Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MGI032-01 Room:102 Time:May 23 16:30-16:45

Introduction of uncertainty of Green's function into waveform inversion for seismic source processes

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In principle, we can never know the true Green's function, which is a major error source in seismic waveform inversion. So far, many studies have devoted their efforts to obtain a Green's function as precise as possible. In the present study, we propose a new strategy to cope with this problem. That is to say, we introduced uncertainty of Green's function into waveform inversion analyses. Due to the propagation law of errors, the uncertainty of Green's function results in a data covariance matrix with significant off-diagonal components, which naturally reduce the weight of observed data in later phases. Because the data covariance matrix depends on the model parameters that express slip distribution, the inverse problem to be solved becomes non-linear. Applying the developed inverse method to the teleseismic P-wave data of the 2006 Java, Indonesia tsunami earthquake, we obtained a reasonable slip distribution and moment rate function without the non-negative slip constraint. The solution was independent of the initial condition of the model parameters. If we neglect the modeling errors due to Green's function as in the conventional formulation, the total slip distribution is much rougher with significant opposite slip components, whereas the moment rate function is much smoother. If we use a stronger smoothing constraint, more plausible slip distribution can be obtained, but then the moment rate function becomes even smoother. By comparing the observed waveforms with the synthetic waveforms, we found that high frequency components were well reproduced only by the new formulation. The modeling error is essentially important in waveform inversion analyses, although they have been commonly neglected.

Keywords: Seismic Source Process, Waveform Inversion, Uncertainty of Green's function, Modeling error, Tsunami Earthquake

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MGI032-02 Room:102 Time:May 23 16:45-17:00

Fault parameters inferred from data assimilation on seismic & acoustic waves due to 2008 Iwate-Miyagi Nairiku Earthquake

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An evidence of seismoacoustic waves due to a big earthquake is sometimes recorded in barometer data at an infrasound observatory several hundred kilometers away from the hypocenter. Such infrasound variations must contain information of the source mechanism of the earthquake and structures of both solid Earth and atmosphere. Therefore it is possible to obtain, from a different perspective from seismic data, knowledge about earthquakes by analyzing the infrasound data.

Here we estimated the fault parameters of the 2008 Iwate-Miyagi Nariku Earthquake carrying out data assimilation on infrasound data. First we calculated a set of eigenfunctions of normal modes (Kobayashi [2007]) related to a one-dimensional coupled model consisting of the solid Earth (PREM; Dziewonski and Anderson [1981]) and the atmosphere (NRLMSISE-00; Picone et al. [2002]). Then we constructed prior distributions for the fault parameters such as rupture length and velocity by integrating models previously proposed from many universities and institutes. Finally we applied a sequential Monte Carlo (SMC) method such as the particle filter algorithm to a combination of simulated waves derived from the eigenfunctions and observed data obtained at CTBTO Isumi microbarometer array. We will discuss especially on the obtained posterior distributions of the fault parameters and differences between our result and the previous ones.

Keywords: data assimilation, Bayesian filter, particle filter, infrasound, seismoacoustic wave, Iwate-Miyagi Nairiku Earthquake

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MGI032-03 Room:102 Time:May 23 17:00-17:15

Identification of hydraulic conductivity of groundwater flow simulaiton using a particle filter

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[1]Shimizu Corpolation

In the groundwater flow simulation, the appropriate setting of the hydraulic parameters is essential for the reliable analysis. In fact, it is difficult to know the actual parameter values, because the available samples are insufficient, or the in-situ measurements are impossible in some cases. Additionally, there is often great difficulty in obtaining the simulation results that match the observed data, in which case many parameters must be determined in the analysis.

In this study, in order to determine the hydraulic parameters used in the groundwater analysis and improve model accuracy, we applied the particle filter, which is one of the sequential data assimilation methods, to the groundwater flow simulation from the perspective of using the observations.

For the validation, 2-dimensional saturated-unsaturated flow simulation of seepage through a rock-fill dam was performed as a test case. Observed data are the amount of the leakage, which are calculated from the forward analysis using the preset hydraulic conductivities. As a result of the sequential data assimilation, the hydraulic conductivities of the impervious zone and the dam-foundation could be estimated precisely, and we verified the effect of these parameters on the observed leakage with the posterior distributions of the state space variables.

In the maintenance management of dam, this technique can be applied to the damage identification of the impervious zone.

