ANNUAL VARIATIONS IN CURRENT SPEEDS IN THE GULF STREAM SYSTEM[1]

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ABSTRACT

The monthly resultant current speeds in ten segments of the Gulf Stream System are calculated from surface current data published by the U. S. Navy Hydrographic Office. Marked annual variations in the current speeds are found in the Florida Current, in the Caribbean Sea, and in the Trade Wind areas. In other segments of the system the annual variations are not so well defined. The maximum current speeds occur during the summer in the southern segments of the Gulf Stream System and during the winter in the northern segments. The minimum speeds occur during the fall months throughout the system. Annual and semiannual periods are calculated and found to be in fair agreement with the observed annual variations in the Florida Current. In the Trade Wind and Caribbean areas the current speed and wind speed fluctuations are approximately the same. A partial correlation is shown to exist between the annual variations in current speeds in the Florida Current and the annual variations in sea level at Miami and Charleston.

The main current system of the North Atlantic Ocean, the Gulf Stream System, obtains its energy of motion principally from the Northeast Trades and the Westerlies. Since the wind system fluctuates in position and velocity with the different seasons of the year, it is to be expected that the current speeds of the Gulf Stream System would also vary with the seasons. Montgomery (1938) and Iselin (1940), on the bases of both hydrographic station data and tide gauge records, showed that there is such an annual fluctuation in the transport of the Florida and the Gulf Stream currents. The purpose of this paper is to show that the many hundreds of surface current observations on file at the U. S. Navy Hydrographic Office also give a consistent picture of annual variations in the current speeds in certain segments of the Gulf Stream System.

The data have been published in the form of an Atlas by the U. S. Navy Hydrographic Office (1946), in which atlas charts are given showing the monthly resultant current direction and speed for each one degree quadrangle in the North Atlantic plus the number of observations used to obtain each value. The following is quoted from the Atlas:

[1] Contribution No. 557 from the Woods Hole Oceanographic Institution. This paper originated as a technical report to the Oceanographic Division of the Hydrographic Office, U. S. Navy Department under a contract with the Office of Naval Research.

> The information relating to monthly resultant surface currents shown on this chart was compiled from observations made during the month for all years prior to 1935 by the cooperating observers of the Hydrographic Office. Observations were not considered reliable where tidal currents prevailed; where winds, sea or swell of force 6 or above were recorded; where the vessel's draft or trim would cause excessive leeway; or when doubt existed as to the meaning of the entry "Nil" on the current report. All current calculations are based on the MEDIAN POSITION method; namely, each observation is applied at only one point, that point being midway between the beginning and end of the ship's run for which the current observation was made.

Because this median position method frequently integrates the speed of the main current with that of possible countercurrents and eddies, the values given in the accompanying tables and figures are much lower than would be the case if they applied only to the main current (Iselin and Fuglister, 1948).

From the Hydrographic Office charts the annual variation in current speeds has been calculated for ten segments of the Gulf Stream System. The areas studied are shown in Fig. 1.

The segments numbered 1 to 7 cover all but the southeastern part of the North Atlantic Eddy, the segments A, B and C take in three branches of the system. The segments were chosen by locating areas where the largest number of observations were available and where the arrows on the charts pointed in approximately the same direction throughout the year. The most doubtful, in regards to area covered, is Segment B in the Antilles Current. The direction of the current arrows and the speeds for each one degree quadrangle varied more in this segment than in any other. Segment 1 in the Trades and Segment A in the Guiana Current have been treated separately because of the marked difference in direction and speed in the two areas. After much of the analysis had been completed, it was found that more quadrangles could have been added to Segment 5 northeast of Hatteras, thus making it a continuous group without changing the results appreciably. Segment 3 in the Florida Current contains the most observations, Segment 1 in the Trade Wind Area the least. For instance, in the month of March, Segment 3 contains 1,468 observations, Segment 1 only 329.

The average of the resultant drifts for all quadrangles in each of the ten segments for each month are given in Table I and are plotted in Figs. 2 and 3. These data indicate that the time of maximum current speed varies as we move around the system. In the southern portions the maximum occurs in summer; in the northern it occurs in winter. On the other hand, the minimum speeds throughout the system occur during the fall months from September to November.

