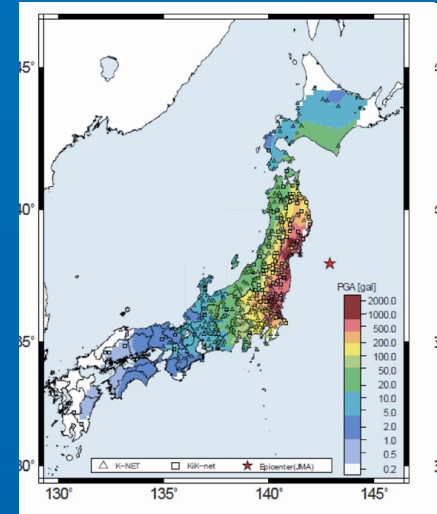


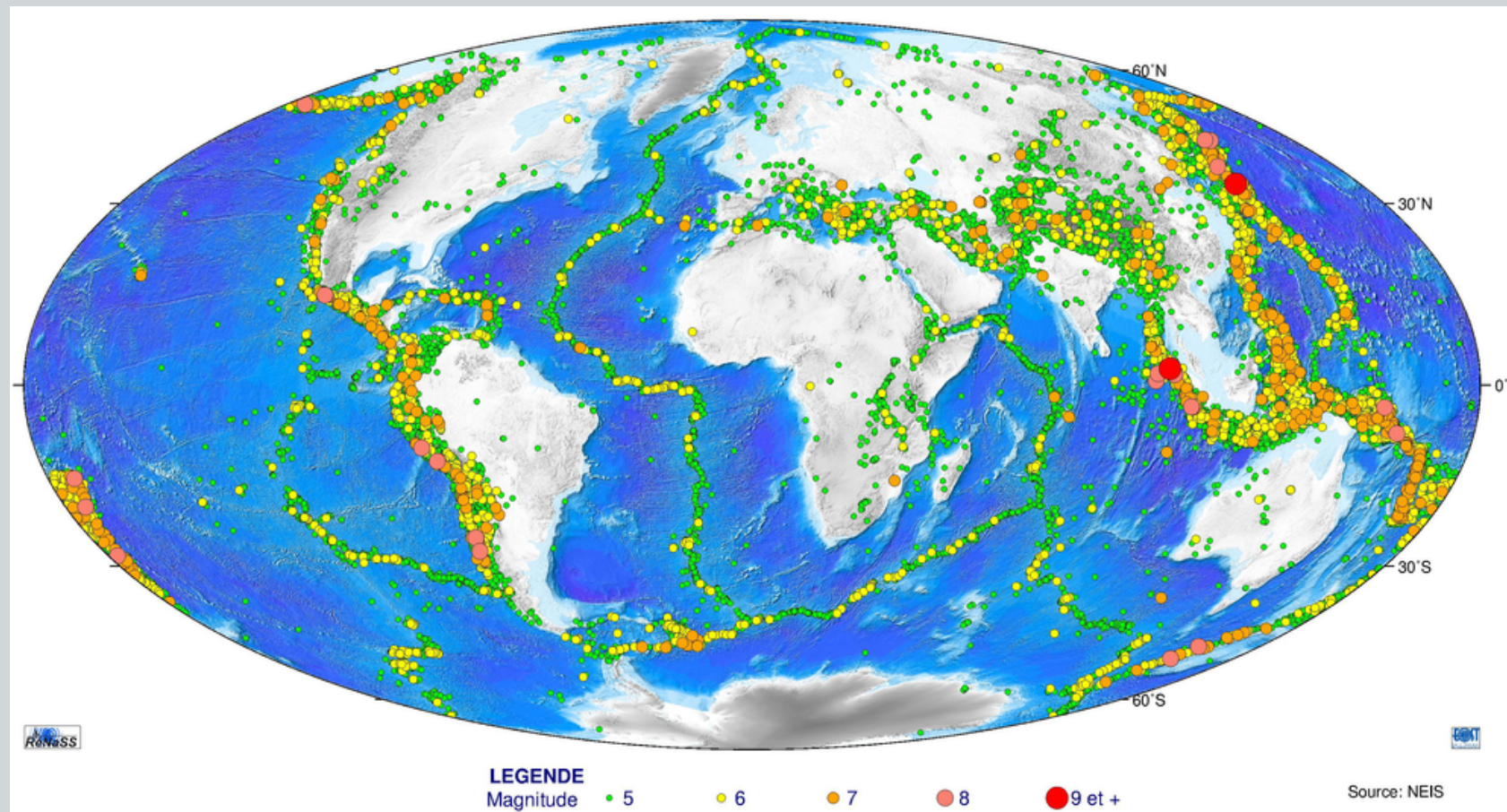


Les séismes : catastrophes imprévisibles aux conséquences incertaines ?

Jean-François Semblat
ENSTA-ParisTech
IMSIA (UMR CEA, EDF, ENSTA)
(21 février 2019)

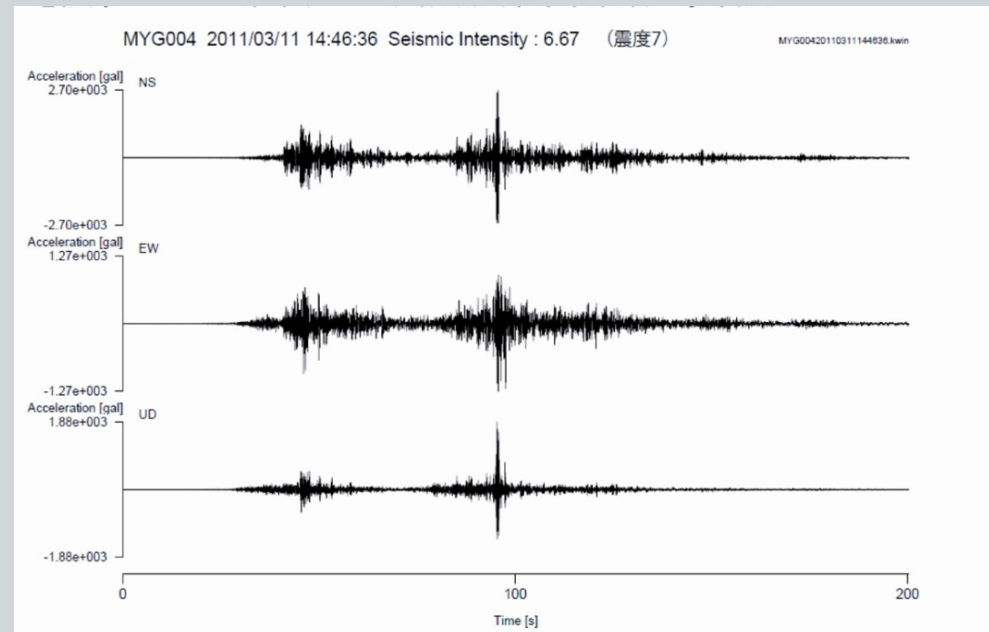
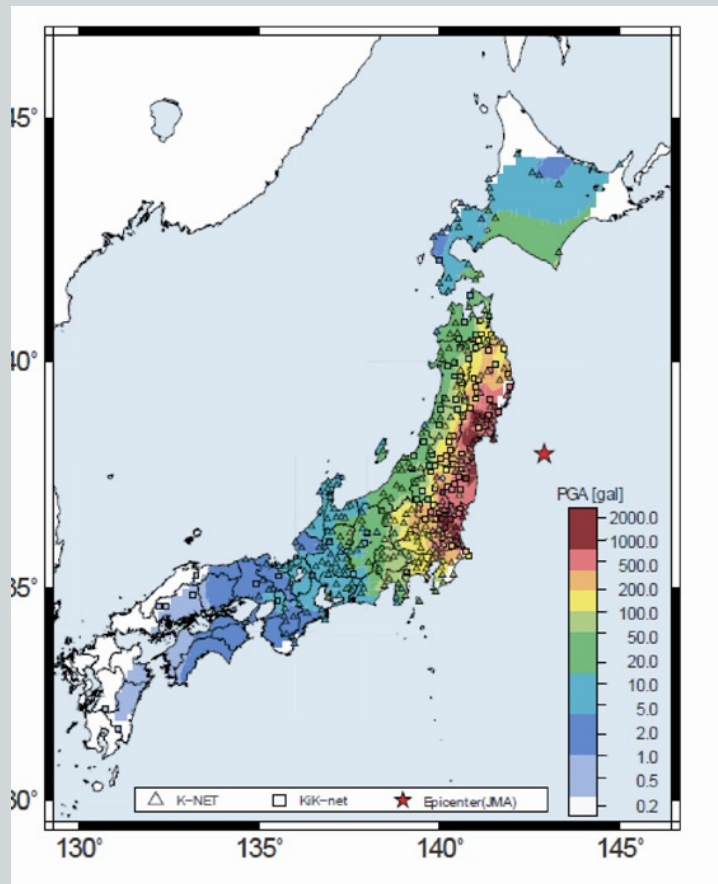
Séismes récents

