Some Observations of Low-Level Wind Variation in the Vertical in Tropical Cyclones

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A report on research conducted under contract No. CWB-9918 between the US Weather Bureau and Colorado State University

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Wind variation in the vertical in tropical cyclones has long been of interest, particularly to those who would infer very low-level wind speeds from ones measured aloft. Although its significant gross features over the whole troposphere are well-known (Jordan, 1952), the variation over the inflow layer (surface to ten thousand feet) has generally been regarded as minor (Riehl, 1954, pp. 291, 301).

During the Atlantic hurricane seasons of 1957 and 1958, National Hurricane Research Project flights into several tropical cyclones yielded wind data at multiple levels below ten thousand feet. The storms and the pressure-altitudes of the low-level flights were:

Storm	Pressure-altitude (feet)
Frieda, 22 Sept. '57	1600, 4780
Frieda, 23 Sept. '57	1600, 9880
Daisy, 25 Aug. '58	1600, 2800, 5500
Daisy, 26 Aug. '58	1600, 3000, 6400
Helene, 24 Sept. '58	3000, 6400, 9880
Helene, 25 Sept. '58	1600, 6400
Janice, 8 Oct. '58	1600, 8200

The Frieda flights were made in a nearly steady-state storm of sub-hurricane intensity; all the others were conducted in developing hurricanes. These data provide material for an investigation of low-level wind variation in the vertical in different kinds of tropical cyclones.

For each storm, the actual winds for each flight level were plotted in a co-ordinate system fixed relative to the storm's radar center. The maps of the various levels were then superimposed in all possible combinations (one combination for two levels, three for three levels) to determine points where the aircraft crossed a given point in the relative coordinate system more than once. The numbers of these points were:

Storm	Number of crossing points	Crossing points with vertical distance > 3000 ft.
Frieda-22	4	4
Frida-23	11	11
Daisy-25	27	16
Daisy-26	17	11
Helene-24	7	7
Helene-25	6	6
Janice-8	2	2
TOTAL	74	57

Next, the speeds and directions of the two winds at each crossing point were read; speed and direction vertical gradients and shear vectors were computed. In view of the irregularity of the shear vectors at crossing points with vertical distances less than 3000 feet, it was decided to exclude these from the analysis. In the residual sample the pressure altitude of the lower level averaged 2050 feet and that of the upper level 7070 feet. For the vertical gradients, selected group and average values were, when $|W|$ is wind speed and θ is wind direction:

Quantity	Type of Case	Frequency Positive*	Zero	Negative	Mean
$\frac{1}{\lvert V\rvert}\frac{\partial\lvert V\rvert}{\partial z}$	Developing	12	0	30	-2.6 per cent/10^3 ft.
$\frac{1}{\lvert V\rvert}\frac{\partial\lvert V\rvert}{\partial z}$	Non Developing	4	1	10	-3.7 per cent/10^3 ft.
$\frac{1}{\lvert V\rvert}\frac{\partial\lvert V\rvert}{\partial z}$	Both	16	1	40	-2.9 per cent/10^3 ft.
$\frac{\partial\theta}{\partial z}$	Developing	18	0	24	-1.6 deg./10^3 ft.
$\frac{\partial\theta}{\partial z}$	Non Developing	6	1	8	-0.5 deg./10^3 ft.
$\frac{\partial\theta}{\partial z}$	Both	24	1	32	-1.3 deg./10^3 ft.

*Clockwise for direction gradient.

The sign distributions of the vertical gradients appear very similar for both types of case. There was a marked tendency for wind speed to decrease with height and a slight tendency for wind direction to turn counter-clockwise with height. Scatter diagrams of the vertical gradients plotted against each other for each type of case are presented in figures 1 and 2; in both types the clockwise-turning winds tended to decrease their speeds with height while the counter-clockwise-turning ones showed more scatter in speed gradient.

