Vol. 34 No. 141 *Journal of the Radio Research Laboratory* *March 1987*
Printed in Tokyo, Japan *pp. 1 – 14*

PACIFIC PLATE MOTION DETECTED BY THE VLBI EXPERIMENTS CONDUCTED IN 1984 – 1985

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(Received on August 8, 1986)

ABSTRACT

The relative motion of the Pacific plate with respect to Kashima, Japan was directly measured for the first time by using the very long baseline interferometer (VLBI). The Japan-US joint VLBI experiments were started in January 1984. By the end of 1985, eight experiments were conducted to detect the relative motion of the Pacific plate with respect to Japan. The baseline lengths between two of stations participating in experiments have been estimated with a formal error of less than 3cm in every experiment. The rates of change in these baseline lengths have also been estimated. Preliminary results show that the detected Pacific plate motion is close to the movement predicted from the plate motion model, i.e., the distance between Kashima and Kauai in the Hawaiian Islands is shortened by 6.9 ± 1.9 cm/year.

1. Introduction

Radio Research Laboratory (RRL) developed the VLBI system called K-3 which was designed so as to be compatible with the MARK-III VLBI system(1),(2),(3). It can be used not only for the precise geodesy but also for the radio astronomy. After the development, Kashima Space Research Center, RRL, has participated in the Crustal Dynamics Project (CDP) VLBI experiment conducted by National Aeronautics and Space Administration (NASA). A part of these experiment data was processed at Kashima and the rest was processed at Haystack Observatory. The data analysis such as baseline analysis has been performed by both Kashima and Goddard Space Flight Center (GSFC) group. Five or six stations participated in each experiment. The baseline lengths between two of these stations have been determined with a formal error of less than 3 cm for all experiments. The measurements made with such a high accuracy enable us to detect the plate motion supposed to be about 10 cm/year in one or two years. This paper reports the preliminary results of the detection of the Pacific plate motion by using the VLBI data.

2. Pacific VLBI Experiments

Table 1 shows the VLBI experiments which Kashima participated in by the end of 1985. In this table, WPAC, EPAC and NPAC denote the western, eastern and northern Pacific experiments, respectively. These are mainly scheduled to detect the Pacific plate

Table 1. Japan-US joint VLBI experiments conducted in 1984–1985.

EXPERIMENT	START (UT) YYMMDDHH	STOP (UT) YYMMDDHH	TAPES/ STATION	STATION
SLE-1	84 01 23 00	84 01 24 00	48	KAS-MOJ
SLE-2	84 02 24 18	84 02 25 18	34	KAS-MOJ-HAT
WPAC-1	84 07 28 09	84 07 30 14	66	KAS-MOJ-KWA-KAU-GIL
WPAC-2	84 08 04 06	84 08 06 14	66	KAS-MOJ-KWA-KAU-GIL
POLAR-1	84 08 30 06	84 08 31 12	30	KAS-MOJ-HAY-WET-GIL-ONS
POLAR-2	84 09 20 06	84 09 03 12	30	KAS-MOJ-HAY-WET-GIL-ONS
NPAC-1	85 05 15 20	85 05 16 20	30	KAS-MOJ-HAT-KAU-GIL-VAN
POLAR-1	85 06 19 20	85 06 21 02	30	KAS-MOJ-WST-WET-GIL-ONS
EPAC-1	85 07 06 06	85 07 08 00	49	KAS-MOJ-KWA-KAU-GIL-VAN
WPAC-1	85 07 20 18	85 07 22 12	50	KAS-MOJ-KWA-KAU-GIL-VAN
EPAC-2	85 07 27 18	85 07 29 12	49	KAS-MOJ-KWA-KAU-GIL-VAN
WPAC-2	85 08 10 06	85 08 12 00	52	KAS-MOJ-KWA-KAU-GIL-VAN
NPAC-2	85 09 30 00	85 10 01 00	30	KAS-MOJ-HAT-KAU-GIL-VAN
POLAR-2	85 11 21 20	85 11 23 02	30	KAS-MOJ-WST-WET-GIL-ONS

SLE: System Level Experiment
WPAC: Western Pacific Experiment
EPAC: Eastern Pacific Experiment
NPAC: Northern Pacific Experiment
POLAR: Polar Experiment
KAS: Kashima

