VLBI, SLR and GPS observations in the Key Stone Project

Yasuhiro Koyama, Ryuichi Ichikawa, Tadahiro Gotoh, Mamoru Sekido,
Tetsuro Kondo, Noriyuki Kurihara, Fujinobu Takahashi,

*Kashima Space Research Center, Communications Research Laboratory,
893-1 Hirai, Kashima, Ibaraki, 314 JAPAN*

Jun Amagai, Toshimichi Otsubo, Hideyuki Nojiri,
Kouichi Sebata, Hiroo Kunimori, Hitoshi Kiuchi, Akihiro Kaneko,
Yukio Takahashi, Shin'ichi Hama, Yuko Hanado, Michito Imae,
Chihiro Miki, Mizuhiko Hosokawa, and Taizoh Yoshino

*Communications Research Laboratory
4-2-1 Nukui-Kita, Koganei, Tokyo, 184 JAPAN*

Abstract

A space geodetic observation network has been established around Tokyo, Japan under a project name of Key Stone Project by Communications Research Laboratory. Three space geodetic methods, i.e. Very Long Baseline Interferometry, Satellite Laser Ranging, and Global Positioning System, are involved in the project. As of September, 1997, VLBI and GPS observation facilities at all four stations are operational, whereas developments of SLR observation facilities are in course of final alignment procedures. Daily VLBI observations began in January 1995 with a single baseline between Koganei and Kashima, and the full network observations with four stations began in September 1996. Observations and data analysis of VLBI measurements are fully automated and the analysis results are produced shortly after all observations of an experiment session finished. GPS observations at four sites began in July 1997 and the automatic data collection and analysis system are under developments.

1. Introduction

Communications Research Laboratory (CRL) has been establishing a compact space geodetic observation network around Tokyo, Japan under a project which was named as Key Stone Project. The Key Stone Project network is consist of four observation sites at Koganei (Tokyo), Kashima (Ibaraki), Miura (Kanagawa), and Tateyama (Chiba). The geographic locations of these four sites are shown in Figure 1.

At each site, observation facilities of three space geodetic techniques, i.e. Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR) and Global Positioning System (SLR), are collocated. An 11m diameter fully steerable cassegrain

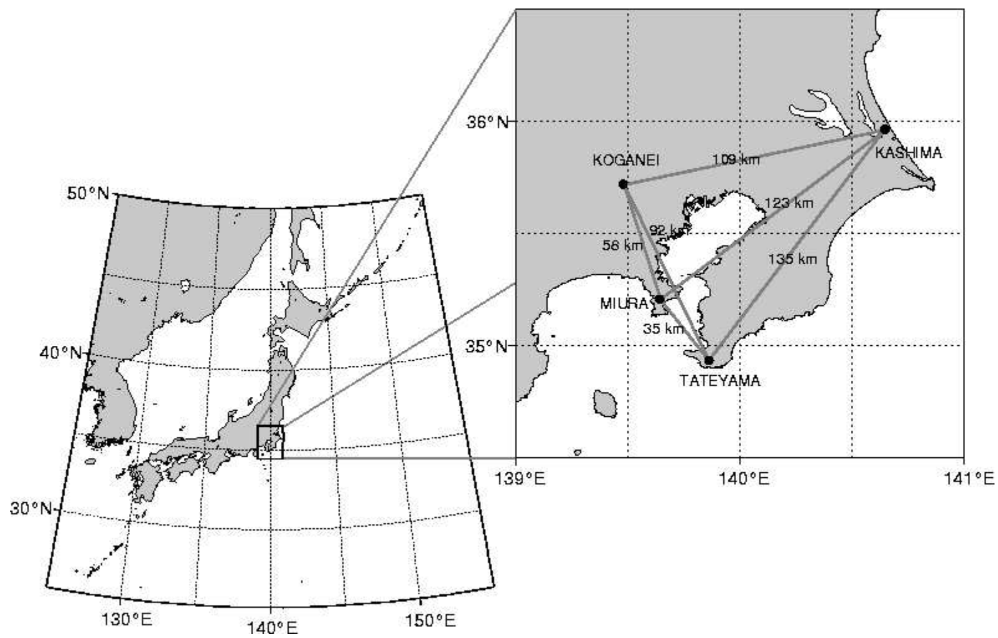

Figure 1. Geographic locations of four observation sites of the Key Stone Project space geodetic network.

