Automated analysis of Kokee–Wettzell intensive sessions

N. Kareinen, T. Hobiger, R. Haas

Abstract We present results from an automated analysis of IVS intensive sessions, carried out between 2001–2015 on the Kokee-Wettzell baseline. The analysis is based on the version 1 X- and S-band databases in Mark3 format, which means that ambiguity resolution and ionosphere correction need to be done within the automated analysis chain. We use the c5++ VLBI analysis software and process all available databases using several different analysis configurations and investigate the impact of a priori information on the obtained UT1-UTC estimates. We also assess whether external information, i.e. cable delay and weather data extracted from the station log files, is required in order to obtain highly accurate UT1-UTC products. This allows us to conclude whether the availability of external information is crucial for real-time analysis of intensive sessions, or if empirical models can be applied without a significant degradation of the target parameters.

Keywords VLBI, automated analysis, intensive sessions, Earth rotation, UT1

1 Introduction

The International VLBI Service for Geodesy and Astrometry (IVS) (Schuh and Behrend, 2012) conducts daily 1-hour Intensive sessions. These sessions are a crucial part for providing daily estimates of UT1, which are important for applications related to Earth- and space-based navigation. There are three types of Intensive sessions (hereafter called INT), which can be distinguished by the day of the week and the observing network. INT1 are observed from Monday to Friday 1730 UTC on the Kokee–Wettzell baseline, INT2 are on Saturdays and Sundays 0730 UTC on Wettzell–Tsukuba, and INT3 are carried out on Mondays 0700 with Wettzell, Tsukuba, and Ny-Ålesund. In our work we focus on a total of 1669 INT1 experiments on the Kokee–Wettzell baseline between 2001 and January of 2015. These sessions were processed with the c5++ VLBI analysis software (Hobiger et al., 2010) starting from version 1 databases for X- and S-band. Version 1 databases contain only the observed group delays and their formal errors. The databases were converted to National Geodetic Survey (NGS) cards (Gordon, 2007) to start the processing with c5++, which was first used to do ambiguity resolution and ionosphere calibration in automatic mode with GMF2 mapping function and pressure data from GPT2 (Lagler et al., 2013). The analysis process is shown schematically in Fig. 1. In c5++ the ambiguity resolution and ionosphere calibration is an iterative process, which yields ambiguity free databases. These ambiguity resolved and ionosphere corrected databases were then processed to derive UT1-UTC. Using different analysis setups, we address the following questions:

1. Do we need the local weather information from the station log files?
2. What is the impact of using different mapping functions?
3. What is the effect of the cable delay data?
4. How accurately do we need to know the a priori polar motion?
5. Can we simultaneously estimate UT1-UTC and the position of one of the stations?

We used several criteria to select the databases that were included in the analysis. Firstly, only the databases that had version 1 available on the IVS Data Centre file server[1] were downloaded for the analysis. From these databases we only included sessions where Kokee–Wettzell was the only available baseline and discarded sessions which had an additional observing station (e.g. Svetloe). We also required that station log files were available for both stations.

2 Analysis strategy

To address the questions posed in Section 1 we processed the sessions following the procedure depicted in Fig. 1 using different analysis strategies with different combinations of mapping functions and choice of applying/not applying station log files. The

Niko Kareinen, Thomas Hobiger, Rüdiger Haas
Department of Earth and Space Sciences, Chalmers University of Technology, Onsala Space Observatory SE-439 92 Onsala, Sweden

