In situ verification of refined predicted vertical gravity gradients on Etna

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ONLINE PRESENTATION

Abstract

In situ values of vertical gradients of gravity (VGGs) are often needed when compiling residual spatiotemporal gravity changes that are interpreted in volcanic areas with the objective of drawing inferences about sources of volcanic unrest or pending eruptions. VGG values are seldom acquired by in situ observations. Their availability in 4D volcano-microgravimetric surveys and studies can be mediated by predicting the VGGs based on high resolution high accuracy DEMs and modelling the topographic component (constituent) of the VGG. Based on a modelling effort and in situ verification of VGG predicted on Etna in the summit craters area, on the north-east rift and on benchmarks of the monitoring network covering the volcano in a wider context, we learned that the VGG prediction can be improved by using drone-borne photogrammetry with GNSS ground control to produce a finer DEM in the closest vicinity of the VGG point (benchmark or field point) with resolution higher than the available high-resolution LiDAR-derived DEM, and using detailed modeling of gravity effect (on VGG) of anthropogenic objects such as walls and buildings adjacent to the VGG points. In this poster we present the methods used in the refined VGG prediction and the results of the verification of VGGs predicted on Etna

The work trek around the summit craters of Etna in July 2018

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Vertical gradient of gravity (VGG)

- Needed in 3D and 4D micro-gravimetric applications
- Can be measured in situ (relative gravimeter in tower mode)
- If not available can be predicted (modelled) based on topographic contribution to VGG

VGG observation

Repeat observations in upper and lower positions (tower mode) using a relative gravimeter (CG5),
a geodetic tripod, and accurate measurement of vertical separation between the two positions.
At the rim of the north-east crater (NEC) on Etna

VGG prediction (modelling) based on topographic contribution

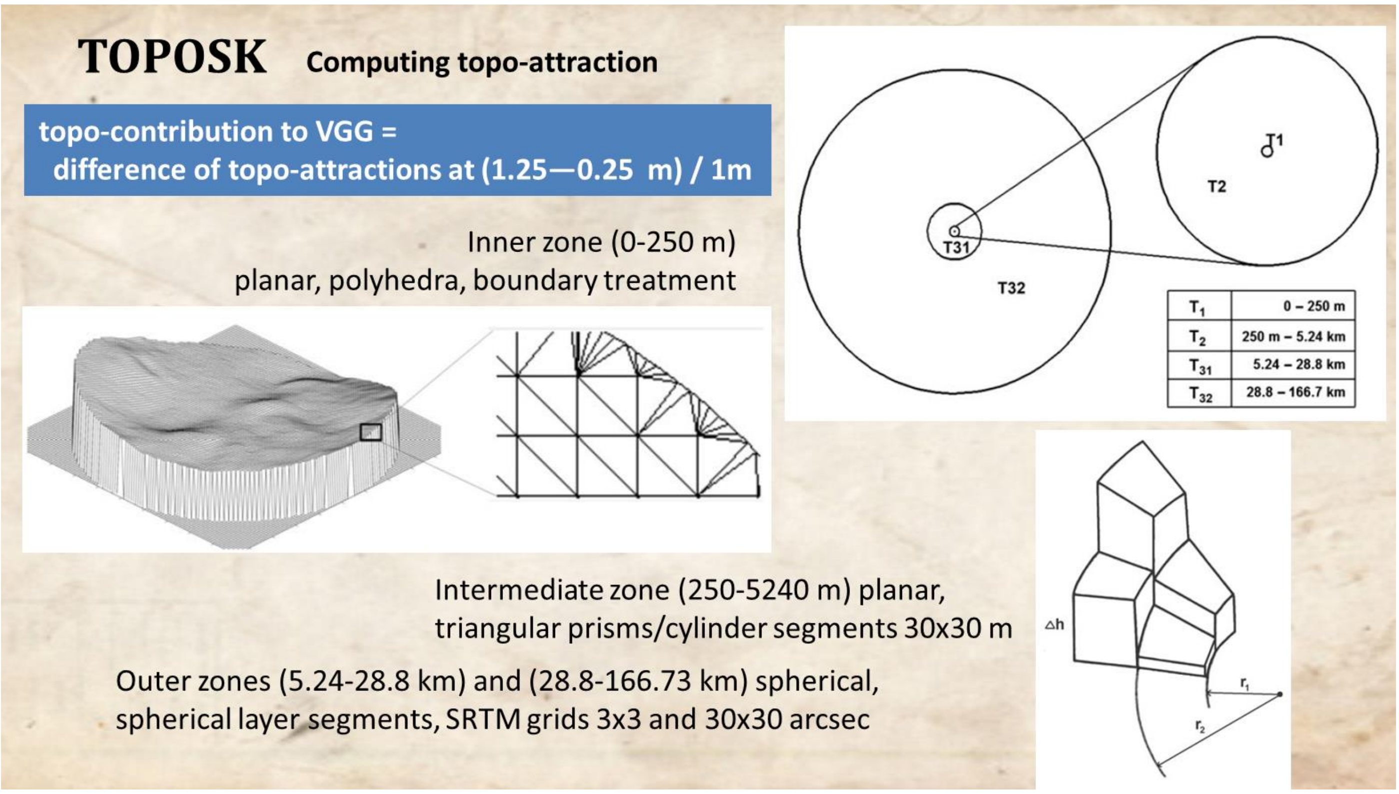
- Prediction based on adding to the constant normal free-air gradient (FAG) the modelled contribution (to VGG) of topographic masses
- High resolution (a few meters) high vertical accuracy (10 cm) DEM (DTM) needed
- Correct choice of representative constant reference topographic density needed
- Accurate numerical volumetric Newtonian integration (e.g., Toposk software)

