then, to this approximation, the sea level density of the air varies inversely as the absolute temperature. But an increase of the temperature of the air not only decreases the surface density owing to expansion, but also, as a result of this expansion, increases the pressure at each level above the surface.

Furthermore, the ratio of both seasonal and latitudinal temperature changes to the absolute temperature are roughly constant from the surface up to the stratosphere. Through this height, therefore, a temperature gain tends, on the one hand, to decrease the density of the air by thermal expansion, and, on the other, to increase it by mechanical compression. Clearly, then, that level at which the one tendency exactly balances the other must be a level of constant density.

To determine this level, let v, p, ρ, and T, be the volume, pressure, density, and absolute temperature, respectively, of a quantity of air at the height h above sea level, and H the height of the homogeneous atmosphere *above* h. Then, up to such height, that is, to the top of the troposphere, as $\Delta T/T$ is constant

$$\frac{\text{pressure contraction}}{v}=-\frac{\delta v}{v}=\frac{\delta p}{p}=\frac{h\rho g\Delta T/T}{H\rho g},$$

and

$$\frac{\text{temperature expansion}}{v}=\frac{\Delta v}{v}=\frac{\Delta T}{T}.$$

But, as explained, density is constant where

$$-\frac{\delta v}{v}=\frac{\Delta v}{v},$$

or where

$$\frac{h\rho g\Delta T/T}{H\rho g}=\frac{\Delta T}{T};$$

that is where

$$h=H$$

But $H=8$ kilometers, about. Hence, the level of constant density is roughly 8 kilometers above sea level, as statistically shown in the papers cited above.

Below this level, density grows greater and above it less, both with the waning of summer and with the increase of latitude; similarly, it grows less below this level and greater above it, both with the passage of winter and with the decrease of latitude.

VARIATIONS IN THE DENSITY OF AIR.[1]

By A. JAQUEROD and C. BOREL.

[Reprinted from *Science Abstracts*, 1921, *24*: 217.]

The authors describe briefly some refined determinations of the density of air, made by them at Neuchâtel, with the object of investigating the unexplained variations in the density pointed out by Morley as long ago as 1875. The law of Loomis-Morley is confirmed, namely, that the maximum density is found with samples of air taken when the atmospheric pressure is a minimum, and *vice versa*. Differences of composition do not seem sufficient to explain these variations, and Guye has suggested that the cause is to be found in the presence of ultramicroscopic dust. To test this the authors propose to experiment with air from which dust has been removed electrically. Samples of air obtained by aeroplane from altitudes between 2 km. and 3 km. have been tested and appear to be subject to the same variations of density as the surface air.—*M. A. G.*

[1] *Archives des Sciences*, Paris, Sept.-Oct., 1920, 2: 411-413.

THE ENERGY OF CYCLONES.

[Reprinted from *Nature*, London, March 3, 1921, pp. 11-12.]

In the recent discussion in *Nature* on the energy of cyclones [1] no mention has been made of tropical cyclones, although these are the most remarkable phenomena of their kind.

It is impossible to apply to these cyclones the theories which ascribe the energy of the rotating-wind system to the re-adjustment of equilibrium of warm and cold masses of air within that system, since in the cyclones of the Tropical Zone temperature and humidity are symmetrically distributed. In these cyclones warm and cold sectors do not exist. The Indian meteorologists Henry Blanford, Sir John Eliot, *Fr.* Chambers, and W. T. Willson have published papers on the cyclones of the Bay of Bengal and the Arabian Sea, giving a full explanation of their origin and development. These very important works no longer receive the attention they deserve. They also throw much light upon the source of energy in these cyclones. I endeavored to make a rough calculation of the energy contained within one of these whirls, taking into account the preceding pressure distribution over the hurricane region, and the results were in good agreement with the observed wind forces. I should therefore like to direct attention to this work.

The calculation was based upon observations of the Backergange cyclone. It is given in my *Lehrbuch der Meteorologie* (1901 edition, *p. 579*, footnote), as well as in a paper, "Remarks on the origin of (tropical) cyclones" (*Meteorologische Zeitschrift*, 1877, Aug., p. 311). My calculation has no application to the cyclones of middle and higher latitudes, as it presupposes simple whirls like the symmertical cyclone of the Tropics.—*J. von Hann*, Vienna, Feb., 1921.

[1] Reprinted in Mo. WEATHER REV., Jan., 1921, 49: 3-5.

A REVIEW OF SOME OF THE LITERATURE ON THE SUNSPOT-PRESSURE RELATIONS.

551.590.2 : 551.54

By ALFRED J. HENRY, Meteorologist.

