CHAPTER 63

SEA-AIR INTERACTIONS IN THE COSTAL CIRCULATION AROUND GRAN CANARIA ISLAND (SPAIN)

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Abstract

This paper presents the results of analyzing six months of simultaneous records of water levels, currents, wind and atmospheric pressure that have been collected outside the surf zone at three locations in the eastern coast of Gran Canaria (Canary Islands, Spain). The results shown in this paper concern mainly one of the coastal stations, placed at the port of Las Palmas city. Although tides and currents use to be astronomically dominated, a non-permanent term appears in certain time intervals, identified as a long wave -rotary type- with a frequency very close to the inertial one. Another interesting result is the appearance of harmonic tidal periodicites in the atmospheric variables, which suggest a higher importance of the meteorological tides or/and a strong interaction sea-air.

Introduction

As it is well known, nearshore currents outside the surf zone use to be mainly dominated by tide and wind. Wind affects the upper layer of water and does not use to produce permanent periodic terms in the currents. But meteorological variations may give rise to important effects in the current patterns, either by enhancing or weaking some existing periodic terms or by generating new ones, that appear in the spectrum as new peaks which can only be explained via sea-air interaction.

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The Canary Islands are a privileged place for observing oceanographic phenomena, as they are oceanic islands that are in the path of a general oceanic circulation and they are wide enough to perturbate it and to super-impose a very interesting local pattern. Moreover, the archipelago is placed between the northern parallels 27°30' and 29°30', in the zone where the intense solar radiation and the local earth parameters enhance sea-air interaction and resonance phenomena, and trade winds are dominant.

In the present work, the attention has been focussed in the eastern coast of Gran Canaria Island (fig. 1), where 3 coastal stations were established and at least six months of simultaneous and continuous records of tide, currents and meteorological variables were collected. The results now shown are mainly obtained from the station No. 3 (port of Las Palmas).

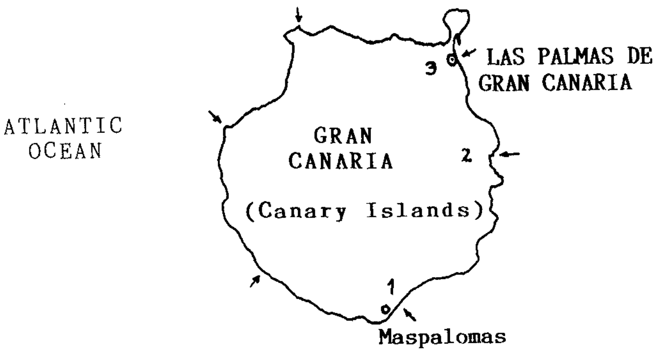

Figure 1.- Location of measurement stations

Data collection and analyzing methods

The measurements of currents are performed by 2 current meters placed at 15 and 30 m depth, in areas of about 45 m total depth. The meteorological data recorded are pressure, temperature and wind velocity at 10 m above the sea surface. The instruments are made by Aanderaa, and the sampling interval is set to 30 minutes.

Current and wind velocities were split into North-South and East-West components, appoximately corresponding to longshore and transverse directions. For data from station No. 1, another pair of axes was also considered, resulting from linear regression in the polar diagram.

As only long period constituents were to be studied, a low pass filter was applied to the series, after which a final lag of 1 hour resulted.

The main analyses were achieved by both harmonic and spectral methods. The harmonic analysis uses 69 astronomical constituents, being possible to add 77 more ones for including shallow water terms. The least-square technique is applied with nodal corrections for the longest constituents that can be resolved over the length of the record. If the record length does not allow to determine a certain constituent, an estimate may be obtained by inference.

The term "component" has been used for longshore or transverse series, while the term "constituent" was used for harmonics.

The results are amplitude and Greenwich phase of every constituent, as well as the axis length and orientation of the ellipses with respect to the reference system and the phase angle.

By means of spectral analysis, the same results are obtained, as well as the cross-spectra between pairs of variables and the clockwise and anticlockwise rotary spectra.

The study was performed for months, quarters and half-years, what allows to estimate the stability of the constituents as a function of time.

