The Australian VGOS Observing Program

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Abstract The AuScope VLBI array is entering the VGOS era: the Hobart 12-m and Katherine 12-m stations have already been upgraded with VGOS systems and Yarragadee will follow soon. However, due to some technical differences, the AuScope stations have not routinely joined the IVS VGOS sessions yet. The AUV observing program is a series of VGOS sessions with fortnightly cadence, aiming eventually at achieving mm precision. The scheduling is being continuously enhanced; for example, session duration was adjusted to 12 hours on a single baseline to optimize for results versus total data volume. Additionally, source behavior is a concern, and we have already identified several unsuitable sources due to bad performance in higher frequency bands (10–12 GHz). These sessions have been used to provide feedback about baseline sensitivity across frequency bands, identify RFI, and adjust the channels distribution accordingly. This paper presents the progress of the AuScope VLBI array's transition toward the VGOS era.

Keywords VGOS, Observing, Scheduling, Correlation, Manual phasecal

1 Introduction

The year 2011 saw the establishment of the AuScope Very Long Baseline Interferometry (VLBI) array, operated by the University of Tasmania (UTAS). The AuScope VLBI array consists of three stations: Hobart (Hb), Katherine (Ke), and Yarragadee (Yg). These stations are fast slewing (5°/s in azimuth and 1.25°/s in elevation), and small telescopes (12 m) to serve the next generation of VLBI, known as the VLBI Global Observing System (VGOS) [Petrachenko et al., 2009]. This new observing system is distinguished by a larger number of observations, a wider spanned bandwidth, and a higher data rate. VLBI, with other space-geodetic techniques, is utilized to achieve the Geodetic Global Observing System (GGOS) reference frame which aims for an accuracy of 1 mm and 0.1 mm/y stability [Plag et al., 2009]. The GGOS reference frame became essential to observe and monitor the Earth and its processes properly. Initially the AuScope VLBI array was commissioned with S/X receivers and participated in the International VLBI Service for Geodesy and Astrometry (IVS) [Nothnagel et al., 2017] experiments regularly such as the rapid-turnaround (R1, R4) sessions. Hb and Ke moved to VGOS in 2017 and 2019, respectively; however, they have not routinely observed in VGOS mode. In 2021, the Australian VGOS observing program (AUV) was initiated by carrying out a series of VGOS experiments on the baseline Hb-Ke aiming for mm precision and determine the optimal way of reaching this goal.

2 Scheduling

AUV operates at a frequency range of 3–13.5 GHz. In this range, neither the system equivalent flux density (SEFD) of the stations nor the fluxes of the sources are well known. VieSched++ [Schartner and Böhm, 2019] is used to schedule the AUV sessions. Fortnightly ca-

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Table 1: Summary of the carried out AUV sessions.

Session	Status	Scan length	Comments
auv001	Failed	60 s	Power outage
auv002	Correlated	60 s	
auv003	Correlated	60 s	
auv004	Correlated	60 s	New frequency setup
auv005	Correlated	45 s	phasecal off
auv006	Correlated	45 s	
auv007	Failed	45 s	Ke cryo failure
auv008	Correlated	45 s	
auv009	Observed	30 s	
auv010	Observed	30 s	New frequency setup
auv011	Observed	30 s	New frequency setup
auv012	Observed	20 s	

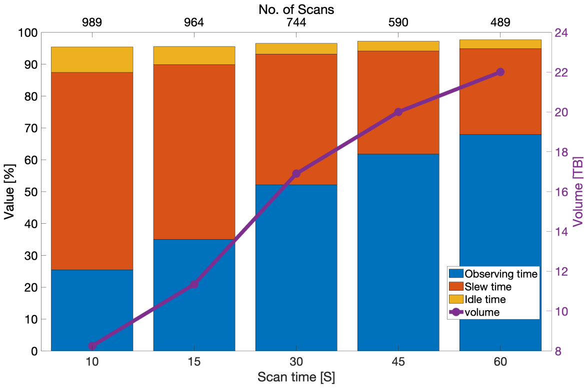

Fig. 1: The relationship between number of scans, slewing time, and the recorded data volume for a 12-h session, with 6-Gbps recording rate, on the baseline Hb-Ke. The left y-axis shows the percentage values of the bar plot. The right y-axis is the data volume in Terabyte (TB) corresponding with the line plot. The upper x-axis presents the number of scans corresponding with scan time in the lower x-axis.

