Surface Currents in the Caribbean Sea as Deduced from Satellite Tracked Drifting Buoys

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RESUMEN

Las corrientes superficiales en el Mar Caribe y Golfo do México fueron determinadas por satélite al detectar boyas a la deriva en las capas superficiales. Mientras duró el experimento, la deriva general a través del Caribe fué hacia el oeste. Sin embargo, la trayectoria individual de las boyas muestran una considerable variabilidad en la deriva media, habiéndose observado movimientos tortuosos y de remolinos. Esta variabilidad dió lugar a que algunas boyas permanecieran mayor tiempo en el Caribe de lo que se había predicho basado en carats históricas.

INTRODUCTION

The distribution of surface currents in the Caribbean Sea is one of several variables required to determine the trajectories of floatable materials which have been injected into the area. For instance, the surface distribution of plankton, fish larvae and pollutants, as well as their residence time in the Caribbean, are affected by the horizontal structure of the current field. Older current charts, as presented by Wust (1964) for instance, depict a surface drift over most of the Caribbean of between 50 cm/sec and 75 cm/sec to the west. This flow pattern would suggest a residence time in the Caribbean Sea of approximately 75 days for surface waters flowing from the passages of the Lesser Antilles to the Yucatan Channel.

An experiment was conducted in the Caribbean Sea from October 1975 through June 1976 to map the distribution of surface currents. Lagrangian drifters tracked by satellite were deployed in the passages of the Lesser Antilles and within the Caribbean Sea. The buoy trajectories were considerably more complex than merely a westward drift, with several scales of meanders and eddies observed. The residence time in the Caribbean Sea for some of these buoys was over 5 months.

EXPERIMENTAL PROCEDURE

The tracking system for the drifters used in this experiment has been described elsewhere (Levanon, 1975). The buoys were coupled to a water parcel at a nominal depth of 30 m by a 3 m by 12 m "window-shade" drogue. The buoys were also equipped with wind speed, sea-surface temperature and drogue line tension sensors.

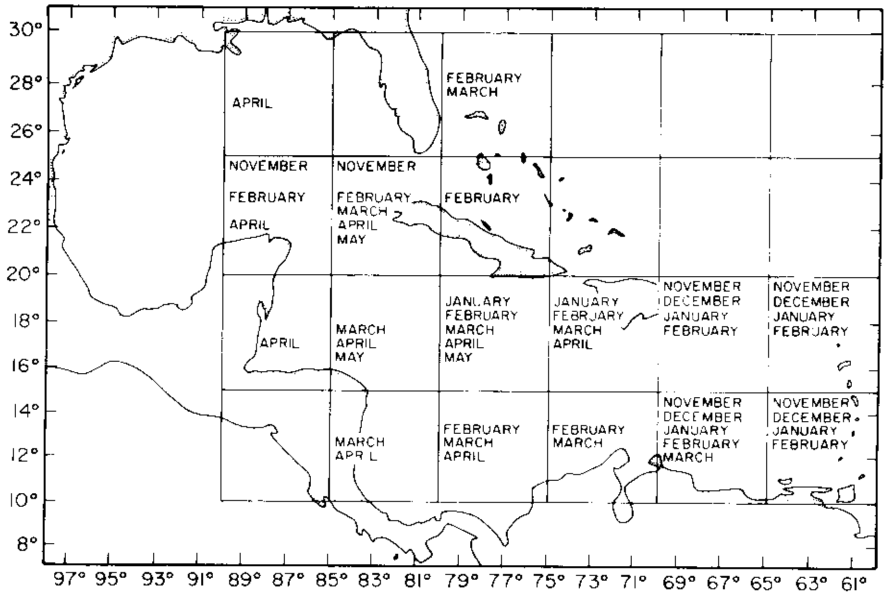

Fig. 1. Data distribution by 5° square and month.

The effect of wind and current shear on the ability of a drifter to track a water parcel has been discussed in Kirwan et al. (1975) and Vachon (1975). The error induced by windage on the drifter is usually less than 3% of the wind speed with or without the drogue attached.

