Observation Level Combination of GNSS and VLBI with VieVS: a simulation based on CONT11

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ABSTRACT GNSS and VLBI antennas were connected to the identical hydrogen maser clocks at seven sites during CONT11, which means that clock parameters can be regarded as common parameters at those sites as well as troposphere parameters. We construct GNSS single differences between the ranges from two stations to a satellite, using corrected phase measurements with the c5++ software. Combining GNSS single difference and VLBI data during CONT11, we estimate station coordinates and site common parameters, i.e. zenith wet delays, troposphere gradients and clock parameters, with the Vienna VLBI Software (VieVS). Local tie vectors, which contribute to the combination of terrestrial frames between GNSS and VLBI, are introduced as fictitious observations. We compare combination solutions with single technique solutions, assess the impact of the combination at the observation level with respect to geodetic results and discuss the current limitation and potentials to be developed.

1. A Global GNSS & VLBI Network during CONT11

Fig 1 Global network: CONT11 sites using the same clock for both VLBI and GNSS.

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                          :
2011  9 15  0  5 15.00 WTZZGNSS WES2GNSS PG10     sc    -0.00193562711807780  ...
2011  9 15  0  5 15.00 WTZZGNSS WES2GNSS PG13     sc     0.01079601557621570  ...
2011  9 15  0  6 50.00    KOKEE TSUKUB32 1144-379 qq     0.00732405933076071  ...
2011  9 15  0  6 50.00    KOKEE TIGOCONC 1144-379 qq     0.00542015727254934  ...
                          :
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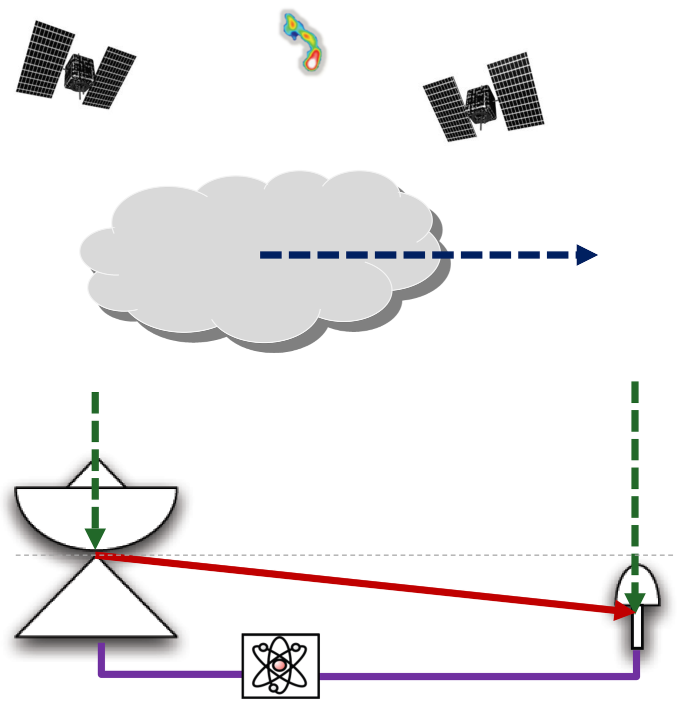
Fig 2 Combined data of two techniques.

In this work, we construct virtual GV hybrid observations during IVS CONT11 campaign. The IVS CONT network has a reasonably balanced geographical distribution of stations between the northern and southern hemispheres and simultaneously acquires GNSS data through International GNSS Service (IGS) sites.

Especially seven sites use the same clocks for VLBI and GNSS during CONT11 (Fig 1). While we take quasar group delay measurements for VLBI, differenced values of post-processed range values (=single differences with most of the errors corrected) are used for GNSS. We regard those data set as GV hybrid observations in this analysis.

