THE NORTH ATLANTIC TRADE WINDS

By C. L. RAY

[Weather Bureau Office, San Juan, P.R., Sept. 30, 1933]

The fact that the area of the trade-wind belt of the North Atlantic is estimated to be 10 million square miles suggests the impracticability of attempting a detailed study of the wind data over the entire region. In the monthly Pilot Charts of the United States Hydrographic Office of the Navy we have a complete set of monthly averages of these winds. Their percentages, including calms, velocities in terms of the Beaufort scale and prevailing directions, within the 8 points of the compass, are given for each 5° of latitude by 5° of longitude. Observations from transatlantic and coastwise ships contributed largely, and continue to do so, to the comprehensive mapping of ocean areas. On the other hand, we lack comparative data for different years, at least in assembled form. The present paper gives a more or less detailed arrangement of the wind data by months and years for one station (San Juan, Puerto Rico) in the trade-wind belt. It includes the variations from year to year in total wind movement; treats of the "trades" as a separate entity; gives the wind velocities and notes the percentage of winds from the east, northeast and southeast. These data also are compared with their normal or average values.

Beals [1] has given an interesting survey of "The Northeast Trades of the North Pacific" from which suggestions have been obtained for the present paper. In referring to the general world pressure system, the following is quoted as applying with equal force to both areas:

> The chief features of world pressure distribution are (1) an equatorial belt or zone of diminished pressure, (2) another of high pressure around the world about 30° north and south of the Equator, and (3) other belts of low pressure about latitude 60° north and south. The high-pressure belts about 30° from the Equator are not continuous around the world but form a series of well-known semipermanent anticyclones, each with its appropriate wind system. The most prominent semipermanent anticyclones in the Northern Hemisphere are the great Siberian anticyclone of winter, and winter only, and the two oceanic anticyclones—the the Azores in the Atlantic and the North Pacific in the ocean of that name. * * * These cyclones and anticyclones must not be confused with the traveling cyclones and anticylones of the daily weather maps. The latter preserve their form and travel in a definite direction over the earth's surface for a time. The former, on the other hand, must not be thought of as having [in any case] a distinct entity which is continuously preserved.

The Azores HIGH, associated with the trade-wind system of the North Atlantic area, attains its greatest extent and force in June and July, with a maximum pressure of 30.25 inches, gradually diminishes during the fall months to a minimum pressure of 30.10 inches in October. In July it extends from latitude 30° N. to 40° N. and longitude 20° W. to 50° W. The wind circulation about the Azores anticyclone is clockwise in direction, northeast predominating in the eastern half of the area, becoming east-northeast to east, with diminishing latitude and east and southeast near the Equator and north of the West Indies under the influence of the southerly circulation in the left half of the formation. Farther north in latitude 35° to 50°, winds become southwesterly. The mean position of the center of this anticyclone shifts somewhat from month to month, reaching in July to approximately 35° N. latitude and 35° W. longitude. In September it is at 30° W. longitude and in December at latitude 35° N., longitude 20° W. Its most southerly position is reached in January, 28° N. at longitude 39° W. The wind velocity over this area is indicated on the pilot charts generally as force 4 of the Beaufort scale (approximately 20 miles per hour). This velocity pertains to all winds having an easterly component except in October and November when it is slightly less. In addition to the above charts there are available daily records from few island and coast stations of the Atlantic and adjacent coasts.

San Juan, latitude 18°29′N., longitude 66°78′W., lies on the north coast of Puerto Rico, 53 feet above sea level, in the south and west portions of the Azores anticyclone area. The prevailing direction of the wind at the station is between east and southeast, and varies with the season and the hour of the day. The anemometer and wind vane are located on a 50-foot steel tower. The exposure to northeast and east winds is excellent. In December and January a somewhat greater amount of northeast wind than southeast is recorded, with the prevailing direction easterly as other parts of the year. A less-satisfactory exposure is afforded to the winds from the southeast, owing to the interference of mountains in the east interior of the island, to the southwest of the station. The velocities of winds from the southeast, as recorded at the station, are noticeably lower than those of northeasterly and easterly direction, although Pilot Charts for the same area, but representing open sea exposure, show equal force from all winds that have an easterly component, whether northeast, east, or southeast. These have an average force of Beaufort 4, compared with a force of 2 to 3 for southeast winds at the Weather Bureau exposure. Another disturbing factor in connection with station velocities from the southeast is the land breeze from the south and southeast, comprising a considerable portion of the wind movement at night, which though distinct from the trade-wind circulation cannot be separated from it.

