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A Comparison of Direct and Electric-current Measurements in the Florida Current[1]

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ABSTRACT

Simultaneous measurements of surface velocity obtained in 1967 by means of geomagnetic electrokinetograph and free-instrument techniques aboard two ships in the Florida Current off Ft. Pierce, Florida have been compared. The results show a varying degree of agreement in magnitude across the stream and good agreement in direction. A surprising result is the high seabed conductance.

Introduction. The many interfering influences that may affect the measurement of ocean currents by means of the geomagnetic electrokinetograph (GEK) have been discussed by Longuet-Higgins et al. (1954). Previous attempts to assess the magnitude of the errors have been based mainly on a comparison of data from ship drifts and GEK readings. These comparisons are usually not satisfactory because the drift cannot be determined with the required accuracy; or, where accuracy at the end of a transect is available, only an average value is obtained (cf. Hela and Wagner 1954).

This is a report on a two-ship study of the Florida Current off Ft. Pierce, Florida, the express purpose of which has been to collect data for a point-by-point cross-stream comparison of direct and electrical surface-current measurements. The ships were the GULF STREAM (Nova University) and the U.S.C. & G.S. Ship PEIRCE.

Measurements. Two transects of the Florida Current (Fig. 1) were made: the first between 1300 hr and 1940 hr on June 14, the second between 1950 hr on June 14 and 0320 hr on June 15, 1967.[4] The winds were variable and
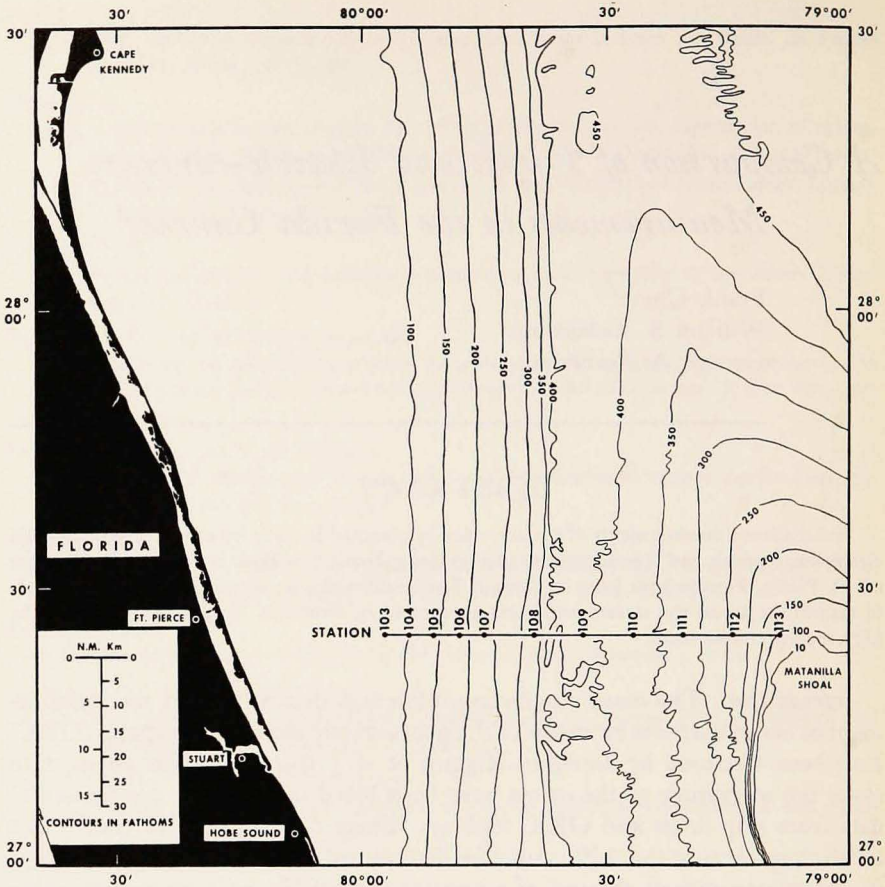

Figure 1. Location of the section and stations.

generally less than 10 knots. The synchronized but separate measurements of the current were made at the same cross-stream positions; however, to avoid possible intereference with the reception of HiFix navigation signals on board the GULF STREAM, the northern limits of the stations occupied by the PEIRCE were 500 m upstream of the southern limits of the stations occupied by the GULF STREAM.