[Weather Bureau, Washington, May, 1921.]

SYNOPSIS.

In the minds of some meteorologists there is an impression amounting almost to conviction in a few cases that there is a distinct response in terrestrial barometric pressure to changes in solar energy as manifested in the changing spottedness of the sun. This study was carried along in connection with an inquiry into the broader relations of sunspots to terrestrial weather. If there is a distinct response in the pressure then we may expect corresponding changes in the temperature, wind movement, and other meteorological elements.

The evidence submitted by various writers on the subject, beginning with Meldrum in 1872, is examined in as much detail as is now possible and the results reached are given in the "conclusions" at the end of the paper.

At the Brighton meeting of the British Association in 1872, Mr. Charles Meldrum, Director of the Observatory of Mauritius, made the statement that for the area comprised between the Equator and 25° South Latitude, and

the meridians 40 to 110 East Longitude, there appears to be a connection between the frequency of cyclones and of sunspots, which is more than a mere coincidence. The evidence that he submitted seemed to show that there were more cyclones at times of sunspot maxima than at sunspot minima, nearly in the ratio of two to one.

At the next meeting of the Association in 1873, Meldrum presented a carefully prepared list of cyclones in the Indian Ocean for the period of 1847–1873. By grouping these numbers according to frequency of sunspots, he found that in years of maximum spots there were 65 cyclones and in years of minimum spots but 34, or a little more than half of the number in years of maximum spots. In determining the number for any particular spot maximum, he took the sum for the year immediately preceding and following the year of maximum spots. Similarly, the number of cyclones at time of minimum of spots was formed by summing the totals for the central year and the years immediately preceding and following. At this meeting he advanced the proposition that years of spot-maximum should also be years of increased precipitation and thus was started a discussion that has been continued ever since. At that time it seems to have been accepted as an established fact that cyclones were more frequent in years of spot-maximum than in years of spot-minimum.

Poey in 1873 [1] announced that the number of hurricanes in the Antilles and the North Atlantic were more frequent at times of spot-maximum than at spot-minimum, thus confirming the view already expressed by Meldrum. Poey published a list giving the number of hurricanes each year from 1750 to 1873, 357 in all or an average of about two per year.

Considering the obstacles in the way of making an accurate count of the number of hurricanes for this rather extensive region, the difficulty in distinguishing between tropical and extra-tropical cyclones, by reason of the incomplete evidence attainable, it is open to doubt as to whether much confidence can be placed in any list compiled under the conditions which existed in 1873. Even at present it is a matter of some difficulty to make a complete list of the cyclones which traverse the West Indies and contiguous waters. Several such lists have been made. The late Maxwell Hall, Government Meteorologist of Jamaica, published a list of severe storms and hurricanes which visited Jamaica during the 260 years, 1655–1915, in all 31, of which number but 5 are classed as great hurricanes. Dr. O. L. Fassig in Weather Bureau Bulletin X, "Hurricanes of the West Indies," has compiled a list of 143 such storms for the period 1878–1911. Bringing this list down to the year 1919, and extending it back to 1871, for which time the record is fairly complete, we get a total of 174 storms or an average of nearly four storms per annum. This record includes, however, many cyclones of little or only moderate intensity, as evidently does Poey's.

I have examined all three of the records, Poey's, Hall's, and Fassig's, as brought up to date by the writer to see whether or not there is reason to believe that the occurrence of tropical cyclones is related to the sunspot cycle. Poey's method of finding congruence between the two phenomena seems to have been a rather elastic one, that is to say, he did not adhere strictly to the central year of the epoch of maximum or minimum and the single years immediately preceding and following that year as did Meldrum, but, on occasions, he used the records of as many as three years before and four years after the epoch of maximum and minimum.

Plotting the data of his list against the curve of sunspots, it becomes apparent at once that whatever relation exists, must be an exceedingly loose one. It is true that a number of the epochs of maximum were preceded and followed by more than the usual number of cyclones, but since the average number per year is but two, it must happen that the occurrence of three or four storms in a year of maximum, spottedness may be given equal weight with the occurrence of twice that number. I have rearranged the data of Poey's table in groups of three years each, having as the central year of the group the year in which the maximum or the minimum of spottedness was reached. The table below presents the data arranged consecutively, beginning with the maximum of 1750 and ending with the maximum of 1870; there are, therefore, 12 complete periods of maxima and 11 of minima.

The totals are given in separate columns so that comparison is easily made and always directly with those of the immediately preceding cycle.

(Poey's table—Comptes Rendus, 77:1226.)

