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II. OUTLINE OF EXPERIMENTS

II. 1 INTERNATIONAL VLBI EXPERIMENTS AT THE COMMUNICATIONS RESEARCH LABORATORY

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ABSTRACT

After completion of the K-3 VLBI system, the Communications Research Laboratory (CRL) started international VLBI experiments in 1983. The K-3 system was developed at CRL and it is compatible with the Mark-III VLBI system developed by NASA. Most of CRL's international experiments were U.S.-Japan joint VLBI experiments. CRL has now been participating in NASA's Crustal Dynamics Project (CDP) for seven years. U.S.-Japan experiments have been very fruitful in the study of crustal plate motion, earth rotation, time transfer, and satellite VLBI.

Besides U.S.-Japan cooperation, CRL now cooperating at government level with, for example, China, Australia, Germany, Canada, and Sweden. This cooperation achieved important geodetic results from joint VLBI experiments in the 1980's.

In the 1990's, CRL's VLBI project has concentrated on experiments relating to Japan Standard Time (CRL) and International Earth Rotation Service (IERS).

1. Introduction

CRL's VLBI network has expanded from the domestic network of the late 1970's to an international and global network in the early 1980's. Figure 1 shows a brief history of CRL's networks from 1977 to 1990. The first Japanese VLBI baseline was about 120 km between Kashima and Yokosuka and experiments were performed with this system in 1977(1)(2). In early 1980's CRL's networks expanded dramatically under cooperation with NASA's Crustal Dynamics Project(3). Also CRL participated in the space VLBI experiment using TDRSE in 1987(4). The following sections elaborate on the extensive bilateral cooperation with foreign countries, especially with the U.S..

Figure 2 shows international trends during the early stages of VLBI experiments which were performed between 1977 to 1984(5). Global geodetic VLBI experiments began during this time. The Mark-I VLBI system (narrow bandwidth) was used for geodetic experiments in 1979. Since 1980, however, the new Mark-III VLBI system has been used for the experiments. Figure 2 shows three types of experiments: trans-continent, trans-ocean, and earth rotation. These three categories also apply to later periods. This graph shows that regular geodetic VLBI experiments began in 1984 from the global point of view. As shown in next section, CRL has carried out regular VLBI experiments since 1984. CRL thus promptly followed the international trend during the initial phase of world VLBI experiments. CRL

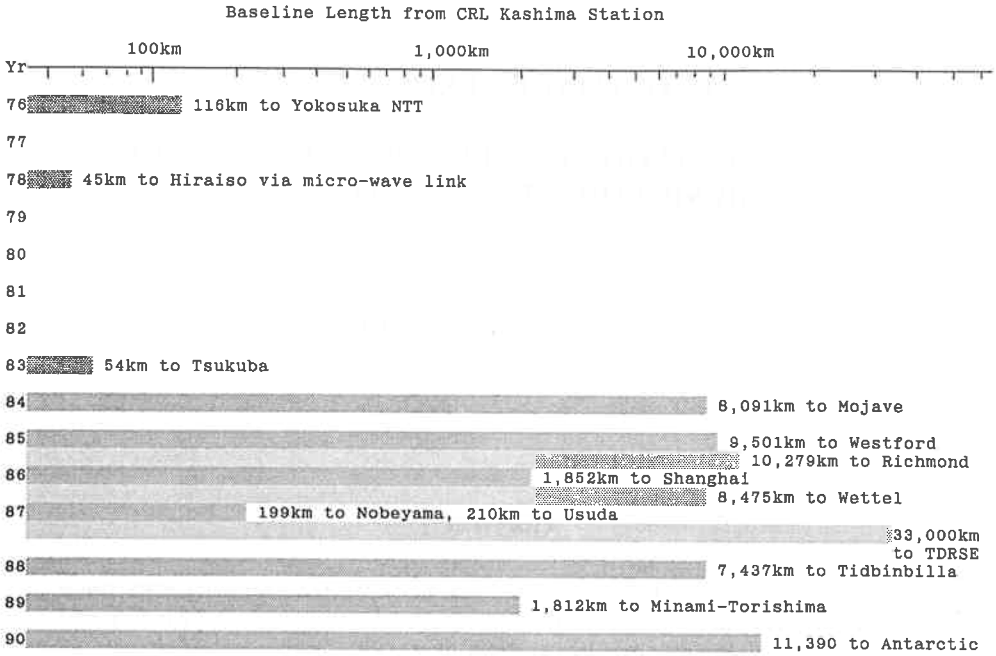

Fig. 1 History of VLBI baseline length from CRL Kashima station.

