LABORATOIRE DE GEOPHYSIQUE
Pamatai
CEA/DAM - Département Analyse Surveillance Environnement

Real-time Earthquake Source Characterization

ITS 50, 21 April 2015

Dominique Reymond

(1) CEA/DASE/Laboratoire de Géophysique
Laboratoire de Géophysique, Tahiti
French Polynesia

The tsunami warning process

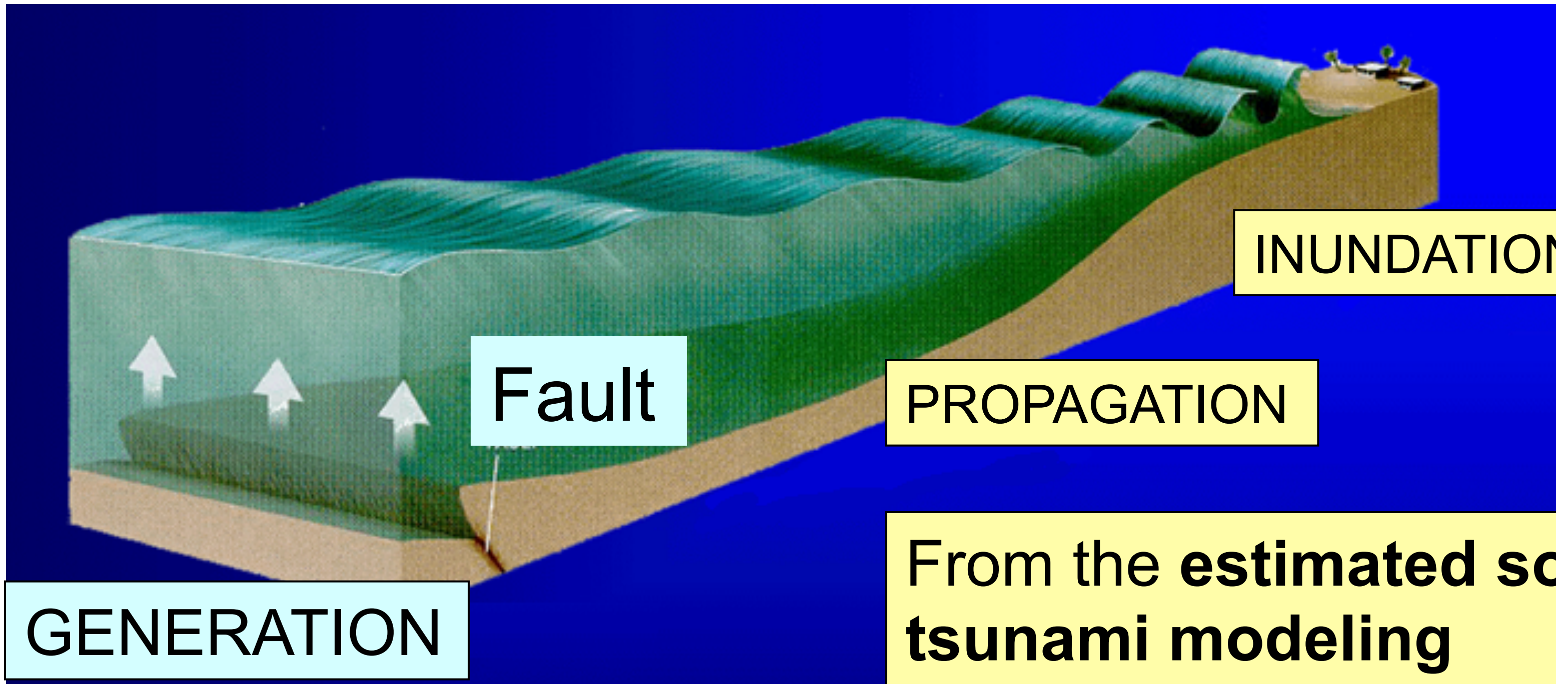
Classically:

1. **Automatic seismic detection**, location, magnitude computation
2. **Warning** in the Tsunami Warning Center (Mw > 7.3)

3. (Rapid) Estimation of the **seismic source**

4. Estimation of the **tsunami amplitudes** *via* **numerical modeling**

The 3 stages of tsunami



From the **estimated source: tsunami modeling** *(a direct problem)*

Source characteristic are **estimated** from seismic data *(an inverse problem)*

The scalar seismic moment, Mo

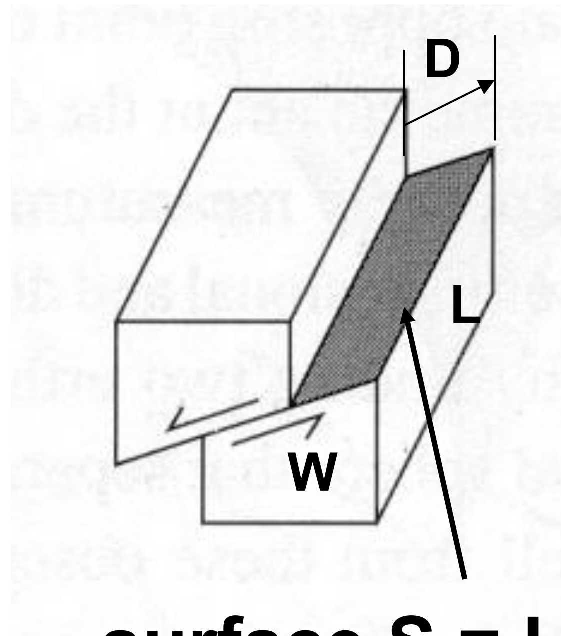
- M_0: (Aki 1966)

