REPRINTED FROM:

PROCEEDINGS OF THE

FIRST INTERNATIONAL SYMPOSIUM ON ROCKET AND SATELLITE METEOROLOGY

WASHINGTON, D.C., APRIL 23–25, 1962

EDITED BY

H. WEXLER and J. E. CASKEY Jr.

1963

NORTH-HOLLAND PUBLISHING COMPANY-AMSTERDAM

UTILIZATION OF METEOROLOGICAL SATELLITE CLOUD DATA IN TROPICAL METEOROLOGY

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Abstract: The tropical region of the earth is a region of very sparse conventional meteorological data in relation to the middle and high latitudes. The TIROS satellites, because of their inclined orbits, have reversed this order of cloud data availability with large volumes of excellent cloud photographs over much of the tropical region. These data, in addition to having great potential in daily analyses for operational purposes, are invaluable to the study and understanding of many tropical atmospheric circulation regimes. Many of these circulation patterns are discussed in relation to the satellite data. A global tropical analysis center is proposed with justifications.

Russian Abstract: not received.

1. Introduction

The most important initial utilization of satellite cloud data has been in the specification and analysis of cloud and circulation patterns over regions of sparse conventional data. The tropics certainly qualify as the largest area in this category of sparse, or even void meteorological data. The tropical meteorologist should, therefore, expect a disproportionately large benefit from the satellite data. He has not been disappointed.

Satellite cloud photography furnishes new and novel data and, whereas the mid-latitude meteorologists are obtaining a new look at more or less known atmospheric circulations, the tropical meteorologist is obtaining not only a new look but, in many areas, the *first* look at unknown or, at best, suspected circulation regimes. The tropical meteorologists have a lot of "catching up" to do in establishing a synoptic climatology of the tropical regions. Not only must new concepts be established, but there remains the

large task of correcting many current concepts which have become well established through use without adequate data. This discussion will concentrate on this topic of synoptic climatology.

The features of greatest and most immediate interest to synoptic meteorologists are usually those which are weather producing. By ignoring orographic influences, these can be lumped into the two general categories of converging air streams and vortices. The tropical atmosphere, is, in general, of a layered character in the wind field and it is, therefore, convenient from a synoptic climatology point of view to further categorize the tropical troposphere into the lower troposphere and upper troposphere.

2. The lower troposphere

The lower troposphere, a layer from the surface to the first wind transition zone, which in general lies near 20000 ft, has received most of the attention in the tropics. This is only natural, since most of the available data are concentrated in the lower levels and there are insufficient data, even at present, to produce an analysis of the upper tropical troposphere with confidence on a global scale. It is within this lower layer that the warm core tropical storms form, and it has been only in recent years that tropical meteorologists have looked to the upper levels for clues to the development and movement of these destructive storms.

The first meteorological satellite, TIROS I, demonstrated the satellite capability of observing the complete tropical storm circulation when it was successfully programmed to photograph a Southern Hemisphere typhoon just east of Australia [1]. During May 1960, TIROS I obtained many successive days of data over the Indian Ocean region, including a six-day surveillance of a tropical storm in the Arabian Sea. These data demonstrated the feasibility of meteorological satellites in the surveillance and tracking of tropical storms and hurricanes [2]. Fig. 1 is a composite of photographs of the Arabian Sea storm during three days of its life cycle. The storm reached hurricane intensity shortly after the time of the photograph on 14 May. The track (fig. 2), as determined by the satellite observations, depicts a rather normal path and allows for the logical dissipation over the rugged terrain of southern Arabia; whereas the positions as determined from conventional data [3], in addition to the consequences of erroneous hurricane warnings, produced for historical purposes a very rare hurricane which dissipated over a tropical ocean far removed from a cold air source.

Another large-scale synoptic feature, which will be of major benefit in producing an analysis for the lower troposphere, is the convergence line or

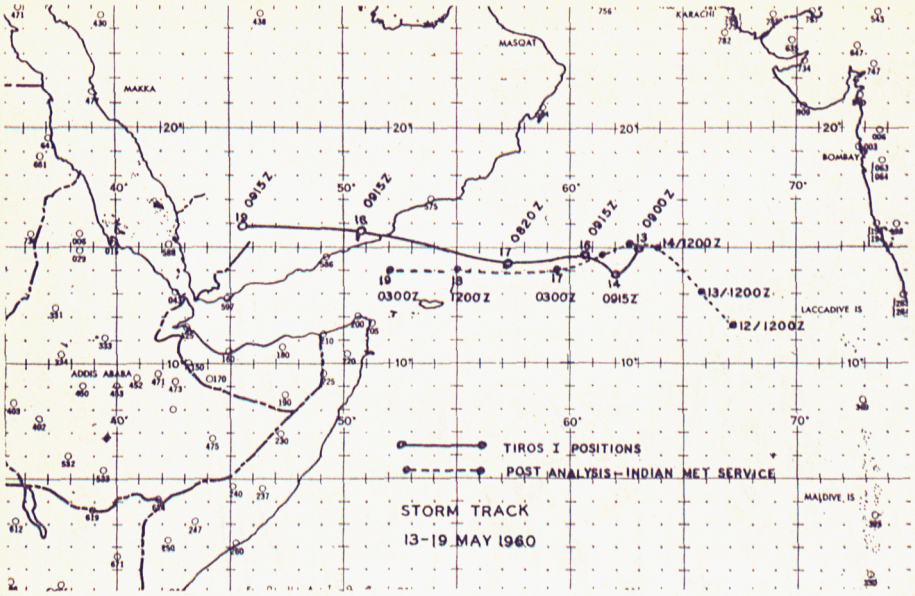


Fig. 2. A comparison plot of the storm track as determined by satellite and conventional data.

zone. Such a feature was evident in the photographic data over the Arabian Sea region during the period of the above-referenced storm. An extensive convergence zone existed on the south side of the trough in which the storm was embedded. A partial view of this convergence zone on 14 May is shown in fig. 3. This extensive cloud system, oriented east-west, was produced by the confluence of the westerly current from northern Somaliland and the south-westerly flow from the equatorial region just south and east of Somaliland. The positioning of the storm and the convergence zone from satellite data, together with the available sparse conventional data, permits a confident analysis of the low level circulation (fig. 4).

Most tropical storms generate from vortices in existing troughs or from vortices which have a history of formation in an existing trough and subsequent movement into an easterly current. The role of the classical unstable easterly wave in the production of tropical weather and vortices has been much overplayed. The prolific and blind use of the easterly wave to explain any and all tropical weather is a greater detriment to an understanding of tropical meteorology than was the frontal regime of some 20 years ago. An extensive statistical program was maintained in the Pacific pertaining to the easterly wave and its relation to forming vortices [4]. Even in a postana-

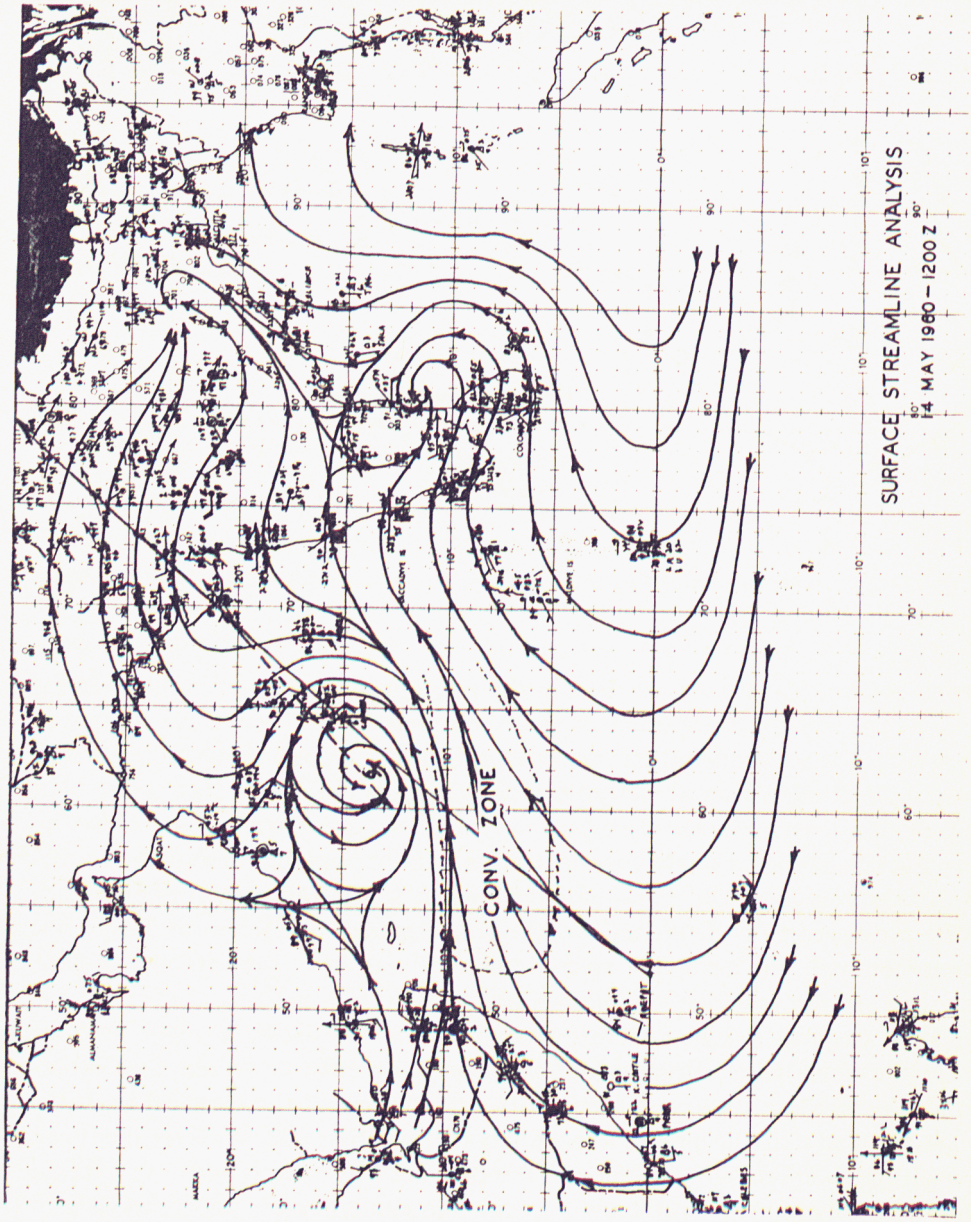
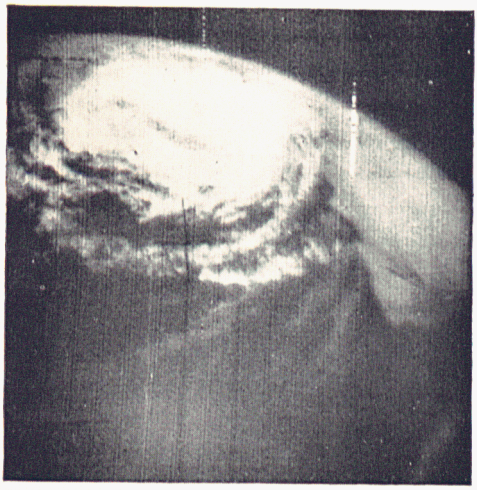


Fig. 4. Surface streamline analysis of the Indian Ocean region for 14 May 1961.



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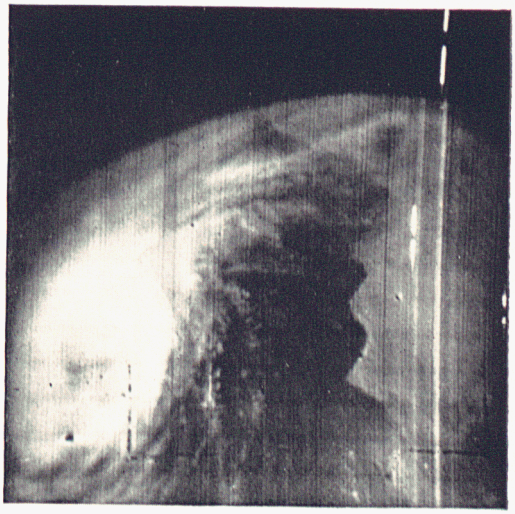

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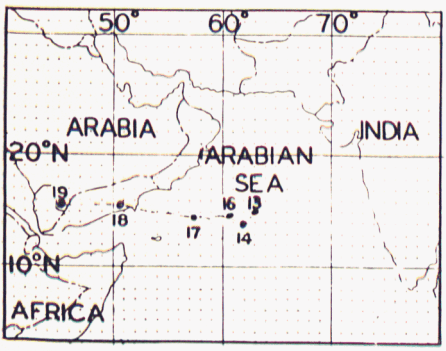
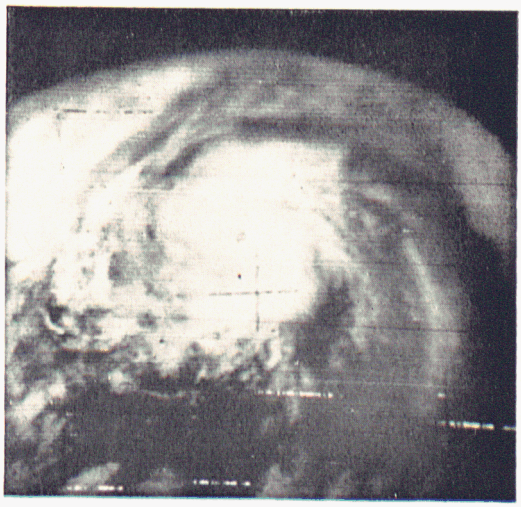


Storm track 13-19 May 1960.



