Geodetic VLBI Experiments Using Two NTSC Stations

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Abstract. Asian Pacific Space Geodynamics (APSG) geodetic Very Long Baseline Interferometry (VLBI) observing sessions are being regularly performed to improve the accuracy of the geocentric coordinates of the participating stations in the Asia-Pacific region. Two small antennas, located at Jilin and Sanya, have been built and operated by the National Time Service Center (NTSC). They have a wide frequency coverage of 1.2-9.0 GHz and no standard geodetic recording mode available. We conducted mixed-mode observations with participation of those two NTSC stations in APSG40 and APSG46 experiments. The observational data have been correlated and analyzed at Shanghai. For the first time we derived the coordinates of JILIN and SANYA at 1 cm level by means of geodetic VLBI technique. The difference of coordinates of JILIN station between two APSG experiments is about 2 cm if the comparison is made on the same epoch of observations. Here we present the experiment setup, data processing method and analysis results.

1. Introduction
One goal of Very Long Baseline Interferometry (VLBI) technique is to determine stations’ coordinates which can be served as fiducial points of global geodetic reference frame [1]. Accurate positions of VLBI stations are essential for the Earth Orientation Parameters (EOP) measurements [2], phase referencing astrometry and deep space navigation [3].

Three small antennas with 13 m aperture have been deployed in Jilin, Sanya and Kashi by the National Time Service Center (NTSC) in order to monitor UT1 [4]. The stations are equipped with a broadband receiver, and have a frequency coverage of 1.2-9.0 GHz. The received signals can be combined and converted into right/left circular polarization.

Asian Pacific Space Geodynamics (APSG) geodetic VLBI observing sessions are being regularly performed within the framework of International VLBI Service for Geodesy & Astrometry (IVS), with a goal to improve the accuracy of the geocentric coordinates of the participating stations in the Asia-Pacific region. In APSG40 and APSG46 experiments, two NTSC stations (JILIN and SANYA) have been tagged along. APSG stations used standard geodetic mode, while NTSC stations used a different mode.

2. Experiment
The primary purpose of APSG experiments are to continue monitoring the relative motions of the plates in the Asia-Pacific region. We planned two JILIN and SANYA to participate in the APSG experiments, in order to obtain their accurate coordinates in the global geodetic reference frame.

APSG40 and APSG46 are 24-h S/X dual-band VLBI geodetic experiment. The interval between the two experiments is about three years. The details of experiments and stations are shown in table 1.
and table 2 respectively. There are twelve stations involved in APSG40 experiment, including ten APSG40 stations and two NTSC stations; A total of nine stations participated in APSG46 experiment, including seven APSG46 stations and two NTSC stations. Those stations are located on the four plates: Australian Plate, Eurasian Plate, Pacific Plate and North America Plate.

| Experiment | Observation Time | Start(UTC) | Duration |
|------------|------------------|------------|----------|
| APSG40     | July 25 2017     | 17:30      | 24h      |
| APSG46     | April 07 2020    | 17:30      | 24h      |

Table 2. Information of stations participating in APSG experiments.

| Station Name | 2-letter name | Country    | Antenna Diameter | Experiment Involved |
|--------------|--------------|------------|------------------|---------------------|
| HOBART26     | Ho           | Australia  | 26.0 m           | APSG46              |
| ISHIIOKA     | Is           | Japan      | 13.2 m           | APSG40/APSG46       |
| JILIN        | Jl           | China      | 13.0 m           | APSG40/APSG46       |
| KASHIM11     | K1           | Japan      | 11.0 m           | APSG40              |
| KATH12M      | Ke           | Australia  | 12.0 m           | APSG40              |
| KOGANEI      | Kg           | Japan      | 11.0 m           | APSG40/APSG46       |
| KOKEE        | Kk           | USA        | 20.0 m           | APSG40/APSG46       |
| KUNMING      | Km           | China      | 40.0 m           | APSG40/APSG46       |
| SANYA        | Sy           | China      | 13.0 m           | APSG40/APSG46       |
| SEJONG       | Kv           | South Korea| 22.0 m           | APSG40              |
| SESHAN25     | Sh           | China      | 25.0 m           | APSG40              |
| URUMQI       | Ur           | China      | 25.0 m           | APSG40/APSG46       |
| YARRA12M     | Yg           | Australia  | 12.0 m           | APSG40/APSG46       |

The software SKED was used for scheduling. The minimum SNR is set to 20 for X band and 15 for S band. We selected about 75 strong and compact radio sources in each APSG session. Those sources are almost evenly distributed over the whole sky. Most of stations have more than 200 scans. The sub-array option was used to assure that the target sources have a better coverage over the local sky of each station.

