Direct Measurements of the Atlantic Equatorial Undercurrent[1]

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ABSTRACT

Measurements from 57 current meters suspended from anchored buoys in a network between 1.5°N and 1.5°S and from 27.5°W to 35°W in the Atlantic Ocean between February and April 1963 show speeds up to 70 cm/sec within the Equatorial Undercurrent. The bottom of the Undercurrent appears to be no deeper than 150 m; below this depth there is a westward-flowing current with speeds up to 25 cm/sec.

During February, March, and April 1963, the R. V. Chain of the Woods Hole Oceanographic Institution was engaged in a study of the currents in the western Equatorial Atlantic Ocean. This work was part of an international cooperative program, known as Equalant I, coordinated by the U. S. Bureau of Commercial Fisheries (Austin 1963) for studying the tropical Atlantic Ocean. The portion of work aboard the Chain reported here consisted of direct measurements of the Atlantic Equatorial Undercurrent using Richardson Current Meters (Richardson et al. 1963).

From earlier studies of the Undercurrent between 13°W and 19°W, it was estimated (Metcalf et al. 1962) that this Undercurrent was approximately 350 m deep and less than 300 km wide. On the basis of these estimates, a grid of anchored current-meter stations was laid out between 1.5°N and 1.5°S from 27.5°W to 35°W, as shown in Fig. 1. At most of these stations, the instruments were left in place for about six days and then shifted to new locations. At these six-day stations, the instruments recorded speed and direction of the current continuously. At 35°W at the Equator, the current meters were left in place for approximately 60 days and were adjusted to record current speed and direction for one minute in each 20-minute interval.

At each station, the current meters were suspended beneath a toroidal surface float that was 2.5 m in diameter and was equipped with a radio homing

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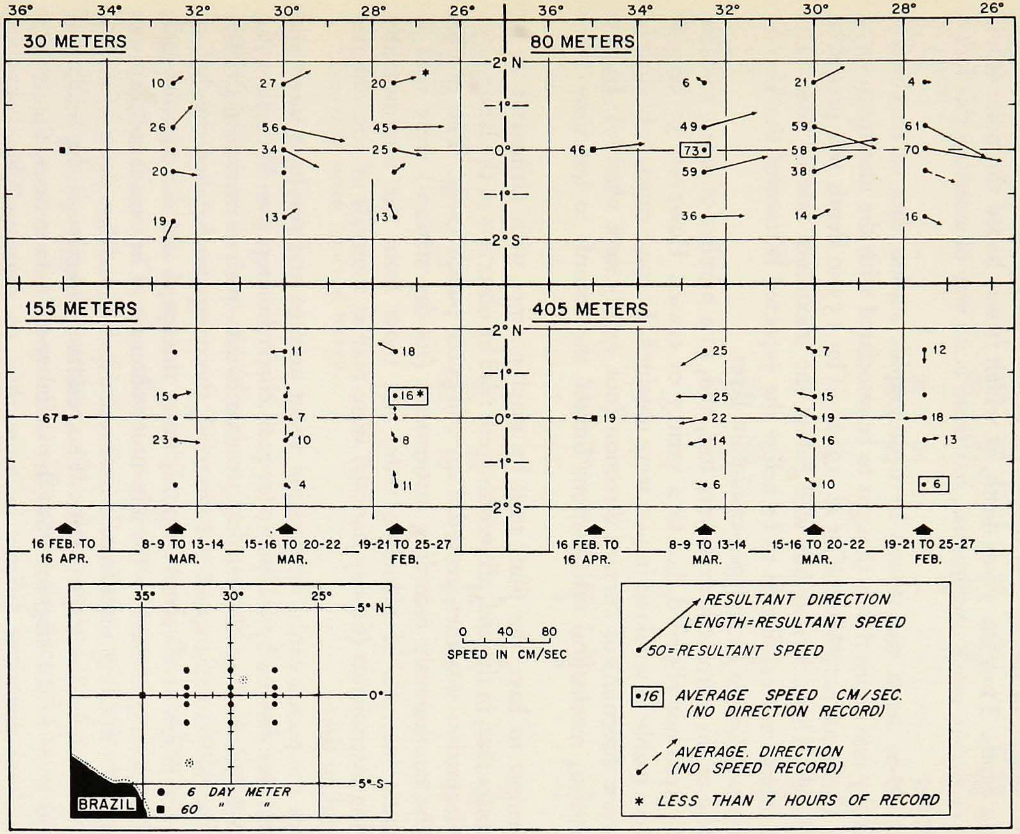

