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LEAST SQUARE PREDICTION APPLIED TO GRAVIMETRIC TIDES IN EUROPE

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Abstract.

The observation of gravimetric tides, which started in a systematic way from the sixties decade onwards, has come presently to cover a great part of the world surface, mainly due to the efforts of the group of Prof. Melchior (Melchior, 1982) and the realization of transcontinental profiles. The density of information existing in Europe and collected in the data bank of the International Center of Earth Tides in Brussels allows to make prediction tests on the main tides harmonics. A first work in this direction has been made for the Iberian Peninsula (Vieira, Camacho, 1988). In this communication there is an extension of such work given to a considerable part of the european continent through the application of the least square prediction method for the obtention of a model of gravimetric tides for Europe; likewise there is an study made on the security and reliability of the model functioning in the area, data density and quality of those data.

1. **Introduction. European net of tidal stations.**

The observed gravity tidal variations on a station can be expressed as:

$$\sum_i A_i \cos(\omega_i t + \varphi_i)$$

where summation is extended along lunisolar frequencies ω_i, with corresponding amplitudes A_i and phases φ_i.

For a rigid and ocean less earth the gravity tidal variations would be:

$$\sum_i A_{0i} \cos(\omega_i t + \varphi_{0i})$$

obtained directly as derivatives of lunisolar potential along local vertical direction. (lunisolar potential being calculated determining the geodetic coefficients and using a development as Cartwright-Tayler ones).

Discrepancies $A_i / A_{0i} = \delta_i$ and $\varphi_i - \varphi_{0i} = \alpha_i$ are associated to non rigidity and ocean effects of the Earth. For each wave, values A_i, α_i can be graphically represented as a vector $\mathbf{A}_i$ of polar coordinates A_i, α_i (figure 1). The usual earth model (elastic with liquid core) of Molodensky supposes $\delta_i \simeq 1.16$ and $\alpha_i \simeq 0$ everywhere and for every waves i. The vector **M** of Molodensky waves is $\mathbf{M} : (M_i = 1.16 * A_{0i},\ \alpha_i = 0)$, see figure 1.

The existing difference vector **B** between observed values and global elastic model values is mainly owen to oceanic effects (loading, newtonian and indirect effects) and to regional reologhic properties.

$$\mathbf{B}:(B,\beta) \quad = \quad \mathbf{A}:(\delta_0 A\ ,\alpha) \quad - \quad \mathbf{M}:(1.16\ A_0,\ 0\ )$$

Nowadays, oceanic effects can be calculated from adjusted models of oceanic tides as model of Schwidersky (1980). Let $\mathbf{L}:(L,\lambda)$ be the vector of externally calculated oceanic effects.

Vectors **B** and **L** will be very similar. The vactor $\mathbf{X}:(X,\kappa)$ of diference $\mathbf{X} = \mathbf{B} - \mathbf{L}$, figure 1, will be determined mainly by regional rheologic properties and deficiencies of oceanic effects model.

Finally vectors $\mathbf{M} + \mathbf{L} = \mathbf{A} - \mathbf{X}$ and $\mathbf{A} - \mathbf{L} = \mathbf{M} + \mathbf{X}$ represent: theoretic model with calculated ocean effect (as advanced model) and observation corrected with calculated ocean effect (as reduced observation).

The tidal data bank collected by the I.C.E.T. (Ducarme, 1983) let us investigate the magnitude and spatial distribution of tidal vectors. For a number of 133 stations on european area, the data file offers values of A, α, δ (and corresponding observation square errors), L, λ, B, β, X, κ, ... for main tidal waves: O1, P1, K1, N2, M2, S2 . Another interesting station values are collected: distance to sea, gravimeter identification, time of observation and useful readings, etc.

We have considered the area limited by latitudes 36° and 72° and longitudes -12° and 36° , containing 128 stations (figure 2). Any data mistake have been corrected, and also we recalculate values of B,β,X,κ.

For the spanish area we have substitute the file data by actualized values, including new stations. Two kind of oceanic effects values are available for iberian stations: those obtained from Schwidersky model and those obtained from an additional study of surrounding oceanic areas (Cantabrico, Mediterranean). For european comparisons we shall use Schwidersky data model.

A first view to data shows us a similarity between values on neighbour stations, that points a certain continuous spatial evolution. But also, we observe, specially for coastal stations, a local deviations or noise. To form spatial models we can only consider regional behavior, filtering punctual deviations. To make a signal-noise separation we use a covariance analysis, and then, by least square prediction, form the filtered and predicted values. The signal define spatial distribution and the noise can contain information about local or punctual circumstances that deviate the tidal reading.

2. Least square prediction. Example of application to κ (M2) .

To can apply least square prediction, data values must offer a random distribution. Usually data values **d** will contain a systematic part **p** :

$$\mathbf{d} = \mathbf{p} + \mathrm{v}$$

We must calculate **p** so that residual values **v** give a random distribution.

For tidal values we can suppose a systematic component. For example, observed amplitudes have a clear N-S systematic effect, while residual values X,κ probably have a very small systematic component.

A simple method to determine **p** is by polynomial approximation (Mussio,1987) of suitable degree (so that it adjusts systematic component but keeps a clear random signal).

Residual values **v** (determined on points P_i, i=1,..,n) will contain a correlated signal **s** and an uncorrelated noise **n** :

$$\mathbf{v} = \mathbf{s} + \mathbf{n}$$

Separation between **s** and **n** can be defined by means of covariance study of data, and then of signal. If we suppose an isotropic and homogeneous field, we can consider that covariance of signal **s** between two points P_i, P_j depends of the corresponding point distance d :

$$C_{ij} = \mathrm{Cov.}(\ s(P_i),\ s(P_j)\ ) = C\ (\ \mathrm{dist.}(P_i,P_j)\ )$$

The covariance C(d) for signal can be obtained adjusting a typical covariance function to the empirical covariance distribution of data values (Barzaghi and Sanso, 1983).For that, we must make a correlation analysis of data values versus mutual point distances: The whole interval of distances is divided on several subintervals of suitable width Δd . If d_k is the mean value of a subinterval, then, the corresponding covariance value can be calculated as:

$$c(d_k) = \frac{1}{n_k} \sum_{i,j} v(P_i) v(P_j)$$

with summation extended to the n_k pairs of point P_i, P_j so that:

$$d_k - \frac{\Delta d}{2} < \mathrm{dist.}(P_i,P_j) \leq d_k + \frac{\Delta d}{2}$$

From calculated values $c(d_k)$, k=1,...,m , ($d_k = \Delta d\ (2k-1)/2$), we can adjust them by an usual covariance function C=C(d) (see Mussio,1984).

The value C(0) is the signal variance σ_s^2 and then:

$$\sigma_n^2 = \sigma_v^2 - \sigma_s^2$$

gives the noise variance from data variance.

The correlation step width Δd must be choice to obtain the best definition of signal. Practically, we can take several values of Δd and then select that to give a lesser resulting value of σ_s^2 ,(which is estimated by $\sigma_s^2 \simeq \sigma_v^2 - c(d_1)$).

Using the obtained covariance function C=C(d), we can apply usual least square prediction formulae (Moritz, 1980) to obtain :

Predicted signal value $\hat{s}$ on point P :

$$\hat{s} = \mathbf{C}_{Ps} \; (\mathbf{C}_{ss} + \mathbf{C}_{nn})^{-1} \; \mathbf{v}$$

where:

n- vector $\mathbf{C}_{Ps} = (\; C\,(s(P_i),\; s(P))\;_i) = (\; C\,(\mathrm{dist}(P_i,P))\;_i)$

n,n- matrix $\mathbf{C}_{ss} = (\; C\,(\; s(P_i),\; s(P_j))_{ij}) = (\; C\,(\mathrm{dist}\,(P_i,P_j)_{ij})$

n.n- matrix $\mathbf{C}_{nn} = \mathbf{I} * (\; \sigma_v^2 - C(0) \;)$

n- vector $\mathbf{v} = (v(P_1),\ldots,\; v(P_n))^T$

For $P = P_i$ we obtained filtered values $\hat{s}(P_i)$, and then adjusted noise $\hat{n}(P_i) = v(P_i) - \hat{s}(P_i)$.

Error matrices are also obtained

$$\mathbf{E}_{\hat{s}\hat{s}} = \mathbf{C}_{PP} - \mathbf{C}_{Ps} \; (\; \mathbf{C}_{ss} + \mathbf{C}_{nn} \;)^{-1} \; \mathbf{C}_{sp}$$

The final model is composed by the adjusted residual signal $\hat{s}$ plus the previously adjusted systematic component p .

As example of application we consider the values of κ (phases of residual vector **X**) for M2 as data values.

First, the number of stations is not too large (moreover taking account the high level of noise), but it is enough to obtain several clear results. If we would have a very small number of stations, they only would show a general systematic component with high level noise and no appreciable signal (flat covariance function). A bigger number of stations let detect a correlated signal of a wave length smaller than of the global systematic component, obtaining a lesser noise level. As bigger the number of stations then smaller wave length of detected signal and bigger signal/noise relation.

In our case the number of stations let us obtain a sensible signal (see covariance functions later) with mean wave length (but with high noise level). If we would have a bigger number of stations a part of noise would appear as correlated signal with lesser wave length.

Taking account the residual character of vector **X**, values κ will present a nearly random distribution. Nevertheless, we have study the possible covariance function using previous polynomial approximations of degree 0, 1, 2, 3.

First, the best correlator step width Δd have been investigated. For that, we study the resulting noise variance $\sigma_n^2 \simeq \sigma_v^2 - c(d_1)$ for several supposed step width (figure 3). We choice the value 2.8 degrees of spherical distance.

The direct correlation analysis of κ data is showed on figure 4.a. Correlation has been investigated taken as mutual distance betweenthe stations the spherical distance ψ :

$$\cos \psi = \operatorname{sen} \varphi_1 \operatorname{sen} \varphi_2 + \cos \varphi_1 \cos \varphi_2 \cos (\lambda_1 - \lambda_2)$$

Empirical covariance distribution (isolated points in figures 4) suggest us to adjust it by a exponential-Bessel function (continuous line):

$$C(d) = a \exp(-b\, d)\; J_0(c\, d)$$

where $J_0(x)$ is the Bessel function of zero order, and a,b,c are parameters to adjust. a represent the value for origin, a=C(0) , c is related to the "wave length" of function C(d), and b is related to dumping of oscillation. We take as width measure of the covariance function the distance for the first null C(d) value : d(0) . In table 1 we give the numerical values for parameters of the adjusted function. The signal level is given by

$$C(0)/\sigma_v^2 = a/\sigma_v^2 = 0.42 \ .$$

We observe a covariance function with too small dumping. For a good random distribution, the covariance function must present a clear dumping with a flat behavior far from the origin. It suggest us to use a previous

Pol. deg.	Δd.	σ_v	a/σ_v^2	b	c	d(0)	σ_n
0	2.8	98.4	0.42	0.1	10.3	6.6	75.0
1	2.8	97.8	0.39	0.0	10.5	6.4	76.4
2	2.8	93.8	0.37	0.5	10.9	6.2	74.5
3	2.8	87.4	0.31	0.3	11.0	6.1	72.6

Table 1. Comparative values of covariance for several previous polynomial approximations.

polynomial adjust to absorb the possible systematic component. Approximations have been calculated (by least square adjustment for the coefficients and using φ and $\lambda \cos(\varphi)$ as coordinates) for polynomial degrees 1,2,3. Figures 4.b ,4.c ,4.d and table 1 show the results.

With higher polynomial degree we observe a bigger dumping (b), a smaller wave length (d(0)), a smaller data variance (σ_v^2), etc. For degree 1 the dumping is not yet clear. We choice as initial values those of second degree polynomial approximation.

For a good application of covariance analysis a consideration about homogeneity and isotropy of the filed can be made. About isotropy we have study the covariance distribution along two directions: N-S and E-W. For that we have consider correlations with points in the same N-S or E-W narrow band. Taking account the less number of related stations we obtain a bigger correlator step width, a smaller level of signal. The covariance function adjusted have been a normal-parabola (figure 5) defined by:

$$C(D) = a\ (1-c\ d^2)\ \exp\ (-b\ d^2)$$

Cov direc	Δd.	σ_v	a/σ_v^2	d(0)	σ_n
E - W	5.4	93.6	0.40	5.8	75.0
N - S	7.6	93.8	0.23	5.9	76.4

Table 2. Comparative values of covariance for E-W and N-S directions.

Values obtained (Table 2) for both directions show a similar distance of null covariance and a better signal/noise relation for E-W direction. Nevertheless, the number of correlation subintervals is too small for assure any conclusion.

To check the homogeneity we have consider the covariance study for two different areas: the quadrants N-W (64 points) and S-E (43 points). Obtained

Area	Δd	σ_v	a/σ_v^2	b	c	d(0)	σ_n
N - W	1.6	98.9	0.38	0.2	6.1	6.3	77.9
S - E	1.7	78.4	0.46	0.0	8.5	4.9	57.6

Table 3. Comparative values of covariance for S-E and N-W areas.

covariances are showed in figure 6 and corresponding values on table 3. They show a better signal/noise relation for S-E area with smaller null covariance distance.

Figure 7 shows the feature of polynomial approximation. Applying the least square formulae to residual values v , we obtain as predicted residual distribution that represented on figure 8 . Adding both fields we obtain the final model for adjusted κ values (on degrees), figure 17.

The root of diagonal elements of $\mathbf{E}_{ss}$ give us the root mean square error for predicted values. They have been represented on figure 9. We observe that the best quality of model is obtained on central Europe, central Iberia and Finland area.

Finally residual noise are represented on figures 10 a,b. Highest noise corresponds mainly to coastal stations.

This process have been applied to the several tidal parameters. The automatic programs of covariance adjustment and least square calculus have been developed on our center.

3. Models of tidal vectors A,δ,α,B,β,... for M2.

Applying the former process, final model for the several tidal vectors and parameters for main component M2 are given by figures 11 to 26. Error maps and noise location are similar to those of κ (M2).

Table 4 shows several comparative parameters from covariance analysis of direct data (without previous approximation)

We cam make several remarks:

Observed amplitudes show a zonal distribution (given by geodetic coefficient expressions), with clear perturbations connected with atlantic influence. The map corresponding to A-L vector (reduced observations) has a more regular zonal distribution, remaining perturbations are around Mediterranean, Artic and North seas.

Maps of amplitude factor and phase show a different form of response to oceanic effect.

A close relation can be observed between graphical representations of **L** (calculated oceanic effect) and **B** (observed values minus simple elastic model). It points that the main part of perturbations of gravimetric tidal recordings are due to oceanic effects. (Phases of vectors **B** and **L** show a bigger discrepancy).