  $M_0 = \mu\, S\, D$ N.m

S : fault surface

D : slip on the fault

μ : bulk modulus N/m²



surface S = L W

$10^{12} < Mo < 10^{24}$ N.m

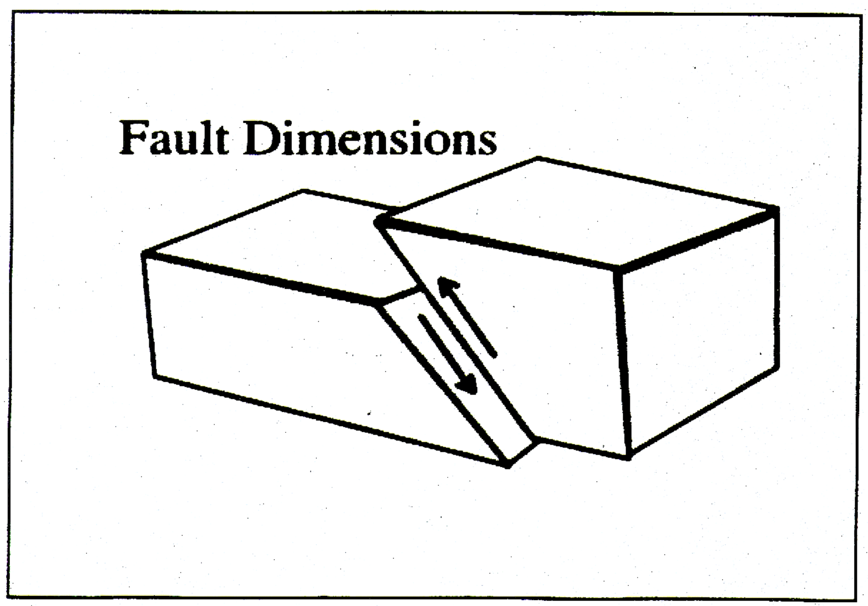
μ # [3 – 7] 10^{10} N/m²

M_0 is **proportional** to the **source dimensions**

Tsunami and seismic source

•The volume of sea-water in motion is directly proportional to the fault dislocation, and area of the rupture zone.

* Therefore it is proportional to seismic moment.



The # first tens minutes …

Seismic data

Location of the source:
T_0, Lat, Lon, ***Depth***

The "**strength**" of the EQ:
Magnitudes
(m_b, $\mathbf{m_{BB}}$, $\mathbf{M_{wP}}$, $\mathbf{M_w}$, Ml, Ms, m_D, $\mathbf{M_m}$, etc.)
Scalar Moment, Mo

Dynamic of the faulting:
Duration *of the source,* ***slowness***

Focal geometry:
Moment tensor : (ϕ, δ, λ, M_o)
Fault dimensions (L,W, D)

Tsunami modeling

Time

The magnitude concept

- **Ignore** the **focal mechanism**
- Take the **measure of a seismic wave** in a given **period range.**
- Very generally made in the **time domain** (**easier, faster**).

- M= Log (Ampl) + Dist_cor + (Source_cor) + K
- M # [0, 10]

The **P wave** magnitudes

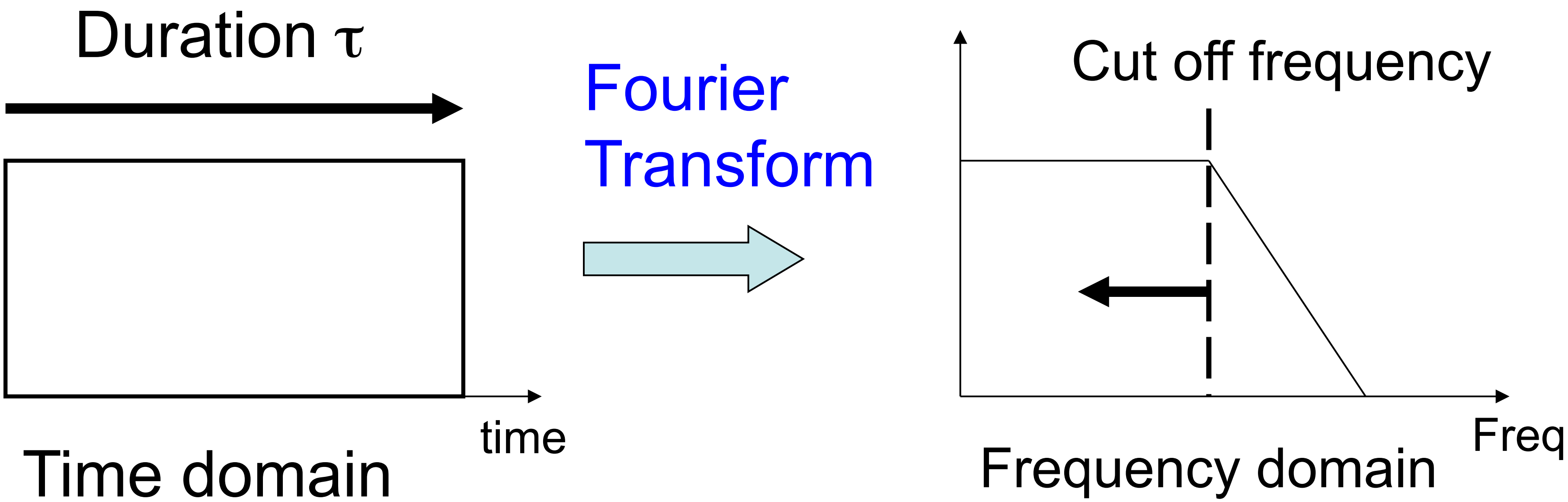
++ The fastest measurement

-- The for **big sources**, the seismic wave amplitudes does not grows with the fault size: the **energy** radiated by the source is **spread along the time**.

