UDC 551.515.2(265.2) "1968"

THE EASTERN PACIFIC HURRICANE SEASON OF 1968

WILLIAM J. DENNEY

Weather Bureau Forecast Office, ESSA, San Francisco, Calif.

ABSTRACT

A statistical resume of the season is presented and the lack of a valid climatology for comparison is pointed out. Background for the report is provided through discussion of limited basic data and description of the unique hurricane environment. Contributions of 1968 hurricanes to general knowledge of storms in the area include new ideas relating to inflow of cool air off cold water to the north and a demonstration that vertical shear has diagnostic value for revealing stoppage of the hurricane convective chimney. A few generalities as to the relationship between 1968 hurricane and storm behavior and middle latitude circulation are considered. A chronicle of individual storms and hurricanes gives particular attention to important data, mainly satellite pictures, and includes an example of a small intense hurricane with radius of tropical storm intensity winds of approximately 40 mi.

1. SEASONAL RESUME

The 1968 hurricane season in the eastern North Pacific[1] opened June 20 with tropical storm Annette and closed October 28 with dissipation of the residual depression from tropical storm Tara. Twenty-four tropical cyclones were followed with advisories and/or bulletins at 6-hr intervals. Six of these cyclones attained hurricane strength; another 13 were tropical storms, and five were no more than depressions. There were 326 advisories and 164 bulletins issued. Hurricane days totaled 17, and tropical storm days 63. (Two storm days were counted on each day having two storms.) This may be compared to the 1967 season which had 19 tropical cyclones, of which six [2] were hurricanes and an additional 11 were tropical storms. Statistics collected prior to regular satellite surveillance were more nearly an index of shipping and its communications than of storm activity; hence, valid normals are not established. The average annual number of tropical storms was estimated at 10 or less (Rosendal, 1962; Hurd, 1948), until Sadler (1963) increased the estimate [3] to 30 through a study relating number detected by conventional means during 1962 to the total number believed to be detected by TIROS satellite.

The advent of daily complete satellite photographic coverage on an operational basis in early 1966, together with systematic methods for using the pictures in estimating tropical cyclone intensity (Fett, 1964; Timchalk, 1965) inspires confidence that the number of storms and hurricanes enumerated is now reasonably near the number that actually occurs. Tabulations of the duration of storms and hurricanes (i.e., storm and hurricane days) are more accurate than presatellite days but are still subject to considerable error, for reasons to be discussed in connection with data problems.

Tracks of those cyclones attaining hurricane or tropical storm intensity, as smoothed in postanalysis for both position and intensity, are shown in figure 1. Position fixes were by satellite only in most cases, with ESSA–6 APT providing a fix for the 1800 GMT map, and ESSA 5 or 7 computer-digitized mosaics giving a check a few hours later. In only three instances were attempts made to show minor oscillations or aberrations from a smooth track, and there were synoptic reports (in one case ship radar) which seemed to require it then. Data were too sparse or of questionable precision at other times.

The criterion applied for determination of tropical storm intensity was simply the estimation of maximum sustained winds of 34 kt or more. This may have operated to classify as storms two or three cyclones that never developed to an organized warm-core stage; it did operate to classify as storms those cyclones in process of dissipation that had lost their convective chimney but were still thought to have wind speeds of 34 kt or more.

2. STORM EFFECTS

Naomi and Pauline were destructive hurricanes for parts of Mexico. Tropical storms Hyacinth, Annette, and Simone may also have been damaging as they moved inland and dissipated; Hyacinth and Annette dissipated over Mexico and Simone dissolved mainly over Guatemala. No serious injuries or deaths were reported from Mexican land areas, but press accounts told of the evacuation of 20,000 residents of small towns from the states of Durango, Sinaloa, Nayarit, and Jalisco as windswept torrential rains associated with Naomi splashed across northern Mexico. Naomi went inland about 40 mi north-

[1] The eastern North Pacific as here discussed is east of 140°W.

[2] The seven hurricanes of 1967 discussed by Gustafson (1968) included all those originating east of the dateline, six of which were discovered east of 140°W.

[3] Sadler (1963) also dealt with all storms east of the dateline.

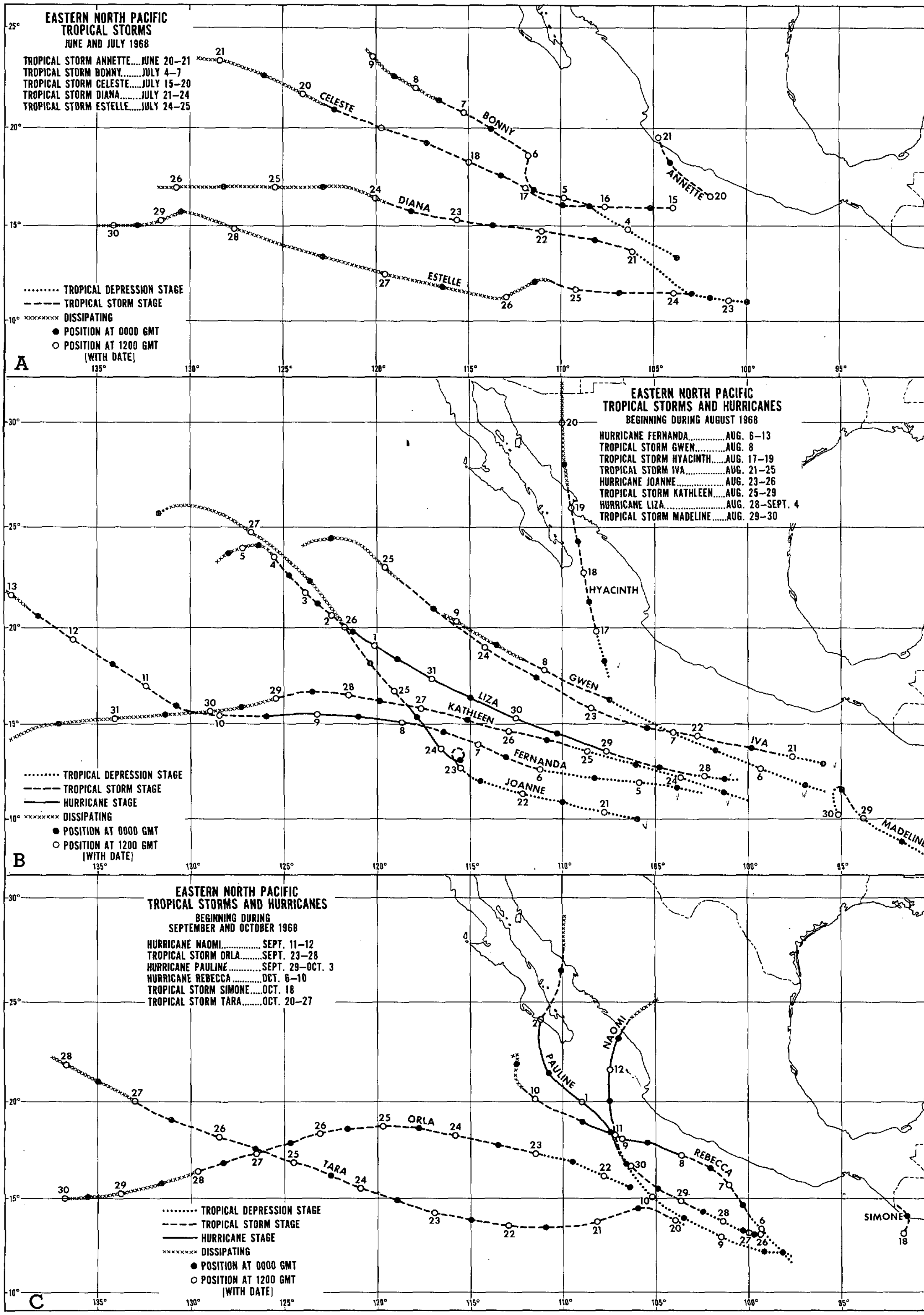

FIGURE 1.—(A) storm tracks beginning during June and July; (B) hurricane and storm tracks beginning during August; (C) hurricane and storm tracks beginning during September and October.

west of Mazatlan producing winds estimated up to 80 kt in the Mazatlan area. Pauline crossed Baja California northwest of La Paz and southeast of Magdalena Bay. Winds up to 100 kt at Magdalena Bay were reported later by the Mexican Navy. The intensity of Pauline was considerably reduced in crossing the Peninsula, but she was still an active tropical storm when moving onto the mainland near Navojoa.

A 40-ft sailboat, the *Tiare*, carrying four or five persons from San Diego to Puerto Vallarta, Mexico, was lost in the vicinity of Magdalena Bay about the time hurricane Pauline hit there and was the object of an extended search by the U.S. Coast Guard.

A list of storms and hurricanes dangerous to fishing and other marine activities concentrated near the Mexican coast should include hurricane Rebecca in addition to those that moved onto Mexico. Rebecca attained hurricane intensity when the center was less than 75 mi from the coast between Acapulco and Manzanillo. She moved west-northwest away from the mainland and dissipated southwest of Cape San Lucas. Winds up to 90 kt were reported by ships near the center of Rebecca, and speeds up to 100 kt were computed from central pressure when she was south of Manzanillo (Fletcher, 1955).

The southern California tuna fleet, which fishes in the area of the eastern North Pacific affected by tropical storms, was successful in taking evasive action to avoid serious damage, largely through following the advisories as broadcast by their communications center in San Diego. The fleet was reported to have lost considerable time from fishing while waiting out storms at a safe anchorage.

Heavy surf from tropical storms was a continuing problem on southern California beaches and piers. Several rescues from the surf were necessary during the Labor Day weekend due to swells generated by hurricane Liza to the south.

3. USE OF LIMITED BASIC DATA

Information for storm tracking and evaluation in this area is still a serious problem, though not as critical as before the advent of operational satellites. Oceanic or island radiosonde and rawin or pibal and land-based radar data are nonexistent here. Ship reports seem to get progressively more sparse each year apparently as a result of improved warnings and reduced radio operator coverage and communications funding.

Reconnaissance was regularly conducted again in 1968 by the U.S. Air Force near the 300-mb level on those storms located over international waters within 1,200-n.mi. range of Sacramento, Calif. Aircraft radar was functioning on each flight.

Full application of satellite pictures required a subjective interpretation in terms of physical processes and their changes from day to day. The objective method of Timchalk et al. (1965), which was developed on storms in other areas, breaks down frequently when applied in the eastern North Pacific. Interruption of the convective chimney sustaining the warm core of a storm in the eastern North Pacific is usually first apparent in the loss or thinning of the cirrus cap, much as in other areas (Anderson, 1966); however, lower clouds may then be revealed in this area in a tightly spiraled and unbroken overcast around a hole where the eye and the eye-wall clouds had been. In such cases the exposed lower clouds generally consisted mainly of layered types with feathered edges characteristic of evaporation. Correct picture interpretation requires ability to distinguish these aspects. At the other end of the scale of activity, the small, young intense hurricanes may have a convective chimney so active that it spews out an amorphous cirrus cap completely obscuring the inner banding.

