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A first GPS measurement of vertical seafloor displacement in the Campi Flegrei caldera (Italy)

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ABSTRACT

This study shows how the GPS technique can be utilized for seafloor displacement measurements and improved the survey control infrastructure in Campi Flegrei caldera, two thirds of which is submerged under the sea. In the Gulf of Pozzuoli, about 2.5 km from the coast where the sea depth is 97 m, a continuous GPS station (CFB1) has been installed since the end of 2011 on the top of a elastic-beacon buoy, rigidly connected by a steel cable to the ballast on the sea bottom. We investigate the use of GPS data to estimate the vertical displacement of the seafloor under the buoy. The GPS data were processed in kinematic mode and the vertical component of the measurements was corrected for the errors due to the horizontal motion of the buoy induced by wind and sea currents. We report here the results for approximately 17 months of continuous GPS data acquisition, and we show, for the first time, a measure of vertical displacement of the seabed in the Gulf of Pozzuoli. From January 2012 to May 2013, the seafloor uplifted by about 3–4 cm. The similarity of the pattern of the CFB1 time-series compared to the permanent GPS stations of the NeVoCGPS network located onshore is remarkable, evaluation of the Pearson's correlation coefficient between these stations and CFB1 indicates that the stations are measuring the same phenomenon. This result is important, because all models of evolution of bradyseism in the Campi Flegrei caldera are based on the interpretation of measures only on the emerged part of the caldera, without use of any measures to date in the Gulf of Pozzuoli.

The methodology shown in this paper is reliable over time and economical, compared to other systems of measurement of marine geodesy. The major limitation is the depth of the sea, confining this technique to the shallow water, up to 100 m depth. However, a large part of the submerged Campi Flegrei caldera is shallower than 100 m, so geodetic monitoring by means of GPS buoys at several sites in the Gulf of Pozzuoli would allow to extend interpretative models to the entire caldera, submerged and emerged.

1. Introduction

The monitoring of ground displacement is fundamental to understanding the evolution of volcanic activity and, consequently, geodetic networks provide an essential contribution to the monitoring of active volcanoes. Geodetic measurements are made using different techniques, including networks of GPS stations, tilt-meters, tide gauges, precision leveling and SAR interferometry. When a volcanic edifice is fully or partially submerged under the sea, standard geodetic methods cannot be applied; measurement and monitoring become difficult and expensive.

One recent seafloor geodetic technique involves kinematic GPS positioning and underwater acoustic ranging. Acoustic waves are used due to the poor penetration of electromagnetic waves in sea water. In these joint GPS–acoustic techniques, a source of acoustic signals (hydrophone) on the sea surface generates acoustic waves that are detected by receivers (acoustic transponder) on the sea floor. By measuring the travel times of acoustic wave between the surface source and an array of seafloor transponders and using an approach similar to the seismological earthquake tomography, the location of the seafloor transponders can be determined. The precise location of the hydrophone, the source, is obtained with standard kinematic GPS techniques. With this technique points on the sea floor can be located with a precision of a few centimeters (Chadwell and Spiess, 2008; Ikuta et al., 2008; Bourne et al., 2009). The main limitation of the joint GPS–acoustic techniques is the variability over time of the acoustic wave velocity propagation in the marine environment, with the consequent difficulty in the conversion of a measured propagation time into a path length. The acoustic wave velocity in sea water depends on the temperature and salinity of the water, which, in turn, are strongly affected by solar radiation, by seasonal cycles, and by mixing of the water due to sea currents. These effects are particularly pronounced in the shallow waters of coastal areas due to strong solar radiation and the presence of rivers or waste waters.

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For the measurement of the vertical component of sea floor displacement, an alternative method based on the use of seawater pressure to infer seafloor depth is available. Vertical movement of the sea floor produces a change in the thickness of the water layer and the pressure measured on the sea bottom reveals this displacement. The measurements are made with a pressure sensor located on the sea floor, with the removal of the mareographic and atmospheric components from the seabed pressure, and then the conversion of this value into the height of the water column. The eruptive activity of the Axial Seamount, a large volcano located about 400 km off of the Oregon coast, was monitored using this methodology (Fox et al, 2001; Chadwick et al., 2006; Dziak et al., 2012).

The combined use of seabed pressure measures and kinematic GPS has been tested for absolute positioning of points on the seafloor (Ballu et al., 2010). This methodology is effective when measures are made over short periods of time, but is difficult to apply over long periods of time (months, years) due to drift phenomena of the pressure measurement instruments (Nooner and Chadwick, 2009; Polster et al., 2009).

The Campi Flegrei caldera, Southern Italy, is one of the most hazardous and populated volcanic areas in the world and, although a significant part of the caldera is submerged under the sea, the monitoring system is completely located on shore. The volcanic surveillance system consists of several networks for continuous monitoring of seismicity, ground deformation and gas emissions from soil and fumaroles (Bottiglieri et al., 2010; D'Auria et al., 2011; Chiodini et al., 2012; De Martino et al., in press). All signals from these networks are transmitted continuously and in real time to the Monitoring Center of the Osservatorio Vesuviano in Naples, where the analyses are performed. The information from the permanent monitoring networks is complemented by periodical survey campaigns for the measurement of additional geophysical and geochemical parameters (Chiodini et al., 2010; Del Gaudio et al., 2010). The permanent GPS network consists of 12 stations (Fig. 1a) forming the Campi Flegrei segment of the Neapolitan Volcanic Continuous GPS (NeVoCGPS) network (Tammaro et al., 2013).