The shear vectors are plotted relative to the center in logarithmic Cartesian co-ordinates[1] for developing and non-developing storms in

[1] Our version of this system telescopes crossing points at or less than two orthogonal nautical miles from an axis onto that axis. Crossing points more than about 100 nautical miles from storm center are not plotted.

in figures 3 and 4, where directions and speeds relative to storm motion have been normalized to 5000 ft. vertical distance. Some difference between the types is apparent. There was a marked direction bias from left to right of the direction of motion in the developing cases; no such bias (if anything, even an opposite one) appeared in the non-developing case.

From the foregoing, both types of case exhibited maximum intensity in the very low levels near two thousand feet, since wind speeds showed a marked tendency to decrease with height. In the developing cases, mass inflow tended to increase with height in the left semicircle and decrease with height in the right one, since there was a marked left-to-right shear vector tendency in these storms. The non-developing case showed none or the opposite tendency.

References:

Jordan, E. S., 1952: J. Meteor., 9, 340.

Riehl, H.: Tropical Meteorology. New York, McGraw-Hill, 1954. 392 pp.

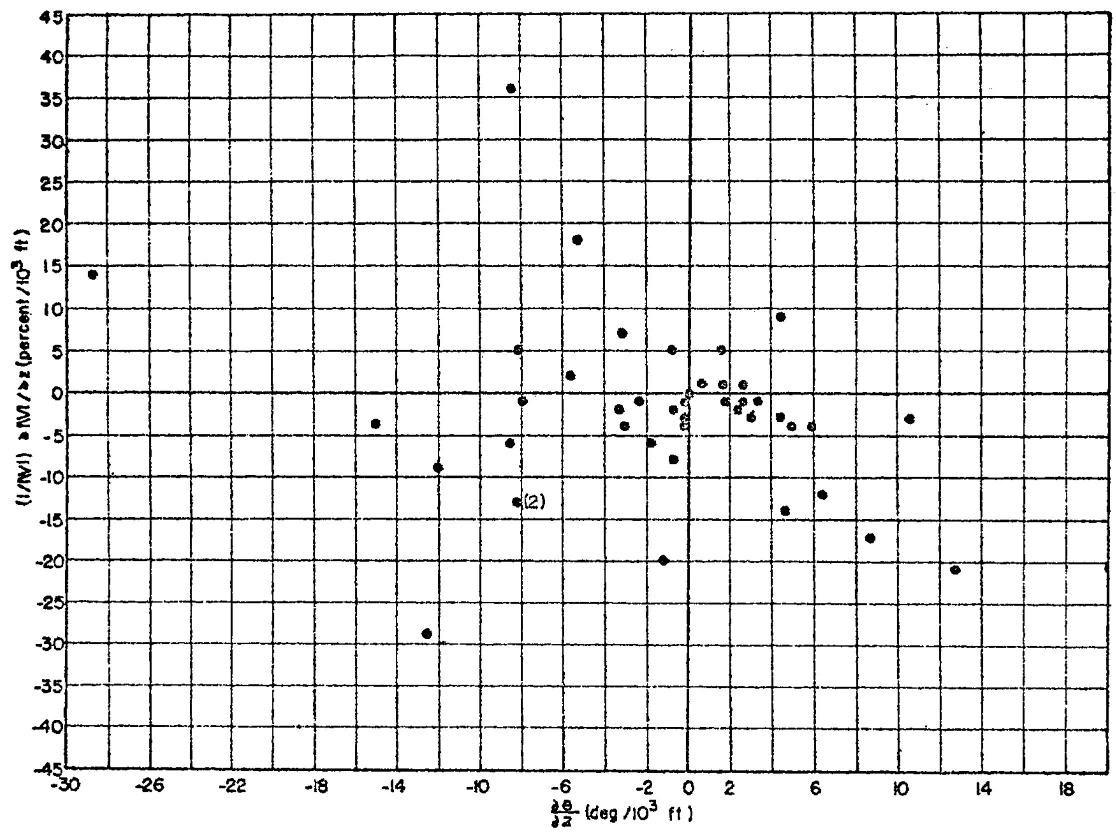

Fig. 1. Speed and direction vertical gradients for developing storms.

