IMPACT OF SEASONAL STATION DISPLACEMENT MODELS ON RADIO SOURCE POSITIONS

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ABSTRACT. The International Terrestrial Reference Frame considers the position at a reference epoch plus a linear velocity term for station coordinates. However, the determination of the actual station position requires several other corrections partially recommended by the IERS Conventions (e.g., solid Earth tides, ocean tidal loading) as well as other non-linear displacements. In this study we focus on the impact of the seasonal station motions on the Celestial Reference Frame (CRF). The increasing accuracy of Very Long Baseline Interferometry (VLBI) observations and the growing time span of available data allow the determination of seasonal signals in station positions which still remain unmodelled in the conventional analysis approach. For that purpose, we create empirical harmonic models for selected stations within a global solution of all suitable VLBI sessions at annual and semi-annual periods. Furthermore, we introduce average annual models created by stacking yearly time series of station positions. The celestial reference frames estimated simultaneously with terrestrial reference frames are compared to each other. We find that seasonal station movements do not yield any significant systematic effect on the CRF but can cause significant changes in positions of radio sources observed only in a small number of sessions non-evenly distributed over the year.

1. INTRODUCTION

The analysis of measurements from space geodetic techniques requires the use of the best available models describing the deformation of Earth surface. The goal is to have a set of models which realistically describe changes in the station positions on the Earth surface during the time when the observations are carried out. As reported, e.g., by Collilieux et al. (2007), van Dam et al. (2007), Tesmer et al. (2009) or Malkin (2013) there are still deficiencies in the modelling of station movements over longer periods and systematic long-period signals are present in the station position time series. Malkin (2013) investigated the impact of the seasonal station movements on the estimated Universal Time (UT1) from the single-baseline intensive sessions. In this paper we consider the impact of the unmodelled effects on the VLBI results obtained from the 24-hour multi-baseline VLBI sessions. In particular we focus on the propagation of the seasonal station movements to the radio source positions building the celestial reference frame (CRF). Two treatment approaches of the unmodelled seasonal station displacement are introduced. First we model the surface deformation as a periodic movement with annual and semi-annual periods, in the second approach we create average annual models.

2. SEASONAL STATION DISPLACEMENT MODELS

About 5.6 million VLBI observations from 1984.0 to 2013.3 were analysed with geodetic VLBI analysis software VieVS (Böhm et al., 2012). The usual analysis strategy was applied, i.e. solid Earth tides, ocean tide loading, pole and ocean pole tide loading were modelled a priori according to the International Earth Rotation and Reference Systems Service (IERS) Conventions 2010 (Petit and Luzum, 2010). Additionally, we corrected a priori for tidal and non-tidal atmosphere loading (Petrov and Boy, 2004) as well as for thermal deformation (Nothnagel, 2009). VieTRF13b and VieCRF13b, the reference frames estimated at the Vienna University of Technology, were used as priori terrestrial (TRF) and celestial reference frames. For each session a normal equation system was set up which included station coordinates and velocities, source coordinates, Earth orientation parameters (one offset), zenith wet delays (constrained with 1.5 cm after 60 minutes), tropospheric gradients (constrained with 0.05 cm after 6 hours), and clock parameters. In the reference solution, where source coordinates were fixed to their a priori values and station coordinates were estimated session-wise with no-net-translation (NNT) and no-net-rotation (NNR) conditions w.r.t. the VieTRF13b, a clear seasonal signal in the station position time series was visible. Therefore, we introduce two empirical models which describe the remaining long-period signal in the station coordinate time series. The first one is a harmonic model for annual and semi-annual periods, and the second one is an averaged model over a year. The average annual models were determined from the reference solution following the approach of Tesmer et al. (2009). First, an offset in each year of the estimated session-wise station coordinates was removed from the time series, then the time series were stacked into one mean year and a smoothing of the position estimates into a mean annual signal was done. For the smoothing a predefined smoothing spline function in the software MatLab was used, as weights the formal errors of the estimated coordinates were applied.

The study of seasonal station displacement was done for all stations which participated in more than 50 sessions and with observations evenly distributed over the yearly period. Consequently, we excluded the station O'Higgins from the study, which - due to its location in Antarctica - only observes during southern hemisphere summer months. Furthermore, with the afore-described parameterisation a global solution (S1G) was run where terrestrial and celestial reference frame were estimated simultaneously. The TRF was aligned to the a priori reference frame with the NNT+NNR condition on a set of 22 core stations, and for the CRF the NNR condition on 285 radio sources was applied. Tropospheric parameters (i.e., zenith wet delay and gradients), clock parameters, and Earth orientation parameters were reduced from the normal equations and estimated as arc parameters, i.e. from single session adjustment.