[1] ftp://cddis.gsfc.nasa.gov/pub/vlbi/ivsdata/db/

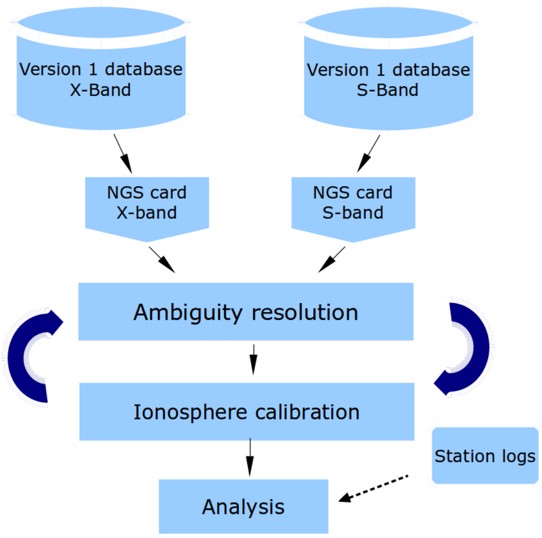

Fig. 1 Flowchart of the automated data analysis with c5++.

strategies, labelled as A, B, C, and D are shown in Table 1. The latest IERS 2010 conventions (Petit and Luzum, 2010) were used in the analysis. The parametrisation options and a priori information used with all strategies are listed in Table 2. C04 refers to the IERS EOP 08 C04 time series (Bizouard and Gambis, 2011). We processed the data with two mapping functions, VMF1 (Boehm et al., 2006) and GMF(GPT2).

Table 1 Overview of the four analysis strategies used.

Strategy	Mapping function	Cable delay data	Pressure data
A	VMF1	Not applied	GPT2
B	GMF(GPT2)	Not applied	GPT2
C	VMF1	Station log files	Station log files
D	GMF(GPT2)	Station log files	Station log files

In all tested analysis runs sessions which resulted in UT1-UTC residuals w.r.t. C04 over 1000 μs (in absolute value) or 50 μs for the formal errors were eliminated as crude outliers. Additionally, a number of sessions were excluded because the UT1-UTC could not be estimated due to insufficient number of good observations w.r.t. number of unknowns.

3 Results

The following subsections discuss the processing results from the different analysis strategies (A-D).

Table 2 Parametrisation and a priori values used in the analysis.

Parameter	Kokee	Wettzell
Station clock	Est. 2nd order polynomial	Reference
Station position	Fix to ITRF2008	Fix to ITRF2008
ZHD	Fix	Fix
ZWD	Solve 1 offset	Solve 1 offset
Source positions	Fix to ICRF2	
UT1-UTC	Est. 1 offset w.r.t. C04	
Polar motion	Fix to C04	
Nutation/Precession	Fix to C04	

3.1 Impact of mapping functions and log files

The results show that the choice of mapping function and the use of log files give differences smaller than 1 μs. Table 3 summarizes statistical information for each solution type. Questions **1** and **2** are addressed in Figures 2 and 3, respectively. In order to make the comparison straightforward, only the sessions appearing in all of the four strategies after the outlier elimination are included in these two figures.

Table 3 Statistical information on individual analysis strategies: rejected sessions (out of 1669), WRMS and weighted bias w.r.t. C04.

Strategy	Rejected sessions	WRMS [μs]	Weighted bias [μs]
A	311	17.63	2.65
B	311	17.64	2.65
C	263	18.03	2.65
D	263	18.04	2.67

The results in Table 3 show that the Weighted Root Mean Square (WRMS) is slightly improved by using the data from the station log files. However, the use of log files also reduces the number of sessions that pass the session-wise outlier rejection criteria (absolute values of estimates <1000 μ, formal errors <50 μs). There is practically no difference in the weighted biases between the processing strategies. Based on the small differences between the processing strategies GMF(GPT2) was chosen for all further investigations.

3.2 Impact of cable delay data

We can investigate the impact of cable delay on the UT1-UTC estimate w.r.t. C04 by differencing the two time series which use the same mapping function, but different station log file setup. As an example, the top graph in Figure 4 depicts the difference of the data in Figures 2B and 3D, respectively.