14 May 0915.

Satellite surveillance and tracking of a hurricane.

Fig. 1. A composite of photographs of an Arabian Sea storm during three days of its life cycle. The south coast of the Arabian Peninsula is visible in each photograph.

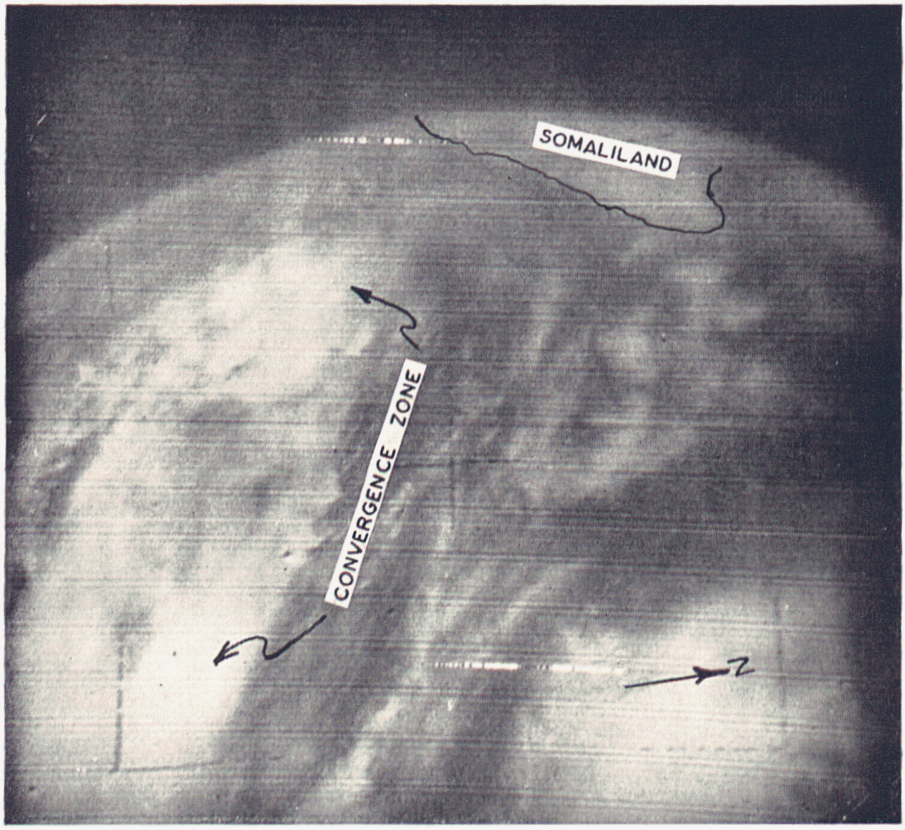


Fig. 3. Convergence zone in the south Arabian Sea.

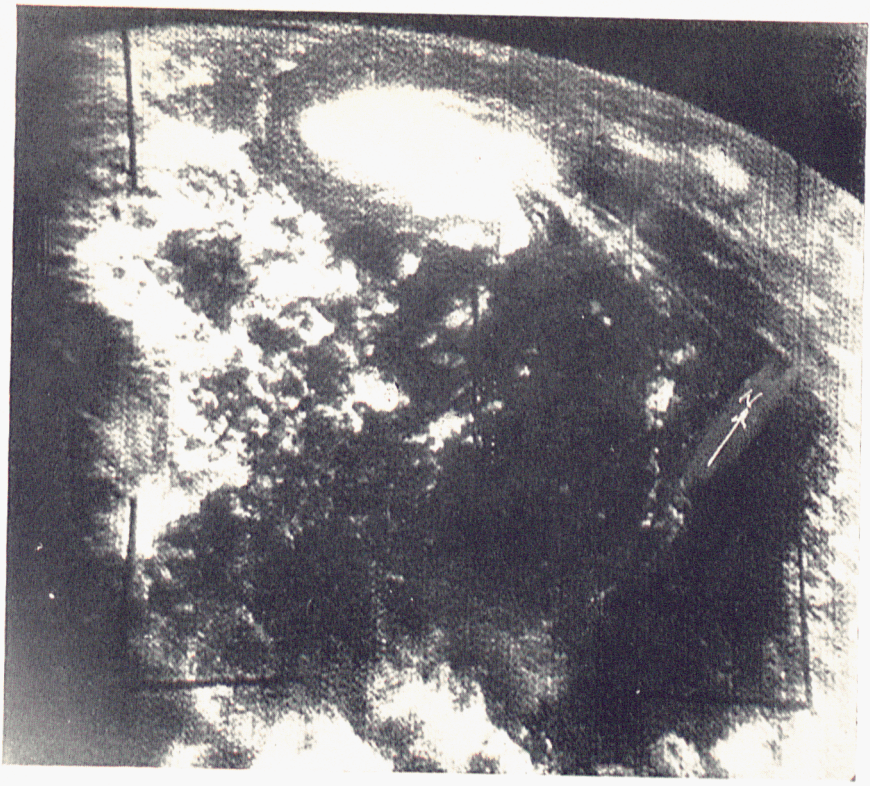


Fig. 6. Hurricane Madeleine at 14° N 111° W from TIROS III orbit 120 on 20 July 1961.

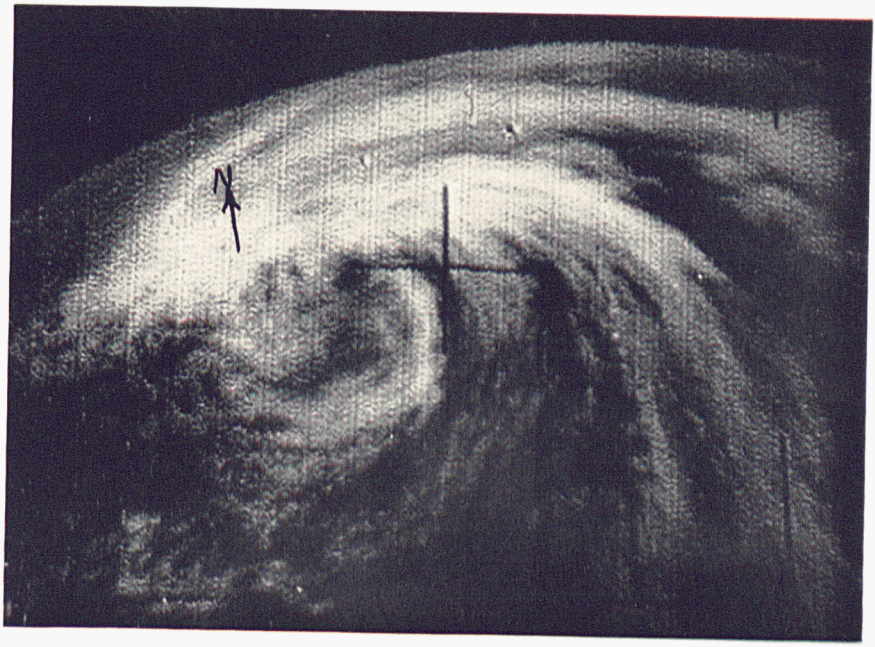


Fig. 7. Tropical storm Liza at 25° N 121° W from TIROS III orbit 105 on 19 July 1961.

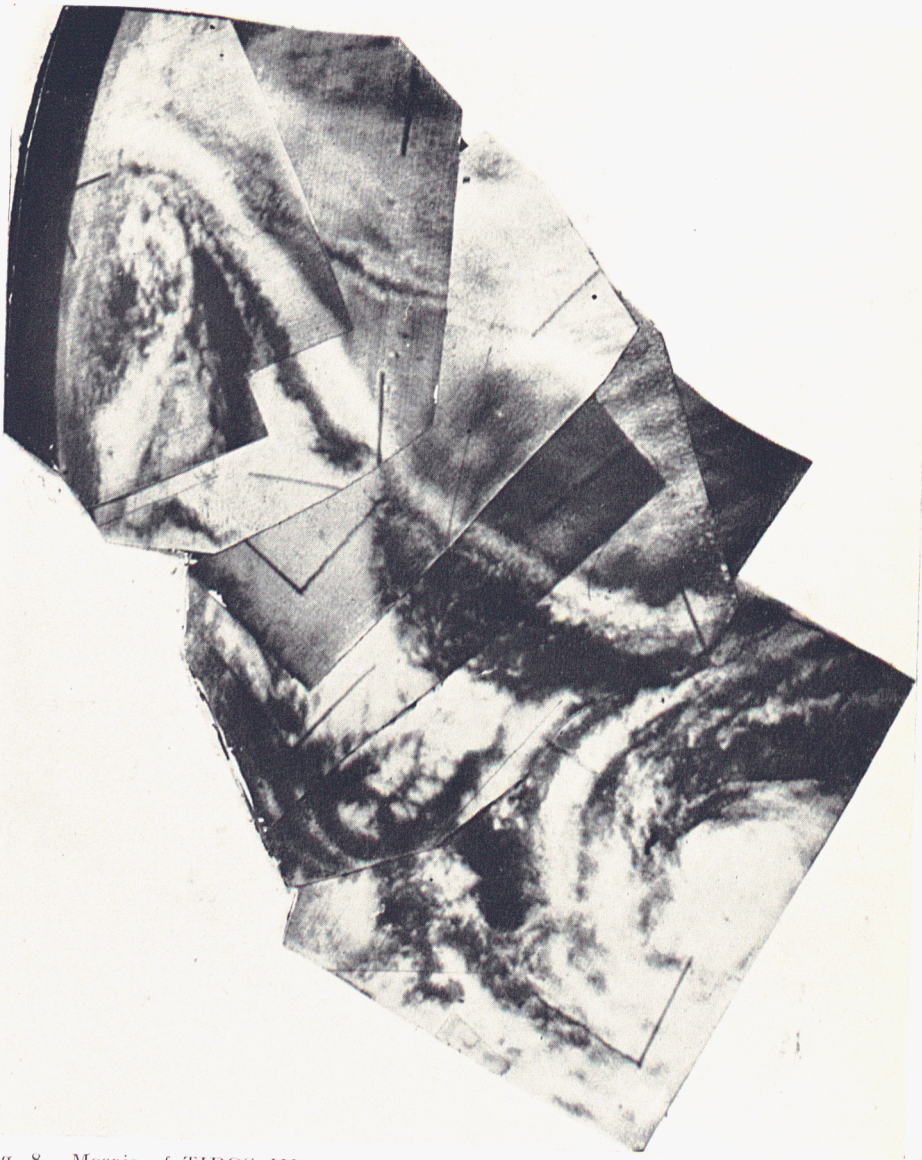


Fig. 8. Mosaic of TIROS III orbit on 23 July 1961 showing Hurricane Madeleine and tropical depression Liza.