In tables 1 and 2 are shown the percentages of winds recorded from the several points of the compass, and also the percentages of northeast, east, and southeast winds for each month, considered as a group. In table 3 the same data are presented in greater detail, and in table 4 a grouping by 5-year periods is made. A change in the direction of the "trades" will be noted for the last 10-year period, 1920–29, indicated by a marked increase in easterly movement with concurrent decrease in the northeast and southeast winds. This is clearly shown in the following table:

	Percentage of winds from—			
	Northeast	East	Southeast	South
1905–20	20	35	26	10
1921–29	6	55	16	15
Entire period, 1905–29	15	44	23	12

A similar shift from the existing normal direction occurred in the North Pacific area at approximately the same period, as discussed by Mr. Beales (see earlier reference). The 5-year average at Honolulu, included as part of table 4, does not fully indicate the extent of the change, which beginning in 1922, showed an increase of 200 percent in the easterly movement at the expense of northeasterly winds. Quoting Mr. Beals in this connection:

> Following a change in exposure of the wind instruments in 1922 [at Honolulu] the average [of east winds] was a little more than

[1] Beals, Edward A., Mo. Wea. Rev., May 1927, vol. 55, p. 211.

tripled, thus one can hardly escape the conclusion that the influence of an unknown factor, which probably existed before the change in exposure, was greatly increased by the change. It is nevertheless possible that a progressive although slight change in the average track of anticyclones in the North Pacific may have caused the change in wind direction under consideration. There is, however, no readily available information as to the track pursued by anticyclones for the years in question.

The analogous condition found at San Juan for the same period, and continuing for another 5-year period thereafter (no data are at hand for the latter years at Honolulu) would seem to indicate that the course of the anticyclone movement has possibly undergone a slight shift to the northward in the North Atlantic. That such a shift has taken place is indicated, but not proved, by the slightly higher pressure—for the year—at Horta, Azores Islands, since 1920. Horta, though within the central area of high pressure in June and July, is normally slightly north of the center. A shift of the track to the north would therefore, of course, be accompanied by higher readings at that station. However this would not take account of regular changes in the strength of the HIGH, which may explain the increase in pressure at Horta observed in this period. Northeast

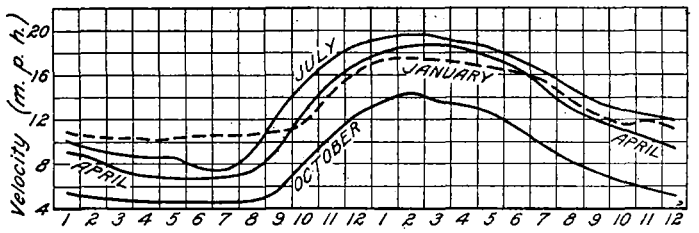

FIGURE 1. Diurnal velocity of winds, San Juan, P.R.

winds, as a rule, attain their greatest frequency at San Juan during January, when the continental high pressure area, central in the North American interior, normally extends its influence eastward, off the southeast United States coast. In this connection, a correlation of the January pressure at Nassau, Bahama Islands, with the northeast wind frequency at San Juan, indicates an apparent relation between the strength of the pressure at that station and the increased northeast movement at San Juan. Average pressure at Nassau for the period between 1921 and 1929 is, however, not immediately available for reference, so that it has not been possible to continue the comparison through the years in question. The above relationship does not appear to hold for other months but relates only to the pressure distribution obtaining during the month of January.

In table 5 is given the total monthly and annual wind movement in miles, and in table 6 the same data for NE., E., and SE. winds. The greatest mileage for all directions, and also for NE., E., and SE. winds, as a group, occurs in July, when the North Atlantic anticyclone is in greatest ascendency. The average hourly velocity is slightly greater in January for all directions, owing to the occurrence of considerable strong north and northwest winds, which are absent during the summer. In table 7 is given the monthly and annual percentage of the normal movement of wind from the NE., E., and SE., by years from 1905–29. In January 1916 the "trades" were 76 percent above normal; in January 1909 they were 47 percent below normal. In July 1917 they were 40 percent above normal; in July 1916, 26 percent below the average. For the year 1922 the annual movement of the "trades" at San Juan was 20 percent above normal; in 1912, 15 percent below the average.

As stated earlier these trade winds show, for open sea exposure, an average velocity of about 20 miles per hour for winds with an easterly component. The diurnal variation in wind velocities at the station is shown in Fig. 1. Lighter winds prevail during the night, with velocities increasing between 8 a.m. and 3 p.m.

