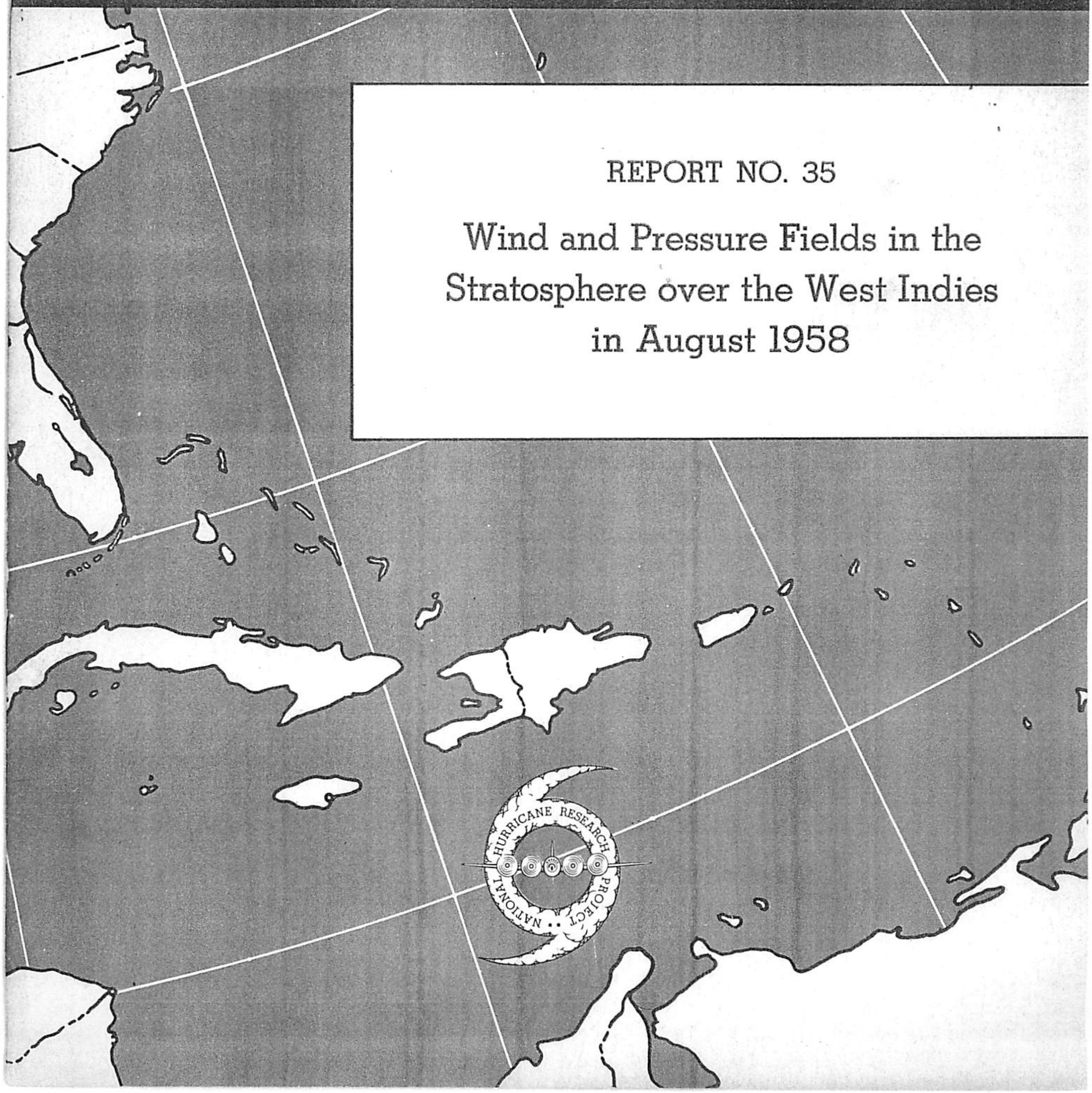
NATIONAL HURRICANE RESEARCH PROJECT

REPORT NO. 35

Wind and Pressure Fields in the Stratosphere over the West Indies in August 1958



U. S. DEPARTMENT OF COMMERCE
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Wind and Pressure Fields in the Stratosphere over the West Indies Region in August 1958

by

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NATIONAL HURRICANE RESEARCH PROJECT REPORTS

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WIND AND PRESSURE FIELDS IN THE STRATOSPHERE OVER THE WEST INDIES REGION IN AUGUST 1958

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ABSTRACT

The high-level wind and pressure fields over the West Indies area in August 1958 are investigated. In the stratosphere, at 50 mb. and 25 mb. the steady easterly flow is found to be quasi-geostrophic. Since contour analyses do not give a true picture of the wind field at these high levels, due to the inaccuracies of the pressure - height data, a method to eliminate these shortcomings is outlined.

