COMPARATIVE STUDY OF THE TIDAL GRAVITY PARAMETERS OBSERVED IN TIMANFAYA, JAMEOS DEL AGUA AND CUEVA DE LOS VERDES STATIONS AT LANZAROTE ISLAND.

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ABSTRACT

The Island of Lanzarote, in the Canarian Archipelago, placed near the western african coast of Morocco has a volcanic origin, like all Canary Islands. The last eruptions in the island have taken place in the XVII and XIX centuries. A very important eruption has ocurred between 1730 and 1736, which is one of the most prolonged volcanic manifestation that we have information about. It has caused important changes in the topography of the island, affecting almost 25% of its surface. As a consequence of this eruption, possibly due to a remaining superficial magma, there is a zone of strong geotermic anomalies. Thus, in the National Volcanic Park of Timanfaya can be measured now temperatures of 600° C order, only a few meters depht. Island's crust determined by gravity investigations as well as through seismic profiles, it is of 14 km order.

Since 1987, the collaboration between the IAG (the Institute of Astronomy and Geodesy) and the Royal Observatory of Belgium (ROB) allows gravity tides observations in three different points of the island. Two of them, *Cueva de los Verdes* and *Jameos del Agua*, at the northern part. The third one it is placed at the *Park of Timanfaya*, just over the anomalies mentioned above. In the present paper we deal with the results which can be related with the crustal structure, geotermic anomalies, ocean effects, etc..

INTRODUCTION

As a consequence of the collaboration supported by the IAG of Madrid and the ROB of Brusels, the gravimeter LC&R nº 336, with feedback system incorporated, remains at Lanzarote (Canary Islands) since March 1990 (see figure 1), recording gravity variations permanently.

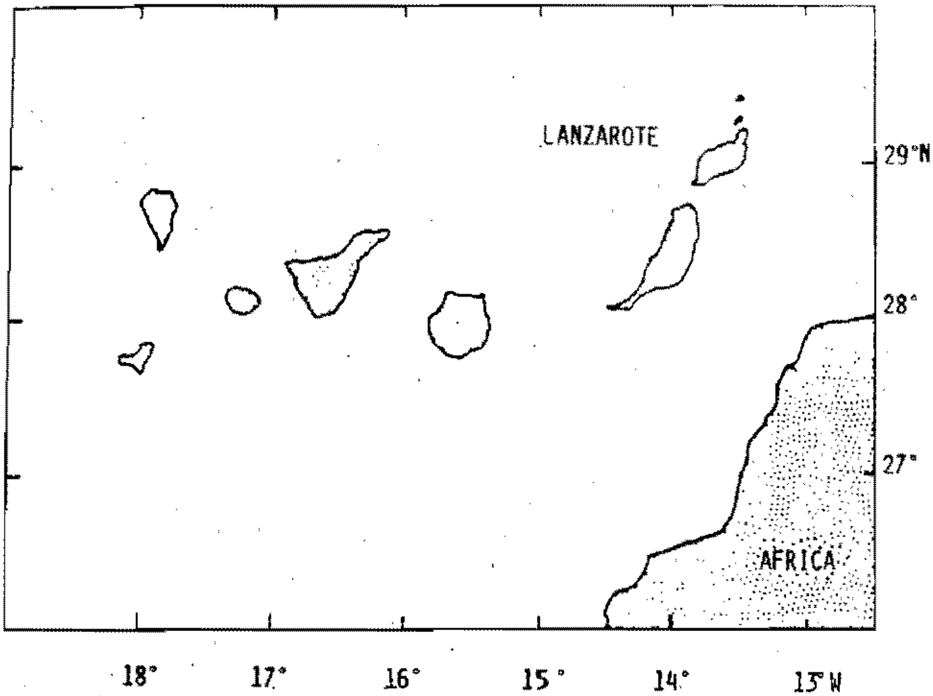


Figure 1.

