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SEA TRIALS OF A PROTOTYPE OF A DEEP-SEA TIDE GAUGE

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SUMMARY

In 1991, SHOM carried out trials, at sea, of a prototype deep-sea tide gauge.

The trials made it possible to verify the appropriateness of a known drift model applied to the response from the PAROSCIENTIFIC pressure sensor which was fit into the prototype and to show the instrument's possibilities studies of tide and mean sea level.

1.- INTRODUCTION

In 1985, a French technical group was created to design a deep-sea tide gauge (down to 6 000 metres). This group included representatives from the MNHN (Muséum National d'Histoire Naturelle), the IMG (Institut Mécanique de Grenoble), IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer) and from SHOM.

In 1991, SHOM carried out trials, at sea, of a prototype tide gauge. The aim was to study the response of the pressure sensor of the prototype, anchored in the abyssal plain of the Bay of Biscay, using as a reference the measurements from a pressure tide gauge for shallow water, anchored close by on the continental shelf.

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2.- PRESENTATION OF THE PROTOTYPE

2.1 - General

The prototype deep-sea tide gauge was developed from technical specifications, specifying in particular the expected performance relative to the measurement of pressure and to the measurement electronics of the instrument.

The instrument constructed by the MORS Group consists of:

- a PAROSCIENTIFIC system for pressure measurement with an observation range of 0 to 69 MPa (serial number: 42 509),
- a central unit for data acquisition and storage,
- a set of lithium batteries ensuring that the tide gauge can function independently,
- an outer covering of titanium able to resist a pressure of 60 MPa (which corresponds to immersion at depths of about 6 000 metres).

2.2 - The PAROSCIENTIFIC system of pressure measurement

The pressure reading system, PAROSCIENTIFIC model 410K-101, is fitted with quartz sensors; one is sensitive to outside pressure, the other only to temperature variations. Formulae and coefficients relative to each sensor are provided by the manufacturer. The instrument provides a measurement of the outside pressure based on the vibration frequencies of the quartz sensors.

2.3 - Incertitude concerning the performance of the measurement electronics

a) Measurement of the vibration frequency of the quartz exposed to outside pressure is effected by a circuit of oscillation counts, the performance of which determines the accuracy of the measurements:

$$F = \frac{N}{I}$$

F : frequency of quartz vibration in Hertz,
N : number of oscillations of the quartz during integration,
I : duration of integration of measurement in seconds.

b) Taking account of the characteristics of the PAROSCIENTIFIC sensor, it can be considered from the following that the pressure P exerted on the quartz is proportional to the frequency F:

$P_{(hPa)} \approx 200.(F - F_o)_{(Hz)}$ (F_o close to 35 kHz is the nominal frequency of quartz)

One error corresponds to an error in counting the oscillations (the number is known to within one oscillation). The counting error inversely proportional to the duration of integration, is of the order of 0.3 hPa for I = 10 min.

A second error represents the uncertainty linked with the instability of the oscillator of the time base of the oscillation-counting circuit. This error, proportional to the frequency of vibration of the quartz is of the order of 0.8 hPa for a drift relative to the oscillator of 10^{-7}.

In fact, the origin of the instability of the oscillator is essentially the variation in temperature. In great depths, the temperature varies little and is between 0°C and 5°C.

2.4 - Performance of the prototype noted in the laboratory

Study of the sensor's response from 1 000 to 27 000 hPa showed a slight reading error of the order of 0.04% (i.e. 0.4 mm per metre of tidal range).

Moreover, trials of the stability of quartz at temperature were carried out in the laboratory (at atmospheric pressure). The relative drift of the quartz observed between 0°C and 5°C is 4.10^{-8} (i.e. for I=10 min. an uncertainty of 0.3 hPa for the pressure reading).

3.- PUTTING THE EQUIPMENT TO WORK AT SEA

The installation of the equipment at sea was carried out by the survey vessel LAPEROUSE.

3.1 - Composition of moorings (Fig. 1)

The moorings for the tide gauges to be deployed on the sea bed were each composed of ballast, a cage to hold the tide gauge and a cluster of floats (for the deep-sea tide gauge: HYPER 6 floats by MORS).

