NGI

Numerical simulations of the Storegga tsunami

Steven J Gibbons, Carl B. Harbitz, Sylfest Glimsdal, Finn Løvholt

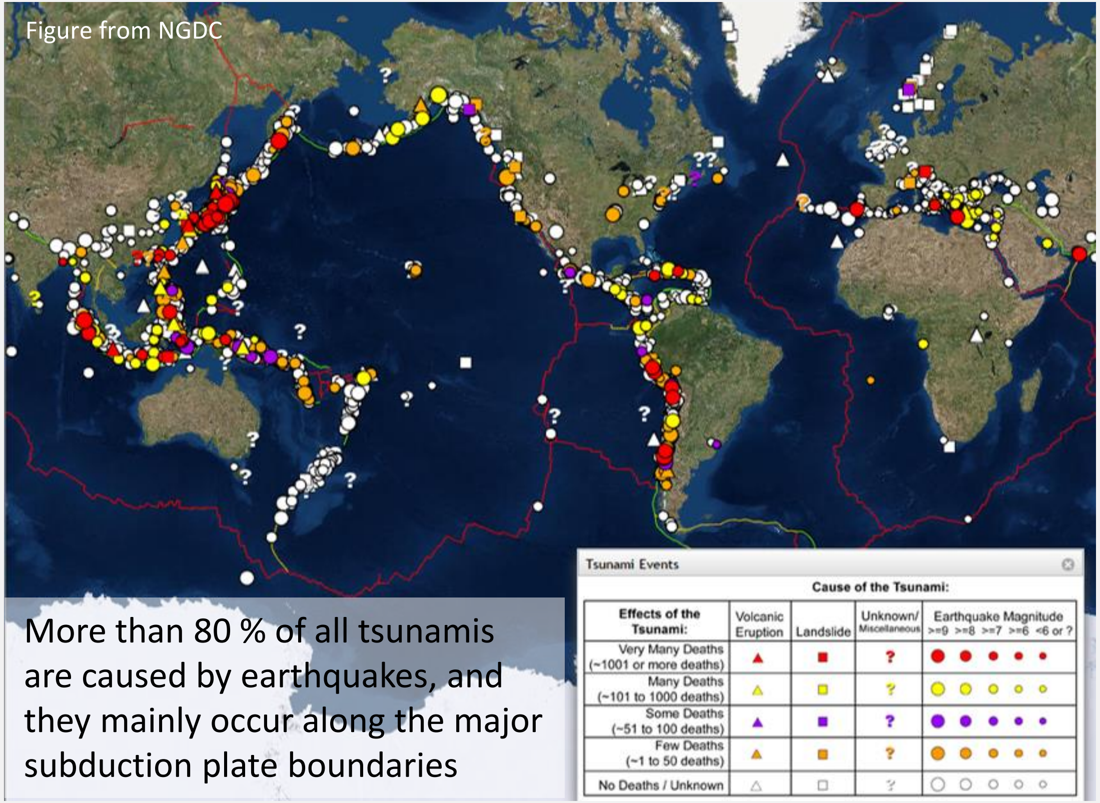
- How to best estimate the inundation from the 8100 Years BP Storegga tsunami using numerical landslide and tsunami models.
- Quantification of Uncertainty?

LAST
LIFE AFTER THE STOREGGA TSUNAMI
ARKEOLOGISK MUSEUM
University of Stavanger

The Research Council of Norway

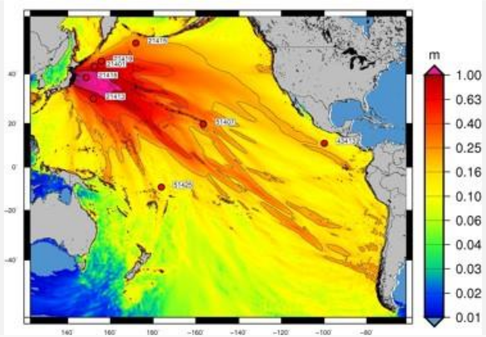
Under Pressure: **Disasters – climate change – societies (past/now)** Stavanger 2022/06/10

Tsunami sources, propagation, and inundation – from the global to the local scale

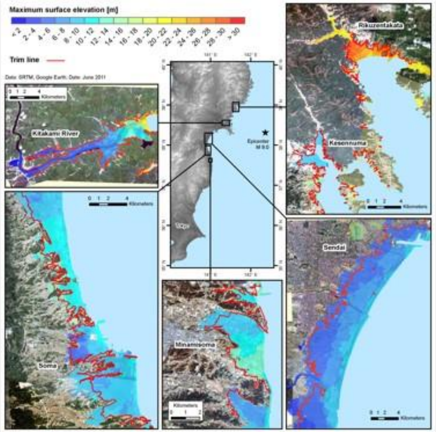


More than 80 % of all tsunamis are caused by earthquakes, and they mainly occur along the major subduction plate boundaries

They propagate efficiently over the ocean

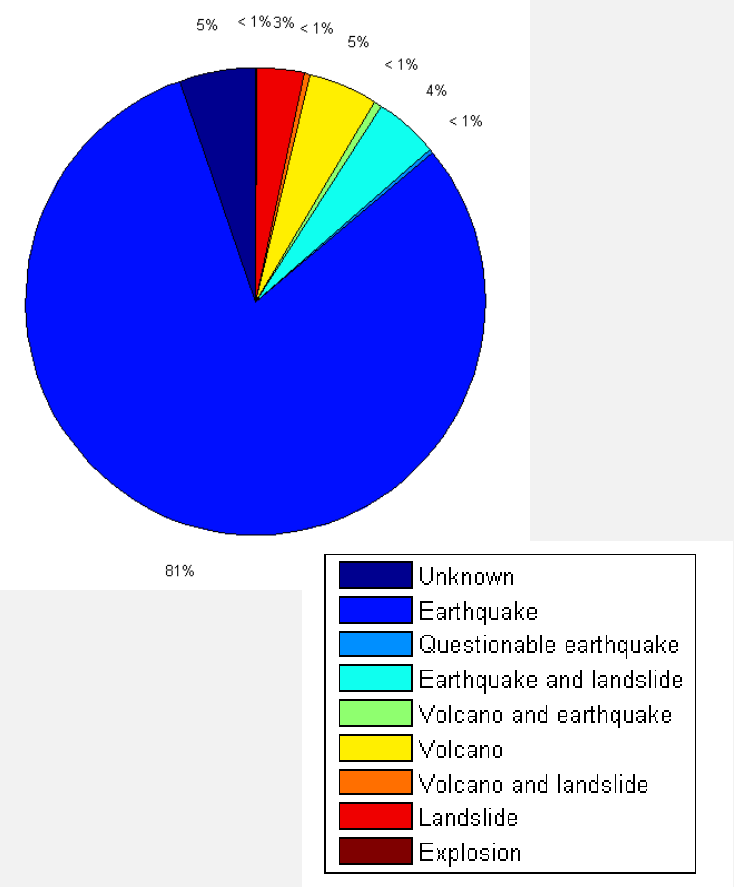


But the largest risk is associated with inundation from local sources



Landslide tsunamis make up a significant portion of the "global tsunami budget"

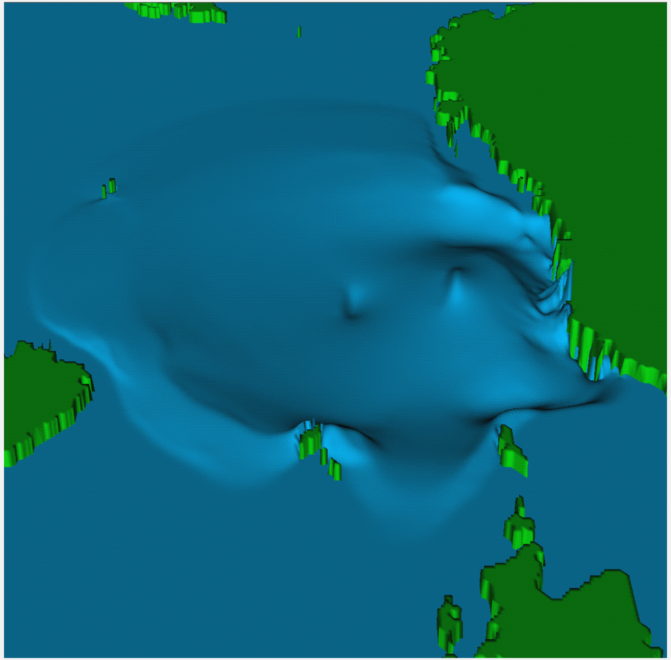
- Earthquakes comprise 80% of the reported sources, the rest by others such as landslides
- Landslides are often the dominating cause when combined with earthquake or volcano
- Likely cause for a majority of the "unknown" events
- Former events may have been underreported / ignored and historical frequencies likely too low