-- **the long source duration** acts like **a low-pass filter** on the seismic wave

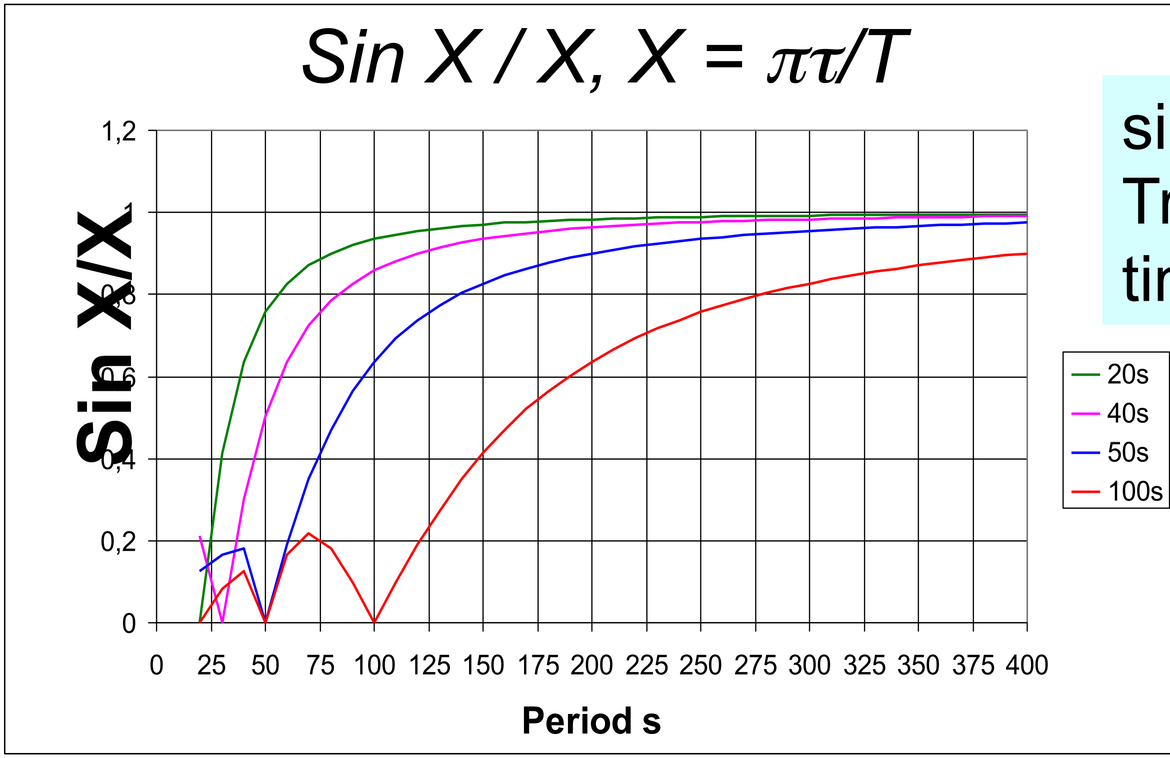
++ Interest of **new broad-band magnitudes** (m_{BB}):
sensitivity to the **source duration** **decrease** with **longer period**.

