

*NOTE ON THE COUNTERCURRENT IN THE YUCATAN CHANNEL
AND THE WESTERN CAYMAN SEA*

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RESUMEN

En Agosto de 1971 se llevaron a cabo observaciones de corrientes en el Canal de Yucatán y en la parte nor-occidental del Mar Caimán, mediante electrokinetógrafo geomagnético, a bordo del Buque Oceanográfico "Cadete Virgilio Uribe", de la Armada de México. Estas observaciones indicaron una corriente de considerable intensidad hacia el sur en la mitad oriental del canal, extendiéndose a la Isla Gran Caimán. La existencia de esta corriente también fue demostrada por la topografía dinámica basada en observaciones hidrográficas realizadas simultáneamente en el área. Las estimaciones mediante un modelo de dos capas con vorticidad potencial uniforme sin fricción, indican que la conservación de vorticidad podría explicar, por lo menos en parte, la contracorriente observada.

ABSTRACT

In August 1971, current observations by means of geomagnetic electrokinetograph were made in the Yucatan Channel and the western Cayman Sea aboard the research vessel "Cadete Virgilio Uribe" of the Mexican Navy. These measurements indicated a south-flowing current of considerable strength in the eastern half of the channel, extending towards the Gran Cayman Island. The existence of this current was also shown by the dynamic topography based on simultaneous hydrographic observations in the area. Estimates based on a two-layer frictionless model with uniform potential vorticity indicate that conservation of vorticity can, at least in part, account for the observed countercurrent.

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INTRODUCCION

Along the borders of the western boundary currents, such as the Gulf Stream and Kuroshio, currents running in the opposite direction are frequently observed. In some cases such counter movements are a permanent or seasonal feature of the current system while in others, their occurrence is apparently occasional.

In the American Mediterranean, the Caribbean Current constitutes part of the North Atlantic western boundary current system. This current flows along the Caribbean proper and enters the Cayman Sea near the Honduras Bank. According to Wüst (1964) and other sources, the velocity of the main current is about 2 knots in July-August. Approaching the Yucatan Channel the current accelerates to 3-4 knots.

This aspect seems to be, indeed, about the only point to which all current charts and descriptions agree (Emilsson, 1971). Near the Cuban side of the Yucatan Channel most authors indicate a narrow countercurrent setting to the south just off Cabo San Antonio and turning to the east along the border of the Cuban south-west shelf. This current may be considered a continuation of the counter flow that can be observed, especially during the summer season, off the north-west coast of Cuba.

This uncertainty regarding the water movement outside the main axis of the Caribbean current is in part due to lack of direct current observations and other relevant data, and also due to the instability of the lateral systems as well as the effects from the adjacent areas such as the Gulf of Mexico, to the north, and the Atlantic and the Caribbean proper to the east and to the south.

During the month of August 1971 the research vessel "Cadete Virgilio Uribe" of the Mexican Navy carried out G.E.K. current observations in the Yucatan Channel and the north-western Cayman Sea. This work was a part of the first simultaneous oceanographic survey operations of C.I.C.A.R.¹. Besides the G.E.K. observations normal hydrocasts to the depth of the bottom or to the 1,500 m level, whichever was smaller, were made on all stations (Fig. 1).

On account of cable break and short-circuiting of the electrodes, reliable G.E.K. data from the southern portion of the area covered by this cruise could not be obtained. The arrows presented on Fig. 2 indicate the direction of the current. If the current factor k (von

¹ Cooperative Investigations of the Caribbean and Adjacent Regions.