DEM

We used the LiDAR DTM 2005 produced by INGV (Sezione di Pisa) from a survey completed in 2005. The original DEM with spatial resolution of 2 m (vertical accuracy of ± 24 cm) was resampled to 5 m resolution. This high resolution DEM was used in the inner integration zone (0–250 m).

Bisson, M., Spinetti, C., Neri, M., & Bonforte, A. (2016)
Mt. Etna volcano high-resolution topography: airborne LiDAR modelling validated by GPS data.
International Journal of Digital Earth. https://doi.org/10.1080/17538947.2015

Numerical volumetric Newtonian integration (Toposk software)



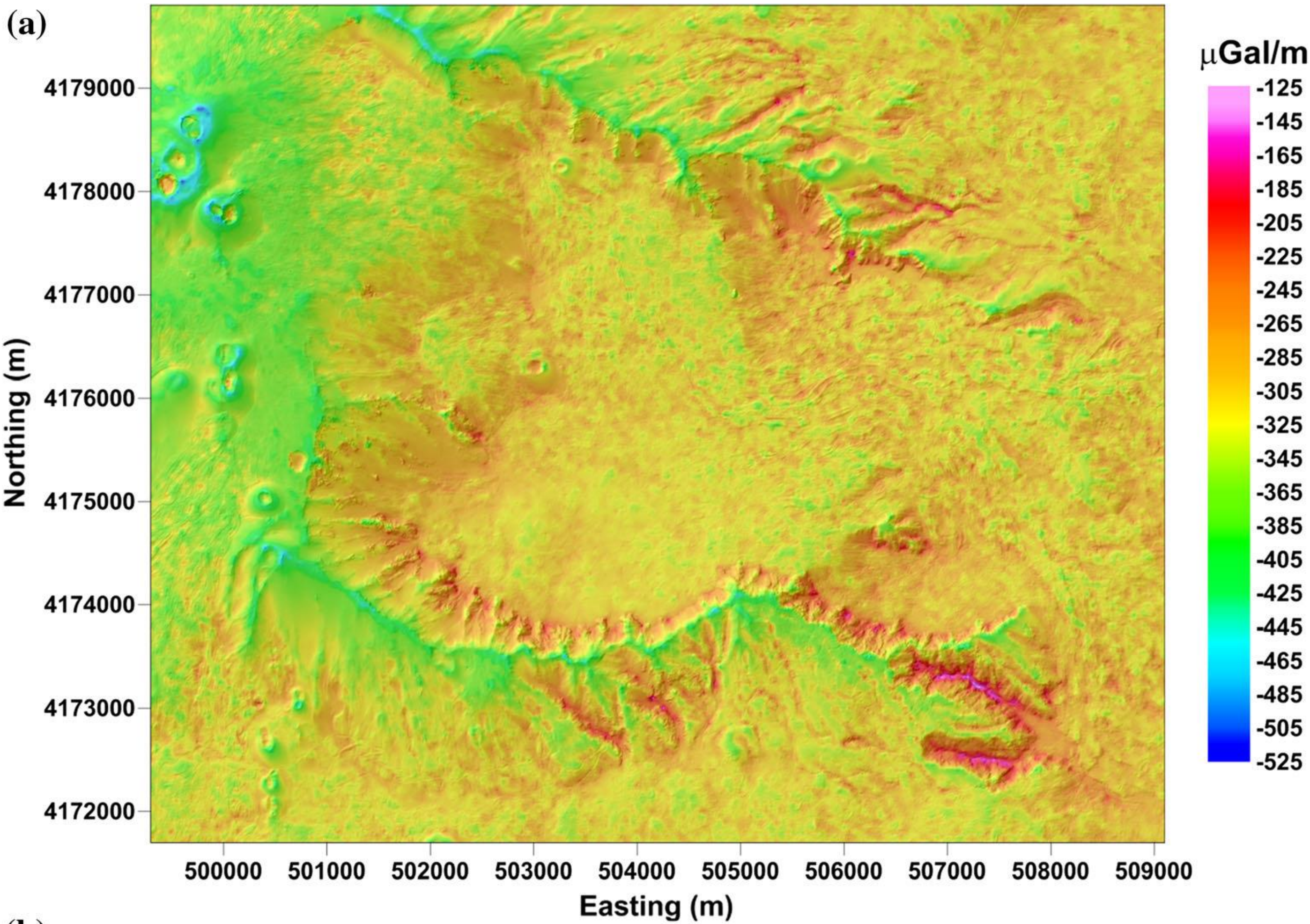
More details in:

Zahorec P, Marušiak I, Mikuška K, Pašteka R, Papčo J (2017)
Numerical calculation of terrain correction within the Bouguer anomaly evaluation (Program Toposk), chapter 5, 79–92. In book: Pašteka R, Mikuška J, Meurers B (eds)
Understanding the Bouguer anomaly: a gravimetry puzzle. Elsevier, ISBN 978-0-12-812913-5.
[*https://doi.org/10.1016/b978-0-12-81291 3-5.00006 -3*](https://doi.org/10.1016/b978-0-12-812913-5.00006-3)

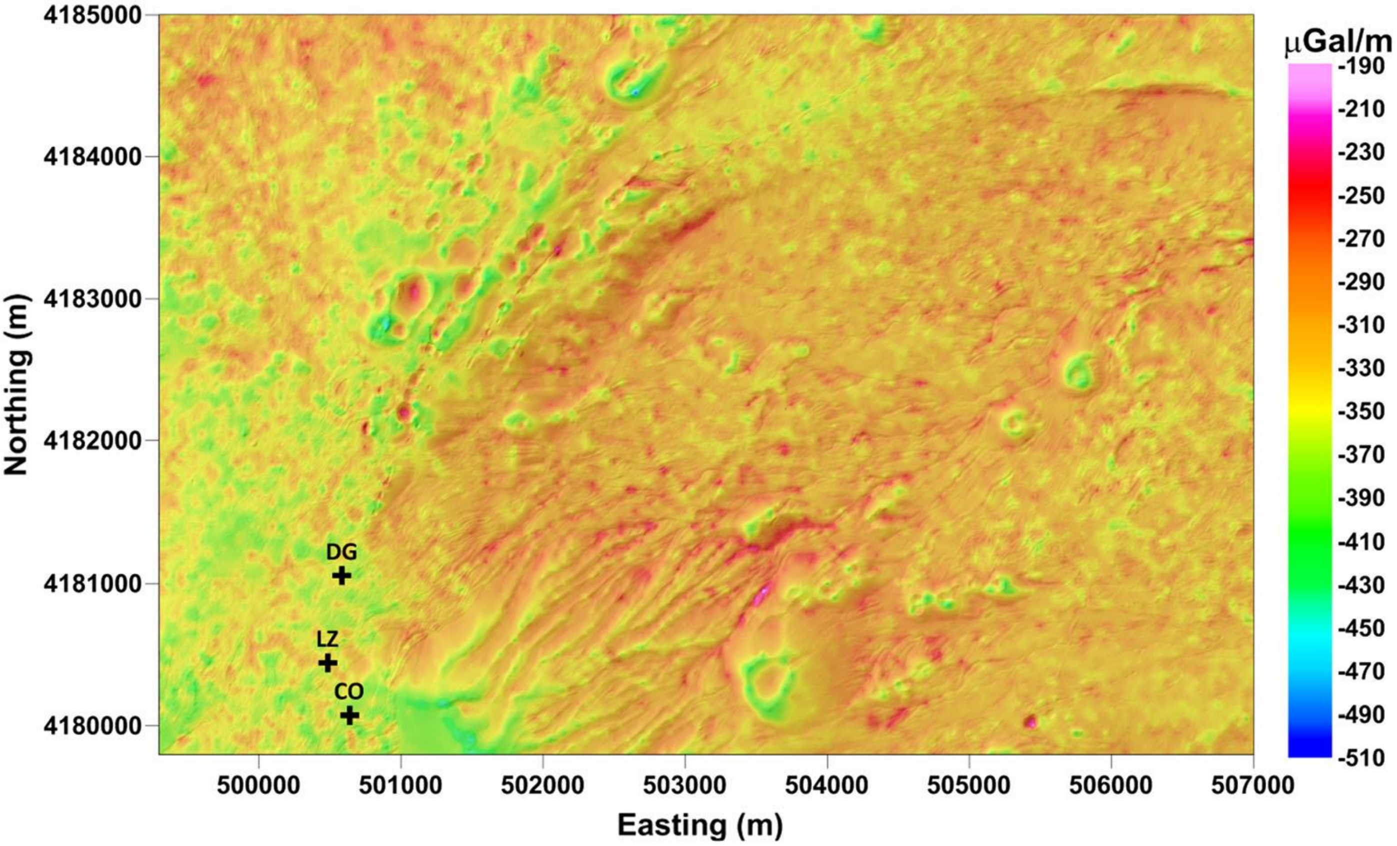
Predicted VGG field on Etna

The predicted VGG field (μGal/m) at the Valle del Bove area and part of the summit craters area (a) and at the NE-rift (NER) area (b). Black crosses indicate locations of gravity points/benchmarks.

(a)



(b)



In-situ verification of the predicted VGG field on Etna

By in situ verification of the predicted VGG values on stations and benchmarks of absolute and relative (respectively) gravity points of the Etna monitoring network, as well as on selected field points, we found out that several matters need to be handled and the VGG prediction refined.

