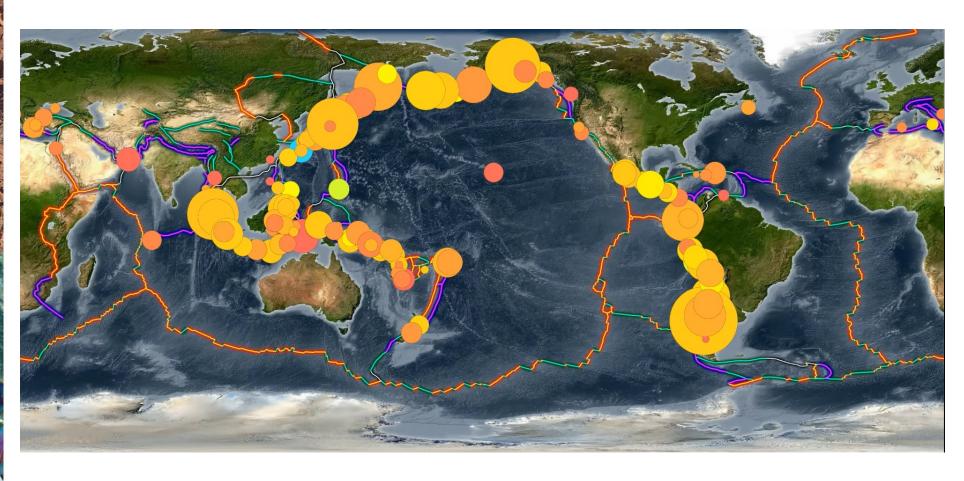
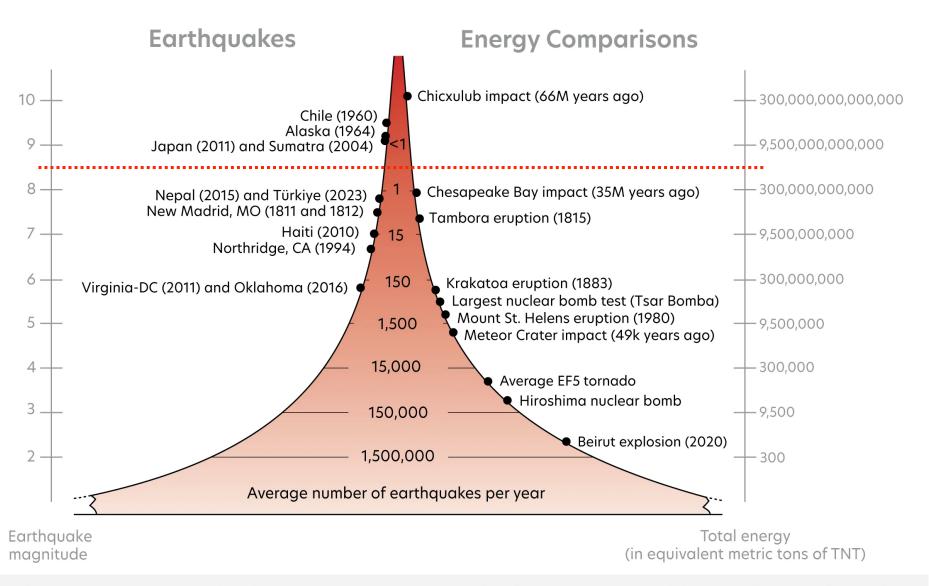


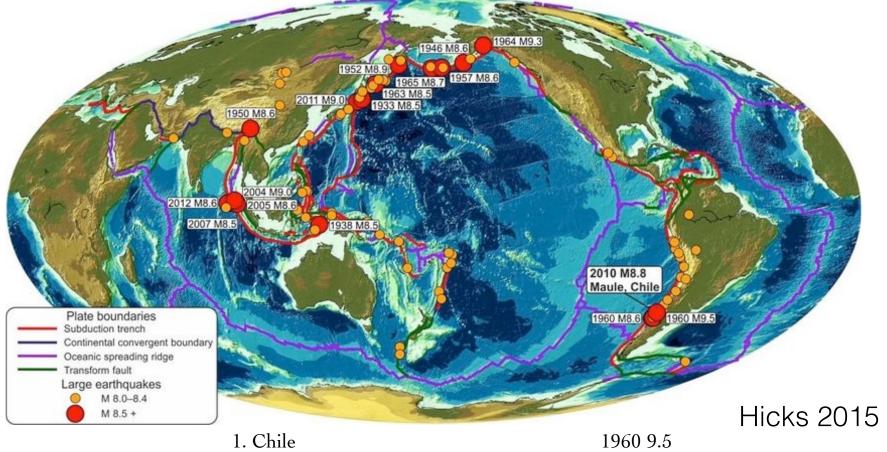
Les grands séismes







The total energy of the earthquake includes the seismic waves that radiate from the epicenter and cause shaking, as well as energy dissipated as heat due to friction along moving faults and energy producing new cracks in the rock. The relative contributions of these processes to the total vary, but the total energy equates to an earthquake's magnitude.

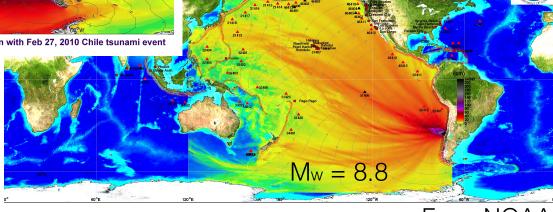


1. Chile	1960 9.5
2. Prince William Sound, Alaska	1964 9.2
3. Off the West Coast of Northern Sumatra	2004 9.1
3. Near the East Coast of Honshu, Japan	2011 9.1
4. Kamchatka	1952 9.0
5. Kamchatka	2025 8.8
5. Offshore Maule, Chile	2010 8.8
5. Off the Coast of Ecuador	1906 8.8
6. Rat Islands, Alaska	1965 8.7
7. Northern Sumatra, Indonesia	2005 8.6
7. Indonesia	2012 8.6
7. Assam - Tibet	1950 8.6
7. Aleutian, Alaska	1957 8.6
7. Aleutian, Alaska	1946 8.6

Mw = 9.5 Amp. (cm) 1960 Chile tsunami (earthquake magnitude Mw 9.5) Maximum amplitude plot -- for comparison with Feb 27, 2010 Chile tsunami event

