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Results of the Japan-US Joint VLBI Experiments and VLBI Activities of RRL

Tetsuro Kondo (Radio Research Laboratories(RRL), Kashima, Japan)
and RRL/NASA Joint experiment group

1. Introduction

Radio Research Laboratories (RRL) has developed the K-3 VLBI system, which includes the correlation system, the analysis software and the data acquisition system. It was designed to be compatible with the Mark-III VLBI system. After the completion of the development, many experiments were successfully performed at both the Japan-US baseline and the domestic baseline. A large amount of data have been processed at Kashima using the K-3 correlation system. In the early stage, only 4 tapes per one station were processed in one day. Now the improvement of the software for correlation processing enables us to process 13 tapes in one day. The data analysis after the correlation processing has also been carried out at Kashima and baseline components were determined.

In this paper, we describe the results of our analysis about the Japan-US joint VLBI experiment. We also introduce the result of domestic VLBI experiment and the super high density recorder being under development.

2. Results of the Japan-US Joint VLBI experiments

After the completion of the development of the K-3 VLBI system, Kashima participated in six big experiments including two "system level experiments" in 1984 (Table 1). The location of stations and the baselines of each experiment are shown in Figure 1. The observed tapes of two "system level experiments" were processed at Kashima using the K-3 correlation system. Fringe search and bandwidth synthesis were then carried out to find the delay and delay rate. These sytem level experiment data were also processed at Haystack to check the K-3 correlation system. In the remaining experiments, the latter half of WPAC2 data were processed at Kashima and other experiment data were at Haystack. We exchanged the data base, which includes the observed delay, delay rate, fringe amplitude, a priori values, etc, with one another.

The data except those of the POLAR1 and the first half of WPAC2, which are now waiting for the analysis, have been analyzed. The station position, clock parameters and the zenith path length of atmosphere are selected as the adjustment parameters. In the analysis, we adopted some important models described below.

We made use of IRIS data for the earth orientation parameters (EOP) and source positions (see Table 2) provided by the NGS. By adopting these two data, we can keep the self-consistency between the EOP and the source positions, because the IRIS data are based on the NGS source catalog. In fact, each station position was able to be estmated within the deviation of 20cm between experiments; it was better than the case that BIH data was used for the EOP. The IRIS data give the EOP of every 5 days without smoothing correction. We calculate the instantaneous value of UT1 from the IRIS data as follows;

UT1 = interpolated value of (IRIS UT1 data - shorter period term)
+ shorter period term

where the shorter period term is a theoretically calculated value using the tidal terms with periods less than 35 days in Yoder's table (Yoder et al., 1981). Figure 2 shows an example of the effect of shorter period term.

We use the Marini model for the atmosphere model, which includes the both effects of dry and wet components. The excess path in the ionosphere is corrected by combining the S and X band data. We also correct the cable delay by using a cable delay counter.

Table 3 summarizes the a priori station positions in the VLBI coordinate, which was defined by Mark-III group with its reference point at Haystack. Kashima's position is derived from the results of land surveying conducted by the Geographical Survey Institute (GSI), Japan. The land surveying result (ϕ, λ, h) is expressed on the Bessel ellipsoid. We have to convert this value into the VLBI coordinate system. The conversion takes two steps as follows. The first step is the conversion from Bessel to WGS72. This conversion is the shift of the origin of coordinate, the difference between the origin of WGS72 and that of Bessel (WGS72-Bessel) is -140. 0m, 516. 0m and 673. 0m in X, Y and Z components, respectively. In the next step, WGS72 is converted into the VLBI coordinate system as follows. The coordinate is rotated by 0. 54" in a clockwise sense around the Z axis. Then each component is multiplied by the scaling factor (1. 000000363) and 4. 0m is added to Z component. The relation between these coordinate system is summarized in Table 4.

The estimated Kashima's position is shown in Table 5 as the deviation from the a priori position. The estimated three components of Kashima's position, X, Y and Z, agreed within 20cm in every experiment. Hence, it was confirmed that the position of Kashima should be shifted by 4. 31 ±0. 17m, 0. 23 ±0. 03m and 3. 38±0. 16m in X, Y and Z directions, respectively. (As the base lines from Kashima to other US stations are mainly oriented in the direction along the Y axis, the error of Y component beccame less than other components.) The imperfection of the coordinate conversion from Bessel to VLBI coordinate is considered to be responsible for this deviation, because the uncertainty of conversion constants, especially the displacement between both coordinates, reaches up to several meters. More accurate conversion constants will be available by VLBI experiments.