Maxima.		Minima.		Difference.	
Epochs.	Cyclones, number of.	Epochs.	Cyclones, number of.		
1750.0	6	1755.5	5	− 1	
1761.5	3	1766.5	11	+ 8	
1769.9	5	1775.8	8	+ 3	
1779.5	10	1784.8	15	+ 5	
1789.0	7	1798.5	1	− 6	
1804.0	7	1810.5	11	+ 4	
1816.8	11	1823.2	5	− 6	
1829.5	12	1833.8	8	− 4	
1837.2	22	1844.0	13	− 9	
1848.6	11	1856.2	6	− 5	
1860.2	3	1867.2	3	± 0	End of Poey's list.
1870.7	10	1878.9	10	± 0	
1883.9	8	1889.6	15	+ 7	
1894.1	14	1901.7	13	− 1	
1906.7	12	1913.4	1	−11	
1917.7	20				

The above arrangement shows that comparing 11 complete cycles (Poey) maxima to the immediately succeeding minima, 6 show a larger number of tropical cyclones in years of maxima, 4 the reverse, and 1 result is negative. Expressed in percentages, the numbers are 54 and 34, respectively, or only a little better than an even chance that the number of tropical cyclones will be greater in times of spot maxima than in time of spot minima. Adding to Poey's data those of recent years, compiled by the Weather Bureau, 15 complete cycles become available. The additional data, however, do not materially change the percentages above given. Out of 15 cycles, 8 show a preponderance of tropical cyclones at times of spot maxima, 5 the reverse, and in 2 cycles the numbers are the same.

Attention is directed to the following. In some years of spot maxima, when the number of spots is large, as in 1837, 1870, and 1779, the number of cyclones in the immediately succeeding minimum is relatively large. But this rule does not hold in all cases, thus in the spot-minimum of 1901–1907, following the comparatively weak spot-maximum of 1904, there were 13 tropical cyclones as against 14 at time of spot-maximum. Also in the spot-minimum of 1889 there were 15 cyclones as against but 8 in the immediately preceding spot-maximum. This would seem to indicate that we do not yet recognize the precise means by which the solar influence is transmitted

[1] Comptes Rendus, LXXVII, 1873, pp. 1223-1226.

to the earth and its atmosphere. If only years of relatively great frequency showed this characteristic, it might be inferred that the solar effect is cumulative and is felt several years after the subsidence of the sunspots.

Two other investigators, Prof. F. H. Bigelow and Prof. C. J. Kullmer, have supported the idea that there is a response to solar influence in the paths of terrestrial anticyclones and cyclones.

Bigelow's studies are scattered through a number of papers, but his conception of a change in the movement of cyclones and anticyclones is summarized and illustrated in the *American Journal of Science*, 3rd series, volume **48**: 435–451. This paper has been widely quoted, but in such a way that it is not generally understood, due to the use of terms which are peculiar to the author's nomenclature and, in my judgment, not understood or recognized by meteorologists in general. Bigelow explains in the paper above quoted that he used the weather maps of the years 1882–1893, inclusive, as his basic data. From these he estimated the positions of the centers of HIGHS and LOWS, and divided them into northern and a southern group which were treated independently. By condensing and tabulating the coordinates by years and magnetic periods, he was able to detect any variations in latitude which took place. He adopted the terms North and South High and North and South Low Pressures as descriptive of the two arbitrary groups into which the HIGHS and LOWS of the period had been separated, and he explains the meaning of these terms in the following words (loc. cit.):

> The North Low and the South High lines are recognized as the axes of Ferrel's Low Pressure belt, which forms a portion of the polar circuit, and the middle latitude high pressure belt, which forms the tropical circuit. The North High track is the average position of the Highs traveling along the polar circuit; the South Low is that of the average position of formation or occurrence of cyclones in the United States. * * * The North High and the South Low tracks are in realty abnormal outgrowths of the atmospheric circulation.
>
> The question is, Do these tracks in general move in latitude during the sunspot period? The result is that the North Low and the South High belts vary in latitude directly with the solar intensity, being farther north at the maximum and farther south at the minimum of the period, while the North High and the South Low belts vary inversely, that is, are farther south during the maximum of sunspots. This means that an increase of solar magnetic intensity generates the cyclones farther south, and causes the anticyclones from the polar circulation to travel to the south.

I have purposely made this rather lengthy quotation because, first of all, Bigelow does not claim that the number of cylones varies directly with the frequency of sun spots, as many writers have assumed, and, second, because a number of meteorologists, unless they have access to the original papers, are in the dark as to what the terms "North and South High and North and South Low" signify.

