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GEODETIC VLBI EXPERIMENTS USING STATIONS IN JAPAN

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ABSTRACT

This paper describes the results of domestic VLBI experiments which were conducted during a period from July 1984 to February 1986. The geodetic VLBI measurement were made on the baseline between the 5-m transportable antenna at Tsukuba and the 26-m antenna at Kashima in July 1984, August 1985 and February 1986. The baseline length of about 54 km was determined with an error less than 2 cm. On the baseline between the 26-m antenna and the 45-m antenna at Nobeyama (about 200 km in length), we made high sensitive VLBI observations in December 1984, March 1985 and February 1986. We obtained not only the geodetic solutions but also a lot of data on the atmospheric fluctuation and the radio source polarization which have a considerable influence upon the reliability of geodetic solution.

1. Introduction

Kashima station, Radio Research Laboratory, is now working in the US-Japan joint VLBI experiments using stations on the North American Plate and the Pacific Plate(1). It is also the base station of the Japanese domestic VLBI experiments which have being carried out in collaboration with stations at Tsukuba, Geographical Survey Institute (GSI) and at Nobeyama, Nobeyama Radio Observatory (NRO). The station locations are shown in Fig. 1.

As the first geodetic VLBI station in Japan, Kashima station was established in 1983 with a 26-m radio telescope and the K-3 VLBI system developed at Kashima. The first Japanese transportable VLBI station with a 5-m radio telescope was developed at Tsukuba, GSI and equipped with the K-3 system in 1984. This station was designed primarily to improve the surveying accuracy of geodetic markers far away from the datum origin and to unify the triangular net over Japan proper in the same quality. A 45-m telescope for radio astronomy founded at Nobeyama in 1982 was equipped with the Mark-III VLBI system in 1983 and a tentative X-band receiver for geodetic VLBI observations in 1984. The baseline length is about 54 km for Kashima-Tsukuba baseline and about 200 km for Kashima-Nobeyama baseline. In such short baseline experiments, it is very convenient for us to evaluate the geodetic performance of the VLBI system because we are able to compensate the complicated physical effects resulting from the radio source structure, the atmospheric and ionospheric condition, the earth rotation, etc.

First we describe the VLBI system at Kashima and in the succeeding chapters we show the results obtained.

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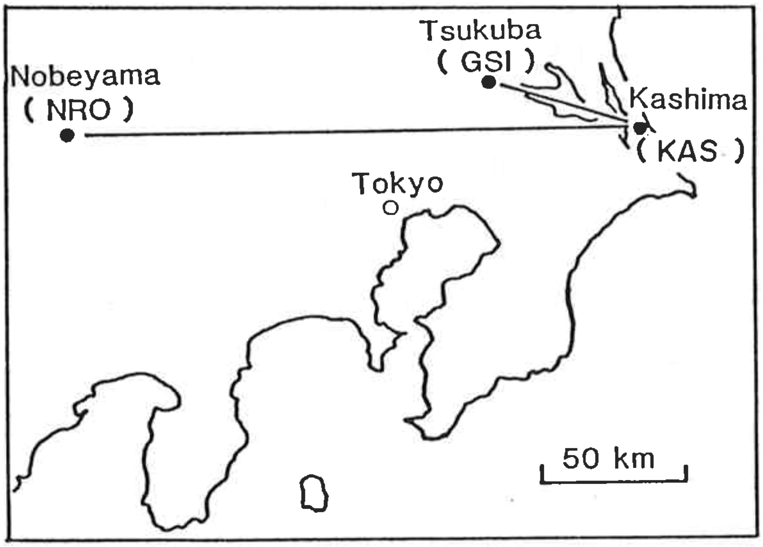


Fig. 1. The Locations of VLBI Stations in Japan

2. Kashima VLBI Station

The 26-m telescope at Kashima station was equipped with S-band and X-band receivers and a K-3 data acquisition terminal in 1983(2). As shown in Fig. 2, the receiving system is composed of an S-band receiver and two independent X-band receivers, which usually receive the right-hand circular polarization (RHCP) signal in S-band and both the RHCP

