Notes on the Surface Velocity Profile and Horizontal Shear across the Width of the Gulf Stream[1]

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Abstract

During a cruise across the Gulf Stream in October 1950 measurements of surface velocity were made both with the Loran-space-dead method and the electromagnetic method. A short account of the results is given with special reference to the velocity profile and the horizontal shear across the Gulf Stream.

The transverse surface velocity profile

In October, 1950, a short cruise was made across the Gulf Stream south of Cape Cod to observe the transverse surface velocity profile. Current velocities were observed by means of dynamic sections (Atlantic stations 4853 to 4865), the Loran space dead reckoning method, and the electromagnetic method (von Arx, 1950). A preliminary reconnaissance of the area revealed an anticyclonic bend which was then crossed repeatedly at nearly right angles to the flow. Some of the results, shown in Figure 1, disagree among themselves but suggest the narrow width and sharply peaked form of profile which seems possibly to be characteristic.

Disagreement among observations stems partly from the average error of Loran, which at a range of several hundred kilometers from the transmitters amounts to about $\pm$ 1 kilometer. This amount of uncertainty in the position of each hydrographic station and of the drift of the ship while on station in the strongest part of the current, leads to a relative error

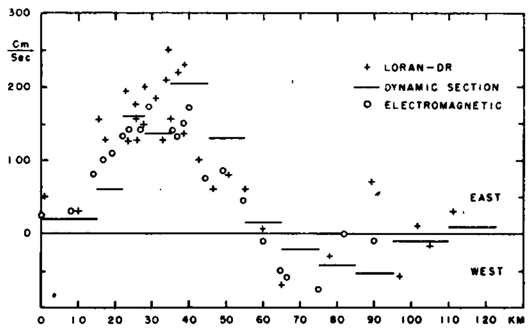

Fig. 1. Comparison of simultaneous measurements of surface velocity across the width of the Gulf Stream near the 69° W meridian, made by navigational, dynamic, and electromagnetic means. The area under a curve drawn through the eastward phase of each set of observations is 6.2, 6.0, and 5.4×10^8 cm²/sec., respectively. The dynamic observations were made and computed by Mr. L. V. Worthington. All observations made in October 1950 from R. V. Atlantis.

