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Lessons learnt from seismic zonation in France:

Sensitivities of probabilistic seismic hazard assessment (PHSA) to methodological and data inputs

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Lessons learnt form seismic zonation in France :

Sensitivities of probabilistic seismic hazard assessment (PSHA) to methodological and data inputs

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Outline

« Probabilistic » Methods

The considered ground motion: corresponds to a probability of exceedance over a specific period of time

A: considered acceleration

Conventional building ↔ There is a probability of 10% that A will be exceed in the next 50 years

T= 475 y

Nuclear Site ↔ There is a probability of 0.5% that A will be exceeded in the next 50 years

T= 10000 y

Context of the study

- **Conventional building** :

  IRSN = expert role for the establishment of the new French seismic zonation, based on probabilistic methods (requirements of Eurocode 8, UE)

- **Nuclear sites** (IRSN) :

  - Seismic hazard estimation : still deterministic
  - Probabilistic methodologies under study

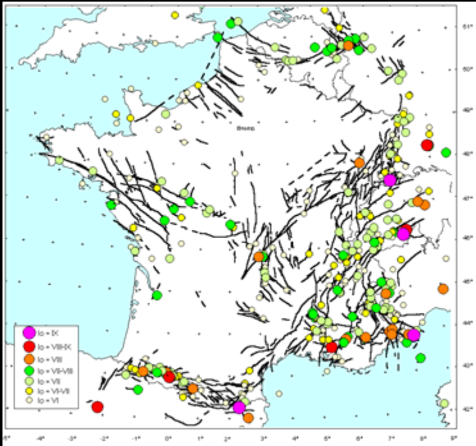
Past studies

Present zonation (1985 - 1991)

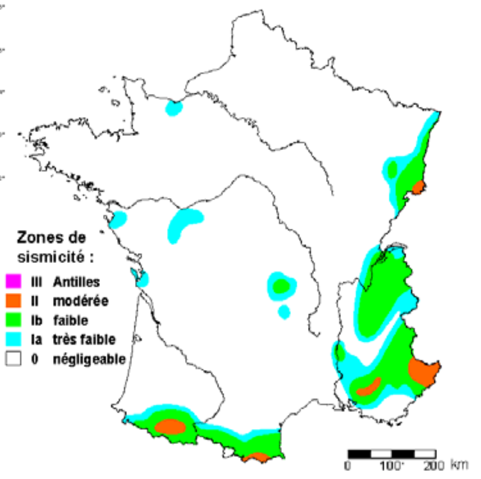
- Based on historical seismicity
  - Mainly deterministic
- Based on Intensity
  - Catalogue : early 80's
- Translation into acceleration values (a_N)
  - Rather subjective

A few PSHA

- Early 80's : attempts from "nuclear world"
  - GM = Intensity
  - Instructive results :
    - PSHA (Regulatory Agency) > PSHA (BRGM) > PSHA (utilities)
- Late 90's : new attempts for common buildings (10^{-3})
  - No logic tree, but "consensus" zonation
  - Completely different map…



Previous study: historical + statistics

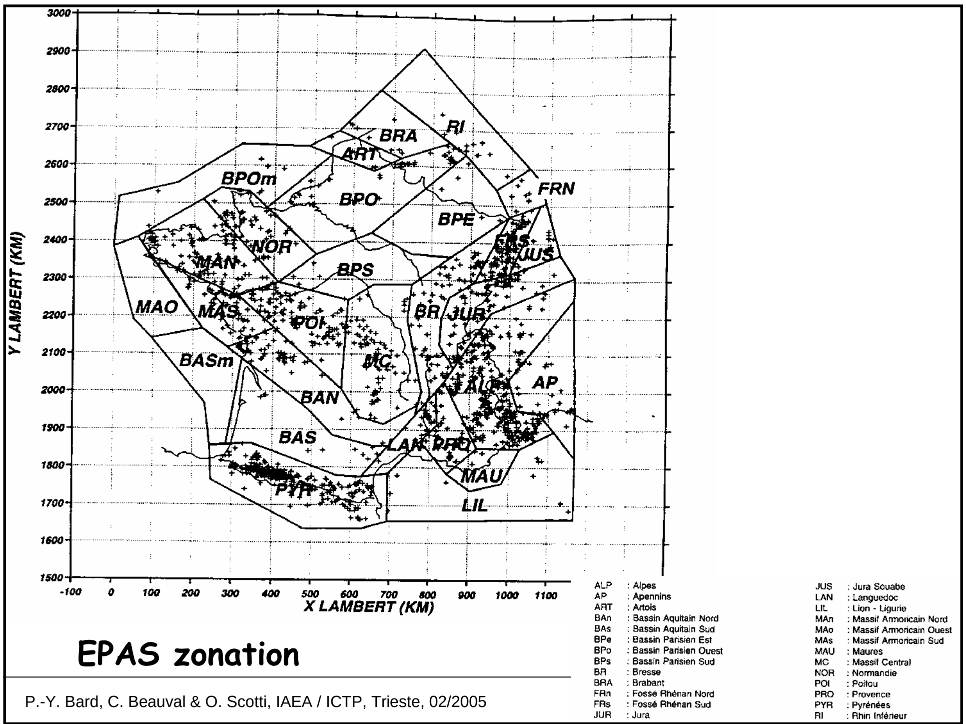


Based on felt intensities

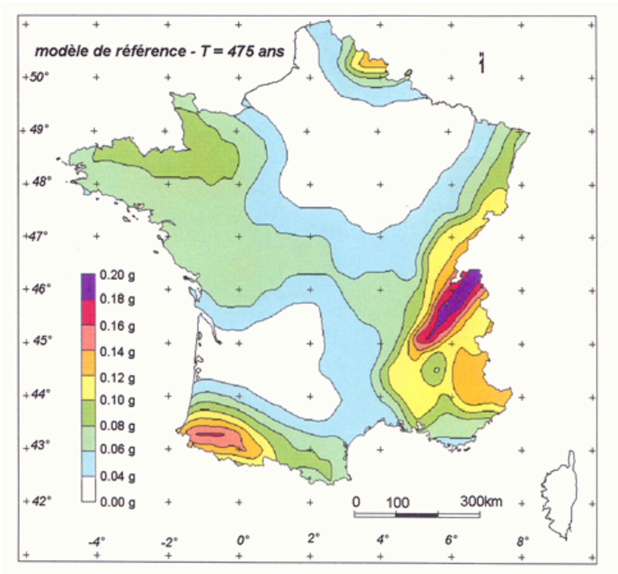
Translated into nominal accelerations

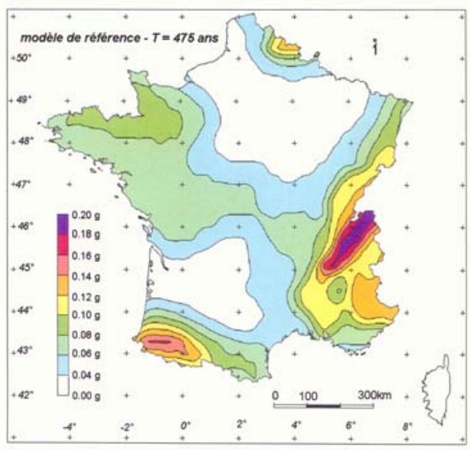
5 zones

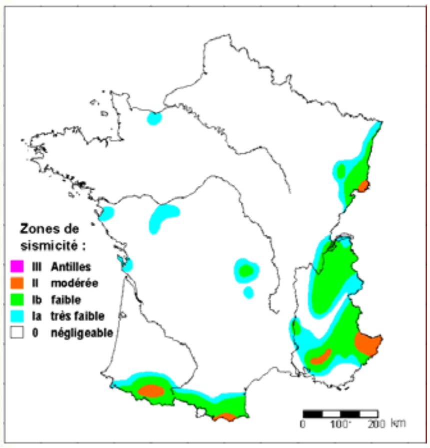
DESPEYROUX & GODEFROY, 1986



EPAS zonation







Probabilistic study (GEOTER / MEDD / GEPP)

Area : Metropolitan France + Antillas

Revised catalogue (M. France)
- Lower intensities
- Magnitudes estimated from Levret formula
- M_{LDG} without correction

