THE LATITUDE DEPENDENCE OF INTENSITY IN CYCLONES AND ANTICYCLONES

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ABSTRACT

An enquiry is made into the way in which the mean intensities of cyclones and anticyclones vary with latitude.

For middle latitudes a linear relation is shown to hold between the mean central pressure of cyclones, and of anticyclones, and the sine of the latitude of their occurrence. This implies that the mean "potential intensity" of anticyclones is independent of the latitude. If, further, it is assumed that the pressure profile is independent of latitude, it can be shown that the total mass-excess and energy of anticyclones is approximately independent of latitude.

1. Introduction

It is an observational fact that the central pressure of closed symmetrical anticyclones tends to increase with latitude, just as the central pressure of lows tends to decrease with increasing latitude. The highest pressures have been recorded in "cold" winter highs of latitudes 60 deg and over, not in the warm anticyclones of subtropical regions.

This observation has been associated with the fact that marked pressure-gradients in low latitudes would involve impossibly high geostrophic wind-speeds. The hurricane is the only disturbance of low latitudes involving high pressure-gradients, and in this case high gradients can only be reached because they are mainly balanced by centrifugal forces, rather than by the Coriolis force.

It is proposed here to examine the way in which this gradient limitation affects the central pressure in highs, and to investigate the point statistically.

It might be thought that, for the present purpose, one should characterize pressure fields by the tightness of gradient within them. However, tight gradients may arise not only from the presence of a discrete system, high or low, but also from the combination of two or more distinct systems in proximity. For this reason, one would hesitate to use, say, maximum pressure-gradient as a parameter characterizing the properties of a single vortex, apart altogether from the practical difficulty of measuring pressure-gradient maxima.

A satisfactory measure of *mean* pressure-gradient within a vortex is the difference from normal pressure at the center. This is, of course, simply the integration of the pressure gradient from periphery to center of the disturbance. High maximum gradients will normally be associated with a high mean gradient. Hence, the total pressure rise (drop) in a high (low) may be taken as a parameter characterizing pressure gradients, which is what we require. This parameter has the added advantage that it is easily obtained. One does not have to measure pressure gradients on the synoptic chart, but merely to read off the central pressure and subtract it from the mean central pressure for the region.

It is customary, in many forecasting services, to term a low with a very low central pressure a *deep* disturbance. This usage is considered unfortunate (Priestley and James, 1948), partly because the word "deep" is sometimes used to connote vertical extent, as in "an invasion of deep cold air," and partly because it is impossible to speak of a "deep" anticyclone in the same sense.

An overhaul of meteorological terminology by an international commission is, perhaps, long overdue; but in the meantime, it is difficult to employ terms, however unambiguously and consistently, which may not have misleading overtones.

For this reason, it is with some trepidation that the writer proposes the term "intensity" for what might sometimes be called the "depth" of a depression. This usage is consistent with previous publications (James, 1950; 1951). Intensity can be used equally for highs and lows, although in the latter case its numerical measure is negative.

2. The mass of an anticyclone

The parametric representation of circular disturbances has been examined elsewhere (James, 1950). The surface pressure-profile of a circular anticyclone may be represented by a relation of the form

$$p = p_0 + h\,f(r/R).$$

Here p_0 is the surface pressure in the absence of any perturbation, the "normal" pressure, while h is the

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central pressure excess, or *intensity*. The function f is termed the *pressure-profile shape*, and has the property $f(0) = 1$, while the scale factor R is termed the *spread* and is defined as the radius (r) at which the pressure gradient is a maximum.

The total excess of pressure (weight) within the anticyclone is termed the *strength* S, and

$$S = 2\pi h \int_0^\infty fr\, dr = 2\pi R^2 h \int_0^\infty f\kappa\, d\kappa, \qquad (1)$$

where $\kappa = r/R$.

The total *mass* M of the anticyclone is related to the strength: $S = Mg$, where g is the acceleration of gravity.

An elliptic anticyclone with a profile shape $f[(x^2/a^2 + y^2/b^2)^{\frac{1}{2}}]$ will have a strength given by (1), if we write $R^2 = ab$. Here a and b ($a > b$) are the semi-major and -minor axes, respectively, of the system. For any elliptical system, we can therefore define an equivalent circular perturbation.

It has been shown elsewhere (James, 1951) that, for a gradient-wind balance to be possible everywhere in an anticyclone, the following relationship must exist between h and R:

$$8h/\rho\lambda^2R^2 \leqslant Q_E, \qquad (2)$$

where ρ is the density, λ the Coriolis parameter, and Q_E is the *equilibrium number*, which depends only on the form of the profile shape.

The writer (1951) has produced statistical evidence in support of the following proposition:

> The profile shape does not vary greatly from anticyclone to anticyclone, in consequence of which Q_E is approximately the same (1.9) for all highs.

