Vol. 38 No. 2 Journal of the Communications Research Laboratory July 1991
Printed in Tokyo, Japan pp.335–340

Short Note

PRECISE POSITION DETERMINATION OF NEW KASHIMA VLBI STATION

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(Received on Dicember 3, 1990)

ABSTRACT

As the main station of the Western Pacific VLBI (Very Long Baseline Interferometry) Network, a large aperture antenna (34 m in diameter) has been constructed at Kashima Space Research Center (KSRC). Precise determination of the antenna position, which is defined as the intersection of azimuth and elevation rotation axes and is often used as a VLBI reference point, has been attempted by means of the geodetic VLBI technique. Each component of the 34 m antenna VLBI reference point in a geocentric Cartesian coordinate system has been estimated from four independent sets of experimental data by referring to the position of nearby 26 m antenna at KSRC. Two problems arise when a geodetic VLBI technique is applied to a short baseline. One is due to a phase calibration signal injected into the received signals, and the other is due to a time code header in a sequence of digitized data. Both largely affect the correlation function for detection of observable time delay. By solving these problems, internal error in estimation was reduced to about 3 mm for each component.

1. Introduction

Kashima Space Research Center (KSRC) is now one of the most active and valuable stations in the global VLBI (Very Long Baseline Interferometer) network. Since 1984, Communications Research Laboratory has regularly participated in a series of international geodetic VLBI experiments, and has obtained a large body of precise geodetic data using the CRL developed K-3 VLBI system.(1) The geodetic VLBI technique is a powerful tool for determining precise distances between two or more widely separated VLBI antennas, and also for monitoring the rotation of the earth. VLBI data has been most useful in investigating a wide variety of fields in Geophysics and Astronomy, such as plate tectonic and plate motion studies(2), studies of the earth's rotational variation in speed and orientation(3) and crustal deformation which occurs around plate boundaries.(4)

At KSRC, CRL has been operating a large 26 m diameter cassegrain antenna as a VLBI antenna since the beginning of its VLBI research. In addition to this antenna, a larger and more sensitive antenna, 34 m in diameter, was constructed in 1989 to act as the main station of the Western Pacific VLBI Network (WPVN) (Fig. 1). The WPVN was proposed by CRL to investigate relative movements of four plates around Japan, i.e. North American plate, Eurasian plate, Philippine Sea plate and Pacific plate, through frequent geodetic VLBI experiments.(5) The WPVN consists of four VLBI stations at Kashima, Shanghai, Minami-Daitojima and Minami-Torishima (Marcus Island). The 34 m antenna began operating in both international and domestic VLBI experiments in 1990, and will perform the role of the main VLBI antenna in KSRC. For this reason, a precise determination of the 34 m antenna's position is a priority. With regard

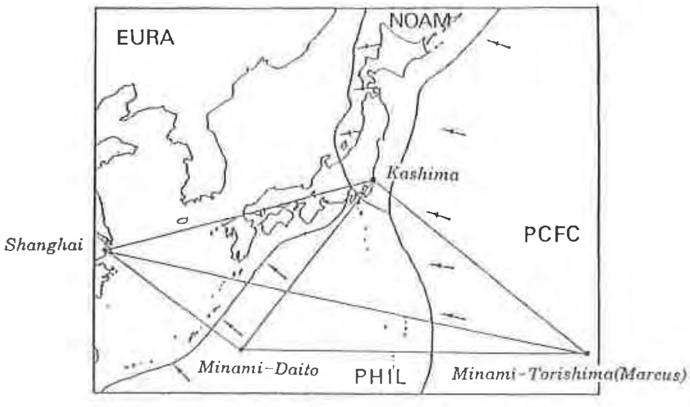

Fig. 1 Western Pacific VLBI Network. The four VLBI stations are indicated by dots and the station names. Note that these four stations are on four different plates, which are the NOAM (North American Plate), PCFC (Pacific Plate), EURA (Eurasian Plate) and PHIL (Philippine Plate) plates. Plate motion directions relative to the Eurasian Plate expected from a plate motion model are also indicated by arrows.

to the 26 m antenna, its position has been measured repeatedly by regular geodetic VLBI experiments, so position determination of the 34 m antenna can be accomplished by measuring the relative positions of the two antennas. If this position relationship can be found with a tolerable uncertainty, geodetic results obtained with the 26 m antenna in the past can be used for further geodetic analyses with those obtained with the 34 m antenna. An uncertainty of about 5 mm in each component is considered acceptable, which is less than the uncertainty achieved with the 26 m antenna through many VLBI experiments.