Thereafter, a second analysis of VLBI data was performed (solution S2G) in which sine and cosine amplitudes belonging to the annual and semi-annual periods were estimated as global parameters in a common adjustment of VLBI sessions together with terrestrial and celestial reference frames. Figure 1 shows the stacked time series of the height, east and north components for the ten most observing stations during the analysed time period. In light red colour the obtained model gained by adding the

http://vievs.geo.tuwien.ac.at/results

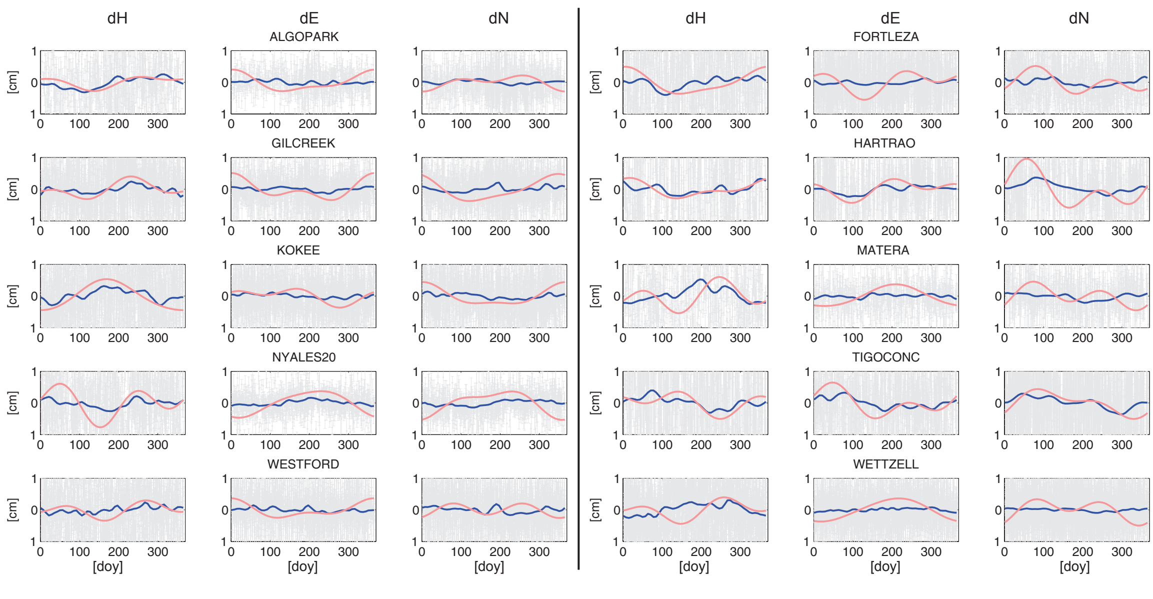

Figure 1: Seasonal station displacement models for ten stations which observed in most of the VLBI sessions. In light red the harmonic model and in blue the mean annual models are shown.

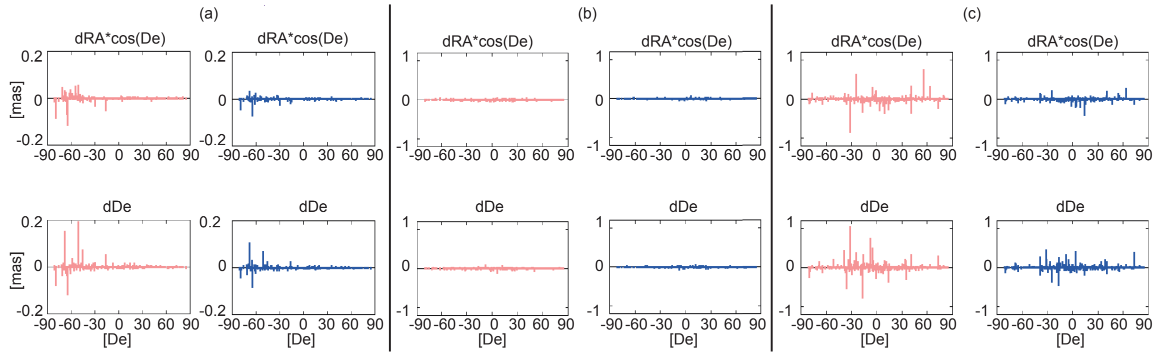

Figure 2: Differences between estimated radio source coordinates in right ascension (upper plots) and declination (lower plots). In light red the differences between solutions 1 and 2 (S1G-S2G) and in blue between solutions 1 and 3 (S1G-S3G) are plotted. The left-hand side plots "(a)" show datum sources, middle plots "(b)" contain only sources observed in at least two sessions with more than 20 observations, and right-hand side plots "(c)" depict all radio sources in the estimated CRF.

two harmonic components with annual and semi-annual periods is plotted. In blue colour the average annual model for the station displacement is shown which was applied a priori on the station coordinates in addition to the standard modelling in the third global solution (S3G). In this way a third pair of celestial and terrestrial reference frames from a global solution was obtained.