On the other hand, the lengths of almost all baselines were estimated with an accuracy of better than 3cm (Table 6). Especially the baseline suitable to detect the plate motion, such as Mojave-Kauai, Kashima-Kwajalein and Kauai-Gilcreek, were estimated with an accuracy of better than 1cm. As shown in Table 7 the changing rates of the baseline lengths due to the plate motion are expected to be several cm/year, so that the plate motion may possibly be detected in the coming experiments.

3. Domestic VLBI experiments

3. 1 RRL-GSI experiment

Geographical Survey Institute (GSI) introduced the K-3 system, i. e. , a hydrogen maser, an acquisition terminal, high density data recorders and automatic operation software, and completed its VLBI system with 5m antenna. In order to check the VLBI system at GSI and to determine the baseline length between Kashima and Tsukuba(GSI) (see Figure 3), we conducted the system level experiment for 27 hours in July, 1984. The baseline length was also determined by land surveying performed by GSI. Both results were compared with one another and agreed within 11cm (Table 8), which is almost comparable with the error of land surveying (about 10cm). This result demonstrates that the VLBI system at GSI is available for the domestic VLBI experiments for the precise geodetic purpose starting from 1985.

3. 2 RRL-NRO experiment

Nobeyama Radio Observatory (NRO) installed a hydrogen maser and a Mark-III acquisition terminal. The first test VLBI observation between Kashima and Nobeyama (Figure 3), baseline length of about 200km, was carried out in December, 1984. A right hand circularly polarized (RHCP) component and a left hand circularly polarized (LHCP) component were recorded alternately at Nobeyama. On the other hand, both components were simultaneously recorded at Kashima. The purpose of this observation is to obtain the full components of the correlated flux of the radio sources, i. e. , R-R, R-L, L-R and L-L. We succeeded in obtaining the correlation for all these combinations of polarization components (Figure 4). Afterwards, we conducted the full 24-hour length experiment on March 31, 1985. The data in this experiment are now being processed.

3. 3 Super high density recording experiment

One station requires more than 30 tapes for 24-hour experiment. These tapes must be manually mounted on a recorder, which becomes the biggest interference to attain the full automatic observation. Moreover, the number of tape recorded in a year at one station reaches up to several hundreds, so that the cost of tapes themselves and the transportation fee become very expensive. If the recording density of ten times higher than currently using recorder is realized, the number of tapes for one day experiment can be reduced down to 3 or 4 and the full automatic observation will be realized. Furthermore, the total cost for the VLBI experiment will be drastically reduced.

The RRL has been developing the super high density recorder for the VLBI experiment in cooperation with SONY Co., Ltd. The recorder is based on a SONY's model VDR-2000, which is a video data recorder for a professional broadcasting station. It has a recording density of about seven times higher than that of the conventional recorder (Honeywell's M96). In order to use it in the VLBI experiment, an Input/Output interface for the K-3 (Mark-III) format data was newly developed. The characteristics of VDR and M96 are shown in Table 9. Additionally, the VDR has a remarkable characteristics in tape positioning. The tape synchronization in correlation processing is easily achieved by using the addressing capability of the VDR in every 1/30 sec on tapes.

We made a test observation between Kashima and Tsukuba by using the VDR and succeeded in detecting fringes for the first time (see Figure 5).

4. Conclusion

The results of our analysis about the Japan-US joint VLBI experiment conducted in 1984 can be summarized as follows;

(1) the position of Kashima was confirmed in the VLBI coordinate with a repeatabilty of better than 20cm,

(2) so that, more accurate conversion constants between Bessel and VLBI coordinate system was obtained by VLBI experiment,

(3) almost all baseline lengths were estimated with an accuracy of better than 3cm (partly better than 1cm), then

(4) the plate motion will be detected by the coming experiments.

This time, each experiment was analyzed independently, but we intend to make a further analysis by combining the WPAC and POLAR experiment. The comparison between the IRIS EOP data and the estimated one from the Japan-US joint VLBI experiments is also planned.

In Japan, the experiment between RRL and GSI for the precise geodetic purpose will be conducted with the rate of two or three times per one year. The VLBI experiment for the radio astronomy purpose, such as the polarization observation, and the development of the super high density recorder will be also continued.

Acknowledgement

We would like to express our great appreciation to NASA, GSFC, Haystack and NGS VLBI staffs for kind cooperation and providing the data.

We are greatly indebted to Dr. Chopo Ma and Dr. T. A. Clark for their kindness and efforts to present this paper at the 1985 spring meeting of the AGU.

