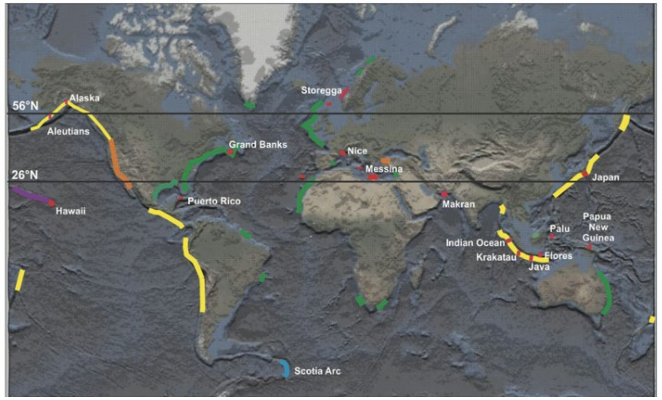
Kyoto Landslide Commitment 2020 and Submarine Landslide Related Activities



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Executive Council Member of WMO

Chair of Inter-Governmental Coordination Group on Indian Ocean Tsunami Warning and Mitigation System

•United Nations Ocean Decade 2021-30 Safe Ocean Laboratory Satellite Activity “Further Challenges for Warnings of Tsunamis”, 7 April 2022

Understanding and Reducing the Disaster Risk of Landslide-induced Tsunamis: Outcome of the Panel Discussion and the World Tsunami Awareness Day Special Event of the Fifth World Landslide Forum

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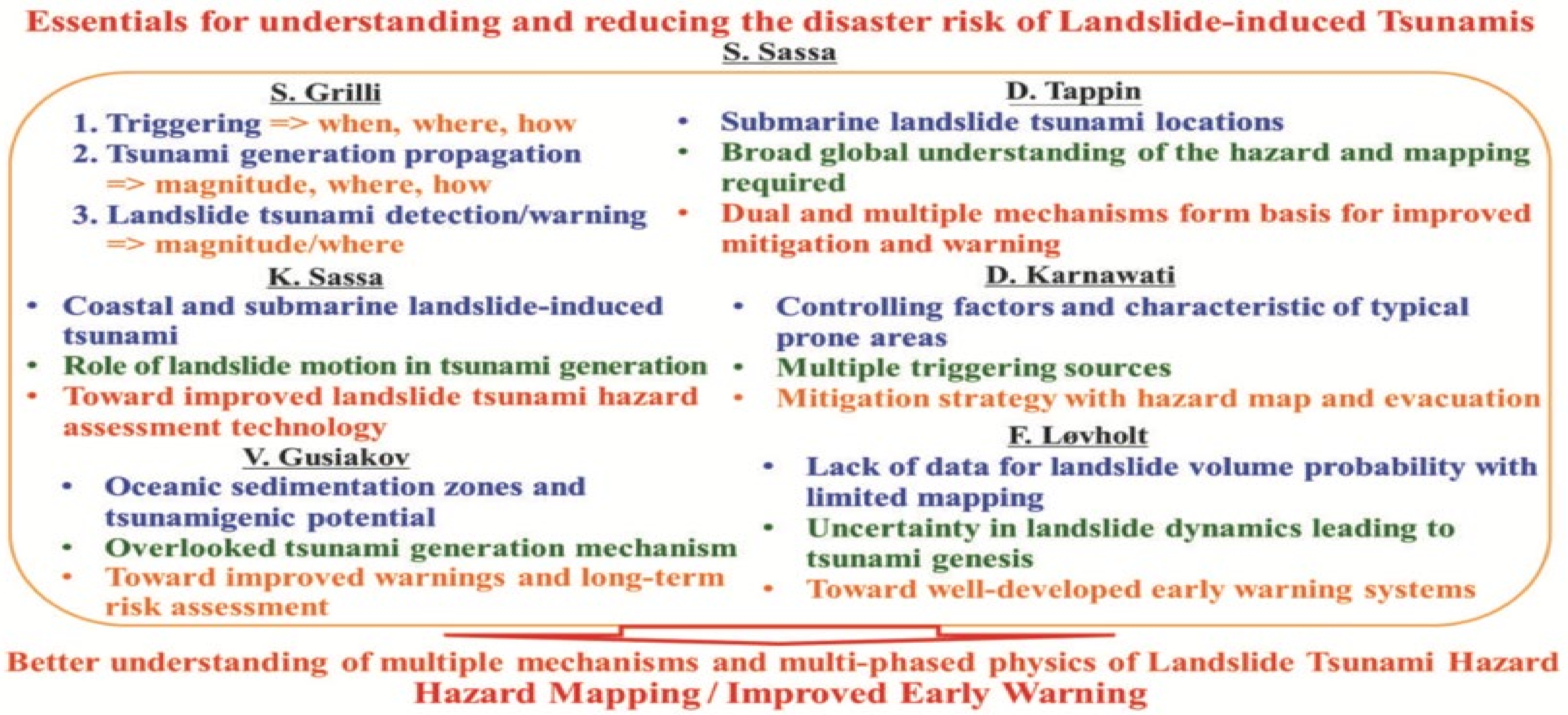


Fig. 22 The framework, essential content and a short summary of the panel discussion in the World Tsunami Awareness Day Special Event of the Fifth World Landslide Forum (Sassa et al. 2022)

TSUNAMI GENERATION BY THE 2018 VOLCANIC FLANK COLLAPSE OF ANAK KRAKATAU IN THE SUNDA STRAITS OF INDONESIA (STEPHAN T. GRILLI)

