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Post-Correlation Processing of VLBI Satellite Observations at SHAO

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Abstract

VLBI technology has been chosen for the first Chinese lunar project "Chang-E", in conjunction with USB technology, to measure the angular position of the spacecraft and to determine its orbit during the approach to the moon and while orbiting the moon. Several experiments have been carried out to investigate the effectivity of the concept and the flexibility of its implementation. In this paper we will give an introduction to the post-correlation processing stage, including how to process the quasar observations and satellite observations and how to apply the quasar observation results for calibrating the satellite observables.

1. Background

The VLBI technology has been chosen for the first Chinese lunar project "Chang-E", in conjunction with USB technology, to measure the angular position of the spacecraft (S/C) and to determine its orbit during the approach to the moon and while orbiting the moon. Several experiments have been carried out to investigate the effectivity of the concept and the flexibility of its implementation. In this paper we will give an introduction to the post-correlation processing done at SHAO.

2. The Processing Scheme

Observation data from four domestic VLBI stations are sent to the correlation center via Internet (quasi real-time mode) or on disks via air freight (batch mode). The correlation is done by a hardware correlator and a software correlator. Both correlators are designed in FX mode, their output being visibility data in the same format and split into files by time. The time unit varies from tens of seconds to several minutes according to the data size and the request. The data are put onto an NFS hard disk server for post-correlation use.

In an accessories directory, quasar coordinates, station positions, EOP, and satellite orbit data are kept as a prioris. The station logs and pcal data are also maintained.

The correlation output is read and checked in the post-correlation, and the VLBI delay and delay rates of the quasars and the S/C are obtained. We will discuss the post-correlation process later.

The propagation medium modeling encompasses the ionospheric and tropospheric corrections to the observations using meteorological data and/or co-located GPS real-time data.

The S/C angular position and orbit are solved for in corresponding solution steps (Figure 1).

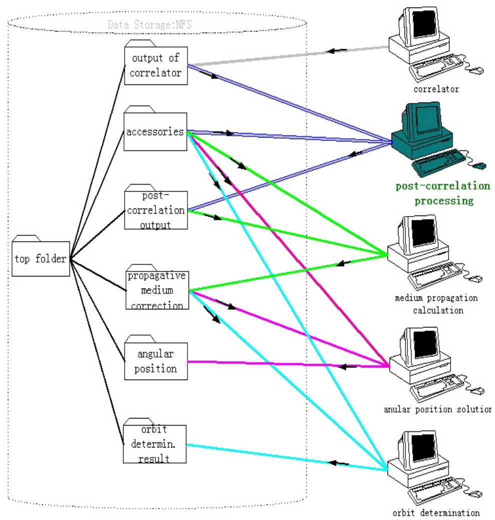

Figure 1. Diagram of the post-correlation processing for the Chang-E project. Arrows indicate the direction of the data flow.

3. The Post-Correlation Strategy

Alternating observations to quasars and the S/C is used to calibrate the S/C result with quasar observations. Generally, about 15 minutes quasar observations are used to correct several minutes to several tens of minutes of S/C observations depending on the required precision. In quasi real-time mode, ten degrees away from the S/C in the sky can be allowed for quasar observation. This mode is used during the approach stage of the S/C and the precision values for the delay and the delay rate for the S/C are at the 0.1 ns and ps/s level, respectively. Observations are taken at two IFs on the S/X band with 1-MHz bandwidth for quasars and S/C. In batch mode, the arc distance between quasars and S/C is limited to a few degrees, and the phase reference is used for high-precision positioning and orbit determination. The delays and delay rates are at less than 100 ps and less than 0.1 ps/s, when phase reference is used. The recording bandwidth for quasars is 8 MHz.

The processing flow is as follows. Firstly, residual delays and delay rates of the quasars are obtained. Single band delay fitting furnishes delays and phases at reference frequencies for two IFs. Using single band phases, multiband delays and delay rates are calculated. Then the atmospheric propagation correction for the quasars is calculated using the propagation medium calculation module and applied to the observations. The atmospheric delay is extrapolated (for quasi real-time mode) or interpolated (for batch mode) to the S/C observation epochs and applied as corrections to the S/C observations. Finally, the propagation corrections are applied to the S/C observations, where the corrections are again determined using the propagation medium calculation module.

4. The Post-Correlation Processing of Real Data

In March 2005, a three-day observation campaign (with about 10 hours of observations per day) was conducted. The satellite observed was TC-1, which is one of two satellites in the Sino-

European joint venture "Earth Space Double Stars Exploration Project". Three stations in China participated: Seshan, Urumqi, and Kunming. Kunming operates a 3-meter antenna. The quasars were observed the first 15 minutes of every hour, and the satellite was observed the remaining 45 minutes. The quasars were observed at S/X band on two frequencies in each band. The satellite was observed at S band and on a single frequency. The bandwidth was all 8 MHz in all cases. Here we show the single band results. The multiband data are still being processed.

