



**NATO Science for Peace and Security Programme**

***CLOSING CONFERENCE  
OF THE NATO SfP 983054 (BSHAP) PROJECT***

*Harmonization of Seismic Hazard Maps  
for the Western Balkan Countries”*

*October 24, 2011  
Ankara, Turkey*

***Unified BSHAP Earthquake Catalogue***

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***Following the conclusions of the Zagreb Workshop of the BSHAP project (12-14 May 2011), we started with the definition of the format required for the catalogue compilation.***

***A detailed format was proposed by Slavica Radovanovic, but only the colleagues for Serbia and Bosnia and Hercegovina filled this format (Serbia sent it on June 30, 2011 and BiH sent it on June 20, 2011).***

***In the present situation it was impossible to produce the BSHAP catalogue in the extended format, as agreed in May 2011, because many data in the national catalogs are missing.***

***Hence, our main intention was to harmonize the indispensable fields required for seismic hazard (date and time origin, epicenter location and all the available data for better magnitude characterization, including the database of ISC ( $M_s$ ,  $m_b$ ), CMT catalog of Harvard, EMMA database, and RCMT catalogs provided by INGV and ETHZ for the BSHAP area ( $12.5-24.5^\circ E$ ,  $38-47.5^\circ N$ ). Using all these data, we have generated the BSHAP catalogue in the extended format (with a lot of data missing), in order that every project partner should be able to complete it later for its country.***

The catalogues used:

**National**

- Albania
- Bosnia and Hercegovina
- Bulgarian
- Croatia
- Greece
- Hungary
- Italy
- Montenegro
- Macedonia
- Romania
- Serbia
- Slovenia

**Regional and Global**

- Karnik 1996
- Shebalin & Leydecker,
- ISC
- NEIC
- CMT Harvard Catalog
- RCMT, INGV, Roma
- RCMT, ETHZ, Zurich
- EMMA database, Version 2

**Geographical limits** 38.0° - 47.5°N, 12.5° - 24.5°E

**Time interval:** up to 31/12/2010

**Magnitude:** larger than 3.5

**Total number of events:** 13341

- ✓ This was a manually merged catalogue
- ✓ Every event was carefully inspected
- ✓ Duplicates are almost excluded

### Criteria for the merging of the catalogues:

1. The project partner's catalogues *have priority* over other catalogues!

***Problems arise in the border area: the event is located from the Catalogue of the Country A on the Country B and the same event is located from the Catalogue of the Country B on the Country A.***

2. *We tried to resolve ambiguities, consulting the respective partners. However, epicenter re-location at the border area still remains problematic.*

***Various magnitude scales are used for different events, even from the same seismological center.***

***Since the moment magnitude characterizes more accurately the earthquake size, it was chosen as a uniform magnitude scale for seismic hazard investigations.***

***The  $M_w$  estimation was preceded by a detailed statistical investigation regarding the relationships between different magnitude scales used by the seismic networks of the region, with a view to check the magnitude consistency reported by the above mentioned agencies with the  $M_w$  magnitude obtained by the centroid moment tensor solutions (Harvard CMT catalog, PDE catalogue) or from RCMT solution (INGV, ETHZ).***

### Converting of $M_{SK}$ , $M_S$ and $m_b$ to $M_W$

The converted or re-estimated macroseismic magnitudes from Karnik and Shebalin catalogues, were converted in  $M_W$  using the relevant regression relations of Scordilis (2006):

$$M_W = 0.80 \times M_{SK} + 1.31 \quad 4.0 \leq M_{SK} < 5.4 \quad (1)$$

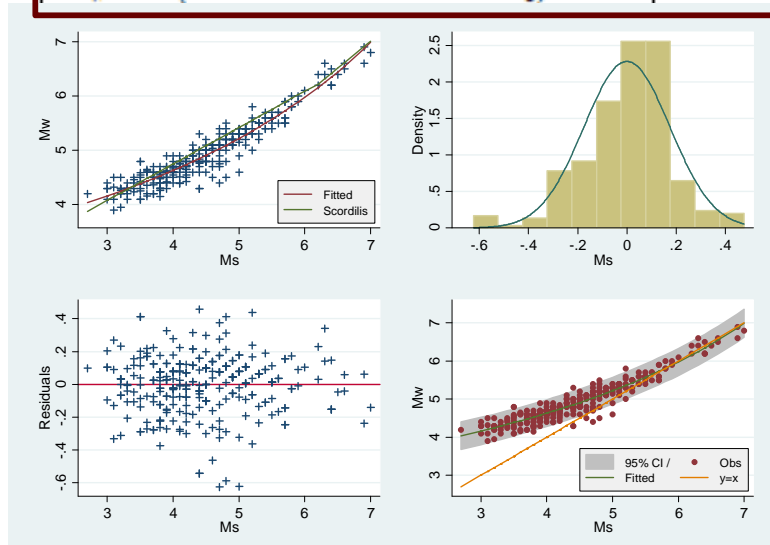
$$M_W = 0.70 \times M_{SK} + 1.80 \quad 5.4 \leq M_{SK} < 6.3 \quad (2)$$

$$M_W = 1.04 \times M_{SK} - 0.33 \quad 6.3 \leq M_{SK} \leq 8.1 \quad (3)$$

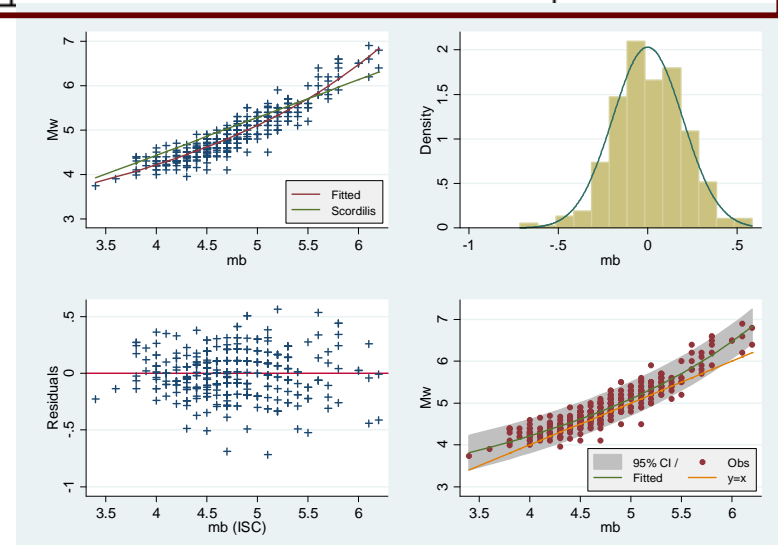
**$M_S$  and  $m_b$  magnitudes reported in the bulletins of ISC are converted in  $M_W$  using equations presented in the Table 1 (Kuka & Duni, 2011)**

**Table 1.** Relationships between moment magnitude  $M_W$ , and  $M_S$  and  $m_b$ .

Regression model $M_W = b_0 + b_1 \cdot M + b_2 \cdot M^2$	Number of events	Determination coefficient, $R^2$	Stand. dev. of regression, $s_v$	Application Range
$M_W = 3.948 - 0.177M_S + 0.08626M_S^2$	293	0.903	0.175	$3.0 \leq M_S \leq 7.0$
$M_W = 5.887 - 1.433m_b + 0.25512m_b^2$	367	0.872	0.197	$3.5 \leq m_b \leq 6.2$
$M_W = 1/(b_0 + b_1 \cdot M)$				$3.0 \leq M_S \leq 7.0$
$M_W = 1/(0.31304 - 0.024282M_S)$	293		0.176	$3.5 \leq m_b \leq 6.2$
$M_W = 1/(0.40266 - 0.041342m_b)$	367		0.198	



**Figure 1.** Relationship between moment magnitude  $M_W$  and the  $M_S$



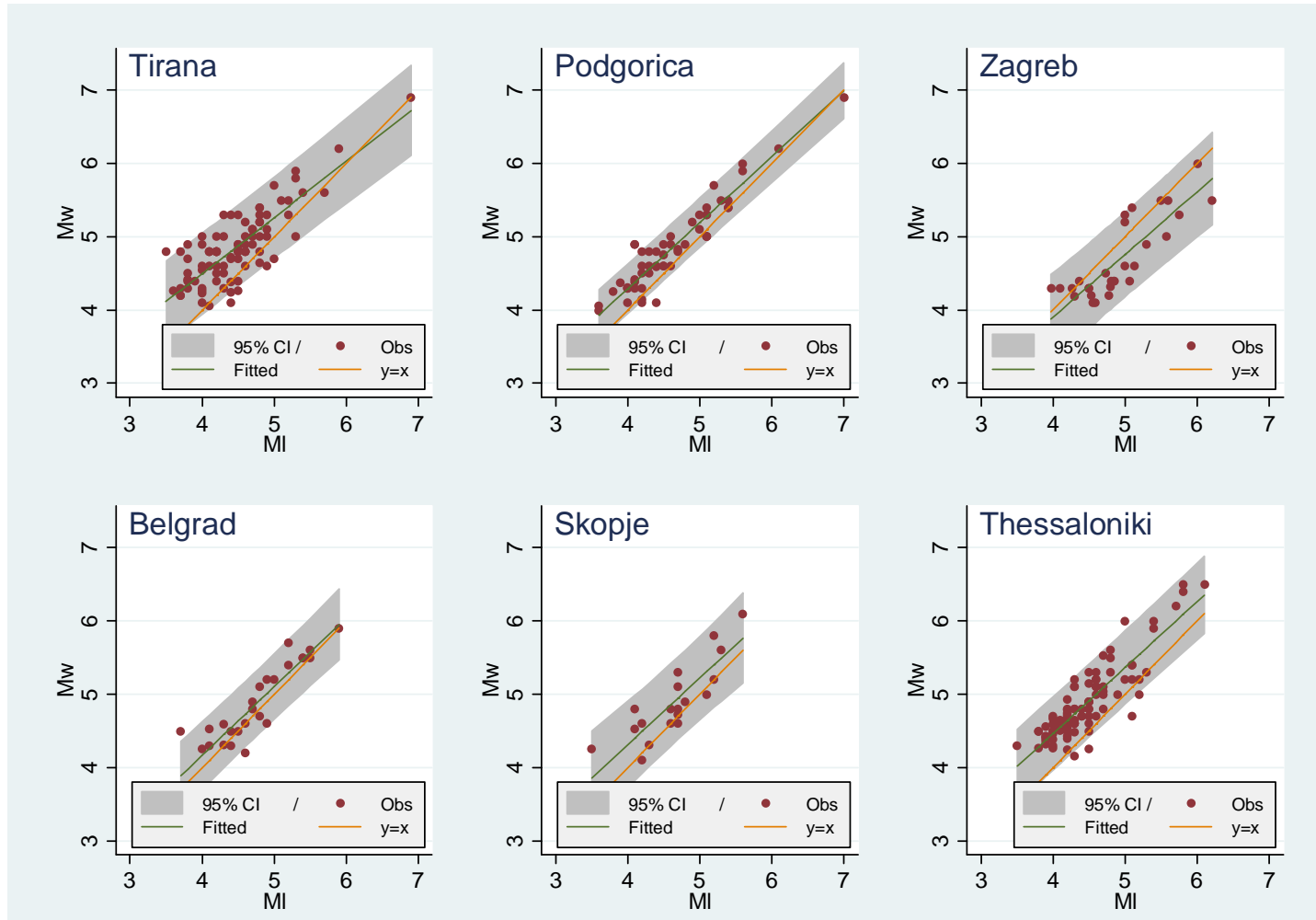
**Figure 2.** Relationship between moment magnitude  $M_W$  and the  $m_b$

**Conversion of  $M_L$  to  $M_W$**

**To enable conversion to  $M_w$  of the local magnitudes  $M_l$  calculated by the seismological centers of the region, we updated the empirical relations derived in 2010 (Duni et al., 2010), using an extended datasets for the BSHAP area, accepting as reference the moment magnitude reported by Harvard CMT solutions (Dziewonski et al., 1981) and the regional moment tensor solutions reported by INGV (Rome) and ETHZ (Zürich) till May 2011. About 500 CMT/RCMT solutions for medium-strong events in the BSHAP area, varying from  $M_w=3.75$  to  $M_w=6.9$ , are used to derive the local relations converting the local magnitudes  $M_l$  to  $M_w$  (Kuka & Duni, 2011).**

**Table 2.** Correlative relationships between moment magnitude  $M_w$  and local magnitude  $M_L$ .

Agency	Regression equation $M_w = b_0 + b_1 \cdot M_L$	Number of events	Determination coefficient, $R^2$	Stand. dev. of regression, $s_e$
Tirana	$M_w = 1.423 + 0.768M_L$	91	0.687	0.273
Pogdorica	$M_w = 0.690 + 0.900M_L$	55	0.921	0.166
Zagreb	$M_w = 0.489 + 0.853M_L$	29	0.735	0.283
Belgrade	$M_w = 0.414 + 0.938M_L$	26	0.855	0.218
Skopje	$M_w = 0.684 + 0.907M_L$	19	0.742	0.273
Thessaloniki	$M_w = 0.383 + 1.010M_L$	109	0.830	0.220



**Fig. 3.** Relationships between moment magnitude  $M_w$  and the local magnitude,  $M_L$

## Calculation of the Homogenous $M_W$ Scale Magnitude for the BSHAP Project

A detailed procedure used for calculation of the homogenous  $M_W$  scale magnitude ( $M_{WU}$ ) for all the events included in the earthquake catalogue of the BSHAP Project is formulated by Prof. Kuka and distributed to all the project partners.

### Calculation of $M_{WU}$ for the events reported by Tirana (TIR)

Tirana reports  $M_m$  ( $M_S$  Karnik) if Year < 1900;  $M_m$ ,  $M_S$ ,  $m_b$  after 1900, and  $M_L$  after 1968.

```
MwML = 0.768*ML+1.423 if (AG == "TIR") & (ML != .)
Mwu = MwISC if AG == "TIR" & MwISC != . & MwML == .
Mwu = MwML if AG == "TIR" & MwISC == . & MwML != .
Mwu = 0.5*(MwISC+MwML) if AG == "TIR" & MwISC != . & MwML != .
```

**Note:** The local magnitude calculated from Tirana is converted to  $M_W$  using the relevant relation. For events for which  $M_S$  and/or  $m_b$  magnitude is available, the magnitude  $M_W$  is calculated as the average of estimations taken from converting to  $M_W$  of the local magnitude  $M_L$  (TIR) and of  $M_S$  and/or  $m_b$  reported in the ISC bulletins (1964-2010).

## Calculation of the Homogenous $M_W$ Scale Magnitude for the BSHAP Project

### *Calculation of $M_{WU}$ for the events reported by Bosnia and Herzegovina (BLY)*

Not any relation to convert local magnitude to  $M_W$  because the relevant data are lacking.

**Note:** Magnitudes reported by BLY are considered as  $M_{WU}$ . Only macroseismic magnitudes ( $M_m$ ) are converted using the Scordilis relations.

### *Calculation of $M_{WU}$ for the events in the Croatian catalogue (ZAG)*

**Note:** Magnitudes reported in the Croatian catalogue (average magnitude - column 11, or  $M_L$  (ZAG) – column 12) are considered as  $M_{WU}$ . Only macroseismic magnitudes ( $M_m$ ) are converted using the Scordilis relations.

### *Calculation of $M_{WU}$ for the earthquake catalogue of Montenegro (PDG)*

Up to the year 1970 earthquakes are reported in terms of macroseismic magnitude  $M_m$ . For the period 1971-1978 magnitude is  $M_L$  of EMSC. Starting from 1979, magnitude used is the local magnitude  $M_L$  (PDG).

**Note:** The local magnitude calculated from Podgorica is considered as  $M_w$ . So only the events up to 1970 are converted to  $M_w$  using the Scordilis relations.

## Calculation of the Homogenous $M_W$ Scale Magnitude for the BSHAP Project

### *Calculation of $M_{WU}$ for the events reported by Skopje (SKO)*

Up to the year 1970 (1970 not included) earthquakes are reported in terms of macroseismic magnitude  $M_m$ . After 1970, magnitude used is the local magnitude  $M_L$  (SKO).

