Development of a Monitoring Technique of Anomalous Crustal Deformations by the Application of Kinematic GPS - Part. II. The Experiment of a Long Baseline and Construction of a Semi-Real Time Monitoring System -

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Synopsis

We researched an anomalous crustal deformation about the motitoring technique by using the GPS. It is because many observation points are being observed in Japan. So, we built the system to detect crustal deformations every moment by using the kinematic positioning method. As a result until last year, we tried an experiment with long base line in this year. We newly established two continuous observation points, Shirahama and Shionomisaki. It found that the accuracy of 1cm was secured by removing the ionospheric and tropospheric delay and so on by using the filterring technique. We constructed a quasi-real time monitoring system. We think that a monitoring system can be made early by making use of this result.

Keywords: kinematic GPS positioning, ionospheric and tropospheric delay, sidereal filter, spatial filter

1. Introduction

Many damage earthquakes appear on the areas surrounding Japan in the past. Though an anomalous crustal deformation appeared before and after these earthquakes, the means to detect it was poor from the viewpoint of time-space scale. For example, an anomalous vertical deformation preceding the 1944 Tonankai Earthquake was detected by leveling survey performed near Kakegawa, Japan, about 300 km away from its epicenter [Mogi, 1982, 1985]. But, as for this result of measurement, contradiction was found by Sagiya (1998, 2004). The occurrence of Nankai earthquake is predicted soon securely again, and it has the possibility that it is caught the similar phenomenon. So, we want to build the system which always monitors small movement with GPS. Now, in the Japanese Islands, the GPS observing stations, GEONET, are built at an interval of about 20 km over the whole region. At present, daily solutions are obtained by static analysis of GEONET data. Therefore we cannot observe deformations with a time constant shorter than 1 day like that in 1944. We must adopt a kinematic GPS positioning method.

2. The Accuracy Experiment of Kinematic GPS Positioning

2.1 Continuous Stations

We pursued the error factor in the kinematic positioning to obtain the same accuracy as that for the static GPS positioning. We conducted an experiment in order to

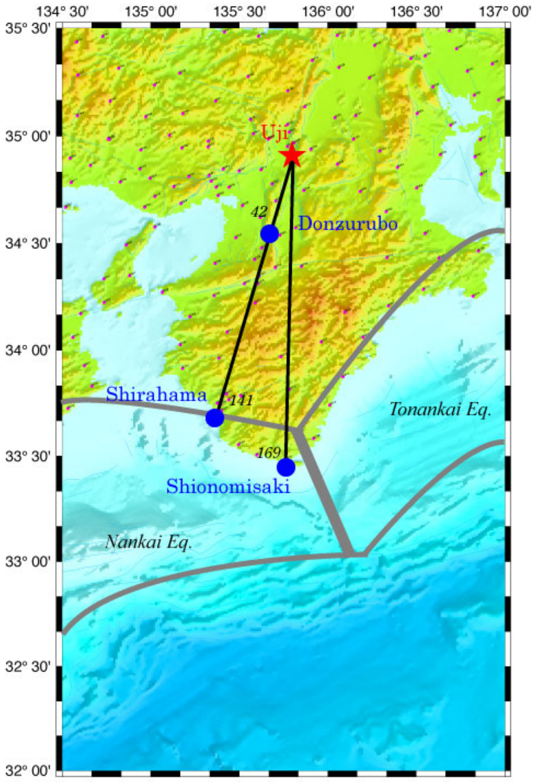

Fig.1. Baseline Map of this experiment. Number of Circles is Baseline length from UJI (km).

