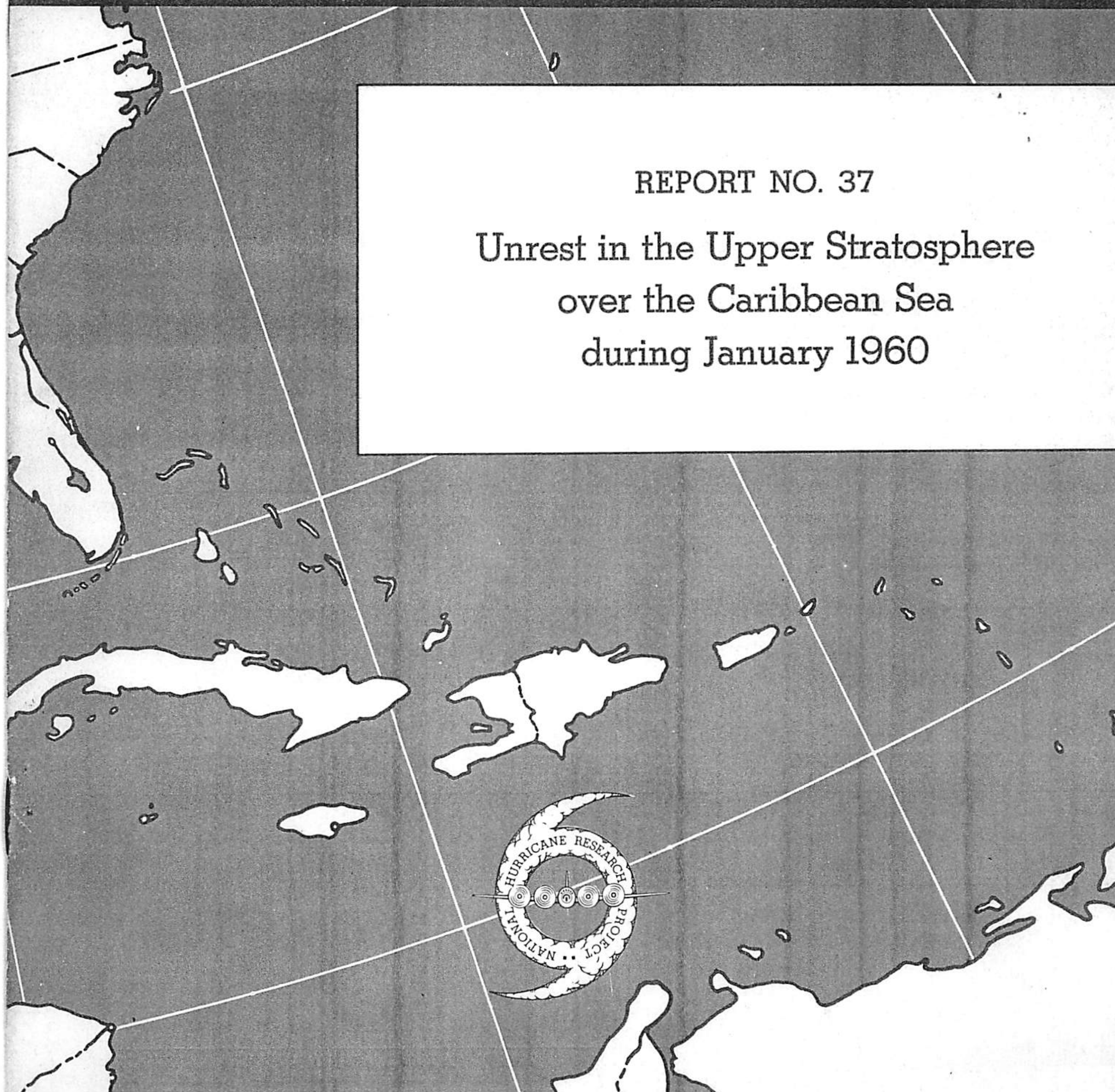
NATIONAL HURRICANE RESEARCH PROJECT

REPORT NO. 37

Unrest in the Upper Stratosphere over the Caribbean Sea during January 1960



U. S. DEPARTMENT OF COMMERCE
Frederick H. Mueller, Secretary
WEATHER BUREAU
F. W. Reichelderfer, Chief

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Unrest in the Upper Stratosphere over the Caribbean Sea during January 1960

by
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NATIONAL HURRICANE RESEARCH PROJECT REPORTS

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UNREST IN THE UPPER STRATOSPHERE OVER THE CARIBBEAN SEA DURING JANUARY 1960

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ABSTRACT

Wind observations were taken at a network of stations around the Caribbean from 100,000 to 120,000 feet altitude in January 1960. After an initial period of strong but variable easterly winds a large disturbance emanated from the equatorial zone with structure similar to what is observed in the low troposphere during the hurricane season. The history of this equatorial shearline is described.

1. INTRODUCTION

From observations of volcanic dust clouds and occasional balloon ascents it has become well established that steady, strong easterlies prevail in the stratosphere over the summer hemisphere Tropics. The outstanding circulation feature of the winter hemisphere is the "polar-night" jet stream, a westerly current. Between these two systems a transition zone must exist where, as noted by Riehl [1], the wind field may be unsteady.

Opportunity to observe the winds in this transition zone for several weeks arose during January 1960 in the Caribbean. Prior to this time only occasional and isolated balloon ascents in different parts of the Tropics penetrated to the altitude range 110,000-120,000 feet (7 to 5 mb.). The Cooperative Hurricane Rawinsonde Observation Network (fig. 1), organized in 1957 to provide upper-level data as an aid to hurricane forecasting and research under the National Hurricane Research Project, offered the means to provide possible insight into the instantaneous flow structure and its time variations at these altitudes, provided special balloons were made available to the stations for reaching the desired heights.

Decision to use the Caribbean Cooperative Network for the purpose of securing observations in the altitude range 110,000-120,000 feet was made when the late Dr. Marcel Schein, Department of Physics, University of Chicago, required flights of several very large balloons at these heights in the Tropics for cosmic-ray measurements. This balloon-launching program, called "Skyhook 60" by the U. S. Navy, was sponsored by the Office of Naval Research and the National Science Foundation; it was carried out in collaboration with numerous laboratories in the United States and abroad.

