Impact of Seasonal Surface Displacement on Earth Rotation and Global Reference Frames

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Abstract The calculation of actual station positions requires several corrections, which are recommended by the International Earth Rotation and Reference Systems Service (IERS) Conventions (e.g., solid Earth tides and ocean tidal loading) as well as other corrections, e.g. for hydrology or atmospheric loading. To investigate the pattern of omitted non-linear seasonal motion, we estimated empirical harmonic models for selected stations within a global solution of suitable Very Long Baseline Interferometry (VLBI) sessions as well as mean annual models by stacking yearly time series of station positions. To validate these models we compare them to displacement series obtained from the Gravity Recovery and Climate Experiment (GRACE) data and to hydrology corrections determined from global models. Furthermore, we assess the impact of the seasonal station motions on the celestial reference frame as well as on Earth Orientation Parameters (EOP) derived from VLBI analysis. Additionally, we demonstrate that a harmonic signal in the station east coordinate with an amplitude of 3 mm propagates into dUT1 (UT1–UTC) with an amplitude of 0.01 ms, by using a set of artificial VLBI observations.

Keywords seasonal surface displacement, Earth Orientation Parameters, global reference frames

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1 Introduction

The position of a station is defined in a terrestrial reference frame as a sum of the position at a certain time epoch and a linear velocity trend. For a better approximation of the actual station position, several tidal and non-tidal corrections are recommended by the International Earth Rotation and Reference Systems Service (IERS) Conventions to be applied to the station coordinates. Krásná et al. (2014) [5] showed that the difference between the modeled time series of the station position and the estimated position series includes a long-periodic signal which is omitted in the recommended a priori models. We developed two empirical models to describe the signal. The first one is a harmonic model at annual and semi-annual periods, where the corresponding amplitudes for the selected stations were estimated within a global adjustment of VLBI data, and the second model is based on a mean annual signal obtained from a stacked time series in a local coordinate system of the stations. In this work we compare our models to the GRACE-derived surface displacement monthly time series provided by M. Weigelt and T. van Dam and to hydrology loading displacement computed from the monthly GLDAS NOAH model provided by the NASA GSFC VLBI group[1] (Eriksson and MacMillan, 2014 [3].) In Section 3 we examine the propagation of the omitted seasonal signal in the station coordinates to the Earth Orientation Parameters (EOP) and the Celestial Reference Frame (CRF).

[1] `http://lacerta.gsfc.nasa.gov/hydlo`

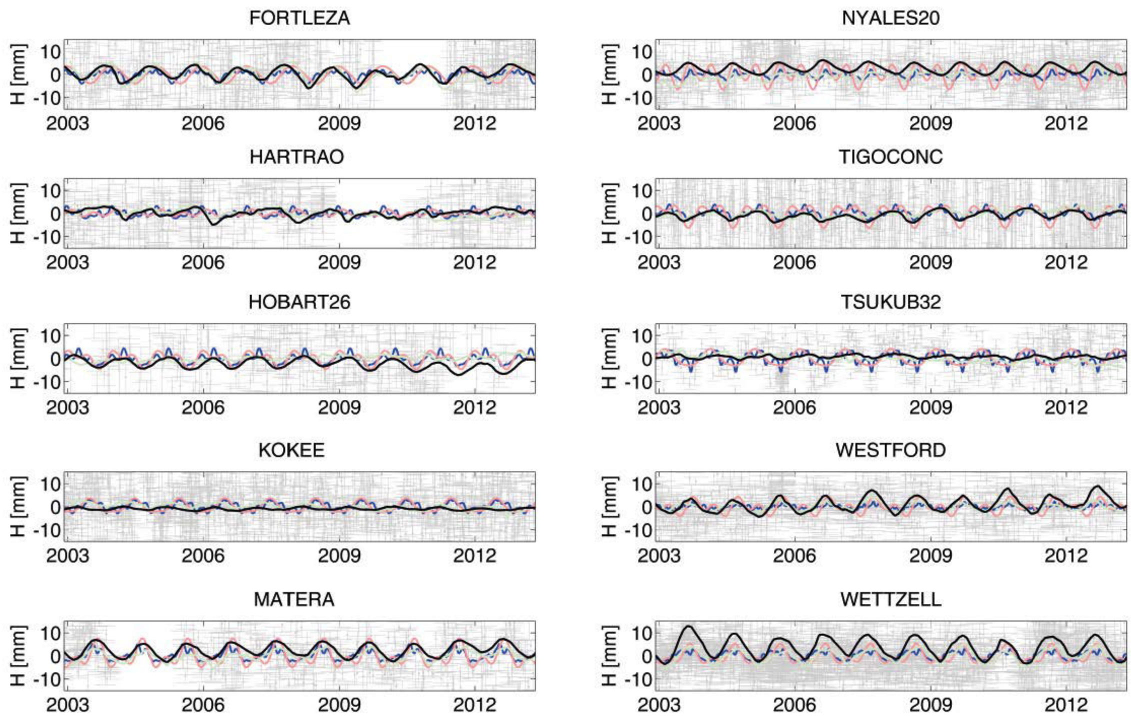

Fig. 1 Monthly GRACE time series (green color) together with the harmonic model at annual and semi-annual periods estimated from VLBI (light red color) and with the mean annual models from VLBI (blue color) at ten selected VLBI stations. In black color, the hydrology loading is plotted. The session-wise corrections of the height component from a VLBI solution without applying the seasonal models' a prioris to station positions are shown as grey error bars. For the colors, we refer to the electronic version of the paper.

