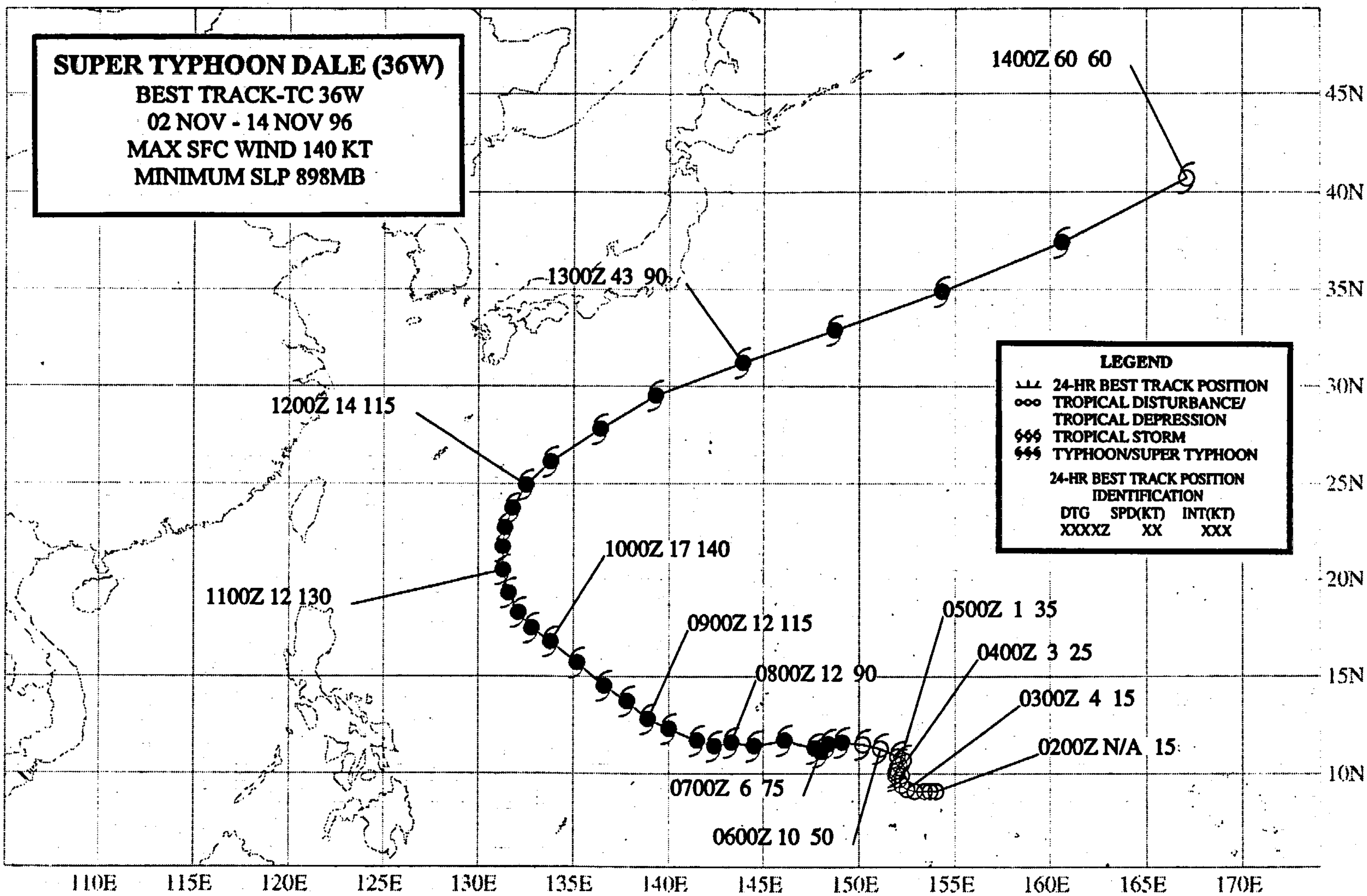

SUPER TYPHOON DALE (36W)
BEST TRACK-TC 36W
02 NOV - 14 NOV 96
MAX SFC WIND 140 KT
MINIMUM SLP 898MB
LEGEND
24-HR BEST TRACK POSITION
TROPICAL DISTURBANCE/ TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON/SUPER TYPHOON
24-HR BEST TRACK POSITION IDENTIFICATION
DTG SPD(KT) INT(KT)
XXXXZ XX XXX
1400Z 60 60
1300Z 43 90
1200Z 14 115
1100Z 12 130
1000Z 17 140
0900Z 12 115
0800Z 12 90
0700Z 6 75
0600Z 10 50
0500Z 1 35
0400Z 3 25
0300Z 4 15
0200Z N/A 15
45N
40N
35N
30N
25N
20N
15N
10N
110E
115E
120E
125E
130E
135E
140E
145E
150E
155E
160E
165E
170E

