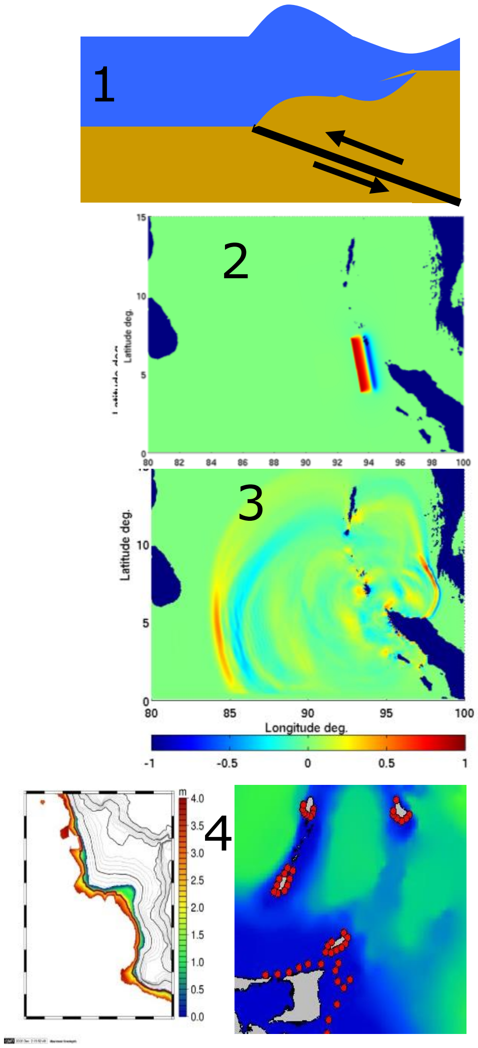
RAPSODI
Risk **A**ssessment and design of **P**revention **S**tructures f**O**r enhanced tsunami **DI**saster resilience

Possible NGI contributions related to tsunami modelling activities

Finn Løvholt and Carl B. Harbitz

Numerical simulations – the standard approach

1. Seabed displacement due to earthquake in subduction zone (or due to landslide)
2. Seabed displacement slightly smoothed ⇒ initial wave for tsunami simulation
3. Numerical oceanic scenario tsunami simulation using a dispersive oceanic wave model. Data extracted from time series in specific locations
4. Run-up / inundation by rough regional “approximate” linear methods or detailed local nonlinear inundation models



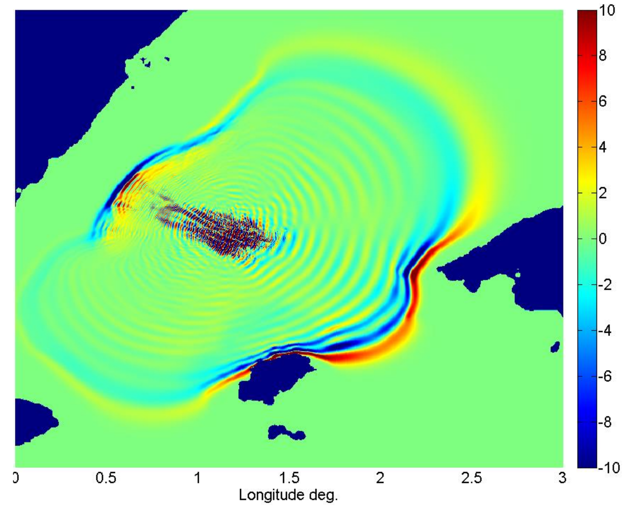
Possible contributions I - Model coupling and nesting (tsunami propagation and run-up)

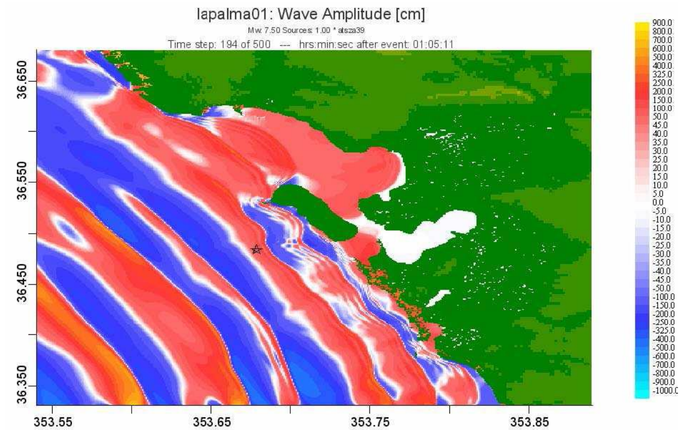
GloBouss: Includes effects of
  frequency dispersion
  Important for shorter waves,
    particularly landslide tsunamis
  Also for seismic scenarios,
    smaller events and over long distances

ComMIT/MOST: Developed by NOAA
  for earthquake tsunamis –
  high number of precomputed events

At NGI/ICG this model is applied for run-up
  calculations with input from nonlinear
  dispersive models

Shock capturing →
  handling steep wave fronts - bores





Possible contributions II – earthquake source modeling

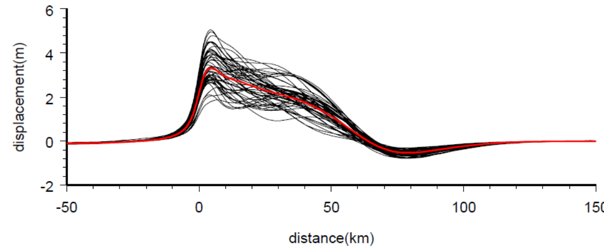
Simplified Okada model

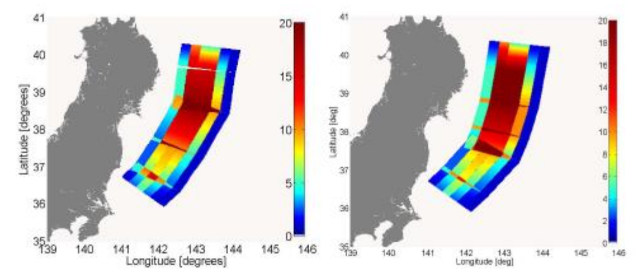
Heterogeneous models, random slip, stochastic modeling superimposing Okadas solution (overlap with EU-ASTARTE project)

