

Onsala Space Observatory — IVS Network Station Activities During 2019–2020

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Abstract During 2019 and 2020 we participated in 88 legacy S/X sessions with the Onsala 20-m telescope. We observed almost 50 VGOS 24-hour sessions with one or both of the Onsala twin telescopes and 49 shorter VGOS sessions. We also performed local interferometry measurements at Onsala.

1 General Information

The Onsala Space Observatory is the national facility for radio astronomy in Sweden with the mission to support high-quality research in radio astronomy and geosciences. The geoscience instrumentation at Onsala includes three antennas used for geodetic VLBI, several GNSS installations, a superconducting gravimeter, a platform for visiting absolute gravimeters, several microwave radiometers for atmospheric measurements, both GNSS-based and conventional tide gauge sensors, and a seismometer. The observatory can thus be regarded as a fundamental geodetic station. The staff members associated with the IVS Network Station at Onsala are listed in Table 1.

2 Legacy S/X VLBI Observations

In total, the 20-m radio telescope (On) participated in 45 and 43 legacy S/X sessions during 2019 and 2020, respectively, see Table 2. The majority were standard IVS sessions, but two special sessions were carried

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out together with Italian stations. All sessions were recorded with the DBBC2/Flexbuff system, and the data were e-transferred for correlation.

Two of the planned IVS sessions were lost. RV133 was lost due to data transfer issues in January 2019. R1943, in April 2020, was not even observed due to Covid-19 issues. Several sessions are still not correlated, including two of the mixed-mode RD-sessions observed in 2020.

3 Local Interferometry Observations

In April 2019 we started local interferometry observations at X-band with the goal of connecting the twin telescopes and the 20-m telescope, see Table 3, the so-called ONTIE sessions. These sessions were planned, scheduled, observed, correlated, fringe-fitted, and analyzed at Onsala. The majority of the sessions were 24 hours long during which typically more than 1,000 scans were observed. The corresponding vgosDb files are available at the IVS. More details about the ONTIE sessions are provided in [2].

4 VGOS Observations

For 2019 and 2020 we planned to participate in 50 international VGOS sessions of 24-hour duration, the VT and VO series. For most of these sessions both Oe and Ow were planned to observe. During March to June 2020 we had problems with the low noise amplifiers (LNAs) of the OTT, which had been damaged by ship radar. As a consequence, several of the VO sessions could not be observed. We were participating in 32 European VGOS sessions during 2019 and 2020, of 4–6 h

Table 1 Staff members associated with the IVS Network Station at Onsala. All e-mail addresses have the ending @chalmers.se, and the complete telephone numbers start with the prefix +46-31-772.

Function	Name	e-mail	telephone
Responsible P.I.s for geodetic VLBI observations	Rüdiger Haas	rudiger.haas	5530
	Eskil Varenius (2019.10.01–)	eskil.varenius	5558
	Karine Le Bail (2020.06.15–)	karine.lebail	5556
Ph.D. students involved in geodetic VLBI	Grzegorz Kłopotek (–2020.05.31)	grzegorz.klopotek	5575
	Periklis-Konstantinos Diamantidis	periklis.diamantidis	5575
Responsible for the VLBI Field System	Michael Lindqvist	michael.lindqvist	5508
	Rüdiger Haas	rudiger.haas	5530
	Eskil Varenius (2019.10.01–)	eskil.varenius	5558
Responsible for the VLBI equipment	Karl-Åke Johansson (–2019.04.30)	karl-ake.johansson	5571
	Magnus Dahlgren (2019.05.01–)	magnus.dahlgren	5594
	Leif Helldner	leif.helldner	5576
Responsible for the VLBI operators and data recording and transfer equipment	Roger Hammargren	roger.hammargren	5551
	Simon Casey	simon.casey	5529
	Eskil Varenius (2019.10.01–)	eskil.varenius	5558
Telescope scientist	Henrik Olofsson	henrik.olofsson	5564
Software engineer	Mikael Lerner	mikael.lerner	5581
Responsible for gravimetry	Maxime Mouyen	maxime.mouyen	5549
Responsible for tide gauge and radiometry	Gunnar Elgered	gunnar.elgered	5565
Responsible for aeronomy and radiometry	Peter Forkman	peter.forkman	5577
Observatory director	John Conway	john.conway	5503