Influence of the source duration



The increasing source duration acts like a low-pass filter

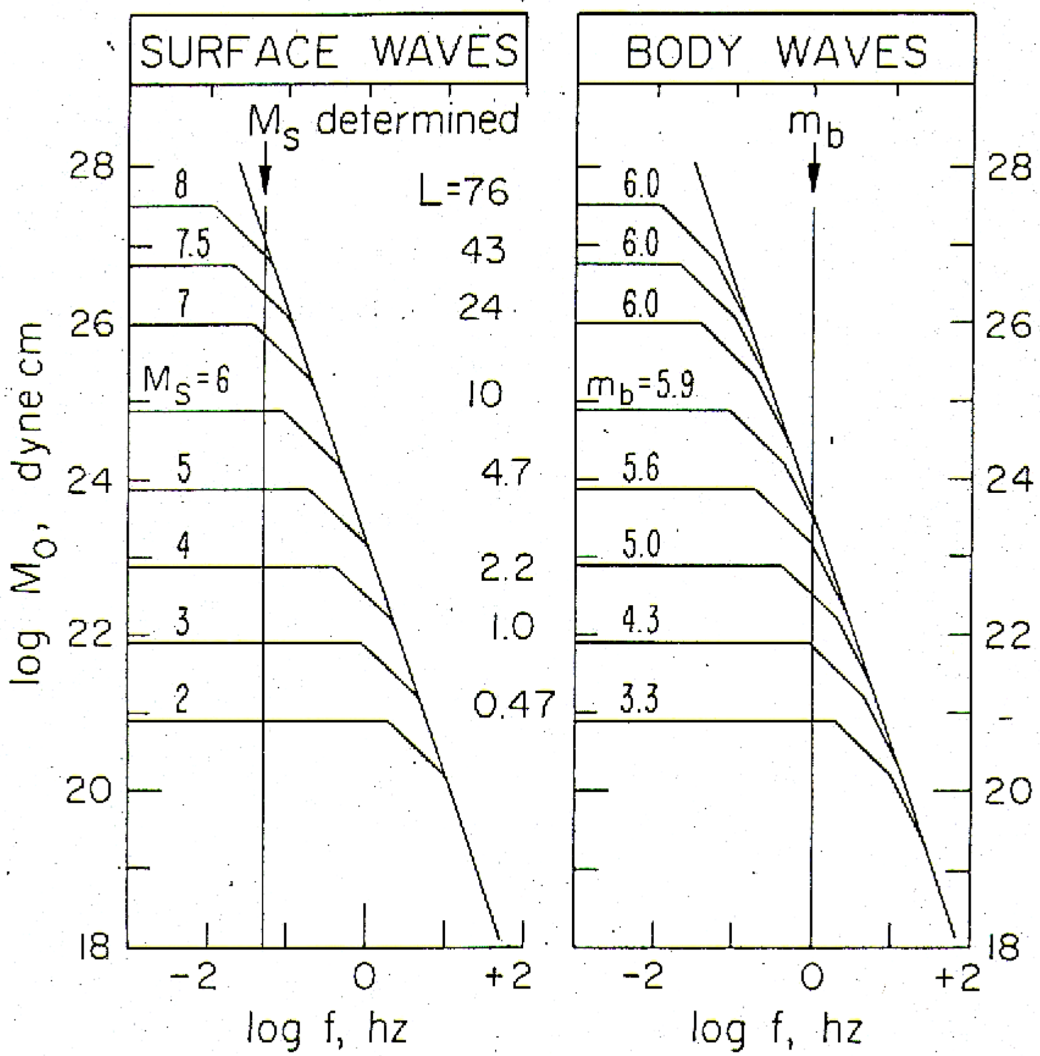
Influence of the source duration, τ



sinc X is the Fourier Transform of the natural time window of duration τ

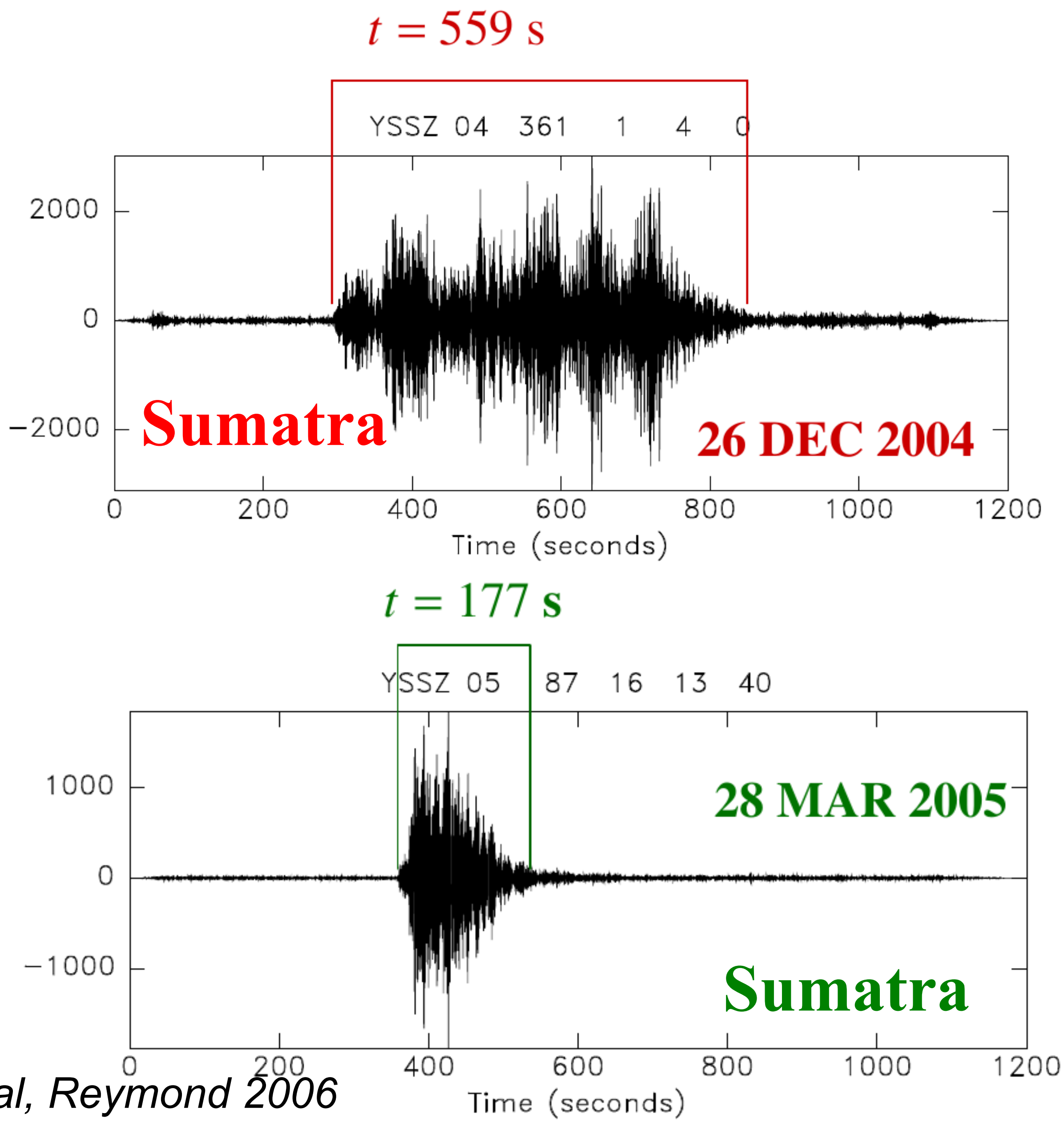
M_0 N.m	Mm	M_w	L km	D m	τ s
10^{17}	4.0	5.27	6	0.1	2
10^{18}	5.0	5.93	13	0.2	5
10^{19}	6.0	6.60	28	0.5	10
10^{20}	7.0	7.27	61	1.1	22
10^{21}	8.0	7.93	132	2.3	47
10^{22}	9.0	8.60	284	5.0	102

