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SOME RESULTS OF ANALYSIS OF INVERTED ECHO-SOUNDER RECORDS FROM THE ATLANTIC EQUATORIAL REGION

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Synopsis

The tidal analysis of data from the Equatorial region, given by inverted echo-sounders, show considerable residuals in the frequency band of approximately 2 cycles per day. In the even harmonics of 4 and 6 cycles per day, tidal components statistically not negligible are also identified. Spectral analysis of temperature series from the same area show, on the other hand, variabilities in the same frequency bands, which suggests the occurrence of internal waves with energy distributed in these frequency bands, in the Atlantic Equatorial area.

Descriptors: Tides, Acoustic measurements, Echosounders, Internal waves, FGGE, Atlantic Ocean, Equatorial region.
Descritores: Marés, Medidas acústicas, Ecobatímetros, Ondas internas, FGGE, Oceano Atlântico, Zona equatorial.

Historical background

In 1979, the oceanographic ship "Prof. W. Besnard", of the "Instituto Oceanográfico da Universidade de São Paulo" joined an international research in the Atlantic Equatorial area (Mesquita *et al.*, in prep.), together with the oceanographic ships "Discovery", of the Institute of Oceanographic Sciences (IOS-UK), "Konrad", of the Lamont-Doherty Geological Observatory (USA), "Oceanus", of the Woods Hole Oceanographic Institution (USA) and other ships, according to the oceanographic programme organized by the Scientific Committee on Oceanographic Research (SCOR - The Oceanographic Programme, 1978 - WG 47 group).

The research programme known as "First GARP Global Experiment (FGGE)" was part of the global experiment "Global Atmospheric Research Programme (GARP)", and was supported by the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU).

The participation of the "Instituto Oceanográfico" in this international programme allowed the obtention of data, in collaboration with other participants, such as those measured by E. J. Katz, of the Lamont-Doherty Geological Observatory, in the Stations "Branca", "Eliana" and "Flavia" (Fig. 1).

Tidal heights in these stations were observed with inverted echo-sounders (Bitterman, 1976), during the following periods. "Branca": from 22/January/1979 06 h 00 min GMT to 25/June/1979 09 h 00 min GMT; "Eliana": since 27/June/1979 14 h 00 min GMT until 03/October/1979 10 h 00 min GMT; and "Flávia": from 18/October/1979 11 h 00 min GMT to 27/February/1980 06 h 00 min GMT. The sampling interval of these observations was of 1 hour. The same data were analysed by Vassie (1982), dealing with the problem of the tidal propagation in the South Atlantic.

Temperature data measured by the oceanographic ship "Almirante Saldanha" (Mesquita, 1975; Mesquita *et al.*, 1976) were spectrally analysed (Mesquita & Morettin, 1979), showing the occurrence of frequencies of 2, 3 and 4 cycles per day, being preponderant those of 2 cpd.

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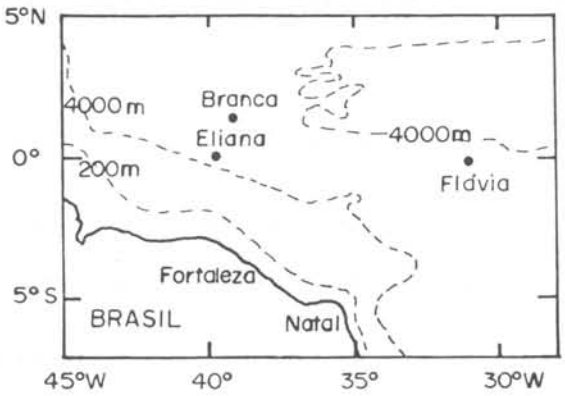

Fig. 1. Geographical position of the stations "Branca", "Eliana" and "Flávia".

These results estimulated the checking of the variability existence, through tidal analysis, in the "Branca", "Eliana" and "Flavia" records. Franco *et al.* (1982) applies the harmonic method to analyse these data, computing the residual spectrum in the tidal bands also, while Cartwright (1982) applies the response method, computing the coherent and non-coherent signals with the tidal potential.

Tidal analysis

Details of the harmonic method for tidal analysis used in the computations are given in Franco (1981). Due to the computationally economic features of the method, normally all the tidal components are analysed, including the shallow-water ones. The constituents with small amplitude are those whose confidence interval can't be determined within a given probability (usually 95%); these constituents appear in the final listing of the computer program results flagged with an asterisk and must be neglected. The statistically useful constituents are shown in Table 1.

