Corso di Laurea in Fisica - UNITS

ISTITUZIONI DI FISICA PER IL SISTEMA TERRA

TSUNAMI

FABIO ROMANELLI

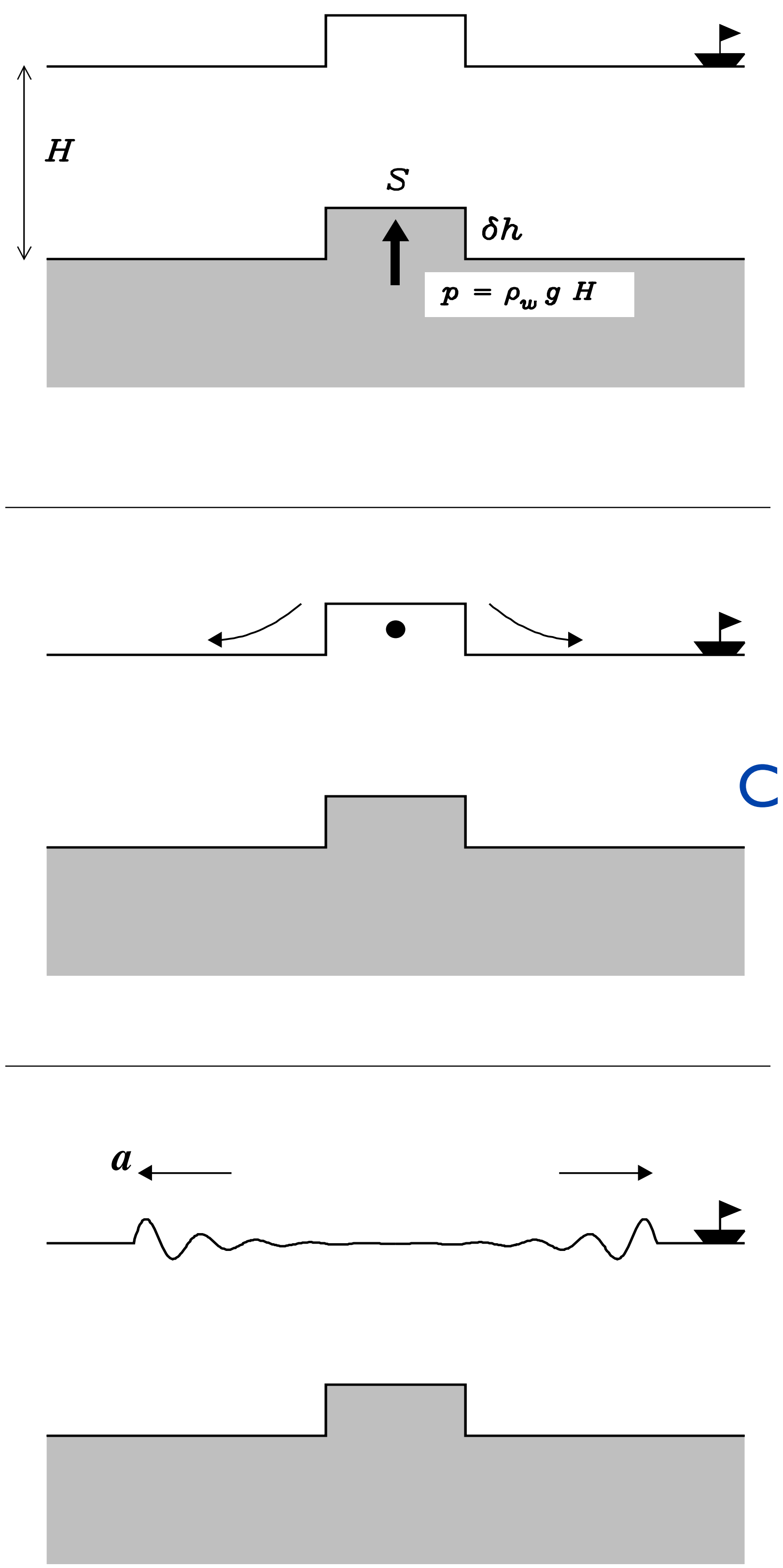
Department of Mathematics & Geosciences

University of Trieste

romanel@units.it

http://moodle2.units.it/course/view.php?id=9059

Very basic tsunami physics...



Bottom uplift
&
Waterberg
formation

Center of mass falls...

Potential
energy goes to
tsunami energy

Energy

$$\log E_R \approx 5.0 + 1.5M$$

$$E_T = \frac{1}{2}\rho g L \lambda (\delta h)^2$$

$$L \sim 10^6 m; \; \lambda \sim 10^4 m; \; \delta h \sim 5m$$

$$E_R \approx 10^{18} j \geq 10^2 E_T$$

Wavelength

$$\frac{\lambda}{H} \sim 40 \; ; \; \frac{H}{a} \sim 3 \cdot 10^3$$

$$\lambda >> H >> a$$

Tsunami is a shallow-water gravity wave with great wavelength and tiny amplitude

Gravity waves: dispersion

From the expression $$F(z) = 2Ae^{-kh}\cosh\left[k(z+h)\right]$$

the boundary at the top gives the dispersion relation for incompressible, irrotational, small amplitude "gravity" waves:

$$\omega^2 = kg\left[\tanh(kh)\right]$$

Deep water
(kh goes to infinity)

$$\omega^2 = kg$$

$$c = \sqrt{\frac{g}{k}} = \sqrt{\frac{g\lambda}{2\pi}}$$

$$u = \frac{\partial\omega}{\partial k} = \frac{1}{2}\sqrt{\frac{g}{k}} = \frac{1}{2}\sqrt{\frac{g\lambda}{2\pi}} = \frac{1}{2}c$$

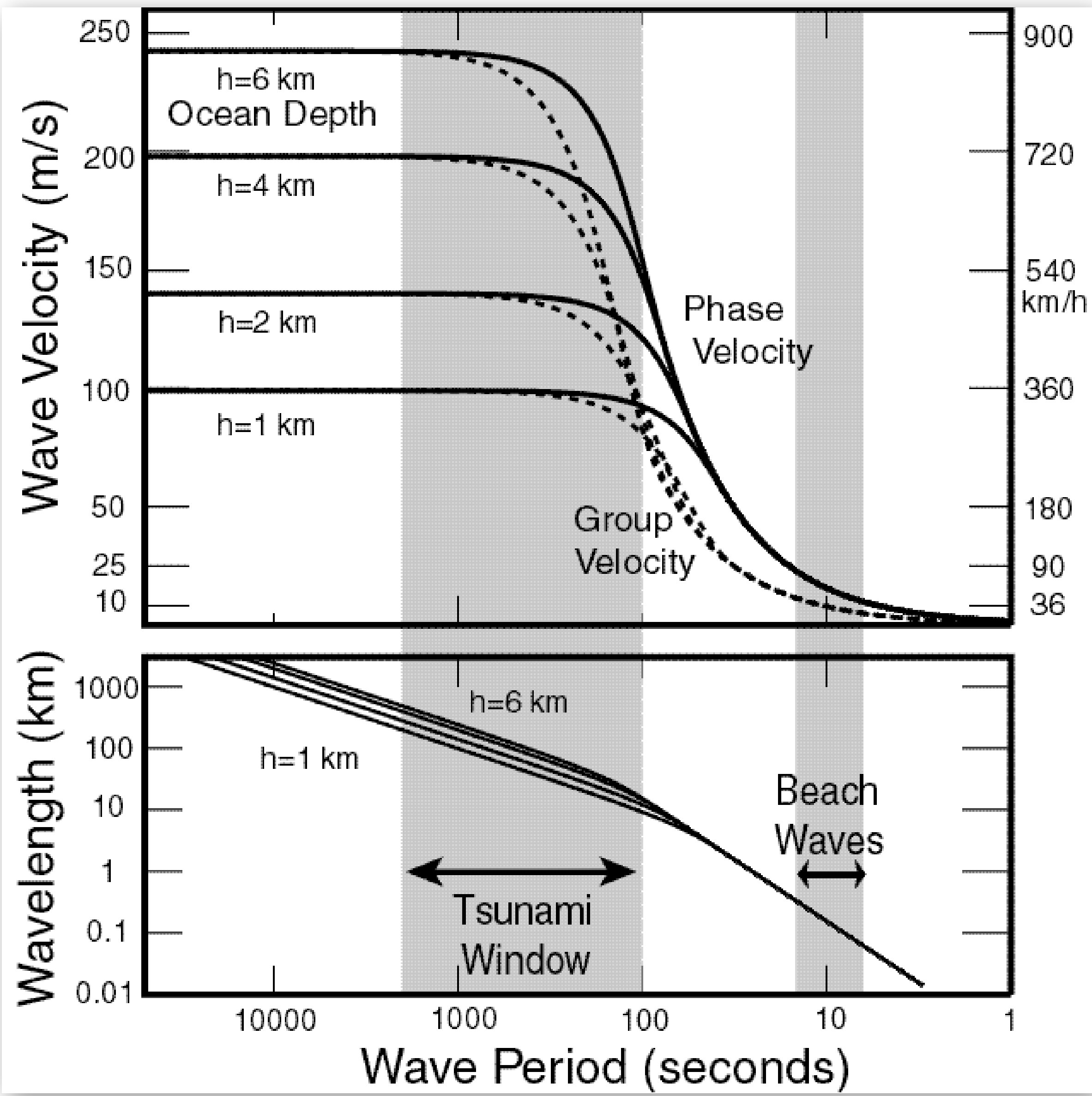
Shallow water
(kh goes to zero)

