CHAPTER 17

Wave Climate off Rio de Janeiro

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ABSTRACT

The objective of this work is to understand the evolution and main features of the wave climate in the offshore area off Rio de Janeiro State - Brazil, using point measurements. Several spectral models are compared with the data and criteria based on Jonswap and Mitsuyasu relationships are established to identify situations of combined sea and swell from different directions. The Toba model is used to get friction wind values from the spectra for comparison with measured winds. After understanding the main features of the wave climate and using visual observations for wave direction and the spectral information, a distribution of average energy vs direction is calculated.

1. INTRODUCTION

The offshore area northern off Rio de Janeiro State (fig. 1a) is a big oil production region known as Campos basin. In some locations oil is being exploited in water depths of 400 meters, among the largest in the world and new promising fields shall be exploited above 1000 meters. The design and operation of structures and other oceanic systems for such depths is being a big challenge for ocean engineers and the knowledge of environmental conditions is of paramount importance. Wave data is still scarce in the area mainly that concerned with directional spectra.

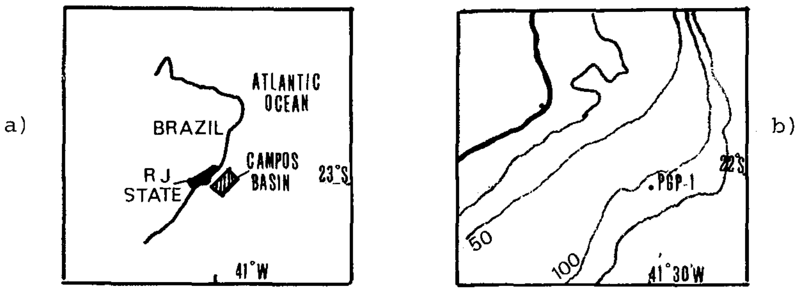

Figure 1.a) The Campos basin; b) Offshore plataform PGP-1

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The weather in the basin is dominated by the presence of a tropical anticyclone and periodically visited by cold fronts and polar masses coming from the south.

This work is an attempt to describe the evolution and main features of the wave climate from point measurements and visual wave direction observations. Several criteria are established for the identification of the different situations most of them of combined seas and swell.

2. DATA ACQUISITION AND ANALYSIS

The wave and wind data used in this work was acquired from May 1984 to June 1985 in an offshore platform in the Campos basin (PGP-1) located as shown in fig.1b. The related information is resumed below.

Wave staff: discrete resistive - magnetic coupling

measurement period:	26.09 minutes
measurement interval:	3 hours
wave direction:	visual observation
wind sensor:	cup anemometer and vane
local depth:	130 mts
FFT analysing period:	17,06 minutes
sampling frequency:	1 Hz
number o samples:	1024
degrees of freedom:	50

Two wavestaffs were used and according to the wave direction the best record was selected.

3. A BRIEF METEOROLOGICAL PICTURE OF THE AREA

The region is deeply influenced by the South Atlantic anticyclone. A typical good weather chart is shown in fig.3a. NE moderate winds and relatively large fetches are common at these times. Polar masses coming from the South reach periodically the region.

a) b)

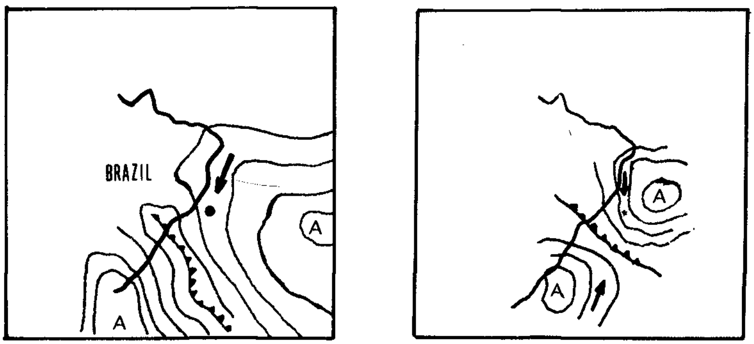

Figure 3. a) good weather; b) cold front approaching

The wind changes sucessivelly from NE to NW and to SW. With strong SW winds and large fetches, big swells and rough seas occur in the area. Fig.4 shows the cold front approaching, producing a strong, limited fetch, NW wind. After the passage of the cold front, SE winds can blow for hours and even days producing big swells in the region. Fig. 4 illustrates this situation.

