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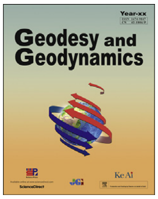

# The deforming and rotating Earth – A review of the 18th International Symposium on Geodynamics and Earth Tide, Trieste 2016

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ABSTRACT

The 18th International Symposium on Geodynamics and Earth Tides 2016 covered phenomena that generate temporal variations in geodetic observations. In calculating the stress field for earth tides, the observed geodetic response is used for defining the Earth's rheology, the Earth internal structure, Earth rotation parameters, and the functioning of the sophisticated instrumentation mounted on Earth and satellites. The instrumentation capable of observing Earth tides, measures changes generated by lithospheric plate movements, as the earthquake cycle and volcanism. Hydrology, temperature, and pressure, either of natural or anthropogenic origin, affect the high precision observations, and therefore must be included in this study-realm.

## 1. Introduction

In the week of 5–9 June 2016, the 18th International Geodynamics and Earth Tides Symposium "Intelligent Earth system sensing, scientific enquiry and discovery" was held at the University of Trieste, in Trieste, Italy, with over 106 presentations. Here a review of the topics discussed at the Symposium is given, with the aim of documenting the rich spectrum of international research activities on these interdisciplinary subjects.

The meeting was the first in which the word *GEODYNAMICS* was added to the classical Earth Tide Symposia, held since 1957. The Symposia were connected to the ICET (International Centre of Earth Tides), which was first housed at the Royal Observatory of Brussels, Belgium, and then was moved to the University of French Polynesia, Tahiti [1] (page 767). The topics of the Earth Tides Symposia have been increasingly linked to geodynamics, leading to the transformation of the IAG (International Association of Geodesy) Scientific Service ICET [2] to the IGETS (International Geodynamics and Earth Tides Service) [3], with Central Bureau hosted at EOST in Strasburg (Ecole et Observatoire des Sciences de la Terre, University Strasbourg, France) and the database held at GFZ (Deutsches GeoForschungsZentrum) Potsdam [4]. The transformation reflects the instrumental innovations and broadened applications of terrestrial and spaceborne geodetic monitoring, instruments that are sensitive to Earth tides. Together with ICET, the GGP (Global Geodynamics Project) which is responsible for supporting research activities using the data from the worldwide network of superconducting gravimeters, was also merged into IGETS.

The 2016 Symposium addressed a wide range of scientific problems in geodynamics research and chose the theme of "Interactions of geophysical fluids with Earth tides phenomena and observations" as a specific focus. The themes were enveloped in the seven sessions of the Symposium. Here a review on the topics discussed at the Symposium is given, which demonstrates the broad spectrum of applications of terrestrial and space geodetic observations of Earth geometry, crustal deformation, Earth global shape parameters, Earth rotation parameters, the gravity field and the changes in time of these effects.

## 2. Review of the topics presented at the symposium

### 2.1. Tides and non-tidal loading

The opening session on tides and tidal loading discussed the tidal signals observed in a number of stations with laser

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extensometers, water tube tiltmeters, ocean bottom and land spring gravimeters and SG (superconducting gravimeters). The fact that the tidal deformation and gravity signal can be calculated and has well defined spectral frequencies, makes the tidal signal a powerful tool to test instrument performance, recover local rheological crustal properties, and test the ocean tidal models through the observed loading tides. Table 1 lists the tilt and extensometric stations mentioned in the text. The location of the stations from Table 1 are displayed in Fig. 1, which shows also the network of the SGs (personal communication S. Rosat).

The Earth elastic response to tides, loads and stresses is expressed by the corresponding Love-Shida numbers. Varga et al. [30] presented the theory to calculate relations between these numbers with an integral approach. The authors analyzed the tidal stresses from Earth surface to the core-mantle boundary with the aim to determine the triggering effect of tides on earthquakes [31].

The SGs have lower noise levels than the quietest seismometer station for frequencies below 1 mHz and above 6 mHz, as was shown by comparing the noise spectra to the “low noise seismologic model” [32]. The SG is, therefore, an ideal instrument in searching for low frequency gravity signals as the Slichter modes [33]. The SGs being relative instruments, their amplitude factor, phase delay and long-term drift must be determined. It was found that the amplitude ratios at tidal spectral frequencies are stable and independent of local effects, and are precise enough to be used to control the amplitude factor of SGs. For the long term drift over several years the absolute gravimeters are most often used for calibration, since there may be an instrumental drift independent from the amplification factor [34–36]. Crossley and Murphy [37] and Wziontek et al. [38] found evidence of the hydrologic signal in SG decades-long time series in the order of ±100 $10^{-9}$ m/s$^2$ in the Apache Point observatory (elevation 2788 m, Sunspot, New Mexico, USA), with trends of 4 $10^{-8}$ m/s$^2$/year [37] and ±40 $10^{-9}$ m/s$^2$ in Medicina (Italy), after having corrected for a global hydrologic mass model [38]. The Apache Point Observatory station serves a lunar laser ranging telescope site and it is necessary to determine the local rheological properties of the crust, in order to determine predicted surface movements at high precision using SG and GPS.

