The Influence of Phase Calibration at the Station Hobart12 on the ICRF

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Abstract Sources in ICRF3 prototype solutions show a systematic shift in declination when compared to the ICRF2. One explanation for this effect is tropospheric mismodeling in the ICRF2. Another possible reason for this bias is a station dependent error from the Australian stations in the ICRF3. We found that the phase calibration system at the station Hobart12 introduces a spurious signal which propagates into source declination. The phase calibration system at Hobart12 was used during 440 sessions and was not used during 140 sessions of the ICRF3 data set (5830 session as of December 2016). When we remove the sessions where phase calibration was used we find that the declination bias vanishes. This indicates that the declination bias is due to a station dependent effect at Hobart12 and not due to tropospheric mismodeling in the ICRF2.

Keywords Phase calibration, ICRF3, Declination bias

1 Introduction

An important product of the geodetic and astrometric VLBI technique is the international celestial reference frame (ICRF). It is defined by the International Celestial Reference System (ICRS) with its current realisation being the ICRF2 (Ma et al., 2009; Fey et al., 2015). The ICRF2 incorporates geodetic VLBI data from 1979 until March 2009. It is defined by 295 defining sources.

The recently launched Gaia satellite mission will produce an optical celestial reference frame with comparable accuracy (Mignard et al., 2016; Petrov and Kovalev, 2016) in the near future (2018). This and the increased amount of data motivated the VLBI community to produce a new realisation of the ICRS which will be released in August 2018 at the 30th General Assembly of the International Astronomical Union in Vienna, Austria. It will be called ICRF3.

In geodetic VLBI the phase shifts induced by the instrumentation have to be corrected. This is done using a technique called phase calibration. A signal of known phase (set of tones) is injected into the front end of the instrumentation and later used for calibration (further information can be found in Sovers et al. (1998) and the references therein). This technique can also account for additional delays due to cable stretching and twisting. However, the uplink cable can cause additional uncompensated phase variation. Usually this is corrected with a cable calibration system which measures the length of this cable. Not all stations are equipped with such a system. The Australian stations do not have a cable calibration system.

There is another option which is used when the phase calibration fails or is not available. It is called manual phase calibration. During the fringe fitting stage, the individual phase offsets per band are manually set using a strong source as calibrator. In this case, the measured phase calibration signal is not used. Hence the phase calibration signal is not used.

2 Motivation

When comparing ICRF3 prototype solutions with the ICRF2, a clear bias in declination of the determined source positions (Figure 1) becomes evident. From here on we will simply refer to this bias as the declination bias. Different groups found that the addition of data from the Australian stations (Hobart12, Kath12M and Yarra12M) is causing this declination bias. However, the actual cause of the declination bias is yet unknown. One possible reason is that the new data from the southern stations correct a bias intrinsic to the ICRF2 (data

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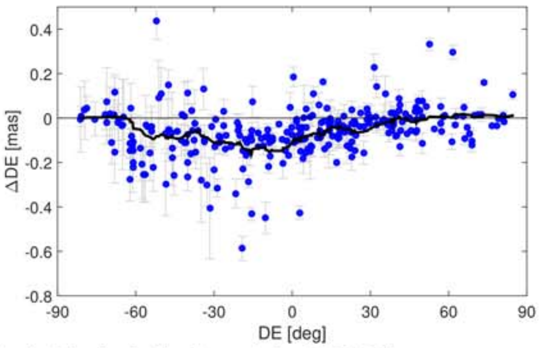

Fig. 1: Bias in declinations of the 295 defining sources as seen between the ICRF3 prototype solution by TU Wien and our own ICRF2 solution. Depicted are the defining sources and a moving average filter.

is mostly from northern stations). The southern sources were mainly observed under low elevation by northern stations. This magnifies tropospheric modeling errors and, because the troposphere has a known north-south gradient, could result in a bias in declination. If this is the case the southern stations helped to reveal this systematic effect and the new solution reflects the truth better. A second possible scenario is that the southern stations experience a systematic error and this distorts the ICRF. This is more critical because it means that the new solution has systematic errors.

In order to investigate this, we had a closer look at session AUG030, on Oct 07, 2016. We processed AUG030 once with the correction from the phase calibration and once with the manual phase calibration correction. Comparing the two solutions, we find a large difference in the group delays of up to 100–150 ps or 3–5 cm (Fig. 2). The differences seems to be mainly azimuth dependent with peaks at each end of the cable wrap. This is an indicator that a systematic error (possible cable twisting of the phase calibration uplink cable) might be introduced into the VLBI data.