First of all, the absolute gravity points are located on Etna mostly in the refuge huts. Consequently the effect on the VGG of the walls (of the building) of the refuge has to be taken into account (computed). We surveyed the buildings and computed the effect on VGG to refine the VGG prediction. The same holds true for relative points that are often located on road side rock walls. The road-side walls were surveyed and their effect computed.

Second, the LiDAR DEM 2005 was not of good enough quality in some spots, or the terrain morphology has changed since 2005 due to volcanic activity in some locations. For this reason we have replaced the DEM in the vicinity of a benchmark, station or field point by a local DEM derived by us from local drone-borne photogrammetry.

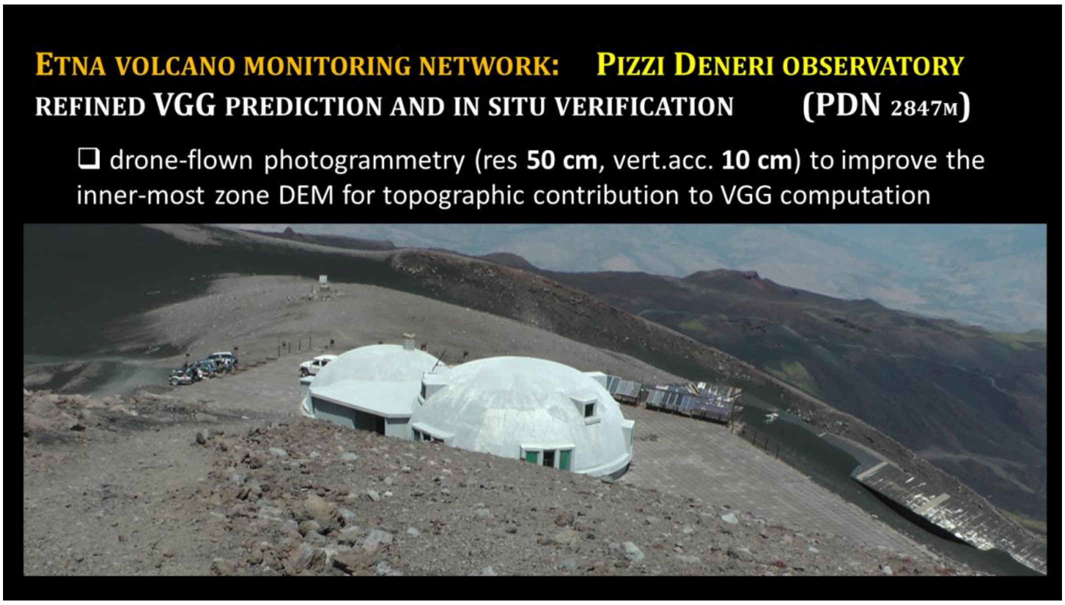
Refined prediction of VGG values on Etna