Even if this proposition is not exactly true, it is approximately so, for Q_E is quite insensitive to the profile shape. Thus, such markedly different shapes as the *normal* profile, $f = \exp - \frac{1}{2}x^2$, and the *sinusoidal* profile, $f = \frac{1}{2}(1 + \cos \frac{1}{2}\pi x)$ with $x \leqslant 2$, yield similar values of Q_E, 2 and 1.63, respectively.

Another proposition with strong supporting evidence is that inequality (2) tends to be an equality for highs, *i.e.*, anticyclones tend to grow until they are effectively limited by the condition for gradient balance. This is true within the (admittedly wide) limits of experimental error for subtropical highs of the Australian region.

We see, then, that there is a relation between size and intensity of anticyclones, intensity being proportional to the spread squared. We may use this relationship to eliminate either h or R from (1).

We may thus express the strength of an anticyclone by either

$$S = K_R\lambda^2R^4 \quad \text{or} \quad S = K_h h^2/\lambda^2, \qquad (3)$$

where the K's depend only on the profile shape.

It has been shown (James, 1951) that the potential and kinetic energies, P and T, are both proportional to the strength, so that we may write

$$P = K_P h^2/\lambda^2, \qquad (4)$$

$$T = K_T h^2/\lambda^2, \qquad (5)$$

where the K's again depend only on the profile shape.

Let us imagine an anticyclone to be transported from latitude φ to the pole ($\sin \varphi = 1$), while retaining the same profile shape, mass, and energy. If the intensity in latitude φ was h, the intensity at the pole must be given by $H = h/\sin \varphi$. Similarly, the spread of the system must alter from R to R_0, where $R_0 = R(\sin \varphi)^{\frac{1}{2}}$. We term H and R_0 the *potential intensity* and *potential spread*, respectively.

In terms of these potential parameters, we may write (3), (4), and (5) as

$$S = 4\omega^2 K_R R_0^4 \quad \text{or} \quad S = K_h H^2/4\omega^2, \qquad (3a)$$

$$P = K_P H^2/4\omega^2, \qquad (4a)$$

$$T = K_T H^2/4\omega^2, \qquad (5a)$$

where ω is the earth's angular speed.

We see, therefore, that the strength, mass, kinetic energy, and potential energy of an anticyclone are all proportional to the square of the potential intensity, or to the fourth power of the potential spread, when the profile shape is specified.

The concepts of potential intensity and potential spread enable us to treat the latitude dependence of anticyclone parameters very simply. A change in the potential intensity may be taken as indicating a change in the energy of the anticyclone. It is true that a compensating rearrangement in the profile shape is possible, but such changes have a limited influence on mass and energy. A transition from latitude 60 deg to latitude 30 deg, with unchanged intensity, would involve a three-fold energy increase, whereas a change from normal to sinusoidal profile would only give a 27 per cent decrease of energy.

Referring to the second equation of (3a), we observe that the mean strength of a population of anticyclones is given by

$$\overline{S} = \overline{K_h H^2}/4\omega^2 = \overline{K_h}\,\overline{H^2}/4\omega^2 + \overline{(K_h - \overline{K_h})(H^2 - \overline{H^2})}/4\omega^2.$$

The second term is zero, if K_h is uncorrelated with H^2. But K_h is a function of Q_E alone. It is found that for twenty anticyclones of the Australian region, the correlation coefficient between Q_E and the intensity is $+0.055$. There may be a slight correlation between the profile shape and the intensity of a disturbance, but the available statistical data do not establish it as significant, and in any event the correlation is so slight that we can, without appreciable error, write

$\overline{S} = \overline{K}_h \overline{H^2}/4\omega^2$. The mean-square intensity may thus be taken as a measure of the mass (and energy) of an anticyclone population.

If, further, the mean-profile shape does not change greatly with latitude, we may take the variation of $\overline{H^2}$ with latitude as proportional to the variation of mean mass *etc.* with latitude.

The implication of the above analysis is that the mean intensity of anticyclones is likely to increase with latitude, assuming the mean mass of anticyclones not to change greatly, while the mean size is likely to decrease. The variation of mean size with latitude will not be considered here; attention will be confined to the latitudinal variation of intensity.

3. The potential intensity of cyclones

Expression (1) gives the strength of a cyclone, but here h is negative (mass defect). The writer (1950) has shown that, for 17 cyclones in the region of the British Isles, the intensity varies with the spread in roughly the same way as for highs, *i.e.*, h is roughly proportional to R^2. This can only be taken as an empirical result; there is no limitation of the pressure gradient in cyclonic circulations, as in the case of anticyclones. Accordingly, a strict one-to-one relationship between h and R^2 is not to be expected, and energy can not be expressed as a function of H^2 only. Nevertheless, it is of interest to study the variation of potential intensity of lows with latitude.

