Istituto Nazionale di Geofisica e Vulcanologia

Gravimetry in the italian area: future developments and perspectives

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Istituto Nazionale di Geofisica e Vulcanologia

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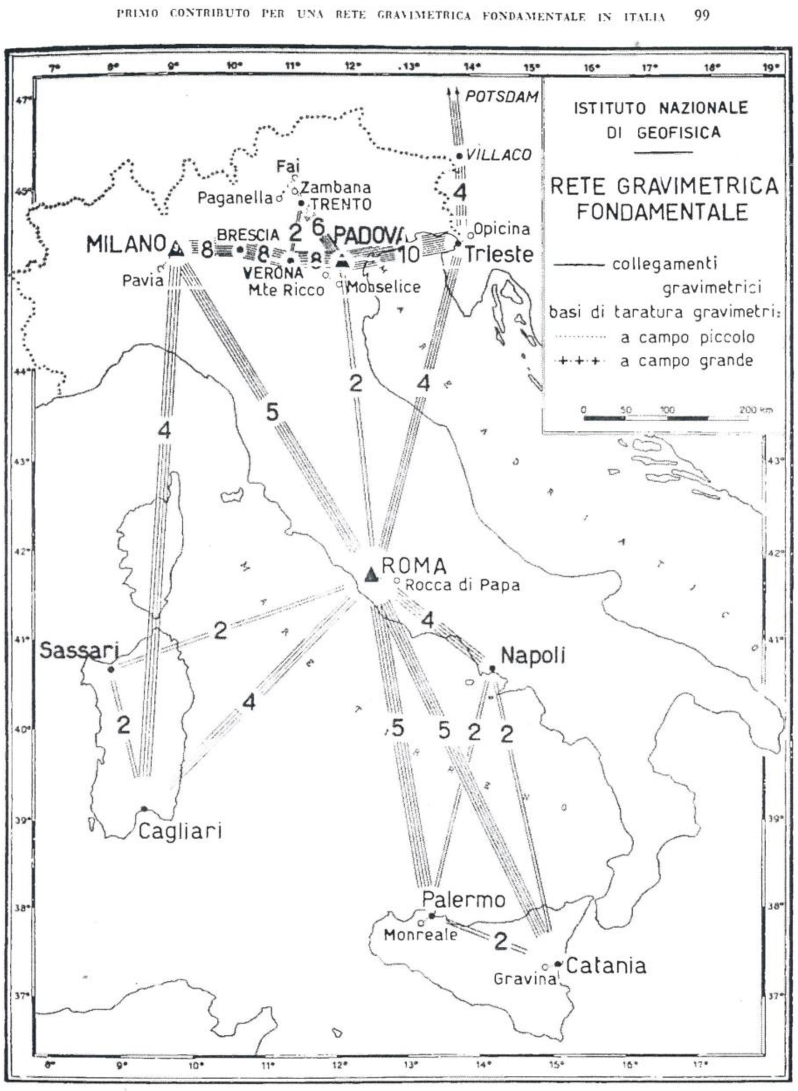
Pisa, June 14 – 16, 2023

Contents:

- ✓ History of the gravity reference networks in Italy
- ✓ State-of-the-art of the **available terrestrial gravimeters** in Italy
- ✓ Gravimetric Networks for **Geodynamic Purposes** in Italy
- ✓ The state-of-the-art of the new **Absolute Reference Gravity Network in Italy (G0)** realized in the frame of several Projects
- ✓ Development and the future trends of the gravimetry in Italy: **The Fiducial Gravity Network** and the **National Gravity Service**

The First Reference Gravity Nets in Italy



Morelli C., 1952. Primo contributo per una rete gravimetrica fondamentale in Italia. Annali di Geofisica, V, 1.0

1 9 5 1

PRIMO CONTRIBUTO PER UNA RETE GRAVIMETRICA FONDAMENTALE IN ITALIA

(First contribution for a Fundamental Gravimetric Network in Italy)

Carlo Morelli (ING)

9 Base Stations
MONOGRAPHS AVAILABLE

Relative measurements
Gravity links made with civil air-lines

2 Worden gravimeters (n.50 e n.52)

Italian National Reference Station
Padova
(980 658.55 ± 0.35)

g value obtained by links with the Potsdam absolute station

1 9 5 5 – RFI55

LA RETE GRAVIMETRICA FONDAMENTALE ITALIANA
(THE FUNDAMENTAL ITALIAN GRAVITY NET)

M. CUNIETTI - G. INGHILLERI
COMMISSIONE GEODETICA ITALIANA

119 STATIONS:
24 NODAL; 44 PRINCIPAL; 51 INTERMEDIATE

MONOGRAPHS AVAILABLE

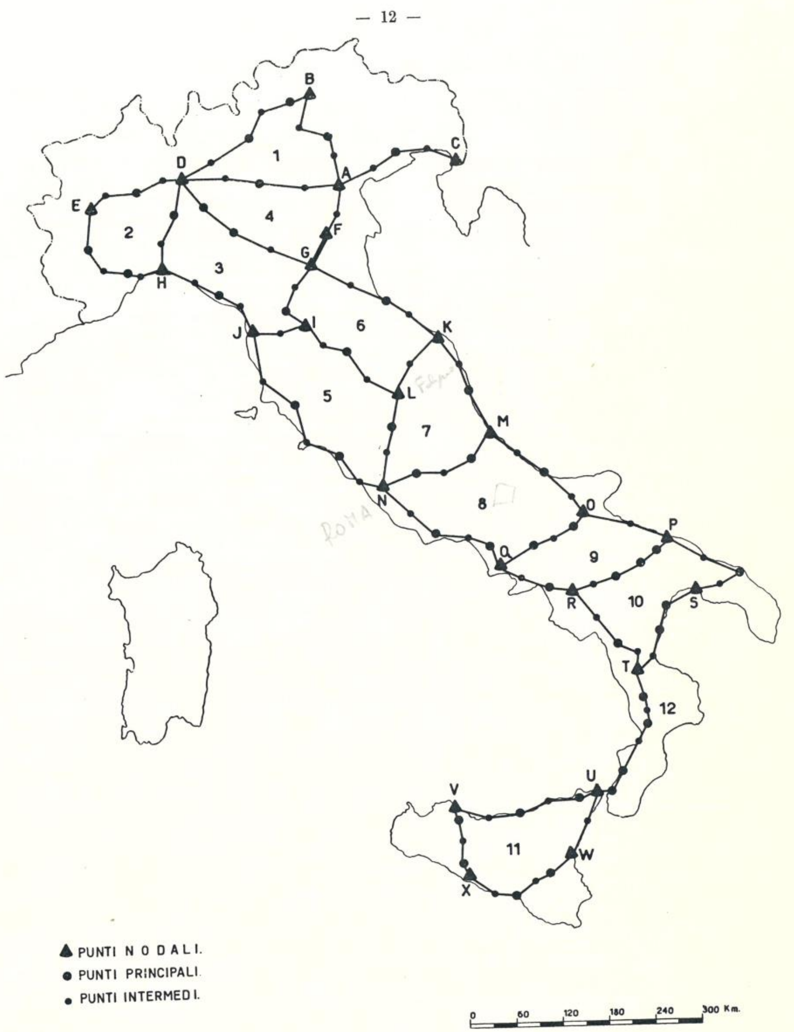


Fig. 1
Schema dei collegamenti della rete gravimetrica fondamentale e delle stazioni che la compongono. Il numero al centro di ogni maglia contraddistingue i poligoni della rete.

Cunietti M., Inghilleri E., 1955. La rete gravimetrica fondamentale italiana. Memorie Commissione Geodetica Italiana, 8, 192 pp.

Relative measurements from 1952 to 1953

3 gravimeters: Worden n.53, Western G.A. n.48, North American n.125

The International Gravity Standardization Net 1971 – IGSN71

Based on measurements collected in the previous 20 years and **50 new absolute measurements**

IGSN71 - ITALIA

IAG (OGS for Italy)

MONOGRAPHS AVAILABLE

Links with 5 different models of relative gravimeters

In IGSN71 Potsdam value was corrected of -14 mGal as from gravimetric links all over the world

Morelli C., et al., 1974. The international Gravity Standardization net 1971 (IGSN71). Special publication n.4, International Association of Geodesy, Paris, 196 pp.

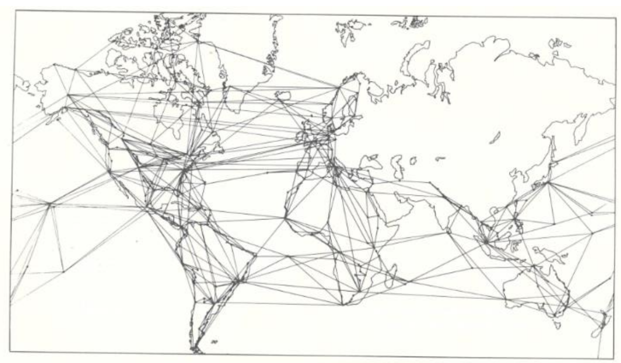


Fig. 4.1 : MAIN GRAVIMETER CONNECTIONS IN IGSN 71

Fig. 1 — Distribuzione dei capisaldi IGSN71 in Italia. Risulta facilmente individuabile la tratta Brennero-Etna della linea di taratura europea.

Stations along the European calibration Line
Hannover-Catania

Combined with many stations in Roma, Milano and Trieste, the main station of the Calibration Line Bologna-Ferrara and 8 stations of the RFI55.

The Italian Reference Network development was favored by the realization in the early '70s of a transportable absolute ballistic gravimeter, studied, designed and built by the **CNR - Istituto di Metrologia “Gustavo Colonnetti”** (IMGC – Turin)

The first measurements were carried out in 1976-1977 in Europe with the aim of perfecting the **World Gravimetric Standard (IGSN71)** with new absolute references
(IAG Resolution No. 16 - 1975)

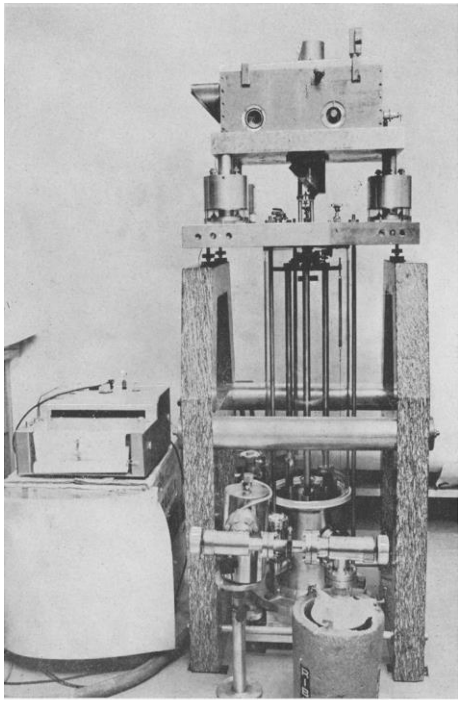


Fig. 5. – Absolute stations in Europe.