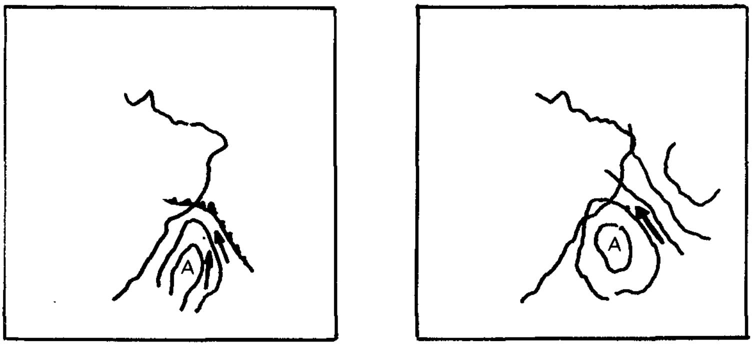

Figure 4. cold front passing over Campos basin

4. SPECTRAL MODELS

The meteorological situations can produce a combination of sea and swell from several directions; by fitting spectral models to the data we try to identify these different contributions in order to have a better understanding of the wave climate.

4.1. THE PIERSON-MOSKOWITZ MODEL (PM)

The PM model for well developed seas, proposed in 1964, is used here to indicate a limiting value for the nondimensional peak frequency. Below this value one considers a developed sea and the presence of swell. The formulation is:

$S(f) = \alpha g^2 (2\pi)^{-4} f^{-5} \exp [-5/4 (f/f_m)^4]$, where:

$\alpha = 8.1 \times 10^{-3}$ - Phillips constant;

$f_m = (2\pi)^{-1} (4 \beta/5)^{1/4} g (U_{19.5})^{-1}$ - peak frequency;

$U_{19.5}$ = wind at 19.5 mts ; $\beta = 0.74$

$\tilde{f}_m = f_m U/g$ - non dimensional frequency

$\tilde{f}_m = 0.14$ for $U_{19.5}$ and $\tilde{f}_m = 0.13$ for U_{10}

4.2. THE JONSWAP (J) MODEL

For fetch limited seas Hasselmann et alli (1973) proposed the JONSWAP model named after an experiment in the North Sea; This model fits a spectrum to the wave data. The formulation is:

$$S(f) = \alpha\, g^2 (2\pi)^{-4} \exp\left[-5/4\, (f/f_m^2)^{-4}\right] \gamma^{\exp[-(f-f_m^2)/2\sigma^2 f_m^2]} \qquad [1]$$

α = scale factor; f_m = peak frequency; γ = scale factor

σ = shape factor

A shape parameter λ is defined as: $\lambda = E\, f_m^4/\alpha g^2$ [2]

E = Energy of the spectrum ; α is calculated by:

$$\alpha = (0.65\, f_m)^{-1} \int_{1.35 f_m}^{2 f_m} (2\pi)^4 f^5 g^2 \exp[5/4\, (f/f_m)^4]\, S(f)\, df \qquad [3]$$

γ is calculated from α and S(f):

$$\gamma = S(f_m)\, (2\pi)^4\, f^5\, e^{(5/4)}\, (\alpha g^2)^{-1} \qquad [4]$$

Hasselmann and alli (1976) have shown that for developing seas λ has an average value of 1.3×10^{-4} with a small scatter.

Considering that E and f_m are parameters measured with confidence if the data quality is good. We decide to compare the value of α obtained from relation [3], called now α', with the one from relation [2] called now α_h .

If there is only a local sea in the area the values of α' and α_h must be very close. If there is a swell mixed with a local sea α' is bigger than α_h. In some situations a peak in the high frequency region due to a mixture of two seas may cause $\alpha_h > \alpha'$. Fig. 5 illustrates these situations.

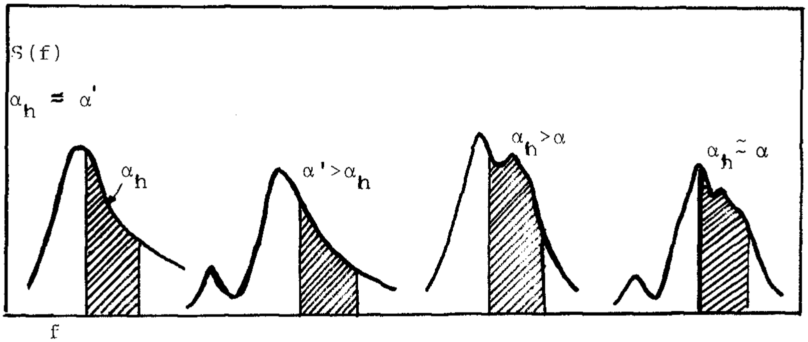

Figure 5. α' and α_h for different situations

In the last example d) we may have a compensation caused by the two effects and both values can remain very close. This comparison of α_h and α' was used to help in the selection of pure and combined seas. See Souza (1988).

4.3. JONSWAP ANO MITSUYASU RELATIONSHIPS

Several nondimensional parameters are used in the data modelling:

$\tilde{f}_m = f_m U_{10}/g$ = non dimensional peak frequency

$\tilde{E} = E g^2/4$; $\tilde{F} = F g/U_{10}^2$

where F is the fetch, E the energy of the spectrum, f_m the peak frequency and U_{10} the wind at 10 mts.

