7.2 ROUTINE OBSERVATION RESULTS OF THE KSP VLBI NETWORK

Masato FURUYA, Koichi SEBATA, Yasuhiro KOYAMA, and Tetsuro KONDO

Abstract

Using the KSP VLBI network, we are routinely monitoring a crustal deformation around the south Kanto area. Though all the stations lie in the same plate, we were able to observe a significant crustal deformation. In particular, the two baseline lengths, Koganei–Miura and Koganei–Tateyama, show a significant decrease: –12 mm/yr and –16 mm/yr, respectively. Moreover, the strain analysis of the triangle formed by Koganei, Kashima, and Tateyama indicate a compression whose principal strain rate is 0.17×10^{-6}/yr along the axis mostly in a north-south direction.

Key words: VLBI, intraplate deformation, strain.

Running Title: Results of the Routine Observation in the KSP VLBI Network

1 Introduction

Plate tectonics theory claims that the Earth's surface can be divided into several 'rigid' plates, and that each plate does not deform during the plate's motion. Although it was originally derived from paleomagnetism in combination with isotope geochronology, the contemporary plate motion has been measured with space geodetic techniques such as Very Long Baseline Interferometry (VLBI) and Satellite Laser Ranging (SLR) over the past decade. These results were found to be largely consistent with the model of plate tectonics(1). However, around plate boundary zones such as those in the Japanese archipelago, sparsely distributed geodetic observation sites have hampered a precise crustal deformation measurement, where significant deviation from rigid plate behavior is expected.

In 1993, the Communications Research Laboratory (CRL) began the Key Stone Project (KSP), which measures crustal deformation around the Tokyo metropolitan area at four stations, using three space geodetic techniques, VLBI, SLR, and the Global Positioning System (GPS). The south Kanto plain has historically suffered from a number of disastrous earthquakes, owing to its proximity to plate boundaries. The ultimate goal of the KSP is to detect a possible precursory signal which may appear in crustal motion prior to a large earthquake such as the disastrous 1923 Kanto earthquake. To this end, we need to monitor the crustal activity with sufficient precision and accuracy, and thus a great deal of effort has been made on improving the system reliability, as discussed in a number of papers in this issue. The purpose of this paper is to describe the results from the routine KSP VLBI observation.

2 Routine VLBI analysis

The specification of the present routine geodetic VLBI observation is summarized in Table 1. The 24 hours observation started on September 30, 1997. Note that some of the latest specifications are different from the previous ones[(2)]. For instance, the observation period for one session is now about 24 hours, while the initial experiment covered only 5 hours. Moreover, the original raw observation data are at present transported at a rate of 256 Mbps via optical fiber over an Asynchronous Transfer Mode network, while the initial experiment was recorded on cassette tapes at the rate of 64 Mbps[(3)].

Both the data reduction and data analysis system are described in other papers in this issue[(4,5,6)]. We will describe below how the routine analysis processings proceed, particularly those after the bandwidth synthesis (Figure 1); we use italics to denote the host name of the workstation, all of which are HP-UX workstations. In the KSP VLBI routine observation, a couple of perl scripts are used in order to automate the analysis processing as well as to make use of former software resources; the perl script is denoted with a suffix of .pl.

During the course of each session, two types of file called a 'komb' file and a 'kross' file are spawned for each baseline and each quasar from the real-time correlation processing software rkats[(4,5)]. In our present routine KSP VLBI experiment, we usually observe about 550 quasars for each session. The rkats software are operated at *komb1* or *komb2*. After the correlation processing, the db.pl on *komb1* (or *komb2*) is called, in which the other db.pl on *washi* is called up, using a remote shell function. Note that these two db.pl scripts are completely different from each other. The db.pl on *washi* does pre-analysis processings, whose six steps are summarized in Figure 1. The main purpose of this process is to make a primary database which accomodates the Mark 3 format. Upon completion of the db.pl on *washi*, one perl script called autoana.pl is spawned at *kouma*. The tasks being done by autoana.pl on *kouma* are also summarized in Figure 1[6]. Once the autoana.pl is started up, it automatically executes the baseline analysis, ending up with the renewal of the KSP home page.

