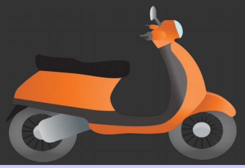
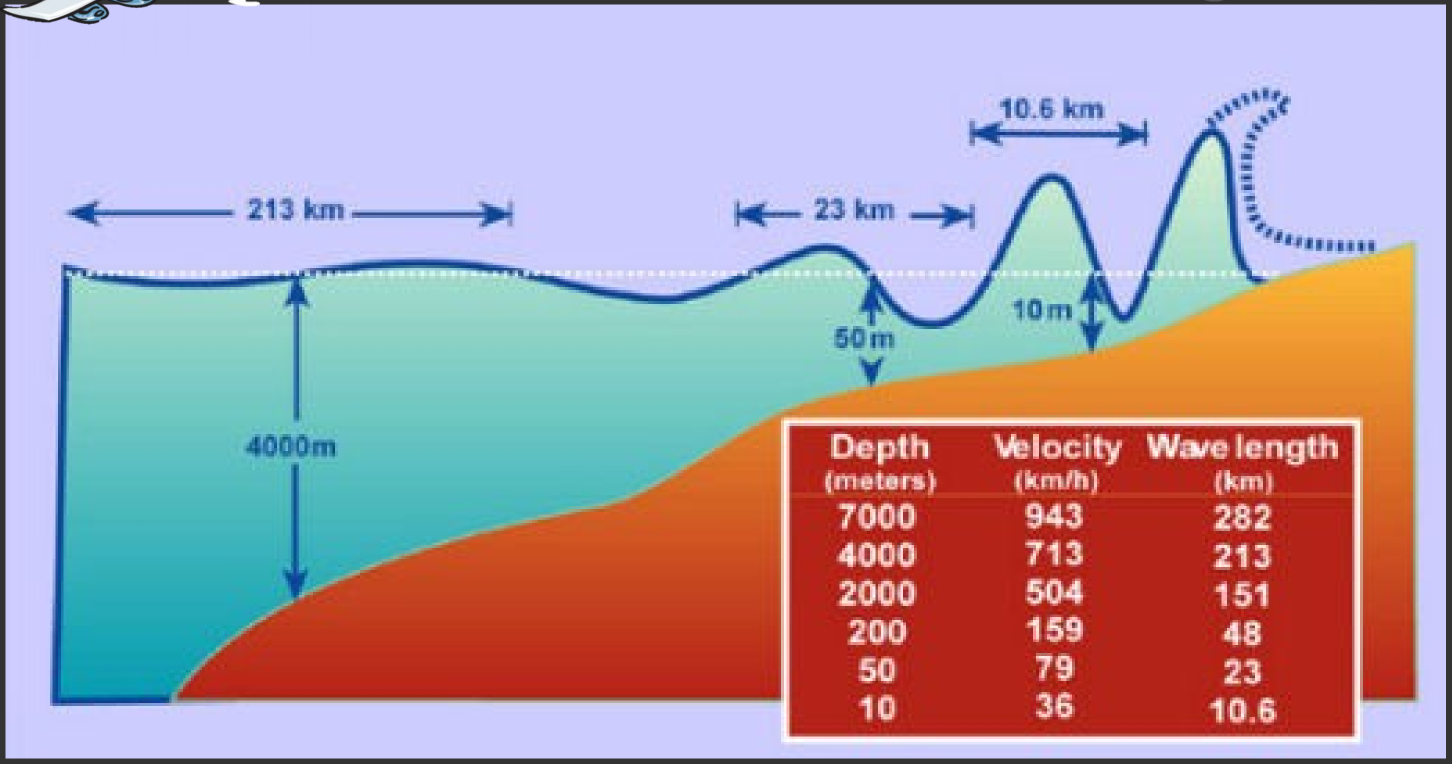
Inversion of tsunami data

A. Sladen – CNRS, Géoazur

DEFINITION

Tsunami waves are gravity wave with a long period
→ need a BIG source !



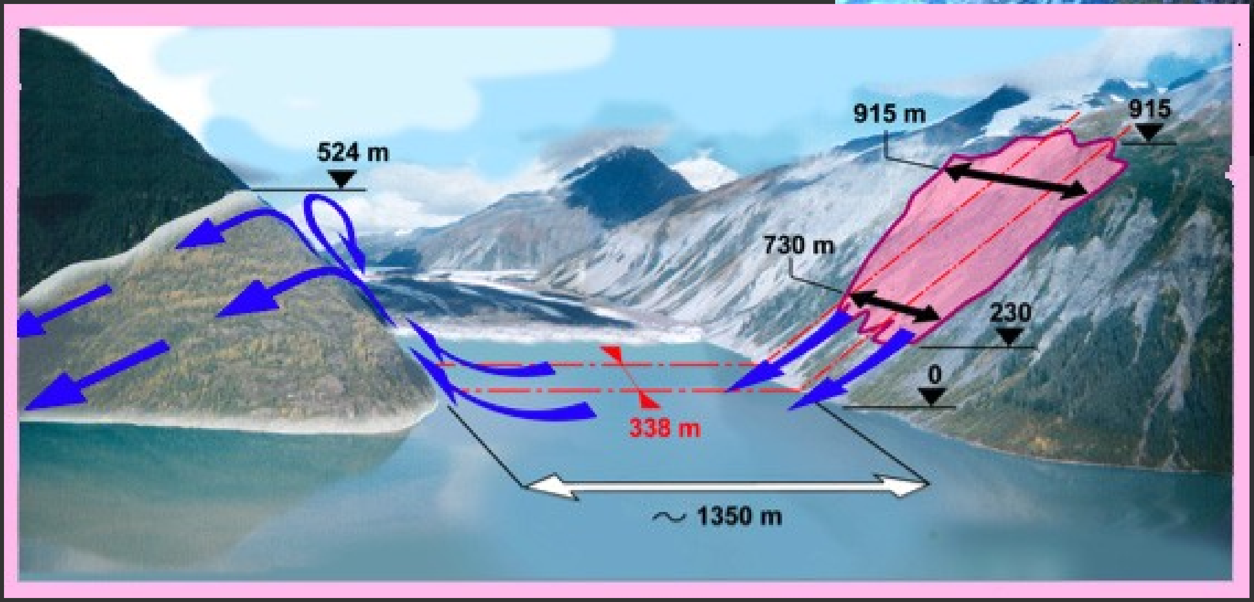


Depth (meters)	Velocity (km/h)	Wave length (km)
7000	943	282
4000	713	213
2000	504	151
200	159	48
50	79	23
10	36	10.6

DEFINITION

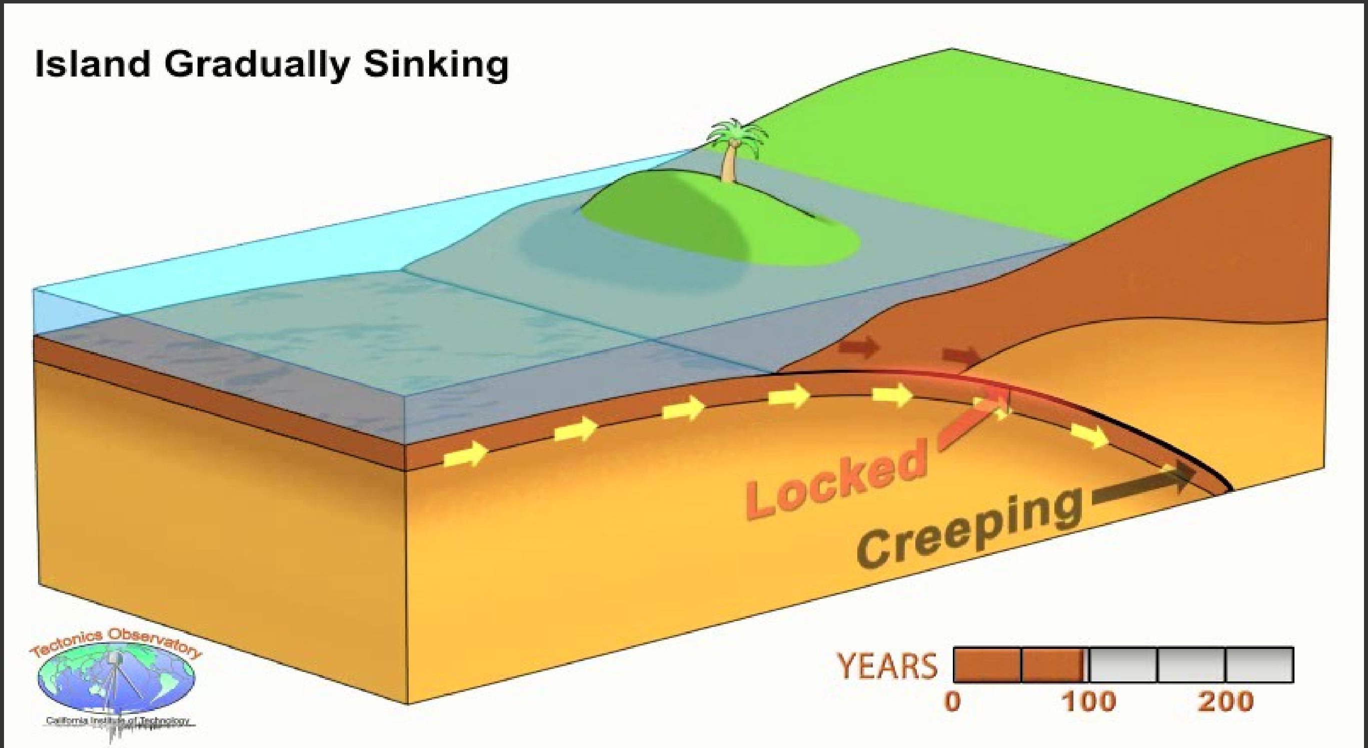
Krakatoa, 1883

Summer 2015,
E.T. pers. comm.



