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Combination of the two radio space geodetic techniques with VieVS during CONT14

Younghee Kwak [1], Johannes Böhm [1], Thomas Hobiger [2], Lucia Plank [3], Kamil Teke [4]

Abstract Unlike CONT11, CONT14 does not have official information on common frequency standards for co-located sites. Nevertheless, according to Kwak et al. (2015) [1], we have a possibility to find the co-located sites, which used the same clocks, through comparing clock rates from single technique solutions. Moreover, CONT14 includes co-located VLBI radio telescopes, i.e. HOBART26 and HOBART12. Therefore, it is also a good test bed to develop the analysis strategy for future twin/sibling telescopes. In this study, we compute VLBI-like GNSS delays (GNSS single differences) between the ranges from two stations to a satellite, using phase measurements with most of the errors corrected by the c5++ software. We estimate station coordinates and site common parameters, i.e. zenith wet delays, troposphere gradients and clock parameters, with the Vienna VLBI Software. Common clock parameters are limited to the sites sharing the same frequency standard and having good performance of it during CONT14. Local tie vectors are introduced as fictitious observations for co-located instruments, GNSS-VLBI and even VLBI-VLBI, i.e. at Hobart. In this paper, we show the comparison results between the combination solutions and the single technique solutions in terms of station position repeatability during 15 days.

Keywords VLBI, GNSS, combination at the observation level, CONT14

1 Introduction

The local tie vectors of co-located sites with several space geodetic techniques play a key role to tie different terrestrial reference frames. However, the local tie vectors at many sites show doubtful quality and, furthermore, there is no independent method to validate them. In order to address the vulnerability, the International VLBI Service for Geodesy and Astrometry (IVS) has organised a working group on Satellite Observations with VLBI which studies possibilities to observe Earth satellites with the VLBI ground network affiliated with the IVS (`http://ivscc.gsfc.nasa.gov/about/wg/wg7`). Other than technical issues, it also puts a premium on developing the geometric model of satellites for analysis. The geometric model for GNSS satellites has been implemented in Vienna VLBI Software (VieVS [2]) according to Klioner (1991) [3] and Plank et al. (2014) [4] and it was tested by Kwak et al. (2015) [5] using real GNSS data. The current accuracy of the model involved for GNSS data in VieVS is at the cm-level [5].

IVS schedules CONT campaigns which are sets of continuous VLBI sessions during 15 days having well balanced the geographical distribution of the observation sites. Most of the CONT sites have co-located International GNSS Service (IGS) stations and simultaneously receive GNSS data. Therefore, the CONT campaign is a proper test bed for handling both VLBI and GNSS data in a common analysis software, e.g. VieVS in this study. Of course, GNSS data, usually GNSS phase measurements, need to be distiled for processing with VieVS. For more details, see Kwak et al. (2015) [5].

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3. University of Tasmania
4. Hacettepe University

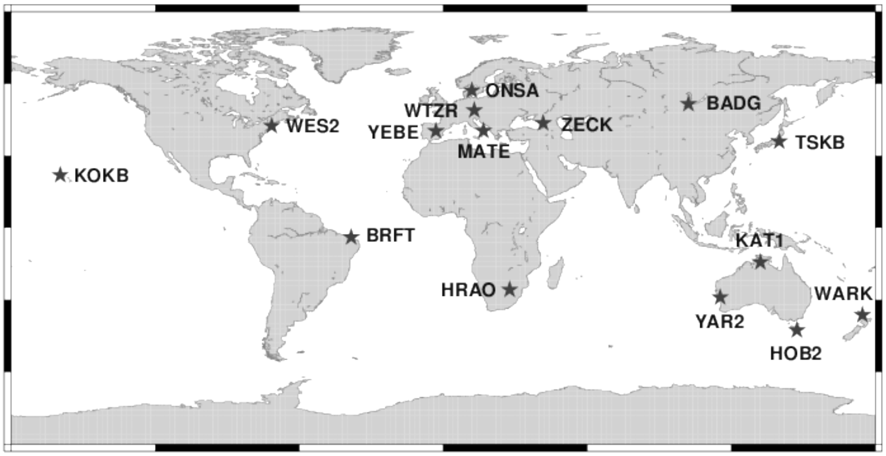


Fig. 1 A global network of co-located sites of IVS and IGS during CONT14. The station codes are written following IGS station code names.

