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

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The relative motion of the Pacific plate 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 from January 1984. By the end of 1985, eight experiments were conducted to detect the relative motion of the Pacific plate to Japan. The baseline lengths between stations have been estimated with a formal error of less than 3cm in every experiment. The changing rate of these has also been estimated. Preliminary results show that the Pacific plate motion close to the movement predicted from the plate tectonic model is detected, i.e., the distance between Kashima and Kauai, Hawaii is shortened by 5.3cm a year.

1. INTRODUCTION

Radio Research Laboratory (RRL) developed the VLBI system called K-3 which was designed to be compatible with the MARK-III VLBI system. 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 the National Aeronoutics and Space Administration (NASA). A part of these experiment data was processed at Kashima and the rest was at Haystack Observatory. 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. Baseline lengths between these stations have been determined with a formal error of less than 3cm for all experiments. This high accuracy measurements enable us to detect the plate motion supposed to be about 10cm/year in one or two years. This paper reports a preliminary result with respect to the detection of the Pacific plate motion by using the VLBI data.

2. PACIFIC VLBI EXPERIMENTS

Table 1 shows the VLBI experiments where Kashima participated 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 motion to the North American plate. During 1984, five stations, which are Kashima, Mojave, Kwajalein, Kauai and Gilcreek, participated in the Pacific experiments. Hatcreek and Vandenberg stations joined the experiments in 1985. The station positions and baseline configurations are shown in Figure 1.

Continuum radio waves radiated from the extragalactic sources (quasars) are received at each station. Dual (2GHz and 8GHz bands) frequencies are used for extraction of the ionospheric delay in the case of geodetic use experiment. Tropospheric propagation delay is corrected from the meteorological data. To determine the delay with high accuracy, the system is calibrated by phase calibration signals injected at the front-end of receiver. Furthermore, 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 period of observation is 60 - 360sec and it depends on the expected correlated flux of radio source. In the Pacific experiment, observations are continued for one or two days with changing the source one after another. Therefore an experiment includes several hundreds of observations.

3. DATA PROCESSING AND ANALYSIS

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 both by our analysis group and by GSFC group independently. The weighted least squares method is used for the analyses. In our analyses, the station positions except for Mojave, clock parameters and the zenith path length of atmosphere for all stations are selected as the adjustment parameters. The International Radio Interferometric Surveying (IRIS) data 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: at first, shorter period tidal terms with period less than 35 days in Yoder's table (Yoder et al., 1981) are subtracted from the IRIS data. Then interpolated value is calculated and formerly subtracted terms are added at last. The radio source position provided by the National Geodetic Survey (NGS) are used in the analyses. The Marini model (Marini, 1972) 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 dual frequency (2GHz and 8GHz 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 earth is covered with a number of pieces of plate and each plate moves without internal deformation. The relative motion among these plates has been considered to cause a various tectonic phenomena and big earthquakes. The motion of each plate is conveniently described by using the Euler pole and rotation rate. These parameters can be derived from the ocean magnetic anomaly lineation, the direction of slip vector of the earthquakes and the azimuth of transform faults. In order to calculate the changing rate of the inter-plate baseline length, we used the model obtained by Minster and Jordan, 1978 (see Table 2). The deviation of the station position caused by the plate motion can be calculated from this plate motion model, so that we can get the changing rate of baseline length. The changing rate for baselines relating to Kashima, Mojave, Kauai, Kwajalein, Vandenberg and Gilcreek are calculated (see Figure 2). In this calculation, the recent hypothesis that Kashima belongs to the North American plate (Kobayashi, 1983: Nakamura, 1983: Seno, 1985) is adopted (this hypothesis is quoted as CASE-A in later). As seen in Figure 2 the baseline length change exceeding 5cm a year is expected for several baselines, such as Kashima-Kwajalein (-8.5cm/year), Kashima-Kauai (-7.7cm/year), Gilcreek-Vandenberg (-5.2cm/year) and Gilcreek-Kauai (-5.0cm/year). We also calculate the baseline length changing rate in the case that Kashima belongs to the Eurasian plate (we call this CASE-B). However, as shown in Table 3, the descrepancy between two cases is only about 1cm/year, because the relative motion between the North American and the Eurasian plates is quite small.