Figure 1. Resultant current and speeds at 30, 80, 155, and 405 m. The dates along the bottom of the figures are those at which the stations were set and recovered.

device. The current meters were placed at depths of 30, 80, 155, and 405 m. A record from depths shallower than 30 m would have been desirable, but it is believed that movement of the toroidal float by wind and wave action produces erratic motions in shallow current meters, thus causing excessive background "noise" in the record; this effect is increasingly damped out with increasing depth. Thus the 30-m depth, at which it was hoped the noise would not be excessive, was a compromise, but there is no way of assessing this factor accurately.

The 80-m depth was shown by hydrographic station data to be close to the salinity maximum that is thought to be associated with the maximum speed of the Undercurrent (Metcalf et al. 1962). The 155-m depth was presumed to be in the Undercurrent but well below the maximum rate of flow. The 405-m depth was considered to be below the expected bottom of the Undercurrent and close to the oxygen-minimum layer.

A few of the current meters were lost, and, in a number of cases, readable records were not obtained due to a variety of causes. However, 57 records that were usable in whole or in part were obtained. In some cases, only current speed (not direction) or current direction (not speed) were obtained. In two instruments, mechanical malfunctions limited the records to less than seven hours.

Attempts to have the films read by machine met with difficulties in so many cases that, in the end, all records were read by observers in the laboratory; this information was then recorded on computer punch cards. The records from the continuously recording instruments (six-day stations) were read at 10-minute intervals of recording time, and those from the intermittently recording instruments (60-day stations) were read at intervals of 100 minutes of recording time.

From the punch cards, information about average and resultant speed and direction was derived by computer for each current meter. (See Webster 1964 for a description of the film-reading process and data-analysis methods.) Briefly, to obtain the resultant speed and direction, the computer handled the data to produce a progressive vector diagram, using the speed and direction of each individual reading as read by the laboratory observer. The resultant speed was calculated by dividing the distance between the first and last point of such a vector diagram by the elapsed time. The resultant direction is the bearing of the final point in the diagram from the initial one. In four cases, the average and resultant directions differed by more than 10 degrees. These cases are marked with asterisks in Fig. 2, where it is seen that the directions fluctuated greatly. In 41 cases, the differences between the average and resultant directions were less than five degrees. The relationship between the average and resultant speeds is listed in Table I.

The relationship between the average and resultant speeds might be considered an index of steadiness in the current direction. If the direction were

Table I. Resultant and average speeds of currents at four depths between 1.5°N and 1.5°S from 27.5°W to 35°W.

	35.0°W		32.5°W		30.0°W		27.5°W	
	Res.	Av.	Res.	Av.	Res.	Av.	Res.	Av.
DEPTH 30 m								
1.5°N	–	–	10	22	27	34	20	21*
0.5°N	–	–	26	34	56	62	45	52
Equator	–	–	–	–	34	37	25	29
0.5°S	–	–	20	34	–	–	12	20
1.5°S	–	–	19	43	13	21	13	23
DEPTH 80 m								
1.5°N	–	–	6	12	21	30	4	14
0.5°N	–	–	49	56	59	63	61	63
Equator	46	63	–	73	58	61	70	74
0.5°S	–	–	59	65	38	42	–	–
1.5°S	–	–	36	39	14	15	16	29
DEPTH 155 m								
1.5°N	–	–	–	–	11	14	18	20
0.5°N	–	–	15	16	–	–	–	16*
Equator	12	18	–	–	7	9	–	–
0.5°S	–	–	23	24	10	13	8	12
1.5°S	–	–	–	–	3	8	11	12
DEPTH 405 m								
1.5°N	–	–	25	27	7	9	12	15
0.5°N	–	–	25	26	14	15	–	–
Equator	19	23	22	23	19	20	18	19
0.5°S	–	–	14	16	16	17	13	17
1.5°S	–	–	6	9	10	13	–	6

