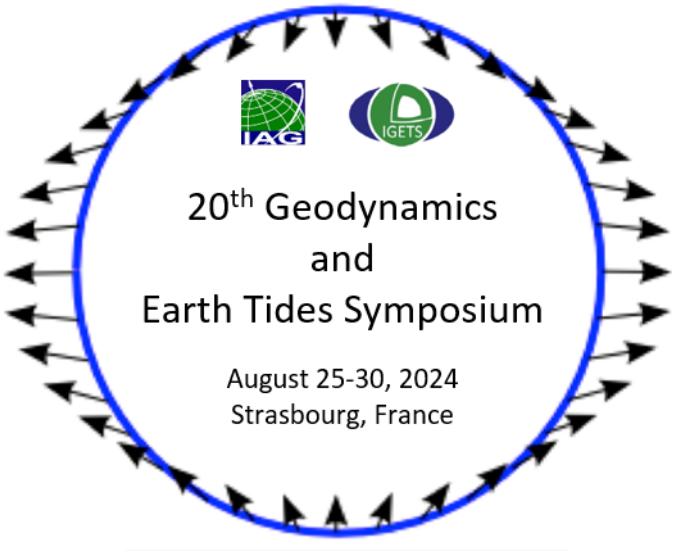
20th G-ETS: book of abstracts



Institut Terre & Environnement de Strasbourg | ITES | UMR 7063 de l'Université de Strasbourg & cnrs & ENGEES

cnrs TERRE & UNIVERS

Université de Strasbourg

FRANCE 2030

CNFGG

Table of contents

Session 1. Tides and non-tidal loading **9**

Poroelasticity for a layered gravitating Earth: Application in tides of well level, Jiangcun Zhou [et al.] 9

Detection and estimation of Slichter mode from IGETS superconducting gravimeter network data after the 2011 Tohoku earthquake, Vadim Milyukov [et al.] . . . 10

Non-linear ocean tidal loading and gravity variations, Jean-Paul Boy [et al.] . . . 12

New and updated long-periodic terms in the Earth tide-generating potential, Sergey Kudryavtsev [et al.] 13

A new tidal solution from thirty years of satellite laser ranging data, Richard Ray [et al.] 14

Ocean tidal parameters from GRACE and SLR data, Minkang Cheng 15

Non-tidal ocean loading signals of the North and Baltic Sea from terrestrial gravimetry, GNSS, and high-resolution modeling, Christian Voigt [et al.] 16

Comparison of atmospheric and non-tidal ocean loading corrections for high-precision terrestrial gravity time series, Ezequiel Antokoletz [et al.] 17

Impact of atmospheric and ocean tides on tidal analysis of superconducting gravity time series, Ezequiel Antokoletz [et al.] 18

IGETS gravity station Hurbanovo: comparison of gPhoneX gravity data with other collocated measurements, Juraj Janák [et al.] 19

Observation and modeling of the gravity signals of the January 15, 2022 Hunga-Tonga air wave A_1 at two stations near Strasbpurg, Walter Zuern [et al.] 20

Analysis with HiCum algorithm of signals generated with different instrumentations developed at ROB, Michel Van Ruymbeke [et al.] 21

Tidal deformations and internal structure of the Moon, Venus and Mars, Anthony Memin [et al.] 23

RAEGE Santa Maria Station: Surface loading in the middle of the Atlantic Ocean, Marta Calvo [et al.] 24

Insights from 26 years of continuous gravity and GPS recording at Medicina/Italy, Hartmut Wziontek [et al.] 25

Earth's Tidal Response for Maxwell, Burgers, and Andrade rheological models, Thiziri Saad [et al.] 26

GNSS processing in Northern Italy at hourly sampling rate, gravity, and detection of the Ocean tide loading, Anna Fantoni [et al.] 27

Effect of Earth equatorial flattening on the tide-generating potential, Sergey Kudryavtsev 28

From hydrological loading geodetic observation to climate change signature, Alicia Tafflet [et al.] 29

Evaluating the Impact of High-Resolution Non-tidal Atmospheric Models on GNSS Time Series in High-Latitude Regions, Fatemeh Khorrami [et al.] 30

Enhancing GNSS Data Accuracy: Implementing Non-Tidal Corrections for Atmosphere, Ocean, and Hydrology Loading at the observation level in GNSS data, Yohannes Getachew Ejigu [et al.] 31

Terrestrial gravity field time series analysis for new insights on the geodynamics of plate motion, Martina Capponi [et al.] 32

Ocean tidal loading tomography as a means of constraining the interior structure of the Earth, Andrei Dmitrovskii [et al.] 33

Tidal and non-tidal time gravity changes observed at Mt. Somma-Vesuvius and Campi Flegrei active volcanoes (Naples-Italy) by means of continuous gravity records, Alessandro Fedele [et al.] 34

Ocean tidal loading at the Finnish Antarctic station Aboa, Dronning Maud Land, Arttu Raja-Halli [et al.] 35

Possible contribution of tidal stress on seismic triggering in clusters of deep-intermediate seismic events around South America, Gloria Alexandra Moncayo [et al.] 36

Invited talk: Modeling gravimetric signals induced by minor ocean tides and their detection in superconducting gravimeter time series, Roman Sulzbach [et al.] 37

Session 2. Geodesy for hazard monitoring (seismo- and volcano-geodesy, etc.) 39

Micro-transient signal detection of episodic deformation of Akutan volcano, Kunpeng Shi [et al.] 39

Precise monitoring of subduction plate coupling status on the basis of DONET and borehole data analyses, Keisuke Ariyoshi [et al.] 40

Geometric controls on cascading rupture of the 2023 Kahramanmaraş earthquake doublet, Yijun Zhang [et al.] 41

Tidal Stress on a Seismic Fault and Its Dominant components of Earthquake Triggering, Xiaodong Chen [et al.] 42

On Some Aspects of the Dynamics of Campi Flegrei and Vesuvio Revealed by SAR Data, Antonella Amoruso [et al.] 43

Insights on glacially induced fault activity from geodynamic modeling and geodetic measurements, Holger Steffen [et al.] 44

The investigation of displacement of reference GNSS-stations in the Urals during 2020–2023 years, Danil Listvin [et al.] 45

Contribution of geodetic monitoring of landslides to the understanding processes at La Valette landslide (Southern Alps, France) and Viella landslide (Pyrenees, France), Gilbert Ferhat [et al.] 46

Long-term subsidence analysis of Oran city, Algeria using PSInSAR technique, Kamel Hasni [et al.] 47

GNSS data processed in PPP mode for the Estimation of the Local Solid Earth Tides: Improvements in Geophysical Investigations, Francesco Vespe [et al.] . . . 48

Seismic gravity variations in Chinese Mainland, Minzhang Hu [et al.] 50

Land Subsidence and Groundwater Storage Change Assessment using InSAR and GRACE in the Arid Environment of Saudi Arabia, Esubalew Yibrie 51

An adapted methodology for connecting InSAR to Earth-fixed terrestrial reference frame in the Chlef region in Algeria, Miloudi Sihem [et al.] 52

Estimating the velocities of space geodetic stations: application to DORIS, Sofiane Khelifa [et al.] 53

Geostatistics as a tool for interpolation and mapping of the gravity anomaly and the geoid height, Ilies Benikhlef 55

Impact of using different time scales on short term GNSS coseismic displacements: a case study of the 2022 Mw 7.6 MICHOACÁN, MEXICO Earthquake, Walid Bouaoula [et al.] 56

Analysis of changes in coordinates before and after the earthquake of 26 november 2019 of geodetic points in the Durres - Tirana area., Eduart Blloshmi [et al.] . . 57

Assessing tectonic velocities and crustal deformation in the Western Mediterranean using GPS measurements, Saddam Housseyn Allal [et al.] 58

Vertical Displacement Monitoring of embankment dams using satellite radar interferometry: Case studies from northwestern Algeria., Slimane Benyahia [et al.] 59

Application of the stacking algorithm HiCum method to analyze volcanic processes, François Beauducel [et al.] 60

Density structure and crustal magma system beneath Wudalianchi Volcano Field from 3D gravity imaging, Weikai Li [et al.] 62

Seismic versus aseismic slip for the 2023 Kahramanmaraş earthquake doublet, Rumeng Guo [et al.] 63

EuVeM2022: a European GNSS velocity model, Rebekka Steffen [et al.] 64

Invited talk: Advancing Geodesy in Hazard Monitoring: Insights from Gravity Measurements and Hydrological Modeling, Cheinway Hwang 65

Session 3. Monitoring of subsurface fluids (hydro-geodesy, hydro-gravimetry, geothermal monitoring, etc.) 67

Investigation of groundwater flows with gravity and seismic velocity changes in the Ailiao Creek and the Laonong River basins, Taiwan, Tzuyi Lien [et al.] . . . 67

Mass Budget at Theistareykir Geothermal reservoir (Northern Iceland) by means of time-lapse relative and absolute gravity measurements, Umberto Riccardi [et al.] 69

Gravity-Monitoring for Alpine Research Catchment Hydrology (G-MONARCH) – Introduction and First Results, Korbinian Achmüller [et al.] 70

Characterizing the drought events in Yangtze river basin via the insight view of its sub-basins water storage variations, Wenjing Ma [et al.] 72

Hydrogravimetric modelling of the Séchilienne landslide, Adrien Windenberger [et al.] 73

On the 3D annual motion for hydrogeodesy determined from different GNSS solutions, Janusz Bogusz [et al.] 74

Monitoring of the Theistareykir geothermal field in Iceland by hybrid gravimetry., Beatrice Giuliante [et al.] 75

Time-lapse relative-gravity measurements down a silo 10 metres deep isolate the gravity effect of local hydrology at Riga absolute-gravity station, Jaakko Mäkinen [et al.] 77

Tectonics and Environmental evidences of the seismological activities in vicinity of Lake Nasser, Egypt as deduced from integrated satellite observations, Khalid Zahran 79

Realization of gravimetric measurements in the local datum of tide gauges in Albania., Bledar Sina [et al.] 80

Using UAV Lidar data to predict sea level changes in Albania., Arli Llabani [et al.] 81

Hydrogeodetic signals from superconducting gravimeters network in Europe: "Ground Truth" for future quantum satellite gravity missions, Umberto Riccardi [et al.] . 82

Evaluation of a regional hydrological model using high-precision terrestrial gravity time series in the surroundings of the Geodetic Observatory Wettzell, Germany, Anna Winter [et al.] 84

Predicting seafloor topography from gravity anomaly and vertical gravity gradient anomaly, Jinhai Yu [et al.] 85

Analysis of water storage redistribution in Africa between 2003 and 2023, Using GRACE, TRMM and GLDAS datasets., Slimane Benyahia [et al.] 86

Invited talk: Geodetic monitoring of ground displacements and mass redistribution induced by deep volcanic fluids and ocean dynamics at the Geosciences Laboratory in Lanzarote (Canary Islands, Spain), Teresa Benavent 87

Session 4. New technologies, software and innovative concepts (cold-atom gravimetry, gradiometry, etc.) 90

Super-resolution of tides demonstrated with regularization, Adam Ciesielski [et al.] 90

Calibration of superconducting gravimeters by artificial accelerations, Hartmut Wziontek [et al.] 92

LUH-JAQGM2024: Joint Measurements with Absolute Quantum Gravimeters at Leibnitz University Hannover, Marvin Reich [et al.] 93

Airborne gravimetry with high-precision strapdown inertial measurement units, Vadim Vyazmin [et al.] 95

Detection limit to Earthquakes and seamounts of Quantum gravimeter payload combined with satellite-satellite tracking from single GRACE type to multiple couples constellations, Carla Braitenberg [et al.] 96

Systematic errors of superconducting gravimeters – An investigation of sensor differences of dual sphere superconducting gravimeters, Clara Beck [et al.] 98

Nano-Torque Induction System Based on Watch's Hands Rotation in Gravity Field, Justine Lebrun [et al.] 99

"B-grav" for very low gravity measurements at the surface of an asteroid, Michel Van Ruymbeke [et al.] 101

Low-frequency earth tides and free oscillations observations using fiber borehole strainmeters, Qi Guoheng [et al.] 102

Invited talk: Differential Quantum Gravimeters - instrumental progress and preparation of field-deployment, Camille Janvier [et al.] 103

Session 5. Time variable gravity and mass redistribution (glacial isostatic adjustment, ice mass changes, ocean dynamics, etc.) 105

Space-time gravity changes within Vrancea active seismic zone, Romania, Lucian Besutiu [et al.] 105

Influence of different ocean areas on the annual variations of the gravimetric M2 tidal parameters studied with a global Hycom ocean model, Eva Schroth [et al.] . 107

An anomalous GRACE gravity signal in the Atlantic Ocean originating from the Earth's deep interior, Charlotte Gaugne [et al.] 109

Progress on temporal gravity field modeling and applications at HUST, Zhou Hao [et al.] 110

HUST-Grace2024: Overview and Evaluation of a New GRACE-Only Temporal Gravity Field Model Series, Lijun Zheng [et al.] 111

Reduction of temporal variations in tidal parameters by application of the local response models at globally distributed SG stations, Adam Ciesielski [et al.] . . . 112

A regional enhanced scenario for next generation gravity mission, Tiantian Qing [et al.] 113

Vertical Displacements: GNSS and Gravimetric Station Collocation Study, Laura Pénzešová [et al.] 114

The Fennoscandian Land Uplift Gravity Lines revisited, Jaakko Mäkinen [et al.] 115

GIA related surface gravity vs. height changes using GRACE and GRACE-Follow on data in Fennoscandia, Mohammad Bagherbandi [et al.] 117

Three years of continuous gPhoneX tidal gravimeter supported with absolute gravity determinations at the SRC PAS Borowiec Astrogeodynamical Observatory, Jolanta Nastula [et al.] 118

Glacial isostatic adjustment and surface-mass changes estimate in Antarctica using multi-geodetic data, Alexandre Boughanemi [et al.] 119

Repeated absolute gravity measurements in Antarctica, Arttu Raja-Halli [et al.] . 120

Invited talk: Antarctic Mass Change and Contributions to Sea Level: Insights From Two Decades of Satellite Gravity Data, Rebecca Mcgirr 121

Session 6. Temporal variations of the Earth's rotation **123**

Simulation analysis on the impact of geophysical excitation on FCN parameters determination with celestial pole offsets, Xiaoming Cui [et al.] 123

Effect of the ocean tide on the Earth nutation from FES 2014 tidal model, Christian Bizouard [et al.] 124

Simulation analysis on the detectability of the FCN period variations in SG observations, Weiwei Yang [et al.] 125

Use of satellite data in the development of Algerian arid zones through ecological analysis of post-fire forest ecosystems, Ahmed Zegrar [et al.] 126

Gravitational Earth Shielding Effect (GESE) Analysis through Long-term Superconducting Gravimeters Data Acquisition, Michel Van Ruymbeke 127

Excitation of length-of-day obtained from various data sources, Malgorzata Winska [et al.] 129

Invited talk: Variations in Earth's rotation due to global mass distribution – assessment based on satellite gravimetry, geophysical models and climate data, Justyna Śliwińska-Bronowicz [et al.] 130

Author Index **130**

Session 1. Tides and non-tidal loading

Poroelasticity for a layered gravitating Earth: Application in tides of well level

Jiangcun Zhou *† [1], Ernian Pan [2], Heping Sun

[1] State Key Laboratory of Geodesy and Earth Dynamics,Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences – China
[2] Civil Engineering and Disaster Prevention & Water Environment Research Center, National Yang Ming Chiao Tung University – China

We propose a fully coupled two-phase (solid and pore fluid) poroelastic deformation theory for a spherically layered and self-gravitating Earth. The earth model consists of a solid inner core, a fluid outer core and poroelastic mantle and crust. The boundary-value problems are posed in the Fourier-transformed domain using the spherical system of vector functions, and analytical solutions are obtained in each layer using the dual-variable and position matrix method. As an application, the well level variation due to tide generating force is modeled, in which two specific kinds, i.e. confined and unconfined, of wells are both taken into account. This new theory shows that well level change is due to pore pressure variation inside the Earth, which is different from the current adopted one-phase (solid) purely elastic theory, in which tidal well level is simulated only by bulk strain. The current theory actually makes use of the simplified undrained condition. Unfortunately, this simplification is not realistic.

*Speaker
†Corresponding author: zjc@apm.ac.cn

Detection and estimation of Slichter mode from IGETS superconducting gravimeter network data after the 2011 Tohoku earthquake

Vadim Milyukov * [1], Michail Vinogradov [1]

[1] Lomonosov Moscow State University, Sternberg Astronomical Institute, Moscow – Russia

The Slichter mode (1S1) is the longest period mode of the Earth's free oscillations, caused by oscillations of the Earth's inner solid core relative to the outer liquid core. The period of the Slichter mode depends directly on the density jump between the outer liquid core and the inner solid core, which makes the detection of this oscillation very important for gaining a more detailed insight into the structure of the Earth's interior. In this work, we search and estimate the parameters of the Slichter mode from the IGETS superconducting gravimeter network data (records from 21 sensors of 16 gravimeters) obtained after the 2011 Tohoku earthquake in Japan (9.0 Mw).
To detect and estimate the Slichter mode, an improved algorithm based on the maximum likelihood method was used. The previous version of the algorithm was used by the authors to search for the mode from strain observations and to estimate the overtone parameters of the Slichter mode.

The new version of the algorithm takes into account the refined prediction of the theoretical mode excitation (in particular, the mutual relationship between the splitting parameters and the degenerate frequency, as well as a wider possible range of splitting parameters). To reduce the influence and to take into account disturbances of different nature (including coherent ones associated with numerous tidal harmonics), the algorithm is supplemented with the procedures of filtering, inertia-free nonlinear input data converter, and a block of whitening of sufficient statistics. The main novelty of the algorithm is the use of optimal data complexing obtained from different gravimeters. For the search of the Slichter mode, the sensitivity of a single gravimeter is not sufficient for its observation, so the combination of 20-30 instruments can provide the necessary increase in the signal-to-noise ratio at the output of the detection system to register the mode.

Based on the results of data processing, estimates of the degenerate period of the Slichter mode and the splitting parameters of the Slichter mode are obtained. We have evaluated the reliability of the obtained results taking into account the correlation properties of sufficient statistics and their distribution density. The two most probable estimates of the Slichter mode (4.61 and 4.63 hours) have a reliability of 77% and 70%, respectively. The third estimate (5.27 hours) has a lower reliability of 16%. The results obtained allow us to conclude that the probability of observing the Slichter mode after the Tohoku earthquake is high. The values of the density jump

*Speaker

at the boundary between the inner and outer core of the Earth (776 kg/m3, 769 kg/m3, and 583 kg/m3) corresponding to the found estimates of the Slichter mode period are also calculated.
This work was supported by RSF Grant № 23-27-00237.

Non-linear ocean tidal loading and gravity variations

Jean-Paul Boy * [1], Richard Ray [2], Florent Lyard [3], Svetlana Erofeeva [4]

[1] Institut Terre Environnement Strasbourg – Centre National de la Recherche Scientifique – France
[2] NASA Goddard Space Flight Center – United States
[3] Laboratoire d'Etudes en Géophysique et Océanographie Spatiales – Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS) – France
[4] Oregon State University – United States

Being one of the most precise and stable geodetic instruments, superconducting gravimeters have the ability to monitor gravity changes with an accuracy of typically one nanogal (10-11 m.s-2). Over the years, gravity measurements have been used to validate ocean tide models, in particular in the diurnal and semi-diurnal bands, but also at monthly and sub-monthly periods. Because of their smaller amplitudes, non-linear ocean tidal loading effects are more challenging to observe in most geodetic observation techniques, but have been clearly identified in ground measurements, such as strainmeters, tiltmeters and superconducting gravimeters.
We revisit our previous study (Boy et al., 2004) which compared 9 gravity records in Western European to available non-linear tidal models and showed their quantitative agreement, at least when the Gulf of Biscay is included in the tidal model.

Over the last two decades, longer time series from worldwide superconducting gravimeters became available thanks to the International Geodynamics and Earth Tide Service (IGETS), and tidal models have been significantly improved, in particular in terms of spatial resolution.
We focus here on the main tidal constituents in the quarter and sixth-diurnal frequency bands, although other constituents exist in the diurnal, semidiurnal and ter-diurnal bands, and show the improved agreement between worldwide gravity tidal observations and the most recent tidal models.

*Speaker

New and updated long-periodic terms in the Earth tide-generating potential

Sergey Kudryavtsev *† [1], Rodolfo G. Cionco [2]

[1] Sternberg Astronomical Institute, M.V. Lomonosov Moscow State University – Russia
[2] CONICET & Grupo de Estudios Ambientales de la UTN, Buenos Aires – Argentina

We present a new solution for long-periodic terms in the Earth tide-generating potential (TGP). The terms are obtained with help of a modified spectral analysis method. It was earlier employed for developing the KSM03 series for the Earth TGP (Kudryavtsev, J. Geodesy, 77:829, 2004). In the present study we made the spectral analysis of TGP numerical values tabulated with a step of 1 day over 30,000 years (13,000 BC – 17,000 AD). The latest long-term numerial ephemerides DE441 (Park et al., Astron. J., 161:105, 2021) were used as the source of the Moon, Sun and planets coordinates. For comparison, KSM03 series were obtained through the spectral analysis of similar values calculated on the basis of DE406 ephemerides (Standish, JPL IOM 312.F, 1998) over 2000 years, 1000 – 3000. Such the increase in the time interval of the developed data, using the newest planetary/lunar ephemerides and some improvements of the method allow us to obtain new Earth TGP terms of centennial and millennial periods and improve the known long-periodic terms. A new catalogue of terms in the Earth TGP development that have a period exceeding one year is presented.

*Speaker
†Corresponding author: ksm@sai.msu.ru

A new tidal solution from thirty years of satellite laser ranging data

Richard Ray * [1], Bryant Loomis , Kenneth Rachlin

[1] NASA Goddard Space Flight Center – United States

We have developed new solutions for certain low-degree spherical harmonics of the tides from 30 years of satellite laser ranging measurements. Eight geodetic (cannonball) satellites were used, including LARES-1 and LARES-2, which were launched in 2012 and 2022, respectively, with unique 70∘ inclinations that helped fill previous sampling gaps. The estimated tidal spherical harmonics are those most responsible for long-period perturbations in the satellite orbits: order-2 semidiurnal, order-1 diurnal, and order-0 (zonal) long-period tides. Partitioning the SLR data shows the solutions are robust, although there remains a slight correlation between degrees 2 and 4. Mean monthly solutions reveal a fairly clear seasonal cycle in some components of M2, likely from true seasonal variability in ocean and/or atmospheric tides. (An annual cycle in the astronomical potential for M2, induced by the so-called "annual equation" of lunar theory, is already accounted for in our solutions.) Of greatest scientific interest are the degree-2 terms that are directly related to the planetary tidal dissipation rate. An ultimate goal is placing improved constraints on mantle anelasticity at tidal periods. However, SLR alone cannot distinguish among solid earth, ocean, and atmospheric tides, so independent models are needed. Altimeter-based ocean tide models are quite consistent for the largest constituents. More work is needed on atmospheric tides; we show that tides extracted from ECMWF ERA5 reanalysis (or any other meteorological reanalysis) are unsatisfactory.

*Speaker

Ocean tidal parameters from GRACE and SLR data

Minkang Cheng * [1]

[1] Center for Space Research, The University of Texas at Austin, USA – United States

Precise knowledge of ocean tides is important for geodynamic study and determining high-resolution temporal gravity fields from, for example, the GRACE missions. The global O1 and M2 ocean tide parameters with sizes of 60x60 or 90x90 were estimated along with 105-month gravity solutions from GRACE data to evaluate the effects of ocean model error on the determination of temporal gravity fields. Tidal parameters up degree 6 for 8 major ocean tides for diurnal and semi-diurnal ocean tides were estimated from GRACE and SLR data of 15 years to evaluate the consistency or accuracy between GOT 4.7/4.8, FES2014 and EOT20 models. A detailed comparison will be presented.

*Speaker

Non-tidal ocean loading signals of the North and Baltic Sea from terrestrial gravimetry, GNSS, and high-resolution modeling

Christian Voigt *† [1], Roman Sulzbach [1], Henryk Dobslaw [1], Adelheid Weise [2], Ludger Timmen [2], Zhiguo Deng [1], Marvin Reich [1], Nico Stolarczuk [1], Heino Peters [3], Michael Fietz [3], Maik Thomas [1], Frank Flechtner [1]

[1] German Research Centre for Geosciences (GFZ), Potsdam, Germany – Germany
[2] Leibniz University Hannover (LUH), Hannover, Germany – Germany
[3] Alfred-Wegener-Institute (AWI), Bremerhaven, Germany – Germany

Non-tidal ocean loading signals are known to be a significant source of geophysically induced noise in gravimetric and geodetic observations also far-away from the coast and especially during extreme events such as storm surges. Operational products suffer from a low temporal and spatial resolution and reveal only small amplitudes on continental stations. Dedicated high-resolution sea-level modelling of the North and Baltic Sea provides a largely improved prediction of non-tidal ocean loading signals. Superconducting gravimeter and GNSS observations on the small offshore island of Heligoland in the North Sea are used for a thorough evaluation of the model values revealing correlations of up to 0.9 and signal reductions of up to 50% during a storm surge period of one month in Jan-Feb 2022. Additional continental superconducting gravimeter stations are used to assess the benefits from high-resolution modelling for an improved signal separation further away from the coast.