Magnitudes and spectra of seismic source: saturation effect of magnitudes



Geller, 1976

Taking into account the **duration of the source**.



Okal, Reymond 2006

Duration of the source:

from the **Duration** of the **high frequency** enveloppe of teleseismic signal **(2- 4Hz)**

Other works:
Ni, 2005
Lomax & Michelini 2012

The slowness discriminant θ

Newman & Okal, 1998

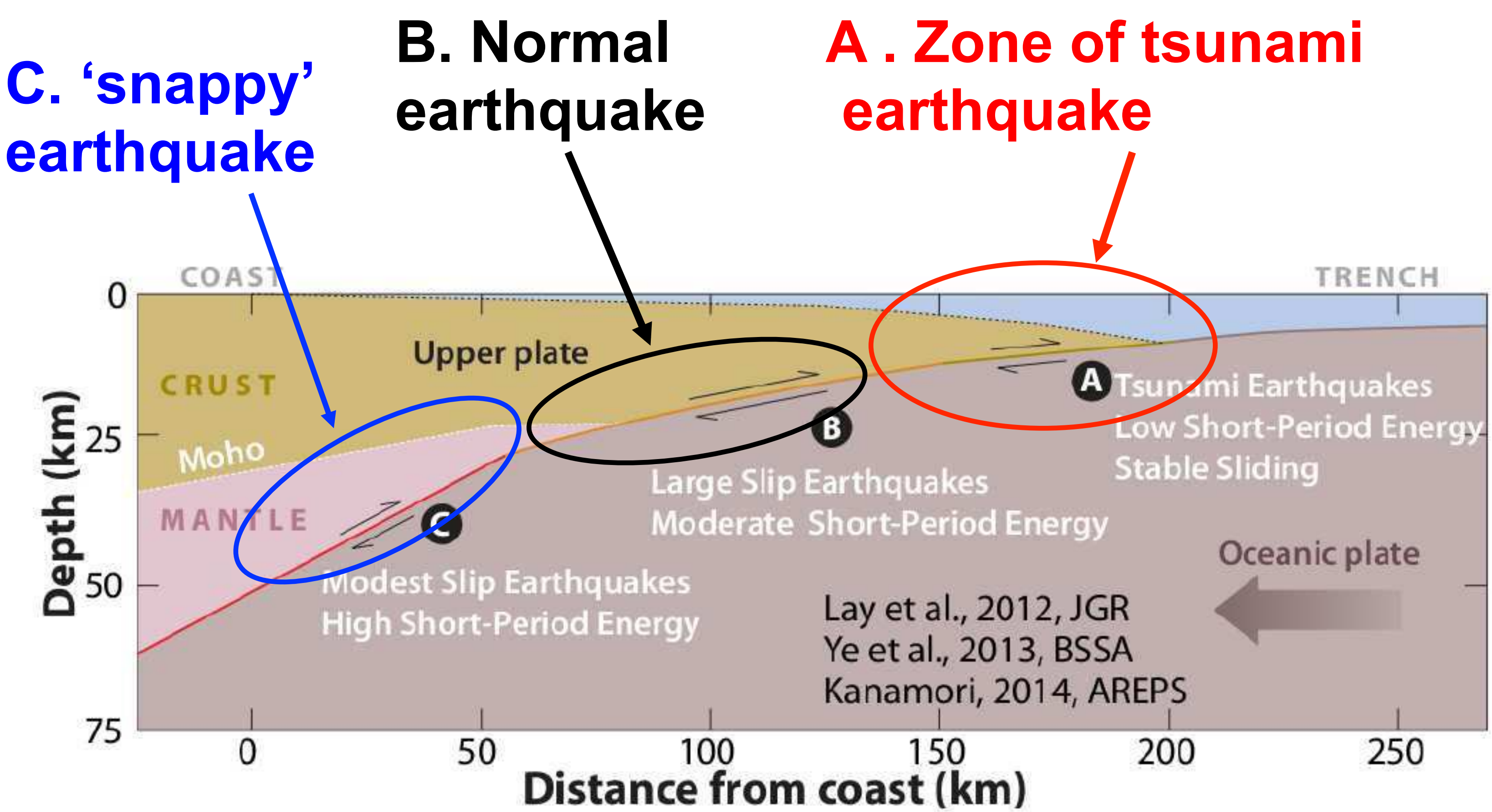
$$\theta = \log_{10}(E_p / M_0)$$

E_p: P wave energy
M_o: seismic moment

– For normal EQ: $\theta = -4.9$
– 'snappy' EQ: $\theta = -3.5$
– Slow event: $\theta = -6.0$

