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Comparison Campaign of VLBI Data Analysis Software - First Results

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Abstract

During the development of the Vienna VLBI Software VieVS at the Institute of Geodesy and Geophysics at Vienna University of Technology, a special comparison setup was developed with the goal of easily finding links between deviations of results achieved with different software packages and certain parameters of the observation. The object of comparison is the computed time delay, a value calculated for each observation including all relevant models and corrections that need to be applied in geodetic VLBI analysis. Besides investigating the effects of the various models on the total delay, results of comparisons between VieVS and Occam 6.1 are shown. Using the same methods, a Comparison Campaign of VLBI data analysis software called DeDeCC is about to be launched within the IVS soon.

1. Introduction

The calculation of the theoretical delay is one of the main tasks in geodetic VLBI analysis. The comparison of the modeled time delays with the observed values together with their partial derivatives is the basis for the subsequent adjustment procedure. While the results of the adjustment can vary depending on the estimation method and time intervals, the calculated delay relies on theoretical knowledge and should be identical in all software realizations. In practice, different VLBI analysis packages follow different calculation strategies, vary in the usage of correction models, and are sometimes limited in their ability to adopt the latest IERS Conventions. During the development of the Vienna VLBI Software (VieVS) (Böhm et al. 2009 [1]) many comparisons of intermediate results with Occam 6.1 (Titov et al. 2004 [2]) have been performed. While actual VLBI delay models ensure accuracy up to one picosecond (0.3 mm) other parts of geodetic VLBI modeling are much more uncertain, and discrepancies at the millimeter level could be found. The goal of the **De**lay and partial **De**rivatives **C**omparison **C**ampaign (DeDeCC) is to compare the various software packages used within the IVS in order to detect present deficiencies in the modeling part which might lead to systematic errors in a final solution. In the following we want to give a short insight into the complexity of delay modeling (Section 2), present the main ideas of the campaign setup (Section 3.1) and show first results of comparisons between VieVS and Occam 6.1 (Section 3.2). This report ends with an outline of upcoming activities within DeDeCC (Section 4).

2. The Computed Time Delay

When radio waves emitted by an extragalactic source are received by two widely separated antennas on the surface of the Earth, the time epoch when the same wavefront reaches station 1 and station 2 is usually different. This time delay for each baseline is the main observable of a VLBI experiment and can be accurately determined by the correlation process. On the other hand, the delay is modeled in the analysis software, which is inspected here. According to Sovers et al. 1998 [3] the geometric time delay in the barycentric coordinate system is

$$\tau_{bary} = (t_2 - t_1)_{bary} = \frac{\vec{k} \cdot \vec{b}/c}{1 - \vec{k} \cdot \beta_2/c} \tag{1}$$

where $\vec{k}$ is the source unit vector in the direction of signal propagation, $\vec{b}$ is the baseline between station 2 and station 1 at the time of signal reception at station 1, β_2 is the barycentric velocity of station 2, and c stands for the velocity of light in vacuum. Considering the fact that the measured time delay is referred to the Earth's surface rather than the barycentric system, as well as the required transformations between the celestial reference frame of the sources and the terrestrial reference frame in which the stations are determined, equation (1) in practice has to be expanded for several relativistic terms. A complete formulation of the VLBI time delay is provided with the IERS consensus model described in Eubanks 1991 [4]. For the calculation of $\vec{b}$ the real station locations are needed, including corrections due to station velocities, solid Earth tides, pole tide, and ocean loading as well as atmosphere loading. For the transformation between the terrestrial and the geocentric reference frame the actual Earth orientation has to be determined beforehand. Besides the geometric delay described above we have to account for the gravitational bending delay τ_{grav} due to celestial bodies and for the propagation delay in the troposphere τ_{trop}. Further corrections due to the ionosphere or clock offsets are often treated separately and are not a matter of comparison here. Generally, the decision of whether a delay correction is either applied directly to the observation or taken into account at the modeled delay is up to each software strategy. This leads to different interpretations of the term *computed delay*. For clarity, equation (2) shows the individual parts which are included in the computed delay used in the comparison campaign.

$$\tau_{comp} = \tau_{geom} + \tau_{grav} + \tau_{trop} + \tau_{axis} + \tau_{thermdef} \tag{2}$$

