Delay Model Comparison for GNSS-VLBI Hybrid Observations

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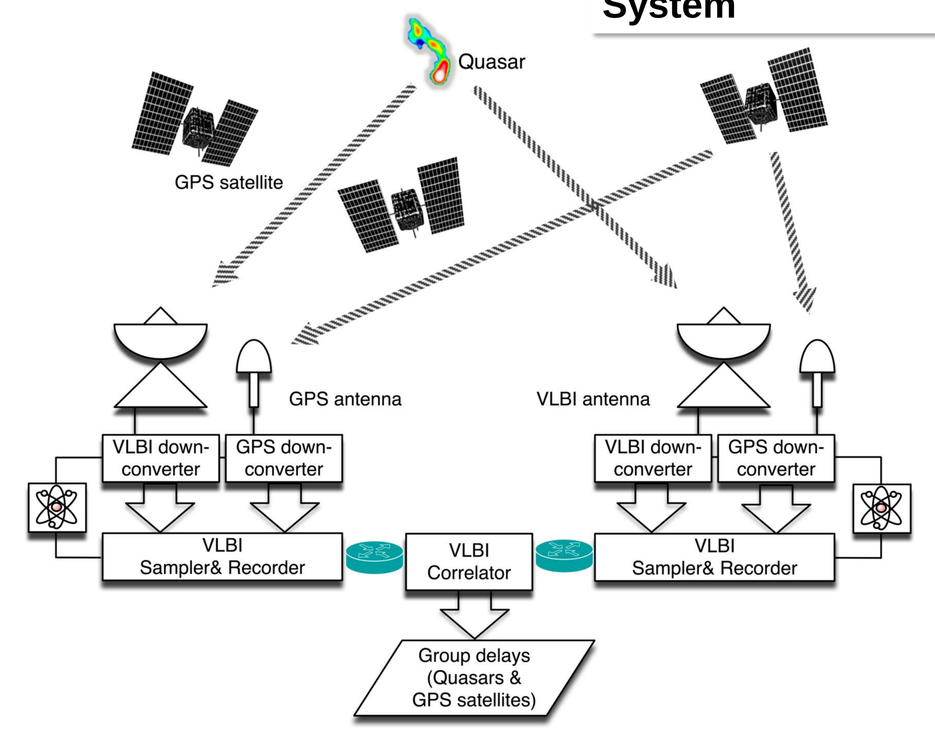
1. GNSS-VLBI Hybrid Observation for Geodesy

The GPS-VLBI (GV) hybrid system is an observation method to combine GPS, one representative of the GNSS, and VLBI techniques at the observation level. In the GV hybrid system, GPS antennas are regarded as small VLBI telescopes that receive GPS satellite signals. In other words, VLBI observations are made to quasars and GPS satellites at the same time and processed in the same way, making use of the big radio telescopes for the quasar signals and the comparatively small and cheap GPS antennas to receive the GPS signals. Both GPS and VLBI antennas are connected to the same hydrogen maser clock at the site, which will diminish systematic errors between both techniques and reduce the number of clock parameters to be estimated. Since GPS antennas are omni-directional, the GV hybrid system collects many observations from various directions at the same time. Simply by this huge increase in the number of observations compared to VLBI alone, the estimation of the atmospheric delays that vary rapidly with time and space will be improved and atmospheric error sources will be mitigated.

This system has been successfully implemented at two test sites, Kashima and Koganei, and its performance was validated in 24 hour experiments by Kwak et al.(2011). Nevertheless, the GV hybrid system is not fully exploited yet and needs further development in the instrument itself and analysis strategies.

Fig 1 Schematic diagram of the GPS-VLBI Hybrid System



The project “GPS-VLBI Hybrid Observation for Geodesy”, which is funded by the Austrian Science Fund (FWF), will conduct those developments in the following aspects.