observing time. Furthermore, we observed 17 VGOS Intensive sessions of 1-hour duration. These were primarily the VGOS-B sessions [1], but for one occasion, day 336 in 2020, the OTT participated simultaneously in a VGOS-B Intensive session (Oe) and a VGOS-V2 Intensive session (Ow).

5 Monitoring Activities

We continued monitoring activities:

Calibration of pressure sensor. Starting in September 2002 the ground pressure sensor at the observatory has been continuously monitored and regularly compared to the Vaisala PA11 “traveling barometer” in order to maintain traceability to SI. This specific type has aged and was calibrated a final time at the SMHI main office in Norrköping on December 17, 2020. The differences were < 0.05 hPa in the interval from 950 to 1050 hPa. A new traveling barometer was installed on December 22, 2020, on recommendation by SMHI. This new type will facilitate future calibrations at SMHI, and furthermore it is set up for a continuous archiving of

the observations (presently one sample per minute) while operating at the observatory.

Vertical changes of the 20-m telescope tower.

We continued to monitor the vertical changes of the telescope tower using the invar rod system at the 20-m telescope. The measurements are available at <http://wx.oso.chalmers.se/pisa/>.

The local geodetic network. In October 2020 a survey was performed to determine the axis intersection of the Onsala twin telescopes. These measurements were performed by colleagues from Lantmäteriet, the Swedish mapping, cadastral, and land registration authority, using a total station mounted on the geodetic survey pillars around the twin telescopes and retro-reflecting prisms mounted on the elevation cabins. A preliminary analysis performed by colleagues from the Frankfurt University of Applied Sciences, Germany, indicates that the axis offset is less than 0.2 mm for both antennas. To connect the reference points of the twin telescopes with the 20-m telescope, further measurements are necessary, including GNSS observations on the survey pillars.

Table 2 Legacy S/X geodetic VLBI observations at Onsala during 2019 and 2020. The third and sixth columns give some general remarks and information about the percentage of the scheduled Onsala (On) observations that were used in the analysis (as reported on the web pages for the IVS session analyses), compared to the station average (StAv) percentage per experiment.

