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Review of ten years of volcano deformations recorded by the ground-based InSAR monitoring system at Stromboli volcano: a tool to mitigate volcano flank dynamics and intense volcanic activity

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ABSTRACT

Stromboli volcano (Southern Italy) is one of the most monitored volcano in the world with a surveillance network that includes a permanently sited ground-based SAR interferometer (GBInSAR). This work is the review of the GBInSAR data gained from the last decade of monitoring activity. The analysis of the entire dataset of GBInSAR measurements allowed the assessment of the deformation field of the northern part of the summit crater area and the Sciara del Fuoco depression. In detail, the main displacements recognized can be related to different factors: 1) the inflation/deflation respectively immediately before and after each new effusive event; 2) the bulging of localized sectors of the volcano involved in the vent opening; 3) the gravitational sliding of the Sciara del Fuoco infill; 4) the movement of lava flows. Accelerations in this sector are related to sheet intrusions, while the possibility of vent opening, associated with small sliding, or catastrophic flank failure are related to highly overpressurized sheets, able to produce high displacement rate in the Sciara del Fuoco.

In the summit crater area, the increases in the displacement rate are related to the pressurization of the shallow conduit system, as the consequence of the variation in the magma level (magmastatic pressure) or to the lateral magma migration (lateral conduit expansion or dike intrusion) in response to the increase of the overpressure component. Fluctuations in the displacement rate in the summit crater area can be related to the magma overturning within the conduit, with the increases in displacement rate during the upwelling of less dense magma, while displacement rate decreases as the degassed magma column is pushed out from the conduit (lava flows or overflows). Instead, the decrease in the displacement rate without coeval lava outpouring could be related to the sink of the degassed magma due to density contrast between the gas-poor and the gas-charged magmas. Using the displacement rate in the summit crater area as a proxy for the variation in the pressure condition in conduit (both magmastatic and overpressure components), thresholds for the crises characterized by the occurrence of overflows (eventually associated with major explosions) and flank effusions (eventually associated with paroxysmal explosions) are identified. Small conduit overpressure will produce overflows (sometimes associated with crater-rim collapses), while large magma overpressure will laterally expand the conduit forming NE-SW striking sheets, feeding eruptive vents at the base of the summit crater area and within the Sciara del Fuoco, generating conditions of instability that can evolve into catastrophic collapse of the instable flank.

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1. Introduction

Since the 2002–03 flank effusion, characterized by a tsunamogenic landslide provoked by the intrusion of a dyke in the Sciara del Fuoco (SdF), together with a paroxysmal explosion (Rosi et al., 2006; Neri et al., 2008), Stromboli became one of the most monitored volcano in the world with a progressive improvement of the surveillance network (Barberi et al., 2009), comprising 13 broadband digital seismometers (Giudicepietro et al., 2009), tiltmeters (Bonaccorso et al., 2009), an automated distance measuring station (Puglisi et al., 2005), a continuous GPS network (Mattia et al., 2004), two strainmeters (Bonaccorso et al., 2012), a network of visual and thermal cameras (Bonaccorso et al., 2012), magnetic and gravity stations (Carbone et al., 2012), a permanent side Ground-based Interferometric Synthetic Aperture Radar (GBInSAR; Antonello et al., 2004), 4 seismo-acoustic stations (Goto et al., 2014), a system of optical radiometers and infrared and visible light cameras and a geochemical network for the automatic monitoring of the SO_2 flux (Burton et al., 2009) and the CO_2/SO_2 ratio of the crater gas plume (Aiuppa et al., 2009), the CO_2 soil flux and the dissolved CO_2 in the thermal water wells (Inguaggiato et al., 2011). The GBInSAR is, so far, the only example in the literature of such technology applied to the surveillance of an active volcano. It is used for landslide monitoring in the area of the Sciara del Fuoco (Casagli et al., 2010; Intrieri et al., 2013; Nolesini et al., 2013), coupled with the automated distance measuring station (Bonforte et al., 2008), and for monitoring inflation-deflation of the summit crater area that can reveal any change in the volcanic activity (Casagli et al., 2009; Di Traglia et al., 2013, 2014a,b). It is considered as the best way to capture short, subtle episodes of conduit pressurization in open vent volcanoes like Stromboli (Chris Newhall, pers. comm.). Stromboli is an open-conduit volcano and does not experience pressurization of the magma storage and/or plumbing system that produces ground deformations at the scale of the volcanic edifice. For any such system, localized inflation or deflation may occur in response to conduit processes, such as magma convection and uprising (Bonaccorso and Davis, 1999; Chaussard et al., 2013). Detectable ground deformation at Stromboli has only been observed in association with dyke intrusion at shallow depth, prior to the opening of new eruptive fractures (Bonaccorso, 1998; Bonaccorso et al., 2008; Casagli et al., 2009).