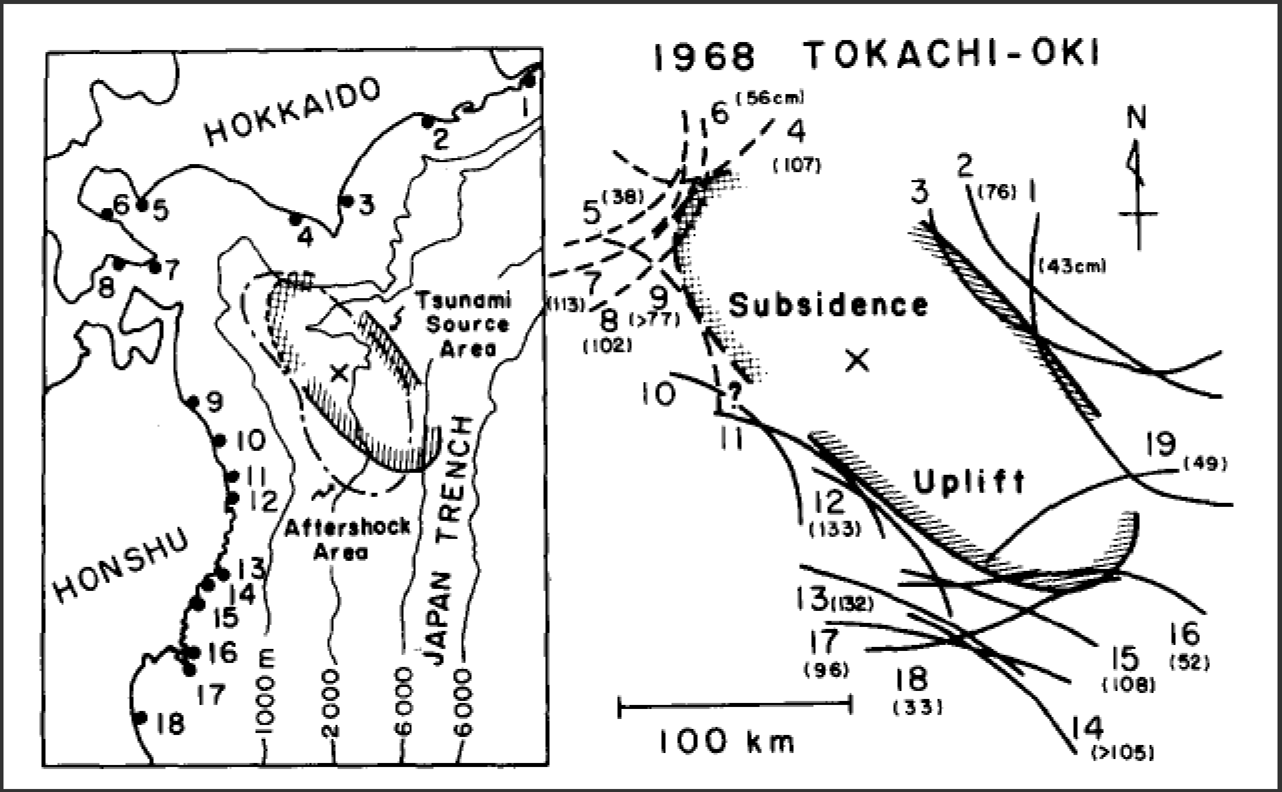
Lituya Bay, Alaska, 1958

DEFINITION



Island Gradually Sinking
Locked
Creeping
YEARS
0
100
200
Tectonics Observatory

M_w8.3 Tokachi-Oki 1968

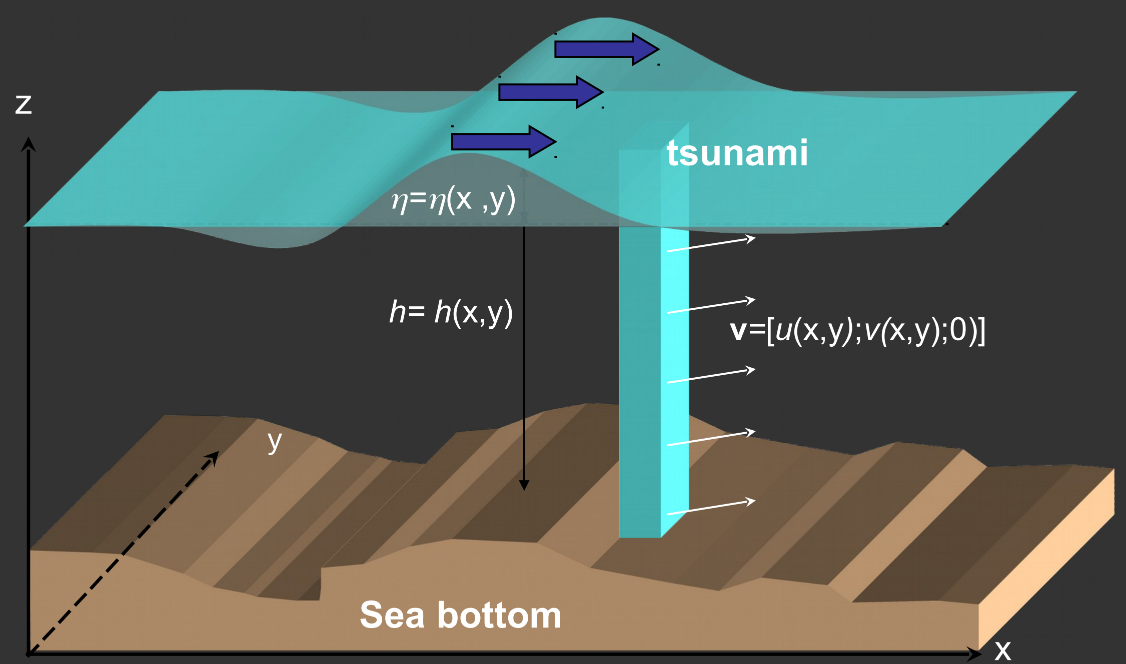


K.Abe,1973

Tsunami equations

L I N E A R

- Assume full-instantaneous transfer of deformation to water column (incompressible)
- Shallow-water equations: depth-average Navier-stokes for long wavelengths (vs depth), only force is gravity, no viscous effect
- linear long wave (λ >> *h)* leads to : $c = \sqrt{gh}$



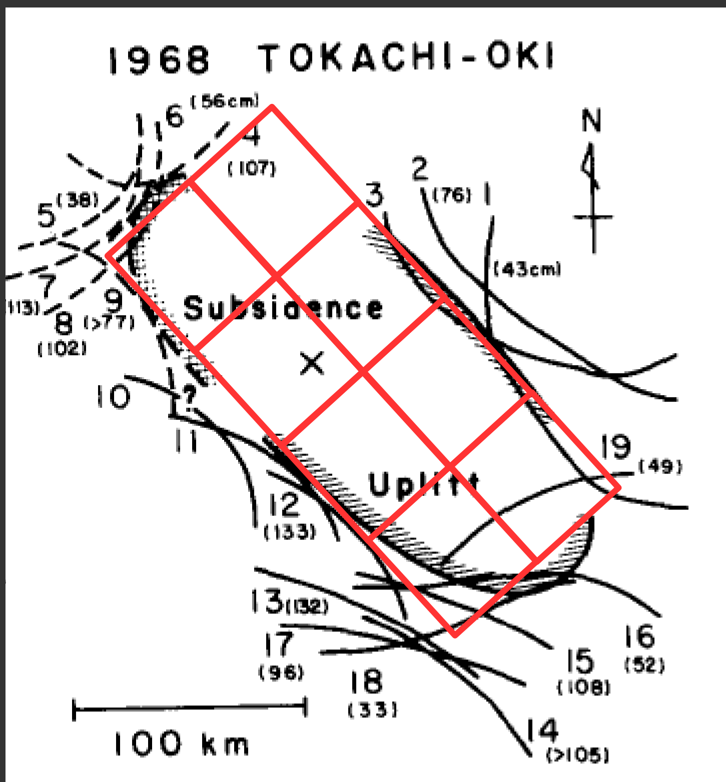
$$\frac{\partial(\eta + h)}{\partial t} + \nabla.\left[\mathbf{v}(\eta + h)\right] = 0$$

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}.\nabla)\mathbf{v} = -\mathbf{g}.\nabla\eta + \Sigma\mathbf{f}$$

