KSP VLBI System and Its Measurement Accuracy

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Abstract

Since 1995, the Communications Research Laboratory has been monitoring crustal deformation in the Tokyo metroplitan area using a compact VLBI network consisting of four fixed stations. This network is called the Key Stone Project (KSP) VLBI network. In 1997 the so-called "real-time" VLBI technique was installed in the KSP VLBI network. Continuous improvement both in system hardware and in the observation method have resulted in a remarkable improvement in measurement accuracy. The accuracies in terms of the repeatability of measured station positions at the present time are 2.4 mm for the horizontal component and 12.3 mm for the vertical component.

1. Introduction

In 1993, the Communications Research Laboratory (CRL) started the establishment of the VLBI network dedicated to monitoring the crustal deformation around the Tokyo metropolitan area in Japan. This VLBI network consists of four stations, and was named "Keystone Project" (KSP) network after the Japanese traditional saying that relates to earthquake prevention. In September, 1996 the KSP entered a full operation phase consisting of daily observations spanning 5 to 6 hours using a conventional tape recording method system. Along with these daily observations, we established a real-time VLBI in cooperation with the Nippon Telephone and Telegraph Co. Real-time VLBI means a correlation processing in real time using high-rate transmission links (maximum network speed is 2.4 Gbps) between the four KSP stations. This real-time processing has been used in routine operations since June 4, 1997. Since then the length of a session, which is a series of scans of quasars, has become free from a restriction arising from the correlation processing in the case of a tape-recording-based VLBI.

After a continuous 120-hour test session using the real-time VLBI technique, we extended the length of each session to 24 hours in order to improve the geodetic precision. But the session frequency was reduced to on every other day basis in order to avoid

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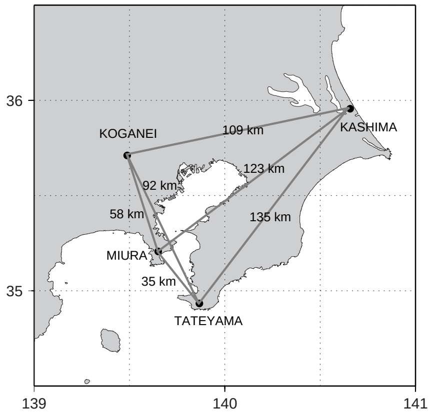

Figure 1. Configuration of the Keystone Project VLBI network.

overloading the system, in particular, on the antenna driving system. We began routine observations under this new strategy on September 30, 1997.

Thus we have been making continuous improvement both in system hardware and in the observation method to improve measurement accuracy. Now repeatability reaches about a 2-mm level in baseline length in our VLBI network [*Kondo et al.,*1998].

In this paper, we discuss the evolution of accuracy using the latest results. We not only follow the method applied in the previous paper to evaluate the accuracy but we extend the evaluation period up to the end of September, 1998.

2. KSP VLBI System

The KSP VLBI system consists of four stations (Kashima, Koganei, Miura and Tateyama) around the Tokyo metropolitan area (Figure 1). The longest distance between any two KSP stations is about 135 km (Kashima-Tateyama). The details of the system and analysis method were described by *Koyama et al.* [1998]. We therefore explain the system briefly here.

The observation system is designed to make an unmanned operation possible and its observation status is always automatically monitored at both Koganei and Kashima stations. Observation schedules are delivered in advance to each station from the Koganei station through the Internet.

Each VLBI station is equipped with the same VLBI facilities dedicated to a geodetic measurement. Dual S (2 GHz) and X (8 GHz) band signals from quasars are received by an antenna with an 11-m diameter, then they are converted into video signals consisting of 16 channels that are assigned to either an S or X band. Either a 2 MHz or 8 MHz bandwidth can be selected as a video bandwidth. Video signals are sampled at a Nyquist frequency and then they are converted into one-bit digital signals. Hence the total data rate is 64 Mbps for a 2 MHz video bandwidth and 256 Mbps for an 8 MHz video bandwidth. A stable Hydrogen maser frequency standard is employed as a station clock and frequency standard.

Digitized signals are recorded on a magnetic tape in the "tape-based" VLBI. After a series of observations, magnetic tapes are sent to Koganei. Therefore after observations are finished, it takes several days to obtain results.

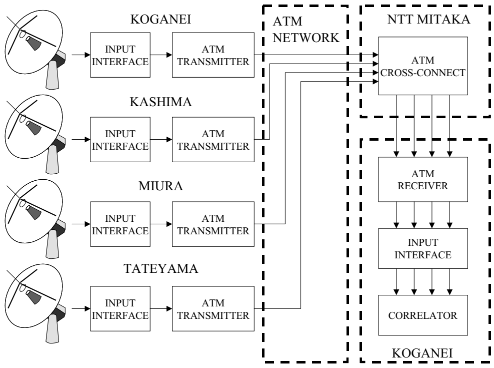

Figure 2. Block diagram of the KSP real-time VLBI system.