During more than three years, the instrument has been placed in three different locations of the island. Since the begining of the experience, until February of 1991, the gravimeter stayed at the geodynamic station of *Cueva de los Verdes* (figure 2) (*Vieira et al., 1991a*) working in parallel with the Lc&R nº 434 gravimeter, that since 1987 it is recording gravity tides at the same place. Later, from February 1991 to September 1992 it was installed at *Casa de los Volcanes*, ~1 km from the first place, in direction to the sea, and no more than 100 m from the actual coast line. In February of the present year, the gravimeter has been moved to *National Park of Timanfaya* station, recording practically over the vertical of the most important geotermic anomaly of the island (close to 600° C at ~14 m depth), originated by the eruption occurred between 1730 and 1736. This eruption has created the National Park and changed almost 25% of the island's topography (*Araña et al., 1978*). The station of Timanfaya has the important characteristic that all the sensors installed there are supplyed by solar energy.

Scientific objectives of the geodynamic investigations developed by the IAG at Lanzarote, in collaboration with another national and international centers (*Vieira et al, 1991a*), are multiple but they are mainly related to the activities of the Working Group "Tidal Measurements and Geodynamic Research", created in 1989 inside the Permanet Commision on Earth Tides.

Taking into account the special characteristics of Lanzarote Island, we are trying to study the