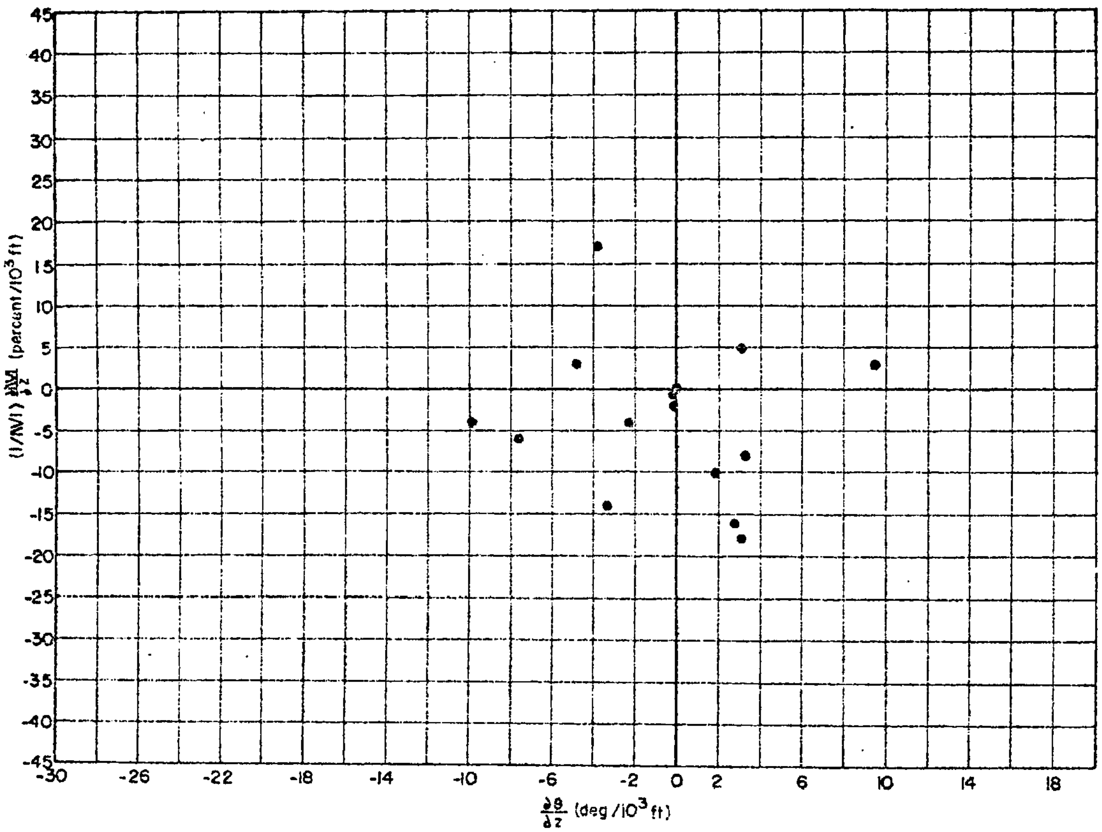

Fig. 2. Speed and direction vertical gradients for non-developing storm.