Hasselmann proposed (1976) the following relationships between these parameters:

$$\tilde{f}_m = 2.84 \times \tilde{F}^{-0.3} \quad [5]$$

$$\alpha = 6.62 \times 10^{-2} \tilde{F}^{-0.2} \quad [6] \qquad \alpha = 3.3 \times 10^{-2} \tilde{f}_m^{2/3} \quad [7]$$

$$\tilde{E} = 5.3 \times 10^{-6} \tilde{f}_m^{-10/3} \quad [8]$$

Mitsuyasu (1980) after experiments in bays and lakes suggested:

$$gE^{1/2}/u_*^2 = 1.31 \times 10^{-2} (gF/u_*^2)^{0.5}$$ and

$$f_m u_*/g = (g F/u_*)^2$$

where u_* is the friction wind

Using $u_* = CD\ U_{10}$ and CD, the drag coefficient, as 1.6×10^{-3} he arrived to the following relationships:

$$\tilde{E}^{1/2} = 5.24 \times 10^{-4} \tilde{F}^{1/2} \quad [9] \qquad \tilde{f}_m = 2.92 \times \tilde{F}^{-1/3} \quad [10]$$

$$\tilde{E} = 6.84 \times 10^{-6} \tilde{f}_n^{-3} \quad [11]$$

The dimensional form of [11] is $E f_m^3 = 6.84 \times 10^{-6} gU_e$. Using E and f from the data an effective wind (U_e) can be calculated for the area. Differences between tne two formulations can be explained by the use of different values for CD (J uses 1.0×10^{-3}).

4.4. THE TOBA MOOEL

The wind was measured at 40 mts. In order to improve the wind values and have more confidence when using the relationships for the nondimensional parameters, we used the model proposed by Toba (1978) for the high frequency part of the spectrum, to calculate u_* and U_{10}. The formulation is:

$$S(f) = \alpha' (2\pi)^{-3} g u_* f^{-4} \quad \text{for} \quad f > f_m \qquad [12]$$

$\alpha' = 8.7 \times 10^{-2}$ (value suggested by Mitsuyasu (1980)

u* is calculated from:

$$u_* = (0.8 f_m)^{-1} \int_{1.2 f_m}^{2 f_m} (\alpha' g)^{-1} S(f) (2\pi)^3 f^4 df \qquad [13]$$

From u* we calculate U_{10} using u* = CD U_{10}. For the calculation of CD we used the formula proposed by Garratt (1977) based in another one by Charnock adapted for an interval for U between 4 and 21 m/s.

$$CO \times 10^{-3} = 0.75 + 0.067 u_* \qquad [14]$$

We can correct U_{10} to 40 meters by:

$$U_{40} = U_{10} (1 + (1/0.4) \sqrt{CO} \ \ell n (40/10)) \qquad [15]$$

and compare with the measured wind V40

5. RESULTS ANO OISCUSSIONS

5.1. CALCULATEO PARAMETERS

The following parameters were calculated for each record: f_m (peak frequency), E (energy) H_S (- significative wave), u*, f_m*=f_mu*/g, f_m, E*=Eg/u*, F, U_{10} - wind at 10_m from u*, CO, V_{10} - measured wind reduced to 10_m, α', α and.

5.2. WINO CALCULATIONS ANO COMPARISONS

For sea states free of swell, produced by local winds over small fetches it was possible to compare the wind at 10_m calculated from u* (U_{10}) with the wind at the same heigth (V_{10}) reduced from the wind measured at 40_m (V_{40}). Table 1 below shows values of U_{10}, V_{10}, U_e and CO for situations of local winds and small fetches. The agreement is considered good, the differences being due to innacurate values of CO, innadequacy of the correction formula or even poor quality wind measurements.

V10	U10	Ue	CD	V10	U10	Ue	CD
14.5	14.4	14.0	1.7	12.1	14.4	13.8	1.7
13.3	15.0	15.4	1.8	12.9	14.5	16.9	1.7
13.4	15.0	16.9	1.8	12.0	15.2	17.9	1.8
12.2	13.6	-	1.7	11.2	14.3	17.8	1.7
12.0	16.9	-	1.9	13.4	14.7	14.5	1.7
15.5	17.4	-	1.9	13.4	13.1	14.5	1.6
13.3	16.6	-	1.9	13.4	12.7	13.6	1.6
9.1	12.0	13.3	1.5	16.0	13.6	13.1	1.7
13.4	14.5	14.7	1.7	10,8	14.4	15.9	1.7
14.3	14.8	16.2	1.7	11.7	12.2	13.6	1.6
12,9	13.7	12.4	1.7	9.0	12.3	13.3	1.6

Table 2 - Wind Comparisons

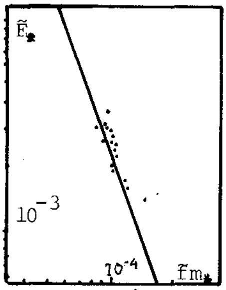

Figure 7. $\tilde{E}_*$ vs $\tilde{f}m_*$

Using relation [11] from Mitsuyasu we can evaluate the quality of the u* values as shown in fig.7 above. The data points refer to situations without swell.