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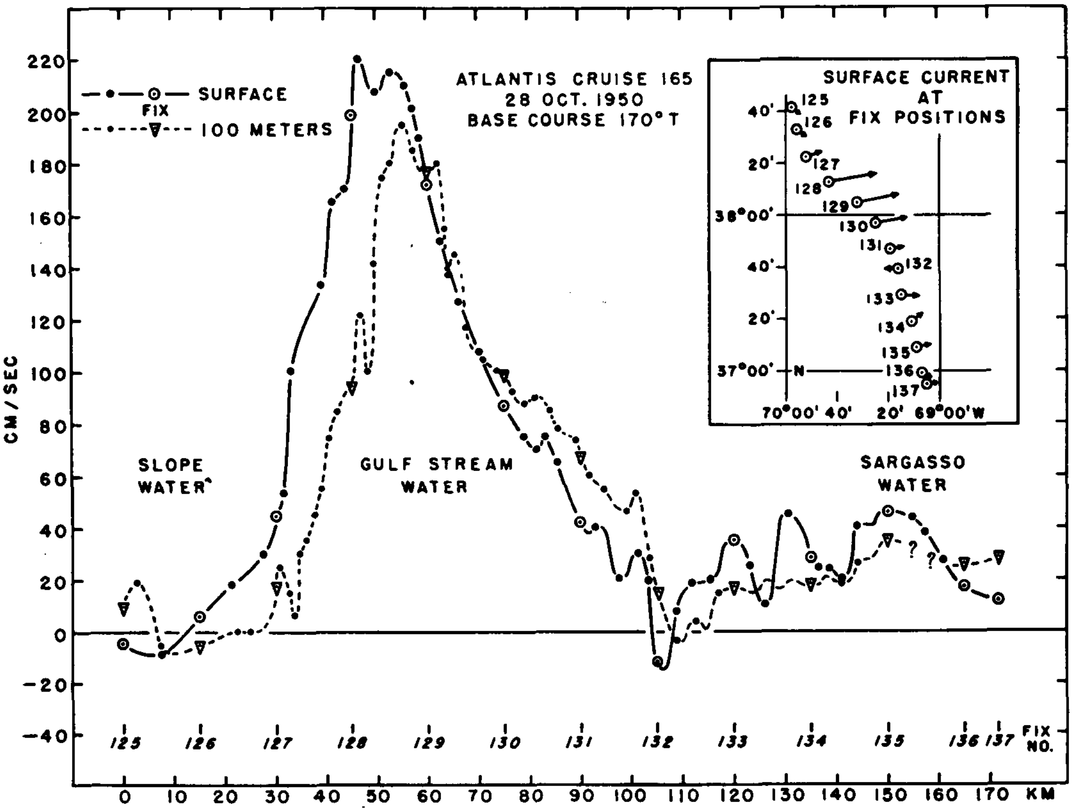
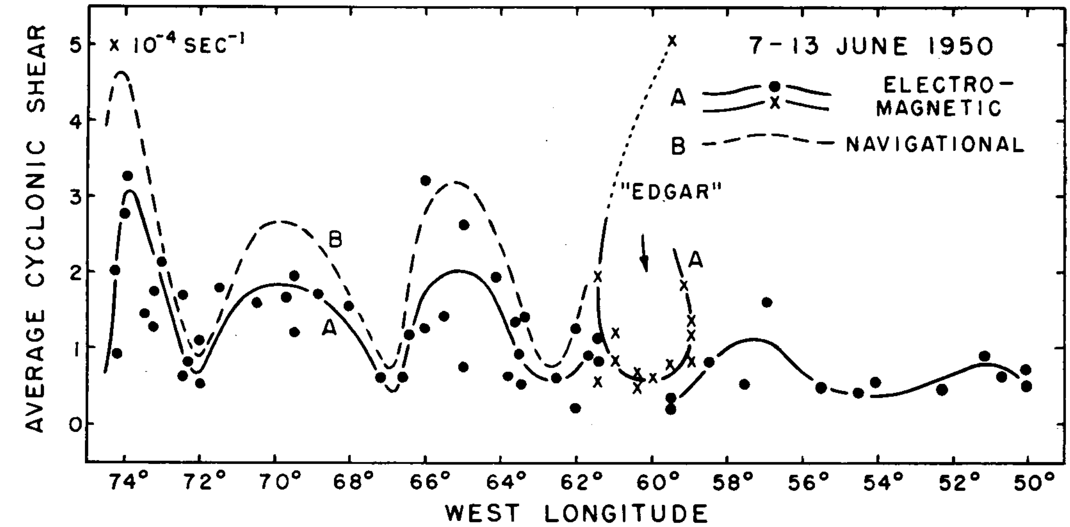


Fig. 2. Results of simultaneous electromagnetic measurements of the velocity at the surface and 100 meter levels. Open symbols denote points at which the direction of flow was measured. Closed symbols and the trend of the lines joining them denote the current speed at intermediate points assuming that the direction remained the same or changed uniformly between fixes of direction. The abscissa was taken at right angles to the direction of flow at fixes 128 and 129. The ordinates shown are 23 per cent less than the average of navigational measurements of current speed.

in the distance between stations 5 km apart perhaps as great as 20 or 30 percent. Similarly the errors of Loran and dead reckoning for navigational current measurements made on an hourly basis, may approach 50 cm/sec and become proportionally larger as the time interval is decreased. Measurements of surface current by the electromagnetic method are reduced in magnitude when the current structure extends downward through more than a negligible fraction of the total depth of water (STOMMEL 1948; MALKUS and STERN 1952). In that the current structure of the Gulf Stream may extend a kilometer or more below the surface, and the loss of signal strength is roughly proportional to the ratio of the depth of quiet water below the current to the total depth, decrements as great as 40 percent are sometimes encountered in the Gulf Stream off the New England coast.

In the face of these uncertainties it has been necessary to counteract the limitations of one method with the advantages of another. In fine weather the evidence of navigation is a useful index of surface motion, but the method lacks resolving power. The electromagnetic method will indicate direction of flow and detailed changes in one component of motion, but requires calibration in magnitude. Both methods can be used underway.

