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INFLUENCE OF GULF WATER-SURFACE TEMPERATURES ON TEXAS WEATHER.

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[Weather Bureau Office, Galveston, Tex., Aug. 23, 1923.]

It has been shown that the distribution of temperature over the interior of Texas and adjoining districts in the summer season, together with the direction and velocity of the prevailing winds, which in a measure result therefrom, exerts a profound influence upon the character and distribution of rainfall over that region.[1] These air currents are induced mainly by temperature differences between land and water. It is therefore necessary to determine the distribution of temperature over the water surface as well as the land surface, and, for several reasons, the former is by far the more important.

Since water has a much higher specific heat, expends a large share of its energy in evaporation, and, by its mobility, absorbs heat to a much greater depth than the land surface, its temperature changes are correspondingly more sluggish over limited ranges as contrasted with land temperature changes.

It is apparent that any given water temperature abnormality is likely to persist and its influence likely to be felt over adjacent land areas for a much longer time than a similar or even greater departure of land temperature from the normal. The assumption that abnormal weather over the United States at any season is due in part to abnormal temperatures over the oceans carries with it the assumption that ocean temperatures at various seasons depart materially from the normal. That the temperature of the ocean water exhibits a well-defined annual variation is understood, but the considerable departures from that mean annual variation are not so well known.

Dr. Hans Pettersson has said:[2]

> Important as the temperature-regulating functions of the ocean undoubtedly are, they would afford but little actual interest were they always, from year to year, exercised in exactly the same manner and with unvarying intensity. However, there is ample evidence to show that this is not the case. * * * There are years when the heat supply runs down to famine values and other years of lavish abundance. Exact proofs of this were first produced 20 years ago by Otto Pettersson, which may be said to open new perspectives on the relationship between oceanography and meteorology. By means of curves extending over many years it was shown that the surface temperatures of the Atlantic off the coast of Norway in winter vary considerably from year to year and that these variations are reflected on a magnified scale in the perfectly parallel fluctuations of the air temperature over central Sweden.

And again, in the same paper, Doctor Pettersson remarks:

> From a theoretical point of view the prevailing conditions of the surface sheet of the ocean ought to have a decided influence on the amount of rain precipitated over the continents. However, so far no very definite proofs have been produced for the actual existence of the supposed relationship. * * *

These and other investigators have found that ocean temperatures do frequently differ considerably from the normal. In a discussion of ocean temperatures and weather in southern California, William E. Ritter and George F. McEwen stated that[3]—

> During July, August, September, and October, 1917, the temperature of the sea at the institution (Scripps) averaged about 5° F. higher than for the same months of the nine preceding years and the force of the northwest ocean wind for the same time was about 20 to 30 per cent below the average. These exceptional conditions of wind and water were followed, as is well known, by exceptional weather conditions of the ensuing winter months.

Temperature of the ocean water is directly dependent upon the amounts of insolation and radiation, but the temperature of the surface water is also dependent upon the direction and velocity of the winds. Dr. Charles F. Brooks states:[4]

> Insolation and radiation are the most important factors in the general heating and cooling of the ocean surface. * * * Departures of the temperatures of the sea surface from the normal are almost wholly the result of variations in wind direction and velocity. * * * The effect of changes in wind velocity is most noticeable in the tropics, where changes in direction are of little or no effect.

It is well known that low temperatures off the west coasts of Africa and South America are due to rise of cold water from the ocean depths under the influence of trade winds.[5] Some remarkably low temperatures are found very near to the Equator due to reduction of the air temperature by cold water alongshore.

For these and other reasons it appears that considerable departures of water surface temperature from the normal are not infrequent. For the Gulf of Mexico there are available no systematic observations of water surface temperatures, but it will be shown that certain weather conditions over Texas are undoubtedly associated with unusual water temperatures.

