Earth Orientation Parameters Estimated From K-band VLBA Measurements

H. Krásná, D. Gordon, A. de Witt, C. S. Jacobs, B. Soja

Abstract The Earth Orientation Parameters (EOP), which connect the Terrestrial and Celestial Reference Frame, are regularly estimated by Very Long Baseline Interferometry (VLBI). The UT1-UTC and nutation components of EOP can only be measured using the VLBI technique. Until recently, published VLBI estimates of EOP were based solely on observations from the S/X frequency band.
We present VLBI estimates of EOP from an observing frequency independent of the traditional SX-band using Very Long Baseline Array (VLBA) measurements at K-band (24 GHz, 1.2 cm). We have over two years of regular VLBA experiments conducted with telescopes located in U.S. territory. We investigate the potential of K-band VLBI to produce more accurate EOP because of its reduced source structure effects relative to S/X-band. We compare our K-band EOP computed with two analyses software packages (Calc/Solve and VieVS) to the IERS C04 data.

Keywords K-band · EOP · VLBA · VLBI

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1 Introduction and data

In this paper we present solutions containing 69 K-band VLBI observing sessions with the first one in May 2002 and the last one in January 2019. From that amount, 52 sessions were observed with the VLBA network on the U.S. territory (15 sessions before 2015). The remaining 17 experiments are the single baseline sessions between HartRAO and Hobart26 which makes less that 1 % of the total number of K-band observations. In these single baseline sessions the Earth Orientation Parameters (EOP) were fixed in the analysis to their a priori values and the sessions are used mainly to strengthen the Celestial Reference Frames (CRF) estimation.
The data rates increased significantly from 128 to 256 Mbps before 2015 to 2048 Mbps after the year 2015. After the Mark6 recorder upgrade a data rate of 4096 Mbps is anticipated. For further information about the K-band project we refer to de Witt et al. (2019); Le Bail et al. (2019); Soja et al. (2019).

2 Parametrization

We show two independent solutions of the EOP. The GSFC-k-190207 was computed at the Goddard Space Flight Center with the software package Calc/Solve and the TUW-k-190223 was processed at the Technische Universität Wien with the VieVS software package (Böhm et al., 2018) using the NGS cards as input. Some of the differences between the TUW and GSFC solution are, e.g., that GSFC includes delay rates to the analysis, and that the Galactic aberration was modeled and applied in the GSFC solution to give source posi-

tions at the 2015.0 epoch.
In both solutions the same global parameters were estimated. The Terrestrial Reference Frame (TRF) was realized with the VLBA station positions and linear velocities for epoch 2010 with applying the No Net Translation (NNT) and No Net Rotation (NNR) condition w.r.t. ITRF2014. The celestial reference frame was estimated with source positions where the TUW solution used an unweighted NNR w.r.t. ICRF2 defining sources, whereas the GSFC solution applied an unweighted NNR constraint on 193 ICRF3 defining sources.
For the session-wise estimated parameters we used a similar parametrization in both solutions:

- TRF — station position of HartRAO, Hobart26, Tianma65, Tidbinbilla70
- Clock parameters — 60 min estimation intervals
- Zenith wet delay — continuous piece-wise linear offsets in 30 min intervals with 1.5 cm relative constraints
- Troposphere gradients –- continuous piece-wise linear offsets in 360 min intervals with 0.05 cm relative constraints
- EOP — 1 offset per session from VLBA
- EOP from single baseline sessions were fixed to IERS 14 C04 combined series (Bizouard et al., 2019).