Value M_2	Δd	data mean	σ_v	a/σ_v^2	σ_n	d(0)
Obs amplit	4.7	34.44	11.44	0.92	3.23	16.66
Amp fac δ	4.7	1.165	0.092	0.53	0.063	12.00
Obs des α	4.3	2.579	3.463	0.39	2.705	13.45
Amplit L	2.8	2.129	2.016	0.70	1.104	16.14
Phase L	3.6	61.02	43.27	0.54	29.34	10.72
Amplit B	2.8	2.212	2.118	0.57	1.389	16.45
Phase B	4.9	51.96	60.41	0.15	55.69	12.71
Amplit X	4.7	0.669	0.774	0.27	0.661	7.22
Phase X	2.8	-25.91	98.43	0.42	74.97	6.57
X cos κ	4.7	0.003	0.830	0.28	0.704	13.39
X sin κ	1.5	-0.225	0.559	0.18	0.506	5.19
Ampl A-L	4.7	33.99	11.39	0.91	3.467	16.89
Fact A-L	4.8	1.152	0.049	0.34	0.040	12.42
Phase A-L	4.5	-0.505	1.367	0.20	1.223	6.82
Ampl M+L	4.7	34.44	11.10	0.92	3.139	16.66
Fact M+L	2.7	1.173	0.057	0.63	0.035	9.34
Phase M+L	2.8	2.893	2.604	0.60	1.647	14.78

Table 4. Comparative values of covariance for tidal vectors of M2.

Residual vector **X** offers a good signal level (at least for M_2) of 40 % (see Tables) in variance of total residual data variance. Perhaps the more significant map is that of X cos κ (cosine component). That picture shows a strong perturbation focused on the North Atlantic - Artic area , prolongated on the North Sea area. A minor perturbations a associated to mediterranean area. (Perspective view of figure 27 shows these circumstances). It is difficult to investigate further non oceanic effects without removing those strong oceanic effects.

Vector **M** + **L** (corrected model) offers an amplitude factor and phase distributions very similar to that of observed values (but something smoother)

Finally, vector **A**-L offers a very similar pictures for amplitude factor and phase to pictures of X cos κ and X sin κ (with another kind of magnitudes). As immediate example of application a values of coefficients for variation of δ along latitude have been obtained using filtered stations:

Theoretic model of Wahr (1981) gives:

$$\delta = \delta_0 + \delta_1 \frac{\sqrt{3}}{2} (7 \operatorname{sen}^2\varphi - 1)$$

with $\delta_0 = 1.1599$ and $\delta_1 = - 0.0045$.

Melchior and De Becker (1983) obtained the empirical values:

$$\delta_0 = 1.175 \ (\pm\ 0.0021) \qquad \delta_1 = -0.0046 \ (\pm\ 0.0010)$$

Here, considering only the sub-diagonal area of figure 27, results:

for non filtered data: $\delta_0 = 1.179$ (± 0.0093) $\delta_1 = -0.0041$ (± 0.0027)

for filtered data: $\delta_0 = 1.184$ (± 0.0036) $\delta_1 = -0.0058$ (± 0.0011)

Nevertheless to obtain a definitive values, data must be reduced with better adjusted oceanic effects (taking account the effect of local oceanic influences).

4. Any values for S2 and O1 components.

For comparison, certain vectors and values associated to S2 and O1 have been also studied. Table 5

For O1, residual vector **X** gives a signal level (in variance respect to total variance) of 10 % for amplitude and 12 % for phase . Distances of (first) null covariance are of $3^o.4$ and $7^o.2$ respectively. Nevertheless, for so small signal level conclusions are doubtful. The maps corresponding to O1 do not show a strong North Atlantic effect. So, the picture of $X \cos \kappa$ shows a nearly flat surface (corresponding to small detected signal with high noise) with distributed rugosities (see figures 28,29,30.31.32).

For S2 detected signal levels are about 18 % (in variance).

5. Conclusions.

It is possible to detect a correlated signal on the residual vector **X**, at least for the main tidal components.

That residual model can be interpreted mainly as small deficiencies of calculated ocean effects. We think that to obtain further reologhic conclusions a better knowledgement of oceanic effect must be applied. For components of minor oceanic sensibility, but enough signal level, other effects can be analyzed.

The error maps show us possible areas for install new stations to obtain a more homogeneous quality map.

Noise maps point the stations of irregular behavior. They are located mostly on the Atlantic coast. Then, local irregular oceanic effects can be suspected. (Any data mistake would be also possible).

The predicted models of amplitude factors and observed phases for every main tidal waves can be automatically used to obtain empirical tidal correction for the gravimetric survey . (For Spain, we use a calculus program that, first, from coordinates, geodetic coefficients and δ,α are calculated and, second, using the Cartwright-Tayler development, gravimetric tidal correction Δg are calculated for desired date). (Vieira et al.).

Acknowledgement.

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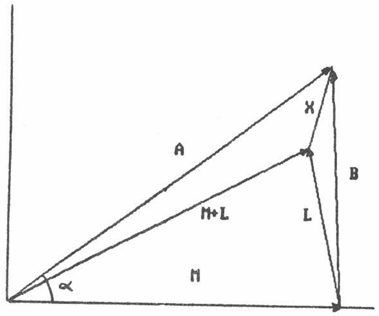


Fig. 1. Tidal vectors.

Fig. 2. European net of tidal stations.

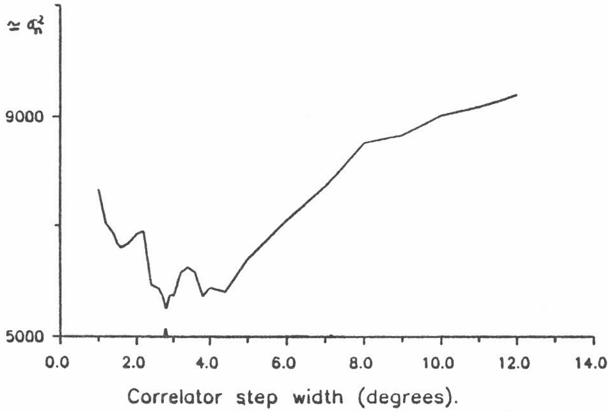


Fig. 3. Determination of the best correlator step width (spherical distance).

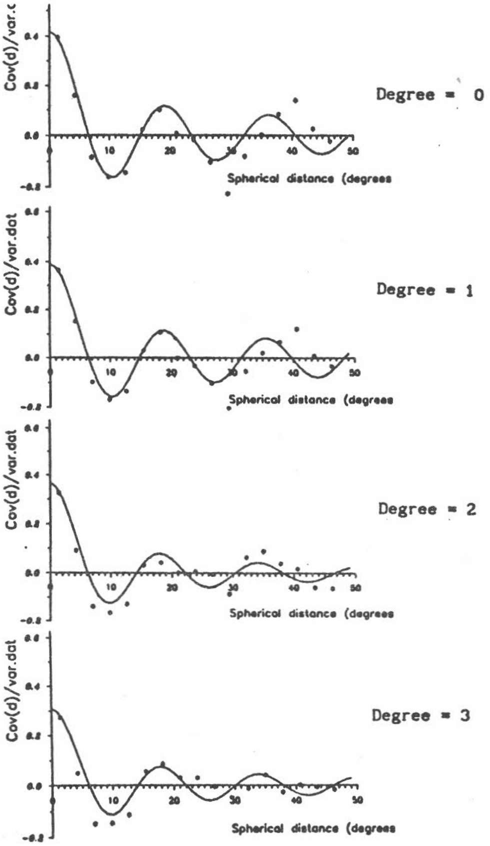


Fig. 4. Correlation study for several initial polynomial approximations.

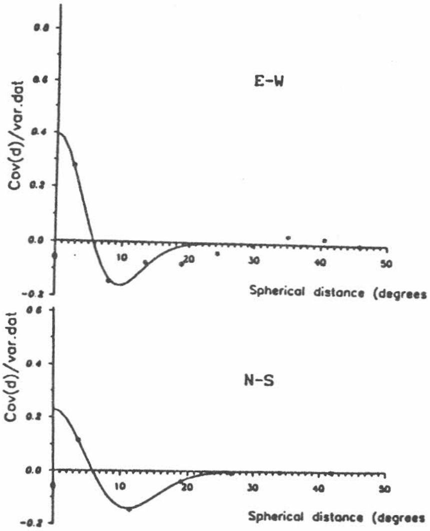


Fig. 5. Comparative study of correlation along N-S and E-W directions.

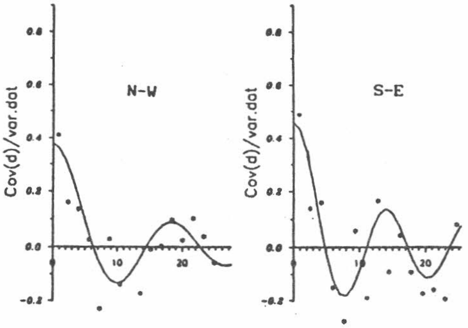


Fig. 6. Comparative correlation study for two extreme areas.

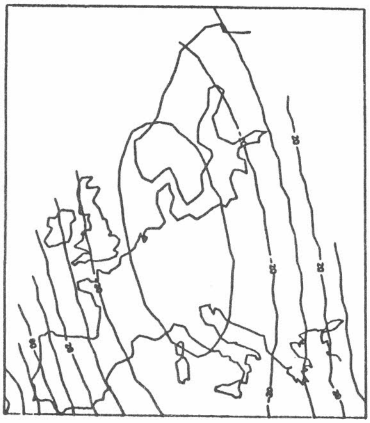


Fig. 7. Polynomial approximation for K (m2). Eq.= 20°.

Fig. 8. Predicted residual values for (M2). Eq. = 20°.

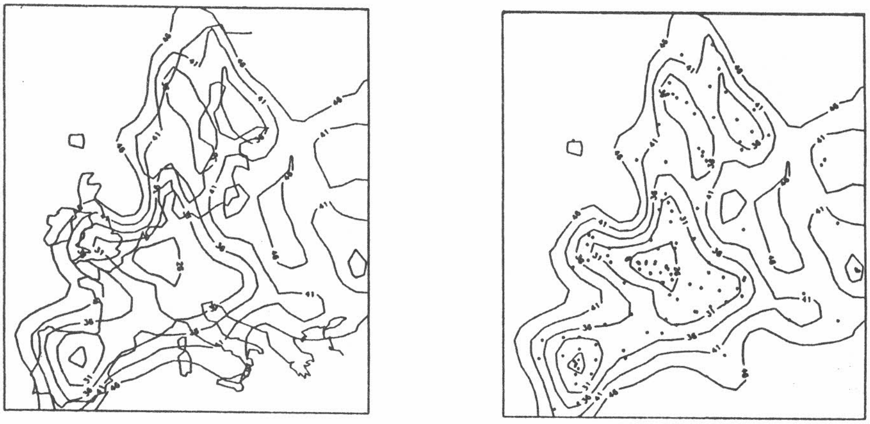
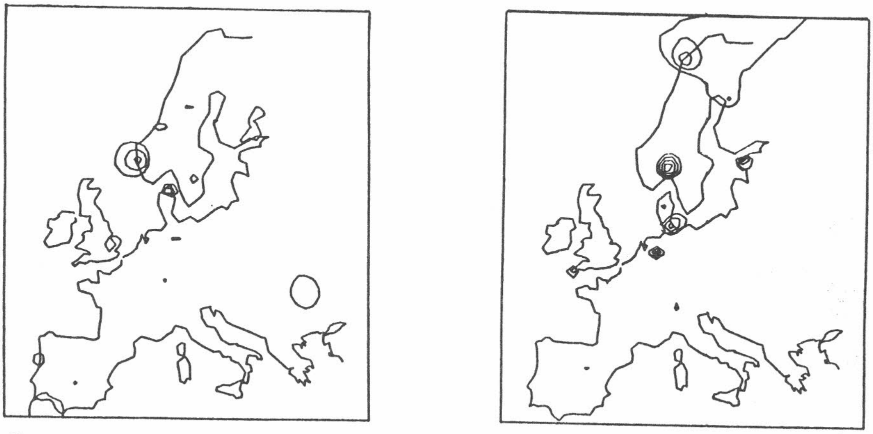


Fig. 9. R.m.s.e. of prediction. Quality of model for k (M2).Eq. = 5°.



a.

Fig. 10. a. Positive noise. b. Negative noise. Anomalous stations.

b.

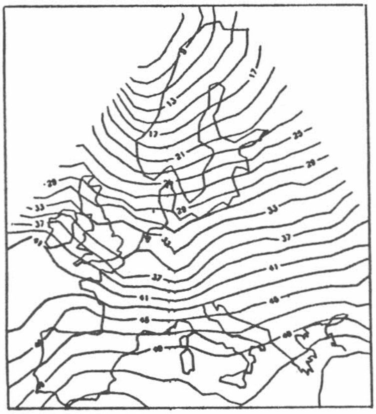


Fig. 11. Observed amplitude M2.
Eq.= 2μgal.

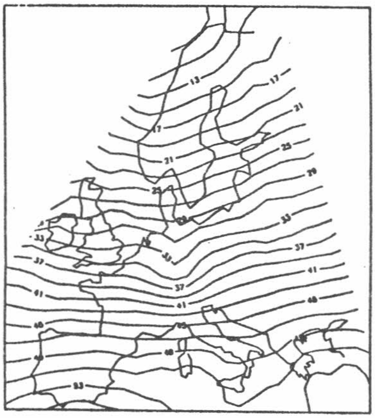


Fig. 12. Amplitude of A-L vector
(reduced observation).
Eq.= 2μgal.

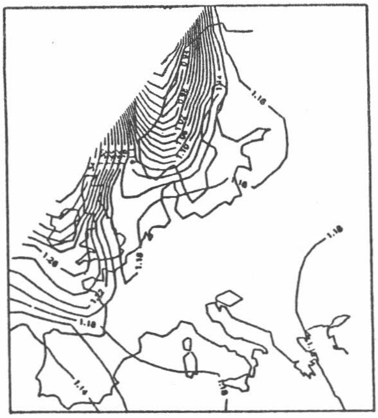


Fig. 13. Amplitude factor of
observed values M2.
Eq.= 0.02.

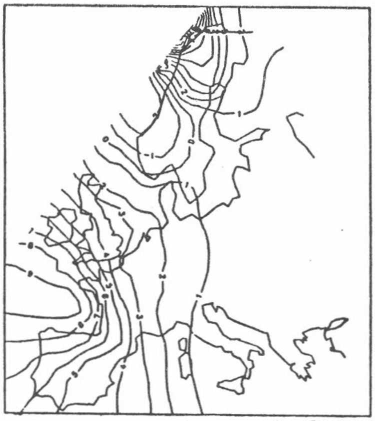


Fig. 14. Phase of observed values
M2. Eq. = 1°.

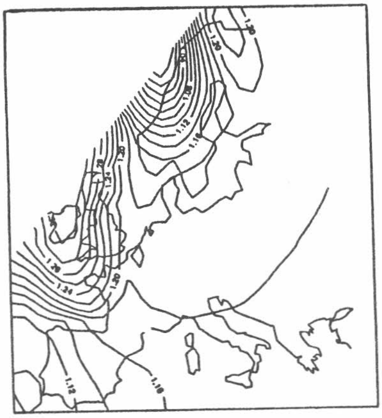


Fig. 15. Amplitude factor of
M + L vector (corrected
model). Eq.= 0.02.

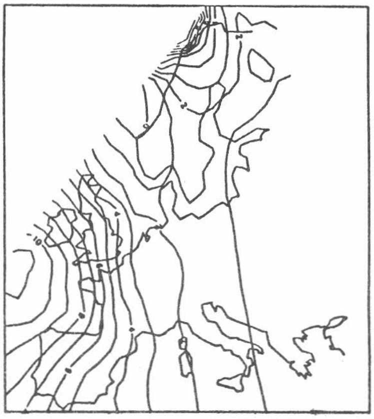


Fig. 16. Phase of M + L vector
(corrected model). Eq.= 1°.

