

abstract

We compared the station positions derived from very long baseline interferometry (VLBI) in the crustal deformation monitoring system in Tokyo metropolitan area with those of the global positioning system (GPS) at the stations of KSP. The current reliability of VLBI was almost the same as that of GPS. The dispersions of measurements in one-day experiments were about 2 mm and 10 mm for horizontal and vertical movements, respectively. The variations longer than one month for the station movements measured by both VLBI in KSP and GPS were 0.5-1 mm and 2-5 mm for horizontal and vertical movements, respectively. However, their variations of VLBI data were different from those of GPS data. The station velocities obtained by VLBI data in KSP agreed well with those by GPS data.

1 Introduction

Station movements have been measured by using very long baseline interferometry (VLBI), satellite laser ranging (SLR) and global positioning system (GPS) within 1 mm/year⁽¹⁾. Communications Research Laboratory (CRL) maintains a domestic network for the Crustal Deformation Monitoring System in the Tokyo Metropolitan Area that is called the "Key Stone Project" (KSP). The network is a good test bench for comparing the results of VLBI, SLR and GPS. A dense network of GPS stations is constructed in Japan by the Geographic Survey Institute (GSI), and there are some GPS stations located near the KSP stations. We discussed the comparison between the VLBI results obtained by KSP till 19th October 1998 and GSI's GPS results during 1st August 1996 to 31th August 1998.

2 Key Stone Project

KSP was constructed using VLBI and SLR facilities at four stations: Koganei in Tokyo, Kashima in Ibaraki, Miura in Kanagawa, and Tateyama in Chiba. The baseline lengths are from 35 to 135 km. The VLBI antenna is an 11 m antenna and the SLR is a 75 cm optical telescope. Daily five-hour VLBI observations began on 31th January 1995 in the 56 Mbps mode on the baseline between Kashima and Koganei stations. The Miura and Tateyama stations were added to the VLBI experiments in December 1995 and September 1996, respectively. A few significant improvements were made to measuring conditions during the project. On 19th February 1997 (epoch 1), the observation mode was changed to 256 Mbps (still five-hour of observation). Around this time, improvements made to the phase calibration system (PCAL) at Kashima station increased the quality of the station's data. On 30th September 1997 (epoch2), the 24-hour experiment in 256 Mbps mode began and it is conducted every other day. We used the GPS results at stations near the KSP stations as part of the dense GPS network of GSI in Japan since a reliable analysis can be carried out using the many stations in the GSI network. One is the Yokosuka station, which is a little far from Miura. Other GPS stations are located within a few kilometer of the VLBI stations. The GSI and KSP data are openly available on the WWW.

Concerning the comparisons between VLBI and GPS movements, we had to consider six types of quantities;

- 1) the dispersions of measurements in the course of a certain time interval,
- 2) the variations of measurements appeared in the course of a certain time interval,
- 3) the dispersions of the positions averaged over a certain time interval,

- 4) the variations of the positions averaged over a certain time interval,
- 5) the velocities of the movements,
- 6) the absolute positions.

The first quantity is an indicator of the reliability (the error) of the data for short term variations. The third gives the reliability (the error) of the slow variations. The fourth gives the slow variations. The fifth is a measure of the reliability (the stability) of the long term variations. The sixth reflects the accuracy of the data. Variations in movement over the short term is not discussed in this paper.

Figure 1 shows the dispersions of the east, north and vertical movements of VLBI data in the course of 20 days on the baseline between Kashima and Koganei. Figure 2 shows the dispersions of GPS data on the baseline between Kashima and Tateyama. The dispersions of VLBI data improved after February 1997 and there was further improvement after October 1997. After October 1997, the quality of the data was similar to that of the GPS data. The dispersions of VLBI data in the summer were about 4 mm and those in the winter are about 1 mm. These seasonal variations may be caused by the atmospheric scintillation. The variations of dispersions in GPS data were about the same as those in VLBI data.

2.1 Quality comparison

We investigated the quality and reliability of KSP's VLBI data and GSI's GPS data. We determined the root mean square of the averaged values in the course of a certain time interval.

The components for periods shorter than the averaged time interval are canceled out. Therefore, the averaged values are indicators of the variations for periods longer than

the averaged time interval.

