41st GNGTS National Conference
Bologna, 7-9 February 2023

Absolute gravity and deformation measurements for a multi-disciplinary study in Central Italy

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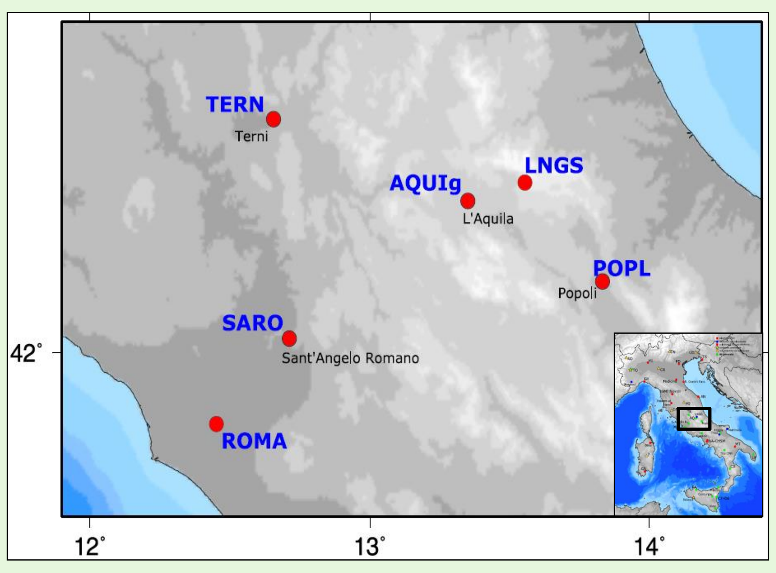
ABSTRACT

Since 2018, INGV funded 3 projects aimed to detect ground deformations and gravity variations over different timescale in the area where the recent seismic events of L’Aquila (2009, Mw 6.3) and Amatrice-Norcia (2016, Mw 6.1 and 6.5) took place. The consequent static deformation field reached several centimetres and the modelled impact of such events could have modified the gravity field up to 170 µGal. Furthermore, the medium-long-term gravity and ground deformation variations related to post-seismic relaxation are expected as consequence of vertical deformation of the Earth surface and/or of the internal boundaries separating layers at depth with different densities. In addition, the L’Aquila area is affected by deformations induced by ground water level changes in the aquifers. Therefore, a multidisciplinary approach carrying out joint measurements of deformation and gravity is fundamental to understand the role of each geophysical process.

To this aim, a network of 3 (Terni, Popoli, Sant’Angelo Romano) new non-permanent GNSS stations was realized outside the buildings hosting the absolute gravity stations. At L’Aquila, a permanent GNSS station managed by the Italian Space Agency (AQUI) is continuously working on the rooftop terrace of the Science Faculty, and positioned vertically with respect to the gravimetric station (AQUIg), which is located 4 floors below. Since 4 absolute gravimetric sites are located indoor, the precise coordinates of the gravity benchmark have been obtained by classical topographic surveys, connecting the indoor site to the outdoor GNSS reference point. Here we present the gravity and ground deformation variations observed in the period 2018-2022 after five measurement campaigns.

THE NETWORK

We selected 5 sites in central Italy **Terni** (**TERN**) and **Popoli** (**POPL**) connected to two sites of the gravimetric survey conducted in 1954; **Sant’Angelo Romano** (**SARO**) established in 2005 as part of the INGV-DPC Colli Albani Project; **Laboratori Nazionali del Gran Sasso** (**LNGS**, outdoor) close to the relative station established in 2010 after the 2009 seismic event; **L’Aquila Università a Coppito** (**AQUIg**) located below the permanent GPS station of AQUI, and **ROMA** located at Sapienza Università (Facoltà di Ingegneria) near the site measured in 1954.