22 mai 1960 Chili M_w 9.5

3 000 à 6 000 morts



From NOAA

© NOAA

L = 800 - 1000 km

W = 200 km

D = 20 m





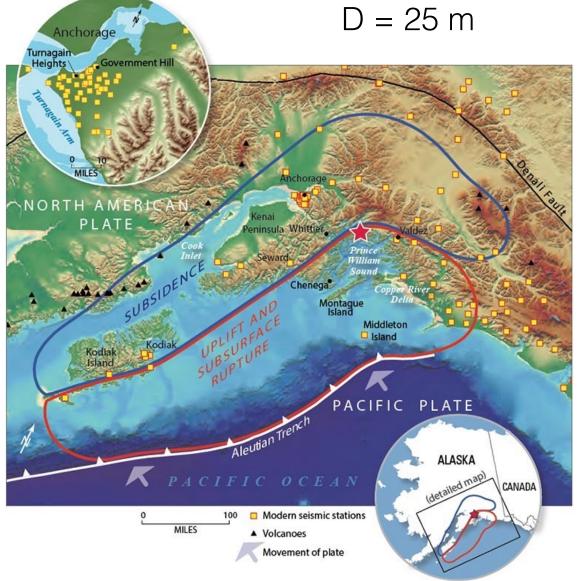
http://pubs.usgs.gov/fs/2014/3018/

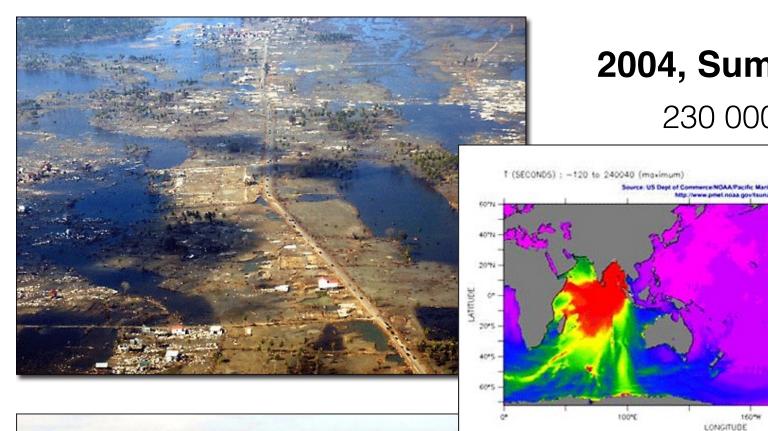
27 mars 1964 - Alaska M_w 9.2

115 morts

L = 800 km

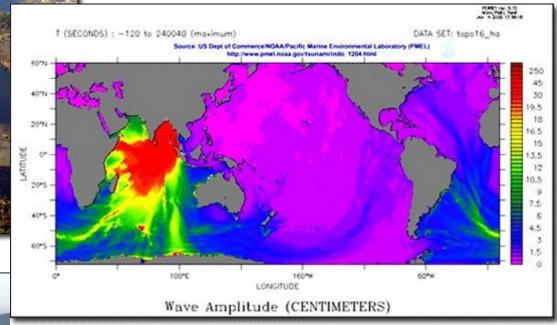
W = 250 km





2004, Sumatra, Mw 9.1

230 000 morts

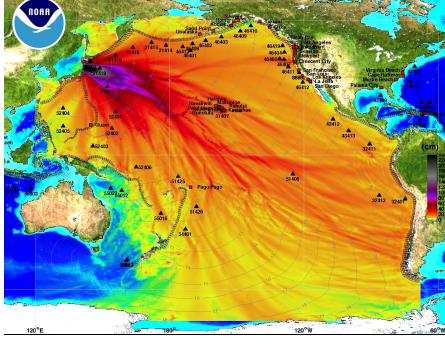






11 mars 2011, Tohoku, M_w 9.0

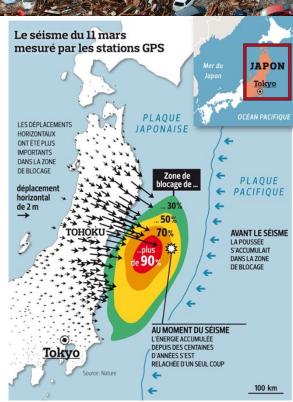




15 000 à 20 000 morts

L = 500 kmW = 200 km

D = 20 m

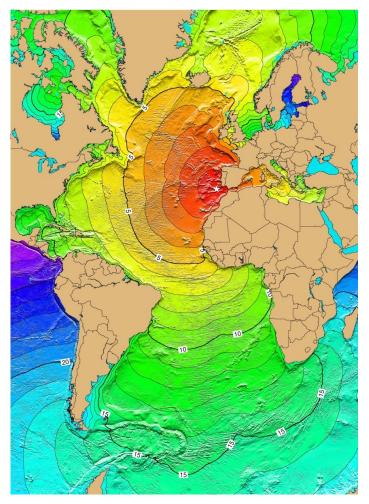




1^{er} novembre 1755 - Lisbonne M_w 8.5 à 9.0

50 000 à 70 000 morts

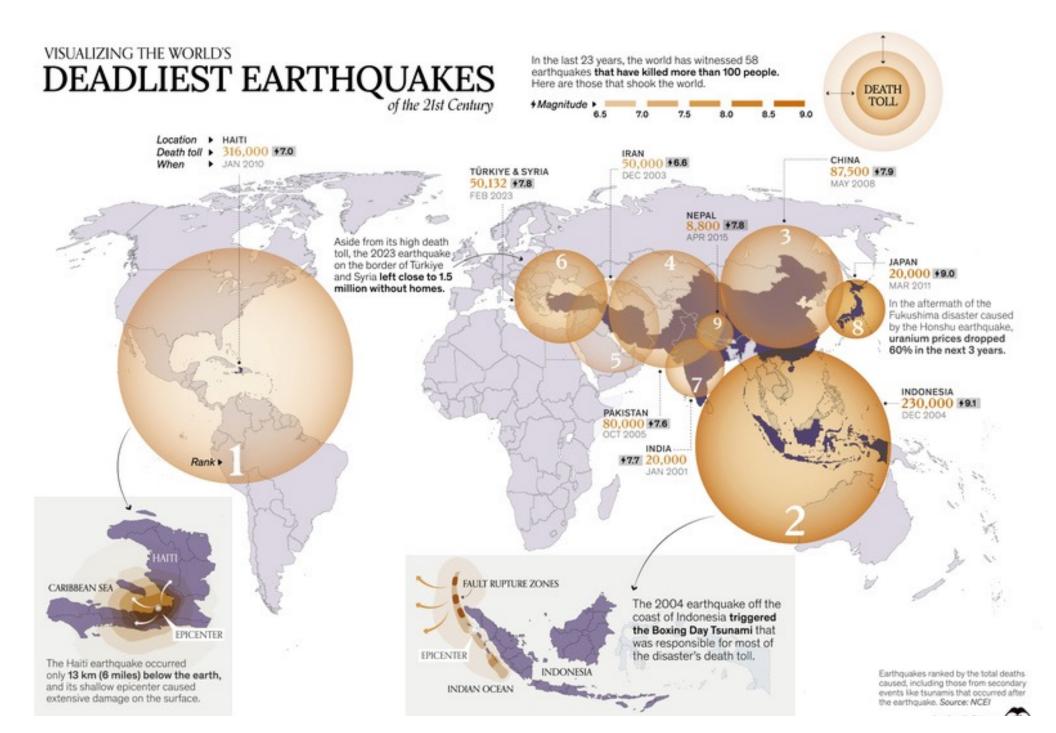




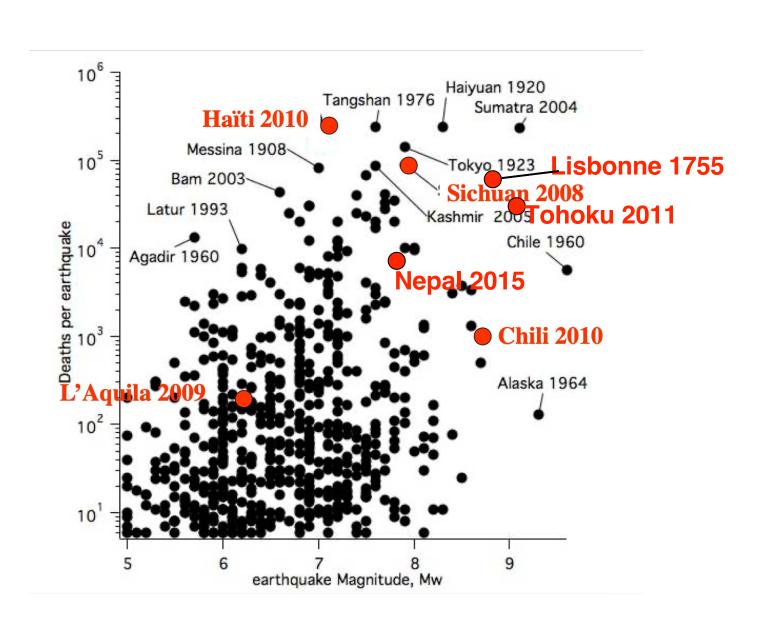
Querelle Voltaire-Rousseau:

Poème sur le désastre de Lisbonne, de Voltaire

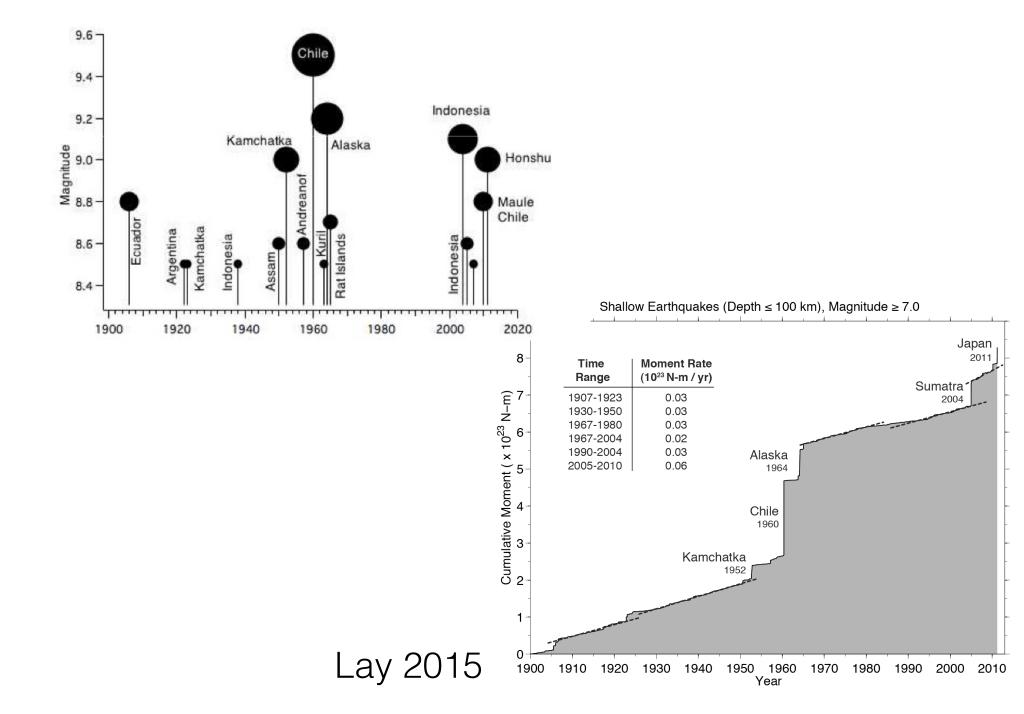
Lettre sur la providence de Jean-Jacques Rousseau