Table 1: Median formal error of the estimated EOP.

		median formal error
x pole	GSFC-k-190207	71
[µas]	(pre-2015 / post-2015)	109 / 58
	TUW-k-190223	80
	(pre-2015 / post-2015)	168 / 72
y pole	GSFC-k-190207	89
[µas]	(pre-2015 / post-2015)	184 / 78
	TUW-k-190223	108
	(pre-2015 / post-2015)	288 / 97
dUT1	GSFC-k-190207	6
[µs]	(pre-2015 / post-2015)	9 / 5
	TUW-k-190223	7
	(pre-2015 / post-2015)	17 / 6
nutation dX	GSFC-k-190207	42
[µas]	(pre-2015 / post-2015)	54 / 38
	TUW-k-190223	50
	(pre-2015 / post-2015)	78 / 45
nutation dY	GSFC-k-190207	41
[µas]	(pre-2015 / post-2015)	58 / 34
	TUW-k-190223	49
	(pre-2015 / post-2015)	72 / 40

Ionosphere corrections were estimated from 2 hour average JPL GPS ionosphere maps by David Gordon and applied in both solutions.

3 Results

Plots in the left-hand side column in Fig. 1 show the session-wise estimated offsets w.r.t. the IERS 14 C04 EOP from the VLBA sessions, and in the right-hand side column the respective formal errors are depicted. The black colour represents the GSFC-k-190207 solution, the light red colour the TUW-k-190223 solution, and the formal errors of the IERS 14 C04 EOP are depicted with blue plus signs. In the Table 1 the median of the formal errors of the two EOP solutions is summarized. In addition we distinguish between the data sets before the year 2015 and after 2015. We see a decrease of the median formal error in all five EOP after 2015 of about a factor of two. Table 2 shows statistics for the EOP estimates w.r.t. IERS 14 C04 time series, such as the weighted mean, median, wRMS, χ^2 and normalized deviation from unity $(\chi^2 - 1)/\sigma(\chi^2)$. Post-2015 wRMS scatter is noticeably improved for the polar motion. However, nutation do not improve much except for Vienna dX nutations. Offset in the y-pole component is related to the VLBA telescope distribution. Future investigations will be devoted to understand why the offset in the y-pole component is so prominent in the TUW-k-190223 solution.

4 Conclusions and outlook

Reasonable EOP series can be produced from the K-band VLBA measurements. Comparison of two independent global adjustments computed with two software analysis packages (VieVS and Calc/Solve) is shown. Future plans: We anticipate a factor of 1.4 increase in sensitivity from doubling the data rates to 4096 Mbps. Testing of the new rate will start this year. Operations may begin in 2019/20. Both the Celestial and Terrestrial Frames should improve with time thereby improving EOP.

Table 2: Statistics of the difference between estimated EOP and IERS 14 C04.

		weighted mean [µas, µs]	median [µas, µs]	wRMS [µas, µs]	χ^2 [–]	$(\chi^2-1)/\sigma(\chi^2)$ [–]
x pole	GSFC-k-190207 (pre-2015 / post-2015)	−49 / 272	−30 / 299	249 / 143	3.69 ± 0.38 / 3.29 ± 0.24	7.11 / 9.71
	TUW-k-190223 (pre-2015 / post-2015)	−102 / 185	−164 / 218	270 / 165	1.92 ± 0.38 / 3.34 ± 0.24	2.42 / 9.94
y pole	GSFC-k-190207 (pre-2015 / post-2015)	−160 / 189	−287 / 232	504 / 203	7.20 ± 0.38 / 5.42 ± 0.24	16.41 / 18.76
	TUW-k-190223 (pre-2015 / post-2015)	−1228 / −72	−1119 / −89	344 / 201	1.28 ± 0.38 / 3.56 ± 0.24	0.74 / 10.85
dUT1	GSFC-k-190207 (pre-2015 / post-2015)	15 / −14	15 / −14	37 / 52	10.48 ± 0.38 / 11.52 ± 0.24	25.08 / 44.63
	TUW-k-190223 (pre-2015 / post-2015)	16 / −18	4 / −18	38 / 52	3.88 ± 0.38 / 10.57 ± 0.24	7.61 / 40.62
nutation dX	GSFC-k-190207 (pre-2015 / post-2015)	−120 / −18	−106 / −45	137 / 129	4.10 ± 0.38 / 3.66 ± 0.24	8.21 / 11.29
	TUW-k-190223 (pre-2015 / post-2015)	−66 / 58	−97 / 20	133 / 105	12.98 ± 0.38 / 4.41 ± 0.24	31.69 / 14.48
nutation dY	GSFC-k-190207 (pre-2015 / post-2015)	−32 / −67	−62 / −58	105 / 109	2.44 ± 0.38 / 2.98 ± 0.24	3.80 / 8.42
	TUW-k-190223 (pre-2015 / post-2015)	−39 / −62	−51 / −53	98 / 104	7.25 ± 0.38 / 5.59 ± 0.24	16.53 / 19.46

