# Structure Health Monitoring Experiment of 10-stories RC building applying i-Jishin

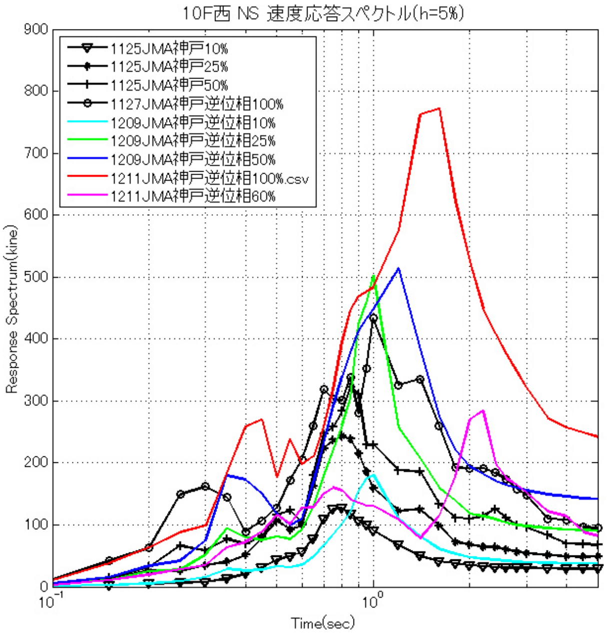
*Hiroki Azuma[1], Shohei Naito[1], Hiroyuki Fujiwara[1]

1.National Research Institute for Earth Science and Disaster Prevention

i-Jishin cloud system is a disaster prevention sensor cloud system consisting of a free iOS app "i-Jishin" and Web services "Geonavi / icomi”. In order to evaluate the applicability of this system for Structual Health Monitoring, it was carried out vibration experiments of 10 layers of RC structures on E-Defense in November-December 2015.
This article does not addressed until more information about the earthquake disaster determination method based on the system, we describe to the state estimated by the data acquisition and building response spectra up to the previous diagnosis.
Experimental methods: Method of the experiment is as follows.
- We attached two iOS terminals installed i-Jishin on the wall of each 10,6,5,1 layer of the RC structure test body, and uploaded the data to icomi via wireless LAN.
- We carried out shaking test held four days of the 2015, on November 25th, 27th, December 9th and 11th, measured microtremor in the same position of the i-Jishin installation floors prior and subsequent to each shake.
- Measurement parameters of i-Jishin were trigger setting 30 gal, trigger duration 2s, pre-trigger 20s, post-trigger 60s.
- As analysis of the acquired data by the MEMS acceleration sensor, seismic intensity, response spectrum (acceleration, velocity, displacement) were calculated respectively.
Result of the experiment: The experimental results are as follows.
- A dominant period prolongation of response spectrum was observed corresponds to the input ground motion.
- This is roughly consistent with the measurement results of the microtremor former and latter the shake.
- Success rate of the data uploaded by the mobile line was 93 percent.
Although structural health monitoring (SHM) systems using acceleration sensors are operating for commercial bases on the high-rise buildings, valuable data obtained are not shared for disaster prevention research for privacy reasons. There is a problem of trade-off between reliability and cost.
This experiment showed possibility to evaluate damage of the medium-sized apartments by earthquake with smartphone’s accelerometer. If it is possible, it can be regarded as an easy and powerful disaster prevention tool at a low cost that contributes to the rapid ensuring safety at the time of disaster. It is still insufficient to allow the disaster judgment in the instant, but state estimation of the structure is possible immediately.

Keywords: SHM, Sensor Cloud, mobile terminal, i-Jishin, E-Defense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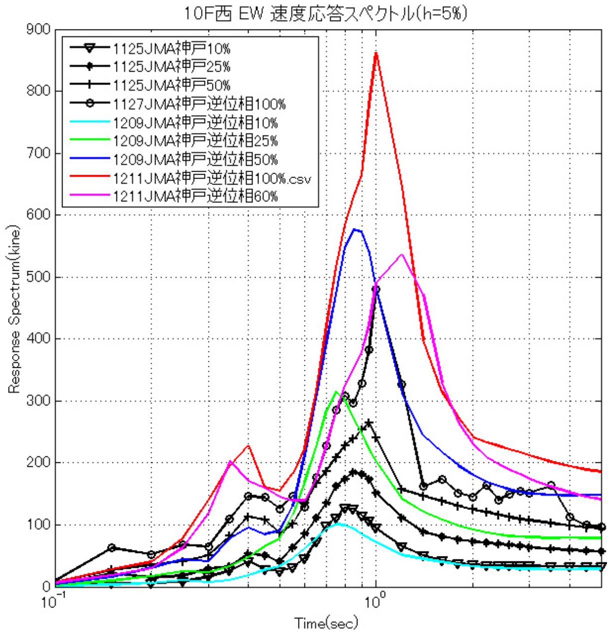
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# Potential for Monitoring Earth Activities using Optical Fiber Network and DAS (Distributed Acoustic Sensing) Technology

*Tsunehisa KIMURA[1], Gareth LEES[1], Arthur HARTOG[1]

1.Schlumberger Fiber-Optic Technology Center

DAS (Distributed Acoustic Sensing) technology has been introduced more than 5 years ago for the demands of pipeline monitoring and intrusion detection in Oil & Gas business. The latest optical fiber sensing technology now allows DAS to record Seismic signal including VSP (Vertical Seismic Profiling). The system is called ‘hDVS’ (heterodyne Distributed Vibration Sensing) in order to distinguish from pipeline monitoring system.
Unlike conventional seismic recording system, which usually use electro-magnetic sensor or Geophone, hDVS/DAS uses optical fiber as vibration sensor. It measures dynamic strain of the optical fiber, either SMF (Single-Mode Fiber) or MMF (Multi-Mode Fiber) for entire length or the section defined by the system. In case of SMF, the maximum length of the optical fiber is around 50km, while the maximum length is reduced to around 10km for MMF with current system, depending on the level of optical signal loss and optical sampling frequency.
Conventional electro-magnetic seismic sensors have been installed all over the places in Japan, especially after the Tohoku earthquake and tsunami in 2011, however, the measurement of the conventional sensors are point basis, while installation cost and environmental ratings of the conventional sensors limits the number and location of the sensor installations.
In case of hDVS/DAS system, any existing optical fiber installations, which have been used for data transmission purpose mainly, would become line shaped seismic sensor instantly. This fact allows installation cost and time minimized. As a part of the IT Revolutions last 20 years, there have been built the network of optical fibers across Japan and over the ocean between Japan and US or other Asian countries. Especially, the international ocean bottom optical fiber cables were installed over the Seismogenic areas. If the ocean bottom cables would become seismic sensor instantly, how would you like to use the data?
In terms of environmental specification of optical fiber, the core part is made of high-silica glass, so that high temperature version of optical fiber is widely available over 200 degC where conventional sensors cannot be installed. There are 500 degC or even higher the temperature rating fibers are available using special coating materials. It means optical fiber sensor would potentially be installed near the Seismogenic layers in deep wells, which would allow real-time seismic activity monitoring with speed of light.
hDVS/DAS technology would potentially allow us to have comprehensive real-time monitoring network on surface, ocean bottom or subsurface of Japan without requiring high cost and time in order to minimize loss of human life and our lovely heritages during upcoming events which we cannot eliminate.
During the presentation, overview of hDVS/DAS system and examples of seismic data recorded during Field trials last few years will be explained, followed by vision of Earth Activities monitoring network in Japan.

