Earth orientation parameters estimated from recent Australian mixed-mode and Southern Intensive sessions

S. Böhm, L. McCallum

Abstract The sensitivity of Very Long Baseline Interferometry (VLBI) measurements toward single Earth orientation parameters (EOP) and the resulting accuracy strongly depends on the network extension. We can expect high-quality estimates from sessions with a well-distributed observation network designed for EOP determination, such as the R1 and R4 sessions. The 24-h sessions observed within the Australian mixed-mode program (AUA/AUM) do not provide a globally extended network of stations. Still, they involve the future potential to deliver results with a short latency. Under this aspect, we investigate the possibilities to determine different sets of or single EOP from the AUA and AUM sessions observed since 2020. By fixing source and station positions and estimating the EOP as one offset each, we can derive all EOP from most of the examined AUA/AUM sessions with acceptable quality. A subset of the telescopes have been or are involved in observing the so-called Southern Intensive sessions since 2020. In addition to the results of the 24-h sessions, we present the UT1−UTC estimates derived from the latest Southern Intensives, now designated IVS-INT-S (IVS: International VLBI Service for Geodesy and Astrometry). Our assessment shows an accuracy of the IVS-INT-S comparable to that of other IVS Intensive sessions.

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1 Introduction

We can determine all five Earth orientation parameters (EOP) within the adjustment process of geodetic very long baseline interferometry (VLBI) data, provided that there is a sufficient number and spatial and temporal distribution of observations. These parameters are the celestial pole offsets (CPO), the polar motion parameters, and the difference of universal time 1 to coordinated universal time, from now on referred to as dX, dY, xPol, yPol, and UT1−UTC.

In this study, we challenge the Australian mixed-mode sessions AUA/AUM (McCallum et al., 2022) regarding EOP determination. Due to their limited network extension, these sessions are not optimal for deriving EOP. Hence, we test different strategies imposing variable constraints.

Furthermore, we explore the UT1−UTC quality of the recent Southern Intensive sessions IVS-INT-S (Böhm et al., 2022).

2 Data and analysis

The considered periods are 2020–2023 for the AUA/AUM sessions and 2022–2023 for the IVS-INT-S. For both session types, the parameter estimation is carried out with the VLBI module of the Vienna VLBI and Satellite Software VieVS (Böhm et al., 2018).

2.1 Australian mixed-mode sessions

To evaluate the AUA/AUM EOP performance, we selected 84 AUA/AUM sessions from January 2020 to March 2023 and 91 R1 and R4 sessions close to the AUA/AUM sessions. The stations participating in the sessions in different constellations are shown in Fig. 1. Since the R1/R4 sessions are specially designed for EOP determination, we regard the derived EOP results as the standard and investigate different processing strategies for the AUA/AUM to get EOP of comparable quality. For the R1/R4 sessions, we use our standard parameterization for EOP determination. We fix sources given in the International Celestial Reference Frame, ICRF3 (Charlot et al., 2020) and estimate non-ICRF sources. The coordinates of the stations are calculated, imposing no-net-rotation and no-net-translation conditions on the positions of the ITRF2020 catalog (International Terrestrial Reference Frame 2020, Altamimi et al., 2023). The parameters xPol, yPol, and UT1−UTC are estimated as piece-wise linear offsets at mid-nights, while dX and dY are estimated as offsets, referring to the middle of the sessions. Because of the spatial limitations of the AUA/AUM session networks, we did not apply the standard approach but fixed ICRF3 and ITRF2020 source and site positions. For EOP, we test three scenarios: estimation of all five parameters as offsets (*EOP*), fixing of CPO and estimation of polar motion and UT1−UTC as offsets (*ERP*: Earth rotation parameters), and an intensive-like setting with only UT1−UTC estimated (*UT1*).

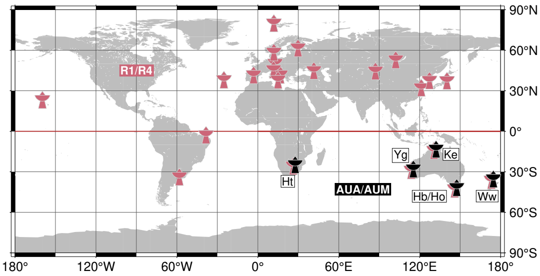

Fig. 1 Possible network stations of the AUA/AUM (black) and R1/R4 (red) sessions from 2020–2023.

2.2 Southern Intensive sessions

The IVS-INT-S are a series of Intensive sessions observed on baselines in the southern hemisphere. The results of the sessions from the years 2020 and 2021 are discussed in detail in Böhm et al. (2022). Here, we present the UT1−UTC results of 50 IVS-INT-S from January 2022 to April 2023 compared to 50 IVS-INT-1/3/00 observed close to the INT-S epochs. Fig. 2 shows the networks of the different types of Intensive sessions analyzed here. As for the AUA/AUM sessions, the coordinates of stations and sources are fixed to the ITRF2020 and ICRF3 positions.