In the "real-time" VLBI [*Kiuchi et al.,* 1999], which was developed by CRL in cooperation with the Nippon Telephone and Telegraph Co., digitized signals observed at each station are transmitted to correlation center (Koganei) in real time through the ATM (Asynchronous Transfer Mode) network of high-rate transmission links (maximum speed is 2.4 Gbps) between the four KSP stations (Figure 2). Thus correlation processing for the 6 baselines is carried out simultaneously with an observation It takes, therefore, only several ten minutes to get results after a series of observations are finished.

The real-time VLBI technique has been used in routine operations since June 4, 1997. Since then the length of a session, which is a series of scans of quasars, has become free from a restriction arising from the correlation processing in the case of a tape-based VLBI. Moreover the time necessary for the synchronization of the two data streams is negligible for the real-time VLBI compared with those for the tape-based VLBI. Hence we could increase the number of scans in a unit time to improve accuracy. We could also extend the length of each session to 24 hours in order to improve the geodetic precision, but the session frequency was reduced to on every other day basis in order to avoid overloading the system, in particular, on the antenna. We began routine observations under this new strategy on September 30, 1997

Baseline analysis is automatically carried out on a session basis using analysis software that was developed for the KSP [*Koyama et al.,*1998] based on that developed by the Goddard VLBI group [*Ma et al.,*1990].

3. Measurement Accuracy

VLBI measurements can give a three-dimensional station position. In this study, we adopt the same method described in *Kondo et al.* [1998] to evaluate the system precision, that is, we define the "repeatability" of the measurement results as a standard deviation of five continuous samples of baseline lengths and station positions. In order to separate long term fluctuations, such as seasonal variation probably arising from model imperfectness in the baseline analysis, from short term ones, we chose five continuous samples as a unit. As for the "formal error" representing the five samples, we take a simple mean of five continuous samples of formal errors. We only take five continuous samples in the time series of data for statistical study. Thus the time span for the five continuous sample is different depending on the session frequency. They span for approximately 5 days for the data measured before September 30, 1997, while for 9 days for the data measured after that time except for a few occasions when routine observations accidently failed. We evaluated the precision of the KSP VLBI system using the repeatability and the formal error.

4. Results

We present the results of standard deviations and mean formal errors by representing six baselines for the Kashima-Koganei baseline because it is the first baseline on which routine obseravtions started in the KSP. Figure 3 shows the evolution of measured baseline lengths for the Kashima-Koganei baseline, and the standard deviations and mean formal errors of the five continuous samples of the baseline length data for the period from January, 1995 to September, 1998. The formal error obtained from each baseline analysis almost corresponds to the standard deviation of O-C residuals after parameter fitting in a session. We can see stepwise structures in the plot of mean formal errors, in particular at three epochs (at the end of October, 1995, at the middle of February, 1997, and at the end of September, 1997). This demonstrates a drastic improvement in system. The first two correspond to improvements in the system hardware (such as an increase in temperature stability in a receiver room) while the last one corresponds to the extension of the session time. On June 4, 1997 we changed the video bandwidth from 2 MHz to 8 MHz. Since the end of September, 1997 the system's operation method and hardware have not experienced any change. Hence to evaluate the system performance we calculated the average value of repeatabilities and the mean formal errors for the period October, 1997 to September, 1998 (i.e., a full year span). As a seasonal effect can be seen in Figure 3, we divided a year into two sub-periods representing winter and summer seasons (i.e, October, 1997 to March, 1998 and April, 1998 to September, 1998) and made statistical calculations for the two sub-periods. In Figure 4 averaged repeatabilities and mean formal errors of baseline length and station positions are plotted for these two sub-periods.

The simple averages of all baselines for repeatabilities (formal errors) for the winter, summer, and full year are 1.8 mm (1.0 mm), 2.9 mm (1.4 mm), and 2.4 mm (1.2 mm), respectively. The simple average of repeatabilities (formal errors) of station positions for all stations for east-west, north-south, and vertical components for the winter season are 1.9 mm (0.9 mm), 1.8 mm (1.0 mm), 9.5 mm (4.7 mm), those for the summer season are 3.0 mm (1.3 mm), 3.0 mm (1.4 mm), and 15.0 mm (6.8 mm), and those for full year are 2.5 mm (1.1 mm), 2.4 mm (1.2 mm), and 12.3 mm (5.9 mm), respectively.

Both repeatability and mean formal error become worse in the summer season by factors about 1.6 and 1.4 compared with those in the winter season. Moreover the repeatability is worse than the mean formal error by about a factor of two.