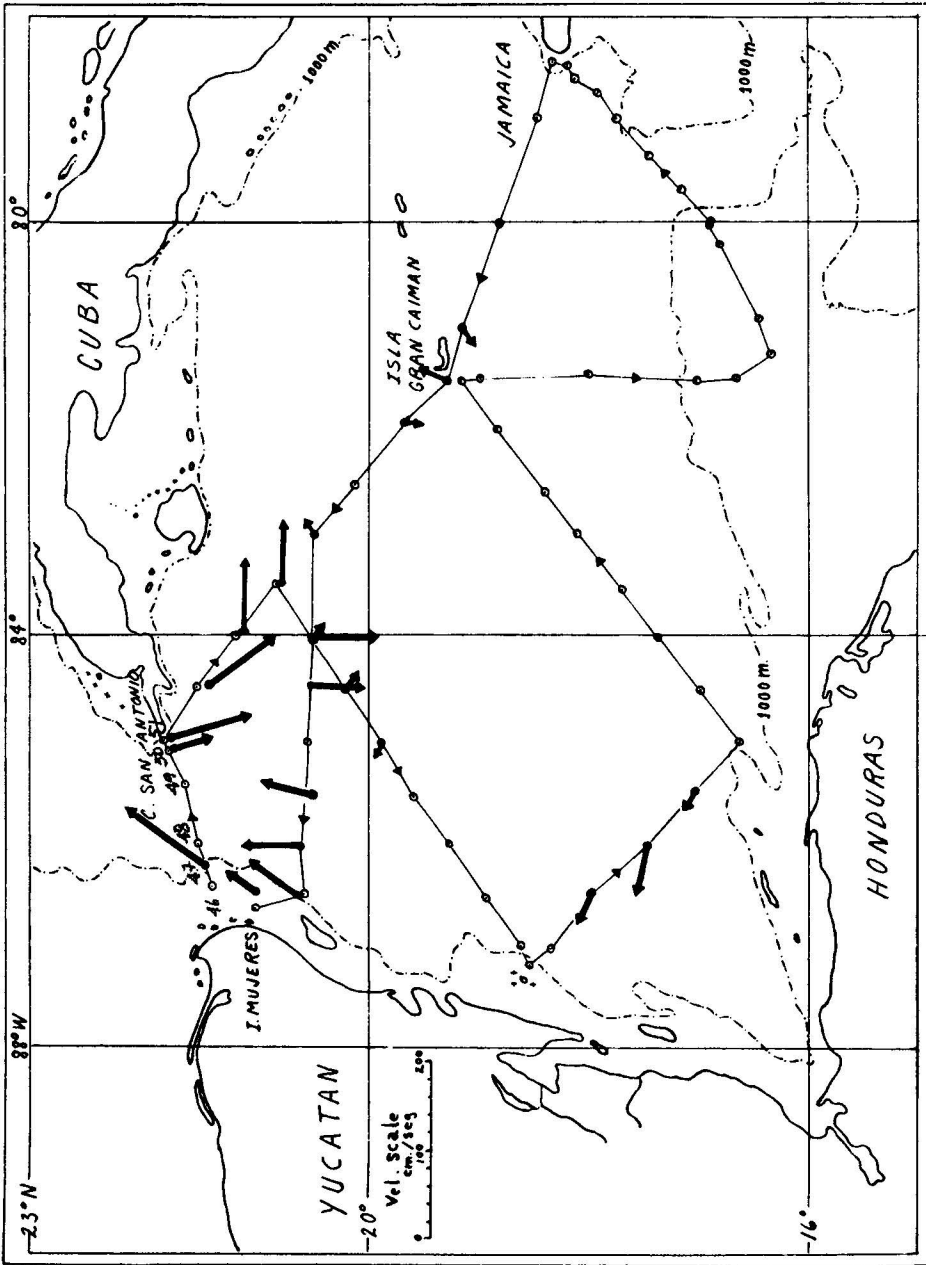


Figure 1. The route and station positions of R. V. "Cadete Virgilio Uribe" from August 15 to 28, 1971. The arrows represent the direction and speed ($k = 1$) of the observed G.E.K. current.