Constituent	Current Component			
	East - West		North - South	
	Mean	σ	Mean	σ
Shallow Water	11.52 %	4.40	4.12 %	1.94
Long Period	4.11 %	2.28	16.83 %	5.13
Diurnal	20.56 %	6.58	20.05 %	4.11
Semidiurnal	30.20 %	12.51	36.85 %	5.75
Third-diurnal	4.36 %	2.21	2.64 %	2.43
Residual	29.25 %	8.48	19.51 %	2.74

Table 1.- **Distribution of variance in the current measurements at the Port of Las Palmas. Depth: 15 m**

Results of harmonic analysis

Table 1 shows the spectral distribution of the mean variance of the current -a measure of the energy-, with the standard deviation, obtained from the half-year records of station No. 3, at a depth of 15 m.

The maximum flood (south-going) reaches 40 cm/s, and the maximum ebb (north-going) attains a value of 30 cm/s. The currents flow predominantly along the North-South direction (longshore). The transverse current records exhibit a higher variability and a strong level of noise.

The frequency band with the greatest amount of energy is the semidiurnal one in both components, what means a 30.2% for the longshore one and a 12.5% for the transverse one. The diurnal band amounts to 20.6% and 6.5% respectively for the longshore and transverse components.

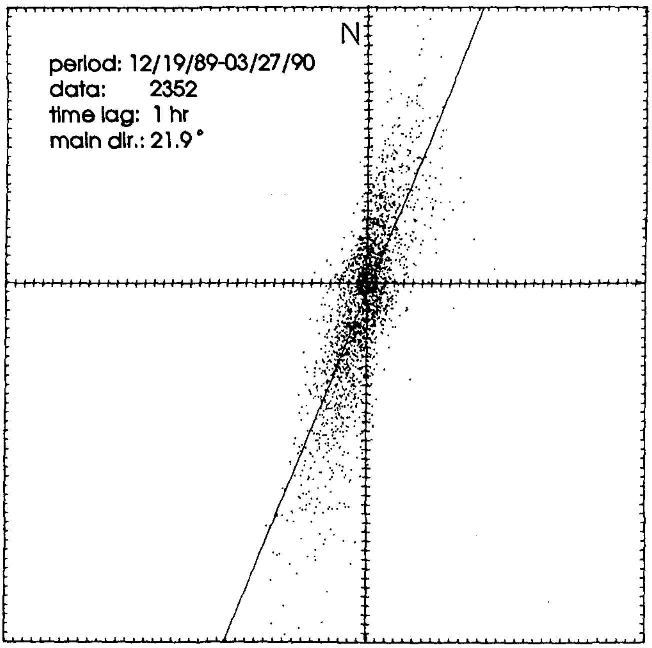

Figure 2.- Polar diagram of currents at the Port of Las Palmas. Depth: 15 m

In the polar representation (fig. 2) it may be seen that the main direction of the current is almost North-South, with a certain asymmetry: data toward the south and with high speed are deflected to the east, probably due to the gradient currents generated after the strong and persistent trade winds blowing to the south and given rise to an over-elevation at the coast.

The amplitudes and phases of the main tidal constituents in the 3 stations are shown in table 2. It can be seen the relative importance of the semidiurnal and diurnal terms. The stability of the tidal constituents was obtained after analyzing monthly records. The greatest deviations correspond to the S_2 constituent, what suggests that this band may be affected by non-tidal phenomena. Some characteristics of the tide at Las Palmas can be deduced from table 3. The ratio $(K_1+O_1)/(M_2+S_2)=0.11$ means a semidiurnal tide.

With respect to the currents, table 4 offers the characteristic parameters of the ellipses of the main constituents (after Godin, 1972): major and minor half-axis, angle with respect to the East-West axis and rotation sense. The axes of the main constituents are orientated parallely to the coast.