antenna for VLBI observations, an optical telescope with an aperture of 75cm in diameter for SLR observations, and a GPS antenna mounted on top of a stable pillar are placed within about 100m from each other. As of September, 1997, VLBI and GPS observation facilities at all four stations are operational. Daily VLBI observations began in January 1995 with a single baseline between Koganei and Kashima, and the full network observations with four stations began in September 1996. Observations and data analysis of VLBI measurements are fully automated and the analysis results are produced shortly after all observations of an experiment session finished. GPS observations at four sites began in July 1997 and the automatic data collection and analysis system are under developments. The first signal of the laser echo from Lageos satellite was detected in December 1996 with the SLR observation system at Kashima. A lot of engineering data were then collected at Kashima and at Koganei in February, 1997 and final alignment procedures of the laser and optical system are on the way at present. The regular SLR observations will begin after automated operation software is completed.

2. VLBI, SLR, and GPS observation and data analysis system

One of the objectives of the Key Stone Project space geodetic network is to measure precise site positions with three space geodetic techniques and to investigate dynamical behaviors which might be seen in the series of estimated site position data before and during seismic activities. Because of this objective, the observations of VLBI, SLR, and GPS are required to be performed as frequently as possible. To achieve

Table 1. Estimated VLBI site positions R on January 1, 1997, and velocities V defined in the ITRF94 coordinate system.

Site		X (mm)	Y (mm)	Z (mm)
Koganei	R	-3941937398.4 ± 5.8	3368150858.3 ± 4.7	3702235261.4 ± 5.0
	V	7.5 ± 0.7	-5.2 ± 0.6	-15.8 ± 0.6
Kashima	R	-3997505622.1 ± 6.1	3276878350.2 ± 4.8	3724240665.9 ± 5.2
	V	5.1 ± 2.3	-3.6 ± 2.0	-19.8 ± 2.5
Miura	R	-3976129918.1 ± 6.9	3377927833.6 ± 5.7	3656753813.7 ± 5.9
	V	24.2 ± 1.1	-6.7 ± 0.9	-15.5 ± 1.0
Tateyama	R	-4000983352.7 ± 5.7	3375275900.1 ± 4.7	3632213145.2 ± 5.0
	V	33.5 ± 1.9	-13.3 ± 1.6	-24.0 ± 1.7

this requirement, observations and data analysis processing have been automated as much as possible.

In the VLBI system, almost all procedures from observations to data analysis are automated (Koyama 1997) and it will be fully automated when the developments of the real-time VLBI data correlation software (RKATS) is completed in the near future (Kiuchi *et al.* 1996). The VLBI observations are performed with two frequency bands at S-band and X-band. Before June 1997, the total data rate of observations were 64 Mbps and the observed data were recorded on ID-1 standard magnetic tapes. These tapes are then shipped to Koganei station everyday and usually delivered next day. The recorded data are processed with a VLBI correlator system developed for the Key Stone Project. Simple operations were required to change observation tapes in the digital mass storage system at each observation station and to ship recorded tapes. Since June 1997, on the other hand, the observations are performed at the total data rate of 256 Mbps and the observed data are transfered to the VLBI correlator at Koganei station with high speed data communication line which can transfer digital data at 2 Gbps using Asynchronous Transfer Mode (ATM). After data correlation processing and following band-width synthesis processing (Kondo *et al.*, 1996), Mark-3 format databases are created and site positions are estimated along with other parameters such as clock offsets and tropospheric delay. In the data analysis, model calculations are performed by a software called CALC which has been developed in Goddard Space Flight Center of National Aeronautics and Space Administration and the least square estimates are performed by a software called VLBEST which has been developed in CRL. The estimated results are made available to public over the Internet via anonymous FTP and World Wide Web accesses.

The estimated site positions and their rates of change are shown in Table 1. Site positions are given on the epoch of January 1, 1997 in the ITRF94 coordinate system based on results of Key Stone Project VLBI experiments and a joint VLBI experiment with 34m antenna station at Kashima on May 1, 1997.

Observations of GPS are performed with the Ashtech Z-X113 data acquisition unit and the Rev. B (Koganei) or Rev. D (Kashima, Miura, and Tateyama) antenna placed on a stable pillar. Data are collected at 30 seconds of intervals for 24 hours a day, and the observed data stored in a PC system are transferred to a GPS data analysis workstation through the computer network configured for the VLBI observation system. Observed data are analyzed by using Bernese Version 4.0 software which has been developed in Bern University. To make the entire process from data transfer to data analysis automated as much as possible, the software developments are under way.