Exp.	Date	Remarks	Exp.	Date	Remarks
R1875	19.01.02	OK: 70.1 % (StAv 62.5 %)	R1928	20.01.07	OK: 58.8 % (StAv 41.9 %)
RV133	19.01.07	-- 0.0 %, data transfer issues	RV139	20.01.08	OK: 84.0 % (StAv 80.8 %)
RD1901	19.01.08	Not correlated yet	R1929	20.01.13	OK: 82.6 % (StAv 71.0 %)
R1877	19.01.14	OK: 83.3 % (StAv 70.6 %)	RD2001	20.01.15	OK: 73.5 % (StAv 54.8 %)
R1879	19.01.28	OK: 67.6 % (StAv 83.3 %)	R1931	20.01.27	OK: 81.4 % (StAv 72.6 %)
T2130	19.01.29	OK: 66.7 % (StAv 57.9 %)	R1932	20.02.03	OK: 84.1 % (StAv 74.4 %)
EURD09	19.01.30	OK: 95.9 % (StAv 93.8 %)	RD2002	20.02.12	OK: 69.3 % (StAv 62.5 %)
R1880	19.02.04	OK: 93.9 % (StAv 92.8 %)	R1934	20.02.17	OK: 85.0 % (StAv 72.3 %)
RD1902	19.02.06	Not correlated yet	R1939	20.03.23	OK: 97.4 % (StAv 93.8 %)
R1881	19.02.11	OK: 92.3 % (StAv 88.7 %)	RD2003	20.03.25	OK: 43.0 % (StAv 28.0 %)
R1882	19.02.19	OK: 91.9 % (StAv 89.4 %)	R1940	20.03.30	OK: 72.1 % (StAv 55.6 %)
R1887	19.03.25	OK: 87.8 % (StAv 77.9 %)	R1942	20.04.14	OK: 85.9 % (StAv 77.1 %)
T2131	19.03.26	OK: 80.2 % (StAv 67.8 %)	R1943	20.04.20	-- 0.0 %, no observations due to Covid-19
EUR149	19.03.27	OK: 97.0 % (StAv 77.8 %)	R1945	20.05.04	OK: 82.8 % (StAv 73.6 %)
R1888	19.04.01	OK: 96.4 % (StAv 89.7 %)	RD2004	20.05.06	OK: 73.7 % (StAv 50.2 %)
R1891	19.04.23	OK: 91.5 % (StAv 77.8 %)	R1947	20.05.18	OK: 96.2 % (StAv 94.1 %)
RV134	19.04.29	OK: 84.4 % (StAv 76.4 %)	R1940	20.05.19	OK: 65.1 % (StAv 96.8 %)
EURD10	19.05.06	OK: 75.2 % (StAv 61.4 %)	R1948	20.05.26	OK: 81.4 % (StAv 72.0 %)
VI007	19.05.19	OK: N/A, Test with Italy.	RD2005	20.06.24	OK: 68.5 % (StAv 52.2 %)
R1895	19.05.20	OK: 92.3 % (StAv 89.6 %)	R1953	20.06.29	OK: 83.6 % (StAv 75.9 %)
T2132	19.05.21	OK: 79.2 % (StAv 62.1 %)	R1954	20.07.06	OK: 83.9 % (StAv 76.1 %)
RV135	19.06.24	OK: 81.4 % (StAv 72.1 %)	RV141	20.07.07	OK: 86.9 % (StAv 83.5 %)
RD1905	19.06.26	OK: 58.2 % (StAv 58.0 %)	RD2006	20.07.08	Not correlated yet
R1901	19.07.01	OK: 83.3 % (StAv 77.9 %)	R1959	20.08.11	OK: 75.6 % (StAv 77.9 %)
RV136	19.07.08	OK: 86.8 % (StAv 76.0 %)	R1960	20.08.18	OK: 88.4 % (StAv 72.6 %)
RD1906	19.07.10	OK: 78.3 % (StAv 64.2 %)	RV142	20.08.19	OK: 73.3 % (StAv 61.8 %)
R1907	19.08.12	OK: 78.7 % (StAv 72.8 %)	R1961	20.08.24	OK: 80.1 % (StAv 63.8 %)
R1908	19.08.19	OK: 75.5 % (StAv 65.1 %)	RD2007	20.08.25	Not correlated yet
R1909	19.08.26	OK: 71.1 % (StAv 53.6 %)	R1962	20.08.31	OK: 78.3 % (StAv 63.2 %)
RD1908	19.08.27	OK: 71.8 % (StAv 59.9 %)	R1963	20.09.08	OK: 76.3 % (StAv 59.9 %)
R1910	19.09.02	OK: 76.7 % (StAv 64.8 %)	RD2008	20.09.09	Not correlated yet
EURD11	19.09.03	OK: 91.1 % (StAv 85.1 %)	R1965	20.09.21	OK: 66.5 % (StAv 53.1 %)
R1911	19.09.09	OK: 72.6 % (StAv 59.5 %)	RV143	20.09.22	OK: 77.6 % (StAv 67.6 %)
RD1909	19.09.11	OK: 77.0 % (StAv 65.3 %)	R1966	20.09.28	OK: 77.5 % (StAv 65.9 %)
R1913	19.09.23	OK: 69.2 % (StAv 52.8 %)	R1972	20.11.09	OK: 112.5 % (StAv 122.7 %), extra stations joined
T2134	19.09.24	OK: 75.1 % (StAv 53.6 %)	T2142	20.11.10	Not correlated yet
RD1910	19.09.25	Not correlated yet	VI008	20.11.14	OK: N/A, Test with Italy
RV137	19.09.30	OK: 49.5 % (StAv 5.6 %)	RV144	20.11.18	OK: 75.3 % (StAv 69.7 %)
R1921	19.11.18	OK: 82.2 % (StAv 74.9 %)	RD2009	20.11.23	Not correlated yet
EUR150	19.11.20	OK: 75.5 % (StAv 58.5 %)	R1974	20.11.24	OK: 89.5 % (StAv 80.3 %)
RV138	19.11.25	OK: 75.5 % (StAv 78.4 %)	RD2010	20.12.02	Not correlated yet
R1924	19.12.09	OK: 72.9 % (StAv 58.0 %)	R1976	20.12.07	OK: 83.1 % (StAv 77.1 %)
T2136	19.12.10	OK: 73.3 % (StAv 47.8 %)	R1977	20.12.14	OK: 73.3 % (StAv 56.0 %)
EURD12	19.12.16	OK: 70.5 % (StAv 53.0 %)	R1978	20.12.21	OK: 86.7 % (StAv 79.9 %)
R1925	19.12.17	OK: 76.5 % (StAv 56.9 %)			