g gravity
v horizontal velocity
η **sea surface height**

Tokachi-Oki 1968

Inversion for seafloor deformation



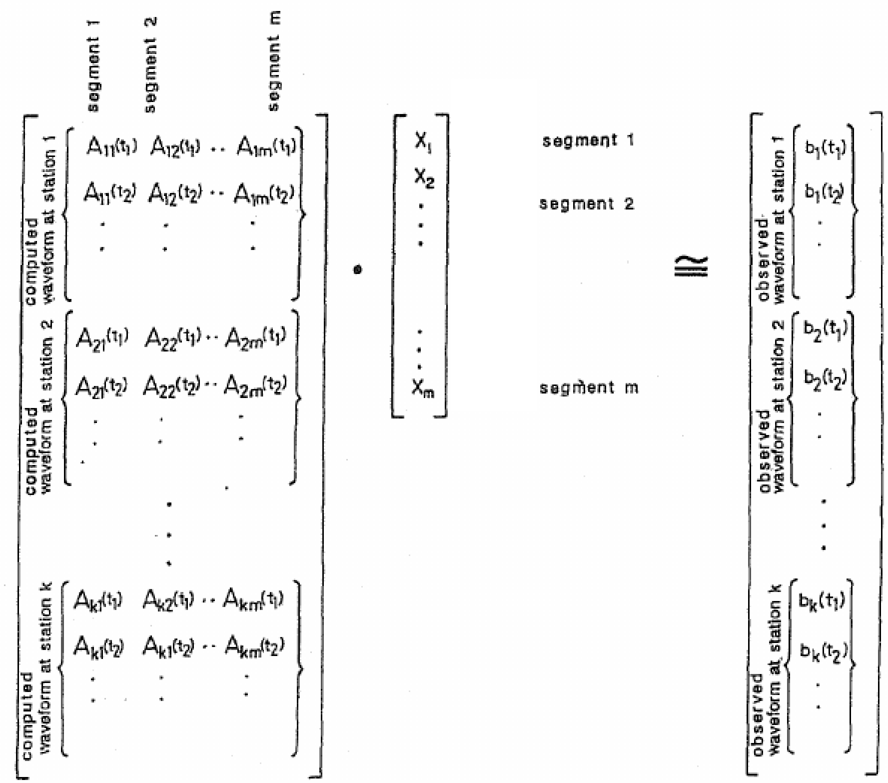
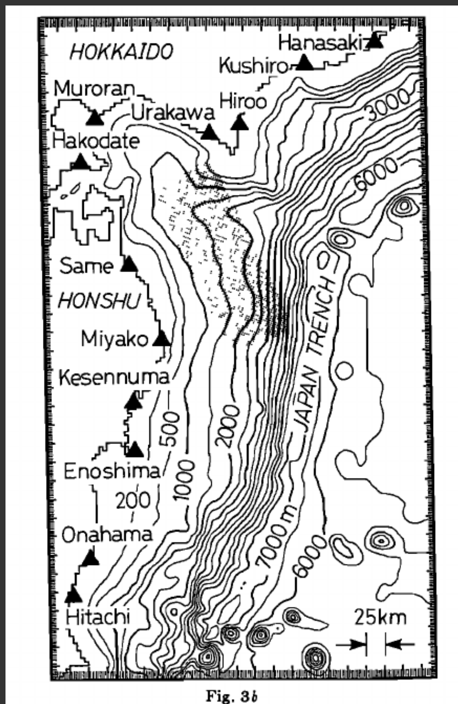


Fig. 4. Matrix representation of Eq. (4).

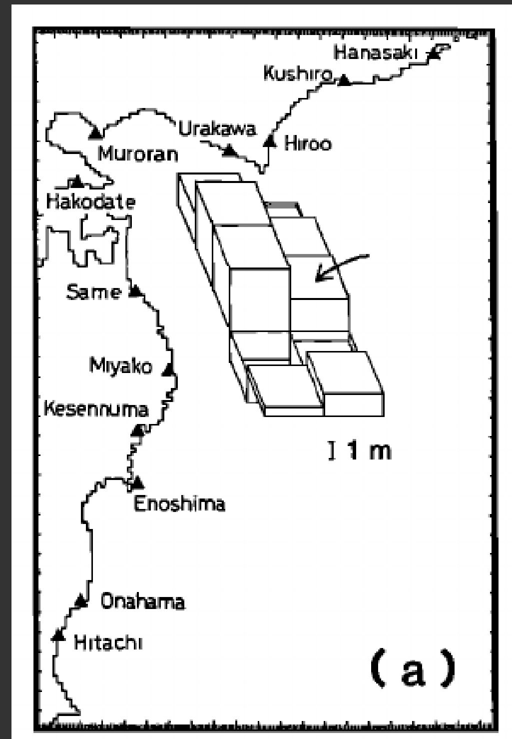
$$A_{ij}(t) \cdot x_j = b_i(t) \quad (4)$$

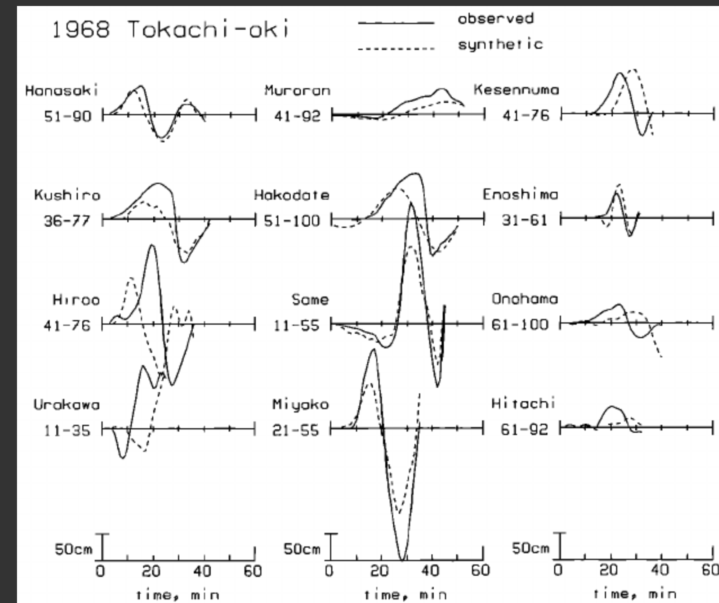
Satake, 1987

Tokachi-Oki 1968



bathymetric grid
resolution ~2.5km





<u>One big limitation</u>

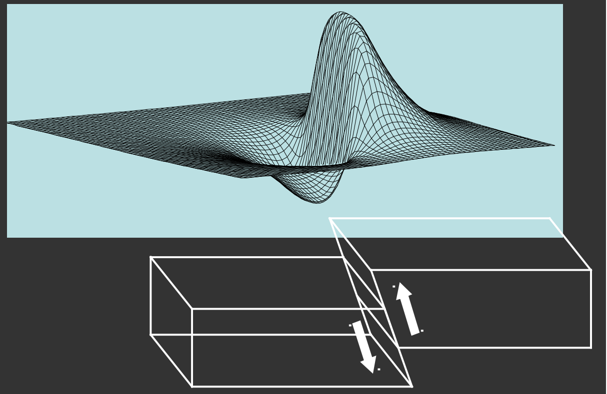
Inversion of tide gauge records ~linear only if large event and inverting 1st oscillation. Tide gauge should not be hidden deep inside a harbor maze

Satake,1989

Tsunami data inversion

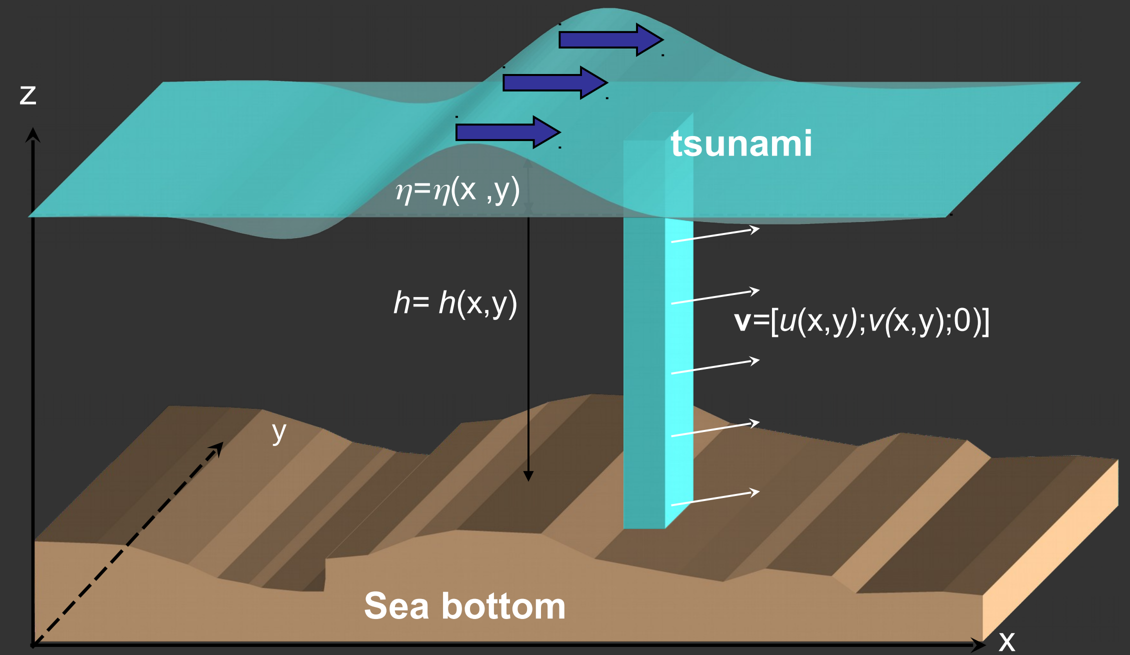
L I N E A R

- Sea-floor deformation caused by earthquake elastic dislocation (e.g. with Okada[1985])
- Assume full-instantaneous transfer of deformation to water column (incompressible)
- Shallow-water equations: depth-average Navier-stokes for long wavelengths
- linear long wave ($\lambda >> h$) leads to : $c = \sqrt{gh}$



$M_0 = \mu ULW$

M_0 seismic moment
U displacement
μ rigidity
L (W) *fault length* (wdth)

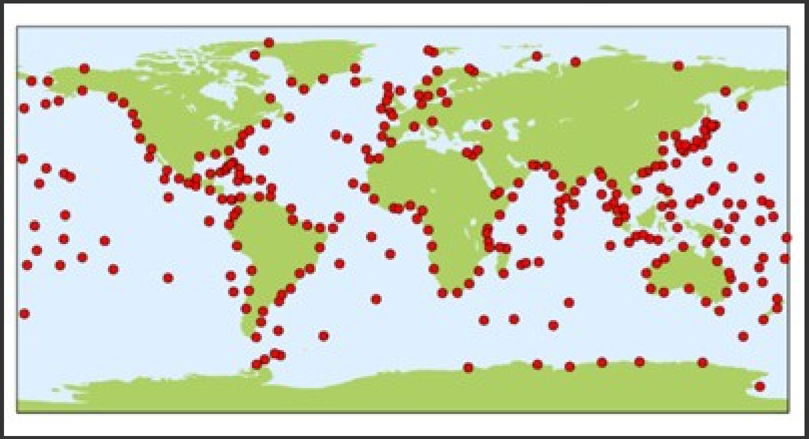


$$\frac{\partial(\eta + h)}{\partial t} + \nabla\left[\mathbf{v}(\eta + h)\right] = 0$$

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}.\nabla)\mathbf{v} = -\mathbf{g}.\nabla\eta + \Sigma\mathbf{f}$$

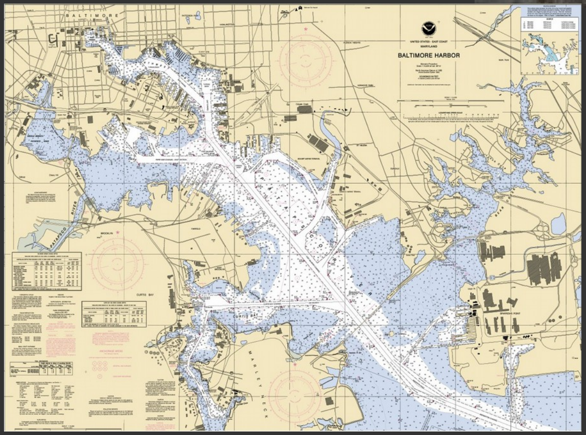
g gravity
v horizontal velocity
η **sea surface height**

Tide gage data today

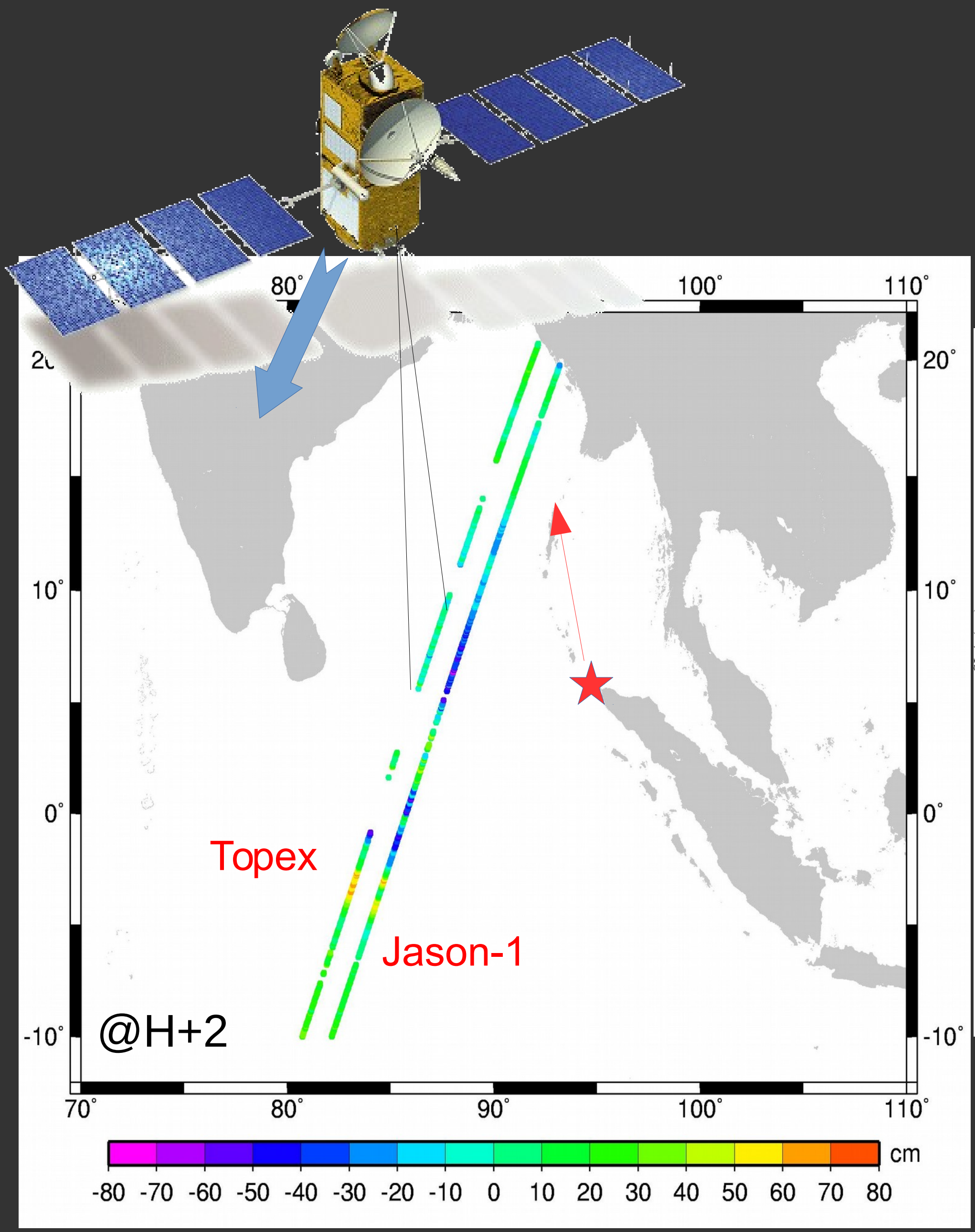


- ✔ Good global coverage,
- ✔ increasing number of stations with rapid sampling (>1/10min),

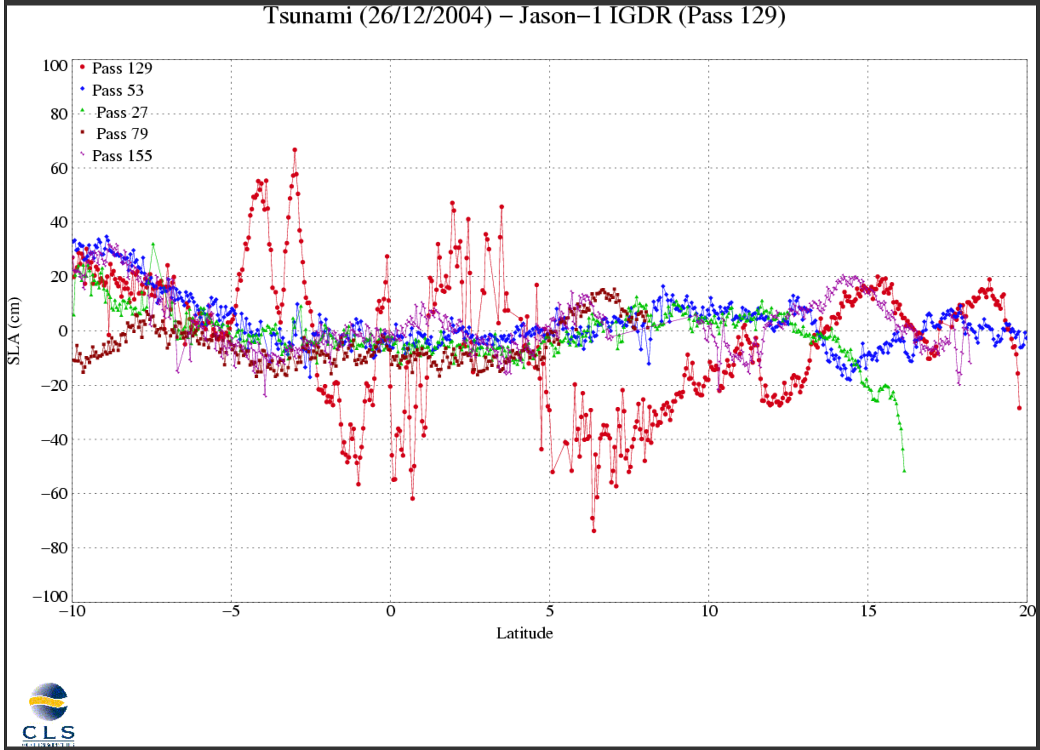
- ✗ cannot record big waves,
- ✗ deep inside harbors, bays to record only tides



Altimetry data of M9.2 Sumatra 2004

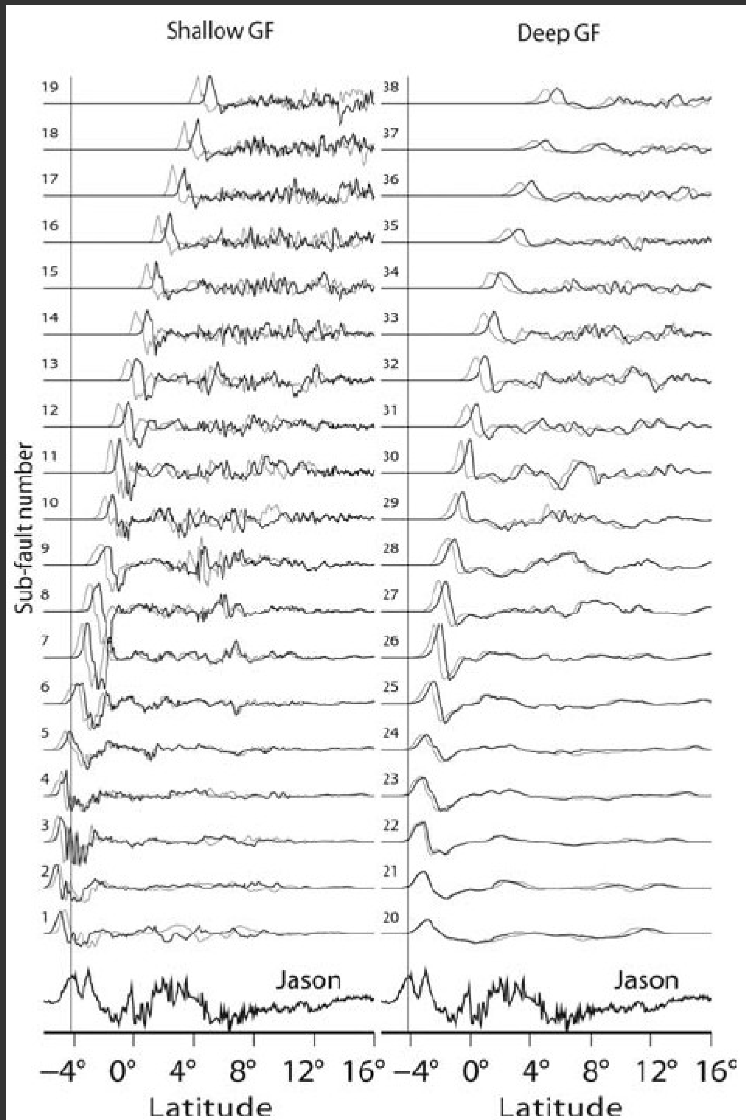


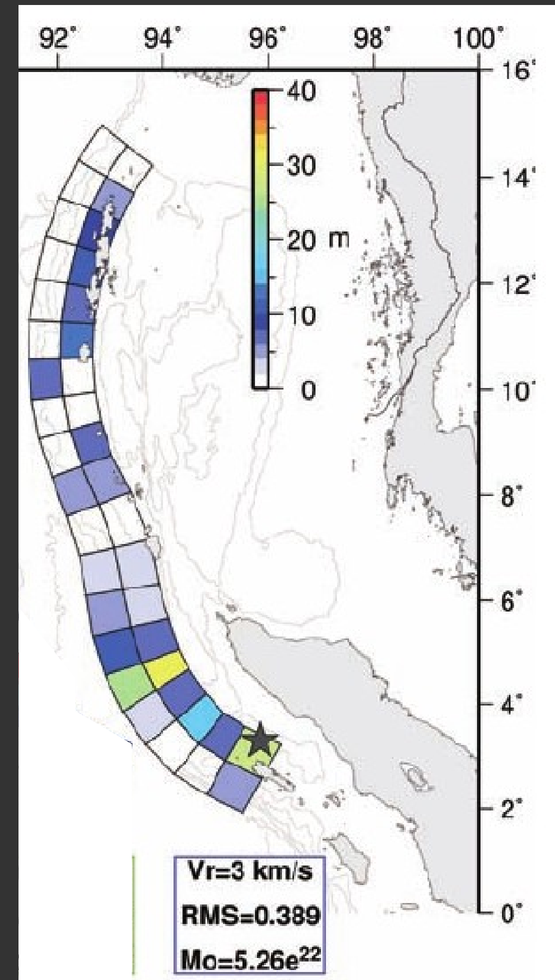
No coastal, harbor propagation effects !

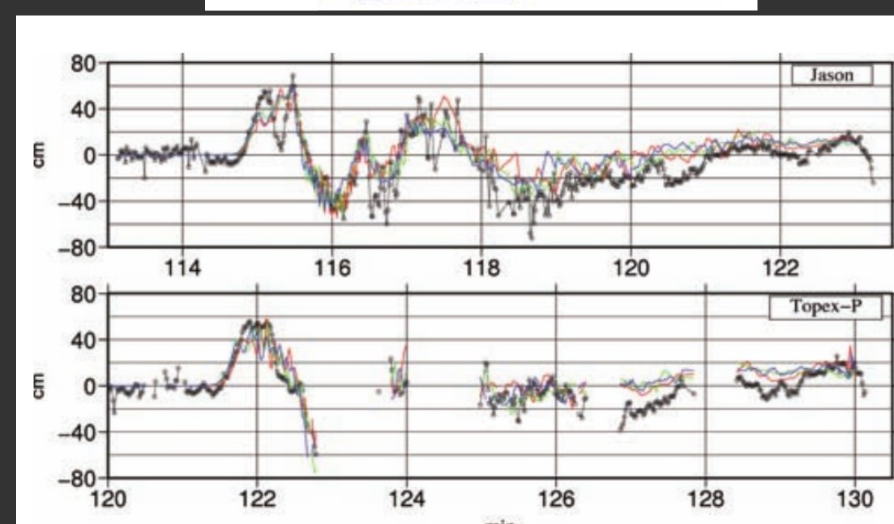


...but quite noisy data

Inversion illustrated



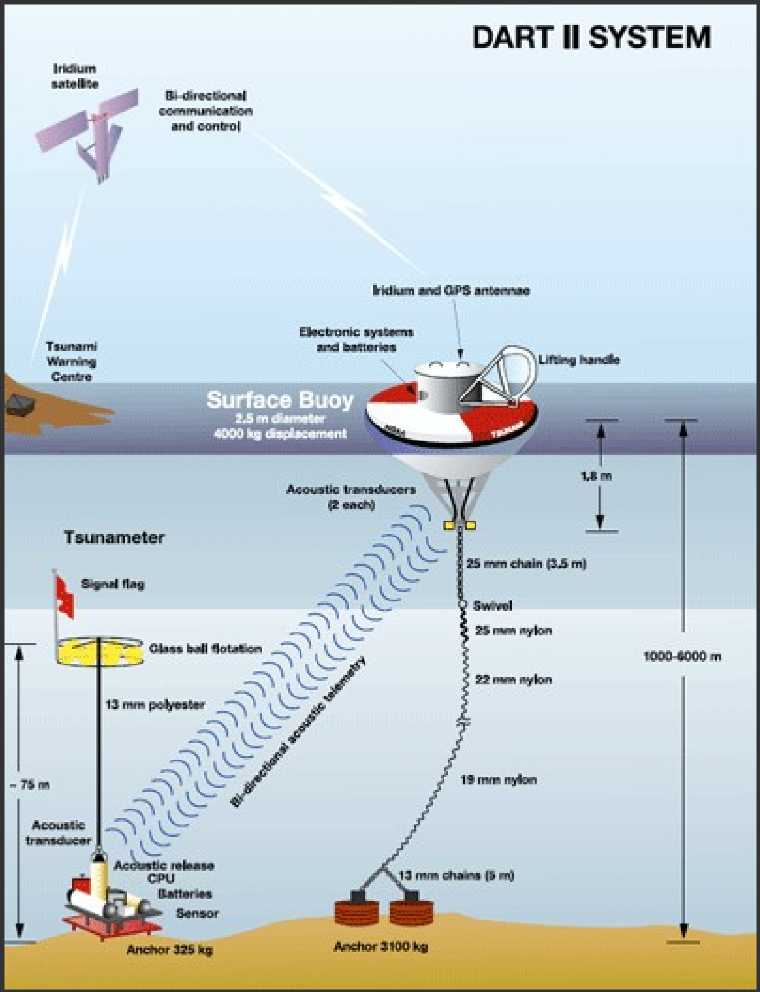




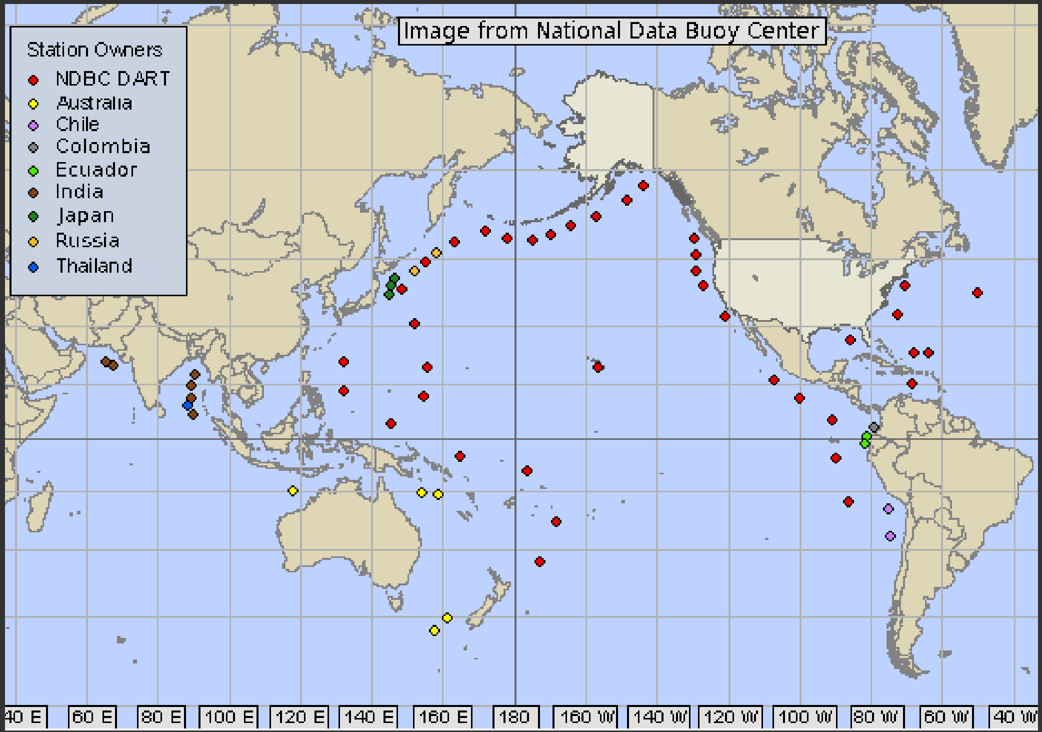
Sladen & Hebert, 2008

Tsunami data

- Sumatra 2004 triggered the fast development of deep-ocean pressure sensors « DART© buoys »



No effect of surface wave currents

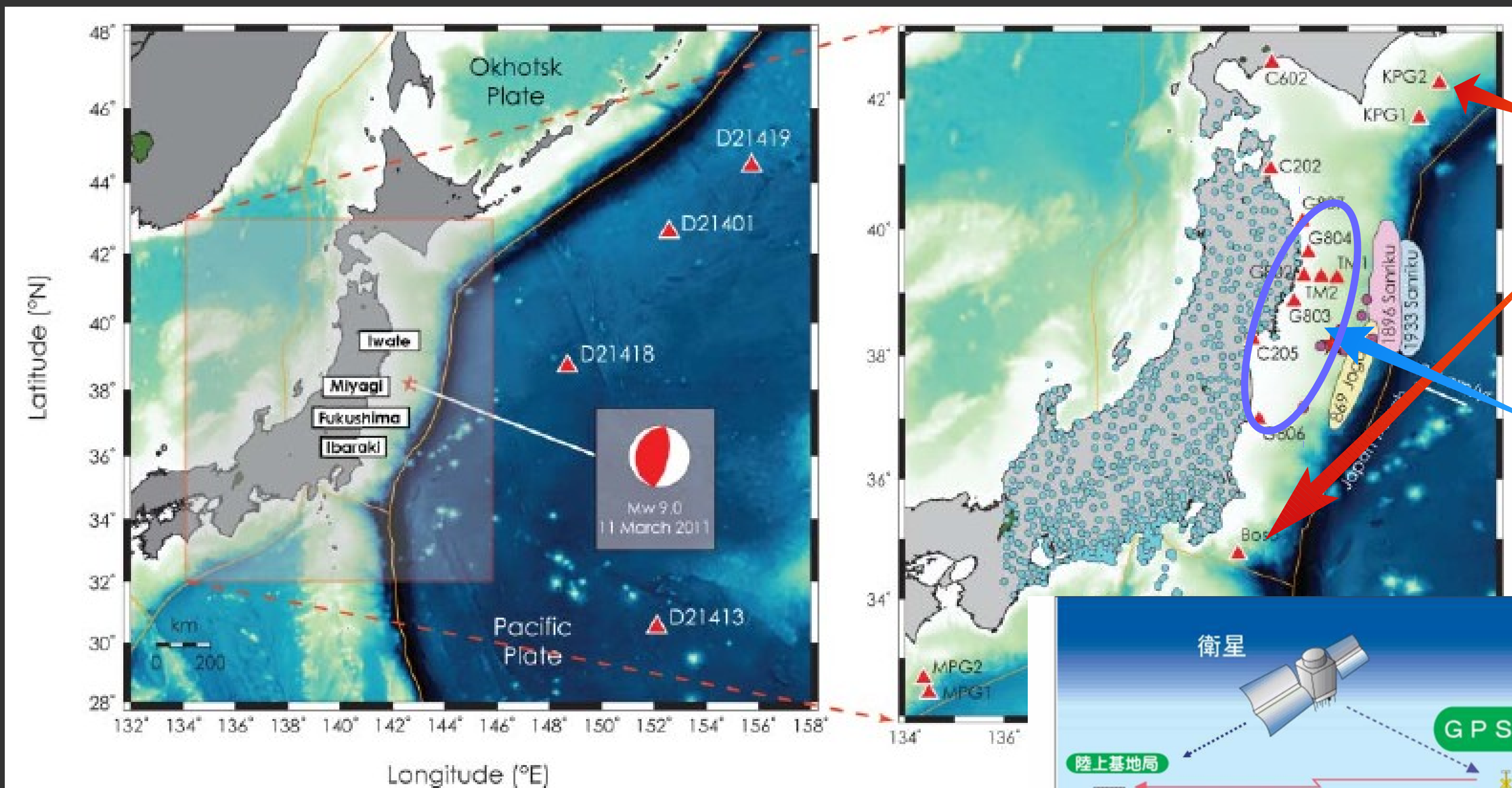


Today's situation ($$)

Data directly available online (link)
More and more source studies using these records

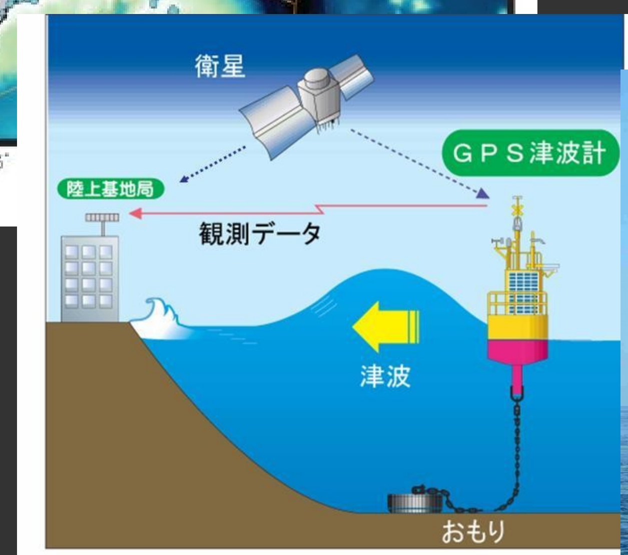
2011 M_w9.0 Japan earthquake

Buoys with pressure sensors



Cabled pressure sensors (1sps)

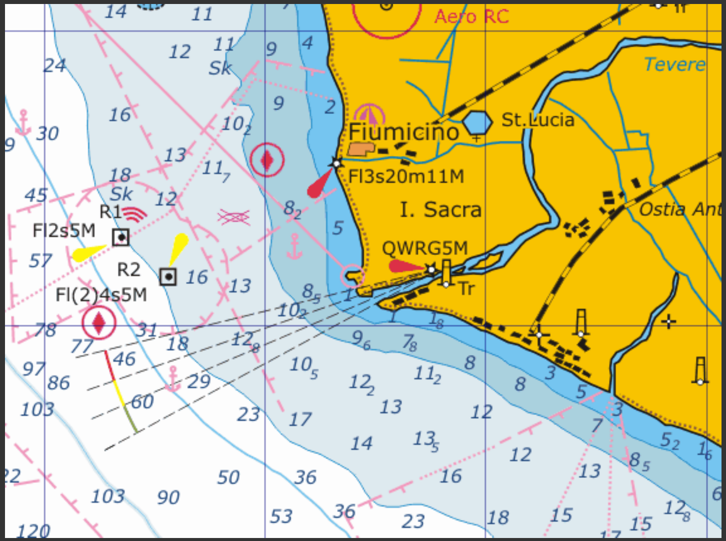
GPS buoy



Almost complete azimuthal coverage of the source!

Bathymetry data

- GEBCO_2014 : a global 30 arc-second (<1km) interval grid based on global altimetry data, nautical charts and bathymetric sounding
- Otherwise → digitize nautical charts ☹

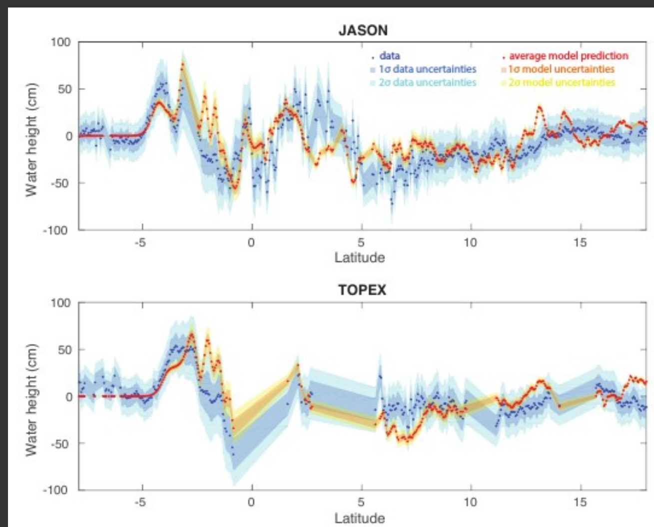


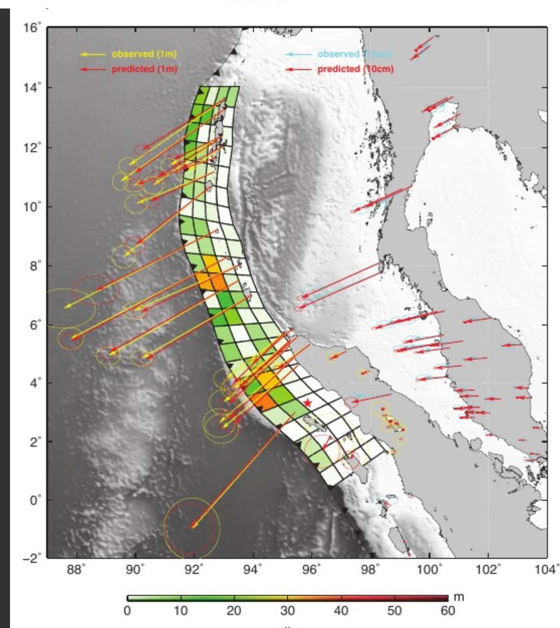
Inversion of tsunami data

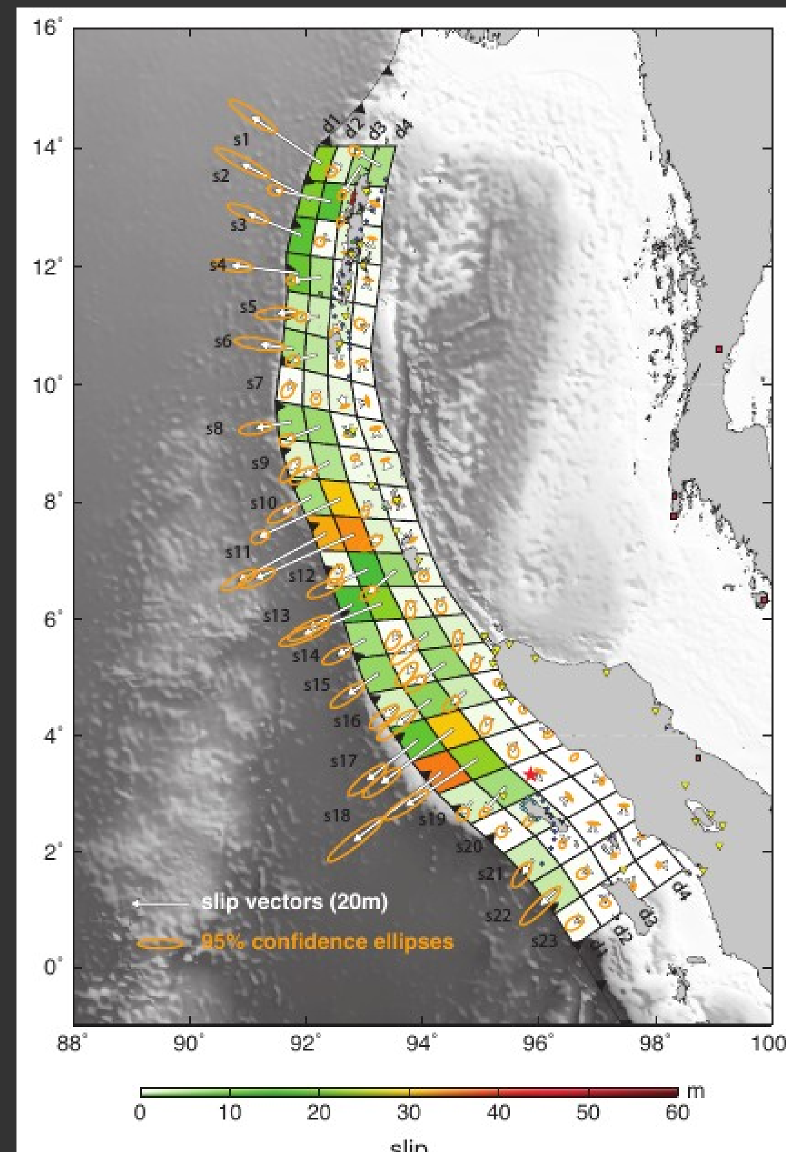
- Advantages :
  - linear problem (for the most part),
  - absolute time!!
  - directly probing of sea-bottom deformation, even if rupture is far offshore!!
  - slow enough to assume static source (in most cases): V_{tsu}~200m/s and Vr~3km/s

Satake, 1987

POSTER on Sumatra 2004 bayesian inversion of tsunami and geodetic data







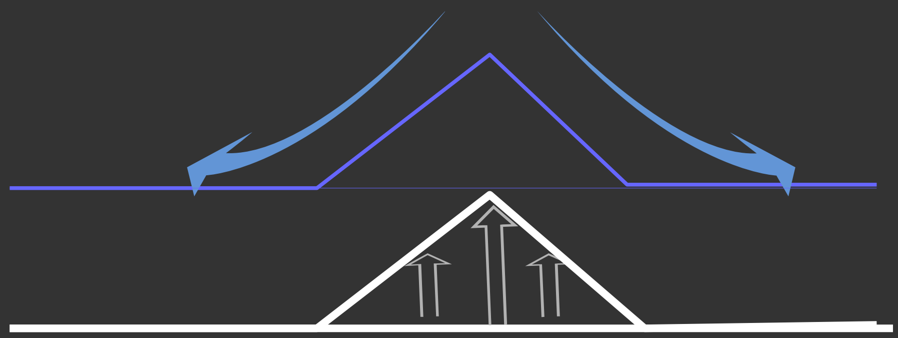
Bletery et al., in prep

Corrections and limitation

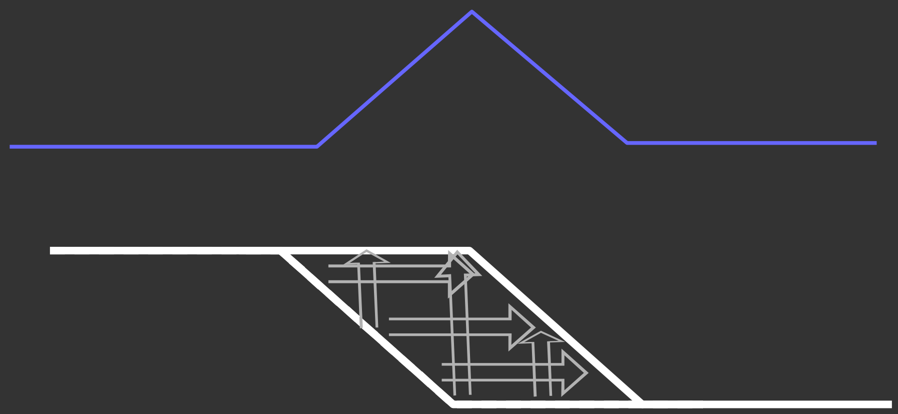
Things you have to check if you get into the buisness

- Water filters freq>depth*3 (Kajiura, 1963)
- If steep bathymetry: extra vertical displacement from horizontal motion,
- Low and high frequency dispersion,