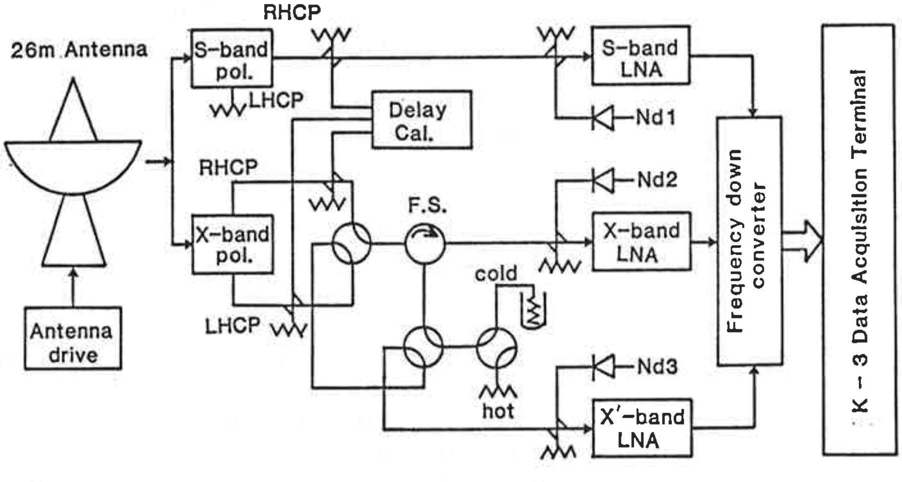


Fig. 2. The Receiving System in the Kashima Station

signal and the left-hand circular polarization (LHCP) signal in X-band. The two X-band receivers differ in the frequency bands, one receivers from 7860 MHz to 8280 MHz (X') and the other from 8170 MHz to 8610 MHz (X). For geodetic VLBI observations, it is usual to receive the RHCP signal in X-band from 8170 MHz to 8610 MHz. In the polarization sensitive VLBI observations, both the RHCP and the LHCP signals from 8170 MHz to 8280 MHz are received simultaneously with the two X-band receivers.

Table 1. The Performance of the Kashima Station

Antenna Diameter	26 m
Aperture Efficiency X-band S-band	 53% 52%
System Noise Temperature X-band (X'-band) S-band	 93 k (219 k) 75 k
Fringe Detectability X-band	 1.10×10^{-3} Jy^{-1}
Data Acquisition Terminal	K – 3

Table 1 summarizes the performance of Kashima station. The aperture efficiency of the 26-m antenna was measured by observing the standard celestial sources, such as Cassiopeia A, Cygnus A and Taurus A. The fringe detectability in the table is defined by the fringe amplitude obtained if a unit strength (1 Jansky) radio source was observed with a pair of the station and its replica. It is a measure of the sensitivity of the VLBI station. The baseline sensitivity between two different stations is defined by the geometric mean of their fringe detectabilities.

The K-3 data acquisition terminal is fully compatible with the U.S. Mark-III system. The performance of the K-3 terminal is almost the same as that of the Mark-III but for the communication manner with a host computer. Since the communication bus is unified to the IEEE-488 standards in the K-3 terminal, it is very easy to control the units in the system and to query the status.

3. Kashima-Tsukuba Experiment

The 5-m telescope at Tsukuba, GSI is located near the Tsukuba datum origin. It is composed of three parts. antenna reflectors, a mount structure and a pedestal as shown in Fig. 3. The main reflector can be divided into 3 parts. It takes 3 days to put the antenna into pieces and 10 days to set them up. The 5-m telescope has a dual S/X band receiver. The electrical performance is listed in Table 2. The aperture efficiency in Table 2 was measured by observing the new moon as brightness standard.