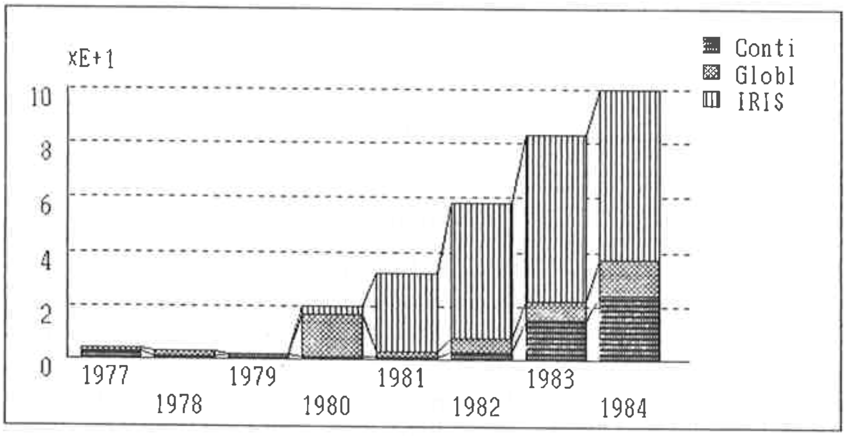

Fig. 2 The numbers of international experiments during the early stages of geodetic VLBI experiments. Conti: Trans-continental experiments, Global: Inter-continental global experiments, IRIS: Earth-rotation experiments.

experiments also covered almost all major VLBI applications from geodesy to astronomy. Refer to Section 2 for details.

Figure 3 shows the countries with which CRL has cooperated at government level. CRL's overseas

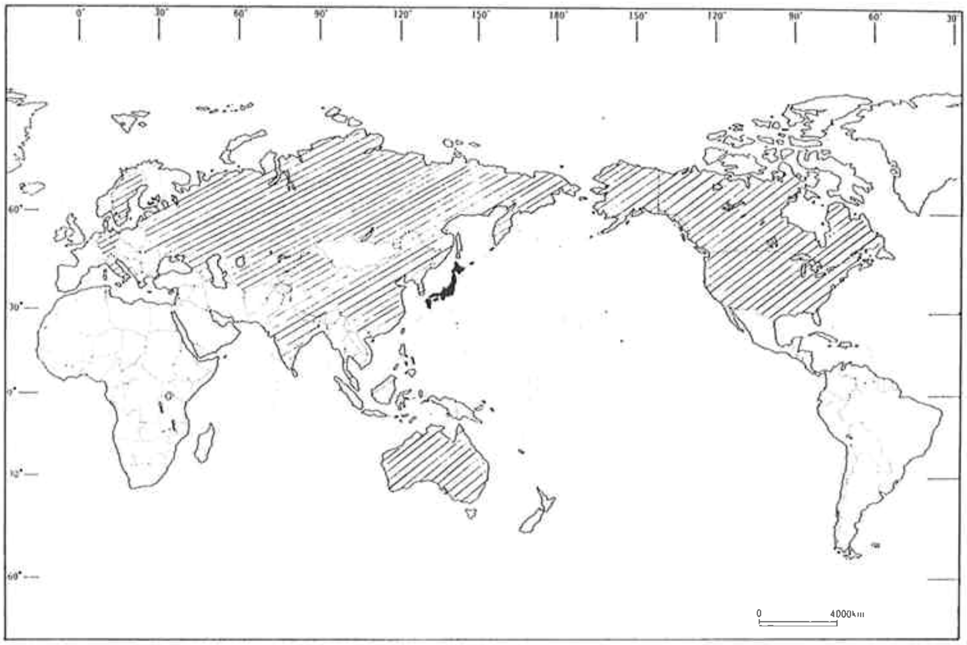

Fig. 3 The hatched areas show the countries with which CRL has government-level cooperation.

cooperation covers most major plates of the northern hemisphere but only Australia in the southern hemisphere. CRL also has plans for future VLBI networks using the space satellites of the 21st century.