1. INTRODUCTION

The West Indies and Gulf of Mexico area is of special meteorological interest, above all in late summer; i.e., during the "hurricane season." A good network of rawinsonde stations yields a fairly adequate coverage of upper-air data extending well into the stratosphere. In order to find out what the stratospheric flow patterns look like and whether the variations in the circulation of the upper (and lower) troposphere exercise an influence on the conditions in the stratosphere, constant pressure surfaces from 200 to 25 mb. were investigated over this area. Observations were compiled from daily teletypewriter data at the National Hurricane Research Project in West Palm Beach, Fla., where the author was located in August and September 1958.

2. METHOD OF WORK

The upper-air data used in this study do not comprise the entire month of August 1958, but are samples for a total of 12 days between August 7 and 26. This is due to the fact that it became evident very soon from inspection of all daily ascents that there were hardly any noticeable interdiurnal changes at the stratospheric levels.

For each of these 12 days, then, the wind direction and speed, pressure height, and temperature (0000 GMT) at the levels 200, 150, 100, 50, 25 mb., and higher up and at the tropopause were plotted at each station, on one large-scale base map so that the vertical gradients of

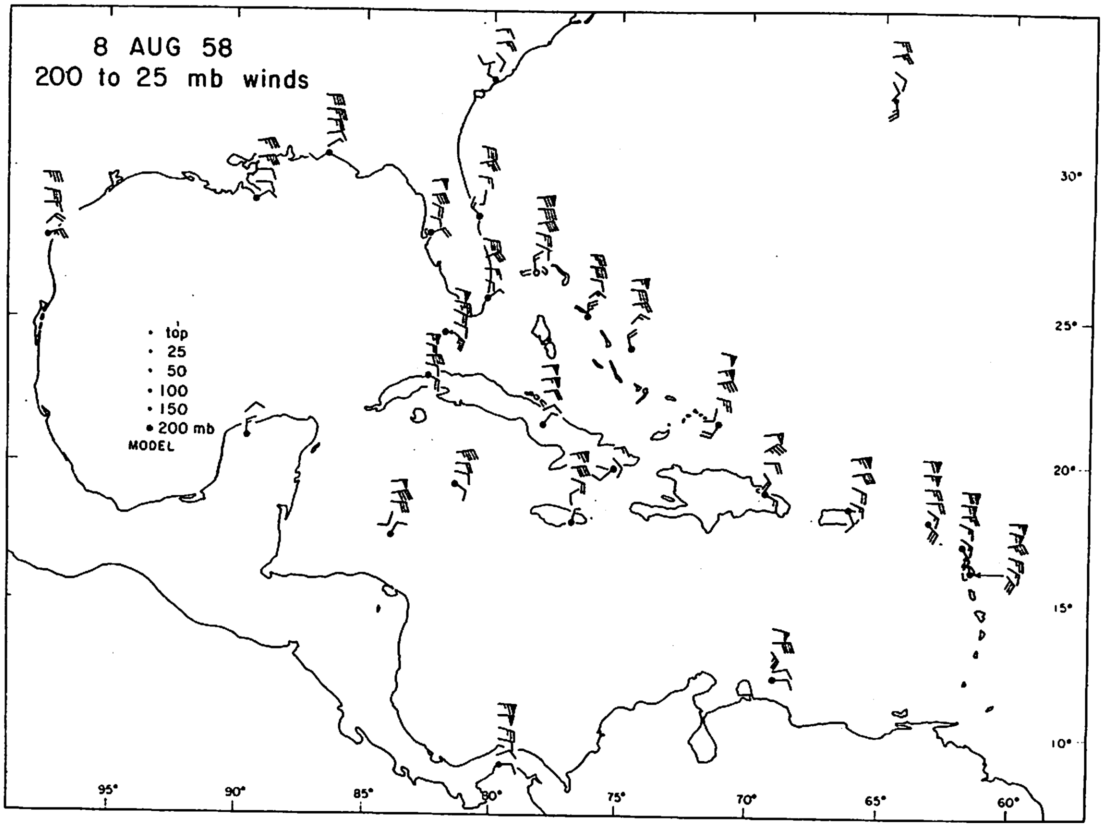


Figure 1. - Winds from 200 mb. upward plotted in ladder form, 8 August 1958, 0000 GMT. Model of ladder shown in Gulf of Mexico.

these quantities could be easily recognized. Figure 1 gives an example of this technique. Besides these large composite base maps, charts of the individual constant pressure surfaces were analyzed.