SUPER TYPHOON DALE (36W)

I. HIGHLIGHTS

Dale was a large and very intense typhoon that formed at the eastern end of the near-equatorial trough. Its passage resulted in phenomenal seas and surf on Guam's western shore. The equatorial westerly wind burst that preceded Dale's formation was accompanied by very low sea-level pressure reports along the equator. Passing 110 nm to the south of Guam, Dale was observed by Guam's NEXRAD. Dale caused an estimated $3.5 million worth of damage on Guam.

II. TRACK AND INTENSITY

From late October through the first day of November, the tropics of the WNP were dominated by easterly low-level wind and upper-level westerly wind; and, with the exception of the South China Sea, deep convection was disorganized and widely scattered. Beginning on 02 November, the amount of deep convection in the low latitudes of the WNP began to increase in association with lowering pressure throughout Micronesia accompanied by the onset of a near-equatorial trough along 5°N. On 03 November, the deep convection consolidated into two distinct clusters: one centered near 7°N 138°E (which became Ernie (37W)), and the other centered near 8°N 150°E (which became Dale). The pre-Dale cluster of deep convection was first mentioned on the 030600Z November Significant Tropical Weather Advisory when satellite imagery and synoptic data indicated the presence of a cyclonic circulation accompanied by a relatively low central pressure (1002 mb) and extensive divergence aloft (as indicated by animated water-vapor GMS imagery). With a continued fall of the central pressure, and improvements to the satellite cloud signature, a Tropical Cyclone Formation Alert was issued at 031800Z, followed by the first warning on Tropical Depression (TD) 36W, valid at 040600Z.

With an extensive surge in the southwesterly flow to its south and equally strong easterly winds to its north, TD 36W remained nearly stationary for approximately 24 hours while it slowly gained intensity. On the warning valid at 151200Z, TD 36W was upgraded to Tropical Storm Dale based upon satellite intensity estimates of 35 kt (18 m/sec) and a buoy report indicating that the central pressure had fallen below 996 mb (indicative of winds of at least 37 kt on the Atkinson and Holliday (1977) wind-pressure relationship). After becoming a tropical storm, Dale began to move westward, intensified, and became a typhoon at 061800Z. At approximately 071400Z Dale (moving west along 11.5°N) passed 110 nm (205 km) to the south of Guam where peak gusts reached 74 kt (38 m/sec) and high waves inundated some coastal roads and overtopped 100-ft (30-m) sea cliffs (see the Discussion and the Impact sections). Dale came within range of Guam's NEXRAD, which detected winds in excess of 100 kt (51 m/sec) in the lower troposphere (see the Discussion section).

On 09 November, while to the west of Guam in the Philippine Sea, Dale became a super typhoon with a peak intensity of 140 kt (72 m/sec) (Figure 3-36-1). On 10 November, Dale slowed and began a turn toward the north, and on 11 November reached its point of recurvature (i.e., the westernmost longitude). After recurvature, Dale accelerated rapidly to the east-northeast reaching translation speeds in excess of 60 kt (110 km/hr) after 140000Z. The final warning was issued, valid at 131800Z, when completion of extratropical transition was expected within six hours.