The work reported this paper has been thanks to much efforts of VLBI researchers at Kashima. The baseline analysis was carried out by Mr. Yukio Takahashi and the changing rate of baseline lengths was calculated by Dr. Kosuke Heki. We wish to thank them and other VLBI staffs of Kashima. We also wish to thank GSI and NRO VLBI staffs for their cooperation.

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Table 1. List of Japan-US joint VLBI experiments (1984.1 - 1984.9).

Table 2. A priori source positions.

Table 3. A priori station positions in the VLBI coordinate system. The position of Kashima is derived from the results of land surveying conducted by the Geographical Survey Institute, Japan.

Table 4. Relation between three ellipsoids: Bessel, WGS72 and VLBI coordinate system.

Table 5. Results of estimated station positions (deviation from the a priori positions shown in Table 3).

Table 6. Observed baseline lengths.

Table 7. Changing rate of baseline lengths expected from the plate motion model proposed by Minster and Jordan (1978).

Table 8. Results of RRL(Kashima)-GSI(Tsukuba) experiments.

Table 9. Characteristics of VDR and M96.

Figure 1. Location of stations and baselines.
(a) : System level experiment (SLE)
(b) : Western Pacific experiment (WPAC)
(c) : Polar experiment (POLAR)

Figure 2. An effect of shorter period tidal term. It is calculated by using the tidal terms with periods less than 35 days in Yoder's table (Yoder et al. , 1981).

Figure 3. Location of domestic VLBI stations.

Figure 4. Examples of correlation obtained by VLBI experiment conducted between RRL(Kashima) and NRO(Nobeyama). Four combinations of polarization components are shown for the coarse fringe search function, i.e., correlation amplitude is given on the trial delay and trial fringe rate diagram in each figure. Maximum amplitude denotes the obtained correlation amplitude and its position represents the residual delay and rate.

Figure 5. Correlation obtained by using VDR. Figure form is same as Fig.4.

Table 1. List of Japan-US joint VLBI experiments (1984.1 - 1984.9).

JAPAN-US JOINT VLBI EXPERIMENT
(1984.1 - 1984.9)

EXPERIMENT	START(UT) YYMMDDHH	STOP(UT) YYMMDDHH	TAPE*/ STATION	STATION
SLE-1	84012300	84012400	48	KAS-MOJ
SLE-2	84022418	84022518	34	KAS-MOJ-HAT
WPAC-1	84072809	84073014	66	KAS-MOJ-KWA-KAU-GIL
WPAC-2	84080406	84080614	66	KAS-MOJ-KWA-KAU-GIL
POLAR-1	84083006	84083112	30	KAS-MOJ-HAY-WET-GIL-ONS
POLAR-2	84090206	84090312	30	KAS-MOJ-HAY-WET-GIL-ONS

SLE : System Level Experiment

KAS : Kashima　　KWA : Kwajalein　　HAY : Haystack

MOJ : Mojave　　KAU : Kauai　　WET : Wettzell

HAT : Hatcreek　　GIL : Gilcreek　　ONS : Onsala

Table 2. A priori source positions.

SOURCE POSITION (J2000.0)

SOURCE NAME IAU	ALTERNATE	RIGHT ASCENSION H	M	S	SIGMA S	DECLINATION D	M	S	SIGMA S
0106+013		1	8	38.77111	.00001	1	35	.3200	.0004
0212+735		2	17	30.81312	.00002	73	49	32.6226	.0001
0224+671	4C67.05	2	28	50.05157	.00003	67	21	3.0307	.0002
0229+131		2	31	45.89407	.00001	13	22	54.719	.0003
0234+285		2	37	52.40567	.00001	28	48	8.9917	.0002
0235+164		2	38	38.93006	.00001	16	36	59.2783	.0005
0300+470		3	3	35.24215	.00003	47	16	16.2776	.0003
0355+508	NRAO150	3	59	29.74724	.00001	50	57	50.1631	.0001
0528+134		5	30	56.41674	.00001	13	31	55.1510	.0003
0552+398		5	55	30.80560	.00001	39	48	49.1665	.0001
0742+103		7	45	33.05954	.00008	10	11	12.6899	.0024
0851+202	OJ287	8	54	48.87491	.00001	20	6	30.6418	.0002
0923+392	4C39.25	9	27	3.01389	.00001	39	2	20.8524	.0001
1226+023	3C273B	12	29	6.6997		2	3	8.5994	.0004
1235-055	3C279	12	56	11.16652	.00006	-5	47	21.523	.0023
1404+286	OQ208	14	7	.39437	.00001	28	27	14.6891	.0001
1637+574		16	38	13.45625	.00001	57	20	23.9790	.0001
1642+690		16	42	7.84825	.00002	68	56	39.7564	.0001
1641+399	3C345	16	42	58.80989	.00001	39	48	36.9942	.0001
1741-038		17	43	58.85609	.00003	-3	50	4.6141	.0015
1803+784		18	0	45.68383	.00002	78	28	4.0178	.0001
1928+738		19	27	48.49164	.00014	73	58	1.5724	.0009
2134+004	2134+00	21	36	38.58631	.00001	0	41	54.2157	.0004
2200+420	VR42220	22	2	43.29128	.00001	42	16	39.9809	.0001
2216-038		22	18	52.03772	.00002	-3	35	36.8769	.0009
2251+158	3C454.3	22	53	57.74788	.00001	16	8	53.5630	.0002

