# **GNSS** slant delays in the analysis of VLBI Intensive sessions



Kamil Teke<sup>(1)</sup>, Johannes Böhm<sup>(2)</sup>, Younghee Kwak<sup>(2)</sup>, Matthias Madzak<sup>(2)</sup>, Peter Steigenberger<sup>(3)</sup> <sup>(1)</sup>Hacettepe University, Turkey <sup>(2)</sup>Vienna University of Technology, Austria <sup>(3)</sup>Deutsches Zentrum für Luft- und Raumfahrt, Germany

IAG Commission 1 Symposium 2014: Reference Frames for Applications in Geosciences (REFAG2014) 13-17 October, 2014 Kirchberg, Luxembourg Session 4: Celestial to Terrestrial Frame Transformations

**1. Abstract:** So-called VLBI Intensive sessions of the International VLBI Service for Geodesy and Astrometry (IVS) are dedicated to the rapid production of UT1-UTC estimates. However, the accuracy achieved with those sessions is still below what could be expected from formal uncertainties of the estimates. One of the reasons for that might be the inappropriate modelling of azimuthal asymmetries of the tropospheric delays, because usually no gradients are modelled or estimated. To overcome that deficiency, we apply tropospheric zenith delays and gradients from the analysis of Global Navigation Satellite Systems (GNSS) observations in the analysis of all VLBI Intensive sessions in 2013 and compare our results to length-of-day estimates determined with GNSS. We find significant improvement for certain types of VLBI Intensive sessions compared to the state-of-the-art analysis.

## 2. VLBI Intensive sessions

- The International VLBI Service for Geodesy and Astrometry (IVS) realises mostly 1-hour one-baseline sessions to estimate the Earth's phase of rotation, expressed as Universal Time (UT1).
- For this purpose dedicated sessions are:
  - INT1: WETTZELL (Germany) and KOKEE (Hawaii, USA) observe from Monday to Friday (session code XU).
  - INT2: TSUKUB32 (Japan) and WETTZELL observe on Saturday and  $\checkmark$ Sunday (session code XK).
  - INT3: WETTZELL, TSUKUBA, and NYALES20 (Norway) observe on Monday (session code XK) (see Figure 1).



## 5. Comparison of troposphere parameters

**Table 3:** Biases and standard deviations of ZWD differences between GNSS CODE and GNSS IGS solutions in mm. Calculation of biases and standard deviations consists of all observation epochs of VLBI Intensive sessions when both GNSS CODE and GNSS IGS troposphere delays are available.

VLBI Intensive	<b>GNSS CODE</b>	<b>GNSS IGS</b>	bias ± std. dev. in mm	total number of
session code			[CODE(ZWD) – IGS(ZWD)]	common epochs
XU	kokb	kokb	-0.9 ± 3.3	2844
XU,XK	wtzr	wtza	$1.3 \pm 2.9$	4394
XK	tskb	tskb	-0.8 ± 3.0	1578
XK	nyal	nya1	$-2.0 \pm 1.8$	230

#### **Table 4:** Biases and standard deviations of ZWD differences between GNSS CODE - VLBI and GNSS IGS - VLBI solutions in mm.

VLBI sites	<b>GNSS CODE</b>	bias ± std. dev. in mm	<b>GNSS IGS</b>	bias ± std. dev. in mm	
		[CODE(ZWD) – VLBI(ZWD)]		[IGS(ZWD) – VLBI(ZWD)]	
		(total number of observations)		(total number of observations)	
KOKEE	kokb	2.7 ± 6.6 (2915)	kokb	3.7 ± 7.1 (2884)	
TSUKUB32	tskb	8.1 ± 6.7 (1829)	tskb	9.4 ± 7.1 (1578)	
WETTZELL	wtzr	4.4 ± 5.2 (4712)	wtza	2.9 ± 5.8 (4434)	
NYALES20	nyal	5.8 ± 1.8 (261)	nya1	7.7 ± 2.1 (230)	

#### For further information: <u>http://ivscc.gsfc.nasa.gov</u>

Figure 1: Baseline geometry of the VLBI Intensive sessions with session codes XU and XK. The XU baseline is plotted in green and the XK baselines in red (stereographic map projection).

## **3. Solution Descriptions**

Intensive sessions XK in 2013.

**Table 1:** VLBI Intensive sessions (XU and XK) solution types

Solution Type	Slant wet delays	Azimuthal asymmetric delay	Additional information about solutions	
Solution1	Zenith Wet Delay (ZWD) estimated	Troposphere gradients not estimated	Standard solution of VLBI Intensive sessions with 5 estimated parameters: a ZWD offset for each VLBI site, one offset and a rate for the clock, UT1-UTC ( $\Delta$ UT1).	
		Gradients from CODE	Center for Orbit Determination in Europe (CODE) and International	
Solution2		Gradients from IGS	parameter estimation.	
ZWD from CODE		Gradients from CODE	A constant total troposphere delay correction due to the height	
Solutions	ZWD from IGS	Gradients from IGS	ZWD offset was estimated per VLBI site.	
Solution4	ZWD from CODE	Gradients from CODE	Neither troposphere delay correction due to the height difference	
	ZWD from IGS	Gradients from IGS	between GNSS and VLBI sites were added to ZHD nor a ZWD offset was estimated per VLBI site.	

