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2.2 Geodetic Results from Domestic VLBI Observations

By

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ABSTRACT

Both the 34-m and 26-m antenna systems at Kashima Space Research Center have played important roles in the history of domestic VLBI observations for geodesy in Japan. They have also contributed to the research and development of observation systems, data processing systems, and data analysis systems. This paper reviews the results and achievements of domestic VLBI observations.

Keywords: Space geodetic technology, VLBI

1. Introduction

In Japan, there are a total of eight research institutions that are active in VLBI observations and developments of technology in the field of VLBI research. These are Communications Research Laboratory (CRL), Geographical Survey Institute (GSI), National Astronomical Observatory (NAO), Institute of Space and Astronautical Science, National Institute of Polar Research, Kagoshima University, Gifu University, and Kyushu Tokai University. At the same time, there are also a good number of researchers involved in the analysis of observation data and development of observation equipment, and their number and the breadth of these activities are expected to expand steadily in the coming years. To put this in perspective, the first symposium was held by the Japanese VLBI consortium in 1990 with the aim of providing researchers in the field of VLBI a forum for exchanging information, and the number of participants in this consortium has come to exceed 160 researchers as of March 2000. In this way, VLBI research in Japan has become quite active and diverse in scope, and it is no exaggeration to say that the 26-m antenna and 34-m antenna VLBI observation stations at the CRL Kashima Space Research Center have played quite a big role in this development. This article reviews the achievements of these two VLBI observation stations paying particular attention to VLBI research with geodetic objectives.

2. Observation Results

Research in VLBI at CRL began in the 1970's with the development of a K-1 system patterned after the Mark-II system in the United States[1]. On completion, the system was used by Kawano *et al.* in 1977 to observe radio-source 3C273B with the 26-m antenna at the Kashima Space Research Center and the 12.8-m antenna at the Yokosuka Electrical Communications Laboratories of the Nippon Telegraph and Telephone Public Corporation (present NTT)[2]. This observation represented Japan's first successful domestic VLBI observation and is now known as the first milestone in the history of Japanese VLBI research. Soon to follow was the development of a K-2 system to perform real-time VLBI observations on the baseline between Kashima and the Hiraiso Solar Terrestrial Research Center, and the development of a K-3 system compatible with the Mark-III system developed in the United States. These developments opened the way to full-scale VLBI research in Japan[3]. The K-3 system, in particular, made it possible for the 26-m antenna to participate in the international VLBI observation network, and many observations were performed centered about geodetic VLBI on Japan-U.S. baselines[4]. This system was also involved at the same time in domestic observations carried out jointly by CRL and GSI. Here, the development of a transportable 5-m antenna system by GSI and the introduction of the K-3 system by CRL produced the VLBI stations for these observations. The first geodetic VLBI observation on the baseline between the transportable 5-m station set up on GSI premises in Tsukuba and the 26-m station at Kashima was performed in 1984. At this time, the results of this observation and those of ground surveys were compared and it was found that accurate positioning could be obtained through geodetic VLBI[5],[6]. The length of this baseline was relatively short at 55 km, and because such a baseline is very suitable for elucidating the source of error and improving accuracy, this experiment was followed by periodic observations that contributed greatly to the improvement of observation and analysis systems[7]. Then, in 1988, a 34-m antenna was set up at Kashima as part of the Western Pacific VLBI Network. This antenna was more sensitive than the 26-m antenna and could perform observations in many frequency bands. The Western Pacific VLBI Network project aimed to measure the positions of four points on four separate plates through geodetic VLBI observations so as to investigate the mutual motion of those plates. These points were Kashima on the North American plate, Minamitorishima on the Pacific plate, Shanghai on the Eurasia plate, and Minamidaitojima on the Philippine Sea plate. Setup of this observation system began in 1988 and observations under a 5-year project got under way in 1989[8]. The Shanghai observation station participating in the network used a 26-m antenna developed through joint research by CRL and Shanghai Observatory of the Chinese Academy of Sciences, while the Minamidaitojima observation station used an ultra-compact transportable VLBI antenna with a 3-m diameter. The Kashima and Minamitorishima observation stations set up a 34-m antenna and 10-m antenna, respectively, to complete the network. In this project, particular attention was paid to the motion of the Minamitorishima station, and in addition to detecting movement of the Pacific plate relative to the North American plate[9], significant movement that could not be explained by rigid motion of the Pacific plate was observed[10]. The first detection by geodetic VLBI of movement of the Philippine Sea plate was also achieved as a result of observing change in the position of the Minamidaitojima station[11].

