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2.3 Geodetic VLBI Activities at GSI

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ABSTRACT

The Geographical Survey Institute (GSI) has been performing geodetic VLBI observations to correct the positions of geodetic control points in Japan and to detect plate motion and crustal deformation around Japan. In 1981, GSI began development of a mobile VLBI system in cooperation with the Communications Research Laboratory, and used this system from 1986 to 1993 in the VLBI Experiment for Geodetic Application (VEGA) project. The most remarkable achievement of the VEGA project was the first detection of motion of the Philippine Sea plate. The GSI also carried out VLBI observations between Japan and Korea in 1995 by transporting a mobile system with a 3.8-m antenna to Korea. In 1994, ownership of the Kashima 26-m antenna was transferred from CRL to GSI, and with this antenna, GSI started to participate in international global observations. The coordinates of the Kashima 26-m antenna in the International Terrestrial Reference Frame (ITRF) have become the primary point of a new Japanese Geodetic Datum. At present, GSI's VLBI network in Japan consists of five stations that are used to perform regular VLBI observations. More than 30 years have passed, however, since the construction of the Kashima 26-m antenna, and its role has been passed on to the Tsukuba station, which will now participate in international global observations and act as the key station of the Japanese VLBI network.

Keywords: VLBI, Geodesy, Geodetic Coordinates 2000

1. Introduction

Since the Meiji era, the Geographical Survey Institute (GSI) has been establishing national geodetic control points throughout Japan by triangulation survey, and has come to survey the whole country and provide maps. Once it was shown, however, that long distances could be accurately measured by Very Long Baseline Interferometry (VLBI) technology, GSI began to perform very long baseline surveys (VLBI observations) in cooperation with the Communications Research Laboratory (CRL) (the former Radio Research Laboratory) to improve and implement the framework of Japan geodetic network and to detect of plate motions and crustal deformation. These observations continue to this day.

This article introduces the history and results of geodetic VLBI activities at GSI with a focus on observations made with the Kashima 26-m antenna.

2. Beginnings of VLBI Observations at GSI

In 1981, GSI began to develop transportable VLBI equipment with a 5-m parabolic antenna to conduct very long baseline surveys using VLBI technology with the main objectives of 1) correcting geodetic control points in Japan and 2) detecting plate motion and crustal deformation (Table 1). The observation system was completed in three years and preliminary experiments began in 1984 by performing a sequence of experiments with the Kashima 26-m antenna. The results were found to match those of ground surveys within 9 cm thereby demonstrating the feasibility of VLBI in surveying. In addition, the repeatability of the VLBI measurements themselves had a standard deviation of 1.5 cm.

Table 1 Construction of transportable VLBI equipment

1981	5-m antenna mechanism
1982	Front end; tracking drive control section
1983	Back end; hydrogen-maser frequency standard section
July 1984 August 1985 February 1986	System-level experiment between Tsukuba and Kashima to check functions

3. Domestic VLBI Observations Using a Mobile Observation System

Next at GSI was the VLBI Experiment for Geodetic Application (VEGA) launched in 1986 to conduct observations throughout Japan by moving the transportable VLBI equipment (Table 2). The objectives of these observations were to detect wide-area crustal deformation, improve the accuracy of Japan geodetic network, and contribute to precise determination of GPS satellite orbits.

In all of these observations, the Kashima 26-m antenna served as the main station.

In more detail, VLBI observations performed at Chichijima in 1987 and 1989 detected that the island, which is on the Philippine Sea plate, was moving in the west-northwest direction at a rate of about 7.4 cm for two years and about 3.7 cm per year. These were the first observations in the world to confirm by actual measurements the movement of the Philippine Sea plate that is asserted to be the main force of earthquakes in the Tokai area. This movement continued to be monitored even after setting up a fixed observation station at Chichijima and similar results have been obtained