The VLBI technique, which is typically applied over a distance of a few thousands of kilometers, was applied to the 26 m–34 m antenna baseline which is only about 311 m long. Strictly speaking, experiments we have done with this short baseline are not VLBI but a kind of connected element interferometry since only one Hydrogen maser system is used as a common frequency standard for both stations. However we used the same equipment and methods as normal VLBI experiments. Furthermore, every parameter was estimated as if different frequency standards were used. Because of these factors, we consider the experiments to be VLBI in this short paper.

2. VLBI Technique for Short Baseline Measurement

The K-3 VLBI system has been developed and designed to be suitable for inter-continental baseline measurements. When this system is applied to a short distance measurement, such as the 26 m–34 m baseline at Kashima, two technical difficulties arise. One is due to the phase calibration (P-cal) signal which is injected into received signal at the point of receiver feed. The P-cal signals consist of a series of continuous wave signals with a constant frequency interval and are recorded in each observation channel as 10 kHz signals by choosing appropriate local frequencies for Video Converters. In a typical case, the frequency interval of the P-cal signals is 1 MHz and the observation bandwidth of each channel is 2 MHz, so that 1010 kHz signals are also recorded in each channel. The phases of the 10 kHz signal in each channel

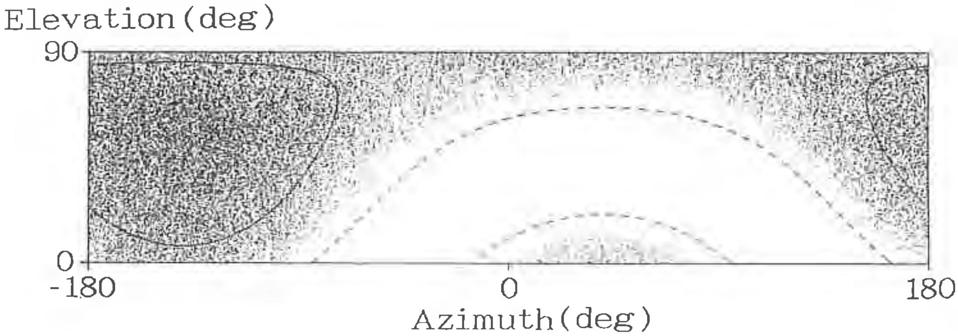

Fig. 2 Distribution of absolute value of delay rate in the sky seen from the 26 m antenna calculated for the baseline to the 34 m antenna. Azimuth angle is measured clockwise from the North direction. The solid line and dashed line represent 50 psec/sec and 20 psec/sec contours respectively. The area where the fringe rotation at 8.3 GHz is more than 1 rotation for each accumulation period of 4 seconds, i.e. delay rate exceeds 30.12 psec/sec, is shown by the gray shaded area.

