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ShakeMap implementation for Pyrenees in France-Spain border: regional adaptation and earthquake rapid response process



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SUMMARY:
The USGS-ShakeMap package is used with a regional adaptation to provide automatic shake maps in rapid response for Pyrenean earthquakes. The Near Real Time system relies on servers designed for data exchange between transborder organizations involved in the Sispyr project. First maps will be provide as soon as possible after the shock, and updated with observed macroseismic intensities on the following hours.
Regional Predictive Equations Tapia (2006) and Goula et al. (2008) are selected after tests with regional data. When data are not sufficient, European relations for similar seismotectonic context are selected (Akkar & Bommer, 2007, 2010). For ground motion/intensity conversions, Souriau (2006) for PGA, Faccioli & Cauzzi (2006) for PGV are preliminary choices. Site effects are taking account from geological considerations. 7 classes of soil are defined, each with their amplification factors deduced from ratio between soil and bedrock spectra, for short and mid period..

Keywords: Shake map, Ground motion, Pyrenees, automatic process

1. INTRODUCTION

A key objective of the SISPyr Interreg project (www.sispyr.eu) is to provide automatic production of shake maps in rapid response for Pyrenean earthquakes. Maps are generated for peak ground motion parameters (PGA, PGV) spectral acceleration (SA) at 0.3, 1.0 and 3.0 seconds and intensity. The most recent version 3.5 of the USGS-ShakeMap package is used with a regional adaptation. This implementation uses the approach developed by Worden et al (2010) for mixing observed data, converted data (using GMICEs relations), and ground motion prediction equations. All of them as input data.

In this study, we describe how the ShakeMap is integrated in the Near Real Time (NRT) process of rapid response and what are the parameters used for regionalization.
The coherence of produced ShakeMaps with observational data (intensities or strong movements) will be verified and illustrated with some recent and historical earthquakes.

