caravan

Central Asia Risk and Vulnerability Analysis Tool

User Manual

software version: v0.2-14-gf8281d3

manual version: v0.1

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Contents

1 Introduction

The CARAVAN platform has been designed to provide decision makers and civil protection authorities with a tool that allows a prompt estimation of the impact of an earthquake. The platform can be used to understand the extent and the amount of loss related to the occurrence of a damaging event, in a simple and intuitive way.

The input scenario can be either specified manually using the left-side tab (see section 2.1), or can be selected from a list of events provided by external services (see section 2.3). The scenario parameters can be anyway modified, before the computation of related ground-motion and loss estimates. For most of the parameters, a related uncertainty can be specified. This uncertainty will be consequently propagated in the internal computation, and accounted for in the resulting estimates.

NOTE: The CARAVAN platform is still in development and testing. As such, some of the described functionalities can be incomplete or can provide unexpected results. In order to provide us with suggestions and comments, and a prompt feedback on bugs and missing features, write an email to *pittore@gfz-potsdam.de*.

1.1 Structure of the application

The caravan platform is composed by a three-layered structure, shown in fig. 1. The back-end relational database is hosting all necessary models for both ground-motion computation and loss estimation. The **database** is based on the well known PostgreSQL/postGIS open-source solution, and its extended geographical support allows for a sophisticated management of spatial information.

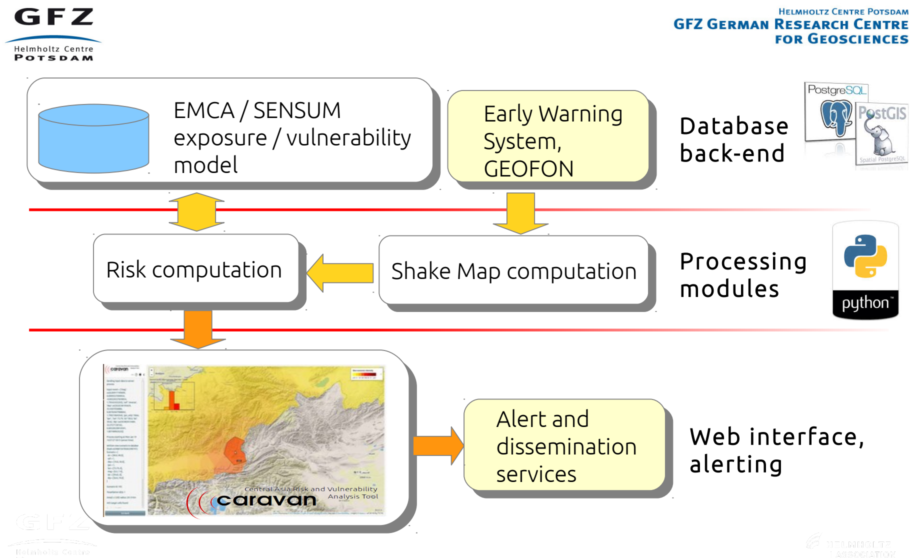


Figure 1: Sketch of CARAVAN platforms structure.

In particular, the database hosts the exposure/vulnerability model of the Country, which is defined over a specific 2-dimensional tessellation of the geographical area.

Note: we define a *tessellation* as a spatial subdivision of a planar surface into a set of neighbouring polygons (referred to as geocells) of different shapes and area.

An example of such tessellation is shown in fig. 2. The tessellation provides the basic spatial support of the computation, since every geocell contains all necessary data to carry out the different computation stages. The area of the geocells is inversely proportional to the estimated number of people living within. Therefore, in densely inhabited areas, a spatially denser dataset is used, and thus a higher spatial resolution of the resulting estimates.

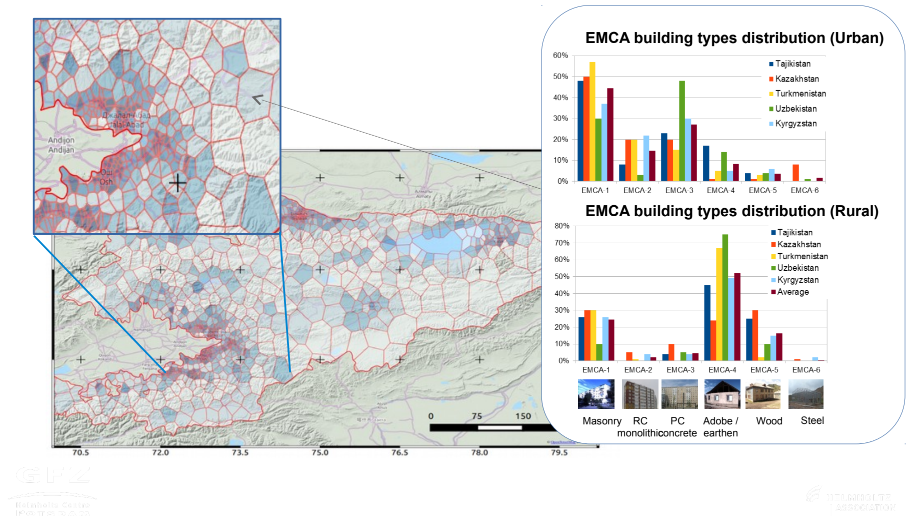


Figure 2: Example of the multi-resolution tessellation used to describe the exposure-vulnerability model. The single geocells are color-mapped according to their density of inhabitants.

