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METEOROLOGICAL ASPECTS OF THE MAMEYES TRAGEDY IN PUERTO RICO, OCTOBER 6-7, 1985

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ABSTRACT

Severe flooding and landslides in Puerto Rico during October 6-7 took about 180 lives and caused extensive damage to public and private property. Twenty-four hour rainfall exceeded 22 inches within a large maximum over the interior hills of the south central coast. Rivers course to a narrow coastal plain and produce hydrographs with early and sharply pronounced crests.

Meteorological aspects of the event can be described best in the context that this was not only a well-developed wave but on its way to becoming Tropical Storm Isabel. Its slowing over the eastern Caribbean under the influence of weaker steering, and its eventual development northward across Puerto Rico into a tropical storm make the circumstances somewhat exceptional.

Besides orographic influences, mechanisms behind the development of such heavy rains are presented. These are (1) a speed maximum in the low-level wind field entering the primary confluent zone trailing the wave axis, (2) surface data supporting the presence of a broad, low-level circulation that had formed over the eastern Caribbean, (3) high-level, anticyclonic shear positioned for wave enhancement, (4) rotational influences that resulted in a more pronounced convergent axis, and (5) multiple, deformation boundaries intersecting over Puerto Rico's south coast with implications as to train echoes, cell mergers, and development of severe thunderstorms over the stricken area.

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1. INTRODUCTION

The severe floods and landslides of October 6-7, 1985 in southern Puerto Rico have established a place of historical notoriety alongside the great hurricane disasters of earlier this century that affected the island. The full impact on lives lost and destruction wrought has yet to be accurately determined. As a human tragedy it is the most significant weather related event since the great San Ciprian Hurricane of September 26-27, 1932. Certainly from the standpoint of its profound effects, the circumstances that surround the flood event make it somewhat exceptional from what normally would be expected from a tropical wave. The meteorological severity of the event can be best understood in the context that this was not just triggered by a well developed tropical wave but by a wave that was also destined to become a tropical storm. Its slowing over the northeast Caribbean as a tropical wave followed by its eventual movement northward and development into Tropical Storm Isabel over the Atlantic north of Hispaniola give perspective to the rapid changes that were occurring and the energy that this weather system was imparting to its environment.

Besides orographic influences, certain other interesting mechanisms are examined in this paper which are believed to be factors behind the wave's development and the heavy rains that were produced. These are (1) a speed maximum within the low-level wind field entering the primary confluent zone trailing the wave axis, (2) rotational and curvature influences that resulted in a more pronounced convergent axis with implications as to train echoes, cell mergers, and development of severe thunderstorms over the stricken area, (3) a migratory high-level, westward moving cyclone properly positioned for wave enhancement, and (4) the presence of a closed low-level circulation that had initially formed in the area of maximum relative vorticity and eventually produced an intersecting asymptote of convergence.

2. FLOODING AND LANDSLIDES

The flooding and landslides that occurred took about 180 lives with damage to public and private property ranging from federal estimates of $50 million to well into the hundreds of millions by local authorities. Most of the victims numbered among the residents of the poor hillside community of Mameyes located in the hilly northwest fringes just above Ponce, the largest city on Puerto Rico's south coast. These people perished on a hillside, not down in valleys where flooding would normally be expected to claim lives. It was here, just after the most intense rains fell during the early morning of 7 October, that the mountain slope gave way burying the homes and trapping the occupants under tons of rock and mud-laden debris. About 90 houses were destroyed in this incident with the number of fatalities at 130.

Two other incidents caused significant loss of life and were more directly related to the consequences of flash flooding. Rushing floodwaters of the Rio Coamo undermined a bridge on the 4-lane Las Americas Expressway, connecting San Juan with Ponce, causing the collapse of one of the spans into the flooded riverbed. Eleven motorists including a police car, apparently unaware of the disappearing taillights in the distance, followed one another to their fate. Here 24 lives were lost. The flood of Quebrada del Agua, normally a dry creek bottom west of Ponce, caused 16 other deaths. The tragedy shook the very roots of public complacency about the potential devastation that heavy rains can bring to an area.

Twenty-four hour rainfall totals exceeded 22 inches within a large isohyetal maximum over the interior hills of the south central coast (figure 1). Many stations within this area and adjacent to it received rainfall totals greater than their previous historical records and eclipsing their climatological 100-year return frequencies. Intensities measured near Tallaboa (west of Ponce) reached values as high as 2.75 inches per hour to about 5.5 inches in two hours. Even higher intensities are likely to have occurred at other locations. A new 24-hour record rainfall for Puerto Rico of 24.6 inches was established at the Fischer-Porter recording gage site at Cerro Maravilla. For Puerto Rico it was one of the greatest known floods of such severity to cover such a wide swath of area.

Serious inundation occurred along almost all drainages of the south central coastal plain from Santa Isabel to Ponce with major bridges and highways washed out and many towns isolated by the floodwaters (figure 2). Rivers course rapidly to a narrow coastal plain and produce hydrographs with early and sharply pronounced crests. Many of the streams drop to the ocean from elevations of 3 to 4 thousand feet and over distances of 15 miles or less. In particular the municipalities of Coamo, Santa Isabel, Juana Diaz, and Ponce were hardest hit. The real killer rains fell during the late night and early morning of 6-7 October when heavy thunderstorms concentrated their most intense rainfall of the entire storm to the area already stricken from moderate to serious flooding.

3. SYNOPTIC/MESOSCALE ASPECTS

3.1 Upper-tropospheric Low and Tropical Wave's Origin/Track

This wave moved off the African coast as a normal sized perturbation traveling in the easterly trades and coupled to the equatorial trough. Satellite pictures prior to 30 September depict little convection with the wave since it was embedded within a thick layer of Saharan dust and much of the tropical Atlantic east of 50W was characterized by strong subsidence. It could only be identified in transit of the eastern Atlantic by the "inverted-V" shaped clearing that it was producing in the dust layer along with some enhanced cumulus that could be seen in the GOES visual pictures. The initial development of heavier convection with the wave resulted from its encountering the sharp, southward penetration of the mid-Atlantic, upper-tropospheric trough that extended southward over the tropical Atlantic between 45 and 50W. The trough had been persistent in that area the last several days of September.

The upper trough was most intense at 200-250 mb with a northeast to southwest orientation and its southern extent overlying the Intertropical Convergence Zone (ITCZ) southward to about 5N. It was very close to its mean position and intensity for the time of year. By 1 October a closed low had formed in the base of the trough near 18N 48W, and pronounced meridional ridging aloft west of its position had begun providing moderate advection of cold air into the system from higher latitudes. The upper low continued to deepen until becoming the dominant regional circulation in the upper atmosphere. This was preliminary to its being cut off from the southern portion of the mid-Atlantic trough in succeeding days.

The perturbation which had slowed with its arrival beneath the upper feature began to increase in amplitude between 30 September and 3 October with good cyclonic turning of winds at the surface indicating a well developed wave had formed. The ITCZ had become very active east of 45W, and convection was increasing along its northward extension into the developing wave.

Frank (1969, 1970) has studied such upper-tropospheric lows extensively and has related their intensities to the downward penetration and accompanying weather that occurs. From his classification of these upper lows, this particular system would definitely be of the more intense "wet" type since considerable low-level moisture was being tapped and transported into the upper atmosphere. Widespread cloudiness and deep convection had developed east of the wave axis and beneath the zone of strong anticyclonic shear aloft. Simpson (1970) proposed that the "blow up" in convection that accompanies the approach of westward propagating, low-level systems beneath these upper-tropospheric troughs is associated with the stimulated high-level outflow that is occurring. As the surface system moves westward to the proximity of the upper trough's position, it tends to develop and become better organized underneath the increasing anticyclonic shear associated with the strong winds to the lee side of the upper trough.

In response to the combined downward penetration and divergent outflow aloft being produced by the upper system, the surface feature continued to develop in the area of 45W until about 3 October. Retrogression of the cut-off low at upper levels then began a renewed westward migration of the tropical wave at the surface.

The 1200 GMT 5 October 250 mb analysis (figure 3) shows the consistent path the upper-tropospheric low followed between 1-5 October and its final position and analysis at that level during the tropical wave's advent into the eastern Caribbean. Of special interest is the strong anticyclone centered near 16N 52W and its southward ridging over the northeastern part of South America. Also significant are the deep southerly wind currents moving from equatorial latitudes over the eastern Caribbean.

Figure 4 shows the 12-hour positions of the tropical wave from where it initially encountered the upper-tropospheric trough. The figure depicts the amplitudes and positions of the wave axes as best could be interpreted and fixed from satellite data. Early movement of the wave shows an above average speed of about 20 kts during the first 24 hours, but then the wave accelerated to almost 30 kts as it approached the Lesser Antilles.

3.2 Tropical Squall

The introduction of the tropical wave's effects into the northeast Caribbean began during the afternoon and evening of 4 October. A low-level wind speed maximum, overriding the crest of the wave and extending well out ahead of its surface axis position, contained 30 and 45 kt winds. By 0000 GMT 5 October (figure 5) the nose of the speed max had traveled well westward across Hispaniola. Contained within the zone of maximum winds was a well developed tropical squall (figure 6) that had separated from the main body of the wave and was speeding across the Leeward Islands as a line of heavy thunderstorms.

