2. OVERVIEW OF THE KEY STONE PROJECT

By

Taizoh YOSHINO

(Received on)

Keywords: VLBI, SLR, collocation, real time VLBI

Running Title: Overview

ABSTRACT

Recent progress in space geodesy has made it possible to measure the position of a station within a few millimeters precision. The Key Stone Project (KSP) is designed to monitor crustal deformation in the Tokyo metropolitan area by using VLBI (very long baseline interferometry) and SLR (satellite laser ranging). The main objective is to measure the crustal deformation for an earthquake research. Because the KSP system is designed to use state-of-the-art technology, it is used also as a test bed for advanced studies in geodynamics and related sciences.

1. Introduction

The Japanese islands are surrounded by several global plates: the North American, Eurasian, Pacific, and Philippine Sea plates. Earthquakes in Japan are caused by the relative motion of these plates as they collide near and/or beneath the Japanese islands.

Since the mid-1970s, the Communications Research Laboratory (CRL), formerly known as the Radio Research Laboratories (RRL), has been conducting pioneering work in very long baseline interferometry (VLBI), using a domestic network to develop and demonstrate a prototype VLBI system. The CRL continued developing VLBI technologies for measuring global geodynamics, for studying the Earth’s rotation, for time synchronization and for studying radio astronomy. The CRL began a satellite laser ranging (SLR) study using a 1.5 m optical telescope at Koganei near Tokyo in 1990.

In 1993, the CRL started constructing a crustal-deformation monitoring system using four VLBI/SLR stations (Koganei, Kashima, Miura, and Tateyama) in the Tokyo metropolitan area (Fig. 1) based on our experiences. We, however, used state-of-the-art technology as much as possible in the system design as long as it does not impair system reliability. This project is called the Key Stone Project (KSP) after a Japanese legend of Kashima shrine regarding the earthquakes [1]. A central station locates at Koganei to control and monitor the other three stations. The Miura and Tateyama stations are closer to the boundary of the Philippine Sea plate, and thus are more susceptible to intra-plate deformation caused by its motion. The systems were constructed in three years as shown by the schedule in Fig. 2.

2. System Design

The primary purpose of KSP is to precisely observe the crustal deformations to study precursors to large earthquakes. Hence, the system is designed for routine observation. The VLBI observations are performed by a single operator working at the central station in Koganei. In other words, unmanned VLBI operation is used for regular observation. The SLR observations are also performed by the operator at the central station in Koganei either controlling the four stations or controlling one station and monitoring the status of the other three stations with the assistance of operators at the other sites.

The system is designed so that every component of the error in baseline vector is better than 1 cm for both the VLBI (five hours observation per day) and SLR observations because it is expected to see a signal of the intra-plate deformation in this precision. Finally, we got two mm in the repeatability in the VLBI baseline length measurement over 24 hours [2]. Because SLR observation is weather dependent and weak in time resolution, the global analysis of SLR data is conducted only after enough data is collected. Hence, the local analysis is being tested for the quick solution. The results of the VLBI data analysis are sent to the Japanese Meteorological Agency, which monitors various seismological data, as soon as they are ready. The observed SLR data is released to the Crustal Dynamics Data Information System (CDDIS) immediately after observation.

The VLBI and SLR techniques are completely independent. First, they depend differently on the atmospheric delay in the wet component. Second, the SLR observations are referenced to the Earth’s center of mass, while the VLBI observations are not. Because the VLBI and SLR facilities are collocated at each KSP site, a contribution to the reference frame study is expected to minimize a possible systematic error in a terrestrial coordinate. The number of collocated stations worldwide, however, is limited. In particular, there are few such stations in Asia. Hence, KSP in Asia may contribute significantly to the global reference frame in spite of its size of a regional observation network. This is because the coordinates of each station are connected to the global frame via the SLR observations and temporal international VLBI experiments.

Crustal deformation in the Tokyo area is also monitored using the nationwide global positioning system (GPS) array of the Geographical Survey Institute (GSI). The spacing of the receivers is about 30 km. The CRL and GSI agreed to place GPS receivers at the Koganei and Kashima stations to be collocated with the KSP points. The CRL also has its own receivers at each site. A bird’s-eye view of the Koganei station is shown in Fig. 3, showing an example of collocation.

