ASSESSING RECENT HIGH-FREQUENCY EARTH ROTATION MODELS WITH VERY LONG BASELINE INTERFEROMETRY

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ABSTRACT. The International Earth Rotation and Reference Systems Service (IERS) Conventions 2010 recommend a model for diurnal and semi-diurnal variations of the Earth Rotation Parameters (ERP, polar motion and UT1) based on a data-constrained ocean tide model which is more than 20 years of age (Egbert et al. 1994). Since that time, the precision of the space geodetic techniques has improved and there is a strong need for an updated high-frequency ERP model, in order to avoid degradation of the geodetic products provided by the several techniques. In this work, we assess several recently published high-frequency ERP models and validate their performance in the analysis of Very Long Baseline Interferometry (VLBI) observations for the time span 1995–2015. Alongside two empirical models, i.e., a GPS-based solution by Steigenberger (2009) and a VLBI-based model by Artz et al. (2011), we test technique-independent estimates derived by Desai and Sibois (2016) from a modern ocean tide atlas. Preliminary results show that Desai and Sibois' hydrodynamic approach is indeed capable of reducing some of the large ERP residuals produced by the old IERS standard, e.g., at semi-diurnal frequencies in both polar motion and UT1. In the diurnal band, improvements using Desai and Sibois' model are less obvious, and particularly large residuals of 20 µas (microarcseconds) are found for K_1 contributions to both polar motion and UT1.

1. INTRODUCTION

The diurnal and semi-diurnal periodic variations of the high-frequency Earth Rotation Parameters (ERP, polar motion and UT1) are predominantly caused by ocean tides. Currently, a set of ocean tide amplitudes made up by 71 terms is recommended by the International Earth Rotation and Reference Systems Service (IERS) Conventions (2010). An assimilation method (Egbert et al. 1994) was utilized in the computation of these amplitudes based on the analysis of TOPEX/Poseidon satellite altimetry measurements (TPXO, version 2). Since then, the accuracy of geodetic techniques has improved significantly, so that a new conventional high-frequency model is required. Following this demand we review four models including the present IERS Conventional model using Very Long Baseline Interferometry (VLBI) analysis. Our assessment of these models is intended to indicate the closest solution to the observed variations. Residuals are compared between hydrodynamic approach constrained by a state-of-the-art altimetry atlas TPXO.8 (Desai and Sibois, 2016) and geodetic technique-dependent empirical solutions (Artz et al., 2011; Steigenberger, 2009). While the geodetic technique-induced deficiencies were rather expected, the altimetry-dependent model also produces sizable residuals.

2. VLBI ANALYSIS

High-frequency tidal variations were derived from the geodetic VLBI analysis using observational data (Schuh and Behrend, 2012) for the last 20 years. Table 1 gives an overview of the analysis data set and the main reduction models; see Girdiuk (2017) for a detailed discussion. ITRF2014 (Altamimi et al., 2016) was included as the terrestrial reference frame, and ICRF2 (Fey et al., 2015) as the celestial reference frame.

VLBI observations and reference frame	Geophysical effects	Model	Tide terms included in model
Time delays for 1995–2015	Ocean tidal loading	FES2004 (Lyard, 2006)	8 major ocean tides
	Atmospheric tidal and non-tidal loadings	TU Wien (Wijaya et al., 2013)	2 atmospheric tides -
Station positions in ITRF2014	High-frequency ocean tides models	IERS Conventional model	71 tide terms
		Desai and Sibois, 2016	159 tide terms
		Artz et al., 2011	71 tide terms
		Steigenberger, 2009	33 tide terms
Source positions in ICRF2	Libration	IERS Conventional model	10 diurnal in PM 11 semi-diurnal in dUT1

Table 1: Observations and specification of the main geophysical reduction sets.

