Project Definition Workshop on M9 Disaster Science

University of Washington, March 13–14, 2019

Extended Abstracts on Potential Collaboration Projects

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Multi-scenario Community Planning for Coastal Hazards

Daniel Abramson, Ann Bostrom, Lan Nguyen and Katherine Idziorek
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Coastal Washington State is historically susceptible to a wide range of natural hazards ranging from relatively frequent threats like flooding, landslides and erosion to rare but potentially catastrophic events such as M9 earthquakes and tsunamis. Meanwhile, changing climatic conditions pose a growing threat to the region's coastlines and communities. The need for credible information and strategies for more effectively adapting and responding to both climate-driven changes and seismic hazards are obvious and immediate.

We propose to test new, values-centered, scenario-based planning to help communities prepare, respond and adapt to coastal hazards and climate change – specifically focusing on tsunamis and sea level rise.

We bring to this task: (1) a view of irreversible changes as opportunities for promoting proactive adaptive planning to build community resilience, social capital, and adaptive capacity, rather than vulnerability-centered short-to-medium-term hazard mitigation; (2) new techniques of participatory scenario building and evaluation that relate scientific and local knowledge; and (3) an action-research methodology that generates tangible benefits for the participating communities as well as improved practices for related professions and their client communities in the broader region.

Implementation of Hard and Soft Exclusion Sources in conjunction with DART 4G Technology for Rapid and Accurate Assessment of Cascadia Events

NOAA Center for Tsunami Research
Diego Arcas and Vasily Titov

In recent years, research at the NOAA Center for Tsunami Research (NCTR) has been focused on the improvement of NOAA's current forecast methodology to improve and expedite tsunami forecast assessment of the near-field. NCTR considers its current forecast methodology based on inversion from DART stations to provide the most accurate forecast results, but at a significant penalty in terms of timeliness. This shortcoming is particularly relevant in the near field, where tsunami impact is expected to be most severe, as will be the case of the Pacific Northwest coast of the US during a Cascadia event. In order, to improve the current situation, research at NCTR has been focused along two lines:

1-Improvement of initial and provisional forecasts for the near-field region prior to the availability of a DART inverted forecast.
2-Reduction of the latency time for a DART inverted forecast

In order to make headway in (1) work has started with collaborators from Central Washington University, NASA, Scripps and the University of Oregon (Diego Melgar, Amy Williamson) to use GPS data of ground displacement in real-time to generate a fast and accurate PGD Magnitude, CMT and finite fault solution of the event (Melgar et al.), tentatively within 5 minutes of rupture initiation.

In addition, tsunami hydrodynamic models have been parallelized and optimized for GPU architecture, resulting in the acceleration of real-time inundation models by a factor of 10 to 20. The goal is to have a preliminary but sufficiently accurate inundation forecast for coastal communities within 10 minutes of the rupture initiation.

Simultaneously, in order to make progress towards (2), a new generation of DART buoys (4G) was developed that can be deployed in close proximity of the rupture area effectively reducing latency time to tsunami detection from 30 minutes to approximately 5 minutes. NCTR has proposed a dense configuration of DART systems along the offshore margin of Cascadia that would guarantee tsunami detection between 5 and 10 minutes after origin time. These dense DART network would require the modification of the current inversion algorithm (Percival et al.) to be used with a fractional inversion approach, whereby each DART station would be exclusively used for inversion of rupture segments located in regions within tsunami travel time of the DART station (Valid Sources), potentially tsunamigenic areas within shorter tsunami travel time than the time of tsunami detection at DART will be excluded (Hard-Exclusion Sources) and potentially tsunamigenic areas with a tsunami travel time larger than the time elapsed since origin time will be conditionally excluded (Soft-exclusion sources). Such approach could result in the generation of a series of partial inversions with local validity along the coast prior to the final generation of a joint inversion solution.

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Tsunami Resonance Along the Chilean Coast: The role of bay shape and source location

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The occurrence of tsunami amplification in coastal areas due to resonance and energy trapping has been a subject of a long history of research. Reports of its occurrence exist for a large number of tsunami events, suggesting it is a fairly ubiquitous process. However, although it is understood that resonance is a relevant process, the characteristics of local responses are not always well understood. For instance, at certain locations existing records suggest that different modes can be excited by different tsunami events, suggesting that while an overall system response can exist, the details of the actual system response can also be dependent on the characteristic of the source. To which extent either mechanism governs the response at a particular location, it is not completely understood. Advancing in this understanding can be of importance in detecting tsunami hot spots, for example.

In order to understand how different locations along the Chilean coast respond to tsunamis, a systematic study of the resonance at number of bays has been conducted, combining different methods. Actual sea level data from tide records (with and without tsunamis) have been used to determine the background spectra and also tsunami spectra. For the latter, we have been able to use up to six tsunami events, thereby allowing assessing source dependencies. Next, numerical solutions of a free oscillation model are estimated to determine potential modes and their spatial structure. Comparison among these modes and background spectra allows identifying natural modes, even though discriminating between local and shelf modes can be difficult. Finally, numerical modeling of simple-source tsunamis located at different locations relative to the location of interest allows estimation of the dependency on tsunami travel path in triggering resonance.

The methodology is applied to five different bay configurations. Results indicate that responses can vary significantly depending on some geometric characteristics of the bay. For instance, well enclosed and shallow bays tend to respond in the same way regardless of source characteristics and relative location. On the other end, more open and deeper bays show sensitivity on either the tsunami source or the relative location of it, thereby exhibiting different behavior for different events. Further work needs to be done aimed at establishing whether bay morphology could be used to predict its behavior.

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What Can We Do to Forecast Tsunami Hazards in the Near Field Given Large Epistemic Uncertainty in Rapid Seismic Source Inversions?

R. Cienfuegos[1] , P.A. Catalán[2], A. Urrutia[3], R. Benavente[4], R. Aránguiz[5], G. González[6]

The variability in obtaining estimates of tsunami inundation and runup on a near real time tsunami hazard assessment setting is evaluated. To this end, 19 different source models of the Maule 2010 Earthquake were considered (Fig. 1) as if they represented the best available knowledge an early tsunami warning system could consider. Results show that large variability can be observed in both coseismic deformation and tsunami variables such as inundated area and maximum runup. This suggests that using single source model solutions might not be appropriate unless categorical thresholds are used.

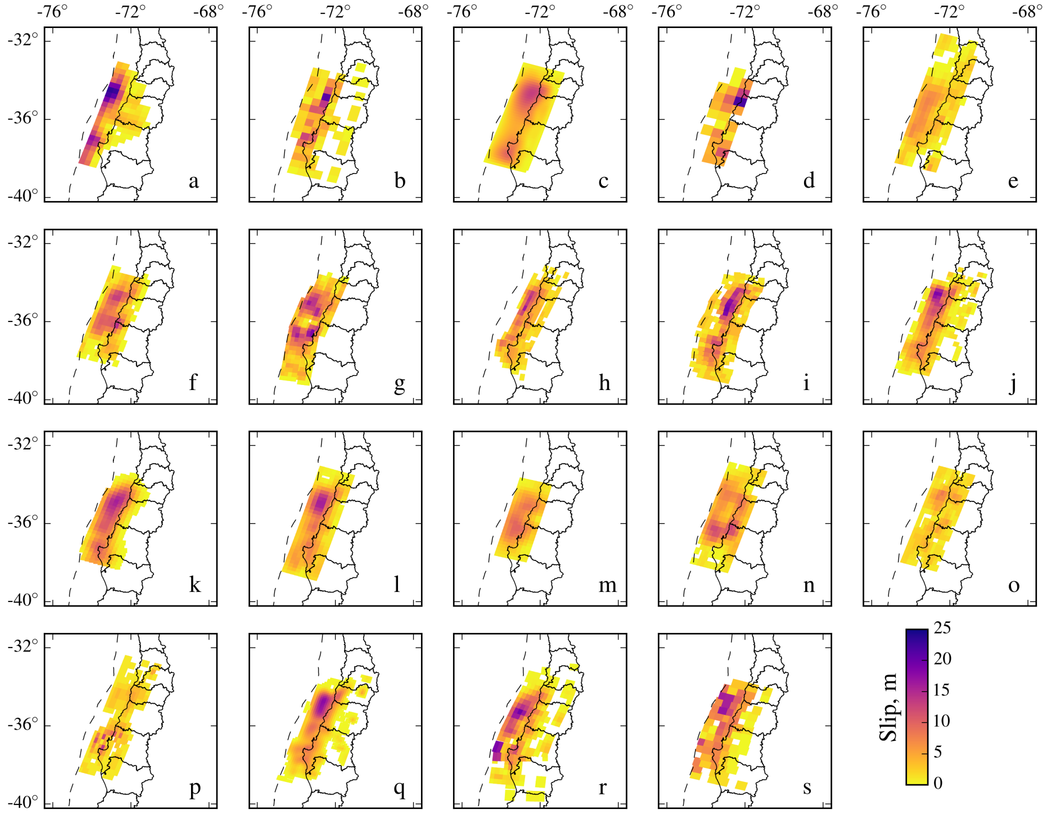

Fig. 1 - Slip distributions for each rupture model considered in the analysis.

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Nevertheless, the tsunami forecast obtained from aggregating all source models is in good agreement with observed quantities (Fig. 2), suggesting that the development of seismic source inversion techniques in a Bayesian framework or generating stochastic finite fault models from a reference inversion solution could be a viable way of dealing with epistemic uncertainties in the framework of nearly real time tsunami hazard mapping.

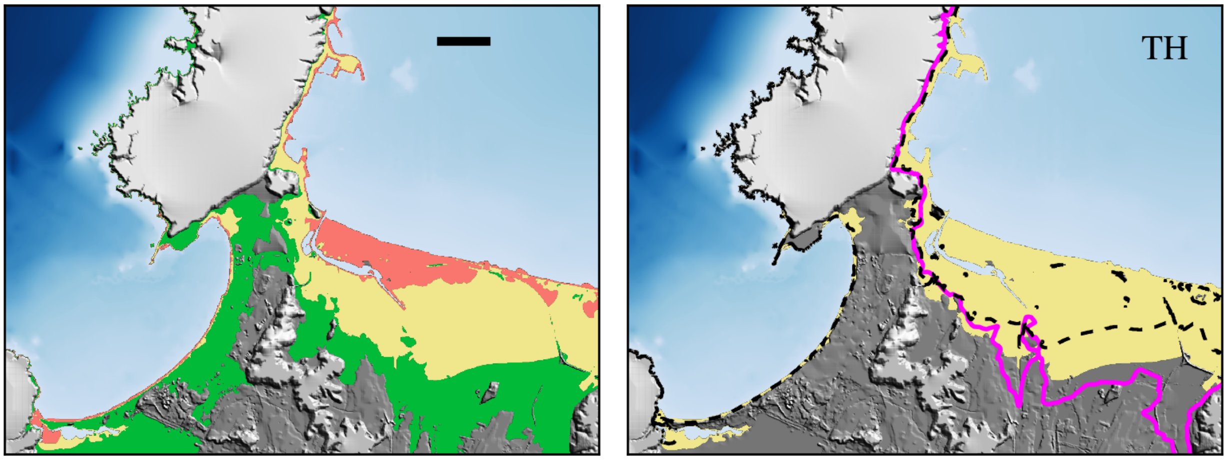

Fig. 2 - Inundation map for Talcahuano. Scale bar represents 1 km. (left) Orange, yellow, and green parts of the maps denote the areas that are inundated by the 97.5%, 50%, and 2.5% of the models, respectively. (right) The yellow part of the map represents the area inundated by 50% of the models, the magenta line indicates the maximum inundation runup estimated from post-tsunami surveys.

Our aim is to analyze to which extent inherent epistemic uncertainties associated to seismic source inversions affect tsunami hazard forecasts and their implications for future developments of operational Tsunami Early Warning Systems (TEWS). To this end, it is important to address whether Near-Real-Time Tsunami Hazard Assessment (NRTTHA) can provide meaningful estimates from the available knowledge and techniques.

R. Cienfuegos, P.A. Catalán, A. Urrutia, R. Benavente, R. Aránguiz, & G. González. (2018). What can we do to forecast tsunami hazards in the near field given large epistemic uncertainty in rapid seismic source inversions? *Geophysical Research Letters*, 45(10), 4944-4955.

Effect of spatial correlations of slip on tsunami intensity inundation parameters

J. G. F. Crempien[1] , A. Urrutia[2], R. Benavente[3], R. Cienfuegos[4]

Abstract

Mega-earthquakes and their respective tsunamis are infrequent and extremely destructive events. Due to the lack of recorded data of tsunami processes, the variability of tsunami intensity parameters is unknown, which motivates us to simulate the physical process of earthquake faulting and tsunami wave propagation. Mai and Beroza (2002) have shown that the magnitude of mega-earthquakes is directly proportional to the average size of slip asperities on the fault. This has been quantified via the calculation of spatial correlations in the wavenumber domain. The spatial heterogeneity of slip in mega-earthquakes, along with bathymetry, controls the intensity of the tsunami processes. Because of this, it is important to quantify the effects of spatial slip correlations have on tsunami intensity parameters, such as runup and wave-height, as well as the between-events variability of said parameters. Preliminary results show that average runup and wave-height do not change with changing spatial correlations. On the contrary, the variability increases considerably with increasing spatial correlations. These findings have great impact on probabilistic tsunami hazard analysis.

