IAEA ANSN / ISSC - REGIONAL WORKSHOP ON
"Volcanic, Seismic, and Tsunami Hazard Assessment Related to NPP Siting Activities and Requirements"
Jakarta, Indonesia, 13-17 June 2011

"Collection and interpretation of seismological data – Seismological Database"

(Ramon Secanell, GEOTER)
INTERNATIONAL SEISMIC SAFETY CENTRE, NSNI/IAEA

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International Atomic Energy Agency

Lecture XX

Safety Requirements:

“establish the requirements that must be met to ensure safety”

NS-R-3

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Safety Requirements (NS-R-3)
Specific requirements for earthquakes

1. **Seismological, geological and geotechnical** conditions shall be evaluated.
2. **Information** shall be collected (prehistorical, historical, instrumental, etc.).
3. **Seismotectonic model** shall be performed to determine the seismic hazard.
4. **Seismic hazard assessment** shall be done taking into account seismotectonic model and site conditions. **Uncertainty** analysis shall be done.

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Safety Requirements (NS-R-3)
Specific requirements for surface faulting

5. Potential **surface faulting** shall be assessed.
6. A **fault is capable** if:
   a) Evidence of past movements
   b) Structural relationship with known capable faults able to produce movement at or near the surface
   c) Maximum magnitude is sufficiently large to produce movement at or near the surface.
7. Surface faulting is an **exclusion criterion**.

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Safety Guide:

“recommend actions, conditions or procedures for meeting safety requirements”

SSG-9

Safety Guide (SSG-9)

INDEX

1. **General recommendations.**
2. **Necessary information: geological, geophysical, geotechnical and seismological database (GIS).**
3. **Seismotectonic model:** definition and characterization of seismic sources.
4. **Ground motion analysis :** parameters and ground motion models.
5. **Probabilistic seismic hazard assessment.**
6. **Deterministic seismic hazard assessment.**
7. **Potential for fault displacement :** probabilistic approach
8. **Design ground motion** (levels and definition: response spectra and time histories**).**
9. **Project Management.**

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1. General recommendations

a) As established by **Safety Requirements**

b) Definition of the **site region** (independently of national borders, etc.)

c) **Size of the region**: depending on the seismotectonic environment

d) **Multidisciplinary Team** (geologists, seismologists, historians, etc.)

e) Objective: To **reduce uncertainties** generating new data if necessary.

f) Treatment of **aleatory and epistemic uncertainties**

g) The uncertainties that can not be reduced does not permit **reduce the hazard below a certain threshold value (0.1 g).**

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2. **Necessary Information and Investigation.**

a) Generation of a geological, geophysical, geotechnical and **seismological database**.

b) 4 **spatial scales**:
   a) Regional (300 km)
   b) Near regional (25 km)
   c) Site vicinity (5 km)
   d) Site area (1 km)

c) Data compiled in a **GIS** (Example in next presentation)

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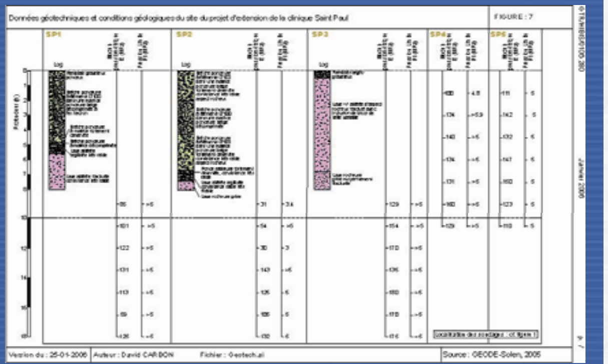
Example of the importance of size region. Case of Mexico Earthquake, 1985:

Soil effects



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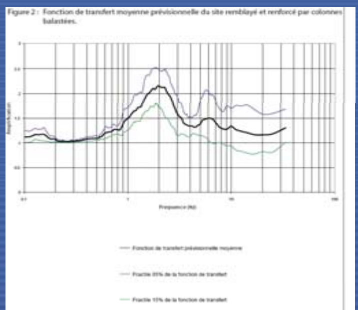

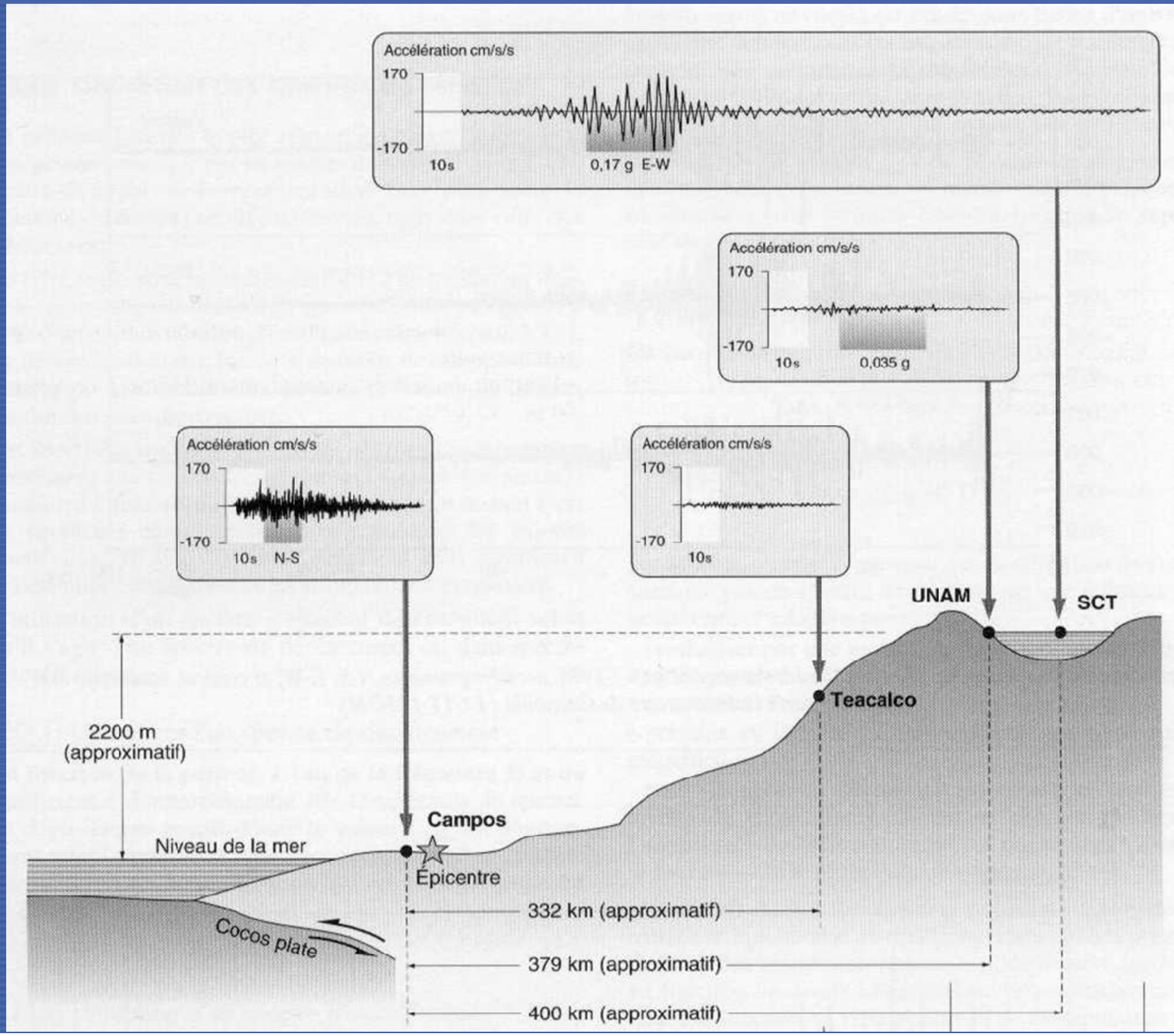

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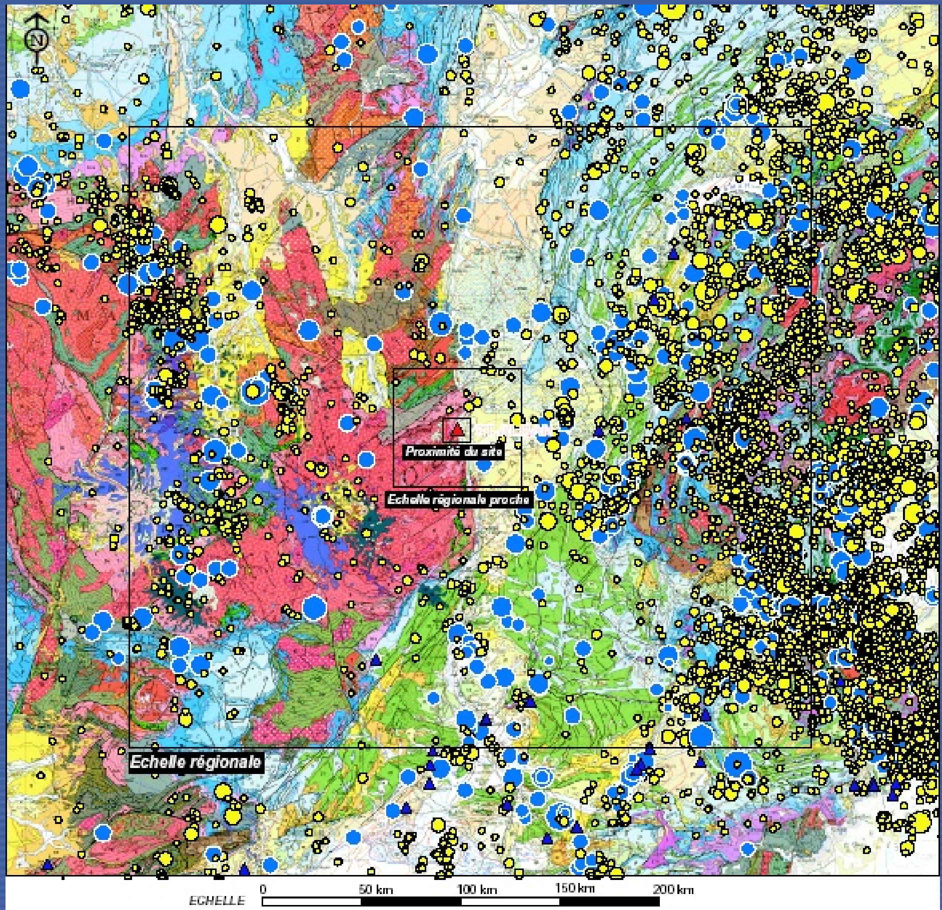
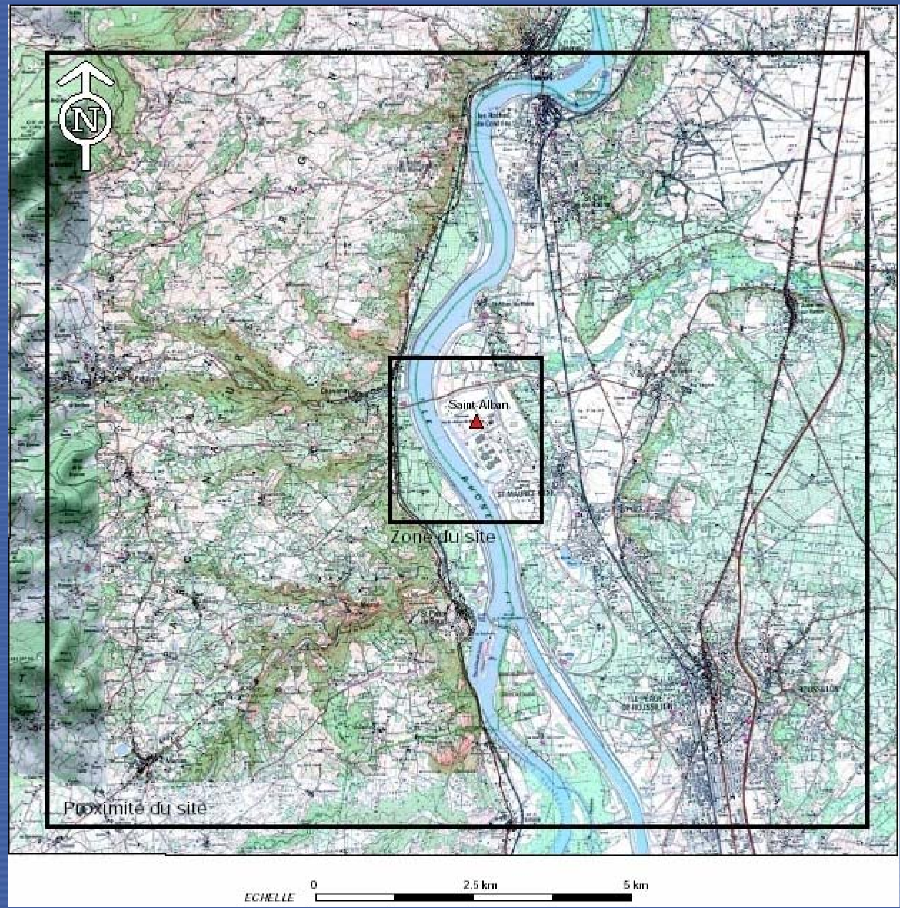
Example of scales





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Safety Guide (NS-G-3.3)

2. Geological, geophysical and geotechnical database

a) Regional investigation.

a) Size depending on the characteristics: potential tsunami, subduction, etc. Typically radius of 300 km.

b) General geodynamic settings. The most important: capable faults.

c) Data provided by published and unpublished sources.

d) Presentation: maps or cross-sections.

e) Map Scale: 1:500.000

f) Generation of new data if it is necessary (paleoseismicity)

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Safety Guide (NS-G-3.3)

2. Geological, geophysical and geotechnical database

b) Near regional investigation.

1. Generation of a more detailed database and definition of seismotectonic characteristics: fault movement, activity rates, segmentation, etc.
2. Specific studies should be included: stratigraphy, structural geology and tectonic history.
3. Use of GPS measurements, photo satellite, geophysical investigations, gravimetry,etc.
4. Map Scale: 1:50.000

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Safety Guide (NS-G-3.3)

2. Geological, geophysical and geotechnical database

c) Site vicinity investigations.

1. Map Scale: 1:5.000
2. Investigations include geomorphological and geological mapping, geophysical investigations, profiling boreholes, trenching
3. Geological map and cross-sections, characterization of the faults located in the area and identification of potential hazards (landslide, karstic, subsidence) should be performed.

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Safety Guide (NS-G-3.3)

2. Geological, geophysical and geotechnical database

d) Site area investigations.

1. Map Scale: 1:500
2. Primary objective: identify potential for **permanent displacement** (fault capability, subsidence, karstic, liquefaction, collapse, etc.) and provide **dynamic properties of soil** (Vs as example) needed in site response analysis.
3. Investigations should be performed using field and laboratory techniques (boreholes, test excavations, Youngs modulus, Poisson ratio, shear modulus, density, hydrogeological investigations, etc.)