Keywords: DAS, hDVS, Optical Fiber Network, Earthquake Monitoring, Seismic

 

# A simple velocity model for hypocenter determinations using data from land and ocean observation networks

*Masaru Nakano[1], Shigeki Horiuchi[2]

1.Japan Agency for Marine-Earth Science and Technology, 2.Home Seismometer Corporation

Introduction:
In order to improve detection capabilities of earthquakes in the ocean, dense observation networks as DONET by JAMSTEC and S-net by NIED have been developing in recent years. Hypocenter determinations using data from these networks and land observation data will improve the accuracy of earthquake source locations in the ocean. On the other hand, 1D velocity structure may not be appropriate because of strong lateral heterogeneities in subduction zones. Nakano et al. (2015) used 3D velocity model for hypocenter determinations. But this method is not appropriate for real-time or routine operations because of its high computational cost.
In this study, we propose a simple 2D velocity model for hypocenter determinations using data from ocean and land observation networks.
Proposed velocity model:
We propose a 2D model of which 1D velocity structures of land and ocean are connected along a plate boundary. The ray path is assumed not to bend in the horizontal direction. For hypocenter determinations, a travel time table with respect to the source depth, epicentral distance, and the depth where the ray path crosses the plate boundary. The plate boundary is defined according to the hypocenter distribution determined by JMA. The boundary is separated to several segments to represent horizontal bending of the plate boundary.
The proposed velocity model is 2D, but it resembles 3D plate model because we have incorporated horizontal plate bending. The implementation is easy because the travel times can be computed using 1D ray tracings.
Hypocenter determinations:
Using the 2D model proposed above, and 1D models assuming land and ocean, we determined hypocenters. We estimated site corrections for the P- and S-wave travel times for each station, and re-determined the hypocenters. We used P- and S- readings from DONET1 and land stations used in Nakano et al. (2015).
Epicenter distributions are almost the same for the three models, but the source depths are distinctly different: 1D land model overestimates the source depths in the ocean.
At stations in the ocean, the obtained site corrections reflect the thickness of the sediments in the basin, a common feature obtained for the three models. At stations on land, we obtained corrections larger than 1 s for 1D ocean model. Correction values were rather small for 1D land and 2D models on land.
The RMS traveltime residual was 0.45 s, 0.52 s, and 0.46 s for 1D land, 1D ocean, and 2D models, respectively.
Discussion:
The RMS traveltime residual indicate that the 1D land model explains the observed ones as well as the 2D model proposed, while the source depths are overestimated. To explain this feature, we conducted the same analysis above but using data from only DONET stations and earthquakes that occurred beneath the sea for the 1D land and ocean models.
Hypocenter distributions were almost same including the source depths, giving almost similar RMS residuals of about 0.25 s. The site corrections, on the other hand, were very different: For the 1D land model, the corrections for P and S waves were positive (to delay observed one) and negative,

 

respectively, at almost all stations. This result indicates that setting uniform corrections for travel times compensated the mismatch of the velocity structure.
From this result, we obtained the conclusion that the overestimation of the source depths for 1D land model using ocean and land data was due to compensations of the late travel times for earthquakes in in the ocean, without much degrading the RMS residuals.
Conclusion:
Use of an accurate velocity structure is necessary for appropriate estimations of earthquake source depth, which is crucial for discussions of seismic activities in the ocean and evaluations for tsunami potential. The 2D model proposed in this study would be appropriate especially for real-time source determinations.

Keywords: DONET, S-net, Subduction zone

# Array observation of strong ground motion for the estimation of current wavefield in real time

*Masashi Ogiso[1], Naoki Hayashimoto[1], Mitsuyuki Hoshiba[1]

1.Meteorological Research Institute, Japan Meteorological Agency

We aim to construct next generation of Earthquake Early Warning (EEW) system with (a) grasp of current wavefield in real time using data assimilation technique and (b) real-time ground motion simulation with current wavefield as an initial condition.

In Hoshiba and Aoki (2015), they used an amplitude distribution of dense seismic network to estimate the current wavefield. However, other observation value should be able to use for estimating current wavefield. Array observation can reveal slowness vector of the wavefield at the observation site. To utilize the array observation for the EEW system, we construct an array network using six acceleration seismometers and conduct some studies using them. Our array size is less than 300 m so that we use 500 Hz for sampling frequency.

Here we adopted semblance analysis (Neidell and Taner, 1971) for estimating slowness vector. Real-time (less than 1 s) semblance calculation is required for making use of analysis result for the EEW system. Oct-tree search (Lomax et al., 2009) enabled us to calculate slowness vector within 1 s using time window of 4 s of 6 stations.

Comparison of estimated backazimuth values and those from the earthquake catalogue showed that backazimuth residual had clear azimuthal dependency. This feature could be explained by the dipping layer beneath the array, and estimated backazimuth values became consistent with those of catalog values through dipping layer correction (Niazi, 1966; Maki et al., 1987).

In addition to the evaluation of estimated slowness vector, we have considered that how the estimated slowness vector affects to the EEW system. In a simple 2-D case, backazimuth information prevents the underprediction of seismic ground motion in the early stage of prediction (i.e. seismic waves have arrived in only one or a few stations). We will further discuss the effects of array observation to the EEW system through some numerical simulations.

Keywords: Earthquake Early Warning, Array observation, real-time calculation

 

# Improvement of Epicentral Direction Estimation by P-wave Polarization Analysis

*Mitsutaka Oshima[1]

1.Shimizu Corporation

Polarization analysis has been used to analyze the polarization characteristics of waves and developed in various spheres, for example, electromagnetics, optics, and seismology. As for seismology, polarization analysis is used to discriminate seismic phases or to enhance specific phase (e.g., Flinn, 1965)[1], by taking advantage of the difference in polarization characteristics of seismic phases.
In earthquake early warning, polarization analysis is used to estimate the epicentral direction using single station, based on the polarization direction of P-wave portion in seismic records (e.g., Smart and Sproules(1981) [2], Noda et al.,(2012) [3]). Therefore, improvement of the Estimation of Epicentral Direction by Polarization Analysis (EEDPA) directly leads to enhance the accuracy and promptness of earthquake early warning.
In this study, the author tried to improve EEDPA by using seismic records of events occurred around Japan from 2003 to 2013. The author selected the events that satisfy following conditions.
1) MJMA larger than 6.5 (JMA: Japan Meteorological Agency).
2) Seismic records are available at least 3 stations within 300km in epicentral distance.
Seismic records obtained at stations with no information on seismometer orientation were excluded, so that precise and quantitative evaluation of accuracy of EEDPA becomes possible. In the analysis, polarization has calculated by Vidale(1986) [4] that extended the method proposed by Montalbetti and Kanasewich(1970)[5] to use analytical signal.
As a result of the analysis, the author found that accuracy of EEDPA improves by about 15% if velocity records, not displacement records, are used contrary to the author’s expectation. Use of velocity records enables reduction of CPU time in integration of seismic records and improvement in promptness of EEDPA, although this analysis is still rough and further scrutiny is essential.
At this moment, the author used seismic records that obtained by simply integrating acceleration records and applied no filtering. Further study on optimal type of filter and its application frequency band is necessary.
In the presentation, the results of aforementioned study shall be shown.