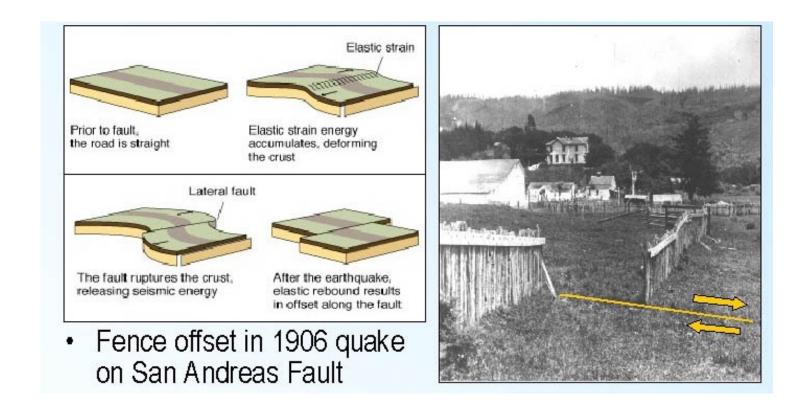
Une relation entre magnitude et dégâts?



La sismicité est aléatoire et imprévisible



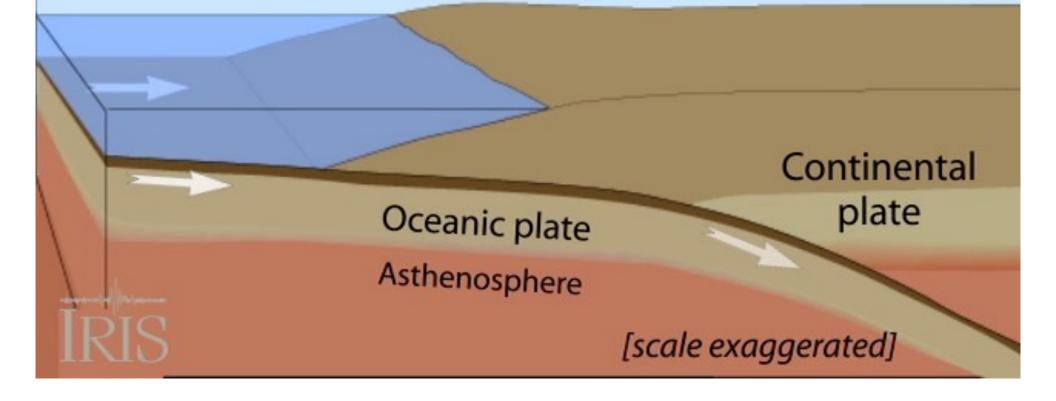
A QUEL MOMENT LES SÉISMES SE PRODUISENT?



Théorie du rebond élastique (Reid, 1910)

CYCLE SISMIQUE = Processus d'accumulation et de relaxation des **contraintes**

Elastic rebound in a subduction zone



Cycle sismique

Intersismique

Accumulation de contrainte (100-1000 ans), chargement

Présismique

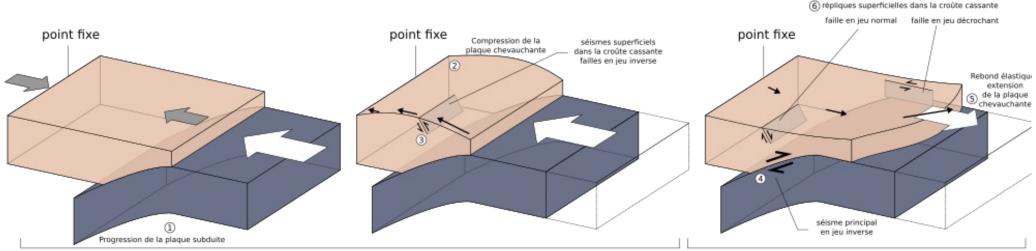
comportement anormal juste avant un séisme (10mn 10 ans)

Cosismique

rupture, libération d'énergie (1-100s)

Postsismique

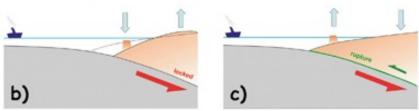
réajustement post-rupture (1 jour - 10 ans)



Phase intersismique

Phase cosismique

Soulèvement & Subsidence





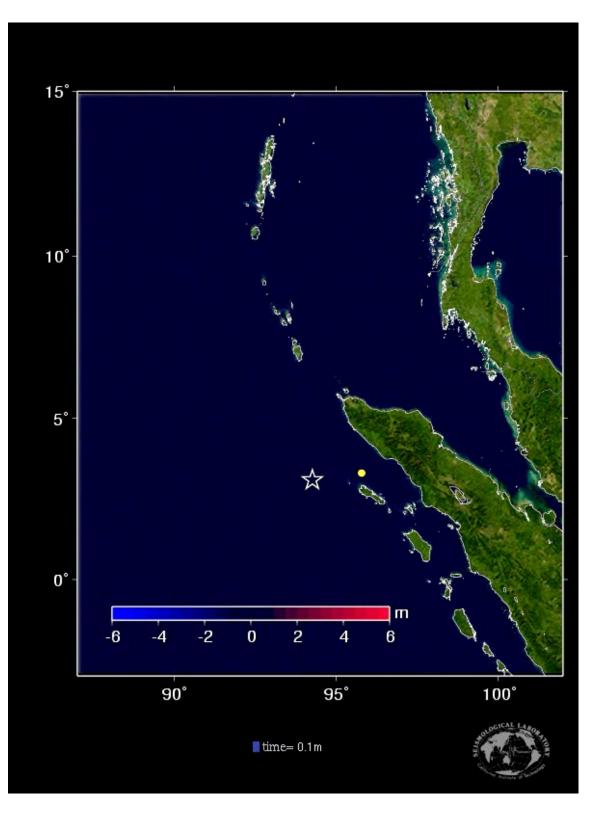


SUMATRA (MW 9.1) 2004

Déplacement en surface dû à la propagation de la rupture :

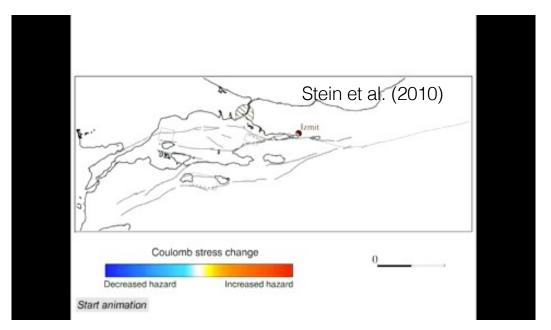
10 minutes 1500 km

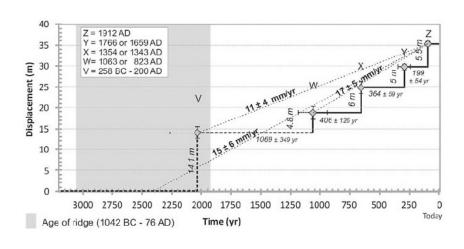
Soulèvement (rouge) Subsidence (bleu). (source: Caltech)



Cycle sismique

Cycle signifie-t-il périodicité et donc prévision ?

