GPS time series analysis from Deception Island Volcano (South Shetland Islands, Antarctica)

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Summary We present the preliminary results from the analysis of GPS time series data from Deception Island Volcano for the period December 2001 to January 2005. The geodetic network, REGID, has been episodically surveyed during every Austral summer since 1998 to monitor the volcanic activity on the island and to determine its crustal deformation. The deformational models show a continuation of the compressive process detected in the previous years. GPS data were processed using 30 min length observational windows, providing the local horizontal deformation between and within each surveying campaign. Wavelet analysis was applied to the data in order to detect the existence of short period components. The wavelet scalegram of the data reveals the presence of seasonal fluctuations that are not detectable with the usual 24 hours session processing approach. Their sources are still not well determined, which motivates the study of other geophysical phenomena that can affect the data.

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Introduction

Deception Island (62.93ºS, 60.57ºW) is situated in a complex geodynamical area, formed by the South Shetland Archipelago, the Bransfield Strait and the Antarctic Peninsula. In fact, it is situated at the spreading centre of the Bransfield Strait back-arc on the south western side of the Scotia Sea region. (Fig. 1) It is a young strato-volcano, 25 km wide in its submerged basal diameter and 15 km diameter in its emerged part (Vila et al., 1992). The interest of this area results from the conjunction of two major tectonic plates (the Antarctic and the South American Plate) together with the interactions among some micro-plates (the Scotia, the Shetland and the Phoenix Plates), some of whose limits are not well defined. In addition, there are also two active fractures zones along the NW-SE direction, the Hero Fracture Zone and the Shackleton Fracture Zone.

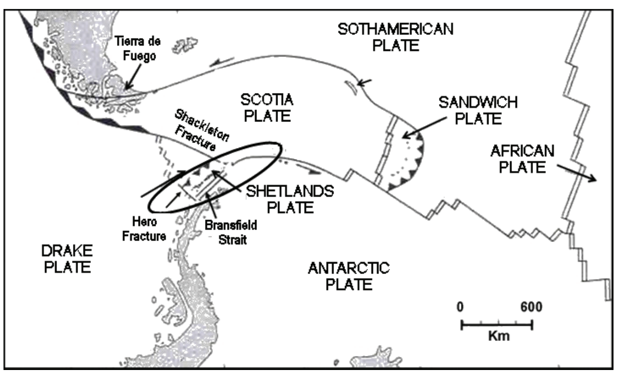

Figure 1. Geodynamical situation of Deception Island Volcano.

The volcanism on Deception Island is characterized by historical eruptions in 1842, 1912, 1917, 1967, 1969, and 1970. During 1967-1970 eruptive process, the high volcanic activity caused the destruction of the Chilean and British Scientific Bases, located in Pendulum Cove and Whaler's Bay respectively. These eruptions changed the morphology of the island, forming an islet that would lately join to the island in Telephone Bay. Due to this eruptive event and their destructive consequences the scientific activities by Argentinean, Chilean and British investigators were interrupted.

From 1987-88 several Spanish Groups have carried out different research projects to study the volcanic activity in the island and its geodynamic consequences. In the last years, two volcanic crises were detected. The first one took place in December 1992, and the last one occurred in December 1998. During the 1998/99 campaign more than 2000 earthquakes were detected (Ibáñez et al., 2000).

The determination of the deformation models caused by the volcanic activity on Deception Island is one of the main objectives of the studies developed on the island through the years (Berrocoso, 1997, Fernández-Ros, 2006, Ramírez, 2006). Nevertheless, no study about the GPS data behaviour within the surveying campaigns has been made. The strategy we have applied for the data processing allows the study of the time series. In particular, we present in this paper the periodicities detected for some of the stations of the network during the 2003-04 and 2004-05 campaigns.

Data acquisition and processing

In order to determine the volcanic deformation and the local deformation on the island, a geodetic network was designed and established (Fig. 2), and it has been surveyed episodically every Austral summer since the 1988/89 campaign. This paper just covers GPS data from the 2001/02 to 2004/05 campaign. We refer to Berrocoso (1997) and Fernández-Ros (2006) for the previous periods.

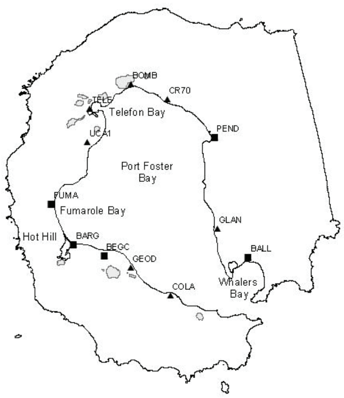

Figure 2. REGID geodetic network distribution.

