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DETERMINATION OF CIRCULATION AND SHORT PERIOD FLUCTUATION IN ILHA GRANDE BAY (RJ), BRAZIL

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Synopsis

A mesoscale study was made of the Ilha Grande area. The local circulation described through progressive vector diagrams showed a clockwise bottom circulation determined in June 1976, while in the upper 10 m the direction of the flow entering the Ilha Grande Bay was towards the center in the west and towards the Marambaia sandbank in the east side of the Bay. Short periods and amplitude fluctuations were evaluted using power spectral analysis, Fourier and Maximum Entropy Method, which showed that in the upper 10 m predominant periods decrease from 1.1h (A = 6.3 cm sec^{-1}) (position = 3C) to 1.0h (A = 7.4 cm sec^{-1}) (position = 2D) and increase to 5.8h (A = 6.8 cm sec^{-1})(position = 1D), while at the bottom layer the predominant period increases from 0.4 h (A = 5.0 cm sec^{-1}) (position = 3G) to 6.4 h (A = 7.0 cm sec^{-1}) (position = 2G) and to 4.4 h (A = 7.9 cm sec^{-1}) (position = 1G). From the original data it has been possible to determine an "intense pulsation" between 30-70 cm sec^{-1} in the upper 10 m with about 1.0h period and 10-20 min duration in all the stations.

Introduction

An oceanographic cruise on board of the R/V "Prof. W. Besnard" was made in June 1976, under the Multinational Marine Sea Science Project supported by OAS (Organization of American States). Our purpose was to determine periodic oscillations between 0.2h-15.0h and also the mean circulation at different (mean and bottom) depths. This kind of work was for the first time carried out in the Ilha Grande area (Fig. 1).

Current measurements

Figure 1 shows the position of the three fixed oceanographic stations and Table I gives the depths of current meter observations. At fixed stations the current direction and velocity were measured by a "BRAYSTOKE", BFM 008 MK2 current meter, with five minute sampling intervals and readings accuracy of (± 5°: direction and ± 3cmsec $^{-1}$: velocity). Three current meters were used: two at the fixed (mean and bottom) depths and one profiling from surface to the bottom every one hour (velocity profile). In this paper, only data from mean and bottom depths were used.

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Current measurement analysis

Current values (velocity and direction) were decomposed into U and V components, positive to east and north, respectively. Several computer programs were used on the B6700 of the University of California, San Diego and on the IBM 1800 of Scripps Institution of Oceanography for the processing of the current meter data and subsequent statistical analysis. These programs were originally written by Stevenson *et al.* (1969), later modified for current measurements and adapted to our data.

The chain of programs was used to successively process current meter data from the raw measurements through evaluation of time dependent motions

