RELATION OF TROPICAL CYCLONE FREQUENCY TO SUMMER PRESSURES AND OCEAN SURFACE-WATER TEMPERATURES

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A correlation of summer and autumn tropical disturbances in the Caribbean Sea and Gulf of Mexico with spring-summer pressure deviations at San Juan was worked out at the beginning of the current (1934) season. The results were of interest in that the well-defined positive pressure sequence, dating this year from April, indicated the probability of a less than normal frequency of disturbances during the June–November period. This relation was found to apply particularly to the eastern Caribbean, due probably to the more direct influence of the northeast winds in the southeast portion of the oceanic HIGH, and indirectly and possibly more significantly to low surface-water temperature of the north equatorial current in comparison with that of the extreme western Caribbean and Gulf. Practically the distinction between East and West Caribbean formations probably is not very important, since many of the storms originating in or east of the eastern portion of the section eventually cross to the Gulf and affect that region to as great an extent as, if not greater than, do those that start in the immediate Gulf or Central American waters. However, it was found that in approximately 30 percent of the 48 years of record, 1887–1934, a season of plus storm frequency in one area was accompanied by less than normal activity in the other, and vice versa. A partial explanation for this disagreement is the lesser chance offered for a subnormal season in the west portion, owing to the small normal number (2.5) of its storms. Thus a season to be considered below normal here must record but two storms, whereas in the eastern portion the normal of 4.3 permits a greater leeway. The highest frequencies which have occurred in the western Caribbean and Gulf in the 48 years of record, 1887–1934, were 9 storms in 1933; 6 in 1912 and 1924; 5 in 1893, 1909, 1932; and 4 in 1892, 1895, 1906, 1922, 1926, and 1934 (estimated). In the same period a frequency of 3 storms occurred on 9 occasions. The general probability of less than a normal frequency is 56 percent for the west portion compared with 60 percent for the eastern Caribbean.

In the correlations made at the beginning of the season, a 35 year period, 1899–1933 was used as the basis, inasmuch as pressure data prior to 1899 were not available from the San Juan records. In the present paper however, as indicated, a 48-year period is used, for which supplementary pressure data from 1888–98 were taken from Port au Prince and for 1887 from Port of Spain, Trinidad. The addition of these years and 1934 has given the results greater dependability without changing materially the original conclusions. The method pursued in the arrangement of the data was to group the years or seasons into 2 or 3 divisions, according to the pressure obtaining during the months of April to July, inclusive: (1) All years of positive deviations; (2) years of pressure deficiency; (3) variables, where 2- or 3-month sequences were being classified. In the 48 years, 27 percent of the period, representing minus pressures in May, June, and July, accounted for 41 percent of the tropical disturbances, while 33 percent of the period, representing pressures above normal, yielded but 25 percent of the total number. Variable pressures, comprising 40 percent of the 48 years, made up the remaining 34 percent of the 324 recorded disturbances of 1887–1934 (data for 1934 partly estimated). This recapitulation gives a general indication of the results shown in greater detail in tables 1 and 2, viz, (*a*) a fairly well-defined connection between positive spring-summer pressures in the North Atlantic and low storm frequencies in the eastern Caribbean and to a lesser extent in the western Caribbean; (*b*) increased frequencies following pressure deficiencies; (*c*) lower frequencies after variable pressures than in (*b*) but more than in (*a*). Similar correlations were worked out, using the pressure characteristics of single months, May, June, July, or combinations of two consecutive months, April–May, May–June, June–July. However as approximately 60 percent of the same data are duplicated in each of the correlations, there are no very material differences in the several resulting values, with the exception that somewhat better probabilities for the western Caribbean are obtained from the May and May–June pressure characteristics. Generally considered, the May–June–July basis appears the more satisfactory key to (1) the eastern Caribbean situation and (2) the entire area as a unit, by indicating more nearly the pressure control of the autumn months. With respect to the western Caribbean and Gulf, however, the verification is but 62 percent, compared with 90 percent for the eastern Caribbean and 80 percent for the entire area. In general, as stated, the May–June or May pressure alone appears to more consistently indicate west Caribbean and Gulf conditions. The May pressure yielded a verification in 17 years out of 24 after plus pressure deviations, or 71 percent; and the May–June minus sequence verified in 12 years out of 17, likewise 71 percent. The mean verification using May pressure is 66 percent compared with 64 percent for the May–June basis.