2. Contents of CRL's International Experiment

Figure 4 shows the history of CRL's international cooperation with VLBI experiments. CRL participated in NASA's CDP experiments from 1983 to 1990 with almost the same number of experiments. In 1987 CRL started to participated in International Radio Interferometry Surveying (IRIS) to precisely monitor the Earth's rotation. In 1990 the number of IRIS experiments became almost half of CRL's experiments.

Figure 5 shows the number of counterpart stations on each techtonic plate. The number of Pacific Plate Stations is almost constant from 1983 to 1990. The numbers of North American and Eurasian Plate stations are also almost consant from 1984; these now form the major part of CRL's cooperation effort. CRL started the north-south baseline experiments in 1987 with the stations on the Australian Plate. In 1990 the number of counterpart stations reached almost twenty and extended even to the South America, Africa and Antarctic Plates.

Figure 6 shows the numbers of experiments multiplied by the numbers of counterparts. The squares of the numbers are almost proportional to the volumes of data produced from the experiments. Figure 5 shows that by 1989 the data collected jointly with the North American Plate Stations were the most important but those with the Australian Plate Stations became significant in 1990. This tendency will continue after 1990 because CRL is interested in the north-south baseline as a technical challenge.

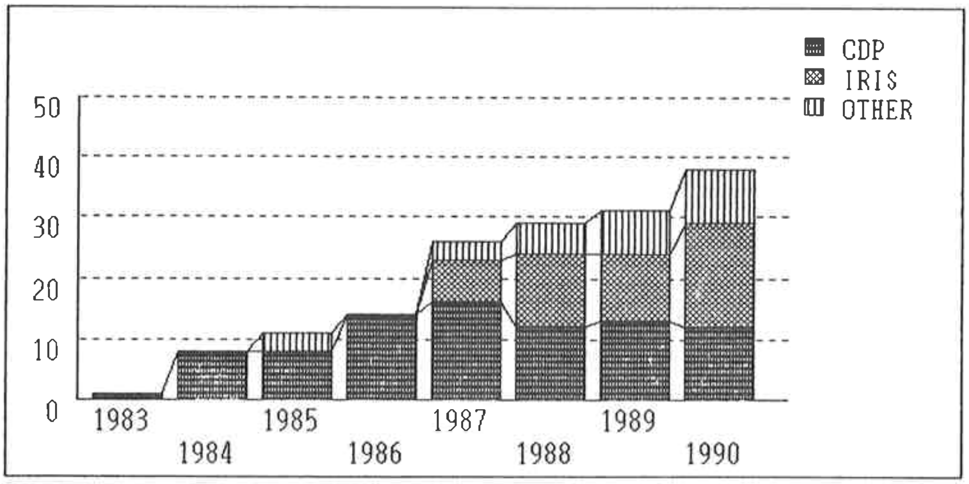

Fig. 4 **The numbers of experiments for each of CRL's international VLBI projects. CDP: NASA's Crustal Dynamics Project, IRIS: International Radio Interferometric Survey, Other: CRL's original international cooperation.**