	Station 1		Station 2		Station 3	
	H(cm)	G(°)	H(cm)	G(°)	H(cm)	G(°)
MSF	0.87	254.8	1.25	251.2	1.64	61.5
$2Q_1$	0.78	317.4	0.73	158.1	0.15	297.6
O_1	4.91	81.0	4.62	268.8	4.95	278.4
NO_1	0.31	194.5	0.68	320.7	0.47	246.1
K_1	6.70	204.0	5.90	7.6	6.05	40.9
N_2	16.72	329.6	14.76	323.5	13.23	348.6
M_2	61.28	343.6	71.01	338.4	73.45	0.4
S_2	29.66	16.8	22.02	7.3	31.07	35.8
MO_3	0.05	295.2	0.09	76.2	0.10	173.6
M_3	0.43	236.1	0.55	67.3	0.49	114.8
M_4	0.66	353.5	0.64	21.0	0.75	47.8

Table 2.- Tidal constituents at the various stations
(H: amplitude; G: phase Greenwich)

	M_2/S_2		K_1/O_1		$\frac{K_1+O_1}{M_2+S_2}$		K_1/NO_1	
Analyses Six Months	2.67		1.31		0.11		21.77	
Analyses Monthly	Mean	σ	Mean	σ	Mean	σ	Mean	σ
	2.69	0.24	1.31	0.08	0.11	0.01	35.42	26.63

Table 3.- **Characteristics of tide at the Port of Las Palmas**

	Station 1				Station 2				Station 3			
	M	m	θ	*	M	m	θ	*	M	m	θ	*
MSF	1.59	0.01	137.7	A	0.69	0.16	23.0	C	1.77	0.12	76.8	A
$2Q_1$	0.60	0.02	139.9	C	0.35	0.13	47.3	A	0.12	0.02	79.8	C
O_1	1.44	0.06	137.2	A	0.16	0.01	94.7	C	0.36	0.08	63.6	C
NO_1	0.81	0.02	131.6	C	0.41	0.16	179.4	A	2.26	0.48	76.8	C
K_1	3.07	0.05	137.1	C	0.29	0.08	15.3	A	2.44	0.30	75.3	C
N_2	0.89	0.04	134.7	C	0.48	0.08	28.7	C	0.63	0.07	86.0	C
M_2	2.78	0.04	139.8	A	1.96	0.03	26.6	A	5.7	0.24	75.7	C
S_2	1.23	0.11	144.8	A	0.72	0.22	19.9	A	2.60	0.08	74.2	C
MO_3	0.05	0.01	110.4	C	0.21	0.03	36.2	C	0.30	0.03	85.3	C
M_3	0.04	0.01	115.5	C	0.29	0.07	34.2	A	0.24	0.18	112.9	C
M_4	0.15	0.01	118.8	A	0.88	0.01	35.3	A	0.62	0.03	82.3	C

Table 4.-**Ellipses of the current constituents at the various stations. Depth 15 m.**
M: major half-axis; m: minor half-axis; Θ: inclination
**: sense of rotation (C: clockw.; A: anticlockw.)*

The stability of the characteristic parameters is shown in table 5, where their amplitudes and phases can be seen. As usual, the stability of the surface displacements is higher than the stability of the currents. Nevertheless, S_2 makes an exception.

The ratio between tidal amplitudes and current amplitudes for the diurnal and semidiurnal bands is not a constant. It gives a significantly higher value for the constituents NO_1 and $2Q_1$ (more important for the first one),

		A (cm)				G (°)			
		Mean	σ	Max	Min	Mean	σ	Max	Min
MSF	u	0.26	0.24	0.67	0.07	227.1	85.3	301.2	183.8
	v	1.20	0.89	2.36	0.14	244.3	91.6	331.4	158.2
$2Q_1$	u	0.28	0.20	0.59	0.09	184.5	60.2	220.7	140.6
	v	0.95	0.49	1.56	0.21	148.1	50.2	170.8	110.1
O_1	u	0.43	0.16	0.53	0.15	172.1	30.0	190.3	155.3
	v	1.31	0.51	1.91	0.50	142.7	20.6	158.3	138.5
NO_1	u	1.18	0.38	1.66	0.67	136.1	40.7	150.8	100.1
	v	3.23	1.15	4.13	1.50	90.7	30.8	110.7	58.4
K_1	u	0.52	0.24	0.90	0.30	38.9	18.1	49.3	22.1
	v	2.33	1.18	3.69	0.62	12.3	11.1	22.4	1.9
N_2	u	0.46	0.14	0.66	0.30	359.6	25.7	358.9	330.4
	v	1.75	0.68	2.79	0.88	302.1	18.8	309.4	298.4
M_2	u	2.10	1.20	4.02	0.98	288.1	27.1	290.6	254.3
	v	6.77	1.46	8.32	4.37	278.0	15.6	283.4	268.1
S_2	u	0.67	0.24	0.94	0.37	12.5	10.5	17.2	4.5
	v	2.45	1.12	3.73	0.87	6.0	10.1	9.1	0.3
MO_3	u	0.23	0.08	0.31	0.10	297.7	30.3	320.0	253.2
	v	0.46	0.08	0.53	0.33	245.9	22.3	250.6	222.8
M_3	u	0.37	0.28	0.84	0.08	243.7	25.7	259.7	220.4
	v	0.82	0.83	2.26	0.25	143.4	18.9	155.2	130.6
M_4	u	0.44	0.52	1.33	0.06	79.5	30.2	100.8	50.1
	v	1.08	0.82	2.50	0.45	60.1	15.2	71.8	46.2