The influence of abnormal water temperatures upon weather over adjacent land areas depends upon the magnitude of the abnormality; that is, a very cold water surface would cause a continuous overflow from water to land, and thus materially reduce the air temperature, whereas a moderately cold surface would give rise to moderate sea winds characterized by absence of cloudiness, and thus possibly produce a higher air temperature than would be the case with a higher water temperature and stagnant conditions attended by frequent rainfall and much cloudiness. In other words, a cool Gulf will not necessarily produce low temperatures over adjacent land areas.

[1] Tannehill, I. R.: Some characteristics of Texas rainfall. MO. WEATHER REV. May, 1923, 51: 250–253.
[2] Pettersson, Dr. Hans: Meteorological aspects of oceanography. MO. WEATHER REV. June, 1916, 44: 338–341.
[3] Ritter, Wm. E., and McEwen, Geo. F.: Ocean temperatures and seasonal weather in Southern California. MO. WEATHER REV., November, 1918, 46: 512.
[4] Brooke, Chas. F.: Ocean temperatures in long-range forecasting. MO. WEATHER REV., November, 1918, 46: 510–512.
[5] Hann, Dr. Julius: *Handbook of Climatology*, p. 185.

Temperature extremes along the coast are due to overflow of air from the land. Offshore winds in the daytime give rise to abnormally high air temperatures. Offshore winds at night cause low morning temperatures. A warm Gulf, then, would obviously result in low wind movement from water to land, with frequent absence of any sea wind, and thus the temperature ranges would increase correspondingly. The frequent rains and cloudiness that would result from such stagnation would act to reduce the temperature.

Now, we do know to a certainty that the Gulf surface-water temperatures rise throughout the summer months, the lag in heating being considerably more than in the case of a land surface. We may then study the changes in weather along the adjacent coast during the summer as water temperatures increase and see what characteristic changes result.

Table 1 gives a few of these. The mean wind velocity at 3 p. m., which in all summer months prevails on shore, gradually diminishes. The frequency of rainfall increases. The mean daily range of temperature increases from June to August. Sunshine decreases. These progressive changes are obviously characteristic of conditions attending a steady rise of water temperature. Temperature extremes become more pronounced. Rainfall and cloudiness are increased.

TABLE 1.—*Means for period 1913-1922, inclusive, at Galveston, Tex., illustrating progressive weather changes attending steady rise of water temperature.*

	Wind velocity, 3 p. m.	Rain frequency.	Mean daily temperature range.	Sunshine (per cent).	
				7 a. m.	Noon.
June	12.5	6.9	8.4	63	92
July	11.8	9.0	8.8	60	90
August	11.6	9.5	8.9	43	86

Of these phenomena, the wind velocity is undoubtedly the best index to water temperature. Consequently it is assumed that in certain years with excessive wind movement the water temperatures were below normal and vice versa.

In Table 2 the mean hourly wind velocities for the month of July are given for stated years in the period 1901–1922, inclusive. During that period the instruments of the Weather Bureau at Galveston were exposed continuously in the same location, with the exception that the elevation of the anemometer was increased from 112 to 114 feet in 1912, this slight change apparently having no appreciable effect on wind velocity records. The mean velocities for July are followed by means for August for corresponding years.

In the first part of the table the five years in which the July wind movement was highest have been grouped according to velocity while in the second part the five years in which July wind movement was lowest have been grouped. These data are followed by frequency of rainy days.

In the years of high wind movement, July averaged 11.1 miles per hour and August 10.4; in years of low movement, July averaged 8.3 miles per hour and the following month of those years averaged 9.3 miles. Apparently the condition which caused high wind movements in July persisted into August, though there was a trend toward normal.

TABLE 2.

