Analysis Center at National Institute of Information and Communications Technology

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Abstract This report summarizes the activities of the Analysis Center at National Institute of Information and Communications Technology (NICT) for 2013.

1 General Information

The NICT Analysis Center is operated by the space-time standards group of NICT and is located in Kashima, Ibaraki; its headquarters are in Koganei, Tokyo. The Analysis Center focuses on the processing of VLBI experiments which are related to NICT's research goals. Effort is spent on developing new VLBI technology for time and frequency transfer, the development of a modern multi-technique analysis software package, prototyping of a compact VLBI system, real-time EOP determination, and atmospheric path delay studies.

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
- ICHIKAWA Ryuichi (Koganei, Tokyo): coordination of activities
- KONDO Tetsuro (Bangkok, Thailand and Kashima): software correlator development
- SEKIDO Mamoru (Kashima): development of VLBI systems, coordination of activities

3 Activities during the Past Year

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

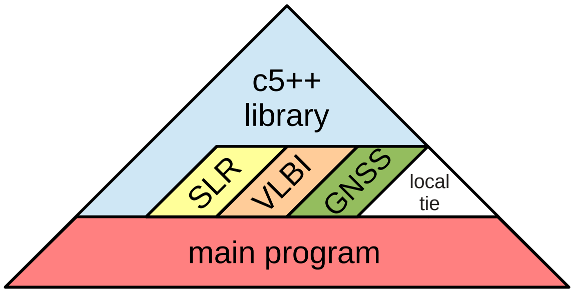

Fig. 1 The basic concept of c5++ allows processing of single- and multi-technique space geodetic observations by taking advantage of the usage of identical geophysical models (from [4]).

Driven by the need to update existing space geodetic analysis software and motivated by the demanding goals of GGOS, a new analysis package named "c5++" was developed. In contrast to the prior version, which was written in Java, the new software was coded in C++, which led to its naming. In doing so, the software was designed to support combination of space geodetic data from Satellite Laser Ranging (SLR), VLBI,

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and Global Navigation Satellite System (GNSS) on the observation level, but it also enables processing of single-technique solutions. VLBI, GNSS, and SLR modules (see Figure 1) 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. In the current version of c5++, a Gauss-Markov model is used for the least-squares adjustment; however, a Kalman filter is expected to be implemented in the future as well.

c5++ was compared against other software packages [6] and is currently being used by the Geospatial Information Authority of Japan (GSI) for ultra-rapid determination of UT1 (see section 3.3 and [1]) on a routine basis.

In contrast to combination of space geodetic results where parameters are derived individually from each technique, 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 [3]. In doing so, it could be demonstrated that the coordinate time series before the Chile 2011 earthquake derived from the combined solution has less scatter than either of the two single-technique solutions (see Figure 2).

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. [4] 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 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 like 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 [4]).

3.2 Frequency Transfer by Means of VLBI

Space geodetic techniques like GNSS have been proven to be a useful tool for time and frequency transfer purposes. Besides SLR, which is currently tested under the name T2L2, 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. As summarized by [7], 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. Our new analysis software (see prior section) is ready to combine VLBI and GNSS data on the observation level and thus support the efforts of this project.

3.3 Ultra-rapid EOP Experiments

Geospatial Information Authority of Japan (GSI), Onsala Space Observatory, University of Tasmania, and the Hartebeesthoek Radio Astronomy Observatory carried out several ultra-rapid EOP experiments which were automatically analyzed with c5++. The analysis process was adopted to handle automated ambiguity resolution of a multi-baseline session and allow for a robust estimation of the three EOP components. First results demonstrated that all three EOPs can be esti-