Table 5.- Stability of current constituents at the Port of Las Palmas from monthly analyses. Depth 15 m

	M_2/S_2		K_1/O_1		$\frac{K_1+O_1}{M_2+S_2}$		K_1/NO_1	
Analyses Six Months	2.72 (2.83)		1.78 (1.84)		0.39 (0.34)		0.72 (0.64)	
Analyses Monthly	Mean	σ	Mean	σ	Mean	σ	Mean	σ
	3.3 (3.1)	2.1 (1.6)	3.2 (3.2)	2.4 (2.4)	0.39 (0.34)	0.04 (0.03)	0.83 (0.93)	0.4 (0.5)

Table 6.- Characteristics of currents at the Port of Las Palmas. N-S component at 15 m. *Major half-axis of the ellipse: ( )*

what is coherent with the presence of non-tidal terms. Some characteristics of the currents can be appreciated in table 6. Although the ratio $(K_1+O_1)/(M_2+S_2) = 0.39$ suggests a mixed tidal current with semidiurnal predominance, the high value of the NO_1 constituent or other waves with close frequencies causes a certain modulation with diurnal effect, which in certain occasions results in more energy in the diurnal band than in the semidiurnal one.

Results of spectral analysis

The spectral analysis of the records confirms the information given by the harmonic analysis. Figure 3 shows a typical spectrum of the longshore component of the current, at 15 m depth and corresponding to station No. 3 (Port of Las Palmas). Maxima corresponding to diurnal, semidiurnal, third-diurnal, quarter-diurnal periods, etc. can be observed, as well as low frequency maxima for 38 hrs., 50 hrs. and 4.7 days. Analogous results are obtained for depth 30 m.

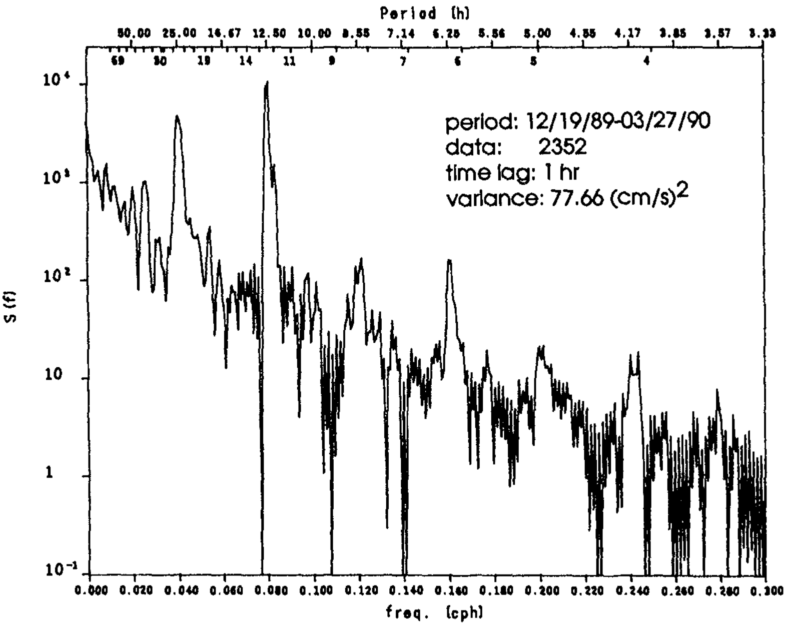

Figure 3.-Power spectrum of the longshore component (N-S) of the current at the Port of Las Palmas. Depth 15 m

In the transverse components of the current (fig. 4) there is less energy and the ratio signal/noise is lower, for what only for the diurnal, semidiurnal, third-diurnal and quarter-diurnal bands maxima are well defined.

