Onsala Space Observatory – IVS Analysis Center Activities during 2015–2016

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Abstract This report gives a short summary on the ongoing and planned future activities of the IVS Analysis Center at the Onsala Space Observatory during 2015–2016.

1 General Information

In this report we describe our research activities related to space geodesy and geosciences at the Onsala Space Observatory. This includes geodetic VLBI and complementary techniques.

2 Activities during the Past Two Years

The main research topics during the time period were:

- Automated analysis of the IVS Intensive sessions and robust ambiguity estimation;
- Combining VLBI and GNSS for intercontinental frequency transfer;
- VLBI analysis software comparison campaign 2015;
- Extension of the c5++ analysis software;
- Ultra-rapid earth rotation determination with VLBI during CONT11 and CONT14;
- VLBI observations of near-field targets;
- Combining multiple signals for GNSS-reflectometry (GNSS-R);
- Ocean tide loading;
- Gravimetry observations.

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Onsala Analysis Center

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3 Automated Analysis of the IVS Intensive Sessions

We explored different ways to improve the IVS Intensive sessions using the c5++ VLBI analysis software in a fully automated fashion. The Intensive sessions between 2001 and 2015 observed on the Kokee–Wettzell baseline were analyzed starting from Version-1 databases [3]. These databases consist of the raw delays from the correlator and thus contain outliers and ambiguities. The software c5++ was used to first resolve the ambiguities, after which the resulting databases were analyzed using different analysis setups. The following aspects were investigated:

- The impact of choosing GMF(GPT2) or VMF1 as the mapping function.
- The effect of applying the cable delay data.
- The dependence of the UT1–UTC accuracy on the a priori EOPs.
- The possibility of simultaneously estimating UT1–UTC and one of the station positions.

Based on the results, we conclude that for UT1–UTC accuracy the most significant factor is the availability of recent (1–2 days) a priori polar motion (see Figure 1). Furthermore, improving the accuracy of UT1–UTC estimated from the Intensive sessions would require implementing fundamental changes in the current Intensive session strategy.

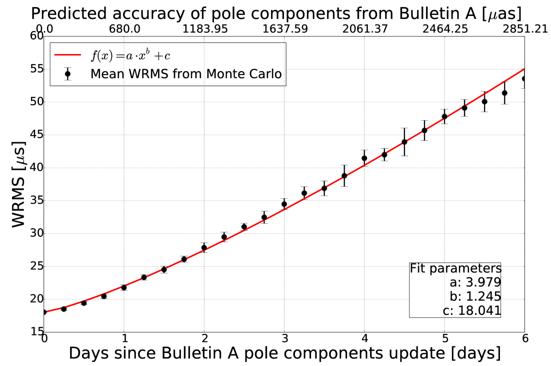

Fig. 1 Mean WRMS of UT1-UTC residuals w.r.t. C04. The X-axis shows days elapsed since the Bulletin A epoch (bottom) and corresponding polar motion accuracy (top).

The standard scheme in c5++ uses least-squares analysis to automatically estimate the group delay ambiguities resulting from bandwidth synthesis. As an alternative to this strategy, we implemented a robust ambiguity estimation method using the L1-norm instead of least-squares adjustment (see Figure 2) [4]). Again, the set of VLBI sessions was the Version-1 databases between 2001 and 2015. The robust estimation method increased the success rate of the ambiguity estimation by approximately 5%.

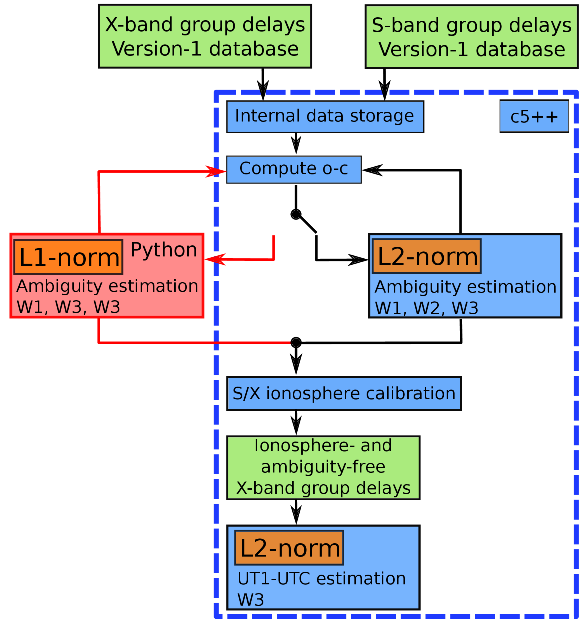

Fig. 2 The schematics of the implemented ambiguity estimation methods in c5++.