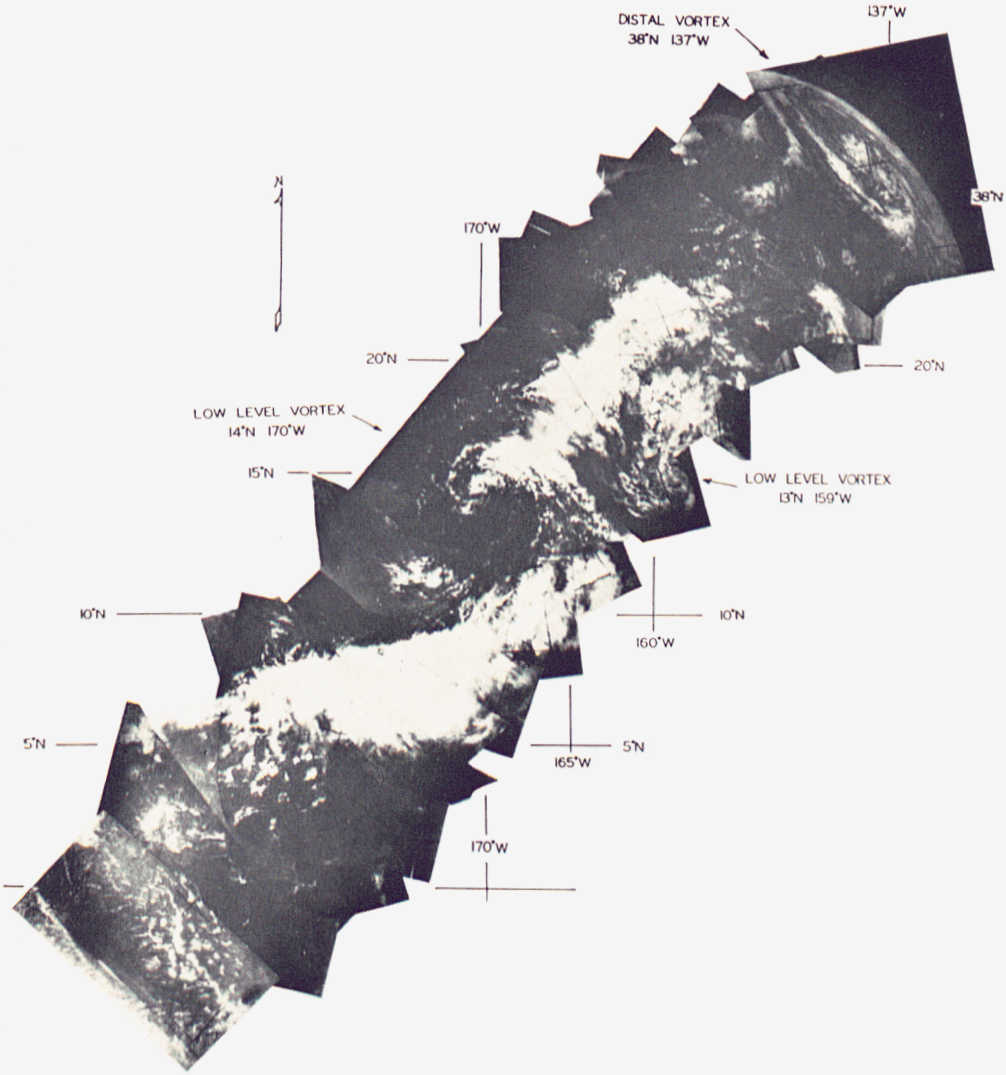


Fig. 10. A mosaic of TIROS III orbit 525 on 18 August 1961.

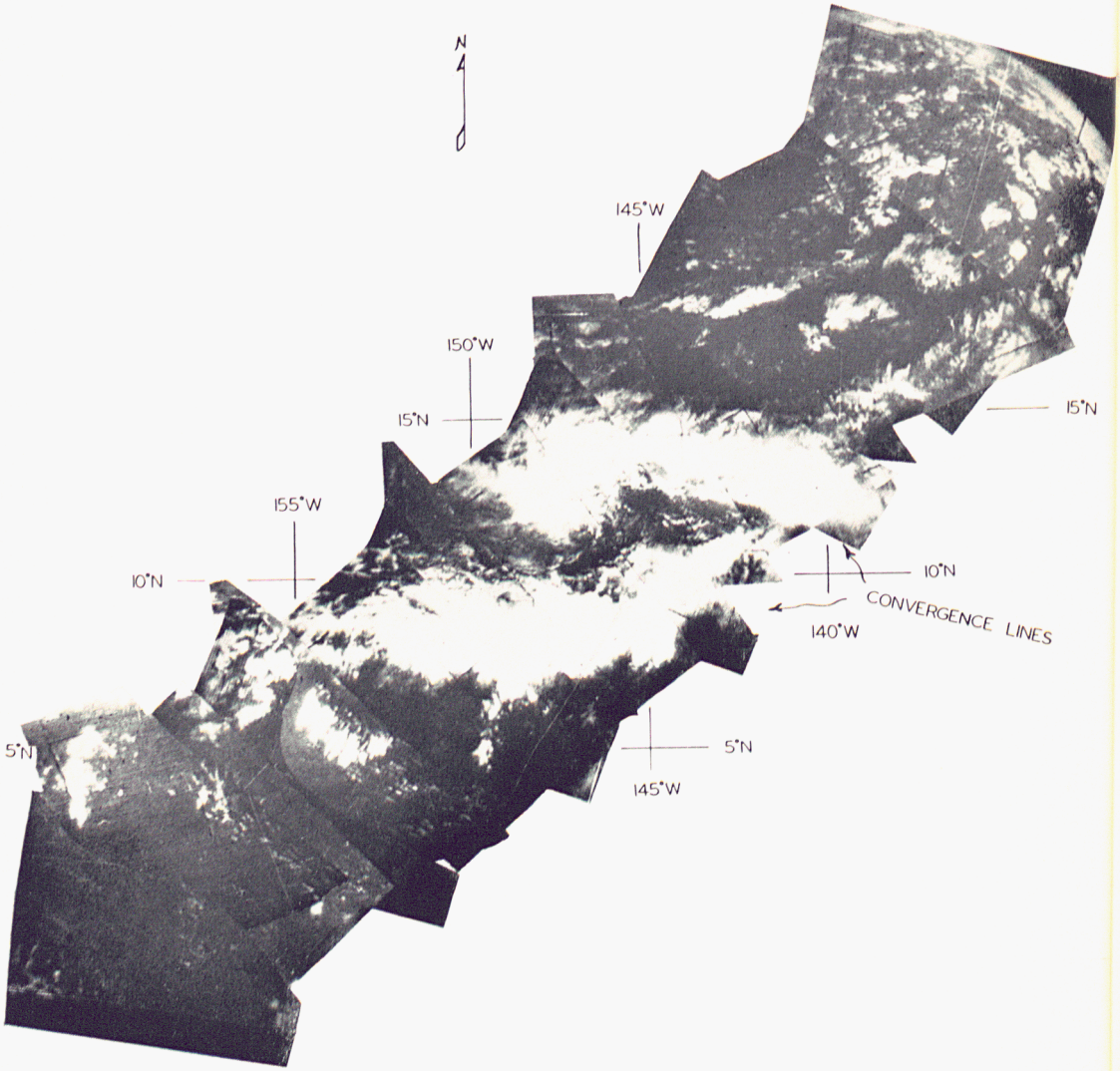


Fig. 11. A mosaic of TIROS III orbit 524 on 18 August 1961.

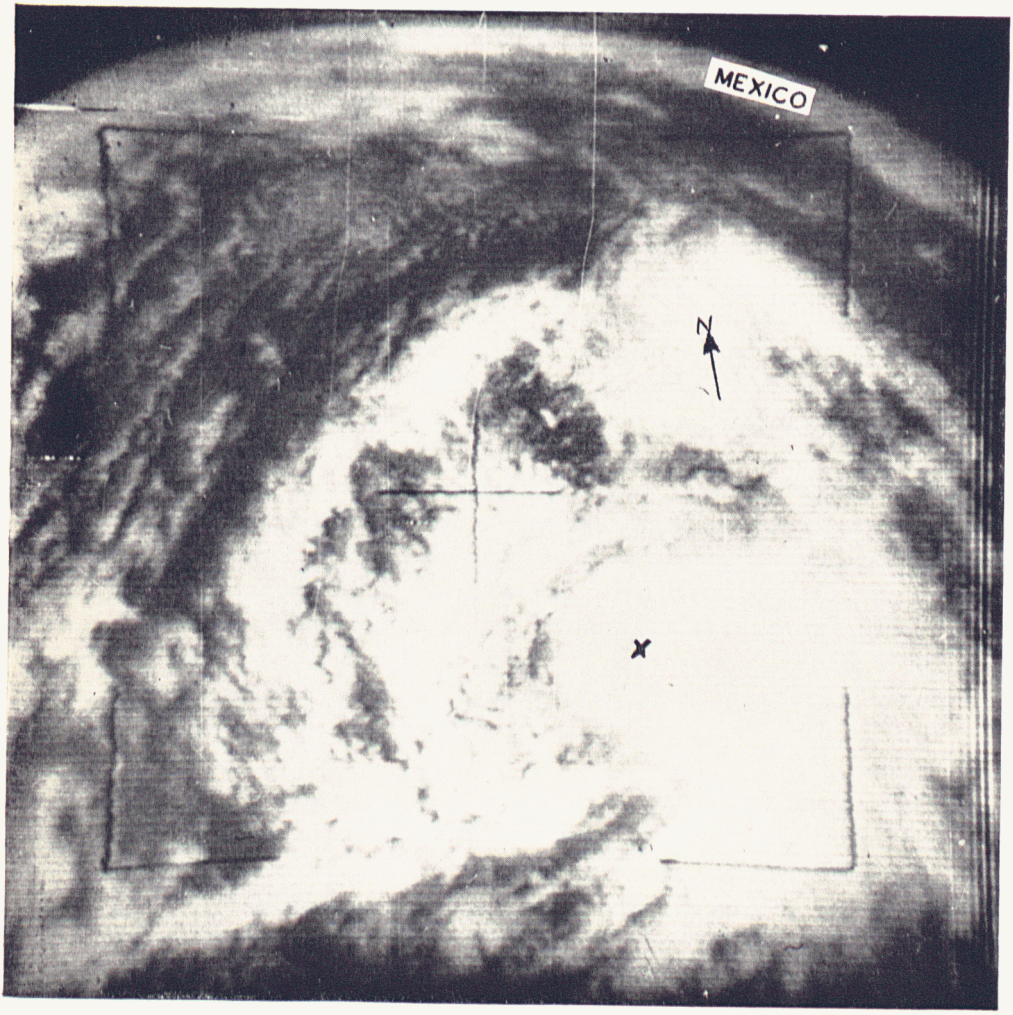


Fig. 12. A tropical storm at 15° N 116° W from TIROS III orbit 523 at 2230 GMT, 17 August 1961. Center is estimated at X.

lysis, no vortex could logically be extrapolated back to an easterly wave beginning. The program was terminated in 1959 for lack of results.

A synoptic-climatological treatment of low-level vortices should, therefore, initially concentrate on the semipermanent troughs in which the vortices form. The general location and orientation of the troughs for the Northern Hemisphere summer season are shown in fig. 5. These troughs are mainly monsoonal, and their orientation is determined, in the mean, by the location of the major land heat sources.

Neither the scope of this paper nor the available meteorological satellite data permit a discussion of all the areas of major low-level troughs. Sufficient data were obtained from TIROS III, during July and August 1961, for some preliminary work on the Eastern Pacific area. This tropical area is of particular interest from a satellite data point of view since it is a region almost void of conventional data, and of considerable tropical storm activity. Observations from the few ships traversing the area indicate the region east of 120° W between 10° N and 20° N to be an area of numerous vortices, many of which are of hurricane intensity. The reports from the few scientific parties which have visited Clipperton Island (10° N, 109° W) during the summer season indicate that an average of greater than one vortex per week passes to the north of the island on a northwesterly course, many of which are deduced to be of hurricane intensity [5]. It is reasonable to assume, from the above and other considerations to be discussed later, that this region is second only to the Western Pacific, on a global scale, in the number of severe tropical storms and hurricanes; however, it is not even included in the climatological records of tropical cyclone frequencies [6, 7], due to lack of definitive data and storm path information.

From 12 July through 11 September 1961, seven tropical storms were detected and named by the U.S. Weather Bureau in the Eastern Pacific, east of 120° W between 10 °N and 25° N. The majority of these were initially detected through evidence of surface data from ships and the west coast of Central America. The data were not of sufficient density to determine exact positioning, intensity, or track. Partial photographic data coverage was obtained by TIROS III over this area during 20 days of the 60-day period. Data from these occasional orbits furnish considerable information on the life history of storms in this region.