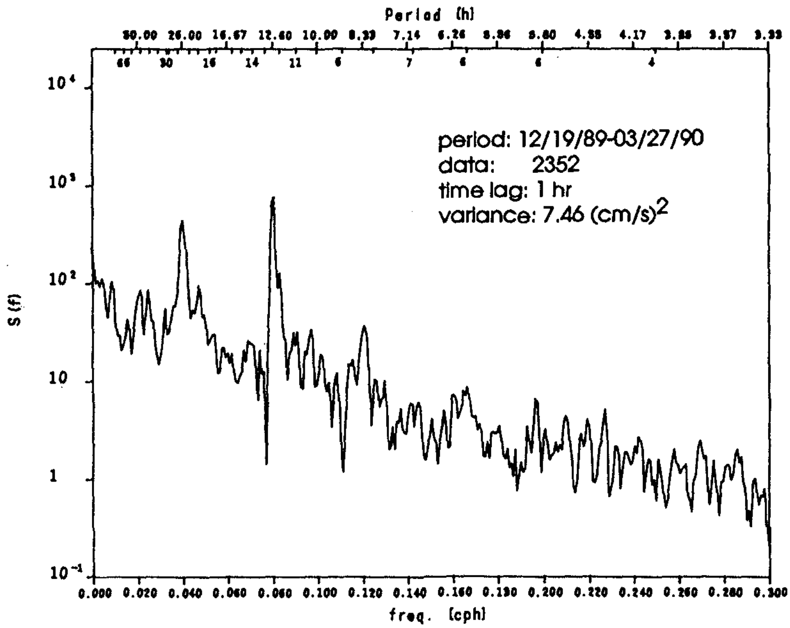

Figure 4.-Power spectrum of the transverse component (E-W) of the current at the Port of Las Palmas. Depth 15 m

Cross-spectra between the series at 15 m and at 30 m below the surface allow to deduce a high coherence (fig. 5), and the phase shift is negligible in the most significant frequencies. Rotary spectra for both depths confirm the clockwise rotation in the astronomical frequencies. So a barotropic movement may be inferred.

In order to correlate the meteorological variables with the currents, the power spectra of the atmospheric pressure and temperature were computed. Figure 6 shows the power spectrum of the pressure. Perhaps surprisingly, the similitude in the energetic distribution is quite high, and what is more, there are maxima at the diurnal, semidiurnal, third diurnal, quarter-diurnal bands, etc. This is not common at all, and a similar trend may be observed in the temperature.

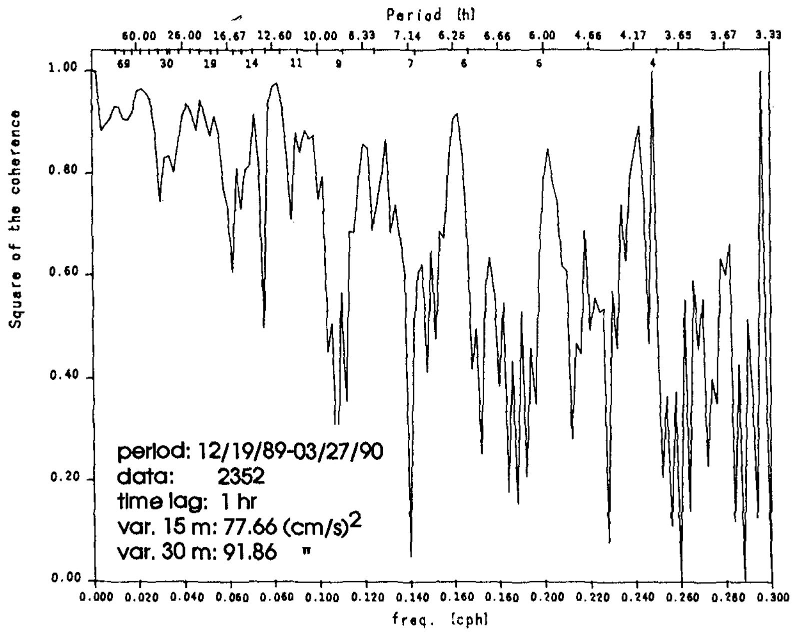

Figure 5.-Cross spectrum of the longshore components (N-S) of the current at the Port of Las Palmas at 15 and 30 m.
Square of the coherence function.

