening the prevailing northeasterly flow over the South China Sea in the lower-levels. Because the forecast significant pressure changes over eastern China would certainly affect Lee's westward movement, the option for a more northward track in the South China Sea was indicated as early as the fourth warning (240000Z). However, as Lee tracked westward, the forecasted deepening of the mid-latitude trough was delayed on each 12-hour numerical forecast series. At 262048Z, when reconnaissance aircraft located Lee still tracking westward and the deepening of the trough had still not materialized, the 261800Z warning was amended to show a more westward track toward central Vietnam and south of a small high over Hai-nan Island. Within 12 hours of the amended warning, surface/gradient level wind reports in the region showed a lessening of low-level wind speeds as the previously strong northeast monsoonal flow off of Asia moved eastward and more directly affected the Philippine Sea. Although not yet forecasted, the effects of the approaching mid-latitude trough were finally changing the synoptic situation and accordingly, Lee gradually inched toward a more northwestward track.

The aircraft data received on 26 December indicated a 990 nm minimum sea-level pressure at Lee's center with a banding-type eye present. Although the banding feature remained for several days, Lee's surface pressure steadily climbed and reached 998 mb as reported by the 271406Z reconnaissance aircraft mission. On 27 December, satellite imagery began showing the effects of increased vertical wind shear on Lee; and by 280000Z, all of Lee's deep-layer convection and upper-level outflow had been advected well east of the low-level center. On the 28th, surface wind reports showed a weakening of Lee's circulation as surface pressures throughout the northern portion of the South China Sea continued to increase.

Despite Lee's more pronounced northward movement, it was not until the 280600Z warning that the JTWC abandoned the westward track forecast. Lacking throughout this period was an appreciation of how much the low-level wind regime had changed and that Lee was moving northward in the absence of any significant low-level steering. The westward track was continually supported by the usually reliable One-way Interactive Tropical Cyclone Model (OTCM/TCMO) which showed a slight northward jog before assuming a west-southwestward track. Finally, when fix-to-fix data from visual satellite imagery showed a northward movement in the six-hour period up to 280600Z, the JTWC forecast swung around to the north. Although the numerically forecast "Shanghai" low did not develop in the East China Sea, the effect of the mid-latitude trough on the low-level wind flow was a significant factor in Lee's northward movement, although somewhat delayed.

The final warning was issued at 290000Z when visual satellite imagery confirmed what synoptic data at 281200Z had indicated: Lee had essentially dissipated as a significant tropical cyclone. Figure 3-29-2 shows the remnants of Lee's circulation center located 150 nm (278 km) south of Hong Kong.