4. THE UNIQUE HURRICANE ENVIRONMENT

The hurricane area of the eastern North Pacific is uniquely located near dissipating influences that greatly complicate daily storm intensity problems. Cold water which upwells along the coast from about lat. 24°N northward spreads to the west-southwest with prevailing currents. Westerly winds in the upper troposphere related to the Hawaiian branch of the subtropical jet are found to the northwest of a ridge line usually oriented east-northeast to west-southwest near the edge of the cold water. According to Riehl (1954, p. 341), a tropical storm will dissipate rapidly upon moving under the equatorward margin of a westerly jet, since the jet favors upper convergence, entrance of cold air aloft, subsidence, and drying. Sadler (1963) attributes the dissipation of a large fraction of eastern North Pacific hurricanes to the shearing off of the upper part of the storm by high-speed tropospheric westerly winds.

Figure 2 (Sadler, 1963) is included for relation to 1968 storm and hurricane dissipation depicted in figure 1 and described in the following discussion of individual storms. Internal forces in hurricanes give them a component of motion toward the north (Cressman, 1952); therefore, the odds favor a storm generated over the eastern North Pacific meeting dissipating influences within a few days.

During most of the 1968 hurricane season, there was no information on which to base an analysis of upper winds, and only limited information for analysis of water temperatures in the storm area. When it was possible to measure variations from Sadler's mean chart, they were relatively small, even during September and October, months to which the chart is not strictly applicable.

5. 1968 HURRICANE CONTRIBUTIONS TO AREA STORM KNOWLEDGE

Experience during the 1968 season leads to a conclusion different from Sadler's (1963) in regard to inflow of cool air off the cold water to the north. It was his conclusion from the TIROS study of 1962 hurricanes that the outer storm circulation usually acts as a barrier keeping cold air to the north from entering directly into the inner storm circulation. Data this year suggest that a hurricane will quite commonly bring the cold air into the spiral inflow, and that it is not extraordinary for inflow of cool stable air to start dissipation processes when the storm center is still more than 150 mi south of the 80°F water

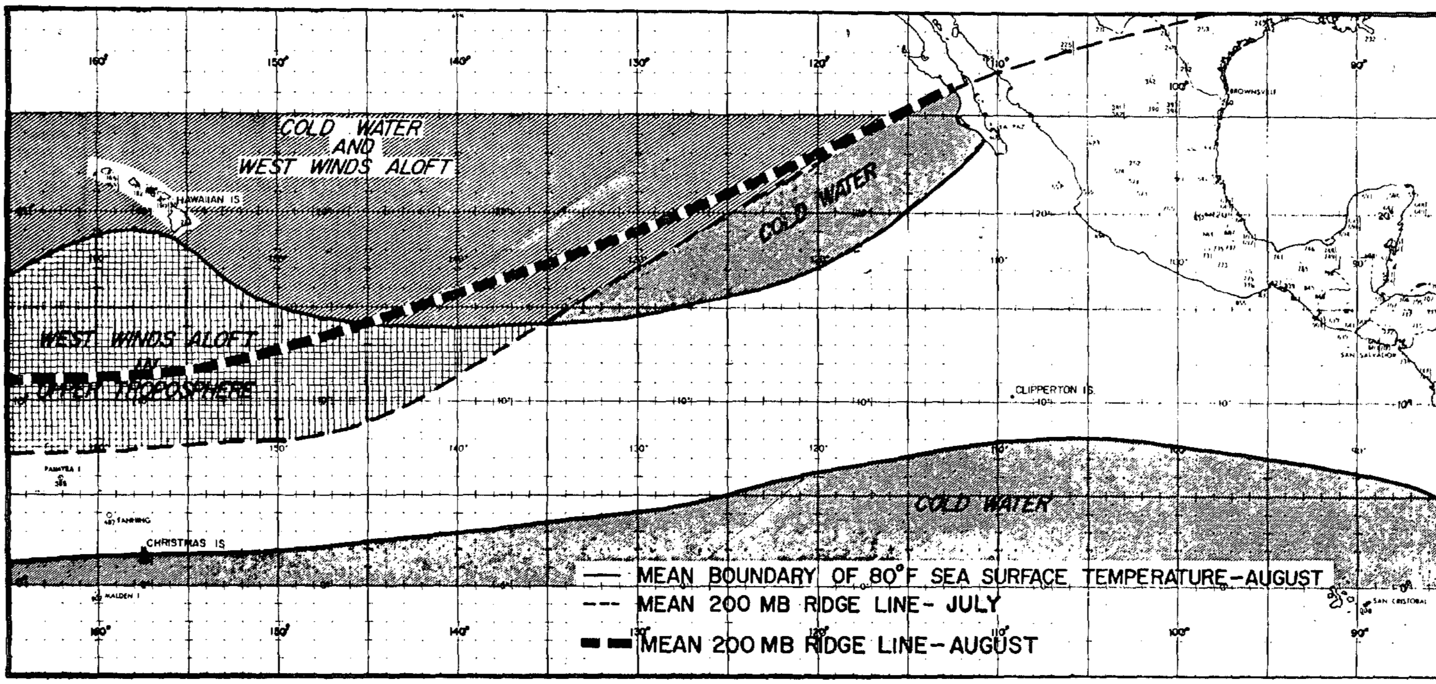

FIGURE 2.—Schematic depicting position of mean 200-mb ridge line and mean August 80°F sea-surface isotherm (from Sadler, 1963).

temperature isotherm (e.g., Rebecca). In a few instances, limited cool air inflow appeared to act as a damper effectively restricting storm development, but not resulting in rapid dissipation (e.g., Fernanda). It may be that the difference between the generalization here advanced and Sadler's illustrates, to a certain extent, seasonal differences that can result from sustained variations in such features as water temperature, water temperature gradient, and the general circulation. Discussion of the individual hurricanes and storms will give special attention to this aspect of storm behavior as revealed through satellite pictures.

Westerly winds in the upper troposphere related to the Hawaiian branch of the subtropical jet are known to have been encountered by only one of this year's hurricanes, Fernanda. The associated vertical shear quite clearly revealed stoppage of the central convective chimney through detachment and eastward movement of the amorphous upper part of the storm cloud system uncovering spiraled lower clouds that were no longer producing cirrus. The role of vertical shear *per se* in the stoppage was questionable (Riehl, 1954, p. 341; Sadler, 1963), but its part in revealing the stoppage was obvious. This sort of revelation was not limited to shear near the subtropical jet but occurred far from the jet in the cases of Celeste, Diana, Gwen, and Iva (figs. 6–11 and 14). The shear in the latter two cases apparently was a matter of a more rapid northwestward acceleration of the lower parts of the storm than of upper parts under the influence of an intensifying hurricane to the southwest (Fujiwhara, 1931; Jager, 1968). Some other storms that continued active and even intensified (e.g., Naomi) were subject to vertical shear, as could be seen through the marked nonsymmetrical spread of their continuing cirrus outflow.

Two ships near the small, intense hurricane Rebecca demonstrated that it is practical to use the relatively short-range radar of commercial ships in avoiding small hurricanes and in providing reports for the safety of others. It has long been thought by forecasters dealing with eastern North Pacific hurricanes that Rebecca's dimensions are typical of a large fraction of the total number of hurricanes occurring in the area; this remains a topic for speculation, but the very fact that minute intense hurricanes can occur is adequate reason for mariners being informed as to the usefulness and manner of application of their radar.

Wind profiles were sought through dissipating storms, but the only basic data available came from sparse ship reports that were inadequate for a quantitative analysis. These limited data did seem to support Colón's (1963) conclusion (also from limited data) that significant filling of the central pressure is invariably accompanied by a significant increase in the radius of maximum winds. It might be postulated that decreased support from the convective chimney sustaining a sharp-edged warm core is followed by lateral diffusion, with the wind maximum displaced progressively outward at the edge of the spreading warm air. The importance of this aspect of the dissipating storm model is obvious in connection with the use of ship reports for evaluation of storm intensity or in connection with warnings as to just where in the storm circulation winds are at a maximum. The standard model regularly used for advisories, which places maximum winds "near the center," even during dissipation, may need a revision.

6. HURRICANE ACTIVITY AND MIDLATITUDE AND SUBTROPICAL CIRCULATION

Data were not adequate to disclose interrelation between hurricane activity and the circulation to the north on a daily basis or for longer periods, with minor exceptions. Behavior of the individual storms as depicted in figure 1 was ordinarily the best available index of daily and long-term changes in the neighboring subtropical high-pressure belt.

During July there was a sustained trend that shows in the southward progression of the storm origin and track (fig. 1) with concurrent increase in the northeast trades and southward shift of the Intertropical Convergence Zone (ITC).

During August there was a blocking cycle at northern midlatitudes with stronger-than-normal westerly flow at southern midlatitudes (Andrews, 1968). A mean trough in the westerlies, which persisted near 125°W until the last week of the month, was reflected in the subtropics by a col in the high-pressure belt aloft. Storm activity in mid-August was unusual over the western United States as several inches of snow fell on the Wasatch Mountains, and heavy rains fell near the coast as far south as northwestern California. Mean 700-mb winds appear to have been from the east-southeast over the tropical storm area of the eastern North Pacific, with an extension of the Bermuda High westward across northern Mexico, though there was a period of southerly winds as shown by the track of tropical storm Hyacinth. (Hyacinth was the only storm of the season whose origin could be traced to an apparent connection with a vorticity pocket from a middle latitude trough.) The eight named hurricanes and storms beginning during August 1968 were more than the number accepted as average for an entire season a little more than a decade earlier (Rosendal, 1962). Their occurrence should put to rest the notion prevalent during past years that August can be expected to bring a lull in tropical cyclone activity.

The changing middle latitude circulation in late August apparently created an environment hostile to hurricane development in the ITC southwest of Tehuantepec. Tropical storm Madeline dissipated August 30 shortly after organization got underway, and Naomi did not get started until September 8.

September and October had periods that were alternately favorable and unfavorable to hurricane development, while some tracks turned toward the northeast and others did not, probably as a result of periodic changes at middle latitudes to the north. A few of those connections, such as a middle latitude trough dipping deep into the subtropics to turn a hurricane toward the northeast, were revealed in the sparse data; the more subtle connections were not.

7. ANALYSIS OF INDIVIDUAL STORMS

TROPICAL STORM ANNETTE

The hurricane and tropical storm season opened June 20 when the Norwegian ship *Kollfinn* sent the cryptic message: "Tropical storm at 17.0°N, 101.0°W. Bad weather here." A report from the *James Lykes* at 16°N, 102°W, with 40-kt south-southwest winds for the same 1200 GMT map supported the conclusion as to storm development but indicated only loose organization. The minor storm then moved north-northwest to pass inland and dissipate near Manzanillo between 0600 and 1200 GMT on June 21.

There was little help from satellites. ESSA 6 showed the storm on the edge of pictures in Orbits 2794 and 2795 with no clear indication of vortex motion. The computer-digitized ESSA–5 mosaics showed a spiral cloud vortex with center on land at a time when ship reports indicated the surface circulation center to be about 50 mi away, over water.

TROPICAL STORM BONNY

Tropical storm Bonny developed rapidly in the ITC from a low-pressure center near 13°N, 104°W, late on July 3. The depression attained storm intensity on July 4; ship reports placed the center of the new storm near 16.0°N, 108.5°W, at 0000 GMT, July 5. Movement was toward the west-northwest at 8 kt for the first 24 hr with only a little increase in intensity. The storm turned north during the night of July 5–6, resulting in 50-kt east winds on Socorro Island at 1200 GMT, July 6, when the center was an estimated 50 mi to the west-southwest. The track toward the west-northwest was then resumed with speed increased to 10 kt.

