Vol. 46 No. 2 Journal of the Communications Research Laboratory July 1999
Printed in Tokyo, Japan pp. 253–258

Recent Activities in CRL

RECENT ACHIEVEMENTS IN VERY LONG BASELINE INTERFEROMETRY

By

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(Received on April 19, 1999)

ABSTRACT

The Communications Research Laboratory has a long history, more than twenty years, of research and developments devoted to Very Long Baseline Interferometry. Recently, a compact observation network which consists of multiple space geodetic techniques has been established under the Key Stone Project and many technical innovations have been made. The measurement precision and the automated features of the system are two remarkable features of the system. And the four observation sites of the Key Stone Project provide valuable information that can be combined with the results of other space geodetic techniques to construct a global terrestrial reference frame. A possibility to shorten the delay to obtain earth's orientation parameters after an experiment has also been demonstrated. This paper will review these new achievements.

Keywords: VLBI, Earth rotation, Geodesy, Collocation

1. Introduction

The research and developments of Very Long Baseline Interferometry (VLBI) technology began in the Communications Research Laboratory (CRL) in the middle 1970s. CRL had developed the K-3 VLBI system in the beginning of 1980s and participated in many international VLBI experiments using the system. The initial results of these experiments verified the steady motions of tectonic plates that were predicted by the plate-motion hypothesis[(1),(2)]. The VLBI technique thus played an important role for the progress of studies for the plate tectonics. As measurement accuracy was improved and more results were accumulated, inconsistencies between the predictions and contemporary site motions actually measured by the VLBI technique gradually became apparent. The first of such inconsistencies was an anomalous motion of the Kashima VLBI station north-westward with respect to the stable interior of the Eurasian plate and North American plate[(3)]. Then the Seshan VLBI station near Shanghai was found to show eastward motion with respect to the stable interior of the Eurasian plate[(4)]. Further detailed investigations also led to the conclusion that the Minami-Torishima (Marcus) and Kwajalein VLBI stations on the Pacific plate have excess westward velocities in addition to that due to the rigid plate motion[(5)]. The discrepancies between the contemporary site motions and the predictions of the plate-motion model are contributing to our understanding of the complicated dynamics of plate tectonics.

Another powerful aspect of the geodetic VLBI is its ability to determine the precise earth's orientation parameters (EOP). Although data derived from the Global Positioning System (GPS) and Satellite Laser Ranging (SLR) observations are used to estimate the earth's pole position and the length of a day, VLBI is still the best technique for determining nutation parameters and the difference between the coordinated universal time (UTC) and the time defined by the earth's rotation (UT1). CRL became one of the VLBI Technical Development Centers of the International Earth Rotation Service (IERS) in 1990 and has since then been active in the development of systems for VLBI observations and data analyses. When the VLBI structure in the IERS was transferred to a new organization, the International VLBI Service for Geodesy and Astrometry (IVS), on 1 March 1999, CRL was designated as the Technology Development Center and as other functions of the IVS, i.e. the Network Stations, the Associate Special Analysis Center, the Correlator Center, and the Data Center. These multiple designations are the consequences of expectations towards CRL and our responsibilities in the research and developments for VLBI technique are quite large. This paper reviews recent CRL VLBI research and development activities. More detailed information can be found in a special issue of this journal[(6)].

2. KSP VLBI System

CRL established a space geodetic observation network which consists of four observation sites in and around Tokyo under a project called Key Stone Project (KSP). Four observation sites of the network are located at Kashima, Koganei, Miura, and Tateyama (Fig. 1). At each site, an 11-m antenna for VLBI, a 75-cm telescope for SLR, and a GPS receiver have been placed close to each other. The KSP VLBI observation system was

