ANALYSIS OF 20-YEAR TERRESTRIAL GRAVITY AND GROUND DEFORMATION CHANGES COLLECTED AT MT. ETNA: COMPARISON WITH SATELLITE DATA

IUGG BERLIN 2023 — THE 28TH GENERAL ASSEMBLY

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INTRODUCTION

- Recent times show the necessity of combining terrestrial and satellite gravity data to achieve better precision for several purposes, such as geological structures determination and geoid models construction.
- A preliminary comparison is presented using satellite and terrestrial gravity data, along with GNSS data, collected over a 20-year period (2002-2022) at Mt. Etna's Serra La Nave station (SLN) in Italy, at about 1.750m above sea level (*Fig. 1*), with the aim of explore the capabilities of this integrated approach to study the dynamics of volcanic phenomena over time spans of months to years.
- Terrestrial gravity data were obtained using an absolute gravimeter through nearly monthly campaigns, while GNSS measurements are continuously collected for monitoring purposes. Satellite data from the Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On (GRACE-FO) L3 solutions from the CNES/GRGS Earth gravity field model were selected, providing high-quality information on mass distribution at regional and global scales in a long-term interval.
- The comparison reveals long-term correlations within the analyzed time series, which could represent volcano-scale variations.

Fig. 1

GRAVITY MEASUREMENTS

The terrestrial gravimetric measurements were carried out at SLN station on almost monthly basis, from 2002 to 2022 [1] using the absolute gravimeter Microg Lacoste FG5 #238, designed for in laboratory or like-laboratory sites gravity measurements.

Typically, the g values were measured at a variable height of approximately 1.3 meters through 20 sets, consisting of 100 drops, which took around 15-20 hours to complete. Dedicated software facilitated automatic data acquisition, real-time processing, and automatic data storage. Additionally, it automatically corrected the measured g value for gravity changes caused by solid-earth tides, ocean tide loadings, polar motion, and local air pressure changes.

GRACE DATA

GRACE (2002-2017), and its successor GRACE-FO (since 2018), are satellite gravimetric missions that provide models reflecting temporal variations in the Earth's gravitational field, primarily caused by mass redistribution processes [2]. These gravity field models are expressed in normalized spherical harmonic coefficients.

Level 3 GRACE [3] products were used from 2002 to 2022, where gravitational variations such as Earth tides, ocean tides, 3D-atmospheric pressure fields and barotropic ocean response models were taken into account. The RL05 data version featured GRACE & GRACE-FO monthly and 10-day solutions up to 90 degree spherical harmonic, offering a spatial resolution of about 300km^2.

GNSS MEASUREMENTS

The GNSS data was collected at SLN station throughout 20 years of daily observations (2002-2022) and processed using GAMIT/GLOBK software, incorporating precise ephemerides from the IGS (International GNSS Service) and IONEX files to apply a second-order ionospheric corrections [4], and Earth orientation parameters from the IERS (International Earth Rotation Service) [5]. To enhance the local reference frame, over 160 continuous GNSS stations located in southern Italy were included in the processing.

Loosely constrained station coordinates were estimated on a daily basis, and subsequently, these daily GAMIT solutions were combined using GLOBK to derive the daily station coordinates in the ITRF14 reference frame [6].

