Comparison Study of VLBI and GPS Carrier Phase Frequency Transfer using IVS and IGS data

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Abstract: We compare the frequency transfer precision between VLBI and GPS carrier phase using IVS and IGS observation data in order to confirm the potential of VLBI time and frequency transfer. The results show that VLBI time transfer is more stable than GPS time transfer on the same baseline and same period.

1. Introduction

Modern cold-atom-based frequency standards have already archived the uncertainty of 10^{-15} at a few days. Moreover cold-atom-based optical clocks have the potential to realize the uncertainty on a 10^{-16} to 10^{-17} level after a few hours (Takamoto et al., 2005 [6]). On the other hand, time transfer precision of two-way satellite time and frequency transfer and GPS carrier phase experiments have reached the 10^{-10}@1sec (10^{-15}@1day) level (Ray and Senior, 2005 [5] etc.). In order to compare such modern standards by these time transfer techniques, it is necessary to average over long periods. Since these techniques are not sufficient to compare next standards improvements of high precision time transfer techniques are strongly desired.

Very Long Baseline Interferometry (VLBI) is one of the space geodetic techniques measures the arrival time delays between multiple stations utilizing radio signals from distant celestial radio sources. By using VLBI, it is possible to measure subtle variations of Earth orientation parameters (EOP). In the usual geodetic VLBI analysis, clock offsets and their rates of change at each station are estimated with respect to a selected reference station. The averaged formal error (1 σ) of the clock offsets is typically about 20 picoseconds when analyzing geodetic VLBI experiments which are regularly conducted by the International VLBI Service for Geodesy and Astrometry (IVS). This precision is nearly one order better than other techniques like GPS or two-way satellite time transfer. It is feasible to use geodetic VLBI for comparison of primary frequency standards when radio telescopes are deployed at time and frequency laboratories. For this purpose, we have started to develop a compact and transportable VLBI system (Ishii et al., 2007 [2]).

To confirm the potential of the current VLBI time and frequency transfer aiming at the practical use in the future, we have compared the results of the VLBI and GPS carrier phase frequency transfer using Kashima-Koganei baseline (Takiguchi et al., 2007 [7]). That study showed that VLBI is more stable than GPS between 2000 seconds to 6000 seconds. In this study, we mainly compared VLBI and GPS carrier phase frequency transfer using data from the IVS and the International GNSS Service (IGS) by the same purpose.

2. The comparison experiments between VLBI and GPS carrier phase using IVS and IGS data

We checked the ability of time transfer of VLBI and GPS carrier phase using IVS and IGS data. We selected two stations (Onsala, Wettzell) which belong to IVS and IGS network. These two stations have in common that at each site VLBI and GPS are sharing the hydrogen maser (Figure 1). Table 1 shows a list of the data used for this study.

The details of the analysis of VLBI and GPS are listed as follows:

VLBI

- Software : CALC/SOLVE
- Strategy
  - multi baseline
  - S/X ionosphere-free linear combination
  - reference station: Wettzell

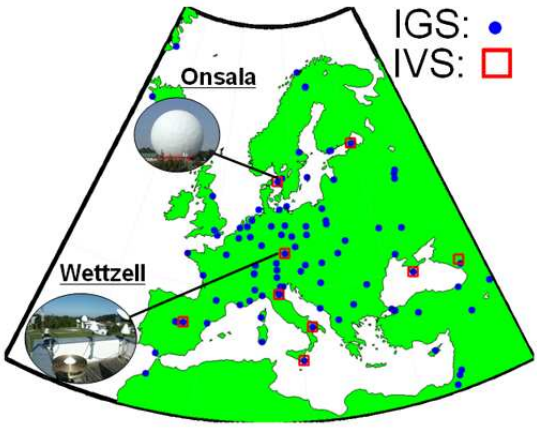

Figure 1. Map of IVS and IGS stations in Europe

Table 1. Data list

DOY (2007)	Session	IVS Station	IGS Station
092	R1270		
100	R1271	ONSALA60,	onsa,
113	R1273	WETTZELL	wtzr
122	R1274		

- Estimate
  - station coordinates
  - atmospheric delay / 1h
  - clock offset / 1h

GPS

- Software : GIPSY-OASIS II
- Strategy
  - Precise Point Positioning (PPP) (Kouba and Heroux, 2001 [4])
- Estimate
  - station coordinates
  - atmospheric delay / 5min
  - clock offset / 5min
- Time Difference
  - *clock offset* A − *clock offset* B

Due to the code noise, the clock offsets of the GPS solutions show discontinuities at the day boundaries. The averaged day boundary discontinuity was 94ps. Figure 2 shows one of the VLBI results of clock offsets. The averaged formal errors (1 σ) of the estimated clock offsets at Onsala station referred to Wettzell station was 16.1ps.