Since the advent of VLBI, the radio signals from celestial sources have been recorded on magnetic tape for off-line data processing. This is because sending all the data to the processing station via a communication network was neither possible nor cost-effective. Hence, the tape recording speed limited the performance of the system. Latest communication technology, however, has enabled high-speed data communication via optical-fiber networks. By using real-time VLBI data processing, the VLBI results can be quickly obtained with unmanned data processing. The KSP uses the communication network in Tokyo to conduct real-time VLBI data processing as a joint research project with NTT (Nippon Telegraph and Telephone). This is the only case we know of in which regular VLBI observations are performed at 256 Mbps.

3. VLBI system

The CRL has developed a series of VLBI systems. For KSP, the system must have high precision, reliability, easy operation, and quickness of getting results. To achieve high precision, a medium-size antenna is used because this size is advantageous for making a number of observations per day by the high speed slewing between sources. It is also relatively easy to maintain. The slewing rate is 3 deg/s for both azimuth and elevation driving. The S and X band frequency is equipped to be compatible with other geodetic VLBI stations. However, the frequency band is wider to enable a wide-bandwidth synthesis. The bandwidth of each channel in the video band is increased from 2 to 32 MHz. A K-4 system is used for the back-end system to allow the above requests. The maximum recording speed of the KSP system is 256 Mbps, because this is the maximum speed of a K-4 system. An automatic tape-changer is used for the unmanned operation for the data recording.

The central station at Koganei performs both observation and data processing. To achieve reliable operation, a sub-central station is located at Kashima. To enable remote control at the Kashima station, most of the fundamental functions are also given to the sub-central station. All of the stations are connected via a wide-area computer network for a remote control besides the network for the high speed data communication.

Regular VLBI observation is performed at 256 Mbps rate since the end of January 1995 along the Koganei-Kashima baseline. As an example of the baseline length evolution, the change of the baseline between Koganei and Tateyama is shown in Fig. 4 to see the largest change among the baselines. It is understood that the change of above baseline by –16.3 mm/yr is caused by the motion of the Philippine Sea plate.

4. SLR system

An SLR system was designed to be installed along with the VLBI system in the KSP because it operates on completely different principles. In VLBI, the position of a ground station is determined using a celestial radio source while SLR uses an orbiting satellite via optical link. It is known that SLR is insensitive to the contribution of the wet component in the excess path delay unlike VLBI and GPS. And independent measurement is important to achieve reliable and accurate results by highly precise geodetic measurements.

The SLR systems consists of the four fixed stations together with one transportable station. Although the optical telescope and dome at each site are fixed, the laser and the time measurement system are installed in a transportable container. The wavelength of the laser is 532 nm. The systems at each site are identical, excluding the transportable station. The four SLR stations were built between 1995 and 1996. The 75 cm telescopes are installed in closed domes, which have a movable window synchronized with the direction of the telescope for transmitting and receiving laser pulses. This design protects the telescopes against rain and strong wind when unmanned operations are performed. Moreover, it helps a temperature control inside the dome to keep the reference point of the SLR telescope stabilized.

Because the stability of the reference point is important for geodetic purposes, it is regularly monitored by the laser signal transmitted from the telescope using several ground targets around and inside the dome. The width of the laser pulse used is better than 50 ps. Digital communication lines facilitate remote operation. Starting in September 1998, the SLR data has been formally released to the international community via CDDIS.

5. Real-Time Data Processing

In spite of some pioneering experiments, the real-time VLBI technique was not widely accepted as being suitable for regular use due to its high cost and insufficient infrastructure. In 1976, VLBI data was first experimentally transferred via a satellite link at 20 Mbps between Algonquin (Canada) and the NRAO (USA) by using a Canadian Technology Satellite (CTS) [3]. In 1979, a domestic Japanese VLBI experiment was performed using a 4 Mbps microwave link between Kashima and Hiraiso station to study atmospheric phase scintillation. This was done by observing a C-band signal from a geosynchronous satellite using the K-2 system [4].

Modern communication technology provides an opportunity to start real-time VLBI with a much broader bandwidth. Real-time VLBI enables the results to be obtained at near real-time and the VLBI systems to be made more sensitive. In 1996, VLBI data was transferred at 256 Mbps via an optical-fiber link within the Key Stone network [5]. In Russia, a satellite link with a 36 MHz bandwidth is being used for VLBI [6].

