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Environmental monitoring of El Hierro Island submarine volcano, by combining low and high resolution satellite imagery

F. Eugenio[a,*], J. Martin[a], J. Marcello[a], E. Fraile-Nuez[b]

[a] *Instituto de Oceanografía y Cambio Global, Universidad de las Palmas de Gran Canaria, Campus Universitario de Tafira, 35017 Las Palmas de Gran Canaria, Spain*
[b] *Instituto Español de Oceanografía, Centro Oceanográfico de Canarias, 38180 Tenerife, Spain*

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ABSTRACT

El Hierro Island, located at the Canary Islands Archipelago in the Atlantic coast of North Africa, has been rocked by thousands of tremors and earthquakes since July 2011. Finally, an underwater volcanic eruption started 300 m below sea level on October 10, 2011. Since then, regular multidisciplinary monitoring has been carried out in order to quantify the environmental impacts caused by the submarine eruption. Thanks to this natural tracer release, multisensorial satellite imagery obtained from MODIS and MERIS sensors have been processed to monitor the volcano activity and to provide information on the concentration of biological, chemical and physical marine parameters. Specifically, low resolution satellite estimations of optimal diffuse attenuation coefficient (K_d) and chlorophyll-*a* (*Chl-a*) concentration under these abnormal conditions have been assessed. These remote sensing data have played a fundamental role during field campaigns guiding the oceanographic vessel to the appropriate sampling areas. In addition, to analyze El Hierro submarine volcano area, WorldView-2 high resolution satellite spectral bands were atmospherically and deglinted processed prior to obtain a high-resolution optimal diffuse attenuation coefficient model. This novel algorithm was developed using a matchup data set with MERIS and MODIS data, in situ transmittances measurements and a seawater radiative transfer model. Multisensor and multitemporal imagery processed from satellite remote sensing sensors have demonstrated to be a powerful tool for monitoring the submarine volcanic activities, such as discolored seawater, floating material and volcanic plume, having shown the capabilities to improve the understanding of submarine volcanic processes.

1. Introduction

After three months of volcanic unrest, characterized by more than 10,000 earthquakes (magnitude ≤4.3) and 5 cm of ground deformation, on October 10, 2011 the Spanish National Seismic Network recorded a substantial decrease of seismicity together with continuous volcanic tremor, indicating the beginning of an eruptive phase. The impact caused by the underwater volcanic eruption, 300 m below sea level, at the El Hierro Island (27.61 N, 18.02 W) has provided a unique and outstanding source of tracer that may allow us to study a variety of structures, as submesoscale front-like and filament-like structures, as shown in Fig. 1. The submarine eruption is the first in the island chain in nearly 500 years and it is just off the southern coast of El Hierro. A milky green plume in the water stretched 25–30 km at its widest and, approximately, 100 km long, as shown in the high resolution color composite images of RapidEye satellite of Fig. 1(c).

Since then, a regular multidisciplinary monitoring, physical–chemical and biological properties, around the volcano has been carried out by the Spanish Oceanographic Institute in order to quantify the environmental impact. Four months after it began, the underwater volcanic eruption off El Hierro Island persisted as shown in the natural-color satellite image (Fig. 1(d)), acquired on February 10, 2012 by the advanced land imager (ALI) aboard the earth observing-1 (EO-1), that displays the site of the eruption, near the fishing village of La Restinga. Bright aquamarine water indicates high concentrations of volcanic material. Immediately above the location of volcano, a patch of brown water resembles a turbulent hot tub and indicates where the eruption is strongest. The El Hierro eruption environmental implications and the comparison with other climate-driven ocean environment changes are discussed in Fraile-Nuez et al. (2012) and Santana-Casiano et al. (2013).

Satellite study of volcanoes can provide data for large areas of the Earth's surface with a range of modalities ranging from visible

* Corresponding author. Tel.: +34 928452979; fax: +34 928451243.
E-mail address: feugenio@dsc.ulpgc.es (F. Eugenio).