This convection had formed along a boundary of longitudinal shear contained within the speed max and produced by a wind velocity rise from 30 to 40 kts. Convection was also responding to the anticyclonic shear aloft as the wind speed differential and convergent flow moved beneath the southwest flow aloft east of the receding upper cyclone. The tropical squall spread convection rapidly from St. Kitts, in the Leewards, to across Puerto Rico (250 nm) in about six hours. Coinciding with the tropical squall's arrival at San Juan, about 0000 GMT 5 October, the arrival of the low-level wind speed max (30 kt isotach) can be seen in the time cross section analysis for San Juan (figure 7). Seen also in the figure, the upper-level cyclone had passed overhead 6 to 12 hours earlier and was in the process of intensifying and deepening the southwesterly flow aloft downward into the middle levels by the following morning. Forty knot wind gusts were recorded at the International Airport in San Juan and at airports throughout the Virgin and Leeward Islands as the squall arrived. Energy was there, but the real potential for dynamics and strong, upward, vertical motion was still occurring rearward of the surface wave which by that time had moved almost to the Windward Islands.

3.3 Low-Level Wind Speed Maximum

As the well developed upper-tropospheric cyclone moved westward to its position over Hispaniola at 1200 GMT 5 October (figure 3), it slowed to a stall and began intensifying. Above 200 mb a strong outflow region had formed over the eastern Caribbean in conjunction with a broad high-level jet containing 50-60 kt winds. Significant deepening of the system had occurred down to the 500 mb level where winds veered 90 degrees into the south and increased in velocity (figure 7). These effects on the lower levels were substantial and critical to the events that followed and which led up to the disaster.

The tropical wave which had crossed the lesser Antilles with above average speed again began to slow beneath the stalled upper trough, and at the same time significant deepening, enhanced curvature, and rotational effects were showing up in the low-level wind pattern. By 1200 GMT 6 October (figure 8), with the wave's axis now west of Puerto Rico, the circulation at 850 mb had formed a closed cyclone over the Gulf of Venezuela. At San Juan (figure 7) winds were now veering sharply into the southeast as the trough became much more accentuated in the lower levels. This developing low-level feature in combination with a strong, southwestward surge of high pressure over northeast South America, had caused a positive, rotational tilting of their respective (trough-ridge) axes. In turn, this was contributing to the lateral confluence and low-level forcing going on within the wind maximum feeding into the wave across the northeast Caribbean.

The core of the wind speed maximum over the top of the wave was now oriented directly across Puerto Rico and the Virgin Islands. Its strength was the result of pressure differences between the developing tropical wave and the subsidence surge of high pressure following the wave that had compressed the gradient. Increased anticyclonic curvature appeared at all levels just east of the Lesser Antilles being the product of the strong subsiding ridge that had followed the upper cyclone westward. At all levels this ridging southward was quite pronounced bringing the winds more into the southeast and amplifying the wave (figures 3, 8). This was indirectly contributing to the rotational energy and vorticity being applied to the wave from the magnification of its cyclonic curvature and the increased cyclonic shear already in place due to the strong winds. As a result, positive relative vorticity was of considerable note at low and middle levels especially within the static flow pattern of the wave. From satellite photos, strong arching in the wave cloud pattern and major convective clusters can be seen in the trailing confluent zone over the Lesser Antilles on 5-6 October (figures 9, 10).

Weldon (1979) has previously described some similar fundamentals of the above pattern from his satellite interpretation of short wave systems in the westerlies that overlie the subtropical easterlies. This pattern differs from his in the respect that the speed maximum at low levels and the deformation occurring in the low-level wind field are the result of the primary subsidence boundary occurring east of a retrograding upper cyclone (not an uncommon pattern in the tropics). The "pumping up" of the mid and upper-level ridge from warm air circulating out of southern latitudes to the lee of a retrograding cyclone is usually the stronger producer of subsidence over the tropics. The Atlantic subtropical high being a warm core system is more dynamically structured to respond to warming. In addition, in this case the well-developed wave containing the maximum low-level vorticity is being directly acted upon in the vertical by a superposed high-level cyclone. Because of these facts resulting in a more favorable dynamic arrangement in the vertical, the subsidence boundary, speed max, and low-level vorticity max described by Weldon are likely to be considerably more significant as weather producers under this type pattern (figure 11).

The "subsidence surge" phenomenon Weldon describes is very typical of many tropical waves observed in the Atlantic easterlies. Nearly all waves propagating within the low-level easterlies seem closely to be followed or driven to some extent by these subsidence surges. The deformation that occurs along the subsidence boundary and the speed maximum in the easterlies occurring on the western end of the boundary are very typical. The "T" shaped cloud pattern in advance of the speed maximum overlying the maximum vorticity center he describes can be applied to the tropical squall pattern discussed earlier (figure 6). It seems logical to postulate that many of the tropical waves moving across the Atlantic may be acting in response to a following undulation or ripple of high pressure (a pressure wave or surge) propagating along the southern base of the subtropical ridge. Certainly much of a wave's kinetic energy and deformation substantially results from the strength of such following surges and the effect they are having on actually inducing the wave.

3.4 Quasi-circulation Centers and Confluent Asymptotes

Weather reconnaissance reports between 1830-2230 GMT on 5 October indicated several south..southwest and one west wind in the vicinity of 14N 63W (figure 12). In this area, an apparent swirl pattern or wrap-around of convection also appeared in the late afternoon visual and nighttime IR satellite photos. The 0000 GMT 6 October IR picture (figure 10) can be used to almost pinpoint a center in the vortical cloud distribution near 15.8N 63.5W. This quasi-circulation center coincided closely with the location of the 1,500 ft recon wind fix (west wind) and had continuity as a persistent feature in later pictures (figure 12). Additional recon information was not available. Due to lack of data and an ill-defined convective pattern, no real conclusions can be made about there actually being a closed, surface center in this area. Most probably, however, satellite pictures were indicating a low-level circulation, not necessarily well defined or occurring at the surface. Time lapse or film loops to determine cloud motion were not available for viewing.

A modeling of the low-level wind max contained within an almost static flow pattern across the northeast Caribbean is presented in figure 13. This figure represents the quadrants within which convergence and divergence resulting from the cyclonic shear were most likely to be occurring and where relative vorticity is increasing and decreasing in relation to the speed max. The left rear quadrant turns out to be the one most favorable for forming a cyclonic vortex. As we would expect, the low-level vortex actually appears to have initially formed in this area (satellite interpretation vicinity 15.8N 63.5W) with the introduction of the speed max and increased cyclonic curvature over the region. An examination of the map sequence at 850 mb shows that the formation of an identifiable vortex from satellite data is coincidental with the setting up of the increased amplification and cyclonic curvature of the wave. The convergent asymptote and speed max now overlay the Leeward Islands having become reorientated more out of the southeast. As air entered and increased in speed toward the core of the wind max, relative vorticity was increasing within the left-rear quadrant.

From satellite interpretation, the quasi-circulation center can be traced along a westward path over the Caribbean south of Puerto Rico and to a point just south of La Romana, Dominican Republic by 1400 GMT 6 October (figure 12). The GOES visual photo at that time (figure 14) shows evidence of the apparent vortex near 16.9N 68.7W. In the data-sparse area there continued to be little conclusive support for the presence of a circulation at the surface other than from what evidence there was of a vortical cloud distribution in the satellite imagery.

Streamline asymptotes of primary, lateral confluence were (as they usually are in the tropics) the focus of heaviest thunderstorm activity. All the ingredients for strong vertical motion were present along the asymptotes: deep, accelerating, convergent flow at lower levels and substantial anticyclonic shear and outflow aloft. In figure 12 these primary, confluent asymptotes were drawn at different points within the displacing wind circulation and deformation field. Their different positions are related to the westward movement of the wave and quasi-circulation center (times shown) and to the eventual formation of the tropical depression north of Hispaniola. The asymptotes corresponded to the deformation pattern within the wind field attendant to these migrating features. As can be seen in figure 12, the initial placement of the asymptote over southern Puerto Rico was coincidental to the beginning of the flood episode. A secondary asymptote (not shown in figure 12) formed later on during the period of major flooding and led to implications as to intersecting boundaries over southern Puerto Rico.

An elongated series of convective clusters began slamming Puerto Rico with heavy rains during the late morning and afternoon of 6 October. These heavy thunderstorms were being generated along the primary asymptote of deep, convergent flow that had trailed the tropical wave as it approached and moved over the eastern Caribbean. Strong, vertical transport of moisture had produced a thick, cirrus canopy engulfing a large area extending several hundred miles to the southeast of Puerto Rico over the Leeward Islands and Caribbean Sea. Ultra-cold tops could be viewed in the GOES IR enhancements (JF curve) showing repeat-grey shading covering the heavier complexes with multiple towers overshooting into the white scale.

The asymptote of convergence is largely defined in this pattern by the "subsidence surge boundary". This feature actually forms the boundary between the strong subsidence going on east of the Lesser Antilles and the ascending motion being produced by the wave and upper cyclone over the eastern Caribbean. After becoming well developed, it shows up on satellite pictures as a long, curving cloud band trailing the wave and arcing south and eastward over the entire central Atlantic (figure 10, 14). It actually exists as the fluent asymptote of the equatorial trough which has been drawn northward by the wave's extension and suppressed southward over the Atlantic by the subsidence ridge. The western extent of this boundary represents an asymptote of vigorous lateral wind confluence, shear and a demarcation across which vertical motion changes abruptly from positive to negative values. As a participant in this event, the strong subsidence ridge following the wave possibly overshadows the wave in importance. It was the dynamic factor primarily responsible for enhancing the deformation boundary. Indeed, it was this boundary that became the most important weather factor in the flood event due to its concentration and focusing of the convective storms over the affected area. However, it did have to combine with the wave to produce the full result.