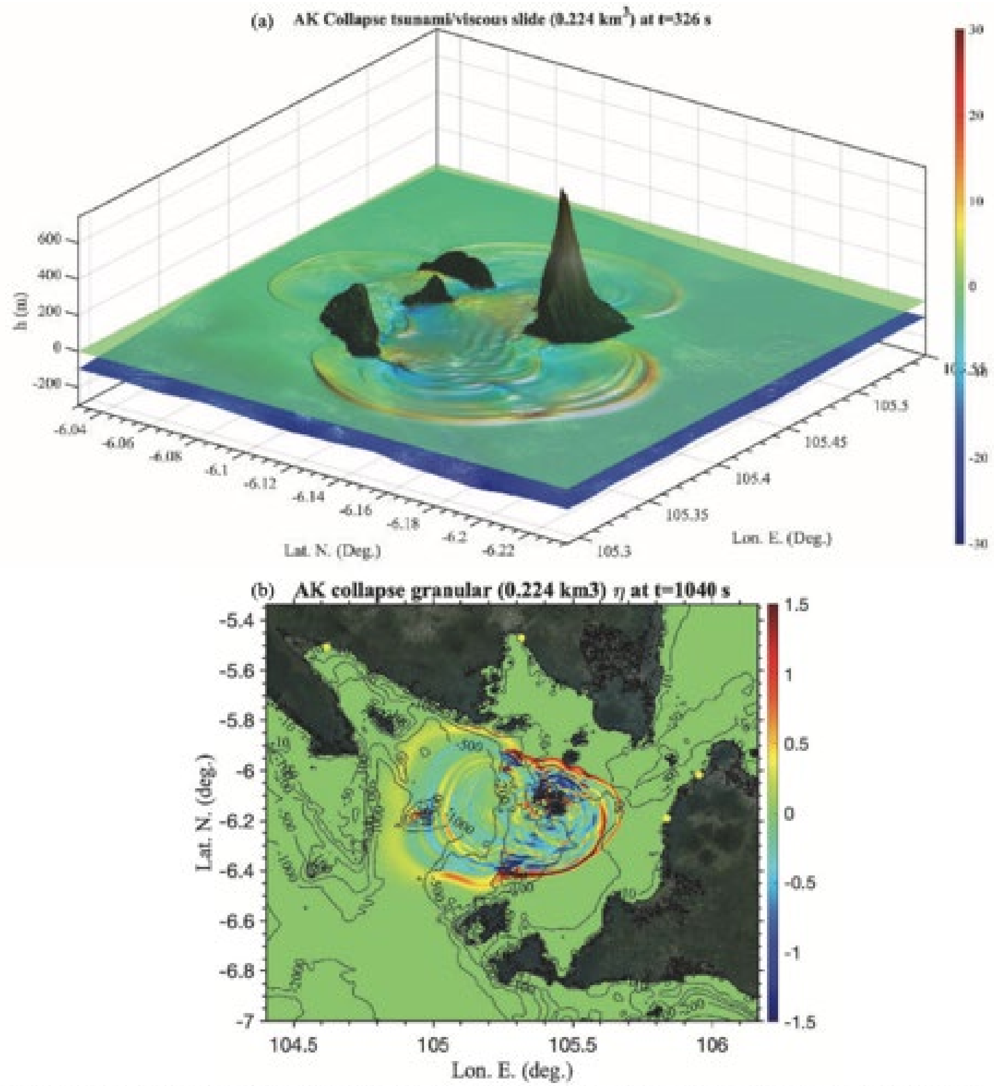


Fig. 12 Tsunami generations from the 2018 volcanic flank collapse of Anak Krakatau for (a) viscous slides and (b) granular slides. (Snapshots from S. Grilli's presentation based on Grilli et al. (2019, 2021))

S. Grilli presented a series of studies on tsunami generation by the 2018 volcanic flank collapse of Anak Krakatau in the Sunda Straits of Indonesia.

New numerical slide/tsunami modelling was developed with a new AK collapse geometric model based on a high-resolution bathymetry-topography data and satellite images.

Simulations for viscous or granular slides (Fig. 12) were conducted and the maximum surface elevations/runup were successfully compared with the field survey data from various researchers.

An improved modeling of catastrophic events such as AK 2018 can help us better prepare for and mitigate hazard posed by future similar events.

THREE FUNDAMENTAL AND IMPORTANT ISSUES: (S. GRILLI)

1. Triggering => when, where, how

For subaerial/submarine mass failures (SMF), simulating slide triggering requires topography/bathymetry and soil properties (physical, cohesiveness/rheology etc.) as well as statistics/probability of peak ground acceleration (PGA). A question here is whether predictive slope stability analyses could be performed together with an estimate of the factor of safety. For tsunami, coupled modeling of slide motion/tsunami generation is necessary. For volcanic tsunamis caused by pyroclastic flows (PF), pyroclastic density currents (PDC) and flank/caldera collapse, assessing triggering requires topography/bathymetry, volcano material/PF/PDC properties (physical, cohesiveness/rheology etc.), and estimates of PF/PDC flow rates and total volume. Monitoring of volcanic physical triggers (e.g., internal pressure, PGA) is also required. For tsunami, coupled modeling of collapse/PF/PDC motion/tsunami generation is necessary.

2. Tsunami generation propagation => magnitude, where, how

Models of tsunami generation (near-field) must feature relevant physics to simulate both slide and tsunami, and their coupling, including strong nonlinearity (in both geometry and flow), dispersion (vertical accel.) in deep water, and three-dimensionality. Models of tsunami propagation (near-to-far-field) must include dispersion and sufficient nonlinearity. Depth-integrated/averaged models are adequate. The necessary slide/wave models exist for the most part: such as in near-field, multi-material Navier-Stokes and various multi-layer non-hydrostatic models, including various rheologies, Newtonian and non-Newtonian such as Boussinesq wave model in the near-to-far-field. These models have been applied and validated on many field case studies, e.g., Storegga, Grand Bank 1929, PNG 1998, Messina 1908, Palu 2018 etc.

3. Landslide tsunami detection/warning => magnitude/where

There may not be an earthquake trigger or even a volcanic eruption. Simulations of potential landslide tsunami scenarios and their induced hazard need to be done in advance for areas deemed at risk that will be monitored. Non-standard detection methods must be implemented, such as High Frequency (HF) radar remote sensing combined with relevant tsunami detection algorithms.

A GLOBAL MAP OF SUBMARINE LANDSLIDE TSUNAMI LOCATIONS (DAVID R. TAPPIN)