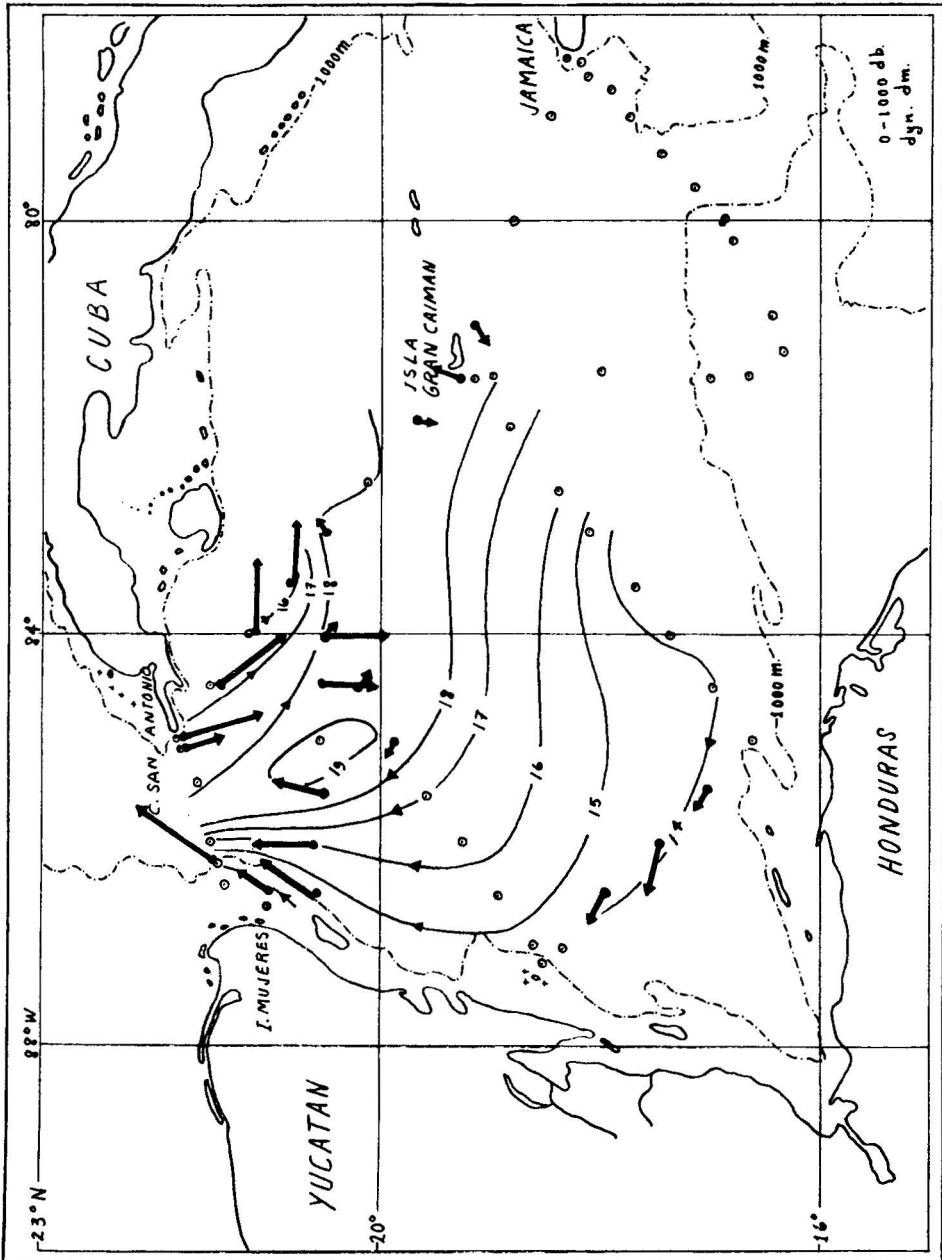


Figure 2. Geopotential topography of the sea surface, in dynamic decimetres, relative to the 1,000-decibars surface. Arrowheads on depth contours indicate the direction of the relative geostrophic current. Superimposed arrows represent the G.E.K. current from Fig. 1.