*Speaker
†Corresponding author: christian.voigt@gfz-potsdam.de

Comparison of atmospheric and non-tidal ocean loading corrections for high-precision terrestrial gravity time series

Ezequiel Antokoletz [*†] [1], Jean-Paul Boy [2], Hartmut Wziontek [1], Kyriakos Balidakis [3], Thomas Klügel [1], Henryk Dobslaw [3], Tocho Claudia [4]

[1] Federal Agency for Cartography and Geodesy (BKG) – Germany
[2] Institut Terre Environnement Strasbourg – CNRS – France
[3] German Research Centre for Geosciences - Helmholtz-Centre Potsdam – Germany
[4] Universidad Nacional de la Plata [Argentine] – Argentina

Besides Earth tides, the atmosphere causes the most significant contributions to time-variable gravity measurements. State-of-the-art modelling approaches of atmospheric loading (Newtonian attraction and deformation) benefit from numerical weather models in order to account for global air mass variations. Atmospheric loading effects are often computed assuming that the oceans respond as an Inverse Barometer (IB) which is not completely valid for periods shorter than a few weeks. Therefore, a more precise modelling is only possible considering the ocean response to atmospheric pressure and winds based on simulations of an ocean dynamic model. Superconducting gravimeters (SGs) measure temporal gravity variations with high-resolution and exceptional stability and are capable to sense mass redistribution in the atmosphere, the oceans and in continental hydrology. In this sense, although SGs provide information for particular stations, they allow for a reliable validation of mass variations represented by models for atmosphere and oceans. In the present study, a comparison of atmospheric and non-tidal ocean loading corrections as calculated by the recently updated Atmospheric attraction computation service (Atmacs) and the EOST Loading Service is performed. For this comparison, a set of SG stations is selected, with focus on stations close to the oceans where non-tidal ocean loading effects are more significant. An emphasis is made on the reduction of gravity residuals by different corrections.

[*]Speaker
[†]Corresponding author: Ezequiel.Antokoletz@bkg.bund.de

Impact of atmospheric and ocean tides on tidal analysis of superconducting gravity time series

Ezequiel Antokoletz [*†] [1], Roman Sulzbach [2], Kyriakos Balidakis [3], Henryk Dobslaw [3], Hartmut Wziontek [1]

[1] Federal Agency for Cartography and Geodesy (BKG) – Germany
[2] German Research Centre for Geosciences (GFZ), Potsdam, Germany – Germany
[3] German Research Centre for Geosciences - Helmholtz-Centre Potsdam – Germany

Time-variable terrestrial gravity measurements are dominated by Earth and ocean tides, which have to be carefully modelled in order to further investigate gravity contributions of smaller magnitude. Although of lower amplitude compared to ocean tide loading effects, the atmosphere causes also effects in the tidal band which are principally excited by radiation. Therefore, atmospheric main tidal constituents are found along the diurnal, semidiurnal and terdiurnal band, with largest amplitudes at the S1 and S2 tidal frequencies. Superconducting gravimeters (SGs) provide the most stable gravity signal with high-precision and temporal resolution and have demonstrated their capability to detect and separate small periodic components in tidal analysis. In the present study, we investigate the impact of atmospheric tides on tidal records from selected stations of the International Geodynamics and Earth Tide Service (IGETS) located in (or close to) the equatorial latitude band where atmospheric tides have larger amplitudes. In order to correctly discriminate between different contributors to tidal waves, a careful consideration of ocean tide loading effects is essential and is based on a consistent and optimal combination of the FES2014b, the EOT20 and TiME22 ocean tide models. Tidal analysis is performed with the latest version of ETERNA-x and atmospheric effects are based on the Atmospheric attraction computation service (Atmacs).

[*]Speaker
[†]Corresponding author: Ezequiel.Antokoletz@bkg.bund.de

IGETS gravity station Hurbanovo: comparison of gPhoneX gravity data with other collocated measurements

Juraj Janák * [1], Laura Pénzešová[1], Ľubomíra Gerhátová [1], Juraj Papčo [1]

[1] Slovak University of Technology in Bratislava – Slovakia

Hurbanovo, as the only station for continuous monitoring of gravity changes in Slovakia, is equipped with a relative spring gravimeter gPhoneX#108. The gravity station was established in 2019 and has been a part of the International Geodynamics and Earth Tide Service (IGETS) since 2021. In addition to gravity measurements, several complementary measurements at this station are carried out, including GNSS for geodetic positioning collocated with InSAR corner reflectors, accelerometer measurements for seismic monitoring, meteorological measurements including atmospheric pressure, temperature, and precipitation, as well as hydrological measurements of soil moisture and groundwater levels. Our contribution includes a fundamental statistical and correlation analysis of the temporal data collected through these diverse techniques and sensors, highlighting foundational insights obtained from the investigation.

*Speaker

Observation and modeling of the gravity signals of the January 15, 2022 Hunga-Tonga air wave A_1 at two stations near Strasbourg

Walter Zuern * [1], Séverine Rosat , Jacques Hinderer [2], Jean-Paul Boy , Fred Littel

[1] Black Forest Observatory and KIT – Germany
[2] Institut Terre Environnement Strasbourg – Université de Strasbourg, CNRS UMR7063 – France

On January 15, 2022 the great volcanic explosion (HTHH) at the Hunga Tonga - Hunga Hua'apai Island in the South Pacific sent several types of waves around the Earth: seismic, oceanic, and atmospheric. The Lamb wave in the atmosphere traveled several times around the Earth and caused clearly observable disturbances on barometers, seismic sensors, and gravimeters.
We show the disturbances on barometers and the superconducting gravimeters at the stations J9, near Strasbourg and BFO, 57 km to the east, from the first arriving Lamb wave pulse A_1, with a double amplitude of 2.3 hPa (ten times the amplizude of the equivalent pulse from the explosion of Mount St. Helens in 1980).

We subsequently make attempts to model these disturbances in gravity using simple physics based models with some success. This modeling is somewhat hampered by the simultaneously arriving Rayleigh waves from HTHH. It turns out that the inertial accelerations due to ground displacement by the pressure loading are very important in this case as already shown by Imanishi (2022) for the superconducting gravimeter at Matsushiro, Japan. We also observed that this inertial effect is much larger at J9 than at BFO, while the pressure pulses have about equal amplitudes. This must with high probability be blamed to the higher deformabilityof the upper layers of the crust at J9 (suft fluvial sediments) compared to the situation at BFO where granites and gneisses make up the rocks near the surface.

*Speaker

Analysis with HiCum algorithm of signals generated with different instrumentations developed at ROB

Michel Van Ruymbeke *† [1], François Beauducel‡ [2], Justine Lebrun [3], Sébastien Toussaint [3]

[1] Royal Observatory of Belgium – Belgium
[2] Institut de Physique du Globe de Paris (IPGP) – Institut National des Sciences de l'Univers, IPG PARIS, Université de la Réunion, Centre National de la Recherche Scientifique : UMR7154, Université Paris Cité : UMR7154 – IPGP, 1 rue Jussieu, 75238 Paris cedex 05 ; Université Paris Diderot, Bât. Lamarck A case postale 7011, 75205 Paris CEDEX 13, France
[3] Institute of Information and Communication Technologies, Electronics and Applied Mathematics – Belgium

In this article, we present an analysis of instrumental developments based on the expertise gained in tidal instrumentation design. Indeed, taking advantage of known signal periodicities, very small signatures can be extracted with the presented HiCum method. With the rejection of random noise increasing with the number of data collected, this method is perfectly suitable for the GGP and its lengthy series. Different instruments served to illustrate the features and selectivity of the signal processing method.
Firstly, oceanic tides' components of the signal resulting from an EDAS sea gage located inside a lava tube in the site of Jameos del Agua (Lanzarote) were separated with the method and analyzed. This confirmed the high dynamics of our sea level probes whose principle is based on weighting the water column over the sea surface. A reference on/off output signal (over or under a certain sea level) was compared to the probes' signal, confirming an annual increase of about 3.8 mm/year in the sea water level.

Then, the observation of tidal modulation on very little water flow feeding droplets dripping from stalactites in the Rochefort karstic cave served as an illustration of tidal effects extraction in a noisy environment. Physical mechanisms at play in this situation may be a reflection of tidal interactions with the stresses causing the rock to crack. Observation of flow changes in volcanic and seismic areas with existing karstic caves could be directly linked to tectonic events, reflecting precursory behaviors of natural hazards. Additionally, in the Rochefort cave data, the HiCum processing method showed systematic modulations induced by solar thermal stress, atmospheric pressure, and Earth tides.

Another sensor, named BOS (for Bolometric Oscillation Sensor), was designed for the PICARD satellite of the CNES. The BOS has monitored the Sun and Earth's radiative energy with very high dynamics. After three years in orbit, the BOS data, after processing, showed long-period

*Speaker
†Corresponding author: oasismini@hotmail.com
‡Corresponding author: beauducel@ipgp.fr

modulation effects corresponding to the phase of the Moon's periodic movement. It confirmed interactions between the mean amplitude of oceanic tides and the Earth's albedo.
Eventually, the HiCum signal processing method can help the calibration procedures when applied simultaneously to the referenced inputs and the monitoring instrument output. The Gravitational Symmetric Vertical Pendulums (GSVP) prepared at ROB (Royal Observatory of Belgium) to measure the gravitational constant G, adopted this approach. In these experiments, the rotation of a watch's hands is used to induce a calibrated stable mass displacement, modifying the gravitational field around the pendulum. HiCum method's resolution allows the extraction of such minute signals as the ones from the watch's hands and their periodic components. With these tools, the transfer function of instruments can be determined and even monitored. This was done for the data treatment of the Inertial lift calibrating the LCR336 in Dourbes' laboratory.

Tidal deformations and internal structure of the Moon, Venus and Mars

Anthony Memin * [1], Agnes Fienga [2], Clement Ganino [3], Alex Guinard [3]

[1] Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, IRD, Géoazur – Université Côte d'Azur (UCA) – France
[2] Observatoire de la Côte d'Azur, Université Côte d'Azur, CNRS, IRD, Géoazur – Observatoire de la Cote d'Azur – France
[3] Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, IRD, Géoazur – Université Côte d'Azur (UCA) – France

We have developed a tidal tomography methodology using tidal deformations of telluric bodies from space-based observations together with the conservation of the mass and the moment of inertia that provides with 1D inner planetary structures. We show that, in order to have conclusive assessments about the internal structure, other arguments that involve temperature profiles for different classes of material have to be considered. We review here the recent results we obtained for the Moon, Venus and Mars. For the Moon, we show how considering the quality factor Q for two periods of excitation (27 days and 1 year), the Love numbers k2 from the GRAIL mission and h2 from LRO and LLR as well as thermo-dynamical profiles for different assumptions of compositions for the Moon mantle, we were able to give conclusive results regarding the existence of the Moon solid inner core. For Venus, we show how the hypothesis of the existence of a solid inner core cannot be excluded by just considering tidal deformations. For Mars, we show that the existence of a mantle basal molten layer, as recently proposed from Insight seismic data, is not compatible with the existence of a solid inner core.

*Speaker

RAEGE Santa Maria Station: Surface loading in the middle of the Atlantic Ocean

Marta Calvo *† [1], Jose Antonio López Perez [2], Gabriel Gómez Molina [2], Abel García-Castellano [2]

[1] Instituto Geografico Nacional – Spain
[2] Observatorio de Yebes – Spain

At the end of 2022, the iGrav#51 superconducting gravimeter was installed at the RAEGE Santa María station. This station is located in the interior of the easternmost island of the Azores archipelago (Portugal) and belongs to RAEGE (Portuguese/Spanish acronym for Atlantic Network of Geodynamic and Space Stations), a unique geodesy project comprising four Fundamental Geodetic Stations strategically located on three different tectonic plates (North American plate, African plate and Eurasian plate)
The location of the island (in the middle of the Atlantic Ocean), and the quite extreme environment due to the islands' dimensions, orography, and exposure to oceanic winds, allow us to study how oceanic and atmospheric loads affect our long gravity records under these circumstances.
Three years earlier (2019), a spring gravimeter (Graviton EG#1183) was installed on the same pillar to carry out preliminary gravity studies on the station, but it was with the arrival of the iGrav#51, thanks to the SG great instrumental improvements respect to the classical spring gravimeters, and with the absolute gravity measures carried out in the spring of 2023, that we can analyze these loading effects in detail.
Prior to its final installation in Santa Maria, the iGrav#51 spent almost a year recording in parallel with the OSG#64 in the RAEGE Yebes station Gravimetry Laboratory, located in Spain mainland. The parallel recording of both instruments allowed us to make several instrumental comparisons with several gravimeters that measured during that period in different pillars, as 2 gPhone gravimeters (#172 and #173) and the absolute FG5#211.

*Speaker
†Corresponding author: mcalvo@transportes.gob.es

Insights from 26 years of continuous gravity and GPS recording at Medicina/Italy

Hartmut Wziontek * [1], Reinhard Falk [1], Susanna Zerbini [2], Luca Tavasci [3], Matteo Berti [4], Ezequiel Antokoletz

[1] Federal Agency for Cartography and Geodesy (BKG) – Germany
[2] Department of Physics and Astronomy (DIFA), University of Bologna – Italy
[3] Department of Civil Engineering, Chemistry, Environment and Materials (DICAM), University of Bologna – Italy
[4] Department of Biological, Geological and Environmental Sciences (BIGEA), University of Bologna – Italy

After more than 26 years, the continuous record of the superconducting gravimeter GWR C-023 at the station Medicina, Italy ended in January 2024. The time series was supported by regular absolute gravity observations and vertical displacements are monitored by continuous GPS. Such a long, almost undisturbed record allows for a detailed tidal analysis, including the 18.6-year period lunar nodal tidal cycle. Local effects from hydrology and soil mechanics will be considered together with global models for continental hydrological loading. Long-term height changes are compared by means of Singular Spectrum Analysis, allowing to separate decadal changes and discuss the gravity to height ratio.

*Speaker

Earth's Tidal Response for Maxwell, Burgers, and Andrade rheological models

Thiziri Saad * [1], Séverine Rosat† [1], Jean-Paul Boy‡ [1]

[1] Institut Terre Environnement Strasbourg – Université de Strasbourg, CNRS UMR7063, EOST – France

The Earth's visco-elastic deformation is commonly represented by Maxwell or, more rarely Burgers models, from tides to the long period glacial isostatic adjustment, or by analogical absorption bands models at seismic frequencies. We present a comparative analysis of three main rheological models – Maxwell, Burgers, and Andrade – to assess their effectiveness in modeling the Earth's rheological responses. Andrade rheology has been merely used for the Earth while it has proven to be efficient to describe the visco-elastic response of other planetary and satellite interiors. We have developed theoretical responses for each of these models from seismic frequencies to very long periods. We first compare the Andrade theoretical behavior to the classical Maxwell and Burgers models. We then focus on the tidal response by comparing the predicted gravimetric factors for these three rheological models with the measured ones from long timeseries from worldwide superconducting gravimeters of the IGETS network.

*Speaker
†Corresponding author: severine.rosat@unistra.fr
‡Corresponding author: jeanpaul.boy@unistra.fr

GNSS processing in Northern Italy at hourly sampling rate, gravity, and detection of the Ocean tide loading

Anna Fantoni *† [1], Carla Braitenberg [1], Roberto Devoti [2]

[1] University of Trieste – Italy
[2] Istituto Nazionale di Geofisica e Vulcanologia - Sezione di Roma – Italy

Ocean tides especially in closed sea areas can deviate significantly from the theoretical values due to the bathymetry. Even though the amplitudes of the ocean tides in the Mediterranean Sea are relatively small, the availability of the best tidal model is essential for geodetic and geodynamic applications.
We analyse different types of geodetic techniques to investigate current ocean tidal models (FES2014b, EOT20, TPOX9-Atlas) for the Adriatic Sea, eventually to further refine the ocean-tide model for this particular area. The data used are GNSS double difference products at hourly sampling rate obtained from processing with GNSS Bernese software. The 60 stations processed over a one-year timespan are collected from different European networks. Furthermore, we process tide gauge observation along the Adriatic coast. Gravity data collected from two relative gravimeters located in the Skocjan cave (Slovenia) are used as a control of the ocean tide models.

By testing two weeks of GNSS data, we discovered a discrepancy in amplitudes and phases for the horizontal components between the observations and the predicted model for FES2014b, while the observed vertical component presents good coherence with the model. We believe that by expanding the timespan interval of observations, investigating other global ocean loading models and adding gravity data, we should be able to obtain a clearer understanding of the identified discrepancies.
In a second step, the analysis looks at the detection of non-tidal loading high stance effects present in GNSS and gravity time series, an important condition for the estimation of accurate rates of the Earth's crust movement in the studied area.

*Speaker
†Corresponding author: anna.fantoni@phd.units.it

Effect of Earth equatorial flattening on the tide-generating potential

Sergey Kudryavtsev *† [1]

[1] Sternberg Astronomical Institute, M.V. Lomonosov Moscow State University – Russia

Latest developments of the Earth tide-generating potential (TGP), e.g. HW95 (Hartmann & Wenzel, Geoph. Res. Lett., 22:3553, 1995), RATGP95 (Roosbeek, Geophys. J. Int., 126:197, 1996), KSM03 (Kudryavtsev, J. Geodesy, 77:829, 2004) include a number of terms caused by the effect of the Earth's *polar* flattening. In the present study we additionally consider the effect of the Earth's *equatorial* flattening. Explicit analytical expressions for the relevant part of the TGP are derived. New terms of the TGP development due to the Earth's tri-axial figure are obtained. Amplitudes of nineteen such terms exceed the cut-off limit used by modern tidal potential catalogues. Three of new terms have the frequency sign negative to that of the Earth rotation. It is not the case for any previously found term of the Earth TGP development. The new terms are suggested for including in the current and future tidal potential catalogues.

*Speaker

†Corresponding author: ksm@sai.msu.ru

From hydrological loading geodetic observation to climate change signature

Alicia Tafflet *† [1], Joëlle * [1], Jean-Paul Boy [2], Lissa Gourillon [3], Frederic Durand [1], Jean-Michel Lemoine [4], Agnès Baltzer [5], Jérôme Verdun [6]

[1] Laboratoire Géomatique et Foncier – le cnam – France
[2] EOST – EOST – Bâtiment Descartes - 5, rue René Descartes - F-67084 Strasbourg, France
[3] Littoral, Environnement, Télédétection, Géomatique – Nantes Université – France
[4] Centre National d'Etudes Spatiales [Toulouse] – Centre National d'Etudes Spatiales - CNES (Toulouse, France) – France
[5] Littoral - Environnement - Télédétection - Géomatique (LETG Nantes) – Université de Nantes, CNRS : UMR6554 – Campus Tertre BP 81227 44312 NANTES Cedex 3, France
[6] Laboratoire Géomatique et foncier – Conservatoire National des Arts et Métiers [CNAM], Conservatoire National des Arts et Métiers [CNAM] : EA4630 – France

Solid Earth's response to water mass transfers leads to variations in the Earth's gravity field and crustal deformations that can be monitored by GNSS (Global Navigation Satellite System) and by GRACE (Gravity Recovery And Climate Experiment) and GRACE Follow-On space gravity missions. Despite the highly complementarity of these observations in terms of both spatial and temporal resolutions, identifying hydrological loading signatures related to climate change is a complex task. To address this challenge, we used the MSSA and seasonal adjustment methods. We demonstrated the efficiency of these methods in two very different areas: Svalbard and South America. In the Svalbard region, the main difficulty is to be able to isolate, in the observed signals, the part due to the current ice melting from the part due to the solid Earth's response to past events (GIA and LIA). Indeed, these phenomena contribute unevenly to the strong uplift observed locally by GNSS in this region, as well as to the gravitational signal observed by GRACE for the region considered as a whole. In South America, the hydrological signal shows huge annual variations superimposed to interannual variations linked to extreme events such as drought or floods. The key is therefore to distinguish the part of the observed signals associated with climate change from the seasonal and well-known trends. Finally, we compared our results with in situ and climatic datasets to assess their reliability.

*Speaker
†Corresponding author: alicia.tafflet@lecnam.net

Evaluating the Impact of High-Resolution Non-tidal Atmospheric Models on GNSS Time Series in High-Latitude Regions

Fatemeh Khorrami *† [1], Yohannes Getachew Ejigu [1], Jyri Näränen [2], Arttu Raja-Halli [2], Maaria Nordman *

1,2

[1] School of Engineering [Aalto] – Finland
[2] Finnish Geospatial Research Institute, National Land Survey – Finland

This study aims to explore the influence of non-tidal atmospheric loading on GNSS time series analysis, focusing on enhancing positioning accuracy. Using GAMIT/GLOBK software, we process a GNSS network covering the Nordic countries, with a specific focus on Finland for dataset from 2020 to 2022. We incorporate a new atmospheric grid model embedded in the software called 'vmfaplnt' derived from the ECMWF numerical weather model. This model offers higher spatial resolutions compared to previous models applicable in GAMIT/GLOBK. The new non-tidal atmospheric grid model, characterized by its high spatial and temporal resolution, not only enhances the accuracy of GNSS positioning but also facilitates a more precise comparison of different methods of correcting loading deformations. Our investigation comprises two stages: first, we apply the 'vmfaplnt' model during data processing to evaluate its impact on GNSS positioning. Secondly, we compare this method with GNSS time series that have been corrected using models provided by loading services in post-processing. By examining both methods, we aim to understand how accurate positioning is achievable with the new grid model. Our research represent the first findings of employing the 'vmfaplnt' grid model.

*Speaker
†Corresponding author: fatemeh.khorrami@aalto.fi

Enhancing GNSS Data Accuracy: Implementing Non-Tidal Corrections for Atmosphere, Ocean, and Hydrology Loading at the observation level in GNSS data

Yohannes Getachew Ejigu *† [1], Arttu Raja-Halli [2], Jyri Näränen [2], Fatemeh Khorrami [1], Maaria Nordman [3,4]

[1] School of Engineering [Aalto] – Finland
[2] Finnish Geospatial Research Institute, National Land Survey – Finland
[3] School of Engineering [Aalto] – Finland
[4] Finnish Geospatial Research Institute, National Land Survey – Finland

Non-tidal atmosphere, ocean, and hydrology loading displacements are sources of both stochastic and systematic effects in Global Navigation Satellite Systems (GNSS) station coordinate time series. Prior research demonstrates that correcting for non-tidal loading displacements in GNSS station coordinate time series enhances coordinate repeatability, thereby improving overall stability. This study compares the performance of various loading products in Northern Europe and investigates their impact on the scatter of GNSS time series in the permanent GNSS stations of Finland (FinnRef). We applied the corrections provided by the School and Observatory of Earth Sciences (EOST) loading service, namely non-tidal atmosphere loading, as well as combinations of atmosphere-ocean and atmosphere-ocean-hydrology loading displacement products at the observation level for the FinnRef network spanning from 2019 to 2023. We also computed and corrected time series in so called post-processing mode, where the original time series is corrected with non-tidal corrections after GNSS analysis is done. Our analysis delves into the individual effects of non-tidal atmosphere loading and its combined impact with ocean and hydrology loading configurations, elucidating how they influence the noise characteristics of GNSS time series when corrected at the observation level and in post-processing.

*Speaker
†Corresponding author: yohannesgetachew.ejigu@aalto.fi

Terrestrial gravity field time series analysis for new insights on the geodynamics of plate motion

Martina Capponi [*†] [1], Daniele Sampietro [1], Filippo Greco [2], Carlo Doglioni [3]

[1] Geomatics Research & Development srl – Italy
[2] Istituto Nazionale di Geofisica e Vulcanologia - Osservatorio Etneo (Catania) – Italy
[3] Istituto Nazionale di Geofisica e Vulcanologia – Italy

The gravity field measurements are direct expression of one of the most important phenomena of interaction between the Earth and Sun and Moon bodies. From the analysis of terrestrial time series of gravity continuously acquired, e.g. at permanent stations which are mainly used in monitoring the subsurface mass variation, it is possible to disentangle the pure effect of gravitational attraction due to the luni-solar attraction forces and the effect of solid earth as well as oceanic masses induced tidal displacements. Employing statistical analysis tools, the authors seek to investigate the temporal discrepancies between observed gravitational residuals anomalies due to the solid earth tidal bulge and theoretical prediction of the maximum/minimum attraction in relation to the Sun-Moon positions. The research aims to provide new insights into the forces and mechanisms driving plate motions to improve our understanding of tectonic phenomena and their implications in complex geodynamic processes evolution. The work has been conducted firstly on one year time series for 2022 of Mount Etna volcano measurements acquired with a precise iGrav superconducting gravimeter continuously operating. This dataset has been integrated with other observations coming from permanent stations of IGETS service of the International Association of Geodesy.

[*]Speaker
[†]Corresponding author: martina.capponi@g-red.eu

Ocean tidal loading tomography as a means of constraining the interior structure of the Earth

Andrei Dmitrovskii * [1], Federico Munch [1], Christian Boehm [1], Hilary Martens [2], Amir Khan [1,3]

[1] Institute of Geophysics, ETH Zürich, Zürich, Switzerland – Switzerland
[2] Department of Geosciences, University of Montana , Missoula 59812, MT, USA – United States
[3] Institute of Geochemistry, ETH Zurich, Zurich, Switzerland – Switzerland

Ocean tide loading (OTL) brings about recurring deformation of the Earth's surface. Some of the OTL harmonics, e.g. M2, O1, Mf, cause sufficiently large surface displacement to be registered by the Global Navigation Satellite Systems (GNSS). These displacements are sensitive to the interior structure of the planet in a broad range of temporal and spatial scales making them a potentially unique source of information about the planet's response at low frequencies. Comparison between observations and predictions for 1D elastic Earth models result in discrepancies of up to 3 mm (Bos et al., 2015, Martens et al., 2016). Spatial coherency of these discrepancies hints to 3D interior structure as one of the main sources of such residuals.
In this context, we present a framework to invert OTL observations for 3D crustal and mantle structure based on a trust-region Newton-type iterative algorithm. Furthermore, we resort to the adjoint approach as an efficient means of computing the gradient for the high-dimensional model space. Focusing on the design of the inverse algorithm, we constrain ourselves to deformations of an isotropic elastic planet, which are governed by a self-adjoint forward operator. In order to assess the robustness of the method, we perform a suite of 3D synthetic inversions for two GNSS station configurations: 1) a uniform distribution of stations across continents; and 2) an actual station network in South America. We demonstrate the effectiveness of the OTL method to reconstruct the elastic structure of the lithosphere and upper mantle.