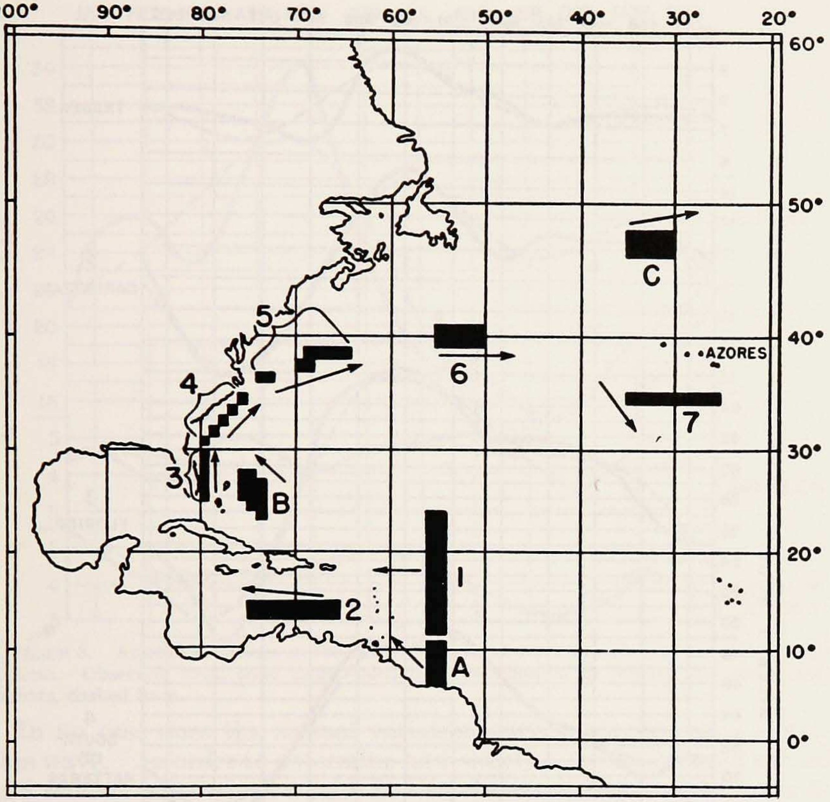

Figure 1. Location of segments of the Gulf Stream System used to calculate annual variations in current speeds. Arrows show resultant current directions within the various segments.

TABLE 1. AVERAGE CURRENT SPEEDS IN THE GULF STREAM SYSTEM (MILES PER DAY).* SEE FIG. 1 FOR AREAS COVERED BY SEGMENTS 1 TO C.

Month	*Segment*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*A*	*B*	*C*
Jan.	7.4	17.2	55.2	41.3	23.0	12.4	3.7	24.6	4.7	4.9
Feb.	7.4	17.3	57.5	39.9	22.3	13.0	4.1	25.9	3.9	4.1
Mar.	7.4	17.3	60.8	42.2	21.0	13.5	4.1	23.5	4.6	4.1
Apr.	7.0	17.5	61.7	43.7	24.0	12.6	3.6	29.3	4.9	4.4
May	7.9	16.7	61.7	46.4	24.1	12.9	4.3	34.2	4.0	4.2
June	8.3	18.3	64.2	49.3	23.9	11.6	4.0	24.3	4.6	4.8
July	9.4	19.6	65.6	48.2	22.8	13.1	3.3	18.4	4.8	4.6
Aug.	8.5	18.0	65.4	48.4	22.0	11.7	3.8	17.4	5.0	3.9
Sept.	6.4	15.5	60.5	44.0	21.4	12.3	3.3	15.3	4.3	3.2
Oct.	6.9	13.5	52.4	39.0	20.2	10.5	3.4	15.5	3.5	3.2
Nov.	7.2	12.9	49.0	36.7	20.4	11.1	3.6	19.0	4.6	4.0
Dec.	7.4	15.0	53.8	39.4	20.8	10.7	4.2	19.5	4.5	5.4
Mean	7.6	16.6	59.0	43.2	22.2	12.1	3.8	22.2	4.4	4.2

* Computed from the Hydrographic Office Chart, H. O. Misc. 10,688.