- Defining a global GV hybrid network and simulate the impact of global GV hybrid observations
- Calibration system design of GPS part
- Correlation model for GPS signals
- Geometric delay model of GPS satellites
- Tying GPS satellites to CRF

In future, GPS of GV Hybrid observation will be extended to GNSS for more general purpose.

In this poster, we discuss geometric delay models of GPS satellites for GV hybrid observation.

2. Delay model for finitely distant GNSS satellites

Since a GNSS satellite is a finitely distant radio source, we cannot apply a normal VLBI delay model for quasars to the GV hybrid observation directly. Klioner(1991) suggested a VLBI delay model of Earth satellites. Both studies, Kwak et al.(2012) and Plank et al.(2014), take the same approach of Klioner(1991)'s model(Eq. [1]).

Light path difference time between two stations from an identical satellite

The retardation of the baseline

Gravitational delay due to the Earth

$$\Delta t = t_2 - t_1 = \Delta t_0\left[1 - \frac{\boldsymbol{n}\cdot\boldsymbol{v}_2(t_1)}{c}\right] + \tau_{gr\oplus} \qquad [1]$$

where

$$\Delta t_0 = \frac{|\boldsymbol{R}_s(t_0) - \boldsymbol{r}_2(t_1)| - |\boldsymbol{R}_s(t_0) - \boldsymbol{r}_1(t_1)|}{c} \qquad [2]$$

$$\boldsymbol{n} = \frac{\boldsymbol{R}_s(t_0) - \boldsymbol{r}_2(t_1)}{|\boldsymbol{R}_s(t_0) - \boldsymbol{r}_2(t_1)|} \qquad [3]$$

$$\tau_{gr\oplus} = (1+\gamma)\frac{GM_\oplus}{c^3}\ln\frac{(|\boldsymbol{r}_2| + |\boldsymbol{R}_s| + |\boldsymbol{r}_2 - \boldsymbol{R}_s|)(|\boldsymbol{r}_1| + |\boldsymbol{R}_s| - |\boldsymbol{r}_1 - \boldsymbol{R}_s|)}{(|\boldsymbol{r}_2| + |\boldsymbol{R}_s| - |\boldsymbol{r}_2 - \boldsymbol{R}_s|)(|\boldsymbol{r}_1| + |\boldsymbol{R}_s| + |\boldsymbol{r}_1 - \boldsymbol{R}_s|)} \qquad [4]$$

All coordinates quantities (position and time) above are defined in geocentric reference system (GCRS). Therefore, Δt needs to be rescaled to obtain the observed time delay τ.

$$\tau = \Delta t(1 - L_G) \qquad [5]$$

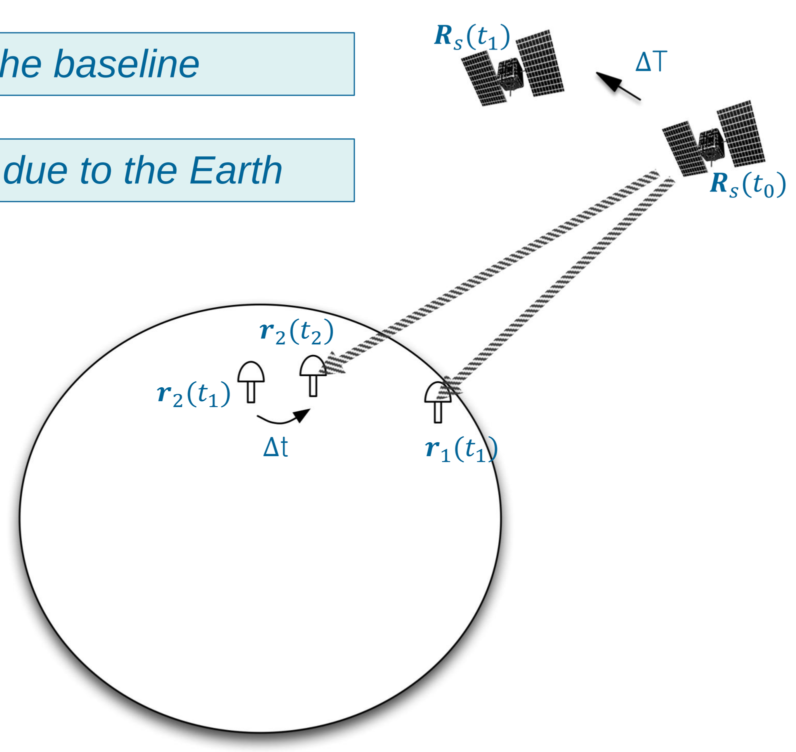


Fig 2 Changes of coordinate and time during the observation.