*Speaker

Tidal and non-tidal time gravity changes observed at Mt. Somma-Vesuvius and Campi Flegrei active volcanoes (Naples-Italy) by means of continuous gravity records

Alessandro Fedele * [1], Umberto Riccardi [2], Tommaso Pivetta [1], Giuseppe Ricciardi , Stefano Carlino

[1] Istituto Nazionale di Geofisica e Vulcanologia - Sezione di Napoli – Italy
[2] Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse (DiSTAR); Università di Napoli "Federico II" – Italy

For at least 40 years, an intensive geodetic monitoring programme has been carried out on the active volcanoes of the Neapolitan area, consisting in the joint measurement of ground deformation and gravity variations. Recently, two permanent gravimetric stations have been set up with a gPhone type spring gravimeter, which has been operating for 9 months at Mt. Somma-Vesuvius, and is currently operating for over a year at the Campi Flegrei caldera, where a superconducting iGrav type gravimeter will soon be installed. The purpose of the continuous recordings is complement the time-lapse observations carried out periodically on networks of benchmarks, in order to continuously monitor the short-term changes in gravity, which could be correlated to the hydrological variation and geothermal reservoir changes in two of the world's highest risk volcanoes. Here we discuss the special efforts made to study instrumental drift, which can mask actual gravity changes due to mass variations in the volcanic and geothermal systems. We even report on the various processing steps and analyses performed to obtain reliable parameters of the Earth's tides, non-tidal corrections and gravity residuals. From the analysis of the gravity records, reliable tidal gravity models have been derived, which will improve the accuracy of volcano monitoring by allowing a precise reduction of tidal effects for both relative and absolute gravity measurements taken in these volcanic areas. Clear hydrological signals were detected in the residual gravity signals collected in the Somma-Vesuvius area, where rainfall peaks cause gravity decreases due to increases in soil moisture above the underground gravity station. Gravity signals collected in the Campi Flegrei caldera show a clear correlation with the more energetic earthquakes that strongly characterise the current bradyseismic crisis.

*Speaker

Ocean tidal loading at the Finnish Antarctic station Aboa, Dronning Maud Land

Arttu Raja-Halli * [1], Jyri Näränen [1], Jaakko Mäkinen [1], Maaria Nordman [1,2], Ulla Kallio [1]

[1] Finnish Geospatial Research Institute, National Land Survey – Finland
[2] School of Engineering [Aalto] – Finland

The Finnish Antarctic base Aboa is situated in western Dronning Maud Land on the slope of Mount Basen, about 470 m above sea level, approximately 20 km from the grounding line of the ice shelf and 100 km from the open sea. The absolute gravity (AG) station at Aboa has been occupied during 8 seasons starting with the austral summer 1993/4. The gravity effect of ocean tidal load at Aboa reaches several microgals and is clearly visible in the AG residuals, as is the difference between different ocean tide models. The tides around Antarctica are poorly known compared with the global ocean, much due to the difficulty in obtaining information about the tides in the ice shelves. The AG observations were conducted in several short batches, with the length between 24 hours and two weeks. The measurement conditions at Aboa are good, with laboratory-level environment and mostly low microseismic noise. Here we report on our attempt to use the AG records to discriminate between the tide models. Due to the short time span of the individual measurements, we are limited to diurnal and semidiurnal periods.

*Speaker

Possible contribution of tidal stress on seismic triggering in clusters of deep-intermediate seismic events around South America

Gloria Alexandra Moncayo [*†] [1], Jorge Ivan Zuluaga [* ‡] [1], Gaspar Monsalve [* §] [2]

[1] Universidad de Antioquia Medellín, Colombia – Colombia
[2] Universidad Nacional de Colombia Sede Medellín – Colombia

We explore the hypothesis that tides may be triggering seismic activity in regions of clusters of intermediate-deep earthquakes, like the Bucaramanga nest in NW Colombia, the Puyo seismic cluster in Ecuador, among others in South America. We estimated the tidal strain tensor considering both, the Earth Body Tides (BT) and the effect of the Ocean Tidal Loading (OTL). Besides, using information of focal mechanism of the earthquakes occurred in the nest or cluster areas, we calculate for each event the Tidal Coulomb Failure Stress (TCFS). TCFS values ware calculated not only for the time of earthquake, but also for the time of the closest maximum strain within a window of a few hours before the events to search the role of the tides in earthquake nucleation. Our results agree with the suggestion that in the zones of seismic clusters and given their intermediate depth conditions where compressional stresses are expected (Turcotte and Schubert, 2002), the lunisolar forces may contribute to facilitate the displacement of blocks, and hence the triggering of seismic activity.

*Speaker
†Corresponding author: gloria.moncayo@udea.edu.co
‡Corresponding author: jorge.zuluaga@udea.edu.co
§Corresponding author: gmonsalvem@unal.edu.co

Invited talk:
Modeling gravimetric signals induced by minor ocean tides and their detection in superconducting gravimeter time series

Roman Sulzbach *† [1,2], Christian Voigt [1], Hartmut Wziontek [3], Henryk Dobslaw [1]

[1] German Research Centre for Geosciences (GFZ), Potsdam, Germany – Germany
[2] Institut für Meteorologie, Freie Universität Berlin (FUB), Berlin, Germany – Germany
[3] Federal Agency for Cartography and Geodesy (BKG), Leipzig, Germany – Germany

The high accuracy of modern charts of the global ocean tide is to large parts based on long-term satellite altimetry observations of high quality. However, the second important pillar founding the basis for present-day ocean tide atlases is the advancement of hydrodynamical ocean tide models. Using data assimilation approaches, hydrodynamical simulations can be combined with empirical observations, so that both techniques contribute to the overall accuracy of the tidal atlas. Accordingly, purely hydrodynamical ocean tide modeling is especially important where observational data is sparse, of lower quality, or completely absent. One example is the prediction of minor ocean tides, which are more elusive to altimetric measurements due to their small amplitude, often below 1 cm. Despite their tiny magnitude, minor tides induce gravimetric signatures through ocean tidal loading and direct Newtonian attraction, relevant to satellite and terrestrial gravimetry. Due to their low noise level, long-term gravity time series by superconducting gravimeters (SGs) are adequate to detect these signals. Combining numerical ocean tide models and careful tidal analyses for a global ensemble of SGs it was possible to verify loading signals of degree three in the gravimetric records. In this contribution, we present an updated approach to reduce the inconsistencies between the ocean model and observational data for an ensemble of minor tides. On the one hand, this comprises model improvements in shallow shelf areas, which can be precisely monitored with an SG positioned at the small off-shore island of Heligoland. On the other hand, a reworked gravimetric modeling framework for near-coastal analysis is considered to reduce the uncertainty of modeled gravimetric signals. Overall, this contribution tends to improve the understanding of tidal variations in gravimetric records by utilizing data-unconstrained ocean tide models.

*Speaker
†Corresponding author: sulzbach@gfz-potsdam.de

Session 2. Geodesy for hazard monitoring (seismo- and volcano-geodesy, etc.)

Micro-transient signal detection of episodic deformation of Akutan volcano

Kunpeng Shi * [1], Xiaodong Cheng† [1], Heping Sun [1], Hao Ding [2], Rumeng Guo [1]

[1] Innovation Academy for Precision Measurement Science and Technology, CAS – China
[2] School of Geodesy and Geomatics, Wuhan university – China

Fine detection of the micro-transient deformations exhibiting diverse spatial-temporal pattern is crucial for unraveling geophysical process in geodetic datasets, despite challenges posed by high noise and correlated periodic signals. In this study, we extent the application of Hankel Spectrum Analysis (HSA, proposed by Shi and Ding, 2023) to record the common modes of transient variability. In the z-plain, the HSA effectively isolated the transient and multi-periodic motions by categorizing the Hankel-z poles in two clusters robustly: 1) pairs of conjugated z-poles ($\exp(\alpha+j\cdot 2\pi f)$) representing the periodic signals; 2) the real-axis z-poles (f-> 0), representing the different complex exponentials. The latter have been validated as the effective function for constructing the multi-transient waveforms. Complemented by unique c-residuals modulating the amplitude/phase, the HSA also defined a measurable temporal evolution and systematic spatial structures of various geophysical filed. This research firstly applied the HSA to GPS observation arrays to detect micro-deformation at the Akutan active volcano. After meticulously filtering out the non-tectonic motions (e.g., sea-level, loading effects) from annual to decadal variability, our algorithm successfully identified the repetitive N-shapes transient cycles corresponding to the coherent spatio-temporal patterns of uplift and subsidence. Further numerical modeling of these continuous transient-deformations allowed us to track the geophysical magma-source migration (shifted to the northwest at a depth of _˜4 km) and the pressure response of storage system (residuals of _˜1.2 (105·m3)). Since 2014 (cycle 3), an abnormal occurrence of the high correlation of transient-earthquake swarms indicates the magma intrusion into the brittle rock.

*Speaker
†Corresponding author: chenxd@whigg.ac.cn

Precise monitoring of subduction plate coupling status on the basis of DONET and borehole data analyses

Keisuke Ariyoshi * [1], Matsumoto Hiroyuki [1]

[1] Japan Agency for Marine-Earth Science and Technology – Japan

We have detected an event of pore pressure changes (hereafter, we refer it to "pore pressure event") from borehole stations in real time in March 2020 and March 2023, owing to the network developed by connecting three borehole stations to the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) observatories near the Nankai Trough. Slow earthquake is thought to have longer duration time with smaller stress drop than regular earthquake under the same magnitude. This means that the slow earthquake is more sensitive to external stress perturbation and useful to monitor the processes of stress accumulation and release. However, the pore pressure is also affected by tidal and oceanic fluctuations. To overcome this problem, we use the seafloor pressure gauges of DONET stations nearby boreholes instead of the reference by introducing time lag between them. The obtained results demonstrate the detectability of volumetric strain change for nano-scale. We also investigate the impact of seafloor pressure due to ocean fluctuation on the basis of ocean modelling, which suggests that the decrease of effective normal stress from the onset to the termination of the SSE is explained by Kuroshio meander and may promote updip slip migration, and that the increase of effective normal stress for the short-term ocean fluctuation may terminate the SSE as observed in the Hikurangi subduction zone.

References:
Ariyoshi, K., Kimura, T., Miyazawa, Y. et al., 2021. Precise monitoring of pore pressure at boreholes around Nankai Trough toward early detecting crustal deformation. Front. Earth Sci. 9, 717696. https://doi.org/10.3389/feart.2021.717696
Ariyoshi, K., Iinuma, T., Nakano, M. et al., 2021. Characteristics of slow slip event in March 2020 revealed from borehole and DONET observatories. Front. Earth Sci. 8, 600793. https://doi.org/10.3389/feart.2020.600793

*Speaker

Geometric controls on cascading rupture of the 2023 Kahramanmaraş earthquake doublet

Yijun Zhang * [1], Xiongwei Tang [1,2], Dechuan Liu [3], Tuncay Taymaz [4], Tuna Eken [4], Rumeng Guo† [1], Yong Zheng [3], Jingqi Wang [1,2], Heping Sun [1,2]

[1] Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences – China
[2] College of Earth and Planetary Sciences, University of Chinese Academy of Sciences – China
[3] State Key Laboratory of Geological Processes and Mineral Resources, School of Geophysics and Geomatics, China University of Geosciences – China
[4] Department of Geophysical Engineering, the Faculty of Mines, İstanbul Technical University – Turkey

How fault geometry controls the rupture propagation and segmentation of a strike-slip event is an open question. Deciphering the relationship between the geometric fault complexity and seismic kinematics is essential for both understanding the seismic hazard posed by a particular fault and gaining insights into the fundamental mechanics of earthquake rupture. Here we integrate the fnite-fault inversion of synthetic aperture radar observations and back projection of high-frequency teleseismic array waveforms to investigate the rupture geometry of the 2023 Mw 7.8 and Mw 7.6 Kahramanmaraş (southeastern Turkey) earthquake doublet and its impact on the kinematics and slip distribution. We find that large slip asperities are separated by fault bends, whereas intense high-frequency (∼1 Hz) sources occur near the branching junctions, suggesting that geometric barriers could decelerate rupture propagation and enhance high-frequency wave radiations. In addition, supershear rupture propagating along the relatively high-velocity material is prone to occur on geometrically simple and smooth faults with relatively few aftershocks. These kinematic characteristics highlight that the geometric complexity of the fault system may be a key factor in the irregular cascading rupture process.

*Speaker
†Corresponding author: guorm@apm.ac.cn

Tidal Stress on a Seismic Fault and Its Dominant components of Earthquake Triggering

Xiaodong Chen * [1], Ruyu Yan [1], Jiangcun Zhou [1], Heping Sun [1]

[1] State Key Laboratory of Geodesy and Earth Dynamics,Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences – China

Tidal triggering of earthquakes was recognized for a long history since some earthquakes were found to be related to the semidiurnal and diurnal tides. But until now, the conclusion is not fully confirmed that earthquakes are triggered by the tide. Nevertheless, more evidence was found in recent years that some earthquakes were surely relevant to the tide (Ide S., et al., 2016; Tananka S., et al., 2002). Tidal triggering occurred preceding large earthquakes(Ide S., et al., 2016), Sumatra earthquake (Mw9.0) of 26 December, 2004 (Tanaka S. 2010) and Tohoku-Oki earthquake (Mw9.1) of 11 March, 2011 (Tanaka S., 2012) for examples. To investigate the relationship between earthquake frequency and the tide, the tidal stress on a seismic fault needs to be well computed because the stress is the main factor that fractures the rock. Six independent tidal stress tensors can characterize the symmetric stress tensor at any given point inside the Earth. When this tensor is rotated to align with the fault plane, we can define the tidal normal component, the shear stress component, and other four components. Furthermore, among these 6 components, only some have strong correlation with the tide. In the study, the computation theory and procedure of the tidal stress tensor, tidal shear and normal stress on a seismic fault are given. And taking the example of the Ridgecrest Earthquake in 2019 which is a typical foreshock-mainshock-aftershock sequence, we can explore the behavior of the relationship between the foreshock/aftershock and stress. We attempt different tidal stress tensors to investigate the tidal triggering of this sequence using Schuster's test. The objective of this research is to examine which tidal stress component(s) is(are) the dominant one(s) of triggering earthquakes based on the seismicity during the period in this area. The results of the research can provide useful reference for earthquake tidal triggering.

*Speaker

On Some Aspects of the Dynamics of Campi Flegrei and Vesuvio Revealed by SAR Data

Antonella Amoruso * [1], Luca Crescentini [1], Adriano Gualandi [2,3]

[1] Dipartimento di Fisica, Università degli Studi di Salerno – Italy
[2] Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Nazionale Terremoti (INGV) – Italy
[3] Department of Earth Sciences, University of Cambridge – United Kingdom

The Campi Flegrei caldera and Vesuvio volcano are two active and high-risk volcanoes located approximately 25 km apart. They are situated on opposite sides of the densely populated city of Naples, Italy.
Although Vesuvio has not shown any significant activity since its last eruption in 1944, Campi Flegrei has experienced at least three significant periods of uplift in 1950-1952, 1969-1972 and 1982-1984. After two decades of sustained subsidence, it has been experiencing an accelerated uplift since 2005, which is currently associated with unusual seismicity and increased degassing. Between 1981 and 2000, the Campi Flegrei large-scale deformation field remained stable. However, after 2000, although it still primarily followed a radial pattern, there were some differences even at large scales.
To determine if the deformation field evolution can be attributed to the action of stationary sources, we utilized Blind Source Separation (BSS) approaches such as Empirical Orthogonal Function (EOF) and Variational Bayesian Independent Component Analysis (vbICA).
The time series of ground displacement at Campi Flegrei and Vesuvio were analysed from 1993 to 2010 and from 2015 to the end of 2022. The data was obtained from ERS/ENVISAT and Sentinel 1 Synthetic Aperture Radar imagery, respectively. The sill-shaped deformation source responsible for the uplift in 1982–1984 and subsequent subsidence, located 3–4 km below Campi Flegrei, is a stable feature throughout the analyzed periods. However, additional deformation sources located at a depth of approximately 8–9 km are required to explain the transition from subsidence to uplift at Campi Flegrei, which occurred in the early 2000s. At the same time, Vesuvius began to experience subsidence, which is attributed to a source approximately 8-9 km deep. The correlation between the onset of uplift at Campi Flegrei and subsidence at Vesuvio suggests the possibility of transfer of magma and/or magmatic fluids between the two plumbing systems at a depth of 8-9 km. The expansion of a deformation source located about 8-9 km below Campi Flegrei is also necessary to justify the differences between the 1993–2000 and 2015–2022 deformation fields. Also the differences between the 1993–2000 and 2015–2022 deformation fields are explained by expansion of a deformation source located about 8-9 km below Campi Flegrei.

*Speaker

Insights on glacially induced fault activity from geodynamic modeling and geodetic measurements

Holger Steffen * [1], Rebekka Steffen [1], Halfdan P. Kierulf [2], Faramarz Nilfouroushan [1]

[1] Lantmäteriet – Sweden
[2] Kartverket – Norway

Glacially triggered faulting is the release of stresses induced by the waxing and waning of ice sheets in addition to other accumulated stresses in the lithosphere. The faulting typically occurred along pre-existing faults or weakness zones before, during or after the last ice melting. Past reactivations were probably accompanied by large-magnitude seismic events at a glacially induced fault (GIF).
Reliable field evidence in and around many formerly glaciated areas has considerably increased the number of confirmed and probable GIFs in recent years. During these studies, the fault reactivation dating at some GIFs exhibited an interesting picture of several reactivation phases after deglaciation. Also, recording of small earthquakes in areas with GIFs point to current motion along these faults.
This presentation will review the latest GIF findings and aims to shed light into the fault activity discussion. We will employ finite element models to identify potential reactivation phases since the last glaciation. We will then evaluate our findings with results from geodetic measurements, i.e., from Global Navigation Satellite System (GNSS) and Interferometric Synthetic Aperture Radar (InSAR).

*Speaker

The investigation of displacement of reference GNSS-stations in the Urals during 2020–2023 years

Danil Listvin * [1], Eduard Kuznetsov [2]

[1] Ural Federal University – Russia
[2] Ural Federal University – Russia

We analyzed the change of coordinates of the points of the continuous operating reference stations network of global navigation satellite systems to investigate the regularities of the Earth's crust movement in the Urals. Access to the measurement data was provided by the PRIN company. Using the GAMIT/GLOBK software, the variations of coordinates of ten base stations during 2020–2023 were investigated. Estimates of station coordinate displacements were obtained: secular trend, amplitudes and periods of variations over a four-year interval. By carrying out the analysis of displacements of station velocities we got azimuths of velocity vectors and their magnitudes.

*Speaker

Contribution of geodetic monitoring of landslides to the understanding processes at La Valette landslide (Southern Alps, France) and Viella landslide (Pyrenees, France)

Gilbert Ferhat * [1,2], Xavier Wanner [3], Maurin Vidal [4], Jean-Philippe Malet [1]

[1] Institut Terre Environnement Strasbourg – University of Strasbourg, CNRS, ENGEES, Institut Terre et Environnement de Strasbourg UMR7063, Strasbourg, France – France
[2] Institut National des Sciences Appliquées - Strasbourg – Department of Surveying Engineering – France
[3] Quadrilaterre – Quadrilaterre, Saint-Hippolyte-du-Fort – France
[4] Géoazur – Université Côte d'Azur, IRD, CNRS, Observatoire de la Côte d'Azur, Géoazur, Sophia Antipolis, France – France

A better understanding of landslide processes requires to characterize the triggering factors and their impacts on landslide motion. These factors are often time dependent and for this reason, it is very complex to have a quantitative approach without permanent and long-term in-situ observations. To better assess landslide hazard, it is crucial to document the surface displacements in space and time and correlate it to meteorological and hydrological conditions. This is why, some landslides are equipped with permanent or semi-permanent monitoring systems. Among these continuous systems, total stations or GNSS antennas are often used as a standard and well constrained technique. We focused here on the LaValette landslide located in the South-East French Alps and on the Viella landslide located in the Pyrenees mountains, France. These two landslides are monitored by the French National Landslide Observatory OMIV " *Observatoire Multidisciplinaire des Instabilités de Versants*". These two landslides are monitored by different techniques (tacheometry, GNSS...). We will present the measurements performed by an automated total station Long-Range Trimble S9 monitoring several reflectors' positions every 1 to 3 hours with respect to several reference control points. Moreover, displacements at few GNSS antennas located in the sliding zones will be shown.

*Speaker

Long-term subsidence analysis of Oran city, Algeria using PSInSAR technique

Kamel Hasni *† [1], Miloudi Sihem‡ [2,3], Saddam Housseyn Allal * § [4]

[1] Centre of Space Techniques – Algeria
[2] University of Strasbourg – Institut Terre et Environnement de Strasbourg – France
[3] Centre of Space Techniques – Algeria
[4] Centre of Space Techniques – Algeria

Monitoring ground motion, particularly subsidence, is crucial in urban areas prone to geologic hazards like landslides. This study investigates subsidence patterns in Oran, Algeria's second-largest city. This study leverages the capabilities of the Persistent Scatterer InSAR (PSInSAR) algorithm. It is a powerful technique that identifies stable scatterers within SAR data, enabling the generation of time series reflecting surface displacement over time.
In this study, we utilized a comprehensive dataset spanning 30 years, consisting of Envisat, ERS and Sentinel-1 C-band satellite data. This extended time period allows us to capture long-term trends in ground motion and assess potential changes in subsidence rates over the past three decades. Extracting time series from the processed data enables the visualization and analysis of displacement patterns across Oran and its surrounding areas.
The analysis revealed stability within the urban center of Oran, with subsidence velocities ranging from 3 to 5 millimeters per year. This suggests minimal vertical ground movement within the city itself. However, the results highlight significant subsidence affecting the areas surrounding Oran, particularly along the coastline. In these regions, subsidence velocities can reach up to 1 centimeter per year, indicating a more substantial vertical displacement. The ongoing subsidence in these coastal areas necessitates continuous monitoring and mitigation strategies to prevent landslides, as exemplified by the bridge failure triggered by a landslide in August 2017. Our findings underscore the importance of long-term InSAR analysis for identifying areas susceptible to subsidence and developing effective risk management plans for urban areas.

*Speaker
†Corresponding author: hasni.kamel@gmail.com
‡Corresponding author: sfz.miloudi@etu.unistra.fr
§Corresponding author: salal@cts.asal.dz

GNSS data processed in PPP mode for the Estimation of the Local Solid Earth Tides: Improvements in Geophysical Investigations

Francesco Vespe [*†] [1,2], Jan Dousa [3], Carlo Doglioni [4,5], Pavel Vaclavovic [6], Jakub Nosek [3], Giovanni Nico [7,8], Eleonora Ficini [9], Olimpia Masci [1], Gianluca Sottili [5], Davide Zaccagnino [5], Luis Mendes [10], Francisco Amarillo-Fernandez [11]

[1] DIAN s.r.l. 75100 Matera – Italy
[2] Italian Space Agency - Space Center - 75100 Matera – Italy
[3] Research Institute of Geodesy Topography and Cartography - Pecný – Czech Republic
[4] Istituto Nazionale di Geofisica e Vulcanologia, Rome – Italy
[5] Sapienza University - Rome – Italy
[6] Research Institute of Geodesy Topography and Cartography - Pecný – Czech Republic
[7] DIAN s.r.l. 75100 Matera – Italy
[8] Institute of Applied Mathematics of the National Research Council - Bari – Italy
[9] Institute of Environmental Geology and Geoengineering of National Research Council , Rome – Italy
[10] ESA/ESAC, Rhea Group for ESA, Madrid – Spain
[11] ESA - ESTEC (Netherlands) – Netherlands

This work presents some results achieved in the frame of TILDE project (Tidal Interplate Lithospheric Deformation of Earth) funded by ESA. GNSS data collected at 98 stations, splitted into global and regional networks have been used. The global network consists of 73 GNSS stations which have piled up a stack of data 20 years long. The regional networks consist of 25 stations, 7 located in New Zealand, 1 in Kamčatka, and 17 stations in Italy for which 3 year-long time series of data are available at least All these big amount of data has been processed in precise point positioning mode (PPP) in order to provide absolute displacements of the stations. These kind of observables are suitable to estimate Local Solid Earth Tides (LSET); i.e, models which depends on the geographical position of the selected sites. The LSET models are built estimating Love and Shida numbers for each station and for each main tidal constituents. The objectives is to investigate possible correlations between LSET and geological/geophysical events, such as tectonic plates movements, as well as earthquakes and volcanic activities/hazards.
GNSS coordinates of the stations, expressed both in geocentric XYZ and local NEU references, have been estimated in Precise Post Processing mode, with a sampling rate in turn of 1 day and 3 hours. Different GNSS solutions have been generated according the objectives of the project. The first one was the background solution in which the full IERS2010 tides model has been applied. The second solution was obtained by switching off all the tides model for all the stations. The third one was the solution, only for global stations, for which only the Long-Periodic Tides (LPT) has been switched off. This last solution has been applied in order to lower the level of flickering of GNSS time series when Love and Shida numbers of LPT had to be estimated.

[*]Speaker
[†]Corresponding author: francesco.vespe@asi.it

This analysis showed that there is a correlation between the latitude measured from the tectonic equator and Love numbers. This confirms the theory that moon tides contribute to trigger tectonic movements.

An interesting result, relevant for the assessment and potential precursiveness of the risk of seismic hazards, was the correlation found between the variation in time of Love numbers of diurnal (K1) and semi-diurnal (M2) tides and the occurrence of earthquakes nearby GNSS sites. At this purpose we selected GNSS global stations which were at a distance < 200 Km from the epicentre of EQ events. The investigation has outlined that almost the seismic events are got ahead by a downfall of Love numbers. It seems that each earthquake event cannot be characterized only by the type of slip occurred along faults: compressive (i.e., reverse fault), extensional (i.e., normal fault), strike slip or combination of them. This result could be explained with the rigidity of the crust/mantle which play a major role in triggering seismic events. For smaller values of Love number we have indeed a more rigid response of Earth to Tidal forcing. Finally we plan to present further LSET solutions using GNSS data coordinates estimated in PPP mode at an higher sampling rate of 30" achieved applying kinematic algorithms.