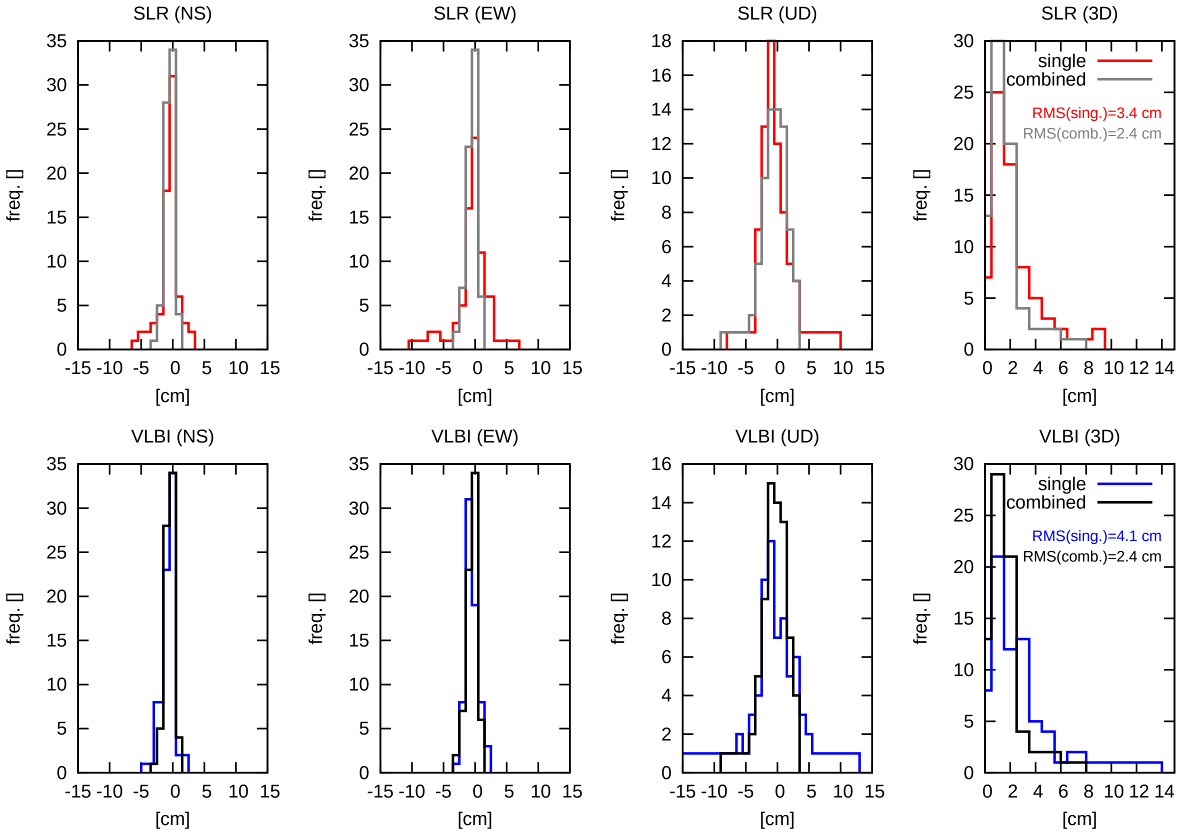

Fig. 2 Histograms of the detrended coordinate time series of the single technique and combined solutions between January 1, 2008 and March 10, 2008 (i.e. the occurrence of the Chile 2010 earthquake) as discussed in [3].

mated from such a dedicated ultra-rapid observation network. However, given the weak geometry of the network and the rather low number of observations, it is not clear whether the current observation strategy is sufficient for an accurate and reliable determination of all three EOP components. In addition to these dedicated ultra-rapid experiments, GSI regularly submits UT1 results automatically processed by c5++ from INT2 sessions on an operational basis (see [1] for details on the processing strategy).

3.4 Ray-traced Troposphere Slant Delay Correction for Space Geodesy

Kashima Ray-tracing Tools (KARAT) is a software package that is capable of transforming numerical weather model data sets to geodetic reference frames, computing fast and accurate ray-traced slant delays, and correcting geodetic data on the observation level. A recent comparison [8] of troposphere delays from space geodetic techniques, water vapor radiometers, and numerical weather models confirmed the ray-tracing concept but made clear that one requires accurate numerical weather models in order to compute a realistic refractivity field around space geodetic instruments.

In addition, KARAT was extended to support frequency dependency of the refractivity in the microwave domain following the Liebe model [5]. By the use of this model, it is possible to compute the complex refractivity based on atmosphere quantities like pressure, temperature and relative humidity. Using these new features, it was studied whether modern space-geodetic microwave techniques (including VLBI2010 and higher dual-frequency VLBI configurations) should be corrected for dispersive troposphere delays. Although the frequency dependent delay contribution appears to be of small order, one has to consider that signals are propagating through a range of a few kilometers of troposphere at high elevations to hundredths of kilometers at low elevations. Thus, it has been investigated whether such an effect has a magnitude above the noise floor of modern space- geodetic instruments or whether it can be safely neglected. The frequency dependent KARAT module was also utilized for the development of a semi-empirical correction model for the microwave link of the Atomic Clock Ensemble in Space (ACES) [2].

In addition, a model for optical (laser) techniques is currently being implemented in order to support all space geodetic techniques, including SLR.

4 Future Plans

For 2014, the plans of the Analysis Center at NICT include:

- Combination of multi-technique space-geodetic data on the observation level with c5++
- Implementation of an interface for c5++, which allows reading and creation of OpenDB data
- Time and frequency transfer experiments by VLBI and combination with other techniques like GNSS or Two-Way Satellite Time and Frequency Transfer (TWSTFT)
- Usage of multi-processors and multi-core processing platforms for the acceleration of space geodetic applications

Acknowledgements

Parts of this work were supported by a Grant-in-Aid for Young Scientists B (No.25740011). Design and implementation of c5++ was a huge effort, requiring the participation and support of many individuals.

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