



## A WEB APPLICATION FOR POST-PROCESSING SEISMIC HAZARD ASSESSMENT RESULTS

### UNA APLICACIÓN WEB PARA EL PROCESADO ULTERIOR DE RESULTADOS DE ESTIMACIÓN DE LA AMENAZA SÍSMICA

Leonardo Alvarez<sup>1,\*</sup> , Conrad Lindholm<sup>2</sup>

<sup>1</sup> Private consultant, Managua, Nicaragua

<sup>2</sup> SeismoConsult, Norway

*(recibido/received: 05-09-2023; aceptado/accepted: 09-05-2024)*

#### ABSTRACT

A web application for post-processing of PSHA results in order to obtain a variety of maps and graphics for user-defined needs is discussed. It was developed for using the results from the R-CRISIS software main calculations, but its principles are universal and may be adapted for any other PSHA software. The process is performed in two steps: the first is to prepare files to be used as input for the web application, and the second step consists of processing these files for new results and plots (through the execution of programs and scripts). The work is organized in a server-client scheme, where the server side has all the required software together with the results and input files from the PSHA calculation. The software is accessed through a Web-Portal on the server side. We present examples of requests and results.

**Keywords:** Seismic Hazard, Web Server, Uniform Hazard Spectra.

#### RESUMEN

Se discute una aplicación web para el postproceso de los resultados de una estimación probabilista de la amenaza sísmica para obtener una variedad de mapas y gráficos de acuerdo con las necesidades del usuario. Fue desarrollada para usar los resultados básicos del programa R-CRISIS, pero sus principios son universales y puede ser adaptada a los resultados de cualquier otro programa de estimación de la amenaza sísmica probabilista. El proceso se realiza en dos etapas: la primera consiste en preparar los archivos que se usarán como entradas a la aplicación web, y la segunda corresponde al procesamiento de esos archivos para la obtención de nuevos resultados y figuras (a través de la ejecución de programas y guiones). El trabajo está organizado en un esquema servidor-cliente. Donde del lado del servidor están todos los programas requeridos con los resultados y datos de entrada para el cálculo de la amenaza sísmica probabilista con el R-CRISIS. Del lado del cliente solo es necesario un navegador y una conexión a red o Internet. Se presentan ejemplos de las peticiones y los resultados.

**Palabras clave:** Amenaza Sísmica, Servidor Web, Espectros de Amenaza Uniforme.

---

\* Corresponding author.

E-mail address: leoalvar50@gmail.com

## 1. INTRODUCTION

The Probabilistic Seismic Hazard Assessment (PSHA) procedures have been described in detail in articles and books and will not be repeated here, e.g. Baker et al. (2022) for general methodology, BSSA (2024) and SRL (2024) for recent developments and Salgado et al. (2023) for insurance applications. It will only be mentioned some of the general characteristics: I) the uniform hazard spectrum (UHS response spectrum) is today used as design basis, formed by damped single-degree-of-freedom spectral amplitudes for a range of periods, II) it is common to calculate PSHA with several branches of input data in a logic tree calculation, III) the results are presented in a series of maps and graphics. Sometimes, when the results of a PSHA work study is presented, the client may formulate a request that is embedded in the results, but which is not explicitly provided in the maps and graphics. What to do then? Provide new calculations from the beginning? Or is there another simpler option that requires much less effort? The answer is: “Yes, it is not necessary to repeat calculations from the beginning, but only from the end of the PSHA process”. In this paper we present a WEB application for new presentations of results from an existing PSHA calculation.

The process of PSHA can be divided in 4 steps: 1) data preparation (earthquake catalog, seismicity, seismic source zones, GMPE selection, logic tree design, etc.), that may take from months to years depending on the complexity and available data, 2) the PSHA process (calculation of each branch of a logic tree) that normally takes from hours to days of computer time, 3) Statistical processing of the logic tree results (from seconds to minutes) and 4) preparation of maps and graphics (from second to minutes) (Figure 1).

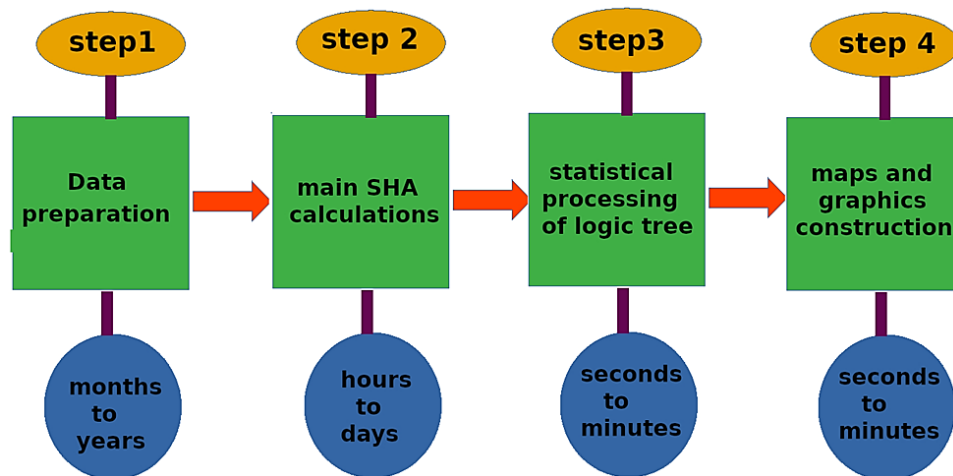


Figure 1. Schematic presentation of the main steps of a seismic hazard assessment work. Using the results of the second step, the last two can be accomplished independently, as explained below.

Although there is a generally accepted convention about which graphics and maps that are preferred, it also depends on the needs of the recipient client. The main challenge is that in general, the common feeling between users is that, if you need something more, you have to repeat the study. In particular, if the relative weighting of the branches in the logic tree needs re-calculation. If the computer program used for hazard calculations is good, it has to output what is called here “main PSHA results”, i.e., a file or a set of files containing information about exceedance probability of the ground shaking intensity. This must be provided for spectral periods and for each point of a gridded study area (Figure 2). Once finished, the obtained PSHA results is the basis for creating additional maps and graphics that enlighten the results for the end user. This can be done with a set of programs and scripts, executed in command line or included as options of the used PSHA software.

