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THE FIRST JAPAN-CHINA VLBI EXPERIMENT

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ABSTRACT

The first Japan-China VLBI experiment was carried out in September, 1985. Using good fringes obtained in two 24-hour observations, we determined the baseline length between Kashima and Shanghai with an error less than 3 centimeters. In the baseline analysis, we applied the kai-square test on the delay residuals in order to see the validity of the axis offset correction and the ionospheric correction. According to the variation of the fringe amplitudes observed on 3C84, we also determined the best time of a fringe test for the next experiment. This experiment was a great step toward a further research work on the geodynamics in the eastern Asia by an international cooperation between Japan and China.

1. Introduction

The plate tectonic theory, which insists that the earth is covered with ten odd plates and the plate movements split a continent into pieces, cause orogenic and volcanic activities along the plate boundaries, is now widely supported by many geological evidences and the measurements of the plate movements by VLBI (Very Long Baseline Interferometer), SLR (Satellite Laser Ranging) and LLR (Lunar Laser Ranging). Among the space techniques, the VLBI is characterized by the solid and fixed reference frame composed of celestial radio sources, such as Quasars, several billion light-years away from the earth.

Radio Research Laboratory (RRL) started the development of a VLBI system called K-3(1) in 1979 and made the first joint VLBI experiment with NASA, U.S.A. in November, 1983(2). The principal objective of the Japan-U.S. experiments was the detection of the Pacific plate motion against Japan by measuring the distances from Japan to U.S. stations on the Pacific islands. The successive two-year experiments revealed the tectonic movements of Hawaii and Kwajalein islands toward Japan(3), but left another question about the plate stability around Japan.

In 1983, the Japan-China Scientific Cooperation Committee decided to conduct the joint VLBI experiments starting from 1986 in order to see the movement of Japan against the Eurasian plate, and prior to the first experiment, the preliminary VLBI observations were made in September, 1985 on the baseline between Kashima, RRL, and Shanghai Observatory, Academia Sinica. It is the purpose of this paper to give the objectives of the Japan-China joint VLBI experiment and to present the results of the preliminary test observations.

2. Purposes of the Japan-China Experiment

According to the plate tectonic theory, the eastern Asia near Japan is composed of four big plates, the Eurasian plate, the North American plate, the Pacific plate and the Philippine Sea plate. Many active volcanoes and big earthquakes around Japan are said to be the results of the relative motions of these plates. Fig. 1 shows the most probable crustal structure around Japan.

There are many discussions, however, on the shaded area in Fig. 1, being questioned which plate the north eastern part of Japan belongs to [(4)]. We have continued making VLBI