SLR observation system consist of an optical telescope with a 75cm primary mirror and a 15cm secondary mirror in a Coude configuration, and a laser optic system. The telescope is placed in a fully covered dome equipped with a high quality glass window through which the ranging observations are performed. Thus the telescope can be operated in a temperature controlled stable environment and is protected against precipitation or harsh weather without an operator attending to the telescope system. By using eye-safe laser system of 1.5 micron of wavelength in addition to the main high power laser transmitting system, any possible hazards are automatically protected. The remote control and data transfer are done over 128kbps computer network independently configured for the SLR observations. The automated operation software and data analysis which are now being developed will allow regular extensive SLR observations in the near future.

3. Ground Survey Measurements

Ground survey measurements were performed with conventional measurement facilities using laser transmissions to measure relative position of three reference points of VLBI, SLR and GPS at each site. The results are tabulated in Table 2. The results obtained from VLBI and GPS observations are also tabulated for comparison.

Table 2. Positions of SLR and GPS reference points seen from VLBI reference point obtained by (1) ground survey measurements and (2) VLBI and GPS observations.

	Site		Eastward (mm)	Northward (mm)	Upward (mm)
(1)	Koganei	SLR	17420.8	−31359.6	−1975.0
		GPS	3493.0	−23843.2	−1769.9
	Kashima	SLR	12387.9	76693.2	7725.0
		GPS	18285.7	−24052.4	−4471.4
	Miura	SLR	16603.7	−74138.4	−2240.0
		GPS	−17032.1	6364.4	···
	Tateyema	SLR	−37205.4	−15229.3	−2056.0
		GPS	−34012.5	−19654.7	···
(2)	Koganei	GPS	3481.1 ± 1.7	-23854.5 ± 1.7	-1741.6 ± 8.6
	Kashima	GPS	18282.3 ± 1.6	-24069.7 ± 1.8	-4429.7 ± 9.1
	Miura	GPS	-17049.2 ± 2.0	6352.5 ± 2.2	-4441.4 ± 10.3
	Tateyama	GPS	-34011.9 ± 1.8	-19674.0 ± 1.6	-259.9 ± 8.6

Reference points of VLBI and SLR are defined as intersection of azimuth and elevation axes of the antenna and the telescope, respectively. Reference point of GPS is defined as a phase center of the antenna. The vertical components of the GPS reference point seen from the VLBI reference points at Miura and Tateyama stations are not yet available since the vertical offsets of GPS antenna phase centers from the top of pillars are not measured yet. VLBI results are obtained from daily regular VLBI observations and a joint VLBI experiment with four stations of the Key Stone Network and 34m antenna station at Kashima. GPS results were obtained from a data analysis of observations on April 21 and 22, 1997 at Kashima, Koganei, and at Tsukuba observed by Geographical Survey Institute, and another five day observations from July 28, 1997 at four stations of Key Stone Project network. The GPS results are obtained based on the ITRF94 global coordinate through a IGS site at Tsukuba (TSKB).

