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A SATELLITE ANALYSIS OF TWIN TROPICAL CYCLONES IN THE WESTERN PACIFIC

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ABSTRACT

Satellite cloud photographs are very important for a clearer understanding of meteorological features of almost every scale and their interrelationships. In this paper, satellite derived information, particularly cirrus-level wind estimates made from cloud photographs, are used to recount the story of twin tropical cyclones--ANNIE and GILDA--which formed about the same time on opposite sides of the equator in the Western Pacific during November 1967. Throughout the life cycle of the twins, it is the change which takes place in the cirrus-level wind field that enables the meteorologist to discern the step by step development of the respective cyclones as well as the interaction between the high-level winds of the two hemispheres and the twins themselves.

INTRODUCTION

Weather satellite photographs are unique in that they provide pictorial representation of the integrated effects of the meteorological processes at work as evidenced in the clouds and cloud systems. Such a perspective permits the meteorologist to deduce many important details regarding meteorological features of almost every scale as well as something about their interrelationships.

In this paper the cyclone twins--ANNIE and GILDA--which occurred in November 1967 are examined using satellite derived data, primarily cirrus-level winds estimated from cloud photographs.

ANNIE and GILDA are of particular interest for at least two reasons. First, they occurred in the Western Pacific from apparently a different cause than that suggested by Kuettner and Soules (1967) for the development of "Sumatra" twin vortices.*

*In satellite pictures the near simultaneous development of twin vortices within 5 to 10 degrees on opposite sides of the equator along approximately the same meridian in the Indian Ocean about 600 miles west of Sumatra has been noted several times.

The repeated occurrence of such twins led Kuettner and Soules to speculate that their formation may be associated with downstream divergence aloft created by a deep easterly flow over the high mountain barrier imposed by Sumatra. Hence, the occurrence of ANNIE and GILDA in the Western Pacific was of special interest in that obviously the barrier principle could not be a factor in their formation.

Historically, Kuettner and Soules were not the first to consider possible relationships between cyclonic storms in the tropics of both hemispheres. Earlier, Malurkar (1950) discussed the possible interaction of nearly contemporary tropical storms on opposite sides of the equator when they exist within a relatively narrow longitudinal belt. His conclusions, however, were based upon his belief that air from one hemisphere crossed over to feed the tropical cyclone in the other hemisphere, and did not provide for the continuing development of both vortices as have been noted in satellite photographs.

The second and more important of the two reasons is that cyclone twins like ANNIE and GILDA are infrequent occurrences in the Western Pacific. They illustrate the valuable role meteorological satellite photographs play in providing meteorologists with a tool for studying tropical disturbances in various stages of their life cycles and their related environments.

Figure 1 shows the tracks of the cyclone twins, ANNIE and GILDA, as constructed from the daily ESSA 5 satellite photographs taken during the period November 5 through 18, 1967. Pictorial inserts are included to provide a composite view showing the changes day by day during the twins' early development.

The interpretation techniques used in this study for estimating upper tropospheric winds over the tropics and subtropics based on the appearance of cirriform clouds in meteorological satellite photographs were developed at the National Environmental Satellite Center (NES) by Jager,

Follansbee, and Oliver (1968). Specifically, cirrus cumulonimbogenitus, cirrus spissatus, and the edges of cirrostratus shields furnish clues to the wind direction and speed in their immediate proximity. The techniques are based on the relationships that the striations, orientation, and configuration of such cirriform clouds have to the winds in which they are embedded. In making wind estimates both vertical and horizontal shear effects have to be considered. Where the direction of shear through the convective layer is considerably different from the direction of the wind at the top of the layer, the orientation of cirrus plumes can be misleading. Only when these directions are essentially parallel do the plumes show wind direction. Fortunately, in the tropics and subtropics the vertical shear and upper level wind vectors are for the most part nearly parallel. Where horizontal shear is great, usually near the edges of jet streams, caution must be exercised in estimating winds from cirrus fingers and striations because the shear rotates the cloud elements toward a cross-wind orientation. Transverse banding, where the small-scale banded structure in the cirrus is perpendicular to the orientation of the large-scale band, is frequently associated with a subtropical wind maximum. In general, the wind direction is perpendicular to the direction of the small-scale bands. Such jet-associated cirrus patterns are easily recognized and pose no particular problem to making estimates of the wind direction in their vicinity. Deducing the corresponding wind speeds is not so simple. Nevertheless, the NESc method for estimating upper tropospheric winds provides the meteorologist much useful information concerning the high-level wind field in the tropics and subtropics. The fact that observed winds at approximately the 200-mb. level generally agree with the estimated winds from satellite photographs is evidence that this is true.