Photo.1. Shionomisaki Continuous Station.

resolve the error factor and improve accuracy. So, we installed two continuous observation points in the short baseline, Uji and Shigaraki, and did the experiment of the positioning accuracy in 2005. We established two continuous observation points newly in the Kii Peninsula to do positioning accuracy experiment in the long-baseline as well as the actual observation in 2006 (Fig.1). These baselines are about 141 and 169 km, respectively. The receivers are Javad Legacy-E +

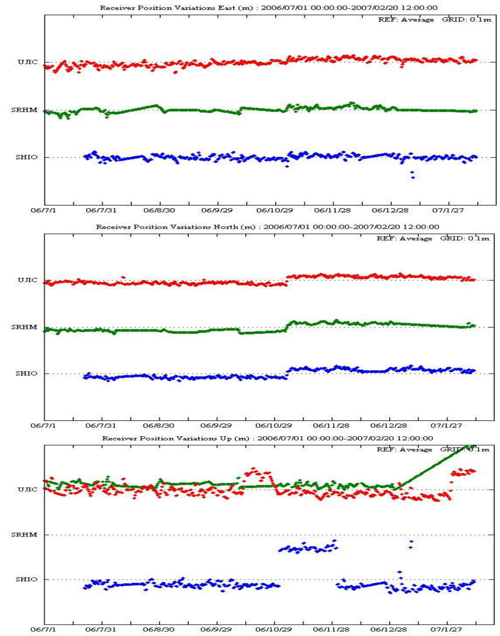

Fig.2. Static analysis result of the continuous observation point established by DPRI, Kyoto University. These graphs show the East-West, North-South, and Up-Down component, respectively. The step seen in the beginning in November is the change of the International Terrestrial Reference Frame (ITRF2000 to ITRF2005).

external frequency standard and the antennas are Ashtech Dorne-Margolin Choke-ring antenna with SCIGN radome (Photo.1). Data sampling rate was 1-second. Positions of these points were determined by the static positioning in advance, and these positions were treated as the “true” positions. Then, the differences between these “true” positions and positions determined by kinematic positioning were measured. These observation points are constructed in the observatory of DPRI, Kyoto University. There are near the last huge earthquake epicenters, and we expect the useful data recording in the near future. Three points of static analytical results until the end of February 2007 are shown in the Fig.2.

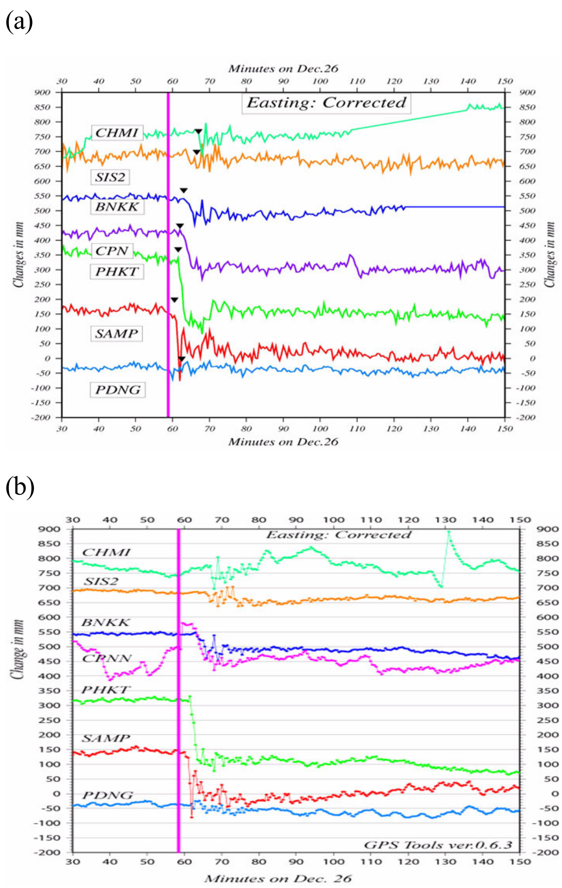

Fig.3. Comparison of kinematic GPS analysis of the 2004 Sumatra-Andaman Earthquake. Upper graph shows the analysis by the GIPSY software [Hashimoto et al., 2006]. Lower graph (b) shows by the GPS-Tools software in this study.

