

AN INVESTIGATION OF THE VALIDITY OF THE GEOSTROPHIC
WIND FLOW ASSUMPTIONS IN TROPICAL AREAS OF AUSTRALIA .

BY K. T. MORLEY.

(Research Section, O.W.B., Melbourne)

This investigation was designed to determine the extent to which constant pressure gradients can be used, in the immediate vicinity of the Tropic of Capricorn, for wind estimation by aviation forecasters. Charts were drawn to approximate to the 0800 hours G.M.T. 700 mb. charts without guidance from observed winds in the tropics by using winds available south of Latitude 26 degrees S. (except Charleville) and all the radiosonde 700 mb. heights. These charts covered all occasions on which pilot balloon flights reached 10,000 ft. at any one or more of Charleville, Alice Springs, Rockhampton and Cloncurry for the periods December, January, February (1950-1951) and May, June, July (1951). C.A.W.D. Section charts were deliberately not used because they were prepared by graphical addition, in which

- a. the 1000 mb. contours are fitted to gradient winds at approximately 2000 ft. to a fair extent, and
- b. the 1000-700 mb. thickness contours are likewise fitted to the wind shears between 2000 and 10000 ft.

Thus it is apparent that C.A.W.D.S. working charts have assumed to a large extent the geostrophic flow the validity of which it is hoped to estimate.

Considerable care was taken in drawing the charts to offset partially the lack of data, 50 ft. contours being drawn where desirable. The observed winds for the above occasions were listed from Hollerith machine data and corresponding geostrophic winds were measured from the charts drawn as mentioned above. The vector differences between observed 10,000 ft. winds and their corresponding geostrophic winds were calculated using a hodograph. The gradient winds were not estimated but the curvature of the 700 mb. contours at the station was noted for each case as cyclonic, anticyclonic or straight.

Scatter diagrams were constructed showing the vector departure from geostrophic conditions at 700 mb. for Charleville, Rockhampton and Cloncurry for -

- a. cases when the geostrophic wind was greater than 10 knots, and
- b. all values of the geostrophic wind.

These diagrams showed, as points on a hodograph, the termini of all vector departures from the geostrophic, assuming the departures to radiate from the same common origin 0 as the vector geostrophic wind, which is directed along the y-axis. The scattering of these points (vector termini) was analysed by placing a square-mesh grid over the scatter diagram and compiling frequency distributions of the number of points in each square. In this way it was possible to obtain frequency distributions of the cross-components and longitudinal components, with respect to the geostrophic vector, of the geostrophic vector departures. These components were expressed as a percentage of the scalar value of the geostrophic wind (Figures 1, 2 and 3).

Figure 1 shows the frequency distributions of the cross-components and longitudinal components with the geostrophic wind greater than 10 knots for (a) Cloncurry, (b) Rockhampton, (c) Charleville, (d) all stations. The cross-components were distributed approximately normally with the modal value and mean value both close to the value of zero cross-component. The distribution of longitudinal components, however, was skew for each of the cases with the modal value of 20% departure from the scalar value of the geostrophic wind, the departure being negative. This showed that for all stations considered the actual wind had a smaller longitudinal component than the geostrophic wind, which did not therefore give a reliable indication of the magnitude of the actual wind. The data for Figure 1, classified according as the actual wind was greater or less than the geostrophic wind, and with respect to the curvature of the contours, may be summarised as follows:

Curvature -	Cyclonic	Straight	Anticyclonic	Calm or insufficient data
Number of cases -	30	61	60	38

For the actual wind classified as less than or greater than the geostrophic wind:

Curvature	- Cyclonic	Anticyclonic	Straight
No. of cases Less	22	21	40
No. of cases Greater	8	39	21

Cyclonic curvature of the contours should result in an actual wind less than the geostrophic wind, but since there were as many anticyclonic situations as cyclonic when the actual wind was sub-geostrophic, some factor appeared to operate strongly enough to

