

Continuous GPS array of Japan and its application to crustal activity modeling

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Abstract

A continuous GPS array is a very useful tool for monitoring and modeling crustal activity. GPS observation has revealed various unknown aspects of tectonic deformation in Japan and other locations. Quasi-real time data acquisition and dense spatial coverage enable incorporation of GPS data into simulation models for crustal activity forecast, which is similar to data assimilation in weather forecast. For that purpose, it is important to develop new techniques of geodetic inversion and time series analysis.

Introduction

Just as in the case of weather forecast, simulations for forecasting future crustal activity require incorporation of observation data and their combination with calculation results. This process is called data assimilation. If we try to forecast crustal activity in a successive manner, quasi-real time data assimilation of continuous observation is mandatory. In earthquake simulations, those observation data must be mathematically connected with a physical process of earthquake generation. Crustal deformation data are one of top candidates for this purpose. It has been proved that dislocation theory works quite well for describing coseismic, postseismic and interseismic deformations. Dense continuous GPS array provides precise locations of GPS stations everyday (or more frequently), and spatial coverage is now becoming satisfactory in Japan and southern California. I brief an outline of the world's largest continuous GPS array in Japan and its recent results. In addition, several techniques used for inversion and assimilation of GPS data are discussed.

Continuous GPS array in Japan

Geographical Survey Institute of Japan (GSI) started construction of its nationwide GPS array in 1993. Operation of the array started in 1994 with 110 stations in the Kanto-Tokai region, central Japan. More and more stations have been installed every year. Presently, the array consists of about 1,000 stations working continuously. Steady deformation of the Japanese islands and seismic deformations associated with some significant events were revealed based on the GPS data (Tada et al., 1997[1]).

Routine processing

GPS phase data acquired at continuous stations are transferred to the central control system at the GSI main office, using public telephone lines. GPS phase data for 24 hours (UT0-UT24, JST9-JST9) are transferred at night (from JST23, which is equal to UT14) because of the telephone cost. After the completion of data transfer, data processing starts. Coordinates of all the stations are calculated using a combination of rapid orbits and predicted orbits of GPS satellites. The first results come up at around JST14 (UT5) on the next day. The time lag between the end of observation and the initial solution is nearly 30 hours. All the station coordinates are calculated again to obtain the final solution using IGS (International GPS Service for geodynamics) orbit after a few weeks. For some special cases, such as an active earthquake swarm or a volcanic eruption, we transfer phase data every 3 hours and calculate baseline components using broadcast orbits in a quasi-real time manner to monitor the crustal activity. GSI is going to start a similar quasi-real time monitoring of crustal movements in the Tokai area, jointly with the Japan Meteorological Agency.

In GSI, time series plots of station coordinates and vector plots of displacement/velocity vectors are looked over for the purpose of routine monitoring of crustal deformation. A database system stores daily coordinate solutions, their covariance matrices, and raw phase data for further analyses.

Tectonic implications of GPS results

GPS-derived velocity/strain field revealed various features of tectonic deformation in the Japanese islands. Following features are examples of important findings and should be considered in modeling. 1) Outstanding landward deformation along major seismogenic megathrust zones such as the Nankai Trough and the Japan Trench. 2) Eastward motion of the western Japan inner zone relative to the Eurasian Plate. 3) A significant deforming zone running NE-SW across the central part of Japan. 4) Seaward motion of Ryukyu islands.

Inversion and assimilation of GPS data

Geodetic inversion is a usual method to translate crustal deformation data into a physical process under the ground. Various techniques of geodetic inversions have been developed. GPS data assimilation process is a combination of geodetic inversion and time series analysis. In addition, the assimilation process must be synchronized with a numerical simulation. We need to construct a well-organized system to realize efficient data assimilation. Examples of inversion/assimilation analyses based on GPS data are discussed below.

Interplate coupling along subduction zones

Interplate coupling distribution is estimated from an inversion analysis of continuous GPS data for several locations around the Japanese islands. In the Tokai region, northeastern end of the Nankai Trough, laterally heterogeneous coupling was found (Sagiya, 1998[2]). The result implies a longer interseismic interval in the Tokai region than previously expected. Similar analyses for the Nankai Trough, the Sagami Trough, and the Japan Trench

show significant interplate coupling at seismogenic depth. These results prescribe spatial extent of interplate locking zones and their strength, which kinematically constrain physical model of a plate boundary process.

Inversion analysis for earthquake deformation cycle

In order to estimate spatio-temporal distribution of interplate sliding along the plate boundary surface, it is necessary to conduct an inversion analysis of historic geodetic data taking viscoelastic effects of asthenosphere into account. Two-dimensional analysis technique was developed and applied to leveling data along the Nankai Trough by Matsu'ura et al.(1998)[3], and it is being extended for a three-dimensional case. The history of interplate sliding is directly connected to a loading process of interplate earthquakes. Precise estimation of the interplate sliding history has valuable implications for the constitutive relation of plate interface.

Although GPS data can constrain present deformation only, continuation of monitoring effort will resolve much more detailed and precise deformation field as well as their temporal variations.

Assimilation of GPS data for crustal activity modeling

GPS data provides important boundary conditions for modeling of crustal deformation in various scales. GPS observation is now widely used for determining global plate motions. But we can make full use of various advantages of GPS in regional or local scales. The Crustal Activity Modeling Project (CAMP) in Japan is trying to incorporate continuous GPS data into a simulation model for crustal activity in the Japanese islands. GPS data assimilation of CAMP is to deduce spatio-temporal distribution and present status of interplate sliding through geodetic inversion of GPS data, and to constrain a simulation model by the inversion results in a quasi-real time manner.

Present root mean squares error of GPS station coordinates is a few millimeters in horizontal and 10-20 millimeters in vertical. This accuracy is good enough to resolve monthly deformation of active regions near plate boundaries though it is too poor for daily assimilation. Thinking of the accuracy and feasibility, monthly assimilation into a simulation model is a target for the time being. There still remain seasonal effects in GPS time series, which are obstacles for obtaining reliable monthly data.

On the other hand, daily or hourly analysis is required for monitoring precursory changes of large earthquakes. We need to process much noisier data to detect small changes. Quasi-real time data assimilation combined with a numerical simulation based on earthquake source physics is necessary to distinguish real precursory changes from false signals. Advanced techniques of time series analysis such as Kalman filtering technique (Segall and Matthews, 1997[4]) would be useful for this purpose.

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References

- [1] Tada, T., Sagiya, T. and Miyazaki, S., 1997, *The deforming Japanese islands as seen by GPS*, *Kagaku*, **67**, 917-927 (in Japanese).
- [2] Sagiya, T., 1998, *Interplate coupling in the Tokai district, central Japan, deduced from continuous GPS data*, submitted to *Geophys. Res. Lett.*
- [3] Matsu'ura, M., Nishitani, A., Fukahata, Y., 1998, *Slip history during one earthquake cycle at the Nankai subduction zone, inferred from the inversion analysis of leveling data with a viscoelastic slip response function*, *Eos Trans. AGU*, **79**(45), Fall Meet. Suppl., F891.
- [4] Segall, P., and Matthews, M., 1997, *Time dependent inversion of geodetic data*, *J. Geophys. Res.*, **102**, 22391-22409.