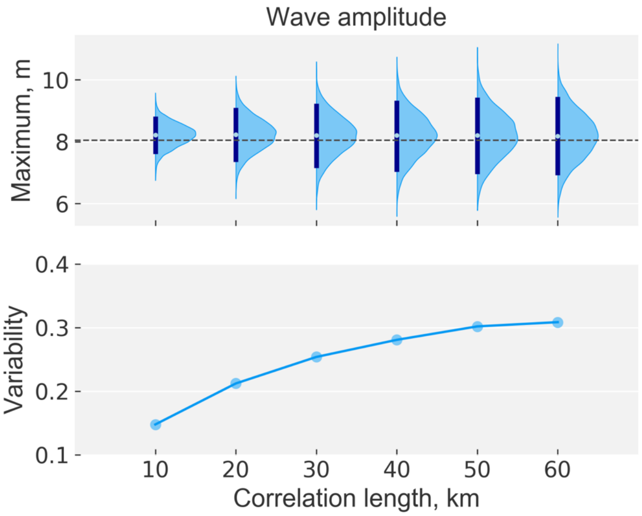

Figure: (top) Probability distribution functions of maximum wave-amplitude (shaded area), the dot corresponds to the mean of the maximum wave amplitude, and the dark blue bar shows the 90th confidence interval. (bottom) The variability corresponds to the 90th confidence interval of the mean.

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Perspectives for Collaboration

We aim to understand the effects of realistic bathymetries and earthquake source complexity have on between-events and within-event variability tsunami intensity parameters, with particular interest of application to probabilistic tsunami hazard assessment (PTHA).

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The possibility of applying layover simulation to change detection caused of natural disasters using multi-temporal SAR images

Yukio Endo[1], Luis Moya[2], Erick Mas[3], Shunichi Koshimura[4]

1. Introduction

Change detection from multi-temporal Synthetic Aperture Radar (SAR) enables the rapid detection of severely damaged areas in the case of natural disasters. Especially, the emergence of meter scale SAR image has opened up the new possibility of detecting damages in a building unit scale. Unfortunately, despite of its outstanding resolution, distortion effects, such as layover and shadow, derived from the side-looking geometry have apparently hampered practical applications of damage detection. Notably, as far as geospatial characteristics of the Washington State is concerned, the presence of tall trees would be an obstacle of analyzing SAR image. In order to overcome this problem, we propose an application of RaySAR based change detection using pre-event LiDAR data to the damaged building detection. RaySAR is a software developed by Technical University of Munich and German Aerospace Center1) 2). As shown in Figure 1, this software computes visible areas of building using LiDAR data, and then, the position of pixels that store backscattering from the building is estimated considering layover effets.

2. Experiments of Layover Simulation Using RaySAR

In this section, the extent of layover was evaluated in several conditions using RaySAR. In this experimental analyses, two virtual cuboids, including Object-A $(30 \times 20 \times 20)$ and Object-B $(25 \times 10 \times 20)$, were manually defined instead of importing LiDAR data. The cross section of the objects is shown in Figure 2. The local incidence angle of radar was set to 45°. Firstly, backscattering only from the Object-A and the floor was simulated. Secondly, backscattering only from the Object-B and the floor was simulated. Finally, the layover area derived from Object-A was detected considering both of the objects and floor. Simulation results are summarized in Figure3. It is obvious from the figure that the layover area of Object-A is decreased by the shadow area of Object-B. As we discussed in this section, extracting detailed backscattering from each building requires RaySAR analysis.

3. Perspectives for Collaboration

RaySAR has been successfully applied to some benchmark problems, such as monitoring city development3). However, its possibility to contribute disaster damage assessment has not been sufficiently examined because of the lack of knowledge about disaster management and the limited accessibility to LiDAR data. During the workshop, we aim to discuss how RaySAR can support change detection of future disasters, and seek the possibility to conduct experiments of this method focusing on the Washington State, whose topography has been surveyed through several forest preservation projects.

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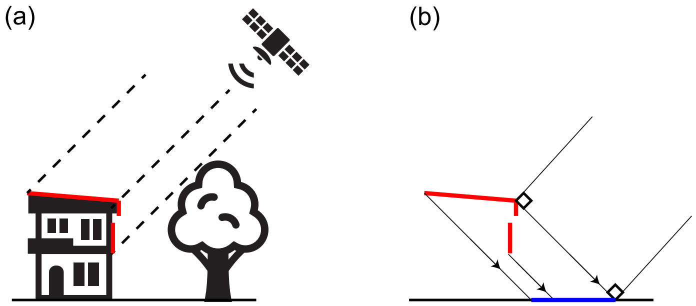

Fig.1 Schematic representation of RaySAR processing steps. The visible area (red line) from sensor is computed considering parameters of image acquisition, as shown in (a). Subsequently, the layover (blue line) derived from this area is detected, as shown in (b).

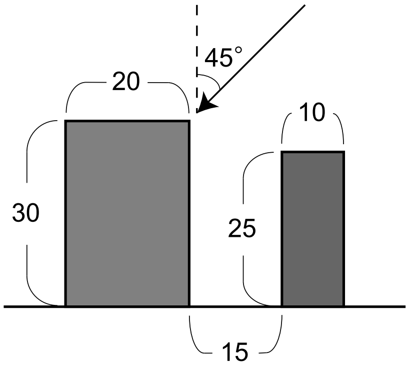

Fig.2 Cross section of target scene defined in POV-Ray. The left object is Object-A, and the right object is Object-B. The depth of them is set to 20.

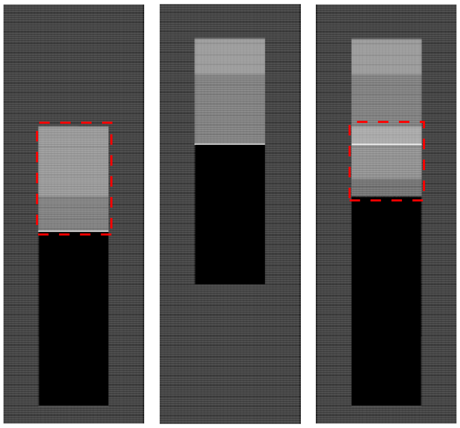

Fig.3 Summary of simulation results. Range coordinate is top-down. The red squares represent layover area derived from Object-A in each condition. (Left: Backscattering only from the Object-A and the floor is simulated. Middle: backscattering only from the Object-B and the floor is simulated. Right: backscattering from all of components is simulated)

Synthesizing and Visualizing the (Many Ways of) Evolution of Possible Precursory Phenomena to Occurrence of Megaquakes

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It has been known for a long time that earthquakes trigger other earthquakes with some probability (Omori's law). Based on such knowledge, routine communication of forecast information when earthquakes of moderate or larger size struck is in operation in a few places in the world. Slow slip phenomena will probably be additionally used in earthquake forecasts before too long, with increasing cases of slow slip events triggering large earthquakes, including 2011 Mw 9.0 Tohoku earthquake in Japan and 2014 Mw 8.1 Iquique earthquake in Chile.

In Japan, a new official forecast information service on impending Nankai trough earthquakes started in November 2017. Based on the earthquake activity and slow slip occurrence, the Japan Meteorological Agency will send warning information when the chances of a megaquake have become "higher than normal". This kind of forecast information is qualitative and includes large uncertainty. While it is challenging for the society to effectively use such obscure information, it is worthwhile (or even responsibility of the research community of disaster science) seeking the way of usage for disaster reduction, considering the huge damage and losses anticipated for the Nankai trough earthquakes. The authority estimates, in the worst-case scenario, more than 200 thousand victims from tsunami. According to their estimate, this number drastically drops to 85 thousand when prompt evacuation takes place. Since huge tsunami (say higher than 10 meters) is expected within a few minutes at many places, systems that issue warnings after the occurrence of earthquake or detection of sea height level change cannot provide enough lead time for everyone. The new kind of forecast information has a potential to solve this problem. Same kind of reasoning holds for earthquake-induced landslide hazard.

With my colleagues at IRIDeS, Tohoku University, we launched a project to develop event tree diagram that graphically shows evolution of geophysical phenomena (giving rough probability information for each branch) starting from precursory phenomena to leading to the occurrence of (or non-occurrence of) a megaquake(s). Of course, an M9 can occur without any precursory signal. But other scenarios are also possible. For example,

- An M8 earthquake occurs, followed by another M8 with some time lag (in fact this occurred multiple times in Nankai). The time lag can be in the order of minutes, hours, days, months, or years.
- Similarly but with smaller probability, an M7 occurs, followed by a megaquake (M8 or M9) with some time lag. (Note that having moderate to large interplate earthquakes is already abnormal in Nankai (we rarely have them), as is also the case for Cascadia.
- A series of smaller earthquakes occur (foreshocks), followed by a megaquake.
- One of the slow slips occurring regularly trigger a megaquake.
- Unusual type of slow slip occurs preceding a megaquake.

Our assumed main target users of the diagram are disaster management personnel (those who have to prepare response plans or manuals in advance for the occasions of warning issuance) of local governments, public institutions, and key private companies of the local society. The diagram will serve

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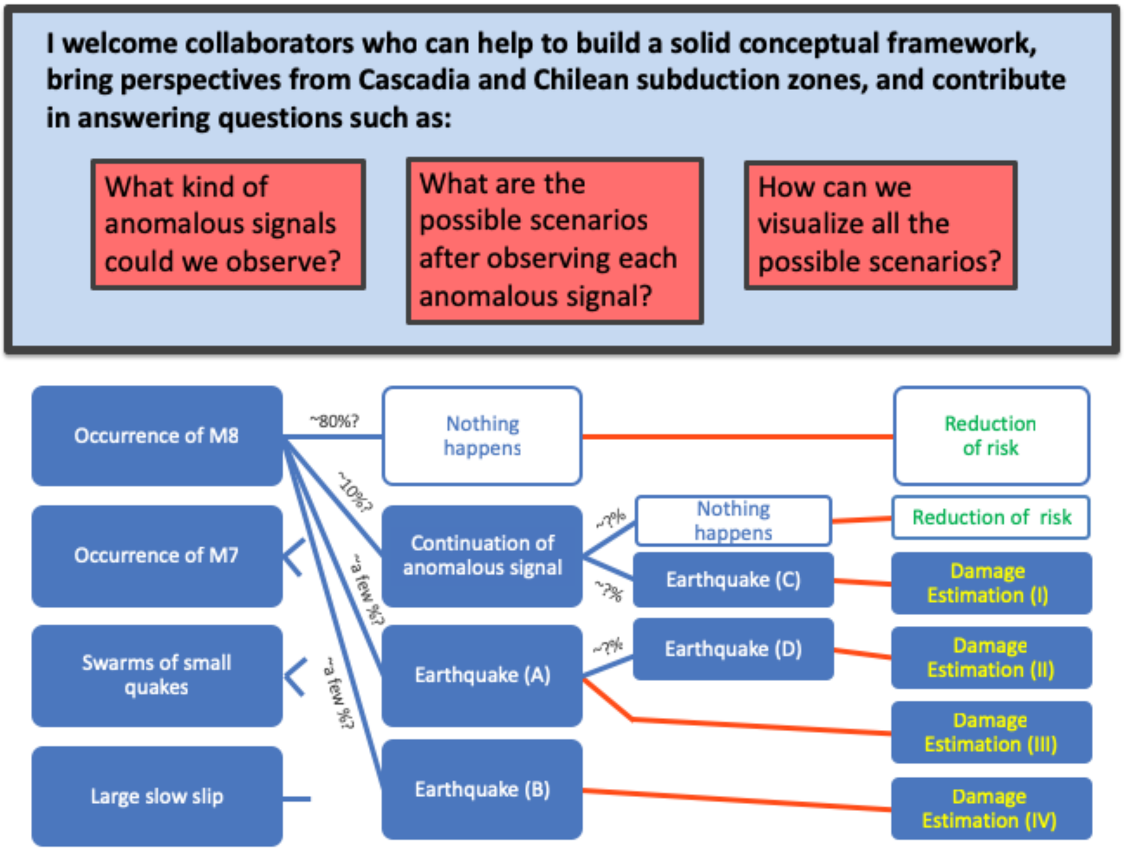
as a tool 1) for understanding the spectrum of possible scenarios, and 2) for planning and verifying the countermeasures (if they are inclusive and flexible enough).

I invite collaborators who can 1) help to build a solid conceptual framework, 2) bring perspectives from Cascadia and Chilean subduction zones and make comparisons with Nankai subduction case, and 3) contribute in synthesizing the precursory phenomena (e.g., probability calculation of abnormal phenomena leading to a megaquake) or raising ideas about the visualization method (e.g., design of graphical representation).



I welcome collaborators who can help to build a solid conceptual framework, bring perspectives from Cascadia and Chilean subduction zones, and contribute in answering questions such as:

What kind of anomalous signals could we observe?

What are the possible scenarios after observing each anomalous signal?

How can we visualize all the possible scenarios?

Earthquake scenarios for active seismic gaps: a hybrid deterministic and stochastic approach for tsunami hazard assessment

J. González[1], G. González[2], R. Aránguiz[3], N. Zamora[4] and D. Melgar[5]

Abstract

Plausible worst-case earthquake scenarios definition plays a relevant role in tsunami hazard assessment focused in emergency preparedness, evacuation planning and optimal location of critical infrastructure for coastal communities located in active seismic gaps. During the last decades, the occurrence of major and moderate tsunamigenic earthquakes along worldwide subduction zones has given clues about critical parameters involved in near-field tsunami inundation processes, i.e. slip spatial distribution, shelf resonance of edge waves and local geomorphology effects. To evaluate the behavior of these geological and hydrodynamic variables over the coastal inundation, we focused in the northern (~17° to 24°S) and central (~30° to 37°S) segments of the chilean continental margin that constitutes an active subduction zones, with a high seismogenic potential to release a $M_w > 9$ earthquakes in a near future and therefore a relevant tsunami threat for all near-field cities in the region. Regarding this fact, we propose a hybrid deterministic and stochastic multi-scenario approach to assess the current state of tsunami hazard of the coastal zone. The deterministic worst-case scenarios are estimated using regional distribution of gravity anomalies, a worldwide model of subduction zones geometry and published interseismic coupling anomalies. Initially, we can find the spatial distribution of major seismic asperities of the studied gaps, used to construct a preliminary group of slip-deficit sources for evaluate the range of magnitudes of expected earthquake scenarios. Subsequently following a stochastic scheme, we implement a Karhunen-Loève expansion (LeVeque *et al.*, 2016; Melgar *et al.*, 2016) to generate a finite number of stochastic scenarios (~500 to 1000) (Figure 1) over the maximum extension of the active seismic gaps (González *et al.*, 2019). All the scenarios are simulated through a non-hydrostatic tsunami model, Neowave 2D, using a classical nesting scheme for all studied cities obtaining high resolution data of inundation depth, runup, coastal currents and sea level elevation. The stochastic kinematic tsunamigenic scenarios give a more realistic slip patterns, similar to maximum slip amount of major past earthquakes occurred in the active seismic gaps.

