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A PROBABILISTIC SEISMIC HAZARD ASSESSMENT USING THE SPECTRAL SOURCE MODEL

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ABSTRACT
To improve the methods for evaluating seismic hazard at regional and local scales, it is necessary to define realistic seismic motions that are adapted to the context of each study. The spectral source model, based on a "k^{-2}" dislocation distribution (Herrero et Bernard, 1994) is particulary well adapted to such applications, allowing to produce broad band realistic accelerograms at any distance from the sources. The main properties of this model are the description of the rupture complexity, and the consideration of the directivity effects. We present here an application of this model in a probabilitic seismic hazard assessment, in the Provence region: we show that taking into account earthquake distribution in space and time laws, we can produce seismic hazard maps associated to specific return period.

KEYWORDS: Ground motion, k^{-2} dislocation, kinematic model, directivity effects , probabilistic application.

Presentation of the spectral source model

The spectral source model called SASSOM (Synthetic Accelerograms from a Spectral Source Model) is a kinematic model in which the fault plane is discretized in many elementary faults. The strong motion is calculated in the far field approximation by summation of all the individual contributions along the isochrone lines. The rupture complexity is described by a particular dislocation distribution characterized in the wavenumber space by a k^{-2} spectral decay and stochastic high wave number phases. Herrero and Bernard (1994) showed that such a dislocation allows to generate realistic accelerograms with ω^0 high frequencies level. Figure 1 presents an example of k^{-2} dislocation, calculated for a magnitude 5.5 event, with a stress drop of 4 MPa.

Realistic broad band accelerograms computation

To compute the strong motion following parameters are needed :
1- The velocity structure (possibility of layered medium)
2- The dimension of the fault, its depth and focal mechanism, and the associated stress drop (or seismic moment)
3- The rupture velocity, the position of the nucleation on the fault, and the type of rupture (circular, Haskell unilateral or bilateral)
4- The maximal desired frequency, which controlls the spatial discretization and the computation time
5- The position of the station (distance and directivity from the source)

The standard model (Herrero, 1994) uses a k^{-2} dislocation distribution. The kinematic of the rupture is described by the rupture velocity and the rise time, which are constant on the whole fault plane. The rise time is very short, i.e. the source time is a quasi Heaviside function. Such a method allows to generate synthetics which have the classical "ω^{-2}" spectral decay, and present a specific directivity effect: for stations in the direction of the rupture propagation the model predicts a C_d^2 amplification of the high frequency spectral level, where C_d is the directivity coefficient defined by,

$$C_d = \frac{1}{1-\frac{c}{V_r}cos(\theta)}$$

(θ is the directivity angle between the station and the rupture propagation, $\frac{c}{V_r}$ is the ratio of S wave velocity and

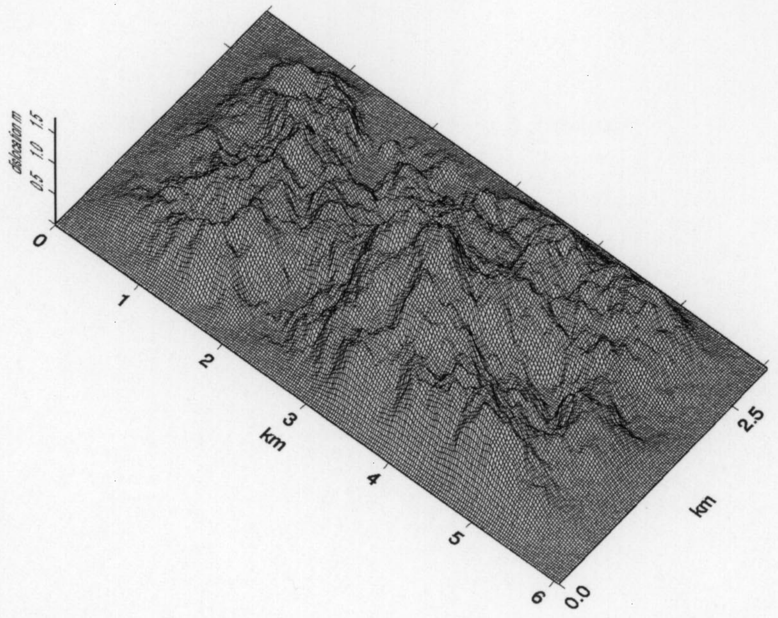


Figure 1: Example of a "k^{-2}" dislocation distribution.