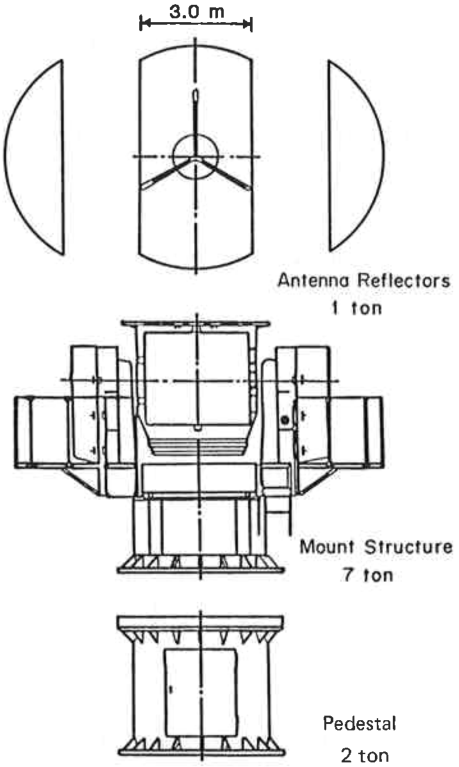


Fig. 3. **The Composition of the Transportable 5-m Telescope**

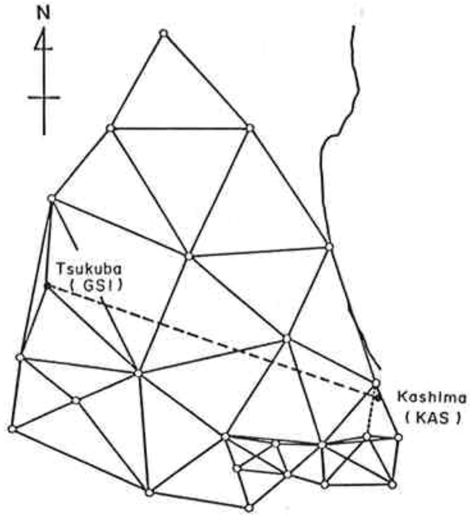


Fig. 4. **The Triangular Net Around the Kashima Station**

Table 2. **The Electrical Performance of the Transportable 5-m Telescope**

Distance from Kashima	54.5 km
Antenna Diameter	5 m
Aperture Efficiency X-band S-band	 72% 30%
System Noise Temperature X-band S-band	 124 k 164 k
Fringe Detectability X-band	 4.13×10^{-5} Jy^{-1}
Data Acquisition Terminal	K – 3

In July 1984, the first geodetic VLBI experiment between Tsukuba and Kashima was conducted; the experiment was named JEG1, in which 16 radio sources were observed for 26 hours. Preceding the experiment, in December 1983, the baseline was surveyed (LAND) by a conventional optical method on the triangular net shown in Fig. 4. The surveying accuracy of baseline length is estimated to be 10 cm. These results are shown in Fig. 5. The difference between the VLBI measurement and the conventional survey was only 5 cm, which was within the error of the survey.

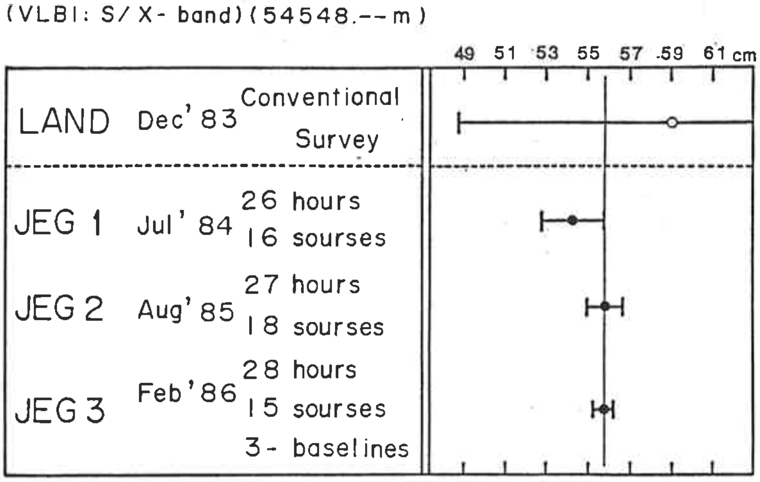


Fig. 5. The Geodetic Solutions in Baseline Length in the Kashima-Tsukuba Experiments

