VELOCITY AND TRANSPORT OF THE ANTILLES CURRENT NORTHEAST OF THE BAHAMA ISLANDS

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ABSTRACT

Meridional geostrophic velocities and volume transports were computed from data collected on six occupations of Standard Section A-7 by U.S. Coast Guard cutters. The section extends offshore from Cape Canaveral, Fla., along lat. 28°35′N for about 520 nautical miles (960 km), but this study involved only that portion seaward of the 800-m isobath (situated at about long. 79° 30′W), a portion which would transect the Antilles Current just before it merges with the Gulf Stream. The velocity sections did not reveal a broad northward flowing Antilles Current in the surface layer as has been shown on many average current charts in the past. Instead, the sections revealed a generally sluggish (≤10 cm/s) surface flow, either northward or southward. Imbedded in the low speed surface flow were two bands of higher speed (10-40 cm/s), one northward and the other southward, usually located in the vicinity of the 1,000-fathom (1,830-m) isobath. Computed net transport for the sections ranged from 30.4×10^6 m³/s northward to 6.4×10^6 m³/s southward, with an average of 8.6×10^6 m³/s northward, which is considerably less than customarily hypothesized in the past to provide for the observed downstream increase in Gulf Stream transport between the Straits of Florida and Cape Hatteras, N.C.

The position of the band of relatively rapid southward flow corresponded approximately with the position suggested by Kort for the southward flowing Antilles-Guiana Countercurrent. A comparison of temperature-salinity properties in the bands showed them to be identical with each other but different from Florida Current water, making it highly unlikely that the bands are manifestations of two continuous currents, the Antilles Current and Antilles-Guiana Countercurrent, from different source areas. The identical temperature-salinity properties of the bands indicate that they are manifestations of eddies or a countercurrent formed by recurving of an adjacent current; the former alternative appears more likely.

The importance of the Antilles Current as a means of transporting significant quantities of pelagic ichthyoplankton into the Gulf Stream system is doubtful. The current speeds and transports appear to be substantially less than hypothesized and highly variable. An alternate means of transport of ichthyoplankton in the surface layer which may be in operation is Ekman drift generated by local winds, yielding a flow which may not be reflected in the field of mass and geostrophic computations.

One of the objectives of the initial ichthyoplankton cruises of the MARMAP (Marine Resources Monitoring Assessment and Prediction) program of the National Marine Fisheries Service was to estimate the transport of eggs and larvae of pelagic fishes into the Gulf Stream system by the Antilles Current. Scientists in the program began gathering information and data from various sources in an attempt to characterize the Antilles Current and other currents in the area of interest, the western North Atlantic and northern Caribbean Sea. These attempts revealed that the portion of the Antilles Current east of the Bahama Islands and northward has been little investigated and is only sketchily described, even though frequently mentioned in general works and shown on charts of "average" or "permanent" surface currents. Descriptions based on ship-drift data (U.S. Naval Oceanographic Office 1965; Boisvert 1967) portray the surface current in this region as having a prevailing direction of flow toward the north-northwest with a modal speed of about 0.5 knot (25 cm/s), an average speed of about 0.7 knot (35 cm/s), and a directional persistence of 40-55% in most of the area, except immediately north of the Bahama Islands, where a pair of eddies are shown (Figure 1). The strongest currents were found in a narrow band 10-30 nautical miles (18-55 km) wide near the Bahama Banks.

The junction of the Antilles Current with the Gulf Stream generally has been thought to occur over about 8° of latitude south of Cape Hatteras, N.C., (about lat. 28°-36°N) with the current supposedly adding about 60×10^6 m³/s to the transport of the Gulf Stream, approximately tripling its flow (Stommel 1965). Knauss (1969) concluded from direct and indirect measurements of Gulf Stream transport in the Florida Straits-Cape Hatteras area that there is a gradual, uniform addition of