3. COMPARISON OF CELESTIAL REFERENCE FRAMES

The three global solutions described above yielded three celestial reference frames. The differences between the CRF where the harmonic signals in the station position were taken into account (S2G) and the standard solution (S1G) are plotted in light red colour in Figure 2. In blue colour the comparison between the CRF with reduced mean annual signal from the station coordinates (S3G) and the standard solution (S1G) is shown. In the upper plots the comparison in right ascension ($dRA \cdot \cos(De)$) and in the lower plots the differences in declination (dDe) are illustrated. The first two columns on the left-hand side designated as "(a)" display the comparison between the datum sources only, in the middle "(b)" differences between sources which participated in at least two sessions and were observed more than 20 times are shown, and the two last columns "(c)" depict the differences between all sources in

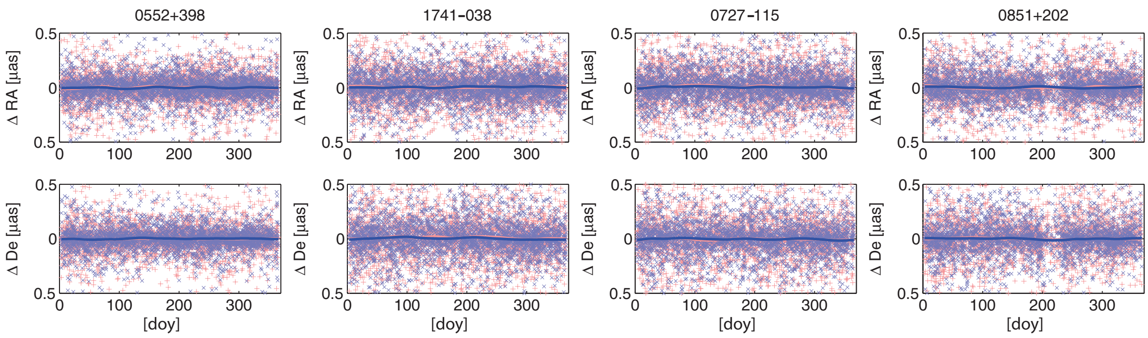

Figure 3: Differences in session-wise estimated coordinates for four most observed sources in right ascension (upper plots) and declination (lower plot) are shown. The light red "+" depict the differences between S2 w.r.t. S1 and the blue "x" show the differences between S3 w.r.t. S1. The lines are smoothed mean annual signal.

the estimated CRF. From the plots it is obvious that the application of seasonal station models does not cause any systematic effect in the estimated source coordinates. However, significant changes in the individual source position appear if the source is observed only in a small number of sessions distributed non-evenly over the year. This happens for the datum sources in the southern hemisphere, where the difference between the solutions reaches up to 0.2 mas. For the other sources observed only in one session with very few observations the difference in the estimated coordinates reaches up to 1 mas (Figure 2 (c)). In the middle plots which contain only sources with more than 20 observations these large differences vanish.

Beside the comparison of celestial reference frames, we also focused on a comparison between estimated time series of the source coordinates. We run again all three global solutions but excluded the four most observed sources from the celestial reference frame and estimated them session-wise as reduced parameters. Figure 3 shows the estimated positions of these most observed sources in our analysis with respect to the solution S1 . The light red "+" show the differences between the session-wise radio source coordinates from solutions S2 and S1, and differences between solutions S3 and S1 are plotted as blue "x". The lines depict the smoothed average annual signal. There is no significant propagation of the neglected seasonal signal from the station coordinates into the radio source positions. The differences between the solutions lie in the sub-microarcsecond range.

4. CONCLUSIONS

Two kinds of models for unmodelled long-period signals in station coordinates were created. One of them being the harmonic model at annual and semi-annual periods, the second one a non-harmonic mean annual model. Seasonal station movements do not yield any significant systematic effect on the CRF but can cause a significant change in position of radio sources with a small number of sessions non-evenly distributed over the year.

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