3. GENERAL FEATURES OF THE WIND FIELD IN THE UPPER TROPOSPHERE AND STRATOSPHERE

From a comparison of the observations on one day (space) and on all days (time), it appears that the stratospheric easterlies are not disturbed by processes taking place in the upper troposphere. The over-all picture in the area under consideration can be described as follows:

At 200 mb., wind speeds are rather low (usually less than 30 knots). There is a day-to-day variation in wind direction due to the changes of the flow pattern in the upper troposphere, which at this time of year is characterized by cyclones and anticyclones. The wind speed decreases with height from there to a minimum (20 to 10 knots) near the tropopause (150 to 100 mb.). The 100-mb. surface is, in most cases, in the stratosphere, and the wind there blows mostly from an easterly direction, no matter whether there is a cyclonic or anticyclonic circulation just beneath the tropopause. In the stratosphere

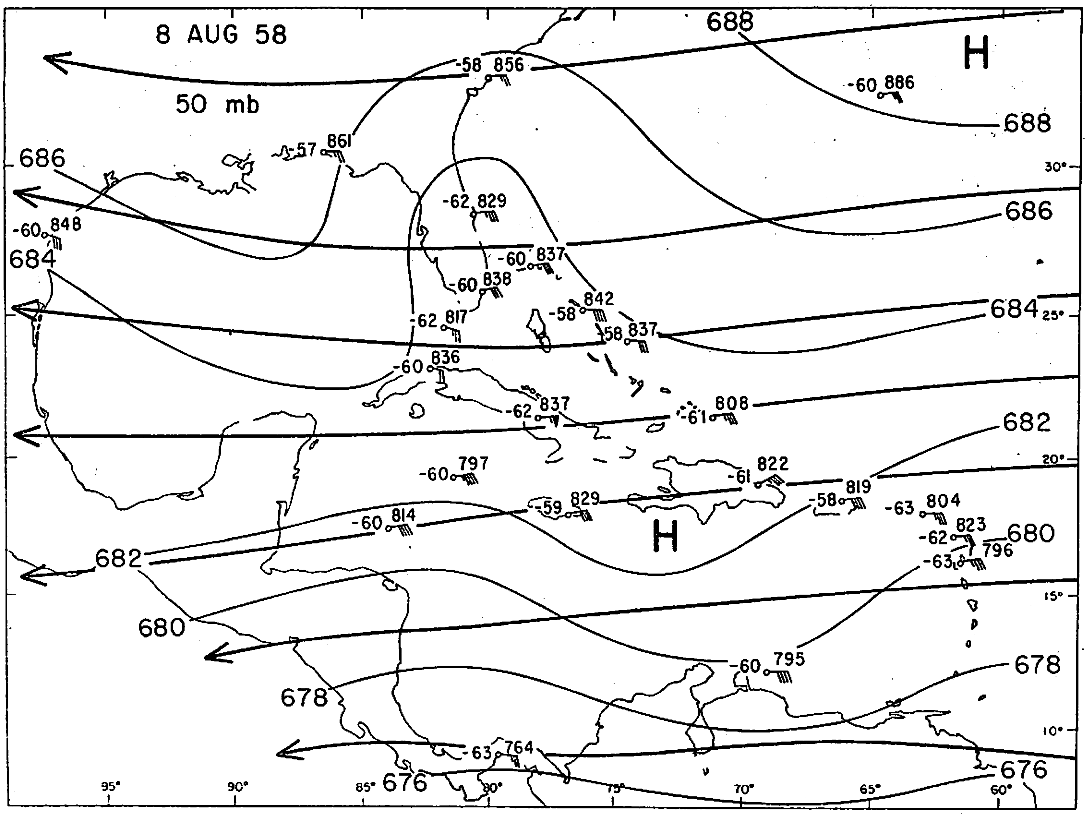


Figure 2. - Streamlines and contours (100's feet) at 50 mb., 8 August 1958, 0000 GMT.