5. Conclusions

We have developed the KSP VLBI system and have been monitoring the crustal deformation around the Tokyo metropolitan area. We have also continued to improve instrumentation as well as observing strategies and analysis models. The current precision in terms of repeatability defined as a standard deviation of five continuous samples of baseline length is about 2.4 mm. The precison for horizontal station position is about 2.4 mm and that for vertical one is about 12.3 mm. This is however about two times larger than that of the formal error of session analysis. This suggests that the model applied in the KSP automatic analysis software for a 24-hour session analysis is insufficient for a time scale longer than one day. Moreover the precision tends to become worse in the summer season by a factor of about 1.5 compared with the winter season. Generally speaking, the

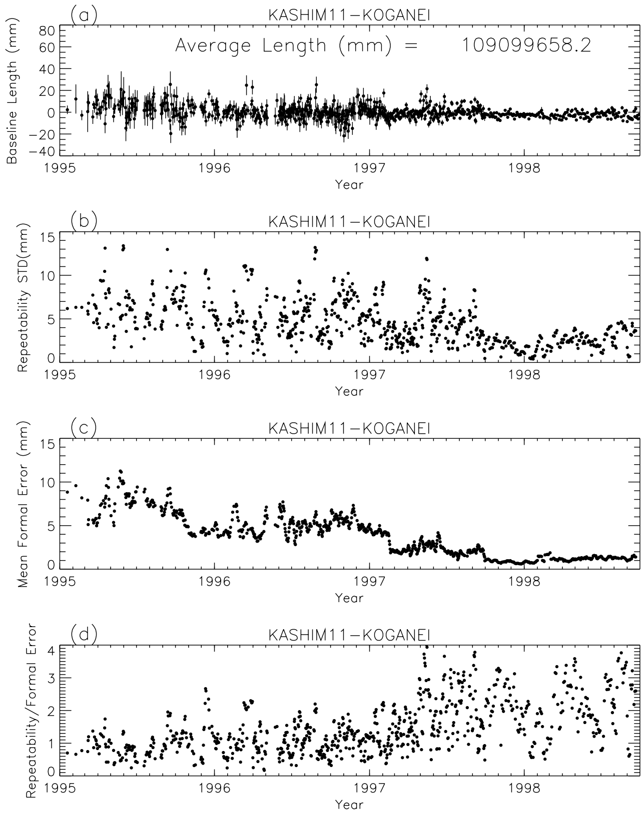

Figure 3. Evolution of baseline length between Kashima and Koganei (a), repeatabilities (b), mean formal errors (c), and ratio of repeatability to mean formal error (d) of five continuous samples of baseline length.

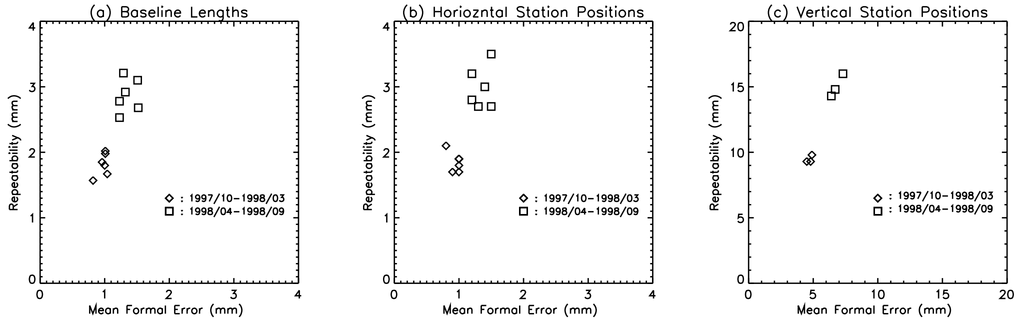

Figure 4. Scatter plots of repeatabilties and formal errors for (a) six baseline combinations, (b) horizontal station positions, and (c) vertical station positions, for the two sub-periods.

summer in Japan is very humid. In the VLBI observation, the propagation delay caused by the water vapor is the most unknown error source at present. It is estimated in the baseline analysis using a proper mapping function that models excess delay with a function of elevation angle. In the current KSP VLBI baseline analysis, azimuthal asymmetries of this mapping function is unmodeled. This might be cause of an error source in a baseline estimation as pointed out by *MacMillan* [1995] and it could account for a larger variation in day to day baseline estimation in the summer season, since the winter season is very dry and the water vapor does not affect VLBI observations so much. Thus improving physical models, such as the azimuthal asynmetry propagation delay models, should be investigated in order to achieve better repeatability over several days. We have started an analysis investigating the relation between the fluctuation of the baseline length and the local weather condition to improve the physical models. Preliminaly results (not shown here) shows a good correlation between position error at Kashima station and local weather condition.

Acknowledgments

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