* Less than seven hours of record.

unvarying, the average and resultant speeds would be identical, regardless of variations in speed. Any directional variability would make the resultant speed less than the average speed. If, in connection with a directional variability, there were a dependent variability in speed, the resultant direction would differ from the average direction unless that variability were perfectly symmetrical about the average direction. Resultant and average directions that differ greatly suggest that the current direction and speed are varying in a systematic manner and not symmetrically about the average direction during the period of observation.

In Fig. 1, arrows point in the direction of the computed resultant flow; the length of the arrow is proportional to the resultant speed, which is also given in numerals. In cases where direction but no speed was obtained, only the average direction could be computed, and this is represented by a dashed arrow of arbitrary length. Where speed but no direction was recorded, only the average speed could be computed, and this is given by the numerals at

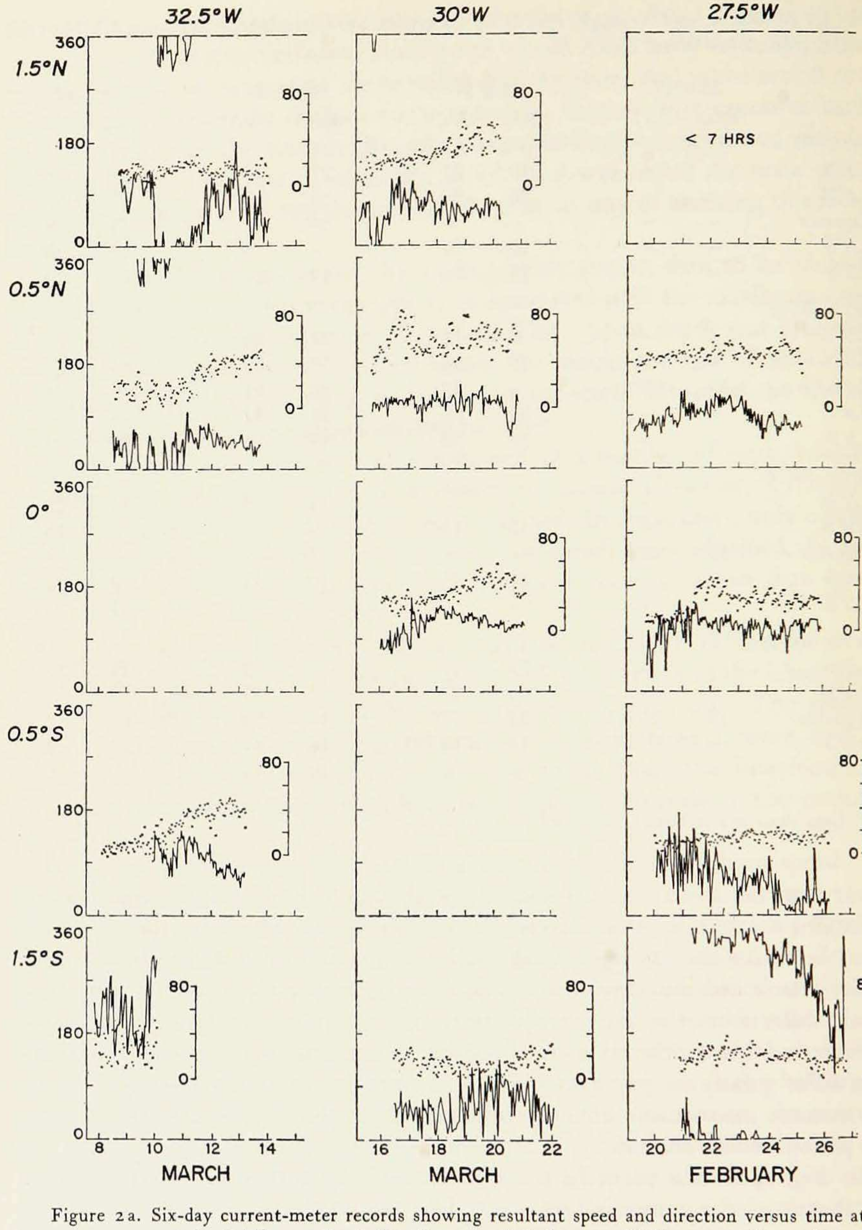

Figure 2a. Six-day current-meter records showing resultant speed and direction versus time at the 30-m level. The resultant directions are plotted as a solid line connecting points representing hourly resultant directions. The resultant speeds are shown by dots, each of which represents the resultant speed for one hour. The directional scale, from 0° to 360° T, is along the left margin of the figures, and the speed scale, from 0 to 80 cm/sec, is at the right of each record. The numbers along the bottom of the figures indicate the days of the month at 1200 local (30th meridian) time. The asterisks indicate those records in which the average and resultant directions differed by more than 10 degrees.