The direct claim is made that due to variations in solar magnetic intensity lows are generated farther south at the minimum sun-spot period. This claim should be susceptible of statistical proof; it will be taken up later.

Prof. C. J. Kullmer, of Syracuse, N. Y., has made an extensive study of the distribution in latitude of cyclone tracks in the United States and Canada, for the years 1883–1912, as published in the MONTHLY WEATHER REVIEW. This period of 30 years, he has divided into three equal portions and he has charted the distribution of the paths of lows for each 10 years separately. From these charts he finds evidence of a progressive southerly shift in the average paths of LOWS in the United States.

While Prof. Kullmer's method of analysis was correct and the work was evidently carefully done, there were two factors of which doubtless he was not cognizant, which lead me to place a somewhat different interpretation upon his results. These factors are, first, an increase during the period considered in the number of barometer reporting stations in the southwest from which the paths of cyclones in that region are plotted, and second, the lack of homogeneity in the series of storm tracks published in the MONTHLY WEATHER REVIEW, particularly for the earlier years. The establishment of the station at Flagstaff, Ariz., in 1898, Grand Junction, Colo., in 1899, and Modena, Utah, in 1901, led to an immediate increase in the number of LOWS plotted as passing over that region as compared with earlier years.

Moreover, several stations in the Southern Plateau Region which were available in 1883, ceased to function before the opening of the stations above named. The fact that charts of cyclonic paths were made by different officials at different times has already been noted.[2]

Notwithstanding these limitations there was, and is, in certain seasons an increase in the number of secondary cyclones which develop over the Middle and Southern Plateau regions, west of the Rocky Mountains. The mistake should not be made, however, of ascribing the increase to any particular area and not to other adjacent regions. It can be shown that in some years an increase in the number of cyclones passing eastward in the higher latitudes 50°–55°, N., is associated with a general increase in all latitudes considered; in other years a decrease in the number observed in the higher latitudes is associated with an increase in some of the latitudes farther south, and in others a decrease. The following examples illustrate the two extremes in distribution.

Departures from average of Lows Crossing the 100th meridian in the latitudes named.

Latitude.	1893	1897	1902	1911	1918
55 to 50 North	+9	+9	−16	−21	+13
50 to 45	+3	−5	− 6	+ 3	+ 4
45 to 40	+7	−4	− 3	+ 6	+ 1
40 to 35	+6	−4	+ 1	+ 5	+ 4
35 to 30	+2	−3	+ 7	− 3	+ 8
30 to 25	−5	−2	.....	− 2	+ 3

Dr. H. Arctowski[3] has tabulated the number of LOWS crossing the 100th meridian in the latitudes corresponding to the above for the years 1883–1913, and I have brought the figures down to include 1920, thus giving a 38-year continuous record. The means for the various steps in latitude have been computed, whence are derived the departures above given. Arctowski's summation shows that on the average more LOWS cross the 100th meridian between 35° and 40° north latitude than in the 5-degree square immediately to the north. The completed table for the 38 years also gives the same result, the averages being 18 LOWS per year at north latitude 40°–45° and 21 LOWS at north latitude 35°–40°. Hence there is not, on the average, a progressive decrease in the number of LOWS crossing the 100th meridian with decrease in latitude.

In another compilation that I have made after the method of Kullmer, it is shown that there is a decided excess of LOWS in the 5-degree squares between 35°–40° north latitude and 95°–115° west longitude, as compared with similar squares between 40°–45° north latitude and the same longitude. A similar result can be seen in the work of Bowie and Weightman, Weather Bureau Supplement No. 1, and these authors indicate the probable

[2] MO. WEATHER REV., Aug., 1915, 43: footnote page 374.
[3] MO. WEATHER REV., Aug., 1915, 43: 384.

explanation on page 7 of SUPPLEMENT No. 4, 1917. The cyclones which develop over the Middle Plateau Region, or move thereto from the northwest, belong to the Colorado type which has a very prominent seasonal distribution, reaching its yearly maximum in March and its minimum in September. It should be kept in mind, therefore, that an increase in the number of the Colorado LOWS in the spring and autumn is to be expected and this increase should not be confounded with a diminution of the number of LOWS in some other latitude, or explained as a latitude shift in storm paths.

Attention has often been called to the fact that when for any reason the eastward progress of a primary Alberta or North Pacific LOW, situated west of the Rocky Mountains is interrupted, a secondary LOW develops over the Southern Plateau. Strictly speaking, then, in all these cases there is not an increase in the number of cyclones, but rather an increase of cyclone activity in southern latitudes and a corresponding decrease in more northern latitudes, the net result of which, according to the rough measures available for counting the number of individual cyclones, is to show an apparent increase in some years as compared with others. Finally, what is the evidence of the statistics of LOWS crossing any given meridian in the United States, admittedly incomplete as they are, with respect to the question of an increase in the number of cyclones corresponding to the period of maximum sunspots?

