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Tidal and Non-tidal Observations in a Volcanic Active Region Review of the Cooperation Between Spain and P. R. of China in the Geodynamic Laboratory of Lanzarote

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Abstract

In 1988 began the cooperation between the Institute of Astronomy and Geodesy (CSIC-UCM) and the Institute of Seismology of Wuhan (CSB) to develop technology and software for tidal and geodynamic investigation and applications in the field of engineering. The Geodynamic Laboratory of Lanzarote (LGL) provides excellent opportunities to the scientific community to test and check sensors and data acquisition developed under real conditions of observation. Eight years ago the first set of water tube and extensometer was installed in the observation module of Cueva de los Verdes of the LGL. Since then different geophysical sensors and programs for the analysis have been developed for the monitoring of the geodynamic activity in Lanzarote. We present here a review of the collaboration, with special interest in the description of the instruments and the most relevant results obtained up to now are introduced briefly.

1. Introduction

Since 1988, the Institute of Astronomy and Geodesy (IAG) and the Institute of Seismology of Wuhan (ISW) maintain a collaboration for development of technology applied to geodynamic investigations (Jun Jiang at al., 1999). The Spanish-Chinese Commission of Science and Technology which, year by year, has sponsored the continuity of this project have financed this collaboration. The first sensors were installed in the Geodynamic Laboratory of Lanzarote (LGL) in 1992. Since then, new instruments had been successively installed in 1994, 1996, 1998 and 1999. Actually, 18 instruments (Table 1) are in continuous operation in two of the observation modules of the LGL, Cueva de los Verdes and National Park of Timanfaya. All data are collected at a sampling rate of 1 sample every 2 seconds and stored with a mean-average decimation of 1 sample every 10 minutes. From there, data are transmitted periodically to Madrid to be stored in the data bank and to analyse.

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Table 1. Sensors installed in LGL. (*values correspond to December'99)

	Sensor	Azimuth (N-E)	Depth (m.)	Base length (m.)	Range	Sensitivity* (Unit/mV)
CUEVA DE LOS VERDES	Water Tube CE-92 nº 444	136º.96	18	38.4	10	2.11 mas
	Water Tube CE-94 nº 666	45º.24	18	8.1	10	2.42 mas
	Extensometer CE-92 nº 555	136º.96	18	38.22	$4x10^{-5}$	0.30 μm
	Extensometer CE-94 nº 777	45º.24	18	8.0	$4x10^{-5}$	0.06 μm
	Rock Thermometer CE-92 nº 166	-	18	-	-10 – 25 ºC	0.01 ºC
	Air Thermometer CE-92 nº 266	-	18.1	-	-10 – 60 ºC	0.1 ºC
NATIONAL PARK OF TIMANFAYA	Water Tube CE-96 nº 446	42º.8	0.6	4.6	200	45.0 mas
	Water Tube CE-99 nº 664	132º.8	0.6	11.6	200	34.2 mas
	Extensometer CE-96 nº 557	42º.8	0.6	4.0	$3x10^{-4}$	0.24 μm
	Extensometer CE-99 nº 775	132º.8	0.6	11.04	$3x10^{-4}$	0.66 μm
	Vertical Pendulum GK-10 CE-96 nº 601	42º.8	0.6	0.27	±5º	506 mas
	Vertical Pendulum GK-10 CE-96 nº 602	132º.8	0.6	0.27	±5º	568 mas
	Air Thermometer CE-96 nº 267	-	-	-	-10 – 60 ºC	0.1 ºC
	Air Thermometer CE-99 nº 367	-	-	-	-10 – 60 ºC	0.1 ºC
	Rock Thermometer CE-96 nº 167	-	0.1	-	-10 – 60 ºC	0.1 ºC
	High Temperature Thermometer CE-98 T_1	-	30	-	0 – 800 ºC	0.2 ºC
	High Temperature Thermometer CE-98 T_2	-	20	-	0 – 800 ºC	1.0 ºC
	High Temperature Thermometer CE-98 T_3	-	10	-	0 – 800 ºC	0.1 ºC

2. The Geodynamic Laboratory of Lanzarote

Lanzarote Island is the most northeastern island of the Canarian Archipelago (Figure1). The landscape of Lanzarote is dominated by numerous quaternary volcanoes and more especially by *La Corona* (609 m), in the northern sector, and by volcanoes of *Timanfaya* or *Montañas del Fuego* (Mountains of Fire) (Araña, 1998).