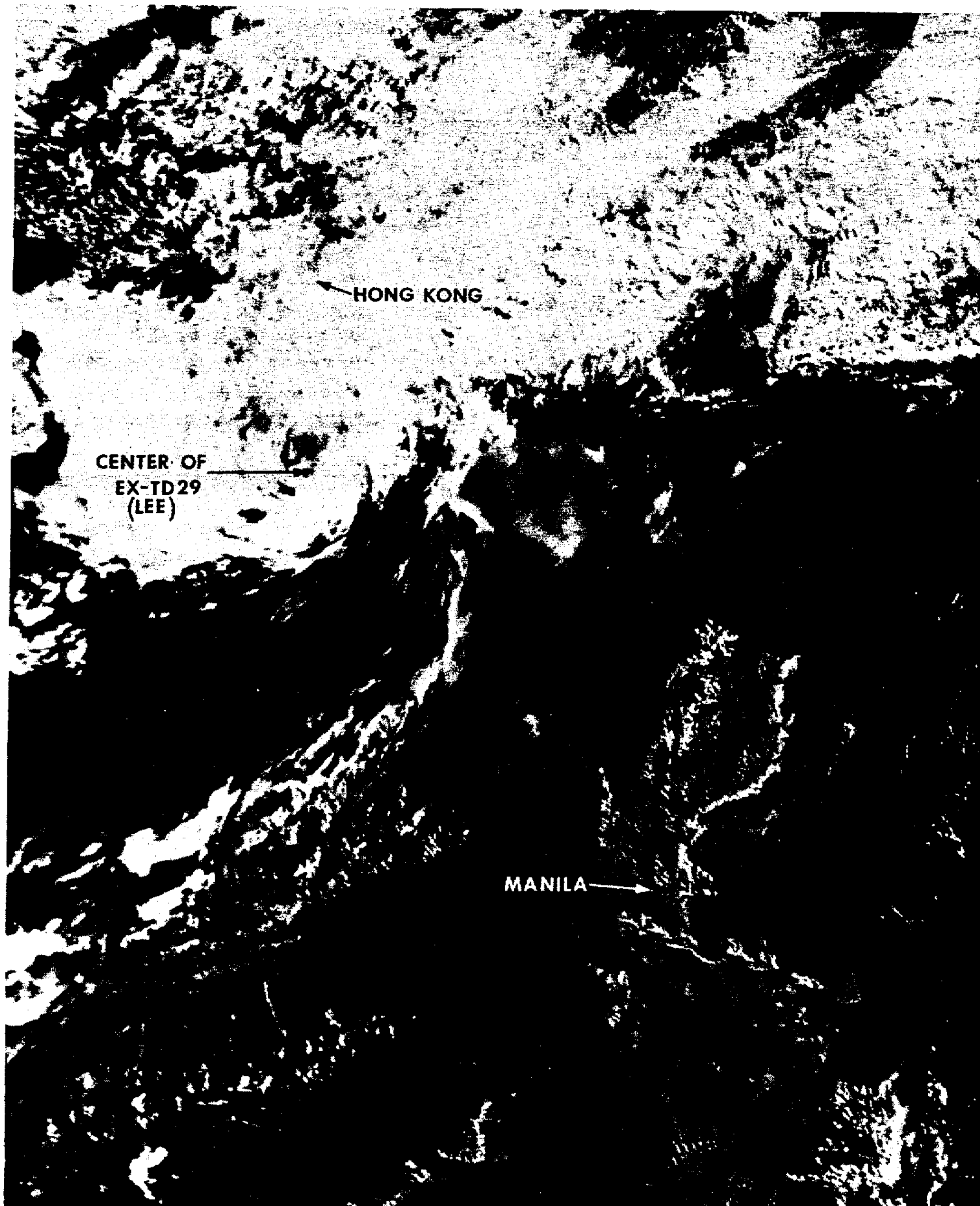


FIGURE 3-29-2. Once Typhoon Lee, now a weak small-scale circulation south of Hong Kong, 290604Z December. (NOAA 7 visual imagery)

2. NORTH INDIAN OCEAN TROPICAL CYCLONES

The 1981 North Indian Ocean tropical cyclone season was near normal. Three tropical cyclones developed during the monsoon transition season as the Northern Hemisphere storm season headed for its conclusion. One cyclone develped in the Arabian Sea and the remaining two cyclones developed in the Bay of Bengal. Tables 3-6 and 3-7 provide a summary of North Indian Ocean tropical cyclones, Tropical Cyclone Formation Alerts and warnings.

TABLE 3-6 NORTH INDIAN OCEAN

1981 SIGNIFICANT TROPICAL CYCLONES

CYCLONE	PERIOD OF WARNING	CALENDAR DAYS OF WARNING	MAX SFC WIND(KT)	EST MIN SLP	NUMBER OF WARNINGS	DISTANCE TRAVELLED(NM)
TC 27-81	30 OCT-02 NOV	4	60	979	13	993
TC 29-81	17 NOV-20 NOV	4	75	964	12	595
TC 31-81	07 DEC-10 DEC	4	75	964	16	1088
	1981 TOTALS	12			41	

TABLE 3-7

1981 SIGNIFICANT TROPICAL CYCLONE STATISTICS

NORTH INDIAN OCEAN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
ALL CYCLONES	0	0	0	0	0	0	0	0	0	1	1	1	3
(1971-1980) AVERAGE*	0.1	0	0	0.2	0.6	0.3	0	0	0.5	0.7	1.4	0.3	4.0

FORMATION ALERTS 3 of the 5 (60%) Formation Alert Events developed into numbered cyclones.