Currently, photographs taken about every 20 minutes by the Applications Technology Satellite (ATS) from its quasi-stationary position at 22,300 miles above the equator are being used to obtain wind estimates. Carefully rectified ATS pictures are viewed by means of time-lapse movies from which cloud motion measurements, rather than estimates, are made. Experience thus far shows that such measurements can be made at more than one level over a given area. Wind measurements from ATS movies are just one of a number of ways in which satellite cloud data are used by the meteorologist to better understand the weather. ATS movies are being used in hurricane and tornado research projects and in various studies of other meteorological features at several universities and at NESc. Operationally, wind estimates from both ATS movies and daily ESSA satellite photographs are being pre-

pared at the Satellite Center.

For this study, satellite derived wind directions were superimposed on the daily ESSA satellite photographs to depict the cirrus-level wind field. The wind estimates were made from the pictures using the techniques developed by Jager, Follansbee, and Oliver (1968) without reference to meteorological soundings and upper air charts. Afterward, observed high-level winds primarily at the 200-mb. and 150-mb. levels were superimposed over the satellite estimated winds for comparison. At times it was necessary to show the 100-mb. level wind in the vicinity of the cirrus canopy enveloping the more mature cyclones. In such cases the 200-mb. wind was often still a part of the cyclonic circulation, and the 150-mb. wind changing toward the anticyclonic flow at the higher cirrus level. Where 300-mb. winds are indicated on the photographs, higher level winds were not reported. The daily series of satellite photographs (figures 2-11) reveal good agreement between the estimated wind directions and the observed winds in nearly every instance.

DAILY SATELLITE ANALYSIS--ANNIE AND GILDA

By way of background, GILDA, the northern twin, was one of a series of tropical cyclones that formed in rapid succession near the intertropical convergence zone (ITCZ) in the vicinity of 165°E. in late October and early November 1967. ANNIE, the southern twin, was a very early season storm in the Southwest Pacific which formed east of the Solomons near 5°S., 160°E. GILDA was the first of the pair to form, with definite evidence of its beginning in the satellite pictures on November 6. For ANNIE, positive evidence was not noted until November 9, at which time her presence was most evident.

November 5

Principal features are the disturbed area near 9°N., 141°E., later to become typhoon FREDa, and areas of extensive convective activity associated with the ITCZ between 5° and 10°N. east of 165°E. and with the South Pacific convergence below the equator (figure 2).

At the cirrus level, sharp anticyclonic curvature in the wind field, stemming from a weak upper level source near 5°N., 145°E. exists over the incipient disturbance FREDa. East of 145°E. and north of the equator, derived cirrus wind information indicates a predominately westerly flow. South of the equator a poleward current stems from a cumulonimbus cloud mass centered near 8°S., 151°E. From the appearance of the

cirrus clouds there is a definite wind maximum along the poleward edge of the current. West of a line joining this southern upper level source and the northern one near 5°N., 145°E. the cirrus level winds are mostly easterly.

Of particular interest with respect to the formation of GILDA is the almost cloud-free area centered near the equator and 165°E. Just south of this area peripheral cirrus-level winds indicate a southerly flow toward the equator in the region between 150° and 170°E. This flow and the westerly flow north of the equator imply a weak anticyclonic flow over the almost clear area of interest. This weak anticyclonic flow aloft and low level heating set the stage for the development of the first positive signs of GILDA.

The surface synoptic situation at 05/0000Z November 1967 indicates a weak ITCZ about 5° to 7°N. and 150° to 180°E. Surface pressures of 1008-1009 mbs. or above with high cirrus and some cumulus activity are reported in the area. No signs of the impending development are evidenced in the surface and upper air reports.

November 6

A marked change is noted (figure 3) with respect to the almost clear area described the previous day. Intense convective cloudiness centered near 2°N., 164°E. now dominates the area. Also noted is a significant change in the cirrus-level wind. Cirrus blowoffs indicate a definite anticyclonic outflow associated with the cloud mass. Elsewhere, the basic cirrus-level flow in the equatorial tropics of both the Northern and Southern Hemispheres is essentially the same as described for the 5th.