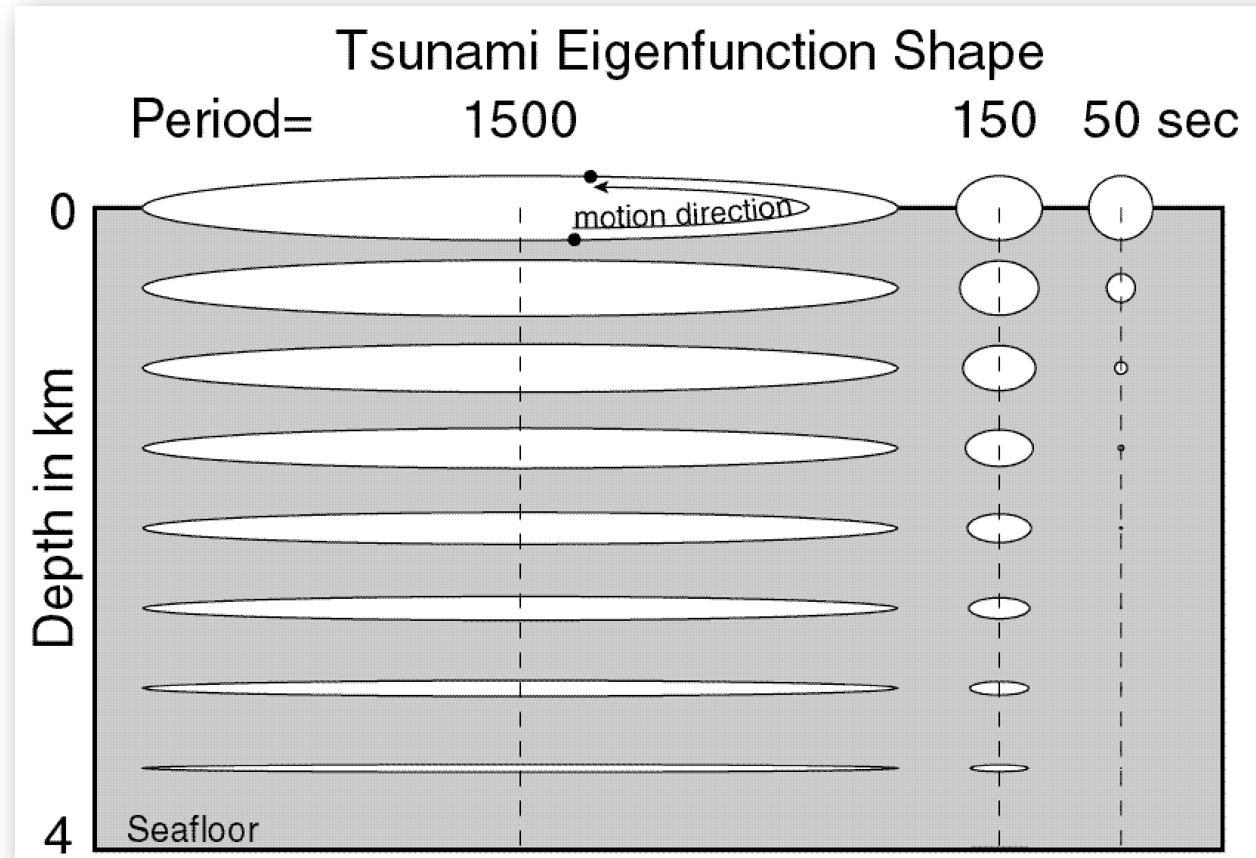
$$\omega^2 = k^2 gh$$

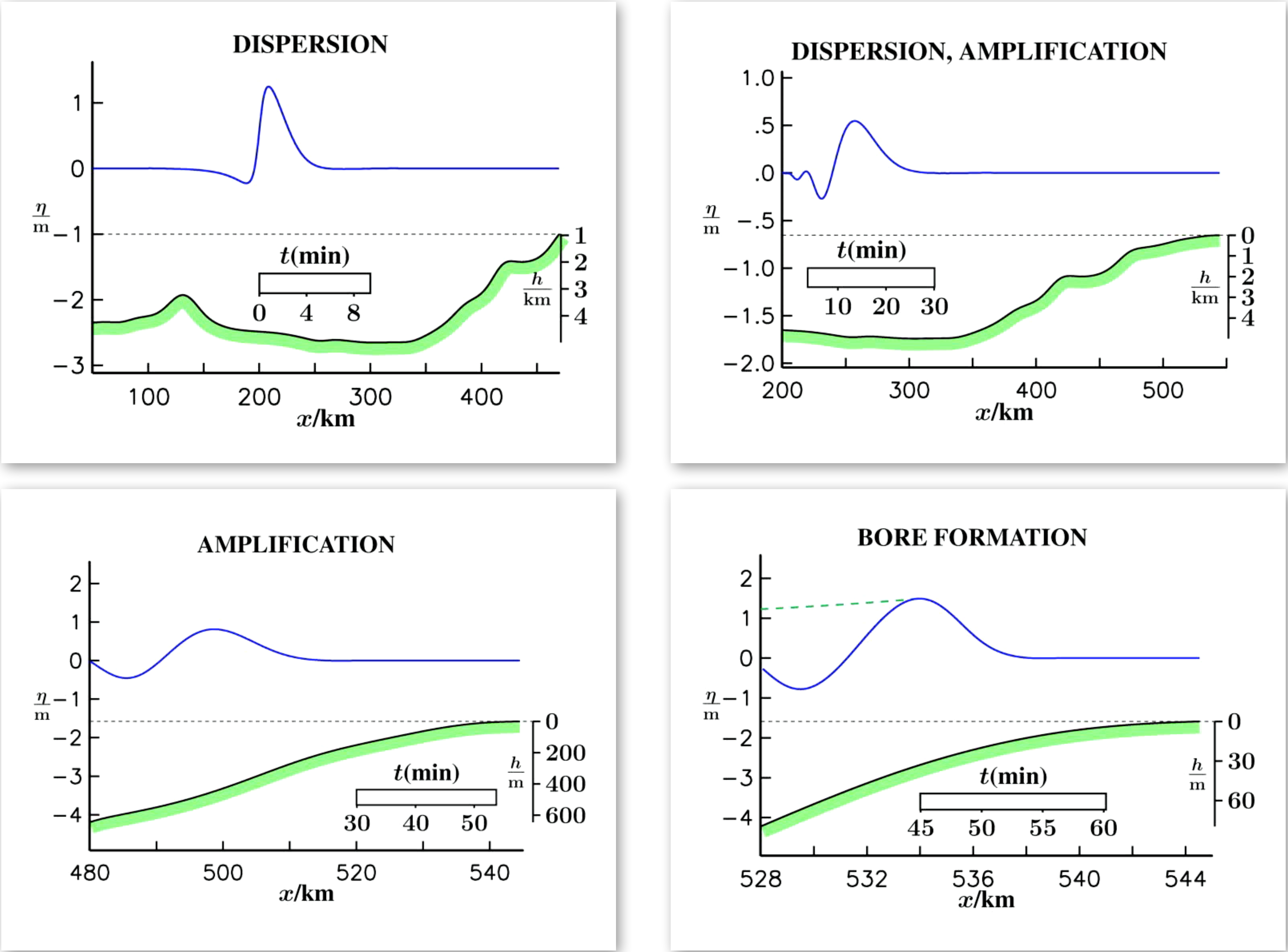
$$c = \sqrt{gh}$$

$$u = \frac{\partial\omega}{\partial k} = c = \sqrt{gh}$$

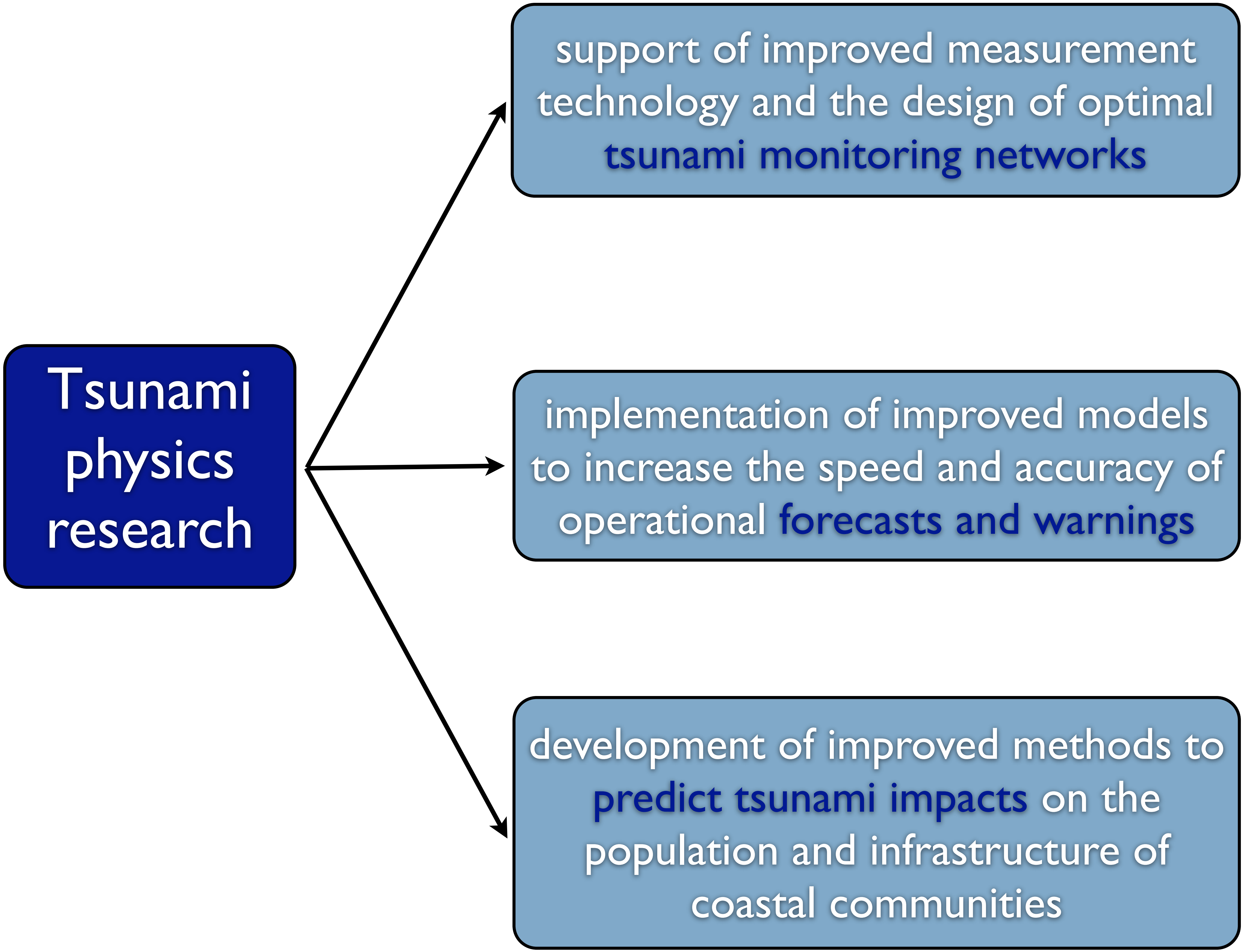
Tsunami eigenvalues & eigenfunctions

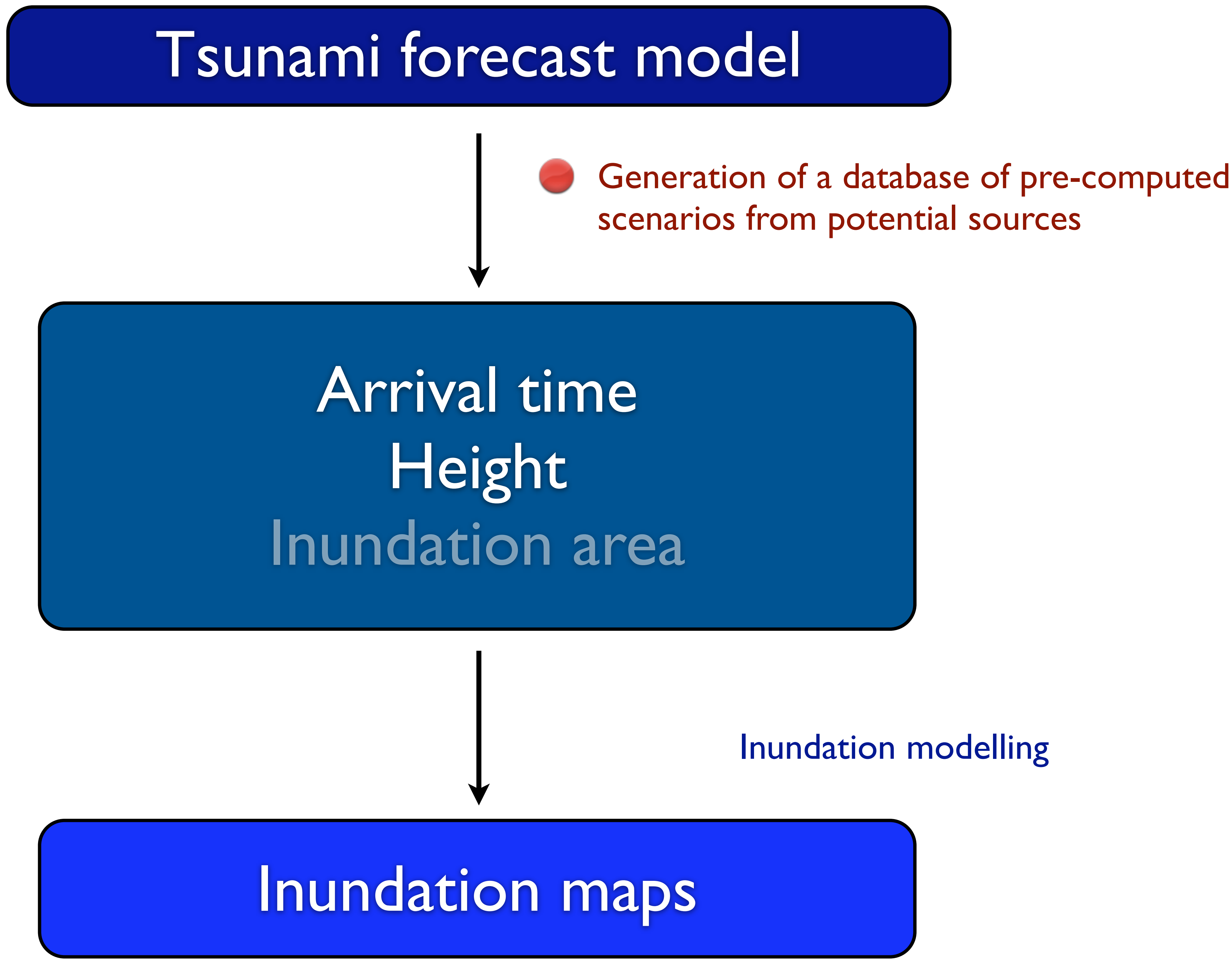






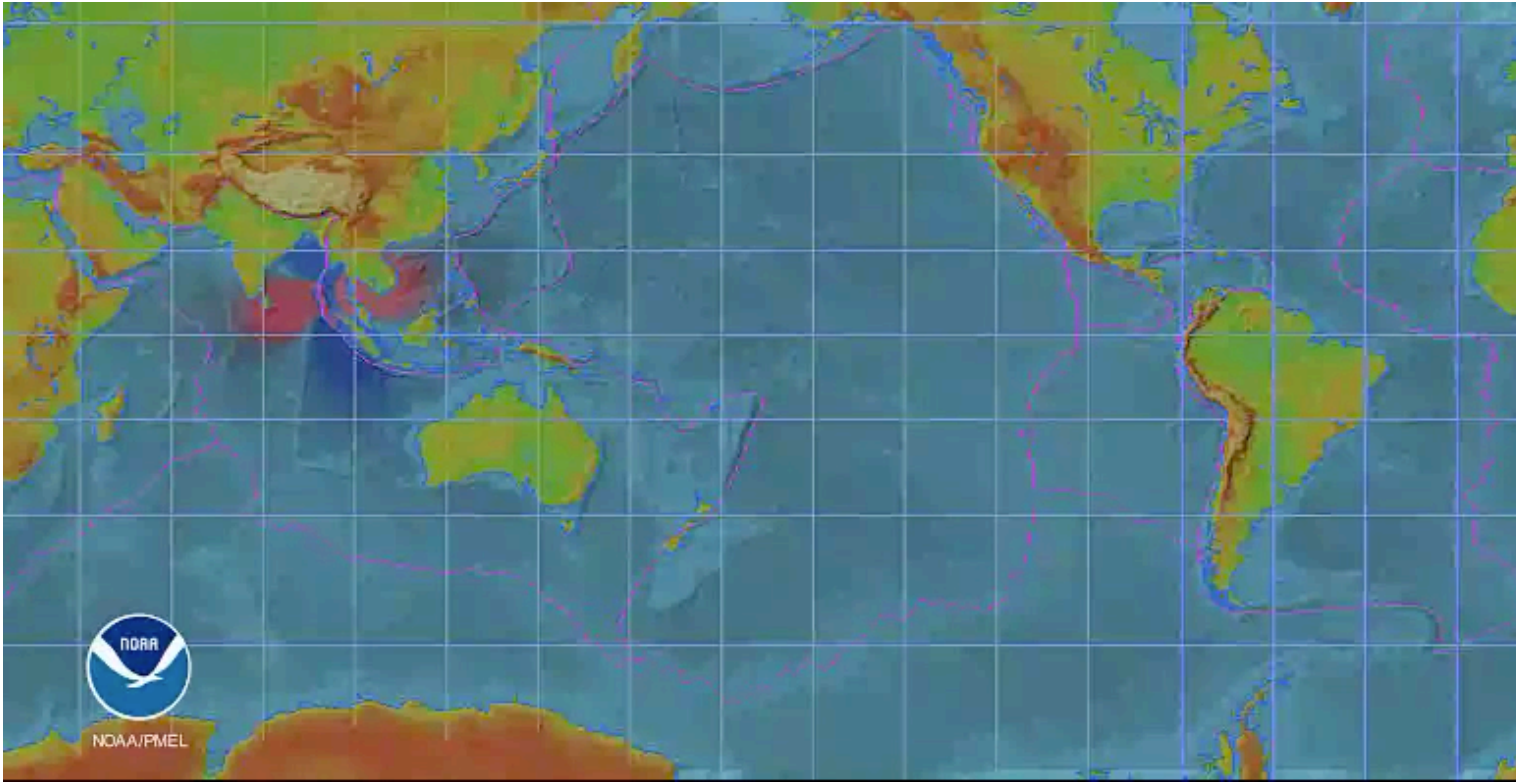
DISPERSION
DISPERSION, AMPLIFICATION
AMPLIFICATION
BORE FORMATION
η/m
h/km
h/m
t(min)
x/km


Tsunami physics research
support of improved measurement technology and the design of optimal tsunami monitoring networks
implementation of improved models to increase the speed and accuracy of operational forecasts and warnings
development of improved methods to predict tsunami impacts on the population and infrastructure of coastal communities