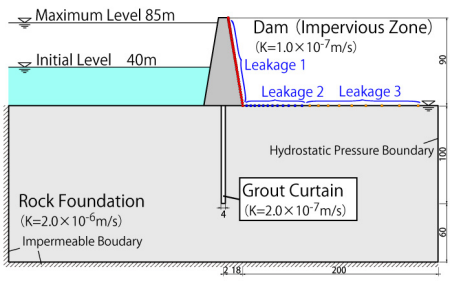

Fig1. Analytical model

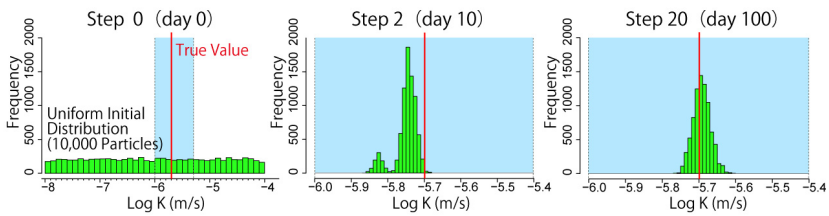

Fig2. Change of particle distribution of the hydraulic conductivity (rock foundation)

Keywords: data assimilation, particle filter, groundwater flow simulation

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Application of the particle filter to data assimilation for a plasmasphere model

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The particle filter (PF) is an algorithm applicable to general data assimilation problems including non-linear and non-Gaussian problems. Since the PF is suitable for parallel computing, it is considered to be one of promising algorithms for data assimilation problems with high nonlinearity. In this study, we applied the PF to data assimilation for the Earth's plasmasphere. The plasmasphere is the innermost region in the magnetosphere filled with cold dense plasma. We describe the technical aspect of our data assimilation method and show results of applying this data assimilation technique to the plasmasphere.

Keywords: particle filter, data assimilation, plasmasphere

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Method for estimating the plasmaspheric density distribution from the ground magnetic field and GPS TEC

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The plasmasphere is the region in space, close to the Earth. It is a part of the magnetosphere (region filled with the Earth-origin magnetic field). The plasmasphere is filled with ionosphere-origin plasma, and the shape of the plasmasphere changes in response to the activity of the magnetosphere. It is important to monitor three-dimensional plasma distribution in and near the plasmasphere; for example, the plasmasphere can affect the progress of magnetic storms via plasmasphere-ring current interactions (the ring current is another region in which strong electric currents, carried by plasma there, flow in the shape of a ring surrounding the Earth).

Measures to monitor the three-dimensional density distribution in and near the plasmasphere includes ground magnetometers and GPS satellites, as follows. From ground magnetometer data one can identify the eigenfrequency of the field line running through the magnetometer. From thus identified frequency (so-called FLR frequency, where FLR stands for "field line resonance"), one can guess the plasma mass density distribution along the field line. Ground coverage by magnetometers is getting thicker day by day toward two-dimensional ground coverage, from which one can guess three-dimensional plasma density in the region threaded by the field lines running through the ground surface.

Each GPS satellite provides TEC (total electron contents) along the line of sight from the satellite to a ground GPS receiver; from the TEC one can guess the electron density distribution along the line of sight. There are 24 GPS satellites, and the ground coverage by GPS receivers is getting thicker day by day, from which one can guess three-dimensional electron plasma density in the region covered by the line of sights from the GPS satellites to the ground GPS receivers.

In this paper we invent a method to evaluate the ground-magnetometer information and the GPS-TEC information at the same time and obtain a unified plasmaspheric plasma density distribution. In essence, the method calculates the differences between the observations and the corresponding quantities calculated from the estimated plasma distribution, and minimizes the sum of the differences for the two types of observations. Details will be given at the presentation. We first realize this method in an iterative manner by using the quasi-Newton method. We have so far tested it with simulated data; we will show the results at the meeting. Further tests with sample data are ongoing.

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MGI032-06 Room:102 Time:May 23 17:45-18:00

Development of Forecasting Method of Spatio-Temporal Afterslip Evolution by Adjoint Method

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We develop a method to forecast spatio-temporal afterslip evolution based on adjoint method for the purpose of predicting the second event of compound earthquakes. One large earthquake sometimes triggers another earthquake nearby with the intervals of hours to years. An example includes megathrust earthquakes at the Kurile Trench. The 2004 November 29 Nemuro-oki earthquake followed the 2003 September 25 Tokachi-oki earthquake. A significant afterslip was observed between those two earthquake rupture regions. Furthermore the afterslip has propagated from the Tokachi-oki earthquake region to the Nemuro-oki region. Thus the Nemuro-oki earthquake is thought to be triggered by the afterslip. In such a case, forecast of afterslip propagation may help to predict the triggering of the second large event (the Nemuro-oki earthquake in this case).

This study is dedicated to develop a forecasting system of afterslip evolution. Evolution of slip velocity and frictional coefficient is governed by a rate- and state- dependent friction law. Three frictional parameters determine the friction that acts on the plate interface. Thus we need to know frictional parameters in addition to the initial conditions of differential equations. Kano et al. (2010, in Japanese) first employed an adjoint method and examined how this method works for our purpose by twin experiments. They used decaying phase of afterslip velocity on the plate surface to update frictional parameters. However, all frictional parameters are not constrained by those data. Thus we use data for the propagation of afterslip and investigate the possibility of estimating other parameters. The results are summarized as follows:

(1) Decaying part of afterslip data constrains the initial value of slip velocity and frictional parameter a-b, but does not either the initial value of state variable or the parameter L.

