TABLE 7.—*Monthly and annual percentage of the normal movement of the wind from NE., E., and SE. at San Juan, P.R., 1905–29*

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1905	75	101	74	95	113	100	90	94	85	100	81	93	92
1906	81	66	87	95	109	101	95	98	93	110	144	113	98
1907	111	79	76	80	102	95	100	97	73	86	82	92	93
1908	62	84	101	107	97	90	79	80	82	96	96	93	90
1909	53	114	78	110	97	102	93	85	99	117	82	60	90
1910	93	119	78	89	108	114	100	104	82	93	57	78	96
1911	117	87	81	95	82	109	77	87	59	70	84	79	90
1912	74	74	119	84	97	98	88	90	74	87	83	86	85
1913	149	94	153	105	107	118	105	108	75	88	159	78	115
1914	68	101	85	105	102	113	114	114	79	93	52	88	98
1915	86	81	59	133	112	107	112	89	77	91	130	117	101
1916	176	117	103	109	96	68	74	120	94	111	149	136	111
1917	121	118	149	94	88	97	140	109	91	107	118	90	114
1918	81	147	104	108	147	99	106	108	93	109	81	105	108
1919	69	77	112	108	126	80	86	127	131	154	69	90	98
1920	126	80	108	94	92	96	138	112	75	88	110	98	107
1921	103	73	152	115	81	76	99	115	87	102	117	72	99
1922	106	157	150	132	114	105	114	101	62	73	112	142	120
1923	122	130	150	87	76	114	98	115	67	80	55	128	108
1924	118	110	55	78	83	103	128	93	86	103	91	144	100
1925	106	74	85	55	93	101	84	109	101	129	96	69	91
1926	91	95	80	100	73	102	91	87	75	96	107	125	93
1927	112	118	82	114	116	110	84	78	82	88	140	102	102
1928	109	107	95	116	68	103	93	80	139	107	84	99	99
1929	95	96	111	95	122	99	112	95	79	110	130	111	104

TABLE 8.—*Percentage of winds with easterly component at San Juan, P.R. (upper air)*

Elevation	1 km	2 km	4 km	6 km	8 km	10 km
Spring	100	93	63	33	13	1
Summer	97	95	84	63	28	31
Autumn	89	81	56	42	33	27
Winter	96	86	61	45	22	4
Annual	94	86	66	47	29	21

TABLE 9.—*Velocities in meters per second, at San Juan, P.R. (upper air)*

Elevation	1 km	2 km	4 km	6 km	8 km	10 km
Spring	9.2	6.1	4.9	6.6	10.9	18.0
Summer	8.7	7.4	5.3	4.8	6.1	8.1
Autumn	5.9	5.0	4.1	4.8	6.6	9.5
Winter	7.9	6.0	5.0	7.2	9.4	17.0
Annual	7.4	6.0	4.7	5.2	7.2	10.7

THE TEMPERATURE RELATIONS BETWEEN WATER AND AIR AT SAINT ANDREWS, N.B.

By H. B. HACHEY

[Atlantic Biological Station, Saint Andrews, N.B., August 1933]

INTRODUCTION

One phase of the hydrographic investigations carried out by the Biological Board of Canada requires the recording of water temperatures throughout the year at various points on the Canadian Atlantic coast. In this connection water and air temperatures have been recorded at Saint Andrews, N.B., for several years past. The records for the period 1921–29, inclusive, have been analyzed and form the subject matter of this paper.

Collection and compilation of data.—The water temperatures were determined twice daily from the end of the pier at the Atlantic Biological Station, usually at 8 a.m. and 5 p.m. The depth of water at the end of the pier varies from approximately 10 feet (3.0 m) to 35 feet (10.6 m), depending upon the time and amplitude of the tide. Maximum and minimum air temperatures were obtained daily by means of a thermometer situated about 20 feet (6.1 m) from high-water mark and about 10 feet (3.0 m) above high-water level.

From the recorded data for the period 1921–29, inclusive, monthly normals for water and air have been determined and are recorded in table 1 and plotted in figure 1.

Analysis of data.—Sine curves were found to fit the plotted data quite closely. The equations representing these curves are as follows:

$$\text{Water, } y_1 = 6.2 - 6.2 \sin \frac{\pi(x+2)}{6} \quad (1)$$

$$\text{Air, } y_2 = 6.0 - 12.4 \sin \frac{\pi(x+3)}{6} \quad (2)$$

where

y_1 = normal water temperature in degrees centigrade.
y_2 = normal air temperature in degrees centigrade.
and x = time expressed in months.

Values of y_1 and y_2 calculated afrom the above equations are given in table 1.