Table 3. A priori station positions in the VLBI coordinate system. The position of Kashima is derived from the results of land surveying conducted by the Geographical Survey Institute, Japan.

A PRIORI STATION POSITION

STATION	X (m)	Y (m)	Z (m)
MOJAVE	-2356169.15	-4646756.83	3668471.22
KASHIMA	-3997894.93	3276580.09	3724115.46
KAUAI	-5543844.50	-2054565.70	2387814.29
KWAJALEIN	-6143535.36	1363995.57	1034707.89
GILCREEK	-2281544.915	-1453645.749	5756994.220
HAYSTACK	1492406.691	-4457267.330	4296882.102
WETTZELL	4075541.906	931734.189	4801629.393
HATCREEK	-2523968.05	-4123507.27	4147753.18
ONSALA60	3370608.0893	711916.4485	5349830.8416

Table 4. Relation between three ellipsoids: Bessel, WGS72 and VLBI coordinate system.

RELATION BETWEEN ELLIPSOIDS

ELLIPSOID	a (m)	f	REMARKS
Bessel	6377397.155	1/299.1528	origin shift is (m) $\Delta X=-140.0$, $\Delta Y=516.0$, $\Delta Z=673.0$
WGS-72	6378135.000	1/298.2600	
VLBI	6378137.079	1/298.2600	rotating by 0.54" in clockwise around the Z axis. scaling facter is $1+0.3263\times10^{-6}$ origin shift is (m) $\Delta X=0.0$, $\Delta Y=0.0$, $\Delta Z=4.0$

Table 5. Results of estimated station positions (deviation from the a priori positions shown in Table 3).

ESTIMATED STATION POSITIONS : ADJUSTMENT TO A PRIORI VALUES (m)

STATION		SLE-1	SLE-2	WPAC1-1	WPAC1-2	WPAC2-2	POLAR2	MEAN
KASHIMA	ΔX	4.33±0.03	4.52±0.02	4.06±0.03	4.15±0.03	4.43±0.03	4.36±0.02*	4.31±0.17
	ΔY	0.20±0.02	0.25±0.02	0.19±0.02	0.25±0.02	0.24±0.02	0.22±0.02*	0.23±0.03
	ΔZ	3.32±0.03	3.26±0.02	3.64±0.03	3.47±0.03	3.21±0.03	3.39±0.02*	3.38±0.16
KAUAI	ΔX	——	——	0.05±0.03	0.10±0.02	0.24±0.03	——	0.13±0.10
	ΔY	——	——	0.23±0.02	0.27±0.02	0.34±0.02	——	0.28±0.06
	ΔZ	——	——	0.22±0.02	0.15±0.02	-0.02±0.03	——	0.12±0.12
KWAJALEIN	ΔX	——	——	0.21±0.05	0.15±0.04	0.37±0.04	——	0.24±0.11
	ΔY	——	——	0.28±0.02	0.36±0.02	0.39±0.02	——	0.34±0.06
	ΔZ	——	——	0.23±0.03	0.14±0.03	-0.12±0.03	——	0.08±0.18
GILCREEK	ΔX	——	——	——	-0.35±0.02	-0.31±0.03	-0.27±0.01*	-0.31±0.04
	ΔY	——	——	——	-0.14±0.02	-0.15±0.02	-0.16±0.02*	-0.15±0.01
	ΔZ	——	——	——	-0.42±0.02	-0.47±0.04	-0.47±0.03*	-0.45±0.03
MOJAVE	ΔX	FIX STATION					0.01±0.01	0.01±0.01
	ΔY						0.17±0.03	0.17±0.03
	ΔZ						-0.11±0.02	-0.11±0.02
WETTZELL	ΔX	——	——	——	——	——	0.03±0.02	0.03±0.02
	ΔY	——	——	——	——	——	0.11±0.03	0.11±0.03
	ΔZ	——	——	——	——	——	-0.00±0.03	-0.00±0.03
HAYSTACK	ΔX	——	——	——	——	——	FIX STATION	——
	ΔY	——	——	——	——	——		——
	ΔZ	——	——	——	——	——		——

NOTES

(1). Value labeled * is referred to Mojave, i.e., Δ= Δstation − ΔMojabe , where Δstation and ΔMojabe are the adjustment values when Haystack was fixed.