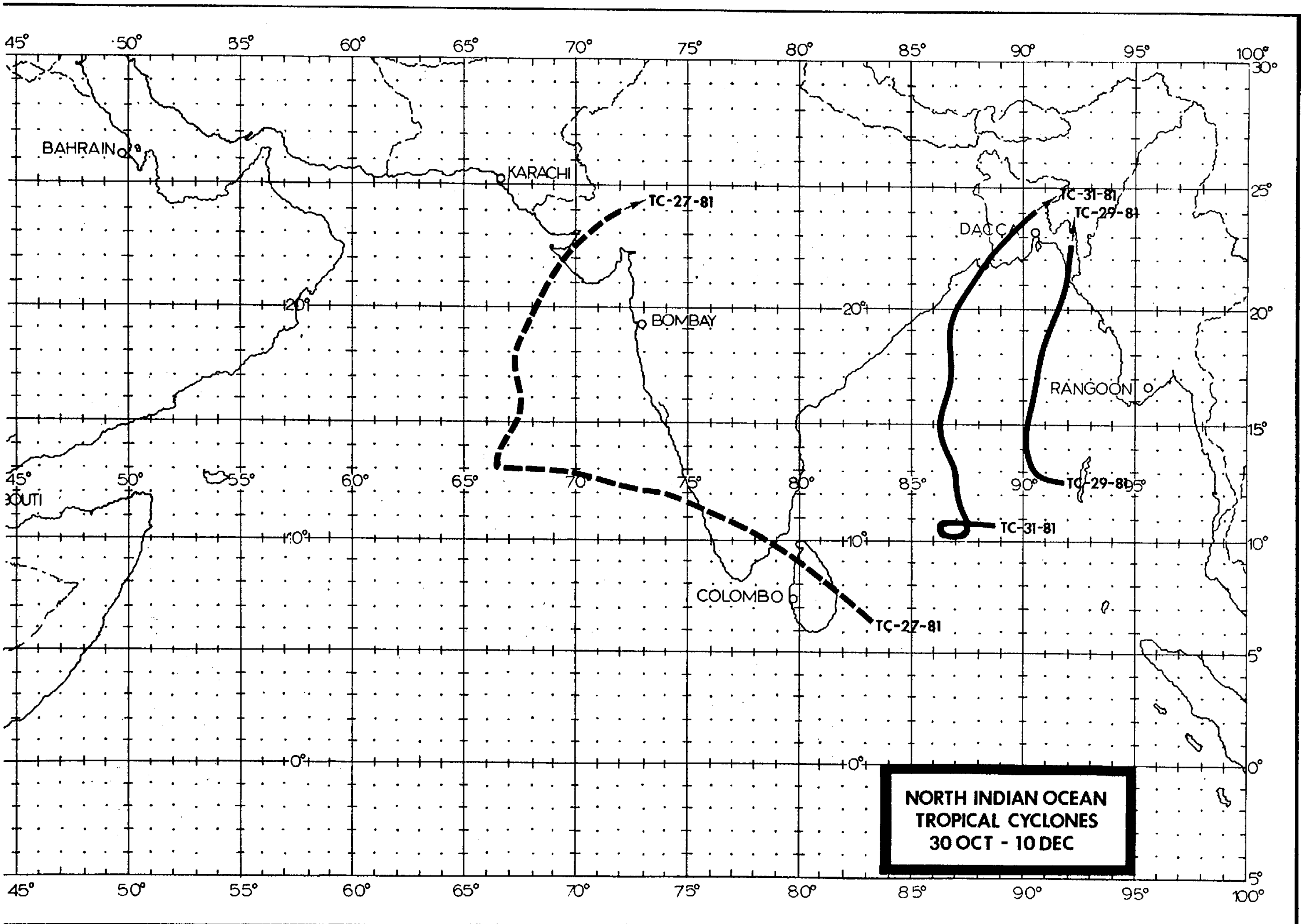
WARNINGS

Number of warning days: 12

Number of warning days with 2 cyclones: 0