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Keywords: polarization analysis, estimation of epicentral direction, earthquake early warning

# Rapid detection of early aftershocks using high-frequency seismogram envelope: improvement of location estimation of energy radiation point

*Kaoru Sawazaki[1]

1.National Research Institute for Earth Science and Disaster Prevention

Because waveforms of many early aftershocks are overlapped in seismograms, conventional hypocenter determination technique based on the picking of P and S wave arrival times does not work well at the early lapse times after a large earthquake. On the other hand, real-time forecasting of aftershock activity requires sufficient amount of aftershock data in the early lapse times. Sawazaki and Enescu (2014) developed the envelope inversion method that can rapidly detect the energy radiation rate from the early aftershock sequence. In their method, propagation of high-frequency (>1Hz) seismic energy is considered to follow the radiative transfer theory, and the observed seismogram envelopes are regarded as the convolution of energy radiation and propagation processes. To locate the energy radiation point, they compute the sum of squared residual between the observed and the theoretical peak amplitude of the envelopes, and search the minimum residual point at each discrete time step. However, because the theoretical envelope synthesized based on the radiative transfer theory cannot describe both the peak arrival time and the peak amplitude well, the detected energy radiation point frequently has a large error. In this study, I synthesize the theoretical envelope based on the forward scattering approximation that can better describe the peak arrival time and the peak amplitude, and use this in combination with the conventional radiative transfer-based envelope to improve location estimation of the energy radiation point. The hybrid envelope used in this study includes not only S wave but also P wave energies because the amplitude of P wave is sometimes comparable to that of S wave and should not be neglected. I examine seismogram envelopes of 8-16 Hz that are recorded by 13 Hi-net and KiK-net stations located within 70 km from the hypocenter of the 2008 Iwate-Miyagi Nairiku earthquake ($M_{JMA}$7.2). In total 91 aftershocks which satisfy $M_{JMA}$>3.4 are detected within half day after the mainshock according to the JMA unified hypocenter catalog. I first perform the conventional detection method that uses the radiative transfer-based envelope, and find that 10 of the 91 aftershocks are located over 20 km apart from the corresponding JMA hypocenters. Next I perform the new detection method that uses the hybrid theoretical envelope, and find that the number of the corresponding aftershocks reduces to one.

Keywords: detection of early aftershocks, analysis of high-frequency envelope

# Real-time Earthquake Magnitude Estimation by Real-time GNSS positioning: the development of GEONET real-time processing system, REGARD

*Satoshi Kawamoto[1], Yohei Hiyama[1], Yudai Sato[1], Tomoaki Furuya[1], Yusaku Ohta[2], Takuya NISHIMURA[3], Masaru Todoriki[4]

1.Geospatial Information Authority of Japan, 2.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University, 3.Disaster Prevention Research Institute, Kyoto University, 4.Earthquake Research Institute,The University of Tokyo

The displacement data produced by GNSS observations never saturate for large earthquakes in contrast to seismometer data that has a limitation of instrument saturation. Recently, many researches recommends to utilize GNSS real-time kinematic analysis for rapid real-time earthquake magnitude estimations that improve tsunami forecasts (e.g., Blewitt et al., 2009; Ohta et al., 2012). This fact actively forward GNSS real-time analysis for disaster preventions after the 2011 Tohoku Earthquake. For example, READI project has started in western U.S. by a team of several universities and agencies which operate GNSS network to advance tsunami forecasts. The International Union of Geodesy and Geophysics 2015 resolved to engage with IUGG member states to promote a GNSS augmentation to the tsunami warning systems. Geospatial Information Authority of Japan, which operates Japan’s national GNSS network GEONET including ~1300 sites, has also launched a project to develop a system that estimates earthquake fault model rapidly using GNSS data in collaboration with the Tohoku University. The system is named REGARD: Real-time GEONET Analysis system for Rapid Deformation monitoring.
In this paper, we show the overview of REGARD and assess the performance of REGARD for the previous large earthquakes. We used the data of four previous large earthquakes occurred on plate boundaries around Japan: 2003 Tokachi-oki earthquake, 2011 Tohoku earthquake and the largest after shock, Ibaraki-oki earthquake. The simulation data of the 1707 Hoei type Nankai trough earthquake (Todoriki, 2013) was also used. The Mw estimates with high variance reductions > 90 % were derived for all the earthquakes within 3 minutes. It is noteworthy that the Mw 8.83 was estimated for the 2011 Tohoku earthquake by 3 minutes without saturations. The performance assessment of REGARD confirmed that the real-time GNSS analysis is very powerful to estimate reliable Mw for large earthquakes with M > 8 rapidly. Future work will involve the improvement of GNSS analysis with multi-GNSS, PPP, etc. to provide more stable fault models.

Keywords: RTK GNSS, Real-time fault model estimation, GNSS seismology

# Improvement of Real-time GEONET Analysis System for Rapid Deformation Monitoring, REGARD

*Yohei Hiyama[1], Satoshi Kawamoto[1], Yudai Sato[1], Tomoaki Furuya[1], Yusaku Ohta[2], Takuya NISHIMURA[3]

1.Geospatial Information Authority of Japan, 2.Graduate School of Science, Tohoku University, 3.Disaster Prevention Research Institute, Kyoto University

Geospatial Information Authority of Japan (GSI) has been operating a continuous GNSS observation network system since 1994. This system is known as GEONET (GNSS Earth Observation Network) and consists of approximately 1300 nationwide GNSS stations (GEONET stations) and the analysis center. Most stations collect GNSS data with 1-Hz sampling and transfer them to the analysis center in real time. Those data are available for surveying or research using real-time kinematic positioning technique. This technique is expected for describing cataclysmic earthquake from crustal displacement in short time especially after the 2011 off the Pacific Coast of Tohoku Earthquake in March 2011.
GSI and Tohoku University have developed the Real-time GEONET Analysis System for Rapid Deformation Monitoring (REGARD) since September 2011 to estimate moment magnitudes (Mw) soon after large earthquakes struck. This system consists of three subsystems. First subsystem does real-time kinematic positioning using RTKLIB (Takasu, 2013) and GSILIB (GSI, 2015). Second one detects seismogenic behavior using the RAPiD algorithm (Ohta et al., 2012) or the Earthquake Early Warning (Kamigaichi et al., 2009) and immediately run the third subsystem. This subsystem estimates Mw within three minutes using displacement vectors of GEONET stations (Kawamoto et al., 2014). Finally, results are mailed to persons involved.
Last year, we expanded its function of real-time kinematic positioning by using multi-GNSS and enhanced its redundancy by carrying out independent processing in parallel. We introduced three fixed points in Hokkaido, Hokuriku and Kyushu districts to monitor kinematic baseline solutions, respectively. We also improved the browser used in the agency to search for previous results and visually recognize results of the real-time kinematic positioning.
In this presentation, we report the overview and the current situation of REGARD, including the operational results.

Keywords: GEONET, RTK-GPS, real-time

# Eruption Notice –information urging people to take swift and appropriate protective action

Takeshi Koizumi[1], *Junichi Miyamura[1], Tomoyuki Kanno[1], Shoji Hashiguchi[1]

1.Japan Meteorological Agency

JMA monitors volcanic phenomena of all the 110 active volcanoes in Japan, evaluates the status of the volcanoes, and issues Volcanic Warnings for them to mitigate the effects of volcanic disasters. When life-threatening phenomena (such as ballistic projectiles and pyroclastic flows) and/or extension of the affected area by the phenomena are expected, JMA issues the Warnings together with target areas where action for disaster mitigation is needed. For volcanoes where Volcanic Alert Levels are in effect, JMA issues Warnings with Alert Levels that are in line with disaster mitigation actions pre-agreed at the relevant local Volcanic Disaster Management Council. Once issued, the Warnings are immediately transmitted to the residents through municipalities concerned as well as mass media. Disaster management organs in the municipalities then take necessary actions such as setting restricted areas and/or evacuation orders.
At the eruption of Ontakesan (Mt. Ontake) on 27 September 2014, JMA issued the first observation report 8 minutes after the eruption. JMA then investigated the eruption details including target areas and issued the first Volcanic Warning 44 minutes after the eruption. However, the eruption killed many climbers around the crater. Study Group on the Provision of Volcano Information under the Coordinating Committee for Prediction of Volcanic Eruption recommended JMA to establish new information which notifies people entering volcanic areas of an eruption immediately in an easy-to-understand manner so that they can take swift protective action. JMA launched the Eruption Notice system on August 2015.
Eruption Notices are issued right after a volcanic eruption is detected. The Notices report only the occurrence of an eruption before evaluating its magnitude to urge climbers and residents around the volcano to take swift protective action. Eruption Notices are issued for volcanoes with continuous monitoring when eruptions occur after a period of inactivity or those on an unprecedented scale. Even when plumes are not identified in visual observations due to bad weather, JMA issues a Notice with supplementary statement “eruptions are thought to have occurred” if an eruption is presumed from seismometer and/or low-frequency microphone data.
Eruption Notices are provided via TV, radio and mobile phones as well as JMA website. As of January 2016, information providing services using mobile apps and e-mails are available from the following three companies: Yahoo! JAPAN, Japan Meteorological Cooperation and WEATHERNEWS INC.