Calms are infrequent in the zone embracing the West Indies. Over the North Atlantic as a whole we find several sections, comparatively small in extent, where little or no wind movement occurs for considerable periods. The "doldrums" are a well-defined quiet area, central at approximately 5° to 10° N. latitude in September. This region is of interest as the breeding locus of the tropical hurricane of late summer and autumn, of greatest frequency in September and August. To the westward, another, though smaller, area of calms is located in the west Caribbean and Gulf of Mexico, longitude 80° to 90° W. from which may form the southwest Caribbean hurricane, frequent in the latter half of September. In the north a third quiet area at approximately latitude 25° to 35° N. between longitude 20° to 50° W. is in the central portion of the Azores anticyclone.

The depth of the trade winds at San Juan and at Honolulu have been previously referred to in the MONTHLY WEATHER REVIEW.[1] These several studies indicate the vertical extent of the easterly winds at between 5,000 and 6,000 meters on the average, varying with the season. They are highest in the summer under the influence of strong convection. Tables 10 and 11 give the percentage of directions for the several levels by seasons and the years, with velocities in meters per second. Approximate equivalents in miles per hour may be derived by multiplying the number of meters per second by 2.2. Upper-air velocities of the "trades" probably do not depart greatly from the averages for all velocities combined—shown in the table—at least through the 6-kilometer level. Above that level observations become fewer in number and the directions more variable if not predominantly from some westerly point.

TABLE 1.—*Percentage of NE., E., and SE. winds for each month of the year, San Juan, P.R.*

Month	Percent	Month	Percent
January	83.6	July	93.0
February	79.2	August	89.3
March	78.2	September	74.3
April	82.9	October	66.0
May	83.5	November	70.0
June	91.8	December	79.1

TABLE 2.—*Percentage of winds from the eight points of the compass—monthly and annual*

	N.	NE.	E.	SE.	S.	SW.	W.	NW.
January	2.2	20.5	45.4	17.7	9.2	3.4	0.6	1.0
February	2.5	18.2	41.6	19.4	11.2	5.5	0.5	1.1
March	3.7	18.9	40.4	18.9	11.4	3.8	0.9	2.0
April	1.6	19.8	41.6	21.5	11.4	2.7	0.7	0.7
May	1.1	11.8	43.8	27.9	12.6	1.8	0.5	0.5
June	0.2	7.5	55.3	29.0	7.0	0.6	0.3	0.1
July	0.2	9.0	61.8	22.2	5.9	0.8	0.1	0.0
August	0.6	12.9	54.6	21.8	8.3	1.2	0.3	0.3
September	1.4	11.9	35.3	27.1	17.9	4.4	1.2	0.8
October	1.3	10.5	29.2	26.3	24.2	6.3	1.2	1.0
November	2.5	17.9	30.2	21.9	18.4	6.2	1.4	1.5
December	3.5	20.2	40.7	18.2	11.1	4.2	1.0	1.1
Annual	1.4	14.9	43.7	22.7	12.4	3.4	0.7	0.8

[1] Beals, E. A. Free-air winds over Honolulu and Guam. May 1927, vol. 55, pp. 222-226; Fassig, O. L. Pilot-balloon observations at San Juan, P.R. January 1924, vol. 52, pp. 22–26; Ray, C. L. Free-air winds at San Juan, P.R. November 1931, vol. 49, 414–416; Fassig. O. L. The trade winds in Puerto Rico. May 1911, vol. 39, pp. 796–799.

TABLE 3.—*Number of hours each year the wind at San Juan was NE., E., and SE., 1905–29, inclusive*