(2). "FIX STATION" means the reference station in the analysis.

(3). WPAC1-1 and WPAC1-2 denote the first half and the latter half of WPAC1 experiment, respectively.

(4). WPAC2-2 is the latter half of WPAC2 experiment.

Table 6. Observed baseline lengths.

OBSERVED BASELINE LENGTHS (MEAN VALUE)

	BASELINE	LENGTH (m)	EXPERIMENTS
	KASHIMA - MOJAVE	8091824.12±0.03	SLE1,SLE2,WPAC1-1,WPAC1-2,WPAC2-2,POLAR2
*	KASHIMA - KAUAI	5709360.50±0.03	WPAC1-1,WPAC1-2,WPAC2-2
*	KASHIMA - KWAJALEIN	3936330.79±0.01	WPAC1-1,WPAC1-2,WPAC2-2
	KASHIMA - GILCREEK	5427104.42±0.03	WPAC1-2,WPAC2-2,POLAR2
	KASHIMA - HAYSTACK	9501780.03±0.03	POLAR2
	KASHIMA - WETTZELL	8475827.11±0.03	POLAR2
*	MOJAVE - KAUAI	4303581.24±0.01	WPAC1-1,WPAC1-2,WPAC2-2
*	MOJAVE - KWAJALEIN	7576938.58±0.07	WPAC1-1,WPAC1-2,WPAC2-2
	MOJAVE - GILCREEK	3816209.20±0.03	WPAC1-2,WPAC2-2
	KAUAI - KWAJALEIN	3725196.32±0.03	WPAC1-1,WPAC1-2,WPAC2-2
*	KAUAI - GILCREEK	4728114.81±0.01	WPAC1-2,WPAC2-2
	KWAJALEIN - GILCREEK	6719676.71±0.04	WPAC1-2,WPAC2-2

* : Baseline suitable for detecting the plate motion (see Table 7).

Table 7. Changing rate of baseline lengths expected from the plate motion model proposed by Minster and Jordan (1978).

CHANGE OF BASELINE LENGTH (EXPECTED VALUE)

BASELINE	ΔLENGTH (cm/year)
KASHIMA - KAUAI	-7.03
KASHIMA - KWAJALEIN	-7.23
GILCREEK - KAUAI	-4.08
GILCREEK - KWAJALEIN	-1.46
MOJAVE - KAUAI	2.60
MOJAVE - KWAJALEIN	2.65

(after HEKI: private communication)

Table 8. Results of RRL(Kashima)-GSI(Tsukuba) experiments.

RESULTS OF RRL (KASHIMA) -GSI (TSUKUBA) EXPERIMENT

METHOD	BASELINE COMPONENTS (GSI-RRL) in VLBI COORDINATE (m)			
	ΔX	ΔY	ΔZ	LENGTH
①LAND SURVEYING	40719.39±0.14	33656.48±0.13	13591.52±0.21	54548.66±0.10
② VLBI	40719.34±0.05	33656.66±0.04	13590.74±0.05	54548.55±0.01
②−①	-0.05	0.18	-0.78	-0.11

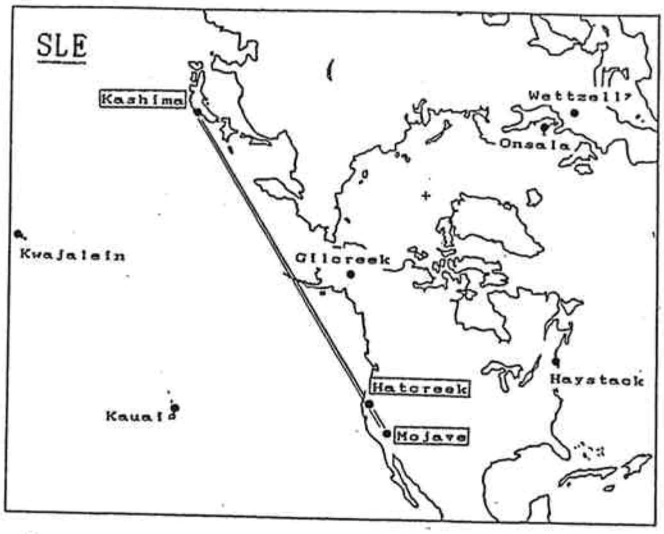
Table 9. Characteristics of VDR and M96.