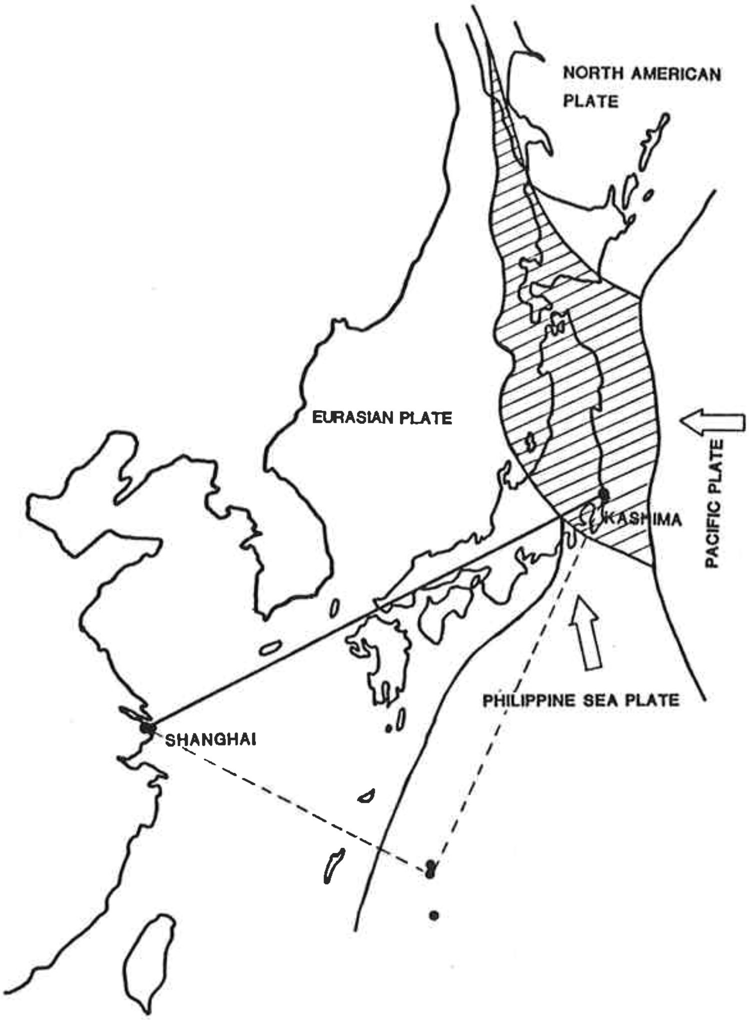

Fig. 1. The most probable crustal structure around Japan and a VLBI network in Japan-China experiment

experiments with NASA to measure the distance from Kashima station in the shaded area to U.S. stations to determine the relative movment of the area against the North American plate since 1984(3). The Japan-China experiment aims at obtaining the relative movement of Kashima against Shanghai on the Eurasian plate. The combination of the Japan-China experiments and the Japan-U.S. experiments will elucidate the crustal structure of the north eastern part of Japan, which is important to consider the occurrence of the big earthquakes in the eastern margin of the Japan Sea (the earthquake off Akita in 1983 for example) and to predict the development of the Japanese islands in the remote future. If the area belongs to the North American plate, the Honshu island, the largest island in Japan, will be separated into two parts along the Fossa Magna.

The goal of the Japan-China experiment is to measure the movement of the Philippine Sea plate which is subsiding under the Eurasian plate. It is feared that a big earthquake will hit the Tokai area due to the tectonic motion along the Nankai Trough. A new highly transportable VLBI station is now under development at RRL and will go into operation at a small island on the Philippine Sea plate. The station will work with the fixed VLBI stations at Kashima and Shanghai to see how far and in what direction the plate is moving. The VLBI network envisaged in the future Japan-China experiments is shown in Fig. 1 with a large triangulation.

Another spin-off is anticipated in accurate time comparison between clocks in Japan and China. RRL and Shanghai Observatory have been working a study on stable frequency standards and have assumed responsibility of keeping the atomic time and of exploiting new space techniques for the time transfer. The Japan-China joint VLBI experiment will give a good chance to compare the results by VLBI with those obtained by other techniques such as the GPS(5) and the GMS satellite time transfers(6).

3. Preliminary Experiment

In September 1985, the first preliminary Japan-China experiment was carried out by RRL in cooperation with Shanghai Observatory. This experiment was planned to establish the basis of VLBI observations, for example, to find the best way of synchronizing the clocks, to achieve close communications during the experiment, to ensure the shipment of tapes for the cross correlations, to have a quick look at the fringes in the test observations and finally to determine the a periori position of Shanghai for further accurate baseline analyses.

In three weeks, from September 1 to September 21, we made a fringe test observation and two 24-hour observations.

3.1 Instruments

We used the 26-m telescope at Kashima Space Research Center, RRL and the 6-m telescope at Shanghai Observatory, Academia Sinica.

The 26-m telescope equipped with the K-3 VLBI system at Kashima has been described in the other paper(1), and here we mainly give an outline of VLBI facilities used at Shanghai. The performance of the 26-m system is summarized in Table 1.