Keywords: eruption, notice, protective action

# Retrospective evaluation of tFISH/RAPiD performance: tsunami forecasting based on offshore tsunami and GNSS data

*Akiko Horiuchi[1], Ryota Hino[1], Yusaku Ohta[1], Tatsuya Kubota[1], Hiroaki Tsushima[2]

1.Graduate School of Science, Tohoku University, 2.Meteorological Research Institute, Japan Meteorological Agency

tFISH (Tsushima et al., 2009) is an algorithm for real-time tsunami forecast that inverts the waveform data recorded offshore to estimate the distribution of the initial sea-surface height, synthesizes tsunami waveforms at coastal tide-gauge stations.
We have been made a retrospective evaluation of tFISH based on the offshore tsunami data of the Sanriku-oki earthquake (Mw7.3) occurred on March 9, 2011, the largest foreshock of the 2011 Tohoku-oki earthquake. By comparing the calculated waveforms with observations, it was confirmed that the coastal tsunami waveforms obtained by tFISH agree well to the observations ~ 6 min after the earthquake, or ~ 25 min before the arrival of the first wave to the coast. However, it is difficult to estimate the initial sea surface height accurately by the offshore tsunami data immediately after the earthquake, and the inaccuracy caused significant underestimation of forecasted tsunami heights along the coast.
In this study we test tFISH/RAPiD (Tsushima et al., 2014) that incorporates RAPiD algorithm (Ohta et al., 2012) into the coastal tsunami forecasting based on the tsunami waveforms synthesized by using a real-time estimated tsunami source model, with using the GNSS data obtained during the same earthquake, as well as the offshore tsunami waveforms.
The onshore GNSS data of GEONET operated by Geospatial Information Authority of Japan (GSI) are available in real time and it is expected that a source model of an M-7 class earthquake can be obtained within ~ 3 min after the earthquake occurrence, giving the initial sea surface height distribution for the tsunami computation, a RAPiD solution. In tFISH/RAPiD, a RAPiD solution is used as a starting model for tsunami forecasting, and then the tsunami source model is iteratively improved with time by including the tsunami waveforms observed at offshore stations into the source estimation.
Our results show that the RAPiD solution obtained after the M 7.3 earthquake provided the coastal tsunami waveforms agree fairly well to the observations and the forecasting based on the real-time geodetic data complement the very early tsunami forecasting. We note here that our test proves that tFISH/RAPiD would work even for M-7 class inter plate earthquakes, much smaller than the case previously tested.
The good agreement of the tsunami waveforms based on the RAPiD solution to the observations further suggests that the tsunami calculation based on the onshore geodetic data can provide a valuable information for early coastal tsunami forecasting, when there are no offshore stations near the source area and tFISH would not work well.

Keywords: Near-field tsunami forecasting, ocean-bottom pressure gauge, tsunami waveform inversion

# A forward analysis approach using ocean-bottom pressure data for real-time tsunami forecast

*Naotaka YAMAMOTO[1], Shin Aoi[1], Kenji Hirata[1], Wataru Suzuki[1], Takashi Kunugi[1], Hiromitsu Nakamura[1]

1.National Research Institute for Earth Science and Disaster Prevention

We developed real-time tsunami forecast methods using only ocean-bottom pressure data from a dense offshore observation network without inversion analyses, which can yield large uncertainties (Aoi et al., 2015, AGU). We propose a rapid and simple method of estimating the approximate tsunami source location using offshore ocean-bottom pressure data and multi-index method to rapidly match between offshore tsunami observations and pre-calculated offshore tsunami waveforms (Yamamoto et al., 2014, AGU; Suzuki et al., 2015, JpGU; Yamamoto et al., 2015, AGU). In these studies, a set of about 2,000 tsunami scenarios prepared for a research project of nationwide probabilistic tsunami hazard assessment for Japan (Hirata et al., 2014, AGU) are used, because they consider any possible tsunami sources that may affect the Pacific coast of Japan. The tsunami waveforms at locations of the Seafloor Observation Network for Earthquakes and Tsunamis along the Japan Trench (S-net) and maximum coastal tsunami heights along the Pacific coasts of Japan are calculated. These data are registered in the proposed Tsunami Scenario Bank (TSB).
To estimate the approximate tsunami source location, we define the tsunami centroid location (TCL), which is the centroid location of the maximum absolute amplitude of the real-time ocean-bottom hydrostatic pressure changes. To determine whether the TCL can approximate the tsunami source location, which is assumed to the centroid location of the absolute values of the initial sea surface height displacements, we examine approximately 1,000 near-field synthetic tsunami scenarios and a realistic tsunami scenario of the 2011 Tohoku earthquake. From these examinations, we confirm that in most scenarios, the TCLs obtained within a few minutes after an earthquake occurrence are close to the corresponding tsunami source locations.
To quickly select dozens of appropriate tsunami scenarios that can explain the offshore observations, we use multiple indices. The key feature of the method is a rapid matching between offshore tsunami observations and pre-calculated offshore tsunami waveforms. We apply three indices, which are the correlation coefficient and two kinds of variance reductions normalized by the L2-norm of either the observed or calculated waveform, to match the observed waveforms with the pre-calculated waveforms in the TSB. To examine whether our method can select appropriate tsunami scenarios, we conduct synthetic tests using “pseudo observations.'' Based on the test results, we confirm that the method can select appropriate tsunami scenarios within a certain precision by using the two kinds of variance reductions, which are sensitive to the tsunami size, and the correlation coefficient, which is sensitive to the tsunami source location. At the same time, the coastal tsunami information coupled with the selected tsunami scenarios are forecast.
This work was supported in part by the Council for Science, Technology and Innovation (CSTI) through the Cross-ministerial Strategic Innovation Promotion Program (SIP), entitled ``Enhancement of societal resiliency against natural disasters'' (Funding agency: JST).

Keywords: Tsunami, Real-time prediction, S-net

# Tsunami simulation method initiated from waveforms observed by ocean bottom pressure sensors for real-time tsunami forecast; Applied for 2011 Tohoku-oki Tsunami

*Yuichiro Tanioka[1], Aditya Gusman[2]