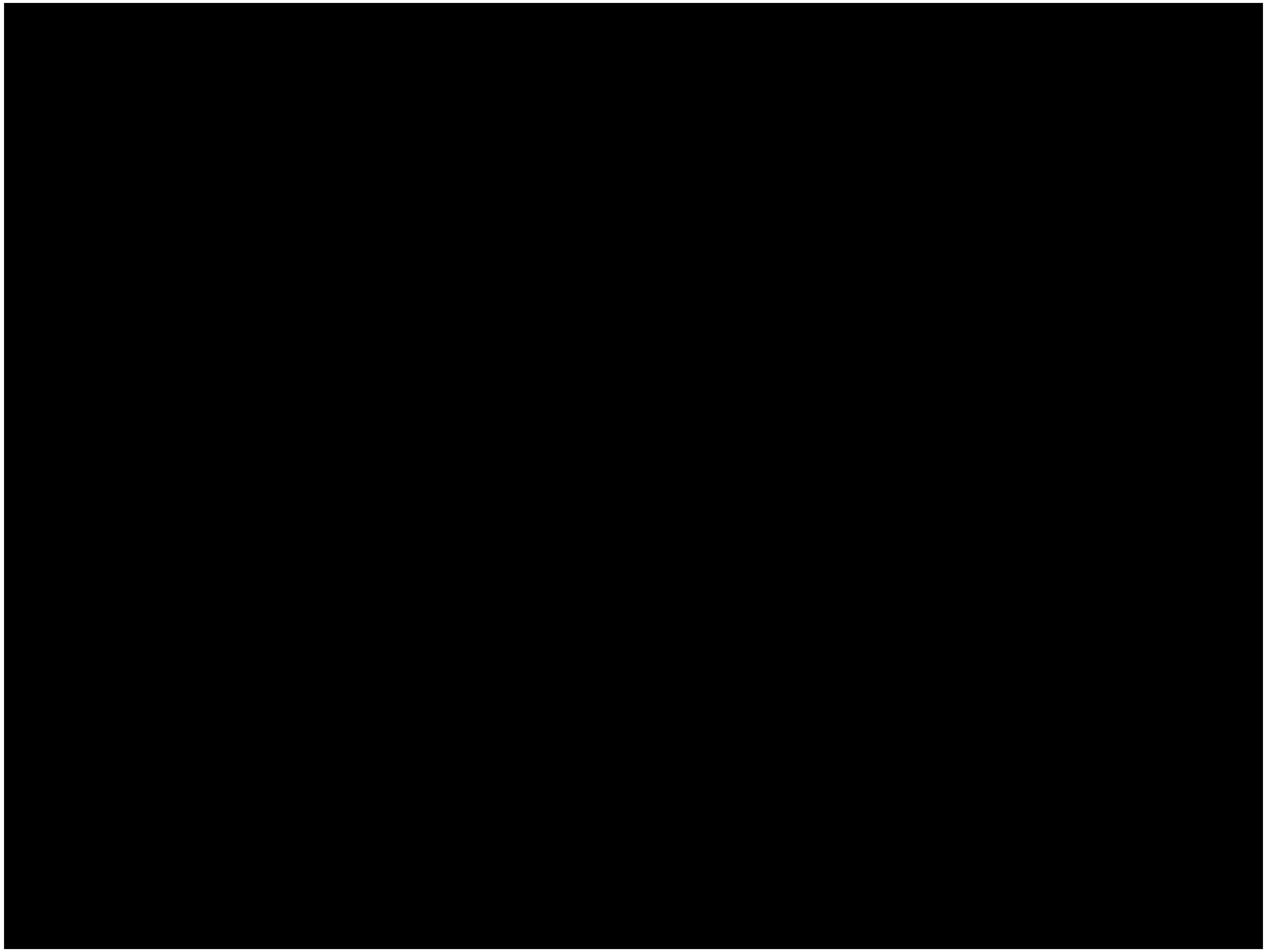
maximum wave height and maximum current speed as a function of location, maximum inundation line, as well as time series of wave height at different locations indicating wave arrival time

December 26, 2004 Indonesia (Sumatra) - Global tsunami propagation



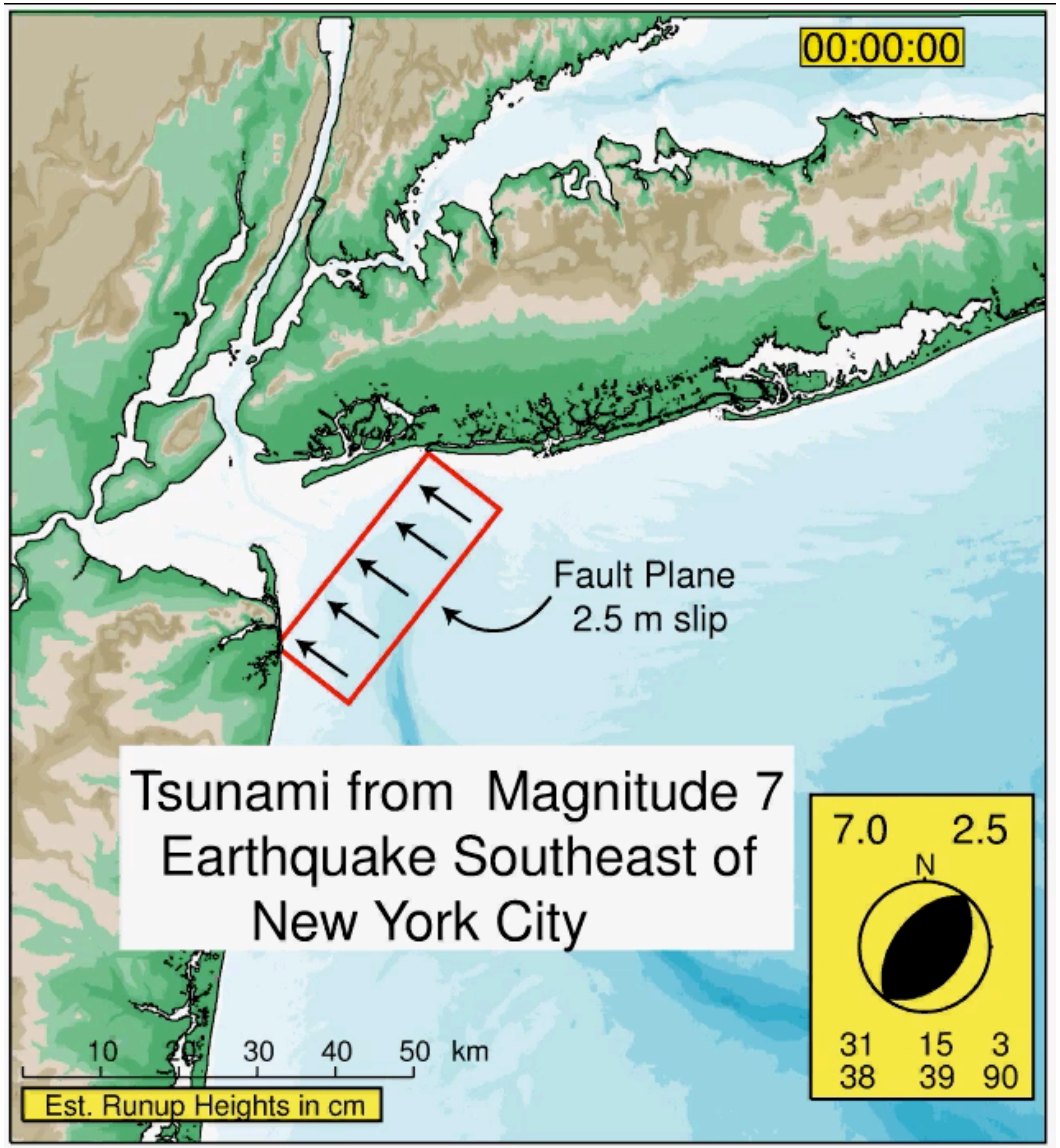
http://nctr.pmel.noaa.gov/model.html

Inundation of the Aonae peninsula during the July 12, 1993 Hokkaido-Nansei-Oki tsunami computed with the MOST inundation model.



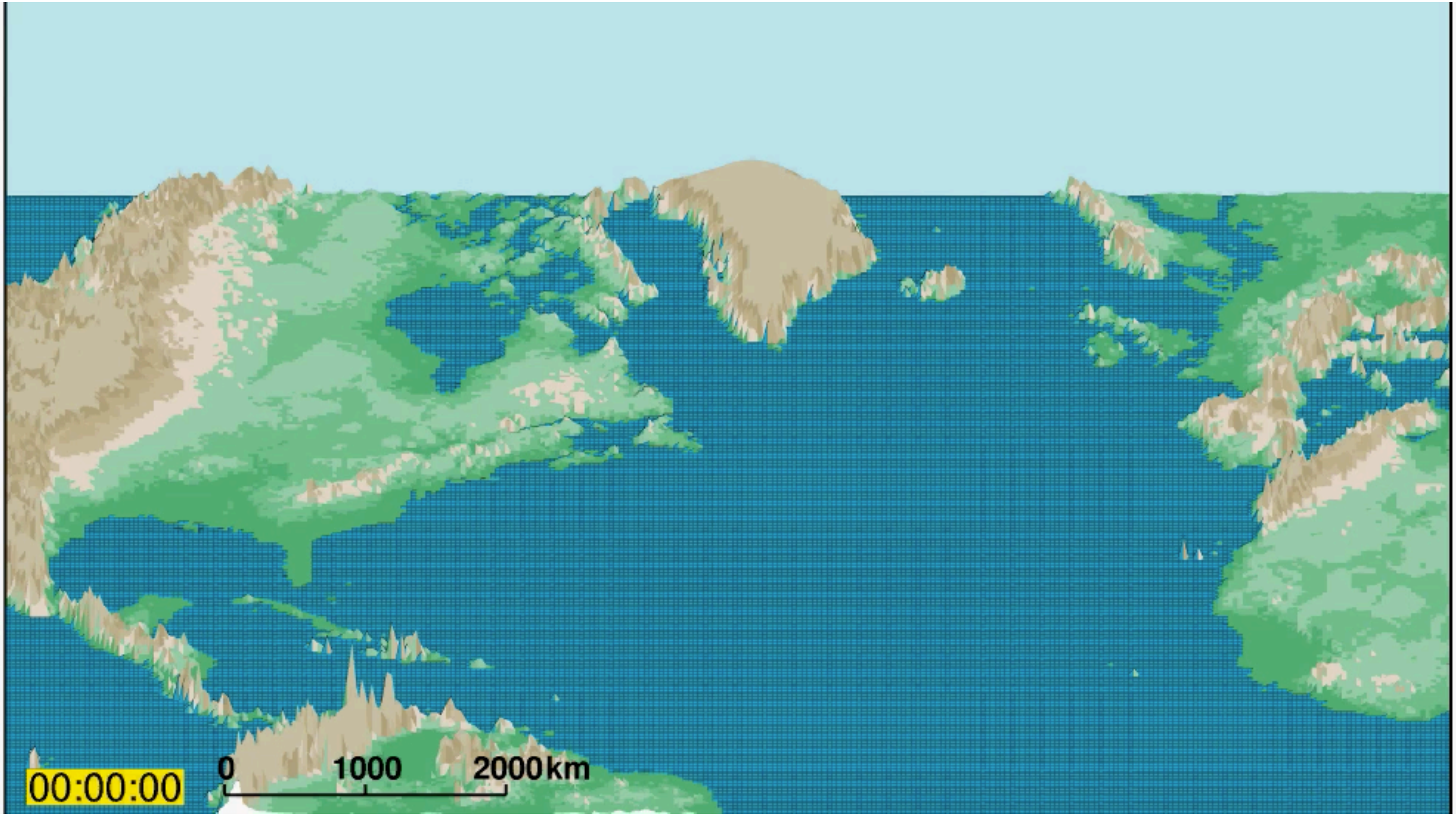
http://nctr.pmel.noaa.gov/model.html

New York City Tsunami from M7 Quake



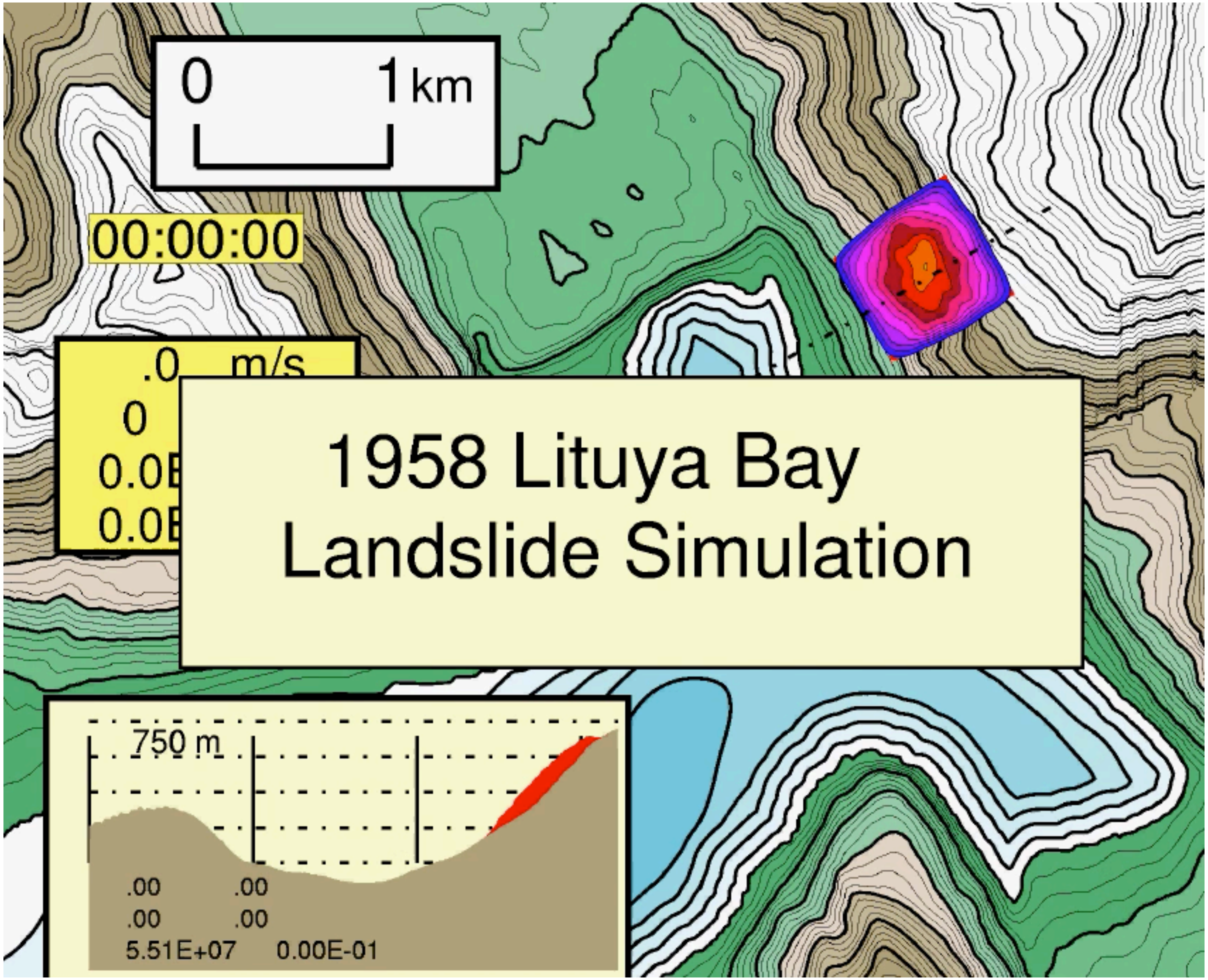
Courtesy of Steven Ward: http://www.es.ucsc.edu/~ward/

