Operational tsunami warning: search for the ad hoc source parameters of rapid/normal/slow sources for tsunami forecast.

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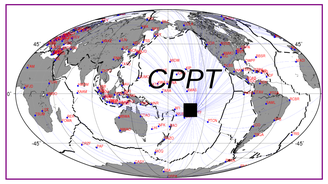
1) The near real-time process



387 stations, 25 networks

A Continuous real time seismic data acquisition

SEISCOMP: triggering **event detection**

EQ T0

SEISCOMP **:** Location, P-wave magnitude **Seismic Warning** **Short period** seismic data **T0 + 12' max**

Ultra-long period *Wphase* inversion ref [3]: Centroïd location **Source duration** **Moment tensor** **T0 + 30'**

***PDFM2* inversion [1]:** P-wave energy Mm magnitude [5] **Moment tensor** **Slowness [4]** **Source duration** **Long period** surface waves **T0 + 45'**

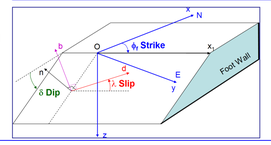
time

PDFM: *Preliminary determination of Focal Mechanism ref [1]*

T0 + 35': Forecast of tsunami amplitudes (MERIT) ref [2]

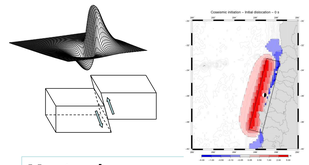
T0 + 50': Forecast of tsunami amplitudes

The **seismic source** parameters *{Lat, Lon, Depth, ϕ, δ, λ, μ, W, L, D}* Rectangular fault with uniform slip in homogeneous medium



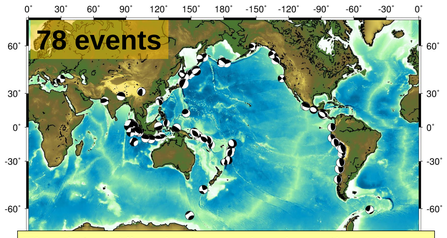
Faults dimensions, assuming:

* Scaling law [6]: L = α M0$^{1/3}$
* similarity conditions: W = L/2, W <= 200 km
* Rigidity is constant **μ** = 40x10^9 Pa



Most unknowns:
Fault length: L, Slip : D
Aspect ratio: L/W
Questions:
Fault parameters of tsunami EQ ?
Dynamic properties ?
Scaling laws ?
μ in the source area

2) Rupture duration, fault length, Radiated energy: dynamics of the fault, scaling laws and medium properties



The data : All major tsunamigenic earthquakes since 1992, including **tsunamis EQ.**

Duration of the source, τ, is obtained using 2 independent methods:

1- Envelop of high-frequencies *P-waves* [2-4 Hz]

2- *WPHASE CMT* inversion (ref [3]) giving **Tc = τ /2, time-shift** (centroid - origin time)

So, the Rupture velocity : Vr = L/τ

Source dimensions: *using Scaling laws,*

**** L = α Mo$^{(1/3)}$, with α = 1,32E-5***

**** W=L / 2, while W <= 200 km***

Ref: [5], [6], [7], [8]

***Radiated* energy (E),** *[10]*

$$E = 53\pi r^2 \rho\alpha \int v^2(t)dt$$

and the slowness discriminant (*θ*) *[4],*

θ = log$_{10}$ E/M$_0$

With ***θ ≈ -5.0 for normal EQ***

θ ≈ -6.0 for tsunami-EQ

M$_0$: Scalar Moment

Tsunami-Earthquake have a ***θ <= -6.0,*** due to a **deficient *radiated energy*.**

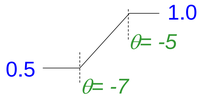
Medium properties: *(Rigidity)*

μ= ρ β² *with (ρ, β) = f(H$_{depth}$, PREM)*

But: ***Tsunami-EQ****, with extreme shallow depth have a low rupture velocity*

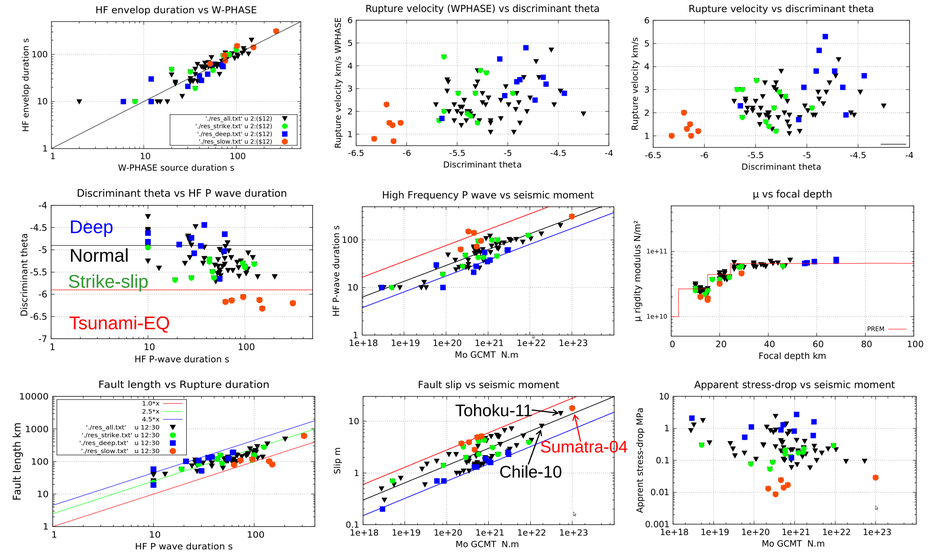
So we Define an ***empirical μ$_{rupture}$ = k μ,***

