Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

HDS26-P01 Room:Convention Hall Time:May 20 18:15-19:30

Forward calculation of the electromagnetic field induced by tsunamis, using non-uniform thin-sheet approximation.

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A seafloor geomagnetic observatory in the northwest Pacific detected clear electromagnetic (EM) variations associated with tsunami passage from two earthquakes that occurred along the Kuril Trench (Toh et al., 2011). Previous seismological analyses indicated that the M8.3 earthquake on 15 November 2006 was an underthrust type on the landward slope of the trench, while the M8.1 earthquake on 13 January 2007 was a normal fault type on the seaward side (Ammon et al., 2008).

We tried to simulate the frequency dependence of the observed EM signals, using a three-dimensional (3-D) non-uniform thin-sheet approximation, which can accommodate not only the inducing non-uniform source fields caused by particle motions of conducting seawater at the time of tsunami passage but also the self-induction effect within the ocean and its conductive substrata. Horizontal particle motions were calculated by Fujii and Satake (2008) with two types of hydrodynamic approximation, viz., the Boussinesq approximation and the long-wave approximation. Because the dispersion effect of each tsunami was more remarkable in the 2007 event, the observed EM variations were expected to be more compatible with the simulated EM signals using the Boussinesq approximation than the long-wave approximation.

As a result of the frequency analysis of the observed EM variations at the time of the 2006 event, the frequency of 1.04mHz is most dominant, which is consistent with the result of the frequency analysis of the simulated horizontal particle motions. Also, We confirmed that synthetic plane waves in a flat ocean induced ?-harmonic EM variations. The calculated EM amplitudes for the 2006 event at a period of 960s using the Boussinesq approximation were smaller than those with the long-wave approximation. This can be interpreted as reflecting the dispersive effect.

In this presentation, we will further discuss the advantages and disadvantages of conducting the simulation in the frequency domain for tsunami EM signals and describe the necessity to use the Boussinesq approximation in order to elucidate the observed EM signals at the time of the dispersive tsunami. Furthermore, we will discuss to what extent we can neglect the presence of the horizontal components of the geomagnetic main field in evaluating the source dynamo currents. Also, we will emphasize the usability and importance of the EM observation on the seafloor for tsunami forecast in comparison with the conventional tsunami-height measurements at sea and/or the geomagnetic observations on land.

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HDS26-P02 Room:Convention Hall Time:May 20 18:15-19:30

Development of Ku-band broad band radar for tsunami monitoring

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We began to develop tsunami monitoring radars based on the idea of Ku-band broadband radars, which estimate precipitation with quite high range resolution. The final goal of the tsunami monitoring radars is to estimate the arrival time of tsunamis and wave heights of them. The basic idea of the tsunami monitoring radars is quite similar to the Ku-band broadband radar; center frequency, frequency band, and range resolution, respectively, are 15.75 GHz, 80MHz, and 5m. Last year we had an observation campaign with a prototype tsunami monitoring radar in Tanabe Bay, Wakayama prefecture, to test our method. We confirmed that the radar detected caps of sea waves and there was a linear relationship between radar reflectivity and the wave heights.

Keywords: tsunami, remote sensing, microwave

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Application of numerical forecast model of storm surge to tidal correction for tsunami survey

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In order to measure tsunami inundation height, a watermark which remained at building or tree is used. The inundation height is measured as a height from nearby sea surface or as an altitude from nearby altitude reference point. Since the tide level is always changed, tidal correction is necessary for accurate measurement of the tsunami height. In case of measurement as the height from sea surface, two tide levels, at the time of measured the height and the time of reached maximum tsunami wave, are necessary for tidal correction. In case of measurement as the altitude, the tide level, at the time of reached maximum tsunami wave, is necessary. Usually tidal correction is done by using the observed data at nearest tide gauge station or computed astronomical tide. However, since the tide level is changed by atmospheric pressures and winds, they become error factors for tidal correction.

A numerical forecast model of storm surge has been developed by Japan Meteorological Agency since 1998 for forecast storm surge by typhoon mainly. Generally tide level consists of two factors, one is astronomical tide and the other is tide level departure caused by atmospheric conditions and ocean current. In the computing procedure of the forecast model, the tide level departure is computed at first, and then computed astronomical tide will be added to the obtained tide level departure. Today the numerical forecast data, called storm surge guidance data, is forecasting the tide level at all along Japanese coastline spacing one km grid, and is used for the storm surge alarming system.

The storm surge hind-cast data, which is initial model of forecasting storm surge, has an advantage over the astronomical tide, because it is including effect of the tide level departure. And one more advantage is that it can offer high density data which is one km spacing of tide level. Therefore, the storm surge hind-cast data may be able to use for tidal correction of tsunami survey.