4. Central pressure of cyclones and anticyclones

Before estimation of potential intensity, it is necessary to enquire into the statistics of highs and lows in different latitudes. The *Monthly weather review* gives the position and central pressure of each migrating cyclone and anticyclone identified on the 1230 GCT surface weather-map for North America. These data were grouped in 5-deg latitude intervals, and the mean central pressure and standard deviation were computed for each group. The period covered was January 1944–June 1948, embracing 2955 anticyclones and 3567 cyclones. The same disturbance may, of course, be entered on consecutive days. The quasi-stationary anticyclonic cells of subtropical latitudes are not incorporated in the data, the bulk of the migrating highs originating at high latitudes. Most of the lows in this study are associated with activity on the polar front, but the occasional poleward-migrating hurricane is not excluded.

Table 1 gives the data for anticyclones. The first column gives the latitude range, the second the frequency of disturbances in this range, expressed as a percentage, the third the mean central pressure, and the fourth the variance. Table 2 gives corresponding values for cyclones.

TABLE 1. Frequency, mean central pressure, and variance for North American anticyclones. N = 2955.

Latitude	Frequency (per cent)	$\bar{p}$ (mb)	σ^2 (mb)^2
25–30	2	1023.5	17
30–35	6	1024.5	28
35–40	15	1026	31.5
40–45	21.5	1027	28.5
45–50	20	1028.5	36.5
50–55	16.5	1028.5	38.5
55–60	10	1029	41
60–65	6.5	1030.5	49.5
65–70	2.5	1030.5	37

The frequency distribution[1] in latitude is approximately normal for both types of disturbance, the mean latitude being 45°N, with a standard deviation of $7\frac{1}{2}$ deg. It will be appreciated that, in the case of anticyclones, this frequency distribution is typical of migrating systems and does not include the semi-permanent subtropical cells.

The salient feature revealed by table 1 is that the mean central pressure of anticyclones increases with latitude. In addition, the variance and standard deviation increase with latitude. High-latitude anticyclones are not only more intense on the average; their variability is also greater. Reference to table 2 shows that the mean central pressure of cyclones decreases with latitude, while the variance increases. High-latitude lows are more intense and more variable.

The question of the variability of central pressures is of some interest in forecasting. Advisories frequently contain reference to an intense low. But what criterion of intensity exists, apart from the subjective evaluation of the meteorologist who issues the information? It is suggested that, as far as possible, verbal qualifications used in forecasts should be based on objective criteria.

When a forecaster says that a particular low is deep (*i.e.*, intense, in our notation), he really means that the central pressure is unusually low for such systems. Thus, an objective criterion of intensity must be based on a frequency table. It is found that the frequency distribution of central pressure in a given

[1] Frequency tables of cyclone and anticyclone distributions have previously been published by Bowie and Weightman (1914), Namias (1947), and Petterssen (1950).

TABLE 2. Frequency, mean central pressure, andvariance for North American cyclones. N = 3567.

Latitude	Frequency (per cent)	$\bar{p}$ (mb)	σ^2 (mb)^2
25–30	3	1008.5	38
30–35	7	1008	39.5
35–40	15	1005	47
40–45	19	1002.5	61.5
45–50	19	1000.5	92
50–55	16	999	107
55–60	11	997	89
60–65	7	996.5	86
65–70	2	999	41

latitude is approximately normal. It is, therefore, suggested that a low can be regarded as of normal intensity if its central pressure lies within the range $\overline{p_0} \pm \sigma$, where $\overline{p_0}$ is the mean central pressure of the population, and σ is the standard deviation. Of all lows in a normal population, 68 per cent will have central pressures in this range. We might term a low intense (1 occurrence in 7) if its central pressure lies in the range $\overline{p_0} - \sigma$ to $\overline{p_0} - 2\sigma$, and very intense (1 in 40) if its central pressure is less than $\overline{p_0} - 2\sigma$. Lows with a central pressure in the range $\overline{p_0} + \sigma$ to $\overline{p_0} + 2\sigma$ may be characterized as of low intensity, while a central pressure higher than $\overline{p_0} + 2\sigma$ characterizes very low-intensity disturbances.

Applying this criterion to lows in the band 35–40°N, we find the following categories: central pressure less than 991 mb, very intense; 991–998 mb, intense; 998–1012 mb, normal; greater than 1012 mb, of low intensity. For 50–55°N, the corresponding categories are: $<$ 979 mb, very intense; 979–989 mb, intense; 989–1009 mb, normal; greater than 1009 mb, of low intensity. We see that the criterion may place lows in different categories, according to latitude. Thus, a low with a central pressure of 990 mb would be regarded as very intense in latitudes 35–40°N, but of normal intensity in latitudes 50–55°N.