Example of VGG prediction refinement: PDN observatory

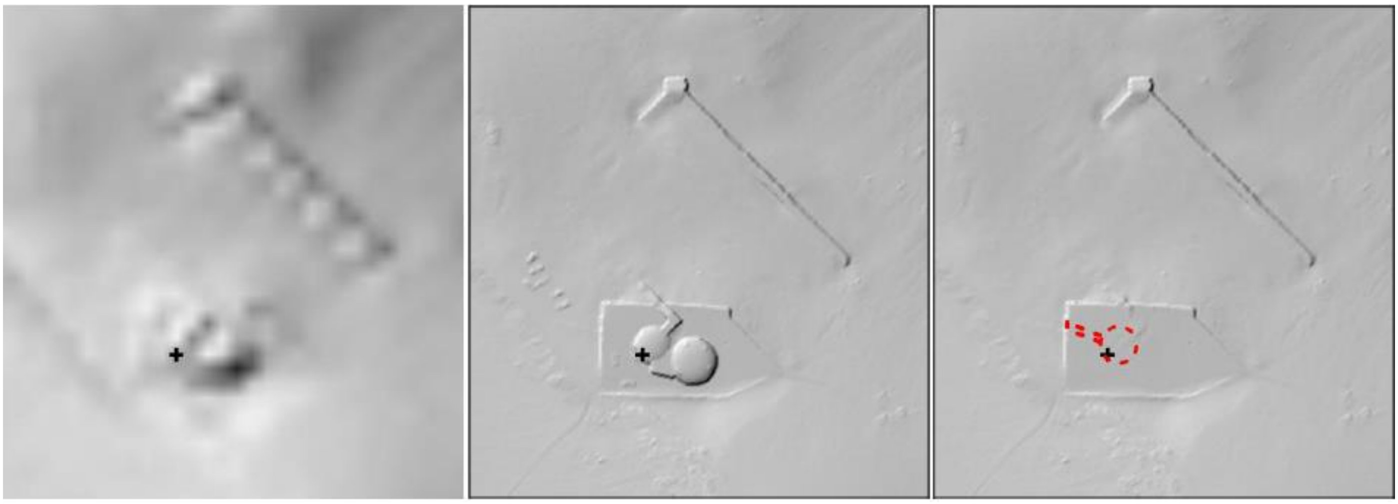
Measured VGG:
- 352 μGal/m

predicted VGG:
- 470 μGal/m

refined predicted VGG:
- 355 μGal/m

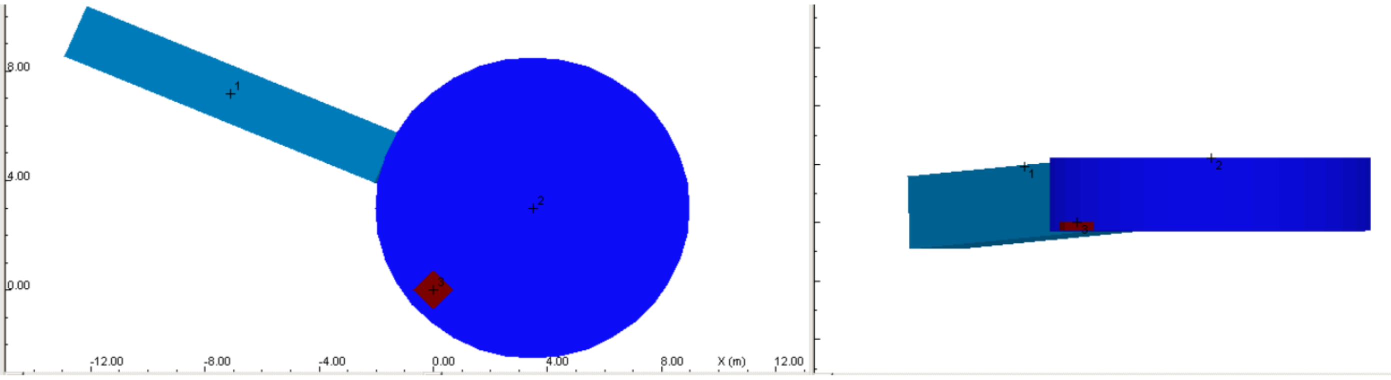


Improvement of the nearest topographic relief DEM using local drone-borne photogrammetry



Comparison of the LiDAR DTM 2005 (left) with our local drone-borne photogrammetric DEM (middle) in the vicinity of the absolute gravity point PDN (black cross) situated in the basement of the Pizzi Deneri volcanological observatory (2820 m a.s.l.). The right picture shows the “cleaned” model that was used for the topographic effect calculation. Red dashed line indicates the position of underground basement, which was subsequently also surveyed and modelled (see next figure)