3 Results and Discussion

Evolutions of six baseline lengths are shown in Fig. 2. In the KSP VLBI network, the first experiment was carried out in August 1994 between Koganei and Kashima stations, followed by participation of Miura in May 1995 and Tateyama in September 1996. During the course of routine experiments, not a few technical changes and modifications have been made, that have contributed to improving the performance of the KSP VLBI facility. In particular, we can obviously see a significant improvement of repeatability as well as a reduction in the error bars, which were associated with the specification change as of September 30, 1997 (see also Table 1). After this change, we do not see such undulated signals that were seen prior to this period[7].

The rate of baseline length changes are shown in Table 2. These rates are computed, based on the data obtained since September 30, 1997. We can see that all the six baselines show a significant negative trend. Since the KSP network lies on the same plate, what we observe routinely is a so-called intraplate deformation. The decreasing trend of baseline length in Fig. 2 indicates that the area covered by the KSP network is contracting.

In order to see the motions of the KSP network, we first compute the velocity of three sites relative to Kashima. However, since geodetic VLBI is a relative positioning technique, the velocity vectors inferred from a local network do not represent motions among the global system of tectonic plate motions. Hence, following the kinematic reference frame[1], we add a velocity vector of 20 mm/yr west to Kashima. Thus, we obtain two types of vectors as indicated in Fig. 3. The filled arrows are inferred from the horizontal site position with the Kashima fixed, while the open arrows represent the motions of each site relative to a stable Eurasian continent.

Moreover, we carried out a strain analysis over the triangle formed by Koganei (A), Tateyama (B), and Kashima (C) assuming a uniform strain field. The rates of change in three baseline lengths $\dot{\epsilon}_{xx} = -\Delta AB/AB$, $\dot{\epsilon}_{x'x'} = -\Delta AC/AC$, and $\dot{\epsilon}_{x''x''} = -\Delta BC/BC$ give the entire rate of strain field $\dot{\epsilon}_{xx}$, $\dot{\epsilon}_{zz}$ and $\dot{\epsilon}_{xz}$[8]:

$$\dot{\epsilon}_{x'x'} = \dot{\epsilon}_{xx}\cos^2\theta_1 + \dot{\epsilon}_{zz}\sin^2\theta_1 + 2\dot{\epsilon}_{xz}\sin\theta_1\cos\theta_1, \qquad (1)$$

$$\dot{\epsilon}_{x''x''} = \dot{\epsilon}_{x''x''}\cos^2\theta_2 + \dot{\epsilon}_{zz}\sin^2\theta_2 + 2\dot{\epsilon}_{xz}\sin\theta_2\cos\theta_2, \qquad (2)$$

where θ_1 and θ_2 are the ∠BAC and the outside angle of ∠CBA, respectively. These equations can be solved for $\dot{\epsilon}_{zz}$ and $\dot{\epsilon}_{xz}$, from which we can infer the directions of principal strain rates.

In order to compute these two angles, the Cartesian coordinate values, which are at present based upon the ITRF96 frame, are first converted to geodetic coordinates in order to find the latitude and longitude, and thus spherical trigonometry formula are employed. The rate of baseline length changes in Table 2 are used to compute the line strain rate. Results are shown in Fig. 4, in which the two principal strain rates are indicated. The principal strain rate is 0.17×10^{-6}/yr along the axis mostly in a north-south direction: a positive value of strain indicates, by convention, a shortening deformation. Both the amplitude and direction of principal strain in Fig. 4 are largely consistent with that inferred from GPS[9]; for instance, the principal compressive strain rate at just the north of Tokyo bay is 0.11×10^{-6}/yr, orienting along N5W.

In view of Fig. 3, we see that while both Koganei and Kashima move in a similar fashion, the motion of both Miura and Tateyama significantly differs from the other two stations. The direction of the former two sites' velocities is largely in accord with that of the subducting Pacific plate relative to the North-American plate, and thus these sites seem to be affected by the Pacific Plate. On the other hand, the latter two sites seem to undergo a compression by the Philippine Sea plate in view of the velocity direction similar to that derived by Seno et al[16].