Because of inflation and launching problems the cosmic-ray measurement balloons were to be released from an aircraft carrier to obtain a no-wind condition at the surface. For the purpose of estimating the trajectory of the balloons, it was necessary to know the wind field at operating altitude over a large area. The U. S. Weather Bureau agreed to take on the task of organizing suitable meteorological balloon ascents during and for some time prior to the time of the actual carrier operation. Three hundred and sixty rubber balloons of 1200 grams were obtained and distributed to the stations encircled in figure 1. In addition, Dr. Schein arranged for ascents of plastic tracer skyhook balloons once daily at San Juan, beginning 15 January 1960. On 21 January the carrier U.S.S. Valley Forge arrived in Puerto Rico and soon thereafter moved to its initial operating area near the Lesser Antilles.

Considerable difficulties were encountered regarding treatment of the 1200-gram balloons, including proper inflation, free lift, and determination of the proper calibration of the pressure switch at very low pressures. These problems will not be discussed here. This is a preliminary note for the purpose of reporting on the principal meteorological features observed. Complete analysis, including recalculation of heights from the original data, has been scheduled. Justification for the present note rests with the fact that space and time continuity of the winds was such as to render it unlikely that instrumental and evaluation errors completely vitiated the picture of the field of motion. Further, the cosmic-ray balloon, tracked continuously by aircraft, moved in conformity with the winds indicated by the weather balloons.

It should be mentioned that Mr. Sidney Teweles, U. S. Weather Bureau, Washington, D. C., extracted 10-mb. data for January 1958 and 1959 for the Caribbean area and placed them at the authors' disposal. The 10-mb. level is situated near the base of the layer here to be treated. Analysis of these charts proved very helpful in anticipating the type of circulation changes which might occur.

2. EQUATORIAL SHEARLINE

During the period 15-27 January the wind field of the upper stratosphere was easterly; figure 2 typifies this regime. It is unknown whether the easterlies were continuous with those of the summer hemisphere. Since the data suggested a velocity maximum in the Caribbean on several of the days, with speeds up to 120 kt., this may not always have been the case. The subtropical ridge was located near 25°N., determined by numerous ascents over Florida and the Missile Range stations of the northern Bahamas. Thus, in outline, the flow pattern resembled that of the surface and differed sharply from the high troposphere, where normal strong westerlies prevailed.

From vertical time sections of the upper winds, as exemplified by those for San Juan (fig. 3) and Curaçao (fig. 4) it is clear that the stratosphere did not act as a body. A marked change occurred near 95,000 feet where a low-stratospheric regime of light winds gave way to a strongly baroclinic current higher up. Changes in wind direction at times were simultaneous throughout the layer above 80,000 feet. At other times, the stratosphere above 100,000 feet acted quite independently. Thus the early hope of using winds at 80,000-90,000 feet, when the balloons failed to go higher, was largely invalidated and could not be depended upon. Correlation of the high stratospheric flow with that of any layer in the troposphere also was not readily apparent. But the connection, if any, may well be of a subtle rather than of an obvious nature.

Figures 3-4 show that the high stratosphere was anything but steady. Wind direction and speed were variable, and speeds of tropospheric jet stream strength occurred several times. Maximum speeds of 115 kt. were measured by the Skyhook ascents at San Juan, and other stations reported speeds nearly as great. The existence of macroturbulence in the upper stratosphere is in itself a very interesting phenomenon. During the easterly regime several surges of high energy appeared to travel westward rapidly. After 27 January a large disturbance moved into the Caribbean area. It was possible to observe some aspects of its structure, time and distance scale, and propagation rate. Two similar events had been indicated by the 10-mb. charts for January 1959.* Therefore, the charts during the period of the expedition were analyzed with intent to discover this development as early as possible, if indeed it should materialize.

In 1959, first indication of the approach of high-stratospheric disturbances was the turning of winds to west or southwest at the stations along the South American north coast (fig. 1). Therefore these disturbances may have originated in the equatorial zone of South America or even farther south. On 28 January 1960, 0000 GMT, the first warning of the approach of a disturbance came when the Curaçao wind suddenly subsided (fig. 4), when strong easterlies appeared in the Florida-Bahamas area where the subtropical ridge had been located earlier, and when the Trinidad wind shifted to southwest just below the 10-mb. level, the top of the run. The pattern, therefore, was similar to that of 1959. Twelve hours later Curaçao was southwest, San Juan had dropped from 110 to 60 kt., St. Maarten and St. Andres reported light winds, and in the Lesser Antilles the balloons ending at lower altitudes had marked shear toward west in the top layer. All this suggested the arrival of a shearline from the south, oriented ENE-WSW (fig. 5). The model of figure 5 was borne out by subsequent data. It resembles the disturbances of January 1959, except that the in latter month the orientation was somewhat more east-west in both of the cases which occurred.

Surprisingly, then, we encounter a high-stratospheric disturbance which, except for the high speeds, has a structure similar to that of equatorial shearlines found at low levels during the hurricane season, occasionally in the Atlantic (fig. 6) and frequently in the western Pacific. The structure of the low-tropospheric disturbances and their role in the general circulation has been related to surface heat sources and surface frictional drag, whereas the heat source for the upper stratosphere is at the altitudes being considered and, even more so, higher up.

Temperature decreases with height in the low troposphere where the lapse rate is unstable with respect to the moist-adiabatic motion in situations as in figure 6; in the high stratosphere temperature generally increases upward. In spite of this fundamental difference, and the fact that a solid surface is missing at high levels, figures 5 and 6 are quite similar, a fact of more than casual interest.

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*Based on very sparce data, there is a suggestion that January 1958 passed without shearline occurrence.

The equatorial shearlines of January 1959 moved northward across the Caribbean at rates of 7-10 kt., which also corresponds to the rates of displacement observed on the average for low-tropospheric shearlines of the warm season. In January 1960 the propagation rate was much faster; it averaged 16 kt. between figures 5 and 7. On 29 January (fig. 7) most Caribbean stations had westerly wind. At Swan Island, the direction was turning toward west at the top of the run, while at Grand Cayman the easterlies were subsiding rapidly and, in the Atlantic, a skyhook tracer balloon sent up by the U.S.S. Valley Forge moved on a clockwise trajectory toward east. These data tie down the shearline position quite well.