Sismicité mondiale de 1973 à 2012



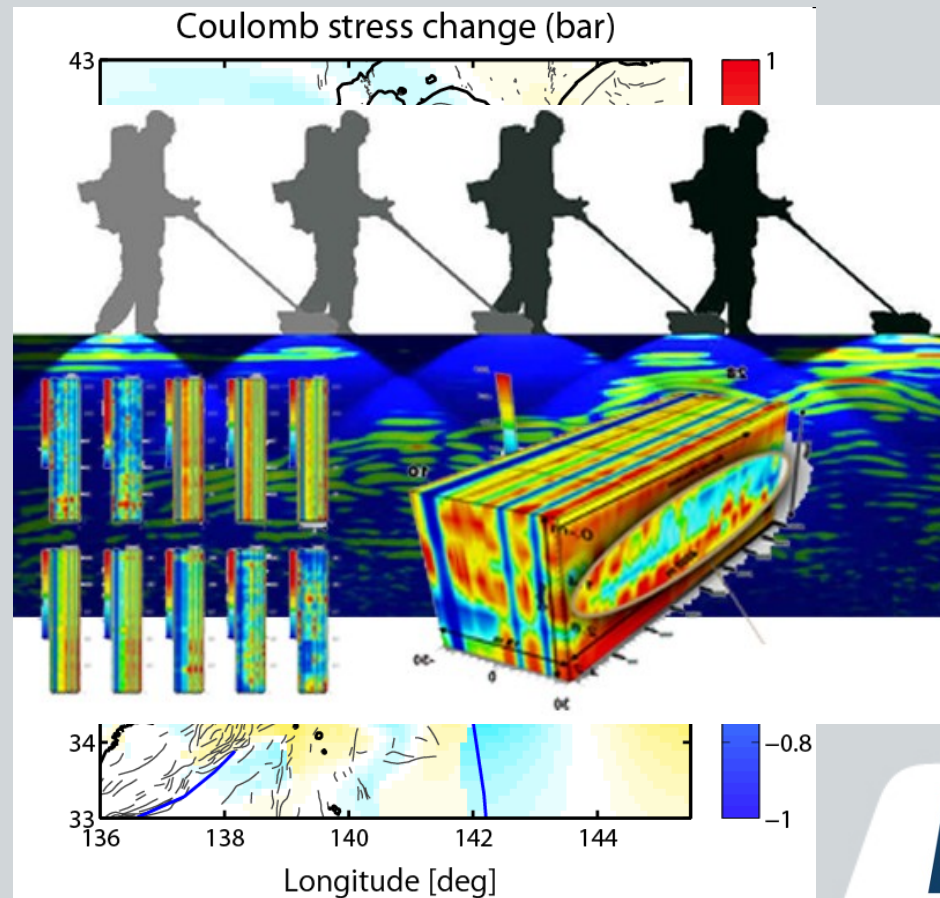
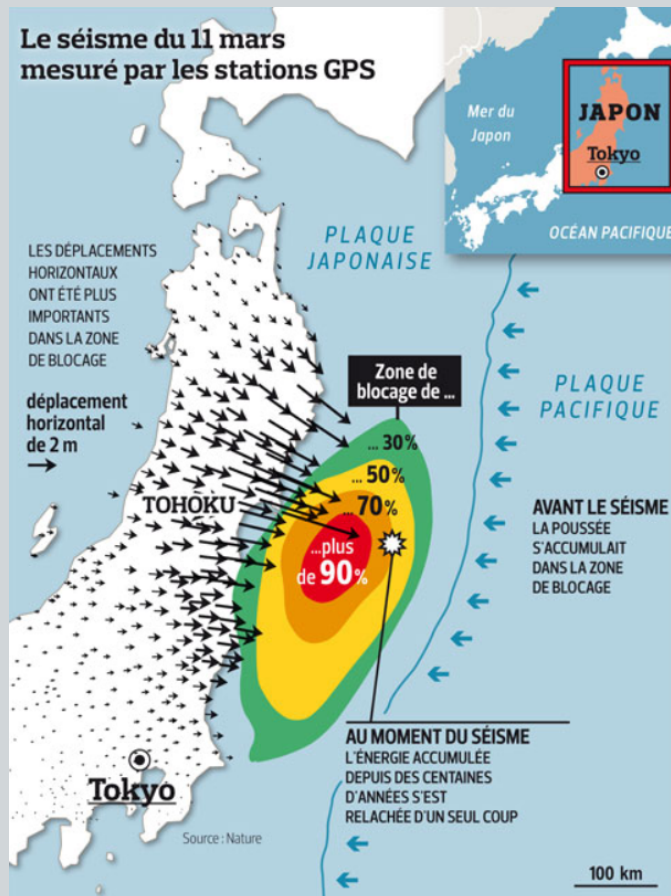
Événements extrêmes

- Séisme de Tohoku (mars 2011)



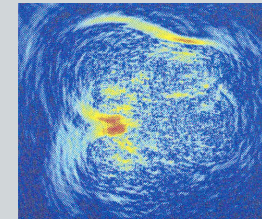
Prévision des séismes ?!

- Mouvements en surface + contraintes en profondeur ?

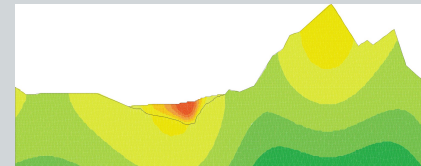


Plan

1. Failles : état de contrainte vs rupture ?



2. Rayonnement et propagation des ondes

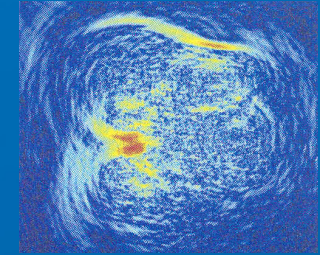


3. Sollicitation structures : forfaitaire/probabiliste



4. Perspectives

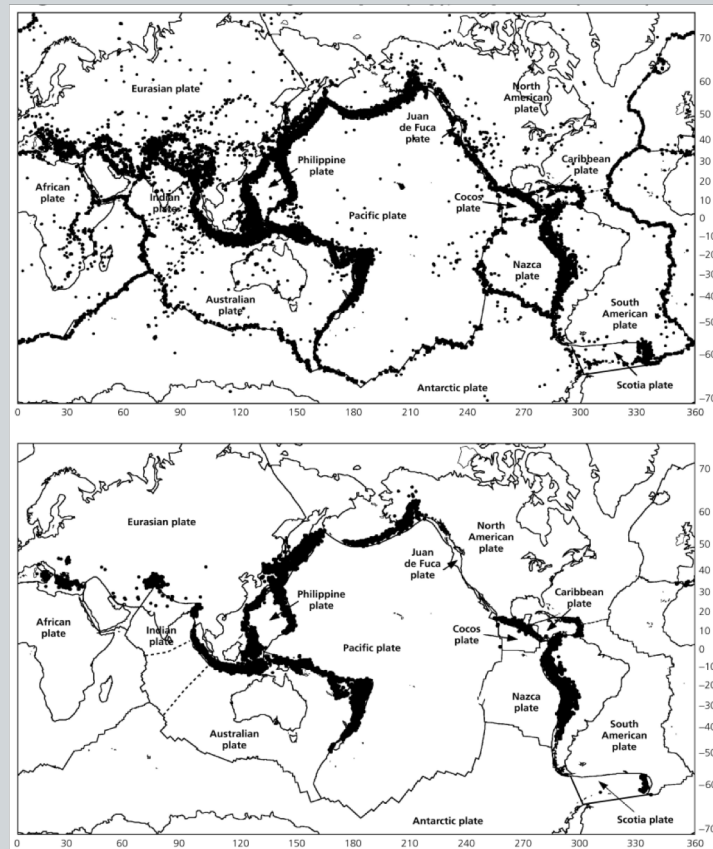




1/ Failles : état de contrainte vs rupture ?

Répartition spatiale

- Sismicité de 1964 à 1997 : tous les séismes (haut) et séismes initiés à plus de 100km de profondeur (bas)



(Stein & Wysession, 2003)

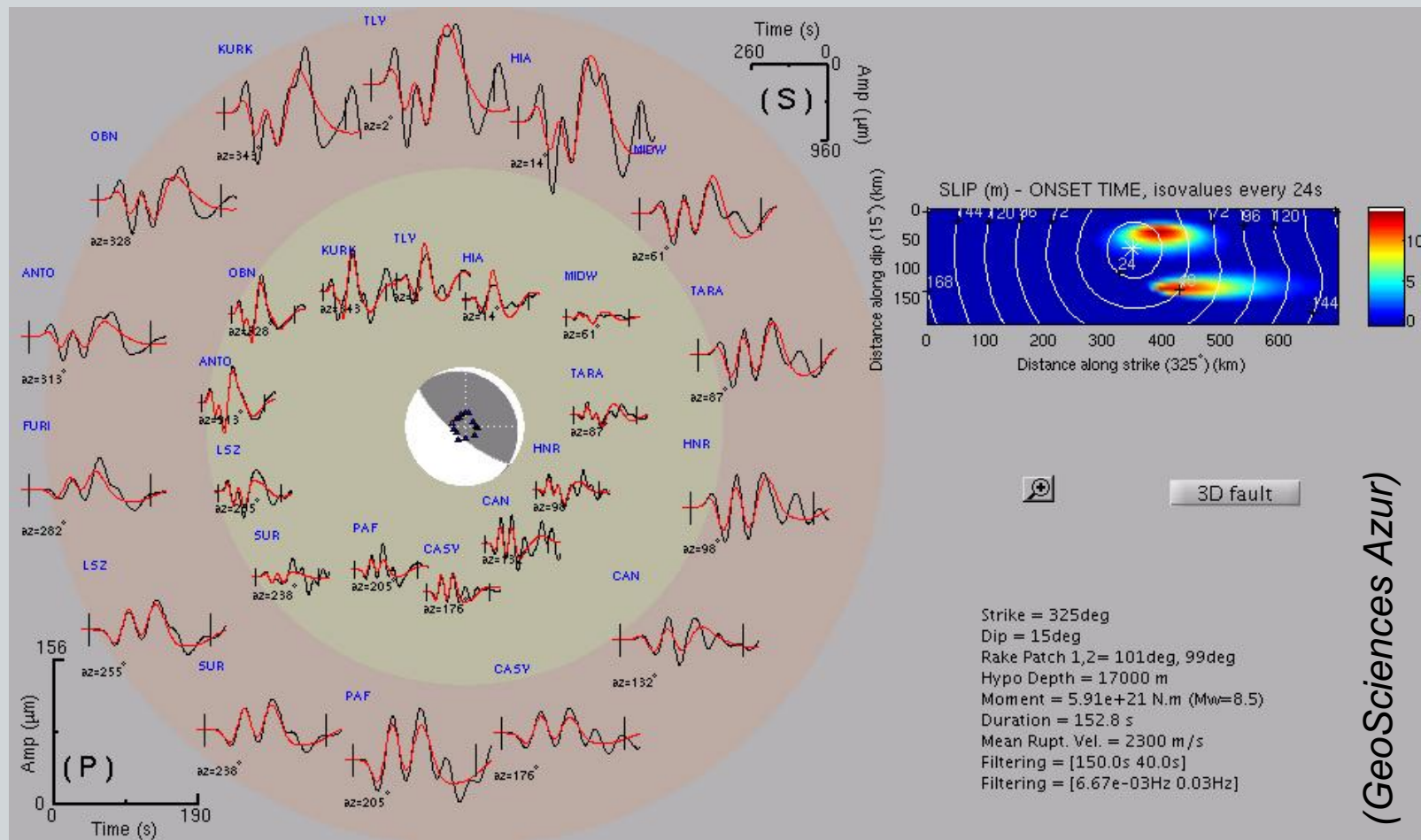
Répartition temporelle

- Séismes historiques et mouvements le long de la faille Nord Anatolienne au 20^è siècle (*AIR*)



Identification des sources

- Séisme de Sumatra (2004)