III. DISCUSSION

a. *Extremely low equatorial sea-level pressure associated with Dale's formation*

The sea-level pressure (SLP) along the equator has spatial and temporal variations of small magnitude when compared with the magnitude of the SLP variations at higher latitudes. In the mean, the global equatorial SLP ranges from a maximum of approximately 1015.5 mb in the eastern Atlantic to a minimum of approximately 1008.5 mb in the WNP (Sadler et al. 1987). Lacking the Coriolis effect, and large inertial forces (e.g., centrifugal forces in atmospheric vortices such as typhoons), the pressure gradients on the equator must only be sufficient to drive the wind against friction. As such, a pressure gradient of 1 mb per 1000 km can support a sustained 10-m marine surface wind of 20 kt (10 m/sec). Even the vast easterly wind flow across the tropical Pacific is accompanied by an east-west pressure drop (along the equator) of only 4 mb from the eastern equatorial Pacific to the WNP. Given this background, it is now clear that the very low SLP readings of 1002 mb, and SLP changes of 10 mb along the equator in the WNP during the life of Dale are extraordinary.

While Dale and Ernie (37W) were forming at low-latitude in the WNP, the SLP throughout Micronesia was steadily falling. Even along the equator, to the south of the developing Dale, the SLP steadily fell to extraordinarily low values (Figures 3-36-2 and 3-36-3). On 04 November, several ships near the equator reported a SLP of 1002 mb or less. Values of SLP this low are rarely seen along the equator. Morrissey (1988) examined the SLP reports of ships within two degrees of the equator along a principal north-south shipping lane between 148°E to 152°E. The ship reports used by Morrissey were extracted from the Comprehensive Ocean-Atmopshere Data Set (COADS) for an 80-year (1900-1979) period. From his analysis (Figure 3-36-4), few, if any, SLP reports below 1004 mb are found along the equator in this region. Ironically, approximately 10 days after the very low SLP readings (and after Dale had exited the tropics), the equatorial SLP and the SLP throughout Micronesia rose to exceedingly high values. The SLP of 1013.5 mb on the equator on 14 November was, according to Figure 3-36-4, about as high as the SLP ever gets there.

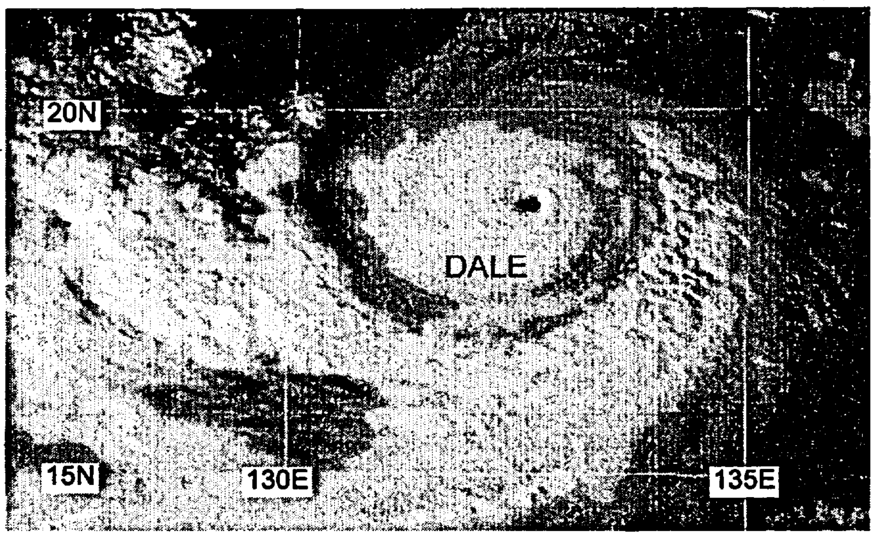


Figure 3-36-1 Dale nears its peak intensity of 140 kt (72 m/sec) (090530Z November visible GMS imagery).

b. Dale as seen by Guam's NEXRAD

On the night of 07 November, Dale passed 110 nm (205 km) to the south of Guam. Guam experienced the peripheral rain bands of Dale, but never entered the eye wall cloud (Figure 3-36-5). For much of the time during Dale's closest point of approach (CPA), Guam remained within a dry wedge between the outer rain bands and the eye wall cloud. The air was laden with salt spray, and some light rain which allowed the NEXRAD to obtain a deep vertical profile of the wind velocity (Figure 3-36-6). The highest winds of approximately 100 kt (51 m/sec), persisted in a layer between about 6,000 and 13,000 ft. At the gradient level (3,000 ft), the NEXRAD detected 75-kt (39-m/sec)

