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

HDS026-01 Room:101 Time:May 22 14:15-14:30

Distribution of the height of the tsunami of the 1707 Hoei earthquake on the coast of Shizuoka prefecture

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A jointed gigantic earthquake called Hoei earthquake occurred in the jointed regions of south offing of the Tokai and the Nankai districts, the western part of the Japanese Islands. It had been well known that the magnitude of this earthquake is larger than those of the 1854 Ansei Nankai and the 1946 Showa Nankai earthquakes. The number of the points where tsunami heights were measured by reliable instruments on the basis of reliable old documents or legends had not been many. We intended to obtain more data of reliable tsunami heights of this event. In the present study, we measured tsunami heights by using the GPS instrument at the points where the record of sea water inundation limit clearly in seven towns and villages on the coast in Shizuoka Prefecture. We interviewed the specialists of local history of the the Shizuoka Prefecture, and several experts of local history at coastal villages. The result is shown in the figure1 ,2 and 3.

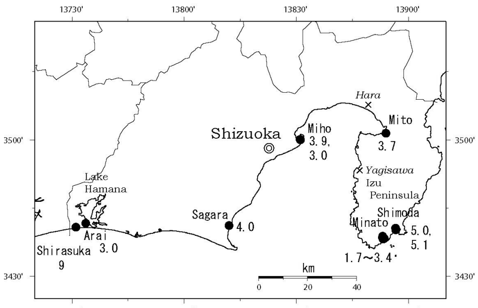

Fig. 1 Tsunami height distribution of the 1707 Hoei earthquake in Shizuoka prefecture

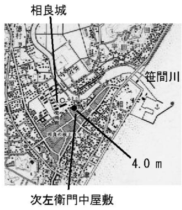

Fig. 2 Detailed map of Sagara

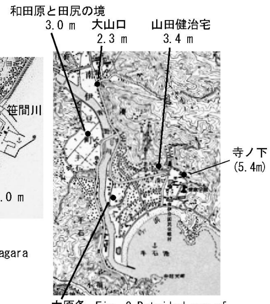

Fig. 3 Detailed map of Minato, Shimoda city

Keywords: the Tokai earthquake, the 1707 Hoei earthquake, joint gigantic earthquake, tsunami, Shizuoka prefecture

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HDS026-02 Room:101 Time:May 22 14:30-14:45

Resonance curve of initial waves in the 2010 Chichijima-kinkai tsunami

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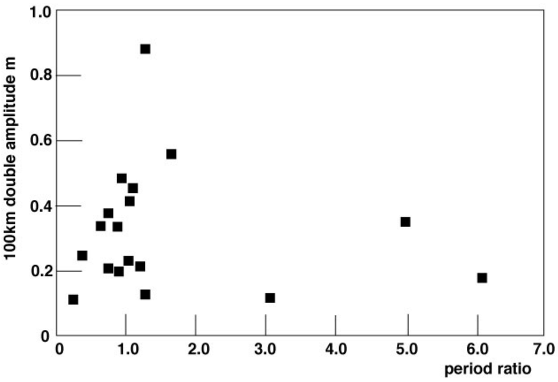
We derived a resonance curve of tsunami initial wave in the 2010 Chichijima-kinkai earthquake tsunami. The data was taken from tide-gauge records of 23 tide stations in Japan. The period and amplitude were used in the records from which the tidal levels were excluded. The resonance curve consists of double amplitude reduced at 100 km in the epicentral distance and period ratio of the initial wave to the dominant period of seiche having been observed in the neighborhood of the tide station. The resonance curve showed a peak at the unit in the period ratio. This result suggests that the initial wave reflects an effect of the local topography.



Keywords: 2010 Chichijima-kinkai Earthquake Tsunami, Initial wave, Period, Resonance curve, Seiche

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HDS026-03 Room:101 Time:May 22 14:45-15:00

Magnitude of the Mentawai, Sumatra earthquake Tsunami of October 25,2010

Tokutaro Hatori[1*]

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Recently, many tsunamis have been generated in the Sumatra region, Indonesia. The earthquake (Mw7.7) occurred near Pagai Is., Kep. Mentawai (3.484S, 100.114E, USGS) on October 25, 2010. A tsunami ran up 5-7m at the Pagai Is. (Satake et al.,2010) and killed 408 persons. The tsunami widely observed in the Indian Ocean (Semi-amplitudes: Padang 35cm, Tanahbalah 25cm, Cocos Is. 20cm, Port Luis 29cm, Marion Is., S. Africa 44cm and Port Elizabeth 23cm (WC/ATWC, NOAA). According to the inverse refraction diagram, the estimated tsunami source is 300km length, lapped over the source area of the 2007 Sumatra tsunami (m=2) along the 2000m-depth counter line. Judging from the attenuation of tsunami height with distance, tsunami magnitude is determined to be m=2. The tsunami grade is normal comparing with earthquake magnitude. Amplitudes in the south Africa region are large for the mean tsunami magnitude. It suggests the effective energy is projected toward the SW direction. The distribution pattern of amplitudes were similar to that of the 2007 tsunami.