Figure 3 shows that the time series of the clock difference between Onsala and Wettzell (session R1274) calculated from GPS and VLBI respectively (upper part). The lower part of Figure 3 is

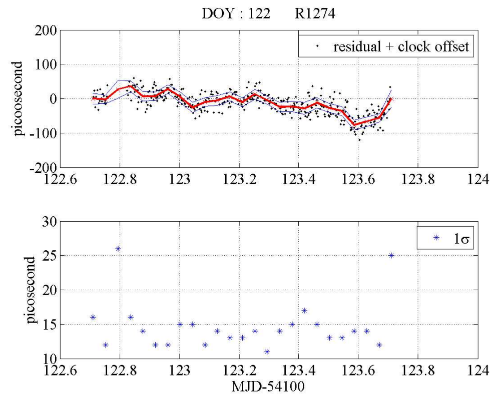

Figure 2. Time series of the clock offsets after removing linear trend (upper) and the formal error (lower) at Onsala station referred to Wettzell station.

the difference between GPS and VLBI clock offsets showing a good agreement within ±200ps.

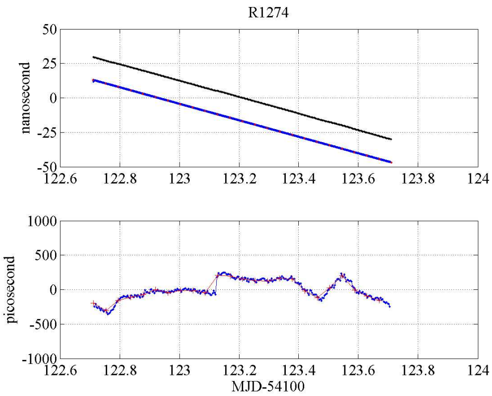

Figure 3. Time series of the clock difference (upper plot) calculated from GPS and VLBI respectively. The lower plot is the difference between GPS and VLBI clock offsets. The gap seen on 123(DOY) was caused by the day-boundary discontinuity of GPS.

Figure 4 and 5 illustrate the frequency stability of clock difference as obtained from VLBI and GPS. The short term stability of GPS carrier phase seems to be slightly better than those from VLBI for averaging periods up to 10^3s. However, VLBI is more stable at averaging periods longer than 10^3s in any sessions (Figure 5).

In general, the VLBI frequency transfer stability follows a $1/\tau$ law very close when averaging up to 10^4s. And that shows that the stability has reached about 2×10^{-11} (20ps) at 1 sec.

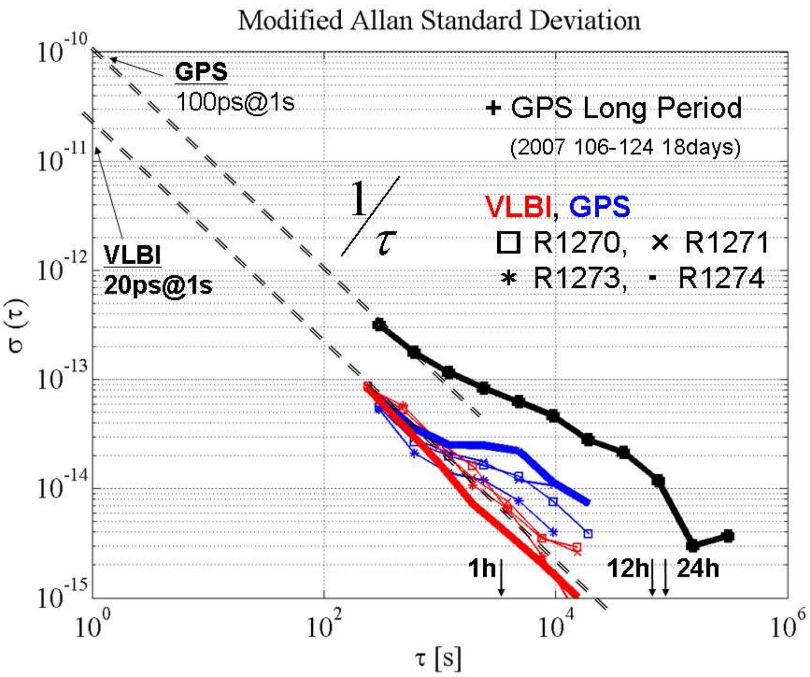

Figure 5. Modified Allan deviation of VLBI and GPS carrier phase results from all sessions.