With ***k =f(θ)***

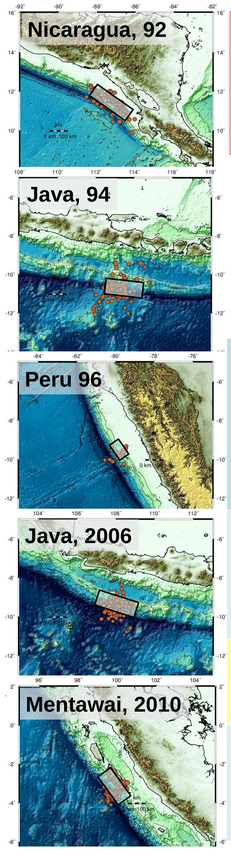


So, we obtain a fault displacement from

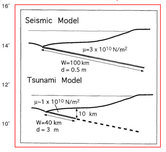
D =M$_0$ / (μ$_{rupture}$ L W)

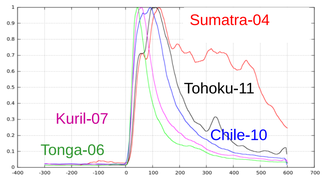


Five tsunami earthquakes :



Tsunami model, Satake [9]

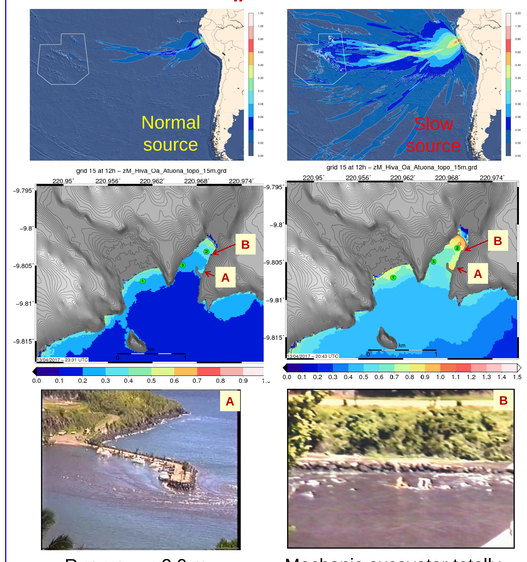




		Nicaragua 1992	Java 1994	Peru 1996	Java 2006	Mentawai 2010
	M$_0$	3.40^{E}20	5.34^{E}20	2.23^{E}20	4.61^{E}20	6.77^{E}20
	θ	-6.32	-6.14	-6.17	-6.13	-6.06
	τ [s]	151	73	63	141	96
Fault area based on the five days after-shocks	L [km]	250	135	90	175	165
	W [km]	80	70	45	88	70
	L/W	3.1	1.9	2	2	2.4
	Vr [km/s]	1.66	1.85	1.43	1.24	1.72
Using scaling laws	L [km]	92	107	80	102	116
	W [km]	46	54	40	51	58
	Vr [km/s]	0.61	1.47	1.27	0.72	1.21
Normal source	μ$_{normal}$	4.00^{E}10	4.00^{E}10	4.00^{E}10	4.00^{E}10	4.00^{E}10
	D(μ$_{normal}$) [m]	2.0	2.3	1.7	2.2	2.5
Slow source	μ$_{rupture}$	1.80^{E}10	1.90^{E}10	1.90^{E}10	3.20^{E}10	2.00^{E}10
	D(μ$_{rupture}$) [m]	3.9	4.9	3.7	2.8	5.1

3) Tsunamis-EQ simulations

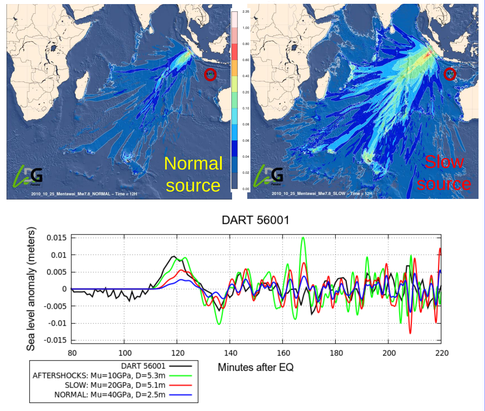
Peru, 21-02-1996, M$_w$=7.5



Run-up$_{MAX}$: 2.0 m

Mechanic excavator totally flooded at the end of the bay.

Mentawai, 25-10-2010, M$_w$=7.8



Conclusions

- **Source size** is estimated from **scaling laws** [5],[7][8]
- 2 independent methods of **source duration: high-frequency P-wave envelope** and **WCMT inversion.**
- **Source duration** of **Sumatra-04** remains **under-estimated.**
- **Rupture velocity** is estimated from **source duration** and **source size.**
- **Long source duration** are **not necessarily tsunami-EQ**.
- But **Tsunami-EQ** have **always long source duration.**
- **Tsunami-EQ** show always slow rupture velocity.
- **Tsunami-EQ** are **identified** by strong **deficiency of P wave energy (discriminant θ, [4]).**
- **Tsunami-EQ** seem to **follow scaling-laws** for the fault area, except for the **slip faulting** that are exceptionally large.
- The definition of the **seismic moment** implies exceptional **low μ rigidity** values for **Tsunami-EQ.**
- **Numerical modeling** of **tsunamis-EQ** confirms the **exceptional large slip values** to reproduce **observations (normal slip** values gives significant **under-estimations**).
- **Tohoku-2011** confirms **large slip value**, but is **not** a Tsunami-EQ.
- **'Snappy events'** shows **high apparent stress-drop**, associated to **small fault displacements** (not tsunami-efficient).

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