An anticyclone with a central pressure greater than 1031.5 mb would be regarded as very intense in latitudes 25–30°N, but normal in latitudes 60–65°N, very intense disturbances here being those with central pressures exceeding 1044.5 mb.

In the above, we have not taken into consideration the seasonal variation in central mean pressure and variance. What has been done is to arrive at a criterion of grade of intensity applicable to a cyclone or anticyclone population drawn randomly from all seasons of the year. Reference to table 3, which gives the frequency, mean central pressure and variance of anticyclones for the four seasons, shows that there are significant seasonal differences in the two latter quantities. Mean central pressure and variance are higher in winter than in summer. Hence, for example, in the belt 45–50°N, the range of normal intensity is 1025.5–1039.5 mb in winter and 1021–1029 mb in summer. An anticyclone with a central pressure of 1038 mb would be of normal intensity if it occurred in winter, and of very high intensity in summer.

On the other hand, it will be seen from table 3 that the latitudinal variation of mean central pressure and of variance is of broadly the same character in all seasons; both are higher in high than in low latitudes.

The above definitions of grades of intensity may not finally be adopted as the most convenient. It may be preferred to regard the limits of normal intensity as those enclosing 50 per cent of the total population, so that a disturbance would be regarded as "normal" if its central pressure lay in the range $\overline{p_0} \pm 0.675\sigma$. It might be thought expedient to alter the agreed limit between the categories "intense" and "very intense," or to divide the intensity into more or fewer categories than is suggested here. The important thing is to reach generally agreed conventions as to the use of qualifying phrases.

5. Anticyclones of the Australian region

A similar analysis was carried out for Australian anticyclones on the 0000 GCT surface charts for the year 1948. The area covered is roughly bounded by the parallels 45 and 10°S, and the meridians 105 and 175°E. There is, thus, an overlap with the North American data in latitudes 25–45 deg. The data for 40–45°S, predominantly a sea area, must be treated with reserve.

The highs of the Australasian region normally migrate eastwards over the continent and adjacent sea-areas, and are mainly identified with cells of the subtropical anticyclonic belt. In this respect, the population is different from that of the United States anticyclones, which, as we have seen, originate mainly in high latitudes. For this reason, the latitude distribution of anticyclone frequency differs conspicuously between the two continents. The annual mean latitude of Australasian anticyclones was 34.5°S, in contrast to 45°N for the North American migrating highs. The winter mean latitude was 31°S, and the summer mean 36.5°S.

TABLE 3. Seasonal frequency, mean central pressure, and variance of North American anticyclones.

Latitude	Winter Frequency (per cent)	Winter $\bar{p}$ (mb)	Winter σ^2 (mb)^2	Spring Frequency (per cent)	Spring $\bar{p}$ (mb)	Spring σ^2 (mb)^2	Summer Frequency (per cent)	Summer $\bar{p}$ (mb)	Summer σ^2 (mb)^2	Autumn Frequency (per cent)	Autumn $\bar{p}$ (mb)	Autumn σ^2 (mb)^2
25–30	4	1024	27	3	1023	10	—	—	—	1	1023	—
30–35	8	27.5	26	7	26	30	3	1020.5	6.5	5	24.5	41
35–40	18	30	33	14	25	26	12	21.5	36	15	25.5	34
40–45	20	31	36	20	27	26.5	21	23	22	25	27.5	31
45–50	19	32.5	48	15	28.5	44	25	25	17.5	23	29	37
50–55	16	32.5	60	14	29.5	37	21	24	19	17	28.5	44
55–60	8	34	69	14	30	53	11	23.5	24	8	29	32
60–65	6	35.5	57	10	32	42.5	6	24.5	30	4	28	85
65–70	2	35.5	36	3	32.5	47	2	23.5	16	2	27	84