are employed for the bandwidth synthesis to precisely obtain time delays. The other problem is due to a header data sequence which contains information concerning both system configuration and the time when the data was recorded. The header data are the first 20 bytes of each data frame where one frame consists of 2500 bytes of digitized data (5 milliseconds of signal in case of 4 MHz sampling). The header data, therefore, occupies 0.8% of data in the observation tape at each station. In normal VLBI experiments, a baseline vector has a large east-west component. When the east-west component of the baseline vector is 3000 km, the time delivertive of delay time (delay rate) between two VLBI stations can reach up to 7.3×10^{-7} sec/sec, which corresponds to 1.5×10^{3} Hz of fringe frequency at 2 GHz. Hence, contributions from the P-cal signal or the header data are averaged out through a process of fringe stopping in a correlator: The unit accumulation period in a correlator is typically set to 2 or 4 seconds, so that a fringe frequency of several kHz is large enough to average out the header and P-cal effects in the period. However, when a VLBI experiment is conducted with a short length baseline like the baseline between the 34 m and 26 m antennas, the fringe frequency becomes 4 orders of magnitude smaller (~0.1 Hz) and it is too small to average out the effects. Fig. 2 shows the distribution of delay rate in the sky calculated for the 26 m–34 m baseline. It can be seen clearly from the figure that quite a large portion of the sky gives a small fringe rotation. When the fringe frequency is smaller than the inverse of an unit accumulation period, no fringe stopping is applied in a correlator. In this case, the contributions of the P-cal signal and header data to the correlated amplitude come to about 0.25% (P-cal signal with a power of 5% of total power are induced at both stations) and 0.8% respectively. These amplitudes are significantly large compared with the amplitude of the radio star signal, which is typically from 0.1% to 1%. Furthermore, sources with low elevation angles are particularly susceptible to these effects. These problems can be solved by increasing the fringe frequency artificially, which is easily realized by setting the frequency of the reference signal at one station to a slightly different value from an original one. The reference signal is used throughout a VLBI system, such as in the station clock, the timing signal of digital sampling of received signal and local signals for frequency down conversion. Therefore, all the signals on a recorded tape are exactly the same except for signals from a radio star which has a shift in frequency. Consequently, the correlated signal has a large fringe rotation, and the effects from the P-cal signal and the header signal are averaged out in a correlator. The frequency offset of the reference signal can easily be estimated from VLBI data along with the baseline estimation and does not affect the results.

3. Experiments

The 34 m antenna at Kashima was used for the first time for a VLBI experiment held in September 1989. Since then, the antenna has been used in several VLBI experiments. In some of these experiments, the 26 m antenna was also operated simultaneously. To determine the 34 m position precisely, we have used VLBI data only for the single baseline between the 34 m antenna and the 26 m antenna in this study, because the effects of the atmosphere and the ionosphere are negligible on a short baseline. We have processed four data sets of VLBI experiments. A list of the four experiments is shown in Table 1. One experiment (#3) was carried out with two antennas (26 m and 34 m) only. With the other three experiments, the session was originally intended for usual geodetic purposes and 34 m antenna was operated in addition to the 26 m antenna.

Table 1 Summary of VLBI experiments

Date	N (correlation)	N (schedule)	N (source)
A Sep. 29, 1989	82	144	16
B Nov. 9, 1989	101	145	17
C May 10, 1990	71	146	15
D June 30, 1990	121	165	18

N (correlation): Number of observations processed
N (schedule): Number of observations scheduled
N (source): Number of radio sources observed

In the first experiment (September 29, 1989), three VLBI stations participated; Kashima 34 m antenna (“O”), Kashima 26 m antenna (“Q”) and Tsukuba 5 m antenna (“T”) of Geodetic Survey Institute of Japan. Because the frequency offset technique was not applied for this experiment, observable delay time for the baseline Q-O ($\tau_{Q\text{-}O}$) was calculated from the two other baseline's data $\tau_{Q\text{-}T}$ and $\tau_{O\text{-}T}$. In contrast, in the second experiment (November 9, 1989), the observation schedule was made using sources with relatively high delay rates. In the third (May 10, 1990) and the fourth (June 30, 1990) experiment, the frequecy offset technique was applied, that is, the reference 10 MHz frequency signal of 34 m antenna was slightly readjusted by 100 Hz. Unlike the 2nd experiment, observation schedules of these experiments covered observation sources in the sky as widely as possible. However, the amount of data available from the third experiment was very limited due to a recorder problem. The fourth experiment was carried out successfully without any troubles.

4. Results

The position of the 26 m antenna and a clock of the time standard at 26 m station were used for reference throughout estimation processes. The reference antenna position in the earth centered Cartesian coordinate system was calculated by extracting the position and velocity data from the GLB401[(1)] solution which was estimated from several years of CDP (Crustal Dynamics Project) experiments. In total, four sets of experimental data have been processed. These experiments are analyzed independently. In the analysis, only the observed delays were used. Atmospheric delay correction and ionospheric delay correction were not applied in the analysis because the baseline length is short enough to disregard these corrections.