Periodic effects in station position variations were described on the basis of eight diurnal and semi-diurnal ocean tides provided by FES2004 (Lyard, 2006). Atmospheric tidal loading (S_1 and S_2 lines) as well as atmospheric non-tidal corrections were adopted from Wijaya et al. (2013), where atmospheric pressure fields were convolved with the proper Green's functions. In accordance with the designed assessment, the analysis setup implements four different a priori models taking into account high-frequency Earth rotation (Table 1). Desai and Sibois (2016)'s model is based on an updated altimetry-constrained ocean tide atlas TPXO.8 (Egbert et al. 1994), validated in terms of ERP against GPS observations. As in the present study the model by Mathews and Bretagnon (2003) was used to account for the libration effects. Another a priori model is the empirical solution obtained by Artz et al. (2011) as a transformation of the normal equation systems of the VLBI observations (including polar motion and dUT1) at a high resolution of 15 minutes. The tide terms were drawn from the high-frequency ERP time series derived in that solution. A second empirical model comes from Steigenberger (2009), in which the GPS observations were processed on the normal equation level in three-day intervals and sub-daily ERP were calculated at two-hour steps. Regarding applied reductions, the IERS Conventional model completes corresponding selection in both empirical models, especially, the adoption of a priori models in the high-frequency band of the ocean tides and libration effects. Also, the set of other geophysical effects (tidal ocean loading and others listed in the IERS Conventions) is mostly consistent with the VLBI analysis performed in this paper and may only differ with respect to the atmospheric effects.

Amplitude residuals were calculated per tide term for the set of 71 constituents, even though the selection of tide harmonics varies among the considered models. For the sake of consistency the same libration effects recommended by the IERS Conventions were applied. Amplitudes of the prograde and retrograde tide terms were obtained as global parameters using the method implemented by Böhm (2012). The terrestrial and celestial reference frames, corresponding tide amplitudes and axis offsets were assessed in the same global adjustment, where normal equations are stacked. The station and source positions were found to represent reasonable values, thus the tide terms and their formal errors were subjected to further analysis.

3. RESULTS

Amplitude differences in prograde polar motion, retrograde polar motion, and dUT1 are shown in Figure 1. Retrograde diurnal components are omitted since the a priori nutation model is assumed to be perfectly accurate. Also, the threefold σ-level (≈ 2.5 µas) added in Figure 1 is approximately similar for the diurnal and semi-diurnal bands of polar motion. In dUT1 this threshold is about 0.2 µs. The global adjustment is performed over a considerable number of observations, thus formal errors might be biased, making the current assessment too optimistic. In any case, residuals within the error circles are statistically insignificant, thus the respective a priori values might provide a sufficient account of those constituents. Note that the amplitudes of some minor ocean tides might experience a slight change, yet such alterations are different to interpreter in face of the error level. We place our emphasis on the major ocean tides marked with corresponding labels (Q_1, O_1, P_1, K_1, N_2, M_2, S_2, K_2). In particular, the model by Artz et al. (2011) yields the smallest scatter of residuals, especially in the semi-diurnal band, though some clear deficiencies are still evident in both polar motion (K_1, O_1) and dUT1 (M_2). The