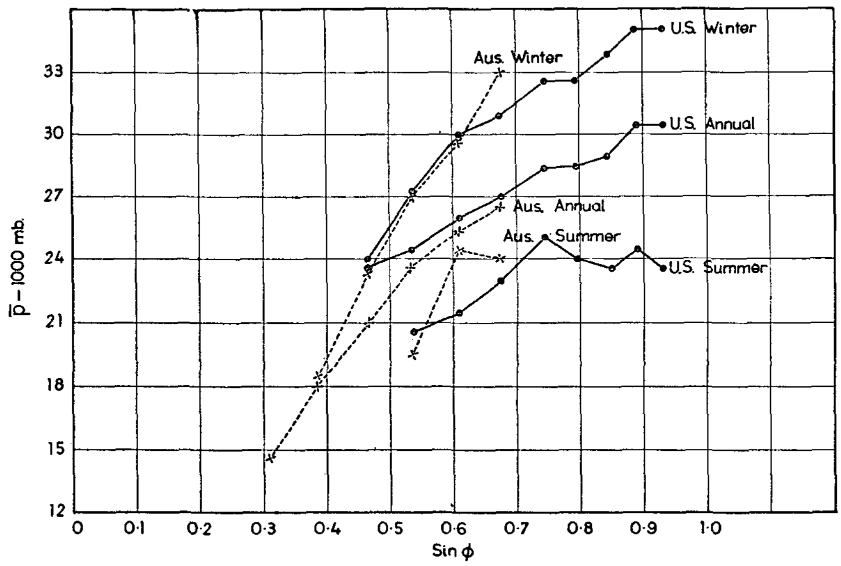

FIG. 1. Mean central pressure of anticyclones against sine of the latitude.

The mean central pressure and standard deviation of Australian anticyclones show the same broad characteristics as these quantities display over North America; both increase with latitude.

6. The $\bar{p}$ − sin ϕ relationship

Fig. 1 shows the mean central pressure of anticyclones plotted against the sine of the latitude of occurrence. The Australian data are indicated by the dashed lines. It will be seen that the mean pressure is very nearly a linear function of sin φ in middle and low latitudes, with a tendency of the curve to flatten out in high latitudes, particularly in summer. A least-squares fit of $\bar{p}$ to sin φ for the North American data, in the range 30–65°N, gives $\bar{p} = 1013 + 25.5 \sin \varphi$ (mb) in winter and $\bar{p} = 1010 + 20 \sin \varphi$ (mb) in summer.

The close agreement between the Australian and United States curves in corresponding latitudes strongly suggests that the relationship $p = a + b \sin \varphi$ (a and b depending only on season) will hold for a representative sample of highs, no matter from which longitude or hemisphere that sample is drawn, or whether the highs constituting the sample are predominantly cells of the subtropical belt or migrating systems originating in middle or high latitudes.

Fig. 2 shows the plot of mean central pressure in cyclones against sin φ (United States data). Again we observe that the relationship is approximately linear. The least-squares fit is found to be $\bar{p} = 1027 - 41 \sin \varphi$ (mb) in winter and $\bar{p} = 1028 - 33.5 \sin \varphi$ (mb) in summer. The linear relationship is not, however, so close as in the case of anticyclones.

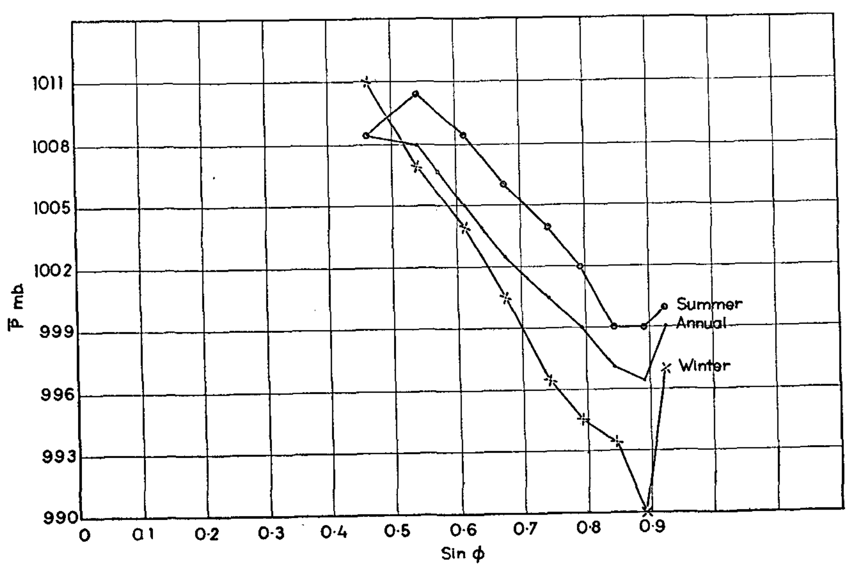

FIG. 2. Mean central pressure of cyclones against sine of the latitude.