The two VLBI-observation stations at Kashima featuring a 26-m antenna and 34-m antenna have also participated in many international VLBI observations, and it is through this activity that their positions and speeds within the International Terrestrial Reference Frame (ITRF) have come to be defined with high accuracy[12]. As a consequence, performing geodetic VLBI observations with these two observation stations would make it possible to determine the positions of other points within the ITRF. Making use of this feature, GSI performed a series of geodetic VLBI observations between 5-m transportable and fixed stations and the Kashima 26-m antenna, and integrated many points in Japan with ITRF. These points were used as reference when making the transition from Japan's traditional geodetic reference system to the new "Japanese Geodetic Datum 2000" (JGD2000). In addition, the position of reference points in the Key Stone Project (KSP), whose setup began in 1994 by CRL to perform crustal deformation observations in the Tokyo metropolitan area, were determined by geodetic VLBI observations including the Kashima 34-m antenna. This likewise integrated the KSP observation network with ITRF. Furthermore, as a result of co-locating at four observation points VLBI with Satellite Laser Ranging (SLR) and Global Positioning System (GPS), which are two other kinds of observation systems based on space geodetic techniques, the positions of each of these reference points in ITRF could be determined independently. Here, by comparing these results with those achieved by ground surveys, it becomes possible to check for consistency among different space geodetic techniques when expressing ITRF, and this contributes to improved consistency overall in the international coordinate system. Points featuring the co-location of observation systems based on three space geodetic techniques, however, are still few in the world. It can therefore be said that points like the Kashima Space Research Center, where three VLBI observation stations, one SLR observation facility, and two GPS receivers are co-located within a short distance of each other, play a major role in this regard. Preliminary comparison results have already been reported by Koyama *et al.*[13], but more detailed studies still need to be performed.

3. Development of Observation and Processing Systems

As reflected in the development of the initial K-1 system, VLBI research at CRL has progressed about the development of observation systems and processing/analysis systems. To develop such systems, it is essential that problem points be identified and resolved using actual data. For this reason, it goes without saying that observations using the Kashima 26-m and 34-m antennas have played a major role in the advancement of VLBI technology. In KSP, moreover, both real-time VLBI observations using a high-speed digital communications network[14] and a fully automated work stream from observation to correlation processing and analysis[15] are examples of cutting-edge technologies. The development of a gigabit VLBI system achieving 4-times the recording speed of past systems has also been progressing since 1998. Using this system, test observations have been performed with various baselines including the one between the Kashima 34-m antenna and an ultra-compact VLBI transportable antenna set up at Gifu University. These tests marked the world's first successful geodetic VLBI observation at a data-recording speed of 1 Gbps[16].

4. Research of Data Analysis Techniques

In addition to the development of observation systems and processing/analysis systems as described in the previous section, research of compensation models in the analysis of observation data and research of ways to improve analysis are also needed to improve the measurement accuracy of geodetic VLBI observations. Using observation data obtained by the baselines between Tsukuba and both observation stations at Kashima, Takahashi has studied an analysis method that estimates unknown parameters like station position from the difference in delay measurement data, and has shown it to be effective[17]. Heki, meanwhile, has focused on position-measurement error in vertical components obtained by geodetic VLBI observations, and has shown that error can be reduced by lowering the minimum elevation angle and by using a delay conversion ratio in analysis[18]. Takahashi has also examined error in data obtained by geodetic VLBI observations. First of all, he has shown that error caused by atmospheric turbulence is large in addition to thermal-noise error theoretically derived from the signal-to-noise ratio (S/N). He has also explained how it is better to perform many observations while keeping S/N constant than increasing S/N to raise the accuracy of position estimation[19]. In all the achievements described above, data processing assumed the simultaneous reception of two observation frequency bands, the S-band and X-band. We mention, however, that there has also been a compact radio-source survey at 22 and 43 GHz with the aim of enabling even higher frequency bands to be used for geodetic VLBI observations[20].

5. Summary

The number of VLBI observation stations in Japan increased dramatically in the 1990's. Indeed, as of the writing of this article, the construction of observation stations for the VLBI Exploration of Radio Astrometry (VERA) project of NAO is in progress, and several plans for building new observation stations have been established. In addition, two of the VLBI observation stations used by KSP, namely, the Miura station and Tateyama station, are scheduled to be moved to Hokkaido University and Gifu University, respectively. Against this background, domestic VLBI research that first began with the two VLBI observation stations at the Kashima Space Research Center should continue to develop and expand all the more. This does not mean, however, that the role assigned to Kashima as a VLBI station will diminish. While it is true that the 26-m antenna is scheduled to be shut down in the near future, it is vitally important that the Kashima 34-m antenna, whose position in ITRF has the most accurate definition in Japan, continue to run a VLBI observation system.