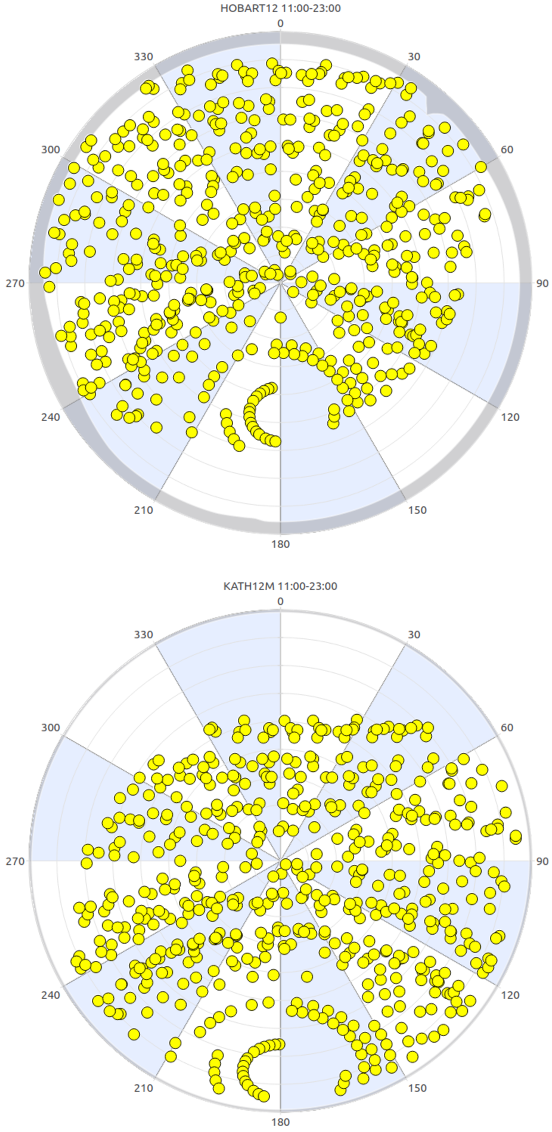

Fig. 2: Sky plot for Hb and Ke during the 12-hour auv008 session. This session has a total of 552 scans and 79 radio sources.

dence, 12 hours duration, 0.8 Jy minimum source flux density, and fixed scan length are the primary scheduling parameters for AUV. The initial scan length was set to 60 seconds and then gradually reduced. Decreasing the scan length is beneficial in two ways: firstly, it increases the number of scans per session, and secondly, the total recorded data volume is reduced. As illustrated in Figure 1, the number of scans increases with decreasing the scan length, as expected. Moreover, the data volume is decreased because the station spends more time slewing between the scans rather than on source time. This is particularly a good point given that data volume is one of the main VGOS limitations. For instance, data recorded in a 24-hour session with 15-s scan length is approximately equal to the recorded data volume in a 12-hour session with 60-s scan length. Figure 2 shows an example of the sky plot for a 12-hour session. This session observed 79 different radio sources with 552 scans and 45-s scan length.

Furthermore, the scheduler is forced to include a calibration scan for a very bright source every two hours with double the scan time of the regular scans. These calibration scans are used later in the correlation and post processing.

3 Observing Mode

Both stations are equipped with a QRFH receiver covering 2.2–14 GHz frequency range. The signal sent via fiber optic to the control room to be bandpass filtered into three bands and input into DBBC3 [Tuccari et al., 2018] for down conversion and sampling. The data recorded using jive5ab[1] onto a Flexbuff machine in VDIF format, with six threads and two-bit sampling.

Each input band to the DBBC3 generates eight channels (using DDC mode with v124 firmware), see Figure 3. DBBC3 at Hb has four bands (32 channels) with 32-MHz bandwidth, whereas DBBC3 at Ke has only three bands (24 channels) with 32-MHz bandwidth as well. For now, the AUV observing mode is using three bands (24 channels), 32-MHz bandwidth, linear dual polarization (X and Y), and 2-bit sampling, which leads to a 6 Gbps recording rate. These bands have a simultaneous 4-GHz input bandwidth with frequency ranges 3–7 GHz, 6–10 GHz, and 9.5–13.5 GHz. The baseband channels can be selected freely within the band.

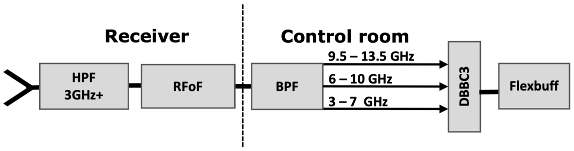

Fig. 3: AUV signal chain.