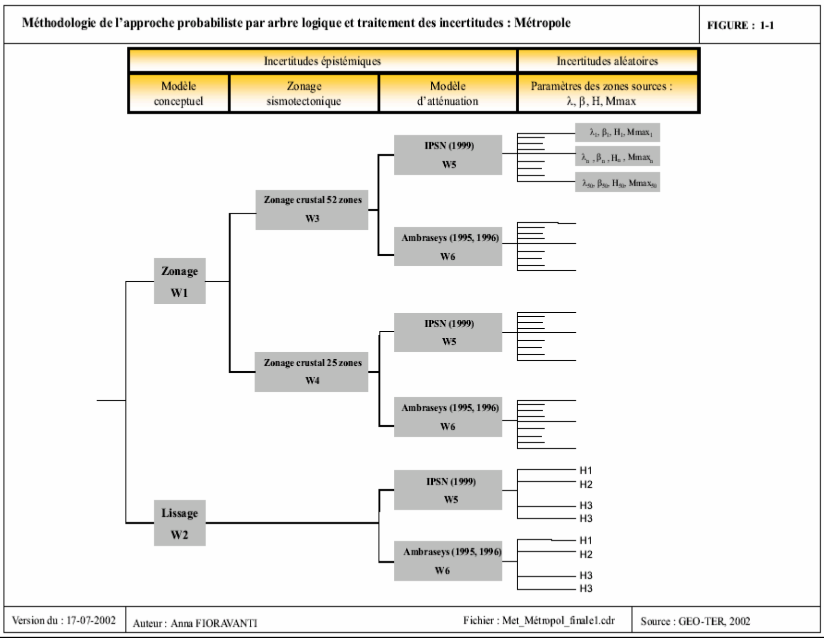
Source zones (M. France)
- EPAS/AFPS (52 zones, no fault) + simplified (25 zones) : 80%
- No zone (smoothing) : 20%

Attenuation relationships (M. France)
- IRSN + Ambraseys
- ROCK
- With σ, without truncation

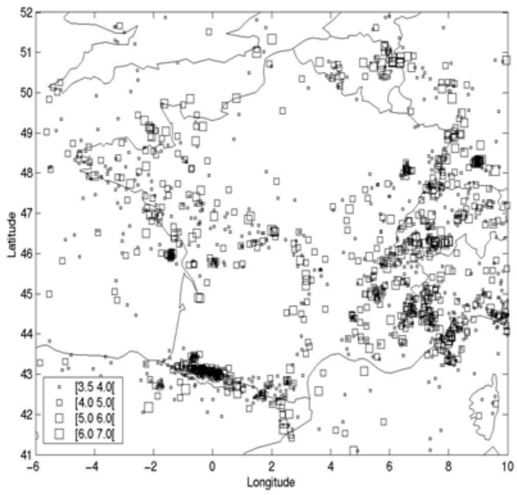
Ground motion parameters
- Pga + Sa(0.2s) + Sa(0.5s) + Sa(1.0s) + Pgv

Program : CRISIS99 (M. Ordaz)

Logic tree, Geoter study



Seismic data (1356-1999)



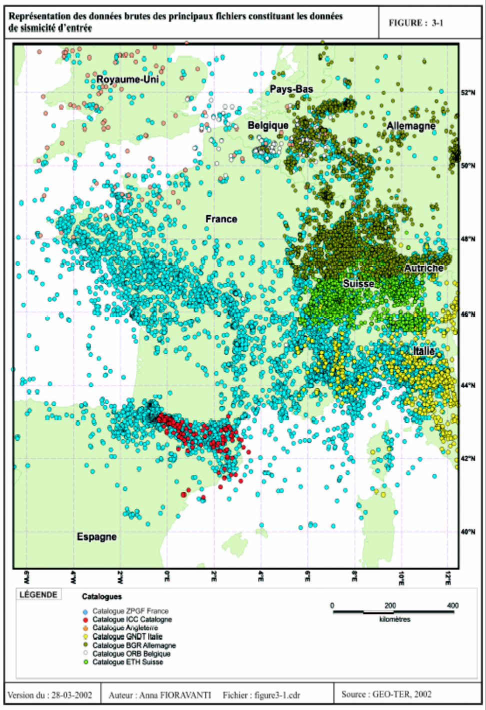
- 1962-1999 : **Instrumental catalog** LDG, M_L
- 1356-1961: **Historical catalog,** SisFrance, correlation M_L-I

Seismicity catalogue

Raw data

Catalogues

- Catalogue ZPGF France
- Catalogue ICC Catalogne
- Catalogue Angleterre
- Catalogue GNDT Italie
- Catalogue BGR Allemagne
- Catalogue ORB Belgique
- Catalogue ETH Suisse



Seismicity catalogue

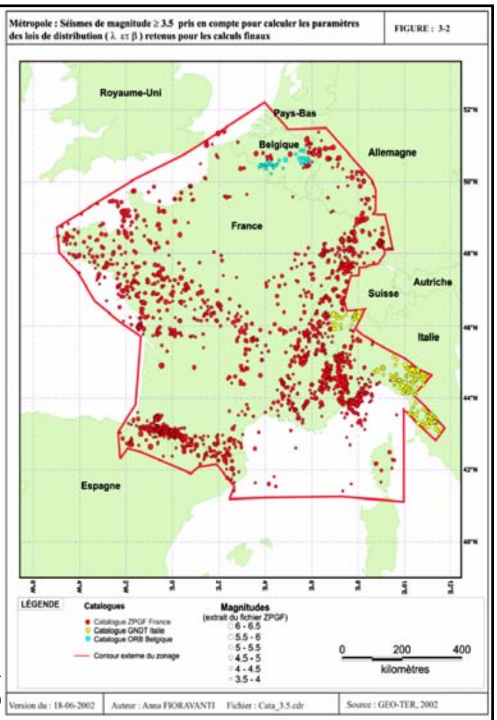
Data taken into account for the estimation of GR parameters

Main issues : magnitudes (systematic instrumental bias, historical / instrumental

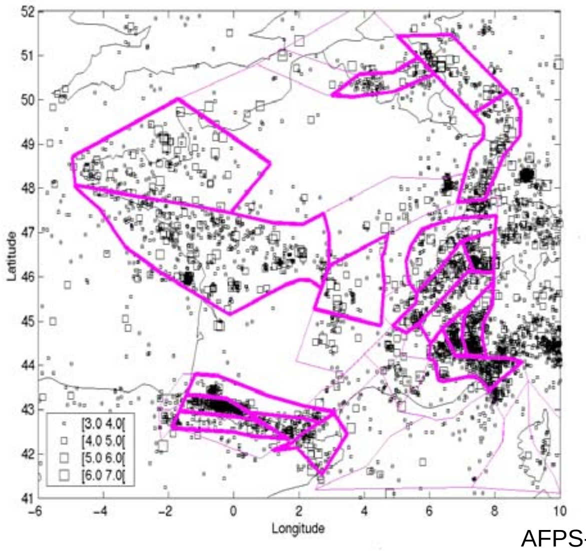
Catalogues

- Catalogue ZPGF France
- Catalogue GNDT Italie
- Catalogue ORB Belgique

Contour externe du zonage



I. Seismotectonic model



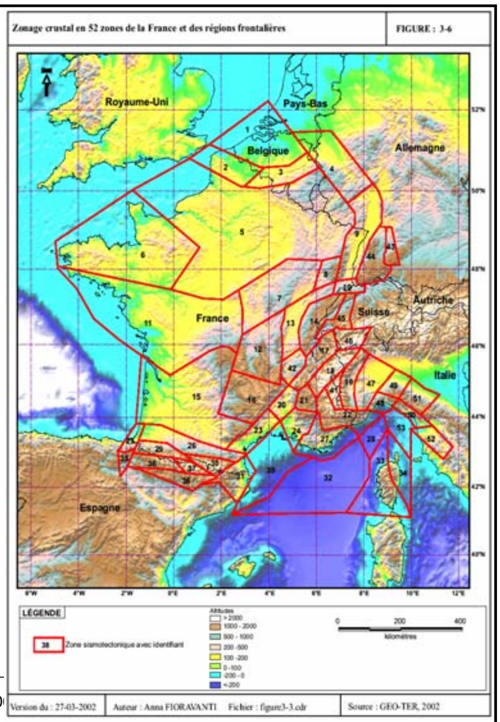
AFPS-EPAS (1999)

Seismic zones 1

52 zones

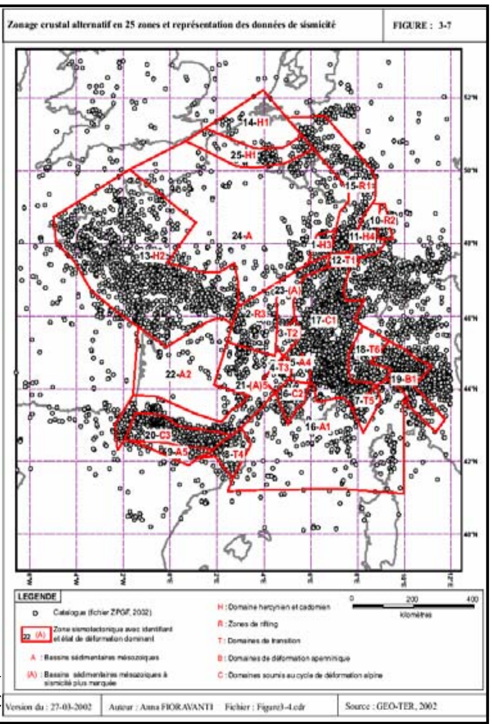
(Based on previous work : EPAS)

Issues : active faults ?