2.2 GPS-Tools

The main error factors of the long baseline kinematic GPS analysis is the estimation of the amount of ionospheric and tropospheric delays. Radio waves surely pass through the ionosphere and the troposphere while they travel from the satellite to the stations on the ground. Therefore we thought about how to remove these error factors to the full. First, we tried a lot of software till now. However, there was a problem not to remove noise well, and all were merits and demerits. GPS-Tools software ver.0.6.3 which we began to use is using the technique called “High-rate sampling Precise Point Positioning (HR-PPP)” method [Takasu and Kasai, 2005]. These characteristics can remove the error influenced by a reference station and a baseline. An error due to the time synchronism is reduced because the algorithm which each satellite clock is re-determined is included. We can automate this program because some filters and models are more satisfactory and the renewal of the program is possible. Furthermore, we can handle data of a wide area in a short time because process speed became faster. It explains about the sidereal filter easily here. Each satellite goes around the earth twice in one day. The sidereal filter is to remove the noise which is characteristic of the station every day at the same time. It is mentioned about a difference in the result that a seismic analysis was done by this software and other software. The result of the kinematic analysis of the 2004 Sumatra-Andaman earthquake was caught near the epicenter is shown in Fig. 3(a) [Hashimoto et al., 2006]. This is an untied result by using software of GIPSY ver.2.6 [Zumberge et al., 1997]. It seems that there is very much noise with each station as well. Fig.3 (b) is the result reanalyzed with GPS-Tools in this study. Noise was reduced in comparison with the Fig.3 (a). We think that there was not approximately influence of the error factor to be caused by the satellite clock and the baseline. As an example, the return of the displacement seen by PHKT was improved.

2.3 Filtering

As even a preceding paragraph expressed, an error factor is complex. So, we thought that it intended to reduce an error by combining a filter. A sidereal filter can get rid of the error to originate in everyday satellite orbit [Choi et al., 2004]. A spatial filter can remove the error to originate in the path as a common mode bias when if it is a comparatively near observation point, it supposes to pass through the almost same route [Wdowinski et al., 1997, Tabei and Amin, 2002]. The error to originate in the route is the ionopheric and tropospheric delay and satellite clock. This method is explained briefly here.

i) Detrending: By a linear regression, determine the best-fit linear trend for each component of coodinate’s time series. Tectonic signal is separated from the raw time series as the trend, since it is considered to be long-term continuous change with a spatial gradient. If abrupt change such as coseismic displacement is involved in the time series, the algorithm is applied separately to the data segments before and after the day of change, though this procedure is not necessary. For each day d and each site s, calculate a redisual $\varepsilon^{S}(d)$