4 Combining VLBI and GNSS for Intercontinental Frequency Transfer

For decades, GPS has been the only space geodetic technique routinely used for inter-continental frequency transfer applications. In the past VLBI has also been considered for this purpose and the method's capabilities were studied several times. However, compared to GPS, current VLBI technology only provides few observations per hour, thus limiting its potential to improve frequency comparisons. We therefore investigated the effect of combining GPS and VLBI on the observation level in order to draw the maximum benefit from the strength of each individual technique. GPS and VLBI single-technique analysis revealed similar frequency link instabilities at the level of 10^{-14} to 10^{-15} (modified Allan deviation) on inter-continental baselines for averaging times of one day (cf. Figure3). A combined analysis of both techniques led to small but consistent improvements for frequency transfer of up to 10, in particular for averaging periods longer than 3,000 s [2].

5 VLBI Analysis Software Comparison Campaign 2015

The aim of the VLBI Analysis Software Comparison Campaign 2015 (VASCC2015) was to compare different VLBI analysis software packages on the basis of computed theoretical delays. This included packages which are used for operational VLBI analysis as well as those which are still under development. During VASCC2015 numerical issues were identified and several bugs could be fixed in some of the analysis packages. The results indicate that a sub-mm agreement of theoretical delays, computed by state-of-the-art VLBI analysis software packages, can be achieved [11].

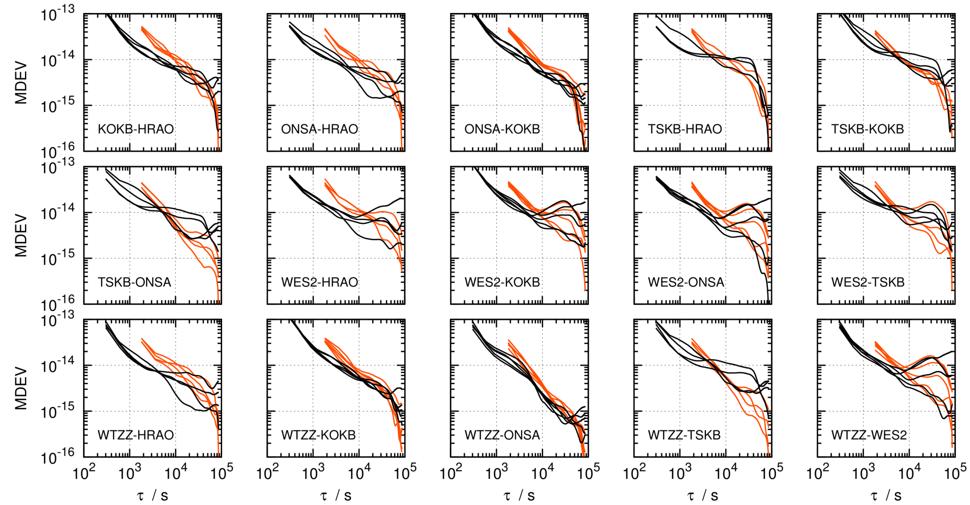

Fig. 3 Modified Allan deviation (MDEV) plots for frequency links over all baselines in a six-station CONT11 network, as obtained from the three-daily GPS (black) and VLBI (orange) single-technique solutions with c5++.

6 Extension of the c5++ Analysis Software

The VLBI part of the c5++ software was extended with an interface capable of reading VLBI observations stored in the vgosDB format. Further changes relate to the implementation of two near-field VLBI delay models described by [9] and [10]. The latter allowed us to correlate test observations to the Chang'E-3 lander that were carried out in April 2014 on the ONSALA–WETTZELL baseline. This was achieved by including c5++ into the processing chain as depicted in Figure 4.

7 Ultra-rapid Earth Rotation Determination with VLBI during CONT11 and CONT14

We compared the earth rotation results derived from the ultra-rapid operations on the Onsala–Tsukuba baseline during the continuous VLBI campaigns CONT11 and CONT14 to results from post-processing of the complete CONT network sessions, as well as Intensive sessions during CONT11 and CONT14 [1]. As a common reference for the comparison we used the IERS 08 C04 series. Our results show that the accuracies of the CONT ultra-rapid single baseline operations are roughly a factor three times worse than the results from both dedicated one-baseline sessions and/or the complete analysis of network sessions. The reason is that the ultra-rapid sessions during the CONTs were not optimized for earth rotation determination.