Seismic zones 2

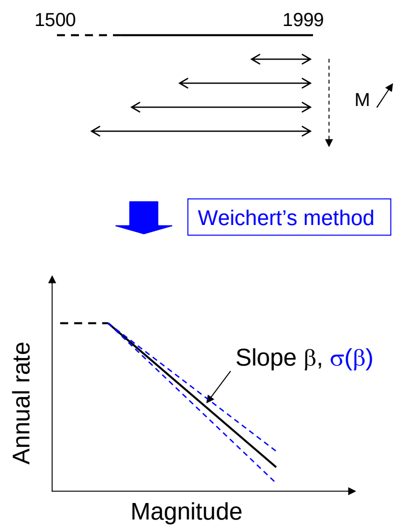
Simplification : 25 zones



II. Seismicity model for each source zone

National scale
Estimation of the periods of completeness for each M

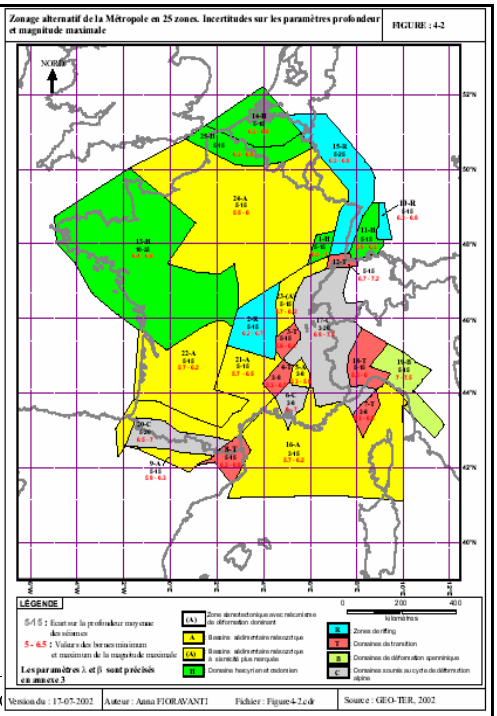
Source zone scale
Recurrence modelling



Uncertainty in seismic parameters

An example for zoning 2

Depth and maximum magnitude



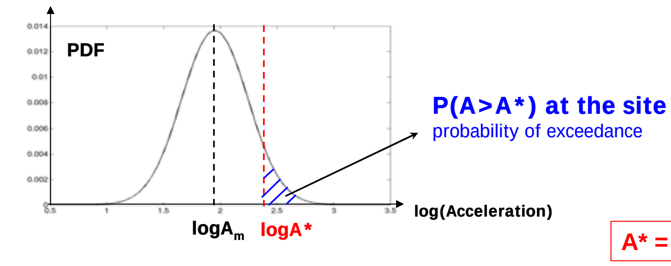
III. Attenuation model of ground-motion

Couple $(M, R_{source-site})$

$\text{Log}(A_m) = aM + bR - \log R + c \quad (\sigma)$

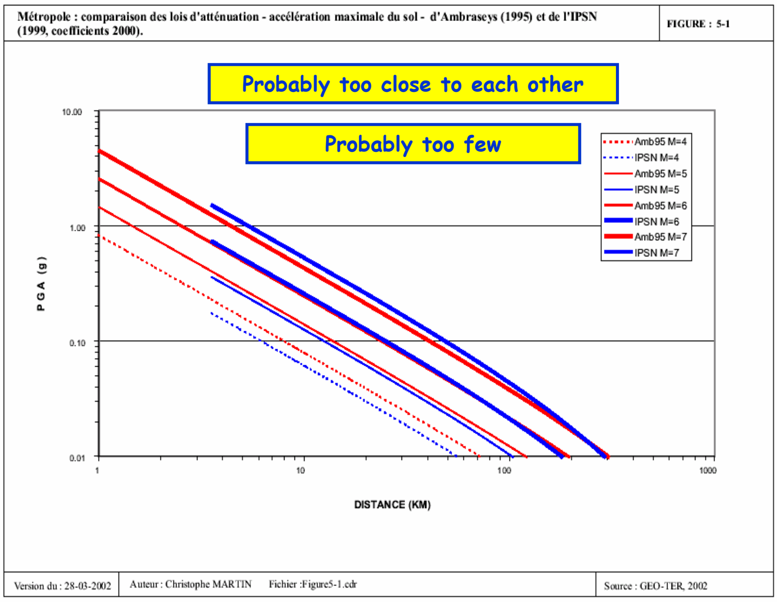
Attenuation relationship: Berge-Thierry et al. (2003)