Fig. 17. Phase of residual vector X for M2. Eq.= 30°.

Fig. 18. Amplitude of residual X for M2. Eq.= 0.2 µgal.

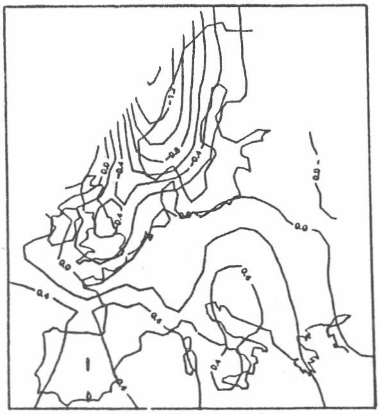


Fig. 19. Cos component of residual vector X of M2. Eq. = 0.2 µgal.

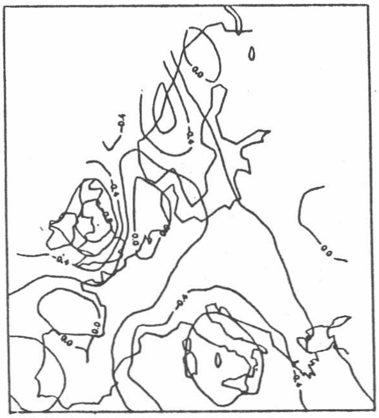


Fig. 20. Sin. component of residual vector X of M2. Eq.= 0.2µgal.

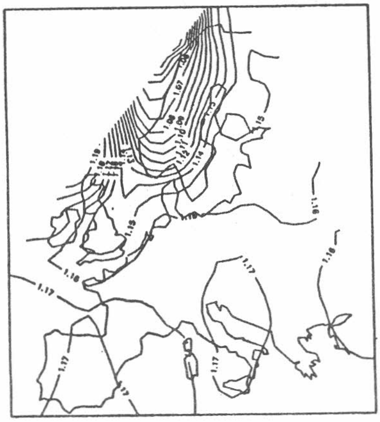


Fig. 21. Amplitude factor of A-L vector (reduced observations), Eq.= 0.01.

Fig. 22. Phase of A-L vector (reduced observations), M2. Eq.=0.4°.

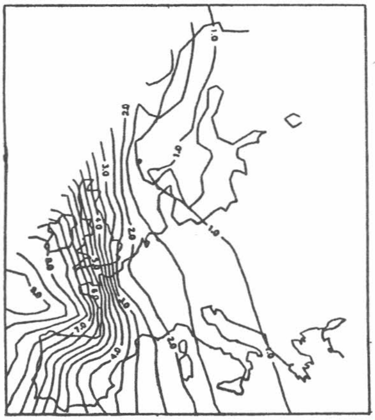


Fig. 23. Amplitude of vector L (oceanic effects), M2. Eq.= 0.5 μgal.

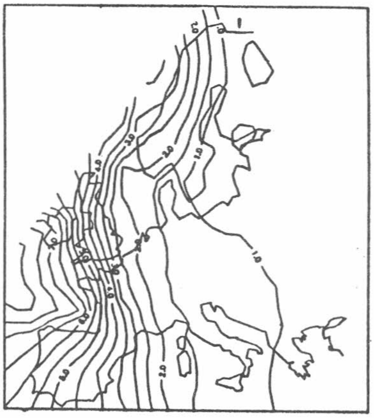


Fig. 24. Amplitude of vector B, M2. Eq.= 0.5 μgal.

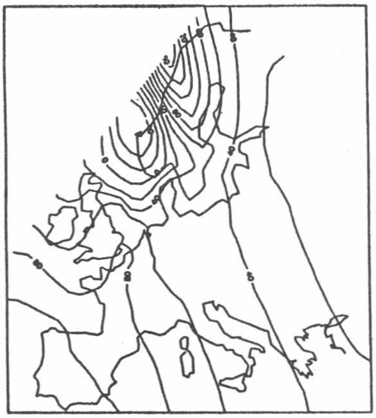


Fig. 25. Phase of vector L (oceanic effects), M2. Eq.= 20°.

Fig. 26. Phase of vector B, M2 Eq. = 20°.

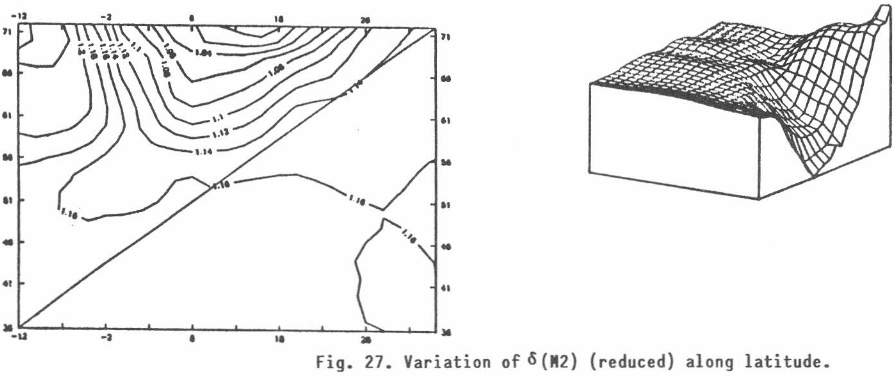


Fig. 27. Variation of δ(M2) (reduced) along latitude.

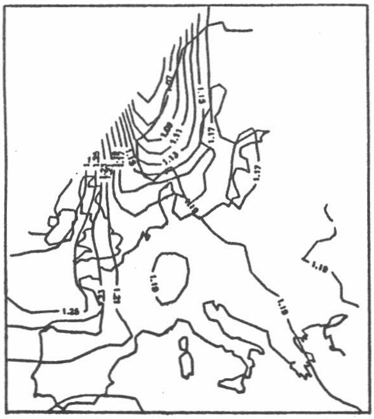


Fig. 28. Amplitude factor of observed values S2. Eq.=0.02.

Fig. 29. Phase of observed values S2. Eq.=1°.

Fig. 30. Amplitude of residual vector X for O1. Eq.=0.1μgal.

Fig. 31. Phase of residual vector X for O1. Eq. = 0°3.

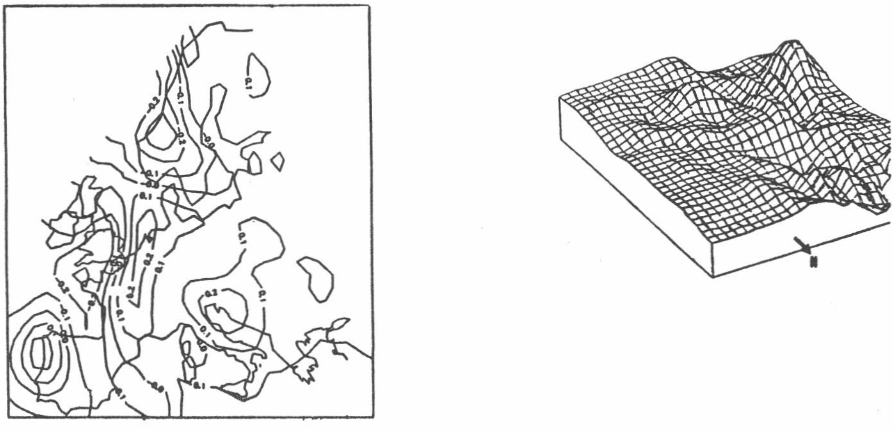


Fig. 32. Cos. component of residual vector X for O1. Eq.=0.1 μgal

XITH INTERNATIONAL SYMPOSIUM ON EARTH TIDES

HELSINKI, AUGUST 1989.

STRUCTURAL AND OCEANIC EFFECTS IN THE GRAVIMETRIC TIDES OBSERVATIONS IN LANZAROTE (CANARY ISLANDS)

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ABSTRACT:

Since 1987, and as part of the research project that the I.A.G. is carrying out in the Canary Islands, records are obtained of gravimetric and ocean tides, pressure, temperature, etc. on the island of Lanzarote. The structural and geodynamic features of the island make our observations especially interesting because they may help to further research of the possible correlations of responses to tidal forces and other parameters such as crust structure and thickness, geothermic anomalies, etc. In this paper, we present the results obtained until now and a preliminary appraisal is given of these results in view of various previous hypotheses.

1. INTRODUCTION

The Island of Lanzarote is the most northerly and easterly of the fundamental islands of the Canary Islands. The historic volcanism of the island last appeared in the 18th and 20th century, being of special importance the eruption which took place from 1730 to 1736 in the southern zone of the island and which gave rise to important morphological changes which affected one quarter of its physiognomy in the zone which today is the National Volcanic Park of Timanfaya. Whereas the geographic and geodynamic characteristics of Lanzarote, it was decided to install, at this island, a geodynamic station as a laboratory of experimentation techniques and in order to improve the sounding systems, to prevent the volcanic risk. The volcanic tunnel of the volcano "La Corona", originated thousands of years ago, northward of Lanzarote island, has been the place chosen for the station. Until now, equipment was installed for the permanent registration of gravity variation and rock temperatures, as well as air temperature sensors, barograph, tiltmeters, seismographs, sea-level gauges, etc.

Currently, there is a series of over two years of high-quality registers of gravity tides. These observations were analized and the results obtained were studied taking into account other results obtained from the analysis of other registers, such as the oceanic tide and the variations of atmospherical pressure. For the best calculation of the oceanic effect, we proceeded to prepare cotidal and corange local charts using empirical data and laying the same conditions that were established for the Iberia maps (R. Vieira el al., 1986).

2. GEODYNAMIC SETTING

Although there still exist many problems both in relation to the genesis and to the overall geodynamic setting of the Canary Islands, the numerous geological and geophysical research projects carried out here enable us to know certain important characteristics which, with regard to Lanzarote Island, we may summarize as follows:

1) According to Ara7a et al., 1978 (figure 1), and other authors, the Canary Islands must be considered as independent volcanic structures and as having different ages and histories.
2) According to Ara7a et al.,1976 (figure 2), Lanzarote consists of a large basaltic intrusion on an anomalous mantle. All the other islands are located on an ocean crust, penetrated by dykes, through which the volcanic eruptions take place.
3) The structural model of Lanzarote obtained by Banda et al.,1981 from deep seismic profiles, may be seen in Figure 3; the discontinuity of Mohorovic is located at a depth of approximately 11 kilometers although in the magnetotelluric studies carried out by Ortiz et al., this discontinuity may be at a depth of 13 kilometers.
4) The gravimetry of Lanzarote, Sevilla and Parra, 1975, and later Vieira et al, 1988, figure 4, enables us to distinguish three zones of maximums: a central zone where the highest gravity values are reached, and two lateral zones, one in the north, which affects the region situated to the north of the La Corona volcano and La Graciosa Island, very close to Lanzarote, and another in the south, of lesser importance. Among the three zones of maximums there are zones of minimums which coincide with the historic and subhistoric eruptions on the island (Fuster et al., 1968; figure 5); one which especially stands out is the zone of the National Volcanic Park of Timanfaya, where we find the minimum of the island. This distribution of anomalies favors the theory of raised and independent blocks with a system of intermediate deep dykes. With this theory, an explanation may be found for the differences seen between the structures of Lanzarote and Fuerteventura, despite their proximity, as may be seen in the structural diagram obtained from the deep seismic profiles which were corroborated by magnetotelluric studies.
5) Lanzarote has important geothermic anomalies in the southern zone of Timanfaya, in the Monta7a del Fuego, with thermic measurements of 6003 C at a depth of only 12m. Nevertheless, this anomaly may be local, as a result of a small residual magmatic chamber of the last important eruption of 1730 - 1736.

3. GEODYNAMIC STATION

In the geodynamic setting described above, and which for obvious reasons is of great scientific interest, in agreement with the local authorities and with the support of the C.S.I.C., it was decided to initiate the installation of various sensors which would allow for permanent auscultation of the dynamics of Lanzarote. While it is true that the last eruption on the island took place several decades ago (1924) and two and a half centuries have passed since the great eruption which resulted in the National Volcanic Park of Timanfaya, it is also certain that these periods of time are very short in what we could term the active life of a volcanic zone; consequently Lanzarote must be considered an island with active volcanism, although it is apparently in a lethargic state.

The volcanic tunnel of the La Corona volcano was selected for the base site of the installation (T. Bravo, 1964; figures 5 and 6). This tunnel was formed by the flow of subhistoric eruption lavas (some three thousand years ago) which affected the northern zone of the island and which gave rise to the extensive "malpais" of La Corona and in its inside to the largest volcanic tunnel known, which starts from the slope of said volcano and runs for approximately 7 km eastward, entering the sea where it goes on for at least another 2 km, according to speleological data of the expedition which in 1987 broke the underwater speleological record.

The station comprises three models:

A) Observation module A; located inside the volcanic tunnel at approximately 1,500m from the coast line.

In module A, the following have been installed:

1- Lacoste Romberg gravimeter, model G N° 434, modified as a zero gravimeter by Dr. Van Ruymbeke.
2- Pressure, temperature and humidity sensors.
3- Short period seismograph of the National Museum of Natural Sciences.
4- High precision sensors for measuring rock temperatures. Collaboration with the O.R.B. and the I.C.S.G.
5- Two component vertical pendulum. Collaboration with the O.R.B. and the I.C.S.G.
6- 16 channel data acquisition system.

B) Module B is located at the intersection of the volcanic tunnel with the ocean, where a lake is formed which is the entrance to the underwater section of the tunnel. In this lake, a pressure sensor has been installed in order to measure sea level variations. The tunnel, although through apparently very small ducts, is in contact with the ocean, and tide variations are obtained, although with a phase lag of around twenty minutes with regard to external variations. Just one month ago, pressure and temperature sensors were installed in the same place.

C) The third module is located in the zone, very close to the mareograph, in which the "Casa de los Volcanes" has been formed. This site is both of scientific and tourist interest, and will be inaugurated next December, coinciding with the Meeting of the Working Group on Volcanism which is being organized by the European Science Foundation. In this third module are to be found recording systems and the central computer, which, as we will see in another paper, collects information from all the sensors that have been installed; some of these outputs are available for use by visitors to the "Casa de los Volcanes".

All the instruments installed, and those others that are expected to be installed in the near future, are connected to what we could term an auscultation of the volcanic activity in the Canary Islands, where an attempt is being made to monitor parameters which at a given moment may provide prior information in the face of possible risks of eruption.

4. RESULTS OBTAINED

The more than two years of records of gravimetric tides obtained to date have been analysed and the results are shown in Table 1. The excellent quality of the station is reflected both in the m.q.e. in the determination of the amplitude/phases of the harmonics, and in the standard deviation of the D, SD and TD bands.