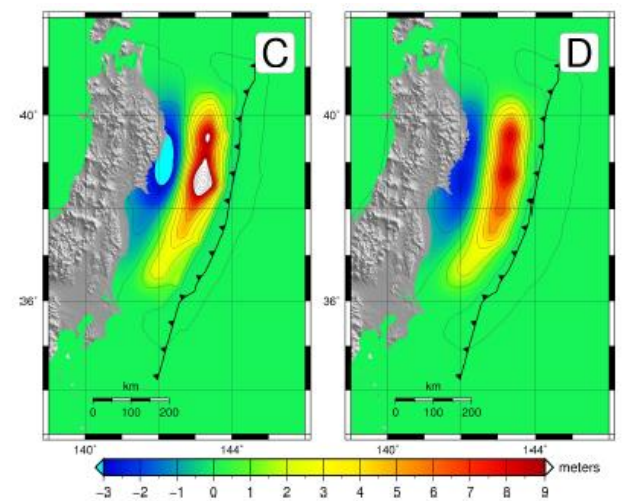
Source realisations for Tohoku event or similar – forecasting and hazard assessment

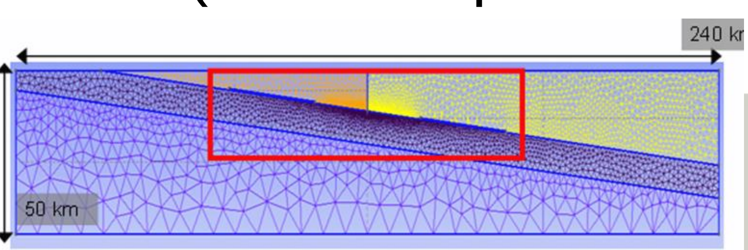
Numerical models → FEM or FDM (would require further development)

Stochastic seabed surface deformation









Possible contributions III – landslide source modelling

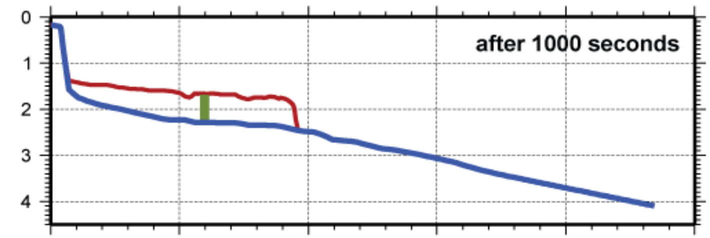
Depth averaged models, e.g. BING

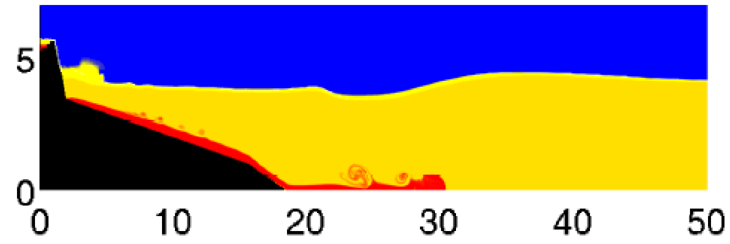
Fully compressible, fully non-linear multi material models, including the generation phase

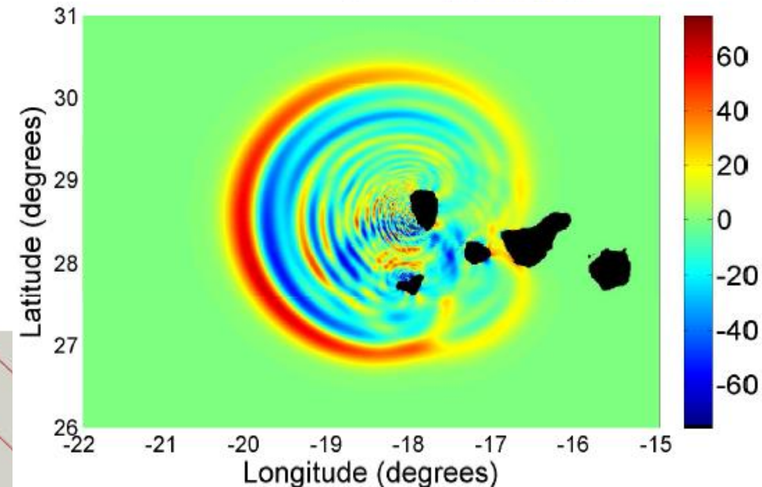
Benefit from other projects

1: Landslide induced tsunamis in ASTARTE (NGI WP leader)

2: At the University of Oslo, modelling of rock slide evolution and landslide impact