The ballast is connected to the cage by two acoustic releases mounted in tandem. The functioning of one or the other of the releases dissociates the ballast from the cage. The speeds of descent and raising of the mooring are of about 1 m/s.

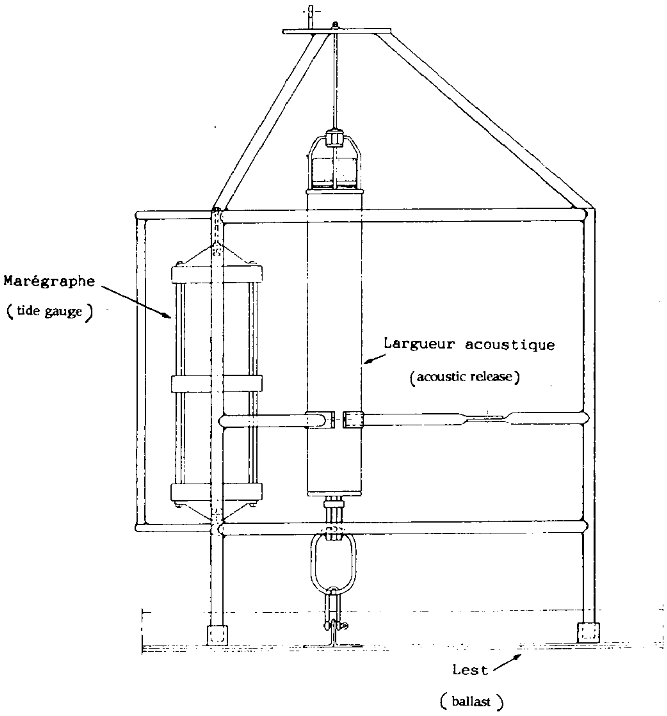

FIG. 1.- Tide gauge moorings (without the cluster of floats).

3.2 - Determination of mooring sites

For the choice of the test site, the following facts were taken into account:

- the activity of internal waves had to be slight,
- the mooring cages had to be placed on the bottom where the slope does not exceed 5% to minimise the risk of them being tipped over.

The tide gauges were put into operation on either side of the continental rise in the Bay of Biscay south of Brest. The prototype was moored at a depth of 4 340 metres at the position 46°20'N and 5°24'W, and the reference tide gauge at a depth of 160 metres at 46°46'N and 4°50'W.

3.3 - Operating conditions

The relevant measuring period, common to both gauges, was from 20 March 1991 at 15.15 (UT) to 22 May 1991 at 07.00 (UT).

The rate of sampling for readings, identical for the two tide gauges, was 15 minutes. The integration period is 4 minutes for the reference tide gauge and 10 minutes for the prototype (the latter figure is imposed by the concern to reduce uncertainty about the measurement of pressure: cf para. 2.3).

3.4 - Supplementary observations

The mean mass volume of the water (which must be known for converting pressures into water heights) were calculated by using bathythermic recordings (SIPPICAN soundings), taken at the times of mooring and reading of the tide gauges, along with data available from SHOM.

Above the continental shelf, the mean mass volume was estimated to be 1027.29 kg/m^3 on 20 March and 1027.27 kg/m^3 on 22 May, and above the abyssal plain it was 1037.633 kg/m^3 on 20 March and 1037.640 kg/m^3 on 24 May.

4.- DRIFT IN THE READING OF THE PROTOTYPE'S SENSOR

4.1 - Drift model

The Applied Physics Laboratory of the University of Washington has published the results of studies conducted on various PAROSCIENTIFIC pressure sensors. All these sensors drifted under pressure. According to the authors of the tests, the source of drift is the elastic deformation of the mechanical parts of the sensors.

This drift is repetitive, roughly proportional to the pressure readings and significant under high pressure (a few hPa in one day's observations). Above all, it is simple to express as a model equation:

$$\Delta P_p(t) = A.(t - t_0)^b + C$$

$\Delta P_p(t)$: drift under pressure P (measured pressure - exerted pressure of value P) at time t.

