Tsunami wave modeling

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« La Fondation des Treilles »

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Outline

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1. Tsunami wave energy
2. Co-seismic sea bed deformation
3. Perspectives

Energy of tsunamis

There is no common definition

Some references :

1. S. Tinti & E. Bortolucci. *Energy of Water Waves Induced by Submarine Landslides*. Pure Appl. Geophys. 157 (2000)
2. Z. Kowalik et al. *The Tsunami of 26 December 2004 : Numerical Modeling and Energy Considerations*. 22nd IUGG International Tsunami Symposium (2005)
3. T. Murty et al. *Leakage of the Indian Ocean Tsunami Energy into the Atlantic and Pacific Ocean*. J. Canadian Association of Exploration Geophysicists (2005)
4. A. Velichko et al. *Amplitude-energy characteristics of tsunami waves for various types of seismic sources generating them*. Physical Oceanography (2002)

Tsunami magnitude

Divergence in the definition

There exist at least **seven** different definitions :

Papadopoulos, Imamura (2001) : 12-point descriptive tsunami intensity scale. This scale is not related to any quantitative physical parameters.

Abe & Hatori (1985) : $M_t := a \lg h + b \log \Delta + c$

Kanamori (1972) : $M_w = \frac{2}{3}(\lg M_0 - 16.1)$

Murty & Loomis (1980) : $ML := 2(\lg E - 19)$

B. Levin, M. Nosov. *Physics of tsunamis*, Springer, 2009

...The definition of magnitude based on the wave energy is, naturally, the most adequate definition, from a physical point of view. However, it is not always possible to calculate the wave energy...

Long wave energy equation

NSW2E : Nonlinear Shallow Water Equations with Energy

- Mass conservation

$$H_t + \nabla \cdot (H\vec{u}) = 0$$

- Momentum conservation

$$(H\vec{u})_t + \nabla \cdot \Big(H\vec{u} \otimes \vec{u} + \frac{g}{2} H^2\Big) = gH\nabla h$$

- Energy equation

$$E_t + \nabla \cdot \Big(\Big(E + \frac{1}{2}\rho g H^2 - \frac{1}{2}\rho g h^2\Big)\vec{u}\Big) = \rho g (H - h)\zeta_t$$

Reference :

D. Dutykh & F. Dias. *Energy of tsunami waves generated by bottom motion*. Proc. R. Soc. A., **465**, 725–744, 2009

Energy reconstruction

Computation of the total energy from NSWE solutions

Why to add a supplementary energy equation ?

1. We solve NSWE $\Rightarrow (h, H, \vec{u})$
2. Using this information, we approximate the energy density :

$$E \approx \frac{1}{2}\rho H|\vec{u}|^2 + \frac{1}{2}\rho g \eta^2$$

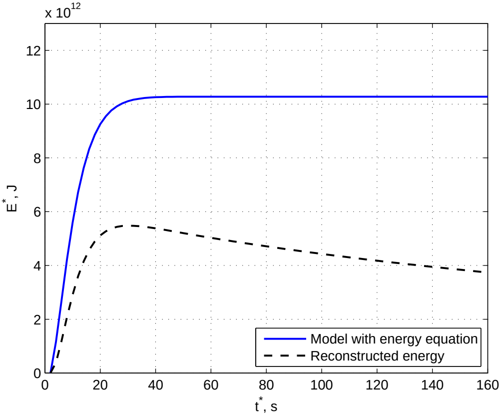
3. To obtain the total **wave** energy, we integrate over the domain Ω :

$$\mathbb{E}(t) = \iint_\Omega E(\vec{x}, t)d\vec{x}$$

Let us compare two methods. . .

Total energy

Comparison between two ways of energy computation



Reference :

D. Dutykh & F. Dias. *Energy of tsunami waves generated by bottom motion*. Proc. R. Soc. A., **465**, 725–744, 2009

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Tsunami generation problem

Illustrated on the exampe of 2006, July 17 Java event (M 7.7)

Main purpose of tsunami generation :

Provide an initial condition (free surface elevation and fluid velocity field) for tsunami propagation and runup codes

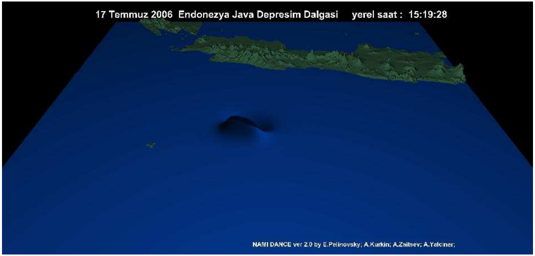


FIG.: by A. Yalciner, E. Pelinovsky et al.

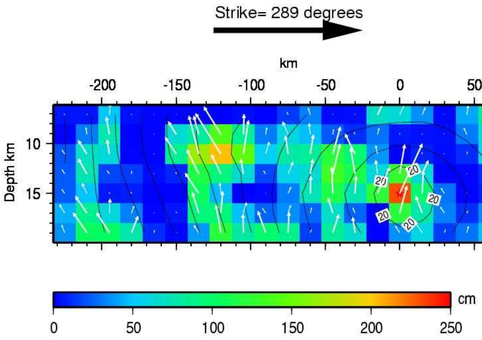
One (sometimes more) computation of Okada solution (1985)