CHARACTERISTICS OF VDR AND M-96

Items	VDR	M-96
Tape using	1"×7200' Hi-co	1"×9200'
Head system	4-head helical scan	28 stationary
Tape speed	0.488m/s	3.43m/s
Tape-head relative speed Revolution of drum	25.83m/s 3600rpm	3.43m/s ——
Track width (with guard)	90μm	875μm
Head material	Ferrite	Ferrite
Data rate	118Mbps(141Mbps)	126Mbps
Capacity per volume	530Gbits(660Gbits)	103Gbits
Recording density	43.5kbpi(54.4kbpi) 6.1Mb/in^2(7.6Mb/in^2)	33.3kbpi 0.93MB/in^2
I/O channel	8 bit parallel	28
Coding Error correcting	8-9 NRZM Reed solomon	NRZM ——
Bit error rate	10^{-8} (10^{-5})	10^{-6}
Fast speed	480ips	270 ～ 360ips
Power	100～ 115V , 2kW	115V , 1kW
Size (W×D×H) mm processor	570× 680× 588 430× 445× 530	560× 737×1650 ——
Weight	150kg	250kg

( ) : no error correcting case

(a)



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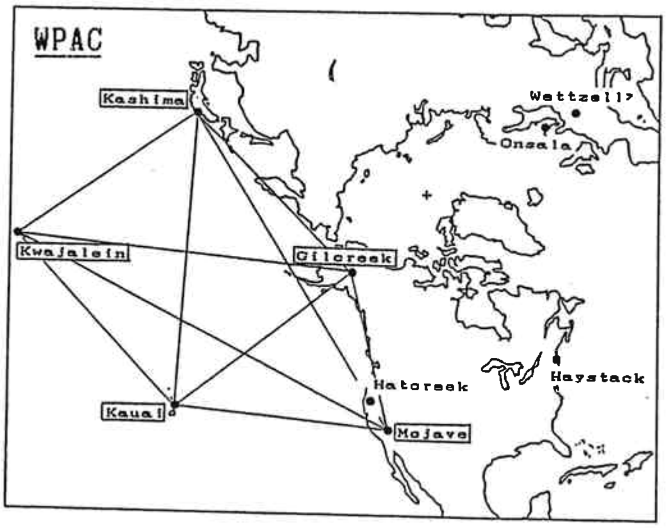

(c)

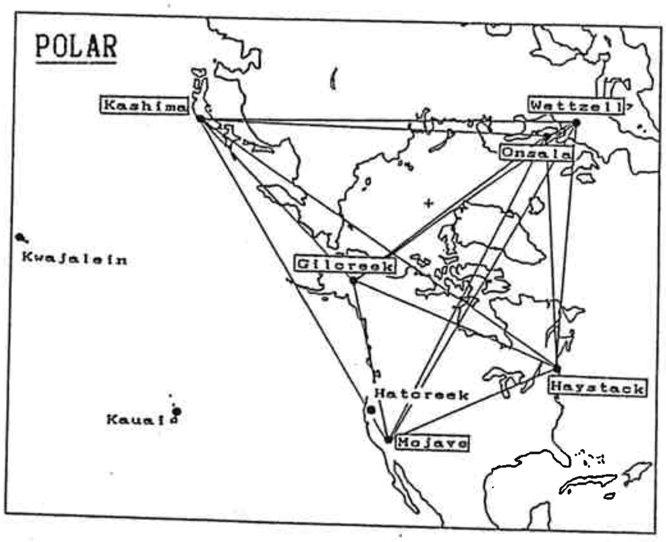

Figure 1. Location of stations and baselines.
(a) : System level experiment (SLE)
(b) : Western Pacific experiment (WPAC)
(c) : Polar experiment (POLAR)