Figure 3 shows the dispersions of the averaged values for the east movements at the Tateyama station relative to the Kashima station: (a) is for the five-hour 64 Mbps (or 54 Mbps) VLBI experiments, (b) is for five-hour 256 Mbps VLBI experiments during epoch 1-2, and (c) is for the 24-hour 256 Mbps VLBI experiments after epoch 2. The dispersions of GPS data collected since August 1996 are also shown in (d). The abscissa is the averaged time interval.

The values for one day (faster variations) correspond to the error for each measurement. The errors in horizontal movements were 4-6, 4, 2 and 2 mm for five-hour 64 Mbps VLBI, five-hour 256 Mbps VLBI, 24-hour 256 Mbps VLBI, and GPS, respectively. All the measured errors in GPS were similar to those in 24-hour VLBI data. The errors in the vertical movements were 2-5, 2-5, 2-5, and 5-10 mm, respectively.

The errors were large and random. When we averaged the data, the large random errors were canceled out, and the systematic variation appeared. We examined the errors (reliability) in the variations for periods longer than one month. For these variations, the horizontal errors were 0.5-1 mm for all of GPS data, five-hour 256 Mbps data and 24-hour 256 Mbps data, respectively. The reason why the dispersions of five-hour 256Mbps data were small in the figure was that the observation data was a few. The vertical errors were 2-5 mm. The reliability of the variations for periods longer than one month in the VLBI data was about the same as that for that of the GPS measurements.

2.2 Pattern of the movements

We compared the pattern of averaged horizontal movements in order to check the reliability of the systematic variations for periods longer than one month. We plot

the trace of the averaged horizontal movements. The trace of the positions is useful to recognize the systematic variations. We computed averages of measurements taken over 20-day intervals, and we used the box average (shifted average). We found systematic variations for periods longer than 30 days. Figure 4 shows the patterns of horizontal movements of Tateyama station relative to Kashima station for both 24-hour 256 Mbps VLBI data and GPS data during 210-day period starting on January 1998. The right figure is the VLBI data, and the left one is the GPS data.

Figure 5 shows the time variations since 1997 in the 30-day box-averaged values for the east movements obtained from VLBI and GPS measurements on the Kashima and Tateyama baseline. The systematic variations in VLBI data differed from that of GPS data. However, the fine variations shorter than one month were sometimes similar. We thought these fine variations were caused by atmospheric effects because atmospheric variations were common in both VLBI and GPS data and they changed irregularly day by day.

3 Comparison of VLBI and GPS data

3.1 Velocities

The velocities of Koganei, Miura and Tateyama stations relative to Kashima stations were compared in Figure 6. The measurement errors in velocities in KSP are 0.2 mm/year for horizontal movements and 1 mm/year for vertical movements. The measurement errors for GPS stations were similar to those of the VLBI data. However, the velocities of GPS stations differed from those of VLBI stations. The discrepancy in the horizontal movements of Koganei station was 0.1 mm/year, and it was of the same order

as the errors. The discrepancy in the horizontal movements of the other stations was 1mm/year, and it was three times the measurement error. The discrepancy in vertical movements was 3-8 mm/year, which was three times greater than the measurement error. It should be noted that the velocities derived during short periods were uncertain since the systematic variations affect the velocity.

We discussed the cause of the variations. The variations of 2 and 10 mm for the horizontal and vertical movements over the course of a few days and the irregular variations during one month in both VLBI and GPS data may be caused by the atmospheric delay. Other causes may be ground water effects, system errors, and antenna deformation.

We examined the correlation between the averaged horizontal and vertical movements. We found a systematic correlation for some baselines. This correlation indicates that the atmospheric effect was related with the systematic variations.

4 Conclusion

We compared VLBI and GPS data by examining variations in station positions. Our conclusions are as follows:

1. The 24-hour 256 Mbps experiments at KSP had the same quality as GPS data quality for measurements during one day.
2. The VLBI data was similar to the GPS data for the variations longer than one month.
3. The pattern of horizontal movements in KSP VLBI data was different from that of the GPS data.
4. Irregular variations over periods less than one month appeared in both VLBI and

GPS data and sometimes, the VLBI and GPS variations were correlated.

5. The velocity of the movements obtained from VLBI data were in good agreement with one what obtained from GPS data, and the discrepancy in the horizontal velocity was less than 1 mm/year during two years.