Substantial cell growth and convective development were occurring only along the western extent of the deformation boundary where the strongest low-level forcing existed. Several phenomena were complementing each other here. Lateral convergence was resulting from not only the effects of the surge off the Atlantic, but the low-level cyclonic circulation over the eastern Caribbean was also contributing to the amount of directional shear along the boundary. The speed max positioned along this segment of the boundary contained both confluent winds and accelerated motion into the packed pressure gradient for net low-level convergence. The confluent asymptote, speed max, and "subsidence surge boundary" were all products of the same dynamic forces being applied within the lower atmosphere. Therefore, they became one in the same phenomenon for producing and forcing convective intensities.

3.5 Intersecting Asymptotes

An examination of satellite imagery during the night of the most intense rains and flooding implies that intersecting boundaries may have been a factor during the disaster. The 0430 GMT GOES IR (JF curve) 7 October picture (figure 15) shows a convective complex directly over the flood stricken area. By looking at pictures several hours before and after this photo one can surmise certain mesoscale changes that were occurring. Prior to the 0430 GMT picture, imagery shows that the large convective storms were initially being generated and orientated along the deformation boundary (convergent asymptote) from the southeast across Puerto Rico. By the 0430 GMT picture, however, the thunderstorm complex over Puerto Rico appeared to have developed twin extensions to its convection. In addition to the extension southeastward, one was now oriented from the southwest. This shows that the wind field overlying the eastern Caribbean now contained two asymptotes. At the same time the heaviest convection along the southeast boundary appears to have lessened or contracted northward with a corresponding increase of convection from the southwest orientation. Possibly in explanation of this, at mid and upper levels the cyclone had rapidly filled with its trough opening up and retreating northward. This was accompanied by weakness in the subsidence ridge north and east of the Antilles. With subsidence also not as strong at the surface, gradients relaxed, wind shear decreased, and the original deformation boundary became more disorganized and ill-defined. Therefore, convective intensities began to wane southeast of Puerto Rico.

The low-level circulation south of Hispaniola now appeared to have gained firmer control and organization of its environmental winds. Earlier visual pictures showed fine, curvilinear cumulus radiating outward and appearing to move cyclonically around a central point southwest of Puerto Rico. As time progressed, the meso-wind field in this area began establishing the new deformation asymptote southwest of Puerto Rico. Further evidence for this was noted by the forecaster on duty during the night of 6 October when radar cell movement onto the south coast of Puerto Rico shifted from out of the southeast almost 60 degrees into the south and south southwest with some of the cells appearing to follow merging paths. This change in steering implies that besides train echoes occurring along a single boundary, intersecting axes or boundaries had set up for cell mergers and enhanced convective energy. Indeed, the complex over Puerto Rico's south coast at that time had intensified considerably with major sizing of the tops into the grey-scale white in black.

It's evident from satellite pictures showing the convective cloud pattern during the night and early morning of 6-7 October that the transition from an unstable wave into a well-developed vortex had already occurred. Palmer (1952) first described the stages through which this transformation occurs, and this particular case seems to pattern itself closely with his description of the field of motion surrounding a newly formed vortex. As he described, the vortex stage is characterized by two singular points in the wind field. In figure 15, satellite interpretation shows the northern point of cyclonic singularity located over the eastern tip of Hispaniola. The other singularity is associated with the neutral point of the col area over the Caribbean Sea to the southwest. The convergent asymptote of the col leading northeastward onto the southern coast of Puerto Rico has become the new deformation boundary along which the convection is being focused from the southwest. It was during this time that the GOES IR enhancement showed a delta-shaped pattern in the solid white in black, grey-scale shading over the south coast of the island. This most intense convection appears to have conformed to the intersecting angle made by the meeting of the two asymptotes. Logic would dictate that in this area the strongest low-level forcing and moisture convergence would have been occurring. The pattern that has formed represents a convective signature within the satellite imagery left by twin asymptotes that merge during the transition of a tropical wave into a vortex. This signature pattern migrated slightly west of its position in figure 15 to where it was directed almost over the Ponce area at the time of the most significant flooding.

The horizontal wind field over the eastern Caribbean at this time could be divided into three different directional flow sectors: (1) east southeast and southeast around the subsiding Atlantic ridge, (2) southerly equatorial, and (3) west and southwest from the vortical motion over eastern Hispaniola. A subjective streamline analysis (figure 16) shows these three flow sectors along with an interpretation from satellite imagery of where the intersecting asymptotes would have met, almost directly over the south central coast of Puerto Rico at the time of the Mameyes landslide. Therefore, a double asymptote of low-level, mass convergence appears to have formed during the period of major storm rainfall late that night, concentrating the flux of moisture and promoting strong, vertical forcing where the two boundaries met with the mountain slope.

Promoting the lateral confluence along the westernmost asymptote was the northward movement of the low-level vortex across the eastern tip of Hispaniola during the night of 6 October (figure 12). By 1200 GMT 7 October, satellite and ship data provided greater evidence for the presence of a vortex at the surface along the north coast of Hispaniola. Although some disruption in the flow was occurring across the central cordilleras of Puerto Rico and Hispaniola, it's probable that eddy and leeside effects were combining with the strong shear and kinetic energy over the Atlantic for rapid intensification of the system, eventually into Tropical Storm Isabel.

4. SUMMARY AND CONCLUSION

The floods and landslides that affected Puerto Rico during 6-7 October 1985 substantially raised public awareness about the potential devastation that heavy rains can bring to the Caribbean. It should be repeatedly emphasized to the public, media and governmental officials that the possibility continues to exist for similar catastrophic rainfalls and flood disasters in the future. This threat exists not just from tropical systems but also with other weather patterns that under certain circumstances will occur over the Caribbean area during any season of the year.

There are certain aspects of this weather event that can lead to an understanding of why some tropical waves may be more intense than others. In this example we are examining a wave that was structurally very mature as it moved over the eastern Caribbean Sea and in the process of upscale development into a tropical storm. The substantial influences of the uppertropospheric cyclone on the movement and development of this system at the surface were critical as was the strong, subsiding ridge that followed the wave. These influences interacted with the wave as it slowed over the northeast Caribbean causing enhanced rotation and curvature within the low-level wind pattern that accompanied the wave's development. Simultaneously with the introduction of the speed max and increased relative vorticity being applied to the wave, evidence exists for the early formation of an incipient circulation within the apex of the wave. Continuity of this feature could be followed with satellite imagery as it crossed the eastern Caribbean and moved northward into the Atlantic as a precursor to the eventual formation of Tropical Storm Isabel. The positioning and development of this mesoscale feature as an incipient vortex are believed also to have been fundamental to the formation of multiple deformation boundaries within the low-level wind field across the eastern Caribbean. Asymptotes of convergence intersecting over the south coast of Puerto Rico were crucial to the focusing and intensification of the severe thunderstorms that led to the major loss of life.

The erratic development and movement of these type systems as well as more organized tropical cyclones that may form under similar circumstances are what make such situations so very dangerous to the Caribbean. In the same respect, the forecast and warning problem for this region is greatly magnified and made considerably more complex and short-fused than what general opinion might be led to believe. Under similar circumstances, climatological tracks and the bias they introduce to the forecast guidance may be misleading. Forecast models have yet to become sophisticated enough to accurately predict such systems within a time frame needed for adequate public warning. Therefore, much of the responsibility for handling and overcoming these problems is still laid squarely upon the shoulders of the forecaster in the field who must assemble and effectively use what other tools and local knowledge he can summon.

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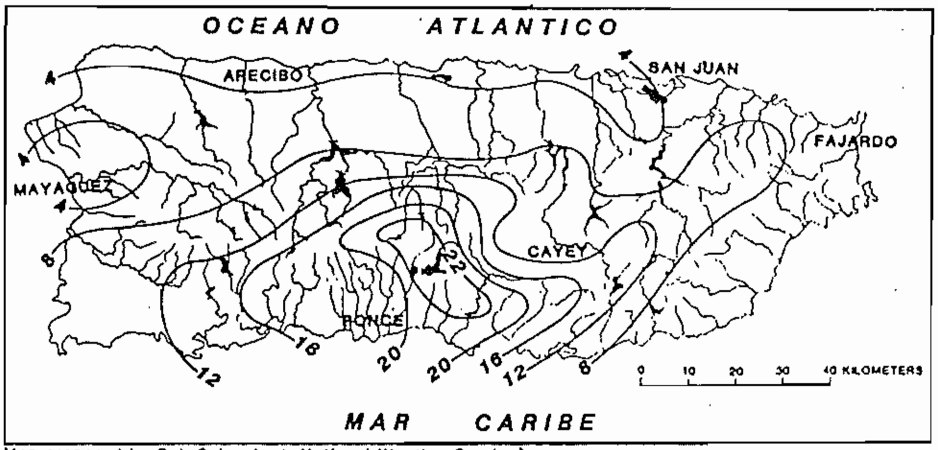


Map prepared by Bob Calvesbert, National Weather Service).