ESSA–6 satellite pictures taken between 1600 and 1900 GMT, July 6 (fig. 3), disclosed an extensive stratus layer south-southwest from the California coast to 15°N. A tongue of stratus clouds from this layer extended into the inflow around the south side of the storm. The dissipating effect on the storm of the cool water to the north and northwest was becoming evident. Inflow of warm moist air from over waters with temperature above 80°F was shown in the picture by feeder bands into the east side of the storm. At 1609 GMT, July 6, U.S. Air Force 300-mb reconnaissance estimated strongest surface winds at 45 kt.

The next definitive information came from a 1611 GMT, July 7 reconnaissance fix at 21.0°N, 116.0°W. The re-

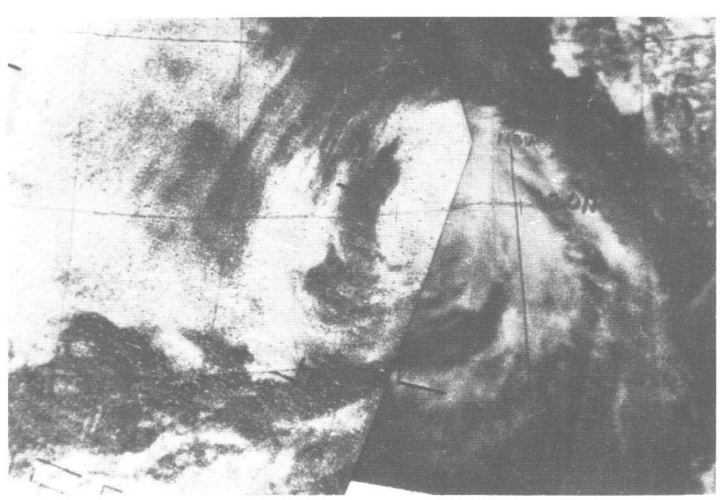

FIGURE 3.—Bonny, July 6; cool inflow defined by stratus.

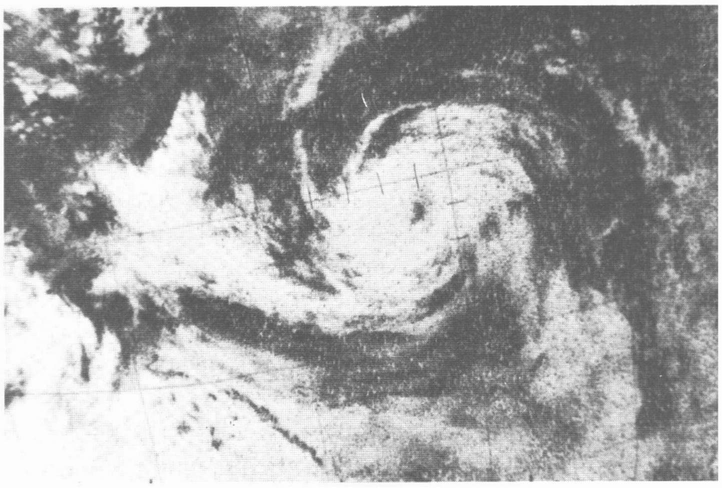

FIGURE 4.—Bonny, July 7, dissipating rapidly.

connaissance observer described the system as having no definite eye, estimated maximum surface winds at 40 kt, and explained in remarks "6/8 AC BASES UNK TOPS 140 4/8 THIN CI 240 7/8 CI 400 NO OTHER CLDS VSBL SOME BUILDUPS TO NW CENTER IS PERFECT VORTEX IN CI CLD SFC OBSCD BY CLDS SFC WINDS ESTIMATED BY CLOSED CIRCULATION." An ESSA–6 picture about an hour later (fig. 4) displayed a vortex with the characteristic ragged edges of stratified clouds. Feeder bands off warm water to the south had disappeared and inflow was dominated by cool air from the northwest.

The MV *Silvercape* was entering the outer circulation of Bonny about the time of the July 7 reconnaissance fix on a west-northwest course that took the ship through the center just before 0600 GMT, July 8. Reports at 6-hr intervals as the ship moved into the storm indicated winds no stronger than 20 kt. At 0600 GMT, the wind was from the north-northwest at 10 kt with pressure 1001.0 mb, tendency −0.6 mb, then steady temperature 22°C, and a heavy drizzle. The storm remnant was without a source of kinetic energy (Malkus et al., 1959) and was practically "run down."

USAF reconnaissance confirmed dissipation of Bonny to no more than a minor depression at 1800 GMT, July 8, but a stratified cloud vortex was still very much in evidence on ESSA–6 pictures (fig. 5). The reconnaissance observer summarized: "NO RADAR RETURNS NO SGNFT CLDS ABV 80 CLD TPS ABV 400 NEG CENTER DATA."

TROPICAL STORM CELESTE

Celeste organized during an approximate 2-day period from a weak disturbance, first evident late on July 13 from ship reports 200–300 mi south and southwest of Tehuantepec. Tropical storm intensity was first estimated from an ESSA–6 picture at 1711 GMT, July 15. However, later data indicated that a maximum wind estimate of about 40 kt at that time would have been more appropriate than the 60-kt estimate made. Storm intensity

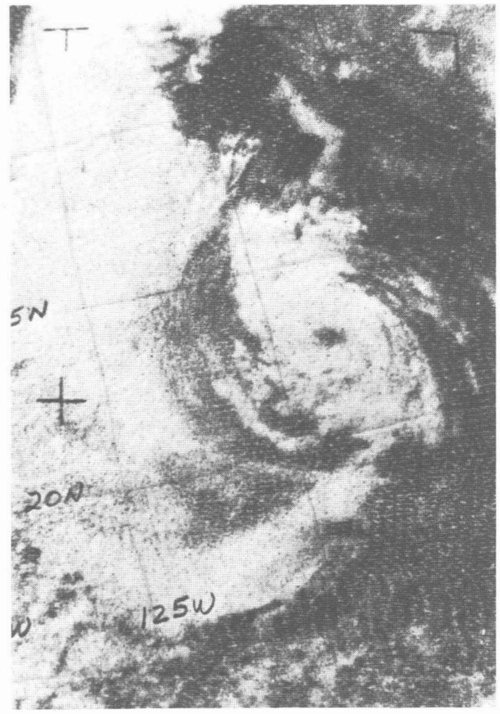

FIGURE 5.—Bonny, July 8, dissipated.

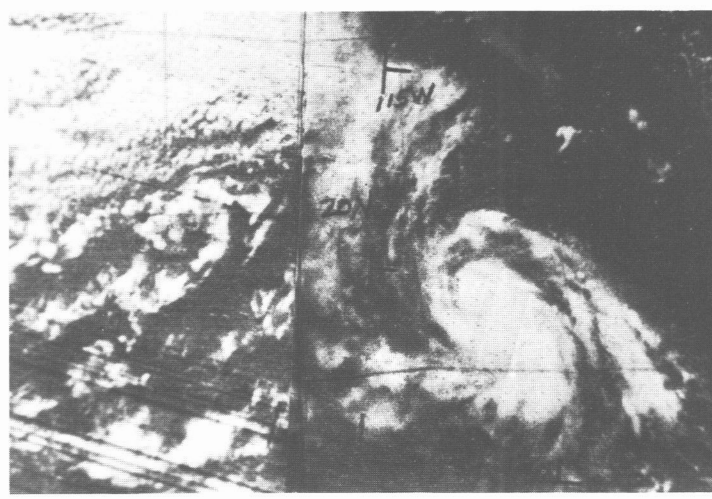

FIGURE 6.—Celeste, July 17; cool inflow has begun.

was apparently overestimated at first due to a brightness saturated print of the initial storm picture.

The storm followed an average track of 290°, 10 kt, for the first 48 hr, then weakened abruptly and averaged 300°, 12 kt, for the following 48 hr. Intensity was near its maximum on July 17 when an ESSA–6 picture (fig. 6) was the basis for an estimate of 55-kt winds prevailing at 1705 GMT. The same picture disclosed the beginning of inflow of stratus-bearing air from the north in a tongue extending around the storm's west side, shortly to interrupt the inflow of warm moist air from the south and southeast. Surface heating and turbulence could be seen to be breaking the stratus as the cool air entered the storm circulation.

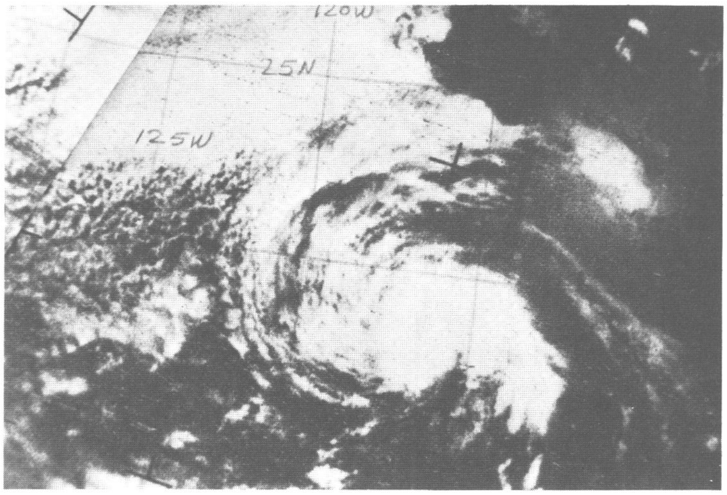

FIGURE 7.—Celeste, July 18; convective chimney stopped; cirrus cap moving away.

Stoppage of the convective chimney had occurred before the ESSA–6 picture of July 18 so that the cirrus cap was becoming detached to leave the western semicircle of the lower cloud spiral uncovered (fig. 7). Celeste was no more than a minimum tropical storm after that, though depth of convection did increase again.

There was apparent ambiguity in the 300-mb reconnaissance report on July 20; the center was fixed at 22.3°N, 125.0°W, at 1800 GMT, with maximum surface winds estimated at 20 kt, an eye of open character, and cumulonimbus tops to 31,000 ft in well-developed feeder bands. Temperature at 300 mb was still 3° warmer over the storm center than it was outside, but the eye equivalent potential temperature was only 348°K, hardly as warm as normal tropical air (Malkus et al., 1959). The cloud vortex was well defined on ESSA–6 pictures at that time, and there was a strong inflow of cool stratus and stratocumulus laden air.

The 1800 GMT, July 21, reconnaissance flight could find no indications of storm activity at all.

Weather-reporting ships managed to avoid the strong winds of Celeste throughout her lifetime.

TROPICAL STORM DIANA

The pre-Diana disturbance had its origin in the ITC 250 mi southwest of Tehuantepec on July 19. The post-storm depression from Celeste was still on the map as Diana acquired her name upon upgrading to tropical storm intensity at 1800 GMT, July 21. A heavy cirrus outflow obscured inner banding of the storm on the ESSA–6 picture which was used to upgrade the initial depression to storm intensity with maximum winds estimated at 50 kt. The *Anco Swan* passed to the north of the storm, first reporting winds from the north at 40 kt, then east at 40 kt 1 hr later, and southeast at 35 kt after 2 more hr, as the ship proceeded east at 10 kt and the barometer first fell rapidly and then rose sharply. Diana was near peak intensity as the *Anco Swan* passed to the north and, judging from satellite pictures, held that

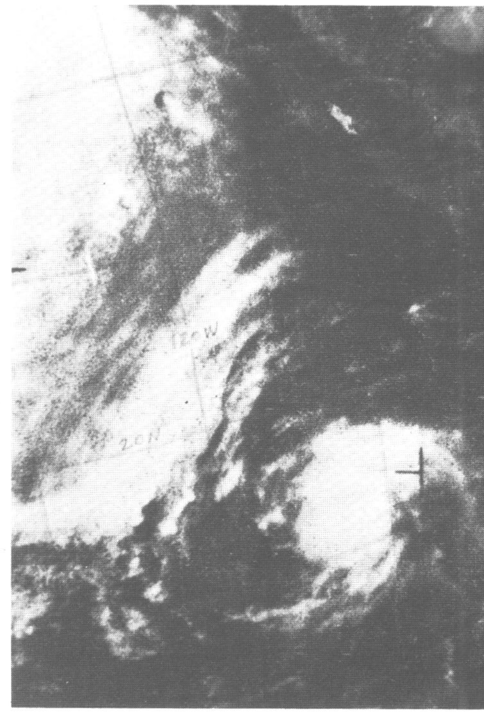

FIGURE 8.—Diana, July 23, has cool inflow.

intensity for about 2 days while following a track toward 280°, at 12 to 15 kt.