- Gives an indicator of the slow character of the source (deficiency of P wave energy).
- **Aleutian 1rst 1946: $\theta = -7.0$**

Slow, normal, and snappy EQ



From T. Lay 2014

Looking for the focal geometry and seismic moment

Older methods (well tested),

***Inversion of P waves** *(Kikuchi &Kanamori (1982, 1991), Dreger et al.(1996)*

***Full waveform inversion** *(**GCMT** project, Woodhouse, Dziewonski, Ekström, ..)*

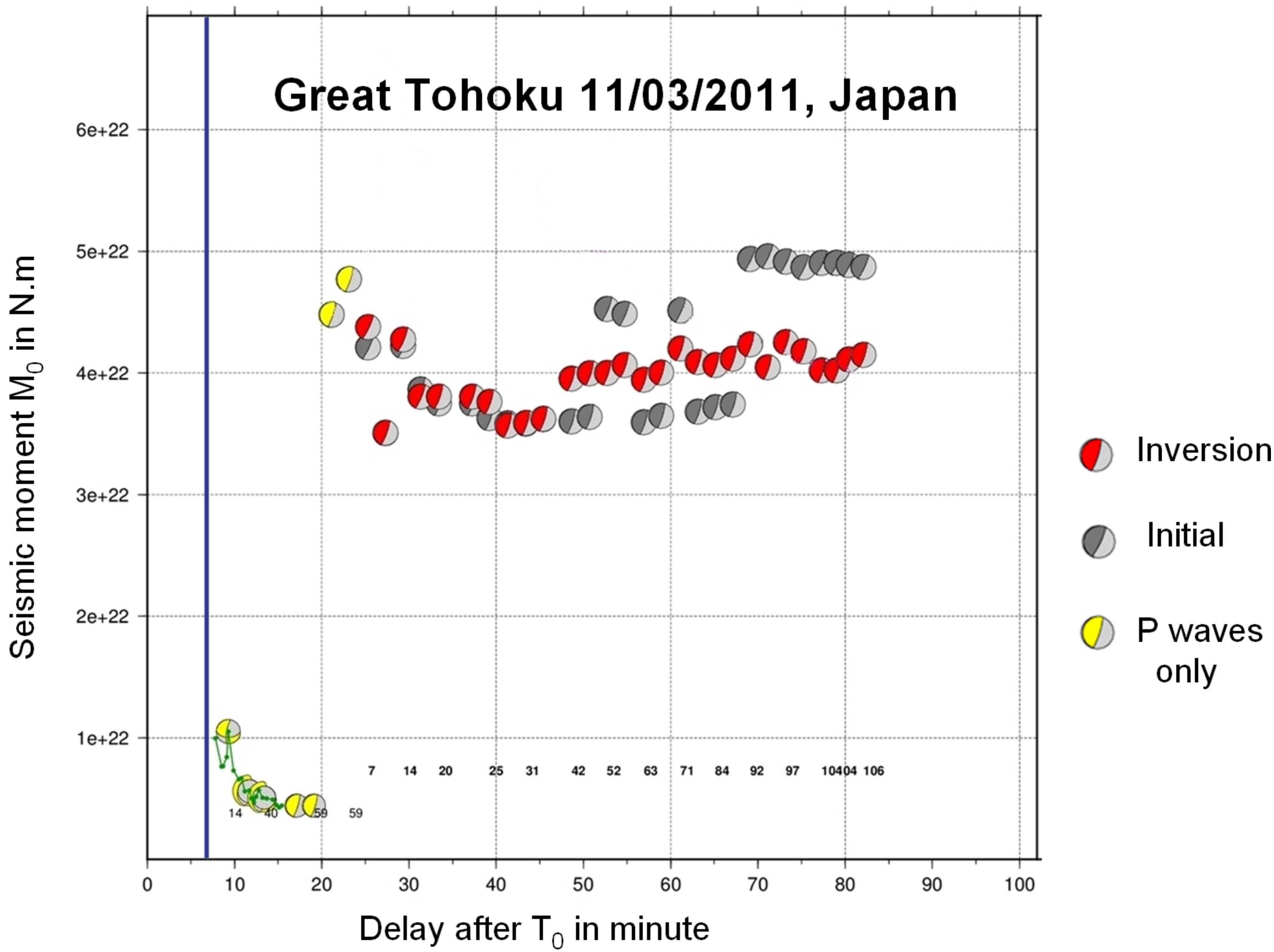
Very accurate: **the reference since the 80's**!

New: Inversion of P and S waves *(M. Vallée, 2011)*

– use P and S waves
– Produces the source time function.
– Fully automatic results in 45 minutes

Looking for the focal geometry and seismic moment (cont.)

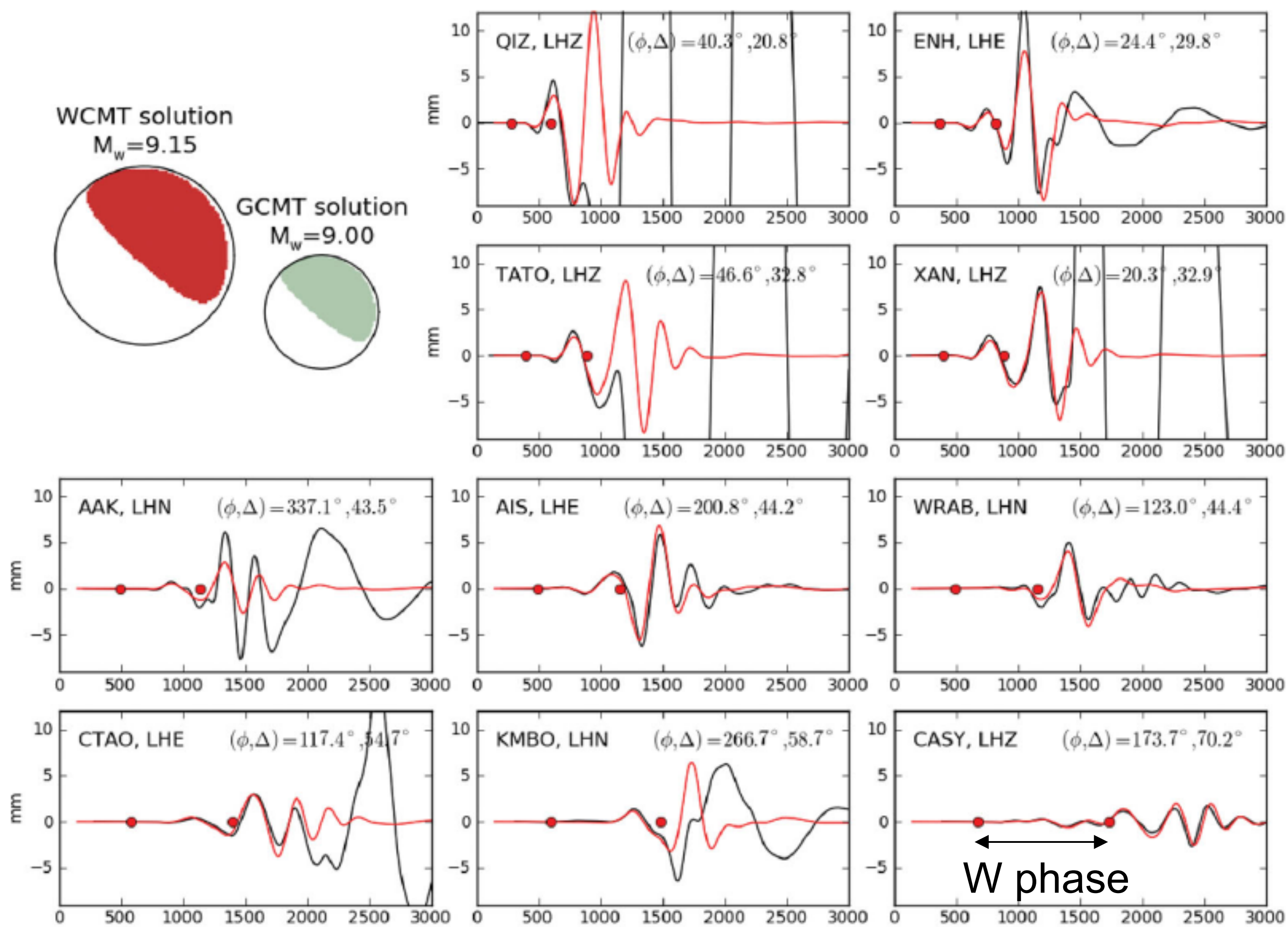
- **Inversion of surface waves** (Rayleigh + love), *J. Clément & D. Reymond, 2014*
  - – use P wave polarity and surface wave spectra
  - – Frequency domain
  - – Long period (until 350 s of period).
  - – Fully automatic results in 45 minutes


Great Tohoku 11/03/2011, Japan
Seismic moment M0 in N.m
Delay after T0 in minute
6e+22
5e+22
4e+22
3e+22
2e+22
1e+22
0
10
20
30
40
50
60
70
80
90
100
7
14
20
25
31
42
52
63
71
84
92
97
10404
106
14
40
59
59
Inversion
Initial
P waves
only

The W phase

Kanamori, 1993

Very long period phase (200s – 1000s)
Deep mantle phase
Higher mode of surface wave



Duputel et al., 2012

The W-phase inversion

(Kanamori & Rivera 2008, Duputel & al. 2012)

- Use **ultra-long period** mantle wave (200s – 1000s)
- **Good insensitivity** to earthquake **duration**, **slow earthquake** (except Sumatra 2004).
- **Total insensivity** to the **heterogeneities** of the earth surface
- **Linear inversion in the time domain** of the seismic moment tensor
- **Automated results in 30 minutes**
- Tests in ***CENALT*** **with near field stations**, and Greens' functions / **automated results in 15 – 20 minutes ?**

Estimation of the fault dimensions
(the largest unknowns)