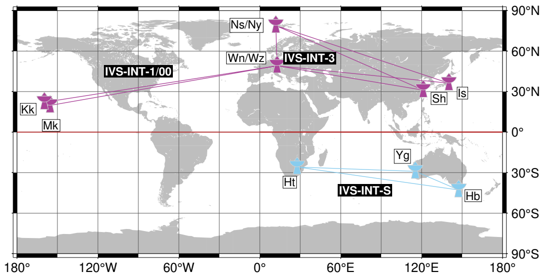

Fig. 2 Stations and baselines of the INT-S (light blue) and INT-1, INT-3, and INT-00 (purple) sessions from 2022–2023.

3 Results

The different analysis strategies applied for the AUA/AUM sessions are compared among each other and with the EOP results of the R1/R4 sessions using so-called boxplots. The statistical measures provided with a boxplot are illustrated in Fig. 3. All EOP results

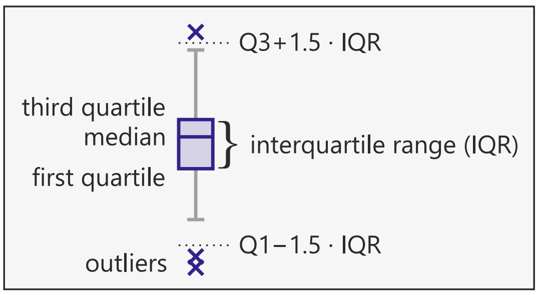

Fig. 3 Illustration of the boxplot concept.

are plotted as differences to the reference EOP time series JPL EOP2 (Chin et al., 2009). Sessions with differences to the reference EOP or formal errors larger than one milliarcsecond are excluded from the comparison and regarded as unsuitable for EOP determination. In the case of the R1/R4, this criterion does not apply to any session. When estimating all EOP or only ERP from the AUA/AUM sessions, 23 sessions are excluded from the comparison. Many deselected sessions are observed without the Ht telescope and, therefore, lack long baselines. If we do an Intensive-like analysis and estimate only UT1−UTC, only one session has to be dropped.

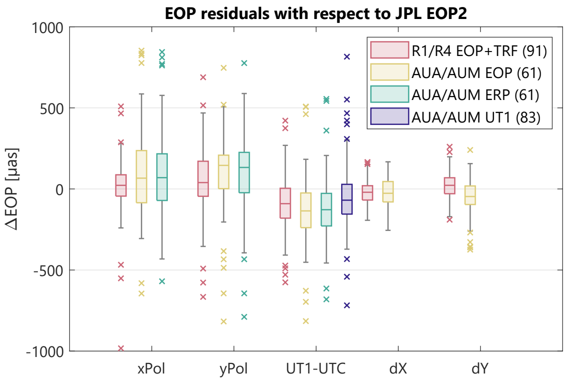

Fig. 4 Boxplots of EOP results (differences to JPL EOP2) from the 24-h sessions in µas. The number of sessions included in the comparison is given in parentheses.

The results of the examined 24-h sessions are displayed in Fig. 4. With the additional constraints added to the standard EOP estimation, the results produced by the different processing scenarios (*EOP*, *ERP*, and *UT1*) can keep up with those of the R1/R4 sessions. However, especially in the case of the xPol-component, the spread of the differences to JPL EOP2 is significantly larger. The reason is probably the poor north-south extension of the AUA/AUM session networks. Interestingly, we do not see much difference between the *EOP* and *ERP* scenarios. Not estimating CPO does not improve the quality of the other EOP results (xPol, yPol, and UT1−UTC), nor does it lead to the inclusion of more sessions. By applying the Intensive-like strategy (UT1), we can keep all but one session in the comparison. The quality of the UT1−UTC estimates is similar to that of the R1/R4 sessions. Yet, with this strategy, we can derive UT1−UTC only. So, it might be more beneficial to use the *EOP* strategy for the 61 sessions where it works and apply the *UT1* approach merely to the 22 sessions where the *EOP* strategy fails.

In Fig. 5, the UT1−UTC results of the different 24-h sessions and processings are shown together with the results of the Intensives IVS-INT-S and IVS-INT-1/3/00, again as differences to the JPL EOP2. The values are presented in µas like in Fig. 4 for better comparability with polar motion and celestial pole offsets. The *UT1*

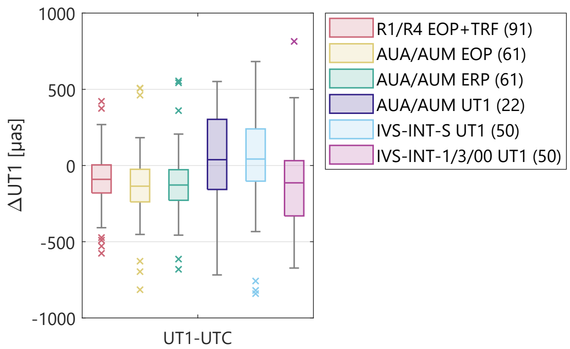

Fig. 5 Boxplots of UT1−UTC results (differences to JPL EOP2) from the 24-h and Intensive sessions in µas. The number of sessions included in the comparison is given in parentheses.

approach is only used for the 22 sessions where the geometry is insufficient for estimating all EOP. Compared with the performance of the southern Intensives and the other IVS Intensives shown here, the Intensive-like analysis yields results with Intensive-like accuracy, which is still better than not using these 22 sessions at all.