Inflow of cool air from the northwest that could markedly weaken the storm could be seen on the ESSA–6 picture of July 23 (fig. 8). Twenty-four hours later, dissipation was well underway on the picture, which showed the cirrus cap detached and moving off the lower cloud vortex centered at 17°N, 121.5°W (fig. 9). The fact that the convective chimney had been stopped was disclosed by vertical shear. Diana was clearly dead on the ESSA–6 picture for July 25, with the persisting cloud whorl apparently consisting mainly of stratocumulus.

TROPICAL STORM ESTELLE

Estelle, the last of the four July storms, originated in a disturbance that formed in the ITC near 10°N between 95° and 100°W. After bulletins were begun from the 0000 GMT, July 23 data with the center at 11°N, 100°W, movement of the depression was toward the west at 5 kt with slow intensification to minimum storm intensity over about a 30-hr period. Estelle then moved toward 280° at 12 kt until crossing 110°W near 12°N, shortly before 1800 GMT on July 25, whereupon she weakened to a depression and turned toward the west-southwest. Intensity estimates were by satellite only.

The dynamic basis for limitation of Estelle's development and for her early weakening to a depression appears to be related to the trend of the previous 3 weeks; this trend showed a shift toward a lower latitude of storm origin and track. The trend accompanied a southward shift of the northeast trades and ITC.

HURRICANE FERNANDA

The northeast trades decreased early in August over the eastern North Pacific, and midlatitude flow went into a

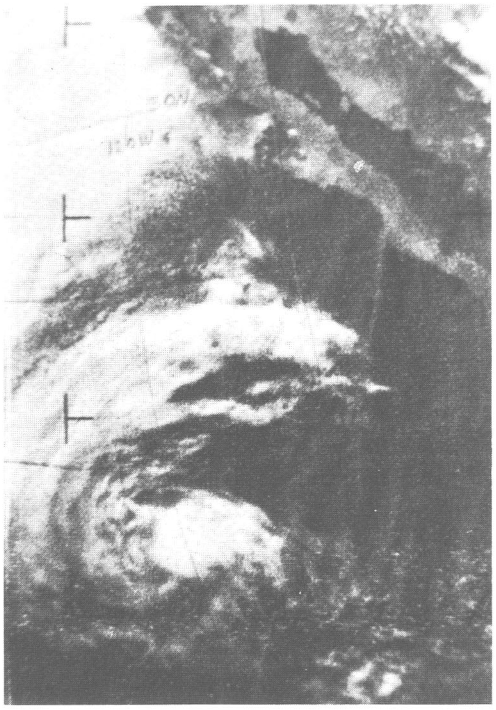

FIGURE 9.—Diana, July 24; convective chimney stopped; cirrus cap moving away.

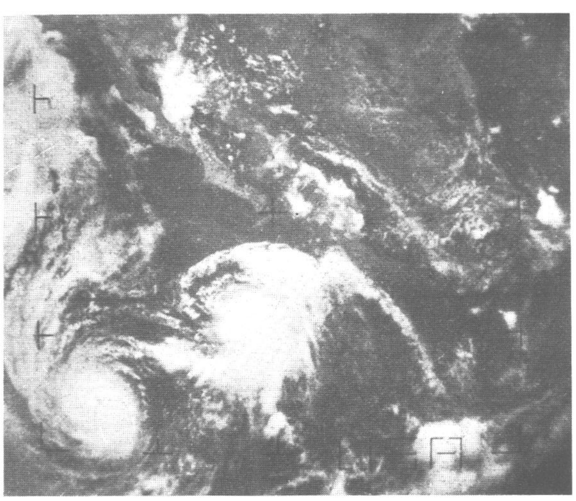

FIGURE 10.—Fernanda and Gwen, August 8; Fernanda is newly a hurricane but has some cool inflow; Gwen is accelerating northwest with cirrus cap lagging.

meridional cycle with a trough near 125°W. Development of the first full hurricane of the season got underway at this time.

Activity increased in the ITC off Central America, and a weak tropical disturbance became evident as a 1012-mb low center near 10°N, 97°W, at 1800 GMT, August 3. Depression intensity was indicated with the center at 11.5°N, 102.0°W, 24 hr later, and at 12.0°N, 106.5°W, after 48 hr. Vortex organization was barely discernible on the ESSA pictures of August 4 and 5.

Tropical storm intensity with considerable cirrus outflow was clearly shown by the August 6 ESSA–6 picture

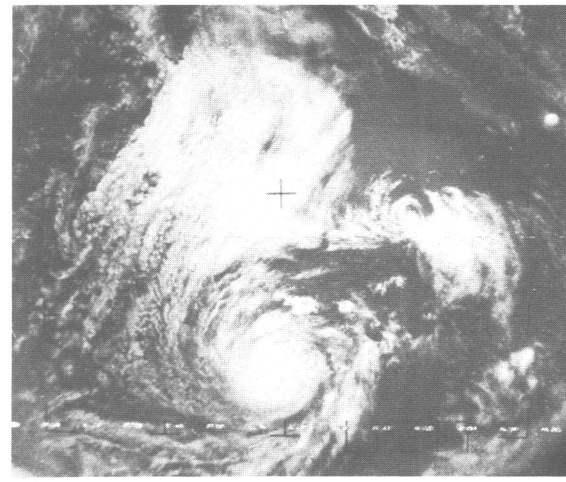

FIGURE 11.—Fernanda and Gwen, August 9; Fernanda has increased cool inflow; Gwen has disintegrated.

with the central overcast being nearly circular and about 4° of latitude in diameter. The developing storm was moving west-northwest at 10 kt at this time. Ships continued to avoid the area of stronger winds.

Hurricane intensity was attained before the ESSA–6 picture of August 8 (fig. 10), which revealed an eye at 15.3°N, 119.7°W, in a tightly spiral overcast 4° of latitude in diameter. (Gwen was 450 mi to the east-northeast in the same picture.) The new hurricane at that time had an incipient inflow from an area of cool stable air to the north and northwest as revealed by the low cloud distribution, and the cool air inflow had reached the outer fringes of the hurricane circulation about 400 mi west of the center. Fernanda was moving toward the west at 10 kt during the hurricane stage.

The cool influx of the ESSA–6 picture of August 9 was defined by a tongue of stratocumulus from the north wrapped around the west side of the hurricane and pointed into the spiral inflow less than 150 mi from the center (fig. 11). Heating from below was changing the stratocumulus to cumulus as it moved over warmer water. A general reduction of cloudiness outside a 75-mi radius from the center was the apparent result seen on the picture of August 10. Inflow of cool stable air continued at a reduced rate; however, it was not sufficient to destroy the storm as its track turned toward the northwest at 10 kt early on the 11th. Pictures on the 10th and 11th seemed to show an active cirrus outflow continuing from part of the convective chimney still intact in the central core. Cumulonimbus feeder bands from warm water to the southeast were evident as late as the 11th.

The final dissipating factor was clearly operating on August 12 when the center was at 20.5°N, 137.5°W, on the ESSA–6 picture. That picture (fig. 12) showed the cirrus cap displaced to the east exposing the west half of the lower storm clouds that appeared to consist of broken bands of cumulus and stratocumulus. Flight reports between Los Angeles and Tahiti revealed that the storm

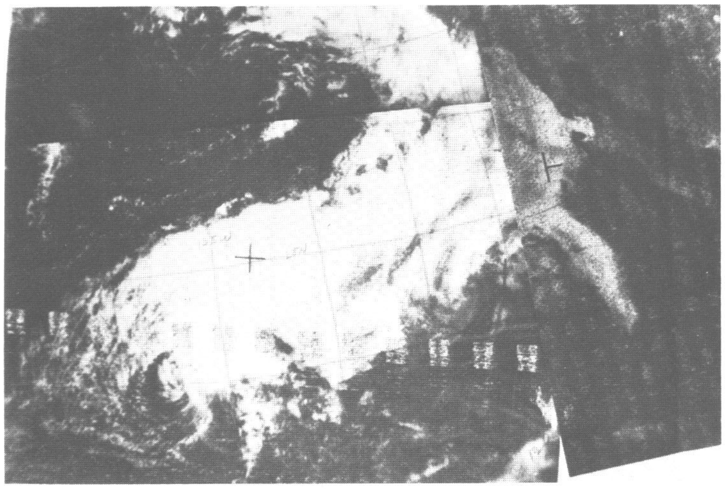

FIGURE 12.—Fernanda (lower left) with cirrus cap moving away, August 12.

had moved under westerly winds in the troposphere above about 500 mb. The lower level remains of dissipating Fernanda crossed 140°W near 21°N on the morning of August 13 with showers out to 300 mi from the center and ship-reported winds up to 30 kt. Shower activity was decreasing rapidly, and the closed circulation disappeared on August 14.

TROPICAL STORM GWEN

The depression preliminary to tropical storm Gwen first came to attention at 1800 GMT on August 5 with a ship report of northeast winds at 35 kt and 14-ft waves in the hurricane-spawning grounds of the ITC 250 mi south of Tehuantepec. Only an amorphous cloud mass was seen on the concurrent ESSA-6 picture. A little vortex organization was evident on the picture 24 hr later, but organization was still slight after 48 hr.

ESSA 5 revealed an apparent increase in rotation and cirrus outflow at 2358 GMT on August 7. Gwen acquired her name after the 0000 GMT, August 8 data included a ship report of 30-kt east winds and 13-ft seas 100 mi north of the center (which was at 16.3°N, 107.5°W); an estimate of 45-kt maximum winds had been made from the ESSA-5 mosaic. The track had changed from the initial 290° at 12 kt of the depression to 300° at 18 kt, apparently under the influence of the stronger Fernanda to the west (Fujiwhara, 1931; Jager, 1968).

Gwen and Fernanda were in the same picture on ESSA 6, Orbit 3409, on August 8 (fig. 10) with the center of Gwen at 18.5°N, 112.5°W, and of Fernanda 450 mi to the west-southwest. A strong cirrus outflow from Gwen had helped produce a highly reflective cloud mass to the east and south of her center. The low-level vortex was exposed on the northwest semicircle as upper parts of the storm were lagging behind the lower parts in northwest movement. A day later the completely exposed low cloud whorl could be seen dissipating at 21°N, 117°W, while clouds from upper parts of the dead storm were evaporating just to the southeast (fig. 11).