It is well known that normally, at the depths were the data were taken (about 1500 m for "Branca", on a submarine mount, and 4000 m for "Eliana" and "Flavia") no shallow--water tidal effects should be observed, but the complete analysis method was applied to the data processing, in order to work out the harmonic constants of many shallow-water components, so that a comparison with the temperature series analysis above mentioned could be performed.

A sub-product of the tidal analysis method used is a residual amplitude spectrum for each tidal frequency band, which allows the checking of the variabilities that do not correspond to the exact tidal frequencies, but are eventually excited by the tides.

Results

Table 1 contains the harmonic constants for the three stations. For "Branca" station (Lat. 1°16'N, Long. 39°12'W), only 11 constituents aren't flagged with an asterisk. Apart from that, there are large confidence intervals both in amplitude H and phase GW, in the semi-diurnal band.

On the other hand, MO_3, M_4, SN_4, MSM_5 and M_6 appear among the 11 selected constituents; in coastal stations, they could be considered as effective shallow-water components, but here they represent a different phenomenon.

Considering that no important effect could disturb the tides at so far away from the coast stations, the single reason to such anomalies could be related to the velocity of sound propagation in the water.

The residual amplitude spectrum of each tidal band of "Branca", given by the tidal analysis, is graphically represented in Figure 2, for the semi-diurnal, fourth diurnal and sixth diurnal bands.

It is very uncommon that coastal stations show such large residuals. Even Maracá Island (Iguarapé do Inferno, Lat. 2°10'S - Long. 50°31'W), where the noise in the semi-diurnal band is quite large, has no residual amplitude larger than 4 cm. And note that Maracá Island tidal range may reach about 11 meters.

The 12 cm residual showed in Figure 2*a*, relative to the 28.80°/h angular frequency, indicates then the existence of a phenomenon responsible for the anomaly in the sound propagation speed.

Figures 2*b* and 2*c* show also significant residuals in the bands of

Table 1. Statistically useful harmonic constants

Constituents		"BRANCA"				"ELIANA"				"FLÁVIA"			
Symbol	Angular Frequency (°/h)	H (cm)	± (cm)	GW (degrees)	± (degrees)	H (cm)	± (cm)	GW (degrees)	± (degrees)	H (cm)	± (cm)	GW (degrees)	± (degrees)
Q_1	13.3986609	-	-	-	-	4.65	2.09	175.19	26.64	-	-	-	-
O_1	13.9430356	4.48	1.28	257.29	16.62	5.82	2.09	217.10	21.00	4.47	1.54	235.54	20.12
K_1	15.0410686	4.30	1.28	236.04	17.35	6.93	2.09	281.59	17.52	1.55	1.54	330.75	82.63
OO_1	16.1391017	-	-	-	-	2.27	2.09	353.08	66.91	1.99	1.54	201.13	30.29
KQ_1	16.6834764	2.07	1.28	83.78	38.21	2.79	2.09	246.57	48.43	4.01	1.54	206.07	22.55
μ_2	27.9682084	-	-	-	-	5.46	5.26	190.25	74.42	-	-	-	-
N_2	28.4397295	15.86	6.95	209.29	26.00	16.05	5.26	194.32	19.14	11.33	4.15	206.14	21.49
M_2	28.9841042	80.73	6.95	206.61	4.94	71.50	5.26	209.11	4.22	61.49	4.15	214.11	3.87
S_2	30.0000000	30.38	6.95	239.16	13.23	31.13	5.26	244.05	9.73	16.77	4.15	230.66	14.33
MSN_2	30.5443747	-	-	-	-	-	-	-	-	4.28	4.15	349.29	76.10
NO_3	42.3827651	-	-	-	-	1.42	1.32	358.03	67.96	-	-	-	-
MO_3	42.9271398	1.52	1.15	184.43	49.29	-	-	-	-	-	-	-	-
MK_3	44.0251728	-	-	-	-	1.64	1.32	311.42	53.53	-	-	-	-
$2MQ_3$	44.5695475	-	-	-	-	-	-	-	-	1.57	1.49	93.64	72.38
M_4	57.9682084	3.92	2.71	34.37	43.84	2.56	2.15	349.07	57.19	-	-	-	-
SN_4	58.4397295	3.09	2.71	201.00	61.49	2.16	2.15	121.03	84.29	-	-	-	-
MSM_5	73.4807981	1.10	0.99	222.66	64.83	-	-	-	-	-	-	-	-
M_6	86.9523127	2.23	1.82	345.58	54.60	-	-	-	-	1.00	0.96	67.82	73.89
$2MS_6$	87.9682084	-	-	-	-	1.73	1.29	350.40	47.85	-	-	-	-
						INFERED CONSTANTS							
P_1	14.9589314	1.42	-	237.63	-	2.29	-	276.76	-	0.51	-	323.61	-
$2N_2$	27.8953548	2.09	-	211.96	-	2.12	-	179.53	-	1.50	-	193.17	-
ν_2	28.5125831	3.01	-	208.93	-	3.05	-	196.30	-	2.15	-	207.21	-
T_2	29.9589333	1.79	-	237.86	-	1.84	-	242.65	-	0.99	-	230.00	-
K_2	30.0821373	8.26	-	241.80	-	8.47	-	246.88	-	4.56	-	232.00	-