the rupture velocity). As the C_d^2 coefficient may reach values as high as several tens, our amplification which is not observed (typical effects range between 2 and 5), this standard model requires some modifications. We therefore introduce a more realistic rupture process using a propagating pulse with a finite width. This pulse is associated to a wavenumber dependent rise time (Bernard et al., 1995) The maximal rise time is directly linked to the pulse width,

$$\tau_{max} = \frac{pulse\ width}{velocity\ rupture}$$

The strong motion is also computed considering separately the long and the short wavelength contributions. The long wavelength contribution (i.e. greater than the pulse width) has radiations of the standard model convolved with a τ_{max} wide boxcar. The short wavelength contribution is radiations of the standard model which are multiplied by a frequency independent but directivity dependent F function defined as,

$$F = \frac{sin(\pi a C_d)}{\pi a C_d}$$

where a is a constant in the order of 1. The final strong motion is obtained by summation of these two contributions. This theory allows to obtain more realistic high frequencies decay in the accelerograms whatever the situation of station with regard to the rupture propagation direction.

Four tests in Figure 2 present typical signals and spectra in 3 different situations of directivity: the source is a pure left lateral strike slip (vertical plane), the rupture is a unilateral Haskell propagation, initiated from the star to the North. The St.1 station is also the directive station, the St.2 the anti-directive, and St.3 is the non-directive reference. These three stations are situated at 30 km from the surface projection of the fault centroid. The fourth station is non-directive too, but closest to the fault plane. For this test, the source is a 16.4 $km \times$ 8.2 km plane.The rupture velocity $V_r = 0.8V_\beta$, so the directivity coefficient has a value of 5. This figure shows that the non-directive reference is well reproduced. The signal of the directive station is shorter than the non-directive, and its spectrum is affected by a hole (near 0.85 Hz associated to the low frequency rise-time of 1.1785 s. The high frequency level of the spectrum is well corrected by a 0.127 factor ($\frac{sin(\pi/2*5)}{\pi/2*5)}$) with respect to a C_d^2 amplification. The anti-directive signal is longer than the non-directive, and its high frequency level just a little lower. The fourth station (situated at 5 km from the centroid fault) is presented to prove the stability of the computation at distances very closed to the fault.

A probabilistic seismic hazard application with the spectral source model

The region and the earthquake distribution recurrence law

We choose the Moyenne-Durance region in the Occidental Provence, in France to use the spectral source model for a probabilistic hazard study. This region is characterized by a moderate sismicity, although it is one of this most active zone in France. A recent study (Mandroux,1995) etablished a recurrence law for the sismicity in a zone very closed to the main Moyenne-Durance fault. Here we evaluate only the contribution of this main fault in the seismic hazard of the region, whitout consideration of other tectonic structures. A complete study