Typical variations of both VLBI and GPS measurements in one day experiments were random, and their dispersions were 2 and 10 mm for the horizontal and vertical movements, respectively. Typical variations for periods longer than one month were systematic and their dispersions were less than 1 mm and 5 mm for horizontal and vertical movements, respectively. These systematic variations in the VLBI data differed from those in the GPS data, but they gave the upper limit of the true variations. The correlated variations for periods shorter than one month may have been caused by error common to both VLBI and GPS data, such as atmospheric delay or the true variations.

Finally, we should note that the variations presented in this paper were the different variations among the stations. We were not able to determine the common variations in this area. Other data beside the KSP data is necessary for the examination of the common variations in this area.

Acknowledgments

The GPS data is produced by the GSI. We are grateful to the GSI staff for their help to provide the GPS data.

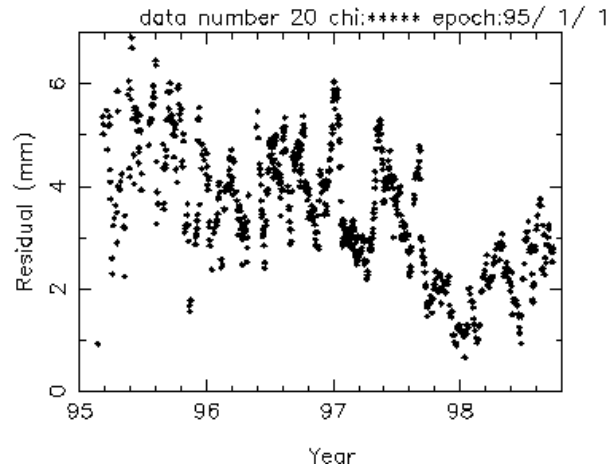
References

- [1] C. Boucher, P. Sillard, 1995. "Evolution of realization of global reference systems from space techniques and their links with ITRF". IERS technical note 20.

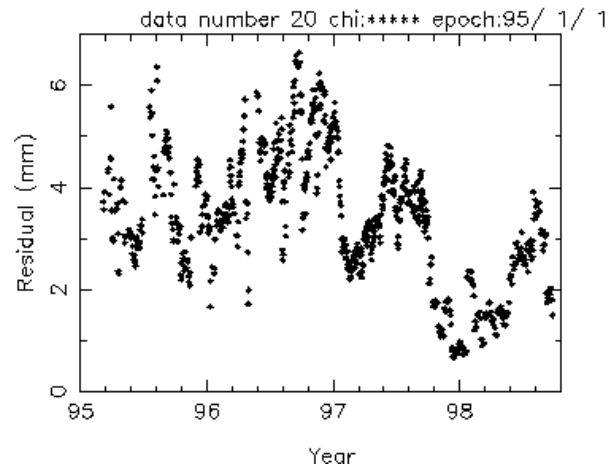
Figure Captions

- Fig.1 The dispersions of the east, north and vertical movements of VLBI data in the course of 20 days on the baseline between Kashima and Koganei. (a) is east movements, (b) is north movements and (c) is vertical movements.
- Fig.2 The dispersions of the east, north and vertical movements of GPS data in the course of 20 days on the baseline between Kashima and Tateyama. (a) is east movements, (b) is north movements and (c) is vertical movements.
- Fig.3 The root mean square of positions averaged in the certain time interval for east movements on the Kashima and Tateyama baseline vs. the averaged time interval.
- Fig.4 Trace of horizontal movements box-averaged in the course of 30 days at the Tateyama station relative to Kashima for 210 days since 1st January 1998. The right figure (a) is VLBI data, and the left figure (b) is GPS data in the same scale.
- Fig.5 Variations of the east movements box-averaged in the course of 30 days at the Tateyama station relative to Kashima vs. time during 1997/1/1-1998/10/19. The variations are after the linear trend is removed. The cross is GPS data and the circle is the KSP's VLBI data.
- Fig.6 Comparison of velocities of KSP stations relative to Kashima for both VLBI data and GPS data.