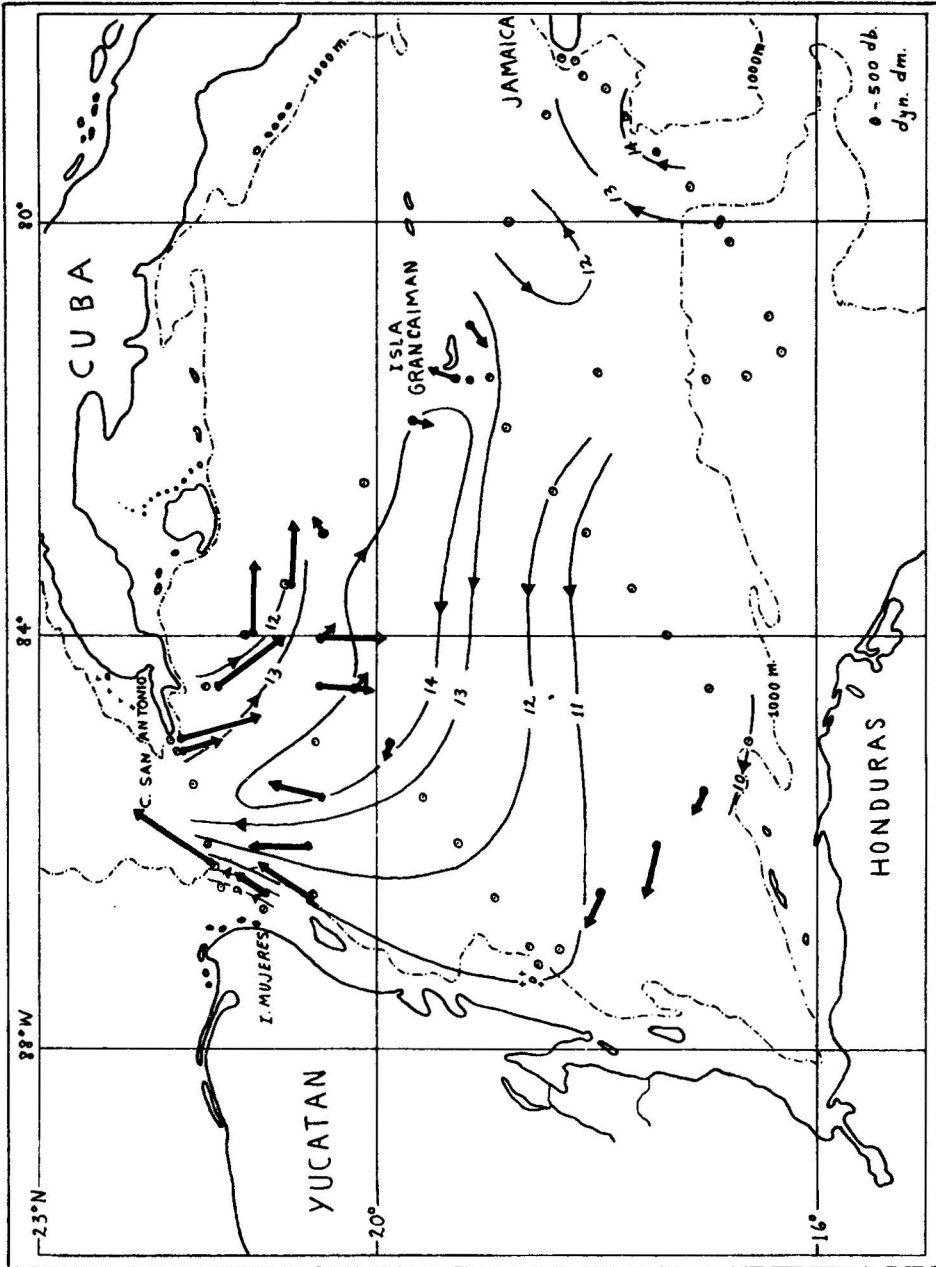


Figure 3. Geopotential topography of the sea surface relative to the 500-decibar surface. See legend of Figure 2.