The tiltmeter stations of St. Croix and Rustrel, France record similar signals correlated to water springs, and the karstic environment in which they are set, and have hydrologic signals with amplitudes of several hundred $10^{-9}$ rad in St. Croix and in Rustrel [7,39].

The Argentinian-German Geodetic Observatory, housing an absolute gravimeter and an SG next to GNSS, VLBI and SLR stations, senses the influence of the Rio de la Plata (river and estuary formed by the confluence of the Uruguay and the Paraná rivers, at the border between Argentina and Uruguay). The effect of storm surges on the SG was successfully modeled [40]. The non-tidal component constitutes 88% of the signal, 12% being the tidal amplitude contribution. After correcting for the storm surge, a hydrologic signal correlated to rainfall emerged.

The ocean loading tides were calculated with different approaches, as the ocean tide loading calculation service of Georg Scherneck (http://holt.oso.chalmers.se/loading) used e.g. in the Lohja station, Finland, or the convolution of the ocean tide models with the ocean loading Green functions [41] used e.g. in the Canfranc, Spain station. Amoruso and Crescentini [5] could identify the presence of nonlinear and minor ocean tides from the localized mismatch of the observed and modeled tidal signals in the underground laser extensometers of Canfranc, more than 120 km from the Bay of Biscay. The signals were quantitatively compared with computations using TPXO8 (MN4, M4, and MS4) and FES2012 (M3, N4, MN4, M4, MS4, and M6) global ocean tide models.

The ocean loading tides were also theoretically considered on GPS stations to find anelastic effects in terms of the Q-value of the crust, which was interpreted as due to interstitial fluid flow in cracks [42]. Boy et al. [43] successfully implemented atmospheric, non-tidal oceanic and hydrological loading in the GAMIT station-processing software. They found that for globally distributed GPS stations a large part of the variability cannot be explained by the loading effects, and that the continental global hydrology model GLDAS [44] has missing components.

Earth tide spring gravimeters are easily installed and do not require particular laboratory equipment as does the superconducting gravimeter. Zahran et al. [45] reported an experiment of two continuously measuring Earth tide gravimeters installed close

**Table 1**
Extensometer and tiltmeter stations discussed at the Symposium.

| Station name | Instrumentation | Year of installation | Abstracts and reference |
|---|---|---|---|
| Canfranc, Spain | Laser extensometers, 70 m length | 2011 | [5,6] |
| St. Croix, Vosges mountains, France | Long base water tube tiltmeter, 100 m length | 2004 | [7,8] |
| BFO, Schiltach, Germany | Horsfall watertube tiltmeter, 110m length; Invar wire strainmeters 10 m length | | [7,9–11] |
| LSBB, Rustrel, France | Long base water tube tiltmeter | 2012 | [7] |
| Tytyri mine,Lohja, Finland | Long base interferometric water level tiltmeter (code NSiWT), 50.4 m length | 2008 | [12,13] |
| Metsähovi, Finland | Research borehole for vertical tilt meters, 2 Superconducting gravimeters collocated with FG5X absolute gravimeter and hydrological monitoring | | [14,15] |
| Conrad observatory, Austria | Interferometric water level tilt meter, 5.5 m length (code W_iWT); Lippmann 2D tiltmeter | 2014 | [16] |
| California and Nevada | 11 long base interferometric extensometers, 380 m to 730 m length | Starting 1976 | [17] |
| Ksiaz-Warsaw, Poland | Water tube tiltmeter, quartz tiltmeter, extensometer, 60 m to 94 m length | | [18] |
| Grotta Gigante, Italy | Horizontal pendulums, 95 m top and bottom height difference, colocated Marussi tiltmeter, 0.7 m horizontal baseline. | Starting 1960 | [19] |
| Grotta Genziana, Italy | Marussi tiltmeter, 0.7 m horizontal baseline. | Starting 2007 | [20] |
| Baksan Observatory, Elbrus volcano, northern Caucasus | Baksan Laser interferometric strainmeter, 75 m length | | [21] |
| Geodynamic Observatory Moxa, Germany | Quartz-tube and laser strainmeter (3 directions), up to 38 m length, Askania borehole tiltmeters, up to 100m deep. Research borehole (20 m and 100 m deep) for injection pumping, superconducting gravimeter. | | [22,23] |
| Sopronbánfalva Geodynamic Observatory, Sopron, Hungary | Quartz-tube extensometer, 22 m length | 1990 | [24,25] |
| Mátyáshegy Gravity and Geodynamic Observatory (Budapest, Hungary) | Two quartz-tube extensometers E1 (21.3 m length) and E2 (13.8 m length) | 1980 | [26] |
| Pécs station in uranium mine (Pécs, Hungary) | Quartz-tube extensometer, 20.5 m length | 1990–1999 | [24,27] |
| Vyhne Tidal Station (Vyhne, Slovakia) | Quartz-tube extensometer, 20.5 m length | 1980 | [28,29] |

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