According to equations (1) and (2) we have the following results:

1. Normally, the maximum daily mean air temperature is reached on July 15, and the maximum daily mean water temperature is reached on August 15.
2. Normally, the minimum daily mean air temperature is reached on January 15, and the minimum daily mean water temperature is reached on February 15.

It is thus shown that in the Saint Andrews region the water temperatures lag behind the air temperatures by approximately 1 month.

Combining equations (1) and (2), we may write

$$y_3 = y_1 - y_2 = .2 - 3.1 \sin \frac{\pi x}{6} + 7.0 \cos \frac{\pi x}{6} \quad (3)$$

where y_3 is the difference between the normal water temperatures and the normal air temperatures, equation (3) is also plotted in figure 1, and the calculated values of y_3 are recorded in table 2.

By means of a simple analysis of the equation for y_3 the following results are obtained:

1. The greatest numerical values of y_3 are found to be
$y_3 = 7.7$ at $x = 5.2$ .... June 21.
$y_3 = 7.9$ at $x = 11.2$ .... Dec. 21–22.
2. Similarly
$y_3 = 0.0$ at $x = 2.2$ .... Mar. 21–22.
and at $x = 8.2$ .... Sept. 21.
3. The average positive value of y_3 is 5.0, and the average negative value of y_3 is 4.7.

Limitations of the formula.—The value of the analysis of the various formulae is limited for the following reasons:

(*a*) The normals have been derived from data obtained over a comparatively short period. The taking of air temperatures has suffered some short interruptions.

(*b*) The variation between the normals derived from the observed data and those derived by means of the formula may be as large as 3.3°.

(*c*) It is possible to determine sine curves which will fit the observed values with greater accuracy. To do this it would be necessary to determine weekly normals. This would result in an increased amplitude and a slight change in the factor determining the phase.

Discussion.—The annual movements of the sun with reference to some fixed point on the earth being truly periodic, various periodic effects are produced. Atmospheric conditions remaining constant, a determination of the intensity of radiation falling daily on a chosen area would show a variation following a periodic law. In such a case a very shallow body of water would exhibit a similar periodic variation in temperature. If the depth of the water was considerable a pronounced lag in the water temperatures would be noted.

In the practical case, atmospheric conditions are anything but constant, and the various bodies of water that concern us are usually subjected to agencies other than direct heat from the sun which tend to determine the temperatures of the surface waters. To illustrate, various waters are frozen over throughout several months of the year with the result that the upper layers of the water have about the same temperature throughout the period of ice. Other waters are subjected to the influence of waters of very pronounced currents which may supply varying amounts of either warm water, or cold water containing much drift ice or icebergs. The surface temperatures of water areas comparatively free from such influences would, however, follow a periodic law.

Similarly, if the air temperatures in a given region were determined solely by direct heat from the sun, the mean daily temperatures would follow a periodic law. Various factors other than direct heat from the sun, particularly air movements, atmospheric conditions, and conditions on the earth's surface, enter to determine the air temperatures in a given locality and consequently a periodic variation is only approximated.

The temperatures of the surface waters in the St. Andrews region are peculiar to the region. A large body of water is concerned with tidal effects which bring about an interchange of surface and bottom water on a large scale. This volume action is responsible for the storing of heat absorbed, and for the releasing of heat when a transference from water to air can take place. That this storing of heat does take place on a large scale is shown by the marked lag of the water temperatures behind those of the air.

The interchange of heat between the air and the water would be controlled by a number of factors. Definitely the temperature gradient would play a large part in determining the magnitude and the direction of the interchange. For this reason it is of interest to note the times of the year when the temperature gradient normally has its maximum and minimum values. The position of the sun with reference to the earth's equator at the times of maximum and minimum values of the temperature gradient is also worthy of note.

The average positive value of the temperature gradient is approximately equal to the average negative value. Hence, insofar as the temperature gradient is concerned, the influence of the water on the air in this region must be approximately the same as the influence of the air on the water.

SUMMARY

1. The normal temperature of the water at St. Andrews, New Brunswick, at any time can be represented by a formula of the form

$$y_1 = 6.2 - 6.2 \sin \frac{\pi(x+2)}{6}$$

where y_1 is the temperature in degrees centigrade, and x is the time in months.

2. The normal temperature of the air at St. Andrews, New Brunswick, at any time can be represented by a formula of the form

$$y_2 = 6.0 - 12.4 \sin \frac{\pi(x+3)}{6}$$

where y_2 is the temperature in degrees centigrade, and x is the time in months.

3. The relation between the water and air normal temperatures at St. Andrews, New Brunswick, can be represented by a formula of the form

$$y_3 = 0.2 - 3.1 \sin \frac{\pi x}{6} + 7.0 \cos \frac{\pi x}{6}$$

where $y_3 = y_1 - y_2$.