(2) Early phase of afterslip data prior to reaching to the steady state constrains the parameter L and initial value of state variable theta.

(3) Data for the propagation of afterslip constrains all of parameters a, a-b, and L.

The adjoint method, which is numerically efficient one, would be one of the future courses of developing a forecasting system of earthquake generation.

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Simultaneous estimation of frictional parameters on earthquake and afterslip rapture areas using an adjoint method

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Recent developments of numerical and observational techniques in seismology and geodesy enhance our ability of drawing more realistic pictures of thrust-type earthquake generation cycles along subduction zones. Forward integrations of the equation of motion with the rate and state friction law (the frictional parameters; A, B, and L) allow to simultaneously depict the multi-time scale ruptures on a fault plane, namely, an earthquake and the associated afterslips. In addition, the denser GPS network such as the GEONET array provides more detailed information of the crustal deformation due to earthquakes. In consequence, for improving our earthquake cycle model, it is expected to assimilate the observational information on the crustal movement into the earthquake cycle model through adjusting the frictional parameters on both earthquake and afterslip surfaces.

In this couple of years, opportunities for the application of the data assimilation technique rapidly increased. However, we still face difficulties. First, few assimilation approaches are successful to simultaneously estimate all the frictional parameters on the earthquake and afterslip planes. An earthquake and the associated afterslips can be in a cause-effect sequence; therefore, their frictional parameters on both surfaces should be simultaneously obtained. However, it is difficult to simultaneously perform data assimilation of the earthquake and afterslips due to their widely-separated time constants (from a few seconds to more than a year). Second, we still make a trial-and-error method to find out an adequate assimilation time window. It is crucial to properly assess the data assimilation window for most efficiently evaluating the frictional parameters.

To tackle the first problem, we develop an adjoint backward technique with adaptive time steps based on the fifth-order Runge-Kutta forward integration (Press et al, 1993). We then apply the adjoint technique for the synthetic ”twin” experiments in which the known true model is tried to be recovered with assimilating the artificial observed data into the iterative model. The synthetic twin experiments show that our adjoint technique with adaptive time steps can estimate all the frictional parameters (A, B, and L) on the earthquake fault plane as well as the afterslip areas even in different time scales.

To find an adequate assimilation time window, we plot and analyze the sensitivities of the slip velocity (V) in terms of the parameters (A, B, and L) on the earthquake and afterslip surfaces. It suggests that the assimilation time window should cover at least that of the acceleration phase of the slip velocity ($dV/dt>0$).

We note that our results account for the possibility of estimating the frictional parameters on earthquake and afterslip surfaces in the theoretical framework. Therefore, we need to develop our adjoint method for more detailed earthquake cycle models with the real observational data.

Keywords: assimilation, adjoint method, earthquake cycle, afterslip, frictional parameter

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An iterative algorithm for estimating the observation error covariance matrix for ensemble-based filters

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In data assimilation, covariance matrices are introduced in order to prescribe the properties of the initial state, the system noise (model error, process noise), and the observation noise (observation error). Suitable specification of the covariance matrices is essential for obtaining sensible estimates, and misspecification of the matrices may lead to over- or under-fitting of the data and/or failure of the assimilation altogether. We present a technique for optimizing covariance matrices for observation noise.

Methods for estimating the optimal covariance are typically based on a common statistic, specifically the so-called "innovation," which is the difference between the observation and the predicted model state. Innovations are evaluated in the methods of minimizing the squared innovations, the maximum likelihood, Bayesian estimation, and the covariance matching. The above-mentioned methods for estimating optimal covariance are, however, originally constructed based on linear-Gaussian state space models, that is, it is assumed that both the system equation and the observation equation are linear, and that both the system noise and the observation noise follows from Gaussian distributions. However, the maximum likelihood can be extended even when the system and observation equations are nonlinear (Ueno et al., 2010). Nonlinearities in the system equation are typically introduced by the advection term in the momentum equation, and can be dealt directly with by ensemble-based assimilation methods such as the ensemble Kalman filter (EnKF) and the particle filter (PF). Ueno et al. (2010) has proposed a method of ensemble-based maximum likelihood, where the likelihood is approximated with the ensemble, and demonstrated that the method can estimate the parameters that describe the covariance for system noise and observation noise. Their procedure of maximizing the likelihood, however, requires huge computational costs; it requires assimilation runs many times that amount to the total number of combinations of the parameters. It means that the method of ensemble-based maximum likelihood may not work in practice where tens or more covariance parameters need to be optimized.

Here we propose an efficient algorithm for the maximum likelihood estimation of the observation noise covariance. The algorithm is based on an analytical derivation of the derivative of the ensemble-approximated likelihood with respect to the observation noise covariance, and forms an iterative updating procedure for estimating the optimal covariance parameters. The algorithm works with the ensemble-based filters in which the likelihood can be approximated with the ensemble. Since the algorithm does not require evaluating likelihood for every combination of the covariance parameters as done in Ueno et al. (2010), it can estimate many elements in the observation noise covariance matrix.