Keywords: Tsunami magnitude, Wave-height deviation, Tsunami source

HDS026-04 Room:101 Time:May 22 15:00-15:15

Ground tilt changes in Japan caused by the 2010 Maule, Chile, earthquake tsunami

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The 2010 Maule, Chile, earthquake generated a tsunami in the Pacific Ocean, and the tsunami reached Japan approximately 24 hours after the earthquake. Ground deformations caused by the tsunami loading were observed in a broad area along Pacific Ocean coastline of Japan by high-sensitivity accelerometers (tiltmeters) installed at Hi-net stations operated by National Research Institute for Earth Science and Disaster Prevention [Kimura et al., 2010]. Some previous studies had already reported that ground deformations were observed at a few seismic and/or geodetic stations caused by several massive tsunamis such as the 1960 Chile tsunami [Ozawa, 1961; Tanaka and Tanaka, 1961] and the 2004 Indian Ocean tsunami [Yuan et al., 2005; Nawa et al., 2007]. However, the 2010 Maule earthquake tsunami is the first case where tsunami-loading effects are detected by a high-density wide area observation network such as Hi-net. In this study, using the ground tilt data observed at Hi-net stations in Japan, we investigate characteristics of ground tilt changes due to the tsunami loading and the availability of these data.

We analyzed ground tilt data in a frequency band of 0.1-1.0 mHz observed at ~570 Hi-net stations and obtained the following results. 1) The directions of ground tilt changes are generally perpendicular to the coastline near each station. 2) Maximum amplitudes of ground tilt changes are ~5 x 10^{-2} micro radian at the distances of several hundred meters to the coastline. The amplitudes decay with the distance and reached ~5 x 10^{-3} micro radian at the distance of ~50 km to the coast. 3) The amplitude decay curve against the distance to the coast has a corner. At the distance of one km or smaller, the amplitudes decay very little, and at larger distances, they decrease inversely with the distance. 4) The rate of amplitude decay against the distance depends on the frequency of tilt changes. In the high frequency band, the amplitudes decay more sharply than those in the low frequencies.

We simulated the propagation of the 2010 Maule earthquake tsunami and the ground tilt changes caused by this tsunami loading, and successfully reproduced above characteristics of the ground tilt changes. This indicates that observed tilt changes must be caused by the ocean loading due to the Maule tsunami.

The observed ground tilt changes induced by the tsunami contain information on the tsunami behavior near the coast. For example, the corner in the amplitude decay curve against the distance to the coast strongly depends on the width of the area where large sea-level variations occur near the coast. Therefore, the ground tilt data observed by the inland network will be important to understand the spatiotemporal evolution of tsunami near the coast.

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HDS026-05 Room:101 Time:May 22 15:15-15:30

Electromagnetic tsunami signals observed by the seafloor geophysical network in the French Polynesia

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The 2010 Chile earthquake (Mw = 8.8) occurred off the coast of Chile (35.846S, 72.719W) on February 27, 2010, at 06:34 UTC. The earthquake triggered a tsunami which spread all over the Pacific ocean, and reached the eastern coastal areas of Japan with the maximum height of about 1 m. At the time of the earthquake, a seafloor geophysical observational network were operating in the French Polynesia area, east to the Tahiti island (Suetsugu et al.,2011). The network consists of nine pairs of broadband ocean bottom seismometers (BBOBS) and ocean bottom electro-magnetometer (OBEM),and one of the BBOBS at the easternmost site (SOC8)is equipped with a Differential Pressure Gauge(DPG). The network apparatuses were installed in March 2009 and recovered in December 2010, the extent of which is about 400 km in east-west and north-south directions,,

. The tsunami from the 2010 Chile earthquake arrived at this region about 10 hours after the origin time of the earthquake, and the DPG recorded the bottom pressure change due to the passage of the tsunami wave. Simultaneously, all the OBEMs clearly recorded the electromagnetic (EM) signals due to the tsunami wave. The EM signals are evident in three components of magnetic field (Bx,By,Bz) and two horizontal components of electric field (Ex,Ey), and the variations of the tsunami signals lasted more than several hours after the passage of the tsunami front. Maximum amplitude of the B-field change is about 0.5 nT and that of the E-field change is about 0.1 microvolt/m, which is 10-50 times higher than the resolution limit of the seafloor apparatuses. Close correlation between the variations of Bx (northern component of the magnetic field) and the sea level change observed by the DPG at site SOC8 indicates that the EM field variations are mainly caused by the tsunami waves and the orientation of the tsunami front is close to the north-south direction. Since the wave forms of the EM field variations are very similar among the 9 stations, the propagation characteristics of the tsunami wave over the network can be accurately restored from the EM measurements. The inferred direction of the restored tsunami propagation is towards N75W and the propagation speed is estimated to be about 720 km/hour. Since the average water depth at the network region is 4000-4800 m, the observed speed is consistent with a long-wave approximation of the tsunami propagation.

Keywords: tsunami, seafloor observation, electromagnetic observation, observationa netwark, ocean dynamo

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HDS026-06 Room:101 Time:May 22 15:30-15:45

Cross-correlation of the sea level changes off Muroto Cape and off Hatsushima Island, Japan

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Recently, seismic interferometry has drawn attention in seismology and exploration geophysics. It estimates the seismic Green's function between two points, one of which is a source and the other is a receiver, by calculating the cross-correlation functions (CCF) of ambient seismic noises recorded at these points. Equivalent approaches have been also applied and validated in other fields, such as oceanic acoustics and helioseismology. However, there seems to be no report of applying such an approach to observed ocean surface waves. In this study, we calculate the CCF of sea level changes recorded at two points off the Pacific coast of Japan, and we examine the possibility of retrieval of Green's function of ocean waves from the CCF. We actually treat long-wavelength ocean waves (or tsunami) with the periods of 10 min or more.