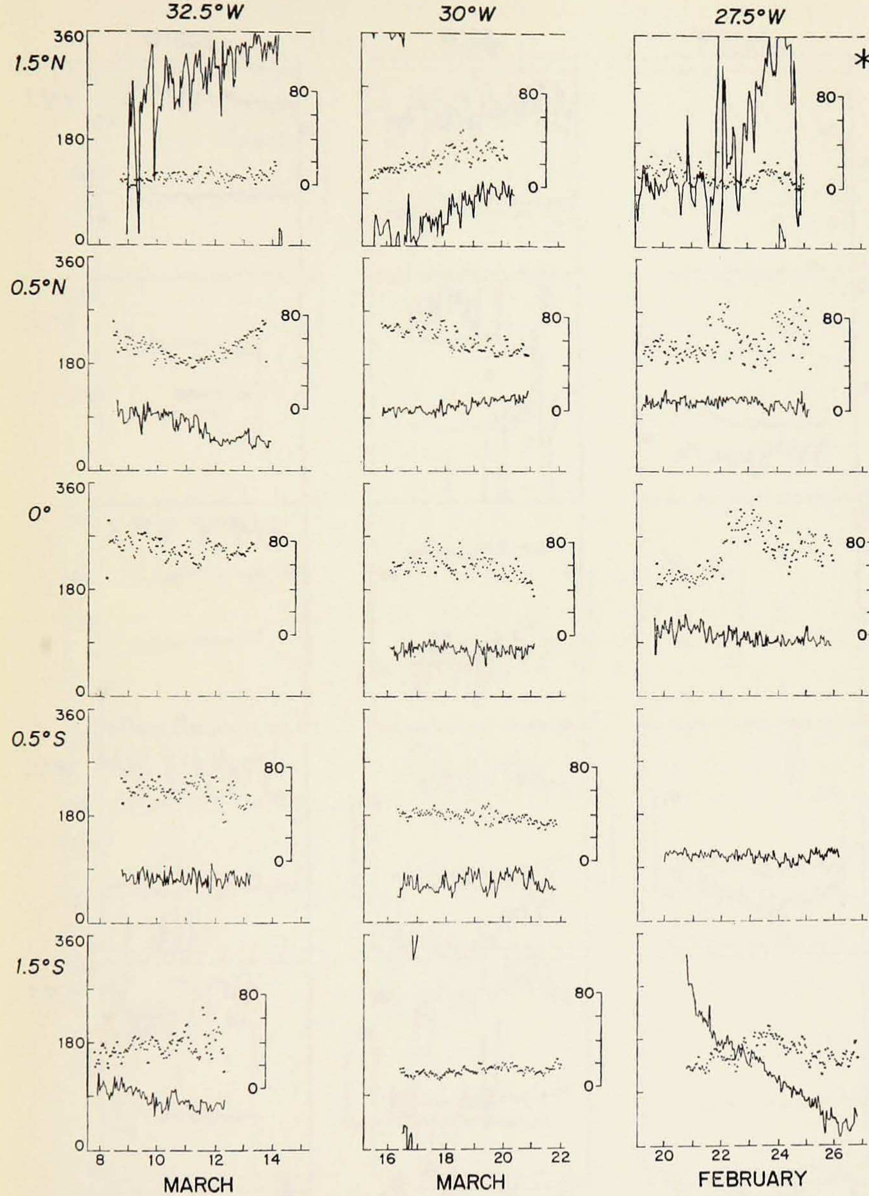

Figure 2b. Six-day current-meter records showing resultant speed and direction versus time at the 80-m level. See Fig. 2a for explanation.