Distribution of accelerations, predicted by the attenuation relationship



A* = target acceleration

Attenuation relationships

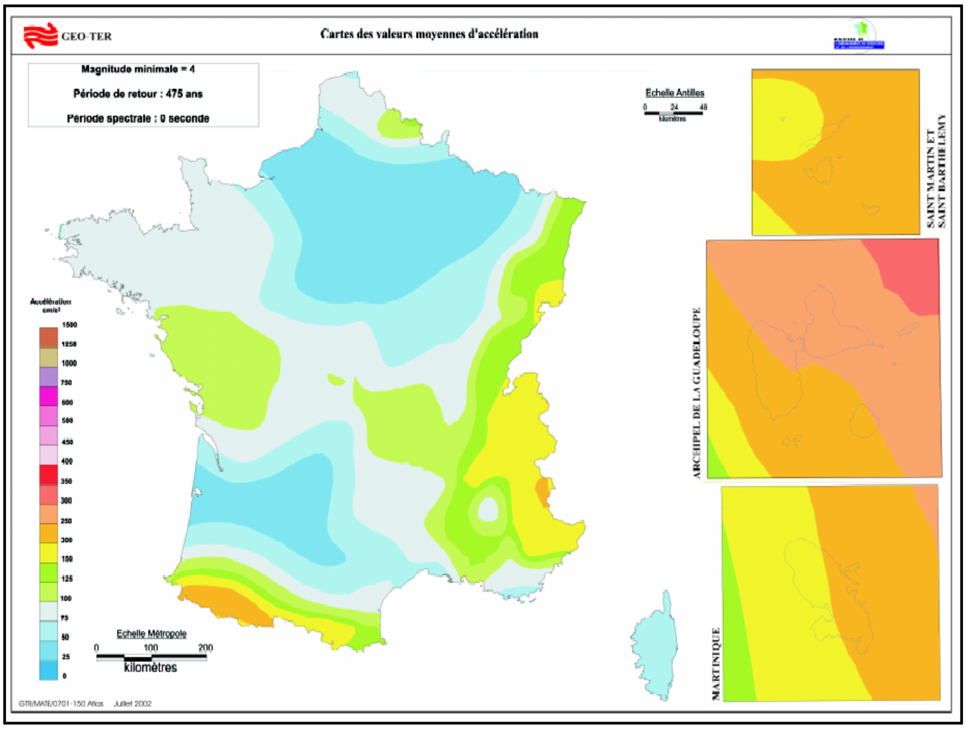


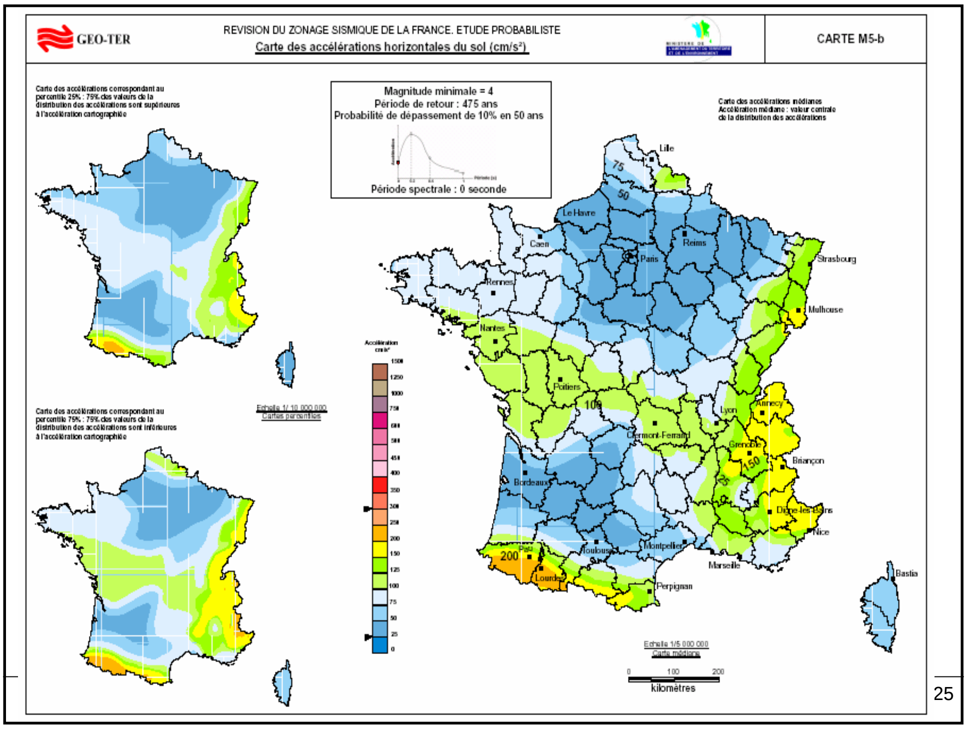
Results

Maps

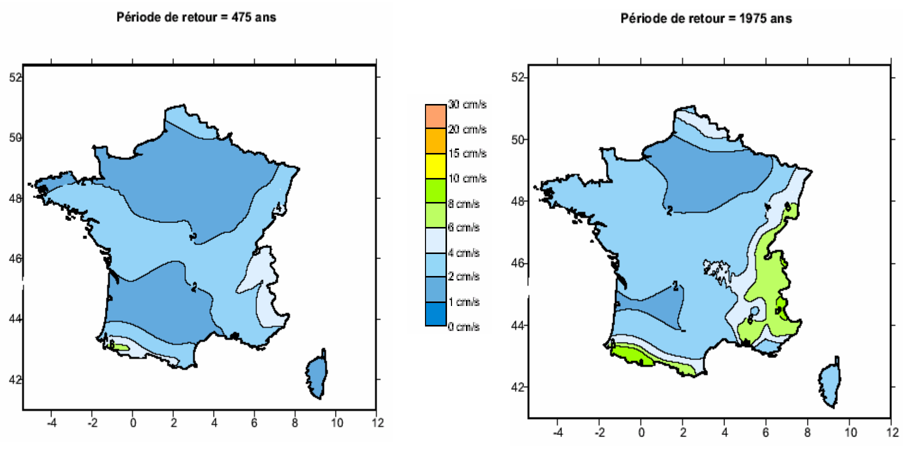
- 4 return periods: 100, 475, 975, 1975 years
- 5 parameters : pga, Sa(0.2s) Sa(0.5s), Sa(1.0s), pgv

Various sensitivity studies


GEO-TER
Cartes des valeurs moyennes d'accélération
Magnitude minimale = 4
Période de retour : 475 ans
Période spectrale : 0 seconde
Echelle Antilles
SAINT MARTIN ET SAINT BARTHELEMY
ARCHIPEL DE LA GUADELOUPE
MARTINIQUE
Echelle Métropole
0 100 200
kilomètres
GTR/MATE/0701-150 Atlas Juillet 2002


GEO-TER
REVISION DU ZONAGE SISMIQUE DE LA FRANCE. ETUDE PROBABILISTE
Carte des accélérations horizontales du sol (cm/s²)
CARTE M5-b
Magnitude minimale = 4
Période de retour : 475 ans
Probabilité de dépassement de 10% en 50 ans
Période spectrale : 0 seconde
Carte des accélérations médianes
Accélération médiane : valeur centrale de la distribution des accélérations
Lille
Le Havre
Caen
Reims
Paris
Strasbourg
Rennes
Mulhouse
Nantes
Poitiers
Lyon
Annecy
Clermont-Ferrand
Grenoble
Briançon
Bordeaux
Digne-les-Bains
Nice
Toulouse
Montpellier
Marseille
Pau
Lourdes
Perpignan
Bastia
Echelle 1/5 000 000
Carte médiane
0 100 200
kilomètres
25

Peak velocity



Issues

? **Overestimation bias**

- Magnitude M_{LDG}
- Actual "rock site" conditions in accelerometric data base

? **Differences with previous map**

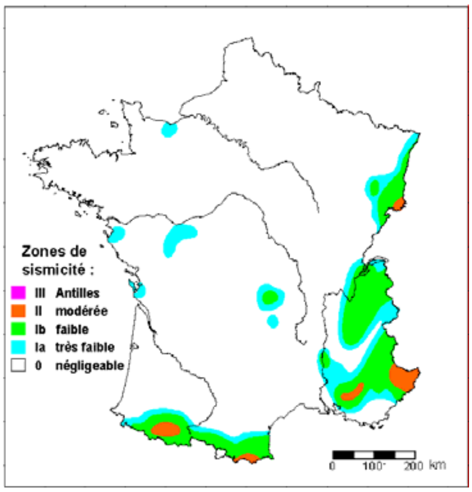
- Large extension of "low seismicity" area (Ia)
  - ? Low seismicity threshold ?
- Historical events : Provence, Catalogne

? **Spectral shapes**

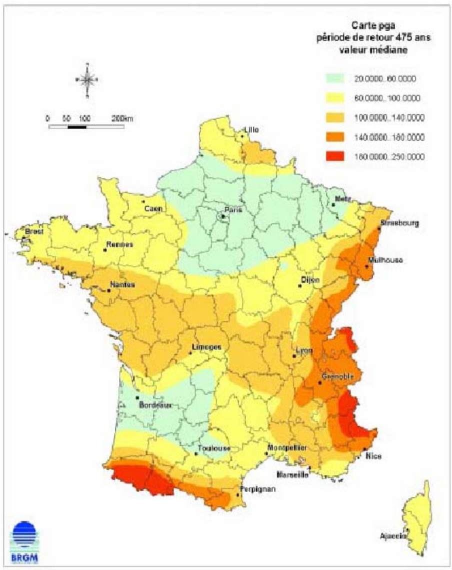
- EC8 S1, EC8 S2, another one ?

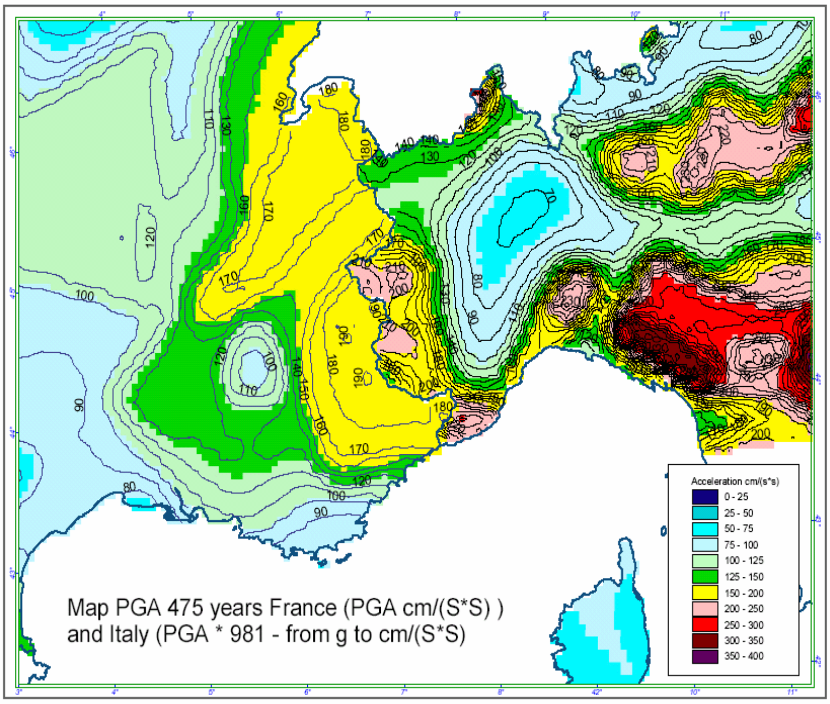
? **Continuity across borders**

Previous map



GEOTER study





Outline

1. Data and et Cornell-McGuire method

Variability of hazard estimates (*Beauval & Scotti*, *GRL* 2003, *BSSA* 2004)

➡ 2. b-value dependence with magnitude range used

3. Impact studies of the parameters choices & deagregation studies (for the PGA)
4. Global variability
5. Results for frequencies 1, 2 and 5 Hz

Alternative methods

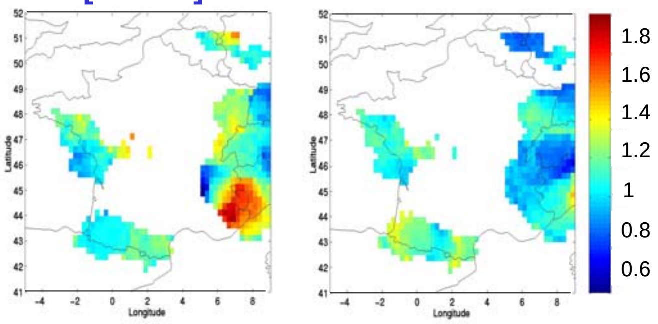
6. Smoothing seismicity model (Woo)

