Vol. 38 No. 3 | Journal of the Communications Research Laboratory | November 1991
Printed in Tokyo, Japan | pp. 513 – 520

IV. EXPERIMENTAL RESULTS

IV. 1 INTERNATIONAL VLBI EXPERIMENTS BETWEEN 1984 AND 1990

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(Received on March 18, 1991)

ABSTRACT

Since 1984, CRL has been conducting international VLBI experiments using a K-3 type VLBI system which is compatible with the Mark III system developed by NASA. Major international VLBI experiments in which Kashima station took part are described, including geodesy experiments, earth's rotation observation, time synchronization and space technology application experiments. Improvements in VLBI technology in the 1980's is compared with the expected performance predicted in 1980. It was found that expected precision in most of fields has already been surpassed.

1. Introduction

Between 1984 and 1990, the Communications Research Laboratory (CRL) conducted a variety of international VLBI experiments in cooperation with many institutions throughout the world. The beginning of this period saw the completion of the Japanese K-3 VLBI system, which was developed to be compatible with the Mark III VLBI system in the United States. Both of these systems are successors to older types of VLBI systems. These systems were used to perform global VLBI experiments usually in S and X frequency bands. The experiments were conducted as part of the Crustal Dynamics Program (CDP) with NASA, the International Earth Rotation Service (IERS) program, in cooperation with the United States Naval Observatory (USNO) and through scientific agreements between Japan and other countries. Through these programs, global VLBI experiments progressed substantially in such fields as geodesy, astrometry and astronomy. The network is being extended to the southern hemisphere to form an actual global VLBI network. In 1990, the 11-m antenna built at Syowa Station in the Antarctica was connected with the Kashima VLBI station in Japan. Improvement in VLBI technology is also reviewed in the case of international VLBI.

2. VLBI Experiments for Global Geodesy

A test VLBI experiment between Kashima and US stations was performed in November, 1983[(1)].

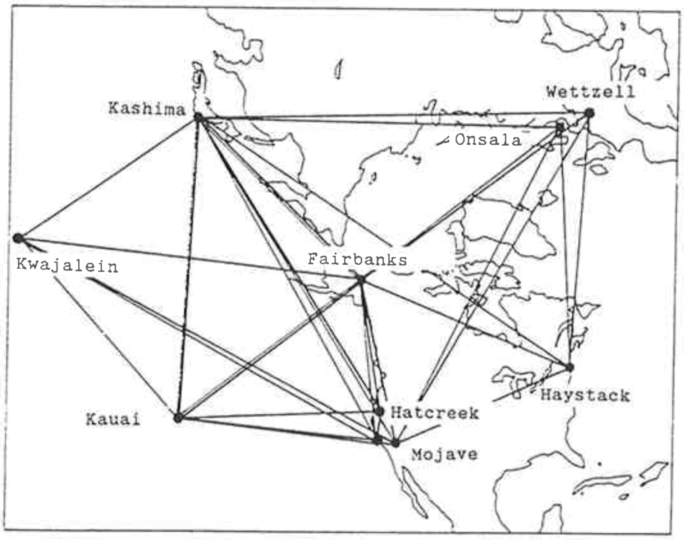

Fig. 1 International VLBI network for the Crustal Dynamics Project.

This was the first international VLBI experiment for CRL. From January 1984, Kashima began Japan-US joint VLBI experiments on a regular basis using a 26 m antenna and the newly developed K-3 type VLBI system. Since then, Kashima has played an important role in global VLBI observation. And its position in network geometry (Fig. 1[(2)]) has made it a key VLBI station in Asia.

Since the main islands of Japan are located on a seismic belt, the detection of plate motion and measurement of its velocity were of much interest for obtaining fundamental data used in earthquake prediction. We thus focused on plate motion monitoring as a major project and, in particular, on the Pacific plate. A number of experiments were carried out between Kashima, Kauai (Hawaii) and Gilcreek (Alaska) stations. The observed plate motions are shown in Fig. 2[(2)].

In September, 1985, a Japan-China joint VLBI experiment was performed. The purpose of this experiment was to confirm the plate boundary between the North American Plate and Eurasian Plate in this region as it was believed that Kashima was located on the former plate and Shanghai on the latter plate. The experiment has been carried out since 1987 with a newly built 25 m antenna in Shanghai. However, since no significant changes in baseline length between the two stations have yet been found, more time is required to arrive at a definite conclusion.

Until recently, the number of VLBI stations in the southern hemisphere was limited, and the VLBI network was mostly located in the northern hemisphere. A long North-South (N-S) baseline was greatly desired, however, due to its advantage over an East-West baseline in observing 1) declination of sources and 2) polar motion. Consequently, in February, 1988, Australian stations were connected with Kashima station, and the baseline vector between Kashima and Tidbinbilla (Australia) is almost N-S.