Exploiting the flexibility of the DBBC3, the frequency setup has changed several times to avoid Radio Frequency Interference (RFI) and to optimize the lag delay function by minimizing the side lobes and the width of the main lobe. Figure 4 presents a comparison between the IVS-VO frequency setup (32 channels) and the latest frequency setup used in AUV (24 channels). The IVS-VO mode has a very high side lobe (90% of the main lobe) where the AUV setup has a very low side lobe (59% of the main lobe) and narrower main lobe (10% narrower). The differential ionospheric (dTEC) estimation function shows a similar improvement with respect to sidelobe performance.

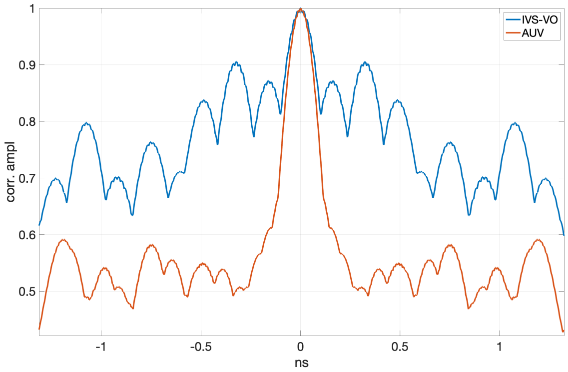

Fig. 4: Comparison between IVS-VO frequency setup and AUV in terms of the lag resolution function. The blue line using the IVS-VO frequency setup (32 channels) and the orange line using the AUV frequency setup (24 channels).

4 Correlation and Fringe-fitting

The data are shipped from Ke to Hb to be correlated at UTAS using DiFX [Deller et al., 2011]. Fringe-fitting is done using HOPS fourfit [MIT/Haystack, 2020] with manual phasecal using a high signal-to-noise ratio (SNR) calibrator scan as mentioned earlier. Manual phasecal (`pc_mode manual`) is used because the phase cal tones were too strong at low frequencies prior to a modification of the phase cal circuit and lead to saturation effects. This affects the sensitivity at lower channels. The phasecal tone generator was fixed at Hb only after auv005, allowing Hb to participate in IVS-VO sessions. However, it has not been fixed at Ke yet.

5 Results

At this stage, the main result we concern about is the baseline sensitivity. Since system temperature (T_{sys})

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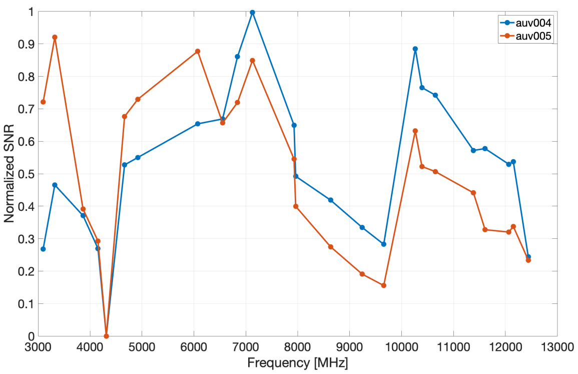
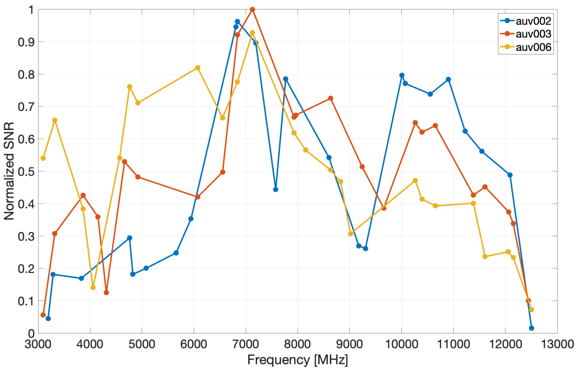
[1] `https://github.com/jive-vlbi/`

measurements were not available at the time because the noise calibration unit is not working properly at either station, only the baseline sensitivity is considered. Figure 5 illustrates a comparison between different sessions using the relative baseline sensitivity, which was produced by normalizing and averaging the SNRs of all scans per session.



(a) Relative baseline sensitivity for auv004 (phasecal on) and auv005 (phasecal off).



(b) Relative baseline sensitivity for auv002, auv003, and auv006. Each session has different frequency setups to avoid RFIs.

Fig. 5: Relative baseline sensitivity for several AUV sessions with different frequency setups.

For instance, Figure 5a depicts the relative baseline sensitivity of two sessions with the same frequency setup (auv004 and auv005), where the phasecal generator was either on or off. The relative baseline sensitivity is higher at the lower channels in auv005 compared with auv004 after switching off the phasecal unit, even with auv005's shorter scan time, which should theoretically yield a higher SNR.