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References

(1) N. Kawajiri, "Introduction to the Entire System", Review of the Radio Research Laboratory, Vol.24, No.130, pp.464-468, 1978. (In Japanese)

(2) N. Kawano, F. Takahashi, K. Koike, "Results of processing Radio-Source data", Review of the Radio Research Laboratory, Vol.24, No.130, pp.525-528, 1978. (In Japanese)

(3) K-3 Very Long Baseline Interferometry (VLBI) System Development, Special Issue, Review of the Radio Research Laboratory, Vol.30, No.1, 1984. (In Japanese)

(4) T. Kondo, "Results of International Geodetic VLBI Observations", Special Issue, Review of the Communications Research Laboratory, 2001. (In Japanese)

(5) Y. Sugimoto, H. Kuroiwa, "Results of Domestic VLBI System-level Experiments (1)", J. Geod. Soc. Jpn., Vol.32, No.1, pp.64-71, 1986. (In Japanese)

(6) T. Saito, S. Matsuzaka, "Results of Domestic VLBI System-level Experiments (2)", J. Geod. Soc. Jpn., Vol.32, No.1, pp.72-78, 1986. (In Japanese)

(7) J. Amagai, "Geodetic Results from Domestic VLBI Experiments (1) JEG Series", J. Commun. Res. Lab., Vol.38, No.3, pp.533-542, 1991.

(8) "Development of the Western Pacific VLBI Network", Special Issue, Review of the Communications Research Laboratory, Vol.36, No.8, 1990.(In Japanese)

(9) Y. Koyama, K. Heki, M. Imae, T. Kondo, H. Kuroiwa, Y. Sugimoto, F. Takahashi, T. Yoshino, C. Miki, and J. Amagai, "Horizontal Movement of Marcus VLBI Station due to the Pacific Plate Motion", Proc. of the International Symposium of Current Research on Crustal Motion, pp.117-122, 1993.

(10) Y. Koyama, "Excess Westward Velocities of Minamitorishima (Marcus) and Kwajalein VLBI Stations from the Expected Velocities Based on Rigid Motion of the Pacific Plate", J. Geod. Soc. Jpn., Vol.42, No.1, pp.43-57, 1996.

(11) J. Amagai, T. Kondo, M. Imae, N. Kurihara, Y. Sugimoto, T. Yoshino, F. Takahashi, H. Kiuchi, S. Hama, Y. Takahashi, H. Takaba, T. Iwata, Y. Koyama, Y. Hanado, M. Sekido, and A. Kaneko, "Movement of the Minamidaito Station", J. Commun. Res. Lab., Vol.42, No.1, pp.57-63, 1995.

(12) C. Boucher, Z. Altamimi, and P. Sillard, "The 1997 International Terrestrial Reference Frame (ITRF97)", IERS Technial Note 27, Paris Observatory, 1999.

(13) Y. Koyama, R. Ichikawa, T. Otsubo, J. Amagai, K. Sebata, T. Kondo, and N. Kurihara, "Recent Achievements in Very Long Baseline Interferometry", J. Commun. Res. Lab., Vol.46, No.2, pp.253-258, 1999.

(14) H. Kiuchi, M. Imae, T. Kondo, M. Sekido, S. Hama, T. Hoshino, H. Uose, and T. Yamamoto, "Real-Time VLBI System Using ATM Network", IEEE Trans. Geosci. Remote Sencing, Vol.38, No.3, pp.1290-1297, 2000.

(15) Y. Koyama, N. Kurihara, T. Kondo, M. Sekido, Y. Takahashi, H. Kiuchi, and K. Heki, "Automated geodetic Very Long Baseline Interferometry observation and data analysis system", Earth Planets Space, Vol.50, pp.709-722, 1998.

(16) J. Nakajima, Y. Koyama, M. Sekido, N. Kurihara, T. Kondo, M. Kimura, and N. Kawaguchi, "1-Gbps VLBI, The First Detection of Fringes", (in press), Experimental Astron., 2001.

(17) Y. Takahashi, "The Baseline Analysis by the Differential Method in the Geodetic VLBI", J. Geod. Soc. Jpn., Vol.38, No.3, pp.283-292, 1992.

(18) K. Heki, "Three Approaches to Improve the Estimation Accuracies of the Vertical VLBI Station Positions", J. Geod. Soc. Jpn., Vol.36, No.3, pp.143-154, 1992.

(19) Y. Takahashi, "Estimation of Errors in VLBI Data and Position Determination Error", J. Geod. Soc. Jpn., Vol.40, No.4, pp.309-331, 1994.

(20) K. Matsumoto, N. Kawaguchi, M. Inoue, M. Miyoshi, S. Kameno, H. Takaba, T. Iwata, and N. Kurihara, "A Radio Source Survey at 22 and 43 GHz for Geodetic VLBI", J. Geod. Soc. Jpn., Vol.40, No.3, pp.255-265, 1994.