2. Combination Strategy



✓ Troposphere gradients

$NGR_{GNSS} - NGR_{VLBI} = 0 \pm 2cm$
$EGR_{GNSS} - EGR_{VLBI} = 0 \pm 2cm$

✓ Zenith Wet Delay (ZWD)

$ZWD_{GNSS} - ZWD_{VLBI} = \Delta ZWD \pm 1cm$

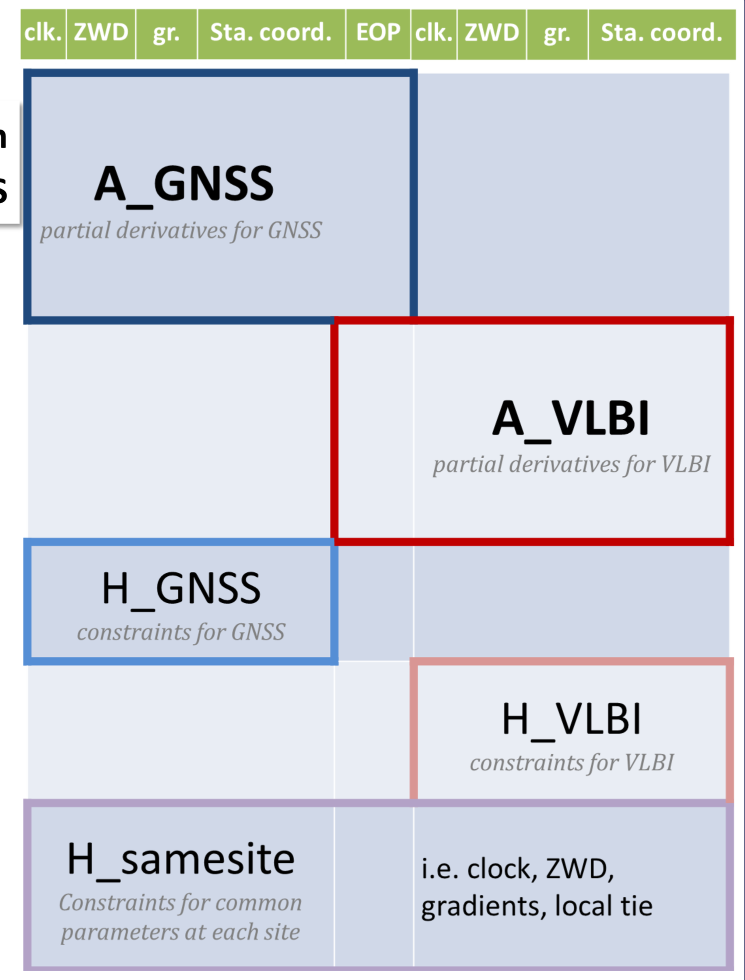
✓ Local tie

$dx_{GNSS} - dx_{VLBI} = \Delta x - (x_{GNSS} - x_{VLBI}) \pm 3cm$

✓ Clock rate

$clk\_rate_{GNSS} - clk\_rate_{VLBI} = 0 \pm 10cm/day$

Fig 3 Combination design matrix implemented in VieVS



	Models & a prioris
Sources	ICRF2/IGS final orbit
Station coordinates	**ITRF2014P**
EOP	IERS 08 C04
Geometric model	Consensus model
	Kliոner (1991)[1]
Solid Earth tide	IERS 2010 conventions

	Parameters	Interval
Clocks	PWL offsets	1hr
	Clock rate	1day
ZWD	PWL offset	2 hr
Gradients	East&west components	6 hr
Station coordinates	NNR/NNT to **ITRF2014P**	1 day
EOP	-	-

[1] Klioner S (1991) General Relativistic Model of VLBI Observables. In: Proceedings of the AGU Chapman Conference on Geodetic VLBI: Monitoring Global Change, pp 188–202