The experiments were performed using mixed-mode frequency setup. All APSG stations have 10 IF channels at the frequency range of [8.2, 8.6] GHz, and 6 IFs at the range of [2.2, 2.3] GHz. However, the NTSC stations have different frequency coverage and bandwidth for each channel. Two NTSC stations have 16 IFs at the X band spread in the range of [8.1, 8.6] GHz, and 4 IFs at the frequency range of [2.2, 2.3] GHz in APSG40 experiment. For APSG46 experiment, NTSC stations have only 8 IFs at the X band spread in the range of [8.1, 8.6] GHz, and 4 IFs at the frequency range of [2.2, 2.3] GHz. Figure 1 shows APSG and NTSC stations X band frequency sequences with respect to the sky frequency 8181 MHz. The specific channel bandwidth and data rate are shown in table 3.
Figure 1. X-band Frequency sequence with respect to the sky frequency 8181 MHz.

| Station        | IF Channels | Channel Bandwidth | Data Rate | IF Channels | Channel Bandwidth | Data Rate |
|----------------|-------------|-------------------|-----------|-------------|-------------------|-----------|
| APSG stations  | 10/6 (X/S band) | 8 MHz             | 512 Mbps  | 10/6 (X/S band) | 16 MHz           | 1024 Mbps |
| NTSC stations  | 16/4 (X/S band) | 32 MHz            | 2 Gbps    | 8/4 (X/S band) | 32 MHz           | 2 Gbps    |

3. Data Processing

3.1. Data Correlation
Data correlation of the experiments were performed at the Shanghai VLBI Correlator [5]. Since the recording channel bandwidth and the frequency coverage were different between APSG and NTSC stations, the zoom mode in the DiFX correlator was used to extract the frequency channels in common with APSG stations [6]. Besides that, we follow the standard pipeline of DIFX to complete data correlation.

JILIN and SANYA stations have very low sensitivities at the S-band. Therefore, only X-band delay observables can be used for post-correlation and data analysis. We converted the DiFX correlator outputs of X band into FITS-ID1 format for further post-correlation.

3.2. Post-correlation Processing
The FITS-ID1 files were loaded into PIMA [7], a post-correlation processing software. Phase calibration was not applied because phase calibration signals for most stations are not available. After skipping the phase calibration step, it is necessary to complete the coarse fringe fitting for all observational data. The goal for coarse fringe fitting is preparation for bandpass computation and for initial data examination. Compared with the coarse fringe fitting, the bandpass is more complex.

The computation of the bandpass depends more on manual judgment. We checked the fringes before computation of a complex bandpass, and masked out cross-spectrum data whose amplitude is less than 0.4 at the edges of each channel. In APSG46 experiment, we removed four X-band channels of KUNMING station because the BBC was unlocked. After data inspection and clean work, we ran bandpass computation command. Some radio sources with high SNR were selected automatically in order to calculate the bandpass for each station. Finally, we performed fine fringe fitting, obtained group delay observables and exported them into the geodetic database in GVF format for data analysis.
3.3. Data Analysis

Psolve is a data analysis software which supports databases in the GVF. At this stage, we removed Kunming, Kashim11 and Koganei related baselines because those delay observables are very noisy in APSG40 experiment.

Since only single band data can be used, we had to apply GPS ionosphere model to correct X-band delay observables. The a priori station coordinates and velocities for APSG stations are based on ITRF2014. JILIN and SANYA stations did not participated in geodetic VLBI observations before. We got their approximate positions with an error less than 10 cm derived from local survey. Their velocities are considered to be 0. Sheshan25 was used as clock reference station in APSG40, as well as HOBART26 was used in APSG46. The estimated parameters include clock, atmosphere, UT1, nutation, and coordinates of two NTSC stations.

4. Results

The Weighted RMS (WRMS) delay residuals for the NTSC stations is 50.7 ps in APSG40 experiment and 82.8 ps in APSG46 experiment. Figure 2 and figure 3 shows the post-fit delay residuals on the baseline ISHIOKA-JILIN in these two experiments and the WRMS delay is 41.7 ps and 55.0 ps respectively.

![Figure 2. Post-fit delay residuals on the baseline ISHIOKA-JILIN in APSG40 experiment.](image1)

![Figure 3. Post-fit delay residuals on the baseline ISHIOKA-JILIN in APSG46 experiment.](image2)

Table 4 shows the adjustments and precisions of NTSC stations in APSG40 and APSG46 experiment. It can be seen that the precisions in XYZ components for each station vary between 2.72 and 11.05 mm. The positions of JILIN and SANYA have been determined with an error at 1 cm level.

| coordinates | APSG40 | APSG46 |
|-------------|--------|--------|
|             | JILIN  | SANYA  | JILIN  | SANYA  |
| adjustment  | -11.67 | -4.37  | -79.63 | -73.26 |
| σ           | -79.39 | -11.05 | -64.68 | -57.51 |
| adjustment  | -4.80  | 4.14   | -29.89 | -44.64 |
| σ           | 4.21   | 3.61   | 3.87   | 9.99   |

Table 4. The adjustments and precisions of NTSC stations in APSG experiments.

There is a satellite laser ranging (SLR) station CHANGCHUN located near JILIN, which velocities are (-25.02, -11.36, -11.32) mm/year as listed in the ITRF2014 solutions [8]. By assuming JILIN has the same velocity as CHANGCHUN, we could shift the positions of JILIN in two experiments to the same epoch, and then obtain the differences of positions are (17.38, -23.44, -17.11) mm in XYZ components. The positioning results of JILIN in two experiments agree very well, which indicate our position estimates are reliable. Unfortunately, there are no velocity information available for SANYA.
5. Summary
The mixed-mode observations with participation of two NTSC stations in APSG40 and APSG46 experiment has been performed. We determined the positions of the two NTSC stations at 1 cm level in geodetic VLBI experiment for the first time. The coordinates of JILIN station are relatively consistent in two APSG experiments, the difference is about 2 cm. We demonstrate that those stations with non-standard geodetic observing mode can be used in geodetic experiments and their precise positions can be determined, even though there is only X-band available. It is suggested that more geodetic experiments are required to obtain accurate positions and velocities estimates of NTSC stations.

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