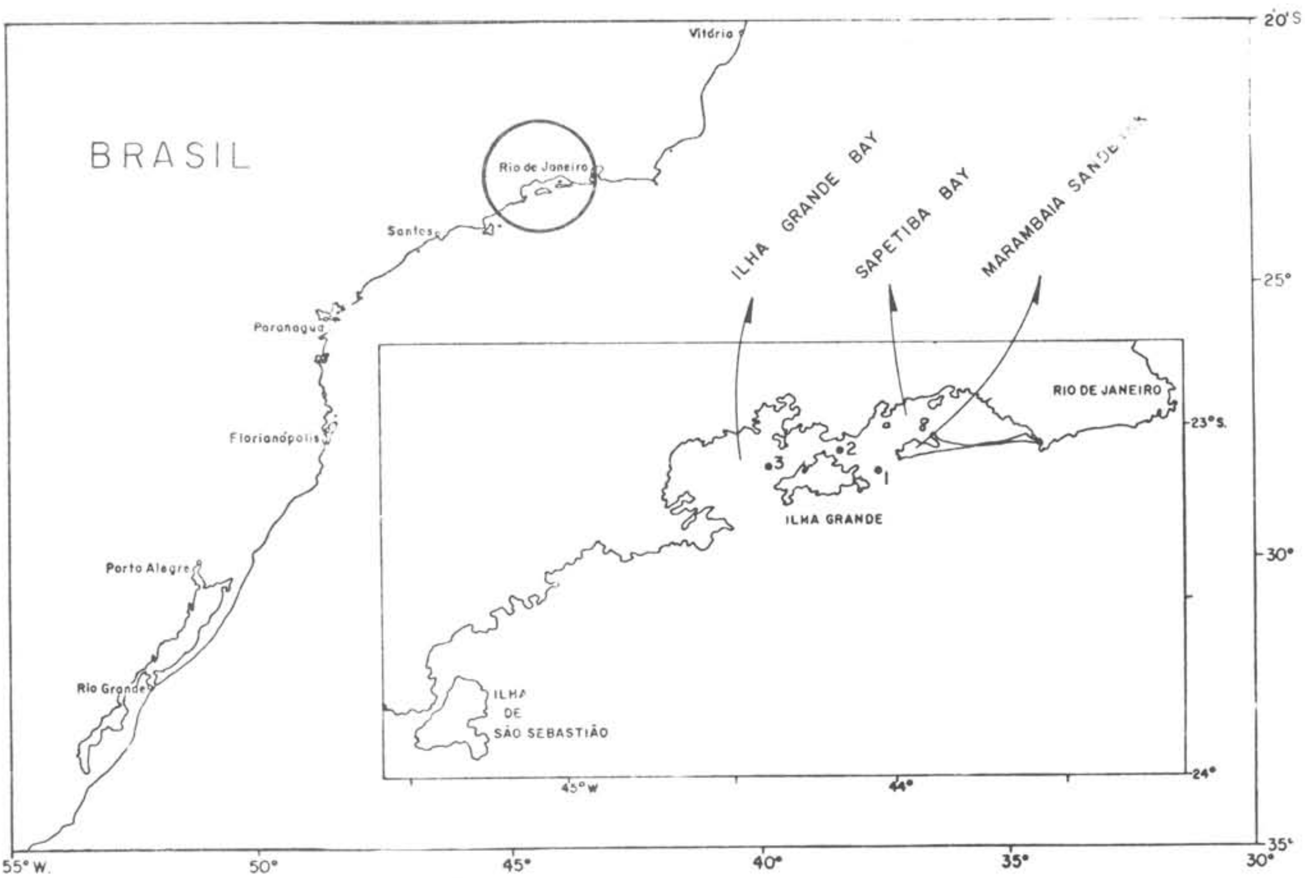

Fig. 1. Positions of fixed oceanographic stations.

Table I - Oceanographic fixed stations and current meter depth measurements (5 min sampling frequency)

Station		1		2		3	
Position	Lat. (S)	23°08'3"		23°04'7"		23°06'7"	
	Long. (W)	044°04'0"		044°11'9"		044°23'3"	
		Depth (m)	Station No.	Depth (m)	Station No.	Depth (m)	Station No.
		10	1D	10	2D	06	3C
		20	1G	17	2G	20	3G
Day		06/12/1976		06/12/1976 - 06/13/1976		06/13/1976 - 06/14/1976	
Hour (GMT)		00:07 - 19:10h		23:30 - 18:35		21:00 - 12:15	

(Table II). The second program determined the mean velocity and acceleration (Table III) for each fixed position time series by means of the least squares method. The program then normalized the time series data and the third program plotted

Table II - Current direction at each two hour intervals

Time (hours)	1D	1G	2D	2G	3C	3G
00-02	NW	WNW	ESE	ESE	N	ENE
02-04	E	SW	ESE	ESE	N	ENE
04-06	SE	SSW	ESE	ESE	N	NNE
06-08	SE	SE	ESE	ESE	N	NNE
08-10	ESE	ESE	ESE	ESE	N	NNE
10-12	ENE	E	ESE	ESE	N	E
12-14	N	WNW	ESE	ESE	N	W
14-16	NE	NNE	ESE	ESE	N	SSW
16-18	ESE	ESE	ESE	ESE	N	SSW

Table III - Mean velocities and accelerations

Station	Mean velocity ($cm\ sec^{-1}$)*		Acceleration ($cm\ sec^{-2}$)**	
	U	V	U	V
1D	6.7	2.7	0.6	0.6
1G	3.8	-4.3	1.1	0.3
2D	15.0	-6.8	0.1	0.1
2G	14.9	-6.1	0.1	-0.1
3C	-0.6	8.8	-12.2	-0.4
3G	4.9	3.6	-1.0	-0.7

* U, V velocity components are positive east and north, respectively

** Positive U, V components indicate increasing velocity

the normalized U and V components time series (Figs 2-7). Power spectra analyses were performed according to Fourier and Maximum Entropy Method (Mesquita & Morettin, 1978) and the results are shown in Table IV.

Progressive vector diagrams

At station 1, at 10 m (position = 1D), the mean current velocity was 7.2$cm sec^{-1}$ towards the ENE while at 20 m (position = 1G), the mean velocity was 5.7$cm sec^{-1}$ towards the SE (Fig. 8). This suggests that ocean water enters the eastern entrace of Ilha Grande Bay at 10 m, while the Bay water exits at 20 m. The mean acceleration at 10 m and 20 m depth was 0.9 $cm\ sec^{-2}$ and 1.2 $cm\ sec^{-2}$, respectively.

At station 2 (Fig. 9), the current velocity vector at 10 m (position = 2D) and 17 m (position = 2G) indicated an outflow in the ESE direction. That is, water flows eastwardly, from the western side of Ilha Grande Bay. At 10 m (position = 2D) the mean velocity was 16.5 $cm\ sec^{-1}$ and acceleration 0.1 $cm\ sec^{-2}$ whereas at 17 m (position = 2G), the mean velocity was 16.1 $cm\ sec^{-1}$ and acceleration 1.2 $cm\ sec^{-2}$.