designed to improve measurement accuracy and sensitivity. The sensitivity of a VLBI observation system is proportional to the square root of the data rate. The data rate was increased from 64 Mbps (bits per second) which was possible with the previous K-4 VLBI system to 256 Mbps for the KSP VLBI system. The KSP VLBI system is the only VLBI observation network making observations at 256 Mbps on a regular basis. The better sensitivity realized by the greater data rate helps to improve accuracy of the VLBI measurements since it enables to increase the number of observations that can be made in an experiment. The frequency bandwidth is also a factor which determines the precision of the measurements. The frequency bandwidths of the KSP VLBI receivers are 900 MHz for the X-band and 400 MHz for the S-band. Assigning 10 frequency channels to the X-band observations made it possible to effectively expand the equivalent frequency bandwidth obtained from bandwidth synthesis processing. The current uncertainty of the baseline lengths from 24 hours observations is about 1 mm in the sense of formal error and about 2 mm in the sense of repeatability[7]. Fig. 2 shows the estimated lengths of the baseline between the Kashima and Koganei VLBI stations since August 1994.

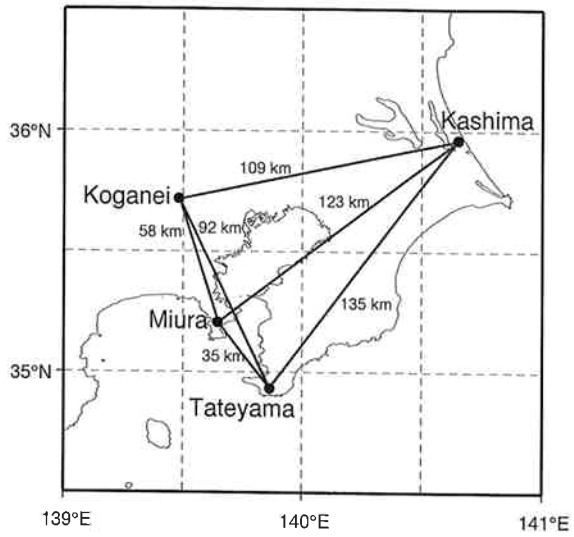

Fig. 1 Geographical positions of the four observation sites of the Key Stone Project.

The other unique points of the KSP VLBI system are its automated features. The observation system and the data analysis system have been designed so that no human operations are needed to conduct experiments or to obtain results. Eliminating the need for human operations made more frequent experiments possible and has reduced the time needed to produce results. Experiments, 24 hours of observations each, are now performed every two days. The signals observed at each station are transferred through high speed digital communication optical fibers to a correlator at the Koganei station and are processed simultaneously during the observations. After all the observations complete, data analysis procedures are performed automatically and the results are made available within half hour. Before the KSP VLBI system was developed, VLBI observations required highly trained personnel at all sites and the data processing and analysis required a time consuming and complicated procedures, but both of them are not necessary any more in the KSP VLBI system.

3. Collocation of Different Space Geodetic Techniques

Since the relative positions between the VLBI, SLR, and GPS reference points within each site of the KSP network have been precisely determined by ground survey measurements[8], comparisons of coordinates and velocities obtained by the three space geodetic techniques are expected to contribute to the construction of a better and reliable terrestrial reference frame. To evaluate the current level of consistency among VLBI, SLR, and GPS

