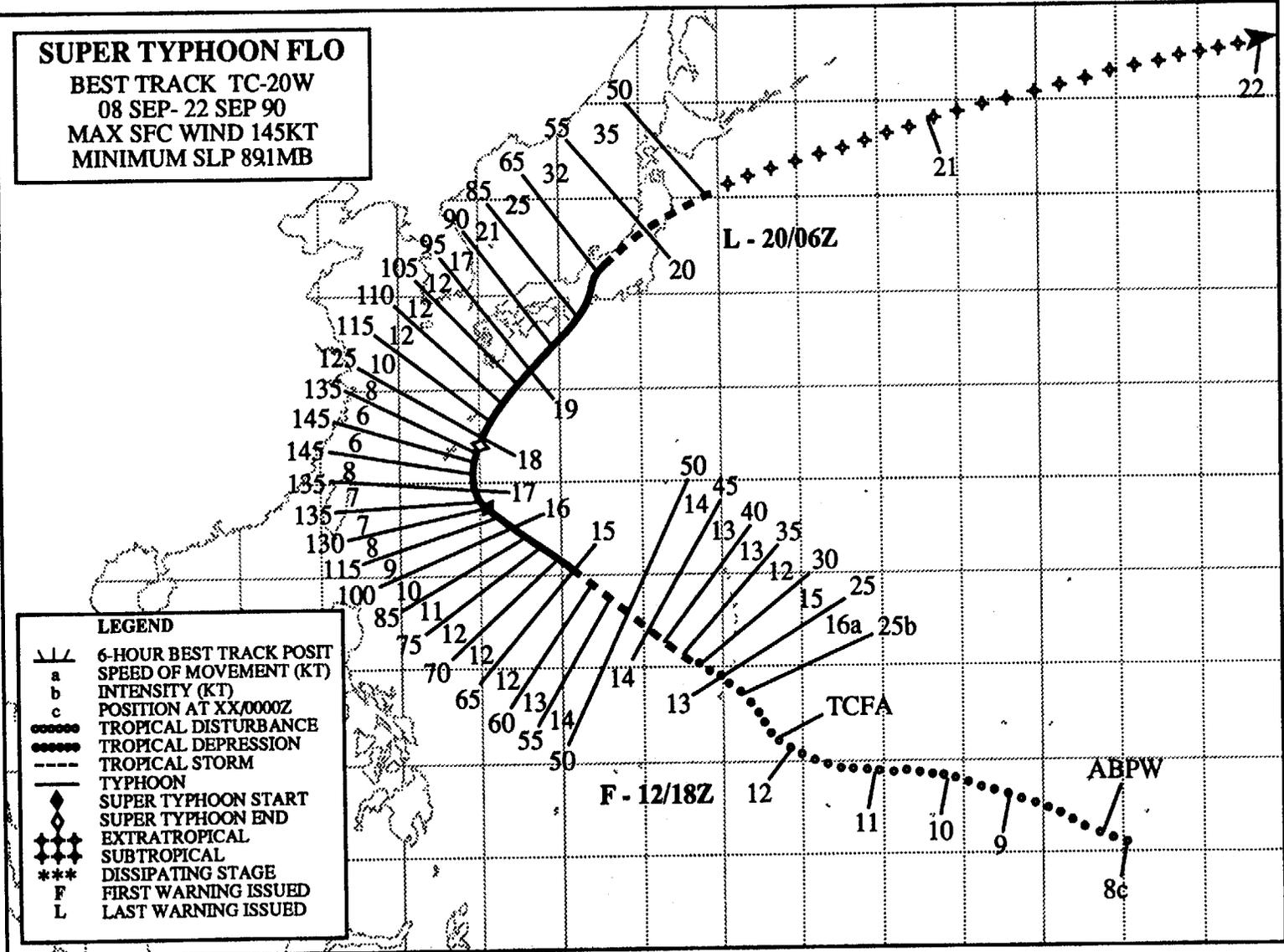


E 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180
 N 50

SUPER TYPHOON FLO
 BEST TRACK TC-20W
 08 SEP- 22 SEP 90
 MAX SFC WIND 145KT
 MINIMUM SLP 891MB

LEGEND

- /—/— 6-HOUR BEST TRACK POSIT
- a SPEED OF MOVEMENT (KT)
- b INTENSITY (KT)
- c POSITION AT XX/0000Z
- TROPICAL DISTURBANCE
- TROPICAL DEPRESSION
- TROPICAL STORM
- TYPHOON
- ◆ SUPER TYPHOON START
- ◇ SUPER TYPHOON END
- ◆◆◆ EXTRATROPICAL
- ◆◆◆◆ SUBTROPICAL
- *** DISSIPATING STAGE
- F FIRST WARNING ISSUED
- L LAST WARNING ISSUED