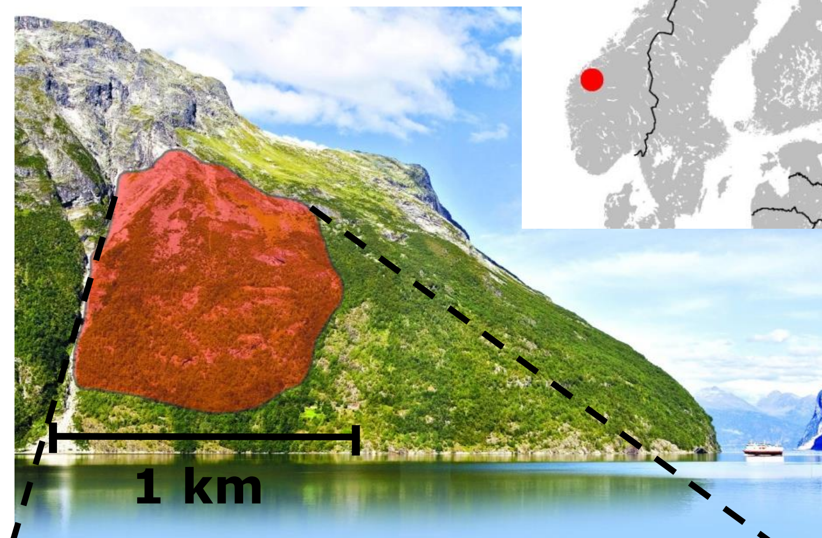


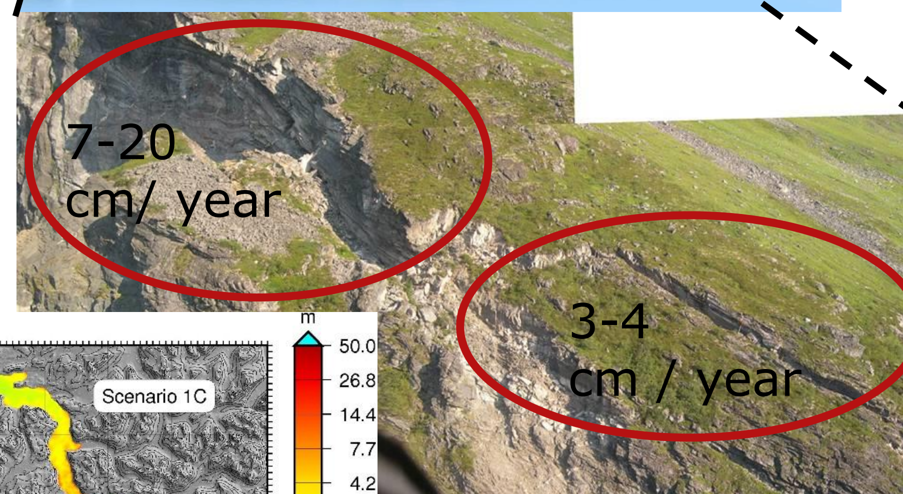


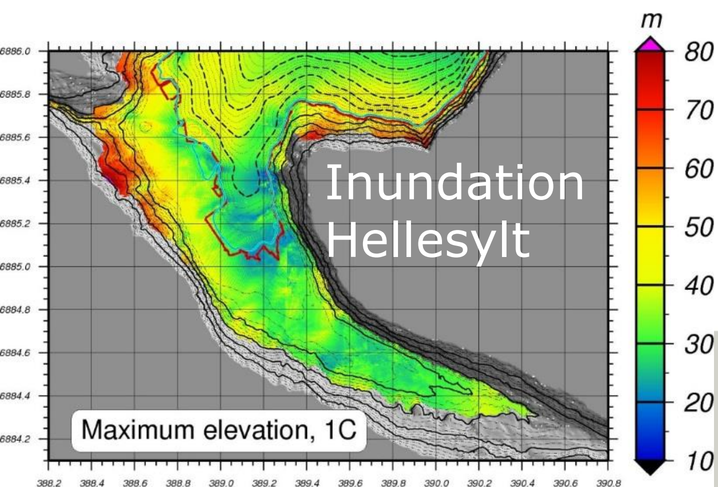


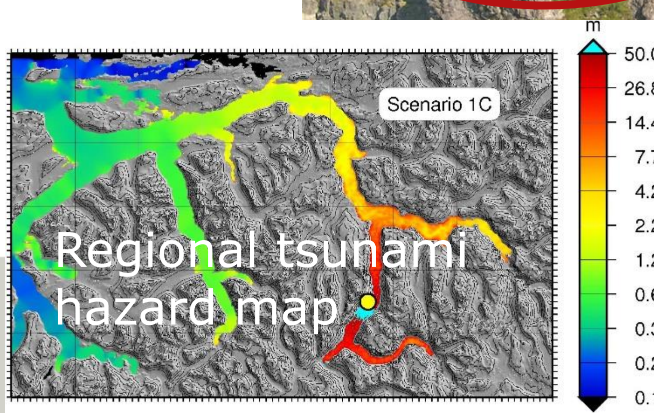
The Åknes-Tafjord project – western Norway

- Largest volume > 50 Mm^3
- Unstable rock slope 150 - 900 m.a.s.l
- Large movements /deformations
- Advanced computational tools needed
- A large number of computations and hazard assessments performed