17 stations (4 of which in Italy) were established

In 1977 they will contribute to the realization of the **'First Order Gravity Net in Italy' (FOGN77)**

This instrument opens a new gravimetric era also in Italy

FOGN77

First Order Gravity Net in Italy
1977

I. Marson & C. Morelli

MONOGRAPHS AVAILABLE

49 Base Stations
(Include RFI55 e 33 IGSN71)

10 principal stations (Trieste, Milan, Turin, Rome, Naples, Brindisi, Cagliari, Catania, Paris, Munich)

6 Absolute Stations
with IMGC gravimeter
(Paris, Munich, Turin, Rome, Naples, Catania)

758 relative links
with 4 LCR mods G e D

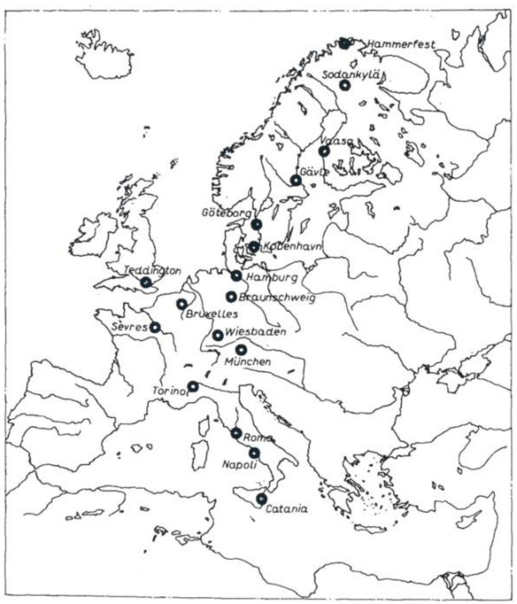


Fig. 5. – Absolute stations in Europe.

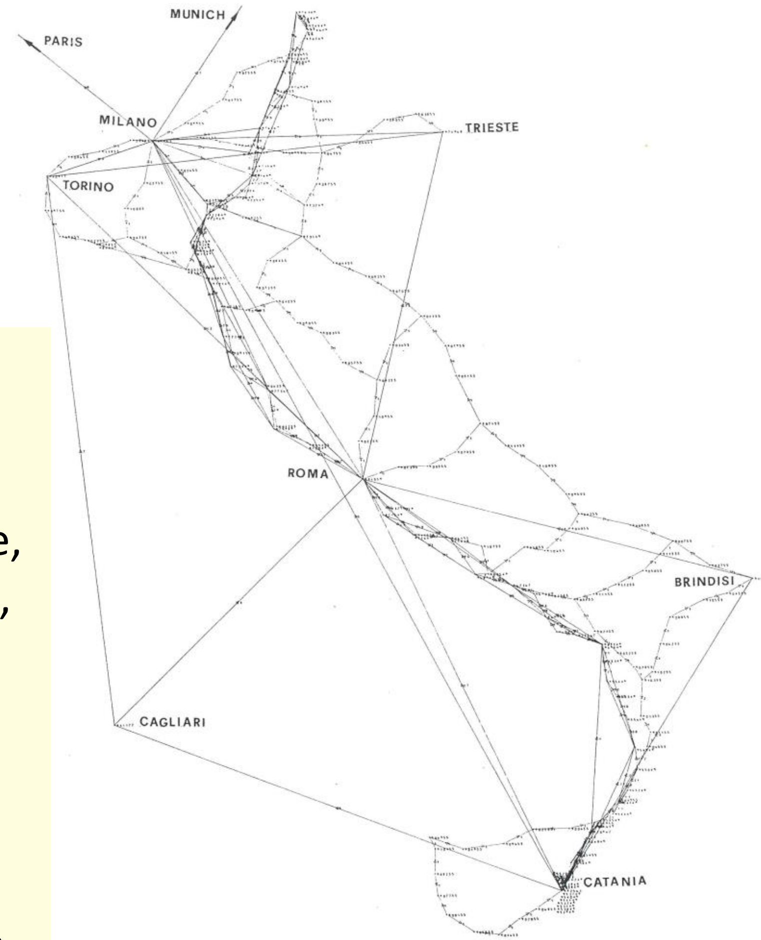


Fig. 4 — Structure of the complete Italian Net.

Marson I., Morelli C., 1977. First Order Gravity Net in Italy. Bollettino di Geodesia e Scienze Affini, XXXVII, 4, 659-689.

IZOGN_1995

Italian Zero Order Gravity Net
1995

(Ref. : – I. Marson [OGS] ; - G. Berrino [OV])

MONOGRAPHS AVAILABLE

Built to link all the absolute gravity station in Italy at that time measured from 1976 to 1994

Relative links with 4 LCR mod. G used simultaneously

Measures made at a fixed height close to or corresponding to those of absolute measures

Not completed on North Italy and Sardinia

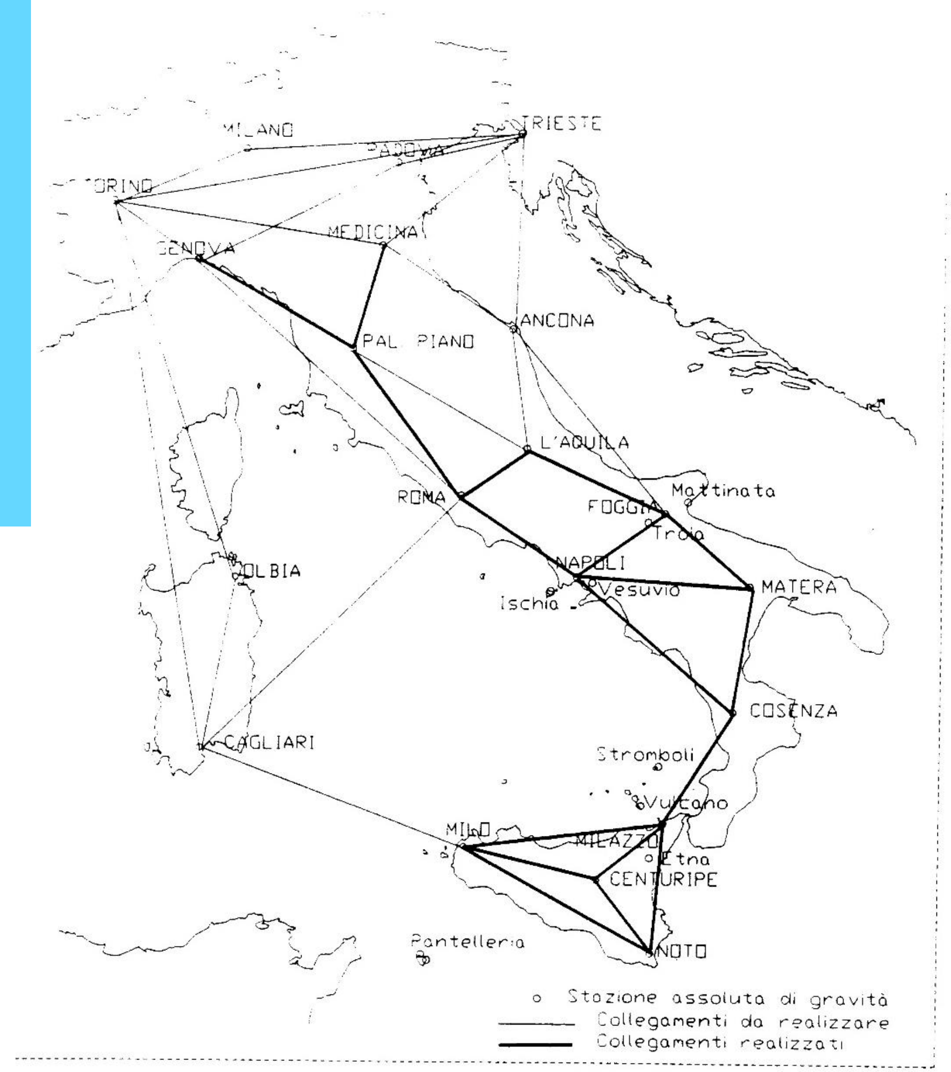
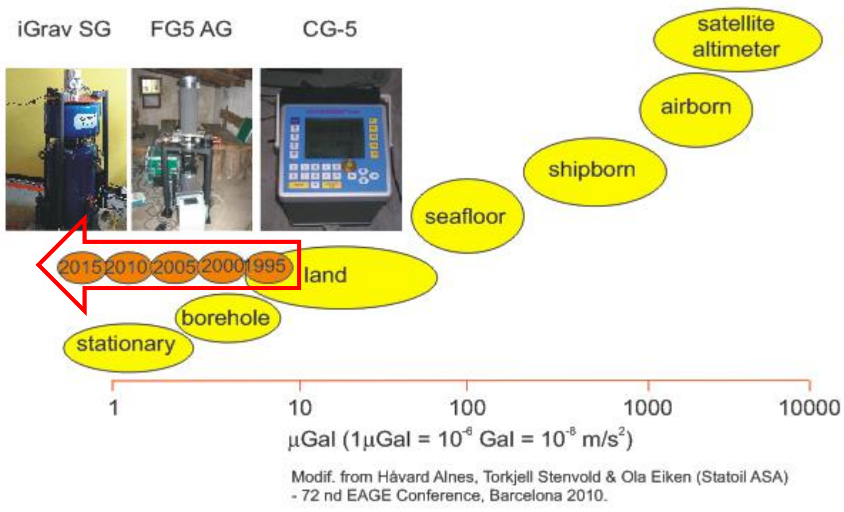


Figura 1: Attuale distribuzione delle stazioni assolute di gravità e schema della nuova rete gravimetrica fondamentale di ordine zero

Berrino G., Marson I., et al., 1995. Rete Gravimetrica Italiana di Ordine Zero. Stato di avanzamento. Proceedings 14° GNGTS Annual Meeting , 453-460

STATE OF THE ART OF AVAILABLE GRAVIMETERS

Measuring gravity: different gravity meters/techniques



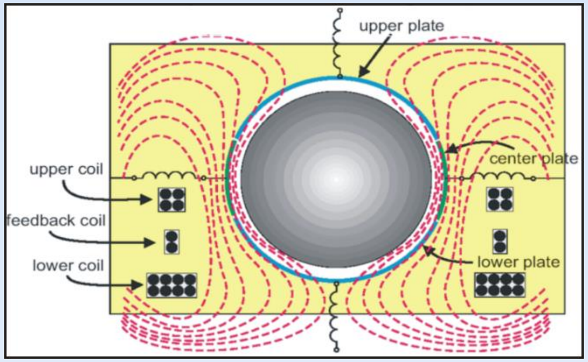
Increase in the precision of gravity measurements over time and with different techniques.