Perspectives of collaboration

- Methodological improvements of proposed approach.
- Implementation in other active seismic gaps (e.g. Cascadia and Japan).
- Reconstruction of major earthquakes scenarios (e.g. 1868 and 1877 earthquakes in southern Peru and northern Chile, 1730 earthquake in central Chile and 1700 earthquake in Cascadia), constraining using historical and geological data.

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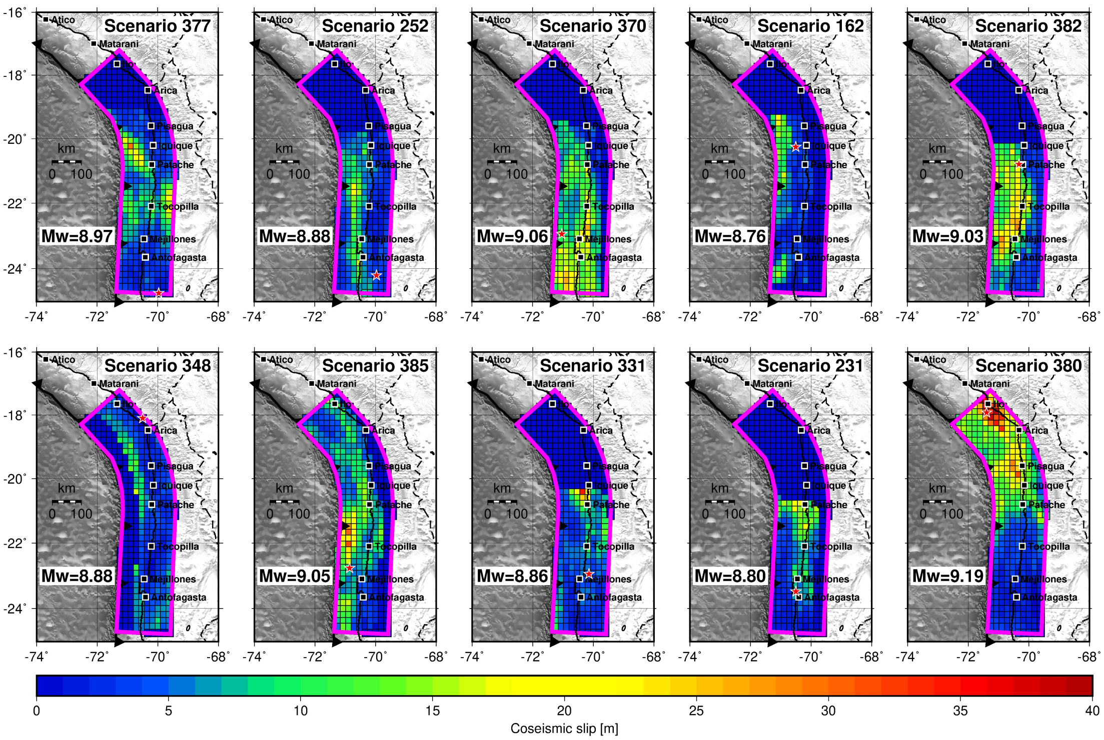

Figure 1. Example of K-L expansion stochastic earthquakes scenarios for southern Peru and northern Chile seismic gap.

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A New Tsunami Numerical Model with the Polygonally Nested Grid System and its MPI-Parallelization for Real-time Tsunami Inundation Forecast on a Regional Scale

Takuya Inoue[1] , Shunichi Koshimura[2]

1. Introduction

A real-time tsunami inundation forecast is expected to make disaster response activities shortly after earthquake occurrence more effective and efficient. Among technologies of real-time tsunami forecasts, “forward simulation” approaches, which simulate tsunami propagation and inundation after earthquake occurrence, has advantages over “database-driven” approaches. This is because the former can incorporate actual sensing data such as tsunami source models based on earthquake information and offshore tsunami observations, resulting in narrowing down the number of possible scenarios and increased precision. It is also a tremendous advantage to refrain from updating massive database of tsunami inundation scenarios. The fundamental bottleneck of the forward simulation approach, however, is computational load. Even adopting so-called supercomputers, it was possible to cover merely a certain city area with the coastline of 20 – 30 km1), 2). A massive tsunami of the M9 level will devastate a series of coastal municipalities. Therefore, inundation forecasting should be conducted on a regional scale. This abstract summarizes our research regarding the development of an efficient tsunami inundation model for real-time tsunami inundation simulation in order to initiate the discussions in the workshop towards future collaborations.

2. A New Tsunami Numerical Model with the Polygonally Nested Grid System

As illustrated in **Fig. 1** (a), two-dimensional tsunami inundation simulation with the conventional rectangular domain will obviously face two obstacles in covering wider areas. Firstly, a computational domain includes high elevations that will not be inundated but increase a load of operation and memory. Secondly, deep waters are also included in the domain, leading to a stringent CFL condition. Therefore, we are obliged to cover the target region with lots of small domains and wastefully repeat computations as shown in **Fig. 2** (a). On the contrary, the newly-developed polygonally nested grid system extents the configuration of domains from conventional rectangular regions to polygonal regions so that deployment of high-resolution grids can be confined to coastal lowland as shown in **Fig. 1** (b), **Fig. 2** (b)3).

We also equipped the new model with functions for one-stop real-time forecasting and validated through the National Tsunami Hazard Mitigation Program benchmark problems, and named RTi (Real-time Tsunami inundation) model. **Fig. 3** shows the computational performance of RTi mode. It takes only 128 cores for 6-hour integration within 10 minutes, corresponding to over 10 times higher efficiency.

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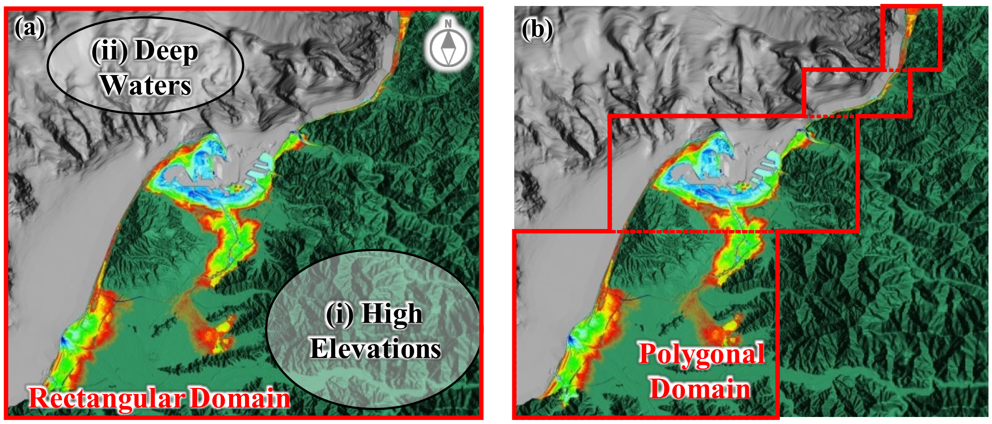

Fig. 1. Schematics of the two obstacles in a wide-area simulation (a) and extension to the polygonal domain (b). Solid lines in red designate borders of computational domain, and dashed lines are borders of polygonal blocks.

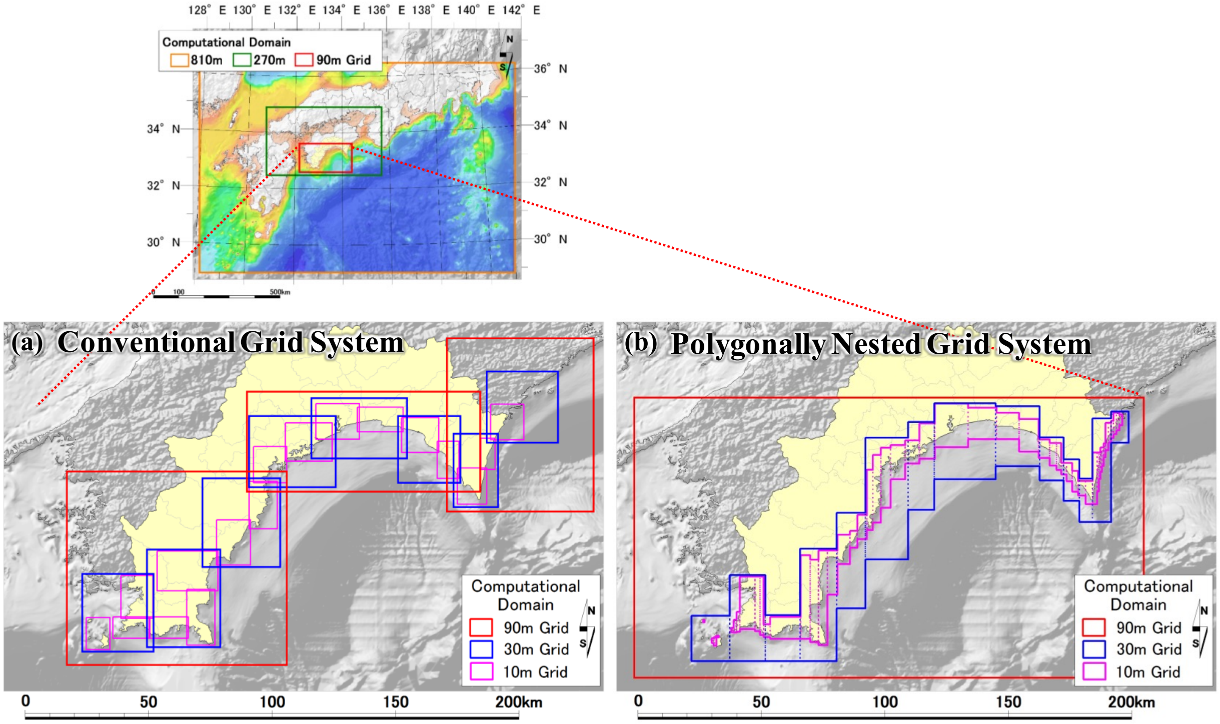

Fig. 2. Examples of grid systems for wide-area tsunami simulation regarding Kochi Prefecture in Japan, together with configurations of offshore domains with coarser grids. The panel (a) gives an example of a grid system with conventional rectangular domains. The polygonally nested grid system is shown in the panel (b). Dashed lines denote borders of polygonal blocks, and NS and EW directions are transposed in computation.

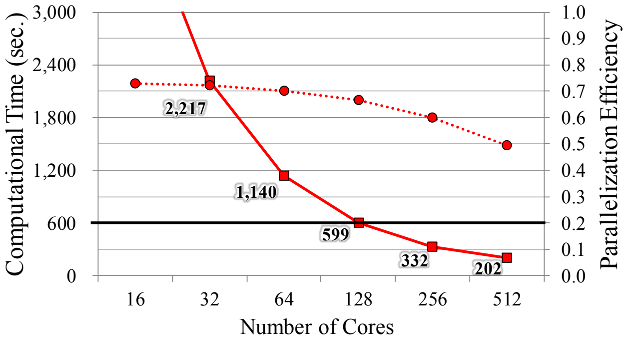

Fig. 3. Computational performance of the RTi model for the 10-meter resolution case of Kochi Prefecture with the coast line of 700 km. Duration of time integration is 6-hours. As a computational environment, SX-ACE, a vector supercomputer installed a Tohoku University is used. Square symbols denote computational time (left axis), and disks are parallelization efficiency (right axis), which is the rate of speed up compared to a single-core calculation normalized by the number of deployed cores.

Real-time Tsunami Inundation and Damage Forecasting with High-Performance Computing Infrastructure

Shunichi Koshimura[1], Yusaku Ohta[2], Takuya Inoue[3]

1. Introduction

In the aftermath of catastrophic tsunami disasters, identifying its impacts in a quantitative manner is crucial for disaster response and relief activities. With the lessons of the past events, the importance of developing technologies to forecast the regional impact of great tsunami disaster has been raised1). However, the extensive scale of catastrophic tsunami makes it difficult to comprehend the whole picture of its impact along the long stretch of coastline, and may disable to prioritize how the limited resources for emergency response and relief should be deployed in such limited amount of time and information. We believe that fusion of high-performance computing and geo-informatics defeats this problem and lead to understanding the whole picture of the tsunami affected areas. This abstract summarizes our research to initiate the discussions in the workshop towards future collaborations.

2. Real-time Tsunami Inundation Forecasting

An automated system for real-time tsunami propagation and inundation forecasting, we established, first uses the information from Earthquake Early Warnings and GNSS crustal deformation monitoring2), 3) (Fig.1). Given the tsunami source, the system moves on to running tsunami propagation and inundation model which was optimized on the vector supercomputer SX-ACE and SX-Aurora4) (Fig.2) to acquire the estimation of time series of tsunami at offshore/coastal tide gauges to determine tsunami travel and arrival time, extent of inundation zone, maximum flow depth distribution. The implemented tsunami numerical model is based on the non-linear shallow-water equations discretized by finite difference method. The merged bathymetry and topography grids are prepared with 10 or 30 m resolution to better estimate the tsunami inland penetration.

3. Damage Estimation and Mapping

Given the maximum flow depth distribution, the system performs GIS analysis to determine the numbers of exposed population and structures using census data, then estimates the numbers of potential death and damaged structures by applying tsunami fragility curves1) (Fig.3), which is structural damage probability as a function of tsunami flow depth1). Since the tsunami source model is determined, the model is to complete the estimation within 10 minutes. The results are disseminated as mapping products (Fig.4) to responders and stakeholders, e.g. national and regional municipalities, to be utilized for their emergency/response activities, e.g. identifying the number of exposed populations, potential damage on houses, road networks, critical infrastructures, search and rescue, and recovery.