Shown in the bottom graph are the same data plotted against the de-trended RMS of cable delays for Kokee (left) and Wettzell

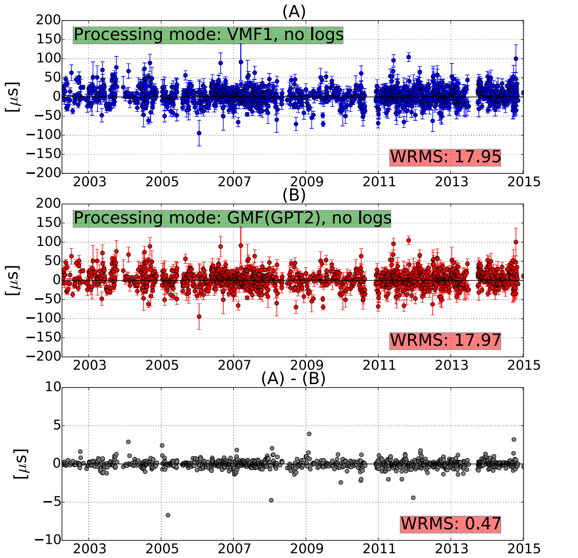

Fig. 2 Processing without log files: UT1-UTC residuals w.r.t. C04 processed with (A) VMF1 and (B) GMF(GPT2). The bottom row presents the difference of time series (A) and (B).

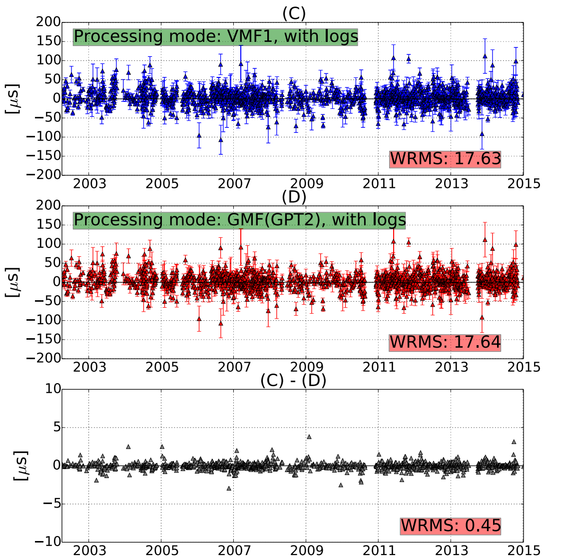

Fig. 3 Processing with log files: UT1-UTC residuals w.r.t. C04 processed with (C) VMF1 and (D) GMF(GPT2). The bottom row presents the difference of time series (C) and (D).

(right). A jump exceeding 5 μs is seen in the difference of the residuals in late 2013 to early 2014. From these station-wise plots we can see, that the jump points are correlated with high RMS values for the cable delay data at Wettzell.

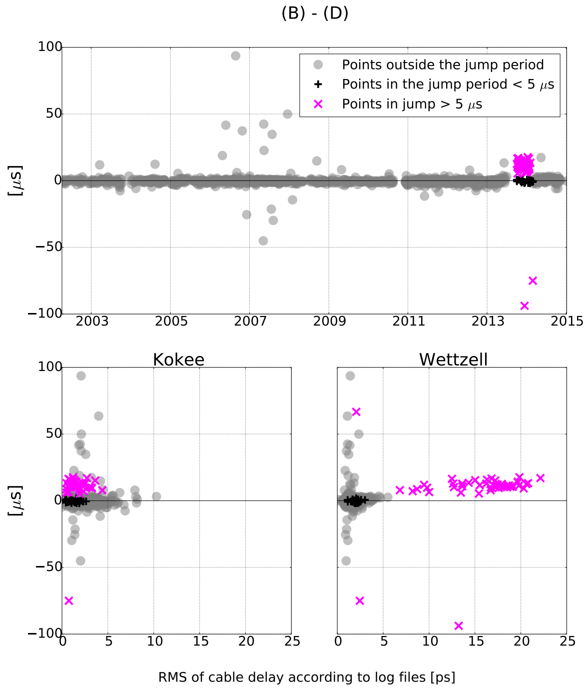

Fig. 4 Top: differences between results presented in Figures 2B and 3D. fig. A systematic behaviour is seen in the end of 2013. Bottom: scatter plots of the differences vs. RMS of de-trended cable delay values for Kokee (left) and Wettzell (right).