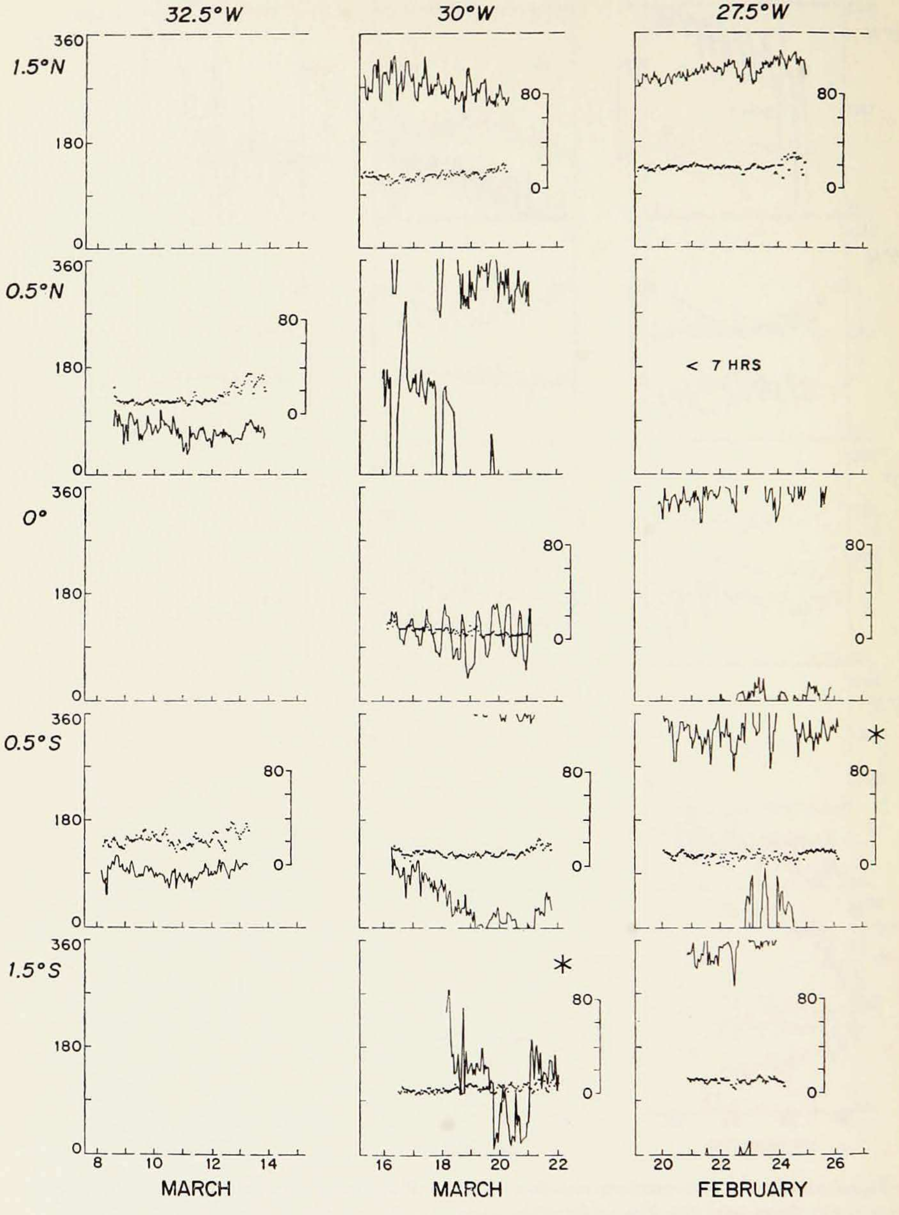

Figure 2c. Six-day current-meter records showing resultant speed and direction versus time at the 155-m level. See Fig. 2a for explanation.