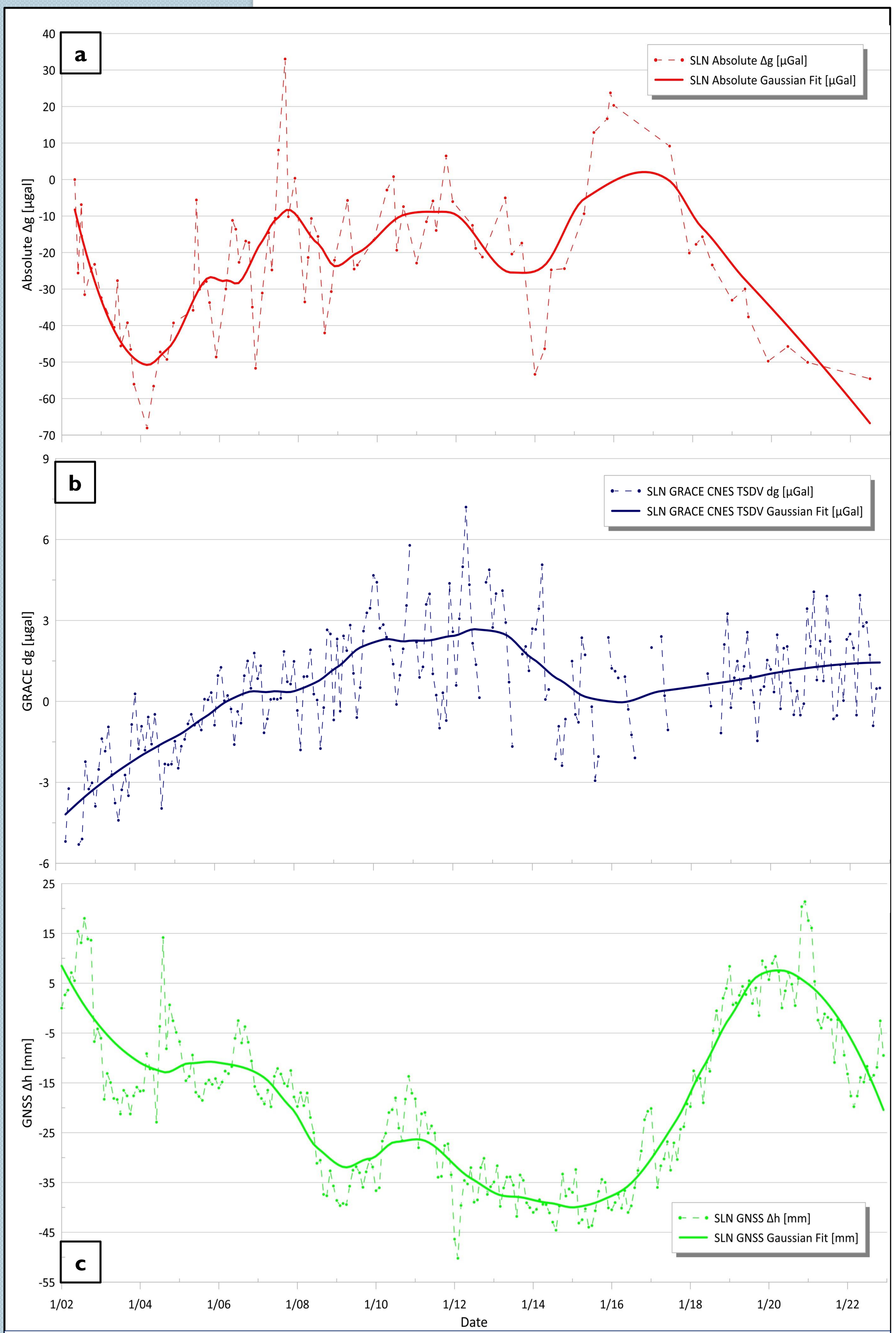

Fig. 3: a) SLN absolute gravity data b) SLN GRACE solutions c) SLN GNSS data.