Table 2 Domestic mobile observations by transportable VLBI equipment

1986	Shintomi (Miyazaki prefecture)
1987	Chichijima (Ogasawara Islands, Tokyo)
1988	Shintomi (Miyazaki prefecture)
1989	Chichijima (Ogasawara Islands, Tokyo)
1990	Shintotsukawa (Hokkaido)
1991	Mizusawa (Iwate prefecture)
1992	Sagara (Shizuoka prefecture)
1993	Kainan (Wakayama prefecture), Shintomi (Miyazaki prefecture)

Table 3 Domestic mobile observations using a 2.4-m transportable antenna

1993	Kanozan (Chiba prefecture)
1994	Tonami (Toyama prefecture), Kanozan (Chiba prefecture)

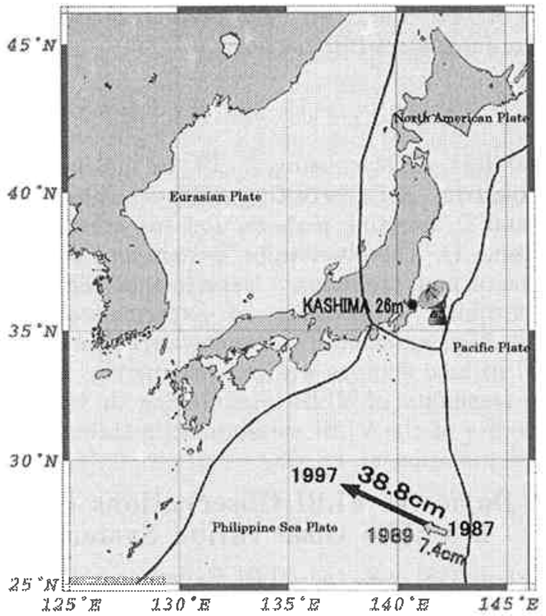

Fig. 1 Movement of Chichijima

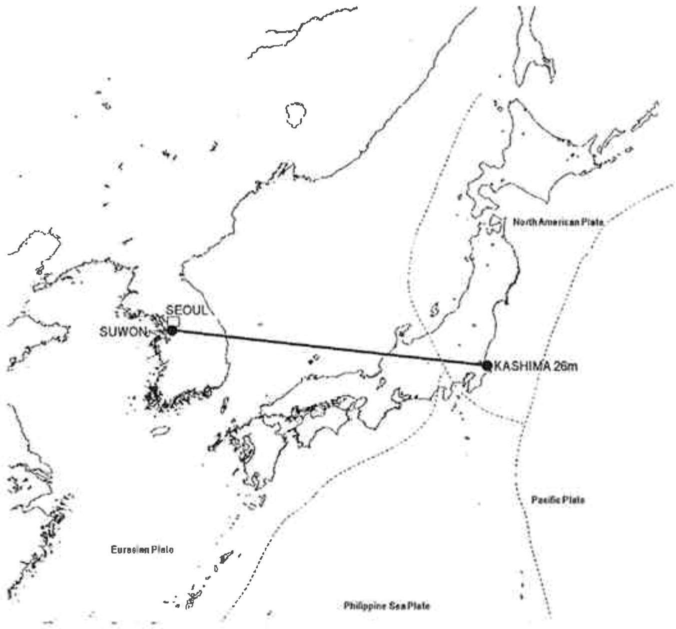

Fig. 2 Japan-Korea VLBI observation

(Fig. 1).

The GSI also conducted VLBI observations at Kanozan and Tonami in 1993 and 1994 using a 2.4-m transportable antenna (Table 3). In these observations, the Kashima 34-m antenna served as the main station.

The results of these domestic very long baseline surveys were used as reference in correcting geodetic control points in Japan and monitoring the sea level rise associated with global warming.

