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ULTRA-RAPID DUT1-OBSERVATIONS WITH E-VLBI

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ABSTRACT. We give a short overview about the achievements of the Fennoscandian-Japanese ultra-rapid dUT1-project that was initiated in early 2007. The combination of real-time data transfer, near real-time data conversion and correlation, together with near-real time data analysis allows to determine dUT1 with a very low latency of less than 5 minutes after the end of a VLBI-session. The accuracy of these ultra-rapid dUT1-results is on the same order than the results of the standard rapid-service of the International Earth Rotation and Reference Frame Service (IERS). The ultra-rapid approach is currently extended to 24 hour sessions and is expected to become an important contribution for the future next generation VLBI system called VLBI2010.

Keywords: Very Long Baseline Interferometry, Earth orientation, dUT1-observations, e-VLBI, VLBI2010

1. INTRODUCTION

The orientation of the earth is variable on a wide range of time scales. Some of the effects that change earth orientation are well understood and can be modeled and predicted accurately. Other effects are still unpredictable and maybe continue to be unpredictable even in the future. Among these are e.g. effects due to exchange of angular momentum between the different spheres of the system earth, and episodic events like earthquakes. Therefore it is necessary to observe earth orientation and its variation. This is done today by using several space geodetic techniques as for example Very Long Baseline Interferometry (VLBI) and satellite techniques like Global Navigation Satellite Systems (GNSS) and Satellite Laser Ranging (SLR). The International Earth Rotation and Reference Systems Service (IERS) uses the results of the space geodetic observations and derives consistent reference frames and time series of earth orientation.

The earth orientation parameters connect the terrestrial and the celestial reference frame. Any user that wants to relate these two reference frames, e.g. for navigation purposes, therefore needs accurate information about the earth orientation. This is valid both for navigation applications on the earth and for space navigation. Navigation in real-time depends on accurate predictions of earth orientation parameters. Predictions of earth orientation are provided by the IERS Rapid Service/Prediction Center. These predictions are based on models and actual observations and need therefore observational results with low latency. In particular predictions of the earth rotation angle, usually expressed as Universal Time (UT1), requires observations with low latency.

The International VLBI Service for Geodesy and Astrometry (IVS) (Schlüter and Behrend, 2007) organizes so-called intensive sessions to derive dUT1, the difference of the earth rotation angle with respect to UTC (Universal time Coordinated). These sessions are performed every day with two radio telescopes forming a long east-west extended baseline. The observations usually last for about 1 hour and a total of 20-30 scans are observed. During the last years the latency of the final dUT1 results from these intensive sessions has been improved from several 2-3 days to 8 hours. This became possible due to the use of electronic transfer of the observational data to the correlator instead of sending the data storage devices by mail service (Luzum and Nothnagel, 2010). Pioneering efforts for the application of electronic data transfer for dUT1-observations were performed by VLBI groups in Japan, Sweden and Finland since early 2007.

2. ULTRA-RAPID VLBI SESSIONS

The VLBI groups in Kashima and Tsukuba (Japan) and Onsala and Metsähovi (Sweden and Finland) started in the spring of 2007 a Fennoscandian-Japanese VLBI project. Figure 1 shows a map with the involved stations and the long east-west oriented baselines. The goals of this project were to achieve low latency for UT1-results using Intensive-style VLBI-sessions, to test different VLBI observation setups and data rates (128, 256, 512 Mbps) and their impact on the dUT1-results, and to check the consistency of UT1-results observed simultaneously on almost parallel baselines

About 40 intensive-style VLBI-sessions were observed between early 2007 and mid 2009. Different baseline configurations, observing setups and data rates were used. During these experiments the observed data of Onsala and Metsähovi were sent in real-time via international optical fibre networks to correlator stations in Japan. There the data were converted to the Japanese K5-format and correlated in near real-time with the observational data of the Japanese partner telescopes. This combination of real-time electronic data transfer and near real-time correlation is usually called e-VLBI. Immediately after the end of the observing session the data were analyzed and dUT1 determined (Sekido et al., 2008). A highlight was the achievement of final dUT1-results within less than 4 minutes after the end of an observing session (Matsuzaka et al., 2008), which is the current world record.

Table 1 shows root-mean-square (RMS) differences between different dUT1-series and the EOP 05 C04 series of the International Earth Rotation and Reference Frame Service (IERS). The EOP 05 C04 series is the long term earth orientation data series of the IERS