Seismic gravity variations in Chinese Mainland

Minzhang Hu *† [1], Hongtao Hao [1], Xinlin Zhang [1], Jian Wang [1], Jiapei Wang [1], Zhongya Li [1]

[1] Institute of Seismology, China Earthquake Administration – China

China is a country frequently attacked by inland earthquakes and some of them may induce serious disasters. In 1976, the whole city was destroyed by the Tangshan M7.8 earthquake, and about 240 thousands people were killed. The Wenchuan M8.0 earthquake destroyed a large number of towns and killed more than 80 thousands people in 2008. Since the 1966 Ms7.2 earthquake in Xingtai, the Chinese government has set up a nationwide earthquake monitoring network and carried out earthquake monitoring and prediction research. Both absolute and relative gravimetry are used. The absolute gravity stations are measured using FG5 or A10 gravimeter. The relative gravity stations are measured using LCR or CG5 gravimeter. Inorder to reduce the effect of gravimeter drift, a round-trip method, A→B→C→D→C→B→A, is designed. The gravity stations are observed repeated and the gravity changes can be captured.The potential precursor gravity changes before the 2013 Lushan Ms7.0, 2015 Menyuan Ms6.4, 2016 Hutubi Ms6.2, 2017 Jiuzhaigou Ms7.0, 2023 Jishishan Ms6.1 earthquakes and so on were captured. At present, China is carrying out repeated gravimetry at least once a year on the mainland, which is expected to provide critical scientific data for earthquake preparation, occurrence and prediction research.

*Speaker

†Corresponding author: huminzhang@126.com

Land Subsidence and Groundwater Storage Change Assessment using InSAR and GRACE in the Arid Environment of Saudi Arabia

Esubalew Yibrie * [1,2]

[1] King Abdulaziz University – Saudi Arabia
[2] Arba Minch University – Ethiopia

Najran region in Saudi Arabia has been affected by groundwater storage decline and consequent land subsidence for a long period of time. In this study, we utilized Sentinel-1 data for ground surface mapping, which was obtained from the Centre for the Observation and Modelling of Earthquakes, Volcanoes, and Tectonics (COMET). Interferograms and coherence maps have been produced automatically using the Looking Into Continents from Space with Synthetic Aperture Radar (LiCSAR) processor. In addition, we also analyzed Gravity Recovery and Climate Experiment (GRACE)-based Terrestrial Water Storage Anomalies (TWSA) observations to estimate ground water depletion trends in the region. LiCSBAS-InSAR technique allowed for the identification and study of the changes in surface deformation over a selected period. We validated the observed displacement field by processing the Global Navigation Satellite System (GNSS) station's time series, which spanned from 2017 to 2019. The result of the study indicates the occurrence of subsidence along the valley, as observed using Small Baseline Subset (SBAS) InSAR technique. The average annual subsidence rate was observed ranging from 1.1 to 5.1 mm per year between 2016 and 2020. Correspondingly, the GRACE analysis showed that groundwater storage depleting at ∼11.2 mm per year. Moreover, this finding provides valuable information about the excessive use of groundwater for growing vegetation. NDVI analysis has shown a considerable an increasing vegetation area change of approximately 34.5 km^2 between 2013 and 2020 with 0.2 threshold. Overall, the analysis reveals that the time series obtained from InSAR, GRACE, GNSS, and well data exhibit a consistent downward trend over time.
Keywords: LiCSBAS, InSAR, GRACE, GNSS, Subsidence, NDVI

*Speaker

An adapted methodology for connecting InSAR to Earth-fixed terrestrial reference frame in the Chlef region in Algeria

Miloudi Sihem * [1,2], Meghraoui Mustapha [3]

[1] University of Strasbourg – Institut Terre et Environnement de Strasbourg – France
[2] Centre des Techniques Spatiales – Algeria
[3] University of Strasbourg – Institut Terre et Environnement de Strasbourg – France

The deformation measurements provided by InSAR are relative; they create a free network referred to an arbitrary point of reference (RP) assuming to be stable. In this study, we analyze the line of sight (LOS) of Sentinel-1A/1B satellite images collected between 2015 and 2022 along the ascending and descending tracks, using a Permanent-Scatterer (PS) method to measure surface displacements at high spatiotemporal resolution. To quantify the active deformation caused by the Asnam and the Boukadir faults system located in Chlef region in the northwestern part of Algeria, we propose an adapted methodology, for connecting the LOS-velocities from InSAR to an Earth-fixed terrestrial frame reference as ITRF2014, using GNSS continuously operating reference stations (CORS). This methodology is based on three steps : (i) decomposing the ascending and descending LOS velocities to 3-D components (up, easting and northing); (ii) establishment of uniform transformation between InSAR RP and the obtained velocity rate from the available GNSS CORS in the scene covered by InSAR; (iii) application of the transformation model to all pixels of the obtained 3-D velocities in step (i). The benefit gained in connecting InSAR network to the Earth-fixed TRF is to obtain a reliable interpretation of the observed physical motion. By providing the components of mean velocities of one GPS-CORS station (EECH) in our study region in ITRF2014 with three options: fixed-EU, fixed-NU and NNR (No Net Rotation), our proposed methodology have been applied, from which we have generated five kinematic motion models and compared to those found elsewhere in the tell Atlas and nearest region from the offshore.

*Speaker

Estimating the velocities of space geodetic stations: application to DORIS

Sofiane Khelifa * [1], Saddam Housseyn Allal *

[1], Hicham Dekkiche *

1

[1] Centre of Space Techniques – Algeria

The velocities of space geodetic stations represent the linear movement of the Earth's crust due to the movements of tectonic plates. However, velocity estimates and their uncertainties derived from time series of space geodetic station positions are affected by seasonal signals and noise contained in these time series. Therefore, the insufficiently modeled linear trend of these time series will distort velocity estimates and their uncertainties.
We use the combined residual coordinate time series of 45 DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) stations that are well-observed and well distributed across the world. These time series are aligned to ITRF2014, expressed into a topocentric coordinate frame (North, East, Up) and include data from 2004 to 2023.5. We assess, on one hand, the velocities of DORIS stations using two different methods, the Singular Spectrum Analysis (SSA) in the phase space and the Wavelet Multiresolution Analysis (WMA) in the frequency space, which allow to extract the trend (velocity) separately from seasonal signals and noise present in the time series. On the other hand, we compare the velocities obtained with those calculated from plate tectonic models (GSRM 2.1, ITRF2014, GEODVEL 2010, REVEL 2000, MORVEL 2010 and NUVEL 1A) using UNAVCO plate motion calculator.
The SSA results show a dominant trend, represented by the Reconstructed Component RC 1, in the horizontal components (North and East) with a variance of more than 99% of the total signal for most stations. These results confirm that the horizontal displacements of the stations are mainly associated with tectonic plate motions. The WMA results show that the trend estimates, determined from the approximation signal at level 6 of decomposition, are generally similar to those obtained by SSA. The results also conclude that the horizontal velocities estimated by SSA and WMA are consistent with those calculated from the plate tectonic models used, except for seven stations (AMSTERDAM, COLD-BAY, DIONYSOS, EVEREST, MANAGUA, MANGILAO and MANILLE). These stations, most of which are located at tectonic plate boundaries, have suffered great earthquakes with a magnitude above to 6.0, in particular the AMSTERDAM station situated at the boundary of the Antarctic and Australian tectonic plates. The AMSTERDAM site is attributed to the Australian tectonic plate by UNAVCO plate motion calculator, but their velocities (North and East) computed by SSA and WMA are in good agreement with those calculated from the Antarctic tectonic plate models which are very

*Speaker

different to those calculated from the Australian tectonic plate models. For the Vertical component, the velocities are much less lower than for the horizontal ones. Their values vary between -3 and 2 mm/year, except for the high latitude stations THULE (76.54°) and NY-ALESUND (78.92°) for which the velocity is about 7.3 and 6.7 mm/year respectively; this can be explained by the fact that these stations undergo strong vertical deformation due to postglacial rebound.

Geostatistics as a tool for interpolation and mapping of the gravity anomaly and the geoid height

Ilies Benikhlef * [1]

[1] Centre National des Techniques Spatiales – Algeria

Geostatistics is a science that deals with regionalized variables that take their values in space which can be located by the GNSS coordinates, and present a characteristic that can be studied by statistical and probabilistic tools, knowing that the majority of the regionalized variables include a physical origin, which justifies the decomposition and trends used for modeling in this science. Being regionalized variables, the gravity anomaly as well as the geoid height can be modeled by geostatistics, taking into account their spatial character and their variation in space. For this purpose we need tools for variographic analysis such as the variogram or the different kind of covariance functions whose definition is based on hypothesis derived from geostatistics. Finally, geostatistics also provides methods such as Kriging which can help us to interpolate from existing data for various purposes such as cross-validation where the estimation of a grid of the same variable or another variable which depends on the previous one, and to map the studied variables which in our case are the gravity anomaly and the geoid height.

*Speaker

Impact of using different time scales on short term GNSS coseismic displacements: a case study of the 2022 Mw 7.6 MICHOACÁN, MEXICO Earthquake

Walid Bouaoula *† [1,2], Hicham Dekkiche [1], Salem Kahlouche , Mohamed Hamoudi [2]

[1] Department of Space Geodesy, Centre of Space Techniques, Algerian Space Agency – Algeria
[2] Department of Geophysics, Faculty of Earth Sciences, Geography and Territorial Planning, University Of Science and Technology Houari Boumediene, Algeria – Algeria

Coseismic GNSS displacements refer to sudden movements of GNSS stations during an earthquake accompanied by strenuous ground shaking, they are known as short term coseismic displacements when they are derived from data covering at most 28 days before and after the earthquake day. Various time scales can be employed to determine short term coseismic displacements, defined by data duration before and after the earthquake day.
In this study, the impact of using different time scales on GNSS coseismic displacements is examined. For this purpose, GNSS data of 16 permanent stations have been processed using Gamit/Globk software, these data belong to the Network Of The Americas (NOTA) and span 57 days (from August 22 to October 17, 2022), covering the MICHOACÁN, MEXICO Earthquake (Mw 7.6) that occurred on September 19, 2022. For epoch-by-epoch solutions, high rate GNSS data (1 Hz) covering the earthquake day have been processed using Pride PPP-AR software. Short term displacements have been calculated using 07 different time scales and their discrepancies with high rate data displacements have been computed in order to assess their agreements.
Results show that, for stations strongly affected by the earthquake, practically the same magnitudes and orientations of displacements are obtained for every timescale. Discrepancies with high rate data displacements are less than 5 cm. Whereas, for stations weakly affected by the earthquake, small discrepancies of about 1 cm were found and displacements orientations of the different timescales solutions are, in general, not well consistent with epoch-by-epoch displacements orientations, this might be explained by the noisy behaviour of PPP kinematic solutions. By comparing the average discrepancies of all stations for the different timescales, it can be noticed that solutions obtained from 28 data days before and after the earthquake day are slightly better than the other timescales solutions.

*Speaker
†Corresponding author: bouaoula.walid@gmail.com

Analysis of changes in coordinates before and after the earthquake of 26 november 2019 of geodetic points in the Durres - Tirana area.

Eduart Blloshmi *† [1], Bledar Sina [1]

[1] Faculty of Civil Engineering, Polytechnic University of Tirana – Albania

The earthquake that struck the Durres-Tirana area on November 26, 2019, left a significant impact on the region's geodetic points. This study aims to analyze the changes in coordinates of these points before and after the seismic event to better understand the deformation caused by the earthquake. Through the utilization of geodetic surveying techniques and precise measurement instruments, a comparative analysis of the coordinates of selected geodetic points in the Durres-Tirana area was conducted. The research encompasses both temporal and spatial analysis, evaluating the extent of displacement and deformation observed in the aftermath of the earthquake. Additionally, factors such as fault movement, ground subsidence, and structural damage are considered in interpreting the observed changes in coordinates. The findings of this study provide valuable insights into the geodynamic processes triggered by the earthquake, aiding in the assessment of seismic hazards and the implementation of effective mitigation strategies in the Durres-Tirana region.

*Speaker
†Corresponding author: eduart.blloshmi@fin.edu.al

Assessing tectonic velocities and crustal deformation in the Western Mediterranean using GPS measurements

Saddam Housseyn Allal *† [1], Hicham Dekkiche * ‡ [1], Kamel Hasni * § [1]

[1] Centre of Space Techniques – Algeria

In recent years, the Global Positioning System (GPS) has emerged as a reliable tool, enabling researchers to address modern geodynamic problems, determine tectonic velocities, and estimate the deformation rates of the Earth's surface with great precision. Assessing tectonic rates in the Western Mediterranean region poses a notable challenge due to the complex tectonic processes. The convergence of the Nubian plate towards Eurasia is responsible for the complex tectonics that characterizes the Western Mediterranean region. The first part of this study leverages velocities from one hundred GPS stations across the Nubian and Eurasian plates used to determine the current relative motion between the two plates. These stations are deployed by various networks including REGAT, ALGEONET (Algeria), and Nevada Geodetic Laboratory (NGL). The key finding of this analysis revealed that the relative velocities of the Nubian plate towards Eurasia range from 1 to 7 mm/yr, with a direction of NW to WNW for the northern Nubian plate. These results are compared to the velocities calculated by geophysical models (NUVEL 1A and MORVEL). In the second part, the crustal deformation rates are quantified. The results demonstrate a rate of deformation estimated in the order of 15 to 25 nstrain/yr at the limit of the Nubian plate. These outcomes contribute to a better understanding and monitoring of recent crustal deformation in our study area.

*Speaker
†Corresponding author: alisadhou@gmail.com
‡Corresponding author: hdekkiche@cts.asal.dz
§Corresponding author: hasni.kamel@gmail.com

Vertical Displacement Monitoring of embankment dams using satellite radar interferometry: Case studies from northwestern Algeria.

Slimane Benyahia *† [1,2], Bouchrit Rouissat [2], Nadia Smail [2], Fatah Touati [1], Nawel Benaraba [3]

[1] Département de Géodésie spatiale, Centre des Techniques Spatiales, Agence Spatiale Algérienne, Oran – Algeria
[2] RISAM Lab, Département de Génie Civil, Faculté de Technologie, Université de Tlemcen – Algeria
[3] LGTE Lab, Département d'hydraulique, Faculté d'Architecture et de Génie Civil, Université des Sciences et de la Technologie d'Oran Mohamed Boudiaf – Algeria

Understanding the behavior of dam deformations holds critical importance for ensuring dam safety and structural integrity. Leveraging satellite radar interferometry techniques provides a distinct advantage by enabling continuous monitoring of dam deformations with uncertainties as low as 1 mm/year. The implemented technique makes it possible to set up a structure monitoring solution having the advantages of a low financial cost in the medium and long term and a significant spatial density of measurement. This method, requiring little or no equipment installed on site, is particularly interesting for the problem of monitoring dams.
This study focuses on applying multi-temporal InSAR (Interferometric Synthetic Aperture Radar) techniques to monitor the vertical displacement from Mars 2015 to Mars 2024 of three types of embankment dams situated in northwestern Algeria: Bouhanifia, a concrete faced rock-fill dam with a height of 54m; Sidi Mhamed Benaouda, a homogeneous earth dam(H=64m); and El Izdihar, a zoned earth dam (H=60m). Utilizing 180 C-band SAR images captured by the European satellites Sentinel-1A/B, the SAR data were processed in IW SLC data format. Both ascending and descending Sentinel-1A/B datasets were analyzed using PSI (Persistent Scatterer Interferometry) techniques with SARPROZ software.

This study presents the initial results of monitoring these dams using this technology. The findings indicate that Sidi Mhamed Benaouda and El Izdihar experienced vertical displacement during this period, with a rate of approximately -3 cm/year in the central part of the dam body. However, Bouhanifia showed no significant displacement during the same period. Further exploration of past data and analysis will make it possible to judge the behavior of this dam in relation to the rate of consolidation of the riprap.
Keywords: Vertical displacement, embankment dam, InSAR, PSI.

*Speaker
†Corresponding author: sbenyahia@cts.asal.dz

Application of the stacking algorithm HiCum method to analyze volcanic processes

François Beauducel *† [1], Michel Van Ruymbeke [2], Christian Bizouard [3], Justine Lebrun [4,5], Sébastien Toussaint [5,6]

[1] Volcanic systems team – Université Paris Cité, Institut de physique du globe de Paris, CNRS, F-75005 Paris, France – France
[2] Royal Observatory of Belgium – Belgium
[3] SYRTE UMR8630 - GRGS – Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Paris, France – France
[4] Institute of Information and Communication Technologies, Electronics and Applied Mathematics – Belgium
[5] Université Catholique de Louvain = Catholic University of Louvain – Belgium
[6] Institute of Information and Communication Technologies, Electronics and Applied Mathematics – Belgium

HiCum method (*Van Ruymbeke* et al., 2003) uses a simple stacking algorithm to determine the amplitude and phase of a periodic signal present in a time series. For a given period P, the technique consists of wrapping the time signal and averaging all data values falling into the same phase bin interval. The shape of the resultant phase histogram, from 0 to $+2\pi$, is fitted by fundamental and harmonic functions given by amplitude and phase values. This technique has a high rejection rate of random noise or any periodic signal outside the search period, in particular for large data series. The method also has some technical advantages: it works in the time domain, accepts non-constant sampling time series, tolerates data gaps, gives the frequency amplitudes directly in the data unit, and eventually keeps the criteria of linearity. In the domain of Earth-tides, for which the frequencies of components are precisely known, HiCum method works much better than with the classical FFT method which can confuse nearby frequencies (see *Van Ruymbeke* et al. presentations in other G-ETS 2024 sessions).
Here we present an enlargement of the HiCum application on single periodic signal by operating HiCum on multi-periods to mimic a spectral analysis and produce amplitude spectrum and spectrograms on long data series.

Following the algorithm of climatologists to extract an average of modulations like air temperature, pressure, rainfalls, etc., we experience a similar approach to detect and characterize external forcing on volcanic systems. Active volcanoes are complex, highly heterogeneous systems in which the circulation of hydro-magmatic fluids is modulated by pressure and mechanical stress variations. Hydrothermal systems, composed of a porous and deformable matrix, are potentially influenced by external cyclical variations, whether atmospheric or astronomical via the Earth's tidal waves, and signatures might be found in external physical measurements like seis-

*Speaker
†Corresponding author: beauducel@ipgp.fr

mic activity, deformation, fluid temperature, ...
Here we present some examples of the analysis of long-term instrumental observations (mainly seismicity and ground deformation) carried out on several active volcanoes. We show how the HiCum tool can be used to detect and characterise clear signatures, demonstrating the origin of the forcing and enabling new quantitative parameters of volcanic processes to be estimated.

Density structure and crustal magma system beneath Wudalianchi Volcano Field from 3D gravity imaging

Weikai Li * [1,2], Meng Yang† [3,4], Wei Feng [3,4], Min Zhong [3,4]

[1] State Key Laboratory of Geodesy and Earth's Dynamics, Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences – China
[2] University of Chinese Academy of Sciences – China
[3] School of Geospatial Engineering and Science, Sun Yat-Sen University – China
[4] Key Laboratory of Comprehensive Observation of Polar Environment (Sun Yat-sen University), Ministry of Education – China

Gravity approach is important for the studies of subsurface material composition and tectonic structures. In volcanic fields, gravity anomalies are related to the distribution of igneous rocks or melts. By means of density inversion processing, the underground geological structures and magmatic systems can be imaged, potentially indicating the mechanism of volcano activities. In this study, we acquire the latest high-quality and high-resolution terrestrial gravimetric data to recover the crustal density structure of Wudalianchi Volcanic Field, Northeastern China. Wudalianchi Volcanic Field is a typical high-potassium volcano field located between the northern Songliao Basin and the Lesser Xing'an Range. The low-density structure exhibits the pattern of shallow magma system. Two regional low-density anomalies appear in the west and northwest below 20 km depth. They reflect the principal pathways of upwelling mantle materials to the lower crust. The western one divides into northward and southward channels and extend to the upper crust, associated with the first episode of volcanism. Then the northern branch extends southeastwards in the upper crust, leading to successive episodes, like Laoheishan, Huoshaoshan and Weishan. In a tectonic view, the dominant west-east extension before the early Pleistocene and shear transpression after the middle Pleistocene contribute to the pattern of magma system. In terms of potential eruption hazards at present, previous studies inferred that a magma chamber with partial melts may exist under Weishan. In this study, we suggest that because the magma channel may have solidified, the chamber cannot be continuously fed by deep hot materials. The remaining melts are possibly uncooled magma from the last eruption, or just normal fluids rather than melts.

*Speaker
†Corresponding author: yangmeng5@mail.sysu.edu.cn

Seismic versus aseismic slip for the 2023 Kahramanmaraş earthquake doublet

Rumeng Guo * [1], Xiongwei Tang [1,2], Yijun Zhang , Wenting Zhang , Ming Qin , Jianqiao Xu , Jiangcun Zhou , Xuhao Zou , Heping Sun

[1] Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences – China
[2] College of Earth and Planetary Sciences, University of Chinese Academy of Sciences – China

Seismic and aseismic slip are two main patterns of fault behavior, and their interplay could shed light on the mechanical properties of fault. The well-recorded 2023 Mw7.8 and Mw7.7 Kahramanmaraş earthquake doublet provides an excellent opportunity to understand earthquake physics on strike-slip faults. Here, we utilize InSAR and strong-motion data to derive the coseismic rupture during the doublet, ∼4-month postseismic afterslip, and slip distribution of two strong aftershocks with Mw> 6.0. Our results show that this doublet ruptured multiple segments of the East Anatolian fault zone, and high-slip asperities are mainly concentrated in the shallow crust. We develop an afterslip model that accounts for kinematic shallow afterslip and stress-driven deep afterslip, which suggests that aseismic afterslip appears to be complementary to coseismic slip and aftershocks, revealing a distinct rate weakening-strengthening transition. It releases ∼10% of the coseismic moment, consistent with the near-linearly coseismic and afterslip moment scale. Aftershocks mainly fall within the regions of positive Coulomb stresses caused by afterslip and follow a similar temporal decay as afterslip, indicating that aftershock production is the failure of small asperities loaded by the afterslip. And the early postseismic afterslip is released ∼93.2% aseismically and ∼6.8% seismically by aftershocks. Our modeling results thus depict a complex fault system with highly variable slip patterns and stresses.

*Speaker

EuVeM2022: a European GNSS velocity model

Rebekka Steffen* [1], Holger Steffen † [1], Ambrus Kenyeres [2], Tobias Nilsson [1], Martin Lidberg [1]

[1] Lantmäteriet – Sweden
[2] Satellite Geodetic Observatory Budapest – Hungary

The European continent is divided into several tectonic plates and velocity variations appear along plate boundaries. However, velocity changes inside a tectonic plate can also occur due to local effects or other geodynamic processes, which is of interest for researchers trying to understand intraplate deformations in the horizontal and vertical directions. These changes can be observed by a dense network of GNSS (Global Navigation Satellite System) stations or more recently by the usage of InSAR (Interferometric Synthetic Aperture Radar). However, a dense GNSS network cannot be maintained over large areas due to, e.g., high costs and topographical obstacles, thus a regional velocity model to study intraplate deformation has to be obtained via an interpolation of scattered GNSS station velocities. In addition, the obtained velocity models can be used to estimate strain rates. The increased availability of GNSS station velocities in Europe via the EUREF Permanent Network Densification (EPND) project (https://epnd.sgo-penc.hu) allows to obtain a complete picture of the horizontal and vertical deformation in Europe via an interpolation. Here, we apply a new interpolation technique to a velocity field solution from EPND. The homogenized and quality-checked velocity field is interpolated via a least-square collocation including the knowledge of existing plate boundaries to avoid a smoothing of nearby velocities on different tectonic plates. We also use a moving variance approach to avoid effects of non-stationarity, which arise due to the variable station densities. We will present the new 3D GNSS velocity model EuVeM2022 and the obtained strain rates.

*Corresponding author: rebekka.steffen@lm.se
†Speaker

Invited talk: Advancing Geodesy in Hazard Monitoring: Insights from Gravity Measurements and Hydrological Modeling

Cheinway Hwang * [1]

[1] Department of Civil Engineering, National Yang Ming Chiao Tung University, 1001 Ta Hsueh Rd., Hsinchu 300, Taiwan, ROC. – Taiwan

In the evolving field of hazard monitoring, particularly concerning seismic and volcanic activities, geodesy offers indispensable tools for understanding subsurface processes and assessing risk. This talk shows four case studies using superconducting gravity and absolute gravity measurements, along with hydrological models to explore the intricate relationships between groundwater dynamics and geological hazards across Taiwan. We first examine the Tatun Volcanic Group (TVG), an active volcanic system in northern Taiwan, where temporal gravity changes, indicative of groundwater migration sensitive to volcanic activities, are scrutinized. Employing time-lapsed absolute gravity measurements and comparing observations with hydrological models, we uncover the unique hydrology of the central TVG and suggest the presence of deep fluid conduits bypassing this area, highlighting the complexity of volcanic hydrogeology. The second example focuses on the Hsinchu Fault (HF) within the Hsinchu Science Park, where a hydrology and gravimetry-based method assesses the fault's activity. By integrating superconducting gravimeter data with groundwater network insights, we show the fault's significant impact on groundwater flows and infer its recent geological activity. In the third example, we address land subsidence issues in central Taiwan, particularly in the Choushui River Alluvial Fan, exacerbated by groundwater over-extraction. Through absolute gravity measurements and the evaluation of artificial recharge lakes, we offer a novel perspective on mitigating subsidence impacts and enhancing groundwater management. The last example is a study in the Pingtung Plain in southern Taiwan, where an alternative gravity-based method for estimating hydrogeological parameters like the infiltration coefficient and percolation rate is proposed. This method, tested near a recharge lake, reveals critical insights into the regional hydrogeology, emphasizing the role of precise gravity measurements in understanding and managing underground water resources. Together, these studies underscore the pivotal role of geodesy in hazard monitoring, offering a multifaceted approach to tackling geodynamic challenges through the lens of gravity measurements and hydrological modeling.

*Speaker

Session 3. Monitoring of subsurface fluids (hydro-geodesy, hydro-gravimetry, geothermal monitoring, etc.)