5. RESULTS

In Figure 3, the estimated baseline lengths of Kashima-Mojave in 1984 are compared between Kashima and GSFC group analyses (Ryan and Ma, 1985). Because good coincidence was obtained between both group results, it can be considered that there is no effect in estimating the rate of baseline length change whether our results are used or GSFC group's are used. Therefore we adopted the both group results to calculate the changing rate. In Figure 4 an example of the baseline length evolution is displayed for Kashima-Kauai baseline. The weighted best fit slope is also drawn by straight line in the figure. This procedure is carried out for all 10 baselines among 5 stations, i.e., Kashima, Mojave, Kauai, Kwajalein and Gilcreek. Derived baseline changing rate is summarized in Table 3 with the expected rate of two cases (CASE-A,B). Figure 5 shows the observed changing rate of baseline lengths as the function of expected value of it for two cases as described in Table 3 (a left panel is for CASE-A and a right is for CASE-B). If the plate moves like a model given in Table 2, the observed changes of baseline lengths should be aligned on the dotted line in the figures. Actually good correlation between the expected value and the observed one can be seen for both cases. Its correlation coefficent reaches up to 0.93 for CASE-A and 0.92 for CASE-B. Furthermore in order to estimate the rotation pole and its speed of plate by using the method of least squares, we have calculated the weighted sum of residual square, $\Sigma\{(O-C)/\sigma\}^2$, where O, σ and C denote the observed rate of baseline lenghth change, its formal error and the rate calculated from the plate motion model of trial pole position and rotation speed, respectively. In our calculation the parameters of plate motion except for the Pacific plate are fixed to the model given in Table 2. Only the parameters of Pacific plate are searched, and it can be estimated as the parameters that make the weighted sum minimum. Figure 6 shows the results of this calculation for CASE-A. An upper panel shows the result with respect to the pole position and a lower panel is for the rotation speed. The same procedure has been carried out for CASE-B. The results are summarized in Table 4. The angle distance of about 20deg. can be seen between the estimated pole position and the that of Minster and Jordan's model, but the rotation rate of model and the estimated rates of CASE-A and B are almost same, i.e., 0.967, 0.970 and 0.951, respectively, where unit is a degree/million years. At present, it is impossible to distinguish which case (CASE-A or B) is better to explain the observed results from these results. To make this porblem clear, it is neccessary to continue the VLBI experiment for a long time.

6. CONCLUSION

The results of baseline length analyses have been described. As described above, the motion of Pacific plate was directly detected by using the data obtained by the VLBI experiments for only two years. However much data are required to discuss the whole aspects of the plate motion. Therefore it is very important to continue the high accuracy measurements using the VLBI technique for a long time.

ACKNOWLEDGEMENT

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Table 1. Japan-US joint VLBI experimens in 1984-1985.

JAPAN-US JOINT VLBI EXPERIMENT
(1984.1 - 1985.12)

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
NPAC-1	85051520	85051620	30	KAS-MOJ-HAT-KAU-GIL-VAN
POLAR-1	85061920	85062102	30	KAS-MOJ-WST-WET-GIL-ONS
EPAC-1	85070606	85070800	49	KAS-MOJ-KWA-KAU-GIL-VAN
WPAC-1	85072018	85072212	50	KAS-MOJ-KWA-KAU-GIL-VAN
EPAC-2	85072718	85072912	49	KAS-MOJ-KWA-KAU-GIL-VAN
WPAC-2	85081006	85081200	52	KAS-MOJ-KWA-KAU-GIL-VAN
NPAC-2	85093000	85100100	30	KAS-MOJ-HAT-KAU-GIL-VAN
POLAR-2	85112120	85112302	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

Table 2. Plate motion model.

PLATE MOTION MODEL

PLATE	Absolute Rotation Vector 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.

CHANGING RATE OF BASELINE LENGTHS

BASELINE			CHANGING RATE OF BASELINE LENGTHS (cm/year)		
			OBSERVED	EXPECTED	
				KASHIMA∈NOAM	KASHIMA∈EURA
KASHIMA	–	KAUAI	−5.3±2.0	−7.7	−8.9
KASHIMA	–	MOJAVE	2.2±2.5	0.0	−0.9
KASHIMA	–	KWAJALEIN	−6.9±2.5	−8.5	−9.4
KASHIMA	–	GILCREEK	0.7±1.5	0.0	−0.7
KAUAI	–	MOJAVE	5.0±1.1	2.4	2.4
KAUAI	–	KWAJALEIN	−0.8±2.1	0.0	0.0
KAUAI	–	GILCREEK	−2.4±1.2	−5.0	−5.0
MOJAVE	–	KWAJALEIN	1.5±5.8	2.5	2.5
MOJAVE	–	GILCREEK	−0.2±0.6	0.0	0.0
KWAJALEIN	–	GILCREEK	−2.4±4.6	−2.3	−2.3