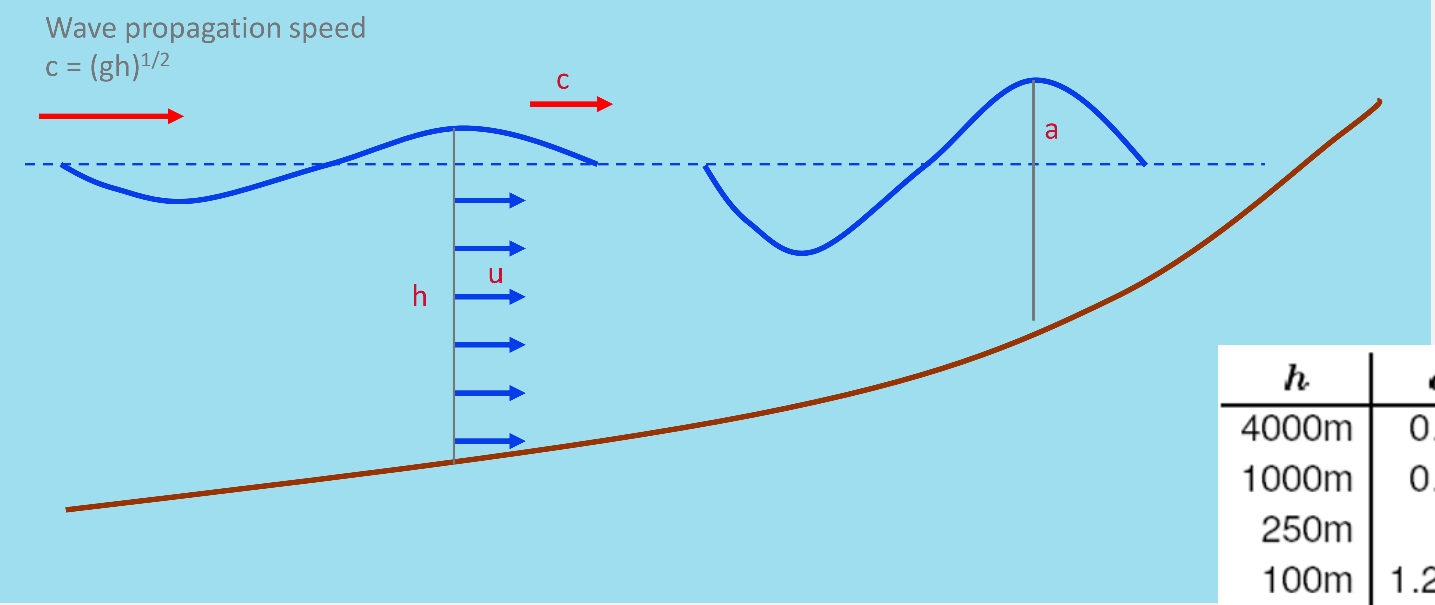
What is a tsunami?

Definition:

- Unusually large wave in a harbour (Japanese)
- Wave generated by huge and sudden displacement of water (e.g. earthquakes, slides, volcanoes, asteroids)
- Run-up heights from cms to hundreds of meters
- Wave period ~1-60 minutes



Tsunamis become shorter and higher when moving from the open sea into shallower waters



h	a	λ	c
4000m	0.5m	100km	713km/t
1000m	0.7m	50km	356km/t
250m	1m	25km	180km/t
100m	1.25m	16km	113km/t
50m	1.5m	11km	80km/t
20m	1.9m	7km	50km/t
10m	2.2m	5km	36km/t

Typical data for the 2004 Indian Ocean Tsunami →

Modelling the Storegga slide

Paleobathymetry from Hill et al. (2014) 10.1016/j.ocemod.2014.08.007
We gratefully acknowledge the use of this model.

- We perform numerical simulations of the landslide and resulting tsunami.
- We apply the paleobathymetry from Hill et al. (2014) *(Ocean Modelling v.83, pp11-25)*

ELSEVIER

Ocean Modelling
Volume 83, November 2014, Pages 11-25

How does multiscale modelling and inclusion of realistic palaeobathymetry affect numerical simulation of the Storegga Slide tsunami?

Jon Hill [a, c], Gareth S. Collins [a, 1], Alexandros Avdis [a, 1], Stephan C. Kramer [a, 1], Matthew D. Piggott [a, b, 1]

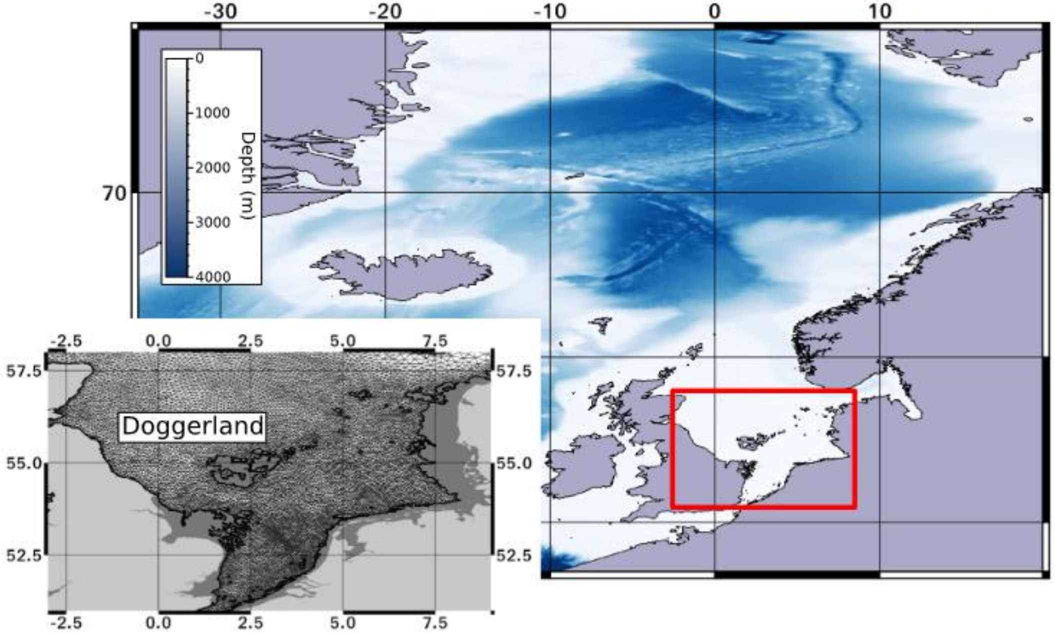


Fig. 1. Bathymetry and coastline used for the simulations using palaeobathymetry (top). A close-up of the east coast of the UK is shown (bottom), including the island known as "Doggerland", where an overlay of the production mesh used in this study is also shown. Shading shows water depth with darker shades indicating deeper water. For the insert the modern coastline is also shown (light grey) over the palaeo-coastline (dark grey).

NGI

Modelling inundation from the Storegga slide is performed in 3 different stages:

Landslide Material Control on Tsunami Genesis—The Storegga Slide and Tsunami (8,100 Years BP)

Jihwan Kim[1,2], Finn Løvholt[1], Dieter Issler[1], and Carl Fredrik Forsberg[1]

[1]Norwegian Geotechnical Institute, Oslo, Norway, [2]Department of Mathematics, University of Oslo, Oslo, Norway

JGR Oceans

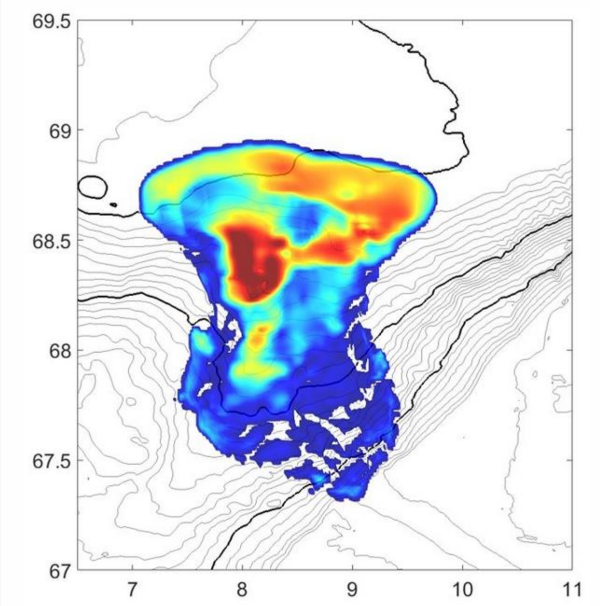
RESEARCH ARTICLE

10.1029/2018JC014893

1) Modelling the landslide

BingClaw: Simulates the dynamics of cohesive landslides

https://www.ngi.no/eng/Services/Technical-expertise/Tsunamis/Model-for-simulating-dynamics-of-cohesive-landslides