Fig. 1. Total 24-hour rainfall amounts (inches) from 0800 6 October 1985 to 0800 7 October 1985 throughout Puerto Rico.

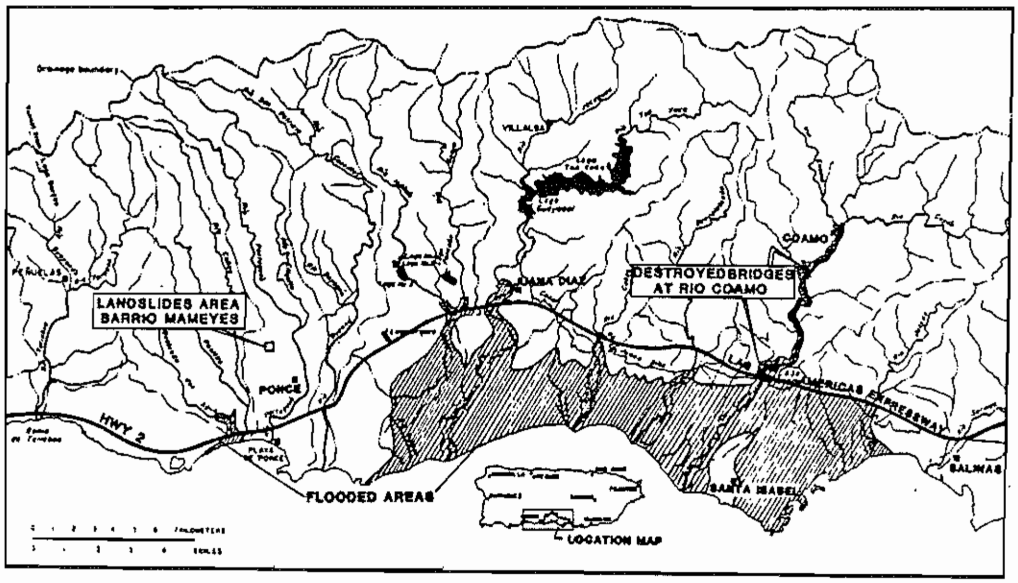


Fig. 2. Areas flooded in Southern Puerto Rico during the 6-7 October 1985 floods. (Courtesy USGS)

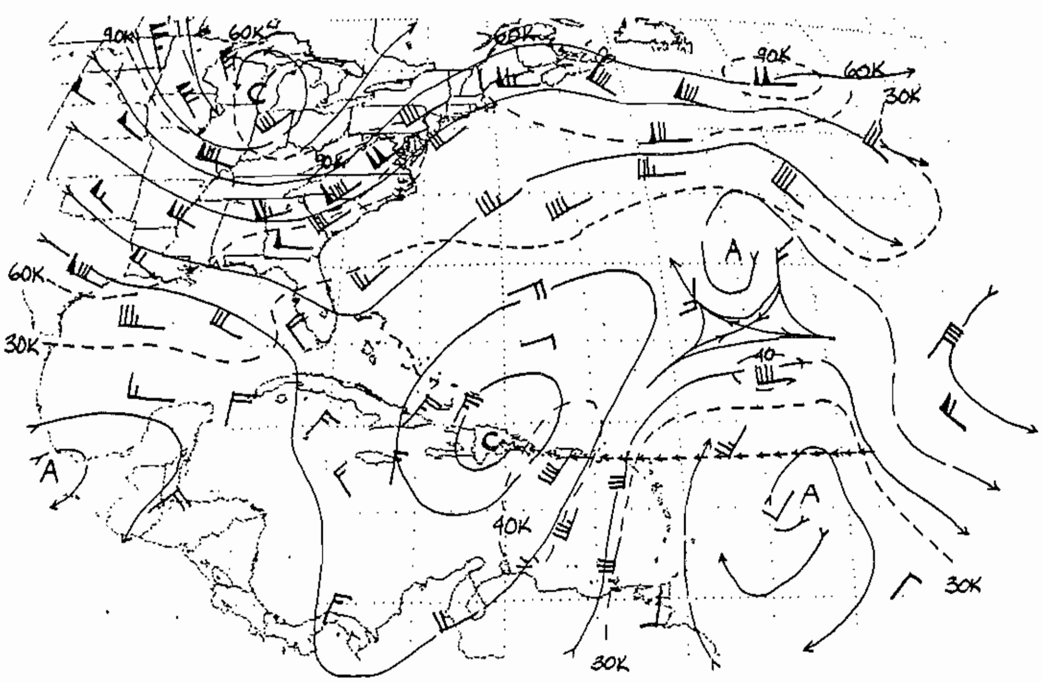


Fig. 3. 1200 GMT 5 October 1985 250 MB analysis: Streamlines, isotachs, origin and track of upper low (←).

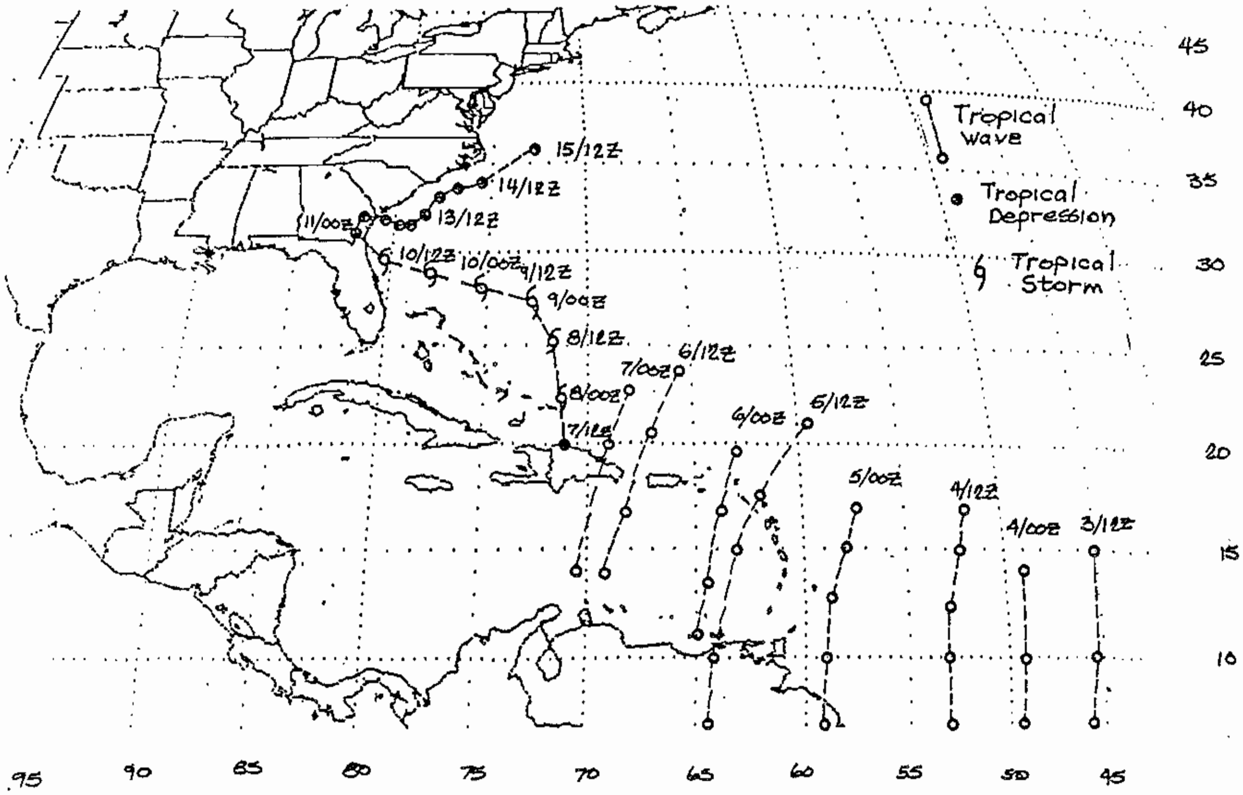


Fig. 4. Tropical Storm Isabel/Tropical Wave (surface positions) October 1985.