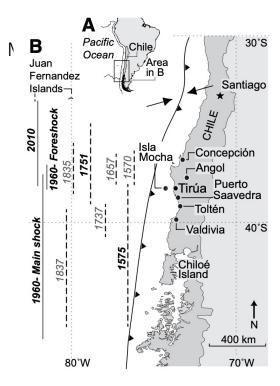




Contraintes de Coulomb

Paléosismologie Sismologie historique

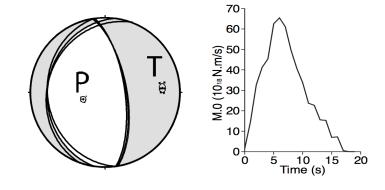
100 ans d'instrumentation... Séismes lents, trémors, glissement asismique...



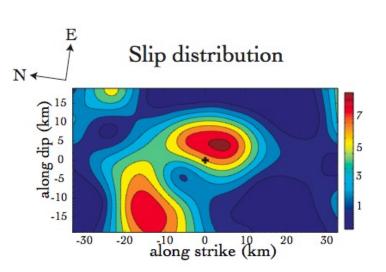
Etudes de la Source des Séismes

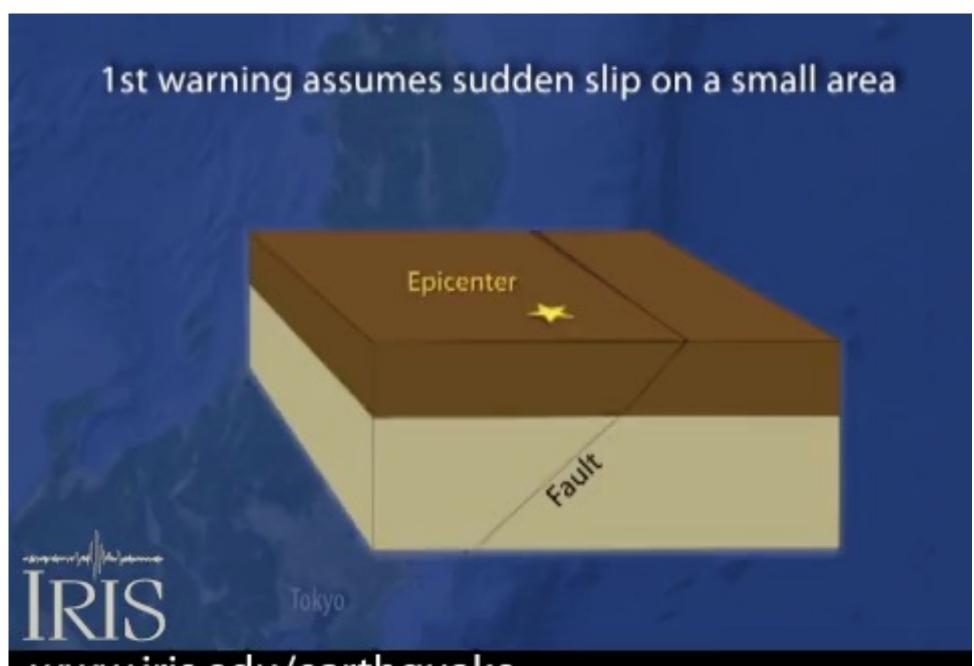
1) Localisation Détermination du Moment, Magnitude

2) Mécanisme focal Fonction Source Temporelle



3) Détails de la rupture: Glissement et vitesse de glissement sur la faille





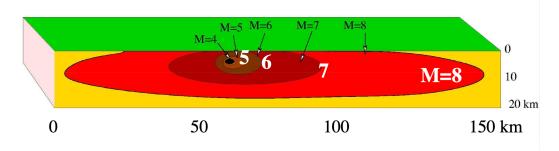
www.iris.edu/earthquake

Loi d'échelle des grands séismes

MAGNITUDES

ET LONGUEUR DE RUPTURE

SUR LES FAILLES



Magnitude 4 = 1 km - ressentie – pas de dommages

Magnitude 6 = 10-20 km - dommages aux structures

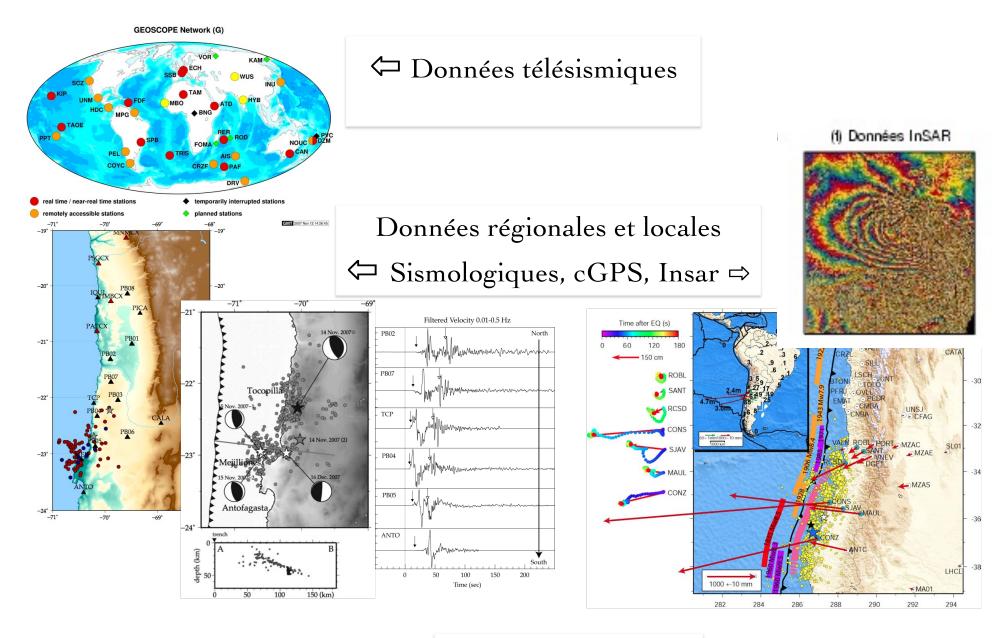
Magnitude 8 = 100-200 km – destructions généralisées

$$M_w = 2/3 \times log(M_0) - 6$$

avec $M_o = \mu \times S \times D$

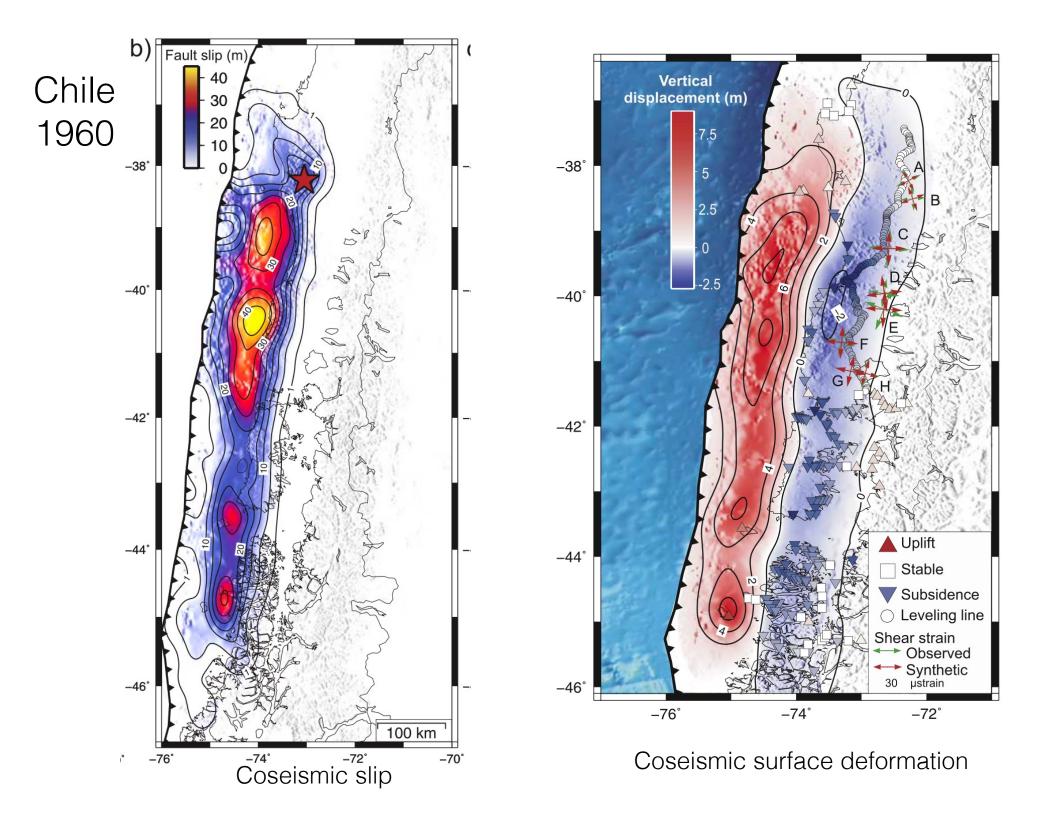
- Mo: moment sismique (en N.m)
- μ: rigidité du milieu(en N.m⁻²)
- D: glissement ou déplacement moyen sur la faille (en m)
- S: surface de la faille (en m²)