8 VLBI Observations of Near-Field Targets

Together with IVS partner telescopes, we performed experimental observations of near-field targets. The latter included the Chinese Chang'E-3 Lunar lander (S/X-band), the Chinese APOD satellite (X-band), and GNSS-satellites (L-band). We used the extended c5++ software (see Section 6) to prepare the necessary a priori files for the data correlation with the software correlator DiFX, and we were able to successfully correlate the observed data.

9 GNSS-R Measurements of the Coastal Sea Level

We investigated new ways of retrieving sea surface height from GNSS-reflectometry (GNSS-R) in which signals from different constellations and frequencies are used in a combined solution. By inverse modeling of the signal-to-noise ratio (SNR), the height can be modeled as a continuous function shared across the different signals available at a single epoch. The results

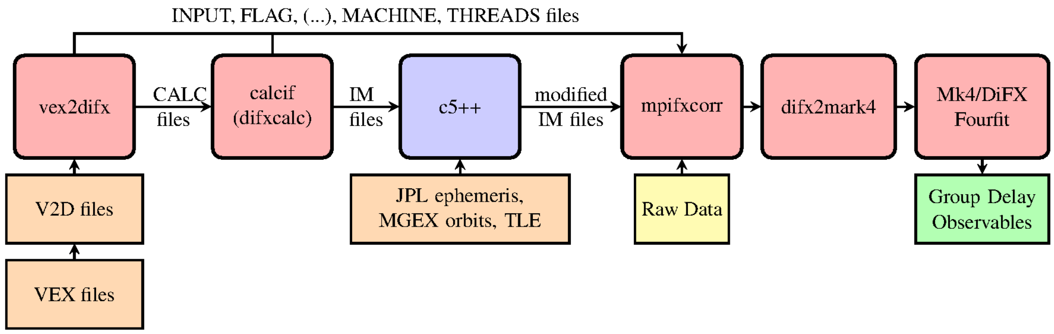

Fig. 4 Simplified schematics of the VLBI data correlation in DiFX and multi-band synthesis using common processing chain supplemented by the c5++ analysis software.

demonstrate that this approach is more precise than the previously used spectral analysis [5]. Even using only a single signal, the method shows an increased precision, and using multiple signals in the processing increases the precision even further. With root mean square differences of about 15 mm w.r.t. an official tide gauge, the method has been proven to lead to an improvement of more than 50% as compared to previous single receiver solutions computed for the same period.

10 Ocean Tide Loading

In 2016, new ocean tide models were added to the catalog of the Free Ocean Tide Loading provider (`http://holt.oso.chalmers.se/loading`), FES2014a [6] and TPXO8-Atlas [7]. Actually, the requests for loading coefficients are forwarded to the computing site at SEGAL located at the University of Beira Interior and Institute Dom Luiz, UBI/IDL in Portugal. Machiel S. Bos has kindly made this computational load relieving facility available. During 2015 and 2016, 12,622 requests were served for 189,515 observing sites.

11 Gravimetry Observations

The Superconducting Gravimeter (SG, model GWR #54, station code OS) has been observing continuously during the period of this report; only one of the 1.5 billion one-second samples has been lost. Efforts are on-going to provide an empirical SG-based station model for reduction of regular and anomalous gravity variations, parameters that we contribute to visiting Absolute Gravity (AG) groups. Four AG campaigns were carried out in the two years, including a visit with a novel quantum interferometer design developed at Humboldt University Berlin, Germany [8]. Observation data are reported to the IGETS (formerly GGP) database at GfZ Potsdam, Germany. A live page rich with links is available at `http://holt.oso.chalmers.se/hgs/SCG/`.

Modeling work for the gravimetry station at OSO makes use of the broadband seismometer station located there and run by Uppsala University within their Swedish National Seismograph Network.

12 Future Plans

The main focus of our work for the coming years will be the Onsala Twin Telescopes project. We look forward to the official inauguration of the telescopes in the spring of 2017. Upon completing the signal chain the project can proceed to the testing phase and later to operational use. We anticipate many interesting experiments and corresponding data analysis that will help to fine-tune the OTT systems. We also will work on tying the new telescopes into the observatory network. In 2017 we also expect to install a new microwave radiometer close to the OTT, which, together with the other sensors, will allow to intensify studies concerning atmospheric turbulence and its impact on space geodetic measurements. The work done with the IVS Intensives to find new and automated ways to analyze VLBI data will be continued, aiming to find improved observing and analysis strategies for VGOS era observations. We will continue with observations of near-field targets and focus on the corresponding data analysis. Furthermore, there is an ongoing effort to greatly improve the GNSS-R observations of the sea level and to further expand the concept.

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