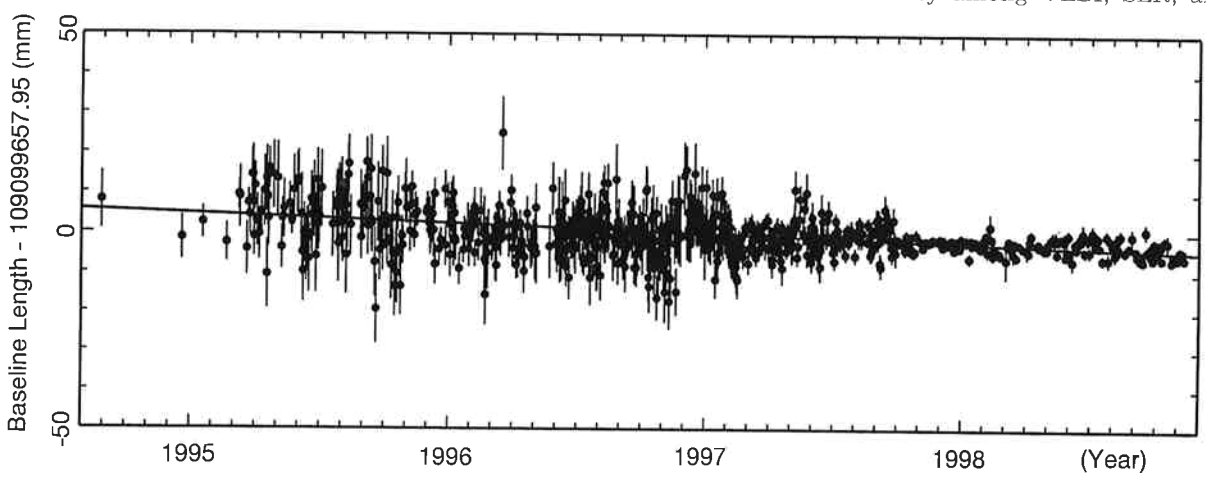

Fig. 2 Evolution of the baseline lengths between the KSP VLBI stations at Kashima and Koganei. Each dot represents the baseline length estimated in one experiment. Error bars are standard deviations, and the slanted line is the least-squares fit.

techniques, the site coordinates on ITRF96 reference frame[9] obtained from KSP observations were compared with each other using the results of the ground survey measurements. ITRF96 is one of the recent realizations of the terrestrial reference system and it defines the coordinates and velocities of space geodetic technique observation sites.

SLR and GPS observation data can be analyzed with data obtained at many other sites, and the ITRF96 coordinates of KSP observation sites can be estimated by constraining the coordinates of sites included in the definition of the ITRF96. On the other hand, data obtained from KSP VLBI experiments provide information only about the relative positions of the four KSP observation sites. Therefore, the ITRF96 coordinates of the VLBI reference points at four KSP sites can not be obtained without doing additional VLBI experiments with other VLBI sites whose coordinates on ITRF96 are known. Seven such VLBI experiments have been performed using a 34-m antenna station at Kashima for this purpose.

The Kashima site coordinates determined from VLBI, SLR, and GPS are compared in Fig. 3. The SLR site coordinates were estimated, from 44 days of data observed starting 1 November 1998, by fixing the site coordinates of the stations defined in ITRF96. GPS site coordinates were estimated from 36 days of data observed starting 29 June 1998. In the data analysis, the coordinates of observation sites at Fairbanks, Kauai, Guam, and Shanghai were strongly constrained to their ITRF96 coordinates. The vectors from SLR and GPS reference points to the VLBI reference point obtained by ground survey measurements were added to the SLR and GPS site coordinates so that those site coordinates could be compared with the VLBI site coordinates. The ground survey results and the three space geodetic measurements showed an agreement within 36mm. The same comparisons were made for other three sites and the results showed a significant trend for the GPS site positions with respect to the VLBI positions whereas no obvious trend was seen for the SLR site positions. Such a common displacement of the GPS site positions with respect to the VLBI site positions may be suggesting inconsistency between VLBI and SLR site coordinates defined in the ITRF96. Further accumulation of observation data for GPS and SLR will contribute further and detailed investigations.