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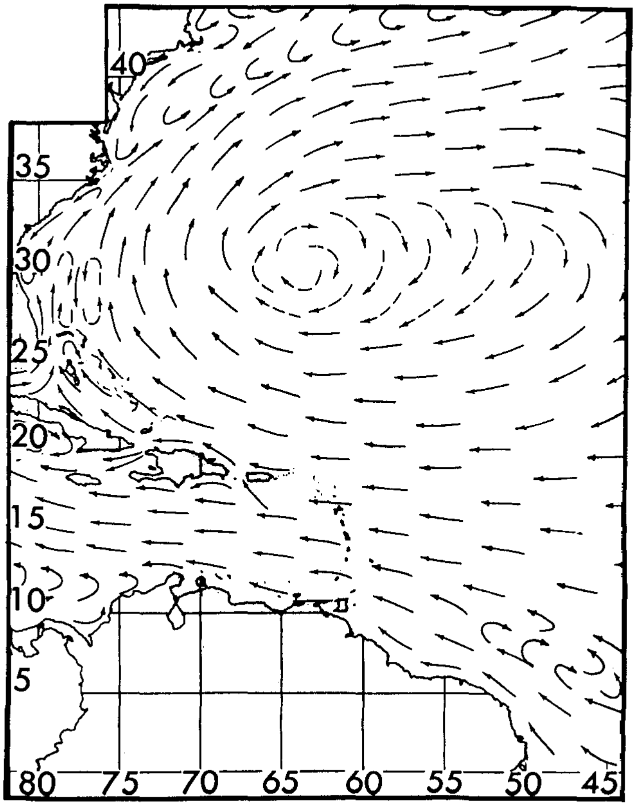

FIGURE 1.–Surface currents in the western North Atlantic and Caribbean during the winter months (from Oceanographic Atlas of the North Atlantic Ocean. Section I. Tides and currents. U.S. Nav. Oceanogr. Off. Publ. 700).

volume to the Gulf Stream at the rate of 7% per 100 km of its path leading to total values off Cape Hatteras of about 60×10^6 m^3/s. Knauss did not speculate on the source of the water added to the Gulf Stream. More recent direct measurements of the transport of the Gulf Stream off Cape Hatteras (Richardson and Knauss 1971) yielded an average value of 63×10^6 m^3/s which means that the addition to the Gulf Stream between the Florida Straits and Cape Hatteras, assumedly from the Antilles Current, amounts to about 30×10^6 m^3/s, approximately doubling its flow.

Some doubt has been cast on the existence of the hypothesized junction of the Antilles Current with the Gulf Stream and even on the existence of the current itself. A study by Day (1954) of drift bottle data and hydrographic data then available from the region northeast of the Bahama Islands revealed little evidence of a surface current with the characteristics attributed to the Antilles Current. Instead of surface flow to the northwest, he found that "... the surface waters in the region tend to move with a pronounced southerly component of direction rather than to the northwest, and that the Antilles Current appears at depth, varies markedly in its transport from one time to another, and should not be considered a permanent, clearly defined tributary to the Gulf Stream current." A hydrographic section occupied between Bermuda and Elbow Cay in the northern Bahamas in February 1933 showed a northwestward transport of 20.3×10^6 m^3/s in a 140-nautical mile band off Elbow Cay (lat. 26° 30′N) which Day identified as the Antilles Current.

Earlier, Iselin (1936) commented on this same section of stations, pointing out that: 1) the temperature field was nearly horizontal except near the Bahamas (within 40 nautical miles) where it indicated southward flow in the upper 400 m and northward flow beneath that; 2) the temperature observations showed no evidence of a "... broad or powerful Antilles Current, readily distinguishable from the general westerly movement continuing from the Northern Equatorial Current . . ."; 3) salinity observations agreed with the thermal trends and afforded little further evidence for the Antilles Current; and 4) at other times of the year, when the trade winds are stronger, the Antilles Current may be better developed.

Day (1954) also points out that a dynamic topography based on a grid of stations occupied northeast of the Bahama Islands in April 1947 showed no general manifestations of the Antilles Current in the upper 150 m, showing southeastward flow instead. In a 330-nautical mile (610-km) section from this grid off Great Abaco Island (about lat. 27° to 28°N), a southeastward flow of 2.8×10^6 m³/s was found in the upper 250 m, and a weak northwestward flow of 0.7×10^6 m³/s was found in the 250- to 1,000-m layer, yielding a net transport through the section of 2.1×10^6 m³/s southeastward.

