SERA
Seismology and Earthquake Engineering
Research Infrastructure Alliance for Europe

DELIVERABLE

D2.14 Stakeholders workshop M30

Work package	WP2 Communication, Outreach, Dissemination
Lead	EUCE
Authors	Helen Crowley, EUCE
Reviewers	
Approval	Management Board
Status	Final
Dissemination level	Public
Delivery deadline	31.10.2019
Submission date	31.10.2019
Intranet path	DOCUMENTS/DELIVERABLES/SERA_D2.14_Stakeholders_workshop_M30

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.

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Summary

The EUCENTRE (Pavia, Italy) organised a workshop with SERA partners, national experts in the field of seismic hazard and members of CEN/TC250/SC8 (responsible for the development of Eurocode 8) as part of the activities of SERA WP2 (communication, outreach, dissemination). The workshop was attended by around 20 participants including SERA partners from WP25, members of CEN/TC 250/SC8 and national experts in the field of seismic hazard assessment. Fruitful discussions on all of the components of the seismic hazard model were had and a presentation on the use of the model within a European seismic risk model was also presented. The main outcome of the workshop was the joint preparation of a 12-month roadmap towards the development of two maps of European seismic hazard that will be voted upon by EC8 national delegates (in October 2020) for inclusion in an informative annex to Eurocode 8 (Part 1).

1 Agenda

The workshop took place on Monday 14th October 2019 and comprised presentations on the developments on all of the components of the European Seismic Hazard Model (ESHM20), as well as a discussion of the first hazard outputs and the requirements of CEN/TC250/SC8. A brief presentation on the use of the hazard model for seismic risk modelling in Europe was also given. The future steps in the collaboration between SERA and CEN/TC250/SC8 were subsequently agreed, as presented in Section 3. The agenda is shown in Table 1 and the slides from the presentations are provided in the appendix of this deliverable.

Table 1: Workshop agenda

9.15 – 9:30	Get together, coffee, aim of the meeting, agenda	
9:30 – 9:45	General Framework of ESHM20	Laurentiu Danciu (ETH)
9:45 – 10:10	Instrumental Earthquake Catalogue - data compilation, harmonization and curation, discussion	Graeme Weatherill (GFZ)
10:10 – 10:30	Historical Earthquake Catalogue - data compilation, harmonization and curation, discussion	Andrea Rovida (INGV)
10:30 – 11:00	Active Faults: data compilation, harmonization	Roberto Basili (INGV)
11:00 – 11:15	Coffee break	
11:15 – 11:45	Seismogenic Sources: Area Sources compilation, harmonization, activity rates, discussion	Stefan Hiemer (ETH)
11:45 – 12:30	Ground Motion Characteristic Model, details of the model development, logic tree, discussions	Graeme Weatherill (GFZ)
12:30 – 13:15	Lunch	
13:15 – 14:15	ESHM20: Hazard Computation and Hazard Results	Laurentiu Danciu (ETH)
14:15 – 14:35	SC8 objective of seismic hazard maps for a possible EC8 informative annex	Pierre Labbé (SC8)
14:35 – 14:50	ESRM20: European Risk Model	Helen Crowley (EUCE)
14:50 – 15:30	Discussions and further steps	All

2 List of Participants

The workshop was attended by about 20 participants (see Table 2) from 6 European countries. The participants were representatives of SERA partners involved in WP25 'Updating and extending the European Seismic Hazard Model', members of CEN/TC 250/SC8 and national experts in the field of seismic hazard assessment.

NAME	AFFILIATION	COUNTRY
Basili Roberto	Istituto Nazionale di Geofisica e Vulcanologia	ITALY
Bazzurro Paolo	IUSS Pavia	ITALY
Bisch Philippe	TC250/SC8 Chair	FRANCE
Correia Antonio	LNEC / SC8 Secretariat	PORTUGAL
Crowley Helen	EUCENTRE	ITALY
Danciu Laurentiu	ETH Zurich	SWITZERLAND
Fardis Michael	University of Patras	GREECE
Hiemer Stefan	ETH Zurich	SWITZERLAND
Labbé Pierre	AFNOR	FRANCE
Nuti Camillo	Università Roma Tre	ITALY
Pagani Marco	GEM Foundation	ITALY
Pecker Alain	AFNOR	FRANCE
Pinho Rui	EUCENTRE	ITALY
Pitilakis Kyriazis	Aristsole University of Thessaloniki	GREECE
Rovida Andrea	Istituto Nazionale di Geofisica e Vulcanologia	ITALY
Schlüter Franz-Hermann	SMP	GERMANY
Traversa Paola	Électricité de France	FRANCE
Tsionis Georgios	Joint Research Centre	ITALY
Viallet Emmanuel	CN/PS	FRANCE
Weatherill Graeme	GFZ Potsdam	GERMANY
Wenk Thomas	Independent Consultant	SWITZERLAND

Figure 1: Workshop participants

3 Main Conclusions and Next Steps

The SERA hazard working group will complete the preparation of the alpha version (i.e. Pavia version) of ESHM20 (see Figure 2) by the end of October 2019 and will create an online platform to share this version, and all of the underlying datasets, sources and assumptions with CEN/TC250/SC8. Antonio Correia (SC8 Secretariat) will then disseminate the information with the national delegates (who will need to sign a non-disclosure agreement to access the data).

The CEN/TC250/SC8 (contact: Pierre Labbè) will provide the SERA hazard working group with a methodology to calculate the plateau of the uniform hazard spectrum by December 2019. Any specific hazard outputs needed for this methodology will be directed (in a timely manner) to Laurentiu Danciu.

The SERA hazard workshop group is planning a meeting with the scientific community for February 2020 to present the beta version of ESHM20.

The beta version of ESHM20 will be presented at the next CEN/TC250/SC8 meeting (taking place in Oslo in March 2020). Maps of the median spectral acceleration of the plateau and at 1 seconds (on reference rock with a Vs30 of 800 m/s) will be produced and presented.

Any feedback on the beta model should arrive by June 2020 so that a final version of the two aforementioned maps can be produced by September 2020 and shared with CEN/TC250/SC8 for dissemination amongst EC8 national delegates.

At the October 2020 CEN/TC250/SC8 meeting a final vote will be taken by the national delegates of EC8 on whether to include the two maps as an informative annex of Eurocode 8 (Part 1).

ESHM20 *alpha version* **(Pavia Version October 2019)**	**ESHM20** *beta version* **(March 2020)**	**ESHM20** *Final version* **(Summer 2020)**
Updated and Cross Border Harmonised Input Catalogues	Revised Input Datasets: faults, Earthquake catalogue (if needed)	Final Input Datasets
Cross Border Harmonised Seismogenic Sources	Consolidated Seismogenic Sources and Ground Motion Models	Final Seismogenic Sources and Ground Motion Models
Newly developed Ground Motion Models		
Output: Informative, not for distribution, not for use	Outputs not for distribution, for use within the scientifical and technical community, SC8 working group, national experts	Main Products released to SC8 commitee Outputs free for distribution and use

Figure 2: Versioning of the ESHM20

Appendix

The slides of all of the presentations are provided at the end of this deliverable.

Contact

Project lead	ETH Zürich
Project coordinator	Prof. Dr. Domenico Giardini
Project manager	Dr. Kauzar Saleh
Project office	ETH Department of Earth Sciences
	Sonneggstrasse 5, NO H62, CH-8092 Zürich
	sera_office@erdw.ethz.ch
	+41 44 632 9690
Project website	www.sera-eu.org

European Mediterranean Earthquake Catalogue (2019)

Graeme Weatherill*, Steffi Lammers, Fabrice Cotton*
Seismic Hazard & Risk Dynamics
GeoForschungsZentrum (GFZ), Potsdam

SERA Review Meeting, EUCENTRE, Pavia, 14 October 2019

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Why a Harmonised Catalogue?

Regional/Global Seismic Recording Networks:

- EMSC, GEOFON, ISC ...
- Different magnitude scales (M_L, M_d, M_W, m_b, M_S) - not always the same reported

National Seismic Recording Networks (e.g. INGV, SED, ...)

- Locally-calibrated magnitude scales and locations

Local Recording Networks

- Locally calibrated magnitude scales and locations

Harmonised Catalogue

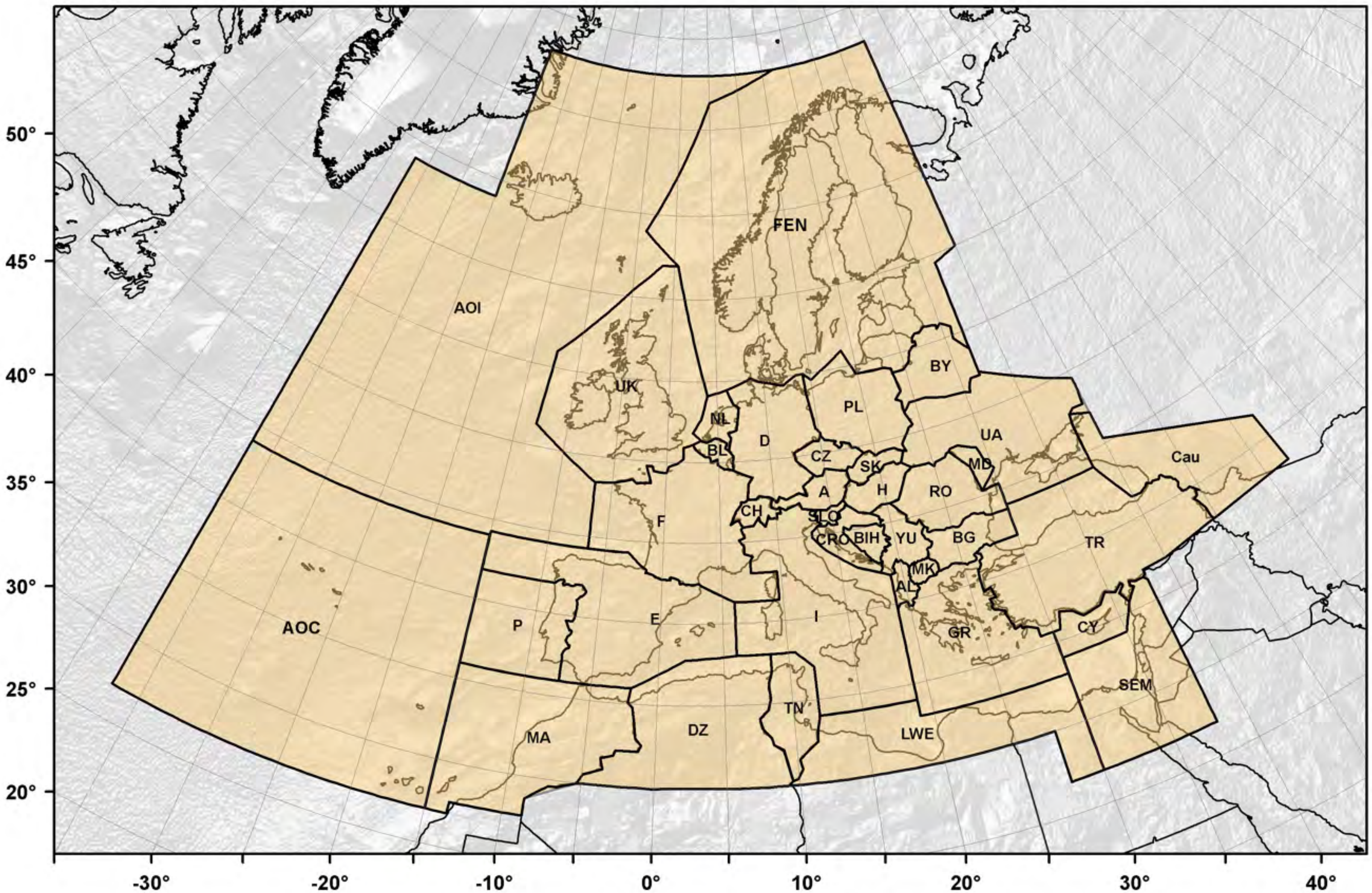
- Unique (preferred) location
- Common magnitude unit (usually Mw – but could consider several)
- Estimate of spatial and temporal completeness

European Mediterranean Earthquake Catalogue (EMEC)

Initially compiled by Grünthal & Wahlström (2012) (later updated for the SHARE project by Grünthal *et al*., 2013):

- > 45,000 earthquakes with unique time, location and moment magnitude (from an input database of over 700,000 earthquakes)
- 1000 CE to 2006 CE
- *Threshold* M_W: 3.5 in northern Europe (north of 44°N), 4.0 in southern Europe
- Source data from 80 domestic catalogues and more than 100 special studies

The EMEC Process: Compilation Regions



GFZ Helmholtz Centre POTSDAM

HELMHOLTZ

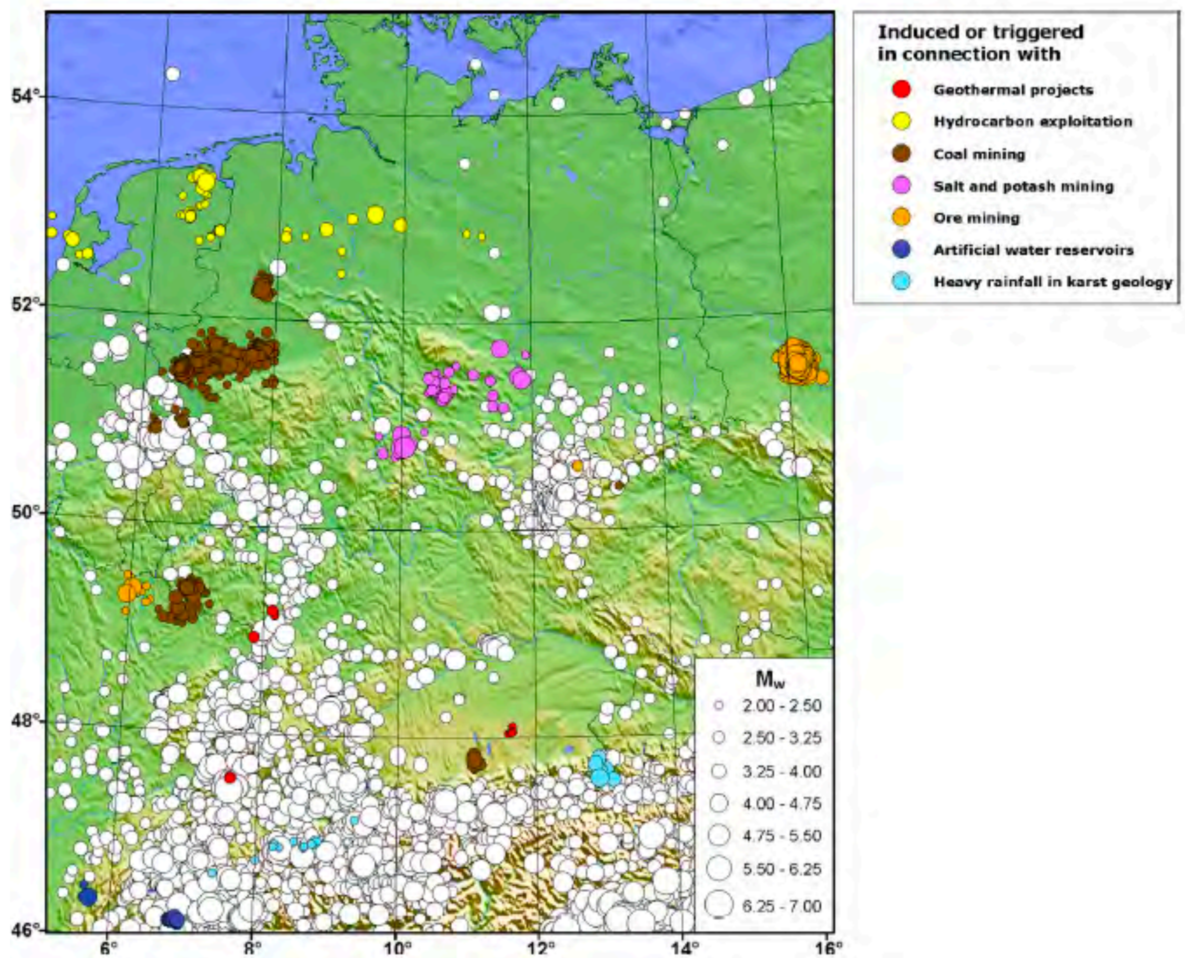
The EMEC Process: Inputs

Events excluded from the catalogue include:

- Duplicates/Fakes
- Suspected explosions
- Induced earthquakes

Identification of induced events described in Grünthal (2014)

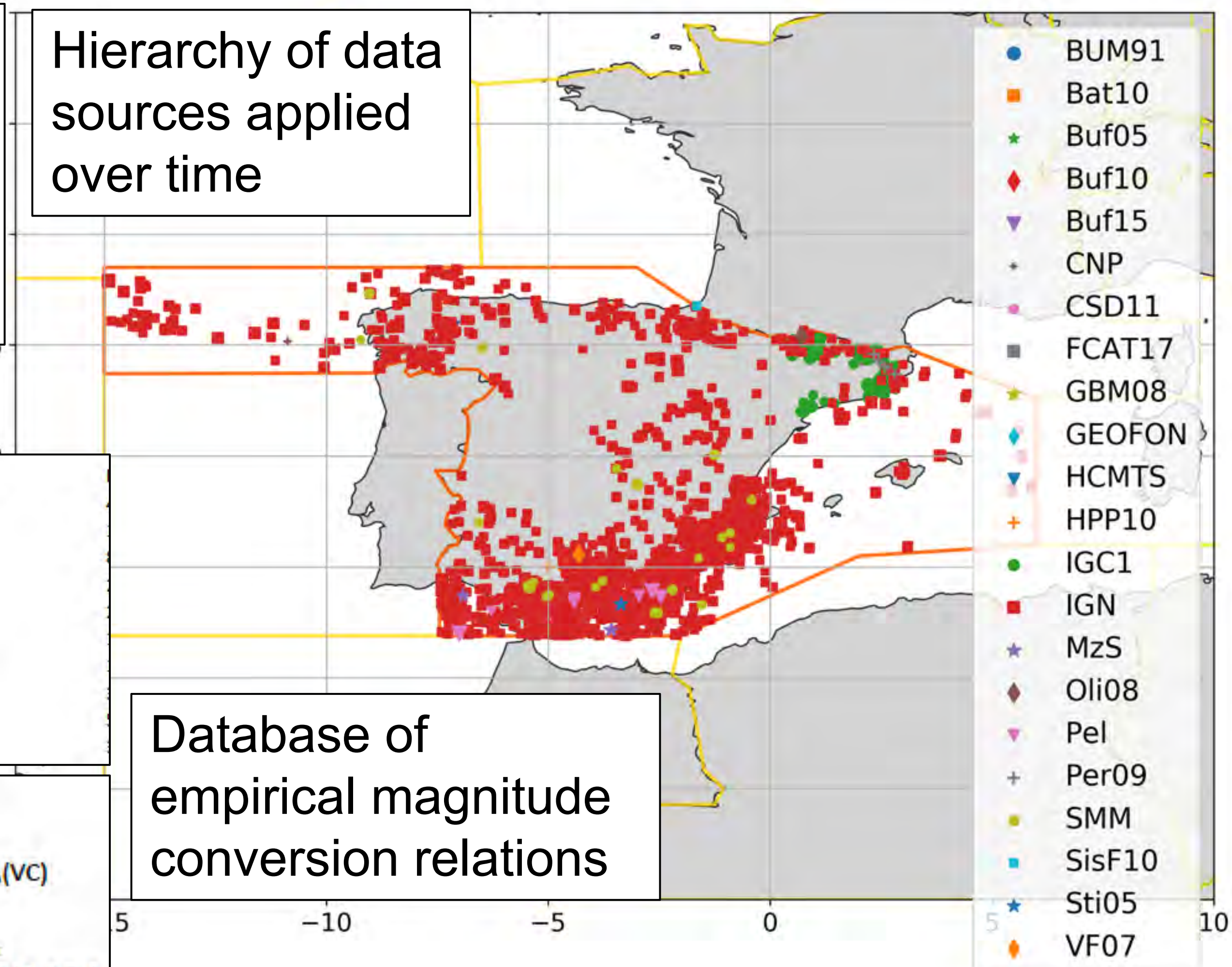
Events with speculated anthropogenic triggering in active regions (e.g. Lorca, 2011) retained



The EMEC Process: Data Assimilation

1000 - 1799	IGC1, Pel, IGN, MzS, SisF10 [1]
1800 - 1899	IGC1, IGN, MzS, SisF10 [1]
1900 - 1960	IGC1, IGN, SisF10 [1]
1961	IGC1, IGN, CNP, SisF10 [1]
1962 - 1995	IGC1, IGN, CNP, SisF10 [1]
1996 - 2000	IGC2, IGN, CNP, SisF10 [1]
2001 - 2002	IGC2, IGN, SisF10 [1]
2003 - 2004	IGC2, IGN, SisF10 [1]
2005 - 2006	SMM, IGN, SisF10 [1]
2007 - 2014	IGN

Hierarchy of data sources applied over time



Katalog	Orig. Mag. Types	Conversions
CNP	M_L	$M_w M_L 110$
HPP10 [2)]	I_0	$M_w I_0 74$
IGC1	I_0	$M_w I_0 74$
IGN	M_w, M_b	M_w-m_b_VC
MzS	M_w	
Pel	M_w	
SisF10	I_0	$M_w I_0$MER
SMM	M_w	
Moment Tensors	M_w	
Special Studies		

$M_w I_0 74$	$M_w = 0.6 * I_{max} + 0.96$
$M_w M_L 110$	$M_w = M_L$
M_w-m_b_VC	$M_w = -1.528 + 1.213 * m_b(VC)$
$M_w I_0$MER	$M_w = 0.682\ I_0 + 0.16$
M_w-I_{max}-IGN	$M_w = 1.656 + 0.545 * I_{max}$
$M_w M_S 54$	$M_w = 0.796\ M_S + 1.280$ for $M_S \geq 5.4$
	$M_w = 0.585\ M_S + 2.422$ for $M_S < 5.4$

Database of empirical magnitude conversion relations

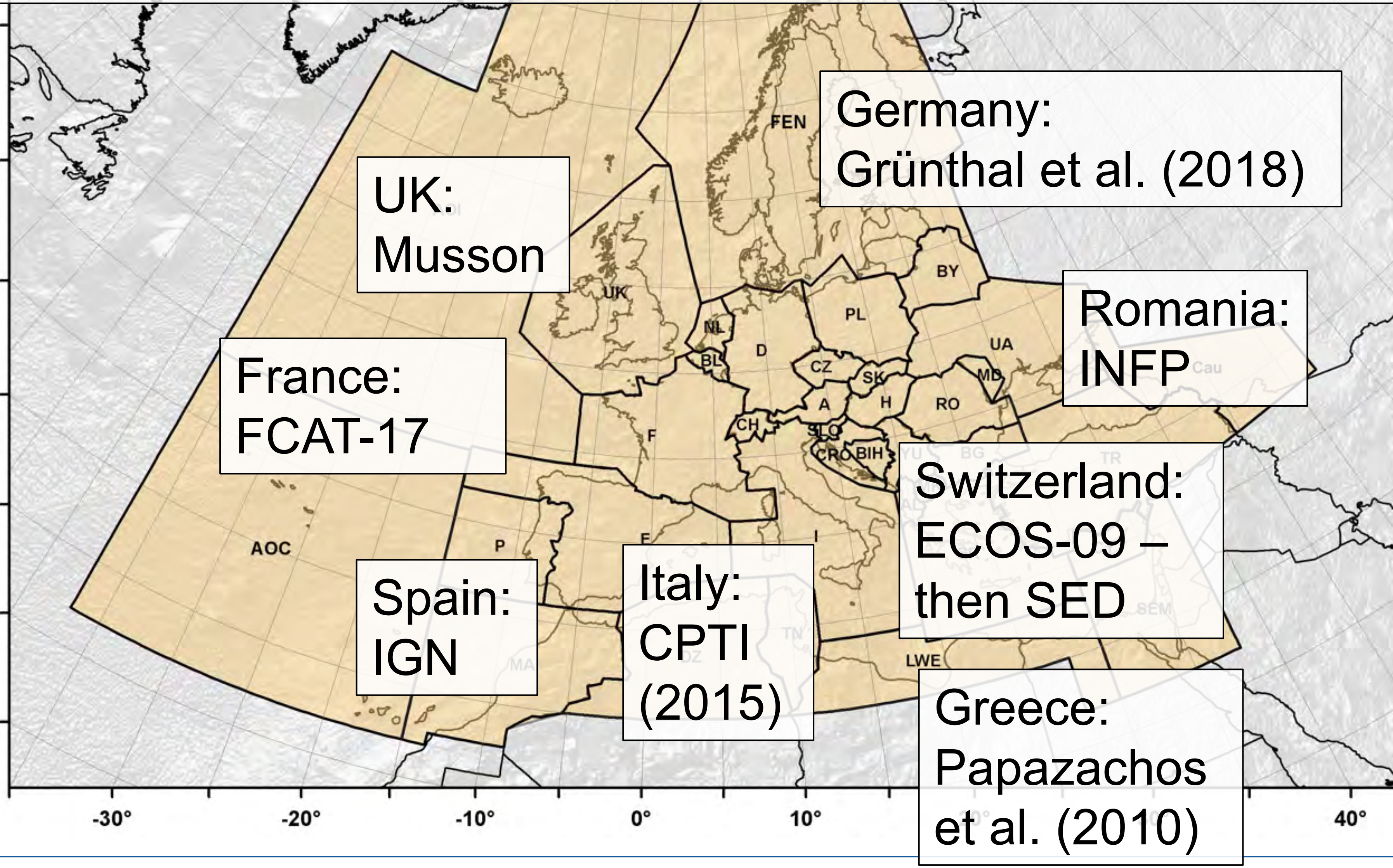
The EMEC Process: Hierarchies

Hierarchies

- Special Studies & Prior Compilations — e.g. Moment tensor investigations, Mw-harmonised national compiled catalogues (e.g. FCAT, CPTI)
- RCMT/SED->GEOFON ->GCMT — Moment tensor databases (with or without reported uncertainty)
- Local/National Bulletins
- International Seismological Centre

For EMEC 2019 update we retain as many of the hierarchies and conversion models from Grünthal & Wahlström (2012) as possible!

Harmonised National Catalogues in EMEC



European Mediterranean Earthquake Catalogue (EMEC)

Initially compiled by Grünthal & Wahlström (2012) (later updated for the SHARE project by Grünthal *et al*., 2013):

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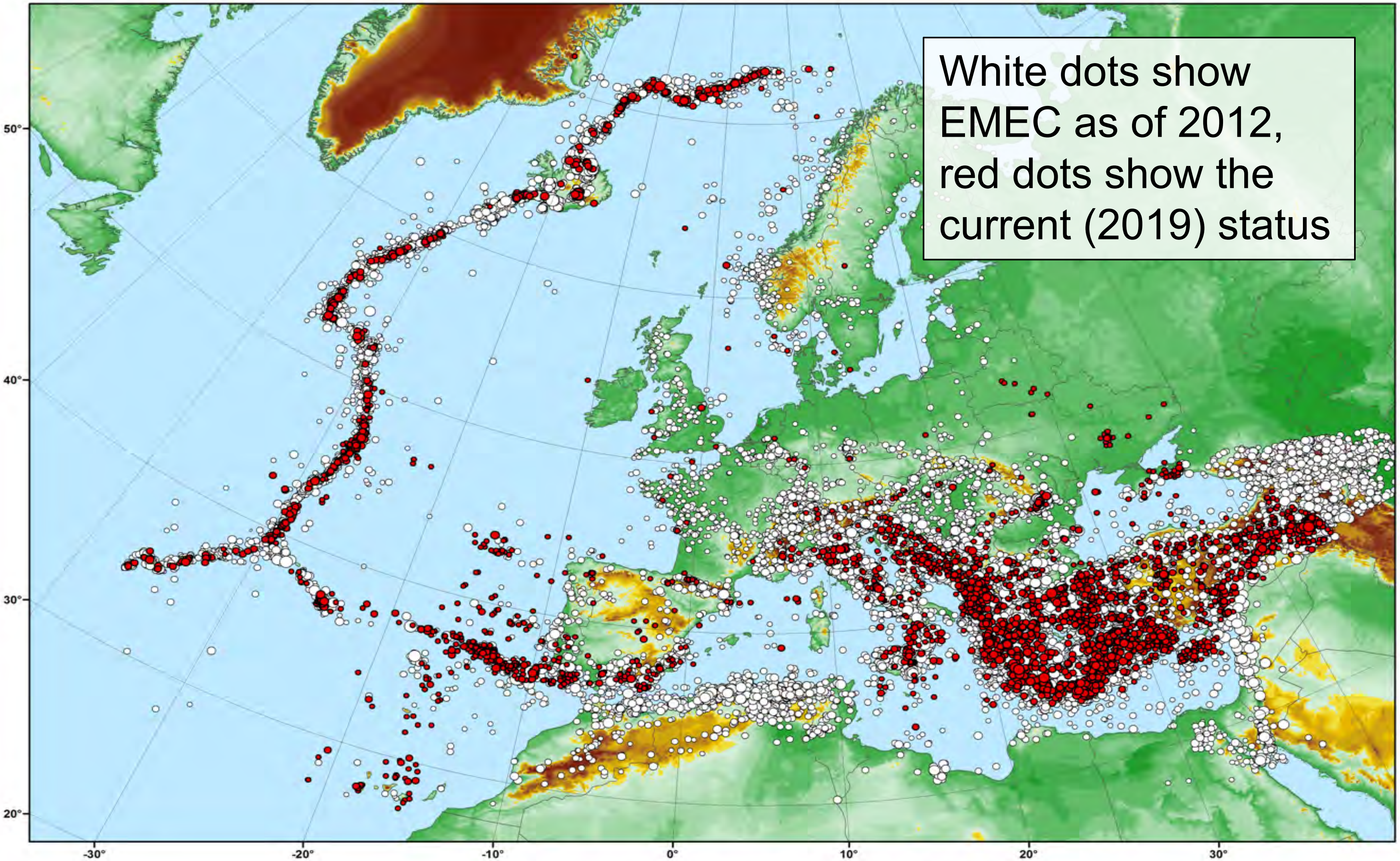
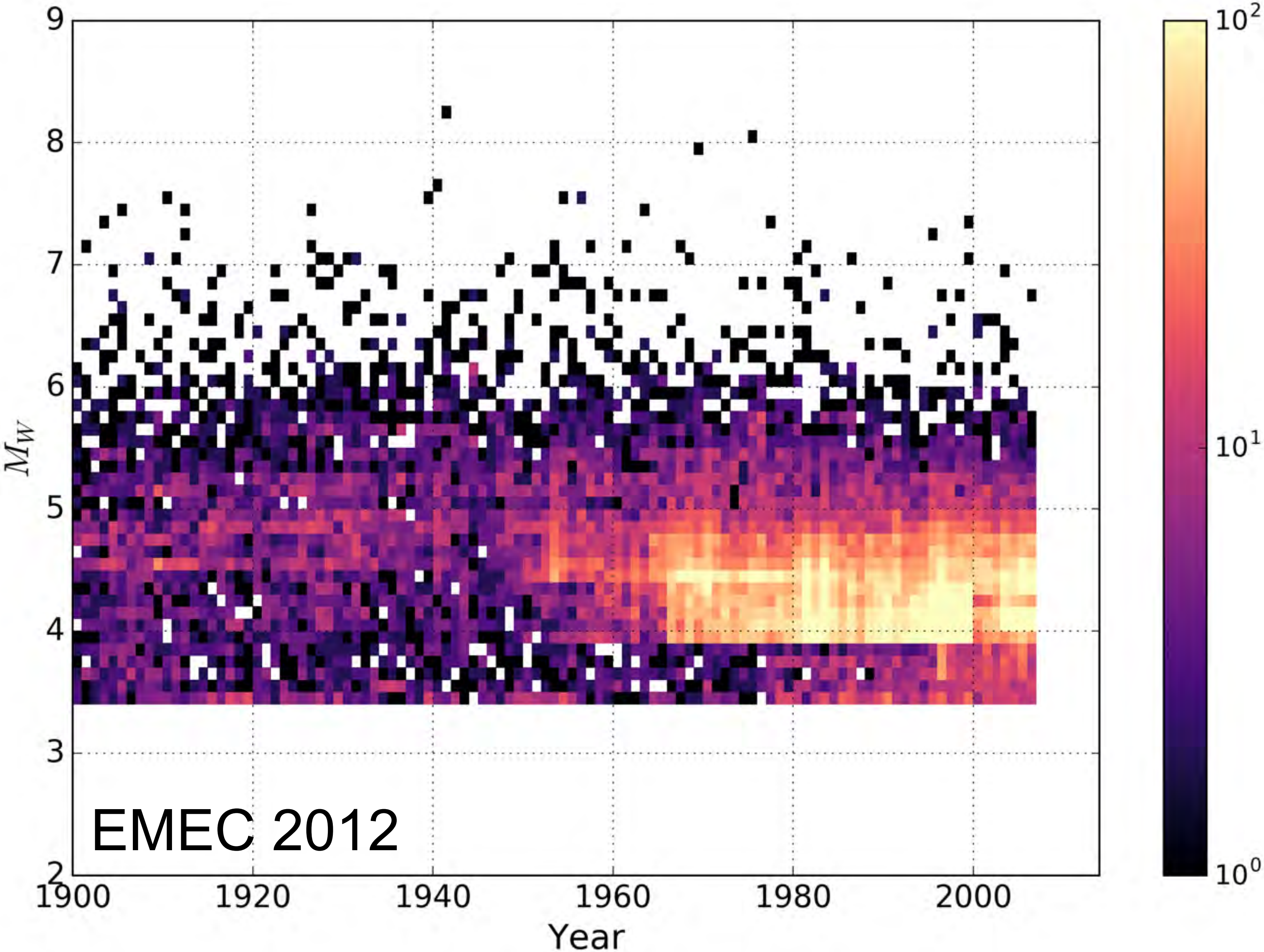
- 1000 CE to 2006 CE
- *Threshold* M_W: 3.5 in northern Europe (north of 44°N), 4.0 in southern Europe
- Source data from 80 domestic catalogues and more than 100 special studies

Update for ESHM2020 (Weatherill, Lammers *et al. 2020? – in prep.*):

- Extended to end of 2014 CE
- Addition of new data sources (e.g. CPTI15, FCAT, GEOFON)
- Threshold dropped to Mw 3.5 for all Europe

EMEC Catalogue





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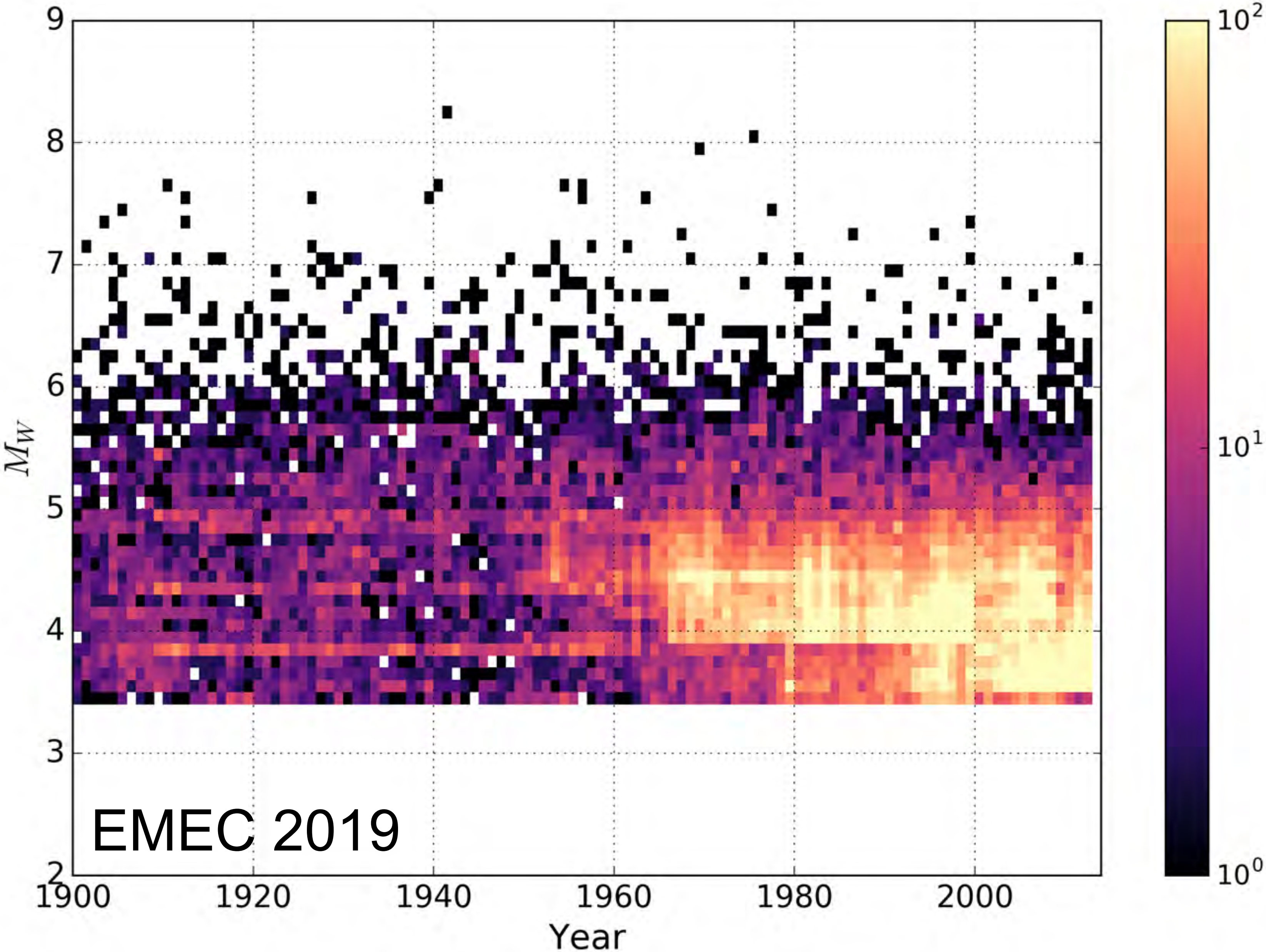
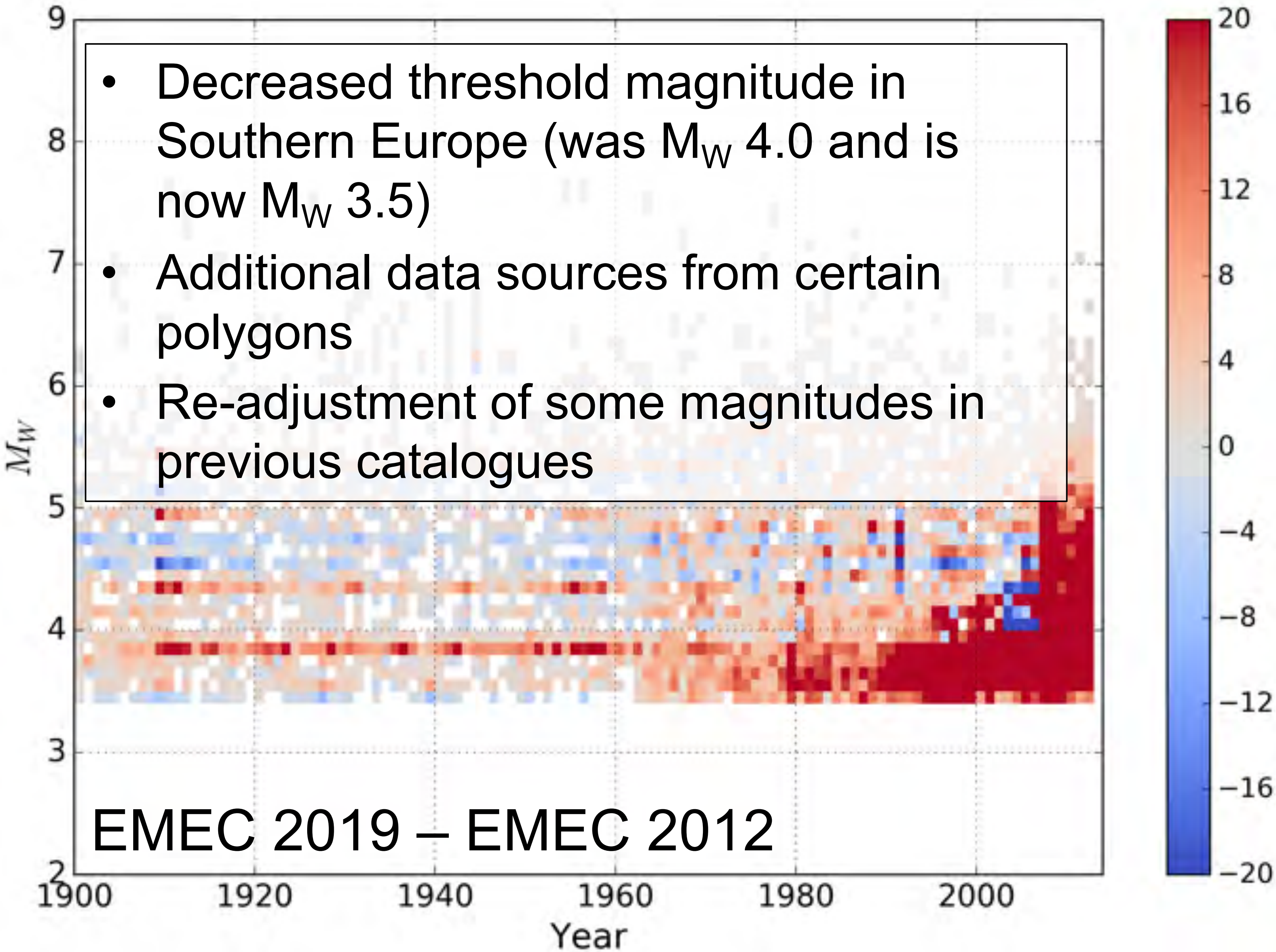

EMEC 2019
M_W
Year
1900
1920
1940
1960
1980
2000
2
3
4
5
6
7
8
9
10^0
10^1
10^2

- Decreased threshold magnitude in Southern Europe (was M_W 4.0 and is now M_W 3.5)
- Additional data sources from certain polygons
- Re-adjustment of some magnitudes in previous catalogues

EMEC 2019 – EMEC 2012

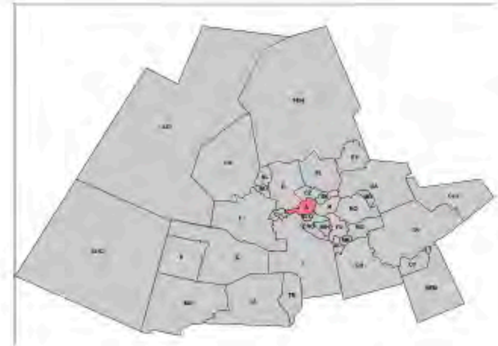


Supporting Documentation

- PDF document compiled with a polygon-by-polygon breakdown of the data sources, hierarchies and conversion models used
- Database of conversion models and hierarchies are integral part of the harmonisation process
- Will be released with new version of EMEC

Austria

A



Number of Events

1000 – 2006: 192
2007 - 2014: 13
Spec Studies: 13
Total: 218

Hierarchy of the national catalogues

1000 - 1993	ZAMG09L, ZAMG, Ley15, HHM, ECOS-09
1994 - 1995	ZAMG09L, ZAMG, GRF, ECOS-09
1996 - 2008	ZAMG09L, GRF, ECOS-09
2009 - 2014	ZAMG

Katalog	Orig. magnitudes	Conversions	No. of events >= 3.5
ECOS-09	Mw		5
HHM	I0, ML	MwI067, MwML	12
Lab	I0 (Ms)	MwMs, I0MS44K2	1
Ley15	I0	MwI042	3
ZAMG*	I0, ML	MwML, MwI033	173
Moment Tensors	Mw		11
Spec studies			13

Conversions

M_wM_L	$M_w = 0.5322+0.6462*M_L+0.0376*M_L^2$	Relation (4) in GW12
M_wI033	MLI033 = 0.79*I0+1.19*Log10(H)-1.44 => MwML	Relation (9) in GWS09
MwI042	MLI042=0.81*I0+0.49*Log10(H)-0.85 => MwML	Relation (12) in GWS09
MWI067	MLI067=0.721*I0+1.283*Log10(H)-1.13 => MwML	Relation (5) & (4)
MWMs	Ms = 0.55 * I0 + 0.93 * Log(H) + 0.14 => Mw = Ms	W.Carpathians , Karnik Mw=Ms siehe GW03

References

ECOS-09	Fäh D, Giardini D, Kästli P, Deichmann N, Gisler M, Schwarz-Zanetti G, Alvarez-Rubio S, Sellami S, Edwards B, Allmann B, Bethmann F, Wössner J, Gassner-Stamm G, Fritsche S, Eberhard D (2011) ECOS-09 Earthquake Catalogue of Switzerland Release 2011. Report and Database. Public catalogue, 17.4.2011. Swiss Seismological Service ETH Zürich, Report SED/RISK/R/001/20110417
HHM	Herak M, Herak D, Markušić S (1996) Revision of the earthquake catalogue and seismicity of Croatia, 1908-1992. Terra Nova 8(1): 86-94; DOI: 10.1111/j.1365-3121.1996.tb00728.x / + Data file until 2004
Ley15	Leydecker G (2011) Erdbebenkatalog für die Bundesrepublik Deutschland mit Randgebieten für die Jahre 800-2008. Geol Jb E59, 198 S., aktualisierte Version Sept. 28, 2015
ZAMG09L	Lenhardt, W (2009) Data file of Austrian earthquakes. Zentralanstalt für Meteorologie und Geodynamik, Hauptabteilung für Geophysik, Vienna, Austria
ZAMG	Lenhardt W (1996) Data file of Austrian earthquakes. Zentralanstalt für Meteorologie und Geodynamik, Hauptabteilung für Geophysik, Vienna, Austria /until 1995/

EMEC Review

- Dissemination of the catalogue to SERA model building participants (February 2019)
- Three review meetings in June/July 2019: Lisbon (Western Europe), Potsdam (Northern Europe) and Athens (Eastern Mediterranean)
  - Direct feedbacks during the meeting – some of which we have been able to act on
  - Feedbacks shortly afterward – still trying to assimilate what we can
- Another update intended before the end of the project – minor changes are expected

When we enact changes (and why we sometimes don't!)

Local experts have been able to provide some new data, and have helped to identify questionable events

- Access to data sources we would otherwise not have found
- Preview publications/reports of ongoing work
- Insights to help adjust hierarchies

But … we have sometimes encountered the following:

- Local experts denying access to their national catalogues
- Access granted only on terms not compatible with intended conditions of release of EMEC
- Local data with quality issues (errors in timing, duplicates, mislocations, erroneous magnitudes)

EMEC Beyond SERA

- EMEC is an ongoing process – but need to *freeze* a version for the purpose of ESHM2020
- Plans to transition away from a fixed activity to a web-service
  - Harmonising the catalogue more regularly
  - Rapid estimation of the harmonised magnitudes
  - Tools for users to explore the database of conversion models and build/apply their own regressions
- Strengthen participation in the EMEC process and bring into alignment national and European catalogues

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ISTITUTO NAZIONALE
DI GEOFISICA E VULCANOLOGIA

EARTHQUAKE CATALOGUE 1000-1899
DATA COMPILATION AND HARMONIZATION

PAVIA, 14 OCTOBER 2019

Andrea ROVIDA – INGV, Milano, Italy
andrea.rovida@ingv.it

Andrea ANTONUCCI – INGV, Milano, Italy

This project has received funding from the European Union's
Horizon 2020 research and innovation programme
under grant agreement No. 691728

OUTLINE

1. Background (SHEEC 1000-1899)
2. The need for homogenization
3. Compilation strategy
4. Content of the catalogue
5. Main changes with respect to SHEEC
6. Regional overview

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BACKGROUND

the SHARE European Earthquake Catalogue (SHEEC) 1000-1899

Requirements: homogeneous catalogue based on the most updated knowledge, relying on published data, and compiled in terms of Mw with transparent and repeatable procedures

J Seismol (2013) 17:523–544
DOI 10.1007/s10950-012-9335-2

ORIGINAL ARTICLE

The SHARE European Earthquake Catalogue (SHEEC) 1000–1899

M. Stucchi · A. Rovida · A. A. Gomez Capera · P. Alexandre · T. Camelbeeck · M. B. Demircioglu · P. Gasperini · V. Kouskouna · R. M. W. Musson · M. Radulian · K. Sesetyan · S. Vilanova · D. Baumont · H. Bungum · D. Fäh · W. Lenhardt · K. Makropoulos · J. M. Martinez Solares · O. Scotti · M. Živčić · P. Albini · J. Batllo · C. Papaioannou · R. Tatevossian · M. Locati · C. Meletti · D. Viganò · D. Giardini

Stucchi et al., 2013 - JoSe

Received: 7 March 2012 / Accepted: 19 September 2012 / Published online: 12 October 2012
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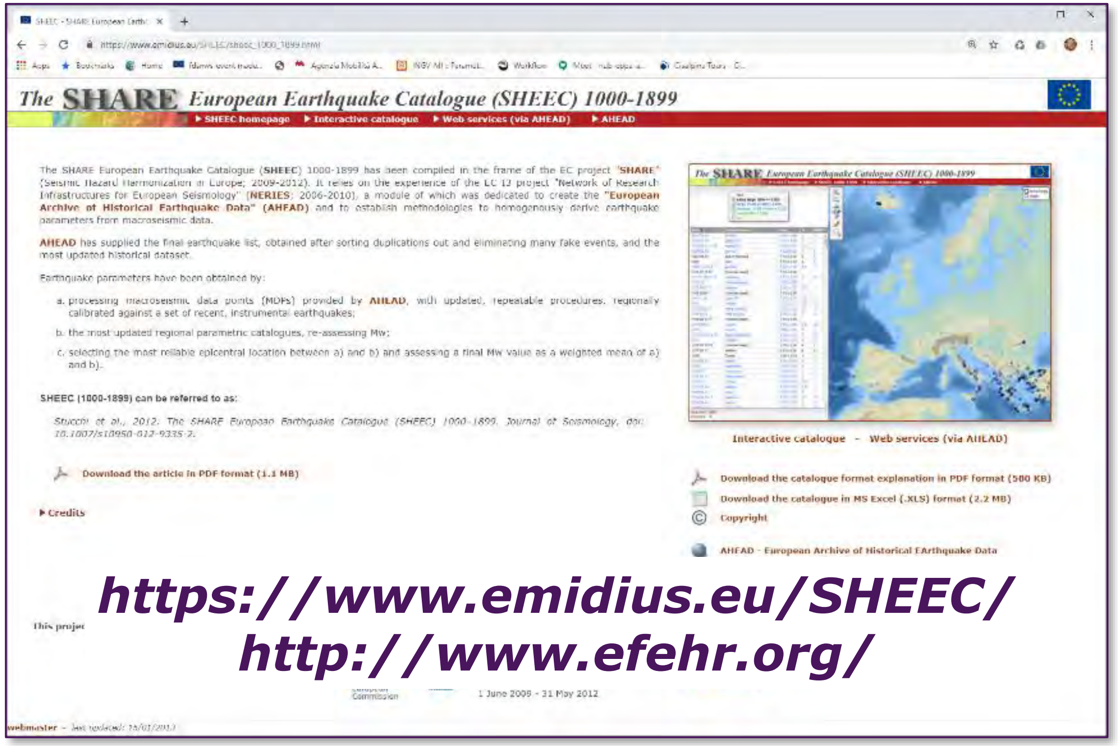

https://www.emidius.eu/SHEEC/
http://www.efehr.org/

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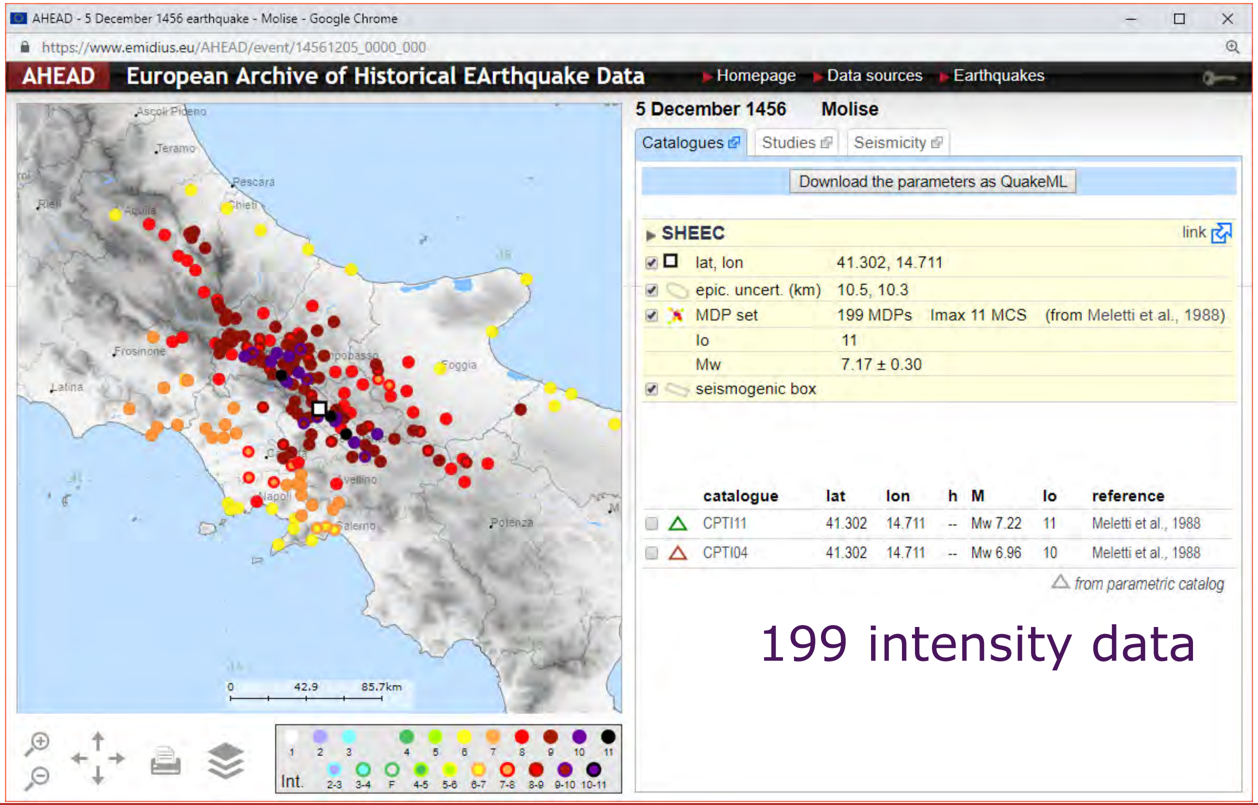
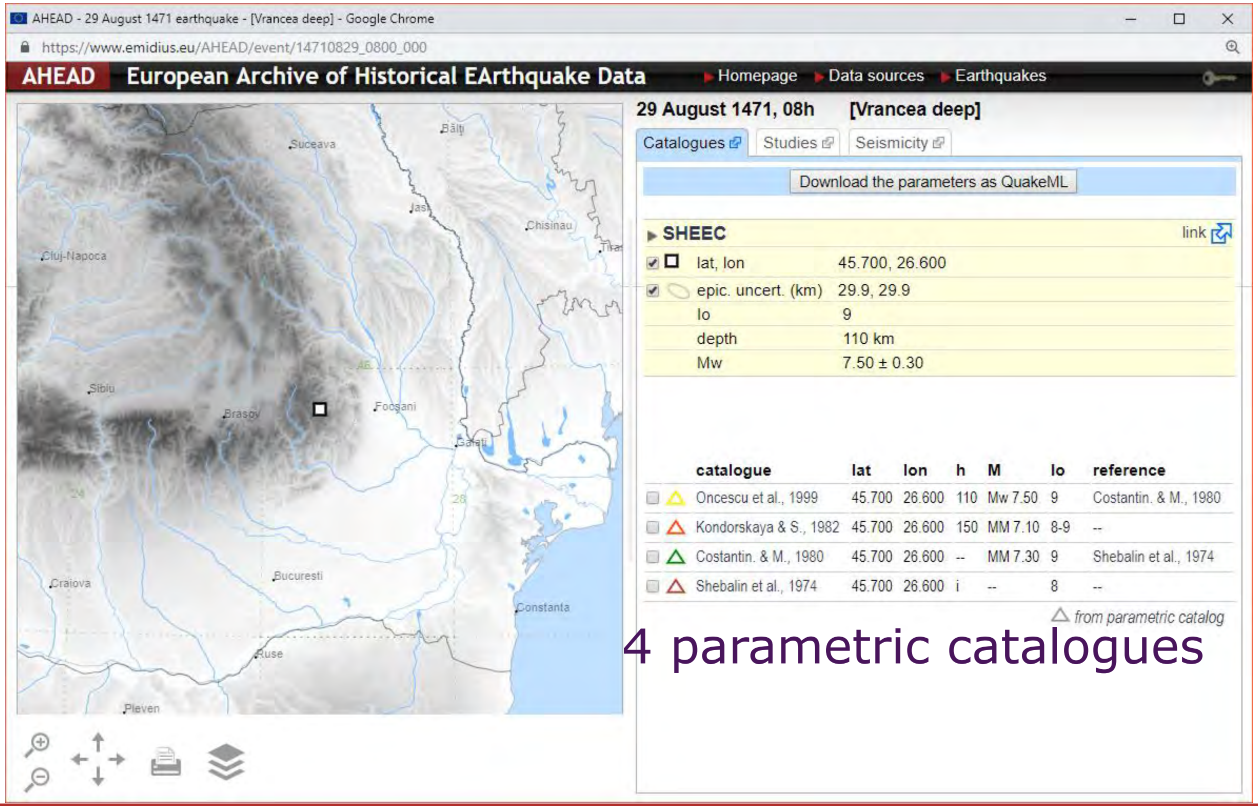
The Need for Homogenization

Earthquake parameters, including M values of 7+, may have diverse provenances:

- the analyses of historical sources, interpreted or not in terms of macroseismic intensities
- other (previous) catalogues



199 intensity data

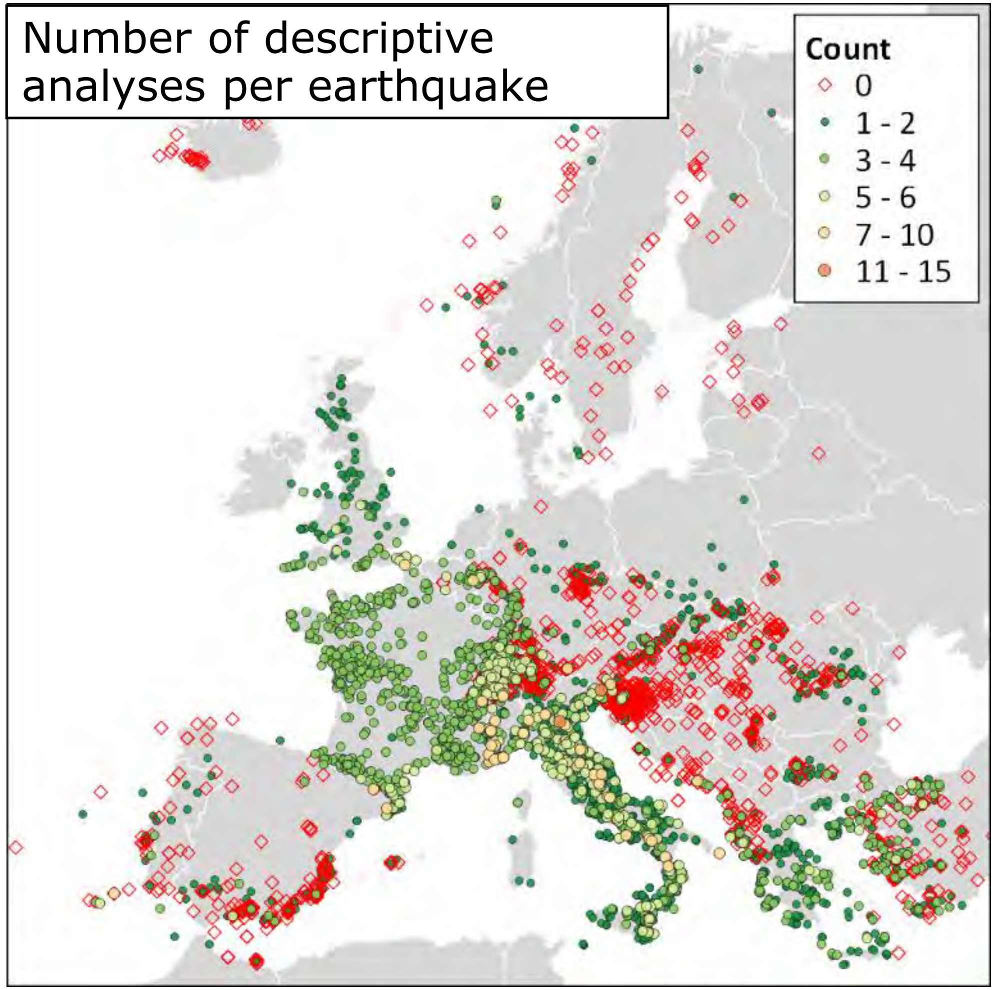


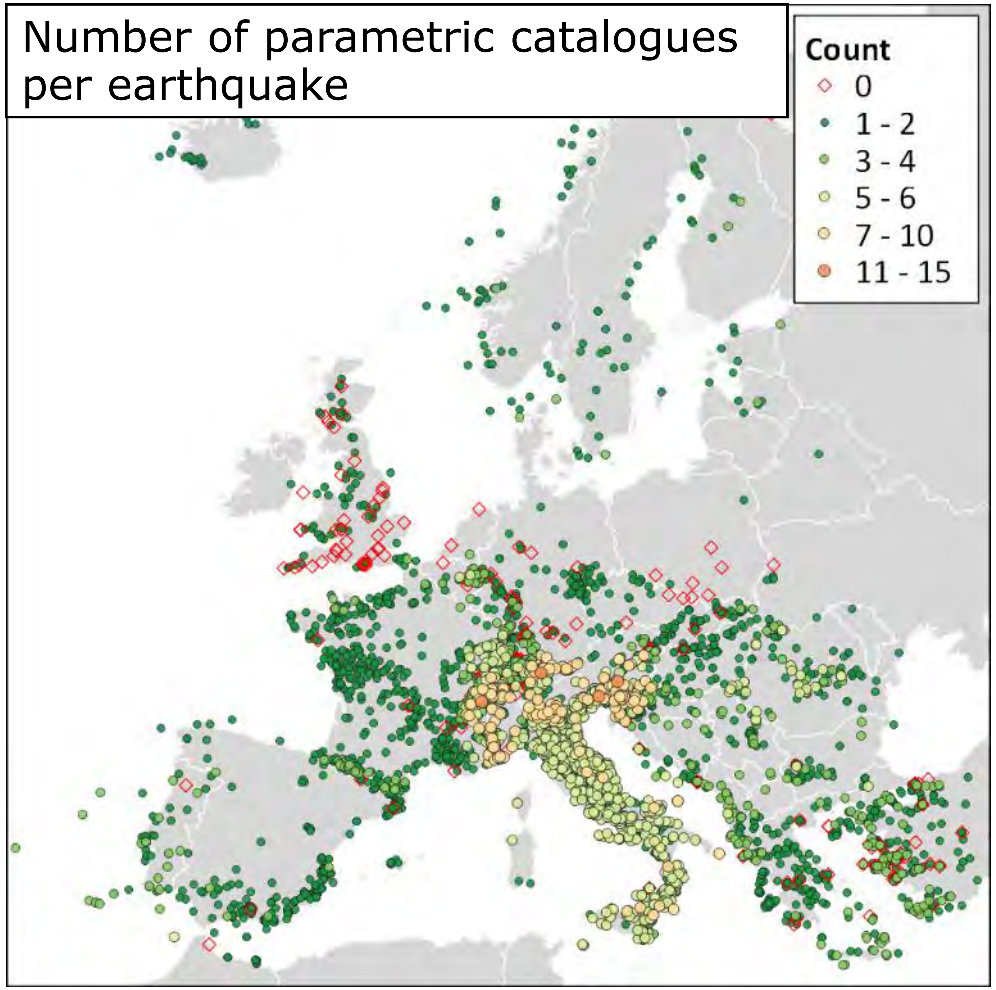
4 parametric catalogues

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 691728

THE NEED FOR HOMOGENIZATION

Throughout Europe, different types of sources of data are available for each earthquake





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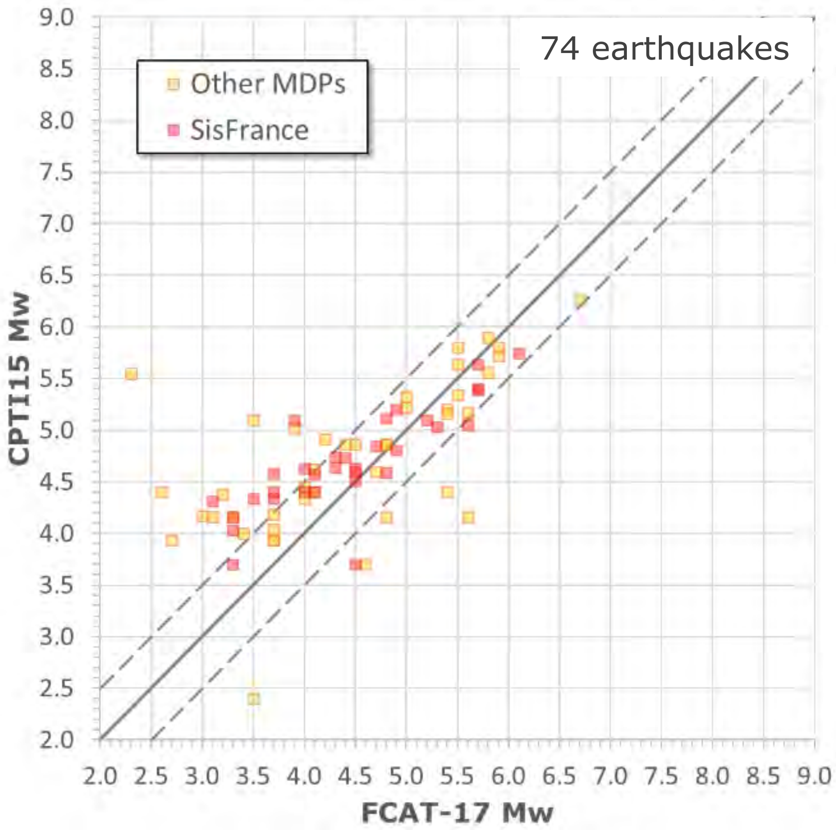
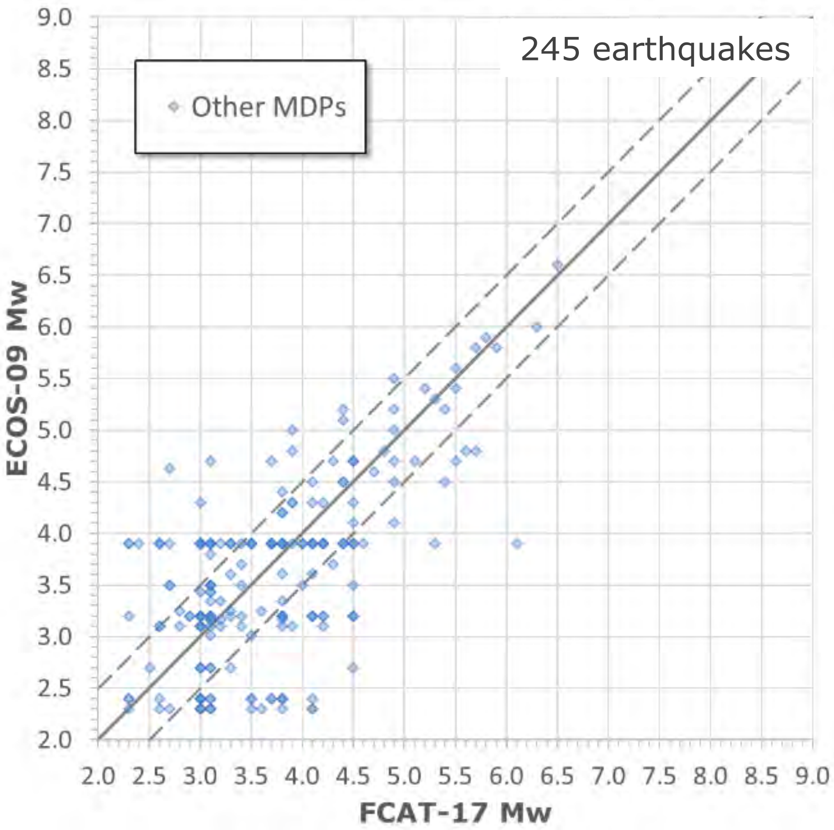
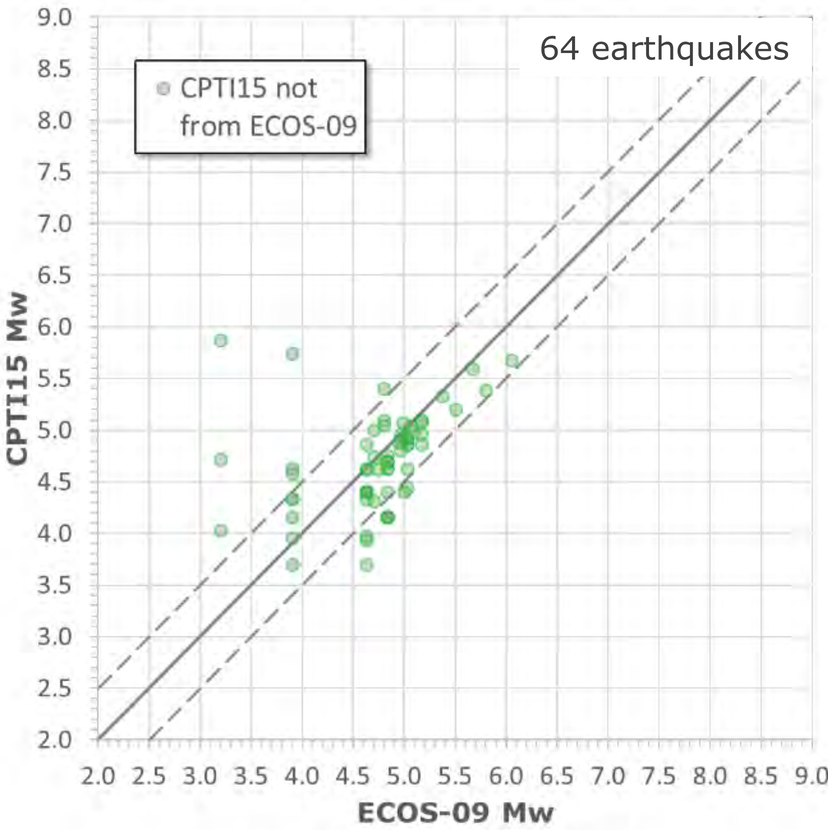
The Need for Homogenization

Common earthquakes (1000-1899) in France, Switzerland, and Italy







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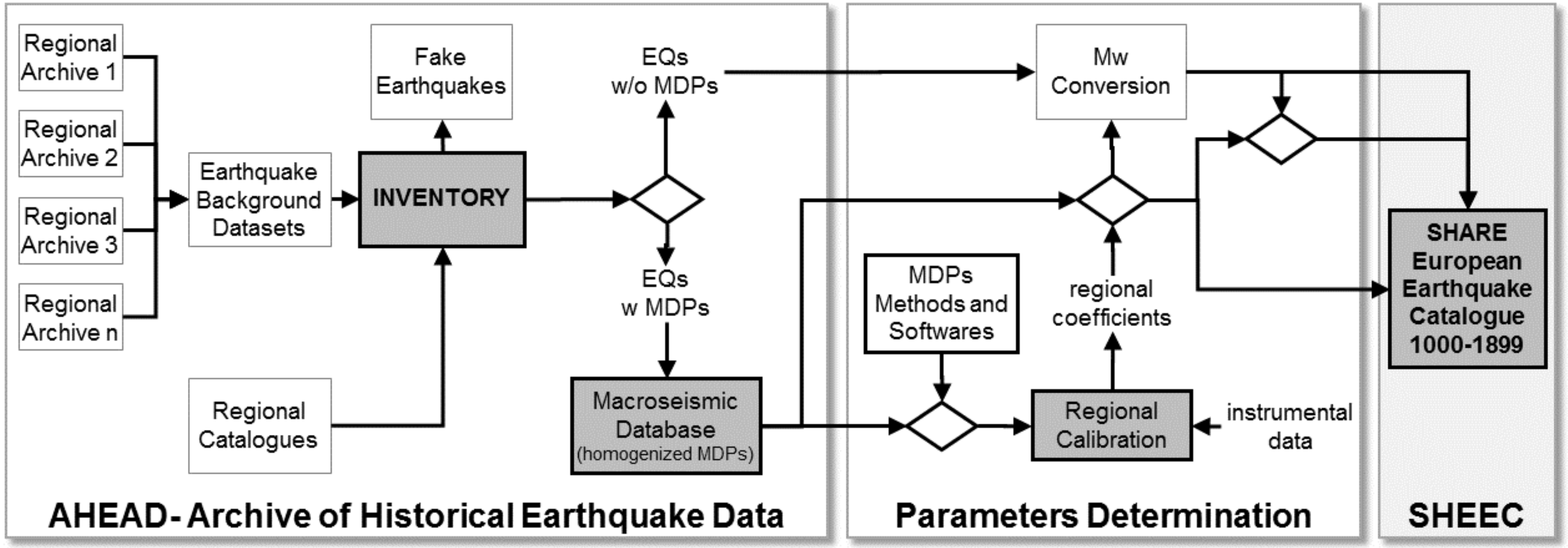
SHEEC 1000-1899 STRATEGY

1. Data from AHEAD, the European Archive of Historical Earthquake Data
- Regional archives of historical earthquake data (Iberia, France, Switzerland, Italy, Greece)
- Historical studies on individual earthquakes
- Regional catalogues

2. Parameters homogeneously determined from the inversion of intensity data, and the homogenization of regional catalogues



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SHEEC 1000-1899 INPUT DATA

AHEAD clusters together different datasets referred to the same earthquake

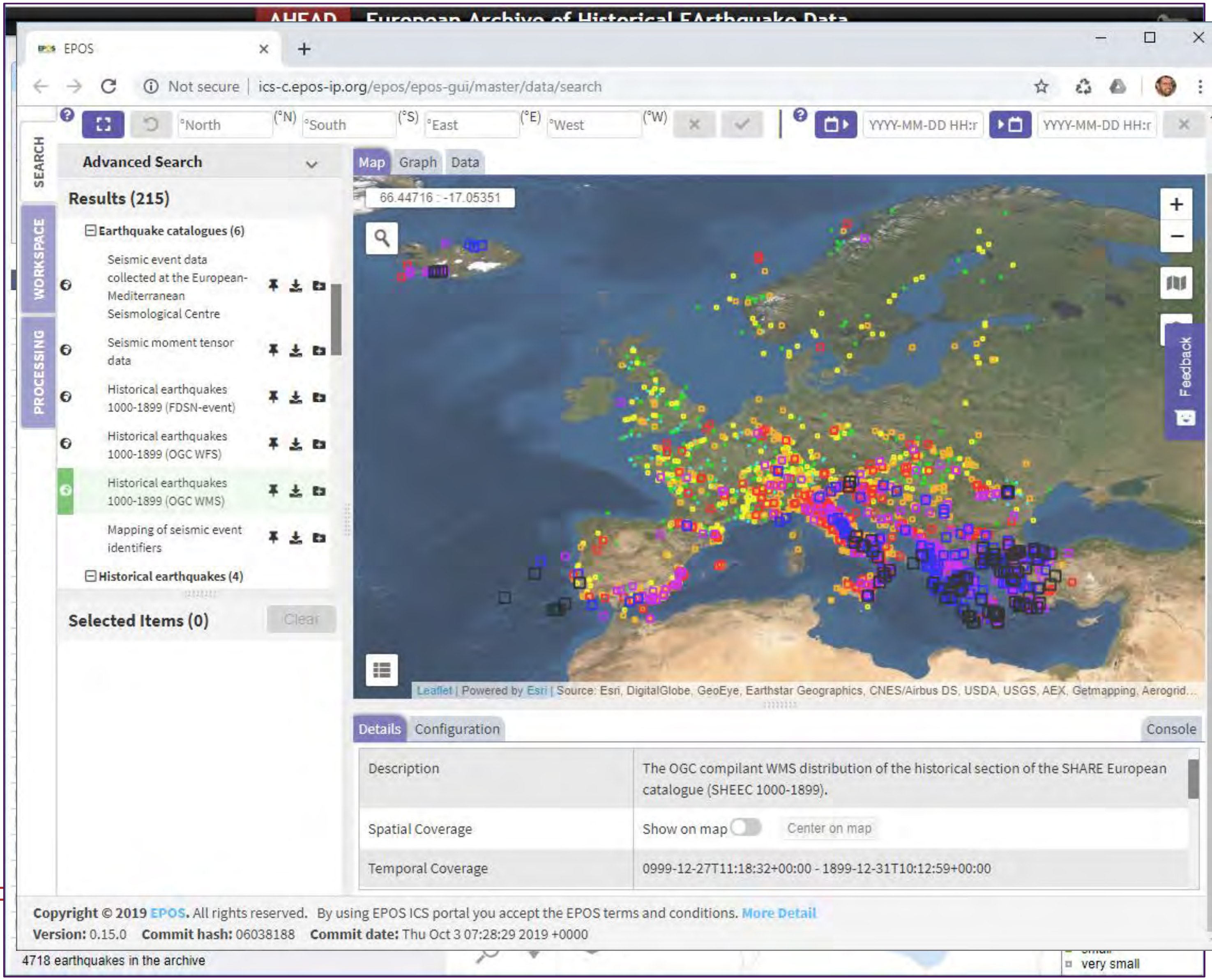
This allows to critically sort out
- Duplications
- Fake events
- Missing entries

129 studies with intensity data
41,425 MDPs
36 regional catalogues

Thematic Core Service for historical earthquake data

EPOS SEISMOLOGY

Locati et al., 2014
Rovida & Locati, 2015



SHEEC 1000-1899 Parameters #1

A. Two sets of parameters (lat, lon, Mw) for each earthquake:

(1) determined from macroseismic data (MDPs) with homogeneous and repeatable procedures

(2) derived from regional catalogues, coherently with (1)

B. Combination of the two sets:

- **Location**: selected from either dataset (1) or (2) according to a priority scheme
- **Magnitude** (according to the availability):
  a. weighted mean of datasets (1) and (2);
  b. from dataset (1)
  c. from dataset (2)

Stucchi et al., 2013

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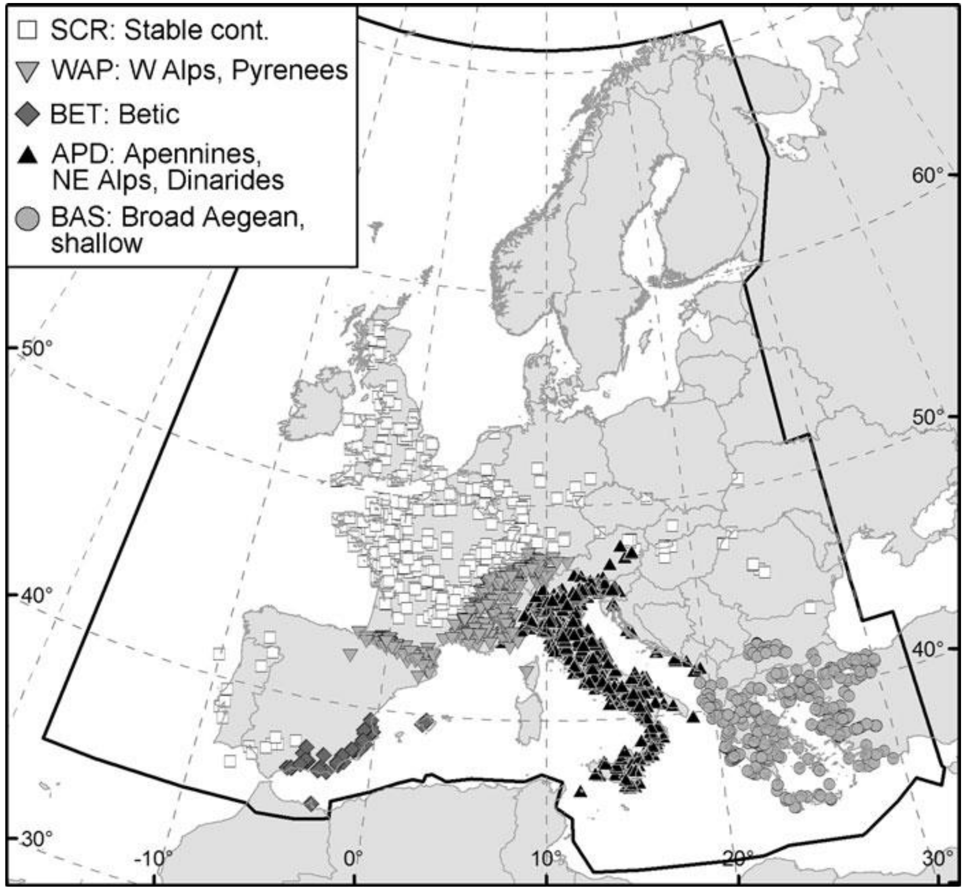
SHEEC 1000-1899 PARAMETERS #2