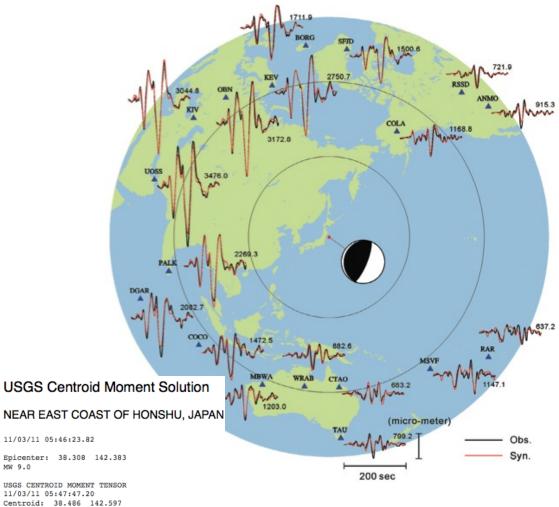
Magnitude	Moment	Longueur	Durée	Glissement
(M_w)	(Nm)	(km)	(s)	(m)
10	10 ²⁴	1000?	300?	100?
9	3.10^{22}	300	100	30
8	10^{21}	100	30	10
7	3.1019	30	10	3
6	10 ¹⁸	10	3	1



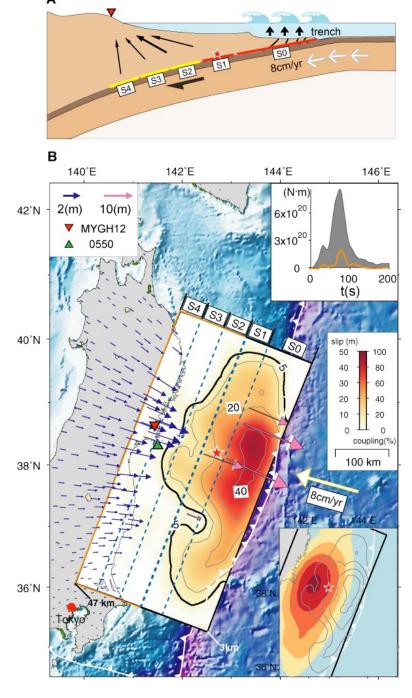
Données géologiques (Trace en surface)⇒







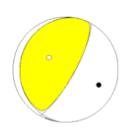
Séisme de Tohoku (Japon 2011) Mw=9

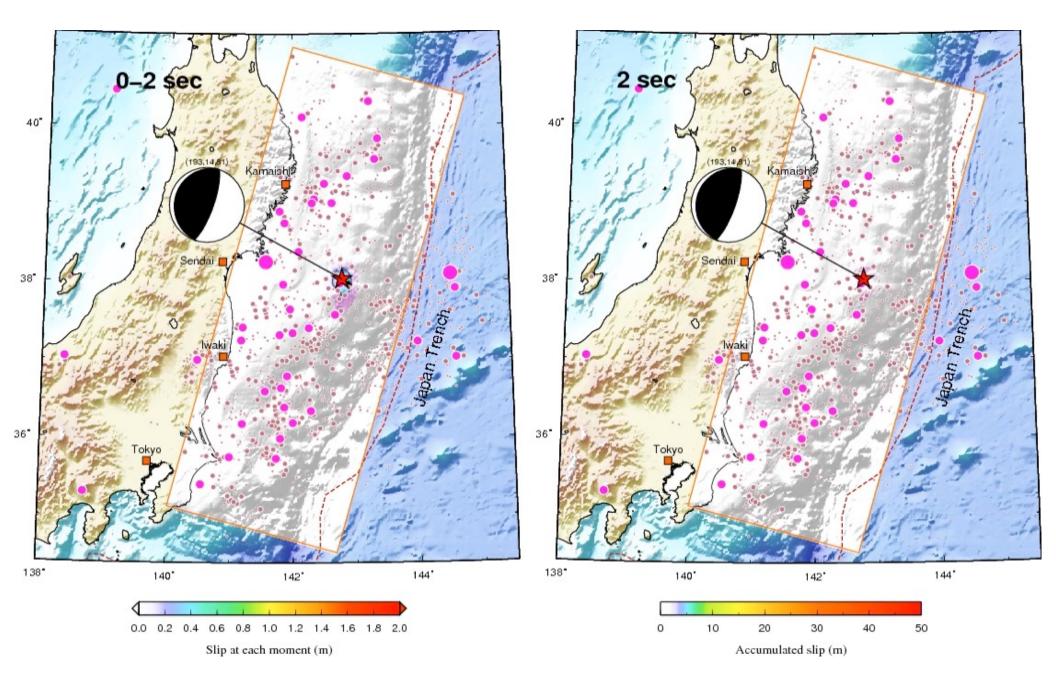


USGS CENTROID MOMENT TENSOR
11/03/11 05:47:47:20
Centroid: 38.486 142.597
Depth 10 No. of sta: 151
Moment Tensor; Scale 10**22 Nm
Mrr= 2.03 Mtt=-0.16
Mpp=-1.87 Mrt= 2.06
Mrp= 3.49 Mtp=-0.60
Principal axes:
T Val= 4.57 Plg=58 Azm=306

T Val= 4.57 Plg=58 Azm=306 N -0.05 5 208 P -4.52 32 115

Best Double Couple:Mo=4.5*10**22 NP1:Strike= 29 Dip=77 Slip= 95 NP2: 187 14 68

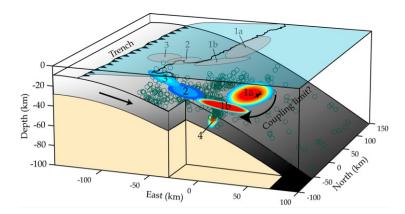




Ingrédients pour faire un mega-séisme

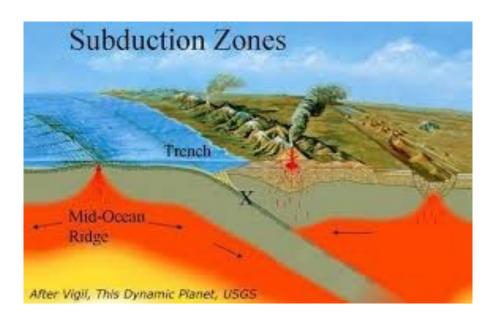
 $M_W > 8.5 \text{ si}$:



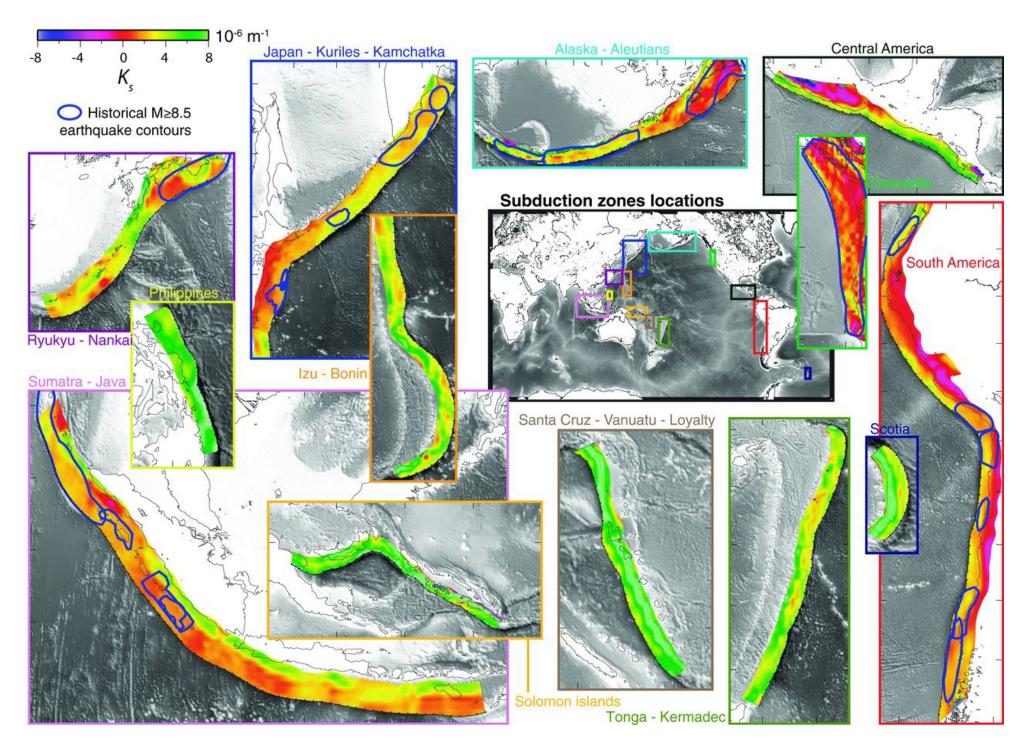


Glissement généré lors du séisme de Tocopilla (Chili 2007) et de ses plus grosses répliques

- grande surface de rupture
- déplacement important

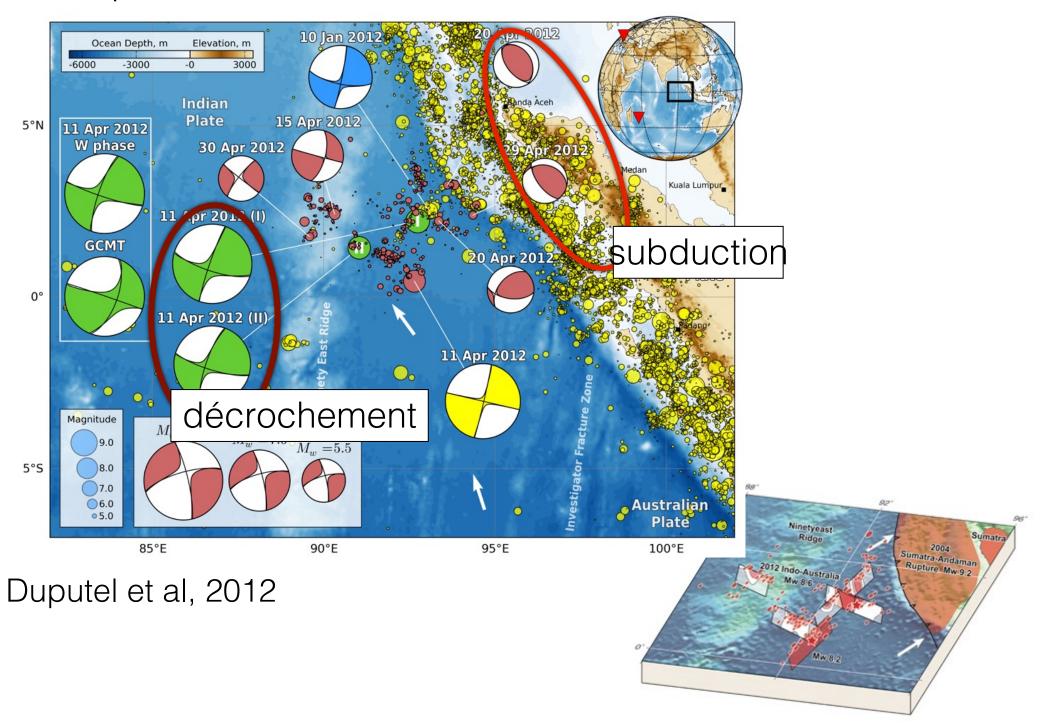


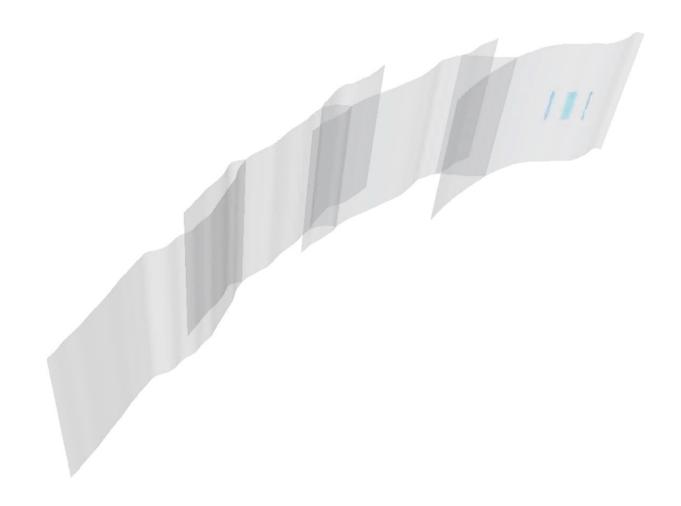
Décrochement?