Table 1. The performance of Kashima VLBI station

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

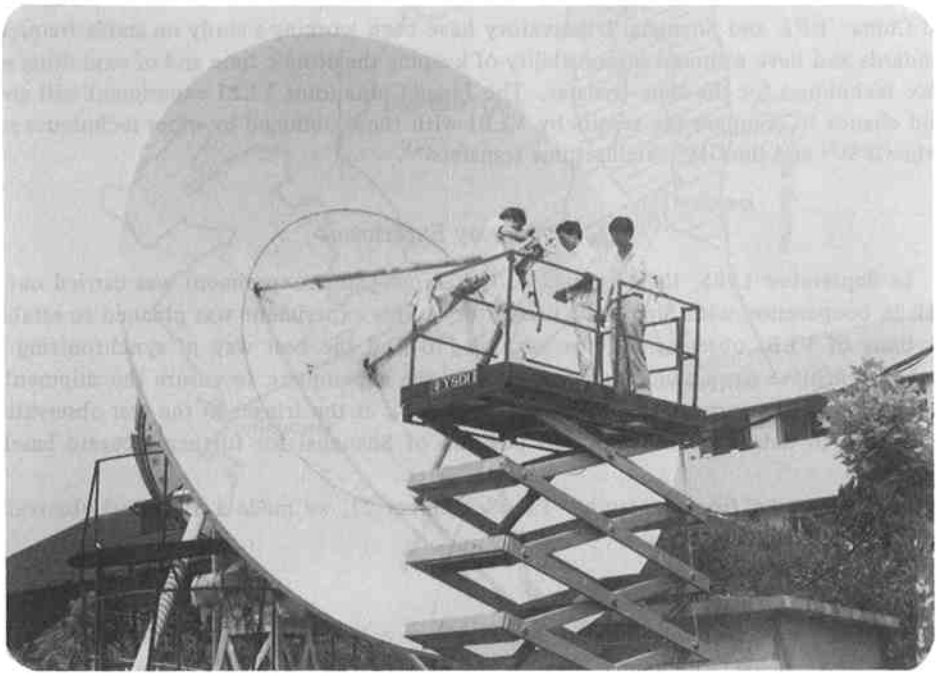

Fig. 2. The 6-m telescope at Shanghai observatory

The 6-m telescope at Shanghai was operated at 1430 MHz in the radio astronomical VLBI observations in 1981 with the 100-m telescope at Effelsberg, West Germany, at the other end of the baseline. It was our first experiment to operate the telescope at X-band frequencies (from 8220 MHz to 8560 MHz) in the geodetic VLBI observations.

An X-band receiver designed for a small aperture antenna at Kashima was shipped to Shanghai and used at the primary focus of the 6-m telescope. In a small box, installed are an X-band polarizer, an X-band FET amplifier, a frequency converter with a local oscillator phase-locked to a reference 10-MHz signal, a noise diode for system noise measurements and a pulse generator for instrumental delay calibration. The receiver was capable of receiving X-band signals for VLBI observations, but due to the size limitation, it was not capable of receiving S-band signals for the ionospheric delay correction. We used the ionosphere sounding data for the delay corrections instead of making S-band observations.

Fig. 2 shows a photo of the 6-m telescope and the receiver at the primary focus. The telescope is on an equatorial mount with the axis offset of 1.12 meters, which should be taken into account in the baseline analysis. The pointing angle was carefully checked up by observing strong celestial radio sources, Cassiopeia A, Taurus A, Orion A and Omega Nebura. The system noise temperature and the aperture efficiency were measured by using a standard noise diode calibrated in advance at Kashima and by observing a standard radio source, the new moon. The measurement results are shown in Table 2.

Table 2. The performance of Shanghai VLBI station

Distance from Kashima	1852 km
Antenna Diameter	6 m
Aperture Efficiency X-band	32 %
System Noise Temperature X-band	400 k
Fringe Detectability X-band	8.20×10^{-6} Jy^{-1}
Data Acquisition Terminal	K – 3

The fringe detectability (see Appendix for the definition) of the 6-m telescope was low owing to high system noise temperature of the receiver and low aperture efficiency of the front feed system. It corresponds to the fringe detectability of a 2-m telescope with a low noise receiver and a high efficient telescope. In spite of the low fringe detectability, we succeeded in finding good fringes and good baseline solutions as will be mentioned in the following section.

Bandwidth synthesis, a technique which improves the ability to determine the delay between two antennas, was used in our observations with seven video converters. The converters are half of the K-3 data aquisition system at Kashima and were shipped to Shanghai for this experiment. The observation frequencies extending over 340 MHz in

X-band (8220 MHz – 8560 MHz) were selected as they formed the minimum redundant frequency pair which would be the most efficient for the bandwidth synthesis. The synthesized equivalent bandwidth was 126 MHz.

The video signals were sampled at the rate of 4 Mbps and recorded on tapes of 3000 feet in length. A high density digital data recorder, SONY VDR-2000, was used and operated by two specialists of SONY.