Assuming M_0 is known
(*Geller 1976, Sholtz 1982, Wells & Coppersmith, 1994):*

- Scaling similarity: **fault length**
  $L = \alpha M_0^{1/3}$ (or $L = \tau / V_r$)
- Aspect ratio: **fault width**
  W = L/2 , W < 300 km
- Centroïd depth, dynamic: **medium rigidity**
  μ estimation = **function(depth, slowness)**
- Finally, compute the **slip**:
  $\mu = M_0/(\mu W L)$

Assume a 'compact' (Tohoku-2011 like):
Divide fault length L by 2, D * 2 , **recompute all**

Other perspectives

- Promising methods and results with **grid methods** for **rapid moment tensor determination** in near field (*A. Guilhem et al., 2013*)

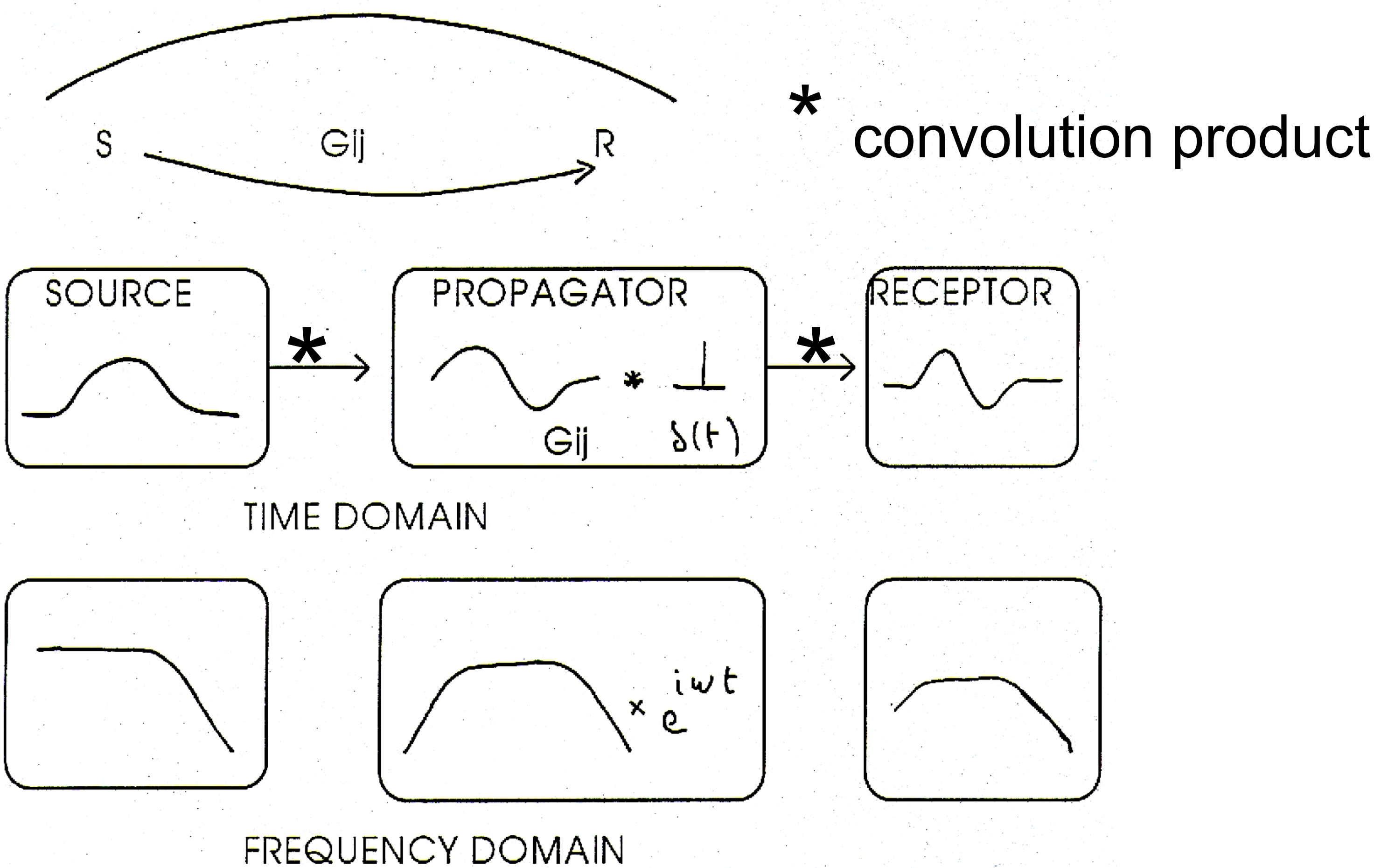
- **Wphase** in **near field** (WCMT in 15 – 20 min)

- **High frequencies GPS** (give directly the ground displacement without saturation in near field).

Thank you for your attention

Third wave of tsunami in Marquesas, Nuku Hiva, Tohoku 2011

The seismic waves in the earth



The green functions represent the impulsionnal response of the earth to the excitation of seismic source, for a type of wave

The main source parameters

interdependant

- 4 ~~independent~~ set of parameters:
  - **Location** (H_0, lat, lon, **depth**)
  - **Medium properties**: rigidity modulus

    $\boldsymbol{\mu} = \rho\, \beta^2 = f(Depth)$

    ρ medium density, β shear velocity
  - Fault dimensions ***(# the strength of the EQ***)
  - Focal geometry