4. Japan-Korea VLBI Observations Using a Mobile Observation System

In the Republic of Korea, the governmental agency that performs the same kind of work as GSI in Japan is the National Geography Institute. These two agencies came to hold annually JAPAN-KOREA Conference for Cooperation in Geodesy and Cartography, and it was during the course of these meetings that an agreement was reached on conducting joint VLBI observations. Based on this agreement, new GSI transportable VLBI equipment (3.8-m antenna) was transported to Korea in 1995 and observations were performed in conjunction with the Kashima 26-m antenna (Fig. 2). The main objectives here were to combine the Japan-Korea geodetic networks with high accuracy and detect crustal deformation. As in Japan, Korea's geodetic network exhibited deviation (distortion, etc.), and to correct this deviation, it was desirable that the network be combined with the International Terrestrial Reference Frame (ITRF) as soon as possible. It was therefore decided to obtain international coordinates for control points in Korea by VLBI observations. At the same time, a continuous GPS observation point was established on the Korea side to detect plate motion in the Japan Sea area, and VLBI observations contributed to improving the accuracy of that point. This GPS observation point continues to accumulate data and to monitor the crustal deformation.

A total of four observations were carried out and three of these data were available. Correlation processing was performed in the Kashima Space Research Center using a K-3 Correlator, and a global solution was calculated at the Goddard Space Flight Center of the National Aeronautics and Space Administration (NASA) in the U.S. The Korean VLBI points in question are registered with the latest ITRF (ITRF 2000).

5. Participation in International Observations After Taking Ownership of the 26-m Antenna

As described above, GSI came to perform mobile observations using transportable VLBI equipment. For a compact transportable antenna, however, it is essential that the main station be a facility having a large antenna, and it was for this reason that the Kashima 26-m antenna came to be used during GSI mobile observations in the form of joint research with CRL. Nevertheless, the fact that GSI did not possess its own large antenna restricted its operations. For example, GSI could not participate in international joint VLBI observations for establishing international geodetic reference points, which is actually one of its tasks as a national survey institute, nor could it engage in domestic mobile observations as frequently as desired. Against this background, jurisdiction of the Kashima 26-m antenna passed to GSI in 1992, and in the years to come, the antenna would be used for international very long baseline surveys (international global observations) and as the main station for domestic observations.

The international global observations began as a part of the Dynamics of Solid Earth (DOSE) project led at the time by NASA. Its main objectives were long-term observations and monitoring of global plate motion and changes in the global environment such as the sea level rise, and construction and maintenance of ITRF. In regard to the latter, ITRF is a standard coordinate system essential to international observation-related projects that are now in progress, such as the making of global maps, which is advocated by GSI for this reason. The ITRF, moreover, provides a foundation for new Japanese Geodetic Datum (Geodetic Coordinates 2000; see section 8) and plays a major role as an infrastructure for the global society of the 21st century.

A key achievement of these international global observations was detection of Pacific plate motion by measuring change in the baseline between the Kashima 26-m antenna and Kokee station (Kauai, Hawaii). The observations for these measurements began in 1984 and continued even after GSI took ownership of the Kashima 26-m antenna (Fig. 3). This baseline is shrinking at a rate of about 6 cm per year.

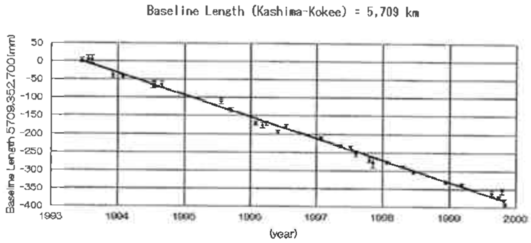

Fig. 3 Change in Kashima-Kokee baseline

6. Launch of Regular Observations with Fixed Observation Stations

As mentioned above, GSI began with mobile observations using transportable VLBI equipment. Establishment of fixed observation stations, however, began in 1994, and at present, GSI operates five fixed stations including the Kashima 26-m antenna (Fig. 4). Observations between the Shintotsukawa station and the Kashima 26-m antenna began in 1996, and the Aira and Chichijima stations came on line in 1997 and Tsukuba station in 1998. These five stations are currently being used to conduct observations on a regular basis over the eight baselines that they form (due to the small aperture of the Shintotsukawa station, though, no fringes appear between the Aira and Chichijima stations). The name of this observation network is GSI Advanced Radiotelescope Network (GARNET), while the name given to these observations is Japanese Dynamic Earth observation by VLBI (JADE). In 2000, the VLBI observation station at Gifu University also began to participate in JADE.