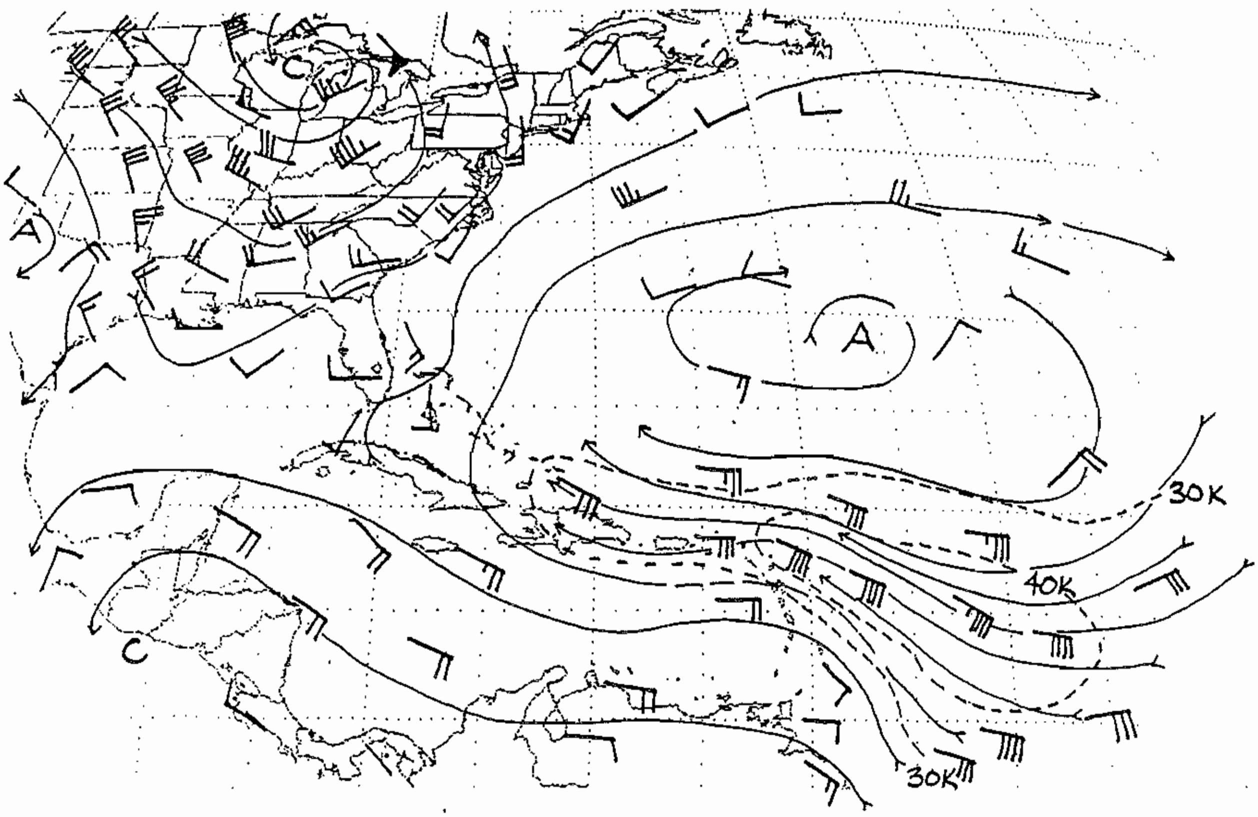


Fig. 5. 0000 GMT 5 OCT 1985 850 MB Analysis: Streamlines, Isotachs.

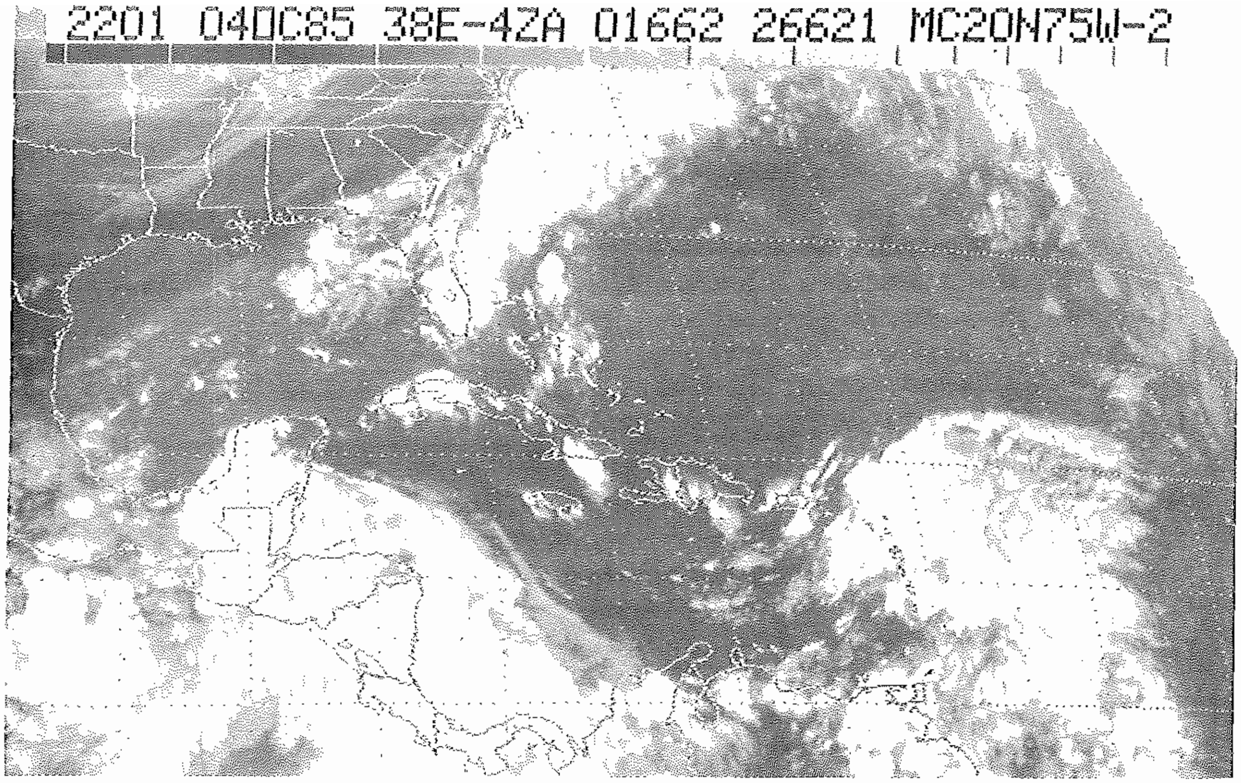


Fig. 6. GOES IR Imagery at 2200 GMT on 4 October 1985 depicting tropical squall across Northern Leeward Islands approaching Puerto Rico and U.S. Virgin Islands.

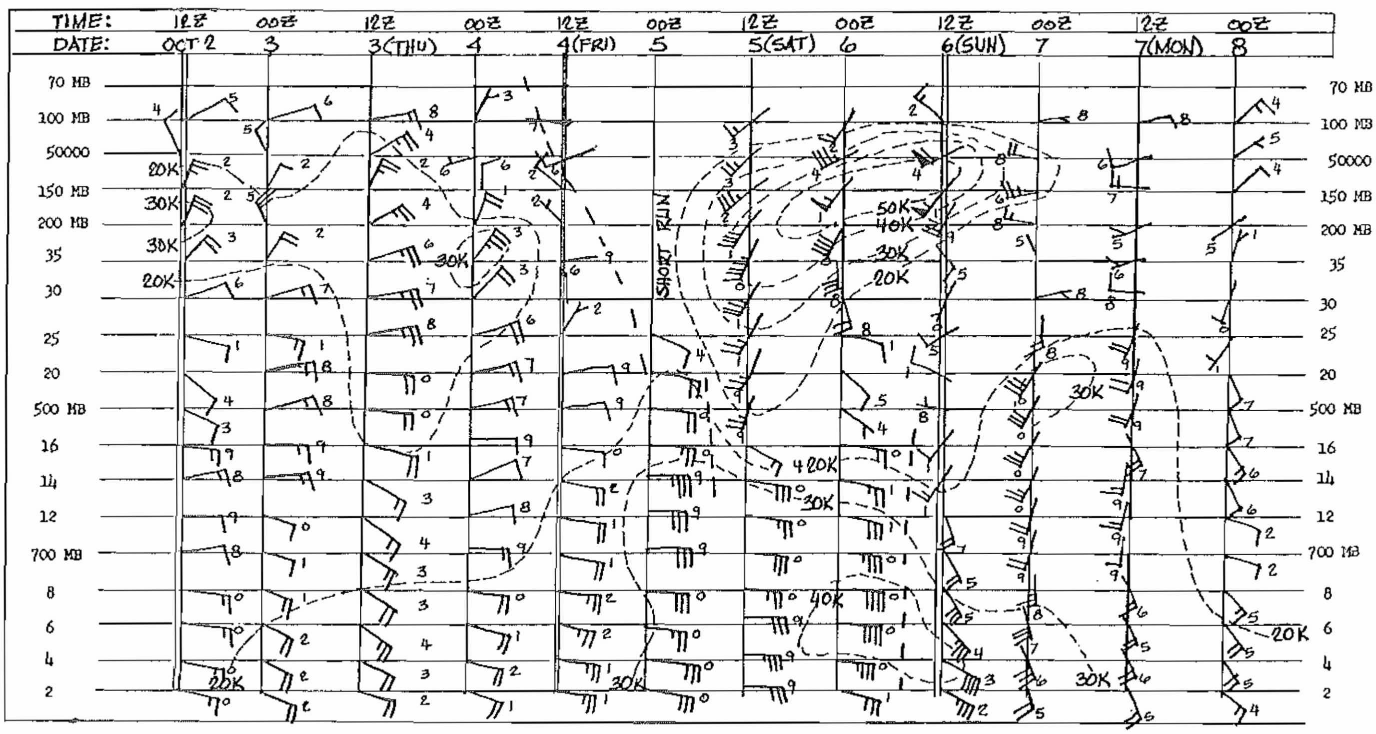


Fig. 7. Vertical time section, San Juan, Puerto Rico, 2-8 OCT 1985.