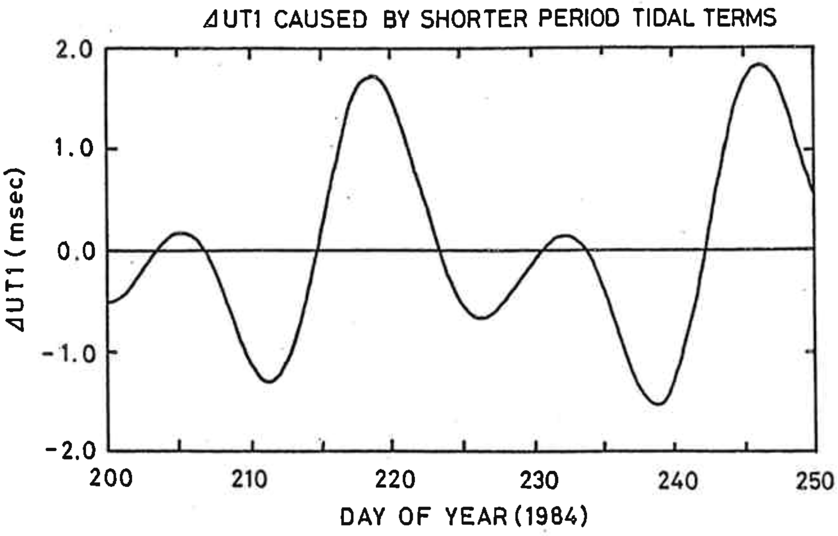

Figure 2. An effect of shorter period tidal term. It is calculated by using the tidal terms with periods less than 35 days in Yoder's table (Yoder et al. , 1981).

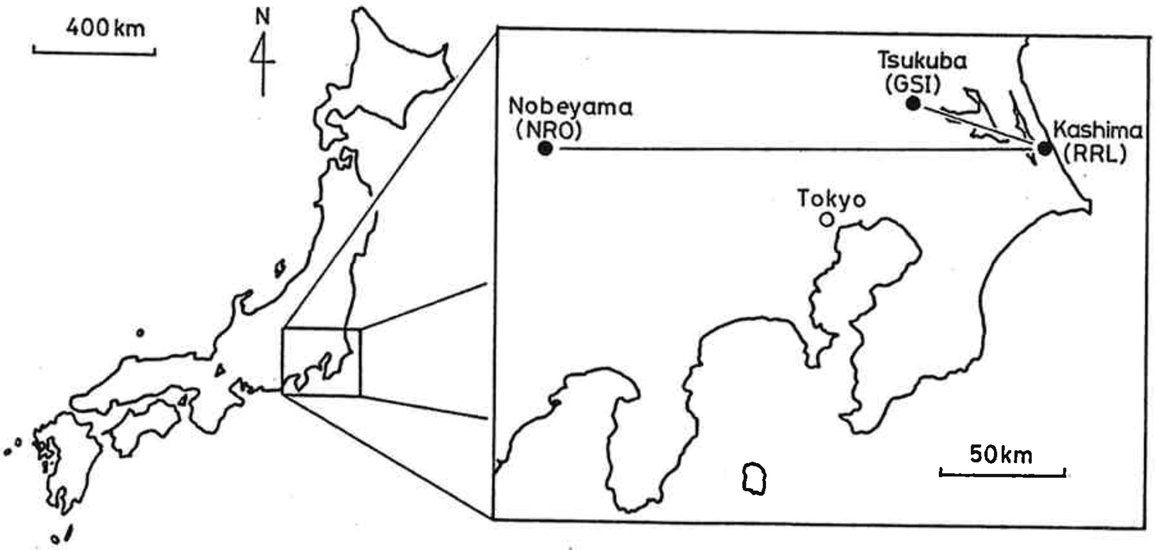

Figure 3. Location of domestic VLBI stations.