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References

Bizouard C, Lambert S, Gattano C, et al. (2019) The IERS EOP 14C04 solution for Earth orientation parameters consistent with ITRF 2014. *J Geod*, 93, 621–633, doi:10.1007/s00190-018-1186-3

Böhm J, Böhm S, Boisits J, et al. (2018) Vienna VLBI and Satellite Software (VieVS) for Geodesy and Astrometry. *PASP*, 130/986, 1–6, doi:10.1088/1538-3873/aaa22b

de Witt A, Gordon D, Jacobs C S, et al. (2019) The K-band (24 GHz) Celestial Reference Frame. Poster at the 24th EVGA Working Meeting, http://www.oan.es/evga2019/EVGA2019_PDF/P306_EVGA2019_deWitt.pdf

Le Bail K, de Witt A, Jacobs C S, et al. (2019) Time stability of the K-band catalog sources. In: R. Haas, S. Garcia-Espada, J. A. López Fernández (eds.): *Proc. 24th EVGA Working Meeting*, 209–213

Soja B, Jacobs C S, Runge T, et al. (2019) Ionospheric calibration for K-band celestial reference frames. Presentation at the 24th EVGA Working Meeting, http://www.oan.es/evga2019/EVGA2019_PDF/O316_EVGA2019_Soja.pdf, doi:10.13140/RG.2.2.34409.95840