Subsequent to the surge of the equatorial westerlies on 28 January the shearline (fig. 10) slowed down and moved at rates comparable to 1959. Observations were few on 30 January (fig. 8), but on 31 January (fig. 9) the line could be located with fair accuracy from the 180° windshift between Patrick AFB and Bonefish Bay, and by the virtual disappearance of easterly wind at Merida. Outstanding on 30 January was the rapid return of the winds to an easterly direction and the constriction of the westerlies, so broad on 29 January, to a very narrow zone. In this respect the situation differed notably from 1959 when the westerlies once established, persisted for 10 days at the 10-mb. level.

3. CONCLUSION

The observations of January 1960 have demonstrated that macroturbulence exists in the upper tropical stratosphere of the winter hemisphere, and that certain disturbances encountered in many respects resemble low-tropospheric equatorial shearlines of the hurricane season. It appears plausible to connect the occurrence of the macroturbulence with poleward heat transport requirements. In contrast to the summer hemisphere, the polar stratosphere of winter is a cold source, and the atmosphere may attempt to minimize the poleward temperature gradient just as at low levels. If so, the series of charts indicates that this may be accomplished by large-scale horizontal disturbances in the daily wind field. It is not obvious whether this is really the case. Temperatures at 10 mb. have been plotted on all charts. This was the highest level transmitted; temperatures to the top of the runs will be evaluated in the post-analysis. The 10-mb. temperatures were rather irregular, and no firm conclusions can be drawn about heat flux. It may be that the irregularities result from errors in the soundings. Inspection of the complete ascents at San Juan, however, indicates that this may not be the case, and that the irregularities may disappear largely if layer-means of temperature are computed over limited isobaric thicknesses.

While the heat flux picture is as yet uncertain, it is obvious that the shearline acted as a mechanism for poleward eddy transport of absolute angular momentum; the same holds for comparable situations at low levels (fig. 6). In the latter cases the disturbances are connected with the surface; there are deep penetrations of convective clouds. Their orientation and momentum transport property is thought to be related to the broadscale distribution of surface stress. No such statement can be made readily for the stratosphere. It is recognized that, because of the low density, the actual momentum transport is very small compared to that at higher density. But the transport may be viewed in the context of balance requirements within the upper stratosphere. On account of the high stability only slight vertical displacements can occur. Moreover, it is generally known that atomic material thrown to great heights remains there for time periods which are orders of magnitude greater than those in question here. Of course, one disturbance in the Caribbean does not permit computation of a line integral around the globe. Nevertheless, an interesting order-of-magnitude estimate can be made, and it remains to be seen whether vertical stresses in the polar-night jet stream are sufficiently large to remove the momentum imported from the Tropics to lower altitudes.

The primary purpose of the meteorological effort was operational support for the U. S. Navy fleet units in launching the balloons and in recovering the payload. But it was hoped from the outset that the program of high-altitude observations would benefit meteorology in its own right. The authors feel that this has been partially accomplished. Clearly, the few observations here described can be viewed only as a starting point toward many facets of investigation; a starting point, however, which has revealed occurrences of such magnitude and interest that it is not considered out of place to express the hope for a much broader program of observations.

ACKNOWLEDGMENT

Special mention is due to the officials and observers of the Caribbean cooperative international network who endeavored to obtain the highest possible balloon altitudes and to assist the meteorological phase of the project to a successful conclusion in every way.

The stratospheric data were gathered at the San Juan office of the U. S. Weather Bureau, where the analyses shown in this paper were made.