	Wind velocity.		Number of rainy days.	
	July.	August.	July.	August.
1902	11.3	9.0	10	0
1915	11.2	12.8	6	11
1909	11.0	10.2	3	9
1917	11.0	10.0	3	7
1907	10.9	10.2	8	7
Mean	11.1	10.4	6.0	6.8
1919	7.1	8.8	10	10
1908	8.1	8.8	16	8
1906	8.5	8.3	11	5
1914	8.7	10.6	6	14
1916	8.9	9.9	12	11
Mean	8.3	9.3	11.0	9.6

In a similar manner the low wind movement continued into August, though increasing. These persistent conditions are thus characteristically of water origin. The frequency of rain is less in windy months. Table 3 shows the mean daily temperature range for July of those years and also the sunshine percentages. A study of this table indicates clearly that the differences in the frequency of rain, the range of temperature, and the velocity of the wind and percentage of sunshine are similar to those progressive differences that attend rising water temperature through the summer months.

It seems reasonable to conclude that in the first group of years the Gulf was cold; in the second group it was warm.

According to a compilation by Prof. A. J. Henry[6] the mean temperature for the United States as a whole was 0.5° F. lower in the first group of years than in the second, as an average.

TABLE 3.

July—	Mean daily temperature range.	Sunshine (per cent).	
		7 a. m.	Noon.
1915	8.0	69	100
1917	7.9	77	85
1902	7.9	30	81
1909	7.1	66	96
1907	7.9	48	99
Mean	7.8	58	92
1919	9.4	60	72
1914	9.0	59	97
1916	9.7	36	80
1906	9.1	44	77
1908	9.7	42	87
Mean	9.4	48	83

The greater frequency of rainfall in quiet years is due to increased opportunity for convection.[7] Note that average number of rainy days for July with excessive wind movement was 6 and for July with low wind movement 11. August of corresponding years averaged 6.8 rainy days following a windy July and 9.6 following a quiet July.

Apparently unusually high wind movement, suppressing convection in July, is likely to persist into August,

[6] Henry, A. J.: Sunspots and terrestrial temperature in the United States. Mo. WEATHER REV. May, 1923, 51: 243–249

[7] Tannehill, I. R.: Correlation of wind velocity and convective rains at Houston, Texas. MO. WEATHER REV., April, 1921. 40: 204–205.

reducing the rain frequency in the same manner, and conversely a quiet and, consequently, a wet July will be followed by a wind movement below normal and rainfall above normal in August. However, it must be noted that this record covers a period of little more than 20 years and that wind movement at one location on the Texas coast is discussed with reference to rainfall which results from showers quite local in character.

Of the above years, 1917 was most remarkable as far as rainfall is concerned. The total rainfall at Galveston that year was 21.43 inches, the least annual amount recorded since the record began in 1871. The average hourly velocity of the wind for 1917 was 11.8 miles, which has been exceeded in only two years of record.

Abnormally high wind movement and a total annual rainfall of 5.38 inches characterized the year at Corpus Christi. The section director at the close of December, 1917, issued in part the following summary: [8]

December was the driest of 16 consecutive dry months, and closed the driest year of the record. The average precipitation for the State was only 7 per cent of the normal * * *. The deficiency was general, and three-fifths of the reporting stations had less than a measurable amount of precipitation.

A persistently high wind movement of this character suggests the maintenance of an abnormally steep temperature gradient from land to water, with the probability that the source lies in low water temperature. Under the heading "Weather Conditions over the North Atlantic Ocean," the WEATHER REVIEW in 1918 included summaries for the year 1917. These were partially as follows:

January: For the month under discussion the water temperatures were somewhat below the normal over practically the entire ocean. * * *

February: The monthly average temperature of the water at the surface was considerably below the normal over the entire ocean with the exception of the region in the vicinity of the Azores and the Madeiras and within the northeast trade wind limits, where the positive departures ranged from 1 to 3 degrees. * * *

March: * * * while in the vicinity of the American coast and in the Gulf of Mexico they were variable, although slightly negative over the greater portion of this territory.

April: The mean monthly surface water temperatures as compared with the normal were about as variable as those of the air. * * *

May: * * * In American waters, including the Gulf of Mexico, negative departures were the rule. * * *

June: The average monthly temperature of the air over the ocean did not, as a rule, vary greatly from the normal. * * * In the Gulf of Mexico they were slightly negative, * * * while over the remainder of the ocean the air and water temperature departures did not differ materially. * * * (Indicated that water temperatures of Gulf were slightly below normal.)