MOJ: Mojave
HAT: Hatcreek
VAN: Vandenberg
KWA: Kwajalein
KAU: Kauai

GIL: Gilcreek
WST: Westford
HAY: Haystack
WET: Wettzell
ONS: Onsala

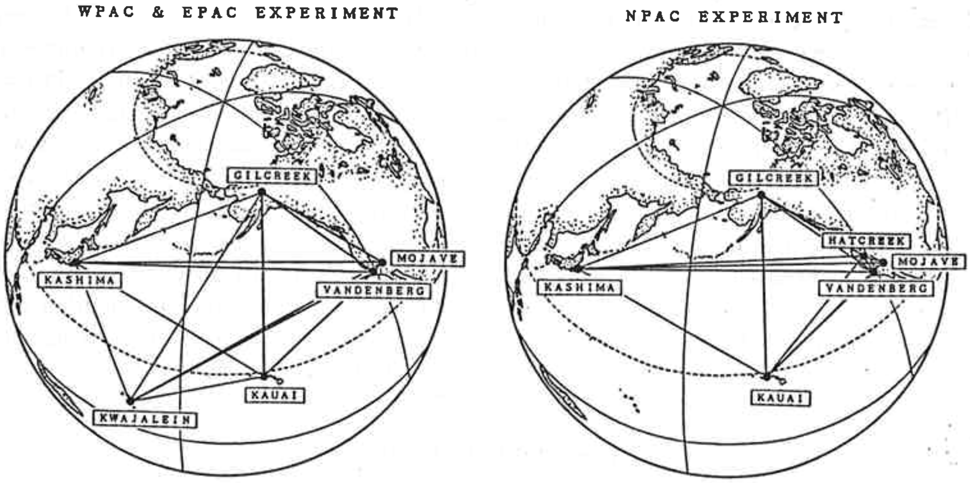


Fig. 1. Station positions and baseline configurations for WPAC, EPAC and NPAC experiments.

motion with respect to the North American plate. During 1984, five stations, such as Kashima, Mojave, Kwajalein, Kauai and Gilcreek, participated in these experiments. Hatcreek and Vandenberg stations joined in the experiments in 1985. The station positions and baseline configurations are shown in Figure 1.

The continuum radio waves radiated from the extragalactic sources (quasars) are received at each station. The dual (2 GHz and 8 GHz bands) frequencies are used for extracting the ionospheric delay in the case of geodetic use experiments. The tropospheric propagation delay is corrected by using the atmospheric model and the meteorological data. To determine the delay with a high accuracy, the system is calibrated by phase calibration signals injected at the front-end of receiver. Furthermore, the cable lengths are always monitored by a cable delay calibrator. A hydrogen maser frequency standard is used for all frequencies and timing signals to keep the coherence of receiving signals.

The integration times are 60–360 sec and they vary with the expected correlated flux of the radio source. In the Pacific experiments, observations are carried out continuously over one or two days by changing sources one after another. Therefore one experiment numbers about one hundred observations(4).

3. Data Processing and Analysis(5),(6)

The cross-correlation processing of two system level experiments (SLE), the latter half of WPAC-2 in 1984 and NPAC-1 in 1985 were carried out at Kashima. Delay time and delay rate that maximize the fringe amplitude were obtained from the cross-correlated data for each pair of stations. Other experiment data relating to Kashima were processed at Haystack Observatory.

Data analyses were performed by our analysis group and GSFC group independently. The weighted least-squares method is used for the analyses. In our analyses, the station positions except Mojave, clock parameters and the zenith path length of atmosphere for all stations are selected as the adjusted parameters. The International Radio Interferometric Surveying (IRIS) data (Carter et al., 1985)(7) are used for the earth orientation parameters (EOP). The IRIS data give the EOP of every 5 days without smoothing correction. Therefore, the instantaneous value of UT1 is calculated from the IRIS data as follows: first, the shorter period tidal terms with a period of less than 35 days in Yoder's table (Yoder et al., 1981)(8) are subtracted from the IRIS data. Then the interpolated value is calculated and the formerly subtracted terms are added. The radio source position provided by the National Geodetic Survey (NGS) are used in the analyses. The Marini model (Marini, 1972: J. W. Marini, unpublished manuscript, 1974: Davis et al., 1985)(9),(10) is used for the atmosphere model, which includes the effects of both dry and wet component. The excess path in magneto-ionic media (ionosphere and solar corona) is corrected by combining the delay observed in the dual frequency (2 GHz and 8 GHz band) data. The cable delay is also corrected by using the cable delay monitor data.

4. Expected Baseline Length Change

According to the plate tectonic model, the surface of the earth is covered with a number of pieces of plate and each plate is considered to move without internal deformation. The relative motion among these plates has been considered to cause various tectonic phenomena and big earthquakes. The instantaneous motion of each plate is expressed by using the Euler pole position and the rotation rate. These parameters can be derived from the ocean magnetic anomaly lineation, the slip vector direction of the earthquakes at plate boundaries and the azimuths of transform faults. In order to calculate the baseline length changing rate (BLCR) of the inter-plate baseline length, we used the AM1-2 model (Minster and Jordan, 1978)(11) (see Table 2). The BLCR relating to Kashima, Mojave, Kauai, Kwajalein,

Table 2. Absolute plate motion model (AM1-2).