The real-time data processing in KSP facilitates unmanned operation and provides timely data on crustal deformation. With fewer mechanical parts in the system than in the system using data recorder, it should be more reliable for regular operation.

A schematic diagram of the high-speed data link between the KSP stations is shown in Fig. 5. The interface between the ATM (asynchronous transfer mode) network and the correlator is the same as that for the tape recording to achieve compatibility. The delay and jitter caused by the ATM network are absorbed in a newly developed ATM receiver so that the data from the different station may be synchronized.

6. Concluding Remarks

The KSP system was developed to enable the study of crustal deformation in the Tokyo metropolitan area. The system comprises four stations. The results are provided to meteorological agency in Japan and to the public via the Internet.

Because the VLBI, SLR and GPS systems are collocated at each site and uses new technologies, it is also useful for advanced studies of space geodesy.

Acknowledgments

We deeply appreciate the NTT's support of the real-time VLBI experiments.

References

[1] Yoshino, T. "Crustal deformation monitoring in Tokyo metropolitan area by space geodetic observation," J. Com. Res. Lab., Vol. 41, No. 3, 1994.

[2] Kondo, T., et al., "Evaluation of repeatability of baseline lengths in the VLBI network around the Tokyo metropolitan area", GRL, Vol. 25, No. 7, 1047-1050, April 1998.

[3] Knowles, S.H., Waltman, W.B., Broten, N.W., Fort, D.H., Kellerman, K.I., Rayrer, B., Yen, J.L., and Swenson, G.W., "First Results from a Satellite Data Link Radio Interferometer, " Proc. PTTI, 1976.

[4] Kawano, N., Takahashi, F., Yoshino, T., Koike, K., Kumagai, H., and Kawajiri, N., "Development of Real-Time VLBI and Measurements of Scintillation", J. Radio Res. Labs., Vol. 29, No. 127, pp. 53-102, 1982.

[5] Kiuchi, H., "Real-Time VLBI of the KSP", Proc. TWAA96 Workshop, Kashima, Dec. 1996.

[6] Kaidanovski, M.N., "Real-Time VLBI", Proc. TWAA96 Workshop, Kashima, Dec. 1996.

Figure captions

Fig. 1	Four VLBI/SLR stations in the Key Stone Project.
Fig. 2	Construction schedule for KSP system.
Fig. 3	Bird's-eye view of Koganei station.
Fig. 4	Baseline length evolution between Koganei and Tateyama.
Fig. 5	Schematic diagram of real-time VLBI system.