4. Perspectives for Collaboration

With use of modern computing power and advanced sensing capabilities, we established a real-time tsunami inundation forecasting, damage estimation and mapping to enhance society's resilience in the aftermath of major tsunami disaster. Through the feasibility study, this system has started its operation since November 2017 as a function of tsunami disaster response system of the government of Japan. And we are willing to expand its capability to the other tsunami-prone areas. During the workshop, we aim to discuss how earth observations and modeling, in combination with local, in situ data and information sources, can support the decision-making process before, during and after a disaster strikes.

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Acknowledgments

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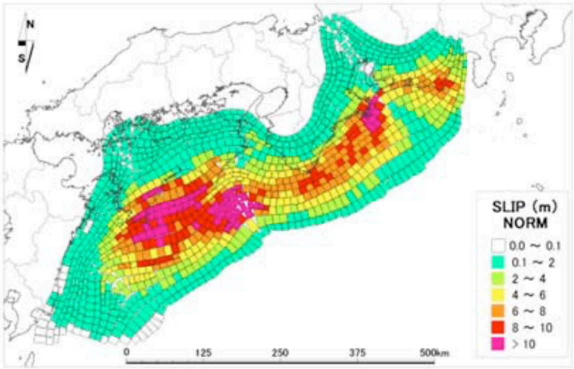


Fig.1 Example of estimated fault slip distribution by GNSS-based real-time finite fault modeling in Nankai Trough[3].

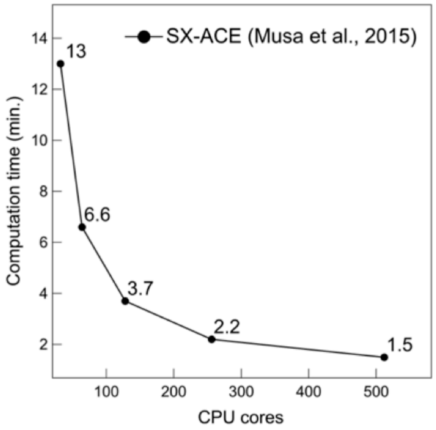


Fig.2 Performance of vector supercomputer SX-ACE in running tsunami numerical simulation for 3-hour forecast with 10 m grid[4]. This implies the advantage of high memory bandwidth and efficiency of vectorization in running tsunami simulation code.

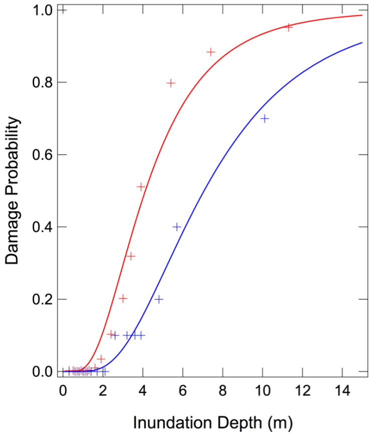


Fig.3 Tsunami fragility curves for estimating structural damage obtained from the 2011 Tohoku tsunami affected areas[1]. The plot shows the probability of structural destruction as a function of tsunami flow depth.

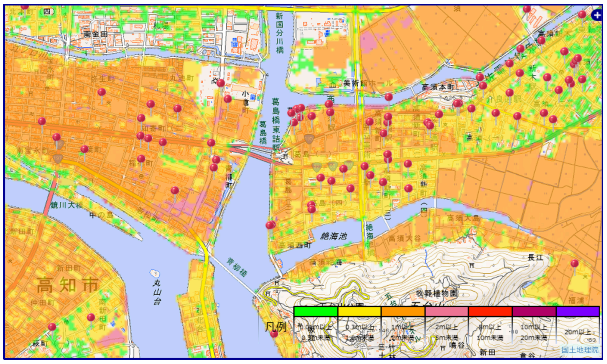


Fig.4 Example of mapping results at the test bed Kochi prefecture (Maximum tsunami inundation depth. The red pins represent the location of tsunami evacuation buildings).

Characteristics of the Disaster Prevention Group Relocation Promotion Project in the Great East Japan Earthquake and Evaluation on Residential Environments after Relocation

N. Kojima[1] , N. Kuriyama[2]

1.Introduction

In promoting reconstruction after the Great East Japan Earthquake of March 11, 2011, the Disaster Prevention Group Relocation Promotion Project (hereinafter referred to as “Prevention Group") has been widely applied as one of the reconstruction methods for promoting relocation to higher ground and for moving inland. Although the size of residential housing complexes after relocation in the conventional Prevention Group is said to require 10 or more houses, there is a special case in which 5 or more houses in the disaster area of the Great East Japan Earthquake can be relieved.

With the passage of time since the earthquake, it became possible to confirm the completion of superficial projects, such as Prevention Group public housing projects (hereinafter referred to as disaster public housing) and the installation of peripheral facilities. In anticipation of future disasters and throughout the process of selecting appropriate projects for reconstruction, understanding the characteristics of reconstruction projects applied after the Great East Japan Earthquake is considered to contribute to future reconstruction.

In this study, we investigate and analyze the residential environments in the prevention area using GIS and discuss their relationship with the Prevention Group.

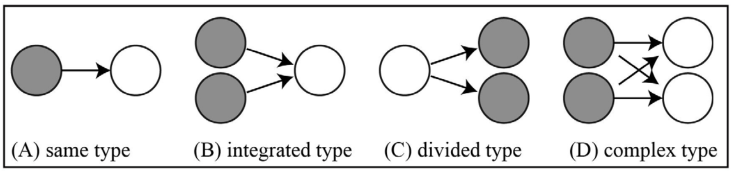
Various research has been conducted on the Prevention Group, but each study employs survey analysis methods in limited municipalities and districts1) and, although research focusing on convenience and residential environments is accumulating, this study is unique in that it surveys and analyzes convenience and residential environments in multiple prefectures, municipalities, and districts and discusses their relationship with the Prevention Group implementation from a bird's eye view.

2. Characteristics of Prevention Group implementation after the Great East Japan Earthquake

We selected Otsuchi Town, Rikuzentakata City, Minami Sanriku Town, and Onagawa Town as research target municipalities because of the following conditions.

1. Multiple municipalities that are under similar circumstances
2. Those with a large number of project implementation districts and housing supply units.
3. Those in the Sanriku Region where the human and property damage was the most violent comparing to Sendai Plain and Fukushima Prefecture.

We focused on the reconstruction project combination, relocation type, the number of dwelling units. In the reconstruction project combination, there are many (1) Prevention Group only and (2) Prevention Group + disaster municipal housing districts, while in the relocation type, there are many (A) same type, (B) integrated type, and (C) divided type districts(Fig.1) ; therefore, the study areas are (1) Prevention Group only and (2) Prevention Group + District of Disaster Public Housing for reconstruction project combinations and for the relocation type. As a result, we were able to select 80 districts as research areas.



(A) same type (B) integrated type (C) divided type (D) complex type

Fig.1. Image of relocation type

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Table 1. Reconstruction project combination / Relocation type / Number of districts / Supplied dwelling units

		Reconstruction project combination			
		(1) Prevention	(2) Prevention + Disaster	(3) Prevention + Disaster + District	(4) Prevention + District
Relocation type	(A) Same type	28 districts 5 to 54 units	10 districts 7 to 25 units		
	(B)Integrated type	7 districts 6 to 40 units	1 district 164 units		
	(C)Divided type	25 districts 5 to 69 units	9 districts 29 to 405 units	4 districts 560 to 1560 units	1 district 48 units
	(D)Complex type		1 district 152 units	1 district 194 units	

※ The bold frame indicates the study area.
※ "Prevention" is Prevention Group, "Disaster" is disaster public housing, "District" is a Land Rearrangement.

3. Consideration and evaluation of residential environments after group relocation

In this study, there are significant differences according to the development of Prevention Group housing complexes, and convenience is subject to residential environment evaluation. The residential environment evaluation index is shown in Table 2. Scoring is conducted in 5 stages for each indicator. The standard for the stages, based on the concept of relative evaluation of the score in this research area, is divided into 5 stages according to the score of each indicator, thus 5 ... 7%, 4 ... 24%, 3 ... 38%, 2 ... 24%, 1 ... 7%, with fine adjustment of the reference value to create a new standard. The residential environment is represented by district with a radar chart.

Table 2. Convenient residential environment evaluation index

Item	Index
Local Government Facility	Distance to administrative facilities
Community Facilities	Location of community facilities
Medical, Welfare	Locations of medical institutions, elderly support facilities, welfare facilities
Child-rearing, Education	Location of nurseries / kindergartens / infant schools, child-rearing support facilities, elementary / junior high schools
Convenience Facility	Location of cultural facilities (libraries, physical education facilities, etc.), commercial facilities (supermarkets-convenience stores, etc.), post offices, banks, parks
Transportation	Distance to nearest railway station, locations of bus stops

Examining the correlation between each indicator, it was clear that there was a strong correlation between completion of child-rearing/educational facilities and lifestyle convenience facilities. In addition, it became clear that there was a positive correlation between most indicators. In other words, the location of various convenience facilities is influenced by the location of other convenience facilities.

The relationship between the Prevention Group's implementation and residential environment evaluation is analyzed. The relocation types were highly evaluated in the following descending order: (C)divided type, (B) integrated type, and (A) same type. Regarding the evaluation of project combinations, only the (1) Prevention Group was evaluated higher. The high evaluation of (C)divided type is considered to be due to the fact that the implementation district is close to the municipal center and, therefore, maintains cohesion. The reason why (a) Prevention Group only is highly evaluated but (2) Disasters + disaster public housing is not is because it is difficult to secure the site when disaster public housing is being maintained by “plug-in” relocation, and it is necessary to develop a new housing complex, which is complicated by the belief that the necessary facilities are not in place.

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Structural Testing in a Wave Flume: An Experimental Perspective and Research Needs

D. Lehman[1] , M. Motley[2], and C. Roeder[3]

Research Impetus

In extreme events, such as major earthquake or tsunamis, public safety is a primary concern. An article in July 2015 of the periodical The New Yorker entitled “The Big One” proclaimed that a major subduction zone earthquake could cause a major tsunami, which would render infrastructure well beyond the coast “useless”. In coastal regions at low elevation, it can be impossible to quickly get to higher ground in the short time between the initial ground shaking and arrival of a tsunami from a subduction earthquake. Vertical evacuation structures (VES) can provide refuge to people in these areas. To protect the community during tsunamis on the upper floors, VESs are designed to: (1) have “sacrificial” lower stories below the inundation depth of the wave and (2) provide seismic resistance with minimal damage while providing resistance to large gravity and tsunami forces. Although evacuation structures have been built in tsunami-prone regions in Japan and the U.S., they are typically low-rise structures with limited shelter capacity. A tall structure could serve other purposes, such as a hotel with lower stories housing retail or conference rooms, rather than only a shelter. Although tempting, is not wise to simply adopt a structural system used in seismic regions for VESs, because the design criteria are different. In earthquake engineering, the structure is designed to sustain damage in the maximum credible event and, unless specific to the site, soil-structure interaction is neglected. This design philosophy does not fit VESs. VESs must be designed to: (1) remain damage-free during the maximum credible earthquake, (2) sustain the maximum considered tsunami at the lower floors, including horizontal and vertical forces, where initial research shows that these tsunami force demands can be 2 to 5 times the design earthquake forces, and (3) account for changes in the stiffness and strength of the soil due to liquefaction and scour.

Research Needs

Design of structures to meet earthquake demand has advanced significantly over the past three decades. It is tempting to utilize seismic structural systems to meet tsunami demands, yet this is not wise since the response required in a tsunami is elastic, whereas the response expected in the maximum earthquake is nonlinear, and therefore deformation capacity is a priority with earthquake resisting systems and strength and stiffness are priorities in tsunami resisting systems.

To meet the needs of the structural engineering community in the design of vertical evacuation and other structural systems in tsunami prone regions, the following research is required:

1. Development of new structural systems to meet tsunami demands
2. Evaluation of the response of the system, including the sub-structure, soil-fluid-structure interaction (as well as scour, etc).
3. Testing of structural and structural and geotechnical systems in large-scale wave flumes using

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state-of-the-art, large-scale testing methods including instrumentation, imaging.
4. Enhancement of or building new large-scale, wave flumes to more accurately simulate tsunami demands including the impact of bathometry.

Collaboration Opportunities

There is a need for testing including new structural systems (both the superstructure and the sub-structure) as well as impact of the geotechnical system (where scour is a critical issues) in flumes capable of simulating tsunami-level forces and bathometry. This requires a multi-investigator team with diverse expertise including (1) structural system development and testing, (2) soil-structure interaction and scour, (3) testing in wave-flume facilities, (4) numerical simulation of soil-structure-fluid interaction. From the PIs perspective the critical need is the wave flume capable of simulating a tsunami and test setup with the wave flume that: (1) simulates the boundary condition of the structure, (2) allows larger scale testing (ideally 1/3 scale), (3) simulates the demands, and (4) supports high-resolution and accurate measurement of soil and structure response.

Probabilistic Earthquake Sources for Tsunami Hazard Assessment or Structural Engineering Design

Randy LeVeque and Frank Gonzalez

Several workshop participants have an interest in the characterization of potential earthquakes on subduction zones, and in the design of earthquake sources for tsunami modeling and hazard assessment. We would like to propose two specific projects related to this.

The first project is to explore techniques for specifying a probability distribution of hypothetical events that is (a) easy to sample from, e.g. in order to generate thousands of sample realizations for Monte Carlo simulation, and (b) geophysically reasonable and defensible, based on the best available science. There is no way to determine the “correct” probability distribution for future events, but many constraints are known (e.g. the subduction zone fault geometry, a reasonable range of slip values and overall magnitude, spatial correlation lengths of slip in past earthquakes, limits on how much subsidence at the coast is realistic, as inferred from records of past events, etc.). How can this information be best incorporated into the probability distribution, and how can the remaining epistemic uncertainty best be modeled?