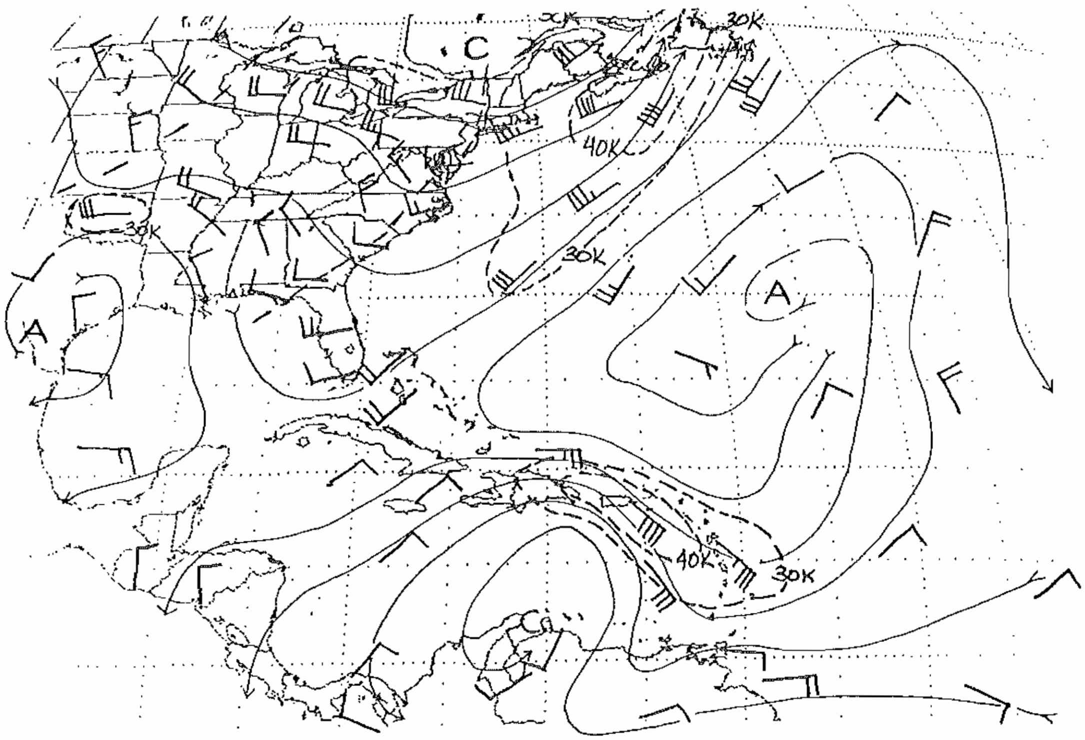


Fig. 8. 1200 GMT 6 OCT 1985, 850 MB Analysis: Streamlines, Isotachs

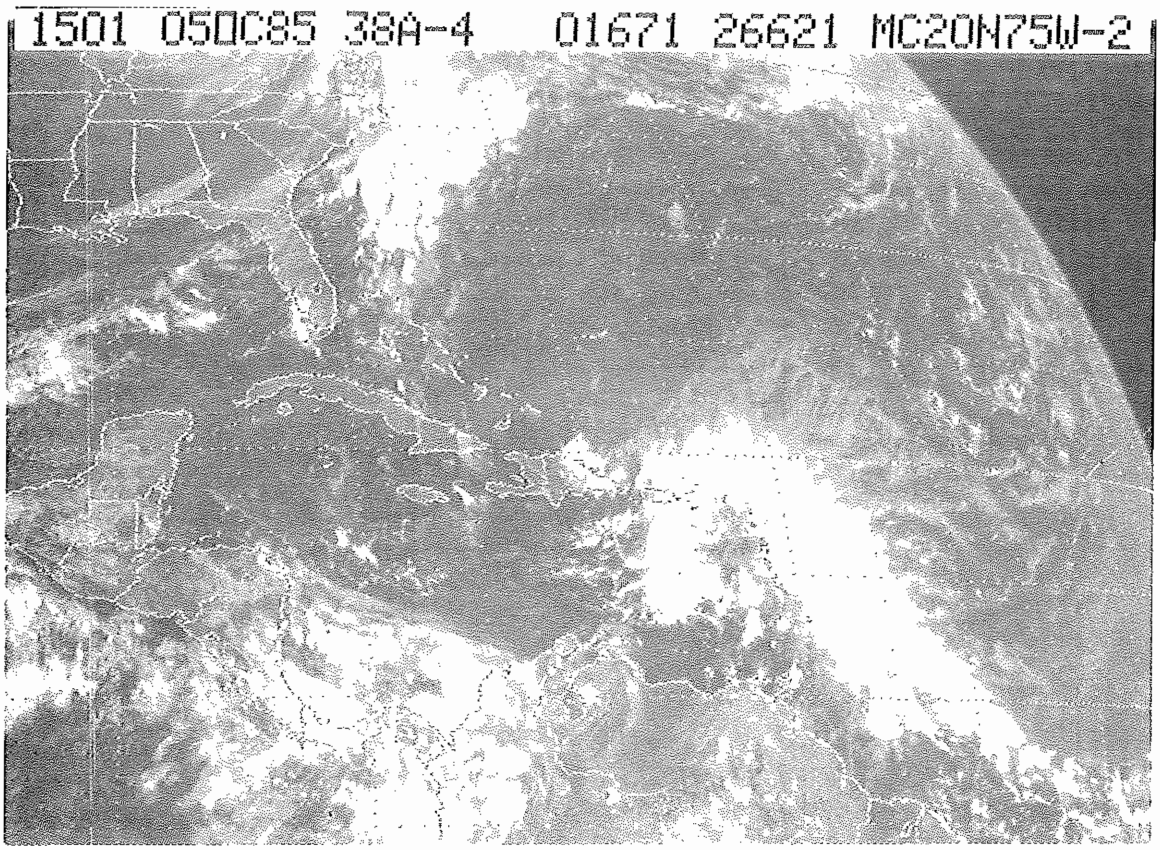


Fig. 9. GOES Visual imagery at 1500 GMT on 5 October 1985 that depicts arching wave cloud pattern.

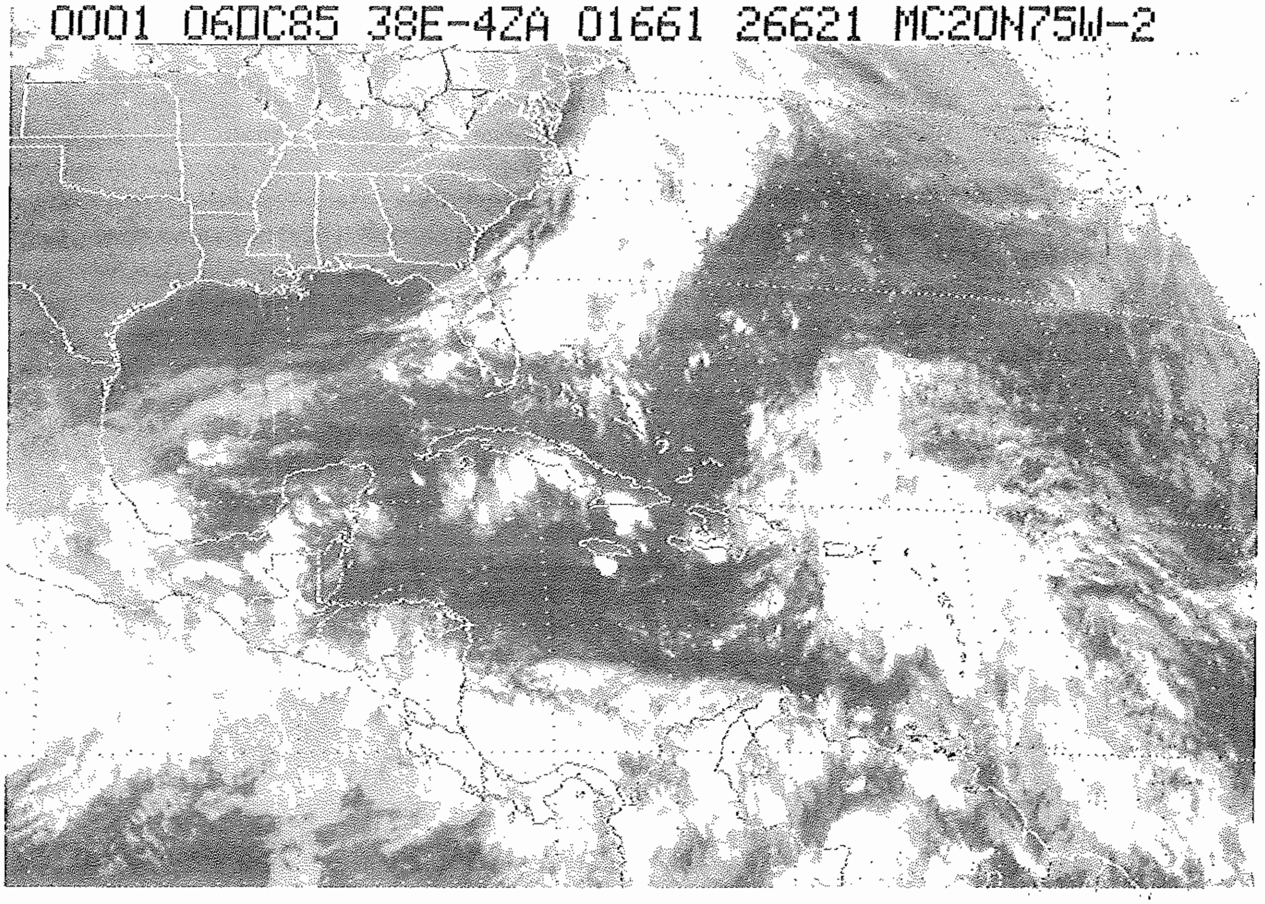


Fig. 10. GOES IR imagery at 0000 GMT 6 October 1985 showing wrap-around convection and apparent vortex near 15.8N 63.5W

