Absolute gravity and GNSS measurements at Etna volcano (Italy) in the period 2009 - 2018

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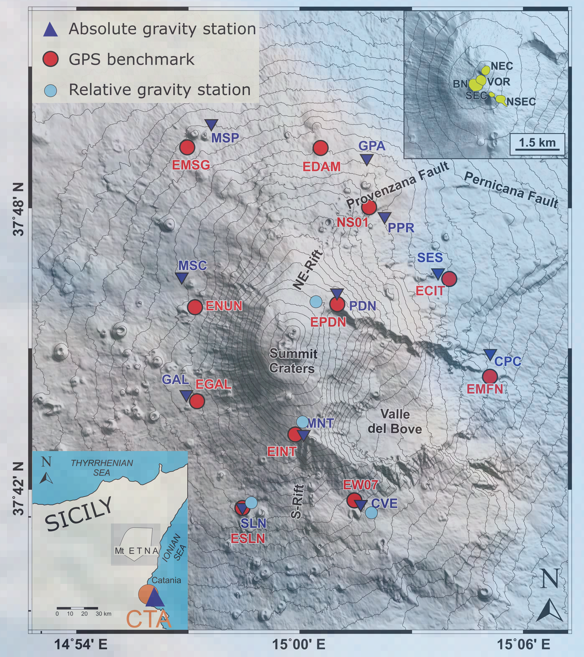
Overview

Here we present the results of repeated Absolute Gravity and GNSS measurements, collected at Mt. Etna (Italy) between 2009 and 2018, with the aim of investigating the capabilities of this integrated approach for understanding the dynamics of magmatic sources over time-scales of months to years, during an interval characterized by tens of lava fountain events from the summit craters. The absolute gravity and GNSS campaign measurements were repeated roughly once a year; in order to improve the time resolution of gravity data, in some stations we integrated the absolute gravity measurements with data performed through relative spring gravimeters at intervals shorter than 1 year and/or in the framework of almost monthly campaigns. After being corrected for the effect of elevation changes, differences reveal gravity increase/decrease cycles, well spatio-temporal correlated with uplift/subsidence patterns, in the period of intense lava fountains, affecting the whole volcano.
Our results provide insight into the processes that controlled the transfer of the magma from deeper to the intermediate–shallow plumbing system of Mt. Etna volcano, in periods preceding/accompanying the eruptive activity during 2009–2018. Specifically, we can state that the decreasing/increasing of both height-corrected gravity and elevation changes might be induced either by the magma storage/withdrawal below the volcanic pile and by fluids pressurization/depressurization effects or by a combination of both effects.

We believe that our results could improve the possibility of detecting unrest and identifying processes that herald eruptions.



Etna volcano map with the location of the gravity and GPS benchmarks. The major surface fault systems bordering the main rigid blocks of the eastern flank, which is delimited by the S-Rift to the South and by the NE-Rift, Provenzana Fault and Pernicana fault to the NE, are also indicated.

VOLCANIC ACTIVITY FROM 2009 TO 2018

After the last flank eruption of 2008-2009, the volcano remained largely quiescent until 2010. The explosive activity with lava fountain episodes resumed on 11 January 2011 from a pit on the east flank of the South-East Crater (SEC), one of the four summit craters of Etna. Since then, 44 paroxysmal eruptive events occurred until December 2013. The main explosive activity built up a new summit cone, the New South-East Crater (NSEC). Generally, all the 2011-2013 lava fountain episodes from the NSEC showed similar main characteristics, with the height of the lava fountains reaching 300-1000 m, ash columns reaching 5-9 km and associated 4-6 km long lava flows, descending the eastern flank of the volcano. The average total DRE (Density Rock Equivalent) volume of magma emitted during each of the NSEC lava fountains, including pyroclastic products and lava flows, was about $2.5 \cdot 10^6$ m^3 per event.