Atlantic Ocean Asteroid Tsunami Simulation - 3d



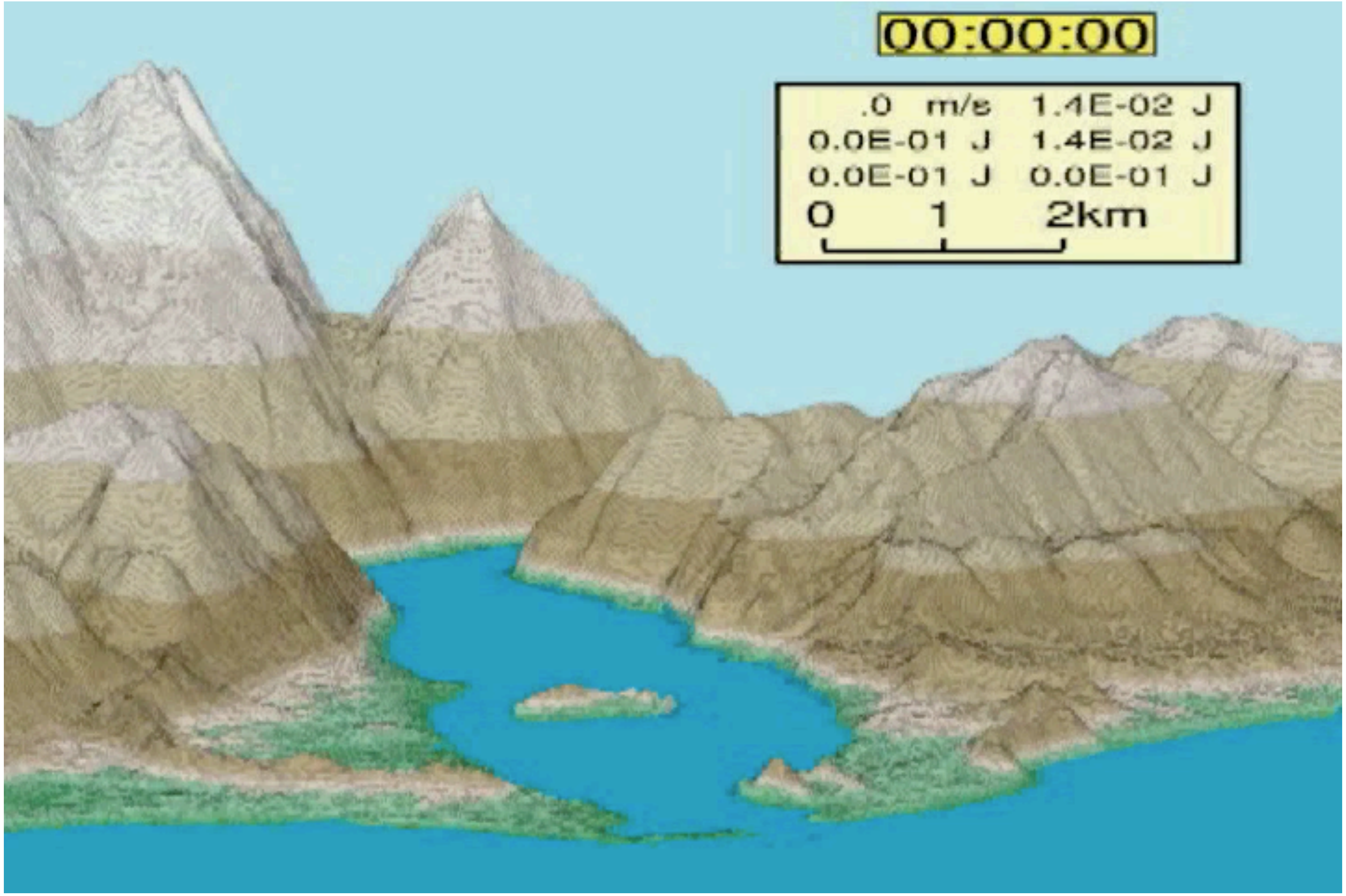
Courtesy of Steven Ward: http://www.es.ucsc.edu/~ward/

1958 Lituya Bay Landslide



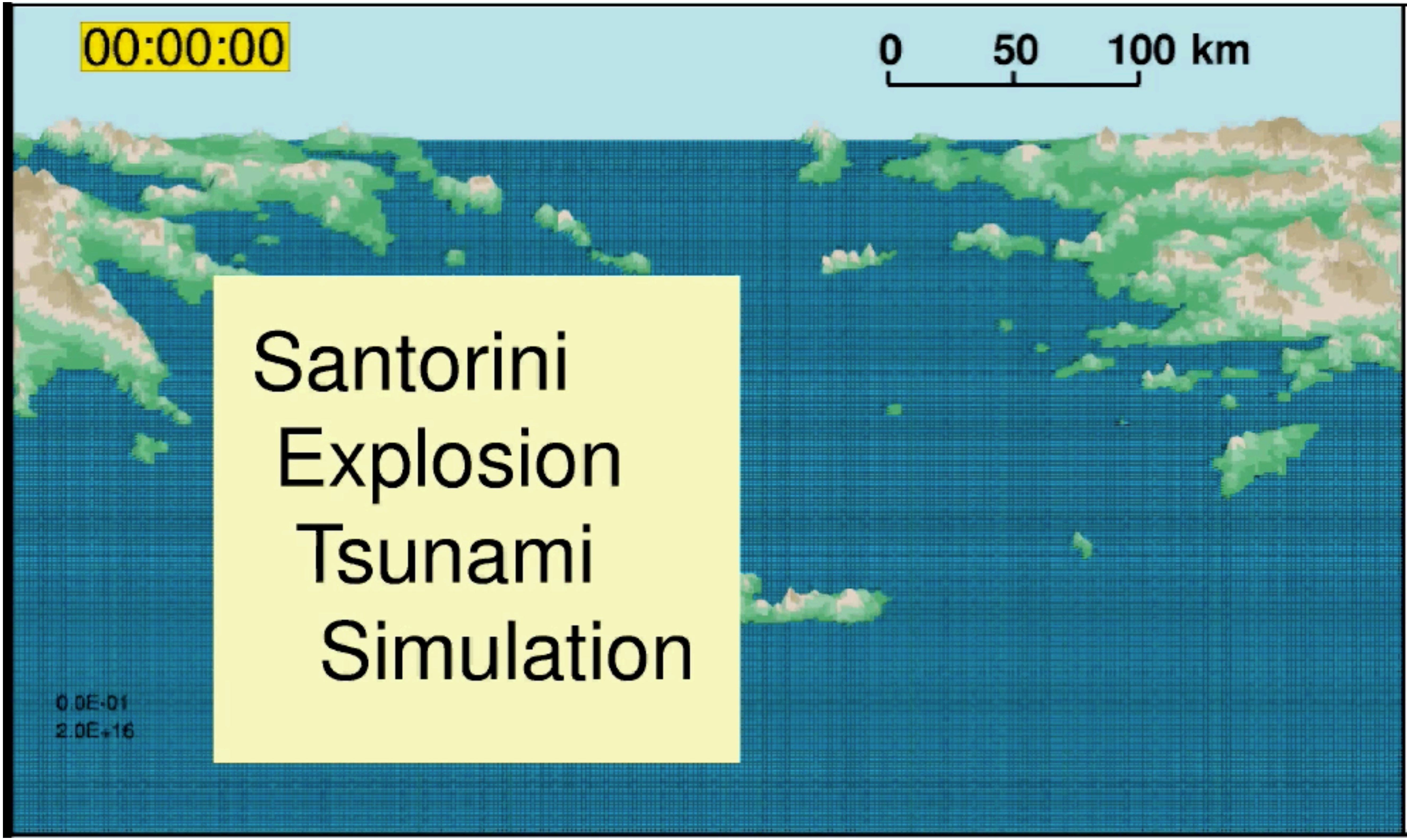
Courtesy of Steven Ward: http://www.es.ucsc.edu/~ward/

1958 Lituya Bay Landslide



Courtesy of Steven Ward: http://www.es.ucsc.edu/~ward/

Santorini Tsunami Simulation 3D



Courtesy of Steven Ward: http://www.es.ucsc.edu/~ward/

Ocean bottom data

The observation record of the ocean bottom pressure gauge. At around 14:46, the ground motion of the earthquake (M9) reaches the pressure gauge and at TM1 (coast-side), the sea level is gradually rising from that point.

The sea level rose 2 m, and after 11 minutes, the level went drastically up to 3m, which makes 5 m of elevation in total. At TM2: located 30km toward the land, a same elevation of sea level was recorded with 4 minutes delay from TM1.

釜石沖海底ケーブル式地震計システムで観測された海面変動

東京大学地震研究所

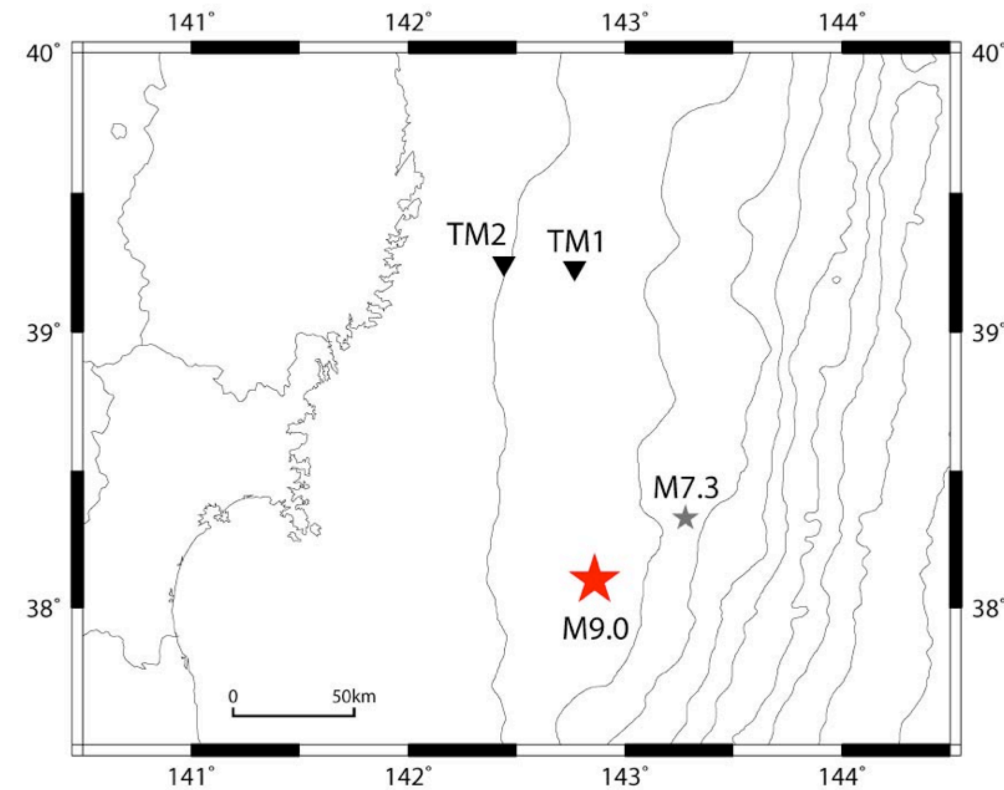


図１　釜石沖ケーブル式海底水圧計の位置

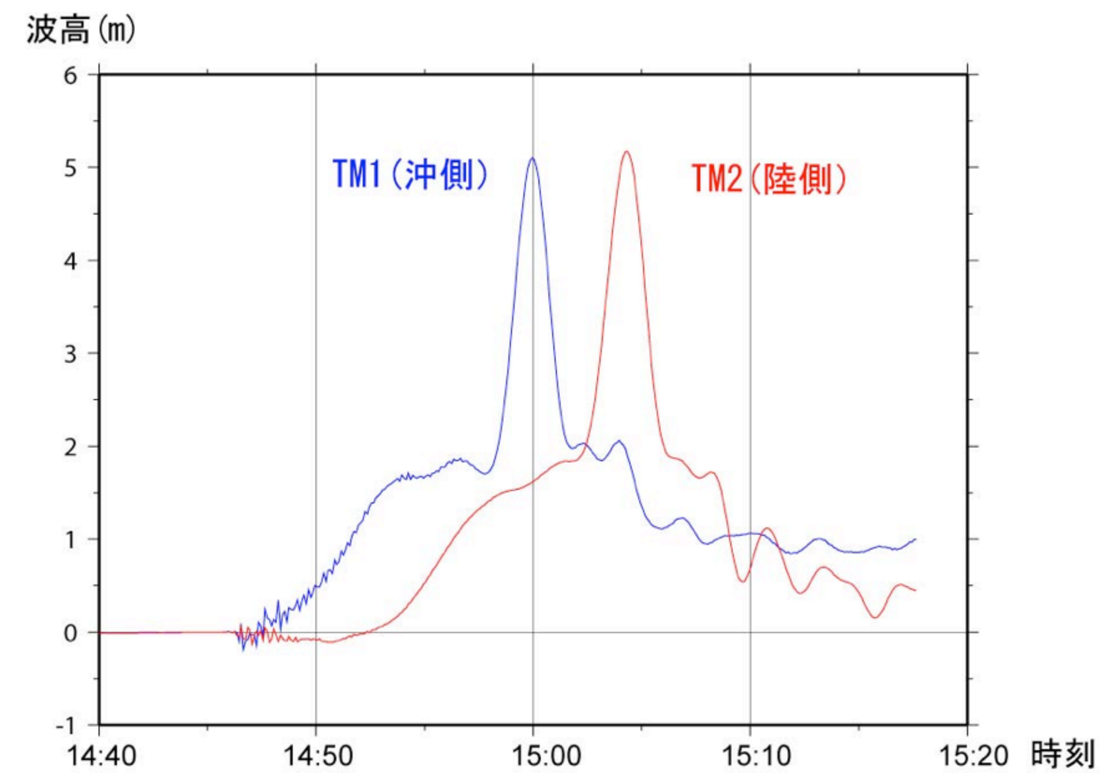
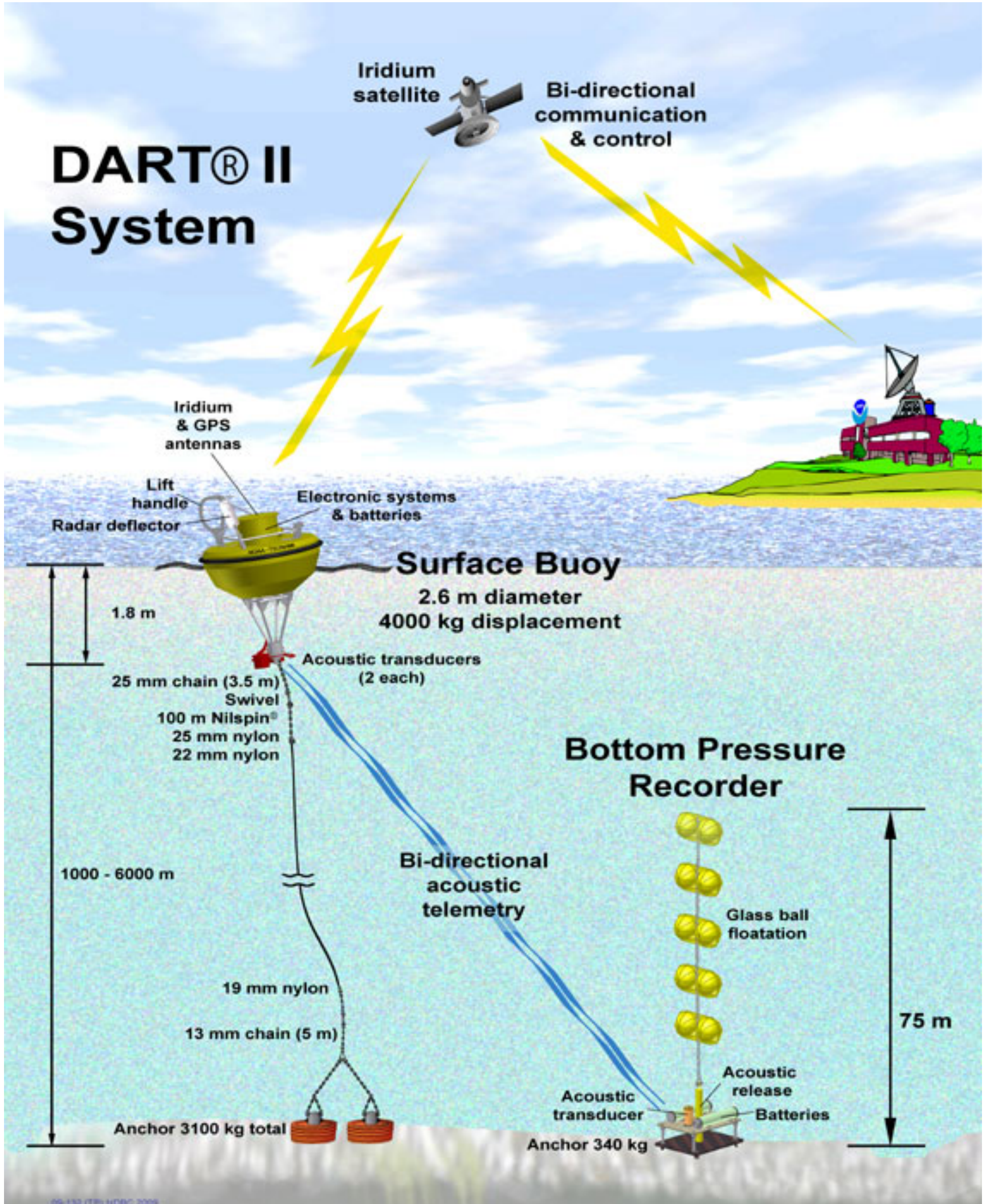