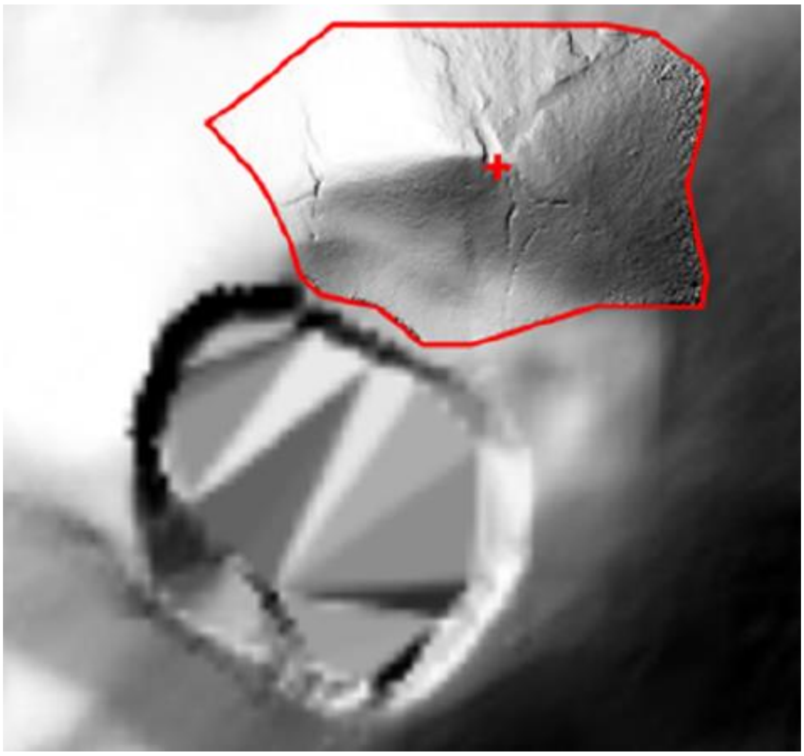
Improvements accounting for underground benchmark location and building effects



Modelled underground spaces around point PDN (left – top view, right – vertical cross-section). Blue model bodies represent basement room with inclined access corridor. Small red prism represents a concrete pillar protruding above the floor level. Snapshot is taken from Potent modeling software interface,

Example of VGG prediction refinement: NEC field point (NE crater site)

VGG values at field point NEC:
observed in situ: - 455 μGal/m
predicted based on the 5 m LiDAR DTM: - 532 μGal/m
predicted based on the LiDAR DTM supplemented with local photogrammetric DTM within the zone up to 70 m: - 508 μGal/m



Shaded relief map of the topography represented by the LiDAR DTM 2005 (5 m resolution) at NEC area. Artefacts inside the NE crater are likely due to the lack of Lidar data. Red cross marks the location of observation point NEC.

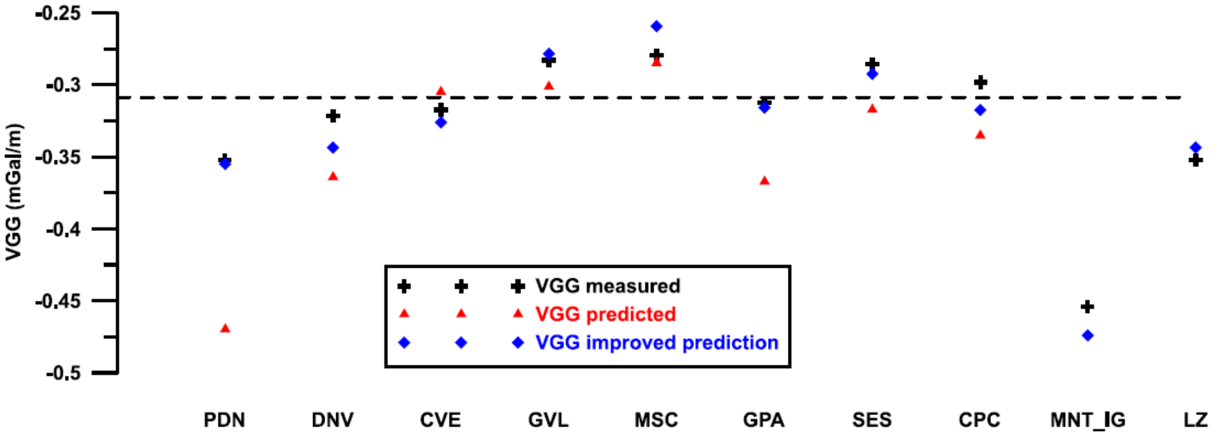
Shaded relief map of the topography refined by our local photogrammetric DTM (50 cm resolution) within the zone delineated by red line.

The misrepresentation of the relief inside the crater is the likely cause of the mismatch not only between the original predicted VGG and the observed VGG, but also in case of the refinement.