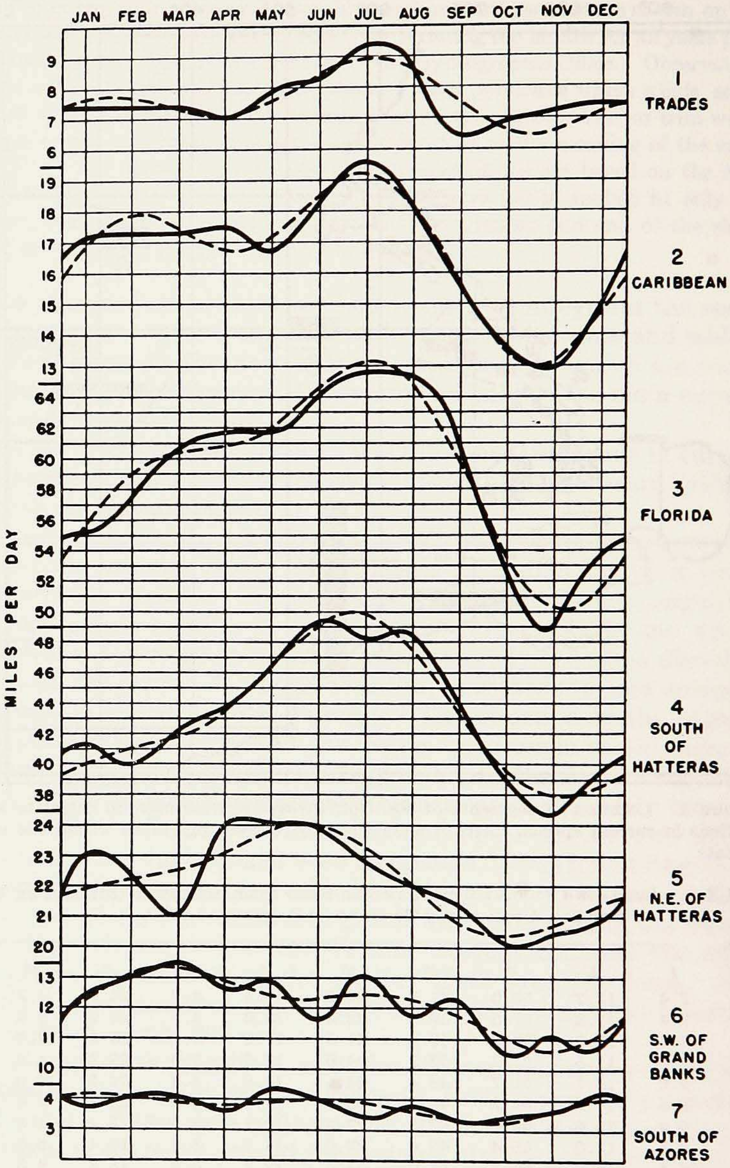

Figure 2. Annual variation in the current speed in seven segments of the Gulf Stream System. Observed data, solid lines; calculated combination of annual and semiannual periods, dashed lines.