Koganei -Kashima :E: residual(mm): 3.54+/- .04mm sig: 1.20 mm



Koganei -Kashima :N: residual(mm): 3.50+/- .04mm sig: 1.28 mm



Koganei -Kashima :U: residual(mm): 18.65+/- .22mm sig: 6.38 mm

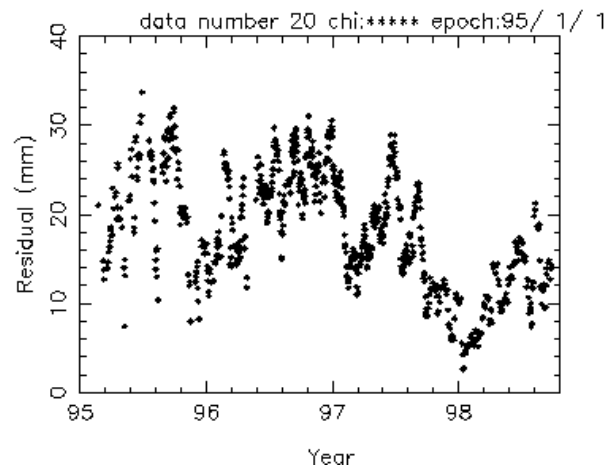
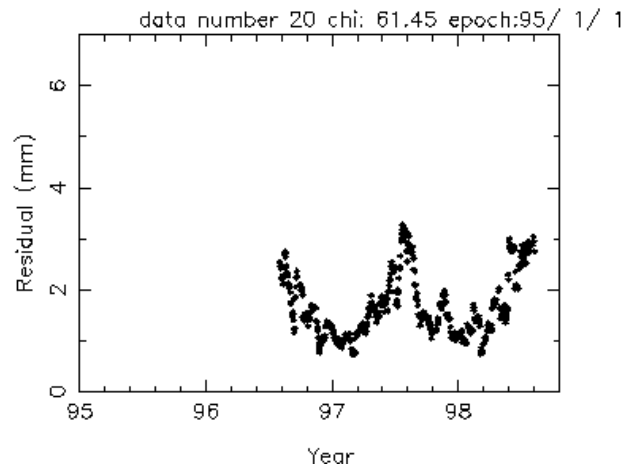
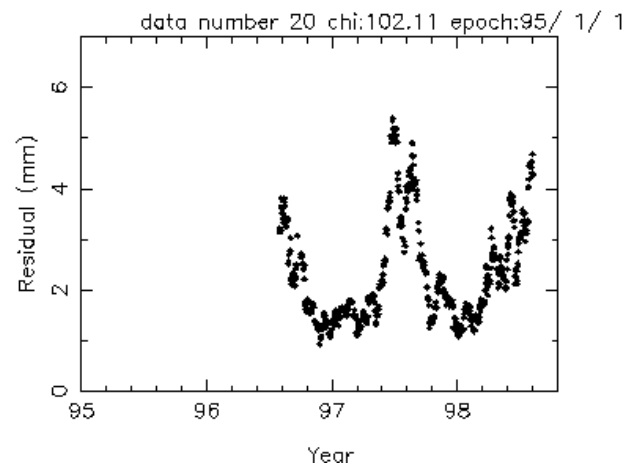


Figure 1: The dispersions of the east, north and vertical movements of VLBI data in the course of 20 days on the baseline between Kashima and Koganei. (a) is east movements, (b) is north movements and (c) is vertical movements.

Tateyama-Kashima :E: residual(mm): 1.66+/- .02mm sig: .61 mm



Tateyama-Kashima :N: residual(mm): 2.29+/- .04mm sig: 1.02 mm



Tateyama-Kashima :U: residual(mm): 7.16+/- .09mm sig: 2.41 mm

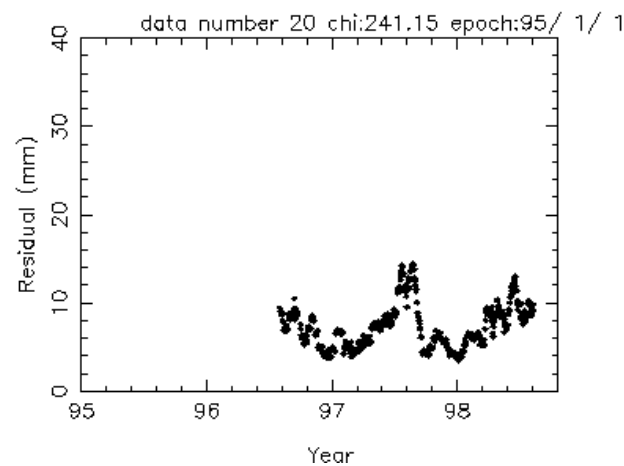


Figure 2: The dispersions of the east, north and vertical movements of GPS data in the course of 20 days on the baseline between Kashima and Tateyama. (a) is east movements, (b) is north movements and (c) is vertical movements