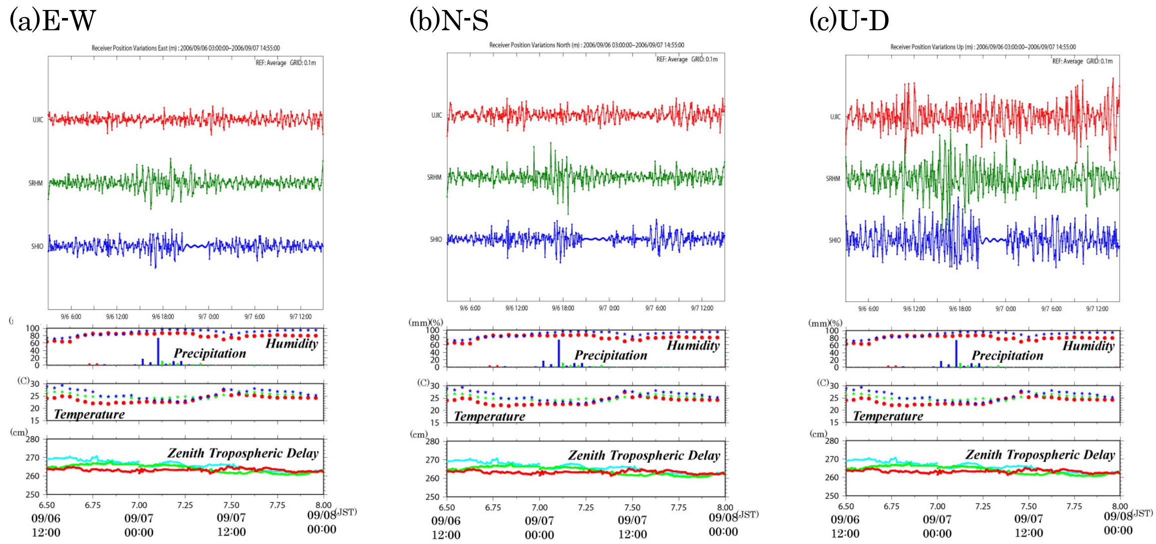

Fig.4. The kinematic GPS results of three observation points, Uji, Shirahama, and Shionomisaki, on September 5-8, 2006. The graph is (a) East-West, (b) North-South, and (c) Up-Down component, respectively. Three lower graphs show the Humidity, Precipitation, Temperature, and Zenith tropospheric delay. Only the record of Shirahama is large at the time of the front passage, and positioning accuracy decreases more.

that is a deviation of observed data $O^S(d)$ from the predicted value $C^S(d)$,

$$\varepsilon^S(d) = O^S(d) - C^S(d) \qquad (1)$$

We define a date point $O^S(d)$ as the outlier and eliminate it from the time series when $\varepsilon^S(d)$ is larger than three times the root-mean-square of all residuals in the corresponding time series.

ii) Stacking: Calculate a daily common-mode bias $\hat{\varepsilon}\ (d)$ by averaging residuals from all N sites,

$$\varepsilon(d) = \sum_{S=1}^{N} \varepsilon^S(d) / N \qquad (2)$$

The minimum criterion of station number used for the stacking is two, that is, when data at all stations but one has been already deleted in the step (i) because of large residuals, no error output is obtained on that day. The result may be dependent on the selection of stations, which we will check in the next section.

iii) Filtering: For each day d and each site s, subtract the common-mode bias from the observed position.

$$O^S(d) = O^S(d) - \hat{\varepsilon}(d) \qquad (3)$$

Finally determine the best-fit linear trend again for the filtered time series.

2.4 Results

Fig.4 shows the kinematic GPS results of three observation points on September 5–8, 2006. A local downpour happens in South of Wakayama Prefecture, and the rainy quantity of 94mm was recorded in Shirahama in 1 hour. It knows that only Shirahama's record changes greatly in the time zone when much rain fell down. The accuracy of about 2cm in the horizontal component is secured in the time zone except for that. But the up-down component is generally improper.

However, a change isn't seen with that in the numerical value of the amount of the zenith tropospheric delay.

2.5 Discussion

First, we discuss about the Fig.2. This is the result of the static analysis of three continuous observation points. A similar step is seen in the whole point in the beginning in November. This is because the reference frame being used for the analysis changed internationally. We must see what kind of modification we will have to give from now on carefully. We think that the steps of the time except for that are the problem of the acquisition and translation of the data, and we re-analyze at present. Moreover, we think that the record of Shirahama's up-down component is improper is that the initial value or the amount of the zenith tropospheric delay can't be estimated.

Next, it is about the comparison of the result by the difference in software. As mentioned, the return of the displacement of Phuket was improved by using GPS-Tools. This result is in harmony with the amount of displacement by the static analysis. Even if the result of which observation point is seen again, it knows that noise is reduced drastically. Furthermore, we can get an answer by the improvement of the Kalman filter when it couldn't be analyzed time zone of CHMI and BNKK by GIPSY. As for the step of 2:10 of CHMI, the number of satellite supplements is less than four. But, as for CPNN, we scan straight data because an result is not desirable and are reanalyze it again.

Finally, we discuss positioning accuracy in the weather disturbance. As shown in Fig.4, positioning accuracy deteriorates locally when the atmosphere upper the observation point is disturbed at the time of the front passage and so on. A difference was confirmed clearly as to 2 points, Shirahama and Shionomisaki, where are only 50 km distance. As for the time of local weather change, we must estimate the amount of the zenith tropospheric delay in each point. It ascertained that an error could be reduced by combining a filter at the usual time, too.