Investigation of groundwater flows with gravity and seismic velocity changes in the Ailiao Creek and the Laonong River basins, Taiwan

Tzuyi Lien * [1], Emmy T. Chang [2], Hou-Sheng Cheng [2], Ta-Kang Yeh [3]

[1] National Taipei University – Taiwan
[2] National Taiwan University – Taiwan
[3] National Taipei University – Taiwan

We investigate an innovative, cost-effective seismological approach combined with gravity measurements to study river water recharge response after groundwater recharge construction carried out with a dredging project in 2023. The project implemented by setting up detention tanks and downstream waterways, as well as micro-embankments built with excess sand and silt after river dredging, the river water ponding area is expanded and the river flow slows down. It accelerates water to infiltrate into the soil, and to further replenish into the groundwater layer. River plays as a boundary to interact with groundwater. Precipitation responses to river flow directly and immediately. In rainy periods, river level is higher than groundwater level and hence the subsurface water flows from river to groundwater.
In our study area, the Ailiao Creek and the Laonong River basins, we employ seismic ambient noise data to detect seismic velocity changes (dvov) in different frequency bands which response to varying velocity changes in corresponding depth. The subsurface water stayed and stored in the stratum would lead to delay of seismic velocity, hence we can convert the velocity changes to groundwater variations. Results of the seismic velocity changes show that dvov is affect by rainfall dominantly. Most of the flow directions detected by seismic pairs are consistent with the direction of groundwater flows. However, the seismic pairs across the Laonong River present opposite flow directions in rainy season, around July, from 2020 to 2023. This reveals that groundwater and river water interactions in the Laonong River area. The interactions are also

*Speaker

observed in the mid-stream of the Ailiao Creek, where the flow directions are different in shallow and deep depth at frequency bands of 0.8-1.4 Hz and 0.4-1.0 Hz, respectively.
Absolute gravity measurements are conducted in our study area as well. The trend of the gravity data shows consistent with groundwater level observations. Gravity changes because of density variations, while seismic velocity changes are affected by both density and water content variations. Therefore, time-varying gravity data can help to verify the sources of seismic velocity changes. Combining gravity and seismic for quantifying groundwater storage and verifying flow directions, respectively, can help to manage and allocate groundwater resources.

Mass Budget at Theistareykir Geothermal reservoir (Northern Iceland) by means of time-lapse relative and absolute gravity measurements

Umberto Riccardi * [1], Jacques Hinderer [2], Tommaso Pivetta [3], Beatrice Giuliante [4], Philippe Jousset [4], Anette Kaergaard Mortensen [5], Nolwenn Portier [6], Jean-Daniel Bernard [2]

[1] Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse (DiSTAR); Università di Napoli "Federico II" – Italy
[2] Institut Terre Environnement Strasbourg – université de Strasbourg, Institut National des Sciences de l'Univers, Centre National de la Recherche Scientifique – France
[3] Istituto Nazionale di Geofisica e Vulcanologia - Sezione di Napoli – Italy
[4] German Research Centre for Geosciences - Helmholtz-Centre Potsdam – Germany
[5] Landsvirkjun – Iceland
[6] ONERA – Département Physique, Unité IEA , ONERA - The French Aerospace Lab, Châtillon – France

Since 2017 a hybrid gravity monitoring program is performed at Theistareykir geothermal field (Northern Iceland) to contribute to the study of the underground mass transfer induced by geothermal harnessing. According to the hybrid concept, both absolute and relative gravity measurements are repeated over time in different operating modes. Relative measurements are yearly collected on a network of 27 sites spanning the area as well as by means of continuous recordings at three selected sites, close to the extraction and injection zones, where two superconducting gravimeters and a g-Phone spring meter, specifically designed for continuous gravity recordings, operate. Moreover, absolute measurements are also yearly repeated at the 3 recording sites as well as at the site used as reference for the relative network, the latter to detect possible gravity changes therein. InSAR and GNSS monitoring of the ground deformations is used to separate geometric (due to height changes) and mass-dependent contributions to the observed time gravity changes. After reducing the contribution of the vertical ground displacement from the recorded signals, gravity residuals are analysed. In this study we focus on the whole gravity measurements dataset collected so far (about 7 years). Three approaches are followed to retrieve the underground mass changes assuming the simplest Mogi's point source: a) forward modelling of gravity changes inferred from the absolute gravity measurements. b) application of the Gauss integral procedure on the spatial gravity changes as inferred from time-lapse observations and c) least-squares inversion of the time-variable gravity field. Our modelling is validated with the extraction and injection data. Based on gravity, geodetic and extraction/injection data, we assess a tentative mass budget in terms of mass discharge into the atmosphere, recharge of the geothermal reservoir and net mass loss. Such a mass budget might contribute to discriminate potential harnessing scenarios and provide sustainability clues for the geothermal field use.

*Speaker

Gravity-Monitoring for Alpine Research Catchment Hydrology (G-MONARCH) – Introduction and First Results

Korbinian Achmüller *† [1,2], Christian Voigt [2], Ludger Timmen [3], Till Rehm [4], Nico Stolarczuk [2], Jakob Knieß [5], Carolin Rempfer [5], Elias Bögl [6], Roberta Facchinetti [6], Paul Schattan [6,7], Karsten Schulz [6], Karl-Friedrich Wetzel [5], Franziska Koch [6], Frank Flechtner [1,2]

[1] Institute of Geodesy and Geoinformation Science, Technische Universität Berlin, Germany – Germany
[2] Section 1.2 Global Geomonitoring and Gravity Field, German Research Centre for Geosciences (GFZ), Potsdam, Germany – Germany
[3] Institute of Geodesy, Leibniz University Hannover (LUH), Hannover, Germany – Germany
[4] Environmental Research Station Schneefernerhaus (UFS), Zugspitze, Germany – Germany
[5] Institute of Geography, University of Augsburg, Germany – Germany
[6] Institute for Hydrology and Water Management, University of Natural Resources and Life Sciences, Vienna, Austria – Austria
[7] Institute of Geography, University of Innsbruck, Austria – Austria

Key challenges in alpine hydrology are currently the behavior of mountain groundwater systems as well as the quantity and spatiotemporal distribution of snow that is relevant for runoff generation. Cryo-hydro-gravimetry is a non-invasive method to observe temporal gravity variations, after reduction of all other geophysical signals, as an integral of all cryospheric and hydrological mass variations, including precipitation, snow accumulation, spring discharge, evapotranspiration/sublimation, glacier, dead ice and permafrost melt and, to a minor extent, erosion and alpine uplift. At the Zugspitze Geodynamic Observatory Germany (ZUGOG) with its unique installation of a superconducting gravimeter (SG) on a high alpine summit (2,962 m a.s.l.) this method is applied for the first time in a well instrumented high alpine catchment. We will use this instrumental setup in synthesis with in situ measurements, snow-karst-hydrological modelling and remote sensing to better understand hydrological processes in high alpine environment. We will introduce the G-MONARCH project, which started at the end of 2023, and show first gravimetric results. In total, the gravimetric work packages focus on enhancing the gravimetric monitoring and improving the gravimetric modelling. This includes: 1) Improving the gravimetric signal separation of the SG time series since 2019 by incorporating snow-hydro-meteorological data and a tank model. 2) Spatially extending the gravimetric monitoring by carrying out time-lapse micro-gravimetric campaigns four times a year with CG-6 spring gravimeters. Due to the large gravity range, precise calibration of the relative gravimeters is of particular importance. 3) Quantifying hydrological mass redistributions within the Zugspitze, especially flow processes through the karst, by installing an additional, continuously recording gPhoneX spring gravimeter 413 m below the SG for a vertical gravity gradiometer setup. In a future step, the gravimetric results can be used to calibrate and validate the snow-hydro-

*Speaker
†Corresponding author: kachm@gfz-potsdam.de

meteorological monitoring and serve as boundary conditions for snow-karst-hydro-meteorological modelling to see to what extent gravimetric measurements can increase our knowledge in alpine hydrology.

Characterizing the drought events in Yangtze river basin via the insight view of its sub-basins water storage variations

Wenjing Ma * [1,2], Hao Zhou† [1,2], Zhicai Luo [1,2]

[1] MOE Key Laboratory of Fundamental Physical Quantities Measurement & Hubei Key Laboratory of Gravitation and Quantum Physics, PGMF and School of Physics, Huazhong University of Science and Technology – China

[2] Institute of Geophysics and PGMF, Huazhong University of Science and Technology – China

GRACE (Gravity Recovery and Climate Experiment) gravity satellites are uniquely popular in drought events monitoring due to their ability to precisely measure variations in all water storage components. Yangtze River Basin (YRB) is the most important strategic base of water resources in China, where drought events occur frequently due to the influence of global climate change and human activities. In this context, it is critical to clarify the characteristics of drought events in different sub-basins. Based on the latest HUST-Grace2020 model released by Huazhong University of Science and Technology, we calculate the terrestrial water storage anomaly (TWSAs) in YRB during January 2003 to July 2016 and combine water storage deficit index (WSDI) with a modified run theory to extract precisely drought events and characteristics in terms of sub-basins. On this basis, the links between drought events and topography as well as climate factors are explored in the YRB. The results indicate that: (1) By quantifying the contributions of water components based on the metric PMVD, it revealed that soil moisture storage anomaly (SMSA) is the uppermost component (44%) of TWSA but the largest contributor (64%) to TWSA trend is groundwater storage anomaly (GWSA). (2) The spatial and temporal characteristics of drought events in the Yangtze River Basin can be summarized as severe drought events mainly occur in autumn, and the drought severity is positively correlated with topography. (3) As for the link between drought and climate factors, drought events are influenced by El Niño, especially in the downstream YRB, which is one of the main reasons for the high frequency of drought events in this region. This study sheds a theoretical basis for drought early warning of different levels in YRB across the various sub-basins.

*Speaker

†Corresponding author: zhouh@hust.edu.cn

Hydrogravimetric modelling of the Séchilienne landslide

Adrien Windenberger [1], Frédéric Masson [*†] [2], Jean-Philippe Malet [1], Catherine Bertrand [3], Jean-Daniel Bernard [1]

[1] Institut Terre et Environnement Strasbourg – Université de Strasbourg, CNRS – France
[2] Institut Terre et Environnement Strasbourg – Université de Strasbourg, CNRS – France
[3] UMR 6249 Chrono-Environnement – Université de Franche-Comté, CNRS – France

Landslide dynamics are characterized by a strong hydromechanical coupling between rock deformation, pore volume variation and fluid pressure (Vallet, 2014). In the case of the unstable Séchilienne zone, landslide dynamics are controlled by stress transfers linked to the circulation of water in fractured media (Cappa et al., 2014). These take place in two subsurface aquifers, perched and deep (Vallet et al., 2015). However, the latter is poorly constrained (Nevers, 2021). We propose to use hydrogravimetric methods (Crossley et al., 2013) through seven measurement campaigns between 2020 and 2023 to better characterize this unit. We carried out gravity measurements using a Scintrex CG5 relative gravimeter at six points and an absolute gravity measurement at one point using an FG5 absolute gravimeter. The absolute point allows the determination of the absolute variation in gravity at all points on the network at each period.

We model density anomalies within the deep aquifer based on these data. We used the PyGIMLi library (Rücker et al., 2017) on Python. We show that these density variations correspond to the presence, and respectively the absence, of volumes of water contained in the low-porosity medium, i.e. storages. We also correlate them with the saturated water table height.

Then, we applied Darcy's law and we integrated rainfall data. Thus, we explain that the contrasts between values in the system originate in a disparity of transmissivities, i.e. the capacity to transfer a $1m^2$ vertical layer of water. We show that the deep aquifer is eight times more transmissive at the top of the landslide than at its center.
These results enable us to characterize the hydrogeological model in the Mont-Sec massif at a greater depth than in previous studies.

[*]Speaker
[†]Corresponding author: frederic.masson@unistra.fr

On the 3D annual motion for hydrogeodesy determined from different GNSS solutions

Janusz Bogusz * [1], Paul Rebischung [2,3], Anna Klos [1]

[1] Military University of Technology – Poland
[2] Institut National de lÍnformation Géographique et Forestière [IGN] (IGN) – IGN – France
[3] Institut de Physique du Globe de Paris (IPGP) – Institut national des sciences de lÚnivers, IPG PARIS, Université Paris Diderot - Paris 7 : UMR7154, Université de la Réunion, Centre National de la Recherche Scientifique : UMR7154, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers – France

Hydrogeodesy is an emerging field of geodesy aiming to turn geodetic instruments into hydrological tools. For more than 20 years, the GRACE/-FO twin satellites have provided very valuable data to support hydrologists, but recently GNSSs (Global Navigation Satellite Systems) were proved to have a potential in this field via sensing the displacements caused by hydrological mass changes. Although some recent studies have shown that hydrological signatures are also observed in GNSS displacements from sub-seasonal to multiyear periods, high compliance is obtained especially at seasonal frequencies. However, signals and errors specific to the GNSS technique may lead to misinterpretations of GNSS-derived position time series. In particular, the estimated annual displacements of GNSS stations depend on many factors related to the processing of GNSS tracking data or the alignment to the reference frame. In this presentation, we discuss major differences between annual displacements determined with Precise Point Positioning (PPP) and Network Solutions (NS) for more than 1000 globally distributed permanent stations in terms of different alignment strategies to the reference frame. A detailed comparison to annual displacements as obtained from GRACE/-FO is also made, providing some insights in potential application of GNSS-derived 3-dimensional annual displacements to hydrological studies.

*Speaker

Monitoring of the Theistareykir geothermal field in Iceland by hybrid gravimetry.

Beatrice Giuliante * [1,2], Philippe Jousset [1], Charlotte Krawczyk [1,2], Jacques Hinderer [3], Umberto Riccardi [4], Nolwenn Portier [5], Florian Forster [6], Anette Kaergaard Mortensen [7]

[1] German Research Centre for Geosciences - Helmholtz-Centre Potsdam – Germany
[2] Technical University of Berlin / Technische Universität Berlin – Germany
[3] Institut Terre Environnement Strasbourg – université de Strasbourg, Institut National des Sciences de l'Univers, Centre National de la Recherche Scientifique – France
[4] Università degli Studi di Napoli Federico II – Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse DiSTAR, Largo San Marcellino, 10 – 80138 Napoli, Italy, Italy
[5] ONERA – Ministère de la Défence – France
[6] Hot dry rocks Pty Ltd, Melburne – Australia
[7] Landsvirkjun – Iceland

Time-lapse gravity measurements can provide useful information about the underground mass redistribution. At Theistareykir geothermal field (Icelandic North volcanic zone) we performed long-term observations, since 2017, in order to monitor the mass transfer of underground fluids, associated with the harnessing of the geothermal field and to assess the sustainability of the anthropogenic activities.
In this study, we aim at modelling the subsurface fluid displacement through the use of the hybrid gravimetry technique. Hybrid gravimetry is a method which consists of the combination of several complementary gravity observations:

- micro-gravity time lapse relative measurements, repeated yearly on a pre-designed network of points, that allows the creation of time lapse gravity changes maps;
- relative gravity measurements, recorded continuously at several multi-parameter stations deployed within and outside the geothermal area. Each station is equipped with a superconducting or a spring gravimeter as well as a GNSS receiver, a broadband seismometer and hydrological and weather sensors.
- absolute gravity measurements, collected yearly, to constrain the instrumental drift of the relative gravimeters.

Here, we present the complete time series recorded by two superconducting gravity meters at Theistareykir since 2017. Thanks to these series an accurate local Earth tide model has been computed. This model, has been subtracted from the raw data, as well as the effect of polar motion, atmospheric pressure, vertical displacement and instrumental drift, in order to obtain

*Speaker

gravity residuals, sensitive to the injection and extraction activities. From the gravity residuals, we observe gravity decrease at the production site and increase at the injection site. These trends, are also visible in the absolute gravity measurements and the time lapse gravity changes maps.
Finally, we apply a forward modelling approach, with the aim of directly quantifying the mass transfer (extraction, injection, recharge, atmospheric losses) within the hydrothermal system.

Time-lapse relative-gravity measurements down a silo 10 metres deep isolate the gravity effect of local hydrology at Riga absolute-gravity station

Jaakko Mäkinen [*†] [1], Ivars Liepiņš [2], Kalvis Salmiņš [3], Vents Zuševics [2], Jānis Kaminskis [4], Reinhard Falk [5], Mirjam Bilker-Koivula [6]

[1] Finnish Geospatial Research Institute FGI, Espoo – Finland
[2] Latvian Geospatial Information Agency (LGIA), Riga – Latvia
[3] Institute of Astronomy, University of Latvia, Riga – Latvia
[4] Riga Technical University, Riga – Latvia
[5] Federal Agency for Cartography and Geodesy (BKG), Frankfurt am Main – Germany
[6] Finnish Geospatial Research Institute FGI, Espoo – Finland

The absolute-gravity (AG) station in Riga (Latvia) is situated at the bottom of an "inverted tower", a concrete silo10 m deep into the ground in a sand-silt-till setting. The site in the Riga Botanical Garden is a geodetic observatory with SLR and permanent GNSS. With the first AG measurement by the JILAg-5 of the FGI in 1995 it was realized that the silo facilitates the monitoring of subsurface water storage by repeated relative-gravity measurements between underground points (water attraction upwards) and surface points (attraction downwards). The AG station was subsequently occupied by the FG5-101 of the BKG in 1996 and BKG further enlarged the local relative network. Later AG station occupations were by the FG5-107 of the National Geospatial Agency (USA) in 1996, and by the FG5(X)-221 of the FGI in 2007, 2013, and 2019.

Relative measurements during AG occupations were not sufficient. Thus, monthly measurements of the local network were started by LGIA in 2013, using Scintrex CG-5 gravimeters. The peak-to-peak variation in the gravity differences between surface and bottom stations is 16 μGal. The results are highly interesting in themselves, beyond the AG application, and here we concentrate on them.

The terrain is flat and from what we know of the soil geology, the assumption of laterally homogeneous 1-D local hydrology is a reasonable approximation. We take into account the dry volume of the silo and of other constructions. Using the model, we can invert the relative-gravity series for both variation in subsurface water mass and for the mean depth of the layers with variable water content, without using any hydrological observations. But in fact, there are hydrological observations at the site, since 1998: the height of the groundwater table in an access tube. This time series has a high correlation with the time series of water mass from gravity inversion. Thus, relative gravity provides a scaling coefficient to obtain the variation in water mass (groundwater+soil moisture) from the water table fluctuation. Then the groundwater

[*]Speaker
[†]Corresponding author: jaakko.makinen@nls.fi

time series together with the 1-D model can provide local hydrological corrections to gravity measurements at any station at the site.

Tectonics and Environmental evidences of the seismological activities in vicinity of Lake Nasser, Egypt as deduced from integrated satellite observations

Khalid Zahran * [1]

[1] National Research Institute of Astronomy and Geophysics – Egypt

The filling of large reservoirs changes the stress regime, either by increasing vertical stress by loading or increasing pore pressure through the decrease of effective normal stress. Thus, crustal deformation and gravity variation are expected as well as induced seismicity.
At Lake Nasser, which impounded as a result of the construction of Aswan High Dam, variations of water level in the lake deform the dynamic stability of the area, either by variable induced loading or variation in the underground water level. On the other hand, continuous seismological activates around Lake Nasser is considered to be of great importance due to its socio-economic risk on the whole region. Reported earthquake activities on this region are clearly crustal due to the existence of an active tectonic pattern. Some studies suggest that the seismicity in the Lake region is driven by the pore pressure due to reservoir impoundment. Therefore, determination whether this deformation is due to environmental or tectonic origin is essential to figure out the geodynamic behavior of the study region and to explain the responsibility of the Lake for the occurred seismic activities.

Satellite altimeter were capable to monitor the Lake level variation. While, GRACE mason solution has been used to determine the mass variation due to underground water activities. Delay between both signals indicate a high pore pressure. On the other hand, geologic subsurface structure obtained from GOCE satellite mission shows important complicated intersections of the faulting system.
The study shows that the most seismological activities located at the fault intersection with higher delay between surface and ground water activities

*Speaker

Realization of gravimetric measurements in the local datum of tide gauges in Albania.

Bledar Sina * [1], Eduart Blloshmi

[1] Faculty of Civil Engineering, Polytechnic University of Tirana – Albania

Gravimetric measurements play a crucial role in understanding the Earth's gravitational field, aiding in various geodetic and geophysical applications. In coastal regions like Albania, where tide gauges are pivotal for monitoring sea level changes, integrating gravimetric data into the local datum of tide gauges becomes essential for accurate assessments. This abstract explores the methodologies and challenges involved in realizing gravimetric measurements within the context of Albania's tide gauge network. It discusses the importance of establishing a consistent vertical reference frame by aligning gravimetric observations with the local datum of tide gauges. Furthermore, it addresses the significance of such integration for coastal management, environmental monitoring, and geodetic studies in Albania. The abstract highlights the need for comprehensive data fusion techniques and quality control measures to ensure the reliability and accuracy of gravimetric measurements within the local datum of tide gauges. Through this integration, a more comprehensive understanding of sea level variations and associated geodynamic processes in Albania's coastal regions can be achieved, facilitating informed decision-making and sustainable development efforts.

*Speaker

Using UAV Lidar data to predict sea level changes in Albania.

Arli Llabani * [1], Namik Kopliku [1]

[1] Faculty of Civil Engineering, Polytechnic University of Tirana – Albania

The rise in sea levels is a critical concern worldwide, particularly for coastal regions like Albania, which face significant socio-economic and environmental risks. This study explores the feasibility of utilizing Unmanned Aerial Vehicle (UAV) Light Detection and Ranging (LiDAR) data to predict sea level changes along the Albanian coastline. The integration of UAV LiDAR technology offers high-resolution elevation data, enabling precise monitoring of coastal topography alterations. By analyzing UAV LiDAR-derived elevation data collected over multiple time intervals, this research aims to develop predictive models for sea level changes in Albania. The methodology involves data preprocessing, feature extraction, and the application of machine learning algorithms to identify patterns and trends in sea level variations. Additionally, factors such as coastal erosion, land subsidence, and climate change indicators will be considered to enhance the accuracy of the predictive models. The findings of this study hold significant implications for coastal management strategies, aiding policymakers, urban planners, and environmental agencies in implementing proactive measures to mitigate the adverse impacts of rising sea levels in Albania.

*Speaker

Hydrogeodetic signals from superconducting gravimeters network in Europe: "Ground Truth" for future quantum satellite gravity missions

Umberto Riccardi * [1], Tommaso Pivetta * † [2], Susanna Zerbini [3]

[1] Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse (DiSTAR); Università di Napoli "Federico II" – Italy
[2] Istituto Nazionale di Geofisica e Vulcanologia - Sezione di Napoli – Italy
[3] Department of Physics and Astronomy, University of Bologna, Italy (DIFA) – Italy

Terrestrial hydrology is expected to largely benefit from future satellite gravity observations like the cooperative ESA-NASA mission "Mass Change and Geophysics International Constellation" (MAGIC). In fact, satellites may provide information on large scale mass fluxes useful to constrain the 4D hydrological models. A mission equipped with a quantum gravimeter, has been recently proposed as a future scenario for the Next Generation Gravity Mission (NGGM). The project "NGGM/MAGIC, una svolta nella comprensione della dinamica della Terra", a collaboration between several italian universities, CNR and ASI, aims at providing realistic simulations of both the expected geophysical signals to be detected and an estimate of the error budget of the mission. Here we present the results of the 1st year of activity of a Work Package (WP) of the project titled "Ground Truth". The WP aims at defining realistic geophysical requirements of NGGM/MAGIC through the analysis of signals coming from a cluster of European superconducting gravimeters (SGs).
SGs are capable to provide long term series of gravity variations with precisions better than 10 nm/s2. The long term stability allows to study in detail the hydrologic cycle, from seasonal signals up to multi-year transients. Given their high precision, SGs are sensitive to both the local hydrologic component and even to the far field one.
The International Geodynamics and Earth Tide Service (IGETS) provides high quality data for several European SGs located in different hydrologic contexts, such as karstic areas or alluvial plains; in this contribution we take advantage of the continuous gravity data to extract the hydrologic signals for 7 SG stations in Europe. Data are analyzed exploiting spectral and Empirical Orthogonal Functions (EOF) methods to recover common modes and to characterize the differences between sites. Hydrologic models, obtained from the EOST/ITES Loading Service loading service, are also processed in a similar way and compared with the SG observations. The EOF analysis allowed to detect similarities between some stations located in the French area that share a clear common mode of the seasonal component. EOF analysis allowed also to distinguish stations located on surface from those located underground: in this last case the first component of the EOF has a reversed sign due to the soil moisture change occurring above the gravimeters. Regarding hydrologic models, EOF and spectral analysis confirm a very good

*Speaker
†Corresponding author: tommaso.pivetta@ingv.it

agreement between models and observations for the stations located on surface.

Evaluation of a regional hydrological model using high-precision terrestrial gravity time series in the surroundings of the Geodetic Observatory Wettzell, Germany

Anna Winter * [1], Marvin Reich [2], Ezequiel Antokoletz [1], Patricio Yeste [2,3], Andreas Güntner [2,3], Hartmut Wziontek [1]

[1] Federal Agency for Cartography and Geodesy (BKG), G4 - Gravity Metrology, Leipzig, Germany – Germany
[2] German Research Centre for Geosciences (GFZ), Potsdam, Germany – Germany
[3] University of Potsdam, Institute of Environmental Science and Geography, Potsdam, Germany – Germany

Compared to hydrological observation methods, which are mostly able to observe water storage changes only in specific depths or single compartments and representative only for a limited volume, gravity measurements are sensitive to mass changes as a spatially integrated signal. This makes them a valuable complementary tool for the monitoring of total water storage changes.
In a case study, we consider the site of the Geodetic Observatory Wettzell (GOW), which is located in the catchment of the river Regen in a low mountain range in East Bavaria. Here, long-term stable records of superconducting gravimeters (SGs) are available at different points at the observatory. The time series are corrected for tidal, atmospheric and other non-hydrological effects. A regional network of 11 points was implemented and observed since 2014 with absolute and relative gravimeters twice per year in order to capture the seasonal hydrological signal. This network with a radius of about 10 km around the GOW allows to assess the spatial variability in the region and how representative terrestrial gravity measurements are on a regional scale. Further, an extensive hydrological sensor network has been operated at GOW for more than a decade and compared with the gravimetric observations in previous studies.
We use the mesoscale Hydrologic Model (mHM, Helmholtz Centre for Environmental Research - UFZ) to predict water storage changes in different subsurface compartments. The model is implemented for the catchment area of the river Regen with a spatial and temporal resolution of one kilometer and one day, respectively, and calibrated against river discharge at a gauge. Based on the mHM simulation results, the expected gravity effects are calculated at selected sites and then compared to the observed gravity changes. First results show a good agreement with the SG records at GOW. The predicted total water storage changes are rather homogenous for the study area, which is confirmed on a seasonal scale by the gravity measurements at the network points. To account for the subsurface complexity at the GOW and the high sensitivity of the gravity measurements on local mass changes, finer resolved hydrological input, derived from in-situ observations, is used in the close vicinity of the SGs. Special attention for the umbrella effect of the buildings and local topography is necessary.

