Velocity Measurements in the Deep Water of the Western North Atlantic[1]

Summary

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In general our knowledge of the deep circulation of the ocean has been deduced indirectly either by a study of the geographical distribution of water masses represented by different temperature and salinity characteristics or by the use of the geostrophic equation. To obtain the pressure field needed in this equation requires, by present techniques, several days' work. Further, the performance of existing instruments precludes, in the face of extremely small pressure gradients, estimates of all but the larger scales of geostrophic motion. Velocities typically of the order of 1 cm/sec or less below a depth of 2000 meters in open ocean are suggested by the observations.

Direct observations with current meters of various types were reviewed by *Bowden* [1954], and for the whole Atlantic he is able to quote only 20 observations lasting from half a day to 4 days in the period 1910–1938. Again, the difficulties of building robust and sensitive instruments to be used from a buoy or drifting ship have limited the accuracy obtainable.

In recent years neutrally buoyant floats fitted with acoustic transmitters (analogous to constant level balloons) and developed originally by *Swallow* [1955] have yielded information in the Atlantic and Pacific on the amplitude and variability of the flow on scales not previously susceptible of observation. This paper is concerned with some aspects of a joint program of Woods Hole Oceanographic Institution and the National Institute of Oceanography, England, with Dr. J. C. Swallow leading the expedition, to observe with these floats the currents at great depth in a limited area and for a prolonged period.

Most observations were made over a 14-month period in 1959–1960 in a region of abyssal plain about 5000 meters deep and 200 miles west of Bermuda. Individual observations of a float determined its position to somewhat better than 0.2 mile, and the trajectory was generally followed for 4 to 10 days with one or more position fixes a day. To make the data as homogeneous as possible, attention was focused on two depths, 2000 and 4000 meters; even so, the total number of 72 trajectories is far too small to discuss the statistical structure of the velocity field in any detail.

Typical of the trajectories are those shown in Figure 1. They have with one exception only slight curvature, and, for example in the last series in August 1960, the fluctuations about a steady speed are barely detectable above the errors of observation. Speeds are of the order of 10 cm/sec, and direction is extremely variable from one series of trajectories to another. This is contrary to the widely held view that the deep ocean is relatively quiescent with velocities of the order of 1 cm/sec. There is a significant contrast between the variability of trajectories between one series and another and the steadiness of individual floats over a duration not much less than the interval between series. This suggests the possibility that the Lagrangian scale is noticeably larger than the Eulerian scale, although no definite figures can be stated at present. It is of interest that these high velocities in the open ocean are of the same order as those found by *Swallow and Worthington* [1961] below the Gulf Stream.

The last series of trajectories illustrates a fur-

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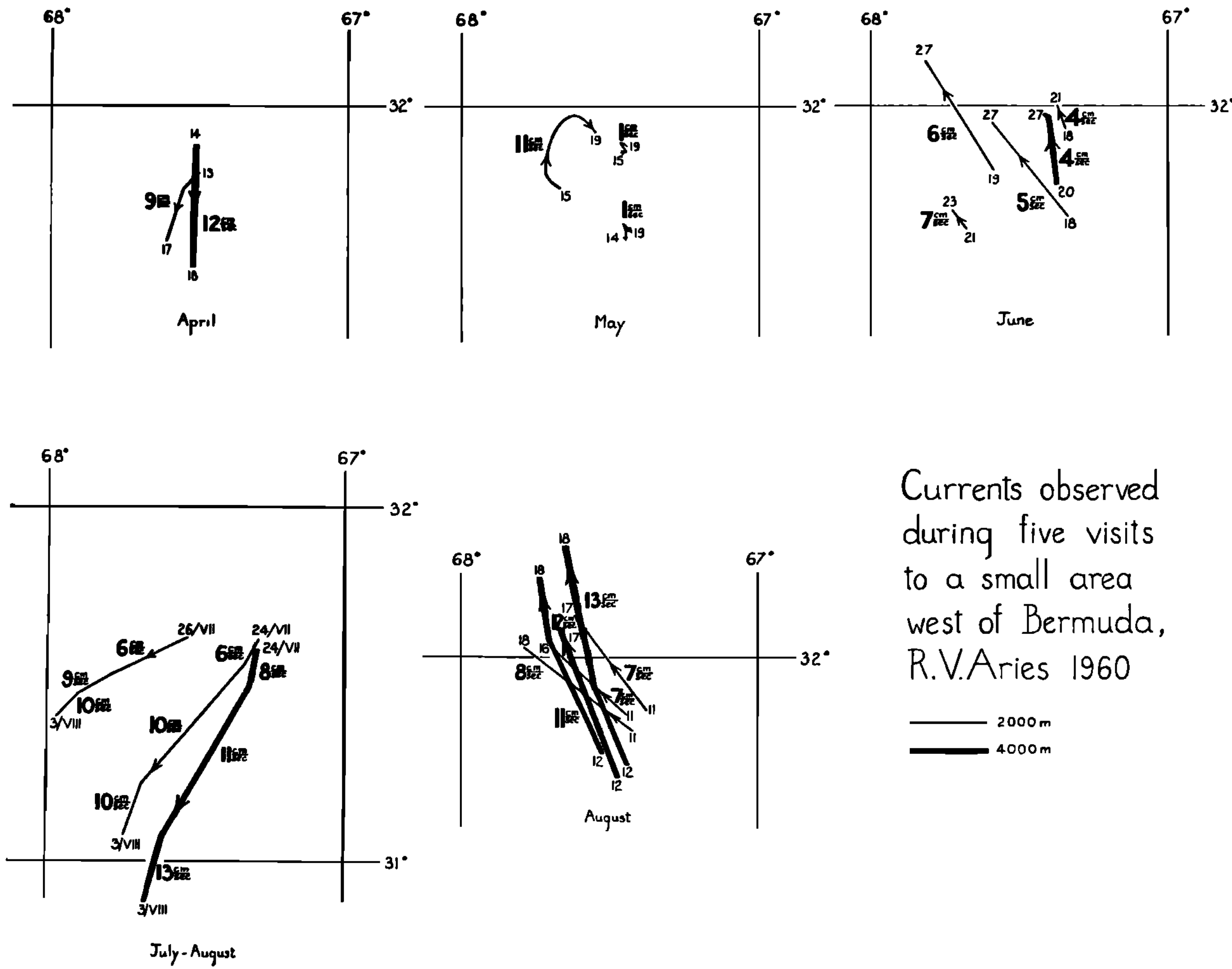