図２　海底水圧計の観測記録。14時46分頃、本震(M9.0)の振動が水圧計に伝わり、TM1(海寄り)では、その時から徐々に海面が上昇している。約２m上昇し、約11分後にはさらに約3m急激に上昇し、合計約5m海面が上昇した。約30km陸寄りに設置されているTM2では、TM1から約4分遅れて同様の海面上昇を記録した。

Dart buoys



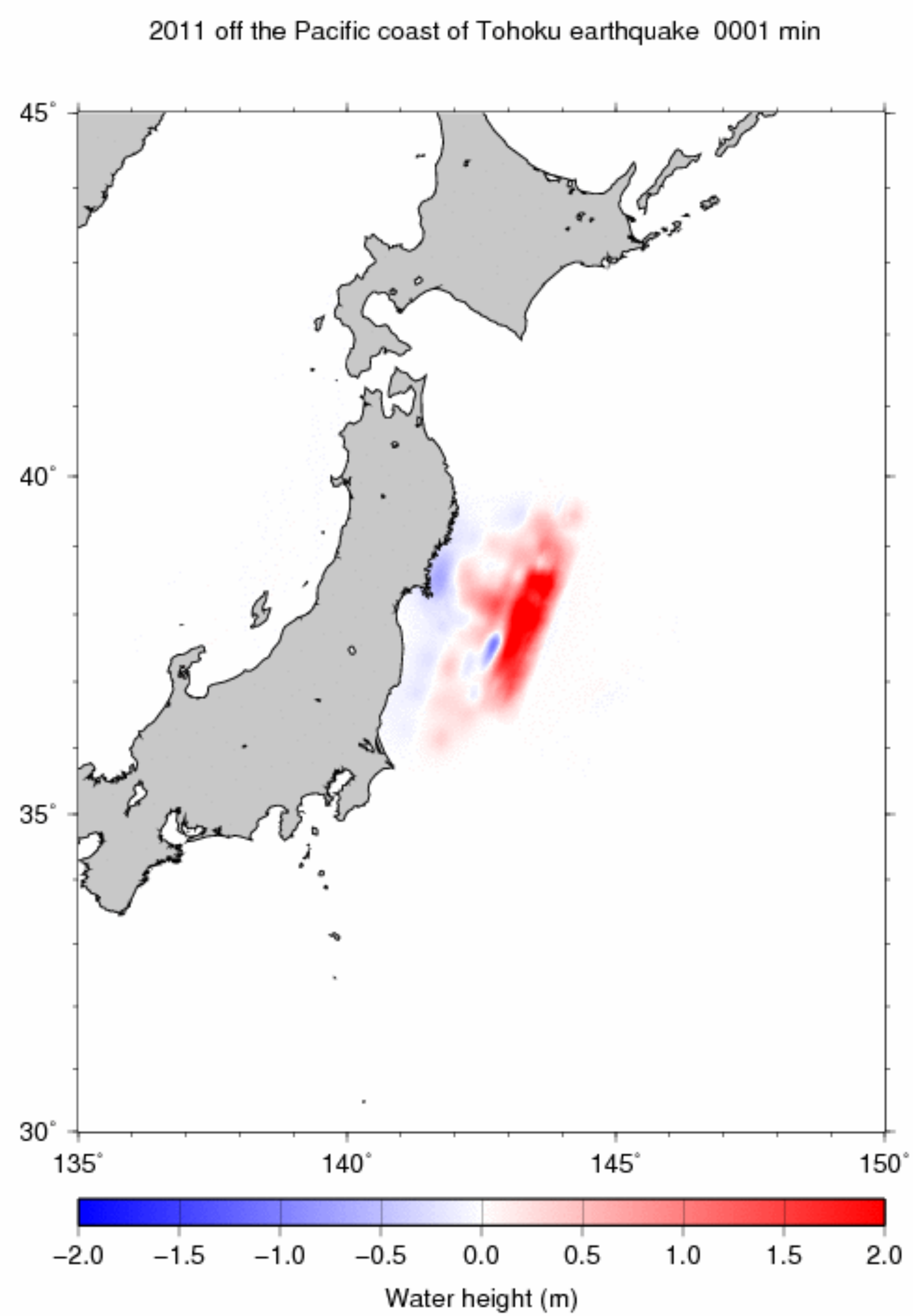
The DART II® system consists of a seafloor bottom pressure recording (BPR) system capable of detecting tsunamis as small as 1 cm, and a moored surface buoy for real-time communications.

DART II has two-way communications between the BPR and the Tsunami Warning Center (TWC) using the Iridium commercial satellite communications system. The two-way communications allow the TWCs to set stations in event mode in anticipation of possible tsunamis or retrieve the high-resolution (15-s intervals) data in one-hour blocks for detailed analysis.

DART II systems transmit standard mode data, containing twenty-four estimated sea-level height observations at 15-minute intervals, once very six hours.

NOAA

Tsunami data and simulations: source

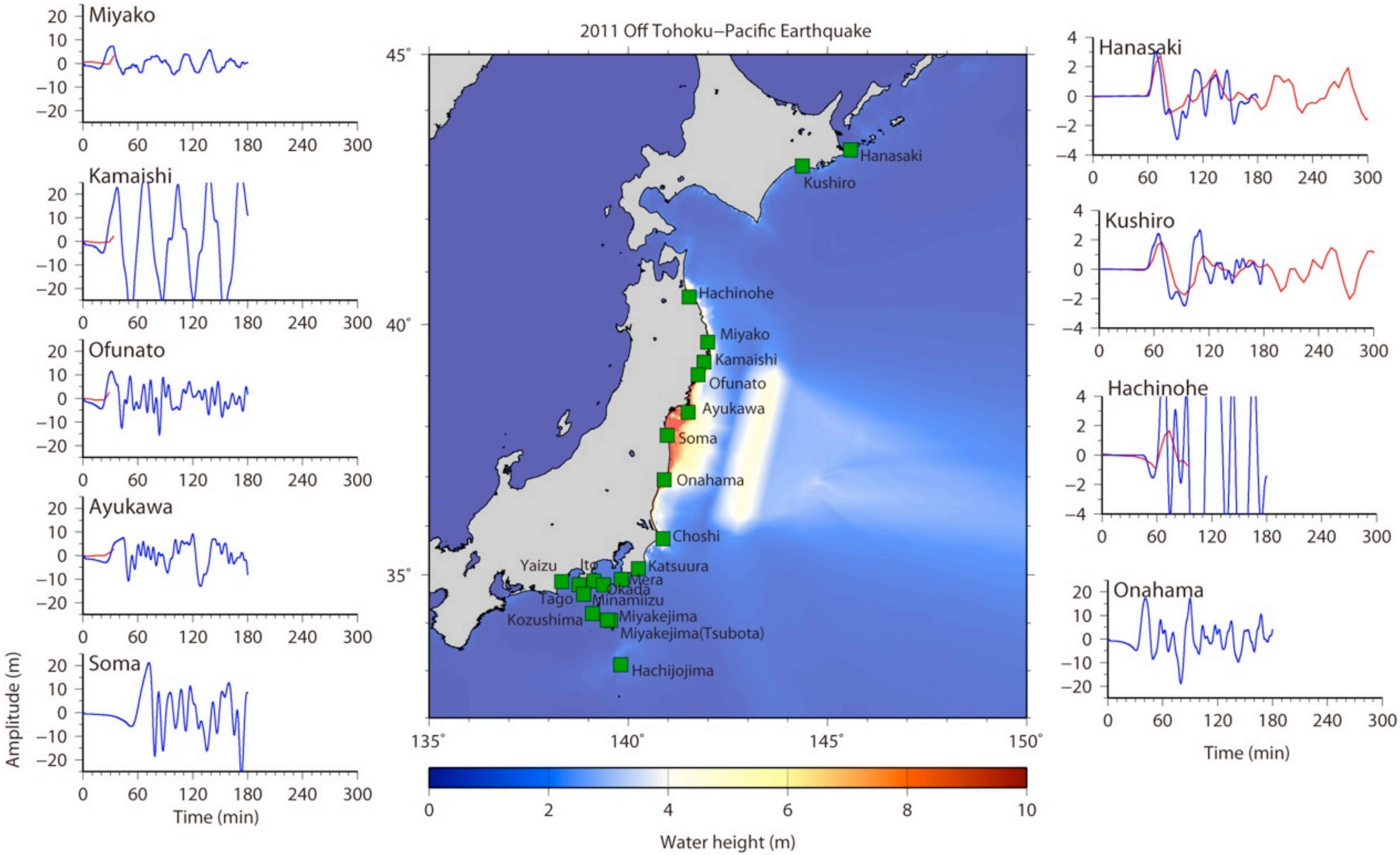


Tsunami Propagation

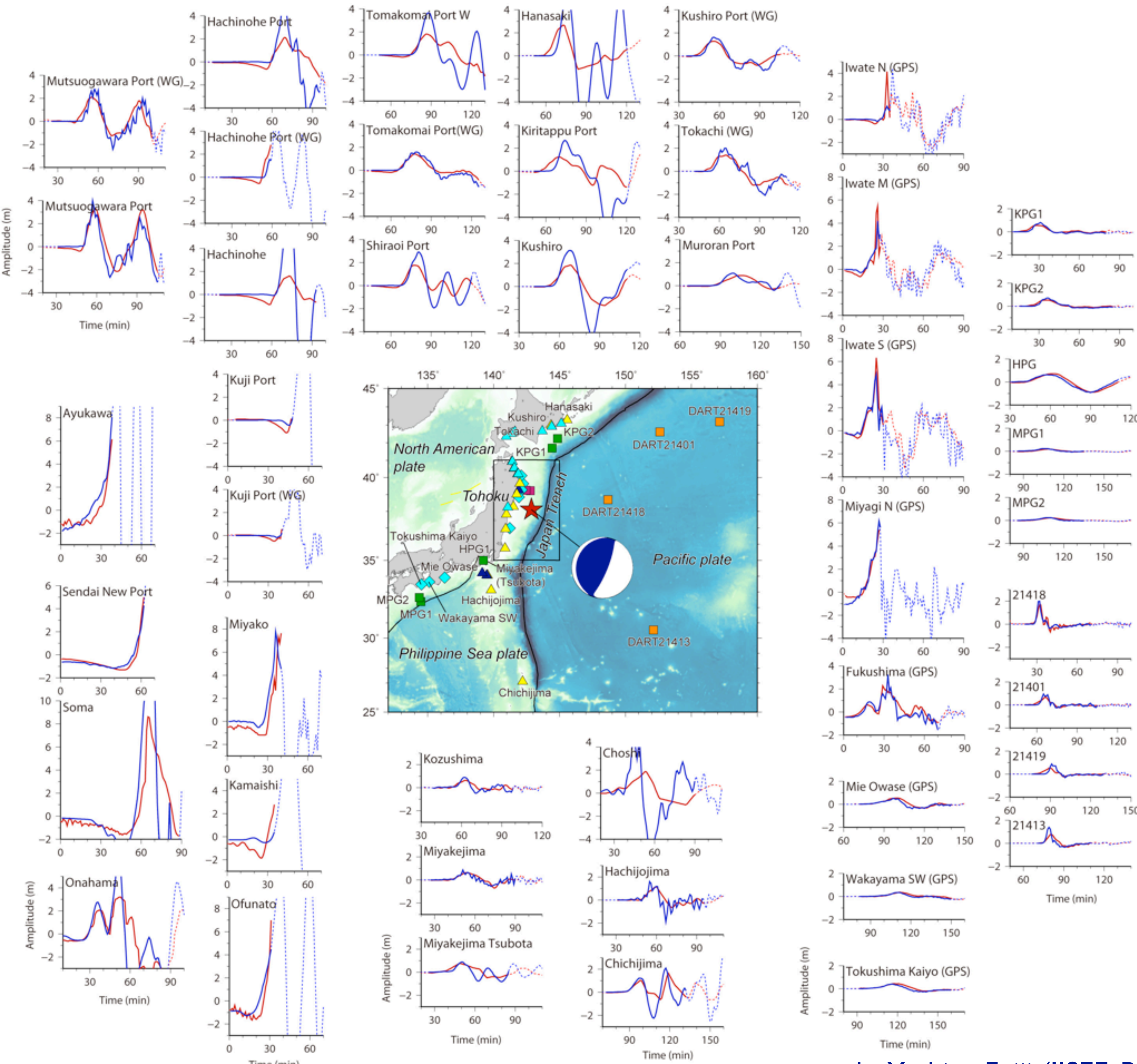
The red color means that the water surface is higher than normal sea level, while the blue means lower.

by Yushiro Fujii (IISEE, BRI) and Kenji Satake (ERI, Univ. of Tokyo)
http://iisee.kenken.go.jp/staff/fujii/OffTohokuPacific2011/tsunami_inv.html