Nineteen drifters were deployed in the eastern Caribbean Sea in two separate deployments. The first group of eight drifters was launched in the passages of the Lesser Antilles in October 1975. The second group of 11 drifters was launched in January-February 1976 in the Antillean passages and within the eastern Caribbean. The deployment strategy during October 1975 was to launch the buoys in those passages described by Stalcup and Metcalf (1972) as providing the majority of the transport into the Caribbean Sea. A similar strategy was employed in January-February 1976, but in addition, several buoys were deployed in regions of intense flow as determined from the trajectories of the October deployment.

Position data were received from one buoy from October 1975 through June 1976, but the other buoys failed or ran aground prior to June. All the position data were edited in an automated computer routine. First the mean and standard deviation of the speed in a two degree square were computed. If an individual speed was greater than the mean plus two times the standard deviation, the corresponding position was removed from the record (Herman and Cardwell, 1977). The remaining position data have an rms error of about 5 km. On the average, one to two positions were available per day after the editing. Speeds were computed from the edited data-set by a forward differencing scheme.

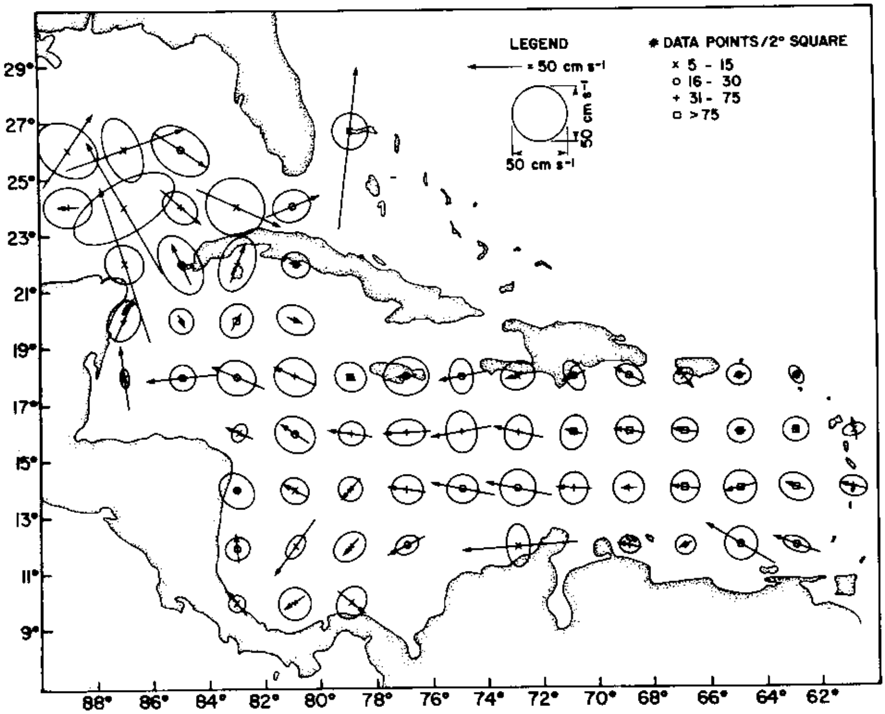

Fig. 2. Average currents in the Caribbean Sea and Gulf of Mexico for the period October 1975 to June 1976 determined by averaging surface currents onto a 2° x 2° grid. The axes of the ellipses centered on the grid points represent the standard deviations of speed components normal to and along the mean flow.

RESULTS

The distribution of available buoy data by 5° square is given on Figure 1. In general, buoy data were collected in the eastern Caribbean Sea during the fall of 1975 and winter of 1976, in the central Caribbean during the winter and early spring of 1976, and in the western Caribbean and Cayman Seas during the spring of 1976. Additional buoy data were obtained in the Gulf of Mexico during the fall of 1975 and winter and spring of 1976.

Mean current vectors, by 2° squares, derived from all the data are shown on Figure 2. Variability about the mean flow is shown in the form of ellipses on Figure 2. The major and minor axes of these ellipses represent the standard deviation of the speeds along and normal to the mean flow.

