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Baseline Analysis of 24-hour GPS-VLBI Hybrid Observation

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Abstract

GPS-VLBI (GV) Hybrid System is being developed to combine the VLBI and GPS techniques at the observation level. In the system, VLBI antennas and GPS antennas located at the same site receive signals from quasars and GPS satellites, respectively. Both signals are recorded and correlated in the normal VLBI way. We carried out a 24-hour validation experiment of the system on the baseline between Kashima and Koganei in 2009. In the experiment, we stably acquired a large amount of GPS data with the VLBI system and obtained correlation fringes with a high signal-to-noise ratio simultaneously from all GPS satellites in the sky. We could eventually ascertain the feasibility of the GV Hybrid System. In this paper, we present the baseline analysis results of the GV Hybrid Observation data and discuss future observation plans.

1. Introduction

In order to determine the full set of reference frames and Earth Orientation Parameters (EOPs), four kinds of space geodetic techniques, Very Long Baseline Interferometry (VLBI), Global Navigation Satellite Systems (GNSS), Satellite Laser Ranging (SLR), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), are combined at the product level by the International Earth Rotation and Reference Systems Service (IERS).

Recently, several ways of combining the space geodetic techniques at the observation level have been suggested for more effective and consistent combinations. Thaller and Rothacher (2002) installed a Global Positioning System (GPS) antenna on a VLBI antenna. Tornatore and Haas (2010) used an L1 feed to receive Globalnaya Navigatsionnaya Sputnikovaya Sistema (GLONASS) signals. The IERS Working Group on Combination at the Observation Level (COL) investigates methods and advantages of combining techniques at the observation level, seeking an optimal strategy to estimate geodetic parameters (`http://www.iers.org/WGCOL`). Kwak et al. (2008) devised the GPS-VLBI (GV) Hybrid System in which GPS and VLBI are combined at the observation level. An analogous approach to the GV Hybrid System was also proposed by Dickey (2010). Following a successful VLBI type observation of GPS [3], we carried out a 24-hour GV hybrid observation on the baseline between Kashima and Koganei, Japan. The 24-hour GV hybrid observation was taken from 12:12:00 UTC 25th to 13:00:00 UTC 26th December, 2009 [2]. In this paper, we discuss the baseline analysis results of the observation and future prospects.

2. 24-hour GV Hybrid Observation

2.1. GPS Cable Offsets

In this experiment, no phase/delay calibration was done in the GPS part although it was applied in the VLBI part. It should be noted that there were cable delay offsets between the VLBI and GPS signals and also between the L1 and L2 GPS signals. The cable offset between the L1 and L2 cables was approximately 10 nanoseconds in this experiment. The cable delay caused unexpected offsets in the ionosphere calibration, and thus the ionospheric delays were not calibrated properly. Hence, we only used L1 signal data for the estimation and assumed that the ionospheric effects for both sites were identical since the baseline was rather short.

2.2. Baseline Analysis

In order to estimate the parameters of the GV hybrid observation data, we constructed the following design matrix A:

$$\mathbf{A} = \begin{pmatrix} \vdots & \vdots & \vdots & \vdots \\ \frac{\partial \tau_{Vi}}{\partial r_V} & 0 & \frac{\partial \tau_{Vi}}{\partial \tau_A} & \frac{\partial \tau_{Vi}}{\partial \tau_C} \\ \vdots & \vdots & \vdots & \vdots \\ 0 & \frac{\partial \tau_{Gj1}}{\partial r_G} & \frac{\partial \tau_{Gj1}}{\partial \tau_A} & \frac{\partial \tau_{Gj1}}{\partial \tau_C} \\ \vdots & \vdots & \vdots & \vdots \\ 0 & \frac{\partial \tau_{Gjn}}{\partial r_G} & \frac{\partial \tau_{Gjn}}{\partial \tau_A} & \frac{\partial \tau_{Gjn}}{\partial \tau_C} \\ \vdots & \vdots & \vdots & \vdots \end{pmatrix}$$

where τ_{Vi} are group delays of quasars at the i-th epoch,
τ_{Gj1} and τ_{Gjn} are group delays of the 1-st and n-th satellites at the j-th epoch, respectively,
r_V and r_G are the station positions of the VLBI and GPS antennas, respectively,
τ_A are atmospheric parameters,
and τ_C are clock parameters.