TROPICAL STORM HYACINTH

Evidence of convergence disappeared from the vital area between 90° and 105°W from 10° to 15°N; pressure rose a few millibars there and over the subtropics to the north after the depressions that led to Gwen and Fernanda moved away around August 7. Pressures dropped back to the 1008- to 1012-mb range over southern Mexico by 1800 GMT on August 14 when a large amorphous rain cloud mass was pictured from the southern Bay of Campeche across the isthmus to about 200 mi south of Tehuantepec. (The rain clouds appeared to have developed in the southwest end of a midlatitude disturbance that had been associated with a cold front over Texas on August 11.) The heavy clouds spread north past 20°N and west past 105°W during the next 24 hr as pressure rose about 3 mb in the Tehuantepec region.

Further expansion of the cloud area was disclosed by ESSA 6 on August 16. The clouds then covered most of Mexico south of 25°N, and there was a nearly circular overcast, 3° of latitude in diameter, breaking away from the main cloud mass in connection with a new 1006-mb Low over the Pacific at 17.5°N, 107.5°W. The Low drifted north-northwest at 8 kt and intensified rapidly to reach storm intensity on the morning of August 17.

Hyacinth continued to move toward the north-northwest at 8 kt into the mouth of the Gulf of California as a ship reported a central pressure of 994 mb at 21.3°N, 108.6°W, at 2345 GMT on August 17. There was another ship report of southerly winds of 55 kt at the same time to substantiate an active storm. The storm center passed about 60 mi east of La Paz early on the afternoon of August 18, moving onto the Mexican mainland near Los Mochis during the morning of August 19 (fig. 13).

The residual cloud mass could be followed northward over eastern Arizona, western New Mexico, and western Colorado with showers and thunderstorms on August 20.

No information as to damage in Mexico was available.

TROPICAL STORM IVA

While the clouds and moisture residual from Hyacinth were moving northward causing showers and thunderstorms over the southwestern United States, the ITC was generating extensive rain clouds from the Gulf of Tehuantepec west-southwest past Clipperton Island. Two weak vortices developed late on August 20 near 13°N, 96°W, and 10°N, 106°W, one disclosed by ship reports and the second by satellite data. The western vortex became hurricane Joanne and the eastern one tropical storm Iva.

Iva was named and advisories begun on the basis of 1800 GMT, August 21 ship reports. Winds were reported up to 30 kt north of the center which was then estimated at 13.5°N, 98.5°W, but little organization of the cloud mass was evident on the concurrent APT picture. The new

FIGURE 13.—Hyacinth on land near Los Mochis, Mexico, August 19.

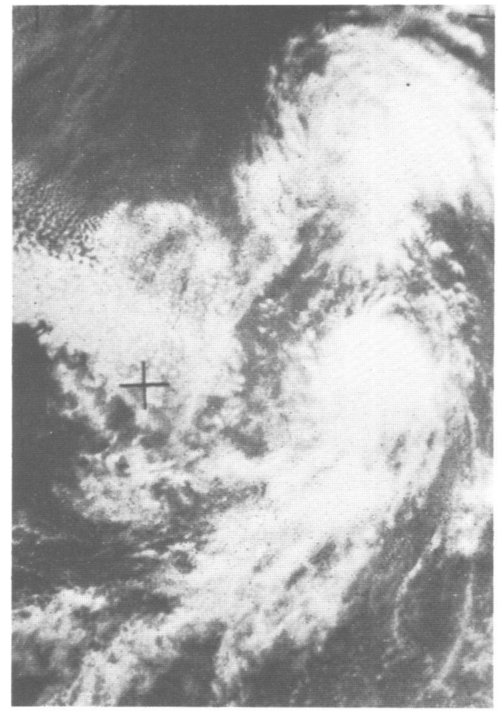

FIGURE 14.—On August 24, Iva accelerating northwest with cirrus production about stopped, and Joanne has stable air inflow.

storm intensified slowly and followed a track toward the west-northwest at 12 kt for 48 hr. Forty-knot winds were reported at Socorro Island as Iva passed an estimated 75 mi to the south at 0000 GMT on August 24. By this time Iva had turned toward the northwest and accelerated to 18 kt under the influence of developing hurricane Joanne to the southwest (Fujiwhara, 1931; Jager, 1968).

A close study of the ESSA-6 picture of Iva for August 24, the northernmost storm in figure 14, indicated that the dense, oval cirrus cap that had been produced over the central part of the storm was becoming separated from the lower clouds of the vortex on the southeast side of the storm. Only a thin cloud veil was left over the central vortex, suggesting that cirrus production had nearly stopped. The storm was moving over water with temperatures below 24°C during the next 24 hr and was down to depression intensity near 24°N, 121°W, at 1800 GMT on August 25. The weakening depression moved west with heavy rains in its northeast quadrant for about 12 hr.

HURRICANE JOANNE

The depression that intensified into hurricane Joanne moved west-northwest at 10 kt for 48 hr from the initial satellite-discovered position at 10°N, 106°W, late on August 20. The center was at 12°N, 114.5°W, at 0000 GMT on August 23 when the *Saikyu Maru* passed directly through the eye of the storm, reporting a minimum pressure of 1007 mb and a calm wind. The wind picked up to 25 kt 3 hr later as the ship moved out to the southeast. Eighteen hours after the *Saikyu Maru* went through the center, a rapid intensification of Joanne was underway: ESSA 6 pictured an exceedingly rapid cirrus outflow obscuring any organization that might have existed in the lower clouds. Ship reports at that time fixed the center near 13.5°N, 116°W, and showed winds of 25 kt with pressure of 1004 mb 50 mi to the northwest and southeast of the center. The *Birgitte Cord*, the ship reporting to the northwest of the storm at 1800 GMT, was buffeted by full hurricane winds up to 68 kt as it moved through the storm. The ship passed through the eye at 13.2°N, 115.4°W, at 2300 GMT on August 23 with a central pressure of 986 mb. The hurricane continued to intensify and expand, so that at 0600 GMT, when the ship's barometer had risen to 1005 mb, winds were still estimated at 60 kt.

Joanne is thought to have decelerated and made a loop during the period of abrupt intensification from depression to hurricane stage, and then moved toward the northwest at 12 kt after 1800 GMT, August 24. The intensification of Joanne was an apparent factor in the northwestward acceleration of Iva some 400 mi to the northeast on August 23 (Fujiwhara, 1931).

On August 24 (fig. 14), isobaric configuration on the west side of Iva (northernmost storm) provided a trajectory over water with temperature near 20°C (at 24°N, 115°W) to the western edge of Joanne. A patch of stratocumulus could be seen on the picture to the west and northwest of Joanne ahead of clear dry air moving down from the north. Inflow of stable air to the hurricane's internal sections was about to begin.

ESSA-6 pictures on August 25 had Joanne on the west side of Orbit 3622 and the east side of 3623 so that detail was poor; however, from the pictures and ship reports it could be determined that stable air with stratocumulus imbedded had moved around the storm to the southeast quadrant, and also that the center was then over water with temperture about 25°C.

Application of the objective technique (Timchalk et al., 1965) to the rectified ESSA–5 picture for 0058 GMT on August 26 led to an interpretation of intensification, possibly with development of an eye. However, reports from the *Eiken Maru*, which passed 50 mi southwest of the center about that time, indicated winds of 20 kt with pressure above 1008 mb and a little drizzle. Since the hurricane had had 60-kt winds at least 50 mi from the center 48 hr earlier, the ship report seemed to conflict with picture interpretation (Colón, 1963). It might be surmised that the apparent eye was a special kind of "false eye" which commonly plagues the hurricane forecaster in this area; that is, the storm was in the dying stage with the convective chimney stopped, and remains of the cirrus cap were dissipating or moving away to reveal a circular opening in the lower cloud spiral where the eye had been.

The ESSA–6 picture on August 26 displayed a cloud spiral appearing to consist mainly of stratocumulus and cumulus around an open center 30 mi in diameter near 21°N, 123.3°W. Dissipating stratified clouds at a distinctly higher level could be seen in an area 100 mi wide by 500 mi long across the west side of the lower cloud whorl. The depression seen on that picture moved northwestward at 14 kt for 24 hr and then turned west to be absorbed into the trades.

TROPICAL STORM KATHLEEN

The disturbance in the ITC that developed into Kathleen first appeared about 400 mi southwest of Tehuantepec at 1800 GMT, August 23. Little information was available on it for 48 hr as it moved west-northwestward at 13 kt to a position near 14°N, 110°W, at 1800 GMT on August 25. At this point advisories were begun. There were ship reports of winds up to 30 kt and heavy rain within 75 mi of the center of Kathleen at this time. Satellite pictures were of insufficient quality to define the degree, if any, of spiral organization of the cloud mass.

Kathleen moved west-northwestward at 10 to 12 kt until late on the 28th, perhaps alternating between a weak tropical storm and a strong depression, then turned west-southwest and weakened to a minor depression. The depression could be followed past 145°W on September 3. Tropical storm intensity was confirmed by the *Denby Grange* at 2000 GMT on August 28 with 40-kt east winds and 1003-mb pressure. Only slight vortex organization was ever shown by satellite pictures.

HURRICANE LIZA

The ITC was quite active in the vicinity of the Guatemalan and Mexican coasts near 15°N beginning on the night of August 25. The U.S. Coast Guard Cutter *Androscoggin* had a south wind of 35 kt with 1010.5-mb pressure and a heavy thundershower with a 9-ft swell about 150 mi south of Tehuantepec at 1200 GMT on August 26. The ITC had a broad bend to the north in this area, which moved westward at 10 kt during the next 48 hr. Liza generated rather suddenly in this northward bend. APT pictures on the 26th and 27th disclosed no organization beyond clusters of rain squalls.

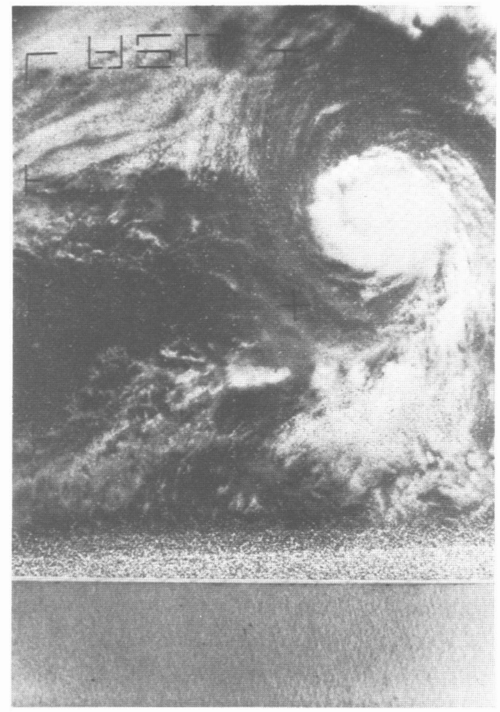

FIGURE 15.—The mature Liza on August 30 has a beginning of stable inflow around the western periphery.

The existence of Liza was first noted by a report at 1800 GMT, August 28, from the *Jag Jawan* of a 50-kt southwest wind with pressure of 1003.2 mb at 11.2°N, 102.7°W. A short time later the *Teverya*, 60 mi to the northwest, sent a special report of a force 10 south wind with a pressure of 998 mb and moderate to heavy southwest swell. The beginnings of a vortex arrangement of highly active convective clouds had been shown by ESSA 6 about 1520 GMT. On that picture one heavy cloud mass 150 mi in diameter was found to the east of the ragged open center, two cloud masses about 60 mi in diameter on the south side, and two bands of cumulonimbus in arcs around the northwest side. There was a strong cirrus outflow from the three cloud masses and the bands. Organization was about the same on the 2301 GMT, ESSA–5 computer-digitized mosaic, from which the National Environmental Satellite Center (NESC) classified it as intensity "C" (Fett, 1964).