The residual delays for the quasars are shown in Figure 2. "S" denotes Seshan station, "U" Urumqi, and "K" Kunming. Thus SU denotes the baseline Seshan-Urumqi. Every point represents a 15-minute average. The delay error is about 1 ns for baseline SU, and 10 ns for SK and UK using one minute integration. Because of the small antenna at Kunming, the baselines with Kunming are by a factor of ten worse than SU. The results are ionosphere-corrected. The ionospheric correction and tropospheric correction are taken from a GPS estimation.

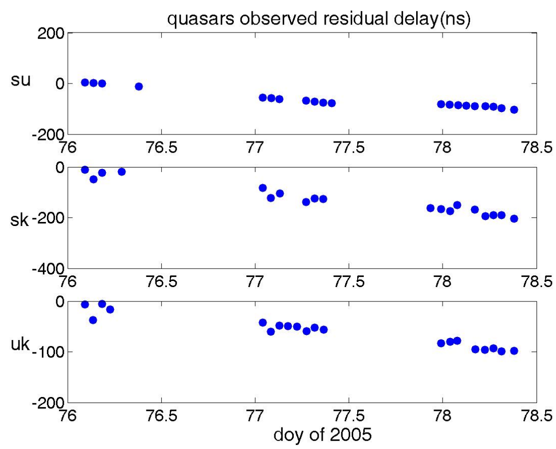

Figure 2. Observed residual delays for the quasars.

Then, 15-minute averages of the quasar delays are interpolated to the satellite observation epochs (see Figure 3). The black dots are the residual delays for the quasars, the green (gray) line are delays interpolated to the satellite epochs.

Finally, the corrections are applied to satellite residual delays (see Figure 4). The red (dark gray) dots are observed satellite residual delays (raw data), the green dots (light gray) are the delays after the quasar calibration has been applied, the blue (black) dots are the resulting residual satellite delays—including quasar calibration and satellite ionospheric/tropospheric delay corrections.

5. Conclusions

The three-day VLBI satellite observation campaign served as a proof-of-concept test. Results are preliminary, and we will continue to work on it. Using this kind of VLBI processing, the orbit determination wrms residual error is at the ns level, and a systematic error at the 10 ns level can be expected when compared to USB results (investigations are ongoing). It must be pointed out that, when combining the VLBI observations with USB data, the orbit determination is quite helpful, especially in orbit prediction. The VLBI results presented here stem from single band estimation.