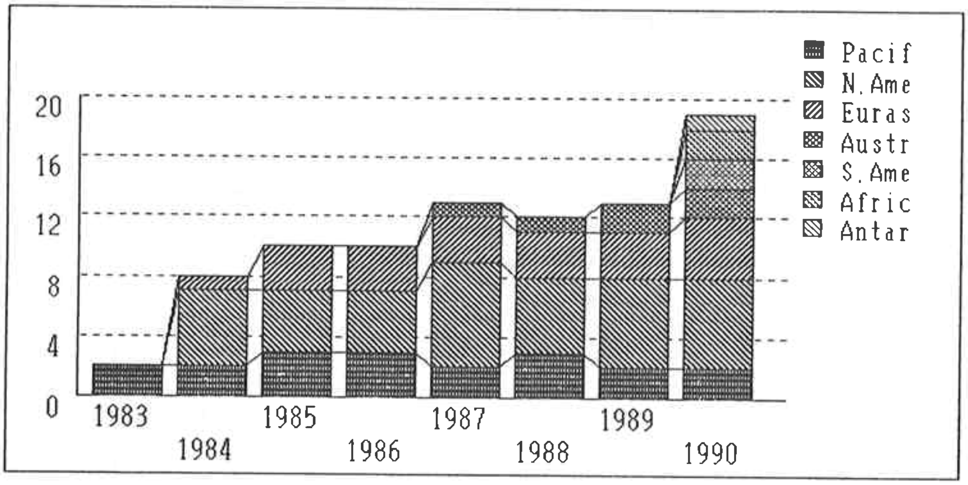

Fig. 5 **The numbers of VLBI stations cooperating with CRL on Various Earth plates. Pacif: Pacific, N. Ame: North America, Euras: Eurasia, S. Ame: South America, Austr: Australia, Afric: Africa, Antar: Antarctic.**

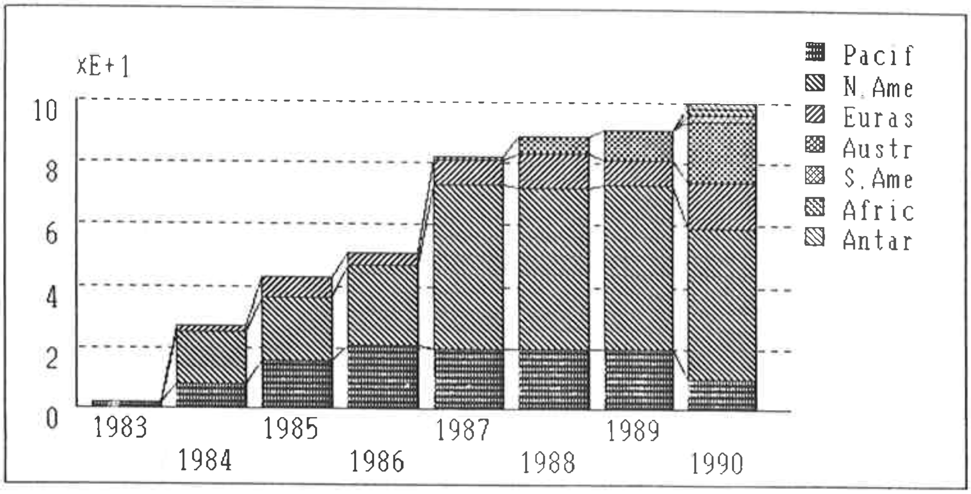

Fig. 6 The numbers of the VLBI stations multiplied by the numbers of experiments. The numbers are nearly proportional to the volume of the output data base and suitable for activity-evaluation.

3. U.S.-Japan Joint VLBI Experiments

To start bi-lateral or multi-lateral international cooperation on a global scale, we usually need international cooperation programs in the form of inter-governmental agreements. CRL's VLBI projects include the following major governmental cooperation programs: U.S.-Japan, China-Japan, Australia-Japan, Canada-Japan, Germany-Japan, and Italy-Japan. Among these, the U.S.-Japan program plays the initiative role and has the most varied content and experience.

In September 1981, the first joint committee for science & technology cooperation between the U.S. and Japan in the non-energy field was held in Washington D.C. This committee decided to proceed with joint VLBI experiments between CRL and NASA(6). The formal theme name of this cooperation is "The study of crustal plate motion". In November 1981, the International Lithosphere Program (ILP) was recommended to the Japanese Government by the Japan Science Council. This ILP also included the new theme: "direct detection of plate motion using space techniques". This recommendation was also a strong support for CRL to get governmental funding for the U.S.-Japan joint experiment. Substantial achievements from this cooperation have been discussed in the periodic meeting of the Standing Senior Liaison Group (SSLG)(6).

After the completion of CRL's K-3 VLBI system, which is compatible with NASA's Mark-III VLBI system, a series of VLBI experiments started in October 1983 on the trans-Pacific baseline. Since then CRL has participated in NASA's Crustal Dynamics Project (CDP)(3). As part of U.S.-Japan cooperation, CRL also initiated and performed sub-nanosecond VLBI time transfer experiments between USNO and CRL(7). The period of this time transfer experiment was one month. Also, the IRIS-P earth rotation program was successful. CRL also participated in both the first space VLBI experiment(4) and the delta-VLBI experiment with JPL, U.S.A.