7. Conclusions & Perspectives

b-value dependence with magnitude range used

σ(b)<0.18

[3.0-4.4] M3.5+ b-value



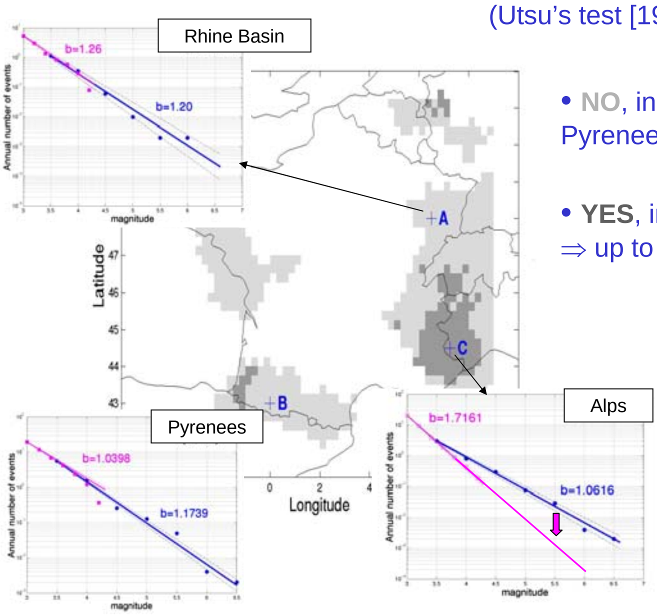
[1962-1999], M_L
Instrumental catalogue

[1500-1999], M_L et $M_{historical\ (computed)}$
Total catalogue

(Beauval & Scotti, *GRL*, 2003)

Are slopes significantly different ?

(Utsu's test [1992], P=99%)



- NO, in the Rhine Basin, the Pyrenees, and in Brittany
- YES, in the Alps
  ⇒ up to 0.8 difference

⇒ Conservative option: computing recurrence curves with **M≥3.5**

Outline

1. Data and et Cornell-McGuire method

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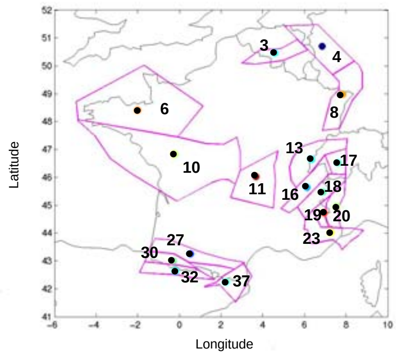
Impact study of parametric choices

Considered sites: the centres of the source zones (N=17)

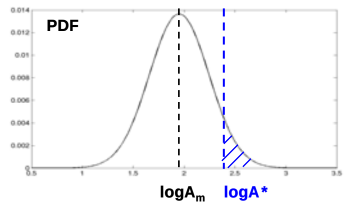
Parameter	Reference	Alternative
M-I correlation	Scotti (2001)	Levret (1994)
Ground motion	no truncation	truncation +2σ
M_{min}	3.5	4.5
M_{max}	7.0	6.5
	Acc1	Acc2



$$\text{Impact} = \frac{\text{Acc1} - \text{Acc2}}{\text{Acc1}} \times 100$$

Truncation parameter

Distribution for the Acceleration predicted by the attenuation relationship

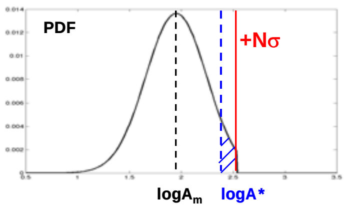


∀A* up to ∞,

P(A>A*) ≠ 0

(probability of exceedance)

Truncation of the predicted distribution ?

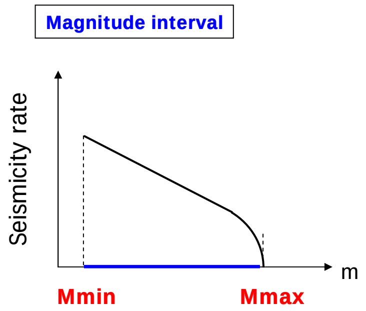


For logA* > $\log A_m$ + Nσ

P(A>A*) = 0

+2σ ↔ ground motions with less than 2.3% probability of being exceeded are not taken into account

Parameters « Mmin » et « Mmax »

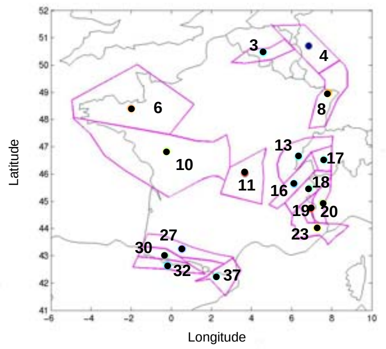


Mmin: does not depend on the source zone

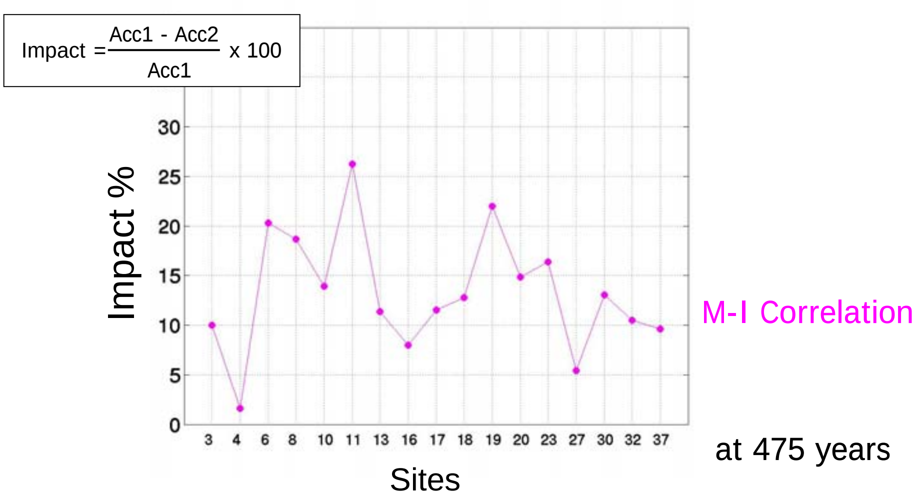
Mmax: does depend on the source zone

Impact study of parametric choices

Considered sites: the centres of the source zones



1. Impact of the choice of the magnitude-intensity correlation on hazard estimates



P.-Y. Bard, C. Beauval & O. Scotti, IAEA / ICTP, Trieste, 02/2005

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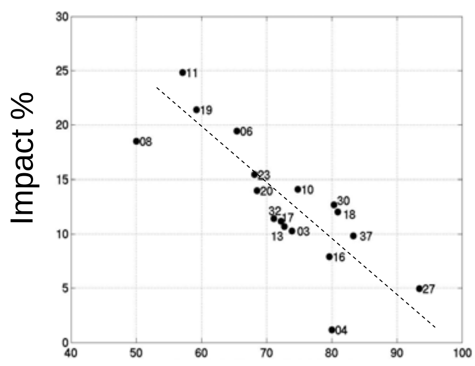
Impact of the choice of the magnitude-intensity correlation on hazard estimates



Percentage of instrumental events
(3.5 ≤M≤ 4.4) participating in the modelling of recurrence

at 475 years

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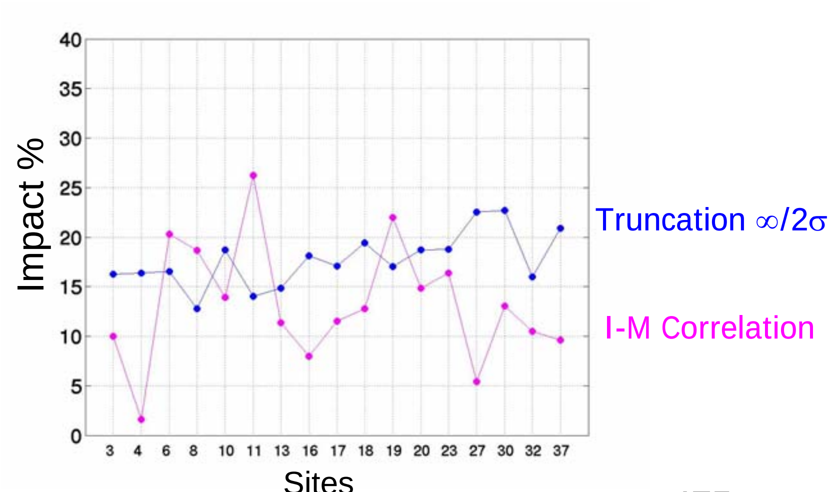
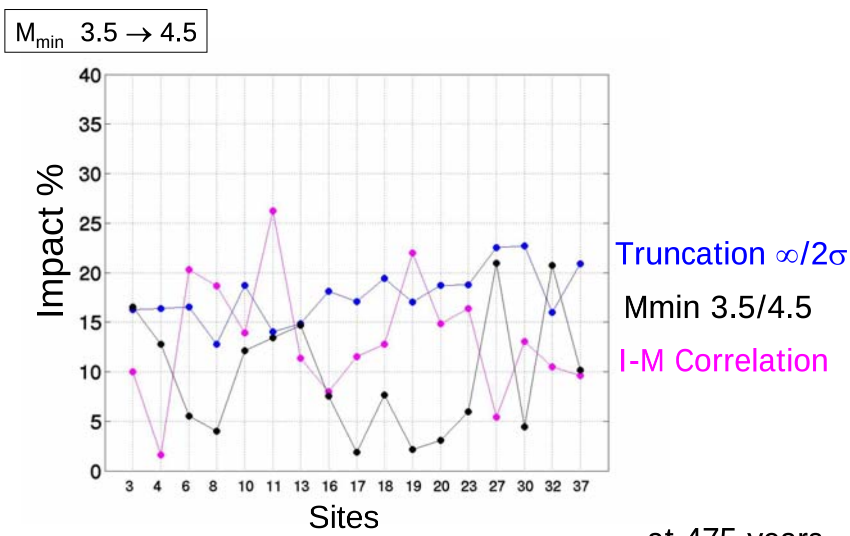
2. Impact of the choice of truncation