	Absolute Rotation Vector		
PLATE	θ (°N)	ϕ (°E)	ω (deg/m.y.)
AFRC	18.76	−21.76	0.139
ANTA	21.85	75.55	0.054
ARAB	27.29	−3.94	0.388
CARB	−42.80	66.75	0.129
COCO	21.89	−115.71	1.422
EURA	0.70	−23.19	0.038
INDI	19.23	35.64	0.716
NAZC	47.99	−93.81	0.585
NOAM	−58.31	−40.67	0.247
PCFC	−61.66	97.19	0.967
SOAM	−82.28	75.67	0.285

(after Minster & Jordan, 1978)

Table 3. Observed and expected rate of baseline length change.

BASELINE	CHANGING RATE OF BASELINE LENGTHS (cm/year)		
	OBSERVED	EXPECTED	
		KASHIMA NOAM	KASHIMA EURA
KASHIMA – KAUAI	−6.9 ± 1.9	−7.7	−8.9
KASHIMA – MOJAVE	4.4 ± 1.8	0.0	−0.9
KASHIMA – KWAJALEIN	−9.0 ± 2.3	−8.5	−9.4
KASHIMA – GILCREEK	1.3 ± 1.6	0.0	−0.7
KAUAI – MAJAVE	2.6 ± 0.8	2.4	2.4
KAUAI – KWAJALEIN	0.0 ± 2.2	0.0	0.0
KAUAI – GILCREEK	−6.3 ± 1.8	−5.0	−5.0
MOJAVE – KWAJALEIN	3.2 ± 6.1	2.5	2.5
MOJAVE – GILCREEK	0.5 ± 1.1	0.0	0.0
KWAJALEIN – GILCREEK	−4.8 ± 4.7	−2.3	−2.3

(Data period: Jan. 23, 1984 – Aug. 10, 1985)

Vandenberg and Gilcreek are calculated (see Figure 2). In this calculation, the recent hypothesis to the effect that Kashima belongs to the North American plate (Kobayashi, 1983: Nakamura, 1983)(12),(13) is adopted (this hypothesis is quoted later as CASE-A). As seen in Figure 2 and Table 3 the BLCR exceeding 5 cm/year is expected for several baselines, such as Kashima-Kwajalein (−8.5 cm/year), Kashima-Kauai (−7.7 cm/year), Gilcreek-Vandenberg (−5.2 cm/year) and Gilcreek-Kauai (−5.0 cm/year). Seno (1985)(14) suggested that the north of Honsyu (Japan proper) might be a microplate behaving sometimes as a part of the Eurasian plate and at other times as a part of the North American plate. Therefore, we also calculate the BLCR on the assumption that Kashima belongs to the Eurasian plate (called CASE-B). However, as shown in Table 3, the discrepancy between two cases is only about 1 cm/year because the relative motion between the North American and the Eurasian plates is relatively small.