In this study, we researched about whether the storm surge hind-cast data is able to use for tidal correction or not. We checked the accuracy of the storm surge hind-cast data by comparing observed tide level at 69 tide gauge stations, which are operated by Japan Meteorological Agency, in the period of November 2012. As the result, it is found that in almost all cases the storm surge hind-cast data is able to use for the tidal correction for tsunami survey.

Keywords: tsunami, tidal correction, tide gauge station, storm surge, watermark of tsunami

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HDS26-P04 Room:Convention Hall Time:May 20 18:15-19:30

Tsunami early prediction using DONET: tsunami amplification factor and area mapping of sudden pressure decrease

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We investigated correlation between coastal and offshore tsunami height for our observational array of ocean-bottom pressure gauges, DONET, in the Nankai trough. Many tsunami calculations were conducted to make correlation diagrams between coastal tsunami height and ocean bottom pressure change. We at first created slip models for the calculations. The slip models were constrained on the plate interface because we focus on near-field great subduction zone earthquakes in this study those likely cause tremendous tsunami disasters. It was found that the tsunami amplification factor of 0.067m/hPa between DONET and Owase tide station, and the standard deviation error from the predicted tsunami height is 0.9m. By the aspect of tsunami amplification factor, we would be able to estimate tsunami height at the coast within roughly 10-15 minutes after earthquake occurrence from the ocean-bottom pressure gauge array.

But unfortunately, it seems to be difficult to predict tsunami accurately within several minutes after the earthquake from the method of tsunami amplification factor. We are also considering another approach to predict it earlier. At the seafloor above the upper edge of fault, ocean bottom pressure indeed suddenly decreases after the earthquake. If we know extent of the region where sudden pressure change occurred after the earthquake, which is consistent with the fault dimension. We finally emphasis that ocean-bottom pressure array should be deployed to cover the whole source region so that tsunami could be predicted with high-accuracy less than several minutes.

Keywords: Tsunami early prediction, DONET

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Development of the synthetic waveform database for tsunami forecasting system based on offshore data assimilation

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Meteorological Research Institute (MRI) and Kokusai Kogyo Co. Ltd. produced the synthetic tsunami waveform database for tsunami forecasting system based on offshore tsunami data assimilation by July, 2012. Database is intended to be utilized as a dataset of Green's functions for the prototype system of "tsunami forecasting based on inversion for initial sea-surface height" (tFISH; Tsushima et al., 2009) developed by MRI and NEC Corporation by 2012. The database system contains of the main database, sub-databases, and data viewer software. Main database is an assembly of synthetic tsunami waveforms at each output point computed by using linear long-wave equation corresponding to each unit tsunami source. Two quake-prone areas, along Japan Trench and along Nankai Trough, are targets of the database system. Shapes of unit tsunami sources were defined by two-dimensional Gauss distribution function with a scale parameter of sigma = 10, 20, or 40km. Total 3345 unit tsunami sources were arranged at regular intervals in two target areas. Total 664 output points near both target areas were selected from the location of offshore observatories and forecast points, which were virtual offshore observatory used for tsunami forecasting. In addition, sea-level data at grid points arranged at regular intervals were saved, so that synthetic tsunami waveforms at any location, where sensors are installed in a future, can be generated by interpolation. Total number of jobs to compute all synthetic tsunami waveforms was 46712. In order to check these enormous computing results, automatic quality control subroutines were developed and added in. Sub-databases will be prepared by extracting from the main database, so that they are consistent to parameters engaged in inversion process of the tFISH system. In addition, data viewer software was developed for conveniences of checking by visualizing these computing results.

Keywords: offshore tsunami data assimilation, synthetic tsunami waveform database, tsunami forecasting

HDS26-P06 Room:Convention Hall Time:May 20 18:15-19:30

Development of Tsunami Forecasting system based on offshore tsunami data assimilation

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Meteorological Research Institute (MRI) and NEC Corporation developed a prototype system for real-time prediction of near-field tsunamis using offshore tsunami data in the first half of 2012. The main part of the system is based on the tFISH algorithm, in which offshore tsunami waveform observations are inverted for spatial distribution of initial sea-surface displacement as a tsunami source model and then tsunami waveforms at an offshore point near a coastal site (a reference point, hereafter) are synthesized by linear superposition of the pre-computed tsunami Green's functions using the estimated source model (Tsushima et al., 2009). The predicted tsunami heights at the reference points are amplified to obtain those at coastal sites using the amplification factors derived from actual tsunami observations empirically (Hayashi 2010). Because the whole system is designed smartly, the single calculation including the low-pass filtering and the preparations for the real-time inversion can be accomplished within a few minutes. Once seismic magnitude fed into the system exceeds the pre-defined threshold, the forecasting calculation starts automatically and is carried out repeatedly at short intervals by renewing the offshore tsunami waveform data. The figures of the forecasting results such as the inverted source model and the predicted tsunami waveforms are also produced automatically and a user can view them with a Web browser. Also in real time the spatio-temporal tsunami wave-field data resulted from the estimated tsunami source model can be calculated. This software is installed on a hardware that is well designed for the operation of the software. The hardware includes servers for real-time analyses as well as large amounts of storage for the database of tsunami Green's functions that Kokusai Kogyo Co. Ltd. constructed. The examples of the application of the system will be presented at the meeting.