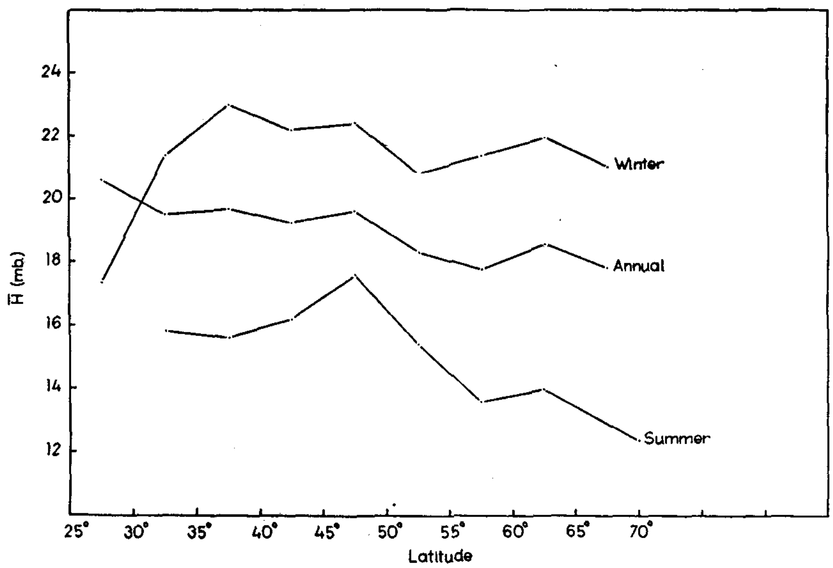

FIG. 3. Mean potential intensity of anticyclones against latitude.

7. The intensity of anticyclones

To determine the mean intensity of anticyclones from the mean central pressure, we must know the mean pressure in the absence of perturbations. The mean pressure reflects the pressure in passing perturbations. If a region is particularly subject to anticyclones, this fact will be reflected in a "higher than average" mean pressure and, hence, we might tend to underestimate the intensity in this way. To take an extreme example, suppose an anticyclonic cell remained stationary over a region for a period. For that period, the mean pressure at the center of the anticyclone would be the central pressure of the high, and hence the computed intensity would be zero!

This difficulty does not arise in connection with the United States anticyclones, for it is found that highs and lows occur about equally frequently in the region covered. When we are dealing with migrating systems, the occurrence of perturbations of both signs may be expected to "keep the average straight" in such a way that the mean pressure may be expected to reflect what the pressure would be in the absence of all perturbations.

The mean pressure distribution over the United States does not vary greatly with latitude, and may be taken as 1016 mb in winter, 1014 mb in spring and autumn, and 1012 mb in summer. With these assumed mean pressures, we find for the mean intensity of winter anticyclones $\bar{h} = 25.5 \sin \varphi - 3$ (mb), while in summer $\bar{h} = 20 \sin \varphi - 2$ (mb). The mean potential intensity is given by $\bar{H} = \bar{h}/\sin \varphi$. Hence, for winter, $\bar{H} = 25.5 - 3/\sin \varphi$ (mb). The first term is much the larger of the two, so that our analysis leads to the conclusion that the mean potential intensity of anticyclones is approximately constant with latitude.

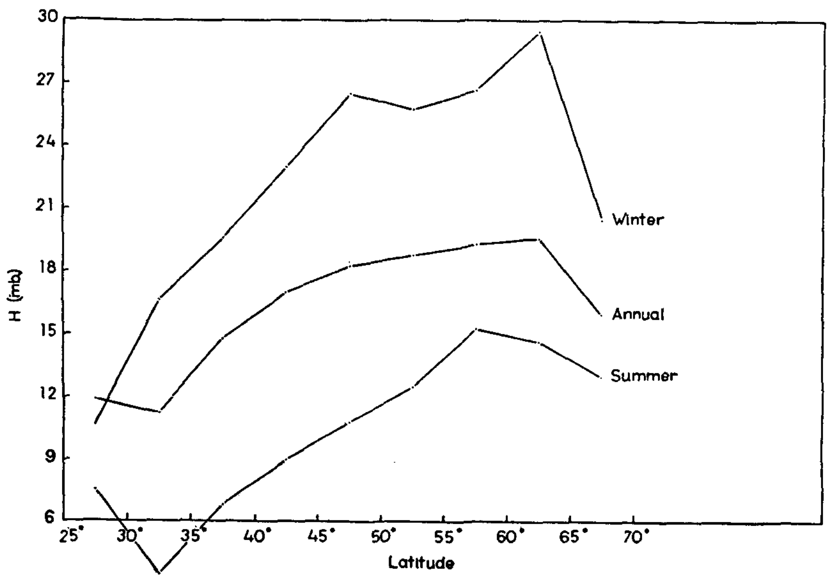

FIG. 4. Mean potential intensity of cyclones against latitude.

The approximate constancy of the mean potential intensity is shown by fig. 3. The mean potential intensity varies much less with latitude than the intensity itself. While the mean annual intensity increases by 40 per cent between latitudes 32.5 and 57.5 deg, the mean potential intensity decreases by only 10 per cent in the same range. The potential intensity of highs is about 15 per cent higher in winter than in the annual average, and lower in summer by about the same amount.

The mean potential intensity of cyclones as a function of latitude is plotted in fig. 4. We observe that $\bar{H}$ for lows increases with latitude. The seasonal change is also greater than in the case of highs, winter figures being about 25 per cent above annual values, and summer figures about 40 per cent below.