SUPER TYPHOON FLO (20W)

I. HIGHLIGHTS

Flo was the fourth of six tropical cyclones to develop in September, the first of four super typhoons this year, and the object of over three consecutive days of upper-tropospheric aircraft reconnaissance missions during the TCM-90 field experiment. Flo formed in the wake of Typhoon Ed (19W), passed close by Guam, then rapidly intensified into a super typhoon as it approached Okinawa. Recurvature was slow before the tropical cyclone accelerated northeastward towards the Japanese mainland where it was called the most powerful typhoon to hit Honshu in 19 years. At least 38 people were reported dead or missing, damage was estimated in the millions of dollars, and transportation, communications and power were disrupted.

II. CHRONOLOGY OF EVENTS

- 080600Z - First mentioned on the Significant Tropical Weather Advisory as an area of convection in the monsoon trough with an estimated sea-level pressure of 1008 mb.
- 120530Z - Tropical Cyclone Formation Alert based on increased organization associated with well defined upper-level circulation center.
- 121800Z - First warning issued due to a continued increase in convective organization.
- 131800Z - Upgraded to tropical storm after a Dvorak intensity estimate of CI 2.5.
- 150600Z - Upgrade to typhoon based on the appearance of a small circular eye and the first CI 4.0.
- 161200Z - Reached super typhoon intensity after undergoing a period of rapid deepening: intensity estimate of CI 7.0.
- 170600Z - Peak intensity - 145 kt (75 m/sec) - based on the 891 mb report from a TCM-90 aircraft reconnaissance dropsonde.
- 180000Z - Downgraded to typhoon intensity after eye became ragged and intensity estimate of CI 6.0.
- 200000Z - Downgraded to a tropical storm due to increased vertical wind shear and the start of extratropical transition.
- 200600Z - Final warning issued as Flo transformed into an extratropical low.

III. TRACK AND MOTION

Within a day after Ed (19W) began to consolidate on 7 September in the monsoon trough 750 nm (1390 km) east of Guam, a persistent area of convection that would become Flo developed farther to the east in the southern Marshall Islands. Under the steering influence of the subtropical ridge to the north, Flo drifted west-northwestward for the next eight days at approximately 12 kt (22 km/hr). As the tropical cyclone approached Okinawa on 15 September, a mid-latitude short wave trough deepened to the northwest and induced a break in the subtropical ridge. On 17 September, Flo slowed and started to recurve around the western periphery of the ridge. It slowly accelerated in response to the passing trough. Finally, on 19 September, the typhoon accelerated northeastward across Honshu, as it became embedded in the stronger mid-latitude westerlies aloft. Flo subsequently transitioned to an extratropical system east of Japan on 20 September.

IV. INTENSITY

Flo existed as a weak disturbance for four and a half days (8 - 12 September) before it started to intensify. Nearing Guam on 12 September, the disturbance's convection and low-level circulation appeared to consolidate (Figure 3-20-1). This consolidation process seemed related to the availability of deeper monsoonal southwesterly flow that was enhanced by the presence of Ed (19W) to the west. During the subsequent intensification process, the TCM-90 Doppler radar profiler on the island of

Saipan, 100 nm (185 km) to the north-northeast of Guam, recorded an interesting event. A time-height cross-section of meridional wind speed for 13 September revealed a mid-tropospheric 50 kt (25 m/sec) wind maximum (Figure 3-20-2) that extended around the eastern edge of Flo. The presence of the mid-level jet was concurrent with the intensification of Flo into a tropical storm.

