Istituto Nazionale di Geofisica e Vulcanologia
Osservatorio Vesuviano

Toward Absolute Gravity Networks to Monitor the Neapolitan Volcanoes

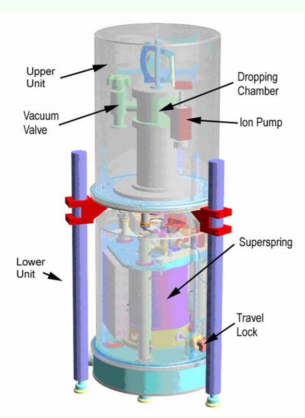
Giovanna BERRINO*, Vincenzo d'ERRICO and Giuseppe RICCIARDI

Istituto Nazionale di Geofisica e Vulcanologia – Sezione di Napoli "Osservatorio Vesuviano", Napoli. *Corresponding author_ e-mail: giovanna.berrino@ingv.it

INTRODUCTION

It is well known that precise gravity measurements are a powerful means to detect the mass change/redistribution in the underground, such as those occurring at volcanoes.
The most common approach is the use of repeated relative measurements at benchmarks on networks. This is very good, but has some and significant limits: 1) the networks must be linked to a reference station stable over long time and if possible external to the active area. This is quite simply for land volcanoes, but is generally difficult for insular volcanoes, particularly when far from the *terra firma*; 2) to reach high precision, measurements require special operative procedures implying long time surveys which therefore are spaced out some months or years; 3) detected gravity variations can be affected over the long-time by changes of instrumental sensitivity and loss of vacuum in the air-tight sealing system, therefore the instruments must be subject to continuous check.
Measurements on network have the advantage to permit to define the position and the geometry of the changed masses. This is a fundamental information in the prediction of the volcanic activity, even if they suffer from the lack of information about the rate and/or quick gravity changes, since variations are assumed linearly changing over the time between two consecutive surveys. Therefore, measurements on networks cannot be excluded from a monitoring program, but moving toward absolute methodologies is advisable.
The main advantages of the absolute measurements on networks are: *a)* the independence from any reference; *b)* field operations are faster and easier, permitting much frequent measurements and reducing the lack of information between two consecutive surveys; *c)* they are directly linked to standards of time and length therefore fairly independent from instrumental references and drift, avoiding loss of long-term information; *d)* the measured value can be used without loop reductions, post processing and benchmark links. All this can be translated into large advantages, such as saving of human resources, survey's time and costs.
Nowadays this is possible due to the commercially availability of a portable field absolute gravimeter (Micro-g_LaCoste A10), which was acquired at the end of 2014 in the framework of the "VULCAMED" PON Project.

Brief description of the A10 portable absolute gravimeter



The Microg_LaCoste A10 ballistic absolute gravimeter is a portable instrument designed on purpose for field measurements of the vertical acceleration of gravity (*g*) and fast field operations, while preserving the characteristics of a laboratory instrument.
It works using a free-fall method and a simple concept: a test mass (retro-reflective Corner Cube) is dropped vertically by a mechanical device (drug-free cart) inside a vacuum dropping chamber, and the time it takes to fall a specific distance is measured. The vacuum is maintained by a ion pump.

The gravity value for each drop is estimated by the falling distance measured by a stabilized laser interferometer, emitting laser beams at two different wavelengths, and the falling time measured by a rubidium atomic clock.
The free-fall trajectory is referenced to a long period active seismic-isolation system (called Superspring) aimed to isolate the test mass from high frequency ground motions.
The instrument is formed by two parts: the Upper Unit (or Dropper) that is the Dropping Chamber, also housing the ion pump; the Lower Unit (or Interferometer Base–IB) consisting of the laser, interferometer, Superspring and automatic levelling unit.
Its diameter is 30 cm (50 cm footprint) and the assembly height is 90 cm. The Upper and Lower Units weigh 19 and 21 kg respectively. It operates at 12V DC power supply and at an operating temperature -18°C – +38°C (internal temperature).
It performs an Accuracy of 10 µGal (Absolute) and reaches a Precision of 10 µGal in 10 minutes at quite sites. *g* is measured at a constant height of 0.72 m but it can be automatically reduced at any convenient height providing the value of the site vertical gravity gradient.