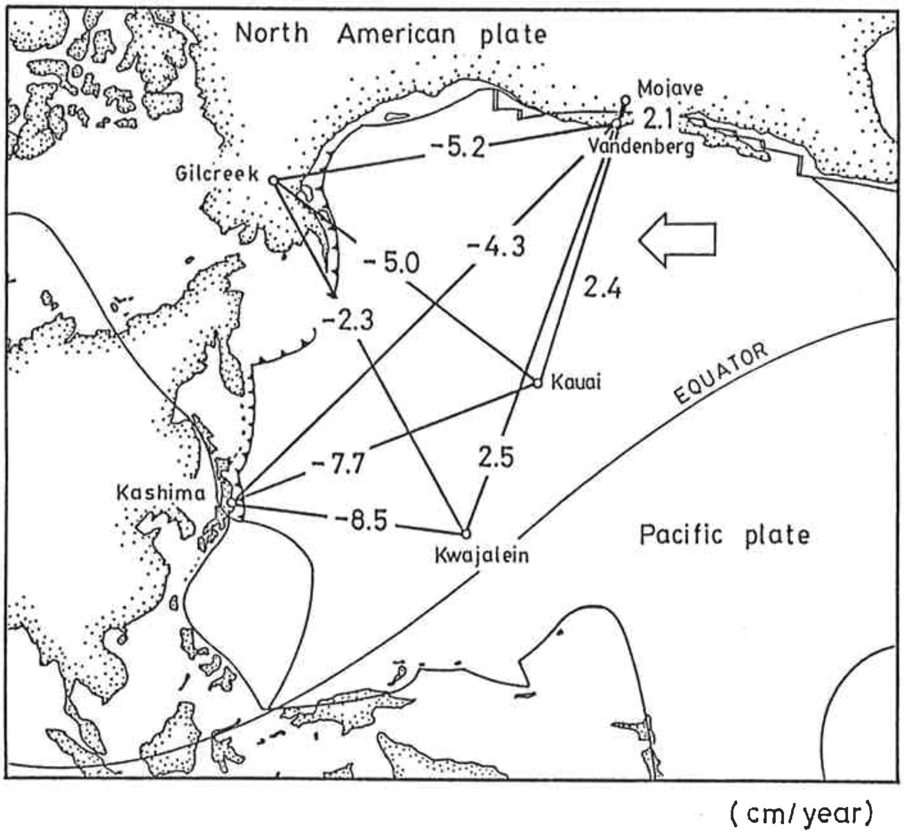


Fig. 2. Expected changing rates of the baseline lengths shown with the plate boundaries. The negative value means the shortening of length. Mercator's projection with the pole at the relative rotation pole of the Pacific plate and North American plate is used. The direction of the movement of the Pacific plate is represented as the linear leftward motion when viewed from the North American plate (large arrow).

5. Results and Discussions

In Figure 3, the baseline lengths of Kashima-Mojave estimated in 1984 are compared between Kashima and GSFC group analyses (Ryan and Ma, 1985)(15). Results of both analyses are well coincident with each other and we may use the results of either of the two analyses in estimating the BLCR. From Figure 4 to Figure 13 the baseline length evolution obtained from our analyses is shown for 10 baselines connecting two of five stations, i.e., Kashima, Mojave, Kauai, Kwajalein and Gilcreek. The weighted best fit slopes are also drawn by solid line in the figures. Derived BLCR's are summarized in Table 3

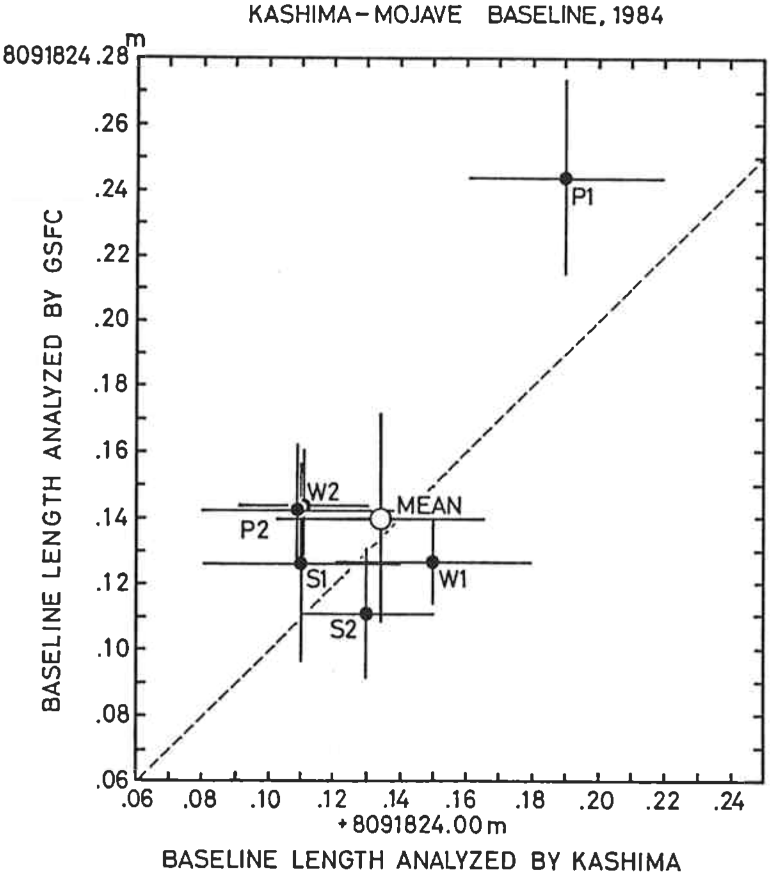


Fig. 3. Observed length of Kashima-Mojave baseline in 1984. The abscissa and ordinate represent the Kashima and GSFC group results, respectively.