4 The impact of polar motion accuracy

According to the IERS Bulletin A[2] (IERS, 2015) (update frequency of one week) the accuracy of the predicted polar motion is

$$\sigma_{x_p,x_p} = 680 \cdot D^{0.80} \quad [\mu as], \tag{1}$$

where D is the days elapsed since the Bulletin A epoch. The impact of the polar motion accuracy on the UT1-UTC estimation was studied by a Monte Carlo simulation. The simulation was carried out by adding a noise term to the a priori polar motion information. This noise term was drawn from a normal distribution with a standard deviation based on the estimated accuracy according to Equation (1). This was done in a Monte Carlo fashion 20 times for each of the 1669 sessions with a prediction interval of 0.25 to 6 days in 24 steps of 0.25 days. For each set of Monte Carlo calculations (1–20) within a noise level a weighted RMS was computed and then these 20 values were averaged over the respective noise level, and a standard deviation for the 20 values was computed as a measure of formal error. Figure 5 presents the result of the Monte Carlo simulation and a power function fit to the data. We can see that the mean WRMS of the UT1-UTC residuals depends strongly on the accuracy of the a priori pole

[2] http://datacenter.iers.org/eop/-/somos/5Rgv/latest/6

components. After 1 day the WRMS degrades from approximately 5 μs from 18 μs to 23 μs.

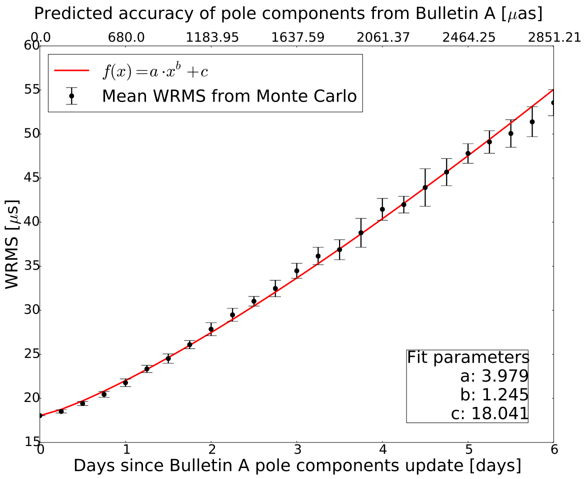

Fig. 5 Mean WRMS of UT1-UTC residuals w.r.t. C04 as a function of polar motion accuracy. The X-axis shows days elapsed since Bulletin A epoch (bottom) and polar motion accuracy (top).

4.1 Impact of estimating the station position

Wettzell was kept as the reference station, while the position of Kokee was estimated with constraints between 0.1 mm to 10 mm, with steps of 0.025 mm in a logarithmic scale. Figure 6 shows the effect of the constraint level on the WRMS of UT1-UTC residuals w.r.t. C04. Also shown is the number of sessions lost relative to the number of sessions. Sessions are lost because estimating the station position of Kokee with too loose constraints sometimes causes solutions to not converge. While the applied constraints remain on the millimetre level or tighter, there is no degradation in terms of WRMS of the UT1-UTC residuals w.r.t. C04. However, no improvement can be seen either. Beyond 1 millimetre constraint level the solution becomes unstable, causing both the accuracy of the UT1-UTC estimate to decrease as well as non-convergence in the least-squares adjustment.