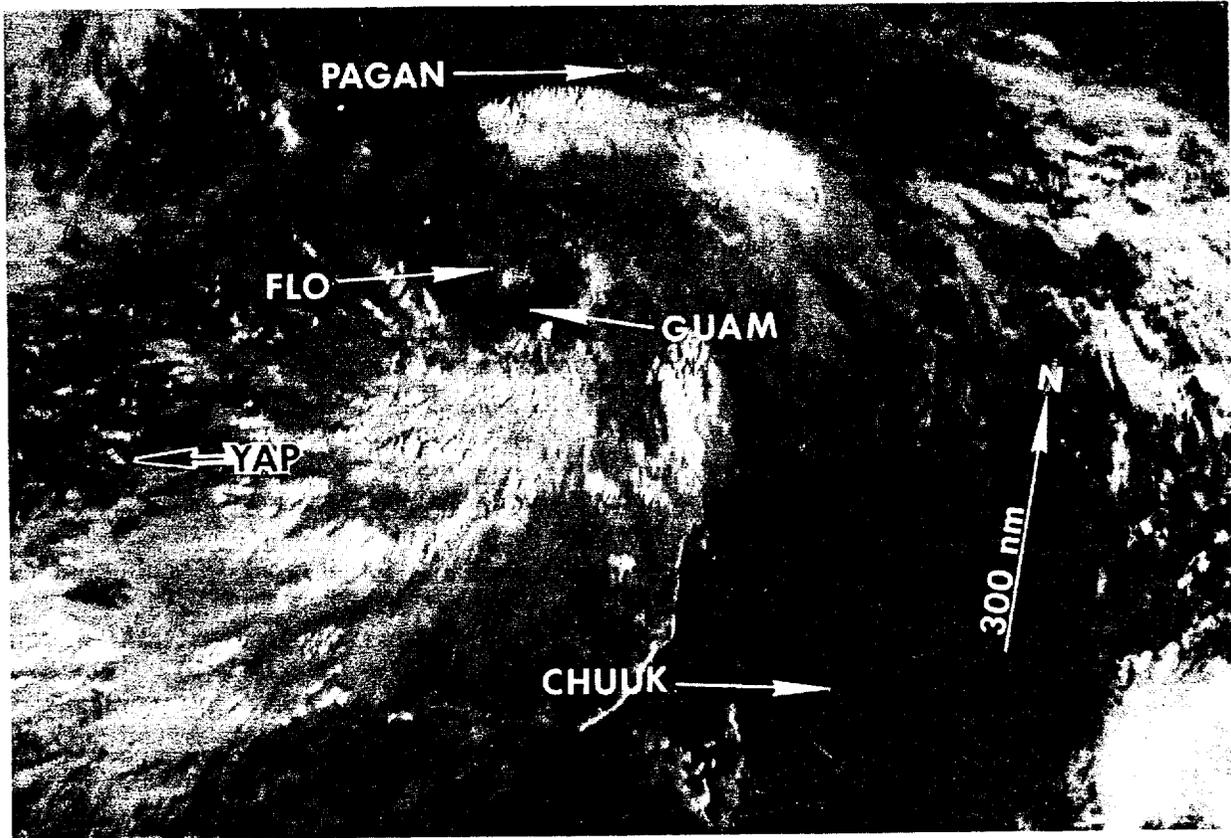


Figure 3-20-1. Flo as a tropical depression near Guam. The relatively clear area northeast of Guam is related to subsidence from Ed (19W), which is just off the top left edge of the photo (122325Z September DMSP visual imagery).