The recording time on the 3000 feet tape was about one hour with the VDR-2000, while the recording time on the 9000 feet tape was also one hour with the Honeywell M-96 recorder at Kashima, so that the recording density of the VDR-2000 was three times as high as that of the M-96. The VDR-2000 in a two-pass operating mode has the density six times as high as the M-96. We tried the two-pass operating mode but failed due to an accident on the recording heads. To reduce the VLBI operation cost, much longer recording time is greatly required, so that the work for the higher density recording should be continued.

For our experiment and future mobile experiments, a new field operating system was developed on a personal computer, HP9816S, and was used to run the data recorder automatically.

Hydrogen maser frequency standards supplied the reference signals for the frequency conversion and the data sampling on both sides. The frequency stabilities were good enough to keep the system coherence over the correlation integration time of around 6 minutes and to keep the atomic time during the whole experiment time of 24 hours. The UTC-times at both sides were compared via the Loran-C signals.

3.2 Observation

We made 24-hour observations twice. Sources and integration time were selected on the expectation of always obtaining fringes on the baseline terminated by one end with the 6-m telescope in low fringe detectability.

In the first 24-hour experiment, we made 149 observations on 13 radio sources. We took much time specially to make 3C84 observations, because the 3C84 has a complex structure and may cause systematic errors on the baseline analysis, which should be examined carefully by measuring the fringe amplitudes and its time dependent variations. If we could determine the structure or could evaluate the structure effect on the baseline analysis, we would be able to have great advantage of the 3C84 in the mobile VLBI experiment, because the 3C84 is the strongest extragalactic radio source which is the best for the observation by a small transportable antenna. The measurement results are presented in Section 3.4.

In the second 24-hour experiment, 5 days after the first experiment, we made 104 observations on the same 13 sources with no stress on the 3C84 observations. The fewer observations than the first experiment was owed to a shortage of tapes. Shortly before the second experiment, we had a trouble on the recorder and failed in the two-pass recording. Although we had to omit some observations from the original schedule, we were able to get a baseline solution with almost the same quality as the first experiment.

After the observations, the data on the tapes of both sides were reproduced and cross-correlated by the K-3 correlation processor and produced many good fringes. From among more than 85 percent of all observations, fringes were detected and classified to Quality 9, the best quality which guarantees to have reliable delay and delay rates observations.

Table 3. Summary of observations in the preliminary Japan-China experiment

Observation Frequency	8390 MHz ± 170 MHz	
Total Bandwidth	14 MHz (2 MHz x 7 Channels)	
Effective Bandwidth	126 MHz	
Observed Sources	13	
	1st 24-hour	2nd 24-hour
Data of Observation	12 Sep. 1985	17 Sep. 1985
Number of Observations	149	104
Number of good Fringes	122	92
Fraction of good Fringes	82%	89%
Delay Observation Error*	0.26 nsec	0.23 nsec
D. Rate Observation Error*	0.14 psec/sec	0.12 psec/sec
Baseline Fitting Error*	4.1 cm	4.0 cm

* Post-fit error: no corrections on source structures and ionospheric delay.

Table 3 summarizes the observations. The observation errors of delays and delay rates were 0.26 nanoseconds and 0.14 picoseconds/second, respectively and two times as large as a usual VLBI observation. Considering the low fringe detectability of the 6-m telescope, however, these errors are quite reasonable. The further discussions about the error analysis will be made in another paper.

Table 4 shows the correlated flux density of each source, which was derived from the observed fringe amplitudes and the fringe detectability of the telescopes involved in the observations. In the table, the corresponding correlated flux densities measured in July 1984, on the baseline between Kashima and Tsukuba (the length of about 56 km)(7) are also shown in comparison with those obtained on our baseline (the length of about 1800 km). As can be seen in the table, almost all correlated flux densities on the Japan-China baseline are lower than those on the Kashima-Tsukuba baseline. The plausible explanations of this fact are the following two.

(1) The sources were resolved into the fragments, giving lower correlated flux density on the longer baseline,

(2) There were some additional loss of coherence due to the undetermined cause in the system at Shanghai.

We have not ascertained the reason yet. More detailed studies should be made on this problem.