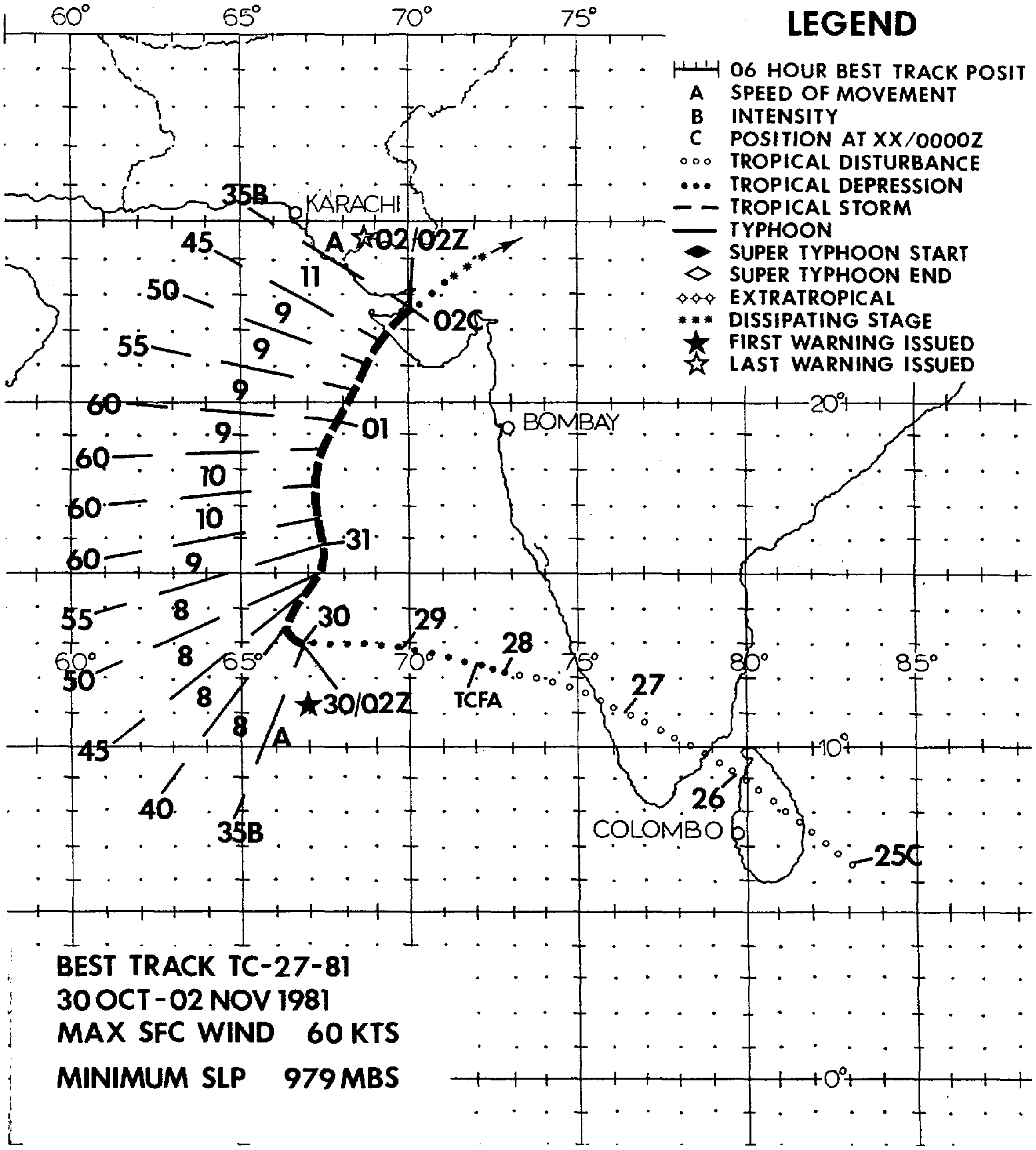
Number of warning days with 3 or more cyclones: 0