Finite fault solution

C. Ji, D.J. Wald, D.V. Helmberger. *Bull. Seism. Soc. Am.*, 2002

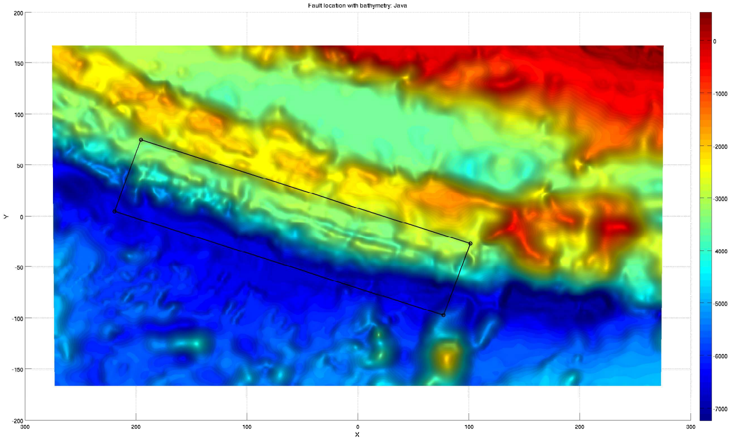
Based on :

- Waveform inversion by finite fault inverse algorithm
- Hypocenter of the USGS
- Fault planes by HARVARD quick moment tensor solution



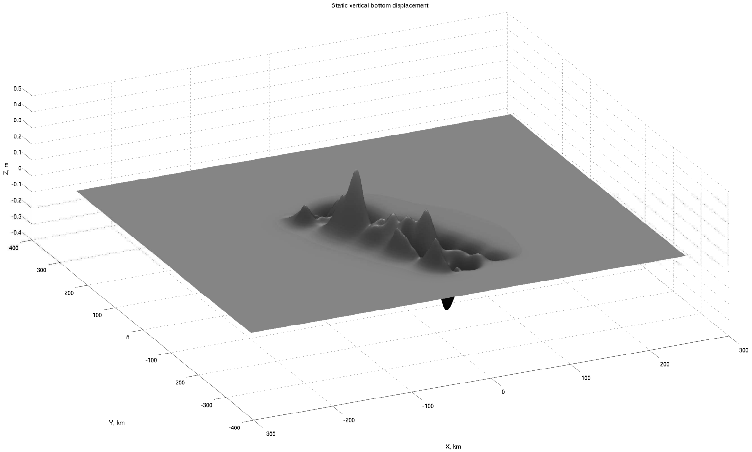
July 17, 2006 Java event

Fault location and bathymetry data (ETOPO1)



Static coseismic vertical displacement

Using finite fault data



Static coseismic vertical displacement

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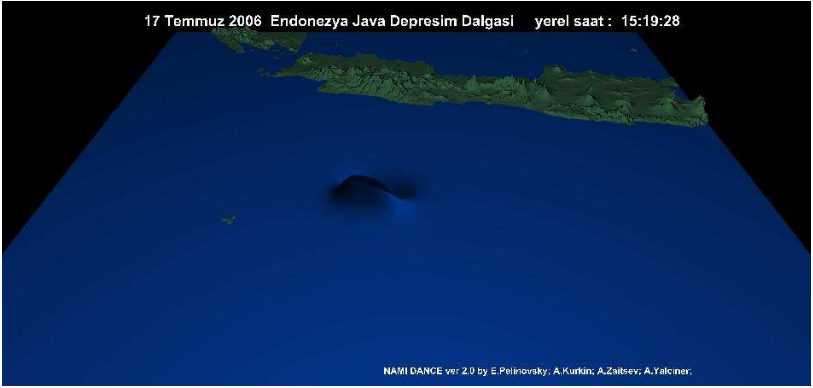
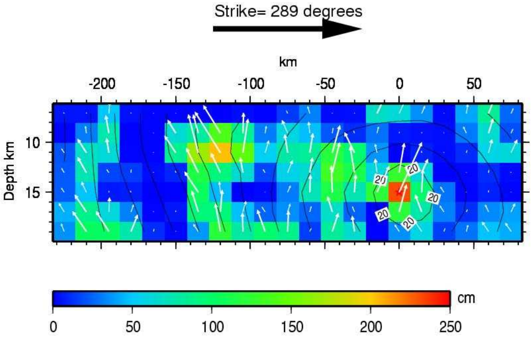


FIG.: by A. Yalciner, E. Pelinovsky et al.

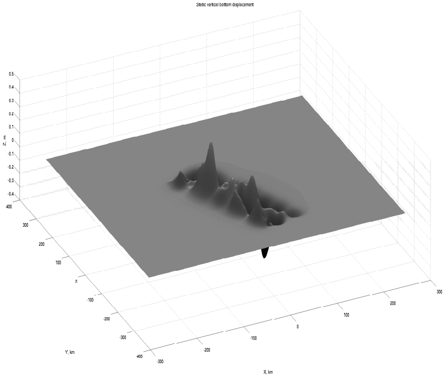
Constructing dynamic bottom displacement

- Average rupture velocity : 1.1 km/s
- Epicenter location
- Rise time : 8 s



Bottom deformation

During first 250 s



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Plans for the nearest future

Until the end of this workshop and the returning trip :)

- Transmete the sea bed motion onto the free surface (fluid domain problem)
    - Go beyond the linearized water wave problem (Cauchy-Poisson problem)
- Taking into account horizontal coseismic displacements

$$z = w + h(x+u, y+v) \approx w + u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} + h.o.t.$$

- Application of this technique to some other events

Thank you for your attention !

http://www.lama.univ-savoie.fr/~dutykh