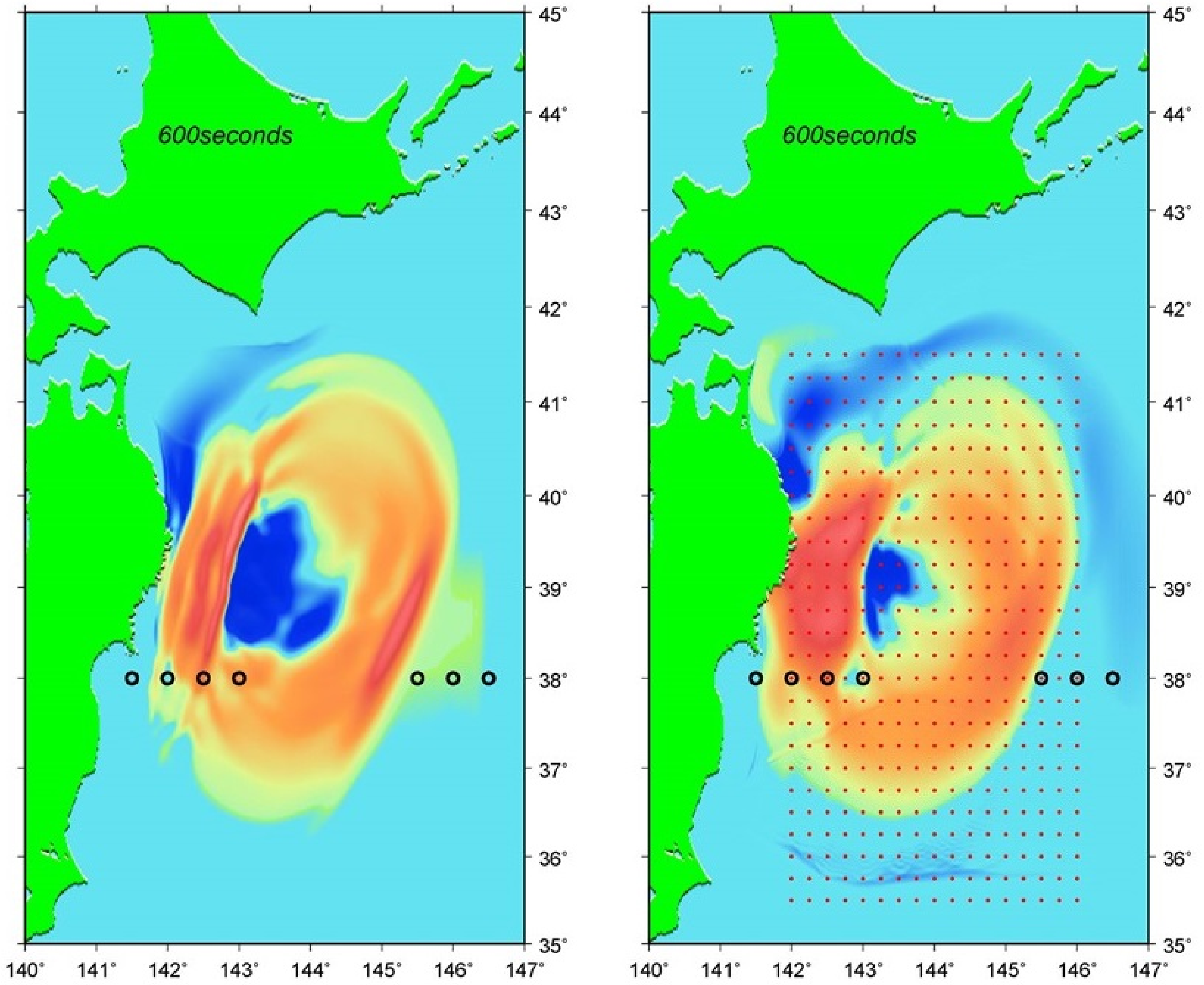
1.Hokkaido University, Institute of Seismology and Volcanology, 2.University of Tokyo, Earthquake Research Institute

After tsunami disaster due to the 2011 Tohoku-oki great earthquake, improvement of the tsunami forecast has been an urgent issue in Japan. National Institute of Disaster Prevention is installing a cable network system of earthquake and tsunami observation (S-NET) at the ocean bottom along the Japan and Kurile trench. This cable system includes 125 pressure sensors (tsunami meters) which are separated by 30 km. This system is the most dense observation network system on top of source areas of great underthrust earthquakes in the world.
Real-time tsunami forecast has depended on estimation of earthquake parameters, such as epicenter, depth, and magnitude of earthquakes. Recently, tsunami forecast method has been developed using the estimation of tsunami source from tsunami waveforms observed at the ocean bottom pressure sensors. However, when we have many pressure sensors separated by 30km on top of the source area, we do not need to estimate the tsunami source or earthquake source to compute tsunami. Instead, we can initiate a tsunami simulation from those dense tsunami observed data. We have already presented a method at the 2015 SSJ meeting. Observed tsunami height differences with a time interval at the ocean bottom pressure sensors separated by 30 km were used to estimate tsunami height distribution at a particular time. Tsunami numerical simulation was initiated from tsunami height distribution. We demonstrated that the method worked well for case studies.
In this paper, the above method is improved and applied for the tsunami generated by the 2011 Tohoku-oki great earthquake. Tsunami source model of the 2011 Tohoku-oki great earthquake estimated using observed tsunami waveforms, coseimic deformation observed by GPS and ocean bottom sensors by Gusman et al. (2012) is used in this study. The ocean surface deformation is computed from the source model and used as an initial condition of tsunami simulation. Linear long wave equations are solved by finite difference scheme. A grid size is 1 min. (about 1.8 km). Figure (left) shows the computed tsunami height distribution at 10 minutes after the earthquake. By assuming that this computed tsunami is a real tsunami and observed at ocean bottom sensors, new tsunami simulation is carried out using the above method. The station distribution (each station is separated by 15 min., about 30 km) observed tsunami waveforms which were actually computed from the source model as an experiment is shown in Figure (right) as red dots. Tsunami height distributions are estimated from the above method at 40, 80, and 120 seconds after the origin time of the earthquake. After interpolation of these tsunami height distribution into a 1 minute grid system, the tsunami numerical simulation is carried out using those tsunami height distribution. Tsunami height distribution computed from the source model includes large short wavelength waves which are originally generated near the trench (see Figure). This is one of important characteristics of the 2011 Tohoku-oki tsunami. However, observed points separated by 30 km are too coarse to describe such a short wavelength wave. Therefore, that causes some error in the overall tsunami height distribution. Also, because this method uses the observed height differences with a time interval as data, a resolution of very long wavelength is low. In this paper, we improve the method by applying a special filter to the estimated tsunami height distribution from the observed tsunami waveforms separated by 30km in order to obtain a stable solution. The tsunami height distribution at 10 minutes after the earthquake estimated from the new method is shown in Figure (right). Comparison between Figure (left) and Figure (right) shows that generally the method works well. The

method developed in this paper is effective as a real-time tsunami forecast.

Keywords: Real time tsunami forecast, Tsunami simulation method, The 2011 Tohoku-oki Tsunami



# Analysis of Site Effects at the Sagami Bay Strong Motion Stations for Real Time Application

*Yadab Prasad Dhakal[1], Wataru Suzuki[1], Takashi Kunugi[1], Shin Aoi[1]

1.National Research Institute for Earth Science and Disaster Prevention

The large scale installation of cable linked network of ocean bottom seismographs (OBS) and pressure gauges (S-net) is undergoing in the Japan Trench area for more accurate and rapid early warning of earthquake and tsunami. It is expected that the data recordings will begin in this year. Previous studies of ground motions recorded at the OBS in the Nankai Trough area in Japan showed that the amplitudes of the ground motions at the OBS are significantly larger than those recorded at the land stations at equal distances. The studies elucidated that the main reason for the large amplitude motions at the OBS is the large amplification effects of low velocity layers beneath the stations. The studies have, therefore, recommended correction for the magnitude estimated by using the current procedures for OBS data. It is important to devise a methodology for accurate magnitude estimation applicable to the S-net seismic data as the S-net stations are expected to record the far offshore events first in the Japan Trench area. In this paper, we obtain site amplifications by spectral inversion method at the K-NET OBS in the Sagami Bay area. There are six such stations, namely KNG201 through KNG206, in the Sagami Bay area. In the inversion, we also included land stations in the Kanto area. Theoretical amplification factors based on PS-logging data at the KNGH21 KiK-net site are used as constraints to minimize the tradeoff between the various parameters. We used recordings from moderate events (Mw 4 ~ 6) and epicentral distances between 30 to 300 km. The PGAs are mostly < 100 gal for the recordings. The obtained results show that the sites at the Sagami Bay area experience amplifications by five to ten folds compared to the reference KiK-net site in wide frequency ranges. These results are similar to those reported for the Tonankai sea floor areas in Japan. Previous researches have shown that the amplifications of high frequency ground motions may differ substantially due to nonlinear site response during strong shaking. It is, therefore, important to consider the effects of nonlinear site amplification as well. This paper focusses mainly on the linear site amplification. We will examine the nonlinear site amplification effects on the OBS recordings in our future study. In this study, the estimated magnitudes based on the inverted source spectra agree well with the F-net Mw. We also found that the estimated Qs values are in the range of previous studies.