The sailing plan of the PEIRCE for GEK measurements was similar to one that von Arx (1950) called A 2, with the difference that, at course changes, the ship always passed to the starboard to minimize the effect of the cross-stream velocity gradient on the downstream component of the measurement. The base course was directed east-west, with each leg on the fix course varying from 2 to 3 km, depending on the rapidity with which the GEK signal ap-

Table I.

Sta. No.	Cross-stream dist. km	Surface current Dir. meas. Magn. (cm/sec)	(V_s) Dir. (°T)	GEK (V_G) Magn. (cm/sec)	Dir. (°T)	k factor $\|\vec{V_s}\|/\|\vec{V_G}\|$	Surface current, N. component Dir. meas. (V_s) (cm/sec)	GEK (V_g) (cm/sec)	N. comp. of av. curr. of water col. $(\bar{V})$ (cm/sec)	m factor $(V_s-V_g)/\bar{V}$	Direction; dir. meas. minus GEK (°)
103......	0	134	345	136	352	1.0	129	135	64	0	−7
104......	5	161	350	165	348	1.0	158	161	64	0	2
105......	10	160	348	155	350	1.0	157	153	91	.04	−2
106......	15	160	349	143	352	1.1	157	142	95	.16	−3
107......	20	155	351	131	355	1.2	153	130	101	.23	−4
108......	30	149	358	96	359	1.6	149	96	111	.48	−1
109......	40	97	351	51	348	1.9	96	50	105	.44	3
110......	50	70	332	25	344	2.8	62	24	93	.41	−12
111......	60	55	352	23	329	2.4	54	20	62	.55	23
112......	70	37	329	23	326	1.6	30	19	50	.22	3
113......	80	7	045	11	045	1.0	5	8	14	0	0
112......	70	48	339	19	325	2.5	45	16	36	.80	14
111......	60	59	348	35	352	1.7	58	35	63	.37	−4
110......	50	98	342	51	342	1.9	93	48	92	.49	0
109......	40	103	338	67	345	1.5	95	65	88	.34	−7
108......	30	−	−	103	351	−	−	102	−	−	−
107......	20	−	−	127	360	−	−	127	−	−	−
106......	15	194	360	178	001	1.1	194	178	116	.14	−1
105......	10	190	001	193	357	1.0	190	193	23	0	4
104......	5	171	359	142	001	1.2	171	142	13	0	−2

proached a consistent steady trace on the recorder. Thus, a complete GEK measurement of four legs took about 15 minutes. The free-drop instrument technique employed on board the GULF STREAM has been described by Richardson and Schmitz (1965). Generally, about 5 minutes were necessary for a determination of the surface velocity; for the current averaged over the whole water column, 5 to 25 minutes were required, depending on the water depth.

Table I summarizes the results of the experiment and Fig. 2 shows the cross-stream profiles of the northward components of the quantities measured. For simplicity, only the results of the west-to-east transect are shown.

There are two interesting features in the profiles of the direct measurements. First, in Fig. 2 there is the negative portion of the $(v_S - \bar{v})$ curve at the eastern stations where the northward component of the average current of the water column $(\bar{v})$ exceeded the directly measured northward component of the surface current (v_S). This is a somewhat atypical situation; $\bar{v}$ appears to be about like the average values given by Richardson et al. (1969), but v_S is significantly lower than their average in this region. Second, Table I shows the profile of v_S changing from one that has a relatively flat speed axis and a low speed on the far anticyclonic flank on the first transect to one of peaked axis and faster eastern flank on the return transect. Also, there are two features in the profiles for the surface current as measured by the GEK (v_G): (i) the sign and magnitude of v_G are always positive and larger than $(v_S - \bar{v})$; (ii) the profile change between the two GEK transects is qualitatively in the same sense as the change in the dropsonde profiles. The general agreement in the directions of the measurements of the surface stream (last column of Table I) and the similarity in the relative change in the two sets of profiles between transects assures us of the consistency of the measurements as well as the reality of the changes in the current.

The k-correction Factor. For the purpose of reducing the GEK data, von Arx (1950) has suggested the use of a k factor, which is defined as the ratio of the actual speed of the water to the speed indicated by the GEK. For the present data, k is listed in column 7 of Table I. At Sts. 103, 104, 113, and 105 (on the return transect), the current recorded by the GEK exceeded the current that was directly measured. However, because the direct-measurement and GEK stations were somewhat separated, the small differences can be reasonably ascribed to spatial changes. Hence, for these four stations we have taken k as unity.