Liza moved toward the west-northwest at 15 kt for 48 hr after being named on August 28. Hurricane intensity was shown by ESSA–2 APT at 1410 GMT on August 29, confirmed at 1709 GMT by Orbit 3672 of ESSA 6 depicting the eye at 14°N, 109°W, and reconfirmed 7 hr later by ESSA 5. Reporting ships managed to keep out of Liza's strong winds and high seas until September 1, so that the next information came on ESSA 6 at 1803 GMT, August 30. The hurricane at that time had a nearly circular central overcast 5° of latitude in diameter, the eye being circular and located at 16°N, 114.3°W (fig. 15).

Inflow from the southeast was marked by multiple feeder bands. There was a large nearly clear area on the north and west sides of the hurricane with a narrowing tongue of relatively dry air on the south side. Whether this clearance had developed from subsidence or from an air trajectory off the continent could not be determined. The dry air was still apparent in a narrow clear band 24 hr later, but an extensive sheet of trade-wind stratocumulus had spread southeastward, almost meeting the external bands of the hurricane.

Hurricane intensity was still indicated by pictures on August 31, though the central overcast was reduced slightly to a diameter of 4° of latitude, and irregular breaks were appearing in the external bands. Movement of the storm had slowed down to 12 kt, directed toward the west-northwest.

The hurricane center crossed the 25°C isotherm toward colder water on September 1. The ESSA–6 picture on that day revealed a tongue of trade-wind stratocumulus from the north side of Liza wrapped around to the southwest and pointed into the low-level inflow about 300 mi from the center. Concentric breaks between external bands had apparently filled with locally formed stratocumulus, presumably developed through cooling of the hurricane air mass from below with mechanical mixing of the shallow surface layer. Inflow from the Tropics was diminished with feeder bands reduced in size and activity. Cirrus outflow was continuing from the central core. A ship reported 75-kt east winds and 40- to 45-ft seas while passing eastward north of the center.

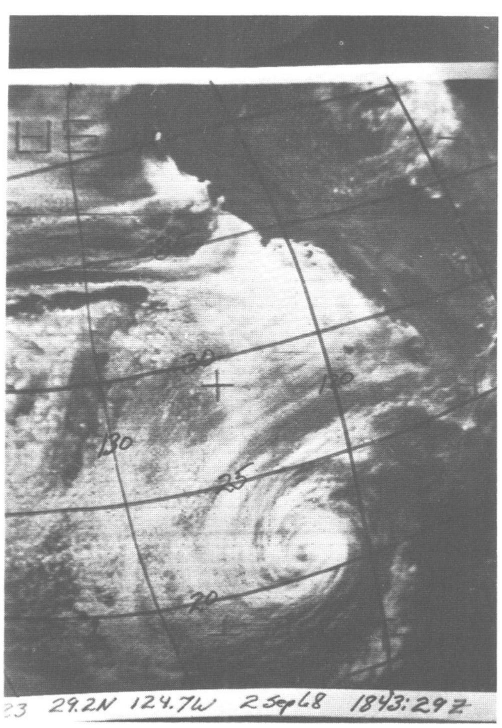

FIGURE 16.—Liza on September 2; convective chimney stopped; cirrus cap dissipating.

Liza weakened rapidly between the APT pictures of September 1 and those of September 2. The picture on the 2d found the cirrus cap dissipating or moving away to the east, partly exposing an open center about 40 mi in diameter (fig. 16). A large part of the cloud vortex appeared to consist of layered low and middle clouds spiraling inward from the north and west. Bands on the south and east still suggested convection, though there was an inflow to those bands from cool water to the northwest. Connection to feeder bands from warm water to the south had been broken completely.

A U.S. Air Force 300-mb reconnaissance plane entered the storm center at 21.2°N, 123.1°W, at 2310 GMT on September 2, finding it uncovered and circular (40 mi in diameter) and poorly defined. The observer remarked that Liza probably could not be classified as a tropical storm. Presumably all radar evidence of a convective chimney to support the warm core had vanished; however, the problem of the strength of surface winds and their rate of diminution remained.

Motion had changed gradually to the northwest after Liza slowed down on September 1, and speed averaged only 5 kt on September 2 and 3. ESSA–6 Orbits 3735 and 3736 on September 3 appeared to show the central area of Liza as consisting mainly of altostratus clouds which had spread a thin veil over the broad open center, but there were narrow bands of towering cumulus or possibly small cumulonimbus spiraling in from about 400 mi southwest of the center. The computer-digitized ESSA–7 mosaic at 2209 GMT revealed little sign of convection to the south or southwest, but did show highly reflective cellular cloud clusters to the northeast of the center.

The ESSA–6 picture of September 4 found further enlargement of the veiled central opening to about 60 mi in diameter. The old storm cloud spiral at that time appeared to consist mainly of thick altostratus with edges feathered by evaporation. Winds probably dropped below tropical storm strength at this time. Remains of Liza then turned toward the southwest and drifted with the trade winds.

Hurricane Liza at no time presented a threat of strong winds over a land area; however, southern California Labor Day beach outings of an estimated 340,000 persons were marred by 12-ft-high breakers generated from swells moving out of the hurricane area. More than three dozen bathers had to be rescued at Zuma Beach despite life guards' warnings to keep out of deep water.

Considering that 75-kt winds were encountered in Liza 2 days after limited cool inflow began, she seems to have been the most intense hurricane of the season. Peak intensity from Timchalk's (1965) objective technique was about 100 kt on August 30.

TROPICAL STORM MADELINE

The depression that became Madeline was first pictured by ESSA 6 as an overcast about 2° of latitude in diameter with cirrus outflow at 8°N, 90.5°W, at 1516 GMT on August 28. Liza had just become a tropical storm 800 mi to the west-northwest and appeared in the same picture.

The cloud mass was considerably enlarged, but still amorphous, when it was found again by ESSA 6 on August 29 near 10.5°N, 94.5°W. A ship 60 mi to the northeast at 1800 GMT reported practically calm winds, wind waves too confused to determine direction or height, and a 1-ft swell from an unknown direction. At 0000 GMT on August 30, the ship was located at 11.8°N, 95.2°W, and reported a 45-kt north-northwest wind, with the same sea condition as at 1800 GMT. Barometric pressure at this time was adjusted to 1009 mb by applying a correction of −4 mb estimated from the 1800 GMT map.

The ESSA–6 picture on August 30 showed the cloud mass breaking up near 10°N, 95°W. The one ship report at 0000 GMT on August 30 was the only direct information supporting storm status at any time. Whether the reported wind on which the storm intensity estimate was based was only a local squall or a representative feature of a young, small tropical storm which later dissipated cannot be determined. There was no storm development for more than a week after Madeline disappeared from the map.

HURRICANE NAOMI

Organization of hurricane Naomi began September 8 in the ITC near 12°N, 98°W. At 1800 GMT the MV *Avisfaith* encountered south-southwest winds of force 7 about 30 mi south of that position. Six ship reports at 0000 GMT on September 9 defined a loosely organized vortex motion around a low-pressure center near 13°N, 101°W with winds up to 30 kt.

The vortex was evident on cloud pictures for the first time at 1719 GMT on September 9, when the center appeared to be a short distance southeast of 14°N, 103°W. Winds of 35 kt were estimated at 0000 GMT on September 10 by the U.S. *Builder* which was near 12°N, south of the Low.

Definition of the vortex had increased on the picture taken on September 10 at 1812 GMT, with a large open center near 16°N, 106°W, and large, loosely spiraled feeder bands apparently derived from the stretched out cloud mass that had been the ITC. Winds up to 40 kt were reported off Manzanillo in squally weather characteristic of these feeder bands just before daybreak on September 10. Fifty-knot winds were reported by the *Allison Lykes* near 13°N, 109°W, late in the day.

Naomi acquired her name as the initial depression was upgraded to tropical storm on data available at 0600 GMT on September 11. Intensification was rapid during the following 12 hr. The 1711 GMT picture (fig. 17) showed large feeder bands going into a tightening spiral with extensive cirrus outflow mainly toward the north-northeast. The picture and ship reports were used to fix the center at 19.2°N, 107.3°W, at 1800 GMT on September 11. Ship reports included one from 40 mi south of the center with 50-kt west winds and one 50 mi to the north with 55-kt east winds.

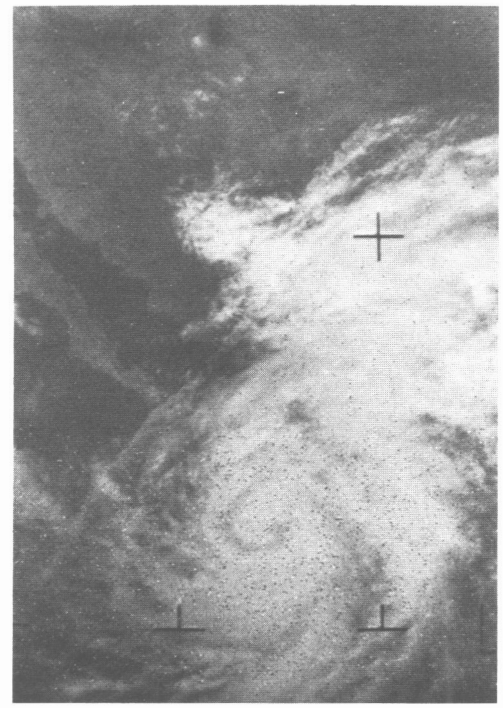

FIGURE 17.—Naomi intensifying rapidly on September 11.

An eye was clearly visible in the computer-digitized mosaic made about 2200 GMT on September 11, and the storm was estimated to have reached hurricane intensity in the next advisory, placing the center at 19.8°N, 106.8°W. Hurricane intensity was confirmed by a report of 65-kt winds from the *Meisei Maru* at 0600 GMT on September 12.

Hurricane Naomi moved northward at 8 kt on September 12, then turned slowly toward the northeast so that the center passed 30 or 40 mi west of Mazatlan and finally accelerated to cross the coastline of Sinaloa, Mexico, near Punta Piaxtla about 0300 GMT on September 13. Figure 18 shows Naomi a few hours before hitting Mazatlan. The strongest wind on hourly reports from Mazatlan airport was from the southeast at 40 to 50 kt with gusts to 60 kt at 2300 GMT on September 12.

An Associated Press dispatch from Mexico City told of the evacuation of 20,000 residents from small towns in the states of Durango, Sinaloa, Nayarit, and Jalisco for protection from floods and winds spawned by hurricane Naomi. The dispatch also mentioned winds estimated up to 80 kt in Mazatlan that damaged homes and knocked out powerlines, with roads and communications destroyed over a large area.