Keywords: Ocean bottom seismographs, S-net, Site effects, Spectral inversion, Sagami bay

# Determination of the coefficients of $M_{hdd}$ for regional data

*Tatsuhiko Hara[1]

1.International Institute of Seismology and Earthquake Engineering, Building Research Institute

Hara (2007, EPS) developed a formula to calculate magnitudes using durations of high frequency energy radiation (HFER) and maximum displacement amplitudes using tele-seismic P waves. Hara (2013, SSJ) referred to a magnitude calculated by this formula as $M_{hdd}$. Hara (2014, JpGU) tried to revise the coefficients of the formula by a grid search to reduce the dependences of differences between $M_{hdd}$ and $M_w$ on epicentral distance and HFER duration. $M_{hdd}$ calculated by the obtained coefficients were underestimates for larger earthquakes.
Hara (2015, SSJ) investigated the characteristics of $M_{hdd}$ for tele-seismic data by another grid search, in which the dependence of $M_{hdd}$ on $M_w$ was taken into account in addition. He proposed a revised formula with small dependences of the differences between $M_{hdd}$ and $M_w$ on epicentral distance, HFER duration, and $M_w$ allowing a slightly larger RMS of their differences.
In this study, we applied the procedure of Hara (2015) to regional data to determine the coefficients of $M_{hdd}$ appropriate for regional distance range. We used broadband data recorded at FDSN stations in the epicentral distance range between 10 and 30 degrees for 60 events that occurred in between 1995 and May 2015. We retrieved data from the IRIS DMC. We conducted the grid search for the $M_{hdd}$ coefficients following Hara (2015) and evaluated the dependences of the differences between $M_{hdd}$ and $M_w$ on epicentral distance, HFER duration, and $M_w$. As was observed for tele-seismic data, there is a significant $M_w$ dependence for the set of the coefficients which provides the minimum RMS of the differences between $M_{hdd}$ and $M_w$. As Hara (2015) showed for tele-seismic data, when we allow a slightly larger RMS of their differences, it is possible to find a set of the coefficients for regional data for which the dependences of their differences on epicentral distance, HFER duration, and $M_w$ are small.

Keywords: Magnitude, High frequency energy radiation

# Magnitude estimation for Earthquake Early Warning applicable for various seismic networks including OBS

*Naoki Hayashimoto[1], Takeshi Nakamura[2], Mitsuyuki Hoshiba[1]

1.Seismology and Tsunami Research Department, Meteorological Research Institute, 2.Japan Agency for Marine-Earth Science and Technology

In JMA EEW system, since source parameters (hypocenter and magnitude) are determined quickly by using real-time data from several stations near the source region, stable observation record near the source area is important for EEW. In recent years, large-scale ocean bottom seismic networks, such as S-net (NIED), DONET1 and DONET2 (JAMSTEC) are currently under construction to make use for real-time monitoring, and it is expected that those OBS systems contribute to rapid EEW issuance. However, several problems were revealed for utilizing OBS data to EEW. One of these problems is acceleration offset caused by slight inclination change of OBS and/or hysteresis of sensors. From the analysis of Off-Kushiro OBS (JAMSTEC) data, it was found that the acceleration offset caused by OBS inclination increases with increasing input acceleration (PGA) when OBS exposed strong shaking (over 100cm/$s^2$) (Hayashimoto et al, 2015, JpGU). Acceleration offsets from inclination or hysteresis of OBS were also found at DONET1.

Magnitude of JMA EEW is mainly determined from the maximum amplitude of 3-component vector summation of displacement waveform. Here displacement waveforms are obtained from acceleration waveforms using the recursive filter by which waveforms are integrated twice and high-pass filtered at 6s. When acceleration offset appears within an acceleration waveform, EEW Magnitude might be overestimated because acceleration offsets lead to the displacement waveforms with large displacement offsets.

In this presentation, we focus on the characteristics of inclination change of OBS. It is found that the acceleration offsets are larger on the horizontal component (perpendicular to the cable line) than the vertical component and the other horizontal component (along the cable line). We proposed new magnitude estimation for EEW by using the maximum amplitude of vertical component displacement waveform. We found that overestimation of magnitude due to the inclination of OBS is able to reduce by using vertical component. Furthermore, it is found that variance of magnitude estimated at each stations becomes small by using vertical component. These improvements can be confirmed not only OBS network but also land stations. By using vertical displacement waveform, we would be able to reduce the effect of difference of site amplification factor and to estimate more stable magnitude.

Acknowledgement: The strong ground motion acceleration waveform data used in this study were obtained from the Japan Meteorological Agency (JMA) network, DONET and Off-Kushiro OBS of the Japan Agency Marine-Earth Science and Technology (JAMSTEC), K-NET and KiK-net of the National Research Institute for Earth Science and Disaster (NIED).

Keywords: Ocean Bottom Seismograph, Earthquake Early Warning, Magnitude estimation, Inclination, Site amplification

# Development of the gathering and analyzing system for seismic response by use of the sensor cloud technology

*Shohei Naito[1], Hiroki Azuma[1], Ken Xiansheng Hao[1], Hiroyuki Fujiwara[1]

1.National Research Institute for Earth Science and Disaster Prevention

Strong motion seismometer network covering all over the country as typified by the K-NET, KiK-net, and the data center which accumulates seismic data recorded by these seismometers have been developed and maintained in Japan for approximately 20 years. Such valuable observation systems have been supported by a number of human resources and investments.
On the other hand, we have been developing the “Sensor Cloud” technology intended to be utilized for a rapidly damage detection of buildings or a real-time data transmission, taking an approach of sensing technology and IT technique such as the cloud computing.
Currently, we are mainly developing the “Sensor Cloud” system by utilizing MEMS (Micro Electro Mechanical Systems) acceleration meters inside mobile terminals. But, we intend to use other micro-sensors such as GPS, gyro, and video pictures. By utilizing these multi-sensors, we aim to capture the seismic response of the building in three dimensions, and then, archive the data on a cloud environment, finally, make benefits of seismic damage estimations.
Until now, we have been performed many monitoring experiments by utilizing plural sensors installed in different types of buildings. These records have been uploaded to the cloud server in a few minutes via internet. Then, we can easily download these data by clicking icons plotted on the map. Moreover, we can make easy analyses such as integral, FFT, orbit, or Seismic Intensity, only by the web browser.
By adding these new features, citizens who have no experiences of analyzing seismic data become available to install their own seismometers, and they can compare waves recorded by another areas from the standpoint of an amplitude or a predominant frequency.
However, these data are not always desirable for owners of each buildings. So, we have developed the hierarchic structure of an account and a limitation of access by the authentication.
As described above, we have produced the correcting and analyzing system working on the cloud recorded by MEMS acceleration sensors inside mobile terminals. In the future, we are going to develop archiving system recorded by multi-sensors, and also we are going to apply machine learning techniques to a large amount of these data.
Finally, it is important to regard not only with a view of the developer but also the user to develop these system as the social implementation. So, it is crucial to cooperate with experimental partners including governments, companies, and citizens.
Acknowledgement:
A series of this research partly owe to the discussion in the “Sensor Cloud study meeting”. So, we express our thanks to all members of the meeting and all cooperators of these experiments.