The LGL is in operation from 1986 and it is dedicated to applied geodesy and geophysical techniques for studying an active or potentially active region of the Earth (Vieira et al., 1995; Cai et al.; 1997). The Laboratory is composed by three permanent observation modules (*Cueva de los Verdes*, *Jameos del Agua* and *Parque Nacional de Timanfaya*) and temporary stations. A gravimetric network, which covers completely the island, and a local levelling network complements the observations.

The laboratory of Cueva de los Verdes is located inside the volcanic tunnel of La Corona, at around 1 km far from the coastline, 5 km far from the volcano and 37 m above the sea level. It is dedicated, principally, to continuous observations of the acceleration of the gravity, deviations of the vertical and ground deformations. There are two sets of water tube tiltmeters, extensometers and thermometers operating since 1992 and 1994. The objective is to obtain the tidal tilt and strain models (Cai et al., 1994; Arnoso, 1996; Arnoso et al., 1998) as well as the study of non-tidal phenomena and anomalous variations that could be related to the geodynamic activity of the island.

The laboratory of the National Park of Timanfaya is located in a zone of geothermal anomalies, caused by a residual magmatic chamber (Araña at al., 1984), where temperatures can reach from 100-200 °C at a few centimetres below the surface to 600 °C at 13 meters depth. The laboratory is divided into two parts. The first one, the laboratory of *Casa de los Camelleros*, is an underground laboratory and it is located in the base of *Timanfaya Volcano*. The second one is an outdoor laboratory, over a geothermal anomaly, 100 meters far from the Casa de los Camelleros. The main problem is the lack of electrical power, which force us to use solar energy. In the National Park of Timanfaya there are installed more than 20 instruments recording continuously. The equipment includes water tube tiltmeters, horizontal extensometers, vertical pendulums, thermometers and auxiliary instrumentation (data acquisition systems, power battery, solar panels, voltage regulator,...) to monitor the crustal deformations and the variations of geothermal anomalies.

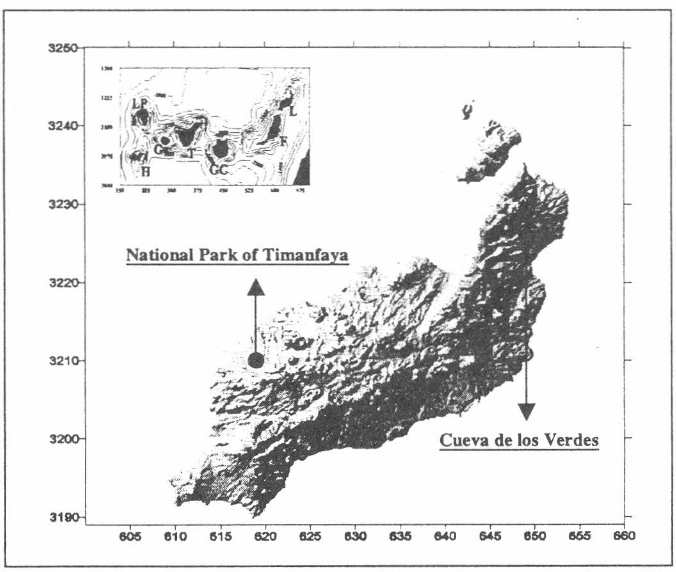

Fig. 1. Map showing the location of Lanzarote Island. The situation of Cueva de los Verdes and National Park of Timanfaya is indicated. (UTM coordinates in kilometres)

3. Instrumentation

The sensitivity of the sensors installed allows to record the signals of tidal tilt and strain. The sensitivity was reduced by a factor of 10 in the National Park of Timanfaya due to the strong local disturbances. The technical features of instruments are shown in Table 1.

The water tube tiltmeters are assembled tubes of glass of pieces 1.5 m long, 1mm thickness and 25 mm diameter. The tubes are connected at the ends with two pots with a diameter of 231 mm. The instrument is refilled with distilled water mixed with alcohol. A thin layer of oil is over the liquid to avoid the evaporation and to reduce high frequency noise. A magnetic sensor fixed to a float detects the water level variations. Both pots are connected with a tube for air pressure compensation. The water tube has a calibration system incorporated that allows in situ calibrations. A plunger device with a micrometer screw is located in the center of the base line (Cai, 1992; Cai et al., 1994). The resolution of the micrometer is 1 mm. The displacement of the plunger produces changes in the water level. Thus, the tilt is computed with $i = (\Delta H * K)/(L * \Delta V)$ where $K = r_p^2/(r_1^2 + r_2^2) * 1/\sin 1''$, being ΔH the displacement produced by the plunger, r_p, r_1 and r_2 the ratios of the plunger and the both pots respectively, and ΔV the displacement of the fluid in the system output (Arnoso et al., 1997).