Table 4. Correlated flux density of the observed radio sources

Radio Sources		Japan-China experiment			JEG-1	Ratio
IAU name	Common name	JC-1	JC-2	AVR		
0106 + 013	4C01.02	2.6 + 0.3	2.8 + 0.5	2.7	2.9	93%
0316 + 413	3C84	6.9 + 2.2	8.5 + 1.7	7.7	53.2	14%
0355 + 508	NRAO150	2.8 + 0.2	3.2 + 0.3	3.0	4.0	75%
0528 + 134	OG147	2.6 + 0.4	3.0 + 0.4	2.8		
0552 + 398	DA193	3.0 + 0.4		3.0	3.8	79%
0851 + 202	OJ287	3.3 + 0.4	3.7 + 0.7	3.5		
0923 + 392	4C39.25	2.6 + 0.3	2.9 + 0.7	2.8	3.8	74%
1226 + 023	3C273b	8.3 + 0.9	9.8 + 1.1	9.1	27.8	33%
1253 – 055	3C279	3.5 + 0.6	3.5 + 0.3	3.5		
1641 + 399	3C345	4.1 + 0.8	5.6 + 1.0	4.9	9.0	54%
1730 – 130	NRAO530	2.9 + 0.4	3.8 + 0.5	3.4		
2134 + 004	OX057	3.1 + 1.0	2.7 + 0.6	2.9		
2251 + 158	3C454.3	3.8 + 0.8	5.2 + 0.8	4.5	6.6	68%

JC1: the first Japan-China 24-hour experiment in September, 1985
JC2: the second Japan-China 24-hour experiment in September, 1985
(Kashima, RRL-Shanghai, SO, 1850 kilometer)
AVR: Average of the JC1 and JC2
JEG1: the first Japanese domestic experiment in July, 1984
(Kashima, RRL-Tsukuba, GSI, 54 kilometer)
Ratio: the flux ratio of the AVR and JEG1

3.3 Baseline Analysis

We got a baseline solution which minimizes the difference between the observed and the calculated delays and delay rates. We calculated the delays and delay rates assuming that the earth orientation parameters (EOP; position of the earth rotation pole and the rotation rate) and the source positions were known. We adopted the EOP values published by the BIH (Bureau International de l'Heure) and cited the source positions from the catalogue made by the VLBI group at Goddard Space Flight Center, NASA.

A priori position of the 6-m telescope was determined from the nearby NNSS (Navy Navigation Satellite System) stations.

First, we made no correction on the axis offset of the 6-m telescope in order to see the systematic errors on delay observations, and then applied the correction of 1.12 meters, the value from the mechanical drawings.

Fig. 3(a) and (b) show the histogram of the delay residuals before the correction and after the correction. We got better Guassian distribution after the axis offset correction. This can be seen more clearly and quantitatively by applying the Chi-square test on the error distribution. Table 5 lists the Chi-square values in several cases. We can see the axis offset correction is really effective and it makes both of the Chi-square value and the rms residual error strikingly small.

Next, we tried the ionospheric delay correction by utilizing the Total Electron Content (TEC) data obtained at the ionospheric sounding stations near Kashima and Shanghai. The correction was required because we had no S-band observations to estimate the ionospheric propagation delay with dual S/X observations as in the usual geodetic VLBI experiment.