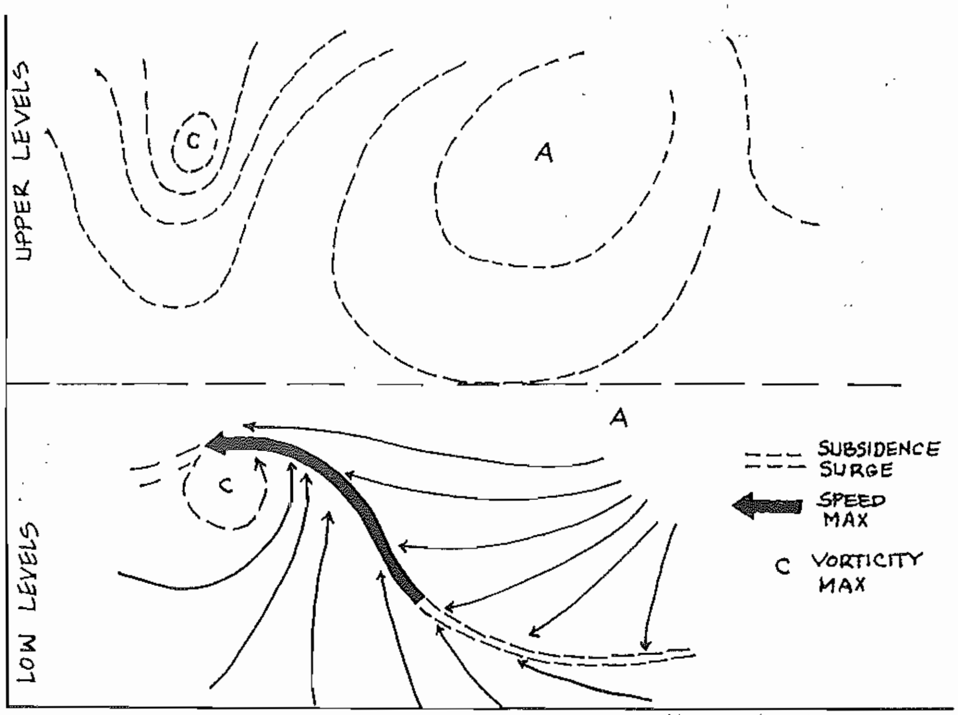


Fig. 11. Vertical representation of subsidence surge boundary/retrograding upper cyclone.

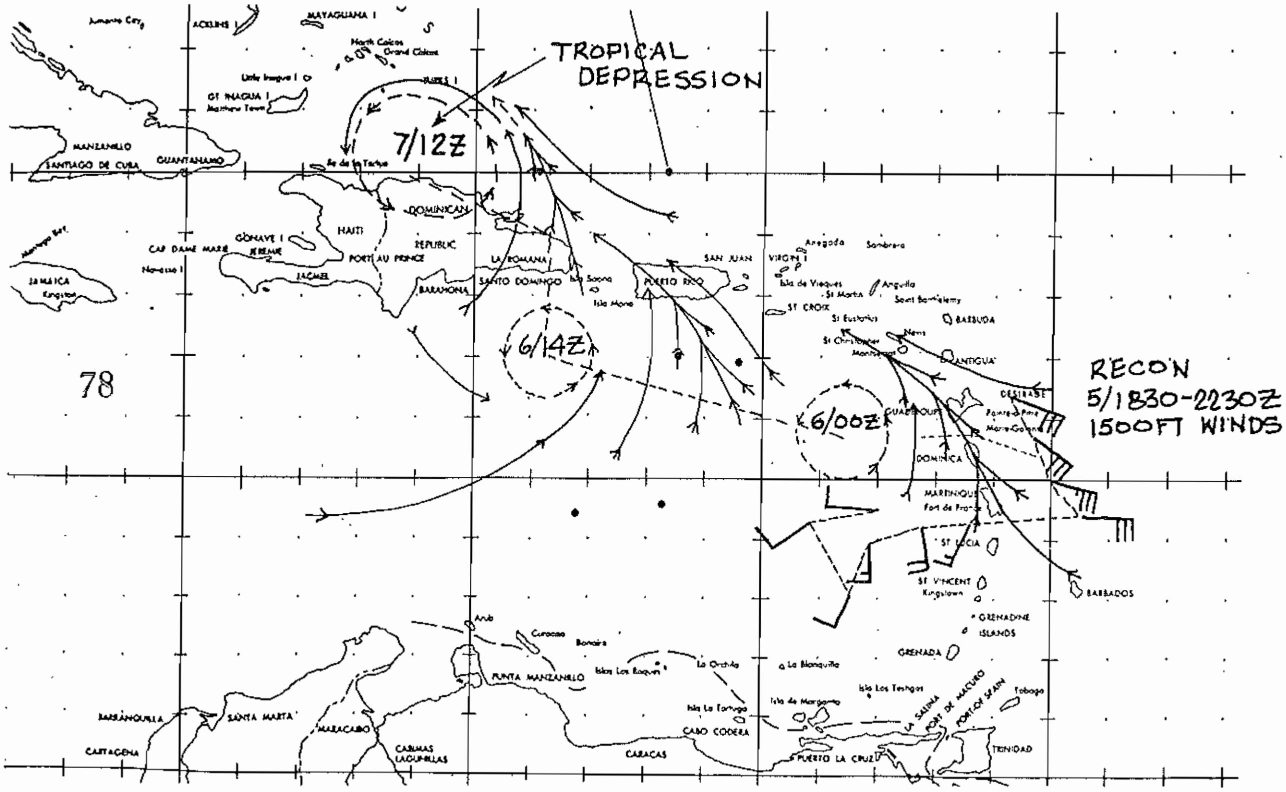
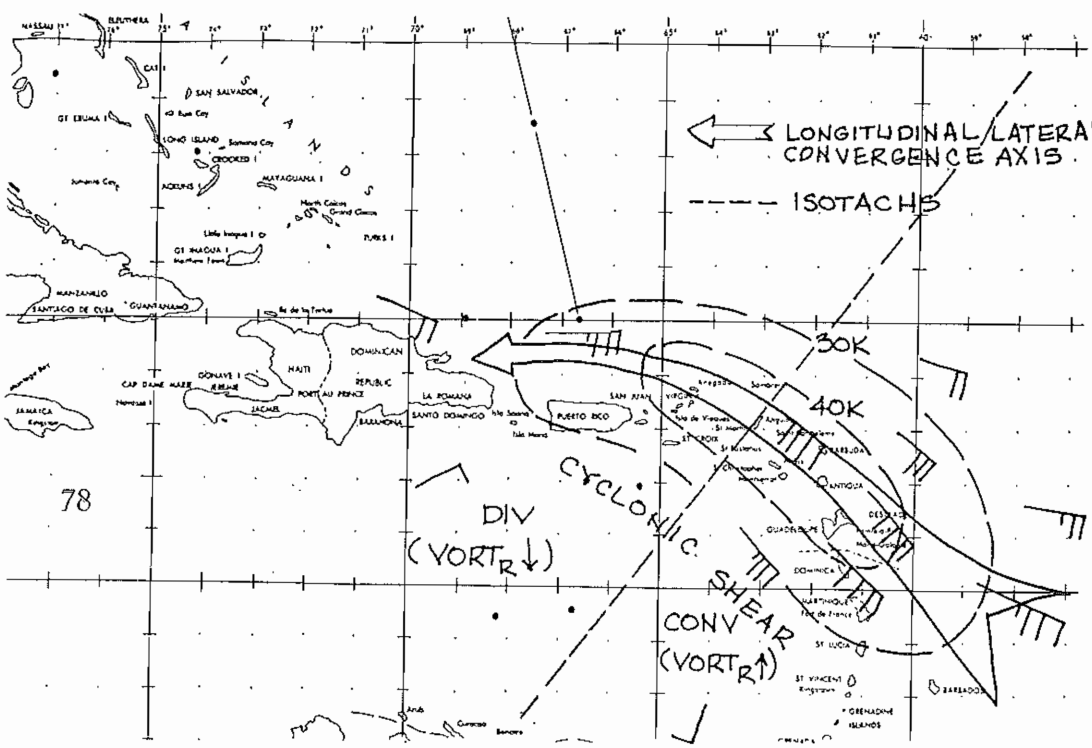


Fig. 12. Displacing quasi-circulation center and primary confluent asymptote derived from observational data/satellite interpretation (5-7 October 1985).



Fig, 13. Modeled pattern (October 5-6, 1985) of low level wind speed maximum: Quadrants of Convergence/Divergence related to changes in relative vorticity.