Stations of absolute gravimetric and GNSS measurements in Central Italy

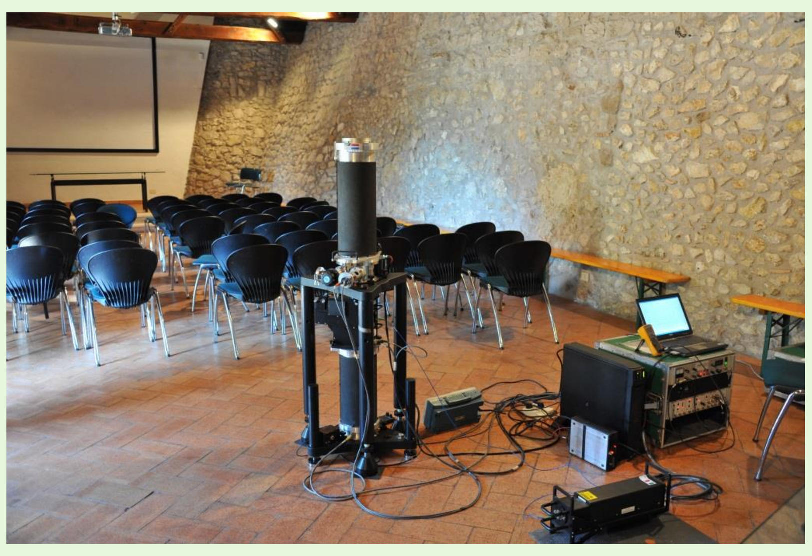
ABSOLUTE GRAVIMETERS

FG5

Requires sessions of 10 to 15 hours; the value of ***g*** refers to a variable height (~1.3 m), depending on the installation set up.

Instrumental characteristics:

Accuracy 2 µGal
Precision 1 µGal in ~ 4 min, 0.1 µGal in 6.25 h; **Repeatability** within 2-3 µGal
It has been compared several times with the Italian Primary Standard gravimeter (IMGC-02)



Measurements with FG5 at SARO

A10

Requires sessions from 0.5 to 1.5 h on the field, but it can operate as FG5 in laboratory. The value of ***g*** refers to a fixed height of 0.72 m.

Instrumental characteristics:

Accuracy 10 µGal;
Precision 10 µGal in 10 min; **Repeatability** within 10 µGal

Measurements with A10 at LNGS

At the end of the first project A10 was compared with the Italian Primary Standard gravimeter (IMGC-02).

RELATIVE GRAVIMETER

Lacoste-Romberg D85

Gravity gradient measurements with LCR D85

We used this spring-type gravimeter

1) to connect the indoor absolute gravity site to outdoor sites, with the aim to provide the value of **g** outside

2) To measure the local gravity gradient at the absolute site, to compute the value of gravity at the same height (ground), since measured with different gravimeters.

MEASUREMENTS

In order to monitor any long-term changes in gravity and ground deformations, 5 measurement campaigns have been carried out from 2018 to date, involving the stations of the network. The Tables report the dates and the instrument of the surveys.

ABSOLUTE GRAVITY & POSITIONING MEASUREMENTS

	2018			2020			2022	2022			
SITES	Jun. & Oct.			Oct.			Feb.	May		Nov. & Dic.	
AQUI	A10	FG5	GPS	A10	FG5	GPS	GPS	GPS	FG5	GNSS	FG5
LNGS	-	-	-	A10	-	-	-	-	-	-	-
POPL	A10	FG5	GPS	A10	FG5	GPS	GPS	GPS	FG5	FG5	FG5
ROMA	-	-	-	-	-	-	-	GPS	FG5	-	-
SARO	A10	FG5	GPS	A10	FG5	GPS	-	GPS	FG5	FG5	FG5
TERN	A10	FG5	GPS	A10	FG5	GPS	GPS	GPS	FG5	-	-

GRAVITY GRADIENT (1) & SATELLITE MEASUREMENTS (2)

	2018	2022	
SITES	Jun.	May	Nov. & Dic
AQUI	LCR (1 & 2)	-	LCR (1 & 2)
LNGS	-	-	-
POPL	LCR (1 & 2)	LCR (2)	LCR (1 & 2)
ROMA	-	LCR (1 & 2)	-
SARO	LCR (1 & 2)	LCR (2)	LCR (1 & 2)
TERN	LCR (1 & 2)	LCR (2)	-