The differences to JPL EOP2 for the INT-S and the INT-1/3/00 are presented as individual values and in a histogram in Fig. 6.

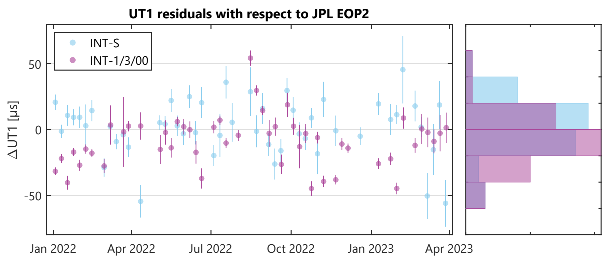

Fig. 6 UT1−UTC results (differences to JPL EOP2) from the IVS-INT-S (light blue) and IVS-INT-1/3/00 (purple) sessions with errorbars in µs.

As can also be read from Tab. 1, the UT1 residuals w.r.t. JPL EOP2 are mainly in the range of about ± 20 µs and rarely over 50 µs absolutely, for all Intensive types. We see a significant negative bias for the IVS-INT-1/3/00 sessions that could be due to the choice of the reference EOP series. The INT-S have a slightly lower weighted standard deviation w.r.t. JPL EOP2 but slightly larger formal errors than the other investigated Intensives during the study period.

Table 1 Statistics of UT1−UTC estimates from Intensive sessions with respect to JPL EOP2.

Statistical quantity [µs]	**INT-S**	**INT-1/3/00**
Weighted standard deviation	16	20
Weighted mean	2	−12
Interquartile range	23	24
Mean formal error	11	7
Median formal error	9	6

4 Conclusions and outlook

Although the AUA/AUM sessions are not designed for deriving EOP, they can be employed for that if certain constraints are imposed. Out of 84 AUA/AUM sessions from 2020–2023, 61 can be used to estimate all five EOP with acceptable accuracy if source and station positions are fixed to a priori values. The deviations w.r.t. a reference time series are slightly higher than those obtained from R1/R4 sessions, especially in the case of polar motion, xPol. We did not find a significant influence on polar motion or UT1−UTC if CPO are estimated or fixed. Sessions that fail when determining all EOP can be analyzed in an Intensive-like mode to retrieve at least UT1−UTC, with the drawback of a reduced accuracy.

The IVS-INT-S sessions from 2022 to April 2023, also assessed in this study, deliver stable UT1−UTC results, able to compete with the results of IVS-INT-1/3/00 Intensives from the same period. The Southern Intensives are operated every Monday at 6:30 UTC on the baseline Ht-Hb (South Africa - Tasmania), as a permanent component of the IVS observing program.

References

McCallum L, Chuan L, Krásná H, McCallum J, Böhm J, McCarthy T, Gruber J, Schartner M, Quick J, Rogers A (2022) The Australian mixed-mode observing program. *J Geod*, 96(67), doi: 10.1007/s00190-022-01657-2.

Böhm S, Böhm J, Gruber J, Kern L, McCallum J, McCallum L, McCarthy T, Quick J, Schartner M (2022) Probing a southern hemisphere VLBI intensive baseline configuration for UT1 determination. *Earth Planets Space*, 74(118), doi: 10.1186/s40623-022-01671-w.

Böhm J, Böhm S, Boisits J, Girdiuk A, Gruber J, Hellerschmied A, Krásná H, Landskron D, Madzak M, Mayer D, McCallum J, McCallum L, Schartner M, Teke K (2018) Vienna VLBI and Satellite Software (VieVS) for Geodesy and Astrometry. *Publ Astron Soc Pac*, 130(986), doi: 10.1088/1538-3873/aaa22b.

Charlot P, Jacobs C S, Gordon D, Lambert S, de Witt A, Böhm J, Fey A L, Heinkelmann R, Skurikhina E, Titov O, Arias E F, Bolotin S, Bourda G, Ma C, Malkin Z, Nothnagel A, Mayer D, MacMillan D S, Nilsson T, Gaume R (2020) The third realization of the International Celestial Reference Frame by very long baseline interferometry. *Astron Astrophys*, 644(A159), doi: 10.1051/0004-6361/202038368.

Altamimi Z, Rebischung P, Collilieux X, Métivier L, Chanard K (2023) ITRF2020: an augmented reference frame refining the modeling of nonlinear station motions. *J Geod*, 97(47), doi: 10.1007/s00190-023-01738-w.

Chin T M, Gross R S, Boggs D H, Ratcliff J T (2009) Dynamical and Observation Models in the Kalman Earth Orientation Filter. *The Interplanetary Network Progress Report*, 42-176.