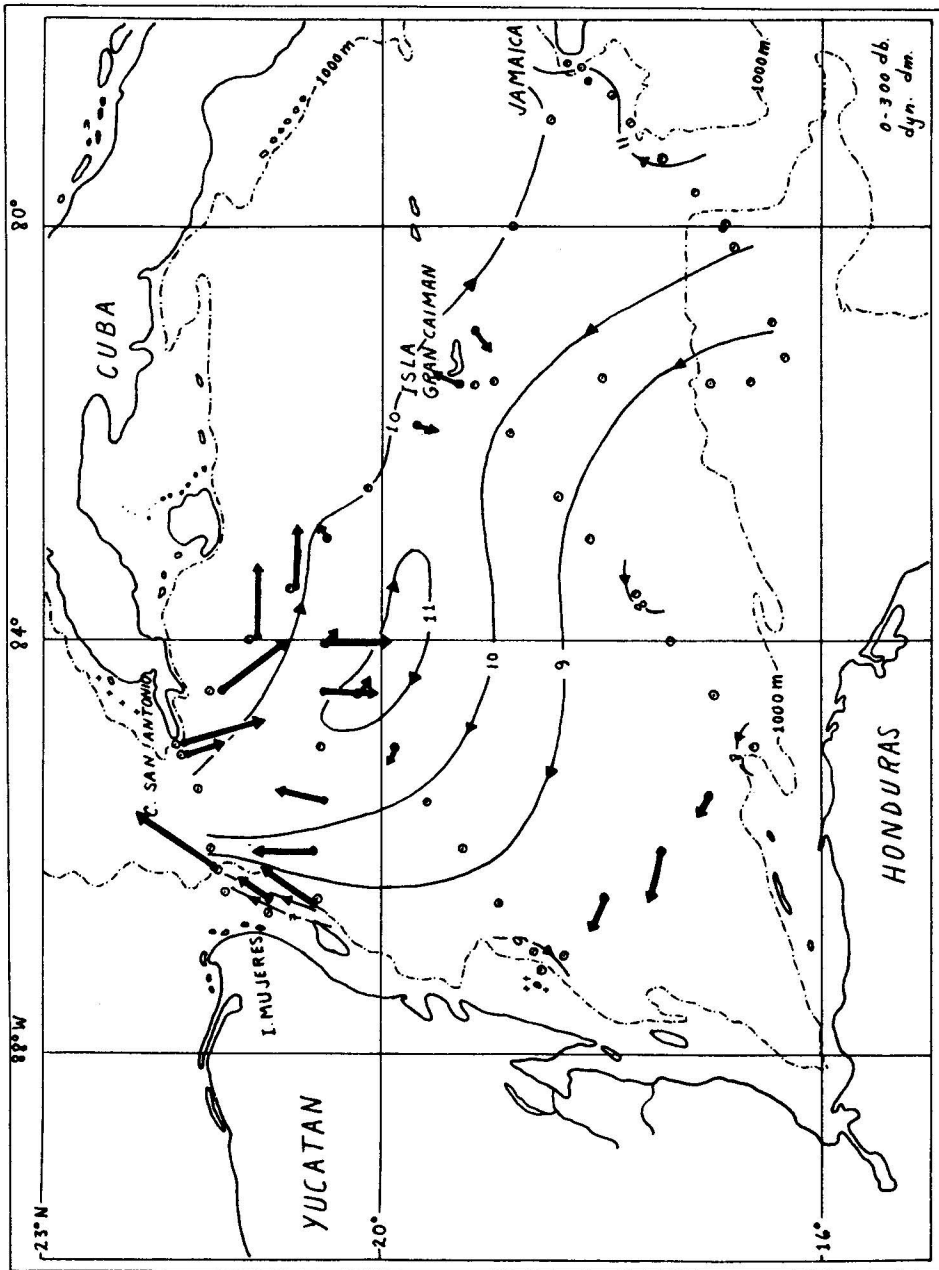


Figure 4. Geopotential topography of the sea surface relative to the 300-decibar surface. See legend of Figure 2.

Arx, 1950) is equal to 1, the length of the arrows represent the speed of the current in cm/seg.

As could be expected, in the western half of the Yucatan Channel the north-flowing Yucatan current was observed, having its main axis near the outer edge of the shelf. However, midway across the channel the current disappeared, and, in the eastern half a current setting southward with a considerable intensity was observed. The measurements farther to the south indicated that this flow continued to the south and south-east towards the Gran Cayman Island.

The occurrence of a countercurrent of such extension and intensity in this area as well as its possible cause is the subject of the present study.

COMPARISON OF THE G.E.K. AND THE DYNAMIC OBSERVATIONS

In order to establish the existence of the countercurrent we have compared the results of the G.E.K. observations with the relative geostrophic current based on the hydrographic data obtained on the same occasion.

Fig. 3 shows the geopotential topography of the sea surface in relation to the 1,000 db isobaric surface. The dynamic contours represent also the streamlines of the relative geostrophic current. The superimposed arrows indicate the G.E.K. observation from Fig. 2. In the areas outside the main current, there is a good agreement between the direction and velocity obtained by the two methods. Along the current axis, however, the direction of the G.E.K. current deviates some 20° to the right in relation to the geostrophic current, suggesting that the main current is crossing the dynamic contours on its way towards the Yucatan Channel. This aspect was pointed out by Parr (1937) by comparing the direction of the geostrophic current with the surface current charts of the time.

The geopotential topography of the surface relative to the 500 db, shown on Fig. 4, presents similar features, which may be interpreted as indicating that the main transport occurs above 500 m depth. On the other hand, the topography of the surface relative to the 300 db is less accentuated suggesting that the main moving layer reaches deeper than 300 m.