The **processing modules** are carrying out the necessary computations. In particular, the ground-motion computation module estimates the probabilistic distribution of ground motion, while the loss computation module estimates the expected impact in terms of the probabilistic distribution of fatalities. Both computation are carried out for each geocell of the tessellation, independently and in parallel. More information is provided in section 3.

The last stage of the CARAVAN platform is the visualization and dissemination interface. This component provides the user with a simple set of components for the selection and modification of scenario event parameters and processing properties. Moreover, an interactive slippy map allows the users to browse the processed data. The elements of the interface are described in more detail in section 2.

2 The CARAVAN Web interface

The CARAVAN main web interface is displayed in fig. 3. The interface is composed by an interactive map (see section 2.4), and a navigation bar hosting both the *event description* and the *process settings* (see respectively 2.1 and 2.2)). A single *run button* is triggering the computation.

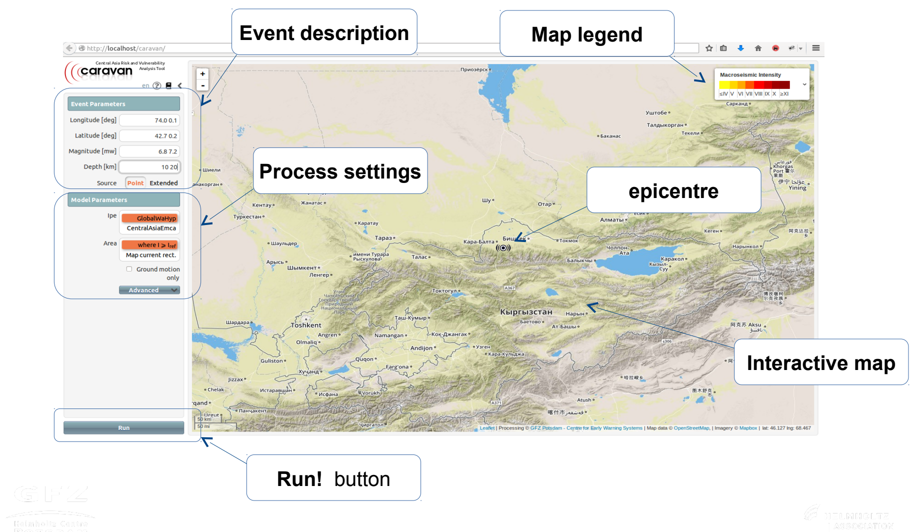


Figure 3: CARAVAN Web graphical User Interface (GUI).

The left side bar of the CARAVAN web interface contains the basic functional buttons and both the event scenario and the model parameters (described in the next sections). The basic functional buttons, shown in fig. 4 (left), allow the users to activate some of the interface functions. In particular:

h) **Multilingual support**. Changes the interface language. Currently available languages are: english, german, russian and chinese. More languages can be added at a later stage.

m) **Tooltips**. When the tooltips are enabled, by clicking on the left-side text of one of the event parameters a pop-up short help will be displayed.

p) **GEOFON link**. Opens the GEOFON event import module. This module, if enabled, continuously download from the GEOFON network all events occurred in the selected Country within a specific magnitude range (currently events with magnitude > 5). **NOTE: experimental feature**.

n) **FDSN event query**. Opens the FDSN event import module. See section 2.3.

2.1 Event description

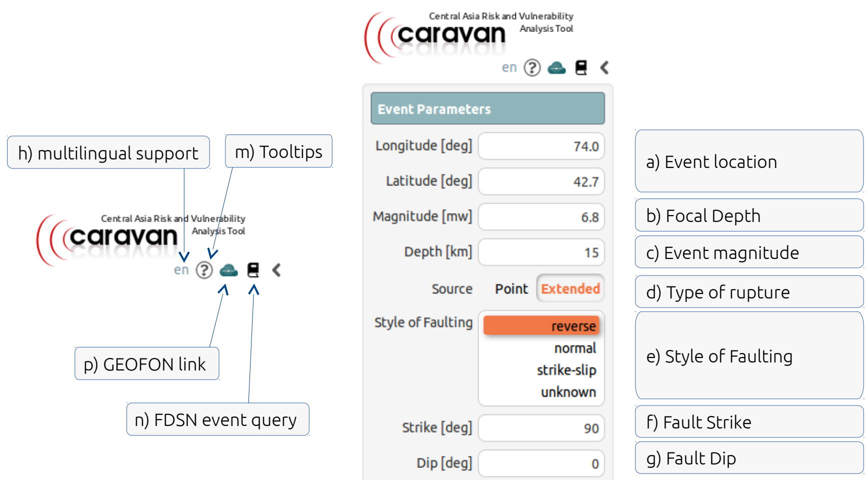


Figure 4: Event description.