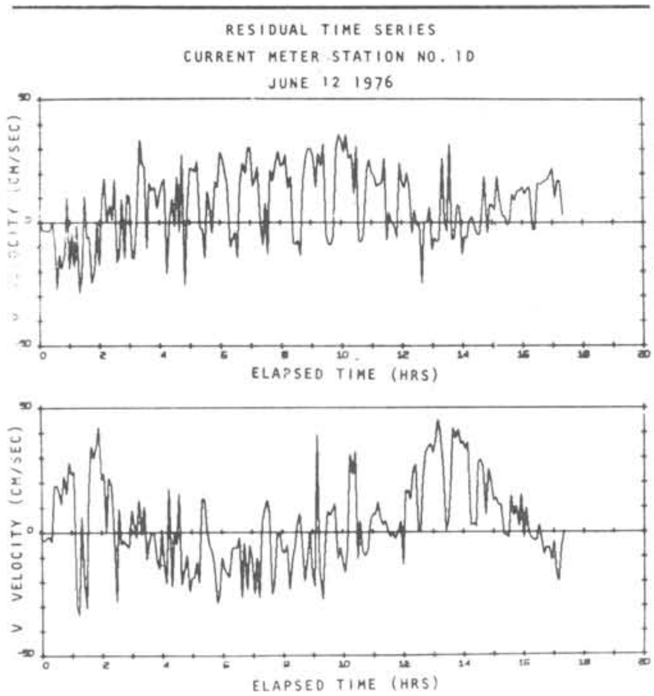

Fig. 2. Original and normalized curve for current meter observations.

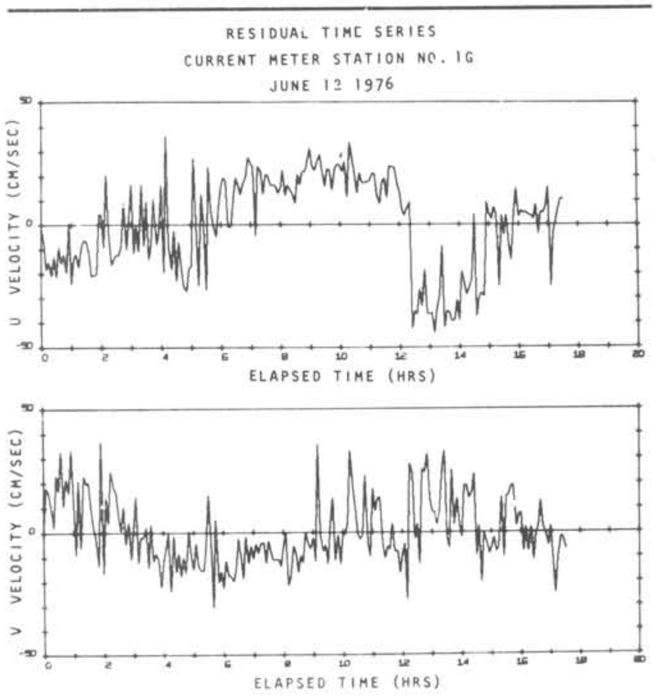

Fig. 3. Original and normalized curve for current meter observations.

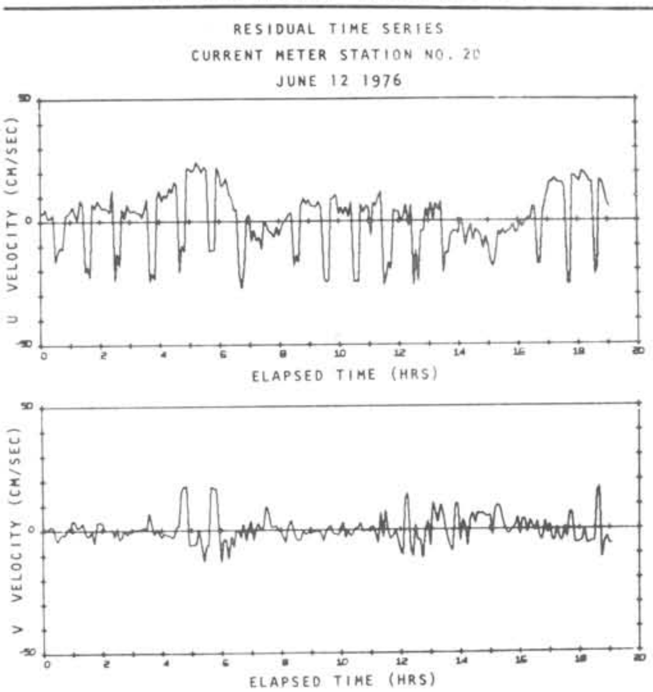

Fig. 4. Original and normalized curve for current meter observations.

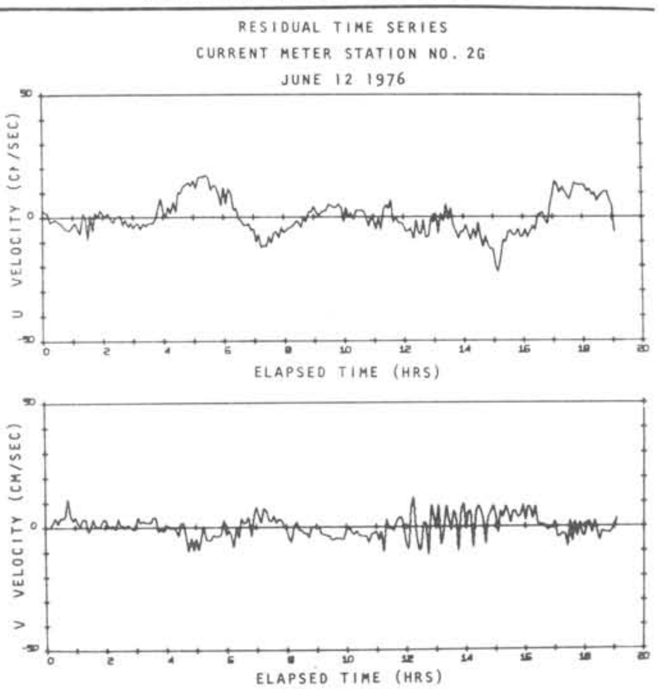

Fig. 5. Original and normalized curve for current meter observations.