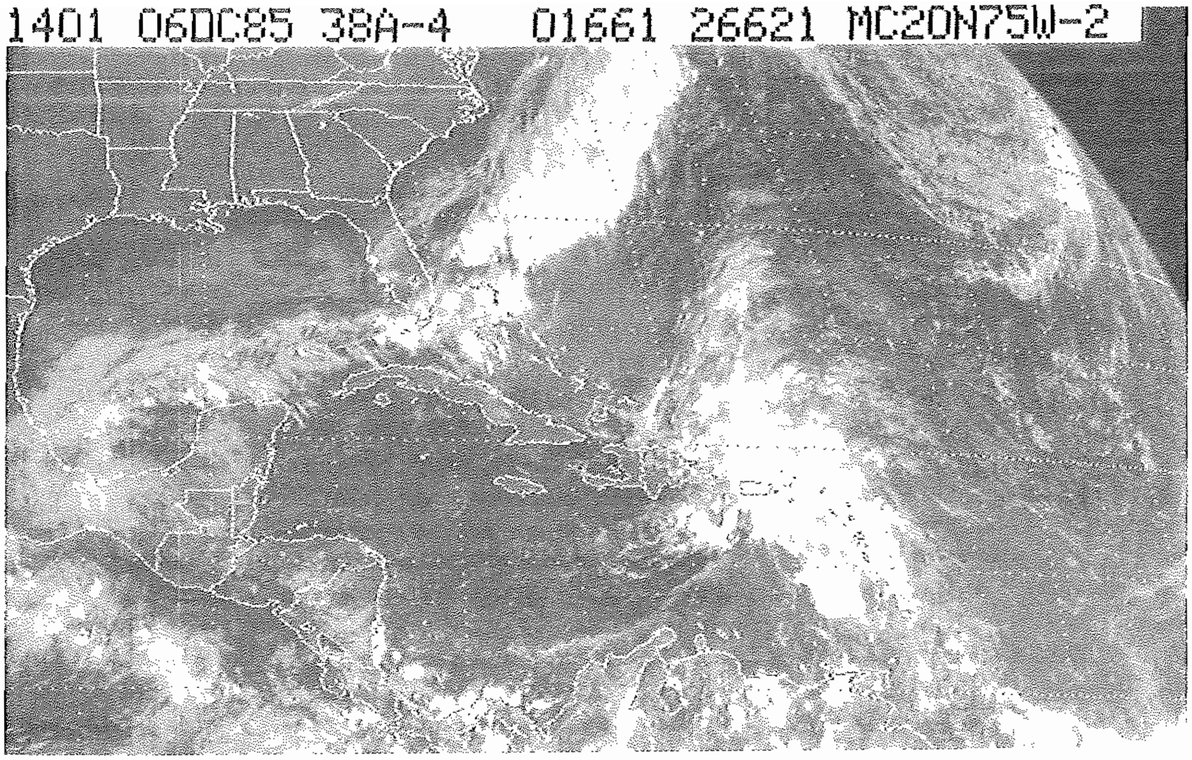


Fig. 14. GOES visual imagery at 1400 GMT on 6 October 1985 showing apparent vortex near 16.9N 68.7W.

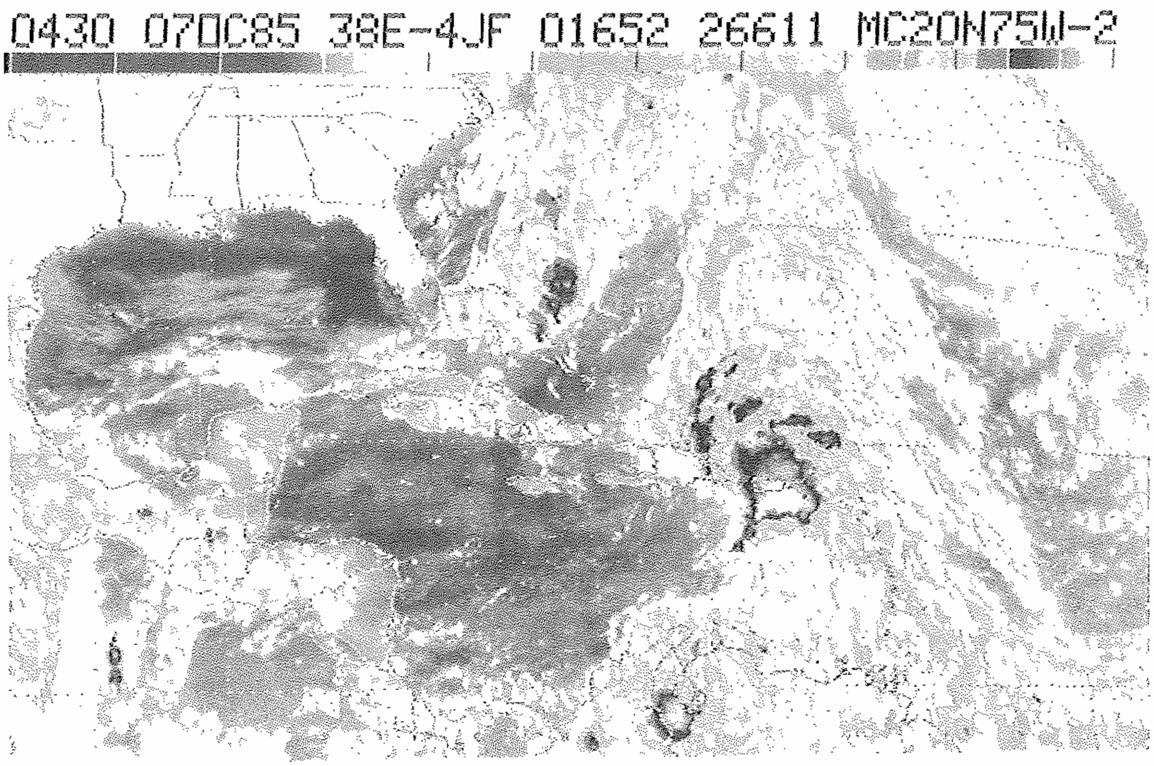


Fig. 15. GOES IR (JF Curve) imagery at 0430 GMT 7 October 1985 depicting thunderstorm complex over southern Puerto Rico and convective signature formed by twin asymptotes of convergence.

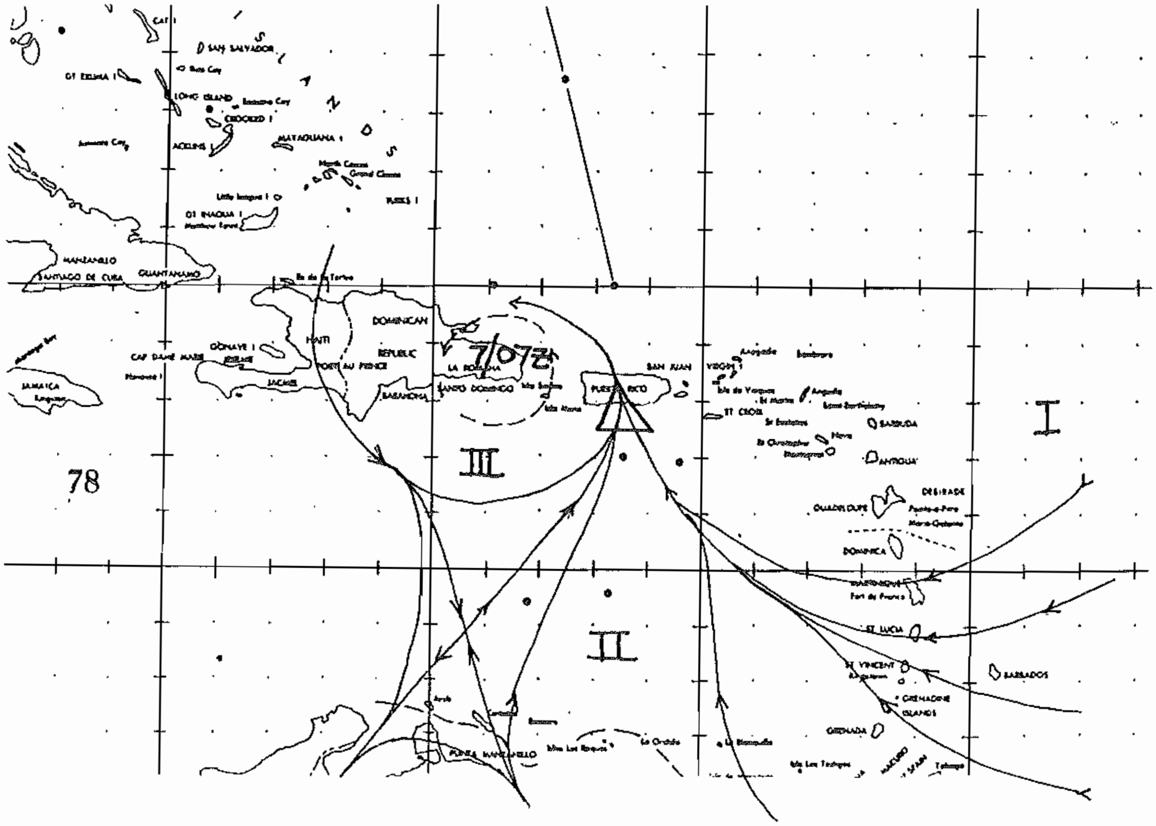


Fig. 16. 0700 GMT 7 October 1985. Horizontal, low-level, wind field depiction of three flow sectors: (I) subsiding Atlantic ridge, (II) southerly equatorial, (III) vortical. Streamlines of intersecting asymptotes and location of delta shaped pattern.