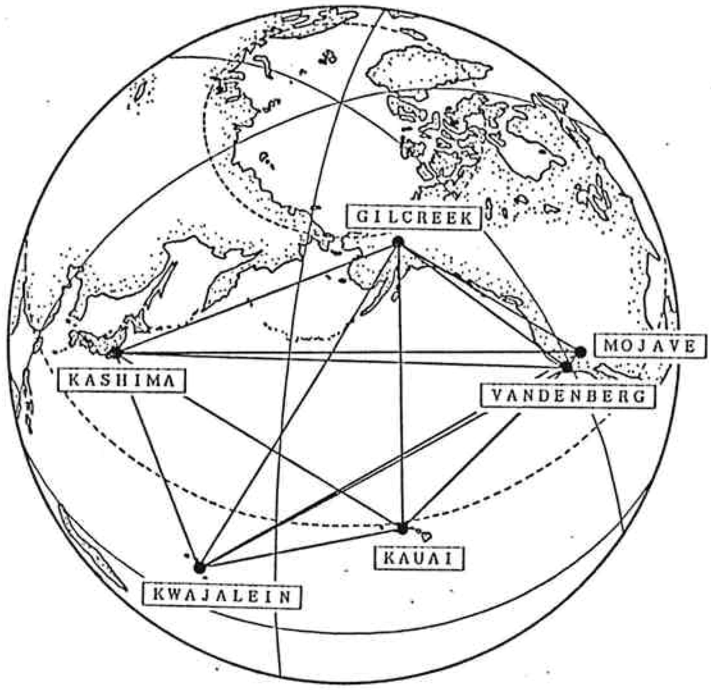
(Data period : Jan. 23, 1984 - Aug. 10, 1985)

Table 4. Obtained plate motion parameters of Pacific plate.

OBSERVED PLATE MOTION PARAMETERS OF PACIFIC PLATE

MODEL	Estimated Rotation Vector			
	θ (°N)	ϕ (°E)	ω (deg/m.y.)	$\Sigma\{(O-C)/\sigma\}^2$
Minster & Jordan	−61.66	97.19	0.967	0.0
KASHIMA∈NOAM	−75.2	59.1	0.970	2.7
KASHIMA∈EURA	−72.5	42.3	0.951	5.2

WPAC & EPAC EXPERIMENT



NPAC EXPERIMENT

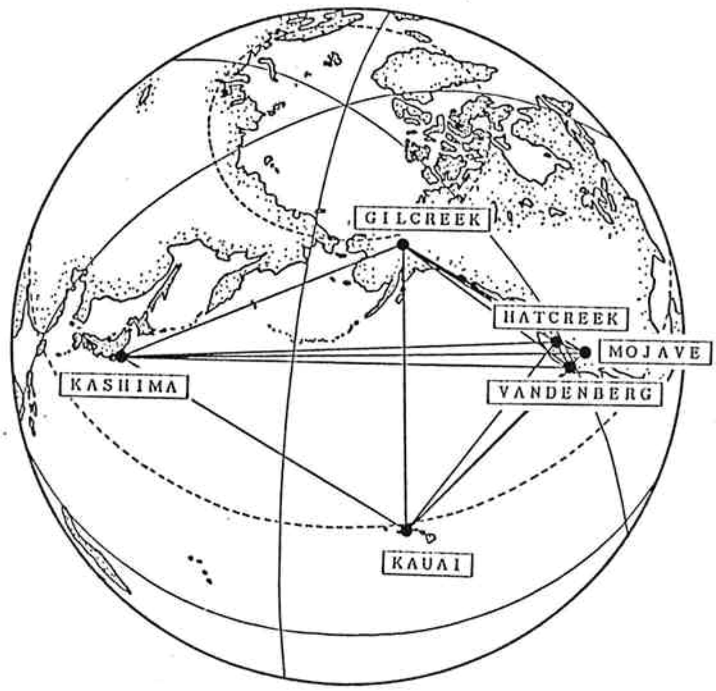


Figure 1. Station positions and baseline configurations for WPAC, EPAC and NPAC experiments.

