Geoscience Activities at the Onsala Space Observatory

Lim Chin Chuan, Rüdiger Haas, Karine Le Bail, Gunnar Elgered, Faustine Mascaut, Maxime Mouyen, Peter Forkman, Jan Johansson, Rebekka Handirk, Peng Feng, Rimsky Wolfs

Abstract The Onsala Space Observatory (OSO) operates multiple geodetic and geophysical instruments, including Very Long Baseline Interferometry (VLBI) radio telescopes, a superconducting gravimeter, Global Navigation Satellite System (GNSS) stations, tide gauges, water vapor radiometers (WVRs), a seismometer station, an aeronomy station, a time and frequency laboratory, and corner-cube reflectors for Interferometric Synthetic Aperture Radar (InSAR). Here, we report the updates of activities for the OSO geodetic facilities in 2022/2023. On the networking backbone, we added new dedicated 100 Gbps fiber lines between the on-site buildings in 2022, which allows the Onsala Twin Telescopes (OTT) to record at a sustained rate of 32 Gbps each. The necessary hardware for 100 Gbps connectivity to the outside world was installed in May 2024. Further highlights are the installation of a new ground-based microwave radiometer in May 2023 and the invar measurement systems on the OTT in December 2023. The new radiometer observes the sky brightness temperatures in 14 different frequency bands (between 22 to 31 GHz and 51 and 58 GHz).

Keywords VLBI, Geodesy, Geoscience, Onsala Space Observatory

1 Introduction

OSO is the Swedish national geodetic fundamental station hosted by Chalmers University of Technology and operated with support by Lantmäteriet[1], which is the Swedish mapping, cadastral, and land registration authority. There are nine groups of instrumentation co-located at OSO in 2024 to facilitate geodetic and geosciences research. This report gives an overview of the recent developments of the instrumentation (see Figure 1).

Chalmers University of Technology

[1] https://www.lantmateriet.se/

2 Geodetic VLBI

Three radio telescopes at OSO participate in the ongoing International VLBI Service for Geodesy and Astrometry (IVS) observations. The 20-m telescope (On) is still equipped with a legacy S/X receiver and has observed about 50 S/X sessions per year during the last decades. The 20-m telescope successfully completed 53 and 50 sessions of 24-hour duration each in 2022 and 2023, respectively, of which nine and four, respectively, were dedicated to local-tie research [1, 2].

The OTT continued participating in the 24-hour VGOS sessions and one-hour VGOS Intensive sessions. The OTT are usually involved in the weekend VGOS-INT-B2/C2 sessions, observing together with Ishioka (Is) every Saturday and Sunday. In 2022, the OTT participated in 44 VGOS 24-hour sessions and 89 VGOS-INT-B2/C2 sessions, and in 2023, in 24 VGOS 24-hour sessions and 101 VGOS-INT-B2/C2 sessions.

Additionally, at the end of 2022 and beginning of 2023, ONSA13NE (Oe) replaced Wettzell (Ws) in the VGOS-INT-A (V2) sessions in five and 52 sessions, respectively. In 2023, we contributed to another ten V2-sessions when Wettzell was back online, six with only Oe and four with both OTT.

Local VGOS sessions are also organized approximately once a month, including local-tie and flux monitoring sessions. All OSO local-tie sessions (except when tagging along an IVS session) are