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2. Seismological database

a) The catalogue should be compiled containing pre-historical (paleoseismicity and archaeological information), historical and instrumental data.

b) Information of historical earthquakes:

1. Date, time and duration.
2. Location of the epicentre (latitude and longitude)
3. Focal depth
4. Estimation of the magnitude and methodology used to calculate it.
5. Maximum, epicentral and punctual intensities (soil conditions if it is possible).
6. Isoseismal contours.
7. Intensity at the site.

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2. Seismological database

b) Information of historical earthquakes :

8. Estimation of the uncertainty.
9. Quality of the data
10. Determination of foreshocks and aftershocks

c) Information of instrumental data:

1. Date, time of origin and duration.
2. Location of the epicentre (latitude and longitude)
3. Focal depth
4. All magnitude determinations.
5. Determination of foreshocks and aftershocks
6. Focal mechanism, stress drop, seismic moment, etc.
7. Macroseismic details.

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2. Seismological database

c) Information of instrumental data:

8. Estimation of the uncertainties
9. Directivity and duration of the rupture
10. Records (broad band seismometers and strong motion accelerographs)

d) After the compilation of the catalogue:

1. Estimation of the completeness periods.
2. Removal of aftershocks and foreshocks
3. Collection of strong motion in order to fit a ground motion attenuation relationship.

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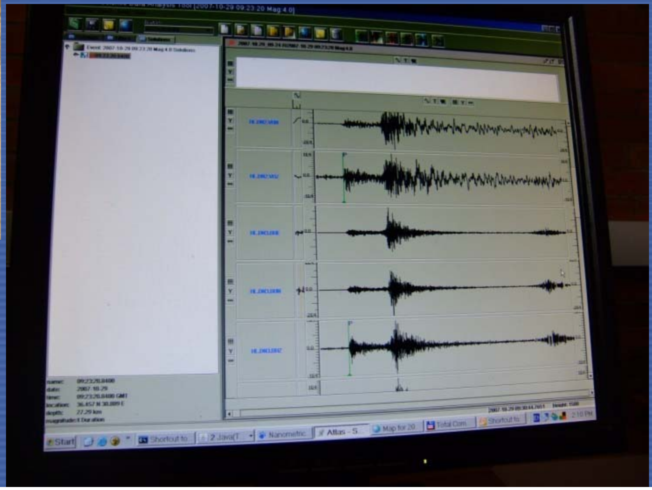
2. Seismological database

e) Local seismic network:

1. Local micro-earthquake network preferably linked to a regional network.
2. Strong motion accelerograph should be installed permanently.
3. Maintenance program of the local seismic network.



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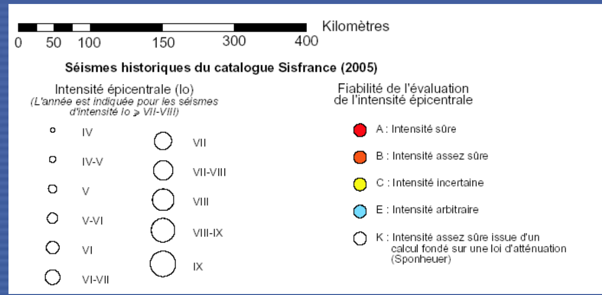
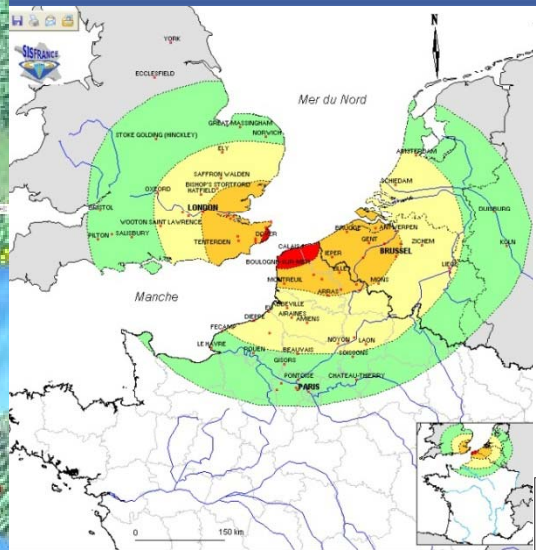
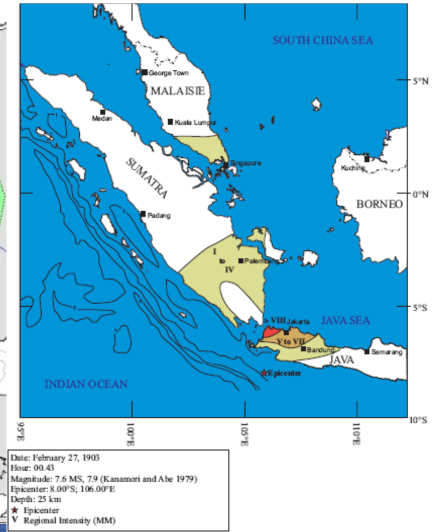
Historical catalogue



Isoseismal map





A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
NUMEVT	QPOS	LONGEPC	LATEPC	COORD_X	COORD_Y	IEPC	QIE	JJ1	MM1	AN1	SECOUSSES	QD	REFEVT	APPELATION
640311.000000000	B	-1.217694000	43.200324000	310700.000000000	1806300.000000000	5.000000000	A	1.000000000	1.000000000	1934.000000000		A	0.000000000	PAYS BASQUE (N. ISPOURE)
260173.000000000	B	4.915877000	45.249633000	802500.000000000	2031000.000000000	5.000000000	A	1.000000000	1.000000000	1937.000000000		A	0.000000000	BAS-PLATEAUX DAUPHINOIS (ST-S
50071.000000000	C	6.599598000	44.483511000	939200.000000000	1951700.000000000	4.000000000	C	1.000000000	1.000000000	1949.000000000		A	0.000000000	QUEYRAS (W. COL DE PARPAILLC
640348.000000000	C	-0.500246000	43.133568000	368800.000000000	1796500.000000000	5.000000000	C	1.000000000	1.000000000	1959.000000000		A	0.000000000	BEARN (BUZIET)
1130060.000000000	D	7.150140000	44.300360000	984200.000000000	1933900.000000000	5.500000000	B	2.000000000	1.000000000	1893.000000000		A	0.000000000	PIEMONT (BAGNI DI VINADIO)
290030.000000000	A	-4.001365000	47.933422000	126900.000000000	2345100.000000000	7.000000000	B	2.000000000	1.000000000	1959.000000000		A	0.000000000	CORNOUAILLE (MELGVEN)

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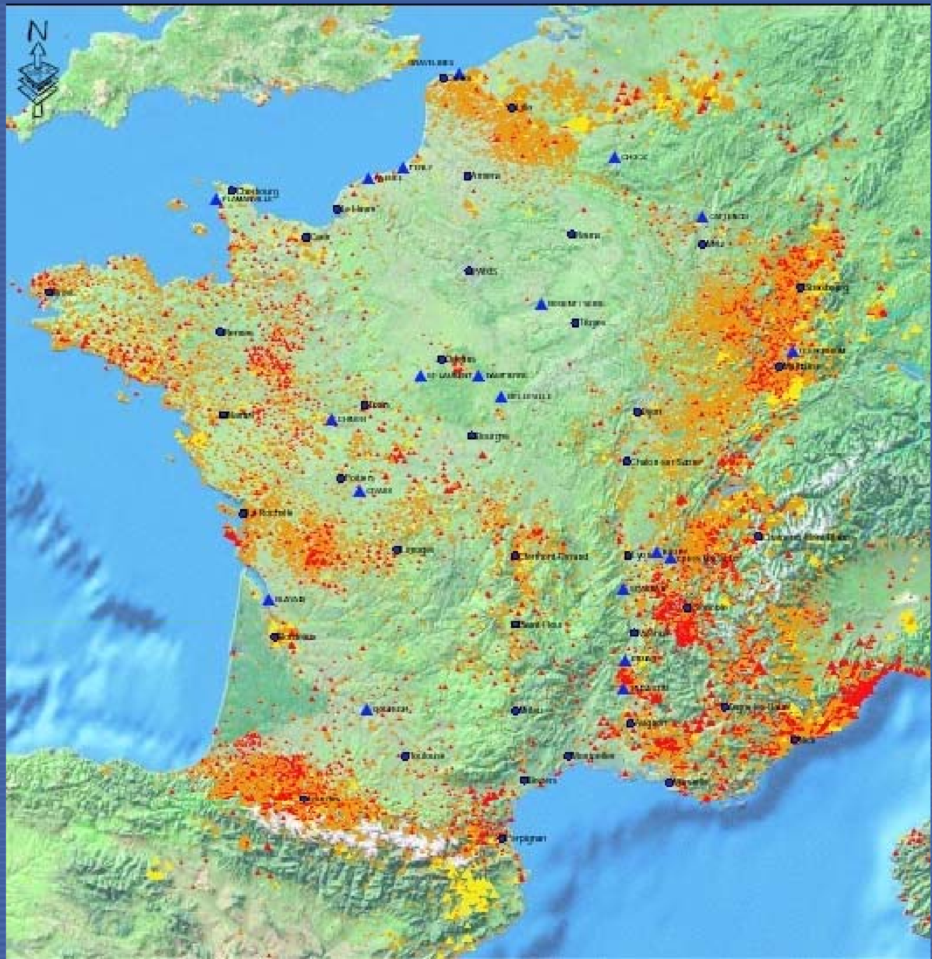
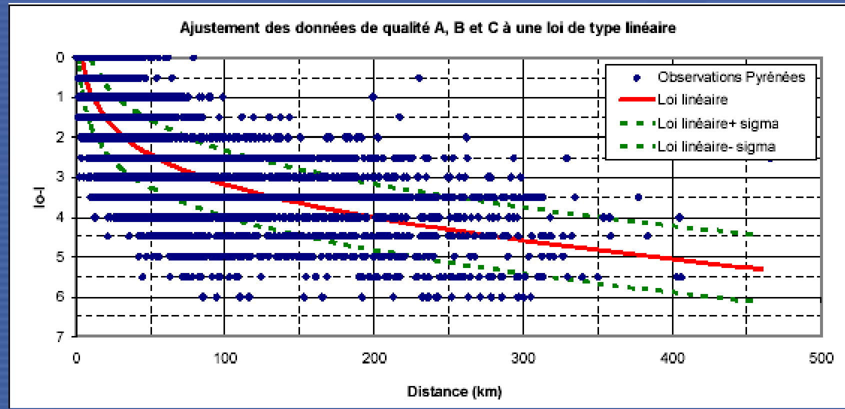
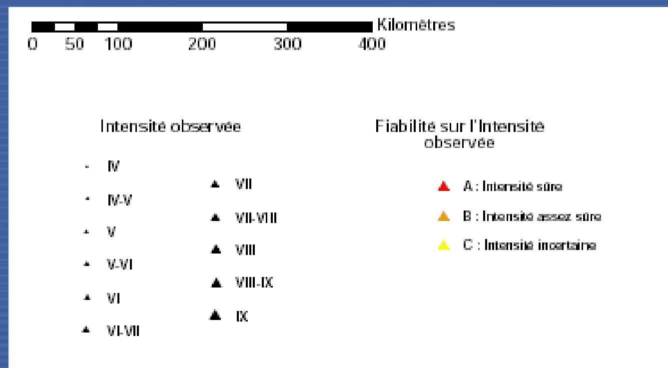
Macroseismic observations



Attenuation relationship





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Complete catalogue:

Intensity-magnitude relation (Levret et al. 1996)

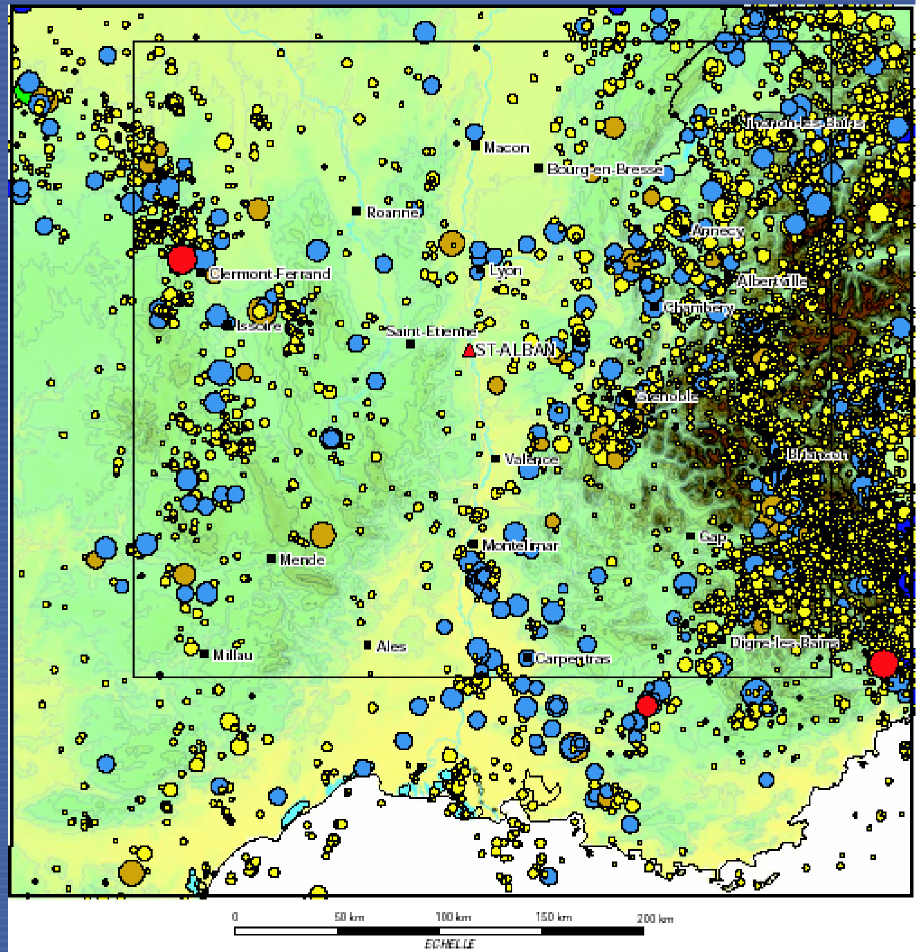
$$M = 0.44\, I_O + 1.48 \log_{10} R + 0.48$$

Transformation of magnitude:

$Ms=0.09+0.93*ML$ (Ambraseys et al. 1996)

$Mw=0.8*ML-0.06$ (Drouet 2006)

$Mw=0.67+0.56*M_{mac}+0.046*M_{mac}$^2 (Grunthal et Wahlstrom, 2003)