The event description (right side, in fig. 4)allows the user to define the basic properties of the desired/selected event:

a) **Event location**. Longitude and latitude, in decimal degrees, of the event. By typing a sequence of two numbers (separated by either spaces, a comma or a semicolon), the coordinate will be considered as following a normal (gaussian) distribution, where the first number is the mean, and the second the standard deviation.
For instance: $\boxed{74.0\ 0.1}$ means that the longitude of the events epicentre is defined by a gaussian distribution with mean $\mu = 74.0$ degrees and standard deviation $\sigma = 0.1$ degrees. In other terms, considering that 95.5% of values of a normal distribution lie within a confidence interval of $\mu \pm 2\sigma$, the longitude of the event will be, with a probability of 95.5%, in the range $(73.8, 74.2)$.

b) **Focal depth**. Indicates the depth of the earthquakes hypocenter, in km. When two values are provided, they will be interpreted as the interval of a uniform distribution. For instance: $\boxed{10\ 20}$ means that the hypocentral depth of the event can be comprised anywhere between 10 and 20 km.

c) **Event magnitude**. Moment magnitude (M_w) of the event. The magnitude measures the size of the event in terms of the energy released, and is based on the seismic moment of the earthquake. When two values are provided, they will be interpreted as the interval of a uniform distribution (see above).

d) **Type of rupture**. Specifies whether the seismic source has to be considered a point, or an extended source. In the latter case, three more parameters have to be provided:

e) **Style of faulting**. A fault is a planar fracture or discontinuity in a volume of rock, along which there has been significant displacement as a result of rock mass movement. Large faults within the Earth's crust result from the action of plate tectonic forces, with the largest forming the boundaries between the plates, such as subduction zones or transform faults. Energy release associated with rapid movement on active faults is the cause of most earthquakes. A fault plane is the plane that represents the fracture surface of a fault. A fault trace or fault line is the intersection of a fault plane with the ground surface. A fault trace is also the line commonly plotted on geologic maps to represent a fault. The two sides of a non-vertical fault are known as the hanging wall and footwall. By definition, the hanging wall occurs above the fault plane and the footwall occurs below the fault.

   Based on the direction of slip (the mechanism of rupturing), the faults ruptures are usually assigned with different categories (see fig. 5), which have to be taken into account in order to estimate the resulting ground motion. The possible options are:

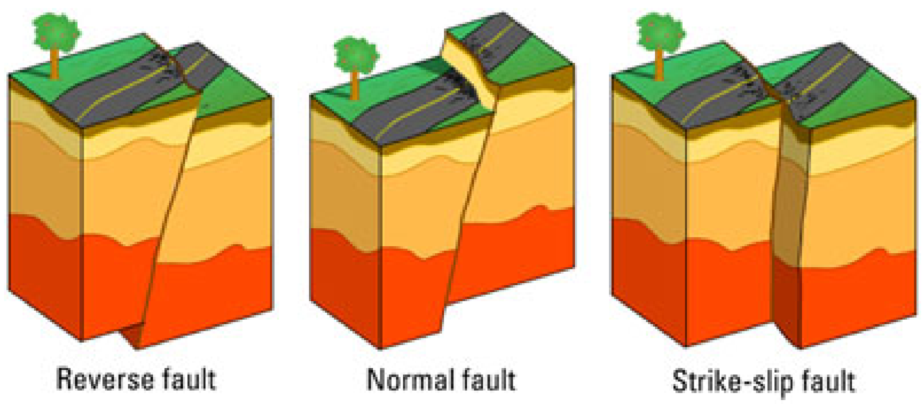


Figure 5: Different faulting styles (image courtesy of SMS-Tsunami-Warning.com).

   * *Normal*. The block above the fault moves down relative to the block below the fault. This fault motion is caused by tensional forces and results in extension.
   * *Reverse*. In a reverse fault, the block above the fault moves up relative to the block below the fault. This fault motion is caused by compressional forces and results in shortening. A reverse fault is called a thrust fault if the dip of the fault plane is small.
   * *Strike-slip*. In a strike-slip fault, the movement of blocks along a fault is horizontal. If the block on the far side of the fault moves to the left, as shown in this animation, the fault is called

left-lateral. If the block on the far side moves to the right, the fault is called right-lateral. The fault motion of a strike-slip fault is caused by shearing forces.

∗ *Unknown*. Select this option if the style of the fault is not known.

f) **Fault strike**. The strike is an angle used to specify the orientation of the fault and measured clockwise from north. For example, a strike of 0 or 180 indicates a fault that is oriented in a north-south direction, 90 or 270 indicates east-west oriented structure. To remove the ambiguity, we always specify the strike such that when you "look" in the strike direction, the fault dips to you right.