In order to examine the stability of the VLBI measurements, the same experiments between Kashima and Tsukuba were repeated in August 1985 (JEG2) and in February 1986 (JEG3). The results are also given in Fig. 5. They agree well within the limits of their experimental errors. The formal errors in the solutions of the baseline length are 2 cm in JEG1 and 1 cm in JEG2. The smaller error in the latter experiment is owing to the more number of fringes which we got in the experiment. The best result of 5 mm error was obtained in JEG3 in which Nobeyama participated for the first time. Table 4(a) lists the results of Kashima-Tsukuba baseline parameters obtained in JEG1, JEG2 and JEG3. In these analysis, S-band VLBI data are used for ionosphere correction and IRIS (International Radio Interferometric Surveying) data are used for the Earth Orientation Parameter (EOP). More data are needed to evaluate the dependence of error on the weather condition. We cannot see any systematic errors in Fig. 5 between the results obtained in summer and winter.

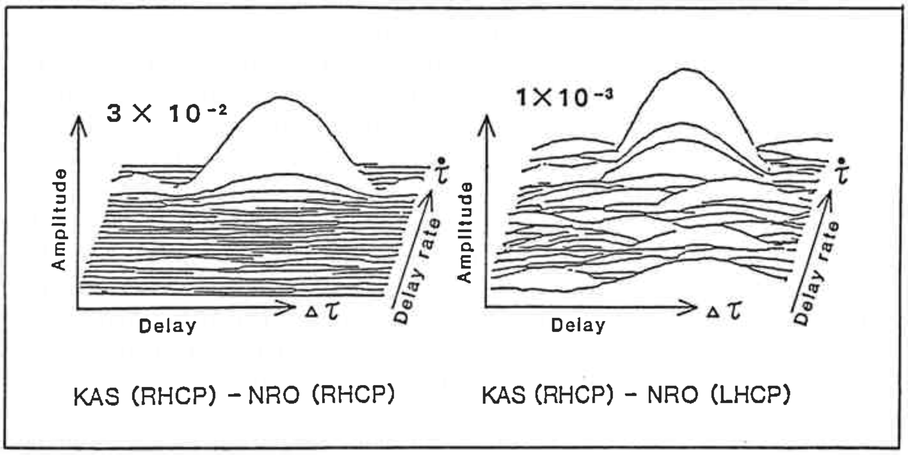
Considering these facts, we can say that the geodetic VLBI measurement by using the 5-m station and the K-3 VLBI system is accurate and reliable enough to regulate the geodetic networks over Japan. In October 1986, the transportable station will be shipped to Miyazaki in Kyushu island, far away about 1000 Km southwest from the datum origin at Tsukuba. During the following years, all the principal islands in Japan will be surveyed with an accuracy of a few cm.

4. Kashima-Nobeyama Experiment

The 45-m telescope at Nobeyama Radio Observatory (NRO) has been dedicated to high frequency radio astronomy. It was equipped with the Mark-III VLBI system in 1983. An X-band reference receiver (REF-RX)(3) developed at Kashima was installed below a 10 GHz feed of the 45-m antenna in 1984 for the following experiments. The performance is listed in Table 3.

Table 3. The Performance of the 45-m Telescope at Nobeyama

Distance from Kashima	197.6 km
Antenna Diameter	45 m
Aperture Efficiency X-band	58%
System Noise Temperature X-band	265 k
Fringe Detectability X-band	1.25×10^{-3} Jy^{-1}
Data Acquisition Terminal	Mark-III



KAS (RHCP) - NRO (RHCP)   KAS (RHCP) - NRO (LHCP)

Fig. 6. The Fringes Detected Between Co-polarized and Cross-polarized Signals

The first 5-hour observations with 6 radio sources were carried out between Kashima and Nobeyama in December 1984 for the polarization sensitive VLBI experiment (XPO1). Kashima station received both the RHCP and LHCP signals simultaneously and Nobeyama station alternatively received them. The REF-RX is designed so that the electrical path length of RHCP and LHCP signal in the receiver is exactly equal.