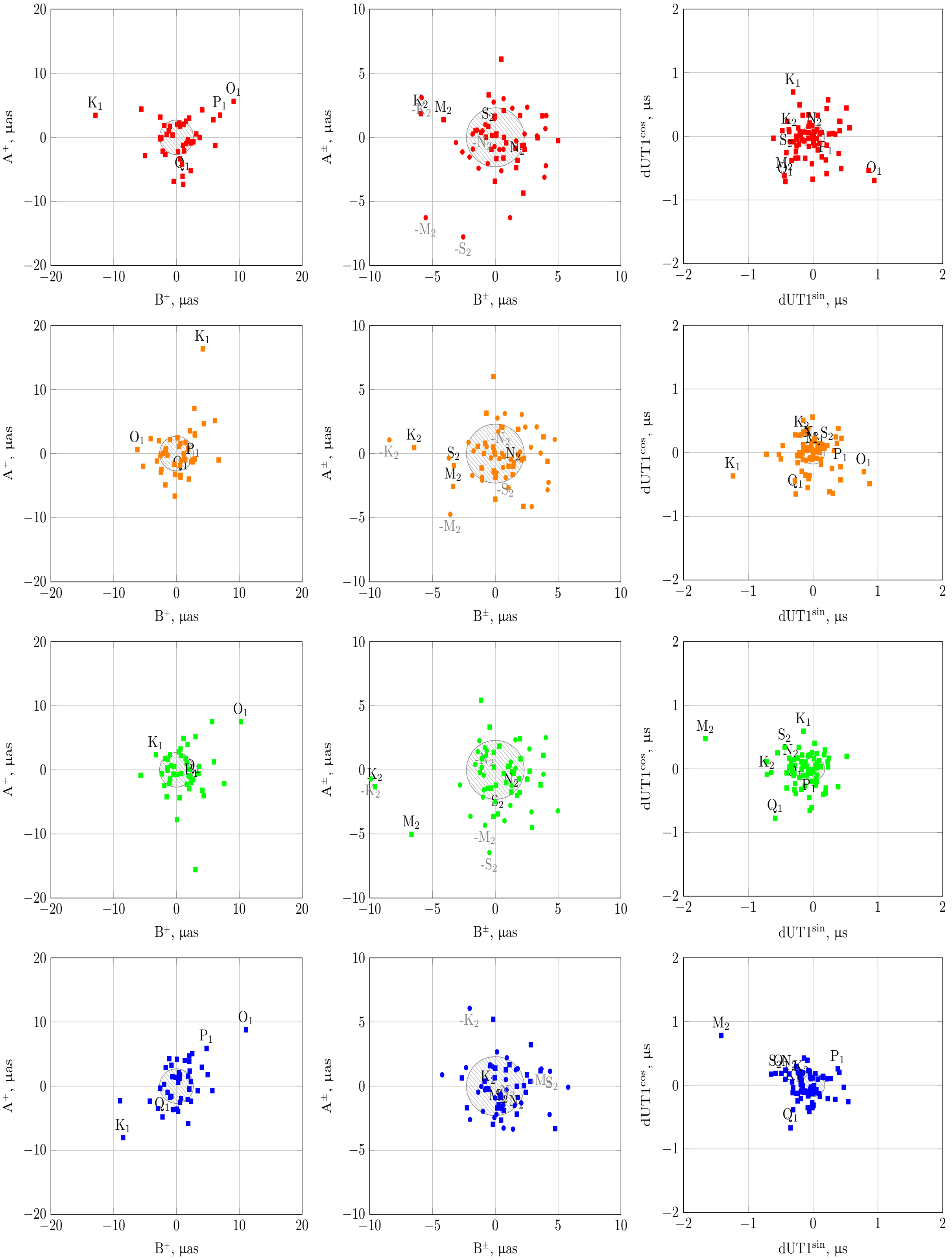

Figure 1: The obtained residuals per tide term for each model. Columns show the estimated amplitude differences for prograde diurnal polar motion, prograde (squares) and retrograde (circles) semi-diurnal polar motion, and dUT1 (from left to right). Annotations mark prograde terms (above the data) and retrograde terms (below the data, in gray). Panels from top to bottom illustrate the results for the Conventional model, Desai and Sibois (2016), Steigenberger (2009), and Artz et al. (2011). Threefold σ-levels are marked by the gray hatched circle.