We treat records of two water pressure gauges (tsunami sensors) deployed on the deep-sea floor by JAMSTEC, Japan. One gauge is PG1 of Long-Term Deep Sea Floor Observatory off Muroto Cape (about 100 km offshore and 2,308 m depth; hereinafter MPG1), and the other is a component of Long-Term Deep Sea Floor Observatory off Hatsushima Island in Sagami Bay (about 6 km offshore and 1,175 m depth; hereinafter HPG1). The records are 1 s sampled water heights, calculated based on measured water pressures. We select good-quality records for 1,130 days in the period from May 19, 2004 to May 31, 2008, which are then resampled at 30 s intervals.

We process the data for each day at the both stations in the following manner. (1) Remove the mean water height from the data for each day. Thereby obtain sea level changes. (2) Apply a harmonic analysis to the sea level changes for each day. Thereby remove the tidal constituents. (3) Bandpass-filter the tide-removed data with the passband from 10 to 60 min, which may be typical periods of tsunami. (4) Apply one-bit normalization to the bandpassed data, in which only the signs of the data are retained by replacing all positive amplitudes with 1 and all negative amplitudes with -1. (5) Calculate the CCF between the processed data at MPG1 and those at HPG1 for each day. Finally, we stack the CCF for all the days to obtain the time-averaged CCF.

It is shown that the obtained CCF denotes roughly harmonic and symmetrical features with respect to time lag. It has large amplitudes at around the absolute time lag from 1 to 6 h. For comparison, we synthesize the tsunami observed at HPG1 due to a source located at MPG1. This is achieved by a finite difference simulation with the linear long-wave approximation, in which we give a Gaussian-type initial disturbance of sea levels in the area around MPG1 with the radius of 50 km. Note that Saito and Kawahara (2011, this meeting) theoretically suggests that tsunami Green's function would be given by the derivative of CCF with respect to time lag. Additionally, a representation theorem denotes that a wave generated by delta function-like initial displacement results in the time-derivative of Green's function. Therefore, we calculate the second derivative of the present CCF with respect to time lag. We then lowpass-filter it with the cutoff of 60 min, in order to match the dominant periods of the synthetic tsunami. Although the function thus obtained and the synthetic tsunami do not agree in the arrival times of first motion, they show good similarity in the overall waveforms. This indicates that the present CCF can partly reflect the tsunami Green's function between the two stations.

Acknowledgements. We used water height data acquired by JAMSTEC. We thank Dr. Ryoichi Iwase (JAMSTEC) and Dr. Ichiro Takahashi (Marine Works Japan, Ltd.) for their help in using the data.

Keywords: Sea level change, Cross-correlation, Tsunami, Green's function

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Three dimensional tsunami propagation simulations based on finite element and finite difference models

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Tsunami propagation simulations play an important role in tsunami disaster mitigation. Such simulations are commonly based on the two dimensional linear or non-linear long-wave equations which assume the wavelength of the disturbance is large in comparison to the depth of the ocean. On the other hand, Furumura and Saito (2009) used high-performance supercomputers to solve the three dimensional Navier-Stokes equations using a finite difference method with orthogonal meshes to achieve more accurate results, e.g. regarding dispersive features of tsunamis.

The goal of our current research is to develop a highly accurate tsunami simulation model which will make use of current and future supercomputers and appropriate numerical methods for the purpose of contributing to tsunami disaster mitigation measures. In the present study, we employ unstructured meshes and solve the three-dimensional Navier-Stokes equations using a finite element method. The simulation code used is Fluidity-ICOM (http://amcg.ese.ic.ac.uk), which is a multi-purpose finite element / control volume based CFD and ocean dynamics code being developed by Imperial College London and collaborators. Fluidity-ICOM is configured to run in parallel and can make use of dynamic mesh adaptivity.

The more complete fluid dynamical equations of our model will lead to more accurate results than the conventional two dimensional equations. The unstructured meshes make it possible to accurately and efficiently represent complex coastlines and bathymetry due to their flexibility and their multi-scale resolution capabilities. This is the key advantage of the present model over the existing three dimensional modal based on a finite difference method with orthogonal meshes. Using the present tsunami simulation model together with high-performance computers, we expect an accurate representation of tsunami generation due to seafloor deformation, propagation and dispersion of tsunami in deep sea, and amplification of onshore tsunami at coastlines.

In the development of a numerical model, especially one dealing with non-linear phenomena, it is critical to compare results against those of other models, and observations where possible. In the present study, we conducted three dimensional simulations of the tsunami resulting from the off Kii peninsula earthquake of 2004 using the present finite element model. The results are compared with those obtained using a finite difference model based on the three dimensional Navier-Stokes equations (Furumura and Saito, 2009). The present model successfully reproduces the propagation of the tsunami including its dispersive feature and shows good agreement with those from the finite difference model. In this presentation, we will introduce the details of the respective models and show a comparison between their results. This will be followed by a discussion regarding the validity and characteristics of each model.