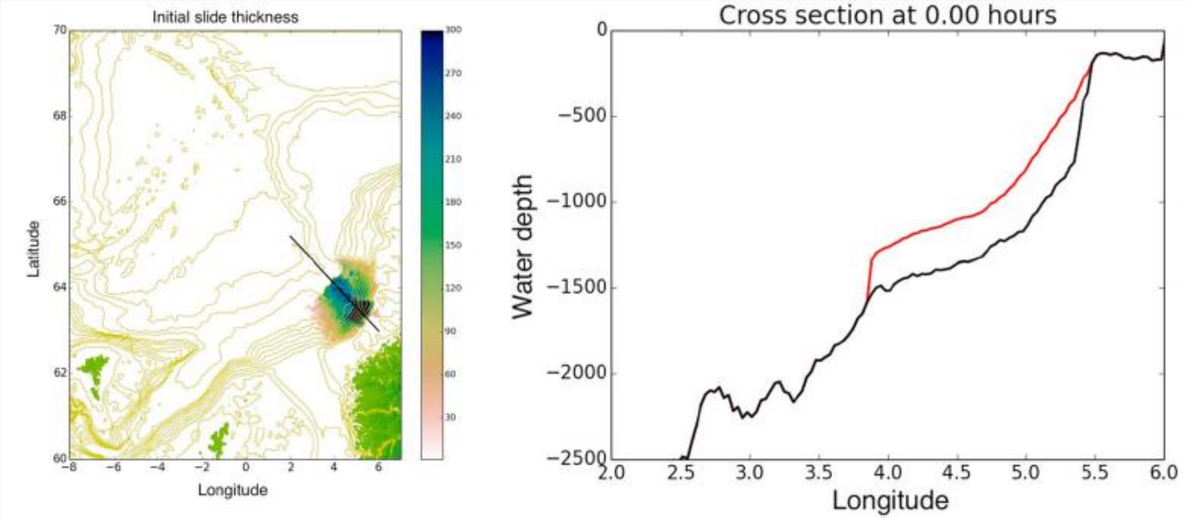


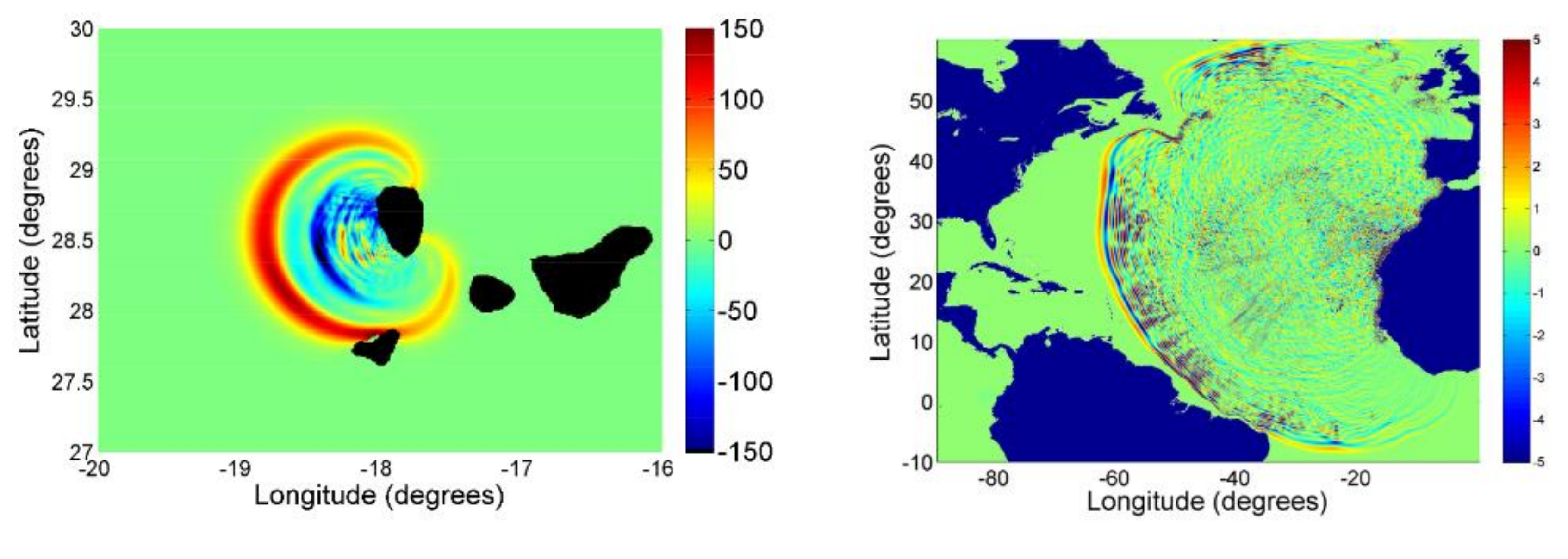
Figure 4. Assumed initial shape of the Storegga Slide simulations with BingClaw: release height distribution (left panel) and longitudinal section (right panel) along the black line in the left panel.

Modelling inundation from the Storegga slide is performed in 3 different stages:

- 2) Modelling the tsunami

  GloBouss: Simulates oceanic tsunami propagation given a dynamically changing seafloor

  https://github.com/geirkp/geirkp.github.io/tree/master/bouss

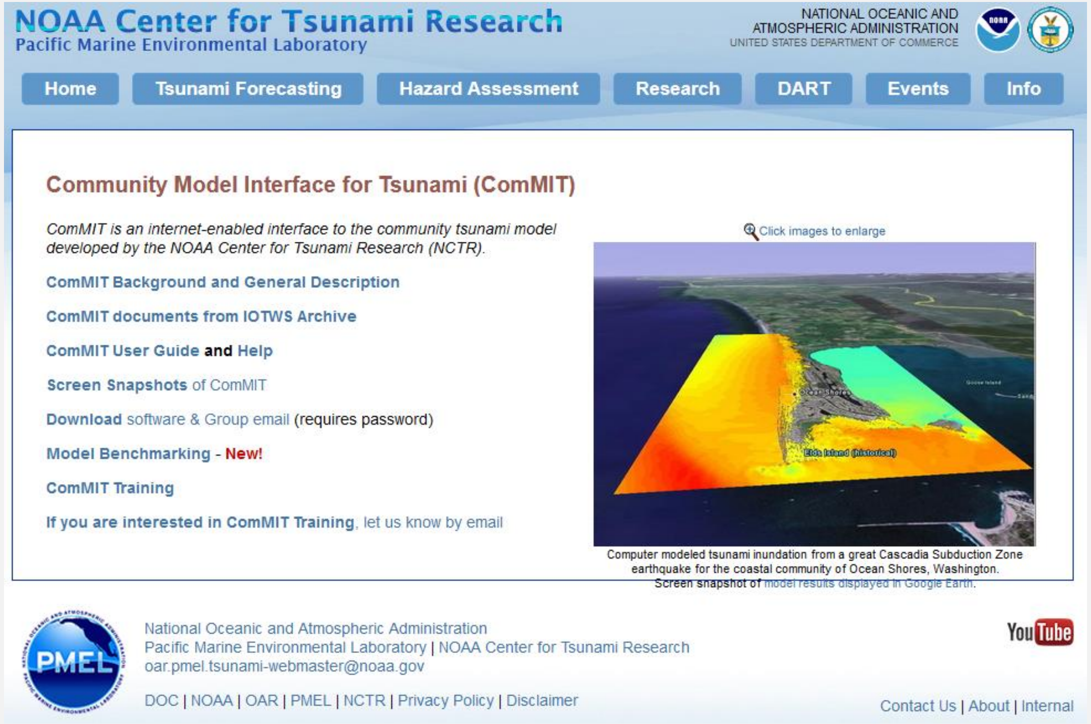


Modelling inundation from the Storegga slide is performed in 3 different stages:

- 3) Modelling the inundation

  MOST/ComMIT(NOAA): Simulates inundation at high resolution

  https://nctr.pmel.noaa.gov/ComMIT/



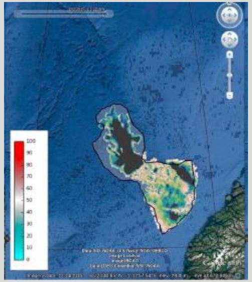
- Uses nested or «telescopic» grid to model the behaviour of the tsunami on and close to the shoreline.

Modelling inundation from the Storegga slide is performed in 3 different stages:

Stage 1: Landslide

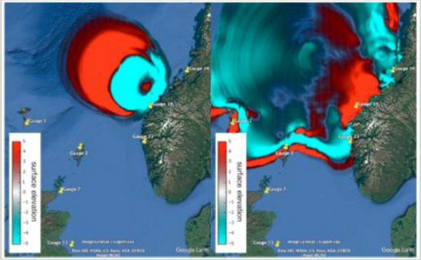
Large number of parameters controlling run-out

- Densities
- Hydrodynamic drag
- Yield strength
- Remolding



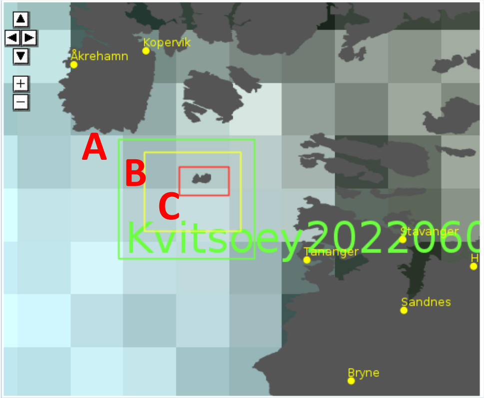
Output:
Sea floor heights as a function of time

Stage 2: Tsunami («global»)

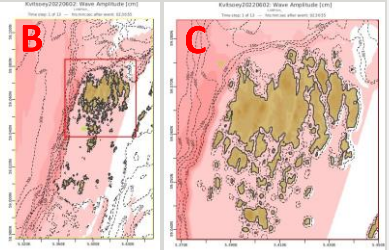


Output:
Sea surface heights and wave velocities as a function of time

Select coastline of interest:



Stage 3: Tsunami («local»)



Modelling inundation from the Storegga slide is performed in 3 different stages:

- 1) Modelling the landslide

  BingClaw: Simulates the dynamics of cohesive landslides

- There are many variables controlling the volume, duration, runout, and dynamics of the slide.
- We need to perform a sensitivity study on the controlling parameters and find what best agrees with observations.

