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SEARS FOUNDATION FOR MARINE RESEARCH
Yale University

Journal of
Marine Research

Volume 30, Number 2

A Vertical Profile of Deep Horizontal Current Near Cape Lookout, North Carolina[1]

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ABSTRACT

The acoustic transit times for a float to sink to a bottom-anchored triangular array of disposable transponders are used to construct a horizontal current profile in the anticyclonic shear region of the Gulf Stream, southeast of Cape Lookout, North Carolina. The main features of the currents and temperatures, including the depth of the layer of no motion, are similar to those obtained by Swallow and Worthington (1961) 13 years earlier from a hydrographic section near this location. Fluctuations in the change of current with depth are small.

Introduction. Detailed measurements of horizontal currents as a function of depth in the deep ocean are practically nonexistent. Most velocity profiles, computed at a small number of depths by using the classical geostrophic method, do not reveal the large temporal variation in horizontal motions that take place as a function of depth (Pochapsky 1966). Rossby (1969) obtained vertical profiles of horizontal currents by using an existing anchored hydrophone array to

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[1] Accepted for publication and submitted to press 11 December 1971.

track a slowly sinking pinger, but such measurements can be made only over that array. We have been investigating profiles by using an instrumented float to communicate with an array of three disposable bottom-anchored transponders that can be installed at any location. The data from an experiment at a location where the western-boundary undercurrent flows under the Gulf Stream (33° 40′N, 75°W) are incomplete because of adverse weather, but they still contain information that is of sufficient interest to merit mention. The experiment also established the utility of the method, even under difficult conditions.

Experimental Procedure. The three coded transponders were anchored 15 m off the bottom in approximately 3550 m of water to form a triangular array; one leg was 1.4 miles long along 180° and another leg was 2 miles long along 118°. An instrumented float was launched just north of the eastern transponder, *C*, at 1815 h on 26 June 1970. Information on the methods and instrumentation has been published by Pochapsky (1966, 1969). As the float sank to the bottom, it not only transmitted its transit times to each of the transponders but reported its own temperature and pressure to the ship every 10.5 seconds. Winds and a noisy sea created difficulties. During its first 30 minutes of sinking, communication of the float with the array was erratic, and then, for 37 minutes, data acquisition was suspended while the drifting vessel was brought back over the array. During the remainder of the descent and for 10 minutes after the float reached bottom, data were received. (The time of descent, from launching until the float reached the bottom, was 3 hours 41 minutes). Unfortunately, at this point, bad weather forced us to leave the operating area and to abandon our plans to listen to the float as it returned.

Results. Temperatures and pressures were received alternately. A smooth quadratic fitted to the pressure data showed that the depth in meters of the sinking float could be expressed as

$$D(t) = -3 + 20t - 0.0184t^2, \tag{1}$$

where t is minutes from launch. The standard deviation of individual readings from this, ± 3.5 m, is equal to the standard deviation from a constant depth that was present in the data received during the time the float was resting on the bottom.

Plotted in Fig. 1 are one-minute averages of temperature versus depth together with discrete temperatures obtained 13 years earlier at R. V. ATLANTIS St. 5552 (33°N, 75°24′W) near the present location. The standard deviation about a constant temperature after the float had reached bottom was ± 0.004°C —a value approximately twice that expected from least-count considerations alone. The small temperature fluctuations have been expressed by subtracting individual determinations from a temperature, T_L, that decreases linearly with