Tsunami data and simulations



Tsunami data and simulations: source

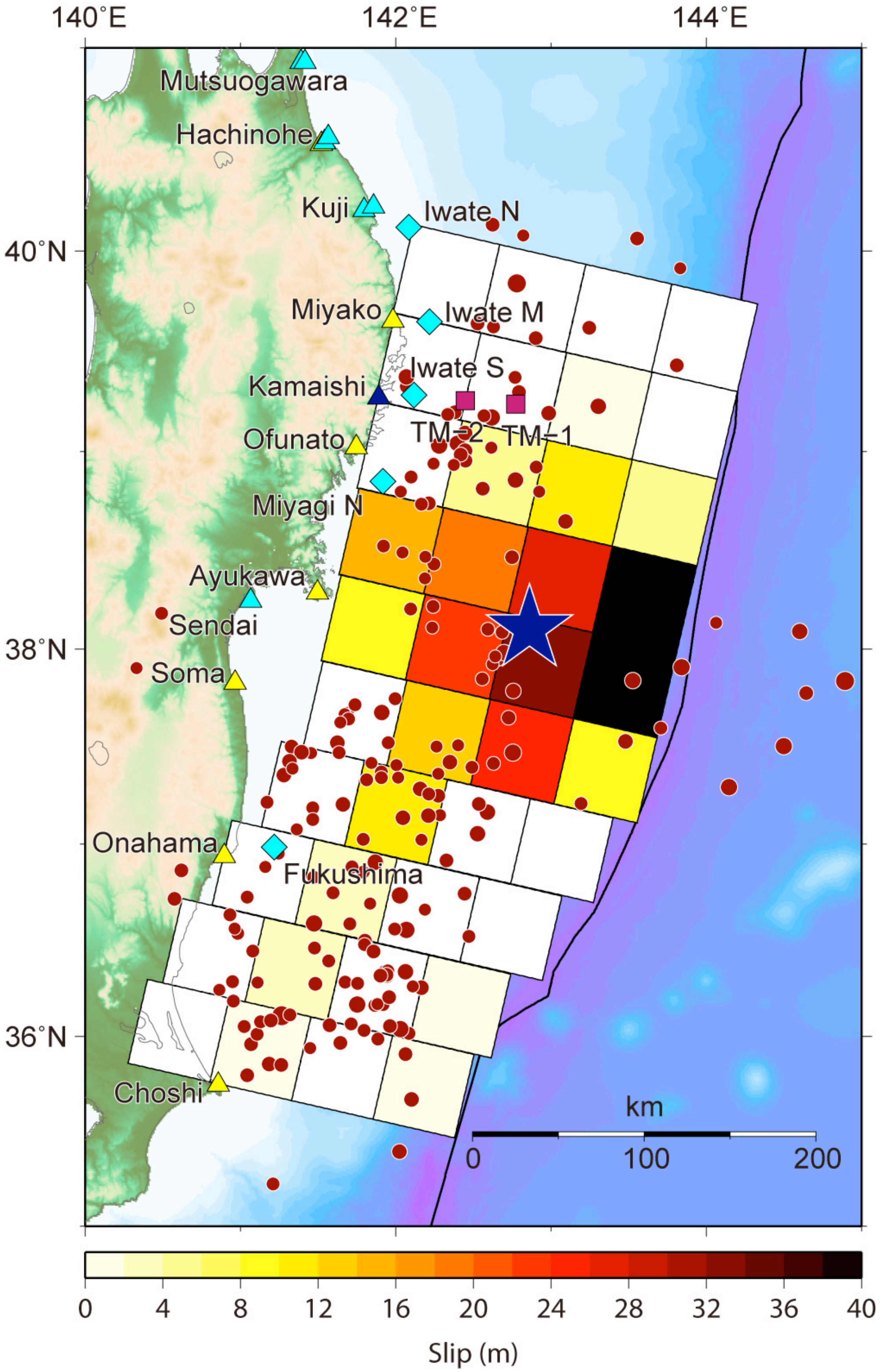


Simulated Tsunami around Japanese coasts

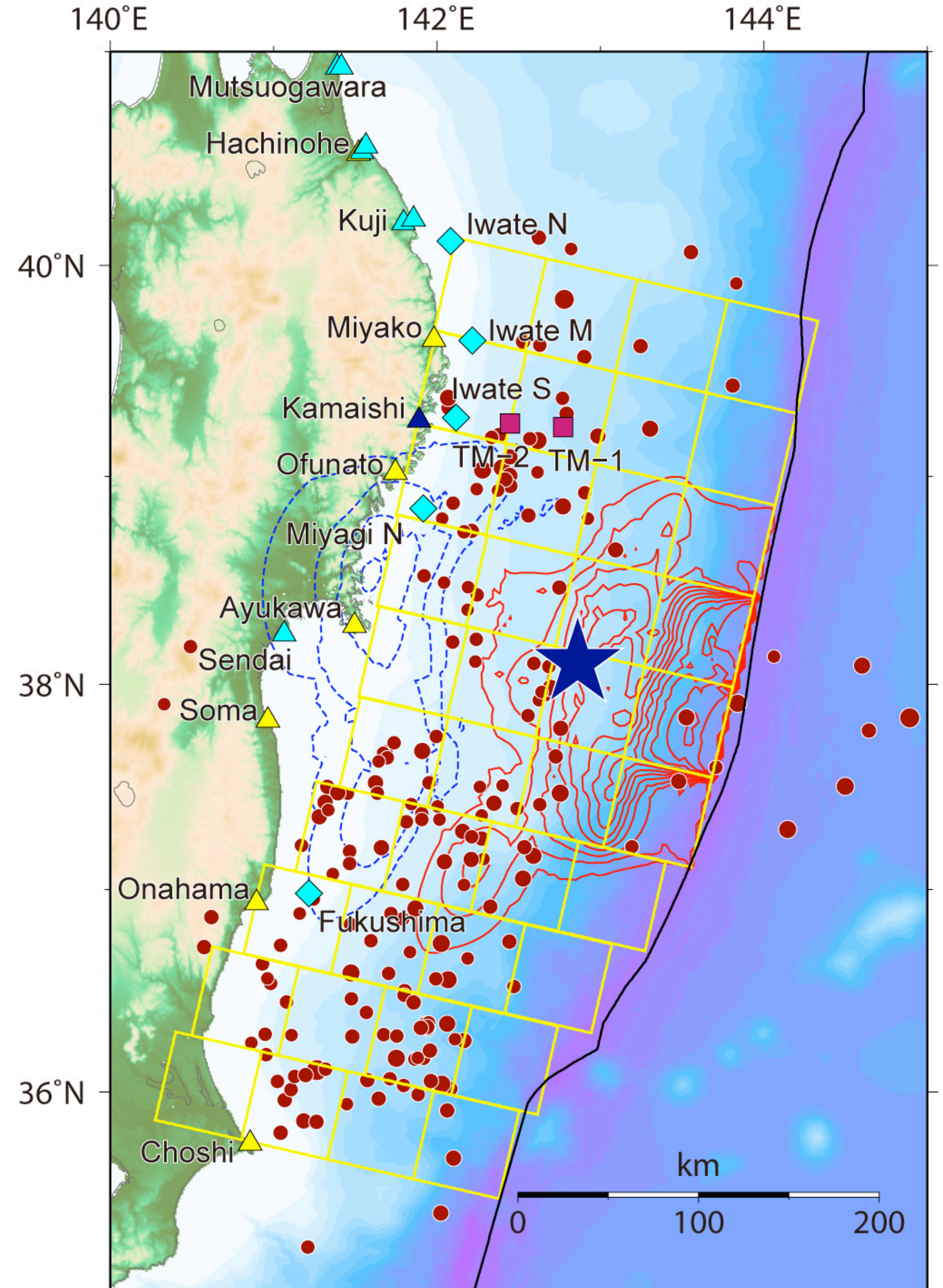
Red and blue lines indicate the observed tsunami waveforms at Japanese tide gauges and ocean bottom tsunami sensors and synthetic ones, respectively. Solid lines show the time windows used for inversion.

by Yushiro Fujii (IISEE, BRI) and Kenji Satake (ERI, Univ. of Tokyo)
http://iisee.kenken.go.jp/staff/fujii/OffTohokuPacific2011/tsunami_inv.html

Tsunami data and simulations: source



Slip distribution on the fault mode



Calculated seafloor deformation due to the fault model

by Yushiro Fujii (IISEE, BRI) and Kenji Satake (ERI, Univ. of Tokyo)

http://iisee.kenken.go.jp/staff/fujii/OffTohokuPacific2011/tsunami_inv.html

Tsunami animation: time scales...

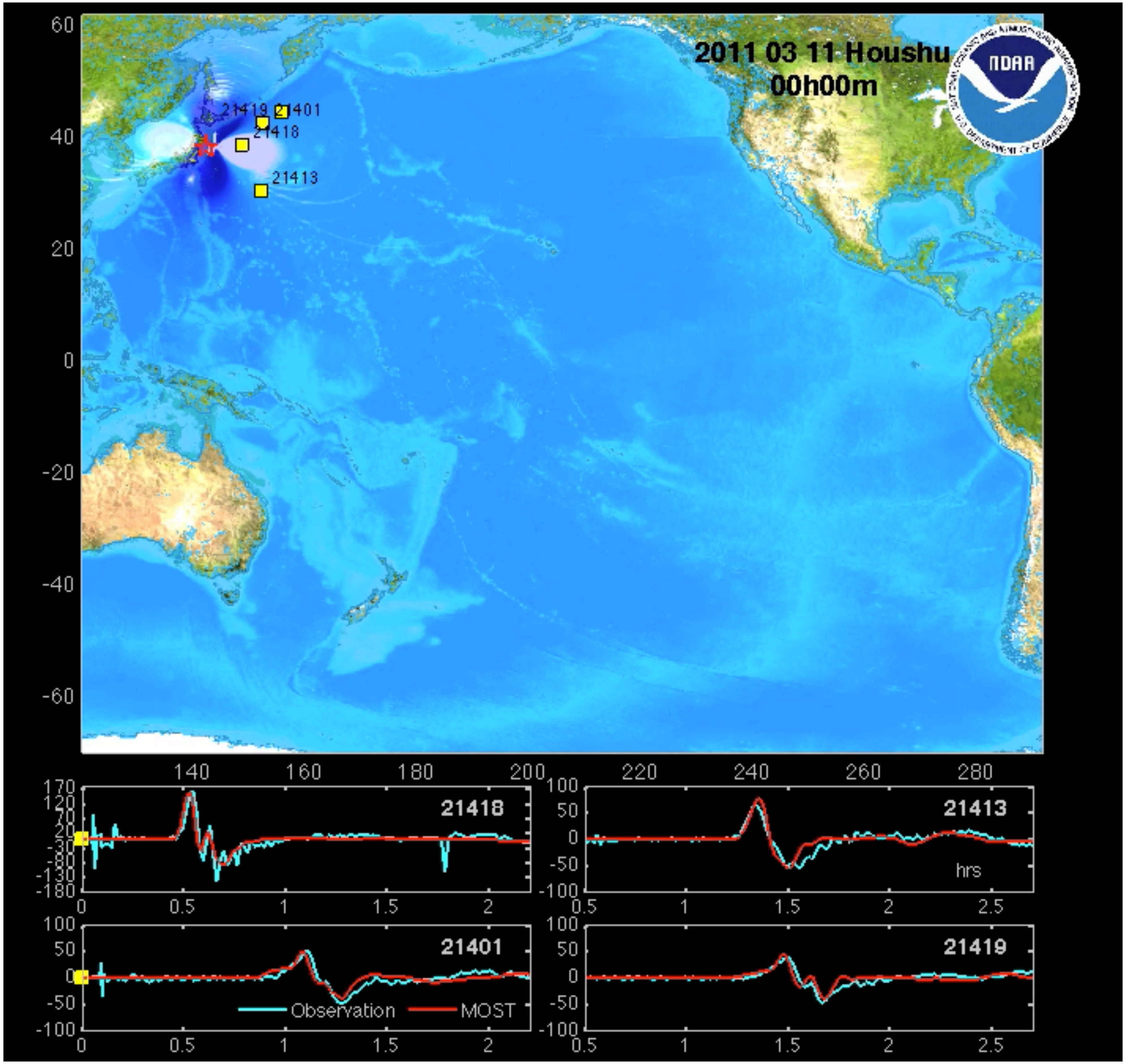
http://outreach.eri.u-tokyo.ac.jp/eqvolc/201103_tohoku/eng/

http://supersites.earthobservations.org/honshu.php

http://eqseis.geosc.psu.edu/~cammon/Japan2011EQ/

“Earthquake Research Institute, University of Tokyo, Prof. Takashi Furumura and Project Researcher Takuto Maeda”