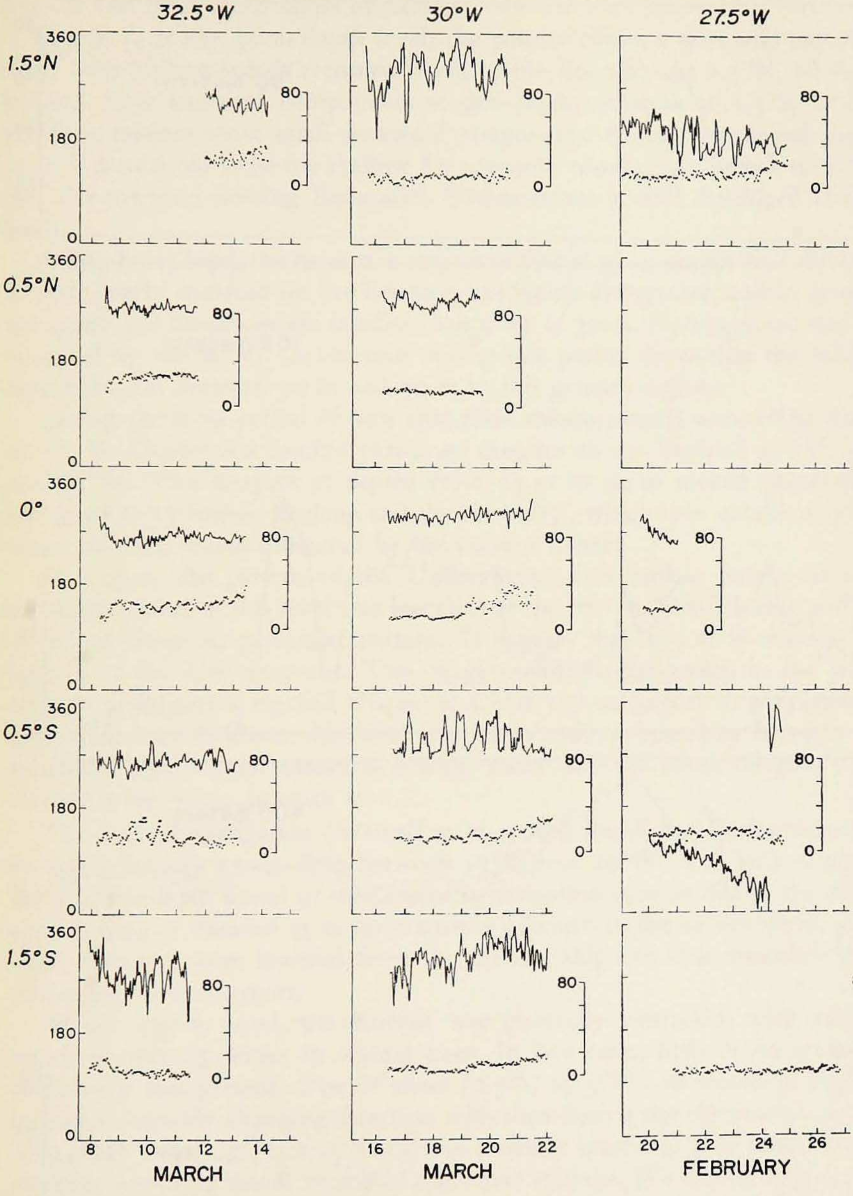

Figure 2d. Six-day current-meter records showing resultant speed and direction versus time at the 405-m level. See Fig. 2a for explanation.