Since the sensitivity of this baseline is extremely high, we can detect the correlation even between the cross-polarized signals. Fig. 6 gives examples of the fringes for the 3C273b; the co-polarized fringe in (a) and the cross-polarized fringe in (b). By accumulating the results of these observations, high resolution maps for the source polarization will be drawn. This will help us to study a radio emission mechanism of the highly polarized BL Lac objects$^{(4)}$. Using the fringes obtained, we also got a geodetic solution for the position of Nobeyama. The baseline length between Kashima and Nobeyama is shown in Fig. 7.

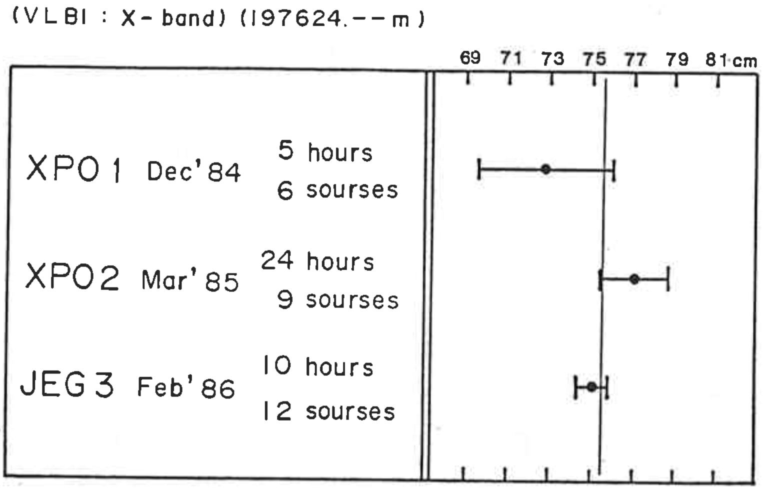


Fig. 7. The Geodetic Solutions in Baseline Length in the Kashima-Nobeyama Experiments

Another polarization sensitive experiment (XPO2) was made in March 1985 by more sources with longer observation periods. At the last stage of baseline analysis in XPO2, we selected the estimation parameters of

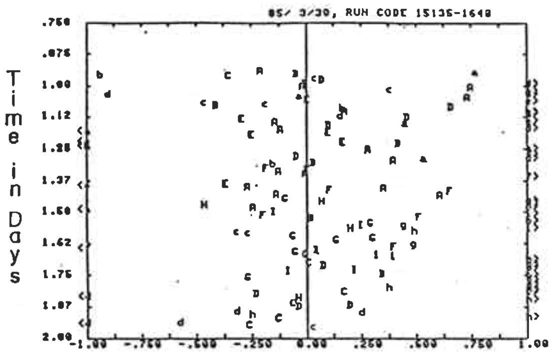
(1) coordinates of NRO (x, y, z)

(2) clock offset and rate at NRO

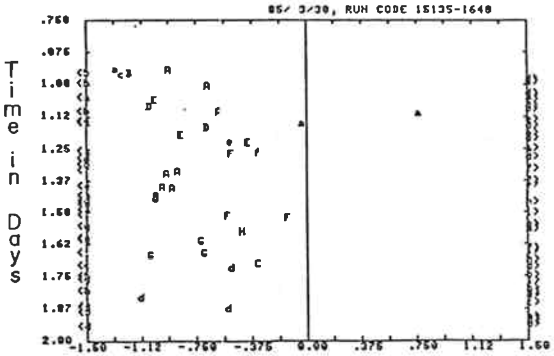
and

(3) zenith atmospheric excess path at NRO.