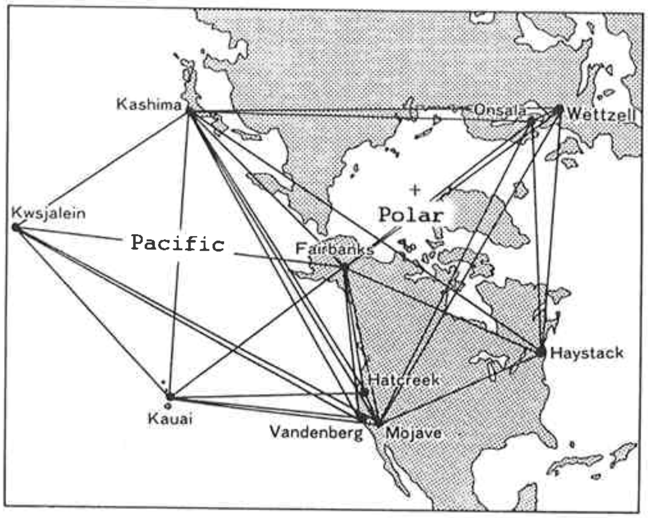

Fig. 7 The baseline allocations for Pacific and Polar experiments during CDP cooperation.

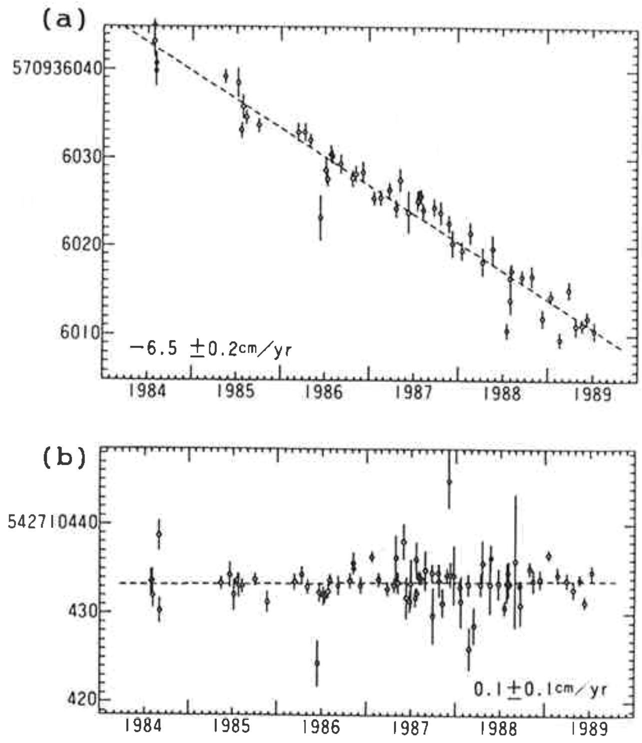

Fig. 8 The rates of change of baseline lengths between Kashima and Kauai (a) and between Kashima and Fairbanks (b).

Most of the geodetic results from this cooperation have been obtained from the Pacific and the Polar VLBI networks as shown in Fig. 7. The pacific network contains stations both on the Pacific and on the North American Plates. VLBI data acquisition systems are the K-3 system for the Kashima station and the Mk-III system for the others. The Polar network consists of stations on the North American and Eurasian Plates.

The rates of change of the baseline lengths were obtained from the slopes of the straight lines obtained from the baseline-length data estimated for individual observing sessions. The Kashima-Kauai baseline-length change (Fig. 8(a)) shows a rapid decrease (6.5 cm/year) reflecting the subduction of the Pacific Plate at the Japan Trench. Rates of change of intra-plate baseline length are believed to be caused by the sum of the effects of plate motion and the apparent uniform contraction of the plates. This baseline change is one of the epoch-making results of U.S.-Japan Joint VLBI experiments(8).