A, b, C: constants for pressure P.

t_0: instant at which the pressure is stabilised to value P.

Four sensors with measuring range from 0 to 62 000 hPa were studied for a period of 160 days under 56 500 hPa, giving rise to the determination of constants A, b and C.

Sensor number	A in hPa.min^{-b}	A/P in min^{-b}	b	C in hPa
1633	-19,896	-3,521.10^{-4}	0,0455	20,27
1650	-0,818	-1,468.10^{-5}	0,2035	0,63
1652	-1,972	-3,490.10^{-5}	0,1556	2,07
1654	-1,427	-2,526.10^{-5}	0,1559	1,73

4.2 - Remarks concerning the study of the drift of the sensor of the prototype

a) The comparison of the pressure readings of the tide gauges makes it possible to obtain, to within one constant, C′, the drift of the prototype's sensor:

$$\Delta P_{MGF}(t) = (P_{MGF}(t) - P_{MPF}(t)) - C' = A.(t-t_0)_b + C$$

$P_{MGF}(t)$: pressure measured by the deep-sea tide gauge
$P_{MPF}(t)$: pressure measured by the shallow-water tide gauge
$\Delta P_{MGF}(t)$: drift of the sensor of the deep-sea tide gauge
C′: constant, corresponding to the difference in the pressures exerted on the sensors of the tide gauges.

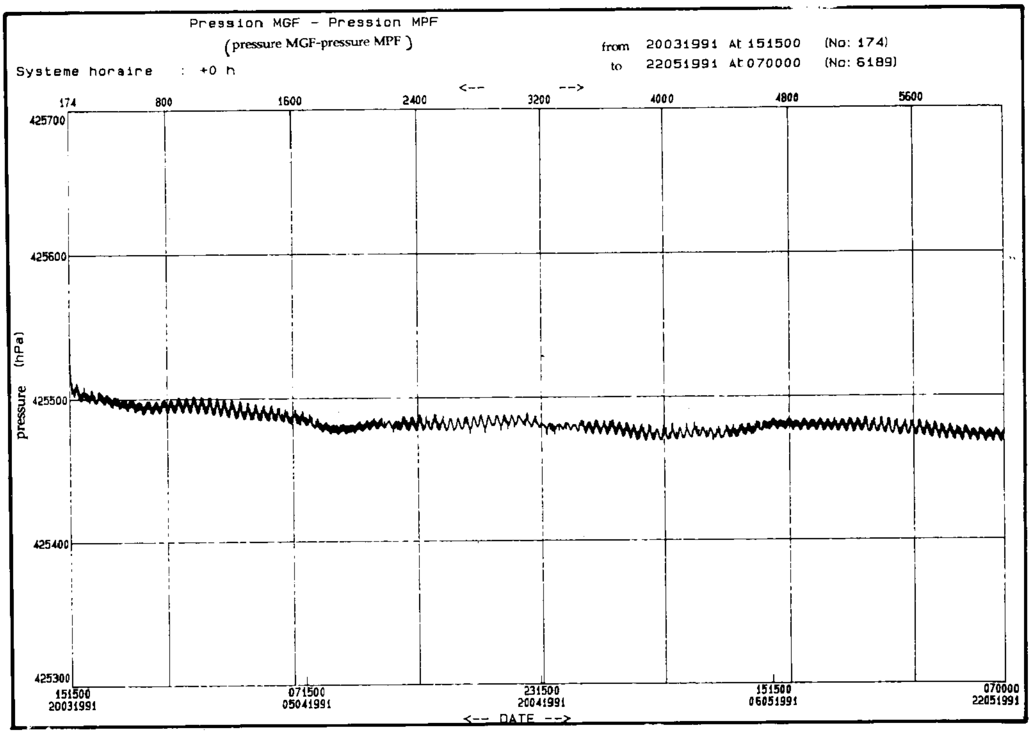

FIG. 2.- Graph of differences $P_{MGF}(t)$ - $P_{MPF}(t)$.

