Onsala Space Observatory – IVS Analysis Center Activities During 2021–2022

Rüdiger Haas[1], Eskil Varenius[1], Rebekka Handirk[1], Karine Le Bail[1], Periklis-Konstantinos Diamantidis[1], Tobias Nilsson[2], Gunnar Elgered[1], Peng Feng[1], Maxime Mouyen[1], Hans-Georg Scherneck[1]

Abstract This report briefly summarizes the activities of the IVS Analysis Center at the Onsala Space Observatory during 2021–2022 and gives examples of results of ongoing work.

1 General Information

We concentrate on research topics that are relevant for space geodesy and geosciences. These research topics are related to data observed with geodetic VLBI and complementing techniques.

2 Activities during the Past Two Years

We worked primarily on the following topics:

- Short-baseline interferometry
- Radio source flux-density monitoring
- Combination on the observation level
- Maintenance of IVS products
- Contribution to ITRF2020
- Investigating the VLBI scale drift
- Analysis of VGOS sessions
- Scheduling IVS R&D sessions
- Atmospheric delays in space geodesy
- Coastal GNSS interferometric reflectometry
- Gravimetry
- Ocean tide loading

3 Short-baseline Interferometry

We extended the ONTIE series [1] of local interferometry observations with the three geodetic stations of the Onsala telescope cluster, i.e., the 20-m radio telescope (On) and the Onsala twin telescopes (Oe, Ow), equaling 20 new sessions during 2021 and 2022. The goal is to monitor the local baselines and their stability and to investigate potential seasonal phenomena due to, e.g., thermal deformation of the radio telescopes [2].

4 Radio Source Flux-density Monitoring

We used data of the so-called VGOS-B2 series, i.e., VGOS Intensives involving the Onsala twin telescopes (OTT) and the VGOS station Ishioka (Japan), to monitor the flux-densities of radio sources [3]. Furthermore, we used the OTT as a standalone instrument in a series of dedicated flux monitoring sessions [4].

5 Combination on the Observation Level

We explored the impact of combination on the observation level (COL) for the analysis of space geodetic data of several different techniques as follows.

The first study was done for the CONT17 campaign [5]. VLBI and GPS data were combined in inter-

[1] Chalmers University of Technology, Department of Space, Earth and Environment, Onsala Space Observatory
[2] Lantmäteriet, the Swedish Mapping, Cadastral and Land Registration Authority

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and intra-technique solutions for the determination of the terrestrial reference frame (TRF) as well as Earth Orientation Parameter (EOP) products [6]. Combining data from different techniques at co-located sites, i.e., VLBI and GPS, addressed the inter-technique aspect. Common tropospheric parameters for the co-located stations were estimated, which led to an improvement in the determination of VLBI station positions and baseline repeatability by up to 25%. By combining data of two different and simultaneously operating VLBI networks, i.e., the so-called L1 and L2 networks during CONT17, the intra-technique aspect was addressed. The estimation of a common set of EOP for both networks resulted in an improvement in the precision of the derived polar motion and UT1 values by 20% to 30% when comparing to independently derived GPS-based estimates.

The second study addressed using COL for VLBI Intensive sessions [7]. Data from co-located GNSS stations were used to provide consistent troposphere information for Intensive VLBI data. This was done by combining three hours of encapsulating GNSS data for a one-hour Intensive VLBI session. This new strategy was used for both legacy S/X and VGOS Intensives [8] and was shown to increase the UT1-UTC precision by 15%. The agreement of the two types of simultaneous VLBI sessions improved by 65% when using COL and estimating gradients with a three-hour temporal resolution. Higher temporal resolution for the gradients improved the agreement even more. Comparing length-of-day with independently derived results from GNSS shows that the COL approach leads to 55% better agreement than individual analyses.

6 Maintenance of IVS Products

We provide and maintain the IVS Source Name Translation Table, available on CDDIS at the url: `https://cddis.nasa.gov/archive/vlbi/gsfc/ancillary/solve_apriori/IVS_SrcNamesTable.txt`.