The surface synoptic conditions for 0000Z on the 6th are not substantially different from those 24 hours earlier. Island stations reflect the increased cloudiness associated with incipient GILDA, centered near 2°N., 164°E., with surface pressures 1007-1008 mbs. --down 1 mb. in the last 24 hours. At this time, the changes leading to the formation of GILDA are evident only in the daily satellite pictures.

November 7

The satellite photographs reveal an explosive change in the character of the developing disturbance (figure 4). Pronounced outflow at the cirrus level from a source near 4°N., 161°E. above incipient GILDA is very much apparent. Such evidence at the cirrus level strongly suggests that low-level cyclonic circulation is already present. Whereas on the previous day there was

no positive evidence of outflow to the south from the anticyclonic outflow aloft, today there is a very pronounced outflow southward across the equator. Below the equator the flow turns anticyclonically, joining the poleward current present on the two previous days. This high-level flow southward across the equator is significant in that the stage is now being set for the development of the Southern Hemisphere twin, ANNIE. Note the evidence of mass outflow feeding from the cirrus-level source region above GILDA into the tropical westerlies of both hemispheres.

Sparse surface reports at 07/0000Z do not reveal the presence of incipient GILDA. However, peripheral low-level upper air information does suggest the possibility of an easterly wave or weak circulation to the south and east of Ponape (7°N., 158°E.). As far as is known, no Western Pacific advisory covered the disturbed area. The first of a daily series of miscellaneous satellite bulletins covering the development of GILDA was issued by NESG on the 7th. The bulletin for that date located the disturbance near 2°N., 159°E. at 0200Z.

November 8

The cirrus-level wind information is very similar to that of the previous day (figure 5). The high-level outflow associated with developing GILDA originates from a source in the vicinity of 6°N., 160°E. At this time the convective cloudiness about the low-level center is not well organized or complete. Note that as the high-level outflow to the south becomes more pronounced, the outflow to the north feeding into the westerlies decreases. This appears to be characteristic of many tropical cyclones during their formative and intensifying stages that originate in the Western Pacific.

Synoptically, surface and low-level upper air data for 08/0000Z are more indicative of a weak tropical disturbance in the vicinity of Ponape, which reported a surface pressure of 1004 mbs.

South of the equator, a marked increase in intense convective type cloudiness has taken place during the past 24 hours where the high-level flow from incipient GILDA crosses the equator and turns anticyclonically southeastward, joining the poleward current which has been evident for several days. Interestingly, the sequence of events now taking place in the Southern Hemisphere is the same as that noted in the satellite pictures during the formation of GILDA, the northern twin.

November 9

There is no need to announce the dramatic birth of the cyclone twins, ANNIE and GILDA; the satellite picture speaks for itself (figure 6). The explosive development of ANNIE, the southern twin, under the anticyclonic cirrus-level flow of the previous day is strikingly evident. Note that the high-level anticyclonic outflow associated with ANNIE is complete. The first miscellaneous satellite bulletin on ANNIE issued by NESC located the center of the disturbance near 5°S., 163°E. at 0246Z, November 9.

One of the more interesting features in figure 6 is the strong high-level easterly current near the equator between the twin cyclones. This current began to form two days earlier, with the southward flow being produced at the cirrus level as GILDA developed. Now the equatorward flow of both cyclones suggests a "venturi" effect where their cirrus-level outflows pass between them. Note that the high-level outflow poleward of each center, which was present initially and fed into the westerlies, has greatly diminished. Most of the cirrus-level mass outflow is now toward the equator where they combine to produce a strong high-level east-northeasterly flow between the two cyclones.

November 10

On this date the strong cirrus-level flow between the twin cyclones was most pronounced (figure 7); after which, the flow gradually diminished as the cyclone twins moved further apart while traveling normal paths in their respective hemispheres. By this time, both twins are well developed tropical storms with GILDA the more intense. During this stage of development most of the high-level outflow of each cyclone is retained in the equatorial tropics, with very little escaping into the westerlies.

November 11

Using the NESC criteria for estimating the intensity of tropical disturbances from satellite photographs, GILDA would now be classified as a tropical cyclone (figure 8). ANNIE, which has become better organized, would still be classified as a tropical storm. Note again that the peripheral high-level winds about the respective centers indicate little flow escaping into the westerlies of either hemisphere.

November 12

Definite wall cloud eyes for both twins are evident in the original satellite pictures (figure 9). ANNIE is now estimated to be of weak tropical cyclone intensity.