EXPECTED RATES OF BASELINE LENGTH CHANGE

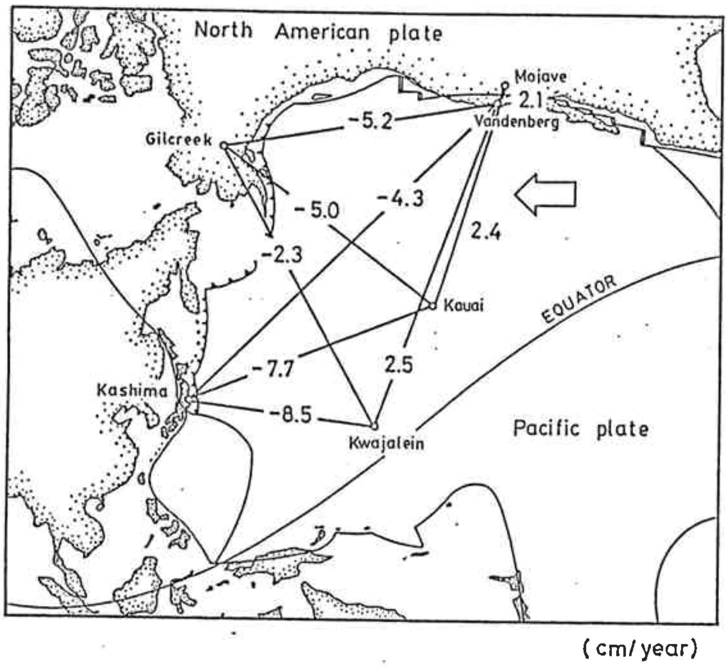


Figure 2. Expected changing rate of baseline length. The negative value means the shortening of length.

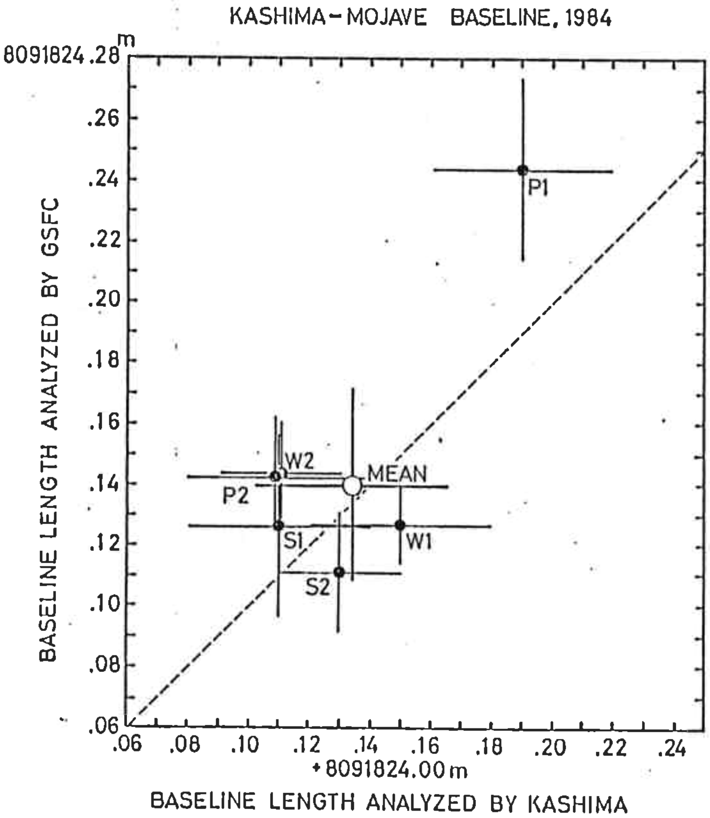


Figure 3. Observed length of Kashima-Mojave baseline in 1984. The abscissa and ordinate represent the Kashima and GSFC group results, respectively.