7 Contribution to ITRF2020

We used the VLBI data analysis software ASCOT [9] and analyzed the full set of vgosDb from 1979 through 2020. The resulting SINEX files of these sessions were submitted to the IVS Combination Center to be included in the official IVS combination solution for the ITRF2020 [10]. Our solution is unique in the sense that it is the only one out of the 11 submissions to the IVS Combination Center that used the ASCOT software. The IVS Combination Center used these 11 submissions to produce the final IVS contribution to the ITRF2020 [11].

8 Investigating the VLBI Scale Drift

The new realization of the International Terrestrial Reference System, the ITRF2020 [11], became available in April 2022. It shows a significant change, after 2013.175, in the behavior of the scale defined by VLBI. We investigated possible reasons for such a change by studying the impact of geophysical mismodeling, observation network non-homogeneity, and including data from stations with technical problems. The scale drift seems to be affected by a combination of these factors. This work is still ongoing.

9 Analysis of VGOS Sessions

We investigated the performance of the 24-hour VGOS sessions observed during 2019–2021 [14]. Station positions and the EOP were compared with corresponding results from legacy S/X VLBI sessions. This study showed that the VGOS station position repeatabilities are significantly better than those obtained from the legacy S/X VLBI sessions. On the other hand, the VGOS-derived EOP were less accurate than those from the legacy S/X sessions. The reason for this is probably the small number of operational VGOS stations and the poor global coverage of the VGOS network.

10 Scheduling IVS R&D Sessions

Between 2013 and 2020 and following the acceptance of the proposal [12], 55 IVS R&D sessions were dedicated to the observation of 195 ICRF2-Gaia transfer sources selected by the Bordeaux Observatory: a set of ICRF2 sources that were observed in the optical realm by the Gaia instrument. The primary goal of these observations is the alignment of the ICRF with the Gaia Celestial Reference Frame (GCRF). In 2021 and 2022, we scheduled 20 IVS R&D sessions (RD2101–RD2110 and RD2201–RD2210) using the scheduling software *sked*, with the same goal of strengthening the observations of a core set of sources observed both by geodetic VLBI and Gaia. Due to the adoption of the ICRF3 [13] by the IAU, the extension of the Gaia mission with the expected release of position time series and the IVS R&D session network, the source selection strategy was revised in November 2020 by K. Le Bail, P. Charlot, and C. Gattano. The source list is now variable: the goal is to build a regular observation history for these sources. This will allow for a comprehensive comparison of the source position time series of the ICRF and the GCRF.

11 Atmospheric Delays in Space Geodesy

We continued our research efforts concerning atmospheric delay effects in space geodesy as follows.

We used GNSS observations at the Onsala Space Observatory from 2019 to estimate linear horizontal gradients in the wet propagation delay, and we compared these to the corresponding ones from a co-located microwave radiometer [15]. Various different temporal resolutions and elevation cutoff angles were tested. Using multi-GNSS data increased the correlation w.r.t. radiometer results by 11% and 20% for the east and north gradients, respectively. The highest correlation was achieved for the east and north gradients with a temporal resolution of two hours and six hours, respectively. Using weak constraints in the GNSS analyses helps to track large short lived gradients.

Using local interferometric observations at Onsala [1] we studied differential zenith wet delays and compared these to linear horizontal gradients derived from the co-located microwave radiometer [16]. The gradients derived from the radiometer were projected on the local baseline between the telescopes. Correlation coefficients in the range of 0 to 0.2 were obtained, which agrees with results based on simulations.

Data of the VGOS R&D VR2101 were analyzed with a five-minute temporal resolution for zenith wet delay and horizontal gradients [17]. This high temporal resolution is equivalent to what is used in standard GNSS processing and the analysis of microwave radiometer data and thus allows comparisons without need of interpolation. The zenith total delays from VGOS and GNSS revealed correlation coefficients larger than 0.9 for all but one of the participating sites in the VR2021 session. The horizontal gradients from VGOS and GNSS had correlation coefficients between 0.2–0.5 for the east components and 0.4–0.7 for the north components. For Onsala, the only site participating in VR2101 that was equipped with a co-located microwave radiometer, the correlation between VGOS and the microwave radiometer was 0.96 for the zenith total delays. The corresponding horizontal gradients showed correlation coefficients of about 0.2 and 0.5 for the east and the north component, respectively.