TROPICAL STORM ORLA

The disturbance that developed into tropical storm Orla was discovered as a heavy cloud mass 150 mi in

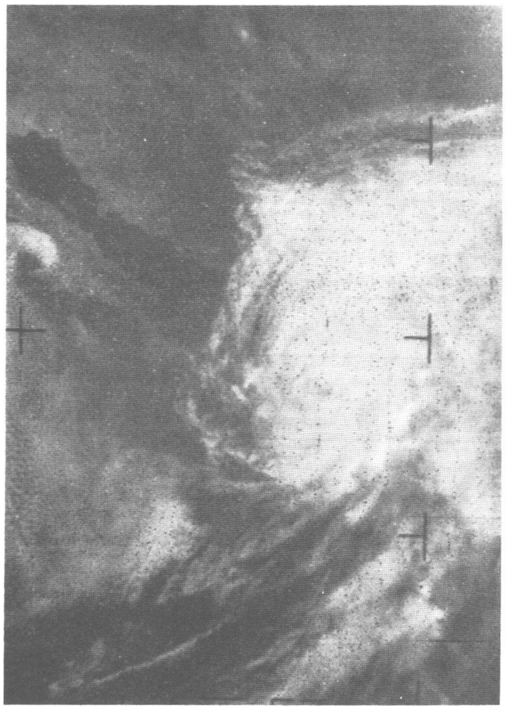

FIGURE 18.—Naomi approaching Mazatlan, Mexico, on September 12.

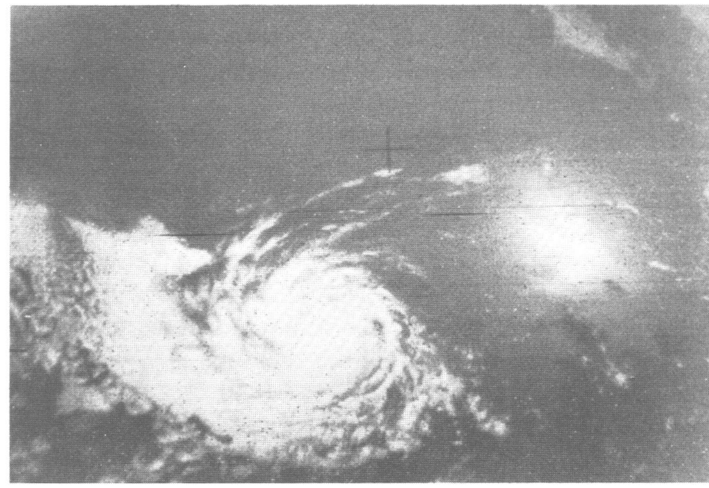

FIGURE 19.—Orla with stable inflow on September 25 (sunglint to the east).

diameter at 15.5°N, 106.0°W, on the ESSA-7 mosaic late on September 21. A weak surface circulation with showers was indicated by ship reports at 1800 GMT on the 22d when ESSA 6 placed the center of a barely discernible vortex at 16.5°N, 108.5°W. Four hours later ESSA 7 indicated an increase in external banding and apparent vortex motion, with diameter of the central overcast increased to 175 mi. Internal banding, if any, was obscured by cirrus.

Bulletins identifying the disturbance as a depression were begun after Socorro Island had a pressure fall of 5 mb/3 hr at 0000 GMT on September 23. At this time the cyclone center was 125 mi to the southeast. The wind at the island was practically calm, sky overcast with low clouds of type 8 and pressure 1008 mb on the same observation.

Orla was shown to be a tropical storm by ESSA 6 shortly after 1800 GMT on September 23 with its center 120 mi southwest of Socorro Island and maximum winds about 50 kt (Timchalk et al., 1965). Ship reports were limited to the storm periphery. Intensity on the ESSA-6 picture of the 24th was little changed, but air inflow from over relatively cool water to the northwest was becoming conspicuous in the form of a stratocumulus layer to the west which had been present since storm generation. The maximum wind estimate was increased to 60 kt when ESSA 7 revealed an eye 3 hr later. Warm dry flow off the continent on the 24th from lat. 35°N southward resulted in a cloudless area extending several hundred miles offshore to the north of the storm. The *Sapporo Maru* passed about 75 mi south of the center between 0000 and 0600 GMT on September 25, reporting no more than 20 kt of wind but having a swell of 9½ ft from the direction of the storm.

Stable air inflow from the northwest was still apparent on the ESSA-6 picture of September 25 (fig. 19). The eye was no longer visible in the center position (at 18.5°N, 120.8°W), and clouds comprising the spiral bands in the northwest semicircle had ragged edges suggesting cessation of convection and onset of evaporation. The southeast semicircle still had apparent multiple bands of cumulonimbus, and cirrus production over the storm center seemed to have increased. Ships 200 mi to the south were estimating swells 3 to 6 ft from the direction of the storm at that time. The ESSA-7 picture a few hours later showed the storm to be shrinking in size and intensity as a result of the stable air inflow. This inflow was delineated by stratocumulus from the northwest, the dominant feature. An eye was barely discernible again.

The APT picture of September 26 displayed stable cloudiness from west of the center spiraling inward around the south side and also showed evidence of active convection in the northeast quadrant fed by two spiral bands of cumulonimbus from the south 150 to 200 mi long (fig. 20). This picture was the basis for speculation that dynamic processes sustaining the storm might involve weak baroclinic effects similar to those ordinarily associated with extratropical storms; the source of cold air would have been that under the trade wind inversion. About 2 hr later the dense clouds that were in the northeast appeared to have spread around the north semicircle, extending out to 100 mi from the center on the new ESSA-7 picture.

On September 27, ESSA 6 pictured a 50-mi-wide band of heavy altostratus clouds making 1½ turns spiraling inward from the east side toward a central area about 60 mi across. The central area (located near 17.0°N, 127.5°W) was covered with clouds of a lesser density. The only ship

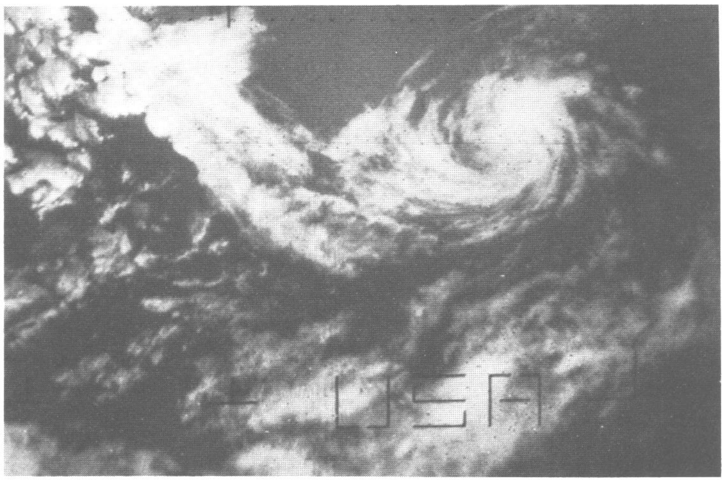

FIGURE 20.—Orla on September 26; later events indicated convection was continuing in northeast quadrant.

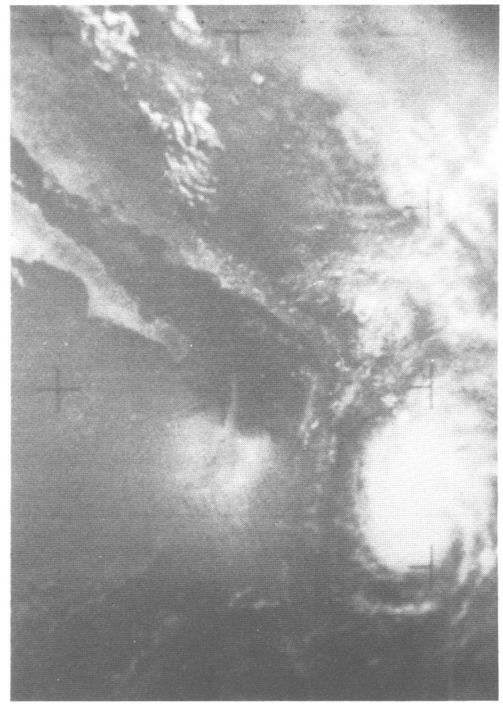

FIGURE 21.—Pauline, an intense and increasing young storm on September 29.

report of winds exceeding 20 kt during the lifetime of the storm came at 1800 GMT of the 27th from the *Shobo Maru*. This ship reported 35-kt winds under the outer turn of the spiral band northeast of the center, and also had heavy showers, an air temperature of 24°C, and a water temperature of 25°C. Weakening of the storm was clearly indicated 3 hr later by ESSA 7, with apparent complete evaporation of clouds from a central area 40 mi across and only a few points of dense cloud left in the main spiral band. It was questionable whether the central break was as much as ½° of latitude inside the overcast (Timchalk et al., 1965).

The storm track had now turned toward the west-southwest, a direction of movement usually associated by operational forecasters with dissipation over these waters. The cloud mass was dissipating when pictured by ESSA 6 on September 28. A residual spiral cloud mass with a weak depression in surface pressures could be followed as late as September 30.

HURRICANE PAULINE

First indications of hurricane Pauline were appearing on the map about 200 mi southeast of Acapulco while Orla was dying some 1,500–2,000 mi to the west. Activity in the ITC was above normal west of Guatemala on September 25 and began to increase across the Gulf of Tehuantepec and for about 500 mi to the west-northwest of there on September 26. ESSA 7 showed an area about 500 mi long and 200 mi wide covered by highly reflective clouds at 2200 GMT. There was a suggestion of an inverted "V" shape in the cloud mass at that time. The few available ship reports showed confluence of southwest and easterly winds. The disturbance was tracked for another 24 hr before being called a depression with its center at 14.5°N, 101.5°W, on data available at 0000 GMT on September 28.

Organization of a spiral vortex was well underway when ESSA 6 showed the center near 14°N, 102°W, at 1700 GMT on the 28th. Further intensification took place between the ESSA-6 orbit and the ESSA-7 orbit at 2117 GMT. Westerly winds of 15 to 20 kt with surface pressure near 1008 mb were reported 200 mi south of the center at 0000 GMT on September 29; otherwise, reporting ships were too far away to note any effects from the developing storm and managed to keep out of the way for another 36 hr. Pauline was estimated to have reached tropical storm intensity by 0600 GMT on September 29, continuing the trend shown by satellite pictures during the preceding day.

A sharp picture made by ESSA 6 on September 29 showed the storm center at 15.2°N, 104.3°W (fig. 21). Internal banding was obscured by cirrus, but the storm was indicated as being tightly coiled by the circular contour of the south two-thirds of the central overcast. The ESSA-7 picture for 2212 GMT of the 29th suggested the presence of a visible eye; but close study led to a determination that it was only a shadow or perhaps a hole between bands, and that the real storm center was still at the center of the circular cloud mass more than 50 mi to the west.

The speed of Pauline increased from 6 to 8 kt early on September 30, and the track, which had been toward 300° then changed to 320°. ESSA 6 at 1655 GMT showed a small perfectly round eye in a heavy cirrus shield 4° of latitude in diameter (fig. 22). A tightly spiraled organization was barely discernible through the cirrus on this picture, which suffered from a "venetian blind" effect due to

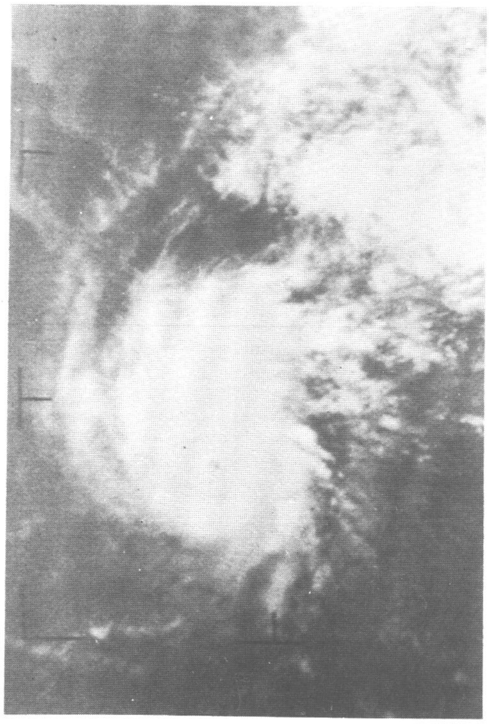

FIGURE 22.—Pauline as a new hurricane, September 30.

electronic problems. Hurricane intensity had now been attained. The ESSA-7 picture 4 hr later indicated a reduction in cirrus shield to reveal large concentric breaks outside a 3° diameter central overcast, with minimum hurricane intensity still indicated by inner coiling of intensity 4 (Timchalk et al., 1965).