The extensometer consists of several porcelain tubes of pieces of 1.5 m length assembled. Porcelain is used because of its low temperature coefficient. The tubes are arranged along several pillars. A special copper thread fastened to an aluminium frame, attached to the pillar, supports the tubes. One of the end of the extensometer is fixed and the other one is free. A magnetic sensor placed in the free end detects the displacement. A micrometer with 0.01 mm of resolution is placed at the fixed end for in situ calibration.

The short base tiltmeters are of the vertical pendulum type. Each one is fixed in a platform over a pillar, which is at 0.6 m depth from the ground. It is covered to insolate them from air currents. The in situ calibration is done using the screw fixed to the platform that allows the displacement in the pendulum direction. The mass is hung up and oscillates inside a stainless box, which has a dimension of 170x110x220 mm and is refilled of oil. A differential capacitive sensor detects the displacement.

All the thermometers installed are a kind of thermocouple. Temperature variations are monitored with a set of three thermometers installed in a borehole at 10, 20 and 30 m depth. The three thermometers are made of steel; with a diameter of 6 mm. T_3 is cased with porcelain pieces of 3 cm length and 6 mm wide.

Taking into account the special features of station Cueva de los Verdes, a data acquisition system was developed with the main interest focused on low power consumption, portability and versatility (Fernández et al., 1989). The data acquisition system is directly linked to a computer located in *Casa de los Volcanes* (House of Volcanoes), over 1 km away, in order to collect all information recorded in the station. From there, data are transmitted, via telephone modem, to another computer located in Madrid to organize a data bank and to analyse the data.

4. Data Analysis

In parallel to this technical improvement, stronger tools for pre-processing, analysis and interpretation were developed (Arnoso et al., 1997; Venedikov et al. 1997). After correcting of spikes, jumps and other disturbances we obtain the local tidal tilt and strain model. Results obtained in Cueva de los Verdes are shown in Table 2. The tidal tilt analysis was done using the NSV program of Venedikov (Venedikov et al. 1997) based on the least square harmonic analysis method of Venedikov (Venedikov, 1966), and the tidal strain analysis was done using the ETERNA program (Wenzel, 1996). The results of the analysis reveal a strong influence of the oceanic effect. The influence of atmospheric parameters, the oceanic loading effect, the inverse barometric effect, tilt ratios and deformation ratios are calculated (Arnoso et al., 2000a; Arnoso et al., 2000b; Arnoso et al., 1997).

Table 2: Main tidal strain and tilt parameters observed in Cueva de los Verdes.

	Wave	Amplitude (nstr.)	signal/noise	Amplitude Factor	stdv.	Phase Lead (degree)	stdv.
EXCE-92 nº 555	O1	0.308	1.5	0.05858	0.03887	16.9974	38.0159
	K1	1.676	8.2	0.22652	0.02764	-56.9755	6.9900
	M2	4.751	62.0	0.43140	0.00696	-23.2880	0.9247
	S2	2.761	36.0	0.53893	0.01496	-46.6419	1.5909
EXCE-94 nº 777	O1	1.203	15.5	0.22803	0.01467	0.3977	3.6856
	K1	1.306	16.9	0.17610	0.01043	17.0372	3.3933
	S2	1.637	92.8	0.14940	0.00161	-35.6677	0.6172
	M2	0.819	46.5	0.16070	0.00346	-4.0391	1.2333

	Wave	Amplitude (mas)	r.m.s.	Amplitude Factor	r.m.s.	Phase Lead (degree)	r.m.s.
WTCE-92 nº 444	O1	3.49	0.03	1.0498	0.0096	-30.1	0.5
	K1	1.31	0.03	0.285	0.0064	-53.3	1.3
	M2	33.02	0.05	3.1093	0.0049	-62.3	0.1
	S2	11.24	0.05	2.2745	0.0108	-82.9	0.269
WTCE-94 nº 666	O1	3.55	0.09	1.0712	0.0279	5.7	1.5
	K1	3.92	0.08	0.8404	0.0182	-19.4	1.2
	M2	18.68	0.05	1.7166	0.0049	58.6	0.2
	S2	5.00	0.06	0.9880	0.0109	44.2	0.6

5. Conclusions

The main interest in these investigations is focused on the development and of new sensors to be applied in the study of Earth's geodynamic. The instruments checked and installed in LGL have shown a very good technical behaviour, with a high stability of the sensitivity along the time (Arnoso et al. 1997). The analysis of the long data series has permitted to obtain the tidal tilt and strain local model as well to evaluate the signals that disturb the observations. The high precision of the sensors used allows to study the non-tidal variations that can be produced by local tectonic movements in relation with the volcanic activity of Lanzarote.

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