Keywords: Sensor, Cloud, Network

# An approach for real time data acquisition from seismic intensity meter maintained by a local government –Case study on Tottori prefecture -

*Takao Kagawa[1], Tatsuya Noguchi[1]

1.Tottori University Graduate School of Engineering

An approach to use real time data from seismic intensity meter maintained by a local government is demonstrated in this presentation. Dense observation network is desirable for upgrading accuracy and quality of Earthquake Early Warning System. Seismic intensity meters installed all municipalities before recently conducted great synoecism are suitable equipment for the purpose. The seismic intensity meters in Tottori prefecture are improved to broadcast peak ground acceleration and seismic intensity every one second. A system that applies the packet data to estimate real time or prospective intensity distribution is prepared. In addition, observed data analyses and field surveys using microtremors are conducted to evaluate site response at the seismic intensity observation stations for more accurate seismic intensity estimations.

Keywords: Local Government, Seismic Intensity Meter, Real Time

# Real-time Earthquake Information Display System

*Tomomichi Furudate[1]

1.Meteorological Research Institute

My laboratory have developed method of prediction of wave field(Hoshiba et al. 2015) and I have developed real-time earthquake information display system.
The system consists of data receiving program rcvt, data format transformation program shmdump and wave server program.
rcvt and shmdump are part of WIN System.
wave server has wave buffer on memory and send JSON format seismic wave data, seismic intensity data and maximum acceleration data to client at request from web browser.
Web browser accesses to wave server per second and display received data using JavaScript program in HTML file.
Wave server needs to process observed data over several hundreds stations and must have high performance processing.
I tested the performance of parallel processing for high performance using GPU.
JMA seismic intensity needs Fourier transform and it is important to speed up Fourier transform.
First, I tested performance of Fourier transform using several libraries.
Test environment consists of OS Windows 8.1(64bit version),
CPU Intel Core i7-4770K(3.5GHz, 4 cores), GPU NVIDIA GeForce GTX 760,
C compiler gcc 4.9, FFT library FFTW 3.3,
FFT library for GPU cuFFT of NVIDIA CUDA Toolkit 7.5.
Number of data is 2 to the 22nd power(4 million).
Performance of cuFFT using GPU is 10 times of its of FFTW.
Next, I tested performance of JMA seismic intensity and real-time seismic intensity.
I used seismic data with 100Hz sampling and 5 minutes data period(number of data is 30000).
Performance of JMA seismic intensity using FFTW is lower than real-time seismic intensity but performance using GPU is faster than real-time seismic intensity.
I plan to test application of GPU to multi station data using parallel processing.

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Keywords: earthquake information, GPU, parallel processing

# The removal of noise to detect volcanic earthquakes which occurred under Hakone volcano

*Shuhei Wakamatu[1], Hironori Kawakata[1], Shiro Hirano[1]

1.College of science and engineering, Ritsumeikan University

There are many kinds of volcanic earthquakes. However, the methods, criteria, and thresholds for their classification are not unified and strongly depend on a researcher and a volcano (Nishimura &Iguchi, 2006). Such dependence in the classification is confusing, and a unified classification framework is desired. Establishment of the framework should be based on enough examples of volcanic earthquakes extracted from continuously recorded seismic data. To that end, at first, to extract volcanic earthquakes from seismic records is required.

However, seismometers installed near a volcano frequently record human-driven noise as well as volcanic earthquakes. Therefore, we should discriminate volcanic earthquakes from other events. For the discrimination, we should investigate a continuous seismic record including signals of many volcanic events and human-driven noise simultaneously. In addition, we should also investigate an inactive term of the volcano because human-driven noise will dominate and be extracted easily from a record at that term; it allows us to understand the intensity and dominant frequencies of the human-driven noise. The understanding may contribute to extracting human-driven noise from seismic records obtained in an active term of the volcano.

From the point mentioned above, we investigate Hakone volcano, which was active from April to September in 2015. We used a continuous seismic record of the Ninotaira observation station published by Japan Meteorological Agency. The continuous record observed at the Ninotaira observation station has been repeatedly contaminated by characteristic waveforms due to every passage of trains near the observation station. Acausality between the waveforms and trains is obvious because the appearance of the waveforms and scheduled arrival and departure of trains described in a timetable of the train are simultaneous.

Using the record, we develop a method to detect noises due to the train passage regarding some of them as templates. First, we divide 20 waveforms of the train noise extracted between 5AM-9PM of March 29, 2015, the day when the volcano is not active, into 54 packets. We regard these 54 packets as templates after calculating their envelopes and smoothing them with a moving average. Next, we apply the aforementioned procedure to the whole part of the continuous record and calculated correlation function of the processed record and the templates.

After evaluation of a threshold to detect the train noises from the correlation function, we can detect 112 out of 116 train passages on March 29, 2015. On the other hand, extra 300 seconds within 24 hours are judged as train noises although no train passed in the terms. This noise detection method may enable us to detect volcanic events in an active term of the volcano. Actually, by applying the method to a record of June 29, 2015, the day of the eruption, some of the train noises dominated by significant seismic signals are not detected. Hence, our development succeeded in view of our purpose, detection of signals due to the volcanic event.

Acknowledgments: We use the data of the Japan Meteorological Agency volcano observation network.

Keywords: volcanic earthquake

# The ambient noise analysis for the Tatun Volcano Group, Northern Taiwan

*Ya-Chuan Lai[1,2], Cheng-Horng Lin[1,2], TVO team[2]

1.Institute of Earth Sciences, Academia Sinica, Taiwan, 2.Taiwan Volcano Observatory at Tatun, Taiwan

The Tatun Volcano Group (TVG) locates in the north part of Taiwan, where is close to the metropolitan Taipei with distance less than 20 km. Thus, the monitoring for the potential activity is required for geohazard assessment. Near forty broadband seismic stations have been installed in the TVG area to monitor the volcanic activity up to recent time. The dense seismic network with long-term continuous seismic data would provide the information to study the temporal or spatial change of properties of the TVG. In the study, we use ambient noise between stations to determine the temporal variation related to the 2014 $M_L$ 4.0 Shilin earthquake, which is one of the largest event occurred in the TVG area. The daily empirical Green's functions are derived from cross-correlation of continuous vertical-component data during the time period one year before and after the earthquake occurrence. The time shift between specified and reference empirical Green's function is then estimated to detect the small seismic velocity change of the medium associated to the Shilin earthquake. Besides, the auto-correlation of individual stations nearby the main shock epicenter is also applied to improve the ability of detection.