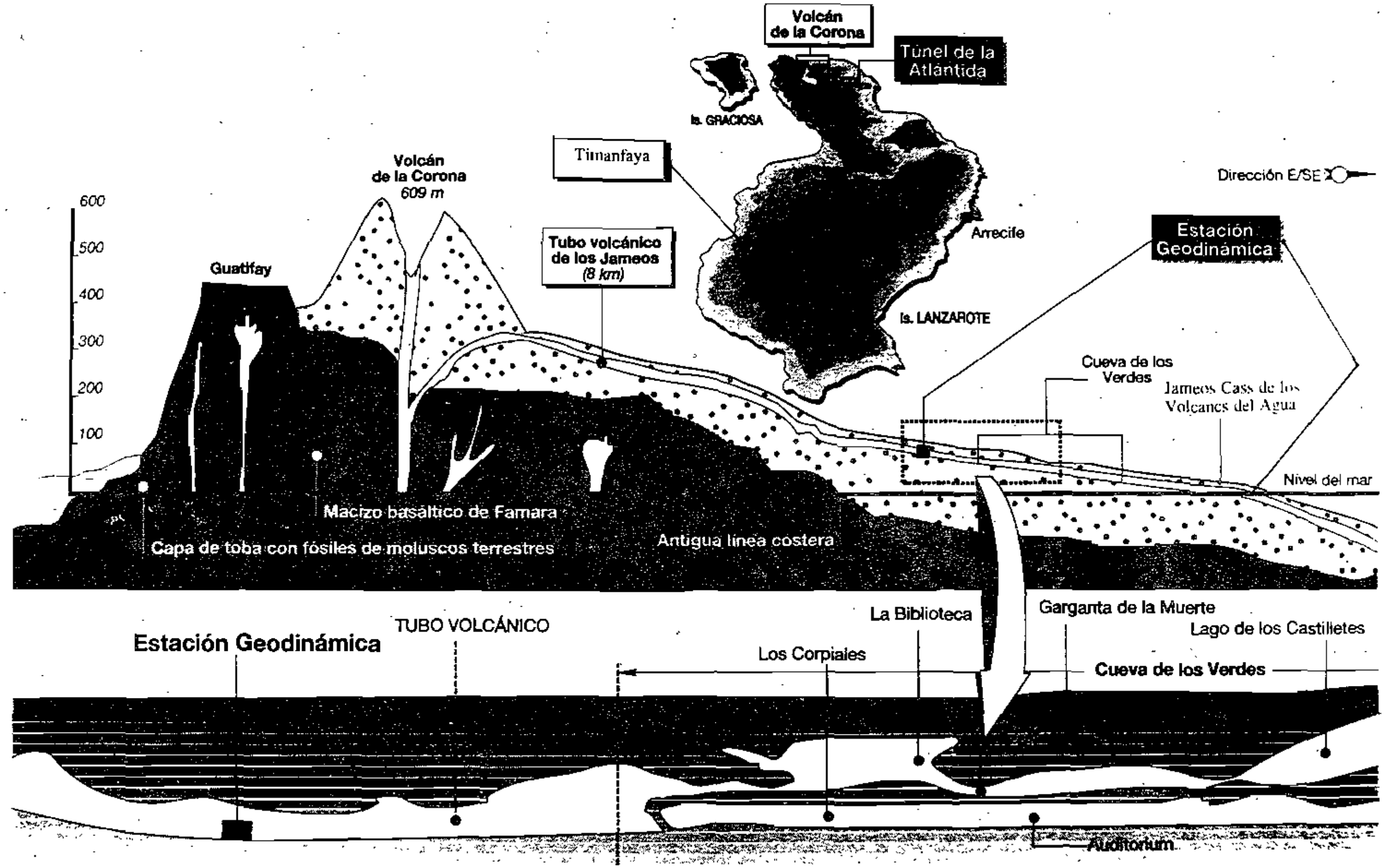

Volcán de la Corona
Túnel de la Atlántida
Is. GRACIOSA
Timanfaya
Volcán de la Corona 609 m
Dirección E/SE
600
500
400
300
200
100
Guatifay
Tubo volcánico de los Jameos (8 km)
Arrecife
Estación Geodinámica
Is. LANZAROTE
Cueva de los Verdes
Jameos Cass de los Volcanes del Agua
Nivel del mar
Macizo basáltico de Famara
Capa de toba con fósiles de moluscos terrestres
Antigua línea costera
La Biblioteca
Garganta de la Muerte
Lago de los Castilletes
TUBO VOLCÁNICO
Estación Geodinámica
Los Corpiales
Cueva de los Verdes
Auditorium

Figure 2

spatial and temporary variations of tidal parameters, in relation with the structure of the crust, heat flow, oceanic and atmospheric effects, seismic and volcanic activity, etc.. It means, finally, a big investigation program which results will produce whereas observation and modelization of different effects and software development, neccssary for the analysis, go ahead.

In this initial work we present only the first results of the Earth tide analysis at the three stations mentioned, as well as a first evaluation of the oceanic effects over themselves.

OCEANIC EFFECT COMPUTATION

To compute the oceanic effect it has been used the program EIO developed by *C. de Toro* at the IAG, as well as the Schwiderski's global charts complemented with the local charts that we named CANARIAS. This chart has been obtained by means empirical tidal data (*Vieira et al., 1991b*). In this first work we will restrict to the main semidiurnal component M_2 (figure 3).

The main interest it is to know the Cueva de los Verdes and Casa de los Volcanes stations. Both are placed at the volcanic tube originated a few thounsand years ago during the eruption of *La Corona* volcano. Such a tube, about 8 km lenght starts, in its first 6 km, under the *malpais's* surface, created in the cruption and catched to the ocean, and follows at least 2 km inside the sea. Free and high porosity lava materials configure the malpais and allows the penetration under the sea and possibly covers until the old coast line, more inner than the geodynamic station. With these characteristics, to model the oceanic effect it is too difficult because it is necessary to know the dynamic of the water table under the malpais. Such a dynamic consists of to continue with the phase lags and attenuation of the tidal period. This research it is going forward because, actually, we have installed several tidal gauges at the coast line and in three points, inside the lava tube where it runs under the sea level. In these points there exist salt lakes with a measurable tidal period. Studying amplitudes and phase lags of the ocean tide in these points, will allow us to study the supplementary oceanic effect, not considerated in this first work.