- Three methods for the parametrization of MDPs (Boxer, MEEP, Bakun & Wentworth)
- Five intensity attenuation regions
- Five Io-to-Mw empirical relationships, applied to regional catalogues
- 36 main regional catalogues
- Magnitude combination through a weighting scheme

Mw = 0.75 * Mw(MDPS) + 0.25 * Mw(CAT)

Stucchi et al., 2013
Gomez Capera et al., 2014

Five attenuation regions



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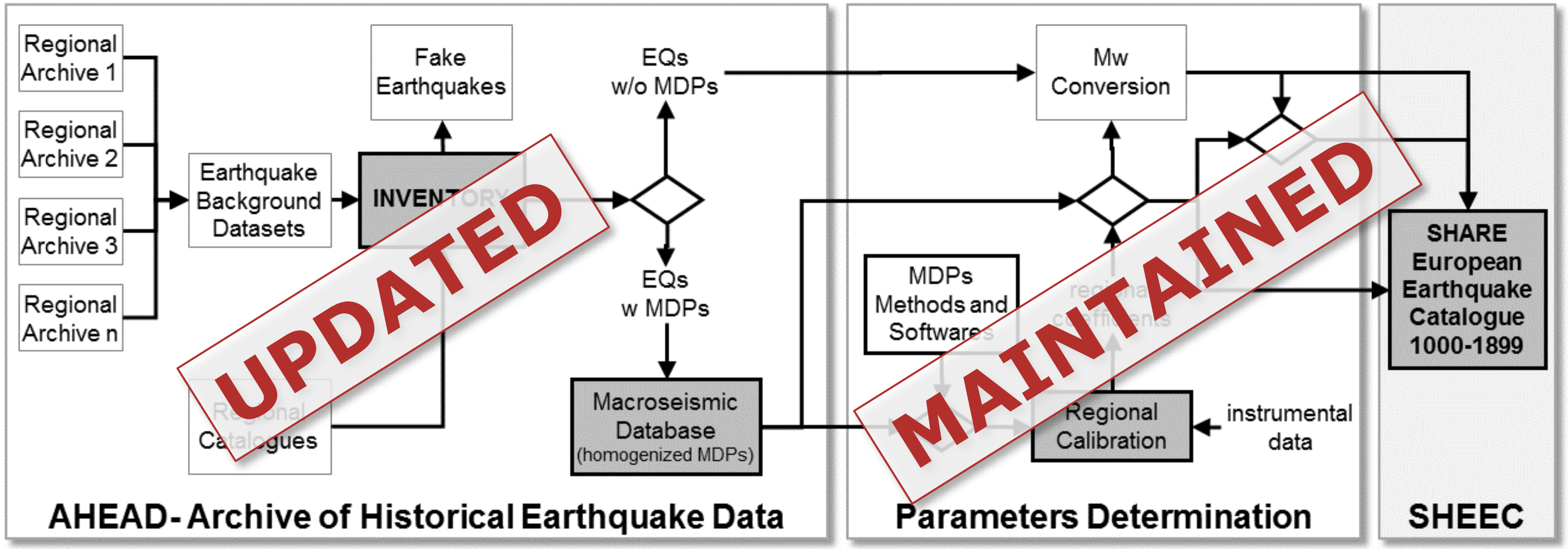
UPDATING SHEEC 1000-1899

1. Data from AHEAD, the European Archive of Historical Earthquake Data

- Updated with studies, catalogues, and intensity data published after 2012 *(not yet visible online)*

2. Parameters

- same strategy and methods as in SHEEC 1000-1899



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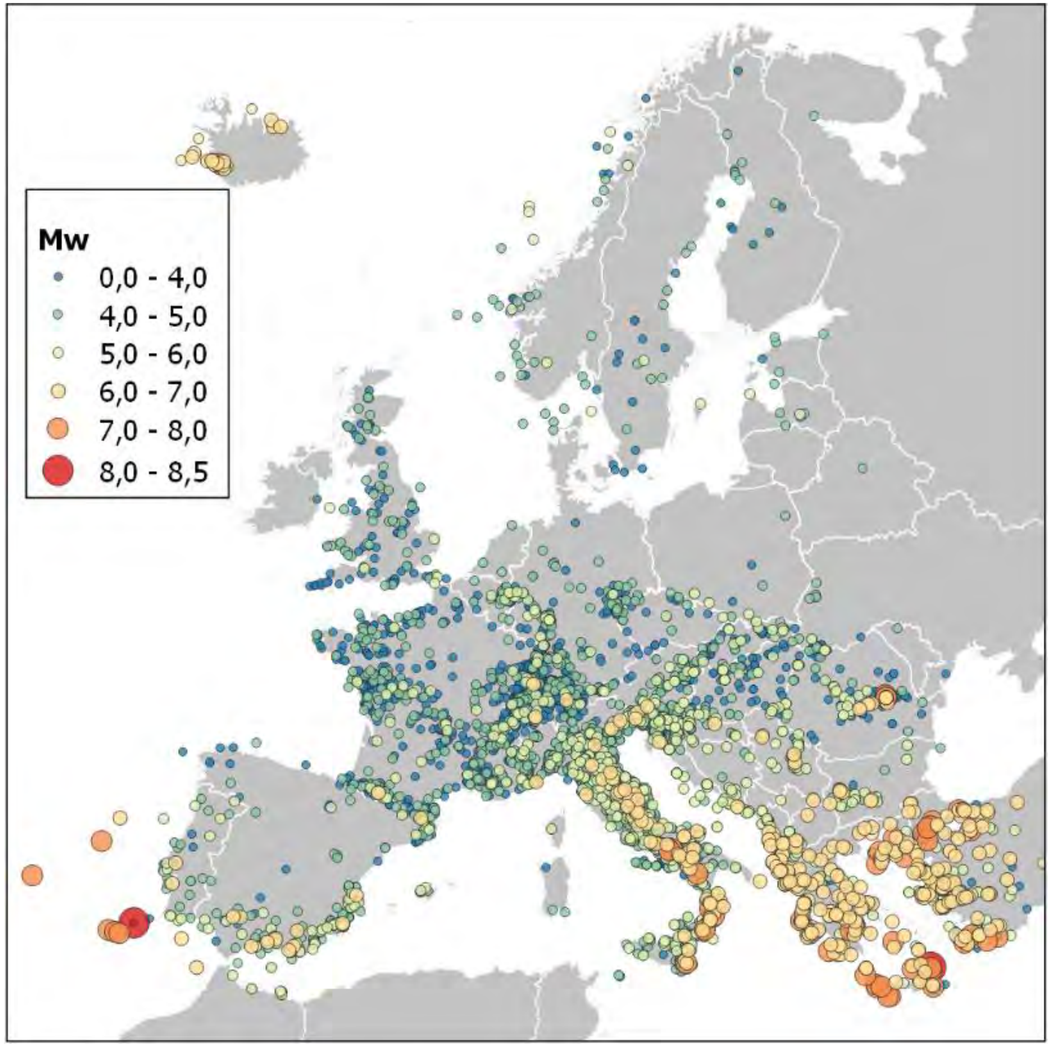
SERA CATALOGUE 1000-1899

Main features

- 5716 earthquakes
- Intensity ≥5 or Mw ≥4.0
- 161 sources for 49’852 intensity data
- 38 regional catalogues
- Same format as SHEEC 1000-1899

  (SHEEC v3.3 EventID added)



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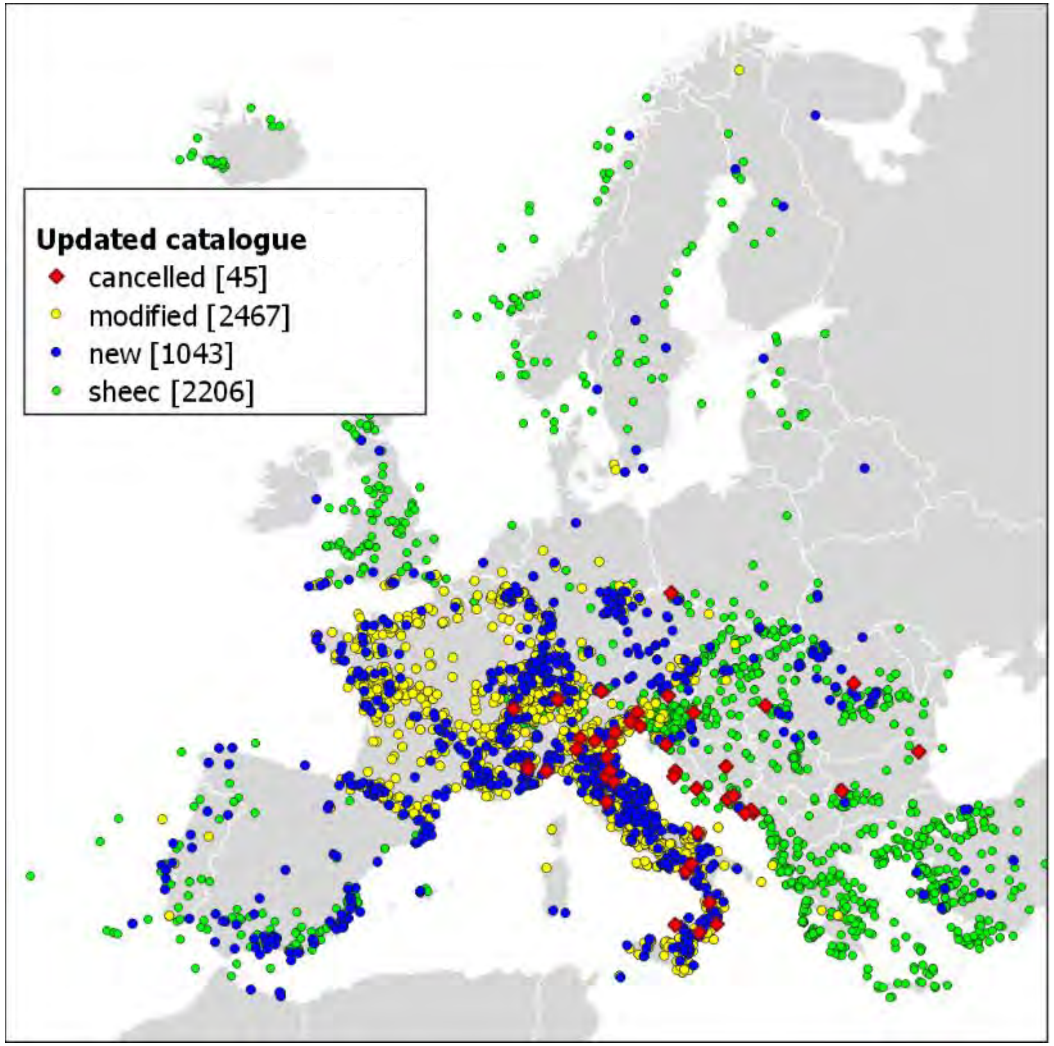
SERA CATALOGUE 1000-1899

- 1043 earthquakes added to SHEEC
- 45 removed
  42 fakes, 3 duplicated
- 47 new macroseismic studies
  ca. 7500 MDPs added
- 5 new/updated regional catalogues
  Including CPTI15, and FCAT-17



	Total	Same as SHEEC			NEW		
		MDPset	Cat	MDPset +Cat	MDPset	Cat	MDPset +Cat
SHEEC	**2206**	64	1563	579	-	-	-
MODIFIED	**2467**	12	11	-	620	511	1313
ADDED	**1043**	27	288	26	74	139	489
Total	**5716**	**103**	**1862**	**605**	**694**	**650**	**1802**

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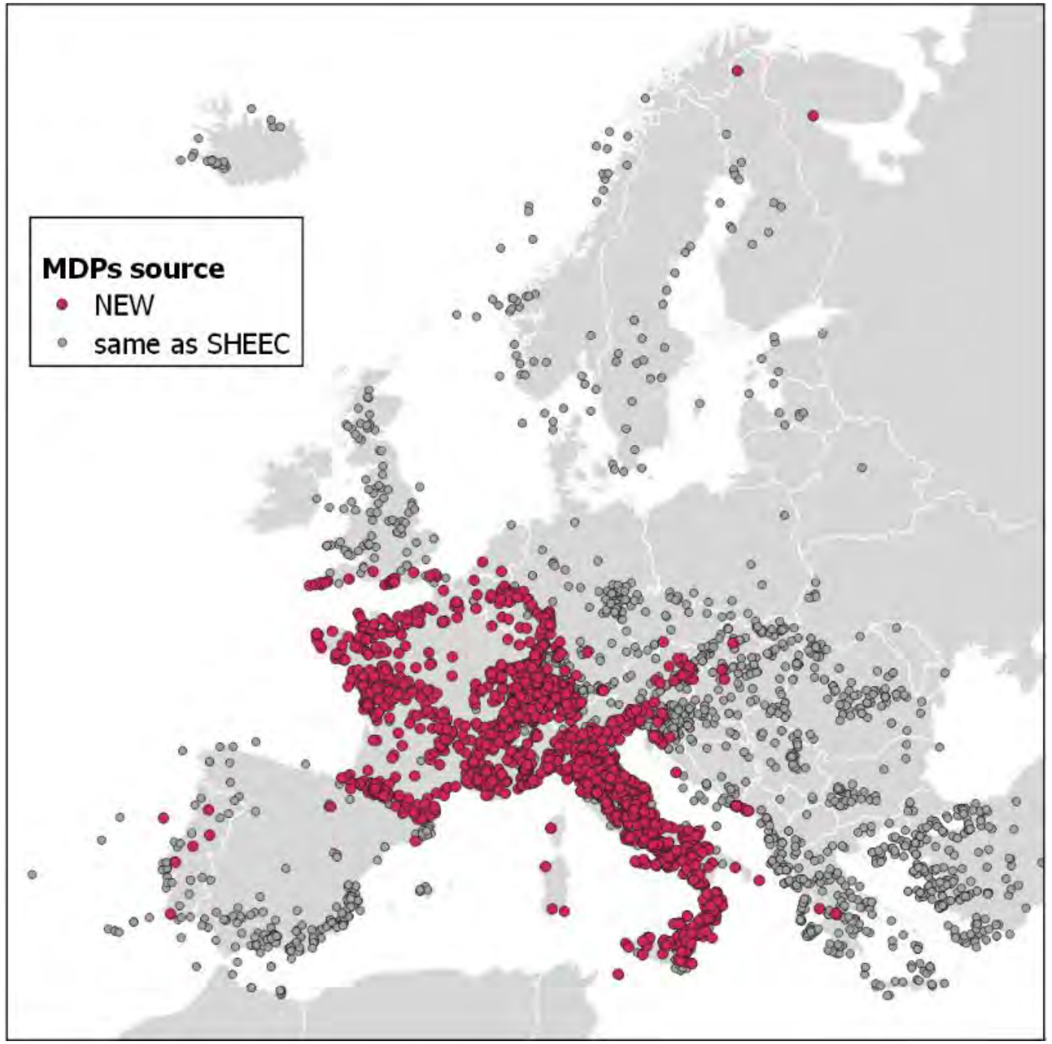
NEW MACROSEISMIC DATA

47 new macroseismic studies published after SHEEC (2012-2018): new data on ~2500 earthquakes

REFERENCE	AREA	EQS.	MDPS
ALBINI & ROVIDA, 2018	Croatia, Montenegro	15	34
ALBINI ET AL., 2017	Greece	5	144
ALBINI, 2015	Croatia, Montenegro	1	37
ALEXANDRE & ALEXANDRE, 2018	Eastern Europe	1	23
BAPTISTA ET AL., 2014	Portugal	1	32
CORREIA & RIBEIRO, 2007	Portugal	2	29
HAMMERL & LENHARDT, 2013	Lower Austria	33	716
HAMMERL, 2015	Austria (Tyrol)	3	43
HERAK ET AL., 2017	Croatia	11	33
HERAK ET AL., 2018	Croatia	5	121
KNUTS ET AL., 2015	Luxembourg	1	15
KNUTS ET AL., 2016	Belgium, Germany	1	75
RIBEIRO ET AL., 2015	Portugal	1	88
SCHWARZ-ZANETTI ET AL., 2017	Switzerland	3	55
TATEVOSSIAN ET AL., 2013	N Russia, Finland	2	5
SISFRANCE 2016	*France*	*(805)*	*(8832)*
ECOS-09*	Switzerland	499	2627
ITALIAN STUDIES (CPTI15)	Italy	1094	19097
ITALIAN STUDIES (NEW)	Italy	30	363
Total		2513	32369



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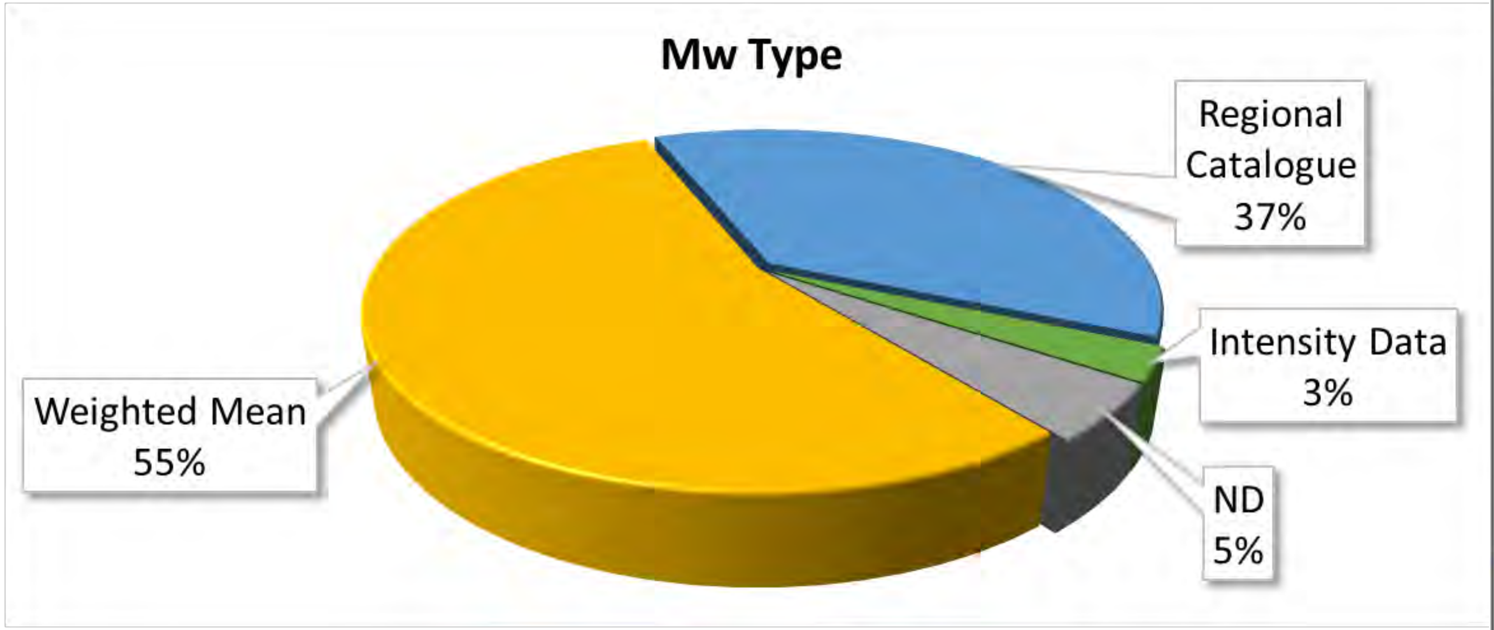
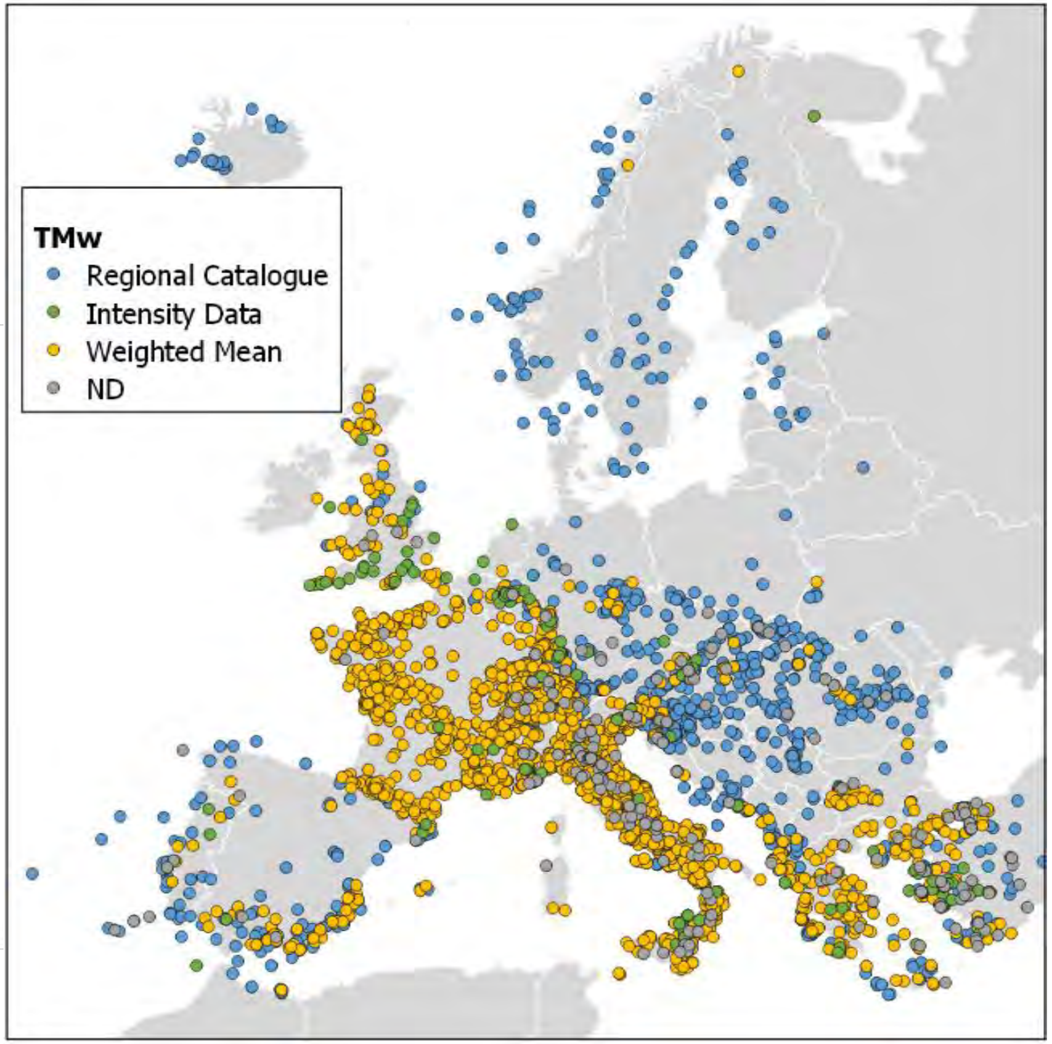
UPDATED CATALOGUE 1000-1899

Magnitude determination

Increased contribution of intensity data from 47% to 58%





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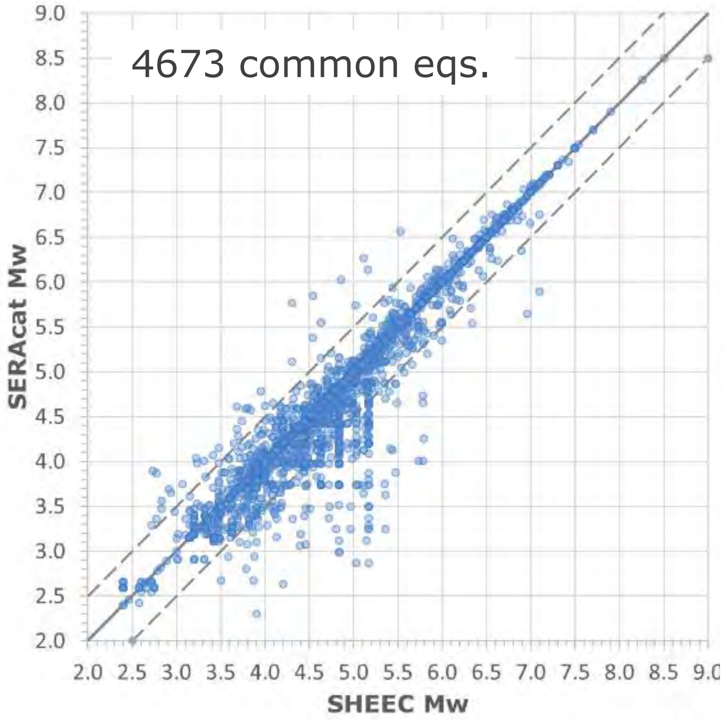
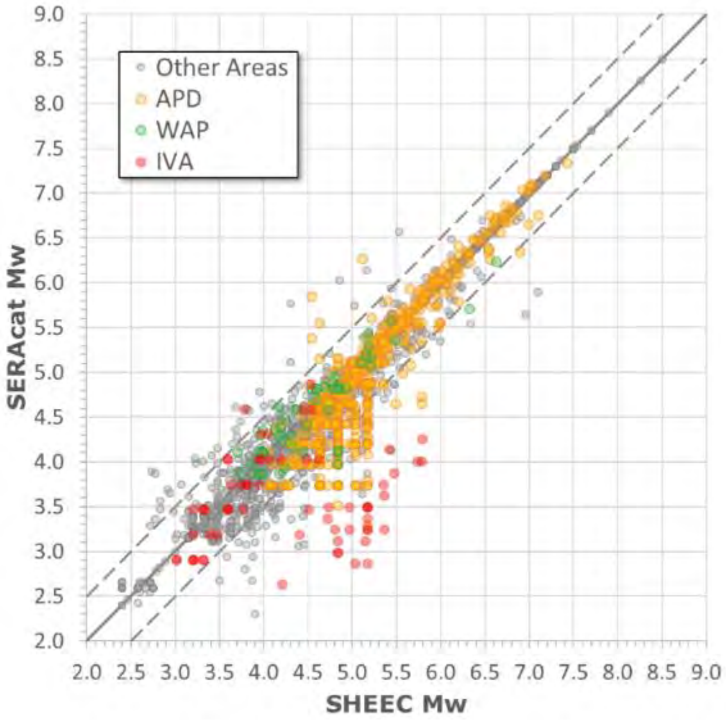
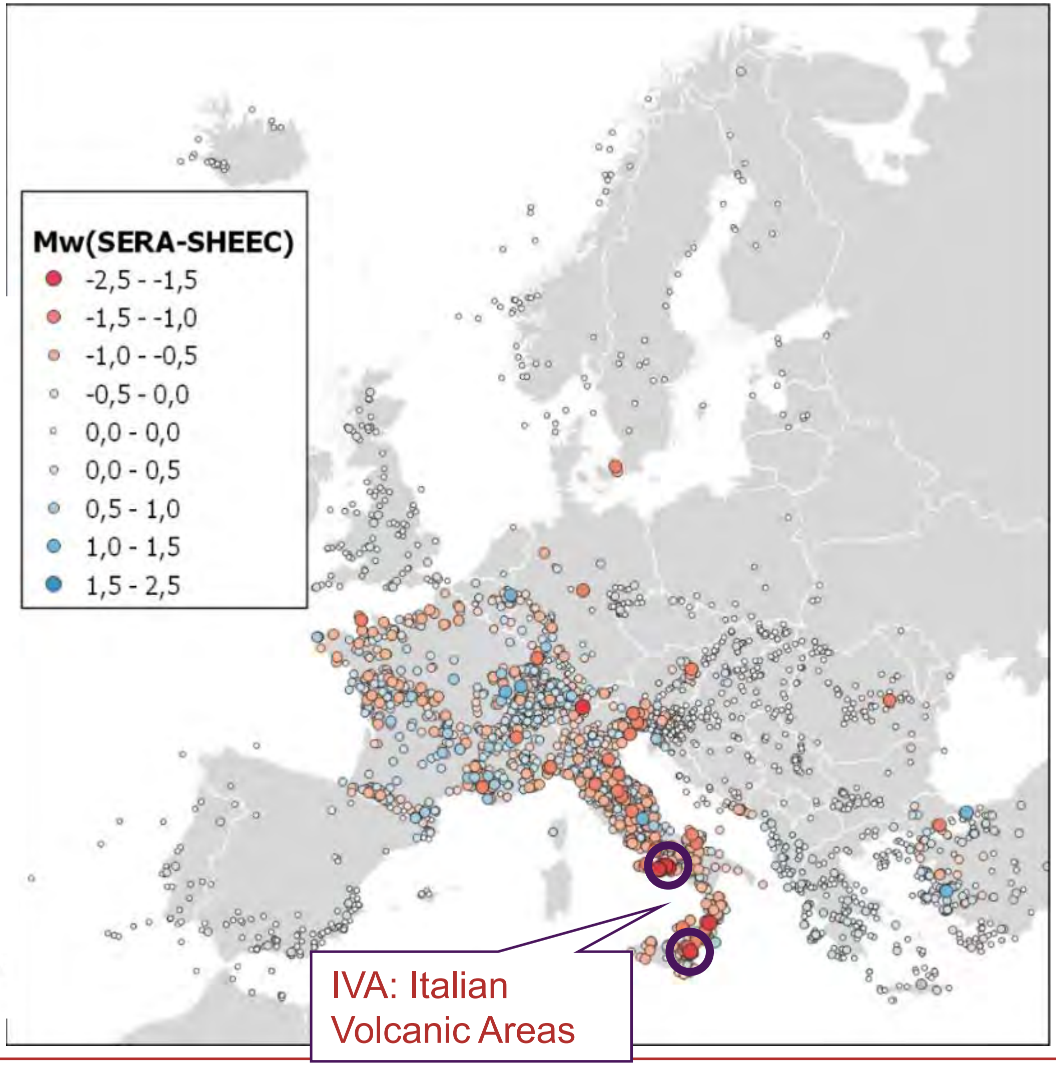
MAGNITUDES' VARIATIONS

- Due to the updated datasets and catalogues
- Italy (esp. volcanic areas), France, Switzerland, Austria
- Few minor corrections (Eastern Europe, Turkey)







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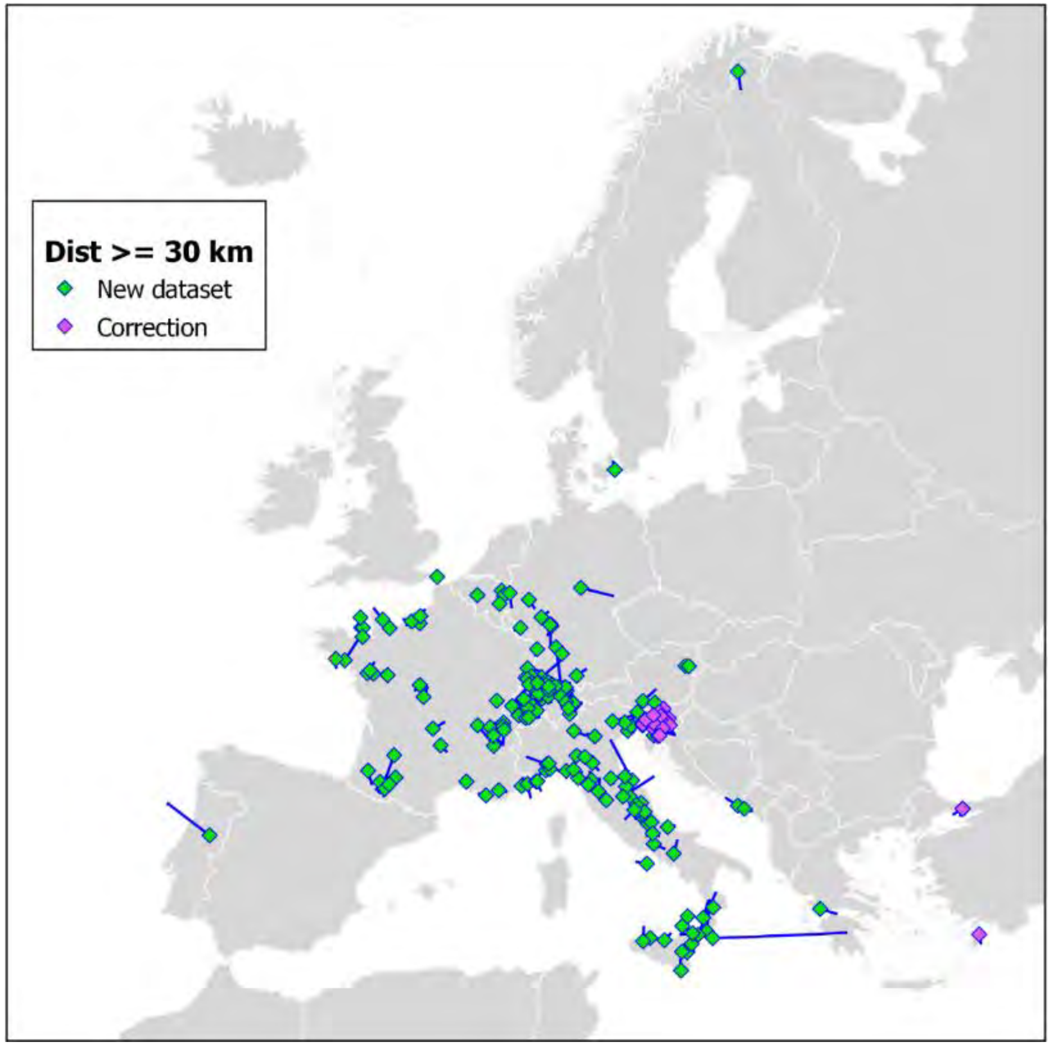
EPICENTRES' VARIATIONS

- 1748 earthquakes with modified location
- 228 to a distance ≥ 30 km

  187 with a new dataset

  41 corrections



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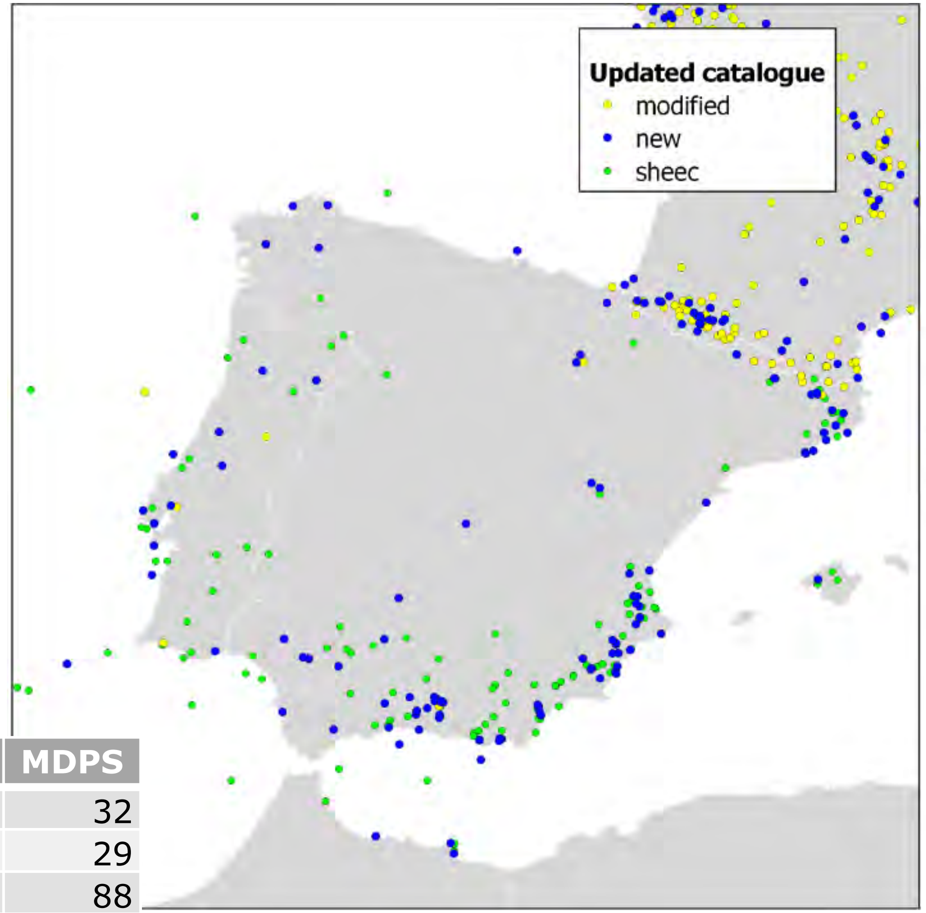
PORTUGAL & SPAIN

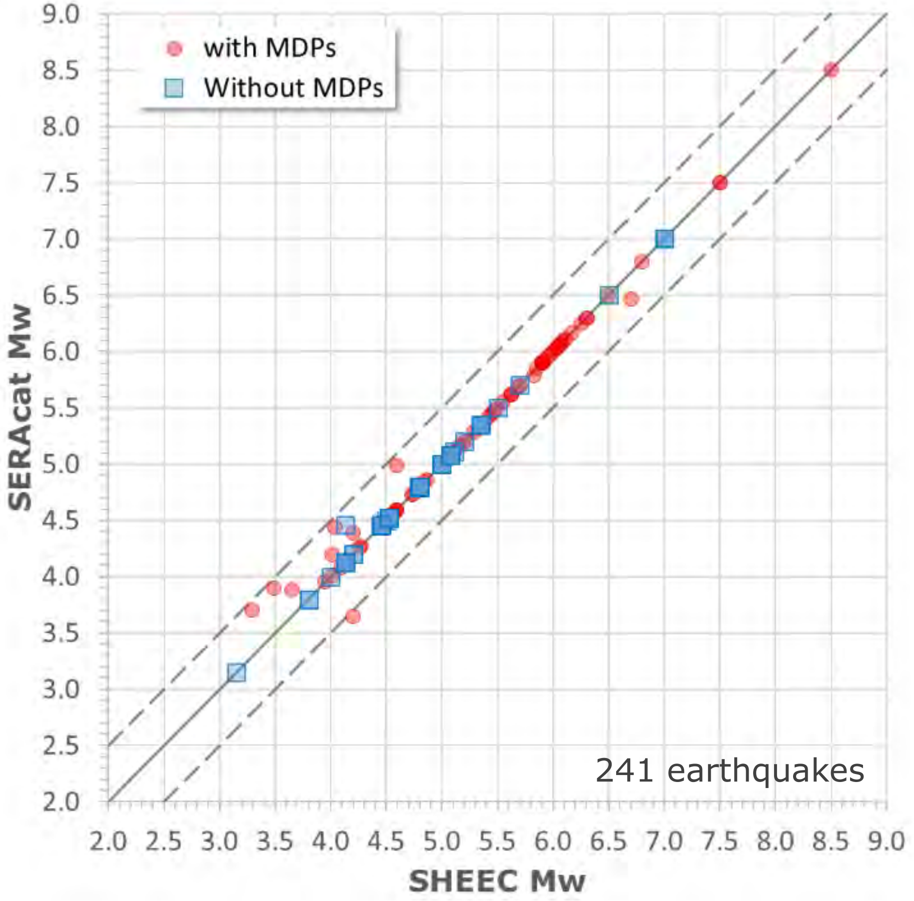
MDPs: IGN and ICGC databases + varied studies
Regional Catalogue: Martinez Solares & Mezcua Rodriguez 2002; LNEC, Martins & Mendes Victor 2001, Vilanova & Fonseca 2007

Several new entries due to lower threshold

Some entries modified after SisFrance 2016 and FCAT-17

3 new studies (Prtugal)





REFERENCE	EQS.	MDPS
BAPTISTA ET AL., 2014	1	32
CORREIA & RIBEIRO, 2007	2	29
RIBEIRO ET AL., 2015	1	88

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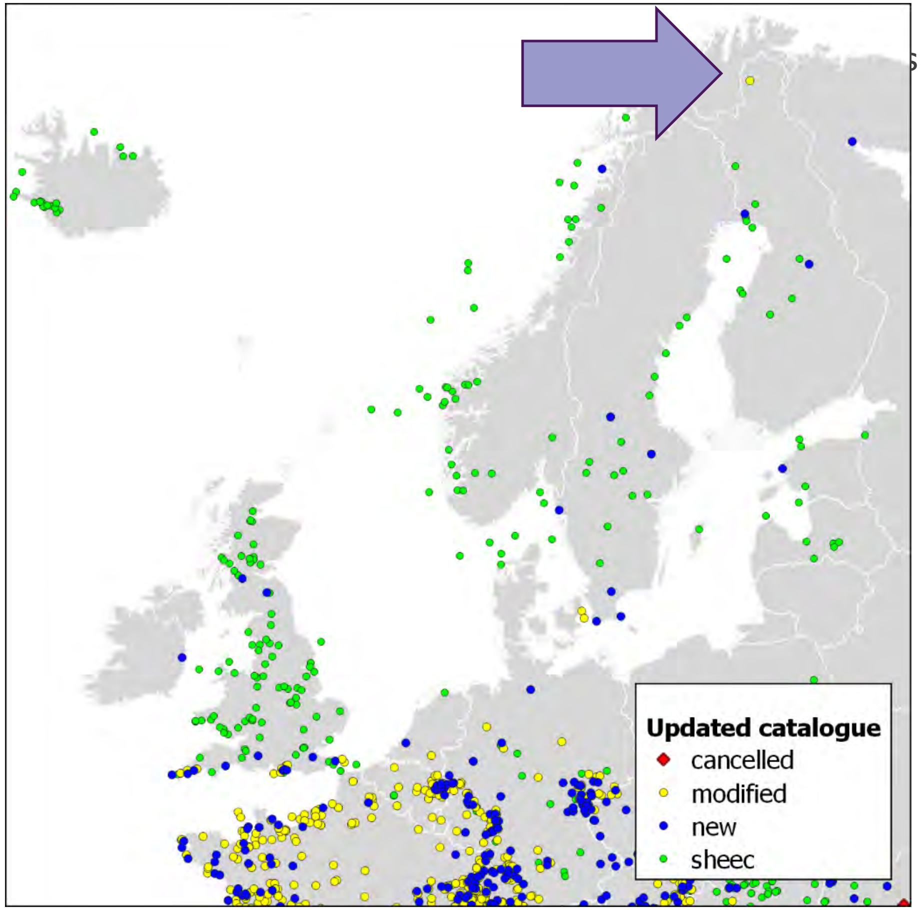
ICELAND, UK & SCANDINAVIA

- **Scandinavia**
  MDPs: none
  Regional Catalogue: IMO, Ambraseys & Sigbjiorsson
- **UK**
  MDPs: UK Historical Earthquake Database
  Regional Catalogue: Musson & Sargeant 2007
- **Scandnavia**
  MDPs: almost none
  Regional Catalogue: FENNOSCANDIAN CAT

Some new entries due to lower threshold

Some entries modified after SisFrance 2016 and FCAT-17 in Southern UK

No significant changes with respect to SHEEC



REFERENCE	EQS.	MDPS
TATEVOSSIAN ET AL., 2013	2	5

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GERMANY, BELGIUM & LUXEMBOURG

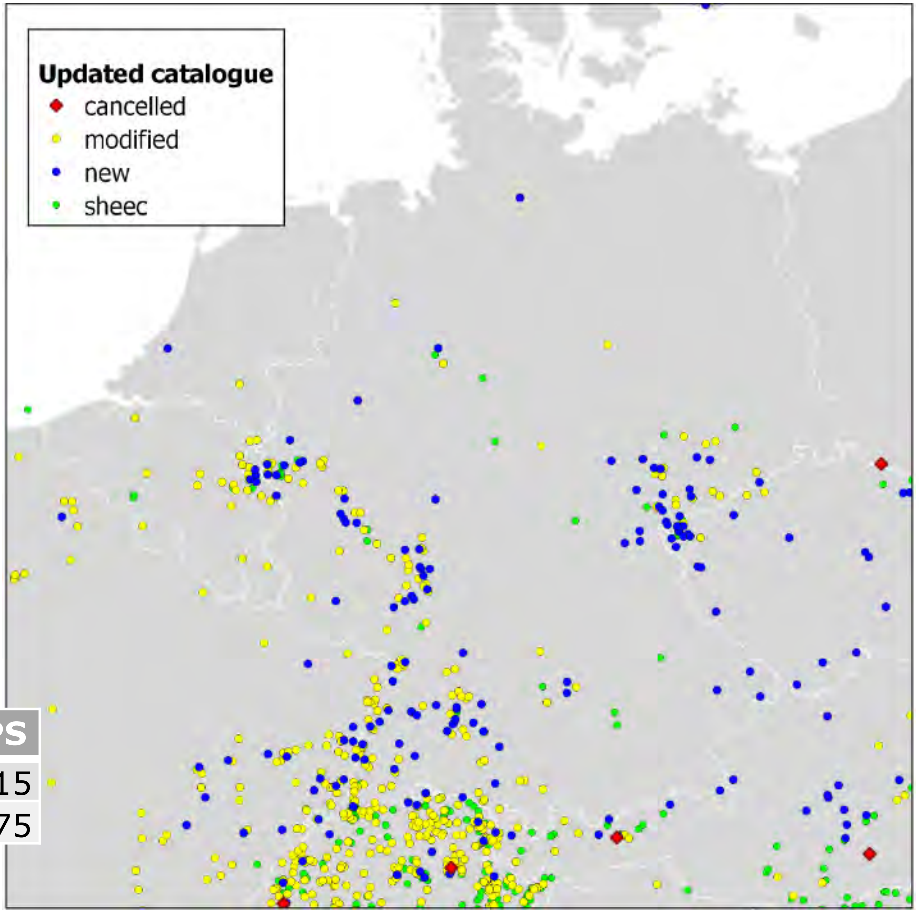
MDPs: few studies + SisFrance 2016, ECOS-09
Regional Catalogues: ORB, Leydecker 2011, EMEC, Grunthal 1988

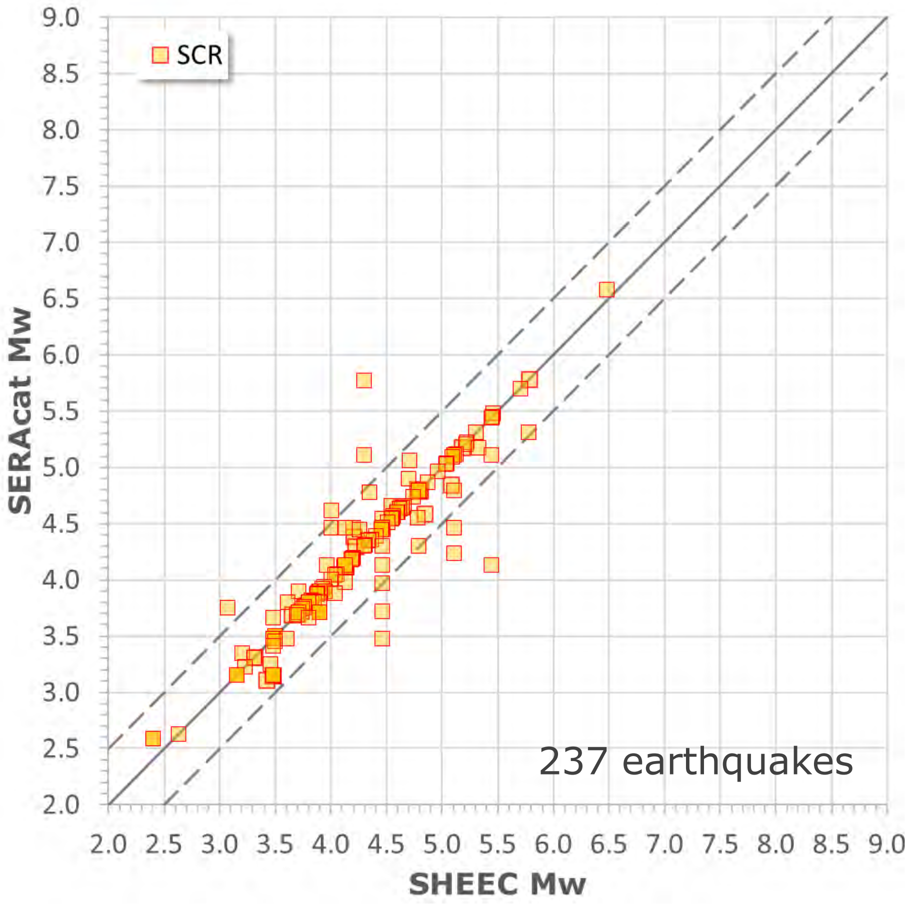
Some new entries due to lower threshold

Variations in magnitude due to some adjustements in the epicentral intensity

Some changes due to SisFrance2016 and FCAT-17

REFERENCE	EQS.	MDPS
KNUTS ET AL., 2015	1	15
KNUTS ET AL., 2016	1	75





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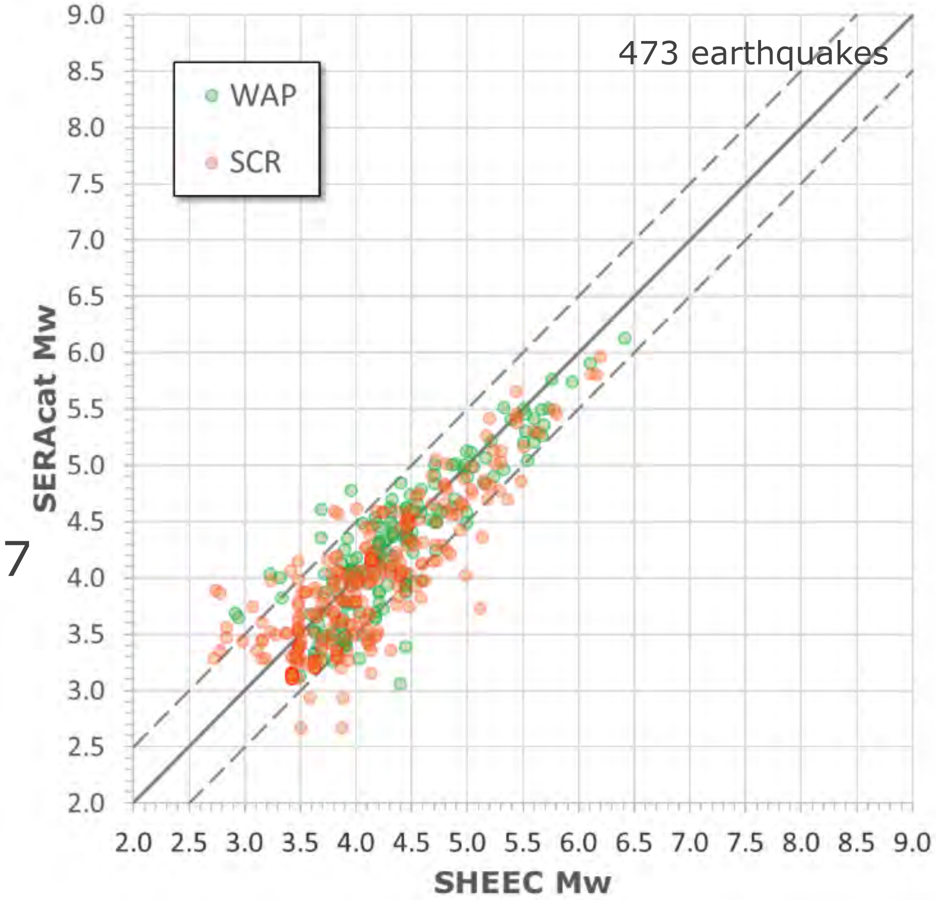
FRANCE

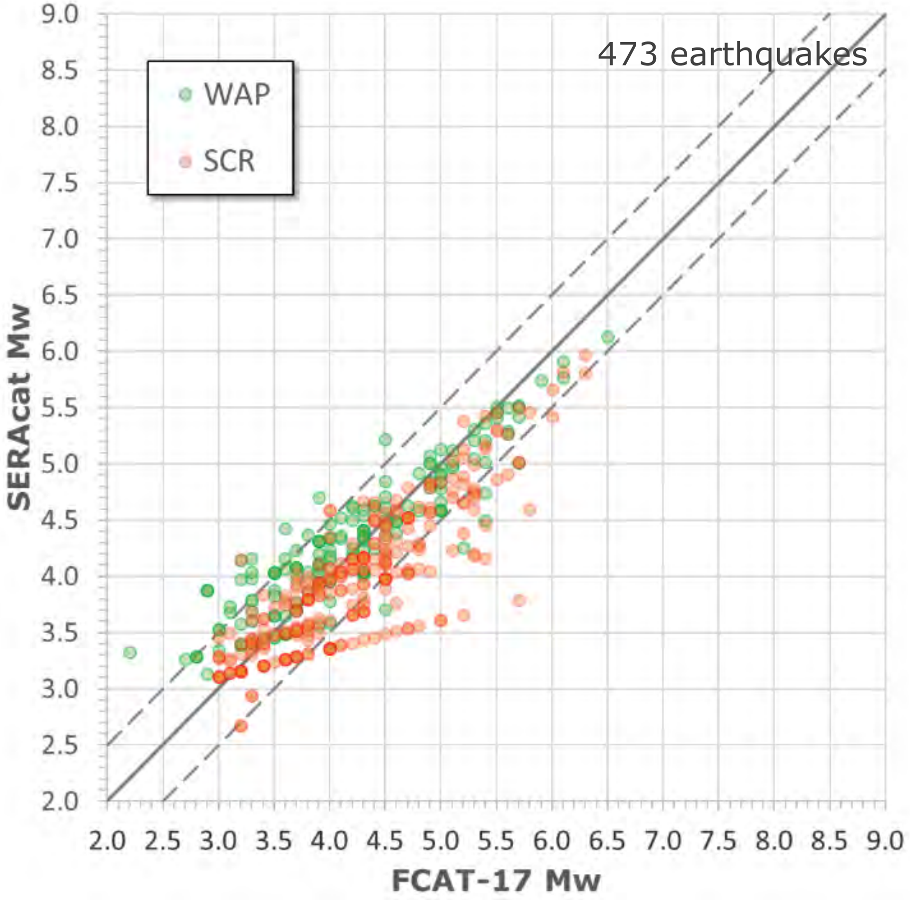
MDPs: SisFrance 2016
Regional Catalogue: FCAT-17

108 earthquakes updated in SisFrance 2016 (no significant changes)

659 earthquakes with FCAT-17 as Regional Catalogue, 473 also in SHEEC

Mw in SERA and FCAT-17 are consistent





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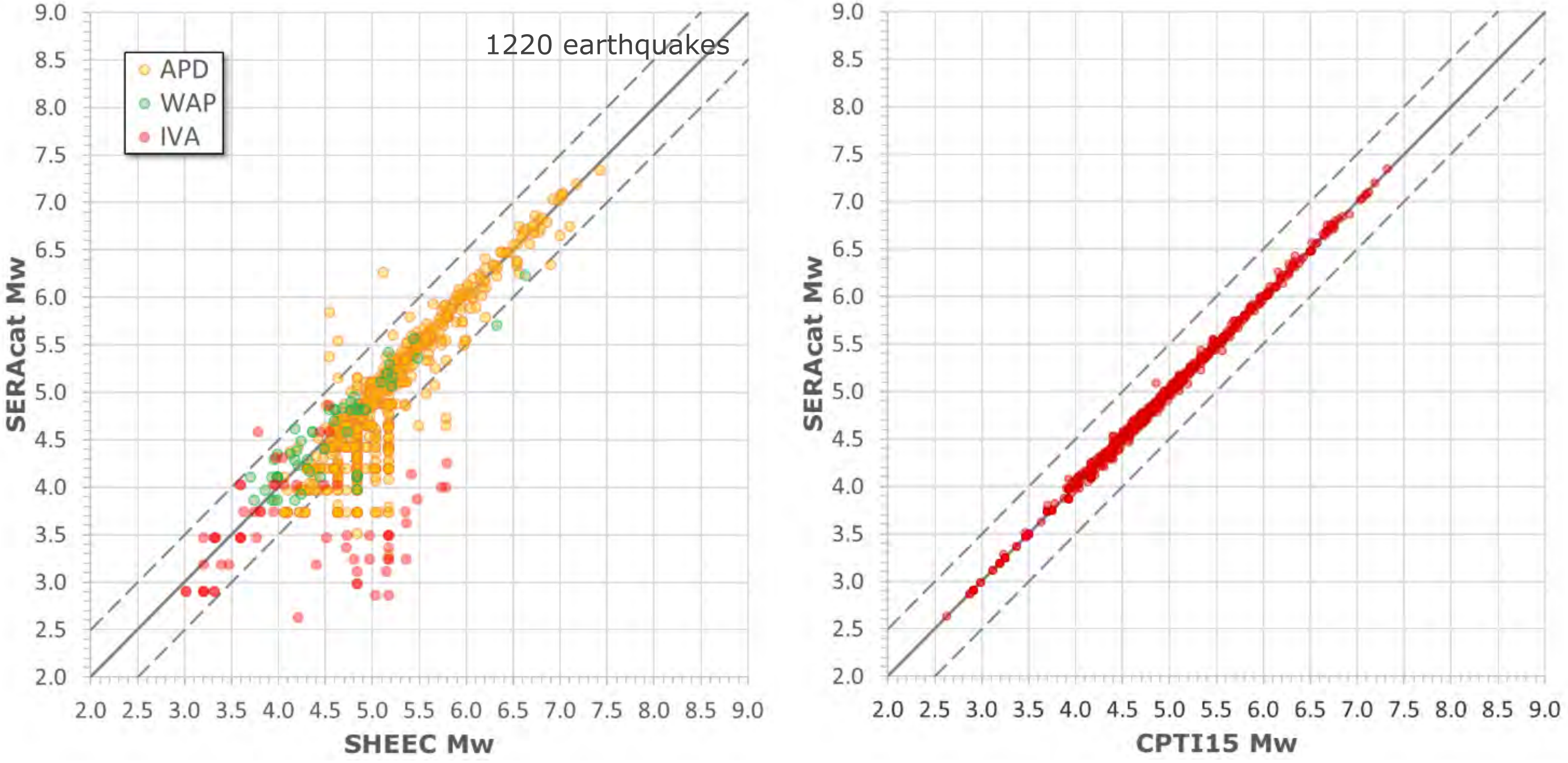
ITALY

MDPs: DBMI15 (185 data sources)
Regional Catalogue: CPTI15

67% of the supporting datasets are new and provide MDPs

Variations in Mw with respect to SHEEC, especially at low values

Mw assessment consistent with CPTI15



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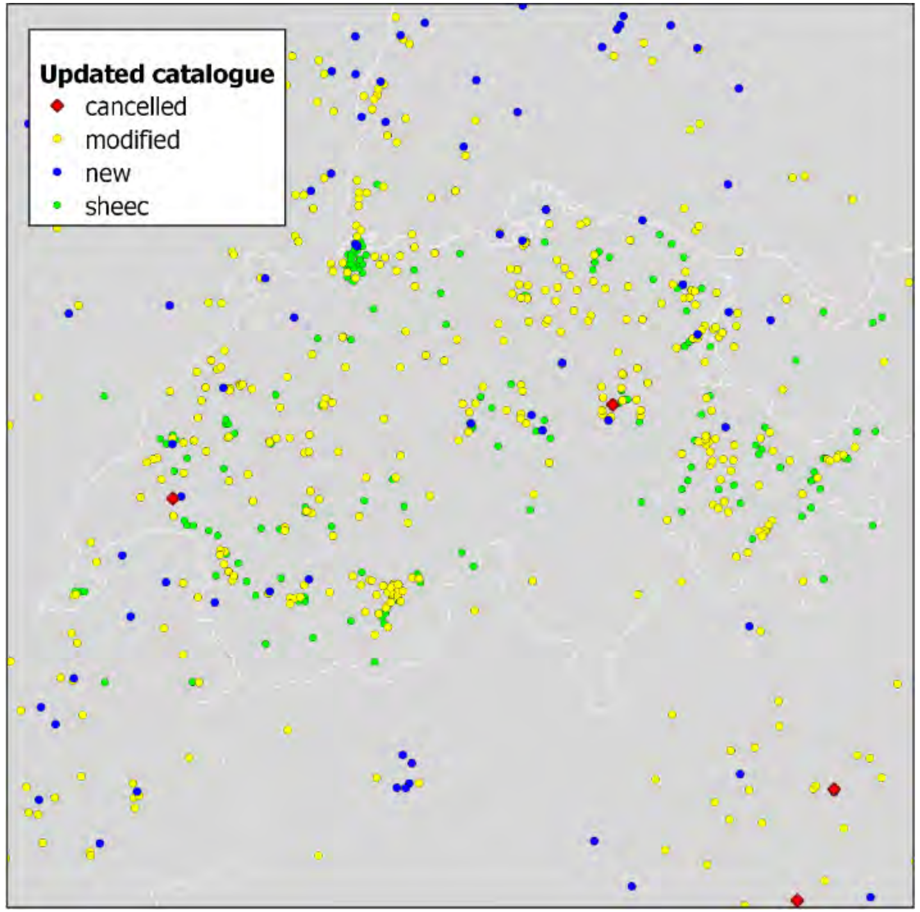
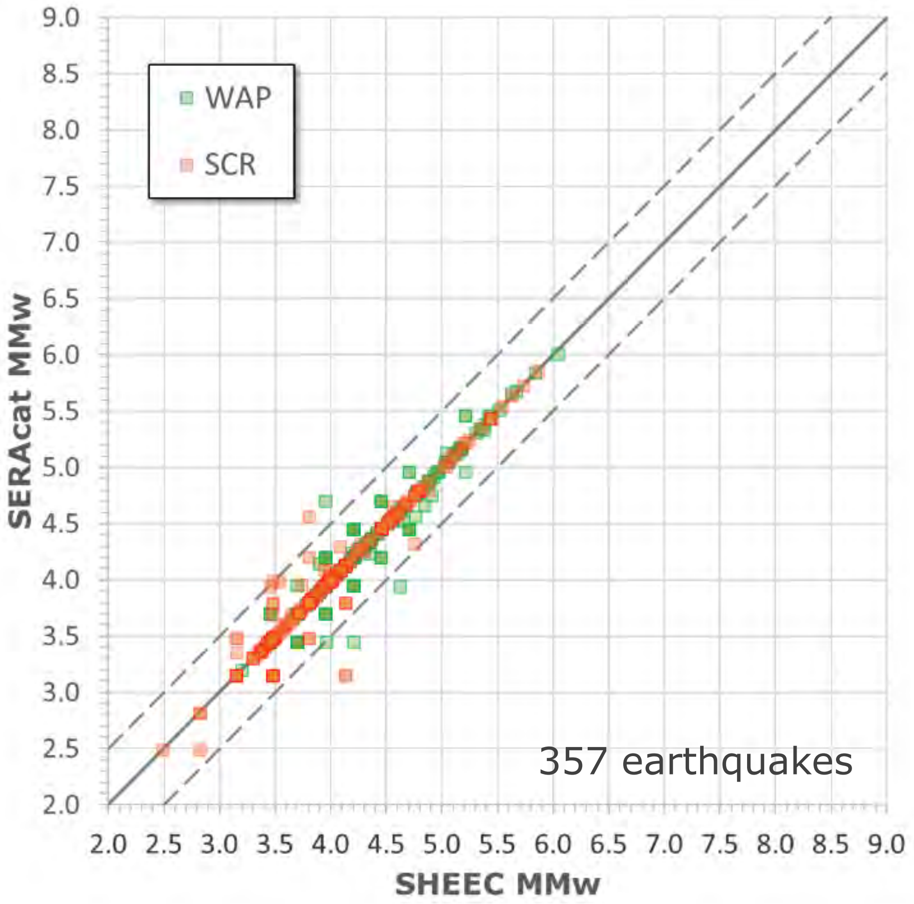
SWITZERLAND

MDPs: ECOS-09 + some study
Regional Catalogue: ECOS-09

In SHEEC, ECOS-09 was considered only as a regional catalogue

Now also parameters from MDPs in ECOS-09 are considered





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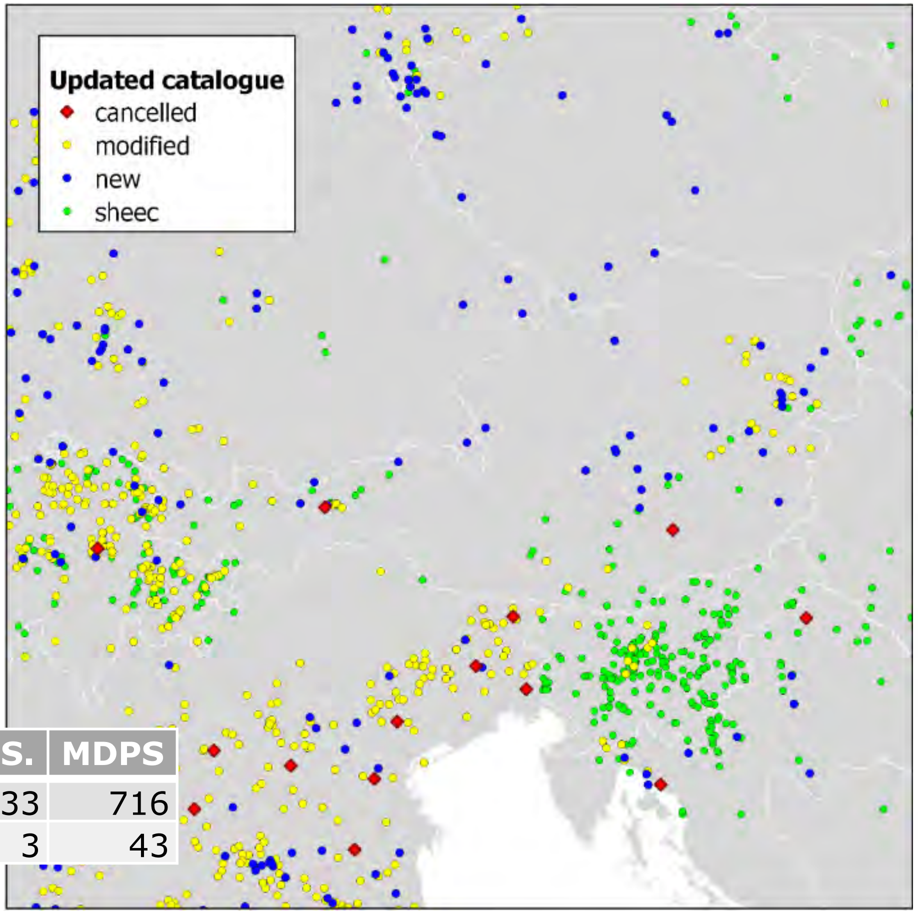
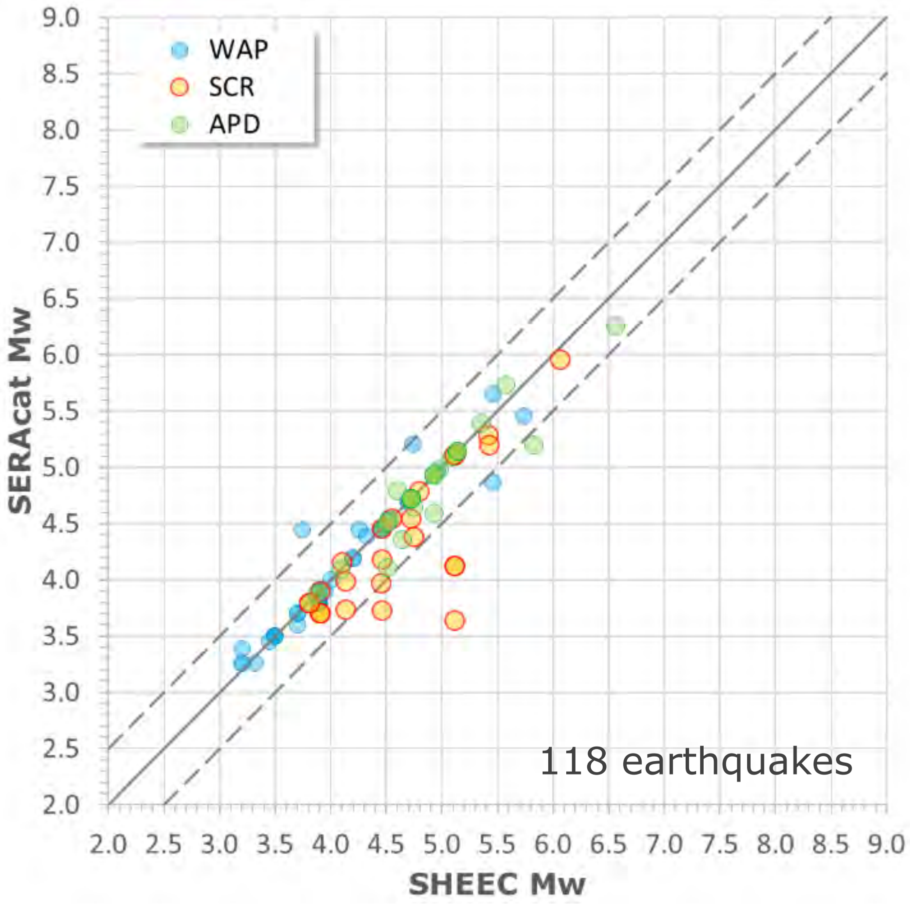
AUSTRIA

MDPs: ZAMG + some studies
Regional Catalogue: ZAMG

New and modified earthquakes thanks to new historical research





REFERENCE	EQS.	MDPS
HAMMERL & LENHARDT, 2013	33	716
HAMMERL, 2015	3	43

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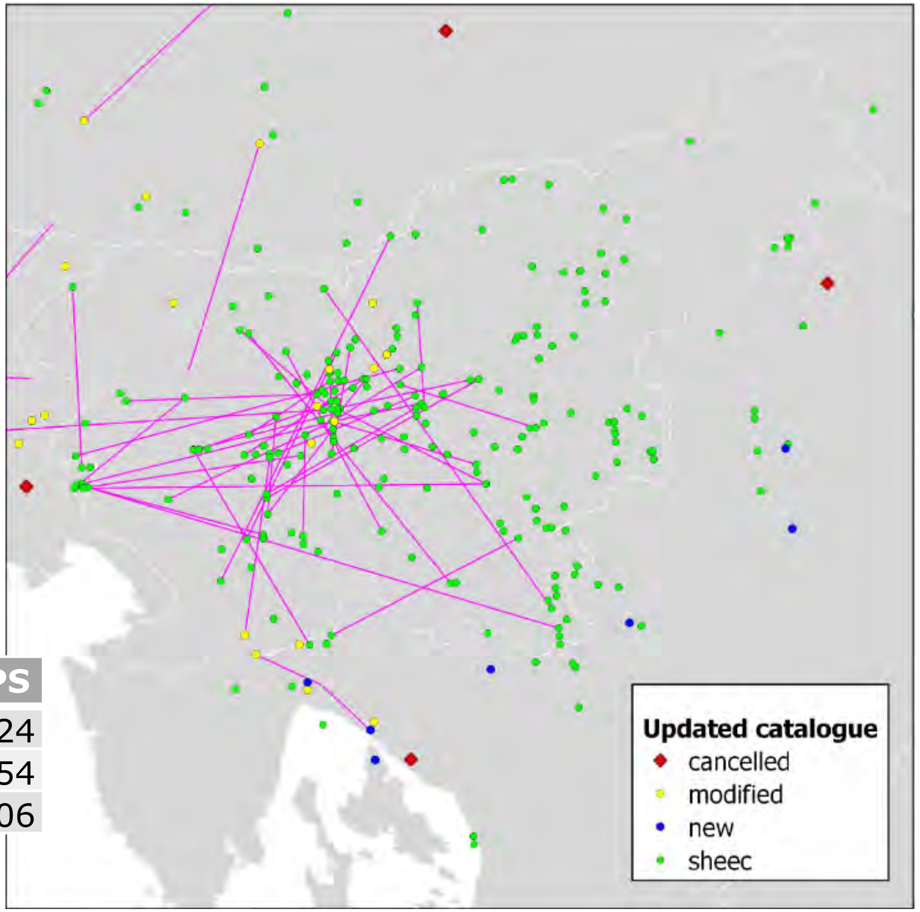
SLOVENIA

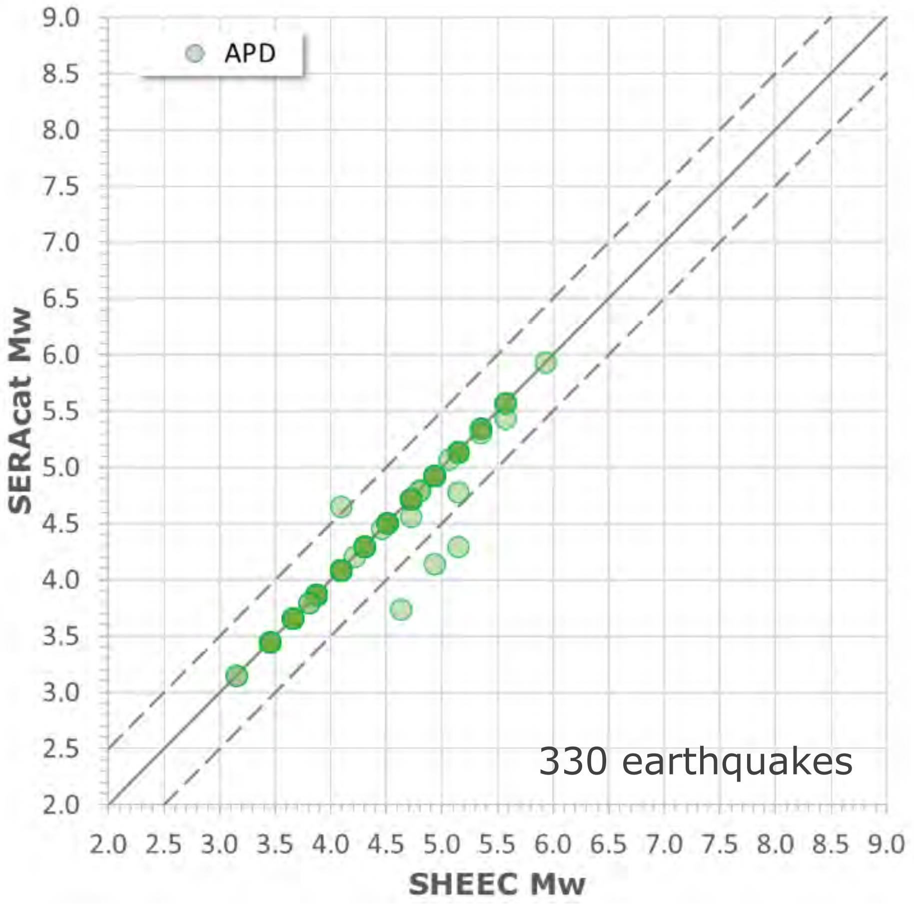
MDPs: varied studies
Regional Catalogue: ARSO

Variations in input data thanks to new macroseismic studies

Corrections of ARSO locations wrongly associated to earthquakes in SHEEC

REFERENCE	EQS.	MDPS
CAMASSI ET AL., 2011	3	124
CECIC, 2015	2	54
HERAK ET AL., 2018	3	106





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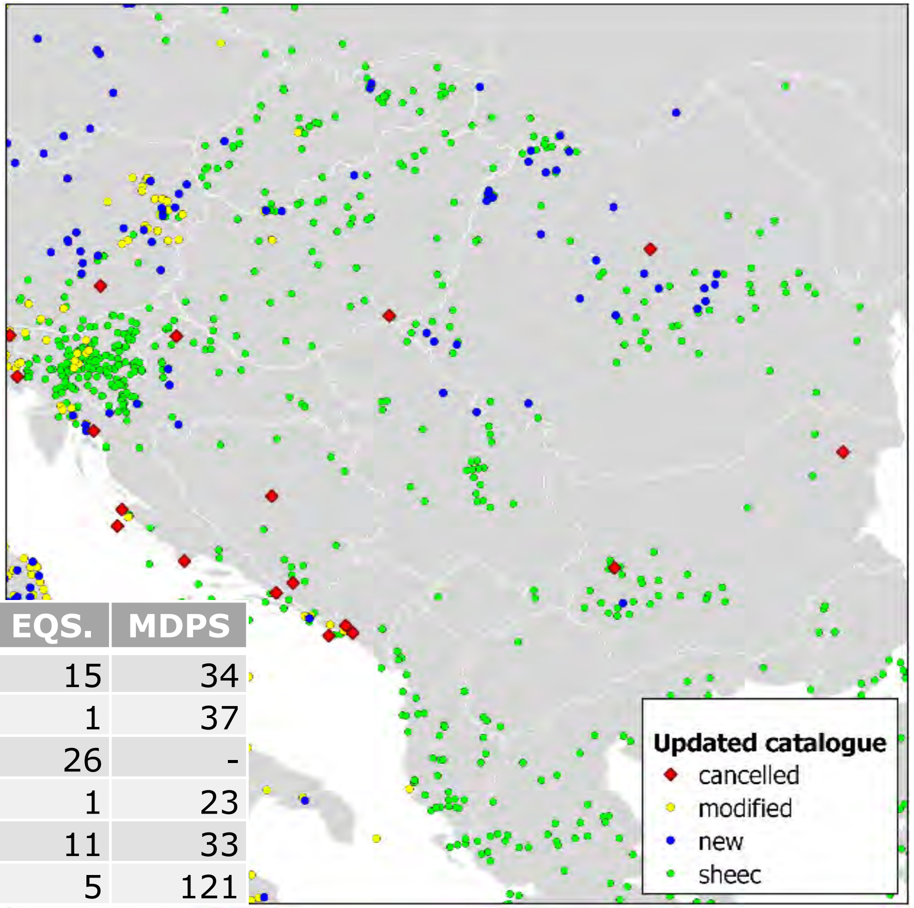
BALKANS

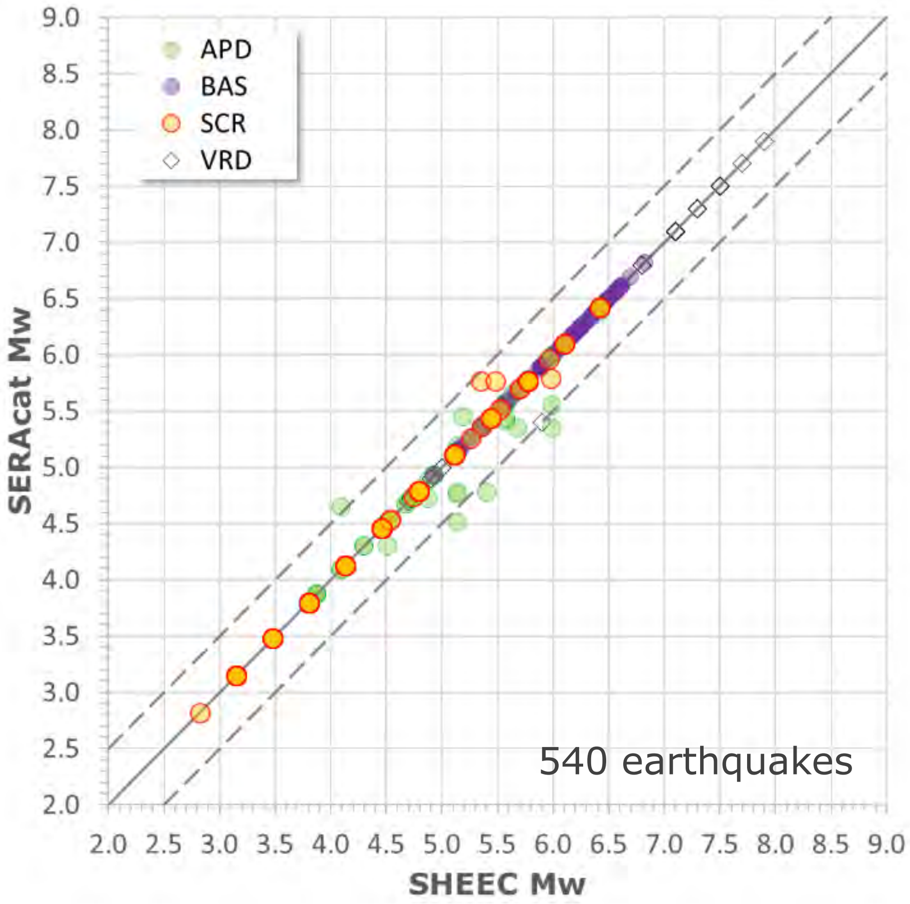
MDPs: few and «sparse» stuides
Regional Catalogues: many, including Herak, Sulstarova, Zsiros, ROMPLUS, Glavcheva, Shebalin…

Recent studies:

- MDPs for N Croatia (*Herak et al., 2017; 2018*), and S Croatia/Montenegro (*Albini, 2015; Albini & Rovida, 2018*)
- cancellations in E Europe (*Alexandre & Alexandre, 2012*)



REFERENCE	EQS.	MDPS
ALBINI & ROVIDA, 2018	15	34
ALBINI, 2015	1	37
ALEXANDRE & ALEXANDRE, 2012	26	-
ALEXANDRE & ALEXANDRE, 2018	1	23
HERAK ET AL., 2017	11	33
HERAK ET AL., 2018	5	121



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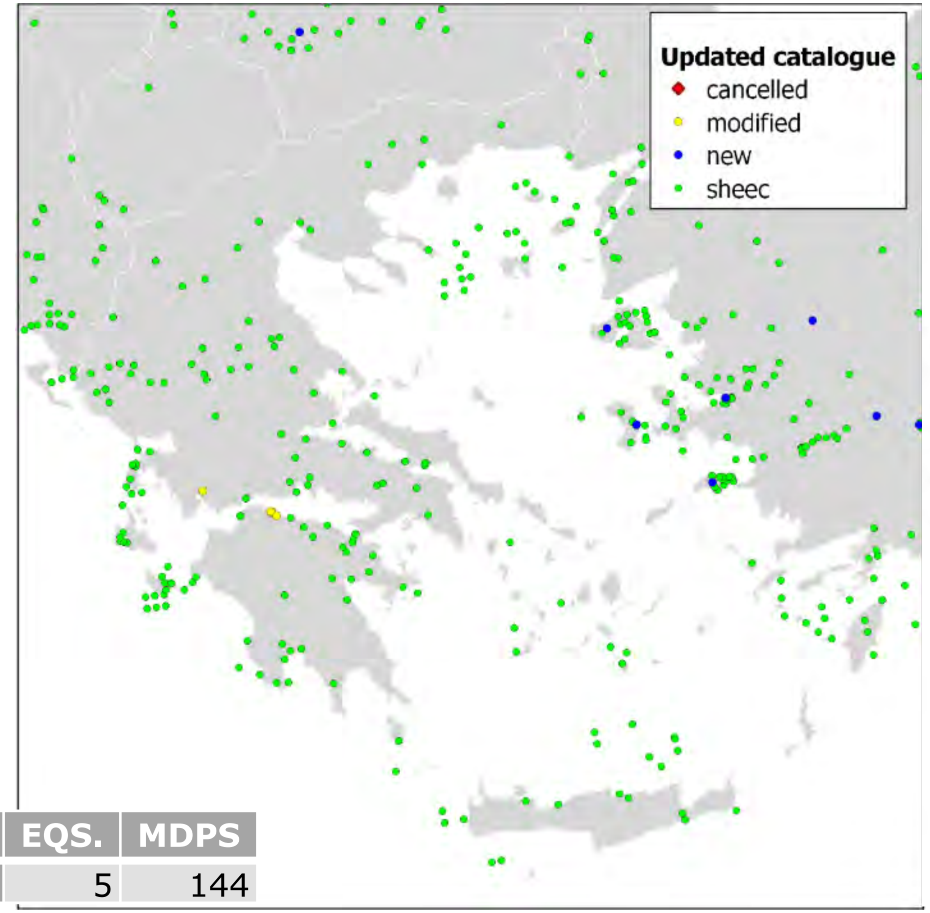
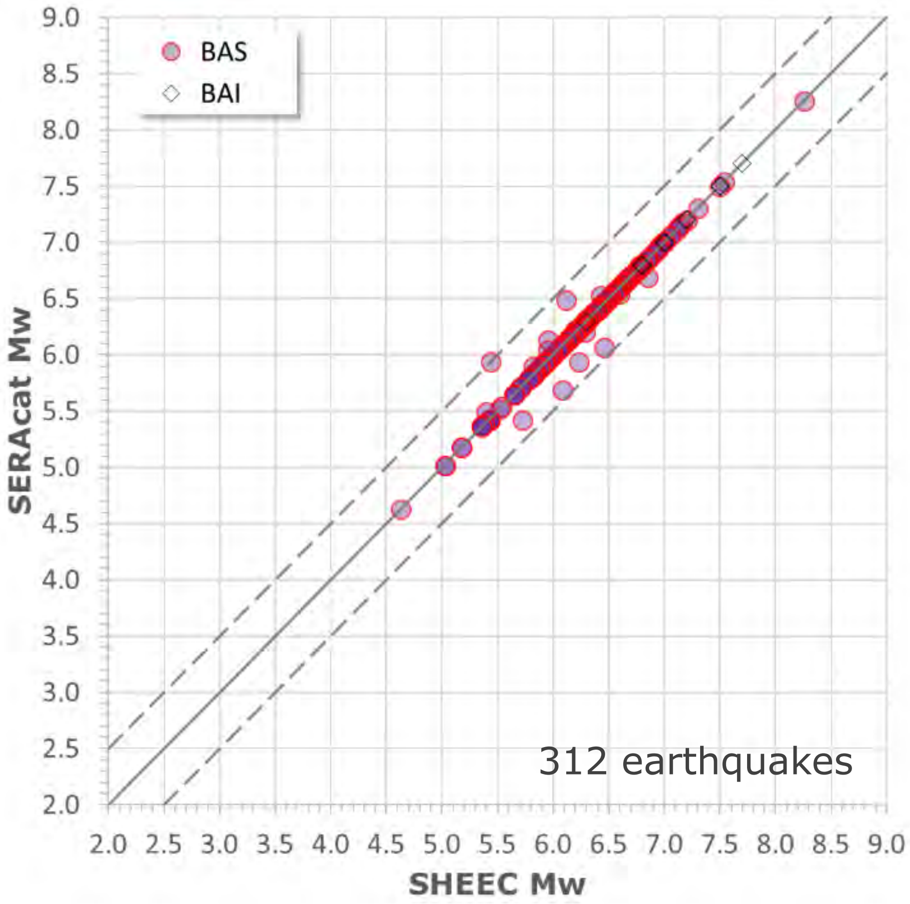
GREECE

MDPs: from the two macorseismic databases of ITSAK and the University of Athens
Regional Catalogues: Papazachos (+ Soysal at the border with Turkey)

- Very few variations due to the lower threshold (Eastern Aegean)
- New intensity distributions for 5 earthquakes in the Gulf of Corinth





REFERENCE	EQS.	MDPS
ALBINI ET AL., 2017	5	144

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CONCLUSIONS

SERA catalogue is an update of SHEEC 1000-1899

1. keeps the same compilation strategy
   - regional calibration
   - procedure to parametrize MDPs
2. updates input macroseismic datasets and catalogues (Italy, France, local/single studies)
3. corrects some compilation errors

SHEEC's data collection and processing principles are maintained, in order to balance between homogenity and regional knowledge across country borders

Thank you for your attention!