RELATIVE GRAVIMETERS

Spring-based gravimeters

With relative gravimeters gravity differences over space or time are accomplished.

Superconducting gravimeter



Superconducting gravimeters furnish high-quality data (high-precision, drift-less, not affected by ambient parameters).

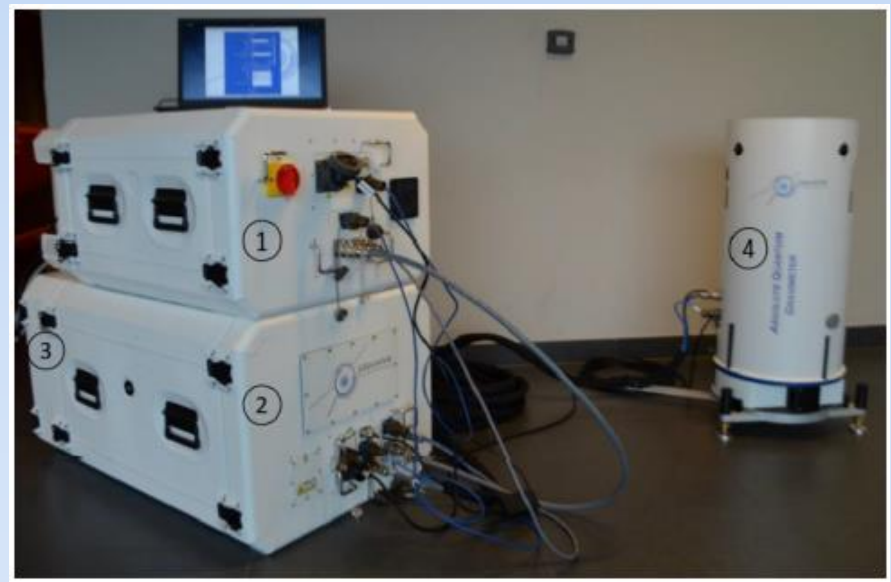
ABSOLUTE GRAVIMETERS

Free fall ballistic gravimeters
(optical interferometry)

Microg LaCoste FG5

Microg LaCoste A10

Free-Fall quantum gravimeter
(atomic interferometry)



The IXblue (ex Muquans) absolute quantum gravimeter AQG, based on laser-cooled ^{87}Rb atoms.

With the absolute gravimeters, it is possible to measure the actual value of the gravitational acceleration at the observation point.

State of the art

Impact of the technologies in the improvement of terrestrial gravimetry

The beneits of using relative superconducting gravimeter (SG):

- furnish higher-quality data than spring gravimeters (high-precision, drift-less, not affected by ambient parameters) and thus allow to track even small gravity changes (< 1 μGal) over a wide range of time scales (minutes to years in continuous).

The benefits of using absolute gravimeters (AB):

- allow to study phenomena whose surface effects have an amplitude not observable with traditional spring gravimeters (~ 1 microGal), also in harsh field conditions while keeping the measurement cost (in terms of person-time) relatively low;

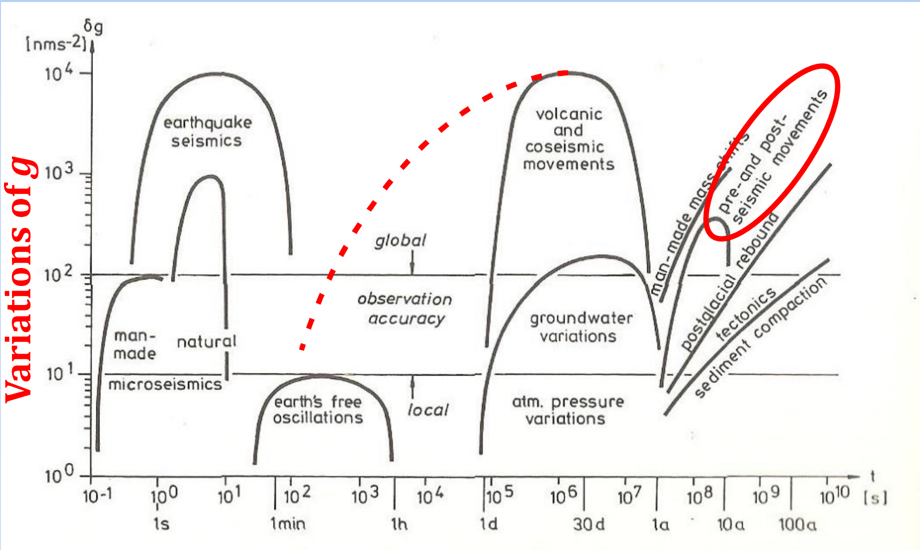
- if used in tandem with relative gravimeters (hybrid gravimetry) in time-lapse surveys, the data quality is significantly improved (the risks of error propagation are reduced), expanding also the spatio-temporal resolution;

- they are especially useful in areas where there is no guarantee of temporally constant gravity at the reference site (e.g., small islands where there are no points far enough away from the active structures).

The benefits of using absolute quantum gravimeters (AQG):

- possibility of measuring the gravity field with high stability and accuracy even continuously for several months; when used for discrete measurements allow to collect reliable data at microGal level in few hours.

Characteristics of gravity variations over time



Non-tidal gravity variations produced by terrestrial mass displacements (From Torge, 1984).

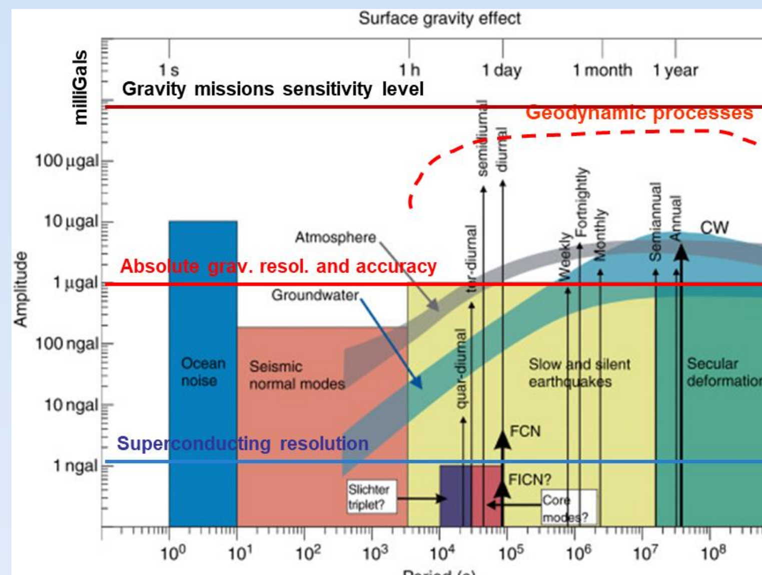
Gravity anomalies depend on source characteristics and vary in:

- ✓ **space** (wavelength between 100s of m and 10s of km; local, regional, global)
- ✓ **time** (periods between minutes and years; sudden, periodic or almost periodic, secular)
- ✓ **amplitude** (a few to 100s of µGal)

The **amplitude** and **wavelength** depend on the mass and depth of the source

The **period** depends on the evolution speed of the source phenomena

Gravity effect of several geophysical phenomena

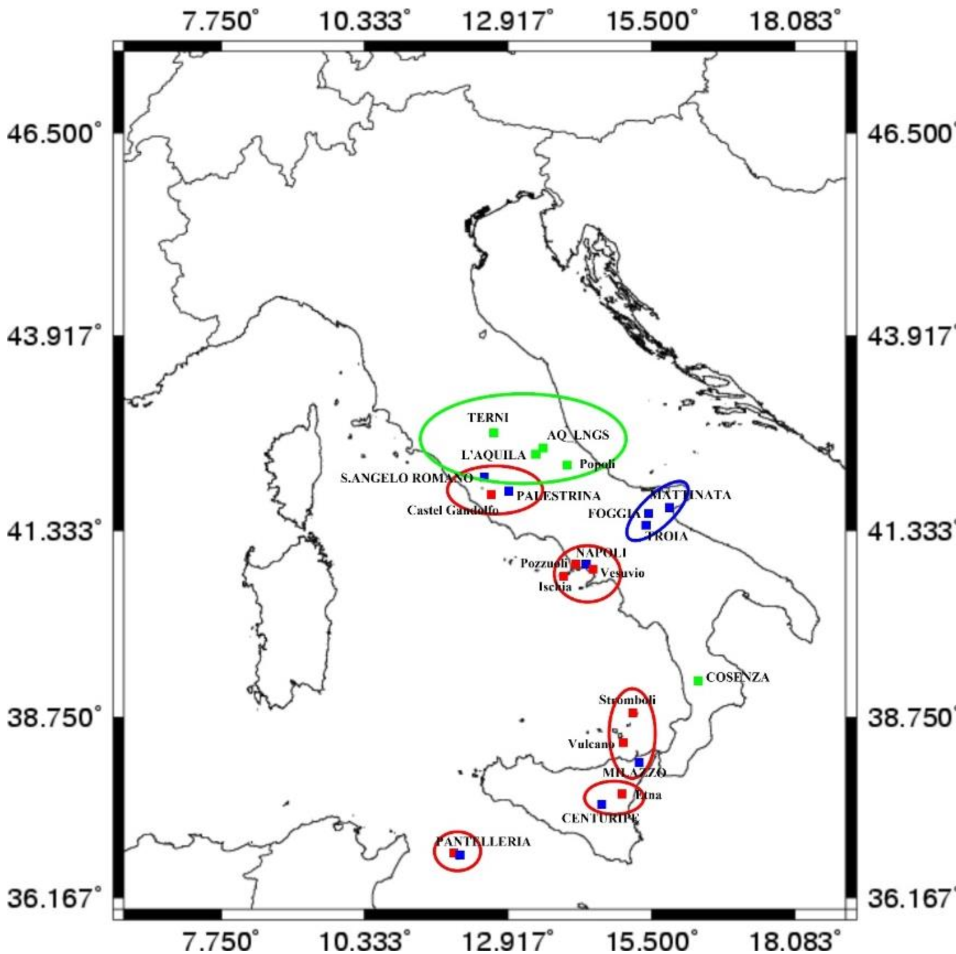


(Modif. from Crossley et al., 2012)