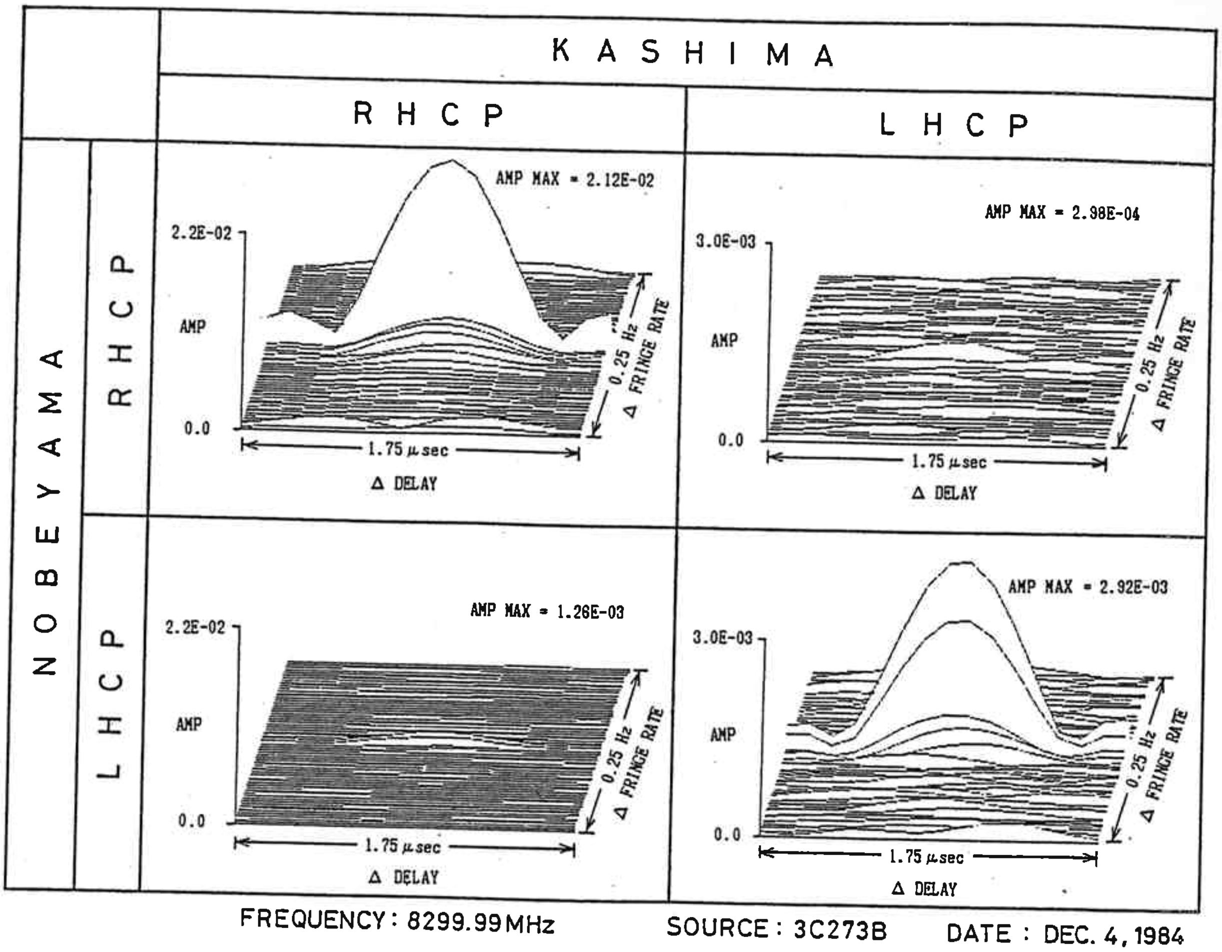

Figure 4. Examples of correlation obtained by VLBI experiment conducted between RRL(Kashima) and NRO(Nobeyama). Four combinations of polarization components are shown for the coarse fringe search function, i.e., correlation amplitude is given on the trial delay and trial fringe rate diagram in each figure. Maximum amplitude denotes the obtained correlation amplitude and its position represents the residual delay and rate.

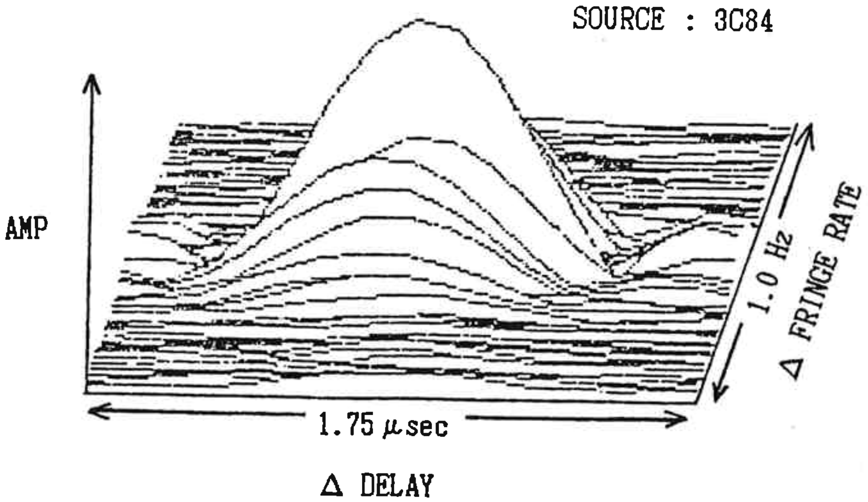

Figure 5. Correlation obtained by using VDR. Figure form is same as Fig.4.