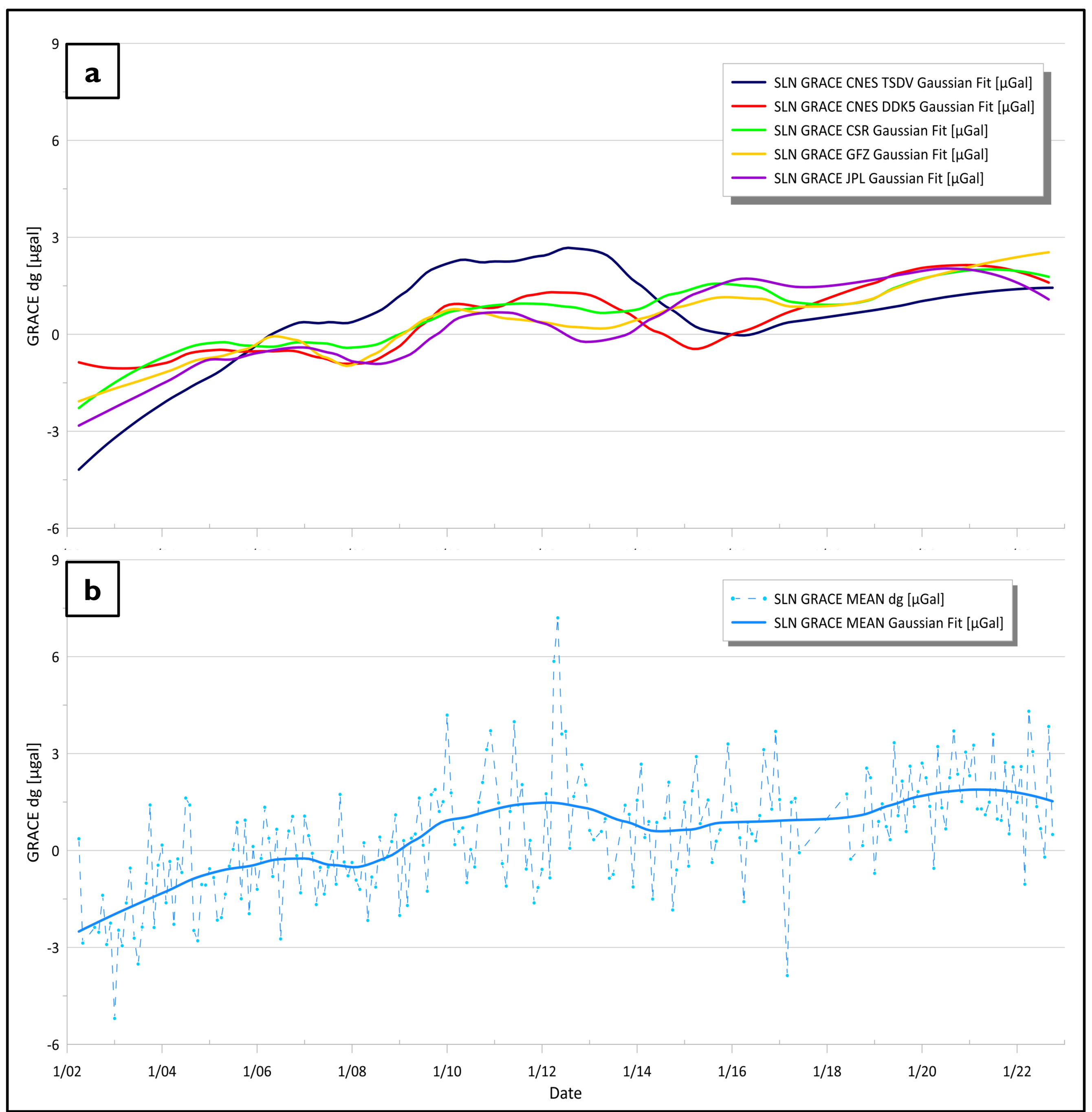

Fig. 2: a) SLN GRACE outcomes from different data centers.
b) SLN GRACE data averaged using results from different data centers.

METHODOLOGY

A 20-year (2002-2022) gravity anomaly comparison among four GRACE data processing centers (CNES/GRGS, CSR, GFZ, JPL) was conducted at SLN station in order to find the response that best adjust the terrestrial absolute gravity signal (*Fig. 2a*). For the CNES/GRGS, the filtered and truncated signals were both used in the analysis. In addition, the average of the five gravity anomaly signals was calculated and compared with the previous time series (*Fig. 2b*).

The CNES/GRGS RL05 TSDV monthly gravity anomalies [6] were chosen to continue with the analysis, due to its superior long-term fit with the terrestrial data. In this GRACE processing, reference field grid is removed, coefficients converted into 1° x 1° gravity anomalies grids, with grid values computed at the center of pixels. No smoothing or filtering was necessary since they have already been stabilized during the generation process.

Following the correction for known effects, reduced terrestrial absolute gravity values and GNSS height variations were compared with satellite data.

RESULTS

It is important to clarify that the following is a qualitative and not a quantitative analysis since GRACE provides gravity anomalies of the terrestrial geopotential, while terrestrial gravimeter offers the variation of absolute gravity over time. Furthermore, GRACE data has a spatial resolution of approximately 300km^2, whereas terrestrial gravimeters and GNSS provide gravity and height values directly at the measured point, respectively.

Considering GRACE resolution, periods with a high association can be observed between terrestrial and satellite signals. A positive trend from 2003 to 2013 can be seen in both gravity signals, and presently, the period from 2013 to 2022 is being investigated, where the absolute gravity measurements show a negative trend in contrast to the one exhibited by GRACE (*Fig. 3a, 3b*), which will be the analysis for further studies.

Moreover, the strongest and longest interrelation is apreciated between the GRACE and GNSS signals, where it is observed in the 2002-2016 period that the variation in altitude has a negative trend over time, while GRACE signal shows a positive trend, which would indicate that the gravity anomaly is due to a change in altitude (*Fig. 3b and 3c*). Currently, the 2016-2022 period is under analysis.

CONCLUSIONS

- The implementation of new technologies such as satellite gravimetry allows to obtain highly relevant information for studying and monitoring geodynamic context, especially in volcanic areas.
- The comparison among the three datasets allowed to estimate the long-term association, revealing a remarkable good fit in the long-term trend, suggesting that gravity changes are most likely attributed to hydrological and volcanological effects.
- This highlights the promise of combining terrestrial and satellite data to obtain a more comprehensive understanding of the temporal characteristics of the studied processes. The combined use of these dataset results crucial, especially in a harsh, unsteady and changing environment as active volcanoes.
- As GRACE provides information regarding the variation of the gravitational field over time, it is important to continue studying and analyzing this technology in conjunction with terrestrial measurements, particularly when gravimetric and GNSS measurements are available on-site over a long period of time and on an important active volcano like Mount Etna.

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