Keywords: Tsunami, Simulation, Unstructured meshes, Finite element method

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Present research status and foresight on timely cancelation of tsunami warning

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[1]Meteorological Research Institute

This presentation reviews researches related to cancelation of tsunami warnings, and then says future prospects toward realizing timely cancelation of tsunami warning. Timely cancelation of tsunami warning is one of the important issues on tsunami information services by Japan Meteorological Agency, because disaster mitigation related organs have strong needs on it. Especially, in case of a far-field tsunami, which in general continues longer than a near-field tsunami, timing of cancelation of tsunami warning becomes crucial. Present research status on timely cancelation of tsunami warning can be summarized that there are strong needs and poor technical seeds. Tsunami forecast based on pre-calculated scenario tsunami database involves difficulties in improving forecasts related to phenomena or features which cannot be simulated well by numerical tsunami calculation. Deterministic prediction of tsunami waveforms many hours after arrival is an example of such disadvantage of scenario tsunami database. Recently developed measures for quantitative description of tsunami decay features, such as moving root mean squared amplitude, tsunami coda and non-dimensional tsunami amplitude, set the course for realizing timely cancelation of tsunami warning; that is to increase knowledge on decay feature of tsunami coda through analyzing various tsunami events by applying new measures. For this reason, archives of historical analogue tsunami records become more important.

Keywords: tsunami warning, cancelation of warning, tsunami decay process, tsunami coda

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HDS026-09 Room:101 Time:May 22 16:30-16:45

The taget and the promotion plan of the tsunami research by the New Promotion of Earthquake Research

yoshinori suzuki[1]*

[1]MEXT

The Great Hanshin-Awaji Earthquake Disaster on January 17, 1995 brought us a number of problems in our national earthquake disaster prevention measures. In August of the same year, the Headquarters for Earthquake Research Promotion was launched based on a Special Measures Law on Earthquake Disaster Prevention, and the Ministry of Education, Culture, Sports, Science and Technology (in short, MEXT) has been given the role to promote and encourage nationwide research and surveys into earthquake activities.

In March 2009, HERP published the report "Next Promotion of Earthquake Research -Comprehensive Basic Policies for the Promotion of Earthquake Research through the Observation, Survey, and Research-", and officially determined it based on the Special Measure Law on Earthquake Disaster Prevention through the decision of Central Disaster Management Council on April, 2009.

In this report, three objectives which should be promoted in the coming ten years are set and one of the objectives is improving the accuracy of the prediction of earthquake occurrence and seismic motion ? tsunami forecast based on the observation and research for the subduction-zone earthquake. In the former report "Promotion of Earthquake Research" that provided the policy till then for ten years, it was given priority in the disaster by the strong ground motion among the seismic hazards, and enough consideration was not performed about the tsunami hazard.

The tsunami forecast includes the tsunami forecast offered before the immediate tsunami forecast (tsunami warning) put out immediately after the occurrence of the earthquake and the prediction for tsunami disaster prevention before earthquake occurrences. As for the former, recently the accuracy is not necessarily good because of presumption based on the data obtained with the seismograph though the tsunami forecast warning is announced for a few minutes by the Japan Meteorological Agency at the level after the earthquake occurs. The accuracy of an immediate tsunami forecast improves greatly if the tsunami data observed in the ocean area near the hypocenter immediately after generation can be used at once by the mechanism similar to the EEW(Earthquake Early Warning). About the latter, Proper recognition by the residents and local governments of the tsunami will occur in the future, promoting effective land use and safe evacuation in case of tsunami disaster mitigation measures and the actual. It can be advanced by the acquisition of detailed topographic data and the correct tsunami source model elaborated in the past.

Therefore, the upgrade of the tsunami forecast technology by the elaboration the tsunami source model is set at once as a basic target about the tsunami data observed in the sea area. Aiming at the achievement

-Installation of tsunami observation net in sea area

-Topography of the seabed and coast geological features investigation

-Surveillance study on tsunami generated by the subduction-zone earthquake

-Upgrade of immediate prediction technique of tsunami

It hangs out promotion overall.

With this lecture, we want to start to discuss how to promote the tsunami research based on New Promotion of Earthquake Research.

Keywords: HERP, tsunami, New Promotion of Earthquake Research

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JMA Tsunami Warning Services' Present Situation and Future Plan

Tomoaki Ozaki[1*]

[1] Japan Meteorological Agency

The Japan Meteorological Agency (JMA) started its tsunami warning operation regulated by the Meteorological Service Act in 1952. In the early years, operators compose tsunami warning bulletins by hand using a tsunami forecast chart, and it took about 20 minutes from the occurrence of earthquakes. But, year by year, the issuance time of tsunami warnings has been speeded up by the upgrade of processing systems and seismic networks. In 1999, JMA introduced quantitative tsunami warning system which stores tsunami numerical simulation results of many cases as a database. This system dramatically shortened the issuance time to around three minutes after events. In 2006, JMA started the earthquake early warning (EEW) services, which has further shorten the issuance time to about two minutes at the earliest cases.

JMA have been installing seismometers for EEW use, and currently, data from about 220 seismometers, including ocean bottom seismometers in Tonankai-oki area, is in use. Data from the National Research Institute for Earth Science and Disaster Prevention (NIED) is also merged into EEW operations. In addition, data from DONET, which is now under construction, would be of help to more swift and accurate tsunami warnings through the improvement of hypocenter determination ability for the earthquakes around the area DONET is installed.

We consider that we have accomplished our goal regarding the immediacy of issuance of tsunami warnings, and that the main challenge remaining is to improve tsunami height forecast. The prompt issuance of tsunami warning involves uncertainties which are inevitably included in various parameters such as focal mechanisms at the initial stage after the event. JMA's tsunami warnings issued within about three minutes are composed based on hypocenter and magnitude calculated from seismological data that is obtained up to that time, and focal mechanism and source region are not clear at this stage. Therefore, JMA assumes 45 degree of reverse faults as the worst case scenario, and in case of a hypocenter close to the Japanese coast, adopts the highest predicted coastal tsunami heights given by all of assumed faults that include the location of hypocenter. We then change/cancel the warning as needed, based on updated data such as CMT solutions.