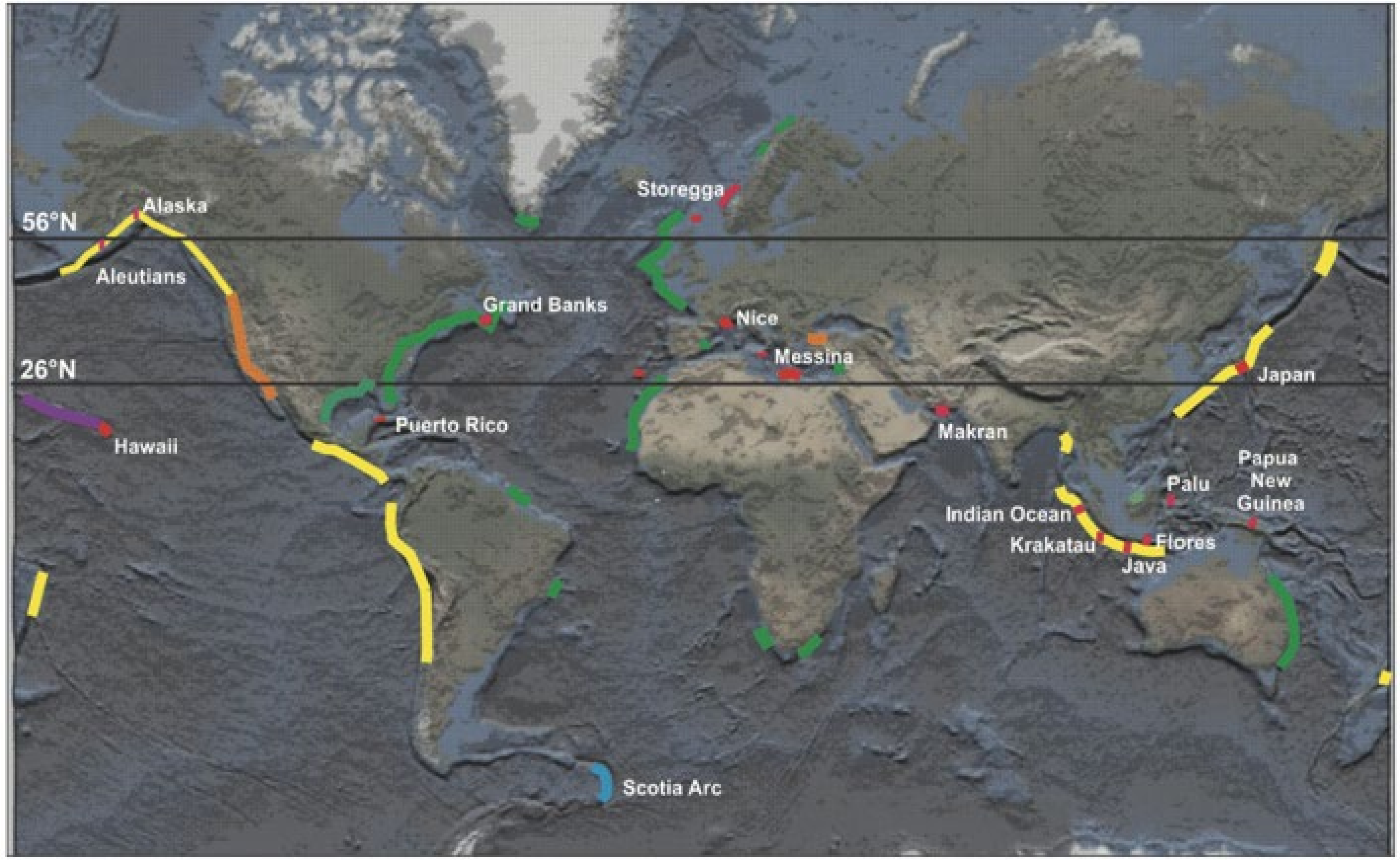


Fig. 17 Global distribution of mapped submarine landslides (SLs): Green, SLs on passive margins; Yellow, SLs located along convergent margins; Orange, SLs on strike slip margins; purple, volcanoes; Red, tsunamis associated with SLs (Tappin and Grilli 2020). Submarine landslide tsunamis (in red) are mainly located along convergent margins, but also along passive and strike slip margins and on flanks of volcanoes

D.Tappin presented a global map of submarine landslide tsunami locations (Fig. 17), noting that a broad global understanding of the hazard and mapping is required.

A learning curve for submarine landslide tsunamis can be described as follows: Most (80%) of tsunamis from earthquakes, but also from seabed slumps, landslides, dual mechanisms and volcanic collapse.

Landslide tsunamis over past few decades improve our understanding of their tsunami hazard. Each new event provides data from new technology such as multibeam bathymetry and new numerical tsunami models, however, there are still too few data to provide a broad global understanding of the hazard.

Mitigation and warning are only confined to earthquake events, with 20% of oceans mapped, so major mapping programmes are required. Recent events flag non-seismic mechanisms, and form basis for improved mitigation and warning.

UNDERESTIMATED TSUNAMI HAZARD FROM SUBMARINE LANDSLIDES (D.TAPPIN)

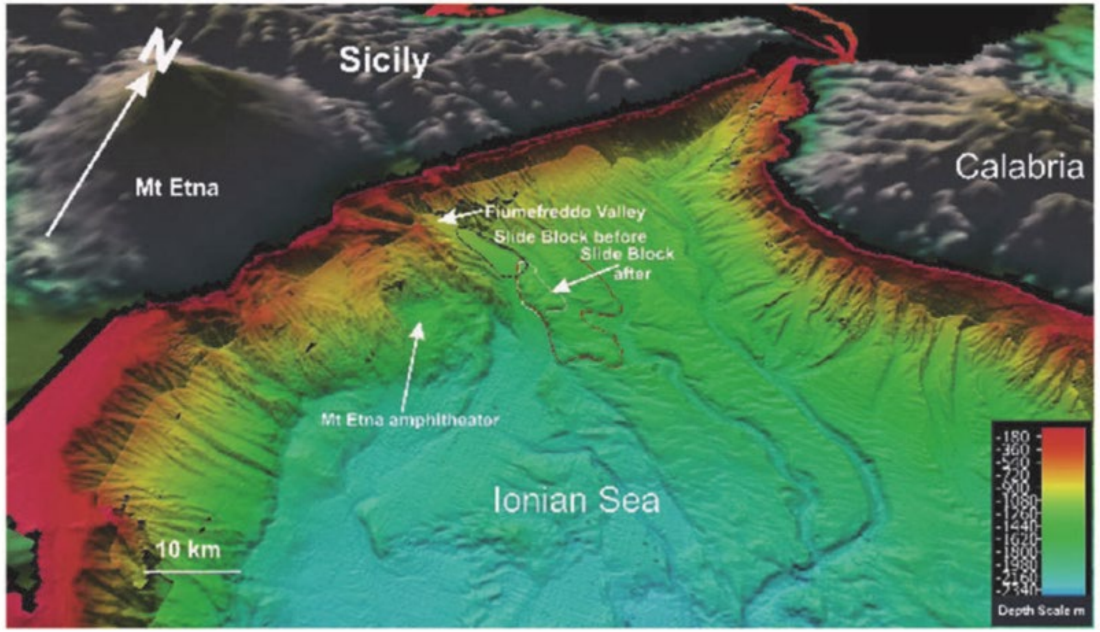


Fig. 13 3D image of the landslide block that contributed to the 1908 Messina tsunami (reproduced from Schambach et al. 2020) (Fig. 5 in Tappin and Grilli 2020)

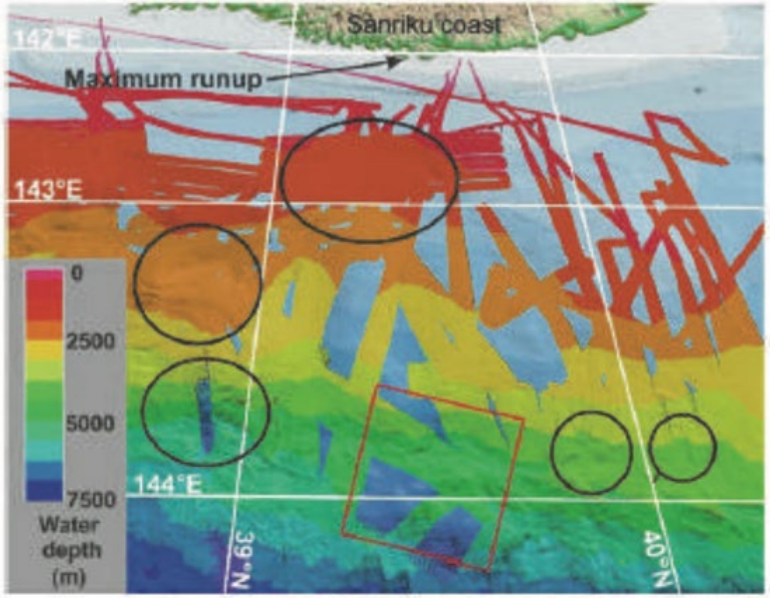


Fig. 14 Mutibeam bathymetry of the east coast of Japan, showing submarine landslides (SLs). Black ellipses/circle are SLs: Red square is the location of the SMF triggered by the March 2011 earthquake (reproduced from Tappin et al. 2014) (Fig. 6 in Tappin and Grilli 2020)

D. Tappin highlighted the continuing underestimated tsunami hazard from submarine landslides.
Recognition of the tsunami hazard from submarine landslides has been possible mainly because of the recent development of advanced technology such as multibeam echosounders.
Accordingly, submarine landslide tsunamis are now seen from all geological environments; passive, convergent and strike-slip margins as well as volcanoes (examples are shown for the 1908 Messina tsunami in Fig. 13 and for the 2011 Tohoku tsunami in Fig. 14).
Despite these new advances in understanding, however, recognition of the tsunami hazard from submarine landslides is still limited.