A sequence of three spring-summer months of like pressure sign occurs on the average in 2 years out of 3. In the 48-year period, there were 29 such examples. Under such well-defined high- or low-pressure conditions, the indications of summer and autumn storm frequency is rather definitely shown. Where the pressure in these months is variable, the problem is less determinate, although we find that with respect to the eastern Caribbean a positive pressure in July has indicated subnormal storm frequencies in 24 years out of 30, or an average of 80 percent, and a minus pressure in the same month was followed by increased or above normal frequency in 13 out of 18 years, or 72 percent. For the entire area, including west Caribbean and Gulf, the same basis yielded a 73 percent probability, or 74 percent after plus pressure and 72 percent following a minus characteristic.

Of the 42 disturbances orginating in the eastern Caribbean area or North Atlantic in the 16 years of positive summer pressures, only a small percentage followed a southerly course through the Caribbean Sea. The great majority formed to the east or northeast of the Leeward Islands, mean position of first location latitude 18°–40°, longitude 57°–30°; and mean recurve at latitude 26°–50°, longitude 80°. These points would not vary greatly in all probability from mean values for the entire record, but the comparative freedom from tropical disturbances of the more southerly portion of the area during years of excess pressure in the North Atlantic is marked. On the other hand several severe storms have been recorded in these years of otherwise favorable conditions, as in September 1908, over Turks Island; and August 1927 in

the North Atlantic, which eventually caused losses on the Canadian coast. Several noteworthy storms that have become important matters in Puerto Rico history, ancient and more recent, might not have been indicated by the summer pressures of those years. The San Ciriaco storm of August 1899 was preceded by positive pressures in May and June, becoming deficient in July. The year was one of less than normal frequency, but San Ciriaco had one of the most severe disturbances in the history of the island. In 1928 the San Felipe storm was of a comparable destructive character; and that it caused less loss of life was due to the advance warnings rather than to any lesser destructive force. Summer pressure preceding this storm was deficient in May and June, but equaled the normal in July. In 1887 the greatest number of disturbances recorded in 1 season occurred, a record until the 21 storms of 1933. In that year, judging from pressures at Port of Spain, Bermuda, and Nassau, there was a deficiency in May and June, followed by a positive departure in July. These instances emphasize the fact that only general indications may be obtained from the pressure deviations of the early months; and each season must necessarily still be watched for developments of the exceptional.

A correlation was made of surface ocean water temperatures of the August to October period with tropical storm frequencies of the eastern Caribbean, using as a basis the years 1920–33, inclusive. A marked positive relation was found in these years, represented by a verification of 87 percent. Accepting the San Juan air temperature as a base, which has been found to be rather closely related to the surface water temperature of the Caribbean, a similar correlation was made, covering the 35-year period, 1899–1933, which yielded a positive value of 72 percent. In this connection, C. F. Brooks writes in the Monthly Weather Review of October 1920 as follows (**1**):

> Water colder than usual in this region (Caribbean Sea) would not only reduce the moisture content of the air, but also, by keeping the air cooler, would reduce the usual intensity of development of the low pressure that marks this region in the warm half of the year, and therefore prevent the attainment of the usual strength of the convectional currents.

The relation of the trades to pressure and temperature deviations and storm frequencies was similarly considered. In an earlier study it was noted that the trades influence on ensuing pressure and temperature is most closely related to the wind movement of the January-to-March period, months of relatively high velocities. The temperature of the ocean surface water is affected in the Caribbean Sea after a lag of some months, and is found to be best defined after a 9-month interval, though persisting perhaps for 15 to 18 months or longer. The inverse relation of these winter trades to the August-to-October ocean temperature of the following year is verified in 80 percent of the years of record. The same relation applied to the air temperatures at San Juan yielded 77 percent. The results derived from a comparison of the trades and the summer temperatures of the same year was less well defined. These relations have been limited to the eastern Caribbean. Summer surface water temperatures in the western Caribbean and Florida Straits are normally higher than in the eastern Caribbean, being more directly affected by the temperature of the south equatorial current and by their contiguity to the warmer continental coasts. In this fact may be one explanation for the lack of agreement of storm frequencies in some years in the two divisions.