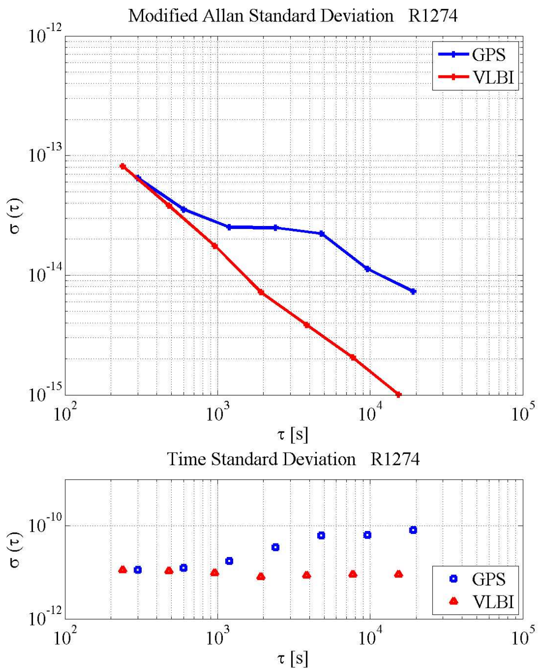

Figure 4. Modified Allan deviation (top) and Time Standard Deviation (bottom) of VLBI and GPS carrier phase results from R1274 session.

3. The comparison experiments using KASHIMA-KOGANEI baseline

We also carried out geodetic VLBI experiments using Kashima-Koganei baseline in order to compare the results with GPS time transfer (carrier phase). We will also use this baseline for test observations of our compact VLBI system which is currently under development. The Kashima station which has a 34-m and a 11-m radio telescope, is located about 100 km East of Tokyo Japan. The Koganei station has a 11-m radio telescope, and is located in the western part of Tokyo. The baseline length is 109 km (Figure 6).

Both stations have a permanent GPS receiver (ksmv, kgni and ks34) which are sharing the H-maser with VLBI since last spring. It was necessary to adopt some parts of these VLBI and GPS equipment for the needs of the time and frequency transfer purpose because these systems are usually set-up for geodetic purposes.

At first, we carried out a test experiment with the unchanged systems. The details and data quality of the performed VLBI and GPS observations are listed in Table 2. The quality of the GPS observations was not good (except for the k08049 experiment) due to troubles with the GPS receivers. In the k08049 experiment we used a new GPS receiver (Trimble NetRS). In this paper, we discuss only k07166 and k08049 experiments.

The analysis setup is almost the same as the one

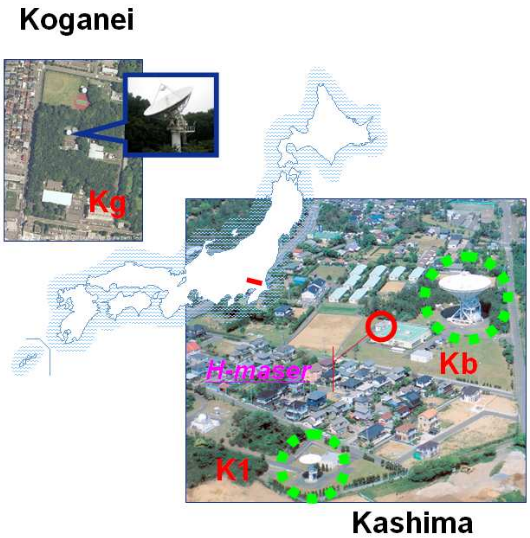

Figure 6. Layout map of KASHIMA and KOGANEI station.

Table 2. Details of VLBI and GPS observations, which were dedicted to time and frequency transfer.

Session	Baseline	Duration	Data Quality	
			VLBI	GPS
k07022	K1-Kg	24 hours	errors	errors
k07059	K1-Kg	3 days	errors	errors
k07166	Kb-Kg	1 week	OK	Failed
k08049	Kb-Kg	3 days	OK	OK

* K1: KASHIM11, Kg : KOGANEI, Kb : KASHIM34

described in the previous section. The averaged formal errors (1 σ) of the estimated clock offsets at Koganei station referred to Kashima station were 23ps (k07166) and 18ps (k08049) in VLBI results.