Figure 8(b) shows the variation of the Kashima-Fairbanks (Alaska) baseline length during 1984–1989. Both stations are believed to be on the North American Plate and their separation is expected to be constant. However the data in this period show a very small contraction of less than 0.1 cm/year(8).

4. China-Japan Joint VLBI Experiments

The second committee of science and technology cooperation between China and Japan was held in Tokyo in October 1983. The committee decided on a joint program including VLBI experiments between Shanghai Observatory (SO) and CRL. In September 1985, the first VLBI experiment was performed between the Kashima 26 m and the Shanghai 6 m antenna(9). In this experiment, CRL transported the K-3 VLBI system with a new VDR-2000 digital data recorder to Shanghai. This was the first time that CRL took their VLBI system abroad. In 1988 a new dual-band 25 m antenna was completed by SO and our joint experiments were then performed using this new antenna.

The results of several experiments show that the baseline length changes at the rate of −1.6 cm/year (see Fig. 9). If both stations are on the same "rigid" Eurasian plate, the distance should not change. However, westward movements of Kashima are possibly due to the compressional stress induced by the Pacific Plate. This would predict a baseline length contraction of about 2 cm/year(10). The data cover only one year so it may be premature to give a decisive geologic interpretations at this stage.

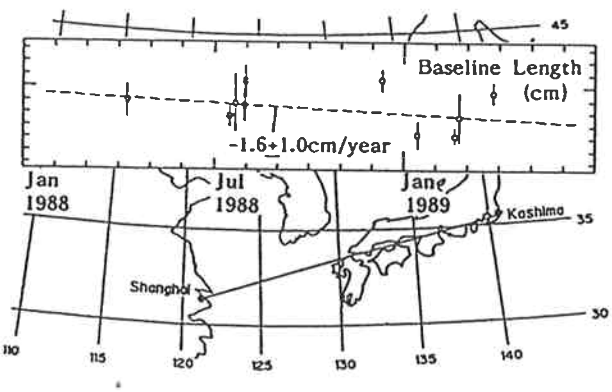

Fig. 9 The change of baseline length between Kashima and Shanghai.

5. Australia-Japan Joint Experiments

There are many VLBI stations on major plates in the northern hemisphere. However, there are very few stations in the southern hemisphere. Thus CRL started cooperating with CSIRO in 1986. CSIRO has VLBI telescopes in Tidbinbilla for cooperation with NASA to track deep space satellites.

Australia is also a very important intermediate station for the Japan-Antarctic VLBI experiments. In the Antarctic experiment, CRL has cooperated with the National Institute of Polar Research (NIPR). The expansion of VLBI to the southern hemisphere is very important for following research purposes:

1) To observe radio sources in the southern celestial hemisphere.

2) To improve the precision of earth rotation parameters by using north-south baseline.

3) To detect movement of the southern hemisphere crustal plate, e.g. the Indo-Australia and Antarctic plates.

4) To observe the global changes of the earth's shape and the mean sea-level. Yukio Takahashi has made a very precise star catalogue using these experiments(11).

In January 1990, CRL performed the first Antarctic VLBI experiment(12) with cooperation from CSIRO, The experiment determined the baseline length between Kashima and the Japanese Syowa Antarctic station with a precision of about 10 cm as shown in Fig. 10.

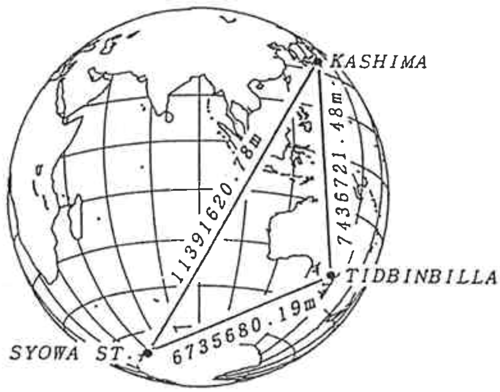

Fig.10 Locations for the VLBI experiment with the Syowa station in Antarctica.

6. Germany-Japan Joint VLBI Experiments

Government level cooperation on VLBI experiments between Germany and Japan started in 1985. The long-term stay of Dr. Yoshino at the Geodetic Institute of Bonn University was an important trigger for this cooperation(12).