The unique features of the station made us consider contrasting the theory put forward in Madrid by Yanshin et al.,1986, on the possible relationship between geothermic flow and tide factors. The problem of calculating the oceanic effect is, as with other stations close to the sea, of great transcendence. The obtention of these correction values directly from the Schwiderski Charts (Schwiderski, E.W.; 1980) are slightly different to those we had obtained from the analysis of close mareographs. For this reason, and maintaining the same conditions that we established for the Iberia Charts (Vieira et al.,1986), we have extended said charts to a zone including the Canary Islands and the Madeira islands (C.Toro; 1989). In the same way, a digitalization grid has been created, which is perfectly adapted to the form of the coastline of the Canary Islands. The value obtained for the oceanic effect in the Cueva de los Verdes station is therefore the result of the Schwyderski Chart, for what we may term the far effect, and within the limits, $25^{\circ}N \leq \varphi \leq 35^{\circ}N$, $-10^{\circ}W \leq \lambda \leq -19^{\circ}W$, the part which is obtained from the new charts of the Canary Islands. In this paper we only refer to the M2 chart, which is the only complete one to date.

We must point out that the amplitude and phases variations effects observed in barographic stations located on the continental shelf are greatly attenuated in Lanzarote, a small volcanic island located over 400 km from the African coast. This constitutes a further incentive for continuing research in the good laboratory formed by the island because pressure correction is easier to model.

The calculated oceanic effect is: total indirect oceanic effect, $L = 7.95$, $\lambda = 165.30$; the vector (B, β) observed with regard to the Molodenski model 1, is $B = 90.4$, $\beta = 162.5$; the residual vector (X, κ), difference between (B, β) and (L, λ), in this case is:

$$X = 1.17,$$
$$\kappa = 144.80.$$

The components $X \cos\kappa$, $X \sin\kappa$, will be :

$$X \cos\kappa = -0.9555,$$
$$X \sin\kappa = 0.6751.$$

The first conclusion of interest is that we observe that the cosine component of the residual vector gives a value of almost minus one, which apparently contradicts the hypothesis of Yanshinet al, 1986, which related the negative anomalies to stable zones and the positive ones to regions with stability problems, such as those of basaltic volcanism and tectonic tension of Iceland the Strait of Badel Manded. So this would seem to be our most coherent result with those encountered in the East of Africa in zones of rift and in which there is also basaltic volcanism.

However, we must stress that the Cueva de los Verdes station is located on the zone recovered from the sea after the eruption of La Corona volcano, some two to three thousand years ago, Despite the good quality of the results, it is a singular station in which elastic response may certainly differ from that of the model.

It would also be of interest to install another gravimeter, because, although the L.R. N° 434 was installed in Lanzarote after being contrasted with others in Madrid, its constants might well vary, and this might affect the values of the vector (B,β) found and as a result, the residual vector (X,κ).

The analysis of pressure observations in "La Cueva de los Verdes" and oceanic tides in "Jameos del Agua" are given in tables 2 and 3. It were developed, for these analysis, the corresponding programs beginning from another in existence, principally of the I.C.E.T. and Venedikov program SV2 (Venedikov, A.P.; 1986). Although we are studying possible correlations and corrections between different parameters, in figure 8 the cotidal and corange oceanic variations for semidiurnal frequency were given; and in figure 9 the results, for the main groups of waves, of the cotidal corresponding to analysis made every 28 days during nine months series; the striped zone in the time axis corresponds to a bad observation period due to instrumental problems.

ACKNOWLEDGEMENTS:

These investigations are subsidized by the Consejo Superior de Investigaciones Cientificas and are achieved with the collaboration of the Cabildo Insular de Lanzarote.

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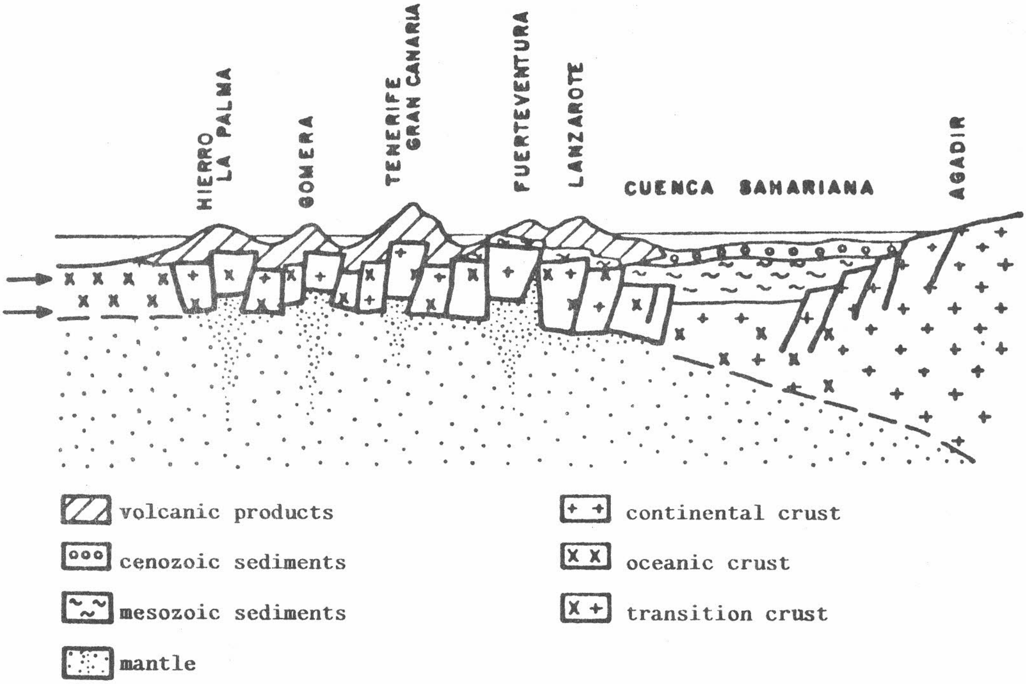


Fig. 1. Genetic model of the Canarian Islands. (Araña y Carracedo, 1978)

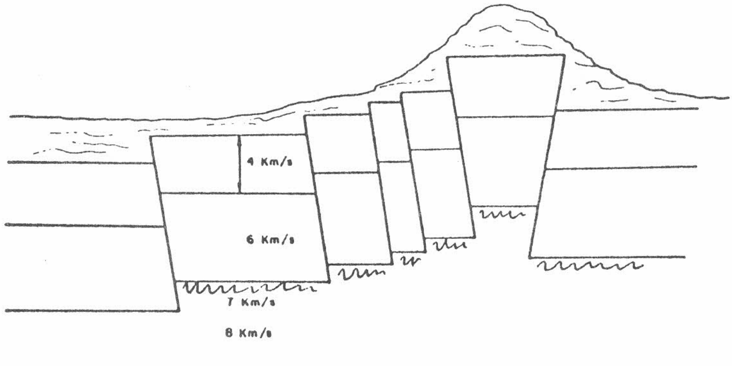


Fig. 2. Global structural model of Lanzarote (Araña et al. 1976)

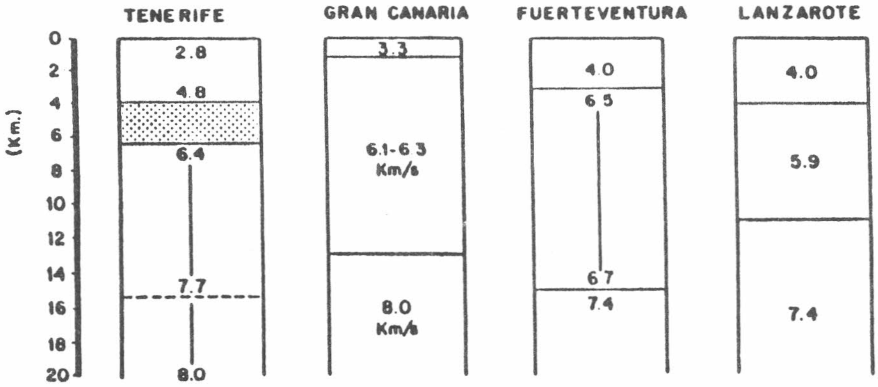


Figure 3. Structural model of Canary Islands (Banda et al. 1981)

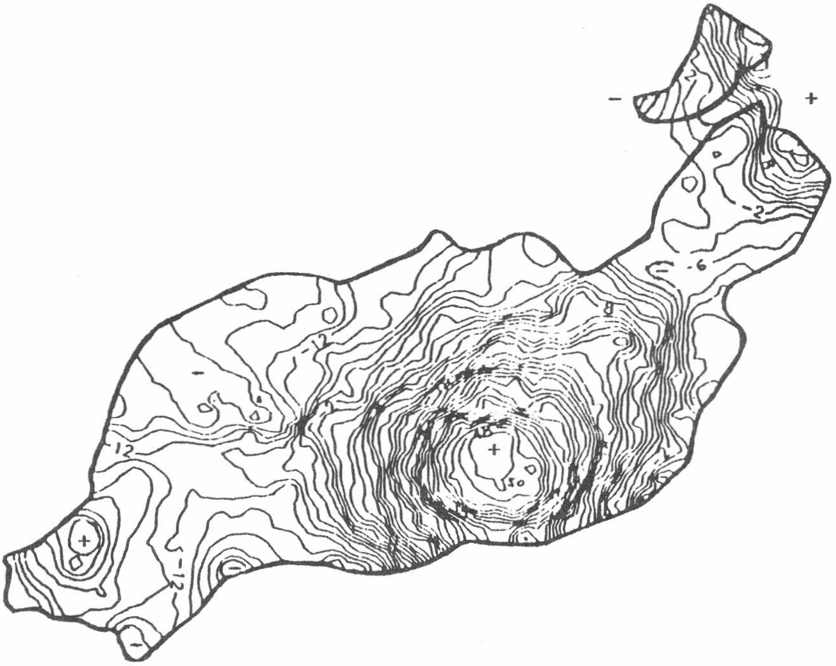


Figure 4.Residual gravity anomalies in Lanzarote (Vieira et al. 1988)

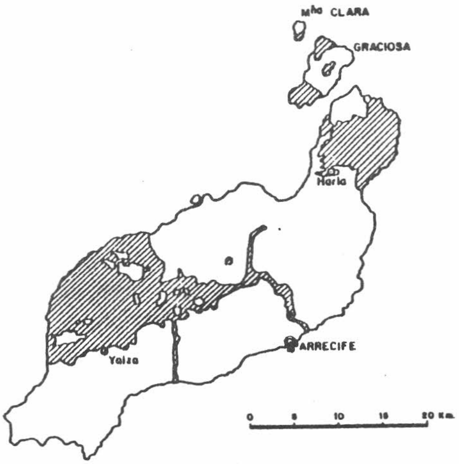


Figura 5. Recent volcanism in Lanzarote (Fuster et al. 1968)

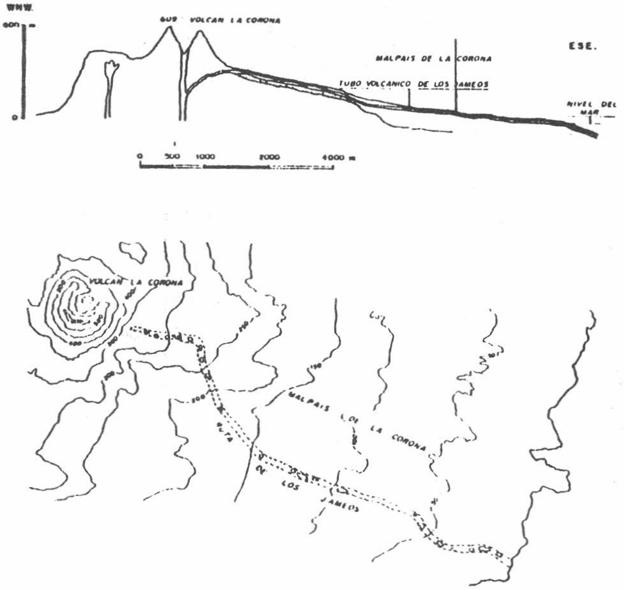


Figure 6. Volcano La Corona and volcanic tube of Jameos
(T. Bravo, 1964)

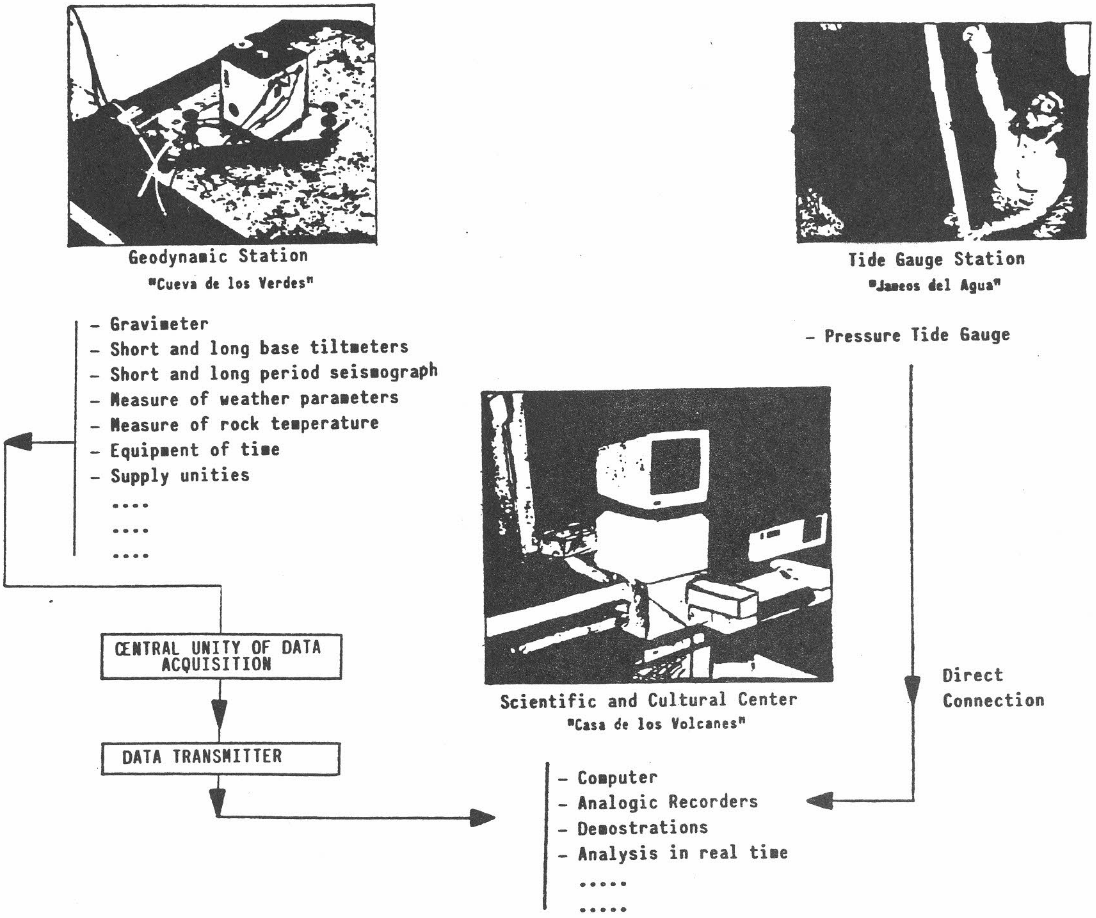
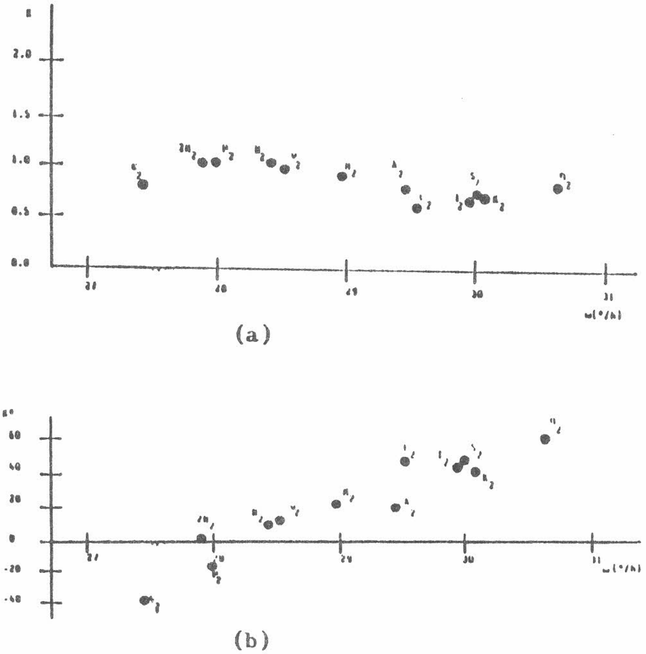

Geodynamic Station
"Cueva de los Verdes"
- Gravimeter
- Short and long base tiltmeters
- Short and long period seismograph
- Measure of weather parameters
- Measure of rock temperature
- Equipment of time
- Supply unities
....
....
....
CENTRAL UNITY OF DATA ACQUISITION
DATA TRANSMITTER
Tide Gauge Station
"Jameos del Agua"
- Pressure Tide Gauge
Direct Connection
Scientific and Cultural Center
"Casa de los Volcanes"
- Computer
- Analogic Recorders
- Demostrations
- Analysis in real time
.....
.....