The influence of such a systematic error on the CRF is discussed in the following sections.

3 Methodology

3.1 Data set

We used data from 1979 to 2016 (5830 sessions) to create ICRF solutions. In this data set we found ~ 140 sessions where the manual phase calibration correction was used (the phase calibration unit was either broken or not used) and ~ 440 sessions where the normal phase calibration correction was used at Hobart12.

3.2 Solutions

In total we created three test solutions (5250 sessions without Hobart12 plus different subsets of the sessions with Hobart12):

1. A first solution where the sessions with normal phase calibration at Hobart12 were used (5690 sessions in total).
2. A second solution where the sessions with manual phase calibration at Hobart12 were used (5390 sessions in total).
3. And a third solution where we reduced the number of sessions from the first solution to match the number of Hobart12 sessions of the second solution (5390 sessions in total).

We would expect the declination bias to become smaller when removing sessions (440 vs 140 sessions). The third solution was generated to mitigate this effect. In order to make this comparison as fair as possible we tried to keep the ratio of R1/R4 and Austral sessions similar in both data sets. Hence, the third solution incorporates ~ 60 R1/R4 sessions, ~ 60 Austral sessions and ~ 20 other sessions where the normal phase calibration correction was used.

4 Results and Discussion

The first solution, depicted in Figure 3, has a clear systematic bias in declination w.r.t. ICRF2 which is very similar to the declination bias seen when using the full set of 5830 sessions.

When looking at the difference plot between the first solution and the ICRF3 prototype solution with all data we do not see any systematic bias in declination, see Figure 4. This demonstrates that the removal of the 140 sessions where the manual phase calibration was used does not affect the declination bias.

However, looking at the difference in source declination of the second solution (using only sessions where the manual phase calibration correction was used at Hobart) w.r.t. the ICRF2 no bias is visible (Fig. 5). This suggests that removing the 440 sessions where normal phase calibration was used also removes the declination bias.

It is conceivable that 140 sessions are not enough to distinguish the declination bias from noise which is why test solution three was created, using a subset of 140 sessions from solution 1. As shown in Figure 6, the systematic is smaller when compared to Figure 3 (as expected, since we use less sessions) but still noticeable.

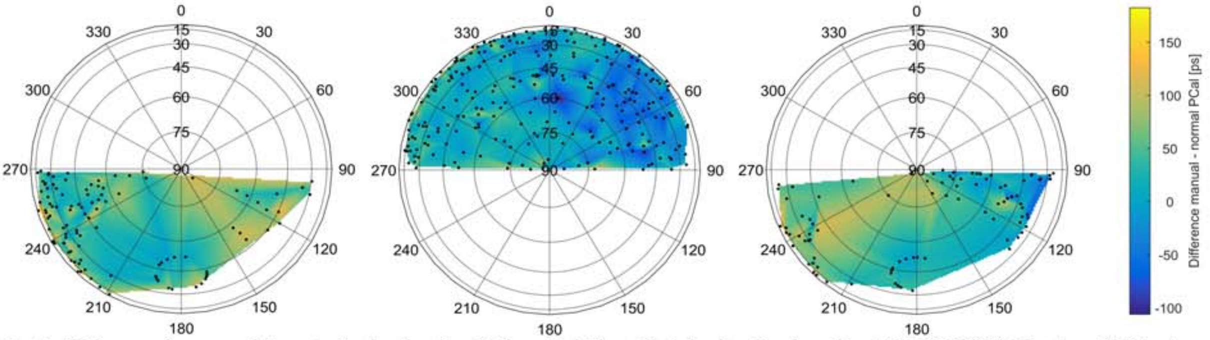

Fig. 2: Difference in group delays (only the baseline Hobart12-Hobart26 is depicted) of session AUS-GEO030 (October 2016) when analysed with the normal phase calibration and the manual phase calibration correction. The skyplot is split into three parts to resemble the different cable wraps counterclockwise, neutral and clockwise (from left to right).

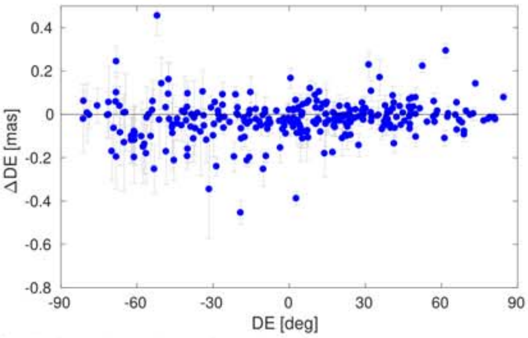

Fig. 5: Solution with 140 sessions where the manual phase calibration at Hobart12 was used. Depicted are the defining sources. The reference is our own ICRF2 solution.