On the 12th and also on the 13th, an anomalous condition is noted with respect to the size of the cirrus overcast associated with GILDA. In spite of a reported increase in the cyclone's intensity, a marked decrease is evident in the size of the cirrus canopy, a parameter used in estimating the intensity of tropical disturbances. Such a decrease has been noted in other storms and is not really understood. Despite the anomalous condition in the size of the central overcast, the character of cirrus, particularly the transverse banding northwest of the center, suggests an increase in mass outflow at the cirrus level and, as a consequence, an increase in the low-level inflow and the circulation intensity of GILDA.

Another interesting feature, frequently observed in fully developed tropical cyclones, is the long thin curved band of cirrus clouds on the periphery to the north of GILDA. This band is believed to denote a wind maximum along the poleward edge of the cirrus-level outflow associated with the cyclone center. Quite possibly, the peripheral band corresponds to the wind maximum immediately inside the outer shear line indicated by Fujita, et al. (1967) in their tropical cyclone model showing the two-dimensional distribution of outflow winds.

November 13

The small size of the central overcast is again noted in the picture of GILDA (figure 10). Nevertheless, the characteristics of external and internal banding indicate a further intensification of GILDA. Note that part of the high-level outflow from GILDA is still crossing the equator into the Southern Hemisphere near 140°E.

As for ANNIE, central cloud characteristics indicate a slight decrease in intensity from the previous day.

November 14

Cirrus is once again evident about GILDA (figure 11), and the size of the central overcast has increased noticeably. Highest winds are estimated to exceed 125 knots. Note that most of the high-level flow revolves about GILDA with little flow feeding into the westerlies or across the equator.

The size and characteristics of the central cloud mass indicate that some re-intensification of ANNIE has taken place during the past 24 hours.

After the 14th

Subsequent to the 14th, both ANNIE and GILDA followed normal paths for their respective hemispheres (figure 1). As GILDA reached higher latitudes, the high-level outflow was again directed northward, feeding into the midlatitude polar trough approaching from the west. By the 19th GILDA had moved inland into China, having crossed Taiwan the previous day. By the 16th, ANNIE which was then moving rapidly toward the southeast had lost most of its tropical characteristics.

The twins, ANNIE and GILDA, are believed to be the first set of Pacific twins observed in satellite photographs since the launching of the first meteorological satellite, TIROS I, in 1960.

AN INDEPENDENT ANALYSIS

Leigh (1969) traces the development and subsequent movement of the twin vortices--ANNIE and GILDA, making estimates of maximum wind speeds and central pressures, by means of satellite photographs. In view of the fact that the appearance of the Southern Hemisphere vortex followed closely on the development of the Northern Hemisphere vortex, Leigh suggests that the first vortex (GILDA) may have triggered the development of the second (ANNIE). He indicates that a possible mechanism for such triggering may be seen by considering the vertical component of relative vorticity. Since, near the equator the vertical component of vorticity due to the earth's rotation is small, the contribution of the vertical component of relative vorticity to the background vorticity is important in determining whether or not a vortex will form. In such a situation, changes in the wind field in an area of low level convergence could be decisive in determining vortex formation.

Leigh's study in no way conflicts with the analysis of the twin cyclones, ANNIE and GILDA, in this paper. In fact, the two supplement each other. Of particular interest are the number of conclusions and suggestions arrived at independently which are similar in the two studies regarding the possible interaction between the cyclone twins and the two hemispheres.

MORE TWINS--GISELE AND JEAN

In April 1968 another set of Pacific twins (figure 12) formed near the equator in the same general vicinity where ANNIE and GILDA originated. Although satellite coverage did not provide the same detailed knowledge of their development, it did reveal basic similarities in the two sets of twins.

The second set of twins, GISELE and JEAN, formed when tropical cyclone activity was shifting into the oncoming summer hemisphere--in this case, the Northern Hemisphere. In both cases of twin formation the cyclone in the autumn hemisphere formed first. As both sets of twins developed, their cirrus-level outflows toward the equator merged to produce an easterly flow near the equator between the two centers. The "venturi" effect created by the interaction of the high-level circulations is evident in the satellite photographs.

In the case of the April twins, GISELE, the southern cyclone, moved rapidly southward into a low complex near New Zealand where it was involved in the sinking of a ferry boat with great loss of life on the 9-10th of April. JEAN, the northern twin, not to be outdone wrought havoc to dwellings on Saipan in the Marianas Islands on the 11-12th of April as it churned through the Western North Pacific.