To improve coverage of the submerged part of the Campi Flegrei caldera, a multi-parametric station, named CUMAS (Cabled Underwater Multidisciplinary Acquisition System) has been installed in the Gulf of Pozzuoli by the Osservatorio Vesuviano. CUMAS forms the first step for the extension to the sea of the monitoring system of the Campi Flegrei (Iannaccone et al., 2009). The CUMAS station consists of an elastic-beacon buoy, connected by cables to a ballast and a sensor module positioned on the seabed to a depth of 97 m (Fig. 1b). The sensor module is equipped with a broadband seismograph, a tri-axial, microelectromechanical system (MEMS) technology accelerometer, a low-frequency hydrophone, a pressure sensor and state of health sensors. The signals from the underwater module are transmitted continuously and in real time to the Monitoring Center in Naples and are integrated into the surveillance system of the Campi Flegrei area.

Since the end of 2011, a GPS station has been installed on the top of the buoy to investigate the use of GPS data to estimate the vertical displacement of the seafloor under the buoy. The elastic-beacon buoy forms a structure which is rigidly connected by a cable to the ballast on the sea bottom, a submerged float at the base of the buoy maintains tension on the cable. In this way, any vertical movement of the seafloor propagates rigidly to the emerged part of the buoy itself, allowing measurement of the vertical movement by the GPS station (Fig. 1b).

This paper describes the configuration and installation of the CUMAS buoy and GPS instrumentation, and reports the results for approximately 17 months of continuous GPS data acquisition, starting from January 1st, 2012. A comparison with the data for the same period from other GPS stations of the NeVoCGPS network (Fig. 1a) shows the limits and potential of this particular methodology for measuring the vertical displacement of the sea floor in the Gulf of Pozzuoli.

2. CUMAS buoy outline and GPS instrumentation

The CUMAS elastic-beacon buoy is installed in the area of Campi Flegrei in the Gulf of Pozzuoli, about 2.5 km from the coast where the sea depth is 97 m (Fig. 1). The buoy consists of an underwater float, located a few meters below the sea level, made of polyurethane foam

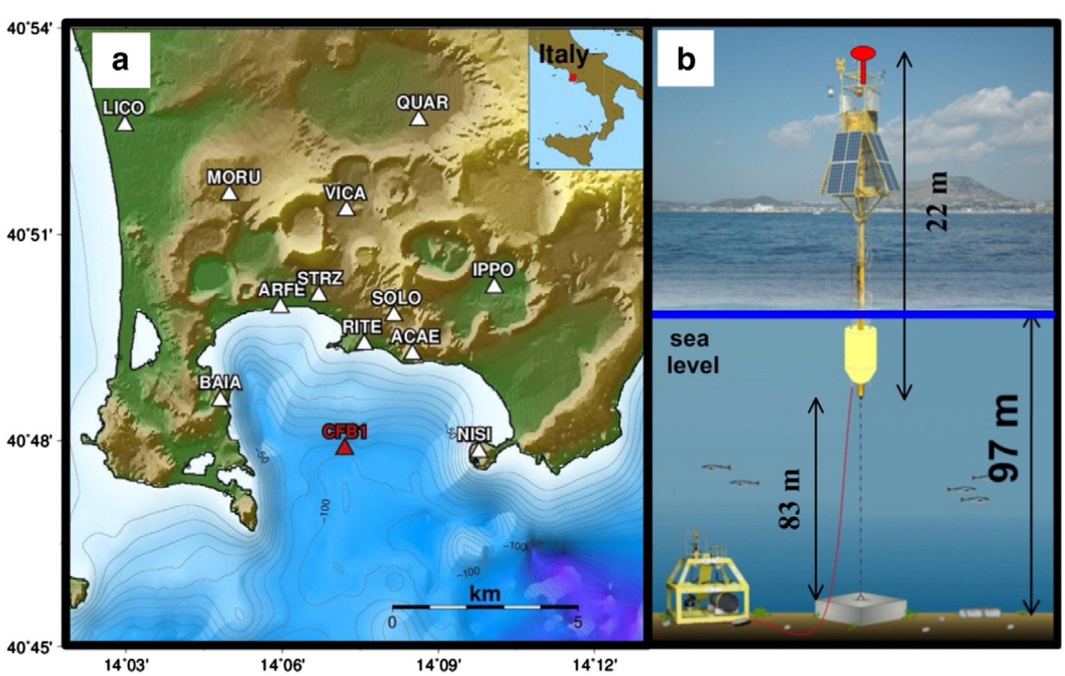

Fig. 1. a — map of the Campi Flegrei volcanic area with the GPS stations (black triangles) of the NeVoCGPS network. Red triangle shows the position of the buoy. b — layout of the multidisciplinary CUMAS system (not to scale) formed by a buoy and sea floor module equipped with geophysical sensors.