Year	Number of hours from—				Percent from—		
	NE.	E.	SE.	NE.-E. SE.	NE.	E.	SE.
1905	610	3,823	2,720	7,153	7	44	31
1906	1,435	3,798	2,101	7,244	17	42	24
1907	1,565	3,819	1,826	7,210	18	44	21
1908	1,173	3,266	2,801	7,240	13	37	32
1909	1,431	3,016	2,749	7,196	16	34	31
1910	1,949	3,320	1,911	7,180	22	38	22
1911	1,661	3,199	2,423	7,283	19	37	28
1912	984	3,498	2,859	7,341	11	40	33
1913	2,216	3,285	2,261	7,762	25	38	26
1914	1,823	2,724	2,609	7,156	21	32	30
1915	2,224	2,426	2,048	6,698	25	28	23
1916	2,651	2,535	2,396	7,582	30	29	27
1917	2,841	2,426	1,822	7,089	32	28	21
1918	2,177	2,983	1,978	7,138	25	34	23
1919	2,071	2,627	2,045	6,743	24	30	23
1920	1,227	4,071	2,187	7,485	14	47	25
1921	355	4,498	1,259	6,112	5	51	14
1922	572	5,391	991	6,954	7	62	11
1923	416	4,905	1,226	6,547	5	56	14
1924	390	4,696	1,721	6,807	4	54	20
1925	452	4,464	1,696	6,612	5	51	19
1926	554	4,551	1,669	6,774	6	52	19
1927	901	4,780	1,103	6,784	10	55	13
1928	550	5,405	1,657	7,612	6	62	19
1929	310	5,629	1,589	7,528	4	64	18
Total	32,538	95,045	49,647	177,230	371	1,089	567
Average	1,301.5	3,801.8	1,985.9	7,093.2	15	44	23

TABLE 4.—*5-year average annual of NE., E., and SE. winds at San Juan, P.R., 1905–29, inclusive*

	San Juan, P.R.			Honolulu	
	NE.	E.	SE.	NE.	E.
1905–09	1,243	3,526	2,439	4,840	2,271
1910–14	1,726	3,205	2,413	4,678	2,493
1915–19	2,393	2,599	2,058	4,211	2,951
1920–24	588	4,712	1,477	4,929	4,303
1925–29	553	4,966	1,543		

TABLE 5.—*Total monthly and annul wind movement in miles at San Juan, P.R., period 1905–29, inclusive*

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1905	7,983	7,990	7,398	8,685	9,348	8,692	9,149	8,683	6,151	6,359	5,726	8,004	94,168
1906	8,135	5,976	8,059	8,635	9,169	8,752	9,525	9,005	7,356	6,860	9,211	10,761	101,444
1907	10,512	6,347	8,434	7,663	8,633	8,518	10,035	8,901	7,173	5,617	5,664	7,819	95,316
1908	6,494	6,960	10,464	8,917	8,069	7,882	8,140	7,648	8,000	6,188	6,410	8,807	93,979
1909	6,701	8,683	7,747	9,326	8,105	8,851	9,243	8,142	5,919	6,818	7,457	6,040	93,032
1910	9,411	9,630	7,871	7,846	8,705	9,827	9,934	9,420	7,363	5,670	4,674	6,903	97,254
1911	11,049	7,223	7,592	8,223	7,128	9,428	7,930	8,070	6,466	4,766	5,697	6,971	90,543
1912	7,229	6,362	8,145	7,437	8,115	8,521	8,785	8,241	4,904	5,572	5,647	7,384	86,342
1913	13,873	7,739	13,234	9,369	9,432	10,185	10,430	9,820	6,496	5,666	9,813	7,290	113,347
1914	7,865	9,134	8,750	8,932	8,924	9,794	11,352	10,312	8,294	5,843	4,939	8,017	102,156
1915	8,739	7,553	7,284	11,733	9,280	9,474	11,191	9,687	6,250	6,043	9,038	10,363	106,635
1916	16,438	9,312	10,092	9,316	8,202	6,509	8,228	10,922	5,958	6,934	9,219	11,353	112,483
1917	11,639	9,763	13,064	8,380	7,971	8,543	13,954	10,132	8,303	6,499	8,437	9,363	116,048
1918	9,223	11,573	9,737	9,413	11,953	8,697	10,791	10,100	7,179	6,462	6,109	9,143	110,380
1919	7,284	7,033	10,879	10,150	10,711	7,341	9,182	11,660	6,633	8,362	6,230	8,479	103,944
1920	12,370	6,677	9,810	8,382	8,505	8,470	13,695	10,450	8,146	5,789	7,280	8,588	108,162
1921	10,460	6,993	13,822	10,246	8,391	8,190	10,079	10,764	6,432	6,980	8,164	7,485	108,006
1922	10,865	12,072	13,572	11,346	9,569	9,429	11,431	9,587	8,292	5,807	7,991	12,257	122,218
1923	11,910	11,078	13,461	8,065	8,020	10,028	10,010	10,834	7,504	5,877	5,481	11,728	112,996
1924	11,325	9,342	7,451	7,719	7,736	9,199	12,762	9,785	6,661	6,730	6,419	11,768	106,897
1925	9,825	6,916	10,489	6,969	8,581	9,093	8,774	9,986	7,113	7,345	7,066	6,831	98,988
1926	8,999	7,941	8,129	8,721	7,297	9,043	9,383	8,477	6,261	6,256	7,296	11,009	98,812
1927	11,058	9,343	8,244	10,114	9,687	9,709	8,973	7,950	6,096	6,181	9,778	10,864	107,997
1928	10,332	8,273	8,899	9,597	7,023	9,066	9,488	7,693	8,607	6,186	6,154	8,609	99,927
1929	9,502	7,628	10,073	8,893	9,961	8,739	11,165	8,741	5,787	6,341	8,329	9,271	104,430
Means	9,969	8,262	9,708	8,963	8,741	8,879	10,145	9,400	6,934	6,286	7,129	9,004	103,420