SUMMARY

Throughout the life cycle of the twins, it is the change which takes place in the cirrus-level wind field that provides insight not only as to the initial conditions but also the sequence of events which take place, particularly during their early stages of development. Moreover, it is the cirrus story which depicts the interaction between the high-level wind fields of the two hemispheres and the twins themselves.

In brief, the daily satellite pictures show that GILDA, the Northern Hemisphere twin, formed near the equator in an area initially under an apparent weak cirrus-level anticyclonic flow over which clear skies prevailed. As GILDA developed its own anticyclonic outflow aloft, the high-level flow into the tropical westerlies diminished and the flow toward the equator increased. Part of the flow crossed the equator, then recurved toward the southeast to produce a weak anticyclonic flow at the cirrus level in the Southern Hemisphere over an area of partly cloudy skies, thus setting the stage for the formation of ANNIE. Once both twins were formed, their equatorward flows at the cirrus level merged to create a strong "venturi"

effect between them which lasted for several days. During maturity, the high-level flows basically revolved about the centers themselves with little apparent flow into the westerlies. Later, from more subtropical latitudes, cirrus-level outflow was directed into the midlatitude westerlies in the final stages of the tropical cyclone cycle.

In the Western South Pacific, the tropical cyclone season is distinctly related to the summer hemisphere. With respect to the two sets of twins, ANNIE (November 1967) was an early season cyclone and GISELE (April 1968) was a late season one. This fact suggests that meteorological conditions are such that the likelihood of Pacific twins occurring is probably greatest during late fall and early spring when tropical cyclone activity is shifting into the oncoming summer hemisphere.

Certainly no other observational means could have provided the degree of insight which satellite photographs have disclosed about the cyclone twins--ANNIE and GILDA. Meteorological satellites play an important role in both meteorological research and operations. They are vital to a clearer understanding of meteorological features of almost every scale and their inter-relationships.

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Figure 1. Track chart of cyclone twins--ANNIE and GILDA--November 1967. ESSA 5 satellite photographs correspond to track days as indicated.

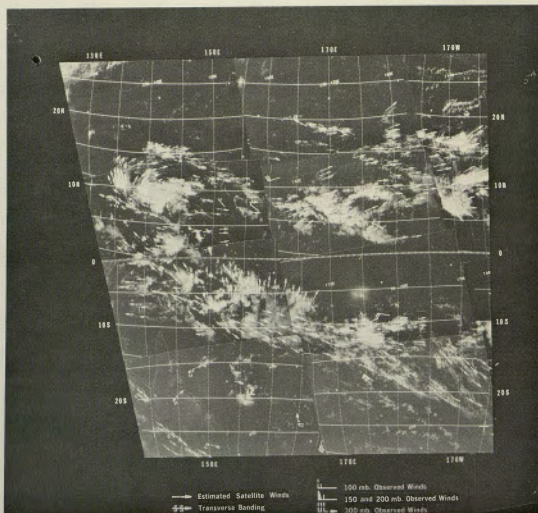


Figure 2. Satellite photographs for November 5, 1967. Note the clear area vicinity of the equator and 165°E.

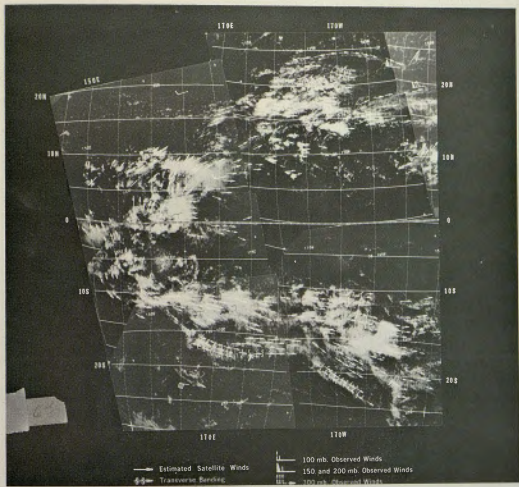


Figure 3. Satellite photographs for November 6, 1967. Note the mass of intense convective clouds centered near 2°N., 164°E.

