Addition of real-time capability to the Japanese dense GPS Network

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Abstract

In 2002-2003, GSI has modified and upgraded the nationwide GPS array of Japan to enhance real-time capabilities. The upgrade covers most of the components including receivers, antennas, data communication, data archive, analysis systems, etc. The 1-Hz data are acquired at the observation sites, and transferred to Geographical Survey Institute (GSI) in Tsukuba through Internet Protocol - Virtual Private Network (IP-VPN) in real-time. In case of emergency, the 1-Hz data are analyzed by RTK-type software for selected baselines. Three types of routine analysis are carried out; final and rapid analysis in daily, and near real-time analysis every 3 hour with sliding data-window of 6 hours. The 1-Hz data are also provided to commercial users (positioning service companies) in real-time through a non-profit organization with charging the cost.

Introduction

GSI has been operating the nationwide GPS network of Japan called GEONET (GPS Earth Observation Network System). The network covers the whole Japan land area with 1200 GPS permanent stations with average spacing of 20 km (as of March, 2004) to monitor crustal deformations and to provide reference stations for users of land surveying by GPS (Fig. 1).

The routine analysis of the system had been carried out daily with 24-hour session. The daily solutions of station coordinates have been used to detect crustal deformation associated with seismic/volcanic activities and to discuss plate motions. It has been recognized, however, that 24-hour solutions are not always provide information timely enough for coping with the emergency situation, and higher temporal resolution and acceleration of the processing had been desired.

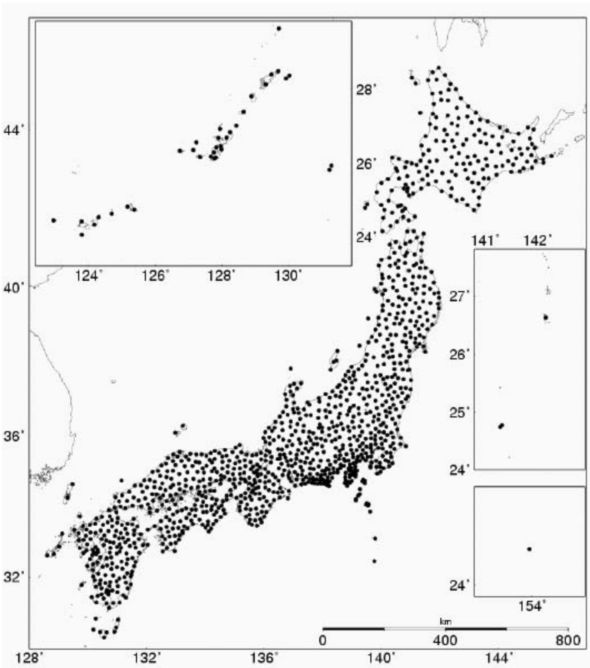

Fig.1 Geographical distribution of GEONET stations.

Impact of near real-time analysis for crustal deformation monitoring was demonstrated for the eruption of Usu volcano. Seismic swarms were activated under the volcano in March, 2000, and were considered as a symptom of eruption. In addition to the routine analysis, a special analysis with 6-houe sessions was carried out every 3 hours. Fig. 1 shows an example of time-series of baseline length of one of the three baselines across the volcano. The circles and triangles plot the daily routine solutions and the special 3-hour solutions, respectively. The 3-hour solutions clearly show the transition of the crustal deformation: It started with slight expansion of baseline, turned to a significant deflection, and a day after the volcano erupted. The deflection is an indication of the movement of magma to a shallower portion. This result gave the government one of strong bases for issuing an announcement for inhabitants to take refuge from the surrounding area of the volcano. For the sake of this announcement, nobody was injured by the eruption.