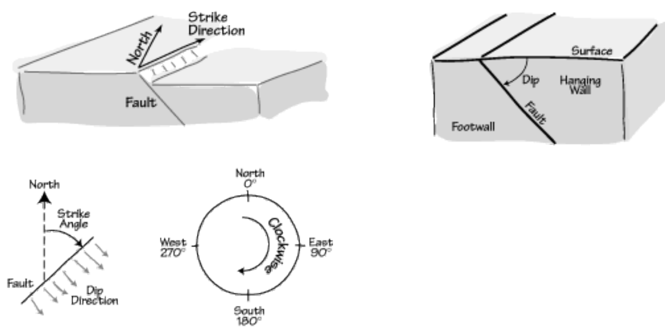


Figure 6: Geometry of Strike (left side) and Dip (right side) of a normal or reverse fault (image courtesy of PennState College of Earth and Mineral Science).

g) **Fault dip**. Indicates the orientation the fault is taking from vertical to horizontal. Dip is the angle that describes the steepness of the fault surface. This angle is measured from Earth's surface, or a plane parallel to Earth's surface. The dip of a horizontal fault is 0 degrees, and the dip of a vertical fault is 90 degrees. When two values are provided, they will be interpreted as the interval of a uniform distribution (see above).

2.2 Process settings

This section of the CARAVAN interface contains several parameters which are currently used in the testing phase. A brief description of the parameters is provided in the following.

NOTE: some of these parameters are experimental, therefore we suggest not to change them!

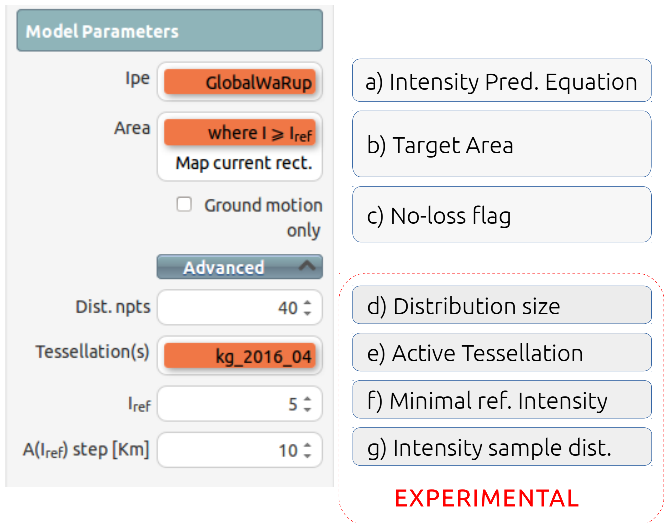


Figure 7: Model parameters.

a) **Intensity Prediction Equation (IPE)**. Specific IPE to be used in the ground motion simulation. More details can be found in section 3.1.

b) **Target Area**. Selection of the geocells involved in the computation can be done based on the minimal expected intensity (e. g. only the cells which will experience an intensity I $\geq I_{ref} = 5$ will be selected), or just the area in view can be selected for the processing.

c) **No-loss binary flag**. If the flag is checked, no loss computation will be carried out, only ground motion.

d) **Distribution size (EXPERIMENTAL)**.In order to propagate uncertainties in the computation, a Monte Carlo sampling approach is followed. Each variable is thus defined by a probability distribution, instead of a single scalar value. This parameter defines the size of the empirical distribution used to carry out the sampling (suggested values: between 40 and 1000).

e) **Active tessellation (EXPERIMENTAL)**. Different tessellations can be implemented, and are stored in the CARAVAN database. This parameter specifies the specific database identifier (ID) of the tessellation to be used for the computation.

f) **Reference intensity**. Minimal intensity (in EMS98 / MSK64) to be reached or exceeded in a geocell for the cell to be selected for computation. The higher is this intensity, the less geocells will be used for the computation, and the smaller will be the area involved in the overall estimation.

g) **Intensity sample distance (EXPERIMENTAL)**. Minimal distance in km between consecutive samples. This parameter is used to compute the spatial extent of the area to be involved in the computation.

2.3 FDSN event sources

The user of the CARAVAN platform can either create an event scenario manually by specifying all the parameters needed, or an already existing event can be downloaded and selected from an external source. Currently, three sources are available, which allow for querying and downloading the events contained in their database systems according to the FDSN standard format provided by the International Federation of Digital Seismograph Networks (see `https://www.fdsn.org/webservices/`). Currently the following sources have been implemented:

- **EMSC**. The European-Mediterranean Seismological Centre was founded in 1975, following a recommendation from the European Seismological Commission (ESC). The ESC is a regional commission of the International Association of Seismology and Physics of the Earth's Interior (IASPEI), itself a specialized association of the International Union of Geodesy and Geophysics (IUGG).

- **IRIS**. Incorporated Research Institutions for Seismology. IRIS is a consortium of over 120 US universities dedicated to the operation of science facilities for the acquisition, management, and distribution of seismological data. IRIS provides management of, and access to, observed and derived data for the global earth science community.

- **INGV**. the Italian *Istituto Nazionale di Geofisica e Vulcanologia* provides access and retrieval of the earthquake information contained in the INGV archives.

More sources will be added in the future platform releases.

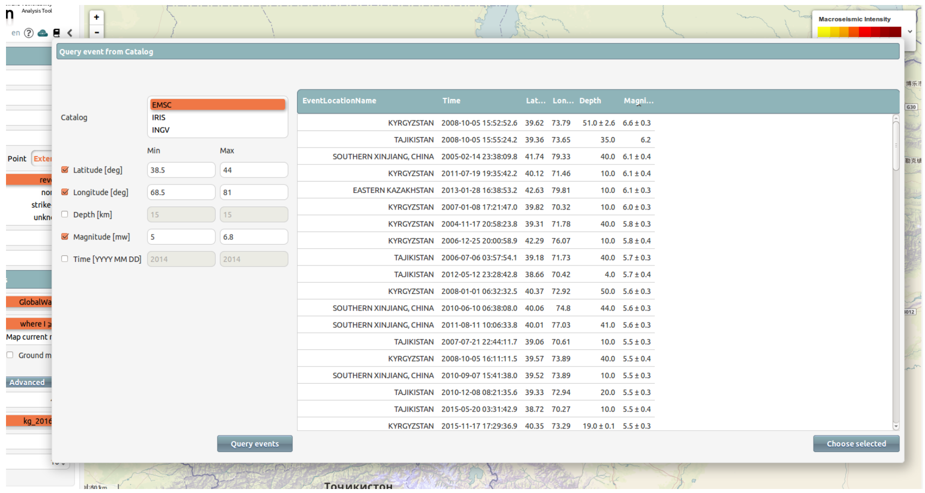


Figure 8: Model parameters.

In order to load a scenario event from a FDSN service, the user has to click on the button (see item *n)* in fig. 4 left). A new pop-up window will be displayed (see fig. 8). On the left, the query parameters allow to specify the main properties of the desired event. In particular it is possible to filter the events based on their geographical coordinates (the query is currently initialized with the boundary of Kyrgyztan), on their magnitude, focal depth or occurrence date. By clicking on the button *Query events* the query is sent and the answer from the remote server is parsed and displayed as a table. If the received data include uncertainty estimates on some of the parameters, these are displayed as well. By clicking on the headers of the different table columns, it is possible to sort the list accordingly (e. g. based on the magnitude). Eventually the user can select a specific event by clicking on it, and load it into the event description by clikcing on the button *Choose selected*. Once the event has been loaded in the event description, all parameters can be further modified before starting over the processsing phases. For instance the user can decide to change some of the values, or to manually add uncertainties to the parameters in order to account for lack of information in the characterization of the scenario.

2.4 Interactive map

The interactive map provides the main interface with the CARAVAN users. The map features a tiled background, shown in fig. 9, which provides the basic information layer. This background is currently queried from the global, opensource OpenStreetMap (OSM, see `http://www.osm.org`) initiative. OpenStreetMap is built by a community of mappers that contribute and maintain data about geographical features, settlements, roads, buildings, and much more at a global scale, although with different levels of completeness and quality. In Kyrgyzstan, the spatial coverage and thematic detail of OSM map is remarkable, and can

be efficiently used as a background providing a basic geographical framework for the localization of the scenario events. Moreover, in Central Asia most of the labels of settlements and topographical features are provided natively in Russian language.
On top of the tiled map, a vector layer is superimposed when the results from the processing stages are available. This vector layer is composed by a set of geometric primitives in form of polygons, each with a set of attributes. The polygons represent the geocells of the tessellation which have been selected for processing (see section 2.2 and 3). The set of attributes, as well as the color of the geocells depends on the specific layer which is visualized.

Figure 9: Interactive map. A graphic symbol denotes the location of the events epicentre.

When visualizing the resulting spatial distribution of ground motion, the geocells attribute used for visualization is the mean value of macroseismic intensity. By hovering the mouse over the geocells, the related probability distribution over the different discrete values of intensity is shown in a separate, overlaying window. The figure 10 shows an example of the resulting distribution. As it is possible to note, in the selected geocell (the one the mouse is currently over) the most likely intensity to be experienced is 7 (we consider EMS-98 and MSK64 scales as effectively equivalent). Nevertheless, there is a significant likelihood (40%) that an intensity 8 will be experienced. This distribution encodes the resulting uncertainty over the event parameters which is propagated throughout the process, as described in section 3.1.

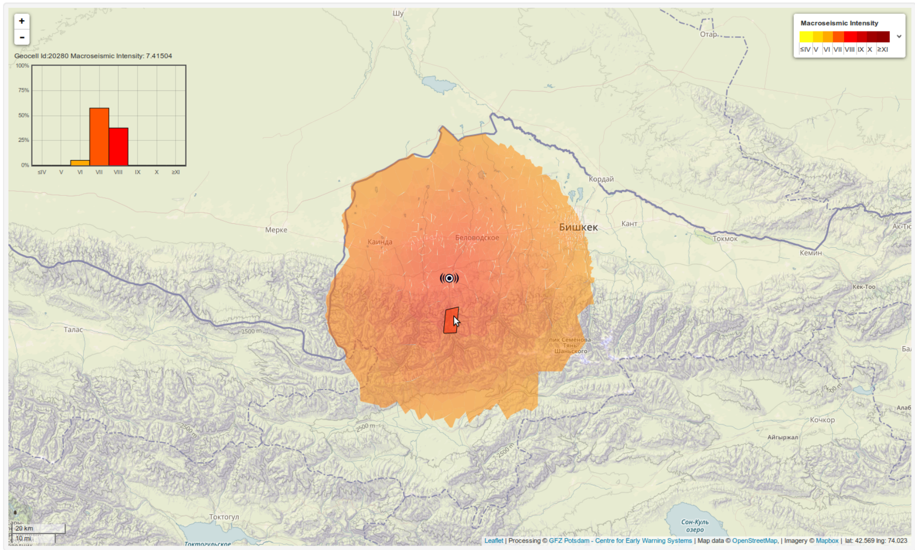


Figure 10: Interactive map of ground motion. By hovering the mouse on the geocells involved in the computation, the probability distribution over the discrete intensity values (in EMS98 / MSK-64) is shown.

In a similar manner, the user can switch from the visualization of ground motion to the visualization of loss. In this case the vector layer superimposed to the background tiles will always be composed by the same geocells, but attributes related to loss estimation will be visualized instead. In figure 11 an example related to the ground motion distribution shown in fig. 10 is provided. The color of the geocells is now proportional to the mean of expected fatalities, and a correponding probability distribution is provided. In the selected cell the expected value of fatalities is 16.3, with a corresponding higher probability of it lying in the 10-20 interval, but still with a significant probability (almost 20%) of a number of fatalities comprised between 20 and 50. Looking at this distribution we can conclude that, given the available information, we can expect with almost 90% probability a number of fatalities between 10 and 50. The colormap used, also depicted in the legend shown in the upper-right corner of the map, provides an immediate panorama of where the loss are expected, and as it is possible to note by comparing the figures 10 and 11, not always the locations with higher expected ground motion are also the ones where highest loss toll is estimated.

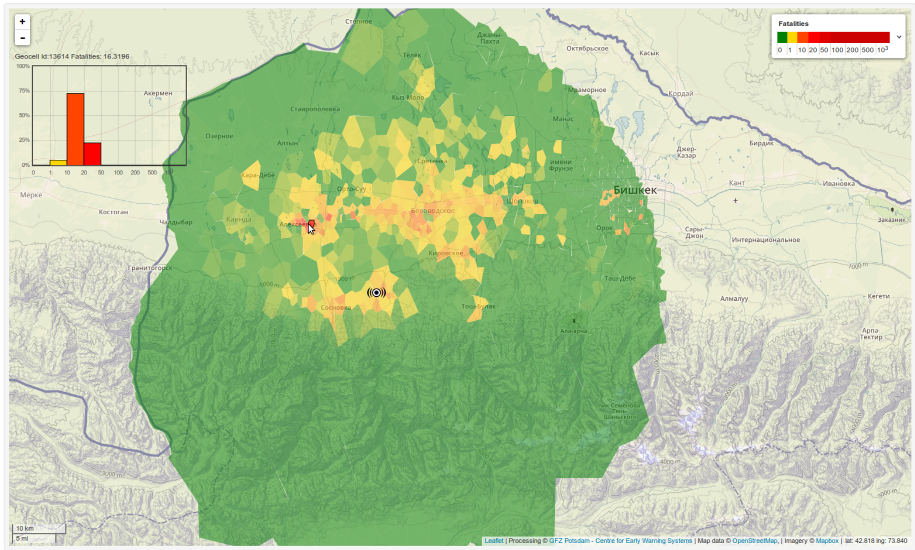


Figure 11: Interactive map of loss. By hovering the mouse on the geocells involved in the computation, the probability distribution over the expected number of fatalities is shown.

3 Scenario Impact computation

Following the selection of a suitable event scenario in terms of earthquake location, magnitude, hypocentral depth and faulting style, the CARAVAN platform can start carrying out the necessary processing. The processing stages can be split in the following steps:

1. The active area, used to select the geocells involved in the computation, is estimated.

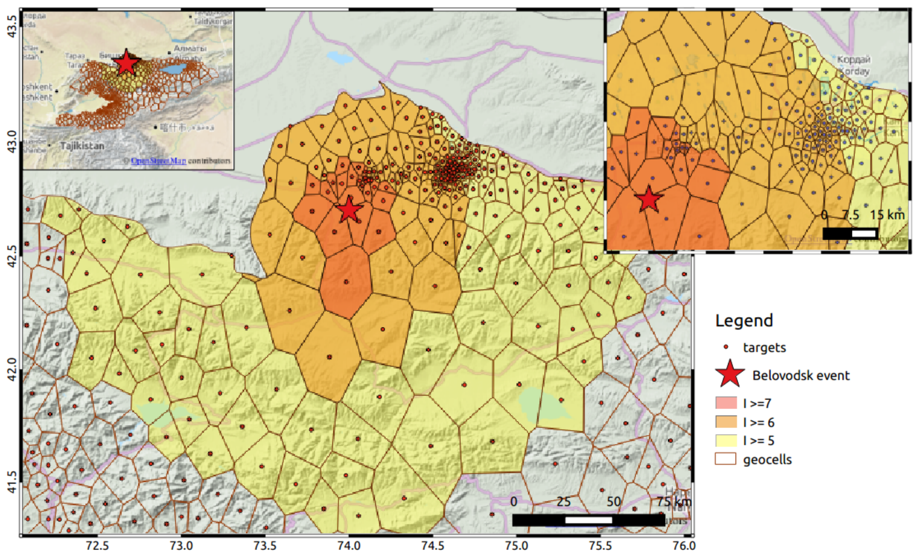


Figure 12: Geocells included in the estimated active area. Also shown are the corresponding mean intensity value for each cell.