Data were processing using the BERNESE v4.2 GPS scientific software, with the usual configuration for local networks in Antarctic environments (Beutler et al., 2001). 30 minutes processing sessions were used and no adjustment of the network was made, but every individual solution for each processed session was considered in this study. This strategy allows us to estimate the deformation on the island, and to study the resulting time series within each surveying period.

Only data from FUMA and PEND geodetic stations in Fumaroles Bay and Pendulum Cove respectively were considered in the study since they both are provided with continuous power and therefore they are permanently surveyed during the austral summer. In addition, due to the improvement of the equipment in the last campaigns, not only in their storage capabilities but also in the supply facilities, the results presented cover the total period of the 2003/04 and the 2004/05 campaigns.

Time series analysis

Preliminary approach

In a first approach time series were preliminary processed in order to detect and reject outliers, to correct the existing offsets and to eliminate the scatter of the data. The reduction of the data deviation was made according to a modified version of the *common-mode* strategy (Bock et al., 2000), by means of a weighted average of the estimations for every session, where the weight for a coordinate j and a day i is given by

$$p_i^j = \frac{ses_i}{48} \cdot \frac{1}{\sigma_i^j},$$

where ses_i denotes the number of processed sessions for the day i, and σ_i^j is the standard deviation for the coordinate j and the day i. Denoting by $x_{i,S}^j$ the coordinate j for day i and session S (S=1,…, 48) and by $\tilde{x}_{i,S}^j$ the filtered one, the filtered series is computed by subtracting this average from the unfiltered data, such as

$$\tilde{x}_{i,S}^j = x_{i,S}^j - \bar{x}_S^j, \text{ with } \bar{x}_S^j = \frac{\sum_i x_{i,S}^j}{N} \text{ and N = the number of processed days.}$$

Volcanic deformation models

This preliminary approach allows the estimation of the deformation that occurred in the island due local tectonic and volcanic activity. Displacements relative to BEJC geodetic station at Livingston Island (approximately 40 km away) were calculated in order to determine the local displacements in the island. BEGC station was set as the fixed set in the processing, and provides an inner perspective of the occurred displacements. The estimated models are shown in Figure 3.

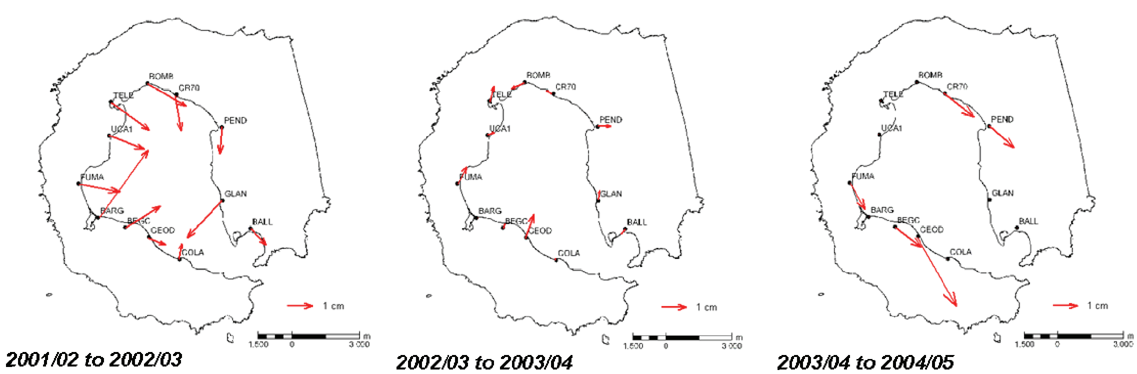

Figure 3. Horizontal displacement models related to the local tectonic and the volcanic activity of Deception Island for the period 2001/02 to 2004/05.

The calculated displacements agree with the pattern detected for the previous period (Fernandez-Ros, 2006, Ramírez, 2006). In fact, during the period 2001/02 to 2002/03 a reversal of the radial extensional process detected after the volcanic crisis in 1998 was observed, which continues in the following period. No significant displacements were detected afterwards, although a change in the trend of the overall movement of the surveyed stations for the 2003/04 to 2004/05 period is observed, aligned according the Hero Fracture Zone.

Wavelet analysis of the time series

The wavelet transform was applied to the data in order to obtain their time-frequency decomposition. This transform provides an analysis of the signal at successive scales, each of them related to a frequency band, by means of the convolution of the data with the dilated version of a wavelet function or *mother wavelet* ψ ,

$$f * \overline{\psi}_s(u) = \int f(t) \frac{1}{\sqrt{s}} \psi\left(\frac{t}{s} - u\right) dt$$

where $\overline{\psi}_s$ is defined by $\overline{\psi}_s(t) = \frac{1}{\sqrt{s}} \psi\left(\frac{-t}{s}\right)$ (Mallat, 1999). The characteristic frequency F_s corresponding to a certain scale s is given by

$$F_s = \frac{F_c}{s \cdot \Delta T},$$

where F_c and ΔT denote the maximum oscillation of the wavelet function and the sampling period, respectively.