At station 3 (Fig. 10), the current velocity vector indicated a direction towards the N at 6 m depth and towards ENE at 20 m. At 6 m (position = 3C), the mean velocity was 8.8 cm sec^{-1} and acceleration 12.2 cm sec^{-2} and at 20 m (position = 3G), the mean velocity was 6.1 cm sec^{-1} and acceleration 1.2 cm sec^{-2}.

Analysing the three stations (Fig. 11), we verified the presence of a significant bottom clockwise circulation, flowing from west to east in Ilha Grande Bay and towards the sea while in the upper 10 m the water flows to the center of the Bay in the western and towards Marambaia sandbank in the eastern side.

Table IV - Power spectra analyses

Station	1D		1G		2D		2G		3C		3G	
Comp	U	V	U	V	U	V	U	V	U	V	U	V
A (cm sec^{-1})	6.8	7.2	7.9	5.8	7.4	4.7	7.0	5.1	6.3	7.2	5.0	4.8
T (h)	5.8	5.8	4.4	0.5	1.0	0.9	6.4	6.4	1.1	1.0	0.4	3.8
A (cm sec^{-1})	6.7	6.4	5.9	5.5	6.5	4.2	6.0	4.0	5.8	6.3	4.6	4.8
T (h)	1.0	0.9	2.7	2.9	6.4	1.1	3.8	3.8	0.5	0.5	3.1	0.4
A (cm sec^{-1})	5.7	6.3	5.6	5.5	5.8	4.1	3.3	2.7	5.6	5.9	4.5	4.3
T (h)	0.5	1.2	0.8	1.1	1.1	0.6	1.4	1.6	0.9	0.3	1.9	0.5
A (cm sec^{-1})	5.4	5.8	5.4	5.4	5.8	4.0	3.1	0.4	5.1	5.7	4.5	4.2
T (h)	0.6	1.8	1.6	0.4	0.5	1.3	0.8	0.4	0.4	5.1	0.3	0.8

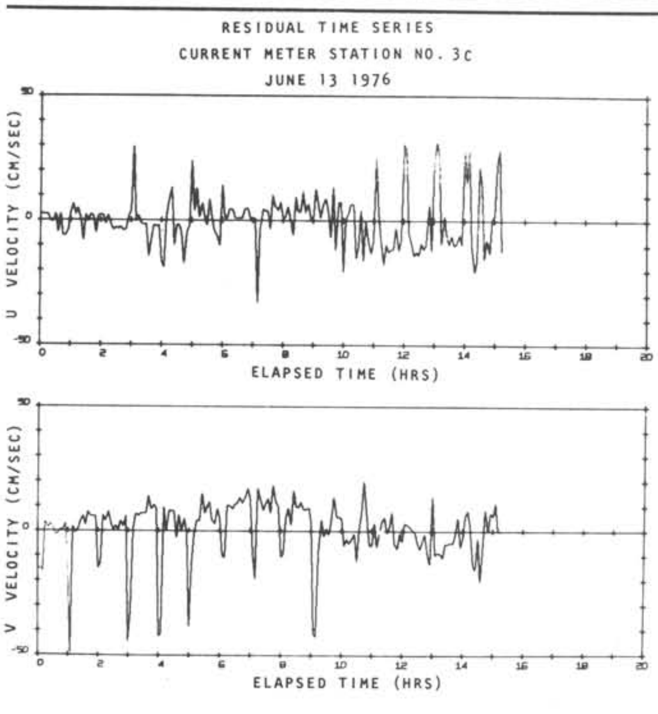

Fig. 6. Original and normalized curve for current meter observations.

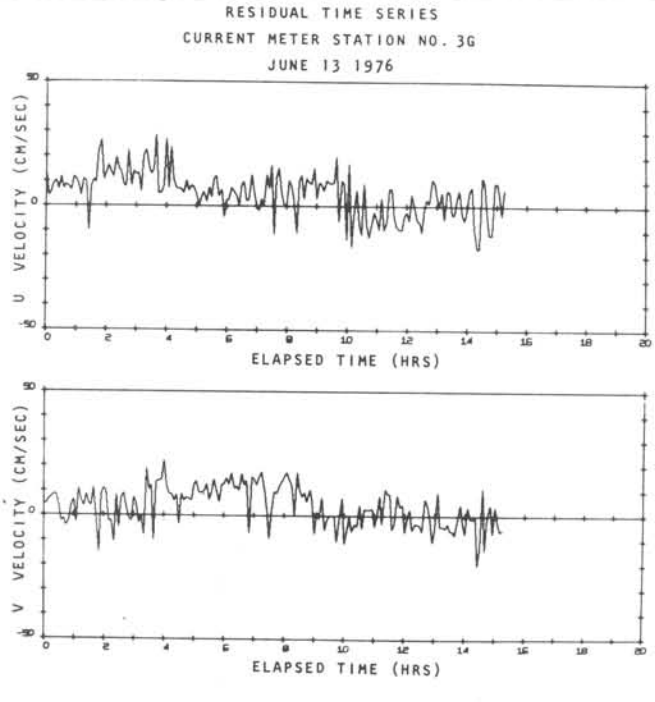

Fig. 7. Original and normalized curve for current meter observations.