*Speaker

Predicting seafloor topography from gravity anomaly and vertical gravity gradient anomaly

Jinhai Yu *† [1], Huan Xu [1]

[1] University of Chinese Academy of Sciences – China

Direct bathymetry is a primary data source for creating high-precision seafloor topography but cannot easily achieve high-resolution global coverage. Therefore, using gravity data for seafloor topography prediction is an alternative method. Current algorithms, reliant on the measurement of ship soundings and geophysical parameters, still have room for improvement in accuracy and coverage. In this study, we establish observation equations based on vertical gravity anomalies (VG, also called gravity anomalies) and vertical gravity gradient (VGG) anomalies generated by a rectangular prism and develop a new analytical algorithm for predicting topography. We validate its effectiveness through numerical simulations and actual applications. We determine the source of the errors, the mid–high frequency error caused by the boundary area is reduced by regularization, whereas the low-frequency error caused by the far area is reduced by the error equation algorithm. In the shallow areas with a maximum depth of 2 kilometers and deep-sea areas with a maximum depth of 5 kilometers, the root mean square errors (RMS) for VGG anomalies prediction are 93.8 m and 233.8 m, respectively, while for VG anomalies prediction they are 101.2 m and 239.4 m. We also find that VGG anomalies are more sensitive to topography fluctuations, but VG anomalies have a stronger linear correlation with topography. Additionally, we propose a cubic spline interpolation algorithm to effectively fuse the prediction results and ship soundings, improving topographic prediction accuracy in shallow and deep-sea areas by up to 53.2% and 39.67%, respectively.

*Speaker

†Corresponding author: yujinhai@ucas.ac.cn

Analysis of water storage redistribution in Africa between 2003 and 2023, Using GRACE, TRMM and GLDAS datasets.

Slimane Benyahia * [1,2], Fatah Touati [1], Nawel Benaraba [3]

[1] Département de Géodésie spatiale, Centre des Techniques Spatiales, Agence Spatiale Algérienne, Oran – Algeria
[2] RISAM Lab, Département de Génie Civil, Faculté de Technologie, Université de Tlemcen – Algeria
[3] LGTE Lab, Département d'hydraulique, Faculté d'Architecture et de Génie Civil, Université des Sciences et de la Technologie d'Oran Mohamed Boudiaf – Algeria

Understanding the water storage redistribution is essential for life on earth. However, several studies have been conducted to analysis spatiotemporal variation of continental water storage, but it's still insuffisante in Africa. Since 2002, the Gravity Recovery and Climate Experiment (GRACE and GRACE follow-on) satellites missions data are used to estimate monthly variation of total water storage (TWS) on earth. In this study, we analysis the intra-annual and inter-annual variation of TWS in Africa for the period between January 2003 and September 2019, using monthly GRACE and GRACE-FO coefficients RL06 from the German Research Centre for Geosciences GFZ. For removing the groundwater variation in TWS, the GLDAS Version 2.1 Noah product was applied in this study, and for relating TWS data to precipitation fields, the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) data product 3B43 was used. The principal component analysis PCA was applied to decompose thespatiotemporal TWS data sets into modes of empirical orthogonal functions (EOFs) and principalcomponents (PCs) corresponding to the spatial and temporal variations, respectively, and was also applied to decompose the TWS timeseries into trend, seasonal and residual signals. The PCA analysis of the regional TWS is used to distinguish different zones that has important water mass variations. Results from this study show largest annual signals of GRACE TWS in Zambezi, Okavango and Volta River basins. From 21 years of GRACE TWS time series, we survey the depletion of groundwater aquifer of the North Western Sahara.These different applications demonstrate the potential of the GRACE mission for the management of water resources at the regional scale. Keywords: GRACE TWS, TRMM, GLDAS, PCA,Africa.

*Speaker

Invited talk:
Geodetic monitoring of ground displacements and mass redistribution induced by deep volcanic fluids and ocean dynamics at the Geosciences Laboratory in Lanzarote (Canary Islands, Spain)

Teresa Benavent *† [1]

[1] Universidad Complutense de Madrid = Complutense University of Madrid [Madrid] – Spain

The Canary Islands are an intraplate oceanic volcanic archipelago consisting of eight major islands and islets, situated in the Atlantic Ocean, close to the Moroccan passive continental margin. Lanzarote is the most northeast and the oldest one, together with Fuerteventura. Both islands were formed by volcanic processes and are the emergent part of the East Canary Ridge. The 1730-1736 Timanfaya eruption was the historical highest magnitude eruptive process that took place in the central-western sector of Lanzarote. It lasted 6 years and formed hundreds of vents aligned along a 14 km eruptive fissure. In Timanfaya area stands out the presence of thermal anomalies explained by remnant hot magma at approximately 4 km depth and by water vapour coming from a deep-seated (3-4 km) water table. The Geosciences Laboratory of Lanzarote manages three observing infrastructures (Cueva de Los Verdes, Jameos de Agua and Timanfaya volcanic area) distributed along the island, where more than 50 instruments provide a multi-parametric monitoring of gravity variations, ground deformations, sea level, seismic activity, meteorological parameters, etc. Continuous recordings are supplemented by periodic measurements on networks that allow multi-scale (local, insular and regional) studies.
Geodetic and geophysical facilities of the Geosciences Laboratory at Timanfaya site allowed us to model the sources that best explain the observed surface deformation related to the existing geothermal system. Our modelling relies on various geodetic techniques: data from 9 continuous operating GNSS stations, tiltmeters and strainmeters (the latter, more than 20 years of continuous recording). To further improve our understanding of the surface thermal anomalies and the active tectonics in the area a thermo-fluid-dynamics model has been implemented.
The facilities of the Geoscience Laboratory of Lanzarote situated in the Cueva de Los Verdes and Jameos del Agua sites, both located along the lava tube of La Corona volcano, to the northeast of the island, consist of several geodetic instruments operating in continuous mode: gravimeters, tiltmeters, strainmeters, GNSS and tide gauges. In order to fully exploit the potential of the collected geodetic data for a variety of geophysical topics in active volcanic areas, it is necessary to address
and accurately remove the disturbance signals (e.g., oceanic, atmospheric) that may otherwise

*Speaker
†Corresponding author: mbena@ucm.es

interfere with or mask the target signals. The most important disturbing signal is the ocean tidal loading (OTL), which has to be carefully modelled in this particular region due to, among other factors, the porosity of the lava rocks in the volcanic tunnel and the surrounding areas. For this
purpose, we developed a local ocean tide model and use specific ocean-earth mask to improve OTL calculations. Also, we have estimated the (periodic and non-periodic) disturbances in the sea level measured and compared the results with vertical land movements in this area.

Session 4. New technologies, software and innovative concepts (cold-atom gravimetry, gradiometry, etc.)

Super-resolution of tides demonstrated with regularization

Adam Ciesielski [*†] [1,2], Thomas Forbriger [2,3], Walter Zürn [3], Andreas Rietbrock [4]

[1] Institute of Geodesy and Cartography – Poland
[2] Karlsruhe Institute of Technology – Germany
[3] Black Forest Observatory (BFO) – Germany
[4] Karlsruhe Institute of Technology – Germany

Harmonic tidal analysis seeks parameters for sums of inseparable harmonics - wave groups - that are estimated using the method of least squares (LS). Since short records and close frequencies result in an ill-conditioned matrix equation, the basic assumption presumes necessitating a record length of T to distinguish harmonics with a frequency separation of 1/T, known as Rayleigh criterion. This approach is used in widely used tidal software such as Eterna or Baytap08. However, since the signal from the next largest harmonic in a group could significantly differ from the theoretical expectation, the grouping parameterization might lead to an inaccurate estimate of tidal parameters.
The new software, RATA (Regularization Approach to Tidal Analysis), does not use the concept of wave groups; instead, each tidal harmonic receives its set of tidal parameters. The resulting ill-posedness of the problem is mitigated by applying Tikhonov regularization in the LS objective function. The simplest regularization - the reference model - is initially chosen to be the Wahr-Dehant-Zschau model, as used in Eterna. Deviation of parameters from the reference model suggests difference between observation and the initial reference response. Hence, tidal parameters are updated iteratively, with the newly estimated model parameters becoming the new reference model. After just a few iterations, a final local response model is estimated. Moreover, the software provides the possibility to test the relevance of tidal parameters by selecting any reference model in the analysis.

[*]Speaker
[†]Corresponding author: adam.ciesielski@igik.edu.pl

The RATA method was successfully tested on gravity data from over 12 superconducting gravimeter sensors distributed within Europe and worldwide, resulting in highly detailed local response models. In most cases, the total number of all identified free parameters (equivalent of groups) of degree 2, 3, and 4 exceeds 50. Typically, resulting RMS values of the residuals decrease by 20% and residual signals exhibit fewer systematic effects when using RATA compared to the wave-group approach. We demonstrate the application of the new analysis method and display resulting models from selected observatories. We illustrate how close harmonics can be safely treated separately, even though they may significantly violate the Rayleigh criterion. We conclude that the harmonic amplitude is a much more relevant criterion for the distinction of tidal harmonics than frequency separation, as demonstrated with various time series lengths.

Calibration of superconducting gravimeters by artificial accelerations

Hartmut Wziontek * [1], Erik Brachmann [1], Michael Kühnel [2], Thomas Fröhlich [3]

[1] Federal Agency for Cartography and Geodesy (BKG) – Germany
[2] SIOS Messtechnik GmbH, Ilmenau – Germany
[3] Institute of Process Measurement and Sensor Technology, TU Ilmenau – Germany

Superconducting gravimeters are the most sensitive and most stable stationary relative gravimeters. As every relative gravimeter, it needs calibration to translate the measured reading units into gravity variations. It is common practice to infer the scale factor from parallel observations with absolute gravimeters. However, the distinct noise level (by roughly a factor of 1000) and small bias changes during the observation period, the achievable uncertainty is limited to about one permille. Therefore, already in the early nineties, a concept to calibrate superconducting gravimeters by artificial accelerations was successfully realized by the so-called Frankfurt Calibration System at BKG.
Limitations of this system were deficiencies in the alignment and an incomplete tilt compensation. In a joint project with TU Ilmenau, Germany, the concept was evaluated and the hardware of the system was renewed. By a new alignment procedure and feedback of the gravimeter tilt into the control loop, the precision of the vertical movement was significantly improved. By this, a relative accuracy of better than 0.1 permille is achievable.
We present and evaluate the new system and the calibration results for the superconducting gravimeters GWR SG029 at Wettzell and GWR SG044 at Bad Homburg and compare it with calibration results with absolute and relative gravimeters.

*Speaker

LUH-JAQGM2024: Joint Measurements with Absolute Quantum Gravimeters at Leibnitz University Hannover

Marvin Reich * [1], Heiko Thoss [1], Przemysław Dykowski [2,3], Marcin Sekowski [2], André Gebauer [4], Mohamed Sobh [5], Jan Bergmann [5], Nicolas Le Moigne [6], Sébastian Merlet [7], Nawel Addi [7], Ludger Timmen [8], Peter Rosenbusch [9], Maxime Arnal [9], Pierre Vermeulen [9]

[1] German Research Centre for Geosciences (GFZ), Potsdam, Germany – Germany
[2] Institute of Geodesy and Cartography, Centre of Geodesy and Geodynamics, Warsaw, Poland – Poland
[3] Central Office of Measures, Warsaw, Poland – Poland
[4] Federal Agency for Cartography and Geodesy, Department Geodesy - Unit G4: Gravity Metrology, Leipzig, Germany – Germany
[5] Leibniz Institute for Applied Geophysics, Hannover, Germany – Germany
[6] Geosciences Montpellier, Univ Montpellier, CNRS, Univ des Antilles, Montpellier, France – CNRS – France
[7] LNE-SYRTE, Observatoire de Paris - Université PSL, CNRS, Sorbonne Université, France – LNE-SYRTE – France
[8] Leibniz University Hannover, Faculty of Civil Engineering and Geodetic Science, Hannover, Germany – Germany
[9] Exail, Quantum Systems, 1 rue Francois Mitterand, 33400 Talence, France – Exail – France

Absolute Quantum Gravimeters (AQG) are commercially available (Exail, France) since 2014. Up to now 16 units of the AQG have been distributed worldwide, most of them in Europe. Organized by the GFZ Section 4.4 "Hydrology" and under the umbrella of the Collaborative Research Centre "TerraQ" (SFB 1464), the world's first AQG comparison took place from 22nd to 26th of January 2024 at Leibniz University Hanover (Germany) in the gravimetric laboratory of the HiTec building.
Five AQG units of the same type (version B – temperature stabilized) participated in the comparison, operated by the following teams: Instrumental Park of Action Spécifique Gravimétrie of Epos-France (AQG-B01), the German Research Center for Geosciences in Potsdam, Germany (AQG-B02), the Institute of Geodesy and Cartography, Poland (AQG-B07), the Leibniz Institute of Applied Geophysics in Hanover, Germany (AQG-B09), and the German Federal Agency for Geodesy and Cartography in Leipzig (AQG-B10).

The measurement activities lasted 5 days (day and night, 11-12h tracking series) and included a series of test measurements aimed at deepening the knowledge on the operation principle of AQGs.

This contribution will present results of the preliminary evaluation of the comparison. This

*Speaker

non-official comparison had the main intention to test device characteristics and behaviors, with the focus on comparing their performances. Among other things, this involved the noise behavior of the devices, their stability during longer measurements and repeatability.
The joint AQG measurements were independently supported by classical relative and absolute gravity measurements with CG6 and FG5 gravimeters from the Leibniz University Hannover and the German Federal Agency for Geodesy and Cartography.

Airborne gravimetry with high-precision strapdown inertial measurement units

Vadim Vyazmin *† [1], Andrey Golovan [1]

[1] Lomonosov Moscow State University – Russia

In 2020-2023, Lomonosov MSU has been developing postprocessing software for the inertial airborne gravimeters based on strapdown technology. Strapdown instruments are alternative to the classical inertial gravimeters based on a gyrostabilized platform (GT-2A, L&R, and others). Due to their much smaller size and less weight, strapdown gravimeters can be installed onboard a small aircraft (or drone), thus allowing measurements to be collected at much lower speed. This is especially important for the aerogravimetry surveys carried out for geological purposes, since in this case gravity data can be collected at a higher spatial resolution.
A strapdown gravimeter is based on an Inertial Measurement Unit (IMU) consisting of high-precision accelerometers and gyroscopes. The IMU is supplemented by a thermal stabilization box (to minimize the instability of accelerometers' bias drift) and geodetic GNSS receivers.

In the presentation we outline challenges of postprocessing raw data from strapdown airborne gravimeters. One of them is the estimation of accelerometers' linear bias drift from measurements before and after the flight. Another challenge is the in-field calibration of the gravimeter's IMU, which is naturally required in long-term campaigns (lasting for several months), since the instrumental errors of inertial sensors slowly evolve in time (the scale factor error, gyroscope in-run bias, etc.). We propose a combination of static and "in-flight" calibration methods to estimate these errors as accurately as possible.
We also present airborne gravimetry results obtained with two strapdown systems, one of which is a new instrument by a domestic manufacturer and the other by iMAR. The data were collected during recent campaigns carried out for geological purposes.

*Speaker
†Corresponding author: vadikmm@yandex.ru

Detection limit to Earthquakes and seamounts of Quantum gravimeter payload combined with satellite-satellite tracking from single GRACE type to multiple couples constellations

Carla Braitenberg * [1], Anna Fantoni [1], Muhammad Tahir Javed , Gerardo Maurizio , Alberto Pastorutti

[1] University of Trieste – Italy

Advancements in space-based gravity observation are poised to undergo a significant transformation in the coming years, propelled by innovations such as the MAGIC constellation, featuring a single polar pair GRACE-C, and the enhanced ESA's NGGM inclined pair, boasting lower orbit altitudes and drag compensation capabilities. This trajectory is further bolstered by the potential integration of augmented satellite constellations equipped with absolute accelerometers utilizing Cold Atom Interferometer technologies. These developments promise lower spectral noise curves, thereby enabling higher time resolution and a superior spatial resolution compared to current standards set by GRACE-FO.

Our exploration extends to pioneering applications within the domain of solid earth sciences, encompassing seismic events, seamount formations, vertical topographic shifts, and fluid reservoir dynamics, all of which stand to benefit from the forthcoming advancements in gravity observation from space. While phenomena linked to the earthquake cycle and postseismic fault movements are effectively monitored on land through SAR and GPS, their observation in remote oceanic regions remains challenging due to the absence of seismic waves generated by slow fault movements. We delineate the observable magnitude limits contingent upon fault mechanisms, depths, and satellite constellations.

Similarly, the detection of seamounts, particularly in remote areas where they may silently grow, altering underwater bathymetry in uncharted ways, presents a formidable task that could potentially be addressed through future spaceborne gravity observations (Braitenberg and Pastorutti, 2024). The vertical topographic movement is documented by GPS and SAR, leading to a mass change which we compare to competing mass changes as the hydrologic and glacial mass loss in the Alps and to the detectability levels of the future satellite constellations.

We finally show that in future the isolated gravity signals for the tectonic movements are complementary to data used in the Copernicus Services of a) Disaster Management and b) Climate Change Monitoring and are prone to improve the completeness of these Services.

Reference

Braitenberg C, Pastorutti, A. (2024) Detectability of Hunga Tonga, Fani Maoré and other

*Speaker

seamount eruptions through the quantum technology gravity mission MOCAST+ and GRACE-FO, in press at Surveys of Geophysics, doi 10.1007/s10712-024-09839-7

Systematic errors of superconducting gravimeters – An investigation of sensor differences of dual sphere superconducting gravimeters

Clara Beck *† [1], Thomas Forbriger [2,3], Rudolf Widmer-Schnidrig [1,2], Walter Zürn [2], Nico Sneeuw [1]

[1] Geodätisches Institut, Universität Stuttgart – Germany
[2] Black Forest Observatory (BFO) – Germany
[3] Karlsruhe Institute of Technology – Germany

We analyze the difference signal of dual sphere superconducting gravimeters (SG) to identify systematic instrumental disturbances, which would otherwise go unnoticed.
Compared to classical spring gravimeters SGs excel by their superior long-term stability. For example, the drift of the upper sensor of the SG056 at the Black Forest Observatory (BFO) is 10 to 100 times smaller than the one of the ET19 LaCoste-Romberg gravimeter at BFO, depending on the time period studied. However, also SG measurements are influenced by systematic errors. One possibility to characterize and quantify them is the analysis of sensor differences of dual sphere instruments. For a perfect instrument the sensor difference should be constant. We studied the sensor differences of all seven dual sphere SGs in the database of the International Geodynamics and Earth Tide Service (IGETS). As expected they show a relative drift between the sensors and steps related to operator interventions. However, we can also identify times, during which the sensor differences show more complicated behavior. The observed differences are too big to be caused by local gravity gradients. Therefore, we think, they indicate more complex systematic errors of SGs. These errors are at the level of microGal and could not be clearly identified as disturbances in the gravity residuals of only one sensor.
Knowledge of the characteristic and size of these errors is important if gravity changes at the microGal level are studied on long time scales, like signals from hydrology, volcanology, polar motion or long period tides. In the future we will study how these errors influence the determination of the gravimeter factor of the Chandler wobble from long time series of SG measurements.

*Speaker
†Corresponding author: clara.beck@gis.uni-stuttgart.de

Nano-Torque Induction System Based on Watch's Hands Rotation in Gravity Field

Justine Lebrun *† [1], Michel Van Ruymbeke‡ [2], François Wielant [1], Jean-Pierre Raskin [1], Sébastien Toussaint§ [1]

[1] Institute of Information and Communication Technologies, Electronics and Applied Mathematics – Belgium
[2] Royal Observatory of Belgium – Belgium

Generation, detection, and calibration of minute torque are crucial in establishing the scale factor of tidal tiltmeters. Induced force, tilt, or torque detection are examples of common approaches. In this study, we investigate the calibration of a nano-torque inductor relying directly on the Earth's local gravitational field which serves as a secondary reference to the SI fundamental standards. In the first part, we describe the prototype, consisting of a horizontal two-plate balance equipped with a capacitance bridge transducer. Its symmetry effectively mitigates undesired effects by inherently rejecting common mode uncertainties. Geometrical stability of the rotation axis is assumed by an innovative mounting.
Secondly, the establishment of the scale factor of the system itself is described. A small stepper motor, controlled by a quartz synchronized interface, modulates the linear motion of a known mass over numerous cycles. Following this, the calibration factor is determined, establishing the correspondence between variations in signal frequency and lever-arm modulated torque. As each capacitance's signal is recorded independently, we access common thermal effects by adding the two signals. Conversely, the output signal is produced by subtracting the two frequency-modulated signals.

Among available torque inducer possibilities, the utilization of a quartz watch's hands emerged as an ideal choice, owing to the consistent amplitude and the stability of the time period of the induced torque. Furthermore, the hermetically sealed casing of the watch eliminates pressure buoyancy modulation within the surrounding environment. Employing continuous signal acquisition, the effects of the watch were isolated by stacking, leveraging its known periodicities (minute, hour, mid-day). The sinusoidal motion intrinsic to the watch's operation was then extracted thanks to the signal processing method's effective attenuation of random noise which scales inversely with the square root of the number of the aggregated sample size.
In summary, our tabletop-sized prototype showed torque transduction capabilities with large dynamics excursions post-stacking, tailored to tidal tiltmeters requirements as the range demonstrated covers the one of tilt induced by Earth tides' effects. Hence allowing the transfer of standard units to instruments with a straightforward method and a continuous recording of their sensitivity. Additionally, the attained torque sensitivity in the capacitive balance and the

*Speaker
†Corresponding author: ju.lebrun@uclouvain.be
‡Corresponding author: oasismini@hotmail.com
§Corresponding author: sebastien.toussaint@uclouvain.be

watch's hands monitoring lends itself to diverse applications such as gravitational pendulum calibration, micro-strain gauges characterization, air density measurements, and more.

"B-grav" for very low gravity measurements at the surface of an asteroid

Michel Van Ruymbeke *† [1], Sébastien Toussaint‡ [2], Ozgur Karatekin§

[1] Royal Observatory of Belgium – Belgium
[2] Institute of Information and Communication Technologies, Electronics and Applied Mathematics – Belgium

As a part of a monitoring package dedicated to small bodies of solar systems such as asteroids, we investigated a 3D compact gravimeter. The described prototype is part of an ESA project dedicated to asteroid monitoring and will be installed on a CubeSats assembly which will land on the secondary object of the Didymos system.
The selected solution specifications address the challenge of measuring an extremely faint $50\mu m/sec^2$ gravimetric field, corresponding to 5 ppm of Earth gravity. The system will operate without leveling in a harsh thermal environment, with strictly limited power, mass, and signal treatment facilities. Three-dimensional sensors are mounted in orthogonal geometry to determine the three components of the gravity field vector, without tilt adjustment. We chose like-proof masses, and small-thickness flat springs rigidly anchored at one of the gravimeter's extremities, with displacements monitored by a capacitance bridge approach. Rejection of the common mode is achieved by simple rotation of the gravimeter along its axis. Hence, local gravity induces torque modulations at a well-known angular speed which can later be determined by applying stacking methods on the output signals.
In the laboratory, the gravimeter was set up in a vertical position, effectively rejecting the Earth's gravity field. In this configuration, it became possible to simulate μ-changes of forces in the same order as the Asteroid's gravity field, by inducing very small tilts. If B-Grav is equipped with two eccentric parallel plates, in-situ monitoring of the system's transfer function could be investigated using centrifugal forces adjusted by the speed of rotation.

*Speaker
†Corresponding author: oasismini@hotmail.com
‡Corresponding author: sebastien.toussaint@uclouvain.be
§Corresponding author: ozgur.karatekin@observatory.be

Low-frequency earth tides and free oscillations observations using fiber borehole strainmeters

Qi Guoheng [1], Wentao Zhang *† [1], Huang Wenzhu [1]

[1] Institute of Semiconductors, Chinese Academy of Sciences – China

Strainmeters are one of the most fundamental instruments to observe the earth tides and geodynamic phenomena. With the development of fiber optic sensing, fiber borehole strainmeters are popular because of the advantages of strong adaptability to the extreme environment and special sensitivity to some low-frequency geodynamic signals especially. In this study, we reported examples of observing solid earth tides and free oscillations of the Earth (FOEs) using fiber borehole strainmeters. From the long-term observations of fiber borehole strainmeters in Huoshan County, Anhui Province, we detected the diurnal, semi-diurnal and 1/3-diurnal tidal constituents. The observations of the four horizontal components appeared to be well self-consistent. Besides, these stations also observed FOEs excited by Philippines Mw7.6 earthquake. Using Bartlett's method (also known as the method of averaged periodograms), almost all of zero-order spherical oscillation modes (0S2 to 0S38) and toroidal oscillations (0T3 to 0T35) between 0.2 and 4.5 mHz were detected. Our results show that fiber borehole strainmeters have benefits of wide frequency band and high sensitivity, providing an interesting complement to classical instrumentations for which tidal phenomena and geodynamics are relevant.

*Speaker

†Corresponding author: zhangwt@semi.ac.cn

Invited talk: Differential Quantum Gravimeters - instrumental progress and preparation of field-deployment

Camille Janvier [*†] [1], Peter Rosenbusch [1], Vincent Ménoret [1], Bruno Desruelle [1], Cédric Majek [1]

[1] Exail Quantum Systems – Exail – France

Since the first demonstration in 1992, several quantum gravimeters have been realised in research laboratories around the world. In 2015 Exail launched the first absolute quantum gravimeter (AQG) on the marketplace and 17 units have been sold to this date making it the first quantum gravimeter in series production. Since 2017, Exail has also developped a Differential Quantum Gravimeter (DQG): conceptually identical to two AQG stacked vertically sharing the same vacuum tube and laser beam, this instrument gives two absolute values of g and is thereby capable of providing both the mean gravity acceleration and its vertical gradient simultaneously. We will present the instrument set-up and lastest features that have allowed to reach sensitivities better than 30E/sqrt(tau) which is the best ever reported sensitivity for such an instrument. We will also report on progress within the Horizon Europe project FIQUgS which realises a field compatible DQG autonomously deployed by a robot. We will detail the hardware and software developments within the project which aims at improving its robustness and ease of data exploitation.