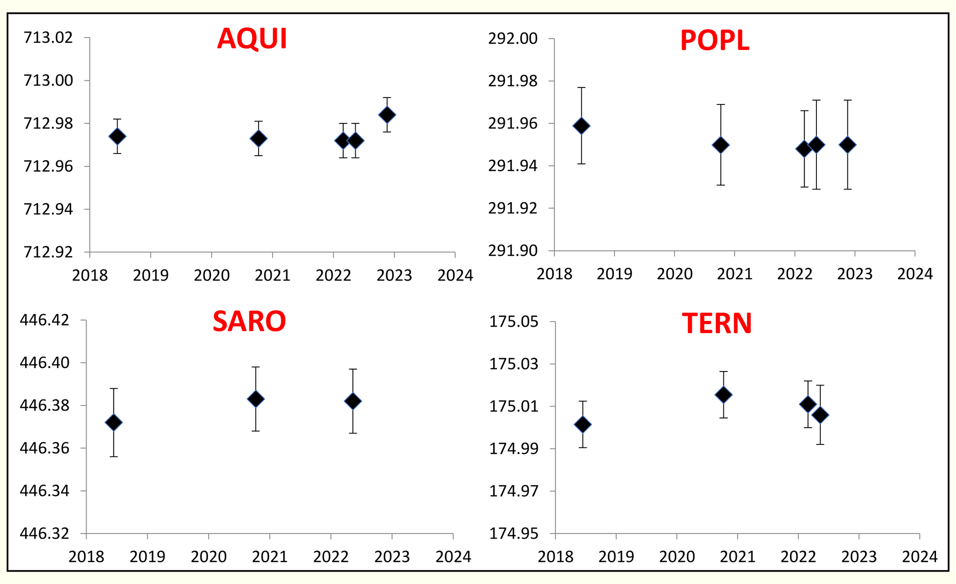
GNSS RESULTS

The GNSS measurements were carried out with Leica GX1230 receiver LEICAAX1202 antenna, recording at least 48 h with 30s sampling rate. The raw data were processed in Precise Point Positioning modality by the software GAPS (http://gaps.gge.unb.ca). The coordinates and heights of the indoor absolute gravity sites were determined connecting the outdoor and indoor points through classical topographic surveys using the optical level station (Leica). The permanent GNSS station (AQUI) is continuously working on the roof-top terrace of the Science Faculty and positioned vertically with respect to the gravimetric station (AQUIg), located 4 floors below so that a survey with a total station (Stonex R2-2 plus) has been employed to measure their height difference.

TERNI **POPL**

AQUI **SARO**

SITE	2020-2018		2022_a -2020		2022_b-2022	
	dh (m)	err	dh (m)	err	dh (m)	err
AQUI	-0.001	0.008	-0.001	0.008	0.012	0.008
POPL	-0.009	0.019	0.000	0.020	0.000	0.021
SARO	0.011	0.016	-0.001	0.015		
TERNI	0.014	0.011	-0.010	0.013		