Table 2 summarizes the estimated baseline vector components. Root mean square (RMS) values of residuals for delays show a remarkably small value for the fourth experiment. Corresponding to this, internal uncertainties of less than 1 cm (~3 mm) were achieved for the three components of 34 m antenna position in the estimation. Figure 3 shows each results of estimated position of 34 m antenna projected on the horizontal plane and to the vertical axis with one sigma error ellipses and bars. Almost all values of *XYZ*-components agree with each other in one sigma error (~2 cm).

Table 2 Estimated results of the 26 m antenna-34 m antenna baseline vector. RMS values of residuals in time delay are also shown in the second column

	Residual	*X*	*Y*	*Z*	Length
A	79 psec.	243.032m ±0.009m	109.479m ±0.010m	160.592m ±0.010m	311.191m ±0.006m
B	47 psec.	243.040m ±0.006m	109.480m ±0.006m	160.590m ±0.005m	311.197m ±0.004m
C	80 psec.	243.023m ±0.010m	109.486m ±0.008m	160.612m ±0.012m	311.197m ±0.006m
D	30 psec.	243.025m ±0.003m	109.489m ±0.003m	160.599m ±0.003m	311.193m ±0.002m

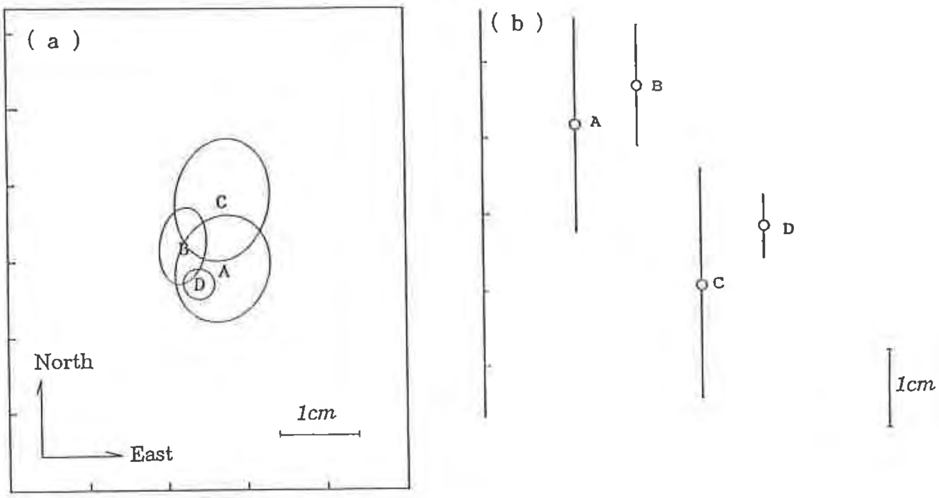

Fig. 3 Estimated positions of 34 m antenna relative to 26 m antenna. (a) horizontal component (b) vertical component. Each letter corresponds to each experiment in Tables 1 and 2. Ellipsoids in (a) and bars in (b) are one sigma of error.

5. Summary

At present, a position of the Kashima 26 m antenna is determined with an error of less than 1 cm in a VLBI global reference frame. It is important for the crustal dynamics study to connect the position data obtained by the 26 m antenna in the past with the position data which will be obtained by 34 m antenna in the future. Therefore, we should know the relative position relationship of these two antennas with an uncertainty of about 5 mm for each component of the vector. The result of the fourth VLBI experiment in July 1990 alone achieved this level of small uncertainty. Results from the other three experiments support this result with a repeatability of slightly less than 2 cm. Although this level of repeatability is not enough for our purposes at present, we are expecting to achieve better repeatability by continuing this kind of VLBI experiment further.

Acknowledgement

The authors would like to thank Geodetic Survey Institute and National Astronomical Observatory of Japan for collaborative operation of their VLBI stations. We also want to express our gratitude to Dr. Kosuke Heki, Mr. Yukio Takahashi and Dr. Chopo Ma for many helpful discussions.

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