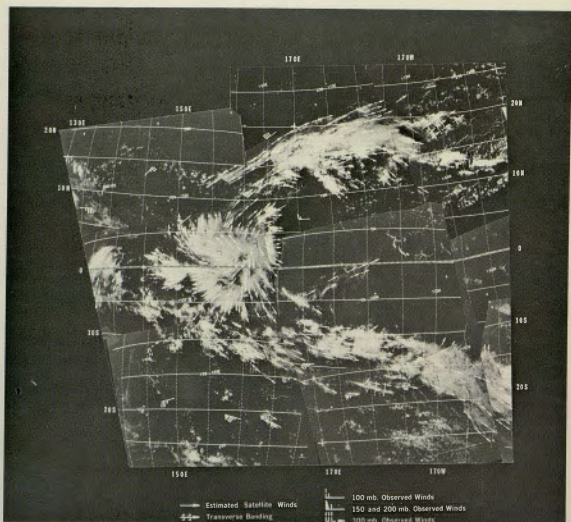


Figure 4. Satellite photographs for November 7, 1967. Note the high-level anticyclonic outflow over incipient GILDA vicinity 4°N., 161°E.

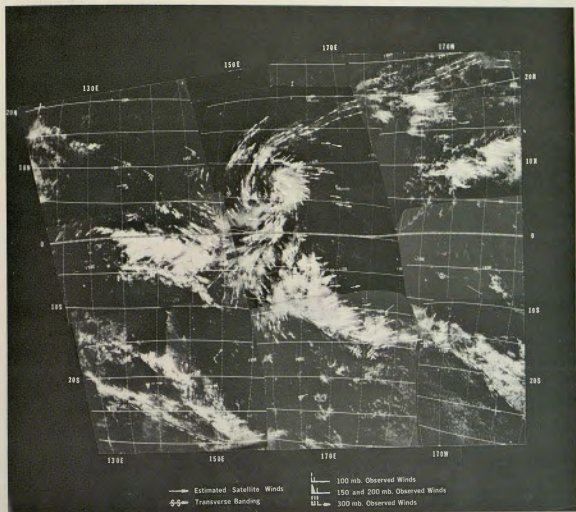


Figure 5. Satellite photographs for November 8, 1967. Developing GILDA is poorly organized in cloud pattern, with center near 6°N., 160°E.

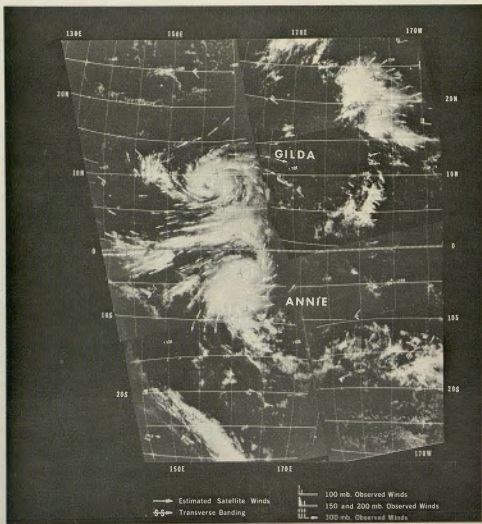


Figure 6. Satellite photographs for November 9, 1967, showing cyclone twins--ANNIE and GILDA.

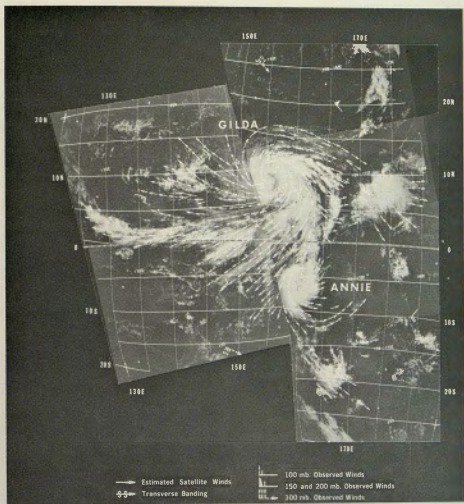


Figure 7. Satellite photographs for November 10, 1967, showing cyclone twins--ANNIE and GILDA.