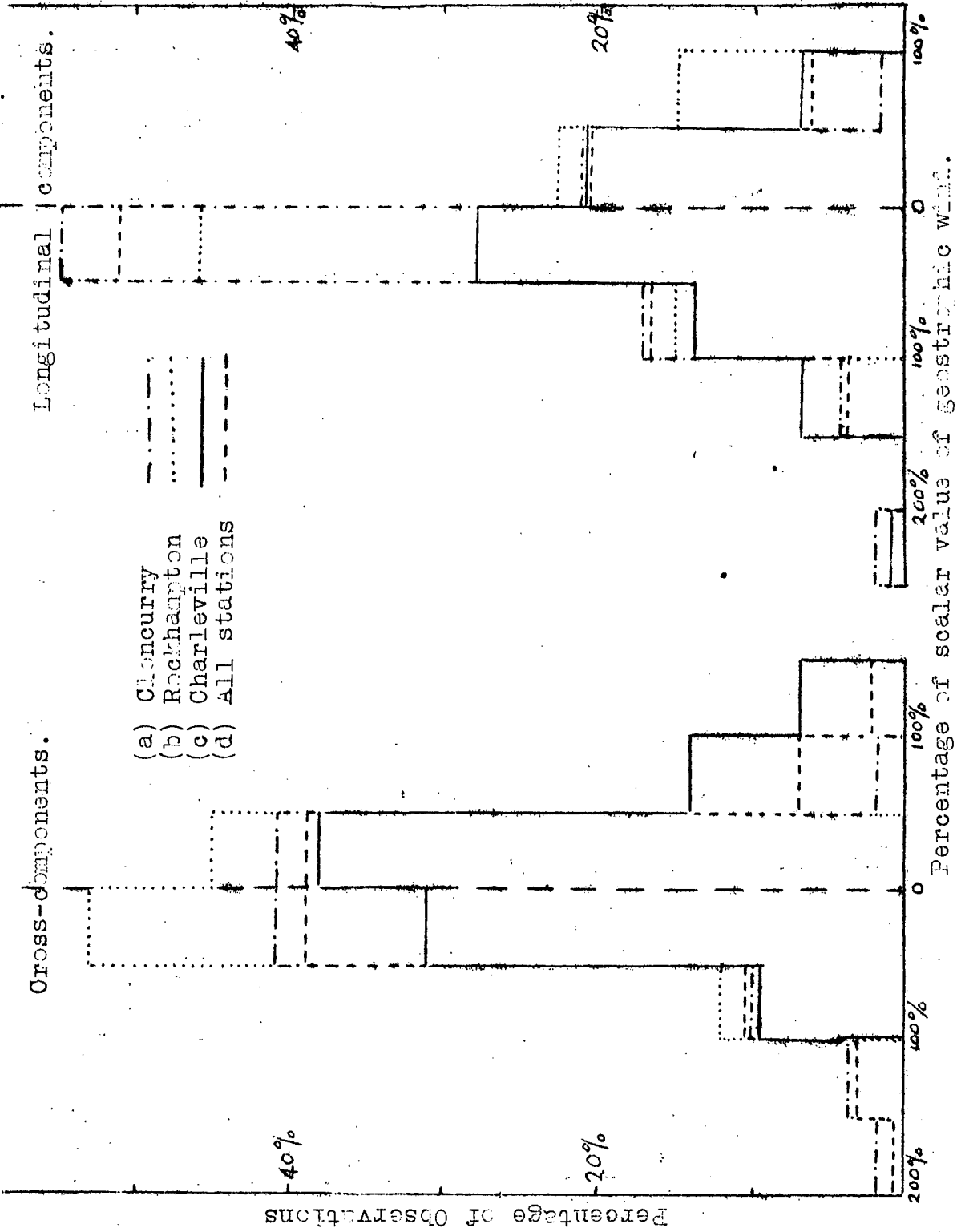