As shown in Figure 1, the order of magnitude at which the various corrections and models contribute to the total delay ranges from a few millimeters up to some tens of meters. The examined time span covers the first three days of DeDeCC1 (see Section 3.1) and refers to a total delay of approximately ±4,000 kilometers, corresponding to ∼13 milliseconds. After the geometry, the biggest effect up to 30 meters comes from the troposphere depending on the local elevation angles. Corrections of some tens of centimeters are made by the antenna axis offsets, the solid Earth tides, and the gravitational influence of the sun. The antenna thermal correction, the gravitational effect of the Earth, and the influence of the ocean on Earth rotation and on station coordinates contribute at the millimeter level.

3. Comparison Campaign

3.1. DeDeCC1

For the first cycle of comparisons, named DeDeCC1, observations of the two stations Westford and Wettzell of the source 0642+449 are examined. The observations are arranged into fifteen 24-hour sessions, fourteen consecutive days from January 1^{st} to January 14^{th} 2001 and a single session one year later, on January 1^{st} 2002. The observation interval is 30 minutes. In the reduced mode, observations with low elevation or beneath the horizon are skipped (every day from 14:00 to 19:30). With an expected agreement at the millimeter level, the usage of identical input parameters

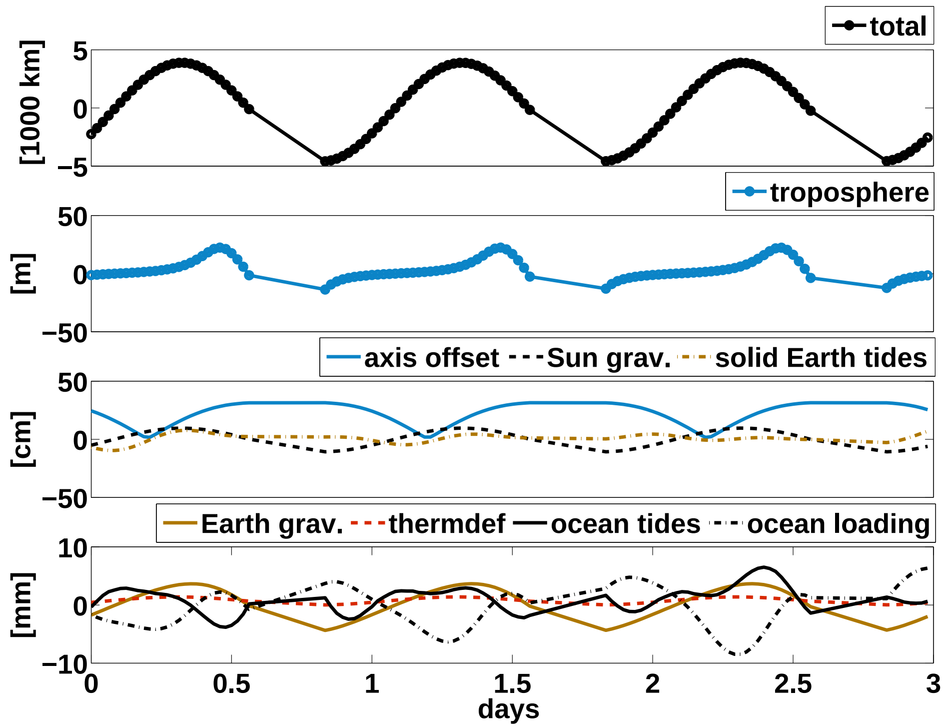

Figure 1. Contribution to the delay at different magnitudes.

and modeling options is essential. Detailed instructions on applied and neglected models, the observation schedule, and the input coordinates can be found at the website of DeDeCC[1]. In order to restrain the effect of the various interpolation methods used in existing software the Earth orientation parameters, air pressure, and temperature are fixed to constant values, and atmosphere loading is not considered in DeDeCC.

3.2. VieVS Versus Occam 6.1

A first run of DeDeCC was made with the two software packages available at our institute, the new VieVS and the formerly used Occam 6.1.