Gravimetric Networks for Geodynamic Purposes in Italy

Development and State of the Art

The availability of high precision gravimeters allows to monitor geodynamical areas through single stations or networks

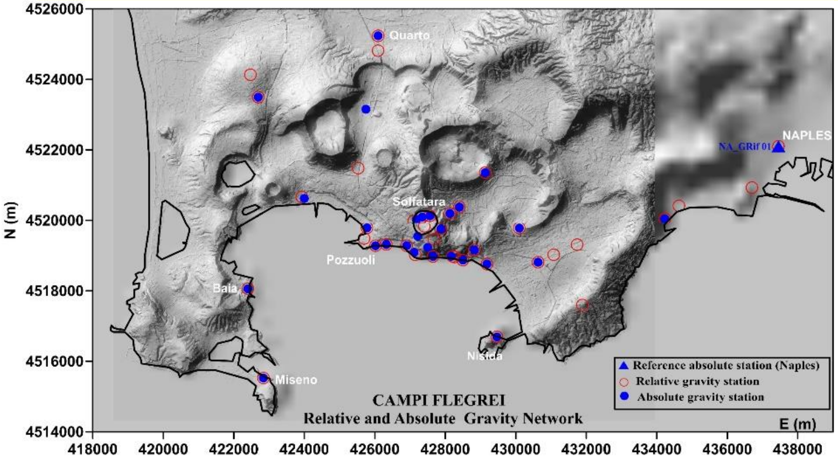


ABSOLUTE GRAVITY STATIONS AND NETWORKS FOR VOLCANOES MONITORING

FG5#238 – working at S.Angelo Romano

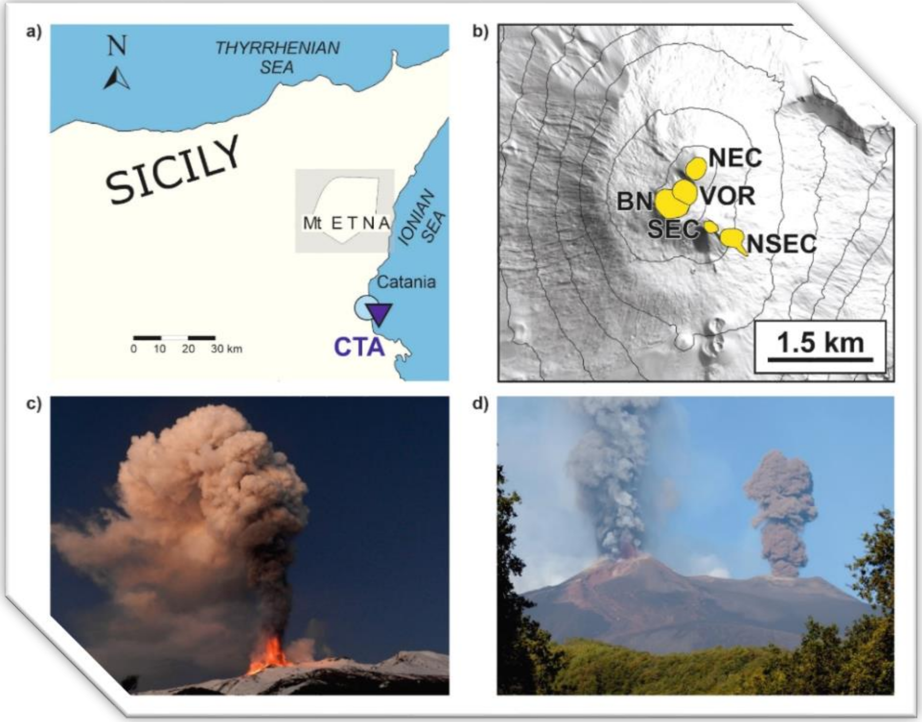
A10#39 – working at L'Aquila LNGS

CAMPI FLEGREI - A10#39 – 27 stations

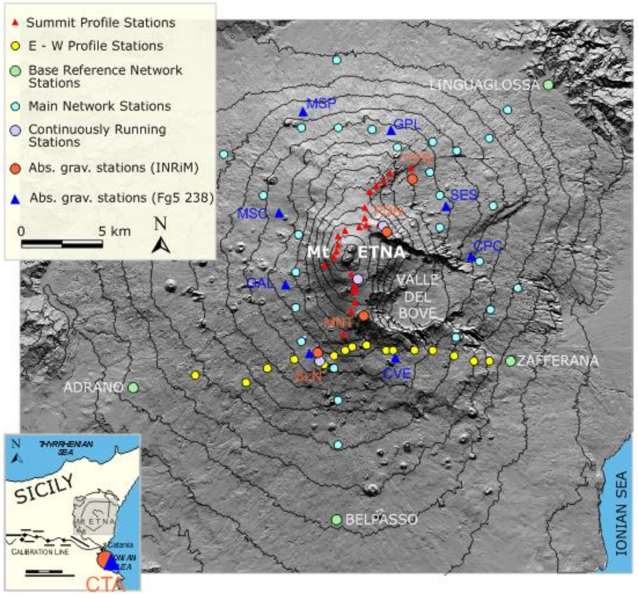


by G. BERRINO - INGV-NA

Mt. Etna (Italy): eruptive activity during 2009 to 2018



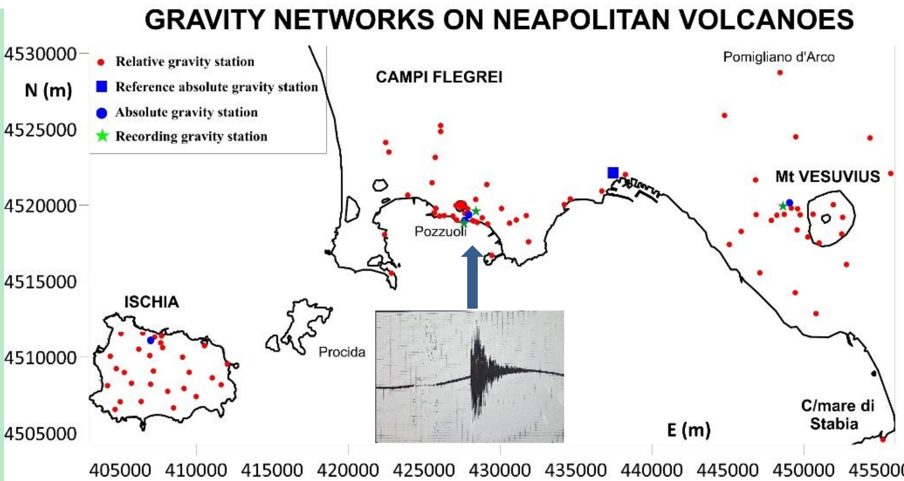
ETNA - FG5#238 – 12 stations

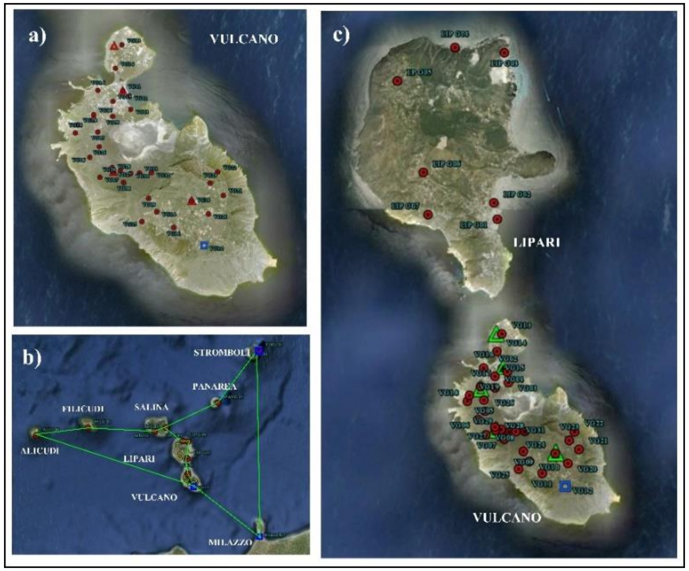


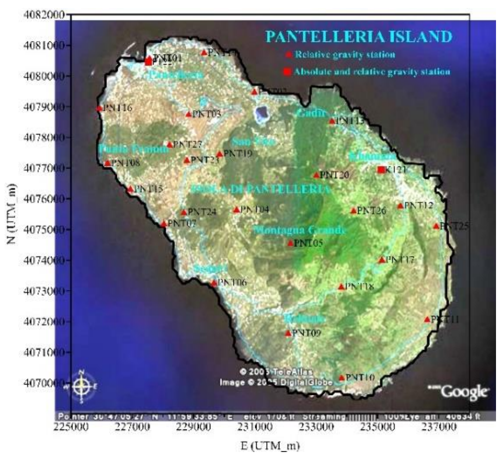
EXAMPLES OF GRAVIMETRIC NETWORKS FOR VOLCANOES MONITORING

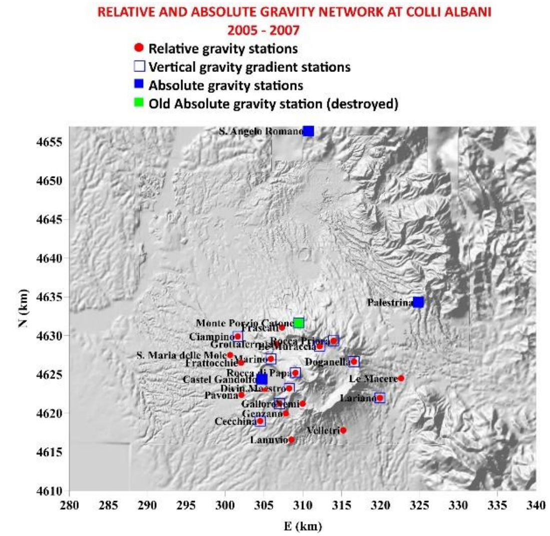
Development of gravimeters permitted since ‘80s to start precise relative gravity measures in dynamic areas. Fit networks were built on the active volcanoes of southern Italy
Recording gravimetry is also performed in some selected stations