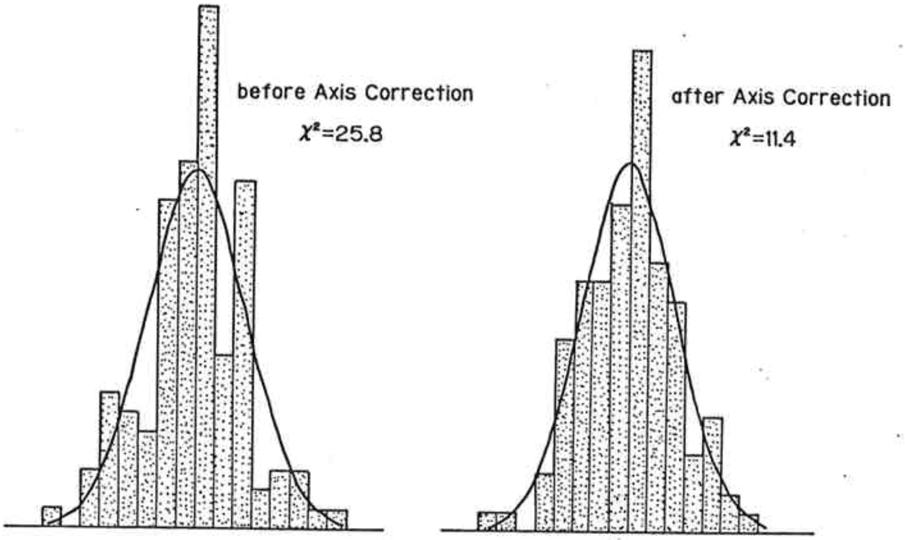

Fig. 3. The delay residual error distributions before and after the axis offset correction

Table 5. The Chi-square value and the rms errors after the least square fitting of the baseline components to the delay observations.

First 24h Obs.

Correction		χ^2 freedom = 14	σ_T (nsec)
Axis Offset	Ionosphere		
×	×	25.7	0.317
○	×	11.4	0.257
○	○ Wuhan Yamagawa	27.3 16.6	0.244 0.242

Second 24h Obs.

Correction		χ^2 freedom = 14	σ_T (nsec)
Axis Offset	Ionosphere		
×	×	16.1	0.269
○	×	7.8	0.229
○	○ Wuhan Yamagawa	6.0 10.8	0.216 0.235

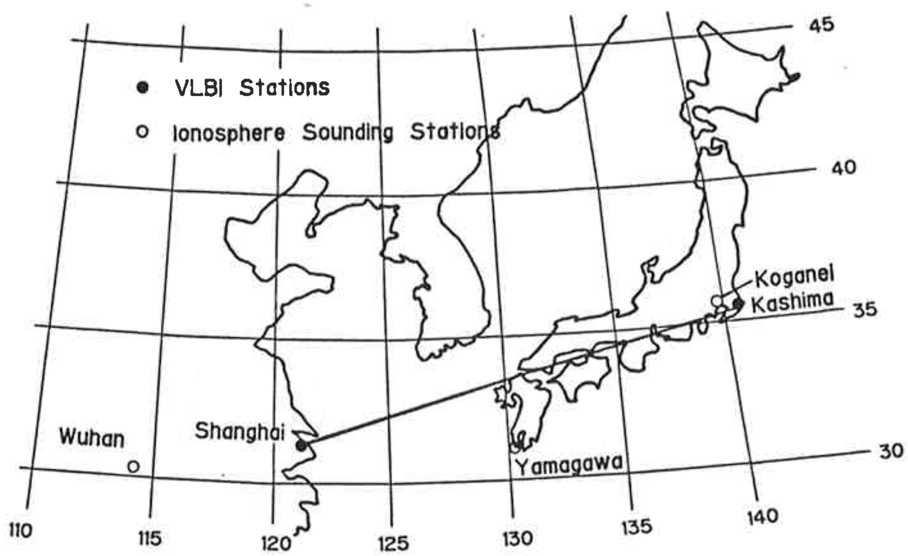

Fig. 4. The locations of ionosphere sounding stations and VLBI stations

We got the TEC data from Wuhan, Yamagawa and Koganei stations. The locations of these stations are shown in Fig. 4 together with the VLBI stations. For the exact correction, we have to know the charged particle distribution just over the VLBI stations. This requirement is partly fulfilled for Kashima, which is located very near the Kokubunji Ionosphere Sounding Station at Koganei. Even in this case, we need to assume the stratified distribution of the charged particles and to consider the small longitudinal difference between Kashima and Koganei.

What is worse, we have a large longitudinal difference between Shanghai and each of the nearby ionosphere stations, Yamagawa or Wuhan. Since it is very difficult to make the exact correction, we simply used the TEC data from Wuhan and Yamagawa only by introducing a time offset corresponding to the longitudinal difference from Shanghai.

The validity of the correction was checked up by applying to Chi-square test again to the delay residual distribution. The results are negative as shown in Table 5. The delay residual error becomes a little smaller but the Chi-square value becomes larger on the other hand.

We decided to adopt the result without the ionospheric correction for the present result, because it is too dangerous to make the unreliable correction which may produce other kind of systematic errors on the baseline solution.