Years 1928–29 from 3-cup anemometer.

TABLE 6.—*Total monthly and annual movement in miles for NE., E., and SE. winds only, at San Juan, P.R., 1905–29*

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1905	6,922	7,568	6,399	7,873	9,015	8,603	8,912	8,456	5,111	5,066	4,868	7,581	86,364
1906	7,507	4,913	7,492	7,860	8,668	8,669	9,390	8,820	5,225	5,595	8,664	9,191	91,994
1907	10,261	5,921	6,557	6,605	8,141	8,127	9,949	8,698	6,824	4,364	4,891	7,519	87,857
1908	5,775	6,344	8,689	8,835	7,741	7,706	7,808	7,233	7,406	4,910	5,795	7,609	85,751
1909	4,926	8,476	6,738	9,044	7,784	8,761	9,181	7,645	5,404	5,991	4,895	4,880	84,725
1910	8,631	8,921	6,722	7,035	8,582	9,777	9,900	9,324	7,098	4,750	3,432	6,340	90,512
1911	10,856	6,466	7,003	7,846	6,556	9,346	7,678	7,810	6,087	3,551	5,068	6,463	84,730
1912	6,884	5,531	7,912	6,937	7,707	8,448	8,696	8,127	3,803	4,462	4,955	7,017	80,479
1913	13,822	7,020	13,208	8,694	8,528	10,155	10,387	9,714	6,031	4,515	9,546	6,364	107,984
1914	6,320	7,546	7,299	8,703	8,121	9,678	11,335	10,277	8,057	4,760	3,146	7,211	92,453
1915	8,030	6,058	5,051	10,985	8,913	9,224	11,064	8,000	5,077	4,647	7,812	9,529	94,390
1916	16,315	8,708	8,828	9,026	7,649	5,797	7,355	10,788	4,914	5,659	8,931	11,082	105,052
1917	11,260	8,857	12,838	7,727	7,002	8,284	13,889	9,852	7,715	5,457	7,052	7,352	107,385
1918	7,543	10,939	8,968	8,913	11,748	8,532	10,515	9,697	6,257	5,559	4,854	8,583	102,108
1919	6,377	5,769	9,682	8,934	10,079	6,830	8,563	11,455	5,011	7,839	4,161	7,378	92,078
1920	11,656	5,918	9,266	7,738	7,342	8,265	13,628	10,093	7,743	4,513	6,583	7,962	100,707
1921	9,520	5,454	13,129	9,449	6,464	6,546	9,819	10,352	4,836	5,200	7,046	5,897	93,712
1922	9,808	11,683	12,889	10,891	9,100	9,039	11,251	9,049	7,205	3,733	6,692	11,574	112,914
1923	11,336	9,761	12,938	7,165	6,031	9,754	9,716	10,462	6,558	4,001	3,294	10,412	101,368
1924	10,927	8,230	4,740	6,449	6,625	8,838	12,638	8,324	5,175	5,236	5,431	11,760	94,373
1925	9,815	5,640	7,296	4,544	7,436	8,632	8,286	9,776	6,048	6,585	5,753	5,624	85,435
1926	8,431	7,088	6,859	8,225	5,795	8,791	8,984	7,859	4,522	4,876	6,430	10,220	88,080
1927	10,368	8,775	7,100	9,441	9,228	9,466	8,363	7,046	4,864	4,495	8,383	8,291	95,820
1928	10,080	7,992	8,170	9,530	5,423	8,874	9,204	7,182	8,322	5,482	5,065	8,064	93,388
1929	8,788	7,154	9,542	7,824	9,702	8,383	11,110	8,511	4,722	5,599	7,839	9,040	98,214
Means	9,286	7,467	8,613	8,251	7,975	8,581	9,905	8,982	6,001	5,074	6,023	8,158	94,316

Years 1928–29 from 3-cup anemometer.

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:

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

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

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

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

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.