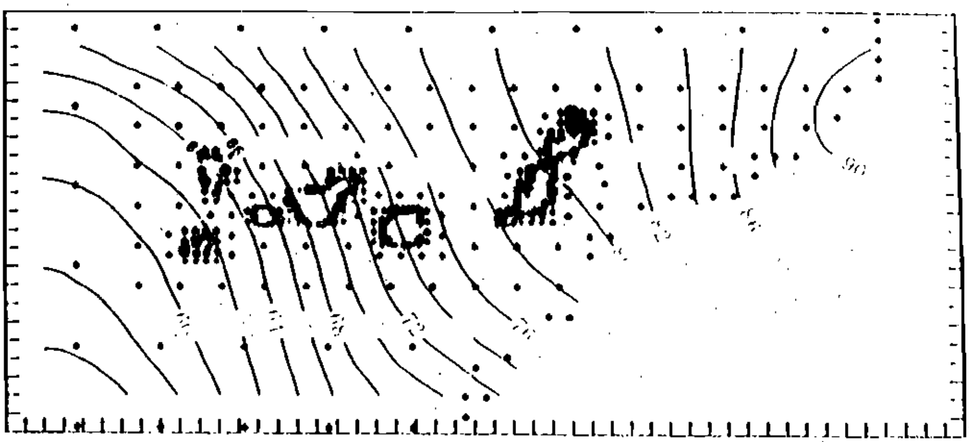
The oceanic effect computation ,according to the actual coast line geometry, it is shown in table 1.

ANALYSIS OF THE GRAVIMETRIC STATIONS

Tables 2, 3 and 4 show the analysis of the observed stations. We have used the classic ICET program as well as a provisional gravimetric factor given by Van Ruymbeke, according to the last observations done with this instrument in Brussels.

In table 5 there is a summary for the values of the vectors (B, β) and (L, λ). Furthermore, the final residue (X, χ) and its cosinus and sinus components are included.

CANARY ISLANDS. M_2 COMPONENT. AMPLITUDES AND PHASE LAGS.



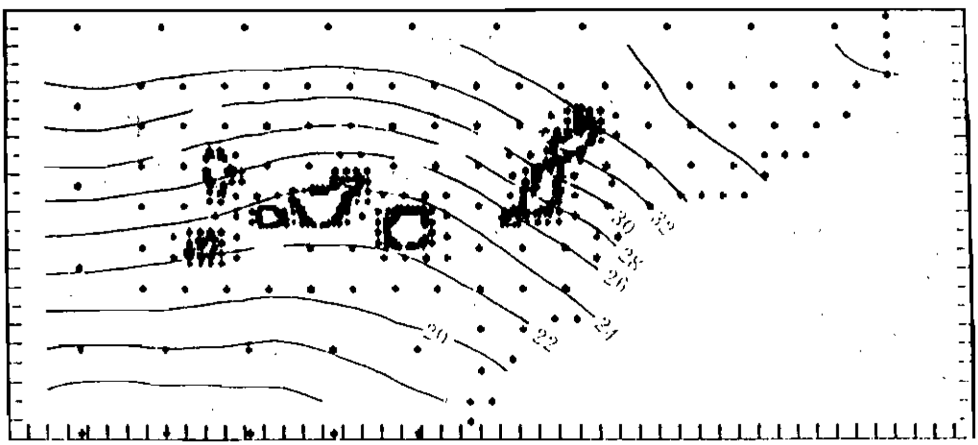


Figure 3

INDIRECT OCEANIC EFFEC ON THE M2 COMPONENT. TIDAL GRAVITY.

ZONE: LANZAROTE. CANARY ISLANDS.