REFERENCE

1. Herbert Riehl, Tropical Meteorology, McGraw-Hill Book Co. Inc., New York, 1954, 385 pp.

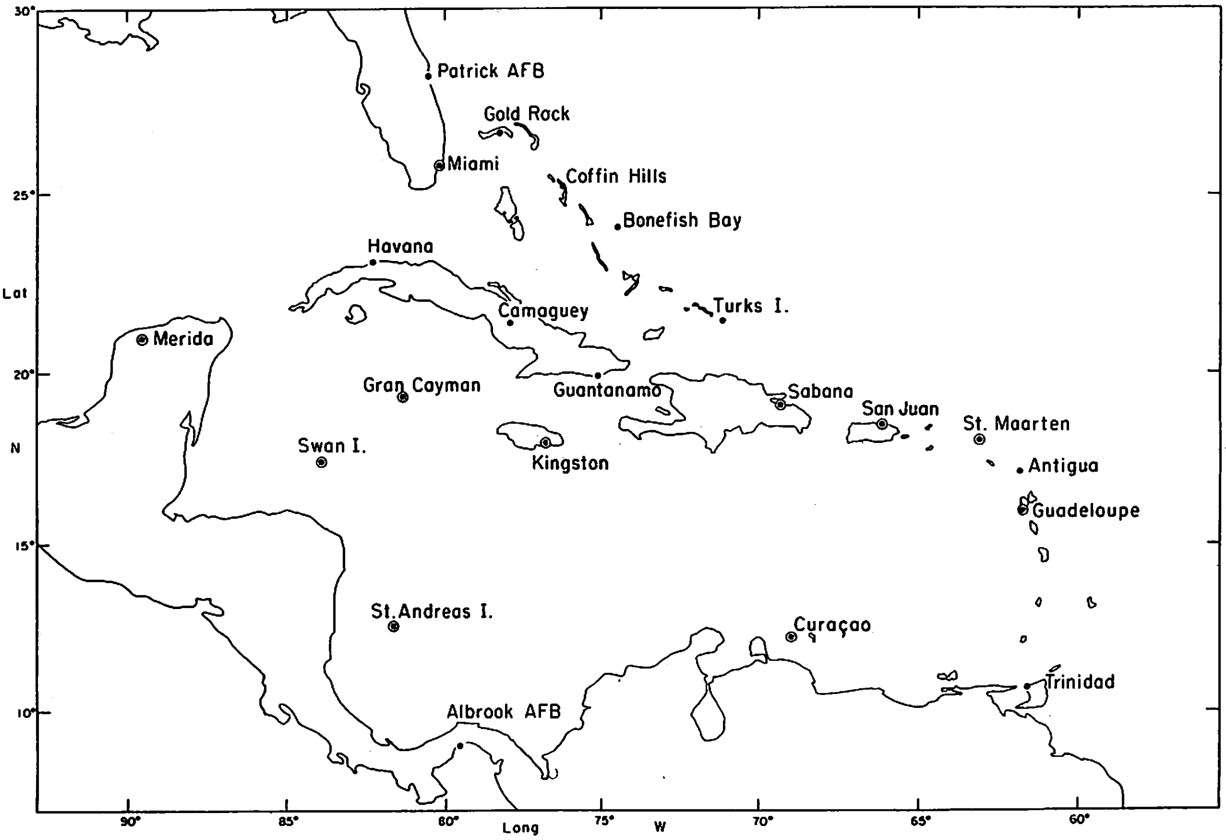

Figure 1. - Network of upper-air stations in the Caribbean area. Special 1200-gram balloons were released at the circled stations.

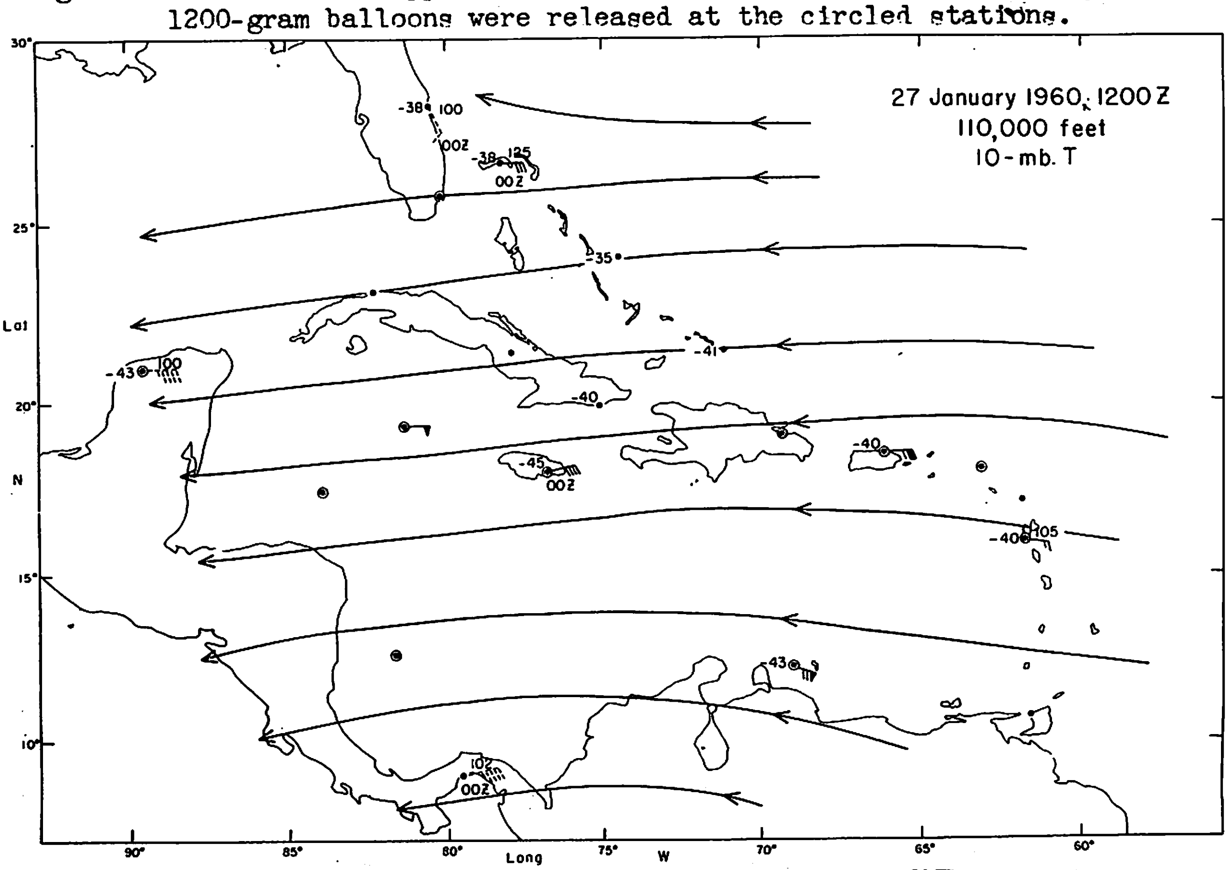

Figure 2. - Winds at 110,000 ft., 27 January 1960, 1200 GMT, and 10-mb. temperatures (°C.). Wind speed in knots. Winds ending at 100,000 ft. or lower, dashed; winds 12 hours old are marked 00Z.