THE IMPORTANT ROLE OF LANDSLIDE MOTION IN TSUNAMI GENERATION (KIYOJI SASSA)

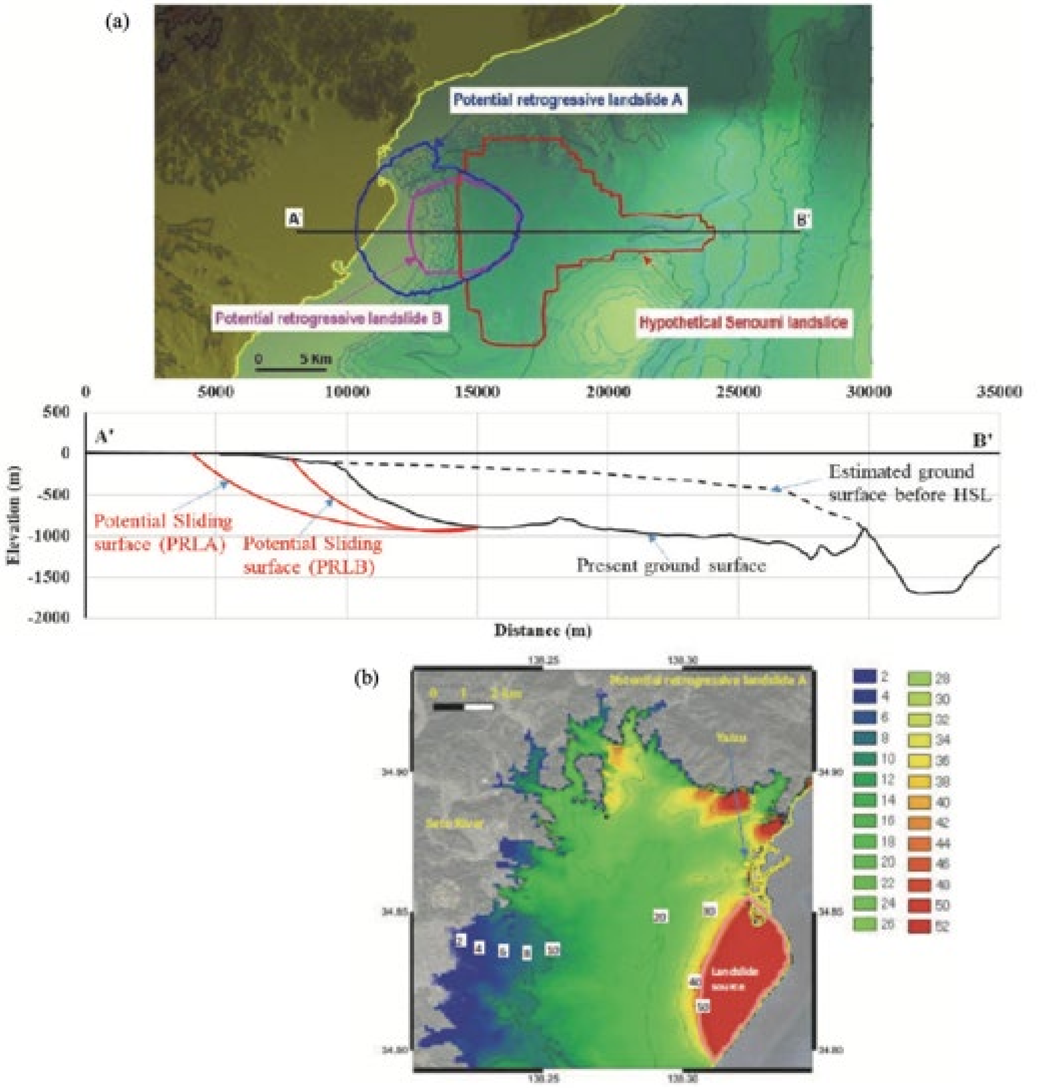


Fig. 18 (a) Shapes and cross sections of hypothetical Senoumi landslide (HSL) and potential retrogressive landslides A and B (PRLA and PRLB, respectively) (b) Inundation map at Yaizu City center caused by PRLA. Inundation depth (color scale in meter) = maximum tsunami height – ground elevation (Figs. 31 and 34(a) in Loi et al. 2020)

K.Sassa presented simulations of coastal and submarine landslide-induced tsunamis and highlighted the important role of landslide motion in tsunami generation.

A hazard assessment of landslide-induced tsunamis along Suruga bay in Japan was presented for a hypothetical Senoumi landslide and potential retrogressive landslides arising from a future mega earthquake along Nankai Trough together with their hazard map (Fig. 18).

How to prepare for possible landslide causing tsunamis was highlighted. Namely, retrogressive landslides are common in many landslides.

However, to investigate the possibility of potential retrogressive landslides at Senoumi, a set of 800 m deep drillings and geophysical exploration are needed.

Hence, we have to discuss how to promote the understanding and reducing landslide disaster risk including both landslide causing tsunami and landslide-induced tsunami for KLC2020.

THE EVALUATION OF THE INITIATION AND MOTION OF LANDSLIDES (K. SASSA)

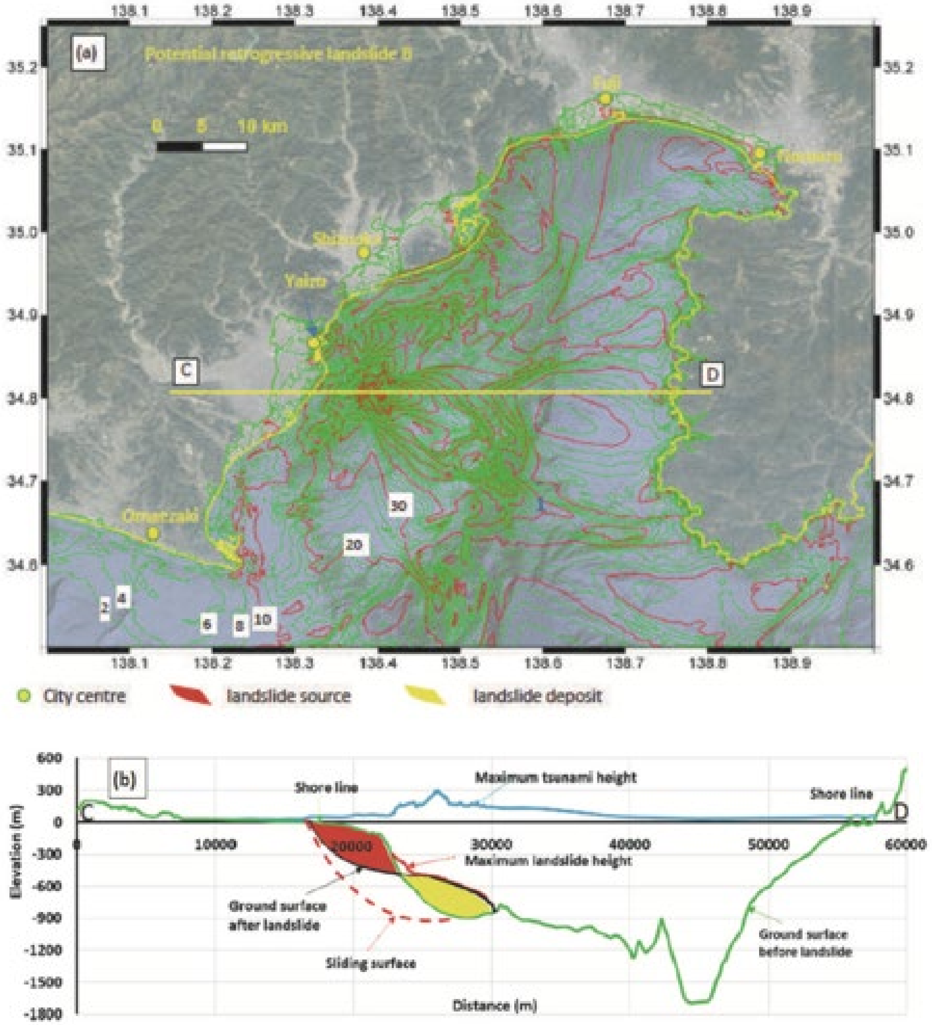


Fig. 11 (a) Contour of the maximum tsunami height caused by a potential retrogressive landslide in Neogene sand triggered by 0.7 ×Tohoku earthquake record (MYG004). Tsunami heights are in meters above sea level with 2m contours in green and 10m contours in blue. (b) The profile of the maximum tsunami height at each mesh along section C-D (Fig. 32 in Loi et al. 2020)

K. Sassa presented the history of development of the undrained dynamic-loading ring-shear apparatus and the integrated simulation model for the evaluation of the initiation and motion of landslides, as well as a new landslide induced tsunami model based on the aforementioned landslide dynamics.