Improvement of VGG prediction due to the refinements

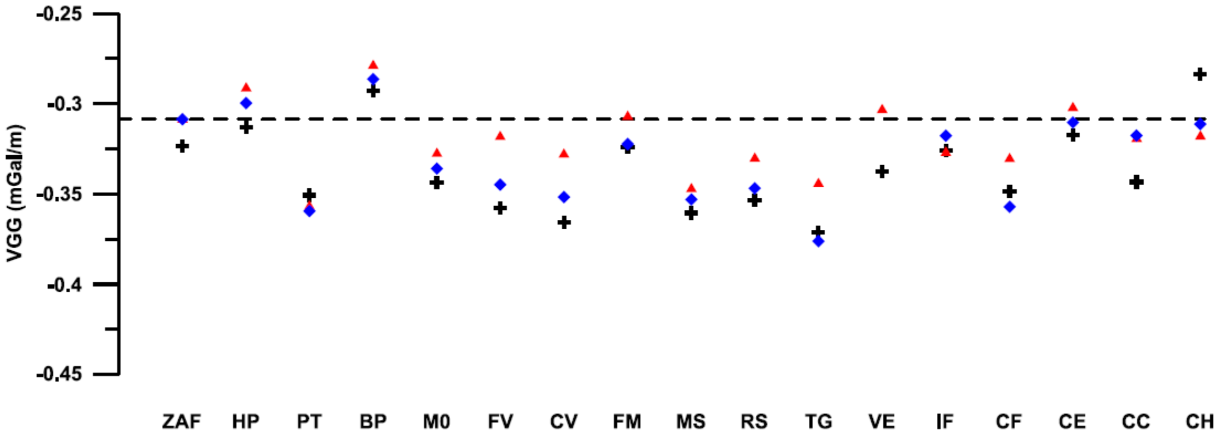
Comparison of measured VGGs (black crosses) with previously predicted VGGs (red triangles) and new predicted values based on the refinements (blue diamonds).
Dashed lines represent theoretical (normal) gradient of –308.6 µGal/m.

Absolute gravity benchmarks



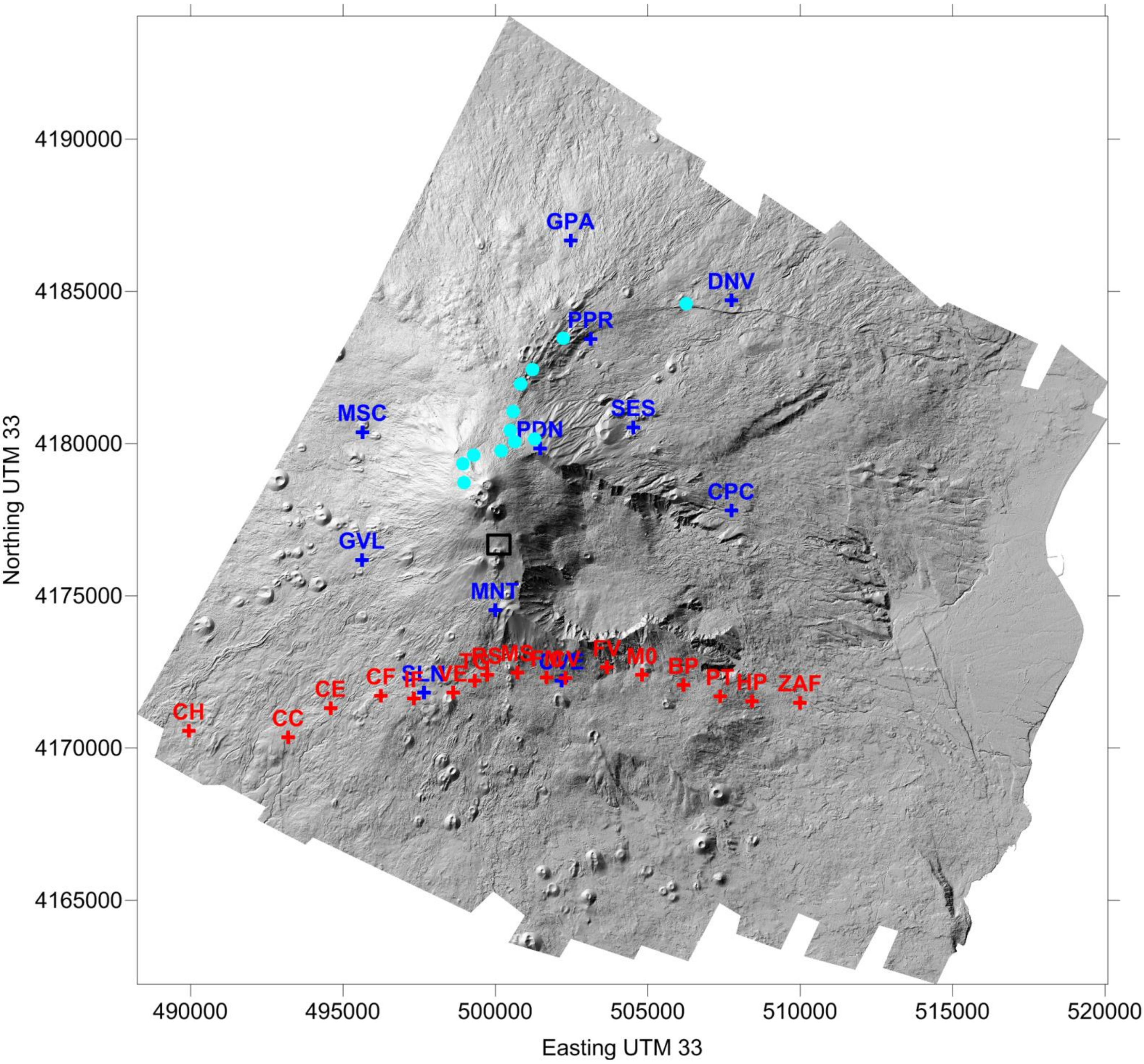
A relatively good improvement of refined VGGs was achieved in comparison with previously predicted values at most benchmarks (shift of blue marks closer to the black ones). Regarding the absolute gravity points, there is a shift towards positive VGG values in most cases, which is mainly the result of introducing the building correction. The most significant improvement has been achieved at PDN.