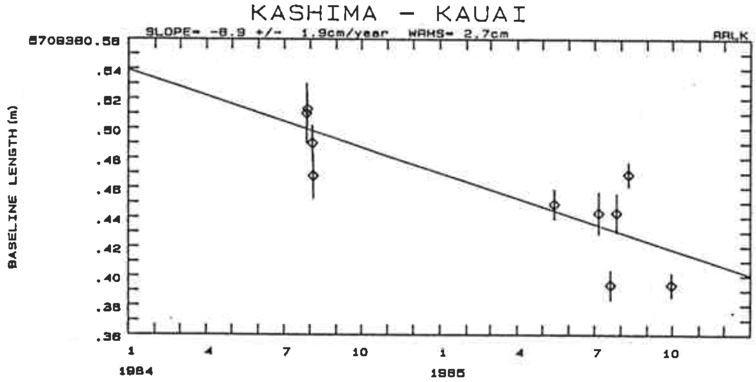


Fig. 4. Baseline length evolution of Kashima-Kauai baseline in the period 1984–1985.

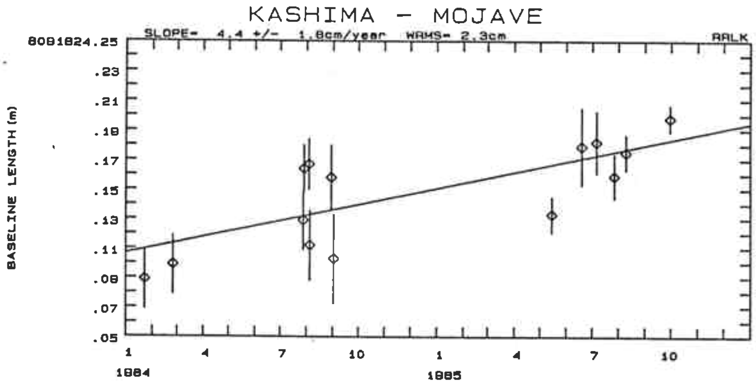


Fig. 5. Kashima-Mojave baseline.

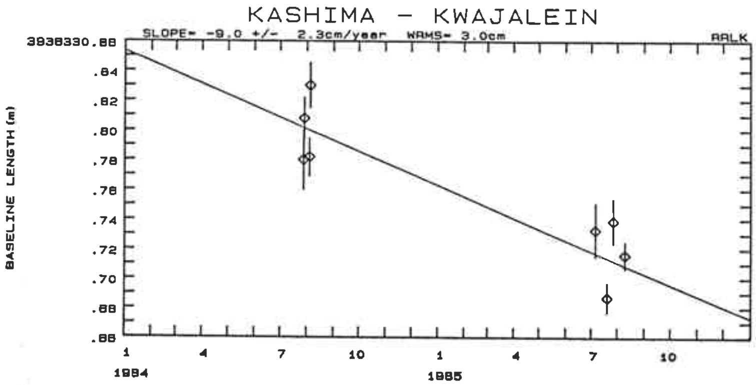


Fig. 6. Kashima-Kwajalein baseline.

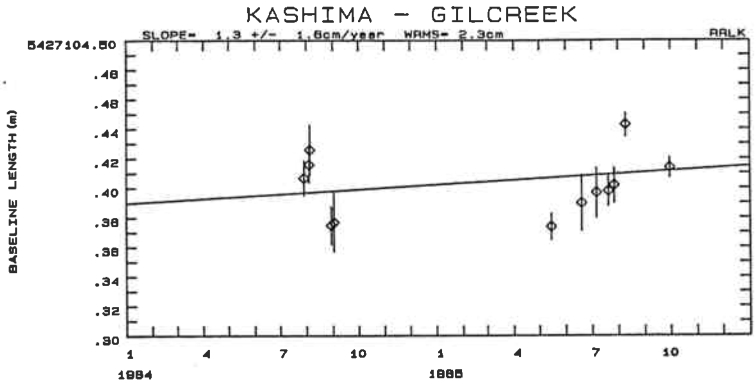


Fig. 7. Kashima-Gilcreek baseline.

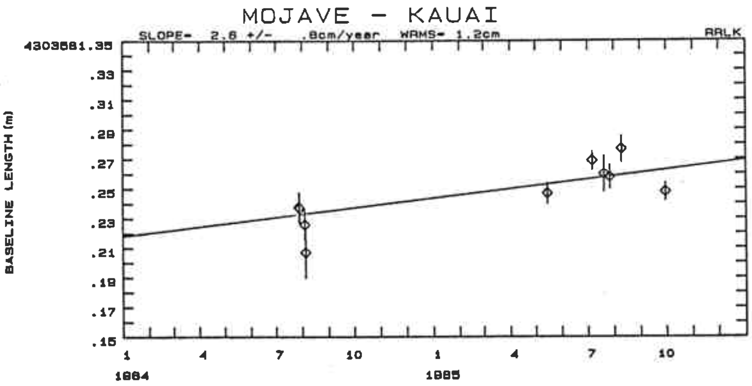


Fig. 8. Mojave-Kauai baseline.