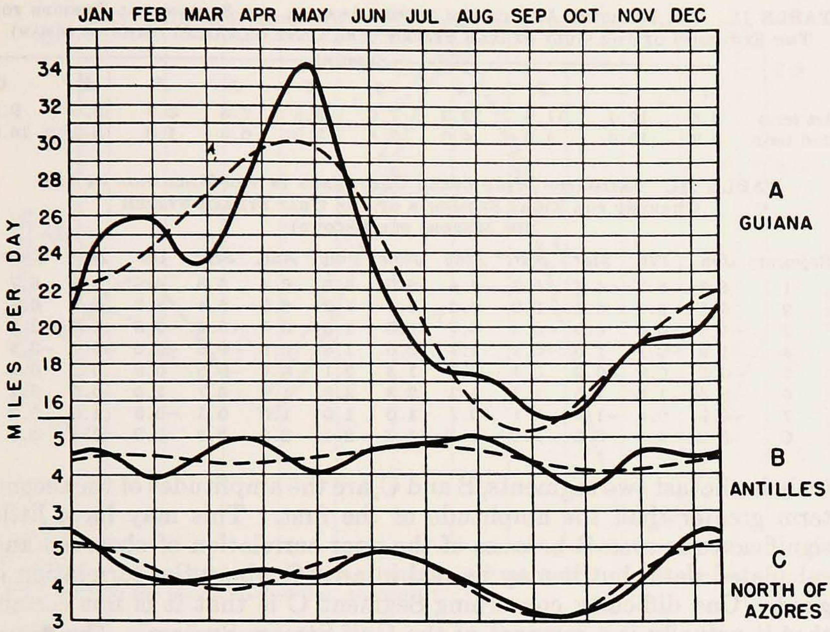

Figure 3. Annual variations in the current speeds of three branches of the Gulf Stream System. Observed data, solid lines; calculated combination of annual and semiannual periods, dashed lines.

In no case does the annual variation curve approximate a simple sine wave. In order to determine how closely a combination of annual and semiannual periods would fit the observed data and in order to determine also the relative importance of these two periods, the values in Table I were analyzed harmonically (Conrad, 1944: 71). The results of these calculations are shown by the dashed lines in Figs. 2 and 3. There is a fair agreement in the calculated and observed annual variations for those segments where the currents are relatively confined, as along the continental shelf south of Cape Hatteras. Because of the meandering nature of the currents in other areas, the actual current speeds and, to a lesser extent, the annual variations are obscured by the averaging processes.

In the southern and eastern segments of the North Atlantic Eddy the amplitudes of the first two harmonic terms, the annual and semiannual periods, are nearly equal. In the Guiana Current and in Segments 3 to 6 in the western and northern part of the eddy the annual period has the greater amplitude. The relative amplitudes, in per cent of the arithmetic mean, for the annual and semiannual periods for each segment are given in Table II.

TABLE II. The Relative Amplitudes of the Annual and Semiannual Periods for Ten Segments of the Gulf Stream System (Per Cent of the Arithmetic Mean)

	Segment									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*A*	*B*	*C*
1st term	8.5	12.4	11.0	12.2	7.0	8.8	7.8	3.1	3.5	9.4
2nd term	8.3	10.6	4.9	4.0	2.6	3.2	6.8	1.0	5.1	16.8

TABLE III. Estimated Wind Speed Component in the Direction of the Current for Eight Segments of the Gulf Stream System (in Meters per Second)

Segment	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
1	4.7	5.1	4.5	5.3	5.4	6.0	6.5	6.4	5.6	4.4	4.8	5.7
2	6.8	6.4	6.0	6.9	6.6	6.7	7.2	6.0	5.4	4.3	4.7	6.1
3	−1.6	0.0	0.3	−0.2	0.7	1.0	1.5	0.8	−0.4	−0.5	−1.5	−2.3
4	−1.9	−0.1	1.0	−0.1	1.7	2.0	1.4	0.8	−0.6	−2.0	−0.4	−3.5
5	−0.2	0.0	0.2	0.4	−0.3	1.3	2.1	0.4	−0.5	0.3	0.2	0.1
6	2.6	1.6	1.5	1.7	1.2	2.3	3.2	1.9	0.7	1.5	0.5	3.2
7	−0.9	0.4	−1.0	1.1	0.7	1.0	1.0	1.5	0.3	−0.3	1.9	0.2
C	5.2	4.5	3.3	2.0	1.7	1.6	2.1	2.3	2.8	2.3	3.4	5.3

Only in the last two segments, B and C, are the amplitudes of the second term greater than the amplitude of the first. This may have little significance in area B because of the poor correlation of observed and calculated data, but it may be real in area C where the correlation is good. One difficulty concerning Segment C is that it is not certain that it actually is a segment of the Gulf Stream System. The directional arrows on the Hydrographic Office chart for this area are uniform throughout the year, but this is not proof that a northern branch of the System consistently passes through the area. It has been assumed that all the segments dealt with in this study form part of a continuous current system. Whether or not a branch of this system passes through area C, the surface current data from the area include the effects of the shallow wind drift currents. A tabulation of the varying wind velocities for this area (see below) indicates that the annual variations in current speed are due only in part to the wind.