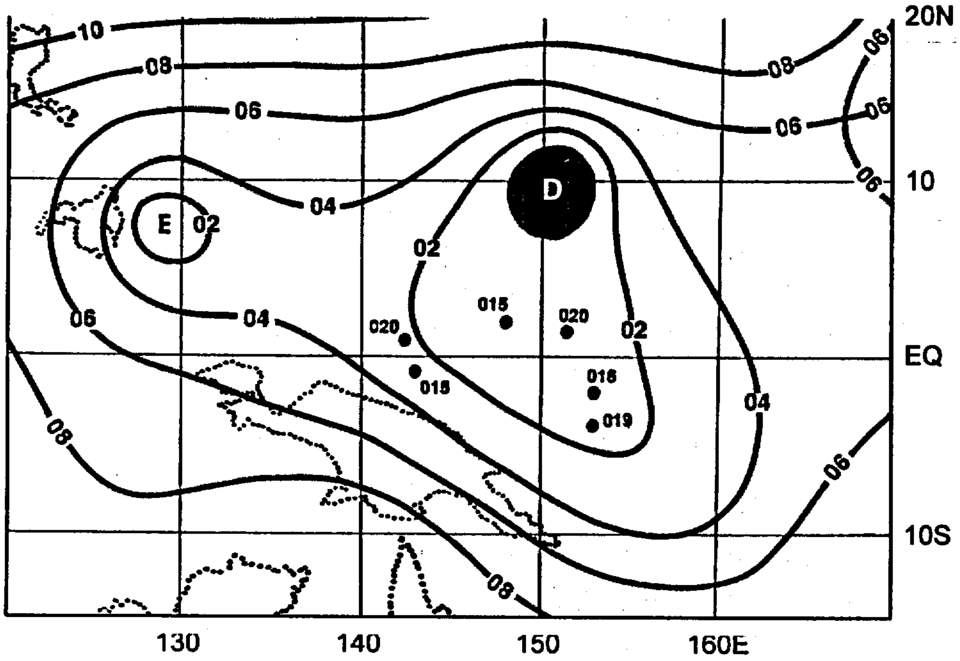


Figure 3-36-2 Sea-level pressure analysis based upon a composite of ship observations at 040600Z and 041800Z November. Individual ships near the equator with reports of 1002 mb or lower are indicated. D = Dale, E = Ernie, and SLP contours are drawn at 2 mb intervals.

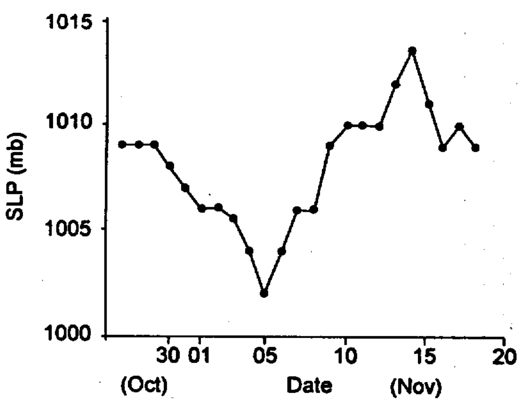


Figure 3-36-3 Time series of the equatorial SLP near 150°E based upon ship observations.

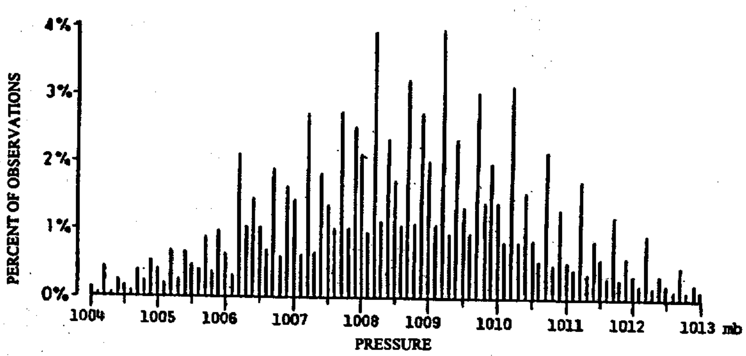
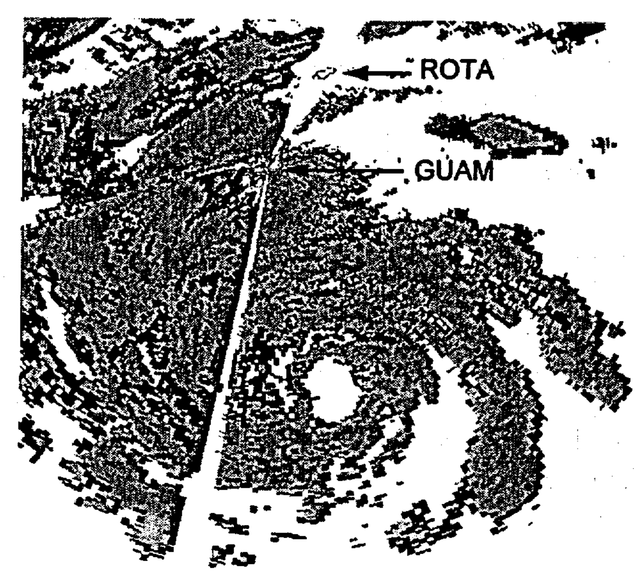