The baseline solutions of two 24-hour experiments are shown in Table 6. Though we made no correction on the ionospheric propagation delay, the two solutions from the independent experiments agree well within their formal errors.

Table 6. The baseline solutions and their formal errors

	First 24 hour (12 September, 1985)	Second 24 hour (17 September, 1985)	Difference	Average
Bx (m)	1150194.27 ± .08	1150194.35 ± .11	−0.08	1150194.31 ± .07
By (m)	1383291.42 ± .13	1383291.41 ± .12	+0.01	1383291.42 ± .09
Bz (m)	−440159.63 ± .09	−440159.70 ± .10	+0.08	−440159.66 ± .07
|B| (m)	1852075.19 ± .04	1852075.25 ± .04	−0.06	1852075.22 ± .03

Table 7. The position of Shanghai in the VLBI coordinate system

	Baseline (SO-KA)
Bx (m)	1150194.31 ± 0.07
By (m)	1383291.42 ± 0.09
Bz (m)	−440159.66 ± 0.07
L (m)	1852075.22 ± 0.03

SO — Shanghai Observatory, Academia Sinica.
KA — Kashima Branch, Radio Research Laboratory.

	Position (KA)*	Position (SO)**	A priori (SO_D)***	Difference (SO-SOp)
X (m)	−3997890.58 ± 0.16	−2847696.27 ± 0.17	−2847697.02	0.75
Y (m)	3276580.38 ± 0.03	4659871.80 ± 0.09	4659879.58	−7.78
Z (m)	3724118.80 ± 0.15	3283959.14 ± 0.17	3283961.56	−2.42

* Come from the Japan-U.S. Joint VLBI Experiments, 1984~1985.
** Derived from the Baseline Vector of this Experiment and the Position of Kashima.
*** Come from the Doppler Observation in WGS-72 System.

From the baseline vector determined, we derived the position of Shanghai in VLBI coordinates as listed in Table 7 assuming that the position of Kashima had already been determined through Japan-U.S. experiments. The difference from the doppler measurement was about 7 meters at the maximum.

3.4 Correlated Flux of 3C84

The Seyfert galaxy, 3C84, is a strong radio source suitable for the use in a fringe test and in geodesic VLBI observations on a relatively short baseline. The one-sided extending structure of the 3C84, however, causes variation in the fringe amplitude and the systematic error on the delay and the delay rate observations on a long baseline.

In the first 24-hour experiment, we took a lot of time in the observation of 3C84 to see the structure effect. We measured the variation of the fringe amplitude and determined the time when the amplitude is the largest. Fig. 5 shows the results with asterisks connected by broken lines. The solid curve on the figure is the calculated correlated flux based on the

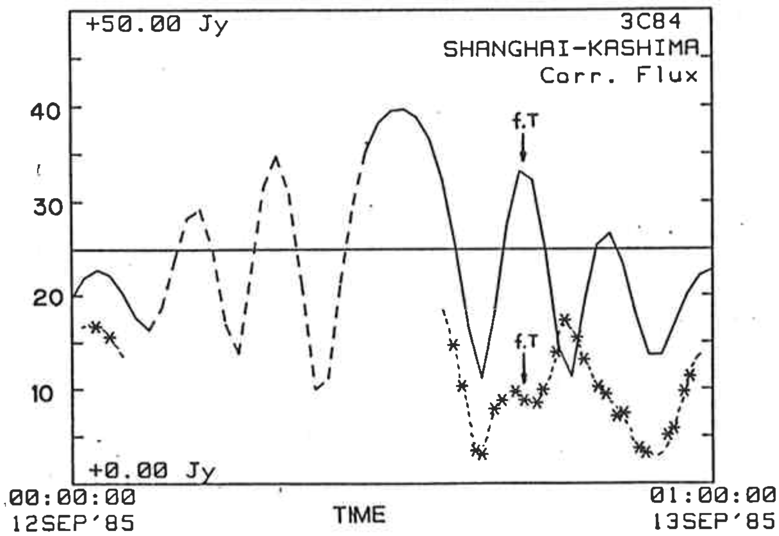

Fig. 5. The observed change in the correlated flux density of 3C84

structure model given by Readhead et al. at 22.2 GHz(8). (the dashed part indicates that the source is set under the horizon.). The "f.T" indicates the time when the fringe test on September 5 was carried out. In the next fringe test observation, the time when the correlated flux has a maximum should be considered.

