Geosciences for a sustainable future

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GNSS and absolute gravity measurements for a multi-disciplinary study of natural risks in Central Italy

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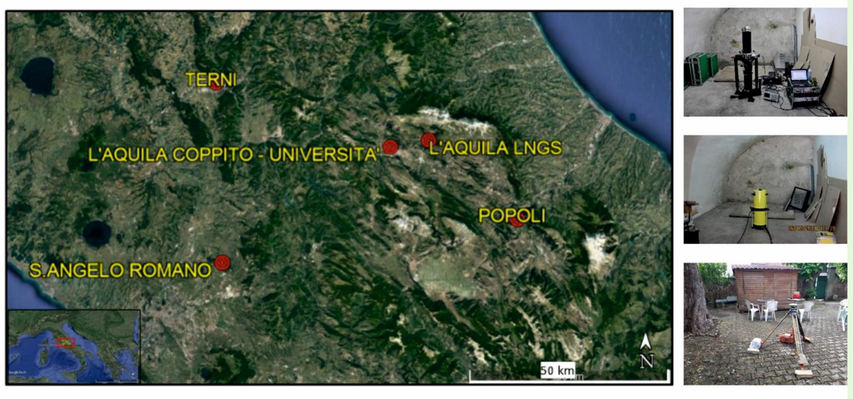
ABSTRACT

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 deformation field reached several centimeters and the modelled impact of such events could have modified the gravity field up to 170 μGal. A medium-long-term gravity and ground deformation variations due to post-seismic relaxation are expected as consequence of large vertical deformation and/or the internal boundaries of separating different densities layers. The L'Aquila area is also 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.
We describe the procedure and results followed to achieve the coordinates of both the GNSS and the absolute gravimetric sites. Furthermore, we also present the results over the short and the medium-long-term obtained by repetitive combined GNSS and integrated absolute and relative gravity measurements.

THE NETWORK

We selected 5 sites between Lazio, Umbria and Abruzzo, **Terni** (**TERN**) and **Popoli** (**POPL**) are connected to two sites of a gravimetric survey conducted by ING in 1954; **Sant'Angelo Romano** (**SARO**) was established in 2005 as part of the INGV-DPC Colli Albani Project; the site **Laboratori Nazionali del Gran Sasso** (**LNGS**, outdoor) is in correspondence with a relative station established in 2010 for investigations carried out following the 2009 seismic event; **L'Aquila Università a Coppito (AQUIg)** replaced a station located in the L'Aquila downtown and established in 2010 but currently not available for use.



Stations selected for absolute gravimetric and GNSS measurements in Central Italy (left). the absolute gravimeter FG5 #238 (top) and the absolute gravimeter A10 #39 (center) during a measurement session in the Popoli station (right); the instrumentation for GNSS measurements (right, down), during the acquisition in the courtyard in front of the room with the gravimetric station.

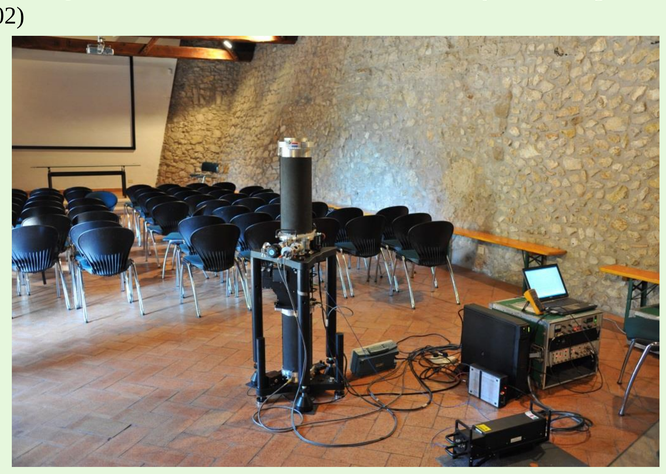
ABSOLUTE GRAVIMETERS

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 μGal

It has been compared several times with the Italian Primary Standard gravimeter (IMGC-02)



S. Angelo Romano site during measurements with FG5 #238

A10

It can operate in any (or nearly all) situation regardless of the need for "laboratory" type sites. It requires sessions from 0.5 to 1.5 h in the countryside and as FG5 in the 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

L'Aquila LNGS site during measurements with A10

At the end of the first project A10 #39 was compared with the Italian Primary Standard gravimeter (IMGC-02).

MEASUREMENTS

In order to monitor any long-term changes in gravity and ground deformations, 4 measurement campaigns have been carried out from 2018 to date, involving the 5 stations of the network.

First surveys (June 2018):
a) absolute measurements of g, with only the FG5 #238;
b) relative gravimetric measurements to connect the various absolute stations to the respective satellite points (located outdoor);
c) measurements of the local vertical gradient of gravity at the absolute stations (**Terni**, left picture) at four different heights (ground, 50 cm, 80 cm and 1.2 m);
d) GNSS measurements (**SARO**, right picture) and classical topographic surveys to obtain precise coordinates of the gravimetric sites, also from IGMI leveling.