The validity has been confirmed with the world’s largest well- documented landslide tsunami disaster with 15,153 deaths in Unzen, Japan in 1972.
The application to potential retrogressive Senoumi landslides in Suruga bay shows tsunami inundation depths of 20-50m in Yaizu city (Fig. 11).

CONTROLLING FACTORS AND CHARACTERISTIC OF TYPICAL PRONE AREAS: GEOLOGY AND BATHYMETRY (DWIKORITA KARNAWATI)

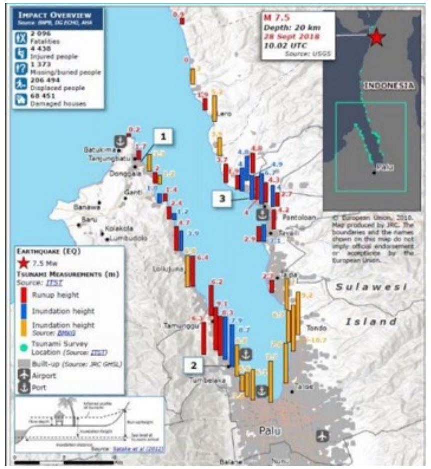
D. Karnawati illustrated some case examples of Palu earthquake and tsunami with liquefaction and submarine landslide, Sunda Straits tsunami due to volcanic eruption, and historical earthquakes and tsunamis in Ambon, Indonesia.

Triggering sources involve earthquake and volcanic eruption.

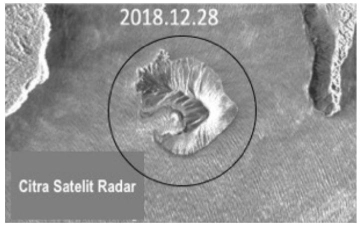
Controlling factors and characteristics of areas typically prone to landslides were presented with reference to geology and bathymetry such as a fault distribution in coastal or near shore areas and position of alluvial fan.

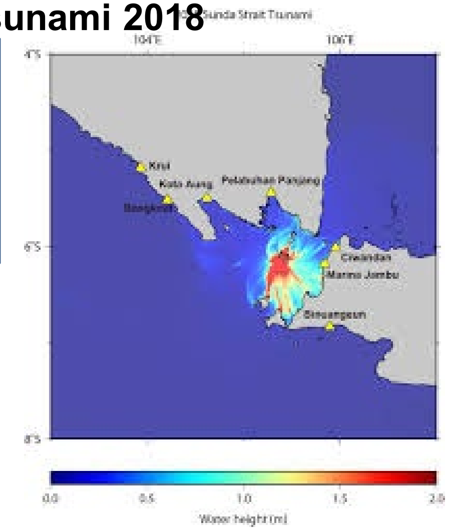
The 2018 catastrophic events highlighted the impact of volcanic flank collapse and landslide induced tsunamis, showing the importance of multi-hazard risks.

Palu Earthquake & Tsunami 2018

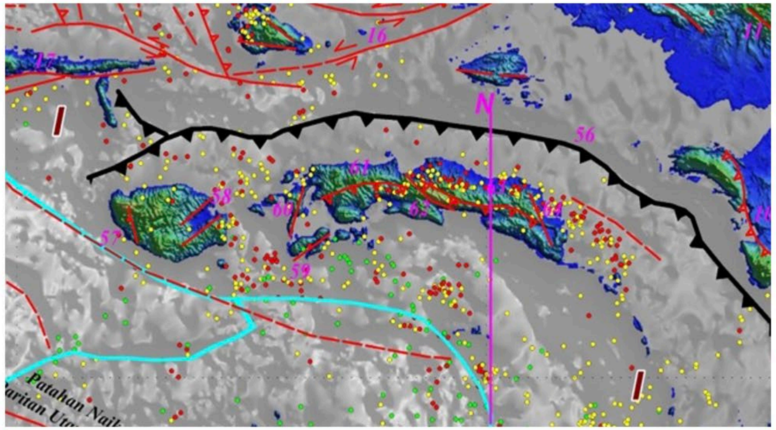


Sunda Strait Tsunami 2018

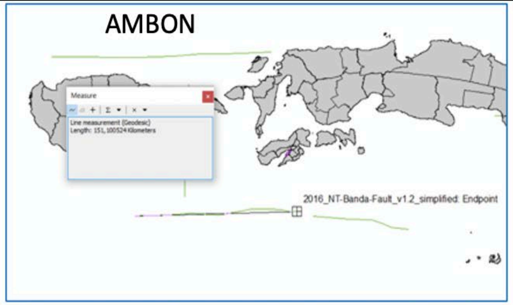


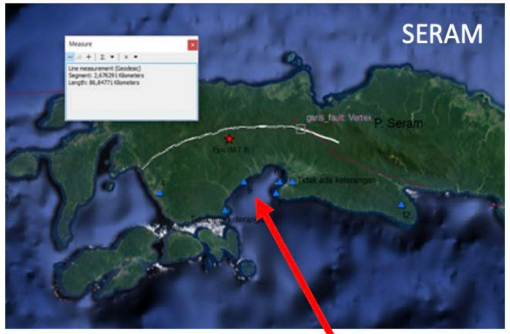


AMBON – SERAM ISLAND, MOLLUCA



Fault distribution/ position in coastal or near shore areas, control the steepness of bathymetry





Position of Alluvial Fan

END TO END TSUNAMI EARLY WARNING SYSTEM (D. KARNAWATI)