Sea level change generated by sea bed deformation is the source of tsunami. But it is difficult to grasp this change accurately. This fact gives us a limit for precise tsunami prediction. In addition, for large events such as much larger than M8, there is another issue that it is difficult to determine magnitude within several minutes after the occurrence of events. It is our goal to introduce techniques that enables us to grasp the scale of generated tsunami accurately at an early stage.

For distant tsunamis, JMA establishes tsunami warning system similar to the system for local tsunamis, using simulation database system installed in 1999 and real time numerical tsunami simulation. We are now upgrading our distant tsunami simulation database, referring to the past events such as the 2010 Chilean earthquake tsunami. The main points of improvement are; 1) increase in number of assumed faults from 260 to 1280, 2) applying finer spatial resolution (5 minutes to 1.5 minutes interval for open ocean), and 3) increase in number of tsunami waveform data output points which are used for calibration by comparing with tide gauge observations, from 12 to 99. The new database will be into operation in FY2011.

Keywords: Tsunami warning operation, Quantitative tsunami warning system, Earthquake Early Warning

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Ocean-bottom pressure observation of Dense Oceanfloor Network System for Earthquakes and Tsunamis

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The source regions of the subduction zone earthquakes are located beneath the sea in the Nankai seismogenic zone except for that of the Tokai earthquake. Real-time seafloor monitoring system for earthquake and tsunami is very important for improvement of early warning system and understanding of the subduction zone earthquakes. The Japan Agency Marine-Science and Technology has constructed the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) at the seafloor just above the source region of the Tonankai earthquake since 2006. Following DONET2 project which aims to cover the eastern half of the source region of the Nankai earthquake was also launched at 2010.

In DONET system, ground motion sensing and pressure sensing packages are connected by a submarine cable so that data is transferred to the landing station in real time. Conventional submarine systems have sensors in submarine cables, but DONET uses science nodes which are devices with the role of hub to connect the submarine cable with instruments directly installed on the seafloor. That makes possible to distribute observation points in dense, to replace instruments at the seafloor, and to make maintenance by using ROV. The pressure sensing package is composed of quartz pressure sensor, differential pressure sensor, hydrophone and precise thermometer to observe broadband tsunami phenomena, which will be installed at twenty sites of the seafloor. Total eight stations had been set by January, 2011

The observed data has been collected since the first sensor was installed in March 2010. In December 2010, the earthquake (M7.4) of Chichijima was accompanied by a small tsunami which was clearly recorded by the ocean-bottom pressure sensors of DONET about an hour and a half later in the earthquake origin time. The tsunami signal reached at DONET stations about 20 minutes earlier than the coast observation points. We accordingly insist that the tsunami early warning will be dramatically improved by using the real-time data observed by DONET. I will show the detail of DONET and a plan of the tsunami real-time analysis in the oral presentation.

Keywords: DONET, Nankai trough, Ocean-bottom pressure observation, Tsunami

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A Development of Tsunami Monitoring System using GPS Buoy

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A new tsunami observation system has been developed, which employs the RTK-GPS technique to detect a tsunami before it reaches the coast. After a series of preliminary experimental studies, the operation-oriented experiments were conducted at two offshore sites. These systems succeeded to detect four 10cm tsunamis on 23rd June 2001 Peru earthquake, 26th September 2003 Tokachi earthquake, 5th September 2004 Kii earthquake and 28th February 2010 Chile earthquake. The newly established Muroto GPS buoy system is continuously operating now. These results well substantiate of a GPS buoy to be a powerful tool for early detection of tsunami.

Currently, the GPS buoy system uses RTK-GPS which requires land base for precise positioning of the buoy. This limits the distance of the buoy from the coast at most 20km. There are two problems to be solved; one is the accuracy of GPS and the other is the data transmission. We are now testing the improved RTK method and 400MHz radio system for 50km long base line in the Muroto GPS buoy, also now planning to introduce the other algorithm of precise point positioning method. As a future scope, we will try to implement some other additional facilities for the GPS buoy system which is so-called GPS/Acoustic system for monitoring ocean bottom crustal deformation and to develop a system to predict the arrival time and tsunami height at the coast by combining the observed tsunami and numerical simulation.

Keywords: GPS, tsunami-meter, tsunami, RTK

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Large-scale FDM Simulation of Seismic Waves and Tsunamis based on Seismic-Tsunami Compound Equation

Takuto Maeda[1*], Takashi Furumura[1]

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1. Introduction

As seismic waves generated from an earthquake source propagate, coseismic deformation occurs on the ground surface. In particular, when earthquakes occur beneath the ocean, the upheaval or submergence of the sea bottom cause sea water change, and it propagates as a tsunami. We have proposed a unified approach for modeling of all of these phenomena from seismic wave to tsunami in a single numerical scheme based on the compound equation of motion (Maeda and Furumura, 2011). Here, we extended our numerical model for large-scale parallel computation, and we performed the finite-difference method (FDM) simulation of seismic waves and tsunamis for 2004 Off-Kii earthquake.

2. Large-Scale Parallel Computation of the Compound Equation

The our method directly solves the equation of motion of linear elasticity in the elastic medium and water taking the effect of gravity into account. By considering equilibrium between quasi-static pressure and gravity, and finite amplitude of displacement amplitude at the ocean surface, we can directly evaluate tsunami in equation of motion. Synthesized dispersive tsunamis by means of the compound equation shows very good agreement with those by Navier-Stokes equation.