4. EOP Measurements Using the Real-time VLBI System

The real-time VLBI system and the automated data analysis system developed for the KSP made it possible to perform data analysis tasks right after all the observations in an experiment were finished. The feasibility of using KSP VLBI data to estimate the earth's rotation pole position (δx and δy) and the difference between UT1 and UTC was investigated using 6 months of the KSP VLBI data. In the data analysis, site coordinates of the four VLBI sites were fixed to the a priori ITRF96 site coordinates. It was necessary because the KSP VLBI network is quite compact and sufficiently stable EOP values can not be estimated while the site coordinates are estimated at the same time. No a priori information was used for δx, δy, and UT1-UTC, so these values were assumed to be zero before the parameter adjustment. The other procedures and conditions were same as in the regular data analysis. In Fig. 4, the estimated values are compared with the EOP97C04 data series maintained by the IERS. Since the KSP VLBI network is considerably compact compared to the size of the earth, there should be strong correlation between the estimated values of δx and δy. Nevertheless, the estimated values are consistent with the EOP97C04 which has been obtained by combining several datasets estimated by various space geodetic techniques. The results demonstrate that UT1-UTC and

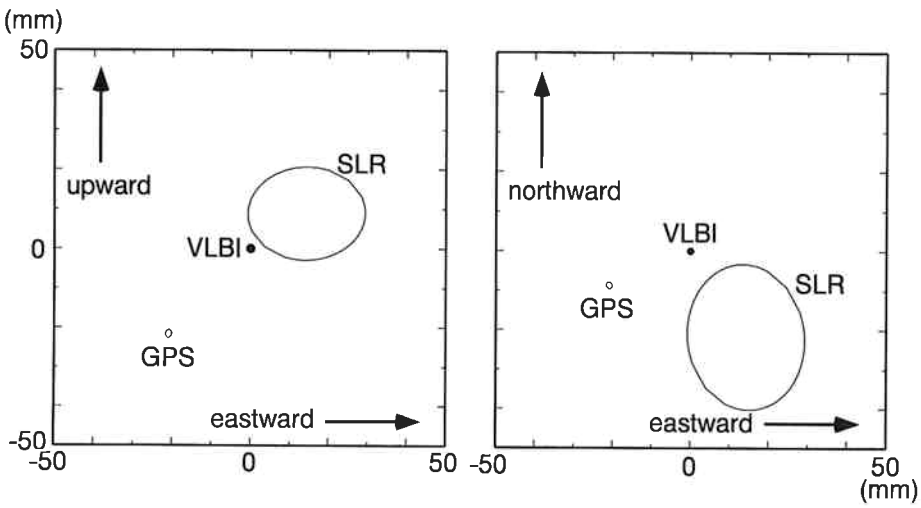

Fig. 3 Comparison of the Kashima site coordinates determined by VLBI, SLR, and the GPS. Relative vectors between reference points determined from ground survey measurements were used to compare the results obtained by these three techniques. The one-sigma uncertainties of position estimates are represented by ellipses.