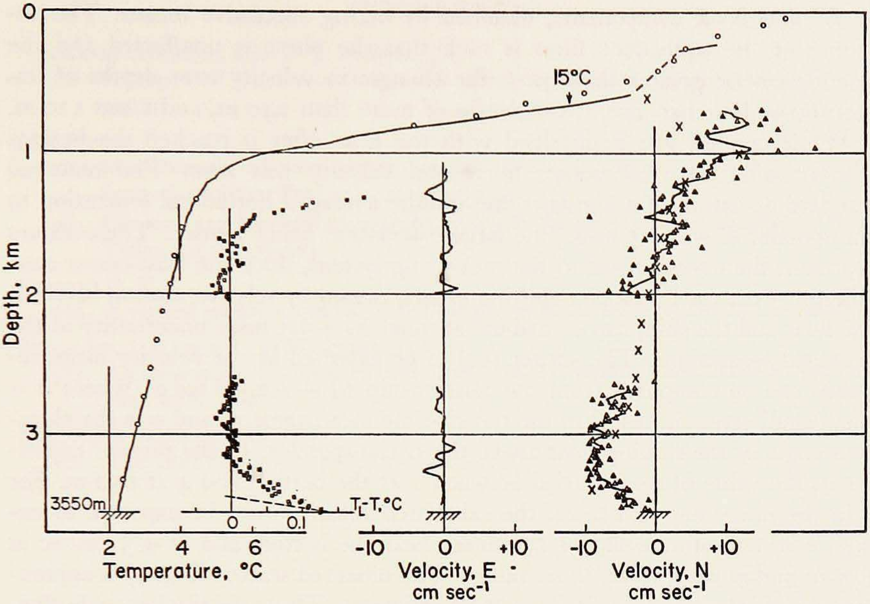

Figure 1. Temperature and velocity profiles. The solid line represents temperatures measured by the sinking float, the open circles are temperatures from Atlantis St. 5552, the open squares are temperature residuals, and the dashed line shows the slope that the residuals would follow if the water temperature increased adiabatically in the lowest 300 m. For the velocity, the solid curves represent the smoothed velocities, the open triangles the individual horizontal float velocities, and the large X's the velocities taken from Swallow and Worthington (1961).

depth by 1.07×10^{-3}°C/m. This difference, $T_L - T$, shown in Fig. 1 in an expanded temperature scale, reveals a significant change in the slope of the mid-depth temperature gradient below 3200 m.

The one-minute averaged transponder distances and the depths calculated from (1) were used to determine the horizontal ranges to each transponder as a function of time. Correction was made for changes in the velocity of sound. During the drop, the float moved back and forth along a line through transponder *C* in the direction 003°, with deviations of less than ±0.5°. Consequently, the separation velocity toward, or away from, that transponder could be used as an accurate measure of the *N–S* velocity component. The *E–W* velocity components were calculated from the radial velocities relative to *A* (the northwestern transponder), using the relationship $u = v_a - r_a \sin \bar{\theta}_a (\Delta\bar{\theta}_a / \Delta t)$, where v_a is the radial velocity, r_a is the horizontal distance from *A* to the float, and $\bar{\theta}_a$ is the smoothed angle between r_a and the *E–W* line through *A*.

In Fig. 1, the *N–S* velocity components are shown as discrete points plotted every minute (approximately every 15 m). The solid curves are the smoothed

E–W and *N–S* components, obtained by taking successive means. The response of the equivalent filter is such that the phase is unaffected and the attenuation is: greater than 90% for changes in velocity over depths of less than 60 m, less than 10% over depths of more than 240 m, and 1/e at 120 m.

While contact was maintained with the float after it reached the bottom (for 10 minutes), the average horizontal velocity was zero. The observed standard deviation of a constant one-minute averaged horizontal separation to transponder *C* was 0.5 msec, the largest deviation being 1 msec. These values represent the overall noise in the measuring system, since the least-count contributes ± 0.4 msec; doppler shifting errors, caused by relative motion between the float and the ship, can contribute as much as ± 0.5 msec uncertainty to the averaged separations. The scatter (v_s) to be expected in the velocity measurements can be computed from the relationship $v_s = \pm 2.5\, \delta \sec \varphi$, where δ = the overall error (in msec) in the transit-time measurement, and φ is the elevation angle of the sinking float above the *C* transponder. In the present experiment, the value of $\sec \varphi$ varied between 1 at the bottom and 4 at 650 m. For δ in the range 0.5 to 1 msec, the calculated velocities can be expected to exhibit a scatter of at least ± 1.25 cm/sec near the bottom and of ± 5 cm/sec at 650 m and at most twice these values. The observed scatter (Fig. 1) is approximately of the same magnitude as these estimates. Thus, the smaller-scale fluctuations in velocity in the directly measured profile may represent errors in measurement, and further investigation is desirable under more favourable conditions.

The velocities, averaged over about 60 m (represented by the solid curve in Fig. 1), show surprisingly small fluctuations with depth and compare remarkably well with results obtained by Swallow and Worthington (1961) for a section (denoted by crosses) made at the end of March 1957 about 40 miles upstream from the present position. However, the agreement may be somewhat fortuitous, considering that our velocity profile is derived from only a single drop. The depth of reversal or the layer of no motion is nearly the same, at about 1800 m, and falls within the range that is to be expected (1500 to 2000 m) in the anticyclonic shear region of the Gulf Stream (Neumann and Pierson 1966). The position of our drop, as indicated by the depth of the 15°C isotherm and the airborne thermometry data (U.S. Naval Oceanographic Office 1970), was just on the seaward edge of the Gulf Stream, which in turn was located approximately 95 km southeast of the northern edge. A velocity decrease and the change in slope of the mid-depth temperature gradient occur in the bottom 300 m. This may be a consequence of bottom topography, and further investigation is desirable.

Acknowledgments. We wish to thank Robert and Linda Bernstein for their help at sea and William Branscomb for the design of the electronic systems. This work was supported by the Office of Naval Research under Contract N00014-67-A-0108-011AA, Project No. NR 083-243.

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