The assembled instrument is connected to a controller and to a laptop on which the Absolute Gravity Data Acquisition and Processing Software is installed to estimate the gravity value for each drop. The software provides the automatic data acquisition, the real time processing and the automatic data storage. It also automatically corrects the measured *g* value for gravity changes due to solid-earth tides, ocean tide loadings, polar motion and local air pressure changes. It also permits to reprocess data.

Giuseppe and Vincenzo during some moments of a field survey

Operating during a measurement

Giuseppe as is positioning and assembling A10

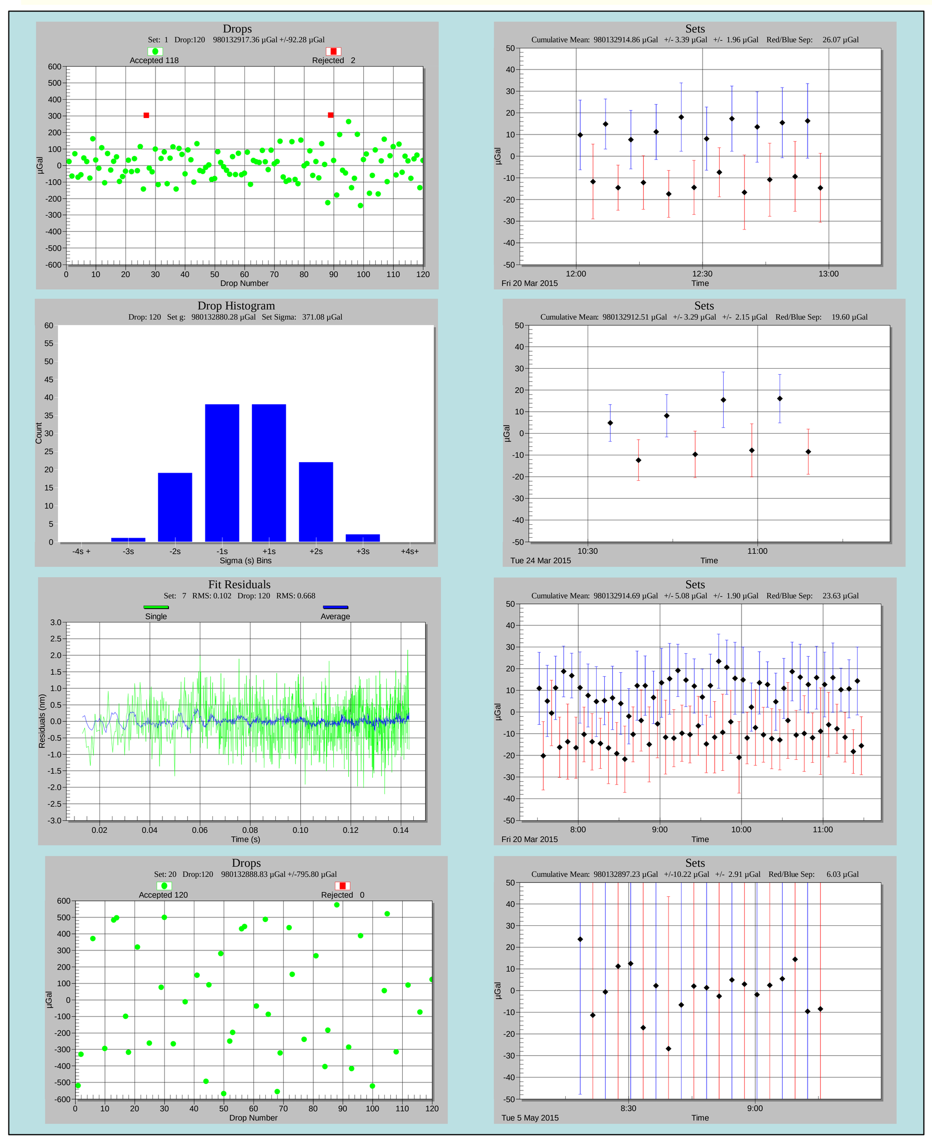
A10 test at the Old Building of the Osservatorio Vesuviano – Mt Vesuvius

Several measurements were carried out to test the performances of the instrument, to verify the repeatability of the measured value and also to take confidence with the instrument.