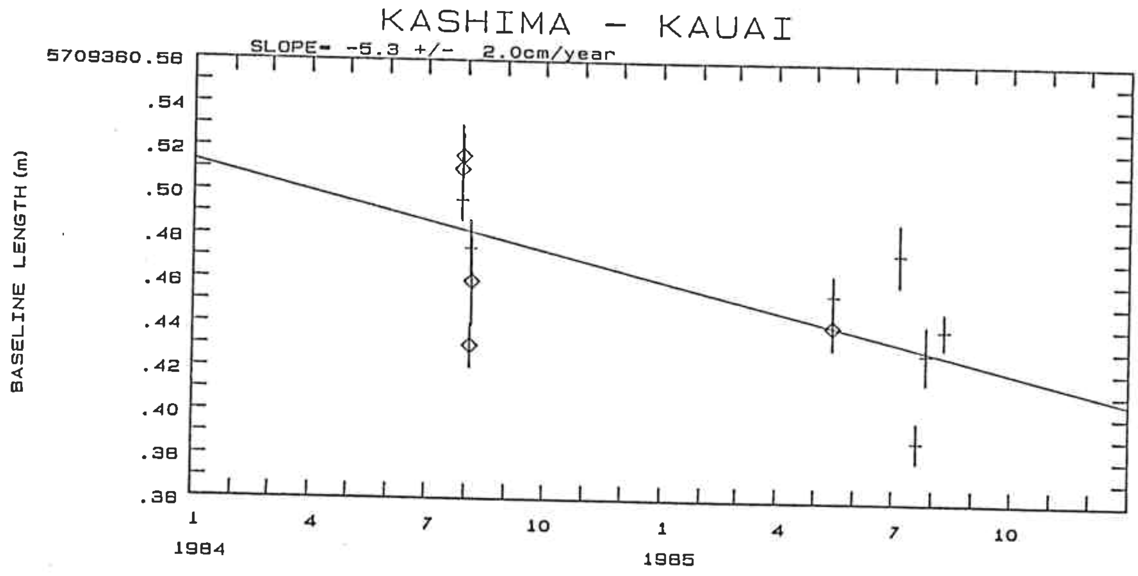


Figure 4. Baseline length evolution of Kashima-Kauai baseline.

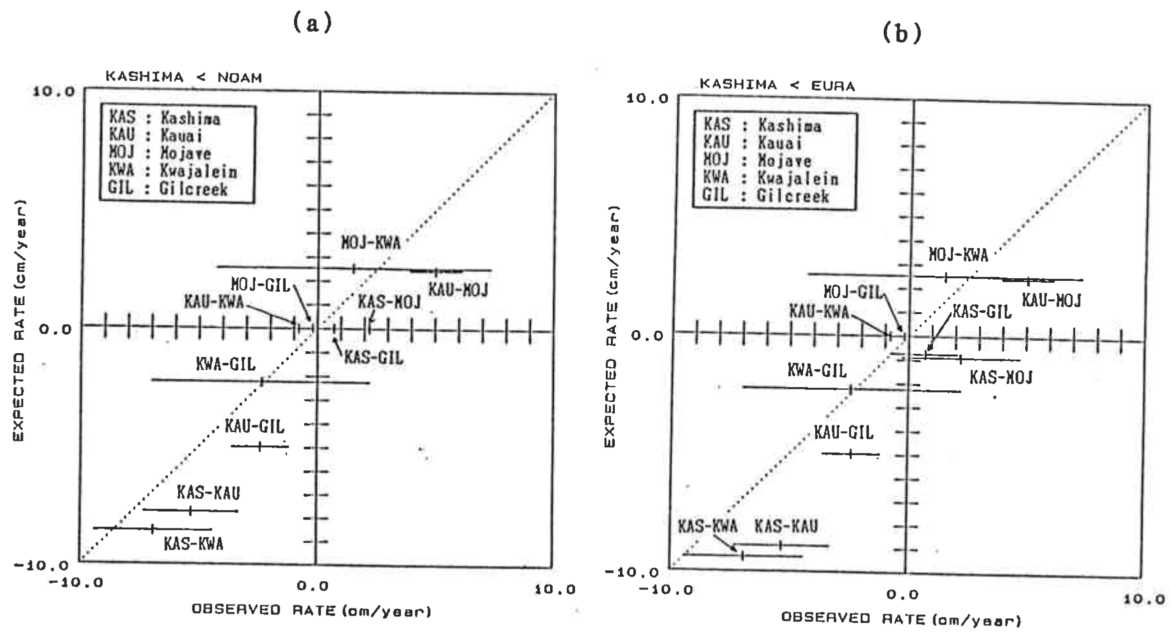
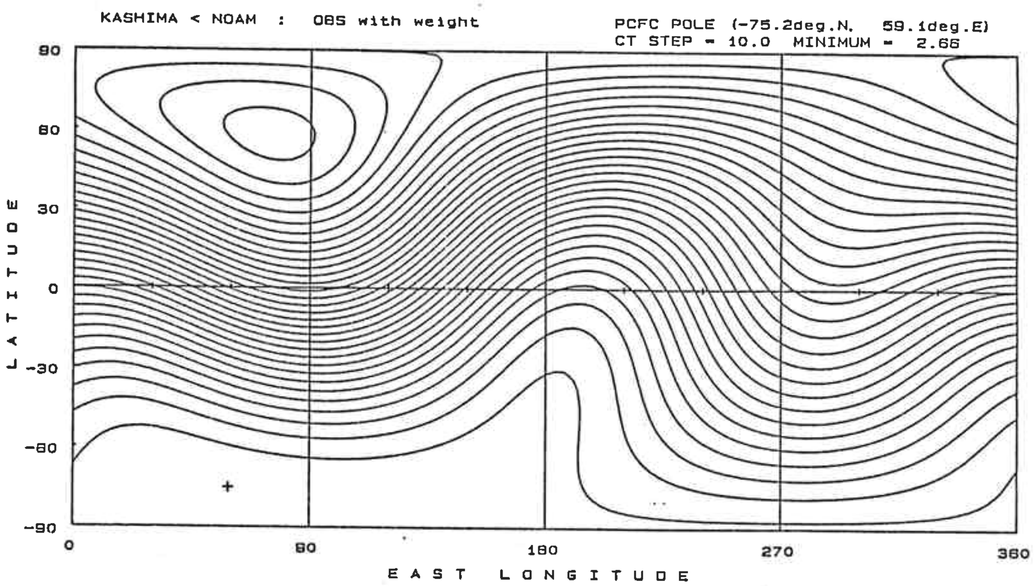