3. Common clocks

Clock parameters are tricky in the estimation. In the analysis, one generally models a station clock by a quadratic polynomial of time plus piecewise linear (PWL) offsets. However, one needs to be careful when defining the actual clock behavior since the cable delay variations and other instrumental delays are also absorbed into the clock parameters. Even though two co-located antennas are connected to the same stable hydrogen maser clock, one cannot simply conclude their clock parameters, i.e. clock offsets, rate and quadratic term, are the same. Therefore, Hobiger and Otsubo (2014)[2] set up a common model for a clock and additionally estimate an inter-technique clock offset with a time dependent model. In this study, we only introduce constraints between site common parameters i.e. troposphere gradients, zenith wet delays, clock parameters. As clock offset differences between the techniques are not consistent, we estimate them as separate parameters. Meanwhile, clock rates look comparable between two techniques (Fig 4). Thus, we apply a loose constraint (10 cm/day or 333 ps/day) for clock rates. We do not consider quadratic terms in this study.

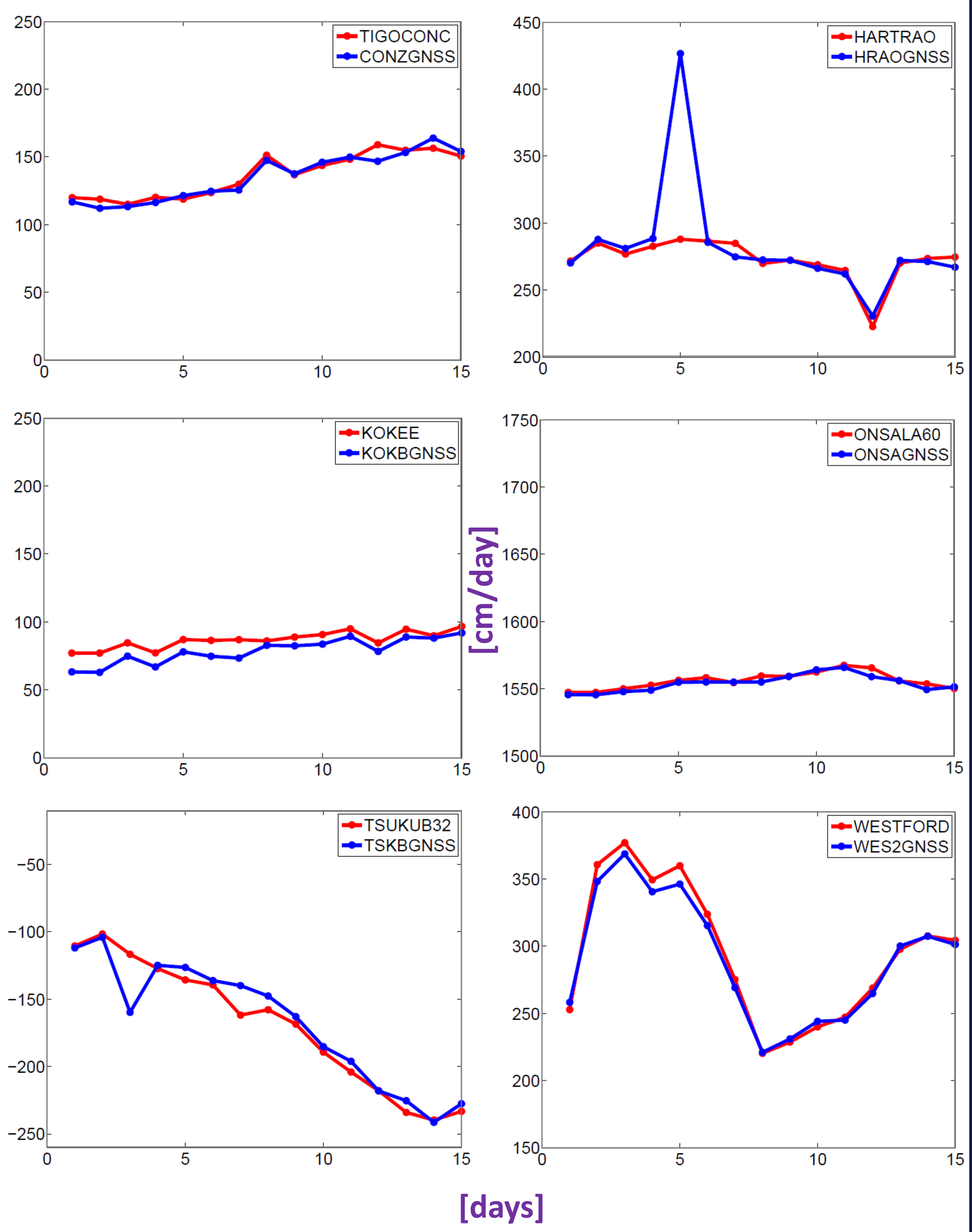
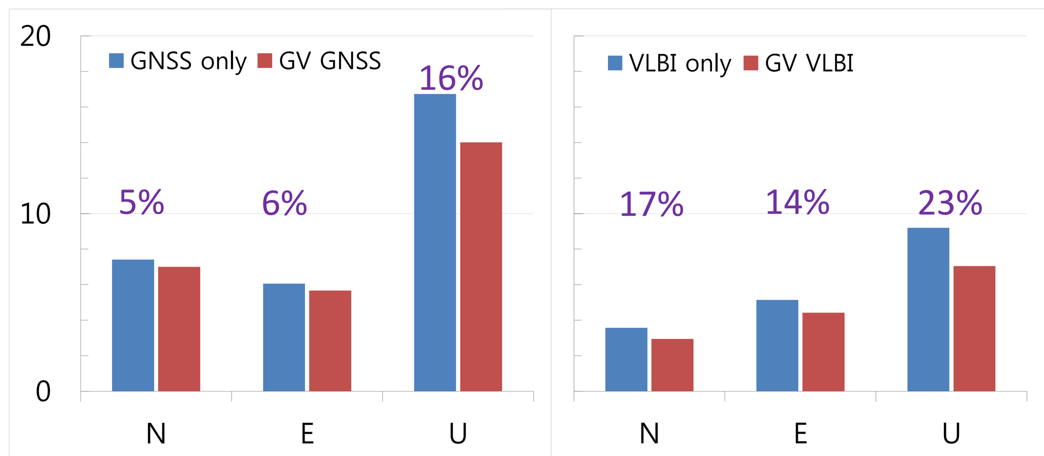