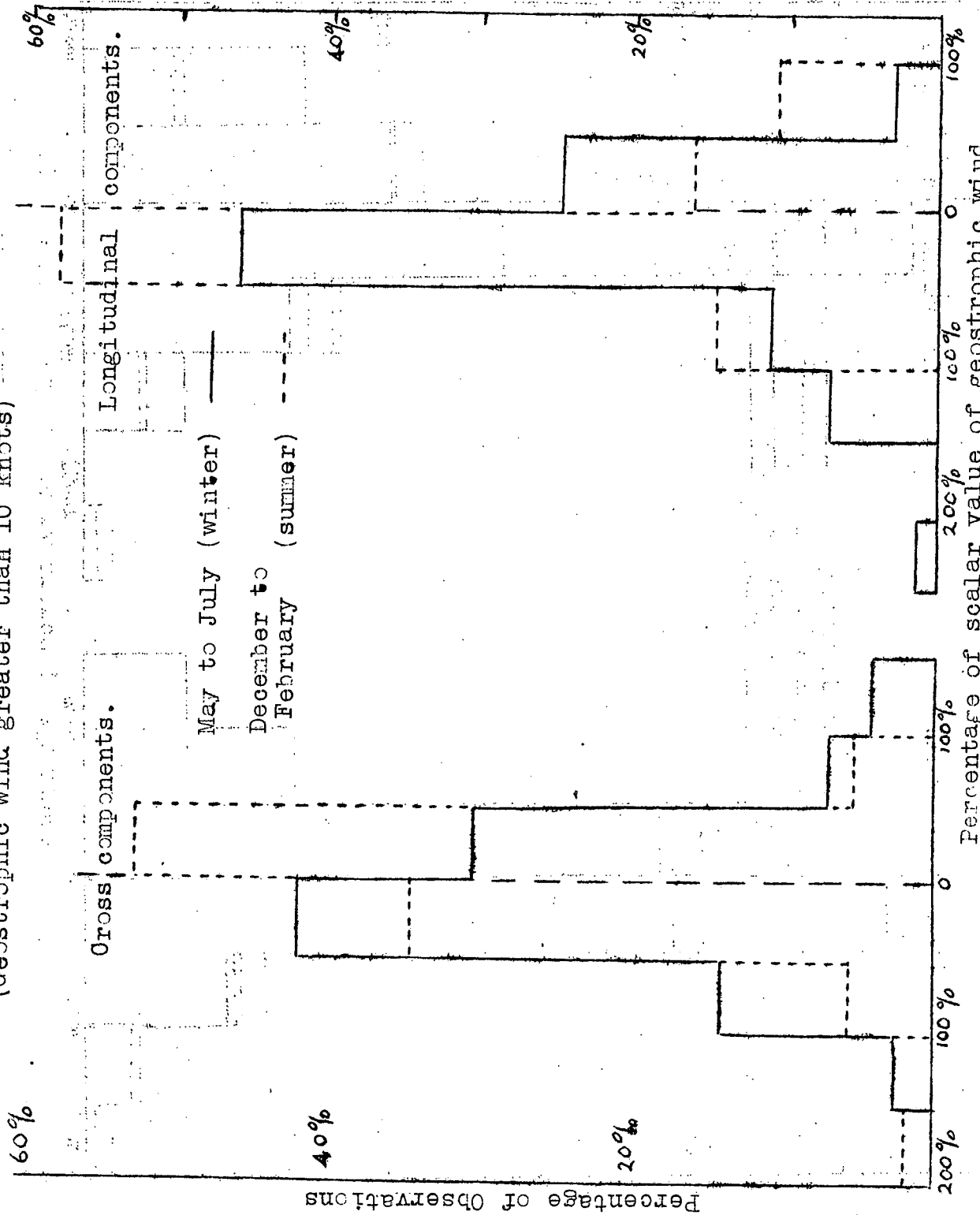