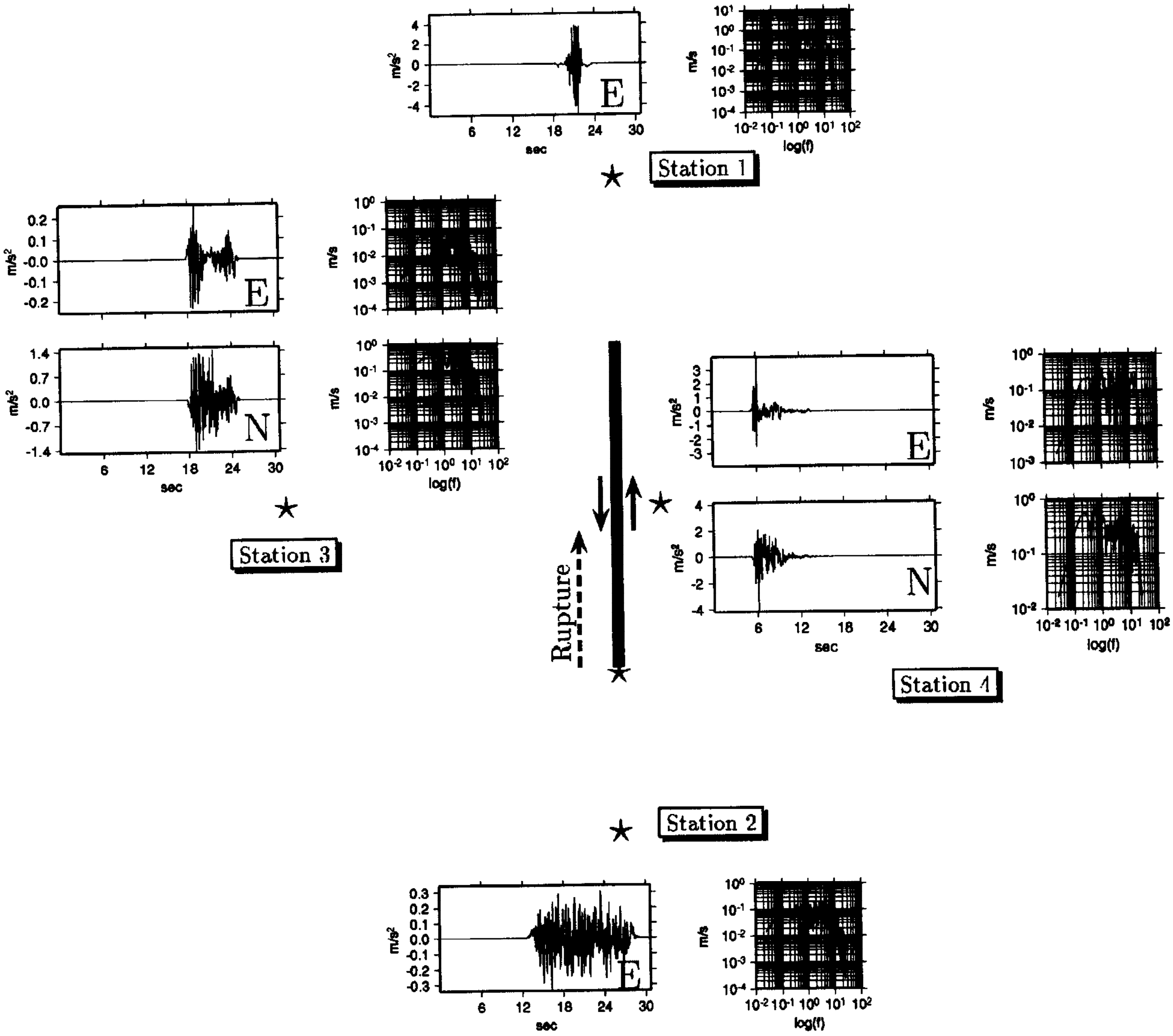
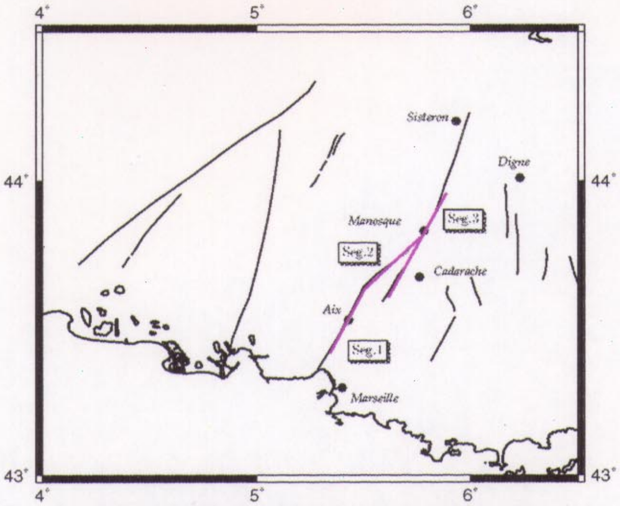


Figure 2: Synthetic accelerograms and spectra for non-directive, directive and anti-directive stations. The real position of the station is represented by the star. The horizontal components of the direct S wave are presented. The time origin is the nucleation time.



Segment	Length (km)	Width (km)	Strike	Dip	Slip
seg1	30.25	9.0	209	80.	0.
seg2	35.50	9.0	229	55.	0.
seg3	49.40	13.0	209	80.	0.