Figure 7 presents the comparison between VLBI and GPS. After removing a linear trend (lower plot), the clock offsets of VLBI reveal a diurnal variation which can not be seen in the GPS results. The cable length between the point where the reference signal from the H-maser is injected and the observing system itself is different for VLBI and GPS as shown in Figure 8. Additionally, the cable of the VLBI system inside the antenna is not temperature controlled. Figure 9 shows the time series of the clock offset of VLBI and the outside temperature. It reveals that the clock offsets of VLBI are strongly affected by the outside temperature (correlation coefficient : -0.72, *lag* : 2hours). Thus, for current experiments, we have decided to monitor variations of the reference signal through the transmission cable of the VLBI system by the Dual Mixer Time Difference (DMTD) method (Komiyama, 1983 [3]).

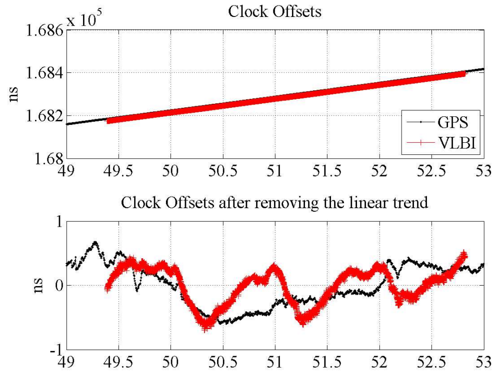

Figure 7. Comparison between VLBI and GPS results (upper plot: clock offsets, lower plot: clock offsets after removing a linear trend).

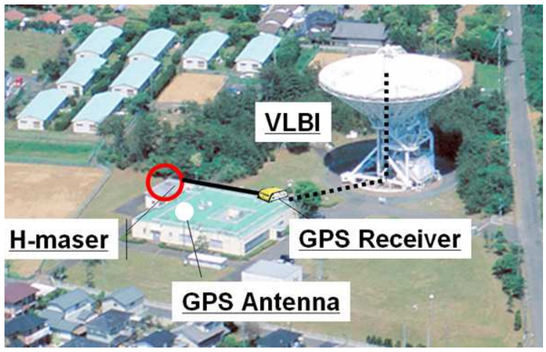

Figure 8. Layout of the H-maser, GPS receiver and VLBI antenna.

These results suggest that it is necessary to calibrate the instrumental delay variation of the VLBI system. In the next step, we are planning to measure the instrumental delay of the VLBI system by the zero baseline interferometry (ZBI) method (Hama et al., 1986 [1], Yoshino et al., 1992 [8]), and we also want to replace the transmission cable by optical fibers.

4. Summary

To compare the results of VLBI and GPS (carrier phase) frequency transfer, we have analyzed IVS and IGS data. The results of the VLBI frequency transfer show that the stability follows a $1/\tau$ law very closely (phase noise dominant). And that shows the stability has reached about 2×10^{-11} (20ps) at 1 sec. In this study, the results show that VLBI frequency transfer is more stable than GPS on the same baseline and same period.

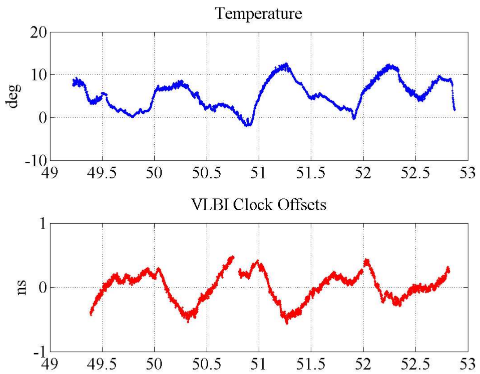

Figure 9. Time series of the outside temperature and clock offsets of VLBI.

Also, we prepared the setup on the Kashima-Koganei baseline for time and frequency transfer tests using our compact VLBI system which is currently under development. Figure 10 shows the future image of the time transfer by the compact VLBI system and high speed networks.

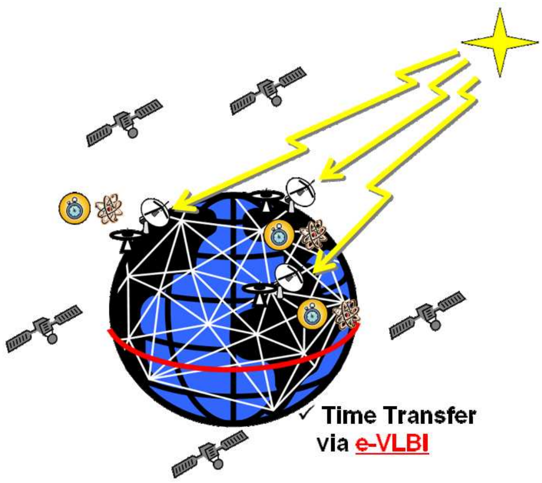

Figure 10. Future image of the time transfer by the compact VLBI system and high speed networks.

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