At 0330 GMT October 1 the SS *Overseas Joyce* felt the hurricane fury of 70–75-kt north-northeast winds at 19.4°N, 108°W, with a very heavy swell from the east-southeast and a pressure of 1002 mb. At that time the center of the eye would have been about 15 or 20 mi away as estimated from apparent dimensions on satellite pictures, if one assumes that the ship was in the maximum winds of the eye wall. The *Golden Eagle*, at that time about 75 mi east of the center, reported 45-kt south-southeast winds with high to very high seas.

Reports were limited to ships on the periphery at 0600 and 1200 GMT so that the next fix came at 1747 GMT on October 1 by ESSA 6. The picture was of poor quality from apparent electronic interference, so detail was quite limited. Tight coiling was implied by the circular shape of the overcast, which was slightly smaller than on September 30, and by the nearly concentric external banding. A U.S. Air Force reconnaissance plane placed the center at 21°27′ N, 110°47′ W, at 2240 GMT on October 1, with the eye wall open on the southwest side and feeder bands on the east and north sides. A second eye was suggested by a break 30 mi north-northwest of the principal eye. Cumulonimbus tops were as high as 35,000 ft. Temperature at 300 mb was reported to be −32°C in the eye and −26° outside, an apparent discrepancy that may have crept in during communications relay.

No information was available during the following night. At 1200 GMT on October 2, La Paz, Baja California, reported winds from the northeast at 50 kt; these decreased abruptly during the next hour and backed gradually to south over a 3-hr period. ESSA 6 showed Pauline in the Gulf of California with intensity decreased to tropical storm. The storm then moved north to pass inland across the Navojoa area late in the day.

After it was learned that the sailboat *Tiare* with four or five people aboard had vanished in the vicinity of Magdalena Bay about the time Pauline passed by, information of 100-kt winds in the hurricane came from the Mexican Navy unit at Magdalena Bay.

Hurricane damage reports from Baja California were not available. Damage was relatively light on the mainland in the Navojoa area.

HURRICANE REBECCA

Hurricane Rebecca was an excellent example of a very small violent storm which occasionally occurs in the shipping lane near the Mexican coast, between the Gulf of Tehuantepec and Cape San Lucas (at the southern tip of Baja California). Danger from such a small storm is increased by tracking difficulties, even with a moderately dense network of ship reports.

An unusually active ITC from about 500 mi south of Tehuantepec eastward nearly to Panama preceded the initial circulation that developed into hurricane Rebecca. A flat, closed Low was first charted at 10°N, 90°W, at 0000 GMT on October 4. This Low remained flat as it moved to 13°N, 97°W, by 1800 on October 4. At this time a cirrus outflow was apparent from an oval cloud mass 4° to 5° of latitude in diameter centered at this point. (There was suspicion that a problem of light saturation of the satellite camera had resulted in a spurious fusing of cloud clusters after ESSA 7, a few hours later, revealed the mass to consist of several separate elements.) Weak circulation continued around 11.5°N, 97.5°W, at 1800 GMT on October 5, when clusters of cumulonimbus with strong cirrus outflow could be seen over an area extending more than 200 mi to the east and west and nearly that far to the north and south.

Intensification began in earnest during the night of October 5–6, as revealed by ESSA 6 at 1635 GMT. The picture displayed a circular overcast about 4° of latitude in diameter centered near 14°N, 100°W, with a strong cirrus outflow obscuring any internal banding, but with incipient external banding. Rebecca was then named and formal advisories initiated. The ESSA-7 computer-digitized mosaic showed continuing organization 5 hr later, leading to a classification of "category 2" by the NESC (Timchalk et al., 1965). The developing storm was moving northwestward to pass 100 mi west-southwest of Acapulco at 1800 GMT on October 7. Intensity was increasing gradually at that time with a cirrus cap 4° of latitude in width remaining over the storm. Ships were avoiding the strong winds of Rebecca, even though her center was directly on the heavily used shipping lane between Panama and American and Asiatic ports on the Pacific. No reports of unusual seas or winds more than 15 kt were received during the afternoon or night of October 7–8, leading to the erroneous conclusion that the small storm had moved to the coastline.

The conclusion that the storm was centered along the coast proved erroneous when a 1500 GMT, October 8 report from the *Mississippi Maru* indicated full hurricane winds of 80 kt 75 mi south of Manzanillo. Pressure rose 25.5 mb and wind decreased to 25 kt as this ship moved to the east side of the storm during the next 3 hr. The *Pacific Stronghold* passed near the south edge of the eye at 1700 GMT reporting winds estimated up to 90 kt and a minimum pressure of 965 mb. That pressure was the basis for computation of 100-kt maximum winds in the hurricane (Fletcher, 1955).

Dimensions and intensity of Rebecca at this stage were similar to those of hurricane King which tore up Miami on the night of October 17–18, 1950 (Norton, 1951). Dimensions were considerably smaller, but intensity almost as great as that of hurricane Daisy of 1958, a storm analyzed in detail by Colón (1963) as an example of a small intense vortex.

As attention became focused on dangerous hurricane Rebecca, ships in the area were using all available means to keep out of her way. Shipboard radar was used successfully in at least two cases. The *Arizona Maru* reported radar fixes at 2000 and 2100 GMT on October 8, and the *Steenwijk* gave an 0800 GMT, October 9 fix. The *Steenwijk* was also able to make a determination of eye movement which checked very closely with movement from the *Arizona Maru* fix 7 hr earlier.

Rebecca moved westward at 7 kt during the night of October 8–9 while the *Steenwijk* pulled away out of radar range on a northwest track parallel to the coast. ESSA 6 showed the center of a circular overcast 3° of latitude in diameter at 18.5°N, 107.5°W, with storm track changed back to west-northwestward at 1718 GMT on October 9. A narrow, spiral feeder band extended northward from the ITC near 12°N, circling around the east side and into the north side of the overcast (fig. 23). Cirrus production was still apparent from the central overcast and from that part of the feeder band to its northeast and north, but the eye which ESSA 7 had shown the evening before was no longer there. The striking feature of the picture was the disclosure of the impending rapid destruction of Rebecca through inflow of cool stable air delineated by extensive stratocumulus to the west and northwest of the hurricane and protruding into the inflow some 200 mi southwest of the center. A similar picture was seen on the ESSA-7 computer-digitized mosaic a few hours later with little banding evident in a

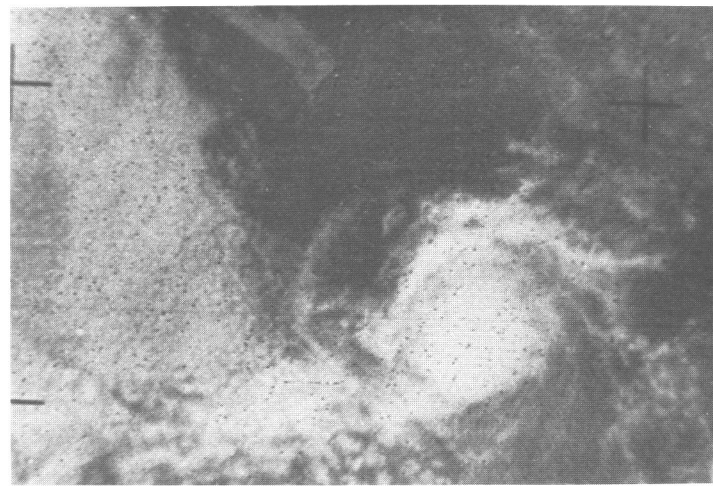

FIGURE 23.—Rebecca on October 9 weakening from cool inflow.

brilliantly depicted disc about 2° of latitude in diameter surrounded by unbroken clouds some 25 to 50 mi farther out from the center.

Tropical storm Rebecca turned from a track toward the west-northwest at 13 kt to a track toward the northwest at the same speed during the night of October 9–10. The center passed 60 mi northwest of Socorro Island about 0600 GMT, but with no report from the island at that time. At 1200 GMT the island reported a nearly calm wind, barometer at 1010 mb with a 3-hr fall of 1.4 mb, and scattered stratocumulus; Rebecca was 80 mi to the north-northwest at that time.

The ESSA–6 picture of October 10 is that of a dead storm (fig. 24). There are no feeder bands from warm waters to the south and east, the band that had been there earlier having been caught up by southwest winds aloft on the north edge of the storm and stretched out onto the Mexican mainland while disintegrating. A non-concentric break of 25 by 50 mi appeared about 50 mi east of the center of the shapeless overcast, and there was no longer a storm circulation drawing in the stratocumulus layer to the west. The higher clouds dissipated or moved away to expose a lower cloud whorl on the ESSA–6 picture of October 10. The whorl drifted slowly westward during the following 24 hr while a peculiar, highly reflective cloud mass formed in a cyclonic shear zone to its southwest around the periphery of the subtropical high.

TROPICAL STORM SIMONE

Tropical storm Simone organized from a collection of squalls in the ITC near the Guatemala coast on October 18. Organization proceeded rapidly to the stage where winds of 40 to 45 kt were reported by the *Villanger* on the southeast and northwest sides of a flat center of a Low 30 mi or so in diameter at 1500 and 1800 GMT. ESSA–6 pictured a loosely spiraled heavy cloud vortex centered over the surface Low.

FIGURE 24.—The dead Rebecca (center) on October 10.

Steering of the storm was apparently toward the north or northeast at that time. Movement of the center of the Low over land with dissipation, probably resulting from the lack of an energy source, was taking place while a new center generated over water to the northwest of the original center. The latter development effectively prolonged the life of the storm and shifted it up the coast to the vicinity of Tapachula, Mexico, before total dissipation took place after a lifetime of about 24 hr.

TROPICAL STORM TARA

Anticyclogenesis aloft over Mexico after Simone dissipated may have been a factor in the generation of Tara. She was already a tropical storm 300 mi southwest of Acapulco when located by ESSA–6 pictures at 1731 GMT on October 20. Maximum winds were estimated at 50 kt from the satellite picture, which also showed a small central overcast about 3° of latitude in diameter, with considerable cirrus outflow and loose external banding. The storm expanded slowly and organization increased gradually during the first 2 days of its known lifetime, while movement was generally toward the west at 10 to 12 kt. Direction of motion changed to west-northwestward at 10 kt from 14°N, 117°W, on October 23, about the time ESSA 6 seemed to show a separation of the cirrus cap from lower parts of the storm. Tara was no more than a minor storm thereafter with convective activity loosely organized and producing little cirrus. From trends in appearance on pictures, final decrease to less than storm intensity was estimated to have occurred early on October 27 near 20°N, 133°W; it may even have been days earlier. No ships reported winds stronger than 30 kt from Tara during her entire lifetime.

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[*Received January 7, 1969*]