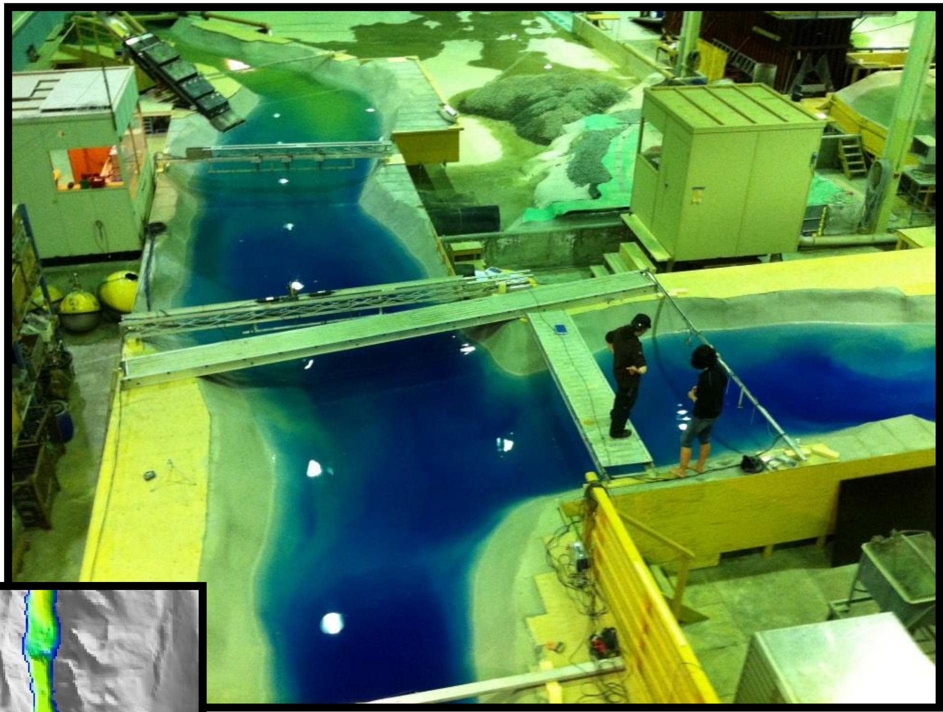
3D laboratory experiments

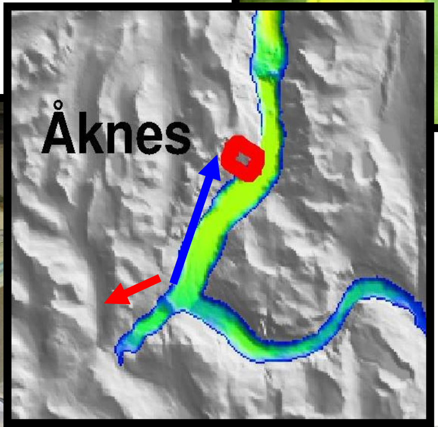
SINTEF Coast and Harbour Research Laboratory, Trondheim

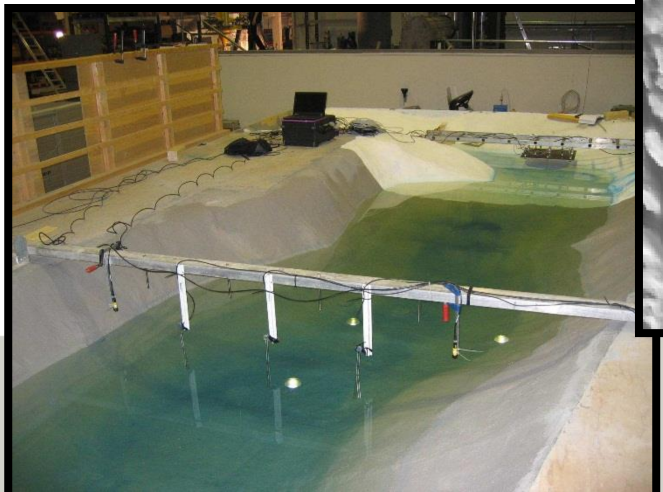
Scale 1:500

Instrumentation and setup is based on numerical simulations and the 2D laboratory experiments at UiO Hydrodynamics Laboratory

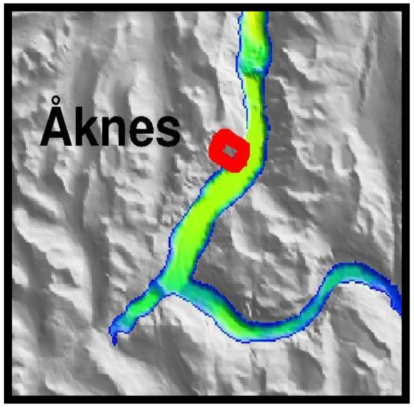
Input to and validation of numerical tsunami models