For large-scale 3D simulations, we partition the 3D model to allow parallel simulation on a large number of processors. This partitioning produces equal sized regions with some degree of overlap between them, and each is assigned to a separate processor or processor core. In addition to the inter-processor communications between neighborhood nodes, the tsunami terms, calculated in the uppermost column of the partitioned domain, should be transferred to all lower subdomains. To do this, we use a collective MPI communication function to send the current values of the tsunami terms downward from the uppermost domain to all subdomains during each time step. The parallel performance for the present simulation is estimated to be 99.839% by measuring relative speedup by increasing number of CPU cores.

3. Numerical Simulation of 2004 Off-Kii earthquake

We applied our parallelized code to the FDM simulation of 2004 Off-Kii earthquake of M7.4. Model area of 460 km x 307 km x 115 km is discretized with grid spacing of 300 m in horizontal and 150 m in vertical directions, respectively. We adopted J-EGG500 for bathymetry, 500 m-mesh GSI model for topography, subsurface structure model by J-SHIS, and plate boundary model from Daidaitoku for constructing velocity and topography models. Finite fault model is set up by referring studies of Yamanaka (2004) and Saito and Furumura (2009).

We confirmed that the clear tsunami initiation together with the radiation of seismic and ocean acoustic waves. In particular, behavior of ocean acoustic waves is quite complex, reflecting the inhomogeneous bathymetry. For example, down-slope conversion to effectively radiate wave energy to deep-ocean side, and boundary wave along the coastline have been observed. Different from the seismic waves in the elastic medium, ocean acoustic waves remain oscillating at around the epicenter up to 10 min. after the earthquake origin time because of multiple reflection between sea surface and bottom. As a result, tsunamis and high-frequency ocean acoustic waves are overlapped each other in a distance range of more than 100 km, suggesting importance on taking the ocean-acoustic waves into account for the study using ocean-bottom pressure gauges.

Acknowledgements

The computations in this study were performed in part at the Earth Simulator at the JAMSTEC and in part on the HA8000 system in the University of Tokyo. This study was supported by the research project "Improvements of strong ground motion and tsunami simulation accuracy for application of realistic disaster prevention of the Nankai-Trough mega-thrust earthquake" of the Ministry of Education, Culture and Sports, Science and Technology.

Keywords: seismic wave, tsunamis, ocean acoustic waves, large scale computation, parallel computation, finite difference method

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

HDS026-14 Room:101 Time:May 22 17:45-18:00

Real-time forecasting of tsunamis associated with earthquakes along the Nankai Trough using offshore tsunami data

Hiroaki Tsushima[1*], Takuto Maeda[2], Takashi Furumura[2], Kenji Hirata[1]

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1. Introduction

To mitigate disasters due to large earthquakes and tsunamis occurring along the Nankai Trough, various instruments such as cabled ocean bottom observatories have being installed. In the region, GPS buoys have been deployed. At the offshore stations, a tsunami can be detected before the tsunami attack coastal communities. Several studies showed that the data are useful for real-time tsunami forecasting (e.g., Titov et al., 2005; Tatsumi and Tomita, 2008; Tsushima et al., 2009; Hayashi, 2010). Recently, realistic simulation of strong motion and tsunami has being conducted by employing supercomputers (Furumura and Saito, 2009; Maeda and Furumura, this meeting). In the present study, taking advantages of these technologies, we develop an algorithm for real-time tsunami forecasting of the Nankai Trough earthquakes.

2. Simulation Procedure of Tsunami Forecasting

As a test case, we simulated tsunami forecasting of the 1944 Tonankai earthquake. The simulation was carried out as follows: (1) Tsunami waveforms were computed for observation points by assuming a fault model and were regarded as the tsunami waveforms observed at the offshore and coastal sites. (2) Coastal tsunami waveforms were then estimated from offshore tsunami data by using a tsunami forecasting algorithm. (3) The results of the tsunami forecasting were evaluated by comparing the observed waveforms at coastal observation points with the predicted waveforms.

For calculation of the observed tsunami waveforms, we assumed the fault model presented by Annaka et al. (2003). Assumed slip on the fault plane was uniform. Tsunami propagation was computed by solving the linear long-wave equation numerically. The remarkable point of this computation code is a new installation of the Pefectly Macthed Layer boundary to reduce the reflection of tsunami at physical boundaries effectively. The grid spacing is 500 m and bathymetry data provided by Japan Oceanographic Data Center were used to produce bathymetry grid data (Maeda and Furumura, this meeting).

Tsunami forecasting was performed by applying an algorithm presented by Tsushima et al. (2009). In the algorithm, offshore tsunami waveform data are inverted for initial sea-surface height distribution in source region, and then prediction of coastal tsunami waveforms are synthesized by using the estimated height and pre-computed Green's functions. To stabilize the solution of the inverse problem, we imposed two constraints on the spatial distribution of sea-surface height. One is the smoothing constraint, and the other is the constraint based on a priori knowledge that initial sea-surface height due to an earthquake should be zero if the epicenter is far enough away.