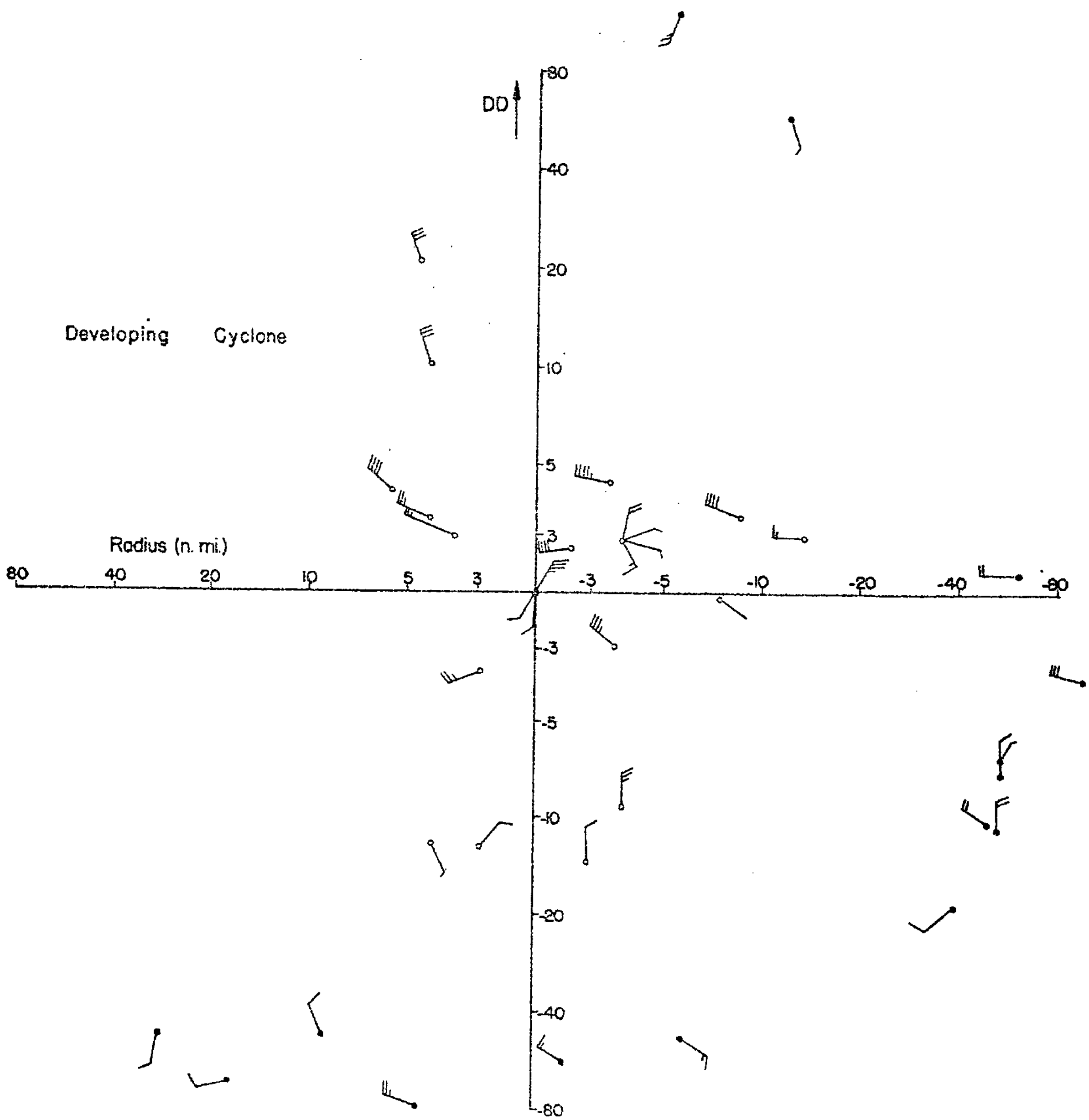

Fig. 3. Relative vertical shear vectors, normalized to $\Delta z = 5000$ feet, for developing storms. Full barb = 10 knots, DD indicates storm motion. Blank circles: cases Daisy-25 and Helene-24, filled circles: cases Daisy-26, Helene-25, and Janice-8.