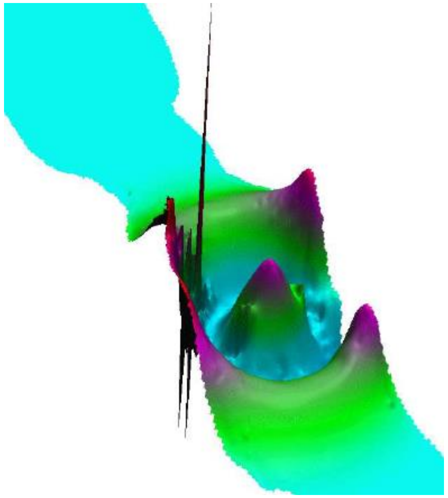






Modeling a complex problem



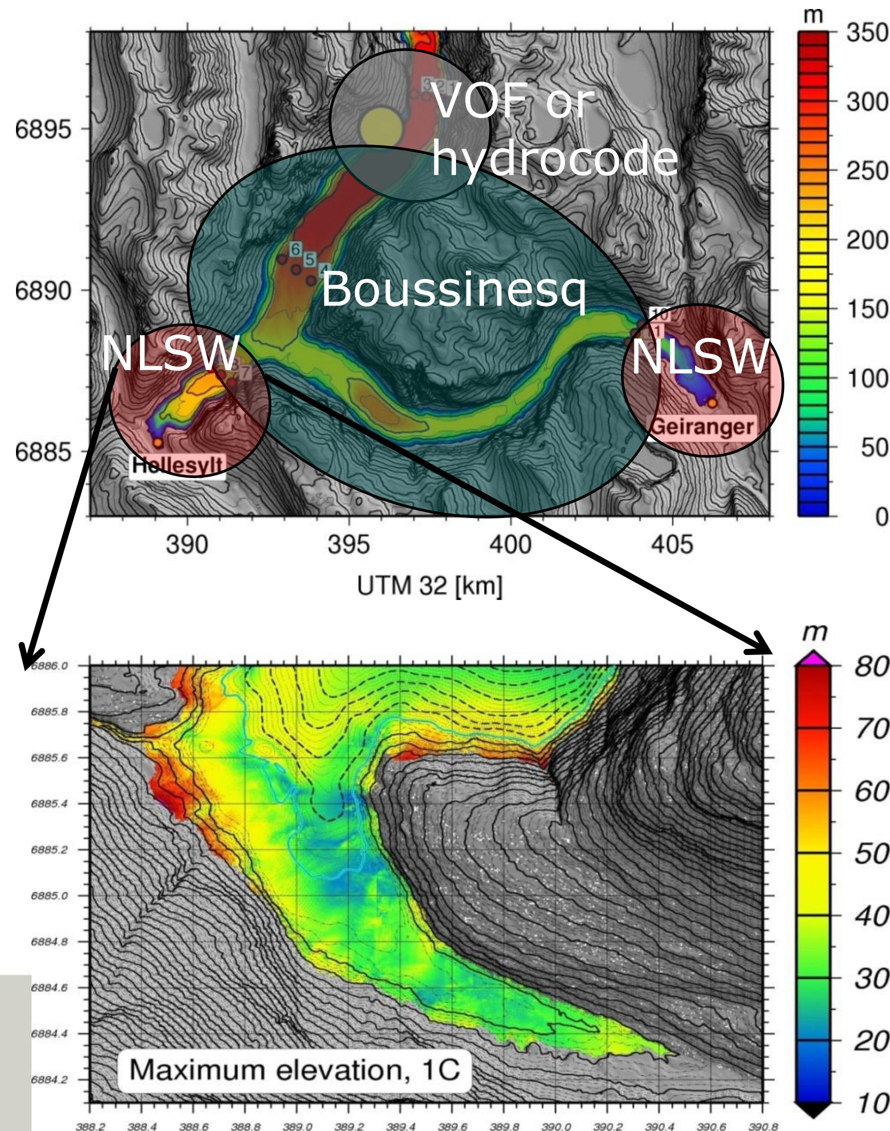


- Large volume and high impact velocity
  - Nonlinear and dispersive effects
- Generation phase important for the resulting waves
  - Deforming (retrogressive) slide or one big block?
  - Shape of the slide when hitting the water
  - Interaction with water during submerged run-out?
- Large bathymetric gradients (ria coasts and fjords)
- Laboratory experiments and numerical simulations

1 - Courtesy "National Land Image Information (Color Aerial Photographs), Ministry of Land, Infrastructure, Transport and Tourism".

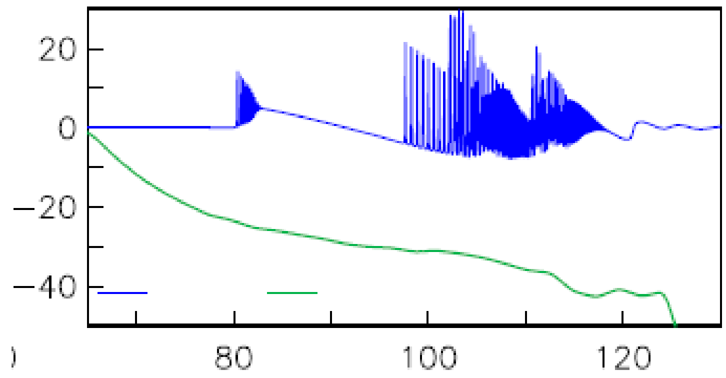
Possible contribution IV – two way coupling - primitive solvers in impact region – long wave solvers for propagation

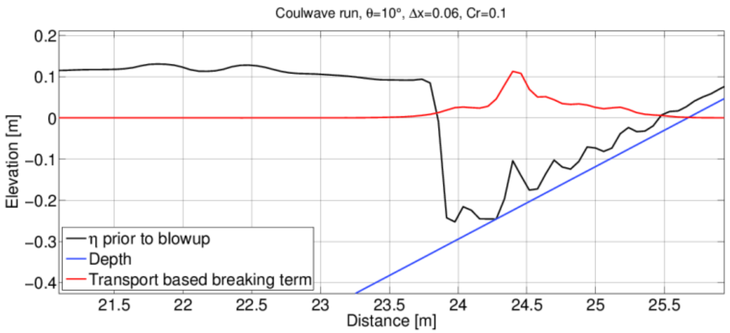
- Near field – primitive models
    - Nested with long wave solver in the far field
- Propagation, necessary factors
    - Dispersion important
    - Non-linearity, sometimes strong
    - Inundation during fjord propagation
    - Rugged terrain, steep slopes
- Boussinesq type models with inundation needed
    - Models must handle steep slopes, rugged terrain and be robust
- Other models may be considered for local inundation (e.g. NLSW)

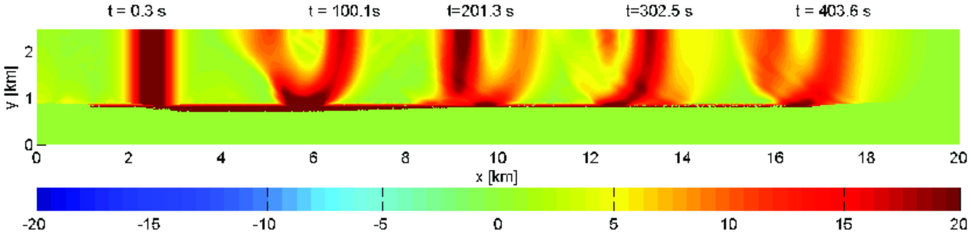


Possible contribution V - Modeling near shore processes with non-hydstatic models

- Modelling combined run-up and propagation in rugged terrain
- Non hydrostatic response and undular bore propagation
- Effect of mitigating structures
- Overcoming spurious effects
- Validation of performance
  - NLSW models
  - 3D models
- Cooperation with USC