8. The mean mass of anticyclones

If we assume that the mean profile-shape of anticyclones is normal, $f = \exp - \frac{1}{2}s^2$, the mass of a disturbance of intensity H will be given by

$$M = 2\pi H^2/\rho g \omega^2. \qquad (6)$$

We shall assume in the following computations that the mean profile-shape is normal, but it may be in order to point out once more that the shape of profile assumed does not greatly affect the mass. If we had assumed a sinusoidal profile, the mass would be only 27 per cent lower than given by (6). Although the absolute values of mass derived from an assumed profile may be in error, because of selection of the "wrong" profile, the relative values in different latitudes would not be greatly in error, for it is unlikely that the mean profile-shape of highs varies greatly with latitude.

The mean mass of anticyclones, under the assumption of a "normal" pressure-profile, is

$$\bar{M} = 2\pi \overline{H^2}/\rho g \omega^2 = 9.3 10^{14}(\bar{H}^2 + \sigma_H^2), \qquad (7)$$

where $\bar{M}$ is expressed in grams, and $\bar{H}$ and σ_H, the standard deviation of H, are expressed in millibars. Since $H = h/\sin\varphi$, $\sigma_H = \sigma/\sin\varphi$, where σ is the standard deviation of h, which is identical with the standard deviation of the central pressure. σ^2 has been tabulated in tables 1 to 3, so that it is possible to estimate the mean mass of anticyclones.

Fig. 5 gives the mean mass of highs as a function of latitude. The mean mass is highest in winter, about 25 per cent above the annual average, and lowest in summer, about 40 per cent below. Thus, winter anticyclones, on the average, are twice as "heavy" as summer highs. In (7), the term in $\bar{H}^2$ constitutes from 70 to 90 per cent of the total mass, the rest being contributed by the variance. Hence, if the variance of H is ignored in computing $\bar{M}$, an appreciable underestimate results.

It has been shown elsewhere (James, 1950) that the potential energy of a perturbation is related to the mass by the relation $P = C_p MgZ/k$, where k is the gas constant, and Z is the equivalent height. Taking the mean equivalent height as 10 km, we find $\bar{p} = 3.5 \times 10^9 \bar{M}$ ergs. From the mean mass of anticyclones in all latitudes, 4×10^{17} g, we derive, as an estimate of the mean potential energy, 1.4×10^{27} ergs. The mean kinetic energy will be about 3 per cent of this, or 4×10^{25} ergs (James, 1951).

9. The mean mass of cyclones

The mean profile for 17 cyclones (James, 1950) indicates that the mean mass defect of lows may be represented by the expression

$$\bar{M} = 5.8 10^{14}\overline{H^2} = 5.8 10^{14}(\bar{H}^2 + \sigma_H^2).$$

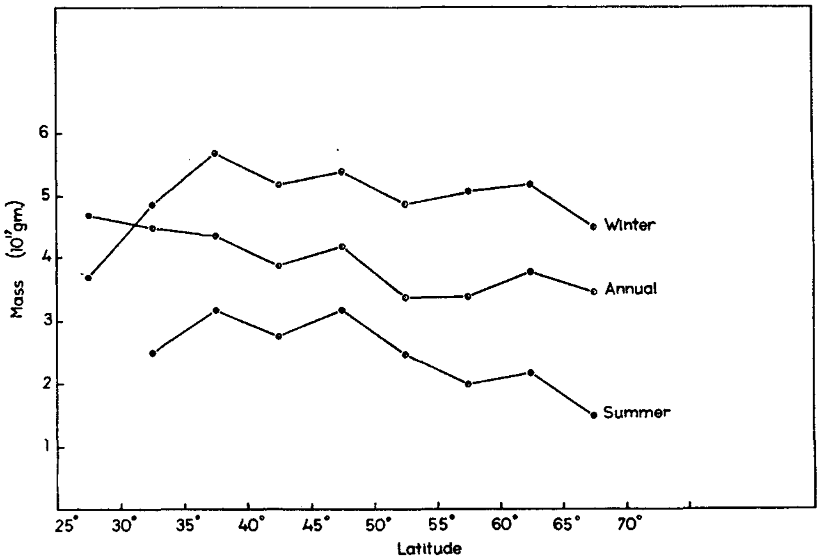

FIG. 5. Mean mass of anticyclones against latitude.

The latitudinal variation of mean mass, based on this formula, is shown in fig. 6. The range of variation of $\bar{M}$ with latitude is greater than for highs, a two-fold increase being indicated in the annual figures between latitudes 32.5 and 52.5 deg. The contribution of $\sigma_H{}^2$ to the total mean mass of lows averages 25 per cent, and in extreme cases is comparable with the contribution from $\bar{H}^2$. To ignore the spread of intensity would therefore lead to a serious underestimation of the mean mass.