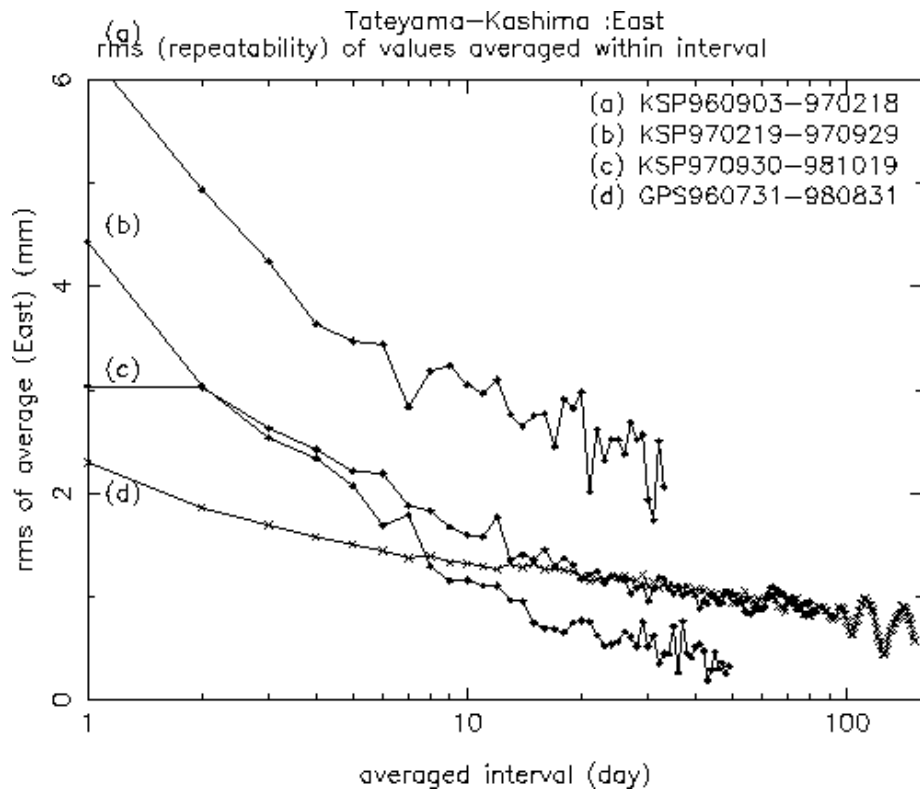
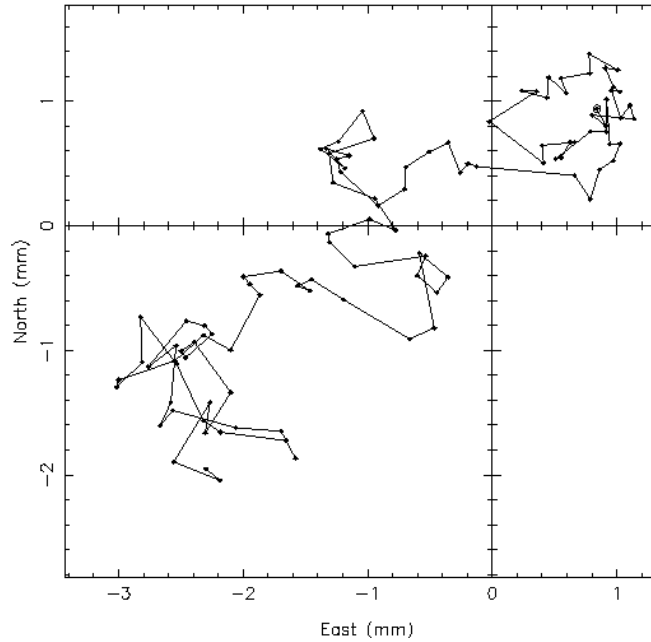


Figure 3: The root mean square of positions averaged in the certain time interval for east movements on the Kashima and Tateyama baseline vs. the averaged time interval.