Superconducting gravimetry (SCG). The superconducting gravimeter operated continuously and produced a highly accurate record of gravity variations. Tide solutions were prepared on a weekly basis, and results are available on the SCG home-

page (<http://holt.oso.chalmers.se/hgs/SCG/toe/toe.html>).

Table 3 2019 and 2020 local X-band interferometry observations involving On, Oe, and Ow. These sessions were planned, scheduled, observed, correlated, fringe-fitted, and analyzed at Onsala. All vgosDb files are available via the IVS Web pages. The third and sixth columns give information about the percentage of the scheduled observations that were used in the final data analysis.

Exp.	Date	Remarks	Exp.	Date	Remarks	Exp.	Date	Remarks
ON9114	19.04.24	OK: 99.0 %	ON0010	20.01.10	OK: 98.2 %	ON0178	20.06.26	OK: 98.9 %
ON9120	19.04.30	OK: 99.4 %	ON0011	20.01.11	OK: 98.2 %	ON0179	20.06.27	OK: 99.2 %
ON9120	19.04.30	OK: 99.4 %	ON0012	20.01.12	OK: 98.2 %	ON0180	20.06.28	OK: 98.9 %
ON9120	19.04.30	OK: 99.4 %	ON0079	20.03.19	OK: 98.3 %	ON0223	20.08.10	OK: 98.2 %
ON9136	19.05.16	OK: 98.9 %	ON0080	20.03.20	OK: 98.6 %	ON0227	20.08.14	OK: 97.3 %
ON9142	19.05.22	OK: 99.3 %	ON0081	20.03.21	OK: 99.1 %	ON0228	20.08.15	OK: 97.7 %
ON9323	19.11.19	OK: 98.2 %	ON0082	20.03.22	OK: 98.8 %	ON0317	20.11.12	OK: 98.8 %
ON9327	19.11.23	OK: 98.1 %	ON0177	20.06.25	OK: 99.0 %	ON0318	20.11.13	OK: 98.7 %
ON9328	19.11.24	OK: 98.4 %						

Absolute gravimetry. Lantmäteriet visited the observatory twice with their FG5 instrument. These measurement campaigns were performed once in 2019 and once in 2020.

Seismological observations. The seismometer owned by Uppsala University and the Swedish National Seismic Network (SNSN) was operated throughout the two-year period.

Water vapor radiometry. The observatory operated two radiometers at the beginning of 2019: Astrid and Konrad. Both were operating continuously until the summer, when a thunder storm hit the observatory and both radiometers failed because many components were damaged. Konrad was repaired and started operating again in early October 2019. After that, Konrad has been operating more or less continuously, but the quality of the data is now and then not satisfactory due to gain jumps. The cause of these jumps has been investigated in the lab on several occasions and was not fully understood at the end of 2020.