A similar conclusion can be drawn concerning a much earlier investigation. Although Bigelow (1917), in his pioneer analysis of the *Bache* data, regarded the northward extension of warm water in the surface layer east and north of the Bahama Islands to be an expression of the Antilles Current, his pertinent vertical section of temperature just north of the Bahamas collected in March 1914 doesn't support that contention. The slope of the temperature isopleths northeast of the Bahama Islands indicated the presence of a southward flowing surface current in the upper 200 m or so, with a northward current at greater depth. Wüst (1924) computed geostrophic current speeds and volume transports from the *Bache* data including the transect of eight stations, from Jupiter Inlet to the Sargasso Sea (SW-NE) crossing just north of the Bahamas. He found an 80-km band of northwestward flow, which he called the Antilles Current, contiguous with southeastward flowing countercurrents on both sides. The transport of the Antilles Current he computed, 12.0×10^6 m³/s, was approximately balanced by the transport of the two countercurrents, 12.4×10^6 m³/s, yielding a net transport through the portion of the section seaward of the Gulf Stream (depths>800-900 m) of 0.4×10^6 m³/s to the southeast.

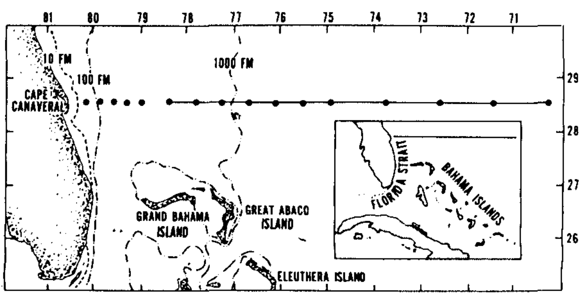

FIGURE 2.—Location of stations occupied by U.S. Coast Guard cutters along Standard Section A-7. The stations connected by the solid line are those generally used in this study.

During 1967-72, vessels of the U.S. Coast Guard made nine occupations of Standard Section A-7, each consisting of 16 oceanographic stations along 28°35′N from near Cape Canaveral at long. 80°10′W to a point about 520 nautical miles (960 km) offshore at long. 70° 15′W (Figure 2). Temperature and salinity data were collected on each station from casts of Nansen bottles located at or near NODC (U.S. National Oceanographic Data Center) standard depths or from lowerings of STD (Salinity Temperature Depth) sensors calibrated against data collected by Nansen bottles and reversing thermometers. Contoured profiles of temperature, salinity, and density are to be published along with lists of the data in the Coast Guard Oceanographic Report series (Robe in press). This section transects the Antilles Current where it is supposed to begin merging with the Gulf Stream, thus providing a portrayal of its potential contribution to the Gulf Stream system. Unfortunately, the occupations are not distributed uniformly throughout the seasons; five are in winter, two in fall, and two in summer, so seasonal variations cannot be discerned from the data.

Geostrophic velocities were computed from the temperature and salinity data utilizing a standard computer program employed by the Coast Guard Oceanographic Unit (Hislop[2]). The velocities were computed relative to the 1,000-decibar surface which was consistently reasonably level, as indicated by the small variation of density at 1,000 m (mean σ_t = 27.547, standard deviation = 0.098, sample size = 52). No attempt was made to carry the computation into water shallower than about 800 m because of the considerable errors introduced by extrapolation of water properties into the bottom and by close approach to the Gulf Stream.

Vertical sections of geostrophic velocity were hand drawn from lists of the computed values by assigning the values to midpoints between stations at middepths between depths of temperature and salinity observations. Interpolations necessary for contouring were based on an assumption of linear variation in properties horizontally and vertically between data points. This procedure was followed for six of the nine occupations of Standard Section A-7. Three occupations were rejected because they contained too many short casts in critical areas.

[2]Hislop, A. S. 1973. Coast Guard Oceanographic Unit DDP-516 programs. Oceanogr. Unit Tech. Rep. 73-2, p. 16-17. Unpubl. manuscr.