Figure 7

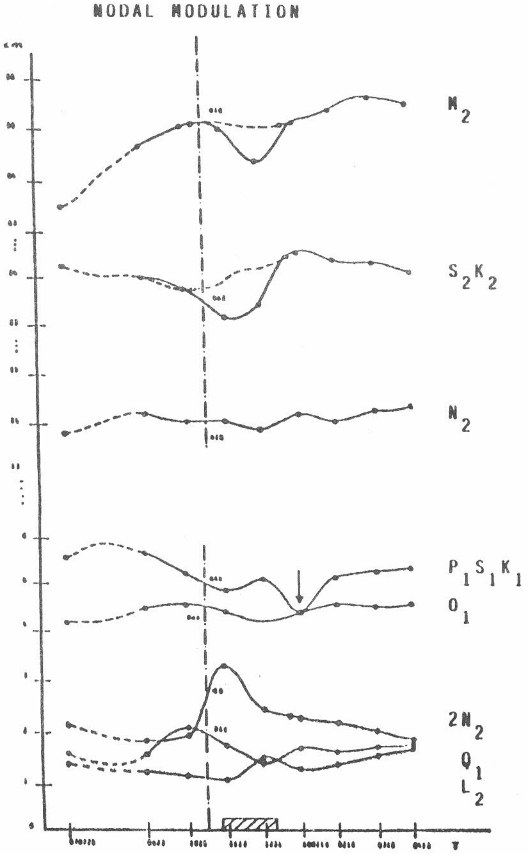


(a)

(b)

Figure 8. (a) Amplitudes factor y (b) phases lag of the ocean semidiurnal tides in Jameos

Figure 9.



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STATION          CUEVA DE LOS VERDES VERTICAL COMPONENT    SPAIN

29 09 N          13 26 W              N  060 M        P  40           D    1 KM


INSTITUTO DE ASTRONOMIA Y GEODESIA.
      C.S.I.C.-U.C.M.
FACULTAD DE CIENCIAS MATEMATICAS.
      28040 - MADRID

GRAVIMETRO  LACOSTE ROMBERG  MOD.G 434 METODO DE CERO (M.VAN RUYMBEKE)
REGISTRADOR MICROSCRIBE
CALIBRATION:   VALLE DE LOS CAIDOS  FUNDAMENTAL STATION
INSTALATION:   R.VIEIRA
MANTENANCE :   R.VIEIRA, J.FERNANDEZ

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B. DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLET DEVELOPMENT
COMPUTING CENTER OF UNIVERSIDAD COMPLUTENSE DE MADRID
COMPUTER   IBM 360     PROCESSED ON   89/ 6/25

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR   0.99203
PHASE LAG  O1  0.25   M2  0.50   O1/M2 0.50
INSTRUMENTAL LAG  173.10 MIN.
CORRECTION FOR DIFFERENTIAL ATTENUATION   M2/O1 1.00151   /MODEL 2/

434   87 515/87 525  87 528/87 6 3  87 711/871011  871111/871129  8712 3/871219
434   871223/88 215  88 219/88 3 4  88 310/88 314  88 317/88 430  88 5 4/88 6 7
434   88 619/88 723  88 727/88 9 9  88 929/8810 5  881013/881015  881022/881022
434   881027/881220  881226/881230  89 1 4/89 1 4  89 110/89 221  89 226/89 226
434   89 3 2/89 4 7  89 411/89 5 1  89 5 5/89 517  89 525/89 527  89 530/89 6 1
434   89 6 7/89 6 9  89 616/89 616

TIME INTERVAL   765.0 DAYS     14544 READINGS        27 BLOCKS

  WAVE GROUP    ESTIMATED AMPL.   AMPL.              PHASE              RESIDUALS
ARGUMENT   N WAVE         R.M.S.  FACTOR  R.M.S.   DIFF.  R.M.S.     AMPL.  PHASE

INVERTED READINGS
115.-11X. 11 SIGMQ1  0.24 0.02   1.2473 0.0886    -1.00   4.06      0.02  -14.0
124.-126. 10 2Q1     0.85 0.02   1.2721 0.0282    -0.78   1.27      0.08   -8.8
127.-129. 11 SIGMA1  0.99 0.02   1.2302 0.0231     1.38   1.07      0.06   22.8
133.-136. 20 Q1      5.95 0.02   1.1757 0.0036    -2.24   0.18      0.25  -71.6
137.-139. 10 RO1     1.15 0.02   1.2006 0.0190    -0.80   0.90      0.04  -22.3
143.-145. 16 O1     30.21 0.02   1.1435 0.0067    -1.37   0.03      0.84 -120.6
146.-149. 10 TAU1    0.30 0.03   0.8545 0.0735    -7.95   4.92      0.12 -159.3
152.-155. 15 NO1     2.37 0.01   1.1430 0.0071     0.07   0.35      0.03  175.3
156.-158.  7 KI1     0.44 0.02   1.1114 0.0435    -0.24   2.24      0.02 -174.3
161.-163. 10 P1     13.74 0.02   1.1177 0.0017     0.33   0.09      0.45  169.8
164.-164.  3 S1      0.20 0.03   0.6926 0.1035     6.33   8.72      0.14  170.6
165.-168. 20 K1     41.27 0.02   1.1106 0.0005     0.46   0.03      1.06  161.7
172.-174.  8 TETA1   0.45 0.02   1.1289 0.0441     4.50   2.24      0.04  112.2
175.-177. 14 J1      2.40 0.02   1.1529 0.0087     0.25   0.43      0.02  148.7
181.-183.  7 SO1     0.36 0.02   1.0300 0.0496    -0.13   2.75      0.05 -179.0
184.-186. 11 OO1     1.30 0.01   1.1396 0.0100     0.77   0.50      0.03  144.0
191.-195. 14 NU1     0.24 0.01   1.1039 0.0550     1.67   2.75      0.01  150.5

INVERTED READINGS
215.-22K. 19 EPS2    0.45 0.02   1.0699 0.0424    -7.55   2.27      0.07 -125.3
233.-236. 10 2N2     1.42 0.02   0.9773 0.0139    -2.80   0.81      0.28 -165.4
237.-23K. 10 MU2     1.72 0.02   0.9828 0.0109    -3.92   0.63      0.34 -159.5
243.-245. 13 N2     10.79 0.02   0.9844 0.0017     1.08   0.10      1.94  174.0
246.-248. 11 NU2     2.10 0.02   1.0088 0.0089     1.62   0.50      0.32  169.4
252.-258. 26 M2     57.83 0.02   1.0105 0.0003     2.69   0.02      9.04  162.5
262.-264.  5 LAMB2   0.46 0.02   1.0896 0.0423     1.23   2.22      0.03  161.7
265.-265.  9 L2      1.70 0.01   1.0514 0.0089     3.25   0.48      0.20  151.7
267.-272.  5 T2      1.62 0.02   1.0364 0.0108     4.60   0.60      0.24  146.8
273.-273.  4 S2     28.24 0.02   1.0605 0.0006     4.57   0.03      3.55  140.6
274.-277. 12 K2      7.64 0.01   1.0536 0.0018     4.38   0.10      0.99  143.7
282.-285. 15 ETA2    0.43 0.01   1.0639 0.0297     6.34   1.60      0.06  131.2
292.-295. 11 2K2     0.11 0.01   1.0570 0.0643     5.29   3.48      0.02  137.8

INVERTED READINGS
335.-375. 16 M3      1.06 0.01   1.0840 0.0097     2.08   0.51      0.10   23.8

STANDARD DEVIATION   D      1.57     SD      1.30      TD      0.68  MICROGAL
STUDENT FACTOR     T(S=95(,N> 589)=1.96

O1/K1  1.0296   1-O1/1-K1  1.2978   M2/O1  0.8837
CENTRAL EPOCH TJJ= 2447312.0
```

Table 1

```
                          MAREA ATMOSFERICA
                          -----------------

ESTACION                  CUEVA DE LOS VERDES (LANZAROTE)
SITUACION                 29 07 N  -  13 26 W
ORGANISMO RESPONSABLE     INSTITUTO DE ASTRONOMIA Y GEODESIA
                          ( C.S.I.C. - U.C.M. )

SENSOR DE PRESION         NUMERO  001
MODULO DE ADQUISICION
DE DATOS
INSTALACION               R.VIEIRA, J.FERNANDEZ
CALIBRACION               I.M.N.
MANTENIMIENTO             O.HERNANDEZ, R.VIEIRA, J.FERNANDEZ

ANALISIS                  MINIMOS CUADRADOS. FILTROS DE VENEDIKOV SOBRE
                          INTERVALOS DE 48 HORAS.
                          POTENCIAL CARTWRIGHT-TAYLER-EDDEN.
                          DESARROLLO COMPLETO
                          CENTRO DE PROCESO DE DATOS DE LA UNIVERSIDAD
                          COMPLUTENSE DE MADRID.   COMPUTADOR I.B.M. 4381
                          PROCESADO EL   89/ 6/25

INTERVALO DE OBSERVACION  871212/8810 7
                          302.0 DIAS      7248 LECTURAS

       GRUPO                 AMPLITUD            FASE
ARGUMENTO  N ONDA           H   E.Q.M.       DIF.  E.Q.M.

115.-11X. 11 SIGMQ1       0.008 0.0109      49.24   74.39
124.-129. 21 SIGMA1       0.014 0.0088      55.15   36.49
133.-139. 30 Q1           0.019 0.0116       7.56   35.04
143.-149. 26 O1           0.012 0.0120      80.66   56.28
152.-158. 22 M1           0.017 0.0095      88.42   32.39
161.-168. 33 P1S1K1       0.057 0.0121      53.24   12.18
172.-177. 22 J1           0.005 0.0112      -6.65  129.44
181.-186. 18 OO1          0.012 0.0075     -31.25   35.96
191.-195. 14 NU1          0.004 0.0075     -84.52   97.23

215.-22X. 19 EPS2         0.014 0.0134       5.35   55.50
233.-23X. 20 2N2          0.005 0.0109     -19.70  135.02
243.-248. 24 N2           0.004 0.0142      -6.69  223.05
252.-258. 26 M2           0.042 0.0142     -12.66   19.41
262.-265. 14 L2           0.023 0.0117      14.04   29.34
267.-277. 21 S2K2         0.527 0.0126     -59.92    1.37
282.-285. 15 ETA2         0.006 0.0093      -4.12   90.94
292.-295. 11 2K2          0.010 0.0052      85.44   31.17

335.-375. 16 M3           0.009 0.0076      74.83   48.85
```

Table 2

```
     RED DE MAREA OCEANICA  -  COMPONENTE VERTICAL
     --- -- ----- --------     ---------- --------

ESTACION                     JAMEOS DEL AGUA. CASA DE LOS VOLCANES. LANZAROTE.
SITUACION                    29 09 N  -  13 25 W
ORGANISMO RESPONSABLE        INSTITUTO DE ASTRONOMIA Y GEODESIA
                             ( C.S.I.C. - U.C.M. )

MAREOGRAFO                   001 (SENSOR DE PRESION)
REGISTRADOR                  MICROSCRIBE
INSTALACION                  R.VIEIRA
CALIBRACION                  R.VIEIRA
MANTENIMIENTO                R.VIEIRA, J.M. ESPINO , J. NAVERAN Y O. HERNANDEZ

ANALISIS                     MINIMOS CUADRADOS. FILTROS DE VENEDIKOV SOBRE
                             INTERVALOS DE 48 HORAS.
                             POTENCIAL CARTWRIGHT-TAYLER-EDDEN.
                             DESARROLLO COMPLETO
                             CENTRO DE PROCESO DE DATOS DE LA UNIVERSIDAD
                             COMPLUTENSE DE MADRID.   COMPUTADOR I.B.M. 4381
                             PROCESADO EL   89/ 1/13

INTERVALO DE OBSERVACION     87 712/87 849  87 9 9/8710 7  871012/88 425
                             290.0 DIAS     6432 LECTURAS       3 BLOQUES
EPOCA CENTRAL                FJ= 2447132.0

      GRUPO            AMPLITUD     FACTOR DE           FASE            RESIDUALES
ARGUMENTO  N ONDA     H  E.Q.M.  AMPL.    E.Q.M.    DIF.   E.Q.M.      AMPL.  FASE

115.-11X. 11 SIGMQ1  0.08 0.04   0.3439 0.1621   -12.16  27.00        0.20 -175.0
124.-126. 10 2Q1     0.43 0.04   0.5222 0.0524    17.84   5.76        0.56  166.4
127.-129. 11 SIGMA1  0.28 0.04   0.2762 0.0434    43.32   9.01        0.97  168.8
133.-136. 20 Q1      1.64 0.04   0.2630 0.0068    63.50   1.48        6.68  167.3
137.-139. 10 RO1     0.33 0.04   0.2746 0.0359    72.43   7.48        1.32  166.3
143.-145. 16 O1      4.51 0.04   0.1380 0.0013   -65.77   0.53       36.22 -173.5
146.-149. 10 TAU1    0.08 0.06   0.1839 0.1371   -69.12  42.72        0.47 -171.1
152.-155. 15 NO1     0.17 0.04   0.0667 0.0161    49.78  13.86        2.87  177.4
156.-158.  7 KI1     0.14 0.04   0.2752 0.0835   -17.13  17.38        0.44 -174.8
161.-163. 10 P1      1.45 0.05   0.0955 0.0033    34.80   2.01       18.35  177.1
164.-164.  3 S1      0.60 0.08   1.6795 0.2180    37.74   7.47        0.38   80.2
165.-168. 20 K1      5.27 0.05   0.1148 0.0010    38.65   0.60       48.21  176.1
172.-174.  8 TETA1   0.06 0.04   0.1128 0.0862    88.13  43.81        0.57  174.4
175.-177. 14 J1      0.08 0.04   0.0312 0.0158   -31.47  29.06        2.91 -179.2
181.-183.  7 SO1     0.06 0.04   0.1480 0.0930    87.60  36.03        0.50  172.7
184.-186. 11 OO1     0.12 0.03   0.0836 0.0202   -28.56  13.86        1.53 -177.9
191.-195. 14 NU1     0.03 0.03   0.1031 0.0996    34.68  55.35        0.29  176.9