Periodicities

Figures 2-7 show the series of current measurements taken at positions 1D, 1G, 2D, 2G, 3C and 3G, plotted with 5 min interval sampling.

From the original data, for the upper 10 m the "pulsation" has occurred in all the stations. These intensities with a 30-70 cm sec^{-1} range and 10-20 min duration, have occurred with a period of about 1.0 h. The "pulsation" observed in the components was always opposite to the movement, rapidly changing in direction in the real motion. At the eastern side, station 1, the "pulsation"

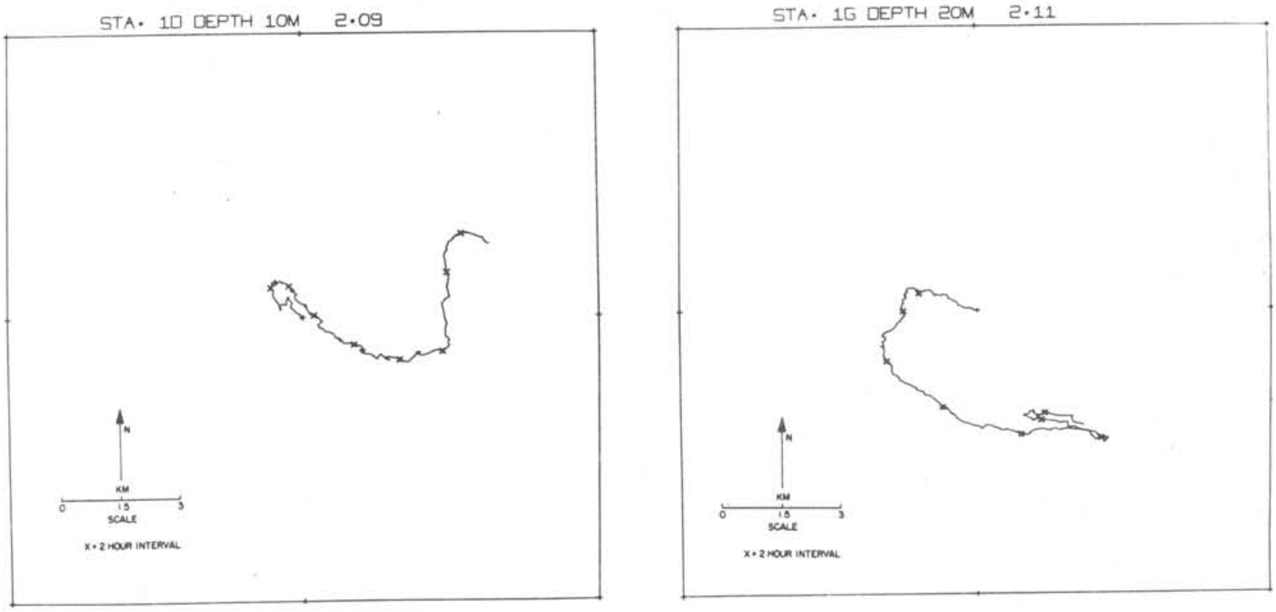

Fig. 8. Progressive vector diagrams for current meter observations at positions 1D (10 m) and 1G (20 m).