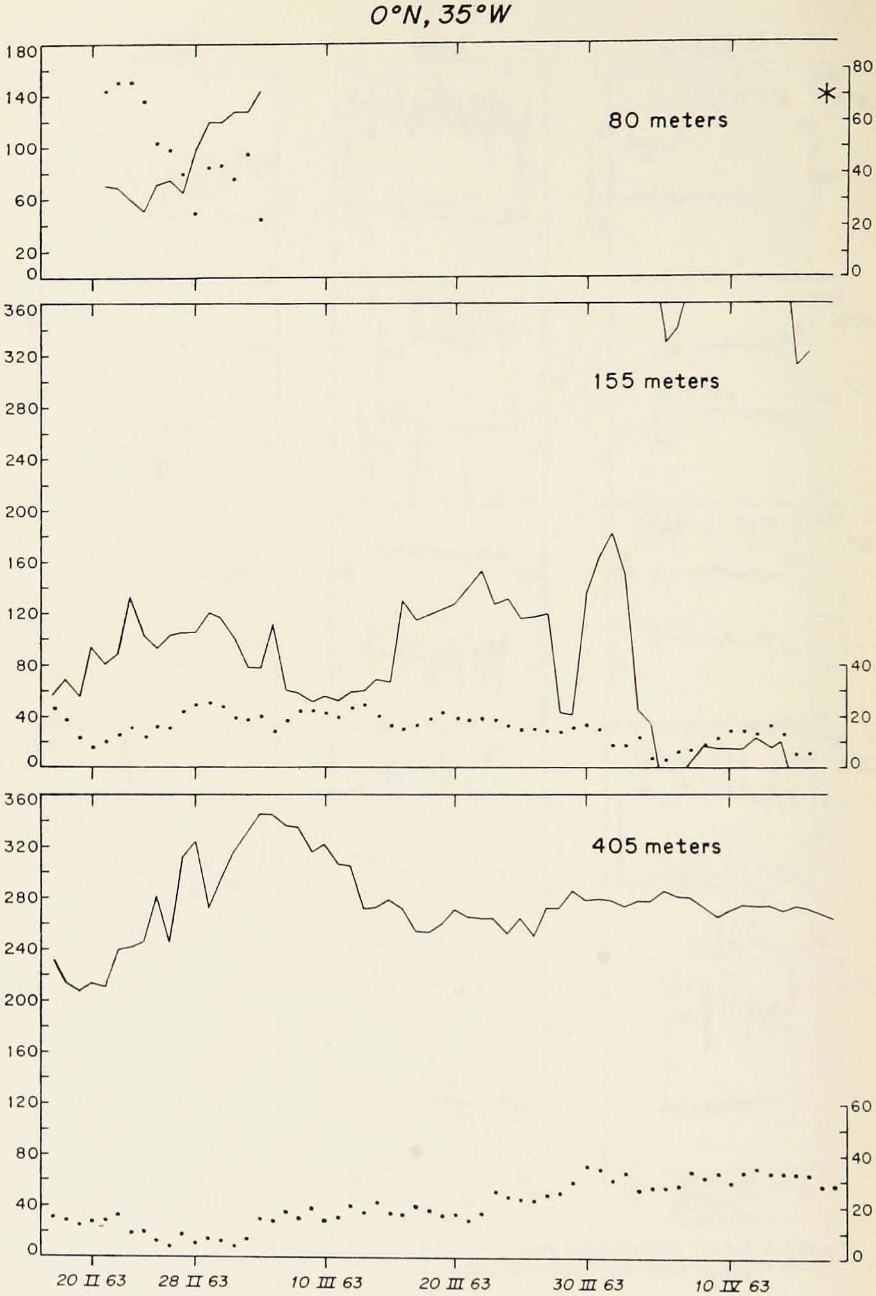

Figure 2e. Longer current-meter records of resultant speed and direction versus time from the station at 0°N, 35°W. The resultant directions are plotted as a solid line connecting points representing daily resultant directions. The resultant speeds are shown by dots, each of which represents the resultant speed for one day. Dates at 10-day intervals are shown along the bottom of the figure.

those stations lacking arrows. Asterisks mark those observations whose records were of less than seven hours duration.