We need validation!

- Validation by comparison with bathymetric runout observations
- Validation (when combined with tsunami simulation) of run-up heights.

Modelling inundation from the Storegga slide is performed in 3 different stages:

- 1) Modelling the landslide: validation by runout

  BingClaw: Simulates the dynamics of cohesive landslides

(from Kim et al: https://doi.org/10.1029/2018JC014893

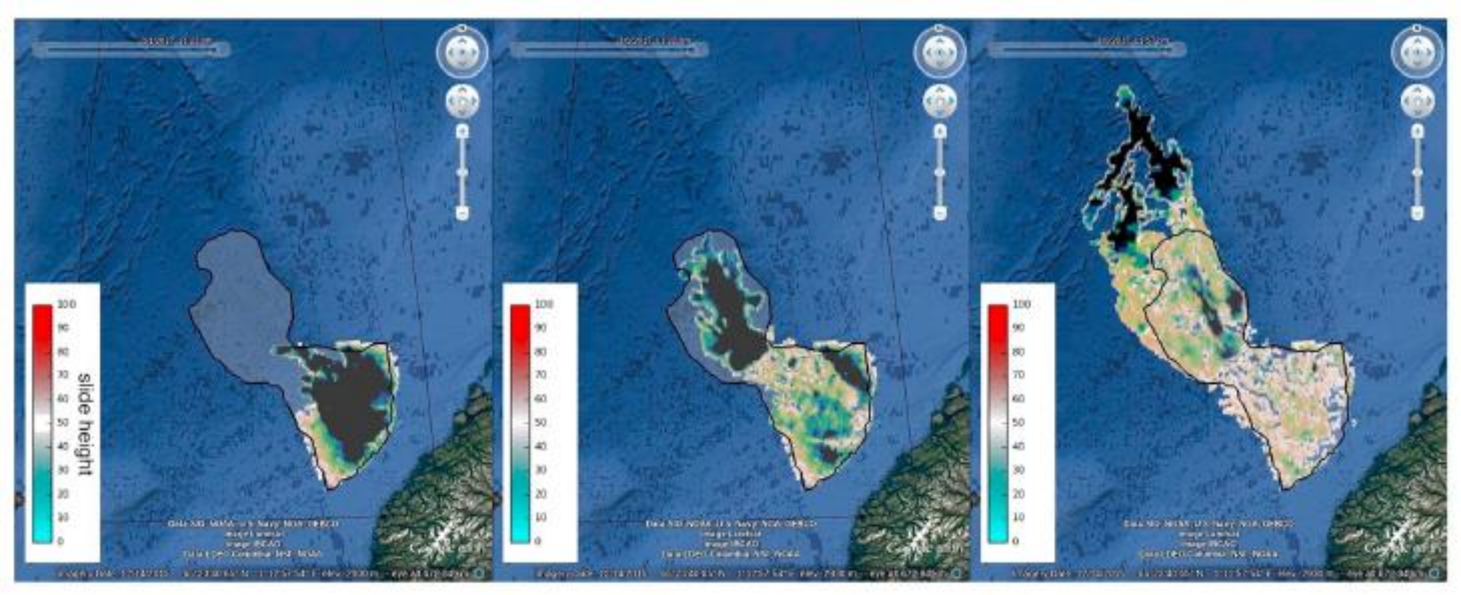


Figure 6. Final runout of the Storegga slide for three cases, simulated with BingClaw: $(\tau_{y,0}, \tau_{y,\infty}, \Gamma)$ = (15 kPa, 3.5 kPa, 5 × 10^{-5}), (12 kPa, 3 kPa, 5 × 10^{-4}), and (7 kPa, 1 kPa, 5 × 10^{-2}) (from left to right). The deposit inferred from the bathymetric analysis is indicated by the black line.

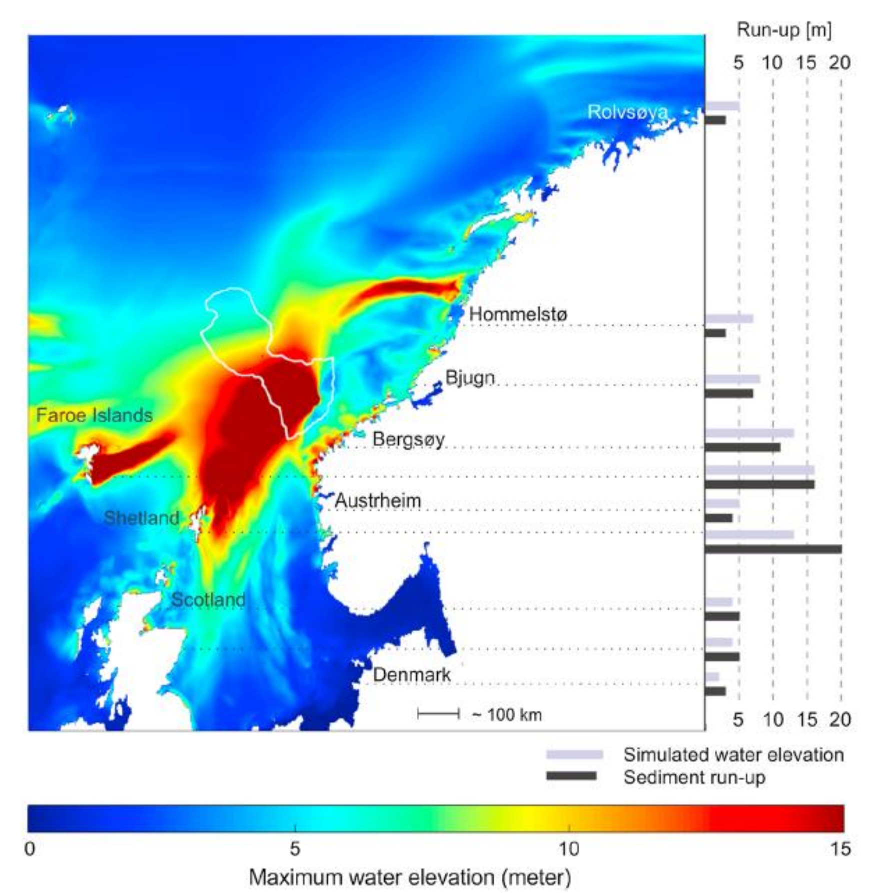
Modelling inundation from the Storegga slide is performed in 3 different stages:

- 1) Modelling the landslide:
  validation by tsunami run-up comparison

  - There are run-up observations and numerous coastal locations along the affected coastlines.
  - A coupled landslide-tsunami model provides time-series of wave-heights for specified locations and we can evaluate which models best fit the observations.

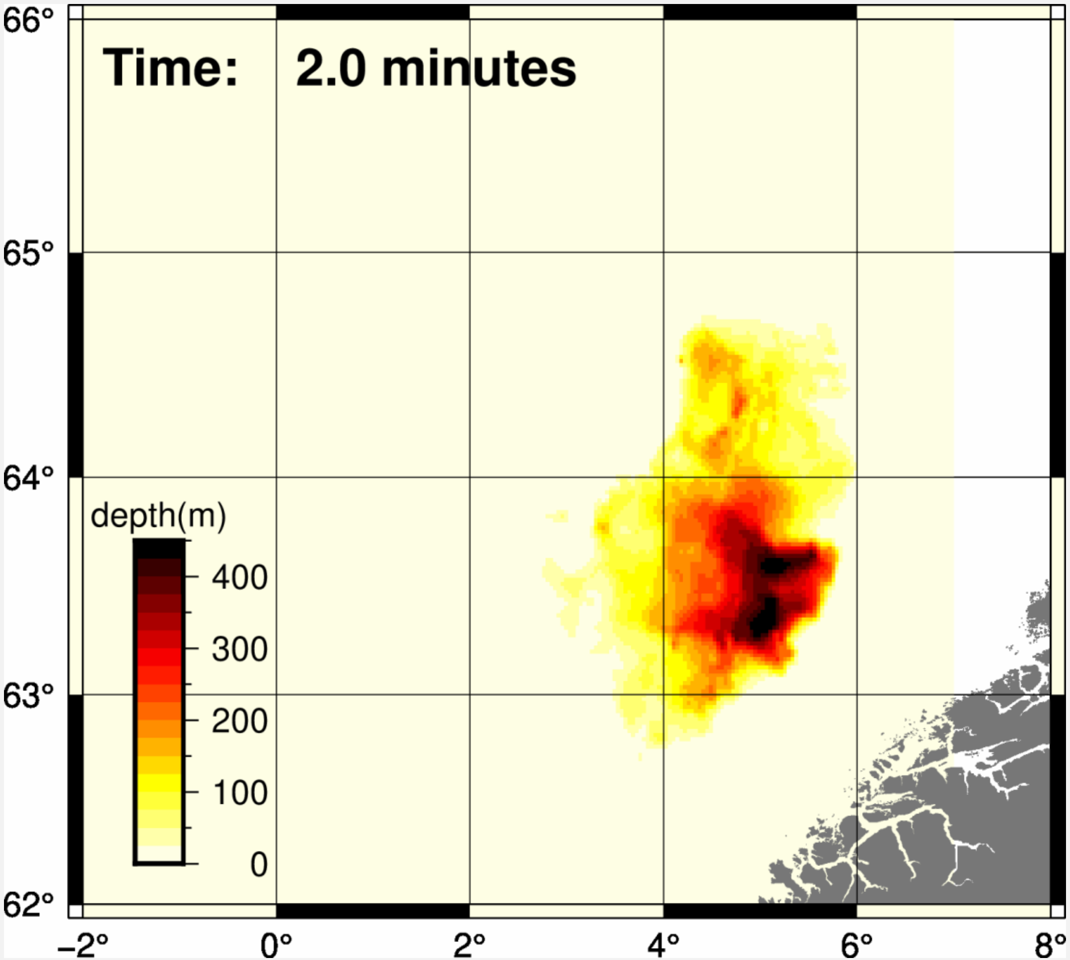
(from Løvholt et al: https://doi.org/10.1002/2017GL074062)

Figure 3. Maximum water elevation for the Storegga Slide tsunami, simulated using the debris flow landslide source. Blue-purple bars show the simulated elevations close to the field sites, black bars show the mean observation heights of sediment run-up [*Smith et al.*, 2004; *Bondevik et al.*, 2005; *Romundset and Bondevik*, 2011; *Fruergaard et al.*, 2015].