The values of the k factor range from values near one at both sides of the stream to a high of 2.8 near the deepest part of the channel. Where k is the largest, the directional discrepancy is also the largest. The pattern of cross-stream variation in k (Fig. 3) is similar for both transects, but there is a numerical difference that may be significant where knowledge of the cross-stream gradient of velocity is desired.
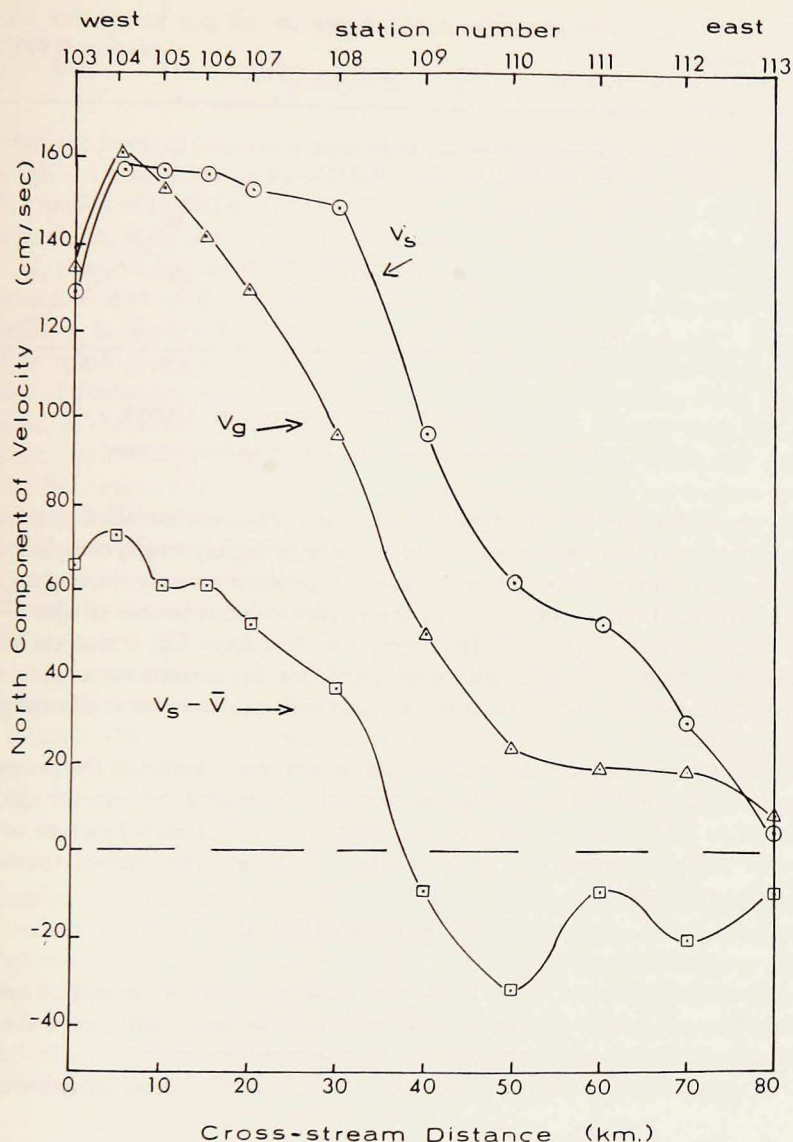
Figure 2. The cross-stream profiles of the northern (downstream) component of the directly measured surface velocity, v_S, the surface velocity from the GEK, v_G, and the difference between v_S and $\bar{v}$, the averaged velocity from surface to bottom (first transect only).

Seabed Conductivity. Our transects of the current were close to where the channel begins to broaden out downstream (Fig. 1). If the structure of the Florida Current is not significantly affected by this broadening, then completion
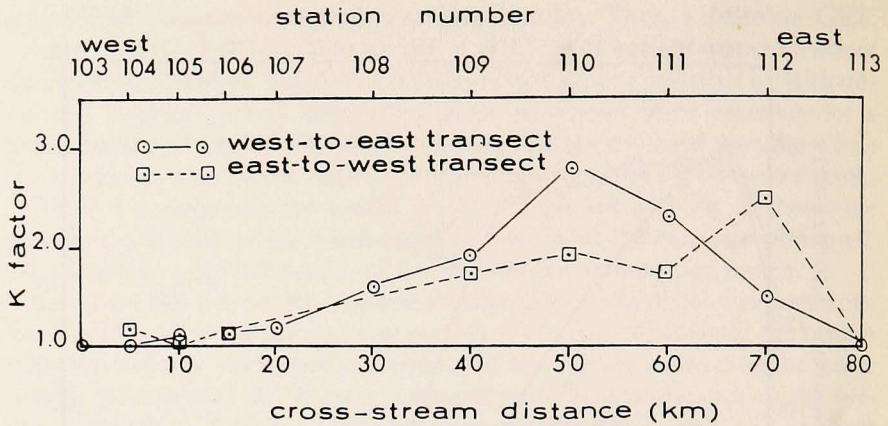
station   number

