Analysis Center at the National Institute of Information and Communications Technology

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Abstract This report summarizes the activities of VLBI data analysis at the National Institute of Information and Communications Technology (NICT) in 2014.

1 General Information

The VLBI Analysis Center is operated by the space-time standards group and is located at the Kashima Space Technology Center and its headquarters of NICT in Tokyo. This analysis report is focused on the processing of VLBI experiments related to NICT's research goals on Geodesy and time and frequency transfer with a compact VLBI system. Development of original software package "C5++" [1], which is for the analysis of Space Geodesy (SLR, VLBI, and GNSS), has been continued under multi-organization collaborations.

2 Staff

Members who are contributing to the Analysis Center at the NICT are listed below (in alphabetical order, with working locations in parentheses):

- HOBIGER Thomas (Koganei, Tokyo): analysis software development and atmospheric modeling. He moved to the Onsala Space Observatory in August 2014.
- ICHIKAWA Ryuichi (Koganei, Tokyo): coordination of activities
- KONDO Tetsuro (Kashima): Maintenance of correlation software K5VSSP and development of broadband synthesis software.
- SEKIDO Mamoru (Kashima): development of VLBI systems, coordination of activities
- TAKIGUCHI Hiroshi (Koganei, Tokyo): GPS analysis for time and frequency transfer.

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3 Current Activities

3.1 Frequency Transfer by Means of VLBI

Space geodetic techniques such as GNSS have been proven to be a useful tool for time and frequency transfer purposes. VLBI could be another space geodetic technique that can be utilized for frequency transfer. In contrast to GNSS, VLBI does not require any orbital information as it directly refers to an inertial reference frame defined by the location of the quasi-stellar objects. Thus day boundary jumps, which are seen in GNSS analysis and are caused by discontinuities of satellite orbits, are avoidable. As summarized by [6], current VLBI systems can provide a frequency link stability of about 2 x 10-15 @ 1d (ADEV). NICT's Space-Time Standards Laboratory is working on the realization of a frequency transfer system based on the principles of VLBI, whereas developments from the upcoming geodetic VLBI2010 system are expected to help to reach these goals.

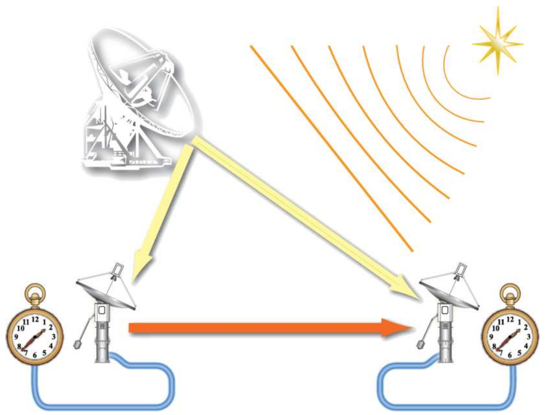

Fig. 1 The concept of the distant frequency comparison system composed of a pair of small-diameter antennas and a large-diameter antenna. Transportable small-diameter antennas are placed in laboratories, where the atomic frequency standards to be compared are being developed. The sensitivity of VLBI observation between a pair of small-diameter antennas is boosted by using a large-diameter antenna.

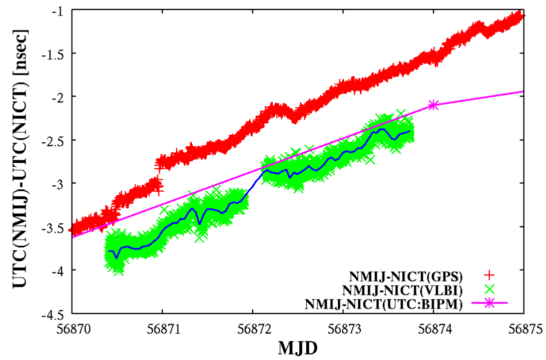

Fig. 2 The clock difference between NICT and NMIJ compared by VLBI('+') and GPS('×') observations. The difference between UTC[NMIJ] and UTC[NICT] reported by BIPM is superimposed with a solid line and '*'.

An overview of the project (Gala-V) is indicated in Figure 1. Transportable small-diameter antennas are placed in laboratories, where atomic frequency standards to be compared are located. By joint observation with small- and large-diameter antennas, the delay observable between a small-antenna pair is derived. Disadvantages of the small-diameter antennas (hereafter referred to as A and B) on sensitivity is compensated by joint observation with a large-diameter antenna (hereafter referred as O) and expanded observation frequency range. The delay observable (τ_{AB}) between the small diameter antenna pair (AB) is computed by linear combination of those (τ_{OA}, τ_{OB}) of the small and large diameter baselines (OA,OB) as follows:

$$
\begin{aligned}
&\tau_{AB}(t_{prt}) \\
&= \tau_{OB}(t_{prt} - \tau_{OA}(t_{prt})) - \tau_{OA}(t_{prt} - \tau_{OA}(t_{prt})) \\
&\cong \tau_{OB}(t_{prt}) - \tau_{OA}(t_{prt}) - \frac{d}{dt}\tau_{AB}(t_{prt}) \times \tau_{OA}(t_{prt}),
\end{aligned} \quad (1)
$$

where t_{prt} is the reference epoch of the observation.