(ground motions with less than 2.3% probability of being exceeded are not taken into account)



at 475 years

3. Impact of the choice of minimum magnitude

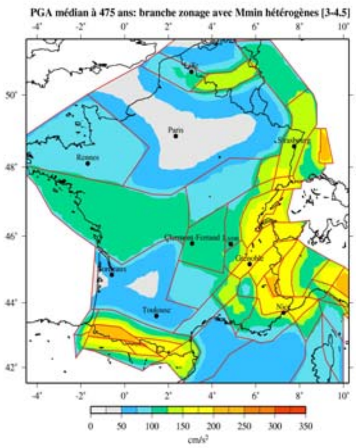


at 475 years

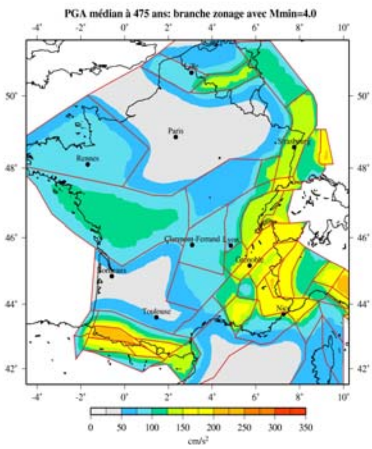
Sensitivity study : Influence of Mmin

the lower Mmin, the higher the estimated hazard

Clermont-Ferrand, (Mmin= 3.0) ; Aix en Provence, (Mmin=4.5).



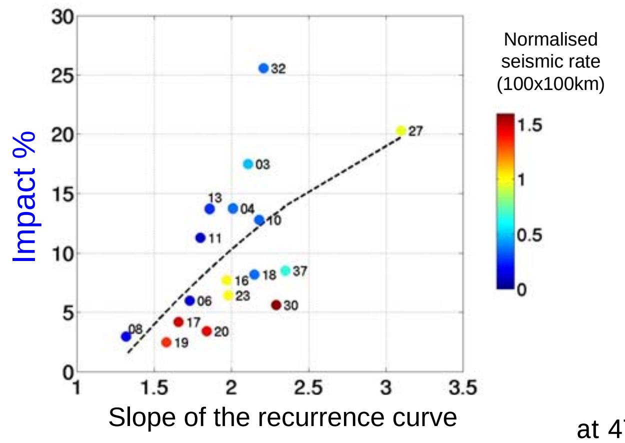
Geoter, variable Mmin (generally 3.5)



IRSN, Mmin = 4

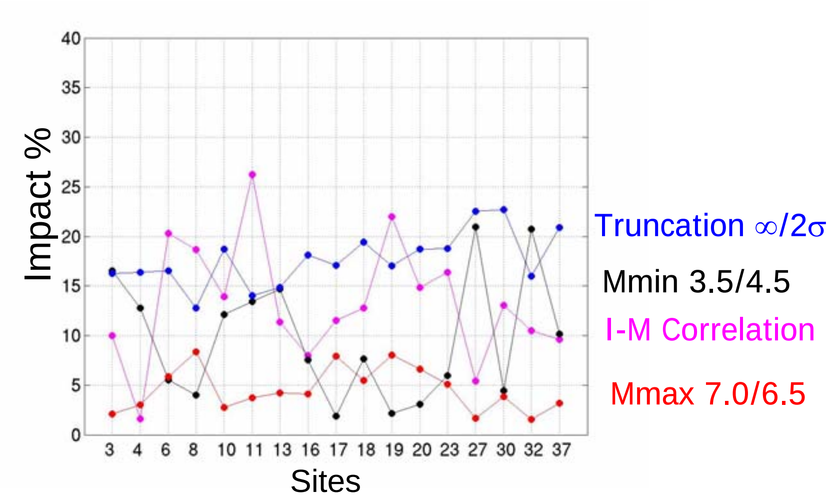
Impact of the choice of minimum magnitude: correlated with β

M_{min} 3.5 → 4.5



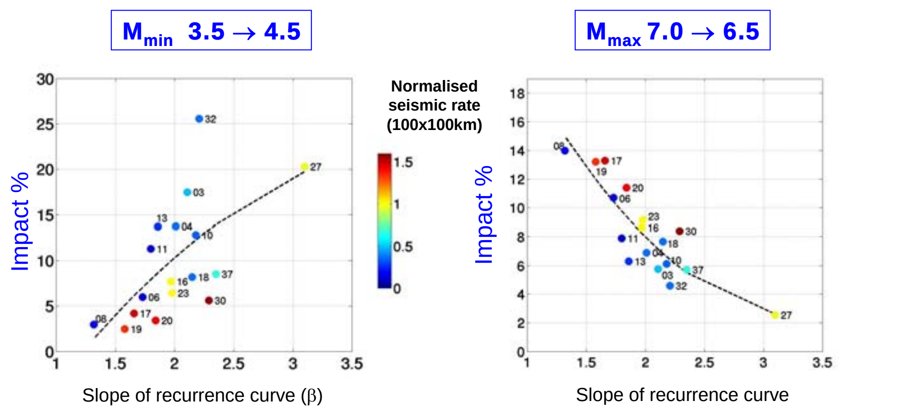
at 475 years

4. Impact of the choice of maximum magnitude



at 475 years

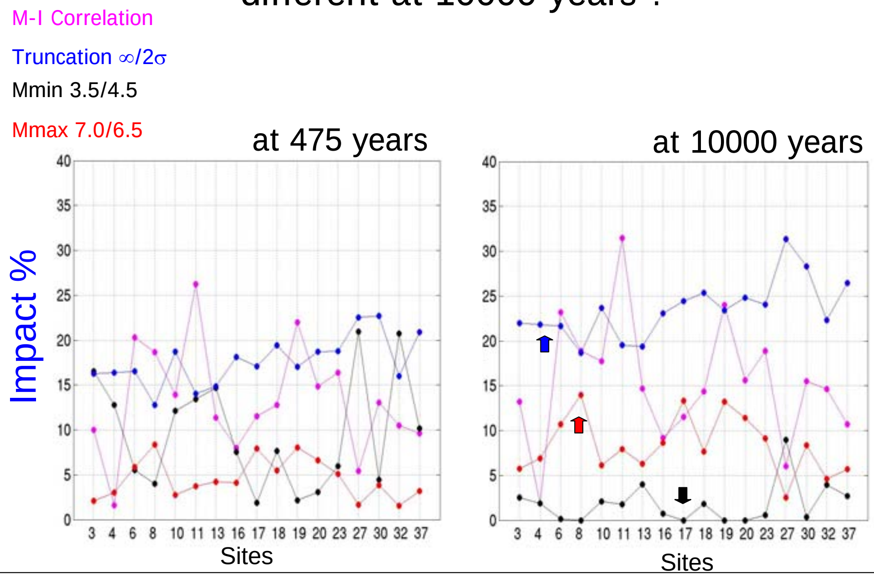
Impact of the choice of maximum magnitude: correlated with β



at 475 years

at 10000 years

Hierarchy of impacts on hazard estimates different at 10000 years ?