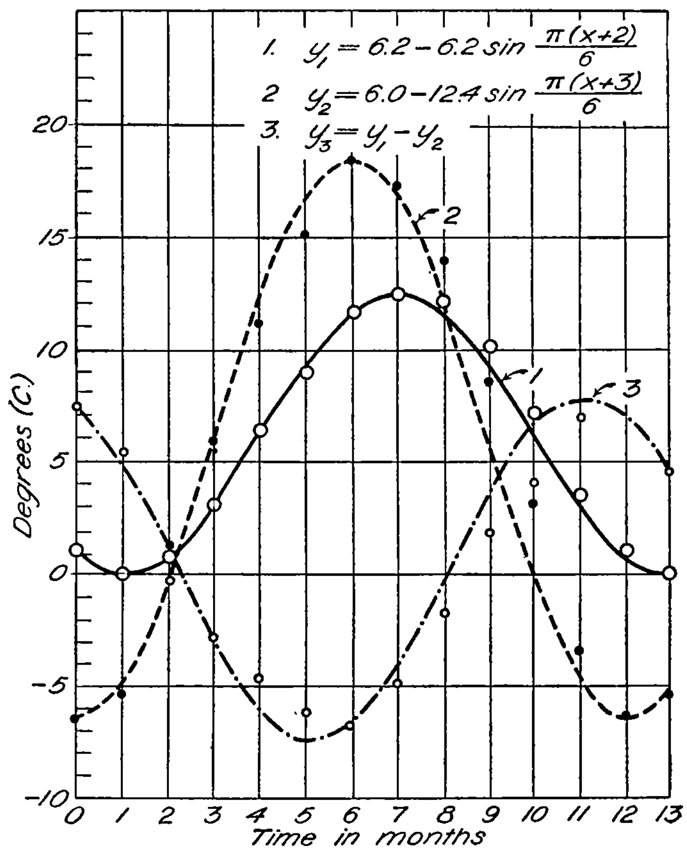


FIGURE 1.

4. On July 15 the maximum temperature of the air is normally reached.

5. On August 15 the water normally reaches its maximum temperature.

6. On January 15 the minimum temperature of the air is normally reached.

7. On February 15 the water normally reaches its minimum temperature.

8. On June 21 y_3 normally has its greatest negative value, i.e., the temperature gradient between the air and the water has reached its greatest positive value.

9. On March 21 y_3 is normally equal to zero, i.e., the temperature gradient between the air and the water is zero.

10. On September 21 y_3 is normally equal to zero, i.e., the temperature gradient between the air and the water is again zero.

11. On December 21 y_3 normally has its greatest positive value, i.e., the temperature gradient between the air and the water has reached its greatest negative value.

12. The average positive value of y_3 is normally 5.0, and the average negative value of y_3 is normally 4.7.

TABLE 1

Month	Air normals			Water normals		
	Observed values	Calculated from equation	Difference	Observed values	Calculated from equation	Difference
	(a)	(b)	(a-b)	(c)	(d)	(c-d)
January	−6.4	−6.4	0.0	1.0	0.8	0.2
February	−5.4	−4.7	−.7	.0	.0	.0
March	1.1	−.2	1.3	.9	.8	.1
April	5.9	6.0	−.1	3.1	3.1	.0
May	11.2	12.2	−1.0	6.5	6.2	.3
June	15.1	16.7	−1.6	8.9	9.3	−.4
July	18.4	18.4	.0	11.6	11.6	.0
August	17.3	16.7	.6	12.4	12.4	.0
September	13.9	12.2	1.7	12.1	11.6	.5
October	8.5	6.0	2.5	10.2	9.3	.9
November	3.1	−.2	3.3	7.1	6.2	.9
December	−3.4	−4.7	1.3	3.5	3.1	.4

TABLE 2

Month	Observed values			Calculated values, y_3
	y_1	y_2	$y_3=y_1-y_2$	
January	1.0	−6.4	7.4	7.2
February	.0	5.4	5.4	4.7
March	.9	1.1	−.2	1.0
April	3.1	5.9	−2.8	−2.9
May	6.5	11.2	−4.7	−6.0
June	8.9	15.1	−6.2	−7.4
July	11.6	18.4	−6.8	−6.8
August	12.4	17.3	−4.9	−4.3
September	12.1	13.9	−1.8	−.6
October	10.2	8.5	1.7	3.3
November	7.1	3.1	4.0	6.6
December	3.5	−3.4	6.9	7.8