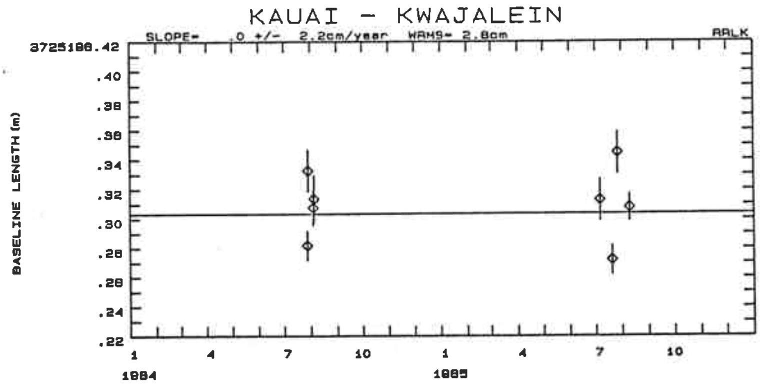


Fig. 9. Kauai-Kwajalein baseline.

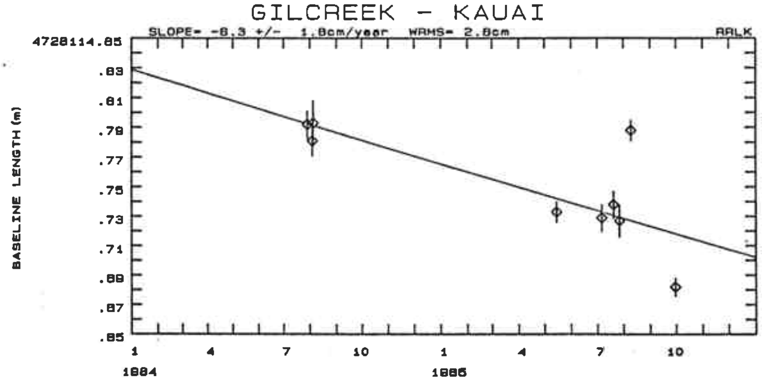


Fig. 10. Gilcreek-Kauai baseline.

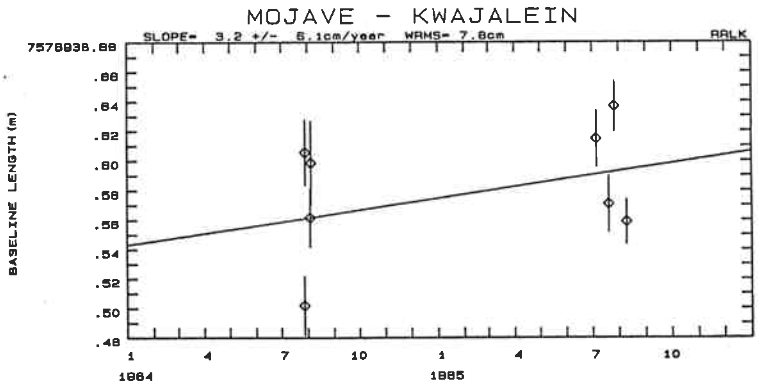


Fig. 11. Mojave-Kwajalein baseline.

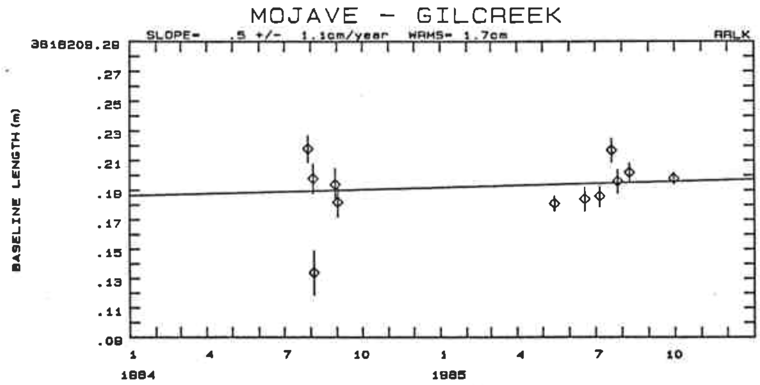


Fig. 12. Mojave-Gilcreek baseline.