FIGURE 1 - GEOSTROPHIC WIND GREATER THAN 10 KNOTS.

FIGURE 2 - SEASONAL COMPARISON, (all stations)
(Geostrophic wind greater than 10 knots)



reduce the actual wind to less than the geostrophic for 21 cases when the wind flow was anticyclonic. Consideration is given later to the probable nature of this factor. Since 80% of the cases were associated with anticyclonic or straight wind flow the negative departure of the longitudinal components could not have been related to the cyclonic or anticyclonic nature of the wind flow.

Figure 2 indicates that when the geostrophic wind was greater than 10 knots the distribution of cross-components was displaced to the right for summer and to the left for winter, but no conclusion could be drawn from this which would be substantiated by the cross-component distributions in Figures 1 and 3. The distribution of longitudinal components was skewed to the left for both summer and winter, showing that for both seasons the actual wind had a sub-geostrophic longitudinal component.

Figure 3 shows that for all stations throughout the year the frequency distribution of cross-components is unimodal and approximately normal whilst that of the longitudinal components is skew with a modal value of 25% departure from the scalar value of the geostrophic wind, the departure being opposed to the direction of the geostrophic wind.

The frequency distributions shown in Figure 4 were constructed for all data available from the stations Alice Springs, Charleville, Rockhampton, Cloncurry and Daly Waters for the levels 10,000, 20,000 and 30,000 ft. The cross-component distribution was displaced to the right, as was the case in Figure 3, but the longitudinal component distribution was displaced to the left, giving additional evidence of a sub-geostrophic value of the actual wind. The left-hand skewness of this distribution was not as great as in Figures 1, 2 and 3.

The tentative conclusion which can be drawn from this study is that the magnitude of the actual wind is less than that of the geostrophic wind in the vicinity of the Tropic of Capricorn and, by inference, at lower latitudes. Godson (1952) has discussed the relative accuracy of Rawins and contour-measured winds and concluded that the standard error of wind velocity measured by Rawin will vary with height in the same manner as the standard error of wind velocity measured by contour heights. Errors of measurement should therefore have the effect of increasing the spread of frequency distributions without altering the modal value. Godson quoted eight different investigations utilising various techniques of the standard vector deviation between the wind velocity and the geostrophic wind velocity.

Inspection of these authors confirmed Godson's view that the most probable values of the vector standard error at 10,000 ft. expressed as a function of geostrophic speed are :

Geostrophic wind (knots)	20	40	60
Standard error as % of geostrophic wind	30	30	40

The non-geostrophic wind component may be considered theoretically by writing the equations of motion in the form

$$\frac{du}{dt} + \frac{1}{\rho} \frac{\partial p}{\partial x} + fv + F_x = 0 \dots\dots\dots 1.$$

$$\frac{dv}{dt} + \frac{1}{\rho} \frac{\partial p}{\partial y} - fu + F_y = 0 \dots\dots\dots 2.$$

where u, v are the components of the velocity along the north-south and east-west axes respectively, $\frac{\partial p}{\partial x}$, $\frac{\partial p}{\partial y}$ are the pressure gradients along these axes, ρ the density, $f = 2\omega \sin\phi$ is the Coriolis parameter, and F_x , F_y represent friction force in the x- and y- directions.

The equations of geostrophic motion are

$$\frac{1}{\rho} \frac{\partial p}{\partial y} - f u_g = 0 \text{ (along the x- axis) } \dots\dots 3.$$

$$\text{and } \frac{1}{\rho} \frac{\partial p}{\partial x} + f v_g = 0 \text{ (along the y- axis) } \dots\dots 4.$$

where u_g , v_g are the components of the geostrophic wind along the x- and y- axes respectively.

By subtracting equation 4 from 1 we obtain an expression for the non-geostrophic component along the y- axis

$$v - v_g = - \frac{1}{f} \left(\frac{du}{dt} + F_x \right) \dots\dots\dots 5.$$

and from 2 - 3 we obtain the component along the x- axis :

$$u - u_g = + \frac{1}{f} \left(\frac{dv}{dt} + F_y \right) \dots\dots\dots 6.$$

The deviation from geostrophic flow can thus be due to an acceleration term ($\frac{du}{dt}$, $\frac{dv}{dt}$) or a friction term (F_x , F_y).

A contribution by the acceleration term to the non-geostrophic component would be due to a change in the velocity of wind flow between two points along a streamline. The tentative conclusion stated earlier would imply that this acceleration should be generally negative if the sub-geostrophic magnitude of the actual wind is due to an acceleration term. Situations with negative acceleration of wind flow (associated with divergent