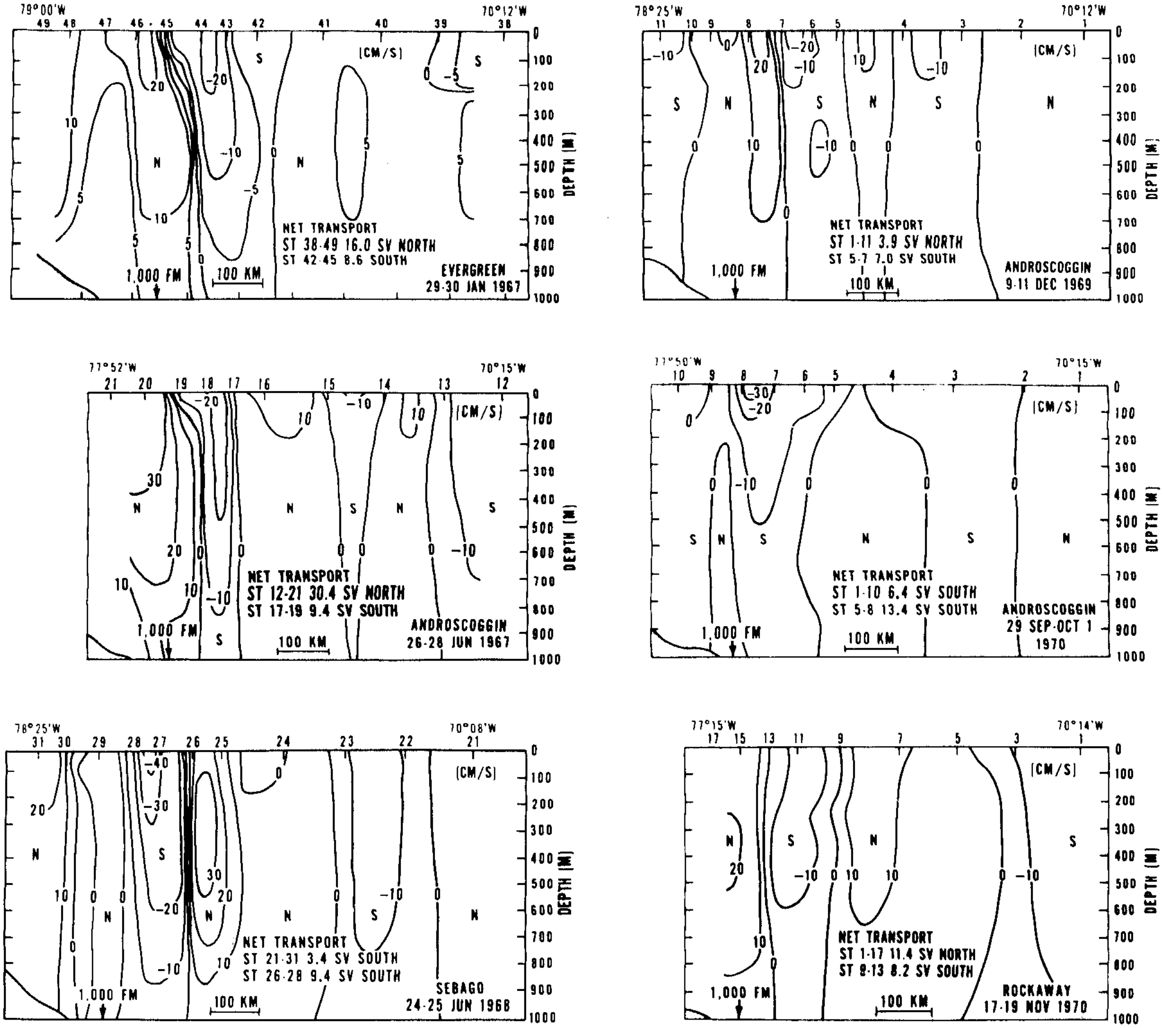

FIGURE 3.—Vertical distributions of meridional geostrophic velocity (cm/s) through Standard Section A-7 computed relative to the 1,000-decibar surface. Net transport values given in Sverdrups (1 SV = 10^6 m^3/s). Station numbers are arrayed along the upper horizontal boundary. Positive velocities are northward.

The vertical sections of geostrophic velocity (Figure 3) revealed a fairly consistent pattern of alternate bands of weak ($\leq$10 cm/s) northward and southward flow in the offshore half of the transect (seaward 400-500 km). West of this, a narrow band of stronger (10-40 cm/s) northward current was found in five of the sections, located generally just seaward of the 1,000-fathom isobath, about where the band of stronger northward Antilles Current was shown by Boisvert (1967). However, a band of southward flow of about the same speed was found nearby in each of the transects. Net transport through the section was northward in four of the occupations and southward in two, ranging from 3.9 to 30.4×10^6 m^3/s northward and 3.4 to 6.4×10^6 m^3/s southward. The mean net transport for the six sections was 8.6×10^6 m^3/s northward. In five of the sections, the northward transport values fall far short of the 30×10^6 m^3/s or more which the Antilles Current is supposed to add to the Gulf Stream, indicating that sources other than the Antilles Current must contribute to the observed increase.