The hypotheses are:

- the variations in the hydrostatic pressure on either side of the continental rise are equal (in particular, the activity of internal waves is ignored),
- the readings of the shallow-water tide gauge are not affected by any drift.
- the graph of differences in measurement (Fig. 2) is evidence of the drift of the prototype's sensor but also of periodical differences (cf. para. 5.2- and 5.3-). Note

- the readings of the shallow-water tide gauge are not affected by any significant drift (this is shown in para. 5.3-).

b) C′ is only known to within several hundred hPas since the immersion of the prototype in particular is estimated to within several metres (uncertainty of the depth reading taken at the time of mooring the tide gauge).

Study of the drift of the prototype's sensor is therefore restricted to determination only of the constants A and b (the determination of C to the nearest hPa in fact supposes that C′ is known with the same precision).

The drift of the sensor thus cannot be known in the absolute. Let us note, however, that for studies of mean sea level, absolute levelling of readings is not important.

c) The instant t_0 of the stabilisation of the pressure exerted on the sensor of the tide gauge, corresponding to the moment when the tide gauge mooring stops its descent, is not known with precision: t_0 falls between 14.55 and 15.10 (UT) on 20 March 1991.

4.3 - Levelling of the drift coefficients

The levelling of the coefficients A and b is done by an iterative calculation of least squares, by adjusting the constant (C + C′) so as to minimise the standard difference among the differences between the graph of differences in measured pressure and the drift model. The calculation leads to the following values:

- for t_0 = 14.55 (UT) on 20 March,
$A = -18{,}446$ hPa.min^{-b} and $A/P_{MGF} = 4{,}2.10^{-5}$ min^{-b}
b= 0,1230
C + C′ = 425 546,9 hPa
standard deviation of adjustment of drift model: 3,68 hPa

- for t_0 = 15.10 (UT) on 20 March,
$A = -17{,}846$ hPa.min^{-b} and $A/P_{MGF} = 4{,}0.10^{-5}$ min^{-b}
b = 0,1247
C + C′ = 425 545,9 hPa
standard deviation of adjustment of drift model: 3,68 hPa

The values of A/P and b obtained are close to those determined by the University of Washington (cf. para. 4.1.-).

The two drift models obtained for the two values of t referred to above coincide to within 0.1 hPa, 5 hours after the beginning of readings and from then onwards during the whole period of measurement. Similarly, in extrapolating over two years of observations (length of autonomy of the apparatus) the drifts coincide to within better than 0.1 hPa. This shows that the uncertainty of a few minutes, linked with the imprecise determination of t_0, has very little effect on the drift quantification according to the model adopted.

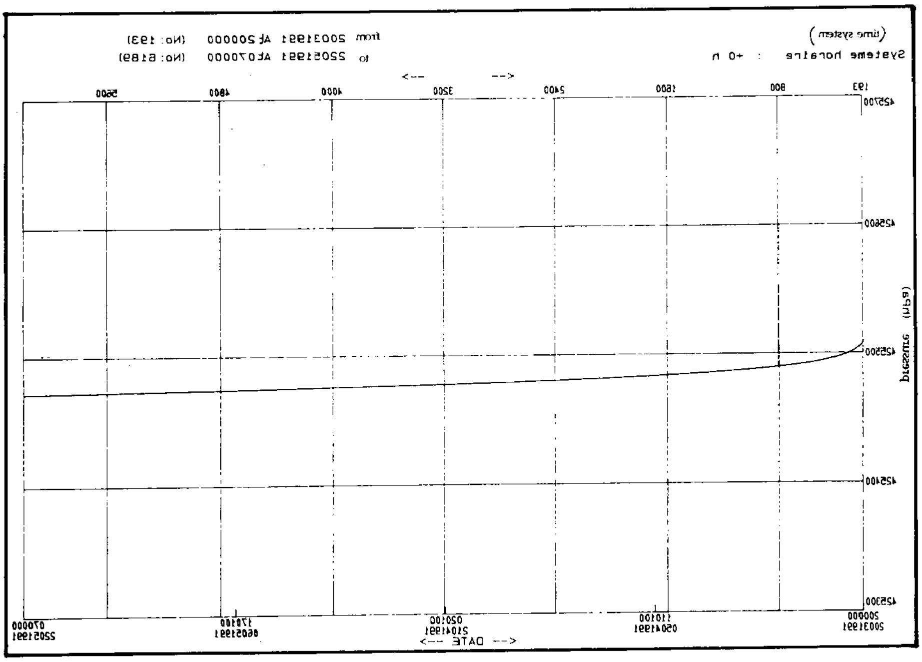

FIG. 3.- Drift obtained according to Model $A(t - t_0)^b$.