One approach we have studied is use of a Karhunen-Loeve (K-L) expansion to generate slip distributions as Gaussian fields with specified means and covariance between subfaults [1]. In joint work with Diego Melgar, 1300 samples from such a distribution on the Cascadia Subduction Zone have been generated [2]. Melgar’s group has used these for testing GPS-based earthquake and tsunami early warning systems. We have used a similarly generated set of 400 realizations to develop and test methodologies for probabilistic tsunami hazard assessment (PTHA) in work funded by FEMA [3]. In these cases, no claim was made that the probability distribution was at all “correct” for CSZ, only that it was easy to sample and sufficiently realistic to give suitable test data for new algorithms. We would like to explore whether it is possible to choose the parameters in these models in such a way that the resulting distribution is defensible as a basis for actual PTHA modeling, in the sense that the probabilities of flooding (hazard curves) that come out of tsunami modeling based on such a distribution can be viewed as “correct” in any sense.

The second project is to develop best practices for defining a single earthquake scenario that in some sense represents a 2500-year event (or some other return time, e.g. as dictated by building codes for vertical evacuation structures). Or perhaps a small ensemble of scenarios that collectively represent this return time (at some particular location). We have faced serious issues in this regard when trying to determine the tsunami modeling necessary to meet new guidelines proposed in ASCE/SEI 7-16 for tsunami evacuation structures [4]. Similar guidelines may be adopted in the international building code (IBC), and so international discussion of this issue would be timely.

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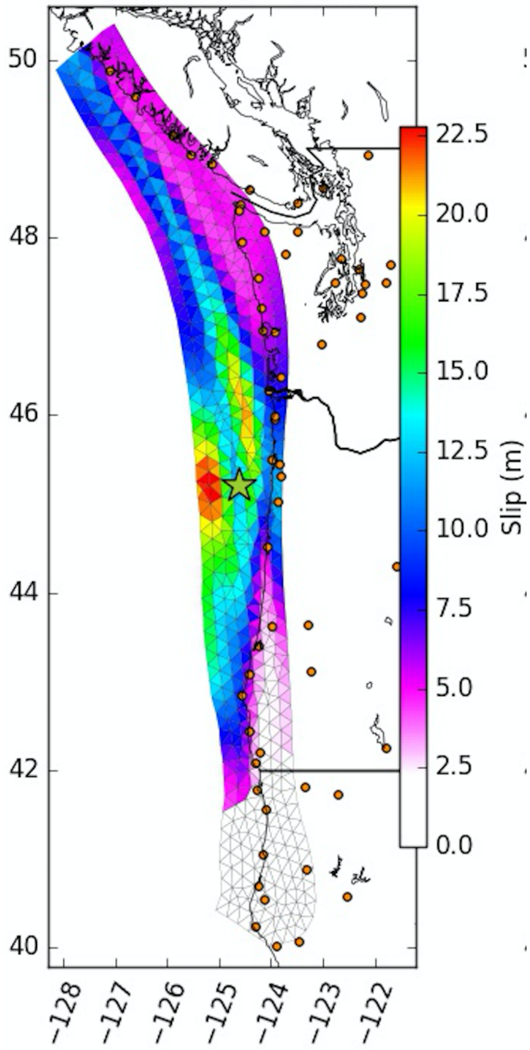
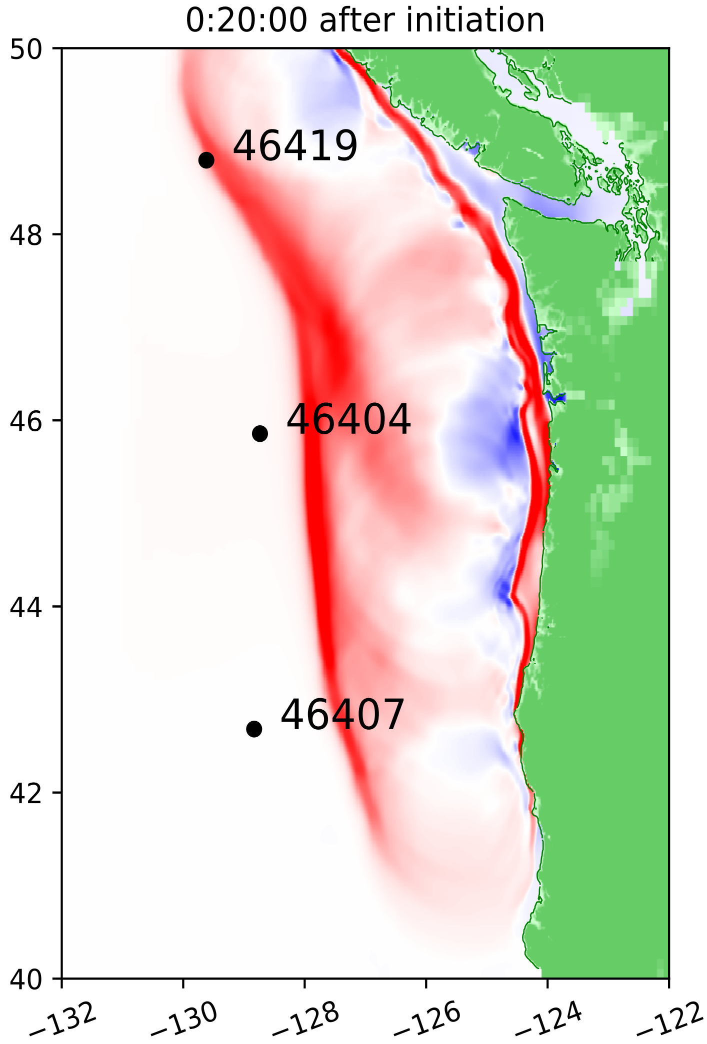
Sample realization from [2]:



Resulting tsunami:



Using geological data to constrain solutions of past earthquakes/tsunamis

B. MacInnes, C. Garrison-Laney

When an earthquake and tsunami occur today, instrumental records can quickly allow us to interpret a wide range of quantitative characteristics of the events, such as earthquake magnitude, rupture location, slip distribution, rupture velocities, etc. and tsunami offshore wave heights, etc. Post-tsunami surveys additionally record inundation, flow depths, runup, etc. However, the same kind of information is not available for pre-instrumental earthquakes and tsunamis, with the exception of eye-witness descriptions from locations with a long written history (like Chile or Japan). Understanding the physics of subduction-zone deformation and accurately assessing the hazards from earthquakes and tsunamis requires earthquake and tsunami histories of considerable detail over multiple earthquake cycles. Imagine the scientific and hazard planning implications of knowing the magnitude of all regional earthquakes for the last few thousand years, or knowing the differences in their slip distributions, or the variations in past tsunamis' over-land flow speeds.

A major goal of our research is to be able to quantify these transient characteristics of known pre-instrumental events by reconstructing parameters of earthquake rupture and tsunami initiation and validating those solutions against geologic field observations. Geologic field studies, especially co-seismic land-level change and tsunami deposit data, are the best resource for validating reconstructions of events that have previously occurred. Advances in land-level change studies are enabling fairly tight constraints on numerical estimates of coastal subsidence or uplift associated with an earthquake, which is tied to the earthquake's source characteristics. Advances in paleotsunami deposits studies are defining proxies for tsunami inundation and sediment transport models of these deposits can calculate flow speeds and flow depths. These kinds of studies are particularly well-advanced in Chile, Japan, and Cascadia, and provide a suite of information to compare to simulations of hypothetical earthquakes. Recently, we have been creating hundreds of randomized slip distributions, forward modeling tsunamis from those earthquakes to sites with geologic data, and performing statistical analyses to determine a range of possible seafloor deformation patterns for known tsunamigenic earthquakes. From the best-fit possible results for specific past events, we can then solve for properties such as earthquake magnitude or slip distribution, and forward model tsunami characteristics to sites with no geologic data.

Successes to date:

1. Isolating locations of high slip (although over low spatial resolution) in past earthquakes by comparing tsunami models to field data and written records: Chile, Aleutians and Kamchatka.
2. Employing randomized slip distributions to create a suite of hypothetical past earthquakes (could be improved).
3. Using AIC statistical methods to differentiate tsunami simulation results to isolate important variables in distinguishing paleo-earthquakes.
4. Converting a geologic/historical observation of a tsunami deposit or land-level change (with all their site-specific variability) into values or value ranges that can be compared to model

results (this is both a success and an ongoing problem)
5. Using geologic data to constrain or ground truth unrealistic earthquake models.
6. Estimating flow depths from sediment deposit grain size and thickness (tsunami sediment modeling such as by R. Weiss, H. Tang, etc).
7. Recreating paleoshorelines for past events to calibrate paleotsunami data (in Kurils and Kamchatka; other researchers have had success in Sendai and Hokkaido), although this is also a problem in that it is not always possible.

Ongoing problems to solve:
1. Quantifying the number of field observations of past tsunamis and land-level change observations necessary to differentiate tsunami models, at what spatial interval, at what accuracy, etc. (i.e. when do you have enough field data and when do you not for statistically significant results?).
2. Finding high-resolution international bathymetry and topography.
3. Reverting bathymetry and topography to its original undeveloped state, if needed.
4. When working with non-subduction zone earthquakes (like in Puget Sound), having confidence of the fault interface parameters.
5. When dealing with older historical records (Japan and Chile), removing the land-level change signal from the tsunami observation of wave heights.
6. Differentiating concentrated high slip in a short but low Mw rupture from more diffused slip in higher Mw ruptures in the local tsunami signal.
7. Distinguishing one large earthquake/tsunami from multiple ones spaced closely in time.
8. Differentiating tsunamis from storms, particularly on shores where a tsunami source does not produce geologically detectable changes in land level.

Community-based disaster recovery planning and relocation

Elizabeth Maly[1]

1. Residential relocation for disaster mitigation after the Great East Japan Earthquake

The 2011 Great East Japan Earthquake and Tsunami caused massive destruction along the northeastern Tohoku coast of Japan. With a history of disasters, Japan has established policies and precedents dealing with disaster recovery and housing reconstruction. Drawing on recovery programs used after previous disasters, the Japanese government created a menu of recovery projects for the municipalities affected the 3.11 earthquake and tsunami. In particular, coastal municipalities in Tohoku are using a program called "Collective Relocation for Disaster Mitigation" at an unprecedented scale.

Similar to funding from the Hazard Mitigation Grant Program for residential buyouts in the United States, in Japan Collective Relocation projects are intended to relocate residents away from hazardous areas, but are often implemented during the recovery process and function and support for household recovery. Unlike residential buyouts in the United States, Collective Relocation in Japan includes both compensation for former land (which is designated as hazardous, and all future residential construction is forbidden by law) along with the provision of new residential lots which residents can rent or buy and use to rebuild a new house.

In the past, Collective Relocation in Japan was used at a smaller scale in rural areas to move residents away from areas at risk of landslides, etc. However, after 3.11, Collective Relocation became a primary recovery program used throughout the disaster area; reconstruction of towns which formerly were home to mixed uses in low-lying central areas are being reshaped by new residential-use areas in high-land areas.

2. Perspectives for collaboration

Can the situations of Tohoku, Japan and coastal Washington be considered through lens of people-centered housing recovery and community-based planning processes? Although the contexts of recovery planning and reconstruction after a mega-disaster in Japan and preparation for a mega disaster predicted for coastal Washington vary both according to the policy contexts of the respective countries, as well as different phases in the disaster cycle, communities in both places are facing similar issues of living with disaster risk.

Potential themes for collaborative research:

- international comparison of policies related to pre-disaster planning and implementation of post-disaster recovery programs framed by the goal of disaster risk reductions
- community involvement in the planning process
- how do residents evaluate impacts of housing recovery and relocation on their lives and living environments?
- how can recovery policies be more supportive of residents' needs?

In addition, other topics for potential long-term collaboration include: community-based evacuation planning, including vertical evacuation and the integration of schools and evaluation buildings.

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Tsunami evacuation modeling and its integration with inundation simulation for planning shelters and evacuation routes

E. Mas[1], L. Moya[2], S. Koshimura[3]

1. Introduction

The 2011 Great East Japan earthquake and tsunami destroyed several structural tsunami countermeasures. However, approximately 90% of the estimated population living in areas at risk of tsunami survived due to a rapid evacuation to higher ground or inland. Once again evacuation proved to be one of the most effective measures to reduce casualties. Thus, understanding the process of tsunami evacuation could lead to finding better solutions to avoid future casualties and ensure people's prompt reaction. This abstract aims to point to past, current and future research towards effectively integrating tsunami inundation simulation and tsunami evacuation modeling.

2. Integrated model of tsunami inundation and evacuation

We developed an evacuation model that integrates tsunami inundation and evacuee's decision and response to tsunami. The model was developed using the multi-agent approach. Figure 1 shows a summarized scheme of the model framework1). It consists of inputs provided by spatial data in GIS format, human data related to evacuee preferences obtained from questionnaire results, a component of hazard which is provided by the TUNAMI inundation model output, and a set of agent behavior rules. Available outputs from the model are casualty estimation, evacuation times, identification of bottlenecks, analysis of shelter demand, etc.

Within the model, we provided agents with the minimum necessary capabilities to process information and execute evacuation actions through simple behaviors divided into layers:

a) Evacuation decision: We studied the decision and timing for starting evacuation based on questionnaire surveys from past and future hypothetical events. Here we proposed tsunami departure curves as an estimation of the overall behavior of the population in study1).
b) Shelter decision: We explored nearest shelter solutions and random selection of shelters. We discuss the demand and capacity of shelters considering spatial allocation2)
c) Route decision and path finding: We used A* (A star) algorithm with heuristics in grid space to ensure continuous dynamics.
d) Pedestrian dynamics: Speed variation is estimated from a one-tail normal distribution of evacuee density in the agent field of view.