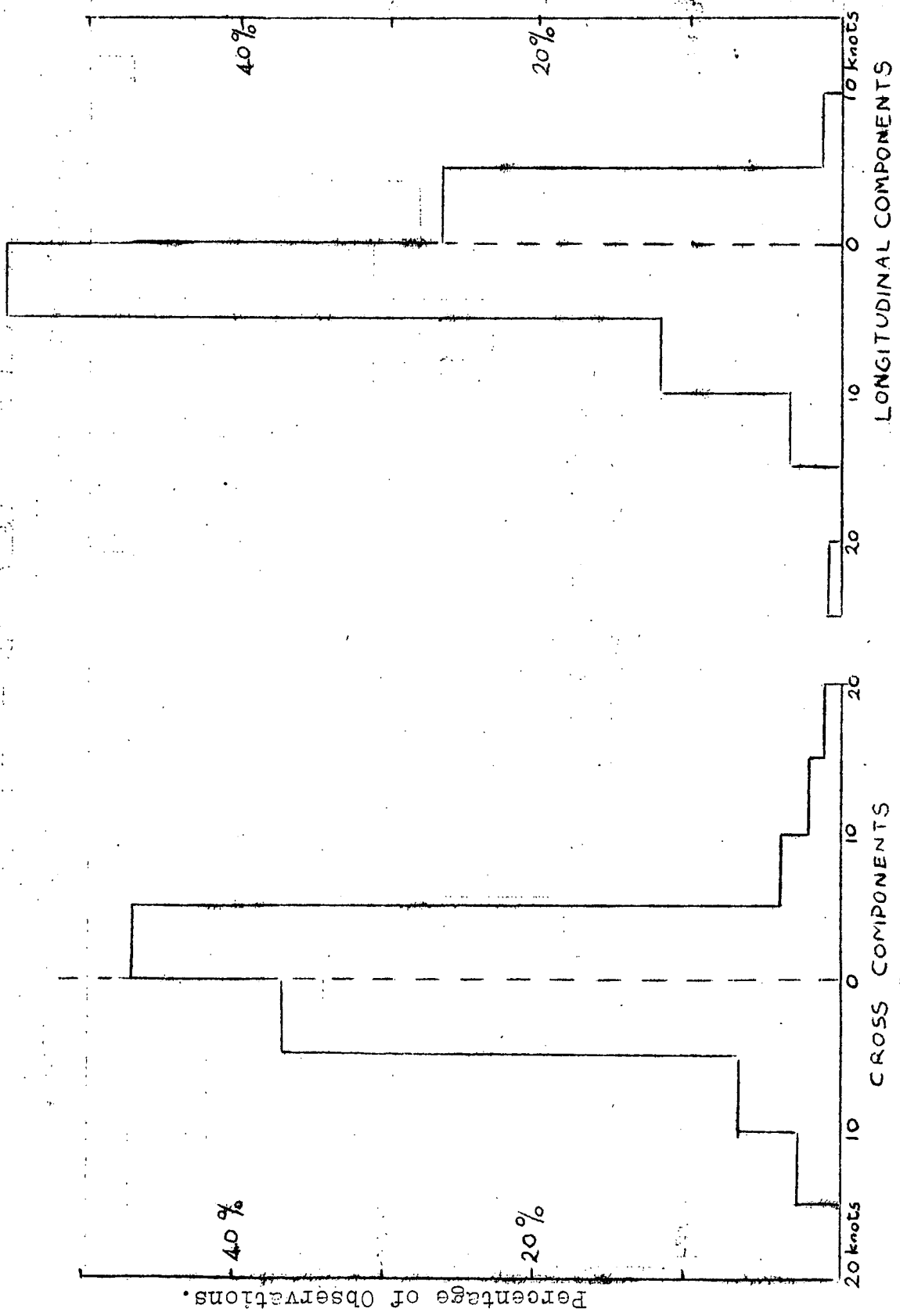


FIGURE 3 - ALL STATIONS THROUGHOUT YEAR.
(ALL VALUES OF GEOSTROPHIC WIND).