5.- STUDY OF READINGS

5.1 - Calculation of heights of water

Heights of water are calculated from pressures measured by the apparatus, the drift of the sensor of the prototype, the atmospheric pressure and the mean volumic masses:

- for the shallow-water tide gauge,

$$H_{MPF}(t) = \frac{P_{MPF}(t) - P_A(t)}{\rho_{MPF}.g}$$

- for the prototype deep-water tide gauge,

$$H_{MGF}(t) = \frac{P_{MGF}(t) - A.(t-t_0)^b - P_A(t)}{\rho_{MGF}.g}$$

g is the universal attraction.

The atmospheric pressure $P_A(t)$ is obtained by parabolic interpolation, from observations taken at the Penmarc'h semaphore (earth site close to the trials area) at a sampling rate of 3 hours.

Furthermore, the following mean mass-volumes are adopted: $\rho_{MPF} = 1027,28$ kg/m^3 and $\rho_{MGF} = 1037,636$ kg/m^3 (cf. para. 3.3_).

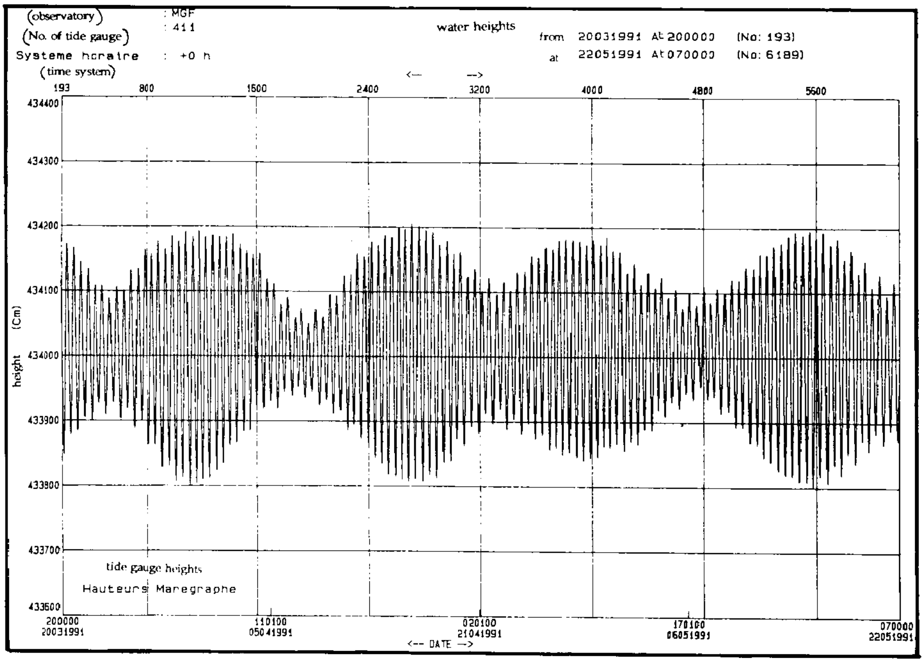

FIG. 4.- Heights of water measured by the prototype (and corrected for sensor drift).

5.2 - Comparative study of the tide

Harmonic analysis of water levels measured by the apparatus gives the following results (next page).

The analysis shows an amplification of the preponderant semi-diurnal waves M2, S2, N2 and K2 on the continental shelf.

The latter explains the semi-diurnal variations of the graph of differences between the hydrostatic pressure readings of the two tide gauges (cf. para. 4.2).