2 Data

CONT14 was observed between May 6th and May 20, 2014. For a period of 15-day CONT14, there were 15 sites co-located with IGS stations (Fig. 1). Especially Hobart (HOB2) had two IVS stations and one IGS station co-located.

We process group delays from CONT14 sessions for VLBI data as usual. In order to process and combine GNSS data together with VLBI data in VieVS, we generate VLBI-like GNSS delays (GNSS single differences) based on real GNSS phase measurements. For more details on production of GNSS delays, see Kwak et al. (2015) [5]. Two kinds of data, i.e. group delays for quasars and VLBI-like GNSS delays for GNSS satellites, are merged into a single file per a 24-hour session.

3 Common clock check

Unlike CONT11, CONT14 has no information about common frequency standards for co-located sites. However, according to Kwak et al. (2015) [1], it is possible to gauge which co-located sites shared the common clocks by way of comparing clock rates from single technique solutions. Fig. 2 shows the comparison of clock rates. Here, the clock rates are relative rates with respect to the reference clock of Wettzell (WTZR). During 15 days, the clock rates of each site except HRAO look comparable between the two techniques and are mostly in the range of ± 20 cm/day which corresponds to around 0.008 ps/s. Some instant peaks of HOB2, KAT1, MATE and ZECK signify clock breaks which are revealed through simple least square estimation (clock offsets and a ZWD). We exclude those sites and HRAO, which did not share the clock, for clock rate combination. The sites, which do not appear in Fig. 2, are initially excluded from clock rate combination. Meanwhile, clock offsets cannot be used for comparison because the cable delay variations and other instrumental delays are also absorbed into the clock parameters. We also do not consider quadratic terms in this study.

4 Combination and Results

In the combination, we do not deal with products (estimated parameters) or normal equations but construct a combined design matrix which contains the partial derivatives of VLBI and GNSS with common geophysical models (Fig. 3)

All the parameters are estimated separately and the constraints for common parameters, i.e. ZWD, troposphere gradients, and clock rates, are additionally given. ZWDs greatly depend on height because they signify the vertical delay values while radio signals go through wet troposphere. Hence, ZWD corrections have to be introduced to account for the height differences between the co-located techniques. We apply