2 Analysis

In our analysis, we included about 3,700 24-hour IVS sessions starting in the year 1984 until April 2013, which represent 5.6 million observations. The GRACE deformation series was provided as a monthly time series in the local coordinate system for the location of the VLBI telescopes. The analysis settings to derive the displacement from the GRACE measurements are summarized in Table 1. Figure 1 shows the surface displacement in height at ten stations which have the largest number of observations during the included time span of data. The visualization of the data starts in 2003 because this is the year when GRACE started to observe. The light red and blue curves show our empirical models: the harmonic model and the mean annual, respectively. The displacement of the VLBI telescopes derived from the GRACE data is plotted in green color. In black, we show the hydrology loading corrections. In Table 2, the correlation coefficients between the seasonal models and the displacement series from GRACE measurements (first and second columns) and from the hydrology loading model (third and fourth columns) are listed. At most of the stations, the correlation for the estimated models is higher with the hydrology loading model rather than with the displacement derived from the GRACE time series, i.e., at 70% of the stations for the harmonic model and at 80% of the stations for the mean annual model. The reason for this is that GRACE can only provide a model with a particular resolution so that the loading at specific sites cannot be retrieved.

3 Differences in Estimated EOP and CRF

To examine the propagation of the omitted signal in the station coordinates to the Earth Orientation Parameters, we artificially constructed the VLBI measurements and

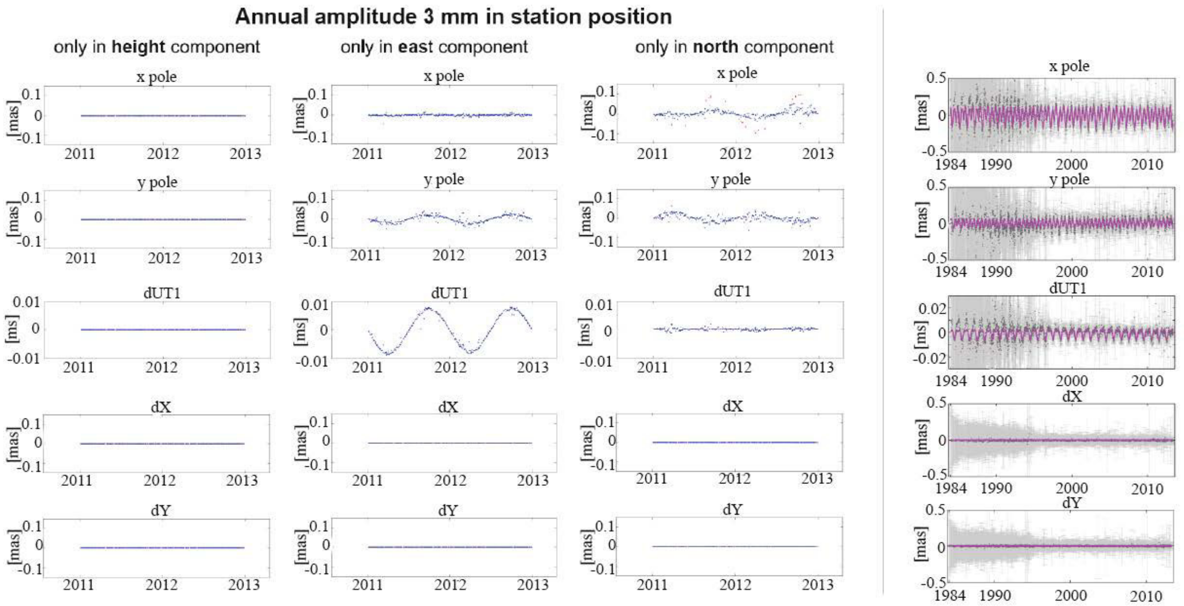

Fig. 2 Estimated EOP from artificial observations (first three columns) and from real observations (fourth column).

Table 1 Settings for GRACE deformation series. Courtesy of M. Weigelt and T. van Dam.

Source	University of Texas CSR
C20	replaced by SLR Rel05 from Cheng and Tapley (2004) [2]
Degree 1	replaced by time series of Swenson et al. (2008) [6]
Descripting	yes
Filtering	Gaussian with 350 km
GAC	not added
Frame	center of figure

Table 2 Correlation coefficients between the seasonal models and the displacement series obtained from GRACE measurements and from hydrology loading models.

