The Zugspitze Geodynamic Observatory Germany (ZUGOG)

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Introduction

The Zugspitze Geodynamic Observatory Germany (ZUGOG) has been setup on the summit of mountain Zugspitze, Germany's highest peak with an altitude of almost 3000 m. The main scientific objective is a better understanding of seasonal and long-term mass redistributions in the Alps. This knowledge is known to be very important, e.g. with regard to water storage and its high sensitivity to climate change, but not very advanced due to sparse data availability. ZUGOG is connected to the Environmental Research Station Schneefernerhaus as the home base of a large research consortium operating a dense sensor network for almost 20 years as well as providing technical support and infrastructure. It is accessible all around the year with cable cars.

Installations

In September 2018, the Observatory Superconducting Gravimeter OSG 052 has been installed at ZUGOG after removal from Sutherland, South Africa, as one of two SGs operating in parallel, and after refurbishment at the manufacturer GWR. This former lab of the Max Planck Society has no mass variations above the sensor, no snow accumulation on the roof and a largely increased gravimetric footprint due to its high altitude. While the first concrete pier is occupied by the SG, the second one is intended for absolute gravimeters (first measurements in Oct 2018) and other instruments. A continuous GNSS station has been installed nearby as well as a snow balance and 3 snow height sensors for the monitoring of near-field effects.

Figure 1. *ZUGOG with nearby GNSS station (top left), Mount Zugspitze with ZUGOG (orange) and the Environmental Research Station (blue) (top right), OSG 052 (bottom left) during absolute measurements with FG5-X 220 of Leibniz University Hannover (bottom middle) and snow height sensors with snow balance for the monitoring of near-field effects (bottom right).*

First Data Analysis

Drift

After cold transport and the first initialization in Sep 2018, an abnormal drift of about -50 nm/s²/day occurred probably due to flux trapping during initialization. At the end of Oct 2018, GWR decided to warm up and recool the SG again without liquid Helium but with dewar evacuation required. Since the last initialization from 29 Dec 2018, the SG is finally in nominal operation.

Calibrations

A preliminary amplitude calibration of -748.6532 (0.2682) nm/s²/V has been done on the basis of theoretical tides, as the first absolute measurements haven't been processed yet. A step response experiment at 1 Mar 2019 has produced a time delay of 4.30 (0.14) s with a much less accuracy compared to Sutherland (0.02 s).

Tidal Analysis

Local tidal parameters for diurnal and shorter waves have been computed on the basis of the gravity data from Jan-Feb 2019 and ET34-ANA-V61-A. The tidal analysis has also produced a very small single admittance factor of -1.9683 (0.0925) nm/s²/hPa due to the high altitude of the site.

Noise Analysis

The Welch method has been applied for PSD estimation of both 1 s and 1 min gravity data from the 5 quietest days in Jan-Feb 2019 at Zugspitze and in 2017 at Sutherland. While the 1s PSDs show much higher noise at Zugspitze, the 1 min noise spectra are comparable, as seismic signals from the nearby active areas in the Inn valley/Ester mountains are largely reduced by the Chebyshev decimation filter.

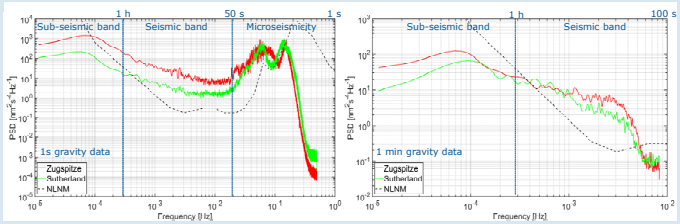


Figure 2. *Noise levels of 1s (left) and 1 min (right) gravity data from OSG 052 at Zugspitze and Sutherland. Seismic noise magnitudes (SNM) are 1.8 and 0.95 for 1s as well as 1.25 and 0.9 for 1 min data, respectively.*

Gravity residuals

After reduction of tidal signals and atmospheric mass redistributions, the gravity residuals primarily reflect water storage variations. Increased gravity can easily be assigned to snowfall events in winter months, while subsequent constant gravity and decrease of snow heights indicate snow densification.

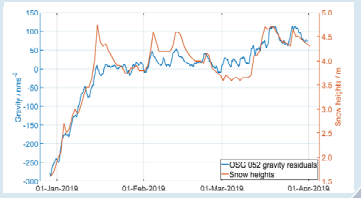


Figure 3. *Gravity residuals from OSG 052 and daily snow heights at Zugspitze with a correlation coefficient of 0.94 and a single admittance factor of 113.4 (0.9) nm/s² per 1 m snow.*

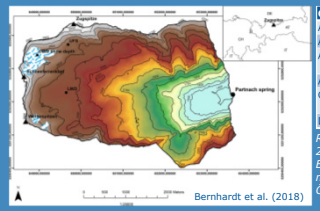
Cooperations

Gravimetry

Episodic absolute gravity measurements have been carried out since 2004 by the Leibniz University Hannover (LUH) and the Federal Agency for Cartography and Geodesy (BKG) for the analysis of long-term gravity changes. Monthly relative gravimetry has been done since 2014 by the Technical University Munich (TUM) for the detection of spatio-temporal gravity changes in a tunnel in mountain Zugspitze for the monitoring of permafrost. The SG fills an important gap in the concept of hybrid gravimetry.

Hydrology

From a hydrological perspective, the conditions of the Research Catchment Zugspitze as a natural lysimeter are very suitable. Various research groups, e.g. the University of Augsburg and the University of Natural Resources and Life Sciences Vienna (BOKU), operate a meteorological and (snow-)hydrological sensor network. In addition to these point measurements, the SG provides the total water storage variations from the summit to be merged in the sense of hydrogravimetry. After reduction of the hydrological effects in the catchment, the SG residuals will be applied for the analysis of large-scale water storage variations to be compared with GRACE Follow-On.



Characteristics of the Research Catchment Zugspitze	
Annual precipitation	2080 mm
Average temperature	-4.5° C
Altitude	1430 m (Partnach spring) to 2962 m (Zugspitze)
Area	11.4 km²
Geology	Northern Limestone Alps, heavily karstified
Drainage	Partnach spring (Natural lysimeter)

Reference: Bernhardt M, Härer S, Feigl M and Schulz K 2018 Der Wert Alpiner Forschungseinzugsgebiete im Bereich der Fernerkundung, der Schneedecken-modellierung und der lokalen Klimamodellierung. Österr Wasser- und Abfallw 70, 9-10, 515-528.

Figure 4. *The Research Catchment Zugspitze and its characteristics.*

Geology

For the monitoring of mountain permafrost in Zugspitze, TUM carries out geoelectric and seismic observations, while the Bavarian State Office of the Environment (LfU) operates permanent temperature profiles. The SG on the summit directly above the permafrost supports the analysis of seasonal and long-term evolution of permafrost and allows for joint interpretation with complementary geophysical observations.

Seismology

First joint measurements of the SG and two pairs of broadband seismometers by the Ludwig-Maximilians-Universität München (LMU) have been carried out in January 2019 for load tests of the summit by cable cars but also for the analysis of permafrost variations.

Conclusions

The OSG 052 on the summit of Zugspitze is an essential, so far missing, central piece for the interdisciplinary long-term research of the Environmental Research Station Schneefernerhaus in the Research Catchment Zugspitze with regard to an improved process understanding, improved modelling and for the mutual evaluation of different sensors and procedures.