Figure 3: Situation of the Moyenne-Durance fault, the pink lines defined the fault used for the modelling. The fault is composed by three segments, whose parameters are described in the lowest table.

should be enriched by the contribution of neighbouring small faults. The recurrence law is defined for a minimal magnitude M_0 of 3.5,

$$log_{10}\lambda(n) = -0.886 - 1.26(M - M_0).$$

To obtain the presented results we work with a return period of 975 years (or with a 10 percent chance of exceedance in exposure time of 100 years) . We considered only the most active part of the Durance fault. We simplify the geometry considering only 3 rectilinear segments (see Figure 3). Each segment has the same probability to be the place of the event than the others.

Variability of signals and spectra in 4 exposed sites, for different magnitude 6.5 events

We present signals and spectra for Marseille, Digne, Manosque and Cadarache, which are very exposed towns, with respect to their population density, or for nuclear risk. Figure 4 and 5 show the variability of the signals (in wave form, amplitude and duration) and of the associated spectra, for 3 different dislocation distributions, and different nucleation positions on the plane, on each segment. All ruptures are circular, but the starting points differ. Note that the position of the 3 events on a same segment differs too (at the extremities and medium of the main segment). These figures clearly show the importance of the nucleation position : for example, for the second and third events on the first segment, Marseille is first in a directive situation, whereas is in anti-directive situation secondly : Manosque, for these two events is naturally in inverted positions with respect to the directivity.

Mean spectra in 6 exposed sites, for magnitude 4.5 and 6.5

Each presented spectrum is the mean from several stochastic events: for the magnitude 4.5 (Figure 6), one spectrum corresponds to the mean of 25 events on each segment. Events are uniformely distributed over the whole plane. We tested several rupture propagations to take into account the directivity effects. Here each event has a circular rupture propagation, but the position of the nucleation point is stochastic, and different for an event to another. Others tests have been made with unilateral rupture propagation to the North , and to the South. For the magnitude 6.5 (Figure 7), spectra are the meaning of less tests than for 4.5 (3 tests on each segment, that is to say meaning of 9 spectra), because the time computation increases with the source size (for example, for a magnitude 3.5 with a maximal frequency of 25 Hz the spatial discretization is 32×16 subfaults, whereas for the 6.5 magnitude and the same maximal frequency we need 512×256 subfaults). Because for magnitude 4.5 the evaluated sites are far from the sources, the spatial extension of the rupture is not very important, and we would obtain comparable results, with a point source and an adequate complex source time function, which would be much quicke.