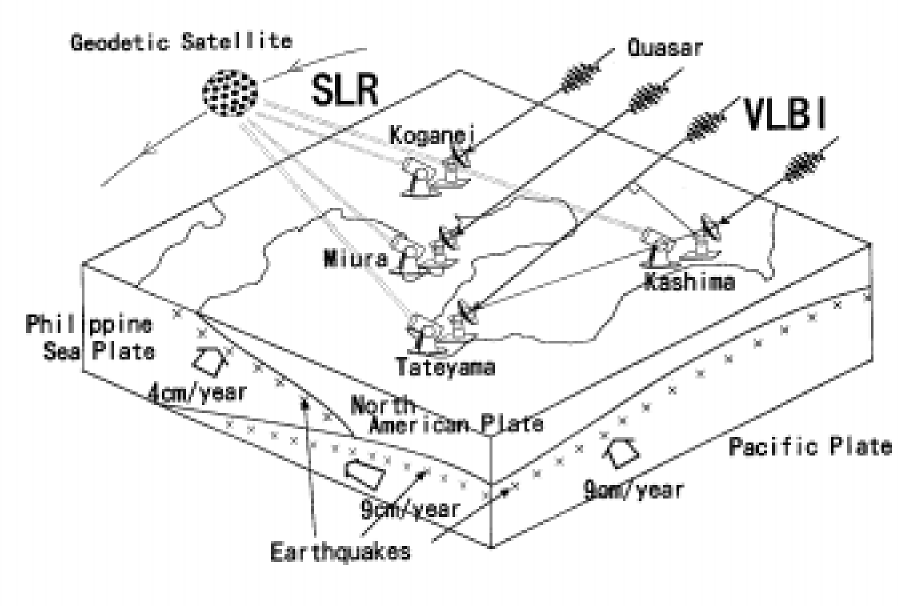
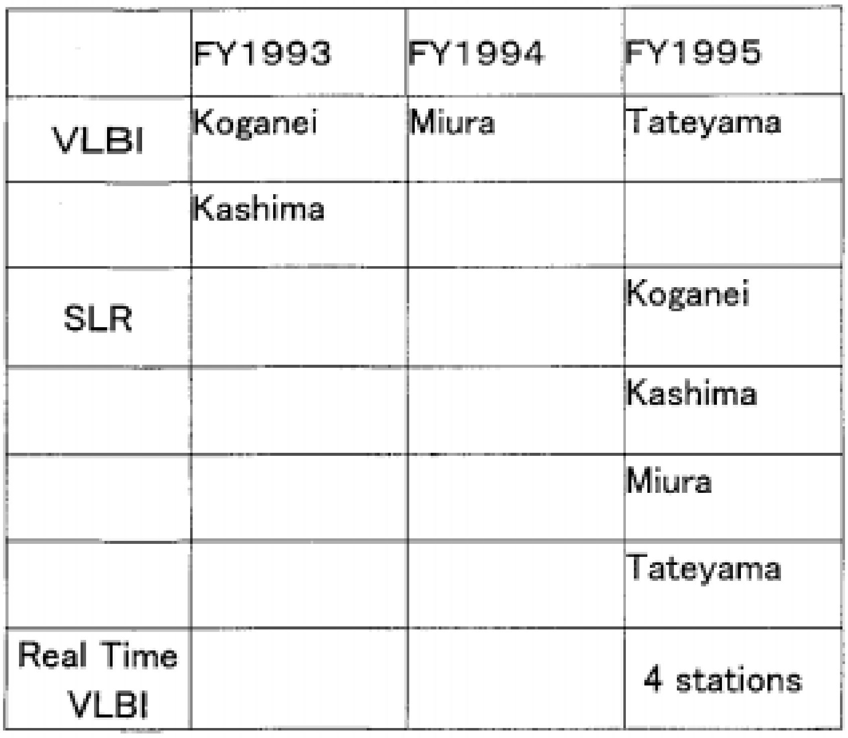


Figure 1:



	FY1993	FY1994	FY1995
VLBI	Koganei	Miura	Tateyama
	Kashima		
SLR			Koganei
			Kashima
			Miura
			Tateyama
Real Time VLBI			4 stations

Figure 2:

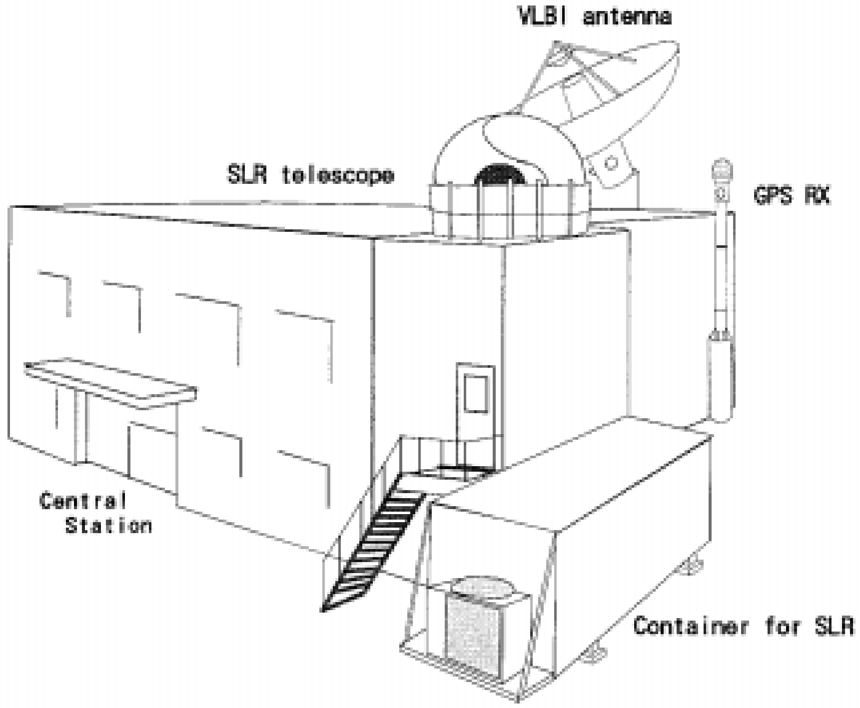


Figure 3:

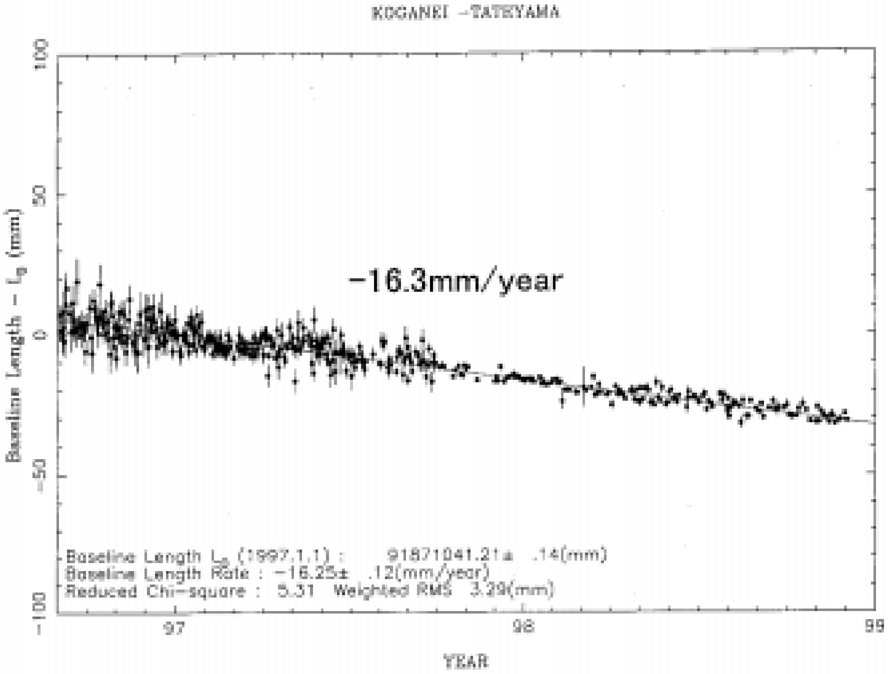


Figure 4:

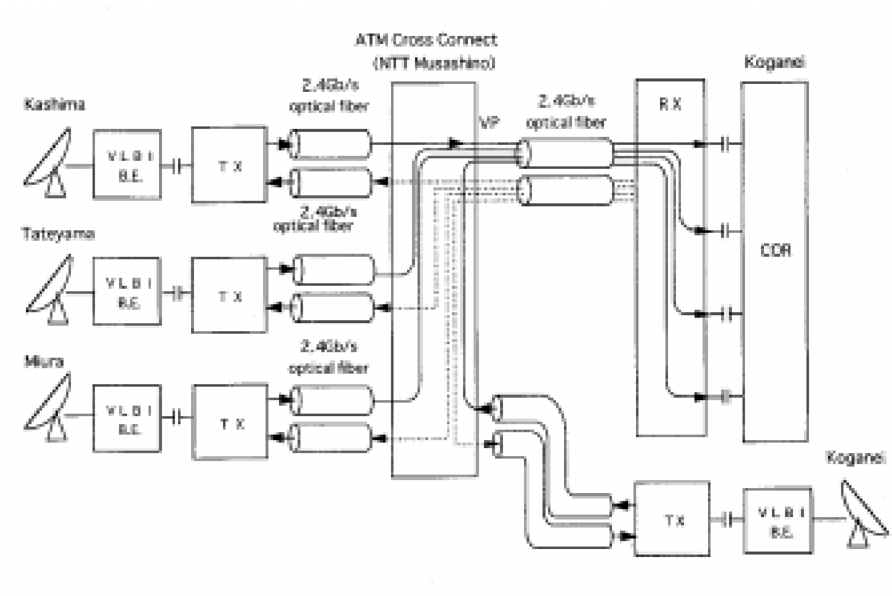

ATM Cross Connect
(NTT Musashino)
Koganei
Kashima
2.4Gb/s
optical fiber
VP
2.4Gb/s
optical fiber
R X
V L B I
B.E.
T X
2.4Gb/s
optical fiber
Tateyama
COR
V L B I
B.E.
T X
2.4Gb/s
optical fiber
Miura
V L B I
B.E.
T X
Koganei
T X
V L B I
B.E.

Figure 5: