

GEOSTROPHIC WIND APPROXIMATION IN LOW LATITUDES \*

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1. The closeness of this approximation in low latitudes for mean and individual winds is not very well known. Knowledge of this relation is thus of some intrinsic importance, and in addition would substantially indicate the degree of accuracy to be expected of forecasts of wind, and also assist in the consideration of the unexpectedly high mean (geostrophic) wind velocities found by Loewe and Radok (1950) at high levels between Latitudes  $19^{\circ}$  and  $27^{\circ}$  in their study of a cross section of the atmosphere along Longitude  $150^{\circ}$ E in the Southern Hemisphere. These authors show mean geostrophic winds of 120 m.p.h. at 12 Kms. in winter at Latitude  $25^{\circ}$ , which are higher than any recorded elsewhere.

2. The geostrophic approximation has been examined using measurements of the W - E pressure gradient and wind components at various levels between Brisbane (Lat.  $27^{\circ}$ S) and Townsville (Lat.  $19^{\circ}$ S) obtained from radiosonde, radio wind and pilot balloon wind observations. Mean cloud speeds and their relation to the geostrophic wind in these longitudes have also been employed, and the theoretical position regarding geostrophic wind balance studied. In addition the effect of instrumental errors and of the real variability of elements on the calculated means has been considered.

3. The results with brief comments may be stated:-

(i) The geostrophic approximation for mean W - E motion seems close. (See Table I).

TABLE I

Mean W - E components (knots) over Brisbane (Latitude  $27^{\circ}$ S) Townsville (Latitude  $19^{\circ}$ S) route on occasions in September and October.

Height (Feet)	5,000	10,000	20,000
Speed - Observed	2	10	23
Geostrophic	4	11	21

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- (ii) Forecasts of W - E components (and probably total) winds for the Brisbane - Townsville stretch would probably on about 80% of occasions be within 10 knots for the range of winds below 10,000 feet, and within 15 knots for the range at 20,000 feet. (See Tables II and III). The deviation from geostrophic wind does not seem to increase with wind speed at these levels. The real deviations and thus the errors of the forecast should be less than the limits stated, owing to the measured winds being not completely representative of the mean wind over the route.

TABLE II

Frequency of deviations of W - E wind components (knots) from W - E component of geostrophic wind over the same route.

Deviation	0-4	5-9	10-14	15-19	20-24	25-29	30-34
5,000 feet	16	14	5		1		
10,000 feet	17	10	5		1		
20,000 feet	7	4	4	2		2	1

- (iii) However even with the above limits forecasts would still be useful as the range of wind velocities met with is of the order of 40 knots at each height, taking into account west and east components separately (Table III).

TABLE III

Frequency of the W - E wind components (knots)

Wind component	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44
5,000 feet	14	13	7	3	2				
10,000 feet	10	4	9	8	3	1		1	
20,000 feet		2	4	2	1	3	2	2	3

- (iv) The relation of mean altocumulus speeds to mean geostrophic wind velocities at Melbourne (Latitude 38° S), Sydney (Latitude 34° S), and Warwick (Latitude 28° S) in Summer and Winter is much the same, indicating that the relatively high geostrophic winds at this altitude at Latitude 28° found by Loewe and Radok are likely to be correct, and that the actual wind should be close to the geostrophic, as is not doubted for higher latitudes (See Table IV). The Ac mean height has been taken as 5 Km.

Actually there is probably a seasonal and latitudinal range of about half a kilometer, but this would not significantly affect conclusions.

TABLE IV

Components of mean W - E speeds (knots) of Ac and geostrophic winds.

	<u>Latitude</u>	<u>Winter</u>		<u>Summer</u>	
	<u>S</u>	<u>Ac</u>	<u>Geostrophic</u>	<u>Ac</u>	<u>Geostrophic</u>
Melbourne	38	27	20	26	27
Sydney	34	23	22	18	22
Warwick	28	39	32	21	14

- (v) A theoretical consideration of the terms in the equation of motion seems to indicate that in the mean geostrophic approximation is likely for these latitudes (19-27°S). This examination shows that terms other than the balancing forces in the geostrophic equation are relatively negligible in their effect on mean winds, and for individual winds above 20 m.p.h. the probable absolute deviation from the geostrophic wind approximates the order of 20 per cent. The comparison of observed and geostrophic winds seems to bear out this conclusion. The approximation for lighter winds is probably poorer due to several factors (See Section 4).
4. Theoretical consideration of geostrophic wind approximation in lower latitudes, especially in relation to high mean W - E geostrophic winds found in winter at high levels between 20°S and 30°S about longitude 150°E.