Other than the linear trends expected from steady plate motion, we can see shorter-period fluctuations. It is uncertain whether this shorter period fluctuation really represents a motion of the crust, or whether it is simply an artifact caused by another effect such as an unmodeled delay due to heterogeneous water vapor distribution. If the signal shows seasonal modulation, it is likely to be due to a meteorological effect. Since the KSP VLBI analysis results with high repeatability span at most 1.1 years at present, it is premature to carry out a convincing spectral analysis. Comparing these VLBI data with those by other geodetic techniques would be more interesting and important[10].

4 Conclusion

Routine observation results of the KSP VLBI Network were shown. We were able to observe a significant intraplate deformation, which illustrates a contraction of the south Kanto area. In particular, the two baseline lengths, Koganei–Miura and Koganei–Tateyama, show a significant decrease: –12 mm/yr and –16 mm/yr, respectively. The strain analysis of the triangle formed by Koganei, Kashima, and Tateyama illustrates a compression with its strain rate of 0.17×10^{-6}/yr along a principal axis mostly in a north-south direction.

5 Acknowledgement

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6 References

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Figure Captions

Figure 2. Baseline length changes in KSP network. Shown in the title is the baseline combination with its length (millimeters) on Jan. 1, 97.

Figure 3. Velocity of each station in KSP network. Filled arrows represent the velocity vector with respect to Kashima. Unfilled arrows represent motions relative to a stable Eurasian continent, which are estimated by adding N82W 20mm/yr velocity to Kashima. PH and NA denote Philippine Sea plate and North-American plate, respectively.

Figure 4. Principal strain and its directions inferred from the three stations. By convention, dotted and solid lines represent compression and tension, respectively. Velocity estimate of Philippine Sea plate by Seno et al. is also shown.

