Comparison of Coordinates and Velocities of the Key Stone Project Observation Sites determined from VLBI, GPS, and SLR.

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Abstract

Communications Research Laboratory has established four space geodetic observation sites in and around Tokyo, Japan under the Key Stone Project. At each of the four sites, an 11-m antenna VLBI system, a 75-cm telescope SLR system, and a geodetic GPS receiver are collocated closely. Site coordinates of the four VLBI stations have been connected to the ITRF96 reference frame from seven tie VLBI experiments with the 34m antenna station at Kashima by using its coordinates as the reference. GPS measurements at four Key Stone Project observation sites began in July, 1997. The GPS antenna positions were estimated by using ITRF96 site coordinates of the surrounding seven IGS sites. Regular SLR observations began in October 1998, and the site coordinates of four sites have been determined from a global solution. These results coincided within a few centimeters by using the results from local ground survey measurements. However, there remained discrepancies of a few centimeters and the cause of the discrepancies are discussed. The precise comparison of the site velocities determined from VLBI and GPS measurements is also becoming possible and the results are presented.

1. Introduction

A space geodetic observation network has been established around Tokyo, Japan under the Key Stone Project (KSP) by Communications Research Laboratory. Three space geodetic methods, i.e. Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and Global Positioning System (GPS), are involved in the project. At each of the four sites, an 11-m antenna VLBI system, a 75-cm telescope SLR system, and a geodetic GPS receiver are collocated closely. Since the relative positions between these reference points have been precisely measured by ground survey measurements, comparisons of coordinates and velocities obtained by different space geodetic techniques are expected to contribute for construction of a better and reliable terrestrial reference frame.

As of January, 1999, all of three space geodetic observation systems are operational. Daily VLBI observations began in January 1995 with a single baseline between Koganei

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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. At present, about 24 hours of observation sessions are performed every two days. GPS observations at four sites began in July 1997 and estimations of the site velocities are becoming realistic. The first signal of the laser echo from Lageos satellite was detected in December 1996 with the SLR observation system at Kashima. Alignment procedures of the laser and optical system were performed since then and the regular SLR observations began in October 1998.

2. Tie of the site coordinates of the KSP VLBI stations to ITRF96

To obtain accurate site coordinates of four VLBI sites of the KSP network in the global terrestrial reference system, seven VLBI experiments have been performed with 34-m antenna station at Kashima and KSP VLBI stations. The site coordinates and velocity of the Kashima 34-m antenna VLBI station is available in the ITRF96 reference frame, which is the latest realization of the terrestrial reference system available at present. By using the ITRF96 site coordinates of the Kashima 34-m antenna VLBI station as the reference, the site coordinates of the KSP VLBI stations were estimated. Figure 1 shows the results for the KSP VLBI station at Kashima. The motion of the station is compensated by using the site velocity of the Kashima 34-m antenna VLBI station given in the ITRF96. In three of the seven experiments, the quality of the obtained data are poorer than the other four experiments due to problems such as a poor phase stability of frequency reference system or a failure of the antenna hardware system (Koyama *et al.*, 1999), and the results from these three experiments have larger error ellipses. On the other hand, the results from the other four experiments have smaller error ellipses and the distribution of the estimated positions are consistent with the small uncertainties. The ITRF96 site coordinates of the Kashima KSP VLBI station was calculated by a weighted mean of the four good quality results and it was taken to the origin of the Figure 1.