Modelling inundation from the Storegga slide is performed in 3 different stages:

- 1) Modelling the landslide:
  - Visco-plastic landslide model.
  - Writes out height of deposit at regular intervals.
  - This changing sea-floor forces the wave-motion in the tsunami simulation.



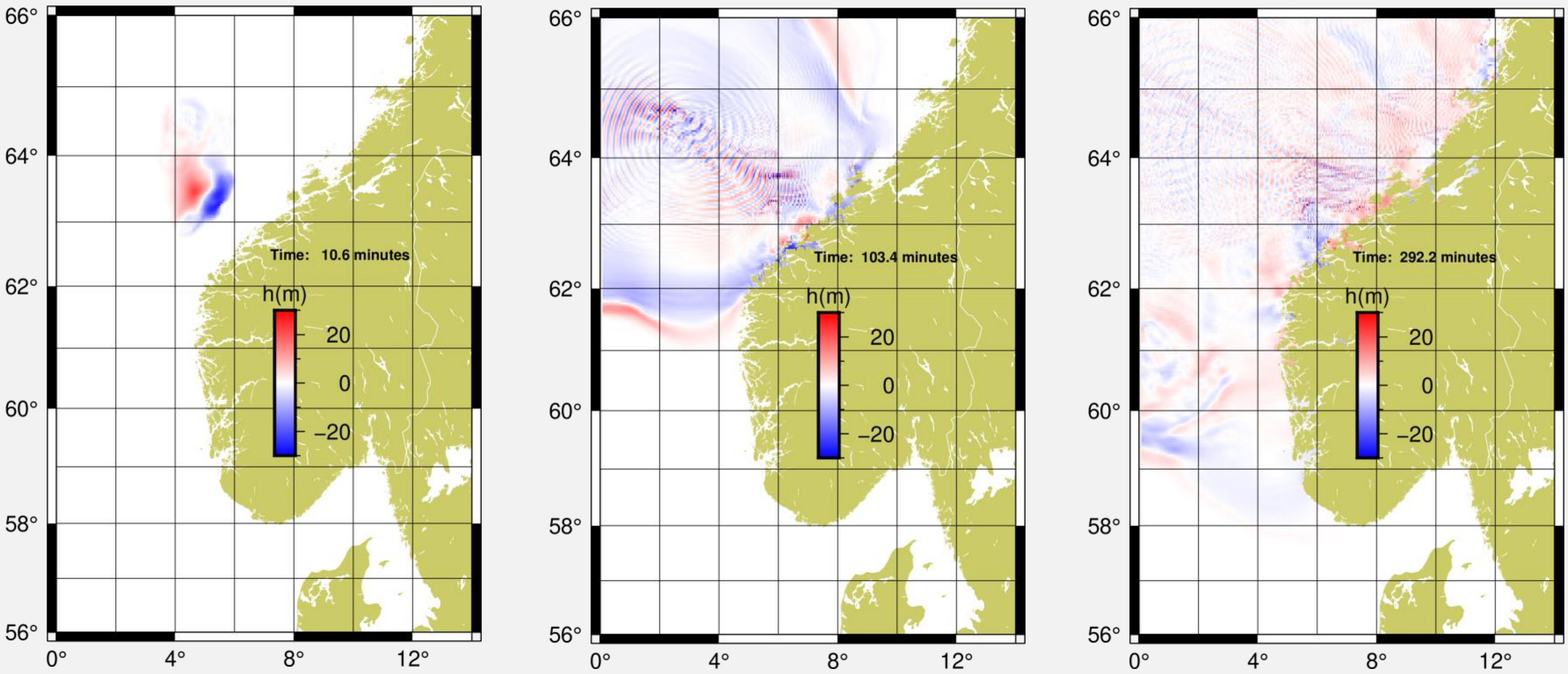
NGI

Under Pressure:

Modelling inundation from the Storegga slide is performed in 3 different stages:

- 2) Modelling the tsunami

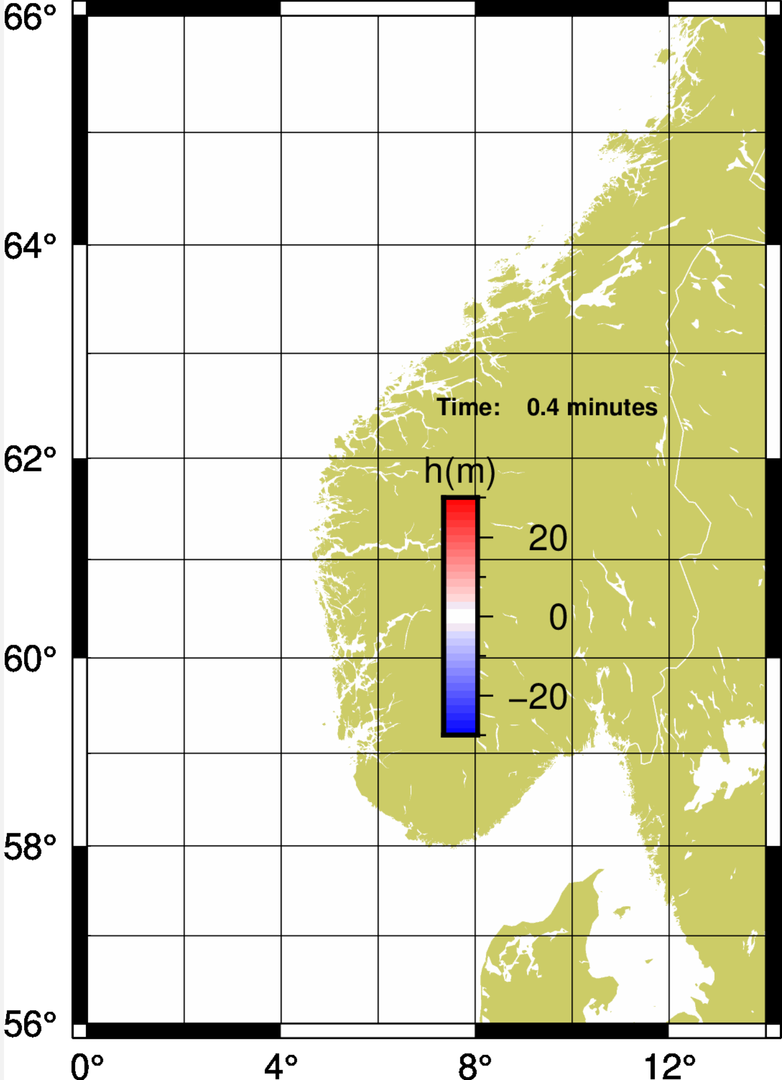
  GloBouss: Simulates oceanic tsunami propagation given a dynamically changing seafloor



2) Modelling the tsunami

GloBouss: Simulates oceanic tsunami propagation given a dynamically changing seafloor