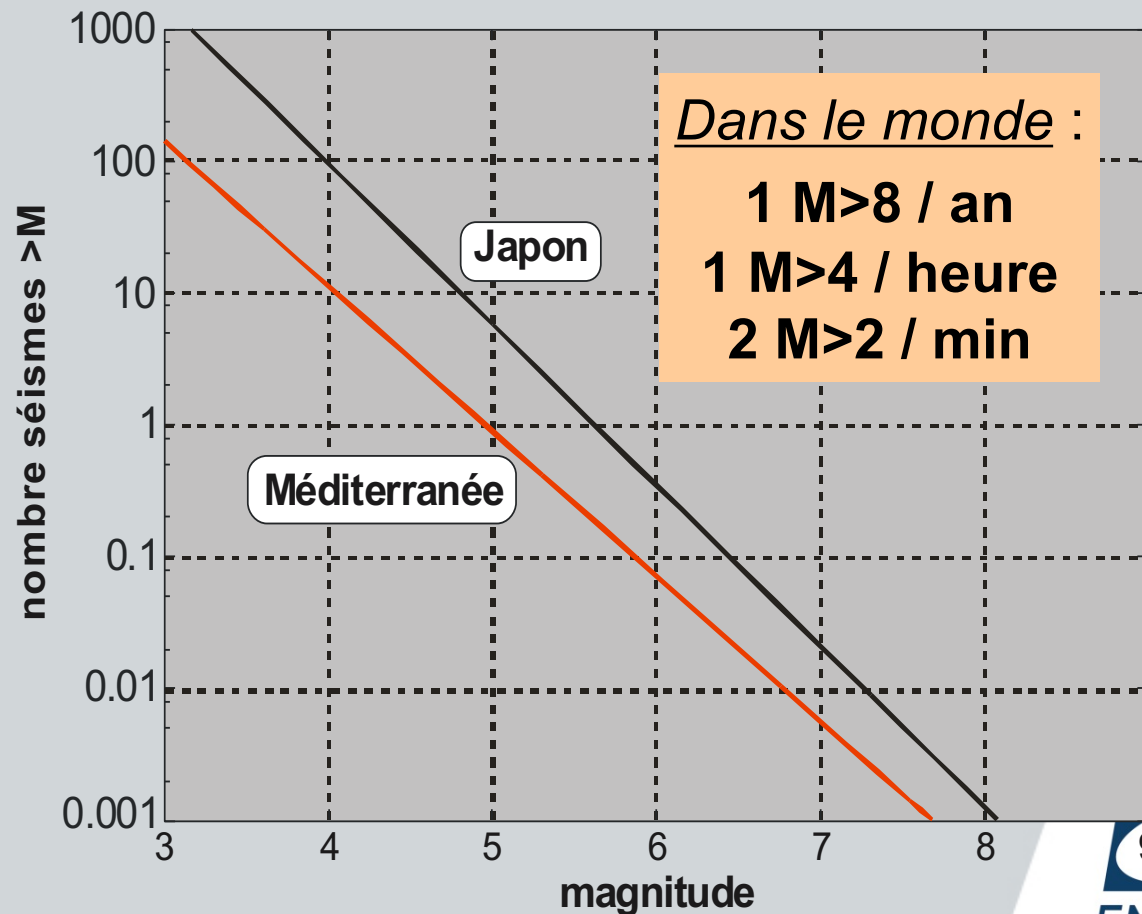
(GeoSciences Azur)

Statistiques des magnitudes

- Loi de Gutenberg-Richter : $\log_{10}(N(M)) = A - bM$

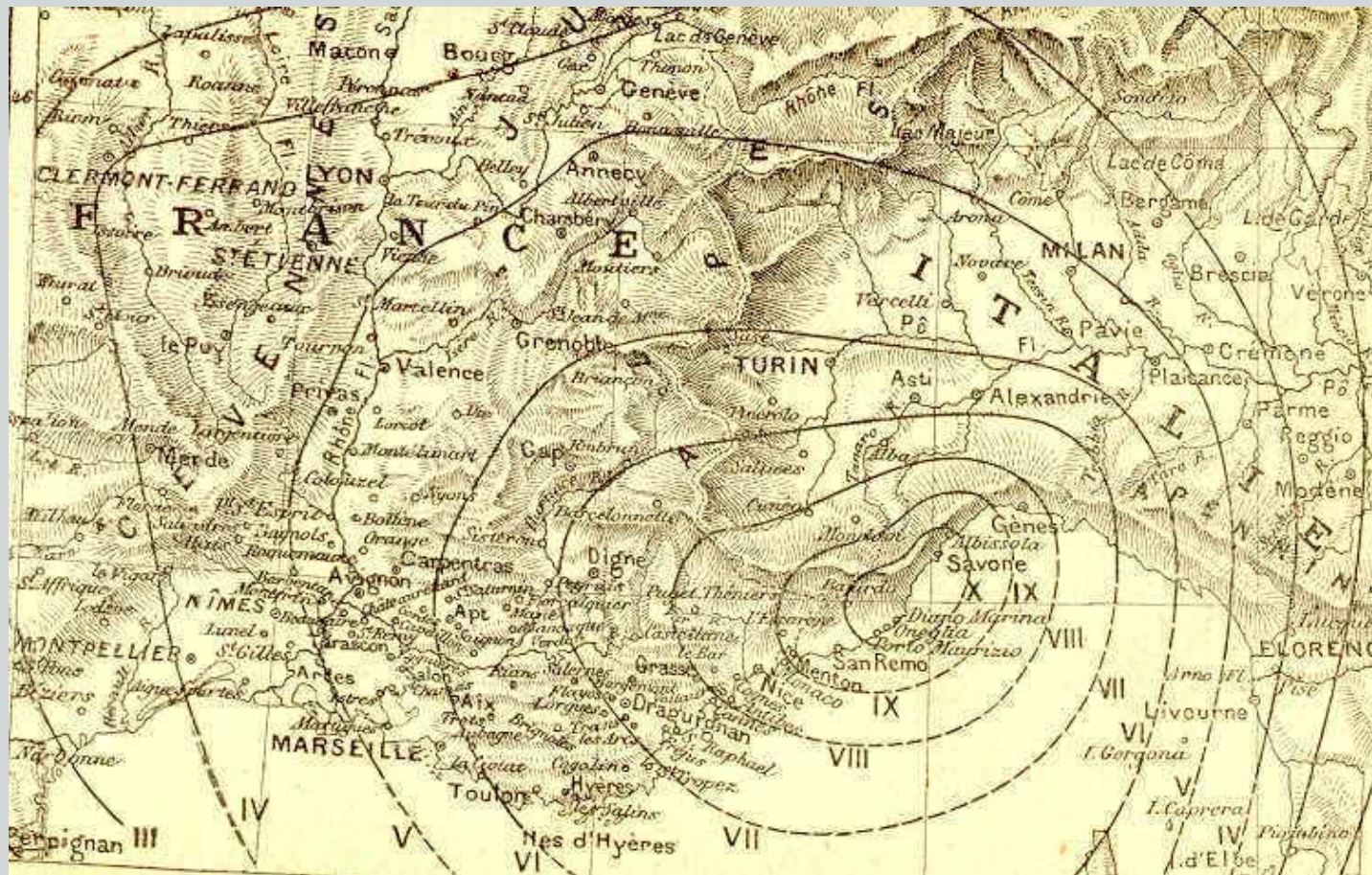
M	nbre/an
≥ 8	1
$7 \leq M < 8$	15
$6 \leq M < 7$	134
$5 \leq M < 6$	1319
$4 \leq M < 5$	13000
$3 \leq M < 4$	130000
$2 \leq M < 3$	1300000

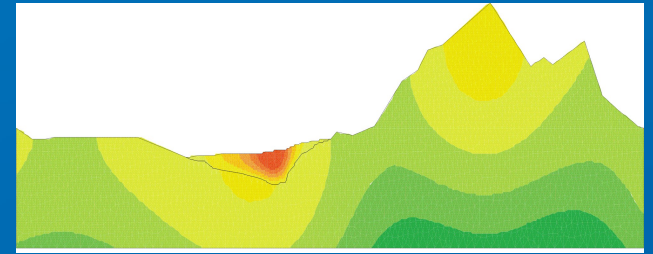
Source USGS



Séismes passés ?

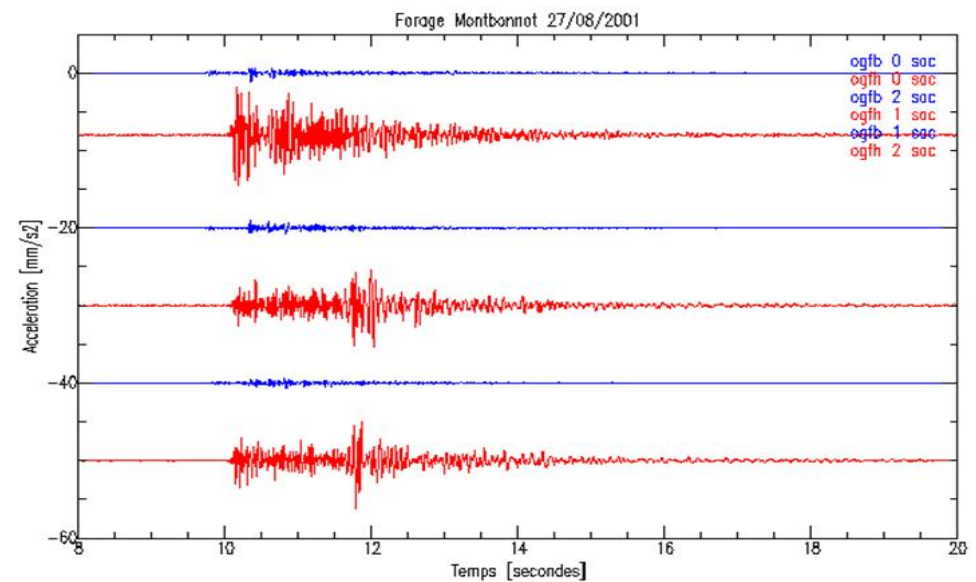
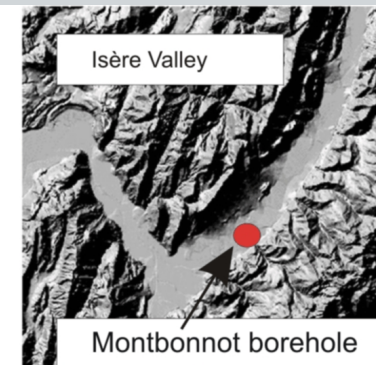
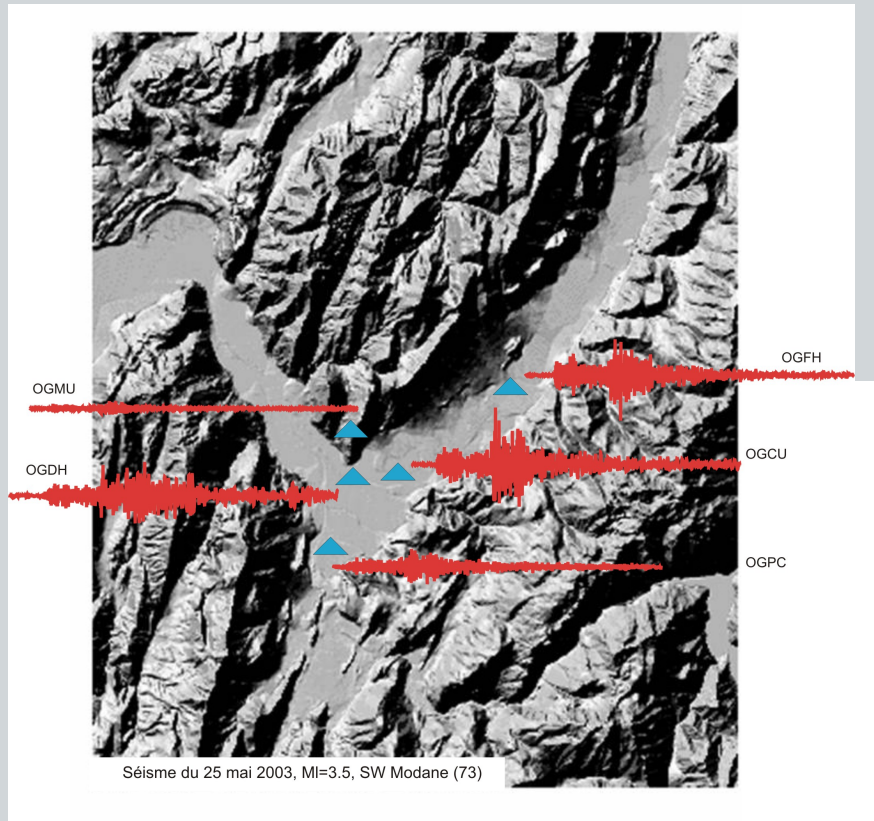
- Séisme de Ligure (1887)