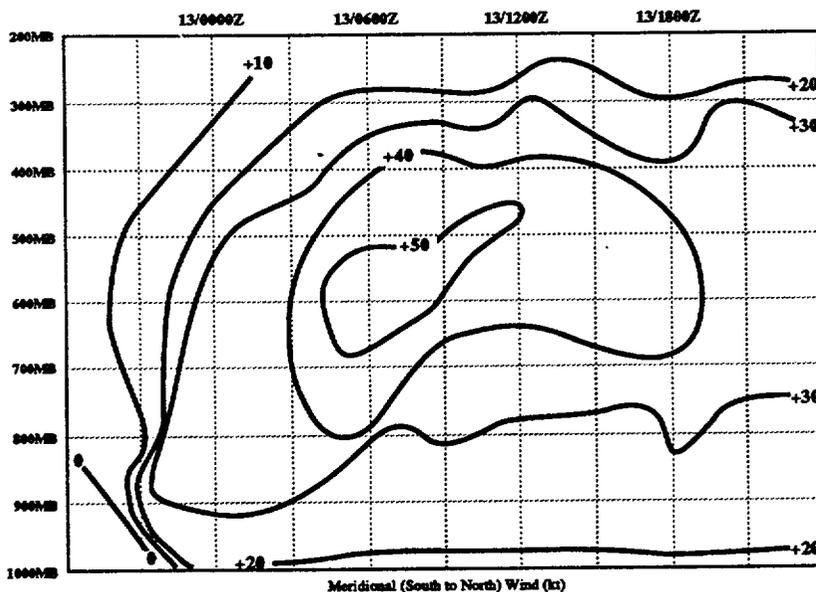


Figure 3-20-2. Time-height cross-section of the meridional wind speed for 13 September from the TCM-90 Doppler radar profiler on Saipan. The analysis shows the mid-level wind maximum that was observed on the east side of Flo.

Subsequently, the tropical cyclone intensified at a normal rate of one T-number per day until it reached typhoon intensity on 15 September (Figure 3-20-3). Then Flo rapidly intensified for the next 36 hours. On 16 September, as Flo was becoming a super typhoon, it also was the subject of an Intensive Observing Period (IOP) as part of the TCM-90 experiment. During the IOP, the NASA DC-8 reconnaissance aircraft provided JTWC with invaluable information on the location, structure, and intensity of Flo as the storm approached Okinawa (Figures 3-20-4 and 3-20-5). These data were the first-ever upper tropospheric (near 200 mb) winds from a western North Pacific tropical cyclone to be collected and used operationally. As a result of the information provided, JTWC increased the maximum winds from 135 kt (69 m/sec) to 145 kt (75 m/sec) at 170600Z September (Figure 3-20-6). The flight level for the reconnaissance missions ranged from 37,000 to 43,000 ft (11.3 km to 13.1 km), approximately the 200-mb level. These data revealed that there was intense cyclonic flow around Flo's core with what appeared to be very little direct outflow evident close to the eye. Flight-level winds of 110 kt (55 m/sec) were recorded just east of the eye on 17 September. In addition, the presence of an anticyclonic eddy to the southeast of the eye was documented. A central pressure of 891 mb obtained via the dropsonde on the same day correlated well with both the Dvorak (1984) estimates of current intensity and the Atkinson-Holliday (1977) pressure-wind relationship.

As Flo began to recurve, it remained over the warm waters of the Kuroshio Current. Vertical wind shear weakened the typhoon, but it still had 90 kt (45 m/sec) sustained surface winds when it slammed into southern Honshu on 19 September. Interaction with land further weakened the tropical cyclone, and it transitioned to an extratropical cyclone the following day.

