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# Precision Observations for Geodynamics, Earthquakes and Earth Tides Phenomena: Introduction

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The International Association of Geodesy (IAG) Sub Commission SC 3.1 has the scope of developing studies and promoting activities around the topic of Geodynamics and Earth Tides. Geodetic instruments are sufficiently sensitive and stable in time to detect a wide range of Earth signals tied to geodynamics, the earthquake cycle and volcanic processes, crustal deformation due to crustal stresses or due to climatic and atmospheric mass loading effects, fluid migration, pressure gradients and thermal stresses. The observations come from both terrestrial and space geodetic intrumentation and payload. It includes measurements of any component of Earth deformation, rotation and gravity field. The increase in sensitivity of satellite-based observations reveals the growing importance of precisely modeling Earth's superficial phenomena like ocean and solid Earth tides. Their improved modeling has been shown to reduce the noise level of the time variable gravity field recoverable from gravity satellite missions (Abrykosov et al., 2022). At regular intervals of 4 years, the SC 3.1 organizes a meeting aiming to bring together scientists working on the forefront of the field, as the 19th International Symposium on Geodynamics and Earth Tides, 23–26 June 2021, Wuhan, China. The years 2020 and 2021 were marked by the COVID19 Pandemics, which made traveling across country borders very difficult, as well as gatherings of people due to the risk of spreading the virus. The GETS Symposium was initially planned for 2020, following the 18th International Symposium on Geodynamics and Earth Tides held in 2016 in Trieste, but was finally shifted to 2021 in a hybrid form, on site and online. The number of participants was half on site and half online. A difficulty in a truly international meeting, with attendants spread over the globe and in very distant time zones, is to find a time window of the day, which can be attended conveniently by all participants, and is logistically feasible on site. The drawback of the online participation is the missing opportunity to discuss personally with other attendants, for which an optimal digital infrastructure is still missing. The meeting organizers decided to represent the symposium by a selection of 20 publications, published in a special volume in two journals: Geodesy and Geodynamics and Pure and Applied Geophysics.

The review of Sun et al. (2022c) presents the gravity observation network of China, which includes superconducting gravimeters, spring-gravimeters (gPhone type) and other kinds of gravity instruments distributed over China, in total up to 67 stations. The network has brought a wealth of data on tidal phenomena, free oscillations of the Earth generated by large earthquakes, but also the background excitation

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termed the "Earth hum", then the liquid core dynamics and geodynamics in general. The Moxa superconducting gravimeter station in Eastern Thuringia (Jahr & Stolz, 2022) has a continuous observational record of 20 years, with main results on the detection of the 430 days period of the Earth pole movement. This component of the polar motion, also called Chandler Wobble is due to the movement of the instantaneous Earth rotation axis around its axis of figure. It was shown that the superconducting gravimeter (SG) observations must be corrected for the local hydrological storage, in order to obtain a good correlation between the seasonal gravity changes of the satellite GRACE representing long wavelengths of 660 km upwards, and the SG observations. It was also shown that the Moxa station senses load effects of large river basins, as the one of the river Elbe, reaching a value of more than 9 $nm/s^2$, significantly above the SG noise level. The available long time series revealed that there is an aging effect on the SG gravimeters, that starts with an age of 10–15 years of the instrumentation, which possibly requires exchange of some electronics (Jahr & Stolz, 2022). The low noise underground laboratory in Rustrel (France) is equipped by a vertical disposition of two superconducting gravimeters (Kumar et al., 2022) providing a large sensitivity of this gradiometric arrangement to the water storage changes. It was shown that for this laboratory located in a karstic geological medium, the greatest mass contribution comes from the hydrologic storage changes in the unsaturated zone, and the gradiometric disposition is sensitive to lateral mass changes up to a distance of 2500 m. The work of Elsaka et al. (2022) deals with a calibration process of a new SG through a parallel record and comparison of earth tides signal in the Walferdange Underground Laboratory for Geodynamics in the Grand Duchy of Luxembourg. The work is helpful as a model for calibrating newly purchased gravimeters and describes the initial instrumental drift behavior. An analogous operation was made for a SG installed in Kunming, where absolute gravity measurements were made for calibration (Luan et al., 2022). Calibration factors of two spring gravimeters were obtained at two stations at Lake Nasser in Egypt, using the Earth and ocean loading tides as a calibration signal. The instruments will be used for defining the crustal deformation and gravity changes induced by the level changes of Lake Nasser (Riccardi et al., 2022). A work demonstrating the benefits of repeated gravity observations refers to South Eastern Tibet, a geodynamically active region (Chen et al., 2022). Although covering a relatively short time span of 2 years, persistent negative gravity changes over a large area can be observed. It will be interesting to see the emerging consistent pattern with a longer time series. The uplift and gravity variations are studied for the Northeastern Tibetan Plateau integrating gravity, GPS and leveling observations (Zhang et al., 2022). Borehole strainmeters are maintained in several networks in Taiwan, and these are used to include shear and dilatation signals from tensor strainmeters in seismic source modeling. It is shown that the strainmeters contribute significantly to better define the seismic source, when compared to a solution based on broad band seismometers and space geodetic observations, due to their higher sensitivity to tectonic deformation (Lin et al., 2022). A methodological study is presented in (Milyukov & Vinogradov, 2022) aiming to detect the 2S1 mode triplet activated by the Chile 2010 earthquake. The paper closing the session is a theoretical study modeling the temperature variations induced by the tide generating force. The temperature variation is induced by the volumetric strain, and is in opposite phase, amplitude variations at 60 m depth for instance being 0.06 mK for a volume strain of 40 $10^{-9}$ (Zhou et al., 2022).