The mean circulation pattern derived from the 8-month data set closely resembles the patterns given by Wust (1964). The flow in the Caribbean Sea is predominantly to the west at speeds of 50 cm/sec to 75 cm/sec. The mean flow accelerates significantly in the Yucatan Strait first, and then again in the Straits of Florida. Downstream of both channels, speeds of over 150 cm/sec are attained. Three gyres appear in the mean circulation pattern (Fig. 2). The

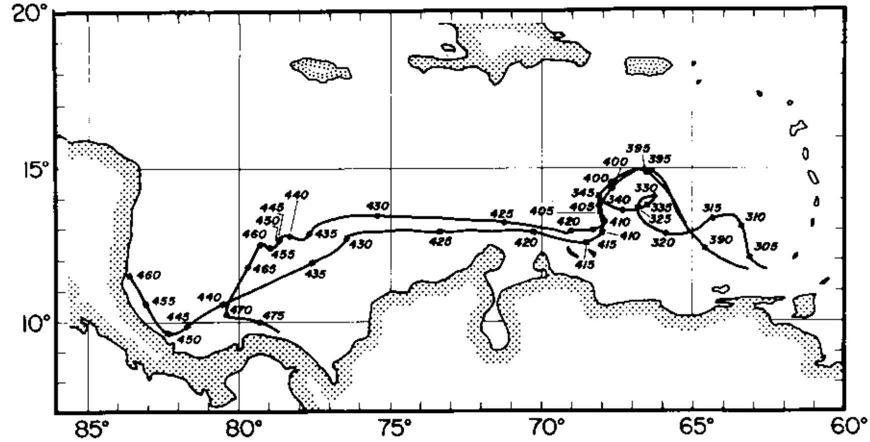

Fig. 3. Trajectories for the satellite tracked drifters deployed south of 12° N. Tick marks represent consecutive day number from 1 January 1975.

anticyclonic gyre in the extreme southwestern corner of the Caribbean Sea is in contrast to the cyclonic gyre shown in this area by Wust (1964), but agrees with the winter circulation pattern of Febres-Ortega (1970). Another anticyclone is observed in the vicinity of the Cayman Ridge. Finally, the Loop Current (Leipper, 1970) appears as an anticyclonic circulation feature in the eastern Gulf of Mexico.

Assuming an rms error of 5 km for the tracking system and a mean time between fixes of 12 hours, the average error introduced into the speed computations by positioning errors is of the order 15 cm/sec. Thus, most of the variability is related to actual conditions rather than instrument error. Throughout the area, both components of standard deviation are frequently the same order of magnitude as the mean speed.

The individual buoy trajectories are shown on Figures 3, 4, 5 and 6. The trajectories are grouped by deployment area. The spatial character of the flow can be discerned from these trajectories. For instance, the area between the Lesser Antilles and 65° W, north of 13° N, is heavily populated with eddies. These eddies are normally less than 50 km in diameter. Large meanders, with north-south amplitudes of some 150 to 200 km, are observed at 66° W, 67° W and 72° W. These meanders do not appear to be permanent circulation features, as they are not evident in all buoy trajectories through these areas. The flow in the central Caribbean basin west of 68° W in the south and 72° W in the north is more zonal. There are some meanders with small amplitudes in these regions (Fig. 3).

Larger eddies appear in the trajectories located in the southwestern Caribbean Sea and eastern Cayman Sea. In the former area, an area with clockwise circulation is flanked on each side by eddies with counterclockwise circulation. The charts of Wust (1964) suggest a large counterclockwise gyre is located in this area which may be related to the gyre in the buoy trajectories