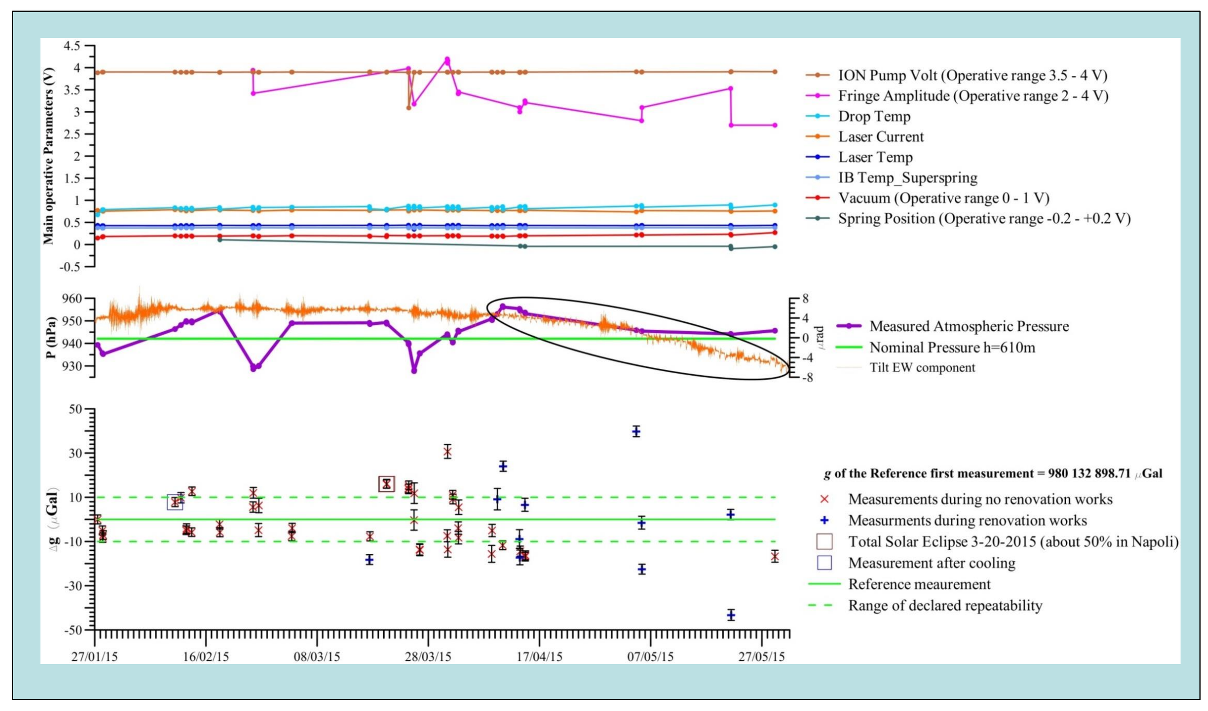
The test was performed at the Old Building of the Osservatorio Vesuviano, on Mount Vesuvius, on an insulated pillar in a room on the ground floor. It is a low noised and good logistic site, also close to the relative gravity station (outside the building) belonging to the Vesuvius monitoring relative gravity network.
It is also the same place where a first absolute measurement was performed in 1986. The *g* value has been measured again several time till 2010 in cooperation with the present Istituto Nazionale per la Ricerca Metrologica (INRiM) of Turin using the IMGC absolute laboratory instrument. During the test we also measured once again the local vertical gravity gradient.

DATA ACQUISITION

From 27 January to 29 May 2015, 54 measurements, at least two per days, were carried out during different weather conditions and with some different acquisition setup. In the second part of our test measurements were conditioned by the renovation works to the Building and all around it; among them also the building of a large septic tank (about 50-80 m far from the station) dug-out with an excavator with hammer on 4-5 May. This helped us to test the instrument response to special anthropic noise since the Neapolitan volcanoes are located in highly urbanized areas. Measurements during works are very scattered, therefore doubtful and unusable, justified by the artificially induced high level of noise, as also recorded by tiltmeter since 7 April. Also a significant seismic activity and a total Solar eclipse (about 50% in Naples) occurred during our test.