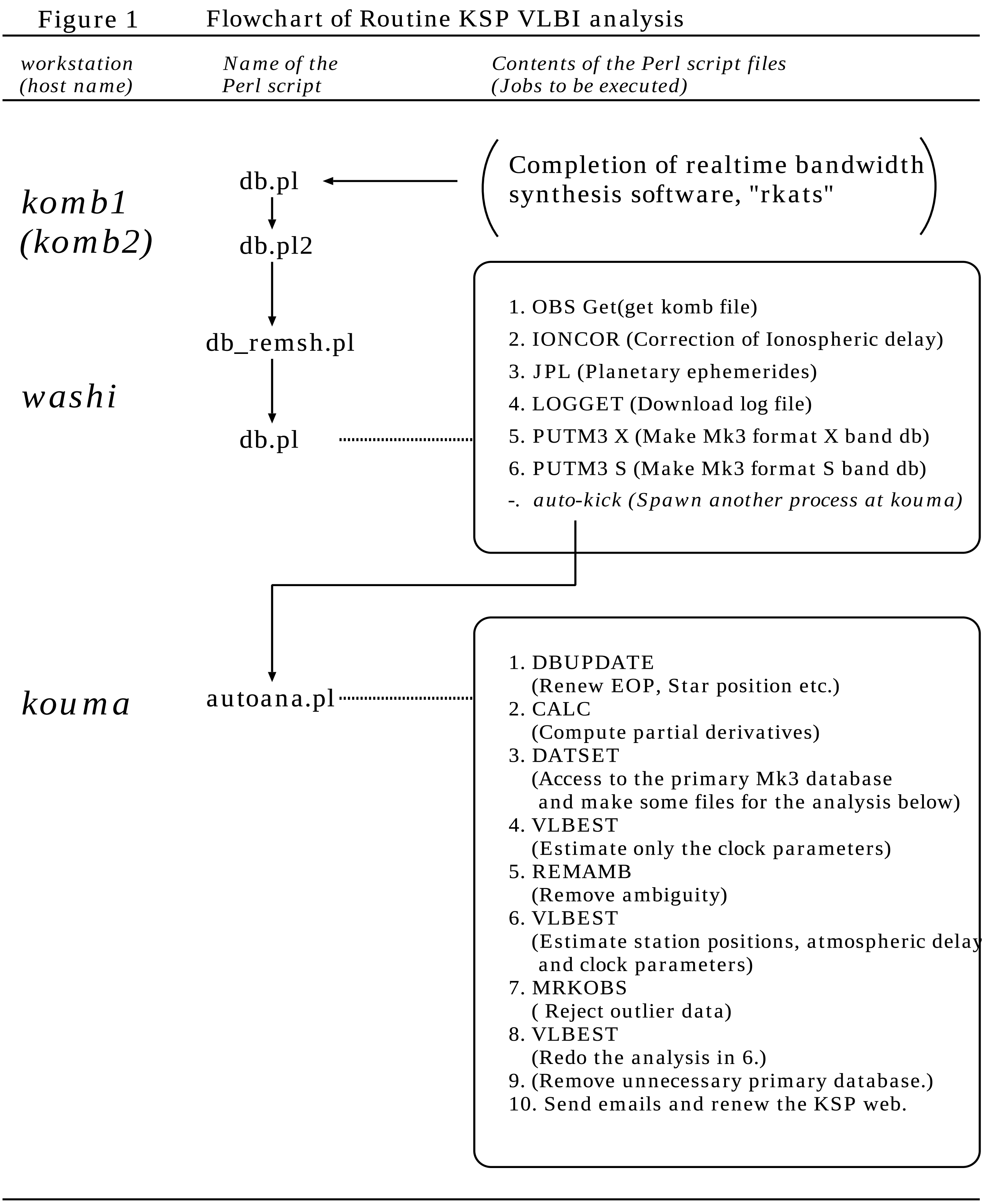


Figure 1 Flowchart of Routine KSP VLBI analysis
workstation (host name)
Name of the Perl script
Contents of the Perl script files (Jobs to be executed)
komb1 (komb2)
db.pl
db.pl2
Completion of realtime bandwidth synthesis software, "rkats"
washi
db_remsh.pl
db.pl
1. OBS Get(get komb file)
2. IONCOR (Correction of Ionospheric delay)
3. JPL (Planetary ephemerides)
4. LOGGET (Download log file)
5. PUTM3 X (Make Mk3 format X band db)
6. PUTM3 S (Make Mk3 format S band db)
-. auto-kick (Spawn another process at kouma)
kouma
autoana.pl
1. DBUPDATE (Renew EOP, Star position etc.)
2. CALC (Compute partial derivatives)
3. DATSET (Access to the primary Mk3 database and make some files for the analysis below)
4. VLBEST (Estimate only the clock parameters)
5. REMAMB (Remove ambiguity)
6. VLBEST (Estimate station positions, atmospheric delay and clock parameters)
7. MRKOBS (Reject outlier data)
8. VLBEST (Redo the analysis in 6.)
9. (Remove unnecessary primary database.)
10. Send emails and renew the KSP web.

Figure 1:

Table 1 Summary of the Present KSP VLBI observation

Stations	Koganei, Kashima, Miura, Tateyama
One session	01:15 – 23:45 (UT)
Since	Sept. 30, 1997 (every other day)
Radio Sources	16 radio sources (0059+581, 3C84, 0420-014, 0552+398
	0727-115, 4C39.25, 3C273B, 3C279, 1308+326, 1334-127, 3C345
	NRAO0530, 1921-293, 2134+00, 2145+067, 3C454.3)
Observation Frequency	S band: 2154.99, 2164.99, 2234.99, 2294.99, 2384.99, 2414.99 (MHz)
	Xl band: 7714.99, 7724.99, 7754.99, 7814.99, 8034.99 (MHz)
	Xh band: 8234.99, 8414.99, 8524.99, 8564.99, 8584.99 (MHz)
	(All 16 channels above are used with a bandwidth of 8 MHz.)

Table 2 Baseline lengths as of Nov. 1, 97 and their rate of change (Oct. 97–Oct. 98)

Baseline	Length (mm)	Rate of change (mm/year)
Koganei – Kashima	109099652.00 ± 0.80	-1.03 ± 0.24
Koganei – Miura	57734558.90 ± 0.70	-11.8 ± 0.25
Koganei – Tateyama	91871028.80 ± 0.80	-15.7 ± 0.26
Kashima – Miura	123379064.80 ± 0.80	-2.64 ± 0.30
Kashima – Tateyama	134771047.10 ± 0.90	-9.30 ± 0.30
Miura – Tateyama	35028132.10 ± 0.60	-3.18 ± 0.24