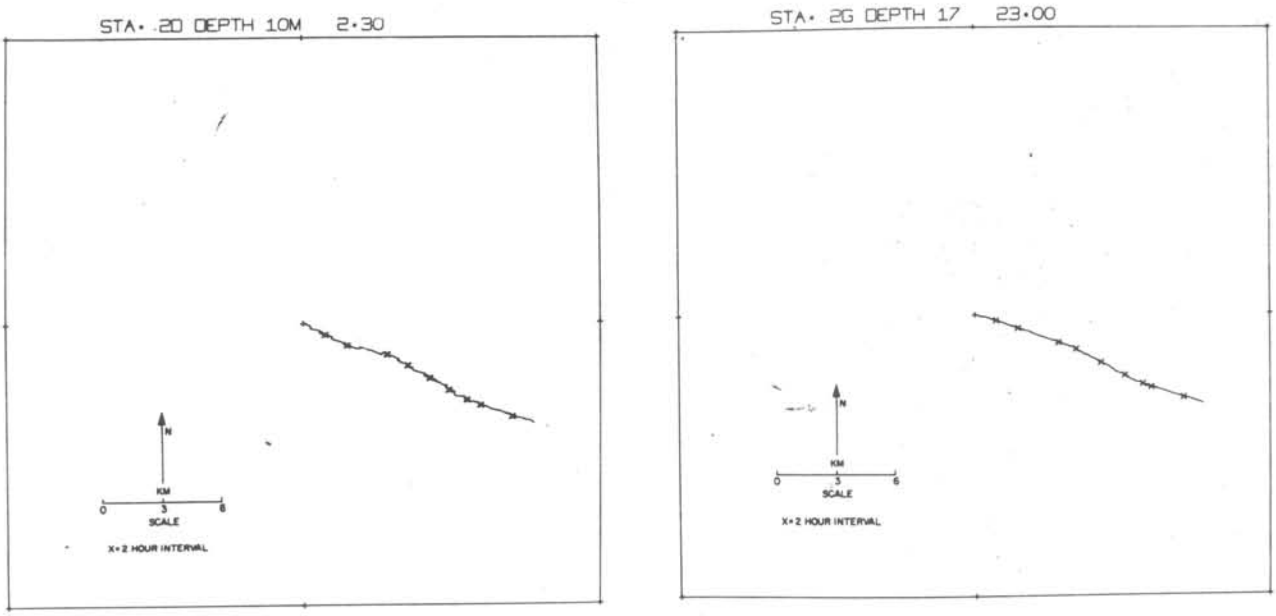

Fig. 9. Progressive vector diagrams for current meter observations at positions 2D (10 m) and 2G (17 m)

was well-defined (Fig. 2), between 5-12 h (eastern component) and 0-6 h, 8-13 h, 17 h till the end of the observation (northern component). At the western side of the Bay, station 3 (Fig. 6), the "pulsation" was well-defined for the western component for the interval 11 h till the end of the observation, and for the northern component for the interval 0-10h. The "pulsation" did not occur in the bottom layer where prominent peaks were recorded.

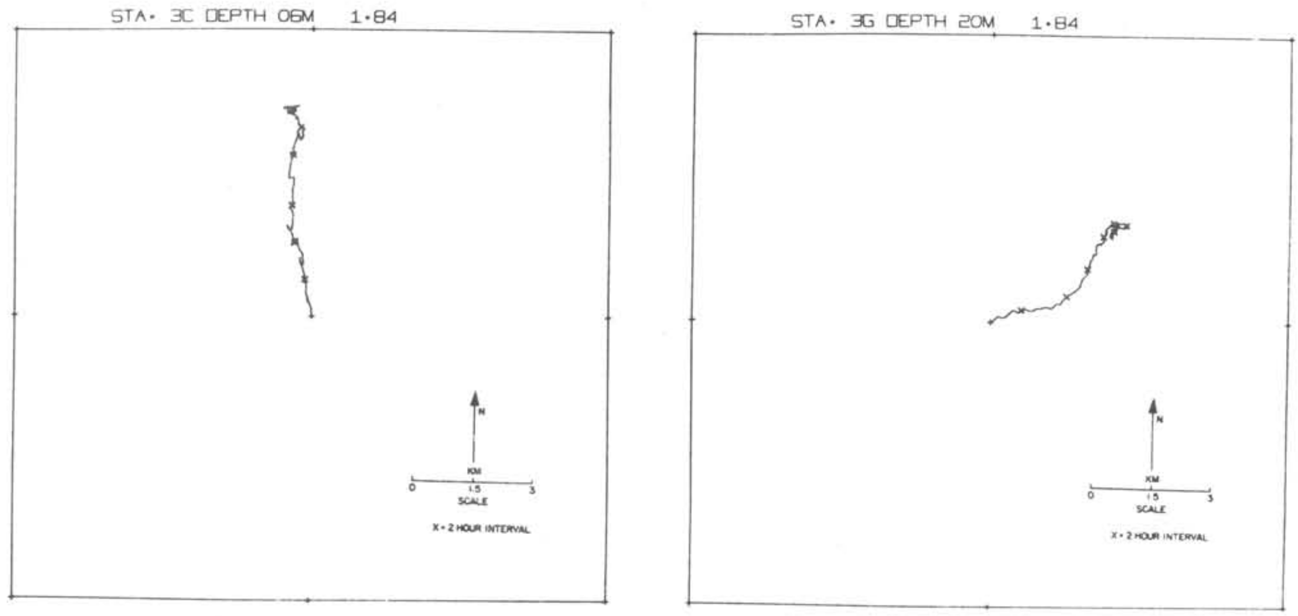

Fig. 10. Progressive vector diagrams for current meter observations at positions 3C (6 m) and 3G (20 m).

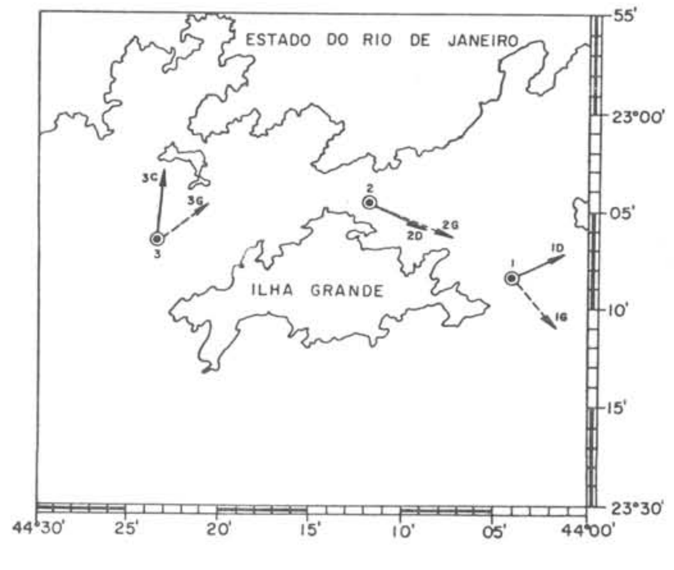

Fig. 11. Outline of speed and direction of mean current observed at Ilha Grande area.