5 Conclusions

Based on our results on the automated analysis of INT1 sessions we can conclude for the research questions posed in Section 1:

1. There is no clear advantage in using local weather data from the station log files compared to using GPT2.

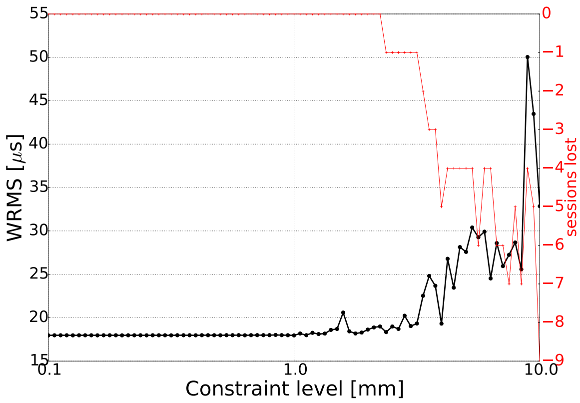

Fig. 6 Effect of constraint level for station position estimation on the WRMS of the UT1-UTC residuals w.r.t. C04 (left scale) and the number of sessions that failed when station position was estimated (right scale).

2. There is no significant difference in using VMF1 or GMF.
3. There is a benefit in using cable delay data, provided that it is reliable.
4. Outdated polar motion values have a significant impact on UT1-UTC estimates. Polar motion with sub-daily resolution is necessary to provide UT1-UTC with a mean accuracy of better than 20 μs.
5. Station position estimation does not degrade UT1-UTC if tight constraints on the millimeter level are applied.

We can conclude from the results of the processing strategies with and without station log files that if the pressure and cable data are reliable the UT1-UTC accuracy is slightly improved. However, when station log data were used, 48 sessions were rejected based on our outlier exclusion criteria (see Section 2). In all instances the rejections were due to bad pressure data in the station log files. Compared to pressure, bad cable calibration data degraded the UT1-UTC estimates to a lesser extent. Rigorous automatic procedures to filter the bad station log data are needed to ensure that if the station log files are used they do not degrade the UT1-UTC estimate. Inaccuracy in a priori polar motion values remain the largest cause to degradation in the accuracy of UT1-UTC estimates. Further details of this study can be found in Kareinen et al. (2015).

References

Bizouard C, Gambis D (2011) The combined solution C04 for Earth Orientation Parameters consistent with International Terrestrial Reference Frame 2008. https://hpiers.obspm.fr/iers/eop/eopc04/C04.guide.pdf. Accessed 17 Aug 2015

Boehm J, Werl B, Schuh H (2006) Troposphere mapping functions for GPS and very long baseline interferometry from

European Centre for Medium-Range Weather Forecasts operational analysis data. *J Geophys Res*, 111(B2). doi: 10.1029/2005JB003629

Gordon D (2007) NGS Format for VLBI Data Transfer – Revised June 11, 2007. http://lacerta.gsfc.nasa.gov/mk5/help/dbngs_format.txt. Accessed 31 Aug 2015

Hobiger T, Otsubo T, Sekido M, Gotoh T, Kubooka T, Takiguchi H (2010) Fully automated VLBI analysis with c5++ for ultra-rapid determination of UT1. *Earth Planets Space*, 62(12), 933–937.

IERS Bulletin A (2015) IERS Rapid Service Prediction Centre. http://hpiers.obspm.fr/eoppc/bul/bulb/explanatory.html. Accessed 17 Aug 2015

Kareinen N, Hobiger T, Haas R (2015) Automated analysis of Kokee–Wettzell Intensive VLBI sessions — algorithms, results, and recommendations. *Earth Planets Space*, 67:181, doi: 10.1186/s40623-015-0340-x.

Lagler K, Schindelegger M, Boehm J, Krásná H, Nilsson T (2013) GPT2: Empirical slant delay model for radio space geodetic techniques. *Geophys Res Lett*, 40, 1069–1073. doi: 10.1002/grl.50288

Petit G, Luzum B (2010) (eds.) IERS Conventions (2010). International Earth Rotation and Reference Systems Service (IERS). IERS Technical Note, No. 36, Frankfurt am Main, Germany: Verlag des Bundesamts für Kartographie und Geodäsie, 179 pp.

Schuh H, Behrend D (2012) VLBI: A fascinating technique for geodesy and astrometry. *J Geodyn*, 61, 68–80. doi: 10.1016/j.jog.2012.07.007