The mean annual mass of cyclones in all latitudes comes out to be 2.4×10^{17} g, somewhat less than the corresponding figure for anticyclones (4.0×10^{17} g). However, since the mean profile is uncertain in both types of disturbances, too much importance should not be attached to this result. What is most firmly established by the analysis are the relative values of mean mass as between different latitudes.

The plot of mean cyclone mass against latitude is shown in fig. 6. Winter mass is about three times the summer mean while a doubling of mean annual mass occurs between low and high latitudes, with a sharp drop in the highest latitude range.

10. Conclusions

Statistical investigation establishes the following properties of cyclones and anticyclones in the North American region:

1. Migrating cyclones and anticyclones are approximately normally distributed in latitude, with a mean latitude of 45 deg and a standard deviation of $7\frac{1}{2}$ deg.
2. The mean central pressure of anticyclones varies seasonally, being greatest in winter, and, for a given season, increases approximately linearly with the sine of the latitude.
3. The mean intensity of anticyclones varies with the sine of the latitude, as also does the standard deviation of intensity.
4. The mean potential intensity of anticyclones is highest in winter, and is approximately independent of latitude. Statements (2), (3), and (4) apply equally to the anticyclonic cells of the Australasian region. They may be regarded as properties of anticyclones regardless of location or mode of formation.
5. The mean central pressure of cyclones is least in winter, and varies approximately linearly with sin φ.
6. The mean intensity of cyclones increases with latitude more rapidly than sin φ.
7. The mean potential intensity of cyclones increases with latitude.

Provided the mean profile-shape of disturbances does not change greatly with season or latitude, we may infer from the above results:

8. The mean mass of anticyclones is greatest in winter, and is approximately independent of latitude.
9. The mean (negative) mass of cyclones is greatest in winter, and increases with latitude.

If, further, the "equivalent height" of disturbances does not depend greatly on season or latitude, we find:

10. The mean kinetic and potential energies of anticyclones are highest in winter, and approximately constant with latitude.
11. The mean kinetic and (negative) potential energies of cyclones are highest in winter, and increase with latitude.

The regularities revealed in the behavior of the mean potential intensity of cyclones and anticyclones encourage a rather more physical approach to the properties of these disturbances than is customary. The intensity is manifestly an important parameter expressing the overall properties of a disturbance. It is, however, no more than a statistical curiosity, unless we can relate it to more immediately interpretable physical properties, such as the overall mass or energy. The connection between potential intensity and mass or energy established in the first part of this paper thus paves the way to an energetic interpretation of isobaric configurations. One might feel tempted to essay an analysis of possible energy interactions, and their correlative reflections in the synoptic chart.

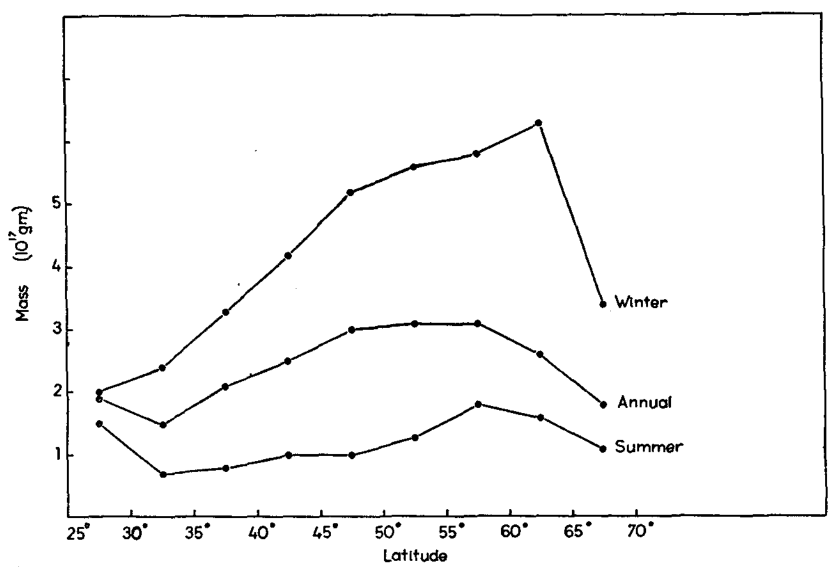

FIG. 6. Mean mass of cyclones against latitude.

Patently, a switch to this particular viewpoint is no forecasting panacea; we know too little about the large-scale transformations of energy in cyclones and anticyclones. However, this point of view offers some hope of opening up a fruitful line of enquiry.

The present investigation has been concerned with the mean energies of cyclones and anticyclones, and reveals certain regularities which would have to be accounted for in a complete energetic theory of the formation and maintenance of cyclones and anticyclones.

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