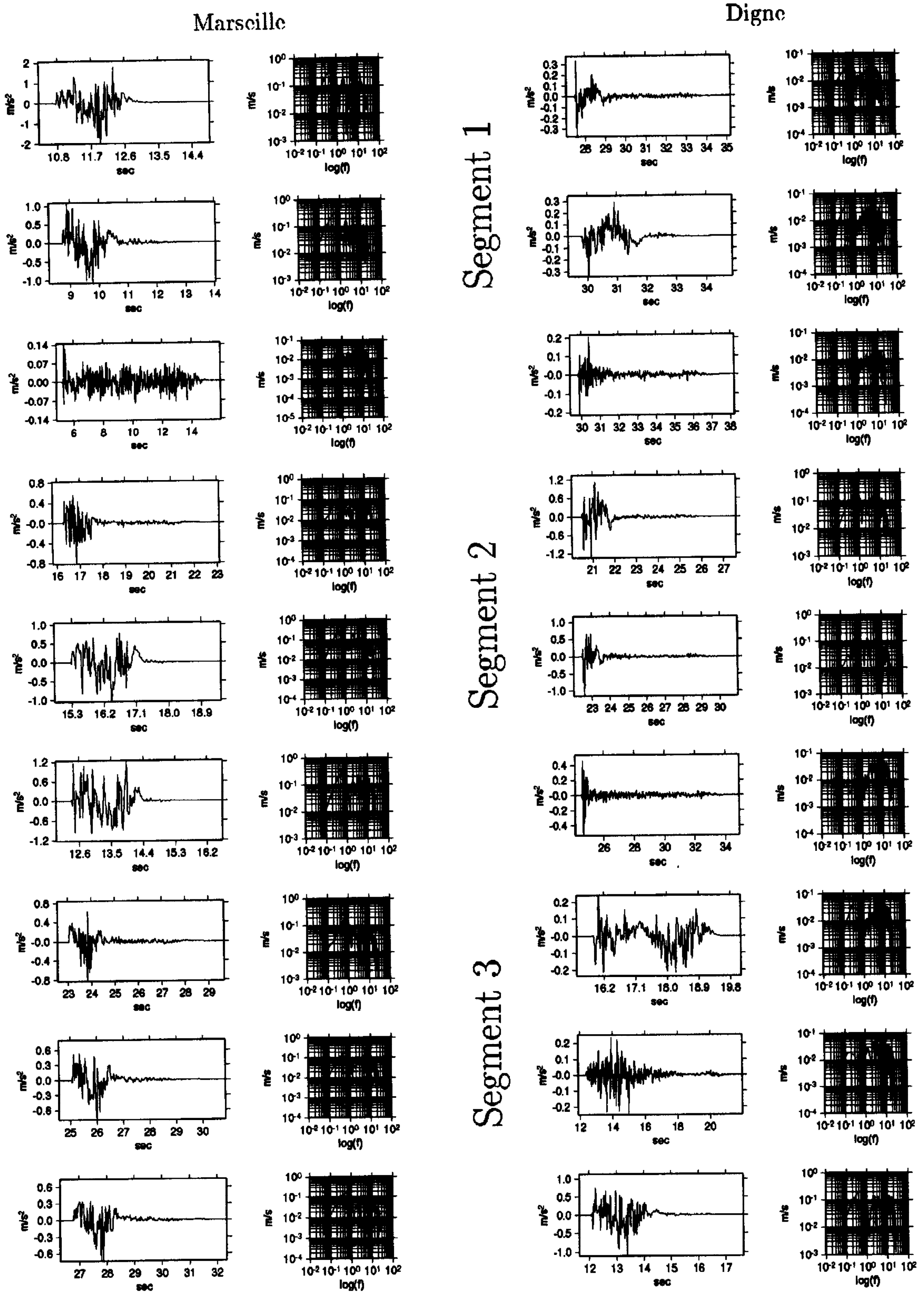


Figure 4: Signals and spectra variations at Marseille and Digne locations, for 3 tests on each segment. The influence of the nucleation position is clearly showed.