The observed flux density was small as a whole. We may have to take account of the loss of coherence due to the phase noise of the overheated PLO in the receiver box as already discussed in Section 3.2. The flux variation was also a little different from the theoretical curve. It seems that the structure of 3C84 observed in X-band slightly differs from the Readhead's map at 22.2 GHz. Much more observations are necessary to determine the structure and to estimate the effect accurately.

4. Conclusion

We presented the purposes of the Japan-China joint VLBI experiment and the results of the preliminary experiment. We successfully got a lot of good fringes on the baseline between Kashima and Shanghai.

From the delay observations, we determined the Japan-China baseline with an error less than 3 centimeters in length and less than 10 centimeters in the vector components. Since the position of Kashima has already been fixed in the global VLBI network through the Japan-U.S. joint VLBI experiments, we simply derived the position of Shanghai from the baseline vector with Kashima at the other end. It was the first time that the Shanghai station was fixed in the global VLBI coordinate system, though the positioning accuracy should be improved by making experiments over again.

From the observed fringe amplitudes, we measured the flux density of 3C84 and its complicated variation with time due to the structure effect. The 3C84 is the strongest extragalactic radio source to be received, and has a great advantage for a fringe test observation and a mobile experiment involved with a small sized antenna. The results of the preliminary experiment will be helpful for the next experiment and will give an important clue to the understanding of the complex structure of 3C84.

In the future Japan-China experiment, a 3-m transportable station will work on a small island on the Philippine Sea plate. We hope that our joint experiments enhance the understanding of the current plate tectonics and bring about fruitful results on the earthquake prediction.

5. Acknowledgment

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Appendix

It is the most important in VLBI to find a "fringe", correlation between signals received by two telescopes at both ends of a baseline. The strong correlation, that is, the large fringe amplitude, we can get if the signal is superior to a noise of each receiver. Unfortunately, however, the signal from the extragalactic radio source is very weak and is a thousandth, or less, of the noise power even if we use an antenna with large collecting area. The quality of delay and delay rate observations, and the precision of a baseline solution are proportional to the fringe amplitude. The large fringe amplitude results in the good baseline solution. Thus the fringe amplitude is the most fundamental quantity one should consider first.

The fringe amplitude, ρ, is defined by the following equation.

$$\rho = L_p F_{12} \sqrt{S_1 S_2}\ S_t R(B_{12}), \quad \text{(A.1)}$$

where

L_p: correlation processing loss,

F_{12}: a coherence loss factor associated with the atmospheric fluctuation,

S_1, S_2: fringe detectability of telescopes 1 and 2 at both ends of the baseline, B_{12},

S_t: total flux density of a radio source,

R: fringe visibility, it becomes unity when the source is perfectly unresolved and becomes zero when the source is resolved. It depends on the source structure and the baseline length.

In Equation (A.1), a VLBI station is characterized by specifying the fringe detectability, which is equivalent to the fringe amplitude obtained by ideal correlation processing ($L_p = 1$) of signals emitted from a unit strength radio source ($S_t = 1$) and received by the VLBI station and the equivalent station close enough to each other ($S_1 = S_2$, $F_{12} = 1$, $R = 1$).

The fringe detectability, S, can be related to the performance of the telescope and the receiver by the following equations.

$$S = L_r L_a (T_a / T_s), \qquad \text{(A.2)}$$

$$T_a = (A_p / 2k)\, \eta L_b L_d, \qquad \text{(A.3)}$$

where L_r: a coherence factor associated with the instability of a receiving system,
L_a: atmospheric attenuation,
T_a: telescope sensitivity,
T_s: system noise temperature,
A_p: physical aperture area of a telescope,
k: Boltzmann's constant,
η: aperture efficiency of a telescope,
L_b: defocusing attenuation,
L_d: diffusive attenuation.

From Equations (A.2) and (A.3), we can get the fringe detectability by calibrating the telescope sensitivity and the system noise temperature, and by giving an estimate of a system coherence factor and atmospheric attenuation.

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