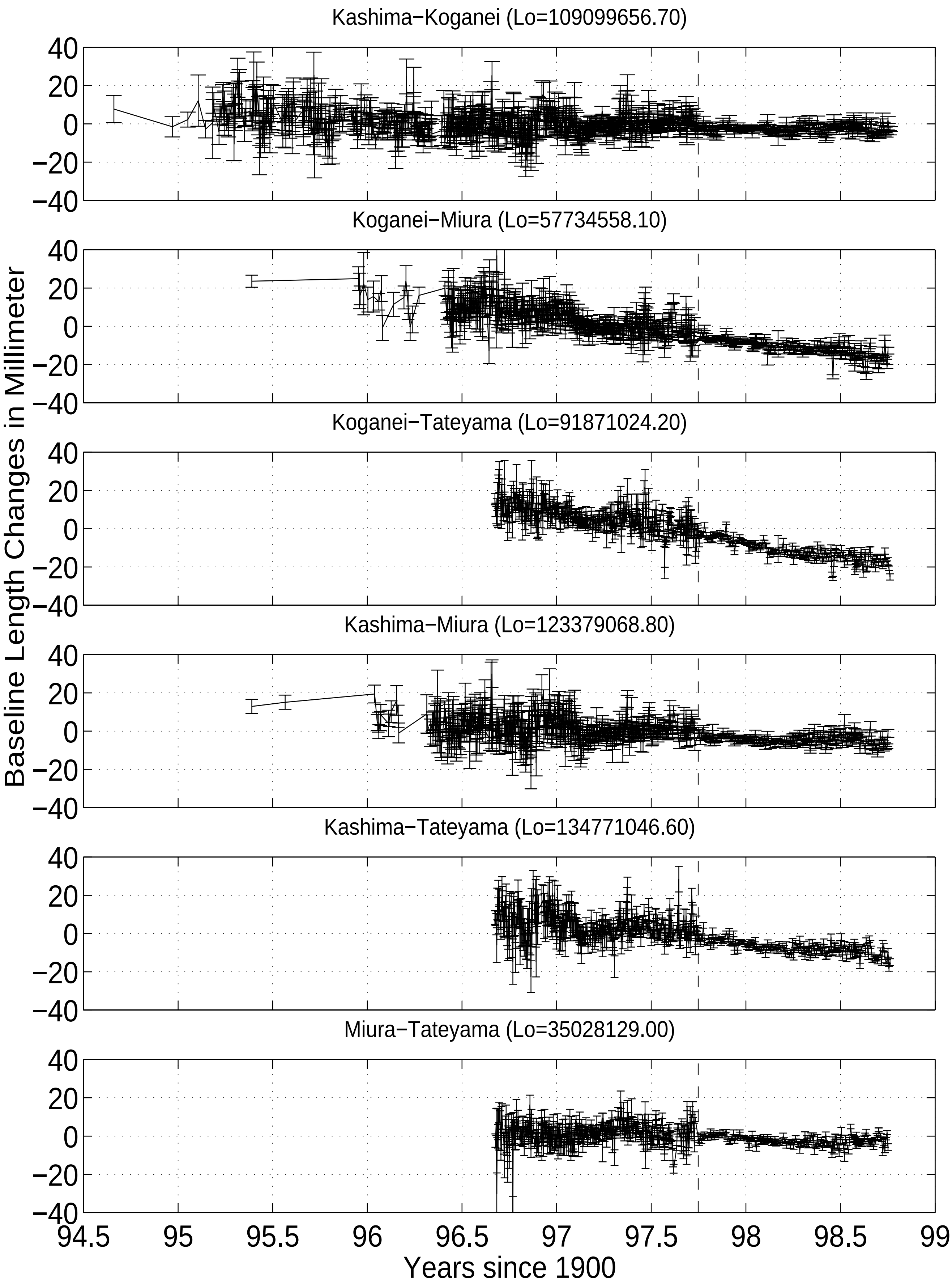