The annual variation in wind force was obtained from the wind roses on the British Admiralty charts of the North Atlantic. These charts show the frequency, force and direction of the wind for each 5° quadrangle for each month. The values shown in Table III are the estimated wind components in the direction of the currents. The values are only approximate owing to the difficulty of reading exact values from the roses and of converting from the Beaufort scale to wind speed. The negative values indicate that the component of the wind force along the streamline of the current is in the opposite direction to its flow.

In only two segments, the Trades (1) and the Caribbean (2), are the wind speed and the current speed fluctuations approximately the same.

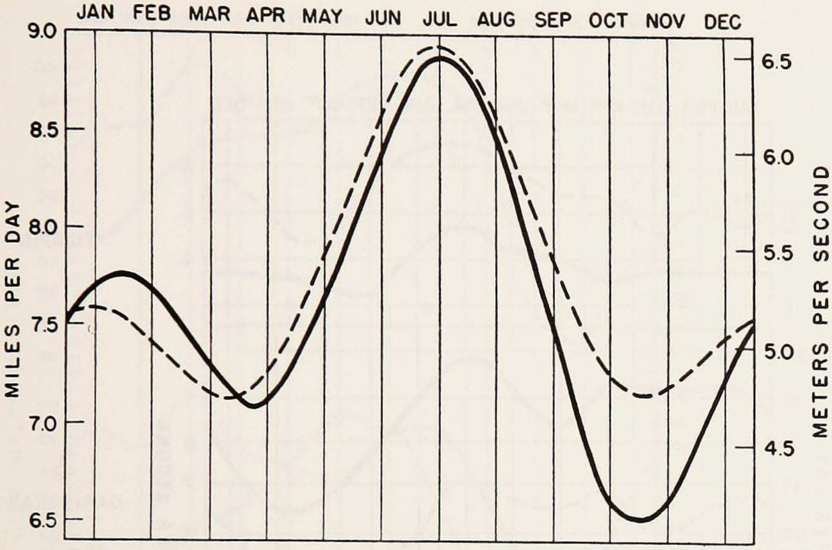

Figure 4. Calculated combination of annual and semiannual periods for the currents, solid line; for the winds, dashed line; segment 1.

This is certainly what should be expected, since these winds are the motive force for the currents. Harmonic analysis of the wind speed data from Segment 1 shows that the resultant of the combined annual and semiannual waves is similar to the resultant for the current speeds (see Fig. 4). The relative amplitudes, in per cent of the arithmetic mean, for the first two terms for the wind data are 12.6 and 9.5 as compared to 8.5 and 8.3 for the current data.

The annual variations in current speed and wind speed for Segments 1, 2 and C are shown in Fig. 5. In Segment C, north of the Azores, it appears evident that the winter maximum in the current speeds must be due in large part to the winds. The secondary maximum in the summer, at a time when the winds are at a minimum, may indicate that this segment is in fact a continuation of the main current system.

Using the method employed by Iselin (1940), the average monthly speeds of Segments 3 and 4 in the Florida Current have been compared with the sea level records from Miami and Charleston. According to this theory the mean sea level is at a maximum when the current speed is at a minimum. The tide gauge records were taken from two papers by Montgomery (1938, 1941). The two sets of curves are shown in Fig. 6. The correlation is only fair; while the winter maximum indicated by the tide gauge records does not appear on the curve of the observed current speeds, both sets of data show the rapid decrease in