Although it is difficult to make a direct comparison with Kort's findings (Kort 1972), because of the small size of his charts, paucity of data portrayed, and the fact that all of his data were collected south of lat. 28° 35′N, the locations of the bands of relatively strong southward current corresponded reasonably well with the location of the southward flowing Antilles-Guiana Countercurrent that he hypothesized (Figure 4). Estimates of transport in the major southward band in each of the Coast Guard sections varied from 7.0 to 13.4×10^6 m^3/s, with an average of 9.3×10^6 m^3/s, which is only about one-third of the southward transport Kort (1972) reported for the Antilles-Guiana Countercurrent. However, Kort's value, computed for the transect near the coast of South America at about lat. 8°N, was based on data throughout the entire water column, not just the upper 1,000 m.

Kort's discussion includes some speculation concerning the source of his hypothesized Antilles-Guiana Countercurrent as follows: "One may suppose that a branch of the Florida or North Tradewind Currents is a source of the Antilles-Guiana Countercurrent. On the other hand, the studies made by Swallow and Worthington (1961) in the Gulf Stream in 1961 enable one to consider that the Antilles-Guiana Countercurrent can be traced far to the north flowing as a southward countercurrent on the oceanward side of the Gulf Stream." His portrayal of the general current pattern (Figure 4), however, shows recurving of the Florida Current, "North Tradewind Current,"

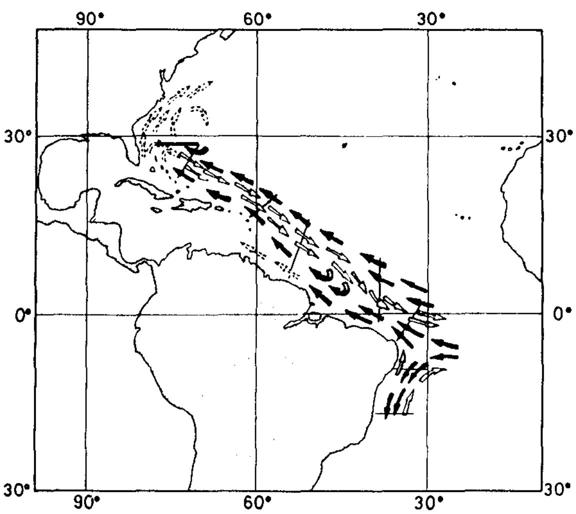

FIGURE 4.—Location of hypothesized Antilles-Guiana Countercurrent (open arrows) according to Kort (1972). Solid lines crossing the arrow field indicate locations of oceanographic transects. The northernmost, broad line represents the portion of the U.S. Coast Guard Standard Section used in this study; the others are sections cited by Kort.

and possibly the Antilles Current, as sources of the countercurrent.

If the bands of southward flowing water found in the Coast Guard transects are manifestations of the Antilles-Guiana Countercurrent and if, as Kort suggested, the source of the hypothesized Antilles-Guiana Countercurrent is (1) the recurving of the Florida Current, (2) the recurving of the North Tradewind Current, or (3) a countercurrent seaward of the Gulf Stream, then the properties of the water masses in the Antilles Current (northward band) and Antilles-Guiana Countercurrent (southward band) should be different. A plot of observed temperature and salinity values (Figure 5) from the bands of northward and southward flowing water detected in the Coast Guard transects shows that the bands have identical temperature-salinity (T-S) characteristics, implying that none of the three sources suggested is valid. Further, the comparison of the T-S characteristics of the southward band with those of the Florida Current (Figure 5) shows them to be significantly different, substantiating the contention that the recurving of the Florida Current is not a source for southward flowing water.

The identical T-S properties of the water in the southward and northward flowing bands leads to the conclusion that one flow is formed by a recurving of the other. Such recurving would lead to the formation of either a countercurrent, such as the hypothetical Antilles-Guiana Countercurrent, or an eddy. On the basis of the Coast Guard transect data it is impossible to determine which feature was present, but the direct measurement of large scale eddies farther south in the Antilles Current performed by satellite tracking of drogue buoys (Hansen[3]) suggests that eddies are more likely. The nearly constant position of the bands of northward and southward flow (eddies) in the transects would suggest that they are formed as a consequence of interaction of the Antilles Current with the Bahama Islands and surrounding banks.