215.-22X. 19 EPS2    0.43 0.06   0.8144 0.1168   -35.48   8.22        0.36 -136.4
233.-236. 10 2N2     1.85 0.07   1.0302 0.0404     2.57   2.25        0.25  160.5
237.-23X. 10 MU2     2.25 0.07   1.0374 0.0305   -15.98   1.68        0.71 -119.7
243.-245. 13 N2     14.08 0.07   1.0362 0.0050    11.24   0.28        3.37  125.4
246.-248. 11 NU2     2.52 0.06   0.9752 0.0250    13.90   1.47        0.82  132.3
252.-258. 26 M2     64.92 0.06   0.9151 0.0009    24.12   0.06       35.15  131.0
262.-264.  5 LAMB2   0.42 0.06   0.8051 0.1190    21.28   8.47        3.26  144.6
265.-265.  9 L2      1.30 0.05   0.6467 0.0226    47.25   2.00        1.73  146.6
267.-272.  5 T2      1.35 0.06   0.6979 0.0319    45.40   2.62        1.61  143.4
273.-273.  4 S2     24.01 0.06   0.7275 0.0019    47.17   0.15       28.16  141.3
274.-277. 12 K2      6.71 0.05   0.7470 0.0050    44.14   0.39        7.30  140.2
282.-285. 15 ETA2    0.41 0.04   0.8207 0.0840    63.09   5.86        0.54  137.1
292.-295. 11 2K2     0.06 0.02   0.4644 0.1822    89.10  22.48        0.16  158.1

DESVIACION TIPICA     D      0.25      SD      0.30      ( 0.1 MM )

  WAVE GROUP          ESTIMATED          PHASE         RESIDUALS
ARGUMENT     N WAVE  AMPL.R.M.S.     DIFF.   R.M.S.  AMPL. PHASE
---------------------------------------------------------------
327.-347.    6 345   0.085 0.028   -32.514  18.745   0.20-166.9
353.-355.    3 M3    0.285 0.028   201.618   5.690   1.24-175.2
363.-375.    8 365   0.031 0.007   159.349  12.735   0.09 172.5
382.-382.    1 S3    0.116 0.022   -25.053  11.660   0.11 -27.3
---------------------------------------------------------------
STANDARD DEVIATIONS     TD   1.09

---------------------------------------------------------------
  WAVE GROUP          ESTIMATED          PHASE         RESIDUALS
ARGUMENT     N WAVE  AMPL.R.M.S.     DIFF.   R.M.S.  AMPL. PHASE
---------------------------------------------------------------
455.-455.    1 M4    0.828 0.041    80.361   2.839   0.83  81.2
491.-491.    1 S4    0.118 0.040   -89.579  19.377   0.12 -95.2
---------------------------------------------------------------
STANDARD DEVIATIONS     QD   2.09
```

Table 3

XITH INTERNATIONAL SYMPOSIUM ON EARTH TIDES

HELSINKI, AUGUST 1989.

DATA ACQUISITION SYSTEMS IN THE "VALLE DE LOS CAIDOS" AND "CUEVA DE LOS VERDES" STATIONS

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ABSTRACT :
Both in the stations of the "Valle de los Caidos", near Madrid, and in the "Cueva de los Verdes", in Lanzarote, Canary Islands, two sets of data acquisition equipment have been set up that allow for the registration of all the information produced in both stations. Taking into account the special features of both locations, the two systems respond to different building principles, but their services are mainly similar. In this communication we give a description of both sets of equipment and present the results obtained.

1. DATA ACQUISITION SYSTEM IN THE "VALLE DE LOS CAIDOS"

The "Valle de los Caidos" (0401) is a geodynamic station, where permanent observation of earth tides (R. Vieira et al.,1986) has been carried out since 1973; it is located near Madrid, at approximately 50 Km., and is visited by staff from the institute once or twice a week. During these years of research, various instruments have been installed (R. Vieira et al, 1986) and new sensors will be installed in the near future (water-tube, extensometer, vertical pendulum,...).
Taking these characteristics into account, thought was given to developing a new data acquisition system, with the main interest being focused on: low power consumption, thus enabling it to operate during power cuts; it should be portable, given the nature of the entrance to the station; it should be versatile, capable of recording data from a large number of different sensors and of acting upon them; and it should be a system open to possible modifications as a result of experience in its use; for this reason, thought was given controlling the system by computer.

1.1. CONFIGURATION

The system was developed in collaboration with the electronics company GEONICA, S.A.; it comprises (figure 1): a central computer (Olivetti M24 with 20 MB hard disk); signal conditioners; a 12 bit A/D converter (DATA TRANSLATION) with differential inputs; variable gain amplifiers(2,4,8,16,32,64); 16 unipolar, or 8 differential input channels; auxiliary D/A outputs and 16 digital outputs for motors control. The measurement range is 5 volts, which varies in terms of the gain selected.

1.2. ACQUISITION PROGRAM

Figure 2 is a diagram of the data acquisition program utilized. The program enables us to collect data from all the sensors connected every dt time. Data is collected by realizing averages centred on the instant of the data, To, of the readings taken every two seconds. The interval of time between each average dt, as well as the period of time used to take the reading, $2\Delta T$, is determined from the computer, and may vary.

It was shown that this sampling method had no effect on the amplitude and that it causes no phase lag either, given that it is a centred average.

The computer stores the readings in its cyclical memory, which enables us to detect and record earthquakes. This is done by comparing the signal with the last average, and when this exceeds by n times the value of the product of a given constant k multiplied by the average, the earthquake recording equipment is activated, and files are formed with data every two seconds.

During the collection of data, the computer responds to the keyboard, in which the function keys have been programmed, and it has a set of screens with: data in real time in mV and in physical units, values of the last averages of all the sensors data on the stations, date and hour, whether an earthquake is being recorded at that moment, etc. Modifications may also be made to a whole range of parameters, such as the date, hour, etc..

In principle, considering international standards for the recording of meterological data, data acquisition was programmed for every ten minutes, and an average was taken of the readings made every two seconds for two minutes.

1.3. INSTALLATION

Once the system had been developed, to make it easier to control, it was first installed in the Madrid station (0402) located in the basements of the I.A.G. The instruments connected to the system were as follows: pressure, temperature and relative humidity sensors and the Lacoste romberg gravimeter, mod. G, N° 655, modified as a zero gravimeter (M.V. Ruymbeke, 1985).

The data was stored in two files, one for the meteorological parameters and another for the other sensors (in this case, only the gravimeter). The results of the analysis of the gravimetric tide data may be seen in Table 1, in which, though using a short serie of data, the errors and standard deviations are small. In the results of the atmospheric pressure data analysis (Table 2), the only relevant effect is semidiurnal; S2K2, with an amplitude of 0.5 mb. One problem that we have found has been the effect of the earthquakes on the tide signal, which is not filtered normally by the sampling method.

To make the handling of the data easier and more efficient, the collection programme was modified so that the files would be daily ones. Also, to facilitate consultation of the data, the hard disk was divided into four directories: tide, meteorological parameters, calibrations and earthquakes. One tide file uses 10657 bytes of memory, a meteorological parameter file uses 8497 bytes, and the calibrations and earthquakes files both use 48664 bytes. Therefore the storage capacity, supposing there are 15 MB free in the PC, would be:

without any earthquake or calibration file aproximately 26 months; with one earthquake or calibration file a day 7.5 months.

The possibility was introduced by pressing a key, of interrupting the programme and going to a menu which allows us to: go to the PC operative system, record the data on a floppy disk, visualize the file contents, and also to graphically represent any parameter. It is similarly easy to return to the acquisition program.

After the satisfactory test in Madrid, it was installed in the Valle de los Caidos station (0401). The pressure, temperature and humidity sensors were connected to it, together with the Askania GS15 gravimeter, modified to a zero instrument at our Institute (M. Orejana et al., 1983).

For diverse reasons unrelated to the data collection system, we have not been able to obtain a sufficiently ample set of gravimetric tide data to be able to make an analysis, from which to draw definitive conclusions. However, we may, by way of example, compare the output obtained with the preprocessing method of S. Nakai (1977, 1979) for two sets of data, one obtained with the Acquisition System and the other with an analogical recorder (Table 3). The greatest standard deviations are due in main to the occurrence of earthquakes or to the realization of drift corrections. In the absence of any of these problems, the quality of the digital register is enhanced. A wider set has been obtained from the atmospheric pressure data, which has enabled us to make an analysis (Table 4) where the clearest effect, again, is semidaily and meteorological (S2 wave). With the continuous register of the meteorological parameters, we have been able to contrast the great thermic stability of the station, where the daily variations in temperature are of around 1 or 2 tenths of a degree.

We have once more encountered the problem of the effect of the earthquakes on the tide signal, and a good example of this is to be seen in Figure 3 We must work on this in two aspects: on the filtering when collecting the data and on the elimination of the residual effect after the filtering. Another path that could be taken would be to use the system's digital outputs for the control of motors, for correcting drift and calibrating the sensors, thus eliminating all possible personal errors.

2.DATA ACQUISITION SYSTEM IN THE "CUEVA DE LOS VERDES" STATION

Due to the characteristics of the Cueva de Los Verdes station in Lanzarote (R. Vieira el al., 1988, 1989), we had to overcome several problems in the installation of a data acquisition system: it should not be difficult to transport, given the difficult access to the station, through the volcanic tunnel; it should work by itself and require minimum maintenance; furthermore, it should be able to transmit the data to a computer located outside the tunnel, and thus at a considerable distance from the station. For this reason, a system developed by GEONICA S.A. (internal document) was chosen and a series of modifications were necessary in order to adapt it to our needs.

2.1. CONFIGURATION AND CHARACTERISTICS

This acquisition module is a closed system, which consists of 16 analog input channels with a range of measurements between 2500mV, with an A/D conversion time of 800 fsec. The input impedance is > 10 MΩ in voltage and 10 Ω ± 0.02 % in current. It has 24 digital input/output signals; a processor and associated logic in CMOS technology, low power consumption; "watch-dog" supply failure detection and data protection monitoring circuit; clock and calendar; memory of 256K RAM CMOS with Li-battery for retaining data; RS232C and FSK communication lines. External supply may be 220 VAC or 12VDC; it also has internal supply of 12VDC/7 Ah NiCd batteries (rechargable from mains).

The input signals are protected with "tranzorb" diodes and "RC" filters, and supply inputs are protected with fuses and varistors. The environmental operating conditions are: between -15 and +70 degrees centrigrade and between 0 and 100% relative humidity, without condensation.

All the components are contained in a lockable box which is protected from humidity by a special covering. To enable its handling and use, there is a display (4x40 alphanumeric characters) and a frontal keyboard which permits us to call up instantaneous values, which will be shown in the relevant units on the display; to call up the results obtained during the latest computation period; to change the computation period; to change the date and time, and data may be transferred to an 80-column serial printer connected to the system via RS232C.

2.2. ACQUISITION AND COMMUNICATION

The programme, as well as the acquisition method, are analog to the acquisition system of the Valle de los Caidos. The main difference is that this system is not equipped to register earthquakes. Furthermore, when the average data is calculated and stored in memory, the maximum and minimum values of the signal during the sampling time, is also stored.

The reading of the data stored in memory, which as we have seen, may be printed out at the site of the system, is normally done directly via a PC, with two communication options (Figure 4):

- by means of on site connection via RS232C
- by means of an internal modem which transmits the data through a two-wire conductor (600 Ω, electrically isolated) through Frequency Shift Modulation (FSK), duplex, with the data being received at the UCO-V21 Communications Unit, which adapts the FSK signal to an RS232C serial interface, thus allowing communication with a computer located at a maximum distance of 5 km.

As was noted before, the communication expected to be used normally in our case is of the second type, where the system communicates with a computer located in the Casa de los Volcanes, over one kilometer away. In both communications it is possible to request instantaneous data, stored data, daily average data, consult the data base (on screen or via the printer); modifications may also be made to the constants or the operating mode, for example, the state of the clock may be corrected or the average period may be modified. all the information is viewed on a series of screens. The data storage capacity, taking one piece of data from all the sensors every 10 minutes, is of 30 days.

2.3. INSTALLATION

This system has been installed recently, and has been connected to the following sensors: Lacoste Romberg gravimeter, model G, N°434, modified as a zero gravimeter by M. Van Ruymbeke; pressure, temperature and humidity sensors, high precision sensors for measuring rock temperature (M.V. Ruymbeke et al., 1989); and a two component vertical pendulum. We hope to obtain results in the near future. To only use the computer when communication is established with the acquisition system, will enable us to develop a series of preprocessing and processing programmes for all the signals collected that are run automatically after each reading of data stored in the system, which provides us quick preliminary results.

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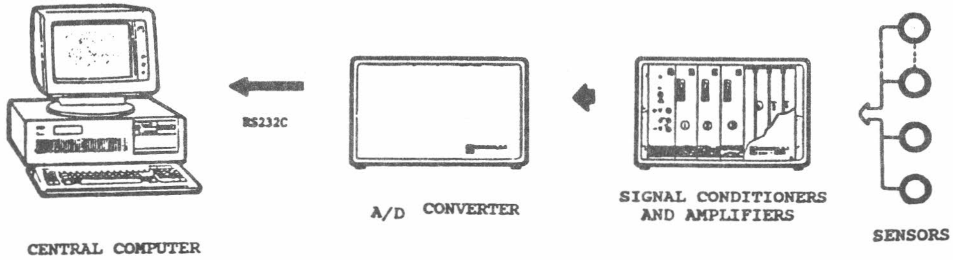

Figure 1

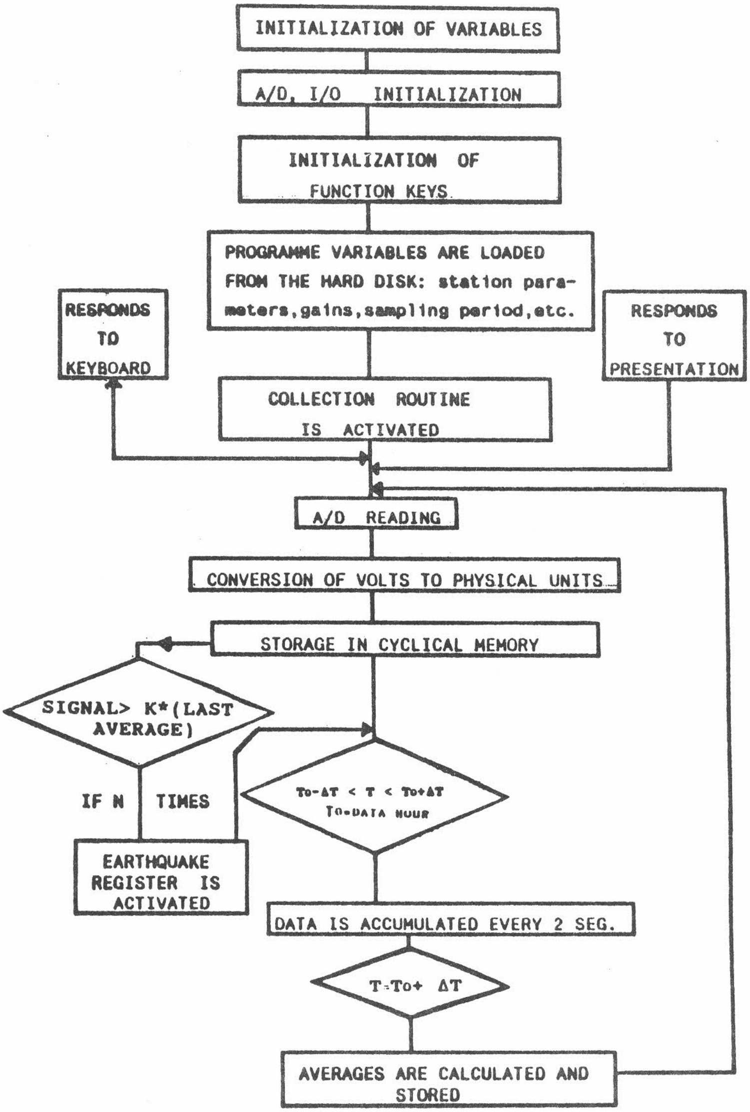

DIAGRAM OF DATA ACQUISITION PROGRAM

Figure 2