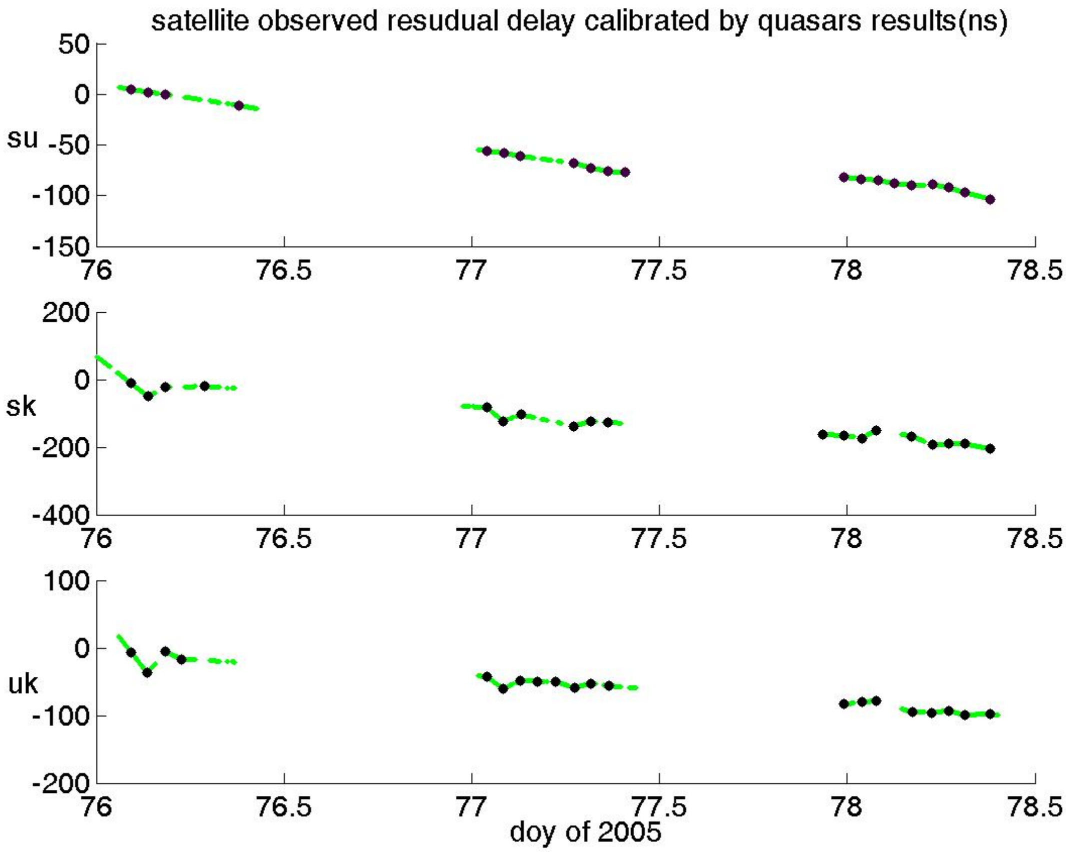

Figure 3. Interpolation of the residual quasar delays to the epochs of the satellite observations (explanation see text).

Preliminary band-synthesized results using two frequencies indicate that the delay errors are better by at least a factor of two.

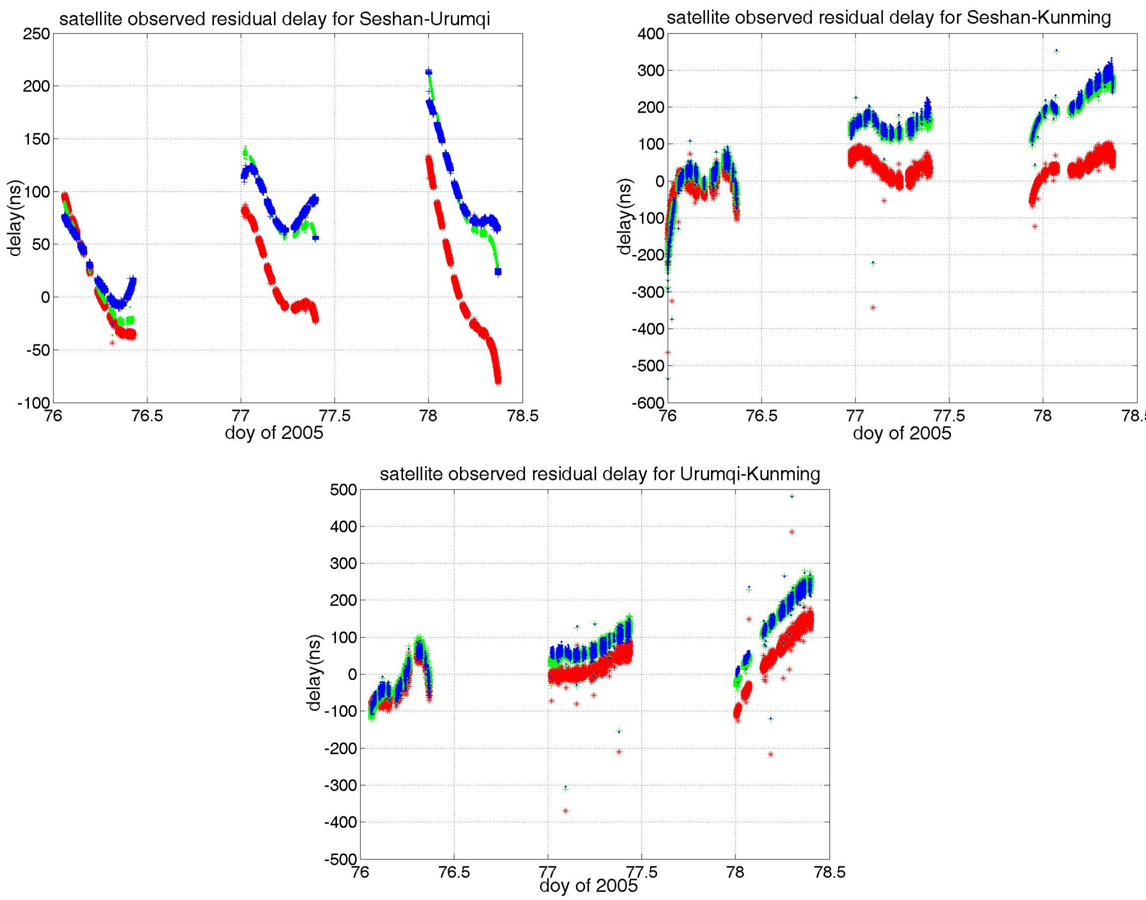

Figure 4. Quasar-calibrated satellite residual delays (explanation see text).