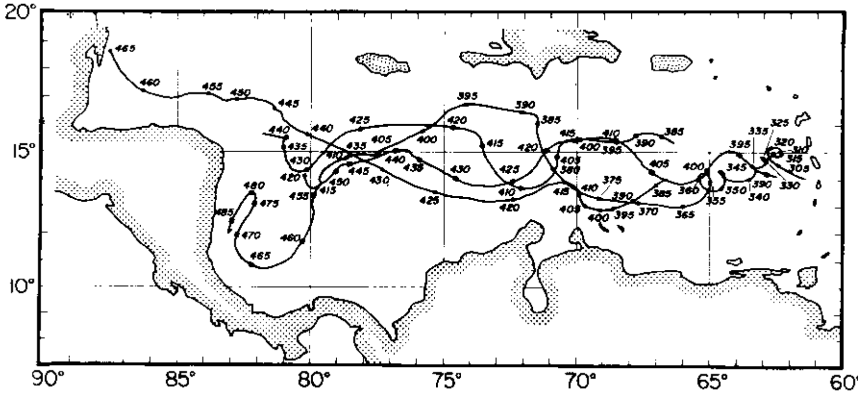

Fig. 4. Trajectories for buoys deployed between 13° N and 16° N. Tick marks represent a consecutive day number from 1 January 1975.

farther to the east. The gyre in the Cayman Sea appears in older representations of the circulation.

In general, the buoys deployed in January 1976 experienced higher drift speeds than those deployed in October 1975. For instance, a buoy deployed south of 12° N in January drifted from 62° W to 71° W in 6 weeks, while one deployed in October drifted from 62° W to 68° W in 6 weeks. A buoy deployed between 14° N and 16° N in January drifted from 61° W to 85° W in 3.5 months. A buoy deployed in October took over 6 months to traverse from 61° W to 80° W.

The spatial variability indicated in the buoy trajectories is not found on the older charts of the circulation in the Caribbean Sea. These features affect the residence time of surface waters for the buoys in the region. The residence times in various portions of the Caribbean Sea are given on Table 1. Residence times estimated from the sea surface current maps of Wust (1964) are also given for comparison. The charts of Wust (1964) show slower surface currents north of 15° N as compared to south of 15° N throughout the Caribbean. Therefore, each longitudinal band is divided into currents north and south of 15° N.

The largest discrepancies between observed and estimated residence times occur in those areas where spatial variability is the largest. For instance, in the northeastern corner of the Caribbean Sea the observed residence times are a factor of two greater than the estimated times. Many eddies appear in the buoy trajectories in this region (Fig. 6). In the Cayman Sea, Wust (1964) shows an anticyclonic gyre north of 20° N, but flow through the area to the south of 20° N. The buoy data indicate a gyre south of 20° N (Fig. 6). The observed residence times are underestimates of time spent in this gyre, as all the buoys considered failed in the feature before leaving the area. The residence times in the central Caribbean Sea are more comparable as the flow is more zonal in the area with few eddies observed (Figs. 3, 4 and 5).

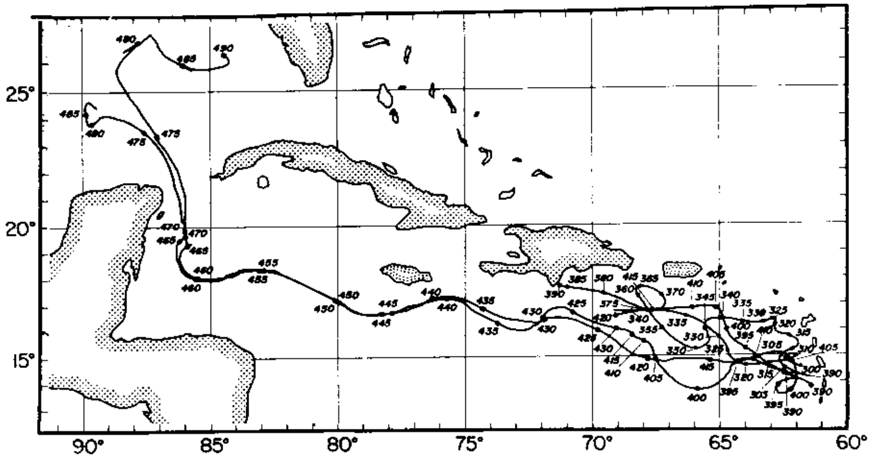

Fig. 5. Same as for Figure 4.