A view of tropical storm Madeleine at 1800 GMT, 20 July, at 14° N, 111° W, is shown in fig. 6. The storm is deduced to be of hurricane intensity due to the large cirrus shield and, in particular, to the surrounding clear zone. Such a clear zone has been noted in most satellite views of tropical storms of hurricane intensity. It is an indication of extreme subsidence being established

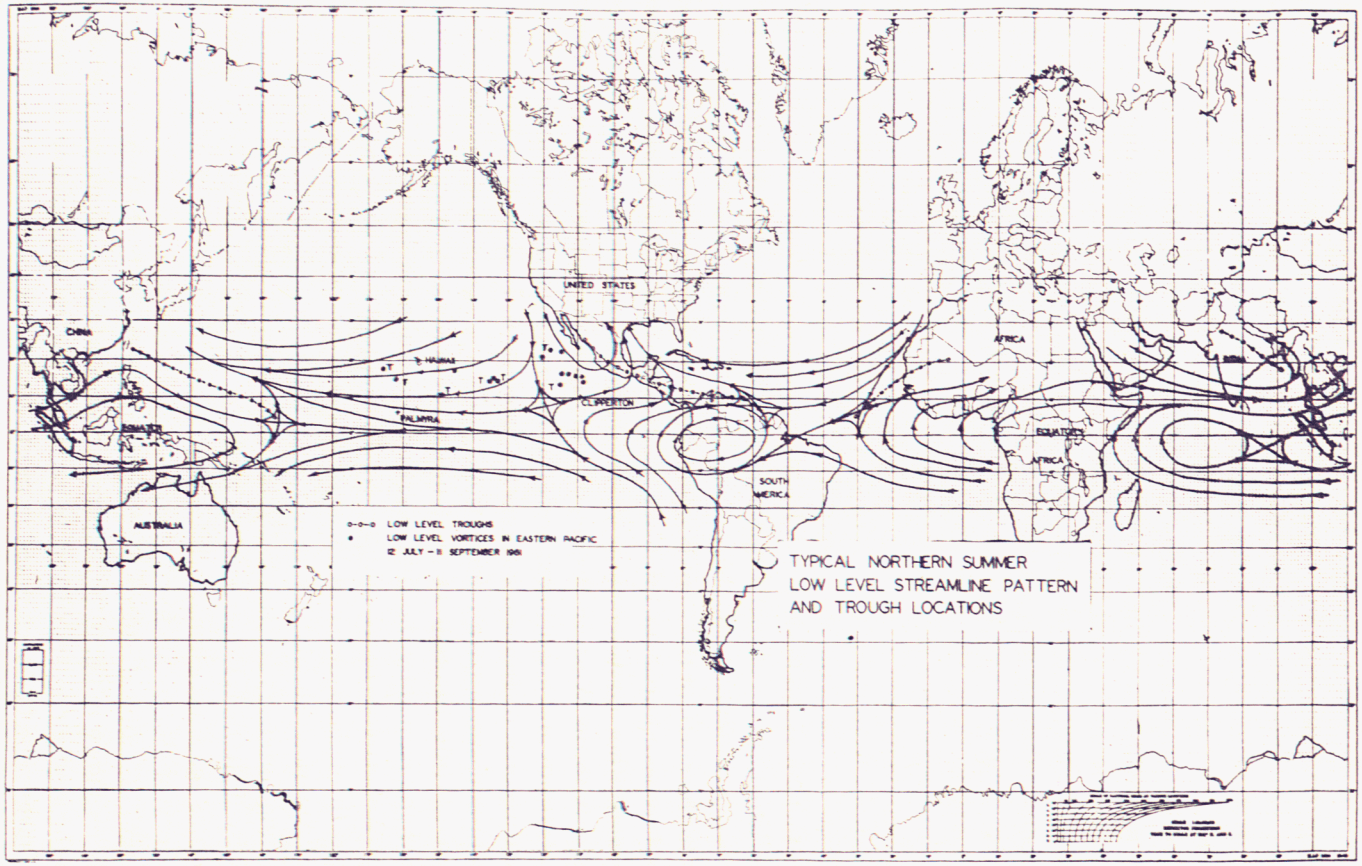


Fig. 5. An idealized northern summer low-level circulation regime with monsoonal trough locations. Vortices of Central Pacific viewed by TIROS are denoted by *T*.

by the storm and must certainly be included in future models of hurricane circulation.

Hurricane Liza was detected, from conventional data, and named on 14 July when located at 14°N 97°W. The subsequent track was WNW; and from sparse conventional data, she was listed as being of hurricane force until 1800 GMT on 19 July, at which time the position was estimated as 21° N, 121° W.TIROS III viewed Liza at 1830 GMT on 19 July at 25° N, 121° W, or about 300 miles from the estimated position. It is evident from the TIROS photograph (fig. 7) that Liza is already a very weak storm and in an advanced decay stage. The cirrus shield has disappeared as has the eye and wall cloud, although the cloud pattern still indicates the existence of a vortex.

Liza and Madeleine were so positioned at 1800 GMT on 23 July that both storms were viewed on the same TIROS III orbit. A mosaic of this orbit is shown in fig. 8. A comparison of figs. 6, 7, and 8 indicates that Madeleine has decreased in intensity in the past three days of westward movement, and that Liza has continued to dissipate. A streamflow analysis, based on the cloud data from the mosaic and scattered ship reports to the north of the systems, is shown in fig. 9. This particular analysis is based heavily on the long, narrow line of cloudiness extending between the northern limits of each storm. North of this line are the typical stratus and stratocumulus clouds associated with southward flowing air over the cold, upswelling water off the western coast of North America. South of this line are cumulus cloud masses and lines associated directly with the two storms and the trough between. This long, narrow cloud line, or "front", is the separation between air masses and, in pictorial mosaic, it furnishes evidence of no breakthrough of northeasterly current between the two storms.

Historically, very few of the severe tropical storms which form just west of Central America recurve sharply into Western Mexico or penetrate as far northwestward as the shipping lanes between Hawaii and the United States mainland. The satellite views of Liza are a graphic confirmation that these northwestward tracking storms move into an unfavorable environment of cold, sea, surface temperatures and dissipate. It is probable that these storms also move into and under an unfavorable upper tropospheric circulation.

What is the history of those storms which track westward and remain at latitudes below 20° N ? These storms move into a region almost void of ship reports and are rarely detected by conventional observations at the widely spaced islands of the Central Pacific, including Hawaii, Palmyra, Johnston, Wake, Kwajelein, and Eniwetok. The most plausible pre-TIROS reasoning was for the storms to dissipate before reaching the longitude of the first

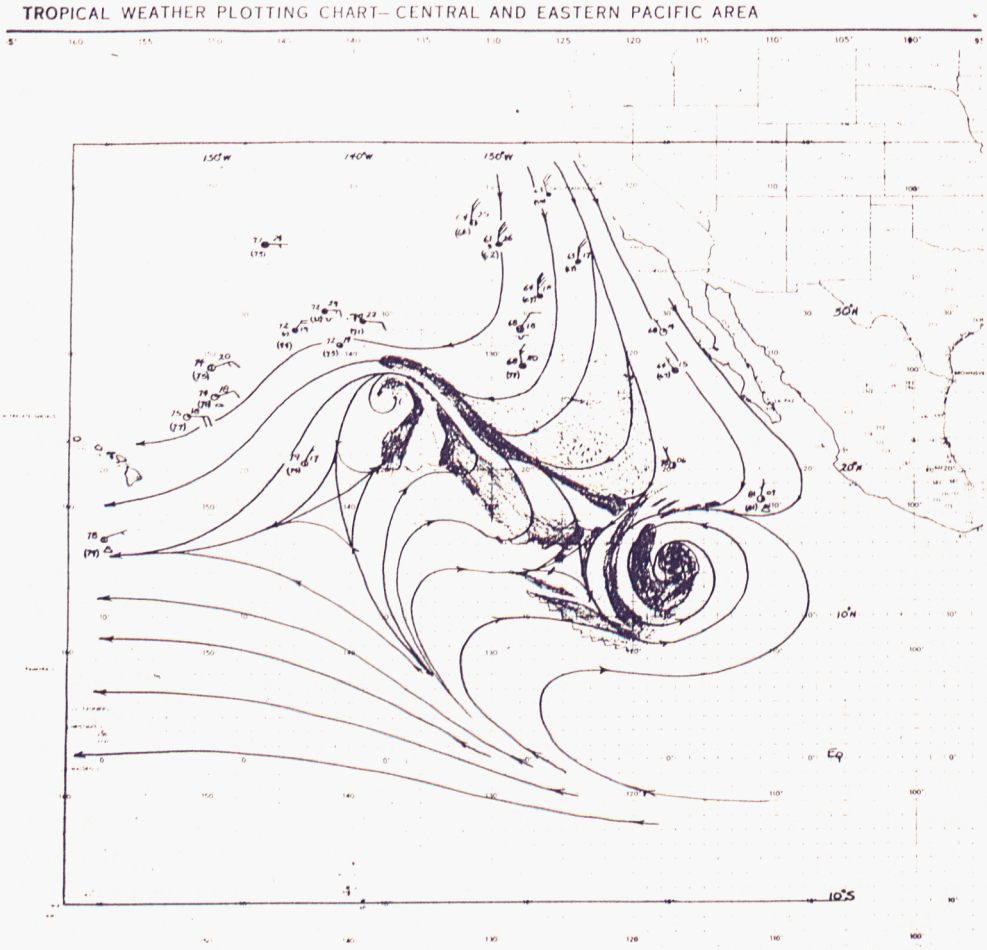


Fig. 9. A surface streamflow analysis based on the mosaic of fig. 8.

island chain at 155° W, some 3000 miles from the formation area, due to unfavorable upper tropospheric circulations. Data from TIROS III have shown that frequently storms do, in fact, move westward between 10° N and 20° N without being detected by the island stations and, although moving through a region having west winds above 5 km, they are able to maintain a vortex circulation during at least 4000 miles of travel.

TIROS III obtained partial coverage of this tropical, central North Pacific region from 15 August through 3 September 1961. During this period, at least six tropical vortices were detected west of 130° W between 10° N and 20° N (fig. 5). A mosaic of orbit 525 on 18 August (fig. 10) shows two of these

vortices, on their track westward, to the south of the Hawaiian Islands. The vortex at 14° N, 170° W, 150 miles south of Johnston Island, has a very tight circulation around what appears to be a well defined wall cloud with a clear eye. The storm is unlikely to be deep or intense, since there is strong shear with west winds over the vortex above 5 km. The alignment of the cloud streets would indicate that the westerlies associated with the vortex extend to 10° N or 250 miles south of the center. These cannot be confirmed as surface westerlies. The only surface observation to the south is a ship report within the convergence line at 7° N, 176° W. The ship observed easterly winds and moderate to heavy rain showers. The trailing vortex at 13° N, 159° W has a distinctive and recognizable circulation but is too near the horizon for detailed consideration.

It is of interest to note from fig. 10 that the traveling vortices appear to establish double and discontinuous convergence lines, one to the north and the other to the south of the vortex latitude. The mosaic of orbit 524, some 24° east of orbit 525, also shows this double convergence line configuration (fig. 11). If we assume that the split is due to a traveling vortex, we could *speculate* the vortex position at approximately 13° N, 147° W.

A severe tropical storm was also observed at 15° N, 116° W from data of orbit 523. This storm was not detected and named by the National Meteorological Center even though it appears from the photograph to be near, if not equal to hurricane intensity (fig. 12).

Such a train of vortices, spaced about 700 miles apart, would seem to require, or by their combined effect establish a pressure trough line from Central America westward through the central North Pacific at approximately 15° N. This proposed circulation regime is much more complicated than the simple easterly regime as typified in fig. 5, which is based on the sparse available conventional data [8]. The true regime will be found only through a synoptic climatological approach, utilizing complete daily satellite coverage in conjunction with conventional data.

The southern portions of figs. 10 and 11 depict very dramatically the widely scattered cloudiness in the equatorial zone. This coincides nicely with the available climatology of the area [8]. This equatorial zone is characterized by a cold water current, diverging low-level winds, little cloudiness, and an arid climate.

The next logical sequence is to determine what happens to these vortices as they move into the Western Pacific. Do they regenerate into typhoons? The climatology of tropical storms and typhoons of the Western Pacific, which is of long record and considered reliable [7], indicates such regeneration to be very rare. The majority of typhoons of the Western Pacific form

at latitudes below 15° N in the permanent low-level trough which has a mean position near 10° N during the summer season (fig. 5) [9, 10]. The vortices, moving west at latitudes of 15° N greater, come under the adverse influence of the upper tropospheric trough whose southwestern extent is near 15° N, 152° E in the July mean (fig. 13). Having been progressively weakened by their long travel under upper tropospheric westerlies (fig. 13), the vortices probably finally dissipate as they move under the convergent zone of the upper trough. The data from TIROS III were not of sufficient coverage or continuity to verify this.

3. The upper troposphere

The upper troposphere is here identified as the layer between approximately 20000 ft and the tropopause. This discussion will be limited to some highlights of preliminary studies of the upper tropospheric circulation of the Northern Hemisphere summer. The most fascinating feature of this circulation is the dominating influence of a persistent cold trough which is oriented more or less east-west and extends at times across more than 200° of longitude. The synoptic climatology of this upper tropospheric stratum, during the summer season, merits high priority for reasons which will be put forth during the following discussions.

3.1. THE CIRCULATION PATTERNS ARE NOT PROPERLY DEPICTED IN MOST UPPER WIND STATISTICS AND ANALYSIS CHARTS OF THE NORTHERN HEMISPHERE [11, 12]

A discussion of the 200 mb level of the Central Pacific region will illustrate this point. The mean 200 mb streamline chart of the mid and western Pacific Ocean region for July is shown in fig. 13. This analysis is based on the actual mean resultant winds and a synoptic-climatological knowledge of the region. Note that the dominant feature of this Pacific region, in the Northern Hemisphere, is the sharp trough extending from 18° N, 150° E to the eastern edge of the analysis at 32° N, 155° W. This trough is embedded between two mean east-west ridge lines, the southern one near 8° N and the northern one extending from 30° N, 115° E to 37° N, 155° W. Fig. 14 is a mean 200 mb streamline chart for the same month and region but with the streamline analysis dictated by the isogon field as published in [12]. The mean wind direction at the five stations between 25° N and 30° N is plotted to emphasize the extreme departure of the analysis from the true measured wind. The number of years of data included in the mean, as shown above the stations, varies from six to nine years.

Fig. 13. Analysis of mean resultant winds for July at 200 mb over the Central and Western Pacific. Data obtained from [9].