The model was verified using the 2011 Great East Japan Earthquake and Tsunami data from the evacuation in Arahama, Sendai and Yuriage, Natori in Japan3).

3. Tsunami evacuation guidance through reinforcement learning algorithm

To estimate human losses and the survivability of evacuees in the case of an earthquake and tsunami we also developed a model that uses a reinforcement learning algorithm. It considers the road network to calculate the best action-to-take at each node which, with higher chances, will lead to safe haven. A matrix

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of nodes and their corresponding best strategy is used when simulating the movement of the population. Within the reinforcement learning framework, the road network represents the environment in which the agents interact, and a state denotes the information an agent perceives from the environment when it is located at a certain node of the network. In the model, a state may be composed of the node in which the agent is located and the links available to move to a consecutive node. These nodes and links carry information of pedestrian density, damaged condition, and so on. When an agent arrives at a node, he/she has a set of options to continue moving: the links, which are called actions. The effect of every chosen action is quantified by a reward. A reward is assigned to an agent based on whether it arrived or not at an evacuation shelter. In reinforcement learning, the main target is to find the best policy that maximizes the long-term reward (i.e. the accumulated reward from the beginning to the end of the simulation), which is intimately associated with the best evacuation route.

4. Perspectives for Collaboration

After a basic understanding of the tsunami evacuation process and a model built from it, we aim to deepen our knowledge on human behavior in emergencies and improve the agent behaviors that are set in the current model. During the workshop we expect to discuss how tsunami evacuation modeling can be used for planning and tsunami disaster mitigation.

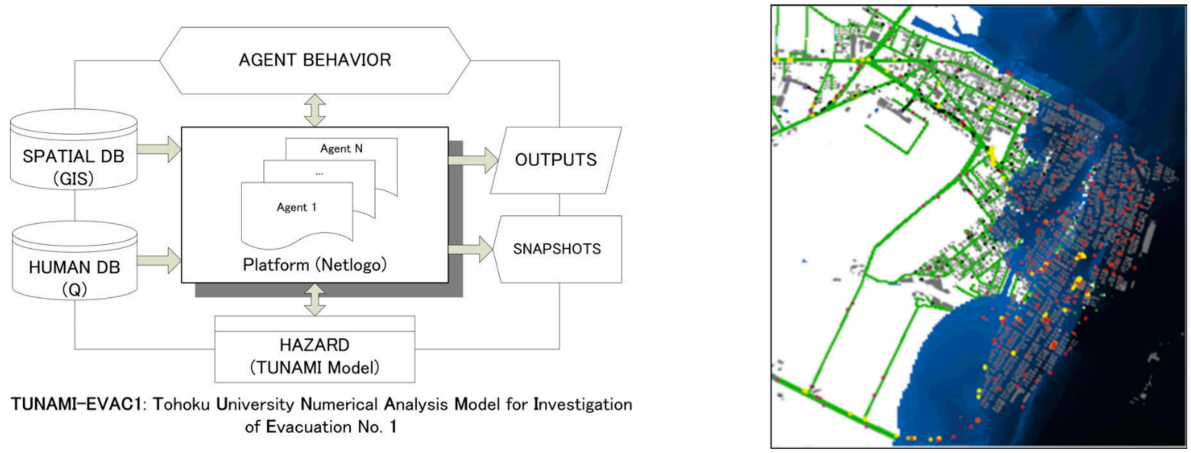

Figure 1 .- (left) Simplified framework of the tsunami evacuation model. (right) A snapshot of the model ran in Yuriage, Natori

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Simulation-based disaster risk analysis using data science techniques

Shuji Moriguchi[1], Kenjiro Terada[2], Hasuka Kanno[3] and Kenta Tozato[4]

1. Research interests

Numerical simulations are becoming more and more important for disaster risk reduction. However, highly developed numerical methods generally have high computational costs. In fact, a number of simulation cases are needed to properly evaluate disaster risk due to uncertainties and variabilities involved in disasters. It is, therefore, necessary to obtain meaningful information from minimum number of calculation cases. Our research group is now trying to maximize the potential of disaster simulations with the help of various data science techniques.

Figure 1 shows an example of rockfall risk analysis in which the Gaussian Mixture Model (GMM) [1] is used to represent the spatial distribution of exceedance probability of the rockfall energy. In this example, based on the analysis results of rockfall paths and energy estimated by Discrete Element Method (DEM) [2,3], the spatial distribution of exceedance probability is obtained. In this study, the GMM, which is usually used for cratering data, is utilized to interpolate the simulated results in space.

Another example is a correlation risk analysis of tsunamis for multiple costal cities as shown in Fig. 2. In the illustrations, the maximum tsunami height is employed as a risk index, and the values are estimated with different combinations of input parameters by tsunami simulations. Response surfaces of the maximum tsunami height at selected coastal cities are then obtained from the simulated results, and then the Monte Calro (MC) simulation is performed to obtain sufficient number of results. The results of the MC are analyzed with the help of the Principal Component Analysis (PCA) to examine a correlation of tsunami risk between coastal cities.

2. Perspectives for collaboration

Possible collaborators in UW would be those who are interested in using data science techniques in the disaster risk analysis based on numerical simulations. Experimental research is also welcome because experimental results would be helpful to develop our research.

Acknowledgments:
The other contributors are: Takuma Kotani[a], Shinsuke Takase[b] (a:Tohoku University; b: Hachinohe Institute of Technology)

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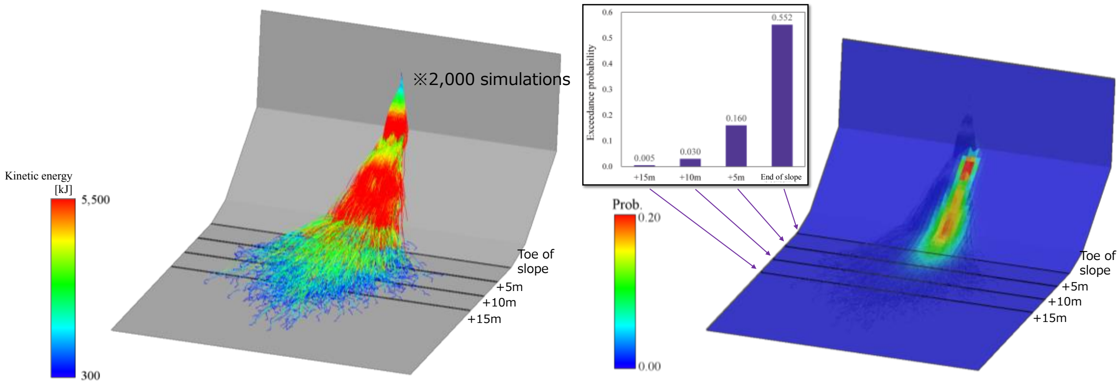
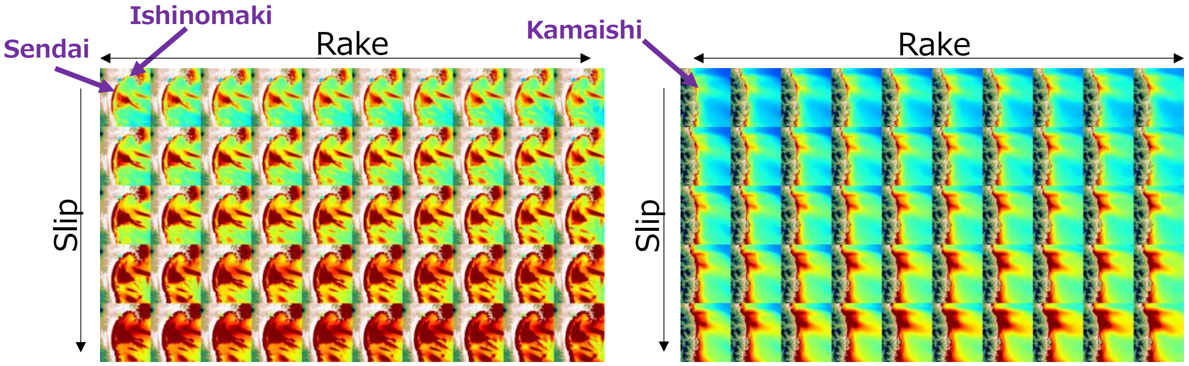
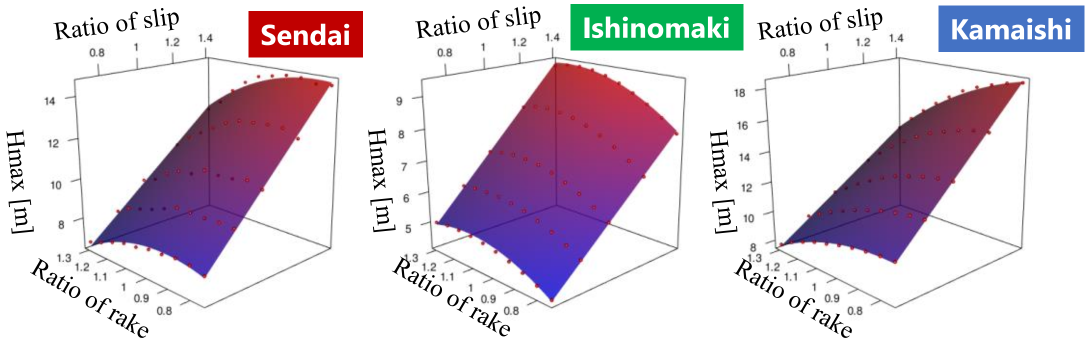


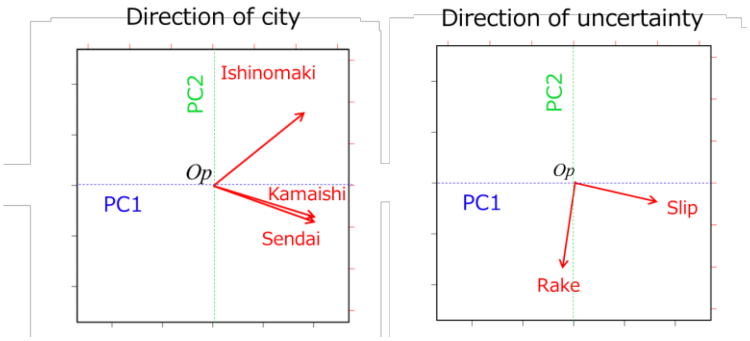
Fig. 1 Quantification of spatial risk distribution of rockfalls using Gaussian Mixture Model



(a) Simulated maximum tsunami height distribution in each calculation case



(b) Response surfaces obtained from simulated results



(c) Results of principal component analysis

Fig. 2 Tsunami risk analysis considering correlations among coastal cities

Fusion of Remote Sensing and Numerical Simulations to Detect Damage in the Infrastructure

Luis Moya[1] , Erick Mas[2], Shunichi Koshimura[3]

1. Introduction

From remote sensing data, the most common procedure to identify the effects of a disaster is by the study of a pair of images recorded before (pre-event) and after (post-event) the event. If the date of both images is close enough, changes observed among them are assumed to be correlated to the effect of the disaster. In order to identify changes, certain features are computed from both images. Discriminant functions using the features were proposed to infer whether a change occurred or not. At first, discriminant functions were set from observations of previous events and applied to subsequent events. Such approach proved to be effective in events such as the 2011 Tohoku-Oki earthquake and tsunami. However, these methods have some limitations. For instance, a discriminant function could not be applied to images recorded from a sensor different than the one used during the calibration. A re-calibration was necessary. Furthermore, the discriminant function was restricted to certain features. If the performance of a new feature wanted to be tested, a new discriminant function has to be built.

The referred issues were addressed by the application of machine learning techniques. Applications of machine learning in remote sensing became popular, including the identification of damaged buildings. Machine learning algorithms offered a robust way to treat *n*-dimensional set of features and, in some way, it could be applied independent of the kind of sensor. However, a new problem showed up when machine learning techniques were applied to identify buildings affected by a large-scale disaster. In the aftermath of a large-scale disaster, all the efforts are spent in rescue and relief distribution. An important contribution from remote sensing data is the identification of collapsed building, for people might be trapped inside and they survival depends on a prompt rescue. Therefore, in order to apply machine learning, training samples has to be gathered the soonest possible. However, it has been observed that gathering training samples right after the occurrence of the disaster is quite complicate. Reports regarding damage in the infrastructure are published several weeks later. Field surveys might take some days as well. Some researchers have adopted to set training data from visual inspection of optical images; a task that requires significant time and might introduce biases. This is an issue that few publications have addressed. A great deal of the scientific publications related to applications of machine learning in remote sensing used training data that were available several weeks, or even months, later.

2. Replacing training data with demand parameters and damage functions

In order to overcome the problem of training samples, we decided to eliminate that requirement, or at least, to avoid the ordinary process of gathering training samples. It came to our knowledge the existence of a relationship between a disaster demand parameter and an expected percentage of damaged buildings. Here, disaster demand parameter refers to a certain metric that express the intensity produced by an arbitrary event at a specific geo-location. Inundation depth and peak ground velocity are such examples for tsunami and earthquake, respectively. It is intuitive to think that areas with large demand parameter contain greater number of affected buildings than areas with low demand parameter. In fact, researchers have been working for decades on this relationship, known as building damage functions or fragility functions, using rigorous statistical analysis and numerical models. It was also noted that because of the great progress regarding instrumentation and numerical modelling of certain disasters, such as tsunamis,

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earthquakes and floods, several new frameworks provide estimations of the demand parameter in almost real time.

We decided to use the demand parameters together with the building damage functions as new constrains to calibrate the discriminant function referred in the previous section. It is expected this new constrain would be enough for the calibration and training samples would not be necessary. The details of our first proposed framework can be found in Moya et al. (2018a). Although the proposed procedure proved to be effective, there was still room for improvements. For instance, the parameters of the discriminant function were computed from an exhaustive search. Such approach is indeed not practical when the dimensional space is significantly large. Thus, a second procedure was then implemented. The fundamental basis lies on modifications of the well-known method *Logistic Regression*. There, we replace training data with weight factors computed from the numerical simulations and damage functions. Details of the method are reported in Moya et al. (2018b).