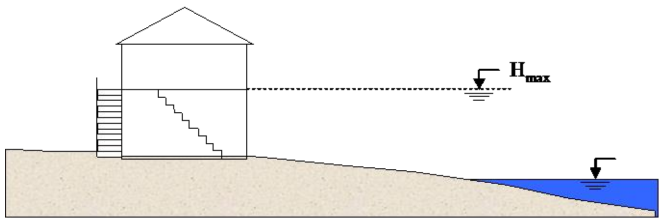




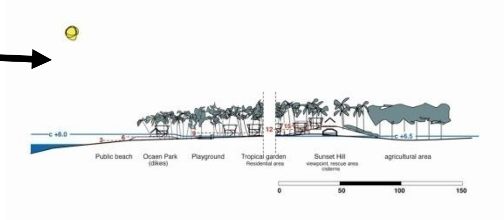


Counter measures and land use planning

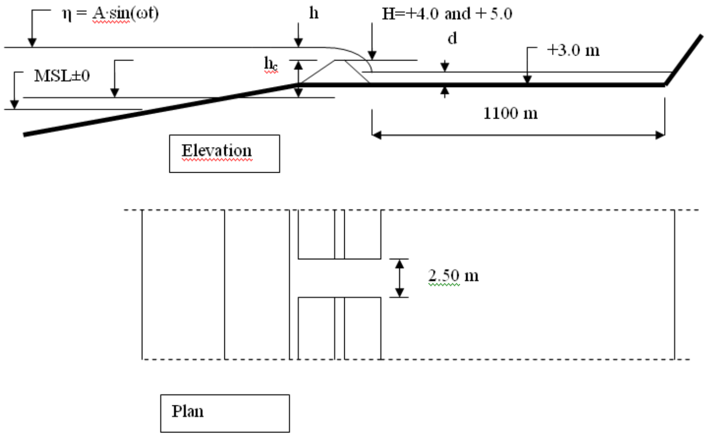
Building measures



Land use planning



Assessment of dykes / sea walls with overtopping / openings



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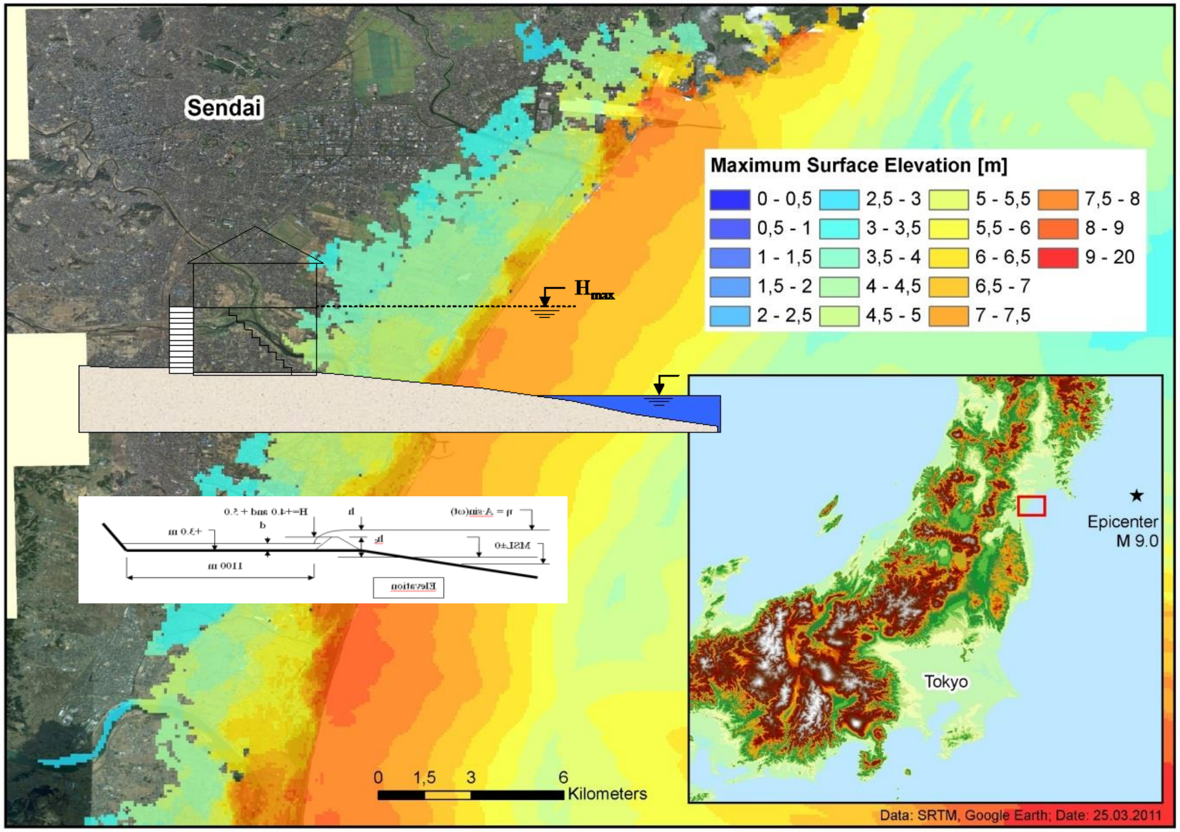
Possible contributions VI – run-up and impact of mitigation structures using depth averaged models



Final remarks – suggested NGI contributions

Literature review of available models (**WP1, D.1**)

Source models – needed in hazard assessment

- Need for **some joint source models** in the present project, but perhaps not extensive (**WP2, D.2, D.5, or D.6**)
- Landslide models considered less relevant here

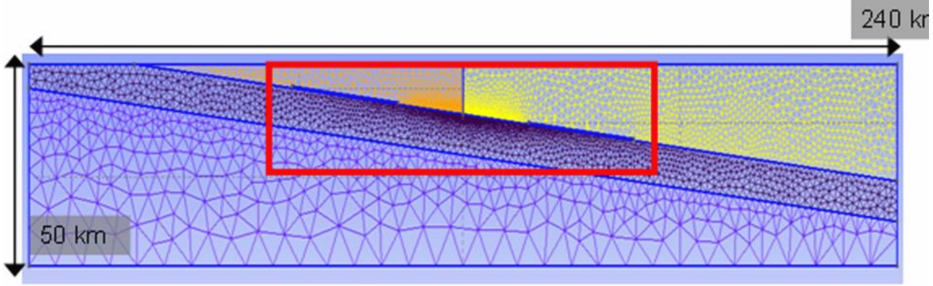
Near shore processes and impact on structures using depth averaged models (**WP2, D.5, or D.6**)