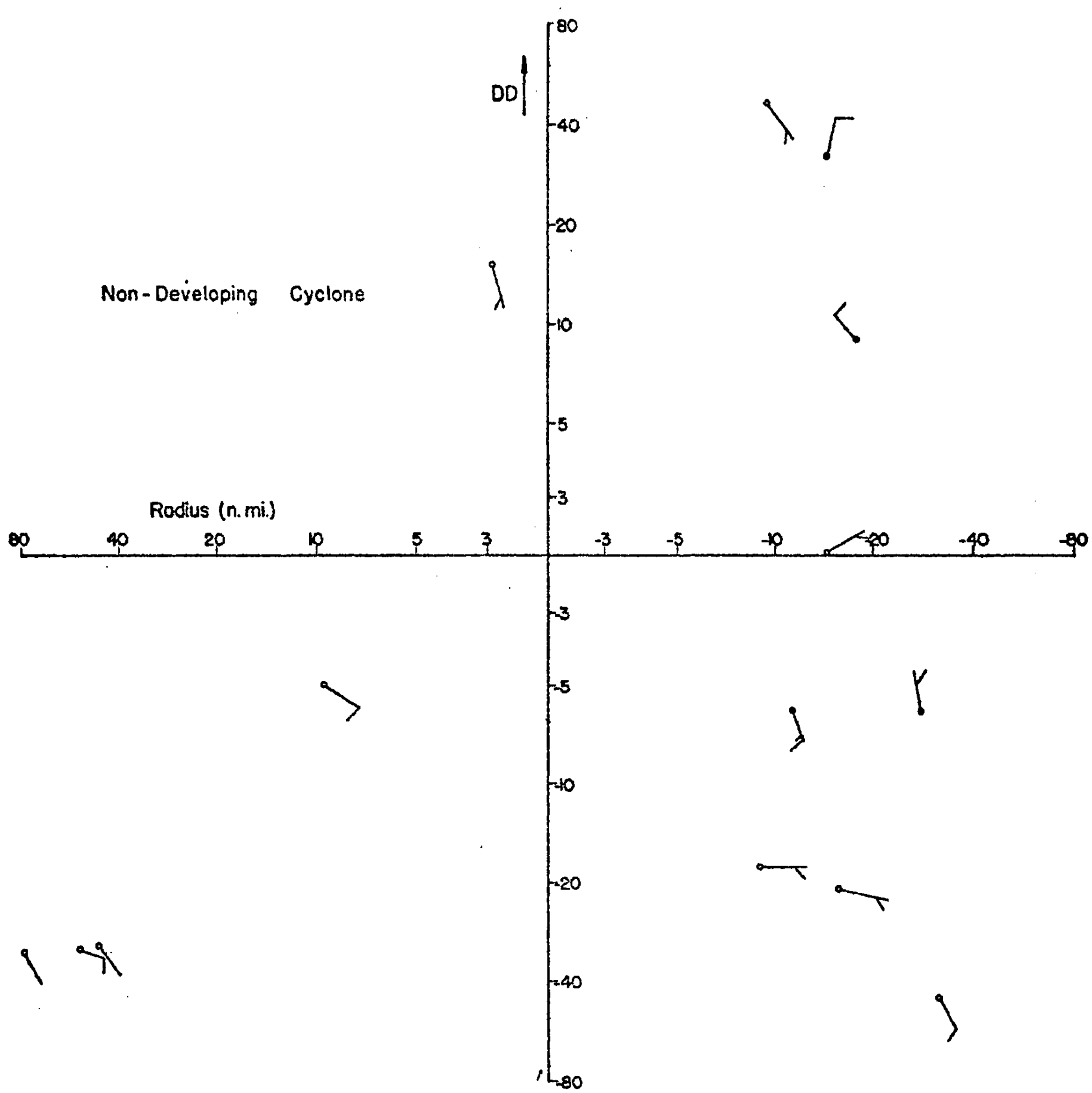

Fig. 4. Relative vertical shear vectors, normalized to Δz = 5000 feet, for non-developing storm. Full barb = 10 knots, DD indicates storm motion. Blank circles: case Frieda-23, filled circles: case Frieda-22.