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Key parameters for a probabilistic seismic hazard estimation in France (for the PGA)

T < 1000 years

Mmin / M-I correlation / truncation

21% 26% 23%

T > 1000 years

M-I correlation / truncation

32% 32%

many PSHA studies ignore these uncertainties

➡ Mmax influence is small

< 8% (475 years)

< 14% (10000 years)

studied in all PSHA sensitivity studies

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Deaggregation: principle

At a site and for a target A*

$$\text{Hazard} = \sum_M \sum_R \sum_\varepsilon \text{contribution of } (M,R,\varepsilon)$$

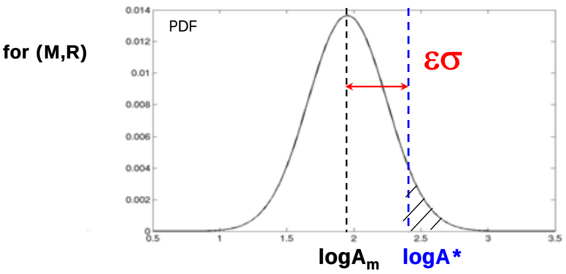
Distribution of contributions ?

→ according to 1 parameter (M or R or ε) 1D

→ according to 2 parameters (here: M&R) 2D

Deviation between target and mean : epsilon (ε)

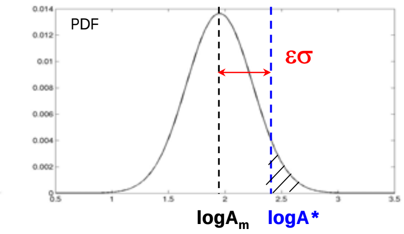
Distribution for the acceleration predicted by the attenuation relationship

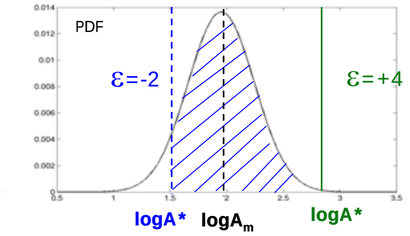


Deviation from the mean predicted by the attenuation relationship, in multiple of σ

Understanding impacts : epsilon deaggregation (ε)

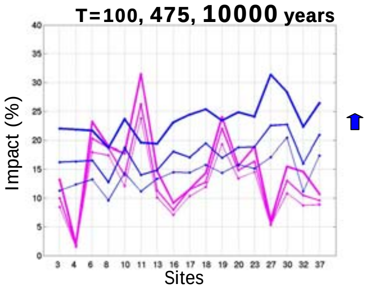
Distribution predicted by the attenuation relationship





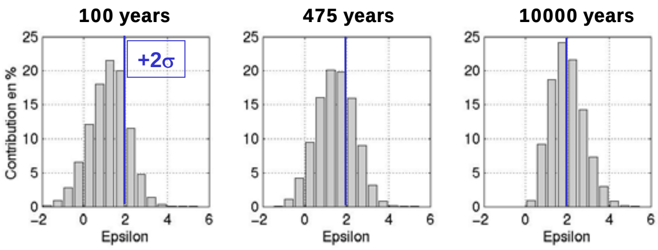
Deviation from the mean predicted by the attenuation relationship, in multiple of σ

Understanding impacts : epsilon deaggregation



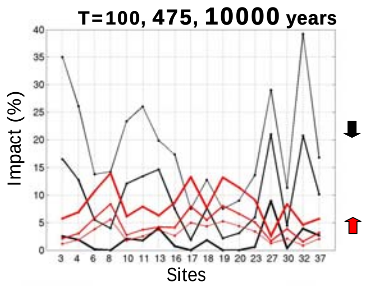
Correlation : stable impact

Truncation : Impact ↗ when T ↗



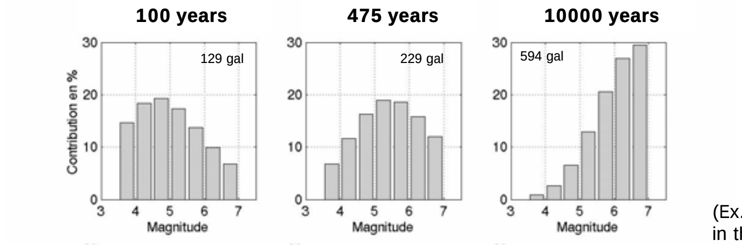
(Ex. zone n°16 in the Alps)

Understanding impacts: magnitude deaggregation



Mmin : Impact ↘ when T ↗

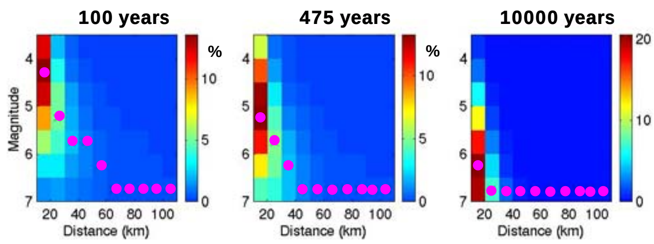
Mmax : Impact ↗ when T ↗



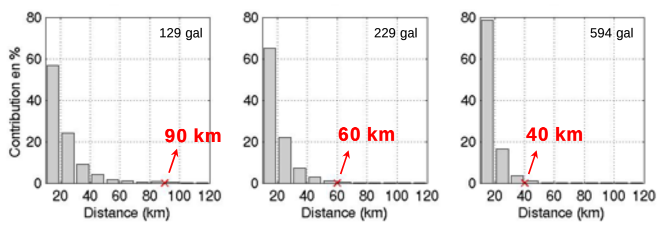
(Ex. zone n°16 in the Alps)

Distance deaggregation

Max of contribution for each distance interval



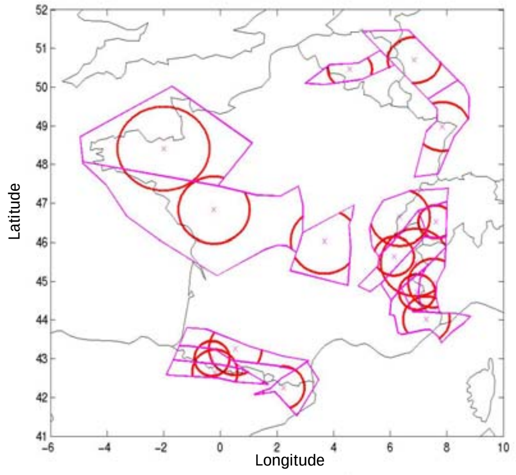
$R_{98\%}$



(Ex. zone n°16 in the Alps)

Radius of influence at 98%

(=maximum distance reached to accumulate 98%
of the contributions to the hazard at the site)



T=475 years

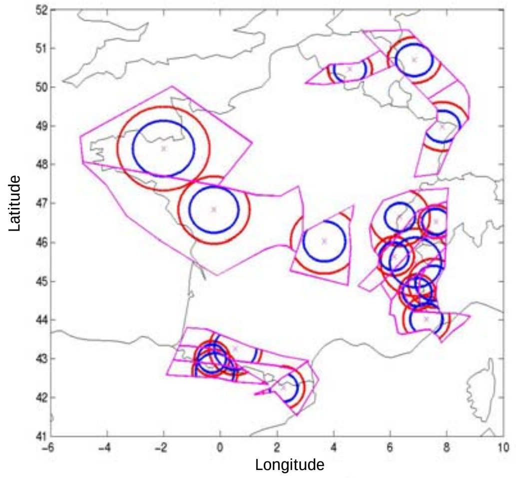
(PGA)

P.-Y. Bard, C. Beauval & O. Scotti, IAEA / ICTP, Trieste, 02/2005

54

Radius of influence at 98%

(=maximum distance reached to accumulate 98%
of the contributions to the hazard at the site)



T= 475 years
T= 10000 years

The contributing area narrows when the return period increases

(PGA)

P.-Y. Bard, C. Beauval & O. Scotti, IAEA / ICTP, Trieste, 02/2005

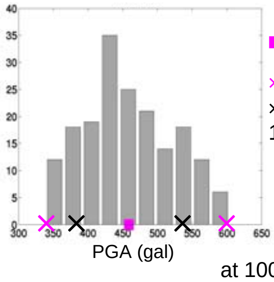
55

Overall variability due to the choice of the 4 parameters

Logic tree: exploration of all possible combinations

Ex: 2×5×6×3=180 combinations

Distribution of possible values

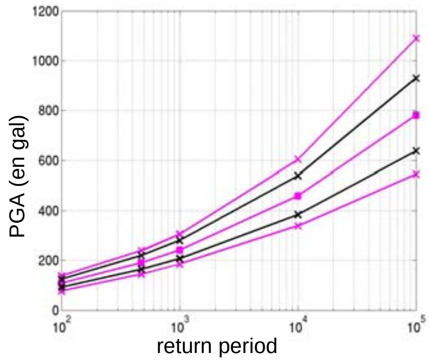


■ mean

× min/max

× Percentile 15/85%

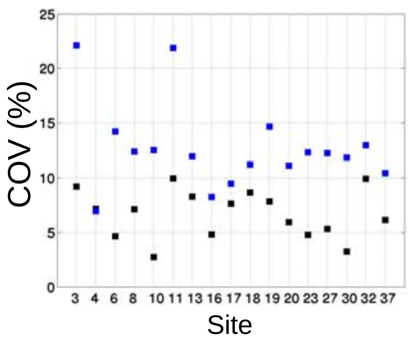
at 10000y



Ex: zone of the Alpes méridionales (n°23)