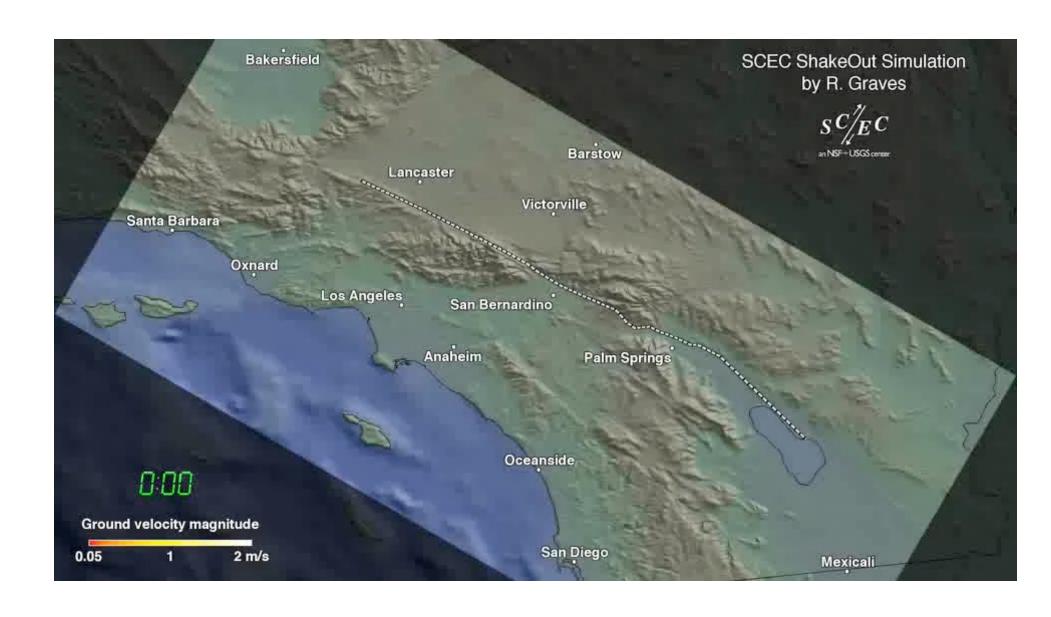


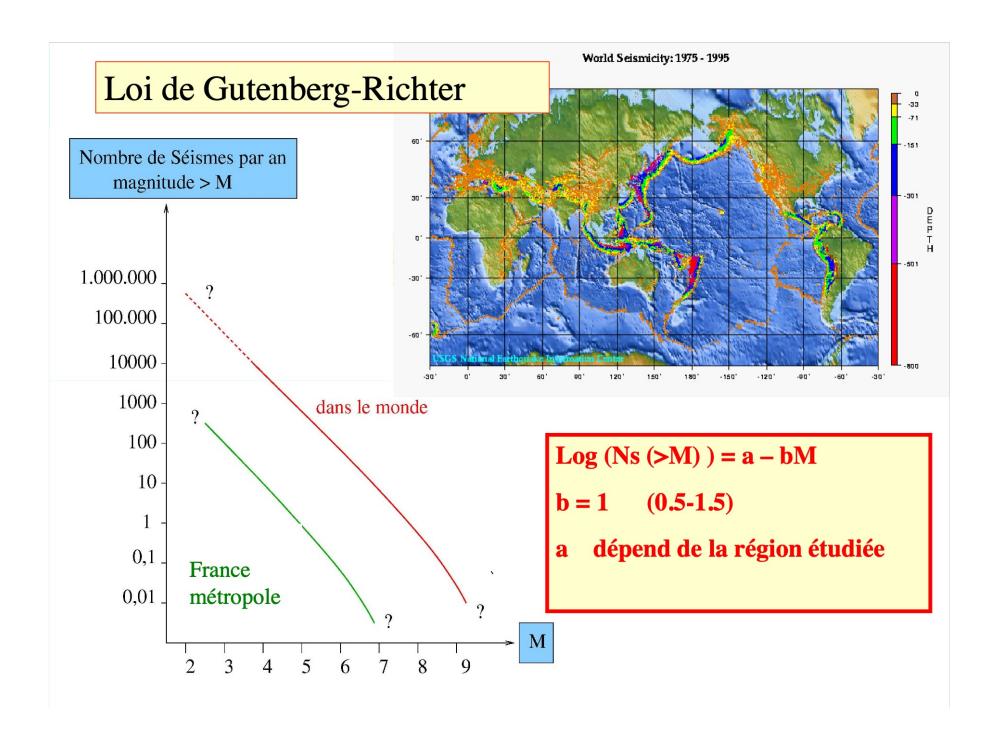
Bletery et al. 2016

Exemple: les séismes de Sumatra le 11/04/2012, Mw 8.6





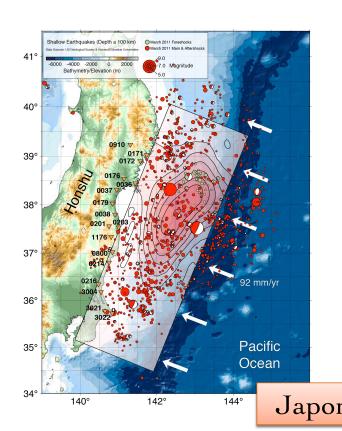


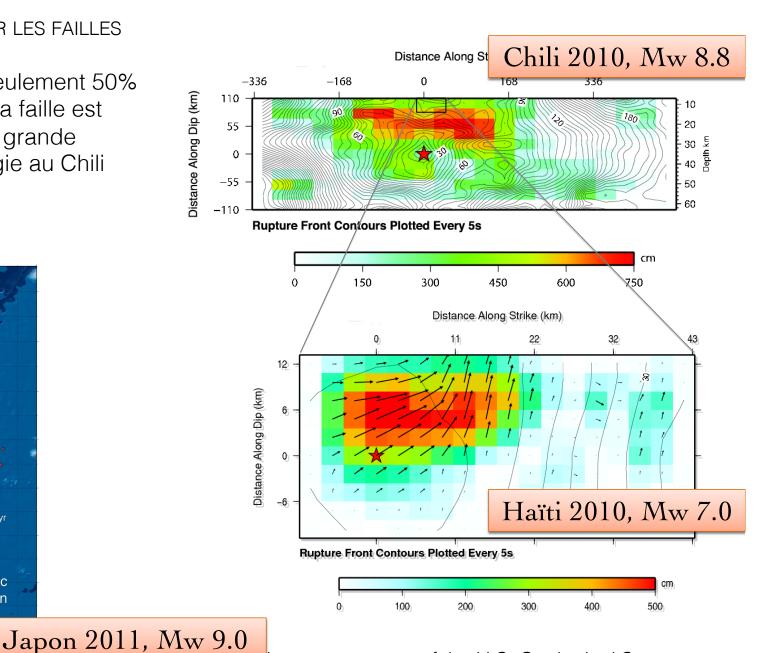


"CARTES"

DES GLISSEMENTS SUR LES FAILLES

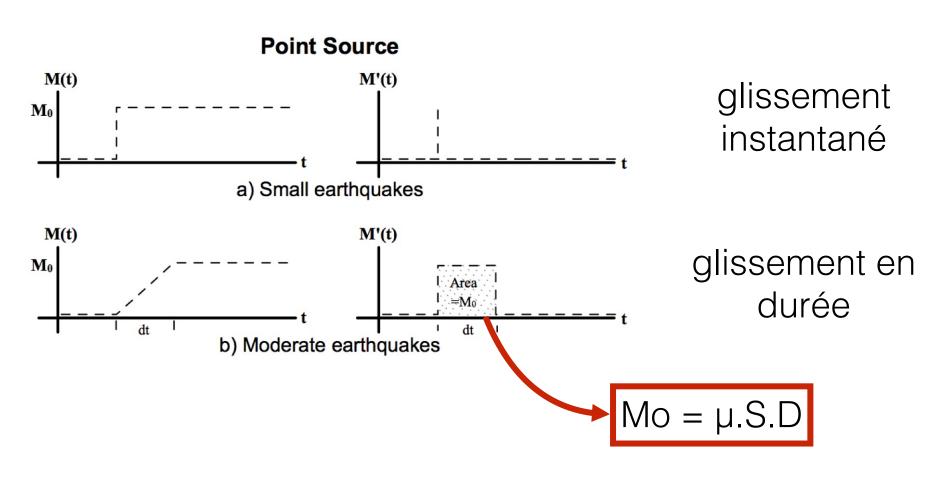
Glissement au chili seulement 50% plus grand, mais la faille est beaucoup plus grande 500 x plus d'énergie au Chili





Images courtesy of the U.S. Geological Survey

Comment les failles glissent-elles ?



Propagation de la rupture

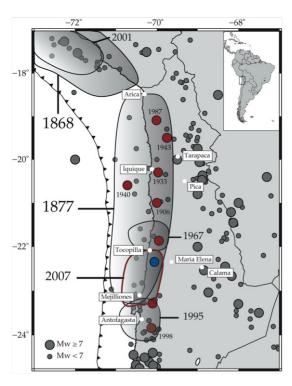
Modèle d'Aspérité Dans les zones de Subductions

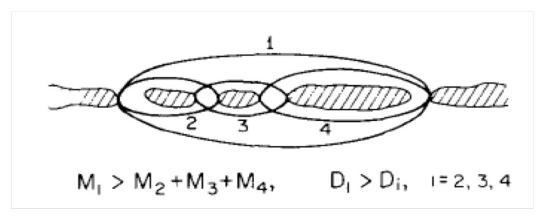
ANALYSE DE LA SISMICITÉ ET MODÈLE D'ASPÉRITÉ

Un explication simple est que les longueurs de la rupture et les glissements varient d'un cycle à l'autre:

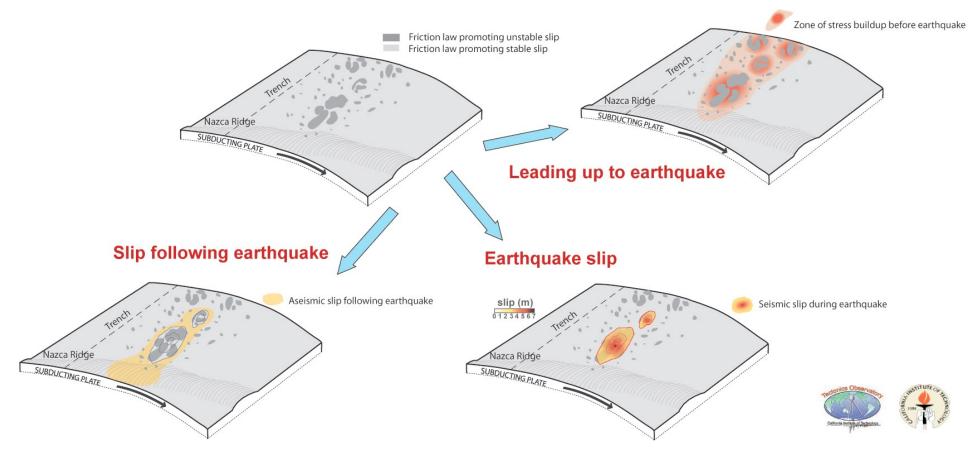
Petit séisme -> une aspérité.

<u>Grand séisme</u> -> plusieurs aspérités selon leur degré d'interactions.