Nevertheless, wind analysis does not provide significant results with respect to this phenomenon, but it may be explained taking into account the strong energy and persistence of the trade winds, which mask weaker terms such as breeze.

Other results

When comparing monthly analyses with the analysis of the whole record, two other significant results appear:

- The constituents with frequencies close to 0.0263 cph use to appear in all records.

- While in the complete half-year record of currents the semidiurnal band has more energy (almost 40% of the total energy) than the diurnal one (25%), in some monthly analyses both bands seem to have similar amounts of energy and, in some cases, the diurnal band even overtake the semidiurnal one. The only logical ex-

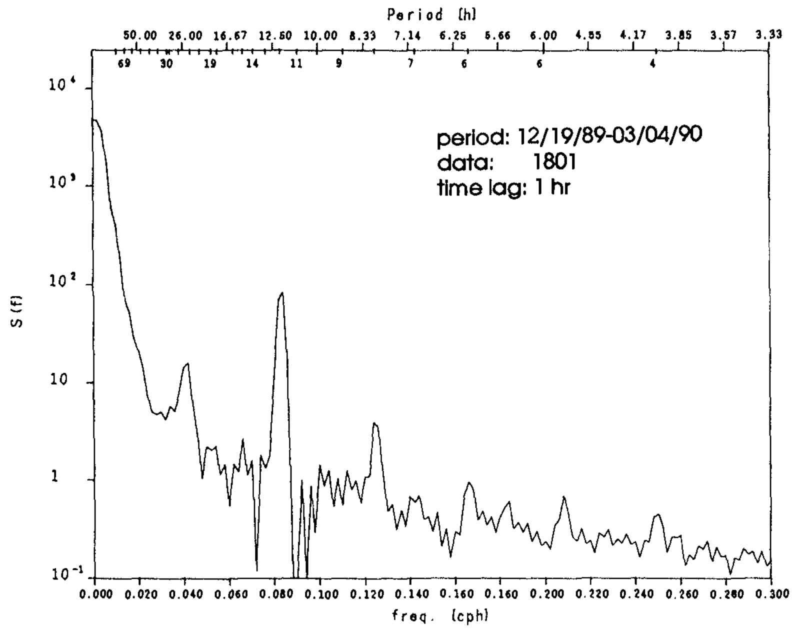

Figure 6.-Power spectrum of the atmospheric pressure at the Port of Las Palmas

planation for this phenomenon is the presence of non-tidal terms in the diurnal band, what is not strange as the inertial frequency is here 0.0391 cph.

In order to catch this wave, analyses were focussed on sections of the records that fulfil the conditions of having more energy in the diurnal band than in the semi-diurnal one and corresponding to neap tide, with the aim of getting the highest signal/noise ratio.

An example of this occurred between the 15th of February and the 4th of March of 1990 (fig. 7). The energy in the diurnal band is 36.9% and in the diurnal one is only 26.3%. Tides were in the neap cycle. In this period, harmonic and spectral analysis provide different importance for the astronomical constituents. The term NO_1 is the paramount one by spectral analysis, but it is of second order by harmonic analysis. So, one may deduce that a wave with frequency close to that of the NO_1 term is present. Its former energy need not be strong, as non-linear interaction and resonance with the astronomical term may give rise to the significant peak reached in the spectrum.