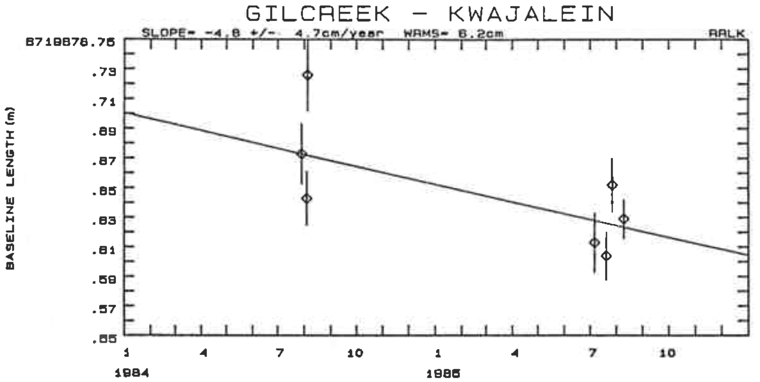
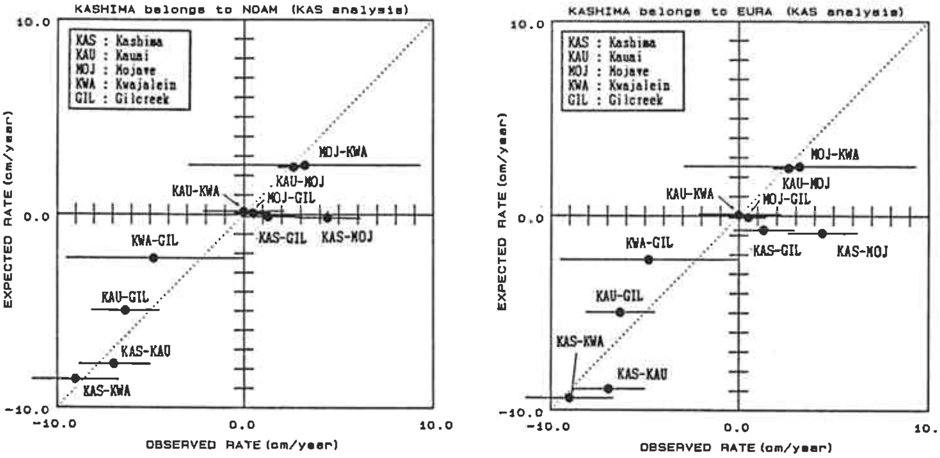


Fig. 13. Gilcreek-Kwajalein baseline.

with the expected rates of two cases (CASE-A,B). Figure 14 shows the observed BLCR as the its function of expected value for two cases as described in Table 3. Formal errors of expected value are so small that they are hidden by the dots in this figure. If the expected value and observed value are consistent, the data are considered to be aligned on the dotted line in the figures. Its correlation coefficent reaches a value up to 0.93 for CASE-A and a



(a). Kashima belongs to the North American plate (CASE-A)

(b). Kashima belongs to the Eurasian plate (CASE-B)

Fig. 14. The change of baseline length in two cases of expected rate. Observed rates are displayed as the function of expected rates.

value up to 0.90 for CASE-B. We have also calculated the rotation pole and rotating rate of the Pacific plate by using the observed results of the rates of change in baseline lengths and they were compared with the model given in Table 2. The weighted least-squares estimation method was used in the estimation. In this estimation only the parameters describing the Pacific plate motion are selected as the adjusted parameters, i.e., Minster and Jordan's AM1-2 model is used for the plate motion parameters of the North American and the Eurasian plates. We can get the pole position and rotating speed of the Pacific plate as the values making the weighted sum of residual square minimum, where it is defined as $\Sigma\{(O - C)/\sigma\}^2$, where O, σ and C denote the observed rate of baseline length change, its formal error and the theoretical changing rate calculated from the model, respectively. The results are summarized in Table 4. In Figure 15, an obtained pole and its one sigma error region of the Pacific plate in the case where Kashima is located on the North American plate (CASE-A) are shown with the baseline configurations. The rotation pole given by the AM1-2 model is also displayed. In this figure, the definition of the pole position which is antipodal to that of the AM1-2 model is adopted for the sake of visual convenience. The pole and one sigma region for CASE-B are not shown in the figure because they are so close to the result obtained in CASE-A. By both the table and the figure it is clear that almost the same pole positions are obtained between two cases (CASE-A,B) and these are also very close to the position given in the AM1-2 model. The rotating rate of model and the estimated rates of CASE-A and CASE-B are not significantly different, i.e., 0.967 ± 0.085, 1.026 ± 0.188 and 0.954 ± 0.189, respectively, where the unit is a degree/My (My: a million year). At present, it is impossible to distinguish which case (CASE-A or B) explains better the observed results. A large number of data are required to solve this question. As summarized in Table 3, the difference between two cases on the BLCR is only about 1 cm/year. Therefore, when the accuracy of 3 cm is supposed, the data extending over at least three years will be required.

Table 4. Obtained plate motion parameters of Pacific plate.