H = amplitude, in cm

GW = phase related to the Greenwich Meridian, in degrees

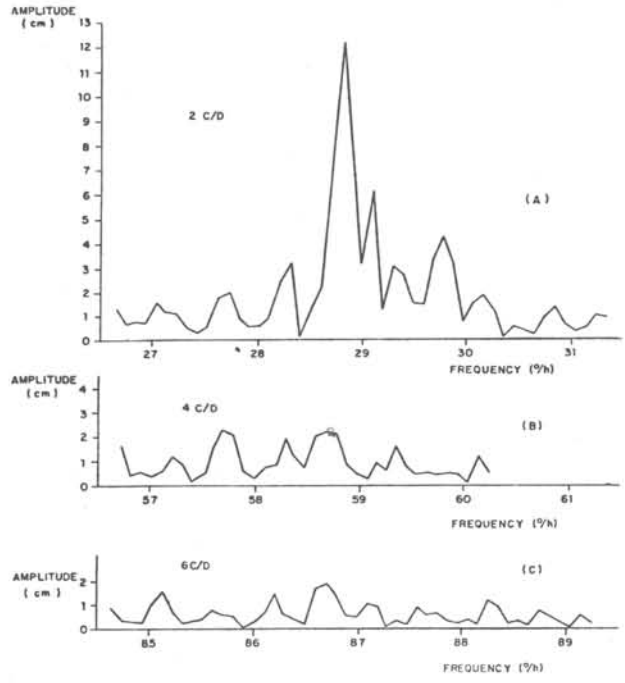

Fig. 2. Amplitude residual spectrum for "Branca" Station: 2 C/D (A), 4 C/D (B) and 6 C/D (C).

4 and 6 cpd, although no pronounced peak such as those of Figure 2*a* is observed.

Mesquita & Morettin (1979) showed results of time-series analysis of sea water temperature at the depths of 60, 90, 100 and 110 meters, at latitude 0° and longitude 35°W; the results show oscillations at the approximate angular frequencies such as 29, 43 and 58 degrees per hour. Considering that this geographical position is reasonably near to "Branca", it may be admitted that the temperature oscillations can produce spurious oscillations in the echo-sounders measurements, with frequencies round to 2, 3 and 4 cpd, then interfering in the determination of the tidal components of the acoustic records.

"Eliana" station (Lat. 0°5'N - Long. 30°45'W) displays 14 constituents (Table 1); NO_3, MK_3, M_4, SN_4 and $2MS_6$ passed the statistical selection, and the amplitude residuals in the semi-diurnal band are significant, with two pronounced peaks in the residual spectrum (Fig. 3*a*). Nevertheless, these peaks are quite smaller than those of Figure 2*a*. Appart from that, the residuals corresponding to 4 and 6 cpd are much smaller too (Fig. 3*b*).

Finally, at "Flávia" station (Lat. 0°3'N - Long. 30°57'W) only three shallow water constituents remain (MSN_2, $2MQ_3$ and M_6) and there is no remarkable peak in the amplitude residuals spectrum, in the semi-diurnal band (Fig. 3*c*). This spectrum has the features of a random noise one; these features are also present in the residuals of the quarter-diurnal band (Fig. 3*d*), which constituents didn't pass the statistical selection, with no exception.

It is then remarkable that both the peaks of the residual spectrum in the tidal bands and the shallow--water constituents are more evident in the western part of the area under acoustic measurements, as the values relative to "Branca" are larger than those of "Flávia", so that the bottom topography also affects such anomalies.