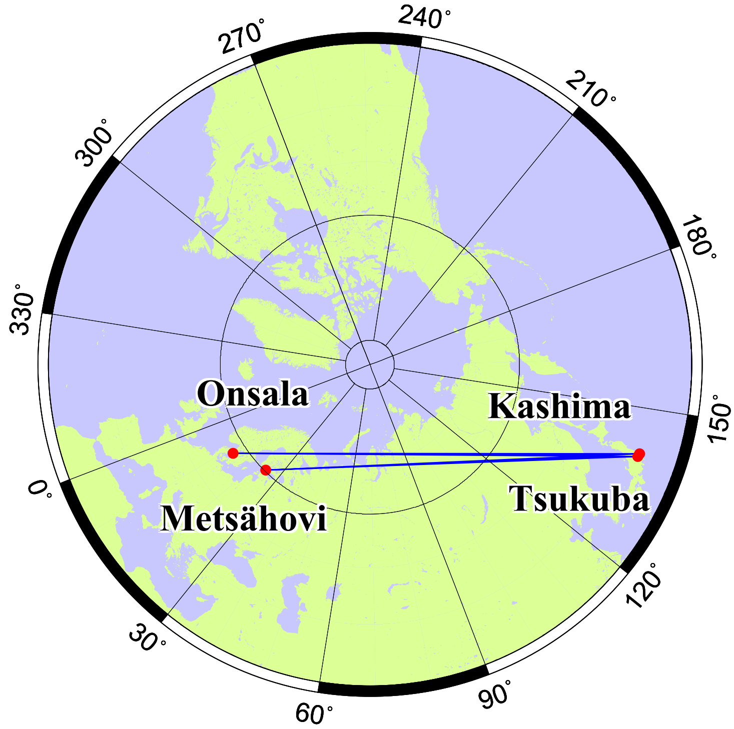

Figure 1: **The network of four stations used for the ultra-rapid dUT1-sessions**

and regarded as the most accurate series. The ultra-rapid results show a performance that is on a comparable accuracy level as the IERS rapid series. The RMS-agreement with respect to the IERS EOP 05 C04 series is on the order of about 30 μs. However, the latency of the ultra-rapid dUT1 values is much lower than the IERS rapid series.

Due to constraints on telescope availability only one out of the 40 ultra-rapid sessions resulted in simultaneous dUT1-observations on almost parallel baselines. Comparing the results of this experiment in July 2007 we found an agreement for dUT1 on the order of 16.7 μs, which is close to the formal uncertainty.

Most of the ultra-rapid dUT1-sessions used a data rate of 256 Mb/s, but some were performed with either lower (128 Mb/s) or higher data rates (512 Mb/s). A comparison of the formal errors shows that the higher data rates give lower formal errors for the dUT1-results, see Table 2.

Table 1: RMS-differences of dUT1-series with respect to the IERS EOP 05 C04 series.

dUT1-series	RMS-difference (μs) w.r.t. IERS EOP 05 C04
IERS Bulletin-A	440.3
IERS-rapid series	28.1
IERS Bulletin-B	12.7
ultra-rapid e-VLBI	32.8

Table 2: Average formal uncertainties for dUT1-results derived from different data rates.

data rate (Mb/s)	dUT1 formal uncertainty (μs)
128	23.1
256	11.3
512	8.1

5. CONCLUSIONS AND OUTLOOK

The Fennoscandian-Japanese ultra-rapid dUT1 project allows to determine accurate UT1 results with very low latency. Final UT1-results can be determined within minutes after the end of a one hour observation session. The agreement with the final IERS 05 EOPC04 values is on the order of 30 microseconds. This is on the same level as the standard IERS rapid solutions, but with a much lower latency.

Simultaneous observations on almost parallel baselines agree on the order of better than 20 microseconds. There is also an indication that higher data rates lead to reduced formal uncertainties of the dUT1-results.

The IERS is very interested to adopt the ultra-rapid concept for the regular intensive sessions. In early 2010 an IVS task force group was asked to work towards a routine application of the ultra-rapid approach and the establishment of reliable data streams to the IERS Rapid Service and Prediction Center.

Currently, we extend the ultra-rapid concept from dedicated one baseline sessions to standard IVS multi-station 24 hour sessions. For those IVS R1-sessions where both Onsala and Tsukuba take part, the observational data are sent in real-time from Onsala to the VLBI correlator at Tsukuba. At the correlator the data are converted to the Japanese K5 data format and successively correlated with the observational data of the Tsukuba station. Once a number of 35 scans has been correlated, i.e. covering usually about 1 to 1.5 hours of observations, the data are analyzed and dUT1 is determined. For every incoming new scan the respectively oldest is left out and the current 35 scans are analyzed again. Using this approach the whole data set is analyzed with a sliding window of 35 scans each while the ongoing 24 hour session. The approach has been tested so far for about 10 IVS sessions and works very successfull.

The next step is to extend the ultra-rapid concept to multi-station observation, correlation and analysis. It is known that dUT1 determined from one-baseline intensive-style sessions are very sensitive to the apriori pole coordinates used in the data analysis (Nothnagel and Schnell, 2007). It would thus be desirable to estimate also pole coordinates simultaneously, which is impossible from just one baseline. However, simultaneous correlation of several baselines of multi-station networks and the subsequent analysis will allow to determine the whole set of earth orientation parameters in ultra-rapid mode during ongoing VLBI sessions. This is very relevant as a preparation step for the operation of the next generation VLBI system VLBI2010 (Petrachenko et al., 2009). Among the goals of VLBI2010 are continuous VLBI observations with a global network of observing stations and low latency for the final results. Thus, VLBI2010 will require to transfer the observational data during the ongoing sessions, correlate the data during the ongoing session, and also analyze the correlation results and derive e.g. earth orientation parameters. The experience gained from the ultra-rapid sessions is therefore an important contribution to the VLBI2010 project.

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