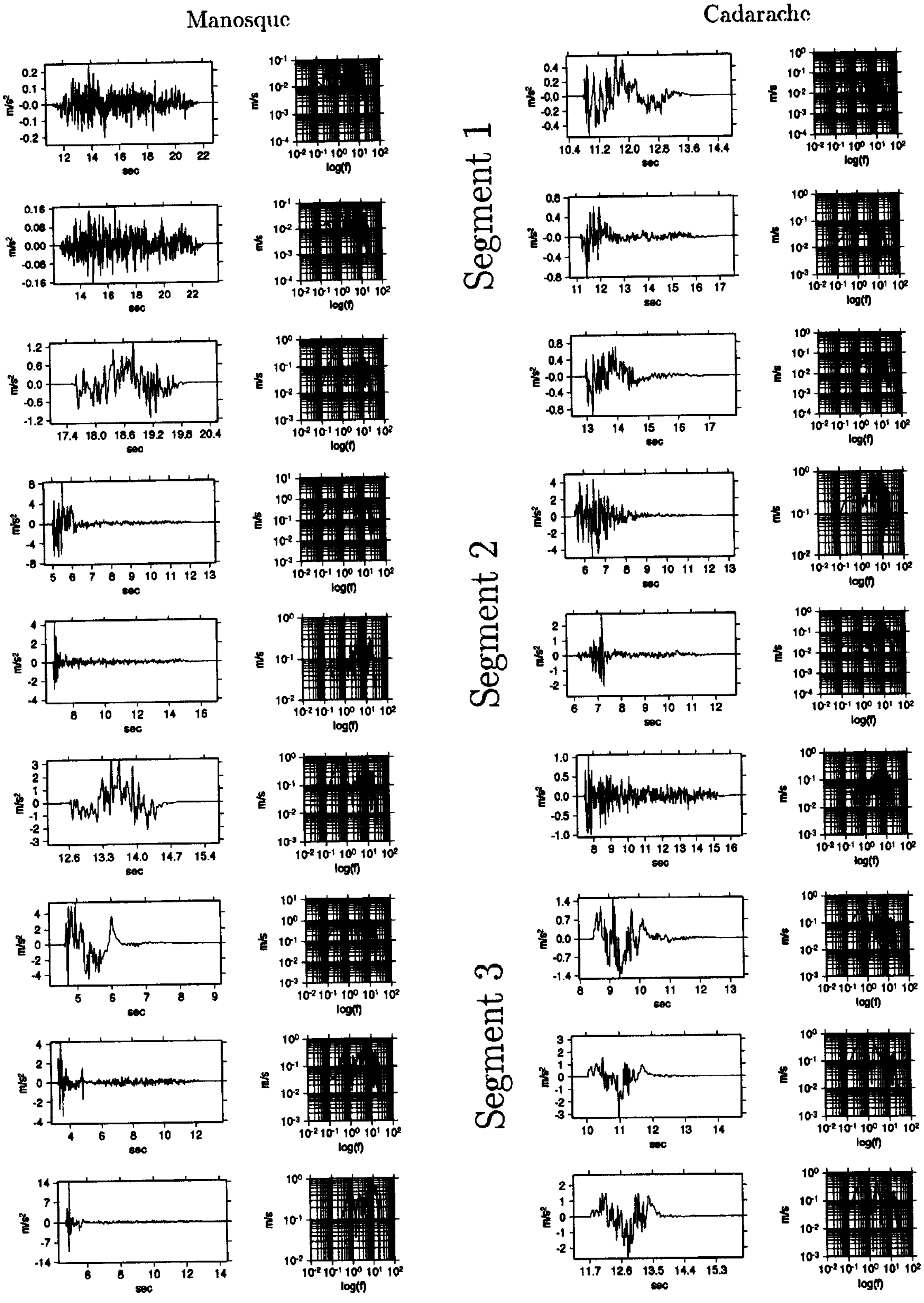


Figure 5: Same comments than for Figure 4, for Manosque and Cadarache

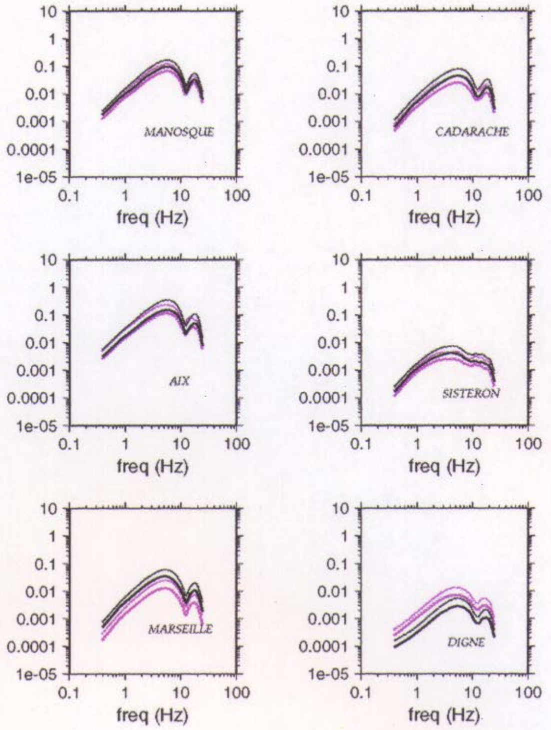


Figure 6: Mean spectra for 6 sites, for magnitude 4.5. Each spectrum is the meaning of 75 spectra. The rupture processes are all circular, with a stochastic nucleation position. Black spectra are East component (continue line), and East + Standard Deviation (black dashed line), Pink spectra are North component (continue line), and North + Standard Deviation (pink dashed line).

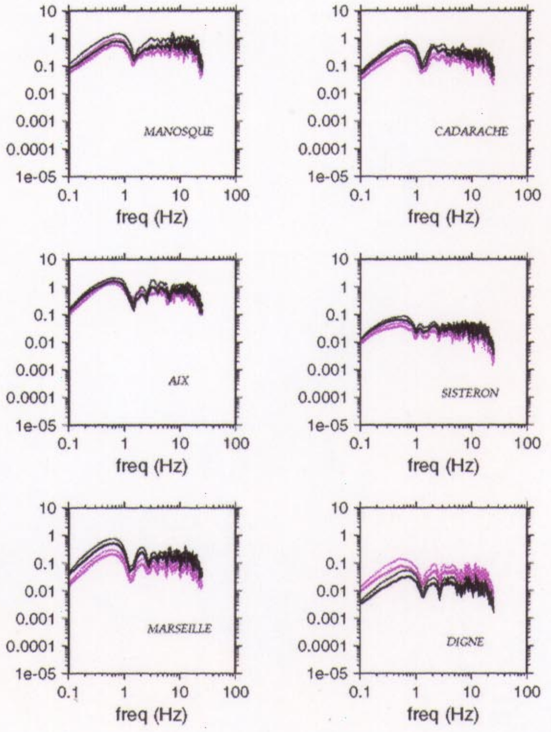


Figure 7: Mean spectra for 6 sites, for magnitude 6.5 events. Each spectrum is the meaning of 9 spectra. Same comments than Figure 5 for ruptures processes and nucleation, and for colors and symbols.