TERNI

SARO

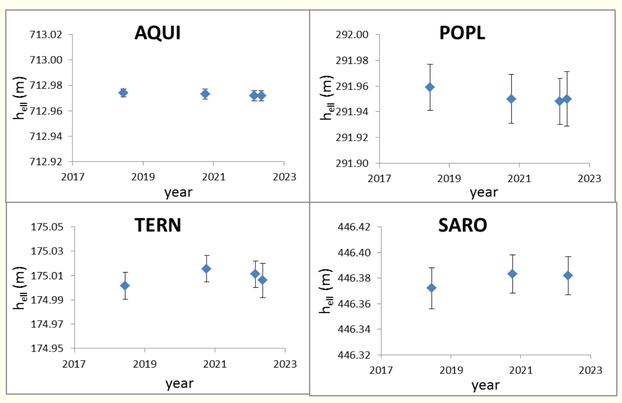
Second surveys (October 2018):
a) absolute gravity measurements with both gravimeters and realization of the outdoor LNGS gravity station;

Third surveys (October 2020):
a) absolute gravity measurements with both gravimeters and realization of the outdoor LNGS gravity station;
b) repetition of GNSS and topographic measurements in order to verify any ground movements beyond the measurement uncertainty;
c) During the surveys, the two absolute gravimeters were also compared through a joint session of measurements carried out at the historic site of the Vesuvius Observatory (Naples).

Fourth surveys (February 2022):
a) New Terni (in the picture) and Popoli GNSS benchmarks (stainless-steel 3D pillar)
b) GNSS measurements and leveling connection between the old and the new GNSS sites

Fifth surveys (May 2022):
a) absolute gravity measurements , with only the FG5 #238
b) Repetition of relative gravimetric measurements to connect the absolute stations to the respective satellite point;
c) Repetition of GNSS and topographic measurements

GNSS RESULTS

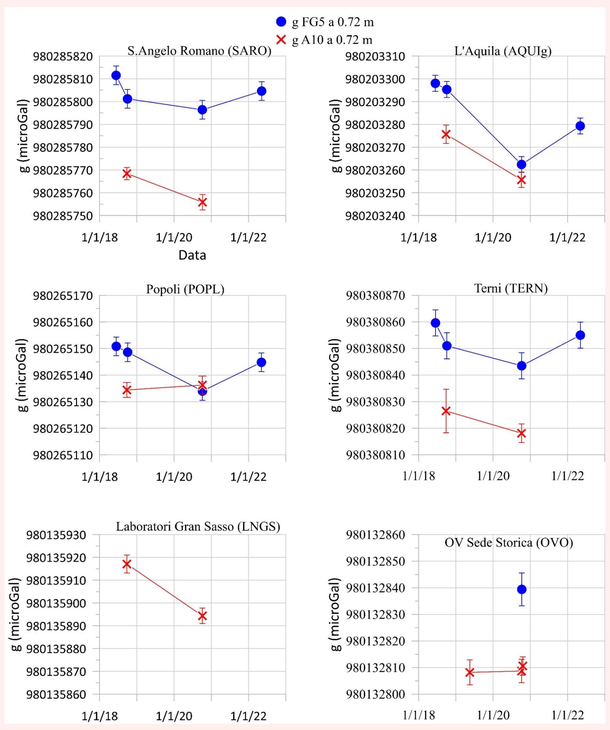


SITE	2020-2018		2022-2020	
	dh (m)	± rms	dh (m)	± rms
AQUI	-0.001	0.004	-0.001	0.004
POPL	-0.009	0.019	0.000	0.020
SARO	0.011	0.016	-0.001	0.015
TERN	0.014	0.011	-0.010	0.013

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

REDUCED GRAVITY VARIATIONS

The figure shows the variations of **g** at the 5 stations in the time intervals 2018-2022. To compare the results, the measured g values were reduced to the same reference height with the use of locally measured vertical gradients. To limit the error as much as possible due to the reduction of the vertical gradient, the values of **g** were also referred to the fixed height of the A10 (0.72 m).
Taking into account the measurement uncertainties, which generally are between 3 and 4 microGal, the variations observed at the different stations with the two instruments follow consistent patterns.
All the stations show a gravity decrease from 2018 to 2020 followed by an almost equivalent gravity increase in the period 2020-2022, which brought the gravity values in SARO, POPL and TERN stations to the same level as in 2018. No gravity changes have been observed in the relative gravity links between the absolute and the satellite stations.



SARO: a cumulative gravity decrease of about -15 μGal from 2018 to 2020 and an increase of 8.2 μGal from 2020 to 2022.

POPL: a global gravity change of -18 μGal from 2018 to 2020 measured with FG5, while A10 did not show any significant variation. From 2020 to 2022 FG5 measured a gravity increase of 10.8 μGal

TERN: a total gravity decrease of about 16 μGal during the time interval 2018-2020, followed by a gravity increase of 11.5 μGal between 2020 and 2022.

AQUIg: a gravity decease of about -35 μGal was measured from 2018 to 2020 with FG5 and A10 showed a lower variation of.-20 μGal as also confirmed by measurements at LNGS. FG5 in 2022 measured a gravity increase of 16.9 μGal with respect 2020.

LNGS: here measurements are carried out using only the A10 gravimeter. A gravity decrease of about -23 μGal was observed form 2018 to 2020 coherent with the results obtained at AQUIg.

OVO: The two instruments were inter-compared at the site located in the Old Building of the Osservatorio Vesuviano where absolute measurements are frequently carried out since 1986. No significant gravity changes are shown from measurements collected with A10 from 2019 to 2020. On the other hand, a gravity difference of about 30 μGal between the two instruments has been observed, which likely indicates a bias between the two instruments. The same difference was found during the measurements in Central Italy.

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 all the stations.
- absence of variations between each absolute station and the associated satellite points (indicating the stability of the chosen sites).
- no significant ground deformation variations were observed during the whole period.

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.

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