3. Current research

It was pointed out that damage functions are available in restricted events, such as tsunamis and earthquakes. There are no damage functions, for instance, to floods or landslides. Therefore, we are currently implementing a new framework that uses only remote sensing data and numerical simulation of disasters. So far, we defined two potential frameworks, which will be published soon.

4. Perspectives for collaboration

It is our belief there are many points to work on this subject. We would like to test our frameworks on more events. We have tested it with tsunamis, earthquakes and floods and we are looking for other types of disasters, such as landslides. Another topic is the damage functions (fragility curves); so far we have used empirical functions. We would like to test analytical damage functions as well. We also would like to exchange ideas on new ways to combine remote sensing data with numerical simulations.

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Tsunami Warning with Data Assimilation of Seafloor and Sea Surface Observations

A. Sheehan[1] , W. Wilcock[2]

We are interested in the use of data assimilation methods for tsunami warning, and potential use of GNSS-derived ship height data in data assimilation to supplement sparse seafloor pressure measurements.

Most tsunami warnings rely on first locating and determining size of a large earthquake and then using a computer model to estimate the amplitude and timing of the resulting tsunami. However, with enough sensors, traditional forecasting methods can be supplemented by models continuously updated with real-time wave data. Progressive data assimilation has been used for many years in weather forecasting (Miller et al., 1994), and recently Maeda et al. (2015) adapted it to tsunami forecasting for eventual use with the Japan Trench (S-net) cabled network. In the tsunami data assimilation method, at every time step the tsunami wavefield for the current time step is approximated by numerically solving the shallow water equations using the wavefield at the previous time step (i.e. by a forward numerical simulation). In the assimilation step, the forecasted tsunami height is compared to that observed at the observing stations (seafloor pressure sensors or other instrument types), and this residual is used as a correction to bring the assimilated wavefield closer to the true wavefield. This method has been applied to seafloor pressure measurements from the Cascadia Initiative (Gusman et al., 2016) and the MOANA ocean bottom seismic network offshore New Zealand (Sheehan et al., 2019). The Cascadia Initiative and MOANA were both temporary standalone experiments that did not provide data in real time. The regional networks of cabled pressure sensors currently deployed off Japan and Cascadia provide data that can be used test data assimilation in real time. However, they have limited footprints and are unlikely to be replicated in many other regions of interest, and it is thus important to seek other sources of real time data that could be incorporated into the data assimilations.

One promising avenue to explore for obtaining more widespread coverage is sea surface height obtained from Global Navigation Satellite Systems (GNSS) on ships or wave gliders, which can be incorporated into the data assimilation. Foster et al. (2012) observed a 10 cm tsunami signal from the 2010 M8.8 Maule, Chile earthquake using the high rate GPS on a research vessel offshore Hawaii, and suggested that tsunami forecasting capabilities could be improved by ingesting precise shipping fleet GPS positions within a real-time operational framework. Subsequently, Inazu et al. (2016) demonstrated that the density of cargo ship traffic in the Nankai Trough would be sufficient for near-field tsunami forecasting. Mulia et al. (2017a), using the same Nankai Trough dataset, explored the optimal combination of traditional offshore geophysical instrumentation and ship-borne GPS.

Making use of existing infrastructure, in the form of the commercial shipping fleet, is a potential method to improve forecasting abilities. Inclusion of ship-borne GNSS sea surface height measurements may reduce the reliance on high-cost offshore arrays. Successful results would also clarify the need for high precision GNSS positioning of vessel traffic, particularly in regions of geophysical interest.

We are working with the US University Research Fleet to log raw GNSS data for measuring precise ship height and exploring its utility for tsunami data assimilation. Our hope is that the navigation systems that are already installed on the research vessels to provide position, attitude and heave data, can be cheaply configured to routinely collect a raw GNSS stream. If not, it may be necessary to install a dedicated GPS system on each ship. Either way, the raw GNSS data could be shared as open source data

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to support tsunami research using the mechanisms that have already been established for UNOLS underway data. We welcome collaboration from those interested in ship-based sea height measurements as well as those interested in tsunami data assimilation.

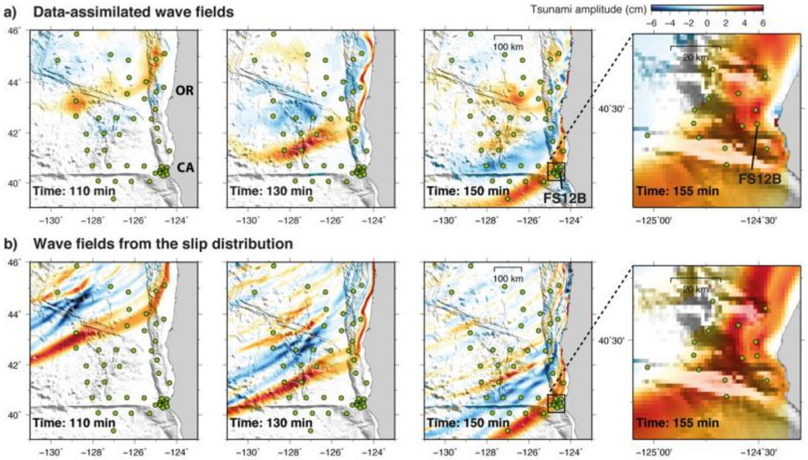

Figure 1. Tsunami propagation forecast offshore the Cascadia subduction zone using data assimilation of Cascadia Initiative seafloor pressure data (Gusman et al., 2016). (a) Wavefield at 110, 130, 150, and 155 minutes after the Haida Gwaii earthquake produced by tsunami data assimilation (DA). Green circles show the station distribution. (b) Wavefield at 110, 130, 150, and 155 min simulated from the estimated slip distribution of the 2012 Haida Gwaii earthquake.

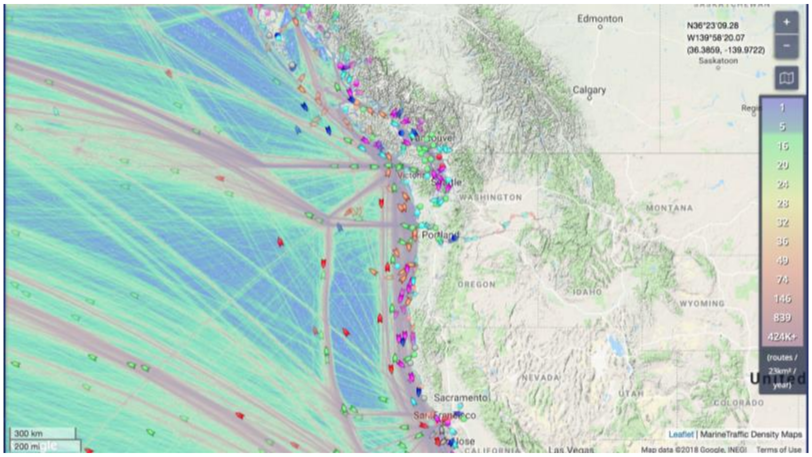

Figure 2: Ships and marine traffic density in the Cascadia region (MarineTraffic.com). Ships shown are a real-time snapshot from 9/7/18. Automatic Identification System (AIS) automatic tracking system used on ships provides information on movements of ships, though raw GPS is not routinely available. The marine traffic density highlights the major ports and shipping lanes in the Cascadia region.

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Applying tsunami numerical simulation for building damage assessment using load-resistance analysis and sediment transport modeling

A. Suppasri[1] , K. Pakoksung[2], R. Masaya[3], K. Yamashita[4], F. Imamura[5]

We wish that both building damage assessment and sediment transport modeling topics can be applied to the US west coast. Please find below for examples of our research activities in both topics.

1. Building damage assessment

Macro scale assessment of building damage by tsunami can be performed using two classical methods namely, fragility functions and weight factors based on their vulnerability. However, these methods do not consider the actual performance nor strength of the buildings and damage might occur before either of flow depth and flow velocity reach maximum values. This study aims to investigate if instead analytical force estimation of tsunami forces and building strength is able to predict building damage. About 20,000 damaged wooden buildings data in Ishinomaki City from the 2011 Great East Japan tsunami were used for this analytical experiment. The impact of floating debris was also added based on weight. Building strength from bearing wall is estimated from building design standard which is mainly based on floor area and building height. Resistance reduction coefficient was also added for aged buildings. Two damage (collapse) patterns (washed away and destroyed) were analytically assessed using sliding and overturning mechanisms. As results, it was found the proposed method could reproduce the actual dam-age condition with very high accuracy for both collapse patterns. Almost destroyed and washed away buildings occurred when the flow velocity is higher than 2 m/s regardless of flow depth. Besides, it was found using the maximum flow depth and flow velocity could underestimate the damage by up to 2-4 times. This new method will be useful for building damage assessment in areas that have no actual tsunami damage experience.

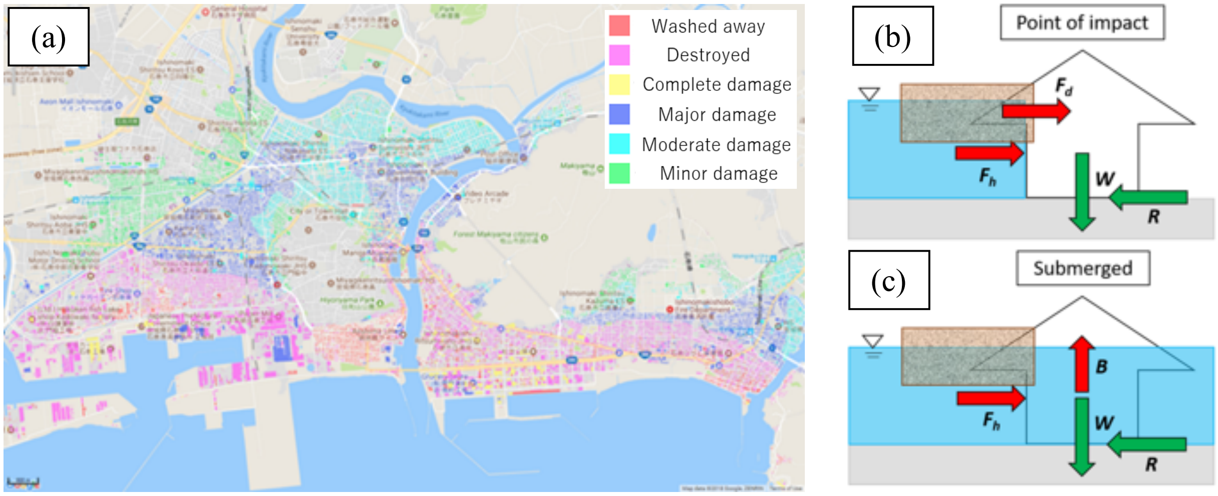

Fig. 1 (a) Distribution of building damage data from higher damage (pink) to lower damage (green): Destroyed and washed away was considered as collapsed (Non-repairable), (b) Building collapse condition: At the moment of impact, (c) Building collapse condition: When being submerged

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2. Sediment transport modeling

Prathong Island is the location where geologists paid attention in surveying tsunami deposits after the 2004 Indian Ocean tsunami because of its good natural condition. In addition, not only the 2004 tsunami deposits but also deposits of earlier tsunamis was also found and the shoreline was recovered to its original position very soon. However, there is still no such numerical simulation approach applied to this study area to understand the sedimentation and recovery process during and after the 2004 tsunami. Therefore, numerical simulation of tsunami and sediment transport was applied to reproduced the 2004 tsunami. The simulation results provided good reproduction as the eroded areas and thickness of deposits against distance from coastline could be confirmed. It is found that the eroded sand occurred at shallow region where less amount of sediments was transported inland during the incoming wave. During the drawback, large erosion occurred near the coastline and deposited again in shallow area. Deposited sediments in shallow is probably the reason of the fast recovery rate of the coastline.