3. Delay Model Comparison

According to Eq [1] and both literatures (Kwak et al.(2012) & Plank et al.(2014)), we calculate respective geometric delays of GV hybrid observation for GPS satellites (Fig 3). Test stations are Kashima and Koganei in Japan and their baseline is 109 km. The observation period is from December 25th (12:12:00 UTC) to 26th (13:00:00 UTC) 2009 for nearly 25 hours.

Fig 4 shows the difference between Kwak et al.(2012) and Plank et al.(2014). They agree with each other under 10ps level. However, there is systematic difference between them.

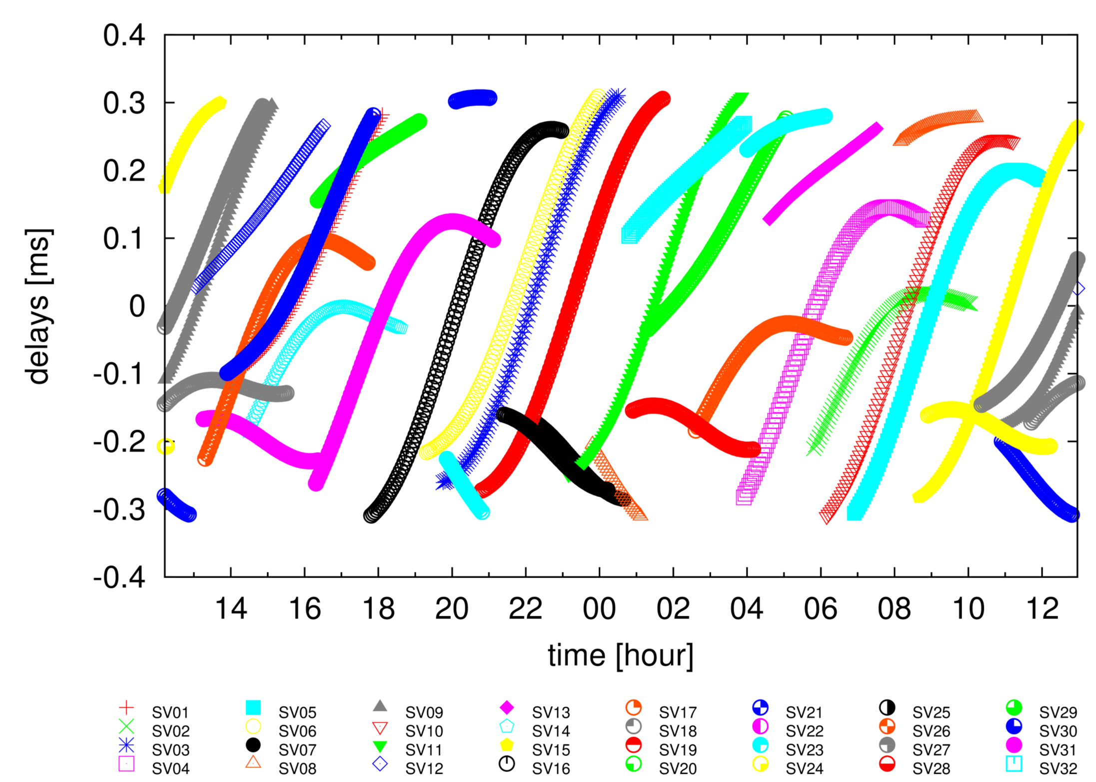


Fig 3 An example of geometric delays of GV hybrid observation for GPS satellites. Those delays have been calculated with the VieVS software, amended for the analysis of VLBI satellite observations (Plank et al., 2014). Every symbol means each satellite.