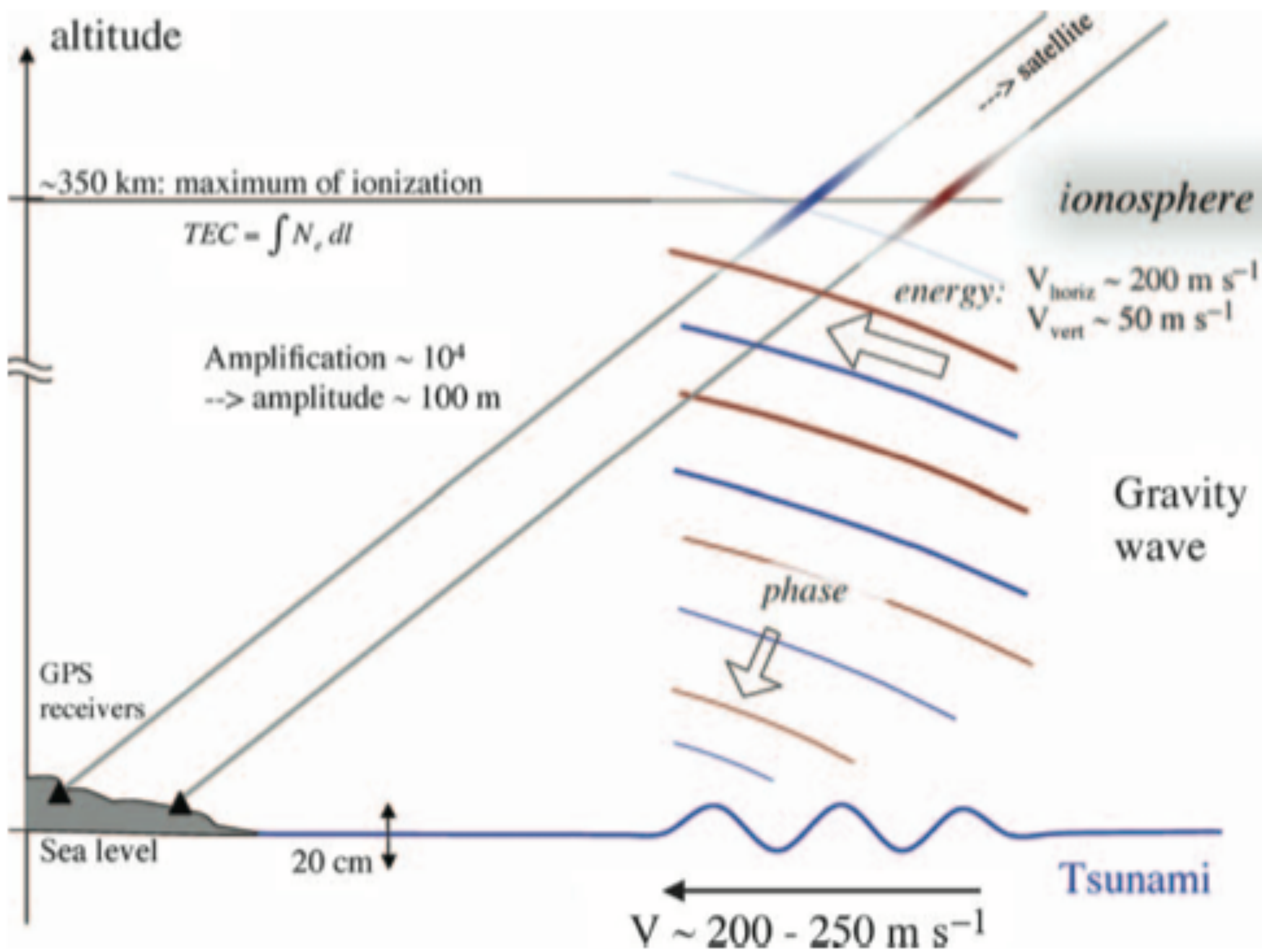
Tsunami animation - NOAA



Tsunami signature in the ionosphere

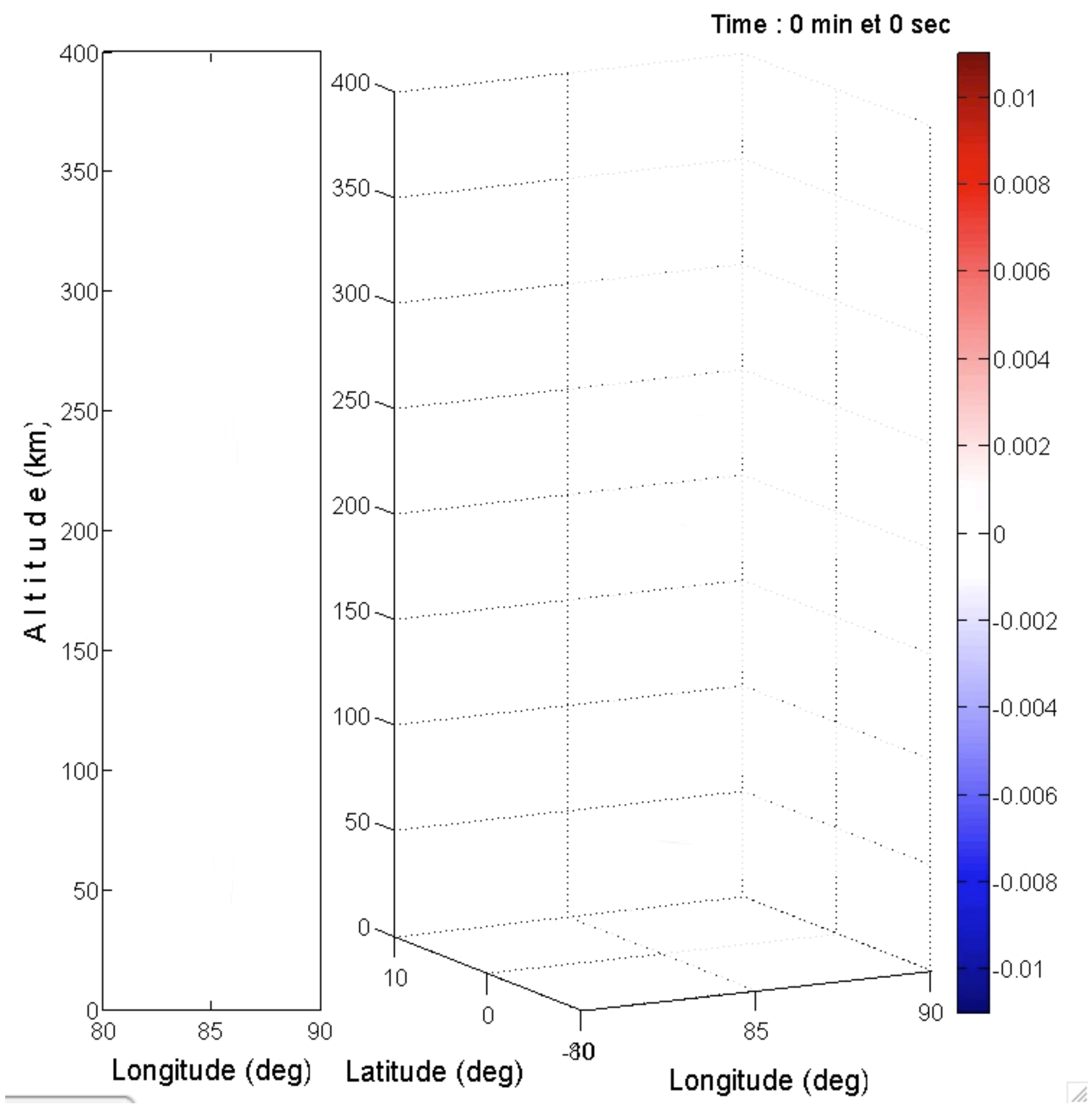
By dynamic coupling with the atmosphere, acoustic-gravity waves are generated

Traveling Ionospheric Disturbances (TID) can be detected and monitored by high-density GPS networks

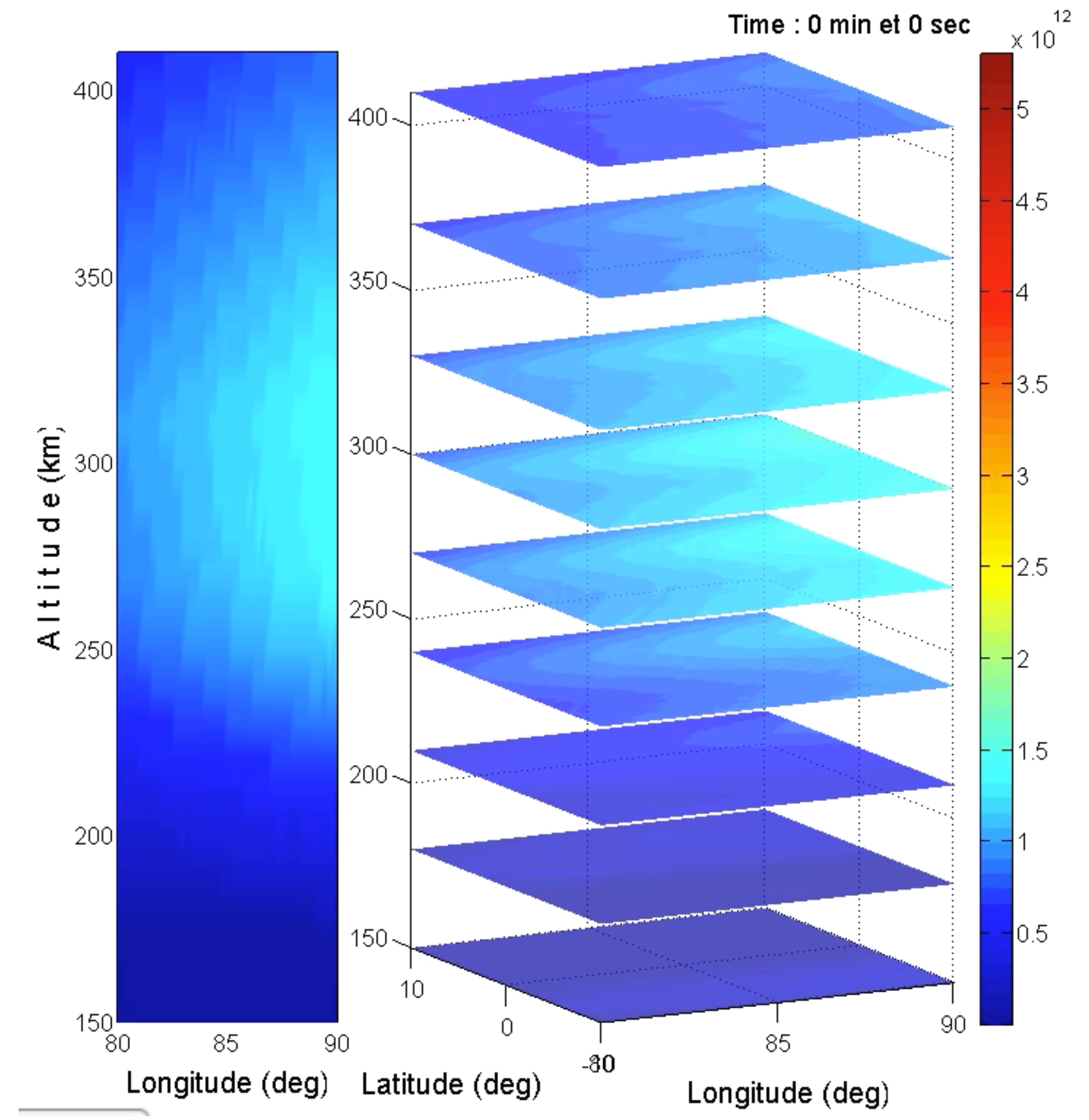


Tsunami signature in the ionosphere

Tsunami-generated IGWs and the response of the ionosphere to neutral motion at 2:40 UT.

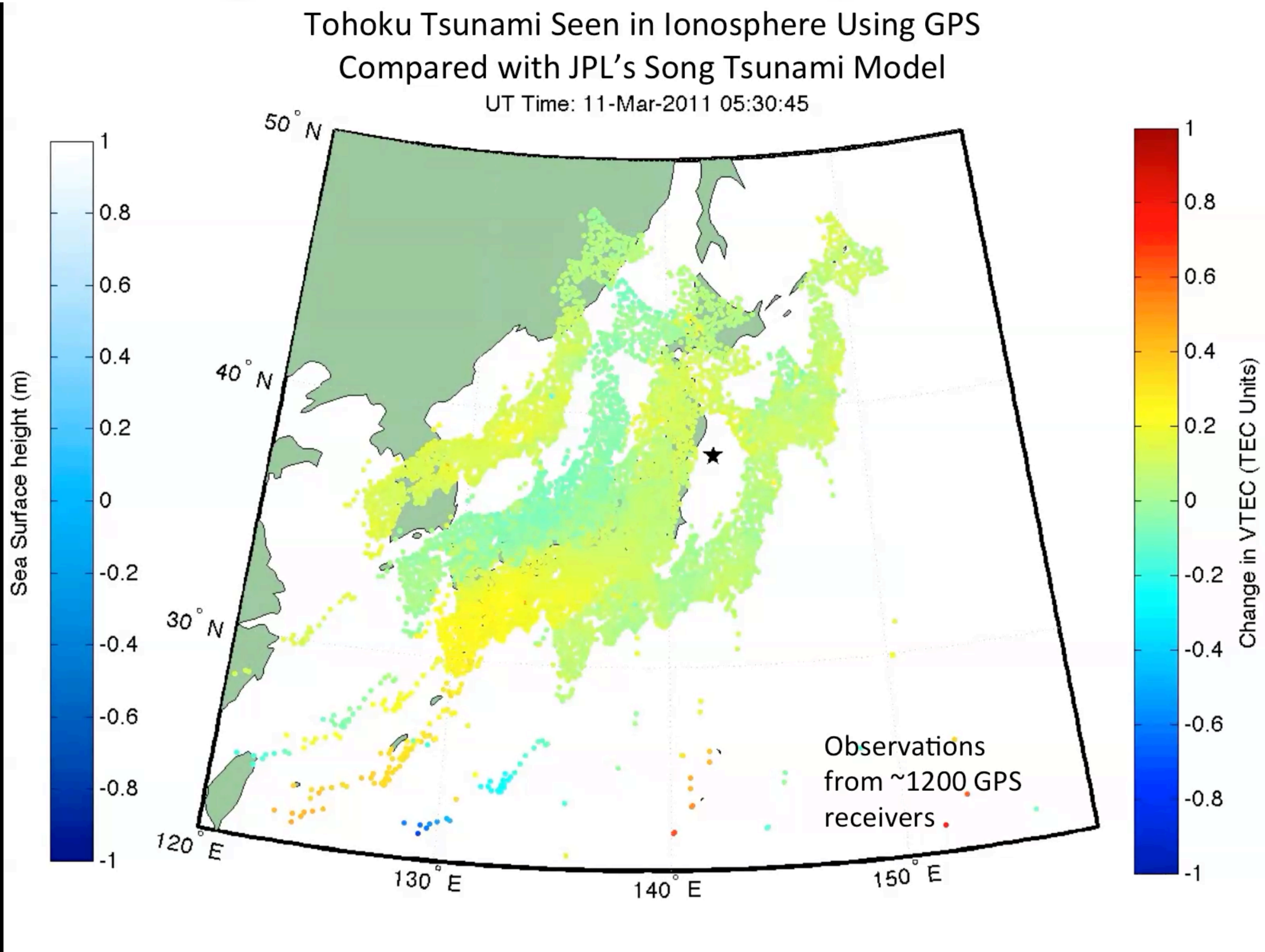


Normalized vertical velocity



Perturbation in the ionospheric plasma

Tsunami signature in the ionosphere



Sea gate in Hachinohe

http://minkara.carview.co.jp/userid/405365/car/375387/1923923/photo.aspx

Sea gate (9.3 m high)

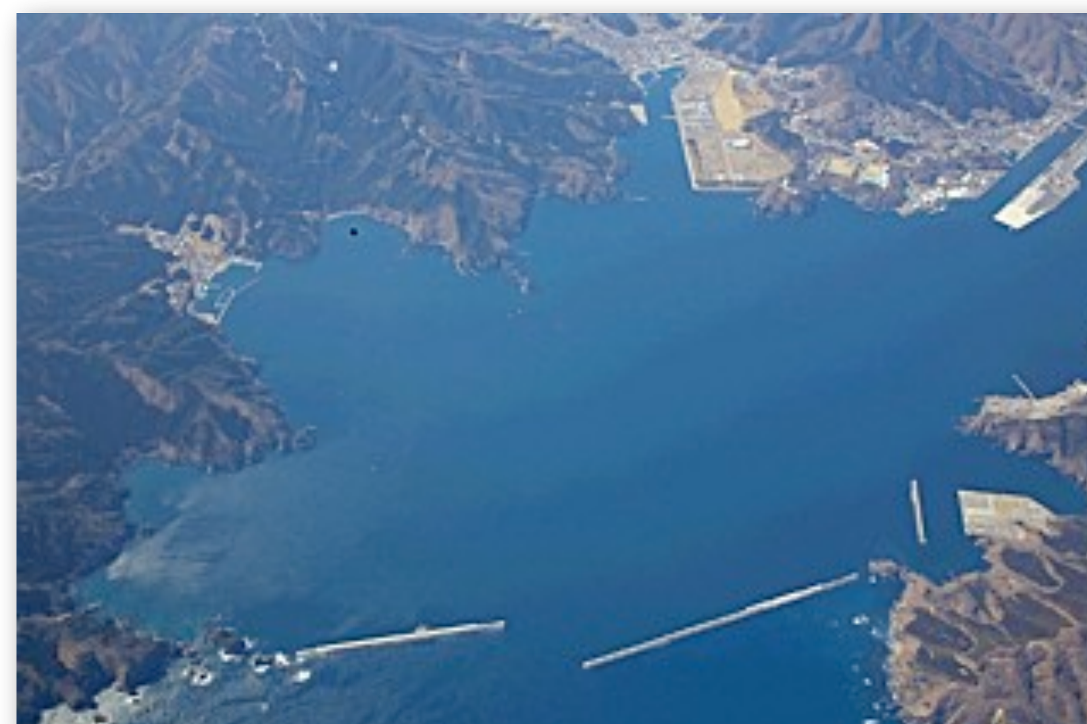
http://ja2xt.mu-sashi.com/Numazu5.htm

Sea walls

Sea wall with stairway evacuation route used to protect a coastal town against tsunami inundation in Japan.

Photo courtesy of River Bureau, Ministry of Land, Infrastructure and Transport, Japan.