July: In the northeast trade wind region and Gulf of Mexico the departures were rather irregular, ranging from minus 1° to plus 4°.

August: The mean temperature of the water at the surface differed but little from that of the air. * * * (Nearly normal in Gulf of Mexico.)

September: * * * in the Gulf of Mexico they were slightly negative—* * *

October: * * * as well as in the Gulf of Mexico, the water temperatures were as a rule from 1° to 4° below the normal.

November: In the Gulf of Mexico the water temperatures were from 2° to 3° lower than usual— * * *

December: The temperatures for the greater part of the northern steamer lanes were somewhat cooler than usual, the same conditions holding true in the Gulf of Mexico and in the waters adjacent to the American coast, * * *

The records indicate that for most of the year 1917 the Gulf water temperatures were somewhat below normal. Such a condition sets up strong temperature gradients and results in increased wind movement over Texas, thus suppressing convectional rains. As a result ranges in 1917 were poor, stock water was scarce, movement of cattle to prevent starvation began in June and continued to the close of the year. Dry weather was unfavorable for crops and poor stands resulted. A large acreage was prepared for winter grain, but most was not sown on account of dry weather.

Table 1 contains data that indicate that dry weather caused by high wind movement is likely to persist. The suggestion is offered that abnormal conditions like those of 1917 are the result of low Gulf water temperatures. It seems more than likely that the temperature of the Gulf water was below the normal during the entire year and that abnormally high wind movement set up thereby served to keep the waters in motion and thus prevent the normal accumulation of warm surface water that would have naturally terminated the abnormal temperature gradient. In short the condition is likely to persist both because of the wind movement set up and because water, by its mobility, high specific heat, and evaporation, responds very sluggishly in temperature changes.

Since changes in the velocity and direction of the prevailing winds over Texas influence the character and distribution of its rainfall (1) and exert a profound influence upon the crop yield, grazing of cattle, and in other ways vitally affect the prosperity of this region, the possibility of long range forecasts based upon a very thorough study of water and land temperatures and other factors demand attention.

The year 1919, with the lowest annual wind movement recorded at Galveston since the anemometer was placed in its present exposure, was an abnormal year over Texas. Data shown in the foregoing tables would indicate that the Gulf in July of that year was abnormally warm. In that respect it was the reverse of the extreme year of 1917 and the effect on the weather of the State was pronounced and its influence upon crops was strikingly in contrast to that of 1917.

The section director in his annual summary for Texas stated: [9]

The year 1919 was the wettest of record from and including 1888 * * *. The excessive precipitation resulted in damaging floods, reduced the cotton crop, deteriorated late corn, stimulated insect pests, and delayed plowing, seeding, and harvesting and other farm work. Cottonseed began to sprout in the bolls and rice and grain in the shock, and peanuts, sweet potatoes, and feed crops were beginning to rot in the fields * * *.

No water temperature records for the Gulf are available for the year 1919.

In conclusion, it can not be said that the evidence is indubitable. The records discussed are rather local in character as regards wind velocity, temperature ranges, and sunshine percentages. Yet the conditions shown therein give every evidence of being fundamentally related to the weather over the State.

It has been shown that the variation in these conditions in July of various years is similar to the variation which results in those conditions from one summer month to the succeeding as the water temperature changes. In the most striking of the windy and dry years, which were assumed to attend an abnormally cold Gulf, it has been shown that in every probability the Gulf surface water temperatures, from reliable records for a portion of the year, were continuously below normal throughout the year.

If, then, abnormal water temperatures are responsible for such striking variations in the weather over the State and the crop yields and in general the comfort and prosperity of the population, or if there is a probability that such is true, it seems highly important that the distribution of water surface temperatures be as well known as that of the land surface.

[8] *Climatological Data for the United States by Sections;* Vol. IV, Part IV, p. 135.

[9] *Climatological Data for the United States by Sections:* Vol. VI, Part V, p. 148.