## 4. Providing external troposphere slant delays

- ZHD were calculated from the pressure values at VLBI sites for each observation epoch (ZHD\_VLBI) of VLBI Intensive sessions.
- ZWD and gradient estimates of GNSS were linearly interpolated to the observation epochs.
- Total troposphere delay correction due to the height difference at co-located sites (ΔZTD = ΔZHD + ΔZWD ) was added to ZHD VLBI.
- ZWD at VLBI site for each observation epoch was derived as: ZWD\_GNSS@VLBI = ZTD\_GNSS (ZHD\_VLBI + ΔZTD). ZHD VLBI and ZWD GNSS@VLBI were mapped to slant direction using VMF. • Gradients were mapped to slant direction as:  $\Delta L = mfg(e) \cdot (Gn \cdot cos(az) + Ge \cdot sin(az))$  with the gradient mapping function mfg(e):  $mfg(e)=1/(sin(e) \cdot tan(e)+0.0032).$

**Table 5:** Biases and standard deviations of north and east gradient differences between GNSS CODE and GNSS IGS solutions in mm.

<b>GNSS CODE</b>	<b>GNSS IGS</b>	bias ± std. dev. in mm	bias ± std. dev. in mm	Total number of
		[CODE(NGR) – IGS(NGR)]	[CODE(EGR) – IGS(EGR)]	common epochs
kokb	kokb	$0.0 \pm 0.5$	$0.1 \pm 0.5$	2915
tskb	tskb	$-0.1 \pm 0.5$	$0.1 \pm 0.4$	1829
wtzr	wtza	$-0.1 \pm 0.4$	$-0.1 \pm 0.3$	4712
nyal	nya1	$-0.4 \pm 0.3$	$0.1 \pm 0.2$	261

## 6. Results

- In total 204 VLBI Intensive sessions (XU and XK) with the GNSS CODE delays and 196 sessions with the GNSS IGS delays were analysed. The XU and XK sessions with  $\Delta$ UT1 formal errors in Solution 1 larger than 30  $\mu$ s were excluded from the statistical comparisons.
- LOD were calculated from the estimated ΔUT1 values of XU and XK sessions using the equation below: LOD( $t_0$ )=[ $\frac{\Delta UT1(t_2) - \Delta UT1(t_1)]}{+ -+}$ ]. 1 day, ( $t_2 - t_1 < 1.2$  day)

where t<sub>2</sub> and t<sub>1</sub> are the consecutive estimation epochs of  $\Delta UT1$ , t<sub>0</sub> denotes the epoch of LOD and calculated as:  $(t_1+t_2)/2$ .

• The daily LOD values from GNSS CODE solution and IERS C04 08 series were interpolated to the LOD epochs of XU and XK VLBI Intensive sessions using ±5 point Lagrange interpolation.



 $\Delta UT1(INT[XU])$  - $\Delta UT1(INT[XK])$  - **Table 6:** Total number of  $\triangle$ UT1 and LOD values used for the statistical comparisons.

	GNSS CODE DELAYS		GNSS IGS DELAYS	
	XU	ХК	XU	ХК
$\Delta$ UT1	159	41	157	35
LOD	85	24	81	18

• For each observation, troposphere slant delays SD are derived as: SD = ZHD\_VLBI mfh<sub>VMF</sub> + ZWD\_GNSS@VLBI mfw<sub>VMF</sub> +  $\Delta$ L

#### **Table 2:** Summary of the properties of external troposphere delays in the analyses of VLBI Intensive sessions

	Zenith total / wet delay	Estimation interval of zenith delays	Estimation interval of gradients	Troposphere mapping function	Elevation cut off angle	<b>Co-located GNSS sites with</b> VLBI
GNSS CODE	ZTD	2 hours	2 hours	VMF	3 degrees	wtzr, kokb, nyal, tskb
GNSS IGS	ZTD	5 minutes	5 minutes	GMF	7 degrees	wtza, kokb, nya1, tskb



ΔUT1(C04 08)	ΔUT1(C04 08)	ΔUT1(C04 08)	ΔUT1(C04 08)
[TROPOSPHERE	[TROPOSPHERE	[TROPOSPHERE	[TROPOSPHERE
ELAYS FROM CODE]	DELAYS FROM IGS]	DELAYS FROM CODE]	DELAYS FROM IGS]

**Figure 3:** Standard deviations of  $\triangle$ UT1 which were estimated from VLBI Intensive sessions, i.e. XU and XK, observed in 2013. The a priori EOP series was set to IERS CO4 08 when analysing the sessions.



*Figure 4:* Standard deviations of LOD differences between the estimates of VLBI Intensive sessions and those derived from a GNSS CODE solution and IERS CO4 08 combined EOP series.

### **7.** Conclusions

- Compared to UT1 values from IERS C04 08, there is no improvement when introducing external tropospheric delays from GNSS for XU sessions and only a small improvement for XK sessions. It should be stressed here that the UT1 values of the IERS C04 08 series heavily rely on UT1 values from VLBI Intensive sessions derived without external delays.
- There is a clear improvement in LOD when compared to LOD estimates from the solutions of GNSS when applying external tropospheric delays. The improvement is largest for XK sessions with gradients from GNSS IGS and GNSS CODE and for XU

#### number of VLBI observations of intensive sessions XK in 2013



#### Figure 2: Troposphere total east gradients at Tsukuba from GNSS CODE and GNSS IGS solutions at each observation epoch of VLBI

We do not see any additional significant improvement of LOD agreement when external ZWD are introduced.