Fig. 1. Trajectories of five series of floats. Figures at ends of trajectory are starting and finishing dates. Figures beside trajectory are average speeds.

ther characteristic of the flow that was invariable over the duration of the measurements. Whenever there were simultaneous measurements on floats at 2000 meters vertically above one at 4000 meters, the deeper float moved in a direction closer to the meridian, and in all but one case its velocity was slightly greater. This preferred direction for the baroclinicity is unexplained.

Some information can be gained on the horizontal scales of the transient motions by considering the differences in velocity between pairs of trajectories at varying separations. In Figure 2 pairs of trajectories have been arranged in groups with separations 0–10, 10–20, 20–30, and 30–50 nautical miles. The mean value $\overline{\Delta V^2}$ for each group is the ordinate, where ΔV is the magnitude of the vector difference in velocity between two trajectories. There is apparently a large increase in the contribution to $\overline{\Delta V^2}$ in scales around 30 nautical miles. The last point on the curve at 40 nautical miles has a $\overline{\Delta V^2}$ equal to the mean square fluctuation in velocity of the individual tracks, suggesting that half the energy is contained in eddies up to 40 nautical miles in extent. This is a surprising result, and without further more extensive investigation it should be viewed with extreme caution in view of the limited data. (There are only six to ten pairs in each group.) There appears to be little in the way of external factors (e.g., depressions in the atmosphere or bottom topography) that would generate motions directly in these scales. Concerning this result it is of interest that an isolated identifiable water mass in the upper 1000 meters of water that drifted through the area and was some 80 nautical miles in extent drifted with a steady velocity for 2 months. This would be consistent with the view that most of the transient energy was on a scale less than the size of the water mass.

In an earlier paragraph the variability in direction from series to series was remarked on, but on even larger time scales the variability is still very noticeable. Over the whole 14-month period the velocity at 2000 meters was $2\frac{1}{2}$ cm/sec

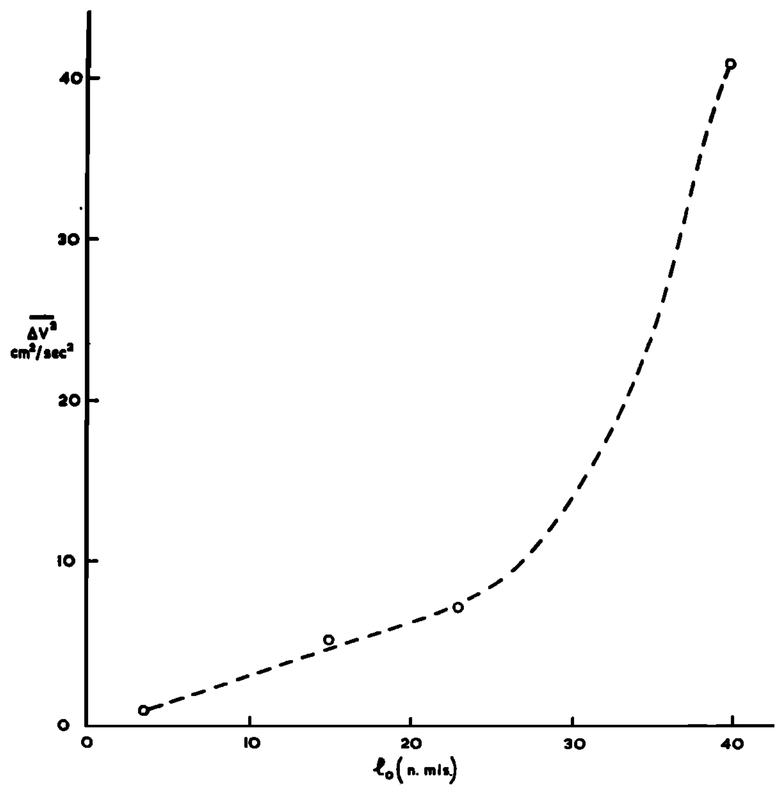

Fig. 2.

due west, but for the first and second halves of the period the directions were 30°–40° south and north of west respectively. It seems doubtful whether the figure of $2\frac{1}{2}$ cm/sec is representative of a long-term mean, and a far longer series of measurements would appear necessary to measure such a mean accurately. This raises the question of just how important the time-independent mean circulation is in the deep water of the open ocean compared with the eddy transport of properties by the transient motions.

References

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