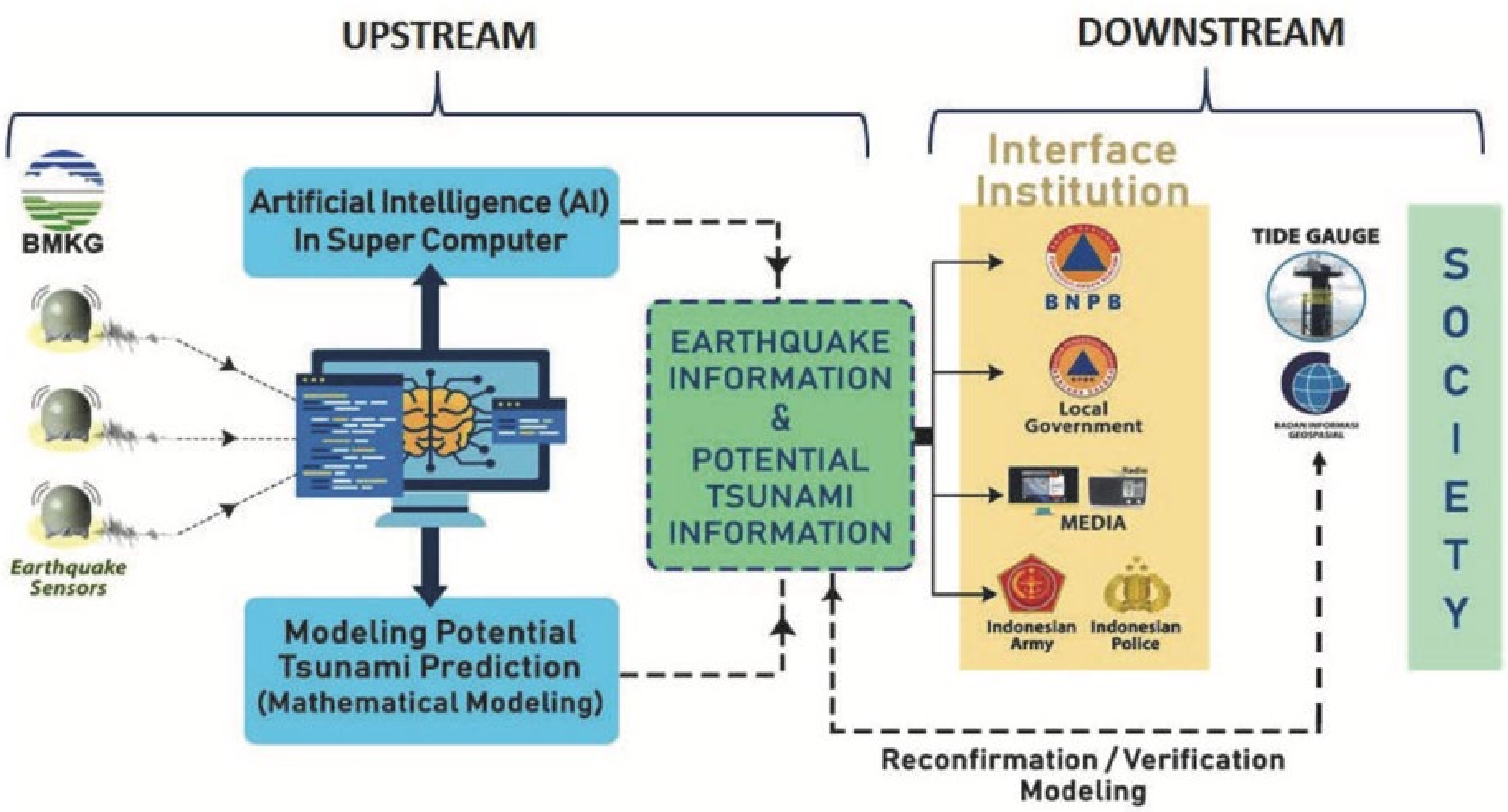


Fig. 16 End to end system for tsunami early warning in Indonesia (Karnawati 2020)

D. Karnawati presented an innovation in tsunami early warning system in Indonesia.

The system aims at a timely detection of earthquake event and provides tsunami warning within 5 minutes after the earthquake takes place.
The end to end system adopted for tsunami early warning is shown in Fig. 16.

It facilitates an appropriate response from the community to reduce and minimize the impact of tsunami disasters.

A MITIGATION STRATEGY (D. KARNAWATI)

A mitigation strategy based on hazard maps and evacuation plans was then provided with field verification and fact findings in order to:

(a) verify the hazard levels and zones (tsunami hazard map)

(b) select and check most appropriate evacuation route (shortest and fastest) with appropriate sign

(c) empower the local capacity to take the rapid or spontaneous actions in response to any ground shaking, coastal subsidence and landslides, by following the determined evacuation route toward the higher/saver area

(d) promote public education and regular drill for self-evacuation (integrate the local wisdom and knowledge)

(e) establish appropriate land use management based on appropriate hazard map

(f) relocate the people from hazard area.

A list of 12 indicators from UNESCO-IOC tsunami community program was presented (Fig. 19).

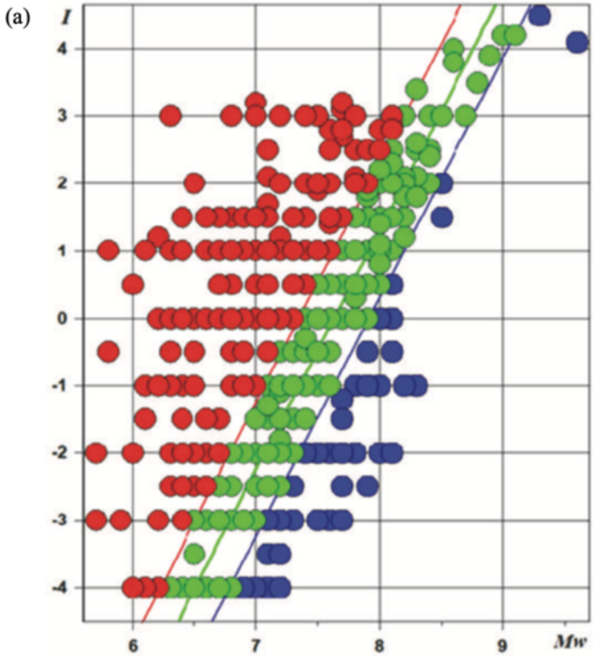
I	MITIGATION (MIT)
1	MIT-1. Tsunami hazard zones are mapped and designated
2	MIT-2. The number of people at risk in the tsunami hazard zone is estimated
3	MIT-3. Available economic, infrastructural, political, and social resources are identified
4	MIT-4. Tsunami information is publicly displayed.
II	PREPAREDNESS (PREP)
5	PREP-1. Easily understood tsunami evacuation maps are developed.
6	PREP-2. Outreach and public awareness and education resources are available and distributed.
7	PREP-3. Outreach or educational activities are held at least 3 times a year.
8	PREP-4: A Tsunami community exercise is conducted at least every two years
III	RESPONSE (RESP)
9	RESP-1. A community tsunami emergency operations plan (EOP) has been prepared
10	RESP-2. The capacity to manage emergency response operations during a tsunami has been established.
11	RESP-3. Redundant and reliable means to timely receive 24-hour official tsunami alerts have been identified.
12	RESP-4. Redundant and reliable means to timely disseminate 24-hour official tsunami alerts to the public have been identified.