- **NLSW** – relatively robust, fast, least general
- **Boussinesq –** less robust, handles undular bores

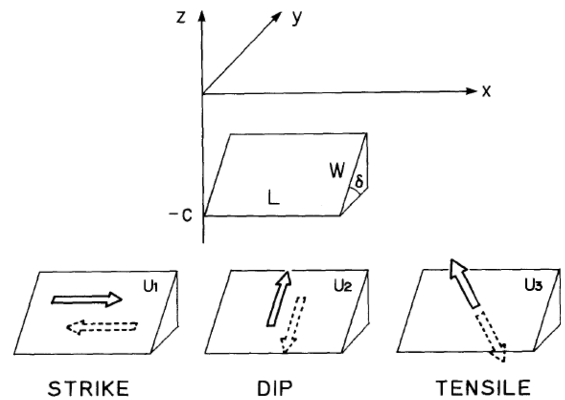
3D models would need adaptation from NGIs side to be employed for run-up and damage calculations

Utilization of results from other projects (ASTARTE, UiO project, and possible other projects)

NGI



Source modelling

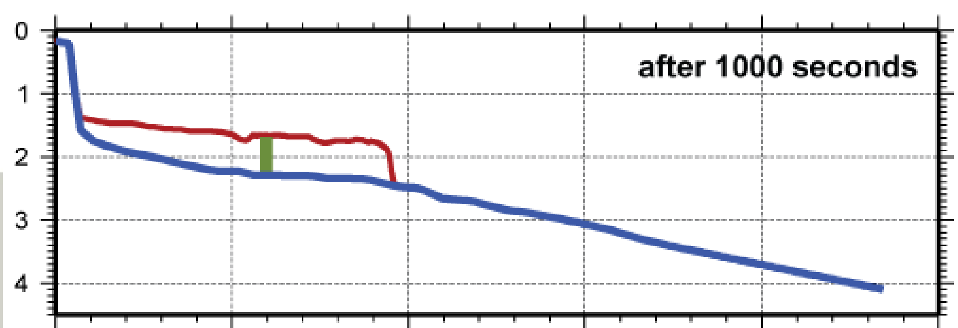


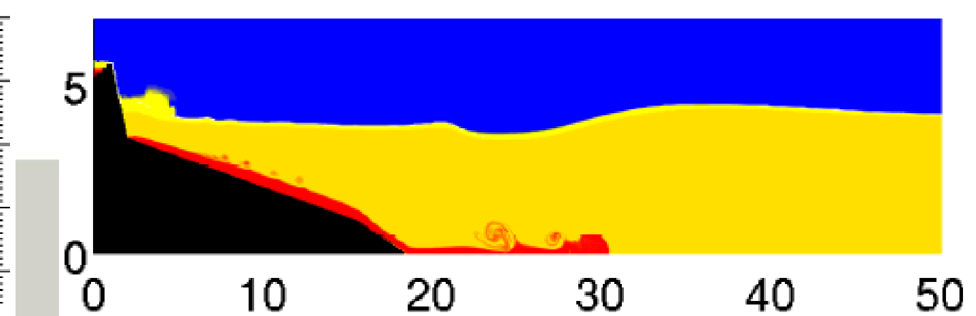
Earthquakes

- Simplified analytical (Okada, 1985) → homogenous
- Numerical models → FEM or FDM
- Heterogeneous models, random slip, stochastic modeling

Landslides and rock slides

- Depth averaged models, e.g. BING → suitable for landslides, debris flows and some rock slides
- Fully compressible, fully non-linear multi material models, including the generation phase → rock slides and volcanoes