A quantitative correlation of the winter trades with the pressure after a lag of 9 months gives a coefficient of +0.31, after 12 months +0.37, and after 16 months (May, June, July period of the following year) +0.53. The strengthening of the ocean high over a period of 18 months or longer after increased winter trades activity explains in part the persistence of definite weather types in the sub-Tropics and likewise the relation of the trades directly and indirectly to tropical storm frequency. A correlation of the winter trades with eastern Caribbean storms of the following year is verified in 83 percent of the years of record. A wind movement of the trades 10 percent above the normal in January, February, or March was used as the dividing line, or point of demarcation between excessive and subnormal conditions.

The inverse effect of an intensified high-pressure area in the North Atlantic on the frequency of tropical storms was noted by E. H. Bowie, in MONTHLY WEATHER REVIEW of September 1923 (**2**):

> The region of the West Indies and Gulf of Mexico was free from tropical disturbances during the month (September 1923), this being accounted for by reason of the fact that the northeast trades extended well south of the north coast of South America throughout the month.

With respect to the current season, pressure was above the normal after early in the year, while surface-water temperatures of the Eastern Caribbean indicated subnormal conditions, based upon deficiencies in the San Juan air temperature in July, August, and September. The general probability of a subnormal storm frequency was therefore well defined with respect to the eastern Caribbean and also for the west portion, though verification in past years in the latter area is approximately 20 percent less definite. Excessive trades in February and March 1933 were apparently being reflected in the strengthened summer HIGH over the ocean, while the completion of a May to July positive pressure sequence at San Juan placed the season in that group which from the previous records of 47 years had averaged 2.6 storms for the eastern Caribbean and 2.5 in the west Caribbean and Gulf. The opposition of the latter section, noted frequently in past years, was again exemplified by the occurrence of two rather severe disturbances in the Gulf early in the season and several less well developed formations later in the season. In the east portion of the Caribbean, however, conditions were generally in line with early indications. Such formations as occurred developed to the east or north of the Leeward Islands and in the warmer waters off the Florida coast, and were not of very marked intensity.

To summarize, it may be said that: (1) Spring and summer pressure deviations in the North Atlantic, as indicated by the pressure at San Juan, have an inverse relation to tropical storm frequencies of the summer and autumn months. This is best indicated where pressure continues above normal from May through July, but is also related definitely to the July departure considered singly, and also as early as April-May. It is less well defined with respect to the west Caribbean, but has a 71-percent probability of verification in relation to the May and June pressure deviation. (2) Ocean temperatures bear an inverse relation to storm frequency in the tropics based upon results of a 15-year period of surface water temperatures 1920–34 (values for 1934 interpolated). (3) Trade winds of the winter months have a correlation coefficient of +0.53 with the pressure over the North Atlantic 16 months later and, therefore, are closely related to tropical storm frequencies of the following year. The trades also have an inverse relation to the temperature of the ocean surface water temperatures, best defined after a lag of 9 months, but continuing after an interval of 12

months and possibly beyond. (4) The probability of storm frequency based upon summer pressures refers more especially to departures from a normal of 2.5 storms for the west Caribbean and Gulf, and 4.3 for the eastern Caribbean. As regards intensity of individual storms, no general rule is indicated, although a greater proportion of mild formations appear to occur in years of increased pressure in the summer months.

REFERENCES TO LITERATURE CITED

(1) The Relation of Prolonged Tropical Droughts to Sun spots, by W. H. Pickering, Mo. WEA. REV., Oct. 1920 (including comments by Dr. C. F. Brooks).
(2) Forecasts and Storm Warnings, E. H. Bowie, Mo. WEA. REV., Sept. 1923.