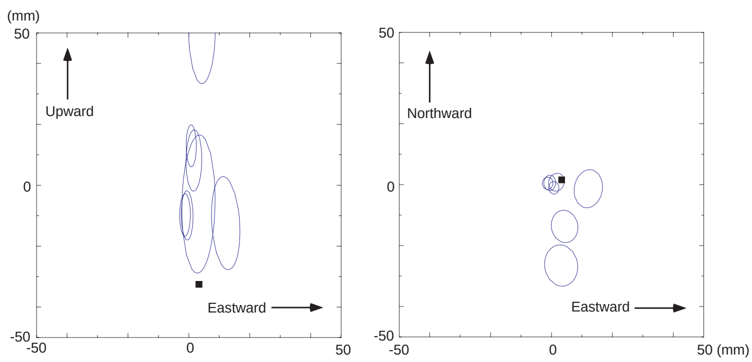

Figure 1. Estimated position of the KSP Kashima VLBI station estimated from seven tie VLBI experiments with the 34-m antenna VLBI station at Kashima. In the figure, the estimated position is shown by ellipses which express 1σ estimation error regions.

Square symbols in the Figure 1 indicate the position of the station obtained through ground survey measurements between Kashima 34-m antenna VLBI station and Kashima KSP VLBI station, performed in 1998 (Xia *et al.*, 1999). Agreement between the results from the ground survey and from the tie VLBI experiments is within few millimeters in

Table 1. Relative positions of GPS and SLR reference points with respect to the VLBI reference point at each site of the KSP measured by ground survey measurements. Vertical offsets of the phase centers of the GPS antennae from the ground survey points are corrected.

Site		Northward (m)	Eastward (m)	Upward (m)
Koganei	VLBI→SLR	−31.3633	17.4228	−1.9743
	VLBI→GPS	−23.8456	3.4921	−1.7705
Kashima	VLBI→SLR	76.6993	12.3899	7.7259
	VLBI→GPS	−24.0569	18.2867	−4.4726
Miura	VLBI→SLR	−74.1472	16.6038	−2.2401
	VLBI→GPS	6.3650	−17.0335	−4.4898
Tateyama	VLBI→SLR	−15.2321	−37.2124	−2.0549
	VLBI→GPS	−19.6579	−34.0153	−0.2961

the horizontal plane, but they differ by more than $30-mm$ vertically. The discrepancy is large considering the accuracy of the ground survey is evaluated as a few millimeters. The reason of the discrepancy is not clear and it should be investigated further.

3. Comparison of site coordinates

Ground survey measurements have been performed to measure relative positions of VLBI, SLR, and GPS reference points at each site (Xia *et al.*, 1999). The results are tabulated in Table 1. The reference points of VLBI and SLR are defined by an intersection of azimuth and elevation axes of an antenna and a telescope, respectively. The reference point of GPS is defined as a phase center of a GPS antenna. Vertical offsets of the GPS reference points from the ground survey points are measured and added to the ground survey results.

By using the results in Table 1, site coordinates obtained by VLBI, SLR, and GPS measurements are compared at four sites. The results are shown in Figure 2. SLR site coordinates are estimated from 44 days of observed data from November 1, 1998 by fixing site coordinates of the stations defined in the ITRF96. GPS site coordinates are estimated from 36 days of observed data from June 29, 1998. In the data analysis, site coordinates of Fairbanks, Kauai, Guam and Shanghai are strongly constrained to their ITRF96 site coordinates.

In the Figure 2, the ground survey results and three space geodetic measurements showed an agreement within $32-mm$ in horizontal and vertical components. While the SLR results do not show clear trend, the GPS results have a tendency common to all sites. Such a common displacement may be suggesting inconsistency between VLBI and GPS site coordinates defined in the ITRF96. Further accumulation of observation data for GPS and SLR will contribute further and detailed investigations.

4. Comparison of site velocities

Data span of the VLBI observation data has become long enough to estimate site velocities with a sufficient accuracy. The GPS observations have been performed for about a year and a half and the estimation of site velocities are becoming feasible. In the Figure 3, site velocities estimated from VLBI and GPS measurements are compared. The VLBI and GPS site velocities disagree more than the estimated velocity uncertainties. If