OCEAN TIDE MODEL: NSWC (SCHWIDERSKI) + CANARIAS M2

NUMBER OF POLYGONS: Total 41741 Local chart 567

ELIMINATED 62 POLYGONS OF THE GLOBAL CHART

LOCAL CHARTS LIMITS: $31° < \phi < 35°$ $-20° < \lambda < -16°$

$25° < \phi < 31°$ $-20° < \lambda < -9°$

EARTH MODEL: OCEANIC CRUST AND MANTLE ON GUTEMBERG-BULLEN NUCLEUS

MASS CONSERVATION CORRECTION PROPORTIONAL TO THE TIDAL AMPLITUDE

STATION 0421 CUEVA DE LOS VERDES

Lat.: 29° 09' 37" N Long.: 13° 26' 28" W

Alt.: 60 m Dist. to the Coast: 1.000 km

INDIRECT OCEANIC EFFECT	L	λ
NEWTONIAN ATTRACTION	2.108	163.898
LOAD	5.800	165.942
TOTAL	**7.907**	**165.397**

STATION 0422 CASA DE LOS VOLCANES

Lat.: 29° 09' 17" N Long.: 13° 25' 43" W

Alt.: 7 m Dist. to the Coast: 0.050 km

INDIRECT OCEANIC EFFECT	L	λ
NEWTONIAN ATTRACTION	1.809	162.492
LOAD	8.422	167.887
TOTAL	**10.224**	**166.934**

STATION 0423 TIMANFAYA

Lat.: 28° 59' 54" N Long.: 13° 44' 30" W

Alt.: 370 m Dist. to the Coast: 6.000 km

INDIRECT OCEANIC EFFECT	L	λ
NEWTONIAN ATTRACTION	3.460	169.189
LOAD	5.716	167.680
TOTAL	**9.176**	**168.249**

Table I

STATION: CUEVA DE LOS VERDES. LANZAROTE. SPAIN
29 09 N 13 26 W H 060 M P 40 D 1 KM

VERTICAL COMPONENT

INSTITUTO DE ASTRONOMIA Y GEODESIA (CSIC-UCM).
FACULTAD DE CIENCIAS MATEMATICAS. 28040, MADRID

GRAVIMETER: LcR G 336 (M-0)
REGISTER: LINSEIS
INSTALLATION: M. VAN RUYMBEKE, N. D'OREYE
CALIBRATION: OBSERVATOIRE ROYAL DE BELGIQUE. FUNDAMENTAL STATION.

LEAST SQUARE ANALYSIS/VENEDIKOV FILTERS ON 48 HOURS
PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN/COMPLETE DEVELOPMENT
COMPUTING CENTER: INSTITUTO DE ASTRONOMIA Y GEODESIA (CSIC-UCM).
INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR: .98653

G336 90 414/90 420 90 425/90 517 90 521/90 523 90 526/90 528 90 6 3/90 619
G336 90 623/90 7 7 90 712/90 714 90 718/90 722 90 726/90 726 90 729/90 812
G336 90 817/90 829 90 9 1/90 925 90 929/9010 9 901013/901021 901029/9012 4
G336 9012 7/901229 91 1 5/91 129 91 2 3/91 217 91 221/91 221

TIME INTERVAL 315.0 DAYS 6480 READINGS 19 BLOKS EFFICIENCY .86

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	PHASE
133.-136.	20	Q1	5.93	.05	1.1725	.0095	-1.768	.464	.19	-71.1
143.-145.	16	O1	30.56	.05	1.1571	.0018	-1.654	.087	.88	-94.7
152.-155.	15	NO1	2.49	.06	1.1974	.0311	-1.413	1.487	.10	-37.6
161.-163.	10	P1	13.95	.05	1.1345	.0042	-.185	.211	.24	-169.2
164.-168.	23	S1K1	41.81	.05	1.1253	.0013	.384	.066	.54	148.6
175.-177.	14	J1	2.40	.05	1.1570	.0219	.721	1.083	.03	107.0
184.-186.	11	OO1	1.33	.04	1.1648	.0348	-.198	1.715	.01	-44.1
233.-23A.	20	2N2	1.73	.02	.9887	.0129	-2.603	.744	.31	-165.4
243.-248.	24	N2	11.06	.03	1.0089	.0027	.284	.152	1.66	178.1
252.-258.	26	M2	58.41	.03	1.0205	.0006	1.920	.031	8.26	166.3
265.-265.	9	L2	1.66	.04	1.0243	.0223	4.777	1.237	.26	148.5
267.-273.	9	S2	27.42	.03	1.0295	.0012	2.959	.064	3.79	158.1
274.-277.	12	K2	7.63	.03	1.0540	.0036	3.255	.195	.89	151.0
327.-375.	17	M3	1.06	.02	1.0813	.0181	.396	.958	.02	28.1

STANDARD DEVIATION D 2.59 SD 1.57 TD .87 MICROGAL

QUALITY FACTORS : Q1= 8.5 Q2= 22.3
O1/K1 1.0282 1-O1/1-K1 1.2535 M2/O1 .8819
CENTRAL EPOCH TJJ= 2448152.0

Table 2. Harmonic analysis on Cueva de los Verdes station.