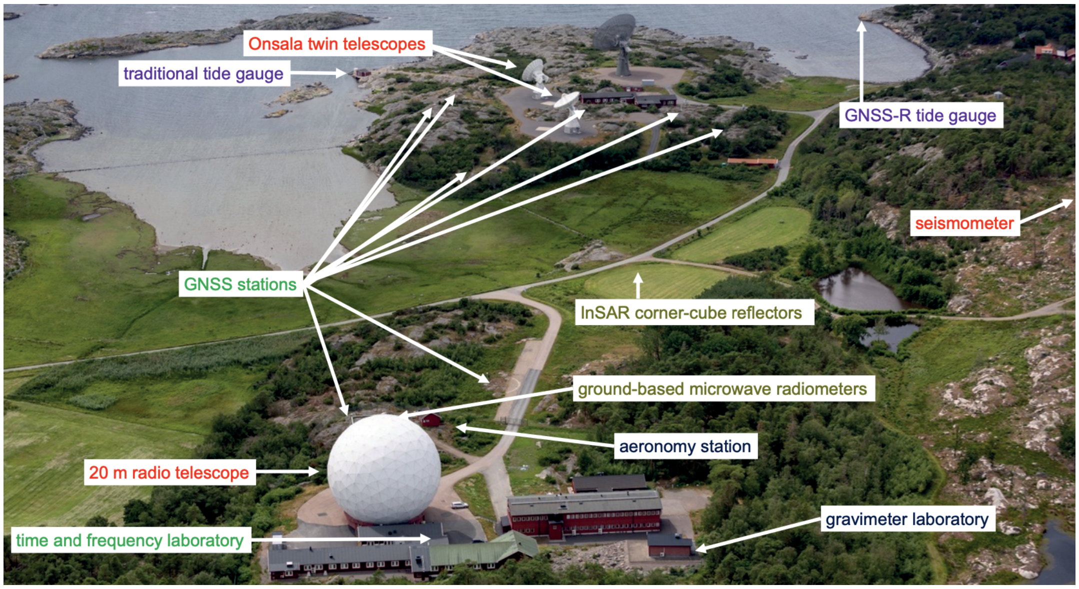

Fig. 1 Aerial photo of the Onsala Space Observatory depicting the location of the telescopes and other geoscientific instrumentation.

planned, scheduled, observed, correlated, fringe-fitted, and analyzed at OSO. In total, more than 270 sessions were completed by the OTT in 2023 alone.

Some repair, maintenance, and upgrades were completed successfully. The S-band low-noise amplifier (LNA) for the 20-m telescope was repaired in early 2024. Corrosion work and some repainting were performed on the OTT in 2022 and 2023. The OTT stow pin mechanism was repaired in the end of 2023.

Two new invar measurement systems were installed in December 2023 to monitor the vertical variation of the telescopes' reference points. Prior to the installation of the invar systems, a dedicated measurement campaign to investigate small variations of the reference points was performed in the summer of 2023 [3]. Figure 2 presents the first month of measurements with the new OTT invar systems. Both the original data with 1 s temporal resolution, as well as various different moving average values with bin sizes between 15 s and 12 h, are depicted. It becomes clear that the OTT invar systems are very noisy, and values with the original 1 s resolution are not meaningful for use in any attempts to correct for vertical height changes. Only when the data are averaged over reasonably long periods, it might make sense to use them to correct, e.g., for vertical height changes on time scales of days to months. It also becomes clear that the invar system in Oe is more disturbed by telescope movements during VLBI observations than the one in ONSA13SW (Ow). This is visible in particular in the graph of the standard deviations (SD) presented in Figure 3, that for Oe very clearly shows higher values during both 24-hour VGOS sessions as well as one-hour VGOS Intensive sessions. Also the actual data for Oe show clearly these telescope movements. This is much less pronounced

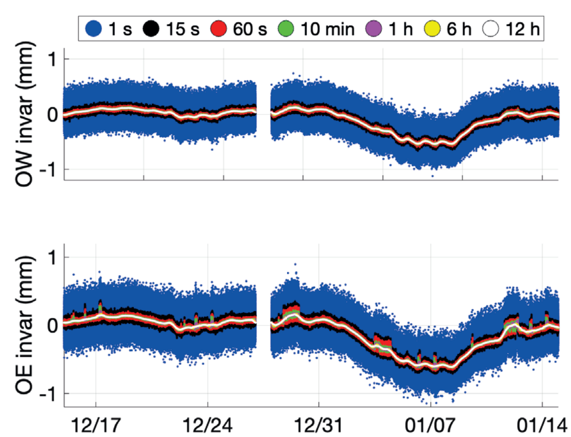

Fig. 2 The first month of measurements with the new OTT invar systems. Shown are the original data with a temporal resolution of 1 s (blue), as well as moving averages with bin sizes of 15 s (black), 60 s (red), 10 min (green), 1 h (magenta), 6 h (yellow), and 12 h (white).