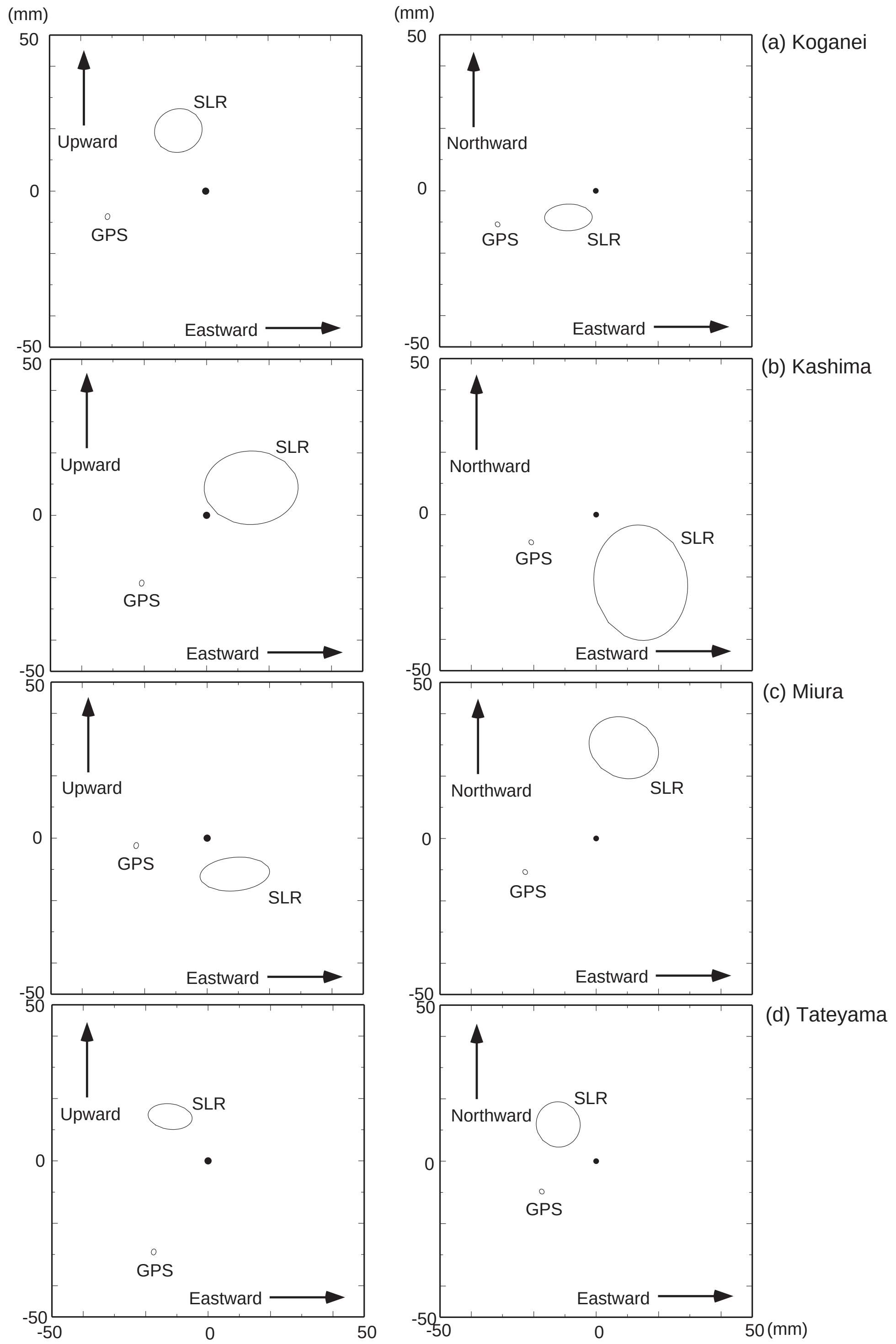

Figure 2. Comparison of site coordinates determined by VLBI, SLR, and GPS measurements. Displacements of the SLR and GPS results are shown with respect to the ground survey vectors added to the VLBI measurements. Ellipses are the 1-σ uncertainties. Larger ellipses are the results from SLR measurements reflecting a smaller number of available data.

the site velocity of Kashima is subtracted from the site velocities of the other stations, VLBI and GPS site velocities show a good agreement as shown in the Figure 4.