Elevated platform used for tsunami evacuation that also serves as a high-elevation scenic vista point for tourist.
Okushiri Island, Japan. Photo courtesy of ITIC



Deepest breakwater in Kamaishi (Iwate)

Topping a 12 m sea wall

Tsunami walls...

The 2.4 km long tsunami wall in Miyako, Iwate Prefecture, was destroyed. The 6 m, 2 km long, wall in Kamaishi, Iwate Prefecture, was overwhelmed but delayed the tsunami inundation by 5 minutes.

The 15.5 m tsunami wall in Fundai, Iwate Prefecture, provided the best protection, but it is good to know that the original design was only 10 m. The village mayor fought to make it higher from information in the village historical records.

The biggest problem is that tsunami walls may give a false sense of security and other preparedness measures may NOT be undertaken.

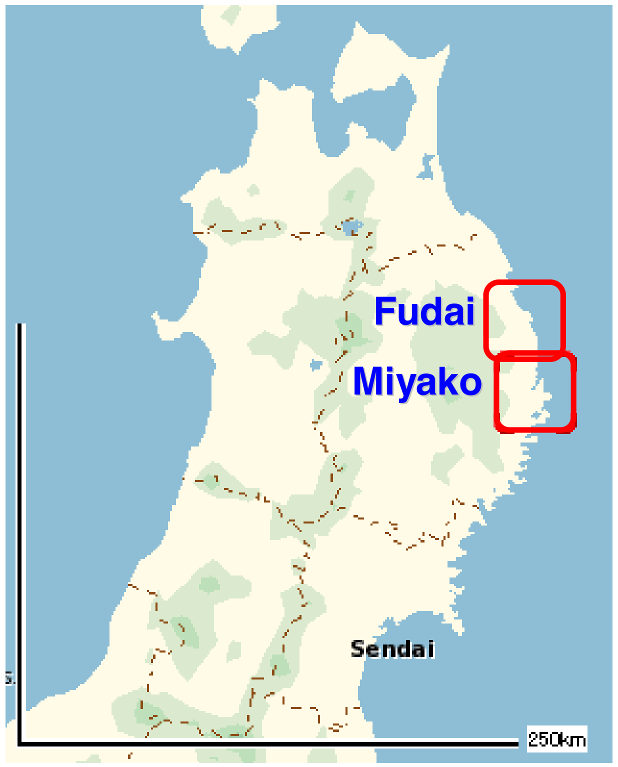
Woody Epstein, 2011

Sea wall at Fudai

49 foot sea wall:
completed in 1967; floodgates were added in 1984.

Following the 1896 Meiji tsunami, village mayor Kotoku Wamura pressed for a seawall at least 15 meters high, often repeating the tales handed down to him growing up: that the devastating tsunami was 15 meters.

Miyako and Fudai...



The 10m-high seawall was destroyed in Taro district, Miyako city, Iwate Pref.

The 15.5m-high seawall was undestroyed in Otabe district, Fudai village, Iwate Pref.

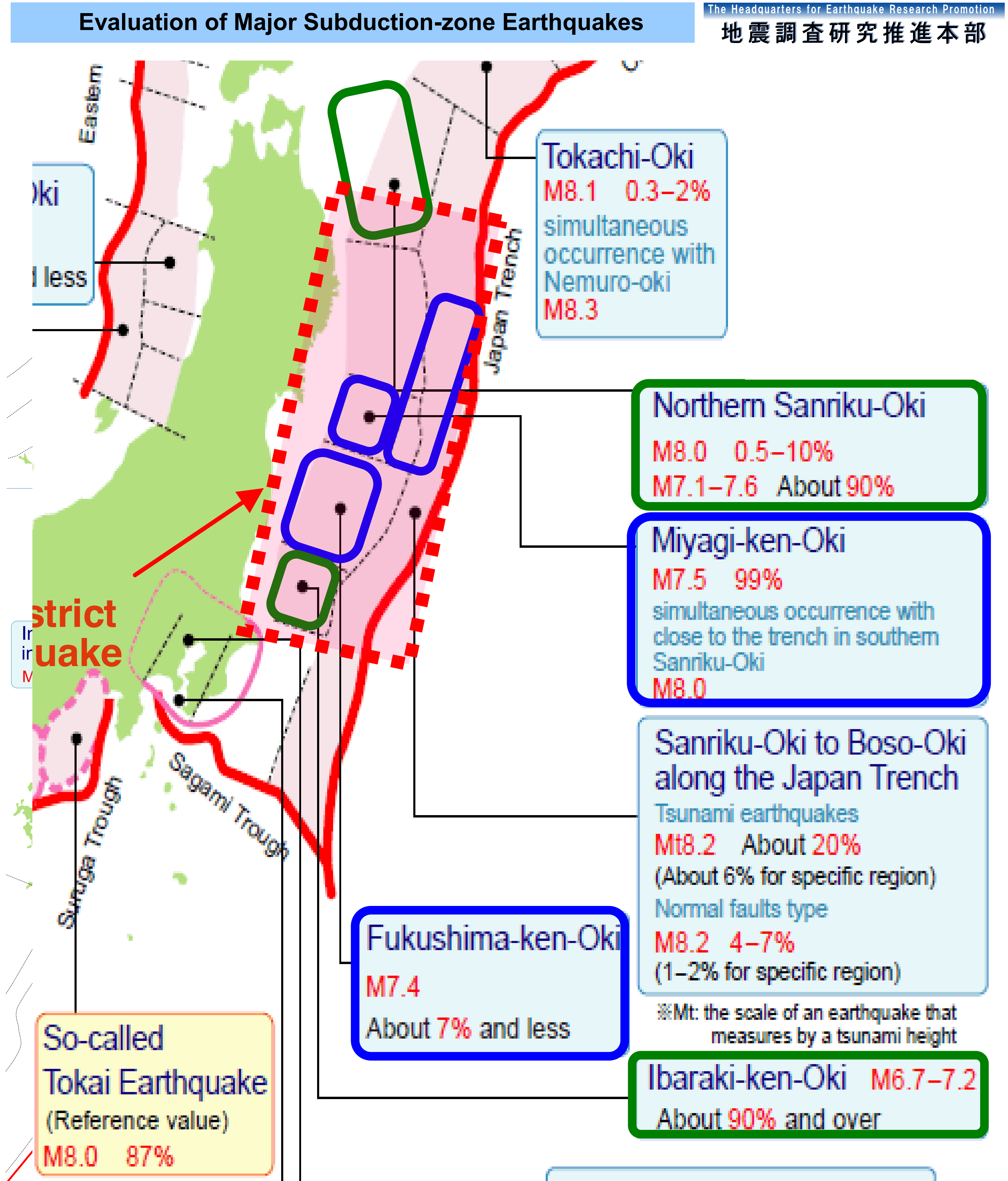
Fig. III-1-16 Difference of seawall heights resulting in different consequence.

A photo from the village's point of view (i.e. facing the coast)

A photo from a viewpoint of facing the village taken at the spot slightly below the stone monument

Tsunami stones (Tsunami-seki)

Expectations...

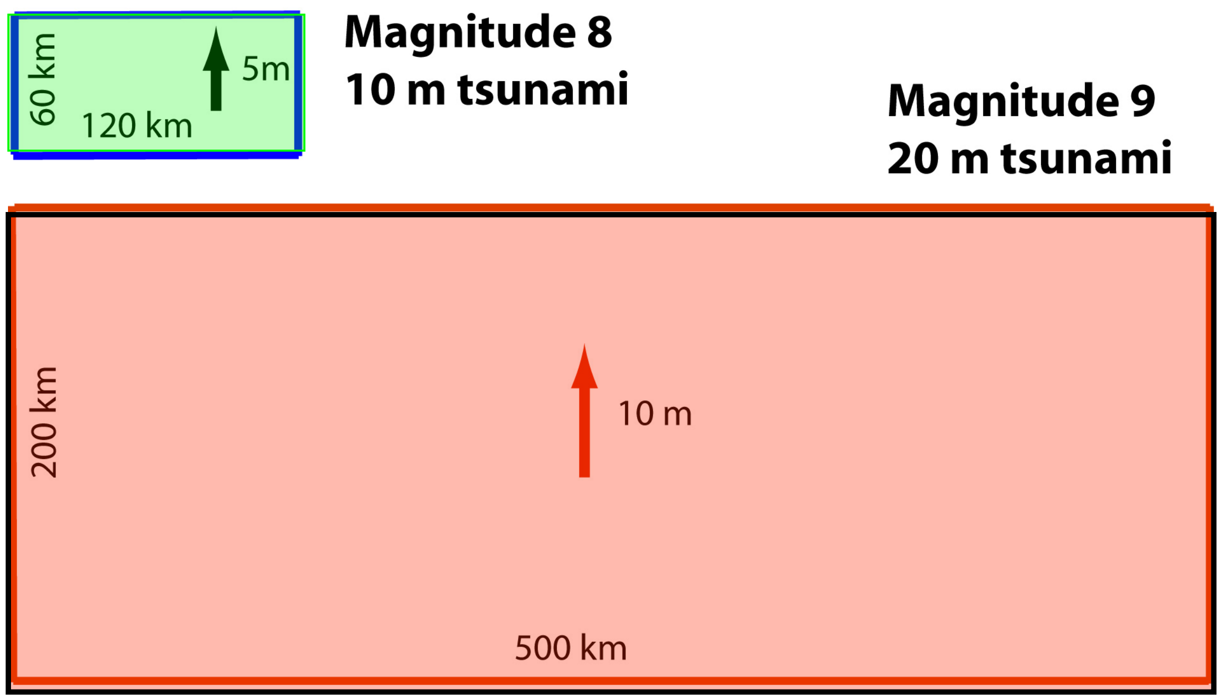


"Estimated magnitude and long-term possibilities within 30 years of earthquakes on regions of offshore based on Jan. 1, 2011."

"Estimated magnitude and long-term possibilities within 30 years of earthquakes on regions of offshore based on Jan. 1, 2008."

Reality...

Planning assumed maximum magnitude 8 Seawalls 5-10 m high



Tsunami runup approximately twice fault slip

M9 generates much larger tsunami

Stein, S. and E. Okal, The size of the 2011 Tohoku earthquake needn't have been a surprise, EOS, 92, 227-228, 2011.

Tsunami Assessment method for NPP in JSCE, Japan

The TSUNAMI EVALUATION SUBCOMMITTEE,
Nuclear Civil Engineering Committee, JSCE

Masafumi Matsuyama (CRIEPI)

Deterministic method (2002)
Main flow chart

Sub flow 1

Verification of fault model(s) and numerical calculation system on the basis of historical tsunami(s)

↓

Sub flow 2

Estimation of the design water levels on the basis of **parametric study** in terms of basis tsunamis

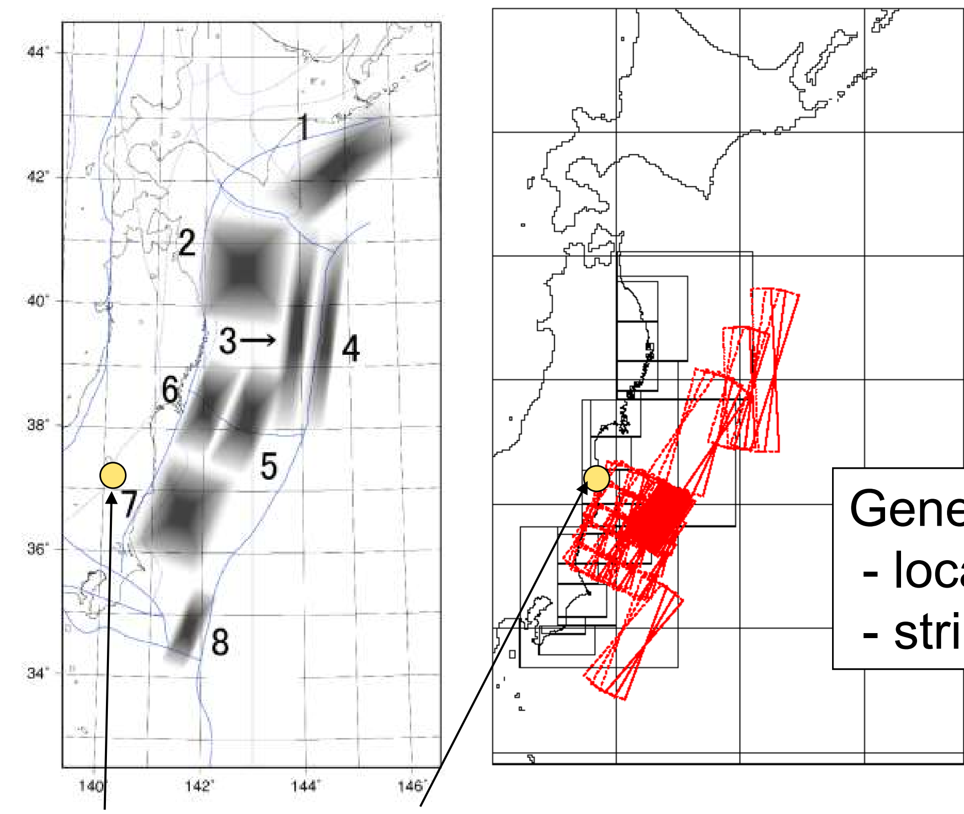
↓

tide → Design high water level
Design low water level

↓

End

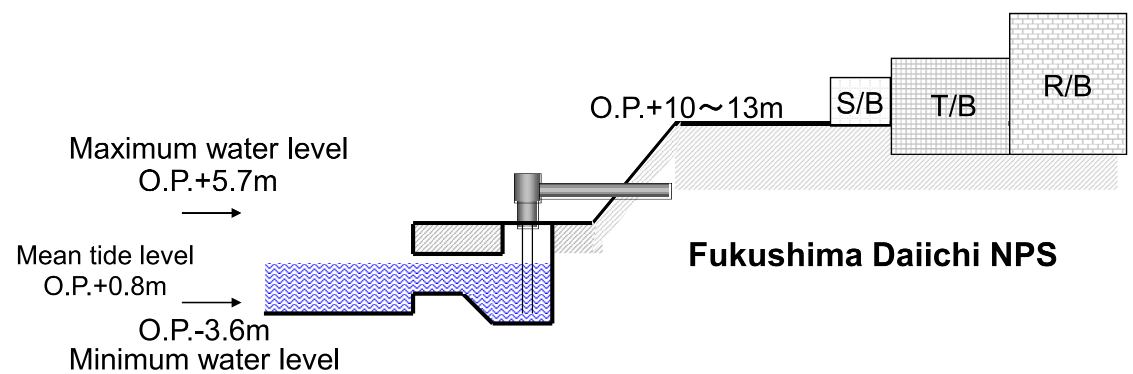
General parametric study in the near field



General parametric study
- location
- strike

Summary of Evaluation

Maximum water level = 4.4m + O.P.＋1.3m = O.P.+5.7m
Minimum water level = -3.6m – O.P.±0.0m = O.P.-3.6m



We assessed and confirmed the safety of the nuclear plants based on the JSCE method which was published in 2002.

Niigata meeting, November 2010
http://www.jnes.go.jp/seismic-symposium10/presentationdata/3_sessionB.html