The atmospheric parameters are identical for GPS and VLBI, since both instruments are under the same sky. The clock parameters are also the same for both techniques, because they are connected to the same clock.

We estimated two piecewise linear (PWL) clock offsets at the starting epoch and the ending epoch, as well as a clock rate. The apparently big clock offset had already been calibrated prior to the estimation. The reference station was Kashima. Table 1 shows the clock parameters which we estimated using only VLBI data and GV hybrid data, respectively. The estimated values are comparable for both cases, but the formal errors of the GV hybrid data are smaller than those of only VLBI data due to the large amount of GPS data.

The atmospheric parameters, only zenith wet delays (ZWD) in this analysis, were also estimated for both cases every ten minutes. Their estimated values are comparable to each other over the observation period, but the formal errors are smaller for the GV hybrid data as shown in Figure 1. The formal errors of the estimates are in the range of 8.1-8.8 mm for only VLBI data and 3.3-3.7 mm for GV hybrid data. Occasionally, the smaller amount of VLBI data leads to a rank deficiency of the normal equations for the atmospheric and clock parameters. Hence, the larger amount of data is highly beneficial for the high frequency parameter estimation.

In the case of station coordinates, we estimated PWL offsets for the baseline adjustments of both VLBI and GPS (Table 2). The formal errors of the VLBI coordinates are comparable to those of single VLBI sessions [5] and decrease when using the GV hybrid data. The formal errors of the GPS coordinates are bigger than the VLBI formal errors due to uncalibrated effects, e.g., ionospheric delays and/or cable delays (Table 3).

Table 1. The clock offsets and rates with only VLBI data and GV hybrid data, respectively.

only VLBI data			
clock offsets (ps)	-612.6	±	167.4
clock rates (ps/s)	-31.0	±	298.1
GV hybrid data			
clock offsets (ps)	-612.6	±	65.8
clock rates (ps/s)	-30.8	±	117.1