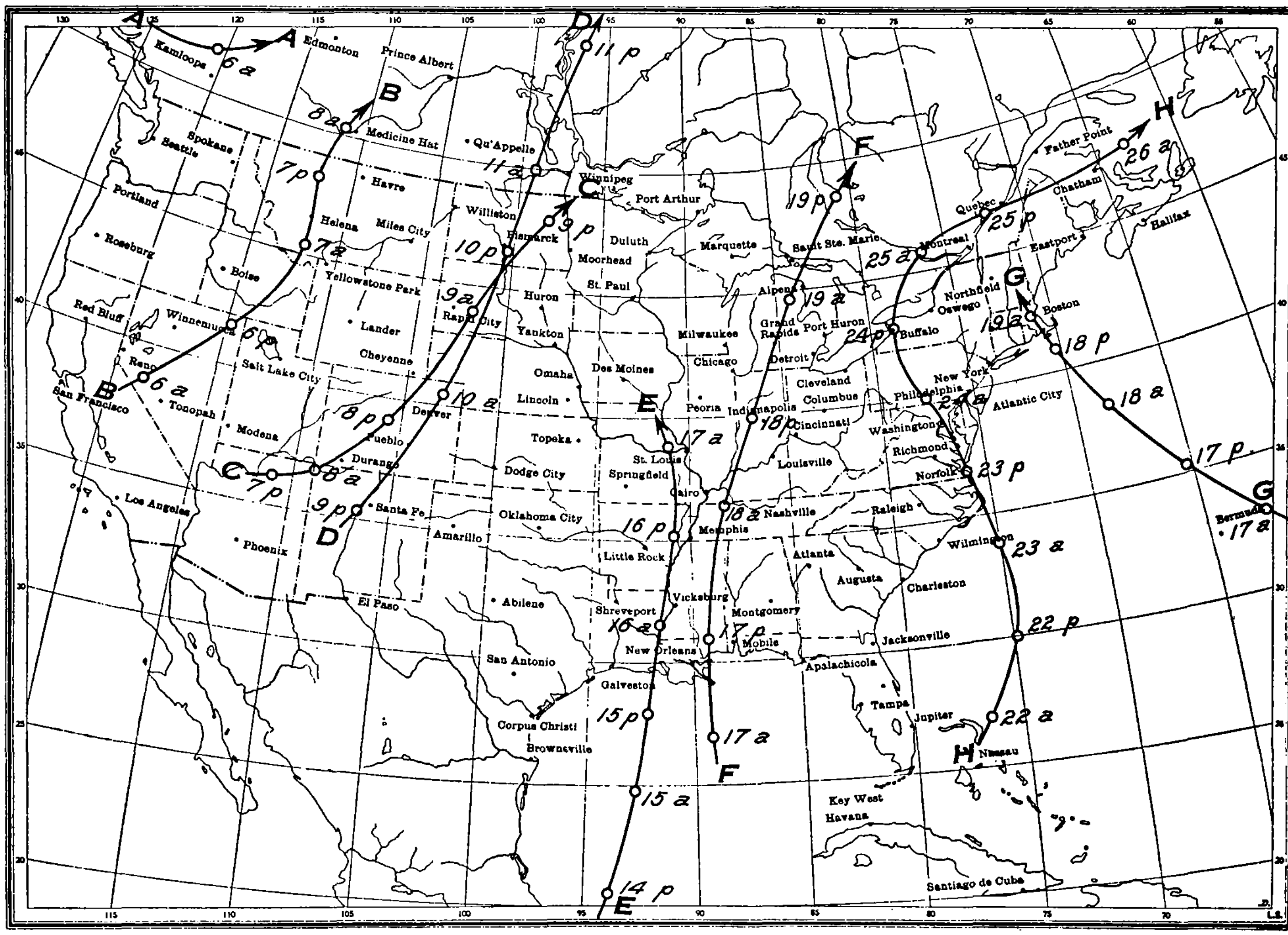
A REMARKABLE OCCURRENCE OF CYCLONES IN SERIES

By EDWARD H. BOWIE
[Weather Bureau, San Francisco, Calif., September 1933]

The occurrence of cyclones in series is a phenomenon with which all those having to do with the preparation of synoptic charts are more or less familiar. In the Bjerknes frontal theory such a series is designated a *cyclone family*.

In an article on "The Planetary System of Convection", by William R. Blair, in the MONTHLY WEATHER REVIEW, April 1916, vol. 44, p. 194, one finds the following:

Some years ago Mr. E. H. Bowie called the writer's attention to the fact that the low-pressure areas enter and cross the United States in series. The first low-pressure area in such a series will enter the country well to the north and pursue a course eastward over the northern States; the second enters somewhat farther south, and so on. The last low-pressure area of the series may enter the extreme southwest, and pass along the Gulf and Atlantic coasts, although the series do not always carry as far south as this. The series follow each other in close succession. The relation between



Tracks of cyclones in the United States during October 1923.