12 Coastal GNSS Interferometric Reflectometry

We continued our research in GNSS interferometric reflectometry (GNSS-IR). One topic was to derive an improved model for the tropospheric error in GNSS-IR. Another topic was to investigate the impact of different GNSS antenna models on the retrieval of sea level results with GNSS-IR. Both topics are under further investigation. Figure 1 depicts a temporary installation of several different GNSS antennas directly at the sea next to the permanent GNSS-R installation at Onsala.

13 Gravimetry

During seven weeks in the summer of 2022, Onsala organized an international comparison campaign for absolute gravimeters. In total, 15 different instruments participated, both ballistic (FG5X, FG5, A10) and quantum (AQG) absolute gravimeters. The

Fig. 1 Several different GNSS antenna types mounted close to the sea next to the permanent GNSS-R installation at Onsala (right).

superconducting gravimeter (SG) located at Onsala continuously kept track of local gravity variations, especially due to hydrological effects. The analysis of the data set is ongoing.

Degree-3 gravimetric tidal constituents were derived for 16 SGs, based on a hypothesis-free wave grouping approach [18]. The agreement of the mean signal amplitude of the derived empirical values was shown to agree to corresponding modeled constituents on a level of 63–80%. The latter were derived using a barotropic, data-unconstrained ocean tide model that is optimized with respect to a tide-gauge data set.

In 2022, the data of the SG, that are publicly shared via the International Geodynamics and Earth Tide Service of the International Association of Geodesy, were given a DOI (Digital Object Identifier), which should be cited [19] when its data are used. Following the publication of the FAIR Data Principles [20], an increasing number of journals encourage/require authors to include data citations as part of their reference list. This should help to enhance the visibility of Onsala's gravimeter data and to monitor their usage.

14 Ocean Tide Loading

The Automatic Ocean Tide Loading service was operated throughout the year. It is heavily used by the international scientific community. Two new ocean models, EOT20 and TPXO.9.5a, were included during the last two years, see `http://holt.oso.chalmers.se/loading/`.

15 Future Plans

The IVS Analysis Center at the Onsala Space Observatory will continue its efforts to work on specific topics relevant to space geodesy and geosciences. We plan to intensify our work in particular concerning tropospheric parameters sensed by space geodetic techniques, as well as monitoring radio source flux-densities with local interferometry. We also plan to analyze the global VLBI data set on a more regular basis and to contribute to, e.g., the IVS quarterly solutions. This work will be done in collaboration with Lantmäteriet, the Swedish mapping, cadastral, and land registration authority.

References

1. Varenius E., Haas R., Nilsson T. (2021). Short-baseline interferometry local-tie experiments at the Onsala Space Observatory. *Journal of Geodesy*, 95:54, doi:10.1007/s00190-021-01509-5
2. Handirk R., Varenius E., Nilsson T., Haas R. (2023). Obtaining Local-Tie Vectors from Short-Baseline Interferometry. In: K. L. Armstrong, D. Behrend, and K. D. Baver (eds.) *IVS 2022 General Meeting Proceedings*, 134–138, NASA/CP-20220018789
3. Le Bail K., Varenius E., Haas R. (2021). Source flux-density monitoring in the VGOS era. In: R. Haas (ed.) *Proc. 25th EVGA Working Meeting*, 90–94,
4. Varenius E., Maio F., Le Bail K., Haas R. (2022). Broad band flux-density monitoring of radio sources with the Onsala twin telescopes. *Experimental Astronomy* 54, 137–155. doi:10.1007/s10686-022-09867-4
5. Behrend D., Thomas C., Gipson J., Himwich E., Le Bail K. (2020). On the organization of CONT17. *Journal of Geodesy* 94:100, doi:10.1007/s00190-020-01436-x
6. Diamantidis P. K., Kłopotek G., Haas R. (2021). VLBI and GPS inter- and intra-technique combinations on the observation level for evaluation of TRF and EOP. *Earth, Planets and Space*, 73:68, doi:10.1186/s40623-021-01389-1
7. Diamantidis P. K., Haas R., Varenius E., Schartner M., Matsumoto S. (2022). Combining VGOS, legacy S/X and GNSS for the determination of UT1. *Journal of Geodesy*, 96:55, doi:10.1007/s00190-022-01648-3
8. Haas R., Varenius E., Matsumoto S., Schartner M. (2021). Observing UT1-UTC with VGOS. *Earth, Planets and Space*, 73:78, doi:10.1186/s40623-021-01396-2