By exploiting this N-S baseline, pioneering work began. To begin with, source surveying experiments were performed, since radio sources in the southern hemisphere are necessary to define the celestial reference frame. In S and X bands, the correlation amplitude and position of the southern sources were determined using data from these experiments. Southern sources are also important for

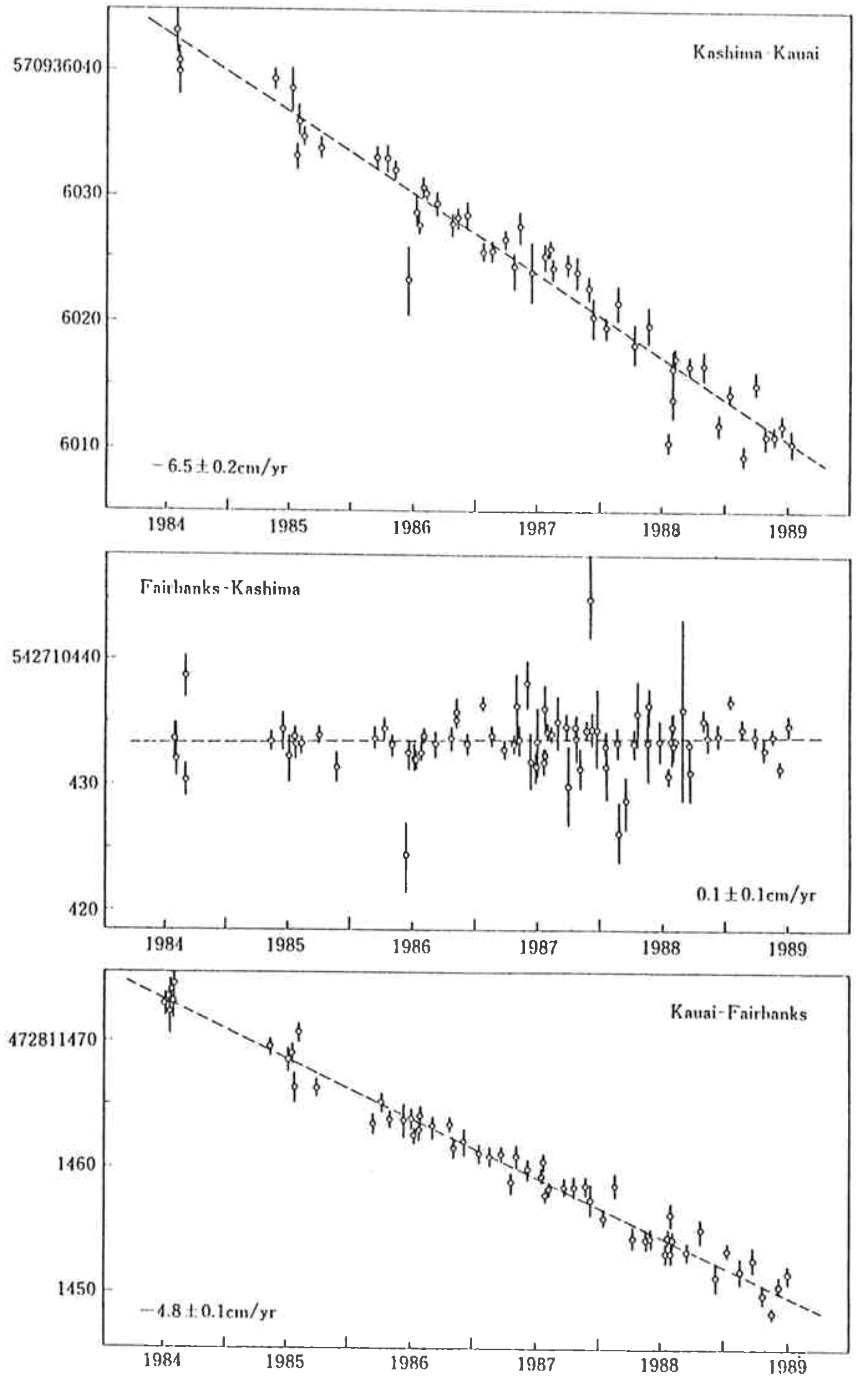

Fig. 2 Change in distances between Kashima, Kauai and Fairbanks.