Figure 3. The cross-stream profile of the *k* factor for both transects.

of the circuit for the flow of an induced electric current is controlled principally
by two factors. When the seabed conductivity is negligibly small, completion of
the circuit is wholly within the water and is dependent on only the mean speed
of the stream. In this circumstance, the northward component of the GEK
signal, v_G, is given by $(v_S - \bar{v})$. However, it is clear from Fig. 2 that v_G differs
considerably from $(v_S - \bar{v})$ in magnitude, and, for the eastern stations, in sign
also. We conclude, therefore, that the seabed conductivity is not at all negligible
in this region.

In terms of the equivalent electric-circuit analogy considered by Longuet-
Higgins et al., significant conduction through the seabed reduces the electric
effect of *v*. The reduction may be expressed in terms of *m*, a function of the
internal seawater resistance (rS/h) relative to the external seabed resistance
$(r'S/H)$, as follows:

$$m = \{1 + (rS/h)/(r'S/H)\}^{-1}; \qquad (1)$$

here *r* and *r'* are, respectively, the electric resistivity of seawater and of seabed,
h and *H* are, respectively, the stream depth and the depth into the seabed to
which the electric current spreads, and *S* is the stream width.

The last column in Table I tabulates the values of *m* computed from

$$m = (v_S - v_G)/\bar{v}, \qquad (2)$$

with the requirement that $0 < m < 1$. As in the computation for the *k* factor,
v_G is taken equal to v_S at Sts. 103, 104, and 113 on the first transect. The cross-
stream pattern of *m* is one of higher seabed conductance along the edges of the
stream. Again, like the *k* factor, *m* varies considerably in the two transects (see,
for instance, St. 112). Considering only the first transect, we find a cross-

stream average of 0.4 for m, weighted according to station spacing. Hence, from (1) we have

$$(rS/h)/(r'S/H) = 1.5, \tag{3}$$

or, that the internal resistance through the seawater and the external resistance through the seabed are of comparable importance.

For the Florida Current off Ft. Pierce, the ratio of the stream width, S, to stream depth, h, is about 200. If, following Longuet-Higgins et al., we take $S = H$, then, on the average, the ratio (r/r') of the electrical resistivity of the seawater to that of the seabed is about 7 times larger than the ratio that is thought to be applicable to the English Channel.

The result given in (3) is supported by voltage measurements obtained by means of stationary electrodes across the Florida Current from Palm Beach, Florida, to the Little Bahamas Bank (Thomas Sanford, Woods Hole Oceanographic Institution, personal communication). On the other hand, the voltage recordings obtained from stationary electrodes placed on the sea bottom at 3.0 and 8.5 nautical miles east of Fowey Rocks off Miami, Florida, indicate otherwise. The voltage recorded continuously from 5 May to 17 November 1969 required, on the average, only a 5% correction for seabed conduction to bring the voltage-indicated transport of the section to the mean transport values given by Schmitz and Richardson (1966) (Harry DeFarrari, University of Miami, personal communication). The small correction required for data off Miami supports the premise of Chew's (1967) estimate of the cross-stream variation in the k factor. Off Miami, the ratio of stream width to stream depth is about 130 —not much different from the corresponding ratio off Ft. Pierce. The large change in seabed conductance over the 200-km distance from Miami to Ft. Pierce is surprising.

Conclusion. The correction required for the GEK measurement of the surface velocity of the Florida Current off Ft. Pierce varies from 0 in the shallower waters to a factor of 2.8 in the deeper portion of the channel. Moreover, the k factor is not locally constant, but varies significantly over a period of a few hours. The situation is further complicated by the surprisingly high seabed electrical conductivity, so that even the trend of correction cannot be extended to other segments of the Current.

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