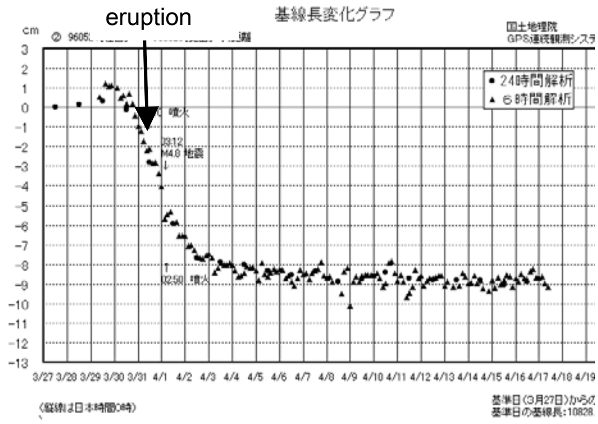

Fig. 2 Time series of length of a baseline across Mt. Usu. Circle and triangle show routine solutions and 3-hour solutions, respectively. The big arrow shows the timing of the eruption.

Another motivation for enhancement of real-time capability is the effect of GEONET as reference network for real-time positioning which has been recognized for long time. The area that RTK is applicable with GEONET was limited by the distance between the reference stations. Recent developments of network-type RTK techniques (e.g. Raquet and Lachapelle, 2001) broke this barrier. GSI gained momentum to add real-time capability and high rate (1-Hz) sampling to enhance function of GEONET as a social infrastructure to aid development of positioning industry.

Reinforcement of the network

253 new stations are added to the preexisting 947 station, and the number of the station became 1200 in total by March, 2003. The old receivers are replaced with new ones that are capable of 1-Hz sampling and real-time data transfer. The antennas-types are unified to the choke ring antennas of Dorne Margolin T-type by replacing the old antennas of preexisting stations. The elevation mask of the receiver setting was changed from 15 degrees to 5 degrees.

Figure 3 shows schematic diagram of the data flow of GEONET. Most of the sites, where broadband line is available, have IP-connection through IP-VPN (Internet Protocol Virtual Private Network). IP-VPN is a communication network provided by communication companies, and realizes IP-connection to the sites with closing the communication within limited users ("virtually private") for high security. The raw data observed in 1 Hz are transferred in real time to the central station at the data center of GSI in Tsukuba city. The 1-Hz data are decimated into 30 second sampling interval and kept in the receiver memory for several days. In case there are troubles in data communication, the 30-second data are retrieved after the recovery of communication. For the sites where broadband line is not available, data are observed with 30 second sampling interval and transferred by telephone line or satellite communication every 3 hours.

The 1-Hz data, transferred to GSI, are saved temporary in hard disks in raw data format and are converted to RINEX format with decimating into 30 second sampling interval every 3 hours. The 3-hour RINEX files are archived in the database and also uploaded to a FTP/Web server. The 1-Hz data are not archived permanently but discarded two weeks after the observation at current procedure except for the case of special experiments or seismic/volcanic events of interest. The data are converted to RINEX format, decimated to 30-second interval and archived for routine analyses.

The 1-Hz real-time data are also provided to commercial users of positioning service through a non-profit organization with charging the costs. Japan Association of Surveyors (JAS) is taking this task of the portal of the real-time data provision, and three positioning service companies contract with JAS at current.