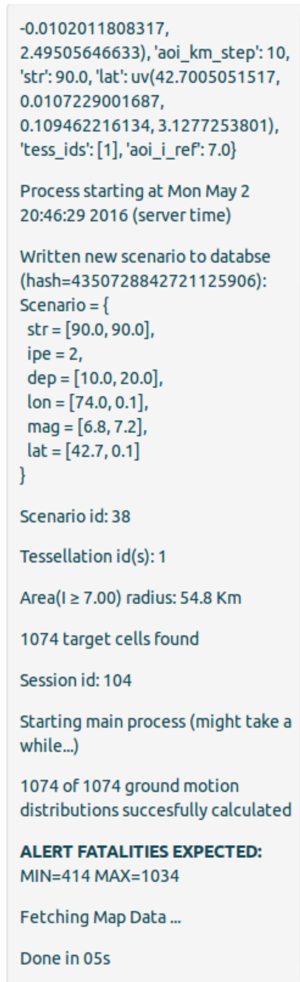
2. The geocells are queried from the database within the computed area.

3. For each geocell, a separate process is spawned and added to a multiprocess pool.

4. Computation of ground and loss distribution is carried out independently and in parallel for each geocell. Every single process in the pool is accessing the database for querying the necessary data and writing back the resulting estimates. A set of real-time messages are output in the console (see figure 13) in the left navigation bar. The log messages include the details of the scenario event used for the simulation, the extent of the active area based on the events properties and the chosen I_{ref}, the number of active geocells, the elapsed time and the 5-95% percentiles of the resulting disrtribution of loss across the active geocells. In case of warnings or errors during the processing, a suitable message is displayed as well in the console.

5. When all processes complete their task, the platform is visualizing the resulting distribution according to the layer chosen by the user.

In the following sections, further details on the specific processing stages related to ground motion and loss estimation are provided.



-0.0102011808317,
2.49505646633), 'aoi_km_step': 10,
'str': 90.0, 'lat': uv(42.7005051517,
0.0107229001687,
0.109462216134, 3.1277253801),
'tess_ids': [1], 'aoi_i_ref': 7.0}

Process starting at Mon May 2
20:46:29 2016 (server time)

Written new scenario to databse
(hash=4350728842721125906):
Scenario = {
str = [90.0, 90.0],
ipe = 2,
dep = [10.0, 20.0],
lon = [74.0, 0.1],
mag = [6.8, 7.2],
lat = [42.7, 0.1]
}

Scenario id: 38

Tessellation id(s): 1

Area(I ≥ 7.00) radius: 54.8 Km

1074 target cells found

Session id: 104

Starting main process (might take a while...)

1074 of 1074 ground motion distributions succesfully calculated

ALERT FATALITIES EXPECTED:
MIN=414 MAX=1034

Fetching Map Data ...

Done in 05s

Figure 13: .

3.1 Ground motion

Each geocell first computes the distribution of ground motion which is expected for the spatial location corresponding to the mass centre of the cell itself (called *target*). The computation depends on the event parameters and the users choice of the Ground Motion Intensity Prediction Equation (IPE) as shown in figure 14. In case uncertainty has been specified for some or all of the event parameters, a corresponding distribution is generated and then propagated through the computation following a Monte Carlo approach based on the latin-hypercube sampling methodology.

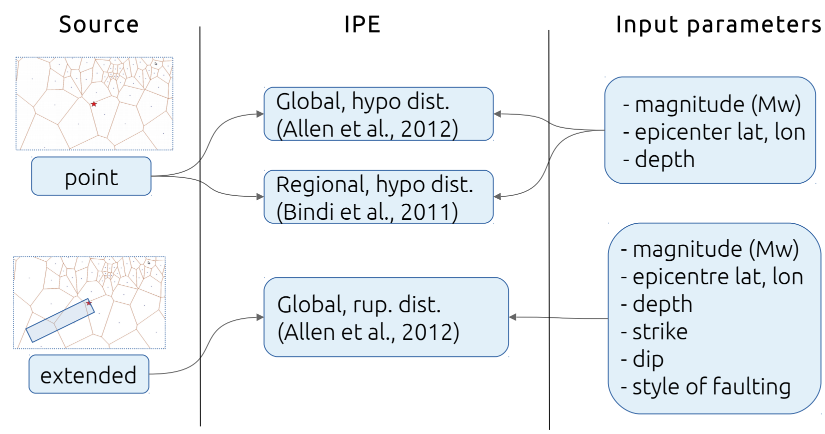


Figure 14: .

In figure 15, upper part, the distributions encoding the uncertainty on the location, magnitude and depth of the scenario event are shown. These distribution are propagated using a specific IPE (actually implemented are either global one proposed by [1] or the one proposed by [2] foe Central Asia) leading to the resulting probability distribution for the expected macroseismic intensity in the two spatial locations (targets) which represent the baricentres of two geocells (see 15, lower part).