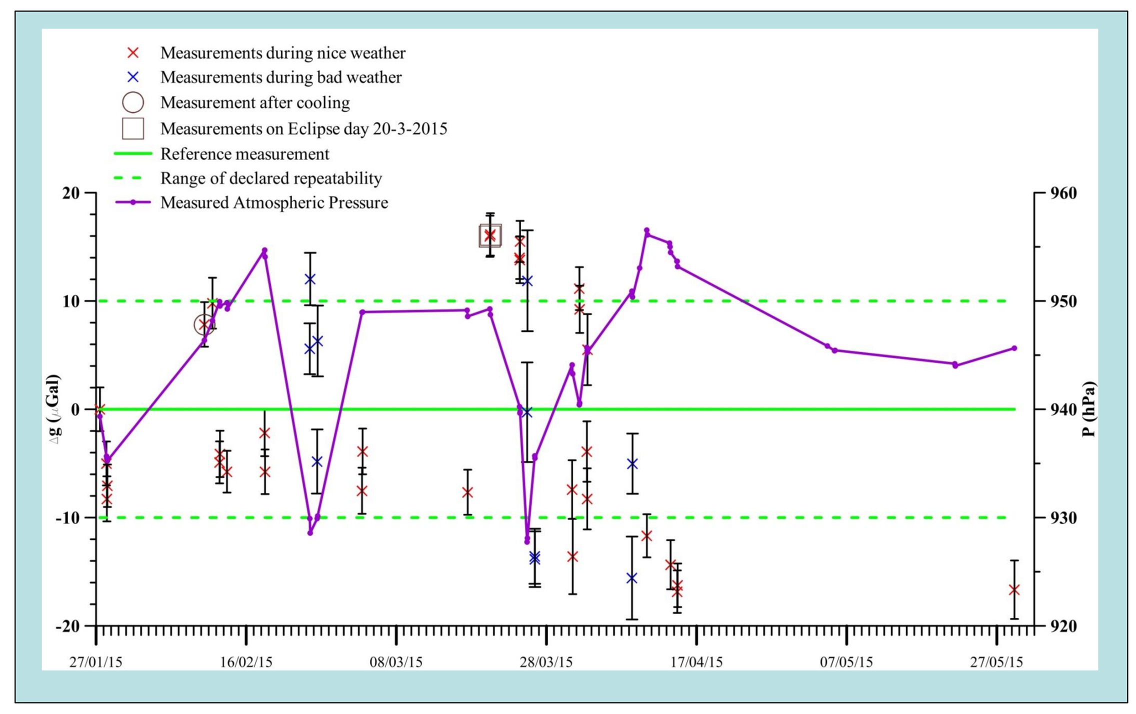


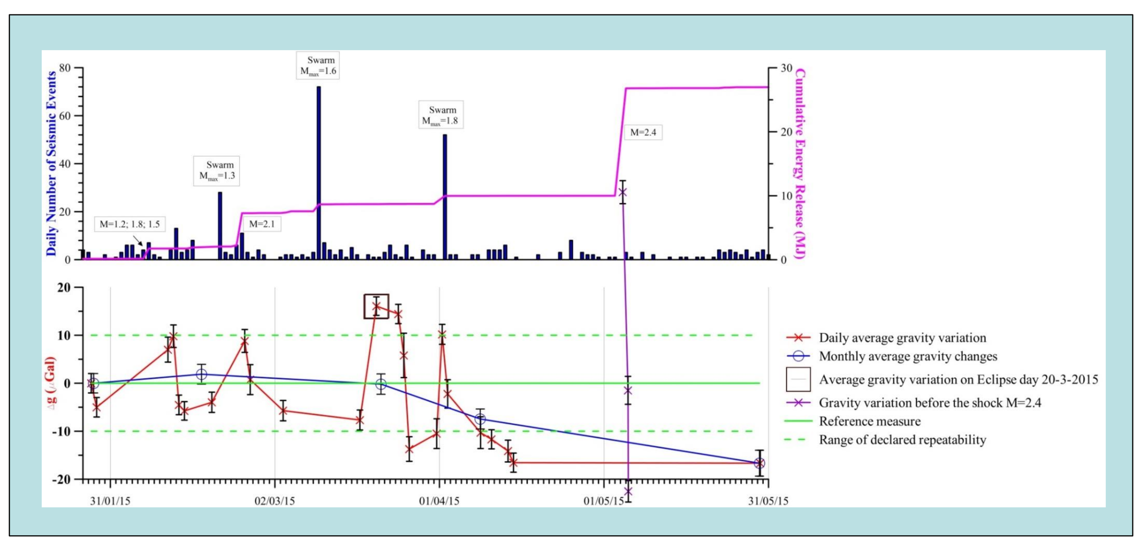
The main control parameters kept constant inside the operative range over the whole period. The bigger value of the Fringe Amplitude (just a little bit out of the operative range) corresponds to an apparently good measure we have not considered, being doubtful about the instrument setting. A 4 hours long measure was made during the eclipse, starting 2 h before. Examples of Drops, Sets and Residuals distribution are shown, including those during the Eclipse and during the digging out.



Measurements cleaned by unusable values

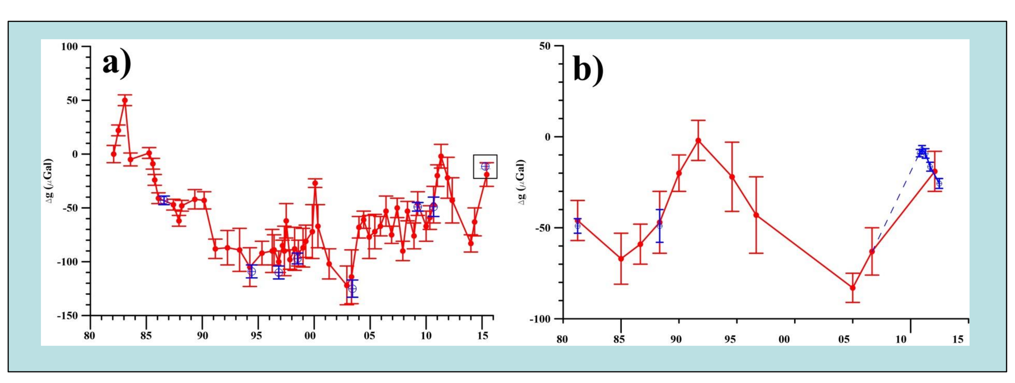
Data collected during bad weather are shown in blue. The repeatability in the same day is less than the declared 10 µGal, a part those during bad weather (see Pressure trend). Really the larger scatters are not simply due to the not good weather, but are mostly associable to the awful sea conditions (very rough sea). Scattered data are measured from 20 March to 14 April. This is also the period when an increasing seismicity occurred. Jumps are visible the day of and some days later the Solar eclipse (value confirmed some days later), and on 1st April the day before a seismic swarm. The last data confirms the values measured in mid-April.





The comparison among gravity changes (daily average), number of shocks and cumulative energy release show that the observed jumps in gravity usually occur just before an increasing seismicity, as highlighted by jumps in the energy release curve, and are followed by a quick decrease of gravity. Most likely this behavior may be associated to the volcanic activity and not to instrumental effect.
The largest jump in the energy release curve is in occasion of the bigger shock occurred on 5 May. Unfortunately works dirtied gravity data measured on 4 and 5 May which we removed. Despite this, without wanting to give any interpretation but only for pure observation, a large jump in the gravity data was measured on 4 May suddenly followed by a gravity decrease (shown in the figure). The monthly average gravity changes are also shown.

In (a) the comparison among the absolute A10 mean value of the whole data set (2015), IMGC (1986-2010) and the relative (1982-2015) gravity changes are shown. To do this, A10 data were reduced to the ground by means of the measured gradient. The good agreement confirms that the observed A10 gravity changes may be due to the dynamics of underground masses. In (b) a zoom on the period 2009-2015 is shown using monthly average data highlighting a better trend of the 2014-2015 gravity changes.
The test carried out is very encouraging and affirms A10 as the appropriate instrument to move toward absolute gravity networks.