It seems reasonable in this problem to assume steady motion, at least for mean motion or on most individual occasions. Thus the causes of deviation from geostrophic balance are likely to be due to the track accelerations or possible frictional forces, which are neglected in forming the equation for the geostrophic wind. The frictional term in equation of motion is the product of the eddy viscosity and the rate of change of the vertical gradient of wind. The second element of this term is much less above the lower frictional layer of the first 1,000 metres, as can be seen even in an extreme case, such as the rapid wind increase in higher layers in winter found by Loewe and Radok; while the eddy viscosity will also be very much lower than in the frictional layer owing to the absence of the powerful ground frictional effect. Thus the frictional term is likely to be much less than ten per cent of the balancing forces

in the geostrophic equation and can be neglected. Before attempting to consider the effect of track accelerations the data of the particular situation of most interest is set out in Table V.

TABLE V

Height Km	Lati- tude	Long.	Season	Mean Geostro- hic Wind m.p.h.	Situation
12	35°S	150°E	Winter	70	A
12	25°S	150°E	Winter	120	A
6	34°S	150°E	Winter	30	B
6	25°S	150°E	Winter	63	B

One way of examining the position would be to find the effect of a track acceleration, which would not be likely to be exceeded for mean winds, and which would also be likely to occur only infrequently on individual occasions. It is thought that such a track acceleration would be that associated with the case of uniformly curved motion over the above region, where the W - E component of the pressure gradient at the higher and lower latitudes corresponded with the mean W - E geostrophic winds set out above, and the direction of the total pressure gradient at the lower latitude corresponded to a westerly wind. The required curvature for such cyclostrophic motion is approximately 1700 and 1400 kms. for situations A and B respectively, and the direction of the cyclostrophic motion at the higher latitude would be more southerly than southwest. The relation at latitude 25° of geostrophic and cyclostrophic winds for different radii of curvature is set out in Table VI below :-

TABLE VI

Radius of Curvature Kms	Geostrophic Wind m.p.h.	Cyclostrophic Wind m.p.h.	Reduction %
3,000	131	105	20
2,000	131	97	26
1,500	131	91	29
1,500	109	79	27
1,500	87	66	24
1,500	66	52	21
1,500	44	37	16
700	35	27	22
600	26	21	20
400	18	14	20

Even with a 3,000 Km. radius of curvature the direction of cyclostrophic motion at latitude 35°S would still be south of southwest if it is to be westerly at latitude 25°. Such a change in direction is not considered likely in the mean motion, and is thought to be of infrequent occurrence on individual occasions, so that even for very high winds a 20 per cent departure from the geostrophic value would hardly be a low estimate of probable error both in the mean and on the great majority of days. Synoptic experience and the consideration of the above table suggests that the same conclusion holds for winds at least down to 20 m.p.h., and for mean winds down to low velocities owing to the more probable variability of the sign of curvature. In individual cases for light winds track acceleration effects might well be relatively greater, but the departure from the geostrophic speed would still be expected to be moderate, as the curvature required for a twenty per cent decrease in cyclostrophic motion is considerable. Table I shows a close correspondence for the W - E wind component between mean geostrophic and mean representative actual winds at 5,000, 10,000, and 20,000 feet over the Brisbane - Townsville route. For geostrophic winds in the 25-35 m.p.h. range the frequency of departures from the geostrophic value were:-

Departure	Knots	0-4	5-9	10-14	15-19	20-24
Frequency		13	4	7	1	2

Table II showing the frequencies of deviations from geostrophic would indicate that the deviations greater than 20 per cent were common for lower velocities, but the deviation from the geostrophic magnitude includes an unknown but probably not insignificant error in the mean route wind due to its representation as the mean of a few observations over a large distance. The error is likely to be greater proportionately for light winds, where in addition to significant track accelerations there are likely to be greater relative variations of pressure gradient over the route.

5. The effects of radiosonde instrumental error on the derived pressure gradient.

The error seems remarkably small. Thus assuming uniform surface pressure, a lapse rate of 5°C per Km. and a constant error of 1°C in the radiosonde reading at one

of two stations  $8^{\circ}$  apart (distance Townsville to Brisbane) the false pressure gradients derived from the readings would correspond to geostrophic winds of 2, 4, 9, and 15 m.p.h. at 1.5, 3, 6, and 12 Kms. respectively. It seems unlikely that such a relative error would arise even infrequently, so that this source of error is probably slight.

6. The effect of variability of pressure gradients on the derived high mean geostrophic winds found by Loewe and Radok.

As some 200 observations were used to derive mean pressures, it does not seem that this source of error is significant. For the thirty occasions of geostrophic wind above 20 m.p.h. between Brisbane and Townsville the mean deviation was 9 knots. Even taking a value of 30 per cent of the mean geostrophic velocity as the mean deviation for the high geostrophic winds the error in the mean of 200 observations would be slight.

Reference:

Loewe, F. and        1950  
Radok, U.

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