```
TRANS  IBERIAN  PENINSULA  PROFILE     STATION  MADRID

STATION   0402    MADRID              VERTICAL COMPONENT    SPAIN
40 27 N         03 43 W            H  630 M         P   5 M         D  310 KM

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FORMACION TERCIARIA (MIOCENO)
ALTERNANCIA DE ARENISCAS ARCILLOSAS Y SABULOSAS, INTERCALANDO LECHOS
CALCAREOS EN LA CAPA SUPERIOR Y CANTOS EN LA INFERIOR
GRAVIMETRO  L.R. MOD G 665 (M-0) (M. VAN RUYMBEKE)
CALIBRATION   VALLE DE LOS CAIDOS.  FUNDAMENTAL  STATION
INSTALATION:    R.VIEIRA
MANTENANCE :    R.VIEIRA, J.FERNANDEZ

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B. DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLET DEVELOPMENT
COMPUTING CENTER OF UNIVERSIDAD COMPLUTENSE DE MADRID
COMPUTER   IBM 360      PROCESSED ON    88/ 5/30

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR   0.99237
PHASE LAG  O1  0.20   M2  0.41   O1/M2 0.49
INSTRUMENTAL LAG    5.41 MIN.
CORRECTION FOR ATTENUATION   O1 1.00001   M2 1.00003   /MODEL 1/

      87 1 8/87 110  87 114/87 120  87 123/87 131  87 2 6/87 2 6  87 210/87 212
      87 215/87 221  87 224/87 3 4  87 3 7/87 3 7  87 310/87 314  87 319/87 319
      87 324/87 328

TIME INTERVAL    80.5 DAYS       1488 READINGS        11 BLOCKS

  WAVE GROUP    ESTIMATED AMPL.   AMPL.           PHASE              RESIDUALS
ARGUMENT   N WAVE         R.M.S.  FACTOR R.M.S.   DIFF.  R.M.S.       AMPL.  PHASE

115.-11X. 11 SIGMQ1   0.35 0.11   1.5408 0.6116     5.31  22.27     0.09   20.8
124.-129. 21 SIGMA1   1.15 0.11   1.2264 0.1176   -15.53   5.51     0.31  -86.2
133.-139. 30 Q1       6.76 0.14   1.1514 0.0233    -1.24   1.15     0.15 -108.5
143.-149. 26 O1      35.25 0.13   1.1490 0.0041    -0.76   0.21     0.57 -124.2
152.-158. 22 M1       2.60 0.15   1.0771 0.0627     3.39   3.33     0.25  142.7
161.-168. 33 P1S1K1  48.16 0.14   1.1162 0.0031    -0.37   0.16     0.98 -161.2
172.-177. 22 J1       2.92 0.14   1.2103 0.0575     1.83   2.71     0.15   38.6
181.-186. 18 OO1      1.58 0.09   1.1960 0.0660    -1.67   3.16     0.07  -45.0
191.-195. 14 NU1      0.15 0.09   0.6111 0.3672    -4.22  34.08     0.14 -175.3

215.-22X. 19   EPS2   0.38 0.06   1.1755 0.1769    -3.31   9.03     0.02  -78.8
233.-23X. 20 2N2      1.45 0.05   1.0909 0.0339     1.63   1.77     0.10  156.1
243.-248. 24 N2       9.36 0.06   1.1244 0.0067     4.93   0.34     0.87  112.4
252.-258. 26 M2      49.83 0.05   1.1457 0.0012     4.44   0.06     3.94  101.4
262.-265. 14 L2       1.39 0.02   1.1273 0.0201     3.20   1.03     0.09  118.8
267.-277. 21 S2K2    24.01 0.04   1.1866 0.0020     3.39   0.10     1.50   70.8
282.-285. 15 ETA2     0.40 0.04   1.2905 0.1305     0.58   5.81     0.04    5.8
292.-295. 11 2K2      0.12 0.02   1.5127 0.2598    10.96   9.80     0.04   41.5

335.-375. 16 M3       0.67 0.02   1.0250 0.0358     1.20   1.96     0.02   35.1

STANDARD DEVIATION    D     3.55     SD      1.11      TD      0.53  MICROGAL
STUDENT FACTOR      T(S=95(,M>  53)=1.96

O1/K1  1.0294   1-O1/1-K1  1.2822   M2/O1  0.9972
CENTRAL EPOCH TJJ= 2446843.0
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Table 1

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                                   MAREA ATMOSFERICA
                                   -----------------

ESTACION                           MADRID (0402).
SITUACION                          40 27 N  -  03 43 W
ORGANISMO RESPONSABLE              INSTITUTO DE ASTRONOMIA Y GEODESIA
                                   ( C.S.I.C. - U.C.M. )

SENSOR DE PRESION                  NUMERO  002
MODULO DE ADQUISICION
DE DATOS
INSTALACION                        F.LAMBAS, R.VIEIRA, C.TORO, J.FERNANDEZ
CALIBRACION                        GEONICA S.A.
MANTENIMIENTO                      J.FERNANDEZ, R.VIEIRA

ANALISIS                           MINIMOS CUADRADOS. FILTROS DE VENEDIKOV SOBRE
                                   INTERVALOS DE 48 HORAS.
                                   POTENCIAL CARTWRIGHT-TAYLER-EDDEN.
                                   DESARROLLO COMPLETO
                                   CENTRO DE PROCESO DE DATOS DE LA UNIVERSIDAD
                                   COMPLUTENSE DE MADRID.   COMPUTADOR I.B.M. 4381
                                   PROCESADO EL    89/ 7/19

INTERVALO DE OBSERVACION           87 1 8/87 118   87 124/87 130   87 2 6/87 328

                                      80.5 DIAS       1728 LECTURAS          3 BLOQ

        GRUPO                         AMPLITUD           FASE
ARGUMENTO  N ONDA                    H   E.Q.M.      DIF.  E.Q.M.

115.-11X. 11 SIGMQ1                0.353 0.1441    -10.59   23.46
124.-129. 21 SIGMA1                0.139 0.1188     85.91   48.57
133.-139. 30 Q1                    0.130 0.1402    -54.35   62.04
143.-149. 26 O1                    0.149 0.1365     82.49   52.27
152.-158. 22 M1                    0.206 0.2009    -77.73   55.69
161.-168. 33 P1S1K1                0.194 0.1486    -36.55   44.02
172.-177. 22 J1                    0.096 0.1287     10.37   76.95
181.-186. 18 OO1                   0.162 0.0905     10.95   31.84
191.-195. 14 NU1                   0.102 0.0910     40.67   51.13

215.-22X. 19 EPS2                  0.022 0.0438    -12.50  113.58
233.-23X. 20 2N2                   0.087 0.0340    -59.85   22.40
243.-248. 24 N2                    0.045 0.0420    -81.45   52.30
252.-258. 26 M2                    0.055 0.0367     58.18   38.31
262.-265. 14 L2                    0.026 0.0212    -72.73   46.11
267.-277. 21 S2K2                  0.529 0.0287    -72.43    3.10
282.-285. 15 ETA2                  0.007 0.0275    -67.22  239.57
292.-295. 11 2K2                   0.015 0.0149    -78.92   55.67

335.-375. 16 M3                    0.061 0.0302     54.77   28.50
```

Table 2

ANALOGIC RECORDING OF DATA										DIGITAL RECORDING OF DATA	
212 4014771389 7 60	1.00356	0.00*	4084.94	1.04		212 4014771389 7 60	1.00618	-0.01	1608.38	0.94	
212 4014771589 7 80	0.99100	0.25*	4031.01	0.79		212 4014771589 7 80	0.99210	0.05	1661.99	0.74	
						212 4014771789 7100	0.99444	0.12	1722.03	0.99	
212 4014772089 7122	0.98866	1.43*	3884.82	0.68		212 4014772089 7122	0.99455	1.06	1791.73	0.59	
212 4014772289 7142	0.99573	0.99*	3804.46	1.11		212 4014772289 7142	0.99929	0.95	1872.00	0.85	
212 4014772489 7162	0.99770	1.13*	3739.48	1.11		212 4014772489 7162	1.00038	1.23	1938.28	0.99	
212 4014772689 7182	1.00154	0.58*	3664.69	1.11		212 4014772689 7182	1.00593	0.50	2013.28	0.62	

Table 3

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                          MAREA ATMOSFERICA
                          -----------------

ESTACION                  VALLE DE LOS CAIDOS (0401).
SITUACION                 40 38 N  -  04 09 W
ORGANISMO RESPONSABLE     INSTITUTO DE ASTRONOMIA Y GEODESIA
                          ( C.S.I.C. - U.C.M. )

SENSOR DE PRESION         NUMERO  002
MODULO DE ADQUISICION
DE DATOS
INSTALACION               J.FERNANDEZ, R.VIEIRA
CALIBRACION               GEONICA S.A.
MANTENIMIENTO             J.FERNANDEZ, R.VIEIRA, J.VELASCO, J.L.VALBUENA

ANALISIS                  MINIMOS CUADRADOS. FILTROS DE VENEDIKOV SOBRE
                          INTERVALOS DE 48 HORAS.
                          POTENCIAL CARTWRIGHT-TAYLER-EDDEN.
                          DESARROLLO COMPLETO
                          CENTRO DE PROCESO DE DATOS DE LA UNIVERSIDAD
                          COMPLUTENSE DE MADRID.   COMPUTADOR I.B.M. 4381
                          PROCESADO EL   89/ 7/19

INTERVALO DE OBSERVACION  871015/8711 2  8711 9/871113  871126/8712 8
                           88 113/88 119 88 2 5/88 227
INTERVALO DE OBSERVACION  88 3 4/88 314  88 4 9/88 419  88 423/88 5 3
                           88 512/88 528 88 6 2/88 720
INTERVALO DE OBSERVACION  88 723/88 816  881119/89 124  89 128/89 213
                           89 3 5/89 510 89 514/89 6 5
                             601.0 DIAS      9120 LECTURAS        15 BLOQ

       GRUPO                AMPLITUD        FASE
ARGUMENTO  N ONDA           H   E.Q.M.    DIF.   E.Q.M.

115.-11X. 11 SIGMQ1       0.031 0.0289   -21.16  53.13
124.-126. 10 2Q1          0.039 0.0294   -24.00  43.47
127.-129. 11 SIGMA1       0.018 0.0292   -40.69  95.49
133.-136. 20 Q1           0.047 0.0284   -89.64  34.43
137.-139. 10 RO1          0.022 0.0287    -7.30  75.55
143.-145. 16 O1           0.048 0.0277    87.96  32.88
146.-149. 10 TAU1         0.031 0.0401   -78.67  73.11
152.-155. 15 NO1          0.026 0.0221    28.41  49.32
156.-158.  7 KI1          0.040 0.0271   -13.54  38.73
161.-163. 10 P1           0.049 0.0322    77.86  37.84
164.-168. 23 S1K1         0.053 0.0288   -49.91  31.16
172.-174.  8 TETA1        0.018 0.0273   -69.92  86.88
175.-177. 14 J1           0.074 0.0279    83.03  21.49
181.-183.  7 SO1          0.027 0.0268    64.69  57.33
184.-186. 11 OO1          0.037 0.0177    70.65  27.60
191.-195. 14 NU1          0.021 0.0187   -17.55  49.73

215.-22X. 19 EPS2         0.008 0.0116   -20.00  83.74
233.-23X. 20 2N2          0.026 0.0098   -48.80  21.29
243.-248. 24 N2           0.007 0.0116     6.32  99.94
252.-258. 26 M2           0.016 0.0111   -17.50  38.77
262.-264.  5 LAMB2        0.006 0.0113    60.57 103.21
265.-265.  9 L2           0.022 0.0107   -70.84  28.15
267.-273.  9 S2           0.543 0.0107   -58.24   1.12
274.-277. 12 K2           0.023 0.0082   -43.18  20.61
282.-285. 15 ETA2         0.006 0.0076    34.66  74.61
292.-295. 11 2K2          0.005 0.0044    -8.42  50.63

335.-375. 16 M3           0.022 0.0100   -74.17  25.93
```

Table 4

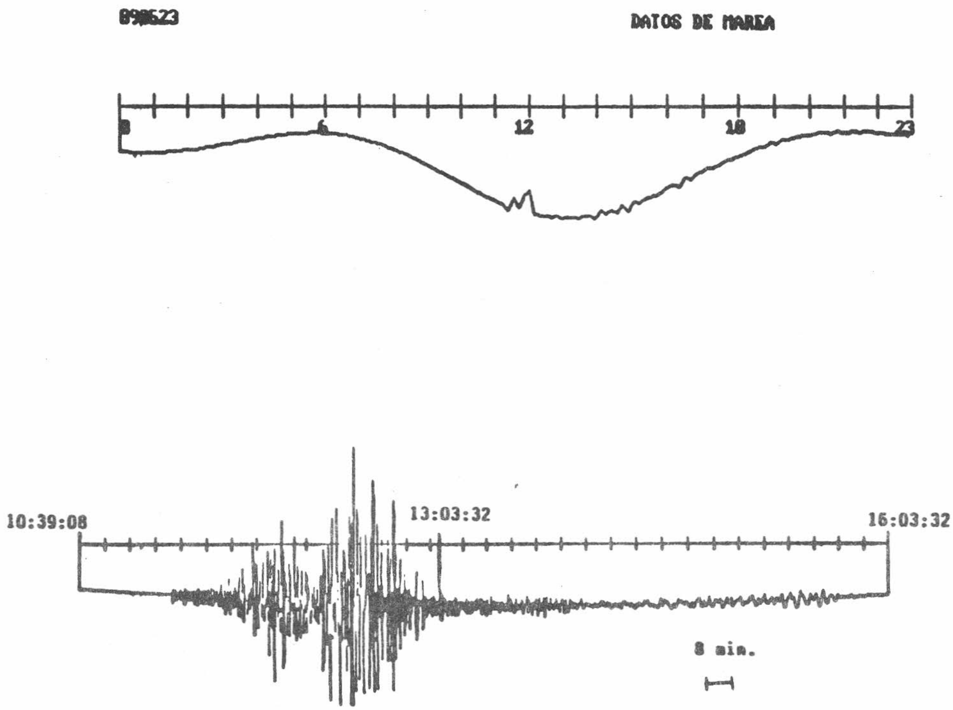
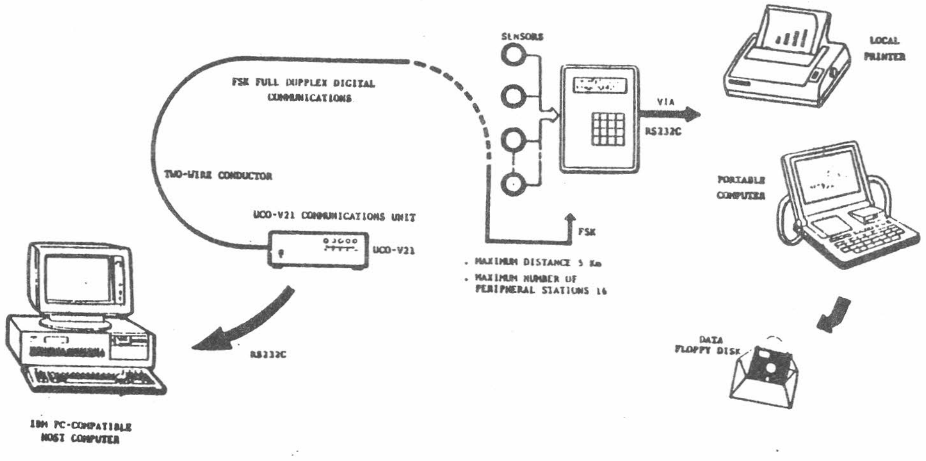