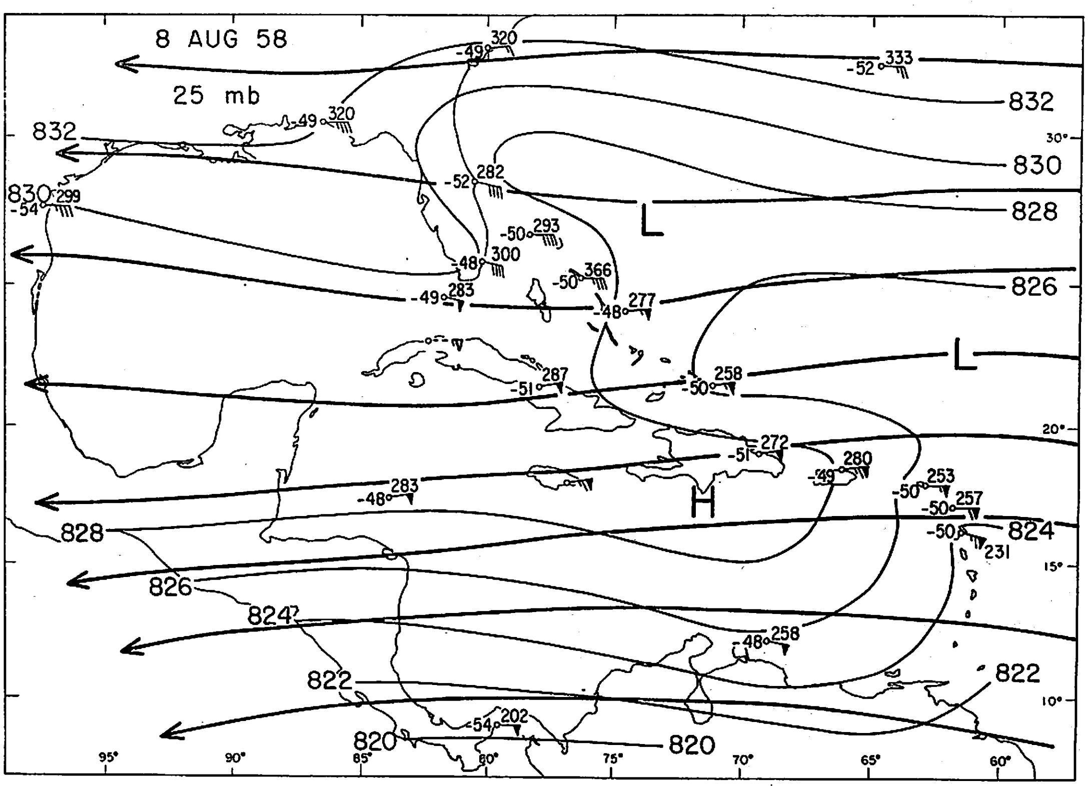


Figure 3. - Streamlines and contours (100's feet) at 25 mb., 8 August 1958, 0000 GMT.

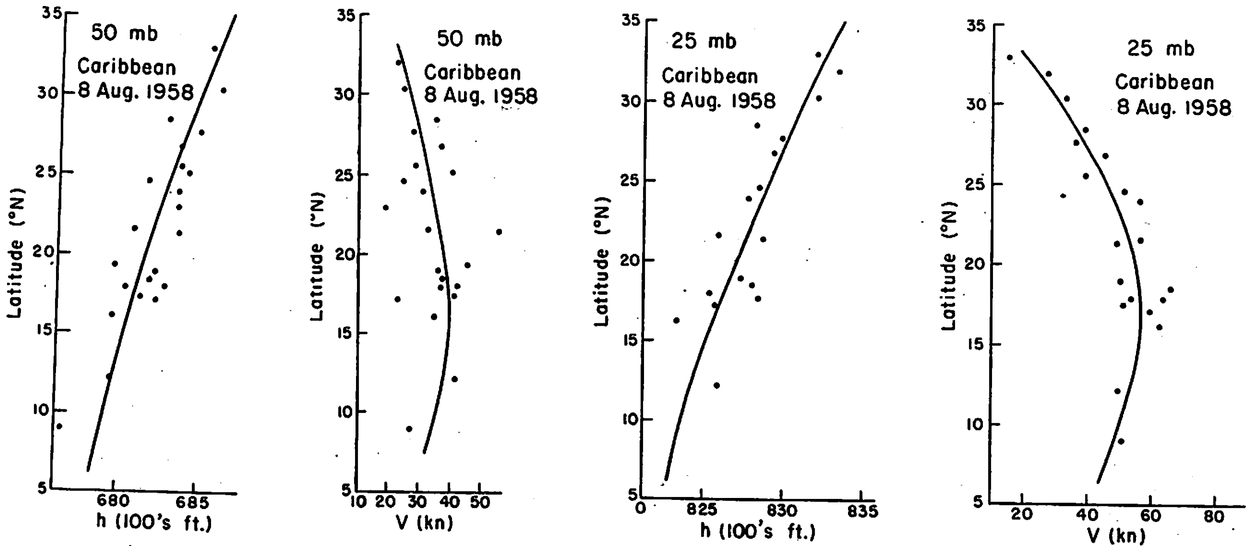


Figure 4. - North-south profiles for 8 August 1958. From left to right: 50-mb. height (100's feet), 50-mb. wind speed (knots), 25-mb. height (100's feet) 25-mb. wind speed (knots).

the wind speed increases with altitude while the variations in wind direction become smaller, reaching a minimum of ± 10 degrees from due east at 25 mb. At this level the wind speed is usually in excess of 50 knots up to about 25° latitude. Occasional runs to heights of 90,000 or 100,000 feet indicate a further increase in wind speed to about 80 knots. It would be desirable to obtain more data, especially wind reports, for surfaces as high as 15, 10, and 5 mb. in order to determine the vertical and horizontal extent of these strong stratospheric easterlies, which may show jet stream features in a limited area.