As shown in Figure 2, the calculated delays of VieVS and Occam 6.1 differ by ±2 millimeters during the inspected time periods. The variations are characterized by a dominant daily period and, looking at the longer time spans, additional periods of one year and longer (approx. 5 years) can be detected. Investigations concerning the sources of discrepancies showed that the disagreement due to inconsistencies in the modeling of solid Earth tides, ocean loading, the troposphere, pole tide, thermal correction, and antenna axis offset is below 75 micrometers, which is not critical. The differences more likely originate in the diverse calculation of the Earth rotation angle realized in both programs. Certainly a comparison with at least one further software package needs to be done to clarify the reason for the discrepancies.

[1] http://mars.hg.tuwien.ac.at/~lplank/DeDeCC/

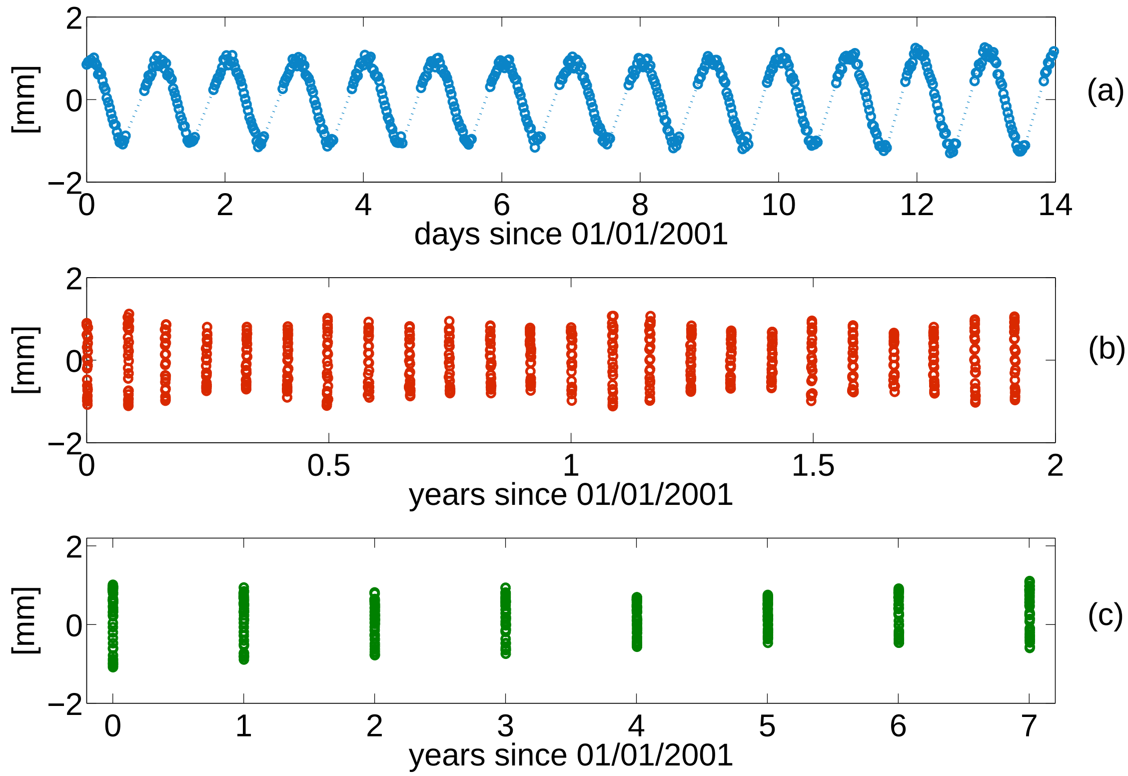

Figure 2. Differences VieVS minus Occam 6.1 of the calculated delays for a period of 14 consecutive days (a), a period of two years with a 24 h session every month (b), and of seven yearly sessions (c).

4. Conclusions and Outlook

So far DeDeCC has helped to detect small bugs and to verify several correction models during the development of VieVS. Under the guidance of the IVS Analysis Coordinator and with the assistance of several IVS analysts, an official Call for Participation in the campaign will be distributed within the IVS soon. Providing comparisons within DeDeCC1 are successful, further investigations including the partial derivatives will follow. Recent developments and upcoming results will be published on the Web (see Section 3.1).

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