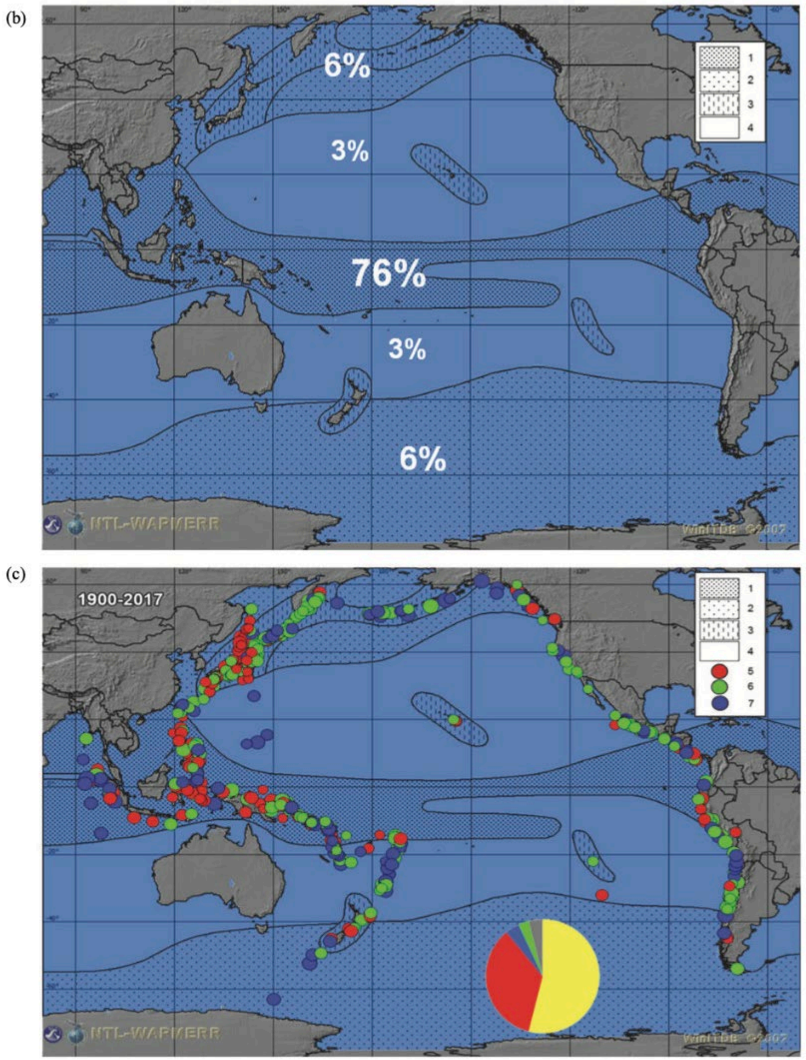
Fig. 19 A list of 12 indicators from UNESCO-IOC TSUNAMI READY COMMUNITY PROGRAM (excerpt from D. Karnawati's presentation)

THE CLOSE RELATIONSHIP BETWEEN OCEANIC SEDIMENTATION ZONES AND LANDSLIDE-TRIGGERED TSUNAMIGENIC POTENTIAL (VIACHESLAV K. GUSIAKOV)

V. Gusiakov demonstrated the close relationship between oceanic sedimentation zones and landslide-triggered tsunamigenic potential, which could directly contribute to improving tsunami early warning and long-term risk assessment.

Fig. 20 (a) Classification of “red”, “green” and “blue” Pacific tsunamigenic earthquakes in the tsunami intensity I - moment magnitude M_w relationship according to Gusiakov (2001) (b) The main zones of lithogenesis in the Pacific Ocean (1 - equatorial humid zone, 2 - northern and southern humid zones, 3 - zone of effusive-sedimentary lithogenesis, 4 - northern and southern arid zones). The digits show a fraction of sediment volume in each zone in the total volume of marine sediments by Lisitsyn (1974) (c) Locations of the "red", "green" and "blue" tsunamigenic earthquakes. The insert figure shows the fractions of landslide-generated tsunamis (red color) in the total number of Pacific tsunamis (excerpts from V. Gusiakov’s presentation)





Specifically, the main zones of lithogenesis in the Pacific Ocean:
1 - equatorial humid zone
2 - northern and southern humid zones
3 - zone of effusive-sedimentary ithogenesis
4 - northern and southern arid zones),

and the classification and locations of "red", "green" and "blue” Pacific tsunamigenic earthquakes were presented (Fig. 20).

It demonstrates that there is a close relationship between oceanic sedimentation zones and tsunamigenic potential of submarine earthquakes.

In spite of greater efforts in recent years to study the slumping mechanism of tsunami generation, this factor is almost completely overlooked in the early tsunami warning and in the long-term tsunami risk assessment (coastal tsunami zoning).

THE POTENTIAL THREAT OF THE SLOPE INSTABILITY AND THE LANDSLIDE-INDUCED WAVES FOR THE SAFETY OF HYDROPOWER PLANT (HPP) DAMS IN A MOUNTAIN REGION (V. GUSIAKOV)

Fig. 15 General view of the landslide scar on the southern bank of the Bureya water reservoir and the body of the landslide with a passage, initially made 1 February 2019 and then extended by the spring flood in April-May 2019. The top left panel shows damaged stumps and exposed tree roots on the gentle coastal slope directly opposite the landslide on the northern bank of the Bureya river (Figs.3 and 9 in Gusiakov and Makhinov 2020)

V. Gusiakov reported the December 11, 2018 landslide and the landslide-induced icy tsunami in the Bureya water reservoir, Russia.

The landslide with an estimated volume of up to 25 million cubic meters generated a destructive tsunami-like wave whose impact on the shore was emphasized by a thick (up to 20cm) ice cover (Fig. 15).

The maximum run-up height turned out to be equal to 90 m above the initial water level.

The event has demonstrated the potential threat of the slope instability and the landslide-induced waves for the safety of hydropower plant (HPP) dams in a mountain region.

LANDSLIDE TSUNAMI UNCERTAINTY AND A PROBABILISTIC TSUNAMI HAZARD ANALYSIS (FINN LØVHOLT)

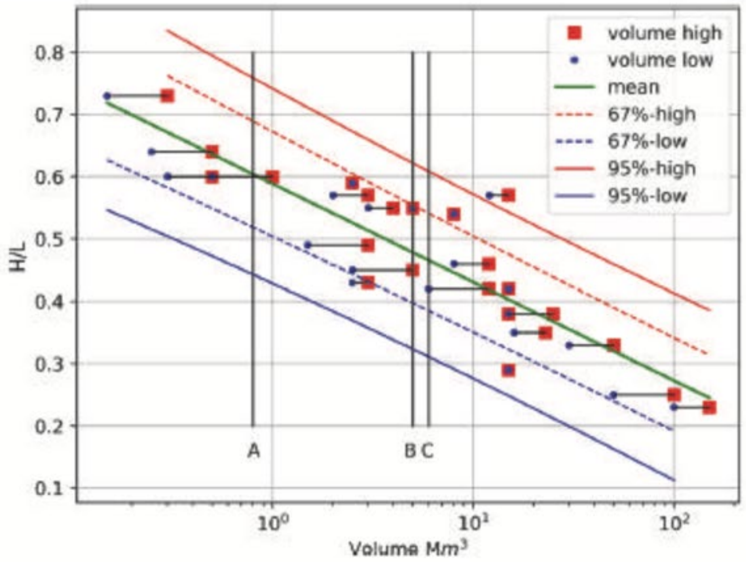


Fig. 1 The regression analysis of the run-out statistics of rock slides in Norway: H is the fall height, L is the total horizontal run out. The vertical lines A, B and C indicate the volumes 0.8, 5 and 6 Mm^3, respectively (Fig. 7 in Løvholt et al. 2020)