Dense relative networks were installed by OV and University of Naples «Federico II» on Neapolitan (Campi Flegrei, Vesuvius and Ischia) and Sicilian volcanoes (Vulcano-Lipari and Aeolian islands, Pantelleria) and more recently by INGV and University «La Sapienza» of Rome (2005) on Colli Albani. Each net is linked to a locally measured absolute gravity station



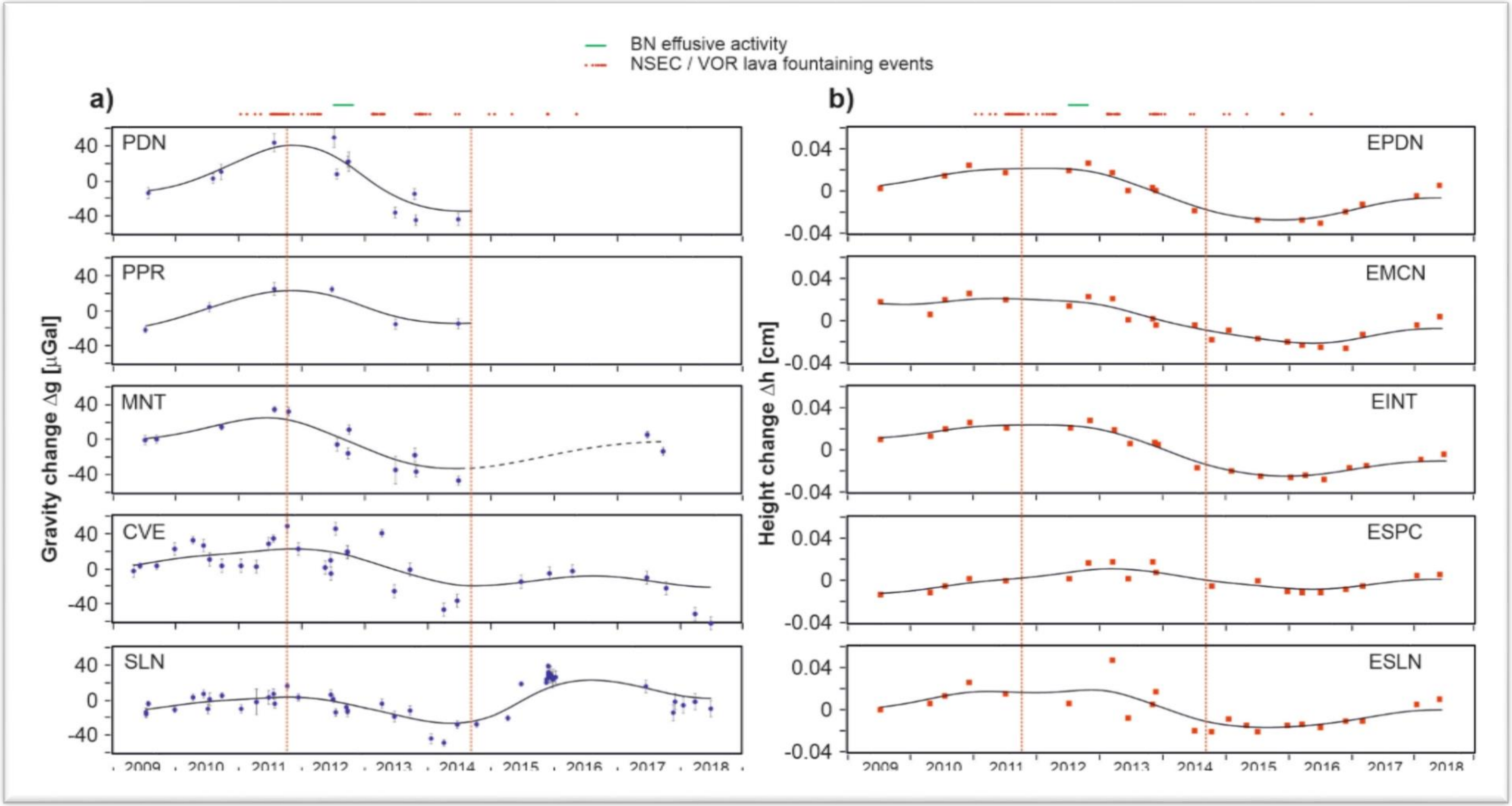






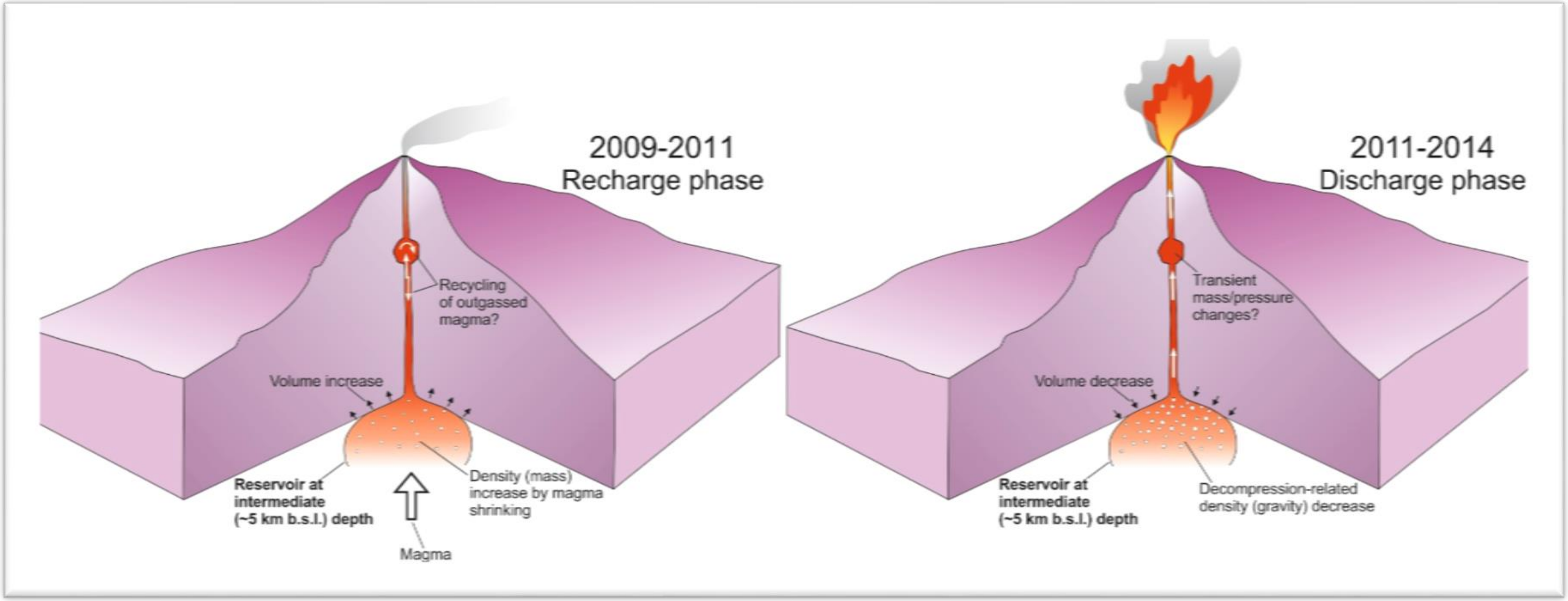
Repeated absolute gravity and GPS measurements

The yellow circles mark 5 key gravity and GPS stations of the network



Left: absolute gravity time series from five key stations of the network.
Right: elevation time series from the five GPS benchmarks closest to the key gravity stations.

Summary cartoon showing the inferred processes during 2009 to 2014, alternating summit eruptions and magma storage



Left: recharge cycle - the gravity and ground deformation data revealed that in the period between 2009 and 2011 there was a magmatic recharge cycle in a reservoir at about 5 km b.s.l. During the recharging phase, only outgassing occurred from the summit craters of the volcano.

Right: discharge cycle - since 2011, the magma fed the exceptional phase of volcanic activity recorded between 2011 and 2014, when numerous episodes of lava fountaining occurred.

Greco et al., 2022 J. Geodesy

Comparison between iGrav#016 SG and FG5#238 absolute gravimeter

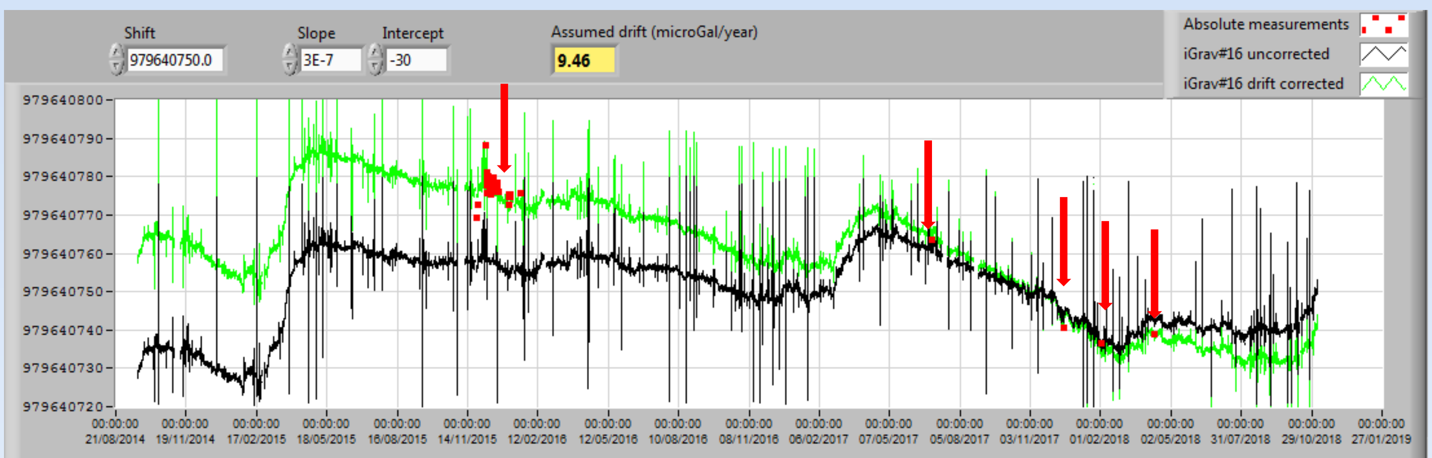
FG5#238 AG

Scintrex CG-5

iGrav#016 SG

This comparison allows to estimate the long-term drift of the iGrav SG, which is of the order of 9 microGal/year.