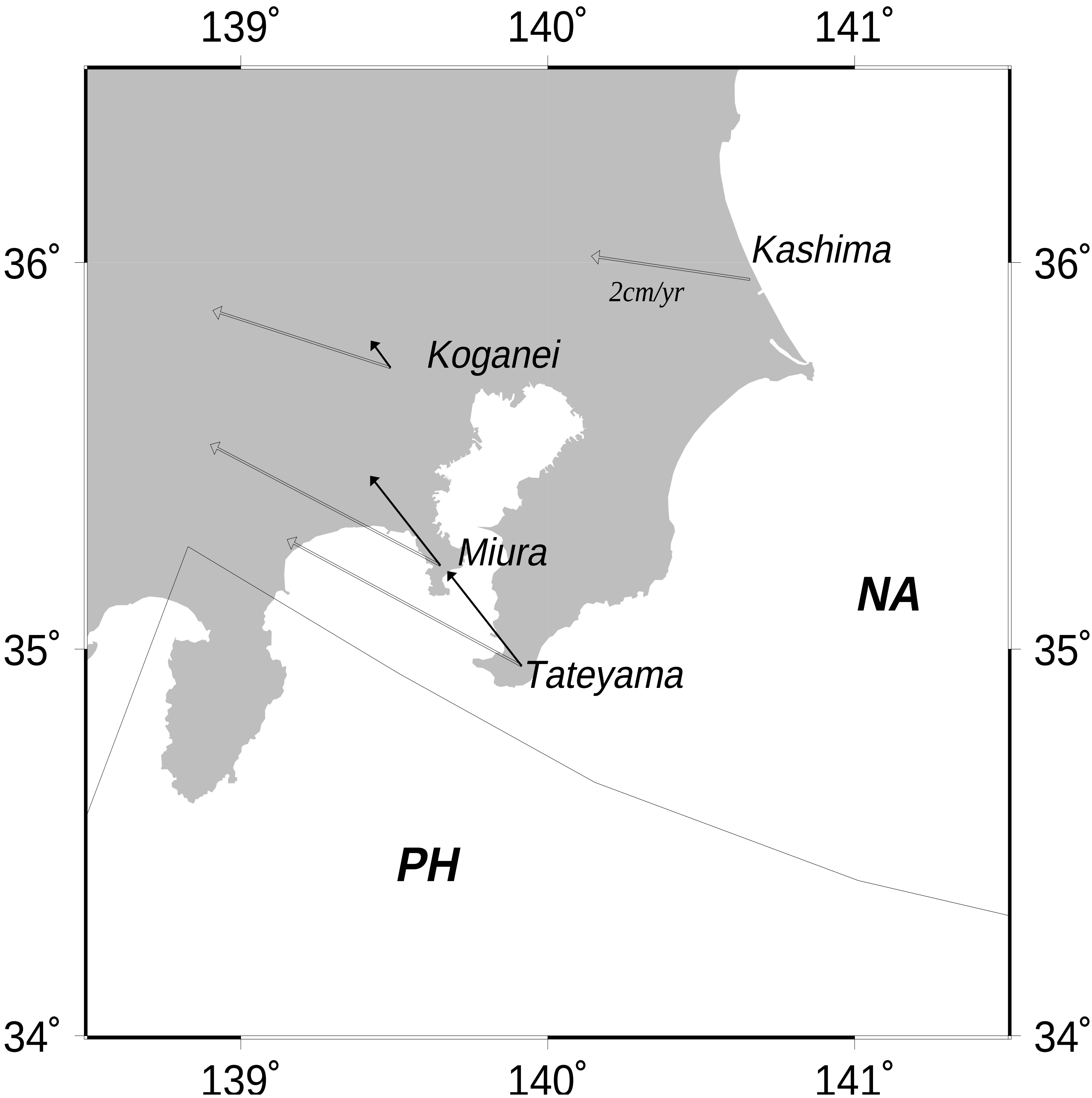