2. NRT PROCESS

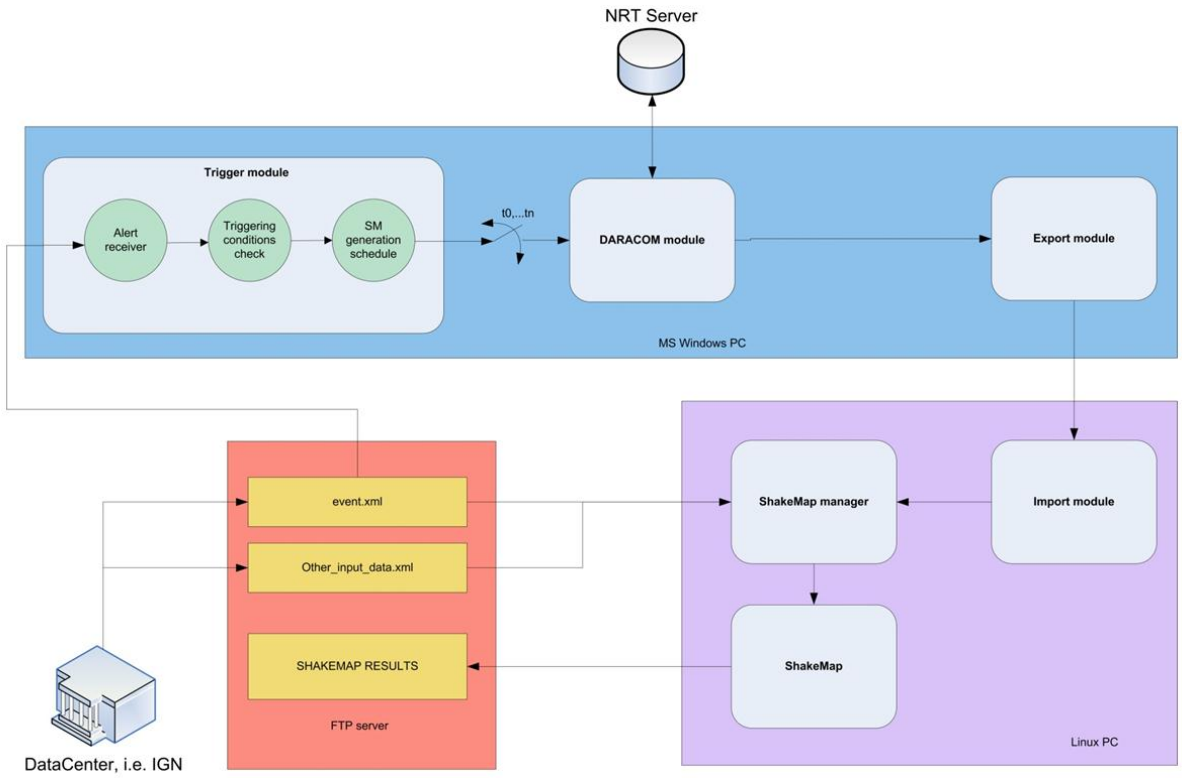


Figure 1. : Schematic diagram for the modules of the NRT process and their interconnection

The system has four main components (Fig. 1):

- an ftp server that receives input data and ShakeMap results,
- an NRT server on which the continuous records of Pyrenean seismic stations are stored for exchange between the SISPyr partners,
- an MS Windows PC that manages the data from the NRT server by an automation system,
- a Linux PC that manages the ShakeMap process.

The process can produce several versions of ShakeMaps for a single event. The initial ShakeMap is triggered by the first alert message with an automatic event location and magnitude assessment send to the ftp site. The final ShakeMap is produced with all the available data after a configurable time limit (beyond 24 hours). The initial ShakeMap is updated whenever new information concerning this event (new event location or macroseismic input data) arrives on the ftp server during the time limit. The automation system can handle multiple processes at once (main event and following aftershocks or several events in Pyrenees the same day).

The event alert message is sent by IGN on the ftp site. Event location and magnitude are automatic calculations sent few minutes after the earthquake. The trigger module checks the triggering conditions: Magnitude greater than 3.0, epicenter inside the Sispyr zone, origin time not below a delay limit, new event data with an update of information.

The system queries the NRT server to find the signals corresponding to the event among the station records. The server is operative since January 2012 and contains 138 continuous real time streams from 46 seismic stations (Fig. 2) shared by IGC, IGN, OMP, BRGMand Institut d'Estudis Andorrans(I EA). Data on server are available for the last 24 hours. The DARACOM module (Fig. 1) retrieves data and computes ground motion parameters (PGA, PGV, SA) for each channel and less than a concrete

epicentral distance..

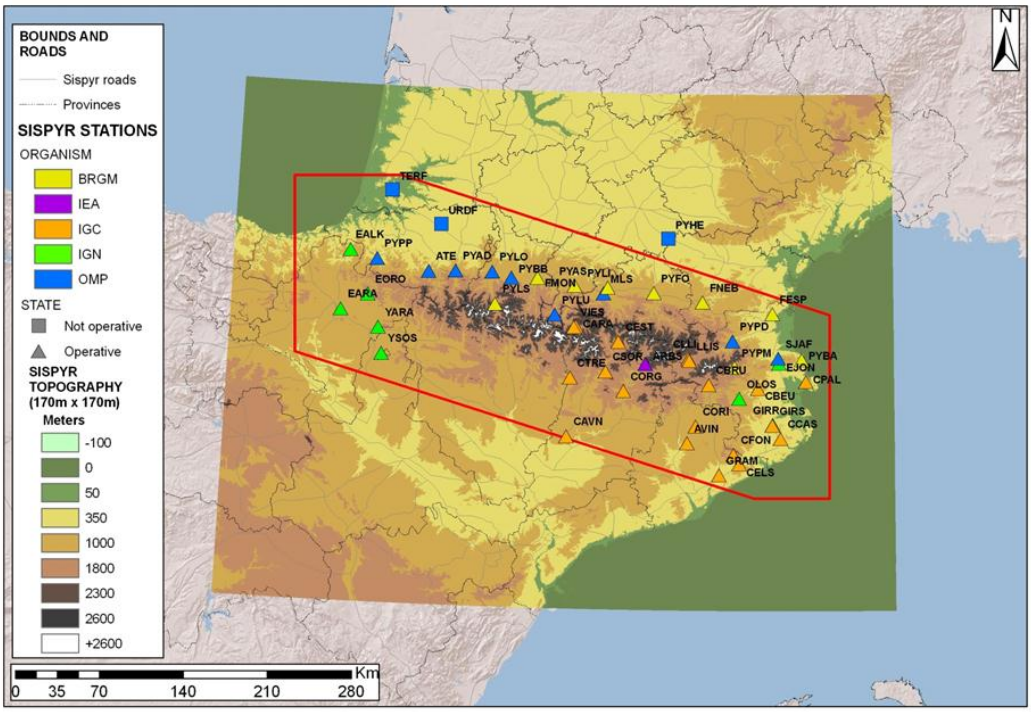


Figure 2 : Seismic stations sharing data on the NRT server (in red the limits of the area concerned by the Sispyr project)

Three agencies contribute to macroseismic data exchanges: IGN and IGC in Spain, BCSF in France. Data consist of EMS intensity estimates at municipality scale around Pyrenean area. Data are sent by agencies as soon as possible inside a 24 hours time delay. The same ftp site, where the alert is being send, is used for the data exchange.

Import and Export modules provide the transmission of the data to the ShakeMap PC. ShakeMaps results are stored on the ftp server for diffusion via the website http://www.sispyr.eu/.
Actually, servers, computers and the website are operational, but some of the modules of the automation process are still under development. The NRT process will operate completely before the end of 2012. The objective is to produce a first ShakeMap as soon as possible after the shock (less than 15 minutes), and updated ShakeMaps scaled with observed macroseismic intensities on the following hours.

3. REGIONALIZED PREDICTIVE RELATIONSHIPS FOR THE GROUND MOTION AND INTENSITY

Ground motion Predictive Equations (GMPEs) are compared with existing data for magnitudes less than 5. A database has been built with records from accelerometric and BB networks, RAP for France, IGN and IGC for Spain: 2200 records (3 components) for 72 Pyrenean earthquakes in a magnitude range Ml_{IGN} 3.0-4.5.
A dozen of GMPEs, mainly specific to the French or Spanish seismotectonic context and some others ones, are selected. Ranking was made (Nus et al., 2011) using a method adapted from Sherbaum et al. (2004). The relationship of Tapia (2006) gives the best results for PGA and the 3 Spectral Accelerations and Akkar and Bommer (2007) for PGV. The lack of regional instrumental data does not allow this type of comparison for magnitudes $\geq$ 5.0. Akkar and Bommer (2010) using a large strong motion data set of European earthquakes is retained in this case.

The same method of ranking is tested for Intensity Predictive Equations (IPE). Macroseismic data

come from a unified database containing SISFRANCE, IGC and IGN data. But a majority of data is associated with intensities less than V. Criteria and ranking statistics do not permit to make a choice among several possible IPE. More statistical analysis is made with a database extended to all the Spain territory with IGN data.
From theses different tests, we concluded that the relationship of Sponheuer (1960) used previously in Pyrenees (Goula et al, 2008) gives acceptable results and can be used in ShakeMap.

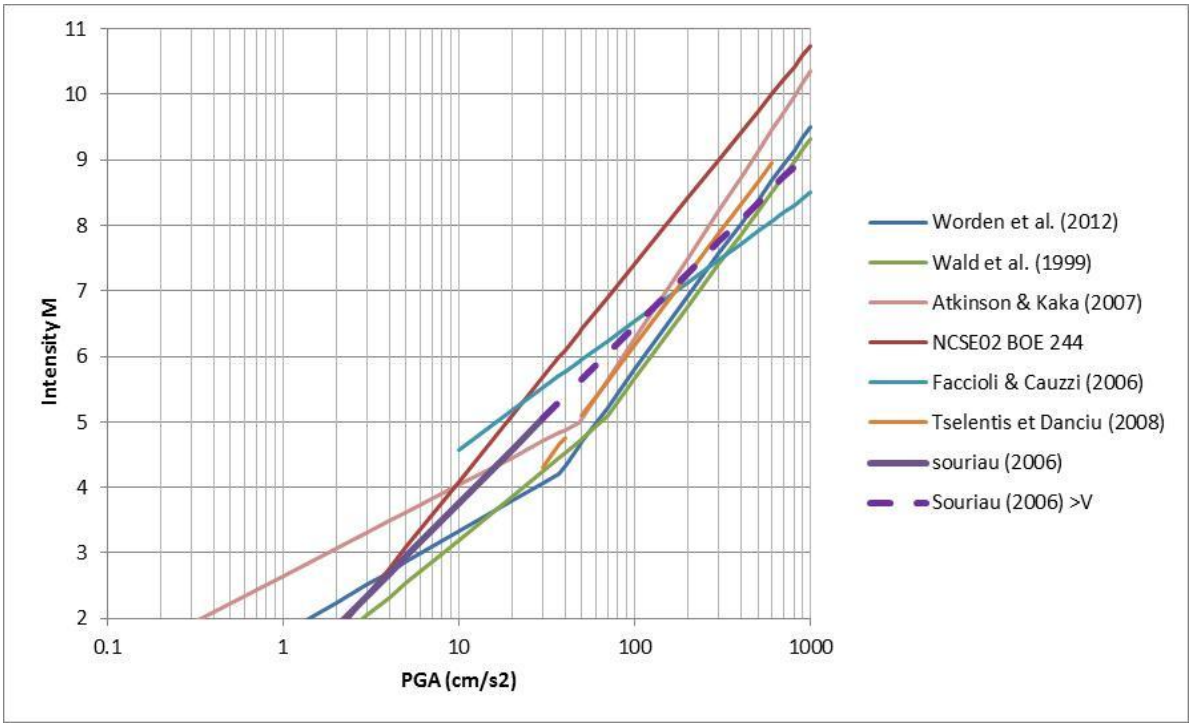


Figure 3: Comparison of GMICE that could be applied on ShakeMaps

Ground Motion Intensity Conversion Equations (GMICEs) can be test in the Pyrenees with a few regional Ground Motion/intensity pairs in III-V intensity range. The extended database gives few more data for intensity > V.
From preliminary studies, the GMICE Souriau (2006), for a mean focal distance of 20 km, for PGA and low intensities and Faccioli and Cauzzi (2006) for PGV are retained. They will be the subject of complementary analyses to study the consistency with the selected IPE and GMPE and are compared with other GMICE used elsewhere in ShakeMaps (Fig. 3). The domain of validity of Souriau (2006) is for intensity ≤ V. The extent of the validity beyond intensity VII can be compatible with other GMICE used in ShakeMap (Wald et al. 1999, Worden et al., 2012) and other European GMICEs (Tselentis & Danciu, 2008).

4. SITE EFFECTS DETERMINATION

The seismic action is amplified due to site effects. Most of ShakeMap applications use Vs30 as a proxy of site effects, with different methodologies to determine this Vs30. Borcherdt (1994) amplification tables is applied to calculate the amplification.

Some studies (Boore, 2004; Castellaro et al, 2008) show limits of this approach and the insufficiency of VS30 to determine amplification.

We preferred an approach based on geological/geotechnical conditions and amplification factors derived from elastic response spectra proposed for each class of soil. The process can be divided in 3 parts: Ground type classification and mapping, characterization of elastic response spectra and

determination of amplification factors (Fa, Fv).

4.1 Ground type classification and mapping

Table 1: Proposed Ground types for Pyrenees

Type	Description	$V_{s,30}$ (m/s)	Thickness (m)	Examples
A	A-EC8 with very low thickness of soft soil	>800	< 5	Many
A’	A-EC8 with very low thickness of soft soil	>800	<5	Quaternary volcanism – Olot region
B	B-EC8 with medium or low thickness	360-800	5-100	Girona, Lourdes, Alluvian fans in Bagnères-de-Luchon
B’	B-EC8 with very big thickness	360-800	>100	Cerdanya
C	C-EC8 with medium or low thickness	180-360	20-100	Luchon, Val d’Aran
D	D-EC8 with medium or low thickness	< 180	20-100	Empordà plain
E	E-EC8	-	5-20	Andorra valley

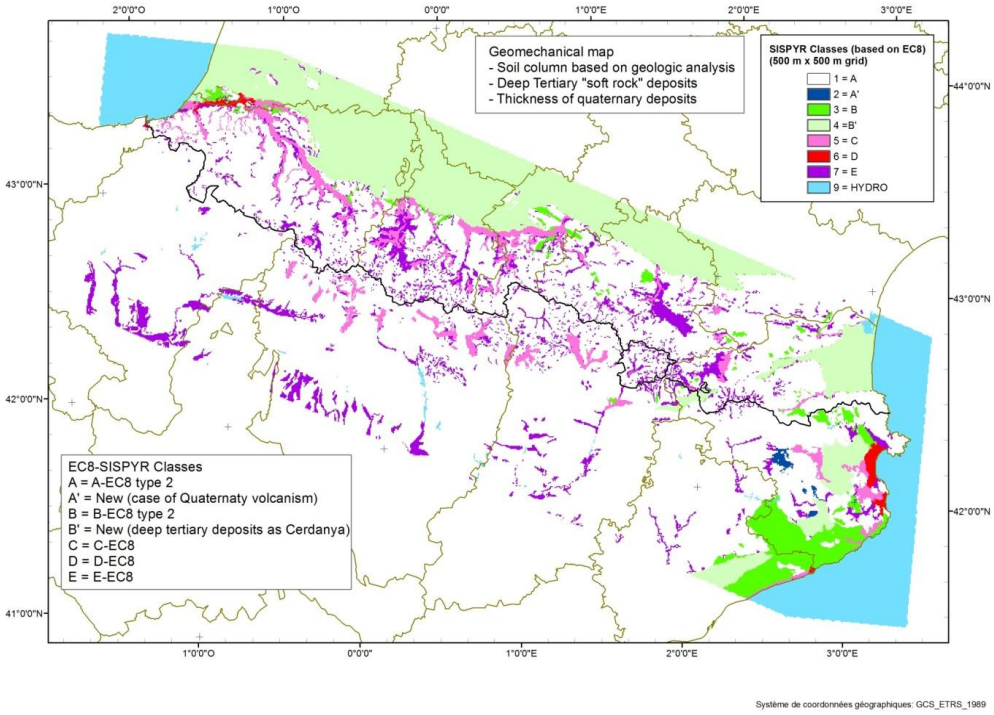


Figure 4: Site condition map based on EC8-type classes of soil

First, a classification of the key superficial lithological units is done by simplifying and crossing the geological map and the quaternary formations map produced by BRGM-IGME (2009a, 2009b) at a 1:400 000 scale. We have five classes defined as Hard Rock, Soft Rock, Altered Rock, Soft Soil, Very Soft Soil. This classification is then extended by taking into account the types of underlying formations and the possible thickness ranges. Finally the soil columns are compared with characteristics of soil classes EC8. The characterization and interpretation of lithology in soil classes are refined using geotechnical borehole data available in the Pyrenees and comparing with the existing seismic microzonation studies in the region.

The final classification consists of 7 ground types illustrated in table 2 and figure 4. Classes A, A', B, B', C D and E are EC8 ground types. The volcanic formations of the Olot region in Catalonia (A' in the map) are assimilated to A class seismic response. B' is a new subclasses proposed in order to take into account the effect of deep geology. Another subclass F is identified near Barcelona but outside the limits of our area.

4.2 Elastic response spectra.

Table 2: Characteristics of the responses spectra

Type	Spectrum	S	Tb(s)	Tc(s)	Td(s)
A-A'	A-EC8 type 2	1.00	0.05	0.25	1.20
B	B-EC8 type 2	1.35	0.05	0.25	1.20
B'	New	1.20	0.05	0.35	1.20
C	C-EC8 type 2 with Tc=0.3s	1.50	0.10	0.30	1.20
D	D EC8 type 2 with S from E	1.60	0.10	0.30	1.20
E	E EC8 type 2 with S from D	1.80	0.05	0.20	1.20

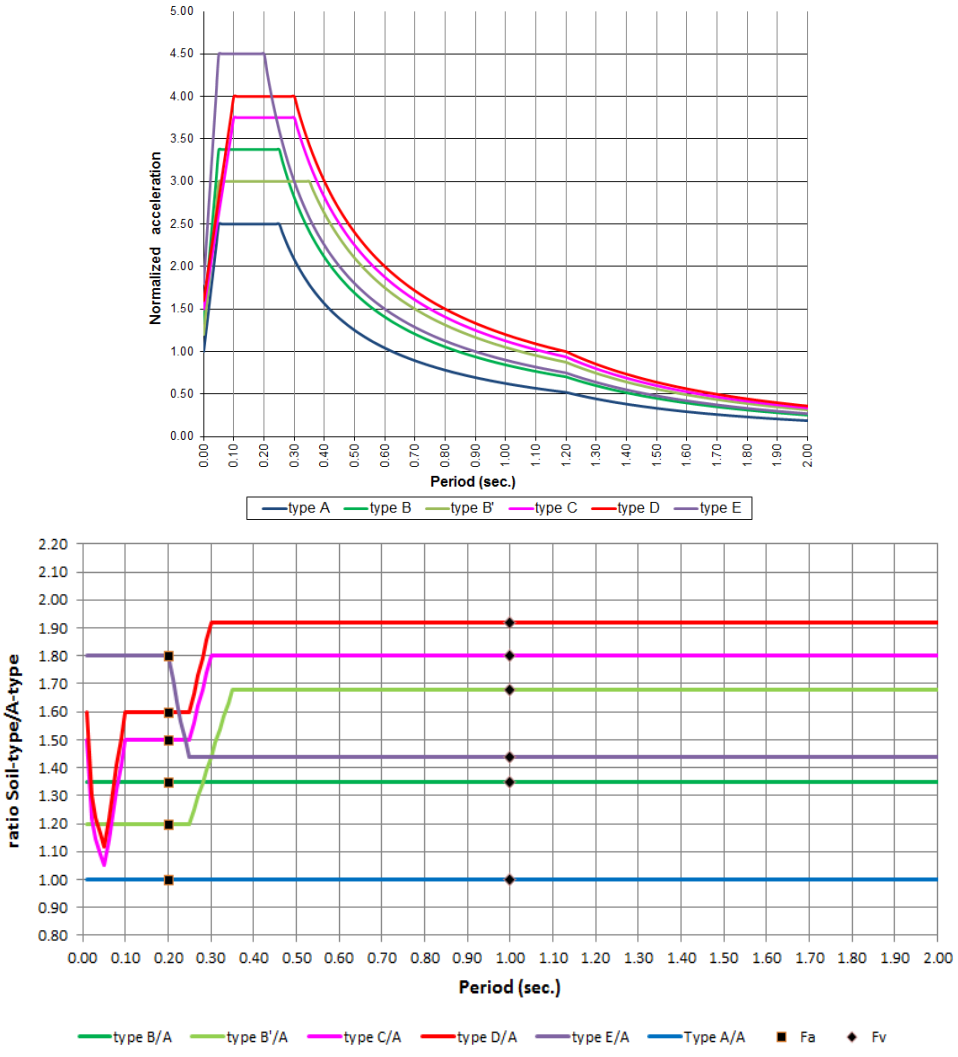


Figure 5: above: proposed normalized response spectra. Below: normalization of the response spectra with rock spectrum. Fa and Fv are deduced from ratio at period 0.2s and 1.0s

For each ground type class an elastic response spectrum is proposed with a shape defined as those of EC-8 (EN-1998-1). S, Tb, Tc, Td are parameters that describe the shape of EC8 spectra. For the Sispyr classes (Table 2, Fig. 5), they are fixed taking into account EC-8 type II (moderate earthquakes with M<5.5) and geology knowledge.

4.3 Amplification factors

Table 3: Amplification factors Fa short period range ; Fv mid-period range

Ground type	Fa	Fv
A	1	1
B	1.35	1.35
B'	1.2	1.7
C	1.5	1.8
D	1.6	1.9
E	1.8	1.4

For Shake Map computation, two amplification factors are defined:
• Fa -> for PGA and short period range- (0.1-0.5s).
• Fv -> for PGV and mid-period range - (0.4-2.0s)
Fa and Fv are obtained with normalization of the response spectra with rock spectrum. Fa is taken as the normalized value of spectra at period 0.2s and Fv, the value at period 1.0 s (Fig. 5). With this approach, there may be more or less amplification whether it is referred to the PGA or PGV. Thus Class E has greater amplification than class D with PGA and less amplification than D with PGV.
Theses amplification factors are defined for input PGA < 0.2g and, according to Borcherdt (2002), we don't have to take into account non-linear effects in this case. From the knowledge of the Pyrenean seismicity, this condition is verified for most of the earthquakes we will have to treat.

5. EXAMPLES AND TESTS

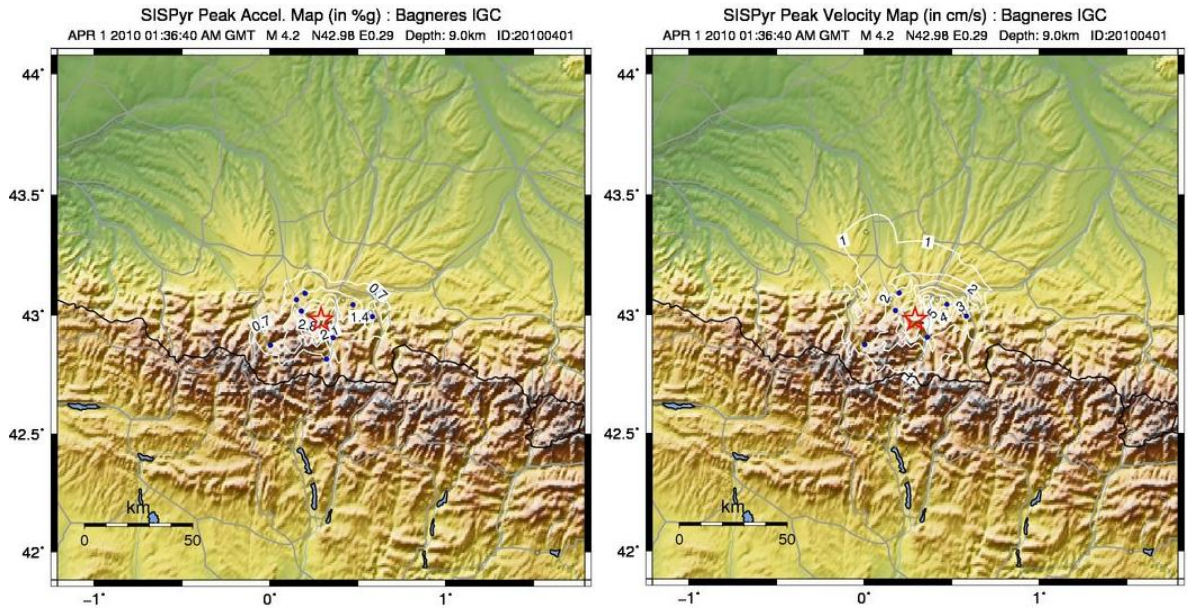


Figure 6 : Example of Pyrenean ShakeMap: PGA map with both ground motion and intensity input data. Preliminary results for 01/04/2010 event with Ml= 4.2 and GMPE Akkar & Bommer (2007)

For validation of the regional adaptation, a series of tests are in progress. Scenarios will be made to verify the coherence of scenario maps obtained with the selected GMPE, IPE, GMICE and Site condition maps with real observation (Fig. 6).
Three kinds of earthquakes are used as input data:

- Most recent small to moderate earthquakes ($3 < M < 4.5$) with data from different sites of Pyrenees (for example 01/04/2010 near Bagneres in France or 19/12/2010 near Caldes in Catalonia)
- Biggest instrumental recent earthquakes (18/2/1996 and 16/05/2002, with $Ml_{IGN} \sim 5.0$)
- Biggest historical events, (18/3/1817, 21/06/1660, 02/02/1428 with magnitudes 5.8-6.0.

Sensitivity of different parameters and uncertainties on input parameters will be tested to evaluate their influence on the ground motion and intensity map.
Sensitive zones for ShakeMap will be identified (areas of high expected amplification, bad seismic station covering etc…).

6. CONCLUSION

The Pyrenees are an area of moderate seismicity with few observations of strong motions or high intensity. Nevertheless, it is possible to test regional relations with the existing regional data to analyse their application for ShakeMaps. Tapia (2006) for GMPE and Goula et al. (2008) for IPE seems well adapted to the local context. When data are not sufficient, the choice is more arbitrary and the preference is on European relations for similar seismotectonic context (Akkar & Bommer, 2007, 2010). GMICEs have to be chosen in consistence with IPE and GMPE. Souriau (2006) for PGA, Faccioli & Cauzzi (2006) for PGV are preliminary choices that will be tested.

Site effects are taking account from geological and geotechnical considerations. 7 classes of soil are defined and are associated to specific response spectra defined with EC8-type shape. Amplification factors Fa and Fv are deduced from ratio between soil and bedrock spectra.
The NRT system, in which the ShakeMap was integrated, relies on servers designed for NRT data exchange between transborder organizations involved in the SISPyr project. This system is well adapted to quick exchanges between agencies and implementing ShakeMap with data of different origins.

The modularity of the process could help to configure different ShakeMaps from one country to another, depending on the specific needs of the civil security services, while sharing the same access NRT system.
This NRT process could be applied to other seismic cross border zones (for example the Alps) where data exchange is necessary to get unbiased seismic information around the border area.

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