The nine papers in the special issue of Geodesy and Geodynamics journal include a review of the Wuhan Symposium (Sun et al. 2022b). A detailed account of the presentations gives an excellent overview of the topics discussed at the Symposium. It will be useful to anyone interested in the topic. The two papers involving the Paul Melchior medalist B. Ducarme discuss pressure waves in continuous gravity observations (Ducarme, 2022) and optimized processing of tide gauge observations using specialized tidal software originally developed for terrestrial tidal effects (Ducarme et al., 2022). Two papers analyze tidal and non-tidal effects and the associated stresses in relation to the occurrence of earthquakes, including the analysis of slow earthquakes, and discuss the long-standing problem of the tidal triggering

of earthquakes (Tanaka et al., 2022; Yan et al., 2022). The frequencies of the Earth normal modes were extracted from a low noise superconducting gravity station located in Gujarat, India. Close to 50 observed normal modes had been activated by the Central Chile 2010, Mw 8.8 and the Tohoku, Japan 2011, Mw 9.1 events. The lowest spheroidal mode 0S2 with a period of 54 min, as well as the radial "breathing mode" 0S0 with a period of 20 min were analyzed (Pedapudi et al., 2022). Two papers included GNSS observations, next to terrestrial geodetic, gravimetric and seismologic observations, in the search for pre-seismic total Electron Content (Eshkuvatov et al., 2022) and induced seismicity due to hydrocarbon production (Abetov & Kudaibergenova, 2022). Finally the space–time variation of Eurasian plate motion was studied through Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) observations, and average horizontal and vertical velocities were defined (Kong et al., 2022).

An important event during the Symposium was the awarding ceremony of the Paul Melchior medalist. The Paul Melchior medal is given since 1997 for awarding outstanding scientists in Geodesy and Earth Tides. The previous awardees are Paul Melchior 1997, Hans-Georg Wenzel 2000, John Goodkind 2004, Bernard Ducarme and Tadahiro Sato 2008, Houtse Hsu 2013, and Trevor F. Baker 2016. The Paul Melchior Medalists 2021 are David Crossley, Gerhard Jentzsch, and Walter Zürn. The laudatios for the 2021 three awardees are found in the appendix of the Editorial of the special volume in Geodesy and Geodynamics (Sun et al. 2022a) and the 89 Symposium abstracts are found in the appendix of the Review of the Symposium (Sun et al. 2022b).

The two special volumes are complementary and give an account of the wide breadth of exciting topics that are studied under the umbrella of the IAG Sub Commission SC 3.1 of Geodynamics and Earth Tides.

## *Data availability*

The data used in this introduction are found in the referenced publications.



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