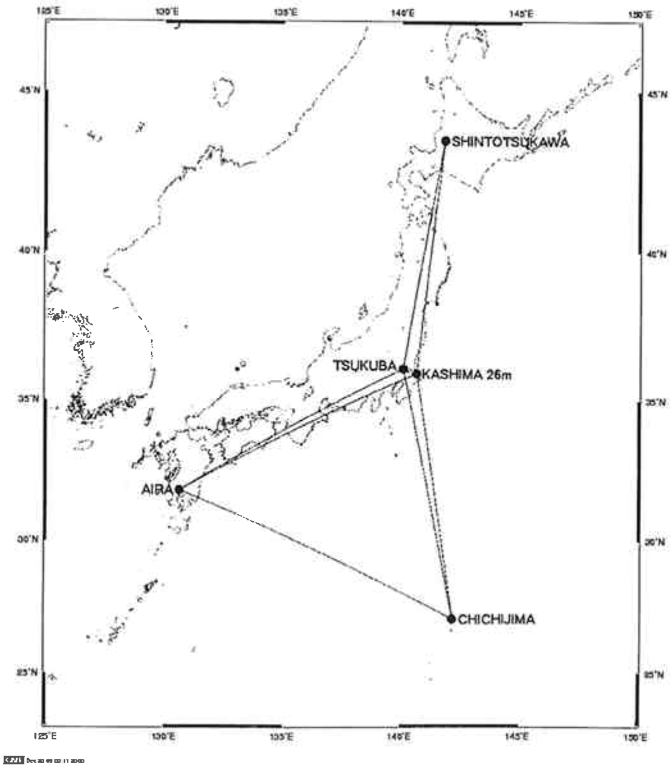

Fig. 4 GSI's domestic observation network

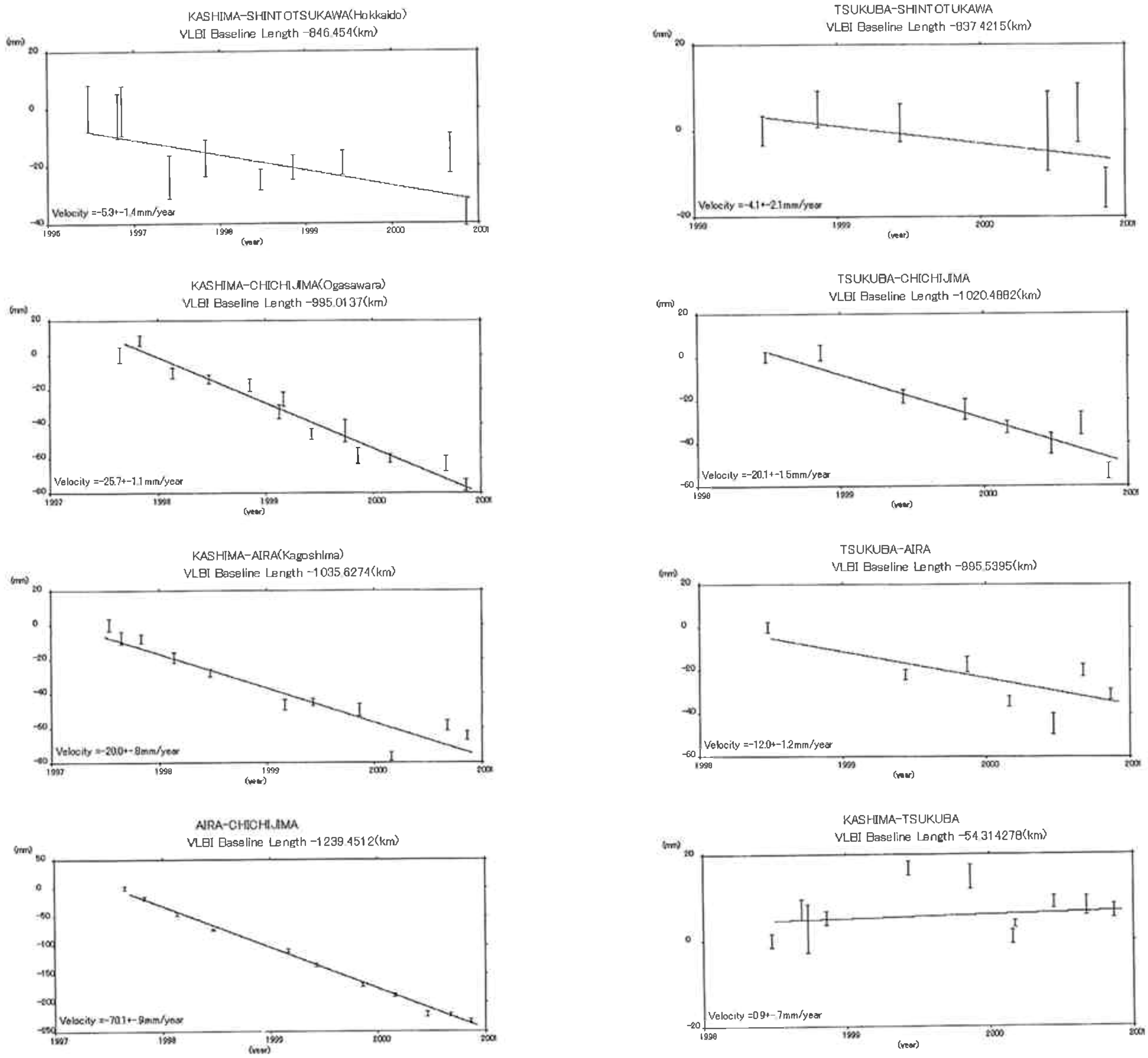

Fig. 5 Domestic observation results

Compared to mobile observations, regular observations by fixed stations are advantageous for three main reasons. These are 1) increased number of observations due to absence of restrictions associated with transportable observation equipment (from once or twice a year to four times a year); 2) more accurate determination of plate motion and crustal deformation because of regular observations; and 3) improvement in precision and accuracy as a result of five stations and eight baselines as opposed to two stations and one baseline.

Figure 5 shows change in each baseline over time based on the observation results obtained up to November 2000. These results reveal that the Aira-Chichijima baseline in particular has shrunken significantly, and that this change is quite linear in nature. This indicates that motion of the Philippine Sea plate that Chichijima is on and the crustal deformation of southern Kyushu near Aira are very regular.

Beginning in 2001, GSI plans to increase the number of observations by remote control from the Tsukuba VLBI center and to carry out eight observations per year. This number of observations is expected to obtain more detailed data on plate motion and crustal deformation.

7. International and Domestic Observations by the Tsukuba Station

In 1998, an observation facility with a 32-m large antenna was completed on the GSI premises in Tsukuba City. This Tsukuba station was expected to take over the role of the very old Kashima 26-m antenna as a participant in international global observations and as the main station in domestic observations. Six months after its completion, however, the antenna rail was damaged, and repair work beginning at the end of 1998 continued well into 1999, with full-scale operation not restarting until

November 1999.

In 2000, international global observations that had been performed by the Kashima 26-m antenna were completely transferred to the Tsukuba station, and 31 observations were carried out in one year. In international observations, the project having the most sessions is Continuous Observations of the Rotation of the Earth (CORE). The scientific objective of this project is to continuously record change in the Earth's rotational motion or so-called Earth Orientation Parameters (EOP), and the main feature of obtained data is its exceptional sensitivity to short-term Atmospheric Angular Momentum (AAM). In this capacity, CORE can contribute to improving the accuracy of ITRF and the international celestial reference frame (ICRF) and to maintaining these frames. It can also play a role in the research of continuous momentum exchange among the oceans, atmosphere (wind), and the solid earth; early detection of El Nino; detection of earthquake signals; research of the geometry and dynamics of the Earth's core; monitoring of change in seal level, etc. The Tsukuba station plans to participate in 15 CORE sessions annually.