Kashima−Koganei (Lo=109099656.70)
Koganei−Miura (Lo=57734558.10)
Koganei−Tateyama (Lo=91871024.20)
Kashima−Miura (Lo=123379068.80)
Kashima−Tateyama (Lo=134771046.60)
Miura−Tateyama (Lo=35028129.00)
Baseline Length Changes in Millimeter
40
20
0
−20
−40
94.5
95
95.5
96
96.5
97
97.5
98
98.5
99
Years since 1900

Figure 2:



139°
140°
141°
36°
35°
34°
Kashima
2cm/yr
Koganei
Miura
Tateyama
NA
PH

Figure 3:

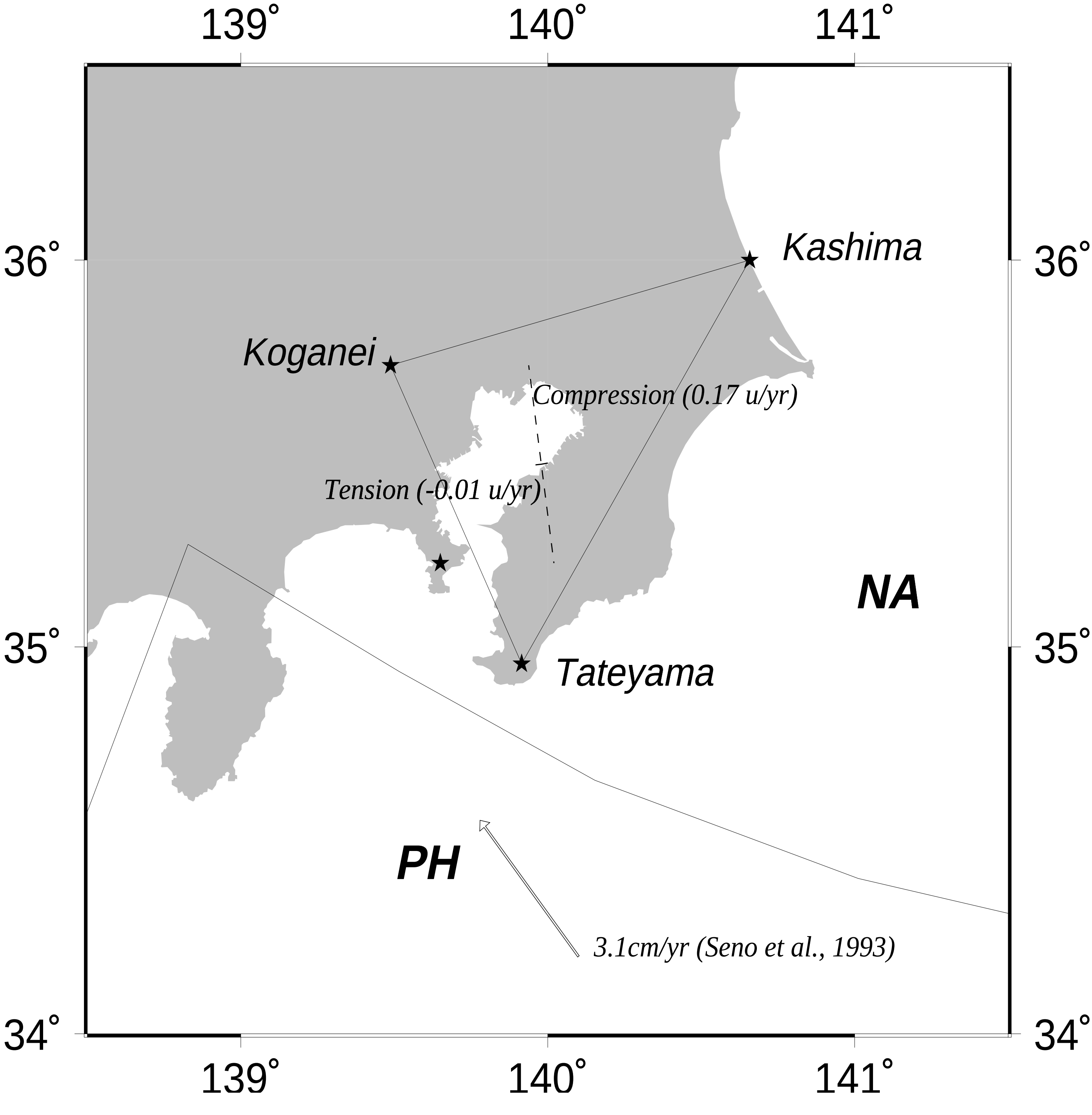

139°
140°
141°
36°
35°
34°
Kashima
Koganei
Compression (0.17 u/yr)
Tension (-0.01 u/yr)
NA
Tateyama
PH
3.1cm/yr (Seno et al., 1993)

Figure 4: