Inversion of tsunami data

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DEFINITION
Tsunami waves are gravity wave with a long period → need a BIG source!
Krakatoa, 1883

Lituya Bay, Alaska, 1958

Summer 2015, E.T. pers. comm.
DEFINITION
Mw 8.3 Tokachi-Oki 1968

K. Abe, 1973
Tsunami equations

- 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 ($\lambda >> h$) leads to:

$$c = \sqrt{gh}$$

\[\begin{align*}
\frac{\partial (\eta + h)}{\partial t} + \nabla [v(\eta + h)] &= 0 \\
\frac{\partial v}{\partial t} + (v \cdot \nabla)v &= -g \nabla \eta + \Sigma f
\end{align*}\]

- $g$ gravity
- $v$ horizontal velocity
- $\eta$ sea surface height
Tokachi-Oki 1968

Inversion for seafloor deformation

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

\[ A_{ij}(t) \cdot x_j = b_i(t) \]  

Satake, 1987
Tokachi-Oki 1968

One big limitation
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

- 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 ($\lambda \gg h$) leads to:

\[ c = \sqrt{gh} \]

\[ M_0 = \mu ULW \]

- $M_o$: seismic moment
- $U$: displacement
- $\mu$: rigidity
- $L(W)$: fault length (width)

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

\[ \frac{\partial v}{\partial t} + (v \cdot \nabla)v = -g \nabla \eta + \Sigma f \]

- $g$: gravity
- $v$: horizontal velocity
- $\eta$: 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 »

Data directly available online (link)
More and more source studies using these records
2011 $M_w 9.0$ 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): $V_{\text{tsu}} \sim 200 \text{m/s}$ and $V_r \sim 3 \text{km/s}$
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 business

- 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
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.