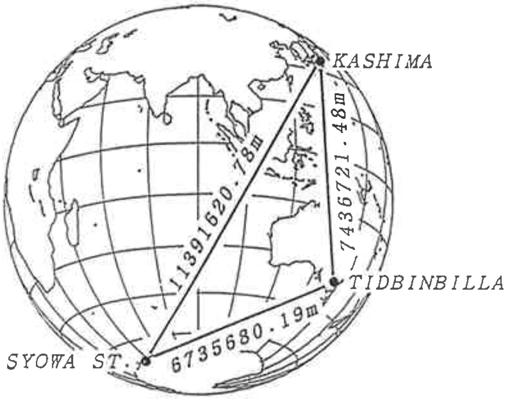

Fig. 3 Baseline geometry of the first Antarctic VLBI experiment.

geodetic experiments with southern VLBI stations. In January, 1990, an Antarctic VLBI experiment was carried out with VLBI stations in the southern hemisphere and northern hemisphere utilizing a 11 m antenna built at Syowa Station, newly developed K-4 type VLBI system[(3)(4)] and compact Cesium-X'tal oscillator[(5)]. The 11 m antenna built at Syowa Station, the 34 m in Tidbinbilla and the 26 m antenna in Kashima participated in this experiment (Fig. 3). Although it was just a test level experiment, the position of Syowa Station was determined[(6)].

3. VLBI Experiments for Earth Rotation Monitoring

Kashima has been a regular station in a NASA CDP (Crustal Dynamics Project) program. Since the measurement of plate motion and crustal deformation is the main objective of the CDP program, experiments to measure the Earth's rotation (called POLAR) were held once or twice a year connecting stations around the Arctic.

European stations, such as Wettzell (FRG) and Onsala (Sweden) in the Atlantic International Radio Interferometric Surveying (IRIS-A) network, also participated in these experiments and contributed to formal error reduction in Earth rotation monitoring. Kashima and Wettzell started observation around the same time.

To utilize VLBI in UT1 monitoring, a campaign called GJRO (German Japanese Earth Rotation Observations) was performed between Kashima (Japan) and Wettzell (FRG) for 14 days in 1985 with a single baseline between Japan and Germany[(7)]. In GJRO a systematic offset in UT1 was found when compared with the published UT1 series by IRIS-Atlantic (IRIS-A). Also in IRIS-Pacific (IRIS-P), a systematic offset was found on each ERP compared with the published ERP by IRIS-A. Consequently, by independent monitoring of the Earth rotation by the various VLBI networks, it is possible to obtain reliable ERP results. ERP offsets among networks are often a good indication of an inconsistent analysis or reference frame. 11月末から 2週間

In principle, it is impossible to solve the three ERP parameters simultaneously with single-baseline VLBI experiment data. However, it is possible to track one ERP parameter with a single-baseline by a series of daily short-term experiments, obtaining the other one or two parameters from

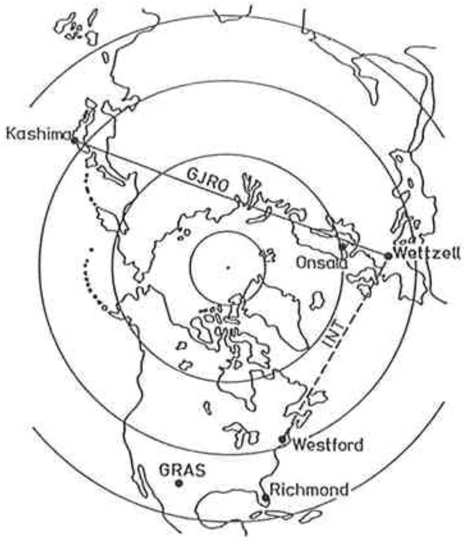

Fig. 4 The GJRO and INT baselines for monitoring UT1 variations.

independent observations. The GJRO and the INT baselines for monitoring UT1 variations are shown in Fig. 4.

A major objective of IERS is to construct and maintain a reference frame for terrestrial coordinates and celestial coordinates, since the relationship between these two coordinates determine Earth rotation. IERS thus involves global geodesy, although crustal deformation is not its main concern. As the number of VLBI observations increase, source position becomes more accurate using global solution software.

Inconsistent solutions due to different reference frames often produce systematic offset in ERP which can be recognized by comparison with independent observation(8). This is a good indication of an inconsistent data set.

CRL started monthly IRIS observations in the Pacific area in 1987 in cooperation with National Astronomical Observatory (NAO)/Mizusawa. In 1988, it became an IERS (International Earth Rotation Service) program. Comparing Earth Rotation Parameters from IRIS-A and -P unified the terrestrial reference frame between CDP and IRIS(9).