Since 1985 CRL has performed the following joint VLBI experiments in cooperation with German VLBI stations:

1) GJRO campaign: Daily VLBI observations over 14 days to observe the short-term variation of Earth rotation (1985)(14).

2) Jupiter gravitational observation: Observations to detect the very small bending of the ray-path

of radio waves from quasars around the Jovian gravitational field by the general relativistic effect (1987).

3) POLAR experiments: Regular VLBI experiments under the NASA Crustal Dynamics Project since 1985.

Because Germany has an Antarctic VLBI program, the cooperation between the Japanese Syowa station and the German Antarctic Peninsula station will be very important for measuring the motion of the crustal plate between the Antarctic Continent and other plates.

7. Canada-Japan Joint VLBI Experiments

Canada has a long history of VLBI development from the early stages, namely analogue VLBI and real-time VLBI using communication satellites. A proposal was made by the Department of Energy, Mines and Resources, Canada to Mizusawa Observatory in 1982. This was a proposal to cooperate in the "Global Dynamics and Crustal Plate Movement" project. The subsequent, joint VLBI experiments between Canada and CRL were found to be very useful.

The idea of a wave-front clock was also proposed by both CRL and the Canadian group. The wave-front clock-rate is controlled to compensate the fringe-rate. Both sides are very interested in the study of the wave-front clock method to make data processing easier than conventional processing. To confirm the feasibility of the wave-front clock method, CRL performed a joint experiment between Argonquin and Kashima in 1990. CRL successfully detected the first fringe from the wave front clock experiment data. The development of this method is continuing in both sides.

8. Sweden-Japan Joint VLBI Experiments

Government-level cooperation between Sweden and Japan started in 1986. Onsala Space Observatory has had a long history of VLBI observations under NASA's CDP since 1983. CRL and the Onsala Space Observatory have a cooperative observation plan to achieve the following by VLBI techniques:

1) Measurements of strength, structure and position of extra-galactic radio sources.

2) Measurements of tectonics movement of the earth's crust by monitoring changes of the baseline between Japan and Sweden.

3) Measurements of the earth rotation parameters.

Sweden has a 20-m mm-wave telescope at Onsala. The new baseline between Sweden and Japan will be the most useful for radio astronomy using mm-wave interferometry for radio astronomy because there are still only a few mm-wave radio telescopes and the available fringe resolution is less than 0.2 mas at 43 GHz. The astronomical community strongly expects that this cooperation will provide a foundation for the ground stations of future space VLBI programs.

9. Italy-Japan Joint VLBI Experiments

Government level cooperation between Italy and Japan started in 1989. Italy has recently installed three fixed VLBI stations: Medicina (32 m), Noto (32 m) and Matera (20 m). The Institut di Radioastronomia is very interested in performing geodetic VLBI experiments with CRL. So far CRL has performed only one experiment with Italian stations. That was a Jovian gravitational experiment as mentioned in reference to German cooperative experiments. Since the German station is always busy with IERS routine work, Italian stations are very useful for making the trans-Eurasian baseline. As Italy is interested in mm-wave VLBI experiments, we have strong common interests between CRL and the Italian group.

10. Conclusion

The precision and repeatability achieved by the international VLBI geodetic experiments was less than a few centimeters. However, each component of baseline vectors has some scattering errors of a few decimeters, which depend on errors in assumptions about the Earth rotation parameters, source positions, propagational effects and observation schedules.

Compensation for the propagation errors is particularly important in improving errors in baseline lengths, vectors and time transfers. The improvement of precision is one of the most important areas for future international experiments. The other important area is the improvement of the international compatibility of VLBI systems.

NASA performed 817 measurement sessions from 1979 to 1989 which included about 350,000 individual time delay measurements from 33 stations. NASA uses these data to establish the fiducial reference on the North American and Pacific plates. This is because NASA has many VLBI stations on these plates. CRL also performed 130 international measurement sessions from 1984 to 1990 which include about 60,000 time delay measurements from Kashima station alone. Because Japanese Islands are spread over four big plates, CRL's data are not sufficient to determine the Japanese fiducial reference frames on each plate. More investment is needed in order to keep several VLBI stations on each plate. This would contribute to VLBI observations for earth quake research.

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