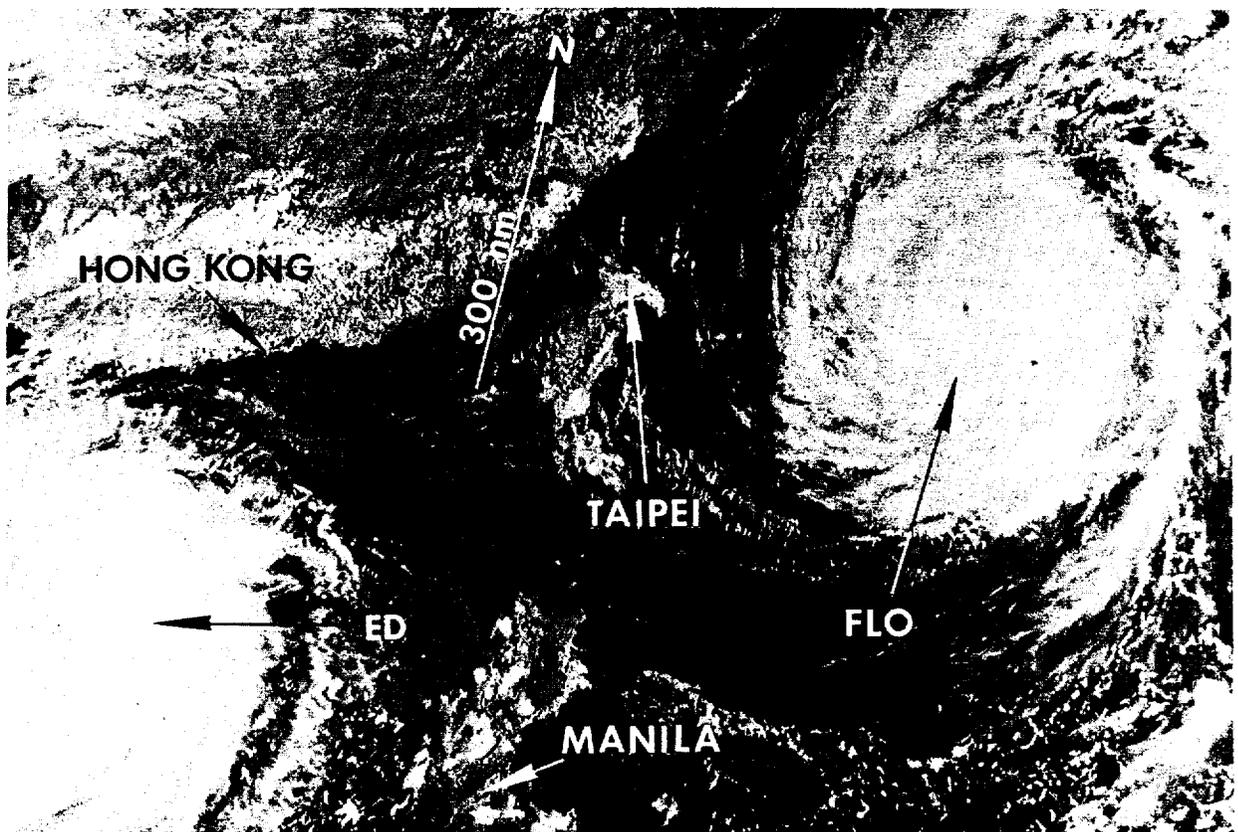


Figure 3-20-3. Flo at maximum intensity is starting to recurve just east of Okinawa while Typhoon Ed (19W) approaches Vietnam (170541Z September DMSF visual imagery).



Figure 3-20-4. Photograph of Flo from the NASA DC-8 reconnaissance aircraft flying near 200 mb on 17 September shows the top and side of the wall cloud (Photo courtesy of Mr. Franz Wen-Ching Yeh, TCM-90 experiment).

V. FORECASTING PERFORMANCE

The overall JTWC forecast performance is shown in Figure 3-20-7. Although the overall 72-hour position error was well below average at 215 nm (395 km), some forecast problems were encountered. Twenty-four hours prior to recurvature, JTWC forecast Flo to make landfall in southern Kyushu whereas the actual landfall was farther east on southern Honshu. A mid-latitude short wave moving off the coast of Asia, deepened more rapidly than anticipated; thus, the forecasts were too far to the west.

VI. IMPACT

Flo passed only 60 nm (110 km) east of Okinawa - close enough to break the drought with 5 to 10 inches (125 to 255 mm) of rain, but just far enough away to spare the island from the most extreme winds near the eye. The maximum wind gusts reported at Naha, Okinawa were 66 kt (35 m/sec). Futenma Marine Corps Air Station and Kadena Air Base reported 64 kt (35 m/sec) and 60 kt (30 m/sec), respectively. The crew of the NASA DC-8 estimated that 100 kt (50 m/sec) winds were just off the east coast of Okinawa. Damage to Okinawa was minor; however, there were news reports that four people died and three were missing in landslides. Flo made landfall on Honshu, 60 nm (110 km) south of Osaka with an intensity of 90 kt (45 m/sec). It was the most powerful typhoon to hit Honshu in 19 years according to news releases. The typhoon brought widespread flooding and caused 115 landslides in Honshu, leaving at least 32 people dead, six missing and 90 people injured. Property and crop damage were estimated in the millions of dollars, and communications, power, and transportation systems were interrupted. A tornado also occurred, injuring 12 people, damaging or destroying 200 homes and other buildings, and downing power lines.



