Cyclic thermal behavior associated to the degassing process at El Hierro submarine volcano, Canary Islands.

Eugenio Fraile-Nuez[1], J. Magdalena Santana-Casiano[2] & Melchor González-Dávila[2]

[1] Instituto Español de Oceanografía, Centro Oceanográfico de Canarias, Santa Cruz de Tenerife, 38180, Spain.
[2] Instituto de Oceanografía y Cambio Global, Universidad de Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, 35017, Spain.

ABSTRACT

One year after the ceasing of magmatic activity in the shallow submarine volcano of the island of El Hierro, significant physical-chemical anomalies produced by the degassing process as: (i) thermal anomalies increase of +0.44 °C, (ii) pH decrease of -0.034 units, (iii) total dissolved inorganic carbon, C_T increase by +43.5 µmol kg^{-1} and (iv) total alkalinity, A_T by +12.81 µmol kg^{-1} were still present in the area. These evidences highlight the potential role of the shallow degassing processes as a natural ecosystem-scale experiments for the study of significant effects of global change stressors on marine environments. Additionally, thermal time series obtained from a temporal yo-yo CTD study, in isopycnal components, over one of the most active points of the submarine volcano have been analyzed in order to investigate the behavior of the system. Signal processing of the thermal time series highlights a strong cyclic temperature period of 125-150 min at 99.9% confidence, due to characteristic time-scales revealed in the periodogram. These long cycles might reflect dynamics occurring within the shallow magma supply system below the island of El Hierro.

INTRODUCTION

Cyclic behavior has been recognized at a number of open-vent volcanoes around the world. Pulsatory patterns in both, degassing and in the behavior of active lava lakes [1], has been observed. However, the processes underlying such activity remain uncertain.

High-time resolution thermal image data-sets recorded at Etna, Stromboli and Kilauea volcano retrieved cycles that vary within similar time windows, grouped into three main classes: (i) cycles with periods <15 s related to Sharp pulses in the thermal signal (gas puff/discrete strombolian explosions [2]), (ii) periods between ~20-50 s and 1–10 min associated with bursting of hot, over-pressured gas bubbles/trains of bubbles [3] at the magma-air interface, and (iii) long cycles with periods of 12–90 min reflecting dynamics occurring within the shallow magma supply system [4].

Periodic volcanic degassing behaviors have also been characterized in the release of gas flux for the Mount Etna at two period bands: 40-250 and 500-1200 s, which suggest a bursting of rising gas bubble trains at the magma-air interface [4]. Cyclic degassing of Erebus volcano in Antarctica has also been register in the total gas column amount, a likely proxy for gas flux, with periodicities of 10, 35 and 70 min, which can be explained in terms of chemical equilibria and pressure-dependent solubilities [5]. Although several studies reveal the existence of cyclic behaviors in the release of heat and gases from different sub-aerial volcanoes [3] underwater studies are in less proportion [6].

The submarine eruption that took place on October 10, 2011 at 1.8 km South of the island of El Hierro, Canary Islands, Spain (27º37'07''N – 017º59'28''W) has allowed the meticulous study of the changes in the physical-chemical properties of the seawater from the beginning of the eruptive phase until the magmatic activity finished, five months later [7-8]. After this, the area evolved to a hydrothermal system offering the opportunity to study both the dynamic associated to the degassing process and changes at the physical-chemical properties of the system.

RESULTS & DISCUSSION

Potential temperature anomaly time series at the level of σ_θ = 26.614 kg m^{-3} (≅ 165 m depth) where the maximum temperature anomaly is found, was investigated (st. 53). At this level, a mean temperature anomaly of +0.25 ± 0.1 °C is found for a whole period of time. However, a cyclic behavior over the mean value of the temperature anomaly is shown at this level, with maximums of 0.4 °C and minimums of 0.1 °C (Fig. 1A). Although the tidal cycle seems to be of greater importance in the driving forces of these variations [9], other periods exist that may be generated by the turbulent mixing occurring in this environment, changes due to the directions of the local currents, and/or by variations in the hydrothermal fluid discharge. In our case, variations due to turbulent mixing or water masses changes have been avoided thank the use of the isopycnal components. VMADCP velocity data (not shown) indicate that the local current in the area were stable, in direction and intensity (to the southwest, with a mean velocity intensity of 0.2±0.1 m/s). Moreover, the in situ sea level time series from the closer gauge in the area shows that the total signal of the tide is explained by M2 type at 97.3% of the total variance with a mean amplitude of 0.92±0.02 meters, a period of 12 h and negligible velocity relative to the predominant local mean current (Egbert, *et al.*, 1994). That means that the behavior shown in (Fig. 1A) seem to have a period too short to depend on the existing M2 type tide of the area as it has also been reported in other similar studies [9].

Fast Fourier Transform and Wavelet analysis, using the Matlab packages, were applied to the potential temperature anomaly time series, in isopycnal components, at st. 53 close to the seabed. Fig. 1B shows the power spectra and statistical significance computed by Fast Fourier transform for the time series. A strong peak of over 99.9% of significance is present in the decomposition of the potential temperature time series anomaly with a period of 125-150 min, which explained the 68.7% of the total variance of the signal. Wavelet Transform has also been applied to the st. 53 time series obtained the same result, a significant period of 125-150 min that are present practically during the whole time (Fig. 1C). The reconstruction of the potential temperature anomaly time series has been possible thank to the unique significant harmonic period extracted from the series, with a final correlation of r^2=0.8286. This cyclic behavior may be related with variations in the hydrothermal fluid discharge reflecting dynamics occurring within the shallow magma supply system [4] or due to magma pulses occurred within a small and well-defined volume resulting in the emplacement of fresh magma along the crust-mantle boundary underneath El Hierro [10]. Our time series data encourage further use of time-frequency analysis using longer and higher time resolution observations such as those recorded by a permanent mooring, and their comparison and integration with geophysical parameters.

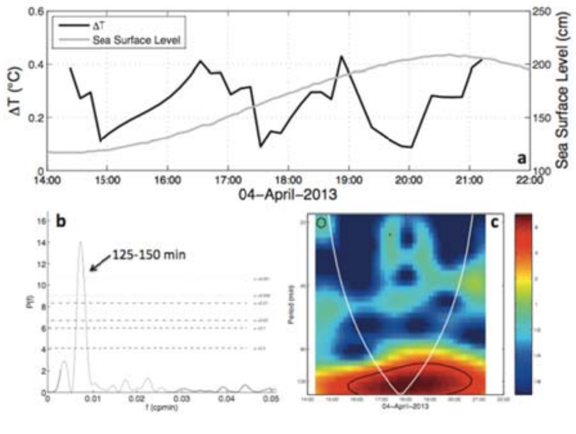

Fig. 1. Time-frecuency analysis. (A) Potential temperature anomaly time series over st. 53. The grey line shows the Sea Surface Level (M2 type tide) at the island of El Hierro. (B) Power spectra and statistical significance computed by Fast Fourier transform for the time series. (C) Wavelet transform computed by Matlab toolbox applied to the thermal data. The thick black contour shows the 95% confidence interval and the cone of influence (COI) where edge effects might distort the picture is shown outside of the white line.

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