	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD
1	SOURCE	AN	MOIS	JOUR	HH	MN	SEC	LONGDECI	ERLON	LATDECI	ERLAT	PROFINS	MLLDG	ERML	ML	MD	ERMD	MS	MB	RMS1	NBPHAS	NUMREG	AZIMU	GAX	PAX	MHOMO	Ms	Mw(D)
2	SIR	858	1	18	0	0	0.00	8.2667	0.0	50.0000	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0	5.10	4.90	4.00
3	SIR	1142	1	7	6	0	0.00	0.9333	0.0	49.4833	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0	4.20	4.10	3.30
4	SIR	1223	1	11	7	0	0.00	6.9500	0.0	50.9333	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0	5.50	5.30	4.30
5	SIR	1241	9	23	20	0	0.00	-0.3667	0.0	49.1833	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0	4.60	4.50	3.60
6	ipsn	1356	10	18	22	0	0.00	7.5500	0.0	47.5167	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0	6.20	6.20	4.90

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Example of catalogue: Historical period

NUMERO	CATALOGUE	SOURCE	AN	MOIS	JOUR	HH	MN	SEC	LON	LAT	PROFINS	MLLDG	MD	MS	MB	TYPHOMO	MHOMO	MS_HOMO	MW_HOMO	NUMEVT	QPOS	QIE	IEPC	ZONE_GTR	ZONE_EDF
3	ZPGF	SIR	1223	1	11	7	0	0	6.9500	50.9333	0.0	0.0	0.0	0.0	0.0	mcl	5.5	5.3	5.1	111148	D	C	7.0	GBP	RHG
4	ZPGF	SIR	1241	9	23	20	0	0	-0.3667	49.1833	0.0	0.0	0.0	0.0	0.0	mcl	4.6	4.5	4.2	142	D	C	5.0	BMO	CAA
5	ZPGF	ipsn	1356	10	18	22	0	0	7.5500	47.5167	0.0	0.0	0.0	0.0	0.0	mlevret	6.2	5.9	5.9	11246	B	B	9.0	ZDB	BAL
6	ZPGF	brgm	1382	5	21	14	0	0	2.0000	51.3333	0.0	0.0	0.0	0.0	0.0	brgm	5.8	5.6	5.5	1151	D	C	7.5	BBR	BRA
7	ZPGF	SIR	1397	5	26	23	55	0	4.7333	43.7833	0.0	0.0	0.0	0.0	0.0	mcl	4.0	3.9	3.6	344	D	C	5.5	ACC	CHA
8	ZPGF	SIR	1427	3	19	21	0	0	2.6000	42.0167	0.0	0.0	0.0	0.0	0.0	mcl	5.5	5.3	5.1	11418	D	C	8.0	ZAO	OCC
9	ZPGF	brgm	1428	2	2	8	0	0	2.3000	42.2667	0.0	0.0	0.0	0.0	0.0	brgm	5.8	5.6	5.5	11414	B	C	9.0	ZAO	OCC
10	GTR	SIR	1448	5	25	0	0	0	2.4000	41.6330	0.0	0.0	0.0	0.0	0.0	mcl	5.5	5.3	5.1	1140017	D	C	7.5	CIS	
11	ZPGF	SIR	1449	4	23	3	0	0	2.2500	51.3833	0.0	0.0	0.0	0.0	0.0	mcl	5.1	4.9	4.7	118	D	E	7.0	BBR	BRA
12	ZPGF	SIR	1477	6	29	7	0	0	3.1000	45.8333	0.0	0.0	0.0	0.0	0.0	mcl	5.3	5.1	4.9	632	C	B	7.5	LIF	LIM

Instrumental period

1	NUMERO	CATALOGUE	SOURCE	AN	MOIS	JOUR	HH	MN	SEC	LON	LAT	PROFINS	MLLDG	MD	MS	MB	TYPHOMO	MHOMO	MS_HOMO	MW_HOMO	NUMEVT	QPOS	QIE	IEPC	ZONE_GTR	ZONE_EDF
26962	26961	LDG_EDF	LDG	2008	6	6	9	56	19	0.5023	42.5448	7.0	2.5	2.6	0.0	0.0	ML	2.5	2.4	1.9	222355			0.0	CSP	FES
26963	26962	LDG_EDF	LDG	2008	6	6	10	39	52	-0.1470	42.9114	2.0	0.0	1.3	0.0	0.0	MD	1.3	1.3	1.0	222356			0.0	NPO	AXO
26964	26963	LDG_EDF	LDG	2008	6	6	14	40	30	6.4814	45.0779	2.0	1.8	1.7	0.0	0.0	ML	1.8	1.8	1.4	222373			0.0	NEX	BRI
26965	26964	LDG_EDF	LDG	2008	6	6	21	54	7	-1.0967	43.1351	15.0	1.4	1.6	0.0	0.0	ML	1.4	1.4	1.1	222376			0.0	NPO	PVA
26966	26965	LDG_EDF	LDG	2008	6	7	1	53	53	6.4778	45.0594	2.0	2.5	0.0	0.0	0.0	ML	2.5	2.4	1.9	222378			0.0	NEX	BRI
26967	26966	LDG_EDF	LDG	2008	6	7	1	54	5	6.4896	45.0682	2.0	2.4	0.0	0.0	0.0	ML	2.4	2.3	1.9	222445			0.0	NEX	BRI
26968	26967	LDG_EDF	LDG	2008	6	7	1	55	31	6.4909	45.0702	2.0	2.3	2.1	0.0	0.0	ML	2.3	2.2	1.8	222379			0.0	NEX	BRI
26969	26968	LDG_EDF	LDG	2008	6	7	1	59	21	6.4934	45.0647	2.0	1.4	1.5	0.0	0.0	ML	1.4	1.4	1.1	222380			0.0	NEX	BRI

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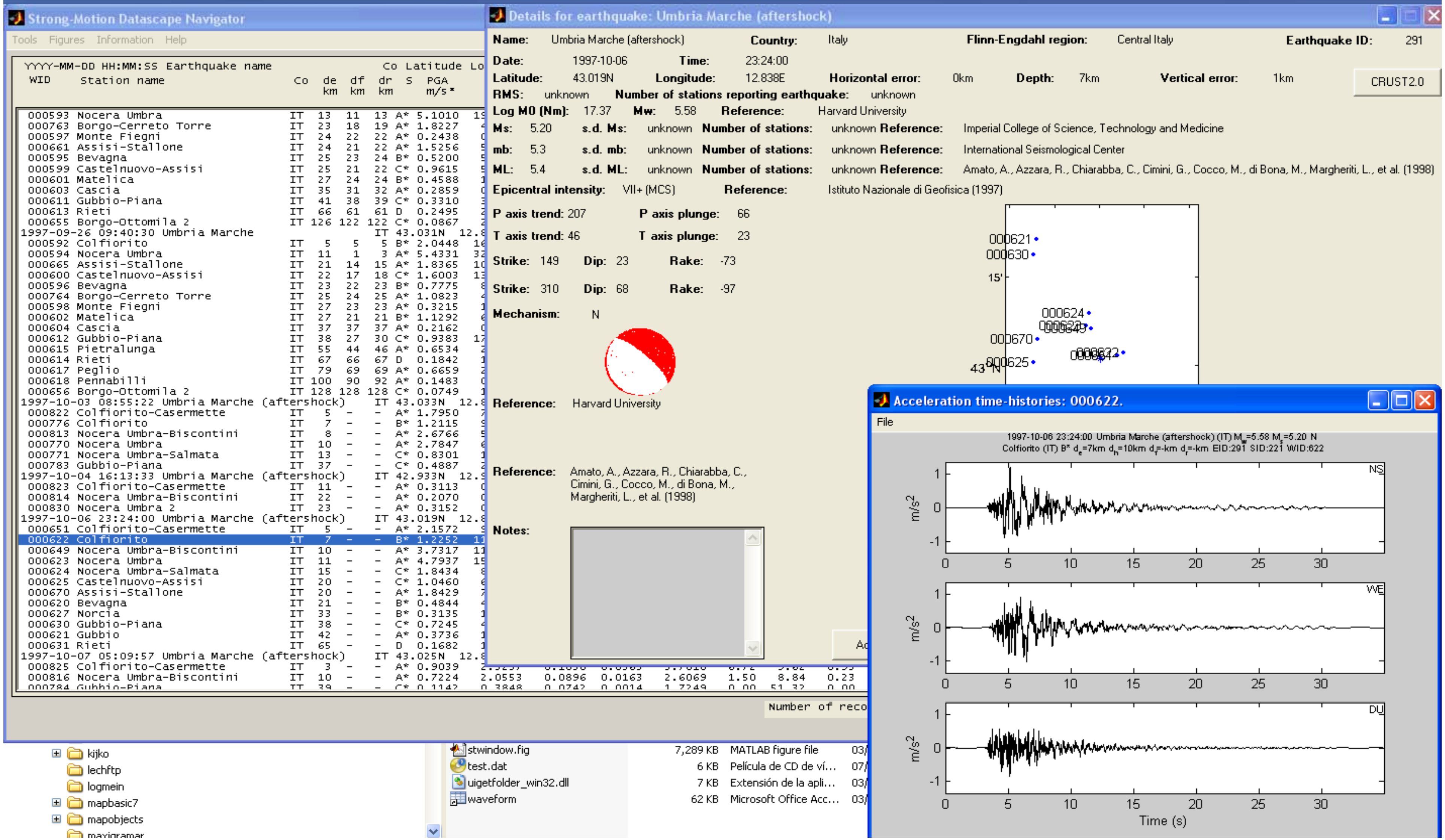
Example of strong motion database:



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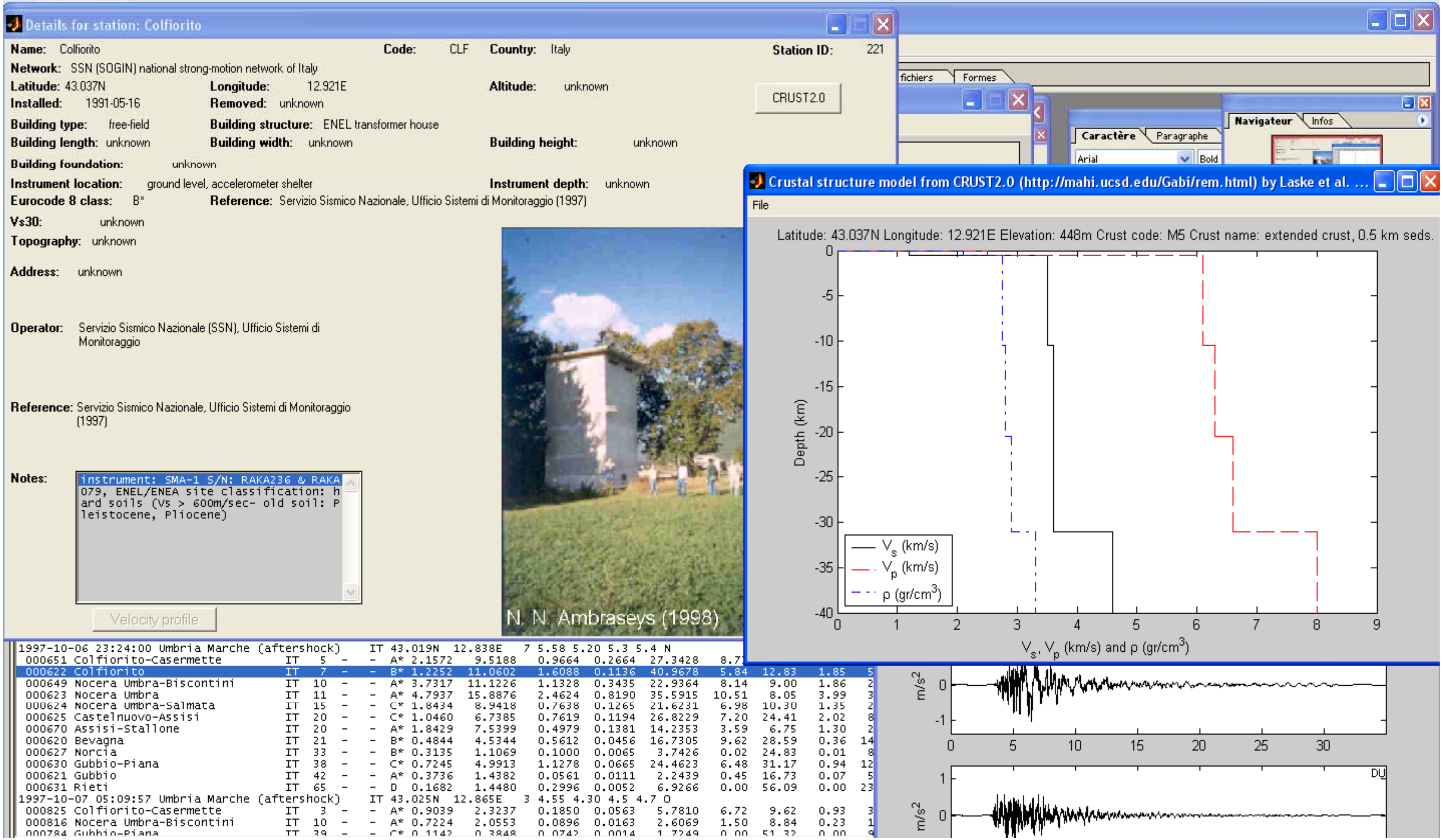
Example of strong motion database:



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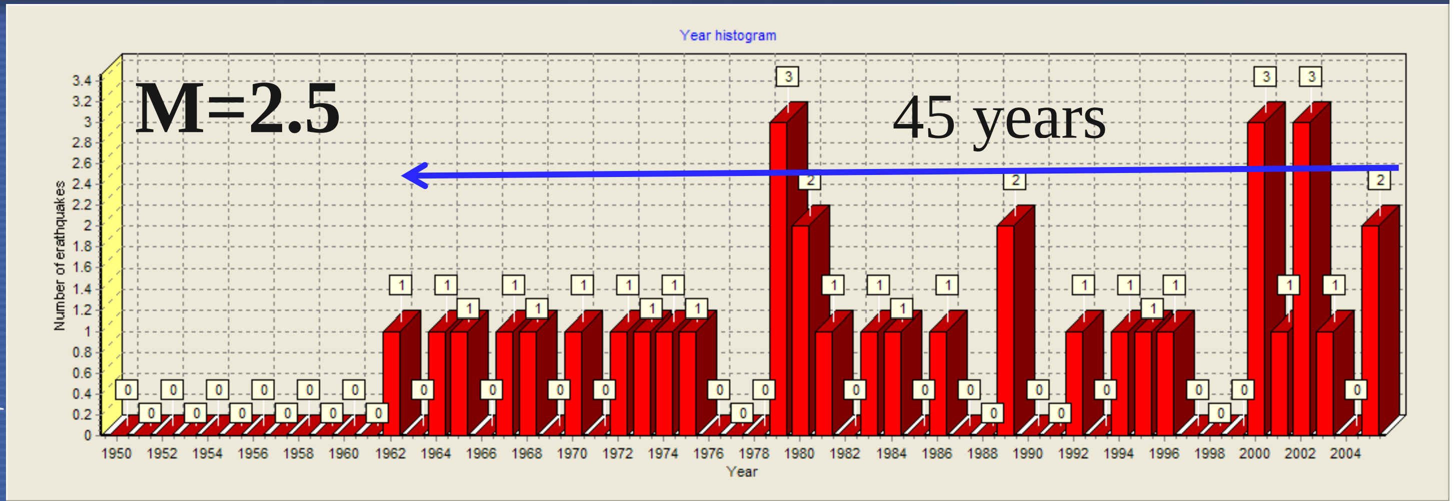
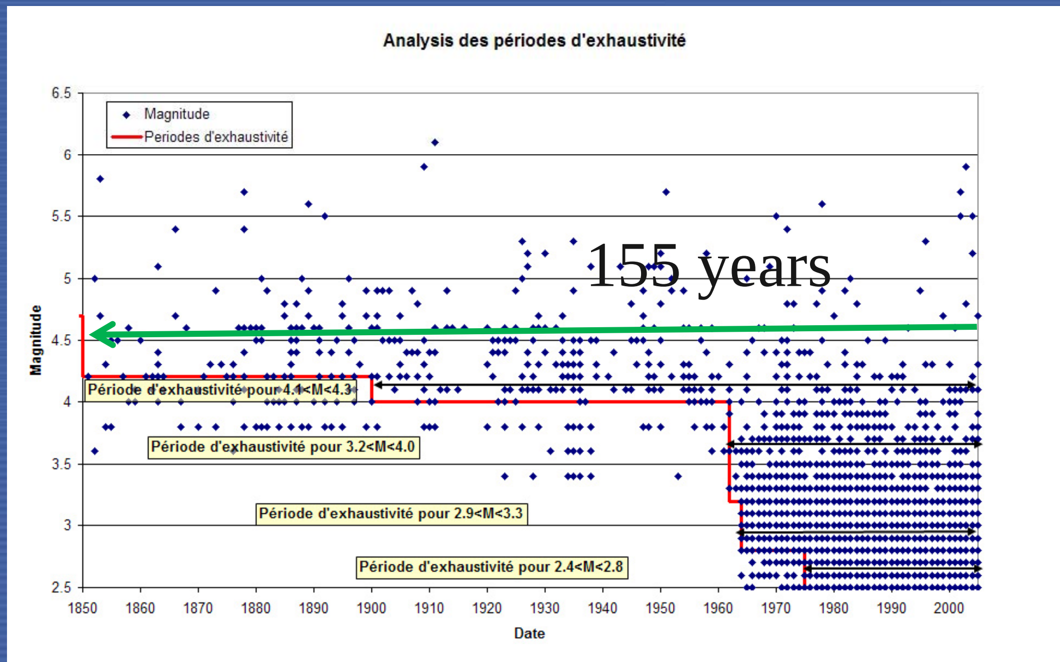
Completeness analysis

1) Year histogram



2) Stepp-plot



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3. Regional seismotectonic model

a) Introduction:

1. Link between geological, geophysical and geotechnical database and seismological database.
2. **Identification of seismogenic structures**: faults or systems of faults and zones of diffuse seismicity.
3. **Evaluation and characterization of seismic sources** and its uncertainty (Characteristic model, Poissonian model).
4. **Epistemic uncertainty** should be considered and weighted. Alternative models should be used.
5. Before fitting the magnitude-frequency distributions the **catalogue should be treated** in order to:
   a) Selection of a homogeneous magnitude for all catalogue.
   b) Identification of main shocks and removal of aftershocks
   c) Regional completeness analysis
   d) Estimation of the uncertainties
6. Use of **palaeoseismology**.

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3. Regional seismotectonic model

a) Introduction:

6. **Magnitude of the catalogue** should be the same as the **magnitude of the attenuation relationship** used (Mw preferred due to the non saturation).

7. The **magnitude-frequency** should identify the parameters describing the seismic exceedance rate in function of magnitude and the maximum magnitude for each source (Typically, b-value, a-value and Mmax).

8. **Uncertainty** in seismic parameters should be considered.

9. Attention to the definition of **Mmax** (key parameter for long return periods).

10. Use of **paleoseismicity** in order to:

   a) Identification of seismogenic structures
   b) Improvement of the completeness (large events, high magnitudes)
   c) Definition of Mmax

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3. Regional seismotectonic model

b) Seismogenic structures:

Identification and characterization:

1. Consideration of seismogenic sources able to produce a ground motion in the site (in the frequency range of interest).
2. Analysis of **surface faulting and fault displacement**.
3. Identification of seismogenic sources using: geological, geophysical, geotechnical and seismological data.
4. Identification of the **geometry**, segmentation, branching, focal mechanism, etc. and its uncertainty.
5. Identification of **Mmax**.
6. Identification of a **magnitude-frequency relationship** (typically characteristic or exponential) and its uncertainties

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3. Regional seismotectonic model

c) Zones of diffusse seismicity:

1. Identification of the diffuse zones taking into account depth of the earthquakes, rates of earthquakes, etc.
2. **Depth** and its uncertainty are a key parameter in PSHA.
3. Identification of **Mmax** with historical and instrumental data., comparison with similar regions, etc.
4. Determination of the magnitude-frequency relation. Attention should be paid to the definition of **b-value**.

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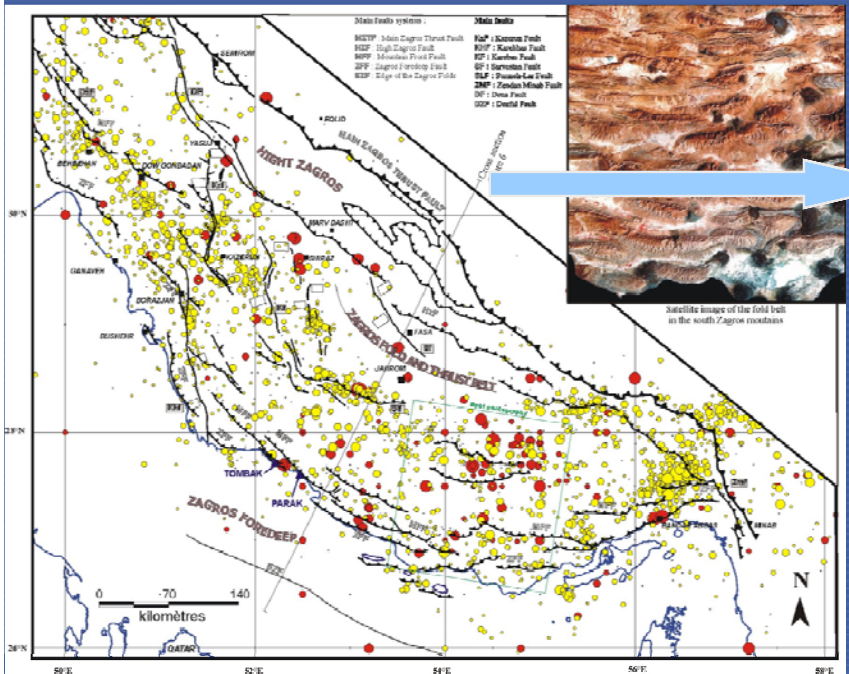

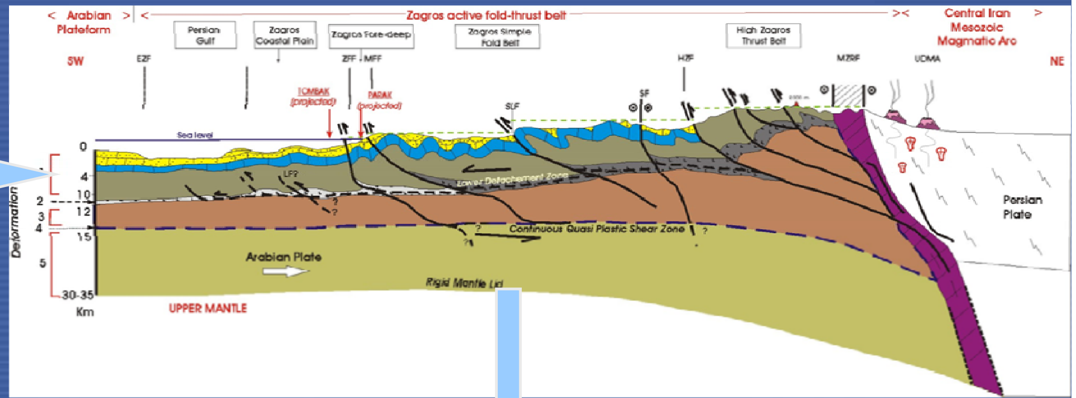

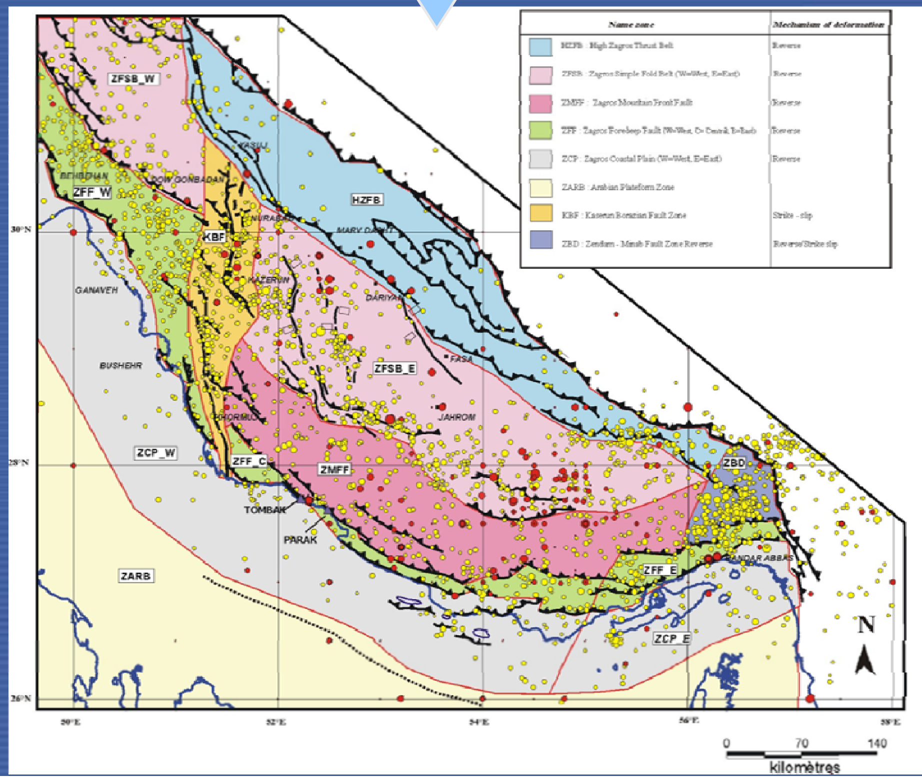

Seismotectonic zonation

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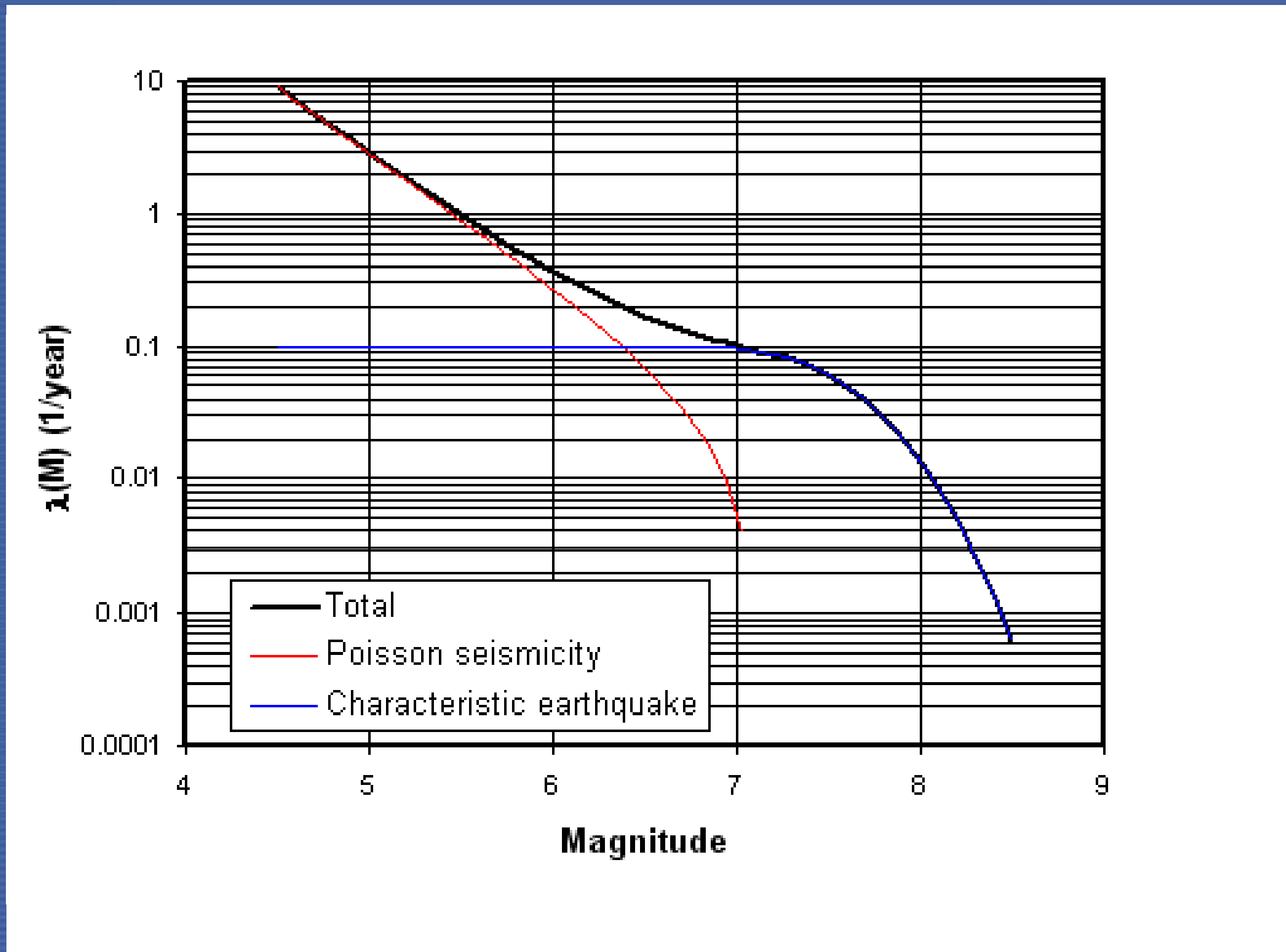
Characterization of the seismic sources



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PSHA study in Provence: example of fault treatment

Uncertainties

Propagated with logic-tree and Monte-Carlo

Seismotectonic models

Revision of the seismotectonic zonation

Consideration of a Fault model in Western Provence

Seismicity models

Gutenberg-Richter based on earthquake catalogue

Characteristic earthquake based on moment rate distribution

Objectives

- ➔ **Compare faults models with zone models**
- ➔ **Include these models in the logic tree**
- ➔ **Impact on the hazard assessment**
- ➔ **Comparison DSHA/PSHA and return periods of deterministic seismic motions for PSA analysis.**