Keywords: seismic ambient noise, cross-correlation

# W-phase analysis and fault parameter estimation by using high-sampling-rate(1Hz) GNSS data (for the case of the 2003 Tokachi-Oki earthquake)

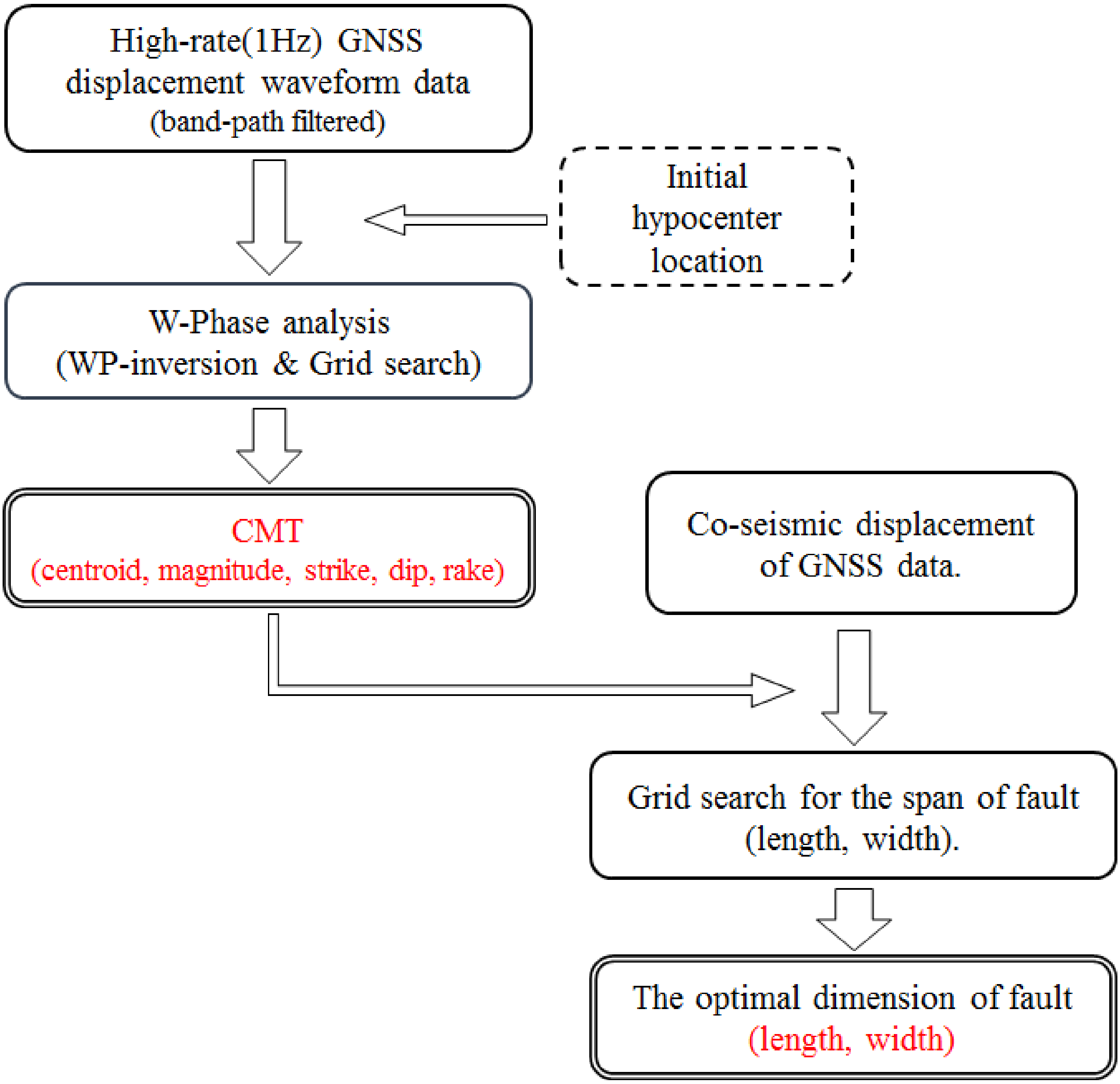
*Kazuki Miyaoka[1], Akio Katsumata[1], Hiroshi UENO[2], Satoshi Kawamoto[3], Yohei Hiyama[3]

1.Meteorological Research Institute, 2.Japan Meteorological Agency, 3.Geospatial Information Authority of Japan

JMA has been issuing tsunami warning immediately, in about three minutes, when a large earthquake occurs in coastal regions of Japan. This initial warning is based on only the information of the hypocenter and the magnitude. Therefore, detailed analysis, such as a centroid moment tensor solution, are needed to update the warning.
Ueno et al. (2014) tried w-phase analysis for the 2011 Tohoku-Oki earthquakes (the main shock and the largest aftershock) using high-sampling-rate (1Hz) GNSS data. Furthermore, Miyaoka et al. (2014) tried to estimate length and width of the fault using the coseismic crustal deformation data observed at each GNSS sites based on the result of the w-phase analysis described above.
These study showed a possibility to obtain the CMT solution and the fault size in six or seven minutes after the event occurrence and pointed out the necessity to analyse other cases.
In this study, we applied these analyses to a case of the 2003 Tokachi-Oki earthquake. We would like to show the result of the analysis.

Keywords: W-phase, GNSS 1Hz data, 2011 Tohoku-Oki earthquake, 2003 Tokachi-Oki eqrthquake


High-rate(1Hz) GNSS
displacement waveform data
(band-path filtered)
Initial
hypocenter
location
W-Phase analysis
(WP-inversion & Grid search)
CMT
(centroid, magnitude, strike, dip, rake)
Co-seismic displacement
of GNSS data.
Grid search for the span of fault
(length, width).
The optimal dimension of fault
(length, width)

# Study on matching method of the ocean bottom pressure waveforms toward real-time tsunami forecast

*Wataru Suzuki[1], Shin Aoi[1], Kenji Hirata[1], Naotaka YAMAMOTO[1], Hiromitsu Nakamura[1], Shingo Suzuki[1], Tetsuya Takeda[1], Makoto MATSUBARA[1], Takashi Kunugi[1]

1.National Research Institute for Earth Science and Disaster Prevention

We are developing a real-time forecast system of the tsunami inundation as well as the coastal tsunami heights for the Pacific coast of Chiba prefecture (Kujukuri and Sotobo regions), using the real-time ocean bottom pressure data (Aoi et al., 2015) observed by the Seafloor Observation Network for Earthquakes and Tsunamis along the Japan Trench (S-net; Kanazawa et al., 2012; Uehira et al., 2015). We employ the database-driven method to forecast the inundation, which is a nonlinear phenomenon, for relatively broad region. We use the densely observed data set probably including the data obtained in or close to the tsunami source area to perform the rapid and accurate tsunami forecast. The database is called as “Tsunami Scenario Bank” and includes “Tsunami Scenario” composed of the possible tsunami source model, and the simulation results of the ocean bottom pressure data at S-net observation stations, coastal tsunami heights, inundation areas and flow depth, for each source model (Suzuki et al., 2015). The system starts to search scenarios whose ocean bottom pressure data match the observed data reasonably well. Selected scenarios from this matching then provide the information of forecasted tsunami heights, inundation areas and flow depth, adequately considering the uncertainties of the forecast. Now, the matching algorithm implemented for the forecast system compares the spatial distributions of ocean bottom pressure changes using the correlation coefficient and two kinds of variance reductions (Yamamoto et al., 2016). To advance the robustness of forecast and warning, it is better to implement several different approach for real-time tsunami detection and forecast. In this study, therefore, we examine the matching for the time series of the ocean bottom pressure change at each station for selecting the tsunami scenarios that explain the observation well.
To evaluate the fitness between the observed and scenario pressure data, we examine the L1 norm---the absolute values of differences---and L2 norm, which corresponds to the least square evaluation. We applied the two norms to the synthetic ocean bottom pressure data at 150 S-net stations calculated from the tsunami source model of the 2011 Tohoku-oki earthquake. For scenario bank, the results calculated from the non-linear tsunami simulation based on approximately 1,800 tsunami source models that would affect the Pacific coast of East Japan (Hirata et al, 2014). Matching using both L1 and L2 norms resulted in slightly underprediction for the amplitude of coastal tsunami height as well as the amplitude of the ocean bottom pressure data. In addition, we found that matching with the L1 norm tends to underestimate the tsunami scale more in the early stage of the tsunami propagation. We will, then, comprehensively capture the characteristics of the evaluation using the L1 and L2 norms from the examination of the other synthetic tsunami data and develop the appropriate method to match the observed and scenario ocean bottom pressure data.
Acknowledgement: This work was partially supported by Council for Science, Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program (SIP), "Enhancement of societal resiliency against natural disasters" (Funding agency: JST).

Keywords: Real-time tsunami forecast, Tsunami inundation, Scenario bank, S-net