Moreover, the baselines relative sensitivity is used to avoid the RFIs as in Figure 5b, which presents three different sessions with different frequency setups, each one encountered a different RFI. RFI is detected at 7.6 GHz, 4.3 GHz, and 4.1 GHz in auv002, auv003, and auv006, respectively.

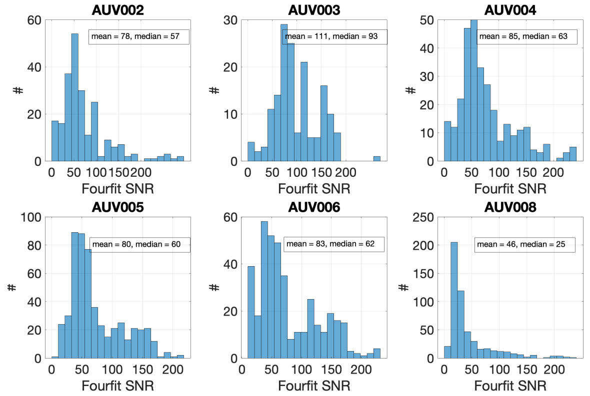


Fig. 6: Histogram of the fourfit SNR for all correlated sessions. The mean and median SNR for each session is shown as well. Values above 200 are excluded for clarity.

Figure 6 presents the distribution of the scans' SNR per session. Even with reducing the scan time from 60 s to 45 s as seen in auv006, the SNR is still high and allows to reduce the scan time even more except for auv008, which appears to have a sensitivity issue during the session.

6 Conclusions and Outlook

AUV is a series of experimental sessions to establish a VGOS observing routine within the AuScope VLBI array and improve stations sensitivity. Currently, AUV is carried out with a biweekly cadence on the baseline Hb-Ke. AUV is planned, scheduled, correlated, fringe-fitted, and analyzed at UTAS. Fixed scan time scheduling is used. After an initial 60 s scan duration, this has been gradually decreased down to 20 s in the latest session. Moreover, different frequency setups have been used to optimize the delay resolution function and avoid RFIs.

Additionally, the noise and phasecal units were repaired at Hb. The noise calibration unit enables T_{sys} measurement to get the SEFD as well as the sources flux density at the observing frequencies (3–13.5 GHz). These two values are fundamental for SNR based scheduling, which is one of the AUV goals. Finally, geodetic analysis for the AUV sessions is on the agenda and the main precision metric is the baseline length repeatability.

References

[Deller et al., 2011] Deller, A., Brisken, W., Phillips, C., Morgan, J., Alef, W., Cappallo, R., Middelberg, E., Romney, J., Rottmann, H., Tingay, S., et al. (2011). Difx-2: a more flexible, efficient, robust, and powerful software correlator. *Publications of the Astronomical Society of the Pacific*, 123(901):275.

[MIT/Haystack, 2020] MIT/Haystack (2020). Haystack observatory postprocessing system (hops). `https://www.haystack.mit.edu/haystack-observatory-postprocessing-system-hops/`. Accessed: 2022-06-30.

[Nothnagel et al., 2017] Nothnagel, A., Artz, T., Behrend, D., and Malkin, Z. (2017). International vlbi service for geodesy and astrometry. *Journal of Geodesy*, 91(7):711–721.

[Petrachenko et al., 2009] Petrachenko, B., Niell, A., Behrend, D., Corey, B., Boehm, J., Charlot, P., Collioud, A., Gipson, J., Haas, R., Hobiger, T., Koyama, Y., Macmillan, D., Malkin, Z., Nilsson, T., Pany, A., Tuccari, G., Whitney, A., and Wresnik, J. (2009). Design aspects of the vlbi2010 system. page pp 56.

[Plag et al., 2009] Plag, H.-P., Rothacher, M., Pearlman, M., Neilan, R., and Ma, C. (2009). The global geodetic observing system. In *Advances in Geosciences: Volume 13: Solid Earth (SE)*, pages 105–127. World Scientific.

[Schartner and Böhm, 2019] Schartner, M. and Böhm, J. (2019). Viesched++: a new vlbi scheduling software for geodesy and astrometry. *Publications of the Astronomical Society of the Pacific*, 131(1002):084501.

[Tuccari et al., 2018] Tuccari, G., Alef, W., Dornbusch, S., Wunderlich, M., Roy, A., Wagner, J., Haas, R., and Johansson, K. (2018). Dbbc3 the new wide-band backend for vlbi. In *Proceedings of the 14th European VLBI Network Symposium & Users Meeting (EVN 2018)*, pages 8–11.