Then we got post fit residuals as shown in Fig. 8(a) (b). The alphabets in Fig. 8 represent the data for each radio source and the character '<' or '>' implies removed bad data. In KAS(RHCP)-NRO baseline (Fig. 8(a)), data are scattered randomly around a solution, while the data are obviously biased toward one side from the solution in KAS(LHCP)-NRO

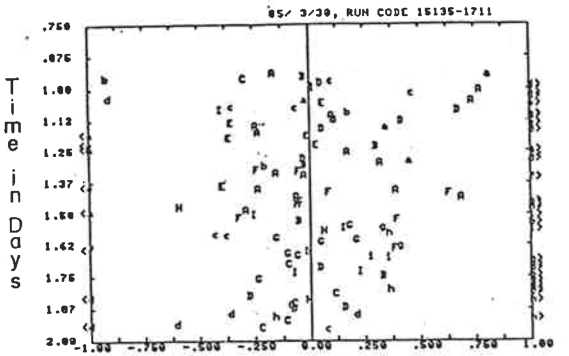


(a) KAS(RHCP)-NRO Baseline

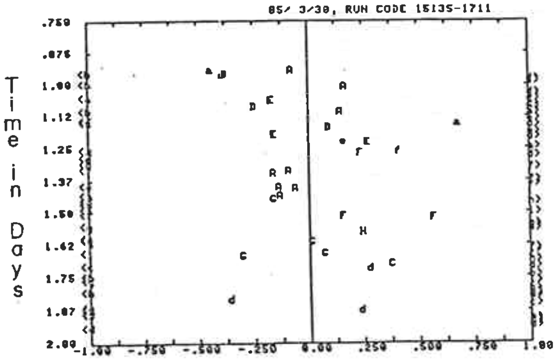


(b) KAS(LHCP)-NRO Baseline

Fig. 8. The Post Fit Residuals before Adjusting KAS(LHCP) Clock Offset



(a) KAS(RHCP)-NRO Baseline



(b) KAS(LHCP)-NRO Baseline

Fig. 9. The Post Fit Residuals after Adjusting KAS(LHCP) Clock Offset

baseline (Fig. 8(b)). In the XPO1 analysis, we also found this kind of offset. Judging from this fact, we introduced a clock-offset-like unknown between KAS(RHCP) and KAS(LHCP). Putting another estimation parameter of

(4) clock offset at KAS(LHCP),

we got post fit residuals as Fig. 9(a) (b). The estimated clock offset at KAS(LHCP) (about +0.81 ns) is considered to be the difference of instrumental delay between KAS(RHCP) and KAS(LHCP) of the receiving system. This value was also obtained by the calibration measurement of length from the injection point of phase calibration signal to the polarizer. After all, the correction of this difference resulted in a better geodetic solution in XPO2 as shown in Fig. 7. The latest experiment conducted among three stations of Kashima, Nobeyama and Tsukuba in February 1986 (JEG3) presented the most accurate solution and all the solutions agree well within the limits of their errors. Table 4(b) lists the results of Kashima-Nobeyama baseline parameters obtained in XPO1, XPO2 and JEG3. In these analysis, no S-band VLBI data are used for ionosphere correction. BIH (Bureau International de l'Heure) data are used for EOP.

Table 4. The Baseline Parameters Obtained in Domestic VLBI Experiments During Jul. 1984 – Feb. 1986 (Unit: in meter)

(a) Kashima-Tsukuba Baseline

Exp. Name	Baseline Length	Baseline Components
JEG1	54548.544 +/– .017	x = 40719.38 +/– .07 y = 33656.64 +/– .06 z = 13590.68 +/– .07
JEG2	54548.558 +/– .009	x = 40719.39 +/– .03 y = 33656.64 +/– .03 z = 13590.69 +/– .03
JEG3	54548.558 +/– .005	x = 40719.35 +/– .01 y = 33656.69 +/– .01 z = 13590.72 +/– .01

(b) Kashima-Nobeyama Baseline

Exp. Name	Baseline Length	Baseline Components
XPO1	197624.728 +/– .033	x = 126867.25 +/– .08 y = 151526.32 +/– .08 z = –79.57 +/– .07
XPO2	197624.770 +/– .017	x = 126867.13 +/– .05 y = 151526.48 +/– .05 z = –79.32 +/– .05
JEG3	197624.751 +/– .007	x = 126867.11 +/– .03 y = 151526.47 +/– .03 z = –79.40 +/– .03