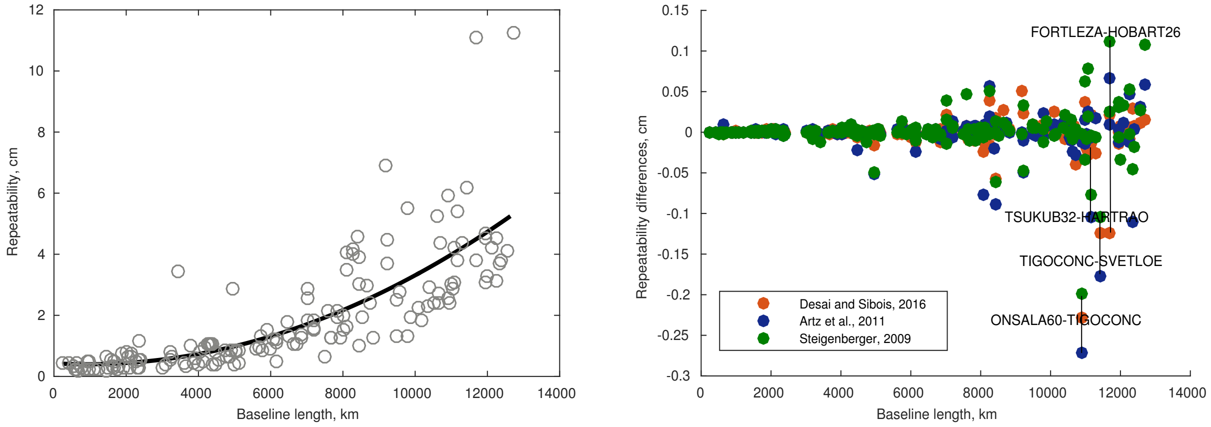

Figure 2: Four VLBI solutions are characterized by baseline length repeatability and fitted quadratic polynomial (left); differences relative to the solution using conventional model as a priori high-frequency ocean tide model (right).

other empirical model by Steigenberger (2009) evidently suffers from the orbit resonance problem in the GPS analysis (K_2) and exhibits sizable residuals in dUT1. The hydrodynamic modeling by Desai and Sibois (2016) reveals a certain improvement in comparison to the conventional model, but large residuals remain for the K_1 tide (> 15 µas in polar motion and > 1 µs in dUT1) and partially for the O_1 and Q_1 tides in dUT1.

The validation of the performed VLBI analyses can be seen in Figure 2 by means of baseline length repeatability. In the VLBI analysis this parameter often characterizes the obtained solution. In this paper, each of the applied high-frequency ERP models produces a reasonable scatter of the baseline length repeatability. The small station position corrections to the a priori values indicate that the adopted models are of high fidelity and have minimal disturbances among each other over the processed data set. On the right side in Figure 2, these minor differences are apparent for individual but very long baselines. Moreover, baseline results involving stations TSUKUB32 (Tsukuba, Japan) and TIGOCONC (Concepcion, Chile) may not be fully trustworthy in view of the occurrence of earthquakes at these sites. In the case of the current analysis we can neglect these outliers.

4. CONCLUSION AND OUTLOOK

This work was dedicated to the assessment of the different models which provide the high-frequency ocean tide terms. Judging from our visualizations, the technique-independent model by Desai and Sibois (2016) is indeed capable of improving upon the conventional model, but before considering it as new standard, imperfections for most of the diurnal tides (K_1, O_1, Q_1) must be addressed. Given that an altimetry-based models (based on TPXO atlases) were demonstrated to provide a close match to the observed ERP variations in the high-frequency band, other empirical solutions, such as the EOT atlas (Savcenko and Bosch, 2012) could be also beneficial for the hydrodynamic modeling. However, neither hydrodynamic nor pure altimetric models take into account the main atmospheric tide (S_1), which the VLBI and GPS methods observe inseparably from the gravitationally-induced signal. Reliable geophysical estimates for the atmospheric tide contribution in the S_1 band were published recently (Schindelegger et al., 2017). As regards polar motion, the effect is below the formal error of the current VLBI solutions (2.5 µas). At the same time, the VLBI-based estimates in polar motion (Girdiuk, 2017) are the closest to Schindelegger et al, (2017), but still in two or three times larger than this reference value. Moreover, an overestimation of amplitudes at the frequencies of the atmospheric tides is seen in empirical solutions, leading to larger S_1 residuals in the present assessment than the hydrodynamic modeling approach. By contrast, the S_1 contributions (1 µs signal magnitude) to dUT1 are significant with an excellent agreement between the VLBI-based and geophysical model estimates.

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