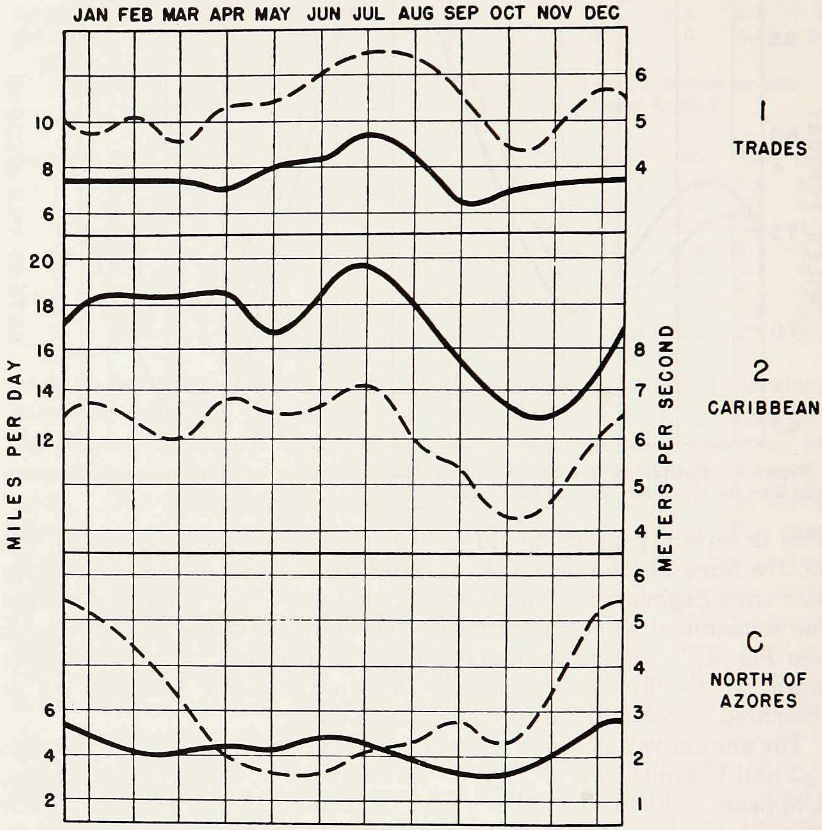

Figure 5. Annual variation in current speed, solid lines; wind components in direction of the currents, dashed lines.

values between July and October. The adverse winds of December and January (see Table III) may account for the absence of a winter maximum in the observed current data.

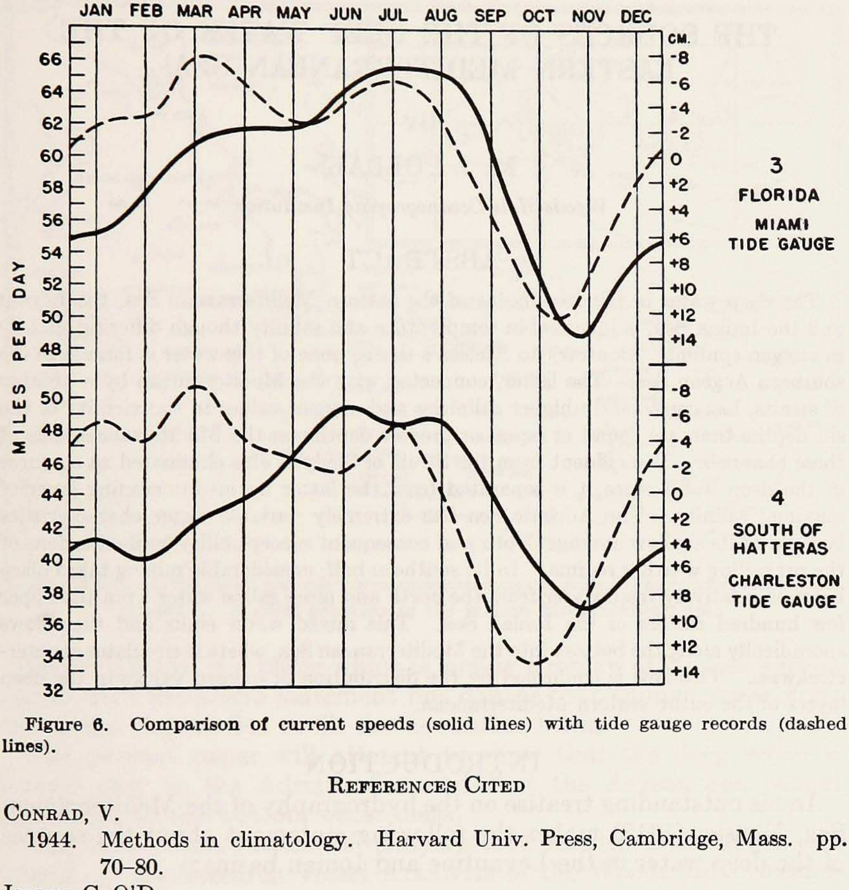

Figure 6. Comparison of current speeds (solid lines) with tide gauge records (dashed lines).

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