**Note:** *The events up to 1970 are converted to  $M_W$  using the Scordilis relations. The local magnitude calculated from Skopje is converted to  $M_W$  using the relevant relation. For events for which  $M_S$  and/or  $m_b$  magnitude is available, the magnitude  $M_W$  is calculated as the average of estimations taken from converting to  $M_W$  of the local magnitude  $M_L$  (SKO) and of  $M_S$  and/or  $m_b$  reported in the ISC bulletins (1964-2010).*

### *Calculation of $M_{WU}$ for the earthquake catalogue of Serbia (BEO)*

Regarding the events from the catalogue Serbia, the unified magnitude is calculated by the Serbian colleagues.

```
* MwML = 0.938*ML + 0.414 if AG == "BEO"  
Mwu = Mu if AG == "BEO" & Mu != .  
Mwu = MwML if (AG == "BEO") & (Mu == .) & (MwML != .)
```

## Calculation of the Homogenous $M_W$ Scale Magnitude for the BSHAP Project

### ***Calculation of $M_W$ for the events from the catalogue of Shebalin 1996 (SHE)***

In the earthquake catalogue of Shebalin et al. 1996, magnitude ( $M_U$ ) is reported in terms of  $M_{SK}$ . The unified magnitude  $M_{WU}$  is calculated using the Scordilis (2006) relations.

### **Recorded $M_W$**

For the events which have a CMT (Harvard or PDE Catalog) or RCMT (INGV, ETHZ) solution, i.e. a recorded  $M_W$ , this value supersedes the  $M_{WU}$  calculated by the above-mentioned procedure. We have accepted also the  $M_W$  value from the EMMA catalogue instead of  $M_{WU}$  for the events reported in this catalogue.