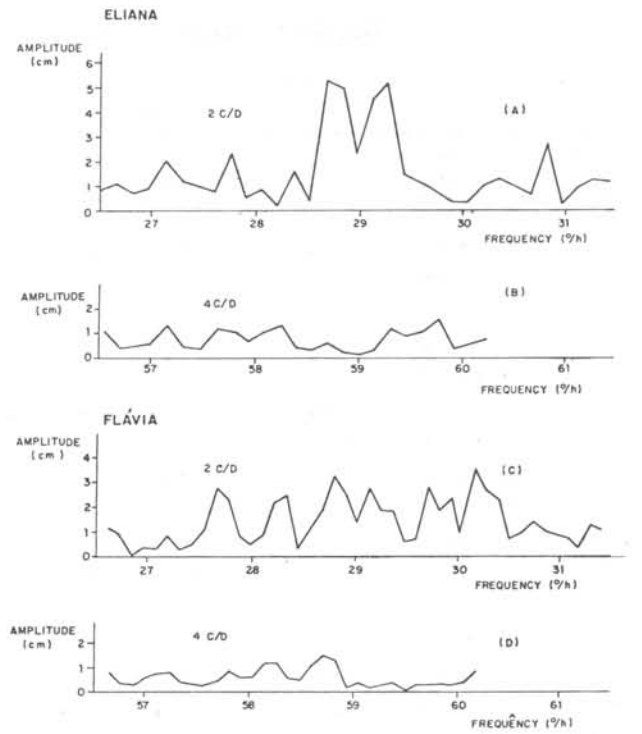

Fig. 3. Amplitude residual spectrum; "Eliana" Station: 2 C/D (A) and 4 C/D (B); "Flávia" Station: 2 C/D (C) and 4 C/D (D).

In all the analysis performed, the tidal constituents constants agree fairly well with those determined by Vassie (1982), with respect to the tidal propagation in the equatorial Atlantic.

Discussion

Coastal researches in the Western part of the United States show that the temperature and salinity of the coastal waters are related to the tides, though these variables, at the same depths, oscillate in accordance with the tides (Lacombe, 1965).

Such phenomenon, due to the pronounced vertical gradient of the specific mass in adjacent layers with relative motion, is known as "internal tides". The frequency of these waves is of approximately 2 cpd, with amplitude of tens of meters and wave length of 100 km (Sverdrup *et al.*, 1942).

In a recent paper, Käse & Siedler (1979) accomplished energy spectral analysis of temperature and currents at their oceanographic station F1 (Lat. 8°N - Long. 22°50'W). The peaks of energy are remarkable both in temper-

ature and current (east and west) components, near to 1.92 cpd. This frequency is approximately the same of the peak in Figure 2*a*.

Considering that in the present case the tide was observed with inverted echo-sounders, every anomaly in the speed of sound propagation in the sea will alter the depth measurement. Consequently, the large residuals mostly in the semi-diurnal band and the shallow-water constituents that appeared improperly in the results may be associated with the anomalies of the sound propagation.

Since the acoustic tidal measurements are disturbed by the specific mass anomalies due to temperature, pressure and salinity variations, they may be useful in researches about internal waves. In fact, the association of these observations together with temperature continuous records will allow researches similar to those of Käse & Siedler (*op. cit.*).

In the results obtained by Mesquita & Morettin (*op. cit.*), the analysed temperature series aren't simultaneous with the present data. Meanwhile, the reasonable agreement in the frequency bands then obtained with the present ones indicate a probable correspondence between the temperature oscillations at the undercurrent level (where there are large variations in the density profile) and tidally originated disturbances, in the bands of 2, 3, 4 and even 6 cpd. That fact indicates the occurrence of oscillations with the same periods, probably associated with internal waves and/or variabilities in the mass field, at the undercurrent level.

In fact, Cartwright (1982), when processing the same data, also finds that the spectral noise level in the tidal bands is about two orders of magnitude higher than that given by sea level conventional records, although the main diurnal and semi-diurnal tides are still coherent with the tidal potential. He shows that the mid ocean record ("Flávia") is the only one that gives amplitudes and phases which correspond closely with the surface tide as given by cotidal lines obtained through sea bed pressure records. On the other hand, "Branca" and "Eliana", located near to the continental shelf, have also strong incoherent tidal signal, showing second harmonic distortions (quarter diurnal components), which is characteristic of internal tides. Finally, Cartwright (*op. cit.*) estimates the acoustic time delay in vertical transmission through long internal waves, concluding that, in this region, pure internal tides of amplitude 10 m at 200 m depth would produce the observed changes in the tidal signal.