Astrid is still broken, and discussions are going on regarding a major upgrade of the instrument, because the data acquisition system is obsolete.

Sea level. The official Onsala tide gauge station is a part of the national observational network for sea level operated by the Swedish Meteorological and Hydrological Institute (SMHI). The data are available via SMHI web pages (open access). It has been in continuous operation since the summer of 2015. During 2020 repeated leveling campaigns have revealed an offset of the reference point on the main sensor, a Campbell CS474 radar. We plan for additional leveling mea-

surements during 2021 in order to have an accuracy at the millimeter level, over the dynamic range of the expected sea level variations, approximately from -1 m to $+2$ m around the mean. Based on these measurements, we will, thereafter, apply a correction to all historical data.

The GNSS-R based tide gauge was operated continuously, and the recorded data were analyzed.

6 Future Plans

In the coming two years we plan to

- participate in about 50 IVS legacy S/X sessions per year with the 20-m telescope;
- participate in as many VGOS sessions as possible;
- continue the local interferometric measurements on a regular basis;
- continue the work to establish local tie vectors between the telescopes' reference points using classical geodetic observations as well as ones made with gimbal-mounted GNSS antennas on the telescopes;
- continue the monitoring activities.

References

1. Haas R, Varenus E, Matsumoto S, Schartner M (2021) Observing UT1-UTC with VGOS. *Earth Planets Space*, 73:78, doi:10.1186/s40623-021-01396-2
2. Varenus E, Haas R, Nilsson T (2021) Short-baseline interferometry local-tie experiments at the Onsala Space Observatory. *J. Geod.*, in press.

Table 4 2019/2020 international (VT, VO) and European (VGT, EV) VGOS, VGOS Intensive (B, V2), and mixed mode (RD) sessions with ONSA13NE (Oe) and/or ONSA13SW (Ow). Filled/open circles mean success/failure; dashes mean “not scheduled.”