Plank et al.(2014) applied station correction according to the IERS Conventions (Chap. 7). Meanwhile, Kwak et al.(2012) calculated delays without those corrections for station positions, because the baseline is rather short(~109 km) so that they simply assumed that those corrections are compensated between two sites.

Those dissimilar corrections of two models are the causes of the differences shown in Fig 4. As 10 ps corresponds to 3 mm, we should take those effects into account in order to achieve sub-mm geodesy.

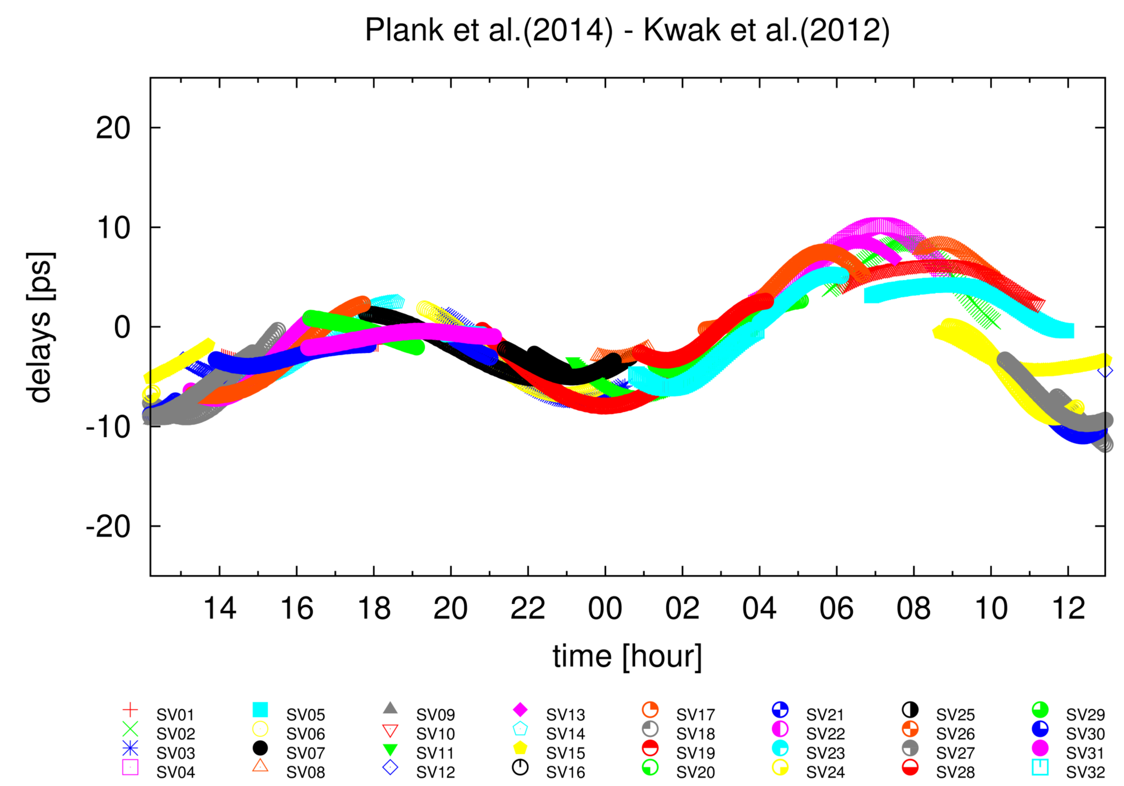


Fig 4 Comparison of geometric delays (w/ relativistic effects) between Kwak et al.(2012) & Plank et al.(2014).