Keywords: Real-time tsunami forecasting, offshore tsunami data assimilation

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Pre-calculated tsunami inundations for site-specific tsunami early warning

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During the 2011 Tohoku tsunami, within only 3 minutes after the earthquake, the JMA issued three types of messages for coastal areas in Japan, which are tsunami advisory, tsunami warning, and major tsunami warning. These advisory and warning messages are visualized as color-coded lines along the Japanese coastlines on a small-scale map and broadcast on television. These messages save many lives but unfortunately, in the case of 2011 Tohoku, are not enough to convince all people to immediately evacuate. We argue that large-scale maps of predicted tsunami inundation area and height could better illustrate impending tsunami dangers and convince more victims to evacuate immediately.

To produce maps of predicted tsunami inundation, accurate information about tsunami source and pre-calculated tsunami inundation are required. In this study we focus on the pre-calculated tsunami inundation aspect. We are building a database of pre-calculated tsunami inundation and developing a method to extract the appropriate scenario from the database for tsunami warning purpose. We have simulated tsunami inundations using a high-resolution bathymetry dataset (1 arc-sec) in Kushiro, Hokkaido from 304 thrust earthquake scenarios in the subduction zone offshore of Hokkaido. The simulated maximum tsunami inundations in Kushiro and tsunami waveforms at 45 observation points within 12 km from the shoreline are stored in a database.

For a test case study, we simulated tsunami inundations in Kushiro from a hypothetical great earthquake offshore Hokkaido using the high-resolution bathymetry dataset to get a reference for validation. The tsunami waveforms at the observation points can be simulated using linear shallow-water equations on a lower resolution grid system to reduce the simulation time. Tsunami waveforms at the observation points from the scenarios in the database can be searched to find ones that best resemble those from the hypothetical event by using RMS analysis with shifting of waveforms by an optimal time shift. Then the simulated tsunami inundation of the corresponding scenario is chosen as the predicted tsunami inundation. When compared with the tsunami inundation of the hypothetical event, the predicted tsunami inundation has Aida number K that is within the threshold of +/- 0.4. To complete the linear tsunami simulation and searching process, it requires less than 3 minutes with a regular laptop computer. We found that the method worked well enough to forecast the tsunami inundation area in Kushiro.

Keywords: Pre-calculated tsunami inundation, tsunami early warning, tsunami waveform

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Slip distribution and Coulomb stress change of the largest foreshock (Mw 7.3) of the 2011 Tohoku earthquake

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The largest foreshock of the 2011 Tohoku earthquake occurred off the coast of Miyagi at 02:45:12 on 9 March 2011 UTC. The epicenters of the largest foreshock (143.28 E and 38.328 N) and the mainshock of the 2011 Tohoku earthquake (Mw 9.0) are separated by approximately 45 km. The tsunami waveforms generated by the largest foreshock were recorded by pressure gages (TM1 and TM2) and GPS buoys (GPSB802, GPSB803, and GPSB804) deployed off the coast of Miyagi. We apply tsunami waveform inversion method and include a spatial smoothness constraint to estimate slip distribution of the largest foreshock. Earthquake parameters of strike = 192, dip = 14, and rake = 81 (USGS W phase centroid moment tensor solution) are used in this study. Then we predict the Coulomb stress change from the slip distribution and evaluate how the largest foreshock led to the rupture of the great 2011 Tohoku earthquake.

The inferred slip distribution has a major slip region with dimension of 45 km x 45 km which is located on the down-dip side of the hypocenter. The slip amounts on the major slip region range from 0.6 to 1.5 m. The major slip region is centered at a depth of approximately 19 km. The center of the major slip region is located near the centroid for this event that was determined by the USGS. By assuming the rigidity of 4 x 10ˆ10 N mˆ-2, the seismic moment calculated from the slip distribution is 1.2 x 10ˆ20 N m which is equivalent to Mw 7.3. The slip distribution indicates that the largest foreshock did not rupture the plate interface where the rupture of the mainshock was initiated. From the slip distribution, we calculated the Coulomb stress change on thrust faults with the same geometry as the largest foreshock. Friction coefficient of 0.4 and rigidity of 4 x 10ˆ10 N mˆ-2 are assumed. The calculation shows that the Coulomb stress increased by 1.6-4.5 bars within a 4 km radius of the hypocenter of the mainshock (depth = 23.7 km). This indicates that the 2011 Tohoku earthquake was brought closer to failure by the largest foreshock.