4. Time-Synchronization Experiments by VLBI

A common observable for VLBI is the difference in arrival time of radio waves from extragalactic sources at two stations. Clock difference of two stations is also available from the observed time delay as one of the variables(10)(11). The first Japan-US VLBI time-synchronization experiments were carried out in 1984 between Kashima (CRL/Japan), Richmond (USNO/USA) and Maryland Point (USNO/USA) stations(12). The clock difference was determined to be within 1 nsec precision but with unknown offset. To obtain the UTC difference between stations without an offset value, the difference in instrumental delay between the two stations should be known because it is coupled with each station

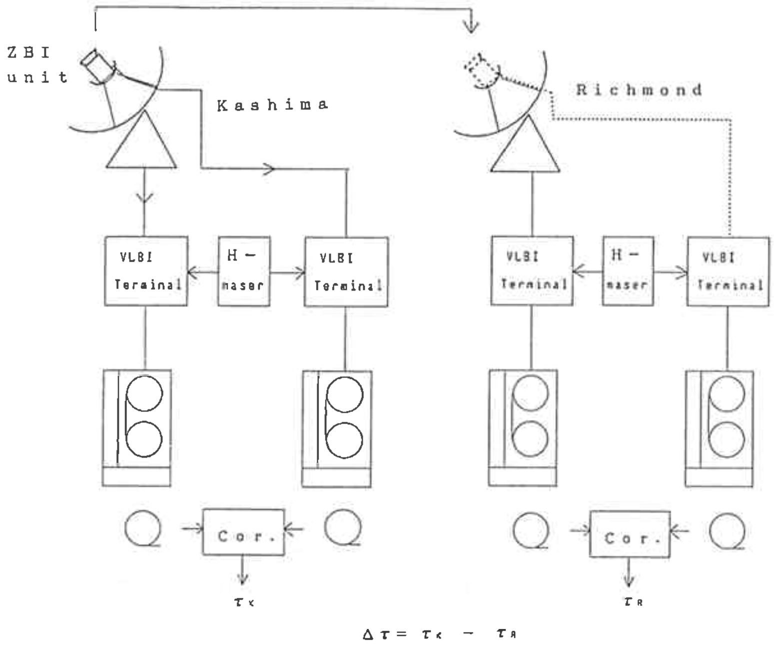

Fig. 5 Zero Baseline Interferometry method for calibrating the instrumental delay difference between two VLBI stations.

clock parameter. Since the instrumental delay difference between Kashima and Richmond was measured using Zero Baseline Interferometry (ZBI) method (Fig. 5)[(13)] in 1986–87, IRIS-P data was also used to monitor the difference in time standards between Japan and the USA. The error in time synchronization is expected to be less than 1 nsec. Time synchronization VLBI experiments require less than one hour of observation time provided the station coordinates and celestial coordinates have been well determined.

5. VLBI Application to Space Technology

To determine the precise orbit of a satellite, Range and Range Rate measurement is not enough. Knowing the tangential component of a satellite's motion, however, will give a more accurate orbit. Delta VLBI was performed using a K-2 system originally developed for real time VLBI. The delta VLBI method removes common errors in VLBI observables from two radio sources, one for geostationary satellites, and the other for quasars[(14)]. In particular, the orbit of a geostationary satellite can be determined within a few meters by using a several-thousand-kilometer baseline.

Another remarkable space-oriented application was a test experiment for space VLBI using a Tracking and Data Relay Satellite (TDRS)[(15)].

6. How Much Have VLBI Techniques Improved in the 1980's?

In a symposium held in 1980, some geophysicists and astronomers discussed how the precision of observables by VLBI could be expected to improve during the coming decade(16). The precision of a variety of observables obtained in 1984 and current values are compared for various VLBI applications in Table 1. Note, however, that it is generally difficult to compare two experiments, since performance depends on the number of observations, baseline length, network geometry, receiving frequency and the method of analysis. Nevertheless the examples shown in the table demonstrate obvious improvements in VLBI technology, more than expected in 1980.

Table 1 VLBI application and the technology level. The level expected in 1980 and achieved in 1990 by CRL is compared. Achieved level in NASA or other institutions are also listed

Application	Expected precision (1980) Achieved level in CRL (1990)	Achieved level (other)
Measurement of long distance	5·E-7 [17] <4·E-9	2.6·E-9 [18]
Earth's rotation monitoring	1 mas [19] ca. 0.5 mas	<0.5 mas
Earth tides study	5–10 mm [20] None	
Time synchronization	None <1 nsec	14 nsec [10]
Astronomy (Angular resolution)	None	0.07 mas by mm wave VLBI 1.5 mas by TDRS space VLBI [15]
Minimum detectable flux density for constructing reference frame	0.01 Jy detection in X-band [21] ca. 0.1 Jy	

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