Relative gravity benchmarks



Points MNT_IG and LZ are new fields points with observed VGG. They show a good correlation between measured and predicted VGG values. Relative benchmarks show an opposite behavior compared to the absolute benchmarks, as they exhibit a shift towards negative VGG values in most cases. This results from the improved topographic correction, as well as the roadside wall corrections. The correlation between measured and refined predicted VGG values is significantly better at most benchmarks compared with the previously predicted values. There are still some benchmarks (like CC and CH), where predictions are not satisfactory. These benchmarks are situated under trees, so it was not possible to perform drone photogrammetry and get more accurate terrain model in the vicinity of the benchmarks.

The positions of the gravity network benchmarks and field points



Shaded relief map of the LiDAR DTM 2005 with the benchmarks, stations and field points of measured and predicted VGGs. Absolute gravity points are blue crosses, relative benchmarks are red crosses. Cyan circles represent points along the NE-rift.

Summarizing the VGG prediction improvements (refinements)

We can statistically evaluate the improvement of the VGG prediction as follows: standard deviation of differences between measured and predicted VGG values decreased from 39 to 13 µGal/m at absolute gravity points and from 18 to 12 µGal/m in case of relative benchmarks. In terms of maximum differences (in absolute sense) we got improvement from 117 to 22 µGal/m (absolute points) and from 39 to 28 µGal/m (relative points). The benchmark at PDN observatory lies underground, therefore the void building spaces contribute significantly here. Also the drone-photogrammetric refinement of the nearby topographic relief was significant here (improvement by 52 µGal/m). The inner-zone topographic contribution improvement was relatively small at other points (less than 10 µGal/m). In the case of absolute gravity points, the correction for the building effect on VGG reached 26 µGal/m. On the other hand, the accurate geodetic re-positioning of benchmarks resulted in an improvement in the topographic contribution to VGG of up to 45 µGal/m. These results indicate that accurate VGG predictions require precise information on topography and point positioning, as well as consideration of the contribution from man-made structures in close proximity to the observation point.

For more details:

Zahorec, P., Papčo, J., Vajda, P., Greco, F., Cantarero, M., & Carbone, D. (2018).
Refined prediction of vertical gradient of gravity at Etna volcano gravity network (Italy).
Contributions to Geophysics and Geodesy, 48(4), 299–317. https://doi.org/10.2478/congeo-2018-0014.

Vajda Peter, Pavol Zahorec, Juraj Papčo, Daniele Carbone, Filippo Greco, Massimo Cantarero, (2020)
Topographically predicted vertical gravity gradient field and its applicability in 3D and 4D microgravimetry:
Etna (Italy) case study, Pure and Applied Geophysics, https://doi.org/10.1007/s00024-020-02435-x

Sample of field work photos (July 2018)

At the edge of the Bocca Nuova crater (above and below) on Etna

Fogged by gases during observation at the summit craters


THANKS FOR YOUR ATTENTION
AND CU OUT THERE
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