Figure 5. The change of baseline length for two cases of expected rate. Observed rates are displayed as the function of expected rates.
(a). Kashima belongs to the North American plate (CASE-A)
(b). Kashima belongs to the Eurasian plate (CASE-B)

(a)



(b)

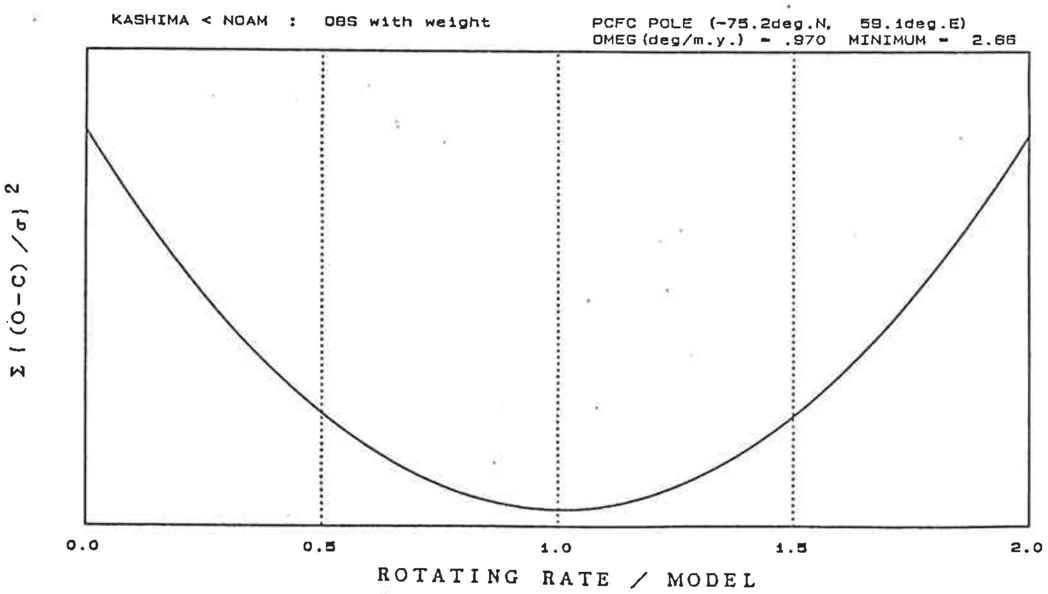


Figure 6. The result of weighted least squares estimation for the parameters of Pacific plate motion in the case that Kashima belongs to the North American plate.
(a). Rotation pole estimation. Estimated pole (-75.2deg.N, 59.1deg.E) denoted by symbol '+' is obtained as the position satisfying the least squares condition.
(b). Rotating rate estimation. The rate of 0.970deg/m.y. is also obtained.