Stromboli (Fig. 1) is one of the most well-known volcanoes in the world and its persistent activity, consisting of frequent, small scale, explosions gave its name to *Strombolian activity* (Blackburn et al., 1976). Intrusion-related landslides from the NW unstable flank of the volcano (the Sciara del Fuoco depression; Fig. 1b) are also frequent (Barberi et al., 1993; Di Roberto et al., 2008, 2010; Rosi et al., 2013) and are the most hazardous phenomena, due to their tsunamogenic potential (Fig. 2; Tinti et al., 2005; Nave et al., 2010; Nolesini et al., 2013). Tsunamis have occurred numerous times in recent centuries and can affect large areas of the coast of Stromboli (Barberi et al., 1993; Tinti et al., 2005; Rosi et al., 2013 and references therein). However, the most frequent hazards at Stromboli are related to the occurrence of higher-intensity Strombolian explosions (paroxysmal or major explosion, based on the scale of the main blast; Barberi et al., 1993). Paroxysmal events affected large zones and produced bombs and blocks that reached inhabited areas (mainly to Ginostra village in the SW part of the Island) and hot avalanches that caused fatalities (i.e. 1930 paroxysm; Bertagnini et al., 2011; Di Roberto et al., 2014).

Stromboli volcano is constantly erupting, with temporal and spatial changes in frequency, intensity, and nature of the activity (see, e.g., Taddeucci et al., 2013). Giving the persistent activity at Stromboli, we prefer to use the term "crisis" instead of "eruption" to describe period characterized by volcanic activity with intensity higher than the "ordinary" strombolian activity. The term "crisis" is more appropriate in the case of Stromboli because it has civil protection implications. A single crisis comprises different phenomena, such as higher-intensity strombolian explosions, lava overflows, major explosions, flank effusions and/or paroxysmal explosions. The large number of crises characterized by higher-intensity volcanic activity that occurred at Stromboli since the 2002–03 crisis has offered a unique opportunity to improve our understanding of how the volcano works. This study is an attempt to elaborate the 10-years-long GBInSAR time series in order to evaluate flank dynamics (and in particular the occurrence of intrusion-related landslides) and the occurrence of higher-intensity volcanic activity at Stromboli, providing an operative tool to mitigate their effects.

2. Geological and volcanological setting

2.1. Geological outlines

The 916 m-high Stromboli Island is the emerged portion of a ~3000 m-high volcano located in the north-eastern tip of the Aeolian Archipelago, in the southern Tyrrhenian Sea (Fig. 1a). The rock composition varies between basaltic andesite, shoshonite and latite-trachyte (e.g. Hornig-Kjarsgaard et al., 1993), with the oldest exposed products dated approximately 100 ka (Gillot and Keller, 1993).

Based on the presence of structural unconformities and changes in rock composition, the volcanic sequence of the subaerial cone has been subdivided into five periods of activity (Rosi, 1980; Hornig-Kjarsgaard et al., 1993; Keller et al., 1993; Tibaldi et al., 2008; Calvari et al., 2011c; Vezzoli et al., 2014): 1) Paleostromboli I (Cavoni synthem; 85–64 ka); 2) Paleostromboli II and Paleostromboli III (Gramigna synthem; 64–26 ka); 3) Lower, Middle and Upper Vancori (Frontone and Vancori synthems; 26–13 ka); 4) Neostromboli (Fossetta synthem; 13–6 ka); 5) Recent Stromboli (Pizzo, Fili di Baraona and Sciara synthems; 6 ka-present day activity).

Stromboli volcano was affected by three caldera collapses and at least five sector collapse events, which were followed by