2/ Rayonnement et propagation des ondes

Structures géologiques de surface



1. Mouvement surface
2. Mouvement profondeur

Réseaux observations (Japon)

Soil & Rock Condition

Station Point: YUNOTANI

Station Code: NIGH12

Location : NIIGATAKEN KITAUONUMAGUN YUNOTANIMURA YOSHIDA 1142

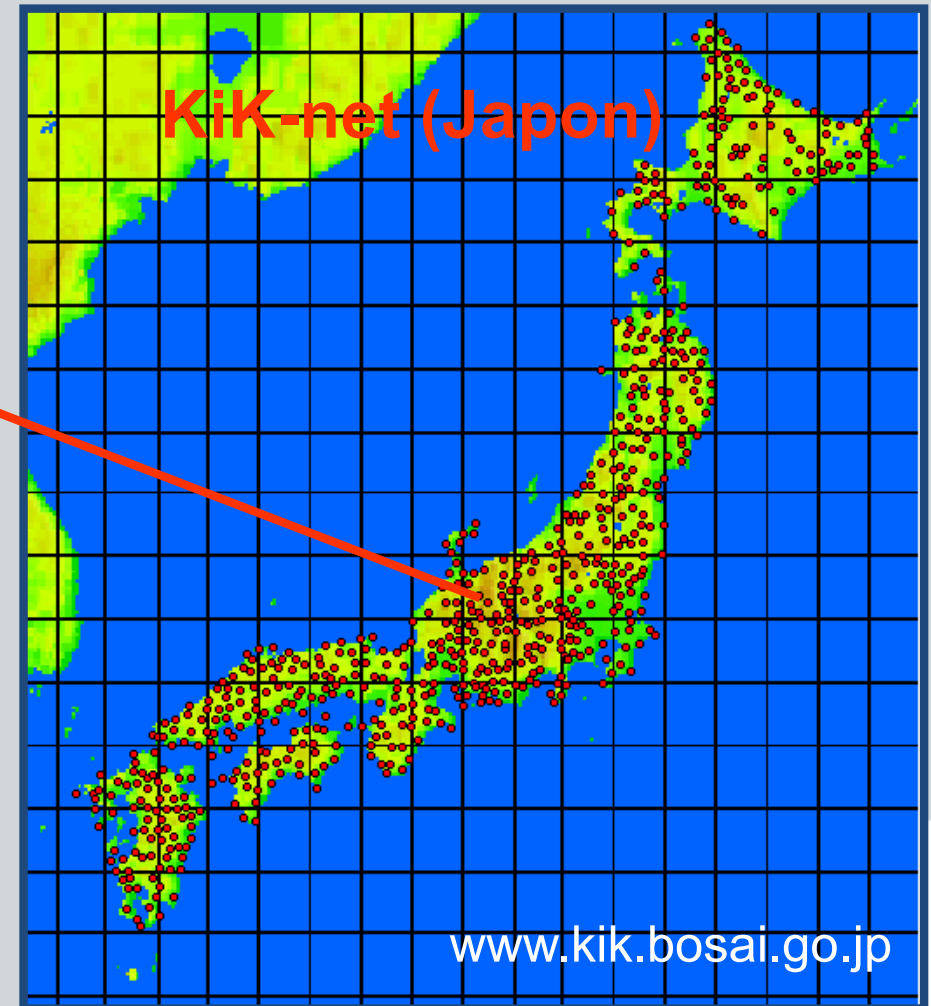
Latitude : 37 deg 13 ' 15.0 ''

Longitude : 138 deg 59 ' 7.0 ''

Altitude : 0m

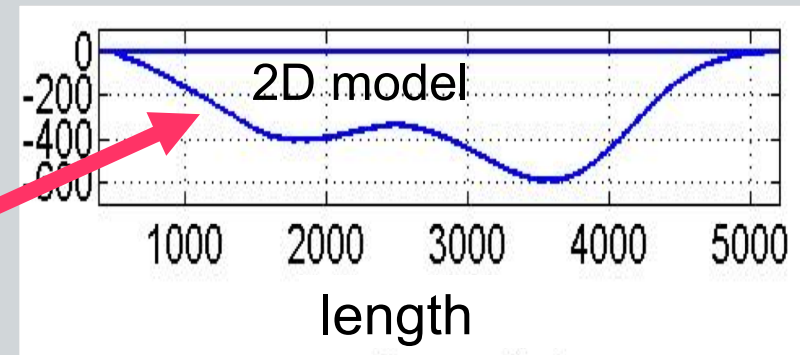
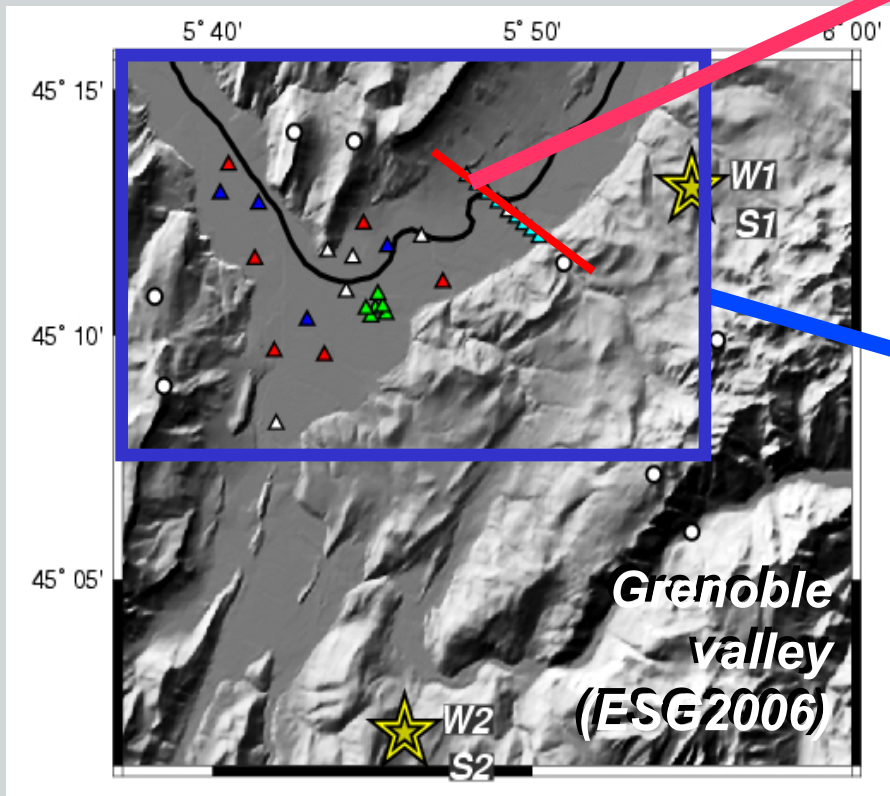
Depth : 113.00m

SCALE (m)	ALTITUDE (m)	DEPTH (m)	LOG	LITHOLOGY	G.T.	P, S VELOCITY		SECTION VELOCITY P-WAVE (m/s)	SECTION VELOCITY S-WAVE (m/s)
						P-WAVE (m/s)	S-WAVE (m/s)		
5	-6.00	6.00		gravel with cobble stone				500	240
10				gravel with sand				1000	500
15	-14.00	14.00							
20				sand with gravel					
25									
30	-32.00	32.00						1980	730
35				sand and gravel with cobble stone					
40									
45	-48.00	48.00							
50	-52.00	52.00		clay with gravel	Q				
55	-54.00	54.00		cobble stone with clay/sand and gravel					
60									

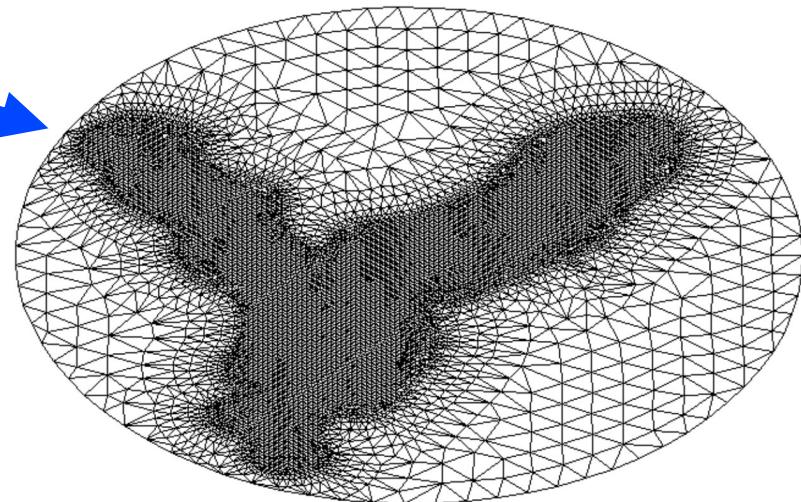


Propagation/amplification: modèles ?