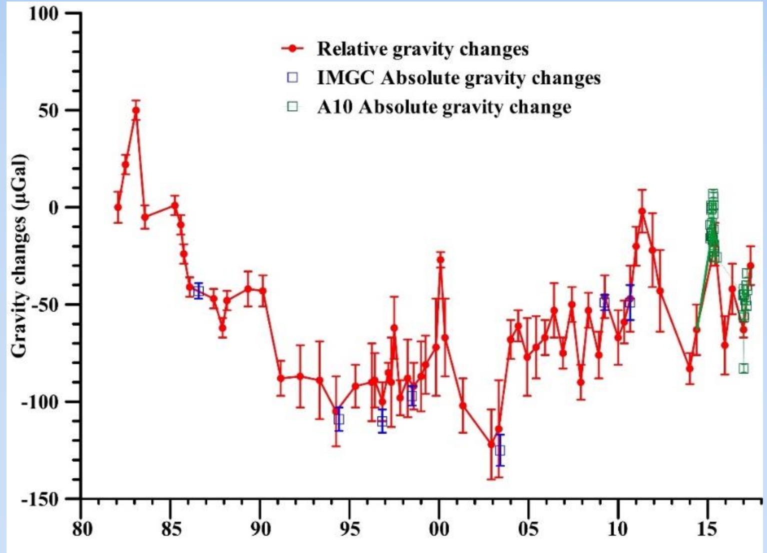
The green curve is the same signal, after correction for a linear trend, deduced from the AG data.



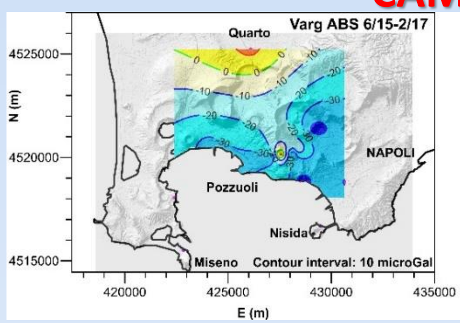
56-month long time series from iGrav#16 SG at SLN station (MT. Etna).

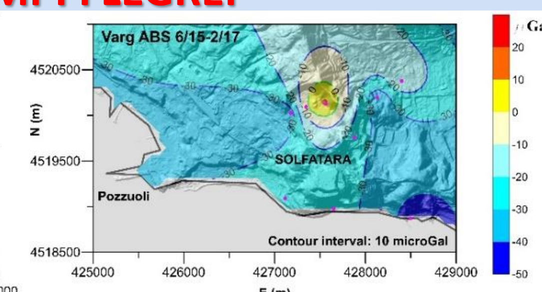
SOME RESULTS OF REPEATED ABSOLUTE GRAVIMETRY IN ACTIVE VOLCANOES

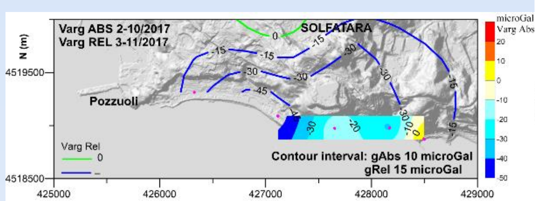
Mt. VESUVIUS

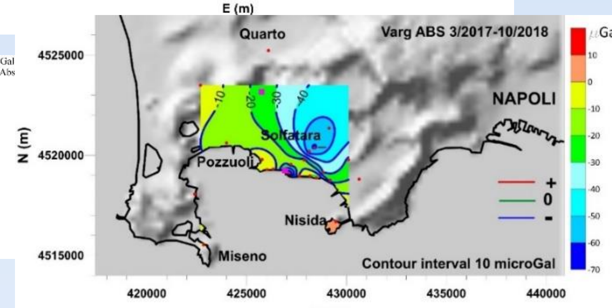


CAMPI FLEGREI









EXAMPLES OF GRAVIMETRIC NETWORKS FOR GEDYNAMIC PURPOSES

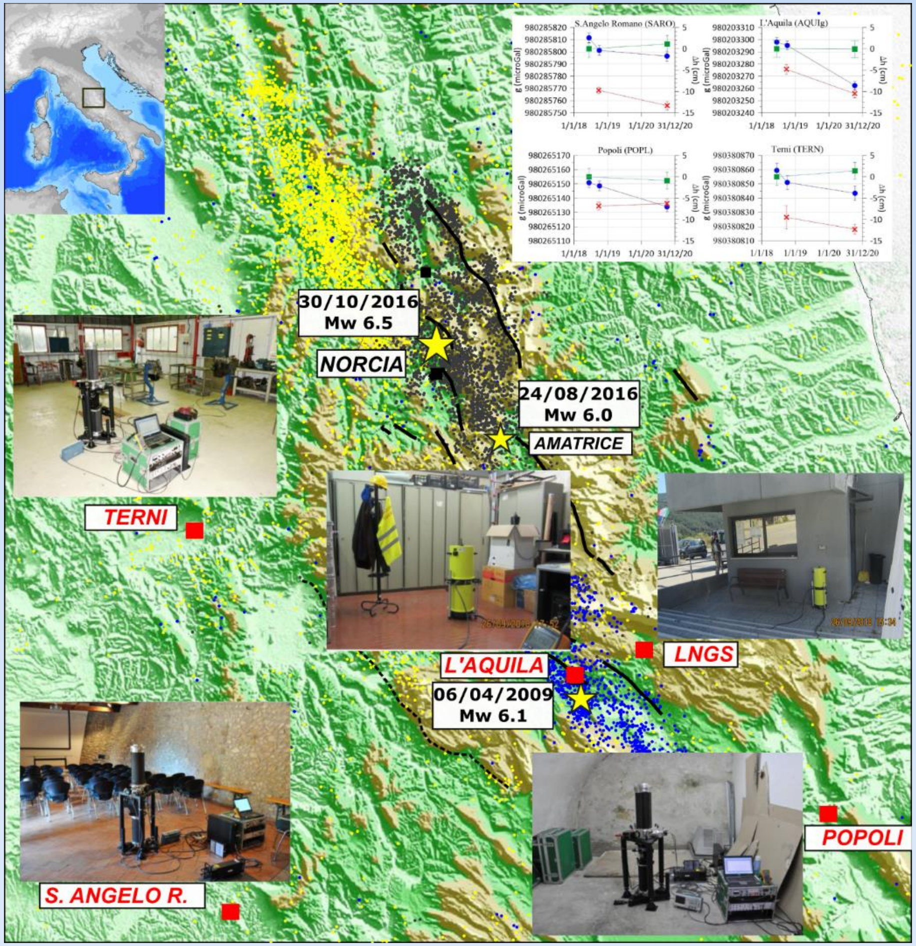
In Italy,

gravimetry is largely carried out since ’80s to study and monitoring active volcanoes of central-southern and insular Italy,

but

gravimetry was not extensively applied in seismic areas, except in Central Italy, where gravity measurements have been performed since 2018, aimed to study the dynamics of the main tectonic processes.

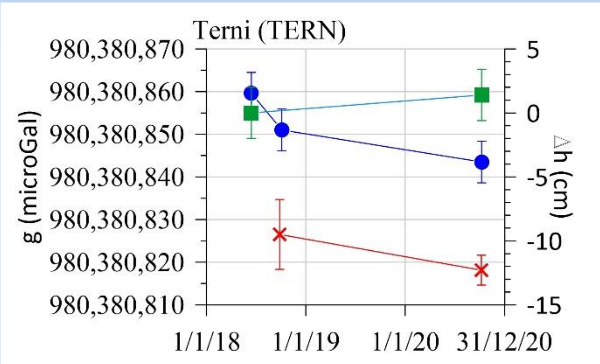
Absolute gravity and GNSS network in Central Italy



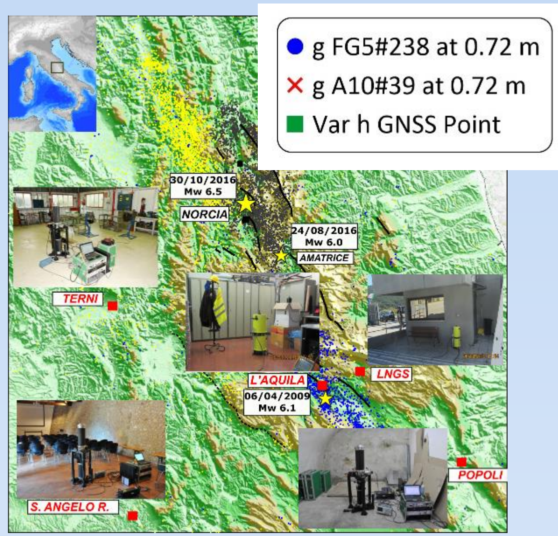
The network includes five stations distributed between the Lazio, Umbria and Abruzzo regions (squares and labels in red), measured since 2018 (date of installation).

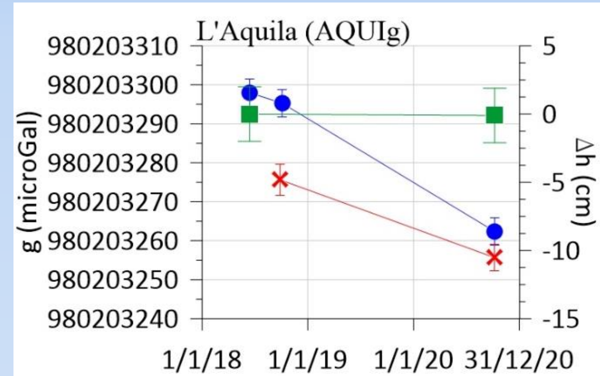
The epicenters of seismic events with Mw ≥ 6.0 (yellow stars) and the background seismicity from INGV databank (M ≥ 2.5, max depth 30 km), for the periods 1 January 1985 – 31 December 2008 (yellow dots), 1 January 2009 – 23 August 2016 (blue dots), and 24 August 2016 – 3 January 2019 (black dots), are also indicated.