STATION: CASA DE LOS VOLCANES. LANZAROTE. SPAIN.
VERTICAL COMPONENT

INSTITUTO DE ASTRONOMIA Y GEODESIA (CSIC-UCM)
FACULTAD DE CIENCIAS MATEMATICAS. 28040. MADRID

GRAVIMETER: LcR G 336 (M-0)
REGISTER: LINSEIS + D.A.S. - O.R.B.
CALLIBRATION: OBSERVATOIRE ROYAL DE BELGIQUE.FUNDAMENTAL STATION.
INSTALLATION: M. VAN RUYMBEKE, N. D'OREYE.

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPUTING CENTER: INSTITUTO DE ASTRONOMIA Y GEODESIA (CSIC-UCM). MADRID.
INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR .98653

G336	91 226/91 3 6	91 3 9/91 321	91 324/91 419	91 424/91 430	91 5 3/91 529
G336	91 6 1/91 6 7	91 612/91 622	91 628/91 710	91 716/91 829	91 9 2/91 912
G336	91 915/91 915	92 213/92 217	92 220/92 3 1	92 3 6/92 312	92 315/92 424
G336	92 428/92 627	92 630/92 817	92 820/92 824	92 9 1/92 9 9	92 916/92 922

TIME INTERVAL 576.5 DAYS 9264 READINGS 20 BLOKS EFFICIENCY .67

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
133.-136.	20	Q1	6.07	.07	1.2009	.0137	-2.509	.652	.33	-52.6
143.-145.	16	O1	30.05	.07	1.1379	.0027	-2.080	.133	1.24	-118.3
152.-155.	15	NO1	2.38	.07	1.1459	.0326	-3.728	1.631	.16	-101.5
161.-163.	10	P1	13.48	.07	1.0970	.0059	-1.055	.308	.74	-160.4
164.-168.	23	S1K1	40.54	.07	1.0914	.0018	.292	.097	1.73	173.1
175.-177.	14	J1	2.34	.07	1.1288	.0317	1.312	1.606	.09	141.8
184.-186.	11	OO1	1.38	.06	1.2151	.0549	-2.134	2.587	.08	-40.1
233.-23A.	20	2N2	1.58	.03	.9051	.0195	-4.877	1.230	.47	-163.4
243.-248.	24	N2	10.13	.04	.9239	.0038	1.509	.235	2.61	174.1
252.-258.	26	M2	54.30	.04	.9487	.0007	4.381	.045	12.94	161.3
265.-265.	9	L2	1.41	.05	.8714	.0328	1.947	2.144	.47	174.2
267.-273.	9	S2	26.16	.04	.9821	.0016	5.354	.094	5.43	153.3
274.-277.	12	K2	7.30	.04	1.0075	.0056	5.732	.314	1.35	147.4
327.-375.	17	M3	1.08	.03	1.1016	.0275	1.934	1.419	.05	47.8

STANDARD DEVIATION D 4.29 SD 2.56 TD 1.60 MICROGAL

QUALITY FACTORS : Q1= 4.0 Q2= 12.2
O1/K1 1.0426 1-O1/1-K1 1.5088 M2/O1 .8337
CENTRAL EPOCH TJJ= 2448601.0

Table 3. Harmonic analysis on Casa de los Volcanes station.

STATION: PARQUE NAL. DE TIMANFAYA. LANZAROTE. SPAIN
29 01 N 13 50 W H 340 M P 03 D 6 KM

VERTICAL COMPONENT

INSTITUTO DE ASTRONOMIA Y GEODESIA (CSIC-UCM)
FACULTAD DE CIENCIAS MATEMATICAS. 28040, MADRID

GRAVIMETER: LcR G 336 (M-0)
REGISTER: D.A.S. - R.O.B. (TOSHIBA T-100 COMPUTER)
INSTALLATION: R. VIEIRA, J. ARNOSO
MANTENANCE: O. HERNANDEZ