Figure 3-20-5. Photograph of Flo from NASA DC-8 reconnaissance aircraft flying near 200mb on 17 September showing the stratocumulus cloud spirals that define the low-level center (Photo courtesy of Mr. Franz Wen-Ching Yeh, TCM-90 experiment).

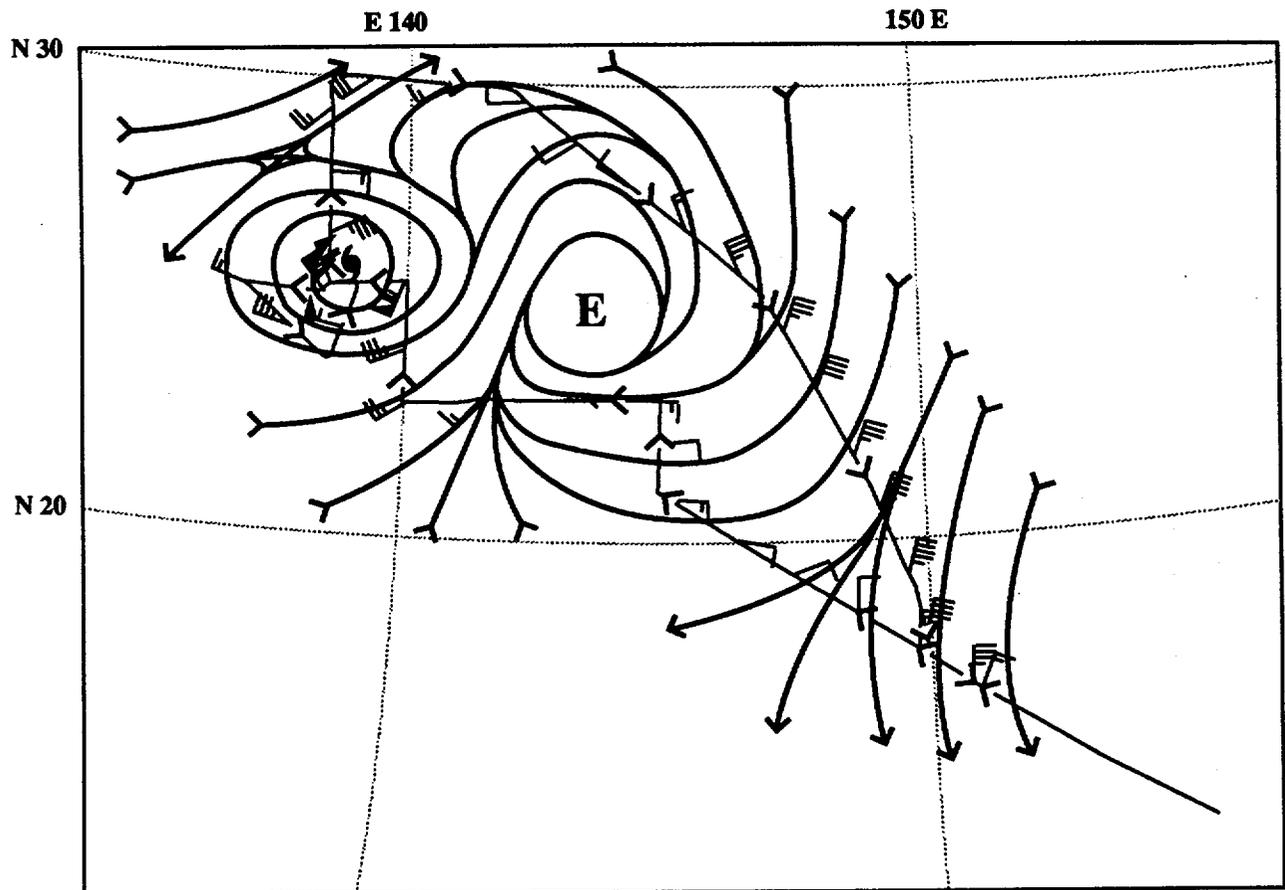


Figure 3-20-6. Flight-level winds reports from aircraft reconnaissance at 37,000-43,000ft for the period 170204Z to 170904Z September show the intense cyclonic circulation near Flo's eye and the anticyclonic eddy to the southeast.