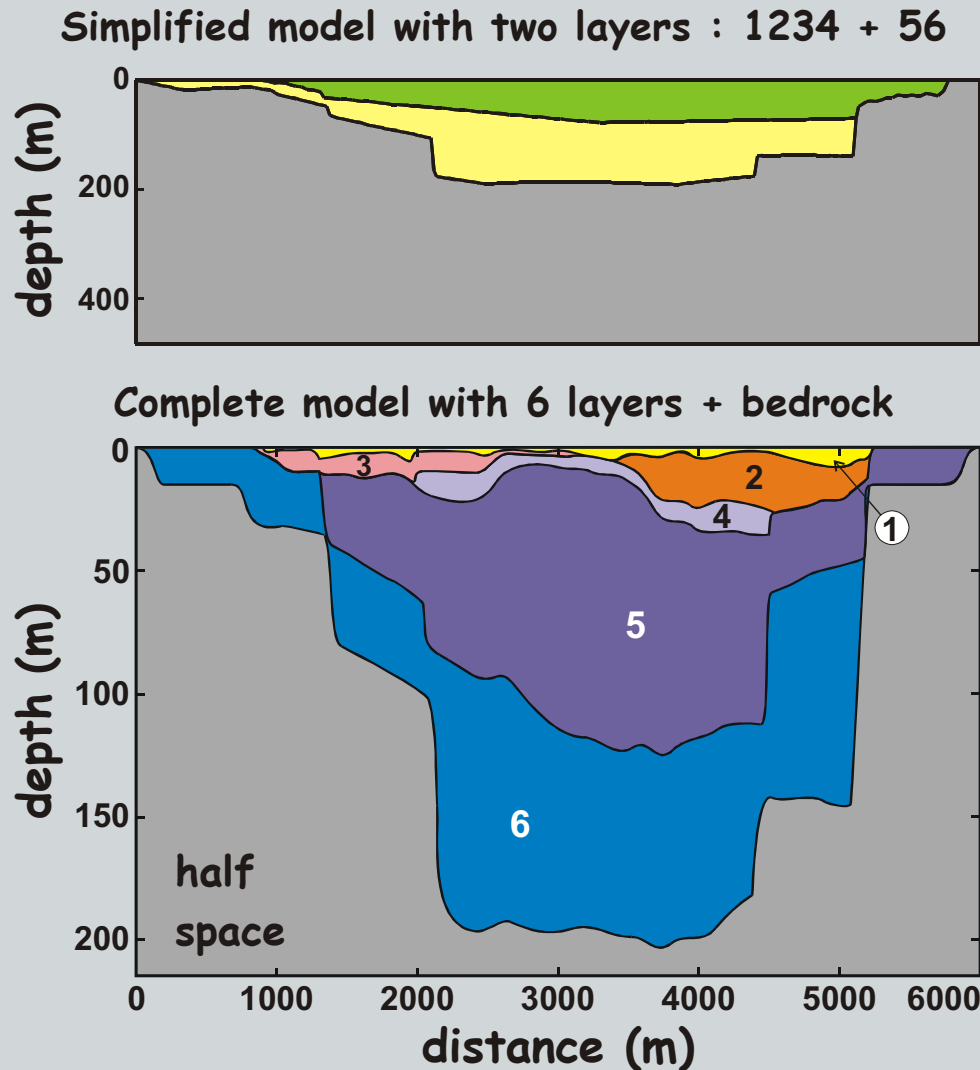
- Propagation 2D
- Propagation 3D
- FEM, SEM, BEM...



3D model



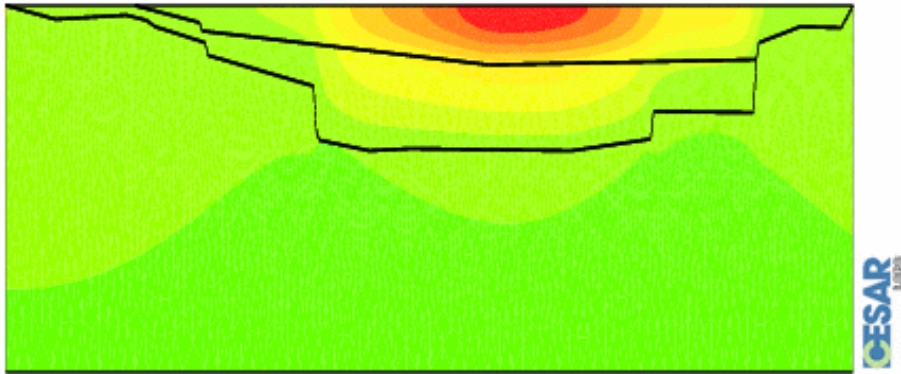
Modèle simple vs complexe ?



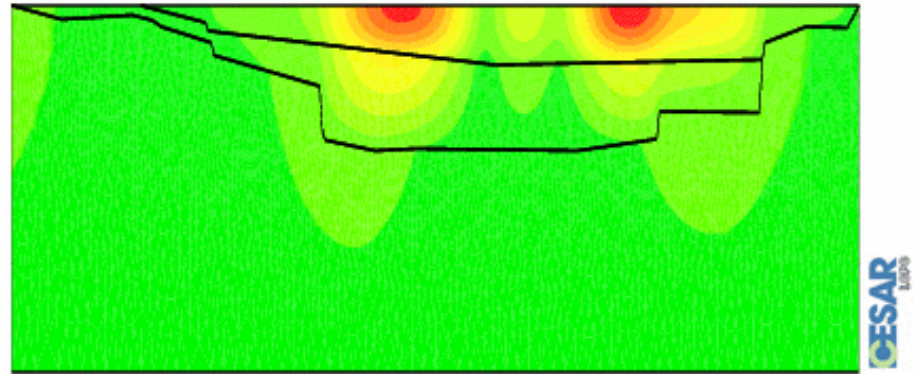
- Bassin Volvi (Grèce)
- Stratification simplifiée/ détaillée
- Méthode BEM
- Influence incertitudes réponse sismique ?