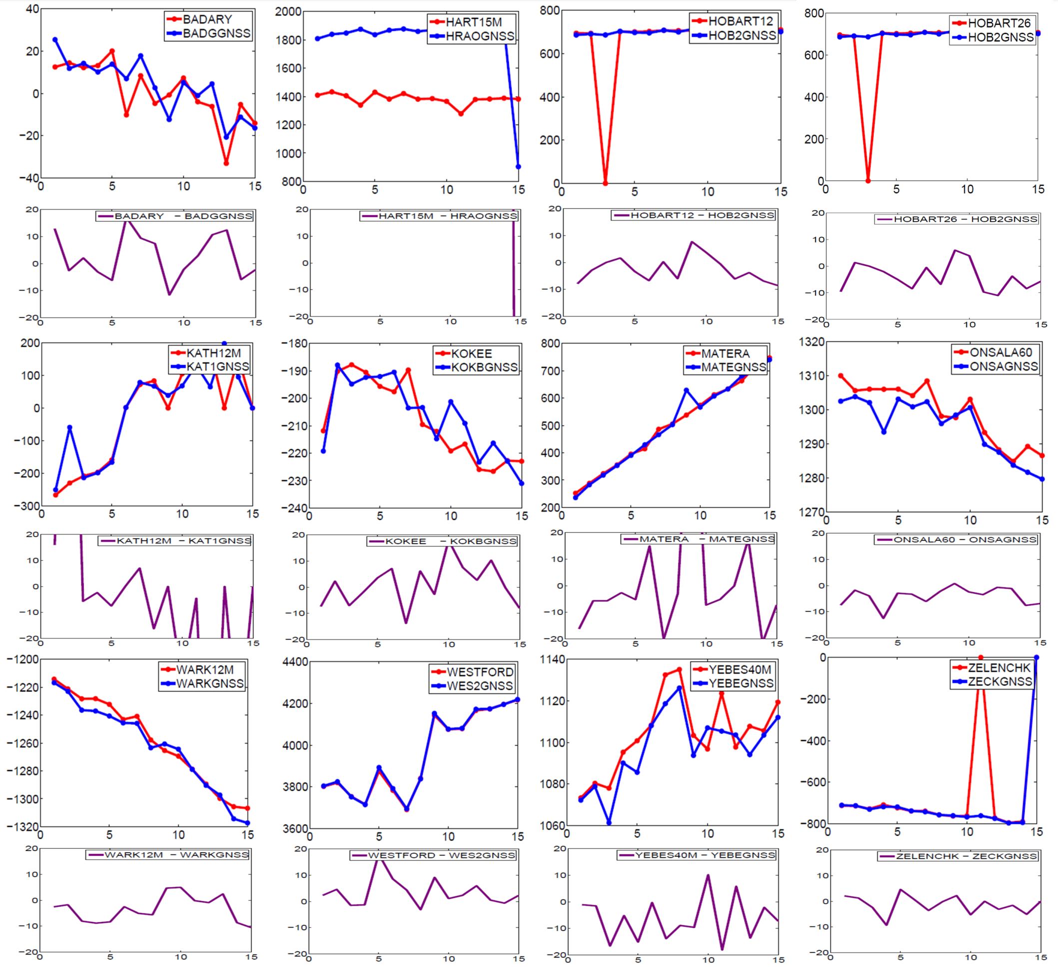


Fig. 2 Clock rates of each site which are derived from single technique solutions (red: VLBI, blue: GNSS, purple: difference) during 15 days of CONT14 campaign. The units of horizontal and vertical axes are days and cm/day, respectively. The clock of WTZZ is set as a reference clock. Except HRAO, the clock rate differences are in the range of ± 20 cm/day corresponding to ± 0.008 ps/s. The instant peaks indicate clock breaks at HOB2, KAT1, MATE and ZECK. The sites, which have been excluded in the analysis at least once because of their data quality, do not appear in this figure.

mean ZWD correction values in accordance with Teke et al. (2011) [7] and use 1 cm constraints. When the horizontal distances between the co-located techniques are close enough, troposphere gradients are supposed to be the same [6]. For troposphere gradients, we apply loose constraints (2 cm). For all the sites, common parameter constraints of ZWDs and troposphere gradients are applied while common clock rates are constrained (10 cm/day) only for chosen sites due to sharing and/or performance of the common clock (Sect. 3 and Fig. 2) during 15-day CONT14.

Besides, we add extra fictitious observations with known local tie vectors (survey measurements) only for several stations, i.e. HRAO, KOKB, ONSA, WES2 and HOB2 (only for VLBI-VLBI). We apply 3 cm for the constraints since the formal errors of the local tie measurement are usually too optimistic.

We have implemented the above combination features in VieVS also for general purposes, e.g. co-located twin/sibling telescopes.

The overview of general analysis strategies is shown in Table 1. The EOP values are fixed to IERS 08 C04 since the partial derivatives of EOP have not been introduced in the GNSS part.

In order to evaluate the combination performance, we compare the mean station position repeatabilities

Table 1 Models and a prioris used in this work

Geometric models	VLBI: Consensus model
	GNSS: Klioner (1991) [3]
Satellite position	IGS final orbit (`http://www.igs.org`)
Station position	ITRF2014 [8]
Solid Earth tide	IERS 2010 Conventions [9]
Ocean loading	FES2004 [10]
Earth orientation parameters	IERS 08 C04 (`http://hpiers.obspm.fr`)
Troposphere delay	Zenith hydrostatic delays from GPT [11]
	VMF [12]
	No a priori for troposphere gradient
Ionosphere	Corrected by using ionospheric linear combination in the PPP processing

of single solutions and combinations. As mentioned in Sect. 1, the current accuracy of the model involved for GNSS data in VieVS is at the cm-level [5] and thus the station position repeatability of GNSS stations is worse than the repeatability of standard GNSS solutions. Therefore, in this paper, we focus on the comparison between single and combination solutions of each technique and the impact of common parameter constraints on combination solutions.

As a results of combination, the mean station position repeatabilities of GNSS solutions are improved by 5, 9 and 13 % for north, east and up components while the ones of VLBI solutions are improved by 4, 6 and 16 % for each component (Fig. 4). The results show that both techniques gain the same level of benefits from combination.