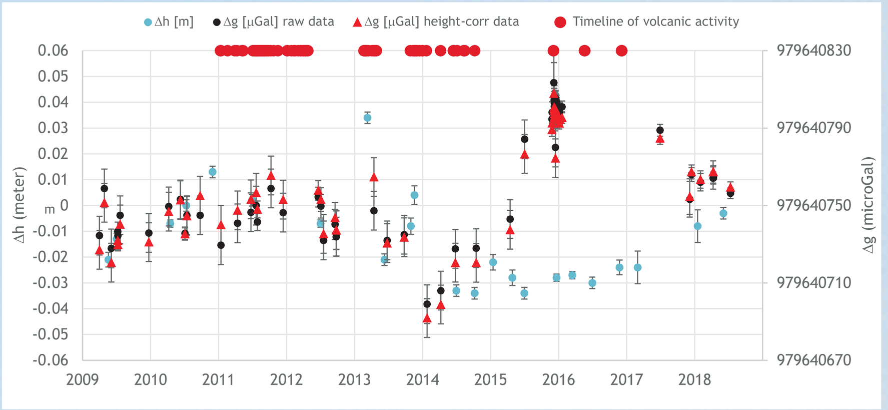
January 5, 2012, fountain eruption at Mount Etna.
(Credit: G. Lanzafame)

After the 2011-2013 NSEC lava fountains, the eruptive activity switched to moderate lava effusion from the NSEC toward NE during January-April and July-August 2014. On 28 December 2014, a further lava fountain episode occurred at the NSEC, bringing the number of events to 45.
Moreover, two sequences of 4 and 3 events took place at the Voragine crater (VOR) on 3–5 December 2016 and 18–21 May 2016, respectively, for a total of 52 lava fountain episodes from January 2011 to May 2016, erupted from Etna's main craters. The lava fountains of 3–5 December 2015 rank among the most violent to have occurred at Etna in the last two decades.

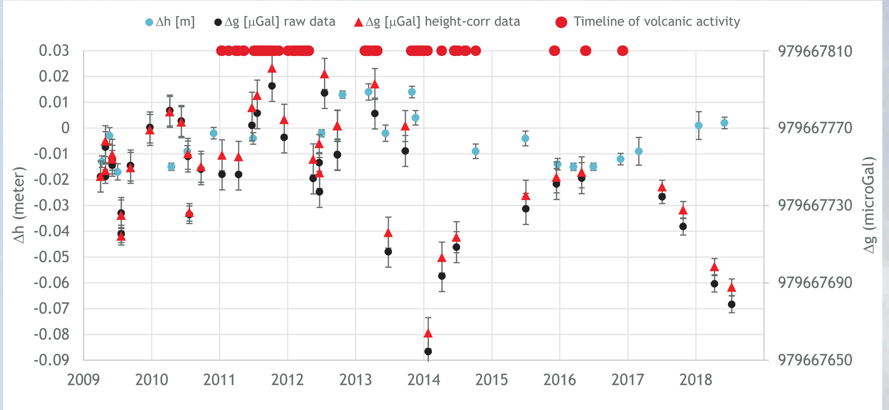
Measurements

Between 2009 and 2018, we conducted almost yearly absolute gravity campaigns at Mt. Etna with the FG5#238 free-fall gravimeter. In the period 2013 - 2016 the absolute gravity meter was not available. Therefore, after 2012 the AG measurements were made in 2017 and then repeated in 2018. In order to reduce the lack of information and avoiding aliasing effects leading to a misinterpretation of the causative subsurface dynamics, we have supplemented the absolute measures with relative gravity data collected by relative spring gravimeter, in the framework of higher frequency (almost monthly) campaigns performed in different sectors of the volcano.
The 2009-2018 period has been marked by significant spatiotemporal changes in gravity and height ground deformation. Using GPS data, gravity measures were corrected for the free-air effect through the value of the vertical gradient of gravity measured at each absolute stations in the same periods.
Figures show gravity data acquired at Serra La Nave (SLN), Casa del Vescovo (CVE), Montagnola (MNT) e Pizzi Deneri (PDN) stations, from 2009 to 2018, compared with height variations at the closest GPS stations, before and after the correction for the effect of the elevation changes. We are aware that the overall patterns of gravimetric and geodetic signals at these stations (where almost yearly absolute gravity and GPS data were integrated with almost monthly measurements) can be considered consistent to represent, in terms of wavelength and period of occurrence (except for the amplitude), what happened throughout the network.
The joint examination of the sequences highlights time intervals in which both signals underwent contemporaneous changes. Furthermore, after being corrected for the effect of elevation changes the gravity and height variations are directly (positively) space–time-correlated (i.e. gravity increases with uplift and vice versa), showing similar up–down patterns at all stations and for almost all the considered periods. Only in the period 2016-2018 the positive correlation inverts and while a gravity decrease was observed, a general uplift occurred.