3. Semi-real time monitoring system

Based on the experiment result of last chapter, we started construction of a monitoring system. We show flow chart of this system in Fig.5. First, we start observation in each station. We collect data in 30-second sampling at first. Using local area network of Kyoto

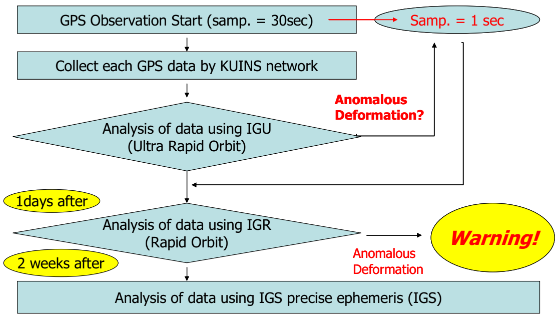

Fig.5. The flow chart of a semi-real time monitoring system.

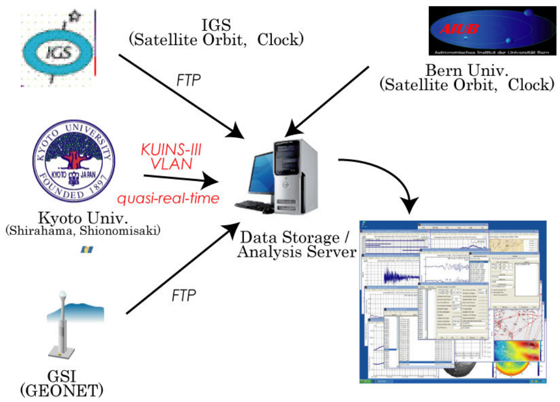

Fig.6. The flow of a information of the semi-real time monitoring system.

University, KUINS, we acquire data in semi-real time from each station to Uji. And we analyze the first. This satellite orbit for analysis is an IGS ultra-rapid orbit (IGU). If an anomalous deformation was seen at some stations, remote control does each station, and we change a sampling for 1-second. Next, we reanalyze after 1 day. We use an IGS rapid orbit (IGR) that accuracy is higher in comparison with an IGU. When the change that is similar to the last analysis is seen at some stations, the computer system alerts automatically. Finally, with an IGS final precise ephemeredes (IGS) announced two weeks later, we perform the last analysis.

Next, we explain about the flow of the information. The data which could get in each station, Geographical Survey Institute (GSI), International GNSS Service (IGS), and Berne University, Switzerland (AIUB) are collected to a data storage server by KUINS LAN or FTP in quasi-real time. When data are updated, the monitoring system begins analysis automatically using by GPS-Tools. It converts the results into a figure so that many people can understand it and presented in the homepage and so on.

4. Conclusions

We apply the kinematic GPS analysis to land observation. Therefore we established two continuous stations, Shirahama and Shionomisaki. We tried to apply the various filters, e.g., spatial filter, sidereal filter and so on. As a result, the positioning accuracy came to converge to about 2 cm in horizontal component except time of weather disturbance. We start HR-PPP technique using GPS-Tools ver.0.6.3 to automate the monitoring system. We connected KUINS Virtual LAN network for quasi-real-time data collection. As a future subject, we try to remove an error factor with ground weather observation data, Ujigawa, Shirahama, and Shionomisaki. And we must build an automatic analysis program and shell script to enhance positioning accuracy more.

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異常地殻変動検出手法の開発（２）
長基線での実験とモニタリングシステムの構築

佐藤一敏・橋本　学・細　善信

要　旨

我々は異常地殻変動検出手法の開発に取り組んでいる。本年度は短基線での実験から長基線へ展開し，誤差要因である電離層・対流圏の影響を評価してきた。今回GPS-Toolsという新たなソフトウェアを使い，恒星日フィルター，空間フィルターを組み合わせることによって，約2cmの測位精度が確保できることが分かった。しかしながら，局地的な気象擾乱時については，それぞれの観測点について正確に推定する必要があることが分かった。これをもとにして，準リアルタイムモニタリングシステムの構築に取り組みはじめた。

キーワード:キネマティックGPS測位，電離層・対流圏遅延，恒星日フィルター，空間フィルター