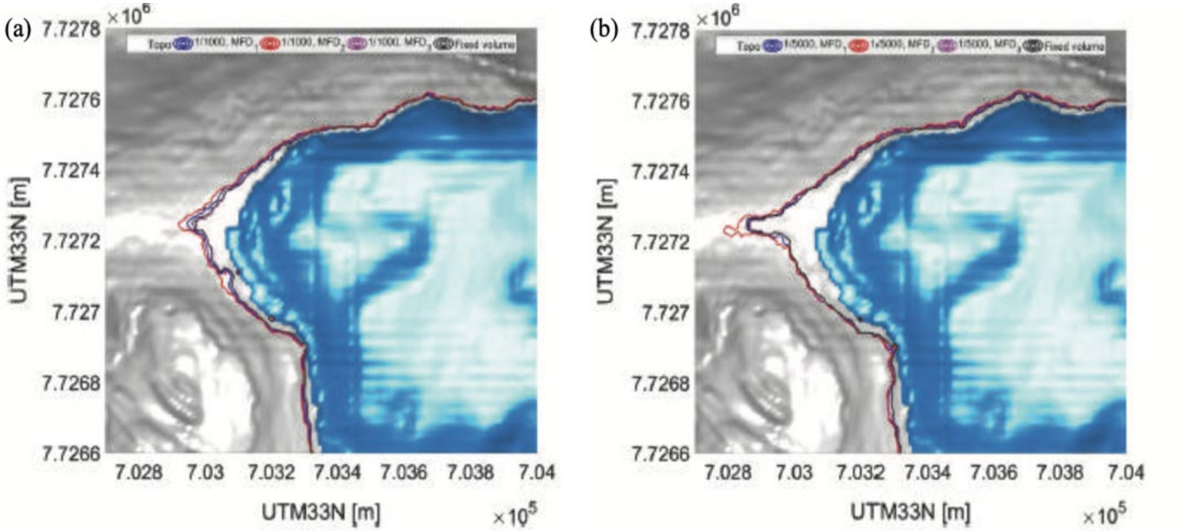


Fig. 2 Comparing tsunami inundation maps using different synthetic MFDs: (a) 1/1000 year^{-1} and (b) 1/5000 year^{-1} exceedance probability (Fig. 9 in Løvholt et al. 2020)

F. Løvholt addressed landslide tsunami uncertainty and presented a probabilistic tsunami hazard analysis (LPTHA) framework for analysing uncertainties emerging from the landslide source processes. An example is presented for the Lyngen fjord in Norway.

The statistics of the fall height (H) to run-out length (L) ratio as a function of the volume for large rockslides in Norway is shown in Fig. 1. Comparing tsunami inundation maps using different magnitude frequency distributions (MFDs, Fig. 2) indicates that the results are sensitive to the choice of MFD to which the uncertainty is directly linked concerning landslide dynamics.

THE OUTSTANDING QUESTIONS AND GAPS FROM THE EUROPEAN TSUNAMI COMMUNITY (FINN LØVHOLT)

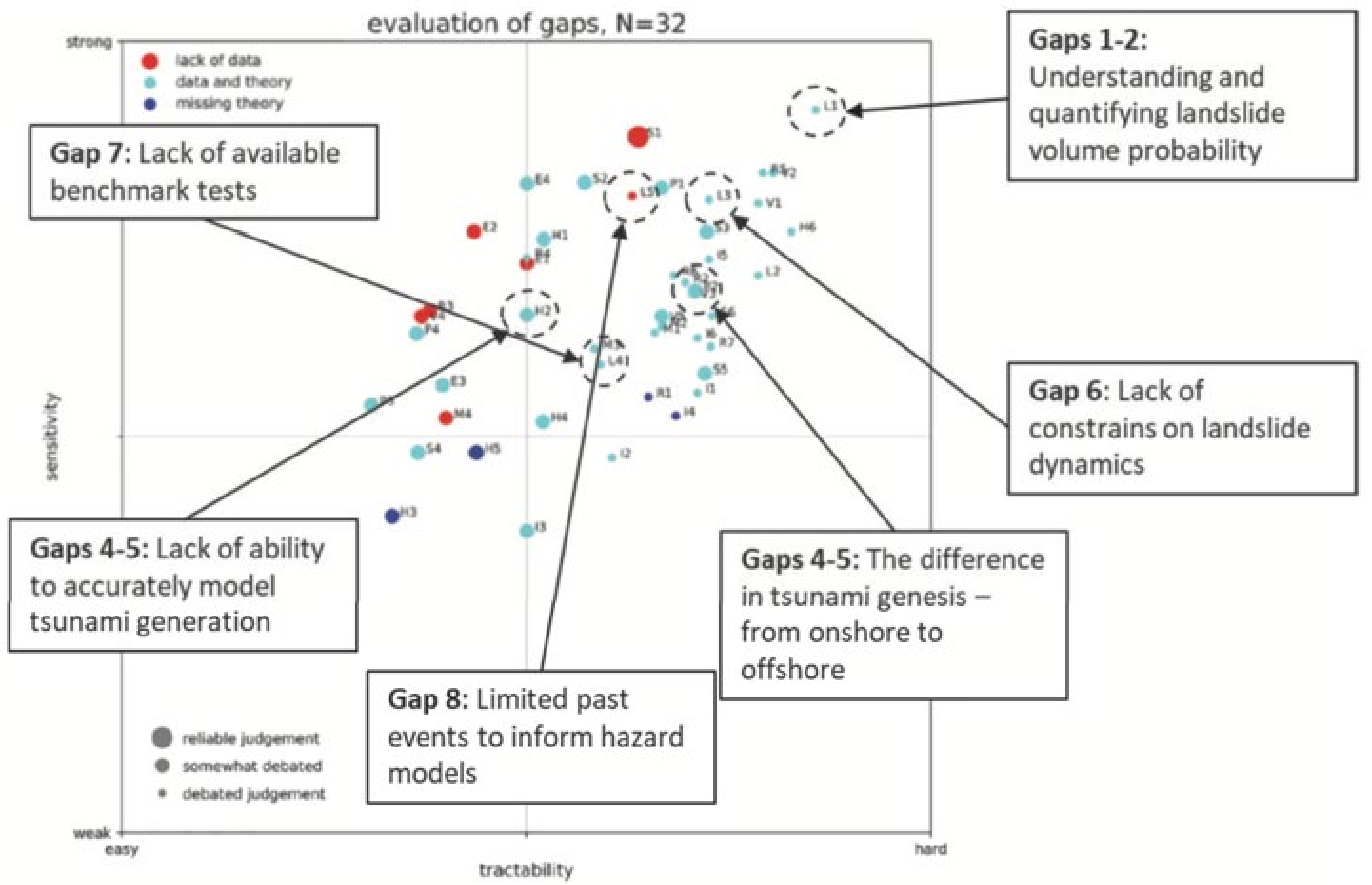


Fig. 21 Outstanding questions and gaps – the European tsunami community response (excerpt from F. Løvholt's presentation based on Behrens et al. (2021))

F.Lovholt stressed the lack of data for landslide volume probability, resulting from limited seafloor sub-bottom mapping, and highlighted the uncertainty in landslide dynamics leading to tsunami genesis.

Although physics of tsunami propagation and inundation are well established and sensitivity to the kinematics of the landslide (i.e. the motion and path) is relatively well known, several cases thoroughly hindcasted represent mainly subaerial landslides.

Accordingly, in most places around the world, we lack data for quantifying temporal landslide volume probability with limited and often non-existing mapping of substrata conditions, thickness of sediments, fractures, geotechnical parameters etc. Landslide friction scales with landslide size, however, implications for hazard are also not well known.

The outstanding questions and gaps from the European tsunami community are shown in Fig. 21.

SUMMARY

- Triggering and source mechanisms need to be well constrained and needs to better understand how both of these affect tsunami generation, in order to more accurately predict/model landslide-induced tsunamis.
- There is still a lot to learn for better understanding and mitigating the disaster risk of landslide-induced tsunamis, regarding hazard mapping and improving warning. Dual and multiple mechanisms must be considered to achieve improved mitigation.
- Limited understanding and characterization of past events makes it difficult to well constrain landslide dynamics. A better integrated understanding of landslide dynamics as well as multi-phased physics of landslide-water interactions are crucial to reducing landslide tsunami disaster risk.
- More data is needed to better constrain geological and geotechnical conditions for hazard mapping.

Better understanding of multiple mechanisms and multi-phased physics of Landslide Tsunami Hazard is important and necessary for improving Landslide Tsunami Hazard Mapping and Early Warning.

THANK YOU