[*]Speaker
[†]Corresponding author:

Session 5. Time variable gravity and mass redistribution (glacial isostatic adjustment, ice mass changes, ocean dynamics, etc.)

Space-time gravity changes within Vrancea active seismic zone, Romania

Lucian Besutiu * [1], Luminita Zlagnean [1]

[1] Institute of Geodynamics of the Romanian Academy – Romania

Vrancea active geodynamic zone is one of the so-called "seismic nests" of the world (along with Bucaramanga in Bolivia and Hindu Kush in Afghanistan), where intermediate-depth earthquakes may occur within full intra-continental environment. The area is in the bend of East Carpathians, and the unusual upper mantle seismicity occur in an almost vertical finger-shaped volume between 70 to about 200 km depth.
With several disastrous events in a century (of Mw above 7) Vrancea put a serious threat on several major cities of Romania, including Bucharest, its capital, where the 4 March 1977 Mw 7.2 earthquake killed 1568 people and injured more than11.300. The total economic loss was estimated at about USD 2 billion at the rate of that time.

Despite many years of national and international research efforts, genesis of the Vrancea subcrustal seismicity still represents a challenge for 21st century.

Whether previous research was mainly based on seismological studies that succeeded to outline the geometry of a high velocity body associated to seismicity, with limited horizontal sizes, but largely extended in depth, little focus has been granted to geodynamic aspects.

Starting from the idea that modifications in the sub-crustal mass architecture should reflect in changes of the gravity field, the Solid Earth Dynamics Department in the Institute of Geodynamics of the Romanian Academy has designed and built up a specific infrastructure for monitoring gravity in the epicentre area. The approach has some peculiarities due to the absence of an absolute meter, but the use of a relative CG5 gravity meter. High accuracy repeated gravity observations have been performed within appropriate circumstances for repeatability

*Speaker

offered by the specially designed steel-reinforced concrete pillars of the network base stations. Corrections for changes in the air pressure, and tide effects have been applied to observations.

Absolute gravity values have been transferred into the network through the special ties to the absolute base stations belonging to both Romanian 2nd order gravity network (valid for the 1980 epoch), and the UNIGRACE European gravity network (offering values for 2000 epoch).

When comparing the pairs of results on each network base station, an overall gravity lowering overlapping the epicentre area has been outlined for the timespan separating the two sets of absolute values. To get things more intriguing, high accuracy geodetic observations have revealed a relative subsidence of the epicentre area superposed on the general uprising of Carpathians following denudation and erosion. Corrections applied for the vertical crust deformation, based on local vertical gradients of gravity did not significantly alter the overall picture.

During a decade of systematic observations, the above-mentioned gravity behaviour has been confirmed, clearly revealing an ongoing geodynamic process in the active seismic zone. A particular gravity decrease related to seismicity in the area was also noticed by successive gravity campaigns conducted prior and after some significant earthquakes (Mw $>$ 5).

Solutions provided by gravity inversion and some 3D forward modelling of the responsible mass deficits were interpreted in terms of vertical stretching of the upper part of the crust under the gravity pull generated by eclogitization of the lower crust penetrating the upper mantle.

Within such circumstances, the intermediate-depth seismicity should be associated to some accommodation processes caused by thermos-baric disequilibrium occurred in the segment of lithosphere sunken into the upper mantle, like, e.g., thermal gradient and/or phase transforms. At the end, discussions/speculations on some potential geodynamic scenarios (e.g., paleo-subduction, Raileigh-Taylor gravitational instability, and unstable triple-junction) are presented.

Influence of different ocean areas on the annual variations of the gravimetric M2 tidal parameters studied with a global Hycom ocean model

Eva Schroth *† [1], Thomas Forbriger [2], Malte Westerhaus [3], Brian K. Arbic [4], Jay F. Shriver [5]

[1] Federal Agency for Cartography and Geodesy, previous: Geodetic Institute, Karlsruhe Institute of Technology – Germany
[2] Black Forest Observatory, Karlsruhe Institute of Technology – Germany
[3] Geodetic Institute, Karlsruhe Institute of Technology – Germany
[4] Department of Earth and Environmental Sciences, University of Michigan – United States
[5] Naval Research Laboratory, Stennis Space Center – United States

Annual variations of the M2 tidal parameters (AVM2) are observed at all superconducting gravimeter (SG) stations. Loading caused by an annual variation of the M2 ocean tide (AVM2ssh) were discussed as the cause. Analyses of synthetic data from non-linear, time-stepping ocean models that potentially describe the effects causing the AVM2ssh support this conception.
AVM2ssh is large in coastal areas and small in the open ocean. The former are close to the SG stations but cover only small areas whereas the open ocean is the main part of the global ocean. This study aims in identifying regions of the ocean which contribute significantly to the AVM2 at the SG stations.

We select model grid points from a global Hycom ocean model by an estimation of their maximum loading contribution to the AVM2 at a SG station. Only the selected grid points are taken into account in a loading calculation for the stations Black Forest Observatory (BFO, Germany) and Cantley (Canada). This time series is added to synthetic Earth tides and analysed in a moving window tidal analysis with Eterna. The resulting AVM2 is compared to that obtained with the whole model. We repeat the analysis using more and more grid points with a smaller contribution to the AVM2. A difference between the AVM2 from the point selection and from the whole model of less than 10% is regarded as sufficient and the considered grid points are necessary for describing the AVM2 at a station. The distribution of the grid points used in this case tells us which regions of the oceans have a significant contribution to the AVM2.

For BFO, these grid points are distributed over larger areas in the North Atlantic, but also in distant ($> 140°$) shelf regions. At Cantley station they cover almost the entire globe. For both stations, there are indications that contributions from different ocean areas have to cancel partly.

*Speaker
†Corresponding author: eva.schroth@bkg.bund.de

We conclude that not only close shelf areas but also distant ocean regions, including open ocean areas, contribute significantly to the AVM2 at the SG stations. This effect has to be studied on a global scale. Additionally, this study shows the potential of SG data for the evaluation of ocean models especially when small effects in the ocean are regarded.

An anomalous GRACE gravity signal in the Atlantic Ocean originating from the Earth's deep interior

Charlotte Gaugne * [1], Isabelle Panet [1,2], Marianne Greff [1], Mioara Mandea [3], Séverine Rosat [4]

[1] Institut de Physique du Globe de Paris – Université Paris Cité, Institut de physique du globe de Paris, CNRS, IGN, F-75005 Paris – France
[2] ENSG Géomatique, IGN, F-77455 Marne-la-Vallée, France – ENSG Géomatique, IGN, F-77455 Marne-la-Vallée – France
[3] Centre National d'Études Spatiales [Paris] – CNES – France
[4] Institut Terre Environnement Strasbourg – Université de Strasbourg, CNRS UMR7063, Strasbourg – France

On Earth, understanding the complex boundary between the core and the mantle (CMB) is challenging. This region might play a role in explaining fast changes of the geomagnetic field, through mass redistribution at the CMB potentially affecting the core flows at the top of the core. The GRACE measurements of the space-time variations of the Earth's gravity field provide a unique opportunity to constrain such deep mass redistributions. To separate the superimposed signals in the total gravity field and guide the identification of their sources by pattern recognition, we use the second-order spatial derivatives of the gravity potential at different spatial scales. Combining this tool with a multi-scale temporal analysis, we can identify rapid signals at large spatial scale, concomitant with geomagnetic jerks. This way, we detect an anomalous North-South oriented gravity signal across the boundary between the Atlantic Ocean and the African continent in January 2007, with a timescale of 2-3 years. To investigate its potential sources, we compare this observed signal with the gravity variations caused by water mass redistributions at the Earth's surface, and show that the studied signal probably originates, at least partly, in the deep Earth. Here, we discuss potential sources at the base of the mantle able to explain these observations.

*Speaker

Progress on temporal gravity field modeling and applications at HUST

Zhou Hao *† [1,2], Zhou Zebing [1,2], Luo Zhicai [1,2]

[1] MOE Key Laboratory of Fundamental Physical Quantities Measurement & Hubei Key Laboratory of Gravitation and Quantum Physic, PGMF andSchool of Physics, Huazhong University of Science and Technology – China

[2] Institute of Geophysics and PGMF, Huazhong University of Science and Technology – China

Abstract: The GRACE and GRACE Follow-On mission has provided unprecedented accuracy observations for tracking the Earth's mass variations. In the past years, our HUST (Huazhong University of Science and Technology) group has focused on processing satellite gravimetric observations, developing temporal gravity field modeling, proposing next generation gravity mission (NGGM) and extending applications in geoscience. In this work, we will overview the recent progresses as follows, (1) the new developed model HUST-Grace2024 shows its better performance than our previously published models including HUST-Grace2020 and HUST-Grace2016, as well as the official SDS RL06 model for GRACE and RL06.1 model for GRACE Follow-On. (2) the new results related to NGGM, including new mission scenarios, new key payloads noise models, new perspective of non-tidal atmospheric and oceanic de-aliasing model, etc. (3) the typical applications via the along-track observations, improved filtering approaches and new fusion methods.

*Speaker

†Corresponding author: zhouh@hust.edu.cn

HUST-Grace2024: Overview and Evaluation of a New GRACE-Only Temporal Gravity Field Model Series

Lijun Zheng * [1,2], Hao Zhou† [1,2], Zebing Zhou [1,2], Zhicai Luo [1,2]

[1] MOE Key Laboratory of Fundamental Physical Quantities Measurement and Hubei Key Laboratory of Gravitation and Quantum Physics, PGMF and School of Physics, Huazhong University of Science and Technology – China

[2] Institute of Geophysics and PGMF, Huazhong University of Science and Technology – China

HUST-Grace2024 is a new temporal gravity field (TVG) model time series based on updating L1B data set (GRACE L1B RL03& GRACE-FO L1B RL04) and the atmosphere and ocean de-aliasing product (AOD1B RL07).Compared to previous HUST TVG release, we make some improvements on the following aspect of (1) using satellite pointing angles computed by SCA1B and GNV1B to detect range rate data loss due to yaw-turns maneuver or center-of-mass calibration maneuver; (2) updating stochastic model building strategy, constructing covariance matrix based on range-rate postfit residual and deriving a variance factor for different types of instruments onboard based on an improved robust estimator; (3) using full scale factor matrix as GRACE/GRACE-FO accelerometer scale factor calibration criteria. With the Level 1B data spanning 2002 to 2023, the impacts of updating TVG processing strategies were assessed in detail. The numerical results indicate that (1) geopotential coefficient C20 derived from HUST-Grace2024 have a good agreement with the coefficients derived from SLR, and its correlation coefficient is 0.8; (2) the geoid height difference per degree computed by HUST-Grace2024 over degree and order 40 can benefit from updating pre-processing strategy and stochastic model; (3) The performance of HUST-Grace2024 is in excellent accordance with other representative GRACE-FO temporal gravity field models, such as ITSG-GraceOP, CSR RL06.1, GFZ RL06.1 and JPL RL06.1.

*Speaker

†Corresponding author: zhouh@hust.edu.cn

Reduction of temporal variations in tidal parameters by application of the local response models at globally distributed SG stations

Adam Ciesielski *† [1,2], Thomas Forbriger [2,3], Walter Zürn [3], Andreas Rietbrock [2], Dykowski Przemysław [4]

[1] Institute of Geodesy and Cartography – Poland
[2] Karlsruhe Institute of Technology – Germany
[3] Black Forest Observatory (BFO) – Germany
[4] Instytut Geodesy and Cartography – Poland

Temporal variations of tidal parameters, seen in the moving window analysis (MWA), are known for all tidal wave groups in gravity data from superconducting gravimeters (SGs) distributed globally. The amplitude of variations usually is greater than the standard deviation by a factor of 2 (minimum) to 32 (maximum) in short periods. However, tidal parameters are not expected to vary with such magnitudes in that short timescales. In our study, we discovered that most of the apparant variations were due to the analysis artifacts.
The harmonic analysis of tides is based on the assumption of separable and non-separable contributions depending on the time series length. A priori *wave groups* have to be composed of different harmonics and their ratios have to be assumed, which leads to an inaccurate (biased) estimate of tidal parameters. In order to perform an analysis of short windows, which are used to study temporal variations of tidal parameters, very coarse grouping scheme is applied. However, recent investigation revealed significant disparities between the observed tidal response (which accounts for the loading signals as well) and the Earth body model assumptions (like Wahr-Dehant-Zschau elastic analysis model). To accound for this effect, we estimated detailed local response models for over 10 stations in Europe and additional 6 across the world with regularization approach to tidal analysis (RATA). Afterwards, wee approximated the effect of the time-invariant ocean loading and radiation tides in the data by application of the local response models instead of body model assumption.
We repeated the MWA of 12 wave groups composed from summed harmonics. We found that the periodic variations of groups M2, K1, μ2, N2, L2, and S2 are reduced by up to a factor of 9 compared to earlier studies. Some long-period variations previously seen in the M1, O1, Q1, and J1 groups are captured as well. The previously neglected influence of radiation tides, degree 3 tides, and significant satellite constituents were the main causes of apparent modulations in previous studies. Therefore, with the local model correction, a proper investigation of the remaining temporal variations to study instrument stability or time-varying contributions of ocean loading is more applicable.

*Speaker
†Corresponding author: adam.ciesielski@igik.edu.pl

A regional enhanced scenario for next generation gravity mission

Tiantian Qing * [1,2], Hao Zhou† [1,2], Zhicai Luo [1,2]

[1] 1: MOE Key Laboratory of Fundamental Physical Quantities Measurement & Hubei Key Laboratory of Gravitation and Quantum Physics, PGMF and School of Physics, Huazhong University of Science and Technology, Wuhan 430074, P. R. China. – China
[2] 2: Institute of Geophysics and PGMF, Huazhong University of Science and Technology, Wuhan 430074, P. R. China. – China

When detecting the Earth's gravity field based on the single polar pair satellites formation, systematic errors such as the north-south stripping noise are unavoidable. In order to reduce the errors, Bender et al. (2008) proposed a Bender-type formation, i.e. a pair of inclined orbit satellites (whose orbital inclination is limited to (55, 80)) is added to the polar pair satellites (whose orbital inclination is (89)). In order to obtain a global gravity field models with higher accuracy, the European Space Agency proposed the optimal Bender-type formation on a global scale in 2014 and determined its orbital inclination as (89+70). Based on this proposal, we propose an optimal Bender-type formation in China to obtain gravity field models with higher accuracy in China. To determine the proposal, we set up a closed-loop simulation experiment. In order to maintain global observations, we keep the orbital inclination of the polar pair satellites at (89). Therefore, the work is mainly to determine the orbital inclination of the inclined pair satellites. Based on the results of spectral and spatial evaluation, orbital inclinations of the optimal Bender-type formation in China is determined to be (89+55). The results show that the accuracy of the optimal Bender-type formation in China is higher than that of the single polar pair satellites formation and the global scale optimal Bender-type formation, with an increase of 84.68% and 37.14% respectively (unfiltered). In addition, in terms of time resolution of the temporal gravity field models in China, the optimal Bender-type formation in China also shows better retrieval performance than the global optimal Bender-type formation (i.e. 3-day solution, 7-day solution). In summary, the optimal Bender-type formation in China not only greatly weakens the north-south stripping noise in China, but also avoids the gravity signals leakage caused by the post-processing procedures, and finally obtains gravity field models with higher accuracy and larger signal-to-noise ratio in China.

*Speaker
†Corresponding author: zhouh@hust.edu.cn

Vertical Displacements: GNSS and Gravimetric Station Collocation Study

Laura Pénzešová *† [1], Jean-Paul Boy*[2], Juraj Janák [1], Barbora Korekáčová [1], Adam Novák [3]

[1] Slovak University of Technology in Bratislava – Slovakia
[2] EOST – EOST – Bâtiment Descartes - 5, rue René Descartes - F-67084 Strasbourg, France
[3] Geodetic and Cartographic Institute in Bratislava – Slovakia

Vertical displacements result from various deformation mechanisms of the Earth, including atmospheric, non-tidal ocean, and hydrological and loading effects, as well as other processes influencing the Earth's dynamics. These deformations are associated mainly with seasonal mass redistribution and manifest at different spatial scales. In this study, we perform the joint analysis of vertical displacements measured by Global Navigation Satellite Systems (GNSS) at 23 European stations collocated with gravimetric stations within the International Geodynamics and Earth Tide Service (IGETS) with the aim of eliminating the load-induced height variations contained in the superconducting gravity measurements. We used 37 time series from superconducting gravimeters and daily time series from 51 permanent GNSS stations. To reduce the local hydrological effect from the gravity time series provided by IGETS as Level-3 products, we removed the influence of soil moisture variation and groundwater level changes based on local soil moisture variation, groundwater level measurements, and precipitation data. Model-driven values based on Global Hydrological Models (GHM) were used for stations without installed in situ hydrological instruments.

*Speaker
†Corresponding author: laura.penzesova@stuba.sk

The Fennoscandian Land Uplift Gravity Lines revisited

Jaakko Mäkinen [*†] [1], Andreas Engfeldt [2], Ove Christian Dahl Omang [3], Hannu Ruotsalainen [4], Gabriel Strykowski [5]

[1] Finnish Geospatial Research Institute, Espoo – Finland
[2] Lantmäteriet, Gävle – Sweden
[3] Norwegian Mapping Authority, Hønefoss – Norway
[4] Finnish Geospatial Research Institute, Espoo – Finland
[5] DTU Space, Copenhagen – Denmark

Observing the secular gravity change associated with the Fennoscandian postglacial rebound became a realistic proposition in the 1960s with the advent of the LaCoste&Romberg relative gravimeters. There were limitations: only the change in gravity differences could be observed, and to diminish the influence of the scale uncertainty those differences had to be small. Starting in 1966 (Kiviniemi, 1974) four land uplift gravity lines were established and measured in a cooperation coordinated by the Nordic Geodetic Commission (NKG). They run in roughly east-west direction across the Nordic countries, along the approximate latitudes 63∘N (1966-), 65∘N (1975-), 61∘N (1976-), and 56∘N (1977-). The maximum vertical velocity in Fennoscandia is about +10 mm/yr; the range of the 63∘N line is about +2 to +10 mm/yr. Major measurement campaigns by Nordic and international expeditions were mounted every 5 years. The last such campaign was in 2003 at the lines 63∘N and 56∘N. The trends in the gravity differences for line 63∘N could by then be determined with standard errors from 0.09 to 0.15 μGal/yr. The ratio of gravity change to vertical velocity was estimated to be -0.16 μGal/mm with (two-sigma) uncertainty 0.04 μGal/mm (Mäkinen et al. 2005).
The stations of the land uplift gravity lines are (except for Denmark) outdoors, without any infrastructure beyond the smoothed bedrock support and a station marker. After 2003 the land uplift lines were superseded by regularly repeated absolute-gravity measurements with FG5(X) gravimeters at tens of laboratory sites, also coordinated by the NKG. The relation between gravity change and vertical velocity found by Olsson et al. (2019) from absolute-gravity data agrees with the relative-gravity result above, to the last decimal quoted.

The land uplift gravity lines provide an opportunity to form combined relative-absolute gravity time series, that together extend 58 years back in time. The NKG has started a project to collect, recompute, re-assess, and publish all the data at the lines, including the original observations. We review the problems, methods, and results obtained so far.

References:

Kiviniemi A (1974) High precision measurements for studying the secular variation in gravity in Finland. Publ FGI 78, Helsinki

[*]Speaker
[†]Corresponding author: jaakko.makinen@nls.fi

Mäkinen J et al (2005) The Fennoscandian Land Uplift Gravity Lines 1966–2003. IAG Symposia 129: 328-332, Springer
Olsson P-A et al (2019) Postglacial gravity change in Fennoscandia - three decades of repeated absolute gravity observations. Geophys J Int 217(2):1141–1156

GIA related surface gravity vs. height changes using GRACE and GRACE-Follow on data in Fennoscandia

Mohammad Bagherbandi *† [1], Lars E. Sjöberg [2]

[1] University of Gävle – Sweden
[2] KTH Royal Institute of Technology, Stockholm – Sweden

Precise gravity measurements have been consistently conducted in Fennoscandia since the 1960s, initially using relative gravimeters and later employing absolute gravimeters, to study the temporal changes in gravity associated with ongoing glacial isostatic adjustment (GIA). We utilized monthly data from the twin satellite missions GRACE and GRACE Follow-on, between 2003 to 2023, to estimate the temporal variations in surface gravity change, its ratio to the land uplift rates, and the upper mantle density associated with viscous mass flow in the mantle. We then compared these results with those obtained by relative and absolute gravity observations collected at 59 stations across Fennoscandia. The findings from these studies are crucial for understanding GIA processes and refining GIA and Earth structure models. In addition, the results show the importance of satellite gravimetry data in GIA modeling and parameters such as land uplift rate and gravity observations. The results show the ratio between the surface gravity and height changes is equal to –0.160 ± 0.003 μGal/mm yielding an upper mantle density of about 3630 kg/m3 which closely aligns with the findings reported by Olsson et al. (2019) i.e. –0.163 ± 0.016 μGal/mm.

*Speaker
†Corresponding author: modbai@hig.se

Three years of continuous gPhoneX tidal gravimeter supported with absolute gravity determinations at the SRC PAS Borowiec Astrogeodynamical Observatory

Jolanta Nastula [*†] [1], Jerzy Nawrocki[‡] [1], Paweł Nogaś[§] [1], Julia Pietrzak[¶1], Dykowski Przemysław[‖] [2]

[1] Centrum Badań Kosmicznych Polskiej Akademii Nauk (CBK PAN) – Poland
[2] Instytut Geodesy and Cartography – Poland

The gPhoneX (s/n 171) tidal gravimeter was installed at the Astrogeodynamical Observatory in Borowiec (CBK PAN) in early 2020. By the end of 2023, a tidal gravity time series spanning more than 3 years was collected, along with repeated absolute gravity determinations using the A10-020 absolute gravimeter and the AQG-B07 quantum gravimeter. This combination allowed for the evaluation of the long-term drift of the gPhoneX gravimeter, demonstrating its stability over time. Additionally, a tidal analysis was performed on a record spanning over 1000 days, enabling the evaluation of the instrument's precision as declared by the manufacturer (Micro-g). Gravimetric measurements complement the satellite data collected at the Observatory, providing valuable insights into the gravitational field's impact on the operation of atomic clocks in Borowiec. Thanks to the installation of the gravimetric station, the Observatory has gained new functionality and complementarity of observational techniques, establishing it as a reference point for geodetic observations.

[*]Speaker
[†]Corresponding author: nastula@cbk.waw.pl
[‡]Corresponding author: nawrocki@cbk.poznan.pl
[§]Corresponding author: pnogas@cbk.poznan.pl
[¶]Corresponding author: jpietrzak@cbk.poznan.pl
[‖]Corresponding author: przemyslaw.dykowski@igik.edu.pl

Glacial isostatic adjustment and surface-mass changes estimate in Antarctica using multi-geodetic data

Alexandre Boughanemi *† [1], Anthony Memin [1], Riad Hassani [1]

[1] Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, IRD, Géoazur – Université Côte d'Azur (UCA) – France

Deformation of the Earth and changes of its gravity field due to Glacial Isostatic Adjustment (GIA) that follow variations in ice mass in Antarctica remains poorly constrained. This is mainly due to the cumulative effect of past and present ice-mass changes, the unknown history of the past ice-mass change, and the uncertainties on the mechanical properties of the Earth. Knowing the viscous surface displacement due to GIA would lead to a thoroughfull understanding of the mechanical behavior of the Earth from yearly to millennial time scales. So far, only satellite observations can provide with a good coverage of Antarctica. Besides, it has been recently shown that combining geodetic and gravity data to invert for GIA is possible under certain conditions. We use the least squares method to invert the spherical harmonic coefficients of the viscous surface displacement in Antarctica and surface-mass change of the ice sheet, using satellite gravity, satellite altimetry and GNSS observations. We characterized our approach using a dataset simulated using realistic GIA map and ice sheet changes. Depending on the observation network we use for the inversion, we manage to retrieve spherical harmonics coefficients up to degree and order 35.

*Speaker

†Corresponding author: alexandre.boughanemi@geoazur.unice.fr

Repeated absolute gravity measurements in Antarctica

Arttu Raja-Halli * [1], Jyri Näränen[1], Jaakko Mäkinen[1], Maaria Nordman[1,2], Ulla Kallio[1]

[1] Finnish Geospatial Research Institute, National Land Survey – Finland
[2] School of Engineering [Aalto] – Finland

The Finnish Geospatial Research Institute (FGI) has made absolute gravity (AG) measurements in Antarctica in 7 locations, starting in the 1993/4 austral summer at the Finnish Antarctic station Aboa. The absolute gravity time series now spans over 30 years at Aboa with 8 measurement campaigns, the latest one in early 2024. Other stations with repeated AG measurements by FGI are Troll (Norway), Sanae IV (South Africa), and Novolazarevskaya Russia) and single measurements have been carried out in Maitri (India), Scott Base (New Zealand) and McMurdo (USA). Aboa is in the western Dronning Maud Land in east Antarctica on the slope of Mount Basen, 470 meters above sea level and 200 m above the surrounding glacier. First two measurement campaigns at Aboa were made with the JILAg-5 absolute gravimeter. Since 2003 FG5 and FG5X gravimeters have been used. Duration of the measurements varies between 24 hours and two weeks.