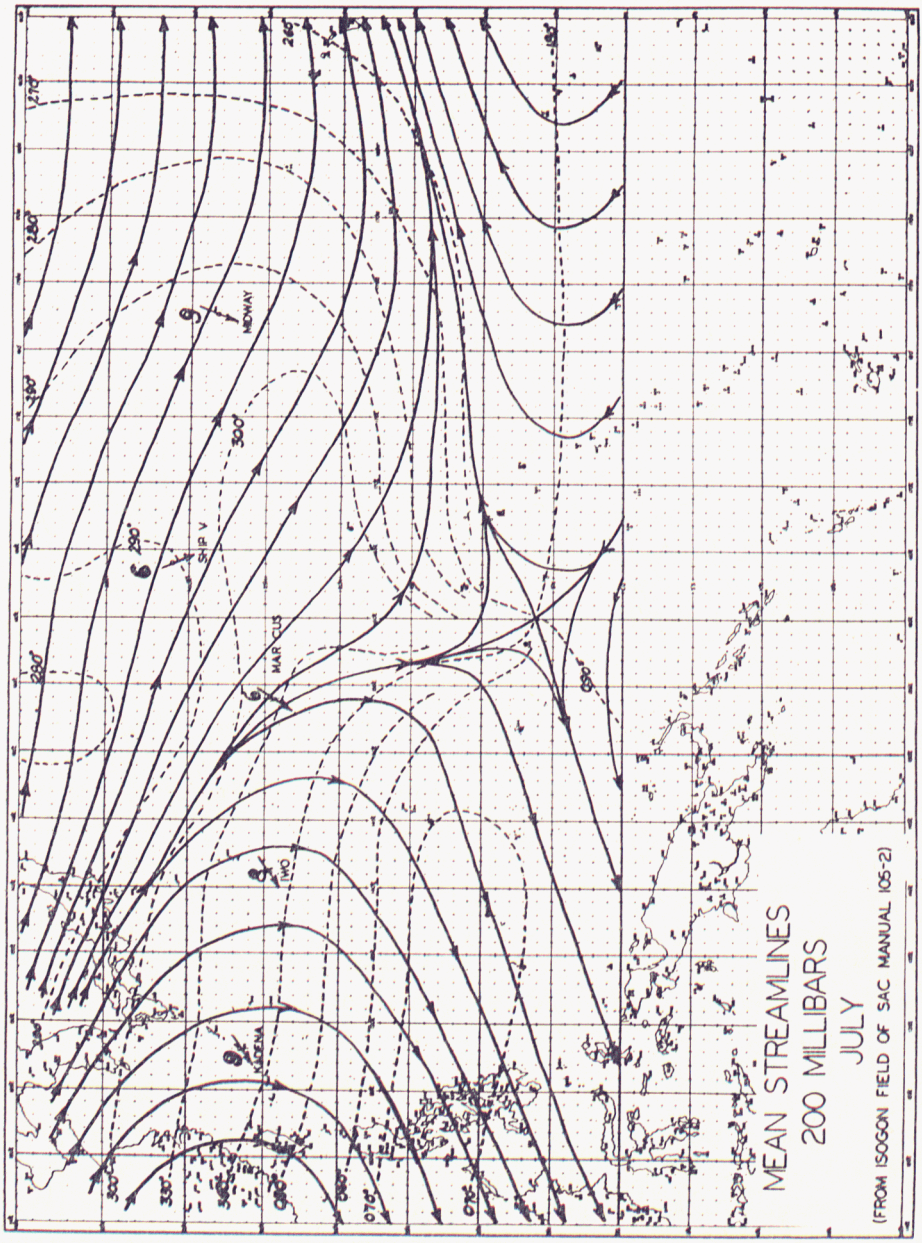


Fig. 14. Mean streamline analysis for July at 200 mb over the Central and Western North Pacific. Isogon data obtained from [12]. Mean resultant wind direction and number of years of data are plotted for the five stations near 25° N.

It is obvious that the circulation patterns bear little resemblance to each other. It would be unkind to speculate on the various reasons for the inaccuracies in the referenced published charts. Mean charts, based on true measured winds, have been available for this Pacific region since 1955 [13, 14, 15].

3.2. THE UPPER TROUGH IS NOT CONFINED TO THE PACIFIC REGION BUT IS ALSO THE DOMINANT UPPER TROPOSPHERIC FEATURE OF THE SUMMER SEASON OVER THE GULF OF MEXICO, CARIBBEAN SEA, AND ATLANTIC OCEAN REGIONS

The majority of the research effort concerning the tropical upper troposphere has been concentrated in the Pacific. This has been due to the operational requirement for detailed wind forecasts in support of nuclear weapons testing. However, some recent investigations have been conducted in the Atlantic region.

Dean, a pioneer in the Pacific program, has produced mean analyses for the Caribbean and Western Atlantic. His analysis of the mean wind field for the 300 mb level during August 1958 is shown in fig. 15. Note that the 17 days of reconnaissance data, east of the conventional upper air network, depict clearly the sharp trough near 25° N; and, in fact, the existence of the trough might be questioned by some without these additional data.

Daily analyses of the 40000 ft surface were produced during the latter part of August 1959 in support of cloud interpretation studies utilizing high altitude photography, from an Atlas missile, over the Atlantic Missile Range [16]. An analysis from this series, for 24 August 1959, extended to a global scale, is shown in fig. 16. The upper trough, depicted by the dotted line, extends westward from an intense cell over the Western Mediterranean Sea, across the Atlantic, Southern United States, Eastern Pacific, and terminates south of Wake Island near 180°. From the available wind data, only the cyclonic cells over the Western Mediterranean and Northern Gulf of Mexico can be positioned with accuracy. Subsequent discussions will concern the use of satellite data in the positioning of cells within the trough over regions of sparse conventional data.

3.3. THE CORRECT CLIMATOLOGY OF THE UPPER TROPOSPHERE SHOULD LEAD TO IMPROVEMENTS IN GENERAL CIRCULATION THEORIES AND MODELS

We have discussed in 3.1. the differences between the circulation pattern derived from published hemispheric mean wind statistics charts and the true pattern as derived from a direct analysis of the mean resultant winds. This comparison was made for the Pacific region where the upper

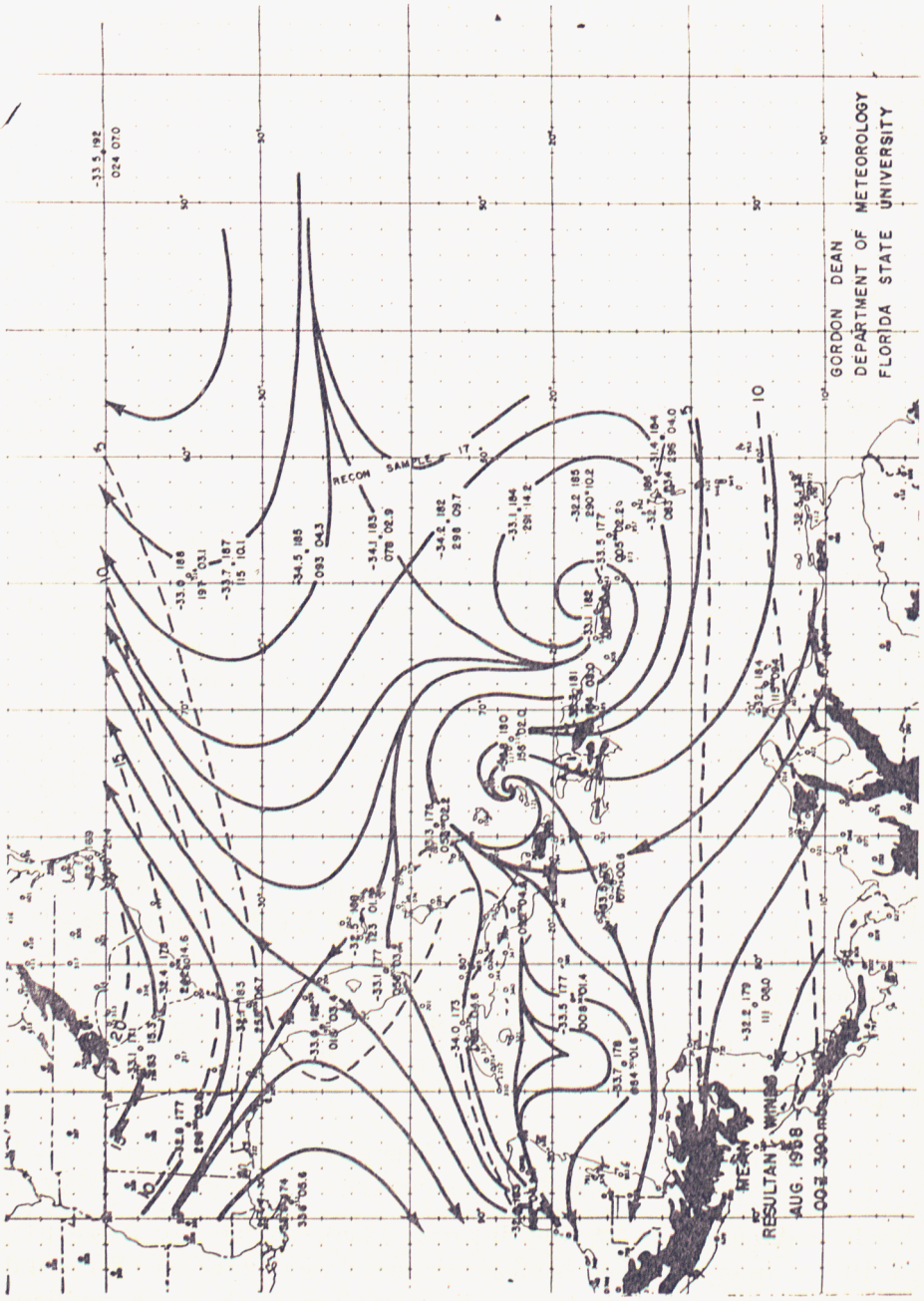


Fig. 15. Mean resultant wind analysis at 300 mb for August 1958 (courtesy of Gordon Dean, Florida State University).

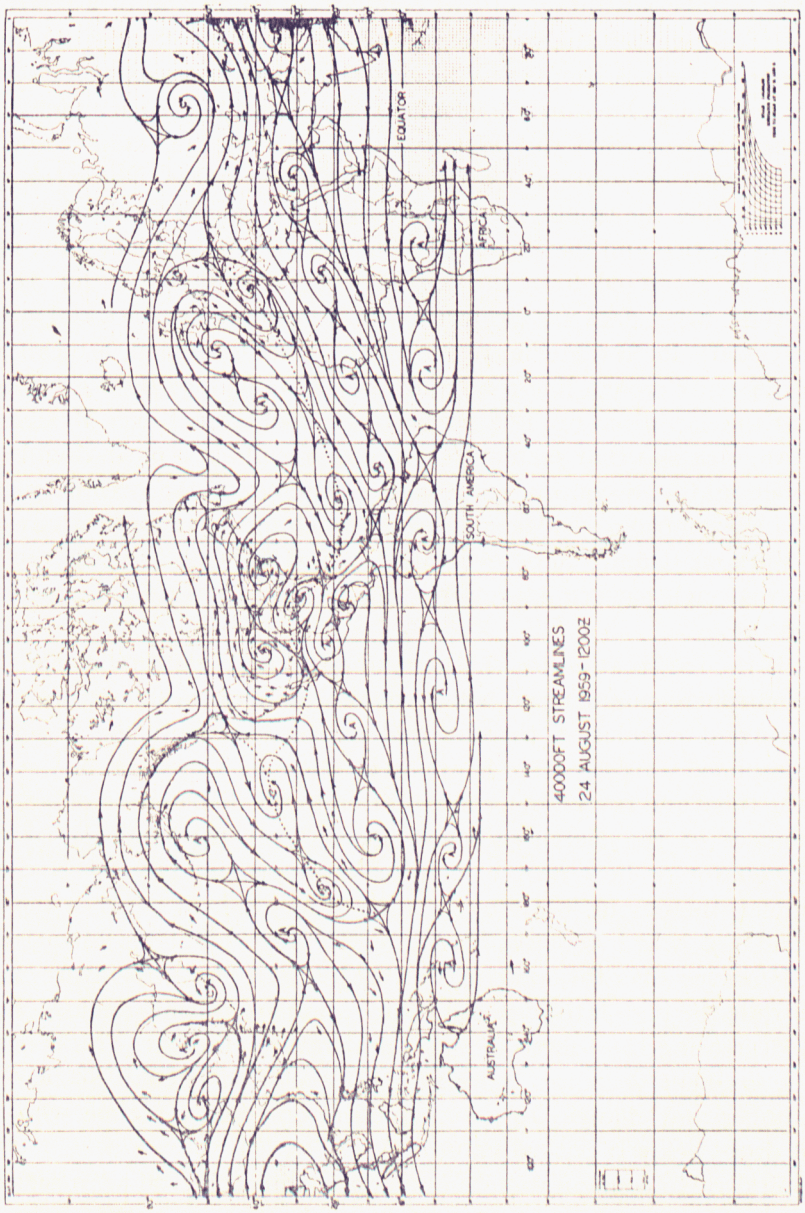


Fig. 16. Wind analysis for the 40 000-ft level at 1200 GMT, 24 August 1959. The upper trough is denoted by the dotted line

wind network, although sparse, is favorably distributed and of sufficient record length for climatological confidence in a very persistent pattern. It is possible to take advantage of this comparison study and of a restricted sample of daily global analyses to postulate a configuration of the mean hemispheric pattern. A simple way to view the pattern is to extract and plot the ridge and trough lines on a hemispheric scale. Fig. 17 is such a plot derived from fig. 16. Note that the ridge line assumes a spiral character and the trough is formed or positioned between the double ridges. The weak data link as to whether the trough is continuous and the ridge an unbroken spiral occurs over Mexico and the Eastern Pacific (see fig. 16). A plot of the mean ridge lines as extracted from the data in [11, 12] is shown in fig. 18. By utilizing these mean data and projecting the known inaccuracies and adjustments necessary for the Pacific region to the Atlantic region, a mean July 200-mb ridge and trough line configuration is obtained, as shown in fig. 19. Note that the data from fig. 18 have been assumed correct over Mexico and Central America and that such an assumption results in a mean double-leaf spiral ridge and a discontinuous trough restricted to the oceanic regions instead of the continuous ridge spiral and trough of the synoptic analysis in fig. 17. Without definite data over Mexico and Central America the discontinuous trough pattern is preferred due to indirect considerations to be discussed below.