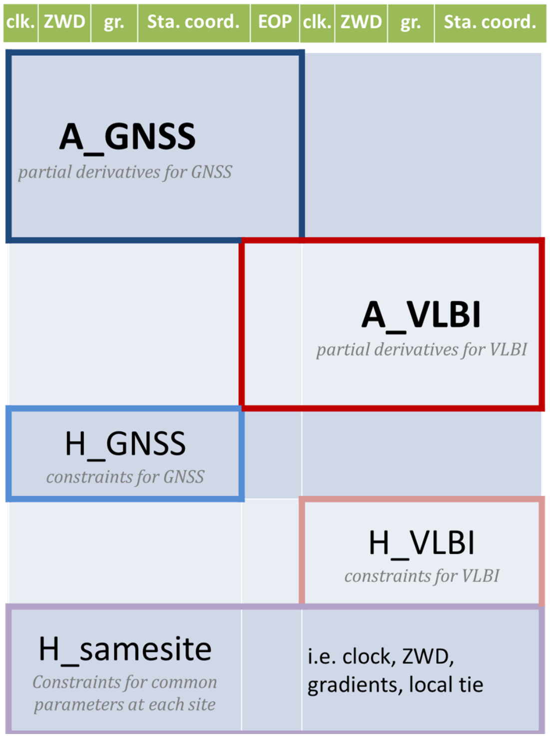
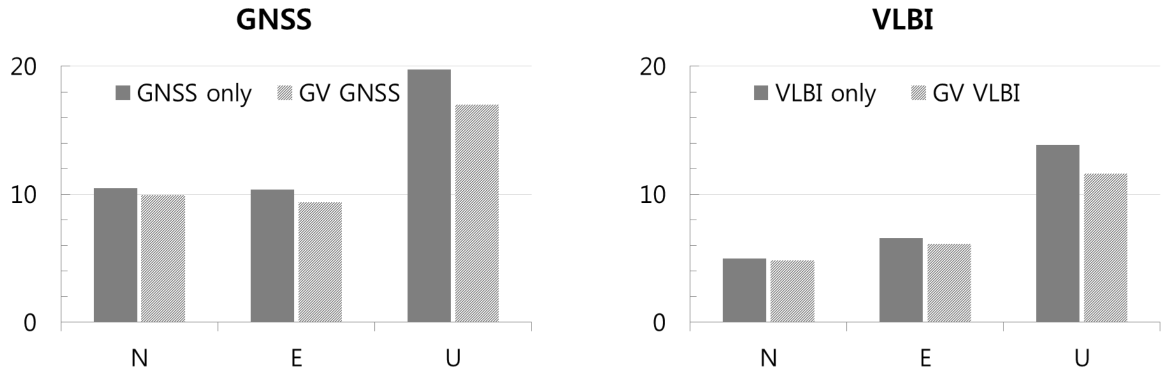


Fig. 3 Construction of the design matrix which consists of partial derivatives (**A_GNSS** and **A_VLBI**) of GNSS and VLBI with respect to clock (column clk.), zenith wet delays (column ZWD), troposphere gradients (column gr.) station coordinates (column Sta. coord.) and Earth orientation parameters (column EOP) and constraints (**H_GNSS** and **H_VLBI**) for them. The partial derivatives with respect to EOP for GNSS have not been implemented yet. The constraints (**H_samesite**) for common parameters and fictitious observations for local ties can be additionally attached for co-located sites.

5 Conclusions

In this paper, we combined VLBI data and VLBI-like GNSS delays for fifteen co-located sites during CONT14. Those data were analyzed in a common VLBI software VieVS as well as single technique data. Comparing clock rates, we could assess if co-located instruments shared the clock at CONT14 sites. For combination, site common parameters (ZWD, troposphere gradients and clock rates) were constrained between two techniques. Furthermore, the local ties of the reference points at the co-located site were selectively introduced. The combination solutions improve mean station position repeatability in comparison with single technique solutions. The analysis strategy of common parameter constraints and local ties can also be applied in co-located VLBI observations with twin/sibling telescopes in the future. As we see from the GNSS results, the GNSS geometric model (near-field model) in VieVS still needs to be improved. Furthermore, the partial derivatives with respect to EOP for GNSS need



(a) (b)

Fig. 4 Mean station position repeatabilities of single solutions (solid box) and combination solutions (box with a pattern of diagonal lines) for north, east and up components. Plot (a) shows the results of GNSS stations and plot (b) the results of VLBI stations. The unit is mm.

to be implemented in VieVS and then one can estimate EOPs and expect better GNSS single solutions and combination results.

Acknowledgements

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