Figure 3-36-4 Histogram of ship SLP reports extracted from the COADS data set in the box bounded by 2°N and 2°S from 148°E to 152°E (adapted from Morrissey, 1988).

Figure 3-36-5 NEXRAD base reflectivity showing the eye, wall cloud and peripheral rain bands of Dale as it nears its CPA to Guam. Guam remained in the dry wedge between the outer rain bands and the eye-wall cloud for an extended period (071458Z NEXRAD base reflectivity product).



winds (not shown in Figure 3-36-6) which correlated well with the peak gusts observed on Guam (Figure 3-36-7). Although the maximum winds in a typical TC are expected to be at the gradient level, NEXRAD coverage of Dale showed they were considerably higher in altitude. Perhaps the lack of deep convection and associated torrential rain were factors in the relatively elevated level of the wind maximum during Dale's passage by Guam.

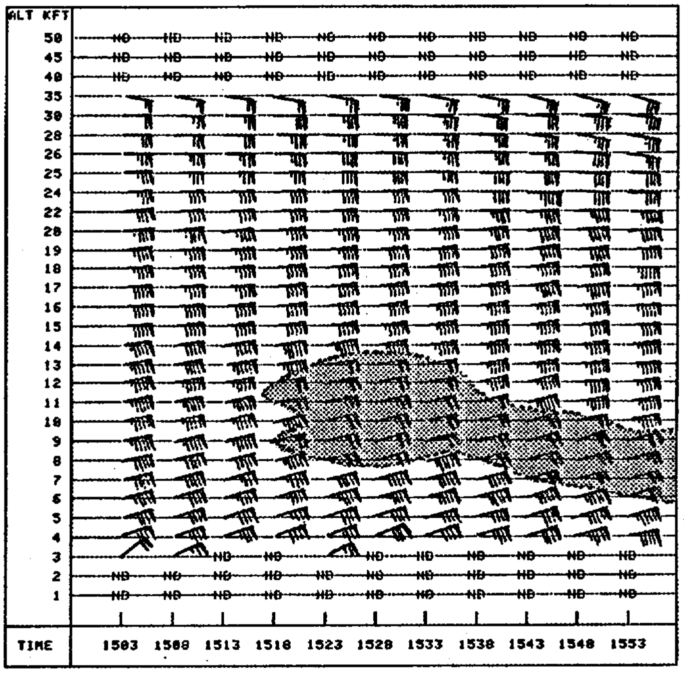


Figure 3-36-6 The NEXRAD velocity azimuth display (VAD) wind profile near the time of Dale's CPA to Guam showing winds of 100 kt (51 m/sec) or more between 6,000 and 12,000 ft (shaded region) (071553Z NEXRAD VAD wind profile product).

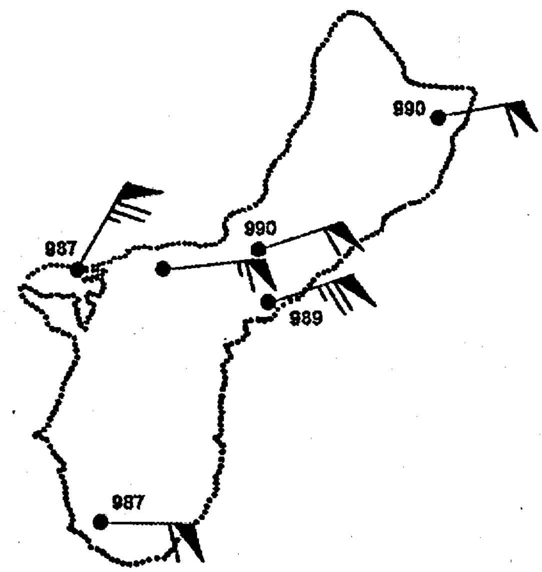


Figure 3-36-7 Peak gusts and minimum SLP recorded at several selected sites on Guam during Dale's passage.