The significance of these findings in relation to the distribution of ichthyoplankton in the area of the northern Antilles Current is difficult to state positively. However, it is clear that eggs and larvae in the upper 200 m in this area cannot be

[3]Hansen, D. V. Mesoscale motions in the Sargasso Sea: A result from the EOLE Complementary Program. Presented to the 54th meeting of the American Geophysical Union, April 18, 1973.

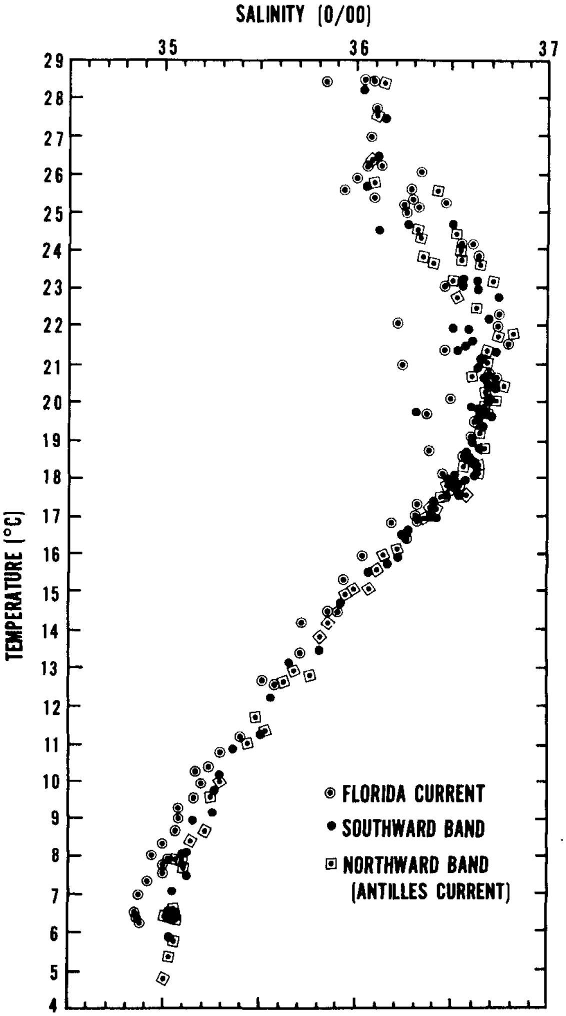

FIGURE 5.–Observed temperature (°C) - salinity (°/oo) points in the northward and southward bands and the Florida Current from six occupations of Standard Section A-7.

assumed to be moving steadily toward the northwest along the path traditionally assigned to the Antilles Current. Planktonic organisms located in water just seaward of the continental shelf at this latitude (28.5°N) are likely to have a northward compoent of velocity of about 10-30 cm/s, while those in deeper water 100-200 km farther offshore are likely to have a southward component of about the same magnitude. Seaward of that, plankton are likely to move either northward or southward at relatively slow speeds, in the range of 5-10 cm/s. If the higher speeds in the northward and southward bands are manifestations of a quasi-permanent eddy or transient eddies passing through, the net northward transport of plankton would be small, even in the area of higher current speeds near the continental shelf. Instead, planktonic organisms may be caught up in eddies or slowly moving water for long periods of time. Since the waters east of the northern Bahama Islands contain a relatively small plankton biomass and are thought to yield low rates of primary and secondary production, pelagic fish larvae held in the area for an extended period of time would have little likelihood of growth and survival.

A clearer resolution of quasi steady-state currents should be realized when analysis of data and geostrophic computations are complete for two MARMAP cruises (July-August 1972 and January-March 1973), which included the area east of the Bahama Islands. However, the transport of planktonic organisms in the surface layer may be governed by local wind-driven currents which may not be manifested as geostrophic currents computed from the density field. Average monthly wind roses (U.S. Naval Oceanographic Office 1963) for the area off the northern Bahamas shows that the winds from the east or northeast occur with greater frequency than those from any other quadrant every month, except June, July, and August, when winds from the south and southeast are more frequent. Such easterly and northeasterly winds would yield northward and northwestward Ekman (wind-driven) transports in the surface layer coinciding with the direction assumed for the Antilles Current. The net Ekman transport in the surface layer depends on the frequency distribution of wind direction and speed during the time period of interest, the subject of further research.

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