Fig 4 Clock rates of each site which are derived from single technique solutions (red: VLBI, blue: GNSS) during 15 days of CONT11 campaign. Clocks of HRAO and TSKB are excluded from the combination because of the big differences in some days. The clock of WTZZ is set as a reference clock.

[2] T. Hobiger and T. Otsubo. (2014) Combination of GPS and VLBI on the observation level during CONT11 - common parameters, ties and inter-technique biases. J. Geodesy, 88(11):1017– 1028

4. Combination Results

(1) Mean station position repeatability [mm]



After combination, both techniques gain the similar level of benefits in vertical components but VLBI benefits more in horizontal components than GNSS. Better sky coverage of GNSS data due to multiple radio sources at one epoch would be the strong candidate for these improvements.

Since we are still in the test phase to process GNSS data using VieVS, the accuracy of the model involved for GNSS data is at the cm-level and thus the station position repeatability of GNSS stations is larger than the repeatability of usual GNSS solutions.

The agreements of ZWD (single vs. combination) throughout 15 days of CONT11 are within 1 cm (RMS of differences) for each reference point except HRAO VLBI (Fig 5).

(2) Zenith Wet Delays [cm]

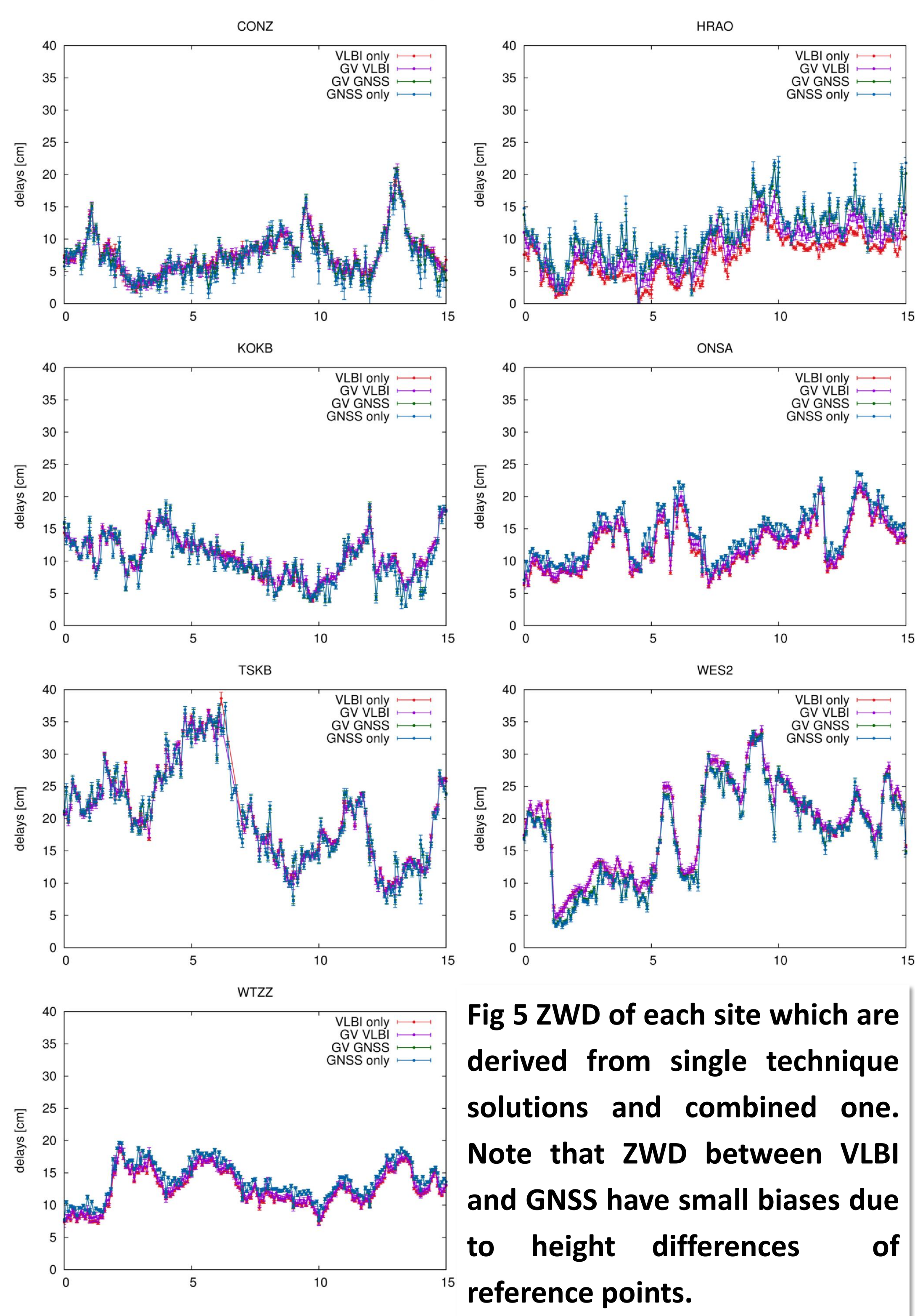


Fig 5 ZWD of each site which are derived from single technique solutions and combined one. Note that ZWD between VLBI and GNSS have small biases due to height differences of reference points.

5. Conclusions

✓ The combined data (CONT11 VLBI + single differenced GNSS) were successfully analyzed in modified VieVS.
✓ For combination, ZWD, troposphere gradients, clocks, and antenna coordinates were constrained using local ties between two techniques.
✓ The combination solutions improve station position repeatability in comparison with single solutions.
✓ The GNSS geometric model in VieVS needs be improved.
✓ The partial derivatives w.r.t. EOP for GNSS will be implemented in VieVS and EOP will be also estimated.