New developments in the evaluation of seismic hazard for Romania

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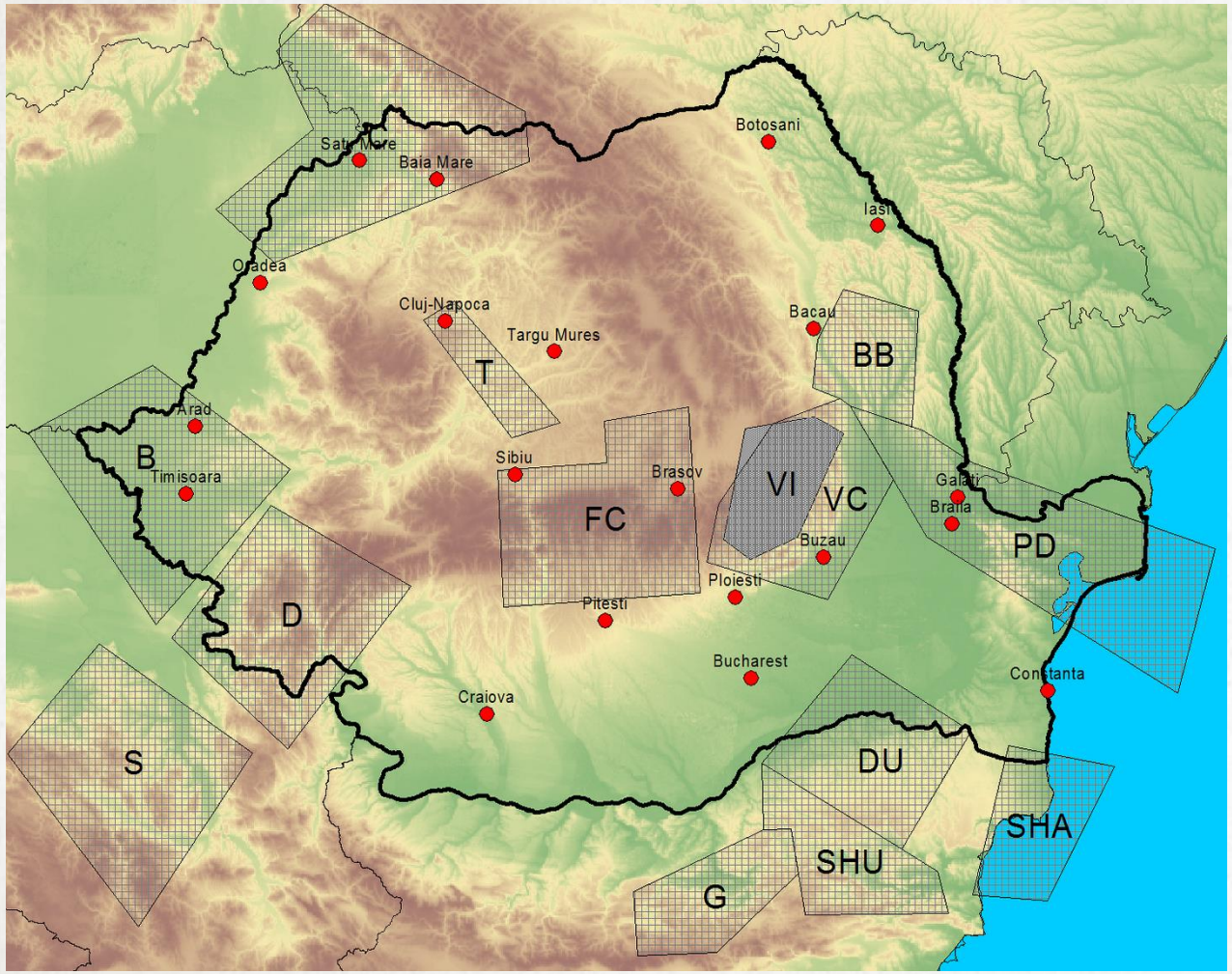
INTRODUCTION

- **BIGSEES** national research project (2012 – 2016) – redefinition of seismic action for Romania according to Eurocode 8 provisions
- Project team:
  - National Institute of Earth Physics (INFP)
  - Technical University of Civil Engineering Bucharest (UTCB)
  - Building Research Institute (INCERC)
  - Aedificia Carpati

SEISMICITY OF ROMANIA



- Seismicity of Romania (INFP):
  - Vrancea subcrustal seismic source ($M_{max} > 8.0$)
  - 13 crustal seismic sources – some can generate earthquakes with $M_{max} \geq 7.0$

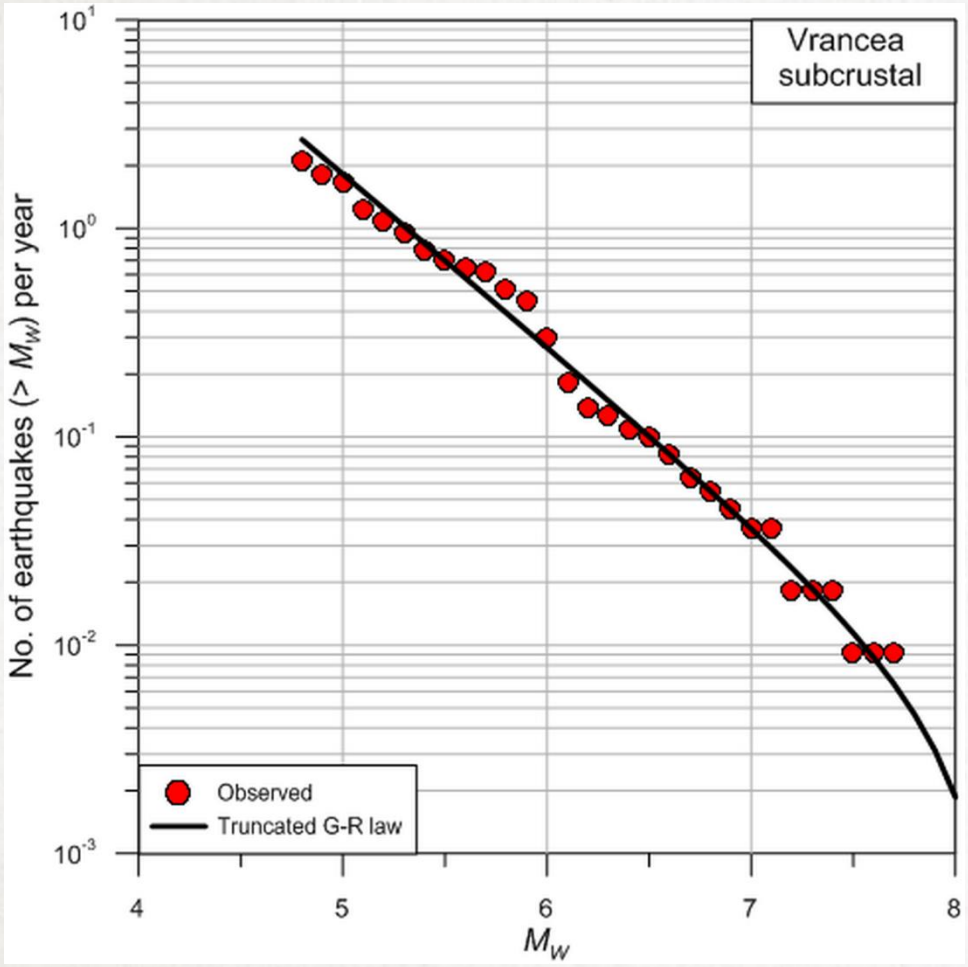
SEISMICITY OF ROMANIA

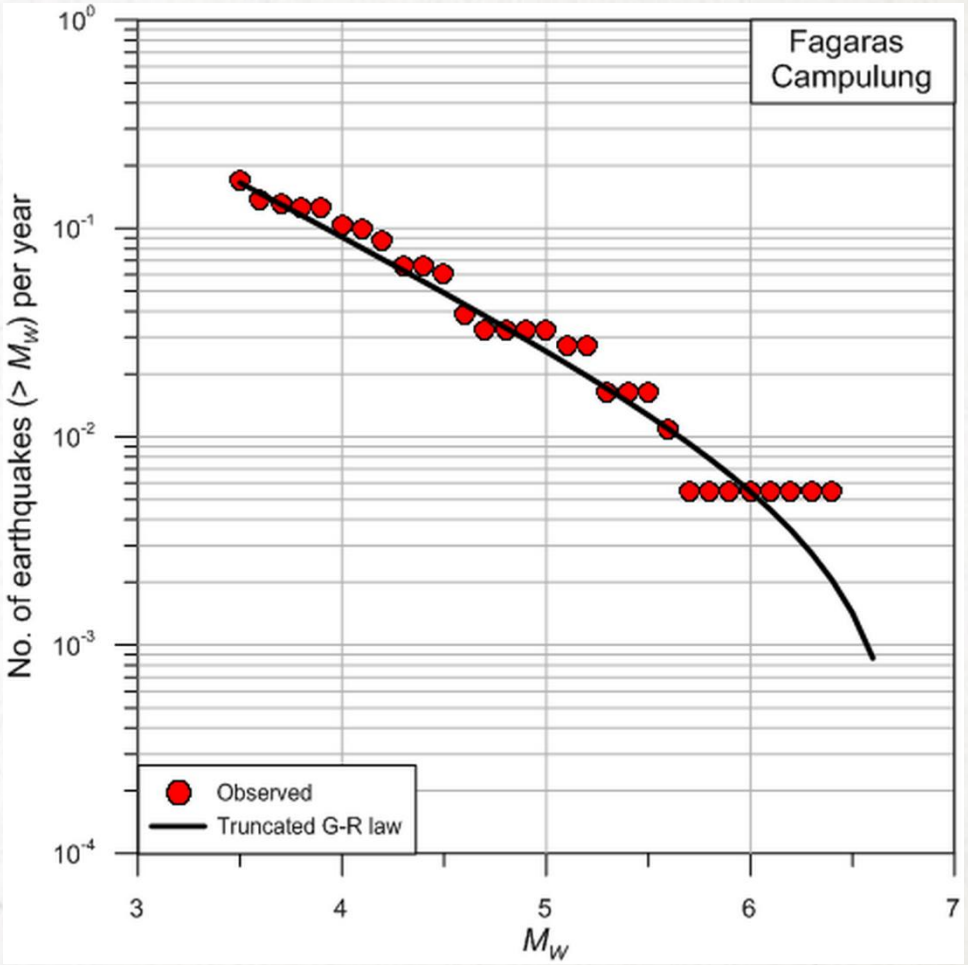
- Seismic moment release:
  - Vrancea seismic source ≈ Southern California (Wenzel et al. 1998)
  - Vrancea seismic source (XX^{th} century) ≈ 3 x Italy (all seismic sources - XX^{th} century)
  - Vrancea seismic source (XX^{th} century) ≈ 0.6 x Vrancea seismic source (XIX^{th} century)
  - Vrancea seismic source (1839-1939) $\Longrightarrow$ $M_w \approx 7.6$ (only from earthquakes with $M_w \leq 7.1$)

SEISMICITY OF ROMANIA

- Vrancea earthquake of Nov. 1940 (Mw = 7.7):
  - Largest intermediate-depth earthquake in Europe (XXth century)
  - 4th largest earthquake in Europe in XXth century (after earthquakes in Turkey, Portugal, Spain - deep)
- Seismic moment release rate - XXth century:
  - 13 crustal seismic sources ≈ 1/6 Vrancea seismic source
  - 80% of Vrancea moment release – earthquakes of 1940 (Mw = 7.7) and 1977 (Mw = 7.4)

SEISMICITY OF ROMANIA





GROUND MOTION MODELS

- GMPEs (ground motion prediction equations) – describe ground motion amplitude (median + std. deviation)

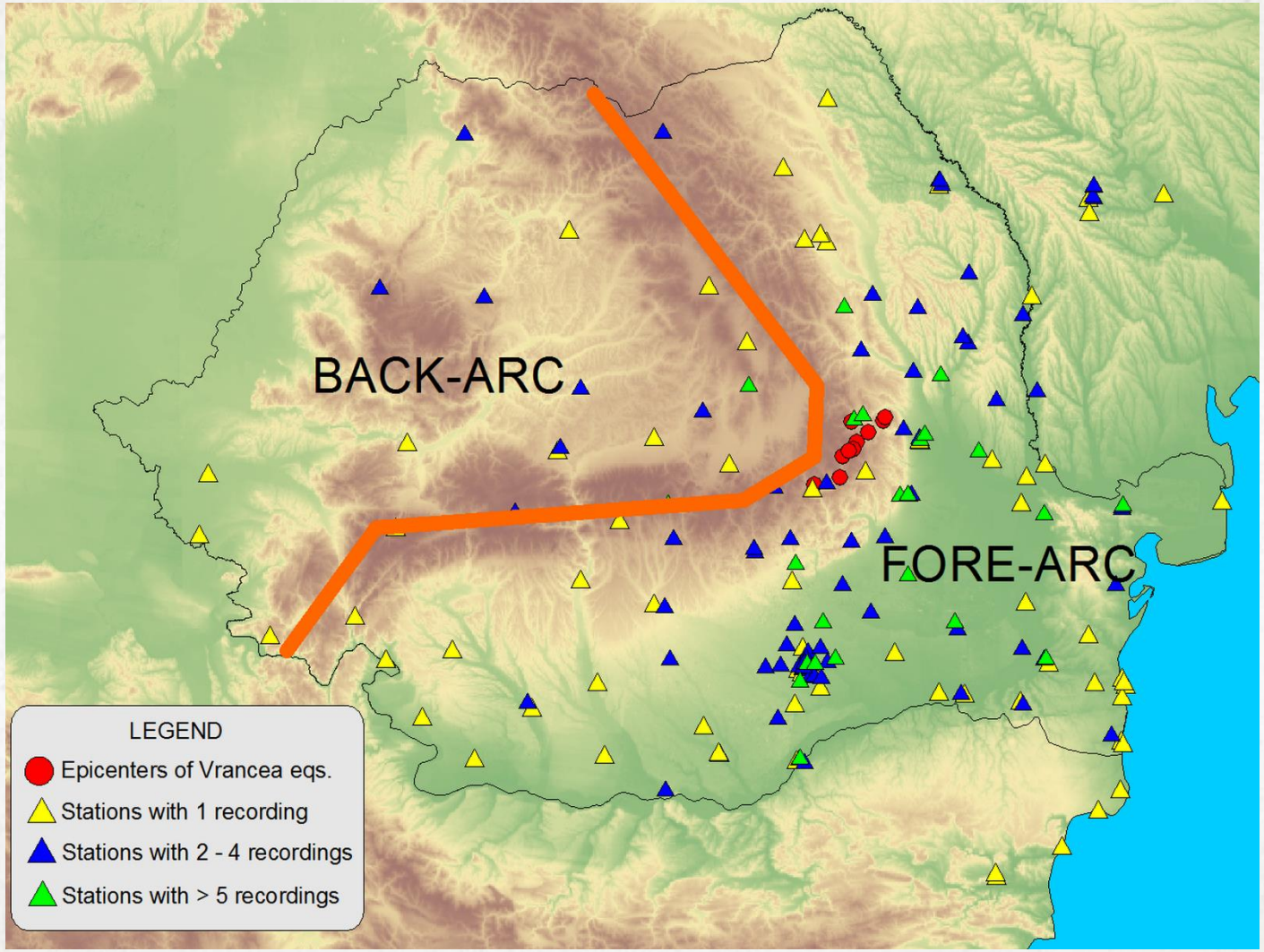
$$\ln Y = c_1 + c_2 M + c_3 \ln\left(R + c_4\right) + c_5 R + c_6 f\left(source\right) + c_7 f\left(soil\right)$$

- Parameters of GMPEs:
  - earthquake magnitude
  - source-site distance
  - soil conditions
  - other parameters (style of faulting, dircectivity effects, hanging-wall effects, etc.)

GROUND MOTION MODELS

- Testing of GMPEs – key step for "reliable" evaluation of seismic hazard
- Testing of GMPEs (e.g. Scherbaum et al, 2004, Delavaud et al, 2012, Kale & Akkar, 2013):
  - Vrancea seismic source
    - fore-arc region (in front of Carpathian Mts.)
    - back-arc region (Tranylvania)
  - crustal seismic sources
- Testing of GMPEs – PSHA weighing scheme (Pavel et al. 2014)

GROUND MOTION MODELS



GROUND MOTION MODELS

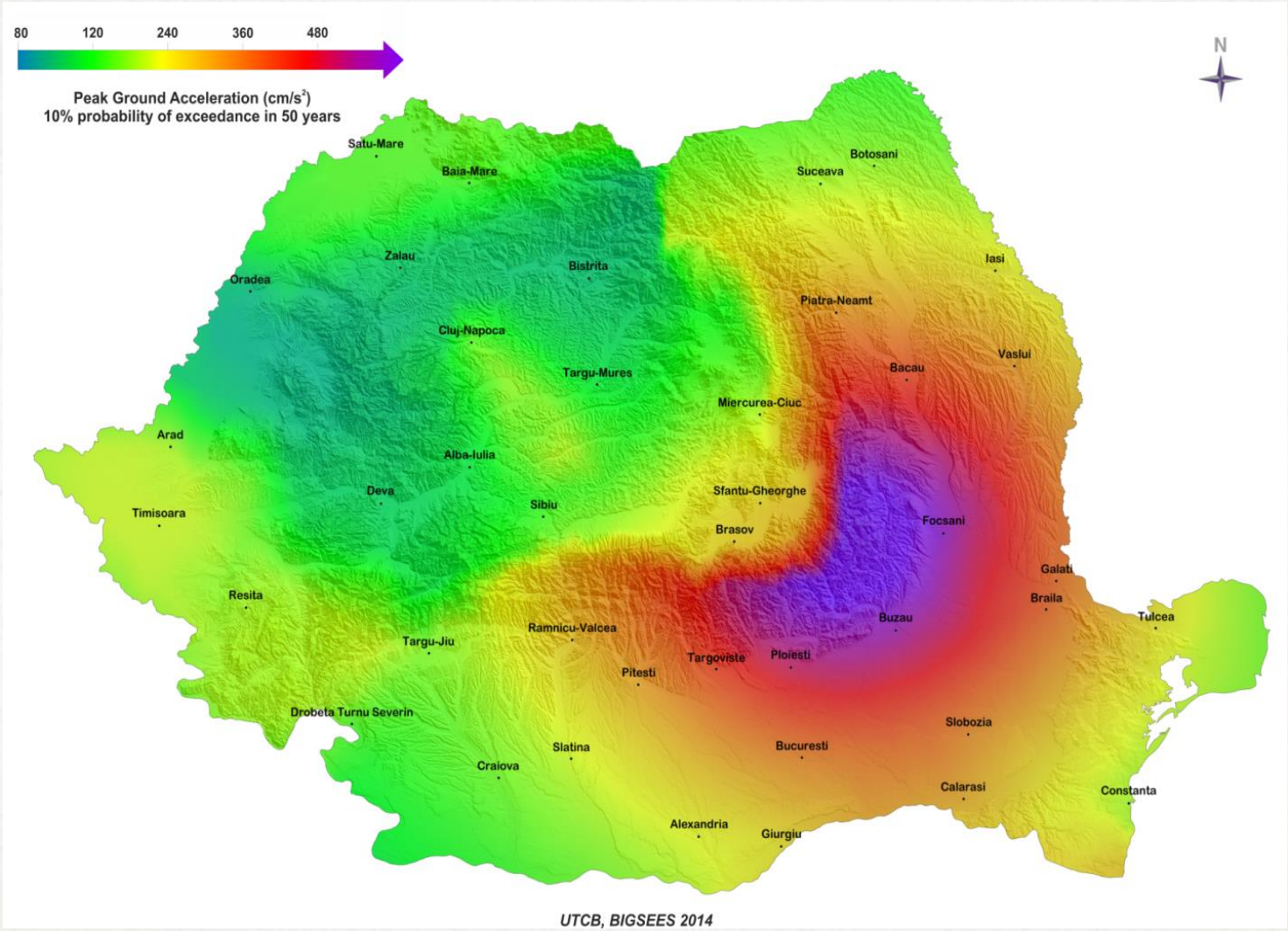
Fore-arc		Back-arc		Crustal	
GMPE	Weighing factors	**GMPE**	Weighing factors	**GMPE**	Weighing factors
VEA15	0.40	**VEA15**	0.60	**CF08**	0.45
YEA97	0.25	**AB03**	0.20	**I08**	0.40
ZEA06	0.25	**YEA97**	0.10	**AB10**	0.15
LL08	0.10	**ZEA06**	0.10		

VEA15 - Vacareanu et al. (2015) GMPE developed in **BIGSEES** project for Vrancea subcrustal seismic source

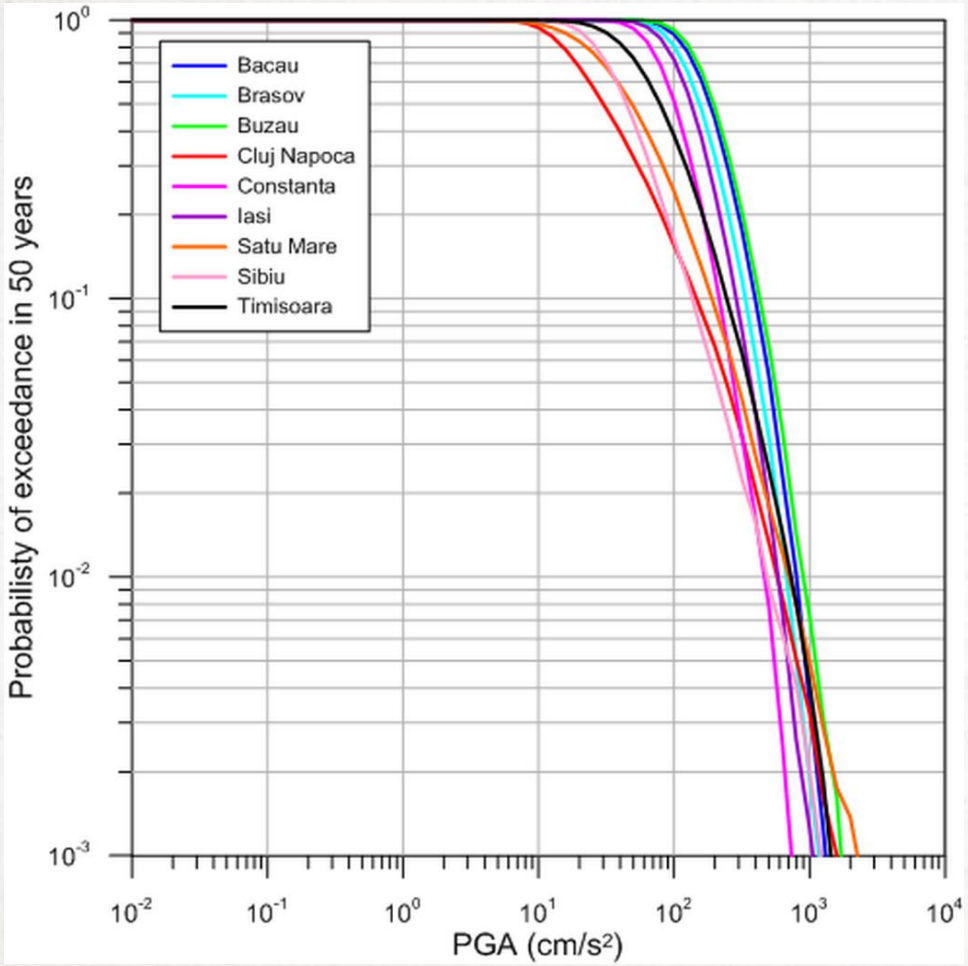
EVALUATION OF SEISMIC HAZARD

- Probabilistic seismic hazard assesment (PSHA):
  - Basic methodology – Cornell (1968) and McGuire (1976)
  - PSHA employs logic-trees – epistemic uncertainty
  - Main result – probability of exceedance (usually median) of a ground motion parameter - hazard curve
  - Other results: uniform hazard spectra (UHS), hazard disaggregation (contribution of magnitudes and source-site distances)

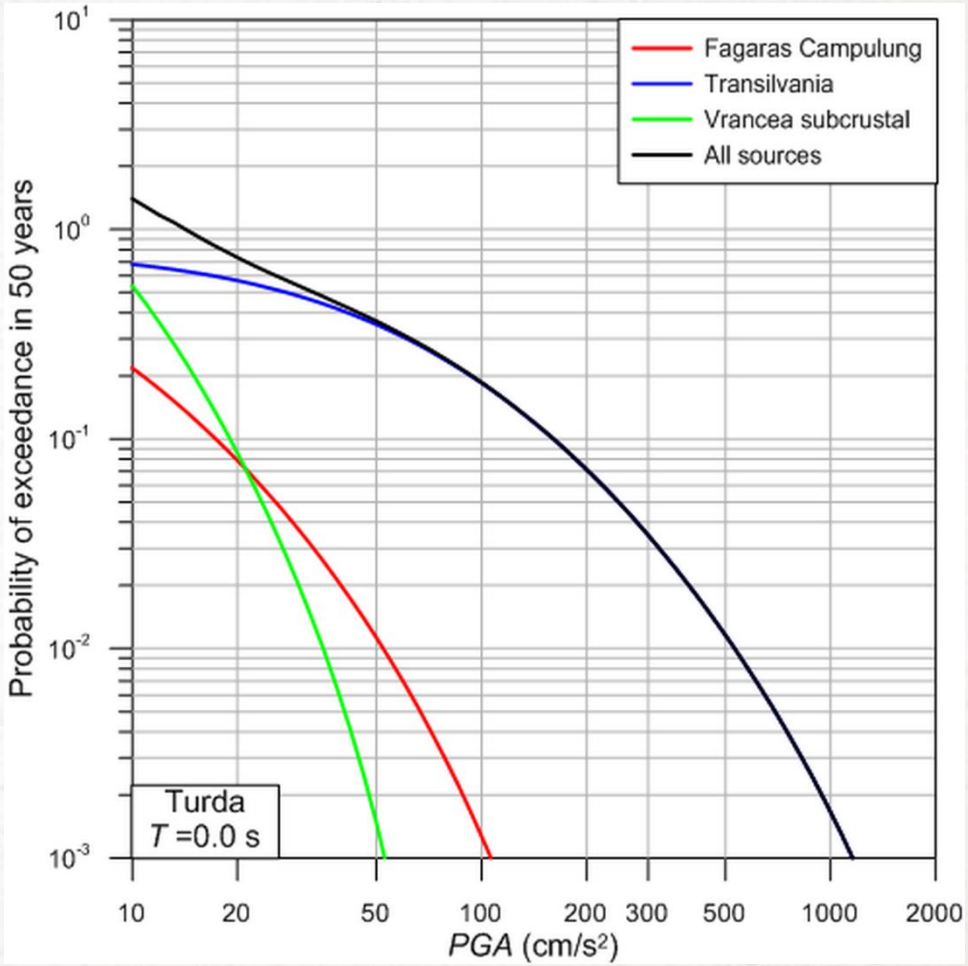
EVALUATION OF SEISMIC HAZARD



EVALUATION OF SEISMIC HAZARD

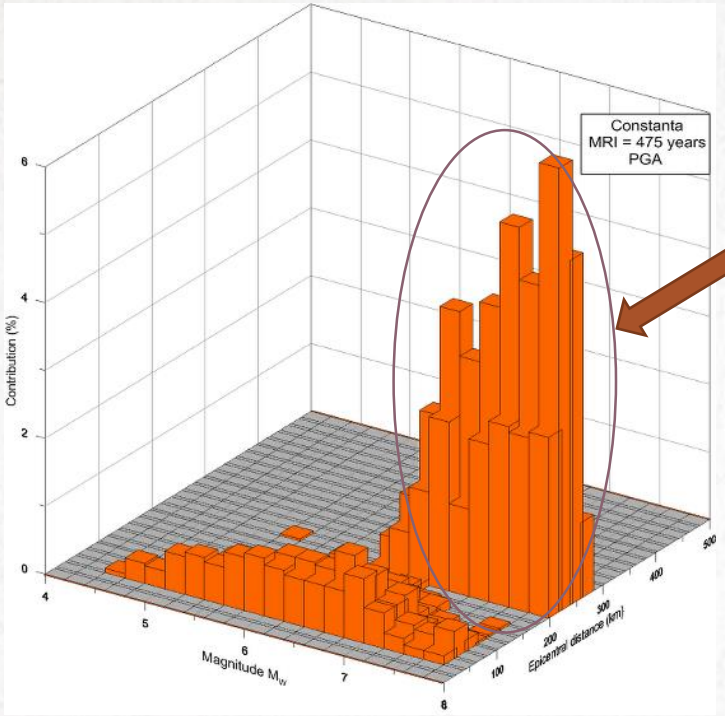


Examples of hazard curves



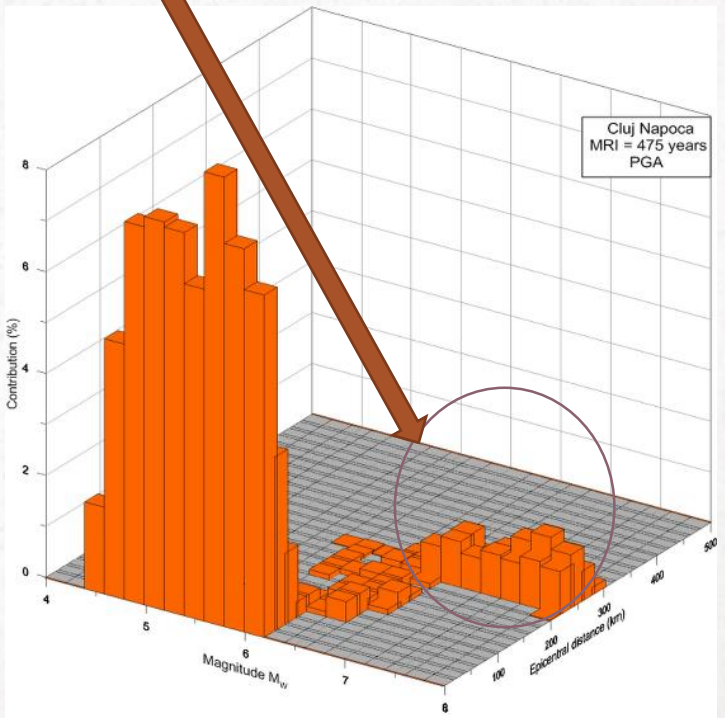
Hazard curves for Turda

EVALUATION OF SEISMIC HAZARD



Constanta
(fore-arc)

Contribution
Vrancea



Cluj-Napoca
(back-arc)

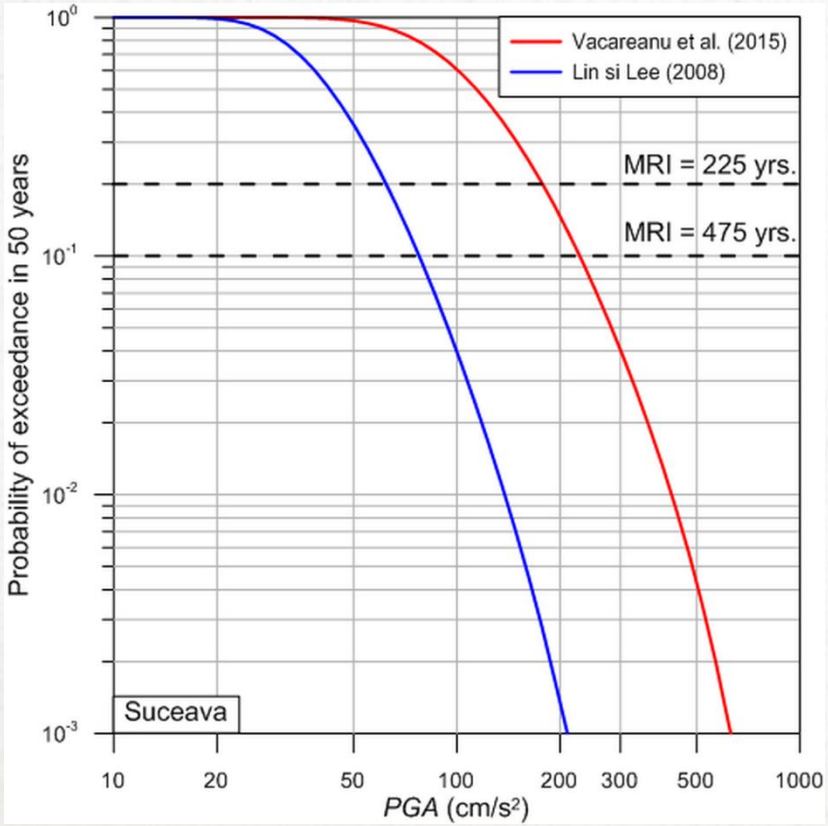
Hazard disaggregation (PGA)

COMMENTS

- Vrancea subcrustal seismic source – very active and concentrated seismicity
- Bucharest – affected by 9 earthquakes with Mw ≥ 7.0 in the past 200 years
- Crustal seismic sources - rather weak activity, but they can influence considerably the seismic hazard levels (especially low exceedance probabilities)
- Earthquake of Nov. 2014 (Mw = 5.7, h = 40 km) near Marasesti – PGA ≈ 0.28 g (Odobesti, d ≈ 15 km)

COMMENTS

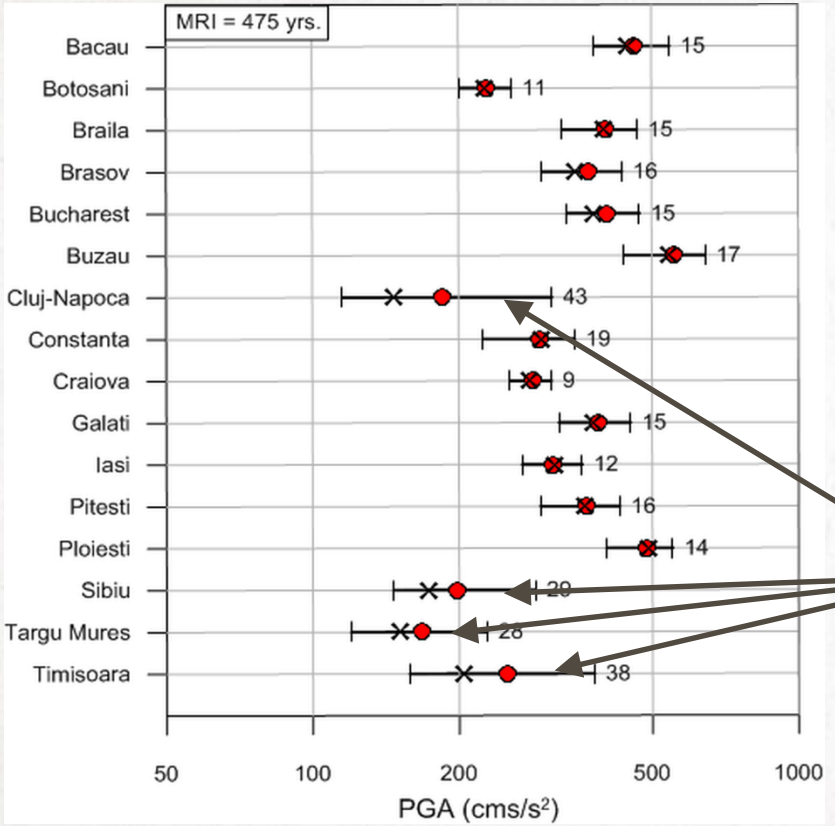
- Selection and testing of GMPEs – critical for a reliable evaluation of seismic hazard

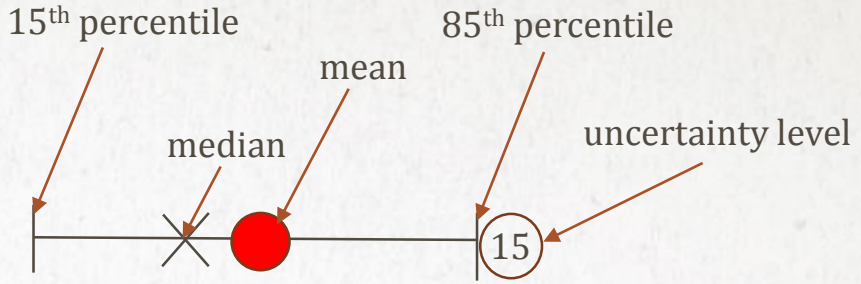


- Validation of PSHA results:
  - ground motion data (few recordings from large earthquakes)
  - intensity data – unreliable
  - Monte Carlo method
  - ground motion simulation

COMMENTS

- Uncertainty in PSHA results:

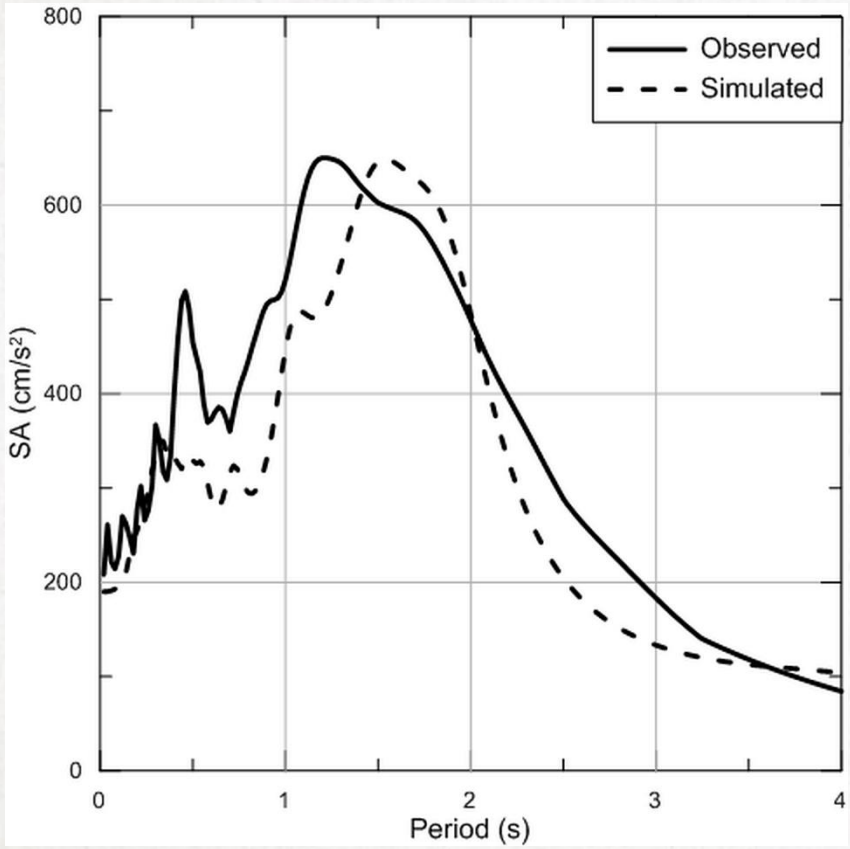




- PSHA results – median values
- Uncertainty (Douglas et al. 2014):
  - small – fore-arc (Vrancea)
  - larger (≈ 3 times) – back-arc (crustal sources)
- "Is the median hazard level adequate for back-arc area?"

COMMENTS

- Simulation of strong ground motions:



(Pavel and Vacareanu, 2015)

- More accurate representation of site-specific seismic action
- Difficult to use due to lack of deep soil profiles (> 200 m)
- Observed and simulated response spectra for INCERC station Bucharest – similar (1977 Vrancea earthquake, soil profile depth ≈ 1.5 km)

CONCLUSIONS

- **BIGSEES** research project – redefinition of seismic action for Romania according to Eurocode 8 provisions
- Seismicity of Romania – Vrancea subcrustal seismic source + 13 crustal seismic sources
- Seismic hazard contributor:
  - Vrancea – southern and eastern Romania
  - crustal (local) seismic sources + Vrancea (limited, mostly long periods) – Transylvania

CONCLUSIONS

- Future research in **BIGSEES** project:
  - Validation of PSHA results:
    - Monte Carlo methods
    - simulation of ground motions (if deep profiles are available)
  - Quantification of associated uncertainty in PSHA results (all sites)
  - Evaluation of nonlinear soil effects (southern Romania)

SELECTED REFERENCES

- Cornell CA (1968) Engineering seismic analysis. Bulletin of the Seismological Society of America 58: 1583 – 1606
- Delavaud E, Cotton F, Akkar S, Scherbaum F, Danciu L, Beauval C, Drouet S, Douglas J, Basili R, Sandikkaya MA, Segou M, Faccioli E, Theodoulidis N (2012a) Toward a ground-motion logic tree for probabilistic seismic hazard assessment in Europe. Journal of Seismology 16(3): 451-473.
- Douglas J, Ulrich T, Bertil D, Rey J (2014) Comparisons of the ranges of uncertainty captured in different seismic-hazard studies. Seismological Research Letters 85: 977-985.

SELECTED REFERENCES

- Kale Ö, Akkar S (2013) A new procedure for selecting and ranking ground-motion prediction equations (GMPEs): the Euclidean distance-based ranking (EDR) method. Bulletin of the Seismological Society of America 103(2A): 1069-1084.
- Pavel F, Văcăreanu R, Arion C, Neagu C (2014) Probabilistic seismic hazard assessment for Romania. Part I: selection of GMPEs. Proceedings of the 5th National Conference on Earthquake Engineering and 1st National Conference on Earthquake Engineering and Seismology, pp. 213-220.
- Pavel F, Văcăreanu R (2015) Assessment of the ground motion levels for the Vrancea (Romania) November 1940 earthquake. Natural Hazards DOI: 10.1007/s11069-015-1767-x.

SELECTED REFERENCES

- Scherbaum F, Cotton F, Smit P (2004) On the use of response spectral-reference data for the selection and ranking of ground-motion models for seismic-hazard analysis in regions of moderate seismicity: the case of rock motions. Bulletin of the Seismological Society of America 94(6): 2164-2185.
- Văcăreanu R, Radulian M, Iancovici M, Pavel F, Neagu C (2015). Fore-arc and back-arc ground motion prediction model for Vrancea intermediate depth seismic source. Journal of Earthquake Engineering 19(3): 535-562.
- Wenzel F, Achauer U, Enescu D, Kissling E, Russo R, Mocanu V, Musacchio G (1998) Detailed look at final stage of plate break-off is target of study in Romania. EOS Transactions American Geophysical Union 79(48): 589-600.