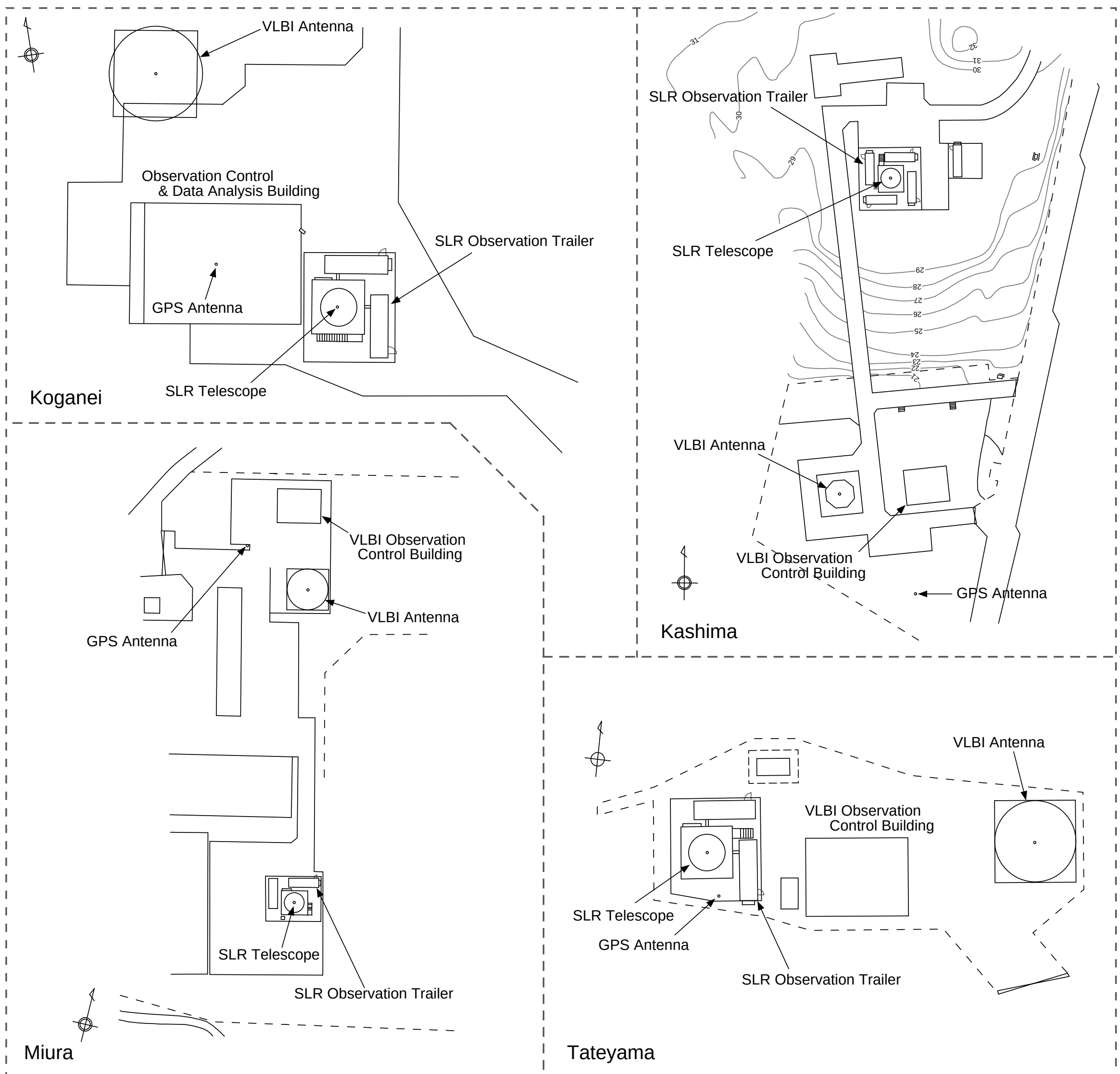

Figure 2. Site map of each observation site.

The comparison between ground survey results and two space geodetic measurements of VLBI and GPS showed an agreement within $2cm$ in horizontal components, and 5cm in a vertical component. The other comparison will be made when SLR results are obtained and the reasons of the discrepancies will be investigated to obtain better agreements. The precise ground survey measurements will be very useful for the collocation studies to tie different space geodetic techniques. Locations of reference points of VLBI, SLR, and GPS are shown in site maps in Figure 2.

4. Concluding Remarks and Future Plans

The system of the Key Stone Project space geodetic network has been described. The network is relatively compact with largest distance of 135km considering that space geodetic techniques are often applied to much longer distances. Because of its compactness and remote operation capabilities, however, the Key Stone Project can be considered as a unique and ideal test-bed of the technical developments and system improvements. Regular and extensive observations of VLBI, SLR, and GPS will be compared with each other to improve consistencies and accuracies. The network will be regularly tied with global space geodetic networks by joint VLBI experiments and interchanges of observation data of SLR and GPS.

Acknowledgments

The authors would like to express appreciations to colleagues in Geographical Survey Institute for GPS observations at Tsukuba and data correlation of a joint VLBI experiment of Key Stone Project and 34m antenna at Kashima. We would also like to appreciate colleagues in Goddard Space Flight Center of National Aeronautics and Space Administration for use of many involved softwares, and members of Communications Research Laboratory at present and in the past for the various system developments.

References

Kiuchi, H., M. Imae, T. Kondo, M. Sekido, S. Hama, T, Yamamoto, H. Uose, and T. Hoshino, "Real-time VLBI of the KSP", proceedings of the Technical Workshop for APT and APSG 1996, p. 125, 1996

Kondo, T., H. Kiuchi, and M. Sekido, "KSP Correlator and Data Reduction System", proceedings of the Technical Workshop for APT and APSG 1996, p. 188, 1996

Koyama, Y., "Automated Remote Operation System and Data Analysis System for the Key Stone Project", proceedings of the Technical Workshop for APT and APSG 1996, p. 139, 1996

Kunimori, H., C. Miki, J. Amagai, H. Nojiri, and T. Otsubo, "Automated SLR Observation System for Keystone Project", proceedings of the Technical Workshop for APT and APSG 1996, p. 144, 1996