Bathymetry effect



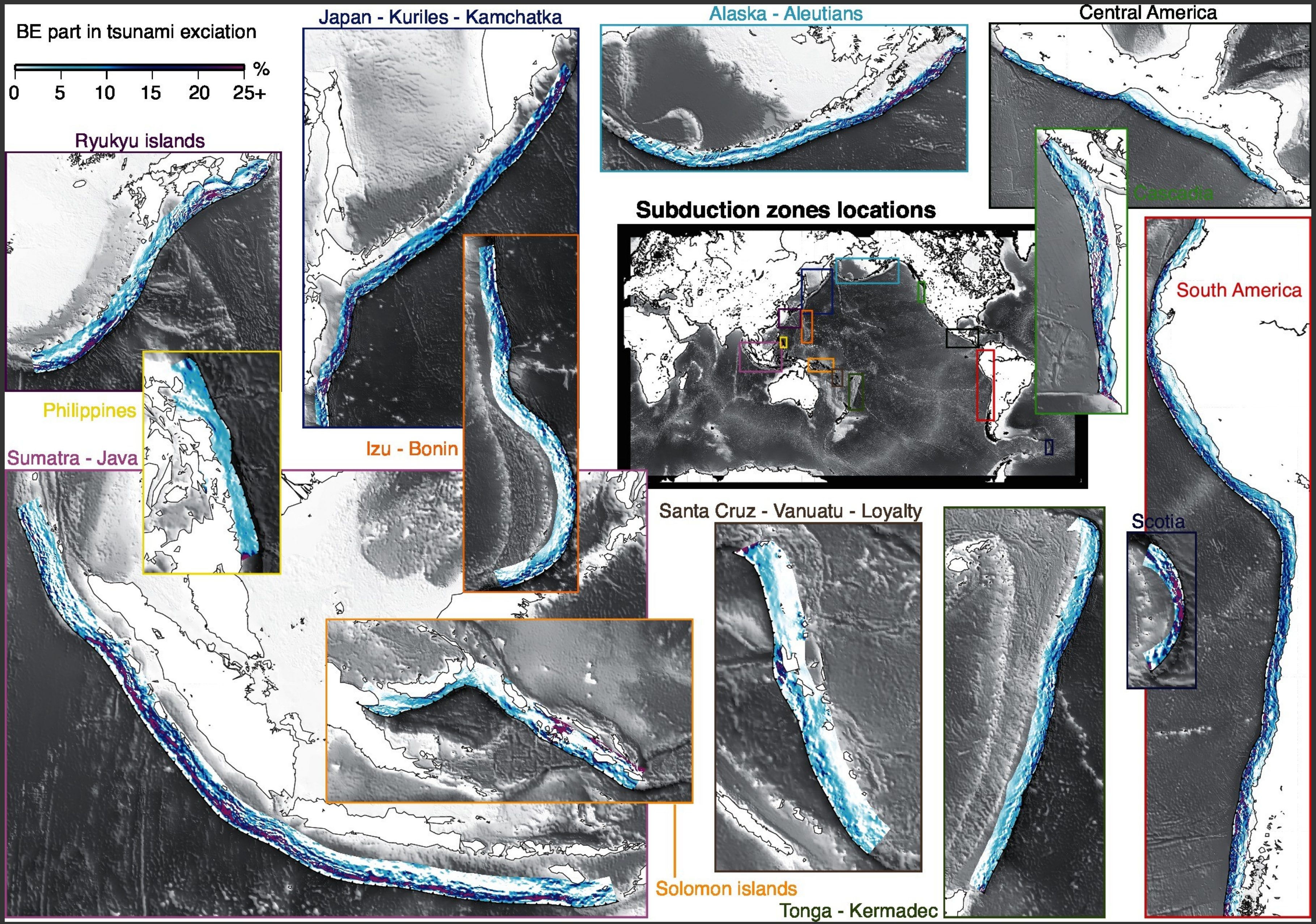
Vertical deformation



Vertical deformation
from horizontal motion

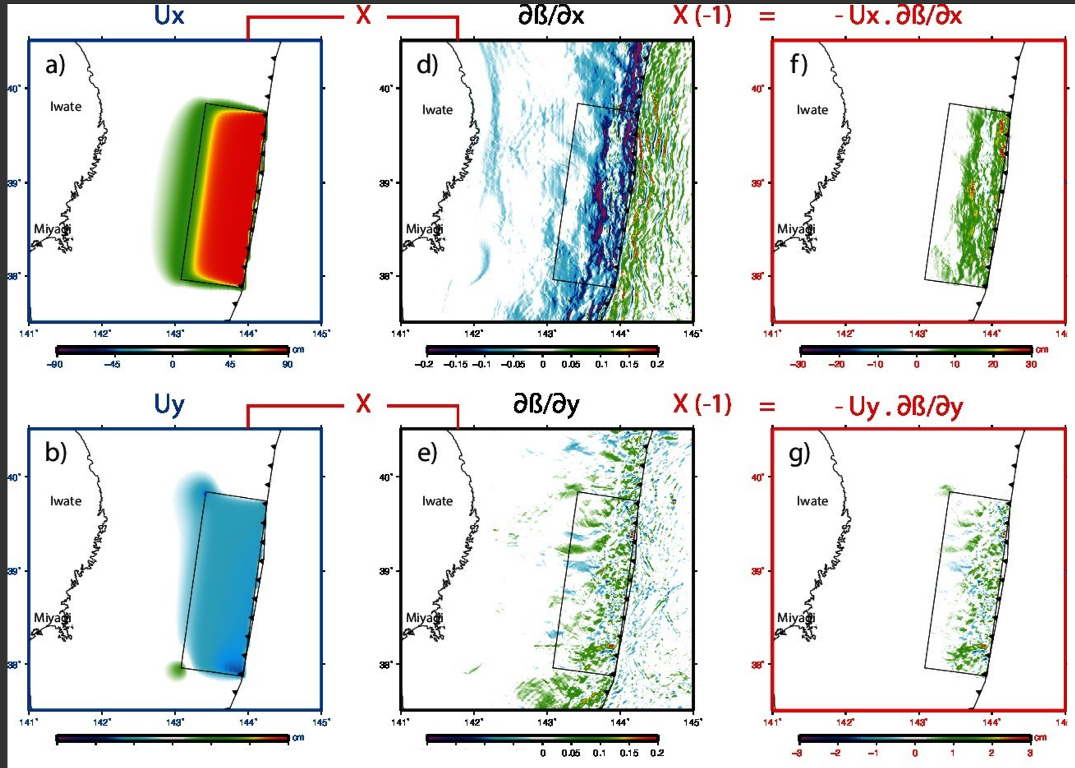
Tanioka and Satake [1996]

Bathymetric effect at global scale



Bletery et al., 2015

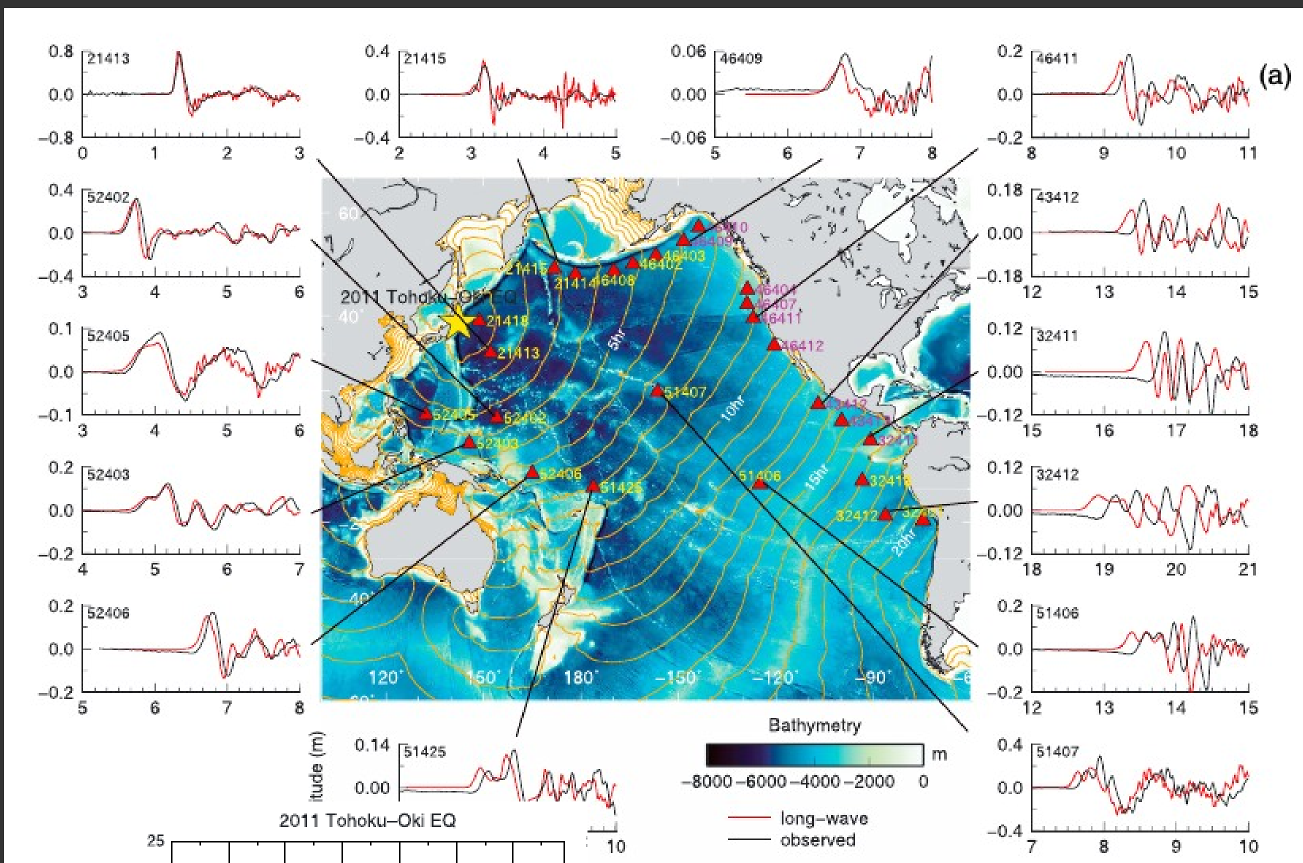
Improving Earth-tsunami coupling

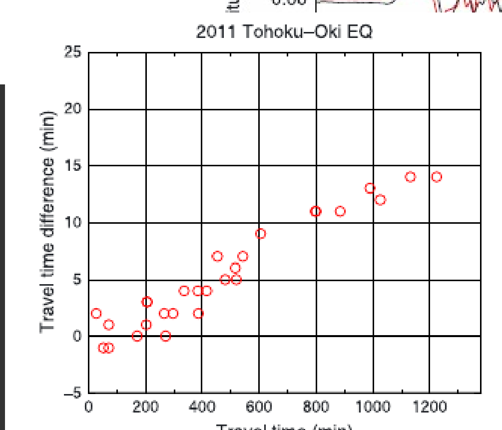


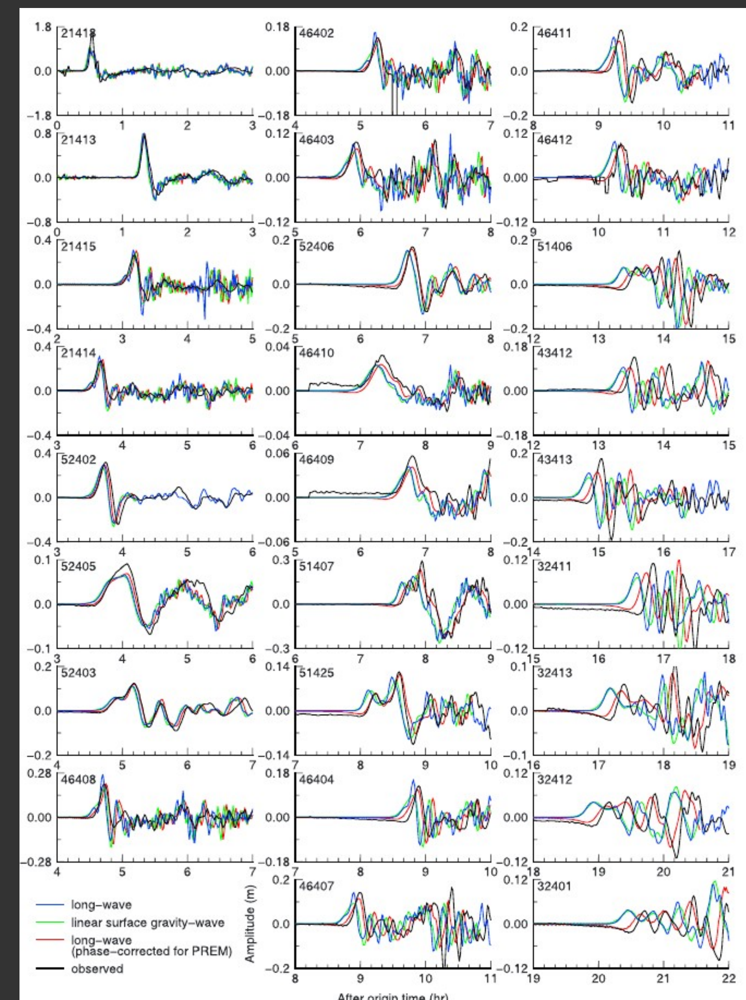
Low frequency dispersion

Dispersion caused by elastic loading
Tsunami speed reduction due to vertical seawater stratification

After correction from 1D Earth dispersion curves







S.Watada JGR 2014

Summary on tsunami data

- Tsunami data are critical to characterize old/future subduction earthquakes,
- “Simple” as geodetic data for earthquakes occurring offshore

And now:

- Dvlpt to improve physics in the models, with faster more efficient simulations,
- deep-ocean buoy program is expensive: different group exploring alternatives...

SIMULATION CODES

- Tunami (Univ. Tohoku): FD shallow-water eq., multi-grid, bottom roughness,
- COMCOT (Univ. Cornell): FD shallow-water eq., multi-grid, bottom roughness,
- Geoclaw (Univ. Washington): subpackage of Clawpack for tsunami. FV shallow-water, adaptative mesh,
- NEOWAVE (Univ. Hawaii) : FD non-hydrostatic SW equations, 2-way nested grid. Distributed upon request.

Summary


SAFETY NET
To detect tsunamis, Japan plans to deploy 154 observing posts linked by sea-floor cables by 2016. This year, it will install three buoys that will relay information from deep-sea tsunami sensors.
Okhotsk plate
Eurasian plate
Kesennuma
Sendai
Pacific plate
JAPAN
Tokyo
Philippine plate
Planned buoys
Planned seismometer and tsunami meter
Deployed seismometer
Deployed tsunami meter