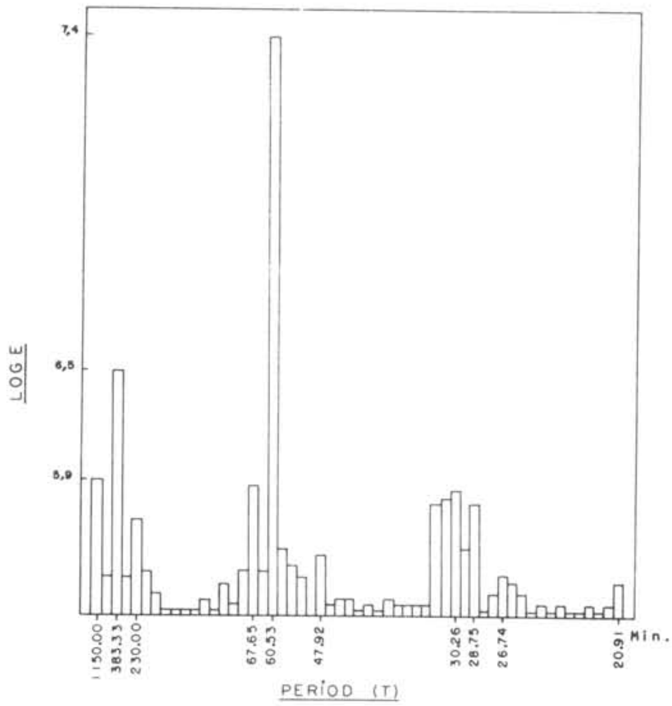

Fig. 12. Fourier analysis for 2D station data (U component).

Figures 12-13 show spectrum for 2D station data (U component), respectively for Fourier Analysis and Maximum Entropy Method. From these Figures, according to Mesquita & Morettin (1978), the amplitudes were better defined by Fourier Analysis and the periods had a better resolution through Maximum Entropy Method.

Table IV was elaborated from Fourier Analysis (amplitudes) and Maximum Entropy Method (periods).

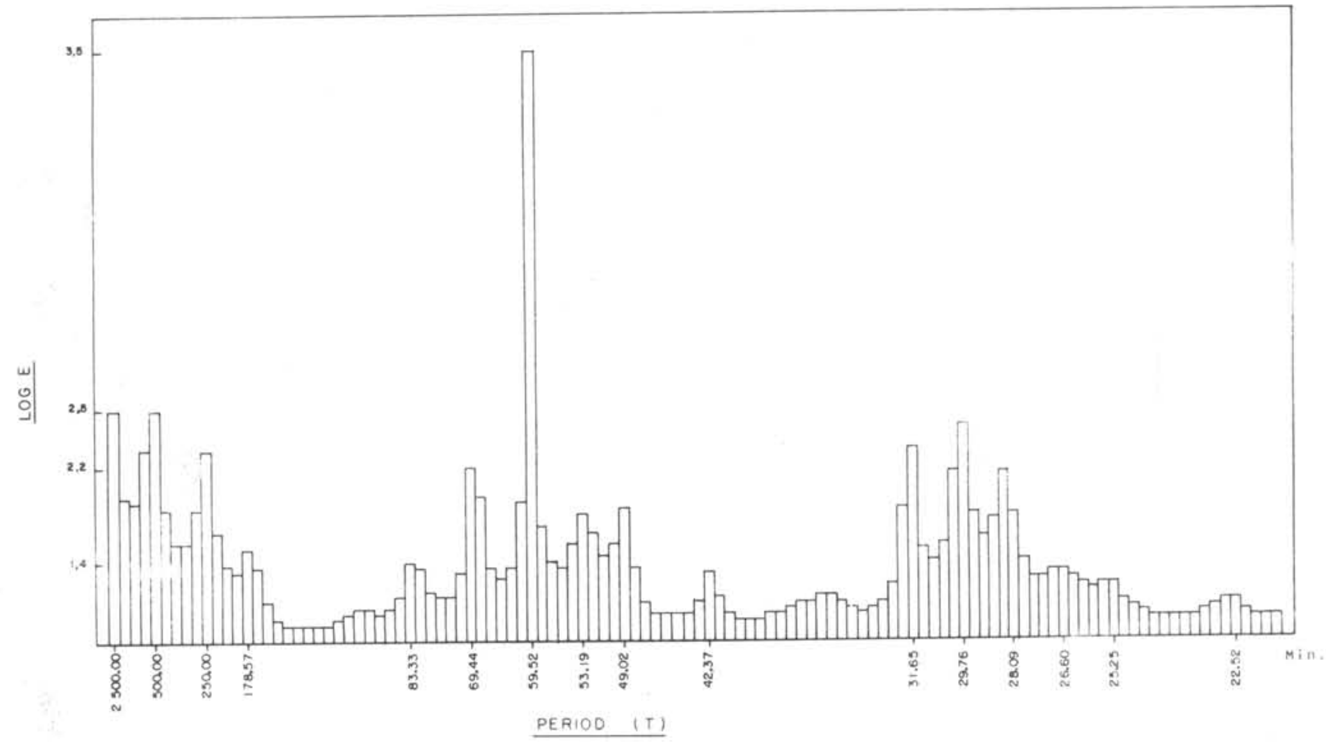

Fig. 13. Maximum Entropy Method for 2D station data (U component).