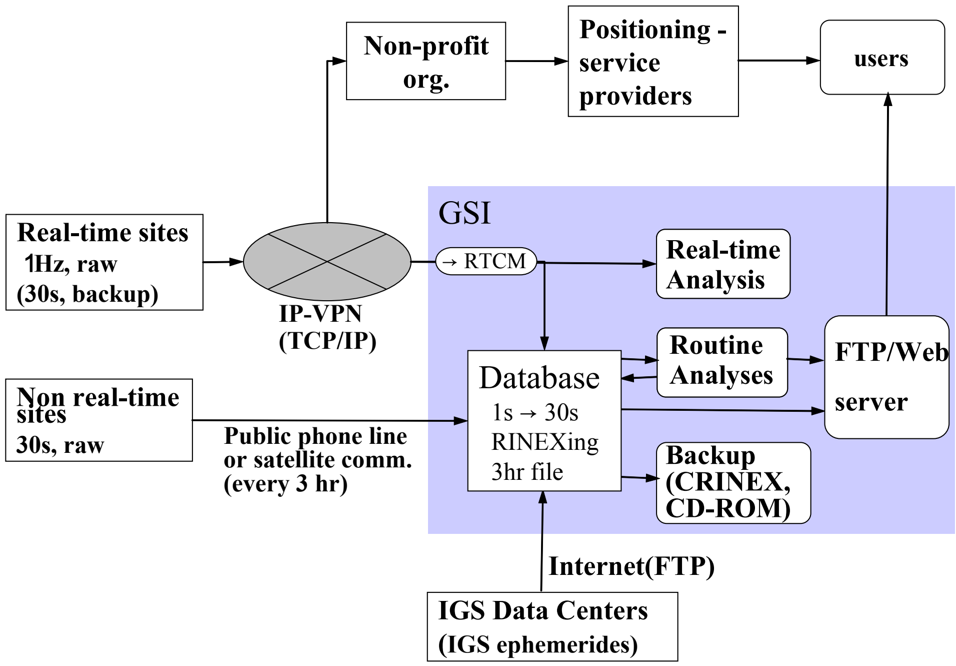

Fig. 3 Schematic diagram of the data flow of the new GEONET system

Data Analysis

Three kinds of routine analyses (Table 1) are carried out with using the data of 30-second sampling; the quick analysis, the rapid analysis, and the final analysis. The quick analysis is carried out in near real-time, every 3 hours with 6 hours data window. The rapid and final analyses produce daily solutions with 24 hours data and much more precise than the quick analysis. The IGS ultra rapid products are used in the quick and rapid analyses. The final analysis is carried out about two weeks later with the IGS final products. The same software package (BERNESE version 4.2; Hugentobler et al, 2001) is used with the same model settings for these three analyses so that the

Table 1 list of routine analyses

Type	Sess.	Freq.	eph.
Quick	6hr	every 3 hr	IGU
Rapid	24hr	daily	IGU
Final	24hr	weekly	IGS

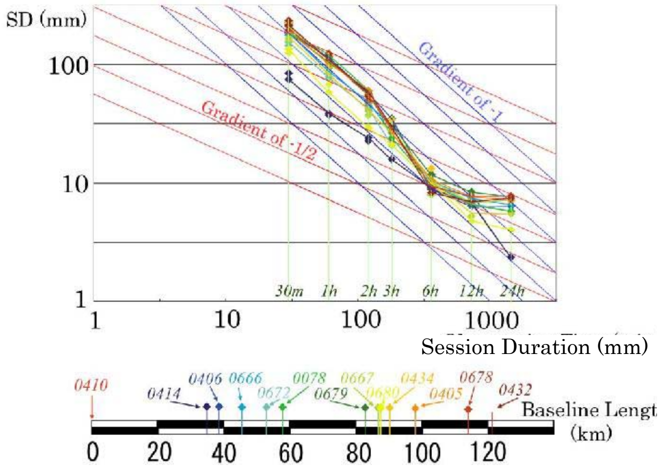

Fig. 4 Trade-off curves between the standard deviation and session duration taken from the test analysis of 13 baselines.

solutions can be compared without significant biases. Most of the settings are the same as the former system (Hatanaka et al., 2003) except that the whole network is fixed by single station at Tsukuba with ITRF2000 coordinates .

The session length of 6 hours for the quick analysis was chosen by checking baseline repeatability for various baseline lengths and session durations. There is trade-off relationship between temporal resolution and precision. As shown in Fig. 4, the shorter the baseline is, the worth the repeatability is. It is also shown in the trade-off curve that increase of standard deviation by shortening of session is less severe at the range of session duration less than 6 hours. Similar results are also obtained by Eckl et al. (2001).

The IGU ephemeredes play an important role in the quick and rapid analyses. The system tries to access several IGS data centers until updated IGU products are obtained. Redundancy of IGS data centers is helpful to minimize troubles with getting IGU products.