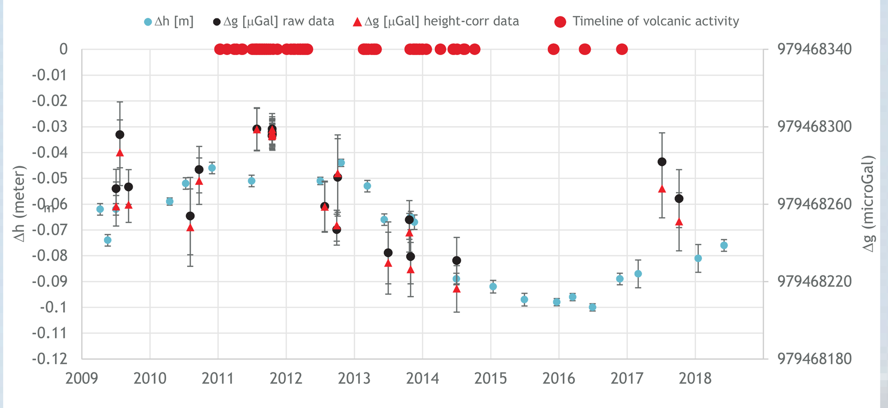
Gravity station SLN - GPS benchmark ESLN



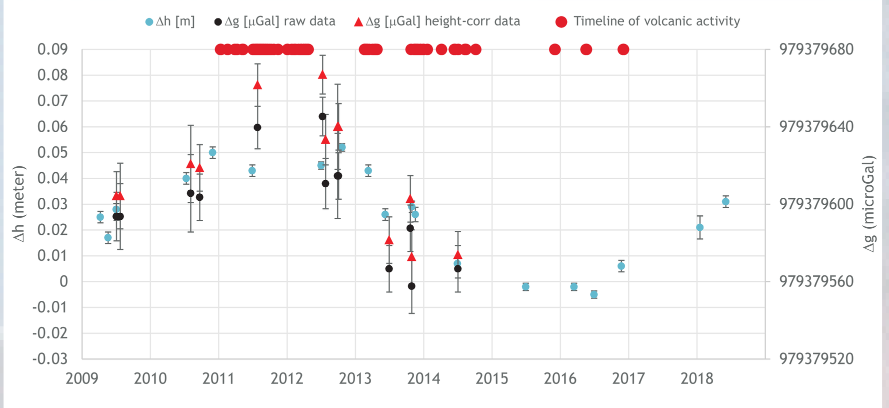
Gravity station CVE - GPS benchmark EW07