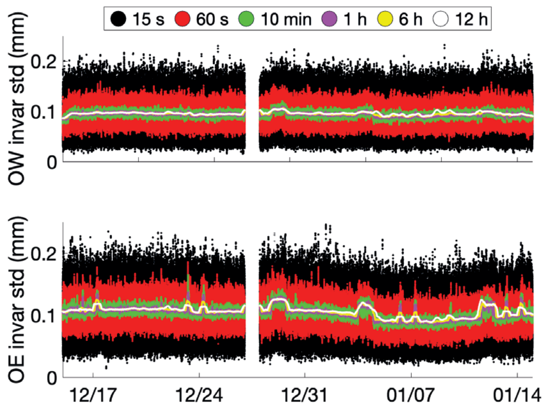

Fig. 3 Standard deviations of binned average values of the OTT invar measurements presented in Figure 2.

in the corresponding graphs for Ow. Further investigations are necessary in order to understand this behavior.

3 Gravimeter Laboratory

The primary instrument is the superconducting gravimeter SG054 (see Figure 4). The continuously operating gravimeter generates a time series of gravity variation, which can be used to monitor geophysical processes that influence gravity [4]. The tilts of the gravimeter were adjusted in October and December 2022 to reduce the excessive power load applied to the continuous self-leveling system of the device, which triggered spikes in the data. The data from the gravimeter are sent to and archived at the International Geodynamics and Earth Tide Service (IGETS)[5]. OSO also provides live monitor pages of the SG054 data with interactive graphs [6] [7].

Fig. 4 The superconducting gravimeter SG054.

4 GNSS Stations

There are eight continuously operating GNSS stations hosted at OSO as of 2024. The primary GNSS stations (ONSA and ONS1) are part of the International GNSS Service (IGS). The data from these two stations can be obtained directly from, e.g., `http://www.epncb.oma.be/`. In addition, six other GNSS antennas are distributed around the OTT (named OTT1 to OTT6), for which the data are stored in an archive at Lantmäteriet. In February 2022, we changed the receivers of the six GNSS stations close to the OTT to the Trimble NetR9. The receiver change solved the issue of signal transmission from the previous Javad Sigma receivers, which interfered with other observations at the observatory, and also improved the quality of signals from multi-GNSS.

5 Microwave Radiometers

Microwave radiometers of relevance to geodesy applications are often referred to as water vapor radiometers (WVRs). The longer operating WVR at OSO (Konrad) was in continuous operation during 2022–2023. The useful data acquired from March 2022 to the end of 2023 cover about 82% of the time, for which most data loss was caused by the weather.

A new RPG-HATPRO-G5 radiometer (Greta) was installed in May 2023. It observes the sky brightness temperatures in 14 different frequency bands, i.e., seven channels in the K- and the Ka-band, between 22 and 31 GHz, and seven channels in the V-band, between 51 and 58 GHz. A preliminary comparison between the two WVRs was made using the first three weeks of data. A root-mean-square difference of 3 mm for the equivalent zenith wet delay (ZWD) was obtained, as shown in Figure 5.

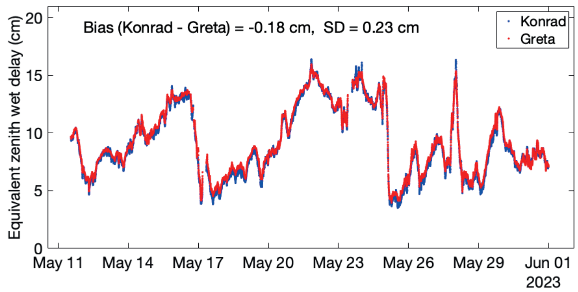

Fig. 5 Two-minute averages of the equivalent ZWD inferred from observations with Greta (red dots) and Konrad (blue dots).