I have smoothed the annual number of cyclones crossing the 100th meridian, using Arctowski's count 1883–1913, and my own 1913 to 1920, and plotted the smoothed numbers in connection with the smoothed sunspot numbers in figure 1 below.

As may be seen from this figure there is good correspondence in the two curves at spot-maximum of 1894 and 1917, respectively, only fair correspondence at spot-maximum of 1906, and very little correspondence at spot-maximum of 1883.

While the curve for the United States for the years 1891–3 shows that a large number of cyclones crossed the 100th meridian, the data for the West Indies do not show a like increase in the number of cyclones in those years. And, moreover, if we take the 80th meridian of West Longitude, instead of the 100th, as our point of reference, we arrive at a distinctly different result, viz, the great peak in the curve of LOWS crossing the 100th meridian in the years 1914–1919 practically disappears. The actual count for the two meridians follows:

Year.	Meridians.		Difference 100–80.
	100	80	
1914	114	103	11
1915	134	107	27
1916	138	108	30
1917	134	102	32
1918	137	104	33
1919	124	104	20
1893	127	102	25
1894	123	102	21

Hence it appears that the large number of LOWS crossing the 100th meridian in the years above enumerated which fact might readily be interpreted as indicating a response to cosmical influences is after all dependent upon terrestrial atmospheric phenomena, perhaps modified to some extent by the relief of the Southern Plateau. Using the figures of Arctowski's table (loc. cit.) for 1893 and 1894, and inserting them at the bottom of the above table it is seen that the same condition held in those years as in the later series; hence what at first seemed to be a confirmation of the proposition advanced by Meldrum and others is, on further inquiry, clearly a result of terrestrial conditions rather than cosmical.

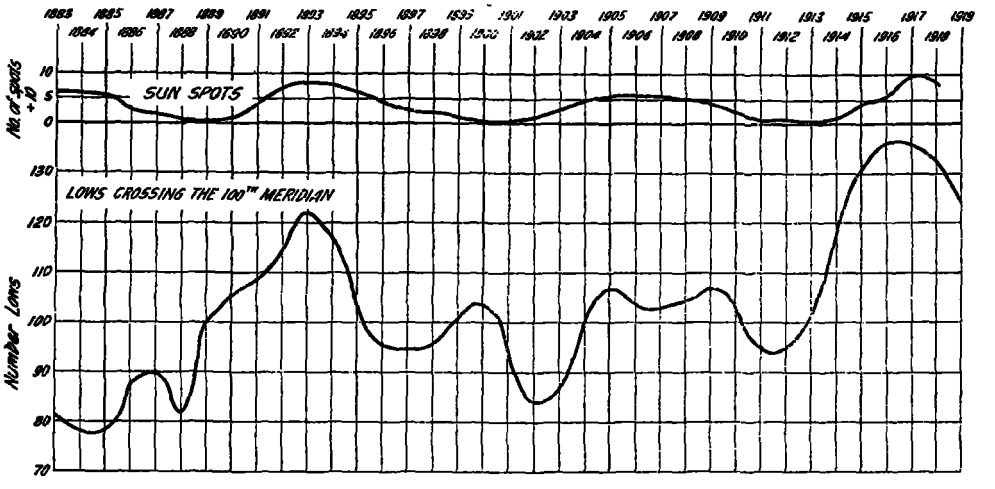

FIG. 1.—Relation of sunspot numbers to the number of LOWS crossing the 100th meridian, 1883 to 1919, inclusive.

The number of cyclones in the West Indies was at a maximum in 1886, 1900–01, and 1916. This is interpreted as evidence of terrestrial control in both regions.

CONCLUSION.

In that part of the Indian Ocean investigated by Meldrum there is convincing evidence that the number of cyclones was greater in years of sunspot maximum than in years of sunspot minimum. No evidence has been submitted or sought to show that the excess in question could not have been explained on terrestrial grounds.

The evidence of the West Indies and the southern portion of the North Atlantic is not convincing either way, although there are indications that the number of cyclones at and near the years of spot-maximum is greater than in years of spot-minimum.

The data for the United States show that an increase or decrease in the number of LOWS is primarily due to the pressure distribution over extensive areas, the co-called "action centers" probably modified to some extent by local atmospheric conditions, which result from orographic control (fig. 1).