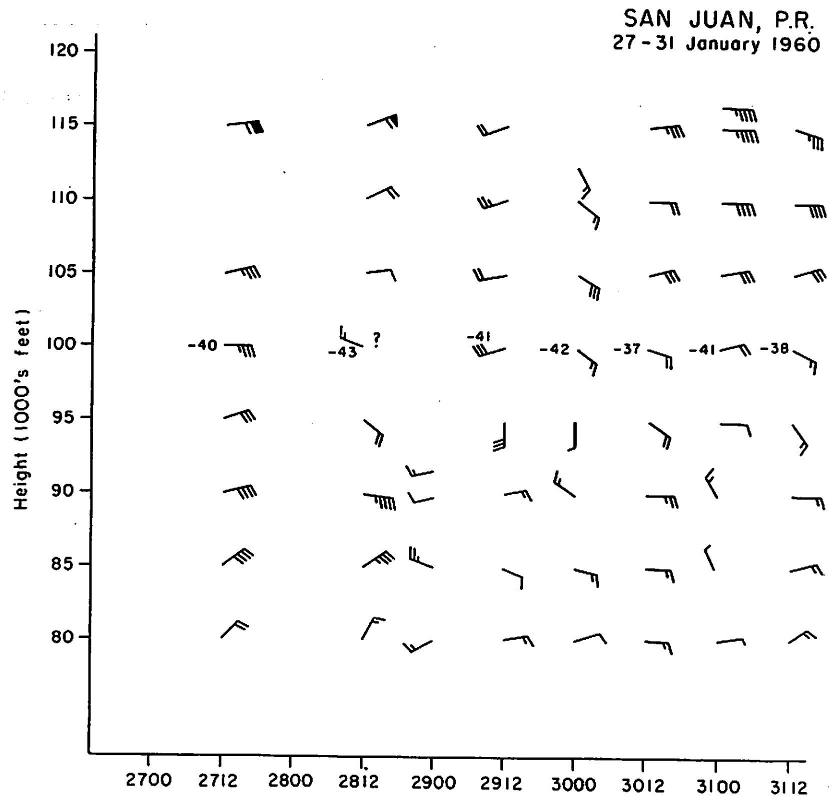

Figure 3. - Time section of stratospheric winds at San Juan, Puerto Rico, and 10-mb. temperatures, 27-31 January 1960. Notation as in figure 2.

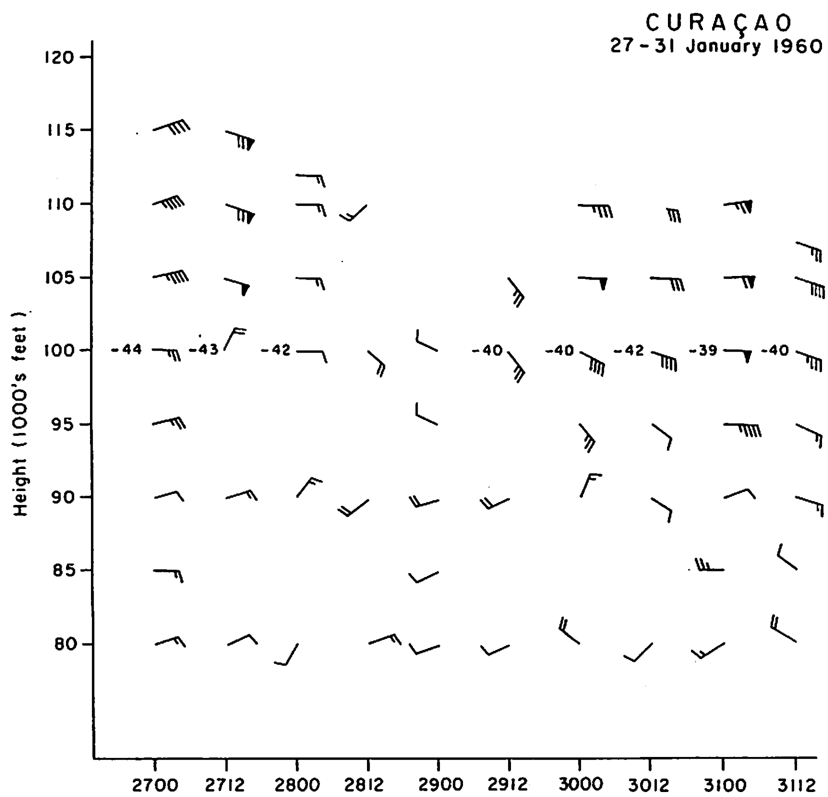

Figure 4. - Time section of upper winds and 10-mb. temperatures at Curacao, 27-31 January 1960.

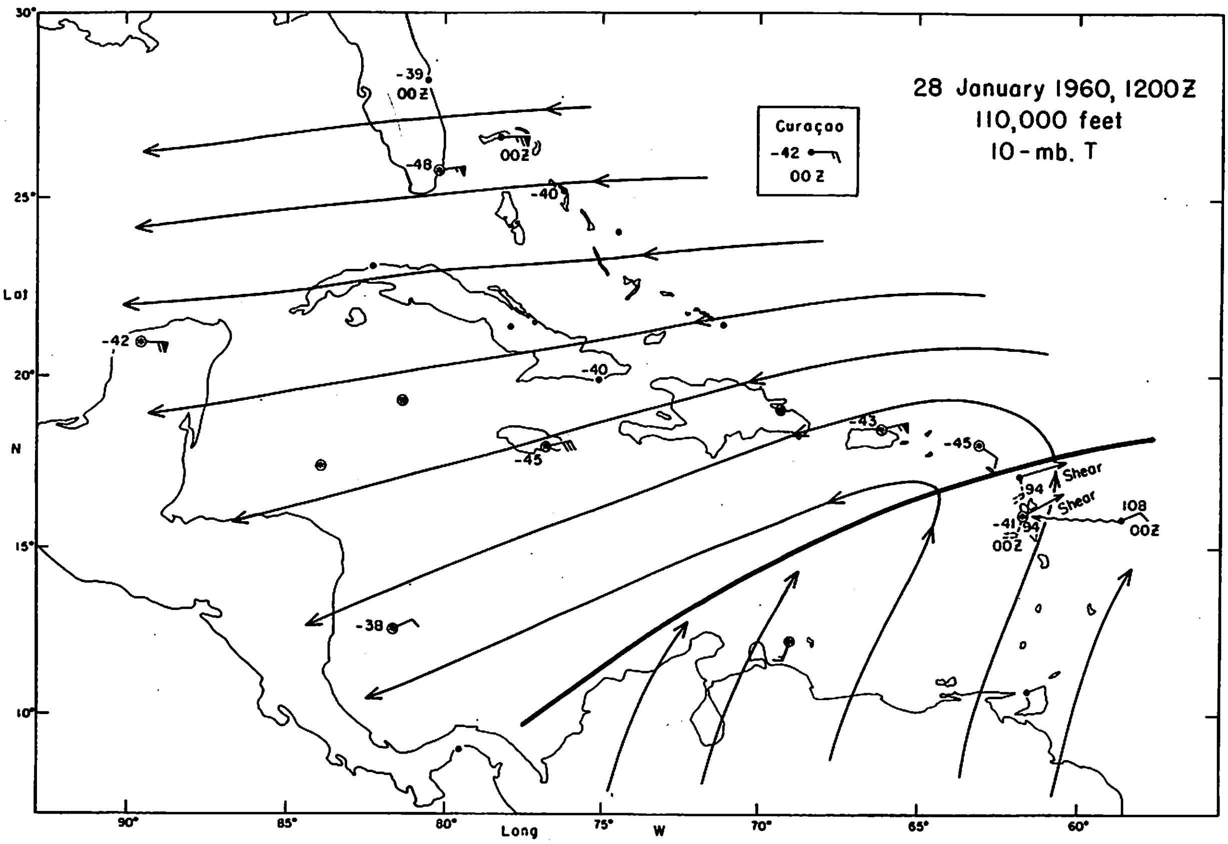

Figure 5. - Winds at 110,000 ft. and 10-mb. temperatures, 28 January 1960, 1200 GMT.

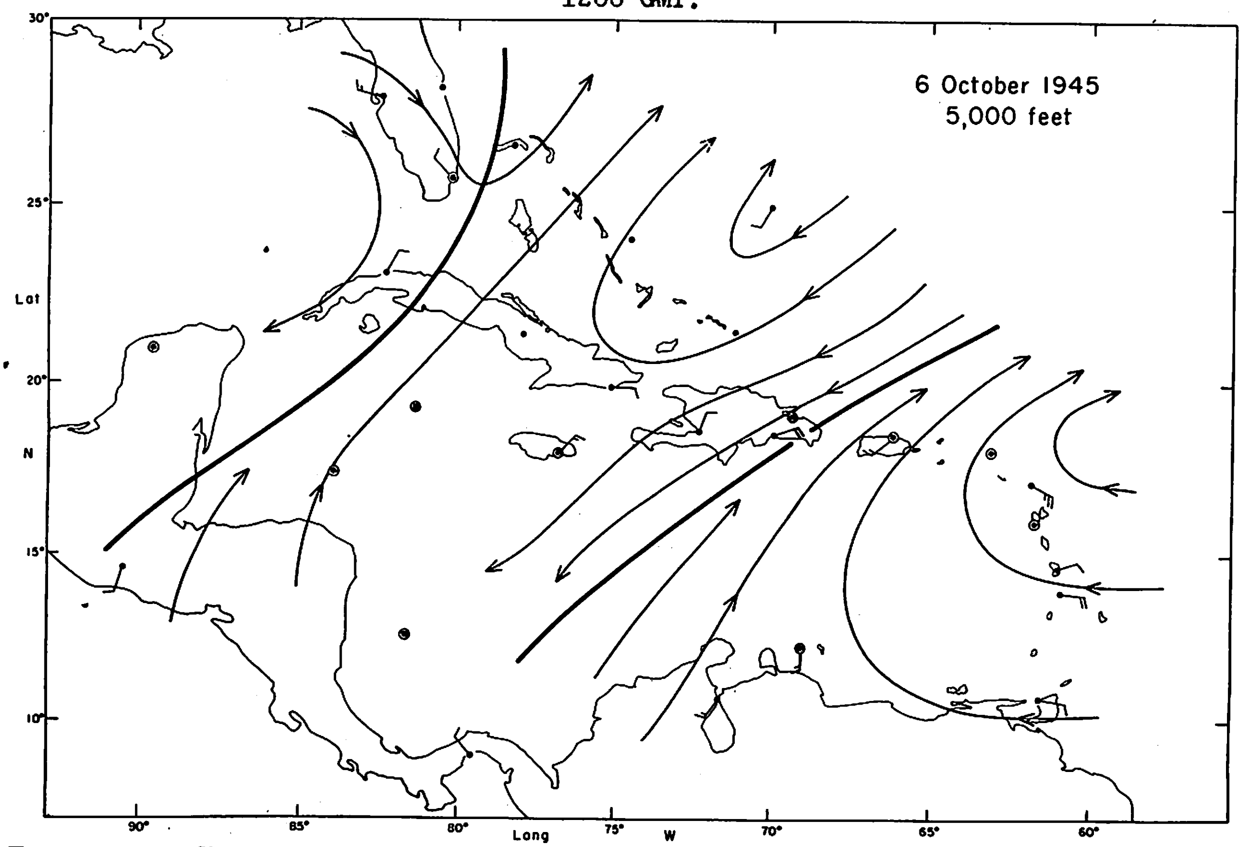

Figure 6. - Equatorial shearline in the Caribbean at 5,000 ft., 6 October 1945. (after Riehl [1])

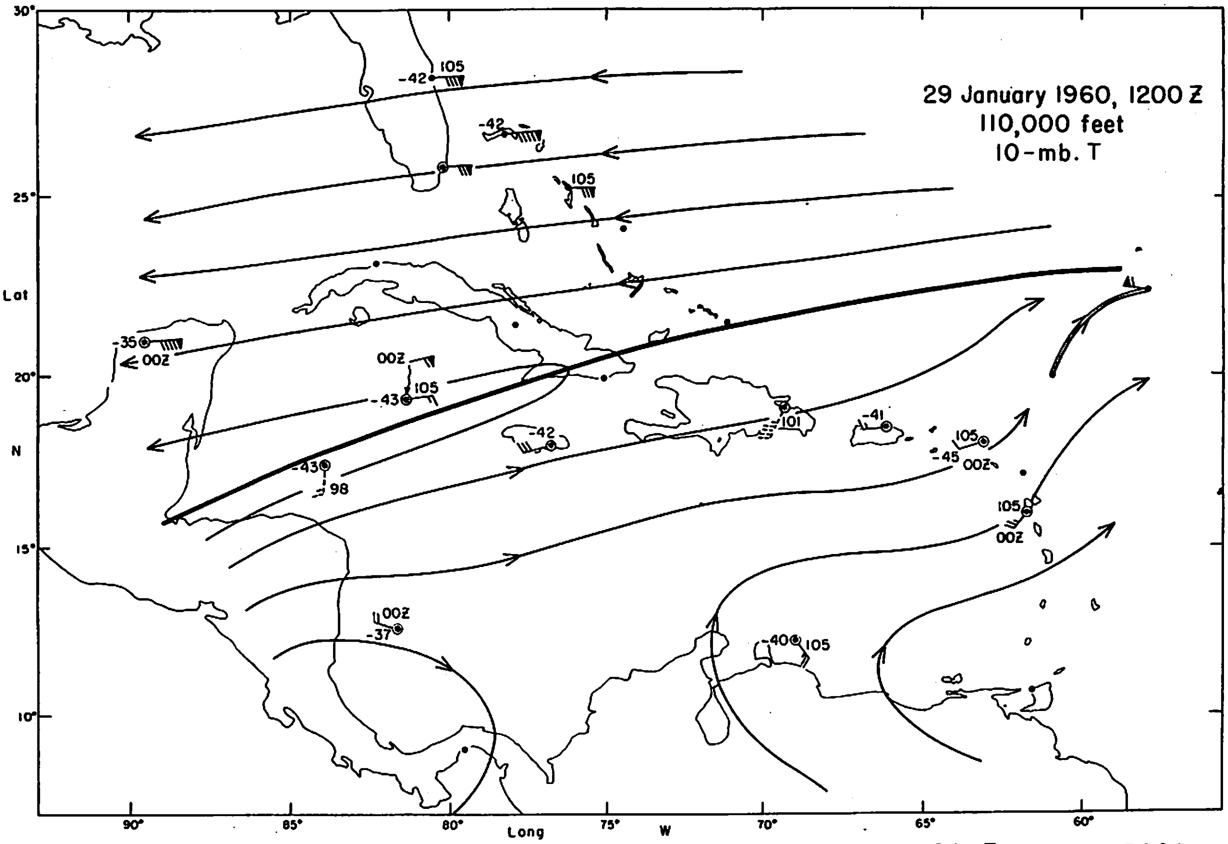

Figure 7. - Winds at 110,000 ft. and 10-mb. temperatures, 29 January 1960, 1200 GMT. Double track in Atlantic shows movement of skyhook tracer balloon as tracked by the Valley Forge.

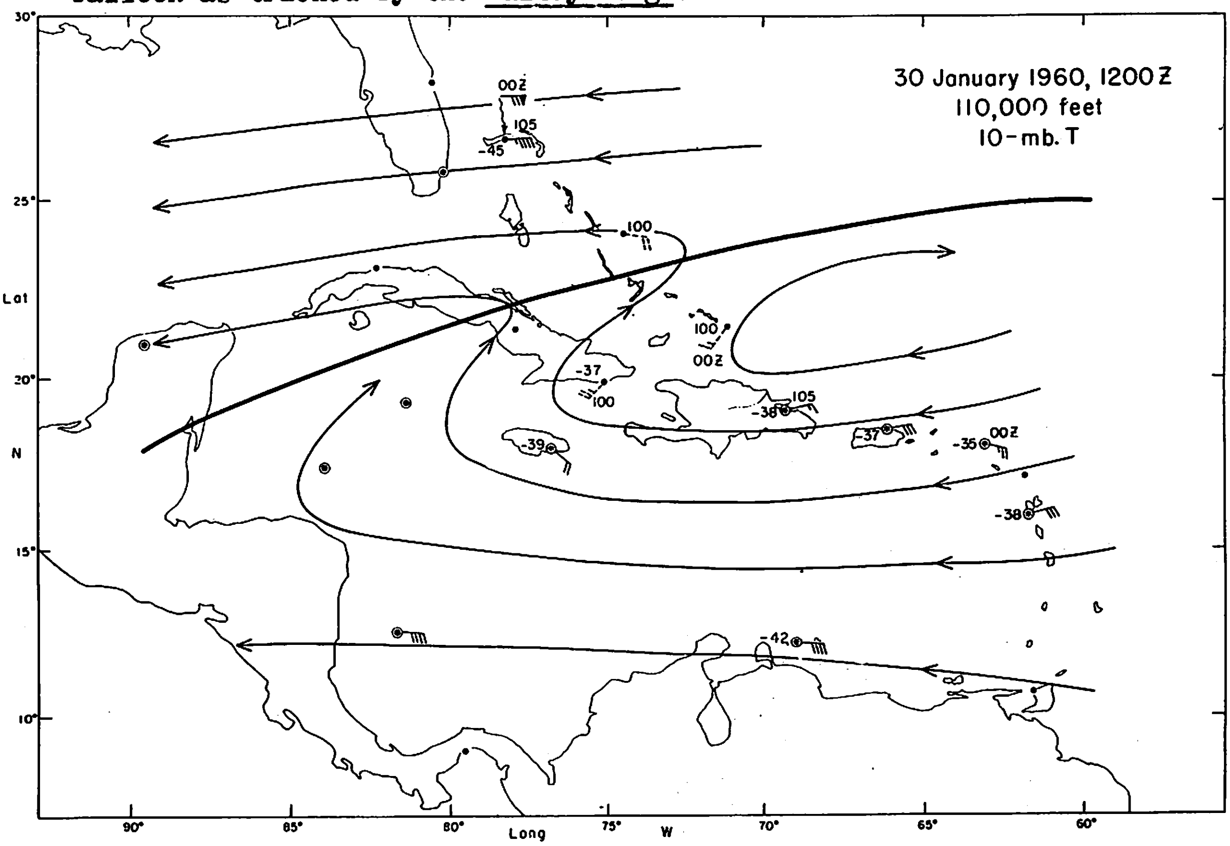

Figure 8. - Winds at 110,000 ft. and 10-mb. temperatures, 30 January 1960.