Although the use of inverted echo-sounders alone proved not being very accurate to tidal measurements in deep-waters, due to the variability introduced by internal waves, the combined use of them together with sea bed pressure records might lead to a complete set of very useful measurements of both the surface and internal waves.

The research developed in 1979 is inserted in the context of the FGGE, which results have some connections with climatological aspects of the North and Northeast of Brazil, so that it should have the necessary continuity.

Conclusions

The analysis of tidal records from the equatorial Atlantic area, obtained by means of acoustic devices, indicates the occurrence of internal waves with semi-diurnal frequencies. The comparison of other spectral bands of this analysis with those of spectral analysis of temperature data in the Atlantic Equatorial area (at the undercurrent level) suggests also the occurrence of variabilities in the 3, 4 and 6 cpd bands, probably associated with internal waves.

Resumo

Análises de dados de maré, da zona equatorial, obtidos com ecobatímetros invertidos, mostram consideráveis resíduos na faixa de freqüências com aproximadamente dois ciclos por dia. Nos harmônicos pares com 4 e 6 ciclos por dia são também identificadas componentes de maré estatisticamente não desprezíveis.

Análises espectrais de séries de temperatura obtidas na mesma área mostram,

por outro lado, variabilidades na mesma faixa de freqüências, o que sugere a ocorrência, na área equatorial Atlântica, de ondas internas com energia distribuída nessas faixas espectrais.

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References

BITTERMAN Jr, D. S. 1976. Inverted echo-sounder instrument report. Tech. Rep. Woods Hole oceanogr. Instn, (76-67).

CARTWRIGHT, D. E. 1982. The tidal signal in inverted echo-sounder records. Deep Sea Res., 29(6A): 767-784.

FRANCO, A. dos S. 1981. Tides: fundamentals, analysis and prediction. São Paulo, IPT, 232p.

———————; HARARI, J. & MESQUITA, A. R. de 1982. Alguns resultados de análises de registros de marés obtidos por métodos acústicos. *In:* Simpósio Naval de Sonar, 1º, Arraial do Cabo, RJ, 1982. Anais ... Rio de Janeiro, Instituto de Pesquisas da Marinha, vol. 1, 9p.

KÄSE, R. H. & SIEDLER, G. 1979. Internal wave kinematics in the upper tropical Atlantic. Deep Sea Res., *26* (Suppl. 1):161-189.

LACOMBE, H. 1965. Cours d'océanographie physique (théories de la circulation général. Houles et vagues). Paris, Gauthier-Villars, 392p.

MESQUITA, A. R. de 1975. Nota sobre a participação brasileira no "GATE" (GARP Atlantic Tropical Experiment) junho/outubro 1974: Oceanografia. Relat. int. Inst. oceanogr. Univ. S Paulo, (2):1-84.

———————; KATZ, E. J.; VILLELA, R. J.; SUN, C. H.; MORAIS, M. & FESTA, M. (in prep.) Primeiro Experimento Mundial do GARP a bordo do N/Oc. "Prof. W. Besnard".

———————— & MORETTIN, P. A. 1979. Análise de séries temporais oceanográficas com pequeno número de observações. *In:* Simpósio Nacional de Probabilidade e Estatística, 3º, São Paulo, 1978. Atas do 3º SINAPE. São Paulo, Instituto de Matemática e Estatística da Universidade de São Paulo, p.165-173.

———————; RAO, N. J. & AMBRÓSIO Jr., O. 1976. Preliminary GATE results from N/Oc. "Almirante Saldanha". Relat. int. Inst. oceanogr. Univ. S Paulo, (3):1-45.

OCEANOGRAPHIC PROGRAMME FOR THE FGGE. 1978. Implementation/Operations Plan, vol. 7. Genève, World Meteorological Organization.

SVERDRUP, H. U.; JOHNSON, M. W. & FLEMING, R. H. 1942. The oceans; their physics, chemistry, and general biology. New York, Prentice-Hall, 1087p.

VASSIE, J. 1982. Tides and low frequency variations in the equatorial Atlantic. Oceanol. Acta, 5(1):3-6.

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