What is the explanation for this general circulation pattern of the Northern Hemisphere summer and will it require changes to, or supply answers for the current circulation theories and models? A simplified – perhaps overly simplified – explanation is apparent from an inspection of the relation of the ridge and trough line configuration to the distribution of land and water masses of the Northern Hemisphere. Over the land masses, the thermal equator or heat source migrates to approximately 25° N during mid-summer, thereby maintaining a temperature gradient between the heat source and sink which requires a wave or Rossby regime for adequate exchange. However, over the ocean masses the low latitude temperature changes little while the high latitudes and polar region are warming considerably, thereby decreasing the source to sink temperature gradient. Theoretically, when the gradient decreases in value the circulation pattern decreases in wave number and changes to a symmetrical or Hadley regime when the gradient drops below a critical value [17].

The spiral ridge configuration is a synoptic-climatological verification of a Rossby regime over the continental areas and a strong tendency toward a symmetrical regime over the oceanic regions. The qualification of "tendency toward" is used because the pattern is not a true symmetrical one and it may

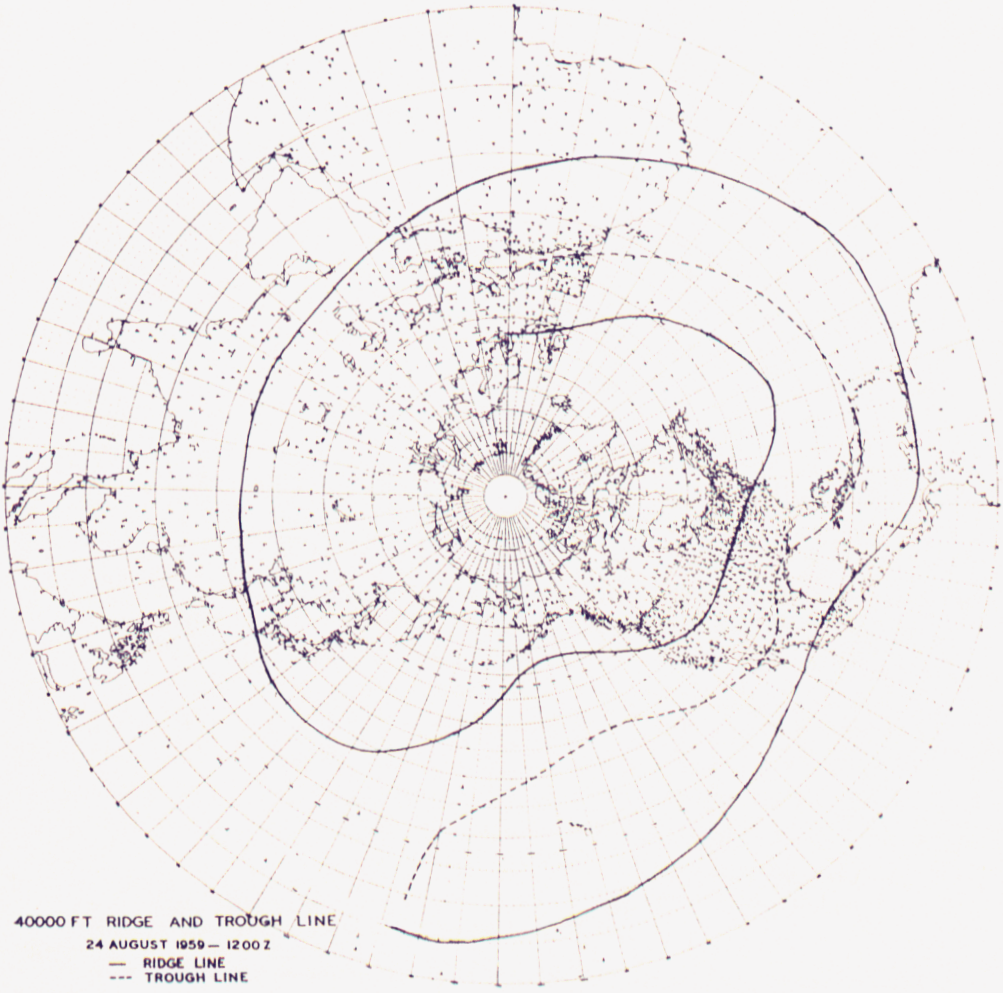


Fig. 17. A hemispheric plot of the ridge and trough lines from fig. 16.

be argued that it is only a Rossby regime of wave number two, with the waves or troughs having extreme tilt back to the west.

A recent theoretical study equated the mean daily latitudional temperatures, net excess of radiation, and zonal winds to the meridional transport of heat by the large eddies of migratory cyclones and anticyclones [18]. A satisfactory balance was obtained except for the months of May, June, July, and August, when the required transport, unexplainably, decreased to zero.

The general circulation studies which have been conducted for the summer

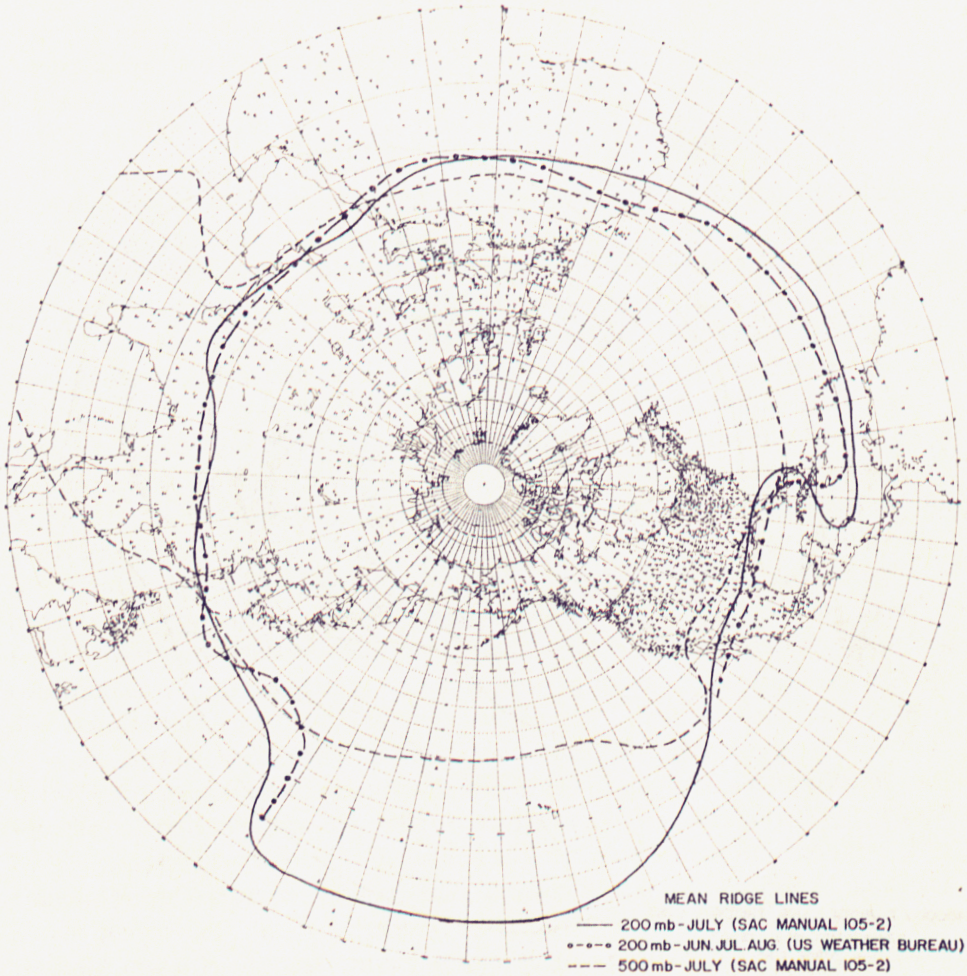


Fig. 18. A hemispheric plot of the ridge lines from [11] and [12].

season should be reviewed, and corrected where necessary, to incorporate the true wind data of the tropical and sub-tropical regions.

3.4. THE EFFECT OF THE UPPER TROPOSPHERIC TROUGH IS ONE OF THE CONTROLLING FACTORS IN THE DEVELOPMENT AND LIFE HISTORY OF HURRICANES AND TYPHOONS

Recent theories and models of hurricane and typhoon development have looked to the upper troposphere for the "triggering" mechanism [19, 20, 21]. The two descriptive models [20, 21] rely on the effect of the upper-level

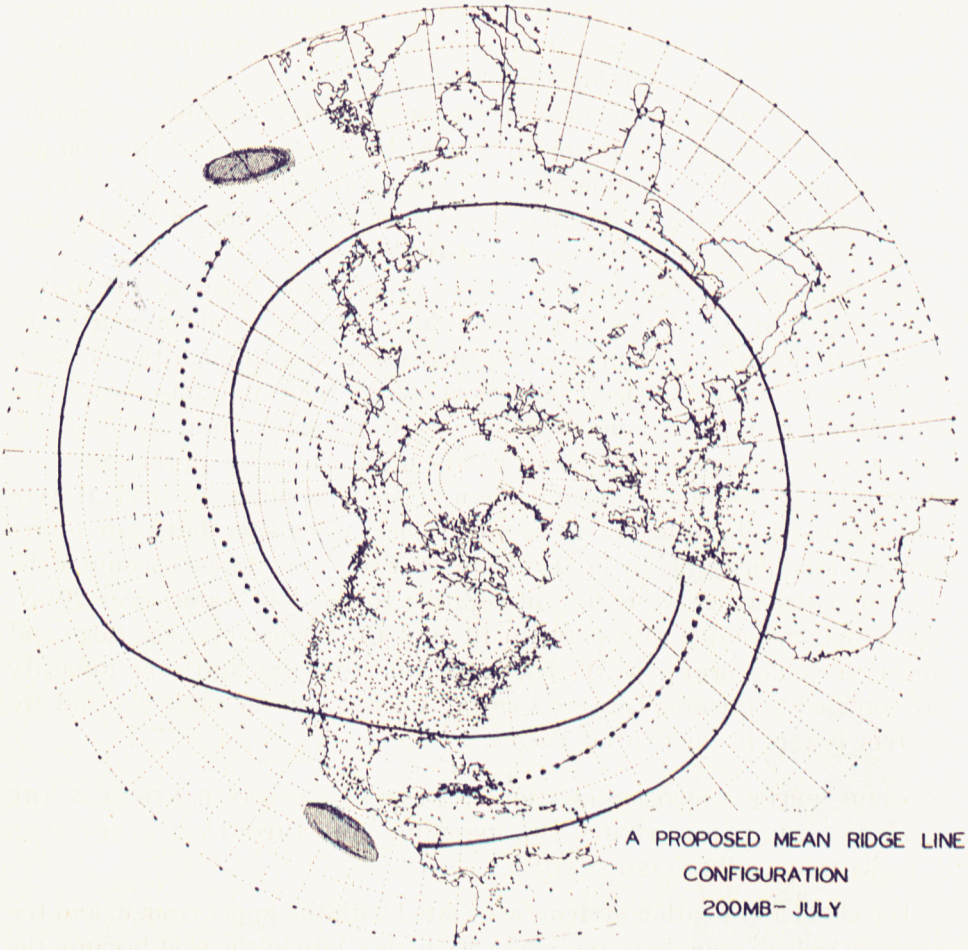


Fig. 19. Proposed mean ridge and trough lines for July at 200 mb. Troughs are denoted by dotted lines.

cyclone in the development process but differ mainly in the relative positioning of the low-level and upper-level vortices.

The effect of the upper troposphere circulation on the life history of Eastern Pacific tropical storms was noted in the preceding discussion of the lower troposphere.