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Updating the European Fault-Source Model 2020 (EFSM20)

WP25-JRA3 ESHM20 User Feedback Meeting

Pavia, Italy, 14th October 2019

Roberto Basili and collaborators, INGV, roberto.basili@ingv.it

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 691728

OUTLINE

- Motivation
- Fault categories
  - status of crustal faults
  - status of subduction systems
- Activity rates

www.seismofaults.eu

EFEHR

Motivation

PROBABILISTIC TREATMENT OF FAULTING

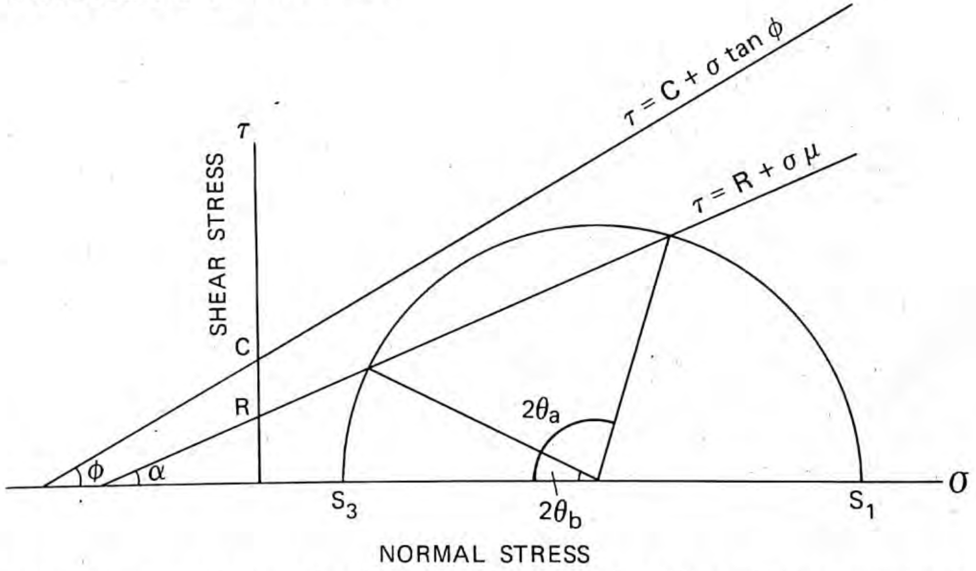
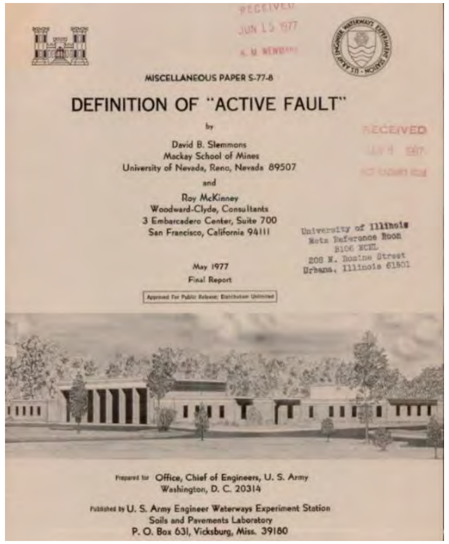


Fig. 5. Criteria for formation of a new fault, $\tau = C + \sigma \tan \phi$, and for sliding along an existing fault, $\tau = R + \sigma\mu$. For intact rocks, C represents the cohesive strength and ϕ the angle of internal friction. For an existing fault surface, R represents the shearing resistance and μ the coefficient of sliding friction. S_1 and S_3 represent the existing maximum and minimum principal stresses, respectively, and points on the circle represent the values of shear and normal stress on planes parallel to S_2 that are inclined to S_1 at an angle θ (see Figure 4).

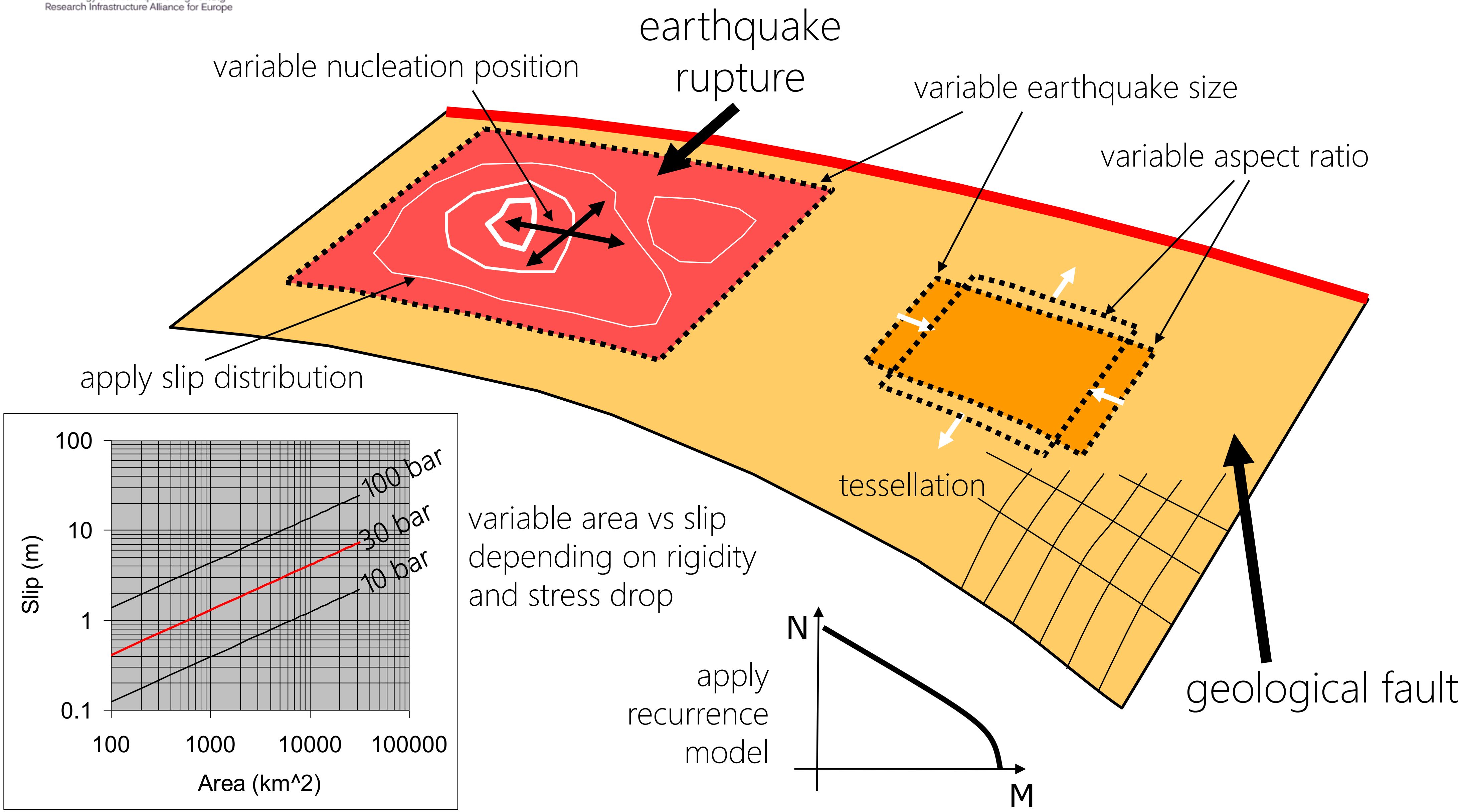
The definition of active fault include the following four essential elements:

1. Active faults **have been** offset during the present tectonic regime
2. Active faults **have** the probability or potential for future renewal or recurrence of offset
3. Active faults have evidence of recent activity, as **may be** shown by physiographic evidence
4. Active faults **may have** associated earthquake activity

(Slemmons and McKinney, 1977)



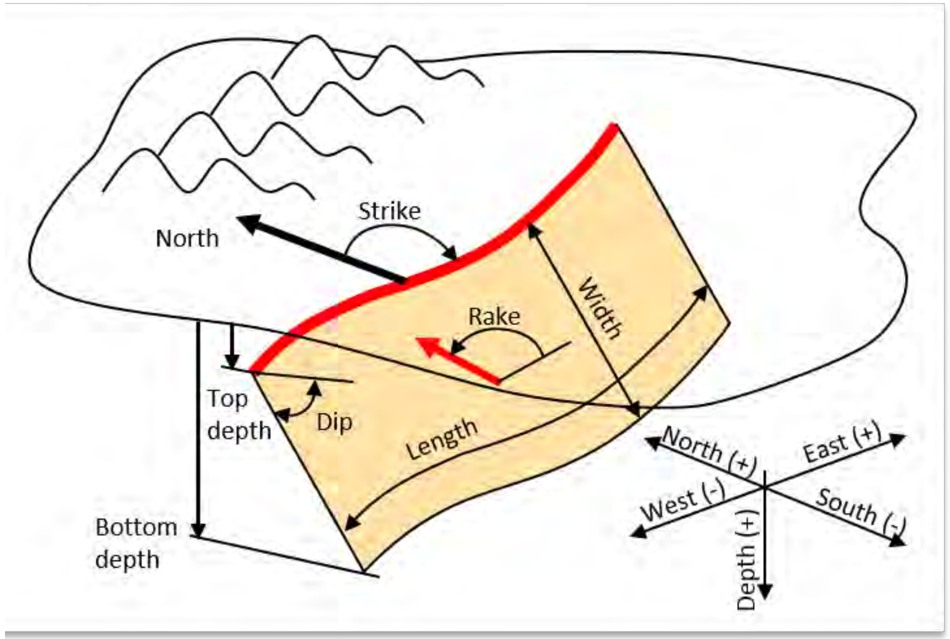
El.	Question	Answer
1	present tectonic regime?	borehole breakouts, earthquake focal mechanisms,…
2	potential for future offset?	slip tendency
3a	how recent?	depends on the application
3b	what physiographic evidence?	depends on the context (offshore: offset, warping, growth strata…)
4	associated earthquakes?	historical seismicity (macroseismic and/or instrumental)



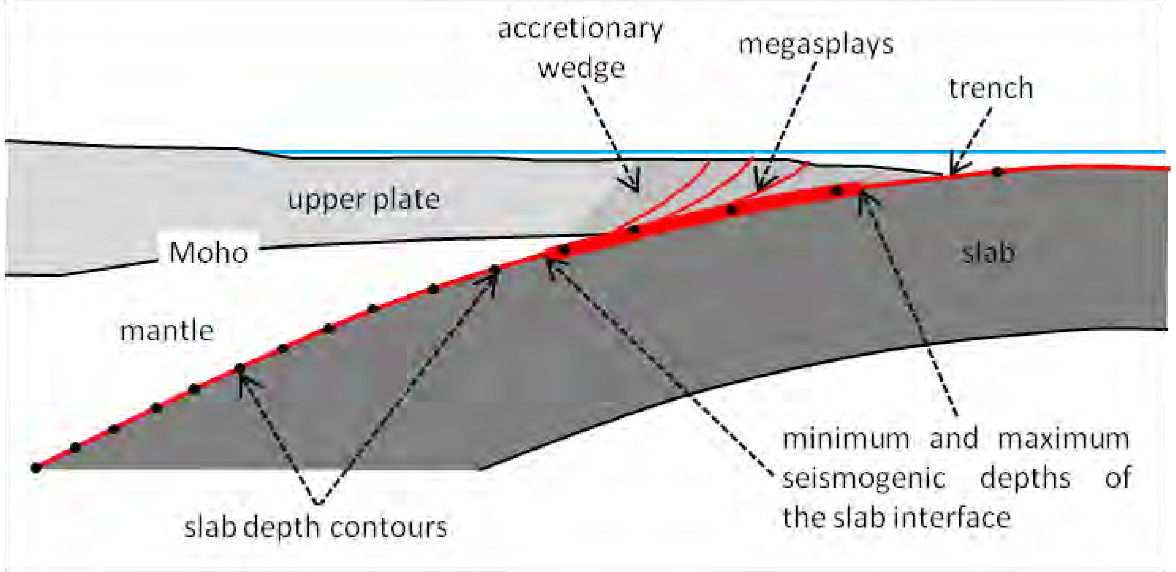
earthquake rupture
variable nucleation position
variable earthquake size
variable aspect ratio
apply slip distribution
tessellation
geological fault
variable area vs slip depending on rigidity and stress drop
100 bar
30 bar
10 bar
Slip (m)
100
10
1
0.1
100
1000
10000
100000
Area (km^2)
apply recurrence model
N
M

FAULT-SOURCE CATEGORIES

Crustal Faults



Subduction Systems (slabs)



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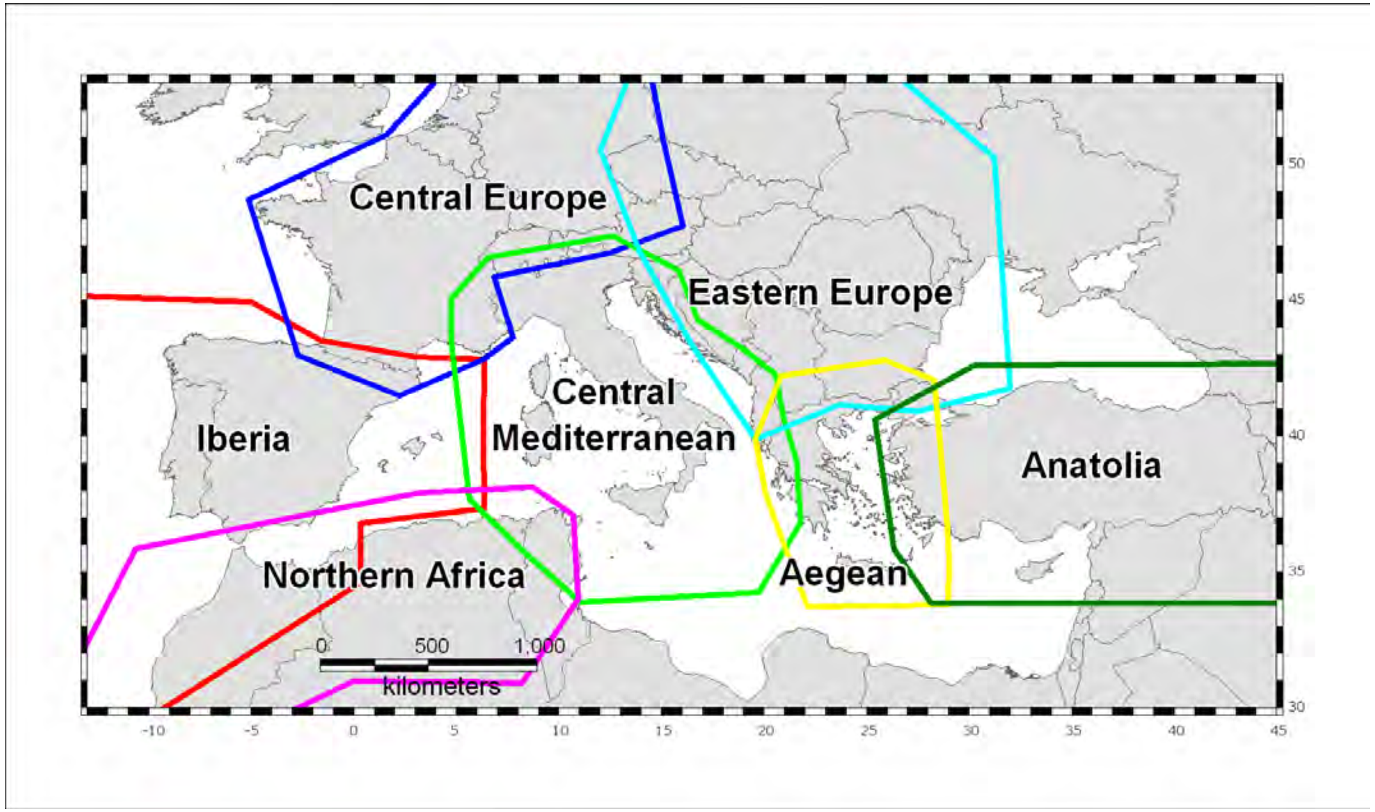
Regional subdivision of the SHARE Project



Region	Institution	Scientist in charge	Main compiler
Central Mediterranean	INGV, Italy	G. Valensise	DISS Working Group INGV, Italy
Northern Africa	CRAAG, Algeria	K. Yelles	P. Petricca INGV, Italy
Iberia	IST, Portugal	J. Fonseca	E. S. Nemser IST, Portugal
Central Europe	ROB, Belgium	T. Camelbeeck	D. Garcia Moreno ROB, Belgium
Eastern Europe	MSO, Montenegro NIEP, Romania	B. Glavatovic M. Radulian	V. Kastelic INGV, Italy
Aegean	NKUA, Greece AUTH, Greece	K. C. Makropoulos S. Pavlides	S. Sboras DST, University of Ferrara, Italy
Anatolia	KOERI, Turkey	M. Erdik	M. B. Demircioglu KOERI, Turkey

CRUSTAL FAULTS

Excerpt from D25.2 Updated databases of seismicity, faults, and strain rates for ESHM20

TITLE	REFERENCE	URL	COVERAGE	LICENSE	ACCESS
EDSF 2013	Basili et al. (2013); Giardini et al. (2013)	http://diss.rm.ingv.it/share-edsf/	Europe and Mediterranean	CC BY-SA 4.0	OGC WFS WMS, file download
QAFI 3	IGME (2015)	http://info.igme.es/qafi/	Iberia	CC BY-SA 4.0	file download
DISS 3.2.1	DISSWG (2018)	http://diss.rm.ingv.it/diss/	Central Mediterranean	CC BY-SA 4.0	OGC WFS WMS, file download
GREDASS 2.0.0	Caputo & Pavlides (2013)	http://gredass.unife.it/	Aegean	Attribution only	file download
LRGM	Vanneste et al. (2013)	--	Lower Rhine Graben	Attribution only	from ROB
AFCD	Emre et al. (2018); Demircioğlu et al. (2017)	http://www.mta.gov.tr/eng/maps/active-fault-1250000	Anatolia	Attribution only	--
EMME FAULT SOURCES	Danciu et al. (2018)	http://www.efehr.org/en/Documentation/specific-hazard-models/middle-east/active-faults/	Middle East	Attribution only	file download
NOAFAULTS	Ganas et al. (2013)	--	Greece	freeware	file download
INFP	Diaconescu et al. (2018)	http://faults.infp.ro/	Northern Black Sea	Attribution only	--
BDFA	Jomard et al. (2017)	https://www.nat-hazards-earth-syst-sci.net/17/1573/2017/	France	CC BY	file download
SLOVENIAN FAULT SOURCE MODEL	Atanackov et al. (2017)	--	Slovenia	Confidential, with permission to use	--
GULF OF CADIZ FAULT MODEL	Original work made in the framework of SERA JRA3	--	Gulf of Cadiz	--	--

Examined datasets for EFSM20:

- one Pan-European (EDSF-2013)
- several regional models, updated or entirely designed during and after the SHARE project.

Actions for ESHM20:

- collate datasets
- homogenize overlaps
- derive parameters for activity rates
- devise strategy for background

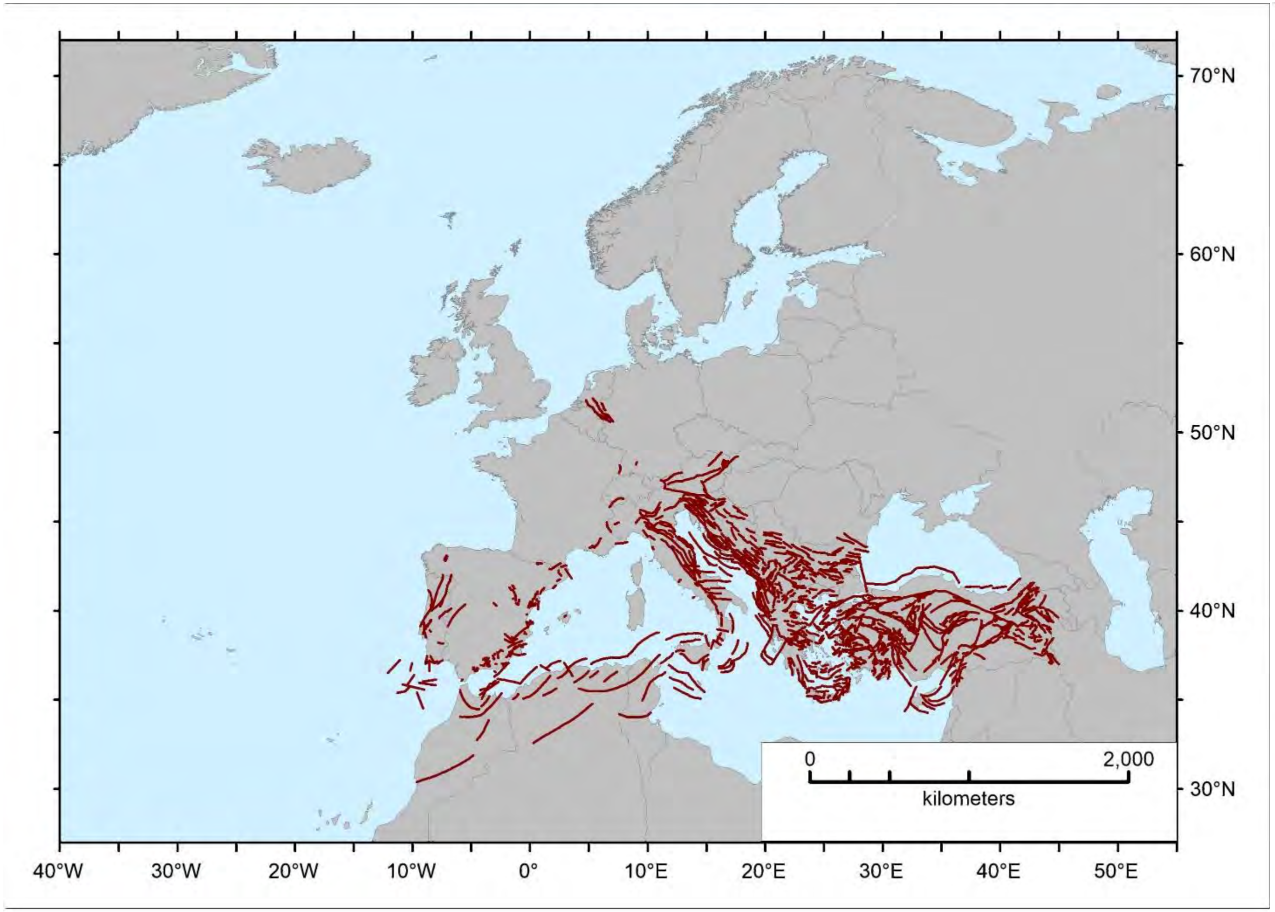
CRUSTAL FAULTS

Requirements of fault information

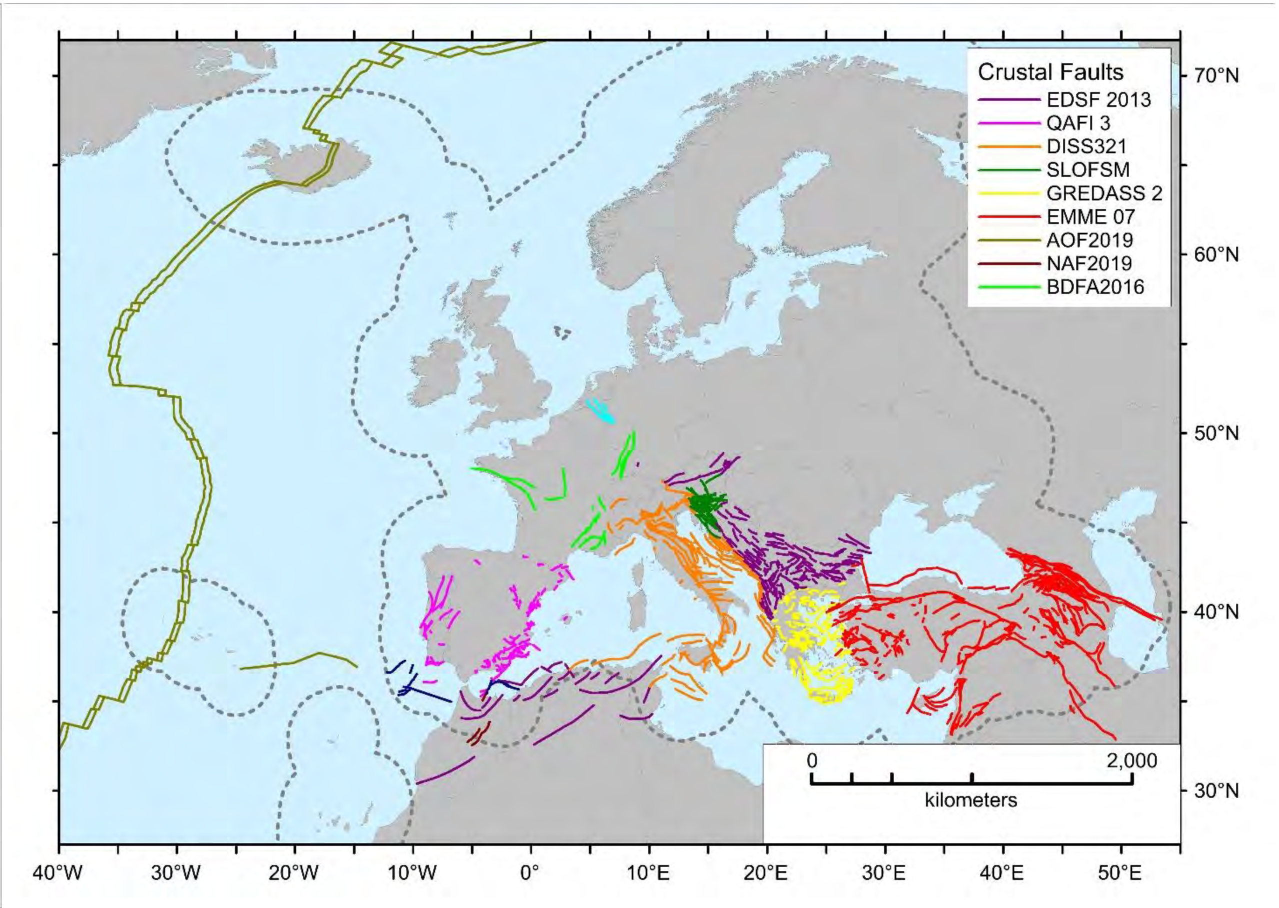
- Be declared active by the authors/contributors
- Fault trace coordinates
- Upper and lower depths
- Dip angle
- Strike or dip direction
- Rake or sense of movement
- Slip rate

Prioritization of fault information

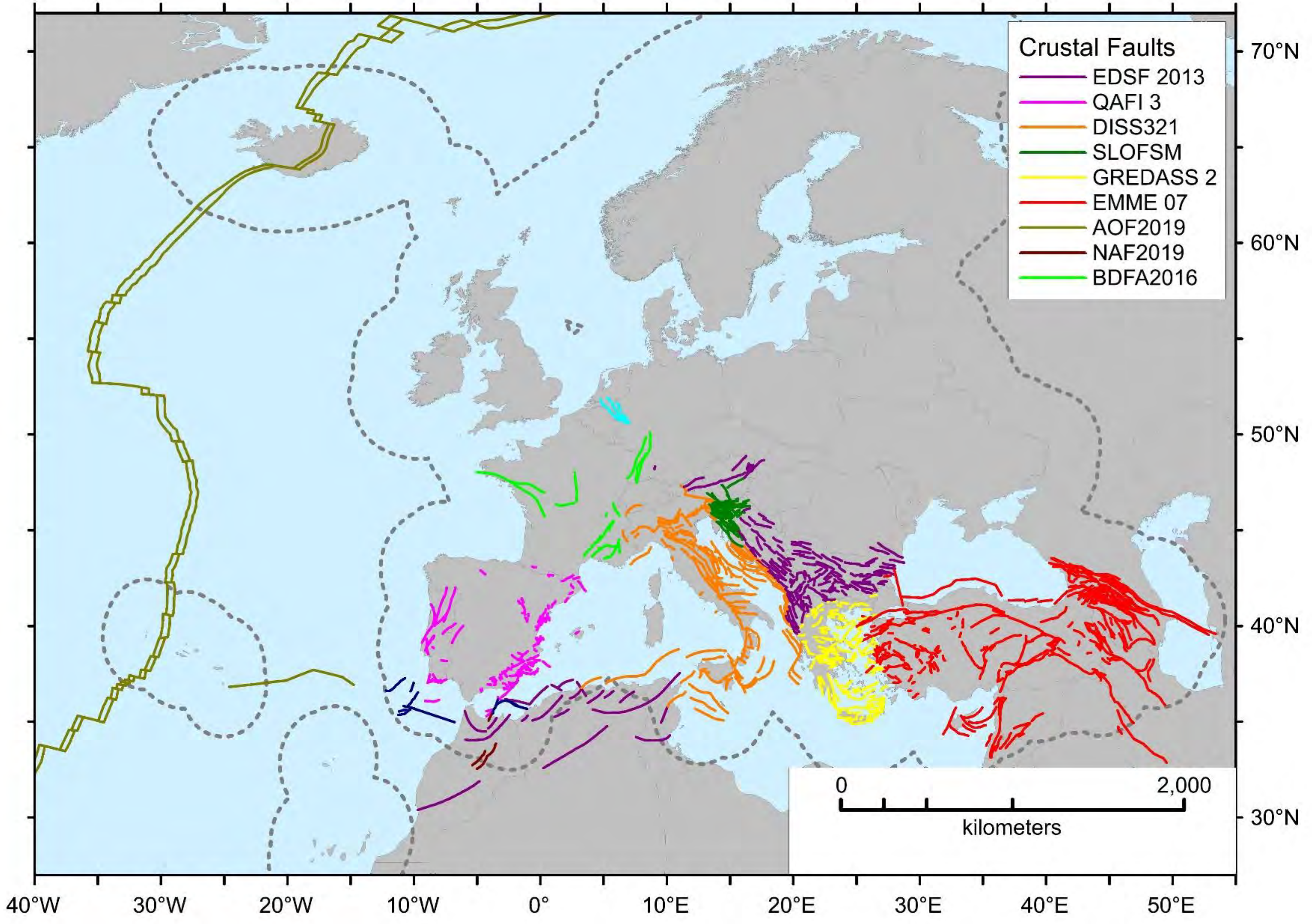
- Priorities for collating:
    1. EDSF 2013
    2. Replacement of EDSF by regional datasets
        a. Publicly available datasets
        b. Voluntarily contributed datasets
        c. Solicited local contributions
- Priorities for handling overlaps:
    1. Newer data
    2. National data
    3. Accuracy and justification
    4. Coherence with surrounding faults



EDSF 2013: 1,128 faults for ~63,775 km



EFSM 2020 v03: 1,256 faults for ~92,906 km.
Only 178 faults (13,114 km) remaining from EDSF 2013 …as of today.



Map of collated datasets

Data processing:

1. Extract relevant information from different datasets and convert into EFSM20 format
2. Review fault trace geometry where needed
3. Assign additional parameters, including tectonic setting for FSL
4. Calculate derived parameters (Mw of max rupture size, moment rate)
5. Identify duplicates
6. Assign unique IDs

Yet to do:

- Address slip rate uncertainty
- Last-minute additions/removals
- Consistency checks
- Remove/correct mistakes

Other processing for all faults:

- EFSM20 unique 7-character persistent IDs:
    - CF/IF/IS – Country ISO 2-letter code – alphanumeric 3-letter code (e.g., CFCH0B5)
- Smoothed traces (5-km-long stick)
- Bottom depth check with Moho depth
- Simple fault vs complex fault index for OQ input

Decisions to be made:

- Exclude very small faults (L or W < 5 km are fewer than 10)?
- Revise geometric extrusion for faults that cross-cut each other at depth?

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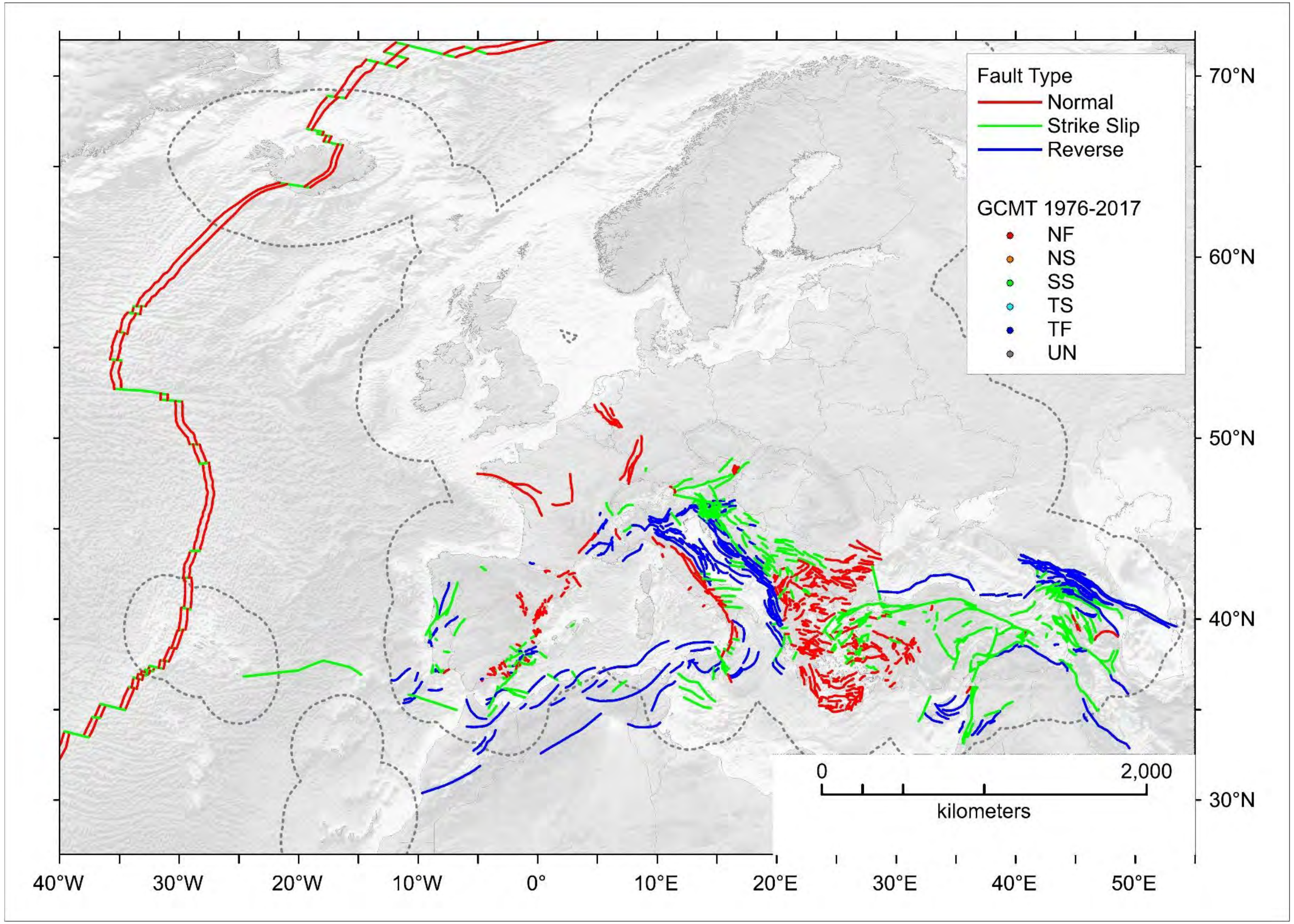

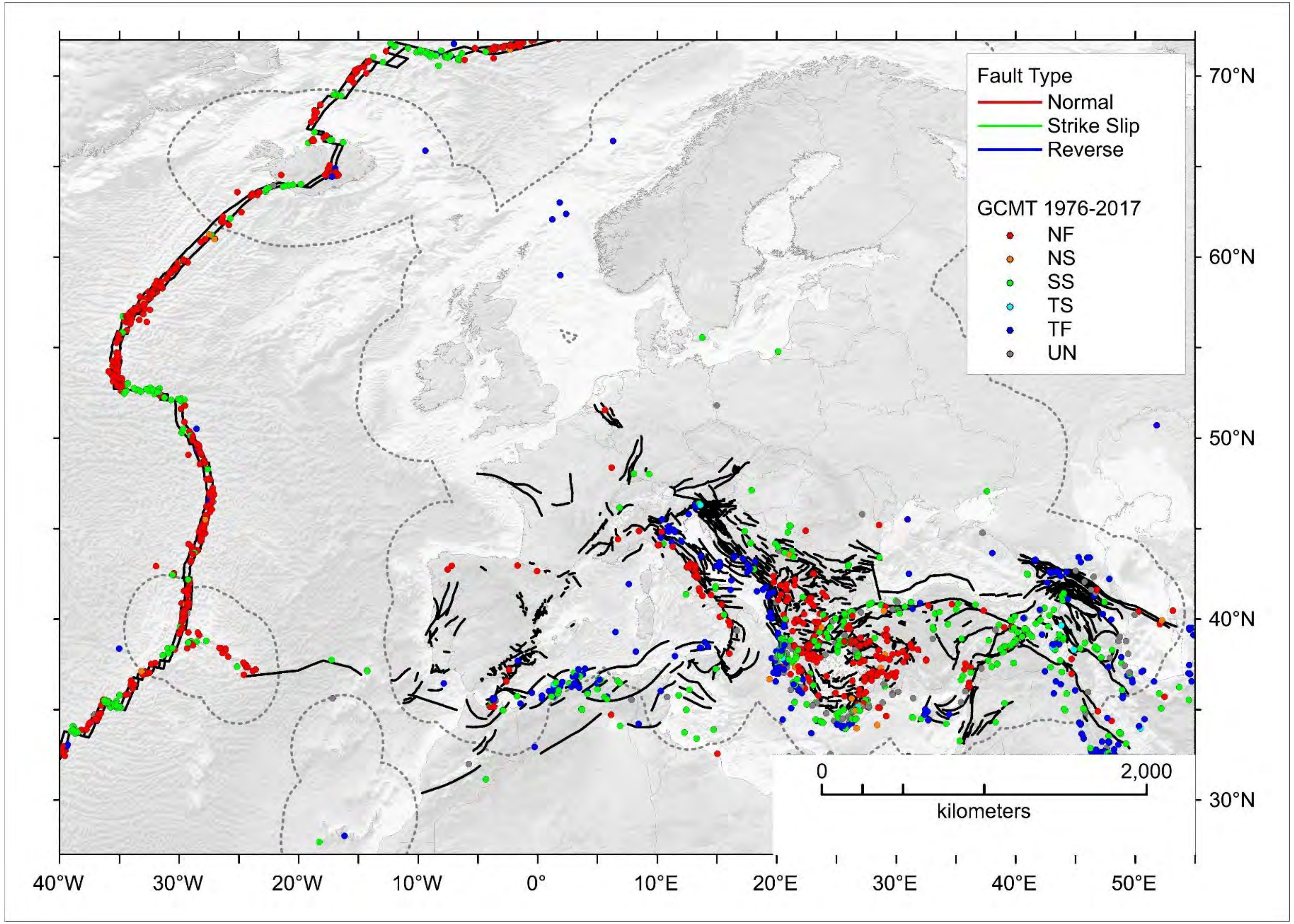
Fault Type
Normal
Strike Slip
Reverse
GCMT 1976-2017
NF
NS
SS
TS
TF
UN
0
2,000
kilometers
70°N
60°N
50°N
40°N
30°N
40°W
30°W
20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E

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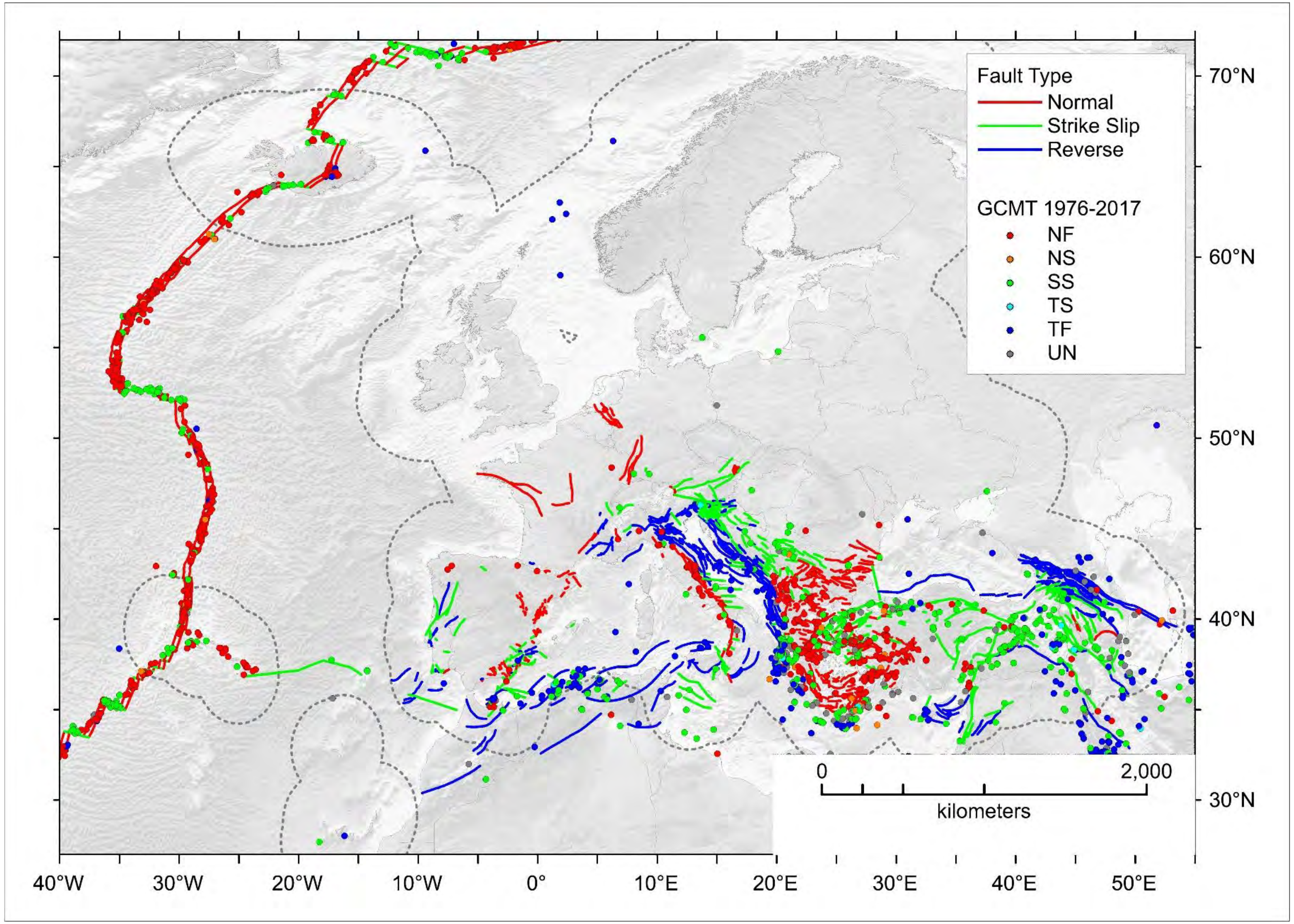
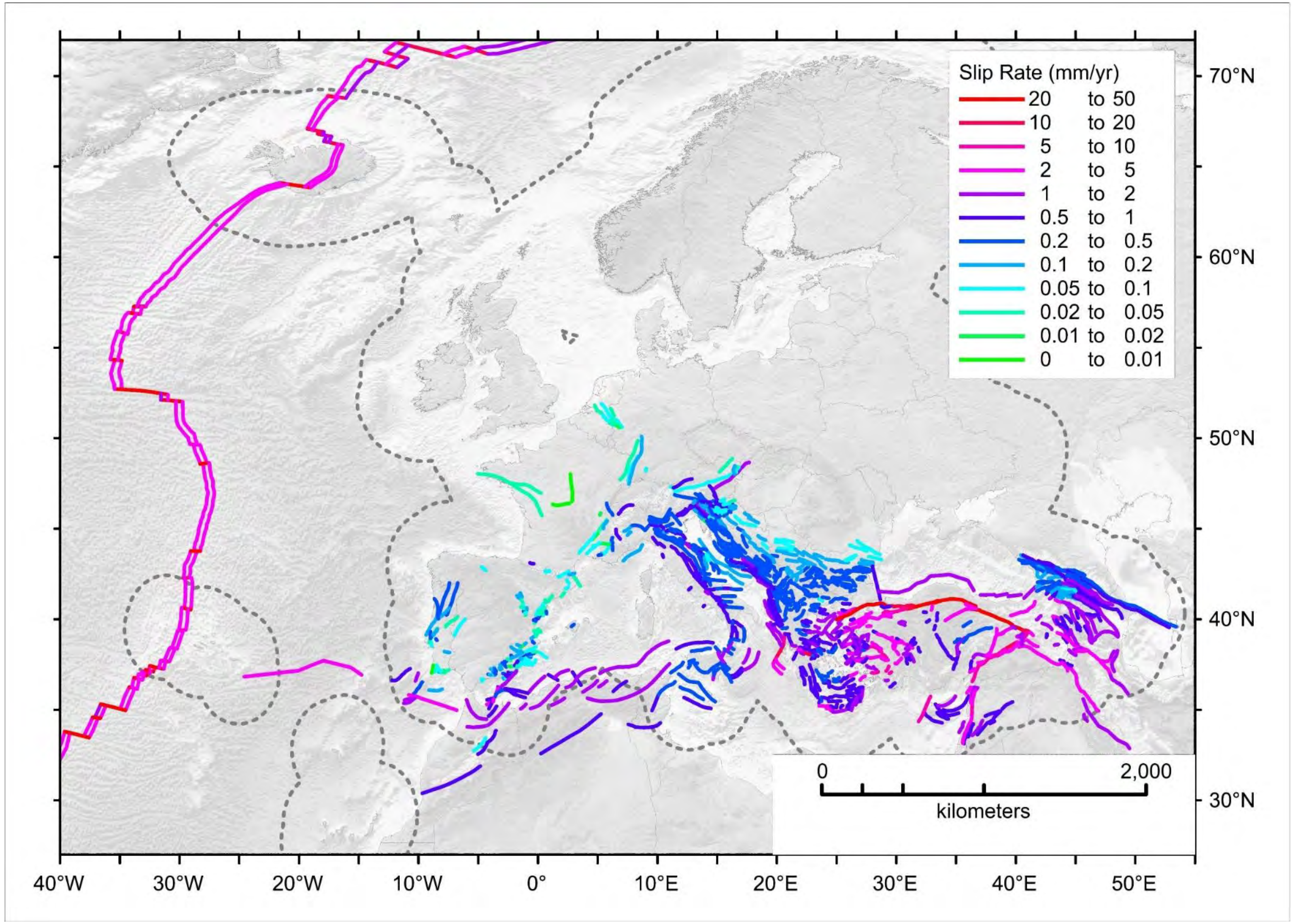
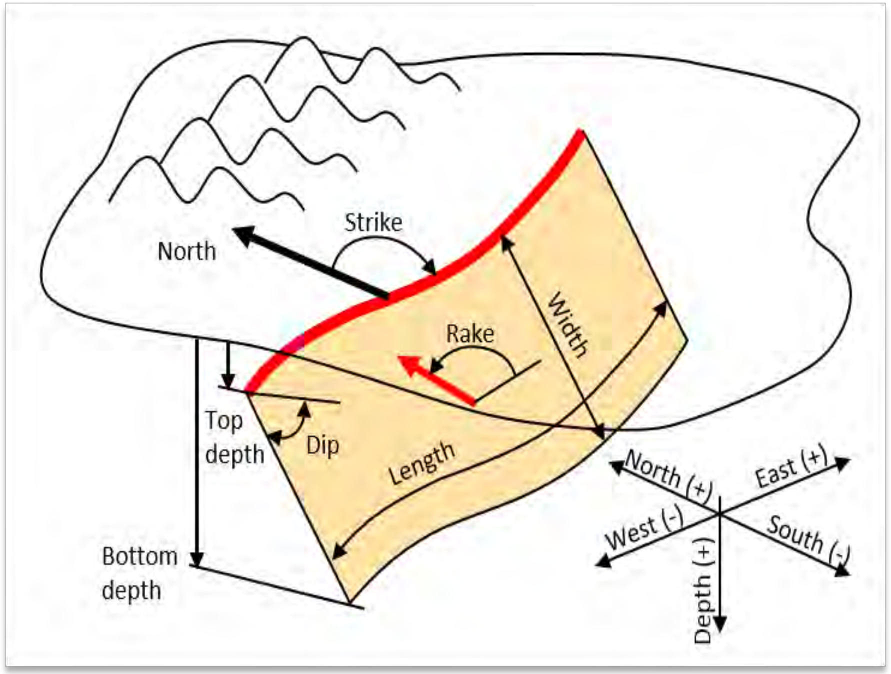
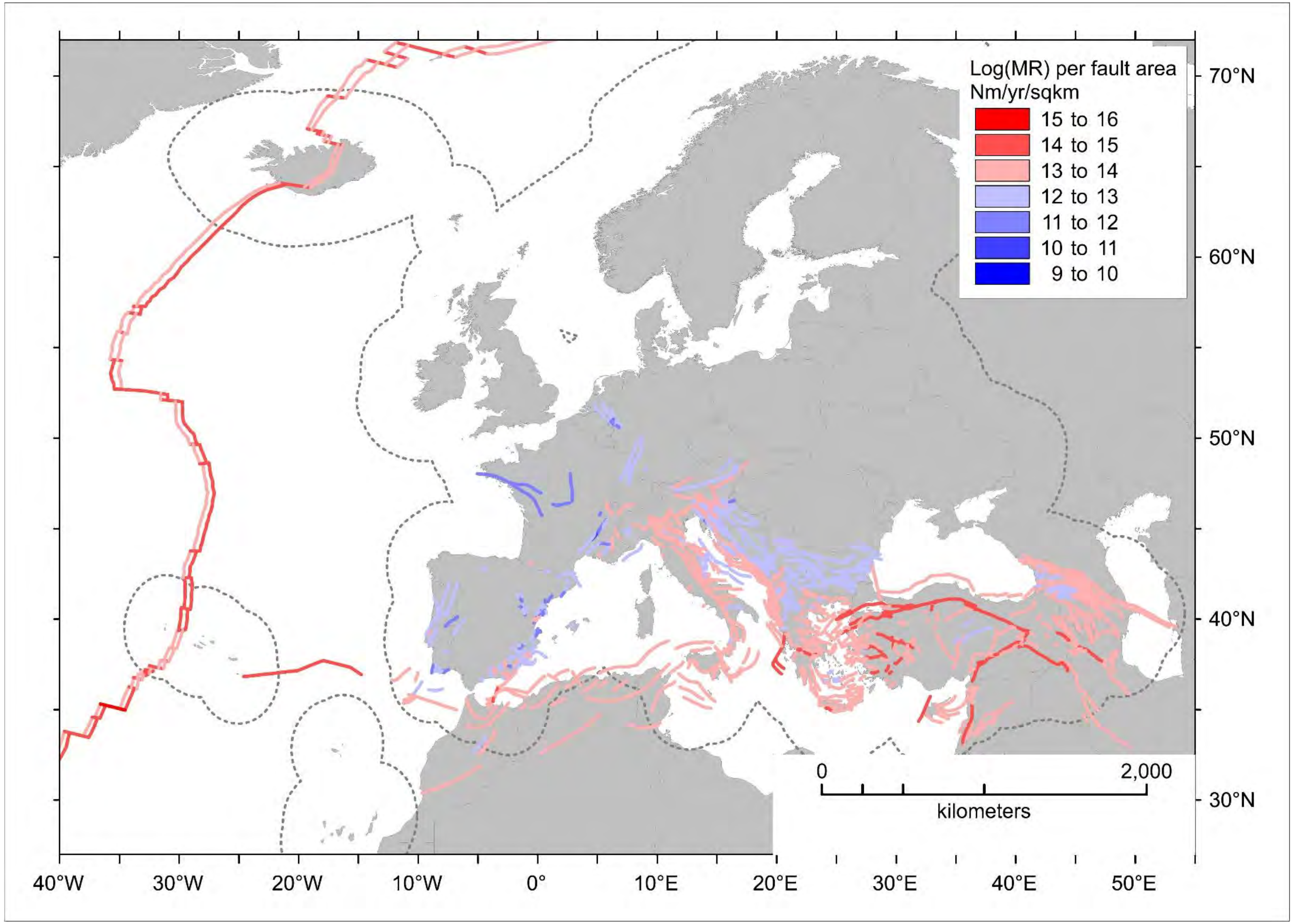


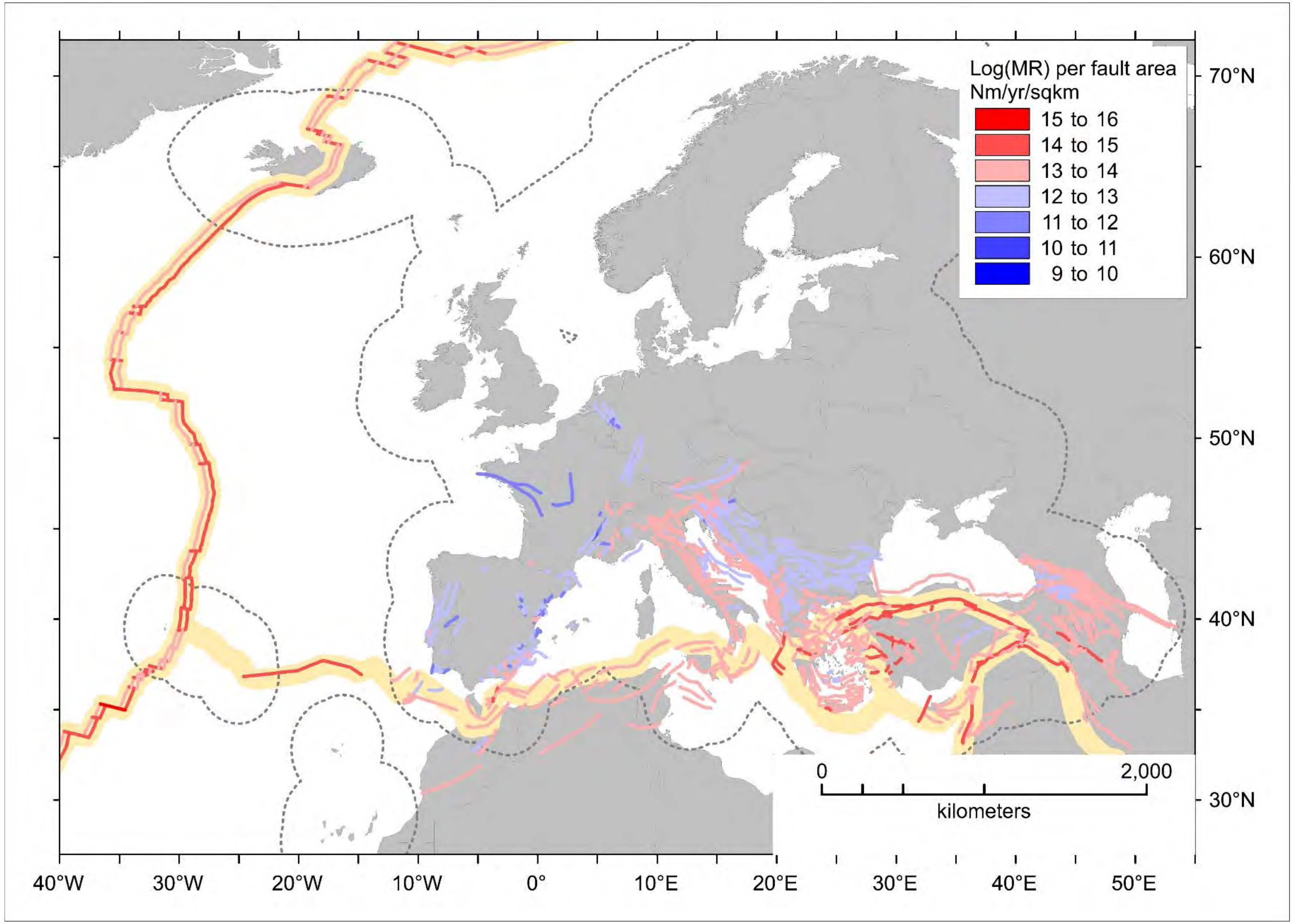

Slip Rate (mm/yr)
20 to 50
10 to 20
5 to 10
2 to 5
1 to 2
0.5 to 1
0.2 to 0.5
0.1 to 0.2
0.05 to 0.1
0.02 to 0.05
0.01 to 0.02
0 to 0.01
0
2,000
kilometers
70°N
60°N
50°N
40°N
30°N
40°W
30°W
20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E



$$\dot{M}_s = \chi \dot{M}_g = \chi \mu L W \dot{D}$$

$\dot{M}_g$: geologic moment rate; $\dot{M}_s$: seismic moment rate

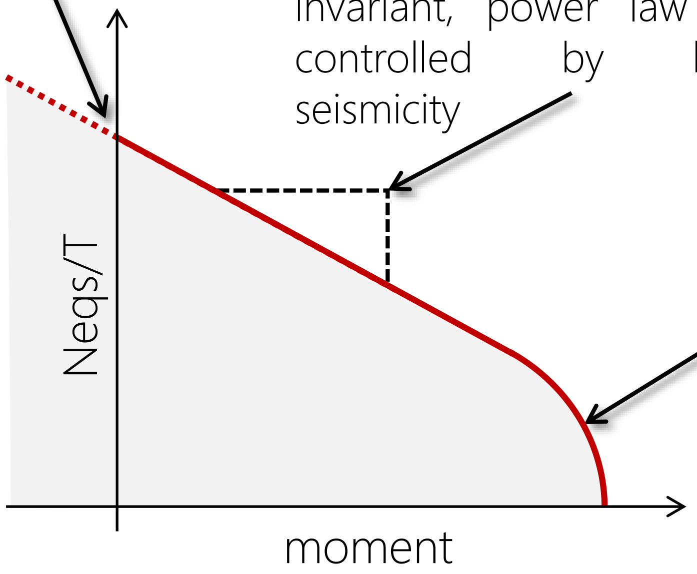

Log(MR) per fault area
Nm/yr/sqkm
15 to 16
14 to 15
13 to 14
12 to 13
11 to 12
10 to 11
9 to 10
0
2,000
kilometers
70°N
60°N
50°N
40°N
30°N
40°W
30°W
20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E


Log(MR) per fault area
Nm/yr/sqkm
15 to 16
14 to 15
13 to 14
12 to 13
11 to 12
10 to 11
9 to 10
0
2,000
kilometers
70°N
60°N
50°N
40°N
30°N
40°W
30°W
20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E

Building the model: FMD

this intersection is controlled by moment rate (*seismic*, ***geologic***, *geodetic*)

the slope of the scale-invariant, power law part is controlled by historical seismicity

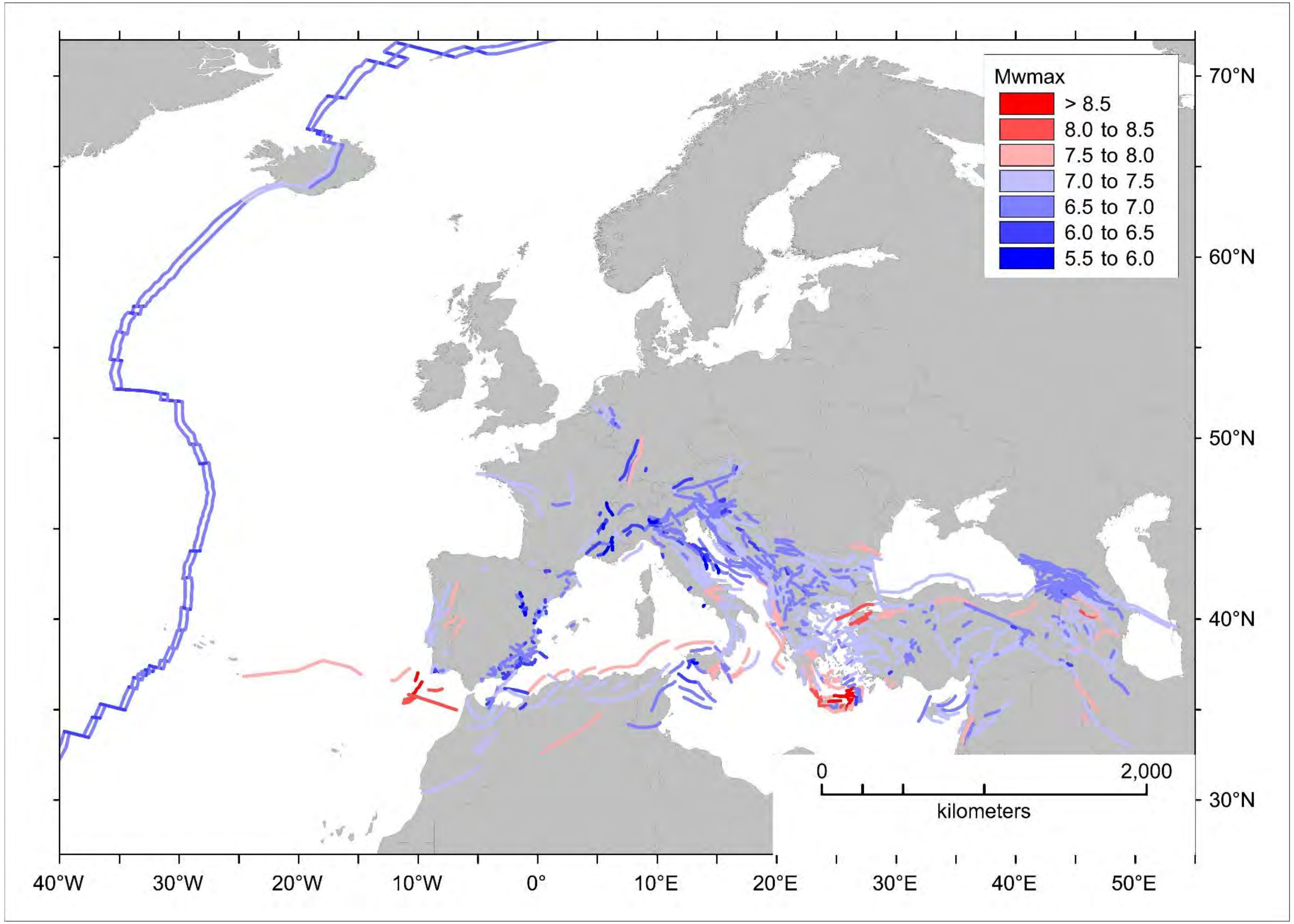


the shape of the right-hand tail (*including moment upper bound or corner moment*) is highly speculative and hardly testable; localized constraints from paleoseismic data or from fault dimension can be used

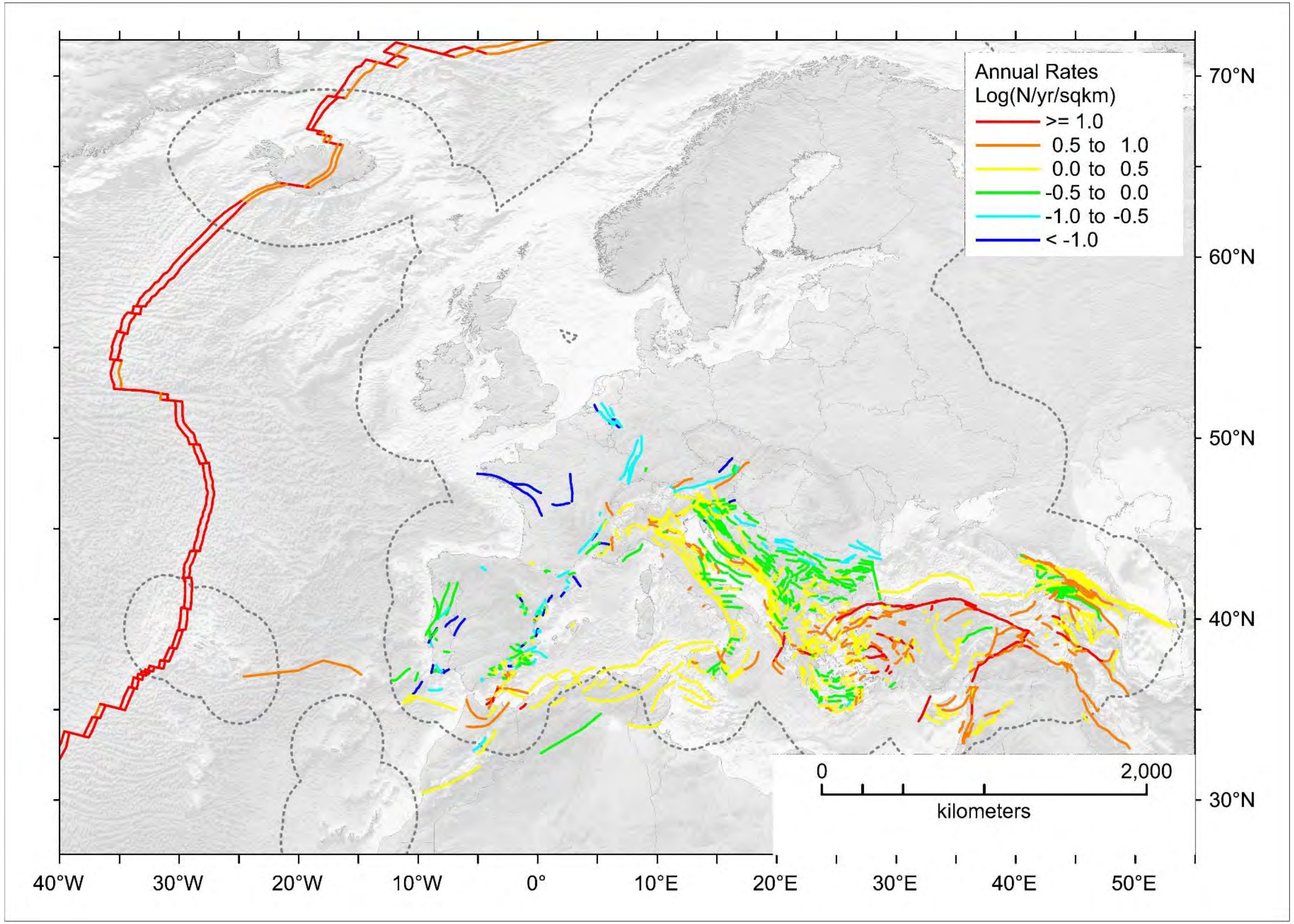
χ = 1
μ = 30 GPa
M_0 = 1.27E+9 Nm ↔ m_0 = 0.0
M_{xp} ↔ m_{xp} = from scaling laws [Leonard 2014, BSSA]
β = 2/3 ↔ b = 1

$$\dot{M}_s = \frac{\alpha_0 M_0^{\beta} \beta}{1-\beta} M_{xp}^{1-\beta} \xi_p \qquad \xi_p = \frac{M_{xp}^{\beta}}{M_{xp}^{\beta} - M_0^{\beta}} \qquad \chi\mu L W \dot{D} = \frac{\alpha_0 M_0^{\beta} \beta}{1-\beta} M_{xp}^{1-\beta} \xi_p$$

[Pareto MFD from Kagan 2002, GJI]

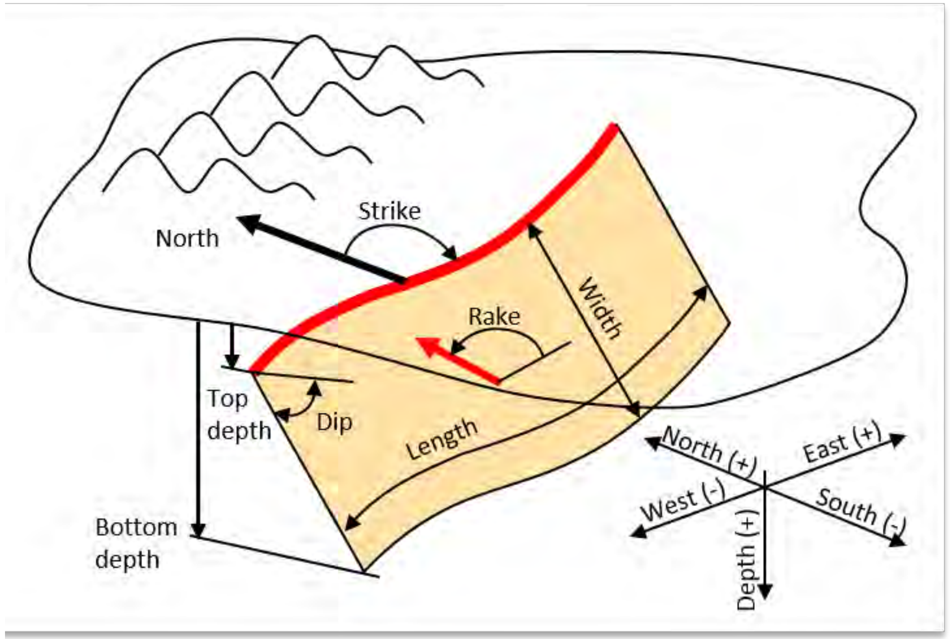

Mwmax
> 8.5
8.0 to 8.5
7.5 to 8.0
7.0 to 7.5
6.5 to 7.0
6.0 to 6.5
5.5 to 6.0
70°N
60°N
50°N
40°N
30°N
0
2,000
kilometers
40°W
30°W
20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E

$$\alpha_0 = \frac{\chi \mu L W \dot{D}(1-\beta)}{\beta \xi_p M_0^{\beta} M_{xp}^{1-\beta}}$$

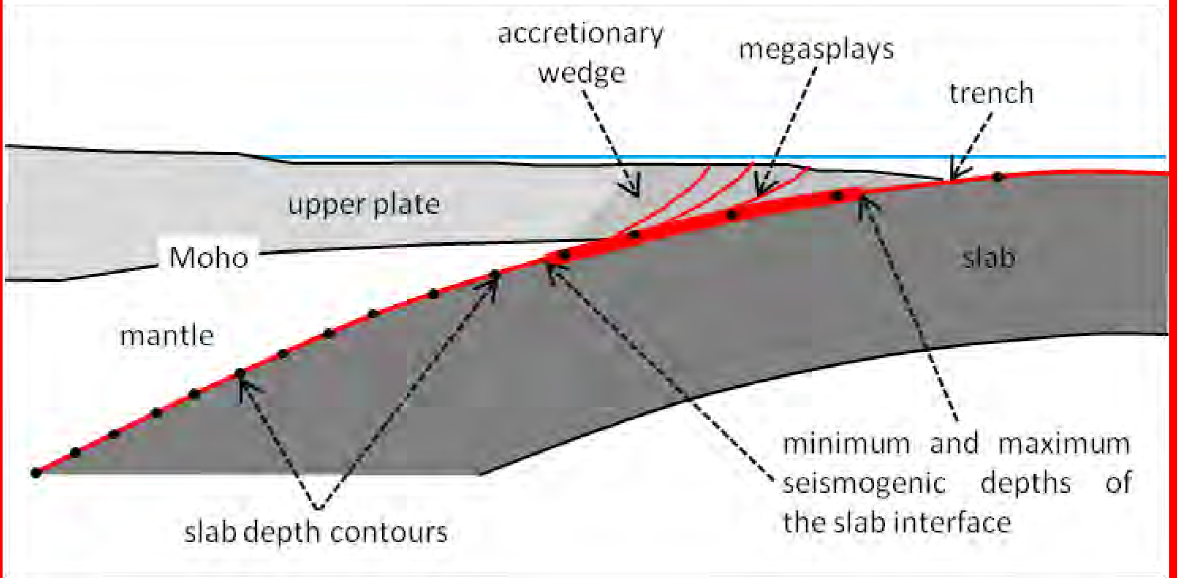


FAULT-SOURCE CATEGORIES

Crustal Faults



Subduction Systems (slabs)