*From 1971 through 1979, only Bay on Bengal cyclones were considered; the JTWC area of responsibility was extended in 1975 to include Arabian Sea cyclones.

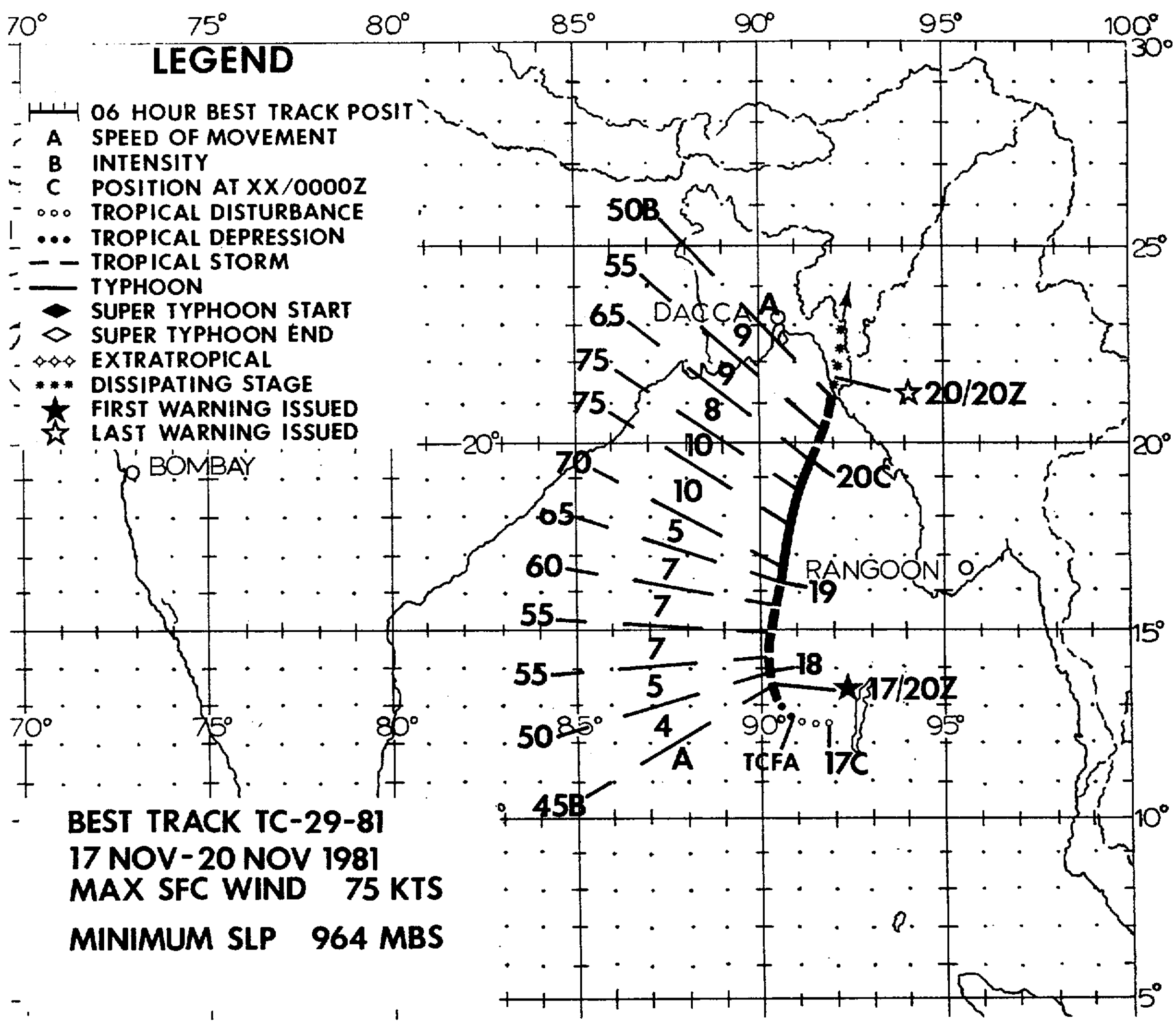

NORTH INDIAN OCEAN
TROPICAL CYCLONES
30 OCT - 10 DEC
TC-27-81
TC-29-81
TC-31-81
BAHRAIN
KARACHI
BOMBAY
DACCA
RANGOON
COLOMBO
45°
50°
55°
60°
65°
70°
75°
80°
85°
90°
95°
100°
30°
25°
20°
15°
10°
5°
0°

TC 27-81 developed from an area of enhanced convection that emerged from the monsoon trough off the southeast coast of India. The Fleet Numerical Oceanography Center 500 mb prognostic series forecasted a break in the subtropical ridge north of the cyclone. This forecast mid-tropospheric pattern formed the basis for the tropical cyclone forecasts issued by JTWC, which predicted a north-northeast movement with eventual dissipation over land.

The system's movement was slow and erratic while it was embedded within the weak steering currents to the south of the 500 mb break; however, by warning number six (310800Z Oct 81) TC 27-81 moved into a region of stronger steering and moved steadily toward the break. North of the break TC 27-81 encountered strong westerly flow near 20N, recurved northeastward and dissipated over land, south of the Gulf of Kutch, 3 days after cyclogenesis.



Tropical Cyclone 29-81 developed rapidly from an area of convection that first appeared on satellite data at 152100Z November. The disturbance which formed about 50 nm (111 km) west of the southern Andaman Islands initially moved northwest, but then went through a 24-hour quasi-stationary period between 170800Z and 180800Z. The first two warnings on TC 29-81 forecasted north-northwest movement, however, by the issuance of warning number three, mid-tropospheric wind data suggested movement toward the north-northeast was more likely. TC 