4. PRESSURE HEIGHTS AND THE WIND FIELD

During the analyses of individual maps of the 50-mb. and 25-mb. surfaces over the West Indies area it was found that there is a striking difference between the contour and the streamline patterns. To illustrate this, figures 2 and 3 show the 50-mb. and 25-mb. contour and streamline analyses on August 8, 1958. The contours were drawn according to the heights given in the data; some pressure height reports obviously in error were recomputed. It must be realized that due to the pressure height - temperature link, small errors in the temperature measurement and evaluation will bring about pronounced errors in the height of these high-altitude pressure surfaces; these errors may be in excess of the actual changes or true diurnal variations. It is seen from the figures that the streamlines cut across the contours toward lower, as well as higher, contours, at 25 mb., at an angle of 90 degrees in places. If the reported pressure heights truly represent the actual height field, there would be strong ageostrophic components of the wind, with marked acceleration toward lower and deceleration toward higher pressure. This however, is not the case; the easterlies maintain nearly the same direction (± 10° from due east) and speed in time and space. Thus, there is

Table 1. - Geostrophic and actual wind speeds at 50 and 25 mb., 0000 GMT, August 8, 1958.

°lat.	f(10^{-4} sec.$^{-1}$)	50 mb.		25 mb.	
		v_g m./sec.	v_{act}	v_g m./sec.	v_{act} m./sec.
30	0.7	14	14	18	16
25	0.6	15	16	22	23
20	0.5	18	19	26	27
15	0.4	21	20	28	28

evidently no correspondence between the pressure field, as computed, and the wind field. This is especially true in the region with the best data coverage; i.e., along the Bahamas and Antilles. It has to be concluded that contour analysis at these levels is a rather poor means of determining the configuration of the flow pattern, because of the inaccuracies in the measurement of the mass distribution.

This brings up the question: To what extent, if any, is the height field as given by the data representative of the wind field and how can one obtain a true picture of the latter in cases where, for some reason, wind reports are not available? An answer to this question can be found by determining whether the observed wind speeds deviate considerably from the geostrophic wind.

From the foregoing it is clear that to use the pressure heights at any two points is not likely to give a correct result. Therefore, all pressure heights of the area were plotted versus latitude on one diagram, and a smoothed profile of the pressure height was obtained for the 50-mb. as well as for the 25-mb. surface. The same was done for the wind speeds. Figure 4 shows these diagrams for August 8, 1958. From the geostrophic wind equation

$$u_g = -\frac{g}{f}\frac{\partial h}{\partial y}, \qquad (1)$$

the geostrophic wind at latitudes 15°, 20°, 25°, and 30°N. was computed from the pressure profiles. In this equation, g is the acceleration of gravity, f the Coriolis parameter, h the height of the pressure surface, y the north-south coordinate, and u_g the geostrophic zonal wind. The result is shown in table 1; the actual wind speeds at these latitudes as read from the corresponding wind profiles are also given for comparison. It is seen that the deviations of the actual wind from the geostrophic wind are very small indeed (less than 10 percent) at both levels; i.e., the wind field as averaged in space is quasi-geostrophic - which the contour pattern as such (figs. 2 and 3) does not indicate.

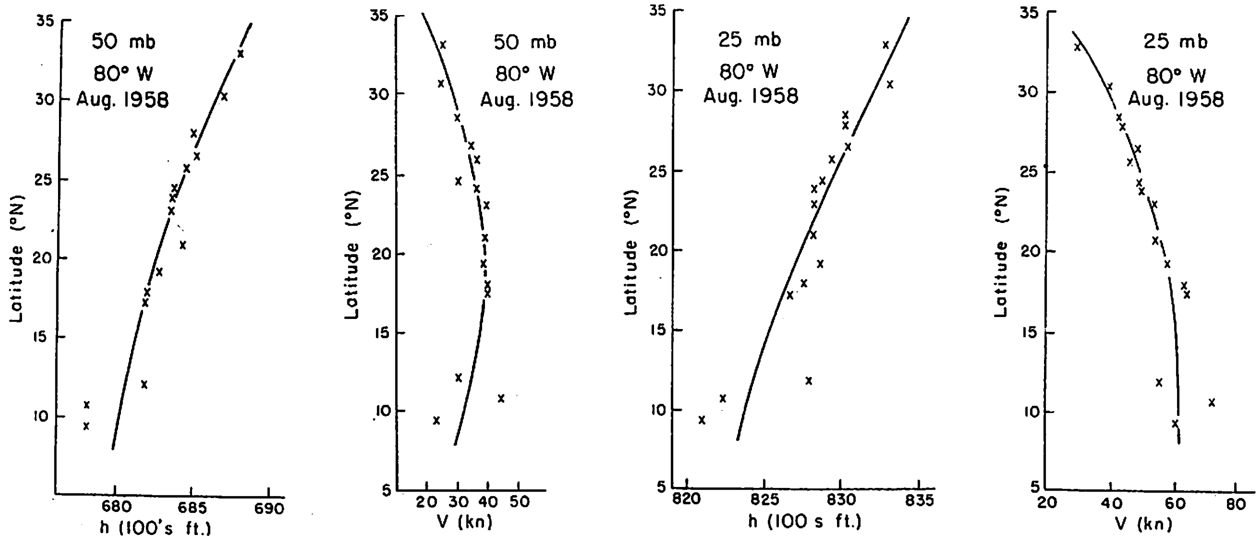


Figure 5. - North-south profiles at 80°W. for August 1958. From left to right: 50-mb. height (100's feet), 50-mb. wind speed (knots), 25-mb. height (100's feet), 25-mb. wind speed (knots).

Since in the present case all observations were put into one profile, one might feel that this method, which is practically an integration over the whole area, smooths the distribution so much that it may not be representative in separate parts of this region. As there are no appreciable changes in the wind field from one day to the next, one should expect to find quasi-geostrophic conditions over the whole period and along limited meridional belts, too. Therefore, mean diagrams were prepared using all observations near 80°W. (75° - 85°W.) (fig. 5). This longitude was chosen because it offers the largest number of data from 9° to 33°N. In order to get some information for the otherwise blank spaces, between 9° and 17°N., Trinidad (967) and Curaçao (988) were included. Additional stations farther north are Merida (644) and Valparaiso (221). Trinidad is in close agreement with Albrook Field (806), whereas Curaçao differs in both pressure height and wind speed. Merida is too high almost all the way up from the low troposphere. The pressure height and wind speed profiles in these composite diagrams were drawn according to the median values for each group of observations (crosses in fig. 5).

It will be noted that the scatter increases going south; in this region the curves were fitted as carefully as possible according to the reliability and frequency of reports from the stations south of 17°N. To check the pressure-height profiles at these latitudes, the pressure heights were computed from the corresponding smoothed wind profiles at intervals of 2° latitude from 19° to 9°N., using the equation

$$-(\Phi_2 - \Phi_1) = \int_{y_1}^{y_2} u\, f\, \delta y \qquad (2)$$

where u is the measured zonal wind speed. These "geostrophic pressure heights" were entered in the original drawings for figures 4 and 5 but so

Table 2. - Geostrophic and actual wind speeds at 50 and 25 mb. along 80°W. in August 1958.

°lat.	$f(10^{-4} sec.^{-1})$	50 mb.		25 mb.	
		v_g m./sec.	v_{act}	v_g m./sec.	v_{act} m./sec
30	0.7	16	14	20	20
25	0.6	18	18	23	25
20	0.5	18	19	25	29
15	0.4	19	18	28	30

nearly coincided with the pressure-height profile obtained from the raobs that they could not be shown on the final drawings. Further, the mean profiles agree very well with those for August 8, 1958, which was picked at random; in other words, there are no significant differences between the conditions on one particular day and in the mean.

In table 2 the geostrophic and actual wind speeds are given in the same form as in table 1. Again the differences are negligible (less than 10 percent); the only one with slightly higher value appears on the 25-mb. surface at 20° latitude, where the geostrophic wind was 14 percent less than the actual wind.

From these results it follows that the wind field at stratospheric pressure levels over the West Indies area was practically geostrophic and that ageostrophic motions indicated by winds crossing contours did not actually exist.

Instead of using the reported pressure heights at these altitudes for a contour analysis which, as has been shown, does not lead to useful information about the flow pattern, it is suggested rather to draw smoothed pressure height and wind profiles along several meridians of the region to be investigated and to determine the deviations of the actual from the geostrophic wind in order to arrive at a better picture of the wind field and the true circulation.

5. GENERAL BALANCE OF FORCES

Large deviations from geostrophic conditions cannot be expected a priori in the Tropics. Even though the Coriolis parameter becomes small at low latitudes, it is hard to see why, with a steady easterly current and in the absence of accelerations and frictional effects, the wind should deviate to a significant degree from the geostrophic wind. The complete second equation of motion is given by

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + f\,u = -g\frac{\partial h}{\partial y} + F_y \qquad (3)$$

where v and w are the meridional and vertical wind components and F_y is the frictional force acting in the north-south direction. The local change is very small in the stratosphere and in part an effect of the evaluation of the wind runs, for the slight changes observed in the data are irregular and show no sign of any organization which might indicate the passage of waves or the like. Thus the first term of the equation drops out. The next three terms as well as the frictional term on the right hand side are of special importance for if there are large ageostrophic motions, they must be apparent here. Now, from the wind data, $u\frac{\partial v}{\partial x}$ and $v\frac{\partial v}{\partial y} \ll fu$. Further, we are far enough into the stratosphere at 50 and 25 mb. to expect that the magnitude of $w\frac{\partial v}{\partial z}$ should be no larger, probably smaller, than that of $u\frac{\partial v}{\partial x}$ and $v\frac{\partial v}{\partial y}$. Finally, on account of the very stable stratification and quasi-linear increase of easterly wind speed with height, the frictional retardation also should not have a magnitude in excess of the convective acceleration. This, then, leaves only fu and $-g\frac{\partial h}{\partial y}$; i. e., the geostrophic formula.

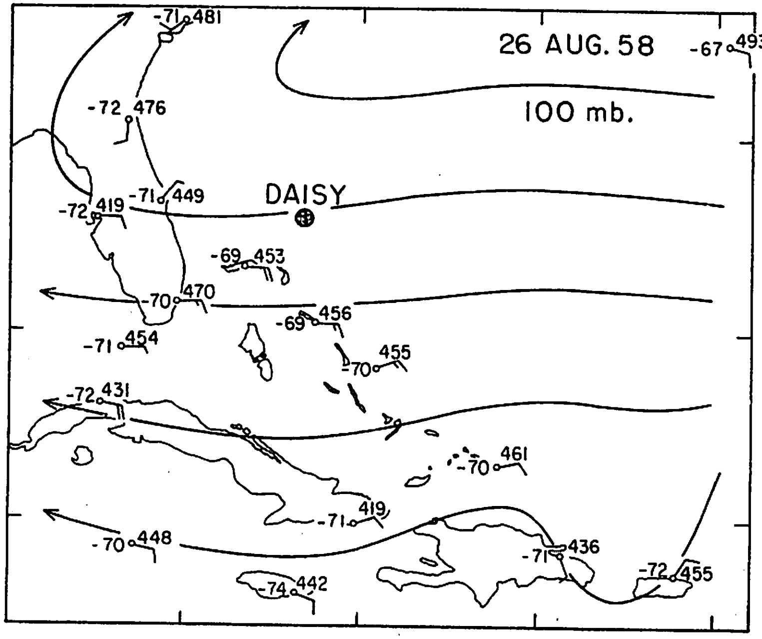
It is apparent that one should not readily discard the geostrophic winds at low latitudes just because the Coriolis parameter becomes small. The situation in the lower troposphere is quite different, even in the steady trades. Below the trade inversion, widespread convection occurs in the current which is heated from below and ground friction is an important factor. In the easterly trade, with wind direction nearly constant along the vertical, the first equation of motion is

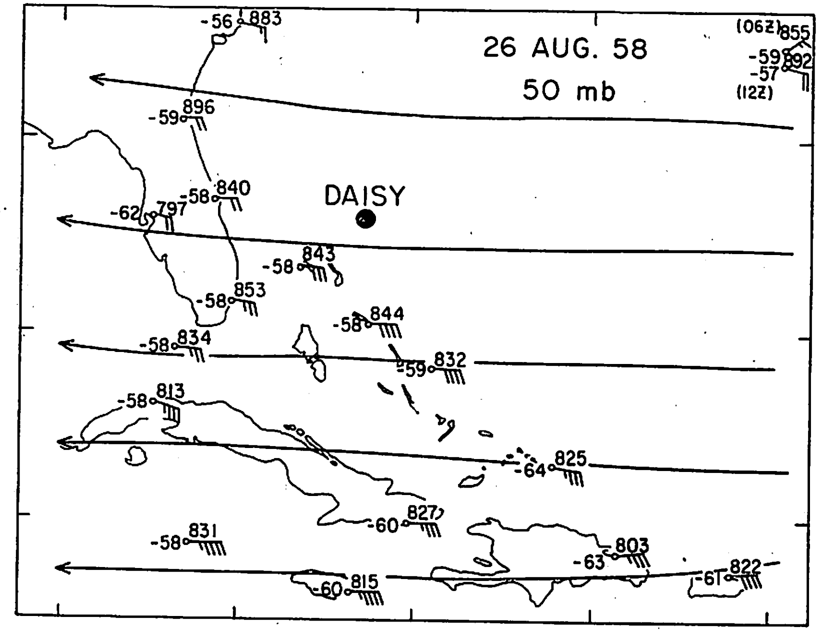
$$\frac{\partial p}{\partial x} - \frac{\partial \tau_{xz}}{\partial z} = 0 \qquad (4)$$

where x is the east-west axis, p pressure, and τ_{xz} the vertical shearing stress along x (Riehl and Malkus [1]). It appears that the non-geostrophic character of the flow in the Tropics arises more from the physical situation - heat and moisture addition from the earth's surface, hence mixing and frictional retardation through the convective layer - rather than from the latitude effect itself. An exception may be found in a limited belt very close to the equator, where the Coriolis parameter is actually, or almost, zero.

6. THE STRATOSPHERIC FLOW PATTERN OVER HURRICANE DAISY

On August 26, 1958, 0000 GMT, hurricane Daisy, then in the process of intensifying, was located at about 28°N. and 76.5°W. Daisy developed into a mature hurricane late on the 26th. At 0000 GMT, on the 26th, the surface pressure in the eye was about 980 mb. and gale force winds (~ 50 knots) extended for about 40 to 50 miles from the center in the eastern semi-circle, while hurricane force winds of approximately 80 knots did not yet cover more than a 10-mile radius. It is not intended here to go into further details about this storm, but to look into the wind field in the stratosphere at this particular time. Figures 6, 7, and 8 show streamline analyses at 100, 50, and 25 mb., respectively. At 50 mb. and 25 mb. we observe that the easterlies are as





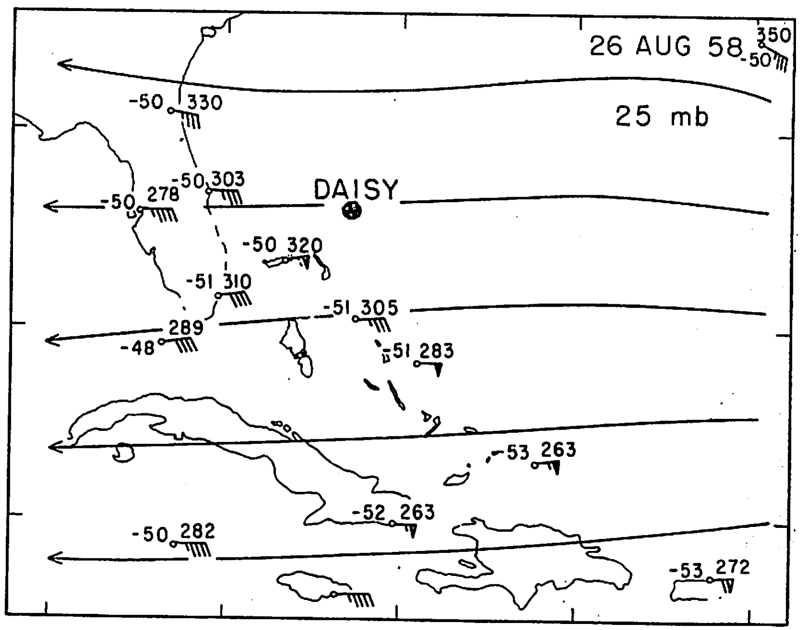


Figure 6. - Streamlines at 100 mb. and raob data, 26 August 1958, 0000 GMT.

Figure 7. - Streamlines at 50 mb. and raob data, 26 August 1958, 0000 GMT.

Figure 8. - Streamlines at 25 mb. and raob data, 26 August 1958, 0000 GMT.

unperturbed as on any other day with no indication of an influence of the low-level circulation. At 100 mb., close to the tropopause, an anticyclonic curvature appears to the northwest of the storm position, which reflects the upper-tropospheric anticyclone. Otherwise the wind field does not show any remarkable perturbation. Whether the stratospheric conditions are really unchanged on a small scale in the immediate vicinity of the vortex cannot be decided from the present data since the nearest station (063) was still some 150 miles away from the storm position.

All that can be said here is that for computational purposes concerning the fluxes and transports of physical quantities over a wider area influenced by the storm, it appears sufficient and justifiable to regard the 100-mb. surface (tropopause) as the upper boundary.

ACKNOWLEDGMENTS

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REFERENCE

1. H. Riehl and J. S. Malkus, "On the Heat Balance and Maintenance of Circulation in the Trades," Quarterly Journal of the Royal Meteorological Society, vol. 83, No. 355, Jan. 1957, pp. 21-29.