Let us specify that the differences in amplitude noted are real ones and are, therefore, not a particular consequence of the measuring conditions:

- the diurnal, semi-diurnal, ter-diurnal and quarter-diurnal tide waves have a wave length well above the depth (example: the wave length of a quarter-diurnal wave at 4 000 metres depth is greater than 4 000 km) and consequently the variations in hydrostatic pressure engendered by these are not diminished at a depth of 4 000 metres,

- the filtering of tide waves relative to the period of integration of readings - 4 minutes for the reference tide gauge and 10 minutes for the prototype - is not significant.

		Reference tide gauge		Prototype	
Wave	Speed in °/h	Amplitude in cm	Phase in °	Amplitude in cm	Phase en °
S2	30,0000	45,8	128,7	44,9	127,6
K2	30,0821	12,5	131,2	12,2	130,1
T2	29,9589	2,7	127,4	2,6	126,3
L2	29,5285	3,7	110,1	3,6	110,4
M2	28,9841	133,8	97,2	131,5	96,2
N2	28,4397	28,2	75,9	27,7	74,9
NU2	28,5126	5,5	78,8	5,4	77,8
2N2	27,8954	3,7	54,7	3,7	53,6
MU2	27,9682	4,8	48,3	4,7	46,3
K1	15,0411	6,8	65,4	7,1	65,7
P1	14,9589	2,3	57,5	2,3	57,7
O1	13,9430	6,9	319,9	7,0	319,5

A harmonic analysis was carried out on water levels obtained from readings from the prototype, uncorrected for drift.

		Prototype	
Wave	Speed in °/h	Amplitude in cm	Phase in °
S2	30,0000	44,8	127,6
K2	30,0821	12,2	130,1
T2	29,9589	2,6	126,3
L2	29,5285	3,6	110,6
M2	28,9841	131,5	96,2
N2	28,4397	27,7	74,9
NU2	28,5126	5,4	77,7
2N2	27,8954	3,7	53,5
MU2	27,9682	4,7	46,3
K1	15,0411	7,1	65,7
P1	14,9589	2,3	57,7
O1	13,9430	6,9	319,6

This verifies the fact that harmonic analysis filters the drift of the sensor: the results are, in fact, almost identical to those obtained earlier. Correcting the readings of the tide gauge for sensor drift is therefore superfluous for study of the tide.

5.3 - Study of daily mean levels

SHOM has permanent tidal observatories close to the test area, at Brest and at Port-Tudy.

As Figure 5 shows, considerable analogy can be observed between the variations in daily mean sea level at these ports and at sea (the readings from the prototype are corrected for sensor drift). It is thus ascertained, moreover, that the readings from the shallow-water tide gauge are not affected by any significant drift (cf. para. 4.2).