29-81 finally headed north-northeast once it resumed significant movement and continued on this track through landfall (approximately 201800Z) and dissipation over southeastern Bangladesh. All cyclone positions and intensity estimates were based upon satellite data provided by Detachment 1, 1st Weather Wing and Air Force Global Weather Central. Synoptic data, sufficient to define the circulation of TC 29-81, was never available due to the sparcity of land stations and the lack of ships in the area coupled with the sporadic reporting of available land stations.



TC 31-81 was the second tropical cyclone to develop during the transition period of the monsoon season in the Bay of Bengal. As a tropical disturbance it was' first detected on satellite imagery at 031200Z December as it began moving westward from the Malay Peninsula. On 5 December the disturbance began to organize and surface pressures dropped to 1005 mb. A Tropical Cyclone Formation Alert (TCFA) was issued the following day as slow intensification continued. The first warning followed the TCFA by 24 hours and was issued at 070200Z.

TC 31-81 moved erratically under the influence of weak low- and mid-level steering until late on 6 December when the system headed north in response to an approaching mid-tropospheric trough. TC 31-81 maintained this northerly track while reaching it's maximum intensity of 75 kt (34 m/sec) at 091400Z. Movement remained slow until the 500 mb trough had passed far enough eastward to cause an increase in the gradient at the low- and mid-tropospheric steering levels. TC 31-81 accelerated in response to the ambient flow and tracked inland making landfall 20 nm (27 km) southeast of Calcutta.

TC 31-81 inflicted widespread destruction to fishing villages along the Bangladesh coast and contributed to at least 92 deaths.