5. Atmospheric Fluctuation Measurement

Due to high sensitivity in Kashima-Nobeyama experiments, the thermal receiver noise may not affect the fringe phase so much. So, we can expect to detect the fringe phase fluctuation caused by the turbulent atmosphere. Fig. 10 shows the Allan standard deviation of the fringe phase fluctuations obtained in XPO1. It indicates the existence of the atmospheric flicker fluctuation, which shows the constant Allan standard deviation of 1.4×10^{-13} at an integration time longer than 10 seconds. This fluctuation level is much higher than that caused by the instability of a hydrogen maser frequency standard of about 1.0×10^{-14}. So, this atmospheric fluctuation may cause the decrease in fringe amplitudes and increase in loss of coherence(5).

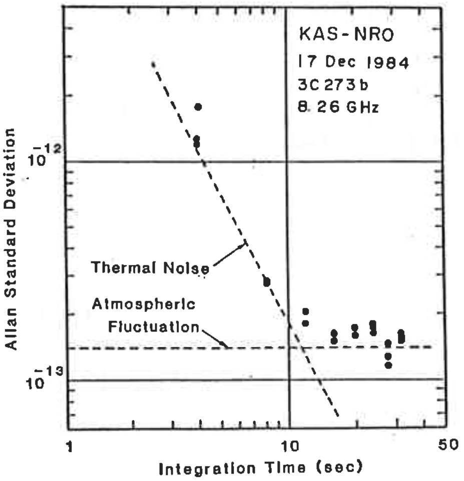


Fig. 10. The Allan Standard Deviations of the Fringe Phase Variation

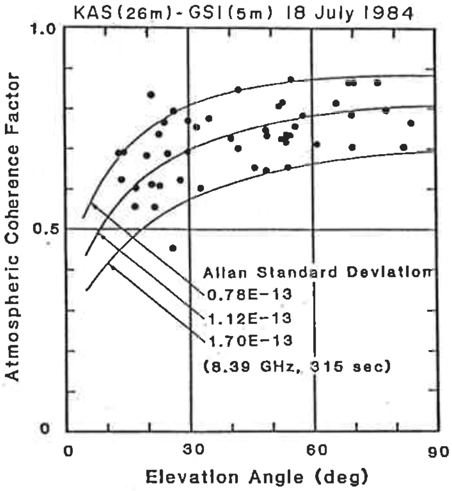


Fig. 11. The Atmospheric Coherence Factors Measured on the Kashima-Tsukuba Baseline

The solid circle in Fig. 11 represents the atmospheric coherence factor (= 1.0, if there is no coherence loss due to the atmosphere in the data) derived from the fringe amplitudes observed on the baseline between Kashima and Tsukuba in JEG1(6). The curves in Fig. 11 are the theoretical estimates of the loss. The Allan standard deviation of 1.1×10^{-13} in Fig. 11 is the most probable value for the atmospheric fluctuation and agrees well with the previous value obtained in Fig. 10. Therefore, it is concluded that the typical value of coherence loss due to the atmospheric fluctuation amounts to the range from 20 to 30%. This result is useful for SNR design of a target VLBI system and for evaluation of the error on geodetic VLBI measurements.

6. Conclusion

We reported the Japanese activities in the geodetic measurements with VLBI and presented the results obtained on the Japanese domestic baselines. These experiments established a basis of the applications of the VLBI technique to the geodetic measurements in Japan. The stability of the measurement results proved to be good enough. Besides, much technical and scientific data were obtained as by-products, such as coherence loss due to the phase fluctuations in turbulent atmosphere and the relation between the VLBI measurement error and the telescope sensitivity.

The accumulated experiences with the VLBI observations will serve as a reliable basis for the application of the VLBI to the land surveying and for the future developments of new VLBI systems in Japan.

Acknowledgments

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