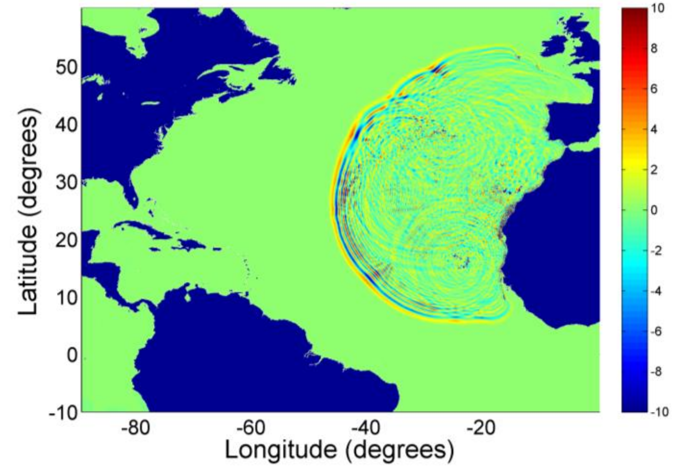
La Palma simulation

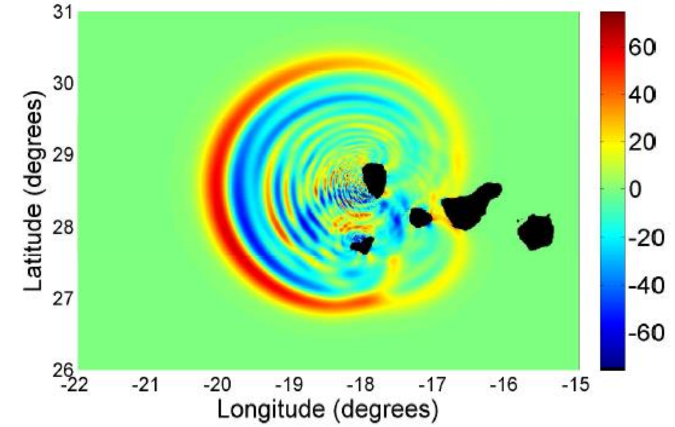
Coupled model

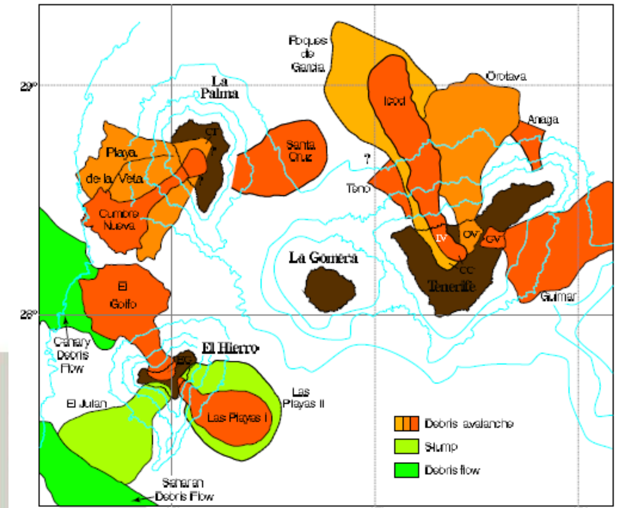
- SAGE (hydrocode) for landslide and wave generation
- ”GloBouss” dispersive tsunami model

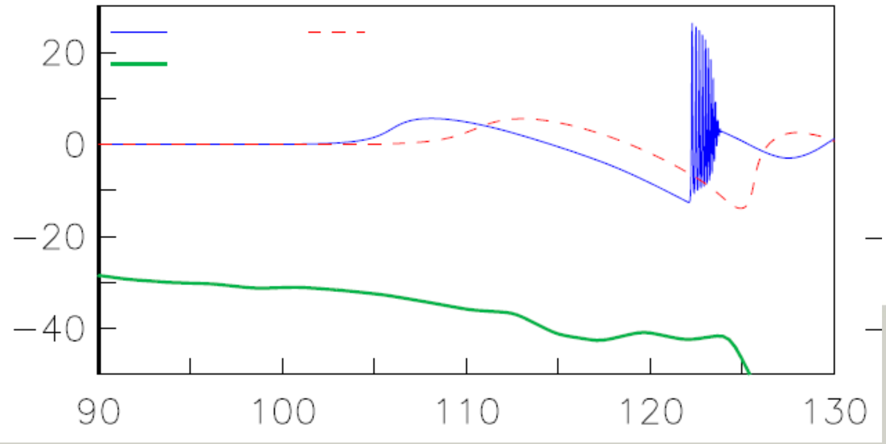
Thorough study of

- Wave evolution and asymptotics
- *Importance of dispersion*
- *Undular bore evolution*

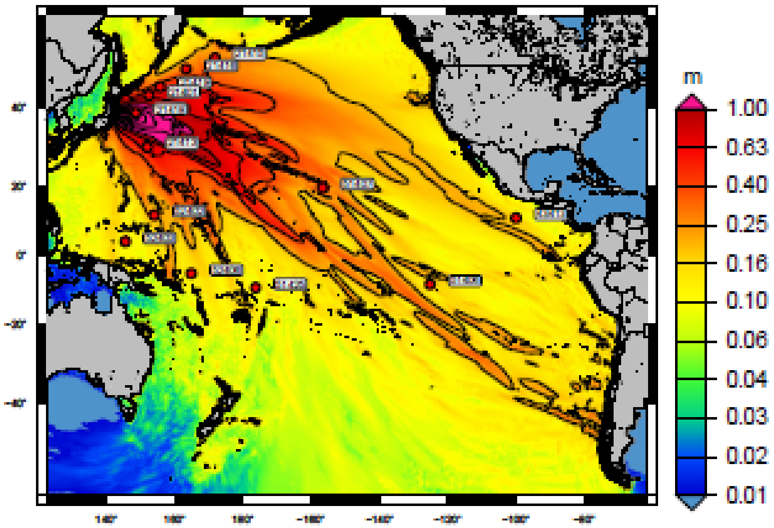


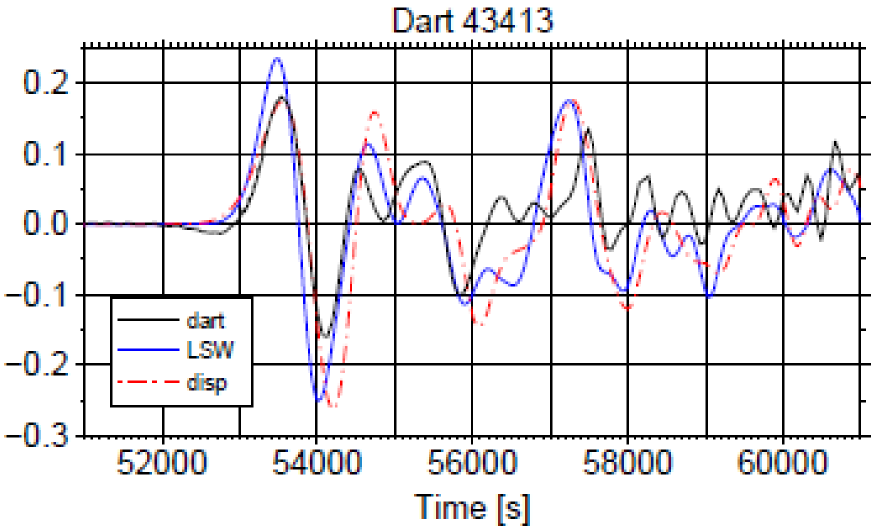






Effects of frequency dispersion





- Non-uniform slip distribution, dip angle 25°
- Minor effect of dispersion close to earthquake
- Clear effect of dispersion for trans-oceanic propagation
  - T=14hrs, L=11000km, $\tau \sim 10^{-1}$


Thank you!