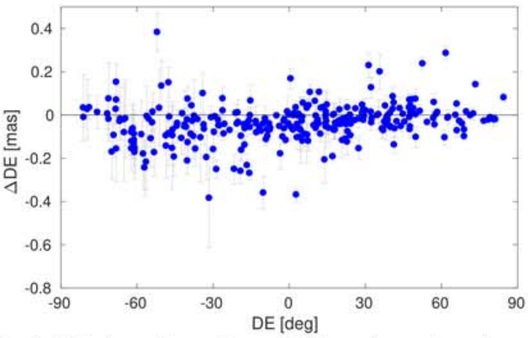

Fig. 6: Solution with a subset of 140 sessions where the normal phase calibration at Hobart12 was used. Depicted are the defining sources. The reference is our own ICRF2 solution.

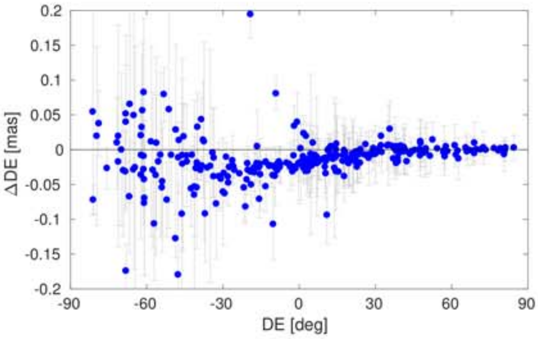

Fig. 7: Difference between solution two (140 manual phase calibration sessions) and solution three (140 normal phase calibration sessions). Depicted are the defining sources.

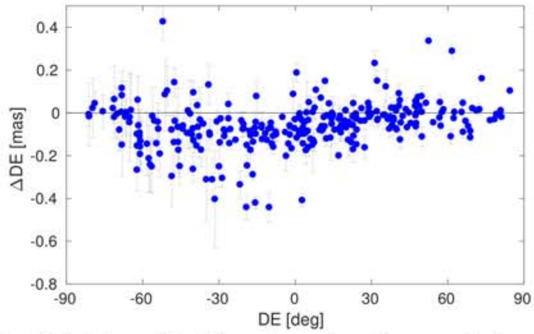

Fig. 3: Solution with 440 sessions where the normal phase calibration at Hobart12 was used. Depicted are the defining sources. The reference is our own ICRF2 solution.

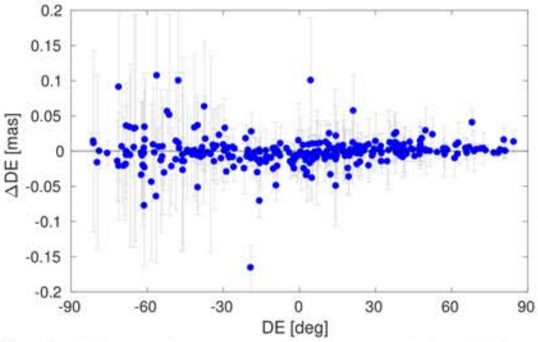

Fig. 4: Difference between our first test solution (440 normal phase calibration sessions) and the ICRF3 prototype solution (all 5830 sessions are used). Depicted are the defining sources.

This demonstrates that 140 sessions are enough to separate the declination bias from noise.

In order to see this effect even clearer we provide the difference plot of both (second and third) solutions, see Figure 7. A bias in declination which looks very similar to the declination bias is evident. This is further evidence that the declination bias is introduced by the normal phase calibration correction.

5 Conclusion

We found a clear (several centimeters) systematic difference in group delays at the station Hobart12 when we use the normal phase calibration versus manual phase calibration.

While a difference per se does not reveal any information about which solution is better, investigations of McCallum et al. (2017) (this edition) indicate that the measured phase calibration signal introduces additional systematic effects into the measurements, rather than correcting for them. This conclusion is supported with the findings of this contribution, looking at effects on the CRF.

When we remove all the sessions where normal phase calibration was used at Hobart12 (sessions where manual phase calibration is used are kept) from the ICRF3 data set, then the declination bias vanishes. We believe that this systematic error propagates into the source declination and causes a major part of the declination bias.

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