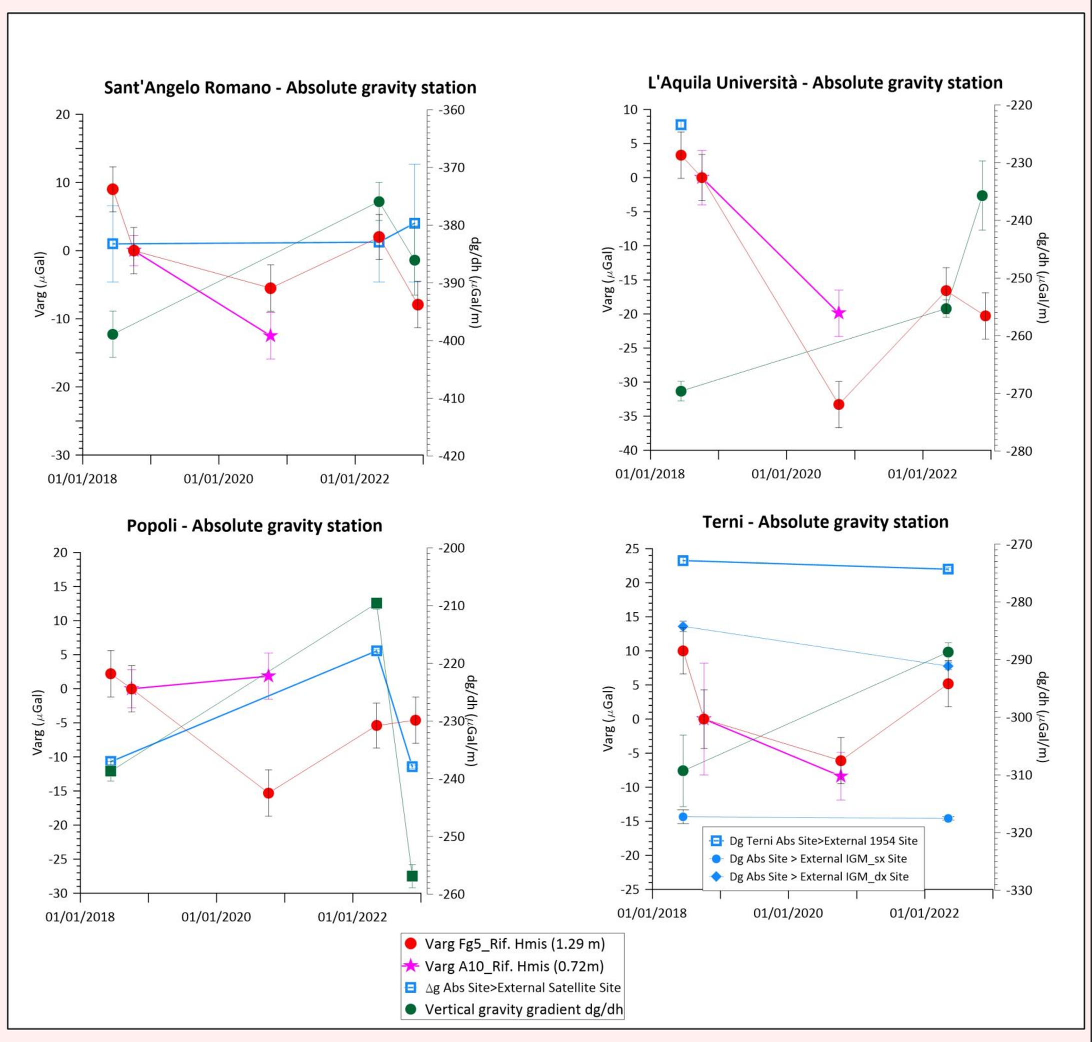


The height variations of each station are within the measurement. They are taken into account to correct the gravimetric data, considering the vertical gravity gradient measured at each station.

RESULTS

The figure shows the variations of *g* at AQUIg, TERN, SARO and POPL stations after 5 measurement campaigns, carried out between 2018 and 2022, with both FG5#238 and A10#32 absolute gravimeters and referred at 1.29 and 0.72 m, respectively (corresponding with the measured heights). Furthermore, the figure also shows the variations of *g* at the satellite stations performed by measuring the Δg between internal and external points, as well as the variation of the VGG (dg/dh). Taking into account the measurement uncertainties, the variations observed at each station follow coherent patterns.

It is also important to note that the variations of the VGG follow the same patterns observed through absolute measurements.



SARO: ***g*** values show a decrease of about -20 µGal from 2018 to 2022, slightly interrupted between 2020 and the first campaign of 2022.
dg/dh increases of about 20 µGal from 2018 to 2022 and then started to decrease.

AQUIg: ***g*** values show a decrease of about -25 µGal from 2018 to 2022, with a negative value of about -40 µGal in October 2020. The negative trend is slightly interrupted between 2020 and the first campaign of 2022.
dg/dh shows a variation of about +30 µGal/m.

POPL: ***g*** values vary of about -7 µGal in a general descreasing pattern from 2018 to 2022, with a negative value of about -15 µGal in October 2020.
dg/dh shows a marked increase from 2018 to 2022 and then start to decrease.

TERN: ***g*** values show a decrease of about -15 µGal from 2018 to 2020. The value measured in 2022 shows an inversion of the trend.
dg/dh increased of +20 µGal/m from 2018 to 2022

CONCLUSIONS

We present gravity and ground deformation variations observed in the period 2018-2022 in a wide mesh absolute gravity and GNSS network set up in central Italy. The network was installed in the area affected by the 2009 (L’Aquila; Mw 6.1) and 2016 (Amatrice-Norcia; Mw 6.0 and 6.5) earthquakes.

The main features of the observed data are:

- very low noise level during the surveys;
- significant gravity decrease (2018-2020) and increase (2020-2022) affecting most of the stations;
- no significant ground deformation variations were observed during the whole period;
- in October 2020 we measured the lowest g-value at all stations.

Remarks:

- the similar patterns involving all the stations suggest that the observed gravity variations are of “regional” origin.
- variations with these characteristics, in this area affected by geodynamic phenomena, are not well documented. The obtained results, are very stimulating and lay the foundations for a multidisciplinary approach towards improving the knowledge of this seismogenetic area of Italy.

Acknowledgements:

These projects were funded by INGV as 3 calls “Bando di Ricerca Libera”

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