6 Tide Gauges

6.1 Official Tide Gauge Station

The tide gauge station designed, constructed, and installed together with the Swedish Meteorological and Hydrological Institute (SMHI) became operational in June 2015. The sea level measured by the principal radar sensor is illustrated in Figure 6. The bottom graph shows that the seasonal and inter-annual variations still significantly impact the overall linear trend after nine years of operation.

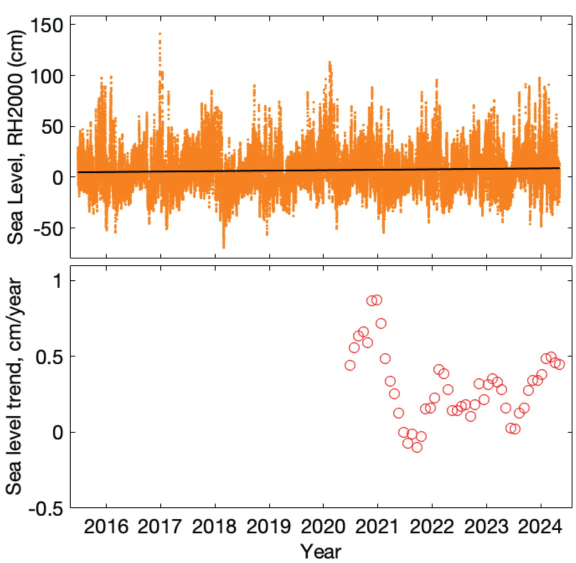

Fig. 6 Top: hourly mean values of the sea level from the tide gauge station at OSO in the Swedish observational network. Bottom: the linear sea level trend estimated up to a specific time on the X axis starting from 2020.

6.2 GNSS Tide Gauges

The use of GNSS signals for sea level measurements using GNSS-R (GNSS reflectometry) and GNSS-IR (GNSS interferometric reflectometry) has been studied at OSO for more than ten years. Presently, several installations are set up in parallel, as shown in Figure 7.

Fig. 7 GNSS antennas used for sea level monitoring.

Some GNSS-IR antennas are pointed towards the horizon, receiving the satellite signals reflected off the sea surface. Doing so, the temporal resolution for sea level monitoring increases down to several minutes. GNSS-IR can provide sea level measurements with a precision close to traditional tide gauges [8].

7 Seismometer Station

The seismometer at OSO (shown in Figure 8) is part of the Swedish National Seismic Network (SNSN [9, 10]). It continuously records and archives data in waveform outputs, which are used in delay calibration of the superconducting gravimeter and for noise reduction in absolute gravity measurements.

8 Aeronomy Station

In 2023, a FTIR (Fourier Transform InfraRed) spectrometer was installed at the OSO. It measures the IR spectrum of absorption or emission of atmospheric gases such as ozone, carbon dioxide, and methane, providing detailed data on their concentrations.

9 Time and Frequency Laboratory

OSO is hosting two hydrogen masers, one of which is owned by the Research Institutes of Sweden (RISE).

Fig. 8 The seismometer is installed on solid rock at the bottom of a 2 m deep well. It is covered with cellular plastic, and the well is surrounded by soil to reduce rapid temperature variations.

RISE also owns a caesium clock at OSO. These instruments are used for comparison measurements and to provide redundancy of accurate reference time and frequency for VLBI observations at the observatory. Unfortunately, both H-masers are deteriorating, and in the near future a new H-maser needs to be installed.

10 InSAR Reflectors

Two corner reflectors were installed in 2021 (see Figure 9). The main application is to provide precise reference points when producing InSAR images. The coordinates of the two reflectors in the local OSO network were determined in 2022 [11].

Fig. 9 The InSAR reflectors at OSO.

11 Outlook

The Onsala Space Observatory plans to continue and extend the above described geoscience activities. In particular, for the upcoming years we intend to intensify the VGOS operations. Among other things, we plan to do measurements of the OTT using aerial drones and holography. Furthermore, we plan for a new H-maser to be installed within the next two years.

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