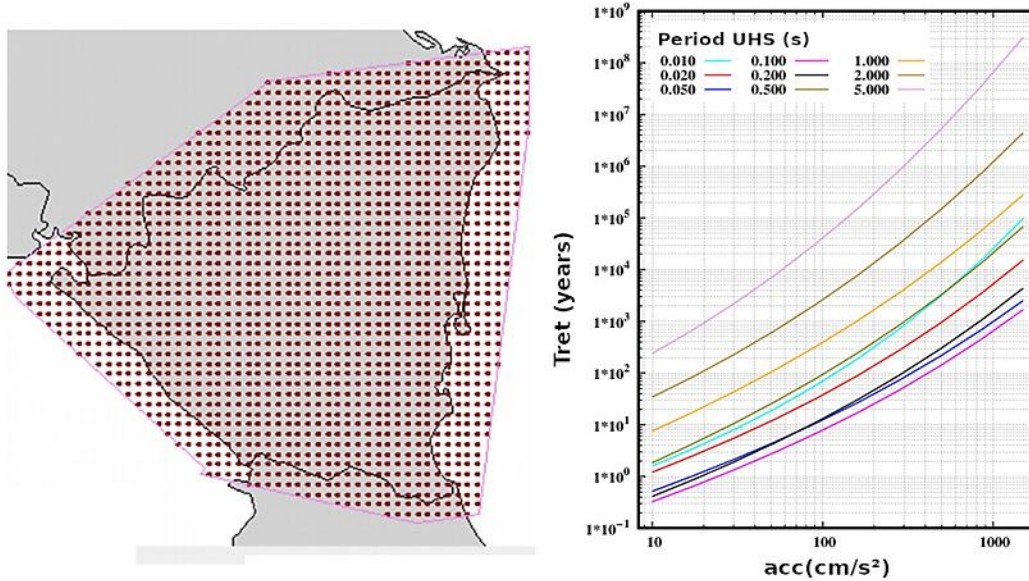


Figure 2. Example of general use of PSHA software. The region of interest is gridded (left). For each point of the grid the exceedance probability of shaking intensity is calculated for different periods  $T_{UHS}$  (right). Instead of frequency, here is plotted its inverse, the return period  $T_{ret}$ . In the x-axis, we have the acceleration [ $cm/s^2$ ].

It was decided to create a web application that makes it easier to take decisions about parameters' selection and logic tree combination for users without special computer skills. The user can then obtain a “personalized” PSHA for his/her application. Following this approach, the second step (the more time consuming) of PSHA computation in Figure 1 is accomplished once, while the last two steps are repeated as often as needed in the web application. The first version of this web application was used for a PSHA work in Cuba (Alvarez et al., 2017) and the last version was used for a Nicaragua PSHA (Alvarez, 2022). A case study with results from the R-CRISIS program (Ordaz et al., 2019, 2022) is discussed below.

## 2. CHARACTERISTICS OF THE MAIN PSHA RESULTS

The PSHA codes are often configured such that hazard is calculated in a spatial grid. Hazard is computed for fixed shaking intensities and for fixed periods (discretized) where each are defined at the outset of the calculation:

$$\alpha_i, i = 1, \dots, n_\alpha \quad (1)$$

$$T_{UHS_j}, j = 1, \dots, m_T \quad (2)$$

Where “ $\alpha$ ” is a measure of earthquake shaking (peak acceleration, response acceleration spectra, Arias intensity, etc.) which is expected to vary inside an interval, for which “ $n_\alpha$ ” distinct values are selected.  $T_{UHS}$  express the period of the Uniform Hazard Spectrum, which is used when the intensity “ $\alpha$ ” is the response acceleration spectra “ $Sa(T)$ ”. Then, the values of the exceedance probability for the intensity “ $\alpha$ ” are computed, from which the equivalent exceedance rate (an annual frequency of occurrence) “ $f$ ” can be calculated, provided a Poissonian character of the hazard. For example, the program R-CRISIS gives the possibility of expressing hazard in three ways: exceedance and not exceedance probabilities and equivalent exceedance rate ( $Pe$  or  $Pne, f$ ). There is a simple relationship between these representations

$$f = \log_e (Pne)/t \quad (3)$$

where “ $t$ ” is the “waiting time” or expected lifetime of a construction.

The return period “ $T_{ret}$ ” is defined as the reciprocal of the exceedance rate and historically have been used as the parameter for which seismic hazard maps are represented. From (3) it is obtained:

$$T_{ret} = t/\log_e (Pne) = 1/f \quad (3a)$$

The more common value of “ $t$ ” is 50 years and it is common to find maps for this value with  $T_{ret}=475$  years ( $Pne=0.9$ ), 4975 years ( $Pne=0.99$ ). As “ $Pe=1-Pne$ ”, the 475 years return period corresponds to the 10% exceedance probability in 50 years, while the 4975 years return period corresponds to 1% exceedance probability in 50 years.

The exceedance or not exceedance probabilities are calculated as a function of this time, while the equivalent exceedance rate is independent of it (annual). We prefer to use the equivalent exceedance rate for its intuitive simplicity. Then, the main results for a branch consist in a set of values

$$f_{ij} = F(\alpha_i, T_{UHS_j}), i = 1, \dots, n_\alpha; j = 1, \dots, m_T \quad (4)$$

where “ $i$ ” runs over the values of intensity, while “ $j$ ” runs over the values of the “ $T_{UHS}$ ”.

In case of maps construction, calculations are made in a grid of points ( $lat_k, long_l$ ) that cover the study region “ $A$ ”

$$A = \{lat_k, long_l | k, l \in A\} \quad (5)$$

Then, considering these space dimensions, the “main PSHA results” will be in terms of

$$f_{ijkl} = F(\alpha_i, T_{UHS_j}, lat_k, long_l); i = 1, \dots, n_\alpha; j = 1, \dots, m_T; k, l \in A \quad (6)$$

In the case of maps the usual way is to divide a geographical region in a regular grid (which guarantees a uniform quality of the final maps), where each node is characterized by its coordinates ( $lat_k, long_l$ ), and “ $A$ ” is an “irregular” sub-region traced over it.

When the PSHA calculation is done for each branch in the logic tree formulation, another dimension adds to the results “ $L$ ” ( $L_n, n=1, \dots, n_L$ )

$$f_{ijkln} = F(\alpha_i, T_{UHS_j}, lat_k, long_l); i = 1, \dots, n_\alpha; j = 1, \dots, m_T; k, l \in A; n = 1, \dots, n_L \quad (7)$$

where “ $i, j, k, l$ ” runs over parameters and coordinates, while “ $n$ ” runs over branches of logic tree.

This is a matrix of fifth order, but the way of processing, combining latitude and longitude in a “name” of each point, reduces the problem to manage data to a fourth order matrix. From this, all the results that are presented to the users are published.

It is important to determine if the hazard code outputs the intermediate results, and in which form. The R-CRISIS does this and we will below use R-CRISIS outputs for the development of the web application.

The program R-CRISIS outputs a file with extension “.gra” that contains results for every branch of the logic tree computation (Ordaz et al., 2008; Ordaz et al., 2019). Regrettably, the OpenQuake Platform (GEM,2022) provides the outputs in <xml> formatted files which are not well explained in the available documentation, and hence not included for in the Web application presented here.

### 2.1) The “.gra” files of R-CRISIS

The format of the “.gra” file is simple. It provides the coordinates of each point, the period “ $T_j$ ” of UHS and the table  $(\alpha_i, f_{ij}, i=1, n_\alpha)$  with equivalent exceedance rates for each predefined “ $\alpha$ ” value, and “ $T_j$ ”. If one used “Exceedance probability” or “Not exceedance probability” output options instead, one will obtain the same kind of table, but with  $(\alpha_i, Pe_{ij}, i=1, n_\alpha)$  or  $(\alpha_i, Pn_{eij}, i=1, n_\alpha)$ , in which cases one has to convert them to the first case using (3) taking into account the time frame “ $t$ ” used. The format in which those values are presented is shown in Table 1.

Table 1. Example of the ‘.gra’ file in the case that you selected the “Equivalent exceedance rate” output. For each site and each period T, the equivalent exceedance rate is provided for 10 (in this example) predefined shaking intensity levels.

<i>9 comment lines</i>	
Site:	-87.9000 12.7000
Intensity 1	T=0.010
Level	Time Frame 1
1.00000E+001	3.27123E+000
1.74497E+001	1.32624E+000
3.04492E+001	4.88708E-001
5.31329E+001	1.65664E-001
9.27154E+001	5.20168E-002
1.61785E+002	1.50962E-002
2.82311E+002	4.00388E-003
4.92624E+002	9.54234E-004
8.59614E+002	2.00744E-004
1.50000E+003	3.66955E-005
Intensity 2	T=0.020
Level	Time Frame 1
1.00000E+001	3.27670E+000
.....	

The file is characterized by three nested cycles. The outer defines the site coordinates, the middle the period “ $T_{UHS}$ ”, while the inner corresponds to predefined values of intensity  $\alpha$  in the first column and equivalent exceedance rate in the second column. The programs for processing these files will be discussed below.

### 2.2 The output files of OpenQuake

The OpenQuake platform, developed under the Global Earthquake Model project, (GEM; <https://www.globalquakemodel.org/>) have been increasingly used over the last years. The platform consists

of several programs, written in Python, which perform different tasks using advanced computing techniques. It allows calculation of seismic hazard and risk for a wide variety of initial conditions. An extensive user manual (Pagani et al., 2023) is updated periodically, where the theoretical foundation is provided by Pagani et al. (2014). The OpenQuake software comes with its own toolkit integrated in QGIS (QGIS, 2024) and is not included in the post-processing software described below.

### 3. THE WEB APPLICATION

#### 3.1 The web server requirements for running the application

Running a web application requires a web server. The work discussed below was done using an Apache2 server with Linux. A set of programs were installed for the application: Perl, CGI, Gfortran, gnuplot (Williams and Kelley, 2022), GMT (Wessel and Smith, 1998, 2019), and auxiliary ones for converting image formats. The configuration of a web server is not the matter of this paper but some general comments will be given: A standard web server works with two directories: “*cgi-bin*” where all the programs and scripts prepared for applications are placed, and “*www*” where the web page of every application, and also data and results can be stored in a particular directory. The precise location and names of these directories depend on the Linux installation and can be modified in the configuration files (under */etc/apache2*) if desired. In the following these directories will be referred simply as “*cgi-bin*” and “*www*”. All the required software is placed on the web server, while in the client side any browser over any operating system can be used. The construction of a web server for seismological applications under these conditions is discussed by Alvarez (2014). This web server can be installed as well in a machine for multi-user access or on a personal computer for individual use.

The general operation of a web application on the web server is the following: a) request data is introduced by the remote user through a web portal, b) control is transferred to a *CGI script* that calls various programs (FORTRAN, C++, Python, R, etc.) or scripts. The programs perform calculations and write result files and “*perl*” scripts that control the preparation of maps and graphics, which are finalized by “*GMT*” and “*gnuplot*”. Finally, the results are represented in the users web browser, from where they can be saved. It is also possible to return to the initial page for repeated tests with new parameter settings (see Figure 3). The use of “*gnuplot*” and “*GMT*” programs and the “*perl*” scripts is the authors' choice. In principle, one may use any other scripting language as well as different graphics and maps' preparation programs that can be controlled from a command line.

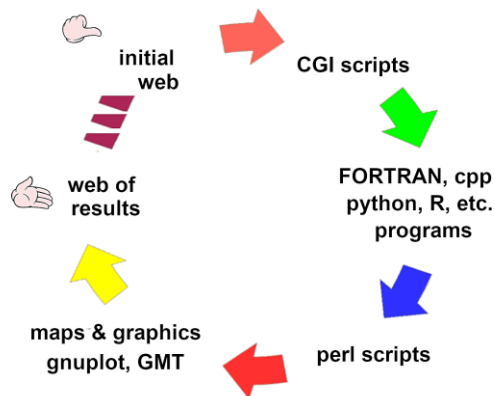


Figure 3. Workflow of the application. It begins from an initial webpage where the parameters for the calculations are provided. It has to be friendly enough for a clear understanding for people without special computer skills. The work is controlled by a CGI script that call programs, other scripts and graphics and maps preparation programs and provide for displaying and saving of results.

### 3.2 The structure of the directory of the web application

The initial portal (PSHA.html) will be placed in “www/PSHA”, and correspondingly, in “cgi-bin” is placed the main CGI script (PSHA.cgi). In particular, for the application, there are created 3 directories inside “www/PSHA” that are required during the execution of “cgi-bin/PSHA.cgi”:

*dat* – the main PSHA results for every branch are placed here together with the results of the pre-processing (see below) and some auxiliary files for maps' preparation

*doc* – the general documentation about the PSHA study and the web application. This can be accessed by the user.

*web* – the directory to save the results of the web app; for each run there is created a user's directory with a name determined by the user.

It has to be remarked that the directory named here “www/PSHA” has to be constructed for every main estimation of seismic hazard. In a web server can coexist several directories of this kind, corresponding to results from different regions, which should be named accordingly (both in main directory and portal) as well in the CGI script.

## 4. DATA PRE-PROCESSING

The graphical outputs (maps and graphics) should be created from the original data,  $f_{ijkln}=F(\alpha_i, Ts_j, lat_k, long_l, l_n)$ . As it was pointed out earlier, it consists of  $n_L$  files (one for each branch of the logic tree) containing the  $f_{ijkl}=F(\alpha_i, Ts_j, lat_k, long_l)$  information. “ $Ts$ ” represents the period of the acceleration response spectrum. The parameter used for maps is not the annual exceedance frequency “ $f$ ”, but its inverse “ $T_{ret}$ ” (return period). This period is easily related to probability of exceedance for a particular combination of waiting time “ $t$ ” and not exceedance probability “ $P_{ne}$ ” (3a).

The process of preparing maps requires interpolation between the “ $\alpha_i$ ” values and statistical processing of branches. For these reasons these initial data are pre-processed before joining them in a file that contains tables of the kind  $f_{in}(\alpha_i, l_n, n=1, \dots, n_L)$ . These tables are prepared for any geographical point ( $lat_k, long_l$ ) and any period of UHS “ $T_{Sj}$ ”. An example is provided in Table 2.

Table 2. Example of the tables to be created in the pre-processing. In the first column are the values of “ $\alpha$ ” (e.g., in cm/s<sup>2</sup>), fixed in the process of calculation of the PSHA. “ $L_n$ ” provide the values of “ $f_{ijkl}$ ” (formula 6) along 6 branches for the a single “ $T_{UHS}$ ”. Similar are constructed for other “ $T_{UHS}$ ”.

$\alpha$	$L_1$	$L_2$	$L_3$	$L_4$	$L_5$	$L_6$
10	3.71	3.67	2.76	2.8	2.73	2.7
17.44	1.55	1.55	1.19	1.19	1.17	1.17
30.44	0.58	0.59	0.46	0.46	0.46	0.46
53.13	0.2	0.2	0.16	0.16	0.17	0.16
92.71	0.07	0.06	0.05	0.05	0.06	0.05
161.78	0.02	0.02	0.01	0.02	0.02	0.02
282.31	0.01	0	0	0	0	0
492.62	0	0	0	0	0	0
859.61	0	0	0	0	0	0
1500	0	0	0	0	0	0

The file shown in Table 2 is the basis for the work in the web application. The file is named “data.txt” and are placed in the PSHA/dat directory. Let  $k_A$  be the number of points inside the region A while  $m_T$  was

defined as the number of periods of UHS processed. Then the file “data.txt” will contain  $k_A \times m_T$  tables adequately referenced by point coordinates, period of UHS and weight of the branches of logic tree. In Annex A it is a description of the format.

*Programs for making pre-processing of ‘.gra’ files:* The main objective of the pre-processing is to prepare the file “data.txt” already discussed. There are 4 programs that do the needed processing:

- *selectSites:* using as input a “.gra” file to select those points for which PSHA calculations were performed (in case of contouring the study area for avoiding unnecessary calculation in main process) and put the selected points in “puntos.dat” (Syntax: 'selectSites “any.gra\_file”')
- *creaInput:* uses the file “puntos.dat” and the files of data used in the original logic tree computation “.LTC” and “.Ltc.dat”. This program creates two main data files for the later process: “selectGRA.inp” with information on the weights of every branch and “selectGRAall.dat” with names the “.gra” files corresponding to each branch (Syntax: 'creaInput “.LTC\_file” “.Ltc.dat\_file”')
- *selectGRAall:* using the two files created by creaInput prepares the file “intCrisisAll.inp. This is a file of the kind “data.txt” discussed before and with the format given in Annex A. It also creates two files that are used in webapp operation: selectGRAdifer.inp and selectGRAigual.inp.
- *intCrisisBDmod:* this program has a dual function; it is used in execution of tasks from the web application and for creation of a file (intCrisisAll.res) that may be necessary for some tasks. It reads results from “creaInput” and “selectGRAall”.

With the four programs described above the process is simple: a) To copy in a working directory the “.gra” files from each branch of the original PSHA calculation and the files “.LTC” and “.Ltc.dat” of the logic tree, b) to execute the above 4 programs and c) to copy in the “web/PSHA/dat” directory of the application intCrisisAll.inp (the so called “data.txt” file), intCrisisAll.res, selectGRAall.dat, selectGRA\*.inp and the “.gra” files.

## 5. WORKING WITH THE APPLICATION

### 5.1 The server side

In the process of preparation of maps there are three steps: statistical analysis of branch values, interpolation and proper maps construction. These processes all start from the file “data.txt”. The programs that do the numerical processing are relatively simple, written in FORTRAN, while maps construction are controlled by Perl scripts calling GMT (Wessel and Smith, 1998, 2019) that use input data files created by FORTRAN programs. The graphics are prepared in gnuplot (Williams and Kelly, 2022) using command files created also by FORTRAN programs. Maps and graphs are presented on the screen for the user and can be downloaded as JPG, EPS or PDF files.

*Statistical processing of logic tree:* The statistical analysis considers weights of the branches, and this is done with the algorithms described in Annex B. Let us start by the file “data.txt”. For every line containing branches' information a statistical analysis is performed, with results in mean, mean+ $\sigma$ , mean- $\sigma$  (where the  $\sigma$  is the standard deviation of Normal distribution), and 10 percentiles calculated with the branch weights used by the user. As a result, a new file is created with the same format as “data.txt” which contains, instead of values of frequencies for arms (Table 2), the results of the statistical analysis, line by line. This is done by program “intCrisisBDmod”, as already mentioned.



*Interpolation:* When a PSHA process is designed, the parameter space of “ $\alpha$ ” is defined in intervals between “ $\alpha_{min}$ ” and “ $\alpha_{max}$ ”. Calculations are done for each of the defined values. Following the statistical analysis the user can select a set of values “ $(\alpha_i, f(S_m))$ ” for each point and the period “ $T_j$ ” that can be used for preparing maps, where “ $f(S_m)$ ” is a particular realization of the statistical analysis (“ $S_m$ ” corresponds to mean, mean+ $\sigma$  ( $\sigma$  is sometimes called “epistemic standard deviation SDe”), median, percentile 84 of the frequencies “ $f$ ” by branch). The maps are normally prepared in terms of “ $\alpha$ ” for a given return period, and this period is fixed according the needs of the user and do not coincide with the values of “ $1/f(S_m)$ ”. Intermediate values corresponding to the user's needs are computed through linear interpolation.

*Maps construction:* The maps are prepared using GMT (Wessel and Smith, 1998, 2019). To this end two input files are prepared with particular map setting parameters needed by GMT. These files and the corresponding maps are prepared for each of the  $T_{S_j}$  periods and two statistical realizations (mean and mean+ $\sigma$ ) or (median and percentile 84) as selected,

*An option for point estimates inside the study region:* Sometimes it is necessary to study the PSHA for particular points. In this case, we prepare the files  $\alpha_{Tr} = G(T_{S_j}, lat_k, long_l)$ . Then, given the  $(lat_0, long_0)$  coordinates of the desired point, we interpolate the results from the surrounding points located at distances less than 2 times the space intervals. Several graphs are then prepared for the point of interest using gnuplot (Williams and Kelley, 2022).

*Site effects consideration:* The PSHA results are always referred to a particular kind of soil, generally rock or hard rock. But this assessment can be adapted to other soil conditions. To this end a conversion procedure that allows to translate the results from rock to soil “ $\alpha(soil) = G(\alpha(rock))$ ” is needed. It may be applied to individual points to prepare a complete map with varying soil conditions. Some PSHA programs may have this included and some may not, in which case this procedure has to be applied off-line. If the original calculation was done for the desired  $V_{S30}$  value, this correction is not necessary. In the relation developed by Chiou and Youngs (2014) the reference velocity of  $V_{S30} = 1130$  m/s is used. To scale the results to a desired “ $V_{S30}$ ” one has to do a two-steps transformation:

$$originalV_{S30} \rightarrow V_{S30} = 1130 \text{ m/s} \rightarrow desiredV_{S30} \quad (8)$$

which is performed by a program included in the web application.

*Giving results related to a seismic building code:* In the web application one can include options for additional processing for point hazard estimates. Normally, the building codes have options for scaling the main spectrum for different soils, design parameters, etc. Considering that the result of the UHS spectrum obtained for a point is the main spectrum corresponding to the code, any transformation may be applied and they are not difficult to program, but will be building and code-specific.

*Overview of the main programs that process the requests:*

1. *SHA.cgi:* main script that manages the process; written in Perl. It takes data from the webpage (transfer in mode “post”) and controls the calling of different programs and scripts.
2. *creaselect:* this program gives the opportunity of changing the weights of the branches of the logic tree. It takes the desired weights for all the branches of logic tree from the user selection, reads file “*selectGRA.inp.igual*”, calculates the new weights and put them in file “*selectGRA.inp.sumin*”. The method of weights' calculation is the one used in R-CRISIS. To each branch it is assigned a numerical number of importance, and the program normalizes them.
3. *intCrisisBDweb:* performs statistical calculations for the problem, and interpolation of  $T_{ret}$ . It is a version for web of *intCrisisBDmod* mentioned above. Parameters are supplied by the user. It reads *intCrisisAll.inp*, *intCrisisAll.res*, *selectGRA.inp* and *selectGRAall.dat* from “dat” directory and give

two main results, file “mapa.xyz” used for maps construction and *intCrisisBD.res* used for point hazard graphics, plus the auxiliary file “*intCrisisAll.prom*” with statistical calculations for the selected weighting criterion.

4. *mapUHSweb*: it reads the file “mapa.xyz” created by *intCrisisBDweb* and creates data (files “.par” with parameters and “.xyz” with PSHA values) for plotting maps, and jobs that call the Perl script *postmapa5web.pl*.
5. *postmapa5web.pl*: makes different calls to GMT programs for constructing maps according to the data (“.xyz” files and parameters (“.par” files) created by “mapUHSweb”. The interpolation of data in files in made by Delaunay triangulation ([Shewchuk, 1996](#)).
6. *interUHSweb1*, *interUHSweb2*, *interUHSweb3*: processes data for creating different kind of point hazard graphics. **a)** *interUHSweb1* – reads “intCrisisAll.res” selects the points closed to investigated site and put them in file “puntos.dat”, **b)** *interUHSweb2* – reads this “puntos.dat” file and the “mapa.xyz” one. Then creates several files with data and others with gnuplot commands and a scripts for preparing these graphics with “gnuplot”. **c)** *interUHSweb3* – reads the “puntos.dat” file and the “intCrisisAll.prom” one. As the previous program, it creates several files with data and others with “gnuplot” commands and a script for obtaining these graphics running “gnuplot” in command line.
7. *efectoSitio\_1*: transforms initial files used for construct maps and graphics, by converting original spectra values to corresponding ones for the desired  $V_{S30}$ .

The data and parameters necessary for doing the general tasks are all supplied by the user through the web portal (from the client side of the web application). For example, units, kind of statistics, return period, detail of isolines, etc. These will be discussed below.

## 5.2 The client side (Web Portal)

General requirements: Since this is a web application, the user only needs a web browser and Internet or network access. The user will open the page PSHA.html in his/her browser. In addition to the PSHA files that reside on the server, the user supplied data needed is of two types: general data, and data for designing maps and graphics. First of all, the user is asked for a code, that is used for creating a user’s directory in web server, which prevents the mixing of requests from several users. After that, it is possible to pass to general data of requests. The data that it is necessary to provide is presented in Figure 4.

Firstly, the user selects the desired output: maps for all region or graphics for a particular point, and the return period “ $T_{ret}$ ”. The selection of “ $T_{ret}$ ” is very important because the calculation is done by interpolation for this period. The next step is the statistical processing of the branches. There are two possibilities: mean and mean + epistemic standard deviation “SDe” or median and 84% percentile (sample statistics); in both cases the results are presented for the two parameters. It is also the possibility of selecting the units for final representations, with independence of which were used in the original PSHA calculations. To establish the weights of the branches in the statistical analysis one provides a wide range of possibilities. The “user selected” weights follow the convention used in R-CRISIS: increased importance of the branch is indicated with growing integer numbers. The program “creaselect” normalizes them to a sum equal 1. Fig. 4d indicates 16 branches, but for simplicity only 4 are specified.

**Kind of assessment:**  maps  point estimate of UHS **(a)**

**Return period (years):**

Return period is related to non exceedance probability in 50 years by  $p=\exp(-50/T_{ret})$ . Is normal the use of the following return periods (in years): 224(p=0.80), 475(p=0.90), 975(p=0.95), 1642(p=0.97), 2475(p=0.98) y 4975(p=0.99).

---

**Kind of statistics to process logic tree:** **(b)**

fit to normal distribution (mean and mean+standard deviation)  
 sample (median and 84% percentil)

---

Initial assessments were done for [cm/seg<sup>2</sup>]. ¿Do you want to express them in [g]?  no  yes

---

There is possible to select to select weights of branches in 3 ways: **(c)**

equal by arm  
 combination selected by the authors of the original PSHA  
 user defined (in this case you have to fill the following section)

---

**Interactive association of weights:** **(d)**

It is used the R-CRISIS convention. Create a scale of of importance in growing integer numbers and classify every branch. Program normalizes them to its sum be equal 1.

**Number of branches: 16**

To the left it is placed the "name" you gave to every branch

1) 9\_Mth\_4.5\_A&B\_C&B   
2) 9\_Mth\_4.5\_Pezeshk\_C&B   
3) 9\_Mth\_4.5\_A&B\_A&S   
4) 9\_Mth\_4.5\_Pezeshk\_A&S

Figure 4. General data to be given: (a) kind of assessment and return period; (b) kind of statistics and units; (c) determination of branches weights; and (d) interactive fixing of user-selected weights.

*Particular specifications for maps and graphics:* Once the general parameters for PSHA calculations are specified, it is necessary to provide details of how to present results in maps and graphs. The main parameters used for the case of maps are presented in Figure 5.

**Use of bathymetry:**  no  yes

**Color of sea areas:**  blue range  white

**Color for PSHA:**  GMT "haxby" palette  gray range

**Isolines labeling:**  yes  no

**Text in the upper part of the maps:**  yes  no

**Superposition of detailed isolines:**  no  yes  yes, maximum detail

**Sub-region selection:**  no  yes (if yes, fix its limits).

Latitude: (degrees) from  to

Longitude: (degrees) from  to

They should be between the limits of study area

Figure 5. Main parameters for the configuration of the output maps.

As can be seen from Figure 5, the majority of needed parameters are very simple, except the superposition of isolines. GMT has a default interval division of intensity range for plotting isolines that often do not satisfy. However, GMT provides the possibility of user-defined intervals. This option requires two files to be prepared, one for “detailed” and the other for “maximum detail” of the isolines. The way of preparing these files is to define the intensity range and then divide the range in a suitable number of intervals. These files have to be prepared both for [cm/s<sup>2</sup>] and [g] and then placed in “web/PSHA/dat” directory. The maps may also be presented with additional information such as political division. See Annex C for details. The specifications for the case of point estimates are very simple. Only the name of the site and its coordinates (Figure 6). The name that you put in this part is placed by the “gnuplot” program into the graphics and it is necessary to obey two restrictions: do not use symbol “\_”, and if there are blank spaces (as in the case shown in Figure 6), it has to be written between quotation marks.

Name of place (it will be used in titles):

Longitude:

Latitude:

Figure 6. Data for point estimate of PSH.

Finally, something that is common to both cases (maps and graphics) is the possibility of converting the results to the desired  $V_{S30}$  using the Chiou and Youngs (2014) relations. See Figure 7 for the user interface.

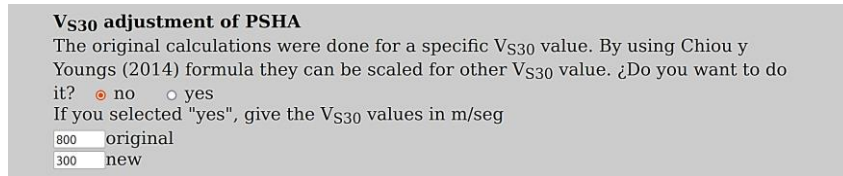


Figure 7. Scaling of results for a “ $V_{S30}$ ” different from the one used in the original PSHA calculation.

## 6. EXAMPLES OF WEBAPP RESULTS

When the data for calculation is submitted, the processing as indicated in Fig. 3 is activated and the user will obtain, in the case of maps “2 X number of  $T_{UHS}$ ” maps (for each  $T_{UHS}$  2 statistical version, e.g., mean and mean+SDe) and in the case of points 4 graphics in the simplest variant (no scaling by “ $V_{S30}$ ”) or 8 ones if scaling by “ $V_{S30}$ ” was selected). All of them are in formats PS, EPS and JPG. The JPG images are provided with some explanations, and the possibility of downloading all results (figures and data for its preparation, and some auxiliary files of the request) is provided. Figure 8 presents an example of some output files for the cases of point estimates.

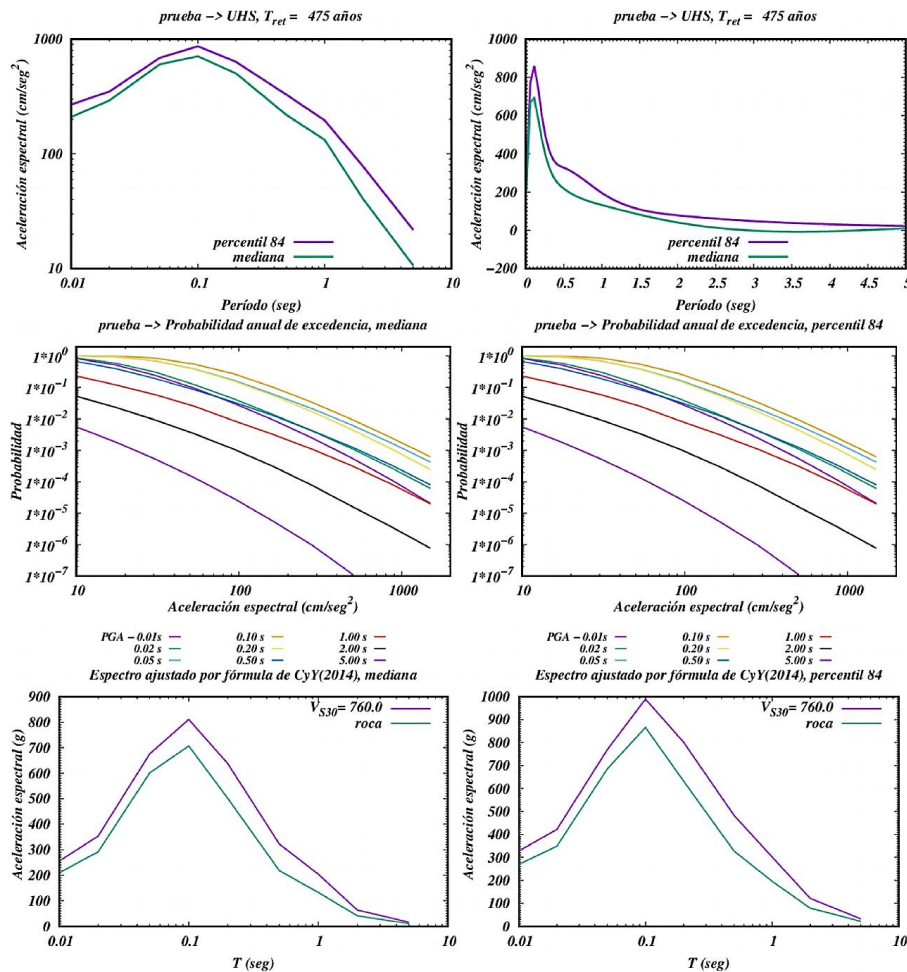


Figure 8. Some of the output files obtained for the case of point estimates.

In Figure 9 some example maps are shown. Finally, Figure 10 shows a case with a defined subregion, where the isolines were provided using the option of “maximum detail” (see Figure 5).

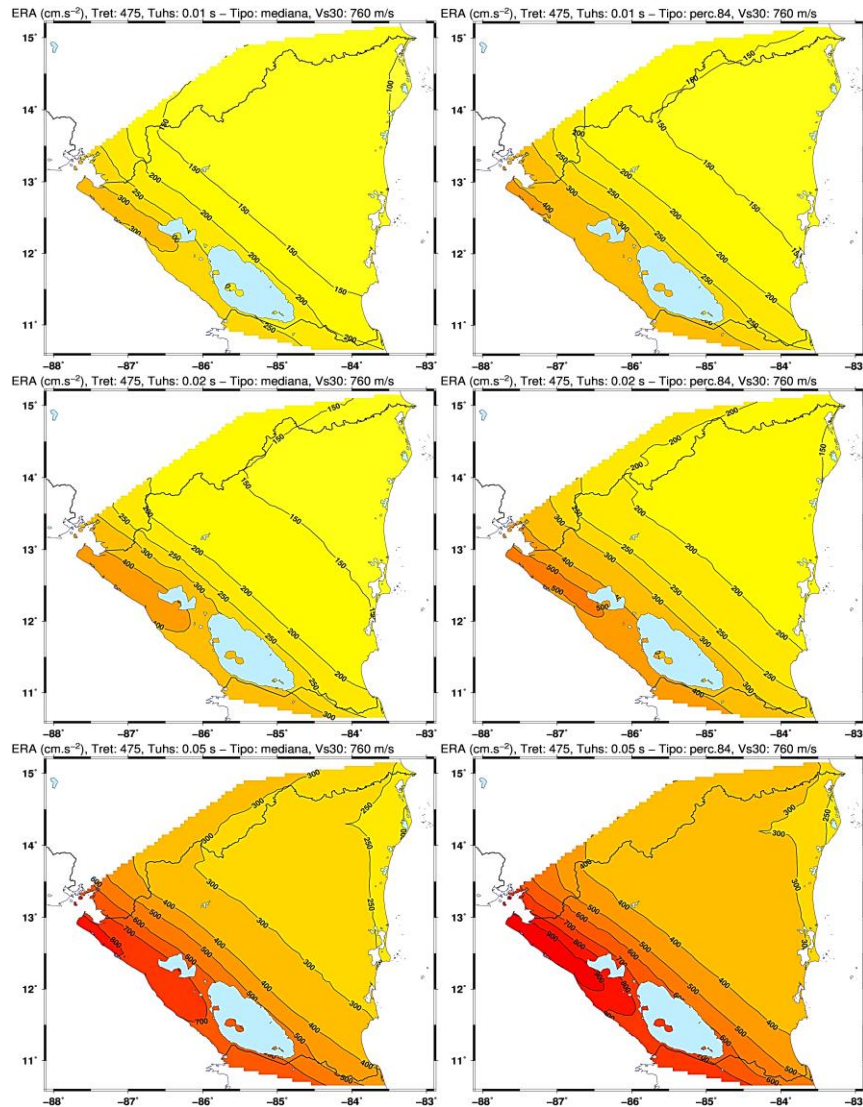


Fig 9. Example of some output files of the case of maps. They correspond to a PSHA study for Nicaragua (Alvarez, 2022), where there were used 9 “ $T_{UHS}$ ” values for a total of 18 maps in running the webapp.

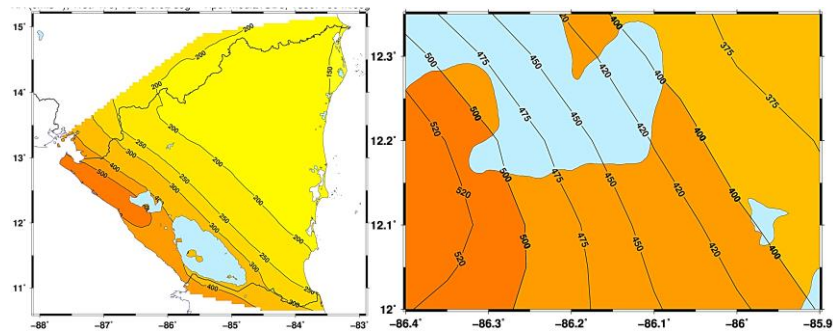


Figure 10. Case in which a subregion is selected. The selected subregion corresponds to Managua region, between the two big lakes of Nicaragua. Compare the spacing of isolines between the maps for the whole region and for a selected subregion.

## 5. CONCLUSIONS

We have described a web application for post-processing and presentation of results from a PSHA computation. The general idea is that one can obtain a lot of alternative PSHA presentations without repeating the main PSHA calculations. The webapp was developed for processing results obtained from R-CRISIS (or some of its predecessors), but in principle it can be adapted to process the results of any other software, provided that the software provides the results in terms of text files. There are two steps, the first is the pre-processing of the R-CRISIS results for obtaining a file with tables of “equivalent intensity rate” for all the branches of the logic tree (performing only once at the webapp preparation) and the second is the processing of this file for obtaining user-defined PSHA (performing each time that a request is done to the webapp). For doing both tasks there were developed some programs and scripts that are discussed above. Each time a request is processed, the complete content of working directory in web server can be downloaded. The webapp is not only an instrument for obtaining new representations of a PSHA already done. In fact, it can be used during main PSHA studies to analyze different criteria of branches' weighting and statistical criteria of their processing.

### AUTHOR CONTRIBUTION CRediT

Author contributions to paper “A web application for post-processing seismic hazard assessment results” by Leonardo Alvarez and Conrad Lindholm

These developments were originated during the work of seismic hazard of Cuba (Alvarez et al., 2017) and were continued with works on Nicaragua (Alvarez 2022). The original idea was from Alvarez, while the programs were developed mainly by him using also some elements developed by Lindholm.

The main contribution of Linholm was a critical review of results that were obtained in the process until the first published ones as maps and graphs were included in the mentioned paper (Alvarez et al., 2017). Some additional developments were done during works on seismic hazard of Nicaragua (Alvarez et al., 2022), mainly in including some new possibilities and improving results presentation.

The preparation of the paper was done in collaboration: agreeing a general structure and writing the different parts.

The correction of final version, after peers' revision, was agreed between both authors. No special funds were required to paper preparation; it was done from results of already funded researches as it is indicated in both cited publications. In both publications are discussed in detail the data and methodologies used for seismic hazard assessment estimations, that were used in preparation of the maps and graphics with the web application discussed in present paper.

### DECLARATION OF COMPETING INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work presented in this article.

### DATA AVAILABILITY

The software together with the data, examples and tutorials is available to those interested under request to [leoalvar50@gmail.com](mailto:leoalvar50@gmail.com).

## REFERENCES

- Alvarez, L. (2014). Sistema de análisis de la sismicidad sobre servidor Web. Ciencias de la Tierra y el Espacio, Vol.15, pp. 184-198.
- Álvarez, L. (2022). Nueva Estimación de la Amenaza Sísmica para Nicaragua. Revista Tierra, Vol. 2, No. 1, 18 pp.
- Alvarez L., Lindholm, C. and Villalón, M. (2017). Seismic Hazard for Cuba: A New Approach. Bull. Seism. Soc. Am., vol 107, pp. 229-239.
- Baker, J., Bradley, B. and Stafford, P. (2021): Seismic Hazard and Risk Analysis. Cambridge University Press. 595 pp.
- BSSA (2024): BSSA Special Issue on Seismic Hazard Models. Bull. Seism. Soc. Am. Vol 114(1).
- Chiou, B. and Youngs, R. (2014). Update of the Chiou and Youngs NGA Model for the Average Horizontal Component of Peak Ground Motion and Response Spectra. Earthq. Spectra. Vol. 30, pp. 1117-1153.
- GEM (2022). The OpenQuake-engine User Manual. Global Earthquake Model (GEM) OpenQuake Manual for Engine version 3.18.0.
- Ordaz, M., Aguilar, A. and Arboleda, J. (2008): CRISIS'2007. Program for computing seismic hazard. Instituto de Ingeniería de la UNAM.
- Ordaz M. and Salgado-Gálvez M.A. (2019). R-CRISIS Validation and Verification Document. ERN Technical Report. Mexico City, Mexico, 310 pp.
- Ordaz, M., Mánica, M.A., Salgado-Gálvez, M.A. and Osorio, L. (2022): Inclusion of site-effects: an approach coherent with contemporary event-based PSHA practices. Soil Dyn. Earthq. Eng., Vol. 158, article 107286.
- Pagani, M., Monelli, D., Weatherill, G. A. and Garcia, J. (2014). The OpenQuake-engine Book: Hazard. GlobalEarthquake Model (GEM) Technical Report 2014-08, 67 pp.
- Pagani, M., Silva, V., Rao, A., Simionato, M., Johnson, K. (2023). OpenQuake Engine Manual. Release 3.16.3, 216 pp.
- QGIS (2024). QGIS. A Free and Open Source Geographic Information System <https://qgis.org/en/site/>
- Salgado-Gálvez, M.A., Ordaz, M., Singh, S.K., Pérez-Campos, X., Huerta, B., Bazzurro, P. and Fagà, E. (2023): A Caribbean and Central America Seismic Hazard Model for Sovereign Parametric Insurance Coverage. Bull. Seism. Soc. Am. Vol.113, pp. 1-22.
- Shewchuk, J.R. (1996): "Triangle: Engineering a 2D quality mesh generator and Delaunay triangulator", in First Workshop on Applied Computational Geometry (Philadelphia, PA), 124-133, ACM.
- SRL (2024): SRL Focus Section on Seismic Hazard Models. Seism. Res. Lett., Vol 95(1).
- Wessel, P. and Smith, W.H.F. (1998). New, improved version of Generic Mapping Tools released, Eos Trans. AGU 79, no. 47, 579.

Wessel, P. and Smith, W.H.F. (2019). GMT, version 4.5.18.

Williams, T. and Kelley, C. (2022). Gnuplot 5.4: An interactive plotting program.



## ANNEX A. FORMAT OF FILE “DATA.TXT”

The file is formed by “ $n_A$ ” blocks, where “ $n_A$ ” is the number of points in the region “ $A$ ” of the map for which SH has been calculated. Each of the blocks has the structure:

1. Three lines characterizing the whole block:

- ‘New site:’ and order number – format (a9, i4)
- Latitude and longitude of the point, number of arms ( $n_L$ ), number of spectral ordinates (periods of UHS -  $m_T$ ) and number of  $\alpha$  values ( $n_\alpha$ ) used in SH calculation – format (2f10.4, 3i5)
- Weights ( $w_n$ ) of the different arms:  $n_L$  values – format (100f10.6); the weights may be arbitrary (under the condition that their sum is equal 1), as they should be modified during application execution in dependence of user’s selection.

2.  $m_T$  sub-blocks with the information

- ‘T=’, period of the UHS – format (a2, f5.3)
- Information presented in Table 1 as:

- ‘level\arm’, numbers of the arms from 1 to  $n_L$  in format (a9,100i14)
- $n_\alpha$  lines with  $[ \alpha_i, f_{ijkln} = F(\alpha_i, T s_j, lat_k, long_l, l_n), l_n = 1, n_L ]$  – format (1pe14.5, 99e14.5)

*Notes:*

- The format specifications correspond to FORTRAN programming.
- They are considered 100 arms as an example. If the numbers of arms are greater, they should be modified the corresponding formats.

## ANNEX B. ALGORITHMS FOR STATISTICAL PROCESSING OF LOGIC TREE

*Weighted normal statistics.*

Let  $x_i$  be the observations and  $w_i$  the weights:

$$\begin{aligned} \text{weights are normalized } & \sum w_i = 1 \\ \text{weighted average: } & x_{mean} = \sum x_i \cdot w_i \\ \text{weighted variance: } & Var = \sum [(x_i - x_{med})^2] \cdot w_i \\ \text{standard deviation: } & \sigma = Var^{1/2} \end{aligned}$$

*Weighted sample statistics*

First, the sample should be ordered. Then, it will be a set of values of PSHA (for simplicity only “SH” is used) ordered from minor to major:

$$\{ SH_1 \leq SH_2 \leq \dots \leq SH_N \}.$$

Every branch has a given weight:

$$weight_i = weight(branch SH_i) \text{ and } \sum weight_i = 1$$

It is calculated the associated probability to every sample:

$$\begin{aligned} prob_1 &= weight_1 & i=1 \\ prob_i &= prob_{i-1} + weight_i & i=2, N \end{aligned}$$

Let ( $vper_j, j=1, m$ ) be the values of sought percentiles and  $SHper_j$  the SH values corresponding to these percentiles. The calculation is:

$$\begin{aligned} SHper_j &= SH_i & \text{if } vper_j = prob_i \text{ (order } 1-e-10) \\ SHper_j &= vper_j \cdot SH_i / prob_1 & \text{if } vper_j < prob_1 \end{aligned}$$

$SH_{per_j} = SH_i + (v_{per_j} - prob_i) \cdot (SH_{i+1} - SH_i) / (prob_{i+1} - prob_i)$  if  $v_{per_j} > prob_i$  and  $v_{per_j} < prob_{i+1}$   
A standard procedure for percentiles' determination is applied.

### ANNEX C. SOME ADDITIONAL FILES NEEDED

*Isolines labeling:* The maps are prepared with color gradation, where it is difficult to estimate the real represented values. For this reason, is convenient to represent isolines with values that have some meaning for the user. There are 6 different files that indicates the desired values of isolines in maps, that correspond to three different detailing and two units [cm/s] and [g]. For preparing these files it is necessary to determine the range of intensity values used in calculations. In the file “.Ltc.dat”, from line 5 to Nper+4 are presented the value of period “ $T_{UHS}$ ” and the maximum and minimum of intensity to be sought. From this information are determined the absolute minimum and maximum that define the range of intensity present in all maps. Then, the range is divided at will at several intervals from less detailed to maximum detail, forming 3 different files. If the units are [cm/s] the files should be named (escala.dat, escalita.dat and escalota.dat), and if the unit is [g] they should be named (escala.dat.g, escalita.dat.g and escalota.dat.g). They are text files with one value per line. The experience shows that it is obtained a good representation when the number of intervals is around (20, 40 and 70).

*Adding political division to maps:* The webapp has the possibility of adding political division to maps. There are two levels, one less detailed for departments (provinces) limits (file “limdep.xy”) and other more detailed for municipalities (parishes) limits (file “limmun.xy”) that has to be prepared according to the study region. The format of these files is very simple. The limits are formed by independent lines given given by a set of points  $(x_i, y_i)$ . Then, the file is formed by putting these lines consecutively, but adding a symbol “>” in column 1 at the beginning of each set.