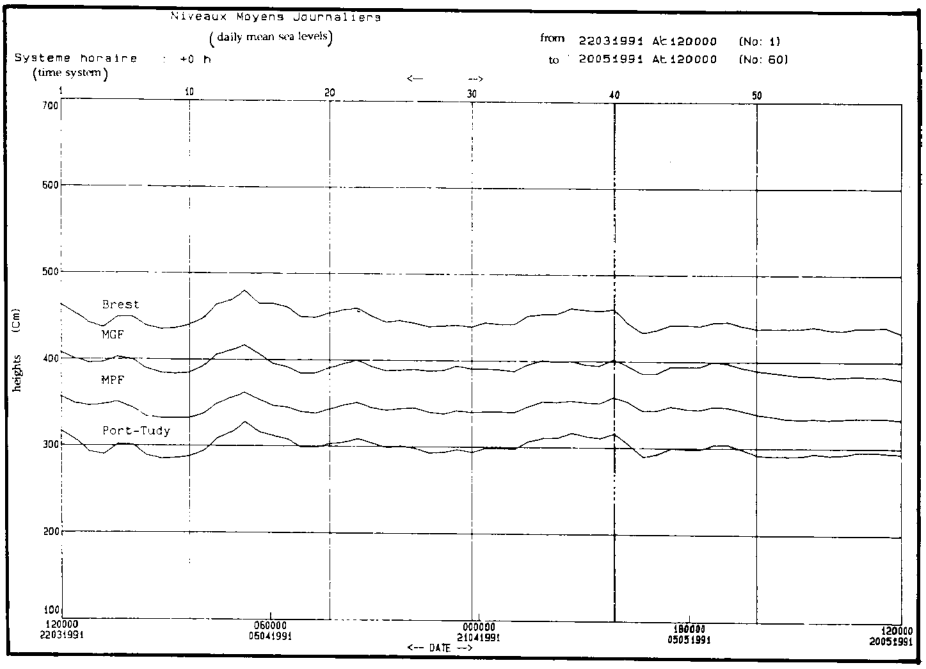

FIG. 5.- Daily mean sea levels (the readings from tide gauges at sea have been reduced by a constant so that the curves appear in the graph).

A more refined analysis of the daily mean level obtained from the readings of the deep-sea tide gauge show a variation of a few centimetres in a period close to 20 days (Fig. 6). This variation, the period of which is not characteristic of the tide, results from other phenomena (variations in density, ...).

6.- CONCLUSION

The comparison of readings from the prototype deep-sea tide gauge, anchored on the abyssal plain, with those of a shallow-water tide gauge, anchored on the continental shelf nearby, made it possible to ascertain that the drift of the PAROSCIENTIFIC pressure sensor is close to the known drift model for similar sensors, and is less than 1 hPa per day, under 440 000 hPa, beyond the seventh day of observations.

The drift, however, cannot be quantified with precision by this method. In particular, study of mean sea levels, with the help of a deep-water tide gauge, cannot be reasonably considered without a pressure tank calibration of the drift of the sensor, of its relationship to the pressure and of its repetivity.

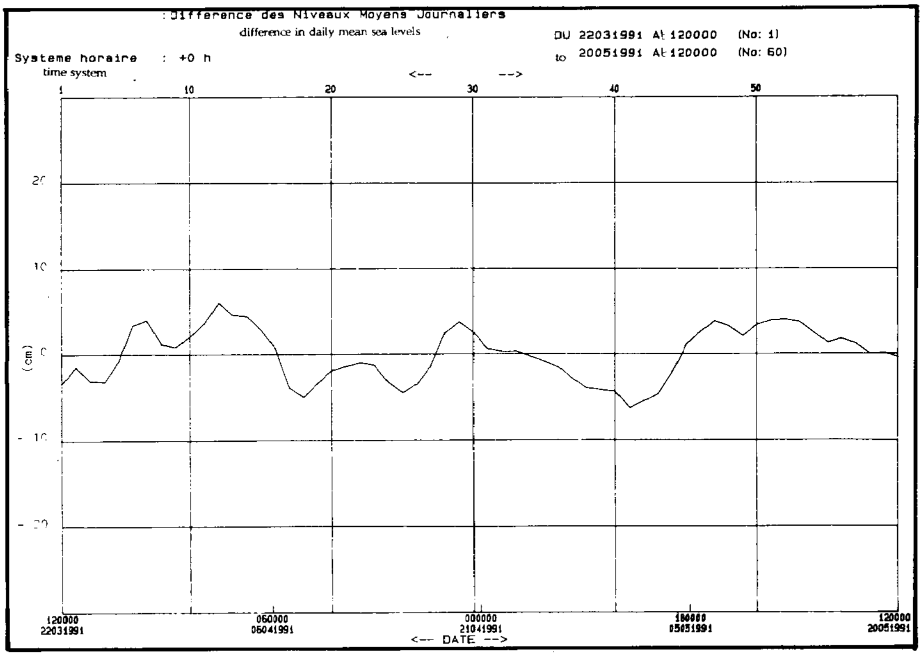

FIG. 6.- Differences between the daily mean sea levels of the tide gauges at sea.

Finally, it has been shown that for study of the tide out at sea, restricted to study of the preponderant waves, correcting the readings for drift of the sensor (and consequently quantifying such drift) is superfluous.

Bibliography

Measurement of the sensitivities and drift of Digiquartz pressure sensors - Richard B. Wear, Jr., and Nordeen G. Larson. Deep-sea Research, Volume 29, N° 1A, pp. 111-134, 1982.