c. *Dale's digital Dvorak (DD) numbers*

The time series of Dale's DD numbers (Figure 3-36-8) peaked at approximately 090600Z with values of approximately T 7.5. After this peak, the DD numbers fell sharply to below T 5.0 by 100000Z. The warning and best-track intensity lag the peak DD numbers by about six hours, and do not reflect the sharp drop in the DD numbers after the peak. As the DD numbers are considered experimental, and are not used operationally, it is not expected that the warning intensity would be strongly tied to them. The DD numbers do, however, often reflect prominent observable changes in the characteristics of the TC. In Dale's case, the rapid drop of the DD numbers after the peak occurred because concentric eye walls formed. At peak intensity, Dale had a well-defined small eye (Figure 3-36-1). When the DD numbers fell, it was because concentric eye walls formed (Figure 3-36-9a, b). The default radius used to define the eye-wall cloud-top temperature in the DD algorithm is 30 nm. This radius fell between the inner and outer eye walls, and resulted in the period of low DD values after the peak. The radius used to define the eye-wall cloud-top temperature is an adjustable parameter on the MIDDAS system, and when set to 10 nm, it was able to measure the inner eye wall. This resulted in DD numbers of about one T number higher than those computed

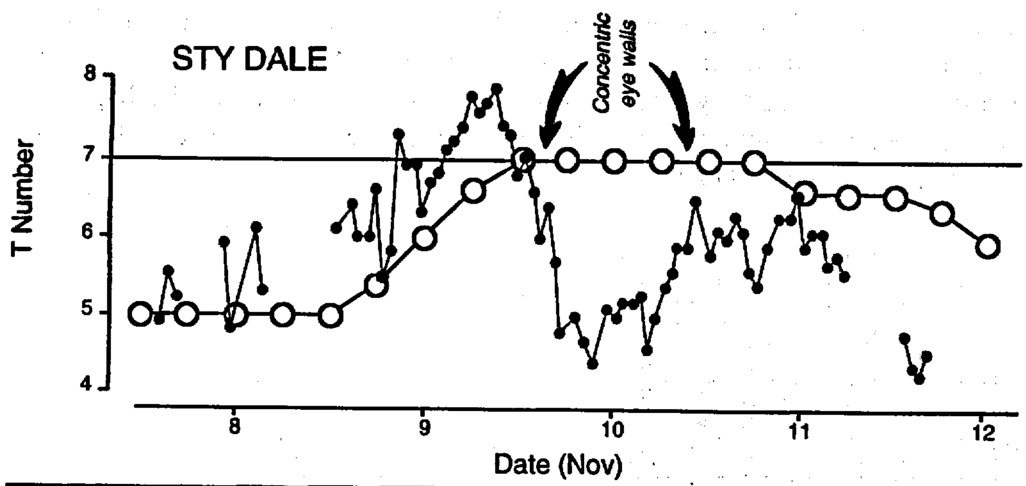


Figure 3-36-8 A time series of Dale's hourly DD numbers (small black dots) compared with the warning intensity converted to a T number (larger open circles at six-hour intervals). The large drop in the DD numbers after the peak was the result of the formation of concentric eye walls.