The Eastern Pacific region is again of particular interest when viewed in comparison with the Western Pacific in relation to the mean upper tropospheric circulation as proposed in fig. 19. The data from TIROS III have shown the Eastern Pacific to be a region of frequent hurricane development,

perhaps even approaching the frequency of typhoon development in the Western Pacific. If there is a dominant influence of the upper trough on hurricane or typhoon development, then it would be reasonable for the two areas of greatest frequency of development to have a similar geographical positioning relative to the mean trough. The two areas are shown on fig. 19 by stippling. Their relationship to the upper trough is strikingly similar. Each area is about 10° south and west of the western end of the troughs and is under mean upper troposphere easterlies.

The similarity, in relation to the upper troposphere, ceases as the storms move westward out of the areas of development. The typhoons remain in deep easterlies and are unimpeded in their movement through the Western Pacific into Southeast Asia. They encounter the ridge and upper westerlies only during recurvature and then quite far to the north, near 30° N. However, the hurricanes of the Eastern Pacific must contend with the southernmost ridge of the double ridge pattern. Their difficulties in survival were covered in detail during the lower troposphere discussion, but perhaps are more vividly illustrated by fig. 19. Those that track northwest encounter the ridge and the upper westerlies, in addition to the cold water, near 20° N. Those that move due west between 10° and 15° N encounter the ridge and upper westerlies near 135° W. Therefore, the storms of hurricane intensity are confined to the area between Central America and the ridge line and are extremely rare in the Central Pacific.

3.5. THE UPPER TROPOSPHERIC TROUGH SYSTEMS—AND IN PARTICULAR THE CYCLONIC CELLS WITHIN THE TROUGHS—ARE IMPORTANT CLOUD AND WEATHER-PRODUCING SYSTEMS

The cloud and weather systems associated with the upper trough, and the cyclonic cells therein, have received very little study in the past because the systems are mainly confined to the data sparse oceanic regions. The most comprehensive discussion of these cloud systems and a descriptive cloud model of the cyclonic cell based on weather reconnaissance aircraft data are contained in [22]. These extensive cloud and weather systems most frequently exist without being reflected in the lower troposphere pressure and wind analyses. The upper cell of fig. 16, located over the Northern Gulf of Mexico, was not detectable in the synoptic analyses at 10000 ft and below, yet it produced widespread precipitation, thunderstorms, and squalls over the Gulf [16]. Unfortunately, the unsuspecting analyst often accounts for this type of widespread cloud and precipitation pattern by placing an erroneous and forced "easterly wave" on the low-level charts.

The meteorological satellite data afford, for the first time, the opportunity

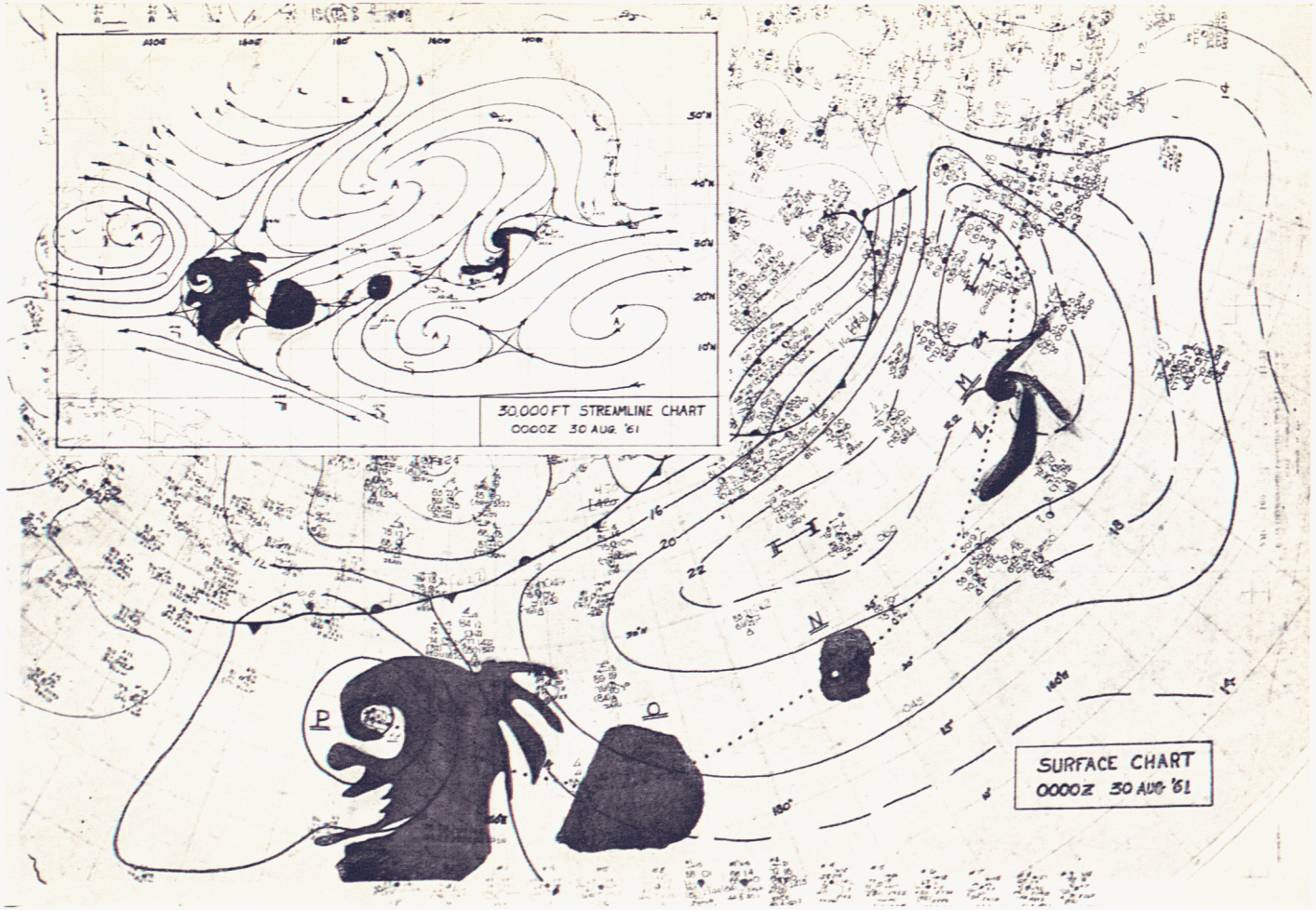


Fig. 20. Surface pressure analysis and 30000-ft streamline analysis for 0000GMT, 30 August 1961. Upper troposphere trough denoted on surface chart by dotted line. Shaded areas were extracted from the transmitted TIROS III nephanalyses.

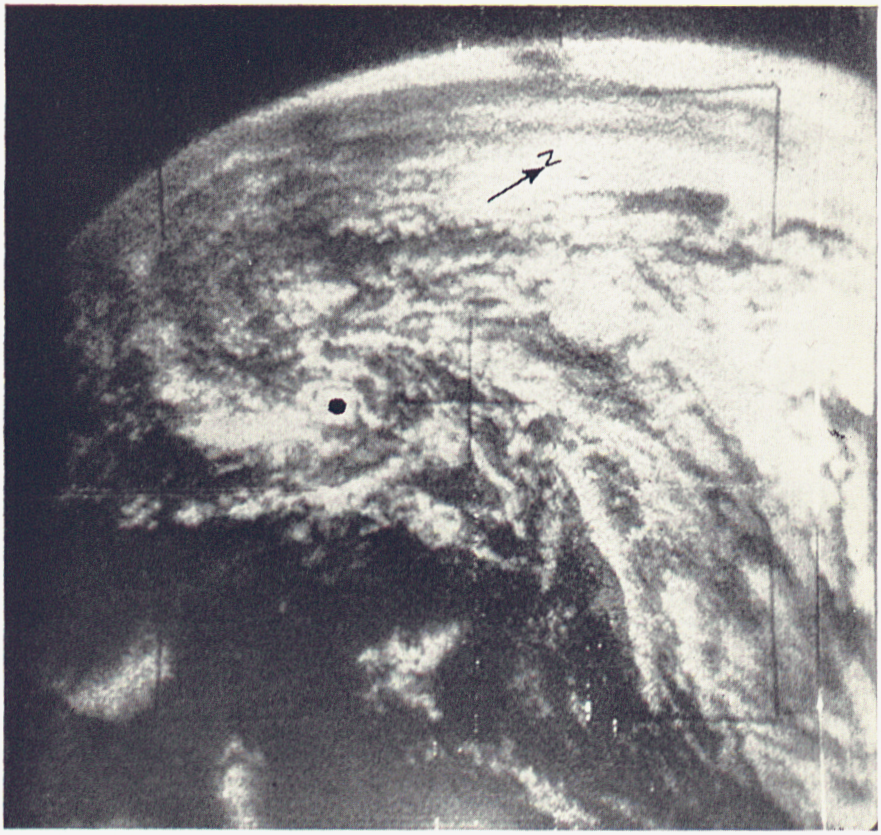


Fig. 21. A view of the cloud system associated with the upper level vortex located at 31° N 147° W from TIROS III orbit 681. System is identified on fig. 20 as *M*.

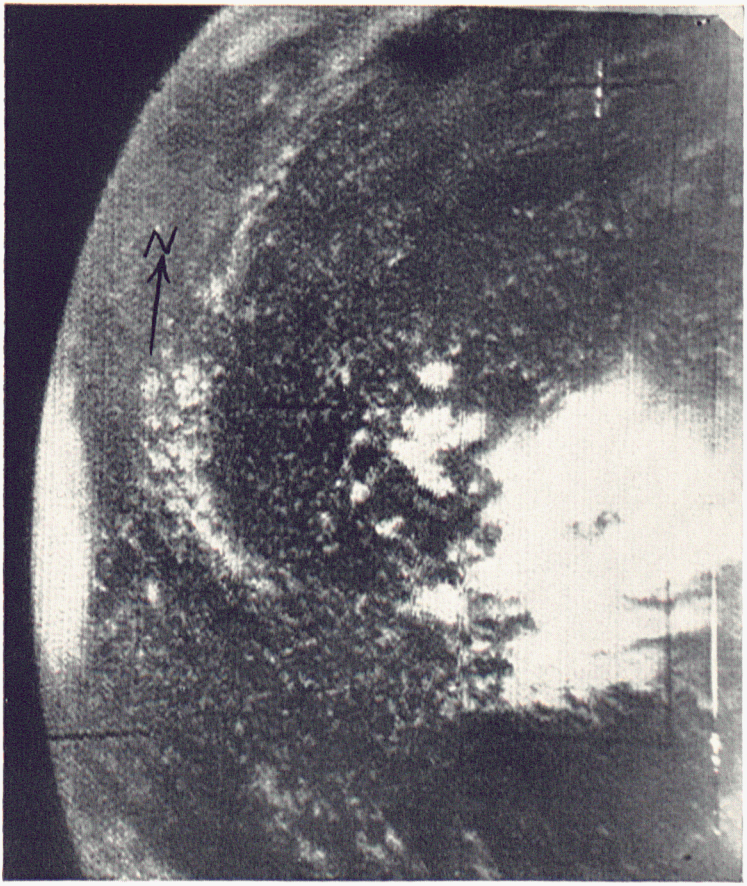


Fig. 22. Satellite view of the cloud mass associated with the upper level vortex located at 22° N 172° W from TIROS III orbit 696. System is identified on fig. 20 as *N*.

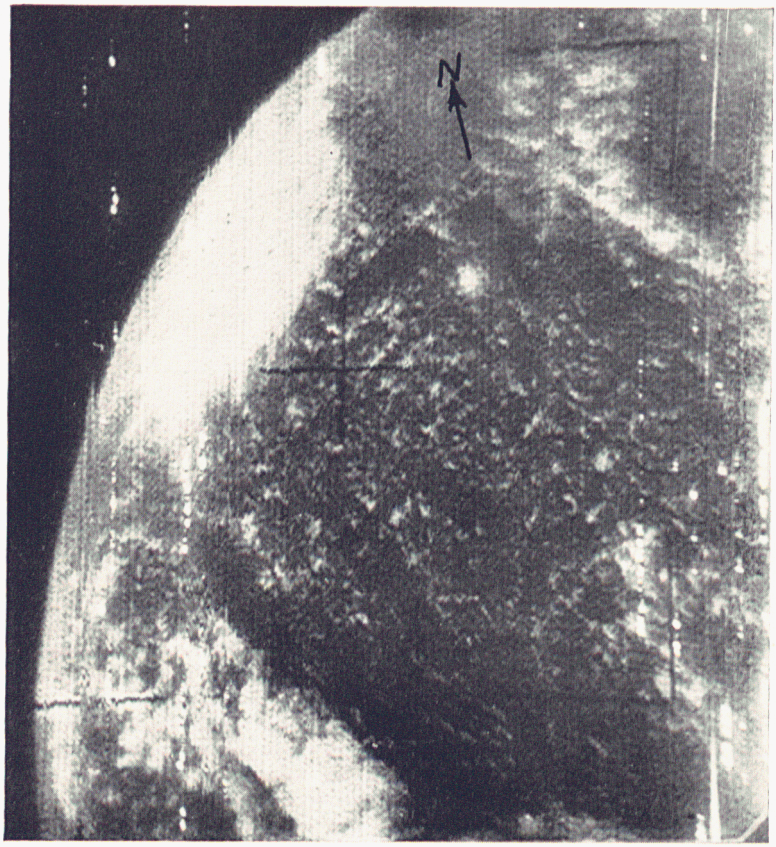


Fig. 23. Satellite view of the cloud system associated with the upper troposphere vortex located at 19° N 170° E from TIROS III orbit 696. System is identified on fig. 20 as *O*.