Short–Term gravity and height variations



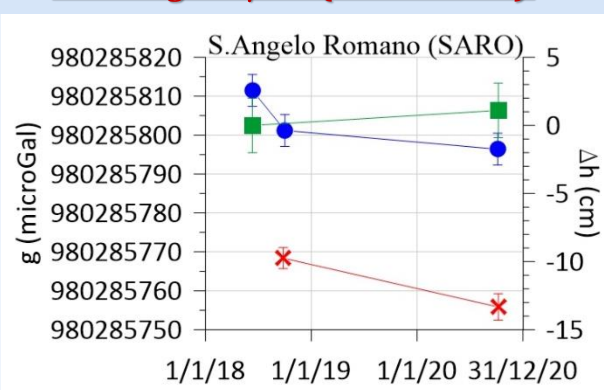
TERN: Δg -16 μGal (2018 – 2020).



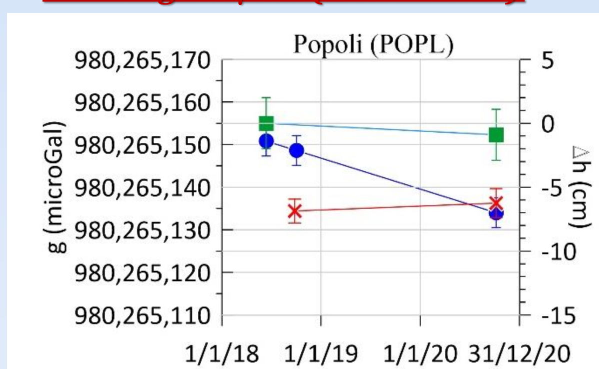


AQUIg: Δg -35 μGal (2018 – 2020).

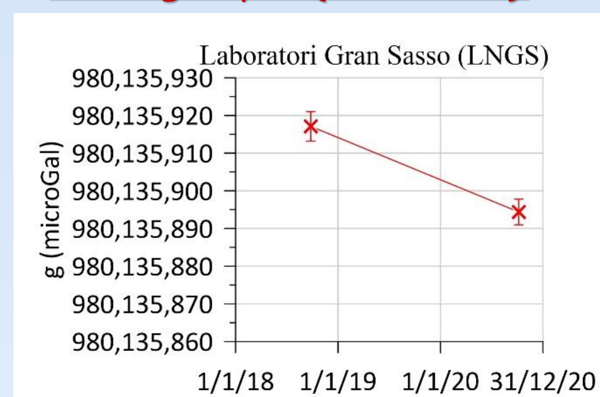
SARO: Δg -15 μGal (2018 – 2020).



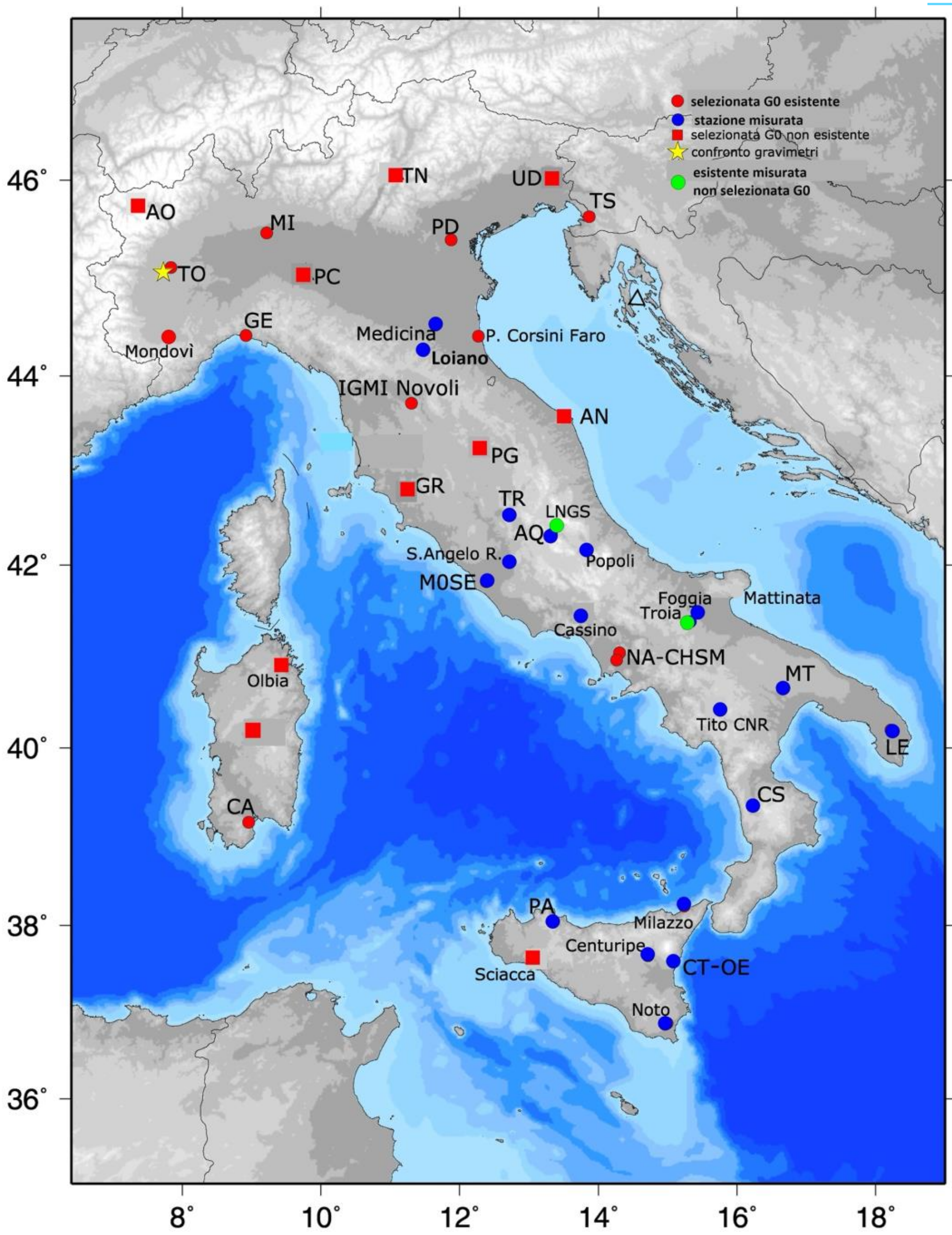
POPL: Δg -18 μGal (2018 – 2020).



LNGS: Δg -23 μGal (2018 – 2020).



The New Reference Absolute Gravity and Height Network in Italy (G0 and H0)



A NEW ITALIAN

REFERENCE GRAVITY AND HEIGHT NETWORK

"*G0 and H0*"

SELECTED STATIONS

- Inter-calibration station
- Already measured
- To be measured
- To be evaluated

REQUIREMENTS FOR THE SITE'S CHOICE

Stations must be:

- Noise-free.
- Accessible place and indoor sites and electricity provided.
- If possible on a pillar or bases isolated from the floor.
- where previous measurements were carried out.
- If possible close to permanent GNSS station.

For each station we collected a monography with the description of the site, the geolocalization of the site, and several pictures obtained during the measurement of the absolute value and the value relative to the satellite station outside the building.
Each Absolute station has one or more satellite stations

Schematic monograph and pictures of the absolute gravity station MLZ. a) Google Earth view of the area where the Milazzo (ME) absolute station is located (coordinates are described at the top of the figure); b) detailed planimetry of the room with the exact location of the absolute measurement point; c) external view of the building and the location of the satellite station, used for fast link with the absolute point; d) the Scintrex CG-6 gravimeter during vertical gravity gradient measurement;e) photo of the stainless steel marker on which the acronym of the station is marked; f) the Micro-g LaCoste FG5#238 during the measurement session; g) Milazzo surveyed network (MLZ - absolute gravity point, 100 - Total Station, 200 and 300 - outdoor reference points (GNSS))

INSTALLATION OF THE BENCHMARK

Precise Point of measurement is identified by a steel benchmark where is indicated the name of the station and related network, and who set up the point.

WORKFLOW AND INSTRUMENTS

- The absolute measurements were carried out with FG5 during the less disturbed night hours, for a duration of at least 10-12 hours.
- In the case of measurements with A10, both the campaign mode was followed (1 hour) with numerous sets each and with numerous drops (e.g. 8 or 20 sets each with 120 drops), and the laboratory mode as with FG5
- The measurements were then corrected for all effects affecting the measurement (Tide, Pressure, Ocean loading, Polar motion)
- In the same site where the absolute measurement was carried out, the local value of the vertical gradient of gravity (VGG) was also measured by the Scintrex CG-6 or LaCoste & Romberg, necessary to bring the g values from the instrumental height to the ground reference.
- Satellite stations were measured where the g-value was reported by relative links

Absolute gravimeters

Microg Lacoste FG5#238

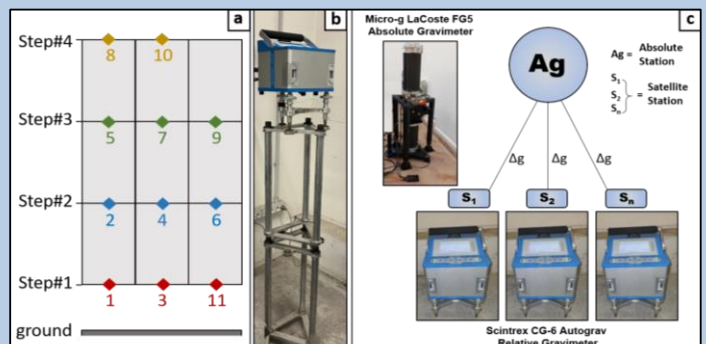
Microg Lacoste A10

Relative gravimeters

Scintrex CG-6

LaCoste & Romberg D85

a) procedure to measure the vertical gravity gradient indicating the measurement progression from 1 to 11 at different heights from the ground (Step#1 = about 15 cm; Step#2 = about 45 cm; Step#3 = about 70 cm; Step#4 = about 125 cm); b) Scintrex CG-6 relative gravimeter during vertical gravity gradient measurement; c) scheme of the connection to calculate the gravity difference (Δg) between the indoor absolute point with one or more outdoor satellite station/s using the CG-6 Scintrex relative gravimeter.