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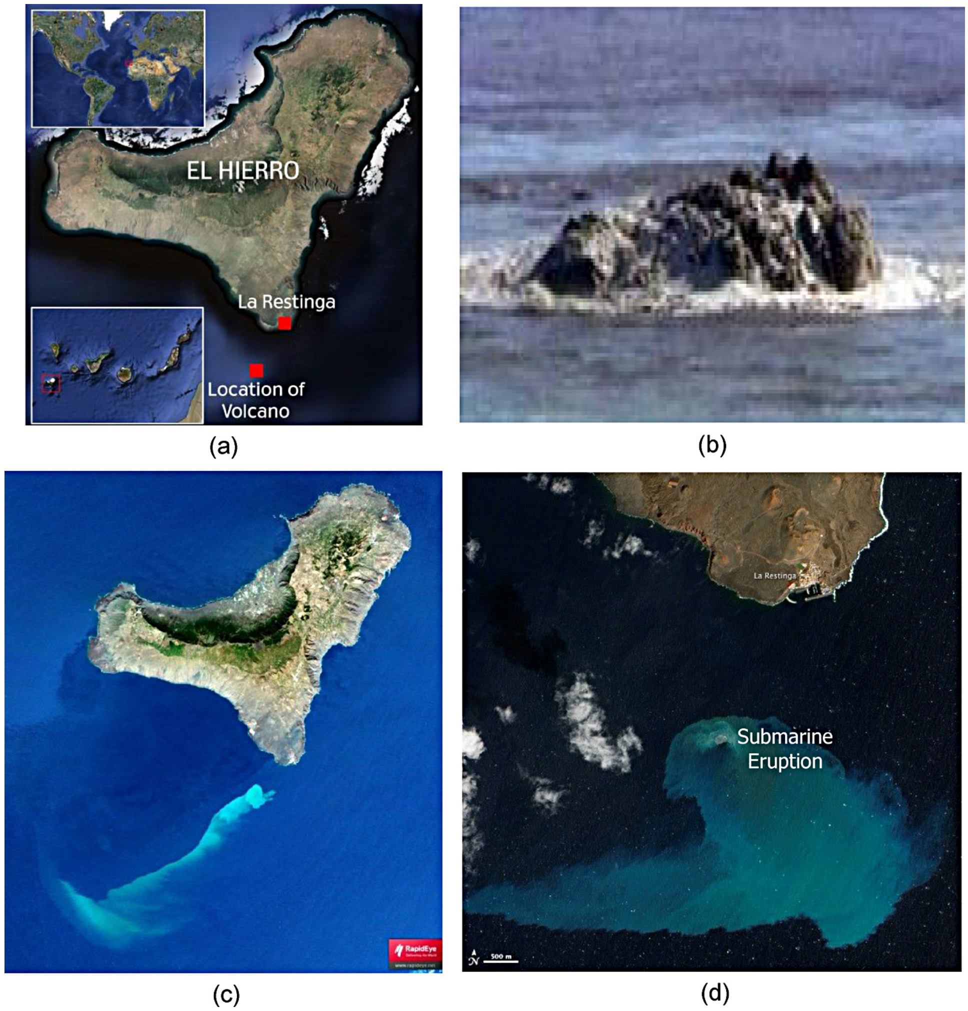

Fig. 1. (a) El Hierro submarine volcano location (27.61 N, 18.02 W), (b) the strong degassing with abundant rock fragments generated large 'bubbles', some of them 10–15 m-high (November 8, 2011), (c) RAPIDEYE© color composite imagery acquired on October 26, 2011 and, (d) natural-color satellite image acquired on February 10, 2012 by the advanced land imager (ALI) aboard the earth observing-1 (EO-1) satellite (NASA©).

to infrared, radar and beyond. Satellite sensing can also access remote locations and hazardous regions without difficulty. A comprehensive review of remote sensing for some natural hazards are provided by Tralli et al. (2005) and Joyce et al. (2009). Accordingly, this work is not intended as a comprehensive treatment of the application of remote sensing to the selected natural hazards but rather as recognition of the contributions of satellite remote sensing to understanding underlying phenomena and providing critical information for decision support by emergency managers and the disaster response community.

Remote sensing data from different sensors including MODIS, ASTER, EO-1 ALI and Landsat-7 ETM+ were used by Urai and Machida (2005), Shi and Wang (2011) and Mantas et al. (2011) to analyze submarine eruption, focusing mainly on the plumes of discolored water, diffuse attenuation coefficient, ocean chlorophyll-*a* concentration and sea surface temperature and highlights the need for continuous monitoring of the submarine volcano eruptions. In this context, Shi and Wang (2011) demonstrate the significant value of multisensor and multispectral satellite data spanning the VNIR through the TIR wavelength regions for monitoring volcanic activity in remote regions. High-spatial-resolution ASTER data measured changes in the size of the island, water discoloration, and surface temperatures. High-temporal-resolution MODIS data determined the timing and duration of the eruption, the distribution of water discoloration, and the extent and volume of pumice rafts as they drifted away. Anomalies in ocean chlorophyll-*a* concentration, measured using MODIS data, were analyzed by Mantas et al. (2011) and a large bloom was identified.

This paper illustrates the capabilities of satellite remote sensing systems to improve understanding of submarine volcanic processes by analyzing low and high resolution remote sensing images providing more frequent observations and scientific information at a wide variety of wavelengths.

In this study multisensor and multitemporal images obtained from MODIS (MODerate resolution Imaging Spectroradiometer), MERIS (MEdium-spectral Resolution Imaging Spectrometer) and WorldView-2 sensors have been processed to monitor the underwater volcanic eruption area and to provide information on the concentration of oceanographic parameters, specifically, diffuse attenuation coefficient (K_d) and chlorophyll-*a* (*Chl-a*). The diffuse attenuation coefficient (Mueller, 2000; Wang et al., 2009; Shi and Wang, 2011) is used as an indicator for the water turbidity near the volcanic eruption location, and its changes during and after the volcanic eruption are evaluated. In addition, ocean biological properties corresponding to the marine ecosystem changes, specifically ocean chlorophyll-*a* concentration (Schiller and Doerffer, 2005; Mantas et al., 2011), is analyzed.

High-spatial-resolution WorldView-2 data processing strategy developed in this work consists in an optimal atmospheric correction model and an improved algorithm for sun-glint removal