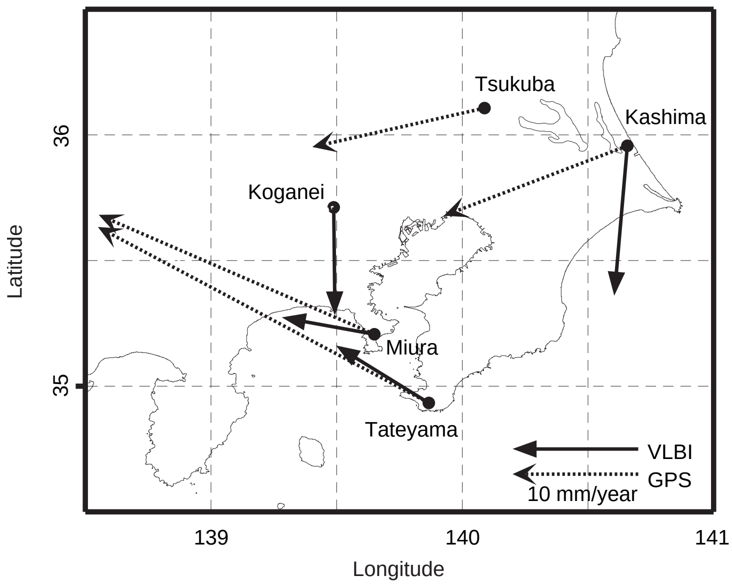

Figure 3. Comparison of horizontal site velocities in the ITRF96 frame reference determined from VLBI and GPS observations.

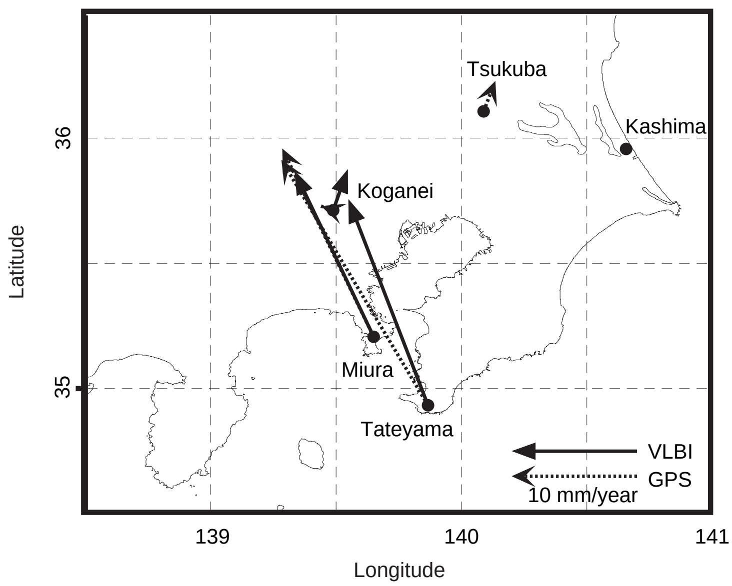

Figure 4. Comparison of horizontal site velocities with respect to the fixed Kashima station.

This result suggest that the site velocity of the Kashima 34-m antenna VLBI station and other GPS site velocities given in the ITRF96 reference frame are not consistent. Joint VLBI experiments with KSP VLBI stations, Fairbanks, Wettzell, Tsukuba, and Urumqi

VLBI stations are currently planned to be performed in the future. It is expected that these experiments will improve the consistency of the KSP VLBI site velocities with the ITRF96 reference frame.

5. Concluding Remarks and Future Plans

The KSP space geodetic 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, the KSP 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 combined solution with the global observation stations of SLR and GPS. The precise ground survey measurements will be very useful for the collocation studies to tie different space geodetic techniques.

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