Title: 'Ground truth': contribution to the study of the sensitivity of the ESA-NASA NGGM-MAGIC satellite mission to time gravity changes.

Tutor: prof. U. Riccardi

Co-tutor(s): Dr. T. Pivetta (INGV), Dr. M. Reich (GFZ-Potsdam),

Proposal

Since 2003 the European Space Agency (ESA) has promoted studies to establish the scientific requirements, to identify the most appropriate measurement techniques and to define the system scenarios for NGGM (Next Generation Gravity Mission). NASA and ESA have agreed to cooperate towards a Next Generation Gravity Mission as a Mass-change And Geosciences International Constellation (NGGM-MAGIC).

The main goal of MAGIC is to identify optimized NGGM constellations for the long term monitoring of the temporal variations of Earth's gravity field at high resolution in time (down to 3 days) and space (75-100 km), providing continuity and improvement of the Earth mass change monitoring (and of the associated geophysical phenomena) service with respect to the predecessor missions (GOCE, GRACE, GRACE-FO). Earth's gravity changes are caused mainly by mass transport processes in continental hydrosphere, oceans, atmosphere, cryosphere, and solid Earth.

The NGGM-MAGIC mission, expected to be launched in 2028, is now in its calibration/- validation phase. Continental hydrology is expected to be the major contributor to the observed non-tidal gravity changes. In fact the Earth is a coupled dynamic system with a climate component, which includes the atmosphere, the oceans, the cryosphere and the continental hydrology. The state of art has demonstrated that separation of the couplings is possible, from the joint analysis of multiple geodetic measurements and/or of the climate and hydrology models.

We consider here the possibility of external validation using data from the superconducting gravimeters (SGs) in the European sub-array of the International Geodynamics and Earth Tide Service (IGETS) as 'ground truth' for comparison with simulated satellite signals. Simulated signals will be made available in the framework of ASI Implementation Agreement No. 2023-22.HH.0 CUP: F43C23000090005 "*NGGM/MAGIC, a breakthrough in understanding the Earth's dynamics*".

Research Program

We propose to carry out the so called "ground truth", that is to say the validation of the simulation of the expected gravity signature at the Earth's surface obtained from the NGGM MAGIC mission.

The "ground truth" in past and ongoing satellite missions, like GRACE and GRACE-FO, has been realized through a "downward continuation" of the satellite field. Satellite gravity variations at a SG location is usually reconstructed from the spherical harmonics (SH) Stokes coefficients provided by different analysis centres, with the help of appropriate combination of load Love numbers, describing the Earth's response to surface loads.

To do so, we need to consider the time gravity changes measurable in a ground area with sides of at least a few hundred km, where gravity records from multiple SG stations can be combined to provide a comparable average to the NGGGM-MAGIC footprint. This is possible only in Western Europe, where a dozen or so of SGs are currently operating fairly close together. The signals coming from the selected cluster of SGs will be collected and processed.

Compared to SG instruments, satellites are sensitive to larger-scale phenomena; therefore, any satellite/SG comparison relies on common variability among the SG timeseries on a regional scale. Empirical orthogonal function (EOF) analysis has proven to be an efficient method for seeking common variability in SG time-series, which can then be compared with gravity variations derived from the simulation of NGGM-MAGIC observations. Indeed, several multivariate statistical techniques, such as PCA and EOF, will be applied to extract the common principal modes from the SG signals. Principal component analysis, often denoted as PCA, is possibly the most widely used multivariate statistical technique in big data analysis. The technique was introduced into the atmospheric science literature by Obukhov (1947) and Lorenz (1956), and became popular for analysis of atmospheric and time-space geophysical data.

When multiple observations of data vectors are available PCA/EOF reduces the data set to a data set containing fewer new variables. These new variables are linear combinations of the original ones, and these linear combinations are chosen to represent the maximum possible fraction of the variability contained in the original data while being uncorrelated with each other. In geophysics it is in use the term empirical orthogonal function (EOF) to refer to geographically weighted PCA. Therefore, as a PCA, this is method of analysis is a decomposition of the signal or data set in terms of orthogonal basis functions, which are determined from the data, aimed at reducing the dimensionality of the matrix data.

<u>The research will be developed, over the three-years of the PhD program, as follows</u>:

1st Year:

Survey of literature data (dealing mainly with NGGM and previous experience of ground truth assessment for GRACE and GRACE-FO);

Attending PhD Courses mainly focused on data analysis, multivariate statistical techniques hydrology modelling;

2nd Year:

2-month at the University of Trieste to study PCA, EOF and other multivariate statistical techniques**;**

2-months abroad internship at GFZ in Potsdam (Germany) to deepen the modelling of gravity variations due to hydrology at different scales.

Presentation of research results at international conferences and in peer-reviewed articles.

3rd Year:

Final model of the expected time gravity signal in the NGGM-MAGIC footprint. Presentation of results at international conferences and in peer-reviewed articles. Writing of PhD thesis

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