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPUTING CENTER: INSTITUTO DE ASTRONOMIA Y GEODESIA (CSIC-UCM). MADRID.
INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR .98653

G336 93 2 7/93 313 93 320/93 411 93 416/93 418
G336 93 421/93 5 3 93 5 7/93 5 9 93 514/93 518

TIME INTERVAL 101.5 DAYS 2112 READINGS 6 BLOKS EFFICIENCY .87

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
133.-136.	20	Q1	6.25	.11	1.2405	.0223	-3.171	1.017	.53	-40.9
143.-145.	16	O1	30.35	.10	1.1524	.0038	-1.335	.192	.73	-105.1
152.-155.	15	NO1	2.56	.07	1.2364	.0350	-1.390	1.637	.17	-21.2
161.-163.	10	P1	13.75	.09	1.1219	.0076	4.834	.393	1.24	110.7
164.-168.	23	S1K1	41.02	.09	1.1074	.0026	-.382	.133	1.15	-166.3
175.-177.	14	J1	2.30	.11	1.1113	.0527	-.822	2.715	.11	-162.4
184.-186.	11	OO1	1.33	.09	1.1727	.0828	5.537	4.050	.13	86.7
233.-23A.	20	2N2	1.78	.03	1.0118	.0156	-6.394	.872	.34	-143.9
243.-248.	24	N2	10.88	.04	.9896	.0035	-.321	.202	1.87	-178.1
252.-258.	26	M2	57.81	.04	1.0072	.0007	2.277	.041	9.12	165.4
265.-265.	9	L2	1.73	.06	1.0649	.0397	-4.822	2.125	.22	-137.9
267.-273.	9	S2	26.87	.05	1.0061	.0018	3.321	.103	4.44	159.5
274.-277.	12	K2	7.61	.05	1.0482	.0073	3.043	.396	.92	153.9
327.-375.	17	M3	1.05	.03	1.0674	.0335	.846	1.798	.02	90.2

STANDARD DEVIATION D 2.15 SD 1.18 TD .99 MICROGAL

QUALITY FACTORS : Q1= 10.9 Q2= 13.3
O1/K1 1.0406 1-O1/1-K1 1.4184 M2/O1 .8740
CENTRAL EPOCH TJJ= 2449076.0

Table 4. Harmonic analysis on Park of Timanfaya station.

	B	β	L	λ	X	χ	Xcosχ	Xsinχ
CUEVAVERDES	8.26	166.3	7.82	165.3	0.46	-176.5	-0.461	-0.028
C. VOLCANES	12.78	161.6	10.22	166.9	2.77	141.7	-2.172	1.717
TIMANFAYA	9.12	165.4	9.17	168.2	0.45	70.4	0.151	0.423

B (B, β) = **A** - **R**

A: (A, α) Observed vector corresponding to the same component

R: (R, 0) Gravity variation vector for one specific tidal component

L (L, λ): Calculated vector representing the **attraction and loading** effect of the corresponding oceanic tide

X (X, χ): **Final residue vector = B - L = A - R - L**

Table 5. Vectors **B**, **L** and **X** computed on the three stations.

CONCLUSIONS

As we mention before, results reached until now must be considered provisionally. That results even can change, mainly the more anomalous station, Casa de los Volcanes, while we do not have a better evaluation of the oceanic effect as well as the deformation, induced by the ocean tide, suffered inside the lava tunnel, where the geodynamic station it is placed. Ressults at Timanfaya station have been obtained during the first three months of recording and it will be better when we have a longer series. Therefore, it is early to do any kind of evaluation of these ressults. Neverthelcs, it is suitable mention the good behaviour of the instruments both the gravimeter, of which sensitivity remained constant during the three years of the experience, and the data acquisition systems and auxiliary equipment. The data acquisition system EDAS, developed by Van Ruymbeke at the Royal Observatory of Belgium, taking data each minute for eight channels simultaneously had no trouble during the recording period. The power supply used at Timanfaya station, by means of solar panels, has been completely efficient to feed the gravimeter and even pressure, temperature and humiddity gages. Solar energy supplies also a seismic equipment working at Timanfaya with its own data aquisition system.

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