In addition to CORE, the Tsukuba station is participating in bimonthly sessions of the U.S. astronomical VLBI observation network called Very Long Baseline Array (VLBA). These sessions consist of large-scale astronomical and geodetic observations using a total of 20 stations achieved by adding ten stations geared to geodetic observations to the ten stations of the VLBA network. The sessions began in 1997, and Tsukuba station has been participating in all since 2000. These sessions are being coordinated by the geodetic VLBI programs of three agencies: United States Naval Observatory (USNO), NASA, and National Radio Astronomy Observatory (NRAO). The acquired data is used by each of these agencies according to their respective objectives and GSI participates in these sessions with the aim of improving the accuracy of the ITRF.

Tsukuba station is also participating in CRF sessions to improve the accuracy of ICRF and SURVEY sessions to search for new radio sources.

In 2000, moreover, Tsukuba station participated in "Japan-tie" (JPNTI) sessions to be tied with the Kashima 26-m and 34-m antennas at high accuracy. In addition to the large antennas of these three stations, four stations of the Key Stone Project (KSP) also participated in these sessions. The goal of making a high-accuracy tying of Tsukuba station with the Kashima 26-m and 34-m antennas was achieved, and as a result, Tsukuba station was able to take over the data obtained by those antennas in the past. Tying of the GSI and CRL VLBI networks was also performed with the result that new high-accuracy international standard coordinates could be given to the Kashima 34-m antenna and the four KSP stations. Also, as these KSP stations were equipped with both VLBI observation facilities and Satellite Laser Ranging (SLR) equipment, it became possible to tie the VLBI network with the SLR network. These observations are expected to determine a high-accuracy baseline vector between Kashima and Tsukuba with length and position within 0.3 mm and 1 mm, respectively. Analysis of obtained data is currently in progress.

The 32-m antenna of the Tsukuba station has about five times the receiving ability of the Kashima 26-m antenna. It also has the highest drive performance in the world at three degrees per second for 30-m-class antennas. This enables the Tsukuba station to participate in a wide variety of international global observations that the Kashima 26-m antenna could not. In particular, considering that there had been no high-performance VLBI antennas in the Asia region, the Tsukuba VLBI station is expected to contribute to VLBI as a prime station in this region.

As for GSI domestic observations, the Gifu station has joined GARNET since 2000, and the Yamaguchi and Mizusawa stations of the National Astronomical Observatory are scheduled to participate in the future. These additions should lead to even more detailed monitoring of plate motion and crustal deformation in Japan. The transfer of the role of major station from the Kashima 26-m antenna to Tsukuba station, and participation by Tsukuba station in international global observations, moreover, will provide international standard coordinates to domestic VLBI network.

8. New Geodetic System: Geodetic Coordinates 2000

At present, Japan's network of control points is founded on the geodetic system established in the Meiji era and does not correspond to the current world geodetic system. To rectify this situation, GSI is now working to achieve a migration to the global geodetic system through activities that include revision of the Survey Law. The new Japanese Geodetic Datum that will conform to the world geodetic system is called "Geodetic Coordinates 2000". To calculate this new system, the coordinates of the Kashima 26-m antenna determined by international global observations have been chosen to be origin. In addition, the three-dimensional coordinates of the antenna in Shintotsukawa and Kainan stations that are used for domestic VLBI observations were calculated using the three-dimensional coordinates in ITRF94 of Kashima-26m antenna determined by the International Earth Rotation Service (IERS) as a given point. These three points become the framework for the Japanese system. Then, by treating these points as zero-order triangulation points, the coordinates of GPS-based control points (GPS continuous observations points), first-order triangulation points, second-order triangulation points, and third-order triangulation points can be recalculated to give a new network of control points. In this way, the results of international global observations performed by the Kashima 26-m antenna have been applied to the development of a new geodetic reference system.

9. Summary

Beginning with very long baseline surveys in 1981, the Geographical Survey Institute has progressed from an era of mobile observations to the present era of regular observations using a network of five stations forming eight baselines. As part of this history, the Kashima 26-m antenna was used as the main station in mobile observations and as a participating station in international global observations. The GSI is also working on a migration to a new geodetic reference system for Japan in the form of Geodetic Coordinates 2000. More than 30 years have passed, however, since the construction of the Kashima 26-m antenna, and because of its age, the Tsukuba station will be taking over its role in the years to come.