Amplification : variabilité spatiale

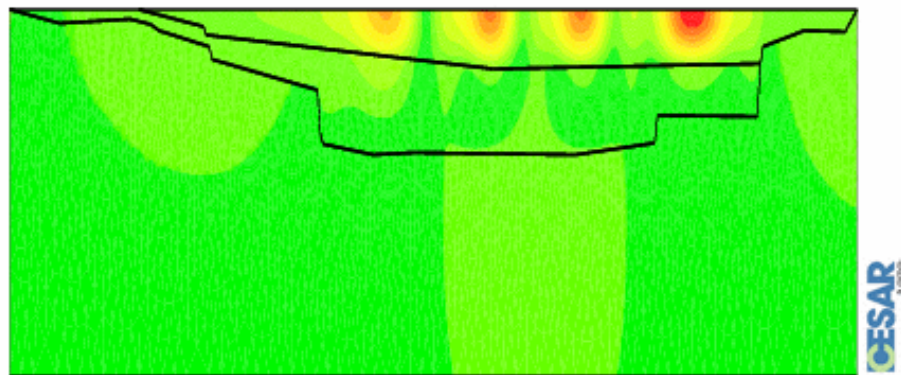
$F=0.6\text{Hz}$, $A=2.9$



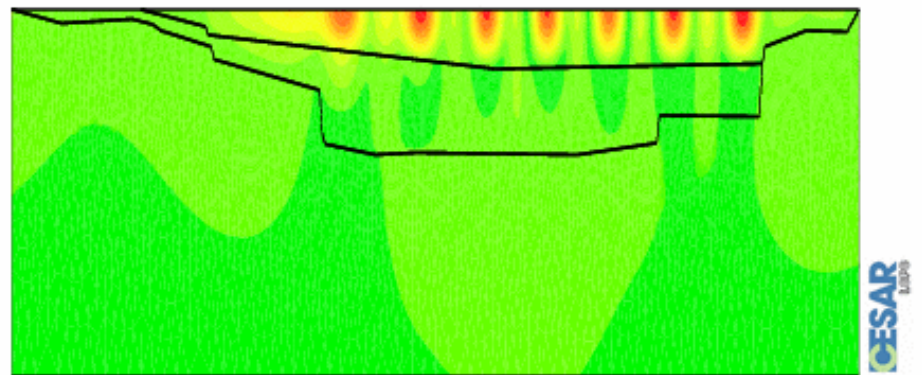
$F=0.8\text{Hz}$, $A=9.5$



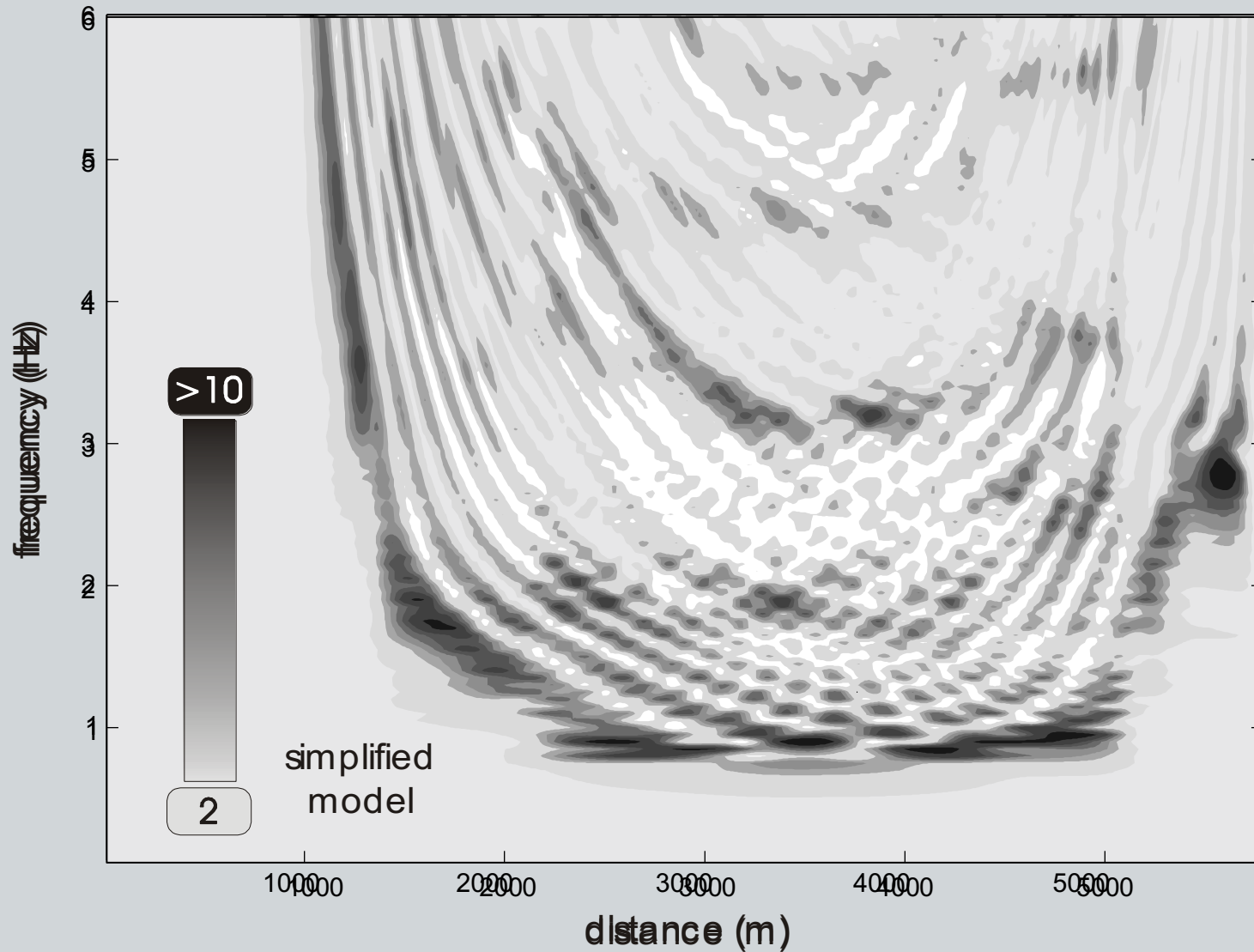
$F=1.0\text{Hz}$, $A=9.5$



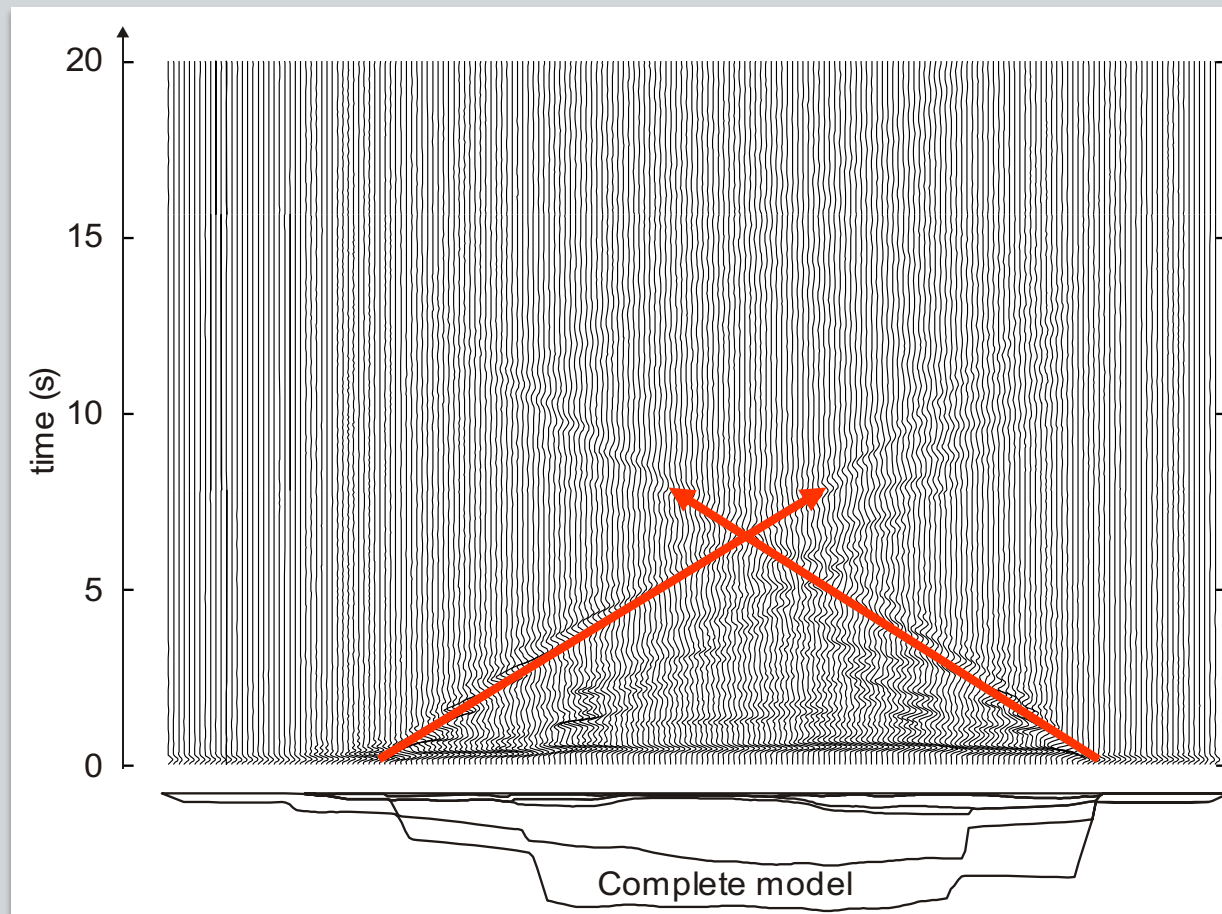
$F=1.2\text{Hz}$, $A=7.5$



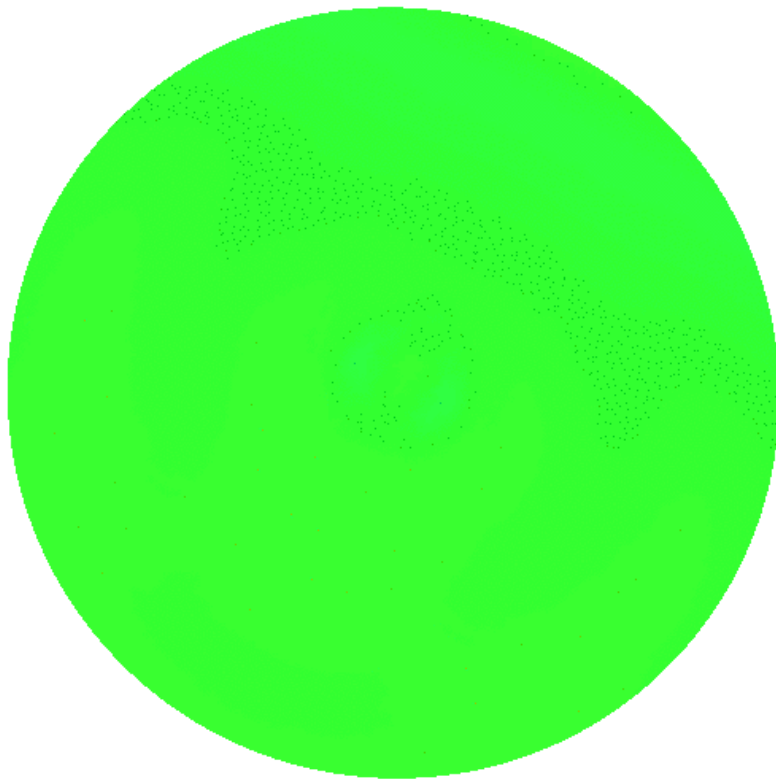
Amplification : modèle simple vs complet



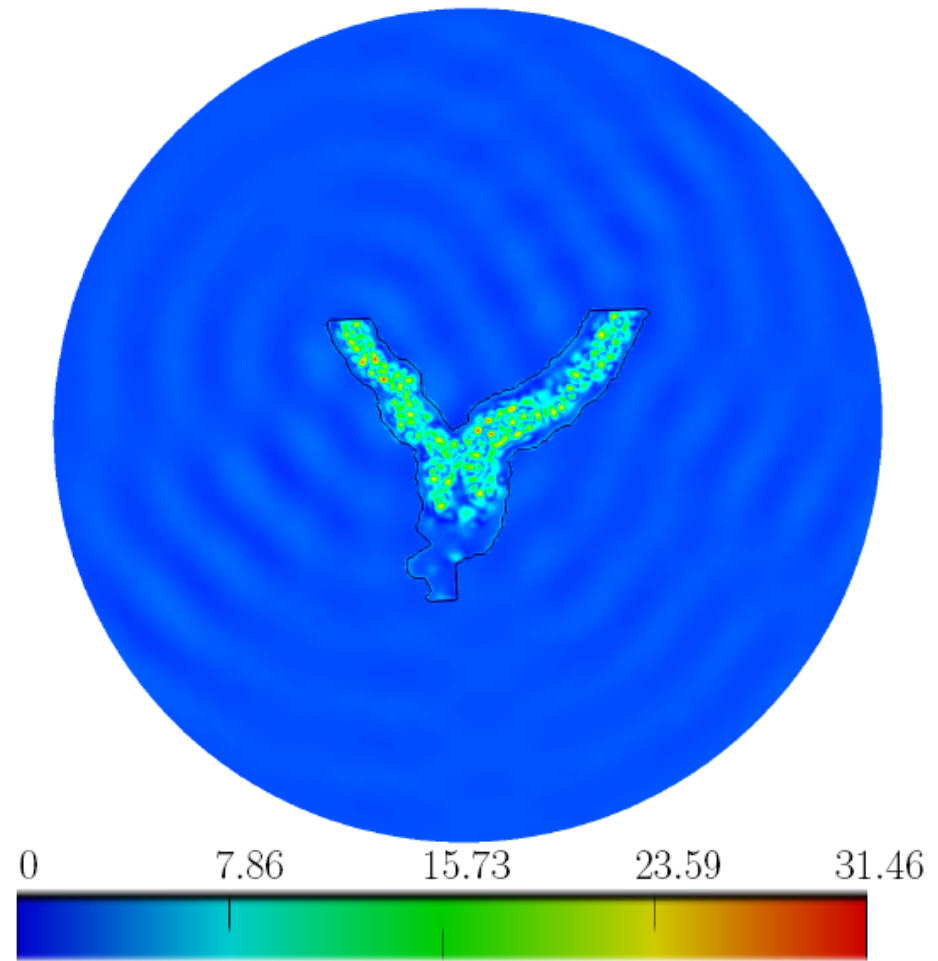
Variabilité et ondes de surface



Amplification tridimensionnelle



(Chaillat et al., Geophysical Jnl Int., 2009)