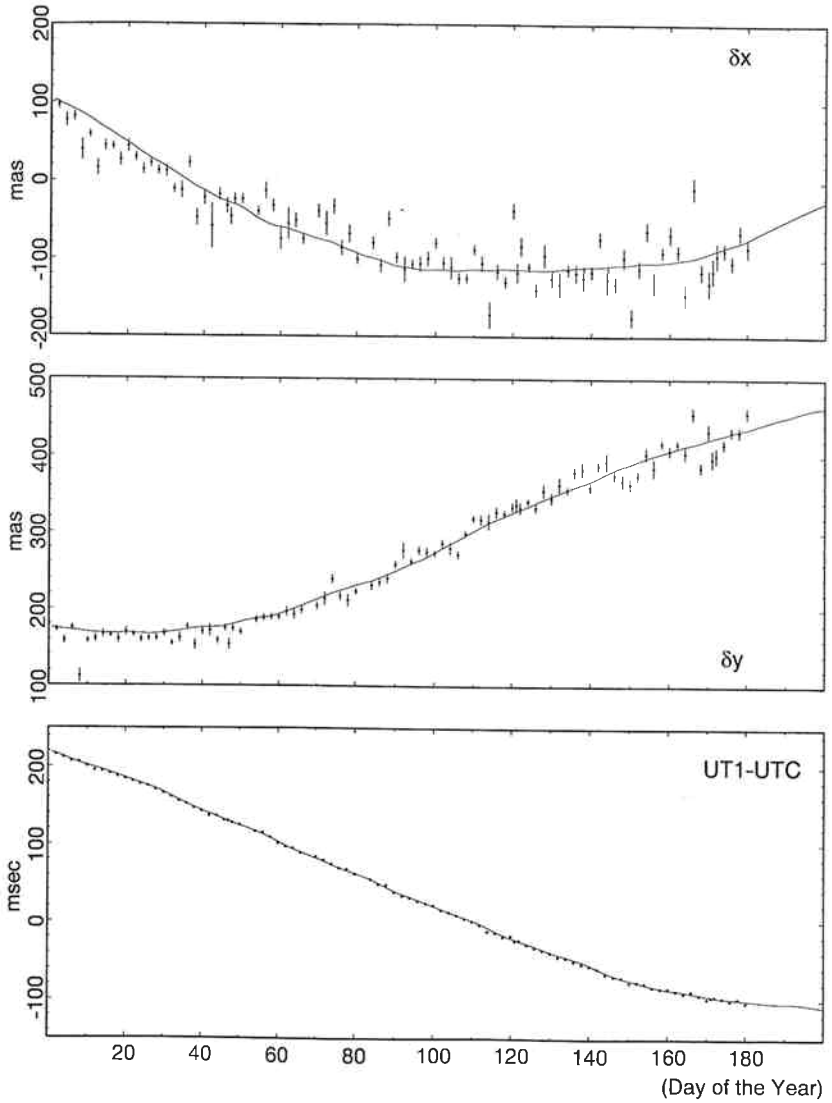

Fig. 4 Earth's rotation pole position (δx, δy) and UT1-UTC estimated from KSP VLBI data. Horizontal axis shows the number of days since 1 January 1998. Solid lines show the EOP97C04 series of data reported in monthly bulletins from IERS. The values estimated from KSP VLBI data are shown by dots with vertical lines which indicate one sigma formal error.

the earth's rotation pole positions can be estimated from the KSP VLBI data.

5. Conclusions and Remarks for the Future

The KSP space geodetic network, with its longest baseline extending only 135 km, is relatively compact in the sense that space geodetic techniques are often applied to much longer distances. The compactness and remote operation capabilities of the KSP make it a unique and ideal test-bed for technical developments and system improvements. Regular and intensive VLBI, SLR, and GPS results will be compared in order to improve their consistency and accuracy. The precise ground survey measurements and repeated joint VLBI experiments with globally distributed VLBI observation sites play a very important role for the collocation studies to tie different space geodetic techniques.

The accuracy with which the EOP values are estimated can be improved by simply extending the baselines of the network. There is no technical reason this can not be done if a high-speed digital communication network is available. The development of the KSP VLBI system was thus an important first step towards a larger real-time VLBI network expected to enhance the capabilities of the VLBI technique. Although there is not a definite plan for international real-time VLBI experiments at present, opportunities to use international high-speed digital links are becoming feasible.

The International VLBI Service for Geodesy and Geodynamics was formed as a new international organization for VLBI research on 1 March 1999. CRL has been designated to be one of the Technology Development

Centers of the organization. It is important for CRL to continue its contributions and leadership in the developments of the VLBI technology. CRL is expected to play an important role in increasing the accuracy and the sensitivity of the VLBI technique and in standardizing VLBI systems.

Acknowledgments

The authors would like to express our appreciations to colleagues in the Communications Research Laboratory who have contributed to the development of the Key Stone Project systems. The development of the real-time VLBI system and the observations made with this system are the fruit of collaboration between CRL and the Telecommunication Network Laboratory Group of Nippon Telegraph and Telephone Corporation. We would also like to thank the International GPS Service and the International Laser Ranging Service for making the GPS and SLR data publicly available. The ground survey measurements were performed by Kokusai Kogyo Co. Ltd.

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