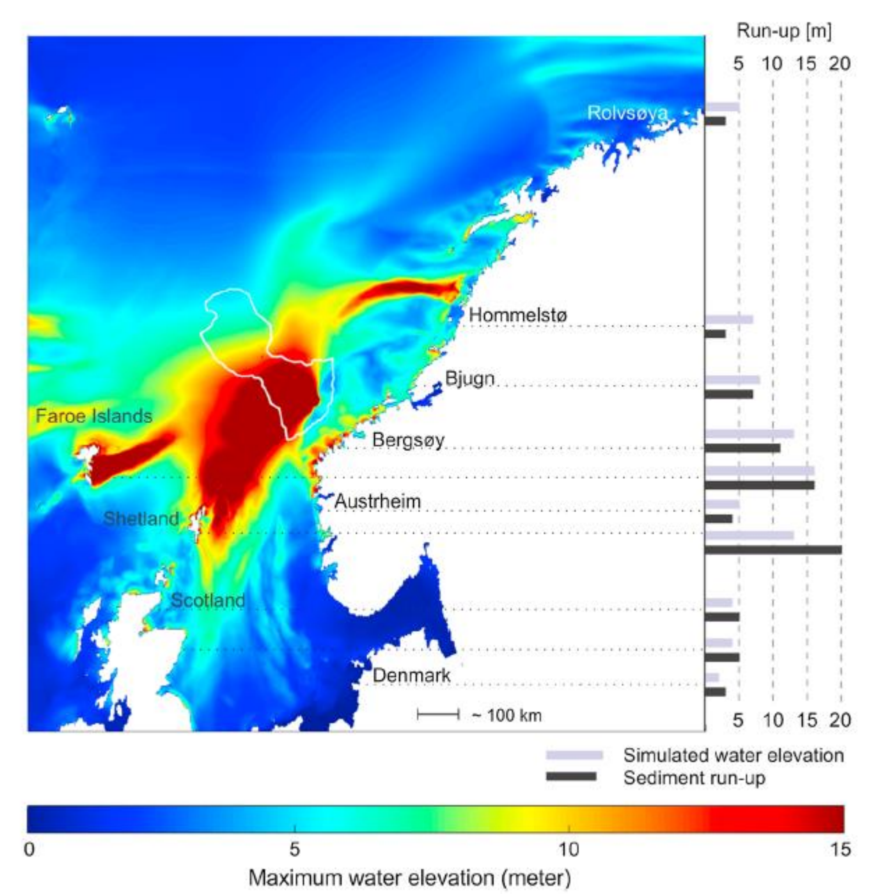
- Approximately 3 hours from the slide initiation are displayed in this animation.
- Notice that the first motion is dominated by very long waves.
- The speed and height of the wavefront varies significantly with direction.



2) Modelling the tsunami

GloBouss: Simulates oceanic tsunami propagation given a dynamically changing seafloor

- We can also calculate the maximum water elevation for all locations and the maximum flow velocities.
- The velocities – and/or the momentum flux – can often be a more pertinent metric of the tsunami impact than the height alone.



Modelling inundation from the Storegga slide is performed in 3 different stages:

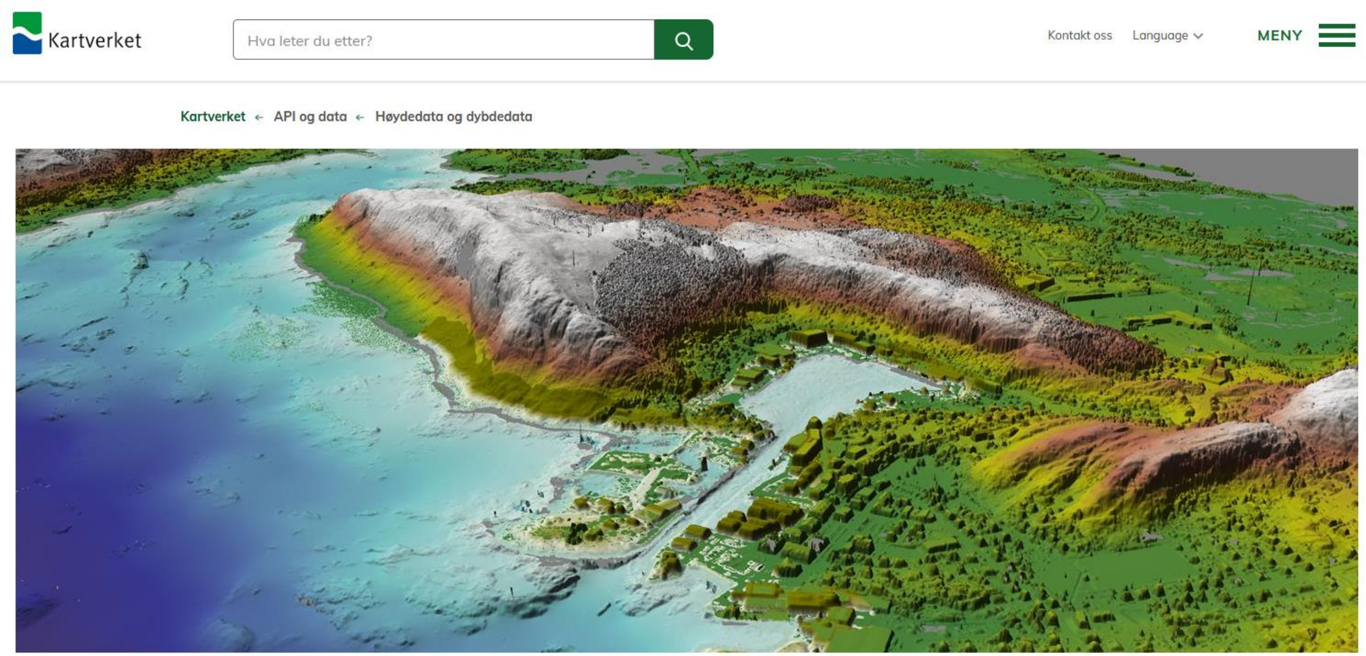
- 3) Modelling the inundation

  MOST/ComMIT(NOAA): Simulates inundation at high resolution

  https://nctr.pmel.noaa.gov/ComMIT/

  https://kartverket.no/api-og-data/terrengdata

  - Need high resolution bathymetry/topography!



TERRENGDATA. Høgdedata og djupnedata kan brukast til å lage terrengmodellar. Illustrasjon: Kartverket

Modelling inundation from the Storegga slide is performed in 3 different stages:

- 3) Modelling the inundation

  MOST/ComMIT(NOAA):

  https://nctr.pmel.noaa.gov/ComMIT/

  - Need high resolution bathymetry/topography!
  - And it needs to be corrected for changes over the last 8000 years(!)

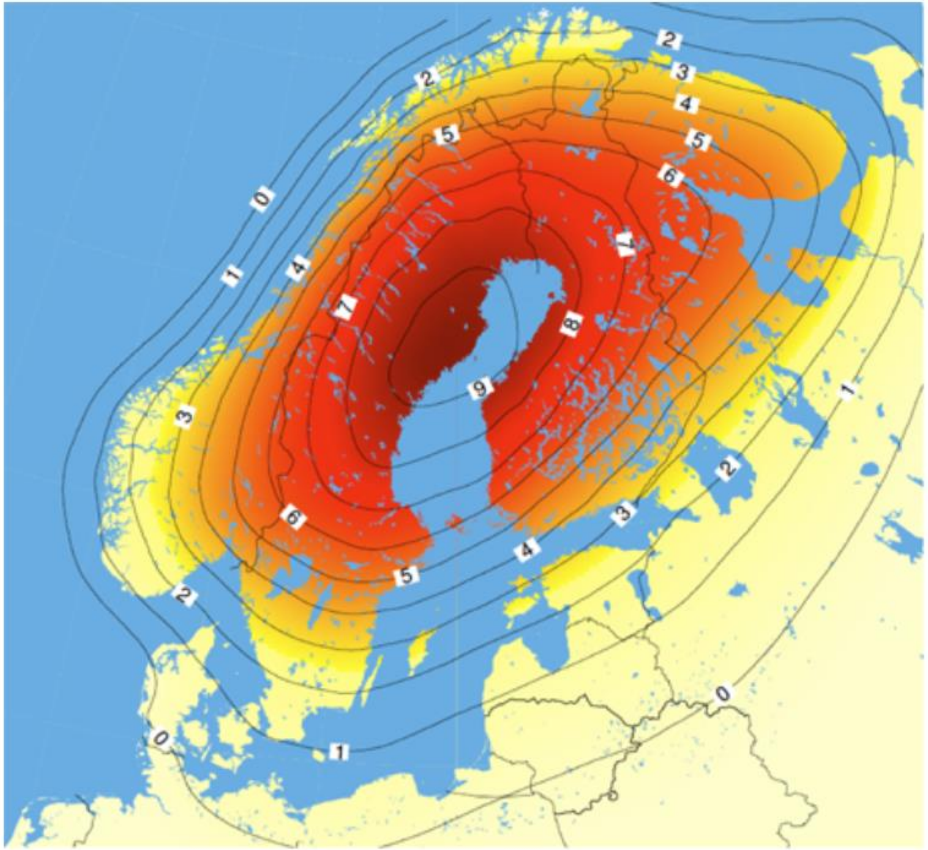
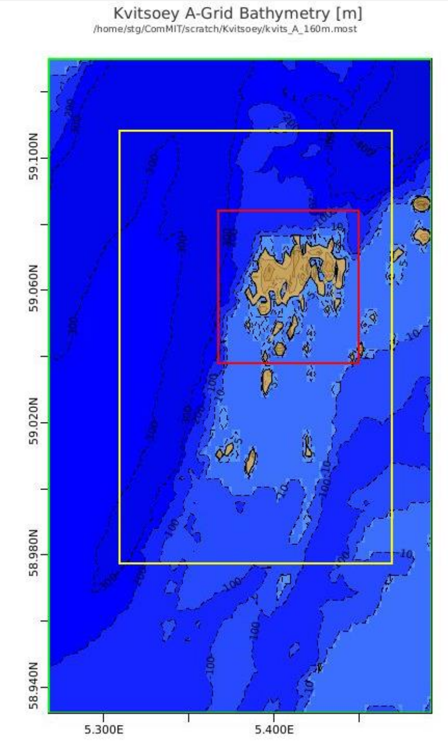


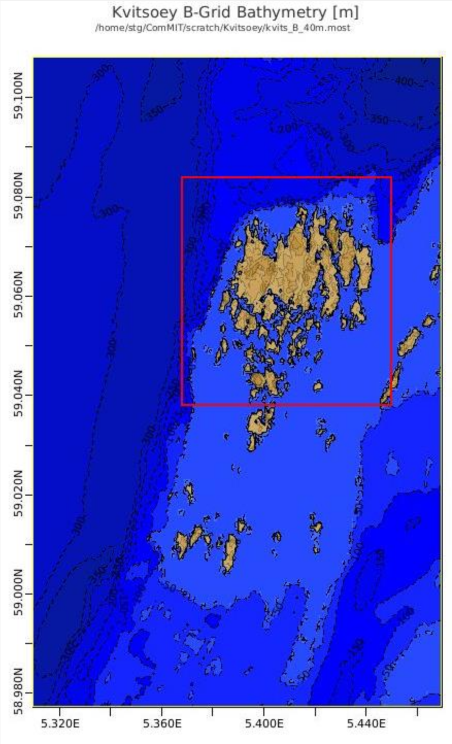
Figure 1. Fennoscandian land uplift (mm/yr) relative to the centre of the Earth.