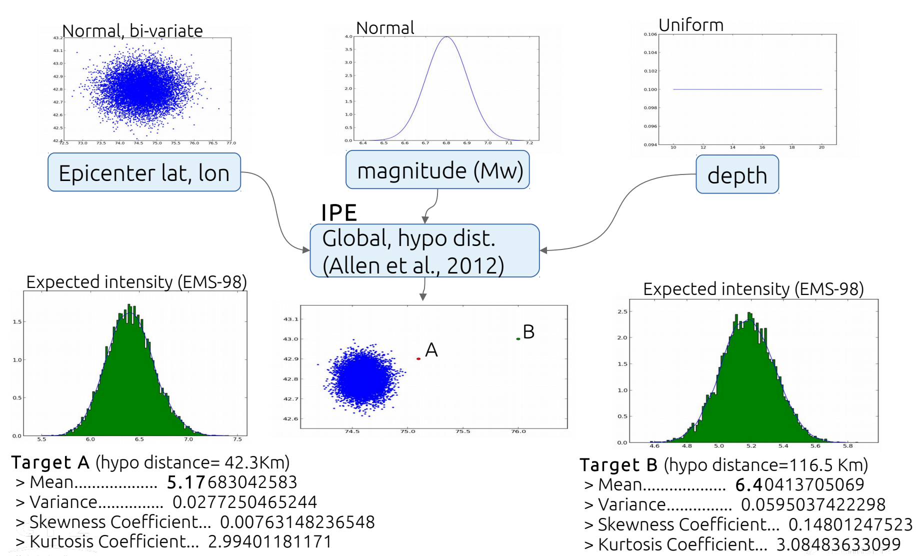


Figure 15: Association between source model, IPE and event parameters.

3.2 Loss estimation

The probabilistic distribution of ground motion estimated for each geocell is used then as input for the loss estimation procedure. The exposure and vulnerability model, which is also included in the CARAVAN database and disaggregated at geocell level, is employed to estimate the expected number of collapsed building for each of the considered building types. The exposure and vulnerability model for Kyrgyzstan for instance has been developed within several international projects. The building typologies are described in [6] and [7], and the model has been developed following the approach described in [5]. The vulnerability model is based on the methodology developed by [4], which proposes a more sophisticated version of the EMS-98 formulation aimed at vulnerability and risk assessment. The Mean Damage Grade (MDG) μ_d of a building structure subject to a ground motion equivalent to macroseismic intensity I, in the proposed approach, is modelled as:

$$\mu_d = 2.5\left(1 + tanh(\frac{I + 6.5V - 13.1}{2.3})\right) \quad (1)$$

where V is the vulnerability index associated to the building (or to its category). If we consider also the related uncertainties, the vulnerability index and the intensity are both described by distributions, as shown in figure 16.

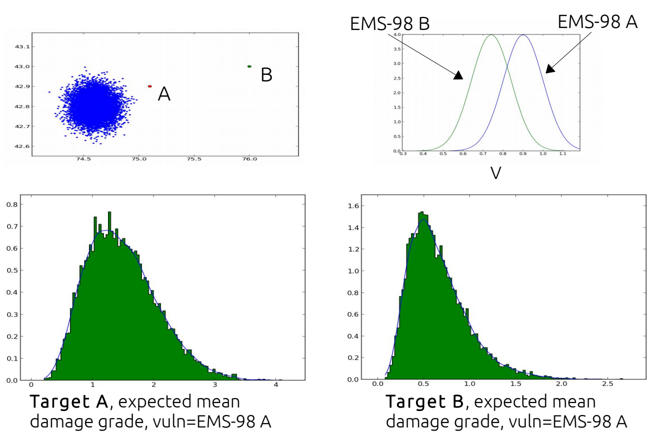


Figure 16: Resulting distribution of Mean Damage Grade, including the uncertainty in ground motion and vulnerability. In the upper right corner, the distribution of the vulnerability index related to two hypotethical structures with EMS98 vulnerability A and B is shown. The lower part shows the resulting distribution of MDR related to the two target locations A and B shown in the upper left inset, resulting from the propagation of the different uncertainties.

For each building typology, the number of collapsed or heavily damaged buildings, respectively corresponding to damage states 5 and 4 on the EMS98 scale, is used to estimate the expected distribution of fatalities, following the approach proposed by Coburn and Spence in 2002 ([3]), as shown in figure 17.

$$K_{sb} = TC_b \times [M_1 \times M_2 \times M_3 \times (M_4 + M_5(1 - M_4))]$$

collapsed buildings

Population per building

Time-dependent occupancy

Percentage of trapped

Injury levels for trapped

Time-dependent Injury levels for trapped

Figure 17: Propagation of uncertainties in the computation of ground motion.

4 Other training resources

Several training videos can be accessed online:

- basic demo: https://vimeo.com/145905920
- fdsn query: https://vimeo.com/145910666

5 Troubleshooting

in construction

References

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[3] Andrew Coburn, Spence. *Earthquake protection*. J. Wiley.

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