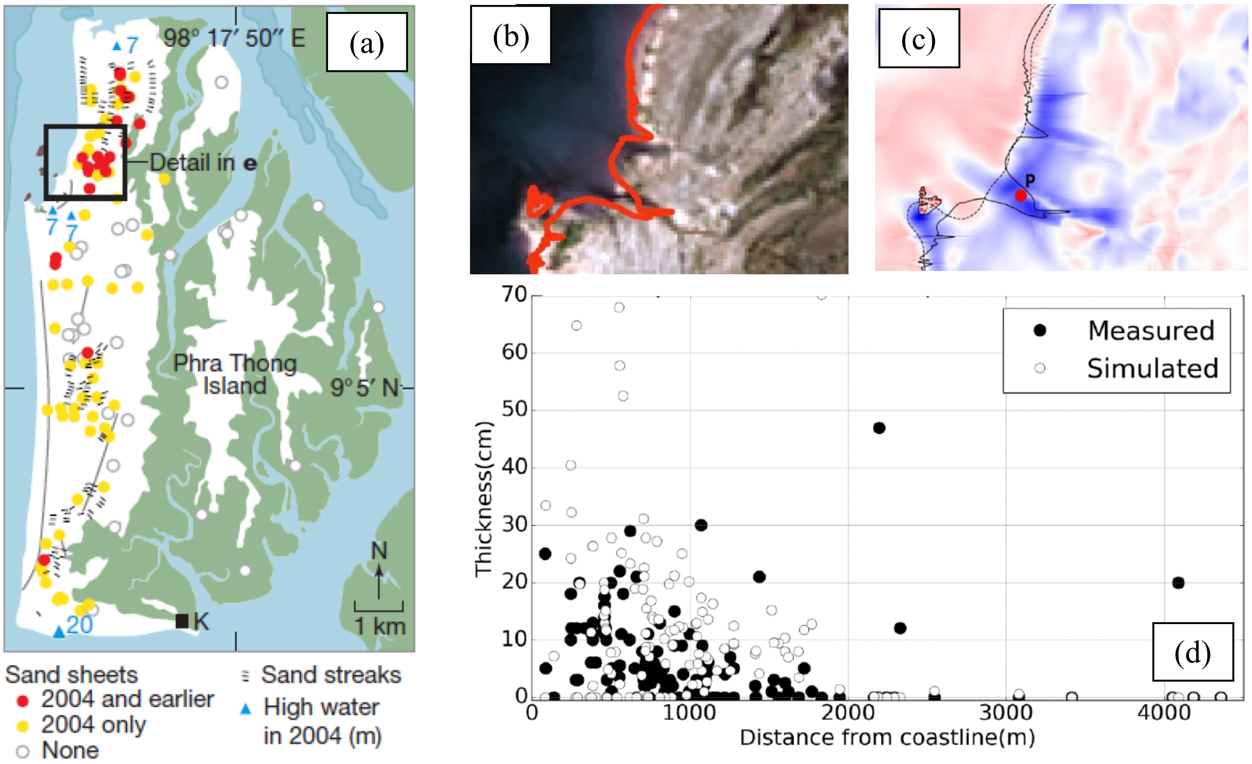

Fig. 2 (a) Distributions of tsunami deposits (Jankaew et al., 2008), (b) Shoreline after the 2004 tsunami and simulation result (red line), (c) Simulated eroded and deposited areas and shoreline before and after the 2004 tsunami, (d) Comparison between measured and simulated thickness of deposits against distance from coastline

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Multi-stage failure simulations for rock mass failure

Kenjiro Terada[1], Shuji Moriguchi[2] and Shun Suzuki[3]

1. Research interests

The main thrust in our research is the exploration of numerical methods for failure simulations of slope disasters involving multiple stages. For example, when we are concerned with slopes with brittle materials and structures, the failure phenomenon must involve the following three stages:

1) At the first stage: a structure deforms in response to dynamic or static excitations and displays cracks along prescribed discontinuities so that it would be separated into several blocks.
2) At the second stage: several sets of blocks lose static equilibria and start to move dynamically.
3) At the third stage: moving blocks collide each other with friction and some of them further break up due to the shock generated by the collision.

To simulate this three-stage failure process involving large deformation and rotations with dynamic frictional-contact behavior, we have developed a new numerical method based on the co-rotational finite element formulation [1,2]. The proposed method is designed to simulate all of these deformation and failure stages in a continuous fashion. In order to represent dynamic frictional contact with large rotations after the crack propagation, we incorporate the effects of dynamics, gluing, and contact within the framework of the co-rotational theory [3,4]. To validate the proposed method, we have been trying to simulate the collapse of a slope involving collision followed by segmentation by cracking.

Fig. 1 illustrate the finite element model for to simulate a slope sliding failure of a rock mass with potential discontinuities. Here, the slope is subjected to the seismic motion caused by the enforced displacement to the bottom of the model and is considered to fail at a certain time after the excitation. This displacement wave is obtained by transforming from the acceleration wave-form observed in the 2016 Kumamoto earthquake. Fig. 2 shows the sequence of the deformed configurations of the rock slope. The blocks that are initially glued together separate and the resulting crack surfaces contact with each other. It is safe to conclude that the rock slope failure could be successfully simulated by the proposed method that is capable of representing the large rotation with frictional contact behavior.

2. Perspectives for collaboration

Since suitable experimental data is insufficient for the validation of the proposed method, possible collaborators in UW would be those who can provide some experimental data of slope failures. Simple experiments are enough to demonstrate its capability of multi-stage failure. Or rather, we welcome case examples of slope failures that were actually occurred in US and/or Japan.

Acknowledgments:
The other contributors are: Yosuke Yamanaka[a], Norio Takeuchi[a] (a:Tohoku University; b: Hosei University)

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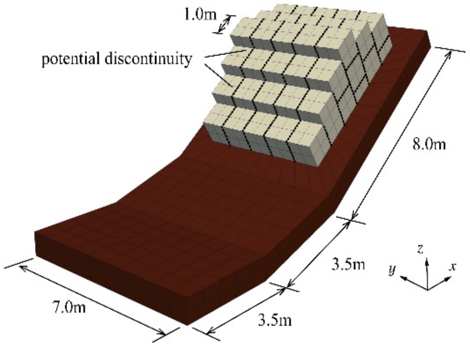

Fig. 1 Finite element model for analysis of a rock slope failure with potential discontinuities.

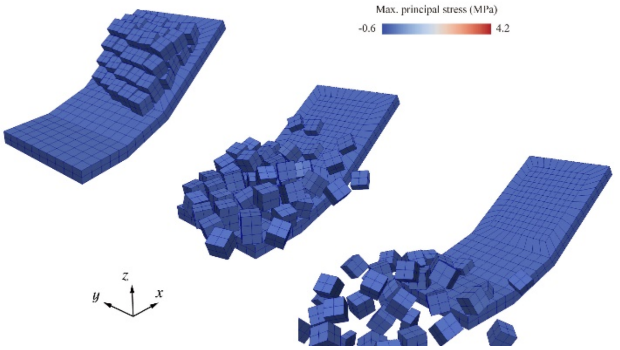

Fig. 2 Sequence of deformed configuration with maximum principal stress distribution

Numerical Modeling of Fluid-Structure-Debris Interaction during a Tsunami Event

A. Winter[1] , M. Motley[2], M. Eberhard[3]

1. Introduction

Major tsunami events in recent history, such as those which occurred in the Indian Ocean in 2004, Japan in 2011, and Indonesia in 2018, have resulted in widespread damage to infrastructure due to fluid impact forces as well as debris impact and damming forces. Engineers have developed new standards to provide methods for designing structures to resist both types of tsunami-related loads in an effort to avoid future losses of the same degree as those observed in the past. For example, ASCE 7-16 has added a new tsunami load chapter and commentary that provide design equations for static and dynamic fluid forces as well as debris impact. However, further development of robust fluid-structure-debris interaction models is needed to give clearer insight to designers in the future, which is feasible with today's efficient solution algorithms and ever evolving computer capabilities.

2. FSI and Wave Generation using OpenFOAM

The most recent releases of OpenFOAM offer a wide array of dynamic mesh motion tools, the overset grid method, and adaptive mesh refinement (AMR), which can be used to simulate the rigid body motion of objects floating in water. Additionally, two fundamental classes of wave generation methods, wave theory-based generation and absorption boundary conditions versus moving boundaries, have been incorporated into OpenFOAM, which allows for accurate recreation of tsunami wave conditions. Using these tools together, a suitable model for simulating the motion of debris objects in tsunami inundation flows can be developed and used to perform a validation study.

3. Estimation of Wave Impact Forces

Experimental data for both wave and debris impact forces was gathered using the large wave flume at the NHERI Coastal Wave/Surge and Tsunami Experimental Facility (NHERI CWST-EF) at Oregon State University [Alam et al. 2018, Winter et al. 2018]. Using this benchmark data set for model validation, an OpenFOAM model was developed and calibrated to accurately reproduce the maximum wave impact forces measured during experiments. By adding dynamic mesh or overset grid functionality to this model, a suitable tsunami debris motion model can be developed and validated using both the ordered and random debris object configurations that were tested during the aforementioned experiments.

4. Proposed Collaboration Approach

Moving forward with this research topic involves developing a robust model that can simulate debris motion and impact forces in addition to accurately modeling tsunami inundation behavior. During this workshop, the goal of collaborating on this topic would be to identify a sufficient set of numerical tools that can be combined either entirely within the framework of OpenFOAM or by coupling it with a finite element method (FEM) software such as OpenSees or Abaqus to achieve the structure-structure interaction occurring between buildings and debris objects. Researchers from other numerical modeling groups could combine their expertise in these fields with those of the University of Washington with the aim of creating a useful engineering modeling software toolset and increased numerical modeling knowledge base that would benefit all parties involved in the collaboration as well as for future similar studies.

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Solid-liquid coupled material point method for sediment disasters

Yuya Yamaguchi[1], Shuji Moriguchi[2] and Kenjiro Terada[3]

1. Research interests

A new solid-liquid coupled material point method (MPM) [1,2] is developed with the aim to simulate a large-scale sediment disasters caused by heavy rainfall, which involves a transition process from a solidus to liquidus behavior of saturated soil. The governing equations are formulated based on the two-phase mixture theory and discretized with two layers of Lagrangian material points, each of which possesses the information about the soil and water separately. The material behavior of the solid phase is represented by elasto-plastic model, whereas the water is assumed to be a Newtonean fluid. In order to improve the robustness and efficiency in comparison with the previous studies, we introduce new discretization method for the governing equations of mixture. For the time discretization, by applying the fractional step projection method [3], the water is assumed to be incompressible to realize high accuracy and low computational costs. For the spatial discretization, we employ B-spline basis functions [4], which are supposed to suppress numerical oscillations induced by material points crossing grid lines, without losing the advantage of MPM that is suitable for parallel computing thanks to the standard domain decomposition technique. Proposed method is applied to simulate a model experiment of wave collision to sandpile to demonstrate the capability of the proposed method in dealing with scouring and transportation of the soil caused by water flow.

Figure 1 shows the schematic views of the model experiment and the numerical model of the sandpile, which is generated by reference to its actual configuration measured by laser distance meter. Snapshots of the numerical results are shown in Fig. 2 along with actual appearance in the experiment. As can be seen from the figure, they are in good agreement. Specifically, some portions of sandpile are washed out by the water flow and is distributed in the downstream side like a long tail. These results indicate that proposed method is capable of representing the characteristic behavior of soil-water mixture.

2. Perspectives for collaboration

Possible collaborators in UW would be those who can provide some experimental data of saturated soil behavior since quantitative validation of proposed method is insufficient now. Also, we would like to conduct numerical simulations of actual sediment disasters occurred in US and/or Japan.

Acknowledgments:
The other contributors are: Kohei Yoshida[a], Shinsuke Takase[b] (a:Tohoku University; b: Hachinohe Institute of Technology)

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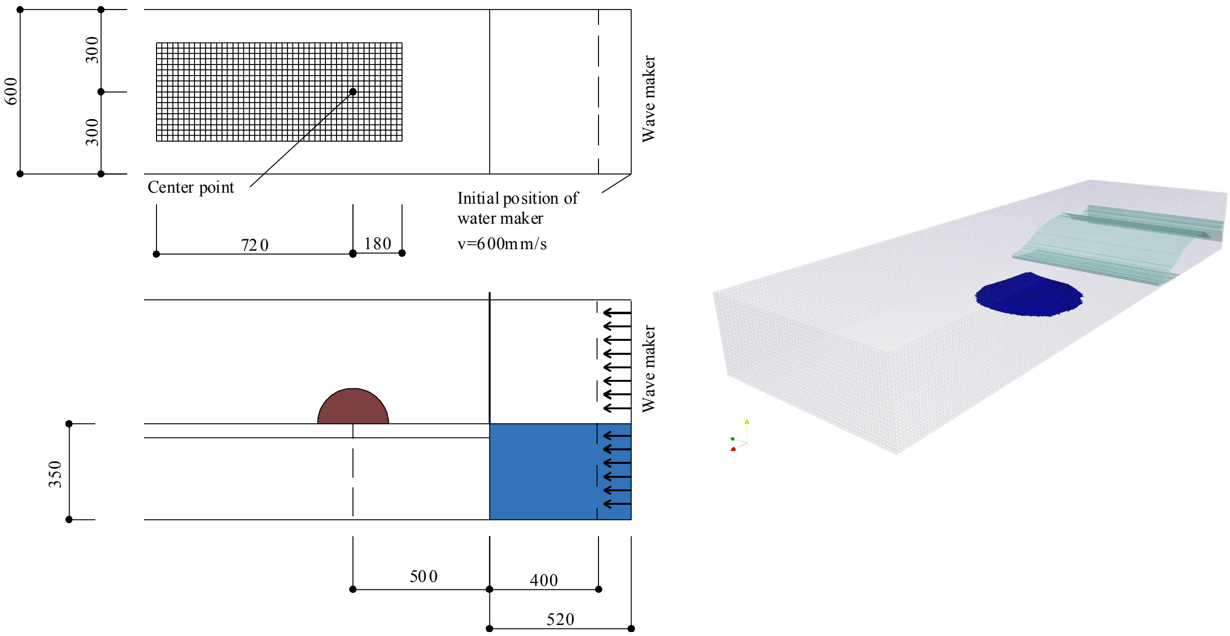

Fig. 1 Schematic views of model experiment of wave collision to sandpile (left) and numerical model (right)

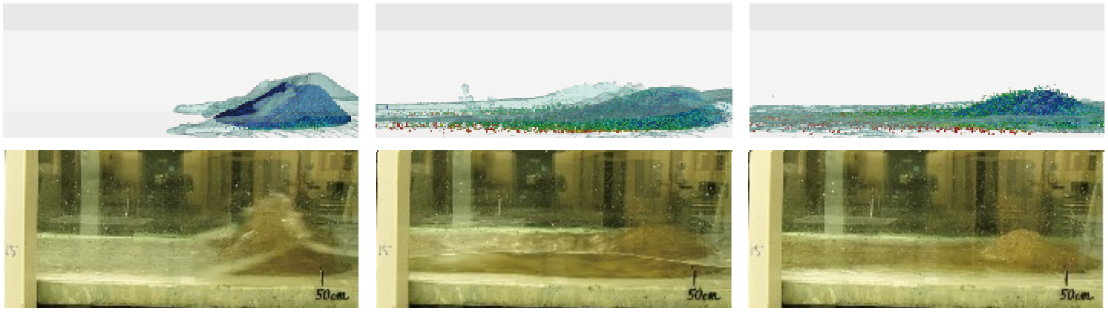

Fig. 2 Snapshots of numerical results: cumulative plastic strain (upper side) and photoglaphs taken during experiment (lower side)