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

By
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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 3 cm 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 sup-
posed 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>
<thead>
<tr>
<th>EXPERIMENT</th>
<th>START (UT) YYMMDHH</th>
<th>STOP (UT) YYMMDHH</th>
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<th>STATION</th>
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<td>84 01 24 00</td>
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<td>84 02 25 18</td>
<td>34</td>
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<tr>
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<td>84 08 31 12</td>
<td>30</td>
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<tr>
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<tr>
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<td>85 06 21 02</td>
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<tr>
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<td>85 07 08 00</td>
<td>49</td>
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<td>EPAC-2</td>
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<tr>
<td>NPAC-2</td>
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<td>85 10 01 00</td>
<td>30</td>
<td>KAS-MOJ-HAT-KAU-GIL-VAN</td>
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<tr>
<td>POLAR-2</td>
<td>85 11 21 20</td>
<td>85 11 23 02</td>
<td>30</td>
<td>KAS-MOJ-WST-WET-GIL-ONS</td>
</tr>
</tbody>
</table>

SLE: System Level Experiment  MOJ: Mojave  GIL: Gilcrest
WPAC: Western Pacific Experiment  HAT: Hatcreek  WST: Westford
EPAC: Eastern Pacific Experiment  VAN: Vandenberg  HAY: Haystack
NPAC: Northern Pacific Experiment  KWA: Kwajalein  WET: Wettzell
POLAR: Polar Experiment  KAU: Kauai  ONS: Onsala
KAS: Kashiima

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.
Hatch Creek 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. There-
fore, 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).

<table>
<thead>
<tr>
<th>PLATE</th>
<th>(\theta) ((^{\circ})N)</th>
<th>(\phi) ((^{\circ})E)</th>
<th>(\omega) (deg/m.y.)</th>
</tr>
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<tbody>
<tr>
<td>AFRC</td>
<td>18.76</td>
<td>-21.76</td>
<td>0.139</td>
</tr>
<tr>
<td>ANTA</td>
<td>21.85</td>
<td>75.55</td>
<td>0.054</td>
</tr>
<tr>
<td>ARAB</td>
<td>27.29</td>
<td>-3.94</td>
<td>0.388</td>
</tr>
<tr>
<td>CARB</td>
<td>-42.80</td>
<td>66.75</td>
<td>0.129</td>
</tr>
<tr>
<td>COCO</td>
<td>21.89</td>
<td>-115.71</td>
<td>1.422</td>
</tr>
<tr>
<td>EURA</td>
<td>0.70</td>
<td>-23.19</td>
<td>0.038</td>
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<tr>
<td>INDI</td>
<td>19.23</td>
<td>35.64</td>
<td>0.716</td>
</tr>
<tr>
<td>NAZC</td>
<td>47.99</td>
<td>-93.81</td>
<td>0.585</td>
</tr>
<tr>
<td>NOAM</td>
<td>-58.31</td>
<td>-40.67</td>
<td>0.247</td>
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<tr>
<td>PCFC</td>
<td>-61.66</td>
<td>97.19</td>
<td>0.967</td>
</tr>
<tr>
<td>SOAM</td>
<td>-82.28</td>
<td>75.67</td>
<td>0.285</td>
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</table>

(after Minster & Jordan, 1978)

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

<table>
<thead>
<tr>
<th>BASELINE</th>
<th>OBSERVED</th>
<th>EXPECTED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CHANGEING RATE OF BASELINE LENGTHS (cm/year)</td>
<td>KASHIMA NOAM</td>
</tr>
<tr>
<td>KASHIMA - KAUAI</td>
<td>-6.9 \pm 1.9</td>
<td>-7.7</td>
</tr>
<tr>
<td>KASHIMA - MOJAVE</td>
<td>4.4 \pm 1.8</td>
<td>0.0</td>
</tr>
<tr>
<td>KASHIMA - KWAJALEIN</td>
<td>-9.0 \pm 2.3</td>
<td>-8.5</td>
</tr>
<tr>
<td>KASHIMA - GILCREEK</td>
<td>1.3 \pm 1.6</td>
<td>0.0</td>
</tr>
<tr>
<td>KAUAI - MAJAVE</td>
<td>2.6 \pm 0.8</td>
<td>2.4</td>
</tr>
<tr>
<td>KAUAI - KWAJALEIN</td>
<td>0.0 \pm 2.2</td>
<td>0.0</td>
</tr>
<tr>
<td>KAUAI - GILCREEK</td>
<td>-6.3 \pm 1.8</td>
<td>-5.0</td>
</tr>
<tr>
<td>MOJAVE - KWAJALEIN</td>
<td>3.2 \pm 6.1</td>
<td>2.5</td>
</tr>
<tr>
<td>MOJAVE - GILCREEK</td>
<td>0.5 \pm 1.1</td>
<td>0.0</td>
</tr>
<tr>
<td>KWAJALEIN - GILCREEK</td>
<td>-4.8 \pm 4.7</td>
<td>-2.3</td>
</tr>
</tbody>
</table>

(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

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

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. 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.
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 coefficient 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 $\sum [(O - C)/\sigma]^2$, where O, $\sigma$ 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., $0.967 \pm 0.085, 1.026 \pm 0.188$ and $0.954 \pm 0.189$, respectively, where the unit is a degree/M.y. (M.y: 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.

<table>
<thead>
<tr>
<th>MODEL</th>
<th>Estimated Rotation Vector</th>
<th>$\Sigma [(O - C)/\sigma]^2$</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>$\theta$ (°N)</td>
<td>$\phi$ (°E)</td>
</tr>
<tr>
<td>AM1-2</td>
<td>$-61.66 \pm 5.11$</td>
<td>$97.19 \pm 7.71$</td>
</tr>
<tr>
<td>KASHIMA NOAM</td>
<td>$-60.12 \pm 4.73$</td>
<td>$89.9 \pm 48.2$</td>
</tr>
<tr>
<td>KASHIMA EURA</td>
<td>$-61.48 \pm 5.19$</td>
<td>$89.3 \pm 54.0$</td>
</tr>
</tbody>
</table>
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

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References