MODEL	Estimated Rotation Vector			$\Sigma\{(O - C)/\sigma\}^2$
	θ (°N)	ϕ (°E)	ω (deg/m.y.)	
AM1–2	–61.66 ± 5.11	97.19 ± 7.71	0.967 ± 0.085	0.0
KASHIMA NOAM	–60.12 ± 4.73	89.9 ± 48.2	1.026 ± 0.188	7.8
KASHIMA EURA	–61.48 ± 5.19	89.3 ± 54.0	0.954 ± 0.189	8.5

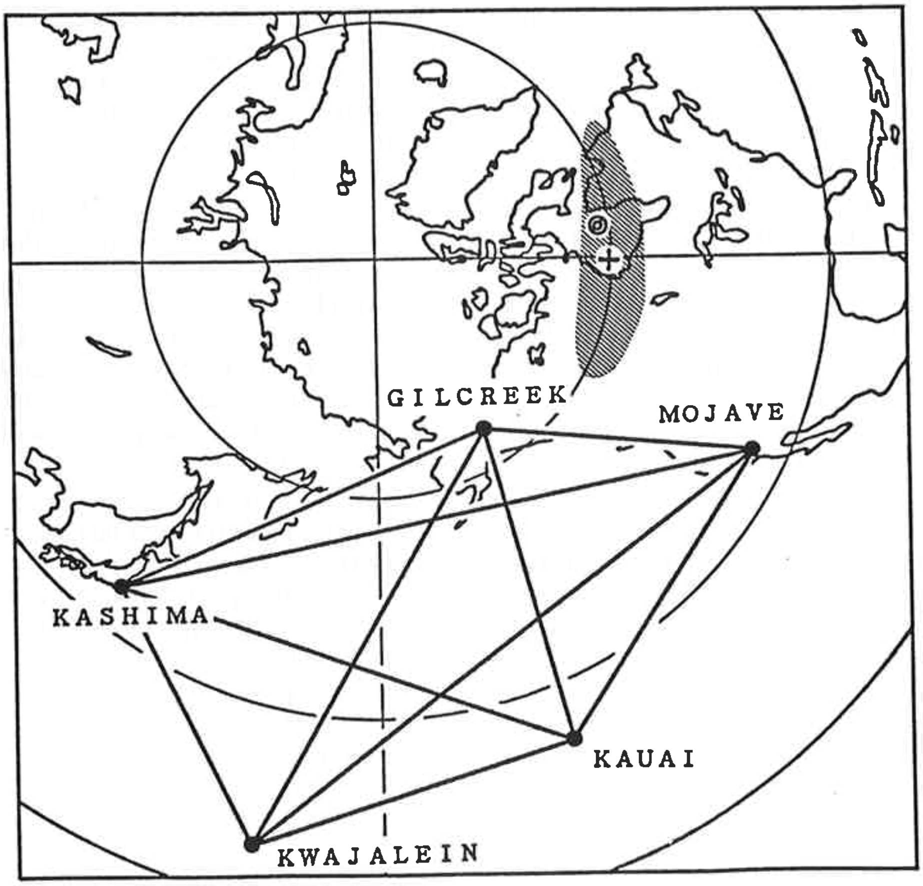


Fig. 15. An obtained rotation pole and its one sigma error region of the Pacific plate with the baseline configurations in the case of Kashima being on the North American plate (CASE-A). The estimated pole position is denoted by a symbol "+" and a shaded area shows a one sigma formal error region. The pole given by the AM1-2 model is also denoted by a symbol "◎". Note that the definition of pole position is antipodal to the AM1-2 model in order to show the pole positions and baseline configurations on the same map.

6. Conclusion

The results of baseline length analyses have been described. The motion of Pacific plate to Japan was directly detected by using the data obtained by the VLBI experiments which cover only two years. The obtained rates of change in the baseline lengths were consistent with the Minster and Jordan's (1978) model. However, the data with wider spatial and temporal coverage are required to discuss the whole aspects of the plate motion more in detail.

Acknowledgement

The authors would like to express their sincere appreciation to NASA/GSFC, Haystack Observatory and NGS staff members for the close cooperation and the supply of the data. They also thank Nobuyuki KAWANO, Noriyuki KAWAGUCHI, Taizo YOSHINO, Yuji SUGIMOTO, Hiroshi KUROIWA, Shin-ichi HAMA, Hiroo KUNIMORI, Noriyuki KURIHARA, Jun AMAGAI, Hitoshi KIUCHI, Akihiro KANEKO, Munetoshi TOKUMARU, Kunimasa KOIKE, Hidetoshi MURAKAMI, Tadashi SHIOMI, and Fujinobu TAKAHASHI for the development of and the continuous improvements in the system.

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