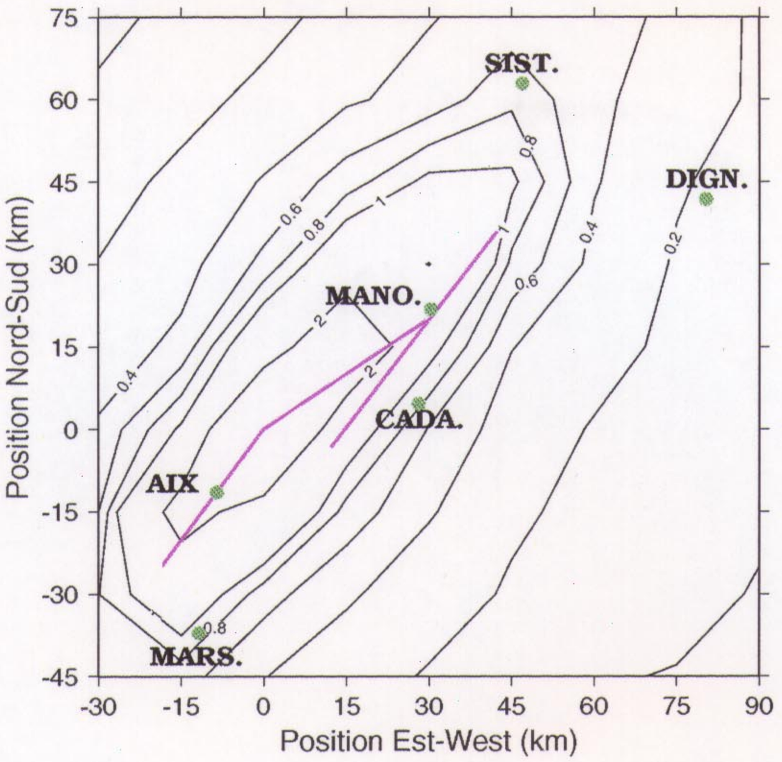


Figure 8: Seismic hazard map for a 975 years return period, that is to say that presented Peak Ground Acceleration (in $m.s^{-2}$) have 10 percent chance to be exceeded in exposure time of 100 years.

Seismic hazard map for a 975 years return period

We computed for 81 stations (discretization 15 $km \times 15$ km) from magnitude 3.5 to 6.5 with .5 magnitude step, several events of same size (number of these events is magnitude dependant for time consuming). We considered first all ruptures processes circular, with a stochastic nucleation position , second ruptures which are directive to the North, and third, directive to the South. The presented map (Figure 8) is the Peak Ground Acceleration value which has 10 percent chance to be exceeded in exposure time of 100 years. This map takes also into account all possible directivity effects at each station, explaining the symetry of the iso-peak acceleration contours.

Conclusions

The kinematic spectral source associated with the "k^{-2}" dislocation appears to be a good tool for probabilistic seismic hazard assessment, as the resulting synthetic accelerograms and spectra contain the complexity of the rupture in a very large frequency range. A strong advantage and clear originality of the model is that it is suitable for sites very close to the fault and properly models the directivity effects. These properties allow to generate reliable probabilistic signals, which can be used to propose response spectra, and seismic hazard maps.

References

Bernard, P.,A. Herrero and C. Berge, Modeling Directivity of Heterogeneous Earthquake Ruptures, Submitted to *Bull. Seism. Soc. Am.*.

Herrero, A., and P. Bernard, A kinematic self-similar rupture process for Earthq uakes, *Bull. Seism. Soc. Am*, 84, pp 1216-1228, 1994.

Mandroux, F., Evaluation probabiliste de l'alea sismique du Sud-Est de la France, *Rapport de stage ingénieur, BRGM, 1995*