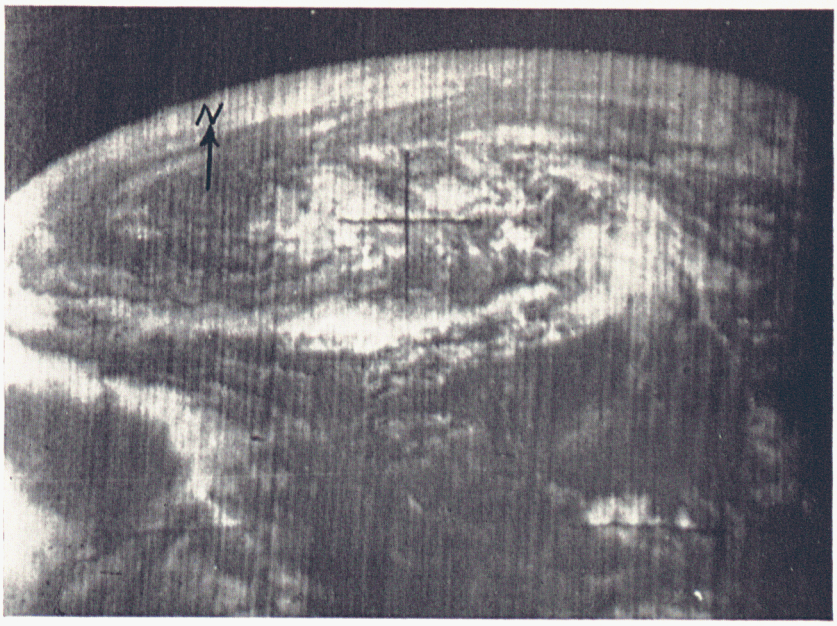


Fig. 25. TIROS III photograph of upper level vortex located at 38° N 137° W from orbit 525. Refer to fig. 10 for orbit mosaic.

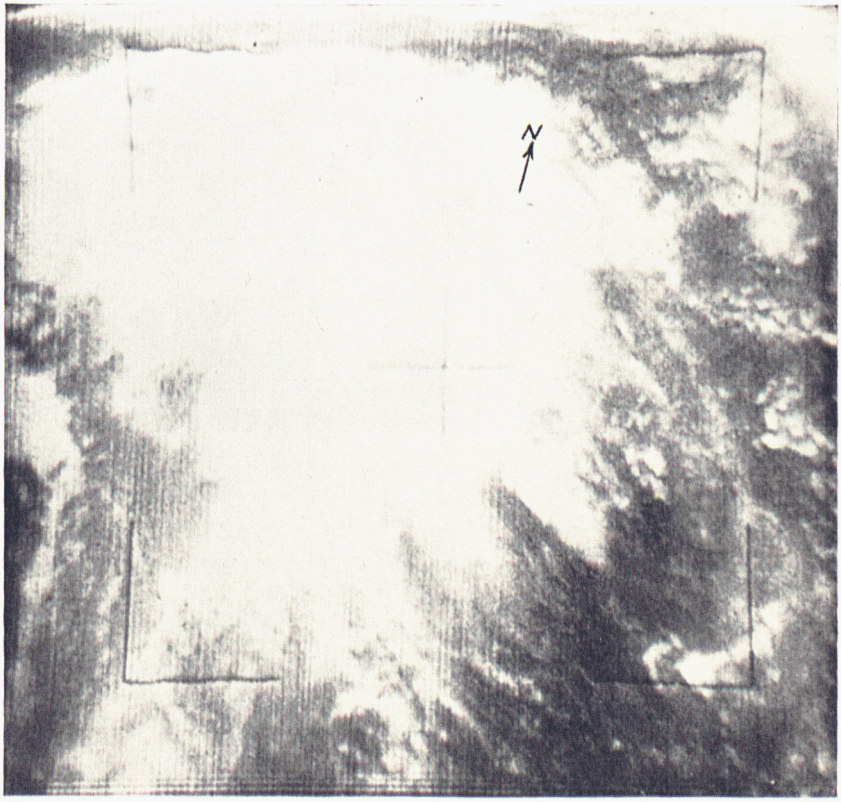


Fig. 26. TIROS III photograph of upper level vortex located at 19° N 150° E from orbit 570.

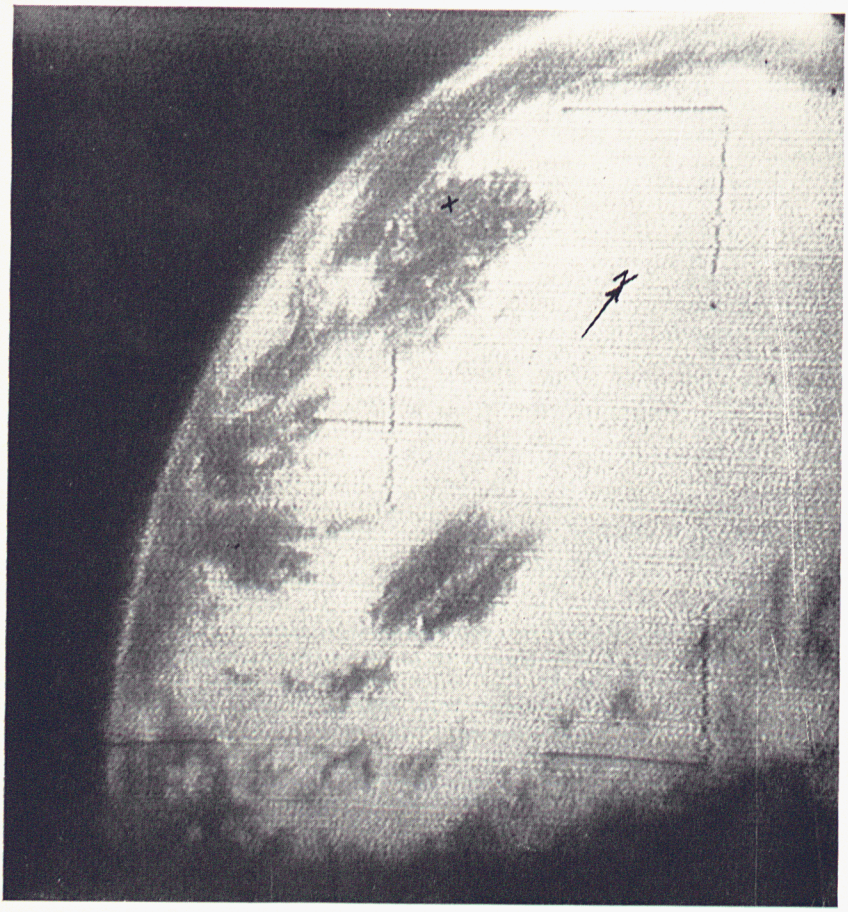


Fig. 24. Satellite photograph of the vortex located at 24° N 149° E from TIROS III orbit 698. Vortex is identified on fig. 20 as *P*.

for daily surveillance of these upper vortices. The changes, if detectable, in the associated cloud mass and precipitation areas, will furnish information on the intensity of the cells as related to their depth and wind structure.

The initial problem is to identify the upper cells from the satellite photographs and be able to distinguish them from the lower troposphere warm-core cells or vortices. False alarms of Atlantic tropical storms transmitted from the TIROS analysis centers during TIROS III were probably due to the inability of the TIROS analyst to recognize and separate the upper cells from the low-level vortices.

A very preliminary study of the TIROS III data over the Central Pacific indicates the upper cells can be identified from the photographs and that under most circumstances they can be distinguished and separated from the low-level vortices. However, the satellite photographs are not sufficient within themselves but must be used in conjunction with the proper tropical synoptic charts and a knowledge of the regional climatology.

Fig. 20 shows synoptic analyses for the Pacific region at 0000 GMT on 30 August 1961. The base chart is a section of the Northern Hemisphere surface chart as analyzed by the National Meteorological Center. The insert chart is a wind analysis of the 30000-ft level from data supplied by the Honolulu Forecast Center of the U.S. Weather Bureau. The data at 30000 ft are sufficient to indicate a sharp upper tropospheric trough extending west-southwest from the western United States to 160° E, but are not sufficient to position any cell within the trough. The relative position of the upper trough is denoted on the surface analysis by the dotted line. The location and general configuration of the cloud systems associated with the upper cells were obtained from the transmitted TIROS III nephanalyses and are shown on the figure by dark shading.

The actual satellite photograph of the cyclonic cell marked *M* in fig. 20 is shown in fig. 21. The estimated center is denoted by a black dot. This vortex would undoubtedly be mistaken for a weak low-level tropical circulation if viewed without reference to position and conventional synoptic analyses. There is no extensive thick cirrus shield over the vortex and the cumulus lines are arranged in a spiral pattern. This arrangement of the low and middle clouds is due to the upper cell penetration into the lower levels. The cell is of sufficient intensity to be reflected as a weak trough within the surface high-pressure system.

Figure 22 is the satellite photograph of the cloud mass associated with the upper cell denoted as *N* on fig. 20. This cell did not penetrate to the 10000-ft level. Weather aircraft reconnaissance at the 700-mb level reported the clouds as broken alto-, overcast cirro-, and normal scattered trade cumulus

except that towering cumulus were observed on the southern edge of the cloud system. There is no apparent spiral organization of the cloud system; therefore, it is difficult to determine the exact relation of the cloud mass to the cyclonic cell center.

The next cell along the trough is just visible on the horizon in fig. 22. A somewhat better view is shown in fig. 23. Although the western edge of the system is not visible, it appears that the extensive cloud mass has a near circular configuration but no obvious spiral pattern. The only reliable observation under the cloud system was at Wake Island which reported scattered cumulus, thick altostratus, and cirrostratus covering the whole sky.

The photograph of fig. 24, an unfortunately poor print, shows the circular cloud pattern which outlines the vortex located at 24° N and 149° E near Marcus Island and indicated on the figure as an X. This vortex, unlike the others, is more evident in the surface analysis, but the possibility of it being a cold-core system which originated aloft should not be overlooked. Such misinterpretation is not uncommon over this portion of the Western Pacific where erroneous typhoon warnings have been issued by reconnoitering cold-core vortices at the 500-mb level and using an extrapolating factor to obtain the surface wind velocity. Further studies on the life history of this vortex are required for proper identification.

Numerous upper troposphere vortices were observed by TIROS III. A subjective screening of the photographs taken over the Pacific region suggests at least two distinctive cloud patterns which are geographically dependent.

Those vortices located on the northeastern end of the trough, poleward of 30° N, between Hawaii and the western United States do not have the massive cirrus shield. Although these vortices are located over the highest surface pressure, their circulations penetrate deep into the lower layers and organize the low and middle clouds into vortex patterns which are apt to be misinterpreted, in the absence of synoptic charts, as belonging to surface storm systems. One example has been discussed and shown in fig. 21. Fig. 25 shows another example located at 38° N 137° W. This cloud pattern could easily be misinterpreted as belonging to a large decaying surface cyclone of the mid-latitudes [23].

Those vortices, located along the central and western portion of the trough, equatorward of 25° N, have a massive shield of alto- and cirro-clouds. Most do not exhibit a vortex pattern in the upper shield, nor do they penetrate sufficiently into the lower layers to organize the cumulus. This is fortunate, for with more spiral organization, they would likely be misinterpreted as severe tropical storms or typhoons. A typical example, in addition to those discussed, is shown in fig. 26.

4. Conclusions

1. Meteorological satellites are ideal platforms for observing the tropical atmosphere. Weather systems within this homogeneous air mass, covering the spectrum from convergence lines to hurricanes, are mirrored in the cloud patterns.

2. Meteorological satellites have shown the conventional data sparse Eastern Pacific to be a region of frequent hurricane development. The satellite data have furnished much information on how, when, and where these hurricanes dissipate or degenerate.

3. The TIROS III data have suggested a low-level, summer circulation regime for the Eastern and Central Pacific which has never been suspected from conventional data.

4. Satellite data are invaluable aids in the positioning and study of the important, but little understood, upper troposphere tropical trough.

5. Excellent tropical data are being obtained by meteorological satellites at a much greater rate than can be assimilated into new or existing circulation concepts. This is due mainly to the fact that satellite data cannot stand alone but must be supported by conventional data in the form of synoptic map files. Such map files do not exist for the tropical regions and are not likely to exist except through the efforts of a global tropical analysis center. The time has passed for *assuming* a tropical atmosphere; therefore, a global tropical analysis center is proposed as a project worthy of support by the three international scientific organizations which are sponsoring this International Symposium.

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