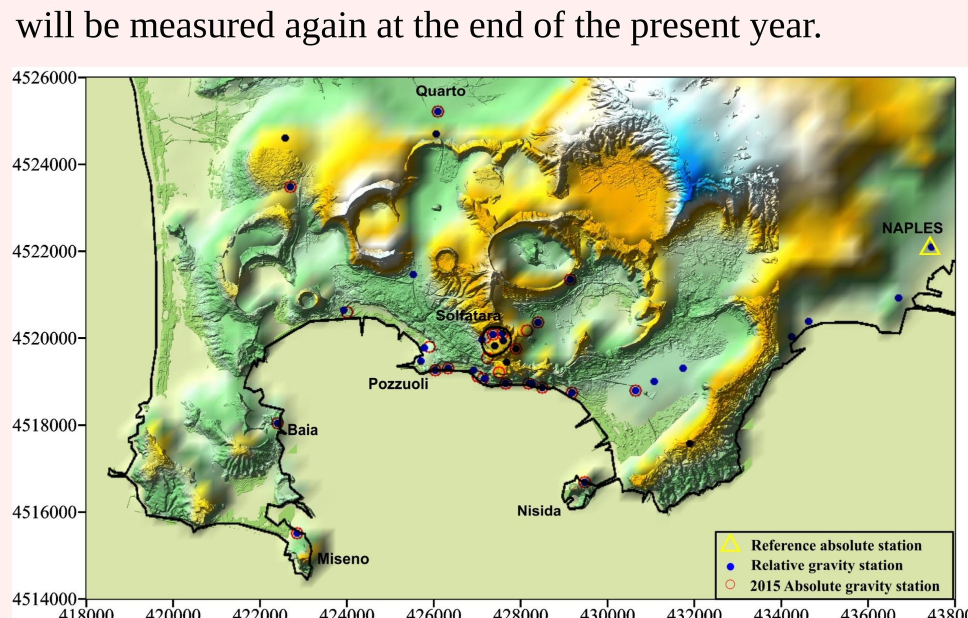


Some references (most references in them)
Berrino G., 1995. Absolute gravimetry and gradiometry on active volcanoes of Southern Italy. *Bollettino di Geofisica Teorica ed Applicata, XXXVII, 146, 131-144.*
Berrino G., 2000. Combined gravimetry in the observation of volcanic processes in Southern Italy. *Journal of Geodynamics,30,*371-388.
Berrino G., d'Errico V., Ricciardi G.pe, 2013. Thirty years of precise gravity measurements at Mt. Vesuvius: an approach to detect underground mass movements. *Annals of Geophysics*, 56, 4, 2013, S0436; doi:10.4401/ag-6442. *Special Issue "Vesuvius monitoringand knowledge: state of the art and perspectives*
D'Agostino G., Desogus S., Germak A. Origlia C. Quagliotti D., Berrino G., Corrado G., d'Errico V., Ricciardi G., 2008. The new IMGC-02 transportable absolute gravimeter: measurements apparatus and applications in Geophysics and Volcanology. *Annals of Geophysics*, Vol.51, n.1, 39-49
Microg_LaCoste, 2008. A10 portable Gravimeter. *User's Manual. July 2008*, www.microglacoste.com

We are very grateful to Drs Ida Aquino and Ciro Ricco and Drs Patrizia Ricciolino and Luca D'Auria who respectively furnished tilt and seismic data over the analysed period.

The first absolute gravity network on the neapolitan volcanoes – Campi Flegrei

In June 2015, starting from Campi Flegrei, we set the first absolute gravity network on the Neapolitan volcanoes. At present it is formed by 24 absolute stations coinciding or close to benchmarks of the already existing relative networks and to altimetric benchmarks. Though Campi Flegrei is a very highly urbanized areas we are satisfied of the instrumental behaviour and of the quality of data which will be measured again at the end of the present year.



A10 working at Serapeo and Solfatara. Examples of data distribution