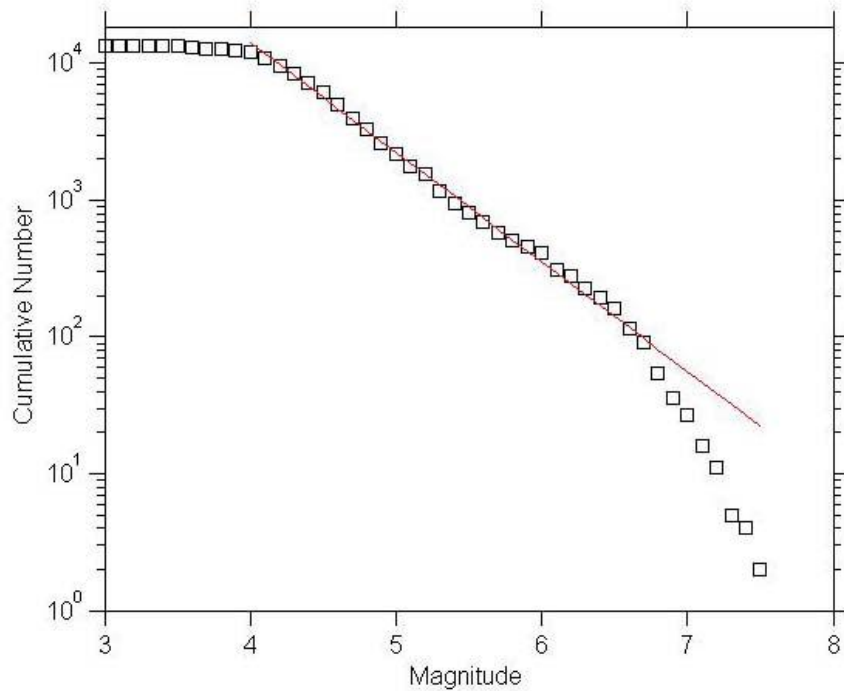
## Catalogue description

Year	M	D	Hr	Mi	Se	Lat	Lon	Dep	Io	I_Sc	Mm	ML	Ag_ML	mb	Ag_mb	Ms	Ag_Ms	Mw	Ag_Mw	Mlh	Ag_Mlh	Md	Ag_Md	S	AG	Mwu
-510	1	1	0	0	0.00	39.300	22.400	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	7.00
-479	1	1	0	0	0.00	39.700	23.300	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	7.00
-427	1	1	0	0	0.00	38.400	23.100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.00
-426	1	1	0	0	0.00	38.850	22.780	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	7.00
-424	3	1	0	0	0.00	38.100	23.400	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.00
-420	1	1	0	0	0.00	38.000	22.800	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.00
-373	1	1	0	0	0.00	38.200	22.200	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.80
-347	1	1	0	0	0.00	38.400	22.500	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.00
-303	1	1	0	0	0.00	38.000	22.700	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.40
-279	1	1	0	0	0.00	38.400	22.400	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.40
-226	1	1	0	0	0.00	38.600	22.700	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.40
-198	1	1	0	0	0.00	38.400	23.700	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.40
-100	1	1	0	0	0.00	43.170	13.500	.	8.5	MMI	.	.	.	.	5.80	Calc	.	.	.	.	.	.	.	.	1ROM	5.84
-99	1	1	0	0	0.00	42.800	13.100	.	8.0	MMI	.	.	.	.	5.40	Calc	.	.	.	.	.	.	.	.	1ROM	5.57
-91	1	1	0	0	0.00	38.100	15.650	.	9.5	MMI	.	.	.	.	6.30	Calc	.	.	.	.	.	.	.	.	1ROM	6.30
-76	1	1	0	0	0.00	42.400	12.870	.	10.0	MMI	.	.	.	.	6.60	Calc	.	.	.	.	.	.	.	.	1ROM	6.60
-58	1	1	0	0	0.00	41.300	19.300	33.0	8.5	MSK64	6.30	.	.	.	.	.	.	.	.	.	.	.	.	.	1TIR	6.22
-56	4	1	0	0	0.00	43.430	13.670	.	8.5	MMI	.	.	.	.	5.80	Calc	.	.	.	.	.	.	.	.	1ROM	5.84
23	1	1	0	0	0.00	38.300	22.100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.30
52	1	1	0	0	0.00	40.800	24.200	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.00
61	1	1	0	0	0.00	38.200	22.000	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.30
62	2	5	0	0	0.00	40.780	14.420	.	8.5	MMI	.	.	.	.	5.84	Calc	.	.	.	.	.	.	.	.	1ROM	5.87
79	8	25	7	0	0.00	40.800	14.380	.	8.0	MMI	.	.	.	.	5.69	Calc	.	.	.	.	.	.	.	.	1ROM	5.77
99	1	1	0	0	0.00	41.350	14.800	.	9.5	MMI	.	.	.	.	6.30	Calc	.	.	.	.	.	.	.	.	1ROM	6.30
101	1	1	0	0	0.00	42.230	13.980	.	9.5	MMI	.	.	.	.	6.30	Calc	.	.	.	.	.	.	.	.	1ROM	6.30
105	1	1	0	0	0.00	38.800	23.000	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.40
217	1	1	0	0	0.00	40.740	19.470	33.0	8.5	MSK64	6.30	.	.	.	.	.	.	.	.	.	.	.	.	.	1TIR	6.22
306	1	1	0	0	0.00	43.020	17.570	.	.	.	.	6.02	ZAG	.	.	.	.	.	.	.	.	.	.	.	1ZAG	6.02
334	1	1	0	0	0.00	41.300	19.500	33.0	8.5	MSK64	6.30	.	.	.	.	.	.	.	.	.	.	.	.	.	1TIR	6.22
346	1	1	0	0	0.00	41.380	14.430	.	9.0	MMI	.	.	.	.	6.00	Calc	.	.	.	.	.	.	.	.	1ROM	6.00
346	1	1	0	0	0.00	41.300	19.300	33.0	9.0	MSK64	6.60	.	.	.	.	.	.	.	.	.	.	.	.	.	1TIR	6.53
358	1	1	0	0	0.00	40.100	20.100	33.0	9.0	MSK64	6.60	.	.	.	.	.	.	.	.	.	.	.	.	.	1TIR	6.53
361	1	1	0	0	0.00	44.000	14.000	.	.	.	.	7.39	ZAG	.	.	.	.	.	.	.	.	.	.	.	1ZAG	7.39
361	1	1	0	0	0.00	38.400	22.600	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.80
367	7	23	0	0	0.00	42.580	18.220	.	.	.	.	6.02	ZAG	.	.	.	.	.	.	.	.	.	.	.	1ZAG	6.02
374	1	1	0	0	0.00	38.100	15.650	.	9.5	MMI	.	.	.	.	6.30	Calc	.	.	.	.	.	.	.	.	1ROM	6.30
375	1	1	0	0	0.00	41.130	14.780	.	9.0	MMI	.	.	.	.	6.00	Calc	.	.	.	.	.	.	.	.	1ROM	6.00
456	9	7	0	0	0.00	47.240	16.620	.	9.0	EMS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1BUD	6.24
506	1	1	0	0	0.00	41.300	19.500	33.0	8.5	MSK64	6.30	.	.	.	.	.	.	.	.	.	.	.	.	.	1TIR	6.22
518	1	1	0	0	0.00	42.100	21.400	.	9.0	MSK64	6.10	.	.	.	.	.	.	.	.	.	.	.	.	.	1TIR	6.00
527	1	1	0	0	0.00	41.100	20.800	.	.	.	6.10	.	.	.	.	.	.	.	.	.	.	.	.	.	1SKO	6.07
551	1	1	0	0	0.00	38.300	21.700	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1THE	6.50

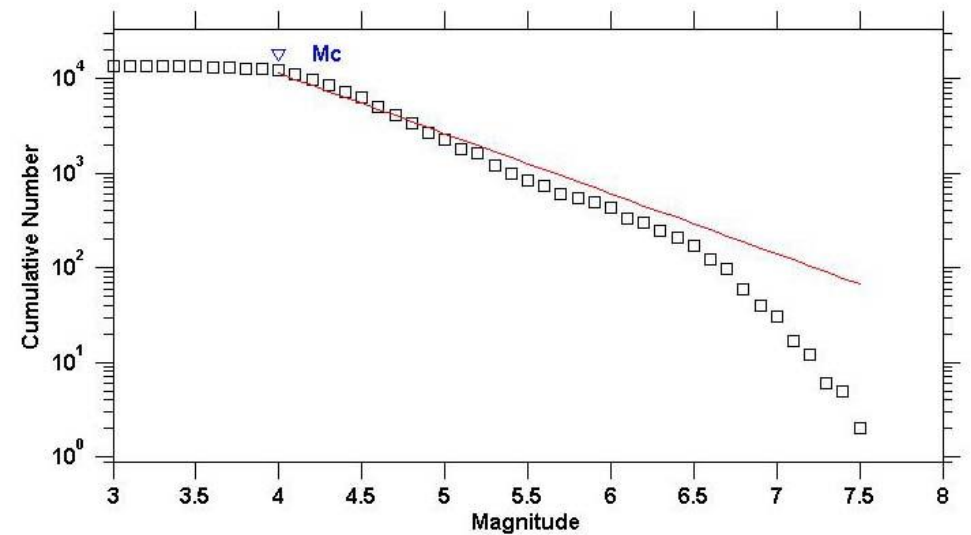
## Catalogue description

3.70	THE	3.80	ISC	.	.	.	.	.	.	0	THE	4.12
4.10	THE	4.10	ISC	2.90	ISC	.	.	.	.	0	THE	4.50
3.50	THE	.	.	.	.	.	.	.	.	0	THE	3.92
3.50	TIR	.	.	.	.	.	.	.	.	1	TIR	4.11
3.70	THE	3.60	ISC	2.80	ISC	.	.	.	.	0	THE	4.12
.	.	4.40	ISC	3.80	ISC	4.10	INGV	.	.	1	THE	4.10
3.90	THE	.	.	.	.	.	.	.	.	0	THE	4.32
4.80	TIR	5.30	ISC	4.00	ISC	5.20	HRV	.	.	1	TIR	5.20
3.50	THE	3.50	ISC	.	.	.	.	.	.	0	THE	3.92
3.70	THF	3.70	TSC	.	.	.	.	.	.	0	THF	4.12
3.50	TIR	.	.	.	.	.	.	.	.	0	TIR	4.11
3.80	SKD	3.40	ISC	2.60	ISC	.	.	.	.	1	SKD	4.02
3.70	TIR	3.90	ISC	2.80	ISC	.	.	.	.	0	TIR	4.19
4.40	THE	4.50	ISC	3.90	ISC	4.70	INGV	.	.	1	THE	4.70
3.50	THE	3.80	ISC	.	.	.	.	.	.	0	THE	3.92
4.20	TIR	3.00	ISC	3.20	ISC	.	.	.	.	1	TIR	4.42
3.60	THF	.	.	.	.	.	.	.	.	0	THF	4.02
3.60	THE	3.50	ISC	.	.	.	.	.	.	1	THE	4.02
.	.	4.80	ISC	.	.	4.80	INGV	.	.	1	THE	4.80
3.70	THE	3.80	ISC	3.90	ISC	.	.	.	.	0	THE	4.12
4.30	THE	4.20	ISC	3.50	ISC	.	.	.	.	1	THE	4.60
3.90	THE	3.80	ISC	.	.	.	.	.	.	0	THE	4.32
4.30	TIC	4.00	ISC	3.60	ISC	.	.	.	.	0	TIC	4.60
3.50	THE	.	.	.	.	.	.	.	.	0	THE	3.92
4.20	THE	4.30	ISC	3.70	ISC	4.40	INGV	.	.	0	THE	4.40
4.00	THE	4.10	ISC	.	.	.	.	.	.	1	THE	4.50
3.50	THE	.	.	.	.	.	.	.	.	1	THE	3.92
.	.	4.50	ISC	3.90	ISC	4.60	INGV	.	.	0	THE	4.60
3.90	HRV	3.60	ISC	.	.	.	.	.	.	1	HRV	4.18
4.70	THE	4.70	ISC	4.30	ISC	4.80	HRV	.	.	1	THE	4.80

The BSHAP catalogue can be considered complete from magnitude Mw 4.0

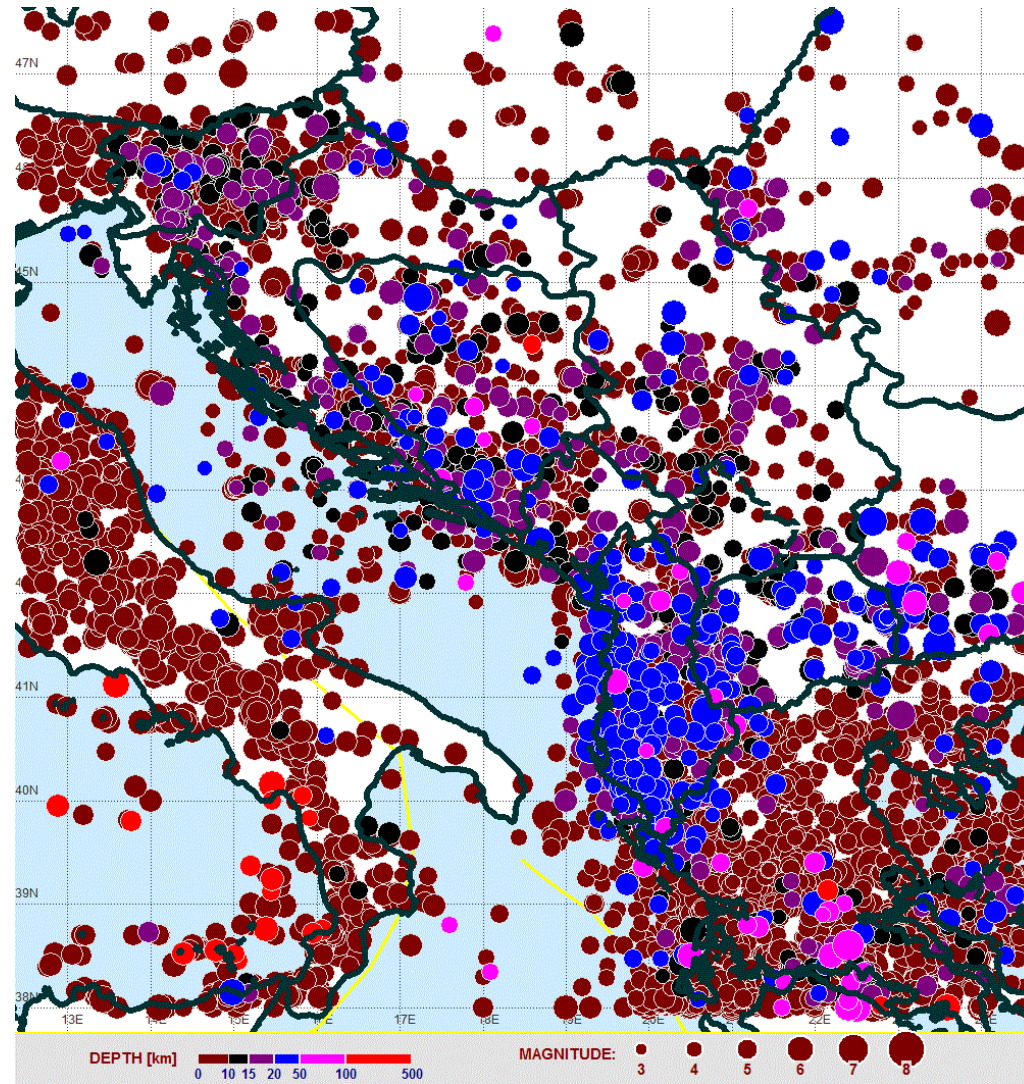


b-value (w LS,  $M \geq 4$ ):  $-0.801 \pm 0.03$ , a-value = 7.3562  
 b-value (max lik,  $M \geq 3.5$ ):  $-0.64 \pm 0.0046$ , a-value = 6.6098



Maximum Likelihood Solution  
 b-value =  $0.635 \pm 0.005$ , a value = 6.59, a value (annual) = 3.19  
 Magnitude of Completeness = 4

Map of earthquake epicenters

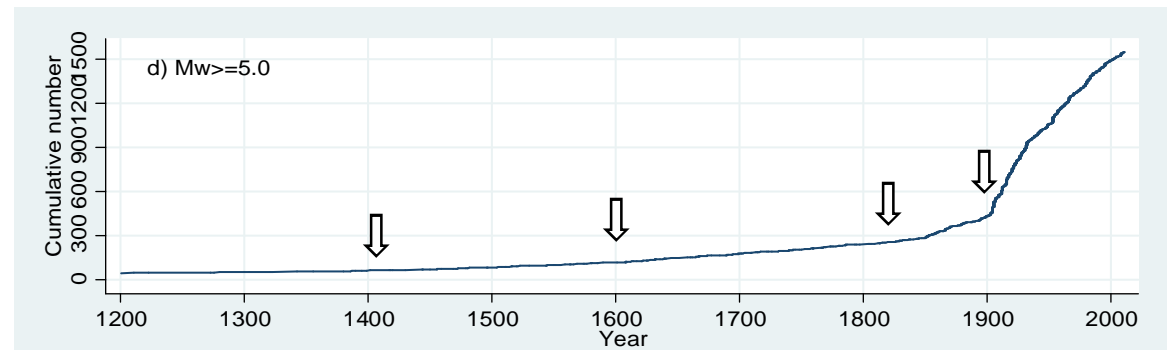
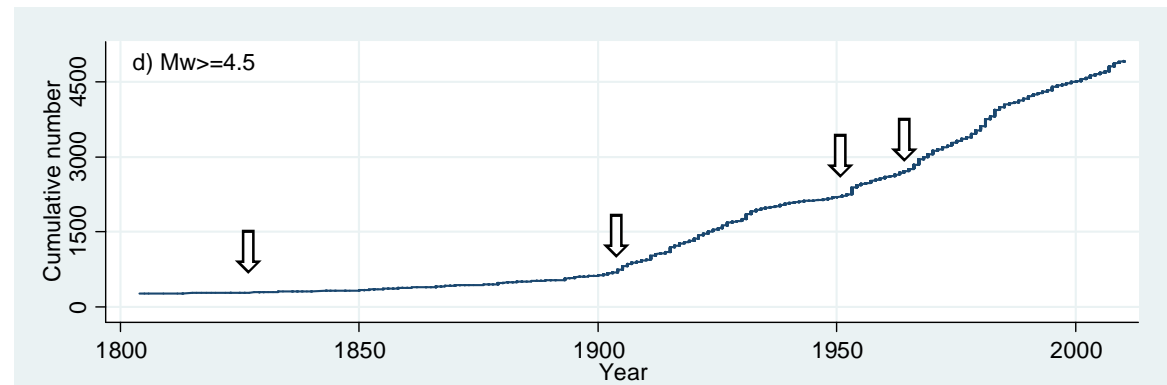
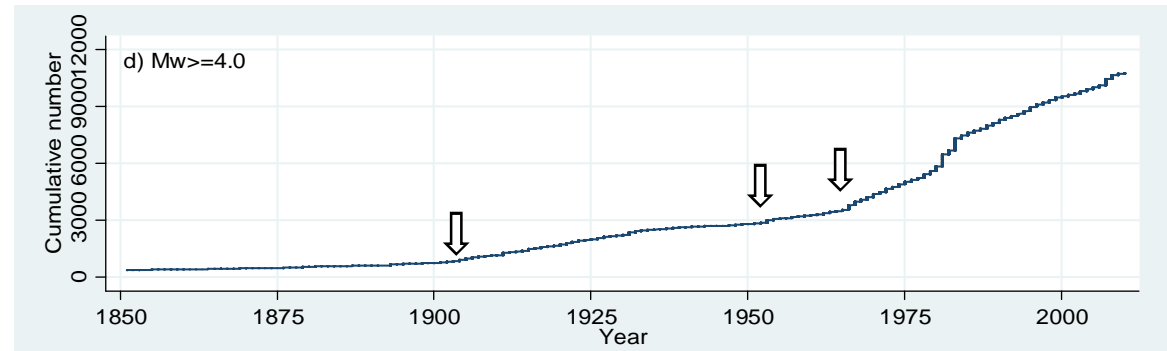


## Data completeness with time

Reliable mean rates of earthquake occurrence for the given magnitude range requires as prerequisite to assess the data completeness, that is to assess the magnitude above which the catalogue can be considered as reasonably complete, or alternatively to assign time intervals in which a certain magnitude range is likely to be completely reported.