TABLE 1.—*Correlation of tropical storm frequencies of the Caribbean and Gulf and spring-summer pressures at San Juan P. R. (1887–1934)*

Pressure	Number of seasons	Tropical storm frequencies: West Caribbean and Gulf — Below normal No.	Below normal Pct.	Above normal No.	Above normal Pct.	East Caribbean — Below normal No.	Below normal Pct.	Above normal No.	Above normal Pct.	Entire area — Below normal No.	Below normal Pct.	Above normal No.	Above normal Pct.
April–May:													
Plus	16	10	62			14	88			12	75		
Minus	13			8	62			10	77			10	77
Variable	19	11				10				10			
Mean	48	62 percent				82 percent				76 percent			
May:													
Plus	24	17	71			20	83			18	75		
Minus	24			15	62			16	67			15	62
Mean	48	66 percent				75 percent				68 percent			
May–June:													
Plus	17	10	58			15	88			12	71		
Minus	17			12	71			14	82			13	76
Variable	14	12				10				11			
Mean	48	64 percent				85 percent				74 percent			
June–July:													
Plus	21	12	57			17	81			14	67		
Minus	15			9	60			14	94			13	87
Variable	12	10				10				11			
Mean	48	58 percent				86 percent				77 percent			
May–June–July:													
Plus	16	9	56			14	88			11	69		
Minus	13			9	69			12	92			12	92
Variable	19	13				14				15			
Mean	48	62 percent				90 percent				80 percent			
July:													
Plus	30	18	60			24	80			22	74		
Minus	18			8	44			13	72			13	72
Mean	48	52 percent				76 percent				73 percent			
General probability		56		44		60		40		56		44	

TABLE 2.—*Mean frequency of tropical disturbances, of Caribbean and Gulf of Mexico, in relation to spring-summer pressure at San Juan, P. R. (1887–1934)*

Pressure	West Caribbean and Gulf — Average number storms	West Caribbean and Gulf — Departure	East Caribbean — Average number storms	East Caribbean — Departure	Entire area — Average number storms	Entire area — Departure
April-May:						
Plus	2.3	−0.2	2.6	−1.7	4.9	−1.9
Minus	3.2	+0.7	6.1	+1.8	9.3	+2.5
May:						
Plus	2.0	−0.5	2.8	−1.5	4.8	−2.0
Minus	2.9	+0.4	5.5	+1.2	8.4	+1.6
May-June:						
Plus	2.5	0.0	2.6	−1.7	5.1	−1.7
Minus	3.1	+0.6	6.2	+1.9	9.3	+2.5
June-July:						
Plus	2.5	0.0	3.0	−1.3	5.5	−1.3
Minus	3.0	+0.5	6.7	+2.4	9.7	+2.9
May-June-July:						
Plus	2.5	0.0	2.6	−1.7	5.1	−1.7
Minus	3.4	+0.9	6.9	+2.6	10.3	+3.5
July:						
Plus	2.2	−0.3	3.2	−1.1	5.4	−1.4
Minus	2.7	+0.2	5.7	+1.4	8.4	+1.6
Normal	2.5		4.3		6.8	

TABLE 3.—*Annual frequency of tropical storms in the Caribbean and Gulf of Mexico, 1887–1934*

Year	West Caribbean	East Caribbean	Year	West Caribbean	East Caribbean	Year	West Caribbean	East Caribbean	Year	West Caribbean	East Caribbean
1887	3	13	1899	2	3	1911	1	1	1923	1	4
1888	3	7	1900	1	5	1912	6	2	1924	6	2
1889	3	5	1901	2	8	1913	2	2	1925	2	1
1890	0	1	1902	3	1	1914	1	1	1926	4	6
1891	2	9	1903	0	8	1915	1	4	1927	1	6
1892	4	5	1904	3	6	1916	3	10	1928	0	6
1893	5	5	1905	2	1	1917	0	2	1929	1	1
1894	2	4	1906	4	5	1918	0	4	1930	0	2
1895	4	2	1907	1	3	1919	1	3	1931	3	5
1896	3	3	1908	2	4	1920	2	2	1932	5	6
1897	2	3	1909	5	7	1921	3	2	1933	9	12
1898	2	5	1910	1	3	1922	4	1	1934	(4)	(3)

Figures in parentheses estimated.

TABLE 4.—*Years of pressure excess or deficiency at San Juan, P. R., during May, June, July, 1887–1934* [1]

Pressure: Above normal	Pressure: Below normal
1890	1888
1892	1889
1895	1891
1896	1893
1908	1901
1910	1903
1912	1906
1913	1915
1914	1916
1917	1926
1922	1931
1923	1932
1924	1933
1927	
1929	
1934	

[1] Data 1887, Port of Spain, Trinidad; 1888–98 from Port au Prince, Haiti.