Keywords: Foreshock, the 2011 Tohoku earthquake, slip distribution, Coulomb stress change, tsunami waveform

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Statistical investigation on tsunami occurred in Japan

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The Great East Japan Earthquake has branded lessons that it is important to predict the risks of tsunami in advance, and it is also important to take necessary safety measures against tsunami disasters. A large body of literature has been devoted to study tsunami. However, the analysis of tsunami, as well as the assessment and prediction of its effects, are difficult and complicated since the heights and scales of tsunami are greatly affected by the local geographical features.

Takahashi [1] tried to analyze tsunami data with eliminating the influence from the geographical features of coastline geometry, such as a bay or a harbor, etc. Takahashi [1] calculated the propagation of the energy of tsunami, from the historical data of tsunami, and provide the detailed map of Japan with the amount of energy reached at the 200-m depth contour of the Pacific Ocean. The amount of energy for every rural areas, prefecture, or narrower area, can be a useful index for planning refuge and also for planning breakwaters construction. This approach enables us to assess the dangers of tsunami to compare areas with a common criterion.

By the way, more than half a century has been passed since the age of Takahashi [1]. The amount of data on geographical feature and tsunami is much more than that used in Takahashi [1]. The computing resources have also become more powerful and faster. Therefore, this research aims to assess the risks of tsunami based on the concept of Takahashi [1], with the updated statistical data on tsunami until now, the updated geographical data, and more precise calculation with every 1km mesh. The result is a more precise quantitative evaluation of the danger of tsunami and can be used to assess the danger of tsunami for every point.

Our calculations show that the danger of tsunami is high in the Nankai Trough with its surrounding area and the northern part of the Tohoku district, compared with other areas. This result is considered to be an effective assessment which shows the danger for planning refuge and planning institutions.

This research implemented the concept of Takahashi [1] with computers and calculated the energy propagation more precisely than before with the current statistical data of tsunami. Moreover, the danger of tsunami could be computed more exactly using more exact geographical feature than that of those days used by Takahashi [1]. The data of the tsunami for 60 years since Takahashi [1] are also added. Since the measure of danger was computed for every 1 km mesh, it may have come to grasp the danger of the tsunami in each area in detail than before. Our approach can follow spreads of tsunami with less computing resources than detailed simulations and can be effective for preliminary estimations before performing more detailed simulations.

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Numerical simulations of tsunami associated with the Sanriku-oki earthquake on December 7, 2012

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An earthquake with magnitude 7.4 occurred off Sanriku on December 7, 2012. According to seismic waveform analysis, this earthquake consisted of two subevents. The first subevent was reverse fault type (M 7.2) followed by the second normal fault type subevent (M 7.4), which occurred eight seconds after the first event. Tsunami waveforms generated by the earthquake were recorded at some tide gauge stations along the Pacific coast of the Tohoku district. In this study, we performed numerical simulations of tsunami associated with the earthquake, and compared the results with the observed tsunami waveforms. We used the fault parameter and epicenter location determined by Japan Meteorological Agency. The slip of the fault plane was assumed to be uniform. Firstly, we calculated tsunami waveforms, by assuming the second subevent alone, which is considered to contribute tsunami waveforms remarkably. The calculated result which was obtained assuming the linear shallow water equations was compared with tsunami waveform at the Soma tide gauge station operated by the Geospatial Information Authority of Japan. The calculated first tsunami wave turned out to be a backwash, which was the same sense as the observed waveform. However, the calculated amplitude was quite large and differed from the observed waveform remarkably. Secondly, assuming the two subevents, we performed numerical simulation. Although amplitude became somewhat smaller than that of the above-mentioned result, calculated wave height was rather different from the observed one. The peak of the first waveform of the observed tsunami was also larger than that of the trough, which was not able to be reproduced by the simulation. When the nonlinear shallow water equations were assumed, the amplitude of the calculated tsunami became small slightly. However, the feature of the observed first waveform was not able to be reproduced. Furthermore, we performed numerical simulations, imposing coseismic slip distributions on divided small subfaults for the two subevents, which were obtained by Japan Meteorological Agency using an inversion analysis of seismic waveforms. Although the tsunami wave height calculated by using this model was still larger than the observed one, the calculated result became close to the observed one. In the calculated results, the amplitude of the peak in the first waveform became larger than that of the trough, which is similar to the observed waveform. We will compare our simulated results with the observed tsunami waveforms at other tide gauge stations along the Pacific coast of the Tohoku district.

Keywords: 2012 Sanriku-oki earthquake, tsunami, numerical simulation