Exp.	Date	Oe	Ow	Remarks	Exp.	Date	Oe	Ow	Remarks
VT9007	19.01.07	○	○	Oe missed 5 h, Ow missed 133 scans	B20007	20.01.07	●	●	OK
VT9022	19.01.22	●	●	Ow weak PCAL	VO0009	20.01.09	●	●	OK
VGT035	19.02.04	●	–	Ow no PCAL	EV0009	20.01.09	●	●	Not yet correlated
VT9035	19.02.04	●	–	Ow no PCAL	B20013	20.01.13	●	●	OK
VT9050	19.02.19	●	–	Ow no PCAL, Oe 12 scans missed	EV0021	20.01.21	●	●	Not yet correlated
VGT050	19.02.19	●	○	Ow clock&PCAL issue, Oe some loss	VO0021	20.01.21	●	●	OK
VT9063	19.03.04	●	–	Ow no PCAL	B20023	20.01.23	●	●	OK
VT9077	19.03.18	●	–	Ow no PCAL	B20027	20.01.27	●	●	OK
VT9091	19.04.01	●	–	Ow no PCAL	VO0034	20.02.03	●	●	OK
VT9105	19.04.15	●	–	Ow no PCAL	EV0034	20.02.03	●	●	Not yet correlated
VGT105	19.04.15	●	–	Ow no PCAL	B20037	20.02.06	●	●	OK
EV9119	19.04.29	●	○	Ow manual PCAL	B20044	20.02.13	●	●	OK
VT9119	19.04.29	●	–	Ow no PCAL	B20048	20.02.17	●	●	OK
VT9133	19.05.13	○	–	Oe lost 12 h; recorder issues	VO0051	20.02.20	●	●	OK
VT9148	19.05.28	●	○	Ow lost 21 h due to ACU	EV0051	20.02.20	●	●	Not yet correlated
EV9162	19.06.11	●	●	PCAL+CDMS issues	B20055	20.02.24	●	●	OK
VT9162	19.06.11	●	○	Ow lost 16 h due to ACU	VO0062	20.03.02	●	●	OK
VT9175	19.06.24	●	○	Ow missed 8 h due to ACU	EV0062	20.03.02	●	●	Not yet correlated
EV9175	19.06.24	●	●	OK	VO0076	20.03.16	●	●	Not yet correlated
EV9189	19.07.08	●	●	Ow missed 7 scans due to ACU	EV0076	20.03.16	●	●	Not yet correlated
VT9189	19.07.08	●	○	Ow missed 6 h due to ACU	VO0090	20.03.30	●	●	Oe and Ow LNA damage
VT9203	19.07.22	●	●	OK	VO0105	20.04.14	○	○	Oe and Ow LNA damage
EV9203	19.07.22	●	●	OK	VO0147	20.05.26	●	○	Ow LNA damaged
VT9217	19.08.05	●	●	OK	VO0160	20.06.08	○	○	Oe netwk. failure, Ow LNA damage
EV9217	19.08.05	●	●	OK	VO0174	20.06.22	●	●	Not yet correlated
VT9231	19.08.19	●	●	Oe RX+CDMS issues	RD2005	20.06.24	●	●	Too strong PCAL
EV9231	19.08.19			Cancelled	VO0188	20.07.06	●	●	Not yet correlated
VT9248	19.09.05	●	●	OK	RD2006	20.07.08	●	●	Not yet correlated
EV9259	19.09.16	●	●	Ow lost 0.5 h to bias issue	VO0202	20.07.20	●	●	Not yet correlated
VT9259	19.09.16	●	●	OK	VO0219	20.08.06	●	●	OK
VT9273	19.09.30	●	●	OK	VO0231	20.08.18	●	●	Not yet correlated
VT9290	19.10.17	●	●	17 % scans with ≥ 10 % data loss	RD2007	20.08.25	●	●	Not yet correlated
EV9290	19.10.17	○	●	Cancelled; station Ws failed	VO0244	20.08.31	●	●	Not yet correlated
EV9301	19.10.28			Cancelled	EV0244	20.08.31	●	●	Not yet correlated
VT9301	19.10.28	●	●	Oe lost 20 min; DBBC3 problem	EV0258	20.09.14	●	●	Not yet correlated
EV9318	19.11.14	●	●	Network switch failure; lost 0.5 h	VO0258	20.09.14	●	●	Not yet correlated
VT9318	19.11.14	●	●	Missed 9 h due to recorder issues	EV0272	20.09.28	●	●	Not yet correlated
EV9329	19.11.25	●	●	OK	VO0272	20.09.28	●	●	Not yet correlated
VT9329	19.11.25	●	●	OK	VO0287	20.10.13	●	●	OK
VT9343	19.12.09	●	●	OK	EV0287	20.10.13	●	●	Not yet correlated
EV9343	19.12.09	●	●	Not yet correlated	EV0303	20.10.29	●	●	Not yet correlated
B19344	19.12.10	●	●	OK	VO0303	20.10.29	●	●	Not yet correlated
B19351	19.12.17	●	●	OK	VO0314	20.11.09	●	●	Not yet correlated
EV9357	19.12.23	●	●	Not yet correlated	EV0314	20.11.09	●	●	Not yet correlated
B19357	19.12.23	●	●	OK	EV0328	20.11.23	●	●	Not yet correlated
VT9360	19.12.26	●	●	OK	VO0328	20.11.23	●	●	Not yet correlated
B19364	19.12.30	●	●	OK	B20329	20.11.24	●	●	Not yet correlated
					B20336	20.12.01	●	–	Not yet correlated
					V20336	20.12.01	–	●	OK
					VO0345	20.12.10	●	●	Not yet correlated
					EV0345	20.12.10	●	●	Not yet correlated
					B20349	20.12.14	●	●	Not yet correlated
					B20356	20.12.21	●	●	Not yet correlated
					VO0357	20.12.22	●	●	Not yet correlated
					EV0357	20.12.22	●	●	Not yet correlated