Temporal resolution higher than 3 hours is desired in emergency situation such that eruption of a volcano is imminent. In such a case, special analysis of RTK-type can be carried out by using the 1-Hz real-time data of dual frequency for selected stations less than 50 as well as routine analysis. The RTNet software (GPS Solutions Inc.) is used for this analysis.

Fig.5 shows an example of time series of baseline components taken from the quick solutions obtained by the new system. Coseismic crustal deformation of the 2003 off-Tokachi earthquake (September 26, 2003, M8.0) is clearly seen as steps of several tens of centimeters and followed by a post-seismic movement of more than 10 cm. The coordinates run off at the session just after the steps and this may be an error caused by the huge movements of the sites in the middle of the session, which is not modeled in the analysis.

Fig. 6 shows an example of kinematic solutions of 1-Hz data for another baseline obtained by RT-Net in post-processing mode. Seismic waves (difference between two sites) are clearly observed as well as the permanent deformation in spite that smoothing condition is slightly imposed to stabilize the solutions. Although accuracy of kinematic solutions is, in general, worse than static solutions, this example demonstrates that the RTK analysis is still useful to detect large crustal movement.

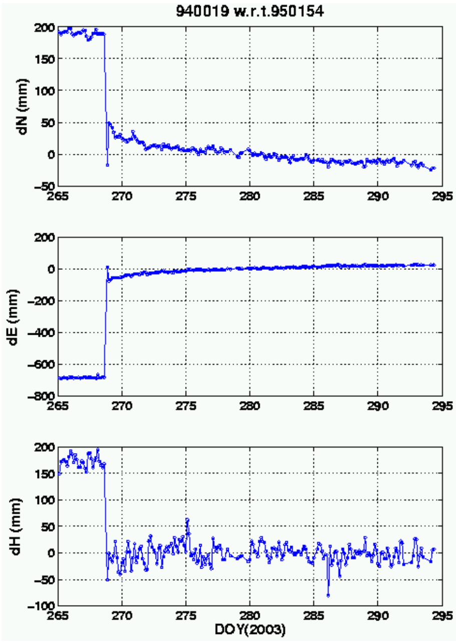

Fig. 5 Time series of three components of baseline vectors of quick solutions for the 2003 off-Tokachi earthquake for a sample baseline (950153-940019).

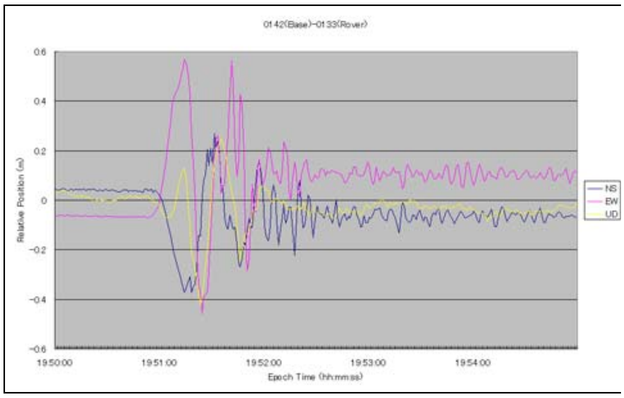

Fig. 6 Example of time series of baseline solutions obtained by the analysis of 1-Hz data with the RTNet software for the 2003 off-Tokachi earthquake. The analysis was done in a post-processing mode and 5-minute results is shown.

Summary

GSI upgraded the GEONET system to enhance the real-time capabilities. 1 Hz data are observed at most of the 1200 stations and transferred to GSI in real-time. The 1-Hz real-time data are also provided to commercial users of positioning service. This would stimulate developments of new industry based on the real-time data of GEONET. As well as the daily analyses, near real-time analysis of the 1200 stations are now carried out routinely, and dual-frequency RTK analysis using real-time 1-Hz data is ready for emergency situation. Quick response to the earthquake/volcanic events is possible.

References

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