The original purpose of the repeated AG work was to study the viscoelastic gravity change due to glacial isostatic adjustment (GIA) after Holocene deglaciation. However, it soon became clear that other gravity-change signals potentially overshadow the GIA signal. The most obvious of these are the direct attraction off mass changes in the seasonal snowpack close to gravity laboratory, and in the surrounding glacier 200 m below the station. Snowpack and glacier heights have been monitored since the season 2000/1, first with tachymetry and then, after the establishment of the Aboa permanent GPS station in 2003, using RTK-GPS and laser scanning on foot, from ski-doos and from drones. The permanent GPS station was upgraded to a GNSS station in February 2024. The increased precipitation in Dronning Maud Land in the 2000's means that we now also must deal with both the direct attraction and elastic deformation from the regional increase in glacier mass.

We present the AG time series of Aboa station, discuss various signals contributing to it, and compare it with the GPS time series and GRACE solutions.

*Speaker

Invited talk:
Antarctic Mass Change and Contributions to Sea Level: Insights From Two Decades of Satellite Gravity Data

Rebecca Mcgirr * [1]

[1] Australian National University – Australia

Over the past two decades, satellite gravity missions have enabled accurate quantification of Earth's changing water masses under the influence of a changing climate, most notably of increasing global sea level and shrinking ice sheets. From 2002 to 2022, estimates from GRACE and GRACE-FO space gravity data show that the Antarctic ice sheet has lost _˜2150 GT of mass to the global ocean, contributing _˜6.1 mm to sea level rise (Otosaka et al., 2023). We assess an ensemble of four mass concentration (mascon) solutions (JPL, CSR, GSFC), including ours (ANU), along with climate reanalysis output to investigate the drivers of long-term trends and interannual variability in Antarctic surface mass balance and dynamic ice mass change. We show that the Antarctic ice sheet has been gaining mass since 2020 due to consecutive years of record-breaking precipitation in East Antarctica and the Antarctic Peninsula, unprecedented over the GRACE and GRACE-FO era. This has resulted in a cessation of Antarctic contributions to sea level rise. However, an analysis of surface mass balance from climate reanalysis output shows that recent increases in precipitation are likely temporary due to decadal variability. Meanwhile, dynamic ice mass loss has continues to accelerate in the Amundsen Sea and Bellingshausen Sea sectors of the West Antarctic ice sheet.

*Speaker

Session 6. Temporal variations of the Earth's rotation

Simulation analysis on the impact of geophysical excitation on FCN parameters determination with celestial pole offsets

Xiaoming Cui * [1], Weiwei Yang [1], Heping Sun [1]

[1] Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences – China

Diurnal tidal oscillations in the coupled atmosphere–ocean system generate important contributions to the Earth's free core nutation (FCN) and annual and sub-annual components of forced nutation in the celestial pole offsets. The determination of FCN parameters cannot avoid the influence of geophysical fluid excitation neither with the direct analysis of FCN signal (direct approaches) nor with the resonance analysis of forced nutation (resonance approaches). There is a significant difference in the FCN parameters obtained with resonance and direct approaches from celestial pole offsets observed through very long baseline interferometry (VLBI). The source of the difference between the two lacks quantitative analysis, which causes difficulties in interpreting the validity of the derived FCN parameters. Using both approaches, we conducted a simulation of celestial pole offsets to quantitatively demonstrate how geophysical fluid excitation affects the determination of FCN parameters from VLBI observations.

*Speaker

Effect of the ocean tide on the Earth nutation from FES 2014 tidal model

Christian Bizouard *†[1], Yu-Ting Cheng*[2]

[1] Observatoire de Paris SYRTE UMR8630 - GRGS - (Systeme de Référence Temps Espace) – CNAP – 61 avenue de l'Observatoire 75014 PARIS, France
[2] Observatoire de Paris / SYRTE – Observatoire de Paris, PSL Research University, CNRS, Sorbonne Université, UPMC Université Paris 06, – France

Ocean tides perturb the nutation of the Earth rotation axis up to 0.001", that is an order of magnitude 20 times larger than the uncertainty with which the nutation is determined. The exact knowledge of that ocean tidal effect is fundamental for the development of nutation theory, in particular for determining the frequencies of the normal modes due to the presence of the fluid outer core and solid inner core. The last published calculation goes back to the 2000's with the model of Mathews, Herring and Buffet that became the standard model used in astronomy and geodesy. We revisit that calculation by using updated values of the principal components of the ocean tidal angular momentum, as derived from FES 2014, TPXO8 and EOT11 ocean tidal models. That work extents the computation of the ocean tidal effect on polar motion and UT1 done recently according to FES 2014 model. We take into account the recent development of Earth rotation theory, especially the frequency dependence of the transfer functions in sub-diurnal bands.
We not only found significant corrections to the terms evaluated by MHB – up to 100 micro-arcseconds –, but also significant contributions for circular terms with periods of +9.13 days, +13.63 days, +121.75 days, -27.52 days, and -9.3 years. From these new predicted effects, only the modelled term of -27.52 day term with an amplitude of 60 micro-arcseconds is clearly reflected in the celestial pole offsets with the same phase (and one third of its amplitude).

*Speaker
†Corresponding author: christian.bizouard@obspm.fr

Simulation analysis on the detectability of the FCN period variations in SG observations

Weiwei Yang *† [1,2], Xiaoming Cui [1], Jianqiao Xu [1]

[1] Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences – China
[2] University of Chinese Academy of Sciences – China

The Free Core Nutation (FCN), one of Earth rotational normal modes, induced by the misalignment between the rotation axis of the mantle and the fluid outer core. And this motion, known as a nearly diurnal free wobble (NDFW), is observed in the Earth-fixed reference system. Due to the effects of surface fluids and coupling between fluid core and mantle, parameters of the FCN (period, amplitude and frequency) are not constant, but exhibits temporality. As a free motion at the core-mantle boundary, the free core nutation (FCN) can effectively constrain the physical parameters of the core-mantle boundary and understand the core-mantle coupling. The temporal variability of FCN also provides unique insights into further exploration of the dynamics of the liquid core.

The resonant effect of FCN amplifies the amplitudes of diurnal tidal waves and the annual nutation terms, so high-precision superconducting gravimeter (SG) and Very Long Baseline Interferometry (VLBI) techniques can be utilized to detect the parameters of FCN. The amplitude of the annual nutation terms, which is close to the frequency of Free Core Nutation (FCN), is substantial and precise. Consequently, the time variation of the FCN period, as derived from VLBI data, exhibits greater stability and ranges from approximately 1 to 2 sidereal days (SDs). But the amplitude of FCN period variation estimated by SG data can reach about ten SDs owing to bad Signal-to-Noise Ratio (SNR) of diurnal tidal wave .

Taking into account the uncertainties present in FCN determination through VLBI, which include the unpredictability of surface fluid excitations and the variations among VLBI sequences calculated by different institutions, coupled with other errors, it becomes clear that relying solely on VLBI is insufficient to conclusively determine the time-varying characteristics of FCN period. Our previous research indicated that in the study of the time-variations of FCN period, the diurnal tidal wave , which has a higher signal-to-noise ratio compared to wave that is closest to the FCN frequency, can more accurately reflect the changes of FCN period. Based on this, we develop a new method and carried out simulation analysis to check the detectability of the FCN period variations in SG observations, in order to accurately extract the time-varying characteristics of FCN period using SG data.

*Speaker
†Corresponding author: cxm@apm.ac.cn

Use of satellite data in the development of Algerian arid zones through ecological analysis of post-fire forest ecosystems

Ahmed Zegrar * [1], Nadjla Bentekhici , Assia Saad

[1] Centre of Spaces techniques (CTS) – BP 13 CTS ARZEW 31200 Algeria, Algeria

"Dryland research" aims to develop a plan for the development of arid zones and combating desertification, the main aim of which is to seek to achieve new socio-economic balances in these regions, based on the rehabilitation of the physical environment following various assaults and food self-sufficiency, and the raising of the living standards of the populations concerned. Following these indicators, the Algerian space agency has set up a 2020 space program, which has just launched three satellites in 2016 to build capacity in the area of space: Alsat-B1, Alsat-B2, Alsat-N Particularly in the areas of applications and technology, the purpose of which is to produce information useful for sustainable development. Our steppe region presents an advanced factor in degradation in the socio-economic field and biodiversity. We will present an approach to the evaluation of the arid regions in the post-forest fire area; the aim is sustainable development using the new techniques of the space domain. Remote sensing and geographic information systems (GIS) offer to environmentalists and managers, an opportunity for the evaluation, the monitoring and analysis of the vegetation for mapping fires and observing post-fire regeneration. Usually NDVI is used, other derived index from radiometric data in remote sensing are widely used to monitor vegetation dynamics. The forest domain has benefited greatly from this approach. In this study we use remote sensing data from several dates (2005, 2007, 2009, 2014 and 2015) such as ALSAT data and Land sat, combined with the topographic parameters, and seems promising in the assessment of the spatial and temporal effects of regeneration after fires. The study area is located in the region of Sebdou in the north of Algeria, burned in 2003 allowed to take into account new factors to explain the regeneration and its spatial and temporal variation. The purpose of this study is to show the potential use of remote sensing data (ALSAT and Land sat images, to quantify derived index such as the normalized difference vegetation index (NDVI) & Ratio vegetation index (RVI), and the index of regeneration (RI), in quantitative assessments of the regeneration after fire in Algerian forest. The software IDRISI Selva and ArcGIS, has been used to analyze different layers of information in evaluation of the regeneration post fires. The results obtained allow us to identify variability in speed of the regeneration influenced by ecology, topographic and climatic conditions. This study serves to understand vegetation regeneration that is vital in wildfire management to permit us to make decision for future management in this area how live disadvantaged population and make a ecological analysis of desertification.

*Speaker

Gravitational Earth Shielding Effect (GESE) Analysis through Long-term Superconducting Gravimeters Data Acquisition

Michel Van Ruymbeke *† [1], Christian Bizouard[2], François Beauducel[3], Sébastien Toussaint[4], Bernard Ducarme[1]

[1] Royal Observatory of Belgium, Belgium
[2] Observatoire de Paris/SYRTE-IERS EOP Center, France
[3] Université Paris Cité, Institut de physique du globe de Paris, France
[4] Université catholique de Louvain, ICTEAM / ELEN, Belgium

Gravitational field absorption by a material body, known as the Majorana effect hypothesis, might provide answers to physicists when searching for gravity origins. During the 1999 eclipse that shadowed Europe, we confirmed, using a Superconducting gravimeter in Vienna, that Majorana shielding by the Moon does not affect the Solar gravitational attraction field (6cm/sec) over a dynamic of 1.66 E-8 as there were no significant signature larger than 1 nm/s^2 (1/10th of μGal).

In this paper, we now investigate the possibility of a screening effect caused by the Earth, affecting the Sun's gravitational attraction. Using tidal hourly data from the superconducting gravimeter and the barometer set-up in Vienna between the years 1995 and 2008, we corrected the gravimeter output from known periodic signals to keep only the residuals. This was done by two different approaches.

Firstly, a theoretical model after the analysis of the record with the ET34-ana-v80 software including the determination of the pole tide amplitude factor and the correction of atmospheric effects was extracted from the raw data. Computed barometric admittance k of the in-situ measured pressure was estimated by a least squares method. The issue then arising is that the absorption effect's impact, if any, might be included in the adjustments made to the analysis's findings. The second alternative to extract residuals consists of removing modeled data, independently from the observations. The model was built following a pure astronomical approach, with normalized amplitude of all the components according to the Earth's response model, and with phase shift equal to zero. Additionally, the 10 major waves of oceanic effects were adjusted from this signal (Q1, O1, P1, K1, N2, M2, S2, K2, Mm, Mf). We used the mean of 9 ocean tide models: CSR4, DTU10, E0T11a, FES04, Hamtide, GOT00, NAO99, OSU12, and TPX07. The GESE theoretical model of screening sensed by the gravimeter rotating with the Earth, was prepared with an arbitrary coefficient of admittance, assuming a proportionality with the crossed material density.

*Speaker
†Corresponding author: oasismini@hotmail.com

Residuals of the gravimeter's observations after subtraction of the two models were compared to a GESE synthetic data set. A signal processing method based on stacking (named HiCum – Histograms Cumulation) allowed spectrum analysis over our long-term signals.
In conclusion, an upper limit for the Majorana shielding of the Earth on the Sun's gravitational attraction was set considering the level of residual uncertainties cited above. The lack of GESE signature we hoped to witness closes a chapter of our knowledge in the understanding of gravity origins connected to electromagnetism, at least for this level of resolution.

Excitation of length-of-day obtained from various data sources

Malgorzata Winska * [1], Justyna Śliwińska-Bronowicz *

[2], Jolanta Nastula [2]

[1] Warsaw University of Technology [Warsaw] – Poland
[2] Centrum Badań Kosmicznych PAN – Poland

Variations in the Earth's rotation, determined with polar motion (PM) and changes in the length of the day (LOD), collectively referred to as Earth Orientation Parameters (EOPs), arise from diverse factors like global mass distribution and its movements, encompassing air and water masses within the climate system, the solid Earth related signals like glacial isostatic adjustment and tectonic signals, and exchanges of angular momentum between the core and mantle. Accurately discerning between these different contributors is crucial for comprehending phenomena occurring near the Earth's surface and within its interior, which affect the rotational motion of our planet. This study focuses on investigating differences between various estimates of axial components of Atmospheric Angular Momentum (AAM), Oceanic Angular Momentum (OAM), and Hydrological Angular Momentum (HAM) and their influence on the agreement between geophysical and geodetic excitation of LOD. To compute LOD excitations, we utilize various geophysical models of the Earth's fluid layers as well as C20 coefficients of geopotential obtained from the Gravity Recovery and Climate Experiment (GRACE), its follow-on mission (GRACE-FO), Satellite Laser Ranging (SLR) and combinations of these techniques. We examine excitation sources' seasonal and non-seasonal budget contributing to LOD variation, comparing them with corresponding geodetic observations. We employ various statistical measures to assess axial components of AAM, OAM, and HAM series and attempt to determine their errors.

*Speaker

Invited talk:
Variations in Earth's rotation due to global mass distribution – assessment based on satellite gravimetry, geophysical models and climate data

Justyna Śliwińska-Bronowicz *† [1], Jolanta Nastula [1]

[1] Centrum Badań Kosmicznych Polskiej Akademii Nauk (CBK PAN) – Poland

The Earth's rotation exhibits irregularities due to heterogeneous internal structure of the planet and various phenomena including gravitational interactions with celestial bodies, and processes taking place both at the surface and within the solid Earth. Any alteration in surface mass distribution impacts Earth's inertia tensor, causing a shift in the rotational axis towards the direction of mass deficit. Additionally, atmospheric and oceanic circulations influence rotational velocity. Therefore, monitoring mass transport within and between the various fluid layers of the Earth is vital for understanding the mechanisms that disrupt its rotation.
Since the beginning of the 21st century, our understanding of the role of mass transport within and between atmosphere, oceans and terrestrial hydrosphere in exciting the Earth's rotation has advanced significantly. This progress was achieved thanks to the measurements made by Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On missions, the refinement of geophysical models of surficial fluid layers, and the development of new coupled climate models integrated with both natural and anthropogenic forces.
This presentation provides comprehensive overview of the advancements made in studying the geophysical excitation of Earth's rotation. We focus on various oscillations in the rotational motion including trends, seasonal, intraseasonal, and interannual changes, aiming to find connections between these variations and different phenomena within the Earth system, including climate change. This investigation involves the utilization of diverse data sources, including temporal gravity field variations obtained from GRACE/GRACE-FO measurements, global models of the atmosphere, ocean, and hydrosphere, as well as climate outputs. Subsequently, geophysical excitation functions of Earth rotation are compared with those derived from geodetic observations of Earth Orientation Parameters. Through this comprehensive approach, we aim to deepen our understanding of the mechanisms governing the rotational motion of our planet and its consequences for the whole Earth system.

*Speaker
†Corresponding author: jsliwinska@cbk.waw.pl

Author Index

Achmüller, Korbinian, 70
Addi, Nawel, 93
Allal, Saddam Housseyn, 47, 53, 58
Amarillo-Fernandez, Francisco, 48
Amoruso, Antonella, 43
Antokoletz, Ezequiel, 17, 18, 25, 84
Arbic, Brian K., 107
Ariyoshi, Keisuke, 40
Arnal, Maxime, 93

Bagherbandi, Mohammad, 117
Balidakis, Kyriakos, 17, 18
Baltzer, Agnès, 29
Beauducel, François, 21, 60
Beck, Clara, 98
Benaraba, Nawel, 59, 86
Benavent, Teresa, 87
Benikhlef, Ilies, 55
Bentekhici, Nadjla, 126
Benyahia, Slimane, 59, 86
Bergmann, Jan, 93
Bernard Ducarme, 127
Bernard, Jean-Daniel, 69, 73
Berti, Matteo, 25
Bertrand, Catherine, 73
Besutiu, Lucian, 105
Bilker-Koivula, Mirjam, 77
Bizouard, Christian, 60, 124
Blloshmi, Eduart, 57, 80
Boehm, Christian, 33
Bogusz, Janusz, 74
Bouaoula, Walid, 56
Boughanemi, Alexandre, 119
Boy, Jean-Paul, 12, 17, 20, 26, 29, 114
Brachmann, Erik, 92
Braitenberg, Carla, 27, 96
Bögl, Elias, 70

Calvo, Marta, 24
Capponi, Martina, 32
Carlino, Stefano, 34
Chang, Emmy T., 67
Chen, Xiaodong, 42
Cheng, Hou-Sheng, 67
Cheng, Minkang, 15
Cheng, Xiaodong, 39
Cheng, Yu-ting, 124
Christian Bizouard, 127
Ciesielski, Adam, 90, 112
Cionco, Rodolfo G., 13
Claudia, Tocho, 17

Cui, Xiaoming, 123, 125

Dekkiche, Hicham, 53, 56, 58
Deng, Zhiguo, 16
Desruelle, Bruno, 103
Devoti, Roberto, 27
Ding, Hao, 39
Dmitrovskii, Andrei, 33
Dobslaw, Henryk, 16–18, 37
Doglioni, Carlo, 32, 48
Dousa, Jan, 48
Durand, Frederic, 29
Dykowski, Przemysław, 93

Ejigu, Yohannes Getachew, 30, 31
Eken, Tuna, 41
Engfeldt, Andreas, 115
Erofeeva, Svetlana, 12

Facchinetti, Roberta, 70
Falk, Reinhard, 25, 77
Fantoni, Anna, 27, 96
Fedele, Alessandro, 34
Feng, Wei, 62
Ferhat, Gilbert, 46
Ficini, Eleonora, 48
Fienga, Agnes, 23
Fietz, Michael, 16
Flechtner, Frank, 16, 70
Forbriger, Thomas, 90, 98, 107, 112
Forster, Florian, 75
François Beauducel, 127
Fröhlich, Thomas, 92

Ganino, Clement, 23
García-Castellano, Abel, 24
Gaugne, Charlotte, 109
Gebauer, André, 93
Gerhátová, Ľubomíra, 19
Giuliante, Beatrice, 69, 75
Golovan, Andrey, 95
Gourillon, Lissa, 29
Greco, Filippo, 32
Greff, Marianne, 109
Gualandi, Adriano, 43

Guinard, Alex, 23
Guo, Rumeng, 39, 41, 63
Guoheng, Qi, 102
Gómez Molina, Gabriel, 24
Güntner, Andreas, 84

Hamoudi, Mohamed, 56
Hao, Hongtao, 50
Hao, Zhou, 110
Hasni, Kamel, 58
Hasni, kamel, 47
Hassani, Riad, 119
Hinderer, Jacques, 20, 69, 75
Hiroyuki, Matsumoto, 40
Hu, Minzhang, 50
Hwang, Cheinway, 65

Janvier, Camille, 103
Janák, Juraj, 19, 114
Javed, Muhammad Tahir, 96
Jousset, Philippe, 69, 75

Kaergaard Mortensen, Anette, 69, 75
Kahlouche, Salem, 56
Kallio, Ulla, 35, 120
Kaminskis, Jānis, 77
Karatekin, Ozgur, 101
Kenyeres, Ambrus, 64
Khan, Amir, 33
Khelifa, Sofiane, 53
Khorrami, Fatemeh, 30, 31
Kierulf, Halfdan P., 44
Klos, Anna, 74
Klügel, Thomas, 17
Knieß, Jakob, 70
Koch, Franziska, 70
Kopliku, Namik, 81
Korekáčová, Barbora, 114
Krawczyk, Charlotte, 75
Kudryavtsev, Sergey, 13, 28
Kuznetsov, Eduard, 45
Kühnel, Michael, 92

Le Moigne, Nicolas, 93
Lebrun, Justine, 21, 60, 99
Lemoine, Jean-Michel, 29
Li, Weikai, 62
Li, Zhongya, 50
Lidberg, Martin, 64
Lien, Tzuyi, 67
Liepiņš, Ivars, 77
Listvin, Danil, 45
Littel, Fred, 20
Liu, Dechuan, 41
Llabani, Arli, 81
Loomis, Bryant, 14
Luo, Zhicai, 72, 111, 113
Lyard, Florent, 12
López Perez, Jose Antonio, 24

Ma, Wenjing, 72
Majek, Cédric, 103
Malet, Jean-Philippe, 46, 73
Mandea, Mioara, 109
Martens, Hilary, 33
Masci, Olimpia, 48
Masson, Frédéric, 73
Maurizio, Gerardo, 96
McGirr, Rebecca, 121
Memin, Anthony, 23, 119
Mendes, Luis, 48
Merlet, Sébastian, 93
Milyukov, Vadim, 10
Moncayo, Gloria Alexandra, 36
Monsalve, Gaspar, 36
Munch, Federico, 33
Mustapha, Meghraoui, 52
Mäkinen, Jaakko, 35, 77, 115, 120
Ménoret, Vincent, 103

Nastula, Jolanta, 118, 129, 130
Nawrocki, Jerzy, 118
Nico, Giovanni, 48
Nicolas, Joëlle, 29
Nilfouroushan, Faramarz, 44
Nilsson, Tobias, 64
Nogaś, Paweł, 118
Nordman, Maaria, 30, 31, 35, 120
Nosek, Jakub, 48
Novák, Adam, 114
Näränen, Jyri, 30, 31, 35, 120

Omang, Ove Christian Dahl, 115

Pan, Ernian, 9
Panet, Isabelle, 109
Papčo, Juraj, 19
Pastorutti, Alberto, 96
Peters, Heino, 16
Pietrzak, Julia, 118
Pivetta, Tommaso, 34, 69, 82
Portier, Nolwenn, 69, 75
Przemysław, Dykowski, 112, 118
Pénzešová, Laura, 19, 114

Qin, Ming, 63

Qing, Tiantian, 113

Rachlin, Kenneth, 14
Raja-Halli, Arttu, 30, 31, 35, 120
Raskin, Jean-Pierre, 99
Ray, Richard, 12, 14
Rebischung, Paul, 74
Rehm, Till, 70
Reich, Marvin, 16, 84, 93
Rempfer, Carolin, 70
Riccardi, Umberto, 34, 69, 75, 82
Ricciardi, Giuseppe, 34
Rietbrock, Andreas, 90, 112
Rosat, Séverine, 20, 26, 109
Rosenbusch, Peter, 93, 103
Rouissat, Bouchrit, 59
Ruotsalainen, Hannu, 115

Saad, Assia, 126
Saad, Thiziri, 26
Salmiņš, Kalvis, 77
Sampietro, Daniele, 32
Schattan, Paul, 70
Schroth, Eva, 107
Schulz, Karsten, 70
Sekowski, Marcin, 93
Shi, Kunpeng, 39
Shriver, Jay F., 107
Sihem, Miloudi, 47, 52
Sina, Bledar, 57, 80
Sjöberg, Lars E., 117
Sliwińska-Bronowicz, Justyna, 129, 130
Smail, Nadia, 59
Sneeuw, Nico, 98
Sobh, Mohamed, 93
Sottili, Gianluca, 48
Steffen, Holger, 44, 64
Steffen, Rebekka, 44, 64
Stolarczuk, Nico, 16, 70
Strykowski, Gabriel, 115
Sulzbach, Roman, 16, 18, 37
Sun, Heping, 9, 39, 41, 42, 63, 123
Sébastien Toussaint, 127

Tafflet, Alicia, 29
Tang, Xiongwei, 41, 63
Tavasci, Luca, 25
Taymaz, Tuncay, 41
Thomas, Maik, 16
Thoss, Heiko, 93
Timmen, Ludger, 16, 70, 93
Touati, Fatah, 59, 86
Toussaint, Sébastien, 21, 60, 99, 101

Vaclavovic, Pavel, 48
Van ruymbeke, Michel, 21, 60, 99, 101, 127
Verdun, Jérôme, 29
Vermeulen, Pierre, 93
Vespe, Francesco, 48
Vidal, Maurin, 46
Vinogradov, Michail, 10
Voigt, Christian, 16, 37, 70
Vyazmin, Vadim, 95

Wang, Jian, 50
Wang, Jiapei, 50
Wang, Jingqi, 41
Wanner, Xavier, 46
Weise, Adelheid, 16
Wenzhu, Huang, 102
Westerhaus, Malte, 107
Wetzel, Karl-Friedrich, 70
Widmer-Schnidrig, Rudolf, 98
Wielant, François, 99
Windenberger, Adrien, 73
Winska, Malgorzata, 129
Winter, Anna, 84
Wziontek, Hartmut, 17, 18, 25, 37, 84, 92

Xu, Huan, 85
Xu, Jianqiao, 63, 125

Yan, Ruyu, 42
Yang, Meng, 62
Yang, Weiwei, 123, 125
Yeh, Ta-Kang, 67
Yeste, Patricio, 84
Yibrie, Esubalew, 51
Yu, Jinhai, 85

Zaccagnino, Davide, 48
Zahran, Khalid, 79
Zebing, Zhou, 110
Zegrar, Ahmed, 126
Zerbini, Susanna, 25, 82
Zhang, Wentao, 102
Zhang, Wenting, 63
Zhang, Xinlin, 50
Zhang, Yijun, 41, 63
Zheng, Lijun, 111
Zheng, Yong, 41
Zhicai, Luo, 110
Zhong, Min, 62
Zhou, Hao, 72, 111, 113
Zhou, Jiangcun, 9, 42, 63
Zhou, Zebing, 111
Zlagnean, Luminita, 105

Zou, Xuhao, 63
Zuluaga, Jorge Ivan, 36
Zuševics, Vents, 77
Zürn, Walter, 20, 90, 98, 112