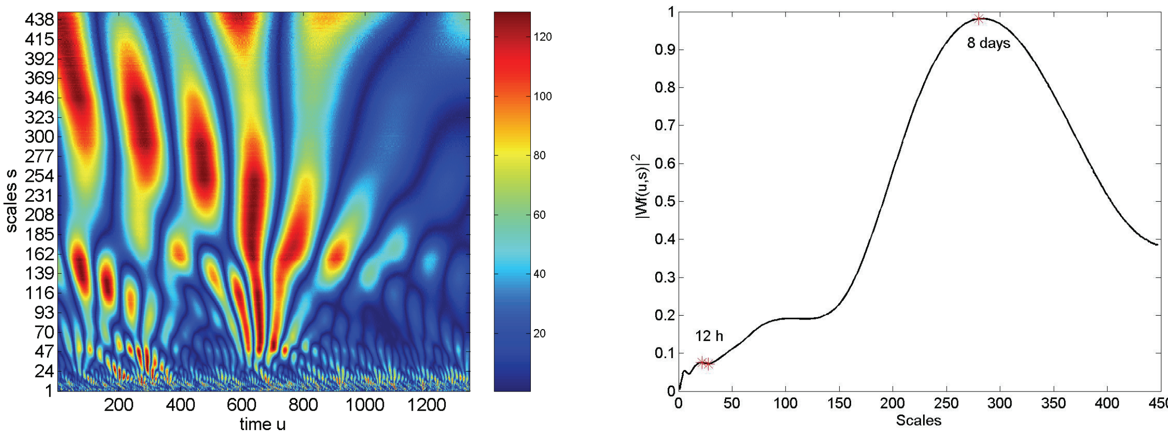

Figure 4. Wavelet spectrum and scalegram for FUMA station and 2003-04 campaign. Detected periodicities are marked on the scalegram.

Taking into account these considerations, the seasonal components in the data will be identified by the scales of greater energy. Thus, the significant frequencies in the data will be detected by the detection of the local maxima in the scalegram of the wavelet spectrum, i.e., in the representation of the scales versus their corresponding energy. As an example Figure 4 shows the wavelet spectrum and the scalegram corresponding to FUMA station at Fumaroles Bay for the 2003-04 campaign. The main periodicities detected for FUMA and PEND geodetic stations following this strategy are listed in Table 1 and 2, respectively.

Table 1. Periodic components in GPS Time Series for FUMA geodetic station

Campaign	East	Scalegram	North	Scalegram	Up	Scalegram
2003-04	12 h	0.05			12 h	1.91
			1 d	0.15	1 d	3.9
	8 d	0.98	7-8 d	0.36	4-5 d	4.59
					12 d	21.18
2004-05	12 h	0.03	12 h	0.08	12 h	1.36
	1 d	0.02	4 d	0.11	3-5 d	1.04
					14 d	0.48

Some of these periodicities can be associated to certain effects as the one of 12 h which can be associated to the satellite orbital period. Medium frequencies can be related to weather cycles (Krynsli and Zanimonsky, 2000; Poutanen et al. 2001) although further studies should be carried out to better understand these fluctuations.

Table 2. Periodic components in the GPS Time Series for PEND geodetic station

Campaign	East	Scalegram	North	Scalegram	Up	Scalegram
2003-04	12 h	0.09	12 h	0.11	12 h	2.34
	8-12 d	0.25	6-9 d	0.15	8 d	8.20
2004-05	12 h	0.08			12 h	1.73
	1 d	0.11	1-2 d	0.12		
	9 d	0.29	6 d	0.43	4-5 d	3.21

Discussion

In this paper we present the results obtained from the GPS data processing of the REGID geodetic network in Deception Island for the period 2001/02 to 2004/05. The estimated deformation models reveal a continuation of the compressive process that was previously detected, after the remission of the extensional radial process originate by the 1998 volcanic crisis (Fernández-Ros 2006). In addition, the applied processing strategy, which considers 30 minutes length sessions, allows the time-frequency study of the GPS time series. In particular, some periodicities were detected after the study of the wavelet spectra and the scalegrams of the data. The sources originating some of these seasonal fluctuations are not well determined and further studies must be done, specially those ones involving other kind of geophysical measurement that can influence the GPS data.

Summary

This abstract present the results obtained from the GPS data processing of the REGID geodetic network in Deception Island Volcano (South Shetland Islands) corresponding to the period 2002/03 to 2004/05. It deals with the determination of the superficial deformation models and the detection of periodic components in the GPS coordinate time series.

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