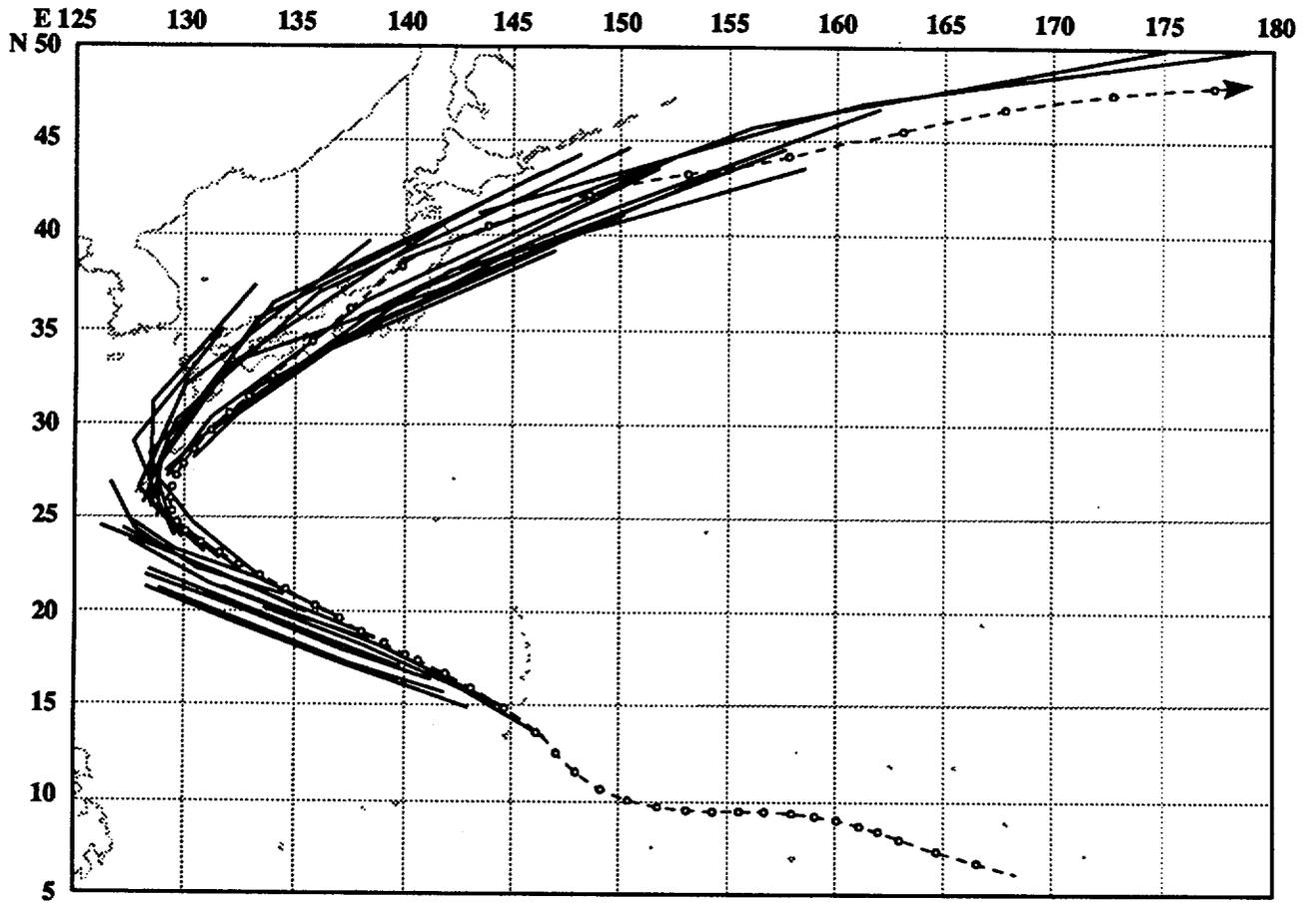


Figure 3-20-7. Summary of JTWC forecasts (solid lines) for Flo is superimposed on the final best track (dashed line).