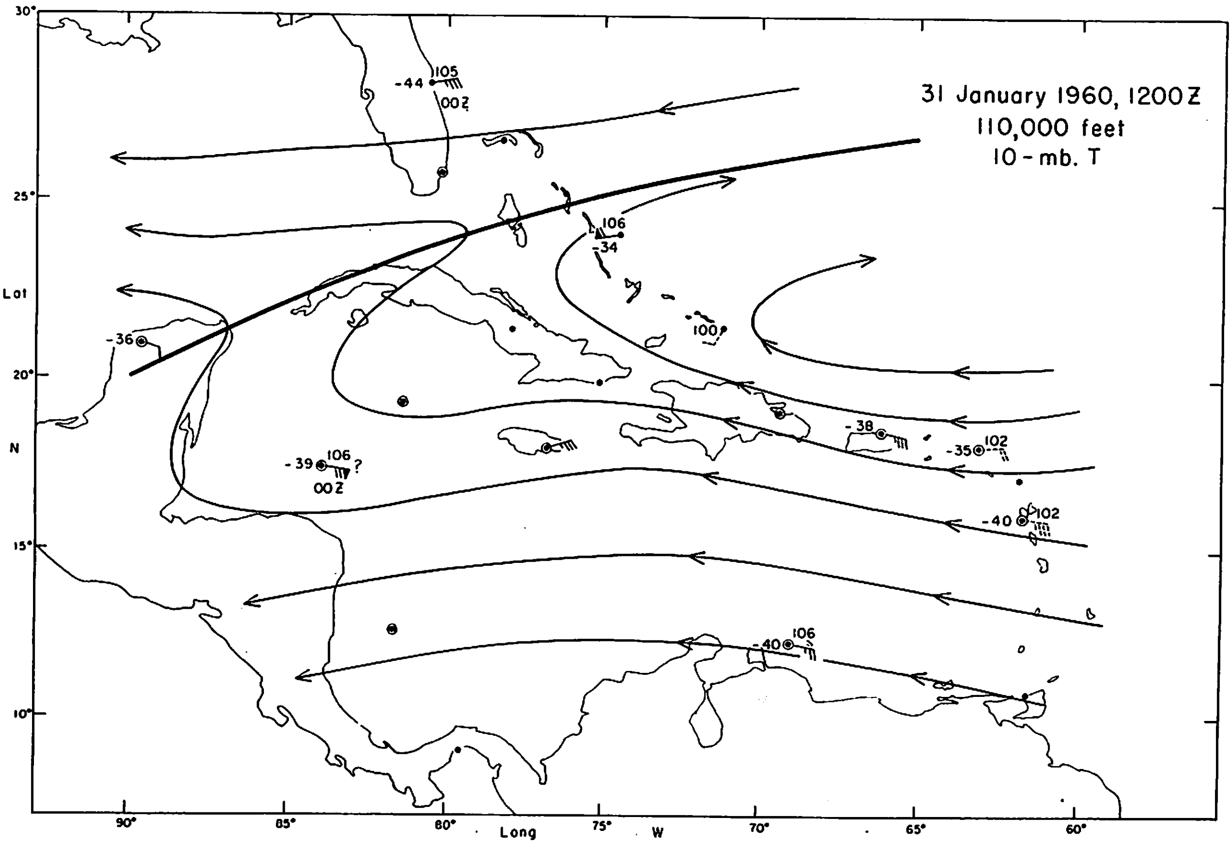

Figure 9. - Winds at 110,000 ft. and 10-mb. temperatures, 31 January 1960.

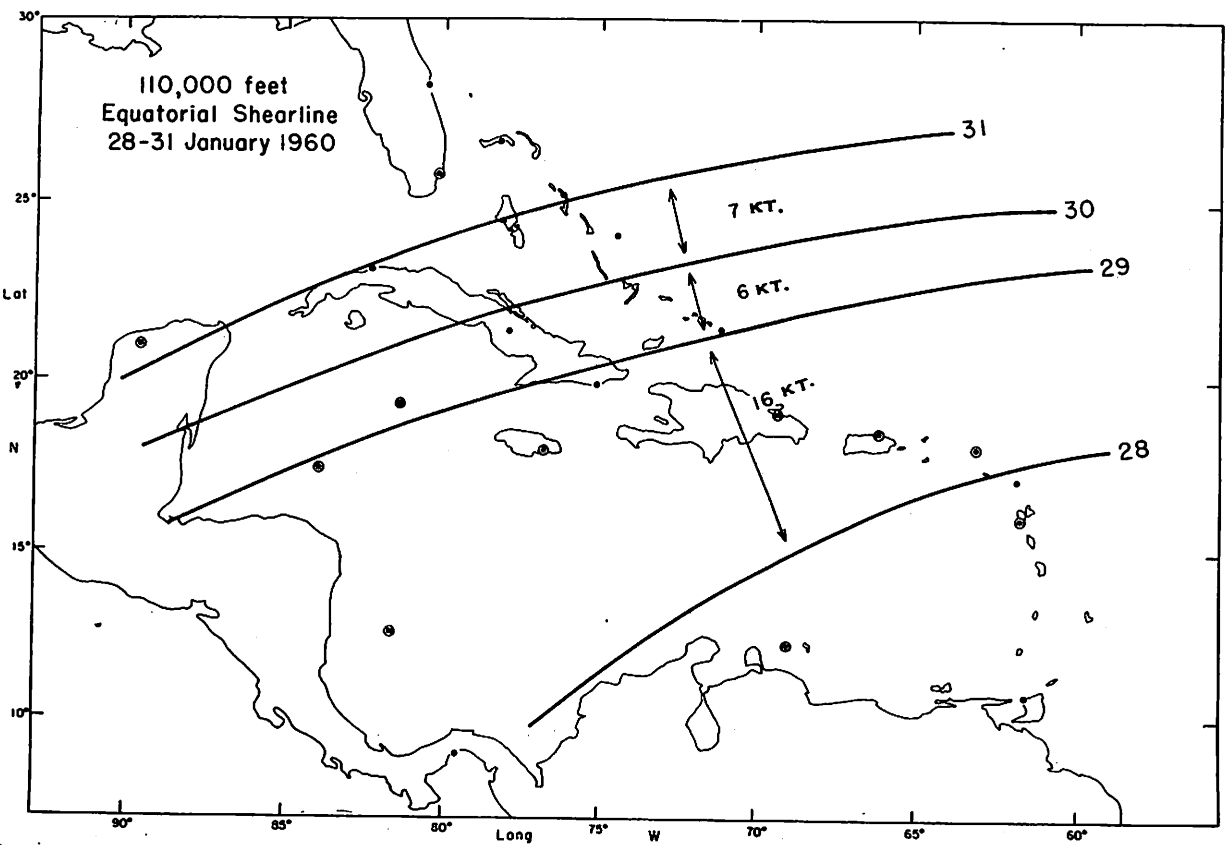

Figure 10. Successive positions of equatorial shearline 28-31 January 1960 and rates of mean 24-hour displacement (kt.).