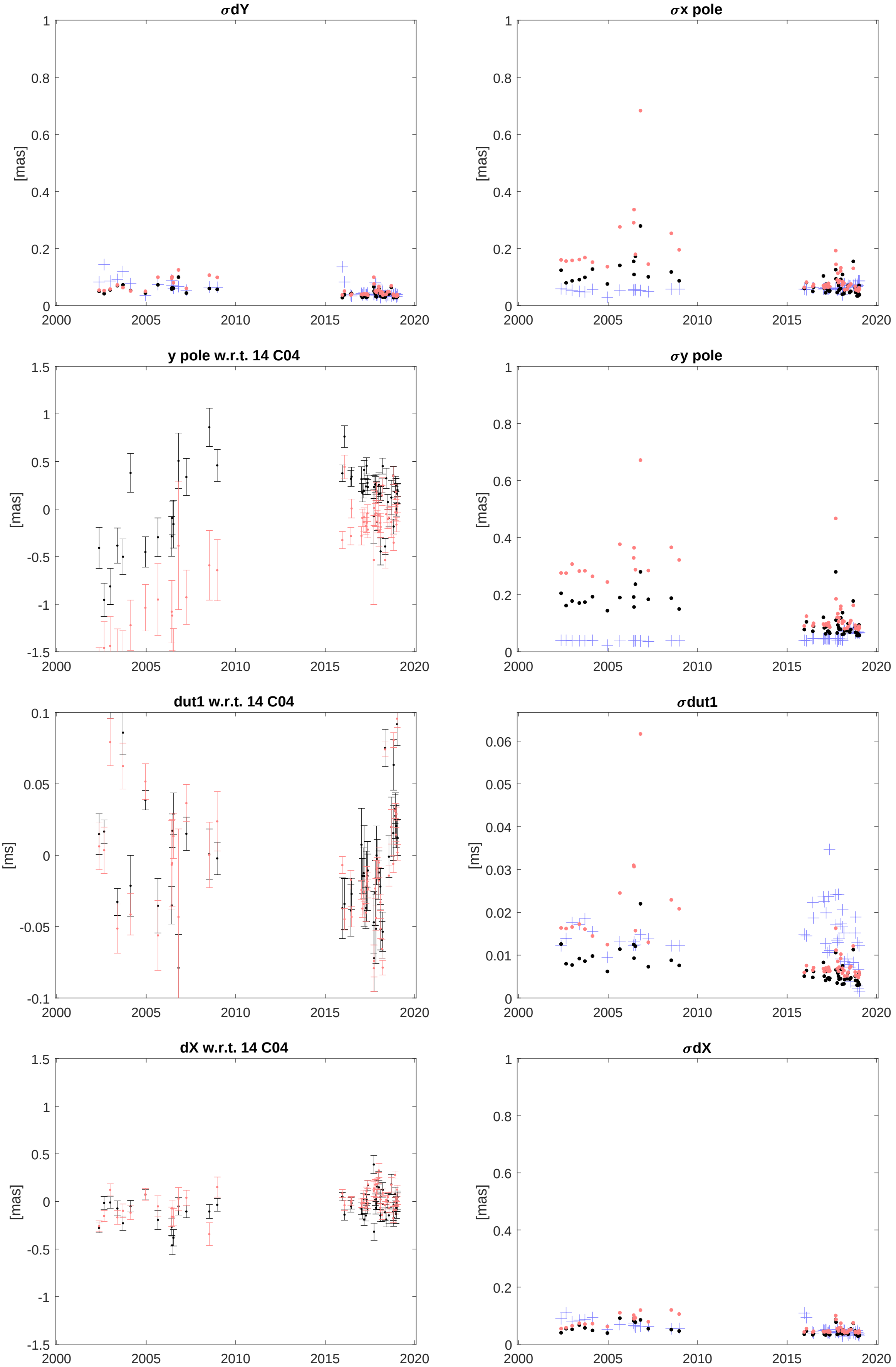

Fig. 1: Caption next page.

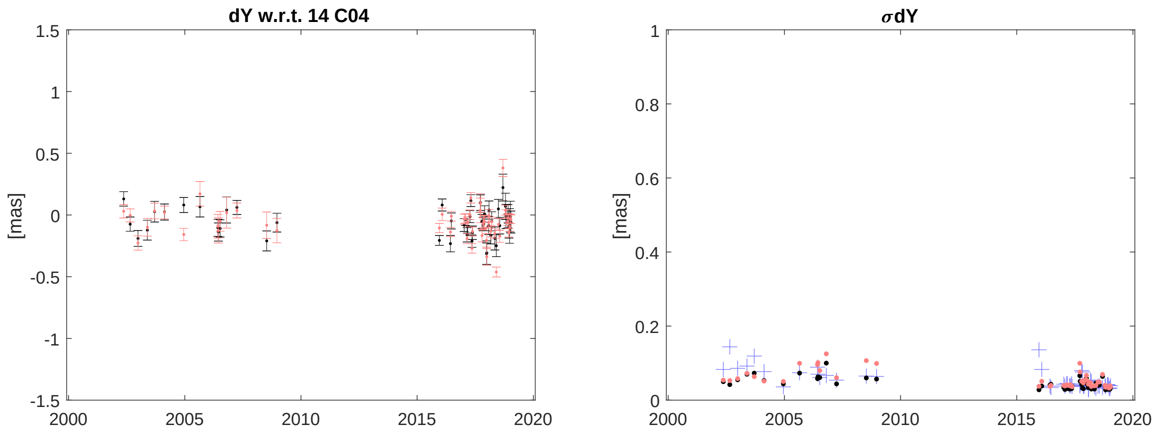

Fig. 1: On the left-hand side EOP offsets w.r.t. the IERS 14 C04 values are shown and on the right-hand side the respective formal errors. The GSFC-k-190207 solution is plotted in black, the TUW-k-190223 solution in light red, and the formal errors of the IERS 14 C04 EOP are depicted with blue plus signs.