Gravity staion MNT - GPS benchmark EINT



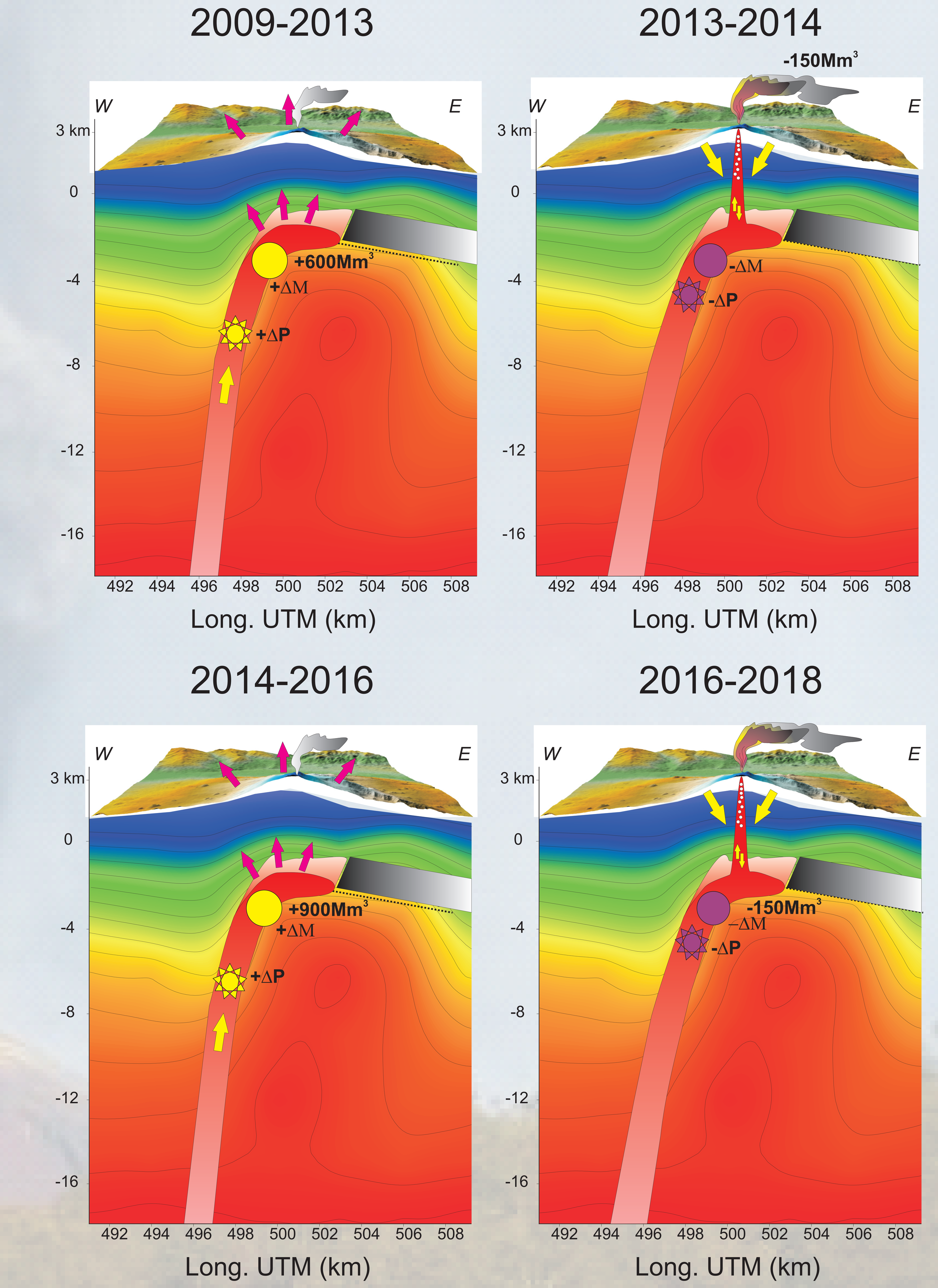
Gravity staion PDN - GPS benchmark EPDN



The general patterns of both signals observed in the period 2009 - 2018, allow us to identify at least two main complete increase/decrease cycles with a duration of several years, affect the whole volcano edifice.
A first complete gravity increase/decrease cycle and an overall inflation/deflaction of the volcano, started in 2009 (gravity increase with contemporaneous uplift), culminated in 2013, and continued until 2014 (gravity decrease accompanied by subsidence), when the mean value of gravity and ground deformation at each station reached a level lower than it was in 2009, before the increase/inflaction took place.
A second increase/decrease gravity cycle, affecting the same stations of the previous one, accompanied by positive and negative height changes, arose in 2014 (gravity increase and inflaction), culminated in 2016, when it reached a maximum amplitude. The amplitude of both gravity and height changes observed in the second cycle presents roughly the same characteristics of the first. In 2016, the gravity field inverted its trend and continuously decreased until 2018, when roughly the value reached the same levels it was in 2009.

Preliminary results

Conceptual sketch of the four time periods defined, alternating summit eruptions and magma storage. Starting from the feeding system depicted by previous geophysical investigations, we hypothesize a storage of magma, rising from depth along the western border of the HVB, at about 2-4 km b.s.l., producing mass increase at depth and inflation of the edifice; from this level, only a fraction of the stored magma occasionally upraise along the shallow feeding system of the volcano to feed eruptions and summit activity, causing mass decrease at depth and short deflation of the edifice.



Our results provide insight into the processes that controlled the passage of the magma from deeper to the intermediate–shallow plumbing system of Mt. Etna volcano, in periods preceding/accompanying the eruptive activity during 2009–2018. Specifically, we can state that the decreasing/increasing of both gravity and height ground deformation values may be induced either by the magma storage/withdrawal below the volcanic pile or by pressurization/depressurization effects or by a combination of both.