Tateyama-Kashima : position move 1998/ 1/ 1: 210 days 30 days mean



Tateyama-Kashima : position move 1998/ 1/ 1: 210 days 30 days mean

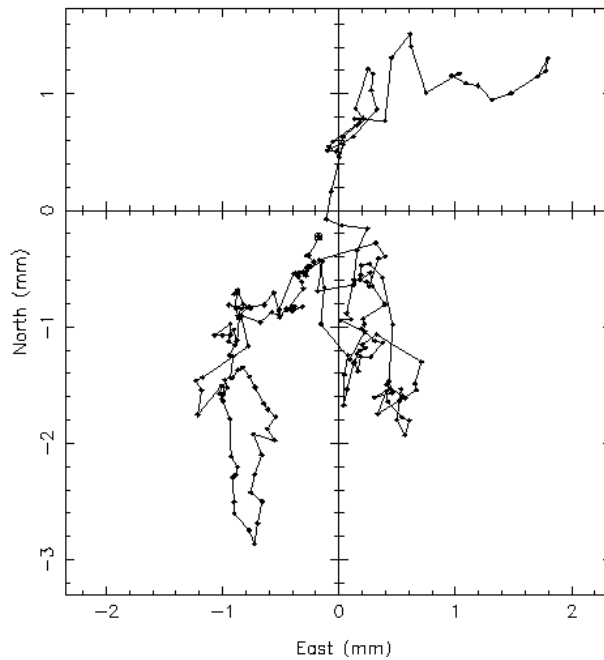


Figure 4: Trace of horizontal movements box-averaged in the course of 30 days at the Tateyama station relative to Kashima for 210 days since 1st January 1998. The figure (a) is VLBI data, and the figure (b) is GPS data in the same scale

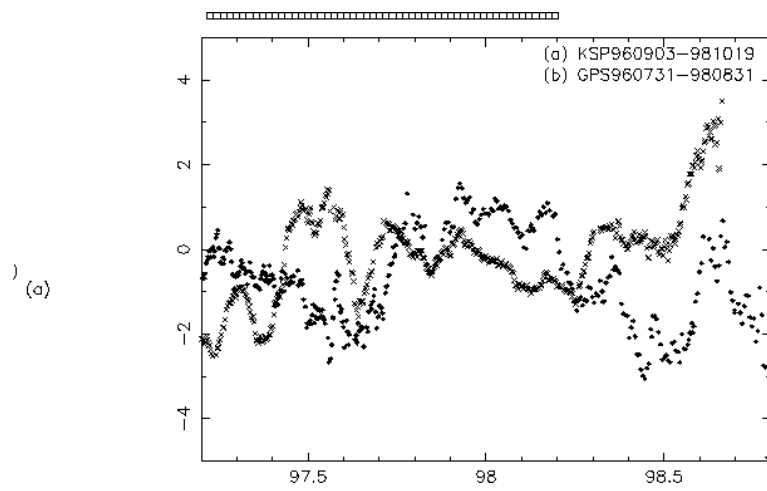


Figure 5: Variations of the east movements box-averaged in the course of 30 days at the Tateyama station relative to Kashima vs. time during 1997/1/1-1998/10/19. The variations are after the linear trend is removed. The cross is GPS data and the circle is the KSP's VLBI data.

KSP station movements vs NORTH American plate

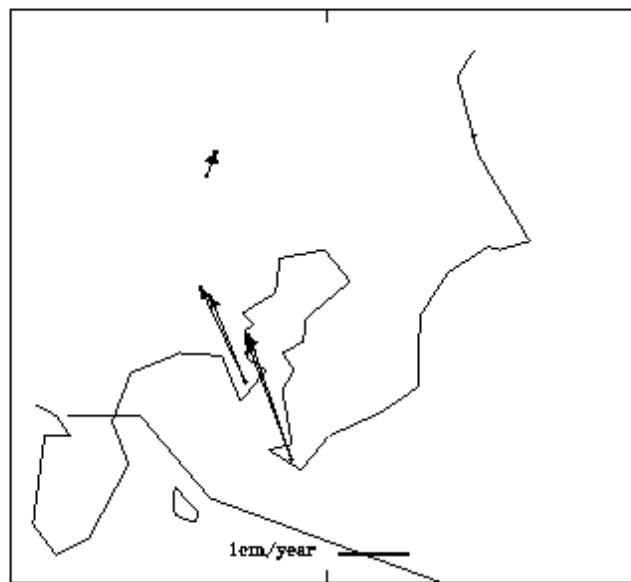


Figure 6: Comparison of velocities of KSP stations relative to Kashima for both VLBI data and GPS data.