CRISIS 2008 USER'S MANUAL

1. Introduction

1.1 Brief description

CRISIS gives a friendly environment to calculate seismic hazard. The program computes seismic hazard using a probabilistic model that considers the earthquake occurrence probabilities, attenuation characteristics and geographical distribution of earthquakes. A friendly graphical interface facilitates data input.

Hazard results are given, for each computation site, in terms of probabilities of exceeding a given intensity value in different time frames. Details on the hazard computation algorithm can be found following the link.

Some of the main features of CRISIS are:

1.1.1. Earthquake occurrence

Earthquake occurrence can be modeled either as a Poissonian process or as a non-Poisson process. For the Poissonian case, CRISIS admits two type of magnitude-frequency relations: modified Gutenberg-Richter law, and Characteristic Earthquake. For Non-Poissonian occurrences, CRISIS can work with a generalized model with which earthquake occurrence probabilities are explicitly given for various time frames.

1.1.2. Source geometry

Regarding their spatial distribution, sources can be modeled as areas, lines and points, as in the older CRISIS versions, although the new point sources permit new modeling options.

1.1.3. Attenuation models

Attenuation models (also called Ground Motion Prediction Models, or GMPM) relate, in probabilistic terms, the earthquake characteristics (*e.g.*, magnitude, hypocentral location) and the site location relative to the source, with the intensities produced at the site by the earthquake.

CRISIS admits three families of GMPM: Attenuation tables furnished by the user, built-in parametric models, and generalized attenuation models. These possibilities give CRISIS great flexibility to perform the hazard computations.

1.1.4. Spatial integration procedure

CRISIS operates with a dynamic integration procedure which allows fast computation of hazard in extended areas.

1.2 About CRISIS

CRISIS has been mainly developed at Instituto de Ingeniería, UNAM, Mexico. It has been developed by:

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2. General Overview

2.1 Basic theoretical background

The purpose of this section is not to describe in detail the techniques to compute seismic hazard. However, we will rapidly describe some of their main aspects.

Starting with CRISIS 2008, the code does not work anymore with intensity exceedance rates as measures of seismic hazard. The more recent versions give seismic hazard in terms of probabilities of exceedance of intensity values in given time frames. For instance, a valid measure of seismic hazard in the newer versions is the probability of experiencing peak ground acceleration greater or equal than 0.2 g in the next 50 years at a given location.

This change was made in order to allow users to introduce in the computations probabilities of earthquake occurrences derived from non-Poissonian models. Poissonian computations, however, are still possible since one can regard this case as a particular case of the non-Poisson computations. We will se later how to compute the probabilities now required by CRISIS from conventional Poissonian models.

In order to compute seismic hazard, the territory under study is first divided into seismic sources according to geotectonic considerations; in most cases, it is assumed that, within a seismic source, an independent earthquake-occurrence process is taking place. For each seismic source, earthquake occurrence probabilities are estimated by means of statistical analysis of earthquake catalogs.

In the more general case, earthquake occurrence probabilities must stipulate the probability of having s events (s=0, 1, …, Ns) of magnitude M_i in the following T_j years at a given source k. We will denote these probabilities as $P_k(s,M_i,T_j)$; they completely characterize the seismicity of source k.

Seismic hazard produced by an earthquake of magnitude M_i at a single point source, say the k-th, and for the next T_j years, can be computed as:

$$\Pr(A \geq a \mid M_i, T_j, k) = 1 - \sum_{s=0}^{Ns} P_k(s, M_i, T_j)\left[1 - \Pr(A \geq a \mid M_i, R_k)\right]^s \quad (1)$$

where $\Pr(A \geq a \mid M_i, R_k)$ is the probability that intensity a is exceeded given that an earthquake of magnitude M_i took place at source k, that is separated from the site of interest by a distance R_k. Please note that this probability depends only on magnitude and source-to-site distance, and it is normally computed giving a probabilistic interpretation to intensities predicted by ground motion prediction models or attenuation relations. We also note that implicit in equation 1 is the assumption that exceedances of intensity values at source k given that an earthquake of magnitude M_i occurred are independent from each other. This is the reason why the non-exceedance probability of a given that s events of magnitude M_i took place at source k can be computed as $[1 - \Pr(A \geq a \mid M_i, R_k)]^s$.

Seismic hazard contained in equation 1 is more easily expressed in terms of non-exceedance probabilities:

$$\Pr(A \le a \mid M_i, T_j, k) = \sum_{s=0}^{Ns} P_k(s, M_i, T_j)\left[\Pr(A \le a \mid M_i, R_k)\right]^s \tag{2}$$

Equation 2 gives the non-exceedance probability of intensity value *a* given that only earthquakes of magnitude M_i took place. The non-exceedance probability of *a* associated to the occurrence of earthquakes of all magnitudes at source *k* in the next T_j years can be computed as:

$$\Pr(A \le a \mid T_j, k) = \prod_{i=1}^{Nm} \Pr(A \le a \mid M_i, T_j, k) \tag{3}$$

where *Nm* is the number of magnitude bins into which the earthquake occurrence process has been discretized. Again, we have used the independence hypothesis among earthquakes of all magnitudes.

But seismic sources are usually points, lines, areas or volumes, so a spatial integration process must be carried out to account for all possible focal locations. We will assume that the spatial integration process leads to *N* sources. So finally, assuming that earthquake occurrences at different sources are independent from each other, we obtain that the non-exceedance probability of intensity *a* in the next T_j years due to earthquakes of all magnitudes located at all sources, can be computed with

$$\Pr(A \le a \mid T_j) = \prod_{k=1}^{N} \Pr(A \le a \mid T_j, k) \tag{4}$$

$$\Pr(A \le a \mid T_j) = \prod_{k=1}^{N} \prod_{i=1}^{Nm} \Pr(A \le a \mid M_i, T_j, k) \tag{5}$$

$$\Pr(A \le a \mid T_j) = \prod_{k=1}^{N} \prod_{i=1}^{Nm} \sum_{s=0}^{Ns} P_k(s, M_i, T_j)\left[\Pr(A \le a \mid M_i, R_k)\right]^s \tag{6}$$

Finally,

$$\Pr(A > a \mid T_j) = 1 - \prod_{k=1}^{N} \prod_{i=1}^{Nm} \sum_{s=0}^{Ns} P_k(s, M_i, T_j)\left[\Pr(A \le a \mid M_i, R_k)\right]^s \tag{7}$$

Equation 7 is the one used by CRISIS to compute seismic hazard for situations in which the sources are spatially distributed (k=1,…,N), there are earthquakes of various magnitudes (M_i, i=1,…Nm) and the earthquake occurrence probabilities in known time frames T_j at source *k* are given by $P_k(s,M_i,T_j)$, that is, the probability of having *s* events of magnitude M_i in the next T_j years at source *k*.

The equations presented here are, in general, applicable to non-Poisson occurrence process. But they are also applicable to the Poisson process. Let us see what results we obtain if we assume that the occurrence process is Poissonian.

Let us assume that at all sources a Poisson occurrence process is taking place for earthquakes of all magnitudes. Under this assumption, $P_k(s,M_i,T_j)$ takes the form of, precisely, a Poisson probability distribution:

$$P_k(s,M_i,T_j) = \frac{\left[\Delta\lambda_k(M_i)T_j\right]^s \exp\left[-\Delta\lambda_k(M_i)T_j\right]}{s!} \quad , \mathrm{s} \geq 0 \qquad (8)$$

where D1$_k(M_i)$ is the number of earthquakes of magnitude M_i that, per unit time, take place at source k. In other words, this quantity is the conventional exceedance rate of earthquakes in the range of magnitudes represented by M_i, that is,

$$\Delta\lambda_k(M_i) = \lambda_k(M_i - \Delta M/2) - \lambda_k(M_i + \Delta M/2) \qquad (9)$$

Replacing equation 8 in equation 2 we obtain:

$$\Pr(A \leq a \mid M_i, T_j, k) = \sum_{s=0}^{\infty} \frac{\left[\Delta\lambda_k(M_i)T_j\right]^s \exp\left[-\Delta\lambda_k(M_i)T_j\right]}{s!} \left[\Pr(A \leq a \mid M_i, R_k)\right]^s \qquad (10)$$

Note that now the sum extends to infinity since, in the Poisson process, the possible range of values of s is 0 to infinity. The sum in equation 10 has analytical solution:

$$\Pr(A \leq a \mid M_i, T_j, k) = \exp\left\{-\Delta\lambda_k(M_i)T_j\left[1 - \Pr(A \leq a \mid M_i, R_k)\right]\right\} \qquad (11)$$

$$\Pr(A \leq a \mid M_i, T_j, k) = \exp\left\{-\Delta\lambda_k(M_i)T_j \Pr(A \geq a \mid M_i, R_k)\right\} \qquad (12)$$

Hence, from equation 7 we get that

$$\Pr(A > a \mid T_j) = 1 - \prod_{k=1}^{N} \prod_{i=1}^{Nm} \exp\left\{-\Delta\lambda_k(M_i)T_j \Pr(A \geq a \mid M_i, R_k)\right\} \qquad (13)$$

$$\Pr(A > a \mid T_j) = 1 - \exp\left\{-\sum_{k=1}^{N} \sum_{i=1}^{Nm} \Delta\lambda_k(M_i)T_j \Pr(A \geq a \mid M_i, R_k)\right\} \qquad (14)$$

But, under the Poisson assumption for the earthquake occurrences, the process of intensity exceedances is also a Poisson process, for which the exceedance probability of intensity *a* during the next T_j years would be given by:

$$\Pr(A > a \mid T_j) = 1 - \exp\{-\nu(a)T_j\} \tag{15}$$

where n(*a*) is the exceedance rate of intensity *a*. Comparing equations 14 and 15 we obtain that

$$\nu(a) = \sum_{k=1}^{N} \sum_{i=1}^{Nm} \Delta\lambda_k(M_i) \Pr(A \geq a \mid M_i, R_k) \tag{16}$$

Note that n(*a*), the well-known Poissonian intensity exceedance rate, does not depend anymore on T_j. In the limit, the inner sum of equation 16 can readily be recognized as the integral with respect to magnitude that is present in the conventional Esteva-Cornell approach to compute Poissonian seismic hazard. The outer sum in equation 16 is simply the aggregation of intensity exceedance rates due to all sources. In other words,

$$\nu(a) = \sum_{k=1}^{N} \sum_{i=1}^{Nm} \frac{\Delta\lambda_k(M_i)}{\Delta M} \Pr(A \geq a \mid M_i, R_k) \Delta M \tag{17}$$

$$\nu(a) = \sum_{k=1}^{N} \int_M -\frac{d\lambda_k(M)}{dM} \Pr(A \geq a \mid M, R_k) dM \tag{18}$$

Note that, due to the definition we used for Dl$_k$(M_i) in equation 9, its sign changed when we converted it to its differential form. We have then shown that equation 7, derived for the general non-Poissonian case, is also valid for the Poissonian case, leading to the well-known Esteva-Cornell expression to compute seismic hazard.

2.2 Spatial integration procedure

CRISIS assumes that, within a source, seismicity is evenly distributed by unit area (area sources) or by unit length (line sources). For point sources, of course, all seismicity is assumed to be concentrated at the points.

In order to correctly account for this modeling assumption, CRISIS performs a spatial integration by subdividing the original sources. Once subdivided into sub-sources, CRISIS assigns to a single point all the seismicity associated to a sub-source, and then the spatial integration adopts a summation form.

The subdivision procedure will be briefly described in the following paragraphs.

2.2.1. Area sources

These sources are originally given by the user as 3D polygons; the user gives the coordinates (longitude, latitude and depth) of the N vertex defining the area source.

First, the area source is subdivided into N-2 triangles. These triangles will be further subdivided until one of the following two conditions are met:

1) The size of the triangle is smaller than the value “Minimum triangle size” given by the user. That is, the triangle is subdivided if it is still big.

2) The ratio between the site-to-source distance and the triangle size is larger than the value “Minimum Distance/Triangle Size ratio” given by the user. In other words, the triangle is subdivided if the site is still not far enough.

The sub-sub divisions are performed by means of a recursive function.

The site-to-source distance is measured from the computation site to the centroid of the triangle whose possible subdivision is being examined. The size of the triangle is simply the square root of its area. The seismicity associated to each centroid is proportional to the triangle’s area.

If CRISIS decides that a triangle has to be subdivided, this is done dividing the triangle into four new ones, whose vertexes are the mid-points of the three sides of the original triangle.

CRISIS uses the following as default parameters: Minimum triangle size = 11 Km; Minimum Distance/Triangle Size ratio = 3. The following graph shows the resulting subdivision of a squared source of size 1°x1° when the computation site is located at the center of the source, using the default integration parameters.

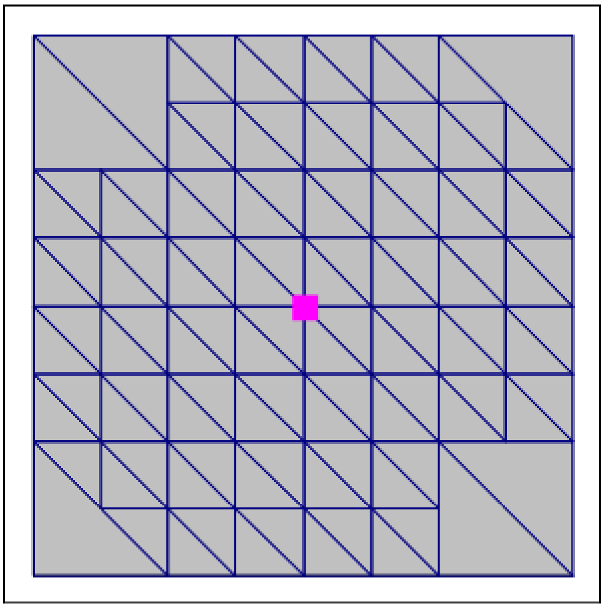


Figura 2.1. Source subdivision with Minimum triangle size = 11 Km, Minimum Distance/Triangle Size ratio = 3

Figure 2 shows the same subdivision but with Minimum triangle size = 5 Km, Minimum Distance/Triangle Size ratio = 3. Note how this subdivision yields smaller triangles in the neighborhood of the computation site.

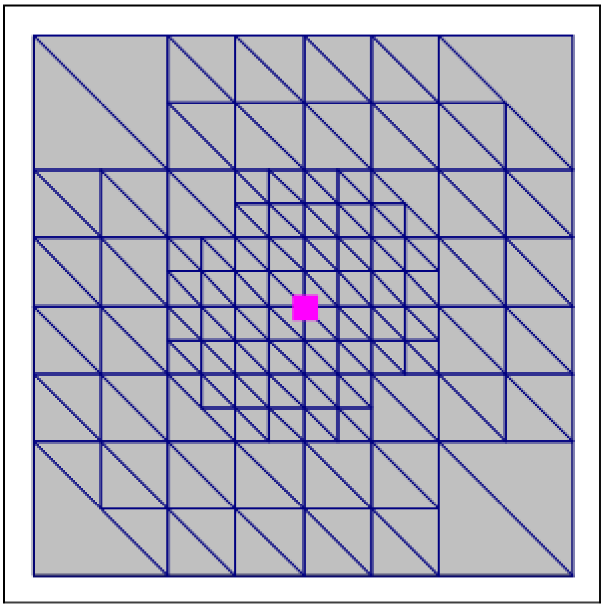


Figura 2.2. Source subdivision with Minimum triangle size = 5 Km, Minimum Distance/Triangle Size ratio = 3

Figure 3 shows the same case but with Minimum triangle size = 5 Km, Minimum Distance/Triangle Size ratio = 4. Note that the smaller triangles cover now a wider area around the computation site.

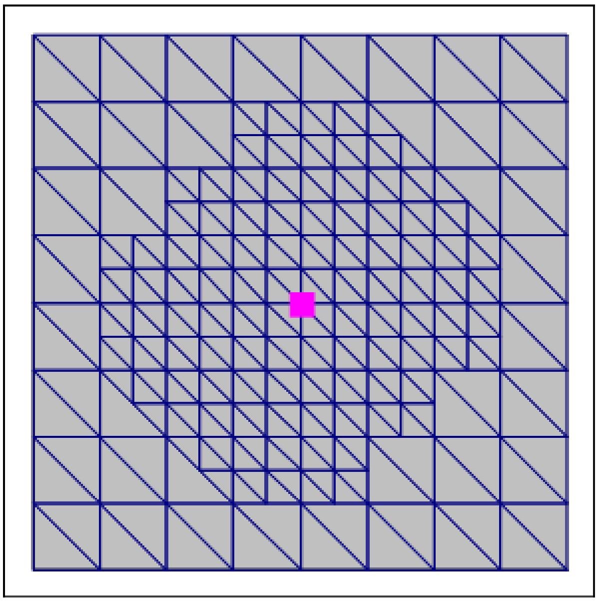


Figura 2.3. Source subdivision with Minimum triangle size = 5 Km, Minimum Distance/Triangle Size ratio = 4

Finally, Figure 4 shows the resulting subdivision with Minimum triangle size =0.5 Km and Minimum Distance/Triangle Size ratio = 4. Note how the density of triangles varies radially as we get away from the computation site.

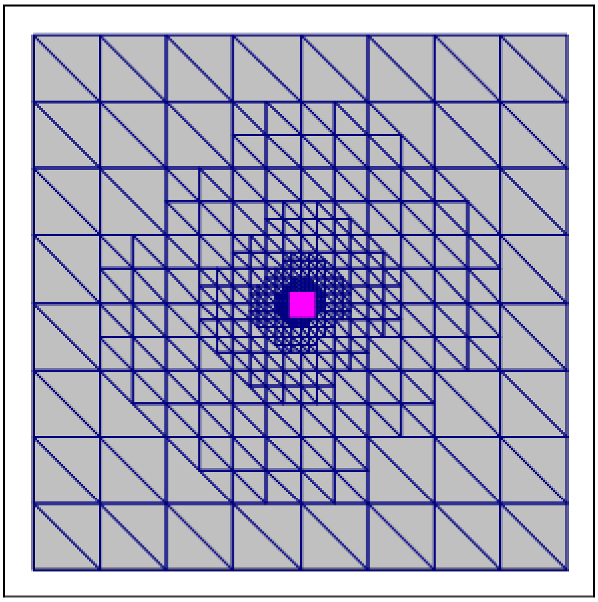


Figura 2.4. Source subdivision with Minimum triangle size =0.5 Km, Minimum Distance/Triangle Size ratio = 4

2.2.2. Line sources

In this case, the subdivision is performed by bi-partition of a fault source segment, again until one of the following criteria are met:

1) The size of the line is smaller than the value “Minimum triangle size” given by the user.

2) The ratio between the site-to-source distance and the line size is larger than the value “Minimum Distance/Triangle Size ratio” given by the user.

The site-to-source distance is measured from the computation site to the midpoint of the line whose possible subdivision is being examined. The size of the line is simply its length. The seismicity associated to each centroid is proportional to the line’s length.

3. Source geometry

In general, sources are the portions of the Earth in which it is possible that earthquakes take place.

CRISIS accepts source geometries of the following three types:

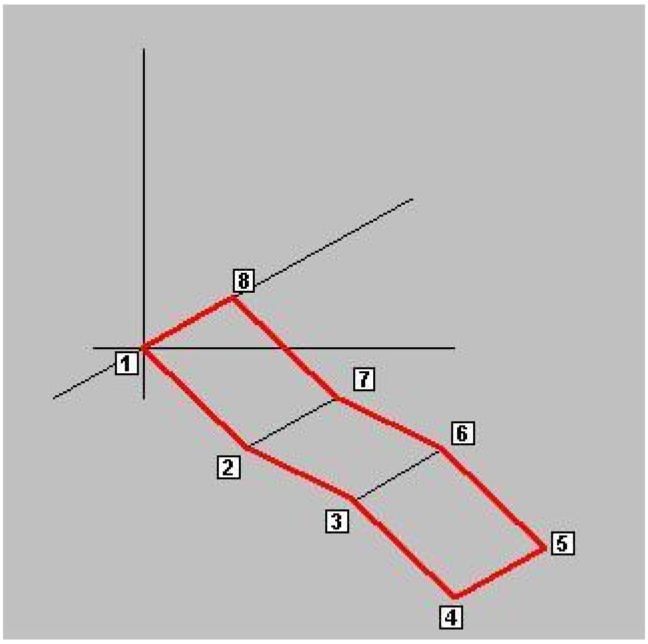
1) Areas (polygons)

2) Faults (polylines)

3) Points

3.1 Area source

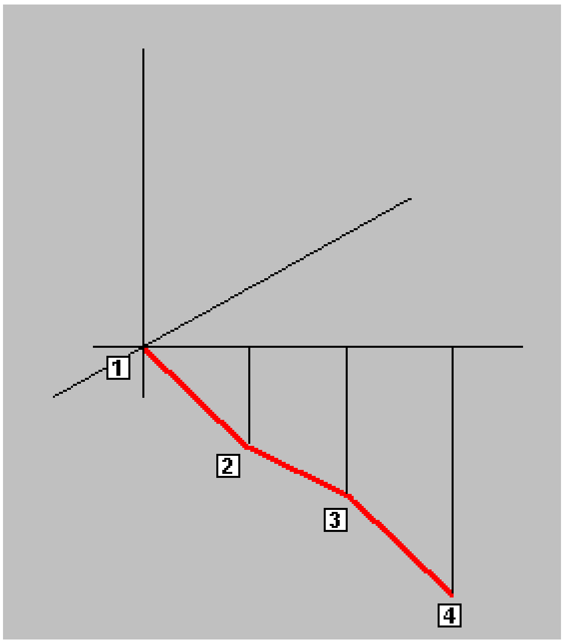
This option defines the active source as an area source. In general, area sources are polygons defined by the 3D coordinates of their vertex. In the example below we have a 3D polygon with 8 vertexes simulating a dipping plate with varying dip angle. Vertical planes are allowed.



In the case of area sources, in order to perform the spatial integration, CRISIS will divide the polygon into triangles. It first checks if triangulation can be made in the XY plane. Numbering of the vertex of the polygon must be done counter-clockwise in this plane when looked from above the surface of the Earth. If there are vertical planes, CRISIS will try to triangulate the area in the XZ plane, so numbering of vertex must be done counterclockwise in this plane. Finally, CRISIS will try to triangulate in the YZ plane. There are some bizarre source geometries that cannot be well resolved by CRISIS; for instance, an L-shaped vertical plane. In these cases, an error will be reported.

3.2 Line source

This option defines the active source as a fault (line) source. Line sources are, in general, polylines defined by the 3D coordinates of their vertexes. The example below shows a fault source of 4 vertexes, located in the XZ plane with varying depth.



3.3 Point sources

This option defines the active source as a collection of point sources, in which each vertex will be a point source.

Each point is a potential earthquake hypocenter, and is defined, in the newer versions of CRISIS, in terms of the following parameters:

1) Longitude, latitude and depth (in Km) of the point.

2) A unit vector normal to the rupture plane associated to each point source. This unit vector is relevant only when the ground motion prediction model associated to this source uses distance measures for which the rupture area is relevant (that is, R_{RUP} or R_{JB}; see the definition of source-to-site distances in this link).

Since point sources are generally used to geometrically describe potentially thousands of hypocentral locations, information about this type of source is given to CRISIS by means of an ASCII file, usually with extension *ssg*, with the following structure:

Point geometry file		
Description	**Variable**	**Type**
ID Header	Header	String
Number of point sources	TotSrc	Integer
Geometry record for source 1	Geom(1)	Geometry record
Geometry record for source 2	Geom(2)	Geometry record

Point geometry file		
Description	**Variable**	**Type**
…	…	…
Geometry record for source TotSrc	Geom(TotSrc)	Geometry record

The following table describes the structure of a geometry record:

Geometry record		
Description	**Variable**	**Comments**
Hypocentral location	h.X	in degrees
	h.Y	in degrees
	h.Z	in Km, always positive
Unit vector describing the orientation of the fault plane	e1.x	These three values describe a unit vector normal to the fault plane. X is longitude, Y is latitude and Z is depth
	e1.y	
	e1.z	

The following table gives and example of a point-source geometry file, where 16 point sources are geometrically described:

Line in file	Comment
Griglia Marzocchi	Header line for identification purposes
16	16 points are described
5.550 44.950 11 0 0 0	These lines give the longitude, latitude and depth (11 Km in this case, always positive) for the 16 sources. Note that the coordinates of the unit vector normal to the fault plane are given as 0, 0, 0. This means that they are unknown, or perhaps irrelevant. They would be irrelevant, for instance, if an attenuation model based on focal distance is going to be used for the hazard computations. If the unit vector normal to the fault plane is described with (0,0,0) a horizontal plane will be the default.
5.550 45.050 11 0 0 0	
5.550 45.150 11 0 0 0	
5.550 45.250 11 0 0 0	
5.650 44.650 11 0 0 0	
5.650 44.750 11 0 0 0	
5.650 44.850 11 0 0 0	
5.650 44.950 11 0 0 0	
5.650 45.050 11 0 0 0	
5.650 45.150 11 0 0 0	
5.650 45.250 11 0 0 0	
5.650 45.350 11 0 0 0	
5.650 45.450 11 0 0 0	
5.650 45.550 11 0 0 0	
5.750 44.450 11 0 0 0	
5.750 44.550 11 0 0 0	

4. Seismicity models used

Speaking generally, CRISIS expects to have the seismicity described by means of the probabilities of having 1, 2, ..., *Ns* earthquakes of given magnitudes, in a given location, during the next *Tf* years. As can be noted, this is the most general description of seismicity that can possibly be given.

In order to get this information, CRISIS admits three types of seismicity models. The first two were already contained in older CRISIS versions, and both are related to Poissonian occurrences, although they differ in the way in which they define the earthquake magnitude exceedance rate. The third model is generalized non-Poissonian model that gives explicitly the required probabilities. See details of the three models in the following links.

Modified Gutenberg-Richter model

Characteristic-earthquake model

Generalized non-Poissonian model

4.1 Modified Gutenberg-Richter model

This model is associated to Poisson occurrences, so the probability of exceeding intensity level *a* in the next T_f years, given that an earthquake with magnitude *M* took place at a distance *R* from the site, is given by:

$$Pe(a,T \mid M,R) = 1 - \exp\left[-\Delta\lambda(M)\, T\; p_1(a \mid, M, R)\right] \qquad (1)$$

where $p_1(a|M,R)$ is the exceedance probability of intensity level *a*, given that a magnitude *M* event occurred at a distance *R* from the site, and $\Delta\lambda(M)$ is the Poissonian magnitude exceedance rate associated to the magnitude range (also called magnitude bin) characterized by magnitude *M*. Note that $p_1(a|M,R)$ depends only on magnitude and site-to-hypocenter distance. This probability does not depend on earthquake occurrence probabilities.

In turn, $\Delta\lambda(M)$can be computed as

$$\Delta\lambda(M) = \lambda(M - \Delta M/2) - \lambda(M + \Delta M/2) \qquad (2)$$

where it is implicit that the magnitude bin characterized by magnitude *M* goes from M-$\Delta M/2$ to M+$\Delta M/2$. For the modified Gutenberg-Richter model, the earthquake magnitude exceedance rate is given by:

$$\lambda(M) = \lambda_0 \frac{\exp(-\beta M) - \exp(-\beta M_u)}{\exp(-\beta M_0) - \exp(-\beta M_u)} \quad M_0 \le M \le M_u \qquad (3)$$

where λ_0 is the exceedance rate of magnitude M_0, β is a parameter equivalent to the "b-value" for the source (except that it is given in terms of the natural logarithm) and M_u is the maximum magnitude for the source.

CRISIS can account for uncertainty in both β and M_u. In this case, the user must give the coefficient of variation of β and give parameters that describe the uncertainty in the maximum magnitude.

4.2 Uncertainty in the maximum magnitude

CRISIS regards M_u, the maximum magnitude, as an unknown quantity. We assign to this variable a uniform probability distribution between M_1 and M_2, which are informed to CRISIS in terms of two values: the expected value of the maximum magnitude, *E(Mu),* and *DM,* such that M_1 and M_2 are given by:

	$M_1=E(Mu)-DM$	(1)
	$M_2=E(Mu)+DM$	(2)

Thus, maximum magnitude is considereder equally likely for all values between M_1 and M_2.

4.3 Characteristic earthquake

This model is associated to Poisson occurrences, so the probability of exceeding intensity level *a* in the next T_f years, given that an earthquake with magnitude *M* took place at a distance *R* from the site, is given by:

$$Pe(a,T \mid M,R) = 1 - \exp\left[-\Delta\lambda(M)\, T\, p_1(a \mid, M, R)\right] \quad (1)$$

where $p_1(a|M,R)$ is the exceedance probability of intensity level *a*, given that a magnitude *M* event occurred at a distance *R* from the site, and $\Delta\lambda(M)$ is the Poissonian magnitude exceedance rate associated to the magnitude range (also called magnitude bin) characterized by magnitude *M*. Note that $p_1(a|M,R)$ depends only on magnitude and site-to-hypocenter distance. This probability does not depend on earthquake occurrence probabilities.

In turn, $\Delta\lambda(M)$ can be computed as

$$\Delta\lambda(M) = \lambda(M - \Delta M/2) - \lambda(M + \Delta M/2) \quad (2)$$

where it is implicit that the magnitude bin characterized by magnitude *M* goes from M-$\Delta M/2$ to M+$\Delta M/2$. For the Characteristic-earthquake model, the earthquake magnitude exceedance rate is given by:

$$\lambda(M) = \lambda_0 \frac{\Phi\left[\dfrac{M_u - EM}{s}\right] - \Phi\left[\dfrac{M - EM}{s}\right]}{\Phi\left[\dfrac{M_u - EM}{s}\right] - \Phi\left[\dfrac{M_0 - EM}{s}\right]}, \; M_0 \le M \le M_u \quad (3)$$

where $\Phi(.)$ is the standard normal cumulative function, M_0 and M_u are the minimum and maximum characteristic magnitudes, respectively, and *EM* and *s* are parameters defining the distribution of *M*. *EM* can be interpreted as the expected value of the characteristic earthquake and *s* as its standard deviation. λ_0 is the exceedance rate of magnitude M_0.

In addition, an slip-predictable behavior can be modeled assuming that *EM* grows with time elapsed since the last characteristic event, *T00*, in the following fashion:

$$E(M) = D + F\ln(T00) \qquad (4)$$

Of course, if *F* is set to zero, then *EM=D*, independently of time elapsed.

4.4 Generalized Non-Poissonian model

This type of seismicity description allows for direct specification of the required probabilities, that is, the probabilities of having 1, 2, ..., *Ns* earthquakes of given magnitudes, in a given location, during the next *Tf* years.

This information is given to CRISIS by means of a binary file, with extension nps (non-Poisson seismicity), which has the following format:

Generalized seismicity file				
Description	**Variable**	**Type**	**Length**	**Comments**
Number of point sources	TotSrc	Integer	4	
Number of magnitude bins	Nbin	Integer	4	
Number of time frames	Nt	Integer	4	
Maximum number of events for which Prob(i,j) is given	Ns	Integer	4	
Magnitude representative of bin 1	M(1)	Double	8	Magnitude values are useful only if parametric attenuation models are used. They are not used in generalized attenuation models
…	…	…	…	
Magnitude representative of bin Nbin	M(Nbin)	Double	8	
Time frame 1	Tf(1)	Double	8	
…	…	…	…	
Time frame Nt	Tf(Nt)	Double	8	
Seismicity record for source 1	Seis(1)	Seismicity record	8+8*Ns*Nt	

Seismicity record for source 2	Seis(2)	Seismicity record	8+8*Ns*Nt	
…	…	…	…	
Seismicity record for source TotSrc	Seis(TotSrc)	Seismicity record	8+8*Ns*Nt	

Seismicity record				
Description	**Variable**	**Type**	**Length**	**Comments**
Probability of having 1, 2,…,Ns events in time frame 1	Prob(1,1)	Double	8	Block associated to time frame 1
	Prob(2,1)	Double	8	
	…			
	Prob(Ns,1)	Double	8	
Probability of having 1, 2,…,Ns events in time frame 2	Prob(1,2)	Double	8	Block associated to time frame 2
	Prob(2,2)	Double	8	
	…			
	Prob(Ns,2)	Double	8	
…	…	…	…	…
Probability of having 1, 2,…,Ns events in time frame Nt	Prob(1,Nt)	Double	8	Block associated to time frame Nt
	Prob(2,Nt)	Double	8	
	…			
	Prob(Ns,Nt)	Double	8	
		Total length	8*Ns*Nt	

5. Ground Motion Prediction Models (GMPM)

In general, ground motion prediction models, also called attenuation relations, establish probabilistic relations between earthquake characteristics and intensities at a site of interest. These relations are probabilistic since, for given earthquake characteristics, the intensities are regarded as random variables, whose probability distribution is completely fixed by the GMPM. In most of the cases this means that at least the first two statistical moments (*e.g.*, the median and the standard deviation of the natural logarithm, in the lognormal case) of the probability distribution must be furnished by the GMPM.

CRISIS recognizes three "families" of GMPM:

Attenuation tables. In these tables, relations between earthquake characteristics and intensities at a site are given in terms of the following parameters: magnitude, structural period, source-site distance and depth. For the first moment (usually the median of a lognormal distribution), the attenuation relations are matrices in which the rows run for the magnitude and the columns run for the distance. Note that when using attenuation tables, the relations between magnitude, distance and intensity do not need to be of parametric nature, since the intensity medians are given, point by point, for magnitude-distance combinations.

Built-In models. These are popular models, published in the literature, in which magnitude, distance and intensity are probabilistically related by, usually, a set of formulas or parametric equations. There is a set of built-in models ready to use in CRISIS and there is also the possibility of adding new models.

Generalized models. Generalized attenuation models are non-parametric probabilistic descriptions of the ground motions produced by an earthquake. In the context of CRISIS, a generalized attenuation model is a collection of probabilistic footprints, one for each of the events considered in the analysis. Each footprint gives, in probabilistic terms, the geographical distribution of the intensities produced by this event.

5.1 Attenuation tables

These tables give CRISIS probabilistic relations between magnitude, source-site distance and intensities. Each attenuation table must be in a different file and must contain the following information:

Attenuation table header

This is a new part of the attenuation table, starting with CRISIS2008. All the lines of this portion are optional, so as to keep back-compatibility with older attenuation tables. The reader, however, must be aware of the default values that are used for the parameters that will be described in this numeral.

This header can contain up to 4 lines that give different characteristics of the attenuation table; lines can be given in any order. Field names (including capital letters) are fixed. All header lines have the following format:

: Field name : Field value

The following table gives the four possible header fields recognized by CRISIS

Field name	Field value	Comments	Default value
Description	A string giving a brief description of the attenuation table. Description usually includes: author, date of publication, type of earthquakes for which the model was derived, and so on.	This information is for presentation purposes in the Attenuation Data screen	"Not available"
Units	A string giving the units for which the model was developed	The original units will appear, for information purposes, in the Attenuation Data screen. However, the original units might be relevant if a Units Coefficient is given in order to convert from these original units to user units, given in the Intensities screen	"Not available"
Distribution	In integer number indicating the probability distribution assigned to the residuals of the attenuation model	Supported values are: Normal=1 Lognormal=2 Beta=3 Gamma=4	2 (Lognormal)
Dimension	A string giving the physical dimension of the intensities described in the attenuation table	See the meaning of physical dimension in this link	"Acceleration"

Parameters defining the magnitude limits (1 line)

MINF, MSUP, NMAG

Variable	Meaning
MINF	Lower limit of magnitude given in the table
MSUP	Upper limit of magnitude given in the table
NMAG	Number of magnitudes for which intensity is given

CRISIS assumes than intensities are given for magnitudes *M(K)*, where

	*M(K)=MINF+(K-1)*DMAG*	(1)
	DMAG=(MSUP-MINF)/(NMAG-1)	(2)

Parameters defining the distance limits and type (1 line)

RINF, RSUP, NRAD, TYPE

Variable	Meaning
RINF	Lower limit of distance given in the table
RSUP	Upper limit of distance given in the table
NRAD	Number of distances for which intensity is given
TYPE	An integer indicating the type of distance used by the attenuation table

CRISIS assumes than intensities are given for distances *R(K)*, where

	$log(R(K))=log(RINF)+(K-1)*DLRAD$	(3)
	$DLRAD=(log(RSUP)-log(RINF))/(NRAD-1)$	(4)

In other words, distances are supposed to be logarithmically spaced.

TYPE can have the following values, depending on the type of distance to be used:

Value	Type of distance
1 (or blank)	Focal
2	Epicentral
3	Joyner and Boore
4	Closest to rupture area (Rrup)

For each of the NT different intensity measures, the following blocks of lines:

T(J), SLA(J,0), AMAX(J), COEFH

Variable	Meaning
T(J)	Structural period of j-th spectral ordinate. It is used only for identification purposes and to plot the uniform-hazard spectrum, so in the cases in which structural period has no meaning, it can be just a sequential number
SLA(J,0)	Standard deviation of the natural logarithm of the j-th measure of intensity. A value of *SLA(J,0)*<=0 implies that the user will give standard deviations that vary with magnitude. In this case, the corresponding σ values, one for each of the *NMAG* magnitudes has to be given after the table of *SA*() values
AMAX(J)	See Probabilistic interpretation of attenuation relations for a definition of this quantity
COEFH	Depth coefficient. See explanation below

Some modern attenuation relations have a coefficient to make the intensity explicitly dependent on focal depth. This information is given with coefficient *COEFH*, so that:

	$MED(A\|M,R)=SA(M,R)*exp(COEFH*H)$	(5)

where *MED(A|M,R)* is the (depth-dependent) median value of intensity for given values of magnitude *M* and distance *R*; *SA(M,R)* is the median intensity given in the table for the same values of magnitude and distance, and *H* is focal depth.

Matrix of median intensities, associated to a magnitude (row) and a distance (column)

SA(1,1,1), SA(1,1,2),…,SA(J,K,L),….,SA(NT,NMAG,NRAD)

SA(J,K,M): Median value of the intensity, for the J-th spectral ordinate, the K-th magnitude and the L-th distance.

Only if SLA(J) <= 0:

SLA(J,1)

SLA(J,2)

…

SLA(J,NMAG)

Example

In this example, an attenuation model for NT=2 periods (or measures of intensity) is given:

#	: Description	: Sample attenuation file constructed for illustration purposes (2008)							
#	: Units	: cm/sec/sec							
#	: Distribution	: 2							
#	: Dimension	: Acceleration							
4.5	8.5	5		5 magnitudes between 4.5 and 8.5					
5.0	500.0	10	1	10 distances, log-spaced between 5 and 500 Km; focal distance					
0.0	0.7	0.0	0.0	Period 0. Sigma=0.7. Amax=0 (no truncation), CoefH=0					
119.3	97.5	70.3	45.3	26.8	14.7	7.3	3.2	1.1	0.3
202.5	165.6	119.4	76.9	45.5	24.9	12.4	5.4	1.9	0.5
344.0	281.2	202.7	130.6	77.3	42.3	21.1	9.1	3.2	0.8
584.1	477.6	344.3	221.8	131.2	71.9	35.9	15.5	5.4	1.3
992.0	811.1	584.7	376.7	222.9	122.1	60.9	26.4	9.1	2.2
0.2	-0.7	0.0	0.0035	Period 0.2. Sigma variable with *M*. Amax=0 (no truncation), CoefH= 0.0035					
250.4	203.2	145.2	92.7	54.2	29.4	14.5	6.2	2.1	0.5
420.4	341.3	244.0	155.7	91.2	49.4	24.3	10.4	3.6	0.8
708.3	575.2	411.3	262.6	153.8	83.4	41.1	17.6	6.0	1.4
1193.5	969.6	693.8	443.3	259.9	141.0	69.5	29.7	10.2	2.4
2014.4	1637.1	1172.1	749.4	439.6	238.6	117.7	50.4	17.3	4.1
0.830				5 values of magnitude-dependent Sigma, one for each magnitude					
0.784									
0.615									
0.623									
0.514									

5.2 Built-in attenuation models

These are popular attenuation equations, published in the literature, that the user can choose as GMPM for CRISIS. These models relate, in probabilistic terms, earthquake magnitude and a certain distance metric with the intensity at a site. (CRISIS can handle 4 types of distance metrics). Also, many of these attenuation equations require specification of additional parameters that the user must select, such as style of faulting and soil type.

The following GMPM are built-in into CRISIS:

Models for active tectonic regions with shallow seismicity

- Abrahamson and Silva, 1997
- SEA99, 1999
- Cauzzi and Faccioli, 2008 (Full model)
- Akkar and Bommer, 2007
- Boore and Atkinson, 2008
- Campbell and Bozorgnia, 2003
- Cauzzi and Faccioli, 2008 (Simple version)
- Cauzzi and Faccioli, 2008 (Vertical, 5% damping)
- Sabetta and Pugliese, 1996 (Fault Distance)
- Sabetta and Pugliese, 1996 (Epicentral Distance)
- Pasolini et al., 2008 (Macroseismic intensity)

Subduction zones

- Arroyo et al., 2010
- Youngs et al., 1997
- Atkinson and Boore, 2003
- Garcia et al. 2005

Note that, besides the parameters that each GMPM uses -such as soil type or style of faulting- all built-in GMPM contain two extra parameters, called "Units coefficient" and "Sigma truncation". The first one is used to change the original units of the model (see details) while the second one is used to truncate the probability distribution of the residuals (see details).

There is also the possibility of adding new built-in models to CRISIS, that, in theory, can be of an arbitrary level of complexity.

5.3 Generalized attenuation models

Generalized attenuation models are non-parametric probabilistic descriptions of the ground motions produced by an earthquake.

Ground motions descriptions obtained when using traditional attenuation models -also called ground motion prediction equations (GMPE)- are generally functions of earthquake magnitude and source-to-site distance.

But generalized attenuation models are not explicit functions of magnitude and distance. They are simply probabilistic “footprints” of the ground motions produced by an individual event.

In the context of CRISIS, a generalized attenuation model is a collection of probabilistic footprints, one for each of the events considered in the analysis. Each footprint gives, in probabilistic terms, the geographical distribution of the intensities produced by this event.

For a given event, the footprint consists of several pairs of grids of values. Each pair of grids is associated to one of the intensity measures for which hazard is to be computed. CRISIS needs two grids for each intensity measure because, as with other ground motion prediction models, the intensity caused by the earthquake is considered probabilistic, so CRISIS requires two statistical moments in order to fix a probability density function of the intensity caused by an earthquake at a particular location.

For instance, assume that one generalized attenuation model will be used to describe the intensities caused by 10 different earthquakes. Also, assume that the hazard analysis is being made for seven intensity measures (for instance, the response spectral ordinates for seven different structural periods). For this example, each event will be described by 14 different grids, two for each intensity measure, the first one giving the geographical distribution of the median intensity and the second one given the geographical distribution of the standard deviation of the natural logarithm of the intensity. Hence, a total of 140 grids will form the generalized attenuation model of this example. It would be natural that all the 140 grids covered exactly the same region; however, there are no restrictions at this respect.

From this description, it is clear that it would be extremely difficult to perform a hazard study of regional (or higher) size using generalized attenuation models. Usually, a hazard model of regional size contains thousands of events, and the task of geographically describing the intensities caused by all of them in non-parametric form would be titanic.

Rather, generalized attenuation models will very likely be used for local studies, for which the relevant earthquakes are few and can be clearly identified. In this case, the grids of required values (geographical distribution of statistical moments of one or more intensity measures for each event) can be constructed using, for instance, advanced ground-motion simulation techniques.

Generalized attenuation models are given to CRISIS in the form of binary generalized attenuation files (GAF). The reason for requiring the GAF’s to be in binary format is the computational need of having random access to individual intensity values. This need is basically dictated by computational speed.

The following tables illustrate the detailed format of GAF’s.

Description	Type	Length	Comments
Custom file description	String	Variable	Give a synthetic description of the main features of the GAF
Original Units	String	Variable	
Intensity physical dimension	String	Variable	

Description	Type	Length	Comments
Data type (short, integer, single, double, long)	Integer	4	
Probability distribution assigned to intensity (normal, lognormal, beta, gamma)	Integer	4	
Number of intensity measures (number of periods)	Integer	4	
Number of sources (locations)	Integer	4	
Number of magnitudes per location	Integer	4	
Number of statistical moments of intensity stored	Integer	4	
Period 1	Double	8	Period values are required because the user might want to compute for arbitrary periods
Period 2	Double	8	
…	…	…	
Period Number of Intensity measures	Double	8	
Magnitude representative of bin 1	Double	8	Magnitude values are required to compute occurrence rates when GR or Characterisitic models are used. When a non-Poissonian seismicity file is given these magnitudes are irrelevant
Magnitude representative	Double	8	

Description	Type	Length	Comments
of bin 2			
…	…	…	
Magnitude representative of last bin	Double	8	
Scenario name	Char	40	Magnitude values are required to compute occurrence rates when GR or Characterisitic models are used. When a non-Poissonian seismicity file is given these magnitudes are irrelevant
Grid for intensity measure 1, moment 1	ModGRN	56+Nbytes*Nx1*Ny1	
Grid for intensity measure 1, moment 2	ModGRN	56+Nbytes*Nx1*Ny1	
…	…	…	
Grid for intensity measure 1, moment NumMoments	ModGRN	56+Nbytes*Nx1*Ny1	
Grid for intensity measure 2, moment 1	ModGRN	56+Nbytes*Nx1*Ny1	
Grid for intensity measure 2, moment 2	ModGRN	56+Nbytes*Nx1*Ny1	
…	…	…	
Grid for intensity measure 2, moment NumMoments	ModGRN	56+Nbytes*Nx1*Ny1	
…	…	…	

Description	Type	Length	Comments
Grid for intensity measure NumInt, moment 1	ModGRN	56+Nbytes*Nx1*Ny1	Then, the actual georeferenced probabilistic intensity values follow
Grid for intensity measure NumInt, moment 2	ModGRN	56+Nbytes*Nx1*Ny1	
…	…	…	
Grid for intensity measure NumInt, moment NumMoments	ModGRN	56+Nbytes*Nx1*Ny1	
Scenario name	Char	40	Magnitude values are required to compute occurrence rates when GR or Characterisitic models are used. When a non-Poissonian seismicity file is given these magnitudes are irrelevant
Grid for intensity measure 1, moment 1	ModGRN	56+Nbytes*Nx2*Ny2	
Grid for intensity measure 1, moment 2	ModGRN	56+Nbytes*Nx2*Ny2	
…	…	…	
Grid for intensity measure 1, moment NumMoments	ModGRN	56+Nbytes*Nx2*Ny2	
Grid for intensity measure 2, moment 1	ModGRN	56+Nbytes*Nx2*Ny2	
Grid for intensity	ModGRN	56+Nbytes*Nx2*Ny2	

Description	Type	Length	Comments
measure 2, moment 2			
…	…	…	
Grid for intensity measure 2, moment NumMoments	ModGRN	56+Nbytes*Nx2*Ny2	
…	…	…	
Grid for intensity measure NumInt, moment 1	ModGRN	56+Nbytes*Nx2*Ny2	Then, the actual georeferenced probabilistic intensity values follow
Grid for intensity measure NumInt, moment 2	ModGRN	56+Nbytes*Nx2*Ny2	
…	…	…	
Grid for intensity measure NumInt, moment NumMoments	ModGRN	56+Nbytes*Nx2*Ny2	
Similar blocks continue for all scenarios			

5.4 Adding new built-in GMPM

In addition to attenuation tables and generalized attenuation models, CRISIS admits built-in GMPM, which are given to the code in the form of classes compiled in a Dynamic Link Library (dll).

CRISIS includes a number of built-in GMPM, which can be consulted in this link. However, this collection can be extended by way of writing code for user-defined GMPM. Each new GMPM must be a new class that implements, at least, the following methods:

No.	Method type	Method name	Type of variable returned	Purpose
1	ReadOnly Property	BriefDescription	String	Returns a brief description of the main model characteristics, in order to inform the user about it
2	ReadOnly Property	DistanceType	TipoDistancia	The distance type which the attenuation model works with. Returning value must belong to enumeration TipoDistancia
3	ReadOnly Property	MaximumValidDistance	Double	Returns the maximum valid distance of the model
4	ReadOnly Property	MaximumValidMagnitude	Double	Returns the maximum valid magnitude of the model
5	ReadOnly Property	MinimumValidDistance	Double	Returns the minimum valid distance of the model
6	ReadOnly Property	MinimumValidMagnitude	Double	Returns the minimum valid magnitude of the model
7	ReadOnly Property	OriginalUnits	String	Returns original units of the model, in text form. E.g. "cm/s/s"
8	ReadOnly Property	PhysicalDimension	Dimensione	Returns the physical dimension of the intensities described in the ground-motion model
9	ReadOnly Property	ResidualDistribution	TipoDistribucion	Returns the type of random variable with which the residuals of this GMPE are

No.	Method type	Method name	Type of variable returned	Purpose
				modeled
10	Public Function	getAcceleration	VariableAleatoria	Returns intensity value for given parameters

Of all the methods presented in the previous table, the first nine do not require parameters and are very simple. For instance, ReadOnly Property MinimumValidDistance must return a Double number that gives the value of the minimum distance for which the model under definition is considered valid. In column **Type of variable returned** of the previous table, the variable types written in green are elements of classes internal to CRISIS.

The tenth method is more complex, and it is the core of the GMPM. Its purpose is to determine the probabilistic intensity that is generated given hypocentral characteristics (that include hypocentral location and earthquake magnitude) and receiver location. Function getAcceleration() requires the following parameters:

Name	Type	Purpose
Period	Double	The value of the period for which intensity is requested
SiteKn	PointType	The location of the site for which intensity is being determined, expressed in the form of x, y and z distances, in Km, with respect to the first vertex of the source to which the hypocenter belons
SiteInDegrees	PointType	The location in degrees of the site for which intensity is being determined
hypocenter	Hypocenter	An element of class hypocenter defining the location and properties of the hypocenter that generates the event for which intensity is being determined

Again, in column **Type of variable returned** of the previous table, the variable types written in green are elements of classes internal to CRISIS.

A detailed, fully documented example of the construction of a ground- motion prediction model implementing the methods just described is presented in the form of VB.Net project GMPETutorial that is distributed as part of CRISIS instalaltion package, with the name GMPETutorial.zip.

5.5 Units coefficient

All GMPM used by CRISIS (attenuation tables, built-in models and generalized models) give probabilistic relations between earthquake properties, site characteristics and intensities at a site. These relations are given in terms of the first and second statistical moments of the intensities, given some earthquake and site parameters. For instance, for the GMPM in which the residuals are lognormally distributed, the GMPM gives the median and the standard deviation of the natural logarithm of the intensity, given a set of earthquake and site parameters.

The GMPM are constructed to express the intensities in certain units. These units are called the "original units". However, the user of CRISIS might want to perform calculations for intensities expressed in other units. For instance, a user could be using a model whose original units are cm/sec^2, but he wants to make hazard calculations for intensities expressed as a fraction of the acceleration of gravity, g. In these case, the g units will be called the "user units", which are given by the user in the Intensities Screen.

The Units Coefficient (UC) is a positive number used to change from the model's original units to the user units, using the following relation:

	1 user unit = UC original units	(1)

For instance, in the example given above, since the original units are cm/sec^2 and the user units are fractions of g, we would have that 1 g = UC cm/sec^2, and hence UC=981, because 1 g = 981 cm/sec^2.

5.6 Physical dimension

In order to have tighter checks of the compatibility among different ground-motion prediction models (GMPM) when performing logic-tree computations, each GMPM must be assigned aphysical dimension of the measures of intensity the model is describing. The physical dimension of most GMPM is acceleration (because they are usually constructed for PGA and the response spectral ordinates at selected periods), but other physical dimensions are also accepted. CRISIS, so far, accepts the following physical dimensions, which correspond to classes defined for this purpose:

Physical dimension	Assembly name
Acceleration	Crisis2008.NewAttenuation.dll
Velocity	Crisis2008.NewAttenuation.dll
Displacement	Crisis2008.NewAttenuation.dll
MMI	Crisis2008.NewAttenuation.dll
MCSI	Crisis2008.NewAttenuation.dll
DuctilityDemand	ExtraDimensions.dll
ISDrift	ExtraDimensions.dll

Although only these physical dimensions are recognized by CRISIS, it is relatively simply to construct additional classes associated to other intensity measures. To do so, the constructed class must implement the following methods:

Method	Purpose
Public ReadOnly Property distancePow() As Integer	Returns an integer indicating the distance power of this dimension
Public ReadOnly Property forcePow() As Integer	Returns an integer indicating the force power of this dimension
Public ReadOnly Property timePow() As Integer	Returns an integer indicating the time power of this dimension

Method	Purpose
Public ReadOnly Property chargePow() As Integer	Returns an integer indicating the charge power of this dimension
Public MustOverride ReadOnly Property name() As String	Provides a number specific to the class
Public Overrides Function Equals(ByVal obj As Object) As Boolean	Checks if the types have same power for MKSA elements describing dimensions

Classes constructed that implement these methods must be compiled to the form of a dll, which must be ste in CRISIS application directory. In addition, file CRISIS2008.dim must be edited to add the new classes. The geral format of the lines of this file is the following:

Full class name, Assembly name

5.7 Special Attenuation Models

In the most frequent case, only one attenuation model will be assigned to a source. However, there is the possibility to assign one ore more special attenuation models to a source, which will be effective only for sites located inside corresponding polygons, called "special attenuation regions" given by the user.

If special attenuation models are given, then CRISIS will proceed in the following way:

When computing hazard from a source, CRISIS will check if this source has special attenuation models. If it does not, then it will use the general attenuation model for the source. If the source was assigned special models, then CRISIS will check if the site of computation is inside one of the user-given polygons. If affirmative, CRISIS will use the model assigned to this source-site combination. If the site is not inside any of the special polygons, then CRISIS will use the general attenuation model of the source.

It must be noted that if site-effects grids are given, the amplification factors will be applied on top of the intensities computed either with the general attenuation model assigned to the source or with attenuation models assigned to special attenuation regions.

5.8 Probabilistic interpretation of attenuation relations

In general, given a magnitude and a distance, intensity A is assumed to be a random variable with a given probability distribution (usually lognormal). Attenuation relations (also called ground motion prediction models, or GMPM) give the two first statistical moments of A given a magnitude and a distance, that is, $A|M,R$. These two moments usually describe the mean or median value of $A|M,R$ and a measure of its uncertainty.

Up to now, CRISIS supports three probability distributions that can be used to describe intensities. These distributions are presented in the following table, along with the two statistical moments that have to be given in order to correctly describe $A|M,R$ as a random variable.

Distribution	1st moment (μ_1)	2nd moment (μ_2)	Lower limit	A_{max}
Lognormal	Median	Standard deviation of the natural logarithm	0	$\mu_1 \exp(K\mu_2)$
Gamma	Mean	Standard deviation	0	$\mu_1+K\mu_2$
Normal	Mean	Standard deviation	-infinity	$\mu_1+K\mu_2$

As part of the hazard computations, CRISIS requires to compute the probability that intensity A at a given site exceeds a known value, a, given that at some hypocentral location, H, an earthquake of magnitude M took place, that is, $\Pr(A>a|M,H)$.

If no truncation is applied to intensity values, this probability is computed with the following expression:

$$\Pr(A>a|M,H)=1-F_A[a;\mu_1(M,H),\mu_2(M,H)] \quad (1)$$

where $\mu_1(M,H)$ and $\mu_2(M,H)$ are the first and second moments, respectively, of intensity A, given that at hypocentral location H an earthquake of magnitude M took place. Depending on the probability distribution assigned to A, the first and second moments have the interpretation presented in the previous table. $F_A[a;\mu_1(M,H),\mu_2(M,H)]$ is the probability distribution of A (also called the cumulative probability function) whose form depends on the type of distribution chosen.

The moments of $A|M,R$, that is, $\mu_1(M,H)$ and $\mu_2(M,H)$ are given by the user by means of attenuation relations or GMPM.

In many cases, truncation is specified in the GMPM trough a parameter called "**Sigma truncation**", Tc. This means that the integration across the attenuation relation uncertainty implied in the previous equations is not carried out up to infinity, but up to a certain value, Tc.

Depending on the value of the truncation coefficient given in the GMPM, the following considerations are made:

Tc=0

In this case, no truncation is applied, so Equation 1 is used.

Tc> 0

In this case, a truncated distribution between the lower limit of A and Tc is assumed, regardless of magnitude and distance. Hence,

$$\Pr(A>a|M,H)=\begin{cases}\dfrac{1-F_A[a;\mu_1(M,H),\mu_2(M,H)]}{1-F_A[Tc;\mu_1(M,H),\mu_2(M,H)]} & a<Tc\\ 0 & a>Tc\end{cases} \quad (2)$$

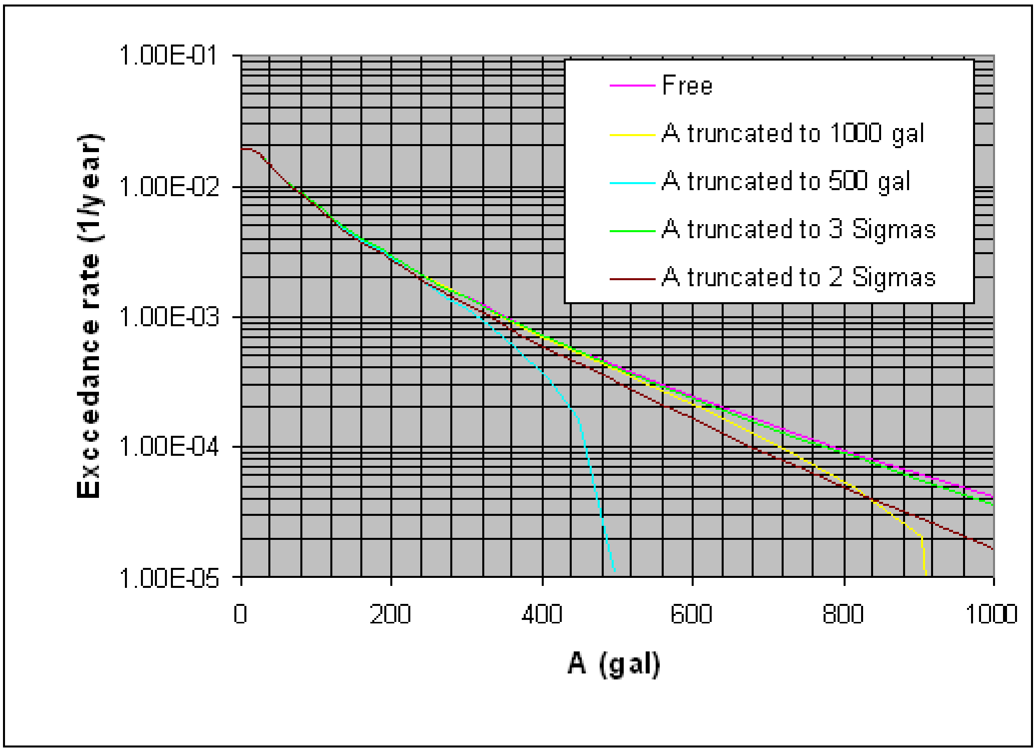
Tc<0

In this case, ABS(Tc) = K, is interpreted as the number of standard deviations, for which integration will be performed. Hence, the integration will be performed between the lower limit and A_{max}, both given in the previous table. Therefore,

$$\Pr(A > a \mid M,H) = \begin{cases} \dfrac{1 - F_A\left[a;\mu_1(M,H),\mu_2(M,H)\right]}{1 - F_A\left[A_{max};\mu_1(M,H),\mu_2(M,H)\right]} & a < A_{max} \\ 0 & a > A_{max} \end{cases} \quad (3)$$

Depending on the distribution chosen, A_{max} takes the values indicated in the previous table. Note that in this case, the actual truncation value for A depends on magnitude and distance.

In the following graph, the effect of the different truncation schemes can be observed:



5.9 Measuring distances (suggested by Dr. R. Secanell)

In CRISIS, there are four ways of measuring site-to-source distances:

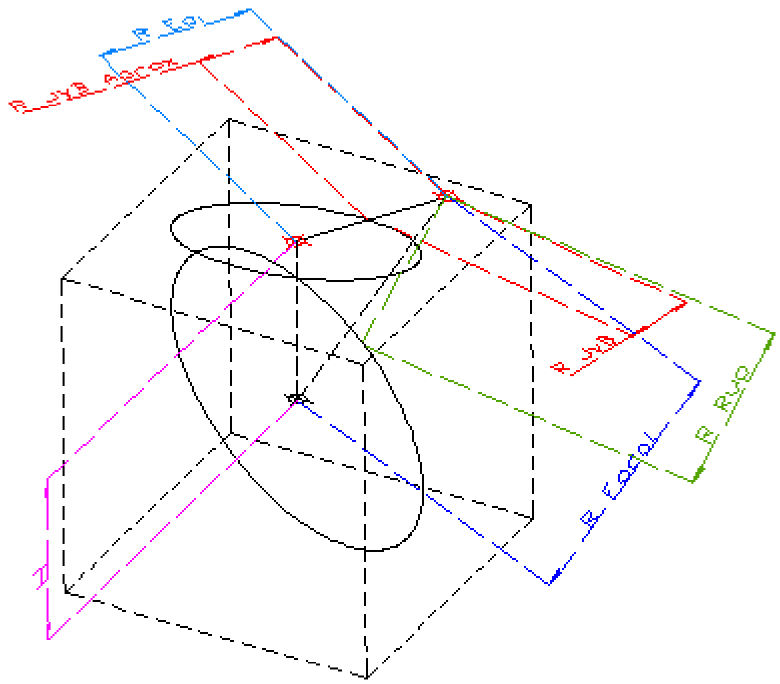
1) Focal (R_F)

2) Epicentral (R_{EPI})

3) Joyner and Boore (closest distance to the projection of the fault plane on the Earth's surface; R_{JB})

4) Closest distance to rupture area (R_{RUP})

The following figure illustrates the different distances:



H is the focal depth. Computation of R_F and R_{EPI} deserves no further comments. Computation of R_{RUP} and R_{JB}, however, require the specification of a rupture area. In CRISIS, the area is specified with the following criteria:

The rupture area is assumed to be circular with radius r, which depends on magnitude in a way specified by the user (see Relation between magnitude and fault radius).

The circular fault is contained in the plane defined by the triangle resulting from source subdivision, whose centroid is assumed to be the hypocentral location.

Note that, if the site is within the projection of the fault in the Earth's surface, R_{JB}=0 and R_{RUP}=H.

The user must indicate to CRISIS what type of distance he wishes to use, depending on the characteristics of the attenuation relation being used. This is done directly in the attenuation relations or ground motion prediction models (GMPM)

Computation of the exact values of distances R_{JB} and R_{RUP} is cumbersome. To save computation time, the exact values are approximated with simpler formulas that produce small errors.

5.10 Relation between magnitude and fault size

In CRISIS, attenuation relations can be specified in terms of 4 different measures of distance. If distances R_{RUP} or R_{JB} are used, CRISIS must have means to know the rupture area or the rupture length, as a function of magnitude, in order to compute the required distances.

In general, CRISIS assumes that the relation between area/rupture length and magnitude is

	$A=K_1 exp(K_2 M)$ (for area sources, A in Km^2)	(1)

	$L=K_3 exp(K_4 M)$ (for line sources, L in Km)	(2)

where A is the source area (in km^2), L is the rupture length (in km), M stands for magnitude and K_1 , K_2, K_3 and K_4 are constants given by the user or chosen from a built-in set of constants.

In the case of area sources and point sources, CRISIS will assume that the earthquake takes place in a plane defined by the source geometry, and that the rupture area will be a circle, within this plane, with area A and, in consequence, with radius

	$r^2=A/\pi$	(3)

In the case of line sources, CRISIS will assume that the earthquake takes place along a line defined by the source geometry, and that the rupture length will be centered at the hypocenter.

CRISIS recognizes also a particular type of magnitude-rupture size relation, indicated by K_1=-1 (for area sources) and K_3=-1 (for line sources). This type of source breaks completely for every earthquake, regardless of magnitude value. In view of this, there is only one hypocenter associated to the area or to the line. This hypocenter is the point within the source closest to the computation site.

6. GeoSeismAtt Combinations

The different geometry / seismicity /attenuation models give raise to the combinations listed in the following table. Follow the link to obtain a more detailed explanation of each combination. In the table, "Normal" attenuation refers to attenuation tables or user coded models, while "General" refers to generalized attenuation models. Also, "GR" and "C" seismicity refer to Gutenberg-Richter and Characteristic Earthquake models, respectively, while "NP" denotes non-Poissonian models.

Option	Geometry	Seismicity	Att	Possible?	Comments
1	Area,Line	(GR,C)	(Normal)	Always	Old CRISIS option
2	Area,Line	(NP)	(Normal)	NSrc=1	Peruzza type
3	Area,Line	(GR,C)	(General)	Never	-
4	Area,Line	(NP)	(General)	NSrc=Nsites and Nbin=Nmag	Stupazzini-Villani type
5	Points	(GR,C)	(Normal)	Always	Old CRISIS option
6	Points	(NP)	(Normal)	Nv=NSrc	Warner type
7	Points	(GR,C)	(General)	Never	-
8	Points	(NP)	(General)	Never	-

Option 1

This is an old CRISIS option, which is valid always.

Option 2

In this new option a source is geometrically modeled as a line or as an area, which means that every point that belongs to the source has the same probability of being a hypocenter; this is the usual assumption when using line or area sources in CRISIS. Attenuation, as in older CRISIS option is modeled with a parametric description (a "normal" GMPM). However, the new option permits stipulation of earthquake occurrence probabilities with a generalized non-Poissonian model, and not through a parametric frequency-magnitude relation (Gutenberg-Richter or Characteristic Earthquake).

The occurrence probabilities given in the non-Poissonian seismicity file correspond to the whole source, that is, they are the probabilities of having and earthquake of given magnitude and in a given time frame in anywhere in the source. Using its standard spatial integration scheme, CRISIS will sample the source in order to compute hazard accounting for all possible locations of the earthquake within the source. Note, however, that when probabilities are specified for the whole source, probabilities associated to segments of the source, or sub-sources, are not univocally defined. The following approach is adopted by CRISIS in order to define the occurrence probabilities associated to sub-sources of known sizes.

Assume first that we have a conventional Poissonian source. The probability of having i events of magnitude M in the next Tf years, due to the effect of the whole fault, $P(i,M,Tf)$ would be given by:

	$P(i,M,Tf)=exp(-\Delta\lambda(M)Tf)$	(1)

where $\Delta\lambda(M)$ is the Poissonian magnitude occurrence rate of earthquakes with magnitudes in the vicinity of M, for the whole source. This occurrence rate can be written as:

$$\Delta\lambda(M)=-ln[P(i,M,Tf)]/Tf \tag{2}$$

In the case of Poissonian occurrences, occurrence rates are additive. Thus, the occurrence rate corresponding to a sub-source of relative size w_j, would simply be:

$$\Delta\lambda_j(M)=\Delta\lambda(M)w_j \tag{3}$$

Note that, for all sub-sources, $\Sigma w_j=1$. Now we can go back to compute the occurrence probability associated to sub-source j:

$$P_j(i,M,Tf)=exp(-\Delta\lambda_j(M)Tf)=exp(-\Delta\lambda(M)Tfw_j)=exp(ln[P(i,M,Tf)]w_j) \tag{4}$$

from which we gather that:

$$P_j(i,M,Tf)=P(i,M,Tf)^{wj} \tag{5}$$

Note that, as we had mentioned, if only the occurrence probabilities for the whole source are specified, there is not a unique way to specify occurrence probabilities associated to sub-sources. However, the path chosen by CRISIS is, in our view, reasonable, and exact for the case of Poissonian sources.

The only compatibility restriction when using this option is that the file that contains the generalized non-Poissonian occurrence probabilities must stipulate (in the *.nps file) that the number of sources is equal to 1, that is, only a set of occurrence probabilities is given. See this link in order to see where this parameter is stipulated.

Within the CRISIS development team, this combination is known as Peruzza-type, since Prof. Laura Peruzza suggested its implementation an used it in her calculations in the context of project S2 (2008-2010) funded by the Italian Civil Protection Authority.

Option 3

In this option, source geometry is a line or an area, but ground-motion characteristics are described with a generalized attenuation model. This option is impossible, due to the fact that generalized attenuation models are associated to known, fixed hypocentral locations, while line or area sources contain, implicitly, uncertainty about future hypocenters. Thus, these source-attenuation choices are incompatible with each other.

In addition, generalized attenuation models contain information about individual events with known (although irrelevant) magnitudes. Since each event is associated to a fixed value of magnitude, occurrence probabilities for each of the events contained in the attenuation model, cannot be computed for continuous, arbitrary values of magnitude with the information provided by parametric seismicity descriptions, as earthquake magnitude exceedance rates. It must be remembered that, starting with magnitude exceedance rates, occurrence probabilities in given time frames can only be computed for magnitude intervals (magnitude "bins") and not for point values.

Option 4

In this option, the source is a line or an area, seismicity is described with a generalized non-Poissonian model an ground motion characteristics are given with a generalized attenuation model.

This option is the only one in which generalized attenuation models can be used. Note that, when using this type of ground motion model, locations of earthquake hypocenters are, in principle, unknown and irrelevant. In consequence, specification of a source location is also, in principle, irrelevant. However, there are two reasons why a source location must be specified: 1) when constructing a hazard model with CRISIS interface, it is useful for the analyst to have a visual feedback of the source location; and 2) for hazard disaggregation purposes, CRISIS must know the location to which the hazard coming from all events has to be assigned. For the purpose of dissaggregation, earthquake location is conventionally considered to be the geometrical center of the source area or line.

On the other hand, since also earthquake magnitudes are fixed (and irrelevant) in generalized attenuation models, and each set of grids represents an individual event, it would be impossible to associate to this events seismicity parameters using parametric descriptions. In view of this, the only possibility is that earthquake occurrence probabilities are assigned using non-Poissonian generalized models.

Compatibility conditions in this option are the following:

1) The number of sources in the generalized attenuation model (*.gaf) must be the same that the number of sites in the generalized non-Poissonian seismicity file (*.nps)

2) The number of magnitudes in the generalized attenuation model (*.gaf) must be the same that the number of sites in the generalized non-Poissonian seismicity file (*.nps)

Within the CRISIS development team, this combination is known as of type Stupazzini-Villani -type, since Marco Stupazzini and Manuela Villani are the two researchers in charge of developing this type of model in the context of project S2 (2008-2010) funded by the Italian Civil Protection Authority

Option 5

In this option, source geometry is given in terms of points, there is a "normal" attenuation model and a parametric seismicity description, either of Gutenberg-Richter or Characteristic Earthquake type. This is an old CRISIS option, which has no compatibility restrictions.

Option 6

In this option, source geometry is given in terms of points, a "normal" ground-motion prediction models is used, and earthquake occurrence probabilities are given with a generalized non-Poissonian seismicity model.

This option is mainly used to model the so called smoothed-seismicity, but now with probabilities obtained with arbitrarily complex non-Poissonian models.

The only compatibility restriction in this option is that the number of vertex given in the point-sources description must be equal to the number of sources given in the non-Poissonian seismicity file.

Within the CRISIS development team, this combination is known as Warner-type, since Warner Marzocchi suggested its implementation an used it in his calculations in the context of project S2 (2008-2010) funded by the Italian Civil Protection Authority.

Option 7

In this option, source geometry is a collection of points, but ground-motion characteristics are described with a generalized attenuation model. This option is considered impossible because generalized attenuation models contain information about individual events with known (although irrelevant) magnitudes. Since each event is associated to a fixed value of magnitude, occurrence probabilities for each of the events contained in the attenuation model, cannot be computed for continuous, arbitrary values of magnitude with the information provided by parametric seismicity descriptions, as earthquake magnitude exceedance rates. It must be remembered that, starting with magnitude exceedance rates, occurrence probabilities in given time frames can only be computed for magnitude intervals (magnitude "bins") and not for point values.

Option 8

Note that this option is similar to option 4, except that source geometry in option 8 is of the point-source type. In principle, this option could have been regarded a valid, since, when using generalized attenuation models, source geometry is irrelevant. However, we felt that option 4, in which the source is an area of a line that is given only for the purpose of visual feedback and dissaggregation, was more useful, and we inhibited this one to avoid confusion.

7. Site Effects

CRISIS permits inclusion of local site effects in hazard computations. Site effects are given to CRISIS in terms of amplification factors, that depend on site location, structural period and ground-motion level (in order to account for soil non-linearity).

Amplification factors are interpreted by CRISIS in the following way. Suppose that during the hazard computations, CRISIS requires to compute the median of the intensity at structural period T that would take place at site S due to an earthquake of magnitude M originating at hypocenter H. We will denote this intensity as $I(S,T,M,H)$.

Normally, $I(S,T,M,H)$ is computed using the attenuation relation or ground motion prediction model that the user has selected for the source to which H belongs, or using the special attenuation model that the user has assigned to the source-site combination to which S and H belong.

The value so computed is interpreted by CRISIS as the median intensity without site effects. But if site effects are given, then the median intensity that CRISIS will use for the hazard computations, I_S, is the product of $I(S,T,M,H)$ and the amplification factor given by the user, which depends on site location, structural period and ground motion level, I_0. We will denote this amplification factor as $A(S,T,I_0)$. In other words,

$$I_S(S,T,M,H)=I(S,T,M,H)\,A(S,T,I_0) \qquad (1)$$

Clearly, if no site effects are present, then $A(S,T,I_0)=1$. Note that while the median intensity is modified to account for site effects, the uncertainty in the intensity after site effects is the same that it was before site effects.

The user has to give CRISIS means to obtain the amplification factors $A(S,T,I_0)$. These factors are given to CRISIS by means of two binary files that will be described in the following paragraphs. Both files must have the same base name, but different extensions.

1) Predominant period file

This is a binary grid file in Surfer 6 binary format (*.grd). The main purpose of this file is to locate in space the grid for which amplification factors are given, as well as to give the grid's resolution. This grid contains as "z-values" the predominant ground periods associated to each point of the grid. Points with positive periods are interpreted as part of the area for which site effects are known. Points with negative periods are interpreted as outside the area for which site effects are known. Hence, for these points, the amplification factor will always be 1, regardless of period and ground motion level.

Extension *grd* is required for this file. For instance, MySiteEffects.grd.

2) Amplification factors file

This is also a binary file, with extension *ft*. For instance, MySiteEffects.ft.

This file contains the amplification factors themselves. As we have indicated, amplification factors depend on site location, structural period and ground-motion level. Dependence on ground-motion level is included to account for non-linear soil behavior. In view of this, amplification factors are given by means of a 4-index matrix.

The first two indexes are used to sweep through space, that is, rows and columns of a grid; please note that the size and location of the grid of amplification factors are exactly the same than for the grid of predominant periods. The third index sweeps through structural periods, while the fourth index sweeps through ground motion levels.

In principle, amplification factors for a given site and period can be different depending on the size of the ground motion. In general, CRISIS uses as an indicator of this size the intensity for the shortest period available for the GMPM that is used to compute the intensity without site effects. In most of the cases (but not always) this intensity corresponds to peak ground acceleration.

The format in which amplification factors must be given is described in the following table:

Block	Variable	Size	Comments
Header	A number 1	Integer	This field is reserved for future use
	Number of ground motion levels, NL	Integer	If NL=1, then elastic behavior is assumed
	Number of periods, NT	Integer	
	Ground motion level 1	Double	
	Ground motion level 2	Double	
	…	…	
	Ground motion level NL	Double	
	Period 1	Double	
	Period 2	Double	
	…	Double	
	Period NT	Double	

<table>
<tr><th>Block</th><th>Variable</th><th>Size</th><th>Comments</th></tr>
<tr><td rowspan="4">For site 1,1</td><td>Amplification function for ground-motion level 1</td><td>NT doubles</td><td rowspan="4">The amplification function for a given site and ground-motion level is a collection of NT numbers, one for each structural period. The first number is associated to Period 1, and so on.</td></tr>
<tr><td>Amplification function for ground-motion level 2</td><td>NT doubles</td></tr>
<tr><td>…</td><td>NT doubles</td></tr>
<tr><td>Amplification function for ground-motion level NL</td><td>NT doubles</td></tr>
<tr><td rowspan="5">For site 1,2</td><td>Amplification function for ground-motion level 1</td><td>NT doubles</td><td rowspan="4">The order of the sites is the same than for the associated predominant period grid, that is, starting from the low- left corner and advancing first the counter for the columns.</td></tr>
<tr><td>Amplification function for ground-motion level 2</td><td>NT doubles</td></tr>
<tr><td>…</td><td>NT doubles</td></tr>
<tr><td>Amplification function for ground-motion level NL</td><td>NT doubles</td></tr>
<tr><td></td><td></td><td>In other words, sites are described following the order of cross sections of constant y</td></tr>
<tr><td rowspan="4">For site Nx,Ny</td><td>Amplification function for ground-motion level 1</td><td>NT doubles</td><td rowspan="4">Nx and Ny are the number of grid lines along the X axis (columns) and the number of grid lines along the Y axis (rows), given in the associated predominant period grid file</td></tr>
<tr><td>Amplification function for ground-motion level 2</td><td>NT doubles</td></tr>
<tr><td>…</td><td>NT doubles</td></tr>
<tr><td>Amplification function for ground-motion level NL</td><td>NT doubles</td></tr>
</table>

The first column of the following table presents an example of the contents of a site-effects file with extension *ft*. We recall, however, that this file must be in binary format.

Value	Comments
1	A number 1, reserved for future use
3	3 ground motion levels
5	5 different structural periods
20	First ground motion level
100	Second ground motion level
300	Third ground motion level
0.0	First period for which amplifications are given
0.2	Second period for which amplifications are given
0.5	Third period for which amplifications are given

Value	Comments
1.0	Fourth period for which amplifications are given
2.0	Fifth period for which amplifications are given
1.3 1.5 2.3 1.0 0.9	Five amplifications factors, one for each structural period, for ground-motion level 1
1.2 1.4 2.2 0.9 0.8	Five amplifications factors, one for each structural period, for ground-motion level 2
1.1 1.3 2.1 0.7 0.7	Five amplifications factors, one for each structural period, for ground-motion level 3
2.3 2.5 3.3 2.0 1.9	Five amplifications factors, one for each structural period, for ground-motion level 1
2.2 2.4 3.2 1.9 1.8	Five amplifications factors, one for each structural period, for ground-motion level 2
2.1 2.3 3.1 1.7 1.7	Five amplifications factors, one for each structural period, for ground-motion level 3
...	
2.3 2.5 3.3 2.0 1.9	Five amplifications factors, one for each structural period, for ground-motion level 1
2.2 2.4 3.2 1.9 1.8	Five amplifications factors, one for each structural period, for ground-motion level 2
2.1 2.3 3.1 1.7 1.7	Five amplifications factors, one for each structural period, for ground-motion level 3

8. Logic trees

The following paragraphs, giving a brief introduction to logic trees in the context of seismic hazard analysis, have been taken from "On the Use of Logic Trees for Ground-Motion Prediction Equations in Seismic-Hazard Analysis" by Julian J. Bommer, Frank Scherbaum, Hilmar Bungum, Fabrice Cotton, Fabio Sabetta, and Norman A. Abrahamson, *Bulletin of the Seismological Society of America*, **Vol. 95**, No. 2, pp. 377–389, April 2005, doi: 10.1785/0120040073:

"Logic trees are widely used in probabilistic seismic hazard analysis as a tool to capture the epistemic uncertainty associated with the seismogenic sources and the ground-motion prediction models used in estimating the hazard..."

"Logic trees were first introduced into probabilistic seismic hazard analysis (PSHA) by Kulkarni et al. (1984) as a tool to capture and quantify the uncertainties associated with the inputs required to perform such an analysis, and they have since become a standard feature of PSHA (Coppersmith and Youngs, 1986; Reiter, 1990)..."

"Handling uncertainties is a key element of SHA [Seismic Hazard Analysis]. Distinction is made between two types of uncertainty in seismic hazard assessment, and these are given the adjectives aleatory and epistemic (e.g., Budnitz et al., 1997), terms used to replace and distinguish between the terms randomness and uncertainty, whose use has become ambiguous (Bommer, 2003). Uncertainties that are related to an apparent randomness in nature, such as the scatter associated with empirical relationships, are referred to as aleatory variability. If the aleatory variability can be measured, usually by fitting observations to an assumed probability distribution, it is then straightforward to incorporate this variability directly into the hazard calculations. The most important aleatory variability in SHA is that associated with ground-motion prediction equations, which is generally represented by the standard deviation of the logarithmic residuals of the predicted parameter. Standard practice in PSHA is now to integrate across this aleatory variability within the hazard calculations..."

"Uncertainties reflecting the incomplete knowledge of, say, seismicity, rupture characteristics, and seismic energy excitation, are referred to as epistemic. There are many epistemic uncertainties in any seismic hazard assessment, including the characteristics of the seismic source zones (be these area zones or specific faults), the model for the recurrence relationship, and the maximum earthquake magnitude. In PSHA, the established procedure is to incorporate the epistemic uncertainty into the calculations through the use of logic trees. The logic tree is set up so that for each of the steps in which there is epistemic uncertainty, separate branches are added for each of the choices that the analyst considers feasible. To each of these a normalized weight is assigned that reflects that analyst's confidence that this is the most correct model, and the weights are generally, but not necessarily, centered on a best estimate. The hazard calculations are then performed following all the possible branches through the logic tree, each analysis producing a single hazard curve showing ground motion against annual frequency of exceedance. The weighting of each hazard curve is determined by multiplying the weights along all the component branches..."

"For every branch added to a logic tree, a penalty is paid in terms of additional calculations; if there are multiple branches for each component of the hazard analysis, the total number of hazard calculations can rapidly become very large. For this reason it is advisable to avoid using branches with very small differences between the options that they carry, in cases when these options result in very similar nodes..."

"An important principle to follow in setting up a logic tree, but not always taken into account, is that the options represented by the branches extending from a single node should encompass the complete range of physical possibilities that particular parameter could be expected to take. This is consistent with the objective of the logic tree in capturing epistemic uncertainty, which arises from lack of knowledge. The branches should be set up so that, as knowledge improves, mainly through the gathering of more and better data, revised estimates for the parameters should fall within the bounds expressed by the logic-tree branches..."

In the context of CRISIS, each branch of a logic tree is formed by one data file (usually with extension *.dat) along with a measure of the degree of belief that the analyst has on each of the branches being the "true" one. Results from the different branches, along with the weights assigned to each branch, are computed using the combination rule that will be described in the following paragraphs.

Assume that the probability of exceeding level a of a intensity measure A at a site, in the i-th time frame, accoring to the j-th branch of a logic tree is $P_{ij}(A>a)$. Assume also that the probability of being the true one assigned to the j-th branch is w_j, $j=1,...,N$. It is required that the N weights add up to unity.

Then, the expected value of $P_{ij}(A>a)$ once all branches have been accounted for, $P_i(A>a)$, is given by:

$$P_i(A > a) = \sum_{j=1}^{N} P_{ij}(A > a)w_j \quad (1)$$

Results of the logic-tree combination will be given in the form of a new hazard model, with an associated *.dat file that will have the base name of the file that described the combination but with the extension *.dat.

This new hazard model can be loaded into CRISIS and the corresponding hazard results can be analyzed with CRISIS (hazard maps, exceedance probability curves, uniform hazard spectra) as if they were the results of a regular *.dat file. Disaggregation results, however, can not be obtained for the hazard resulting from the logic-tree combination.

9. Hazard disaggregation

Magnitude-distance disaggregation

Consider the basic hazard computation equation (see the basic theoretical background):

$$\Pr(A \le a \mid T_j) = \prod_{k=1}^{N} \prod_{i=1}^{Nm} \Pr(A \le a \mid M_i, T_j, k) \quad (1)$$

where $\Pr(A<a|T_j)$ is the probability of not exceeding intensity a at a site in the next T_j years, when subjected to a seismic regime composed by N point sources, each of which produces earthquakes of magnitudes M_1, M_2,...,M_{NM}. It can be noted that the product in equation 1 is composed by many terms, each of which corresponds to a particular magnitude value, M_i, and to a specific source-to-site distance, which is the one from source k to the site for which hazard is being computed.

In view of this, the contributions to $Pr(A<a|T_j)$ or to $Pr(A>a|T_j)$ could be grouped for a range of magnitudes (say, from M_1 to M_2) and a range of distances. This is the magnitude-distance disaggregation. These results indicate which combinations of magnitude and distance contribute more to the seismic hazard at a site, for a given intensity measure, for a given time frame, and at certain level of intensity, a in this case.

Let's say that hazard has been disaggregated, leading to a matrix of Ng rows (one for each magnitude range) and Nr columns (one for each distance range). The contents of each cell must be such that the following relation is satisfied:

$$\Pr(A \le a | T_j) = \prod_{l=1}^{Nr} \prod_{m=1}^{Nm} P_{lm} \quad (2)$$

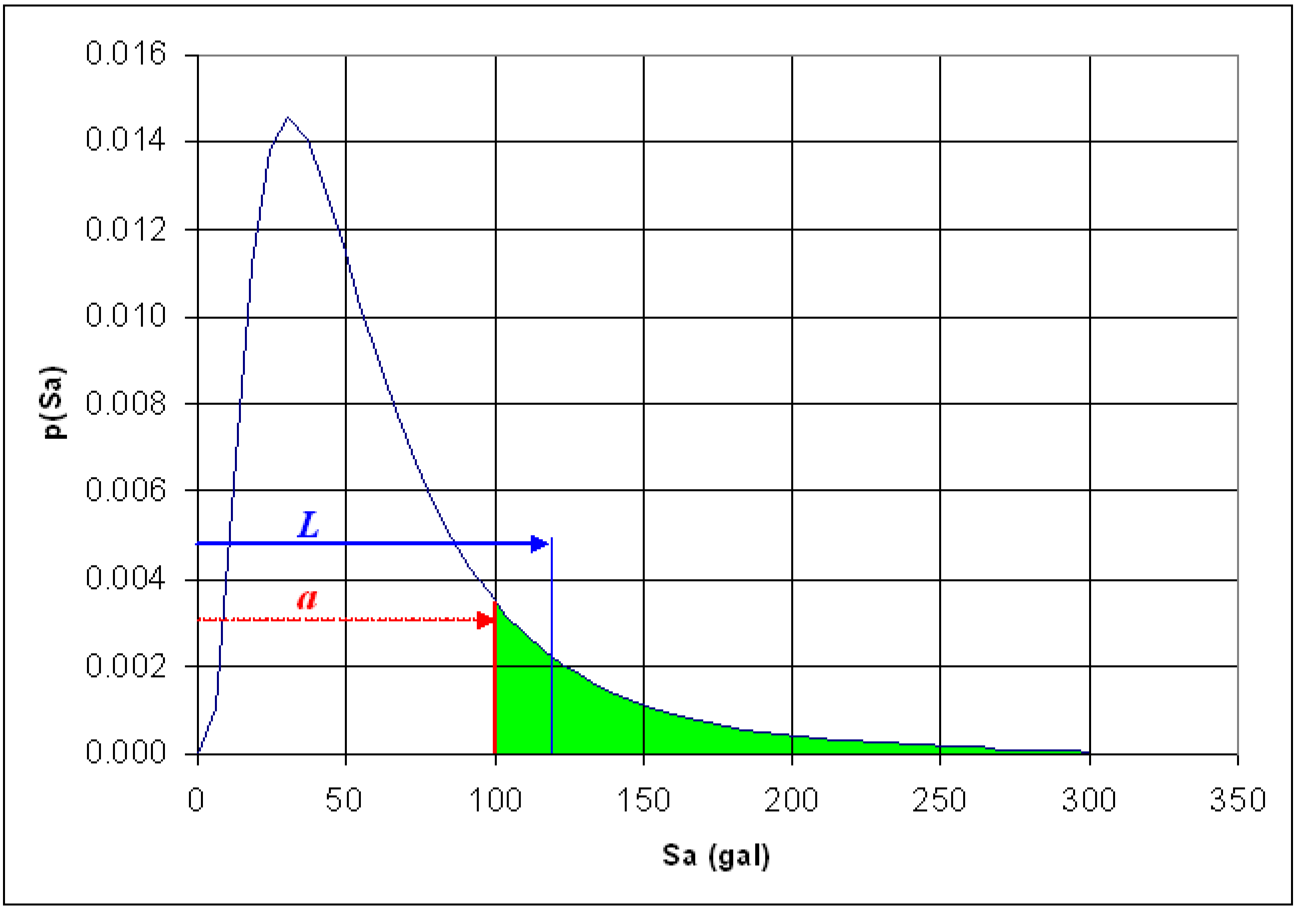
In other words, the original non-exceedance probability must be equal to the product of the non-exceedance probabilities disaggregated for each magnitude-distance bin. This means that, oppositely to what happens with intensity exceedance rates, which are additive, non-exceedance probabilities (or exceedance probabilities) are not additive, but multiplicative in the sense expressed by equation 2 above. In view of this, when seeing CRISIS disaggregation results, the user must not expect that the exceedance probabilities associated to each cell used for the disaggregation add up to the total exceedance probability computed for the same site, intensity value and time frame. As shown by the previous paragraphs, arithmetic of exceedance probabilities is more complex to that of intensity exceedance rates used in conventional hazard studies.

Epsilon disaggregation

In occasions, it is interesting to know which portions of the intensity probability density function contribute most to the seismic hazard at a given site. Consider the following equation, which is equation 1 but written in terms of exceedance probabilities:

$$\Pr(A > a \mid T_j) = 1 - \prod_{k=1}^{N} \prod_{i=1}^{Nm} \left[1 - \Pr(A > a \mid M_i, T_j, k)\right] \tag{3}$$

For given magnitude, time frame and source location, the term *Pr(A>a|Mi, Tj, k)* will be computed by calculating the area shown in green in the following figure:



The shape of the probability density function of *Sa* (shown in black in the previous figure) depends on magnitude, distance, and ground-motion prediction model employed, while *a* is an arbitrarily fixed value: the one for which seismic hazard is being computed.

However, it is sometimes of interest to know how much of the probability marked in green comes from the high percentiles of the distribution. For instance, how much of the probability comes from the area to the right of value *L*, shown in blue in the previous figure. Normally, *L* is indexed to an "epsilon" (ε) value, such that:

$$L = MED(A \mid M_i, T_j, k) \exp\left[\varepsilon \sigma_{LN}(A \mid M_i, T_j, k)\right] \tag{4}$$

where *MED(A|Mi, Tj, k)* and σ_{LN}*(A|Mi, Tj, k)* are, respectively, the median and the logarithmic standard deviation of *A* given magnitude *Mi* at source *k*; the value of ε is kept fixed for the whole analysis. In view of this, when an epsilon disaggregation is required, exceedance probabilities required to evaluate equation 4 are computed with:

$$\Pr(A > a \mid M_i, T_j, k) = \int_{L_{\max}}^{\infty} p_{A|M_i,T_j,k}(u)\,du \tag{5}$$

where $p_{A|Mi,\ Tj,\ k}()$ is the probability density function of A given magnitude Mi at source k, and:

$$L_{\max} = \max(L, a) \tag{6}$$

Interpretation of ε for other probability distributions

Usually, intensity A is assigned a lognormal probability distribution, so Equation 4 can be used to compute the lower integration limit, L. However, admits the possibility of using four different types of probability distributions: Lognormal, Gamma, Normal and Beta. In the three last cases, the meaning of ε is not unambiguously defined. In CRISIS, the following interpretations of ε are adopted:

For the Gamma distribution

$$L = E(A \mid M_i, T_j, k) + \varepsilon\sigma(A \mid M_i, T_j, k), \quad L \geq 0 \tag{7}$$

For the Normal distribution

$$L = E(A \mid M_i, T_j, k) + \varepsilon\sigma(A \mid M_i, T_j, k) \tag{8}$$

For the Beta distribution

$$L = E(A \mid M_i, T_j, k) + \varepsilon\sigma(A \mid M_i, T_j, k), \quad 0 \leq L \leq 1 \tag{9}$$

In the three cases above, $E(A|Mi,\ Tj,\ k)$ and $\sigma(A|Mi,\ Tj,\ k)$ are, respectively, the expected value and the standard deviation of A given magnitude Mi at source k.

10. Building a data file

CRISIS data files are constructed via a user graphic interface that is comprised of several screens and menu items. See below what pieces of information are given in each screen.

10.1 Open an existing input file

Button: 

Menu: File - Open

This command triggers an open file dialog to open an existing data file, usually with extension *.dat

10.2 Save data to a file

Button: 

Menu: File - Save As...

This command allows saving data into a data file, normally with extension *.dat.

Although data are written in a plain-text file, care must be taken when editing this file by hand.

10.3 Map and cities file selection

Button: 

Menu: Input - Maps

Give the name and path of the map file and the cities file. Both files are optional. By double clicking in the text box you can choose an existing file.

The map and cities information is a helpful visual reference but has not any influence on the computations.

10.4 Grid or list of sites

Button: 

Menu: Input - Grid of sites

This screen allows you to input the grid or list of sites for which seismic hazard will be computed. There are two options:

Grid of sites

Compute for a grid, defined by its origin, longitude and latitude increments, and number of lines in both directions. Hazard will be computed at the nodes of this grid.

List of sites

Select this option if you want to compute hazard for a list of sites with given coordinates. Double-click in the box to read the name of the file that contains the list of sites. The format of this text file is the following:

Number of cities

State_1, City_1, Longitude_1, Latitude_1

State_2, City_2, Longitude_2, Latitude_2

Grid reduction

It is possible to modify the basic rectangular grid by using optional polygons. Introducing one or more boundary polygons can reduce the initial rectangular grid of points. If polygons are given, the computation of hazard will be performed only for those points of the grid which are inside at least one of the polygons.

The polygon must be described in counter-clockwise order.

Select the Start polygon command to start drawing the polygon. Each click of the mouse defines a point of the polygon.

Choose End polygon command to close the polygon.

Command Delete selected polygon allows you to remove the selected polygon. To see the selected polygon, choose a polygon number and press the command draw. The polygon with the widest line is the selected polygon.

10.5 Geometry of the sources

Button: 

Menu: Input - Source Geometry

This screen allows entering the geometry of each seismic source. Sources can be areas, lines or points.

10.5.1. Source operations

Add Area: Use this button to add an area source to the hazard model.

Add Fault: Use this button to add a line source to the hazard model.

Delete: Delete the active source

Rename: Rename the active source

Import: Import fault geometry from a shape file or from an ssg file

Name: Select the active source using this combo box

Source is alive: Select if the source is alive or not. A source that is not alive is simply ignored in the hazard computations.

The total number of sources and the number of the active source will be shown in the corresponding labels.

10.5.2. Source vertex

For area or line sources, use this grid control to give the coordinates of the vertex of the active source. Use the right mouse button to insert or delete columns. Depths are always positive. In the case of point sources, vertex coordinates cannot be edited from this screen, and all changes must be made in their corresponding ssg file.

10.5.3. Fault length/rupture radius

Give parameters that relate magnitude to rupture length or rupture radius

10.5.4. Draw options

Choose whether the map, cities and computation sites will appear, for your reference, in the graphs. Choose also if the triangularization of the area sources will appear in the graphs.

10.5.5. Sources to draw

Active: Graphs will show only the active source

Selection: Graphs will show only the sources selected

Range: Graphs will show all sources with numbers in the range Start to End

Long/Lat plane: See the sources selected to draw in the horizontal (longitude-latitude) plane

Several planes: See the sources selected to draw in the three different planes

10.6 Rupture Area/Rupture Length

CRISIS allows choosing, for each source, the parameters that relate rupture area or rupture length with magnitude. These parameters can be either given by the user or chosen from a set of constants.

10.6.1. Area sources or Smoothed-seismicity geometries

The general relation is the following:

$$A = K_1 e^{K_2 M}$$

where A is the source area (in km^2), M stands for magnitude and K_1 and K_2 are constants given by the user or chosen from a set of constants. CRISIS has the following built-in sets of constants:

Model	K_1	K_2
Brune (1970)	0.00381	1.15130
Singh et al. (1980)	0.00564	1.15130

Model	K_1	K_2
Wells and Coppersmith (1994) Strike-slip	0.01100	1.03616
Wells and Coppersmith (1994) Reverse	0.00571	1.12827
Wells and Coppersmith (1994) Normal	0.02072	0.94406
Wells and Coppersmith (1994) All	0.01015	1.04768

10.6.2. Line sources

In this case, the fault length L (in km) is related to magnitude through:

$$L = K_3 e^{K_4 M}$$

The corresponding built-in set of constants, taken from Wells and Coppersmith (1994) are

Model	K_3	K_4
Surface Rupture Length (SRL), Strike-Slip	0.00028	1.70391
Surface Rupture Length (SRL), Reverse	0.00138	1.45063
Surface Rupture Length (SRL), Normal	0.00977	1.15129
Surface Rupture Length (SRL), All	0.00060	1.58878
Subsurface Rupture Length (RLD), Strike-Slip	0.00269	1.42760
Subsurface Rupture Length (RLD), Reverse	0.00380	1.33550
Subsurface Rupture Length (RLD), Normal	0.01318	1.15129

The built-in sets of constants presented in the previous tables are given in file CRISIS2008.rpr, located in the installation directory of the CRISIS executable file. These constants can be edited, or new constants can be manually added to this file. The general format for a new constant would be, in a single row, separated by commas, the following:

Author , K_1, K_2, K_3, K_4

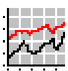
Where *Author* is a string used for identification purposes (normally indicating the author of the corresponding relation) and K_1, K_2, K_3, K_4 are the given constants. For area sources, it is required that $K_3 = K_4 = 0$, while for line sources it is required that $K_1 = K_2 = 0$.

10.6.3. References:

Donald L. Wells and Kevin J. Coppersmith (1994). New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement. Bulletin of the Seismological Society of America, Vol. 84, No. 4, pp. 974-1002, August 1994.

S. K. Singh, E. Bazan, and L. Esteva (1980). Expected Earthquake Magnitude from a Fault. Bulletin of the Seismological Society of America, Vol. 70, No. 3, pp. 903-914, June 1980.

10.7 Data on spectral ordinates

Button: 

Menu: Input - Spectral ordinates

This screen allows entering the parameters for each spectral ordinate (or, in general, intensity measure) for which seismic hazard will be computed.

10.7.1. Total number of spectral ordinates

Is the total number of different intensity measures for which hazard is to be computed. Frequently, the different intensity measures refer to spectral ordinates for different structural periods. In this case, spectral attenuation relations are needed.

10.7.2. Actual spectral ordinate

Use this control to move from one intensity measure to the other.

10.7.3. Structural period of spectral ordinate

This is the value of the structural period associated to this measure of intensity. The values given in the attenuation tables must be coherent with the period values given here.

10.7.4. Lower limit of intensity level

See Points defining exceedance rate curves

10.7.5. Upper limit for intensity level

See Points defining exceedance rate curves

10.7.6. Units

The units of the intensity measures (for reference only).

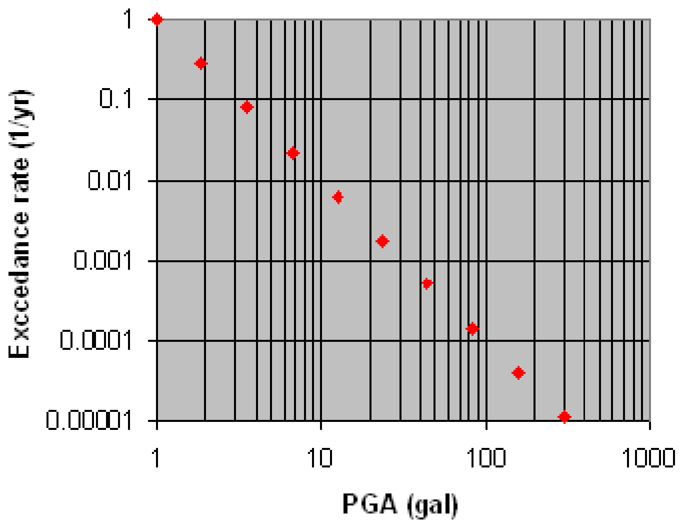
10.7.7. Number of levels of intensity for which seismic hazard will be computed.

See Points defining exceedance rate curves

10.8 Points defining exceedance probability curves

Lower limit, upper limit and number of levels for hazard computation

Exceedance probabilities will be computed for the number of levels selected and between the lower and upper limit given by the user, with logarithmic spacing. For instance, if 10 levels of intensity (PGA in this case) are chosen between, say, 1 gal and 300 gal, the exceedance probabilities will be given as shown in the following figure:



There is always a compromise between speed and precision: the larger the number of points to define the curve or the larger the intensity range, the slower the computation time. Usually, not more than 20 points are required to accurately define the exceedance probability curves.

10.9 Seismicity

Button: 

Menu: Input - Source seismicity

This screen allows you to enter the information about the seismicity of each source.

1. Select an occurrence model: Gutenberg-Richter, Characteristic Earthquake or Non-Poisson. See Seismicity models used for more details.

2. Give the appropriate data.

10.9.1. For the Gutenberg-Richter model

GR Model

Threshold magnitude(M_0). The catalog of earthquakes is assumed to be complete for $M>M_0$. Earthquakes with $M<M_0$ are absolutely ignored.

Lambda(M0): Exceedance rate of magnitude M_0. The units are earthquakes/year.

Expected value of beta. Expectation of the "b-value" for the source, given in terms of the natural logarithm.

Coefficient of variation of beta. Coefficient of variation of the "b-value" for the source, given in terms of the natural logarithm.

Parameters defining Mu

Expected value. Expected value of the maximum magnitude for the source. See details

Uncertainty range (+/-). A number indicating that the maximum magnitude will have a uniform probability density function, centered at its expected value, plus minus this number. See details

10.9.2. For the characteristic model

Median value of the times between characteristic earthquakes with $M>M_0$. This is the inverse of the exceedance rate for $M>M_0$.

Standard deviation of the magnitude of the characteristic earthquake. It is assumed independent of time.

Minimum possible magnitude of a characteristic earthquake. Earthquakes with $M<M_0$ are absolutely ignored

Maximum magnitude of the characteristic earthquake to be used in the integration process.

Parameters *D* and *F* define the expected magnitude as a function of time, as in the slip-predictable model. It is assumed that

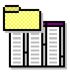
$$E(M|T00)=max(M_0,D+F*LN(T00))$$

where *T00* is the time elapsed since the last characteristic event. Of course, if *F* is set to zero, then *D* becomes the expected time-independent magnitude of the characteristic earthquake.

10.9.3. For the Non-Poisson model

Give, by double-clicking, the name of the nps file that stores the non-Poissonian earthquake occurrence probabilities associated to this source.

10.10 Attenuation data

Button: 

Menu: Input - Attenuation data

This screen allows entering information about the attenuation relations to be used in the hazard analysis. In general, an attenuation relation describes the probabilistic link between earthquake magnitudes, source to site distance, and intensity (see Probabilistic interpretation of attenuation relations).

In general, CRISIS must know what relation to use to attenuate earthquakes generated in each source. In principle, each source could have its associated attenuation relation. In practice, only a few different attenuation relations are used in a particular analysis (e.g., one for subduction events and another for shallow crustal earthquakes).

CRISIS can perform a simultaneous hazard analysis for several intensity measures (e.g., PGA and spectral accelerations for different periods). Therefore, CRISIS must also know for how many different intensity measures the analysis will be carried out, and the associated attenuation relations. Frequently, the different intensity measures are spectral response values for different periods, so a uniform hazard spectrum can be constructed.

In view of this, the general operations that have to be performed in this screen are:

- Select and add the attenuation models to be used in the analysis.
- Assign one of these models to each source.

10.10.1. Selection of attenuation models

CRISIS admits three families of attenuation models:

Attenuation tables. In these tables, relations between earthquake characteristics and intensities at a site are given in terms of the following parameters: magnitude, structural period, source-site distance and depth. For the first moment (usually the median of a lognormal distribution), the attenuation relations are matrices in which the rows run for the magnitude and the columns run for the distance. Note that when using attenuation tables, the relations between magnitude, distance and intensity do not need to be of parametric nature, since the intensity medians are given, point by point, for magnitude-distance combinations.

Built-In models. These are popular models, published in the literature, in which magnitude, distance and intensity are probabilistically related by, usually, a set of formulas or parametric equations. There is a set of built-in models ready to use in CRISIS and there is also the possibility of adding new models.

Generalized models. Generalized attenuation models are non-parametric probabilistic descriptions of the ground motions produced by an earthquake. In the context of CRISIS, a generalized attenuation model is a collection of probabilistic footprints, one for each of the events considered in the analysis. Each footprint gives, in probabilistic terms, the geographical distribution of the intensities produced by this event.

Use the following buttons to create and edit the collection of attenuation models:

Add Model

Edit model

Delete model

10.10.2. Assignment of attenuation models

Once one or several attenuation models have been added, the user must assign one attenuation model to each source.

See special attenuation models for a more complex use of attenuation models.

10.11 Site effects

Button: 

Menu: Input - Site effects

Add or delete site effects grids to be used in the hazard analysis. See the format of the site effects grids in this link.

10.12 Global parameters

Button: Σ

Menu: Input - Global parameters

This screen allows you to enter information concerning:

The spatial integration procedure

The value of the time frames for which seismic hazard will be computed

The distance to be used for M-R disaggregation

10.12.1. Integration parameters

Parameter controlling the integration process

All sources or sub-sources farther away than this number (in Km) will be ignored in the spatial integration process.

Minimum triangle size

Sources will be subdivided into sub-sources whose characteristic size will not be less than this number. For area sources, the characteristic size is the square root of its area. For a fault source, the characteristic size is its length.

Minimum (Distance/Triangle size) ratio

Sources will be subdivided until the ratio between source-site distance and characteristic size of the sub-source is larger than this number.

10.12.2. Time frames for which hazard will be computed

Give in this table the values of the time frames for which hazard will be computed. These values must be coherent with those given in the non-Poissonian seismicity files (nps) associated to the sources.

10.12.3. Distance used for M-R disaggregation

The M-R disaggregation results give, for a site, intensity measure and intensity level, the distribution of exceedance rates as a function of magnitude and distance. Choose which distance will be used as the argument of this M-R distribution.

10.13 Logic tree computation

Button:

This screen allows definition of a logic tree, a tool that is frequently used to account for epistemic uncertainty in the computation of seismic hazard.

In the context of CRISIS, each branch of a logic tree is formed by one data file (usually with extension *.dat) along with a measure of the degree of belief that the analyst has on each of the branches being the "true" one. Therefore, this screen allows construction of the logic tree by way of informing CRISIS which *.dat files form the branches of the tree and what weight is assigned to each of the branches. The functions provided for this aim are the following:

 Use this option to create a new logic tree.

 Use this option to open a previously created logic tree. Logic trees are defined in text files, usually with extension *.ltc (logic.tree combination) that contains, for each branch, the name (path included) of the CRISIS input data file associated to this branch, as well as the weight assigned to each branch, in the form of a numerical integer. This weight, normalized by the sum of the weights of all branches, is interpreted as the probability of being the "true" one.

The format of the text file is the following:

FileName1.dat, Weight 1

FileName2.dat, Weight 2

...

FileNameN.dat, Weight N

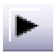
Note that the file name and its associated probability must be separated by a comma.

 Use this option to save a logic tree, usually in a text file with extension *.ltc

 Add a new branch to the logic tree

 Delete the selected branch of the logic tree

 Change the weight of the selected branch

 Perform the logic-tree combination. Before proceeding to do the logic-tree computations, CRISIS will perform the following checks:

1) That all *.dat files exist and contain data of a valid hazard model.

2) That there is coherency among the various *.dat files.

Also, CRISIS will only recompute the branches whose associated *.dat files have changed since the last execution. In other words, CRISIS will not recompute branches that have already been computed.

Results of the logic-tree combination will be given in the form of a new hazard model, with an associated *.dat file that will have the base name of the *.ltc file that described the combination but with the extension *.dat.

This new hazard model can be loaded into CRISIS and the corresponding hazard results can be analyzed with CRISIS (hazard maps, exceedance probability curves, uniform hazard spectra) as if they were the results of a regular *.dat file. Disaggregation results, however, can not be obtained for the hazard resulting from the logic-tree combination.

10.14 Validate data, save and start execution

Button: 

Menu: Run - Validate and Run

This command allows you to execute a run after you have finished with the input.

If data are still required when this command is executed, CRISIS will issue a message showing the data required. Enter the data needed, save the data file, and choose Run to initiate execution.

Also, in some cases CRISIS will issue a set of warnings, pointing to possible inconsistencies in the input data. While these warning do not prevent the user from computing hazard, CRISIS issues them so the user is aware of potential problems.

After a successful run, a success screen appears showing which output files were generated and where they are located.

10.15 Hazard maps

This command is enabled after a successful CRISIS run and allows seeing hazard maps, exceedance probability curves and uniform hazard spectra, with the following options:

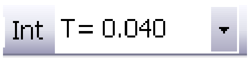
10.15.1. Types of hazard maps

Two types of hazard maps can be generated:

1. If switch  is selected, the map will show intensities associated to a fixed exceedance probability in a given time frame. Give the required exceedance probability and time frame the corresponding boxes.
2. If switch  is selected, the map will show exceedance probabilities associated to fixed values of time frame and intensity. Give the required values of time frame and intensity in the corresponding boxes.

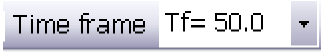
In both cases, the map will be generated for the intensity measure chosen in the box Intensity.

10.15.2. Intensity measure



Select in this combo box the intensity measure for which maps and hazard curves are to be generated.

10.15.3. Time frame



Select in this combo box the time frame for which maps and hazard curves are to be generated

10.15.4. City Selection

Select a city of the list in order to see:

1. The hazard curve at the city for the selected intensity measure and time frame.
2. Depending on whether the fixed intensity or the fixed exceedance probability switch is selected:

- The uniform hazard spectrum
- A graph showing the exceedance probabilities associated to a fixed value of spectral intensity and time frame

10.15.5. Exceedance probability

Give the exceedance probability that will be used to draw a hazard map or a uniform hazard spectrum.

10.15.6. Intensity value

Give the fixed intensity value that will be used to draw a map with show exceedance probabilities associated to fixed values of time frame and intensity or to draw a spectrum showing the exceedance probabilities associated to a fixed value of spectral intensity and time frame, as a function of period.

10.15.7. Save hazard map

Give a name to the file in which the hazard map will be saved and the format for the map. There are three format options:

Bitmap

The file saved will be simply a bitmap image of the map shown in CRISIS hazard-map screen.

DSSA Surfer ASCII format (Taken from SURFER 8 Help file)

DSSA grid files contain five header lines that provide information about the size and limits of the grid, followed by a list of Z values. See details.

XYZ file

This is an ASCII file containing (longitude, latitude, hazard) sets for all the nodes in the computation grid.

10.15.8. Draw hazard map

Draws the hazard map with the selected options

10.15.9. Site Selection

Click into a point of the hazard map in order to see:

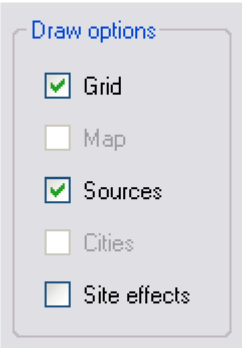
1. The hazard curve for the selected intensity measure and time frame
2. Depending on whether the fixed intensity or the fixed probability switch is selected:

- The uniform hazard spectrum
- A graph showing the exceedance probabilities associated to fixed values of time frame and spectral intensity

10.15.10. Zoom Tools

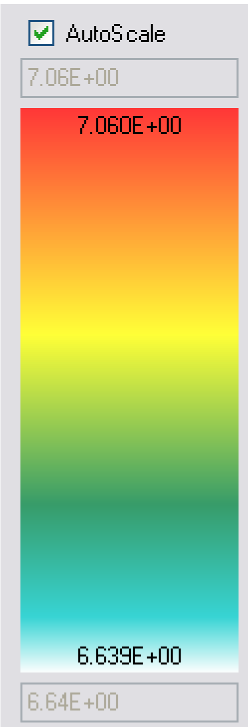
 Use these tools to zoom-in and zoom-out from the map, or to define a rectangular area to zoom-in.

10.15.11. Draw options



Check in this frame the drawing items that will appear in the hazard map.

10.15.12. Color scale



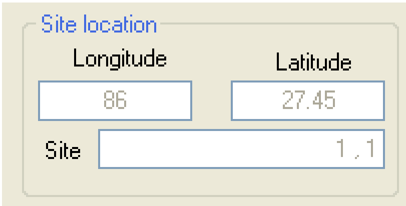
Select in this section whether or not you want CRISIS to auto-scale the colors associated to the map. In case that auto-scale is not chosen, the user must give upper and lower values for the scaling process. Also, moving the mouse along the color scale will indicate the numerical values associated to a particular color.

10.16 Magnitude-Distance disaggregation results

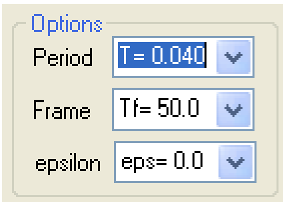
CRISIS can generate exceedance rates disaggregated by magnitude, distance and "epsilon" value. The program presents these values graphically, in the disaggregation screen.

To see disaggregation results in this screen the following operations are needed:

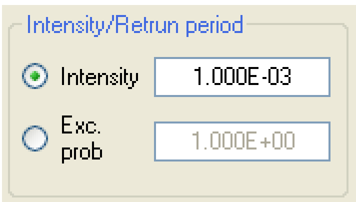
Select the site for which results are desired by pointing to it with the mouse in the right-hand side picture box, which shows either the computation grid or the list of sites. The actual point used for the disaggregation computations will be the one belonging to the grid or list of computation sites that is the closest to the point clicked by the user. The actual point used for disaggregation will be indicated in the "Site Location" frame:



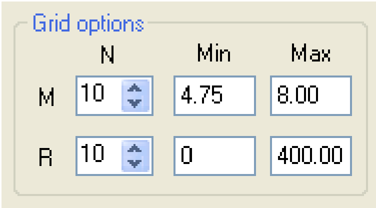
Choose the desired intensity measure (usually, a spectral ordinate associated to a structural period), time frame and epsilon value in the "Options" frame:



Choose, in the "Intensity/Return period" frame, the value of intensity for which disaggregation results will be presented or choose the desired exceedance probability (CRISIS will compute exceedance probability if intensity is given or intensity if exceedance probability is given):

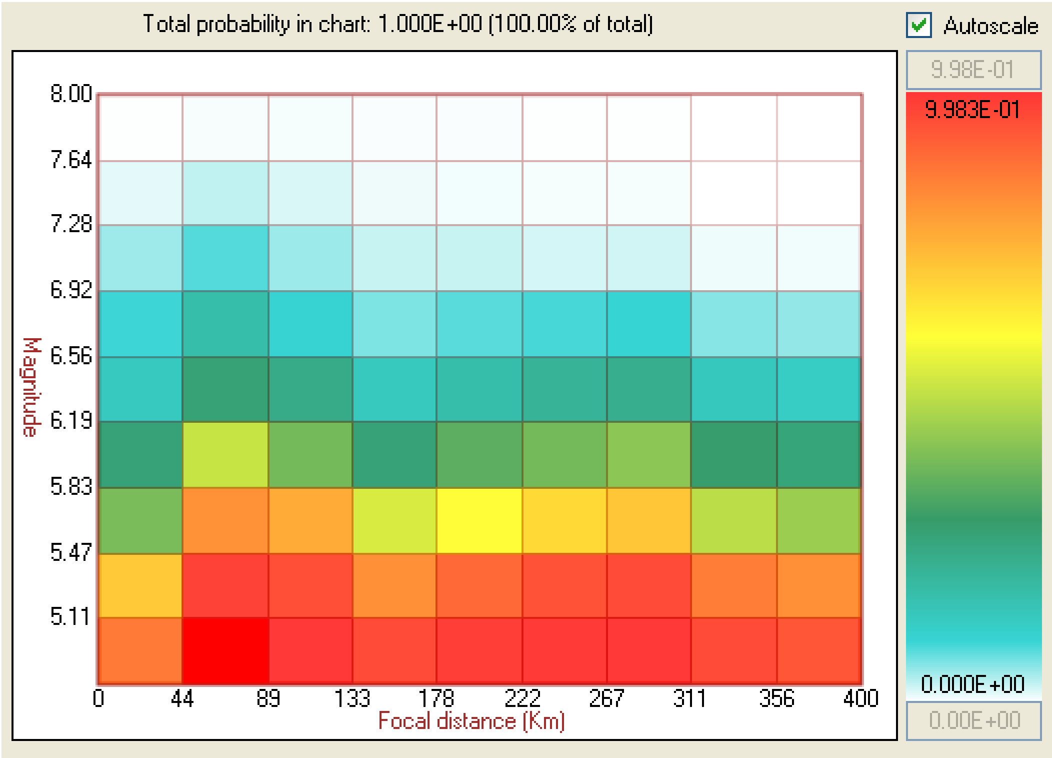


Use the "Grid options" frame to define the size of the disaggregation chart, giving the limits for magnitude and distance, as well as the number of cells in each direction:



In general, disaggregation charts will be redrawn every time a parameter change is made.

Results will be shown in a disaggregation chart like the following:



The value in each cell is the probability that the selected intensity level is exceeded in a given time frame if only earthquakes with magnitudes and distance within the cell's range are accounted for. The color scale will adjust automatically if "Autoscale" is selected. The user, however, can change the upper (red color) and lower (white color) limits of the scale, once the "Autoscale" option is disactivated.

On top of the disaggregation chart, CRISIS shows the following legend:

"Total probability in chart: 0.000E+00 (100.00% of total)"

This legend indicates that, with the current grid settings (magnitude and distance limits) and the selected "epsilon" level, the total probability of exceedance is a certain percentage of the total exceedance probability (for all magnitudes and distances, and epsilon equal to minus infinity).

However, the total probability is computed by interpolation of a previously computed hazard curve for the site. If computation of this hazard curve was made for a small number of intensity levels, the interpolation will not be exact, and percentages reported by the legend could be somehow inexact. To solve this problem, simply compute the hazard curves with a larger number of intensity levels.

When seeing CRISIS disaggregation results, the user must not expect that the exceedance probabilities associated to each cell used for the disaggregation add up to the total exceedance probability computed for the same site, intensity value and time frame. As shown in this link, arithmetic of exceedance probabilities is more complex to that of intensity exceedance rates used in conventional hazard studies.

Disaggregation charts can be saved using button “Save”, which will save in a text file the currently displayed chart settings, as well as the matrix of disaggregated hazard values.

10.17 Help

Opens the help file of CRISIS

11. Output Files

Upon the user's selection, CRISIS can generate several output files. The possible output files are:

Results file (*.res)

This file contains a printout of the name of the run, the values assigned to the variables, characteristics of the attenuation models, geometrical and seismicity description of the sources, the data defining the computation grid, etc. It also gives a summary of the computations for each site, indicating which sources are of interest the site and which sources were skipped. The computer times are also written.

If the users chooses to do so, this file also gives the final results, that is, exceedance probabilities for each time frame, site and type of intensity. See an example of the *.res file

Graphics file (*.gra)

This file contains a brief identification header, and the exceedance rates for the types and levels of intensity requested. This file can be used as input file to plot intensity versus exceedance rate curves. See an example of the *.gra file.

Source by source results (*.fue)

This file contains exceedance probabilities by source, for each site and time frame. See an example of the *.fue file.

Additionally, CRISIS will generate binary files (one for each intensity measure used in the analysis) to be able to generate its own maps.

11.1 Example RES file

The following is an example of the *.res file. Basically, it contains all the data given by the user to define source geometry, source seismicity and attenuation characteristics, as well as other global parameters.

```
*********************************************

CRISIS 2009 Version 3.4.2.0

15/04/2010 07:33:20 p.m.


La Arbolada-Jalisco
```

VALUES OF PARAMETERS FOR THE PRESENT PROJECT

Number of regions or seismic sources: 45

Number of attenuation models: 3

Number of structural periods: 9

Number of intensity levels: 15

Number of magnitudes for integration: 9

Type of computation sites: Lista

Max. dist. of integration: 500.000

Min. distance/Triangle size ratio 5.000

Minimum triangle size (km) 7.000

INTENSITIES

I T(I) A0(I) AU(I) UNITS

1 1.00E-02 1.00E+00 1.50E+03

2 1.50E-01 1.00E+00 4.00E+03

3 3.00E-01 1.00E+00 3.30E+03

4 5.00E-01 1.00E+00 2.20E+03

5 1.00E+00 1.00E+00 1.30E+03

6 2.00E+00 1.00E+00 7.50E+02

7 3.00E+00 1.00E+00 6.00E+02

8 4.00E+00 1.00E+00 4.00E+02

9 5.00E+00 1.00E+00 3.00E+02

TIME FRAMES

I TF(I)

1 5.00E+01

INITIAL GRID OF POINTS

File of list of sites: C:\Crisis 2008 Extra\Pruebas\México\CD_3Ciudades.TXT

THE INITIAL GRID WAS MODIFIED WITH THE FOLLOWING POLYGONS:

Number of polygons: 1

Polygon 1. Number of vertex: 16

LONG LAT

-117.7324 32.7306

-116.4633 27.6343

-113.8458 24.3694

-110.0386 21.7417

-104.1692 17.0435

-97.5065 14.1769

-89.8128 13.7787

-86.1642 18.9546

-85.6883 23.2546

-90.7646 22.9361

-94.3339 21.0250

-95.8409 27.3157

-100.5999 31.1380

-105.8348 32.6509

-111.9422 33.4472

-117.0185 33.9250

ATTENUATION MODELS

Model: 1 ATCOSTAm_Trunc

Of class: Crisis2008.NewAttenuation.AttenuationClasses.AttenuationTable

Brief description: Not available

Original units: Not available

Dimension: Acceleration

Spectral period range: 0.005 to 6

Valid distance range: 5 to 500

Valid magnitude range: 4 to 8.5

Type of distance metric: Focal

Residuals distribution: LogNormal

Parameter: Units coefficient=1

Parameter: Attenuation Table=C:\Crisis 2008 Extra\Pruebas\México\ATCOSTAm_Trunc.ATN

Model: 2 Abrahamson y Silva No HW S/S

Of class: Crisis2008.NewAttenuation.AttenuationClasses.AbrahamsonAndSilva97

Brief description: Model by Abrahamon and Silva...

Original units: cm/s/s

Dimension: Acceleration

Spectral period range: 0.01 to 5

Valid distance range: 0.1 to 200

Valid magnitude range: 4 to 7.5

Type of distance metric: Rrup

Residuals distribution: LogNormal

Parameter: Units coefficient=1

Parameter: Site is in the hanging wall=False

Parameter: Sigma truncation=-1

Parameter: Soil Type=0

Parameter: Style of fault=2

Model: 3 NormalDaniel_RRup_5_Trunc_CR2007

Of class: Crisis2008.NewAttenuation.AttenuationClasses.AttenuationTable

Brief description: Not available

Original units: Not available

Dimension: Acceleration

Spectral period range: 0.005 to 6

Valid distance range: 0.01 to 500

Valid magnitude range: 4 to 8.5

Type of distance metric: Focal

Residuals distribution: LogNormal

Parameter: Units coefficient=1

Parameter: Attenuation Table=C:\Crisis 2008 Extra\Pruebas\México\NormalDaniel_RRup_5_Trunc_CR2007.atn

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PROPERTIES OF THE SOURCES

REGION: 1 Baja California intraplaca norte

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 10

Long Lat Depth(km)

-119.2500 34.5600 10.0000

-118.1250 33.0600 10.0000

-117.0000 31.5600 10.0000

-115.8750 30.0600 10.0000

-114.7500 28.5600 10.0000

-113.5800 29.4400 10.0000

-114.7050 30.9400 10.0000

-115.8300 32.4400 10.0000

-116.9950 33.9400 10.0000

-118.0800 35.4400 10.0000

REGION: 2 Baja California intraplaca sur

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 10

Long Lat Depth(km)

-114.7500 28.5600 10.0000

-113.6250 27.0600 10.0000

-112.5000 25.5600 10.0000

-111.3750 24.0600 10.0000

-110.2500 22.5600 10.0000

-109.0800 23.4400 10.0000

-110.2050 24.9400 10.0000

-111.3300 26.4400 10.0000

-112.4550 27.9400 10.0000

-113.5800 29.4400 10.0000

REGION: 3 Baja California interplaca norte

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 10

Long Lat Depth(km)

-117.0000 33.9900 7.0000

-116.3050 33.0680 7.0000

-115.6100 32.1450 7.0000

-114.9150 31.2230 7.0000

-114.2200 30.3000 7.0000

-113.5300 30.8200 7.0000

-114.2230 31.7430 7.0000

-114.9150 32.6650 7.0000

-115.6080 33.5880 7.0000

-116.3000 34.5100 7.0000

REGION: 4 Baja California interplaca centro

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 6

Long Lat Depth(km)

-114.2200 30.3000 10.0000

-113.3600 29.1550 10.0000

-112.5000 28.0100 10.0000

-111.8100 28.5300 10.0000

-112.6700 29.6750 10.0000

-113.5300 30.8200 10.0000

REGION: 5 Baja California interplaca sur

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 7

Long Lat Depth(km)

-108.0000 22.0000 10.0000

-107.1000 23.0000 10.0000

-108.6500 25.0000 10.0000

-110.5500 27.6100 10.0000

-111.8600 28.4800 10.0000

-112.5000 28.0000 10.0000

-110.2500 25.0000 10.0000

REGION: 6 Sierra Madre Occidental

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 5

Long Lat Depth(km)

-110.0000 29.0000 20.0000

-110.5500 27.6100 20.0000

-108.6500 25.0000 20.0000

-106.0000 25.0000 20.0000

-106.0000 29.0000 20.0000

REGION: 7 Cuencas y Sierras

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 7

Long Lat Depth(km)

-110.0000 34.0000 20.0000

-110.0000 29.0000 20.0000

-106.0000 29.0000 20.0000

-106.0000 25.0000 20.0000

-104.0000 25.0000 20.0000

-104.0000 29.0000 20.0000

-105.0000 34.0000 20.0000

REGION: 8 Cuenca de Burgos

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 4

Long Lat Depth(km)

-104.0000 27.5000 20.0000

-104.0000 22.0000 20.0000

-99.5000 22.0000 20.0000

-99.5000 27.5000 20.0000

REGION: 9 Interfaz Pacífico-Rivera

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 6

Long Lat Depth(km)

-110.0000 18.5000 5.0000

-106.0000 18.5000 5.0000

-106.0000 20.0000 5.0000

-108.0000 20.0000 5.0000

-108.0000 22.0000 5.0000

-110.0000 22.0000 5.0000

REGION: 10 Sismicidad difusa 1

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 14

Long Lat Depth(km)

-105.0000 34.0000 20.0000

-104.0000 29.0000 20.0000

-104.0000 27.5000 20.0000

-99.5000 27.5000 20.0000

-99.5000 22.0000 20.0000

-104.0000 22.0000 20.0000

-104.0000 25.0000 20.0000

-108.6500 25.0000 20.0000

-106.0000 21.5000 20.0000

-105.5000 20.0000 20.0000

-105.0000 21.0000 20.0000

-100.2800 20.5400 20.0000

-96.5000 20.2000 20.0000

-97.0000 34.0000 20.0000

REGION: 11 Sismicidad difusa 2

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 6

Long Lat Depth(km)

-116.3000 34.5100 20.0000

-113.5300 30.8200 20.0000

-111.8100 28.5300 20.0000

-110.5500 27.6100 20.0000

-110.0000 29.0000 20.0000

-110.0000 34.0000 20.0000

REGION: 12 Centroamérica

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 4

Long Lat Depth(km)

-88.2000 15.8000 5.0000

-85.3000 15.8000 5.0000

-85.3000 17.0000 5.0000

-88.2000 17.0000 5.0000

REGION: 13 Subducción Chiapas

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 4

Long Lat Depth(km)

-94.0180 14.5270 15.0000

-92.6670 13.6200 15.0000

-92.3010 14.0690 30.0000

-93.6130 15.1000 30.0000

REGION: 14 Subducción Brecha de Tehuantepec

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 5

Long Lat Depth(km)

-95.0000 15.1970 15.0000

-94.0180 14.5270 15.0000

-93.6130 15.1000 30.0000

-93.9870 15.3920 30.0000

-95.0000 15.9100 30.0000

REGION: 15 Subducción Oaxaca Este

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 5

Long Lat Depth(km)

-96.3490 15.5260 15.0000

-96.0000 15.5000 15.0000

-95.0000 15.1970 15.0000

-95.0000 15.9100 30.0000

-96.2670 16.2570 30.0000

REGION: 16 Subducción Oaxaca 1

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 4

Long Lat Depth(km)

-97.3540 15.6700 15.0000

-96.3490 15.5260 15.0000

-96.2670 16.2570 30.0000

-97.2100 16.4430 30.0000

REGION: 17 Subducción Oaxaca 2

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 4

Long Lat Depth(km)

-97.8770 15.7750 15.0000

-97.3540 15.6700 15.0000

-97.2100 16.4430 30.0000

-97.6550 16.5280 30.0000

REGION: 18 Subducción Oaxaca Oeste

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 4

Long Lat Depth(km)

-98.2420 15.8730 15.0000

-97.8870 15.7750 15.0000

-97.6550 16.5280 30.0000

-98.0350 16.5910 30.0000

REGION: 19 Subducción Ometepec

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 4

Long Lat Depth(km)

-99.6630 16.3430 15.0000

-98.2420 15.8730 15.0000

-98.0350 16.5910 30.0000

-99.4380 17.0100 30.0000

REGION: 20 Subducción San Marcos

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 4

Long Lat Depth(km)

-100.0620 16.4730 15.0000

-99.6630 16.3430 15.0000

-99.4380 17.0100 30.0000

-99.8360 17.1430 30.0000

REGION: 21 Subducción Guerrero

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 4

Long Lat Depth(km)

-101.0050 16.7970 15.0000

-100.0620 16.4730 15.0000

-99.8360 17.1430 30.0000

-100.8100 17.4370 30.0000

REGION: 22 Subducción Petatlán

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 4

Long Lat Depth(km)

-101.7010 17.0440 15.0000

-101.0050 16.7970 15.0000

-100.8100 17.4370 30.0000

-101.4990 17.7090 30.0000

REGION: 23 Subducción Michoacán

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 4

Long Lat Depth(km)

-103.1350 17.7010 15.0000

-101.7010 17.0440 15.0000

-101.4990 17.7090 30.0000

-102.9160 18.3930 30.0000

REGION: 24 Subducción Colima 1

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 4

Long Lat Depth(km)

-103.8680 18.3000 15.0000

-103.1350 17.7010 15.0000

-102.9160 18.3930 30.0000

-103.6120 18.7610 30.0000

REGION: 25 Subducción Brecha de Colima

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 4

Long Lat Depth(km)

-104.4570 18.7170 15.0000

-103.8680 18.3000 15.0000

-103.6120 18.7610 30.0000

-104.1820 19.1730 30.0000

REGION: 26 Subducción Jalisco

Characteristic model

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 8

Long Lat Depth(km)

-104.4570 18.7170 15.0000

-104.1820 19.1730 15.0000

-105.0000 20.0000 15.0000

-105.1300 20.2560 15.0000

-105.5000 21.0000 30.0000

-106.0000 21.0000 30.0000

-105.7000 20.0000 30.0000

-105.0000 19.1000 30.0000

REGION: 27 Jalisco nuevo

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 8

Long Lat Depth(km)

-106.0000 21.0000 15.0000

-105.7000 20.0000 15.0000

-105.0000 19.1000 15.0000

-104.0000 18.4000 15.0000

-103.7300 18.8400 30.0000

-104.0000 19.0000 30.0000

-105.0000 20.0000 30.0000

-105.5000 21.0000 30.0000

REGION: 28 Gro-Mich nuevo

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 11

Long Lat Depth(km)

-104.0000 18.4000 15.0000

-103.0000 17.6000 15.0000

-102.0000 17.1500 15.0000

-101.0000 16.8000 15.0000

-100.0000 16.4500 15.0000

-99.0000 16.1000 15.0000

-98.8200 16.8100 30.0000

-100.0000 17.2000 30.0000

-101.0000 17.5000 30.0000

-102.0000 17.9000 30.0000

-103.7300 18.8400 30.0000

REGION: 29 Oaxaca nuevo

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 10

Long Lat Depth(km)

-99.0000 16.1000 15.0000

-98.0000 15.8000 15.0000

-97.0000 15.6000 15.0000

-96.0000 15.5000 15.0000

-95.0000 15.2000 15.0000

-95.0000 15.9000 30.0000

-96.0000 16.2000 30.0000

-97.0000 16.4000 30.0000

-98.0000 16.6000 30.0000

-98.8200 16.8100 30.0000

REGION: 30 Chiapas nuevo

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: ATCOSTAm_Trunc

Area source

Number of vertex : 5

Long Lat Depth(km)

-95.0000 15.2000 15.0000

-92.6700 13.6200 15.0000

-92.3000 14.0800 30.0000

-94.0000 15.4000 30.0000

-95.0000 15.9000 30.0000

REGION: 31 Prof. Interm Oeste nueva

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: NormalDaniel_RRup_5_Trunc_CR2007

Area source

Number of vertex : 14

Long Lat Depth(km)

-105.5000 21.0000 30.0000

-105.0000 20.0000 30.0000

-104.0000 19.0000 30.0000

-102.0000 17.9000 30.0000

-101.0000 17.5000 30.0000

-100.0000 17.2000 30.0000

-99.0000 16.8500 30.0000

-99.0000 19.1000 100.0000

-100.0000 19.2000 100.0000

-101.0000 19.1000 100.0000

-102.0000 19.2000 100.0000

-103.3000 19.3000 100.0000

-104.0000 19.8000 100.0000

-105.0000 21.0000 100.0000

REGION: 32 Prof. int. centro nueva

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: NormalDaniel_RRup_5_Trunc_CR2007

Area source

Number of vertex : 10

Long Lat Depth(km)

-99.0000 16.8500 30.0000

-98.0000 16.6000 30.0000

-97.0000 16.4000 30.0000

-96.0000 16.2000 30.0000

-95.0000 15.9000 30.0000

-95.0000 17.2000 100.0000

-96.0000 18.3000 100.0000

-97.0000 18.8000 100.0000

-98.0000 18.9000 100.0000

-99.0000 19.1000 100.0000

REGION: 33 Prof. int. Este nueva

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: NormalDaniel_RRup_5_Trunc_CR2007

Area source

Number of vertex : 6

Long Lat Depth(km)

-95.0000 15.9000 30.0000

-94.0000 15.4000 30.0000

-92.3000 14.0800 30.0000

-91.5000 14.9000 100.0000

-94.0000 16.5000 100.0000

-95.0000 17.2000 100.0000

REGION: 34 Petrolera

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 10

Long Lat Depth(km)

-92.5000 18.5000 30.0000

-92.0000 19.0000 30.0000

-93.0000 19.1250 30.0000

-94.0000 19.2500 30.0000

-96.0000 19.5000 30.0000

-96.0000 18.5000 30.0000

-95.5000 18.0000 30.0000

-95.0000 17.5000 30.0000

-94.0000 17.5000 30.0000

-93.0000 17.5000 30.0000

REGION: 35 Golfo

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 6

Long Lat Depth(km)

-96.5000 21.0000 15.0000

-96.5000 20.2000 15.0000

-96.0000 19.5000 15.0000

-92.0000 19.0000 15.0000

-91.0000 21.0000 15.0000

-94.0000 21.0000 15.0000

REGION: 36 Eje volcánico

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 8

Long Lat Depth(km)

-105.5000 20.0000 15.0000

-103.1500 18.5000 15.0000

-99.0000 18.5000 15.0000

-96.0000 18.5000 15.0000

-96.0000 19.5000 15.0000

-96.5000 20.2000 15.0000

-100.2800 20.5400 15.0000

-105.0000 21.0000 15.0000

REGION: 37 Intraplaca

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 7

Long Lat Depth(km)

-103.1500 18.5000 15.0000

-97.0000 16.0000 15.0000

-95.0000 16.2000 15.0000

-94.0000 16.0000 15.0000

-93.0000 17.5000 15.0000

-96.0000 18.5000 15.0000

-99.0000 18.5000 15.0000

REGION: 38 Chiapas Volcán

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 6

Long Lat Depth(km)

-93.0000 17.5000 15.0000

-94.0000 16.0000 15.0000

-91.8000 14.0000 15.0000

-89.0000 14.0000 15.0000

-88.0000 16.0000 15.0000

-90.2500 17.2500 15.0000

REGION: 39 Profundos Chiapas

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: NormalDaniel_RRup_5_Trunc_CR2007

Area source

Number of vertex : 7

Long Lat Depth(km)

-96.0000 18.3000 100.0000

-95.0000 17.2000 100.0000

-94.0000 16.5000 100.0000

-91.9000 15.1500 100.0000

-91.6000 15.5000 200.0000

-93.3000 16.7500 200.0000

-95.0000 18.0000 200.0000

REGION: 40 Motagua 1

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 7

Long Lat Depth(km)

-93.0000 15.2000 5.0000

-92.4000 14.4500 5.0000

-90.0000 14.5000 5.0000

-89.0000 14.5000 5.0000

-88.0000 15.1000 5.0000

-88.0000 16.3000 5.0000

-89.5500 15.2000 5.0000

REGION: 41 Motagua 2

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 7

Long Lat Depth(km)

-93.0000 15.2000 10.0000

-92.4000 14.4500 10.0000

-90.0000 14.5000 10.0000

-89.0000 14.5000 10.0000

-88.0000 15.1000 10.0000

-88.0000 16.3000 10.0000

-89.5500 15.2000 10.0000

REGION: 42 Motagua 3

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 7

Long Lat Depth(km)

-93.0000 15.2000 15.0000

-92.4000 14.4500 15.0000

-90.0000 14.5000 15.0000

-89.0000 14.5000 15.0000

-88.0000 15.1000 15.0000

-88.0000 16.3000 15.0000

-89.5500 15.2000 15.0000

REGION: 43 Polochic 1

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 4

Long Lat Depth(km)

-94.0000 16.0000 5.0000

-93.0000 15.2000 5.0000

-89.5500 15.2000 5.0000

-88.0000 16.3000 5.0000

REGION: 44 Polochic 2

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 4

Long Lat Depth(km)

-94.0000 16.0000 10.0000

-93.0000 15.2000 10.0000

-89.5500 15.2000 10.0000

-88.0000 16.3000 10.0000

REGION: 45 Polochic 3

Gutenberg-Richter

SOURCE IS ACTIVE

Base Attenuation model: Abrahamson y Silva No HW S/S

Area source

Number of vertex : 4

Long Lat Depth(km)

-94.0000 16.0000 15.0000

-93.0000 15.2000 15.0000

-89.5500 15.2000 15.0000

-88.0000 16.3000 15.0000

SEISMICITY

Gutenberg-Richter sources

Source name M0 Lambda0 E(Beta) c(Beta) E(Mu) D(Mu)

Baja California intraplaca nor 4.500 1.14E+00 0.970 0.097 5.800 0.000

Baja California intraplaca sur 4.500 1.21E+00 0.933 0.036 5.800 0.000

Baja California interplaca nor 4.500 2.51E+00 1.782 0.093 7.700 0.300

Baja California interplaca cen 4.500 7.26E-01 1.637 0.168 7.400 0.400

Baja California interplaca sur 4.500 2.09E+00 1.674 0.082 7.200 0.600

Sierra Madre Occidental 4.500 1.16E-01 2.880 0.030 5.600 0.000

Cuencas y Sierras 4.500 2.69E-01 2.880 0.030 5.600 0.000

Cuenca de Burgos 4.500 1.87E-01 2.880 0.030 5.600 0.000

Interfaz Pacífico-Rivera 4.500 3.41E+00 1.736 0.088 7.200 0.000

Sismicidad difusa 1 4.500 6.58E-01 2.880 0.030 5.600 0.000

Sismicidad difusa 2 4.500 1.80E-01 2.880 0.030 5.600 0.000

Centroamérica 4.500 4.97E-01 1.942 0.180 7.700 0.300

Jalisco nuevo 4.500 2.01E+00 1.827 0.110 7.200 0.000

Gro-Mich nuevo 4.500 4.79E+00 1.547 0.077 7.200 0.000

Oaxaca nuevo 4.500 6.72E+00 1.847 0.063 7.200 0.000

Chiapas nuevo 4.500 1.89E+01 2.059 0.037 7.200 0.000

Prof. Interm Oeste nueva 4.500 2.16E+00 1.699 0.097 7.800 0.200

Prof. int. centro nueva 4.500 1.71E+00 1.576 0.110 7.900 0.200

Prof. int. Este nueva 4.500 2.78E+00 1.761 0.087 7.800 0.200

Petrolera 4.500 6.05E-01 3.050 0.209 6.700 0.500

Golfo 4.100 1.05E-01 2.704 0.459 6.500 0.500

Eje volcánico 4.500 2.49E-01 1.884 0.223 7.200 0.300

Intraplaca 4.500 1.44E+00 1.889 0.124 6.500 0.500

Chiapas Volcán 4.500 1.61E+00 2.005 0.119 7.000 0.200

Profundos Chiapas 4.500 2.52E+00 2.207 0.093 7.500 0.300

Motagua 1 5.000 2.77E-01 2.234 0.309 7.800 0.000

Motagua 2 5.000 2.77E-01 2.234 0.309 7.800 0.000

Motagua 3 5.000 2.77E-01 2.234 0.309 7.800 0.000

Polochic 1 5.000 1.20E-01 2.187 0.105 7.800 0.000

Polochic 2 5.000 1.20E-01 2.187 0.105 7.800 0.000

Polochic 3 5.000 1.20E-01 2.187 0.105 7.800 0.000

Characteristic model sources

Source name Med(T) T0 D F sM M0 Mu

Subducción Chiapas 18.700 20.000 7.500 0.000 0.270 7.000 8.400

Subducción Brecha de Tehuantep 24.700 200.000 7.500 0.000 0.270 7.000 8.400

Subducción Oaxaca Este 24.800 26.000 7.500 0.000 0.270 7.000 8.400

Subducción Oaxaca 1 39.400 13.000 7.500 0.000 0.270 7.000 8.400

Subducción Oaxaca 2 77.900 63.000 7.500 0.000 0.270 7.000 8.400

Subducción Oaxaca Oeste 104.700 23.000 7.500 0.000 0.270 7.000 8.400

Subducción Ometepec 26.700 9.000 7.500 0.000 0.270 7.000 8.400

Subducción San Marcos 89.900 29.000 7.500 0.000 0.270 7.000 8.400

Subducción Guerrero 39.700 80.000 7.500 0.000 0.270 7.000 8.400

Subducción Petatlán 52.600 12.000 7.500 0.000 0.270 7.000 8.400

Subducción Michoacán 25.600 6.000 7.500 0.000 0.270 7.000 8.400

Subducción Colima 1 47.500 18.000 7.500 0.000 0.270 7.000 8.400

Subducción Brecha de Colima 56.700 183.000 7.500 0.000 0.270 7.000 8.400

Subducción Jalisco 19.800 57.000 7.500 0.000 0.270 7.000 8.400

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WARNINGS ABOUT MAGNITUDE-DISTANCE RANGES VALIDITY

Region 3, Baja California interplaca norte: The maximum magnitude in the region is larger than the maximum valid magnitude of GMPE Abrahamson y Silva No HW S/S (7.7 > 7.5)

Region 12, Centroamérica: The maximum magnitude in the region is larger than the maximum valid magnitude of GMPE Abrahamson y Silva No HW S/S (7.7 > 7.5)

Region 40, Motagua 1: The maximum magnitude in the region is larger than the maximum valid magnitude of GMPE Abrahamson y Silva No HW S/S (7.8 > 7.5)

Region 41, Motagua 2: The maximum magnitude in the region is larger than the maximum valid magnitude of GMPE Abrahamson y Silva No HW S/S (7.8 > 7.5)

Region 42, Motagua 3: The maximum magnitude in the region is larger than the maximum valid magnitude of GMPE Abrahamson y Silva No HW S/S (7.8 > 7.5)

Region 43, Polochic 1: The maximum magnitude in the region is larger than the maximum valid magnitude of GMPE Abrahamson y Silva No HW S/S (7.8 > 7.5)

Region 44, Polochic 2: The maximum magnitude in the region is larger than the maximum valid magnitude of GMPE Abrahamson y Silva No HW S/S (7.8 > 7.5)

Region 45, Polochic 3: The maximum magnitude in the region is larger than the maximum valid magnitude of GMPE Abrahamson y Silva No HW S/S (7.8 > 7.5)

The integration distance Rmax is greater than the maximum valid distance of GMPE Abrahamson y Silva No HW S/S (500 > 200)

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11.2 Example GRA file

This files gives hazard results in terms of probabilities of exceeding intensity values in different time frames. In the following example we show the portion of the file that corresponds to only one site. In the cases of computations for several sites, blocks of data similar to the one presented will be written for each site.

The example presented was computed for 3 intensity measures, each with 10 intensity levels, and for 3 different time frames.

Example gra file				
CRISIS 2009	Version 2.8.0.0		Program name and version	File header
17/12/2009 00:00	03:58:55 a.m.		Date and time of the run	
Prueba No Poissoniana			Name of the run	

Example gra file					
Site:	-0.2	-0.25	Site coordinates		
Intensity 1	T=0.050			This block gives hazard values for the same site	
Level	Time Frame 1	Time Frame 2	Time Frame 3		
1.00E+02	8.10E-01	9.84E-01	1.00E+00	Probability of exceeding the level of intensity number 1 indicated in the first column, in three different time frames	
1.54E+02	3.93E-01	7.13E-01	9.17E-01		
2.39E+02	9.72E-02	2.26E-01	4.00E-01		
3.68E+02	1.26E-02	3.13E-02	6.16E-02		
5.69E+02	8.78E-04	2.19E-03	4.38E-03		
8.79E+02	3.28E-05	8.19E-05	1.64E-04		
1.36E+03	6.97E-07	1.74E-06	3.48E-06		
2.10E+03	9.66E-09	2.42E-08	4.82E-08		
3.24E+03	9.99E-11	2.50E-10	4.98E-10		
5.00E+03	8.06E-13	2.01E-12	3.99E-12		
Intensity 2	T=0.150				
Level	Time Frame 1	Time Frame 2	Time Frame 3		
1.00E+02	9.80E-01	1.00E+00	1.00E+00	Probability of exceeding the level of intensity number 2 indicated in the first column, in three different time frames	
1.62E+02	7.77E-01	9.76E-01	9.99E-01		
2.61E+02	3.47E-01	6.55E-01	8.81E-01		
4.22E+02	7.74E-02	1.82E-01	3.32E-01		
6.81E+02	8.90E-03	2.21E-02	4.37E-02		
1.10E+03	5.24E-04	1.31E-03	2.62E-03		
1.78E+03	1.54E-05	3.84E-05	7.68E-05		
2.87E+03	2.26E-07	5.65E-07	1.13E-06		
4.64E+03	1.84E-09	4.60E-09	9.20E-09		
7.50E+03	1.00E-11	2.51E-11	5.01E-11		
Intensity 3	T=0.300				

Example gra file					
Level	Time Frame 1	Time Frame 2	Time Frame 3		
1.00E+02	9.62E-01	1.00E+00	1.00E+00	Probability of exceeding the level of intensity number 3 indicated in the first column, in three different time frames	
1.62E+02	7.33E-01	9.63E-01	9.99E-01		
2.61E+02	3.38E-01	6.43E-01	8.72E-01		
4.22E+02	8.60E-02	2.01E-01	3.62E-01		
6.81E+02	1.23E-02	3.04E-02	5.99E-02		
1.10E+03	9.69E-04	2.42E-03	4.84E-03		
1.78E+03	4.03E-05	1.01E-04	2.02E-04		
2.87E+03	8.43E-07	2.11E-06	4.22E-06		
4.64E+03	8.60E-09	2.15E-08	4.30E-08		
7.50E+03	4.31E-11	1.08E-10	2.15E-10		

11.3 Example FUE file

This file gives of the contribution of each source to the exceedance probabilities at a site. In the example below, for a single site, values of probability of exceedance generated by each of the 2 sources present in the model are shown, for 2 different intensity measures, ten different intensity values and three different rime frames.

The user should remember that probabilities are not additive. This means that, for the same site, intensity measure, intensity level and time frame, the addition of the exceedance probabilities associated to all the individual sources does not give the total probability of exceedance. Please see the basic theoretical background in order to know how the arithmetic of exceedance probabilities works.

Site: -0.2 -0.25		
Intensity 1 T=0.050 Time frame 1 Tf=10.000		
Level	Region 01	Region 02
1.00E+02	5.64E-01	5.64E-01
1.54E+02	2.21E-01	2.21E-01
2.39E+02	4.98E-02	4.98E-02
3.68E+02	6.34E-03	6.34E-03
5.69E+02	4.39E-04	4.39E-04
8.79E+02	1.64E-05	1.64E-05
1.36E+03	3.48E-07	3.48E-07
2.10E+03	4.83E-09	4.83E-09
3.24E+03	4.99E-11	4.99E-11

5.00E+03	4.05E-13	4.01E-13
Intensity 1 T=0.050 Time frame 2 Tf=25.000		
Level	Region 01	Region 02
1.00E+02	8.74E-01	8.74E-01
1.54E+02	4.64E-01	4.64E-01
2.39E+02	1.20E-01	1.20E-01
3.68E+02	1.58E-02	1.58E-02
5.69E+02	1.10E-03	1.10E-03
8.79E+02	4.10E-05	4.10E-05
1.36E+03	8.71E-07	8.71E-07
2.10E+03	1.21E-08	1.21E-08
3.24E+03	1.25E-10	1.25E-10
5.00E+03	1.01E-12	1.00E-12
Intensity 1 T=0.050 Time frame 3 Tf=50.000		
Level	Region 01	Region 02
1.00E+02	9.84E-01	9.84E-01
1.54E+02	7.12E-01	7.13E-01
2.39E+02	2.25E-01	2.26E-01
3.68E+02	3.13E-02	3.13E-02
5.69E+02	2.19E-03	2.19E-03
8.79E+02	8.18E-05	8.19E-05
1.36E+03	1.74E-06	1.74E-06
2.10E+03	2.41E-08	2.42E-08
3.24E+03	2.49E-10	2.50E-10
5.00E+03	1.99E-12	2.00E-12
Intensity 2 T=0.150 Time frame 1 Tf=10.000		
Level	Region 01	Region 02
1.00E+02	8.60E-01	8.60E-01
1.62E+02	5.27E-01	5.27E-01
2.61E+02	1.92E-01	1.92E-01
4.22E+02	3.95E-02	3.95E-02
6.81E+02	4.46E-03	4.46E-03
1.10E+03	2.62E-04	2.62E-04
1.78E+03	7.68E-06	7.68E-06
2.87E+03	1.13E-07	1.13E-07
4.64E+03	9.20E-10	9.20E-10

7.50E+03	5.02E-12	5.02E-12
Intensity 2 T=0.150 Time frame 2 Tf=25.000		
Level	Region 01	Region 02
1.00E+02	9.93E-01	9.93E-01
1.62E+02	8.46E-01	8.46E-01
2.61E+02	4.13E-01	4.13E-01
4.22E+02	9.58E-02	9.58E-02
6.81E+02	1.11E-02	1.11E-02
1.10E+03	6.55E-04	6.55E-04
1.78E+03	1.92E-05	1.92E-05
2.87E+03	2.82E-07	2.82E-07
4.64E+03	2.30E-09	2.30E-09
7.50E+03	1.25E-11	1.25E-11
Intensity 2 T=0.150 Time frame 3 Tf=50.000		
Level	Region 01	Region 02
1.00E+02	1.00E+00	1.00E+00
1.62E+02	9.76E-01	9.76E-01
2.61E+02	6.55E-01	6.55E-01
4.22E+02	1.82E-01	1.82E-01
6.81E+02	2.21E-02	2.21E-02
1.10E+03	1.31E-03	1.31E-03
1.78E+03	3.84E-05	3.84E-05
2.87E+03	5.64E-07	5.65E-07
4.64E+03	4.60E-09	4.60E-09
7.50E+03	2.50E-11	2.51E-11

12. Appendix: GMPM currently supported by CRISIS

12.1 Abrahamson and Silva (1997)

Class name	Crisis2008.NewAttenuation.AttenuationClasses.AbrahamsonAndSilva97
Distance metric	Rrup
Valid distance range	0.1 to 200 Km
Valid magnitude range	4 to 7.5
Valid period range	0.01 to 5 (sec)
Original units	cm/s/s
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal
Short name	Abrahamson and Silva (1997)
Brief description	Horizontal spectral accelerations for shallow crustal earthquakes in tectonically active regions, world-wide
Number of parameters	5
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Site is in the hanging wall
Possible values	True or False
Parameter name	Sigma truncation
Possible values	-1E+20 to 1E+20
Parameter name	Soil Type
Possible values	Deep soil; Rock or shallow soil;
Parameter name	Style of fault
Possible values	Other (including strike-slip); Reverse/Oblique; Reverse;

Reference: N.A. Abrahamson and W. Silva, Empirical Response Spectral Attenuation Relations for Shallow Crustal Earthquakes, *Seismological Research Letters*, vol 68, num 1, pp 94- 127), January/February 1997

12.2 Akkar and Bommer (2007)

Class name	Crisis2008.ExtraGMPE.AkkarBommer07
Distance metric	JyB

Valid distance range	1 to 100 Km
Valid magnitude range	5 to 7.6
Valid period range	0 to 4 (sec)
Original units	cm/s/s
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal
Short name	Akkar and Bommer (2007)
Brief description	Attenuation relation obtained from 532 accelerograms from the strong motion databank of Europe and Middle East.
Number of parameters	5
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Damping
Possible values	30 %; 20 %; 10 %; 5 %; 2 %;
Parameter name	Sigma truncation
Possible values	-1E+20 to 1E+20
Parameter name	Fault type
Possible values	Unspecified; Reverse; Normal;
Parameter name	Ground type
Possible values	Stiff Soil; Soft Soil; Otherwise;

Reference: Akkar and J. Bommer, Prediction of elastic displacement response spectra in Europe and the Middle East, *Earthquake Engineering and Structural Dynamics*, Pages 1275–1301, February 2007, DOI: 10.1002/eqe.679.

12.3 Boore and Atkinson (2008)

Class name	Crisis2008.ExtraGMPE.BooreAtkinson08
Distance metric	JyB
Valid distance range	1 to 200 Km
Valid magnitude range	5 to 8
Valid period range	0 to 10 (sec)
Original units	g
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal
Short name	Boore and Atkinson (2008)
Brief description	Attenuation relationships for PGA and 5% damped PSA, for shallow crustal earthquakes in active tectonic enviroments, worldwide.

Number of parameters	7
Parameter name	Data
Possible values	Vs30; Ground type and Geom mean of Vs30;
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Sigma truncation
Possible values	-1E+20 to 1E+20
Parameter name	Geometric mean of Vs30
Possible values	NEHRP Class Boundaries (rounded); Based on Measured Velocities in NGA Flatfile (Suggested); Vs30 in Boore(2003); Measured & Inferred Vs30 in NGA Flatfile; Measured Vs30 in NGA flatfile;
Parameter name	Fault type
Possible values	Thrust/reverse; Normal; Strike-slip; Unspecified;
Parameter name	Ground type
Possible values	NERHP E; NERHP D; NERHP C; NERHP B; NERHP A;
Parameter name	Vs30
Possible values	1E-20 to 1E+20

Reference: D. Boore and G. Atkinson, Ground-Motion Prediction Equations for the Average Horizontal Component of PGA, PGV, and 5%-Damped PSA at Spectral Periods between 0.01 s and 10.0 s, *Earthquake Spectra*, Volume 24- 1, pages 99–138, February 2008

12.4 Cambell and Bozorgnia (2003)

Class name	Crisis2008.ExtraGMPE.CampbellBozorgnia04
Distance metric	JyB
Valid distance range	1 to 60 Km
Valid magnitude range	5 to 7.5
Valid period range	0.03 to 4 (sec)
Original units	g
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal
Short name	Campbell and Bozorgnia (2003)
Brief description	Equations developed for and tectonically active, shallow crustal regions located troughout the world, for 5% damping ratio.
Number of parameters	7

Parameter name	Component
Possible values	Vertical; Horizontal;
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Sigma truncation
Possible values	-1E+20 to 1E+20
Parameter name	Fault type
Possible values	Generic(unknown); Reverse or thrust; Thrust; Reverse; Strike slip or normal;
Parameter name	Ground type
Possible values	BC boundary; Generic rock; Generic soil; Firm rock; Soft rock; Very firm soil; Firm Soil;
Parameter name	PGA type
Possible values	Uncorrected; Corrected;
Parameter name	Standard deviation calculate
Possible values	By Mw; By PGA(recomended);

Reference: K. Campell and B. Bozorgnia, Updated Near-Source Ground-Motion (Attenuation) Relations for the Horizontal and Vertical Components of Peak Ground Acceleration and Acceleration Response Spectra, *Bulletin of the Seismological Society of America*, Vol. 93-1, pages 314–331, February 2003.

12.5 Cauzzi and Faccioli (2008) (Vertical, 5% damped)

Class name	Crisis2008.ExtraGMPE.CauzziFaccioli08Vertical
Distance metric	Focal
Valid distance range	6 to 150 Km
Valid magnitude range	5 to 7.2
Valid period range	0.05 to 20.0000000000001 (sec)
Original units	cm/s/s
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal
Short name	Cauzzi and Faccioli (2008; vertical SA)
Brief description	Empirical equations for attenuation of crustal earthquakes worldwide, for vertical the vertical component of the spectral acceleration, for 5% damping
Number of parameters	3
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Ground type

Possible values	D; C; B; A;
Parameter name	Sigma truncation
Possible values	-1E+20 to 1E+20

Reference: C. Cauzzi and E. Faccioli. Broadband (0.05 to 20 s) prediction of displacement response spectra based on worldwide digital records, *J Seismol* 12, Pages 453–475, April 2008, DOI 10.1007/s10950-008-9098-y. 2008.

12.6 Cauzzi and Faccioli (2008) Simple version

Class name	Crisis2008.ExtraGMPE.CauzziFaccioli08Simple
Distance metric	Focal
Valid distance range	6 to 150 Km
Valid magnitude range	5 to 7.2
Valid period range	0.033 to 20 (sec)
Original units	cm/s/s
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal
Short name	Cauzzi and Faccioli (2008; simple version)
Brief description	Empirical equations for attenuation of crustal earthquakes in tectonically active zones, worldwide. This simple version does not require parameters, and corresponds to the complex GMPM of Cauzzi and Faccioli (2008) for 5% damping and unspecified ground and fault types.
Number of parameters	2
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Sigma truncation
Possible values	-1E+20 to 1E+20

Reference: C. Cauzzi and E. Faccioli. Broadband (0.05 to 20 s) prediction of displacement response spectra based on worldwide digital records, *J Seismol* 12, Pages 453–475, April 2008, DOI 10.1007/s10950-008-9098-y. 2008.

12.7 Cauzzi and Faccioli (2008) (Full model)

Class name	Crisis2008.NewAttenuation.AttenuationClasses.CauzziFaccioli08
Distance metric	Focal
Valid distance range	6 to 150 Km
Valid magnitude range	5 to 7.2
Valid period range	0.033 to 20 (sec)

Original units	cm/s/s
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal
Short name	Cauzzi and Faccioli (2008)
Brief description	Empirical equations for attenuation of horizontal spectral accelerations for crustal earthquakes in tectonically active zones, worldwide
Number of parameters	6
Parameter name	Damping ratio
Possible values	30%; 20%; 10%; 5%;
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Ground type
Possible values	D; C; B; A; Unspecified. In this case, Vs30 applies;
Parameter name	Fault type
Possible values	Strike-slip; Reverse; Normal; Unspecified;
Parameter name	Sigma truncation
Possible values	-1E+20 to 1E+20
Parameter name	Vs30
Possible values	-1E+20 to 1E+20

Reference: C. Cauzzi and E. Faccioli. Broadband (0.05 to 20 s) prediction of displacement response spectra based on worldwide digital records, *J Seismol* 12, Pages 453–475, April 2008, DOI 10.1007/s10950-008-9098-y. 2008.

12.8 Pasolini et al. (2008)

Class name	Crisis2008.ExtraGMPE.PasoliniEtAl08
Distance metric	Epicentral
Valid distance range	0 to 140 Km
Valid magnitude range	4 to 7
Valid period range	0 to 0 (sec)
Original units	Mercalli-Cancani-Sieberg Intensity
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.MCSI
Residual distribution	Normal
Short name	Pasolini et al. (2008)
Brief description	Relationships for attenuation of seismic intensity in Italy, using the Parametric Catalog of Italian Earthquakes (CPTI04) and the related database of macroseismic intensity observations in Italy (DBMI04).

Number of parameters	0

Reference: Pasolini et al., The Attenuation of Seismic Intensity in Italy, Part II: Modeling and Validation, *Bulletin of the Seismological Society of America*, Vol. 98-2, pages 692–708, April 2008, DOI: 10.1785/0120070021

12.9 Sabetta and Pugliese (1996) Fault distance

Class name	Crisis2008.ExtraGMPE.SabettaPugliese96FaultDist
Distance metric	JyB
Valid distance range	0 to 100 Km
Valid magnitude range	4.6 to 6.8
Valid period range	0.01 to 4 (sec)
Original units	cm/s/s
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal
Short name	Sabetta and Pugliese (1996; fault distance)
Brief description	Developed using Italian strong-ground motion data. Original coefficients are for PGA and spectral pseudovelocities; the latter have been converted to pseaudoaccelerations. This version uses Joyner and Boore distance.
Number of parameters	3
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Sigma truncation
Possible values	-1E+20 to 1E+20
Parameter name	Soil type
Possible values	Deep alluvium; Shallow alluvium; Rock;

Reference: F. Sabetta and Pugliese, Estimation of Response Spectra and Simulation of Nonstationary Earthquake Ground Motions, *Bulletin of the Seismological Society of America*, Vol. 86- 2, pages 337-352, April 1996.

12.10 Sabetta and Pugliese (1996) Epicentral distance

Class name	Crisis2008.ExtraGMPE.SabettaPugliese96EpicDist
Distance metric	Epicentral
Valid distance range	1 to 100 Km
Valid magnitude range	4.6 to 6.8
Valid period range	0 to 4 (sec)

Original units	cm/s/s
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal
Short name	Sabeta and Pugliese (1996; epicentral Distance)
Brief description	Developed using Italian strong-ground motion data. Original coefficients are for PGA and spectral pseudovelocities; the latter have been converted to pseaudoaccelerations. This version uses epicentral distance.
Number of parameters	4
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Sigma truncation
Possible values	-1E+20 to 1E+20
Parameter name	Ground type
Possible values	Deep Alluvium Sites; Shallow Alluvium Sites; Otherwise;
Parameter name	Type of Coefficients
Possible values	Smooth; Raw;

Reference: F. Sabetta and Pugliese, Estimation of Response Spectra and Simulation of Nonstationary Earthquake Ground Motions, *Bulletin of the Seismological Society of America*, Vol. 86- 2, pages 337-352, April 1996.

12.11 SEA99, Spudich et al. (1999)

Class name	Crisis2008.NewAttenuation.AttenuationClasses.SEA99
Distance metric	JyB
Valid distance range	0.1 to 100 Km
Valid magnitude range	5 to 7.5
Valid period range	0 to 2 (sec)
Original units	cm/s/s
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal
Short name	Spudich et al. (1999; SEA99)
Brief description	Horizontal spectral accelerations (5% damping) for events in extensional tectonic regimes, world-wide
Number of parameters	3
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Sigma truncation

Possible values	-1E+20 to 1E+20
Parameter name	Soil type
Possible values	Soil; Rock;

Reference: P. Spudich, W. B. Joyner, A. G. Lindh, D. M. Boore, B. M. Margaris, and J. B. Fletcher, SEA99: A Revised Ground Motion Prediction Relation for Use in Extensional Tectonic Regimes, *Bulletin of the Seismological Society of America*, 89, 5, pp. 1156-1170, October 1999

See also: P. Spudich and D.M. Boore, ERRATUM to SEA99: A Revised Ground Motion Prediction Relation for Use in Extensional Tectonic Regimes, *Bulletin of the Seismological Society of America*, 95, 3, p. 1209, June 2005

12.12 Arroyo et al. (2010)

Class name	Crisis2008.ExtraGMPE.Arroyoetal09
Distance metric	Rrup
Valid distance range	16 to 400 Km
Valid magnitude range	5 to 8.5
Valid period range	0.001 to 5 (sec)
Original units	cm/s/s
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal
Short name	Arroyo et al. (2010)
Brief description	Spectral horizontal accelerations (5% damping) on rock for Mexican subduction-zone interface earthquakes.
Number of parameters	2
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Sigma truncation
Possible values	-1E+20 to 1E+20

12.13 Atkinson and Boore (2003)

Class name	Crisis2008.ExtraGMPE.AtkinsonBoore03
Distance metric	Rrup
Valid distance range	1 to 300 Km
Valid magnitude range	5 to 8.5
Valid period range	0.01 to 3.03 (sec)
Original units	cm/s/s
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal

Short name	Atkinson and Boore (2003)
Brief description	Relations for subduction-zone (interface and inslab) earthquakes for the Cascadia and other regions, with 5% damping ratio.
Number of parameters	5
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Sigma truncation
Possible values	-1E+20 to 1E+20
Parameter name	Fault type
Possible values	In Slab; Interface;
Parameter name	Ground type
Possible values	NERHP E; NERHP D; NERHP C; NERHP B;
Parameter name	Zone
Possible values	Japan; Cascadia; General;

Reference: G. Atkinson and D. Boore, Empirical Ground-Motion Relations for Subduction-Zone Earthquakes and Their Application to Cascadia and Other Regions, *Bulletin of the Seismological Society of America*, Vol 93 -4, Pages 1703-1729, August 2003

12.14 García et al. (2005)

Class name	Crisis2008.NewAttenuation.AttenuationClasses.DGarcia05
Distance metric	Rrup
Valid distance range	0.1 to 400 Km
Valid magnitude range	5 to 7.5
Valid period range	0 to 5 (sec)
Original units	cm/s/s
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal
Short name	García et al. (2005)
Brief description	Ground-motion prediction model for the horizontal spectral acceleration produced by intra-slab subduction earthquakes, obtained with intermediate-depth Mexican earthquakes
Number of parameters	2
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Sigma truncation
Possible values	-1E+20 to 1E+20

Reference: D. García, S. K. Singh, M. Herráiz, M. Ordaz, and J. Pacheco, Inslab Earthquakes of Central Mexico: Peak Ground-Motion Parameters and Response Spectra, *Bulletin of the Seismological Society of America*, Vol. 95, No. 6, pp. 2272–2282, December 2005

12.15 Youngs et al. (1997)

Class name	Crisis2008.NewAttenuation.AttenuationClasses.Youngs97
Distance metric	Rrup
Valid distance range	10 to 500 Km
Valid magnitude range	5 to 8.5
Valid period range	0 to 3 (sec)
Original units	cm/s/s
Intensity dimension	Crisis2008.NewAttenuation.DimensionClasses.Acceleration
Residual distribution	LogNormal
Short name	Youngs et al. (1997)
Brief description	Ground-motion prediction model for subduction zone earthquakes (interface and intraslab) determined with world-wide data
Number of parameters	4
Parameter name	Units coefficient
Possible values	1E-20 to 1E+20
Parameter name	Fault location
Possible values	Intraslab; Interface;
Parameter name	Sigma truncation
Possible values	-1E+20 to 1E+20
Parameter name	Soil type
Possible values	Soil; Rock;

Reference: R.R. Youngs, S.J. Chiou, W.J. Silva and J.R.Humphrey, Strong Motion Attenuation Relations for Subduction Zone Earthquakes, Seismological Research Letters, Vo. 68, No. 1, pp- 58- 73, January/February 1997.

13. File Formats

The following is a description of the various file formats in use by CRISIS.

13.1 Format of modGRN grids

modGRN format is an extension of binary Golden Surfer 6 format.

While binary Golden Surfer 6 format consists on a header and a succession of values stored as 4-byte single numbers, modGRN format allows to store the values with other types of variables.

The only difference between modGRN and binary Golden Surfer 6 formats is the first byte in the header, that in the case of the modGRN format indicates what type of variables are being stored.

The structure of a modGRN binary file is the following:

Name	Variable type	Description
Header	GridHeader	Grid header
z11, z12, ...	The type is that indicated by grid header byte ID. It can be byte, short, integer, single, double or long.	First grid row Each row has constant Y value. First row corresponds to Ylo and the last row corresponds to Yhi. Within a row, values are ordered form Xlo to Xhi.
z21, z22, ...	The type is that indicated by grid header byte ID	Second grid row
z31, z32, ...	The type is that indicated by grid header byte ID	Third grid row
...	The type is that indicated by grid header byte ID	The remaining rows until reaching that corresponding to Yhi

13.2 Grid Header

This is the header of modGRN files. Its structure is very similar to that of the header of binary Surfer 6 files, except that the first byte indicates what type of variable will be stored.

Name	Type	Length	Description	Comments
IDD	Byte	4	4 identification bytes	The first byte indicates what type of variables will be stores. See codes in the following table
Nx	Short	2	Number of columns in the X direction	
Ny	Short	2	Number of rows in the Y direction	
Xlo	Double	8	Minimum longitude of the grid	

Name	Type	Length	Description	Comments
Xhi	Double	8	Maximum longitude of the grid	
Ylo	Double	8	Minimum latitude of the grid	
Yhi	Double	8	Maximum latiitude of the grid	
Zlo	Double	8	Maximum Z value in the grid	
Zhi	Double	8	Minimum Z value in the grid	

The first byte indicates what type of variables will be stores, according to the following codes:

Name	Value	Comments
Byte	1	
Short	2	
Integer	3	
Single	68	Corresponds to character "D". This code is used for compatibility with binary Surfer 6 format
Double	5	
Long	6	

13.3 SHP files

A shapefile stores non-topological geometry and attribute information for the spatial features in a data set. The geometry for a feature is stored as a shape comprising a set of vector coordinates.

An ESRI shapefile consists of a main file, an index file, and a dBASE table. The main file is a direct access, variable-record-length file in which each record describes a shape with a list of its vertices. In the index file, each record contains the offset of the corresponding main file record from the beginning of the main file. The dBASE table contains feature attributes with one record per feature. The one-to-one relationship between geometry and attributes is based on record number. Attribute records in the dBASE file must be in the same order as records in the main file.

(This description was taken from: "*ESRI Shapefile Technical Description: an ESRI White Paper*"—July 1998. See this report for further information on shapefiles)

13.4 Surfer 6 ASCII Grid Format

This section has been taken from SURFER 8 Help File

DSSA grid files contain five header lines that provide information about the size and limits of the grid, followed by a list of Z values. The fields within DSSA files must be space delimited.

The listing of Z values follows the header information in the file. The Z values are stored in row-major order starting with the minimum Y coordinate. The first Z value in the grid file corresponds to the lower left corner of the map. This can also be thought of as the southwest corner of the map, or, more specifically, the grid node of minimum X and minimum Y. The second Z value is the next adjacent grid node in the same row (the same Y coordinate but the next higher X coordinate). When the maximum X value is reached in the row, the list of Z values continues with the next higher row, until all the rows of Z values have been included.

The general format of a DSSA grid file is:

Value	Comment
Id	The identification string DSAA that identifies the file as an ASCII grid file
nx ny	nx is the integer number of grid lines along the X axis (columns)
	ny is the integer number of grid lines along the Y axis (rows)
xlo xhi	xlo is the minimum X value of the grid
	xhi is the maximum X value of the grid
ylo yhi	ylo is the minimum Y value of the grid
	yhi is the maximum Y value of the grid
zlo zhi	zlo is the minimum Z value of the grid
	zhi is the maximum Z value of the grid
grid row 1	These are the rows of Z values of the grid, organized in row order. Each row has a constant Y coordinate. Grid row 1 corresponds to ylo and the last grid row corresponds to yhi. Within each row, the Z values are arranged from xlo to xhi
grid row 2	
grid row 3	
…	

…

The following example grid file is ten rows high by ten columns wide. The first five lines of the file contain header information. X ranges from 0 to 9, Y ranges from 0 to 7, and Z ranges from 25 to 97.19. The first Z value shown corresponds to the lower left corner of the map and the following values correspond to the increasing X positions along the bottom row of the grid file. This file has a total of 100 Z values.

DSAA

10 10

0.0 9.0

0.0 7.0

25.00 97.19

91.03 77.21 60.55 46.67 52.73 64.05 41.19 54.99 44.30 25.00

96.04 81.10 62.38 48.74 57.50 63.27 48.67 60.81 51.78 33.63

92.10 85.05 65.09 53.01 64.44 65.64 52.53 66.54 59.29 41.33

94.04 85.63 65.56 55.32 73.18 70.88 55.35 76.27 67.20 45.78

97.19 82.00 64.21 61.97 82.99 80.34 58.55 86.28 75.02 48.75

91.36 78.73 64.05 65.60 82.58 81.37 61.16 89.09 81.36 54.87

86.31 77.58 67.71 68.50 73.37 74.84 65.35 95.55 85.92 55.76

80.88 75.56 74.35 72.47 66.93 75.49 86.39 92.10 84.41 55.00

74.77 66.02 70.29 75.16 60.56 65.56 85.07 89.81 74.53 51.69

70.00 54.19 62.27 74.51 55.95 55.42 71.21 74.63 63.14 44.99

13.5 Surfer 6 Binary Grid file format

This section has been taken from SURFER 8 Help File

Surfer 6 grid files [.GRD] use a layout similar to the ASCII Surfer 6 file format. The only difference is in the identification string and that Surfer 6 grid files are binary. Data types used in Surfer 6 grid files include:

Type	Description
char	single byte
short	16 bit signed integer
float	32 bit single precision floating point value
double	64 bit double precision floating point value

The Surfer 6 format has the following layout:

Element	Type	Description
id	char	4 byte identification string 'DSBB' which identifies the file as a Surfer 6 binary grid file.
nx	short	number of grid lines along the X axis (columns)
ny	short	number of grid lines along the Y axis (rows)
xlo	double	minimum X value of the grid
xhi	double	maximum X value of the grid
ylo	double	minimum Y value of the grid
yhi	double	maximum Y value of the grid
zlo	double	minimum Z value of the grid
zhi	double	maximum Z value of the grid
z11, z12, …	float	first row of the grid. Each row has a constant Y coordinate. The first row corresponds to ylo, and the last row corresponds to yhi. Within each row, the Z values are ordered from xlo to xhi.
z21, z22, …	float	second row of the grid
z31, z32, …	float	third row of the grid
…	float	all other rows of the grid up to yhi

13.6 Data Types

Type of stored variables has the following codes:

Name	Value	Comments
Byte	1	
Short	2	
Integer	3	
Single	68	Corresponds to character "D". This code is used for compatibility with binary Surfer 6 format
Double	5	
Long	6	

13.7 Cities file

The city file is in ASCII format and must contain the following data:

Number of cities

Name of the state, name of the city, longitude and latitude of the city (1 line for each city).

Example:

2	Number of cities		
GUERRERO,	Acapulco,	-99.900,	16.850
AGUASCALIENTES,	Aguascalientes,	-102.300,	21.883
State	City	Longitude	Latitude

13.8 Map file

The map file must contain the following data:

Number of polygons

For each polygon:

Name of the polygon

Number of vertex of the polygon

For each vertex: Latitude and longitude

Example:

2		Number of polygons
State 1		Name of polygon 1

6		Number of vertex of polygon 1
13	10	Coordinates of the six vertex of polygon 1
12	11	
11	10	
10	10	
10	8	
12	8.5	
State 2		Name of polygon 2
6		Number of vertex of polygon 2
10	10	Coordinates of the six vertex of polygon 2
11	10	
12	11	
13	10	
13	12.4	
12	13.1	