In Fig. 1, at the 30-m depth level, the pattern shows a generally eastward flow, with highest speeds recorded north of the Equator. At 1.5°N, all three stations show eastward components at this depth, whereas at 1.5°S, two of the three stations show small westward components. As was mentioned above, 30 m is considered to be too shallow for optimum results, but there is no doubt that the eastward-flowing Equatorial Undercurrent is well developed at that level.

At the 80-m level, the pattern is similar to that at 30 m except that the flow is more nearly centered on the Equator, the speeds are greater, and in general the speeds and directions are steadier than those at 30 m. Hydrographic stations occupied by the R. V. CRAWFORD during this period show that the salinity maximum lies between 70 m and 90 m in this general region.

During the same period of time that these measurements were being made, the R. V. CRAWFORD tracked parachute drogues on the Equator at 25°, 30°, and 35°W. The drogues at depths from 75 m to 90 m moved eastward at speeds up to 75 cm/sec (Stalcup and Parker 1965), which is in excellent agreement with the speeds measured by the current meters.

At 155 m, the pattern of the Undercurrent had broken down. At each station the speed at this level was less than at the two shallower levels, and the directions show no particular pattern. It appears that 155 m is close to the bottom of the Undercurrent. The oxygen-salinity relationship in the water column undergoes a marked change at about 150 m (report in preparation), suggesting that at about this level there may exist a boundary between the relatively high-oxygen eastward-flowing water and the lower-oxygen, westward-flowing water beneath it.

The 1961 investigation (Metcalf et al. 1962) found the Undercurrent to be approximately 350 m deep between 13°W and 19°W. The lack of agreement in the depth found in the present investigation may be due to the difference in time or distance or to uncertainties inherent in the earlier study, when current meters were lowered from the drifting ship and thus measured sheer rather than true currents.

At the 405-m level, the current was generally westward, with average speeds of over 25 cm/sec in several cases. In two cases, little or no westward component was present. One of these (0.5°S, 27.5°W), as shown in Fig. 2d, indicates a steadily changing direction with time during the observation period. The other case (1.5°N, 27.5°W) shows a steady southerly flow that does not resemble anything found at any of the other stations. We cannot explain this flow. It is interesting to note that, at 405 m, the westward current appears to be concentrated at the Equator.

Figs. 2 a–e have been presented to illustrate the character of the current-meter records and to show the temporal changes that took place in the speed and direction of the flow at each station during the observational period. For the six-day stations, where the original records were read every ten minutes of recording time, the resultant speed and direction were computed for each one-hour period (six consecutive readings).

In some instances, the resultant direction was apparently changing steadily, and the six-day period of observation sampled the current in the course of a much longer term change. An example of this is the 80-m observation at 1.5°S, 27.5°W (Fig. 2 b). Had this flow been observed during another six-day period, the resultant direction might have been quite different.

On the other hand, some of the records show an impressive steadiness in both speed and direction and probably give a very reliable picture of the true current.

The six-day records are too short for resolution of any periodic fluctuation in speed or direction that is greater than six hours. Many of the records in Figs. 2 a–d, on visual inspection, appear to show a semidiurnal period in both speed and direction that can be assumed to be tidal. A spectral analysis of the 60-day records shows a marked 12.4-hour periodicity. This is approximately the same period as that found by M. O. Rinkel (personal communication) in current-speed measurements in April 1965 in the Undercurrent at 8°W at the Equator.

The picture of the Undercurrent outlined above is certainly far from complete. Limitations in time and equipment made it necessary to shift the current meters to new locations after brief intervals; thus the over-all picture is not synoptic, and most of the records are not long enough for demonstration of the presence or absence of the semidiurnal period such as that found in the longer records from other areas. On the other hand, the information derived from these records provides a convincing picture of a strong shallow eastward-flowing Undercurrent that has a velocity core with speeds of 70 cm/sec at or near the Equator and that is apparently closely associated with the high-salinity core. The records also indicate a westward flow of 25 cm/sec in the oxygen-minimum water below the Undercurrent.

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