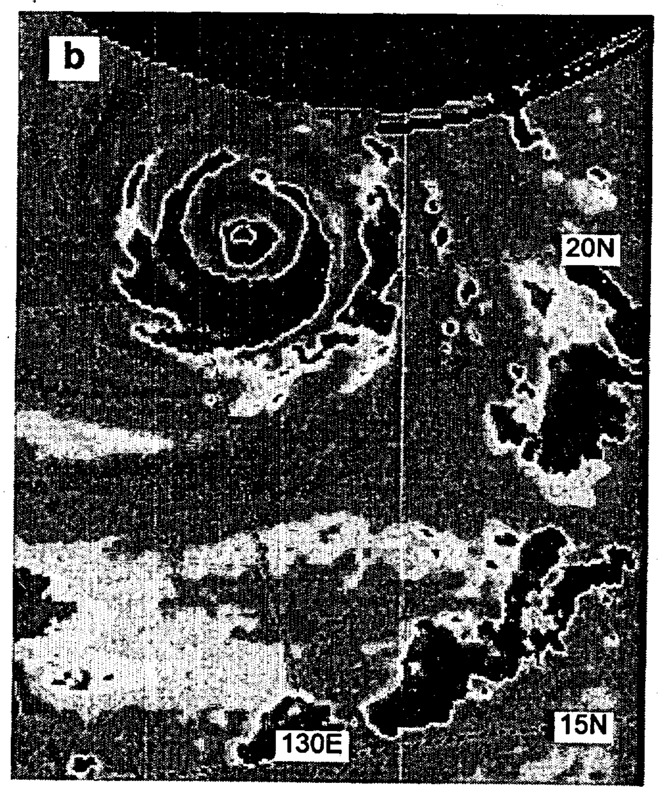


Figure 3-36-9 Dale's concentric eye walls as indicated by (a) visible satellite imagery (092331Z visible GMS imagery), and (b) microwave imagery (110117Z November 85 GHz SSM/I DMSP imagery).

using the default radius during the time when Dale possessed concentric eye walls. The structural changes of Dale show that, though automated, the DD algorithm still requires a satellite analyst to adjust its adaptable parameters and determine the quality of its output.

d. The generation of phenomenal seas in the periphery of a typhoon

While phenomenal surf is common on the eastern shores of Guam when typhoons pass to the south, it is rare that a typhoon produces phenomenal surf on the west side of Guam. Generally, on the north side of a westward moving typhoon, the seas are increased due to the increased wind on that side, but more importantly, due to the artificial fetch that is created as the moving typhoon keeps up with its own wave train and allows the sea state to rise to its full potential. On the south side of westward-moving typhoons, there is a severe fetch restriction, and the seas can't reach their fully arisen state.

After Dale passed Guam, a very large swell of 20 to 30 feet pounded the western shores of Guam for two days. The wave run-up overtopped 100 ft (30 m) sea cliffs on Orote Point on the west side of Guam (Figure 3-36-10). Such extreme swell from the west is not common on Guam. Even the passage of the large Super Typhoon Yuri only 80-nm south of Guam during November 1991 and the direct eye passage over Guam of the 105-kt (54-m/sec) Omar (1992) did not result in very large westerly swell on Guam. Clearly, some special conditions are required for a typhoon to generate these conditions. Such swell is clearly not directly related to the intensity of the typhoon or even to its size (Yuri was both very intense and very large). It appears that in order for a typhoon to generate phenomenal westerly swell on Guam it must be accompanied by a large region of monsoonal gales extending to its south and west. This was true of Dale and also of the only other typhoon in recent history (Andy, 1989) that was known to have produced phenomenal surf on the west side of Guam. Another phenomenal surf event on the west side of Guam was not produced by a typhoon at all, but by a persistent monsoonal gale area that was associated with a monsoon gyre in the Philippine Sea in 1974.

IV. IMPACT

Dale affected the island of Guam and caused problems for ships at sea. Damage on Guam was mainly caused by high surf, first from the east and later from the west. High surf from the east washed out sections of the coastal road on the southeastern side of the island. Later, surf run-up from the west overtopped 100 ft sea cliffs and damaged Navy housing on Orote Point Naval Activities. Currents and surges inside the reef generated by the west swell also eroded and flooded the beach fronts. Damage estimates for Guam were approximately $3.5 million. Dale also caused damage in the Pulep Atoll, the Hall Islands and several islands of the Chuuk Atoll. The U.S. Coast Guard provided relief supplies to people on these islands. High seas contributed to the loss of the cattle ship, M/V Guernsey Express, enroute for Japan from Australia. Navy helicopters from Guam, USNS Zeus and Kilauea and U.S. Coast Guard search and rescue worked together to rescue the crew of 18 as the ship was sinking.

Figure 3-36-10 Sea water explodes 100 ft into the air as a wave reflecting off the Orote Point cliff line meets an oncoming breaker (Photo courtesy of Major R. Edson).