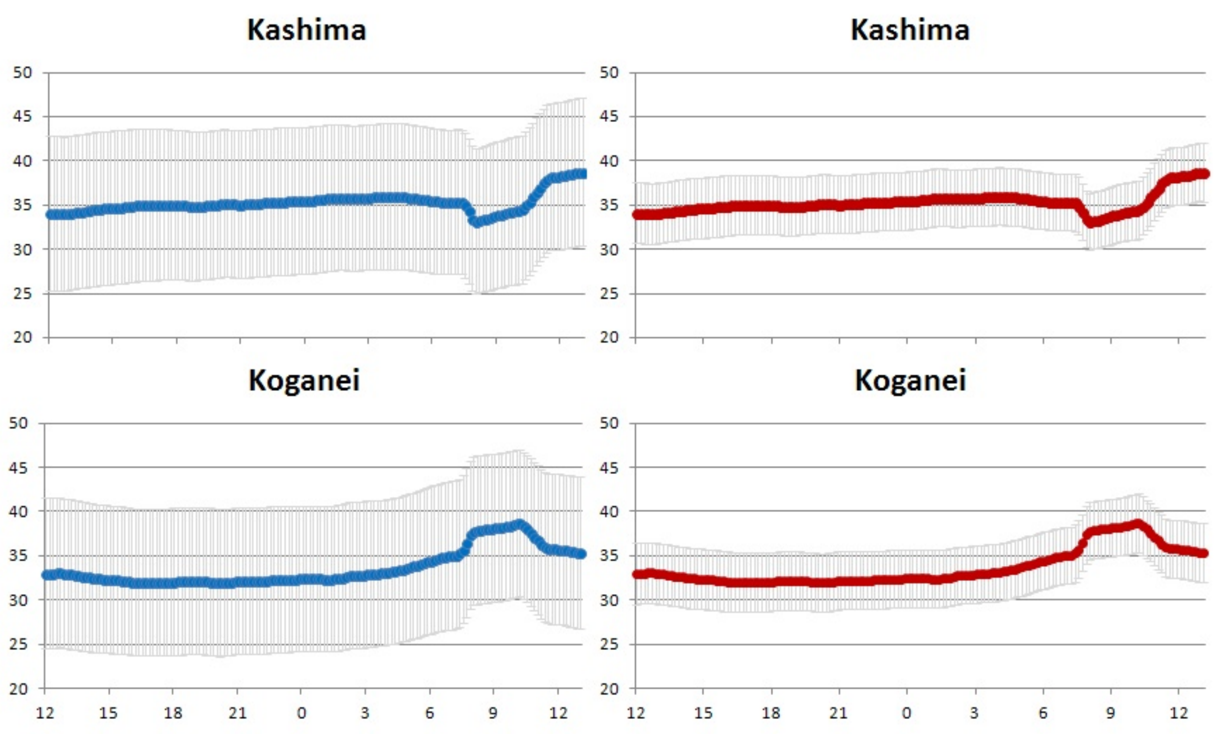

Figure 1. The ZWD with only VLBI data (left) and GV hybrid data (right) at Kashima (top) and Koganei (bottom), respectively. The horizontal axis represents the hour of the day, and the vertical axis represents ZWD in centimeters. The interval of the estimates is ten minutes.

Table 2. The estimated adjustments of the VLBI antenna baseline (Koganei-Kashima) vectors with only VLBI data and GV hybrid data, respectively.

	only VLBI data					
	at 12UTC 25th			at 13UTC 26th		
Δ DX(mm)	-11.3	±	15.1	-11.8	±	15.1
Δ DY(mm)	-15.5	±	14.8	-15.9	±	14.8
Δ DZ(mm)	6.1	±	14.7	6.1	±	14.7
	GV hybrid data					
	at 12UTC 25th			at 13UTC 26th		
Δ DX(mm)	-11.6	±	6.3	-12.0	±	6.3
Δ DY(mm)	-15.4	±	6.1	-15.8	±	6.1
Δ DZ(mm)	6.2	±	6.1	6.3	±	6.1

Table 3. The estimated adjustments of the GPS antenna baseline (Koganei-Kashima) with GV hybrid data.

	at 12UTC 25th			at 13UTC 26th		
Δ DX(mm)	-20.7	±	78.4	-20.0	±	78.4
Δ DY(mm)	-17.8	±	78.4	-17.0	±	78.4
Δ DZ(mm)	2.2	±	78.4	2.1	±	78.4

3. Conclusion

As a result of the baseline analysis, the estimated parameters, i.e., clock offsets, clock rates, ZWD, and baseline components of VLBI antennas, with only VLBI data and GV hybrid data are comparable with each other over the observation period. Their formal errors are smaller with GV hybrid data than with only VLBI data. The formal errors of the baseline components for the GV hybrid data are around 6 mm for the VLBI antennas and 78 mm for the GPS antennas. Those results show that there are several imperfections in the current system.

The current experiment was carried out on a single and short (109 km) baseline, and thus global parameters, e.g., satellite positions, source coordinates, and EOPs, could not be determined. Hence, these parameters were fixed during the estimation, and occasionally incorrect values would cause errors in the estimated parameters. A global GV hybrid network will allow the estimation of those parameters and yield better precision. Moreover, the combination of the VLBI technique, which determines International Celestial Reference Frame (ICRF), and the GPS technique, which determines the orbit of the GPS satellite, will allow the GPS satellite orbit to be expressed directly in the ICRF (Kwak et al., 2010). The combination of GPS, which determines the center of the earth, and VLBI, which determines only the relative baselines of the antennas, will also enable the direct connection of the VLBI terrestrial reference frame to the center of the earth (Dickey, 2010). The global GV hybrid observation will also resolve the correlation between the longitude of the ascending node of the satellite orbit and UT1. This means that GPS would contribute to the determination of UT1.

When compensations are made for the shortcomings of the current GV hybrid system, a future global GV hybrid observation would ultimately contribute to the ideal combination of space geodetic techniques and the desirable realization of a global geodetic observation system.

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