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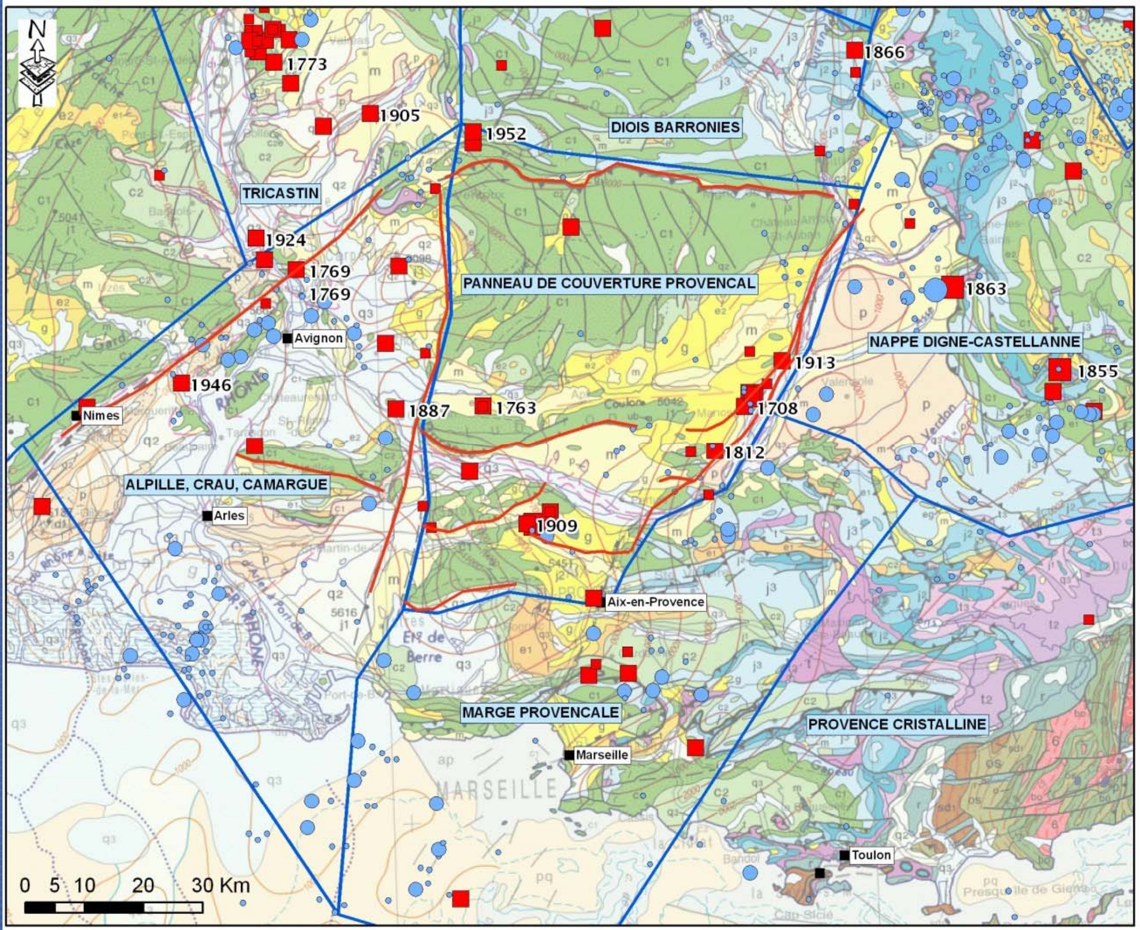
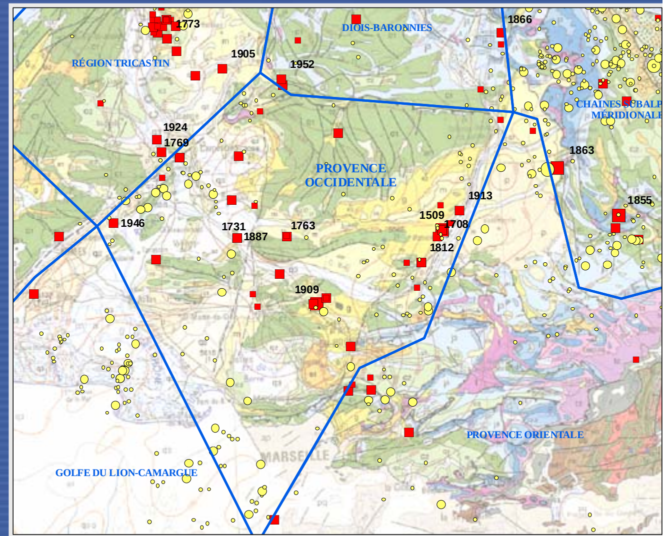
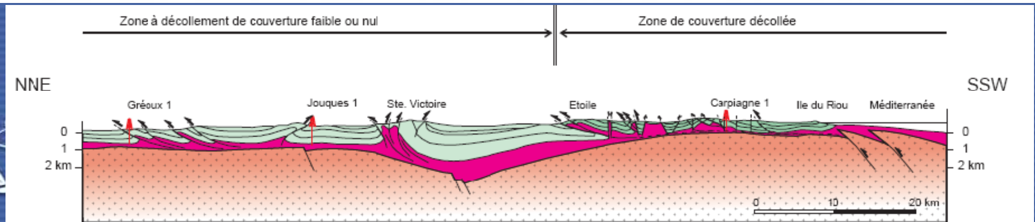
New Seismotectonic zonation







- Refined model / 2002 model (CEREGE works of Guignard and Bellier)

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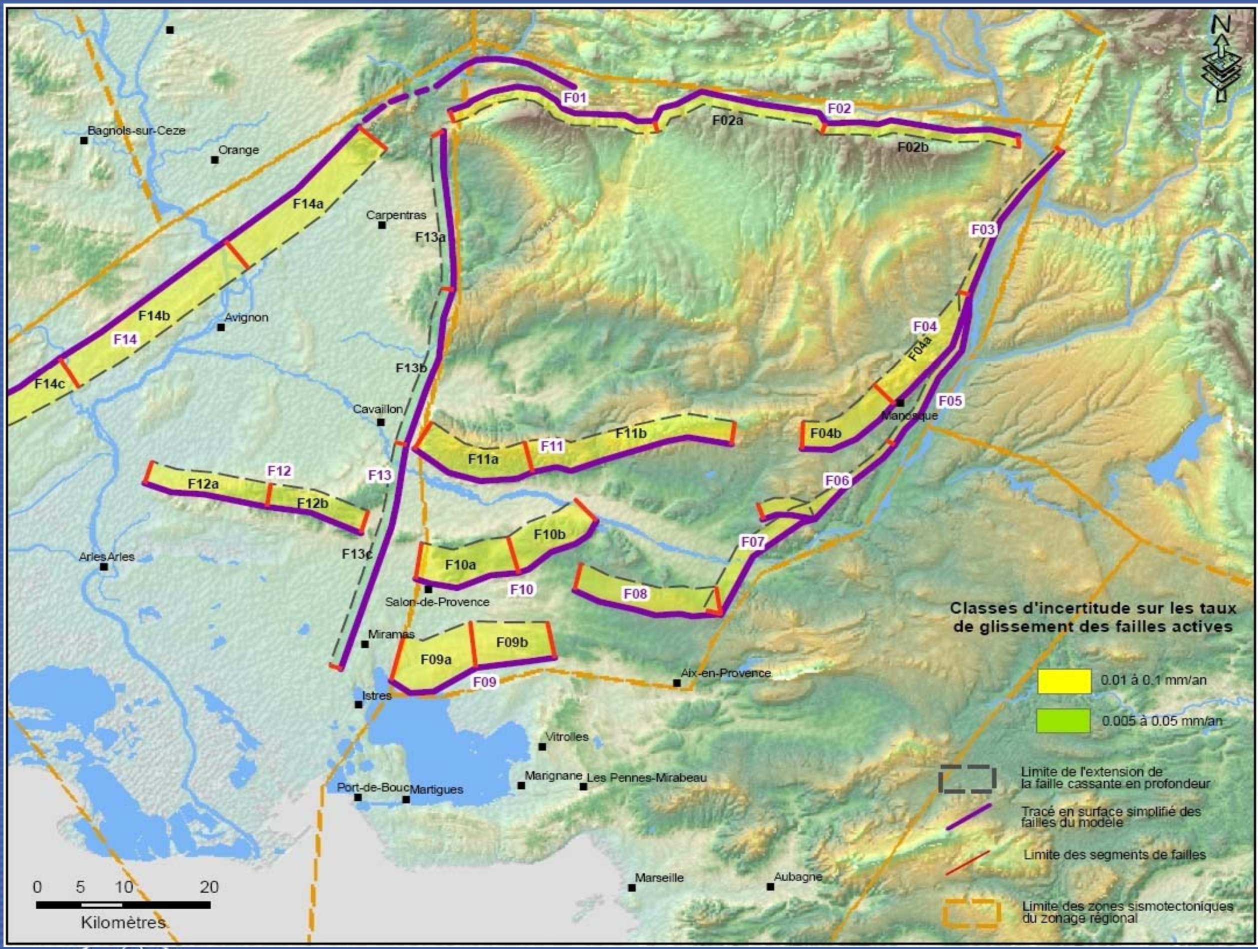
Western Provence fault model for PSHA



UNCERTAINTIES

- Geometry
  - trace
  - segmentation
  - dip
  - depth
- Slip rate
- Single/multi segment rupture
- Recurrence model
- Background seismicity

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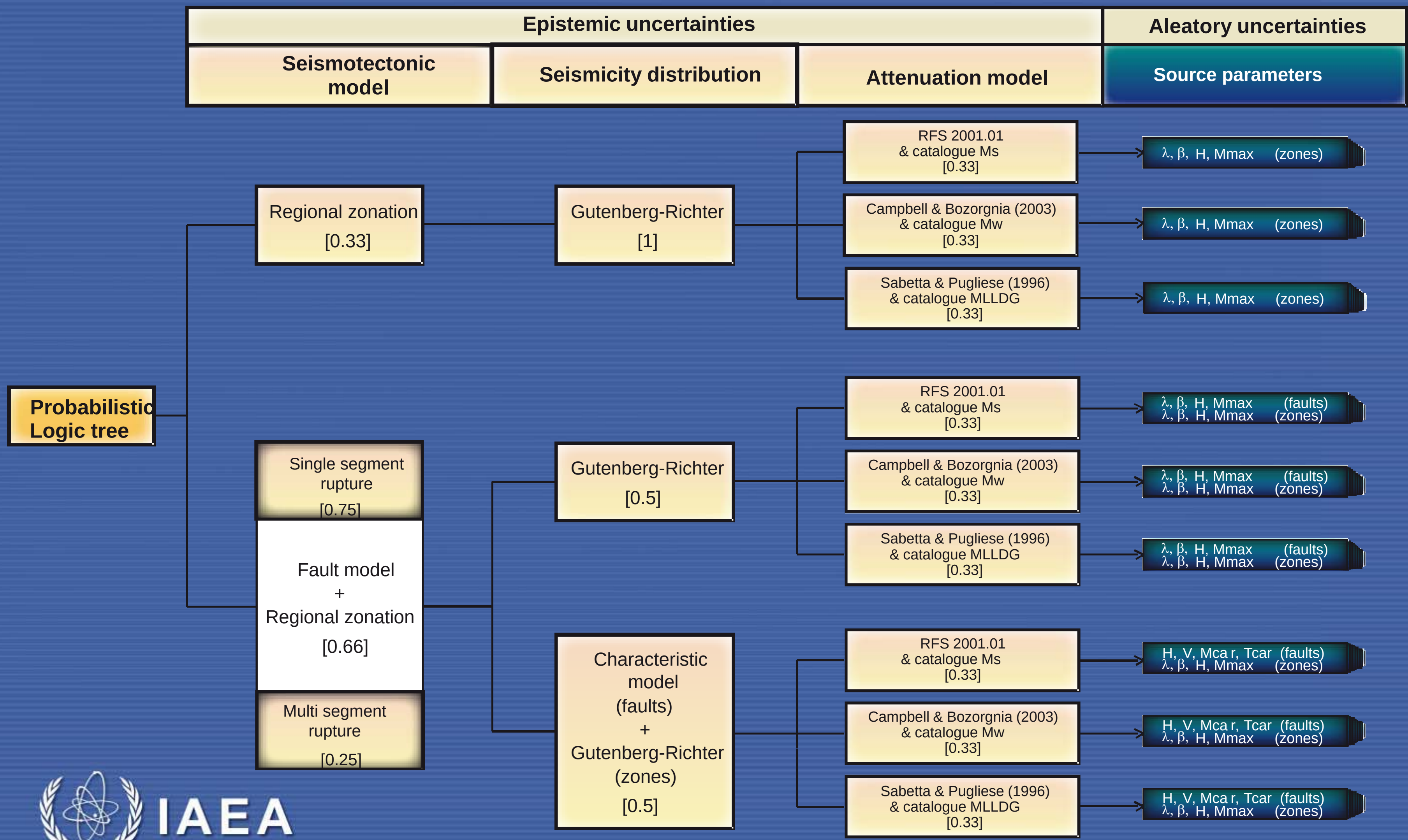
Probabilistic logic tree