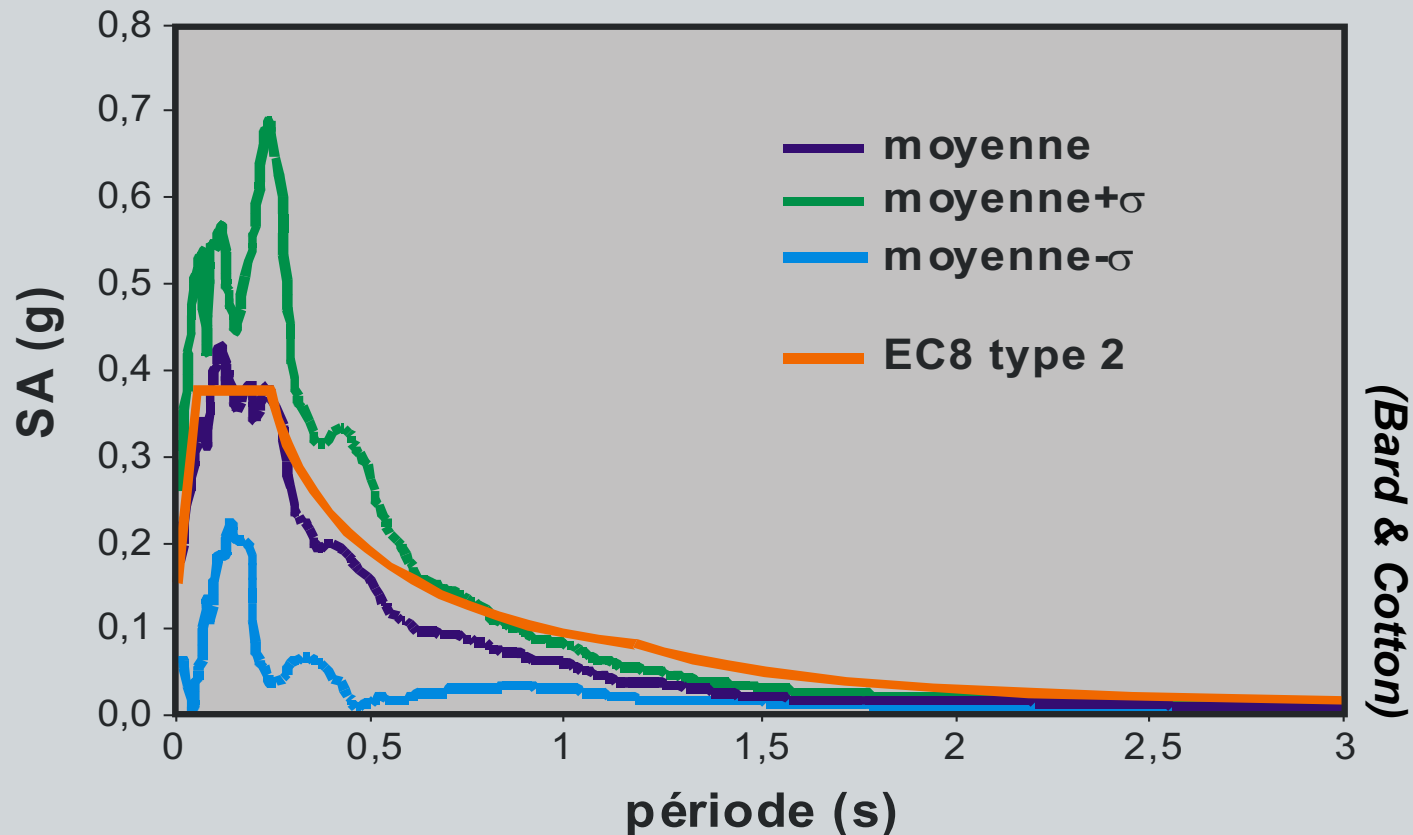
(S. Chaillat, J-F Semblat, M. Bonnet, CiCP, 2012)



3/ Sollicitation des structures : *forfaitaire* vs probabiliste

Simplification / réglementation

- Raisonnement sur des *événements moyens*.
Ex.: moyenne de 9 séismes européens ($0,048g < PGA < 0,348g$)



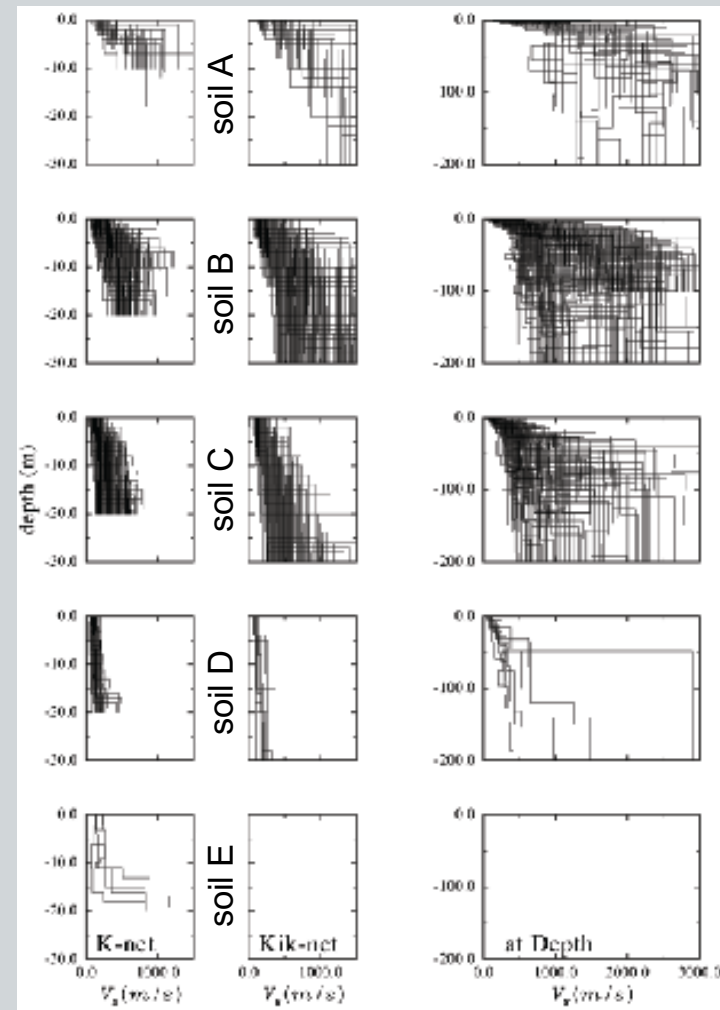
Influence du type de sol

Classe	Description	Paramètres		
		$V_{S,30}$ (m/s)	N (SPT)	C_u (kPa)
A	Rocher – alluvions < 5m	> 800	-	-
B	Sable très dense, gravier ; h>10m	360-800	> 50	> 250
C	Sable dense, moy ^t denses, argile raide ; h=10-100m	180-360	15-50	70-250
D	Sable lâche, moy ^t dense ; argile ferme à molle	< 180	< 15	< 70
E	Alluvions C ou D, h=5-20m sur rocher			
S ₁	Couches av.strates h>10m argile molle (IP>40), w élevée	< 100	-	10-20
S ₂	Sites liquéfiables			

$$V_{S,30} = \frac{H}{\sum_{i=1}^N \frac{h_i}{V_i}}$$

Variabilité des profils géologiques

- Exemple pour des profils de sols japonais



Approches probabilistes

$$\lambda_{y^*} = \sum_{i=1}^{N_S} \sum_{j=1}^{N_M} \sum_{k=1}^{N_R} \nu_i \int \int P[Y > y^* | m_j, r_k] P[M = m_j] P[R = r_k]$$

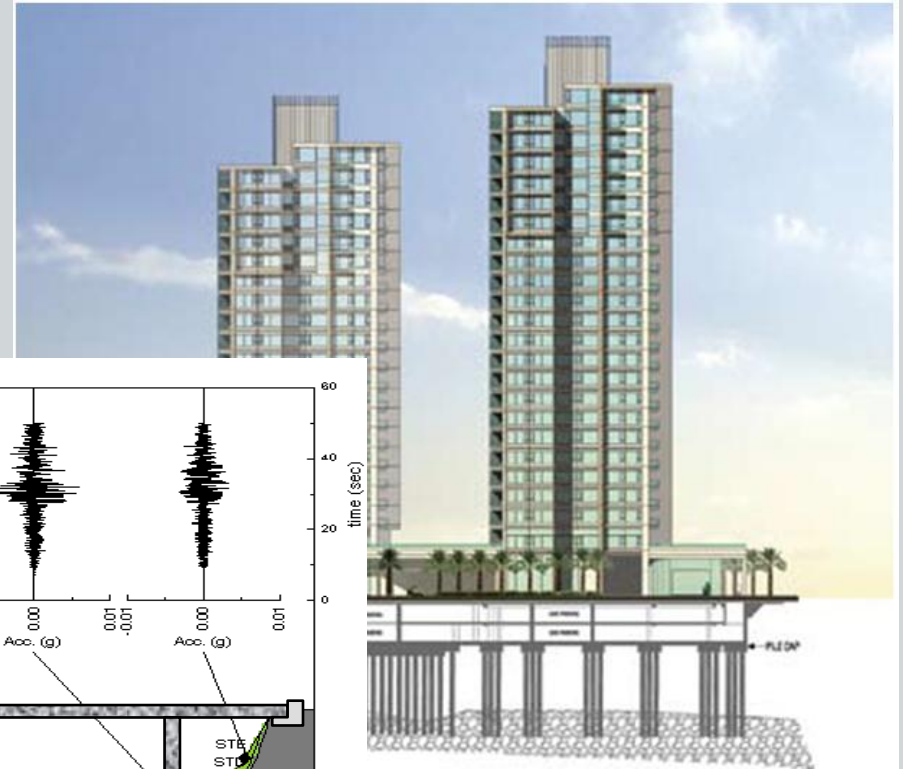
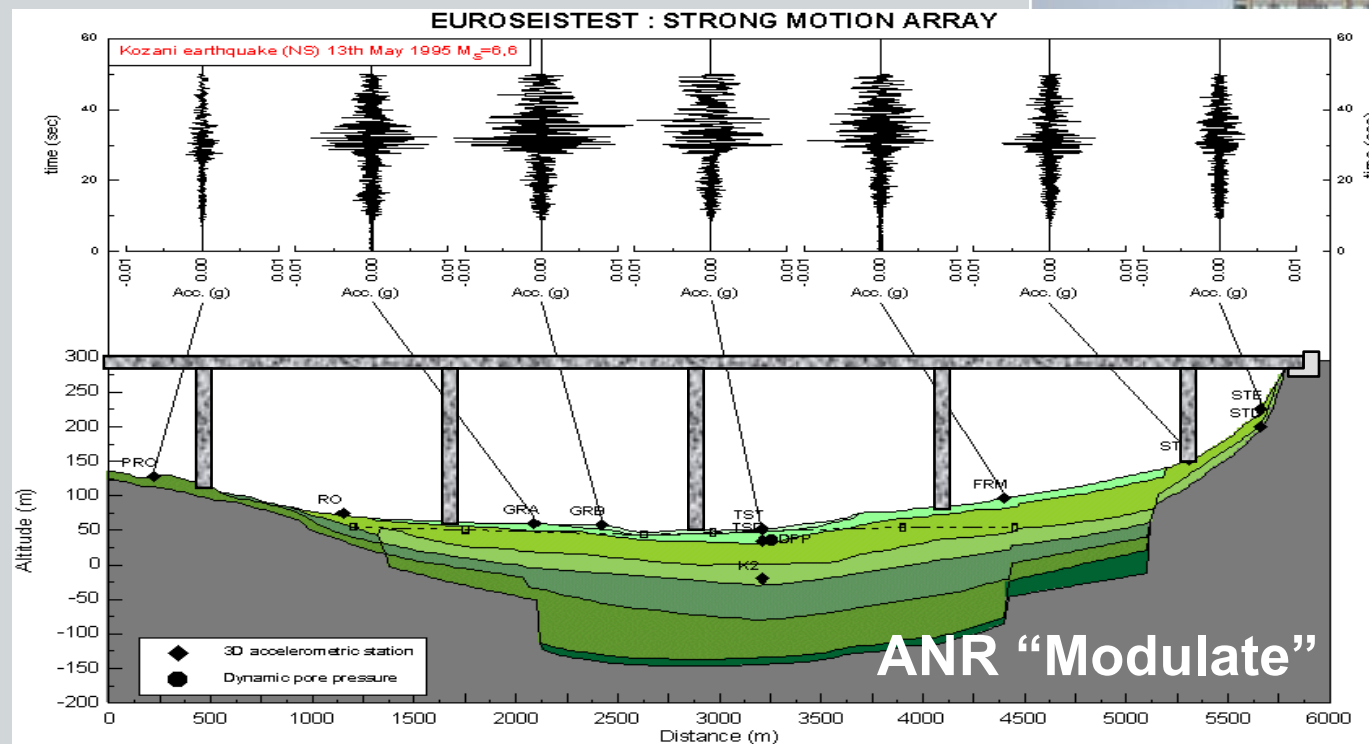
All sites are considered

