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Modeling hydrothermal fluid circulation and gravity signals at the Phlegraean Fields caldera

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Abstract

The Phlegraean Fields caldera is an active volcanic system where episodes of ground deformation are accompanied by significant changes in geochemical and geophysical parameters monitored at the surface. These changes derive from a complex interaction between magmatic system and hydrothermal fluid circulation. We calculate the gravity changes associated with the variable density of hydrothermal fluids. We simulate the multi-phase and multi-component fluid circulation triggered by a pulsating magma degassing, periodically increasing the discharge of CO_2-enriched fluids into the shallow hydrothermal system. The simulated evolution of the hydrothermal system successfully reproduces the observed composition of gas discharged at the surface. At the same time, results indicate that changes in average fluid density generate a detectable gravity signal that is of the same order of magnitude of the observed changes. This contribution to gravity changes can explain the peculiar behavior of gravity data collected at Solfatara, where surface hydrothermal phenomena are present. Simultaneous fitting of two independent sets of monitoring data (gas composition and gravity changes) confirms the conceptual model proposed for the hydrothermal system at Solfatara, and it provides new insights for the interpretation of gravity data.

Keywords: Phlegraean Fields; Gas composition; Gravity; Hydrothermal circulation; Monitoring; Models

1. Introduction

Non-eruptive unrest is rather common in active calderas [1], but given the large urban development of the Phlegraean Fields, even minor and non-eruptive activity may (and did) pose emergency management problems. A proper, real-time interpretation of monitoring data, collected before and during the crisis, is essential to ensure an early warning, a proper understanding of the nature of unrest, and an evaluation of its extreme consequences. This requires the development of a comprehensive conceptual model describing the complex and coupled processes which control the caldera evolution. Several features may generate or modify the geochemical and geophysical signals that we monitor at the surface, including changes at the magma chamber level, hydrothermal fluids circulation, or regional tectonics. In theory, a sound interpretation of monitoring data should take into account all these possible effects to understand the origin of the recorded signals. In practice, however, this is not always feasible and moni-

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toring data are commonly interpreted within the frame of a given specific geochemical or geophysical process. When possible, physical modeling of the process investigated is performed to test the interpretation proposed. This was done recently with geochemical data: a conceptual model of hydrothermal fluid circulation at Solfatara was proposed based on geochemical data and later evaluated by modeling heat and fluid flow through porous media [2]. The aim of this work is to verify whether the conceptual model proposed by Chiodini et al. [2] is also consistent with gravity measurements. To this purpose, we investigated the contribution of circulating fluids to gravity changes recorded at the surface. The influence of hydrothermal fluids on gravity signals is confirmed by measurements carried out near the fumarolic field, at Solfatara, which significantly differ from data collected at different locations in the caldera (Fig. 1). Ascent of hot fluids, phase changes and variable gas composition all affect the subsurface distribution of fluid density. Even though the corresponding mass change is not comparable to that one induced by arrival of a new magma batch, such modifications occur at very shallow depth, and may produce a detectable gravity change. Gravity data are commonly acquired during exploitation of geothermal fields as a way to determine reservoir properties and to constrain numerical modeling of fluid production [3,4]. In this work, results from numerical modeling of hydrothermal fluid circulation were used to calculate the gravity signal corresponding to the simulated evolution at Solfatara. This has two main objectives: on one hand, to highlight and quantify the gravity changes that may be due to hydrothermal fluids; on the other hand, to compare modeling results with a different and independent data set that will further constrain the physical model of hydrothermal circulation.

2. Recent evolution of Phlegraean Fields caldera

The Phlegraean Fields caldera is an active and densely populated volcanic complex, located near the urban area of Naples (Fig. 1). Last eruptive event in the

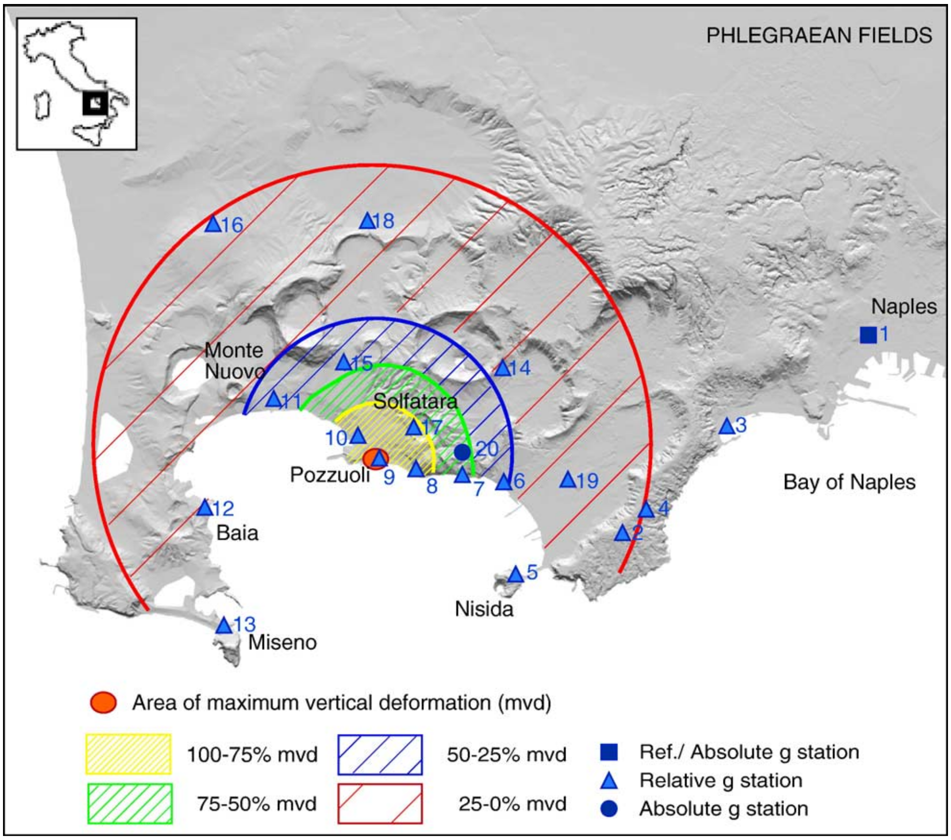

Fig. 1. The Phlegraean Fields caldera and Solfatara crater. Gravity stations considered in the work are also shown: Bagnoli, n. 6; La Pietra, n. 7; Serapeo, n. 10; Arco Felice, n. 11; Miseno, n. 13; via Campana, n.15; Solfatara, n. 17; Piazza Esedra, n. 19. Different shading indicates different amounts of vertical displacement, normalized with respect to the maximum value (modified after [28]).