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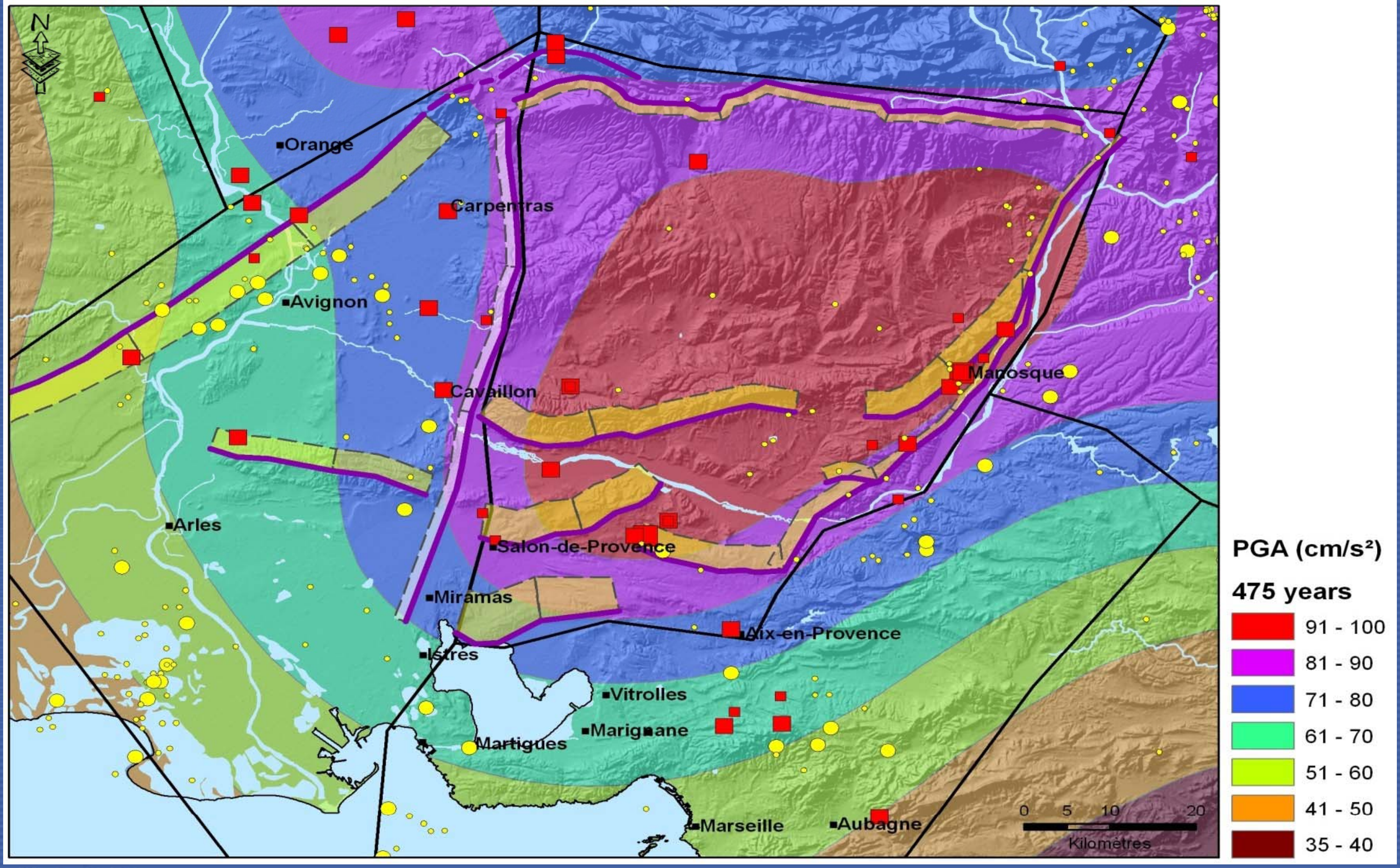
Total Logic tree : Seismic hazard map 475 years



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→ **Negligible contribution of faults**

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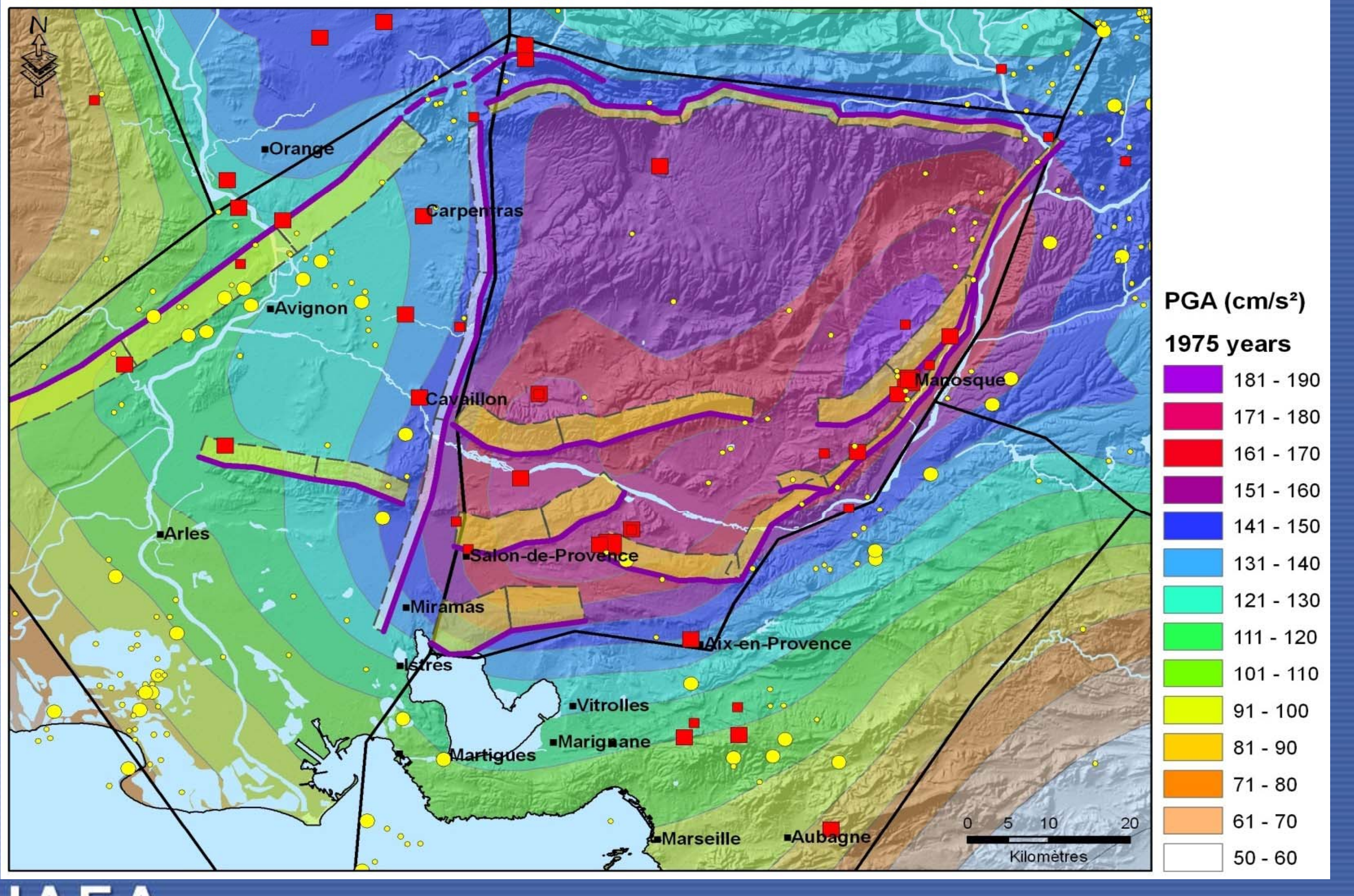
Total Logic tree : Seismic hazard map 1975 years



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→ **Low contribution of faults**

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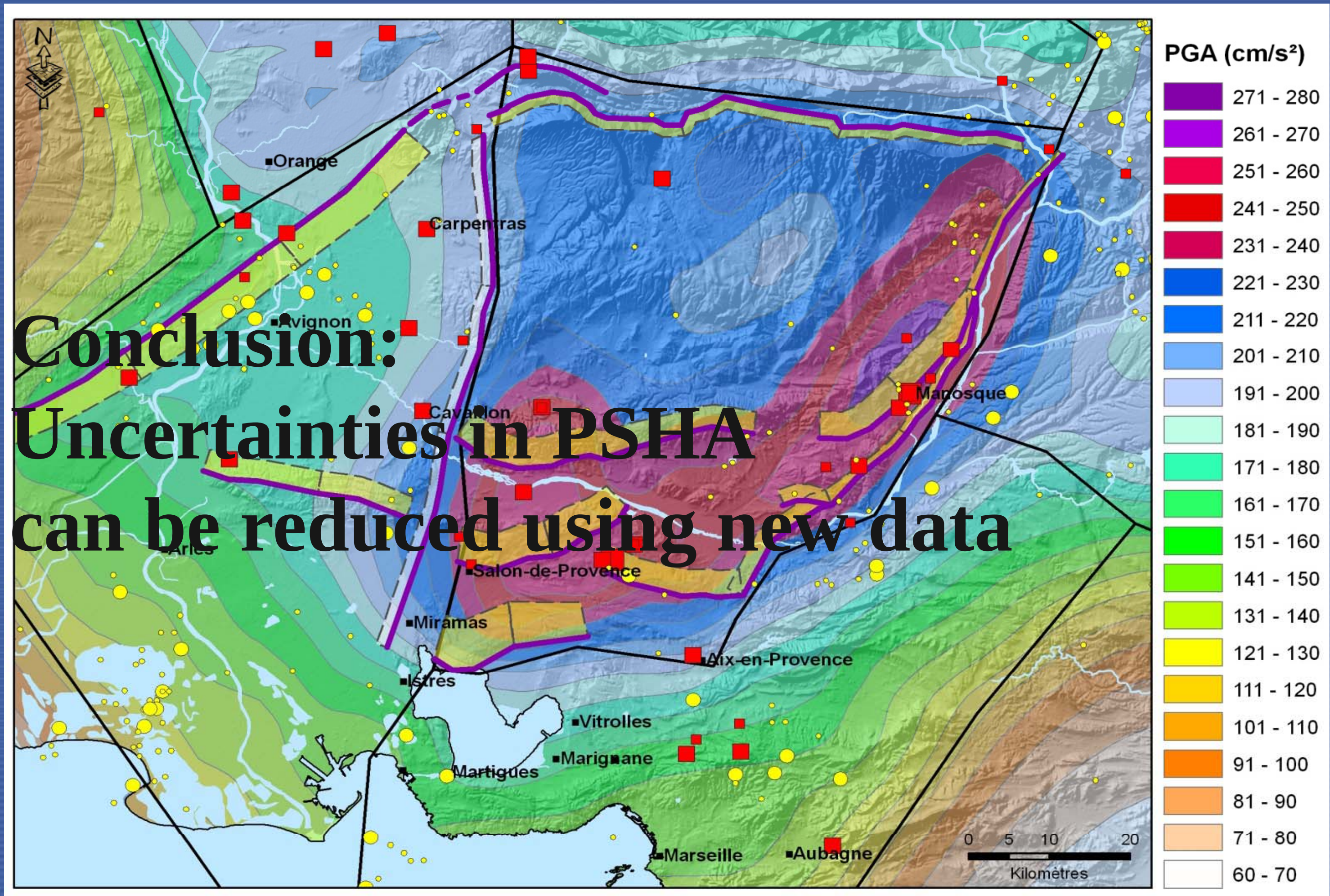
Total Logic tree : Seismic hazard map 5000 years



Conclusion:

Uncertainties in PSHA

can be reduced using new data

→ **Significant contribution of faults**

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4. Evaluation of the ground motion

a) Introduction:

1. Ground motion hazard should *preferably* be evaluated using both **probabilistic and deterministic** approaches.
2. Deterministic approaches could be used to check the probabilistic results (reasonableness of the results)
3. The probabilistic results allow to evaluate deterministic results within a probabilistic framework (annual frequency of exceedance of deterministic SA(T) is known).
4. Consideration of **aleatory and epistemic** uncertainties.
5. PSHA is useful for seismic Probabilistic Safety Assessment
6. Attention to the **software** used: able to treat different geometries of the sources, different attenuation laws, uncertainties, etc.

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4. Evaluation of the ground motion

a) Ground motion characterization:

- **Ground motion parameters**: PGA, PSA, PGV, PSV, PGD, PSD at specified damping ratios, ground motion duration, power spectral intensity, CAV, etc.
- **Ground motion components**: largest horizontal component, geometric mean of two horizontal components, the vertical component, etc.
- **Ground motion prediction models**: $GM=g(M,R,C_i) + \varepsilon_{gm} + \varepsilon_c$
  - GM is the median estimate of the ground motion parameter
  - g is the mathematical function
  - M is the Magnitude
  - R is the site-source distance.
  - C_i corresponds to other parameters (style of faulting, hanwing-wall effects, local site conditions, intraslab earthquakes etc.
  - $\varepsilon_{gm} + \varepsilon_c$ corresponds to the aleatory uncertainty and component to component uncertainty.

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4. Evaluation of the ground motion

a) Ground motion characterization:

- Magnitude, distance and other parameters should be consistent with the characterization of seismic sources.
- **Validity domain** of attenuation relationship should be checked
- Attenuation relationship **compatible with site conditions**.
- Main **selection criteria**:
  - Current and well established
  - Consistent with the type of earthquakes (subduction, intra-plate, etc.)
  - Consistent with the general tectonic environment of the region
  - Comparison with local records
- **Epistemic uncertainty** treated with the selection of different attenuation relationships and the use of **logic tree** technique.
- Possibility to use **intensity data** (attenuation relationships in terms of intensity)

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4. Evaluation of the ground motion

a) Ground motion characterization:

- In very active regions where data from ground motion caused by identified faults is able, **simulation of the fault rupture and wave propagation path** is other recommended procedure. Parameters needed are:
  - Fault geometry (length, width, depth, dip angle, etc.)
  - Macro parameters: seismic moment, rupture velocity, stress drop, etc.
  - Micro parameters: dislocation, stress parameters for finite fault elements, etc.
  - Shear wave velocity, Q value, etc.
- Lower bound motion filter to be used: magnitude, CAV…..