THE POSSIBLE ORIGIN OF THE COUNTERCURRENT

As a countercurrent of such intensity and extension has apparently

not been observed before in this area, one may speculate on its causes and ask whether we are confronted with a permanent, seasonal or accidental phenomenon. A possible cause of the current fluctuation in the area may be found in the variation of the atmospheric pressure field giving rise to a readjustment of the sea level in the Cayman Sea in relation to adjacent areas; such a readjustment, due to its barotropic nature, will in first instance affect uniformly the entire current system.

Thus, the relative current at different points in the Yucatan Channel should remain unchangeable. Another cause could be found in the varying wind field which in certain situations may give rise to the return into the Cayman Sea of waters transported northward by the Yucatan Current and that, normally, would be compensated by an outflow through the Florida Straits. On the other hand, should further investigations reveal that this countercurrent is a permanent part of the current system in the Cayman Sea, its existence must be based on the general structure of the western boundary current.

To account for such currents many mathematical and physical models have been constructed. Since most of these models involve equations that omit the inertial terms, it is necessary to give an unrealistic importance to the lateral friction in order to obtain a stable system. There can be little doubt, however, that in the case of the Yucatan Current the inertial terms play an important role in view of the increase in velocity as the water passes through the channel.

Stommel (1955) has shown that the cross-stream velocity distribution at the right hand side of the Gulf Stream can be remarkably well accounted for by a frictionless two-layer model with a uniform potential vorticity. Due to its simplicity it is interesting to apply a similar procedure to explain the countercurrent in the Yucatan Channel area.

The equation expressing the conservation of potential vorticity in a water column of thickness h , when frictional effects are omitted, is

$$\frac{\zeta + f}{h} = \text{const} \quad (1)$$

Where $\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$ is the relative vorticity, and f the Coriolis parameter.

We take, as usual, the x-axis and the y-axis pointing to the east and north, respectively, and let u and v be the corresponding components of velocity. In the case of the Yucatan Channel, the east component u can be taken as zero, so equation (1) takes the form

$$\frac{\partial v}{\partial x} + \frac{f}{h} = \text{const} \quad (2)$$

To estimate the thickness of the upper layer many criteria are at hand. The depth of the subtropical salinity maximum could be used if we had means to determine it within sufficiently narrow limits. This is unfortunately not the case, since the salinity maximum can easily fall between two sampling points, 50 m apart, in the vertical. Instead we have chosen the depth of the 36‰ isohaline below the salinity maximum to represent the lower limit of the upper layer. The depth of this isohaline varies from some 180 m on station 46 near the western side to 460 m at station 50 at the eastern half of the channel.

If we now assume that $\frac{\partial v}{\partial x} = 0$ at the point in the channel where the upper ~~upper~~ layer goes deepest, and since f is constant, we have for the potential vorticity across the channel

$$\frac{\partial v}{\partial x} = \frac{f}{H} \Delta h \quad (3)$$

where H is the maximum depth of the upper layer, and $\frac{\Delta h}{\lambda}$ the deviation from that depth across the channel.

Integration of equation (3) will render the velocity in relation to some known velocity v_0 at a point x_0 in the channel

$$v - v_0 = \frac{f}{H} \int_{x_0}^x \Delta h \, dx$$

From the dynamic topography of the sea surface in the channel it may be deduced that $v = 0$ at a point approximately midway between stations 48 and 49.

TABLE I. VELOCITY OF THE UPPER LAYER IN THE YUCATAN CHANNEL. POSITIVE VALUES REPRESENT CURRENT SETTING NORTHWARD, NEGATIVE SOUTHWARD.

U.P.V.: Current obtained from the integrated equation of uniform potential vorticity.

R.G.C.: The geostrophic surface current in relation to the 1000 db.

G.E.K.: Current obtained by the geomagnetic electrokinetograph assuming the correction factor, k , equal to unity.

Station	V. (cm/seg)		
	U.P.V.	R.G.C.	G.E.K.
46	149	151	
47	96	150	108
48	32	140	
X ₀	0	0	
49	-16	-10	
50	-25	-25	-44
51	-32	-30	-90

The integrated velocity is presented in Table I. For the purpose of comparison, this table presents also the speed of the relative geostrophic current as well as the G.E.K. determinations ($k=1$).

Considering the approximate nature of the computations, the agreement seems to be significant which, in turn, suggests that the conservation of potential vorticity plays, indeed, a certain role in the maintenance of the countercurrent that was observed at the right-hand side of the main current in the Cayman Sea and the Yucatan Channel.

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