5.3 - COMPARISONS OF α with $\tilde{f}_m$ and $\tilde{F}$

Fig. 8 shows plots of α vs $\tilde{f}_m$, α vs $\tilde{F}$ and γ vs $\tilde{F}$ for the selected situations. The basic criterium for this selection is α' close to α_h

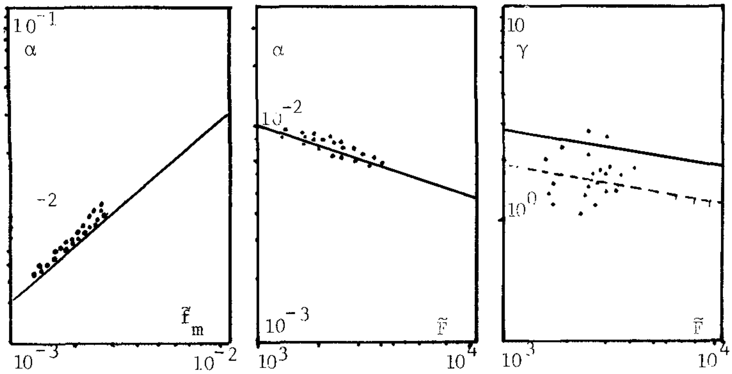

Figure 8. Comparison between parameters

5.4. CRITERIA FOR SELECTION OF SEA STATES

The following criteria were used to identify the different sea states in the area:

a) fetch limited seas: high values of u*, f_m* and αh; αh close to α' .
b) developed seas: f_m < 0.13; u* values indicating local sea and sufficient wind duration.
c) swell (unimodal): no local wind; low values of f_m*, αh and α'
d) fetch limited sea and swell: α'>>αh; high vslues of f_m*.

5.5. ENERGY DISTRIBUTION

Using visual observations and establishing several criteria to separate different combinations of sea and swell it was possible to calculate a daily average of energy distribution per 22.5 degrees sector for every month. A computer program was written to compare values of α' and α_h and with this information and taking into account the peak frequency value to verity the quality of the visual observations and also the make a partition of the energy between the sectors. Table 2 below show this result.

MONTH	000	022	045	067	090	112	135	157	180	202	225	247	270	292	315	337
JUN	1	2	8	15	0	14	142	135	14	14	21	0	10	7	0	38
JUL	5	62	65	45	72	35	80	124	130	320	63	12	5	0	5	0
AUG	11	74	46	36	0	5	0	35	147	364	0	0	0	0	0	0
SEP	0	8	20	33	67	37	28	54	97	48	4	2	1	0	1	6
OCT	0	13	13	12	18	16	45	67	78	64	63	1	0	0	0	0
NOV	3	0	19	78	51	3	25	33	20	20	0	0	0	0	0	0
DEC	17	55	27	11	27	45	11	43	45	64	8	14	0	0	0	0
JAN	13	73	46	2	0	0	11	22	25	26	5	1	2	3	2	4
FEV	14	28	49	10	9	13	14	31	32	25	0	5	0	0	0	0
MAR	10	9	22	20	17	27	6	72	77	69	35	0	0	0	0	1
APR	2	19	10	6	54	18	42	94	100	76	0	0	0	1	0	0
MAI	5	8	38	24	15	24	12	91	110	98	2	3	8	2	0	4

Table 2 - Energy distribution - daily average in kw-hr per sector.

6. CONCLUSIONS

The techniques presented in this work made possible to characterize the main features of the wave climate in the Campos basin based on wave data from point measurements.

The comparison of α_h and α' and the calculation of U_{10} from u_* produced good results and made possible an automatic identification of different sea states.

The South Atlantic anticyclone has an strong influence in the wave climate of the basin. The good weather prevails most of the time with NE winds and a combination of velocity and fetch in such a way that peak periods are allways less than 7.5 seconds.

When the cold front is approaching the intensification of the NE wind is associated with small fetches so that again the peak period remains under 7.5 seconds.

The cold front bring strong SW winds and large fetches producing rough seas and peak periods between 11 and 15 seconds. When the front passes can produce SE winds with moderate fetches. A swell from SE occurs very often with the NE wind blowing again and closing the cycle.

7. BIBLIOGRAFY

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