All possible effects are considered - each weighted by its conditional probability of occurrence

All possible distances are considered - contribution of each is weighted by its probability of occurrence

All possible magnitudes are considered - contribution of each is weighted by its probability of occurrence

Fondations et structures





Perspectives

Effet induit (1) : liquéfaction (ANR 'ISOLATE')



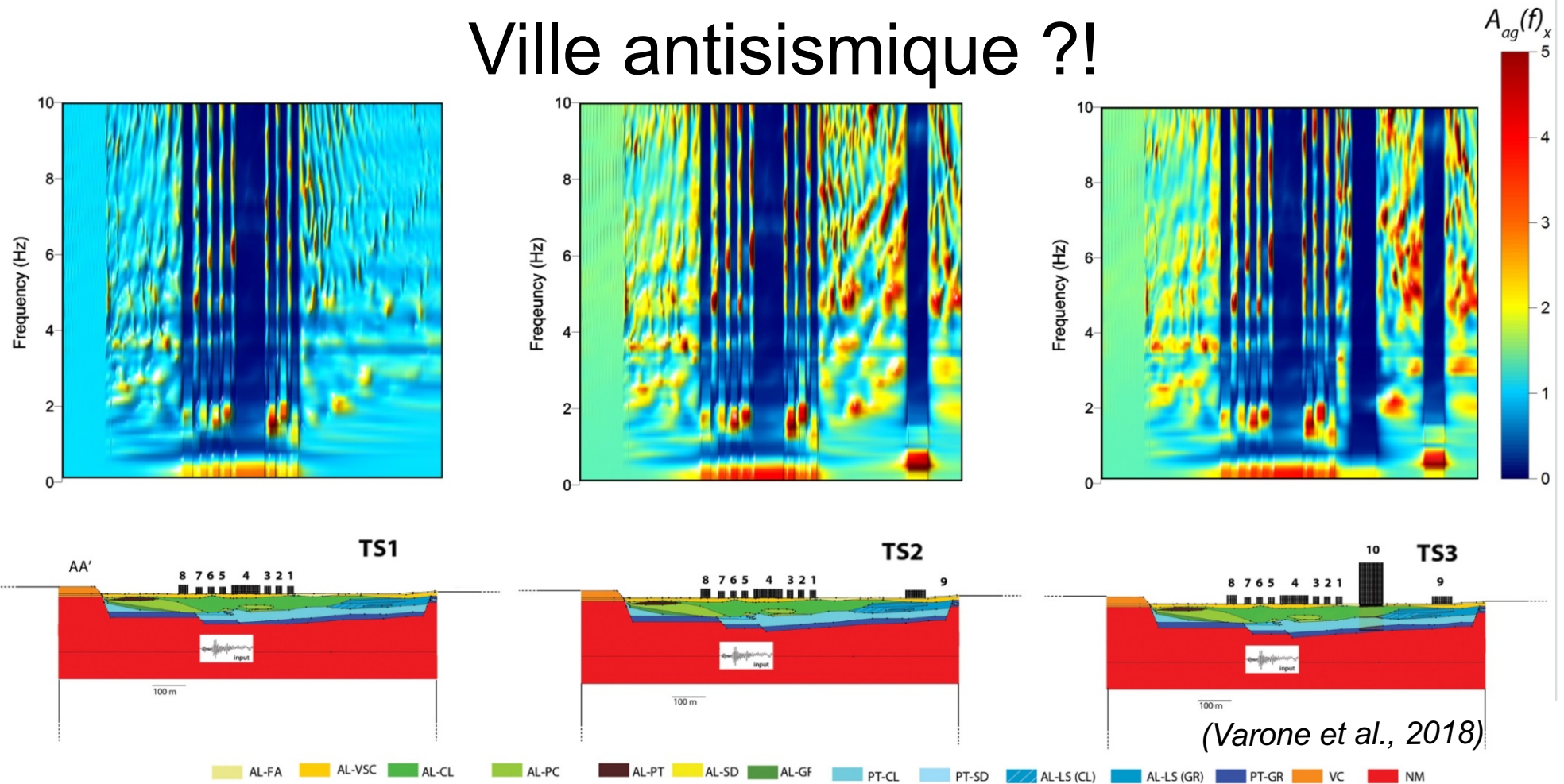
(Niigata, Japon)

Effet induit (2) : glissement de terrain



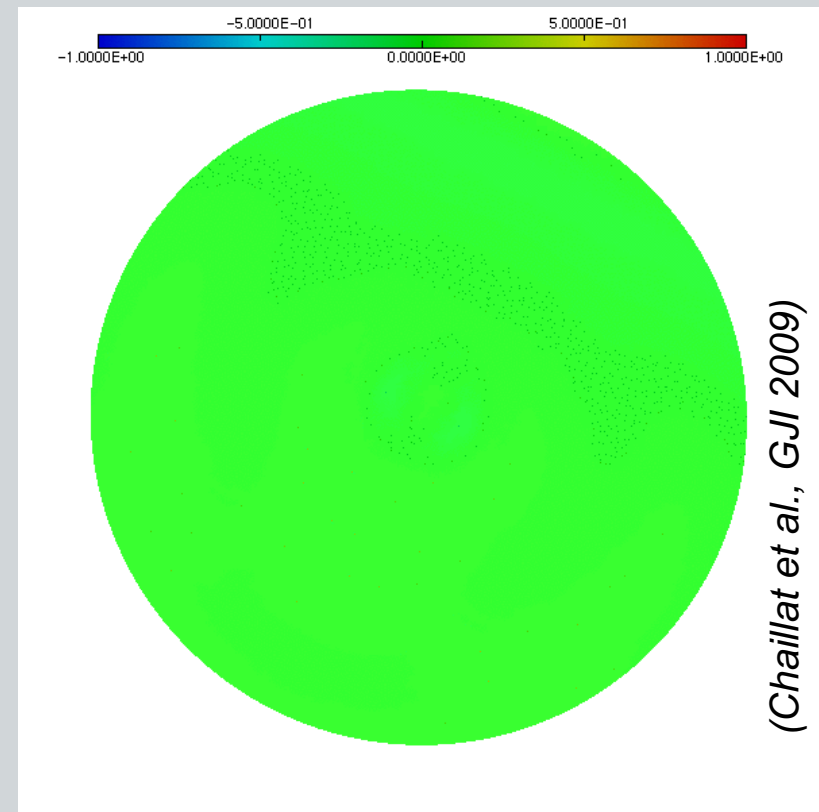
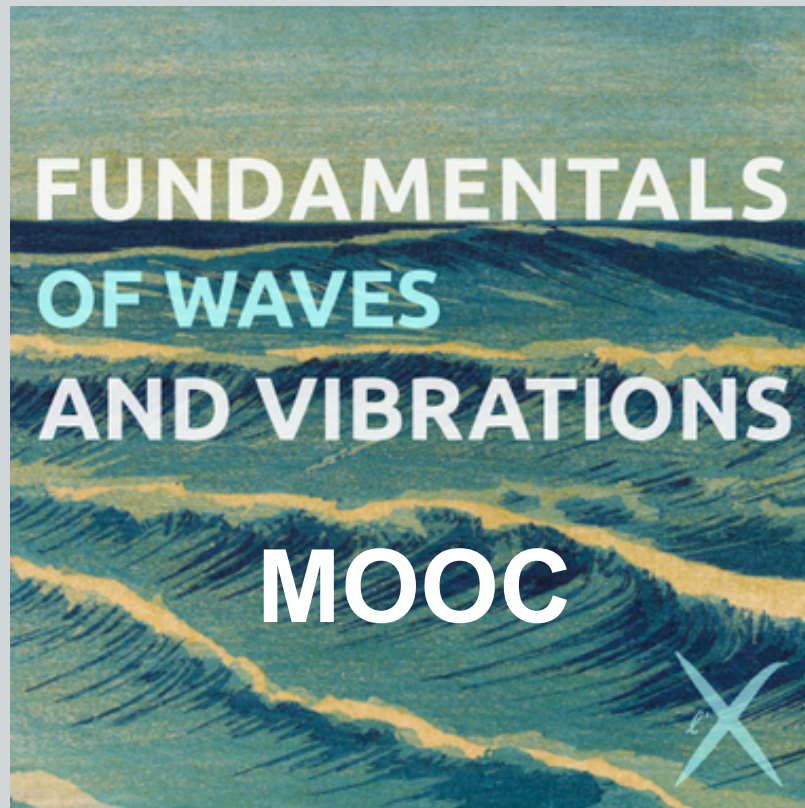
Complexité échelle urbaine

Ville antisismique ?!



(Varone et al., 2018)

Merci de votre attention



Références



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Seismic site effects

From Wikipedia, the free encyclopedia

Seismic site effects are related to the amplification of [seismic waves](#) in surficial geological layers.^[1] The surface conditions are unfavourable (e.g. sediments). The damages due to an [earthquake](#) may thus be aggravated as in

Chaillat S., Bonnet M., Semblat J.F. (2009). A new fast multi-domain BEM to model seismic wave propagation and amplification in 3D geological structures, *Geophys. Journal Int.*, 177(2): 509-531.

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Kham M., Semblat J.F., Bard P.Y., Dangla P. (2006). Site-City Interaction: Main Governing Phenomena Through Simplified Numerical Models, *Bull. Seism. Soc. Am.*, 96(5): 1934-1951.

Meza-Fajardo K.C., Semblat J.F., Chaillat S., Lenti L. (2016). Seismic-Wave Amplification in 3D Alluvial Basins: 3D/1D Amplification Ratios from Fast Multipole BEM Simulations *Bull. Seism. Soc. Am.*, 106(3): 1267-1281.

Meza-Fajardo KC, Papageorgiou AS, Semblat JF. (2015). Identification and extraction of surface waves from three-component seismograms based on the Normalized Inner Product, *Bull. Seism. Soc. Am.*, 105(1): 210-229.

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Semblat J.F., Pecker A. (2009). *Waves and vibrations in soils: Earthquakes, Vibrations, Shocks, Construction works*, IUSS Press, Pavia, Italy, 499 p.

Semblat J.F., Kham M., Bard P.Y. (2008). Seismic wave propagation in alluvial basins and influence of Site-City Interaction, *Bull. Seism. Soc. of America*, 98(4).

Semblat J.F., Kham M., Parara E., Bard P.Y., Pitilakis K., Makra K., Raptakis D. (2005). Site effects: basin geometry vs soil layering, *Soil Dyn. & Earthquake Eng.*, 25(7-10): 529-538.