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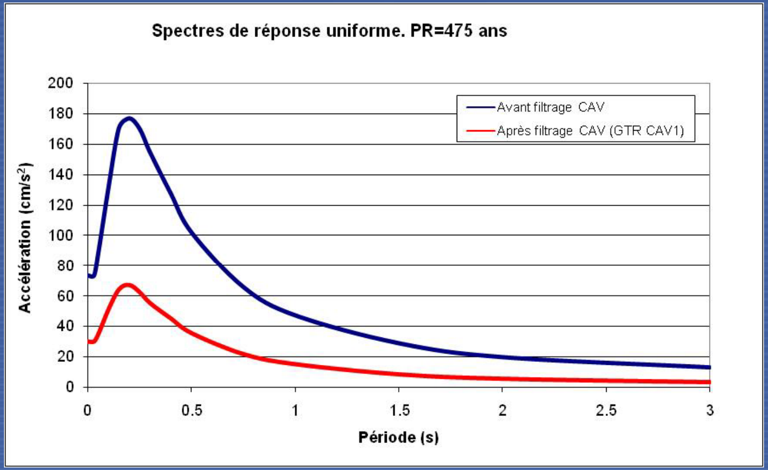
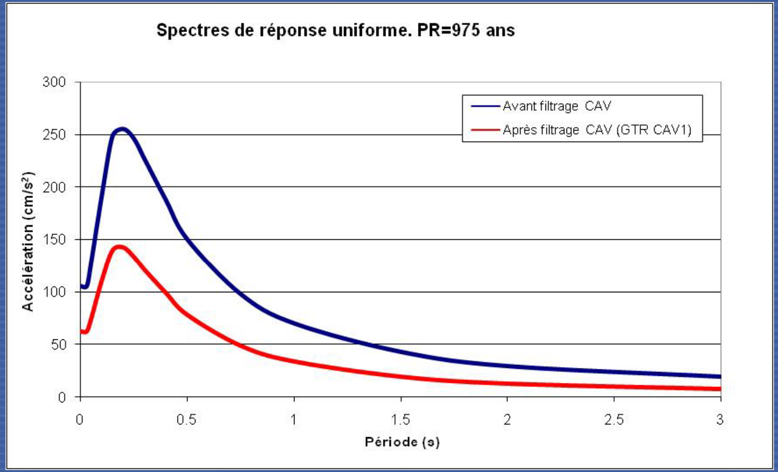
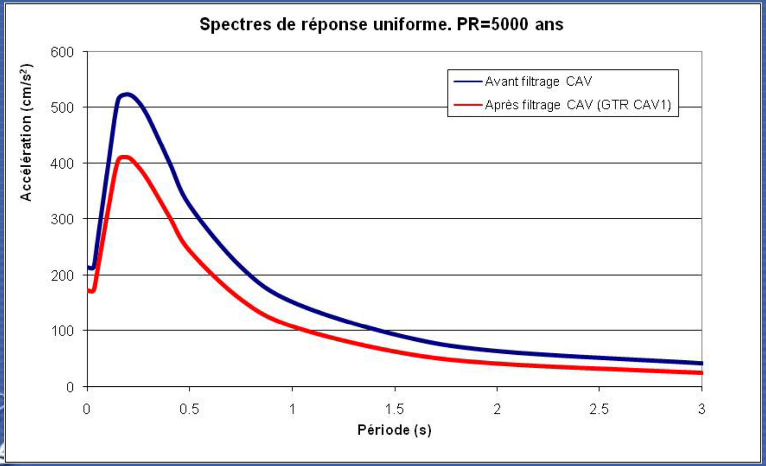
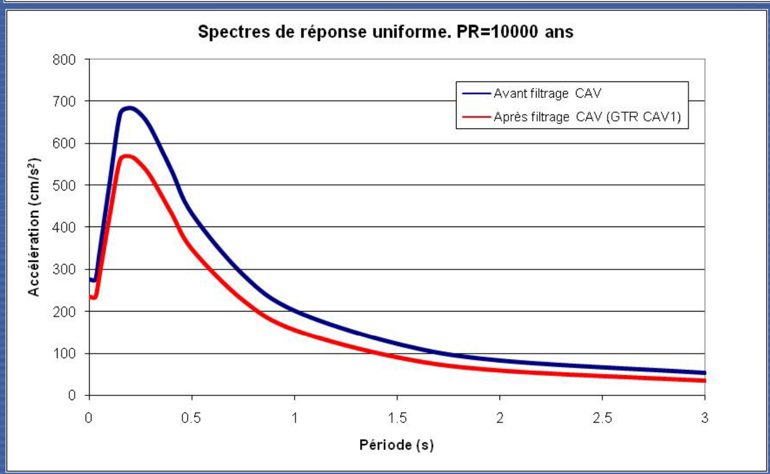
4. Evaluation of the ground motion

Example of CAV filter:









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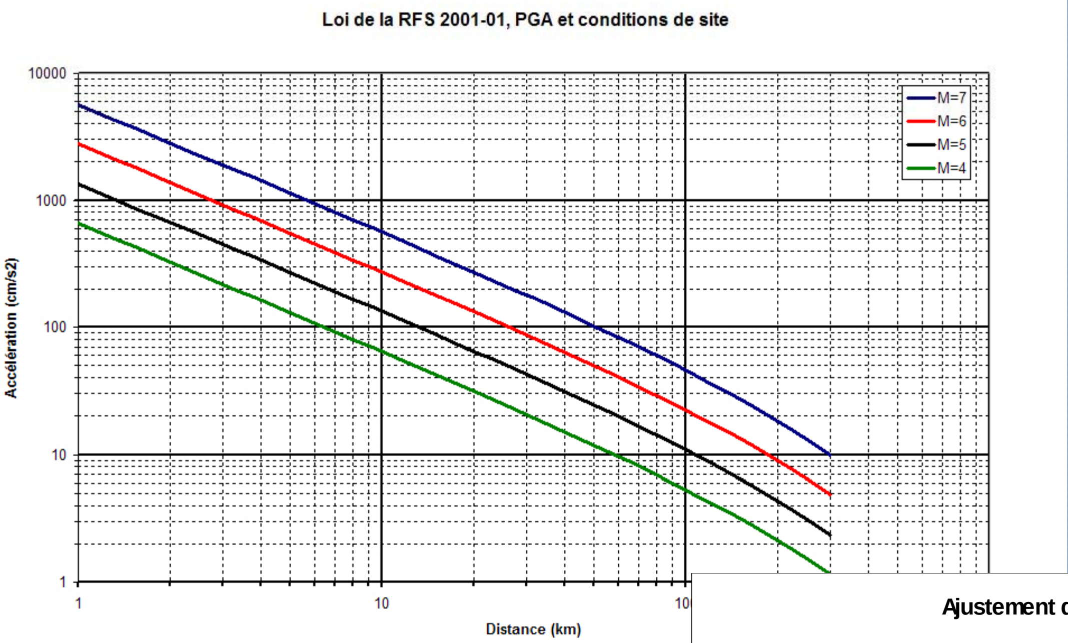
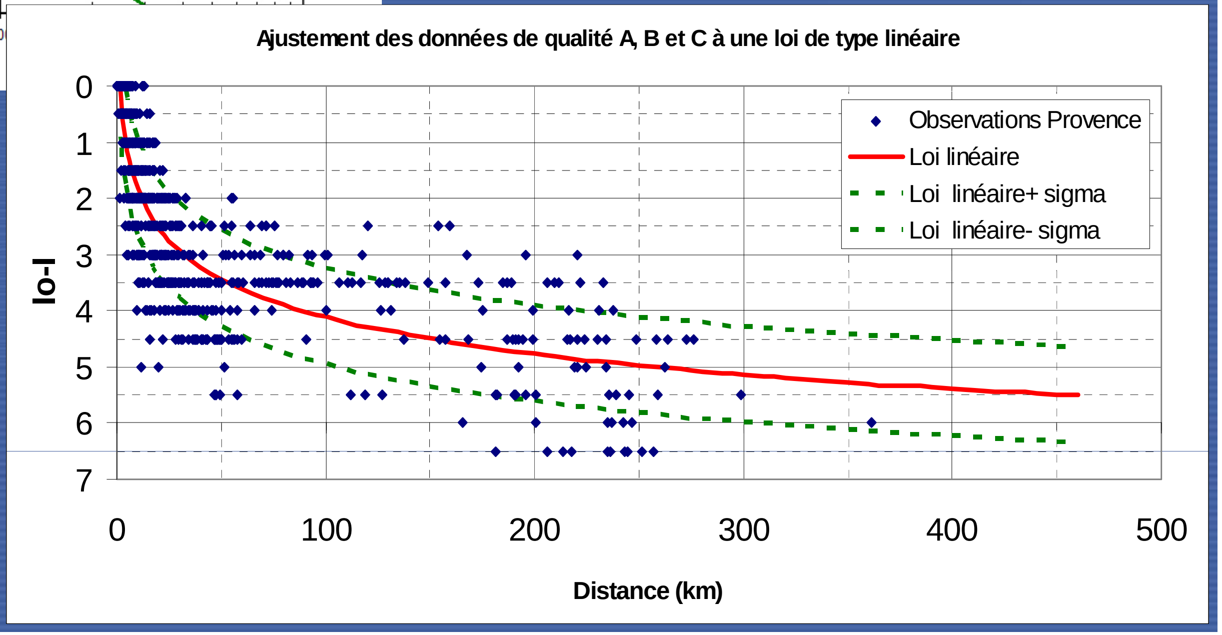


Attenuation relationship in terms of PSA

Attenuation relationship in terms of intensity



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5. Probabilistic seismic hazard assessment.

a) The PSHA should use all elements and parameters of seismotectonic model.

b) Smallest annual exceedance frequency of interest: Depending on project plan (typically from 10^{-6} to 10^{-8}).

c) Main Steps for a PSHA

   a) Evaluation of the seismotectonic model

   b) For each zone source: magnitude-frequency distribution parameters, Mmax, depth and its uncertainies.

   c) Selection of attenuation relationships.

   d) Performing seismic hazard calculation

   e) Taking into account site response.

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5. Probabilistic seismic hazard assessment

d) Results of a PSHA: seismic hazard curves for different spectral periods for fractiles 16%, 50% and 84% (also mean).

e) The uniform response spectra can be obtained from seismic hazard curves

f) Methodology to propagate the uncertainties:

  d) Logic tree techniques.

  e) Monte-Carlo simulation

g) To determine the ground motion characteristics it is useful to perform:

  a) A source deaggregation

  b) A magnitude-distance deaggregation

d) Hazard integral

$$\nu(i) = \int_{M_o}^{M_{max}} -\frac{d\lambda}{dM} \Pr(I > i | M, R) dM$$

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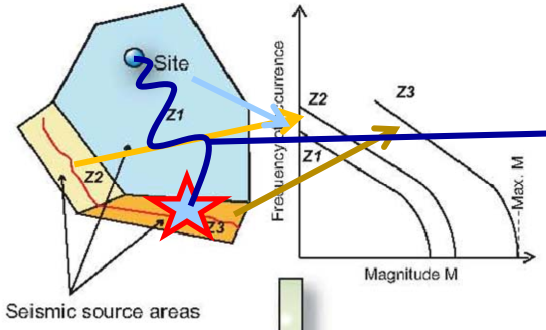
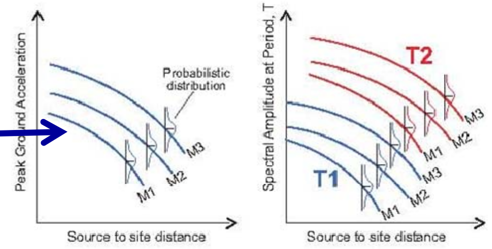
PSHA calculation process

1. Define and characterize seismic sources

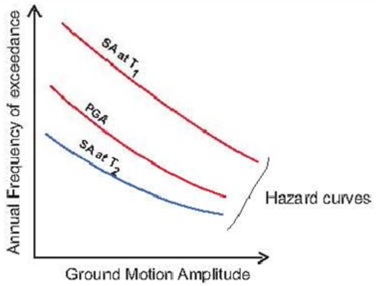
2. Define attenuation law



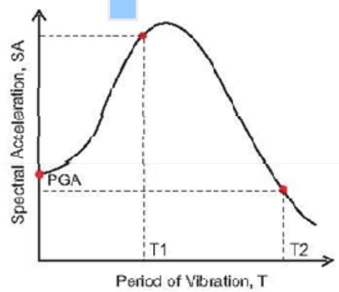


$$\nu(a) = \int_{R\min}^{R\max} \int_{Mo}^{M\max} -\frac{d\lambda(M)}{dM} \Pr(A > a | M, R) dM dR$$

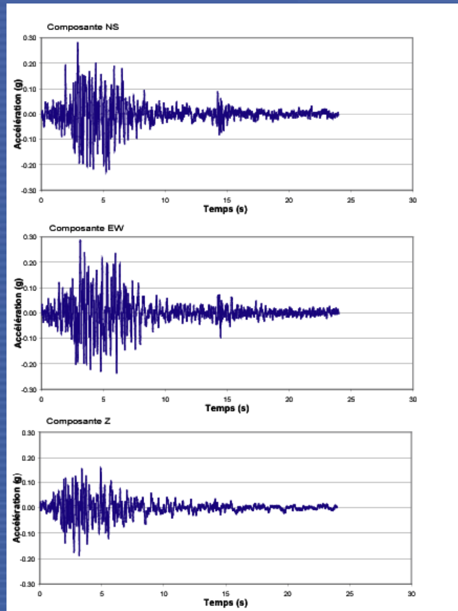
3. PSHA calculation: Seismic hazard curves



4. Uniform response spectra



5. Definition of time histories



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6. Deterministic seismic hazard assessment

a) The main steps of a DSHA are:

1) Evaluation of a seismotectonic model
2) For each seismic source, evaluation of Mmax.
3) Selection of attenuation relationships.
4) Performing the hazard calculation:
    1) For each seismic zone, Mmax is assumed to occur at the point of the structure closest to the site area.
    2) For zones adjoining the site, Mmax is supposed to occur at the closest point of the boundary.
    3) For the zone where NPP is situated, Mmax is supposed to be in the capable seismotectonic sources (in the most penalizing point).
5) Several attenuation relationships should be used.
6) Aleatory and epistemic uncertainties should be taken into account
7) Site response should be incorporated

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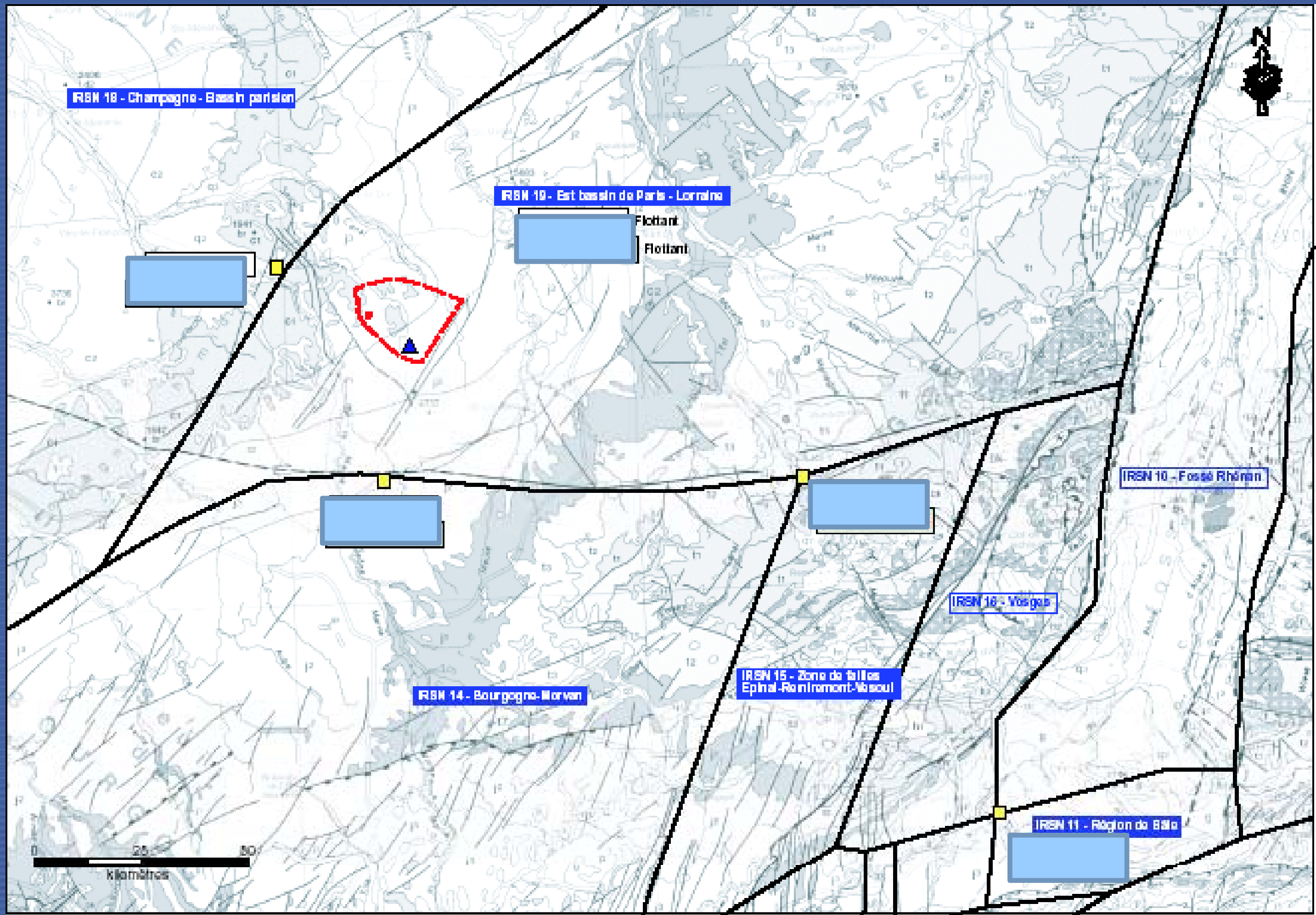
Deterministic model: treatment of boundary seismic sources