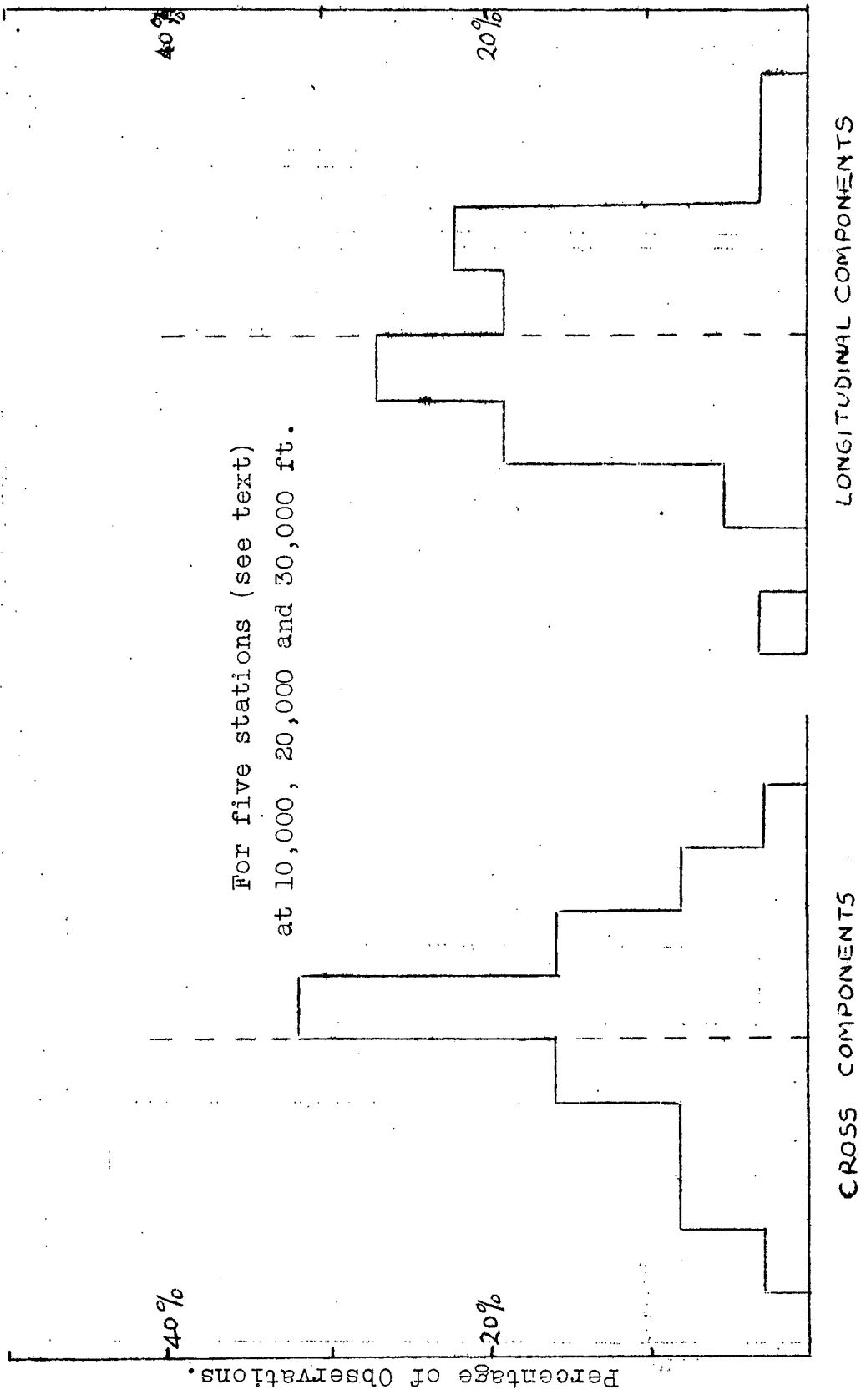


FIGURE 4 - COLLECTIVE FREQUENCY DISTRIBUTION OF GEOSTROPHIC DEPARTURES.

constant pressure contours) are not more likely to occur in tropical latitudes than synoptic situations associated with positive acceleration term, so that whilst the acceleration term may in some situations contribute to the magnitude of the non-geostrophic component it is not an adequate explanation.

Friction force is a more probable explanation of the non-geostrophic component, and is generally thought to oppose the wind flow. Gibbs (1945) investigated the motion of air in low latitudes and computed values of kV , the acceleration due to friction for a horizontal velocity V , assuming that friction was linearly proportional to and opposite to the wind velocity. It cannot be shown theoretically that friction is linearly proportional to wind velocity and Brunt (1939) considered it likely that friction acts at $22\frac{1}{2}$ degrees to the direction assumed, which would modify the conclusions derived by Gibbs, but it would be interesting to examine the computed values of kV in the light of their possible relation to the non-geostrophic component of the wind flow.

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References :

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COMINGS AND GOINGS AMONG THE FIELD STAFF.

After a preliminary test flight, JACK (Cold Pool) GRAY taxied on to the runway on Friday, 10th July, for the long flight from Research Section, C.W.B. to Eagle Farm. Refueling was a long process requiring the co-operation of many friends and interrupted from time to time by a slight haze over the strip, but at six o'clock, with tanks filled, flaps up and engines racing, Jack was seen heading down-wind with the apparent intention of buzzing Bourke Street.