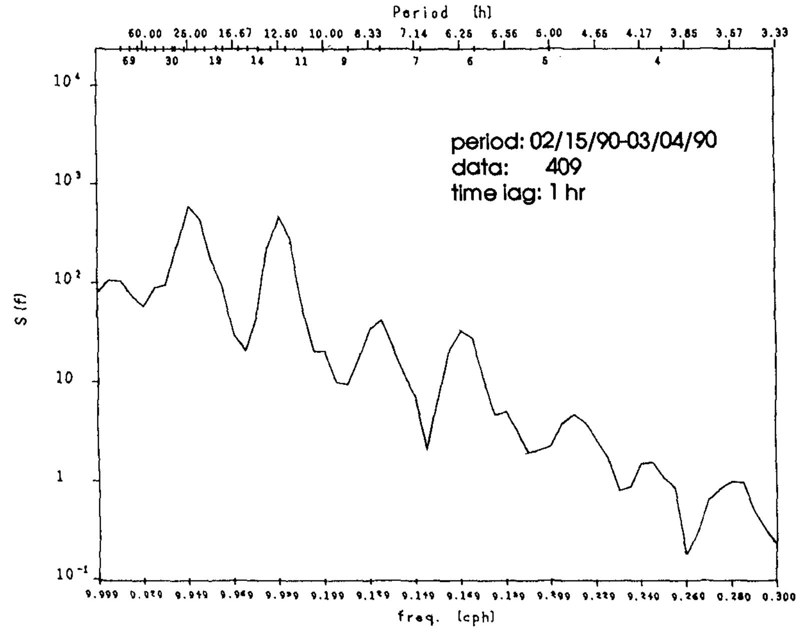

Figure 7.-Power spectrum of the longshore component (N-S) of the current at the Port of Las Palmas. Depth 15 m

An iterative approach was used in order to define the parameters of this wave. A scanning of the frequencies between the O_1 and the K_1 on the residual series resulting after substracting the predicted series due to astronomical terms only from the recorded series (Pugh and Vassie, 1976), and fitting by least squares, gives an amplitude of 2.16 cm/s (for the major half-axis) and a frequency of 0.0398 cph, very close to the inertial frequency 0.0391 cph. The generation and propagation of this wave are presently being studied, but a rotary, Kelvin wave is assumed, as water over-elevations are negligible. After substracting this term to the observed series, the results of the spectral analysis are normal and they are coherent with those obtained by harmonic analysis.

Finally, it is interesting to compare the power spectra of currents and meteorological variables (fig. 8).

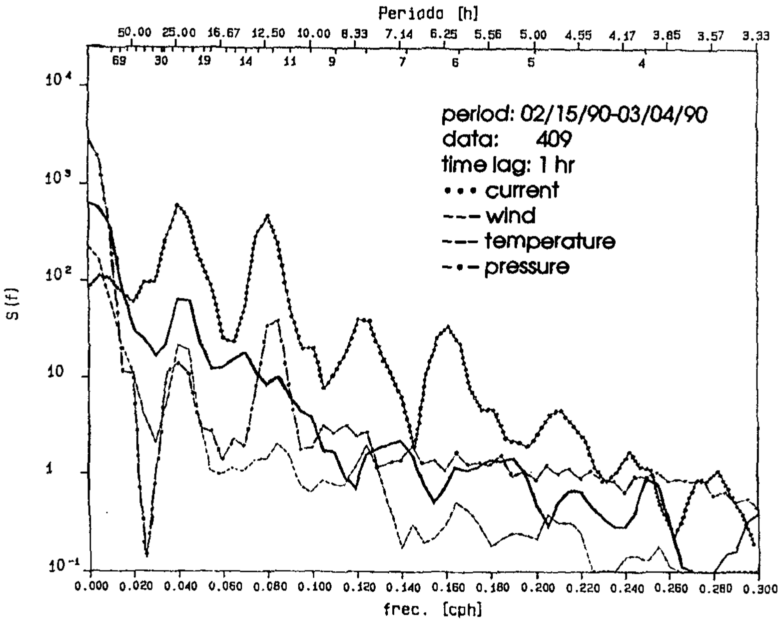

Figure 8.-Power spectra of the longshore components (N-S) of the current at 15 m and the wind, the atmospheric temperature and the atmospheric pressure at the Port of Las Palmas

Conclusions

As main conclusions of this work, we can underline:

- The characteristics of the tides and currents use to be astronomically dominated, with a clear influence of the wind in the layer close to the surface.

- A non-permanent term appears in certain intervals of the current records. This term is identified as a long wave with a frequency very close to the inertial one. As there is small correspondence with the elevation of the surface, a rotary wave is assumed.

- Rather surprisingly, the periodicities involved in the meteorological variables go beyond the traditionally assumed ones, showing a pattern very similar to that of the oceanic tide and currents. This important observation agrees with other recent observations (Cartwright *et al.*, 1985), and suggests a higher importance of the meteorological tides or/and a strong interaction sea-air.

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