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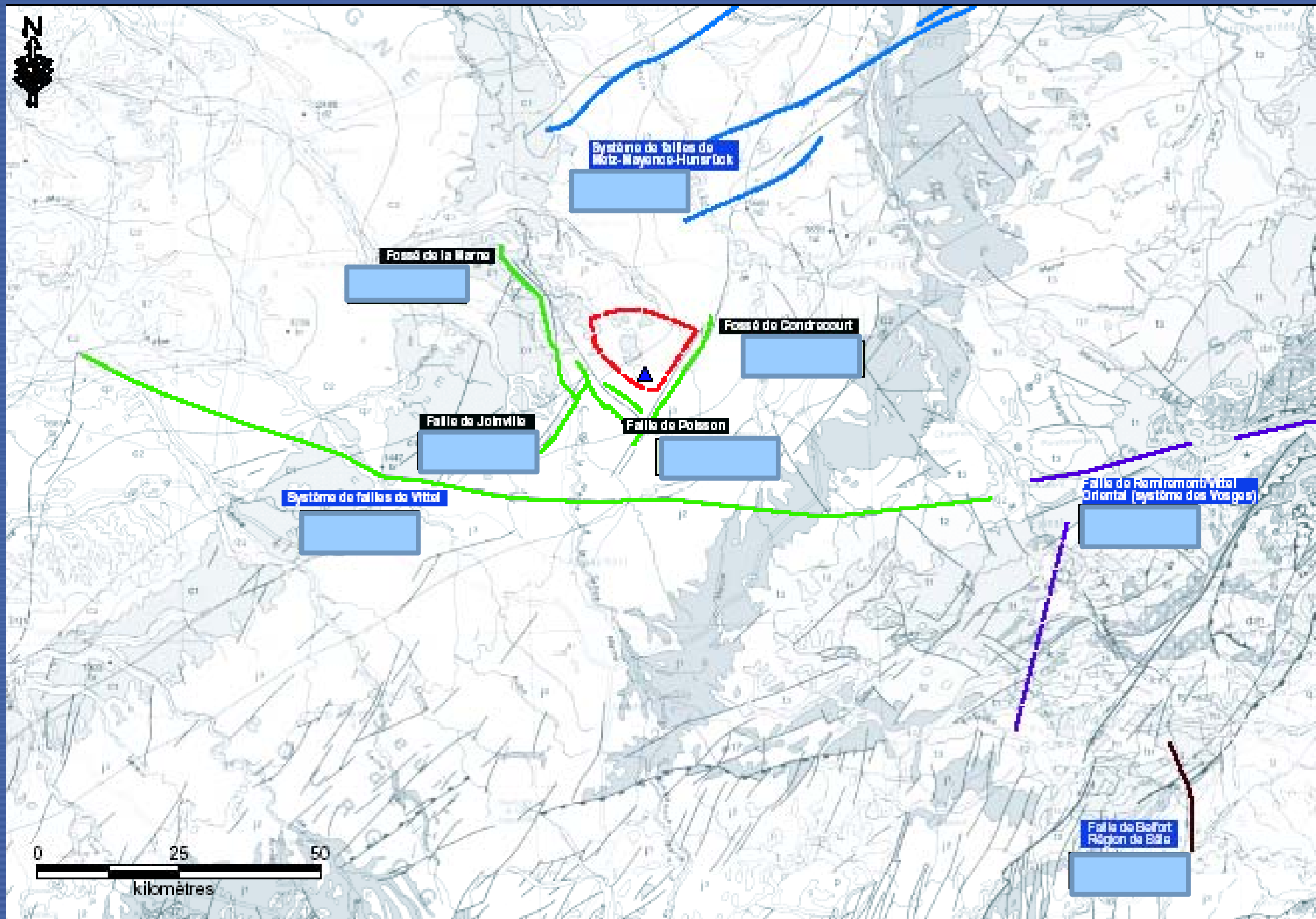
Deterministic model: treatment of site seismic source



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7. Potential for fault displacement at the site

a) Determination of **capability of the faults** based in the geological, geophysical, geotechnical and seismological database.

b) A **fault is capable** if:

   a) Evidence of past movements

   b) Structural relationship with known capable faults able to produce movement at or near the surface

   c) Maximum magnitude is sufficiently large to produce movement at or near the surface.

c) **Sufficient investigations should be made** to show the absence. If faults are known or suspected → trenching, borehole, geodesy, geophysics, etc.

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7. Potential for fault displacement at the site

d) Capable fault for new sites ➡ exclusion criterion.

e) Capable faults for existing sites:

1. Acquisition new data.
2. Deterministic approaches may give information about capability.
3. If deterministic approaches are not enough, a probabilistic approach to know the exceedance rate of some level of displacement should be done
4. The probabilistic fault displacement should be done using the same criteria used in PSHA ➡ fault displacement hazard curves.

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7. Potential for fault displacement at the site

Probabilistic approach :

P(Dsite>dmax)=

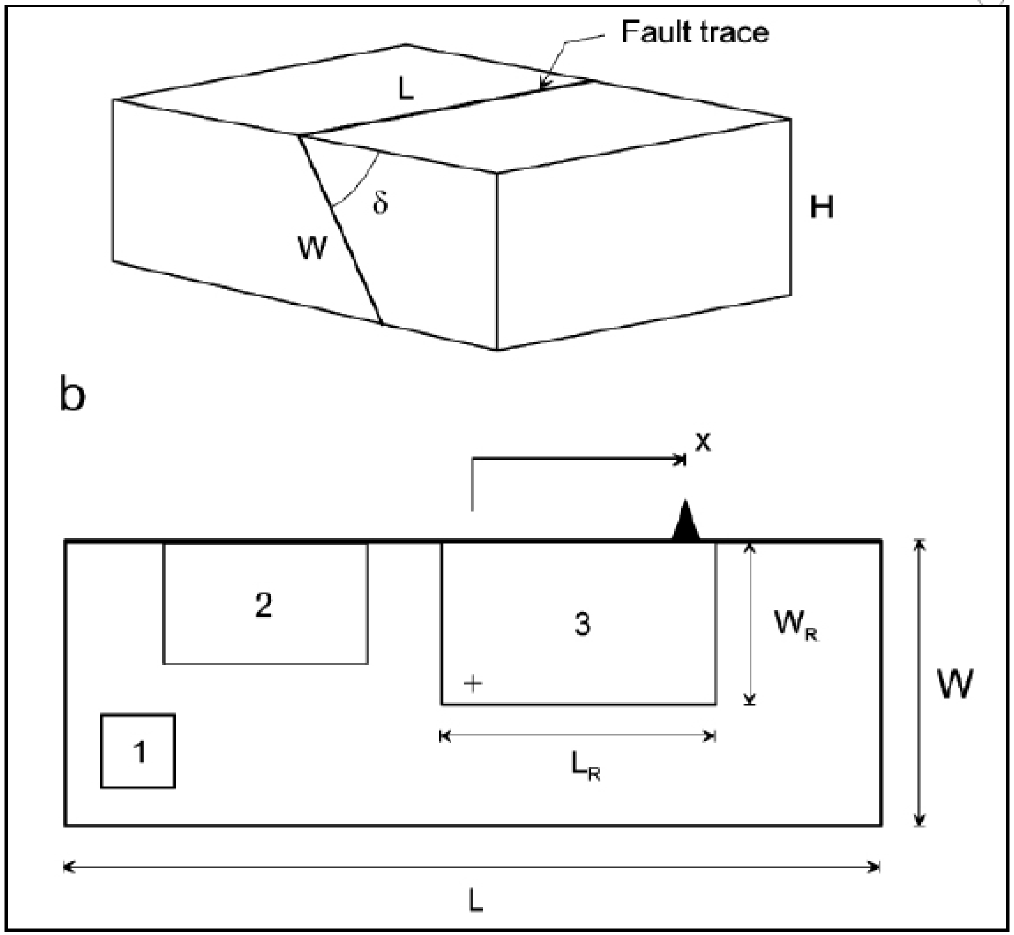
P(occurrence earthquake M=M')

P(rupture in surface)

P(rupture in the site)

P(D>dmax/ if M occurs)

$$\nu(Dsite > d\max) = \sum_{Mi=0}^{Mi=n} P(rupture) * P(site) * \frac{d\lambda(Mi)}{dM} * P(D > d\max / si \quad M \quad produit) \qquad (1)$$



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8. DESIGN BASIS GROUND MOTION

- **a) Levels of ground motion**: SL-2 (most stringent safety requirements) and SL-1 (less severe).
- b) SL-1 and SL-2 should be defined by means of **response spectra** and **time histories**.
- c) Ground motion should be calculated for **free field conditions** (ground motion in bedrock conditions + transfer function to take into account the soil layers).
- **d) Response spectra** could be calculated by:
  - a) Using appropriate attenuation relationships taking into account the site conditions.
  - b) Conducting a site response analysis

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8. DESIGN BASIS GROUND MOTION

e) The **response spectra** could be found using:

   a) The PSHA results → **Uniform Spectra**

   b) Standardized spectra (Peak ground Acceleration + spectral shape taking into account several sources)

f) The **selected time histories** should take into account:

   a) The dominant magnitude-distance couples.

   b) Duration of the time histories

   c) Spectral shape of response spectra.

g) **Methods of developing design time histories**:

   a) Appropriate selected and scaled recorded time histories.

   b) Spectral matching methods (RSPMATCH, WES RASCAL)

   c) Artificial time histories (SIMQKE).

   d) Simulated time histories based on numerical modelling.

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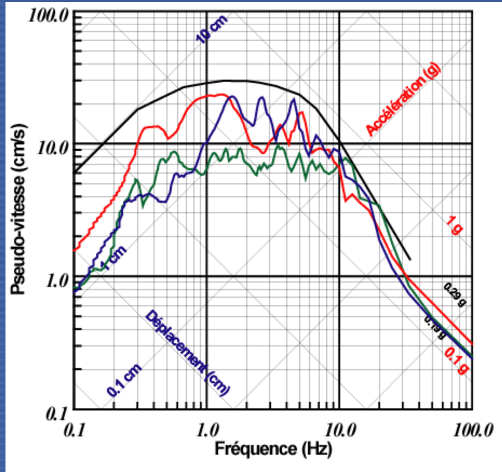
8. DESIGN BASIS GROUND MOTION

h) Vertical ground motion should be defined using the same process used with the horizontal components. If vertical attenuation relationships are not available a ratio could be used (0.5 to 1, typically 2/3).

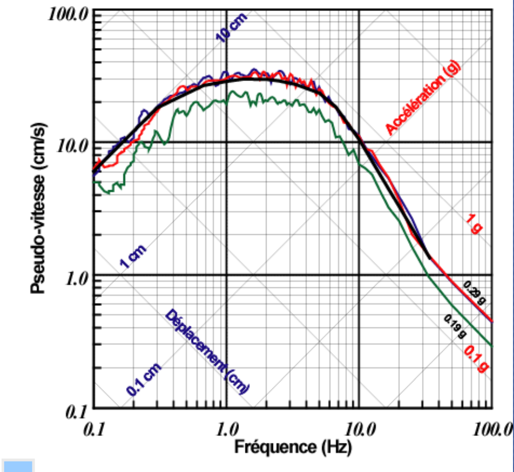
i) Finally, if some isolation system exist, additional consideration may be necessary.

Developing of time histories: example

Original spectra



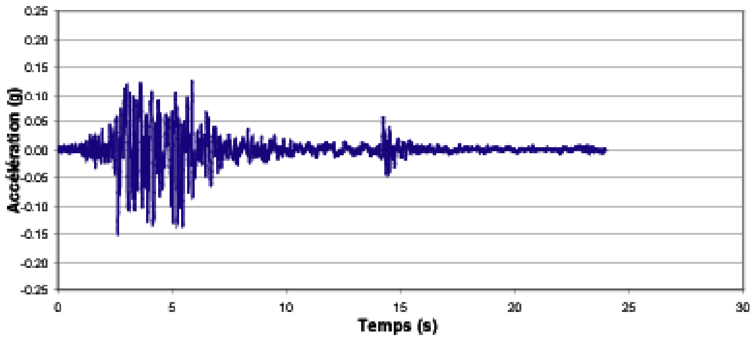
Espectros originales



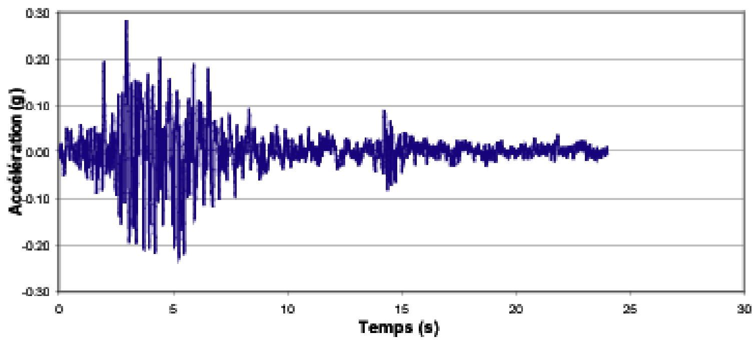
Espetros después de ajuste espectral

Fitted spectra

Original accelerogram



Fitted accelerogram (spectral matching)



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9. Project Management

- A **Project Plan** should be prepared prior to the seismic hazard assessment
- A **management system** program should be established
- Input data and output data should be specified.
- The **traceability and transparency** of the information should be clear.
- Input and output data should be **accessible, usable and auditable**.
- The **computer codes** should be identified.
- An independent **Peer Review** should be conducted. Participatory Peer Review reduces the probability of rejection of the study.

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Software

- Software to assess the **completeness periods** (normally internal and non commercial codes)
- Software to remove **aftershocks and forechocks** (normally internal and non commercial codes)
- Software to calculate **frequency-magnitude parameters** (commercial or free codes: Kijko code, Weichert code, etc.)
- Software for **PSHA calculations** (commercial or free codes: EZ-Frisk, CRISIS, etc.)
- Software for **DSHA calculations** (normally internal and non commercial codes).
- Software to obtain **time histories** (commercial or free codes: SIMQUAKE, Wes Rascal, Rspmatch, etc.)

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Thank you for your attention

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