Figure 3



- MAXIMUM DISTANCE 5 Km
- MAXIMUM NUMBER OF PERIPHERAL STATIONS 16

Figure 4

PUBLICACIONES DEL INSTITUTO DE ASTRONOMIA Y GEODESIA DE LA UNIVERSIDAD COMPLUTENSE — MADRID

(Antes Seminario de Astronomía y Geodesia)

1.—Efemérides de 63 Asteroides para la oposición de 1950 (1949).
2.—E. Pajares: Sobre el cálculo gráfico de valores medios (1949).
3.—J. Pensado: Orbita del sistema visual σ^2 U Maj (1950).
4.—Efemérides de 79 Asteroides para la oposición de 1951 (1950).
5.—J. M. Torroja: Corrección de la órbita del Asteroide 1395 "Aribeda" (1950).
6.—R. Carrasco y J. M. Torroja: Rectificación de la órbita del Asteroide 1371 "Resi" (1971).
7.—J. M. Torroja y R. Carrasco: Rectificación de la órbita del Asteroide 1560 (1942 XB) y efemérides para la oposición de 1951 (1951).
8.—M. L. Siegrist: Orbita provisional del sistema visual Σ 728-32 Orionis (1951).
9.—Efemérides de 79 Asteroides para la oposición de 1952 (1951).
10.—J. Pensado: Orbita provisional de Σ 1883 (1951).
11.—M. L. Siegrist: Orbita provisional del sistema visual Σ 2052 (1952).
12.—Efemérides de 88 Asteroides para la oposición de 1953 (1952).
13.—J. Pensado: Orbita de ADS 9380 = Σ 1879 (1952).
14.—F. Alcázar: Aplicaciones del Radar a la Geodesia (1952).
15.—J. Pensado: Orbita de ADS 11897 = Σ 2438 (1952).
16.—B. Rodríguez-Salinas: Sobre varias formas de proceder en la determinación de períodos de las marcas y predicción de las mismas en un cierto lugar (1952).
17.—R. Carrasco y M. Pascual: Rectificación de la órbita del Asteroide 1528 "Conrada" (1953).
18.—J. M. González-Aboin: Orbita de ADS 1709 = Σ 228 (1953).
19.—J. Baltá: Recientes progresos en Radioastronomía. Radiación solar hiperfrecuente (1953).
20.—J. M. Torroja y A. Vélez: Corrección de la órbita del Asteroide 1452 (1938 DZ_1) (1953).
21.—J. M. Torroja: Cálculo con Cracovianos (1953).
22.—S. Arend: Los polinomios ortogonales y su aplicación en la representación matemática de fenómenos experimentales (1953).
23.—J. M. Torroja y V. Bongera: Determinación de los instantes de los contactos en el eclipse total de Sol de 25 de febrero de 1952 en Cogo (Guinea Española) (1954).
24.—J. Pensado: Orbita de la estrella doble Σ 2 (1954).
25.—J. M. Torroja: Nueva órbita del Asteroide 1420 "Radcliffe" (1954).
26.—J. M. Torroja: Nueva órbita del Asteroide 1557 (1942 AD) (1954).
27.—R. Carrasco y M. L. Siegrist: Rectificación de la órbita del Asteroide 1290 "Albertine" (1954).
28.—J. Pensado: Distribución de los períodos y excentricidades y relación período-excentricidad en las binarias visuales (1955).
29.—J. M. González-Aboin: Nueva órbita del Asteroide 1372 "Haremari" (1955).
30.—M. de Pascual: Rectificación de la órbita del Asteroide 1547 (1929 CZ) (1955).
31.—J. M. Torroja: Orbita del Asteroide 1554 "Yugoslavia" (1955).
32.—J. Pensado: Nueva órbita del Asteroide 1401 "Lavonne" (1956).
33.—J. M. Torroja: Nuevos métodos astronómicos en el estudio de la figura de la Tierra (1956).
34.—D. Calvo: Rectificación de la órbita del Asteroide 1466 "Mündleira" (1956).
35.—M. L. Siegrist: Rectificación de la órbita del Asteroide 1238 "Predappia" (1956).

36.—J. PENSADO: Distribución de las inclinaciones y de los polos de las órbitas de las estrellas dobles visuales (1956).

37.—J. M. TORROJA y V. BONGERA: Resultados de la observación del eclipse total de Sol de 30 de junio de 1954 en Sydkoster (Suecia) (1957).

38.—ST. WIERZBINSKI: Solution des équations normales par l'algorithme des cracoviens (1958).

39.—J. M. GONZÁLEZ-ABOIN: Rectificación de la órbita del Asteroide 1192 "Prisma" (1958).

40.—M. LÓPEZ ARROYO: Sobre la distribución en longitud heliográfica de las manchas solares (1958).

41.—F. MÚGICA: Sobre la ecuación de Laplace (1958).

42.—F. MARTÍN ASÍN: Un estudio estadístico sobre las coordenadas de los vértices de la triangulación de primer orden española (1958).

43.—ST. WIERZBINSKI: Orbite améliorée de h 4530 = γ Cen = Cpd —48°, 4965 (1958).

44.—D. CALVO BARRENA: Rectificación de la órbita del Asteroide 1164 "Kobolda" (1958).

45.—M. LÓPEZ ARROYO: El ciclo largo de la actividad solar (1959).

46.—F. MÚGICA: Un nuevo método para la determinación de la latitud (1959).

47.—J. M. TORROJA: La observación del eclipse de 2 de octubre de 1959 desde El Aaiun (Sahara) (1960).

48.—J. M. TORROJA, P. JIMÉNEZ-LANDI y M. SOLÍS: Estudio de la polarización de la luz de la corona solar durante el eclipse total de Sol del día 2 de octubre de 1959 (1960).

49.—E. PAJARES: Sobre el mecanismo diferencial de un celóstato (1960).

50.—J. M. GONZÁLEZ-ABOIN: Sobre la diferencia entre los radios vectores del elipsoide internacional y el esferoide de nivel (1960).

51.—J. M. TORROJA: Resultado de las observaciones del paso de Mercurio por delante del disco solar del 7 de noviembre de 1960 efectuadas en los observatorios españoles (1961).

52.—F. MÚGICA: Determinación de la latitud por el método de los verticales simétricos (1961).

53.—M. LÓPEZ ARROYO: La evolución del área de las manchas solares (1962).

54.—F. MÚGICA: Determinación simultánea e independiente de la latitud y longitud mediante verticales simétricos (1962).

55.—P. DÍEZ-PICAZO: Elementos de la órbita de la variable eclipsante V 499 Scorpionis (1964).

56.—J. M. TORROJA: Los Observatorios Astronómicos en la era espacial (1965).

57.—F. MARTÍN ASÍN: Nueva aportación al estudio de la red geodésica de primer orden española y su comparación con la red compensada del sistema europeo (1966).

58.—F. SÁNCHEZ MARTÍNEZ: La Luz Zodiacal. Luz del espacio interplanetario (1966).

59.—J. M. GONZÁLEZ-ABOÍN: Variaciones de las coordenadas geodésicas de los vértices de una red, por cambio de elipsoide de referencia (1966).

60.—F. SÁNCHEZ MARTÍNEZ y R. DUMONT: Fotometría absoluta de la raya verde y del continuo atmosférico en el Observatorio Astronómico del Teide (Tenerife), de enero de 1964 a julio de 1965 (1967).

61.—M. REGO: Estudio del espectro de la estrella 31 Aql. en la región $\lambda\lambda$ 4000-6600 A (1969).

62.—C. MACHÍN: Mareas terrestres (1969).

63.—J. M. TORROJA: La estación para la observación de satélites geodésicos de la Facultad de Ciencias de la Universidad de Madrid (1969).

64.—M. J. SEVILLA: Reducción automática de posiciones de estrellas (1970).

65.—J. M. TORROJA: Memoria de las actividades del Seminario de Astronomía y Geodesia de la Facultad de Ciencias de la Universidad de Madrid en 1969 (1970).

66.—M. J. SEVILLA: Los cálculos de estación en triangulación espacial (1970).

67.—MANUEL E. REGO: Determinación de las abundancias de los elementos en la atmósfera de la estrella de alta velocidad 31 Aql. (1970).

68.—M. J. FERNÁNDEZ-FIGUEROA: Análisis cualitativo del espectro de la estrella peculiar HD 18474 (1971).

69.—J. M. TORROJA: Memoria de las actividades del Seminario de Astronomía y Geodesia de la Universidad Complutense de Madrid en 1970 (1971).

70.—R. Vieira y R. Ortiz: Descripción de un aparato para medida de coordenadas (1971).
71.—J. M. Torroja: Memoria de las actividades del Seminario de Astronomía y Geodesia de la Universidad Complutense de Madrid en 1971 (1972).
72.—M. J. Fernández-Figueroa: Observación y estudio teórico del espectro de la estrella peculiar HD 18474 (1972).
73.—M. J. Sevilla: Cálculo de las constantes de distorsión y parámetros del disco obturador para cámaras balísticas (1973).
74.—R. Parra y M. J. Sevilla: Cálculo de efemérides y previsiones de pasos de satélites geodésicos (1973).
75.—M. Rego y M. J. Fernández-Figueroa: Resultado de las observaciones de α Peg efectuadas desde el satélite europeo TDI (1973).
76.—E. Simonneau: Problemas en la determinación de abundancias de elementos en las estrellas en condiciones de equilibrio termodinámico local y alejadas del equilibrio termodinámico local (1974).
77.—J. Aranda: Construcción de modelos de estructura interna para estrellas en la secuencia principal inicial (1974).
78.—R. Ortiz, M. J. Sevilla y R. Vieira: Estudio de la calibración, técnica de medida y automatización de datos en un comparador para medidas de placas estelares (1974).
79.—M. J. Sevilla: Método autocorrector para el cálculo de direcciones de satélites geodésicos y análisis de los errores en la restitución de un arco de órbita (1974).
80.—M. A. Acosta, R. Ortiz y R. Vieira: Diseño y construcción de un fotómetro fotoeléctrico para la observación de ocultaciones de estrellas por la Luna (1974).
81.—T. J. Vives, C. Morales, J. García-Pelayo y J. Barbero: Fotometría fotográfica UBV del cúmulo galáctico King 19 (1974).
82.—R. Ortiz y R. Vieira: Control automático en posición y tiempo de los sistemas de obturación de las cámaras de observación de satélites geodésicos (1974).
83.—J. M. Torroja: Memoria de las actividades del Seminario de Astronomía y Geodesia de la Universidad Complutense de Madrid en 1972 y 1973 (1974).
84.—M. J. Fernández-Figueroa y M. Rego: α CrB en el ultravioleta lejano (1975).
85.—J. M. Torroja, R. Vieira, R. Ortiz y M. J. Sevilla: Estudio de mareas terrestres en España (1975).
86.—M. J. Sevilla y R. Parra: Levantamiento gravimétrico de Lanzarote (1975).
87.—P. Kundanmal Sukhwani: Modelos teóricos de curvas de luz. Su aplicación al sistema β Lyrae (1975).
88.—M. J. Sevilla: Coordenadas astronómicas y geodésicas. Desviación relativa de la vertical (1975).
89.—C. Tejedor: Fotometría fotoeléctrica R. G. U. del cúmulo galáctico IC 2581 (1976).
90.—M. J. Sevilla: Nuevos coeficientes para la reducción automática de posiciones de estrellas (1976).
91.—M. Rego: Técnicas observacionales en espectroscopía astrofísica (1976).
92.—M. J. Sevilla: Determinación de la latitud por distancias cenitales de la polar, método de Littrow (1976).
93.—T. J. Vives: Determinación fotométrica del tipo espectral de la componente desconocida de una estrella binaria eclipsante (1976).
94.—M. Rego y M. J. Fernández-Figueroa: Contraste y determinación por métodos astrofísicos de fuerzas de oscilador (1977).
95.—M. J. Sevilla y R. Chueca: Determinación de acimutes por observación de la Polar. Método micrométrico (1977).
96.—José M. García-Pelayo: Fotometría R G U en un campo del anticentro galáctico, cerca del NGC 581 (1977).
97.—José M. García-Pelayo: Datos fotométricos de 2.445 estrellas estudiadas en la región de Casiopea, entre los cúmulos abiertos Trumpler 1 y NGC 581 (1977).
98.—Prem K. Sukhwani y Ricardo Vieira: Spectral Analysis of Earth Tides (1977).
99.—José M. Torroja y Ricardo Vieira: Earth Tides in Spain. Preliminary results (1977).
100.—Prem K. Sukhwani y Ricardo Vieira: Three different methods for taking in account the gaps in spectral analysis of Earth Tides records (1978).
101.—R. Vieira: Mareas terrestres (1978).
102.—M. J. Sevilla y A. Núñez: Determinación de la longitud por el método de Mayer. Programas de cálculo automático (1979).
103.—M. J. Sevilla y A. Núñez: Determinación de la latitud por el método de Sterneck. Programas de cálculo automático (1979).
104.—M. J. Sevilla: Determinación de la latitud y la longitud por el método de alturas iguales. Programas de cálculo automático (1979).
105.—P. K. Sukhwani y A. Giménez: Corrección de efectos atmosféricos para imágenes tomadas desde satélites Landsat (1979).
106.—M. J. Sevilla: Inversión de Matrices Simétricas en el método de mínimos cuadrados (1979).

(continúa en la cuarta de cubierta)

107.—A. Giménez: Análisis de la curva de luz del sistema binario eclipsante S Velorum (1979).
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