Overall variability / « minimum » variability

$$COV = \frac{\sigma}{mean}$$



- Overall variability (choice of the 4 parameters); ~ stable for all return periods
- Variability due to catalogue uncertainties (magnitude and location determinations)

Outline

1. Data and et Cornell-McGuire method

Variability of hazard estimates

2. b-value dependence with magnitude range used
3. Impact studies of the parameters choices & deagregation studies (at 34 Hz, PGA)
4. Global variability
5. ➡ Results for frequencies 1, 2 and 5 Hz

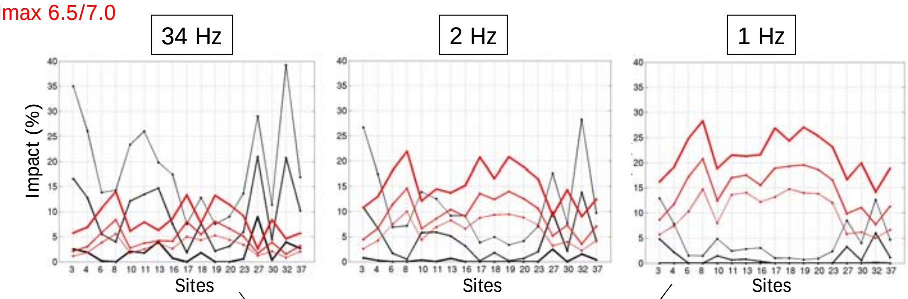
Alternative method

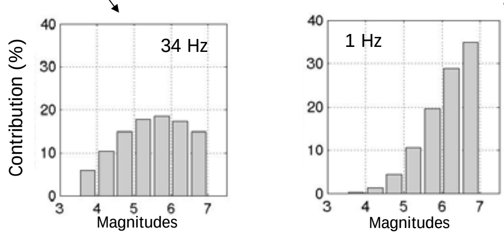
6. Alternative method: smoothing seismicity model (Woo)

7. Conclusions & Perspectives

And for other frequencies?

Mmin 3.5/4.5
Mmax 6.5/7.0



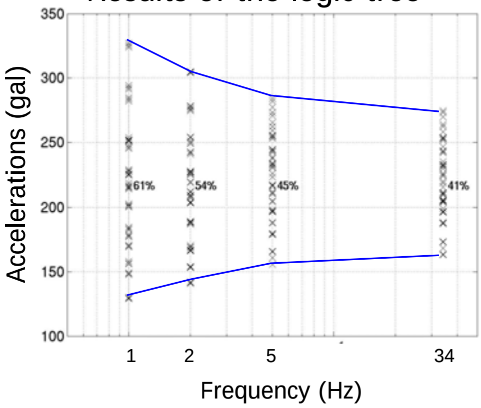


Mmax becomes a key parameter

Zone Alpes méridionales (n°23)
475y
234 / 117 gal

And for other frequencies?

Results of the logic tree



The overall variability increases when the frequency decreases

Ex: zone Pyrénées occidentales nord (n°30)

Outline

1. Data and et Cornell-McGuire method

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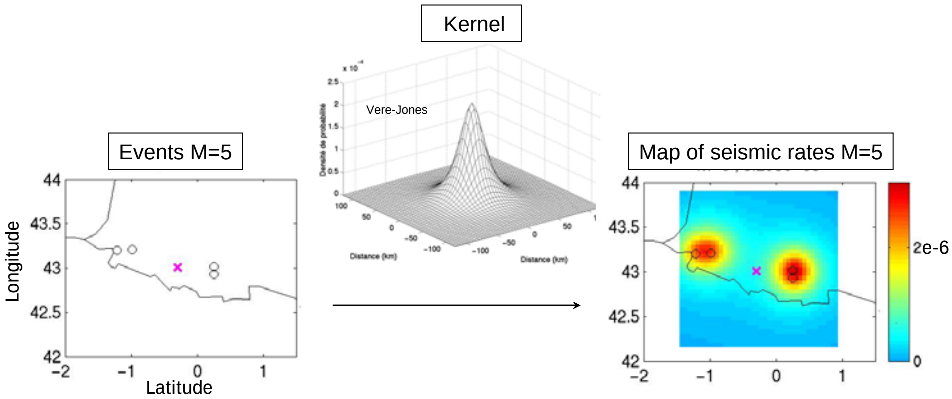
Alternative methods

➡ 6. Alternative method: smoothing seismicity model (Woo)

7. Conclusions & Perspectives

Woo's method: a different seismicity model

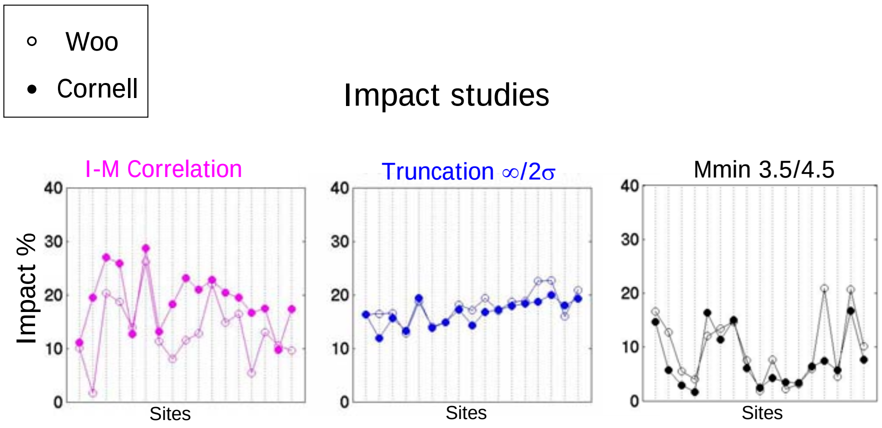
~~Seismotectonic zonation~~
~~Gutenberg-Richter curve~~ ⇒ Smoothing of past earthquakes epicenters locations



Ex. in the Pyrenees (Zone 30)

Woo's method: alternative?

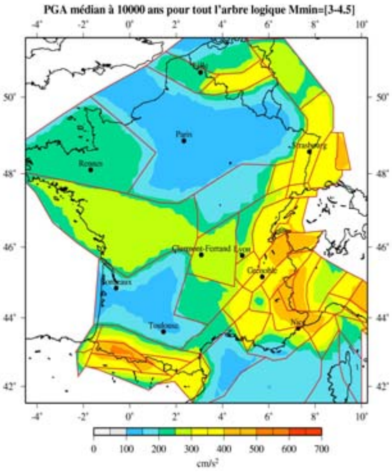
Impact studies



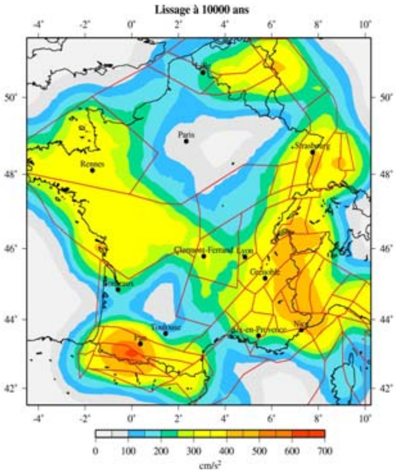
⇒ similar Impacts

at 475 years

T = 10 000 years, weighted result



T = 10 000 years, smoothing alone



IRSN

Outline

1. Data and et Cornell-McGuire method

Variability of hazard estimates

2. b-value dependence with magnitude range used
3. Impact studies of the parameters choices & deagregation studies (at 34 Hz, PGA)
4. Global variability
5. Results for frequencies 1, 2 and 5 Hz

Alternative methods

6. Alternative method, without zoning (Woo)

➡ 7. Conclusions & Perspectives

Conclusions

Uncertainties due to the 4 parameters considered have to be taken into account in every probabilistic seismic hazard study

I-M correlation — **Key role**, ∀ return period & frequency

Ground-motion variability — **Key role**, ∀ return period & frequency

Mmin — Important impact for T < 1000 years & for PGA

Mmax — Important impact for f < 5Hz

Prospects

! Attenuation relationship
Seismotectonic zonation

Not studied here, but all sensitivity studies in PSHA show a key role

- Determine upper bounds to earthquake ground motions (truncating at the same percentage above the mean for all earthquakes is arbitrary)
- Determine attenuation relationships depending on M, in order to reduce the dispersion σ

Until better physical models are obtained,
the uncertainty on hazard estimates might be reduced by:

- Working on a more appropriate M-I correlation