4. Comparison of Broadcast and Final Orbits

The Broadcast orbits provide orbital element values for each GPS satellite every 2 hours. The accuracy for the Broadcast orbits (~1m) is relatively lower than those of other GPS satellite ephemerides(Ultra-rapid, Rapid, Final). However, since the Broadcast orbits are given at the same time when the observation is carried out, it can be used as a priori value during data processing. IGS calculates and provides the precise Final orbits based on the observation data given by the IGS network distributed throughout the world. The Final orbits are provided every 15 minutes with 2.5 cm accuracy.

Fig 5 shows the delay differences based on the two orbits. Most of them are within 100 ps. Such values are relatively small compared to the current GV observation errors(>1ns). However, those errors are unexpectedly huge because of insufficient implementation (Kwak et al., 2011). If we need precision geodesy, Final orbit is desirable for delay modeling.

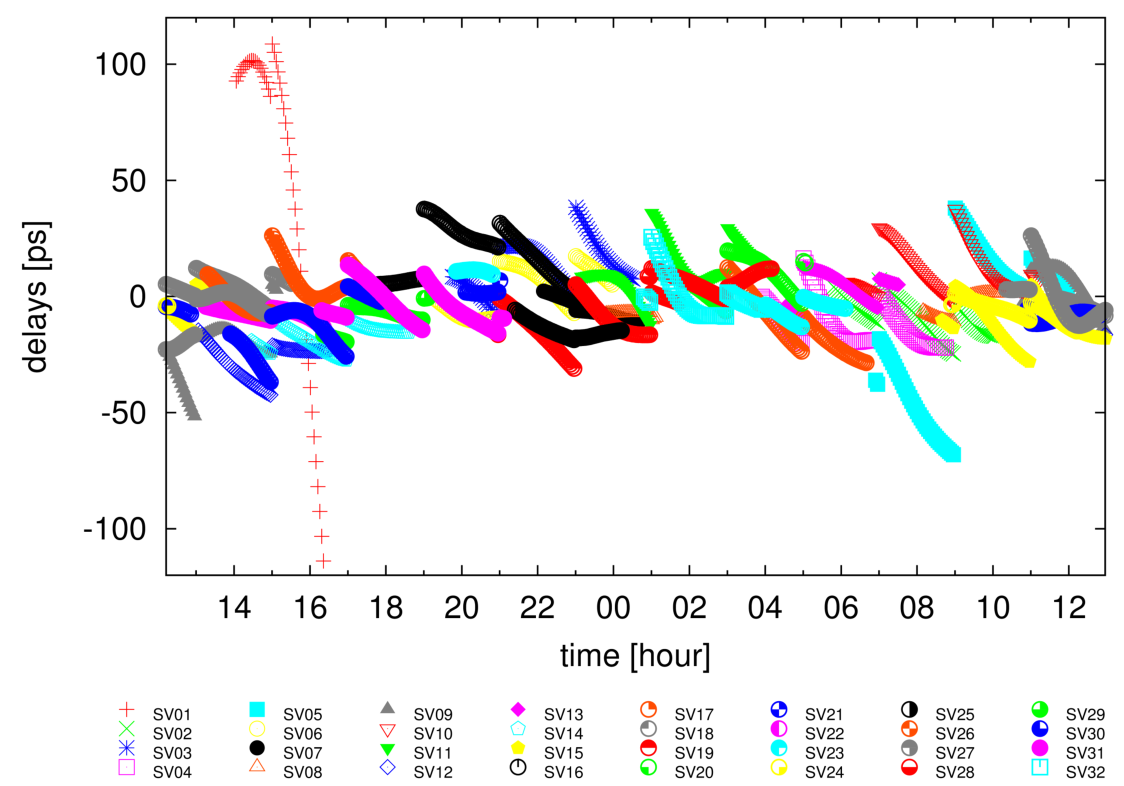


Fig 5 The delay differences based on the Broadcast orbits and the Final ones. Except for the pseudorandom noise (PRN) 01 satellite in the state of "Unhealthy", all other satellites show the differences within 100 picoseconds. As Broadcast orbits are provided every 2 hours, there are 2-hour discontinuities in the plot

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