3. Results

We performed the simulated tsunami forecast 15 minutes after the 1944 Tonankai earthquake using the observed tsunami data at 37 offshore stations. At this timing, the pressure variation due to the coseismic seafloor deformation appears in the records at most offshore stations. These sufficient data are expected to constrain the source model strongly, resulting in providing accurate tsunami forecasts. At the coastal sites along the Kii Peninsula and to the west, the forecasted arrival times and peak amplitude of the first tsunami explain well the observations. At the sites along the Shima Peninsula and to the east, the tsunami amplitudes are underestimated. It may be caused by the excessive effect of the damping constraint. The weight of the damping constraint become large at the eastern part of the source region far from the epicenter, resulting in underestimation of initial sea-surface height and coastal tsunami amplitude. However, if we do not impose the constraint, the solution of the inversion become unstable and the forecasting accuracy becomes low. In future, the modification of the constraint or joint use of the other geophysical data such as strong motion and GPS (Tsushima et al., the 2010 JpGU Meeting) is required.

Keywords: real-time tsunami forecasting, ocean bottom pressure gauge, GPS buoy

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

HDS026-15 Room:101 Time:May 22 18:00-18:15

Real-time Tsunami Inundation Prediction Using Inversion Method and GPU

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The present authors have developed the method to predict tsunami inundation quickly from the tsunami profiles observed at the offshore locations such as GPS Buoy. This prediction method consists of the following two steps: First, the tsunami profiles in near shore areas where non-linear effect is negligible are predicted from the offshore tsunami observation by the inversion method and the principle of linear superposition. Secondly, the fast tsunami numerical calculation using Graphics Processing Unit (GPU) predicts tsunami inundation from the predicted tsunami profiles in near shore areas.

One of the innovative features of this prediction method is to reduce the tsunami observation time required for the inversion method by using the location of the epicenter as a priori information. Furthermore, the present authors reduce the time required for tsunami numerical calculation by the utilization of GPU.

The accuracy of this prediction method is confirmed by the numerical experiments using the actual bathymetry and the historical earthquakes in Nankai Trough. The tsunami arrival time, and the tsunami height and the inundation caused by the first wave of tsunami can be predicted from the tsunami profiles observed for 15 minutes at the five offshore locations. The whole prediction procedure can be completed in from 15 minutes to 20 minutes after the occurrence of earthquake.

Also, the developed real-time tsunami inundation prediction is applied to 2010 Chilean Tsunami, and the results of this application will be presented.

Keywords: tsunami prediction, inversion method, GPU, GPS Buoy, 2010 Chilean Tsunami

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

HDS026-16 Room:101 Time:May 22 18:15-18:30

Comprehensive discussions: What should we do for innovation of tsunami early warning

Yutaka Hayashi[1*], Toshitaka Baba[2]

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This session, "H-DS26 Tsunami and Tsunami Early Warning", discusses issues related to improving prediction accuracy of tsunami, which includes such as a better understanding of tsunami dynamics, new real-time tsunami observing systems deployed in the open ocean and coastal waters, methodologies of more rapid and accurate prediction during tsunami emergencies and more extensive and accurate inundation maps.

At the last of the oral session, we arrange short time for the comprehensive discussions; its theme is "What should we do for innovation of tsunami early warning?" Issues related to this discussion theme can be listed as below.

(1) Development and installation of offshore tsunami observation networks.
(2) Distribution of tsunami observation data.
(3) Advanced methods for real-time tsunami forecasting.
(4) Appropriate framework for promoting essential researches.
(5) Challenges and future direction.
(6) Others.

All presenters of this session and everyone who is interested in tsunami early warning are requested to attend this comprehensive discussion time. The conveners also hope that this session gives orientation of our future works on tsunami early warning through it.

Keywords: session summary, tsunami early warning

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

HDS026-P01 Room:Convention Hall Time:May 22 10:30-13:00

Rupture area of the 1958 Etorofu earthquake occurred in Kurile subduction zone estimated from tsunami waveforms

Kei Ioki[1*], Yuichiro Tanioka[1]

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The great Etorofu earthquake (Mw 8.3) occurred in Kurile-Kamchatka subduction zone on 6 November 1958. A location of the epicenter of the 1958 great earthquake is 44.38?N, 148.58?E, depth = 80 km. This earthquake was originally defined as an interplate earthquake although the depth was slightly deep. However, the earthquake was characterized by a high stress drop, a low aftershock activity at shallow depth, large high-frequency seismic waves, a large felt area, and a relatively small aftershock area. Therefore, the 1958 great earthquake was recently defined as a slab event. The 1963 great Kurile earthquake (Mw 8.5) occurred on the east of the 1958 earthquake. The 1969 great Kurile earthquake (Mw 8.2) and 1994 great Kurile earthquake (Mw 8.3) occurred on west of the 1958 earthquake. The 1963 and 1969 events were interplate earthquakes, but the 1994 event was a slab earthquake. The 1958 earthquake generated a tsunami which propagated through the Pacific Ocean. Maximum height of the observed tsunami was 4-5 m in Shikotan Island. In this paper, parameters (dip, depth, slip amount) of the 1958 great earthquake were estimated using tsunami waveforms recorded at 13 tide gauge stations along the Pacific Ocean. Strike and Rake of the fault model were fixed to be 225 and 90 degrees, respectively. A rupture area previously estimated from aftershocks within 3 days, 150 km*80 km, was used at first. The tsunami was numerically computed using interplate and slab earthquake model changing dip and depth. Parameters of the interplate earthquake model are dip = 20 degree, depth = 16 km. Parameters of slab earthquake models are dip = from 20 to 60 degree every 10 degree, depth = from 27.5 km to 47.5 km every 10 km. We found that a slab earthquake model of dip = 40 degree, depth = 37.5 km best fit observed and computed tsunami waveforms. Next, tsunami waveforms were calculated using various source models which have different rupture area at the same other parameters. However, the computed tsunami waveforms from the original rupture area, 150 km*80 km, best explained the observed tsunami waveforms. The seismic moment was calculated to be 1.5*10**21 Nm (Mw 8.1) assuming that the rigidity is 6.5*10**10 N/m**2.