Advantages of absolute gravity measurements

1. They are independent of any reference

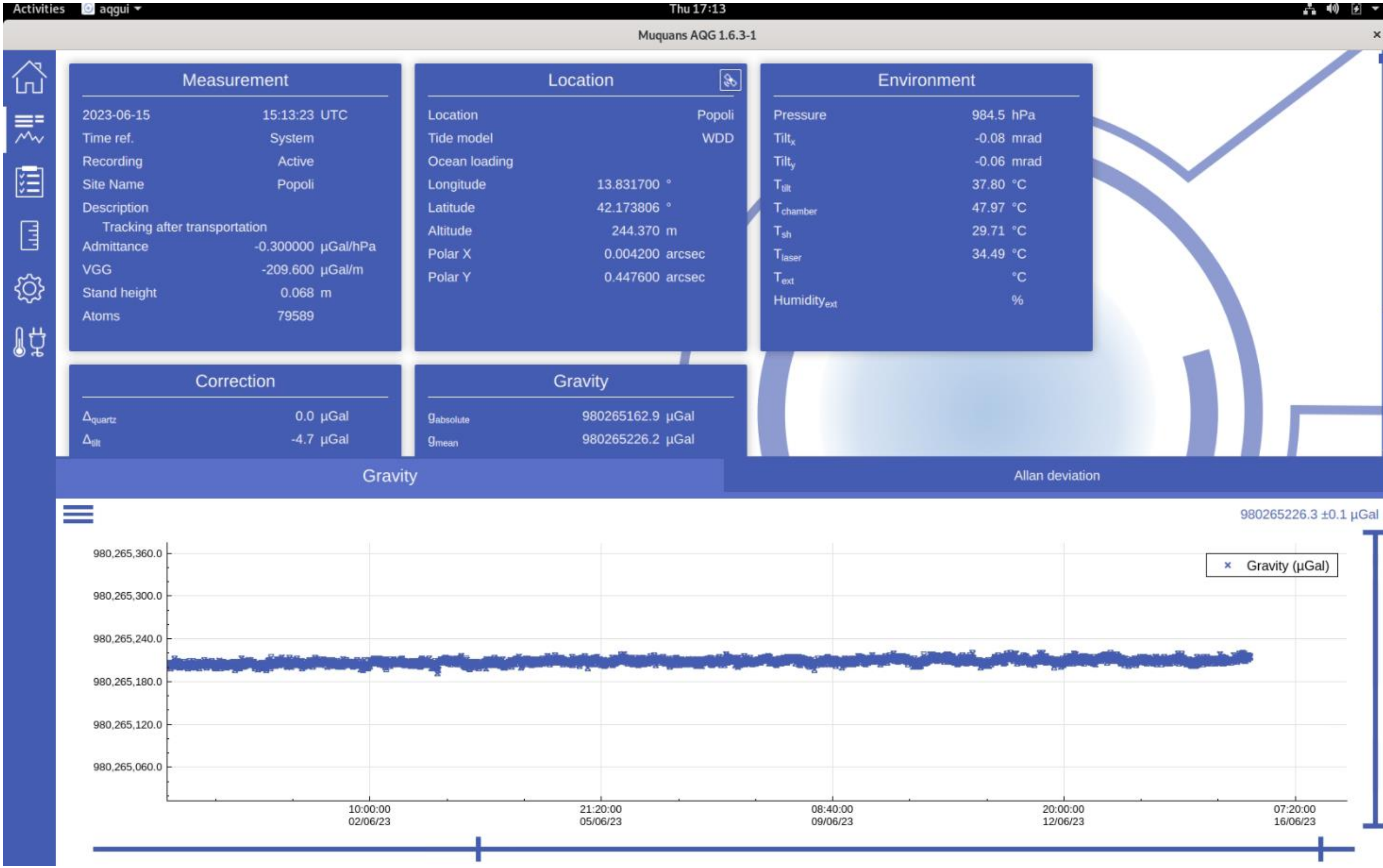
2. Field operations are fast and easy to perfom, allowing frequent measurements.

3. They are not affected by instrumental drift.

4. The absolute gravity values can be immediately used without post processing (e.g. error compensation procedures) and reference links.

5. They allow to define the "base station" and, if repeated over time, to detect its long-term variations or confirm its stability.

Advantages of absolute gravity measurements



Absolute Quantum Gravimeter (AQG) at Popoli town in continuous recording since May 24, 2023.

SOME REMARKS FOR FUTURE PERSPECTIVES

A new National Absolute Reference Gravity and Height Network

The **National Absolute Reference Gravity and Height Network** will permit to align Italy to the new international standards and to replace the current reference (IGSN71) that is quite an obsolete network. In turn, this will be useful to multidisciplinary approaches for technological and scientific activities in geodesy and geophysics framework.

- Homogenize the previous gravimetric/altimetric data.
- Homogenize the existent Bouguer maps
- Update the geoid model estimation
- Refer new gravimetric measurements to a unique system
- Revise the existent gravimetric data to investigate and reprocess the lithospheric structure

RETE H0 - PIANETA DINAMICO						
PUNTI G0	EPOCA DI MISURA	COORDINATE ELLISSOIDICHE ITRF14			GEOIDE ITALGEO	QUOTE ORTOMETRICHE
		h (m)	LAT	LONG	N(m)	H (m)
AQUI		698.00	42.36824	13.35025	48.69	649.31
CATANIA	2022.419	71.32	37.5137922	15.0819436	41.11	30.21
CASSINO		425	41.488	13.826		
CENTURIPE	2022.413	713.21	37.6271528	14.7378358	42.09	671.12
COSENZA		260	39.3600	16.2267	44.15	215.85
FOGGIA		91.88	41.50657	15.60865	47.39	44.49
LECCE	2021.953	59.36	40.335619	18.111455	40.03	19.33
MATERA		530.30	40.649534	16.704074		
MILAZZO	2022.411	44.74	38.2208923	15.2420093	42.75	1.99
MOSE	2022.339	94.38	41.8934495	12.4929922	48.11	46.27
MOSE (AUSILIARIO - ESTERNO)	2022.339	93.46	41.8932151	12.4928795	48.11	45.35
NOTO	2022.416	124.78	36.8760409	14.9890523	41.36	83.42
PALERMO		80	38.1054	13.3483	43.52	36.48
POPOLI		291.90	42.1738	13.8317	47.53	244.37
S. ANGELO ROMANO		446.93	42.0351	12.7125	48.53	398.40
TERNI		175.12	42.5658	12.6557	48.59	126.53
TITO		760	40.6013	15.7237		

Future Trends…

The results achieved with the data collected in recent years constitute a benchmark for the scientific community working in the field of gravity applications and related sciences.

The INGV is planning the realization of the **Italian Fiducial Gravimetric Network** equipped with superconducting and absolute gravimeters in continuous (or quasi-continuous) recording.

ITALIAN FIDUCIAL GRAVIMETRIC NETWORK

In order to lay the foundations for a multidisciplinary approach to natural risk assessment, a large-scale gravity network in Italy, which in the most advanced development **will consist of about 10 sites**, homogeneously distributed throughout the country, is under realization.

The network will allow for determining the temporal variations of the **long-term and long-wavelength gravity field in seismic and volcanic areas**.

The sites will be equipped with absolute or relative gravimeters in continuous or pseudo-continuous recording (e.g. 1 measurement every week). For this purpose, superconducting gravimeters and atomic and ballistic absolute gravimeters will be used, the only instruments capable of providing a highly precise and stable signal even in the long term.

This network, **will supplements the newly established National Reference Gravimetric Network (G0)** and the National Gravimetric Service in the planning stage.

ITALIAN FIDUCIAL GRAVIMETRIC NETWORK

In addition to the gravimeters already available at the INGV or being acquired:

- Superconducting gravimeter iGrav#25 (by GWR)
- Absolute Quantum Gravimeter (AQG; by Ixblu ex Muquans)
- Micro-g LaCoste gPhoneX
- Micro-g LaCoste FG5#238 absolute gravimeter
- Micro-g LaCoste A10#039 absolute gravimeter

To these instruments we can add those of other Institutes:

- Micro-g LaCoste FG5 managed by ASI
- IMGC-02 developed and manged by INRiM

in perspective, the Gravimetric Fiducial Network could be integrated by 2 other stations/gravimeters:

- ✓ Sos Enattos (Sardinia), where the installation of an IGrav superconducting gravimeter is planned as part of the MEET/FABER project
- ✓ L'Aquila (Gran Sasso National Laboratory) where the installation of an iGrav superconducting gravimeter is planned as part of a PNRR project (INFN-INGV joint activity)

Future Trends…

NATIONAL GRAVIMETRIC SERVICE (NGS)

To coordinate all the described activities, INGV is planning the realization of a National Gravimetric Service (NGS) whose purpose are to:

- Realize an infrastructure of fixed gravimeters (fiducial gravity network) for long-wavelength monitoring of the temporal variations of the gravity field and of the geoid, according to the international indications defined by the International Association Geodesy (ref. IAG Resolution n. 2, 2015 and IAG Resolution n. 4, 2019).

- Promote the repetition of the absolute gravity measurements at least every five years in the stations of the reference gravity network G0.

- Provide a high spatial and temporal resolution database of gravity and of the geoid in Italy constantly updated (integrated also by aerogravimetric data), both to the scientific community and to the Public Institutions of national service.

Conclusions & Future Trends

The precision, stability and accuracy of the state-of-the-art of terrestrial gravimeters are not a limitation anymore to detect gravity variations at microGal level.

High quality data with high temporal and spatial resolution can be collected.

Considering the difficulties in the use of terrestrial gravimeters in remote or dangerous areas, data from aircrafts could help to overcome this restriction.

Future network for monitoring geodynamic processes. **Requirements**:

1. **Improving the resolution** of observable variations **to microGal level**, fundamental requirement in time-variable gravity.
2. **Improving the spatial resolution** in order to allow the study of phenomena from the regional / local scale **(spatial scale < 100 km**)
3. **Improving temporal resolution** to allow the study of phenomena with **period from minutes to years**.
4. **Stability of the measuring system** over time (in the case of relative measurements).
5. **Metrological traceability** to the international system of units (in the case of absolute measurements).

Istituto Nazionale di
Geofisica e Vulcanologia

**Thanks for
Your Attention!**