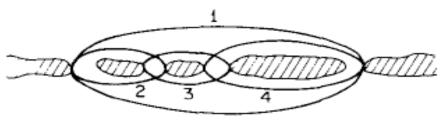




Kanamori and McNally, 1982

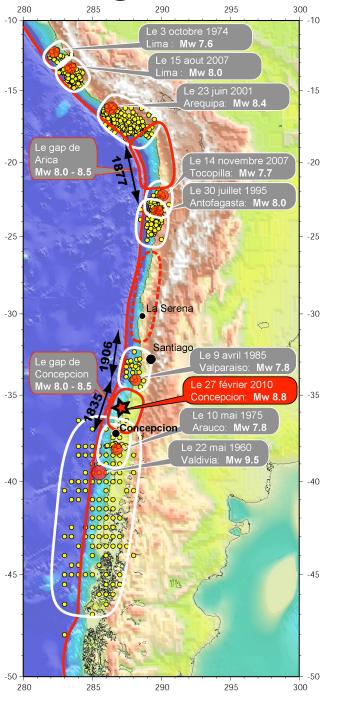


MODÈLE D'ASPÉRITÉ

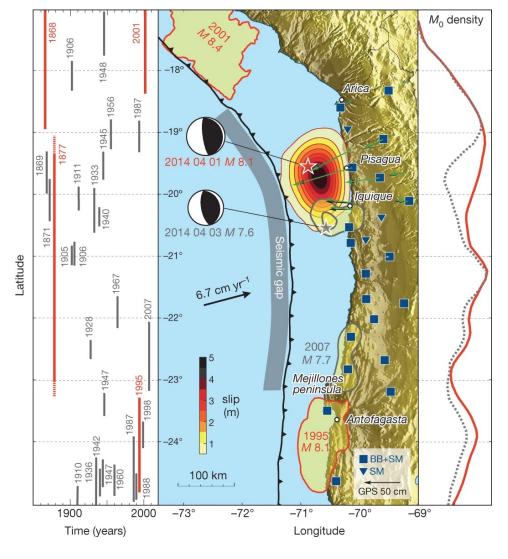


 $M_1 > M_2 + M_3 + M_4$, $D_1 > D_1$, i = 2, 3, 4

Kanamori and McNally, 1982



Modèle d'aspérités ?



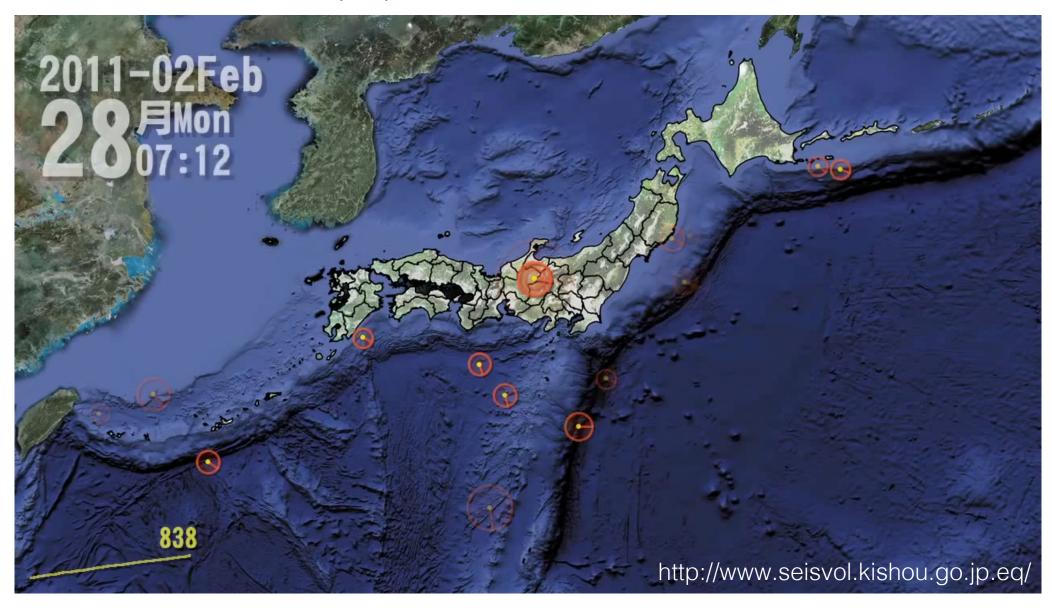


Modèle d'aspérités ?

Surface de rupture Mw > 8.0 depuis le XXème siècle

Séisme de Tohoku (2011, Mw = 9.2) reprend des zones ayant déjà rompu...

Un gros séisme est suivi par une succession de plus petits événements : les répliques

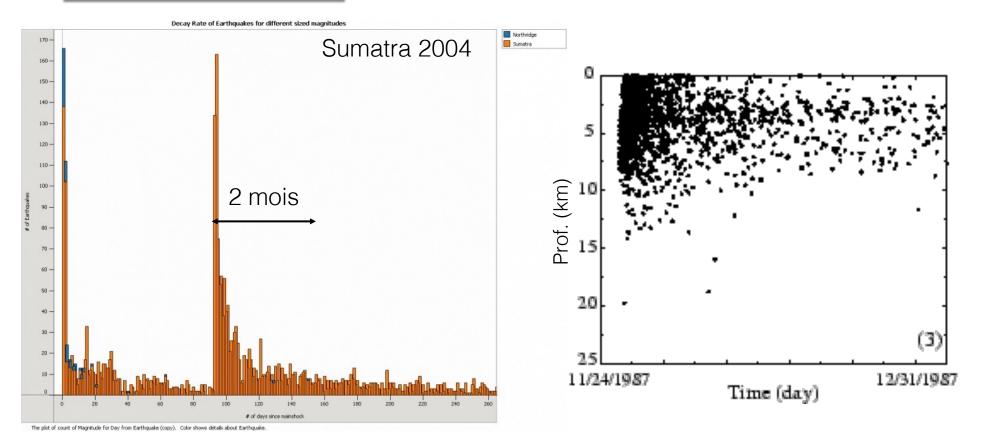


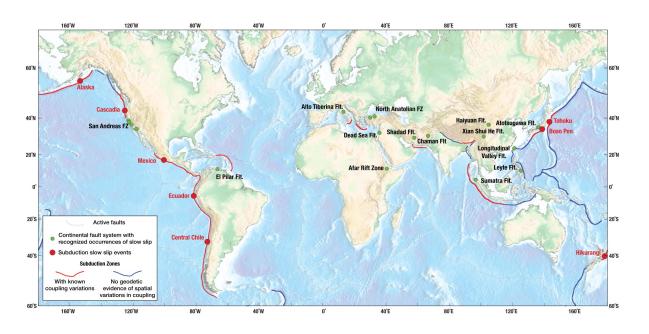
Un gros séisme est suivi par une succession de plus petits événements : les répliques

Le nombre de répliques N(t) suit une décroissance régulière :

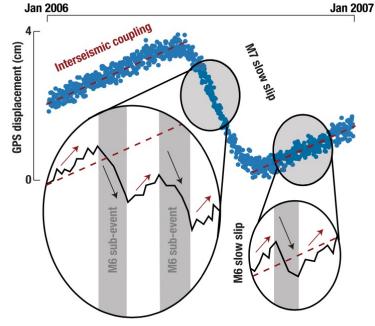
$$N(t) = \frac{K}{(t+c)^{\theta}}$$

Loi d'Omori



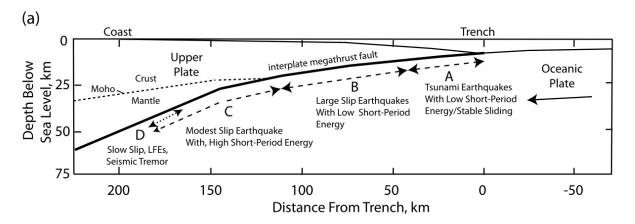


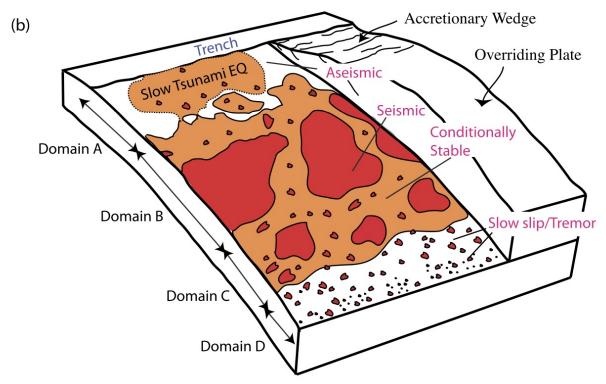
Nouveaux phénomènes identifiés: Séismes lents, tremors....



A: Subduction Megathrust

T. Lay / Earth and Planetary Science Letters 409 (2015) 133-146





Nouveaux phénomènes identifiés: Séismes lents, tremors....