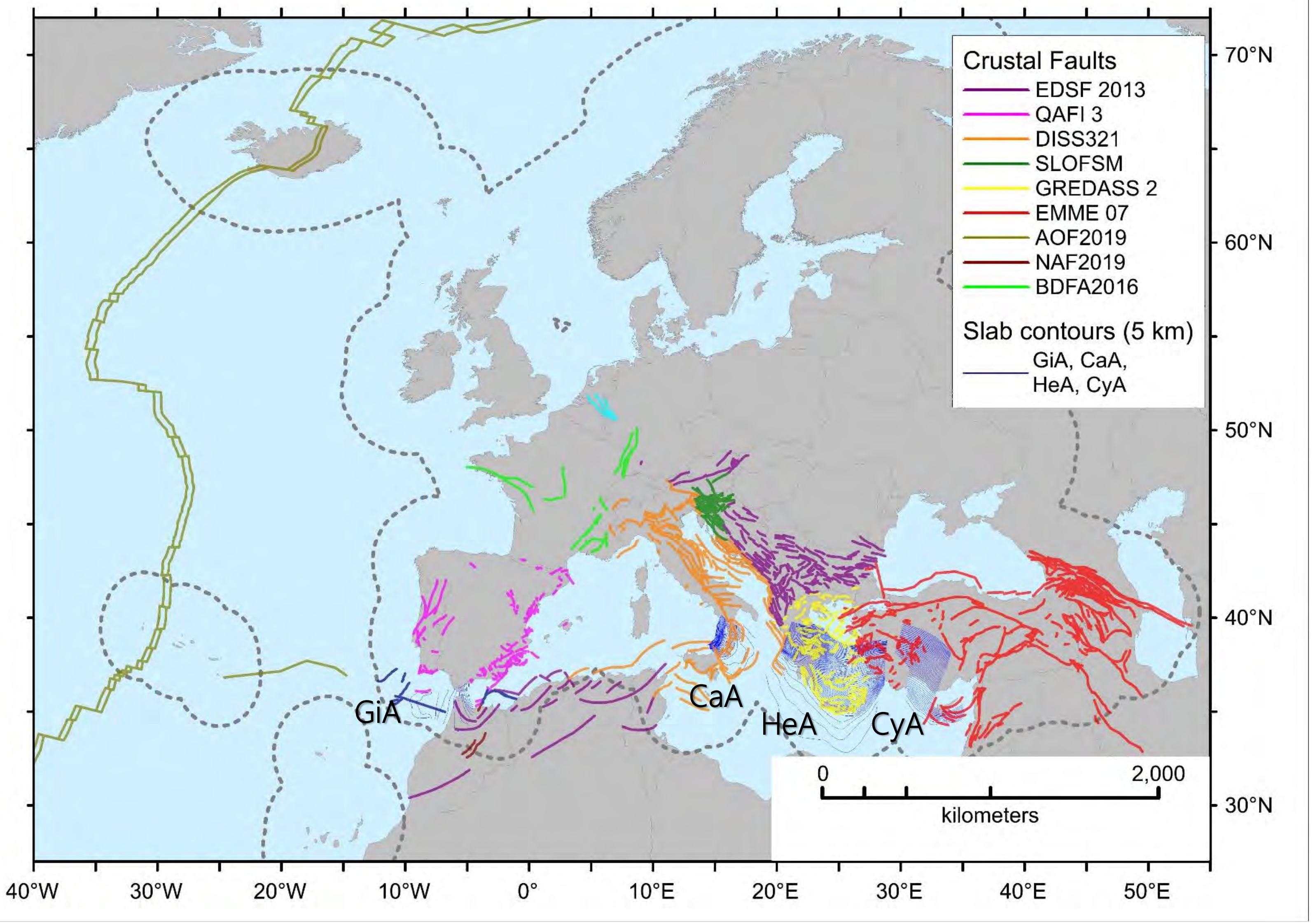
SUBDUCTION SYSTEMS

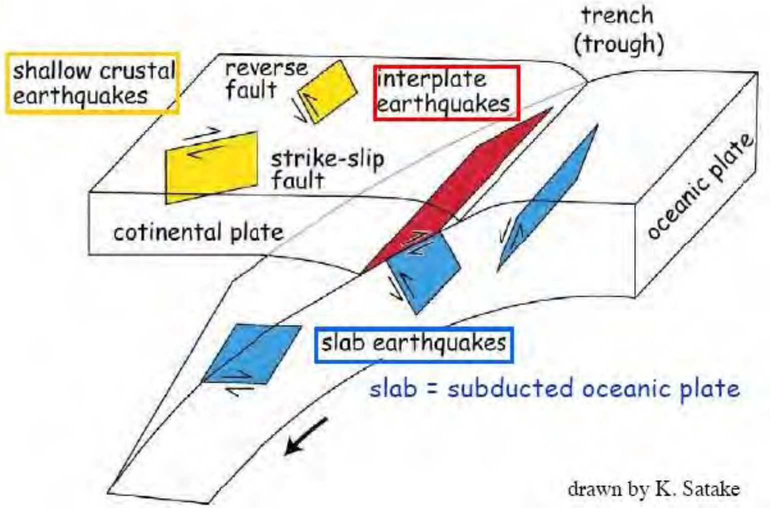
Excerpt from D25.2 Updated databases of seismicity, faults, and strain rates for ESHM20

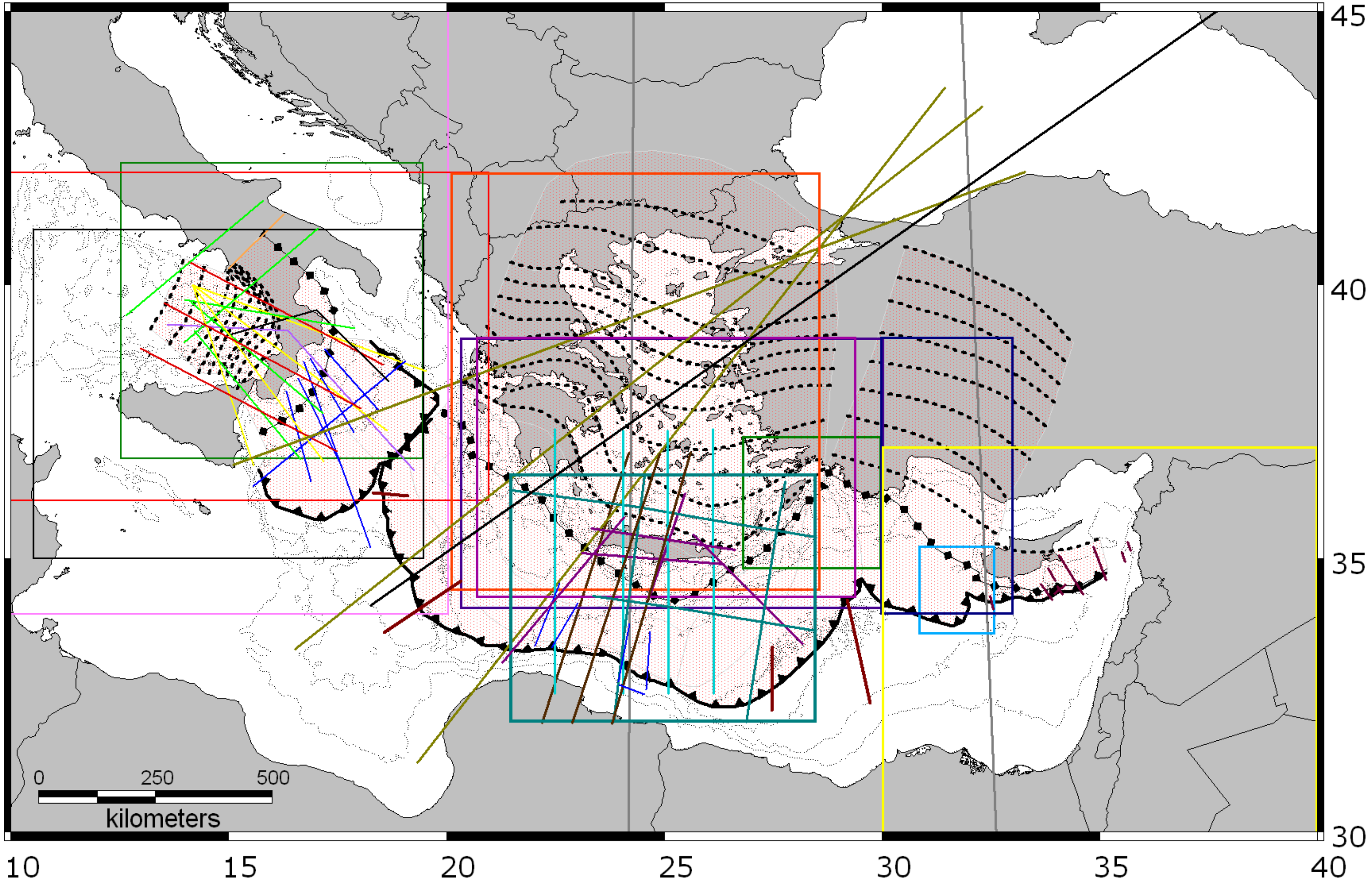
TITLE	REFERENCE	URL	COVERAGE	LICENSE	ACCESS
EDSF 2013	Basili et al. (2013); Giardini et al. (2013)	http://diss.rm.ingv.it/share-edsf/	Central-Eastern Mediterranean	CC BY-SA 4.0	OGC WFS WMS, file download
DISS 3.2.1	DISSWG (2018)	http://diss.rm.ingv.it/diss/	Central-Eastern Mediterranean	CC BY-SA 4.0	OGC WFS WMS, file download
CAM	Maesano et al. (2017)	https://www.nature.com/articles/s41598-017-09074-8	Central Mediterranean	CC BY 4.0	file download
SLAB 2.0	Hayes (2018); Hayes et al. (2018)	https://doi.org/10.5066/F7PV6JNV	World	Public Domain	WMS, file download
GEM-FE SICP 2.0	Berryman et al. (2015)	--	World	CC BY 3.0	file download
SUBMAP 4.2	Heuret & Lallemand (2005)	http://submap.gm.univ-montp2.fr/index.php	World	Attribution only	file download
PB2002	Bird et al. (2003)	http://peterbird.name/publications/2003_PB2002/2003_PB2002.htm	World	Attribution only	file download
GULF OF CADIZ FAULT MODEL	Original work made in the framework of SERA JRA3	--	Gulf of Cadiz	--	--

Subduction zones models:

- three slabs in the eastern Mediterranean region (Calabrian Arc, Hellenic Arc, Cyprus Arc)
- one slab in the Strait of Gibraltar


Crustal Faults
EDSF 2013
QAFI 3
DISS321
SLOFSM
GREDASS 2
EMME 07
AOF2019
NAF2019
BDFA2016
Slab contours (5 km)
GiA, CaA, HeA, CyA
GiA
CaA
HeA
CyA
0
2,000
kilometers
70°N
60°N
50°N
40°N
30°N
40°W
30°W
20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E

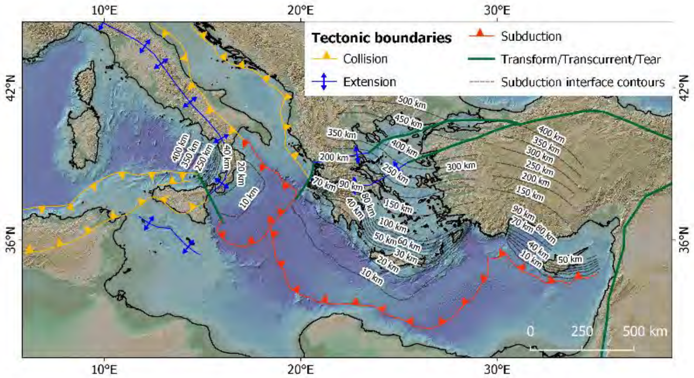

trench (trough)
shallow crustal earthquakes
reverse fault
interplate earthquakes
strike-slip fault
cotinental plate
oceanic plate
slab earthquakes
slab = subducted oceanic plate
drawn by K. Satake

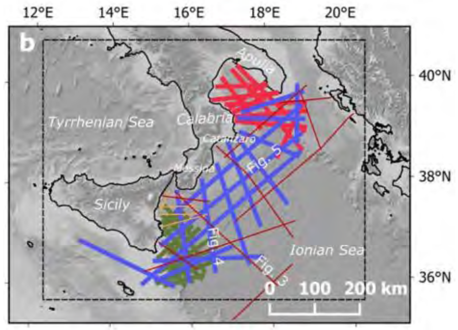

45
40
35
30
0
250
500
kilometers
10
15
20
25
30
35
40

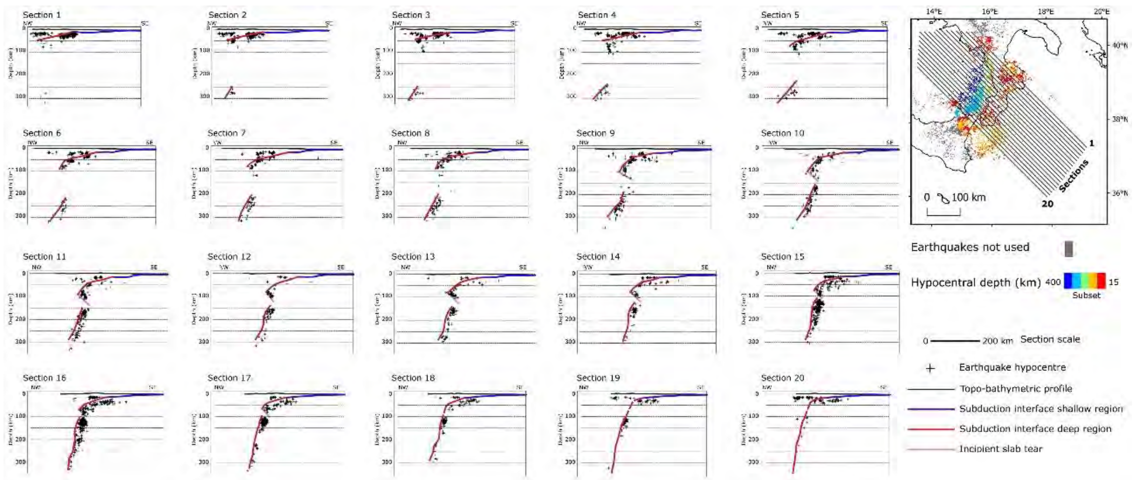
ID	Name	Description	Method	Information	Reference	File_name	Location
1	Northern Shore Profile	Seismic Profile	WARRP (Wide Angle Reflection Refraction Profile)	Vp distribution	Bonhoff et al., 2001; Makris and Yegorova, 2006	Makris&Yegorova_Pr1	M&Y Fig. 2a
2	Southern Shore Profile	Seismic Profile	WARRP (Wide Angle Reflection Refraction Profile)	Vp distribution	Bonhoff et al., 2001; Makris and Yegorova, 2006	Makris&Yegorova_Pr2	M&Y Fig. 2b
3	North South Traverse	Seismic Profile	WARRP (Wide Angle Reflection Refraction Profile)	Vp distribution	Bonhoff et al., 2001; Makris and Yegorova, 2006	Makris&Yegorova_Pr4	M&Y Fig. 2d
4	Profile Pr3	Seismic Profile	WARRP (Wide Angle Reflection Refraction Profile)	Vp distribution	Makris and Yegorova, 2006	Makris&Yegorova_Pr3	Fig. 2c
5	Profile Pr5	Seismic Profile	WARRP (Wide Angle Reflection Refraction Profile)	Vp distribution	Makris and Yegorova, 2006	Makris&Yegorova_Pr5	Fig. 2e
6	Profile 2we	Gravity profile	Gravity modelling	Density distribution	Makris and Yegorova, 2006		Fig. 10
7	Profile 1we	Gravity profile	Gravity modelling	Density distribution	Makris and Yegorova, 2006		Fig. 10
8	Profile 1sn	Gravity profile	Gravity modelling	Density distribution	Makris and Yegorova, 2006	Makris&Yegorova_GrPr1sn	Fig. 9

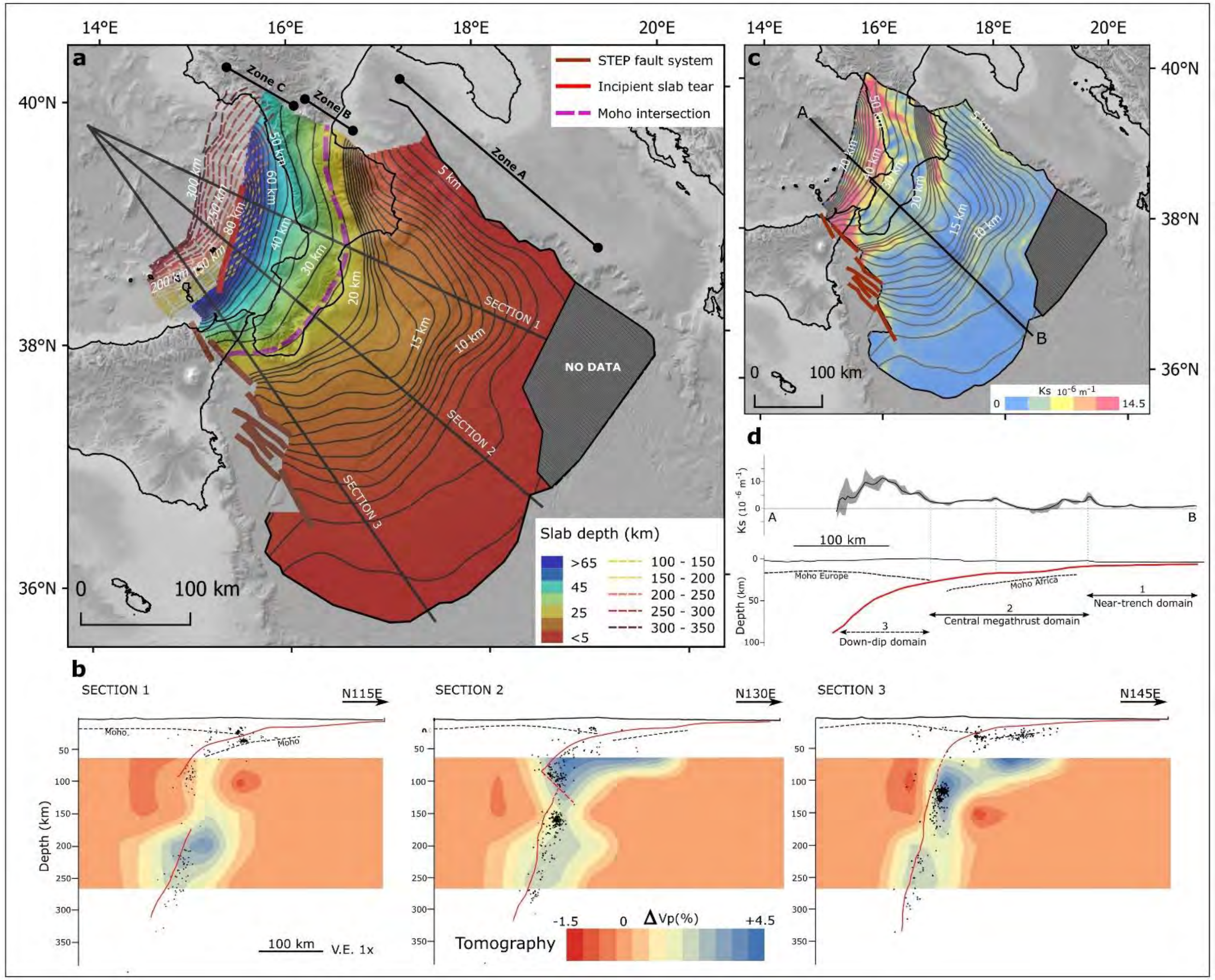
total of 100 entries including data from…

seismic profiles, gravity data, receiver functions Moho depth,
tomography data, earthquake focal mechanisms and hypocentre location, etc.

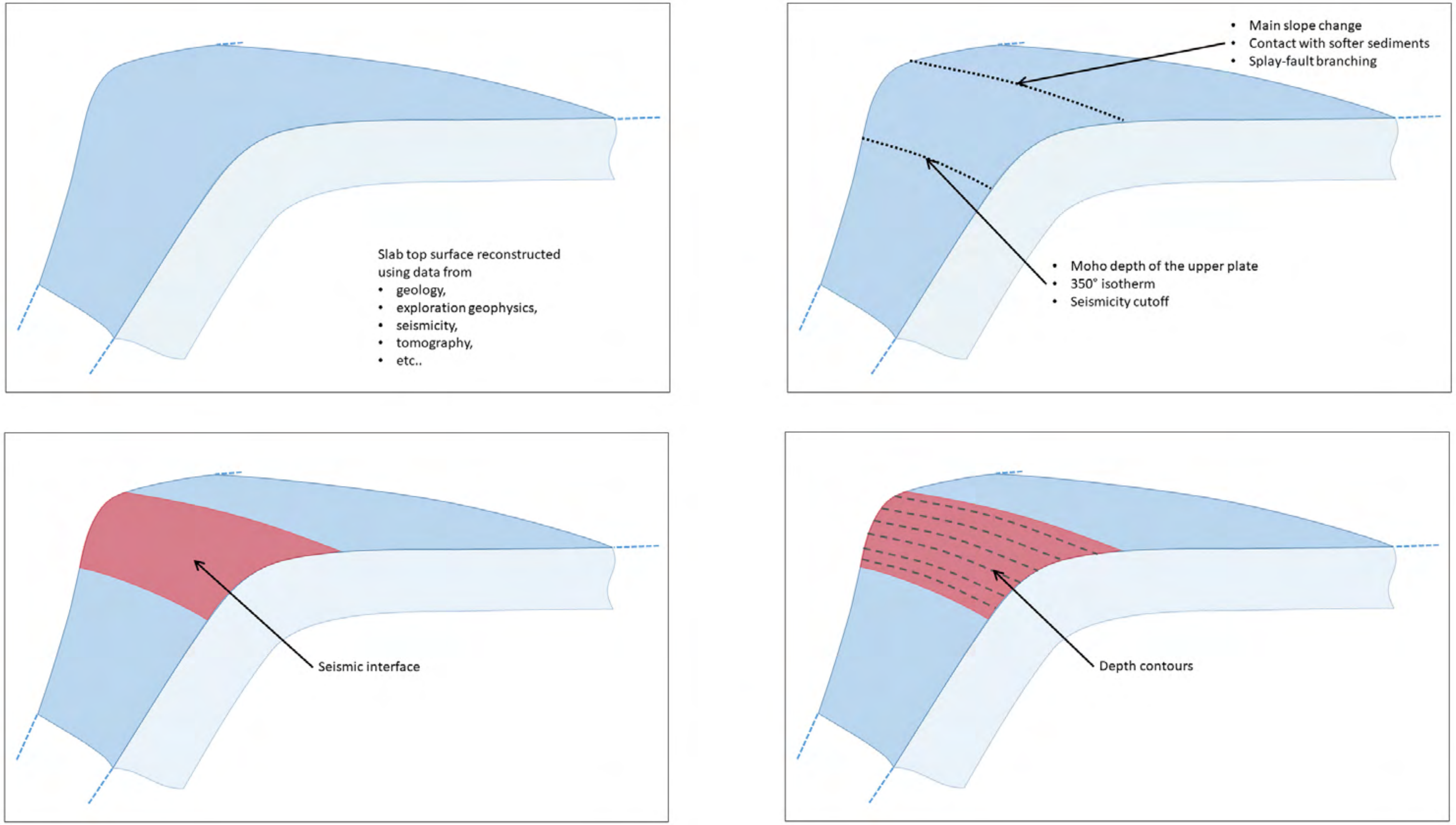


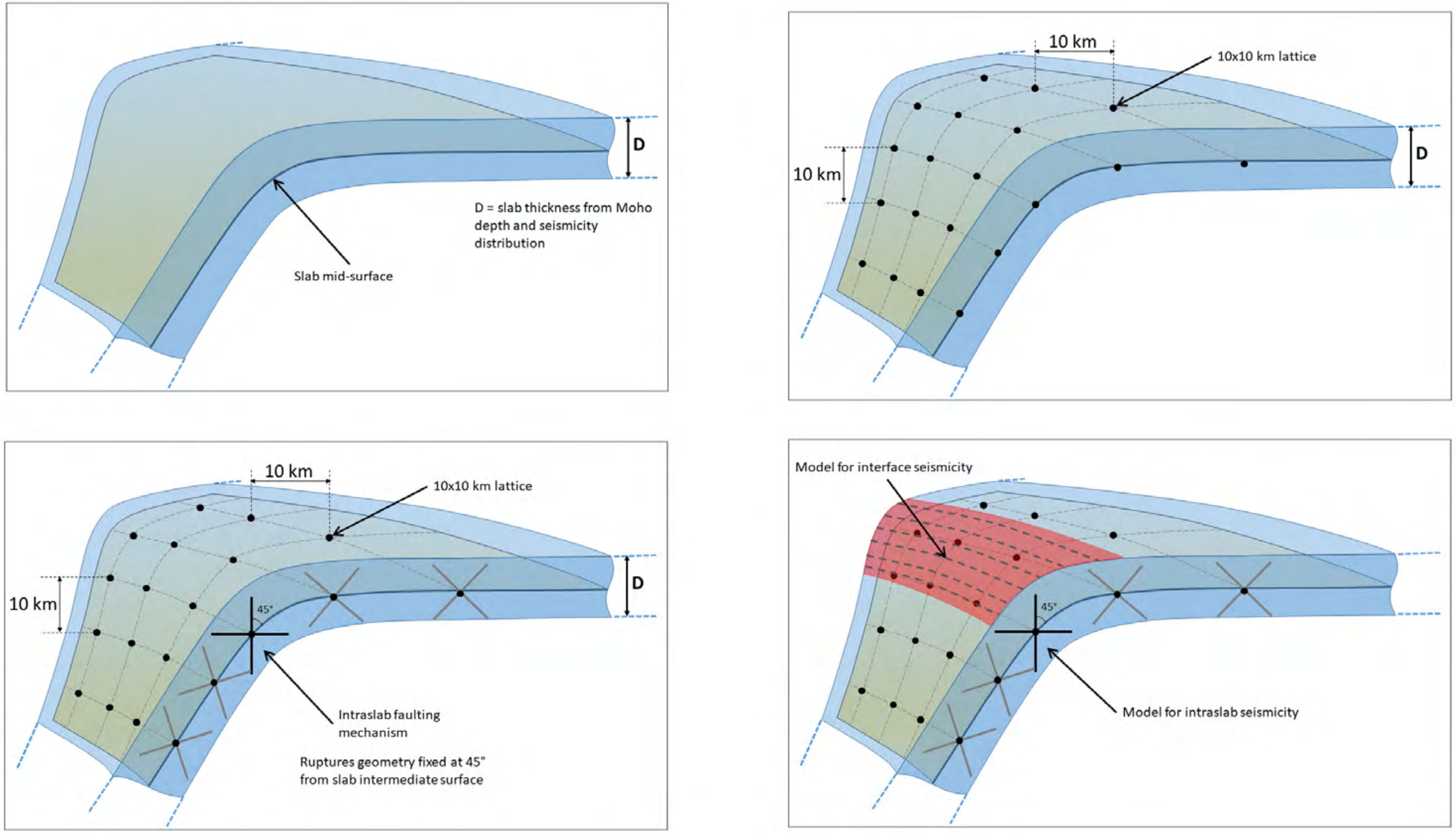




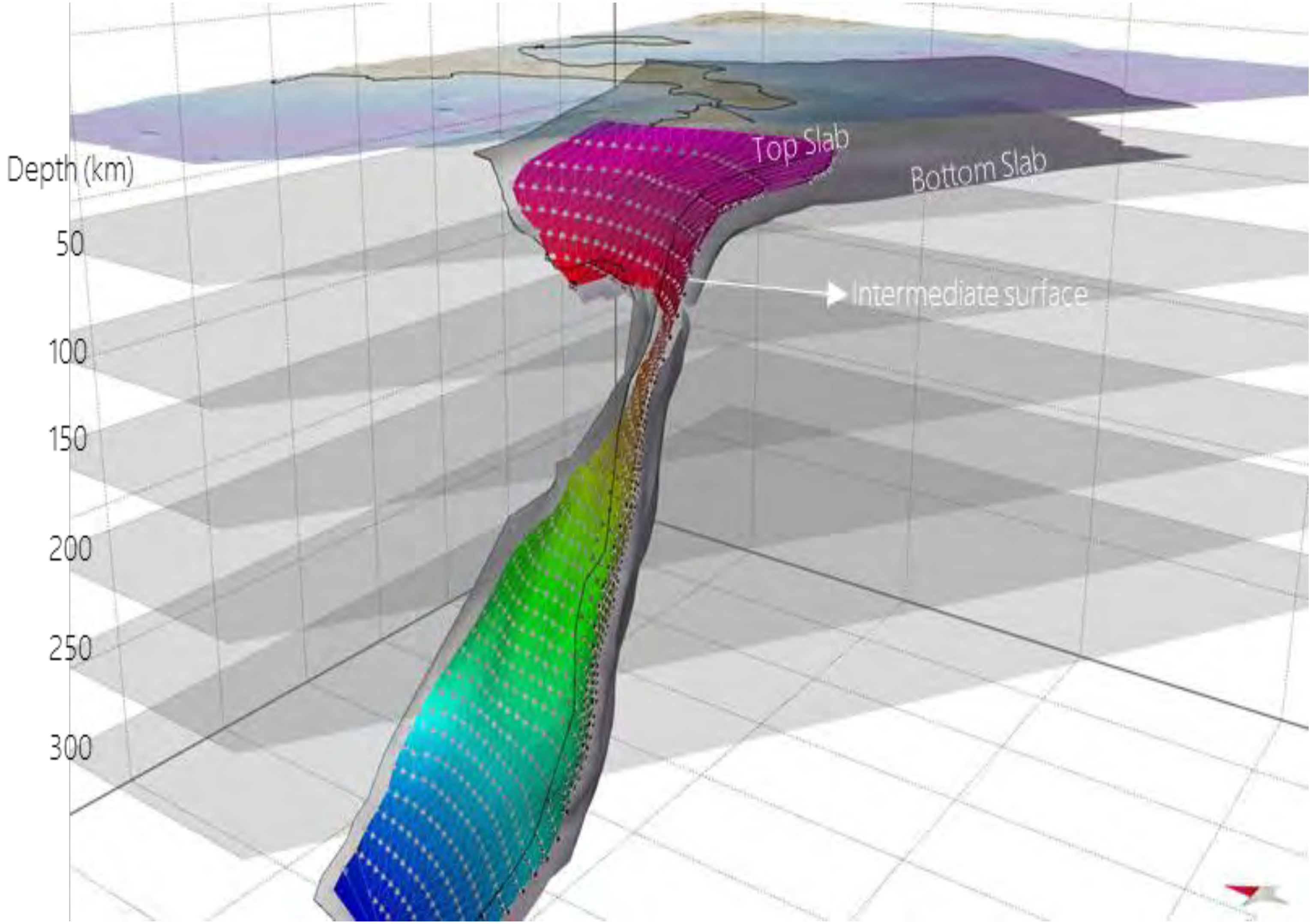


Maesano et al., 2017, SREP

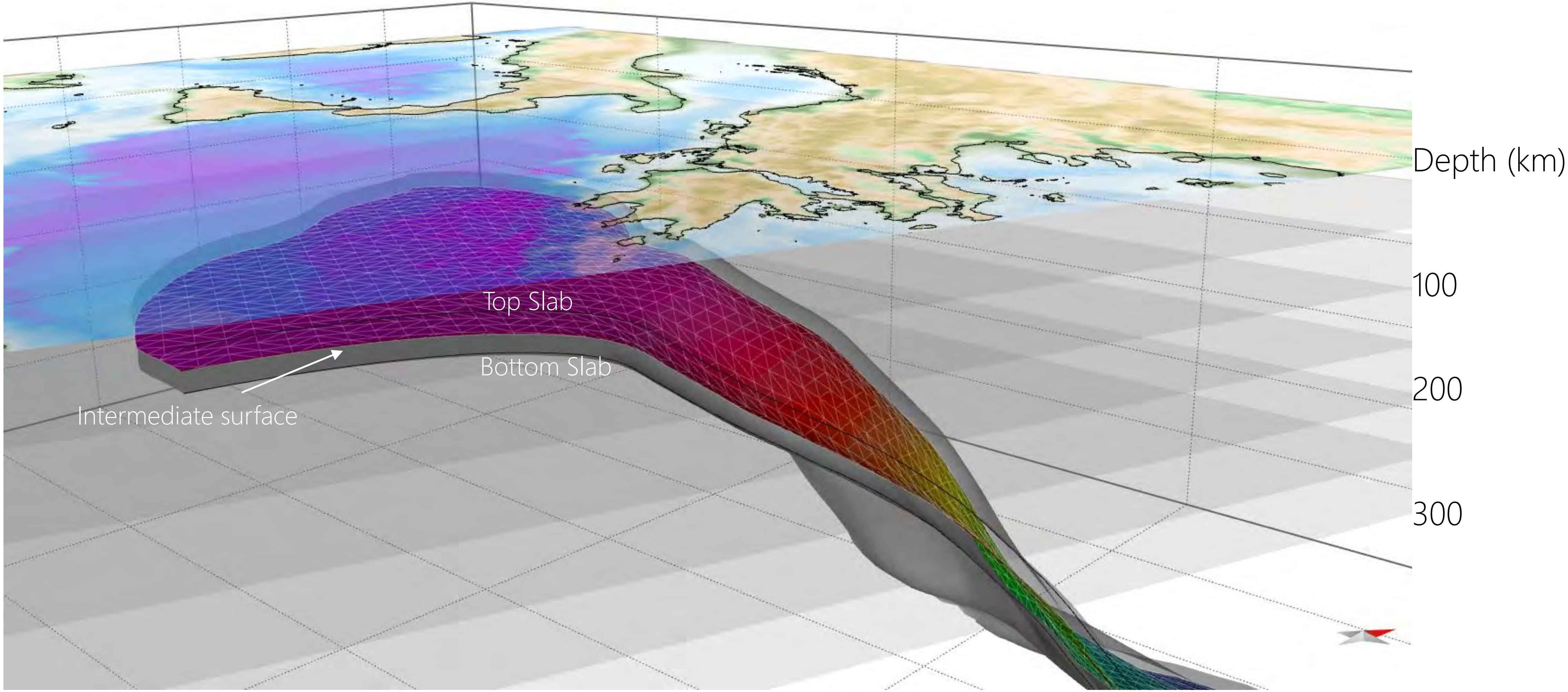

Slab top surface reconstructed
using data from
• geology,
• exploration geophysics,
• seismicity,
• tomography,
• etc..
• Main slope change
• Contact with softer sediments
• Splay-fault branching
• Moho depth of the upper plate
• 350° isotherm
• Seismicity cutoff
Seismic interface
Depth contours


D
D = slab thickness from Moho depth and seismicity distribution
Slab mid-surface
10 km
10x10 km lattice
10 km
D
10 km
10x10 km lattice
10 km
D
45°
Intraslab faulting mechanism
Ruptures geometry fixed at 45° from slab intermediate surface
Model for interface seismicity
45°
Model for intraslab seismicity

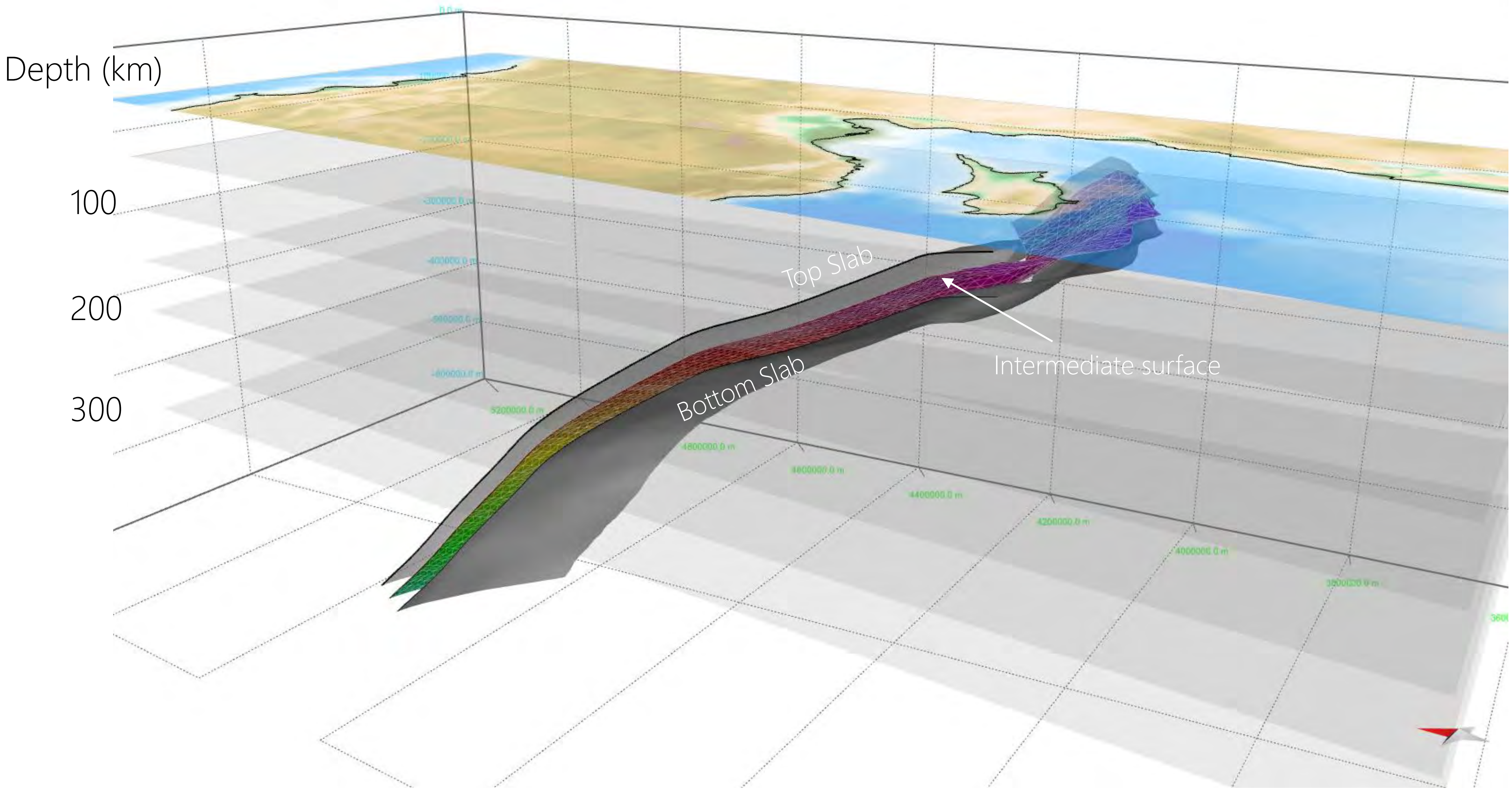
Calabrian Arc



Hellenic Arc

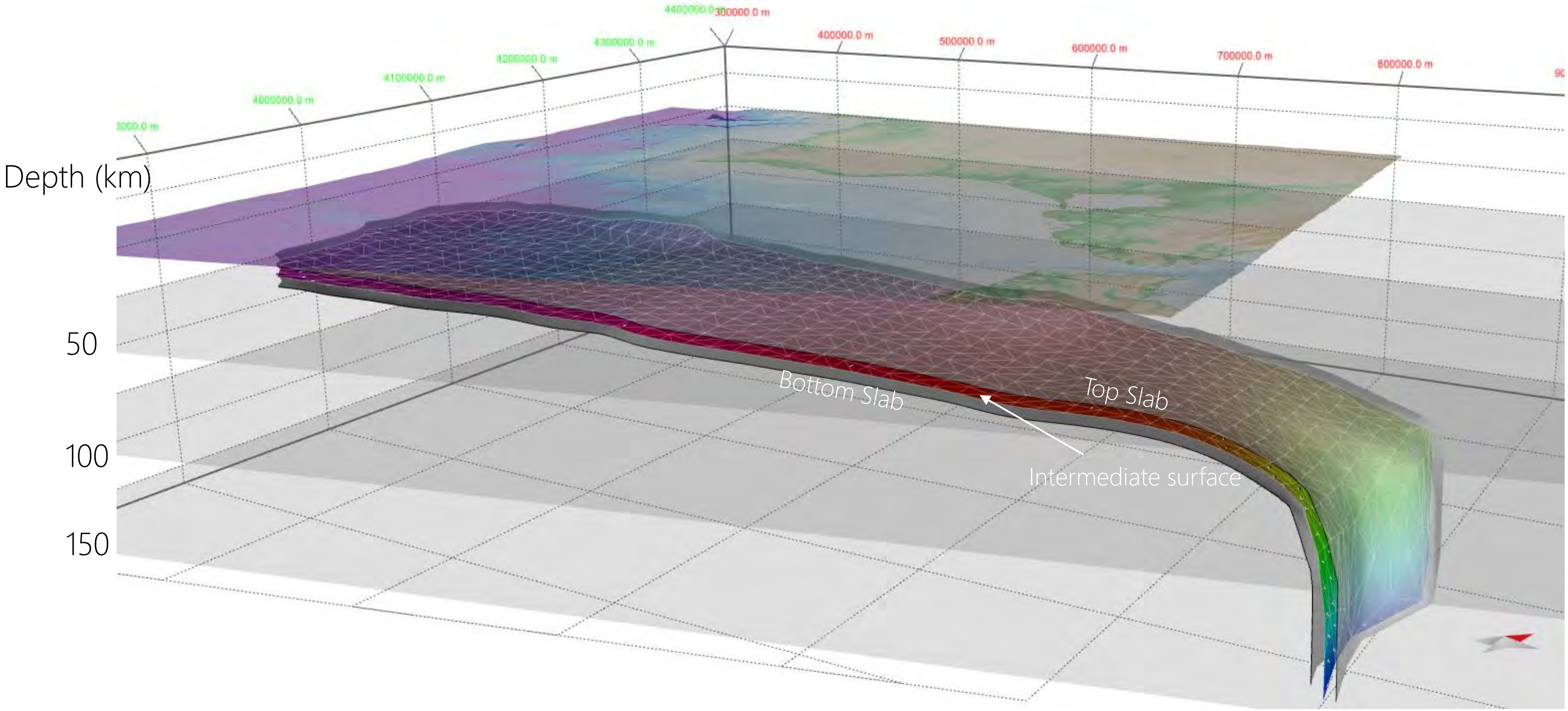


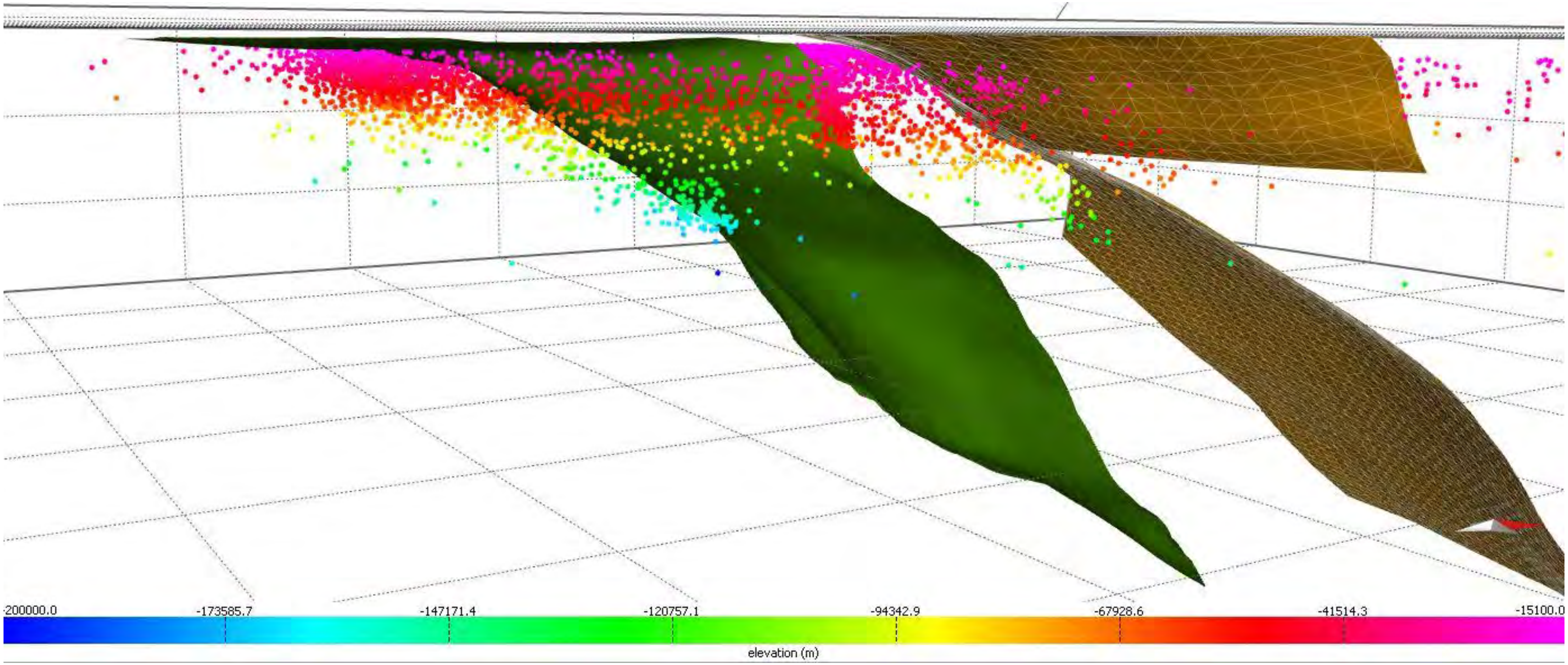
Cyprus Arc



Depth (km)
100
200
300
Top Slab
Intermediate surface
Bottom Slab

Gibraltar Arc




-200000.0
-173585.7
-147171.4
-120757.1
-94342.9
-67928.6
-41514.3
-15100.0
elevation (m)

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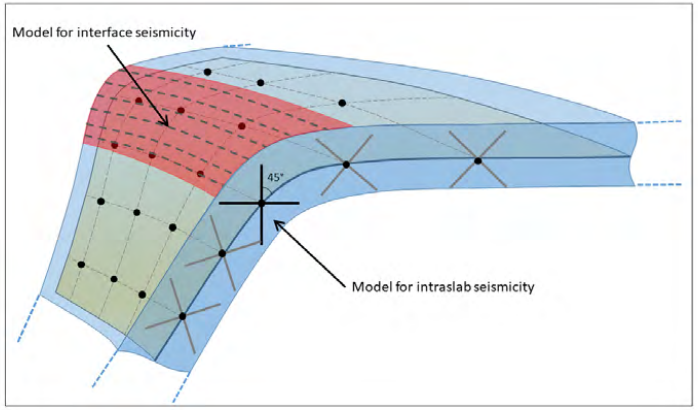
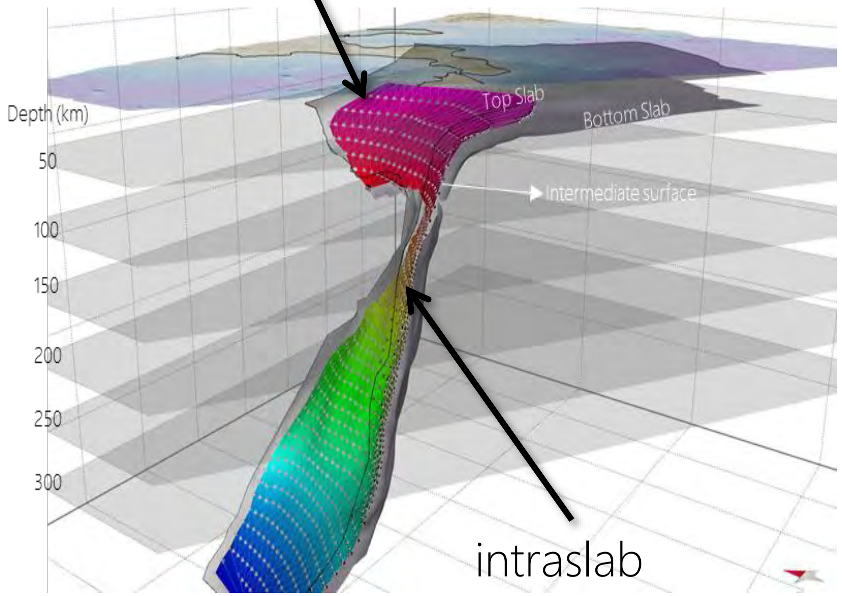
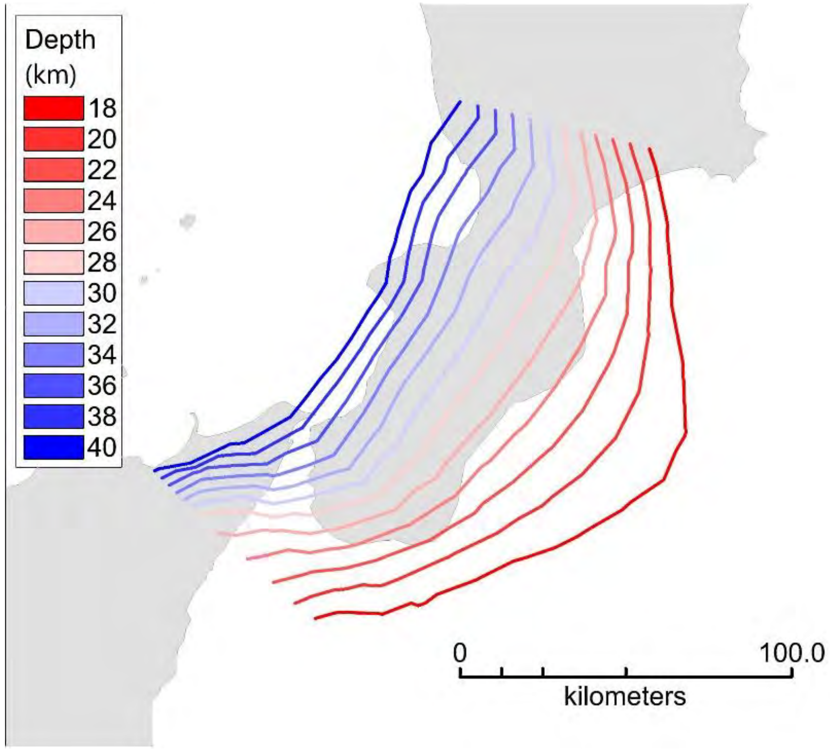
Two types of seismicity in the subduction zone



interface seismicity



intraslab seismicity



Intraslab

- D = slab thickness from Moho depth and seismicity distribution
- Node separation = 10 km
- Ruptures modeled at 45° to slab local dip

Interface

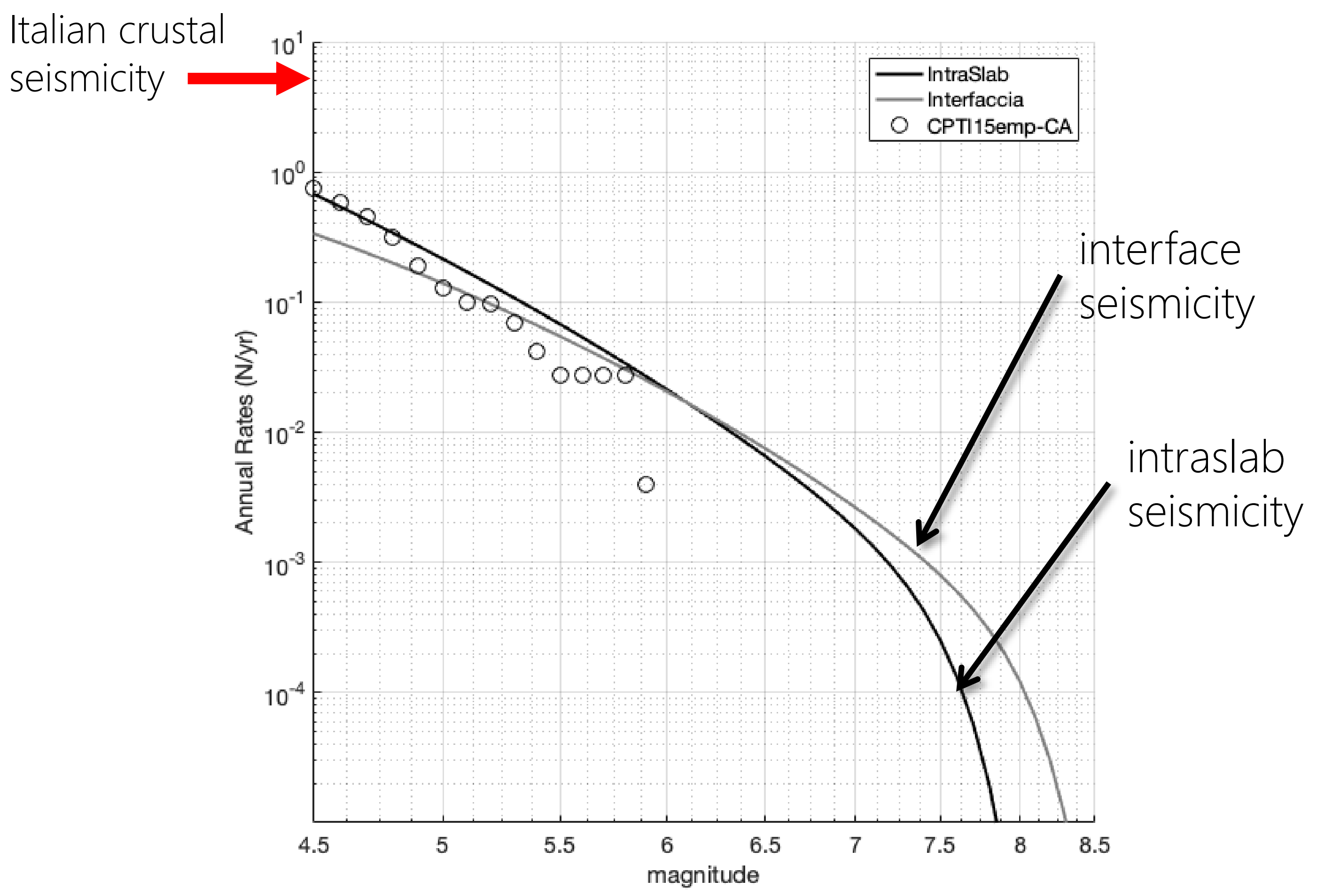
- Depth between 18 km (slab slope main change) and 40 km (upper-plate Moho intersection with slab)
- Contour interval = 2 km
- Ruptures follow the interface geometry

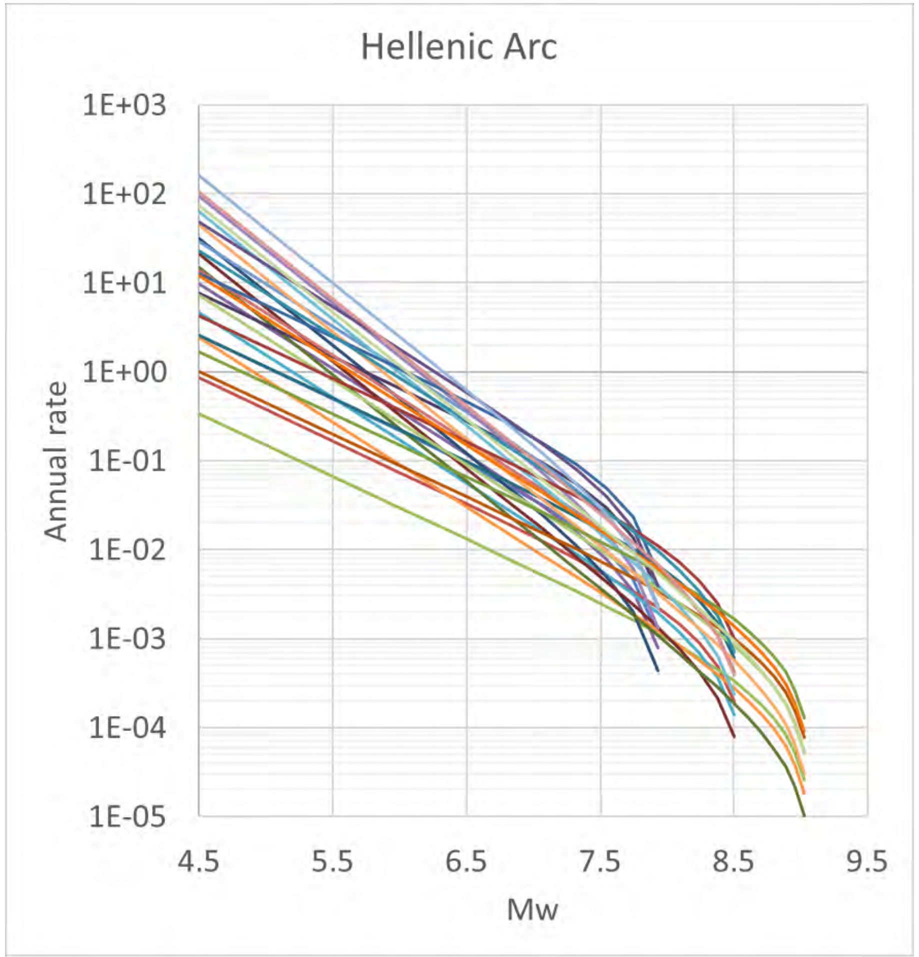
	Rel. Plate Vel.	Azimuth	Reference	Notes
Calabrian Arc				
Calabria	5 mm/y	100-140°	Devoti et al., 2008	
	1.5-1.6 mm/y		Carafa et al., 2018	if creeping
	2.7-3.0 mm/y		Carafa et al., 2018	if temporarily locked
Hellenic Arc				
Ionian Island	23 mm/y	229°	Hollenstein et al., 2008	
Western Hellenic Arc	35 mm/y	180-250°	Reilinger et al., 2006	
Eastern Hellenic Arc	10 mm/y	200-220°	Reilinger et al., 2006	
Cyprus Arc				
W of Antalya	23 mm/y		Howell et al., 2017	
NW of Paphos fault	12 mm/y		Howell et al., 2017	
	18 mm/y	200-220°	Reilinger et al., 2006	
	8-9 mm/y	200-230°	Wdowinsky et al., 2006	
	5-8 mm/y		Noquet, 2012	
SE of Paphos fault	7-8 mm/y	200-230°	Wdowinsky et al., 2006	
Gibraltar Arc				
Gulf of Cadiz	0.3 mm/y		Palano et al., 2015	shortening across internal and external part of the arc
	1 mm/y		Stich et al., 2006	relative movement between SFER and LAGO, on either side of the external front
	2.6-4.4 mm/y		Stich et al., 2006	westward motion of the arc relative to stable Europe

Activity rates

Interface: from convergence rates and coupling from Chistophersen et al. (2015), Davies et al. (2017), Carafa et al. (2018)

Intraslab: from seismicity (depth > 40 km) CPTI15 (Rovida et al., 2016)

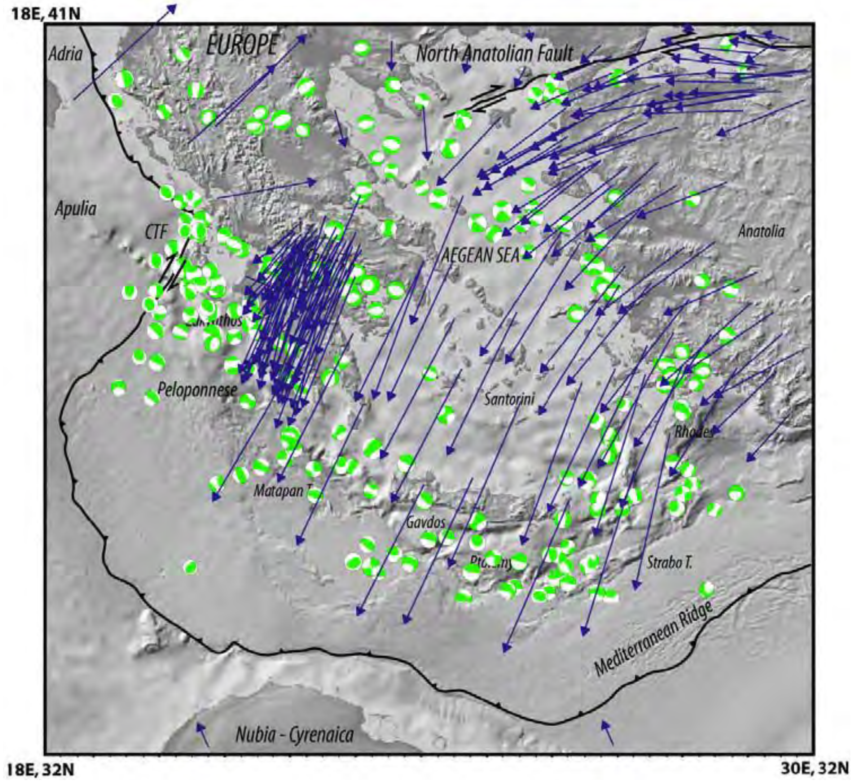




b = 0.70, 0.95, 1.20
c = 0.2, 0.6, 1.0
Mx = 8.0, 8.6, 9.1

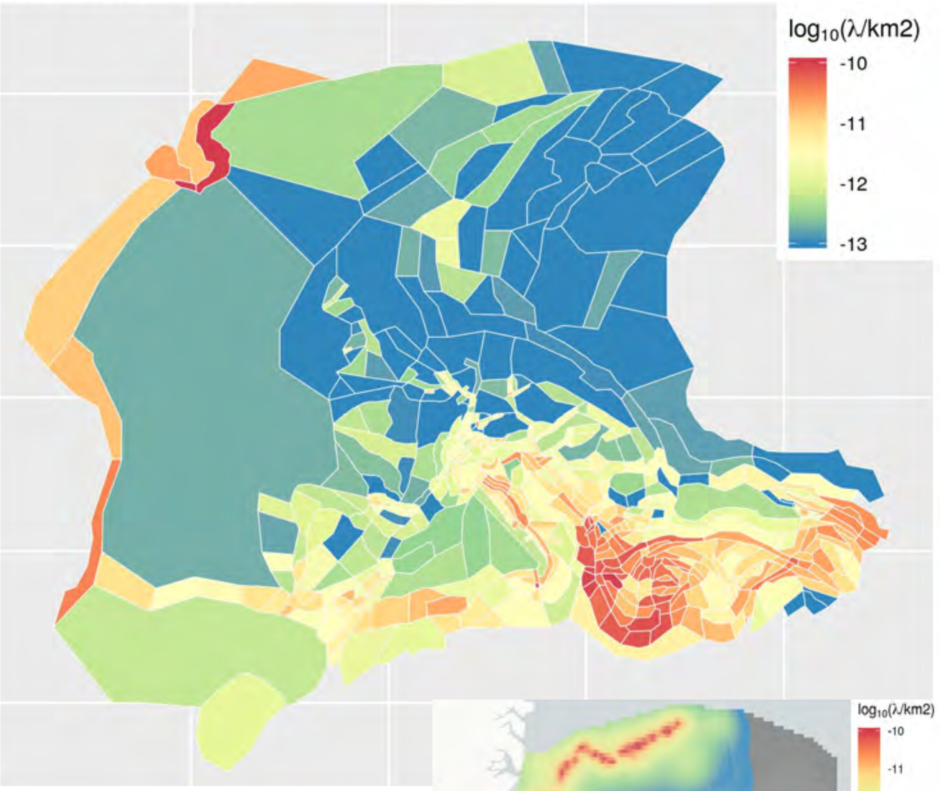
Data of convergence rates, b-value, coupling, and Mmax from Davies et al. (2018)

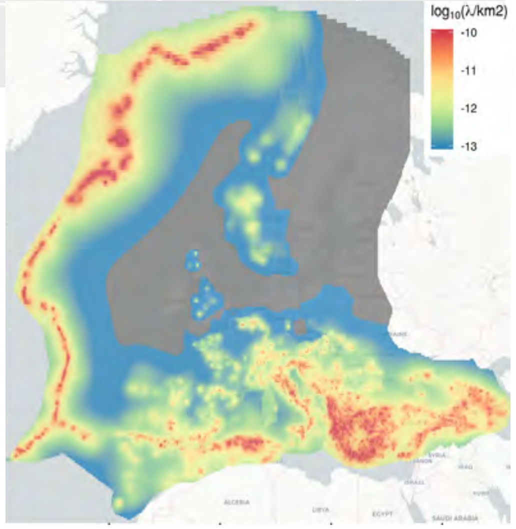
Truncated MFD model from Kagan (2002)



GPS velocities in the Hellenic Arc, figure from Ganas and Parsons (2009)

ESHM 2020: European Seismic Source Model





S. **H**iemer
ETH Zurich

and the SERA JRA3 Working Group: L. Danciu, S. Nandan, G. Weatherill, R. Basili, A. Rovida, C. Beauval, S. Villanova, K. Sesetyan, P.-Y. Bard, F. Cotton, S. Wiemer, D. Giardini

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.

ESHM20: Scope

- Main goal:
  Construct a fully harmonized, cross-border European Seismogenic Source Model

- Build upon experience:
  ESHM20 Source Model as an update of the ESHM13 European Seismic Source Model

- Setting new standards in accessibility/transparency:
  www.efehr.org

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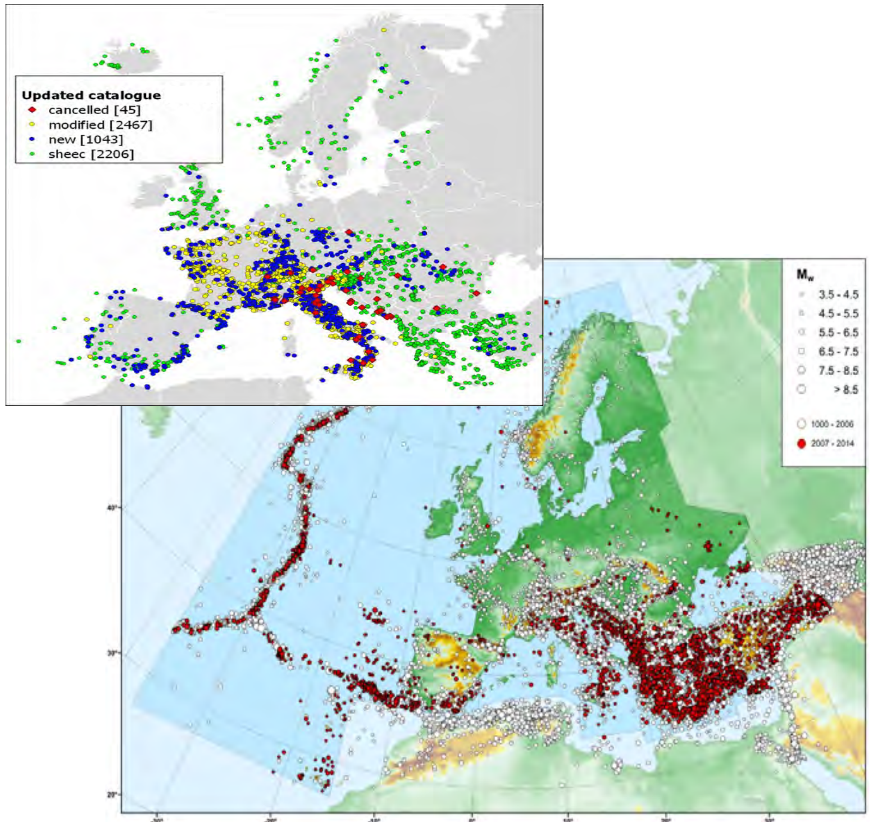
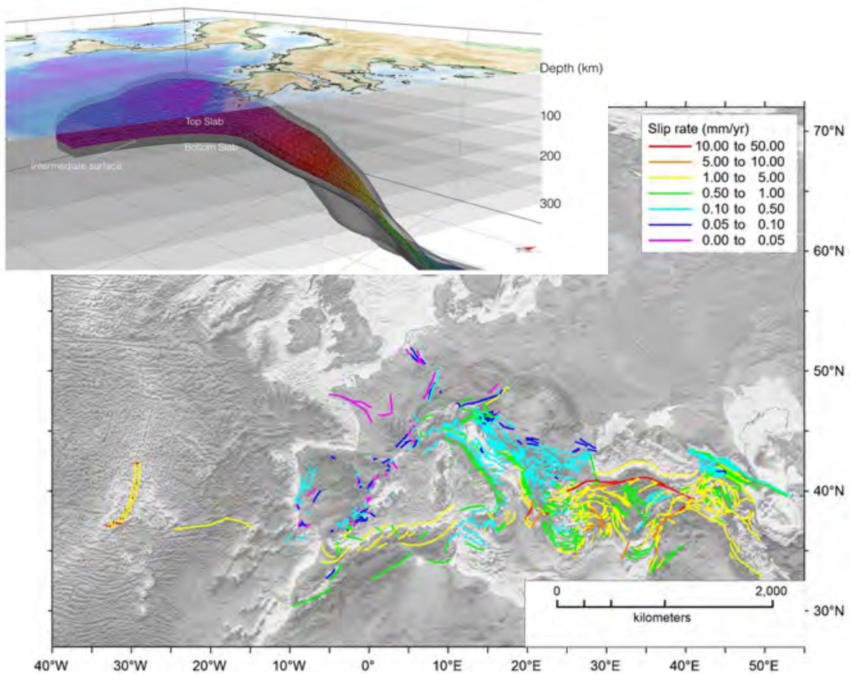
ESHM20: Input Data

- Harmonized Historical Catalog 1000-1900
  A. Rovida/ A. Antonucci (INGV)

- Harmonized Instrumental Catalog 1900-2014 (EMEC)
  G. Weatherill and Working Group (GfZ)

- Harmonized European crustal fault database and subduction zone data
  R. Basili and Working Group (INGV)





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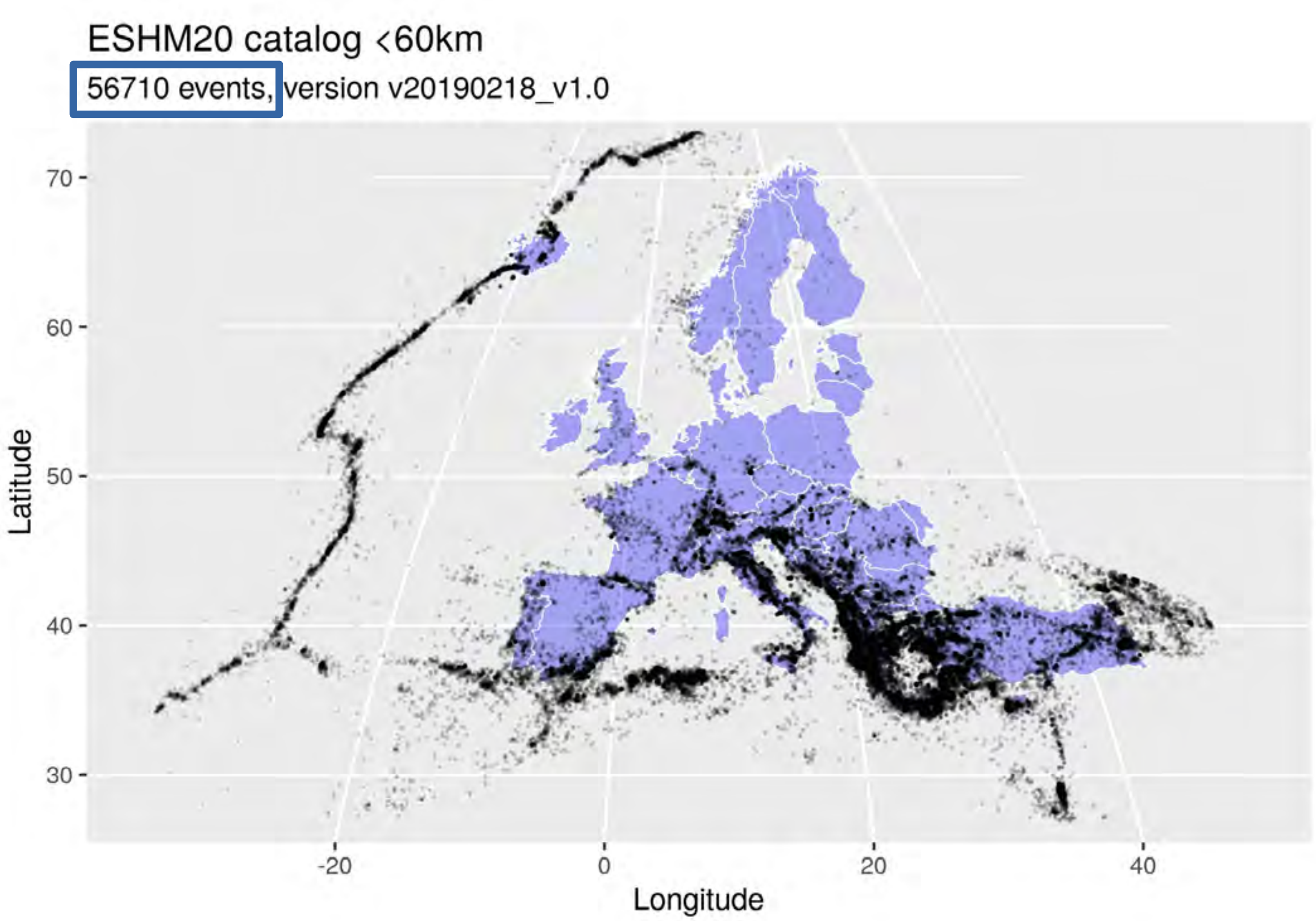
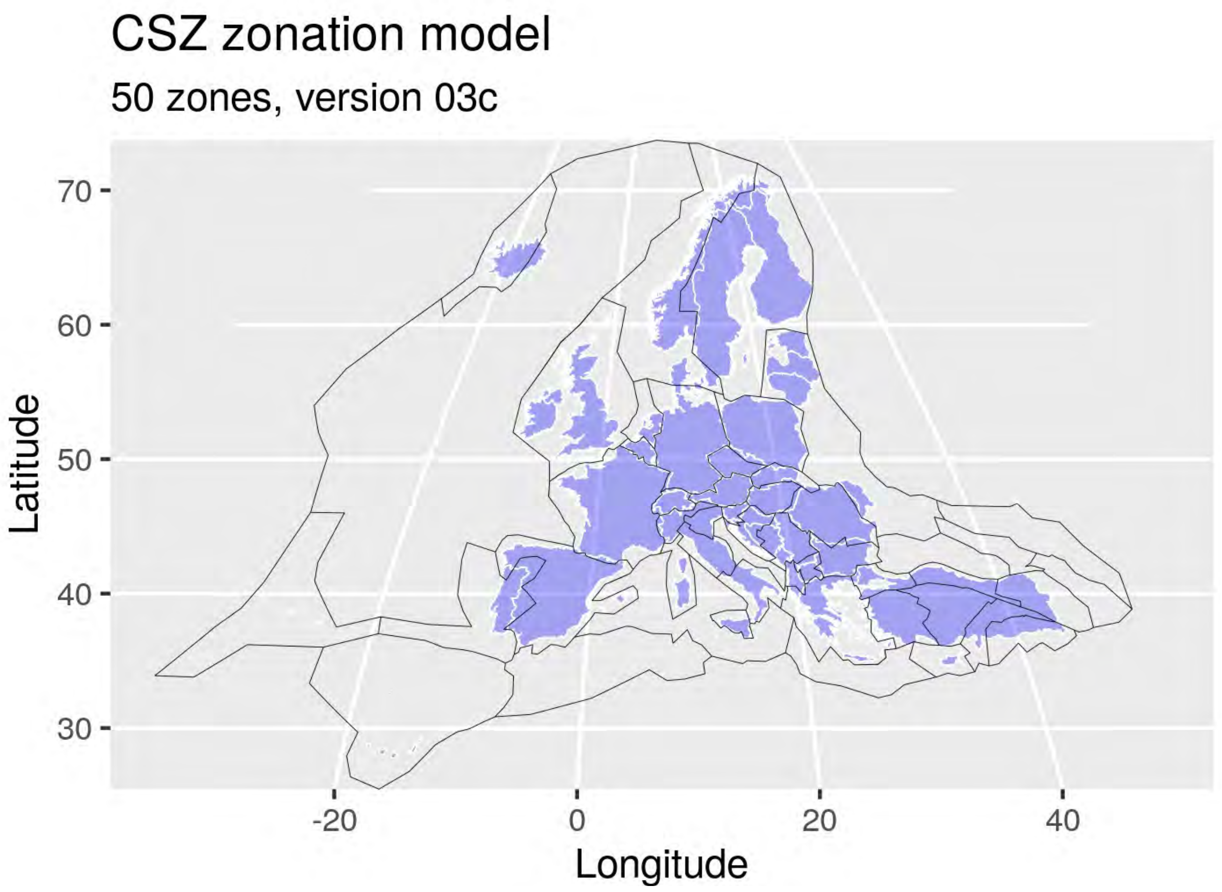
ESHM20: Catalog processing

- **(1) Seismicity Declustering**
  Remove seismicity clusters and identify all mainshock events that are independent of each other
- **(2) Magnitude of Completeness Assessment**
  Estimate temporal variation of Mc within predefined large-scale completeness superzones (CSZ)





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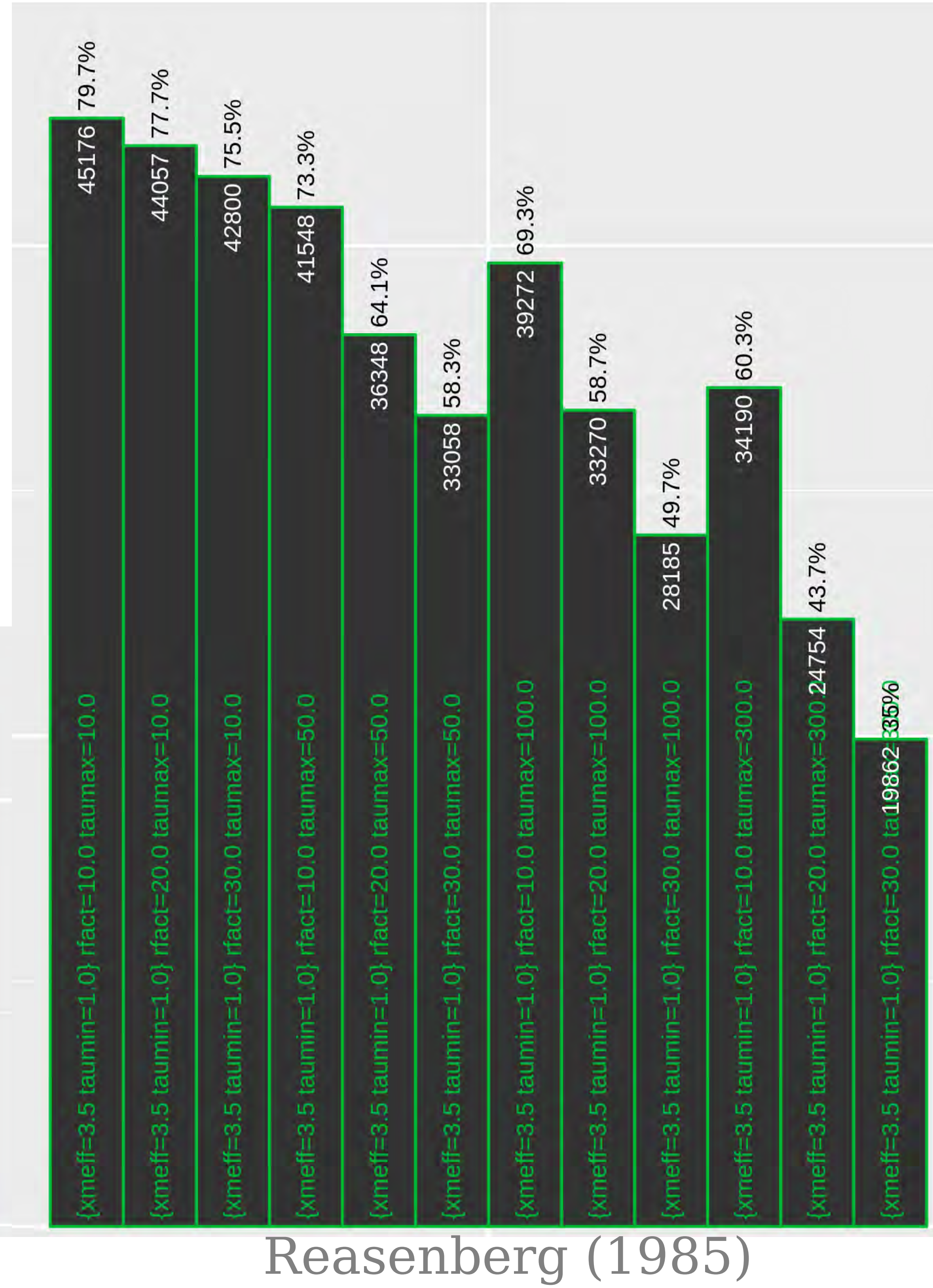
ESHM20: Declustering

- Objective:
  Create a mainshock catalog
  (stationary Poisson assumption)
- Process:
  Parameter sensitivity study
  considering a wide range of
  declustering algorithms
- Selection:
  Window-based Gruenthal Approach
  56710 Events → 23137 Mainshocks



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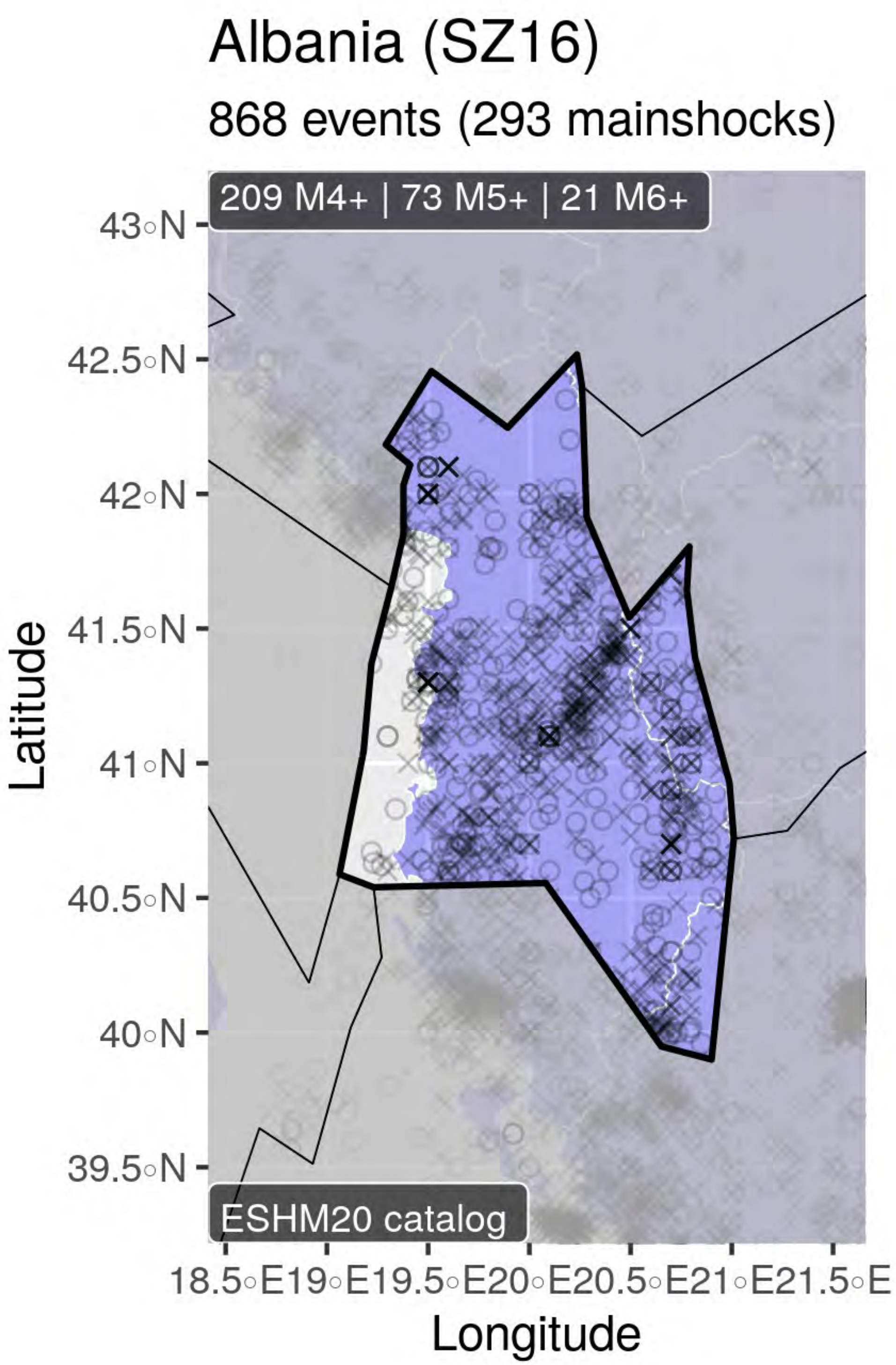
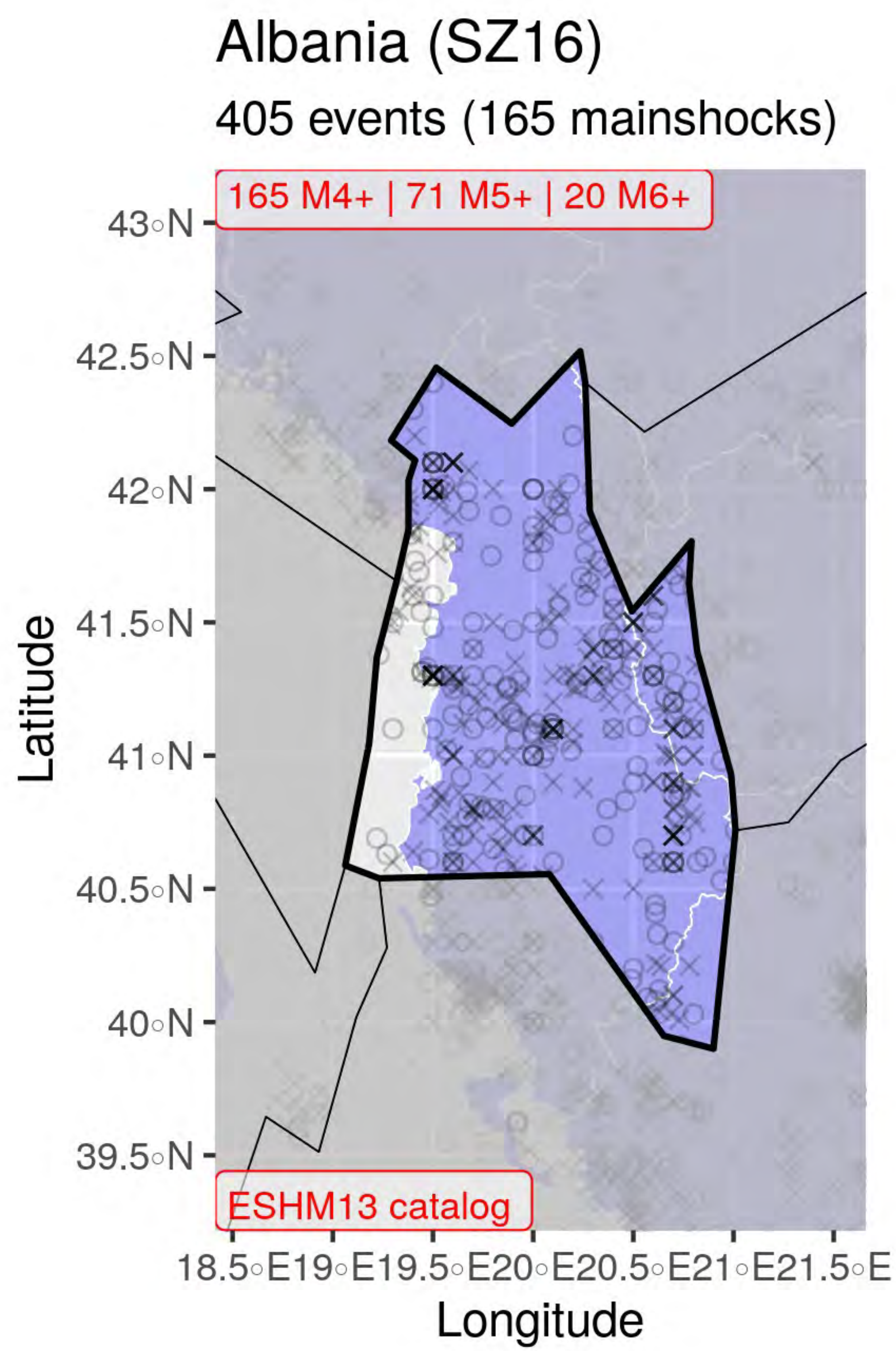
ESHM20: Catalog by country





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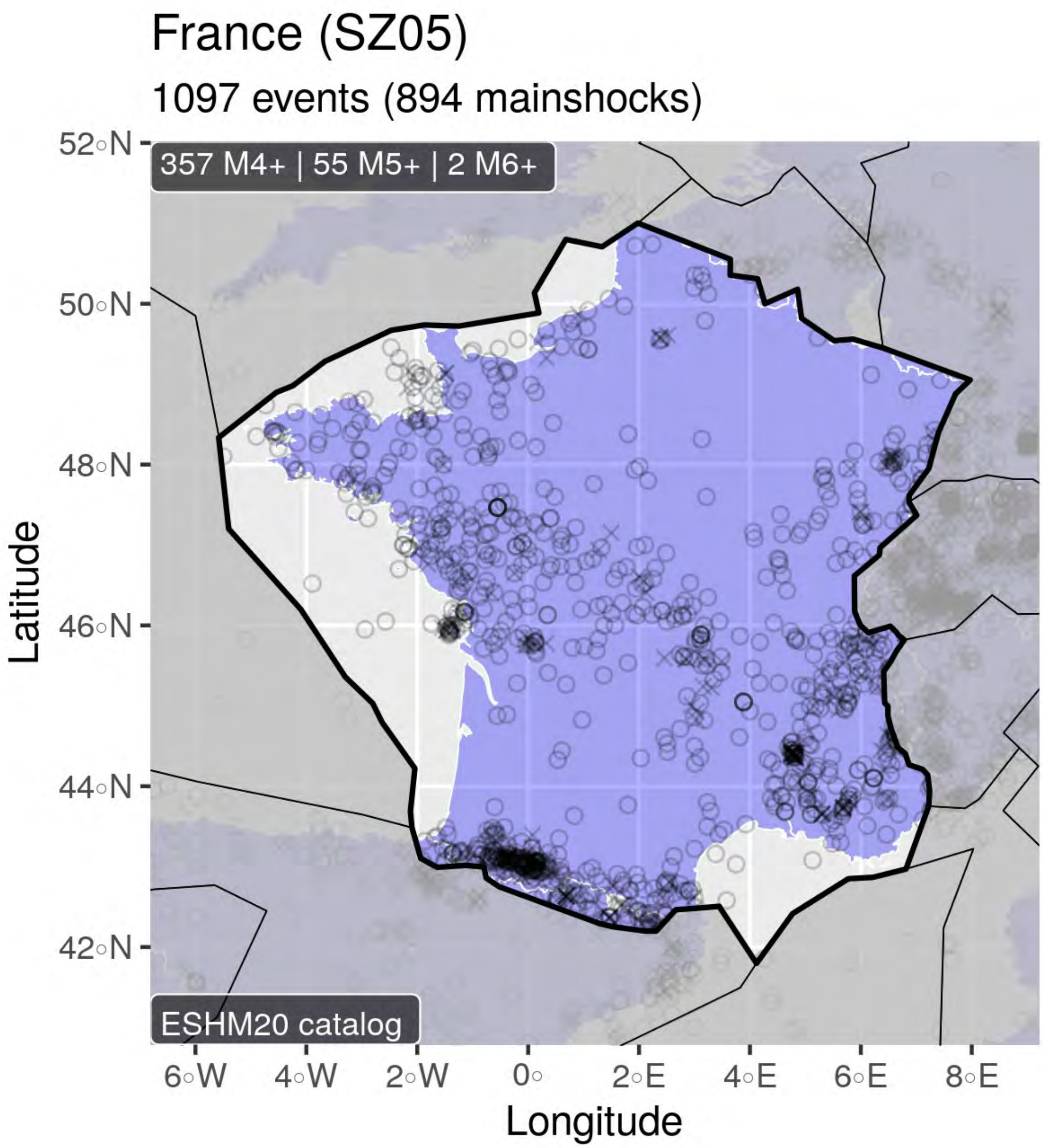

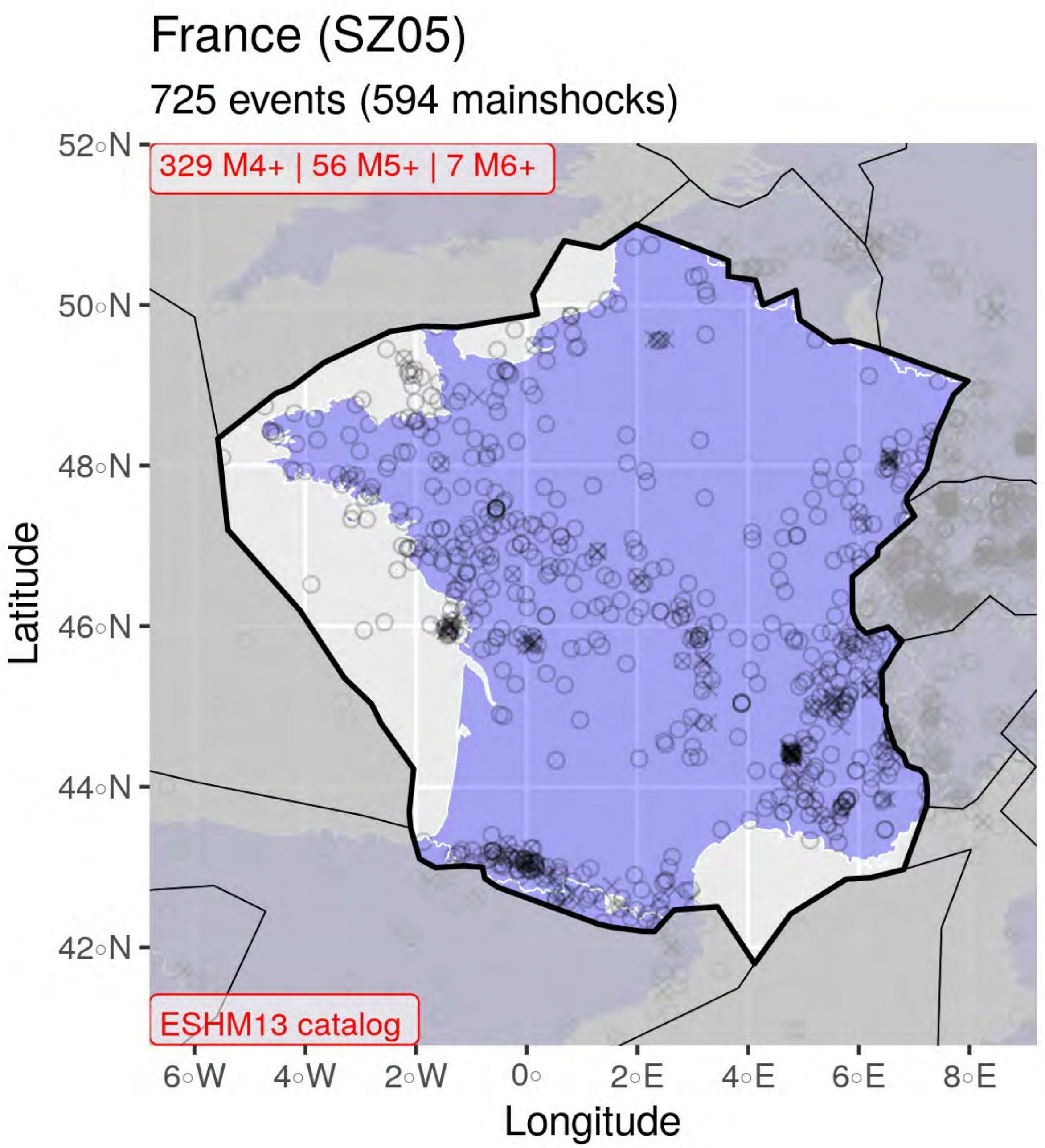

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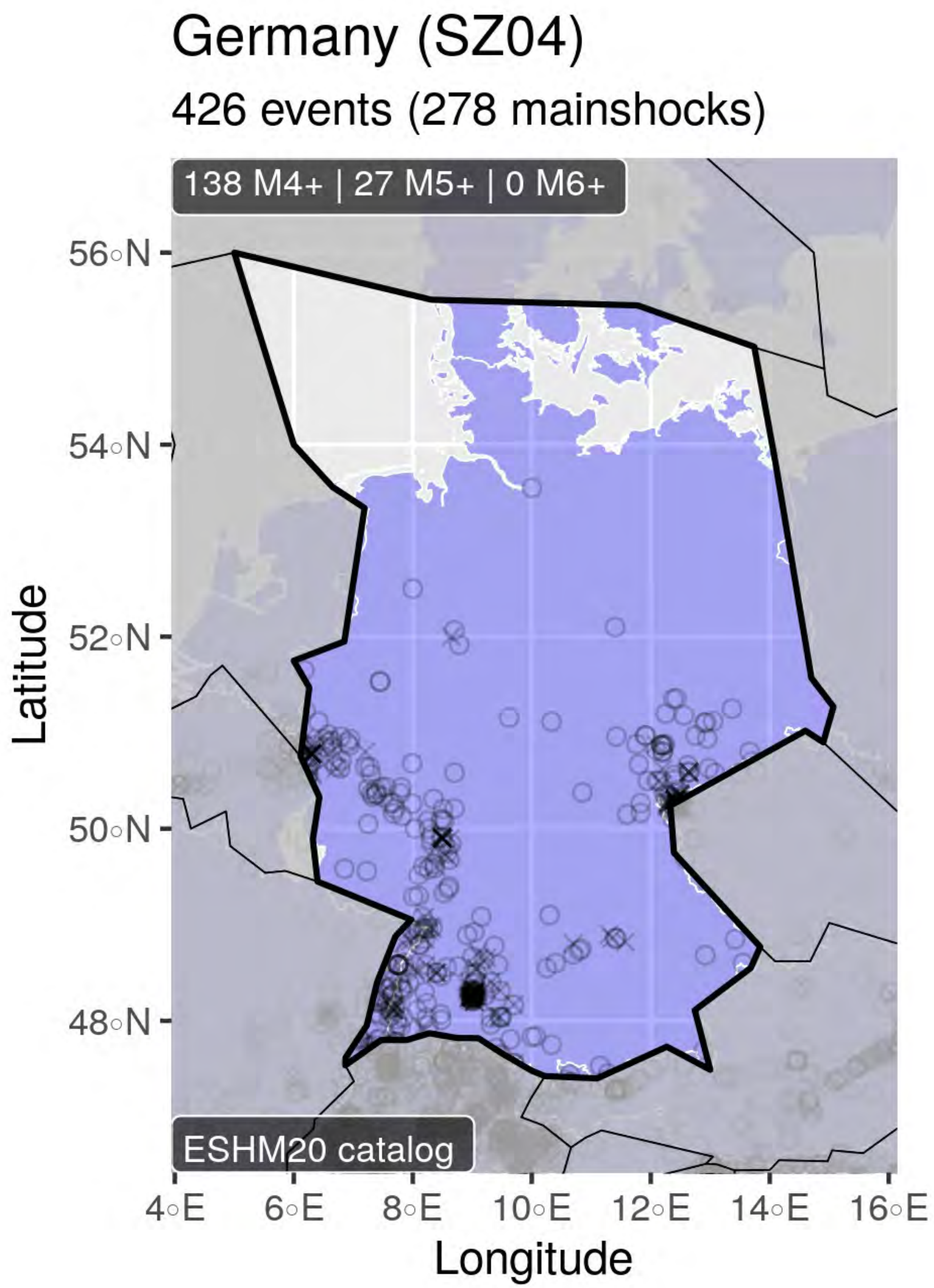

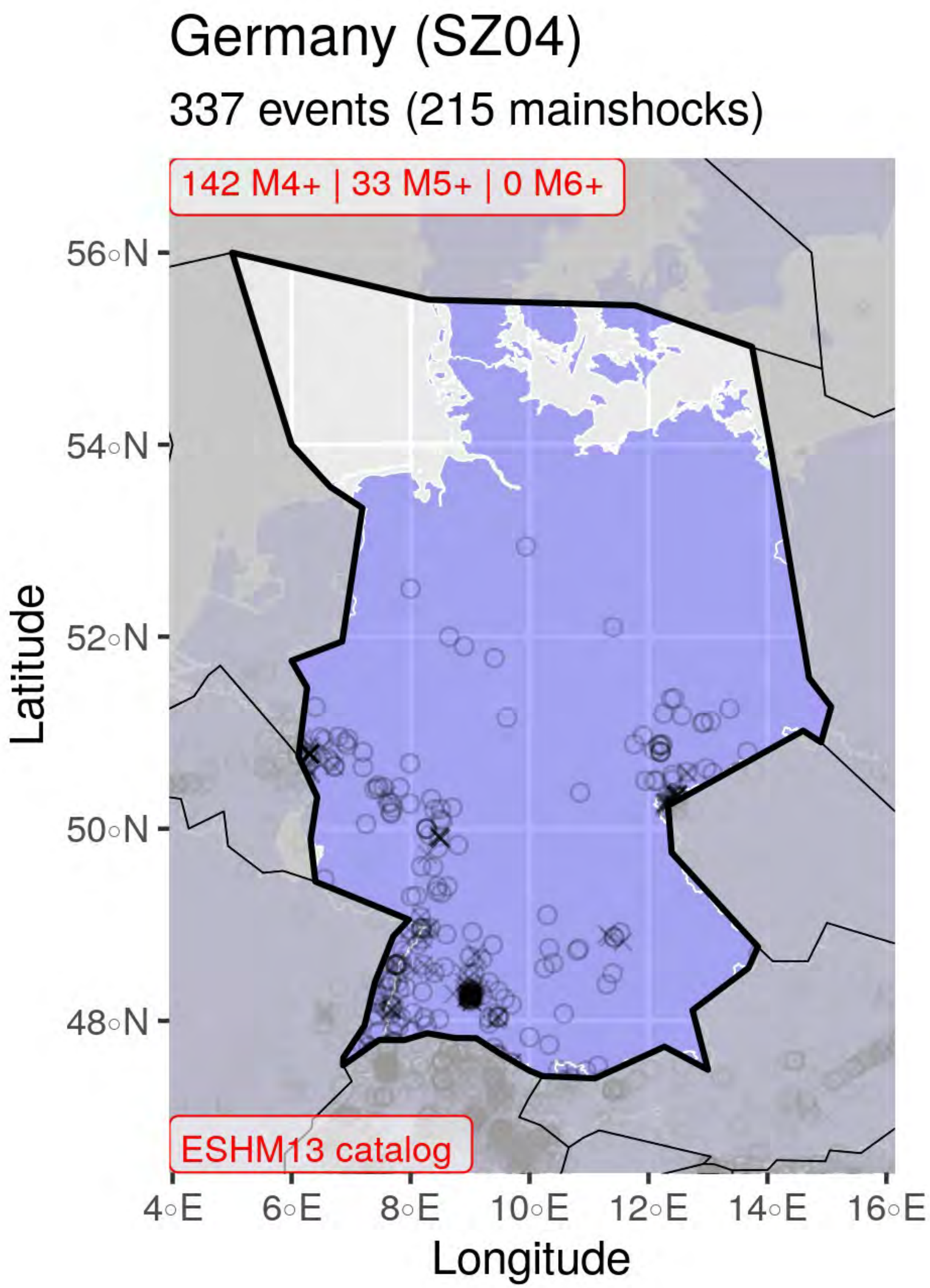

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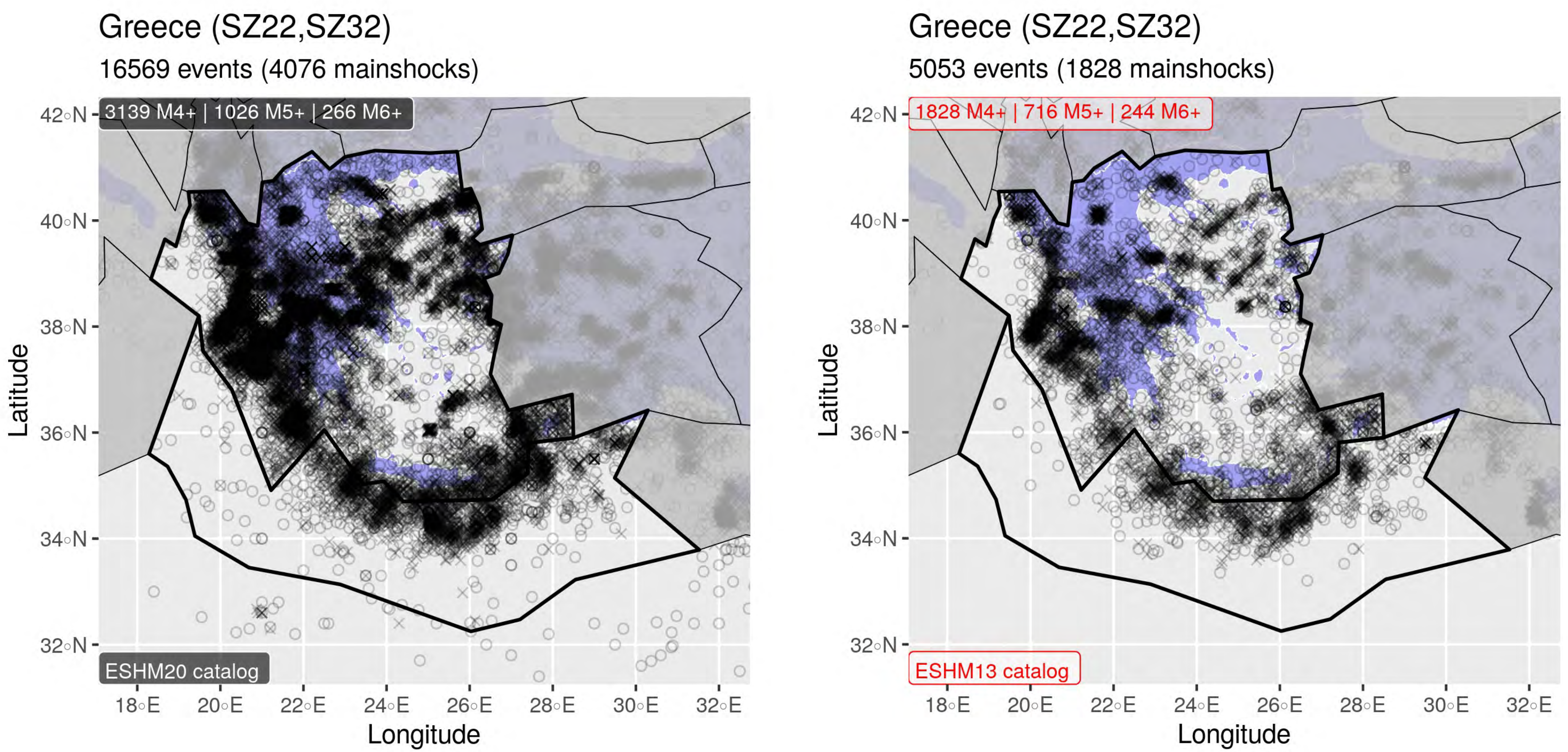

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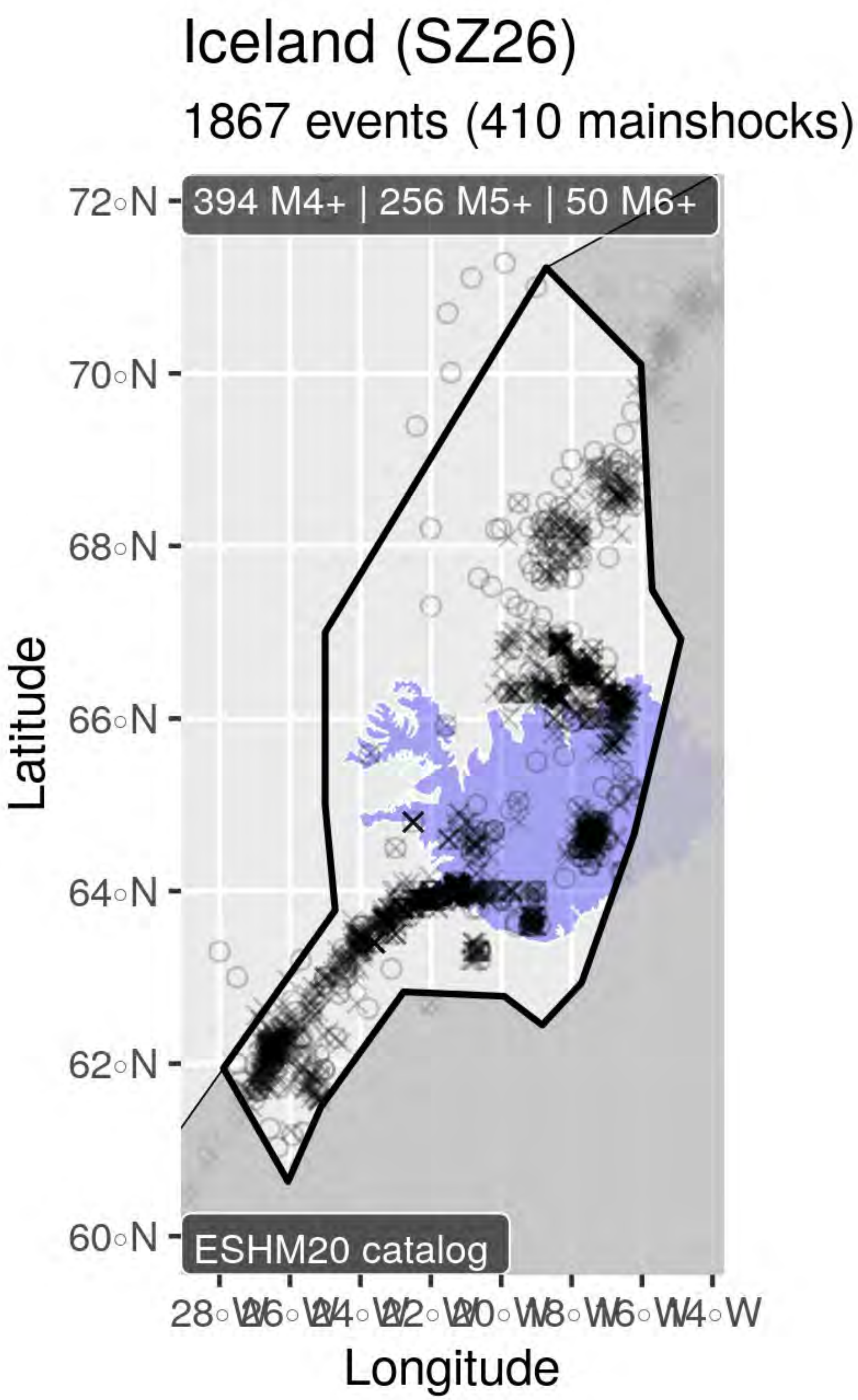

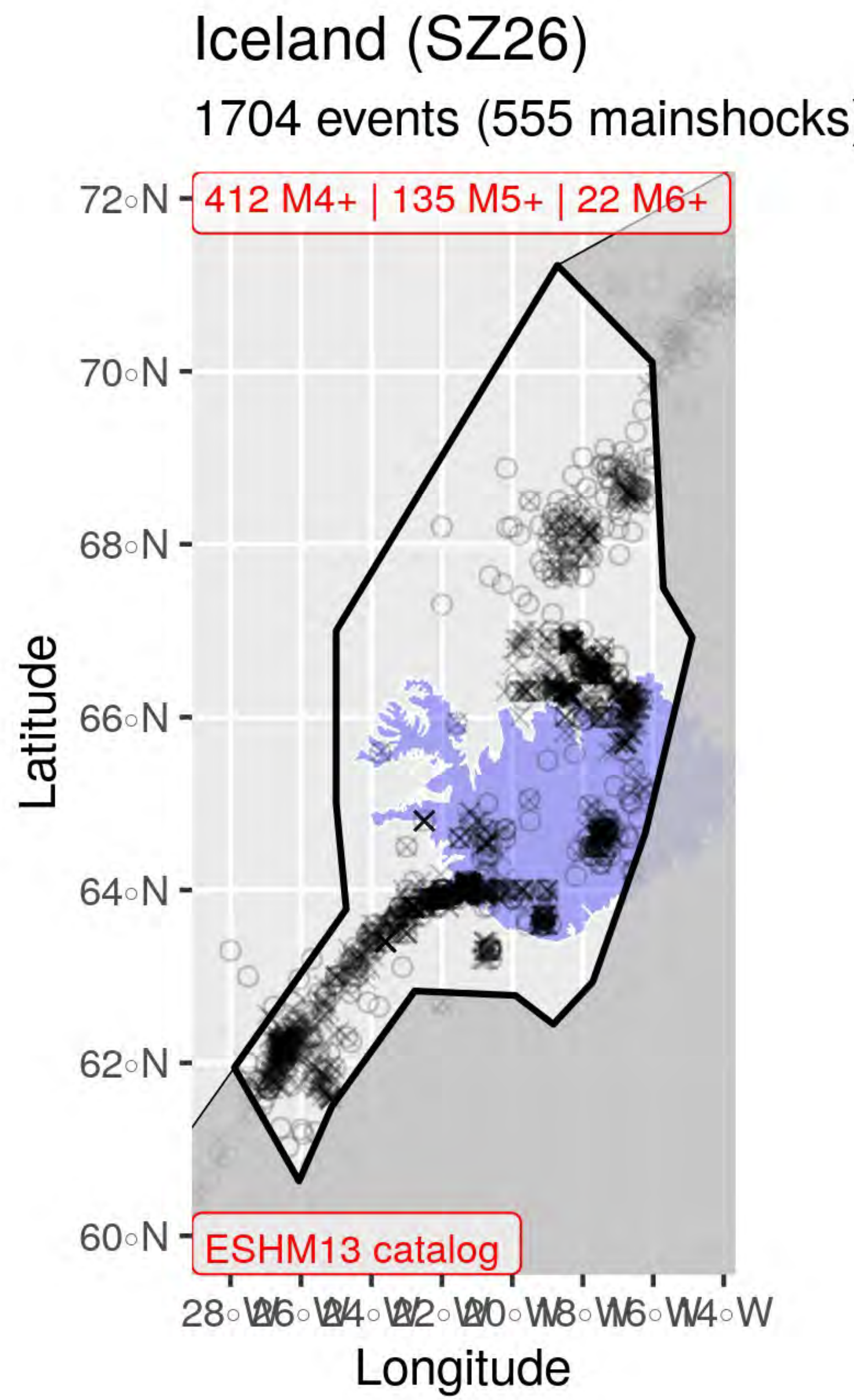

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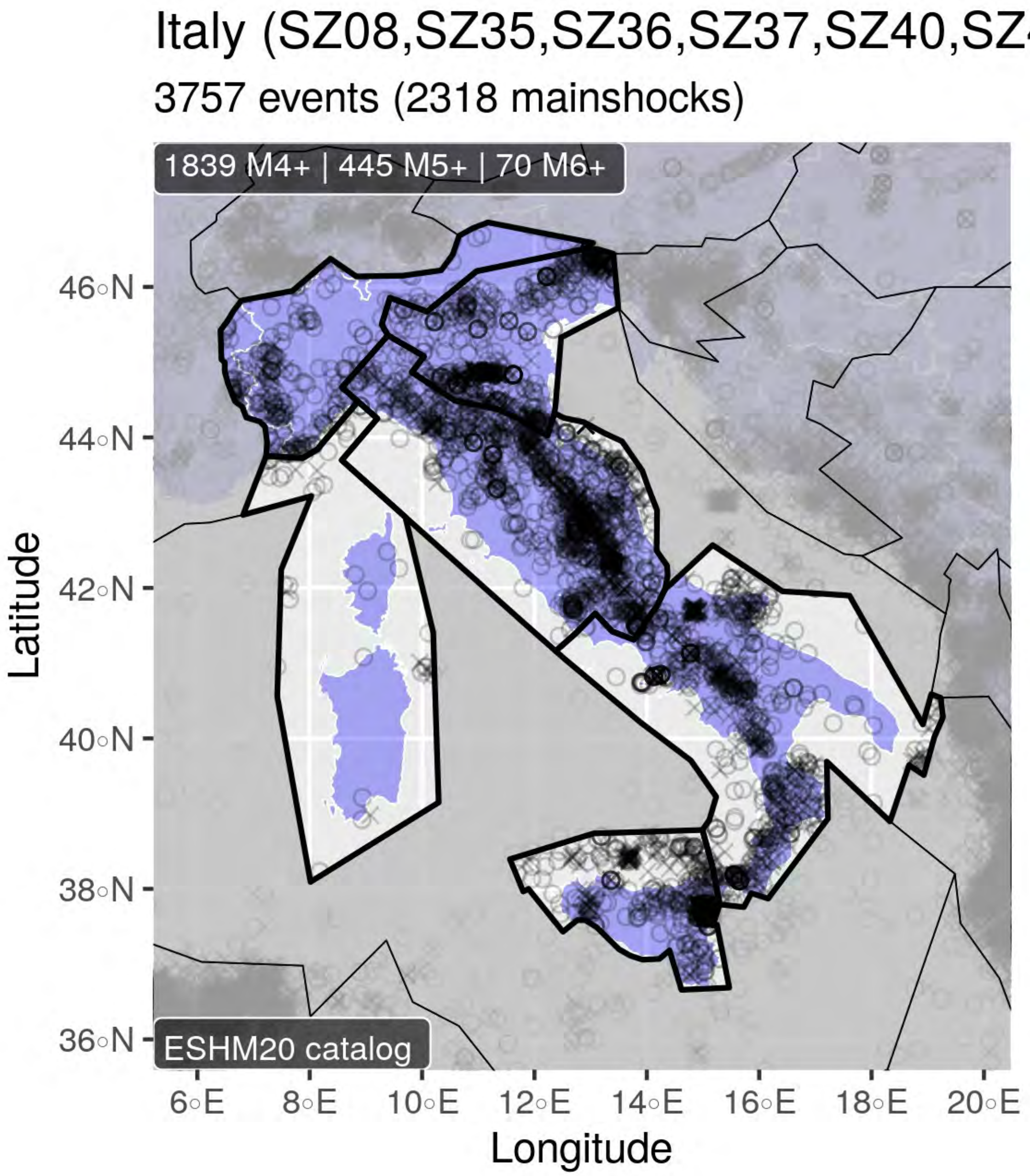

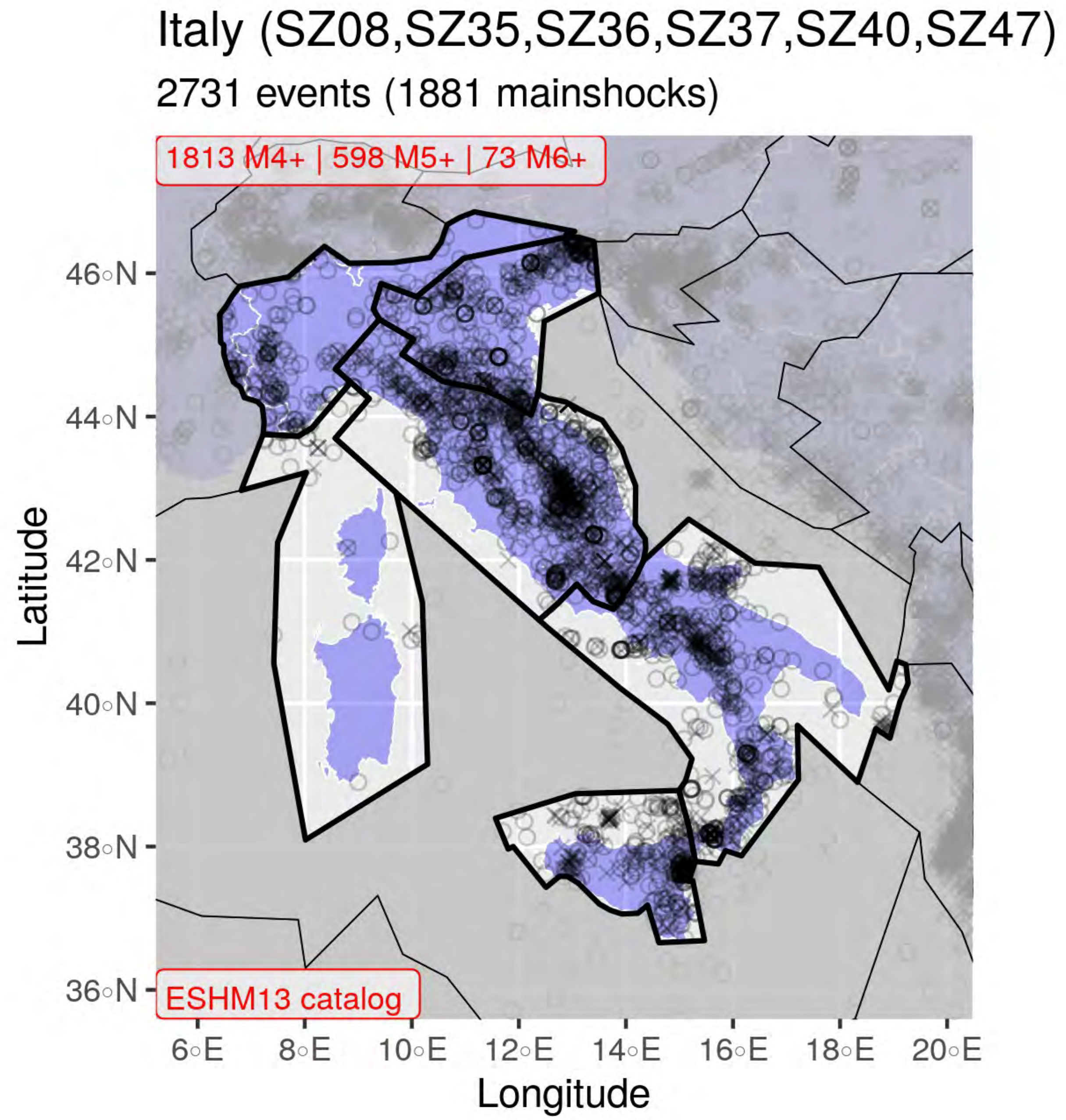

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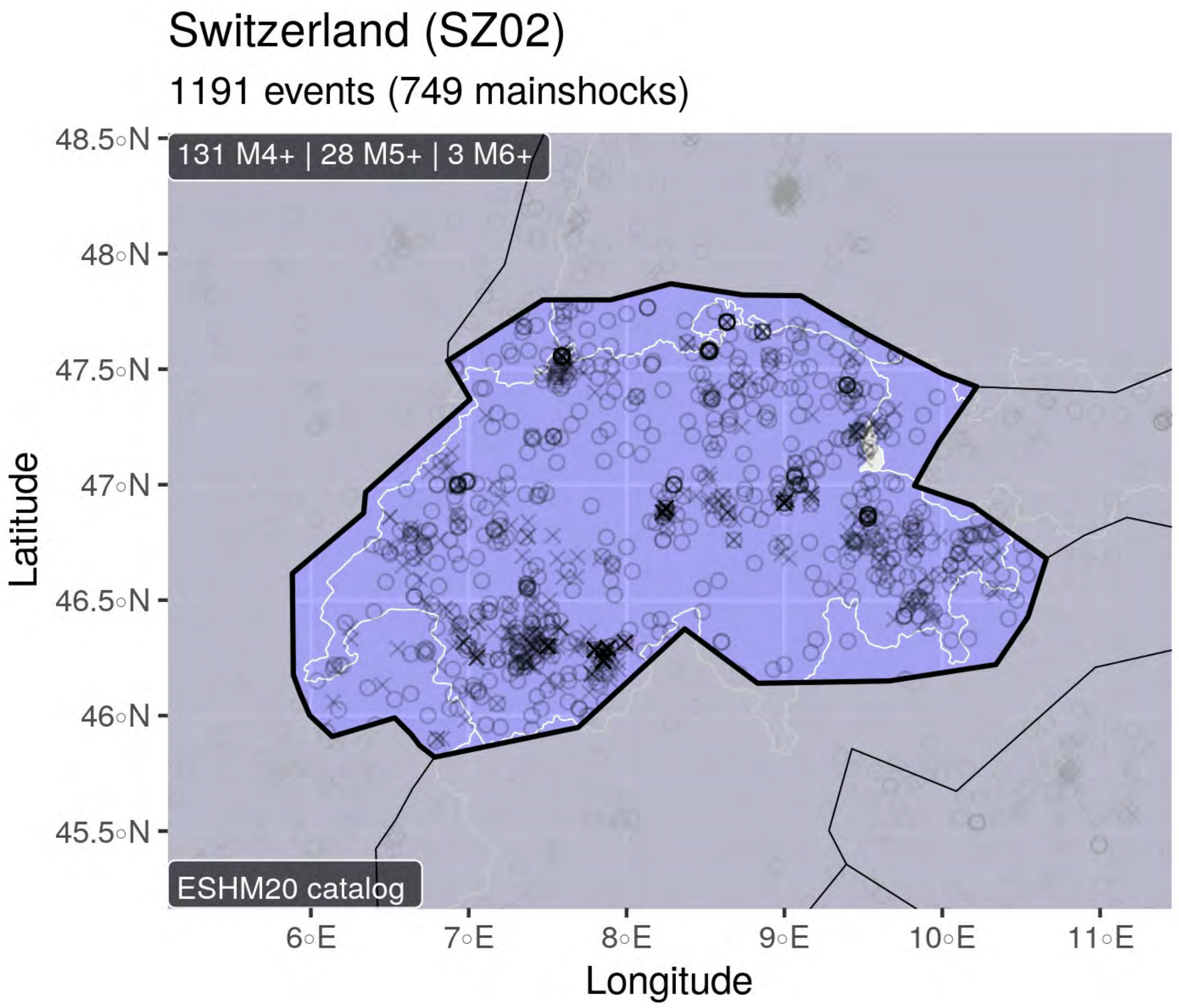

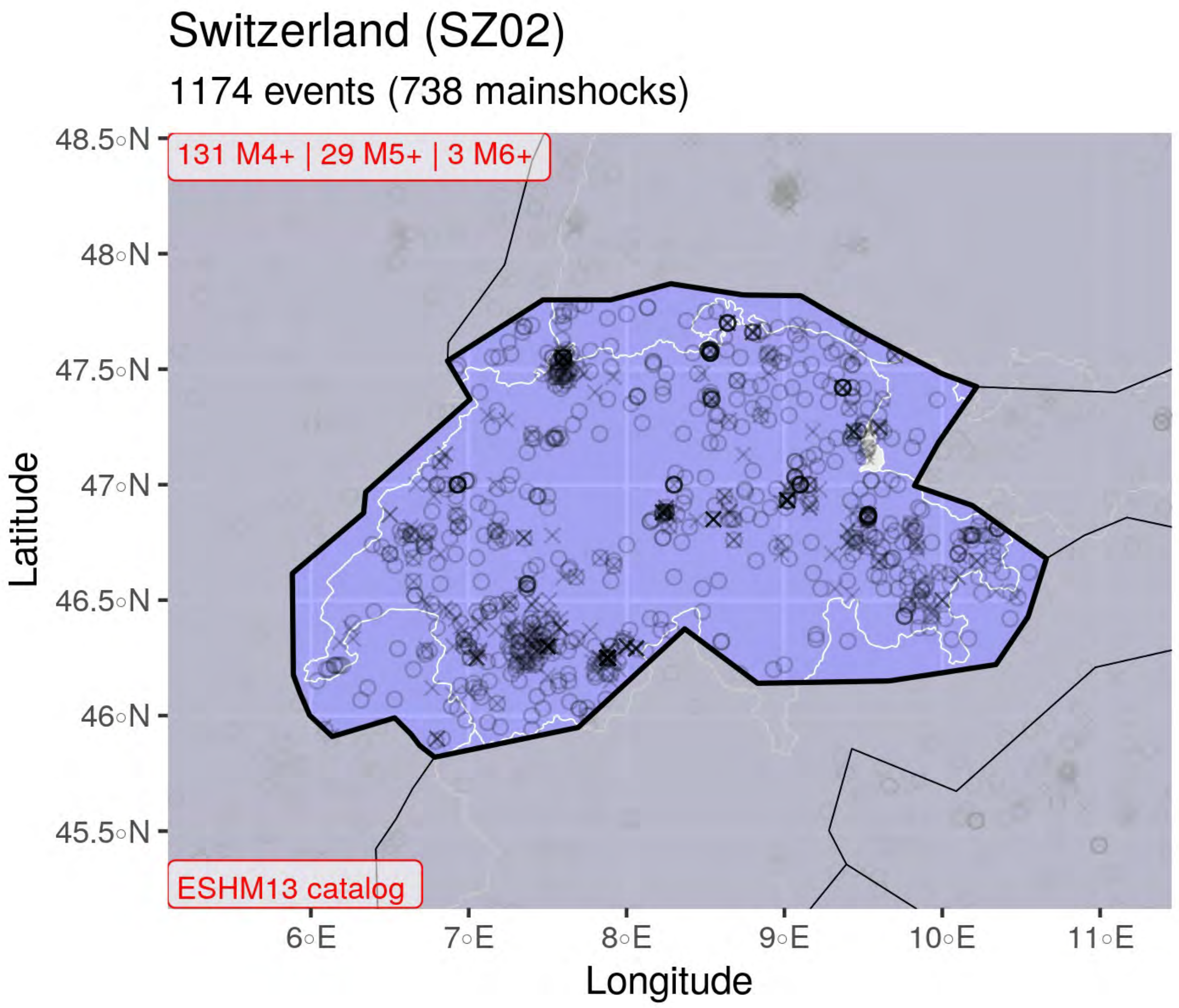

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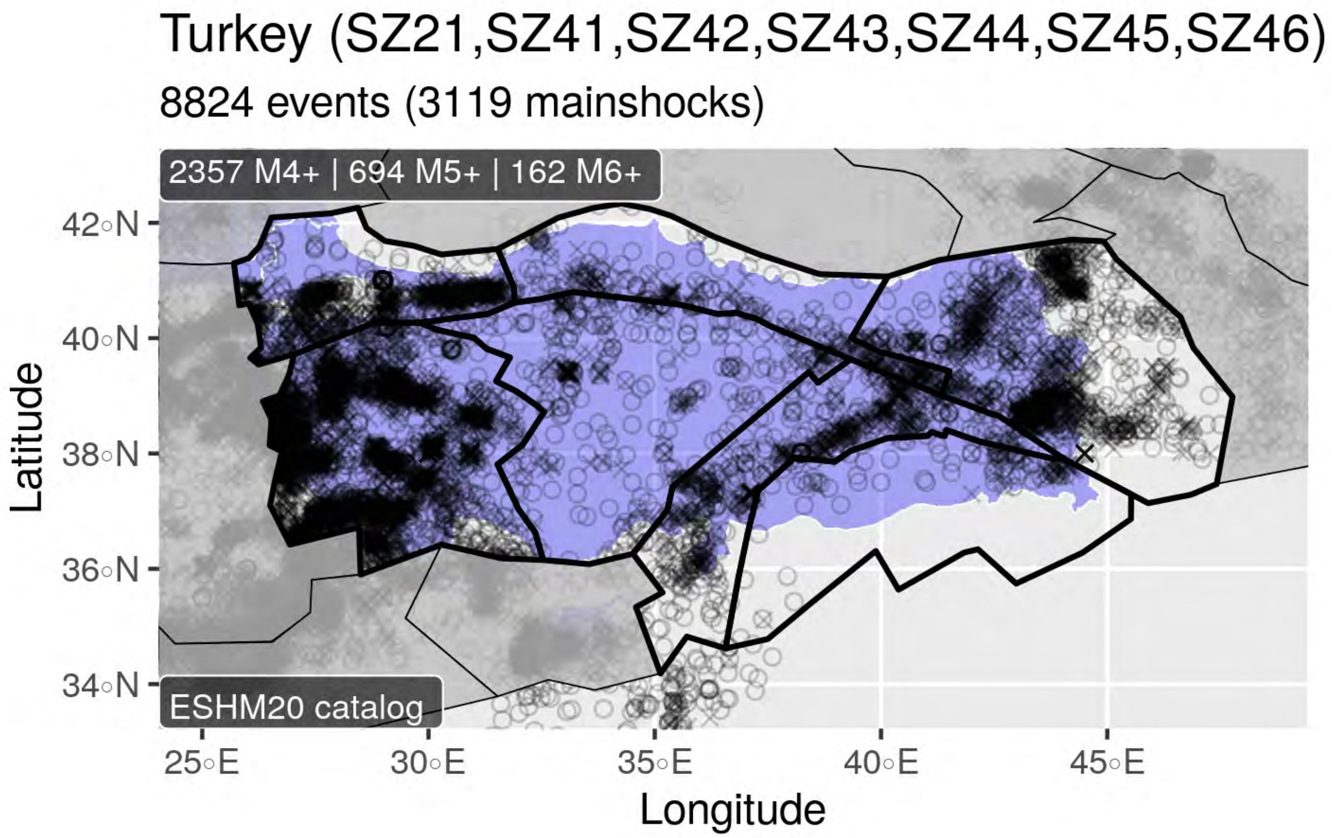

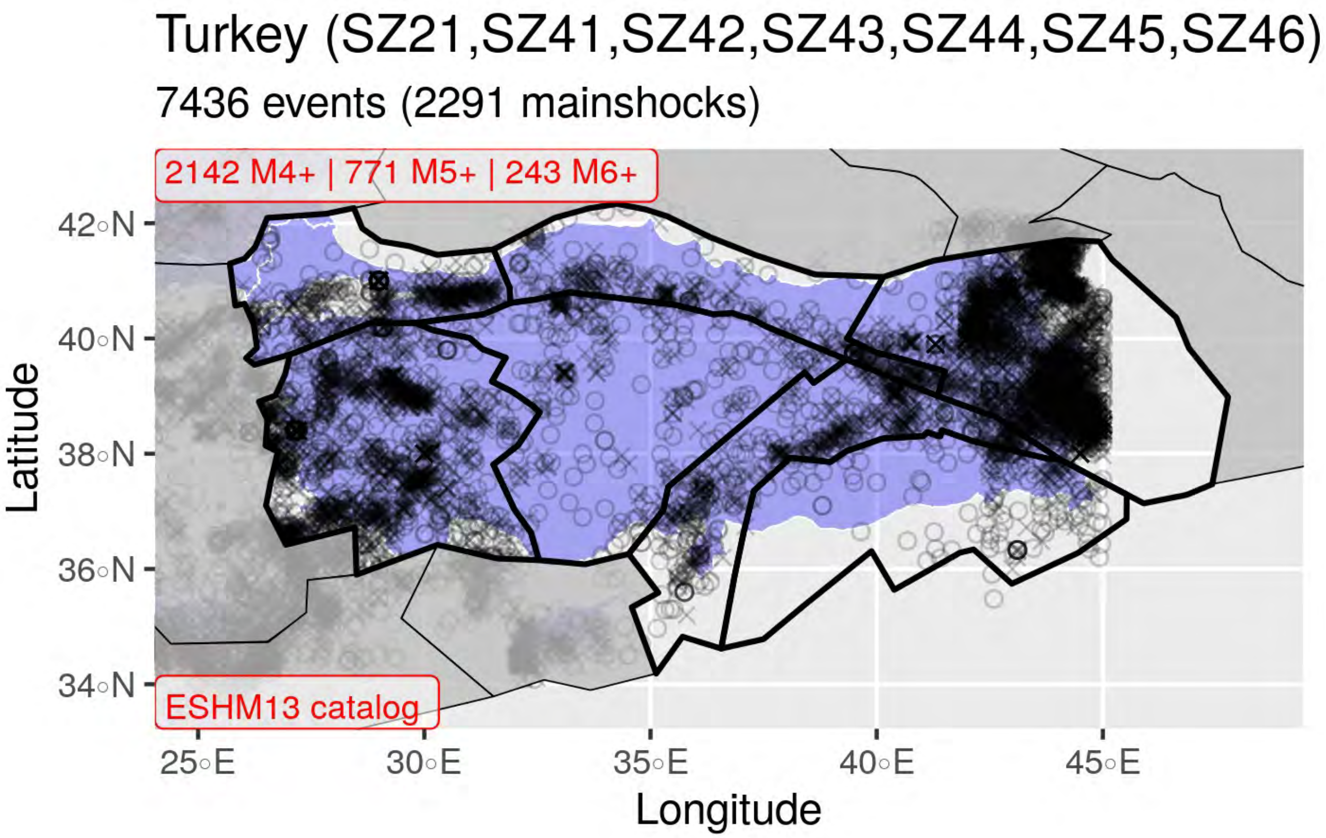

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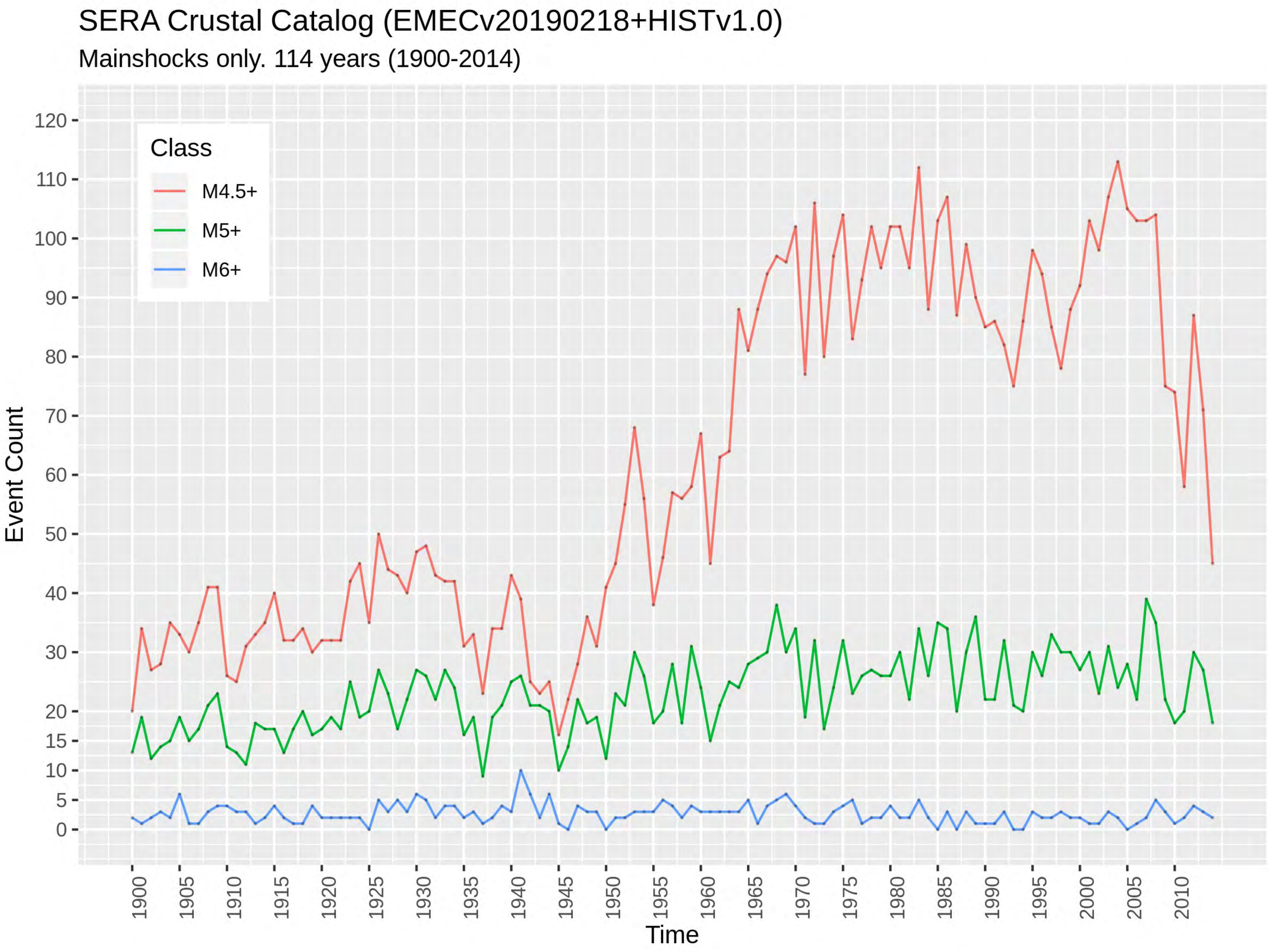
ESHM20: Catalog Completeness



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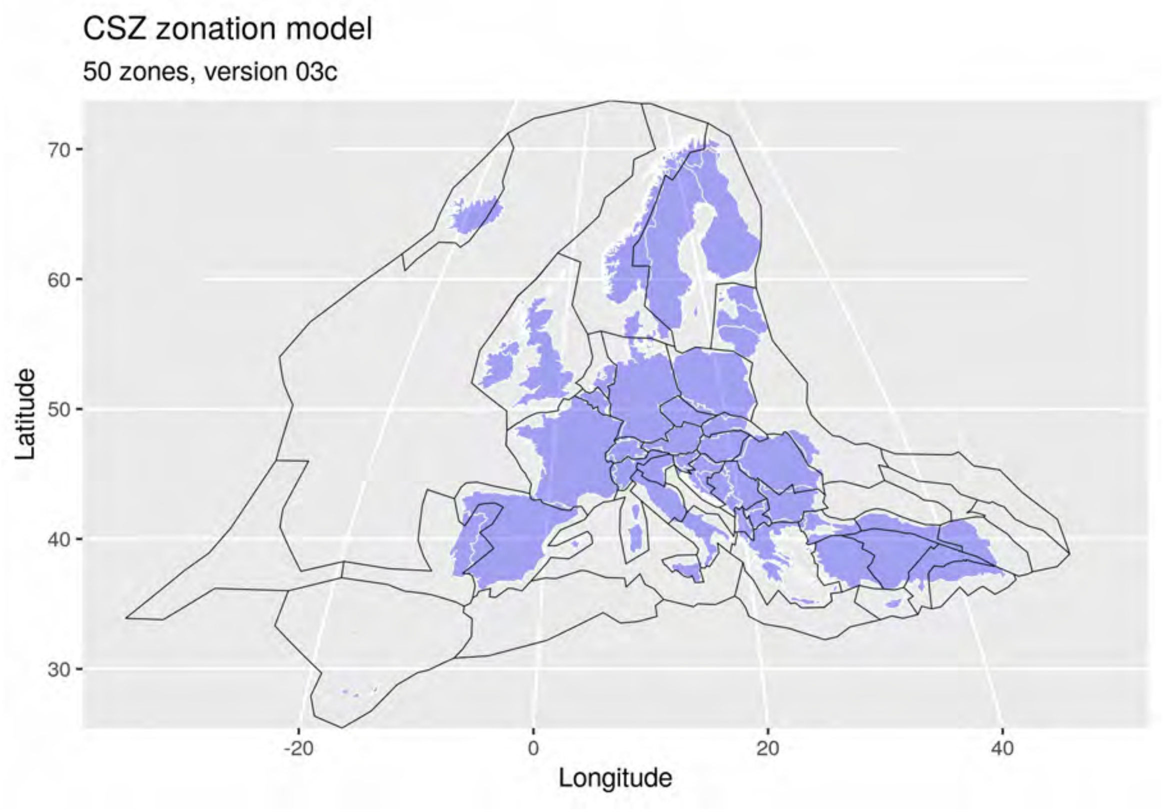
ESHM20: Catalog Completeness



- Post-declustering: Any deviation from uniform time distribution can be attributed to changes in Mc
- Make use of KS test (based on normalized cumulative time-series) to objectively identify change points in Mc
- Result:
  50 Mc-time tables (corresponding to predefined completeness super zone)

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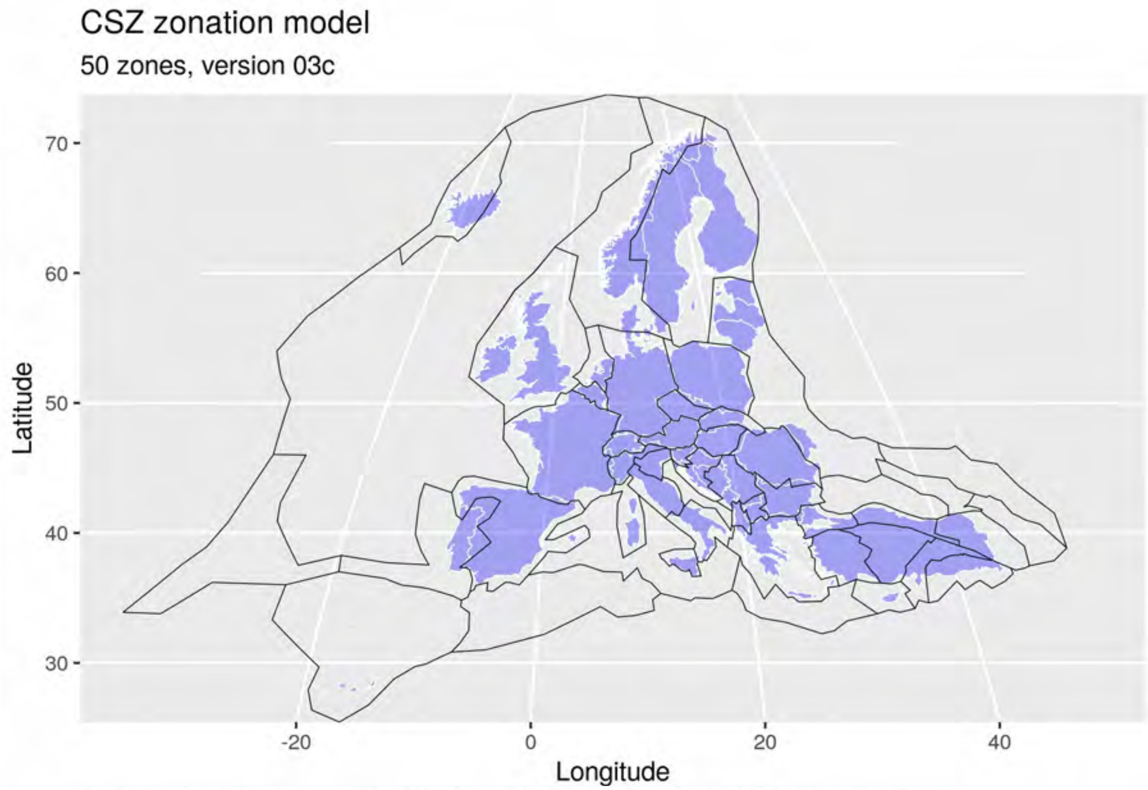

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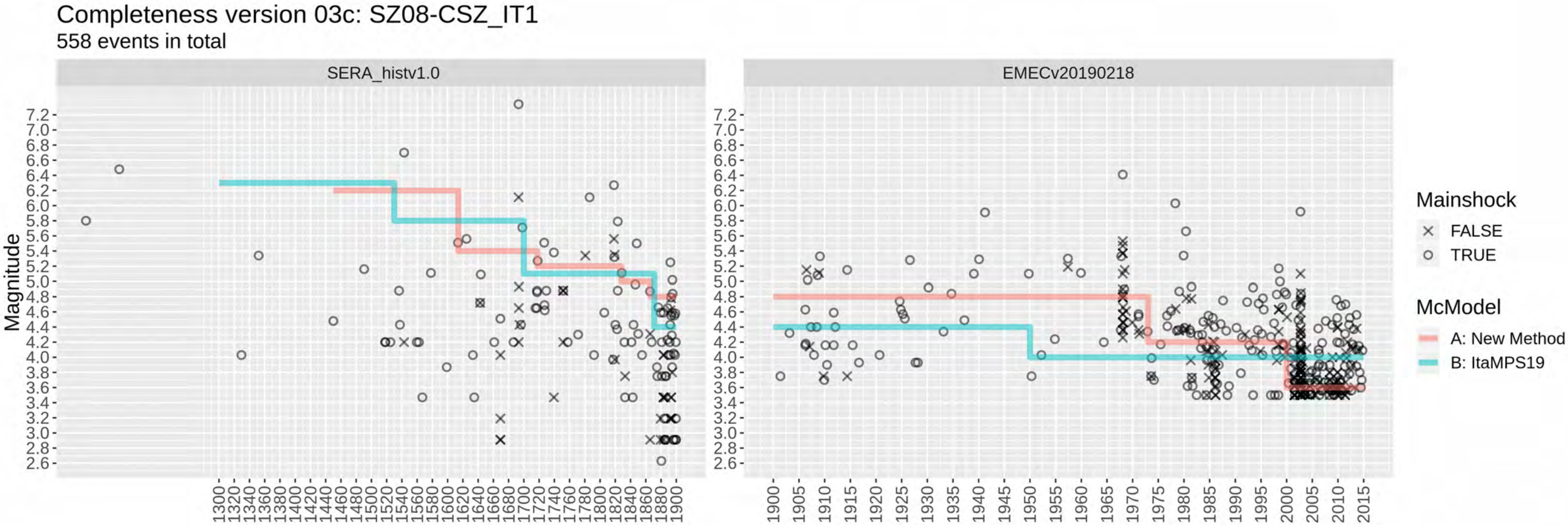

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ESHM20: Catalog Completeness

Entire Catalog (within CSZs)
54892 Events

↓

Mainshocks
22098 Events

↓

ESHM20 Completeness
12142 Events

(National Completeness)
(11086 Events)

$\log_{10}$(Count): 1.0 1.5 2.0 2.5 3.0

Zone	Full	Mainshocks	McNational	McNandanEtAl
SZ50-CSZ_CAUN	419	159	42	124
SZ49-CSZ_NO	242	230	153	188
SZ48-CSZ_CAR	582	267	137	197
SZ47-CSZ_IT3	247	207	89	88
SZ46-CSZ_TR6	342	167	93	125
SZ45-CSZ_TR3	1763	542	340	367
SZ44-CSZ_TR5	128	78	44	44
SZ43-CSZ_TR4	387	234	142	167
SZ42-CSZ_TR1	758	376	247	264
SZ41-CSZ_TR7	1096	372	163	204
SZ40-CSZ_IT6	666	392	209	180
SZ39-CSZ_MM	109	30	10	31
SZ38-CSZ_SM	205	162	47	105
SZ37-CSZ_IT2	805	507	248	258
SZ36-CSZ_IT4	1400	844	445	436
SZ35-CSZ_IT5	41	32	18	13
SZ34-CSZ_BIH	907	507	111	237
SZ33-CSZ_BS	48	45	23	23
SZ32-CSZ_SG	2276	776	496	517
SZ31-CSZ_RU	58	48	18	33
SZ30-CSZ_MA	4098	1217	417	257
SZ29-CSZ_AB	3219	1291	636	682
SZ28-CSZ_CA	276	227	48	91
SZ27-CSZ_AZ	1139	547	346	235
SZ26-CSZ_IC	1867	410	301	237
SZ25-CSZ_CY	1047	398	162	246
SZ24-CSZ_CAUS	688	418	89	305
SZ23-CSZ_MK	389	189	84	81
SZ22-CSZ_GR	14271	3280	2021	2267
SZ21-CSZ_TR2	4246	1263	579	874
SZ20-CSZ_PT	1201	861	533	258
SZ19-CSZ_ESP	2227	1332	744	481
SZ18-CSZ_SRB	1229	613	165	311
SZ17-CSZ_BG	471	247	68	120
SZ16-CSZ_AL	867	292	199	199
SZ15-CSZ_SC	68	65	24	43
SZ14-CSZ_CZ	50	27	6	25
SZ13-CSZ_SLO	657	356	209	252
SZ12-CSZ_SK	156	121	61	80
SZ11-CSZ_RO	278	198	78	129
SZ10-CSZ_PL	38	29	13	19
SZ09-CSZ_NL	22	18	8	13
SZ08-CSZ_IT1	556	296	136	128
SZ07-CSZ_HR	192	130	34	48
SZ06-CSZ_UK	161	144	71	85
SZ05-CSZ_FR	1081	878	565	543
SZ04-CSZ_DE	400	253	152	146
SZ03-CSZ_BL	67	52	30	28
SZ02-CSZ_CH	1187	745	118	221
SZ01-CSZ_AT	265	226	114	137
All-Zones	54892	22098	11086	12142

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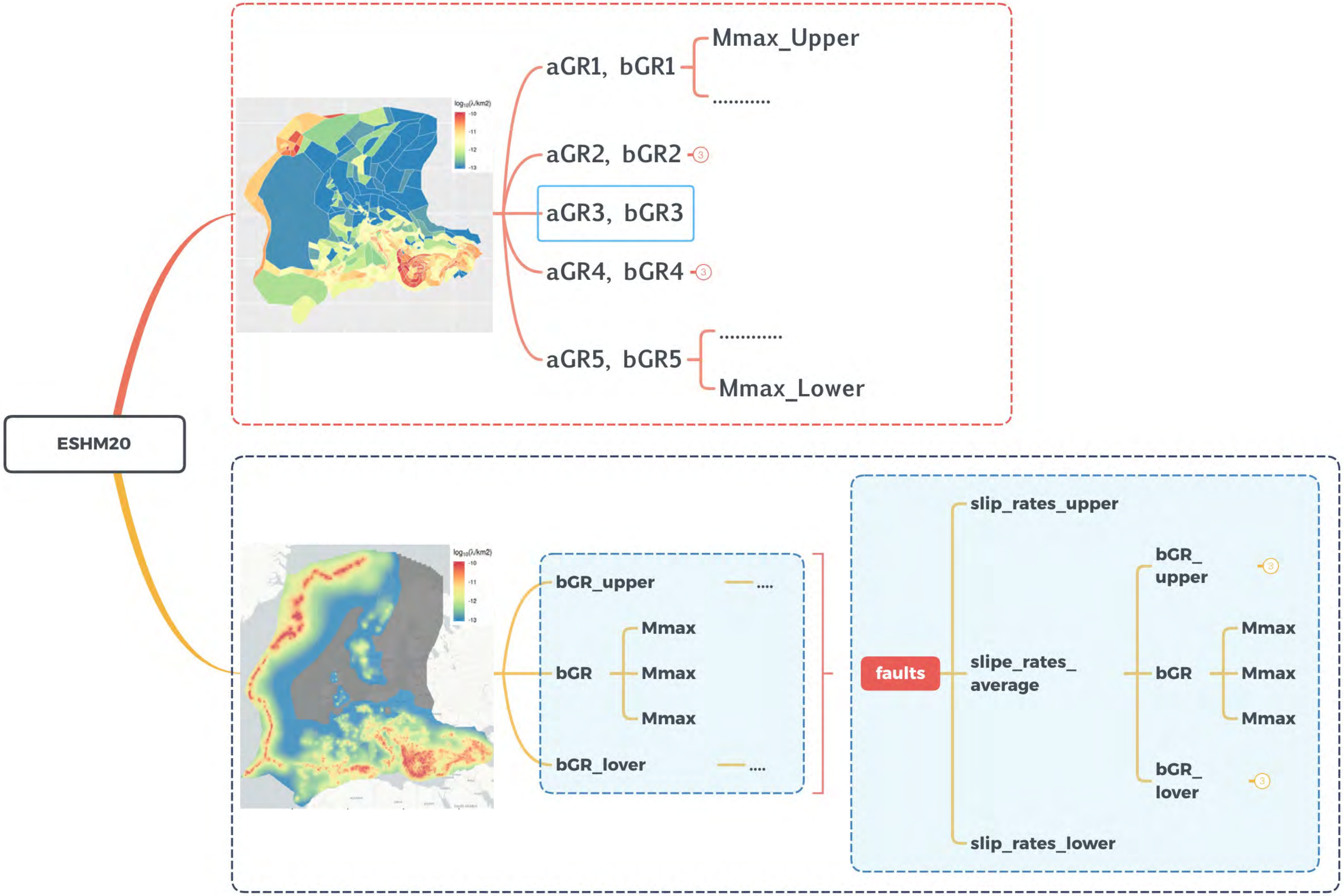
ESHM20: Source Model Logic Tree

Captures the inherent uncertainties of the data, information, knowledge as well as uncertainties in model construction (delineation of areal sources, completeness, reliability of fault source information)



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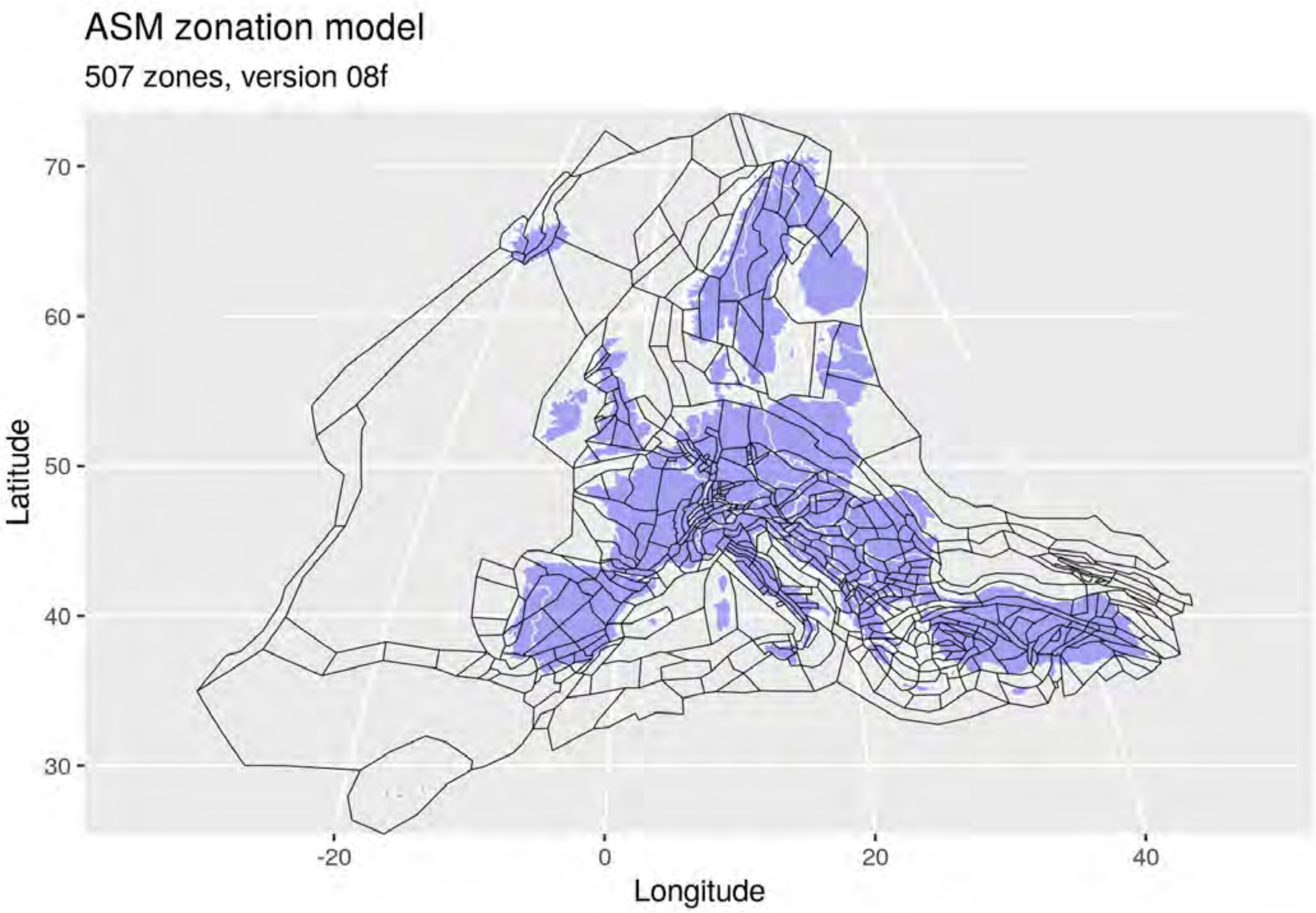
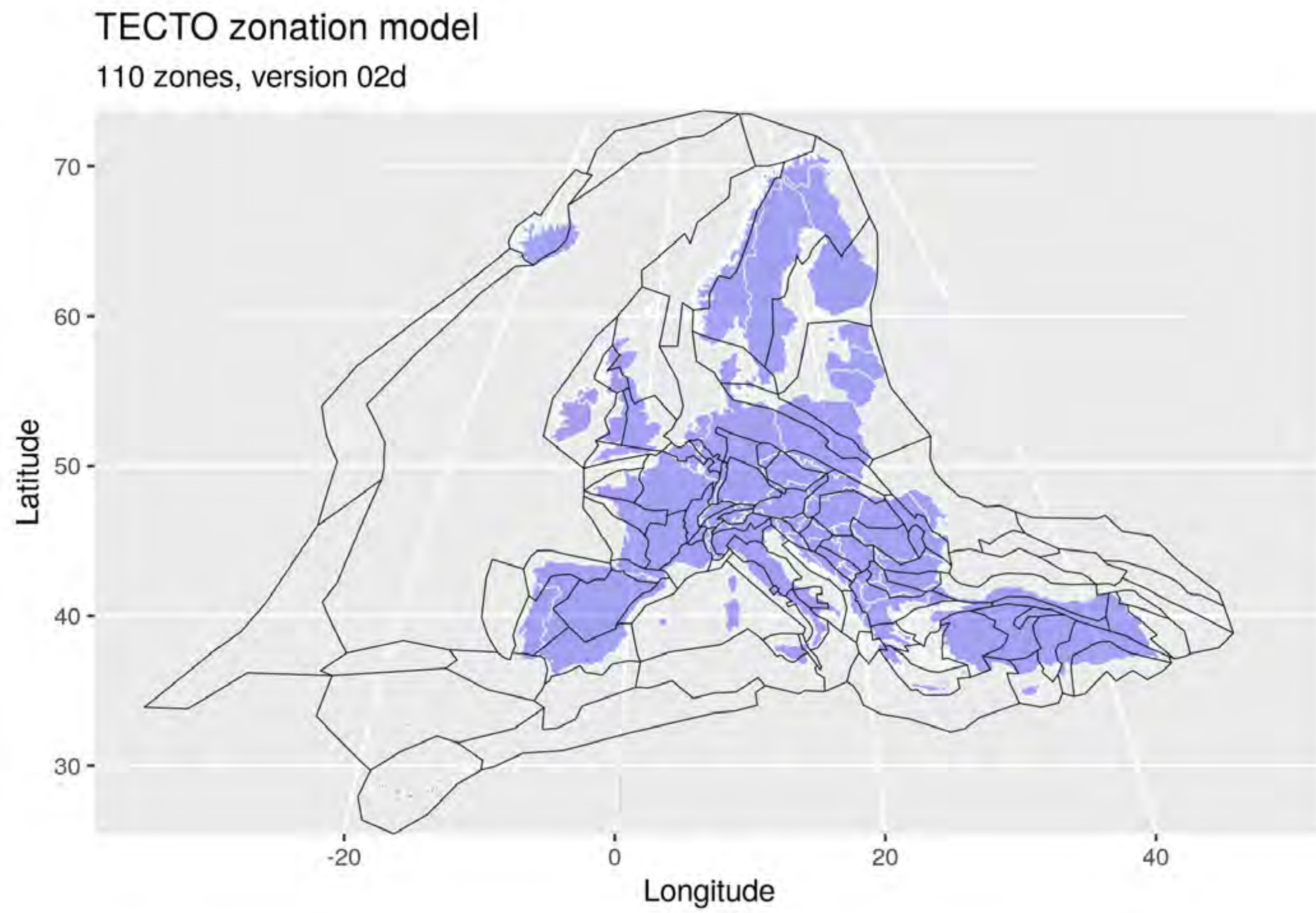
ESHM20: Area Source Model

Continuation of the vision of SHARE/ESHM13 "…area source model is regarded as a **consensus model** meaning that agreement has been reached by the participating experts in the various regions."





- Contribution from Spain, Belgium, Germany, Switzerland, Slovenia, Romania, Turkey, Macedonia, Bulgaria, France, Portugal, Italy, UK, Iceland, Austria
- Northern Africa and Eastern Europe (Russia, Ukraine, Belarus) from fully harmonized Global Hazard Model (GEM)

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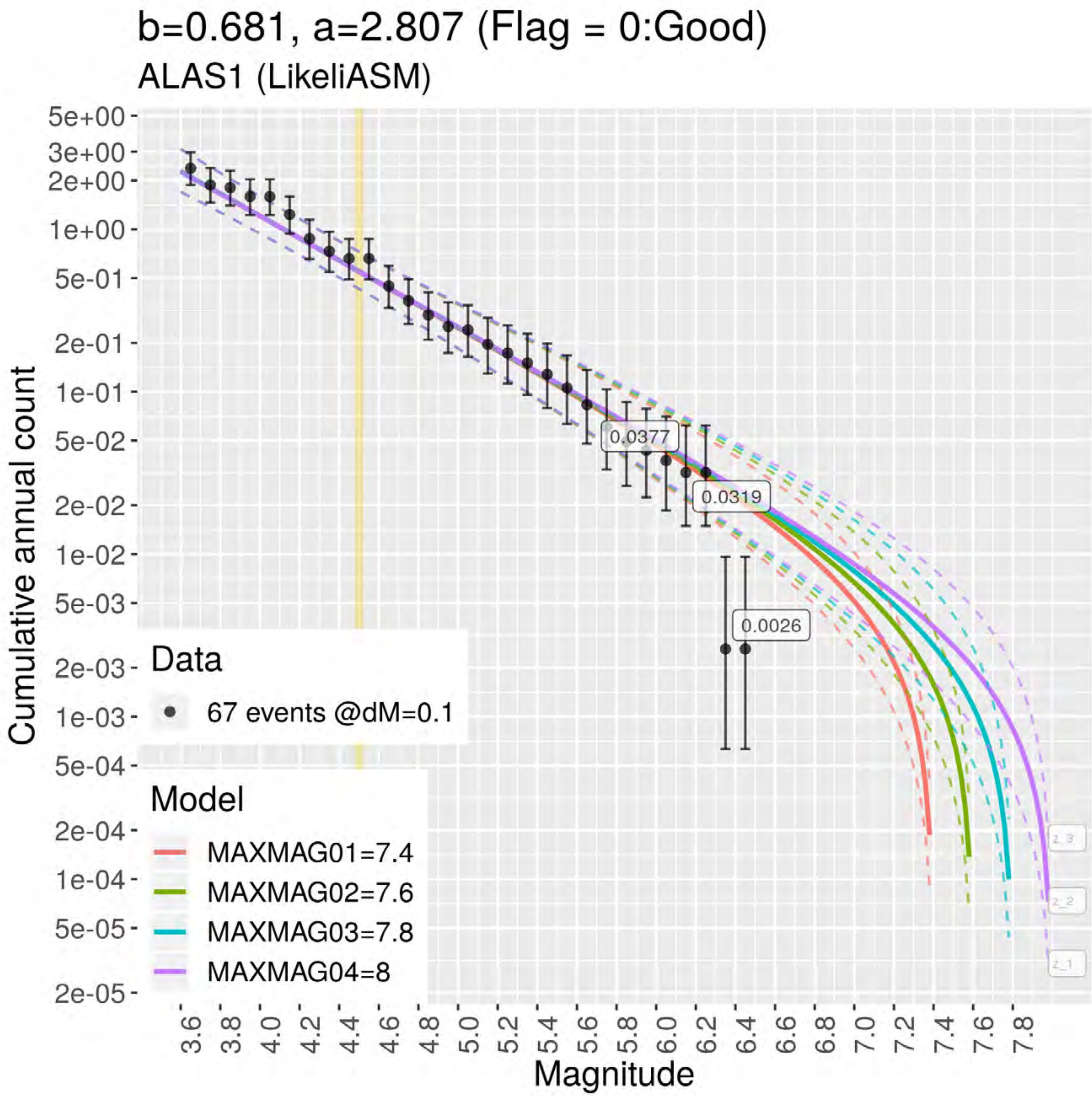
ESHM20: Area Source Model



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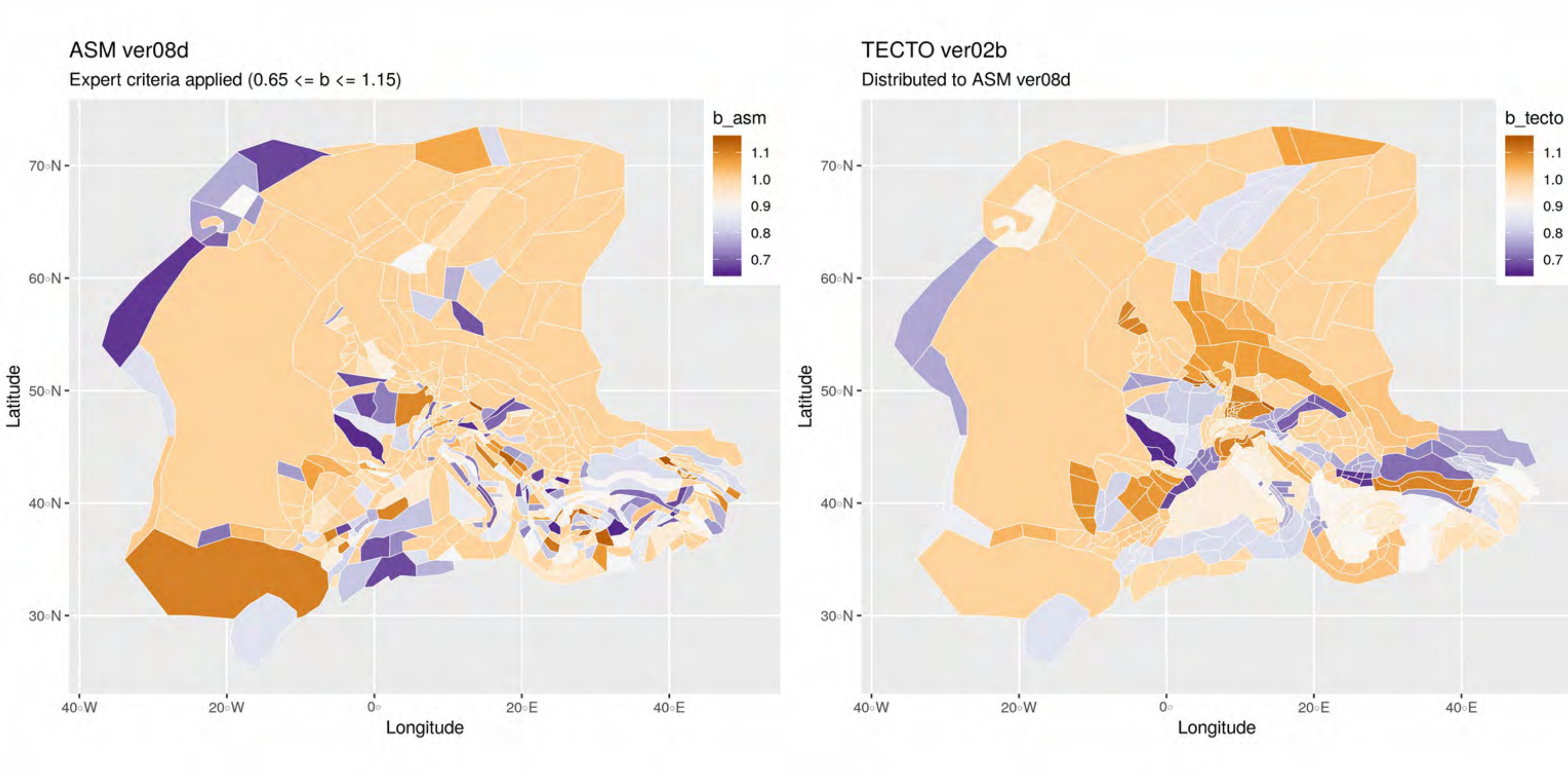

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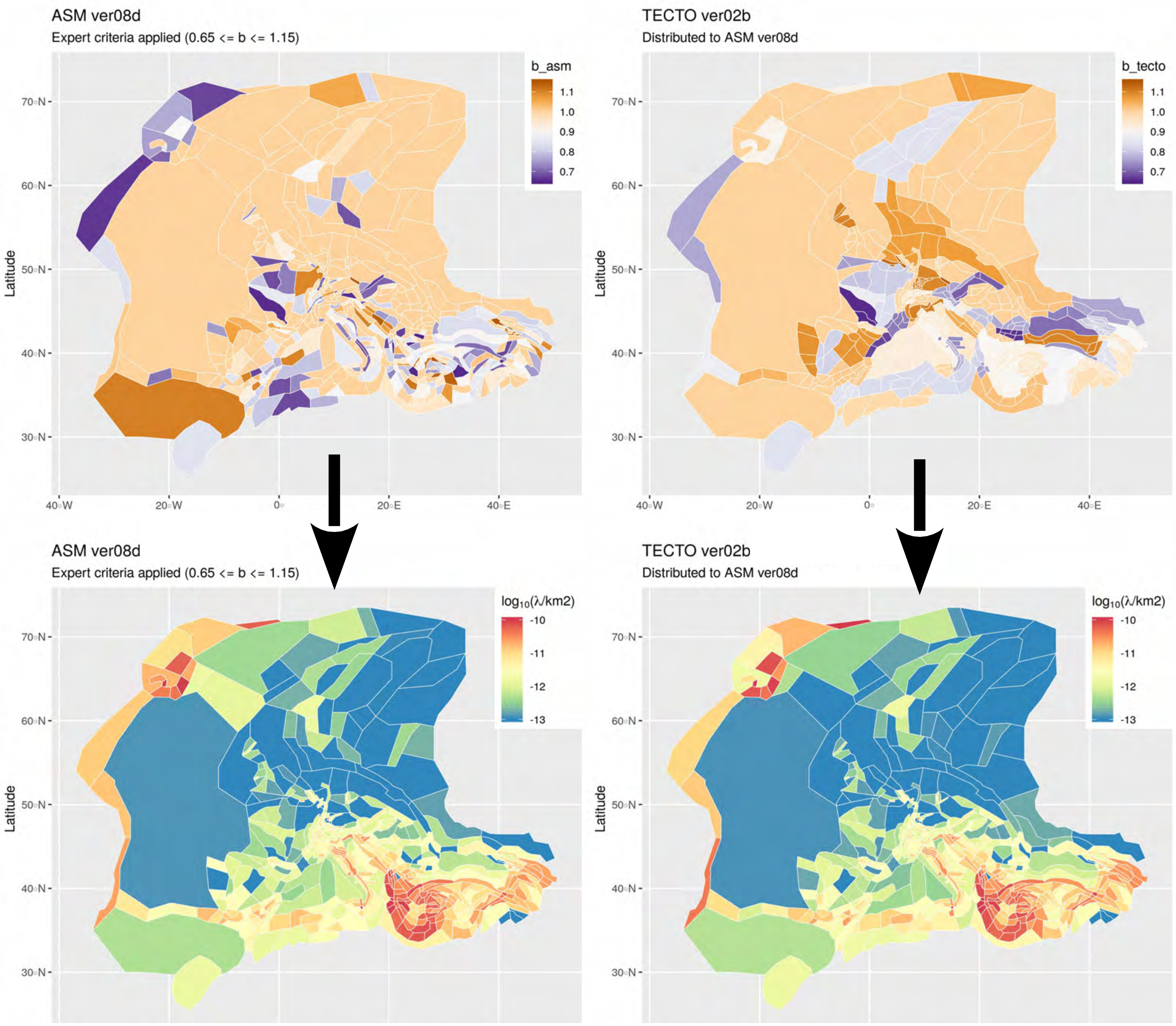

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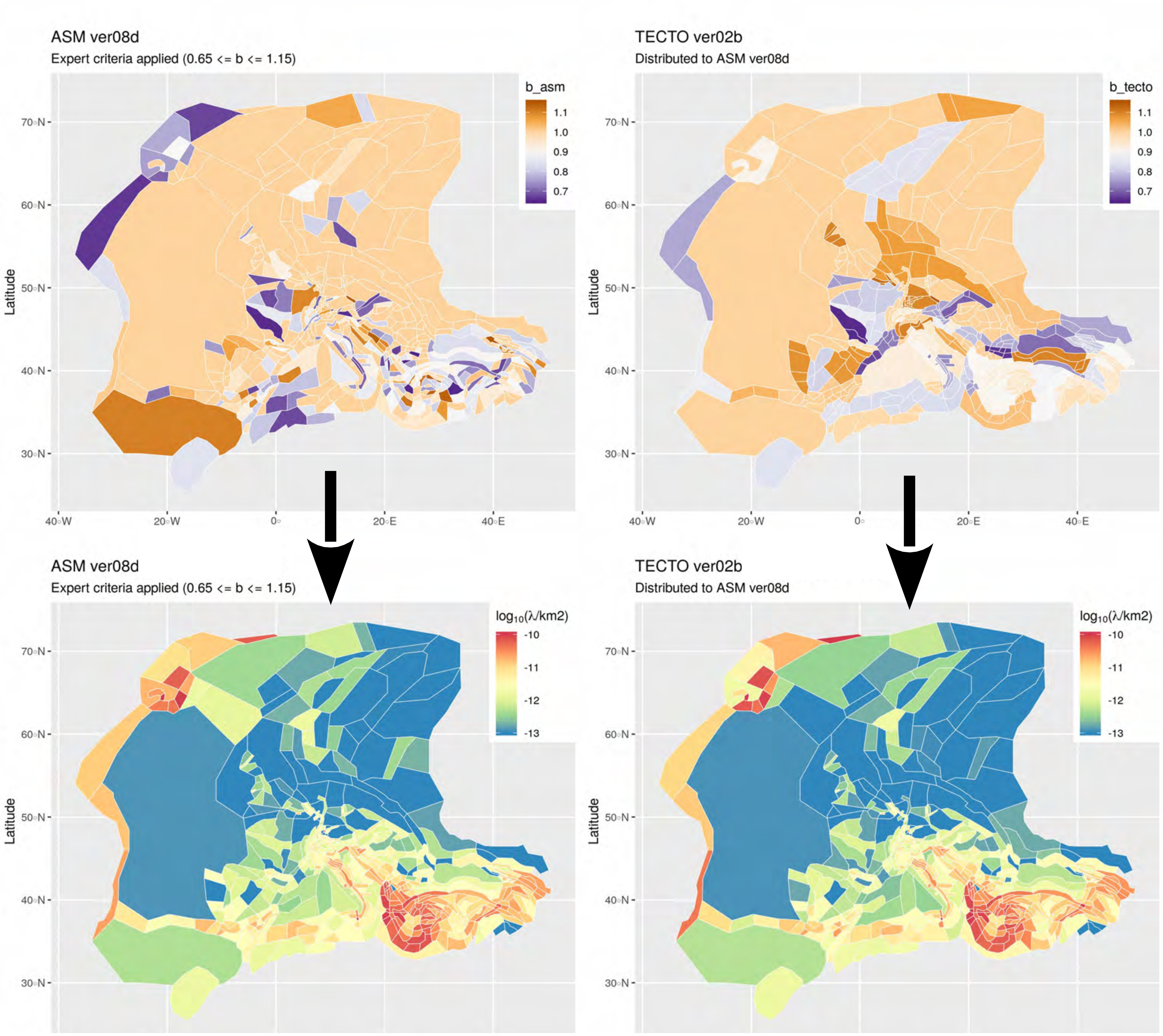

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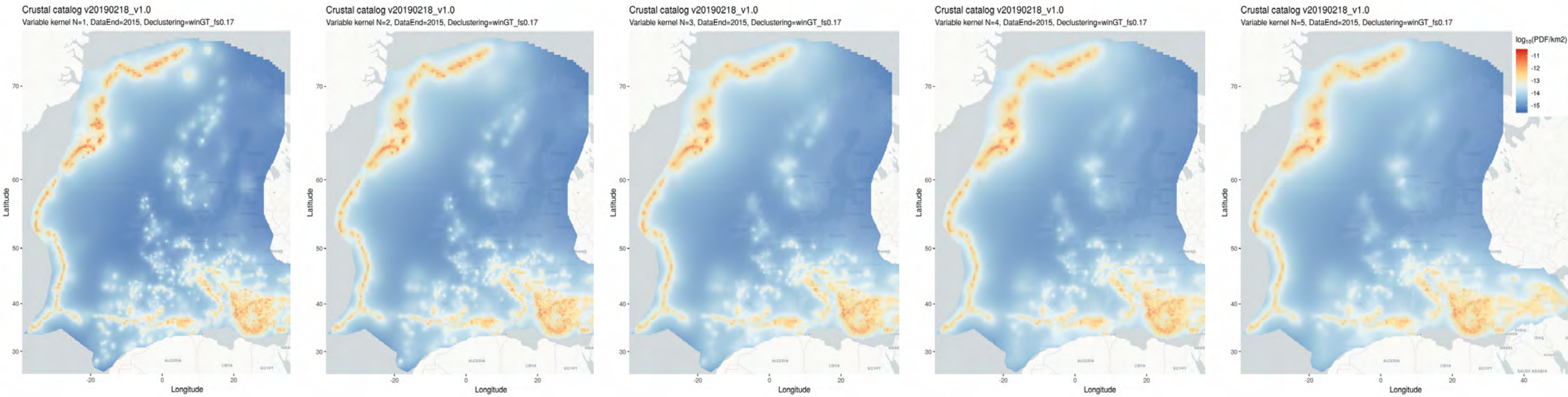
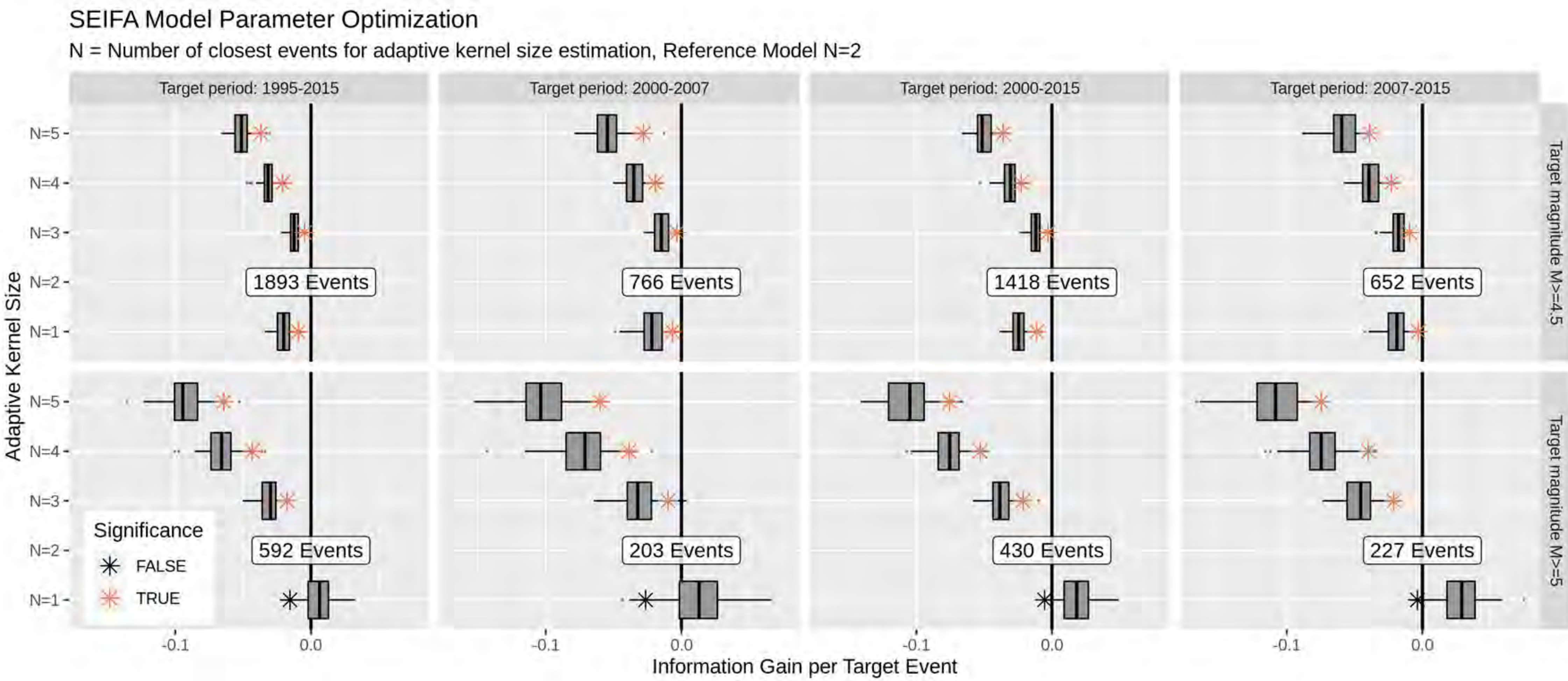
ESHM20: Smoothed Seismicity





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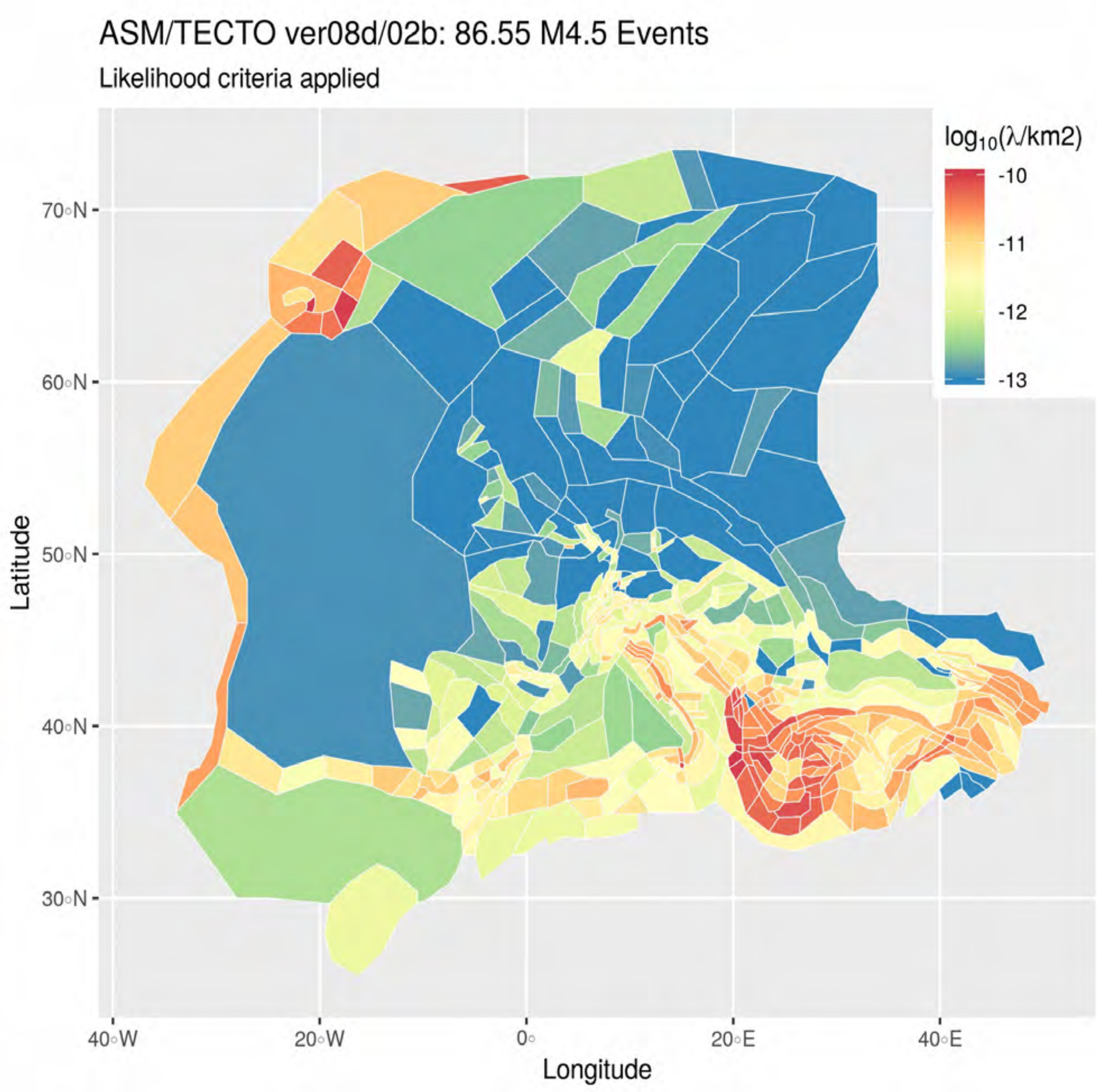
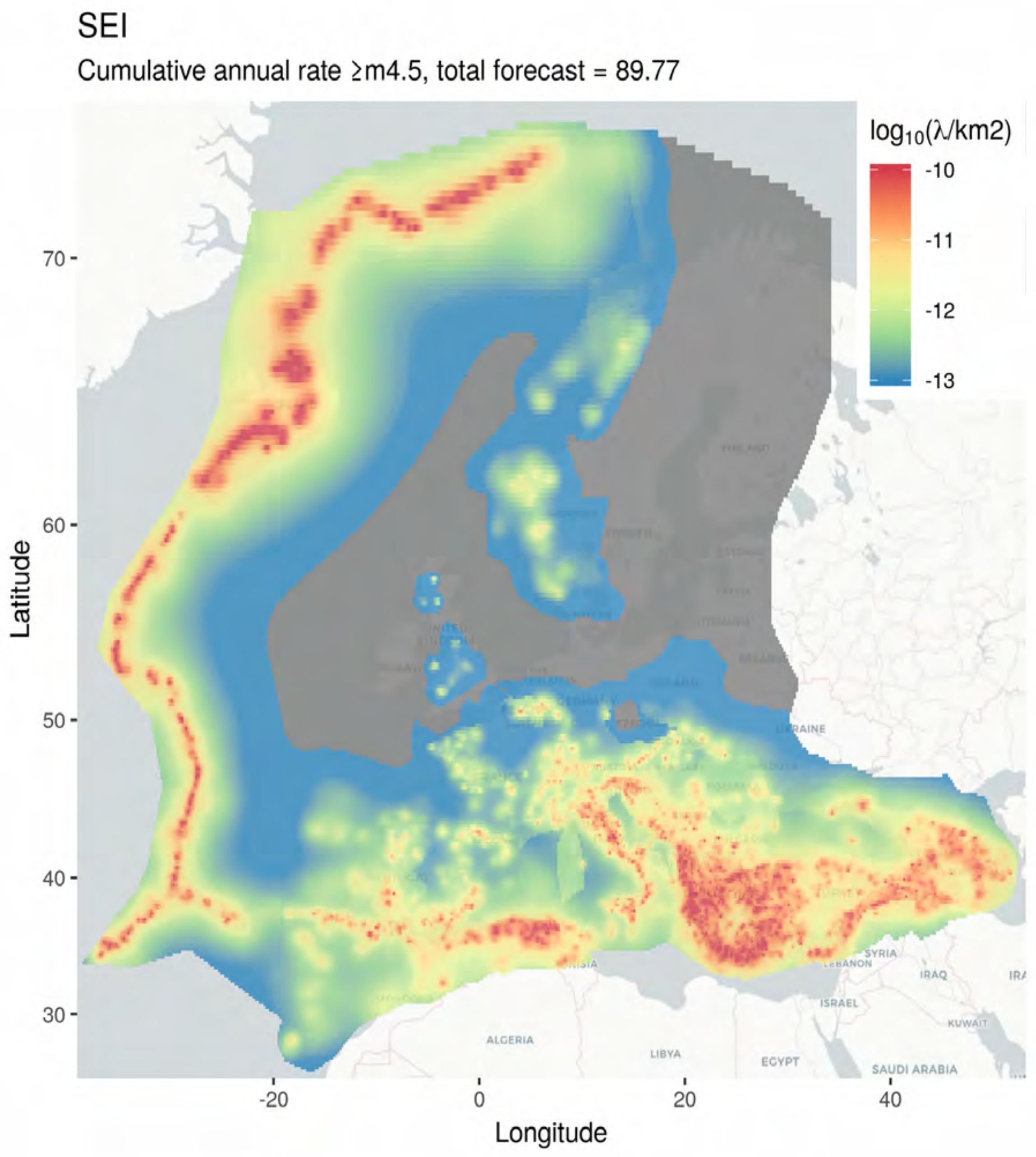
ESHM20: Area Sources vs. Smoothed Seismicity





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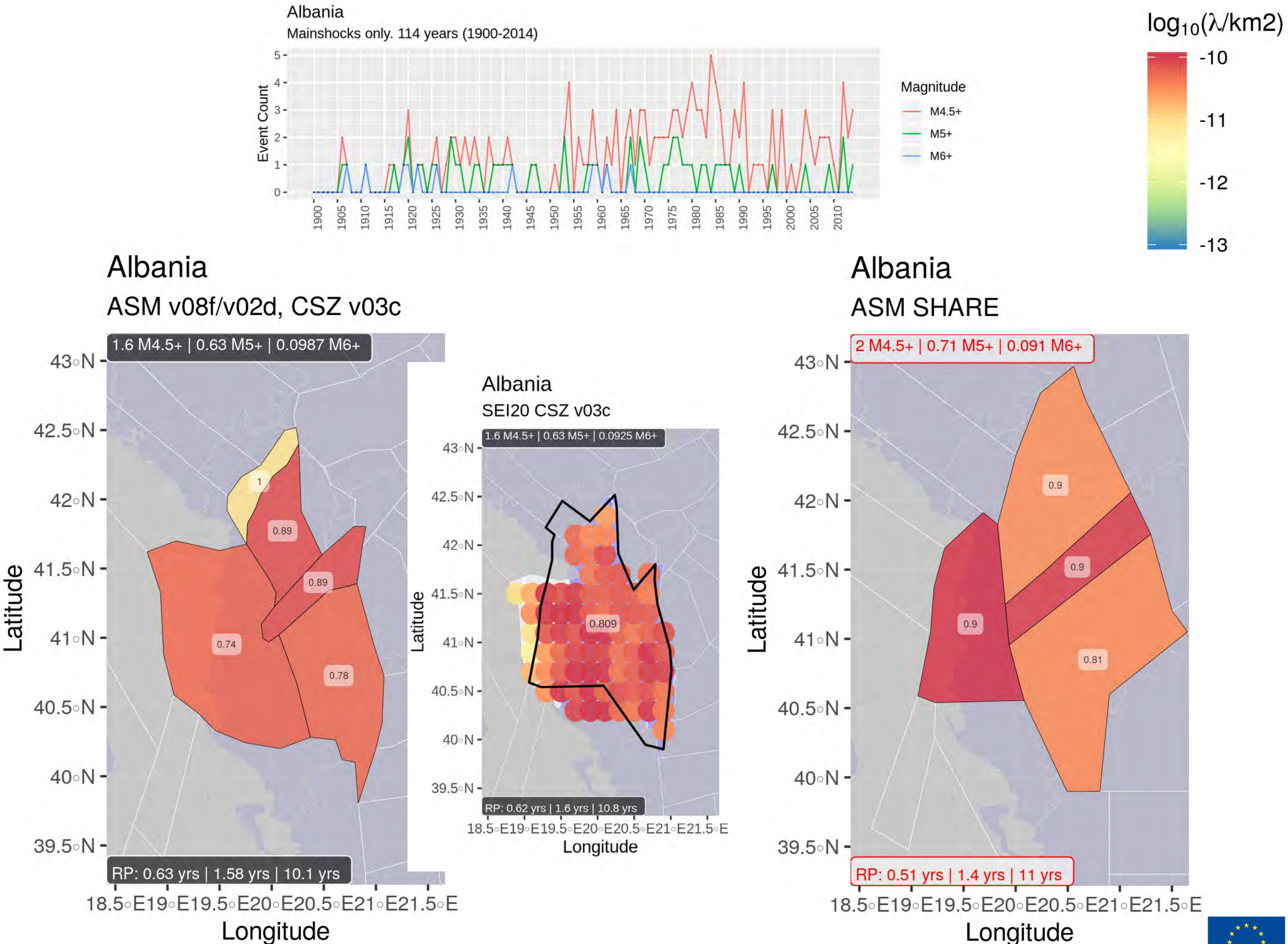
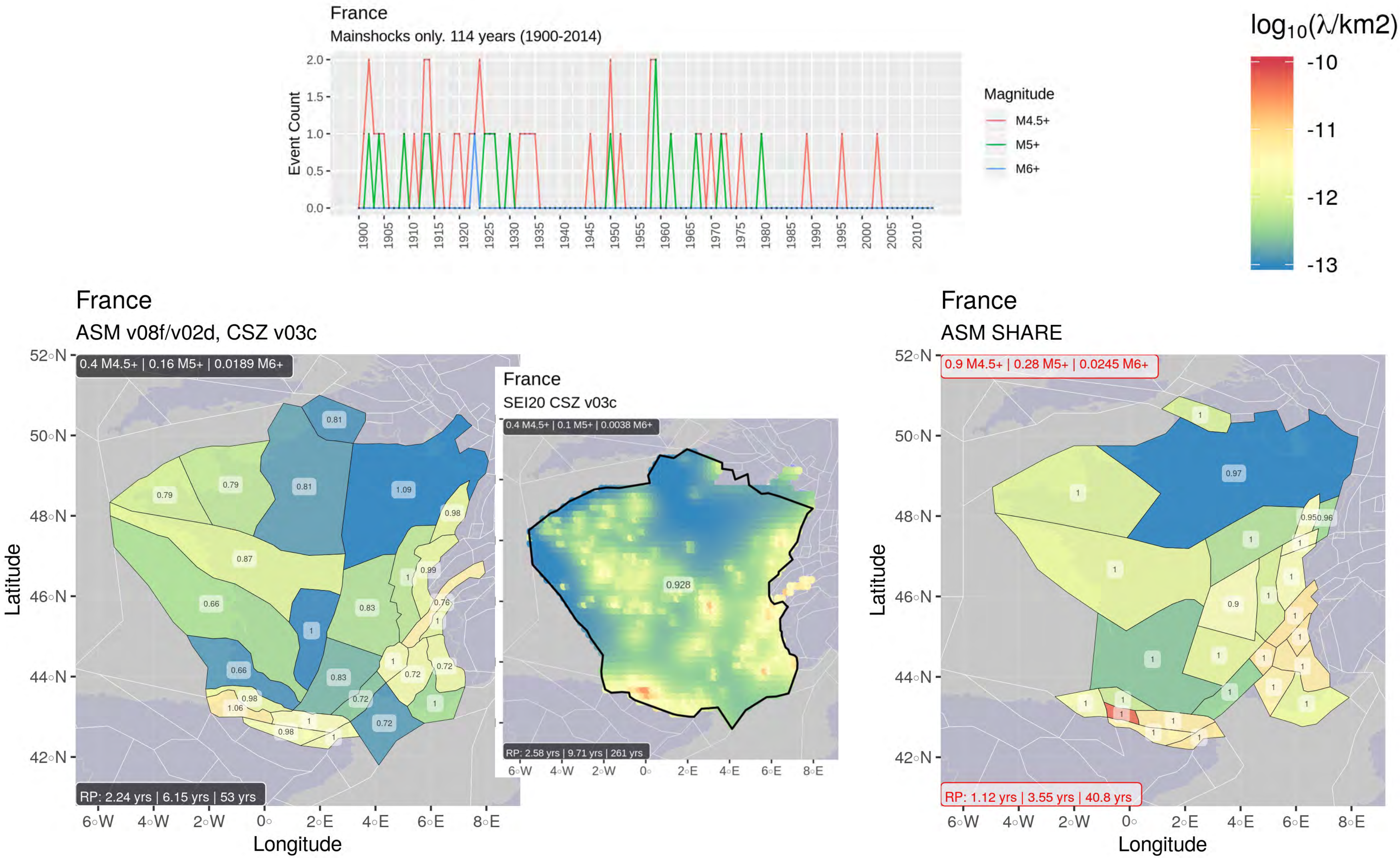

Albania
Mainshocks only. 114 years (1900-2014)
Event Count
Magnitude
M4.5+
M5+
M6+
log10(λ/km2)
-10
-11
-12
-13
Albania
ASM v08f/v02d, CSZ v03c
1.6 M4.5+ | 0.63 M5+ | 0.0987 M6+
RP: 0.63 yrs | 1.58 yrs | 10.1 yrs
Latitude
Longitude
Albania
SEI20 CSZ v03c
1.6 M4.5+ | 0.63 M5+ | 0.0925 M6+
0.809
RP: 0.62 yrs | 1.6 yrs | 10.8 yrs
Albania
ASM SHARE
2 M4.5+ | 0.71 M5+ | 0.091 M6+
RP: 0.51 yrs | 1.4 yrs | 11 yrs



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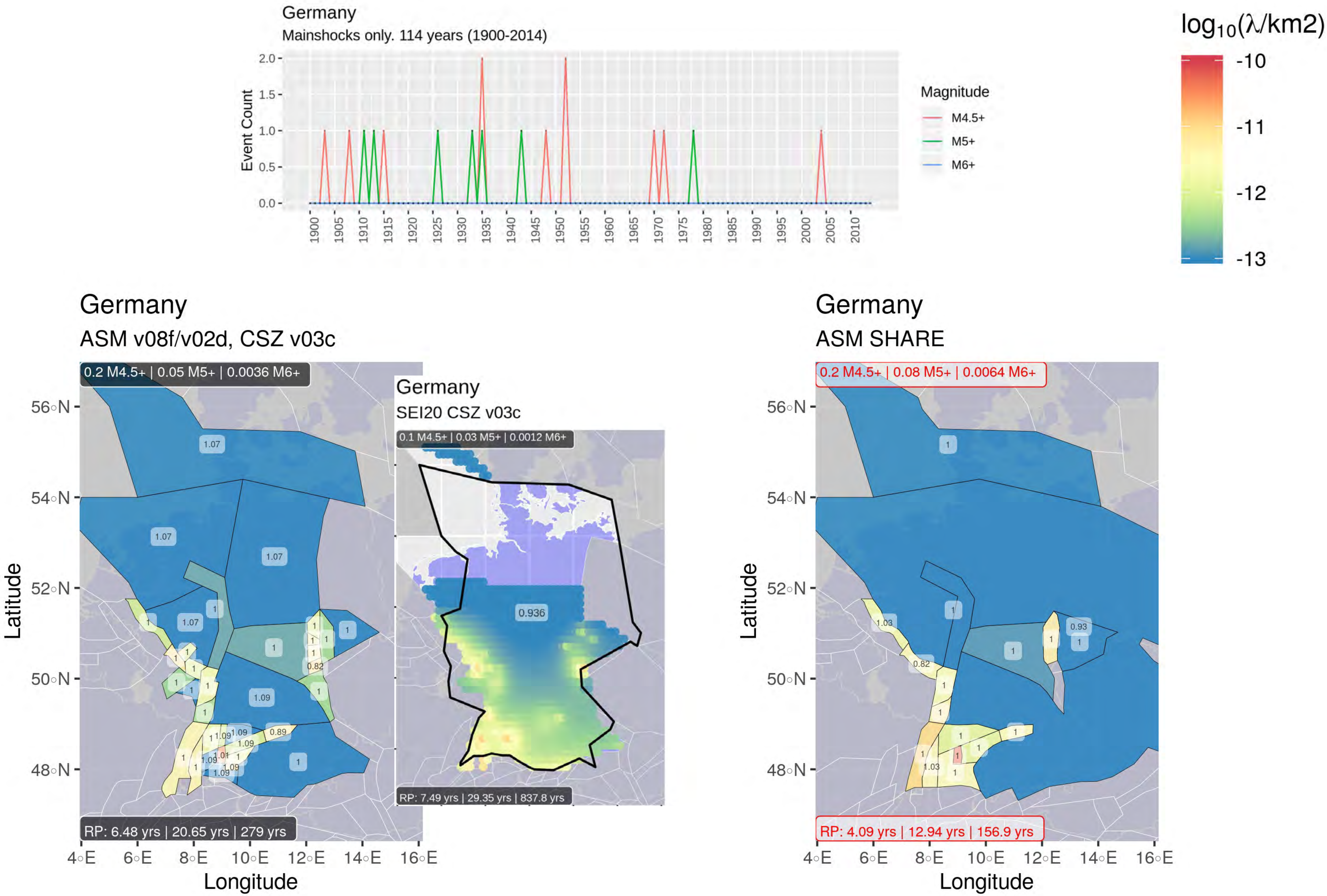

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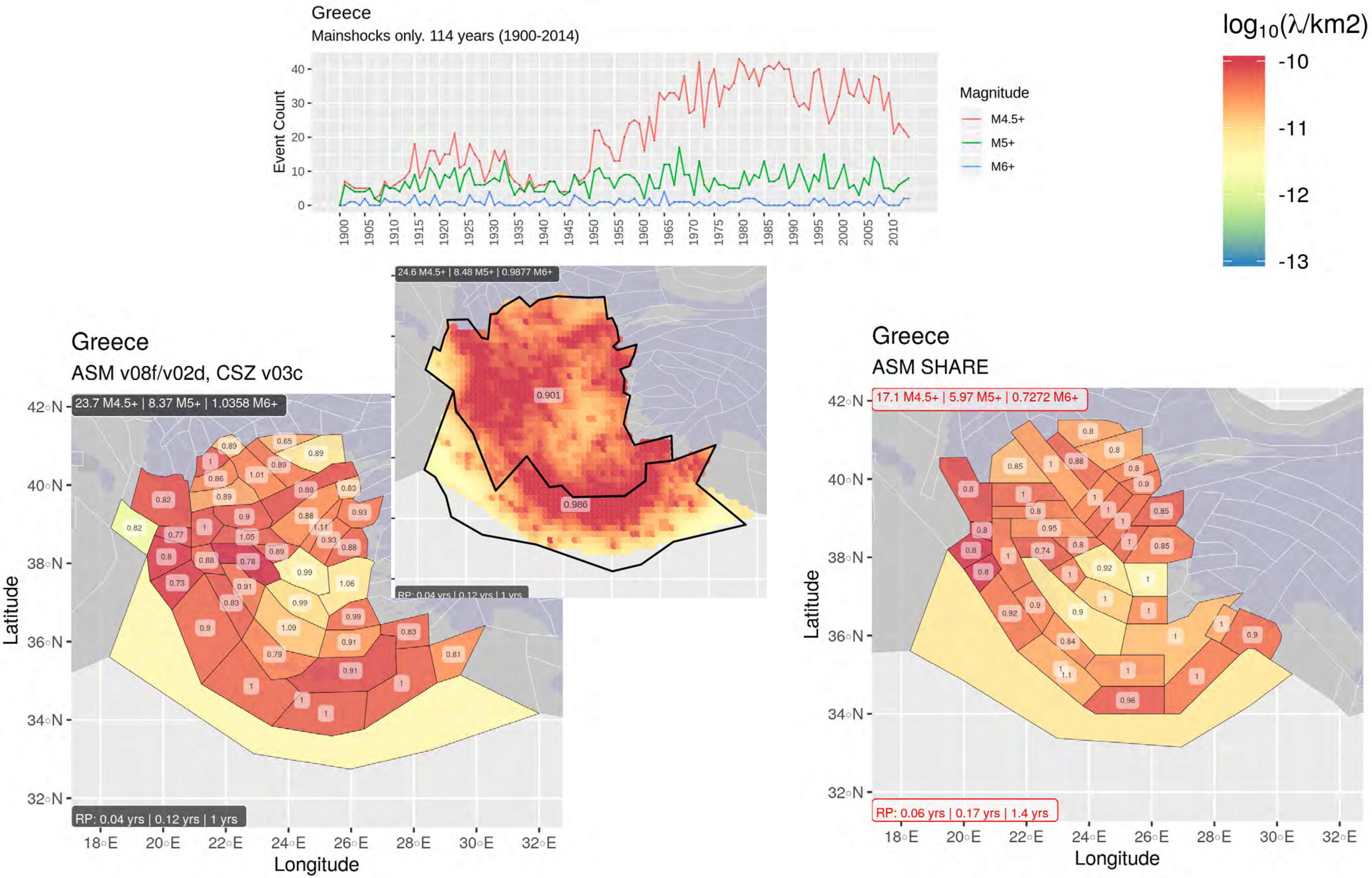

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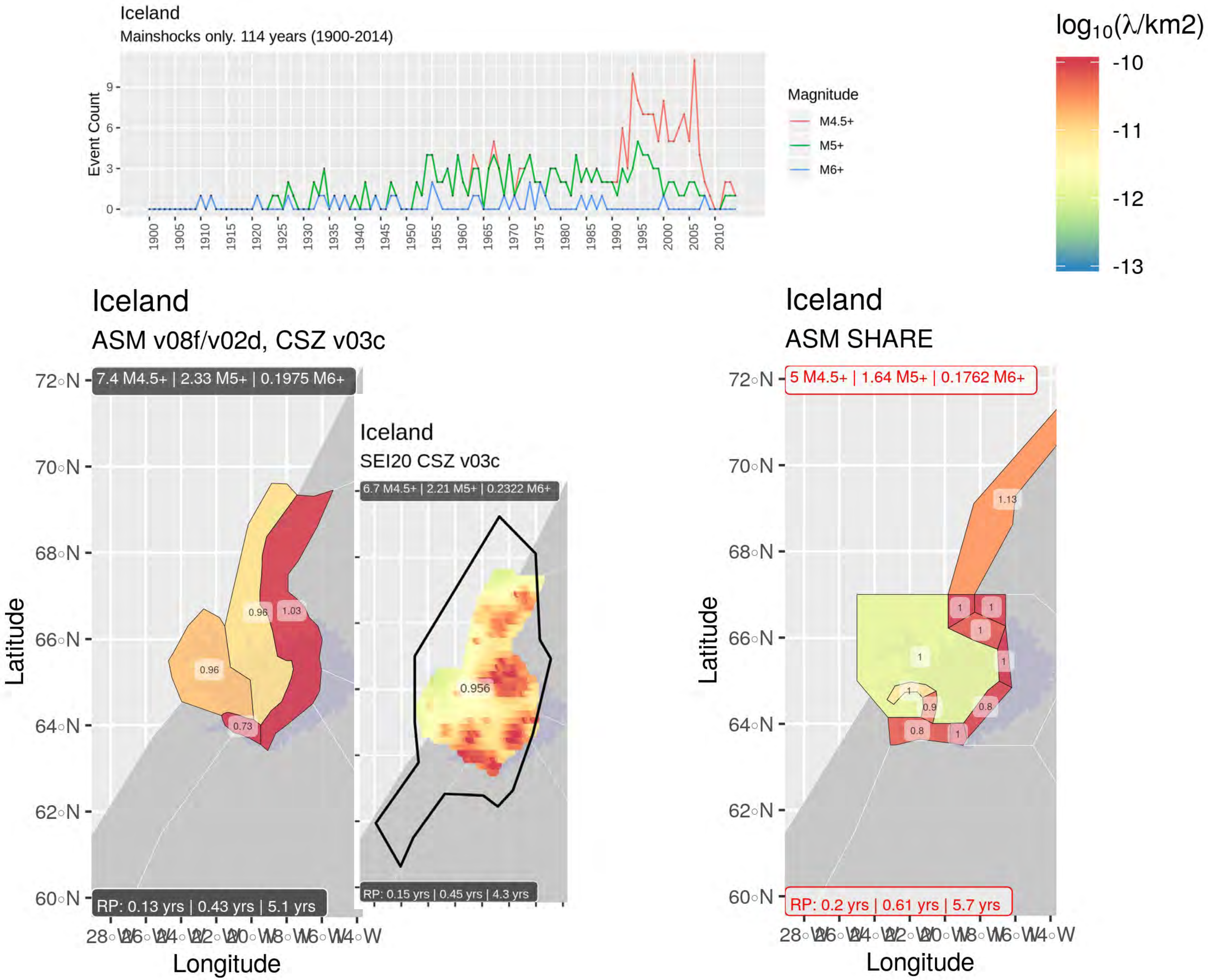

Horizon 2020 research and innovation programme under grant
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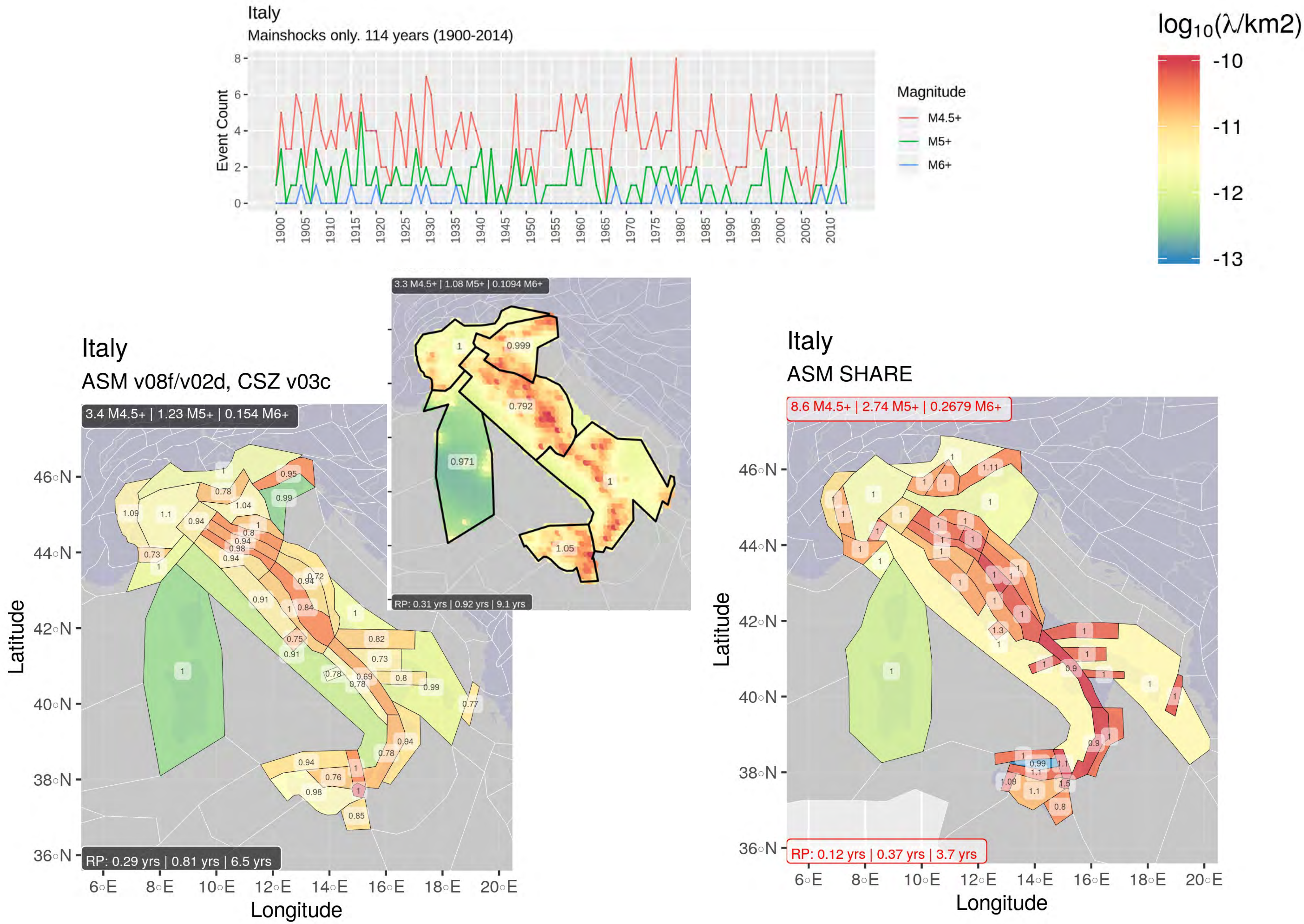

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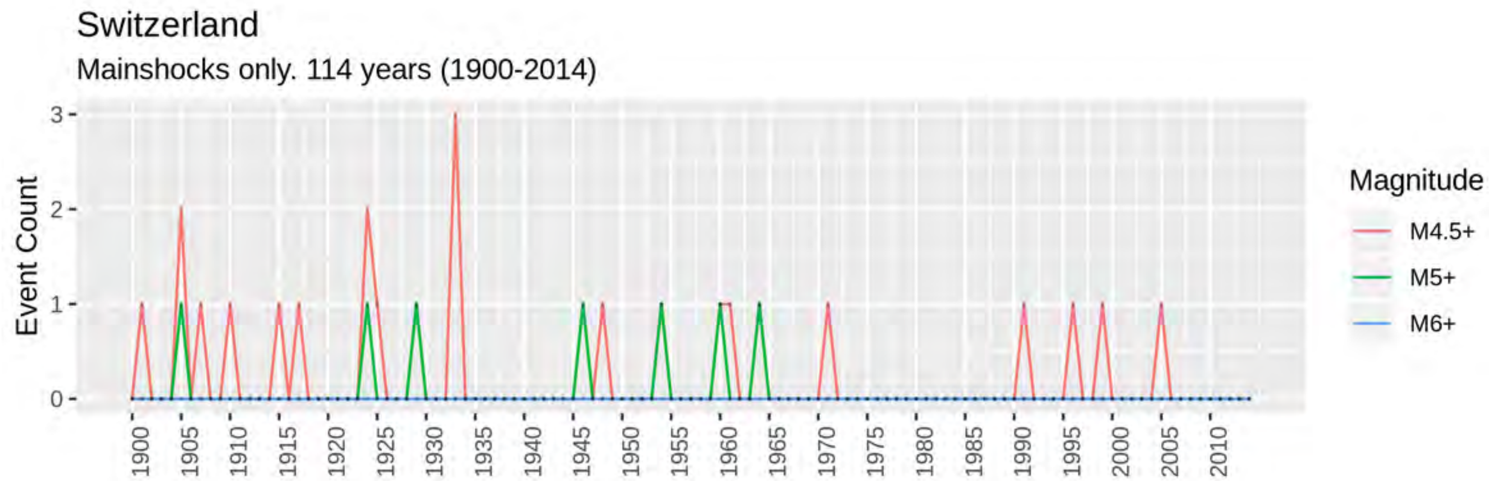

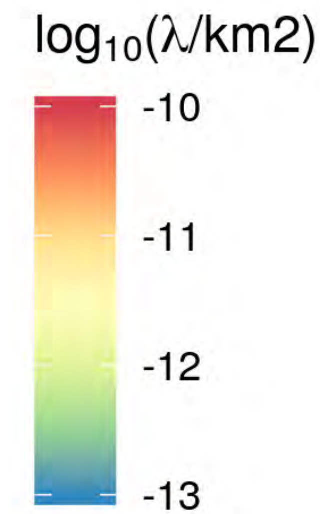

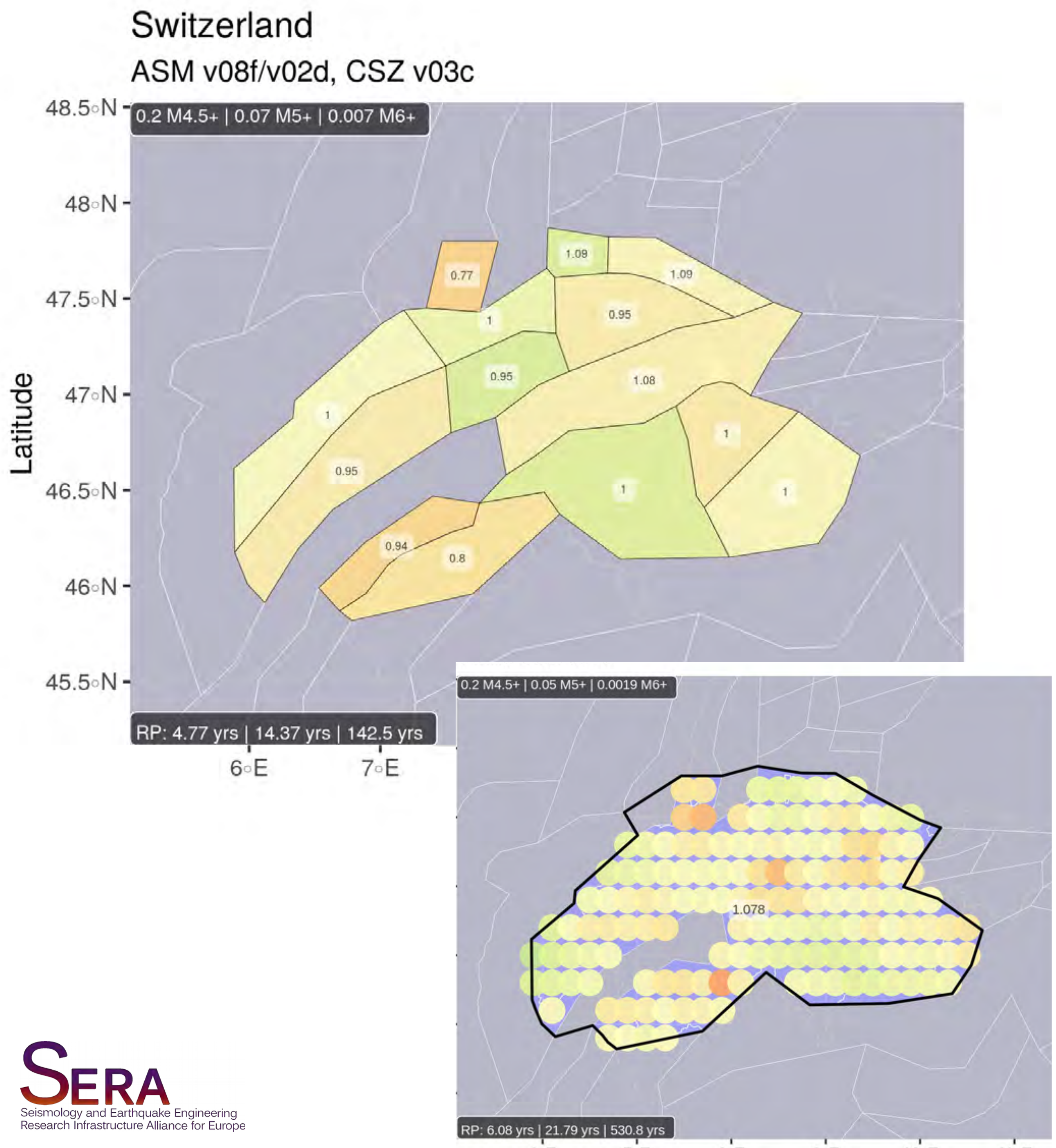

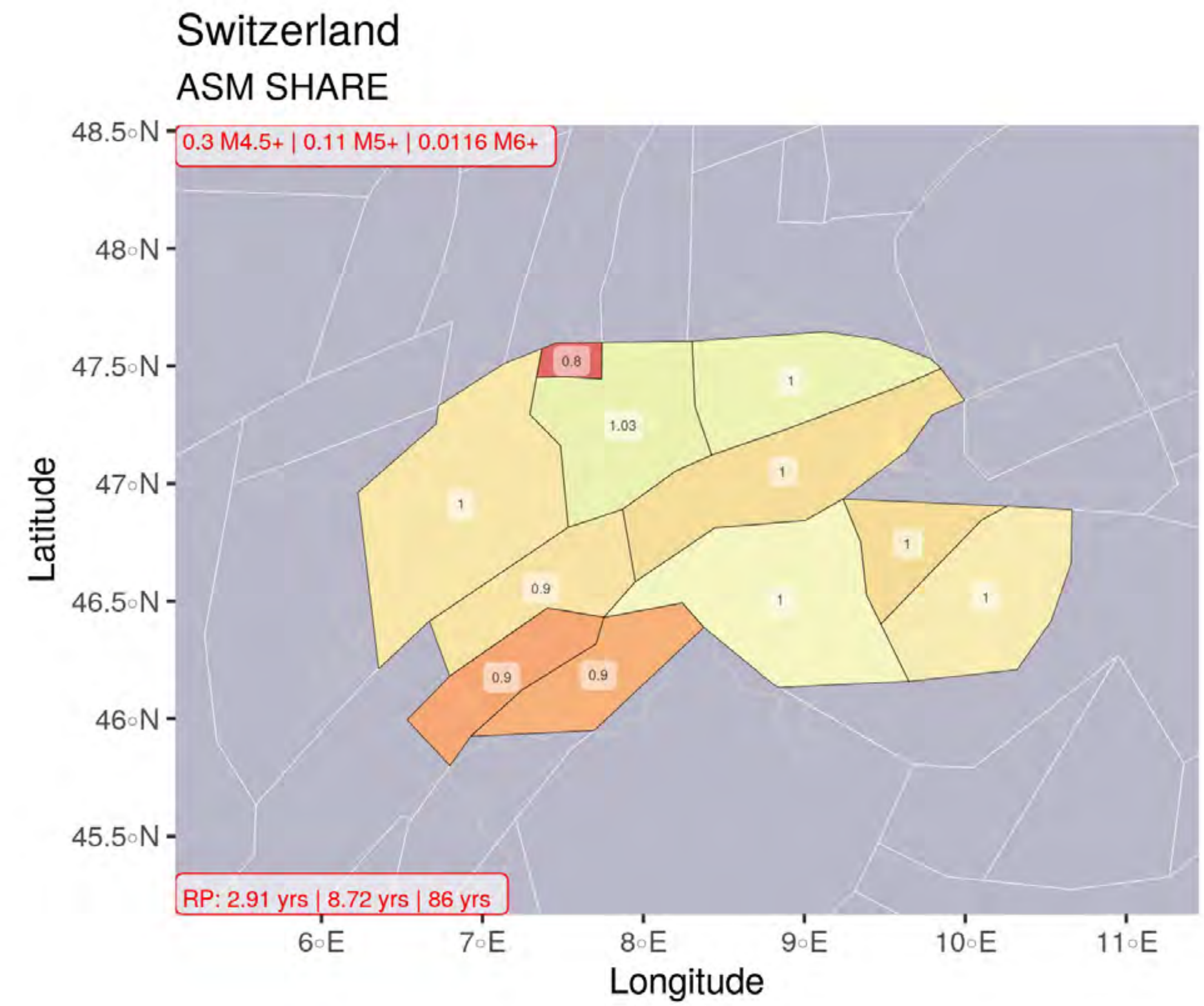

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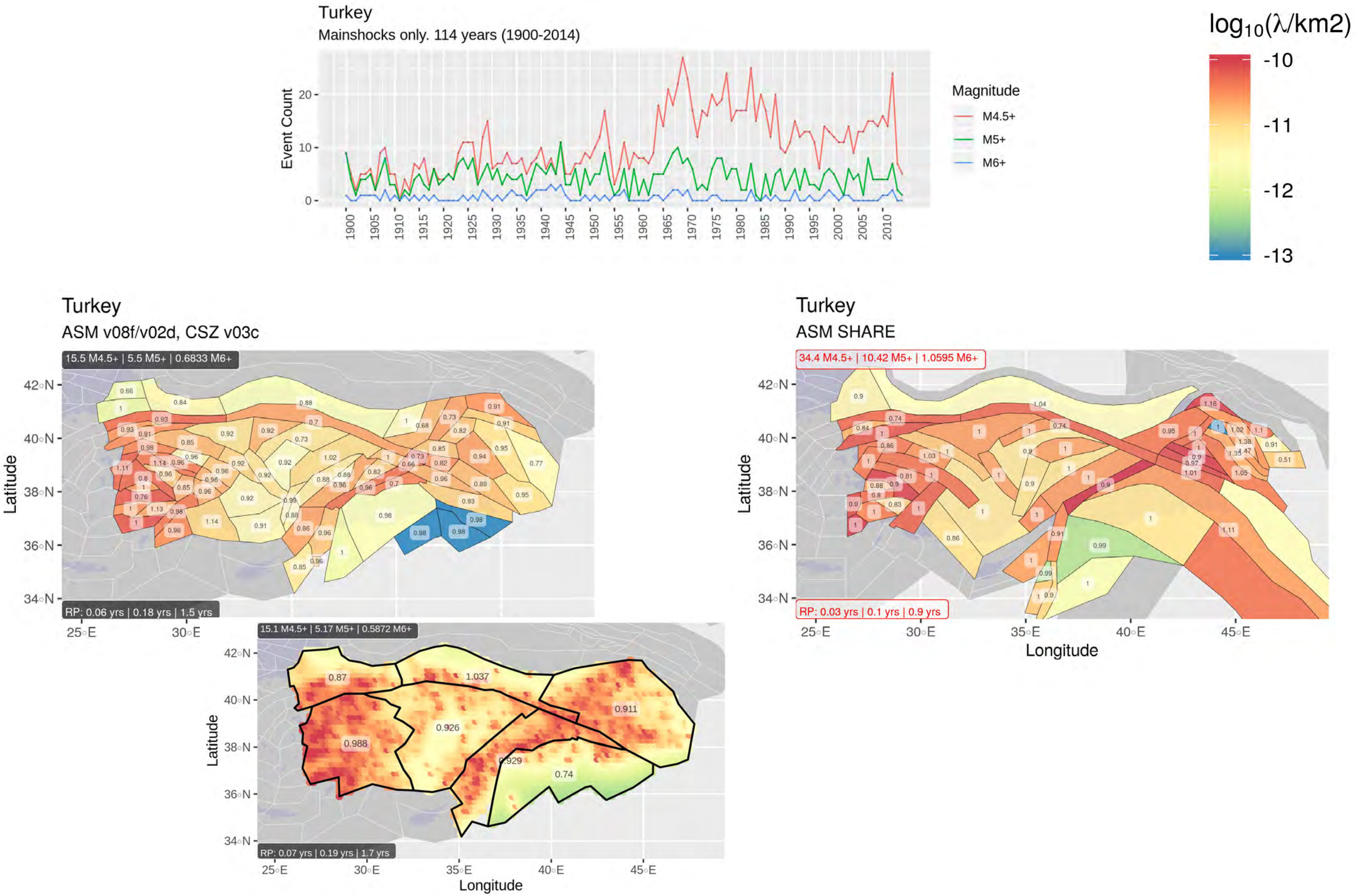

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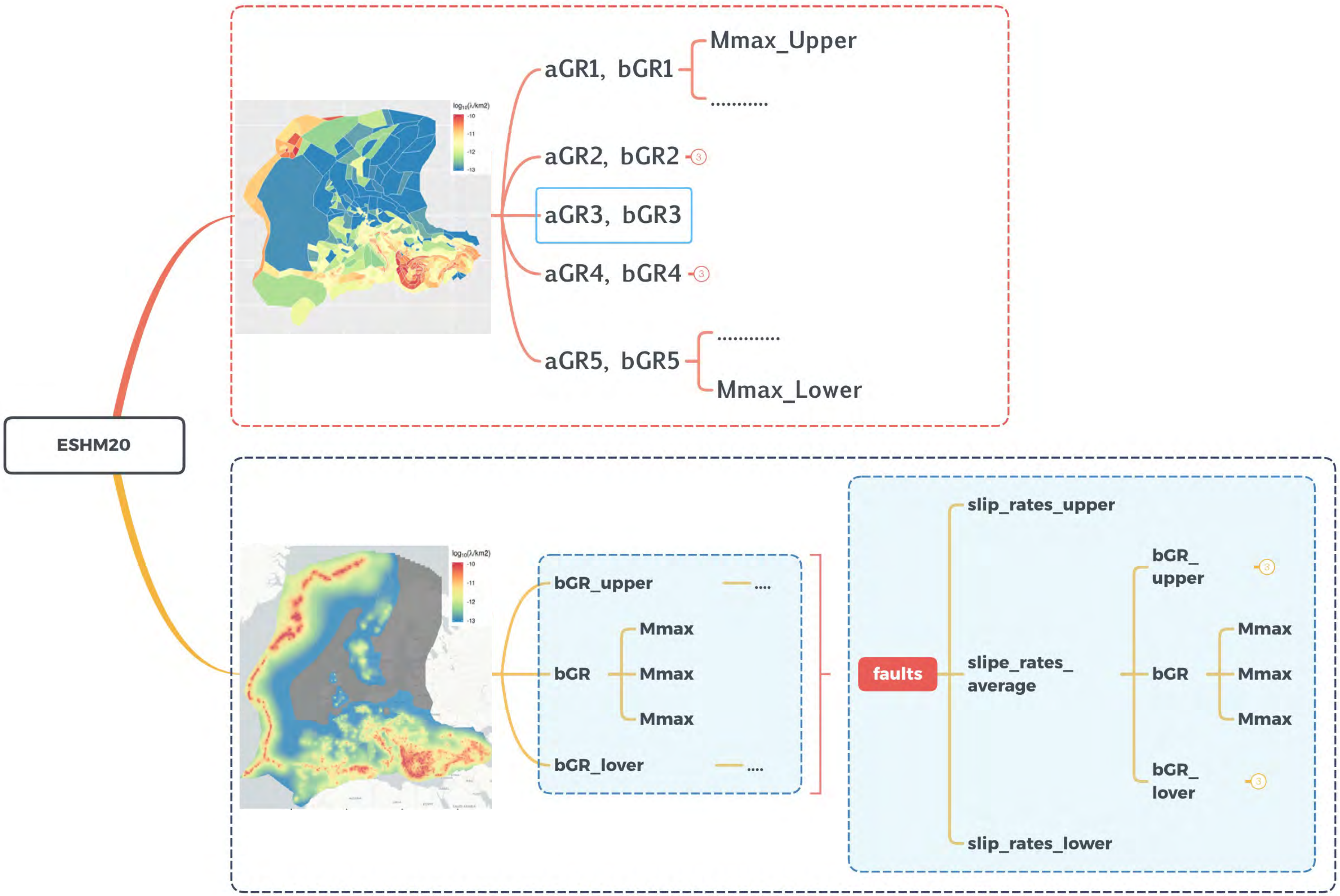
ESHM20: Source Model Logic Tree

Captures the inherent uncertainties of the data, information, knowledge as well as uncertainties in model construction (delineation of areal sources, completeness, reliability of fault source information)



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Appendix

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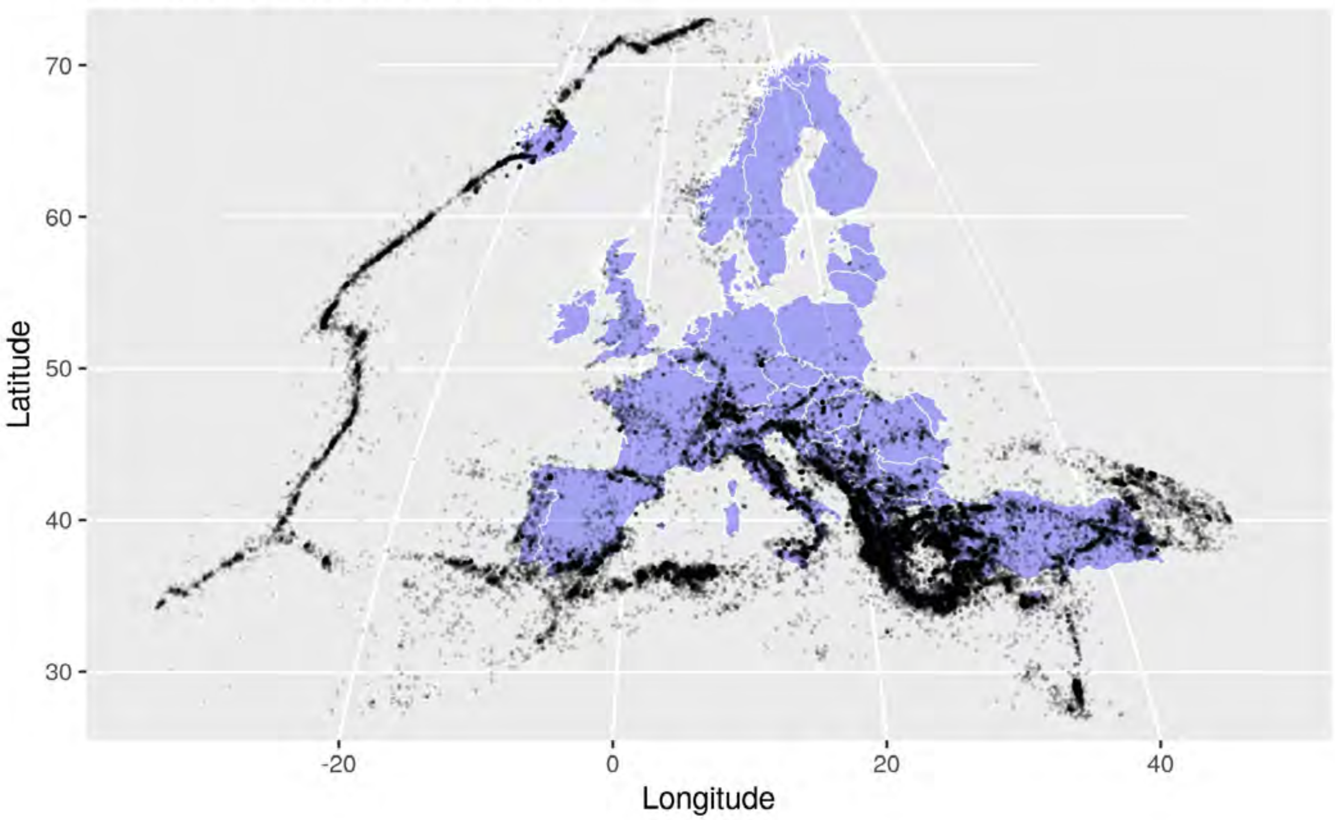
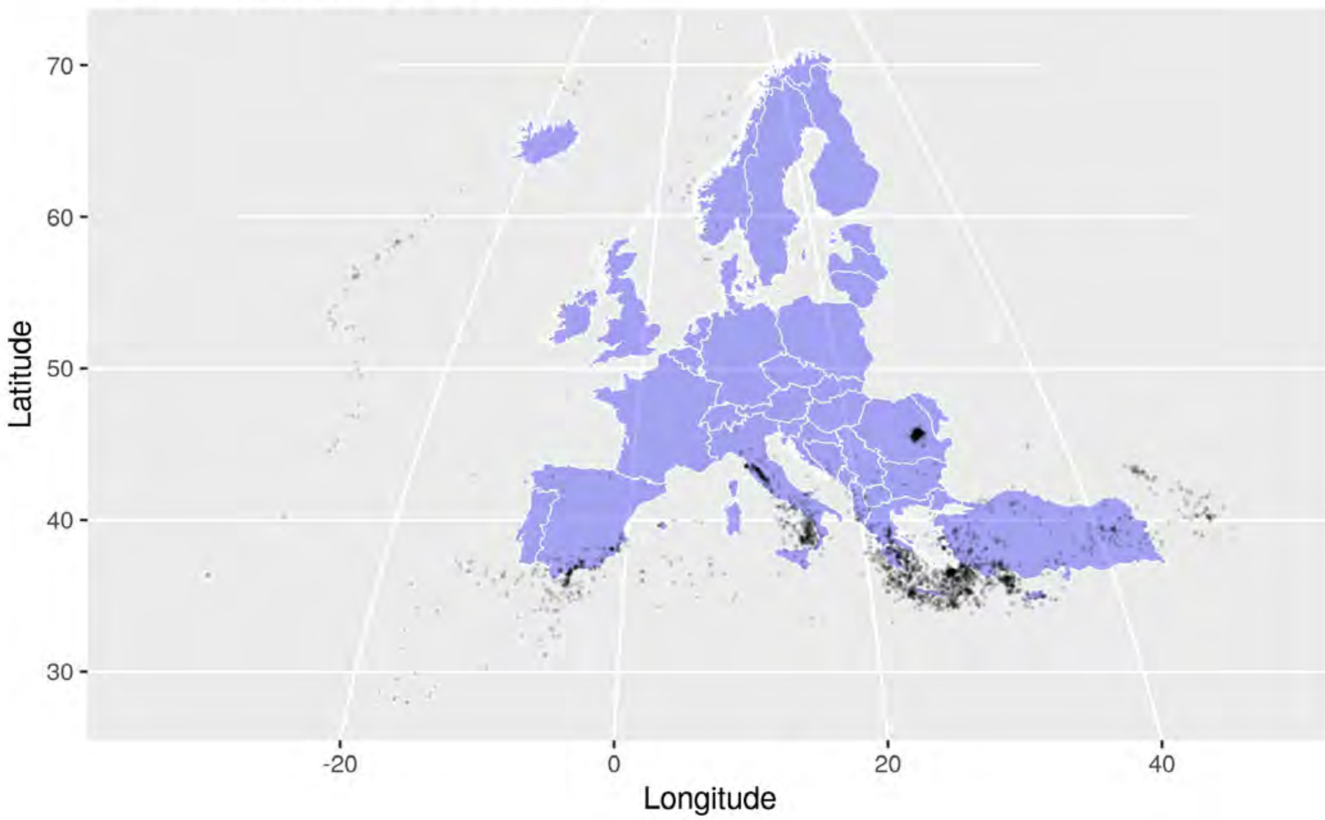
ESHM20: Appendix

ESHM20 catalog <60km
56710 events, version v20190218_v1.0

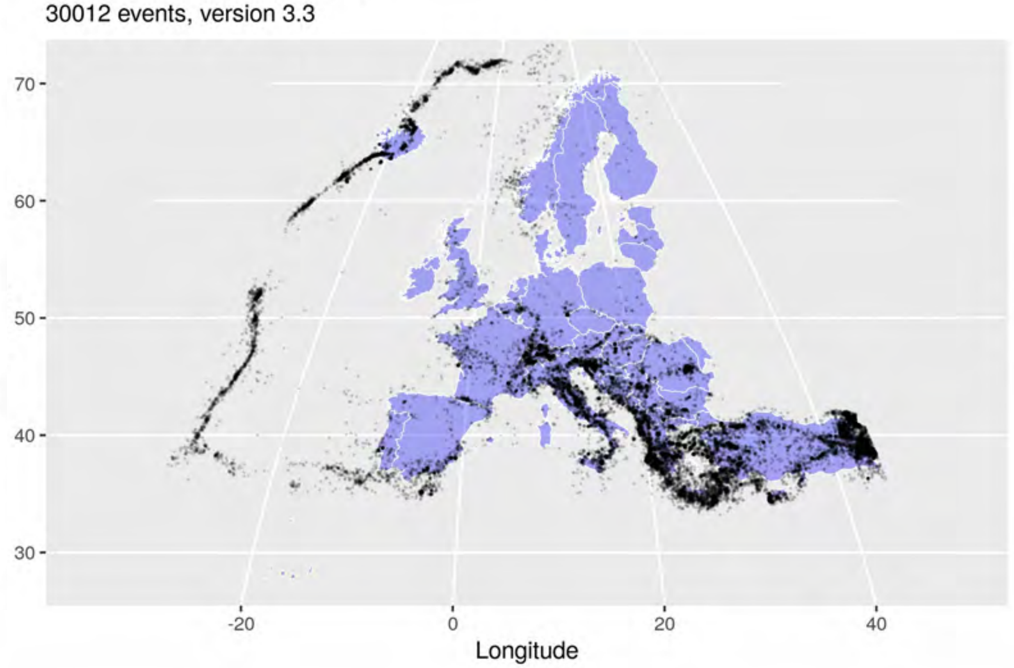


ESHM20 catalog >=60km
4135 events, version v20190218_v1.0



	(1) Historical: SERA v1.0	(2) Instrumental: EMEC v20190218	(1)+(2): Unified ESHM20	Compare Unified ESHM13
Time span	1000/1900	1900/31-12-2014	1000/31-12-2014	1000/31-12-2006
Magnitude span	1.9/8.5	3.49/8.3	1.7/8.5	1.7/8.5
Longitude span	-23.5°/32.413°	-37.0°/51.9°	-37.0°/51.9°	-31.65°/45.0°
Latitude span	35.0°/69.43°	26.9°/73.0°	26.9°/73.0°	33.2°/73.32°
# Total Number	5716	55411	61127	30012
# magnitude ≥ 4.5	2340	20388	22728	13284
# magnitude ≥ 5.0	1552	6013	7565	5585
# magnitude ≥ 5.5	885	1920	2805	2066

ESHM13 SHEEC catalog
30012 events, version 3.3



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ESHM20: Appendix

1. Windowing techniques with space-time-windows as defined by Gruenthal, Gardner & Knopoff (1974) and Uhrhammer (1986).

2. Cluster method introduced by Reasenberg (1985). The method aims at identifying dependent earthquakes by linking them to clusters according to spatial and temporal interaction zones.

3. Declustering based on a correlation metric (Zaliapin et al. 2008). The technique is based on a space-time metric to correlate earthquakes with each other. By comparing rescaled times to rescaled distances it is possible to identify two distinct populations.

Parameter	Description	Range
fs_time_prop	fraction of the time window used for foreshocks	[1.0, 0.5, 0.1, **0.17**, 0.01, 0.001]
taumin	Minimum look ahead time for clustered events	[1.0] day
taumax	maximum look ahead time for clustered events	[5.0, 10.0, 15.0] days
xmeff	effective magnitude to define magnitude cutoff (with xk=0.5)	[3.5, 4.5, 5.5, 6.5, 7.5]
rfact	factor for interaction radius for dependent events	[8.0, 10.0, 12.0]
fractal_dim	spatial weighting factor	[1.4, 1.6, 1.8]
b_value	magnitude weighting factor	[0.9, 1.0, 1.1]
theta	temporal weighting factor	[0.5, 1.0, 2.0]

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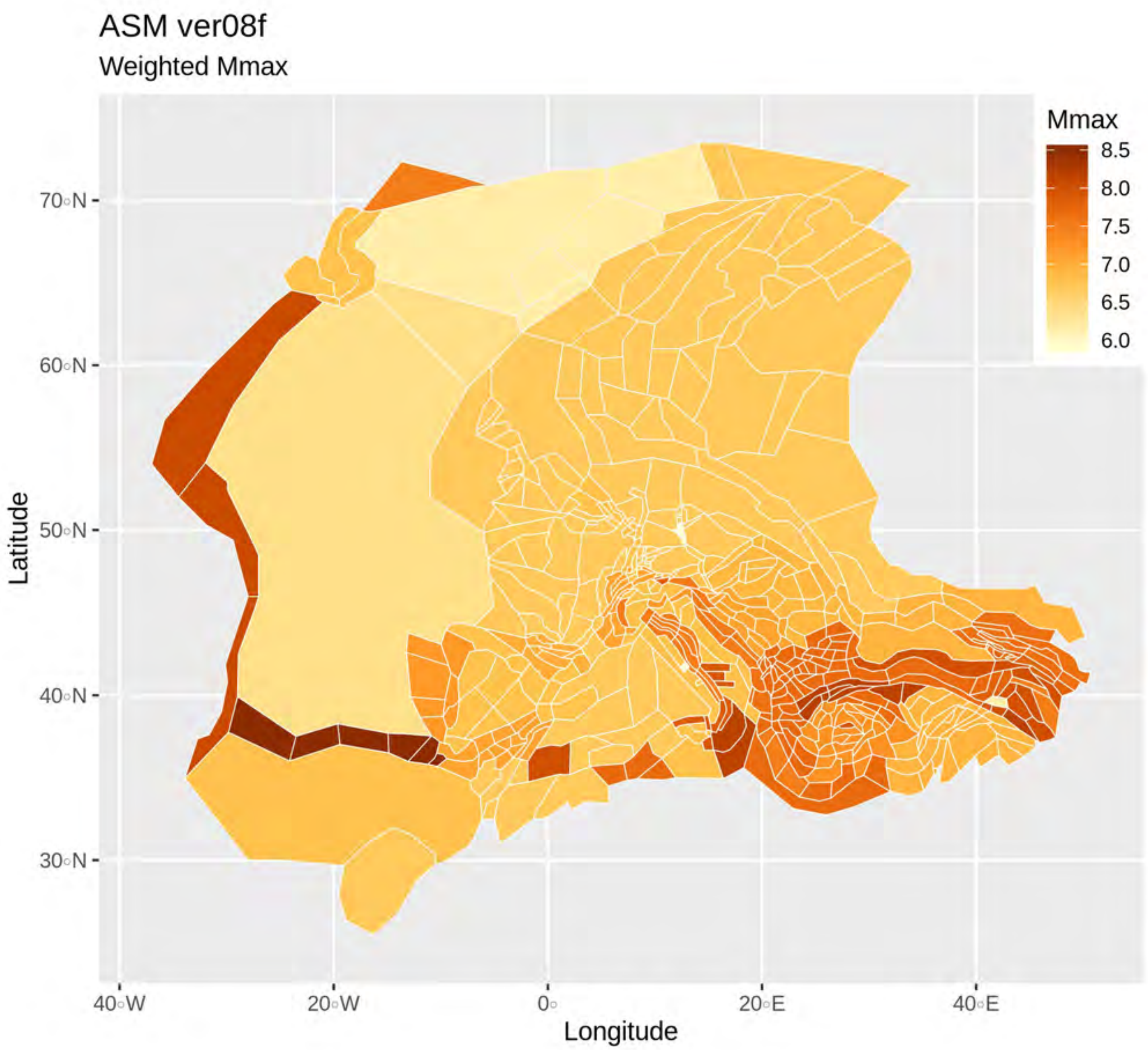
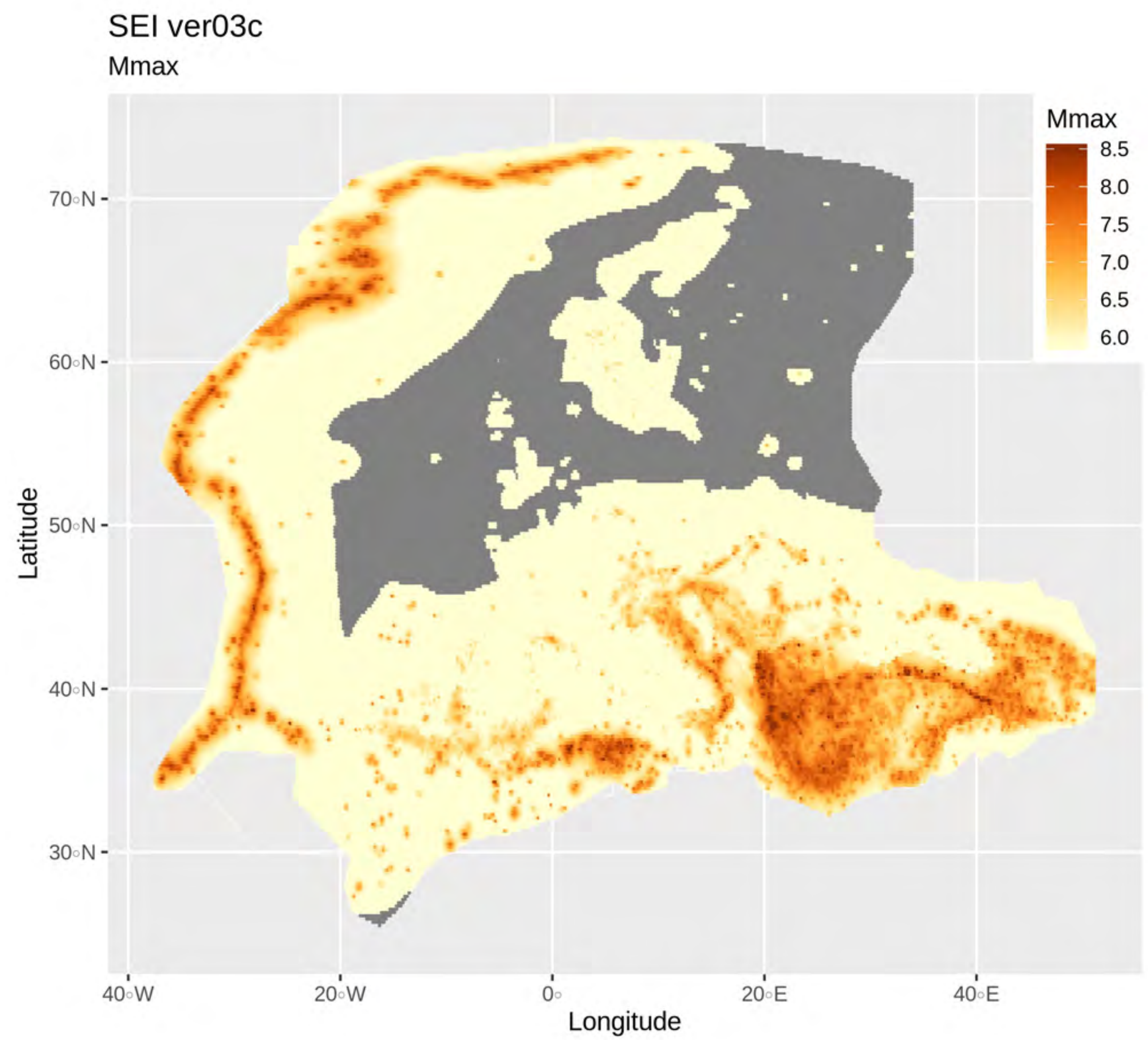
ESHM20: Appendix





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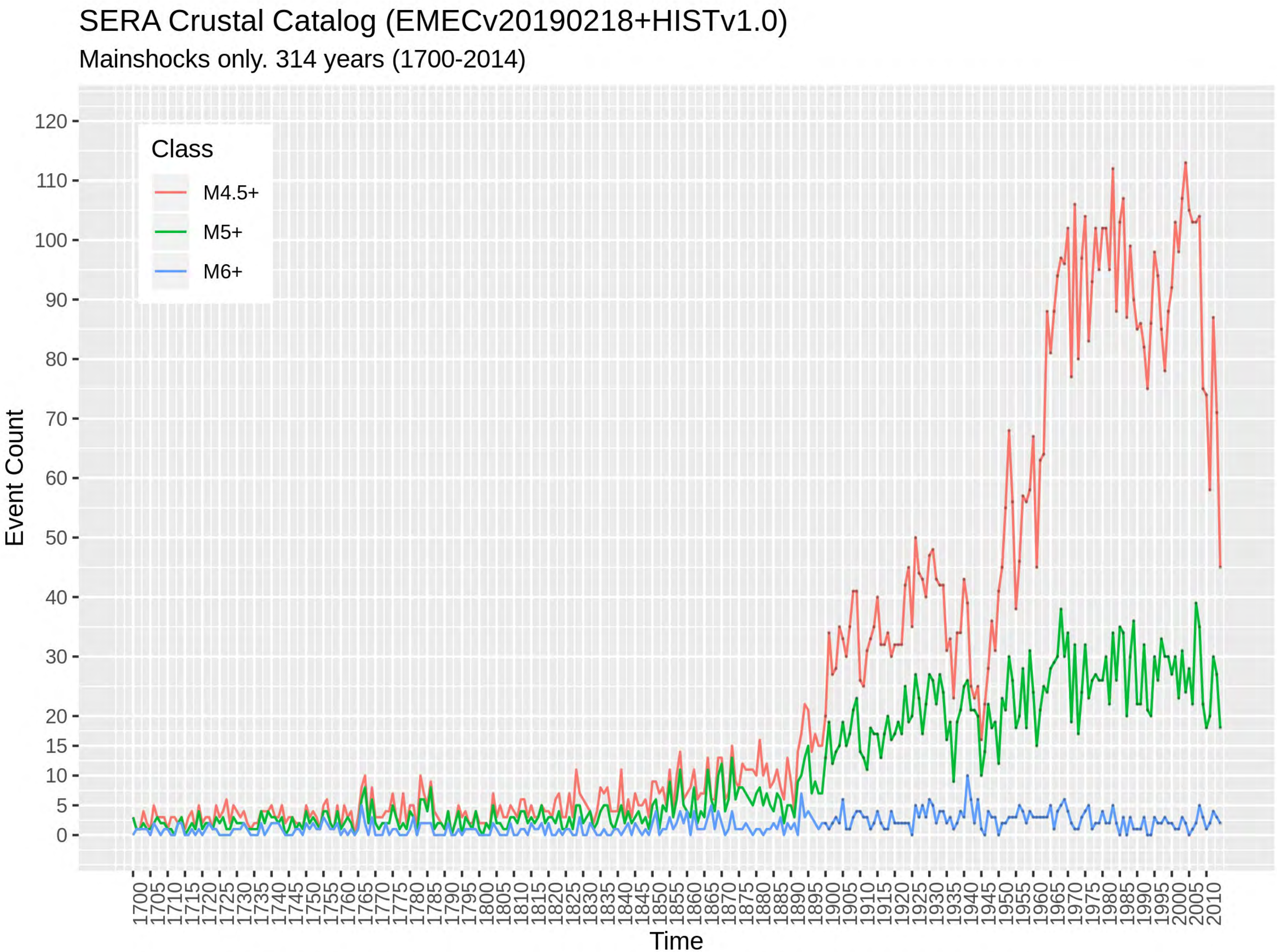
ESHM20: Appendix



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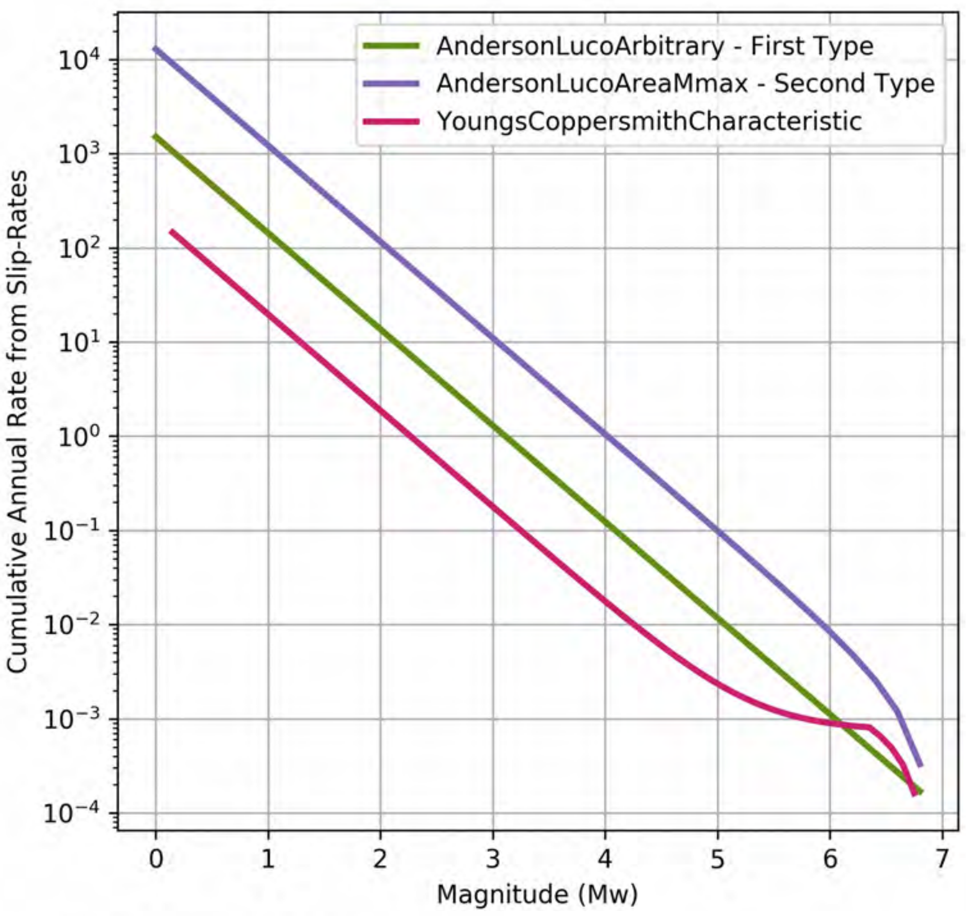
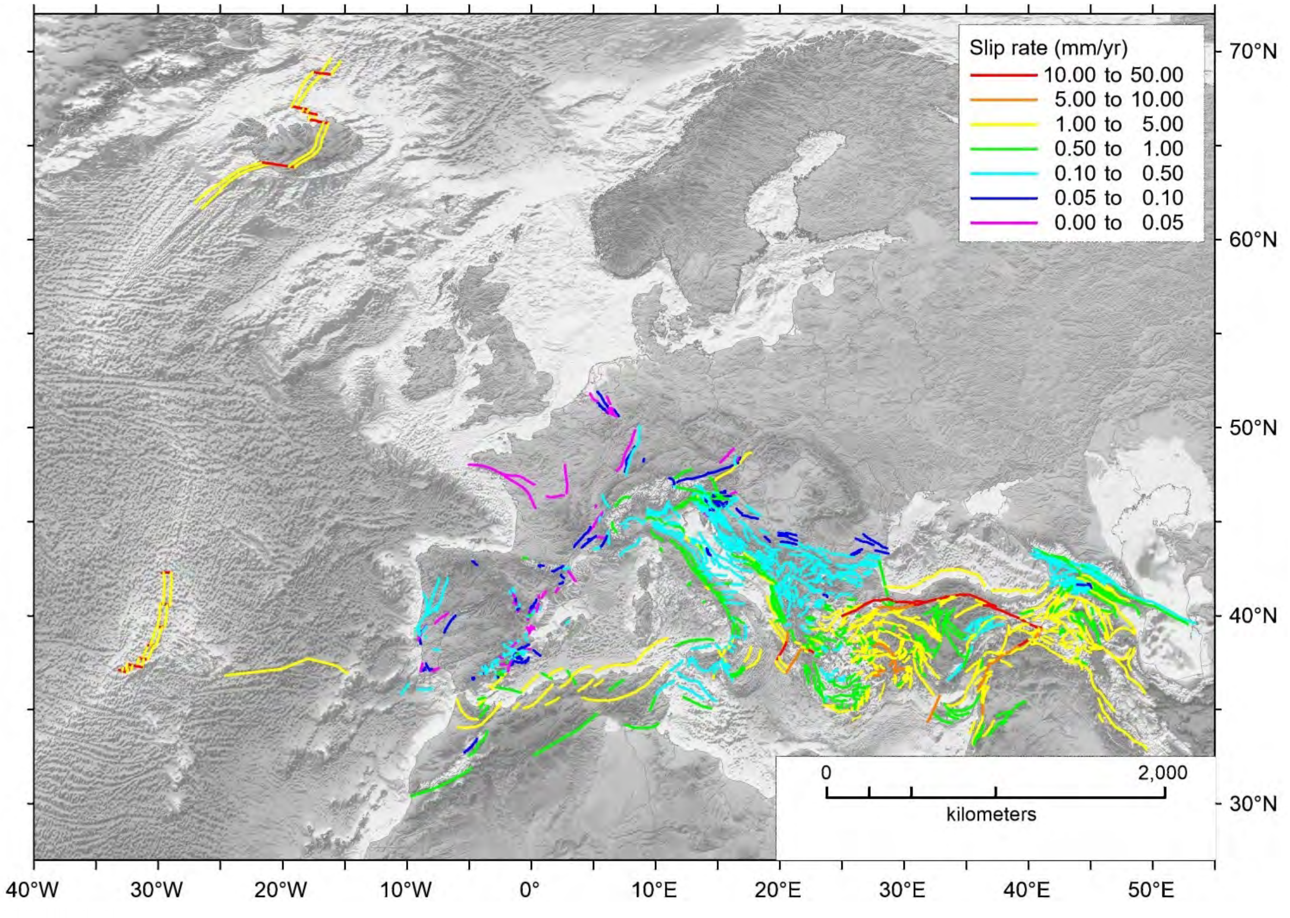
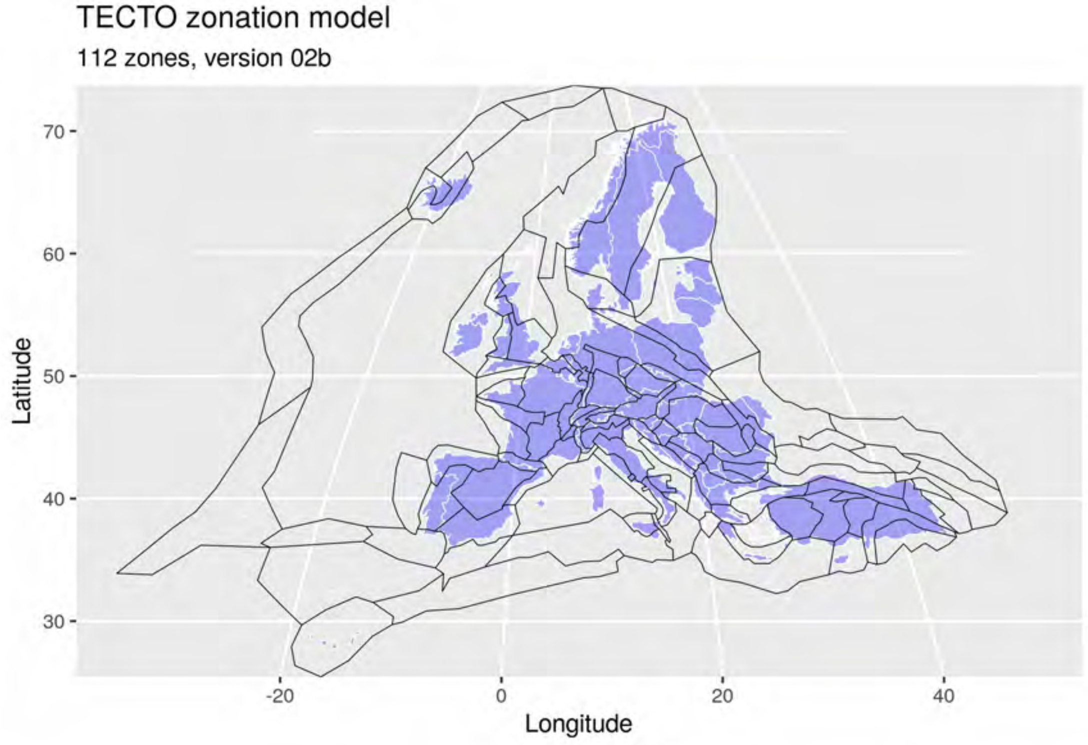
ESHM20: Appendix

Main Assumptions:
Slip rate to seismic activity
Fault slips entirely seismically
Prior b-value
Fault width, fault area
Lower bound, upper bound (magnitude)
Recurrence Models:
Anderson & Luco (1983) Model 1, 2
Young and Coppersmith (1985) Exponential Model







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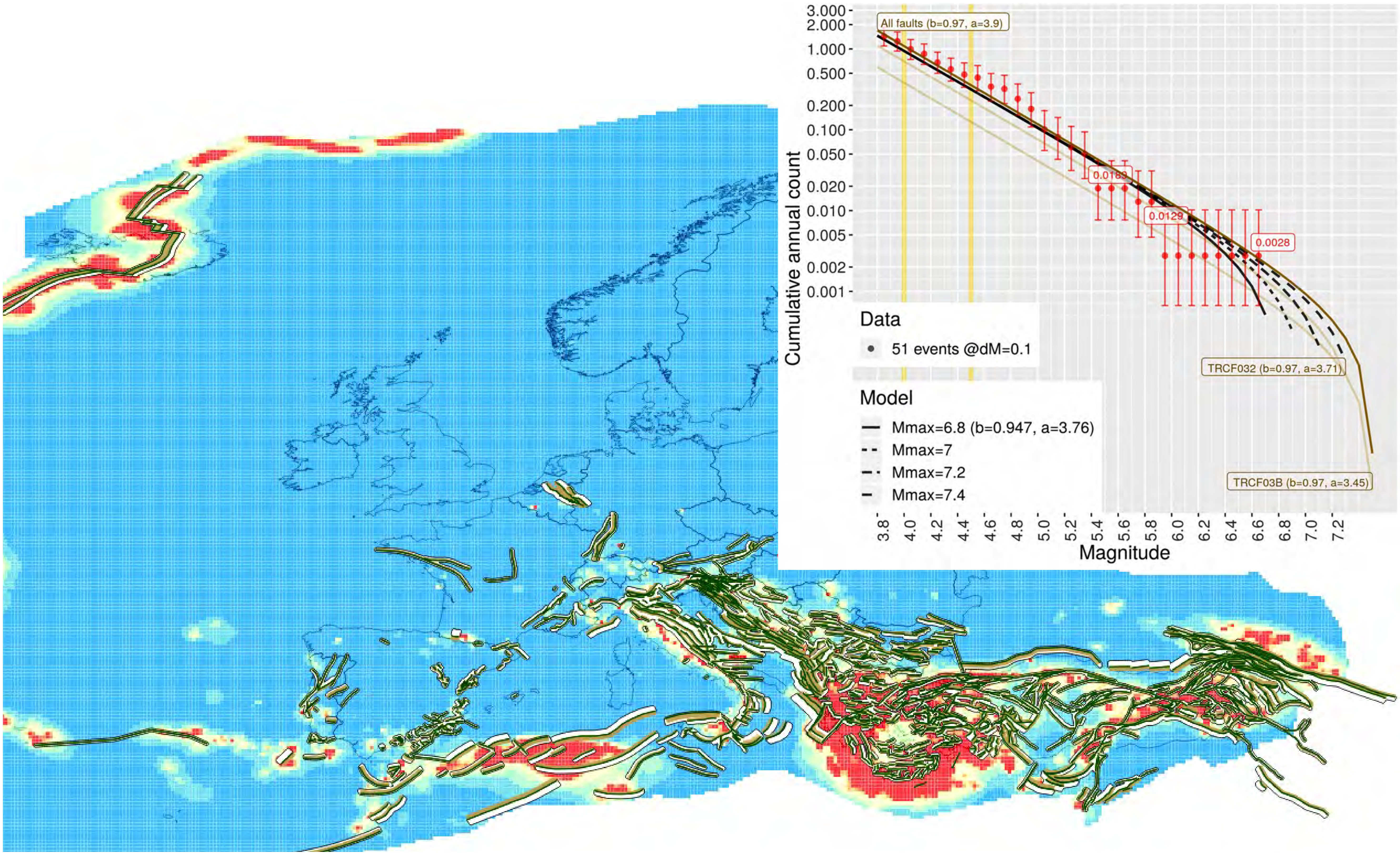

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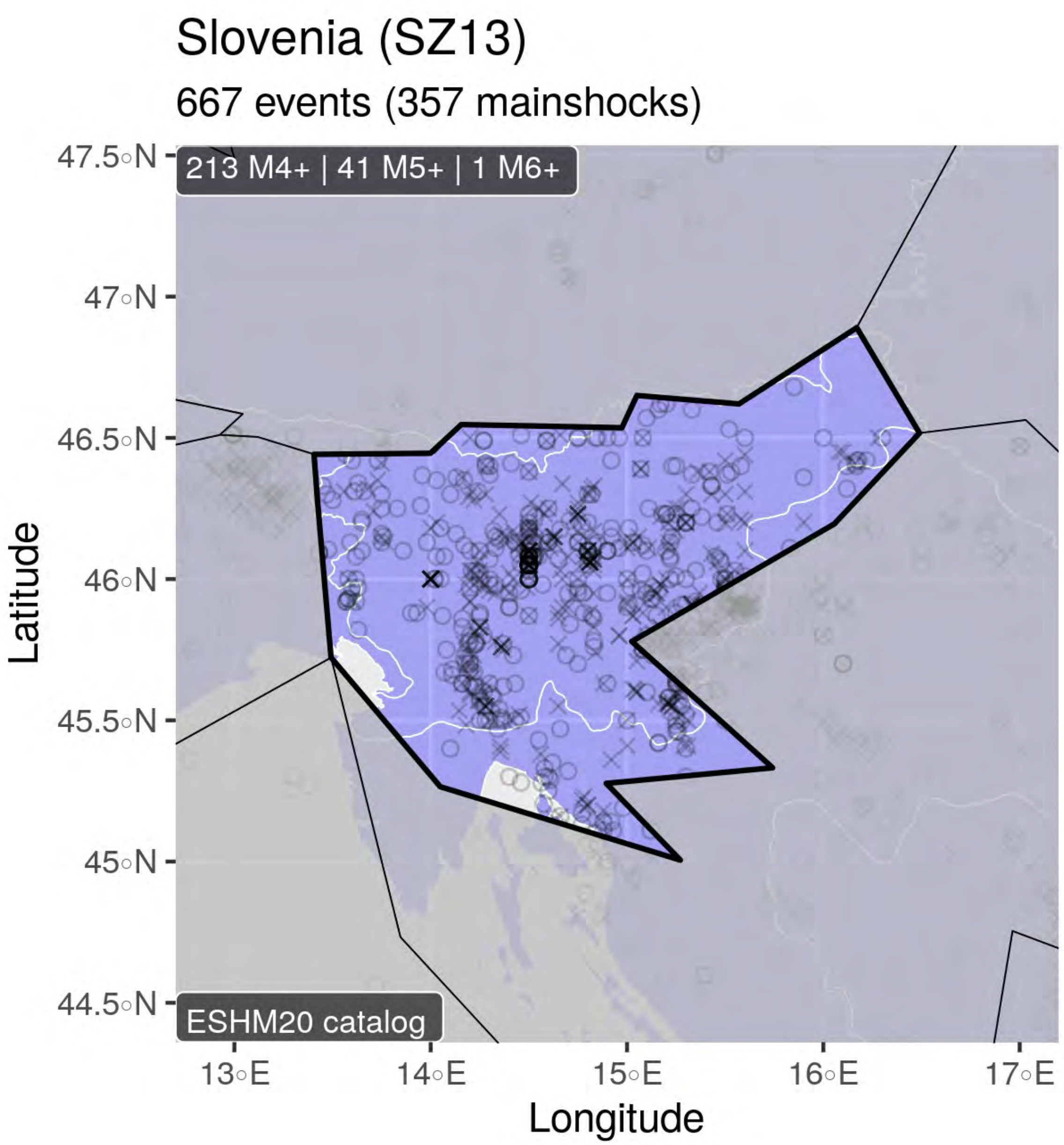
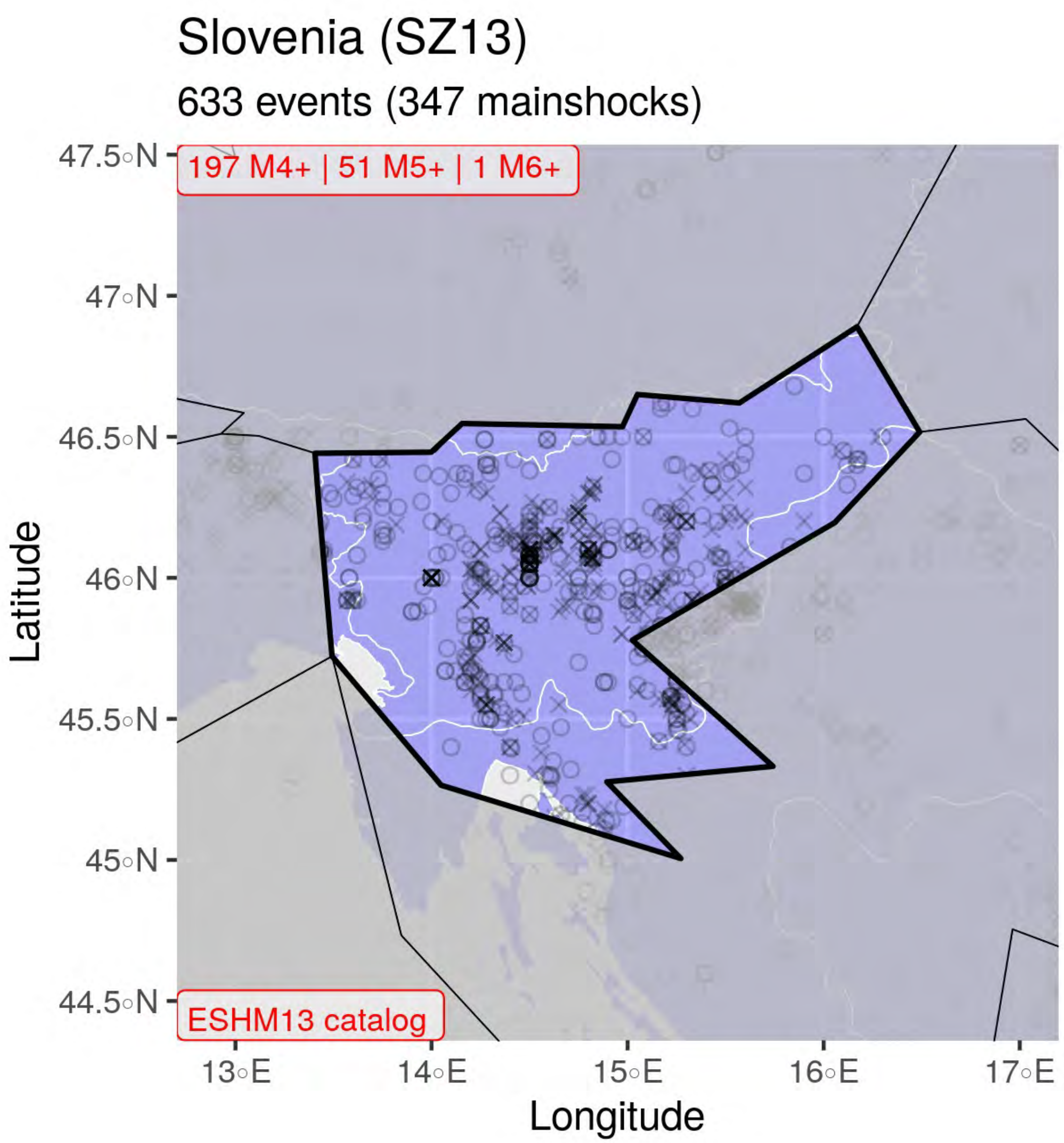
ESHM20: Catalog by country





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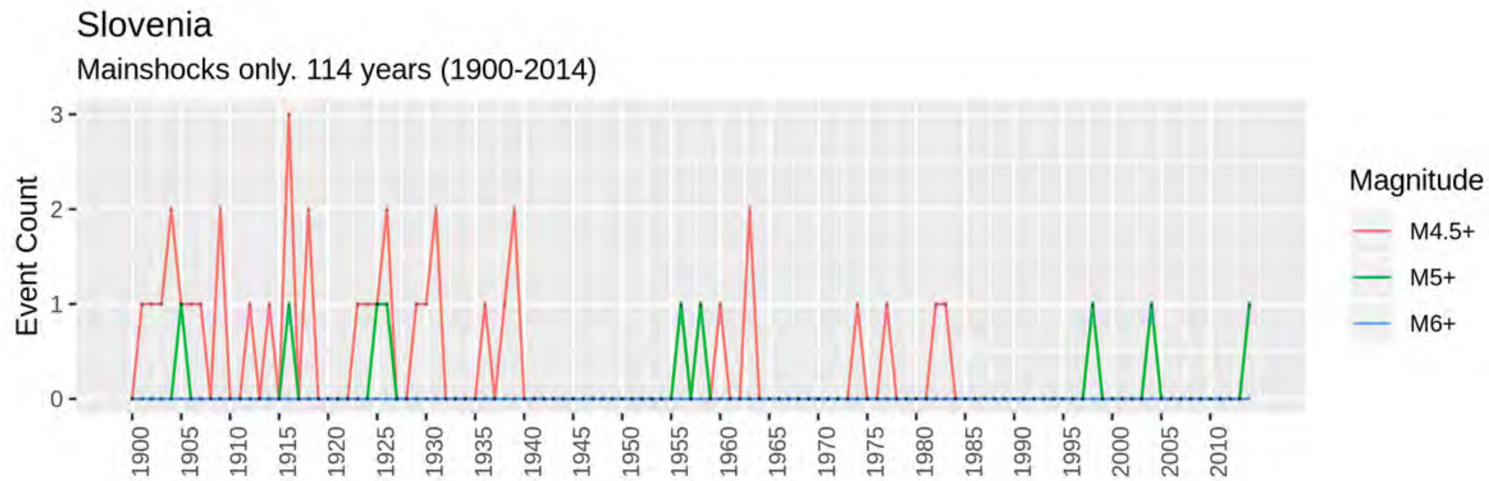

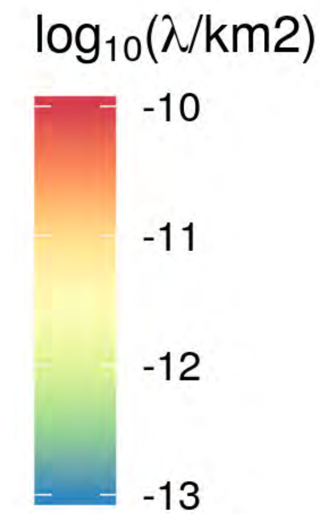

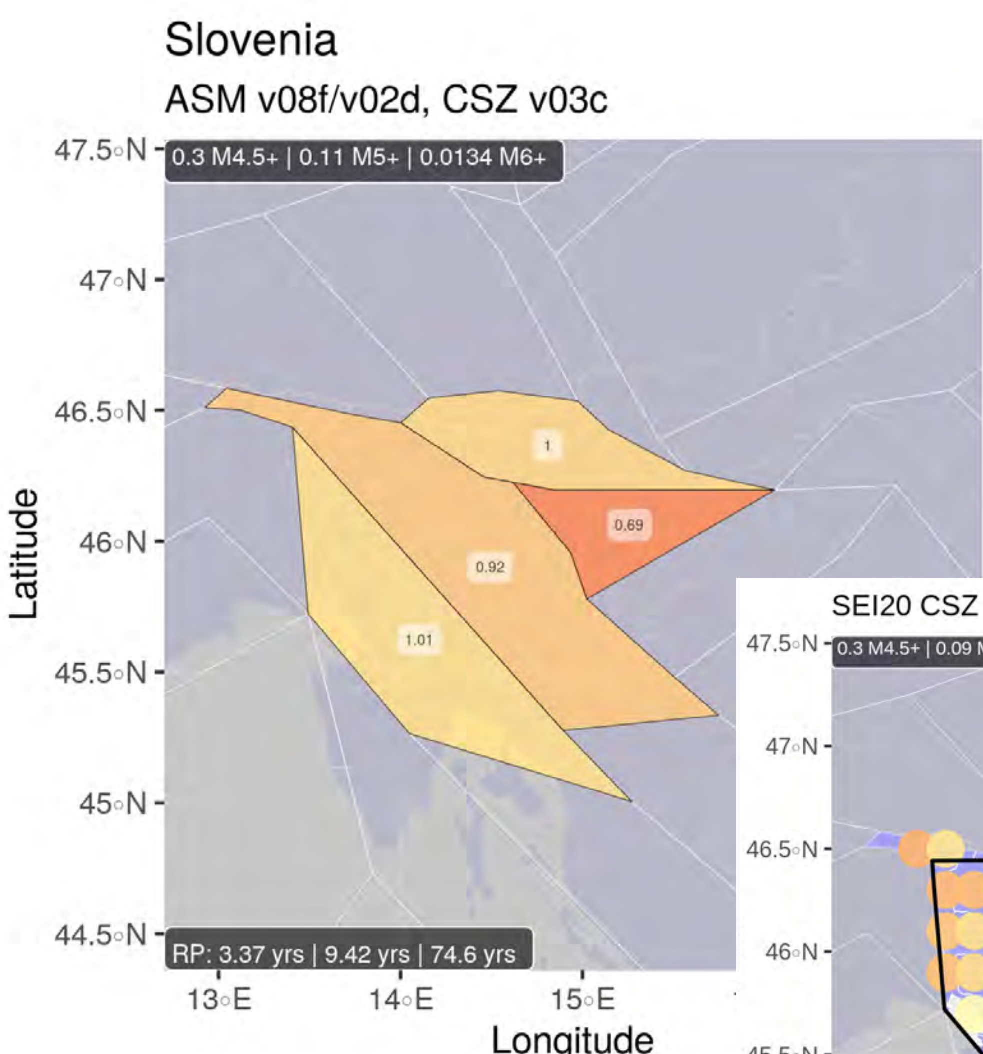

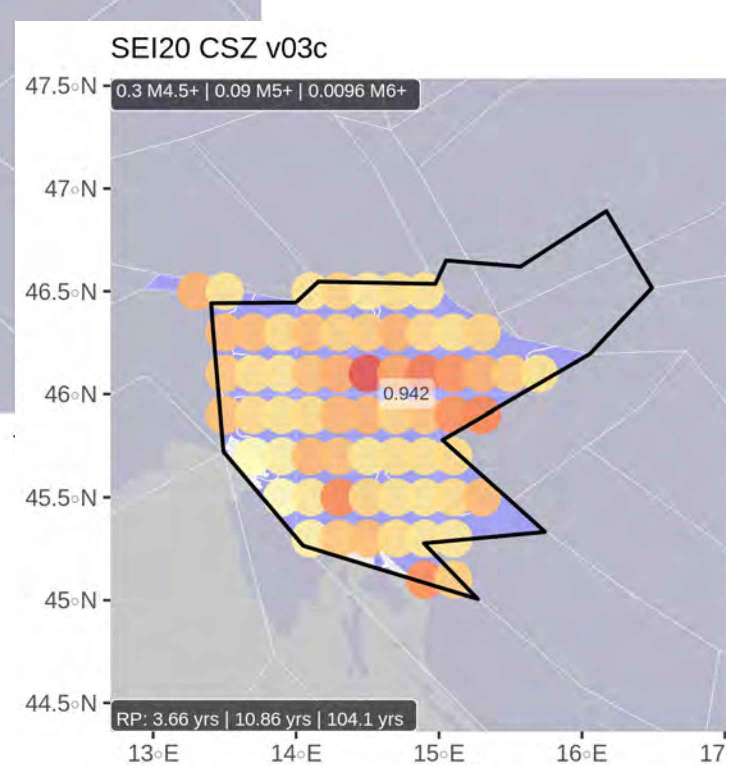

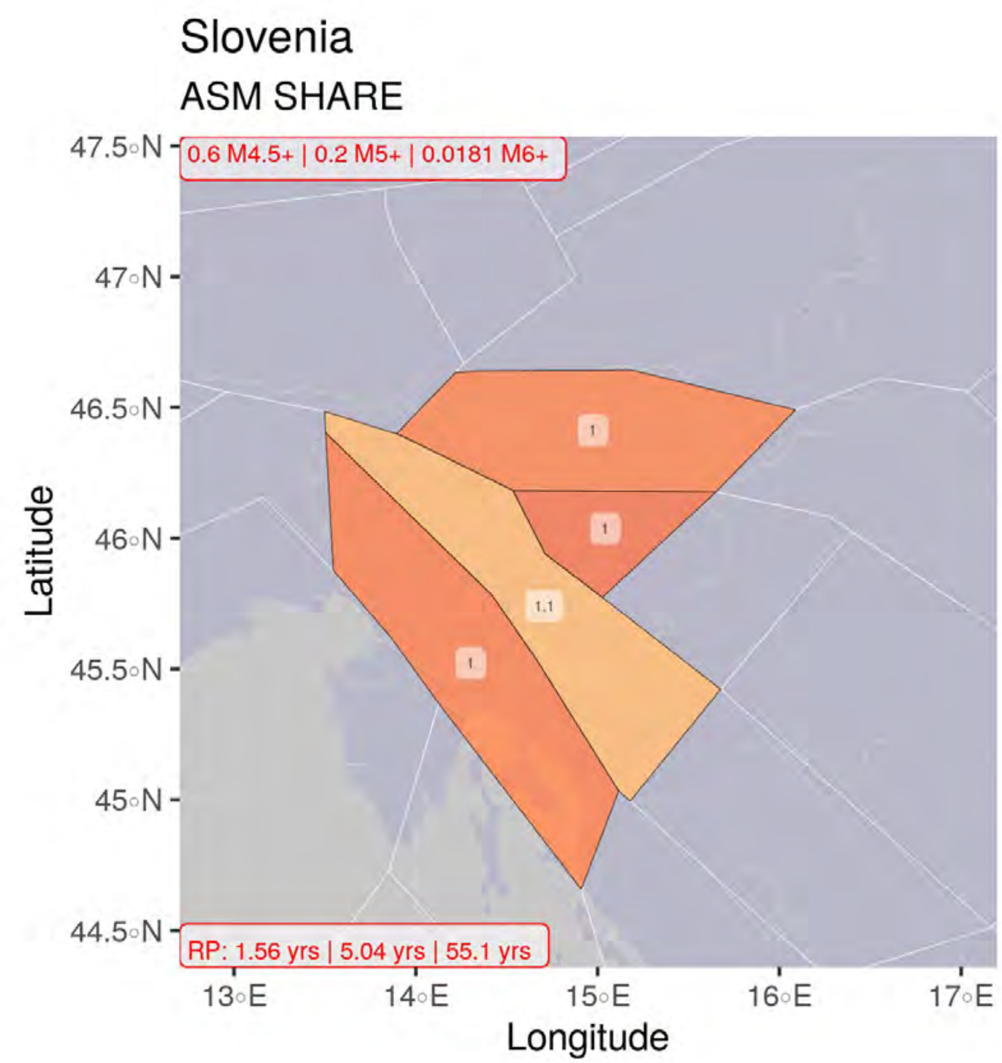

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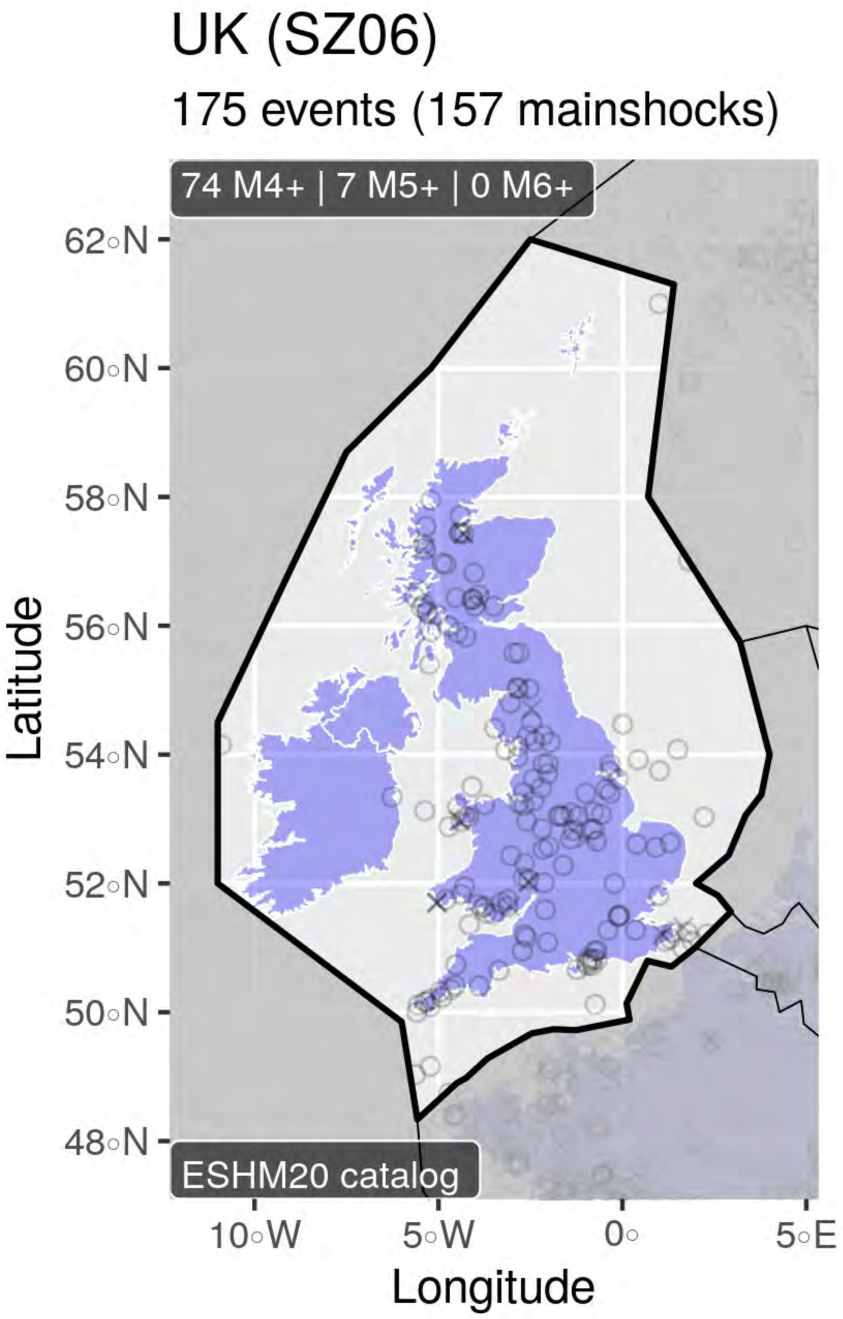

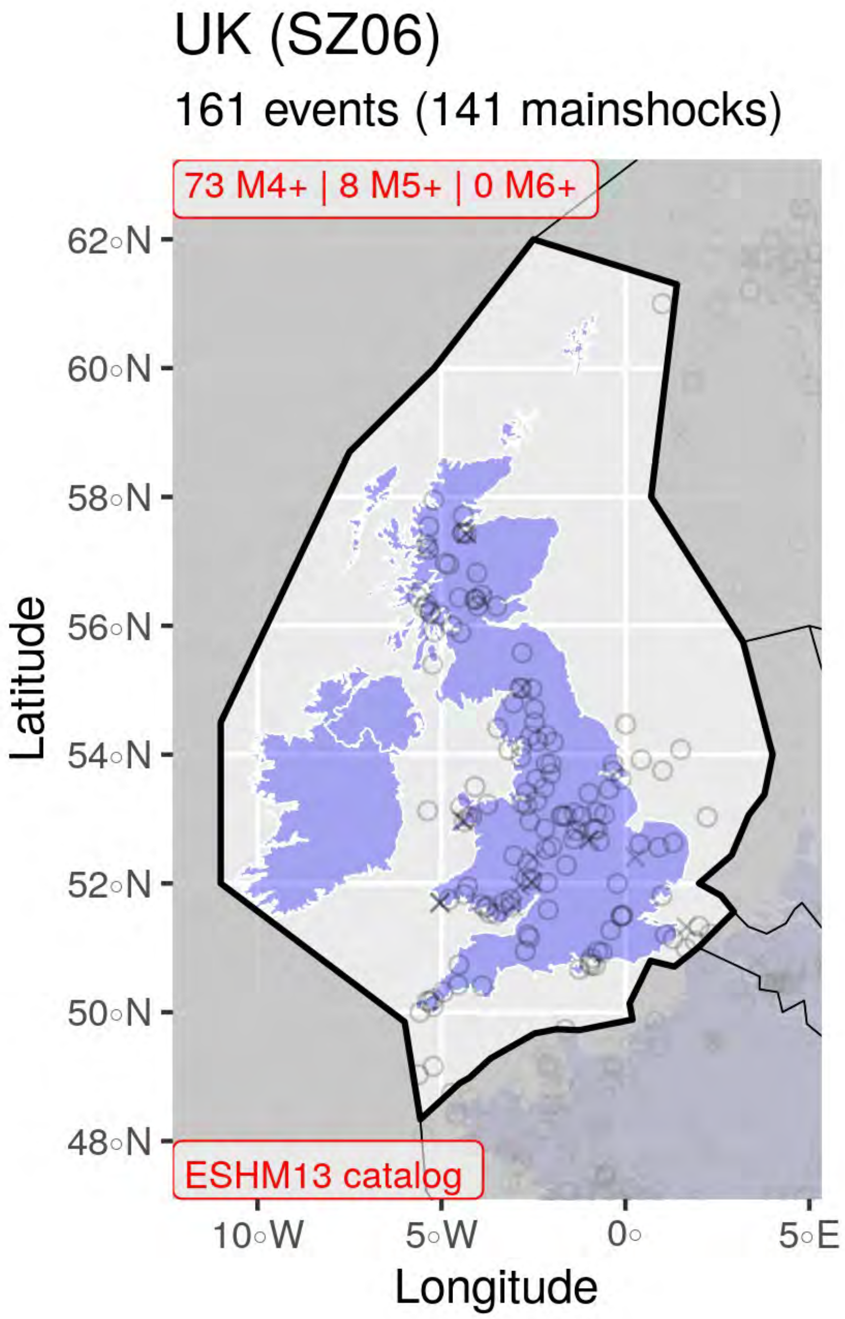

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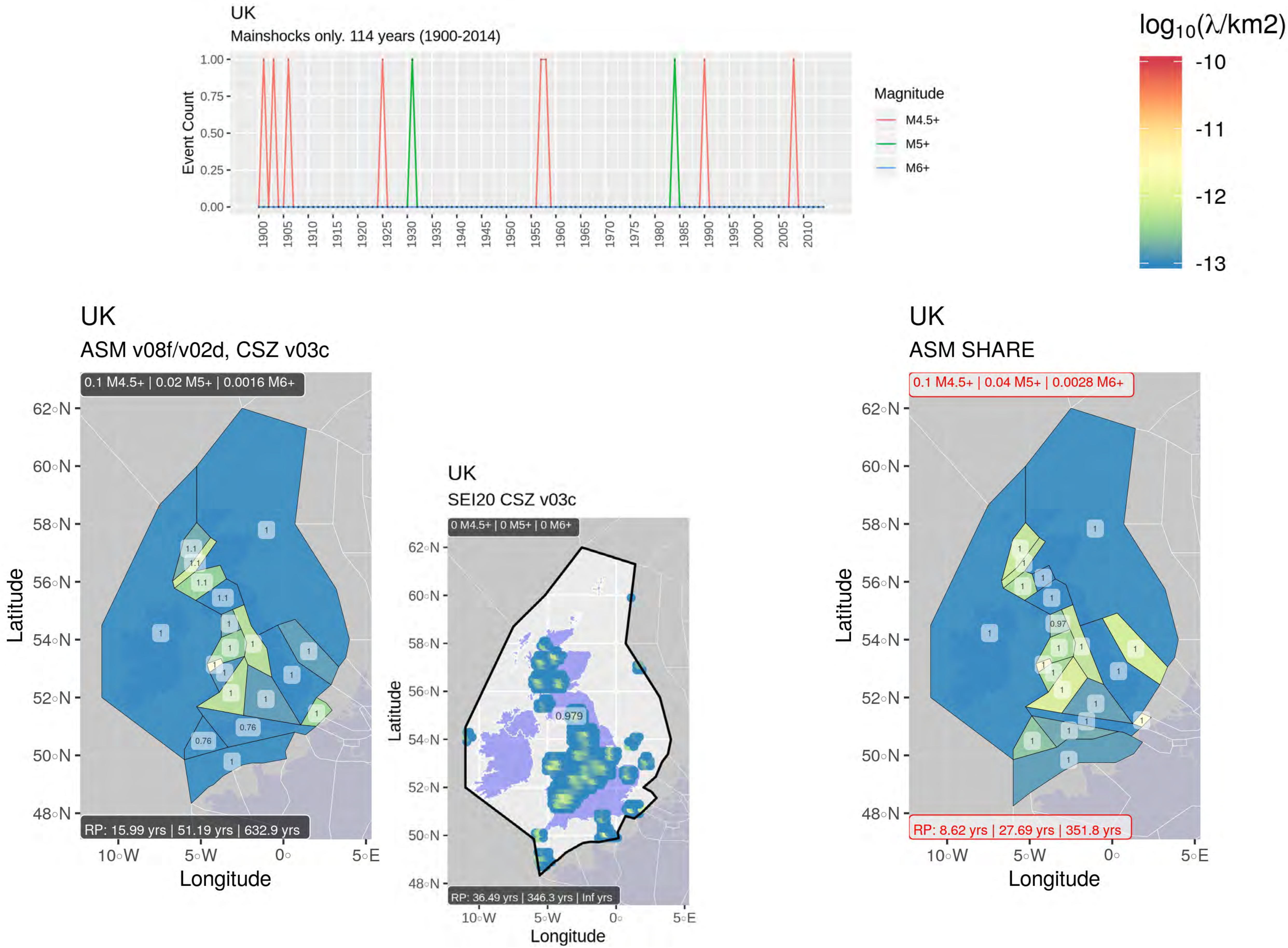

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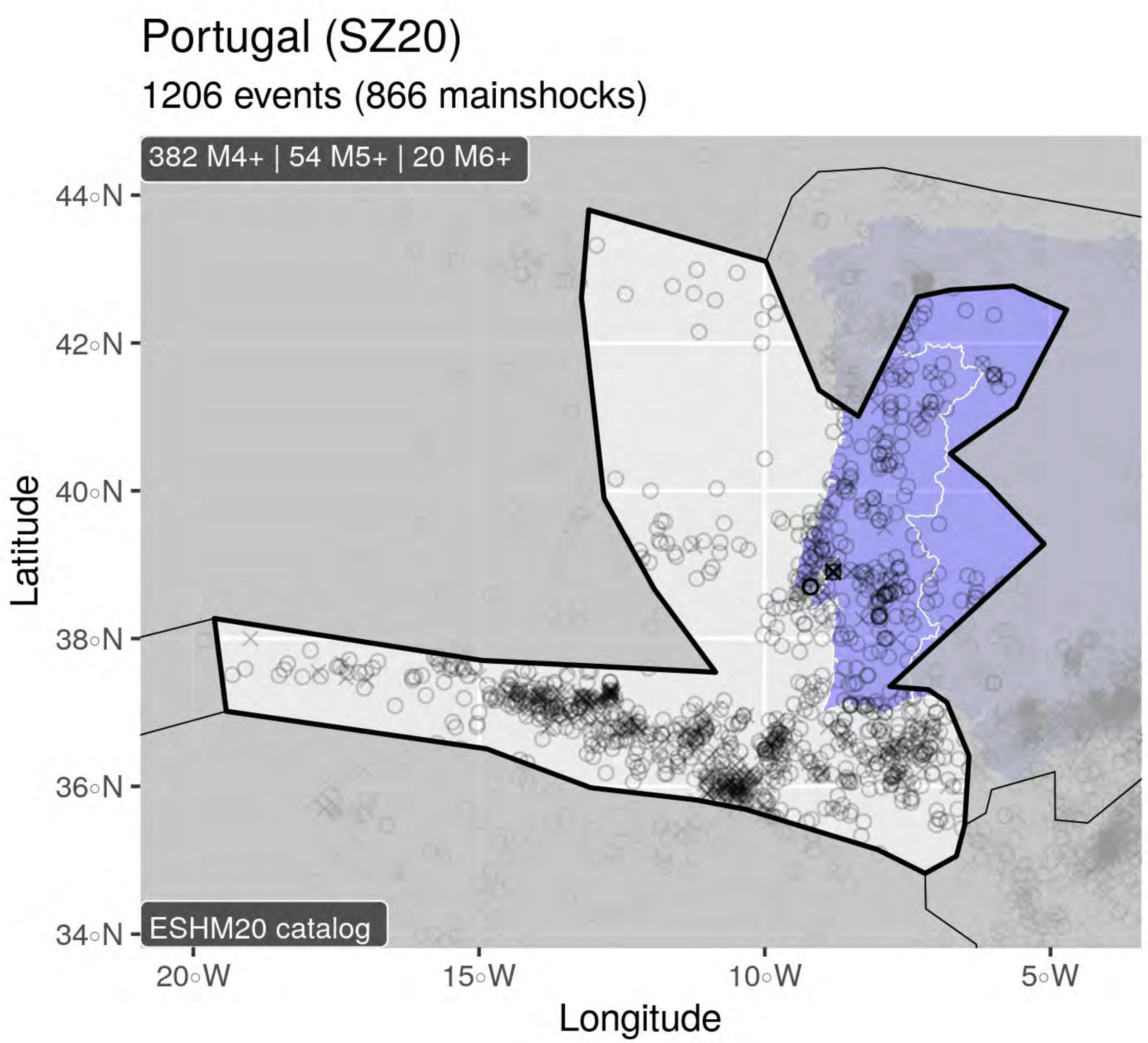

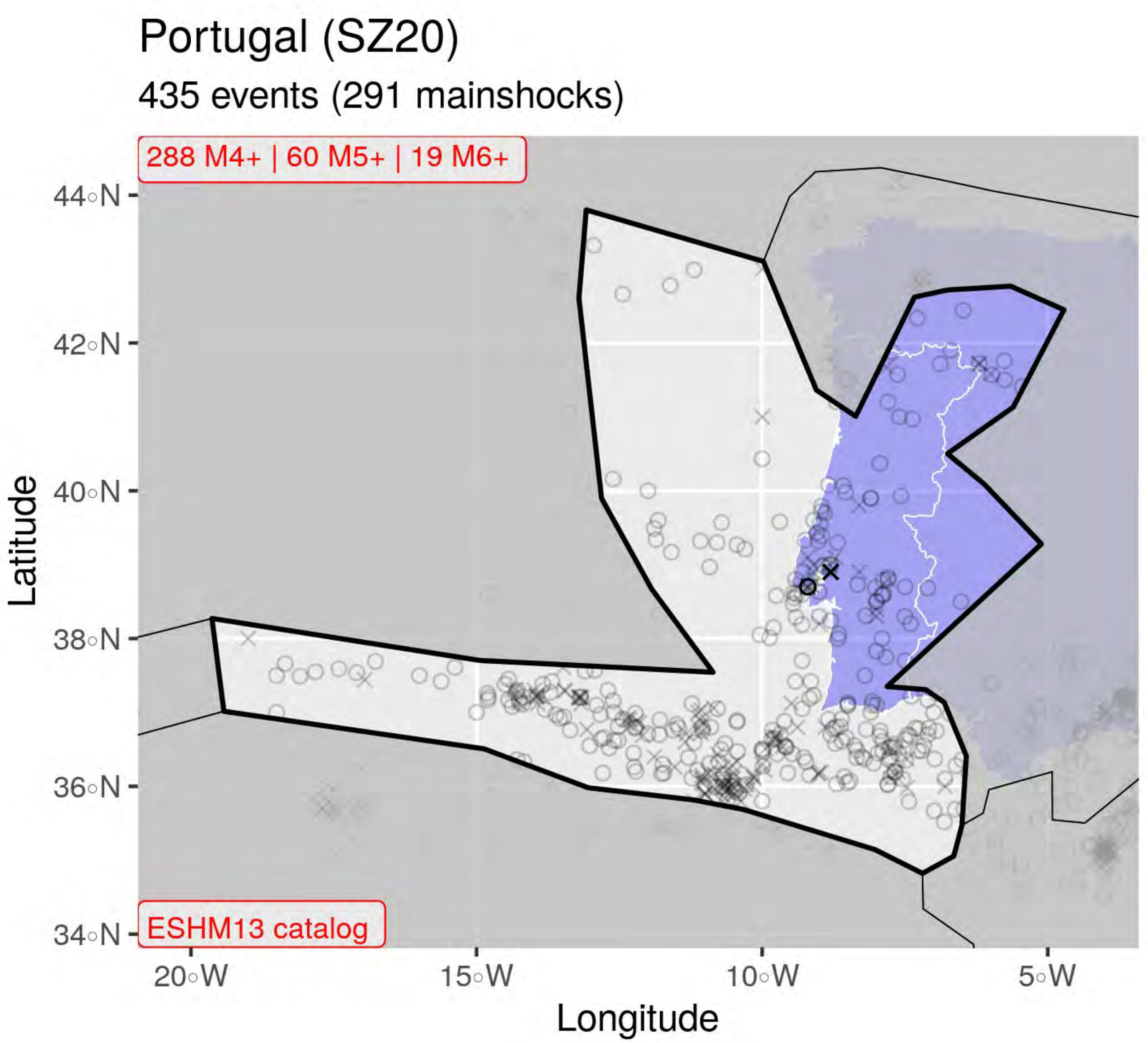

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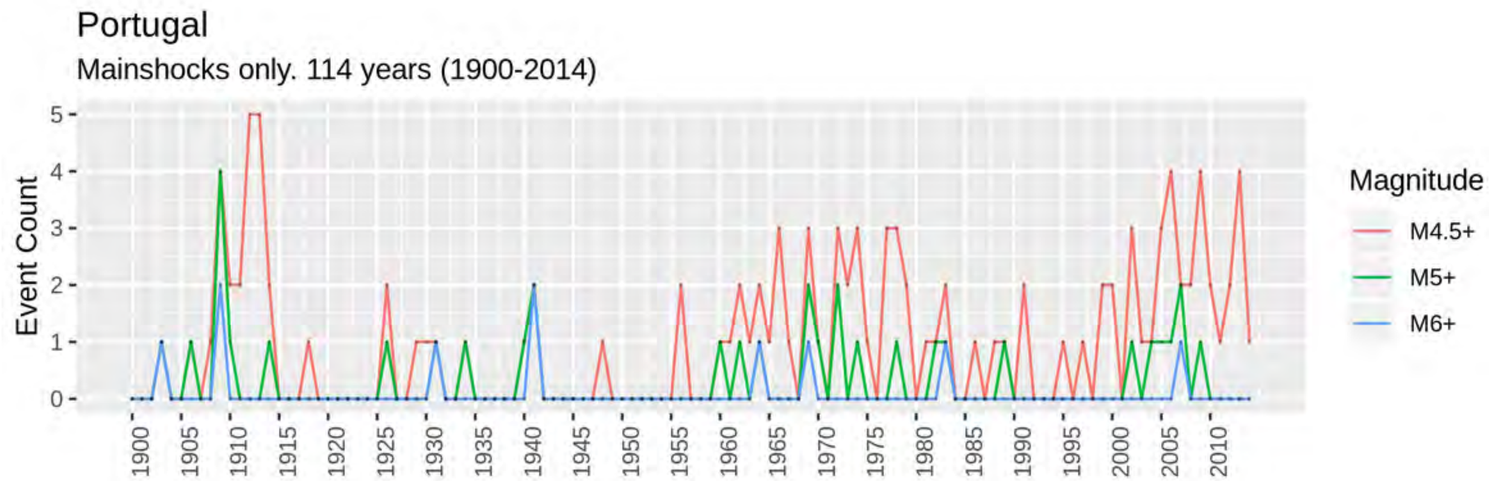

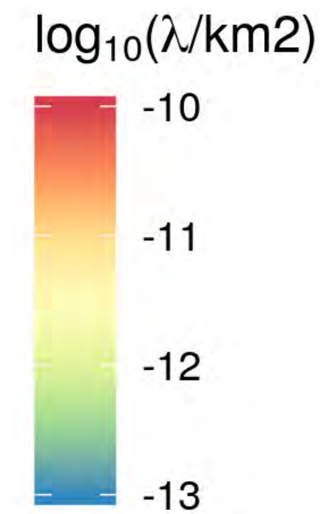

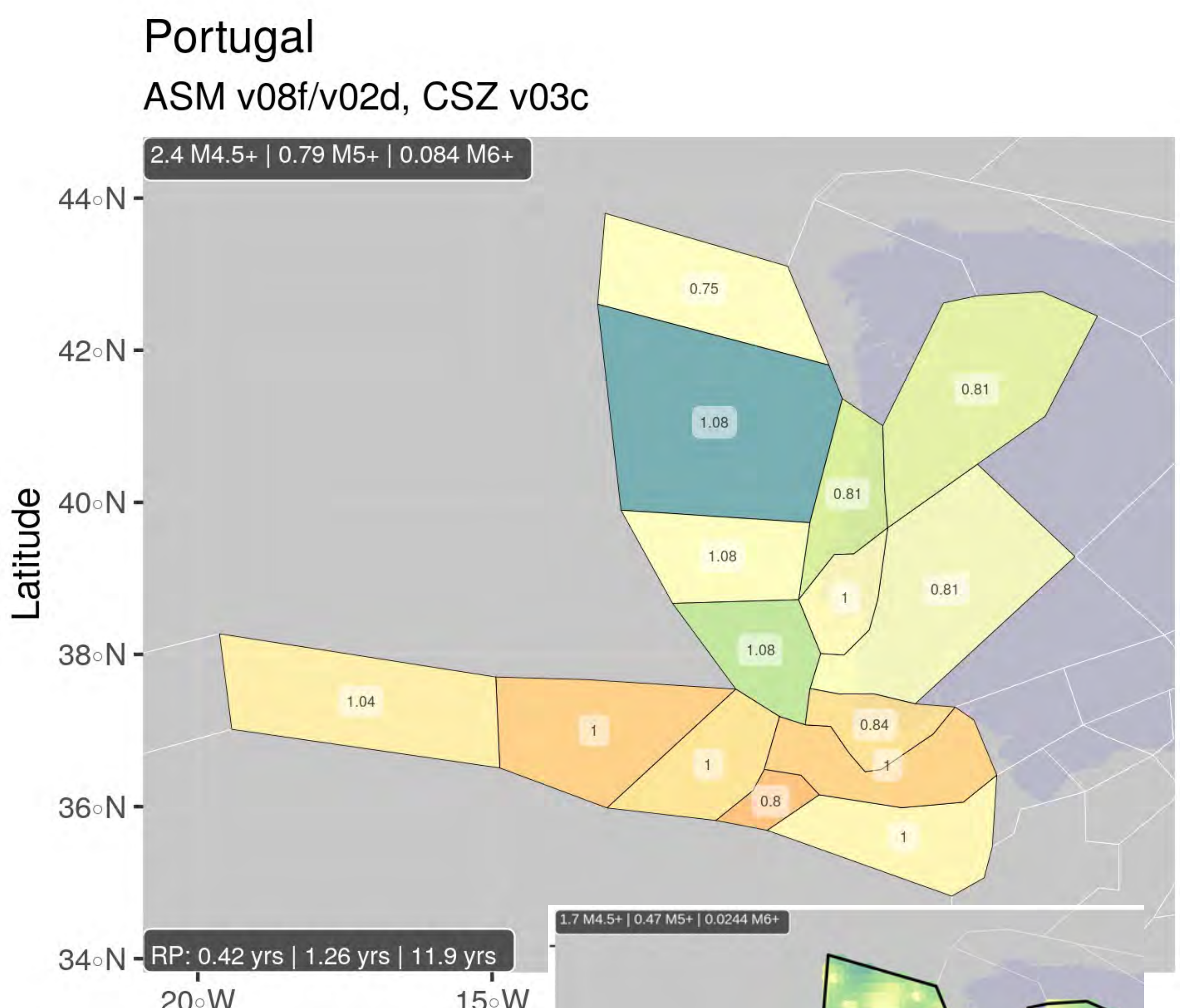

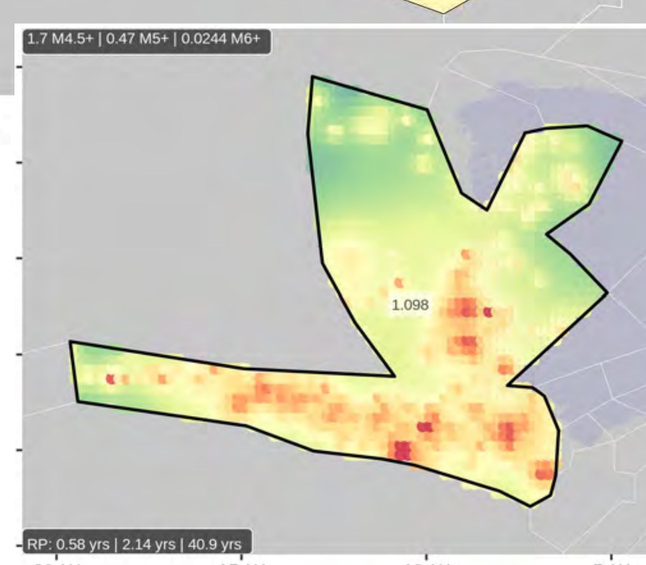

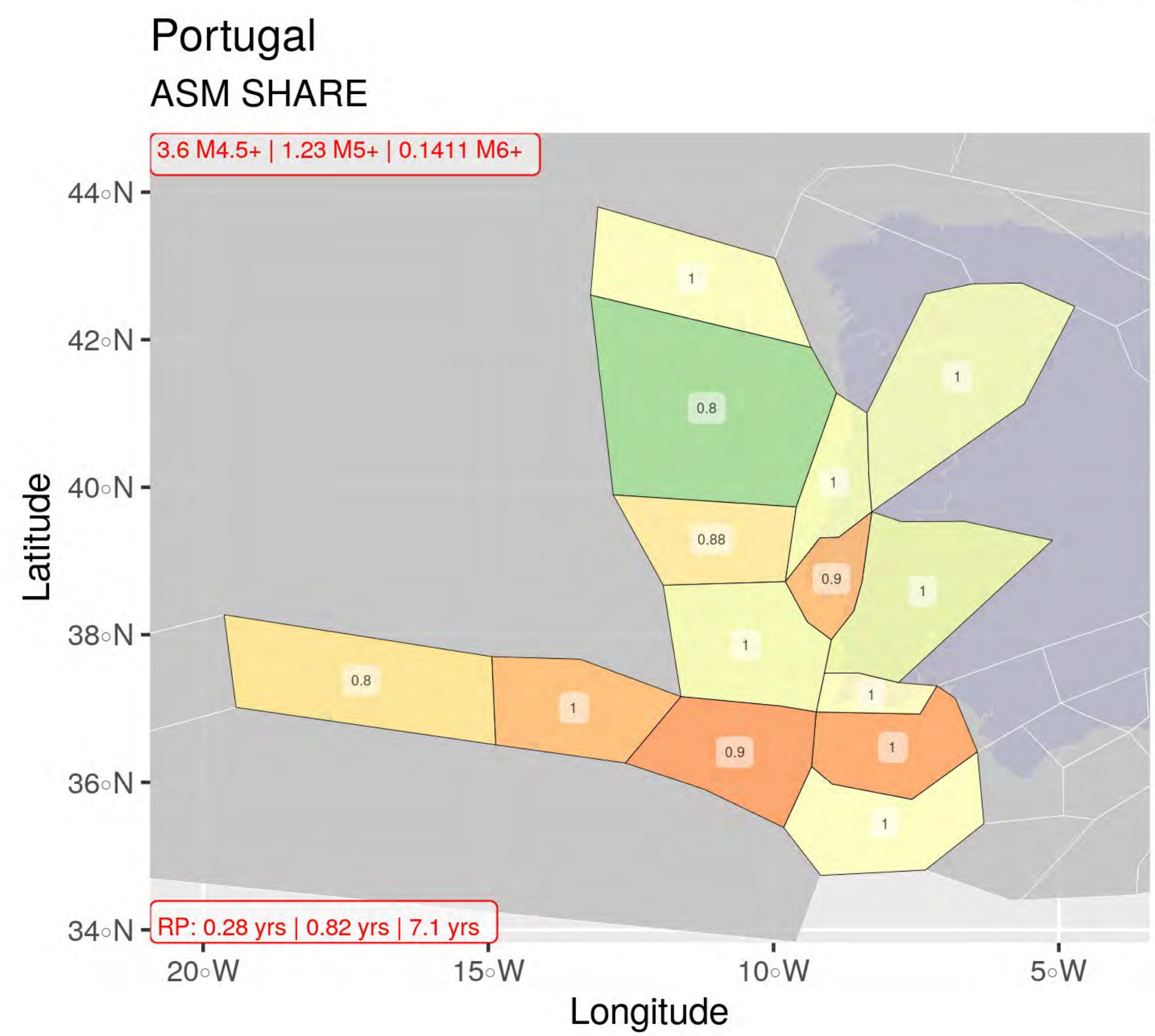

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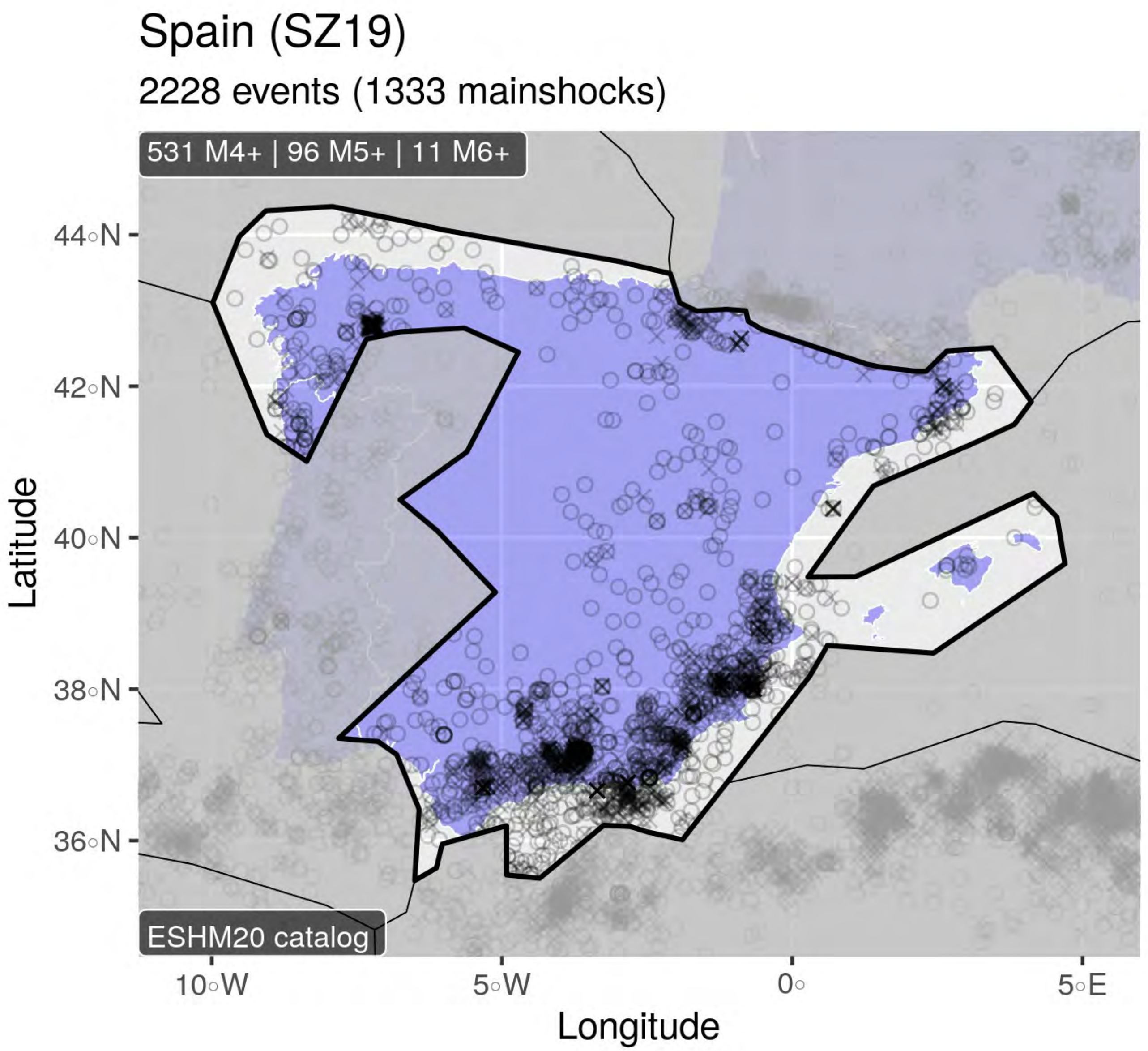