### Completeness:

- Since 1965 for  $M_w \geq 4.0$
- +1955,  $M_w \geq 4.5$
- +1905,  $M_w \geq 5.0$

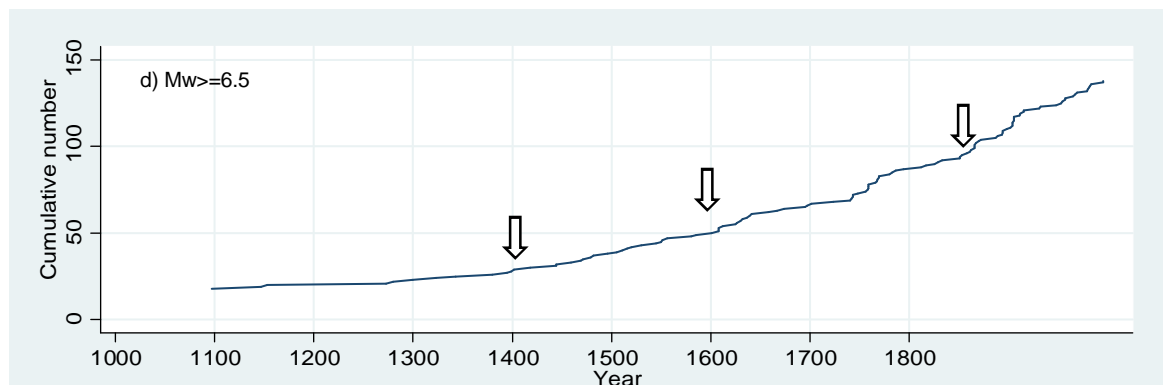
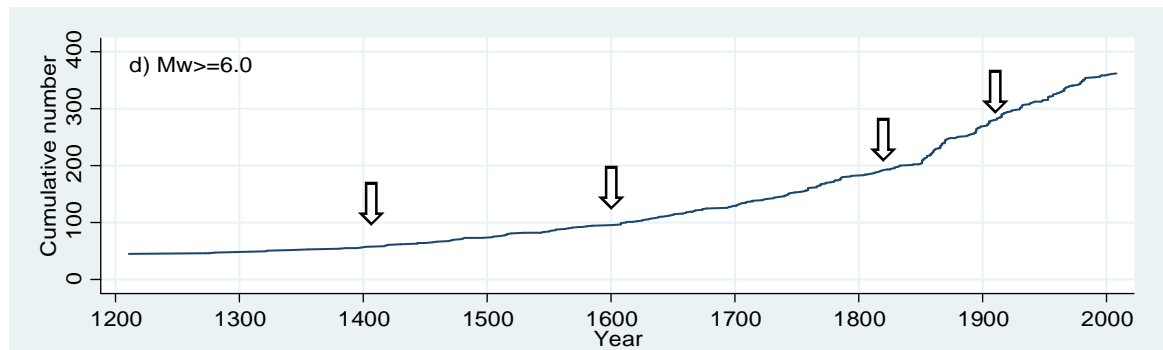
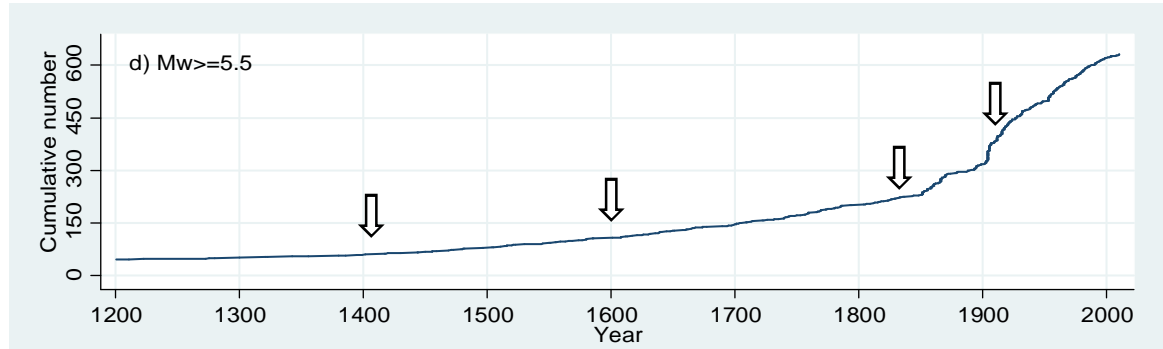


## Completeness with time

Completeness levels are estimated from the catalog, by using the cumulative number of events *versus* time graphs, in order to evidence slope changes, assuming that the most recent change in slope occurs when the data become complete for magnitudes  $\geq$  the reference.

### Completeness:

Since 1830 for  $M_w \geq 5.5$   
 +1600,  $M_w \geq 6.0$   
 +1400,  $M_w \geq 6.5$



## *Declustering of the catalogue*

One basic assumption in the PSHA is that earthquake occurrences are statistically independent. It is assumed that the earthquake occurrences follow a Poisson process with constant recurrence rate  $\lambda$ .

Usually, earthquakes are spatially and temporally clustered. Therefore, the earthquake catalogue to be used for hazard studies must be free of dependent events, such as foreshocks and aftershocks, prior to modeling of the magnitude frequency distribution in order to avoid biasing the average-rate assessments.

Declustering of the BSHAP catalogue is accomplished by B. Glavatović and S. Radovanović (ZMAP software).

This subcatalogue, purged of aftershocks and foreshocks, can be considered that reflects a Poisson process and can be used to estimate adequately the seismicity parameters, and in the further calculations for seismic hazard assessment.

## **Conclusions**

- 1. The Unified BSHAP 3.5 earthquake catalogue was compiled by merging together the national catalogues .**
- 2 Since the moment magnitude characterizes more accurately the earthquake size, it was chosen as a uniform magnitude scale for seismic hazard investigations.**
- 3 New equations relating the  $M_w$  with  $M_s$  and  $m_b$  have been derived for the BSHAP area. Also, an update of the already previously derived relations between  $M_w$  and  $M_L$  has been done.**
- 4 The catalogue is considered complete for the whole BSHAP region for magnitudes  $M_w$  larger than 4.0. However, the completeness is not homogenous everywhere.**
- 5 This catalogue is a first attempt. It needs to be improved in the future.**



*Unified BSHAP Earthquake Catalogue*

***Thank You!***