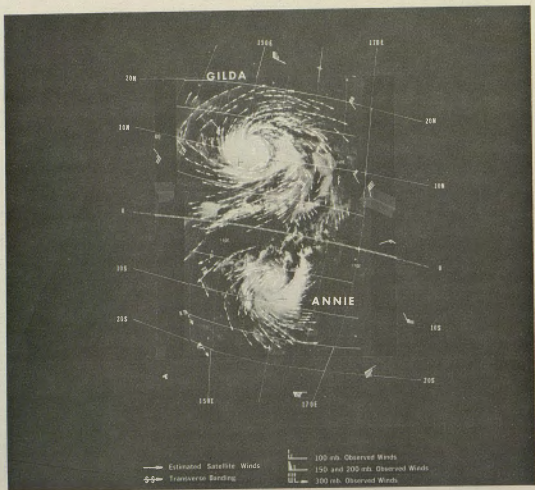


Figure 8. Satellite photographs for November 11, 1967, showing cyclone twins--ANNIE and GILDA.

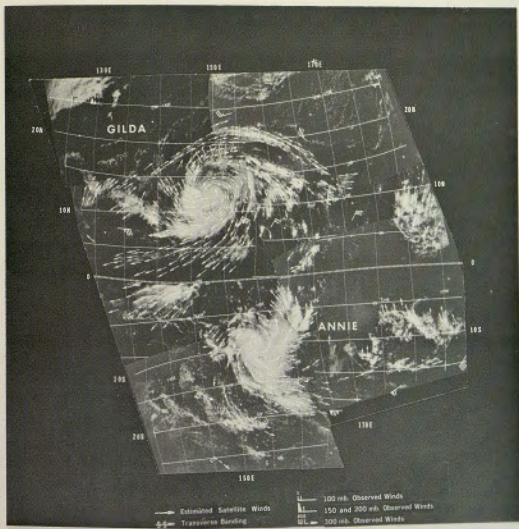


Figure 9. Satellite photographs for November 12, 1967, showing cyclone twins--ANNIE and GILDA.

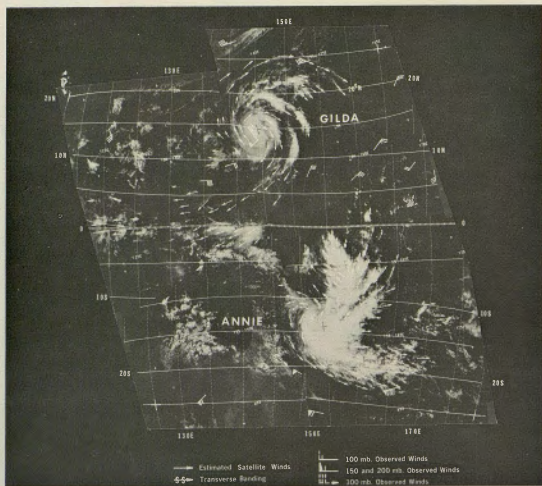


Figure 10. Satellite photographs for November 13, 1967, showing cyclone twins--ANNIE and GILDA.

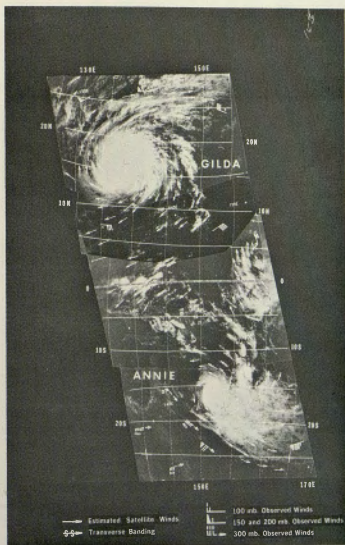


Figure 11. Satellite photographs for November 14, 1967, showing cyclone twins--ANNIE and GILDA.

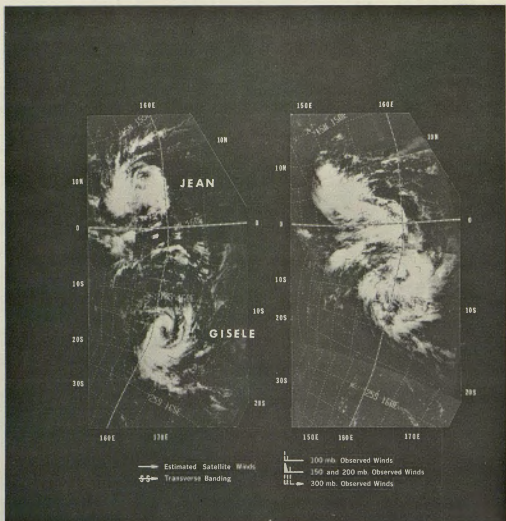


Figure 12. Satellite photographs showing cyclone twins--GISELE and JEAN: Right, April 4, 1968; left, April 6, 1968.