Keywords: 1958 Etorofu earthquake, Kurile, tsunami, great earthquake

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

HDS026-P02 Room:Convention Hall Time:May 22 10:30-13:00

Finite-difference modeling of tsunami as a seismic wave based on the Cowling approximation of self-gravitation effect

Toshihiro Kuramoto[1*], Hiroshi Takenaka[1], Takeshi Nakamura[2], Taro Okamoto[3], Genti Toyokuni[4]

[1]Kyushu University, [2]JAMSTEC, [3]Tokyo Institute of Technology, [4]National Institute of Polar Research

Since Ward(1980,JPE), farfield tsunami simulations have been done based on the normal mode theory for a self-gravitating global earth model with sea layer. Recently, this method was extended to the modeling of atmospheric gravity wave (infrasound) as well as long-period seismic waves (solid-earth oscillation) and/or tsunami (e.g. Kobayashi, 2007, GJI; Watada, 2009, JFM). In this study, we focus on the shallow part of the earth including sea and use a local version of elastodynamic equation for self-gravitating flat earth model to simulate nearfield tsunami. We simplify the equation by ignoring the perturbation of the gravitation potential (i.e. retaining the initial acceleration of gravity; called the Cowling approximation) and assuming the acceleration of gravity to be constant over the computational domain. We reformulate the equation into a velocity-stress form which is a set of the first-order equations and does not include the displacement but the particle velocity, and discretize it with a staggered-grid finite-difference time-domain method which is often employed for strong-motion simulation. This scheme can model both of seismic waves and tsunami due to nearfield oceanic earthquakes at the same time. In the presentation we will show some computational examples.

Keywords: Tsunami, numerical simulation, Cowling approximation, self-gravitating effect, seismic wave

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

HDS026-P03 Room:Convention Hall Time:May 22 10:30-13:00

Thermal correction at a tsunami frequency of ocean bottom pressure gauges of real-time observatories around Japan

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In-situ ocean bottom pressure (OBP) records obtained from data acquisition system of Hewlett-Packard, Inc. (hereafter HP) are known to include significant, spurious pressure signals correlated to output changes of the mounted thermometer. The data acquisition system of OBP is mostly adapted to cabled, real-time seafloor observatories around Japan. We reported overall dependency of the OBP records on the temperature changes in broad frequency bands from a secular change to a tsunami range (Inazu et al., 2010, Meeting of Seismological Society of Japan). In this paper, effects of rapid temperature changes ($>$ 0.003deg.C/min.) on the OBP records at the tsunami period range ($<$ 30min.) are evaluated and corrected. Similar investigation was conducted by Hirata and Baba (2006) for the station data off Kushiro under JAMSTEC. In this study, OBP data derived from the HP acquisition system at six stations of the off Cape Muroto system (JAMSTEC) and the off Kamaishi system (ERI/Univ. of Tokyo) in addition to the off Kushiro system. The correction suggested in the present study can reduce spurious pressure signals correlated to the rapid temperature changes by millimeters in amplitude at the tsunami period in which representative standard deviation of OBP is around 1 mm. The correction is especially necessary for the OBP records obtained at one station of the Cape Muroto system (MPG2). Because the rapid temperature changes occur most frequently (O (1/day)) at the MPG2 station while such temperature changes are found to occur less frequently ($<$ O (1/year)) at other stations.

Keywords: ocean bottom pressure, tsunami, temperature, correction

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

HDS026-P04 Room:Convention Hall Time:May 22 10:30-13:00

Contribution of DONET to early tsunami forecasting: Brief review and status report

Hiroyuki Matsumoto[1*], Eiichiro Araki[1], Katsuyoshi Kawaguchi[1], Takeshi Nakamura[1], Toshitaka Baba[1], Yoshiyuki Kaneda[1]

[1]JAMSTEC

DONET, i.e., Dense Ocean-floor Network System for Earthquakes and Tsunamis has started in partly operation since 2010. DONET has been developed for the purpose of not only geophysical scientific use but also mega-thrust earthquake-related disaster mitigation. An observatory of DONET consists of various sensors, such as broadband seismometer, seismic accelerometer, tsunami meter, differential pressure gauge, hydrophone, and thermometer. In the current presentation, we focus on tsunami meters, of which a quartz crystal broadband pressure sensor with thermal compensating is employed. We need to evaluate long term sensor drift and carry out tide assimilation in order to extract tsunami component from the original observation with high accuracy. Before deployment of tsunami meter under the ocean-bottom, we carried out the laboratory experiment, which demonstrated both the constant loading pressure of 20 MPa, i.e., equivalent 2,000 meters deep and the constant temperature of 2 degree C environment for duration of one month. Initial sensor drift could be observed to be 5 to 20 centimetres at the end of the laboratory experiment. After the deployment under the ocean-bottom, we compute tide component based on the series of pressure observation by using harmonic coefficient technique. Thus predicted tide component is subtracted from the pressure observation in real-time. Although a few centimetres low frequency residuals remains, we could observe several tsunamis from the recent far-field earthquakes by DONET tsunami meters. About 20 min earlier tsunami detection prior to the coastal tide gauges could be achieved. Thus DONET now can contribute to effective tsunami observation in SW Japan.

Keywords: tsunami, DONET, quartz pressure gauge, Nankai Trough