VLBI telescope	correlation coefficients: Harmonic model x GRACE	Mean Annual model x GRACE	Harmonic model x Hydrological loading	Mean Annual model x Hydrological loading
Fortleza	0.65	0.61	0.41	0.71
HartRAO	0.20	0.08	0.23	0.10
Hobart26	0.11	0.02	0.66	0.71
Kokee	0.29	0.10	0.14	0.33
Matera	0.58	0.49	0.70	0.67
NyAles20	0.35	0.29	0.20	0.09
Tigoconc	0.31	0.22	0.73	0.64
Tsukub32	0.00	0.02	0.34	0.21
Westford	0.28	0.60	0.41	0.59
Wettzell	0.67	0.62	0.73	0.74

analyzed them in a standard analysis approach using the software VieVS (Böhm et al., 2012 [1]). We took the real schedules of the IVS sessions over two years from 2011.0 until 2013.0, and we filled up these schedules with the so-called zero-input time delay, i.e., with a time delay which is equal to the calculated delay from the models. In total we ran four data analyses, and in each of them, the five EOP were estimated. The first solution was the reference. In the three further analyses, a harmonic signal with an amplitude of 3 mm was added into one of the station local coordinate components (height, east, and north) at all VLBI telescopes. The difference in the estimated EOP between these three solutions with respect to the reference is plotted in the first three columns of Figure 2. It can be seen that the annual harmonic signal in the station height component does not propagate into the EOP (first column), but the neglected signal in the east coordinate (second column) propagates directly into dUT1 (causes differences up to 0.01 ms) and into the y-pole coordinate (difference up to 0.04 mas). Signals in the north station coordinate influence both the x- and y-pole coordinates. Especially in regional European networks (red dots in the upper plot in column three of Figure 2), the omitted harmonic displacement propagates directly into the x-pole coordinate, where the difference reaches up to 0.1 mas. The estimated celestial pole coordinates dX and dY are not affected. The last column of Figure 2 shows the difference in estimated EOP from the real VLBI observations between the solutions from data analysis with and without applying the harmonic displacement model. The range of the difference in the estimated EOP corresponds to the results from the simulations.

To investigate the effect of the seasonal displacement in the station coordinates on celestial reference frames, we ran the following three global solutions in which we estimated the terrestrial and celestial reference frames together with EOP. The first solution S1 was the reference, in the second solution S2 the harmonic model was applied a priori to the station coordinates, and in the third solution S3 the mean annual model was applied. We plot the differences in the estimated CRF with respect to the solution S1 for three sets of radio sources. The upper plot in Figure 3 contains only datum sources where larger differences between the estimated positions at sources in the southern hemisphere are present, which were observed only in a limited number of sessions. The middle plot of Figure 3 shows sources which were observed more than twenty times in at least two sessions. Note that the scale of this plot is two times larger than for the defining sources. The lower plot contains all radio sources. The scale of the obtained differences is five times larger when the sources with fewer than twenty observations are examined.

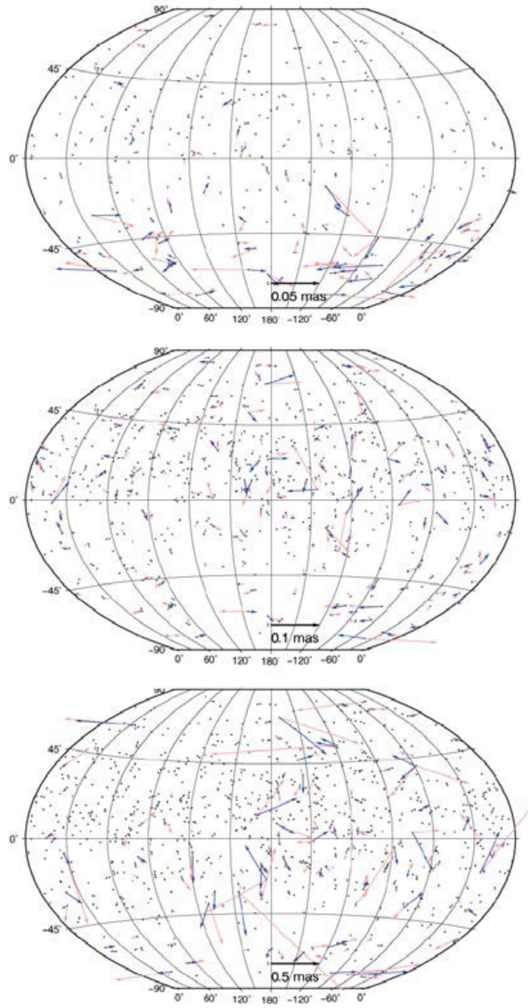

Fig. 3 Comparison of CRF from solution S2 (light red) and S3 (blue) with respect to S1 for datum sources (upper plot), sources with more than 20 observations (middle plot), and all sources (lower plot).

4 Conclusions

Two kinds of empirical models were created for unmodeled seasonal signals in station coordinates. For validation, we compared them to displacement series obtained from the GRACE data and to hydrology loading corrections. We showed that the unmodeled harmonic signal propagates from station coordinates into the Earth rotation parameters. Especially the signal in the station east coordinates with an amplitude of 3 mm propagates into dUT1 with an amplitude of 0.01 ms. The seasonal station movements do not yield any significant systematic effect on the CRF but can cause a significant change in the positions of radio sources from a small number of sessions unevenly distributed over the year.

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