9. Artz T., Halsig S., Iddink A., Nothnagel A. (2016). ivg::ASCOT: Development of a New VLBI Software Package. In: D. Behrend, K. D. Baver, and K. L. Armstrong (eds.) *IVS 2016 General Meeting Proceedings*, 217–221, NASA/CP-2016-219016
10. Hellmers H., Modiri S., Bachmann S., Thaller D., Bloßfeld M., Seitz M., Gipson J. (2022). Combined IVS Contribution to the ITRF2020. In: International Association of Geodesy Symposia. Springer, Berlin, Heidelberg. doi:10.1007/1345_2022_170
11. ITRF2020 (2022) `https://itrf.ign.fr/en/homepage`
12. Bourda G., Charlot P. (2012). Observations of ICRF2 Sources to Improve the Astrometry of the Future Radio-optical Transfer Sources. IVS Memorandum 2012-001v01 (`https://ivscc.gsfc.nasa.gov/publications/memos/index.html`)
13. Charlot P., Jacobs C., Gordon D., Lambert S., de Witt A., Böhm J., Fey A., Heinkelmann R., Skurikhina E., Titov O., Arias F., Bolotin, S., Bourda G., Ma C., Malkin Z., Nothnagel A., Mayer D., MacMillan D., Nilsson T., Gaume R. (2020). The third realization of the International Celestial Reference Frame by very long baseline interferometry. *Astronomy & Astrophysics*, 644, A159; 1–28, doi:10.1051/0004-6361/202038368
14. Nilsson T., Haas R., Varenius E. (2023). The Current and Future Performance of VGOS. In: K. L. Armstrong, D. Behrend, and K. D. Baver (eds.) *IVS 2022 General Meeting Proceedings*, 192–196, NASA/CP–20220018789
15. Ning T., Elgered G. (2021). High temporal resolution wet delay gradients estimated from multi-GNSS and microwave radiometer observations. *Atmospheric Measurement Techniques*, 14(8), 5593–5605, doi:10.5194/amt-14-5593-2021
16. Elgered G., Haas R. (2021). Small scale atmospheric variations sensed with very short baseline interferometry (VSBI) and microwave radiometry. In: R.Haas (ed.) *Proc. 25th EVGA Working Meeting*, 110–114
17. Haas R., Johansson J., Elgered G., Diamantidis P. K., Nilsson T. (2023). Assessment of Parameters Describing the Signal Delay in the Neutral Atmosphere Derived from VGOS Observations. In: K. L. Armstrong, D. Behrend, and K. D. Baver (eds.) *IVS 2022 General Meeting Proceedings*, 248–252, NASA/CP-20220018789
18. Sulzbach R., Wziontek H., Hart-Davis M., Dobslaw H., Scherneck H. G., Van Camp M., Dahl Omang O. C., Antokoletz E. D., Voigt C., Dettmering D., Thomas M. (2022). Modeling gravimetric signatures of third-degree ocean tides and their detection in superconducting gravimeter records. *Journal of Geodesy*, 96(35), doi:10.1007/s00190-022-01609-w
19. Scherneck H. G., Mouyen M., Reldin J. (2022). Superconducting Gravimeter Data from Onsala - Level 1 *GFZ Data Services*, doi:10.5880/igets.os.l1.001
20. Wilkinson M., Dumontier M., Aalbersberg J., Appleton G., Axton M., Baak A., Blomberg N., Boiten J. et al. (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data*, doi:10.1038/sdata.2016.18