U component

For the upper 10 m the common period was about 1.0 h for all the stations and had a predominant amplitude, the greater one located at position 2D. From Table IV, we verified that the predominant periods decrease from 1.1 h (A = 6.3 cm sec^{-1})(position = 3C) to 1.0 h (A = 7.4 cm sec^{-1}) (position = 2D) and increase to 5.8 h (A = 6.8 cm sec^{-1})(position = 1D). For the bottom layer the common period was not determined except for positions 1G and 2G, where the greatest amplitude was recorded in position 1G. The predominant period increased from 0.4 h(A = 5.0 cm sec^{-1}) (position = 3G) to 6.4 h(A = 7.0 cm sec^{-1}) (position = 2C) and decrease to 4.4 h (A = 7.9 cm sec^{-1}) (position = 1G).

V component

For the upper 10 m the common period of about 1.0 h was determined for all the stations and the greatest one was located at 3C position. This amplitude had almost the same magnitude of that of position 2D, upper 10m U component. From Table IV, we verified that the periods decrease from 1.0 h (A = 7.2 cm sec^{-1})(position = 3C) to 0.9 h (A = 4.7 cm sec^{-1}) (position = 2D) and increase to 5.8 h (A = 7.2 cm sec^{-1})(position = 1D) in the upper 10 m. For the bottom layer, the common period was observed only for positions 2G and 3G, with a period of 0.4 h, the greatest one located at position 3G. The periods increase from 3.8 h (A = 4.8 cm sec^{-1}) (position = 3G) to 6.4 h (A = 5.1 cm sec^{-1}) (position = 2G) and decrease to 0.5 h (A = 5.8 cm sec^{-1}) (position = 1G).

Results

The summary of all data showed that there is a significant bottom clockwise circulation from west to east and towards the sea in Ilha Grande Bay, while in the upper 10 m, the water flows to the center of the Bay in the western side and towards Marambaia sandbank in the eastern side of the Bay (Fig. 11).

In the upper 10 m (U and V components) a periodic 1.0h "pulsation" occurred with 10-20 min duration in all the stations, with almost the same magnitude of intensity in

2D (U component) and 3C (V component) and with a smaller one in station 1D, while at the bottom layer prominents peaks have occurred.

Discussion

A comparative analysis of the three fixed oceanographic stations indicated that at the upper 10 m the water flows to the center of the Bay in the western side of it and at the eastern side towards Marambaia sandbank, while at the bottom layer it exhibited a predominant clockwise circulation from west to east and towards the sea in Ilha Grande Bay.

Our results showed the occurrence of a "pulsation" with about 1.0 h period and with 10-20 min duration. The 1.0 h common period determined for the upper 10 m probably indicates the natural ressonant frequency of that portion of the Bay. Merian's Method (Proudman, 1952) indicated for the eastern and western parts of the Bay a natural frequency of about 1,0 h, well within the period detected. However, the "pulsation" observed does not seem to support the above idea since it does not show a characteristic variability of "seiches" but a rather, sudden, strong and periodic change of intensity of the flow. Also this variability cannot be related to the findings of Cartwright & Young (1974) for the Shetland Island. Cartwright & Young (*op. cit.*), studying "seiches" and tidal ringing in the sea near Shetland, through spectral analysis, found a narrow peak about 2.1 h prominent at two pelagic sites close to the shelf edge and at Baltsound but negligible at shallow water sites and at Leowick. They explained this fact in terms of trapped edge waves and tidal ringing.

Cartwright & Young (*op. cit.*) open a new research program to be developed here aiming at the determination of the probable cause of the "pulsation" occurrence. Studies on wave and tide propagation at adjacent oceanic area would answer this question.

Conclusion

From the results obtained through visual inspection of the original data, progressive vectorial diagrams, Fourier Analysis and Maximum Entropy Method, the following observations can be made:

1. A predominant bottom clockwise circulation was observed (6.1 cm sec^{-1}, at the western entrace, 16.1 cm sec^{-1}, channel and 5.7 cm sec ^{1}, at the eastern entrace);
2. in the upper 10 m this circulation was not observed but the inflow of water in both entrances of the Bay (8.8 cm sec^{-1}, western entrance and 7.2 cm sec^{-1}, eastern entrance);
3. the most important periods determined can be summarized as follows:

Position	Amplitude (cm sec^{-1})	Period (hour)
1D	7.2	5.8
1G	7.9	4.4
2D	7.4	1.0
2G	7.0	6.4
3C	7.2	1.0
3G	5.0	0.4

An interpretation of the dynamical aspects of the variability shown above and phase studies will be given in a future paper.

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