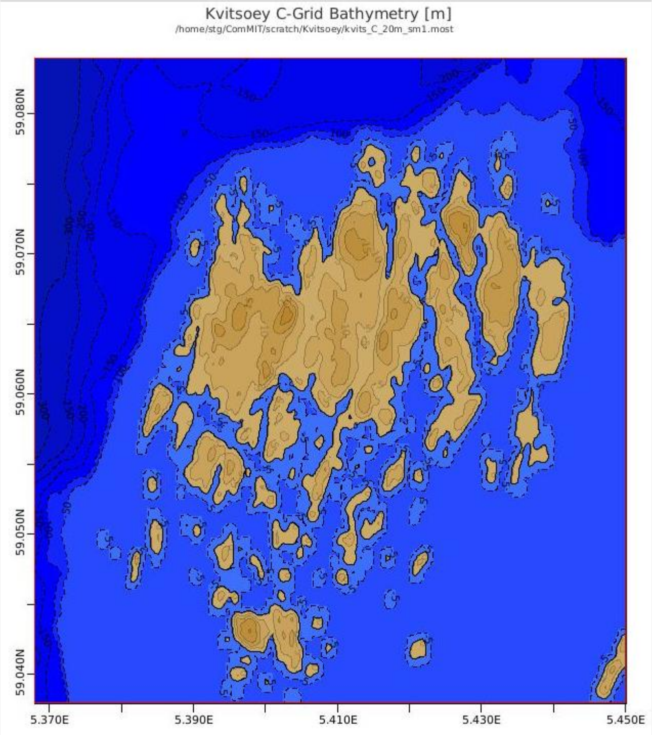
Figure: https://www.maanmittauslaitos.fi/en/research/interesting-topics/land-uplift

Modelling inundation from the Storegga slide is performed in 3 different stages:

- 3) Modelling the inundation
  - MOST/ComMIT(NOAA): Simulates inundation at high resolution





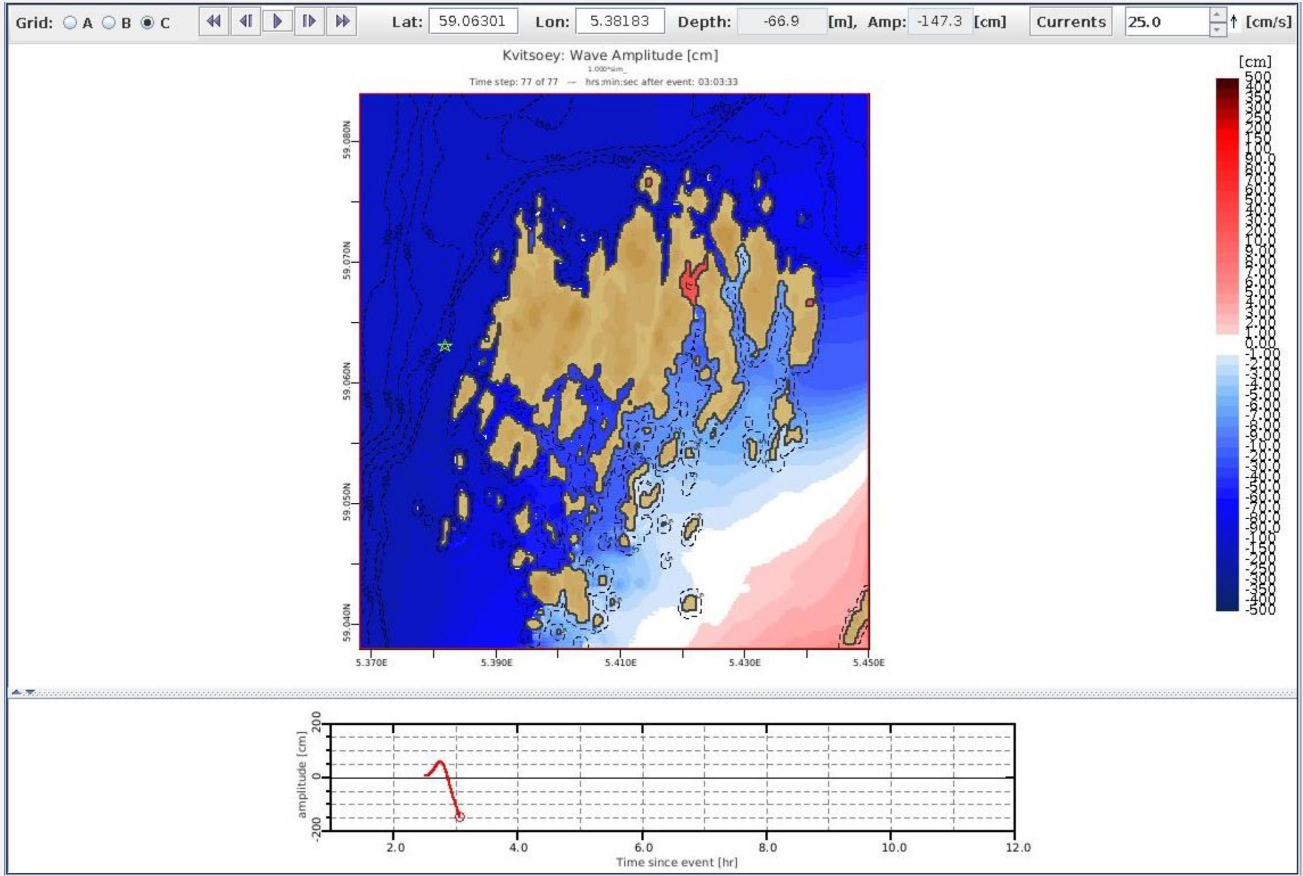


Modelling inundation from the Storegga slide is performed in 3 different stages:

- 3) Modelling the inundation

  MOST/ComMIT(NOAA): Simulates inundation at high resolution

  https://nctr.pmel.noaa.gov/ComMIT/

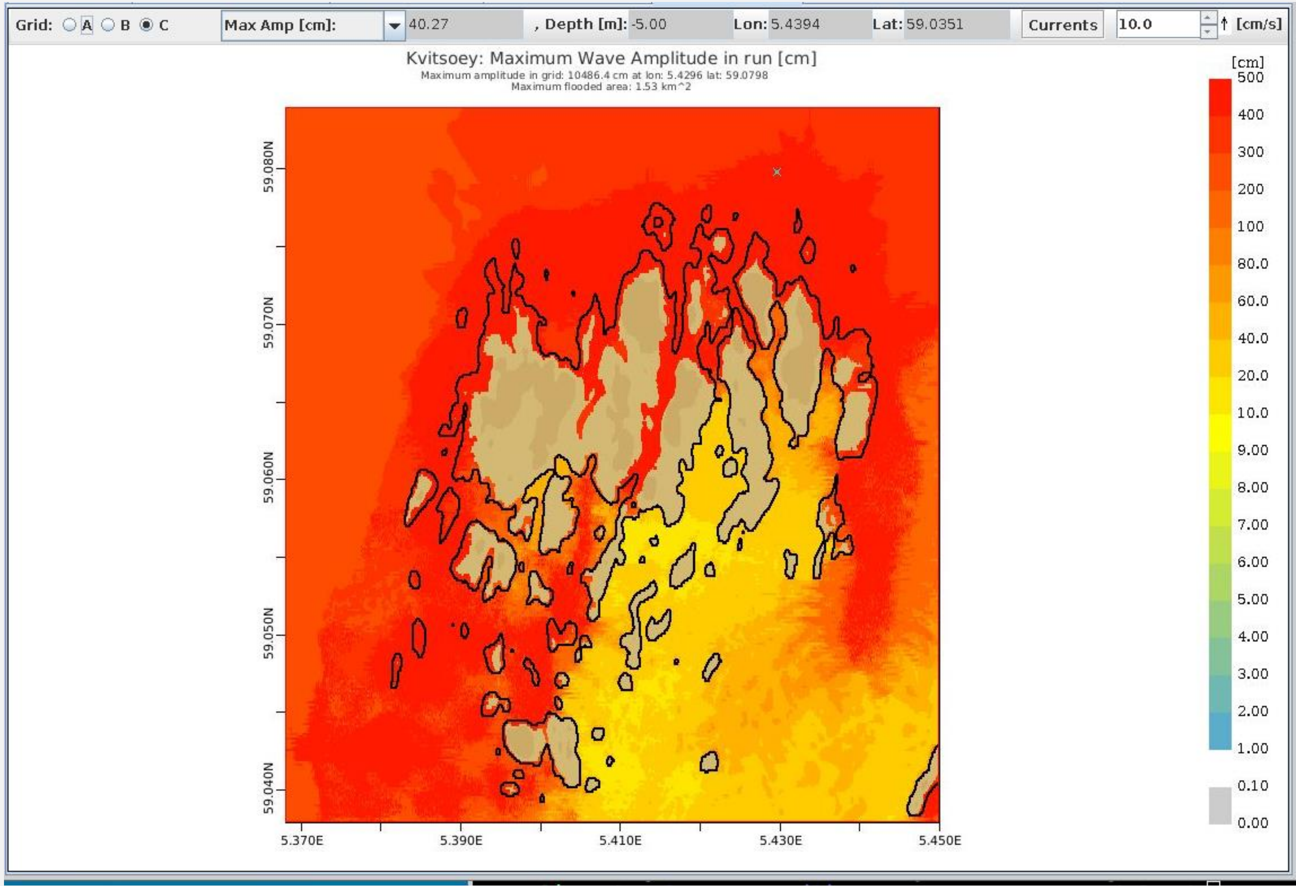


NGI

Under Pressure:

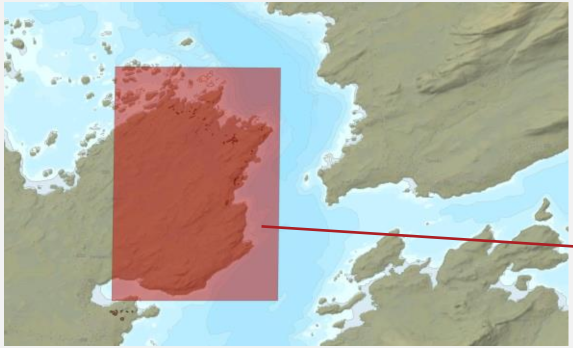
Modelling inundation from the Storegga slide is performed in 3 different stages:

- 3) Modelling the inundation
  - MOST/ComMIT(NOAA): Simulates inundation at high resolution
  - https://nctr.pmel.noaa.gov/ComMIT/

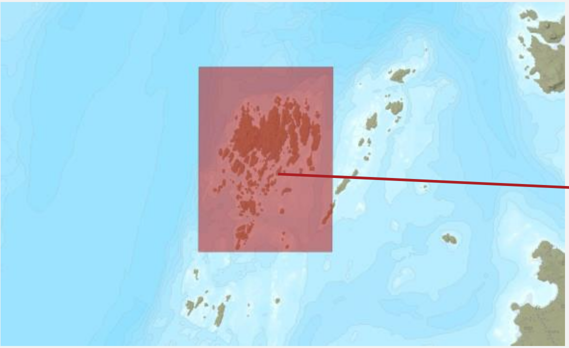


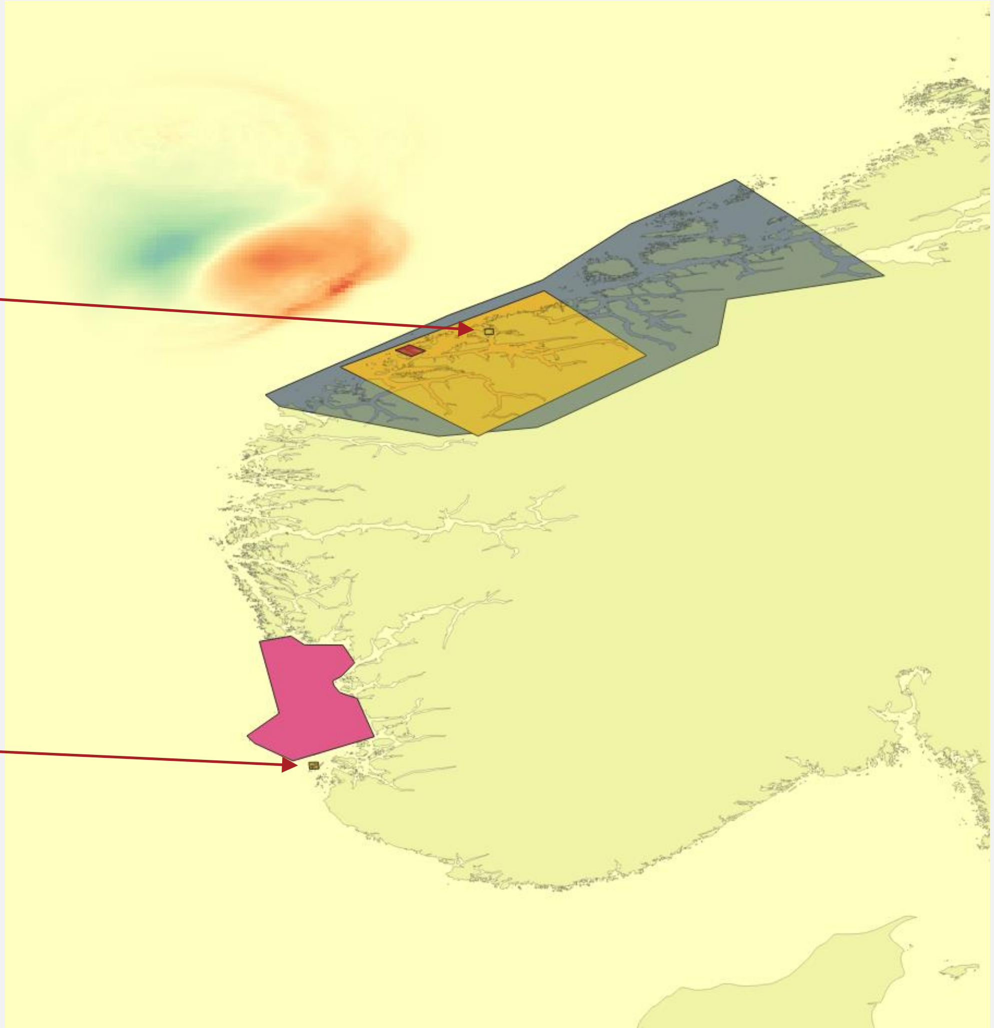
Under Pressure:

Regions of interest:



- Aukra (62.8N, 6.90E)
- Kvitsøy (59.1N, 5.37E)

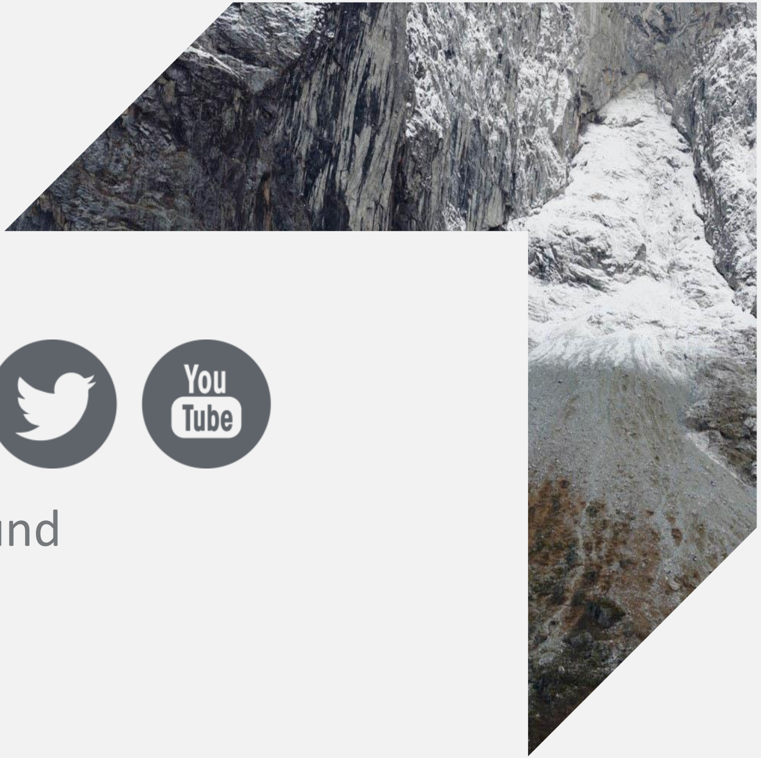




Storegga Tsunami Simulations

- Three Stage (linked) Process for estimating runup:
  - Cohesive landslide simulation (BingClaw)
  - Wide-scale tsunami simulation (GloBouss)
  - High-resolution inundation simulations over detailed coastal model (ComMIT/MOST)
- Current status:
  - Large number of landslide simulations performed coupled to tsunami simulations using "paleo-bathymetry" of the Norwegian and North Seas
  - Significant ranges of parameters applied
  - High resolution inundation simulation performed for Kvitsøy
  - Workflow operational to apply to other regions.

NGI



#onsafeground

Thank you!

NORWEGIAN GEOTECHNICAL INSTITUTE
NGI.NO