Figure 2 shows the uncorrected results of electromagnetic sections made simultaneously at the surface and 100 meter levels. Navigational measurements made on the same traverse indicate that the electromagnetic measurements of surface current speed averaged 23



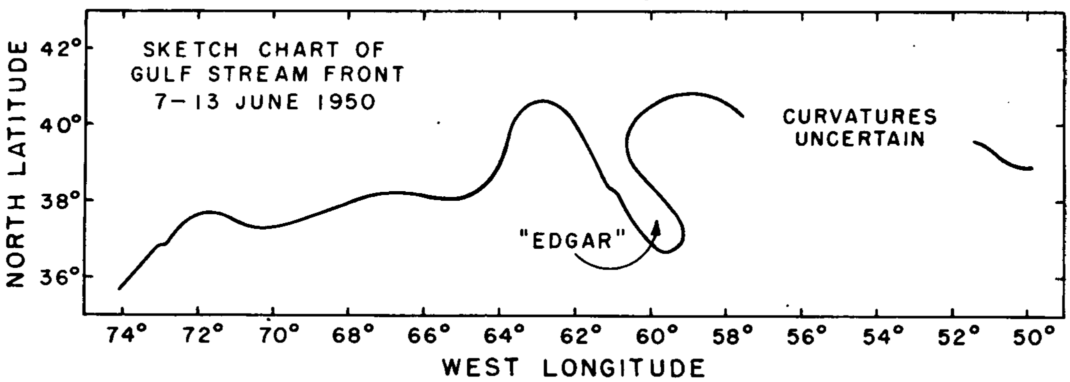


Fig. 3. Comparison of the intensity of cyclonic shear (between the Gulf Stream front and the current maximum) with the curvature of the front. Curves A and B in the upper frame represent the smoothed results of electromagnetic and navigational measurements of shear, respectively. The chart of the position of the Gulf Stream front in the lower frame was made from measurements of the greatest change of average temperature in the upper 200 meter layer. "Edgar" is a deep cyclonic bend that was observed to detach from the main current. Within this feature navigational measurements of shear were 1.7 times greater than electromagnetic measurements.

percent too small. Nevertheless a sharply peaked distribution of velocity across the current seems evident. The similar pattern of motion at the 100 meter level was displaced to the right of the surface profile along a seaward slope of approximately 1/80. The horizontal normal shear on either side of the current maximum was asymmetrical.

Horizontal shear

Data obtained during the multiple ship survey of the Gulf Stream of 1950 (FUGLISTER and WORTHINGTON, 1951) made possible a study of the change of the intensity of horizontal shear along the meandering current. The intensity of shear was first evaluated from a comparison of Loran and dead reckoning navigation, and then corrected for the local obliquity of the traverse to the direction of flow as indicated by electromagnetic measurements. In order that the curvature of flow might be neglected, the shear was evaluated and corrected for the obliquity of traverse to the direction of flow in increments of one or two hour's run.

It was found that the average intensity of horizontal shear normal to the flow on the right of the current maximum was equal to or less than the Coriolis parameter, while the average values of cyclonic shear on the left were equal to or greater than this. Such asymmetry of shear has been suggested from theory by HAURWITZ and PANOFSKY (1950).

These data from the multiple ship survey also show that the intensity of cyclonic shear on the left of the current maximum varies systematically with the sense of curvature of flow. Greater than average intensities seemed to be associated with cyclonic curvatures, while less than average intensities seemed to occur where the sense of curvature was anticyclonic. Due to the unsuitable distribution of observations, it was not possible to test for a similar correspondence of curvature with the intensity of anticyclonic shear on the right of the current maximum, or for the persistance of a seaward counter current.

In Figure 3 the upper frame contains the measurements of horizontal cyclonic shear, and the lower frame a schematic chart of the curvatures of the Gulf Stream front during the period when these observations were made. It can be seen from a comparison of the curves in the upper and lower frames that the intensity of shear does not seem to depend on the length of the radius of curvature of flow. The points through which curve A was drawn represent electromagnetic measurements of shear, and curve B represents the smoothed result of the navigational measurements. There is a systematic increase in the proportion of disagreement between the electromagnetic and navigational estimates of shear in the vicinity of cyclonic curvatures which suggests that the current extends to greater depths in the vicinity of cyclonic curvatures. Such an interpretation is consistent with an increase in cyclonic shear since vertical stretching and horizontal convergence of the flow in cyclonic curvatures would result in increased cyclonic vorticity on the left of the current maximum. There is some evidence that the current maximum itself shifts toward the left as well as that surface current speeds are a little higher in cyclonic curvatures of flow.

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