One of the small-diameter antennas equipped with a broadband feed and high speed data acquisition system was moved to the National Meteorology Institute of Japan (NMIJ) in Tsukuba by the end of March 2014. Another small antenna was installed at NICT Headquarters in Koganei, Tokyo. Both NMIJ and NICT are the national institutes engaged in the development of atomic frequency standards and are keeping the time series of UTC[NMIJ] and UTC[NICT], respectively. Therefore, the NMIJ and NICT baseline is a good test bed for developing the frequency comparison system. An example of the result of a clock comparison experiment conducted in August 2014 is displayed in Figure 2. Observations were made 1-3 August 2014 with two small antennas at NMIJ and NICT and with the Kashima 34-m antenna with X-band. Clock difference behaviors were estimated by GPS observation and VLBI observations. Because the clock behaviors of both institutes are regularly reported to the Bureau International des Poids et Mesures (BIPM), the clock difference deduced from BIPM publication is superimposed in the plot. All of these data are almost consistent.

Figure 3 shows the histogram of delay residual distribution of the VLBI analysis. Because the errors of the OA and OB baselines are added in linear combination of equation (1), the delay residual distribution of the AB baseline is increased by the root-sum-square of the two observables.

3.2 Broadband System

A prototype of a broadband feed (6.5 - 15 GHz) was originally developed by and at NICT and installed at the Kashima 34-m antenna at the end of 2013. Its first light observation was successful in January 2014. This achievement demonstrated that a broadband an-

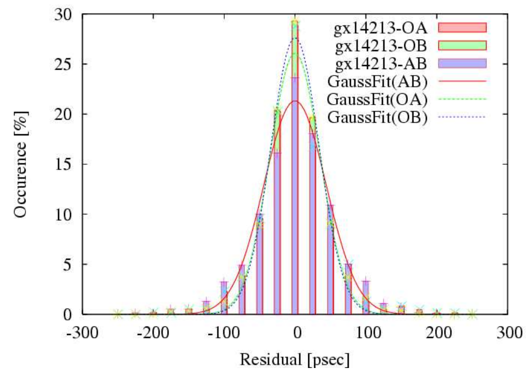

Fig. 3 Histograms of the VLBI analysis residual distribution of the OA, OB, and AB baselines are indicated. The residual distribution of the AB baseline increased by the root-sum-squre of the residuals of the OA and OB baselines.

tenna can be realized without building a new telescope, and an existing Cassegrain antenna can be updated for broadband observation. The system equivalent flux density (SEFD) of the current broadband system is 1000 - 2000 Jy in a 6.5-15 GHz frequency range. Improvement of the receiver is planned by upgrading the broadband feed, so that the observation frequency range will become fully compatible with the VGOS system. VLBI experiments for fringe testing and broadband bandwidth delay measurements were conducted on the Kashima - Ishioka (GSI) baseline at the end of 2014.

3.3 Development of a Multi-technique Space-geodetic Analysis Software Package

Driven by the need to update the existing space geodetic analysis software and motivated by the demanding goals of GGOS, an analysis software package named "c5++" was developed. The software was designed to support the combination of space geodetic data of SLR, VLBI, and GNSS on the observation level, but it also enables processing of single-technique solutions. VLBI, GNSS, and SLR modules (see Figure 4) share the same library, which contains all geophysical models according to the latest IERS Conventions. In addition, local tie information can be included as virtual observations which relate between technique-specific reference points. The library also provides interfaces to various space geodetic data formats, enables reading/writing of SINEX files, and supports all necessary mathematical functions for the parameter adjustment process. c5++ does not have a graphical user interface (GUI) but is called directly from the command line and controlled via a configuration file.

c5++ was compared against other software packages [2] and is currently being used by the Geospatial Information Authority of Japan (GSI) for ultra-rapid determination of UT1 [3] on a routine basis.

In contrast to a combination of space geodetic results where parameters are derived individually from each technique, the combination of all available space geodetic observations on the observation level is expected to obtain more robust parameters. Outliers are less likely to bias the solution as data from other techniques helps to identify such data artifacts. Moreover, weaknesses of one technique can be compensated by adding a second technique, improving geometrical coverage and stabilizing the estimation of parameters which otherwise would depend on observations from that single technique. In order to demonstrate the capability of the software to combine data at the observation level, SLR and VLBI observations were processed together, with the goal of studying site motions at TIGO and revealing the benefits of this approach [4].

In addition to local tie information, site-wise common parameters, i.e. troposphere and clocks, can be estimated when microwave-based techniques are combined on the observation level. Hobiger et al. [5] discusses how common parameters between GNSS and VLBI have to be estimated and where biases/offsets need to be taken into account. In order to test this concept, GPS and VLBI data from the CONT11 campaign

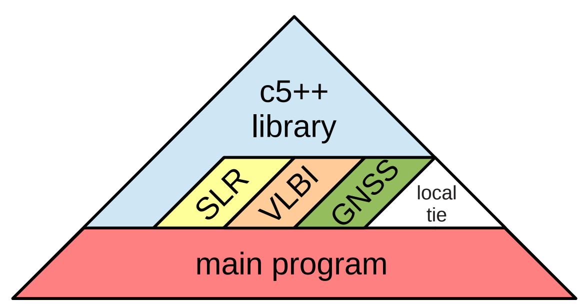

Fig. 4 The basic concept of c5++ allows processing of single- and multi-technique space geodetic observations by taking advantage of the usage of identical geophysical models (from [5]).

were utilized. Obtained results show that the combination of space geodetic data on the observation level leads to a consistent improvement of station position repeatability and Earth orientation parameters as well as nuisance parameters such as troposphere estimates. Furthermore, estimation of common parameters (troposphere or clocks) at co-located sites helps to improve the solution further and derive an utmost physically consistent model of the concerned parameters (see details in [5]).

4 Future Plans

Plans and tasks in 2015 are (1) the development of broadband phase synthesis technique, (2) conducting frequency transfer experiments with the broadband VLBI system, and (3) establishing its processing chain to analysis.

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References

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