DISCUSSION

Several observed features of the buoy trajectories suggest that the drifters are advected in the surface wind drift layer. For instance, the buoys deployed during January experienced greater drift speeds than those deployed in October. Climatological wind data, Hastenrath and Lamb (1977), indicate that the late winter surface winds are more intense than the fall winds. In addition, the NE winds in the southeastern Caribbean occur over a region in which the surface drift of the buoys was predominantly to the southwest.

However, dynamic topographies collected previously in the eastern Caribbean indicate that the drifters may also drift with the geostrophic flow. Febres-Ortega (1970) shows a meander in the southern Caribbean at 67° W in the location of the meander shown in Figure 3. He also shows a meander in the northern Caribbean at about 70° W, somewhat to the west of those shown on Figure 5. However, the buoy trajectories do suggest some movement of this feature. Thus, some of the motions given by the buoys are probably in geostrophic balance.

There appeared to be a preference for the buoys deployed south of 14° N to remain in the southern Caribbean Sea, the buoys deployed between 14° N and 16° N to flow through the Caribbean, and the buoys deployed north of 16° N to remain in the northern Caribbean Sea. The southern and northern buoys either ran aground or failed before they could exit the Caribbean-Cayman basins. These buoys exhibited the longest residence time in the area.

The trajectories show that the surface currents are more complex than those previously depicted. In particular, the frequent occurrences of meanders and eddies in the flow are responsible for longer residence time of surface water parcels in the Caribbean Sea than would be predicted from historical charts. These results must now be considered by those concerned with the fate of material entrained in the surface waters of the Caribbean Sea.

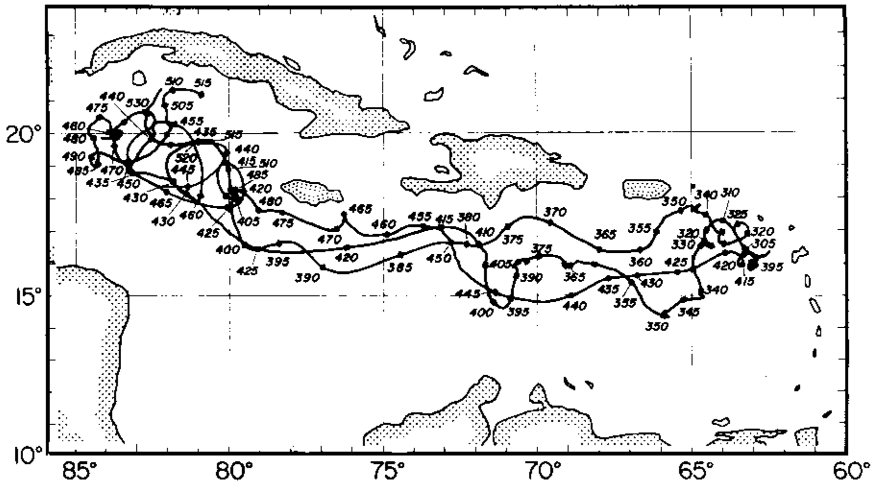

Fig. 6. Trajectories for buoys deployed north of 16° N. Tick marks represent a consecutive day number from 1 January 1975.

Table 1. A comparison of residence times (in days) estimated from the surface current charts of Wust (1964) versus those of the drifting buoys

	Residence Times (days)	
Area	Estimated from Wust (1964)	Observed
62° W-65° W		
a) >15° N	10-20	30-40
b) <15° N	7-10	15-30
65° W-70° W		
a) >15° N	17-35	20-35
b) <15° N	11-17	30-40
70° W-75° W		
a) >15° N	17-35	10-45
b) <15° N	11-17	10-15
75° W-80° W		
a) >15° N	17-35	10-25
b) <15° N	11-17	15-25
Eastern Cayman Sea	17-26	30-110*

*Buoys failed in Cayman Sea

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