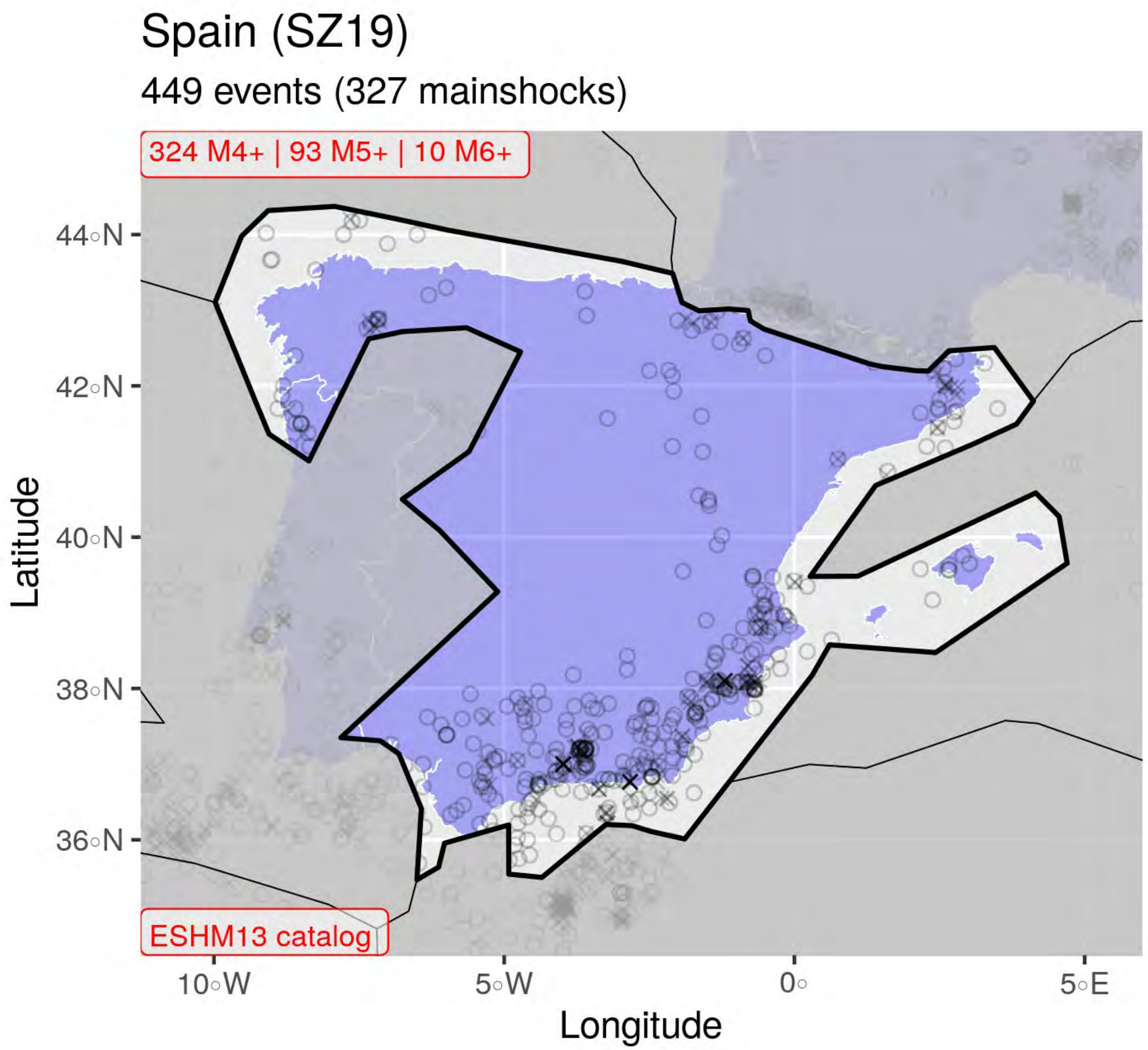

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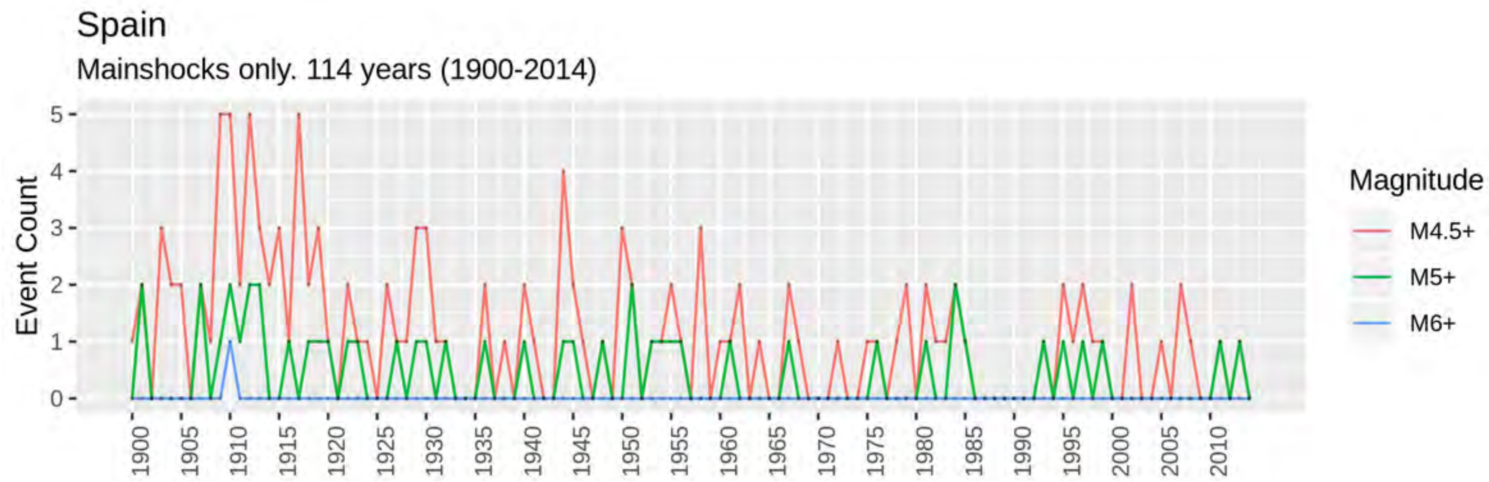

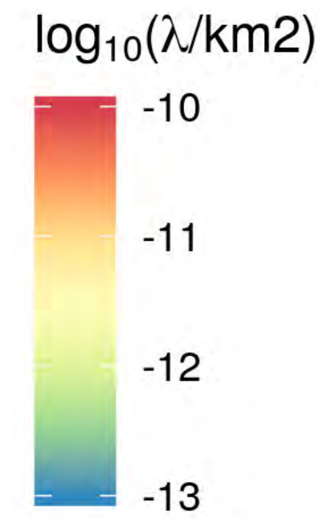

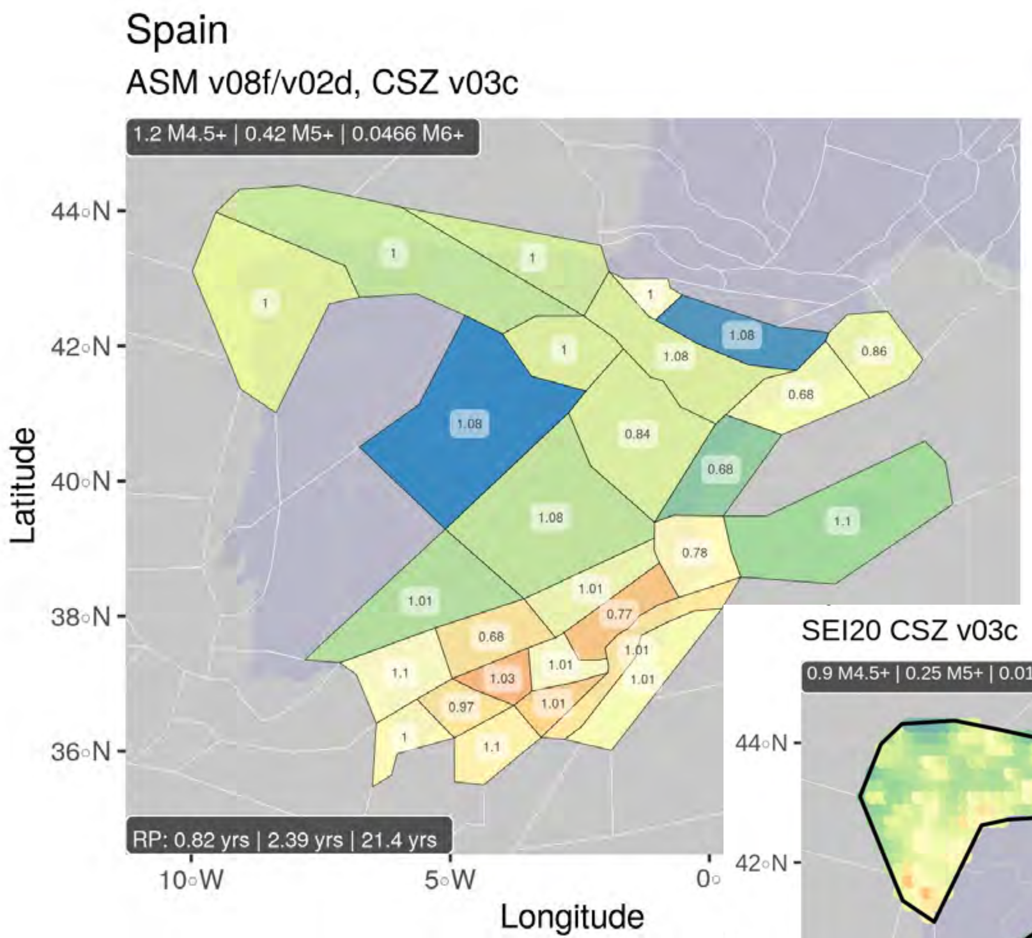

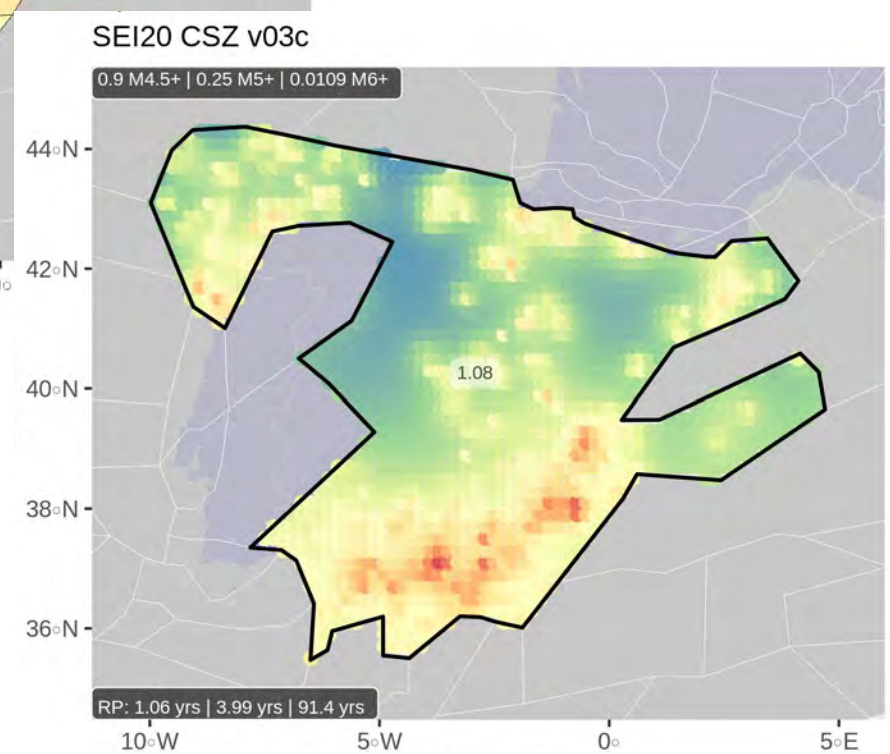

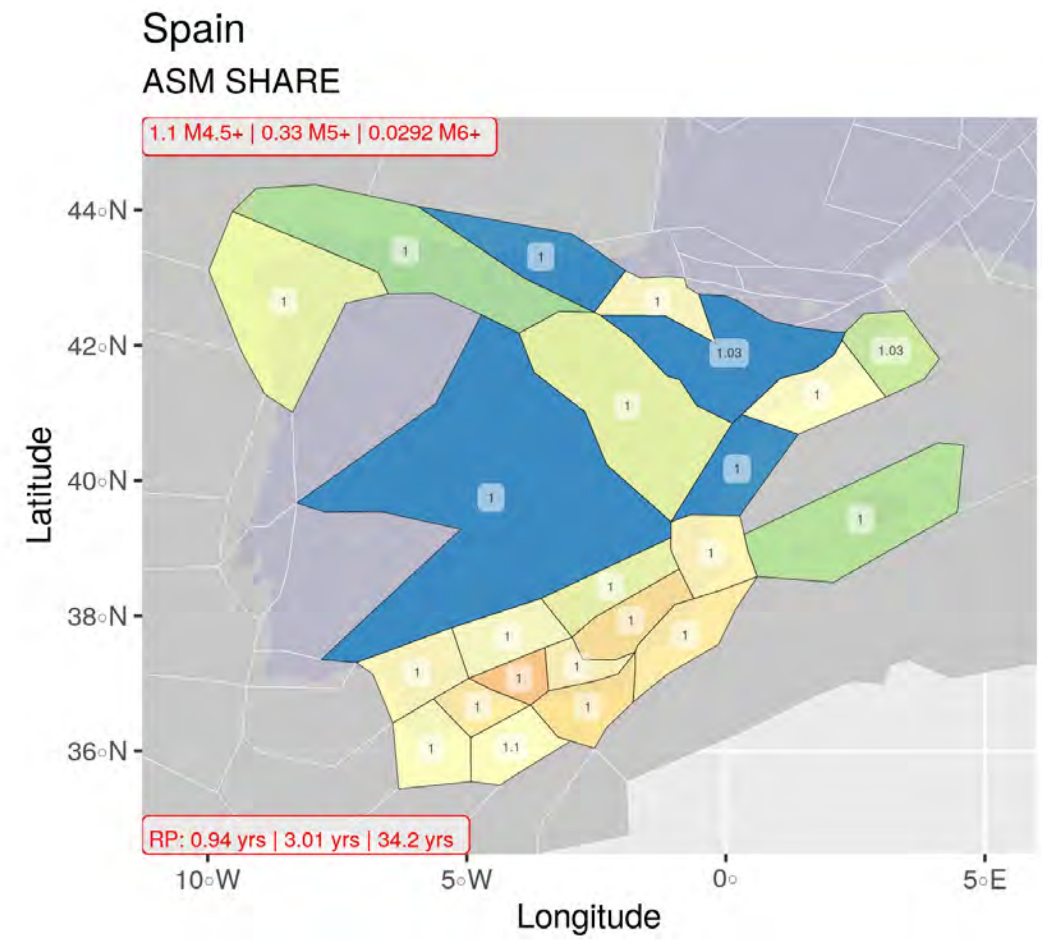

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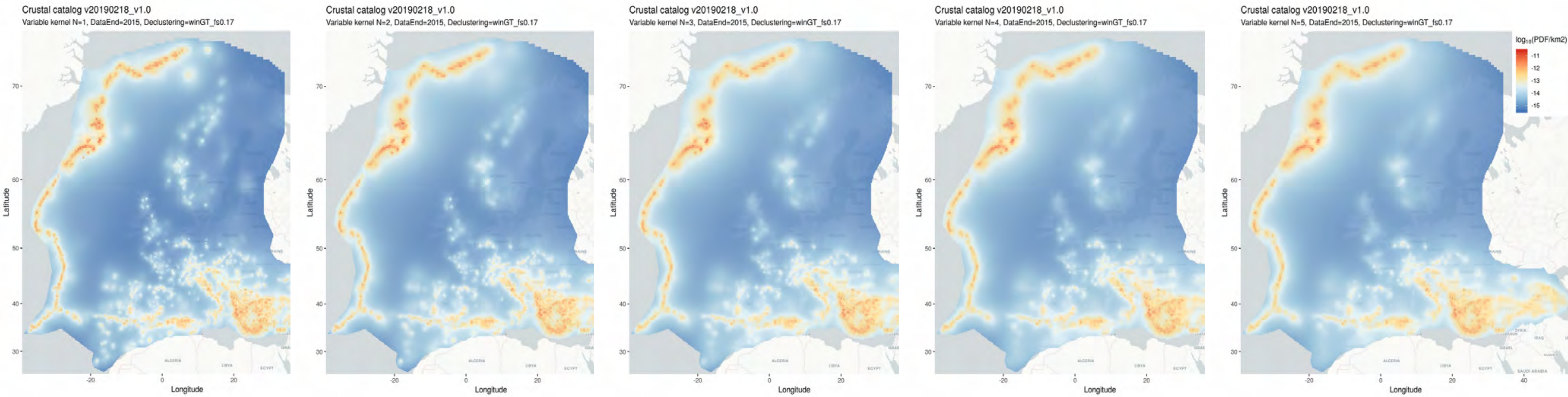
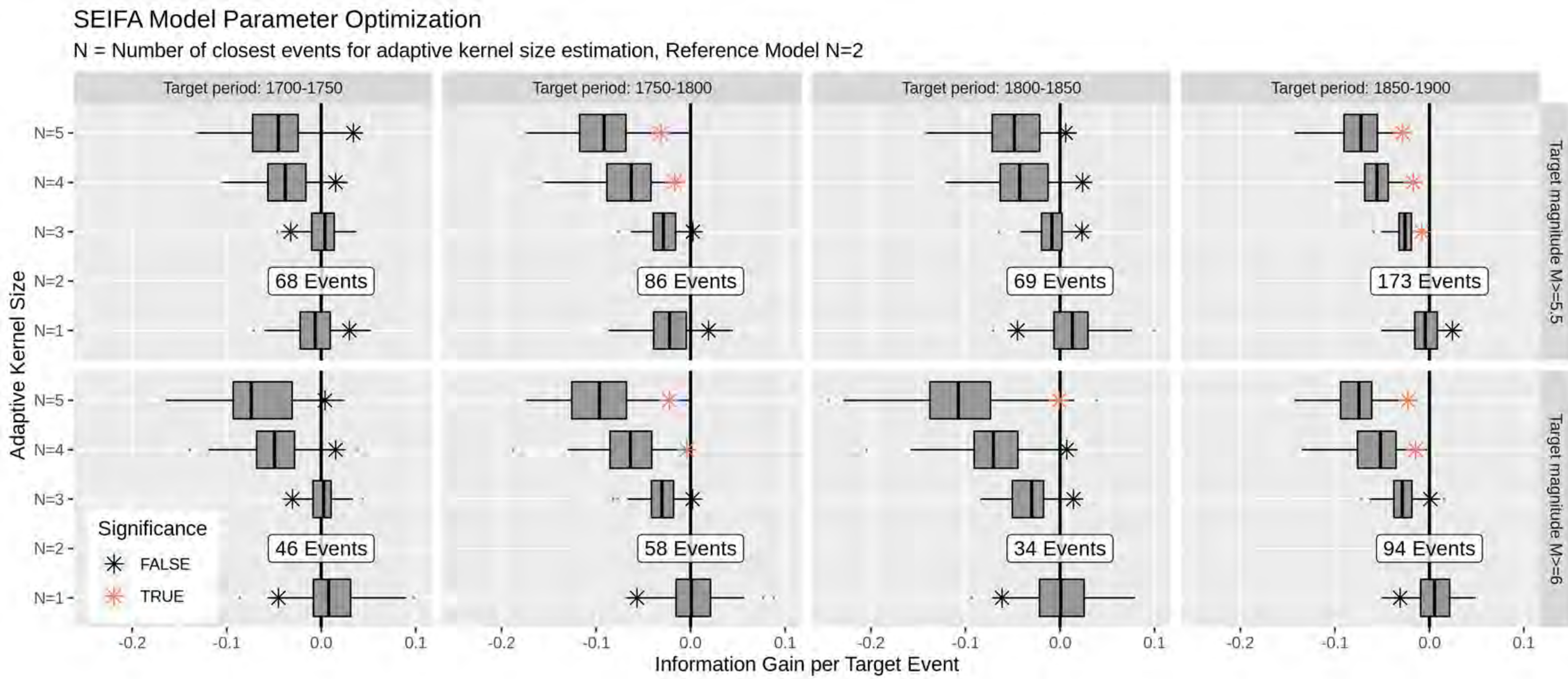
ESHM20: Smoothed Seismicity





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A New Ground Motion Model Logic Tree for Earthquake Hazard and Risk Assessment in Europe

Graeme Weatherill, *Sreeram Reddy Kotha, Fabrice Cotton, Laurentiu Danciu*

Seismic Hazard & Risk Dynamics

GeoForschungsZentrum (GFZ), Potsdam

SERA Eurocode 8 Meeting, EUCENTRE, Pavia, 14 October 2019

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Helmholtz Centre
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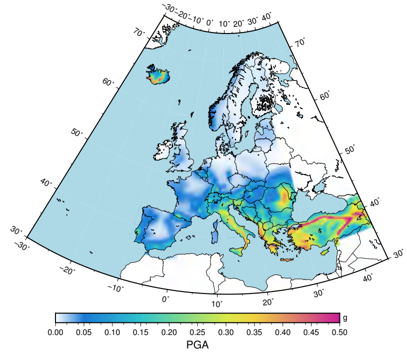
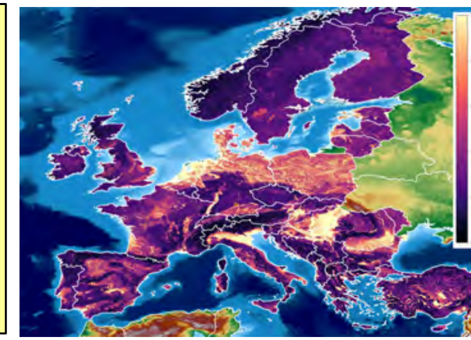
Hazard Maps/curves/ UHS on EC8 Class A rock

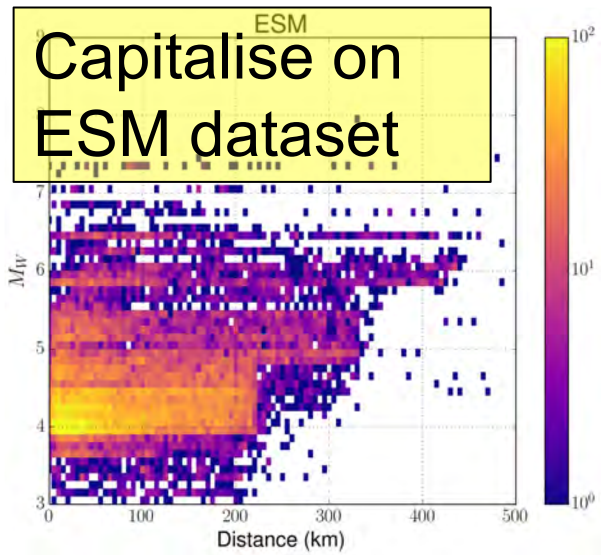


Amplification to surface condition for ESRM2020



Broad(er)band: 0.01 to > 5 s (ideally 10 s)

Capitalise on ESM dataset



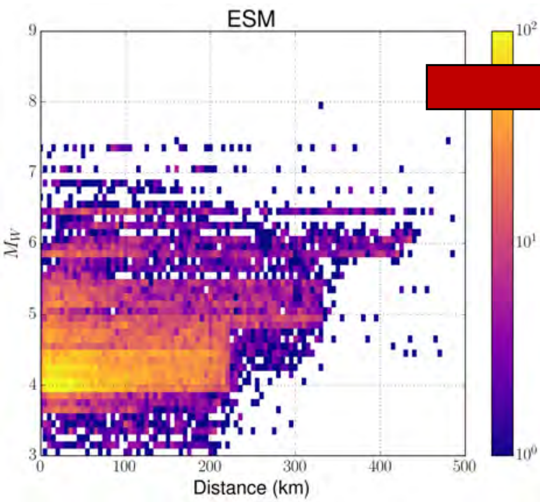
ESHM2020 Ground Motion Model Logic Tree for Europe – what do we need to do?

Be practical and scalable

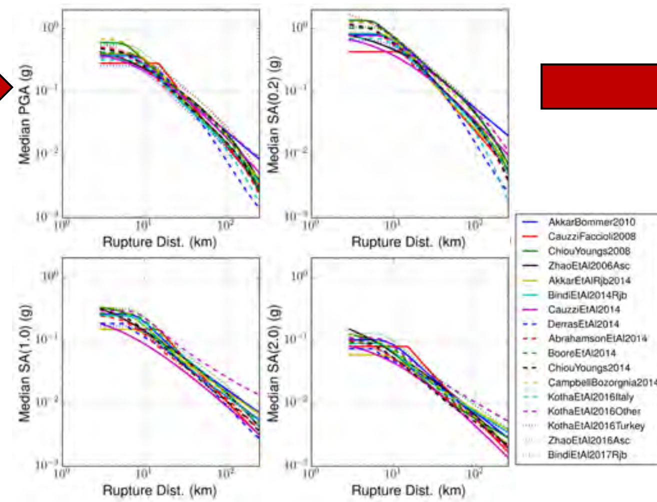
Include new ideas and insights from recent ground motion analysis

Strategies for a Ground Motion Logic Tree

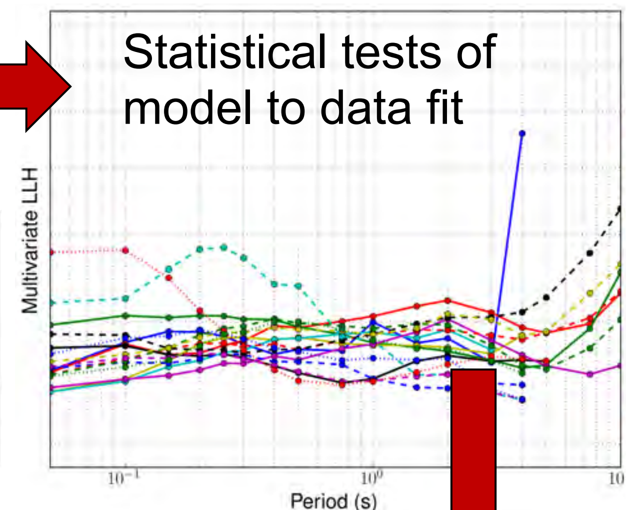
Multi-Model (e.g. ESHM2013, many national models)



Database of strong motion records



"pre-selected" ground motion models



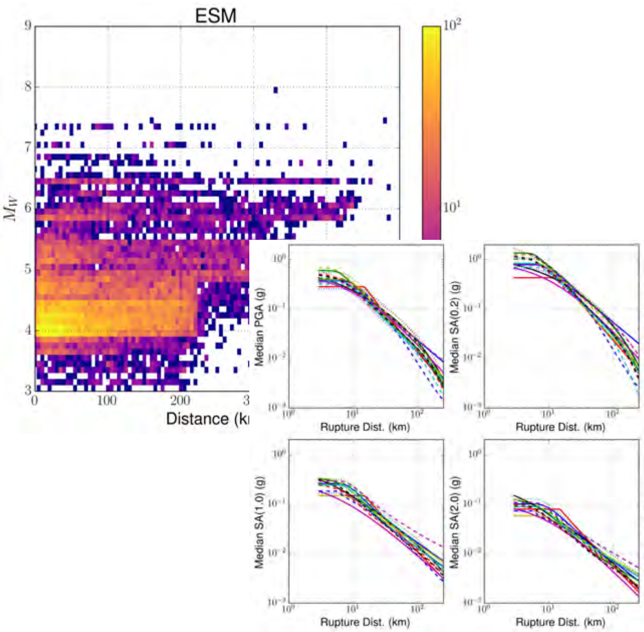
How many models? Where to apply?
How "different" (*MECE*)?
Which source, path & site parameters do I need?

N GMMs and corresponding weights

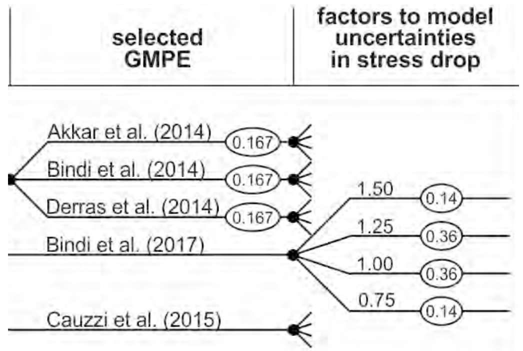
Model 1 (w_1)
Model 2 (w_2)
…
Model N (w_N)

Strategies for a Ground Motion Logic Tree

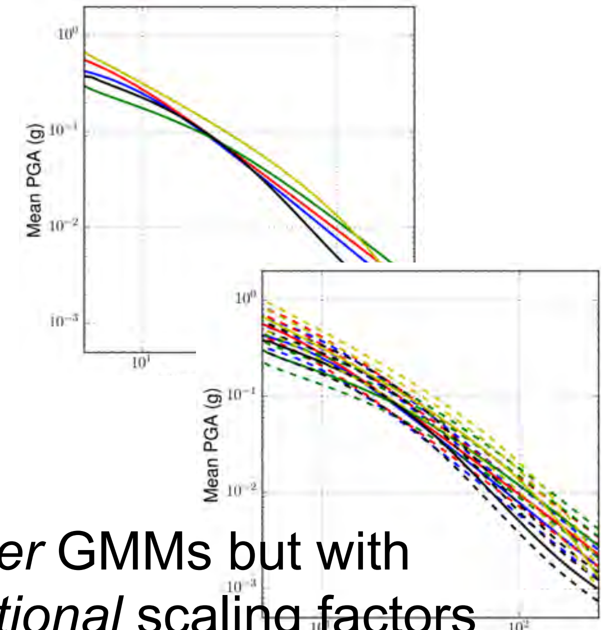
Hybrid Backbone (e.g. Switzerland, Germany, UK etc.)



Strong motion data & candidate models



Seismological uncertainties to represent



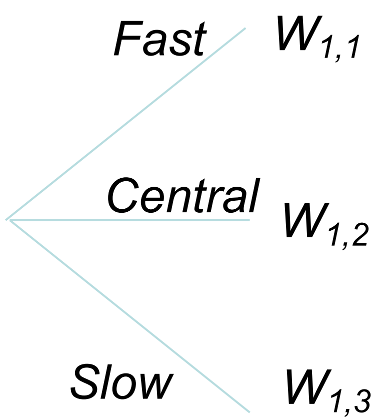
Fewer GMMs but with *additional* scaling factors

Which seismological properties are uncertain?
How much do they influence?
How do we calibrate and weight them?

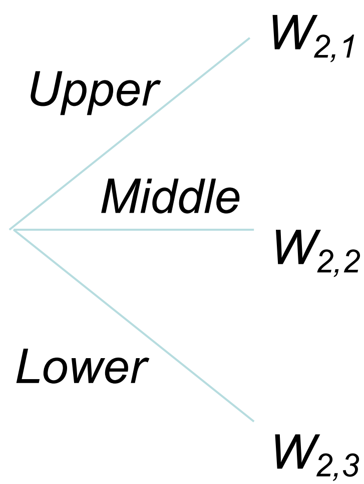
Strategies for a Ground Motion Logic Tree

The general *backbone* approach (Douglas, 2018)

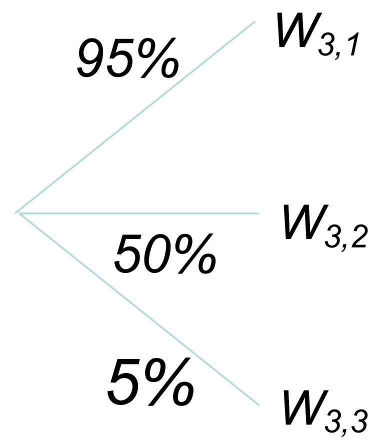
Requires a single core *backbone* GMM



Anelastic attenuation uncertainty



Average "stress drop" uncertainty



Statistical uncertainty from <u>confidence limits</u> of regression (e.g. Al Atik and Youngs, 2014)

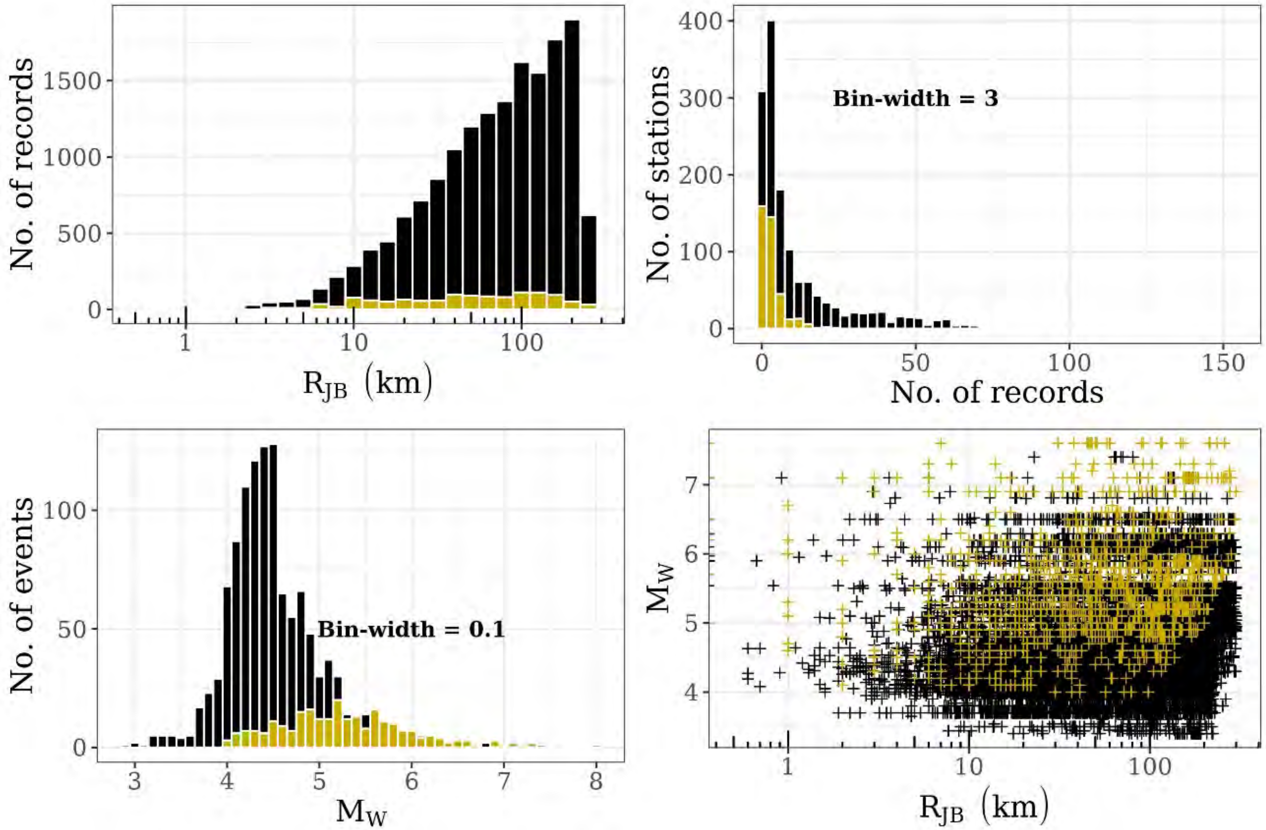
The Backbone GMM: Shallow Crust

Increase in data since 2014:

- from 1251 to 14973 records (12x)
- from 63 to 644 sites with ≥5 records
- $3.3 \leq M_w \leq 7.6$ instead of $4 \leq M_w \leq 7.6$
- Response and Fourier spectra (T = 0.01 – 8s)

Kotha *et al.* (*in prep.*)

ESM (2018) compared to RESORCE (2014)



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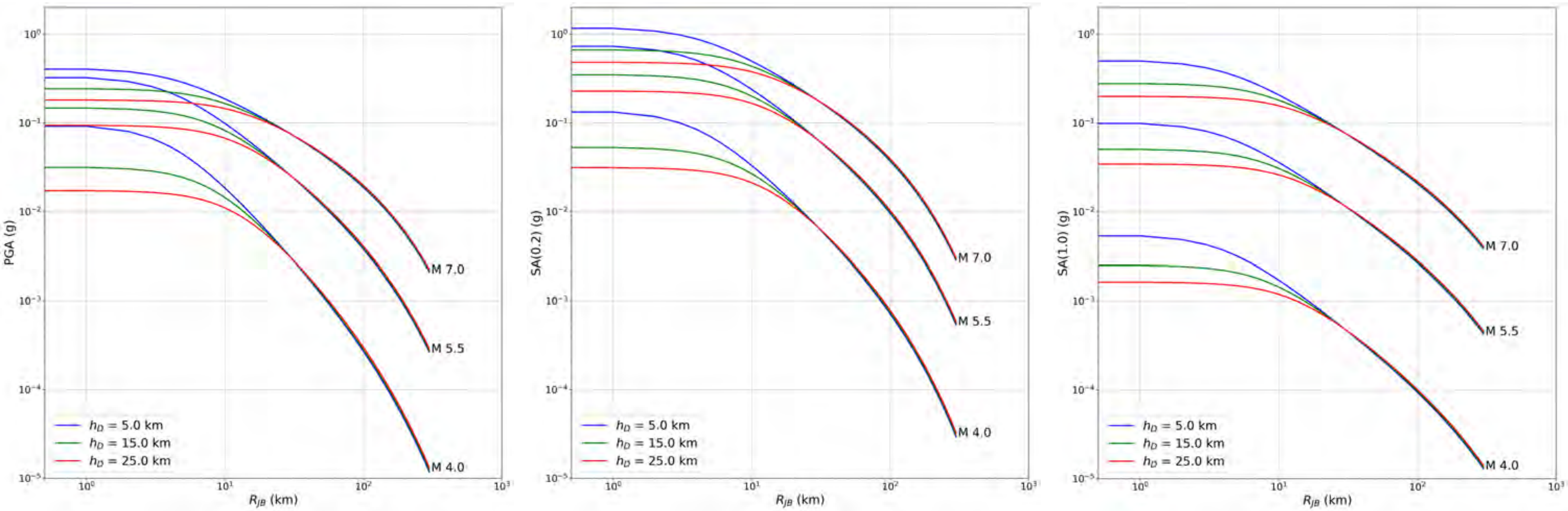
The Backbone GMM

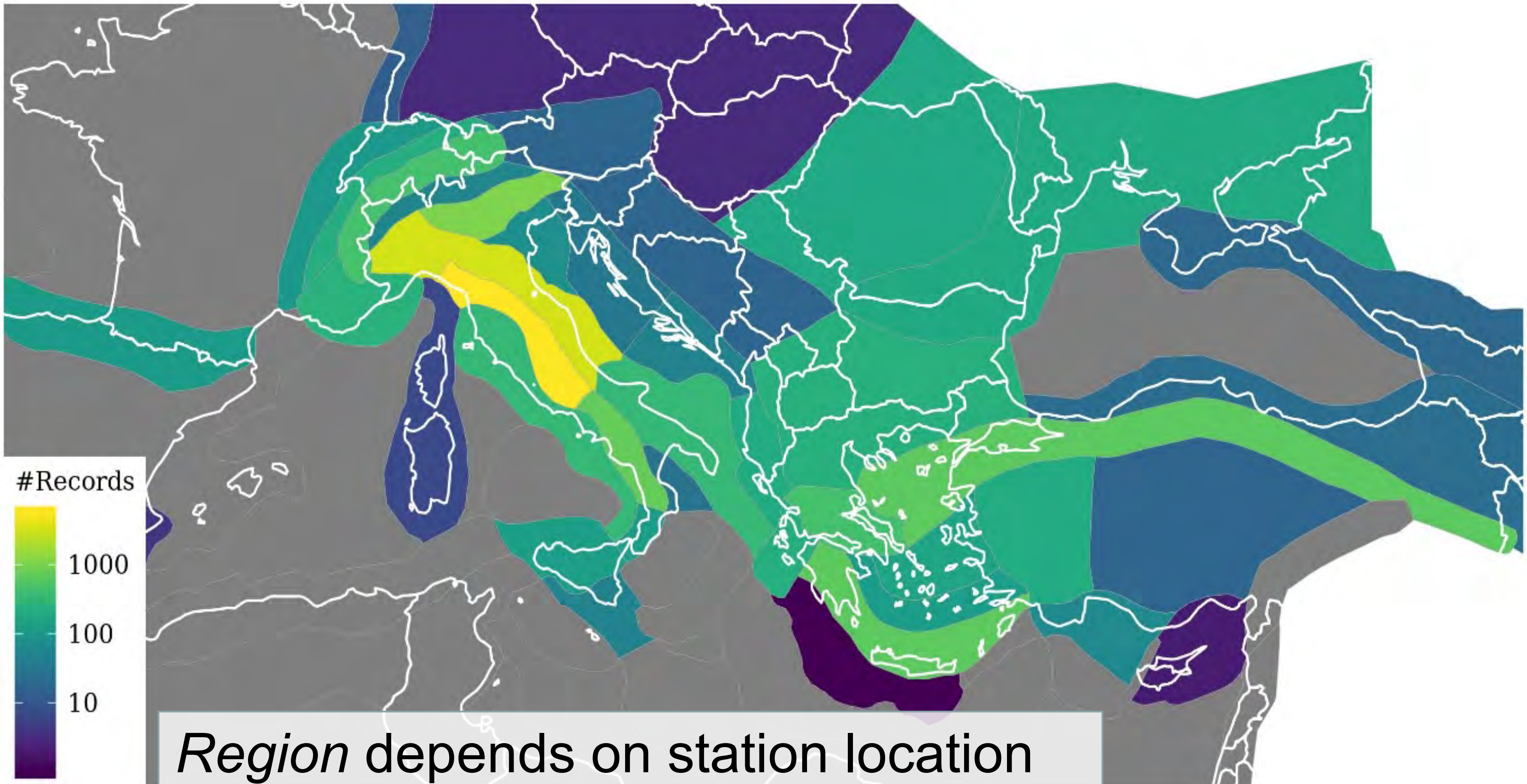


$$\ln Y = e_1 + f_M(M_W) + f_{R,g}(R_{JB}, M_W, h_D) + \left(\frac{c_{3,r} \pm \delta c_{3,r}}{100}\right) \cdot f_{R,a}(R_{JB}) + $$
$$+\delta B_e + \delta B_f + \delta S2S_s + \delta W_{e,s}$$

Use Joyner-Boore distance (R_{JB}) but with different geometric spreading coefficients for different depth ranges (≤10 km, 10 – 20 km, ≥ 20 km)

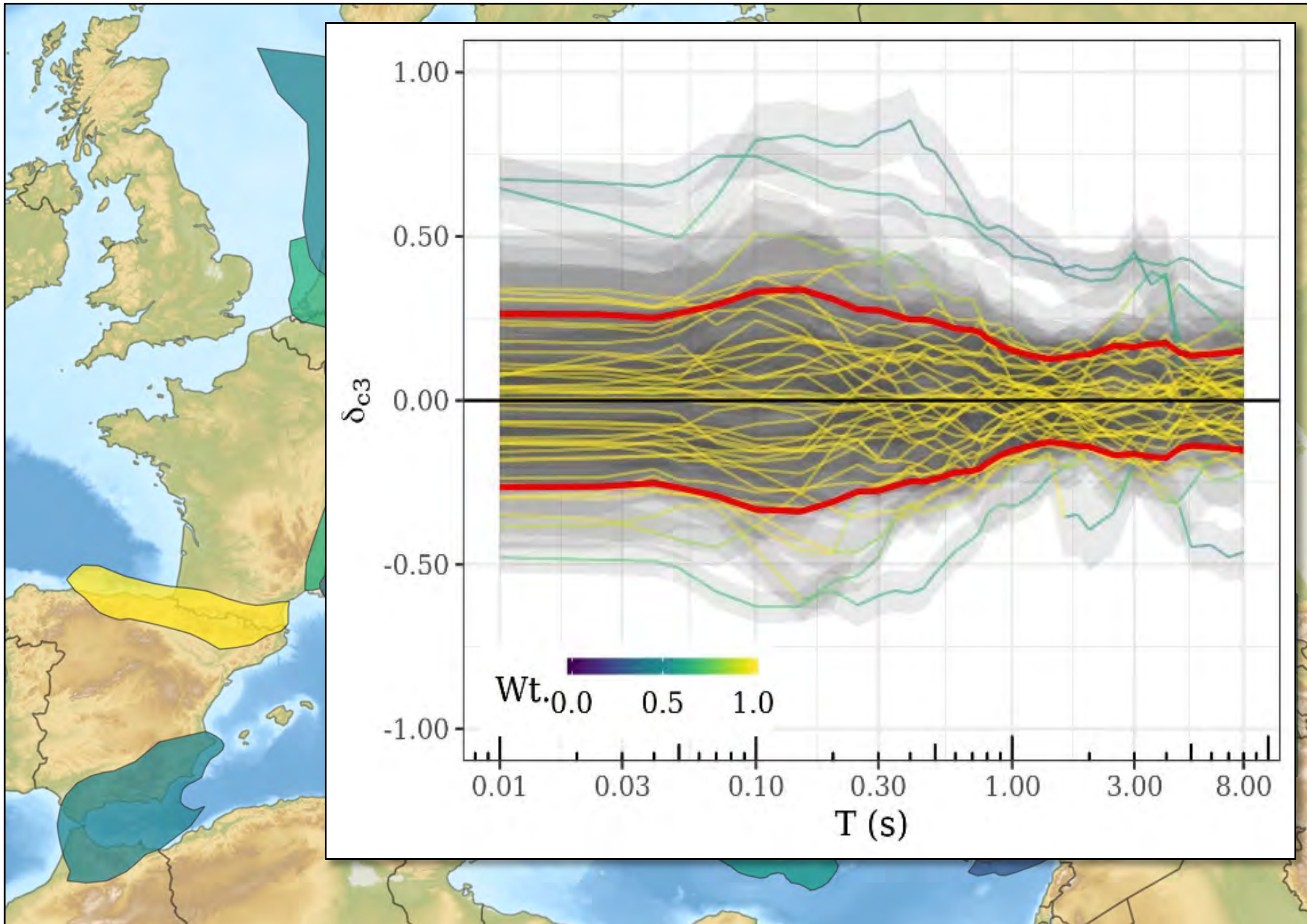
Regionalisation of Distance Decay ($\delta c_{3,r}$)

TSUMAPS-NEAM Regionalisation (Basili et al., 2018)



Region depends on station location

Regional Attenuation Uncertainty



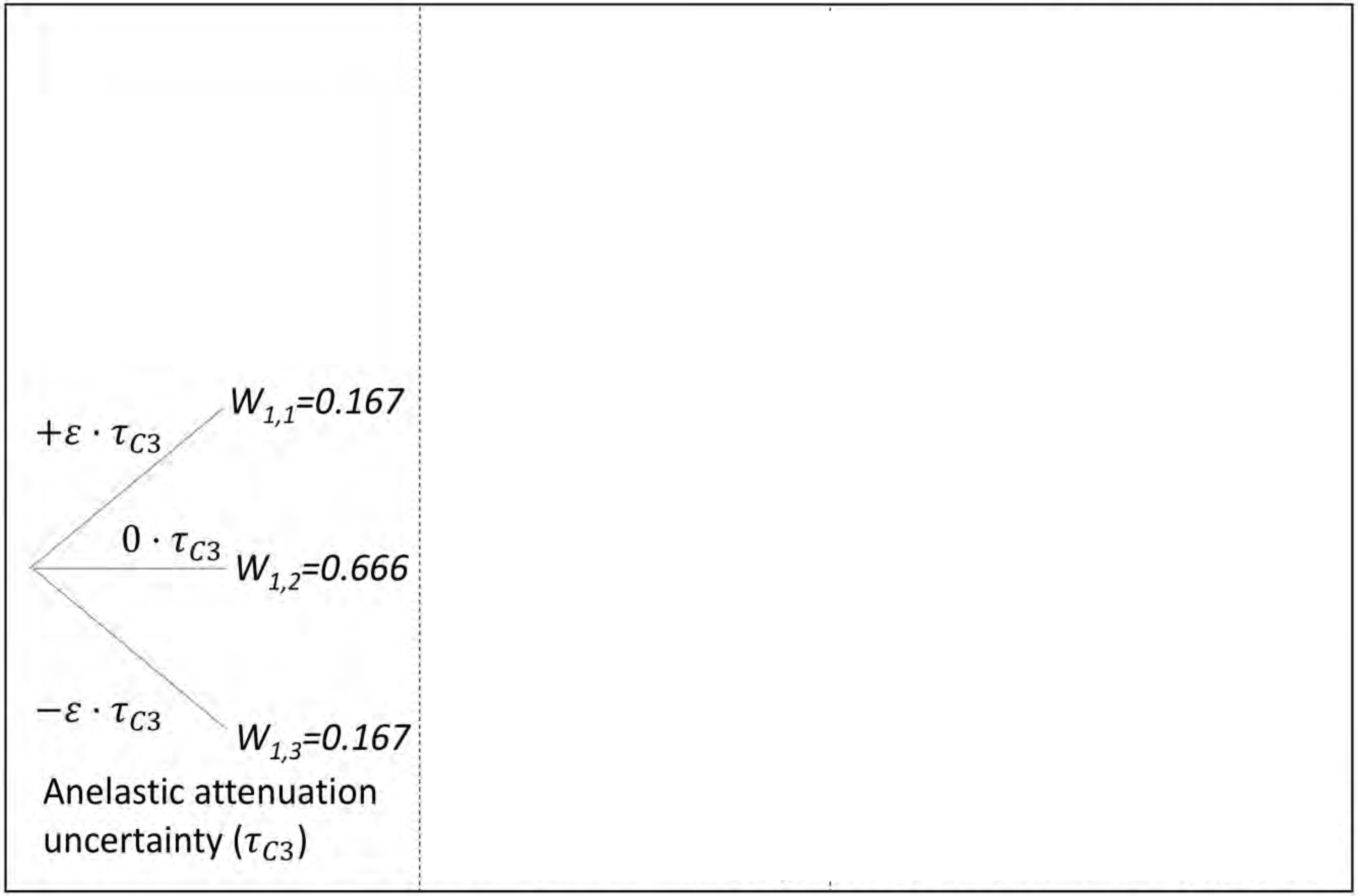
The offset c_3 term ($\delta c_{3,r}$) is distributed:

$$\delta c_{3,r} = N(0, \tau_{c3})$$

Describes the full possible regional variation in c_3

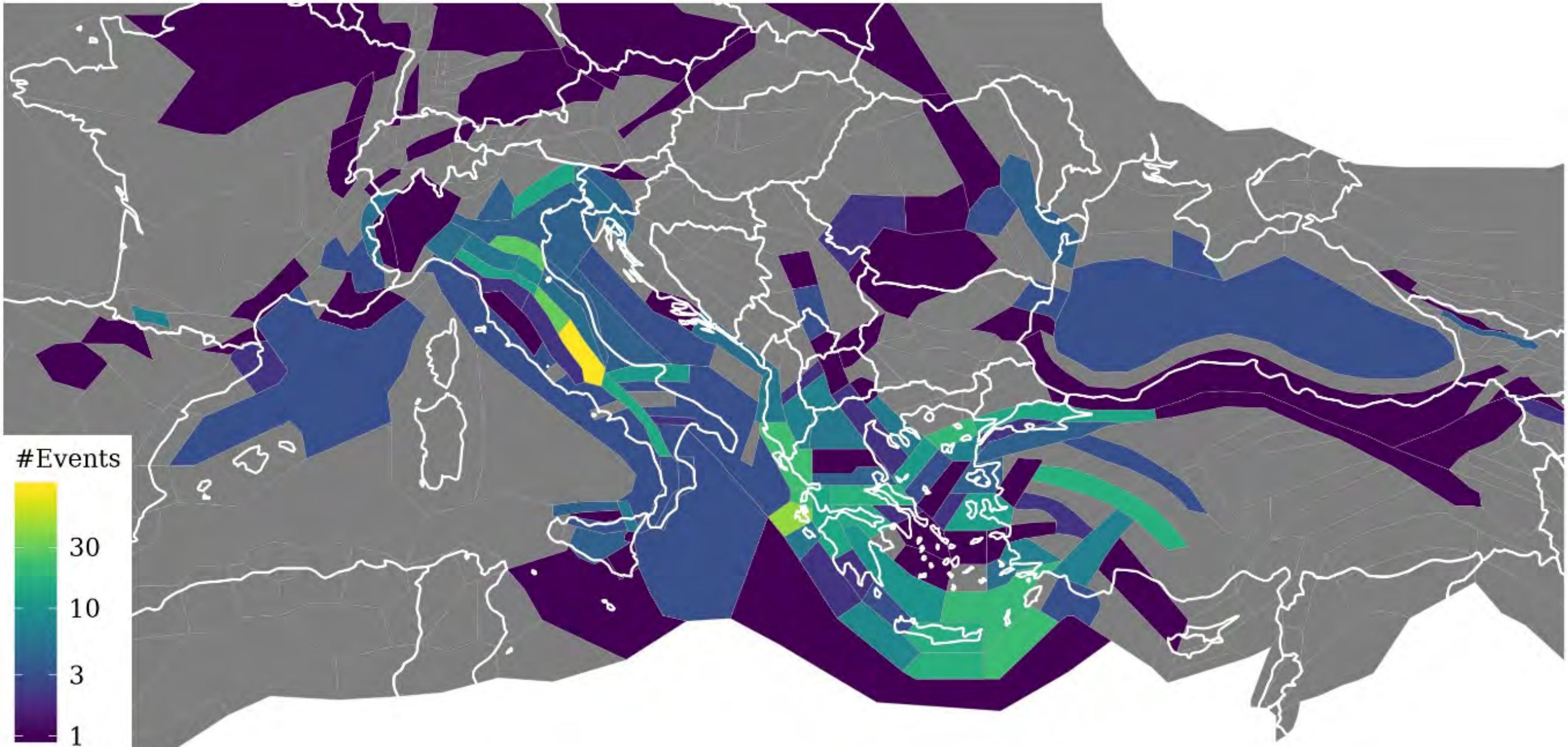
Centre and range of the distribution from mean and 5 % - 95 % quantiles

Shallow Crustal Logic Tree



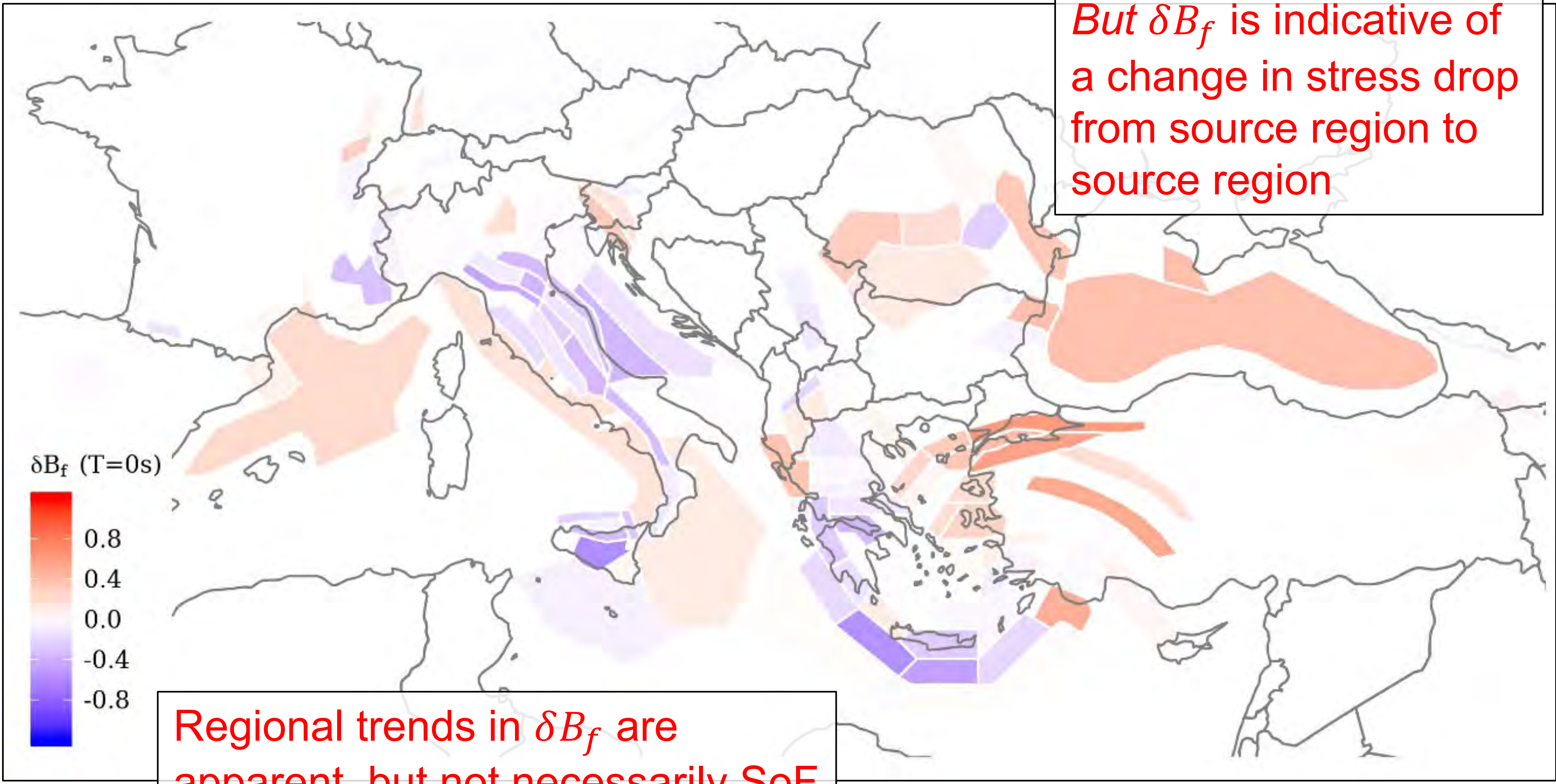
$\varepsilon \approx 1.732$ (Miller & Rice, 1983)

Regionalisation of Sources (δB_f)



- Source regionalisation depends on event location
- Polygons taken from ESHM area source model

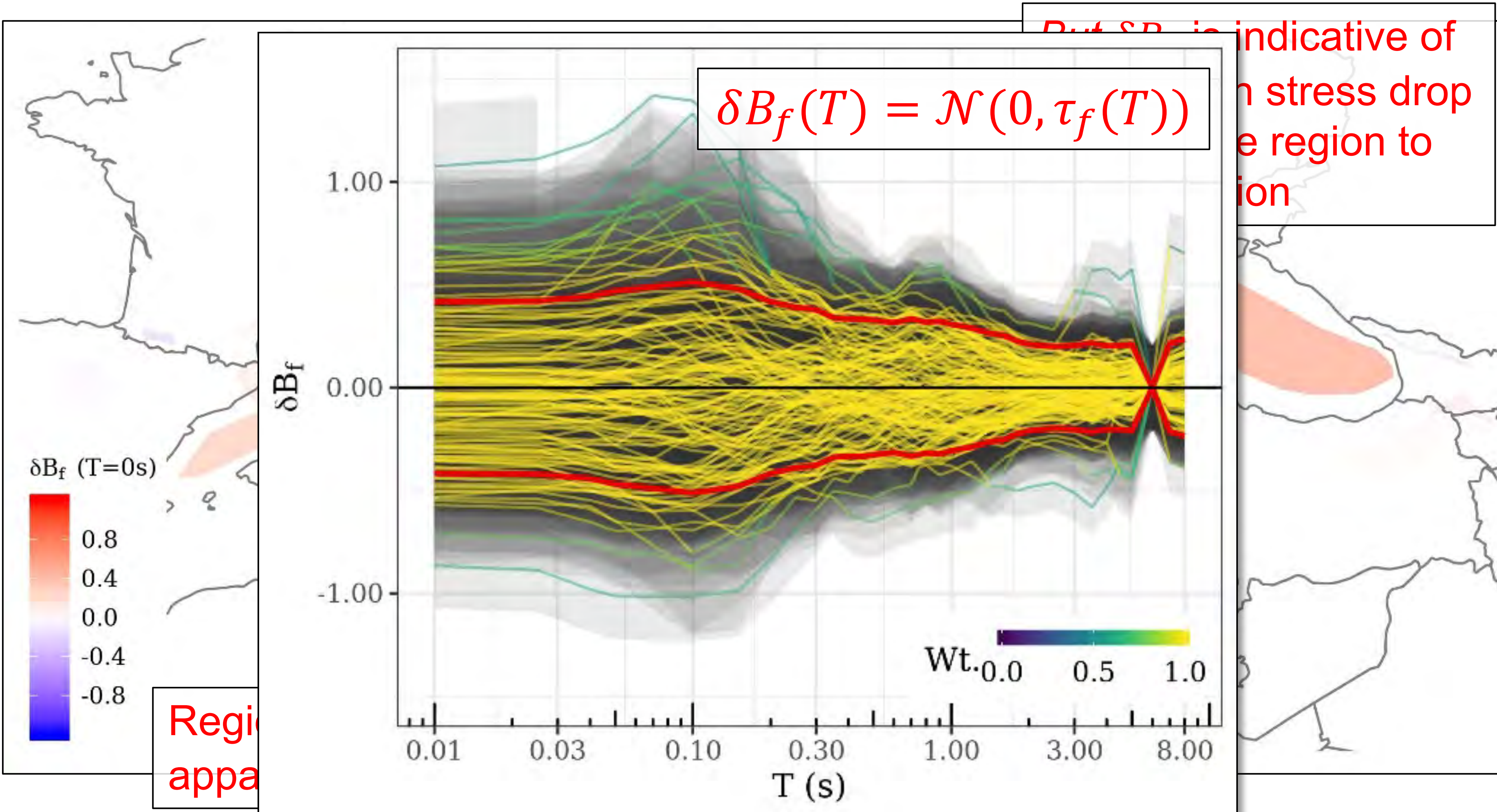
Regional Variation in Stress Parameter



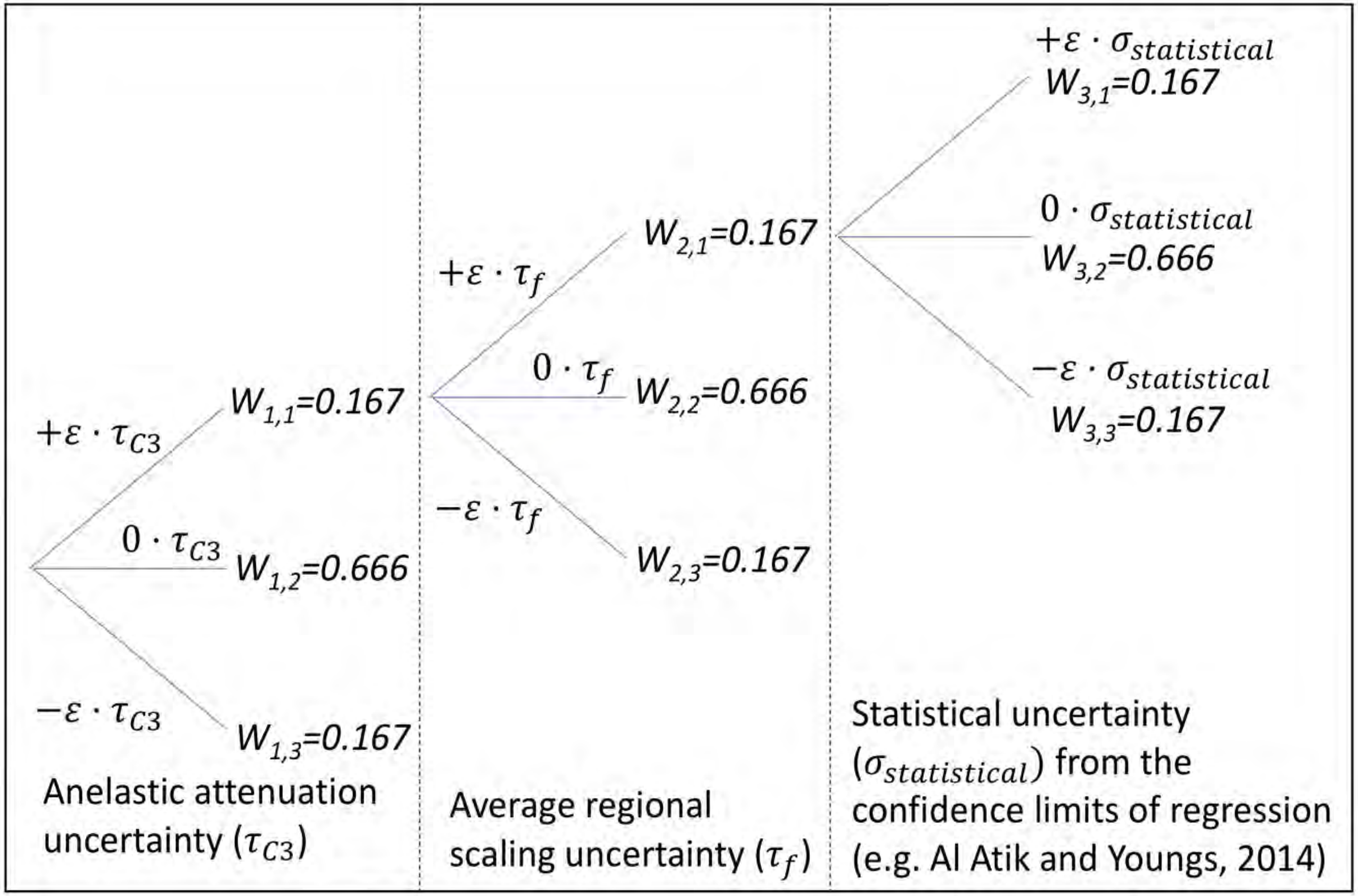
But δB_f is indicative of a change in stress drop from source region to source region

Regional trends in δB_f are apparent, but not necessarily SoF

Regional Variation in Stress Parameter

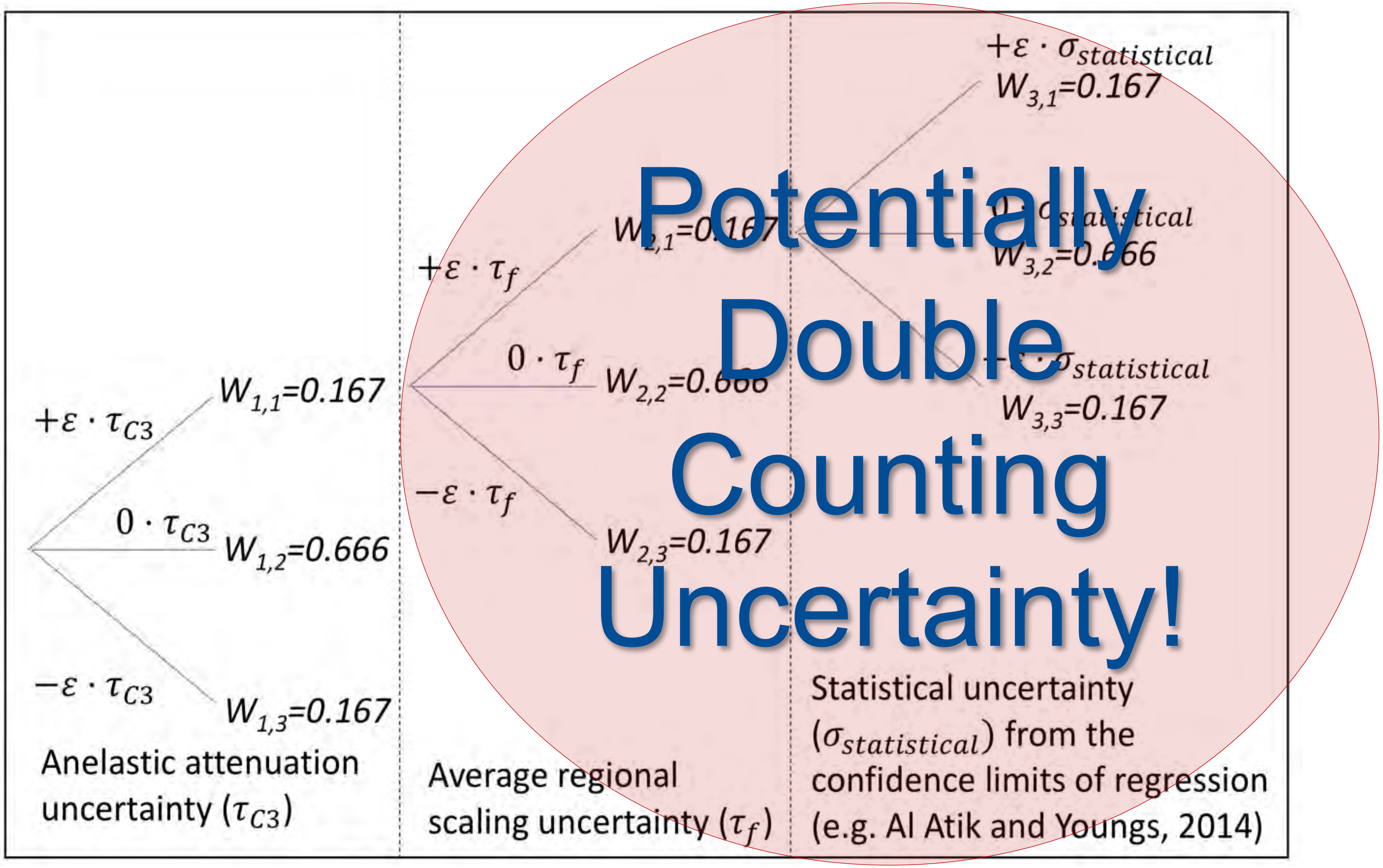


Shallow Crustal Logic Tree



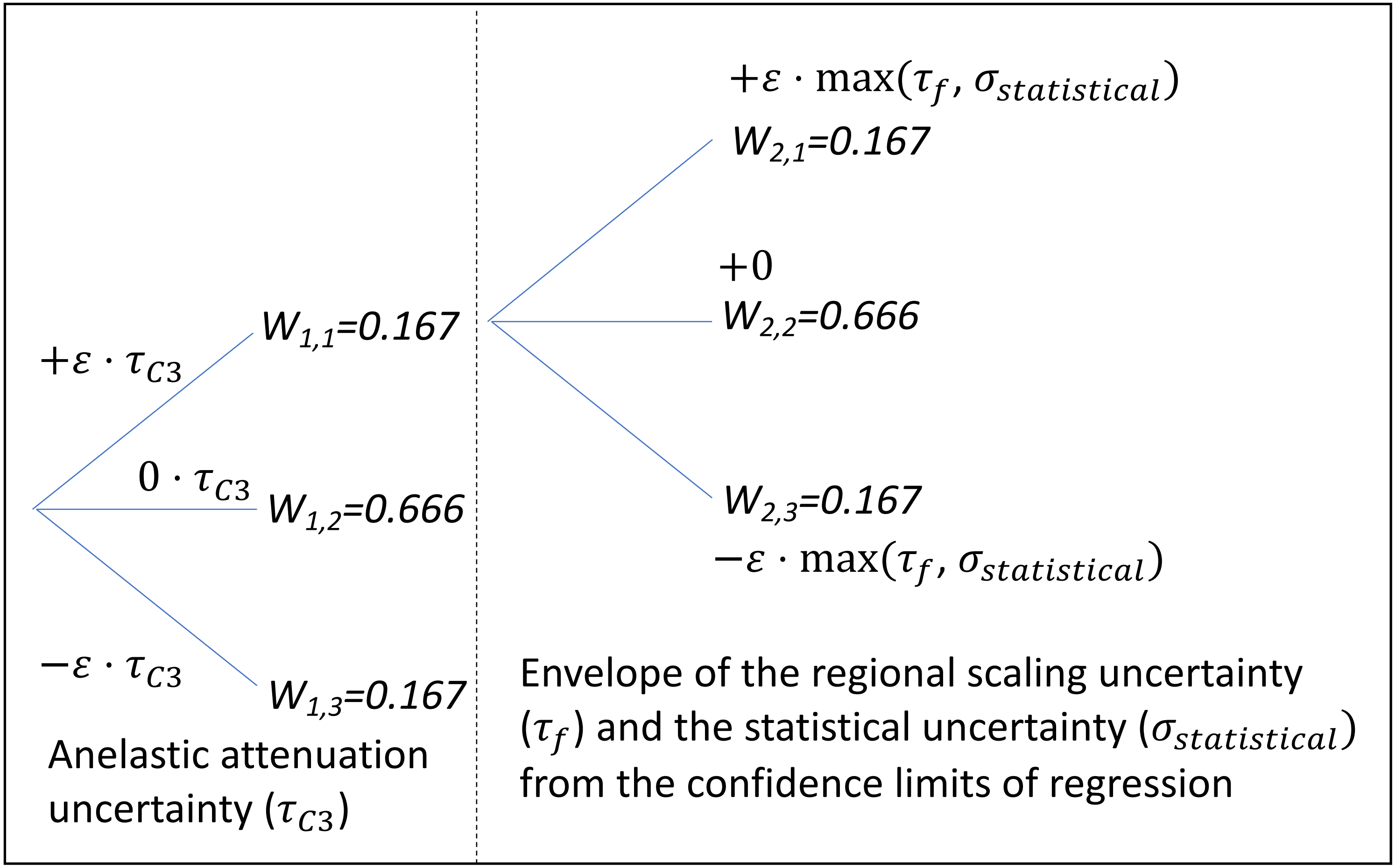
$\varepsilon \approx 1.732$ (Miller & Rice, 1983)

Shallow Crustal Logic Tree

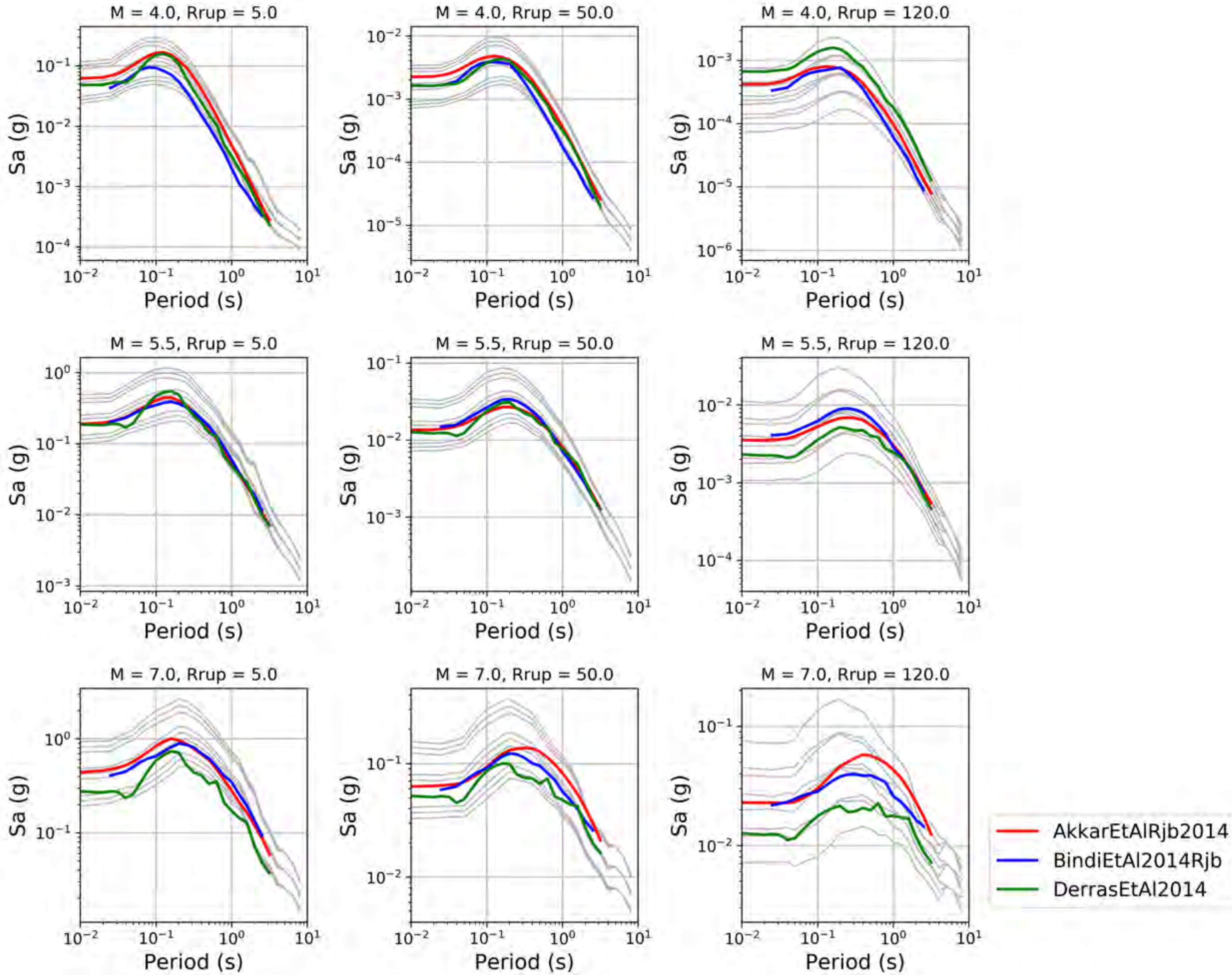


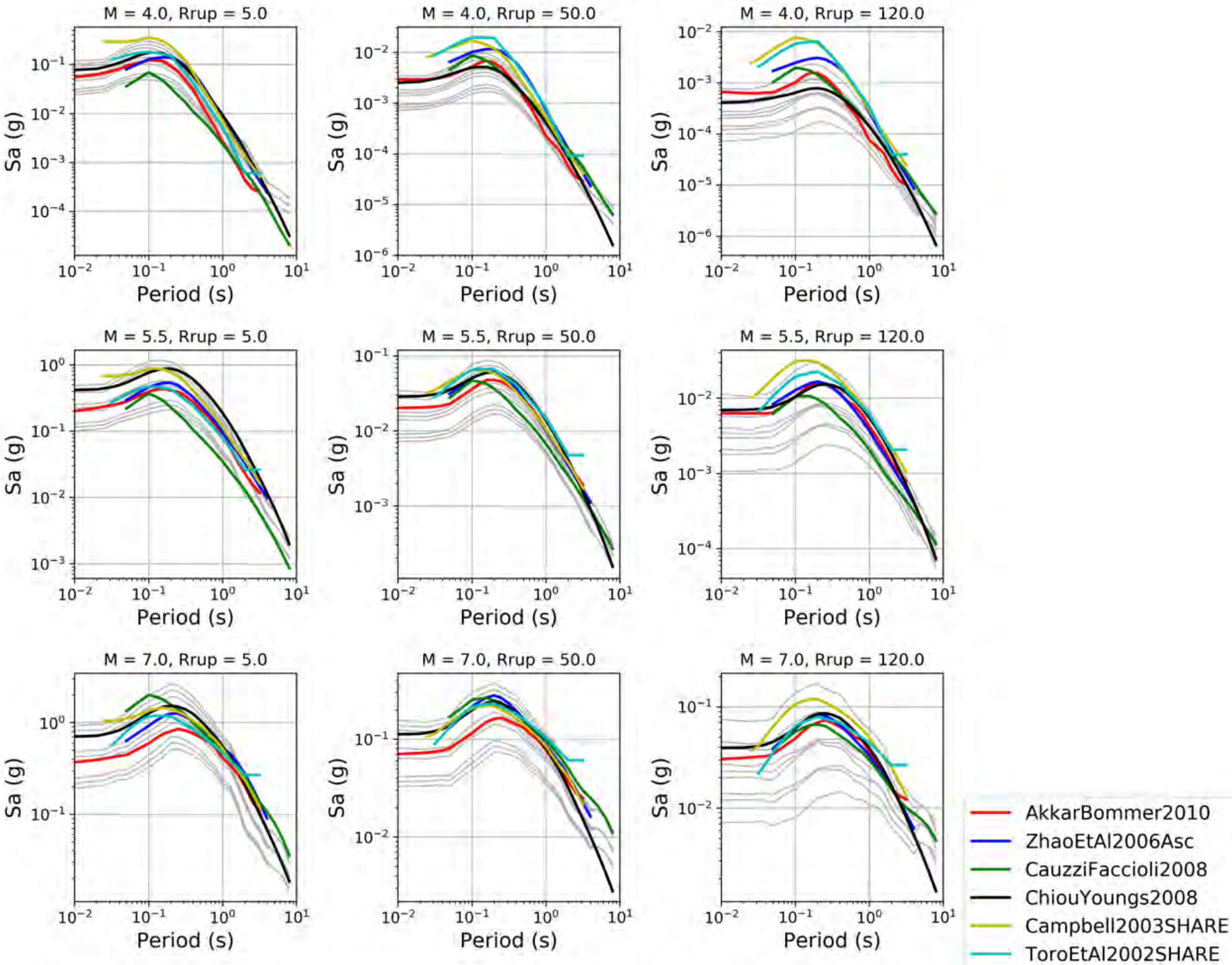
$\varepsilon \approx 1.732$ (Miller & Rice, 1983)

Shallow Crustal Logic Tree

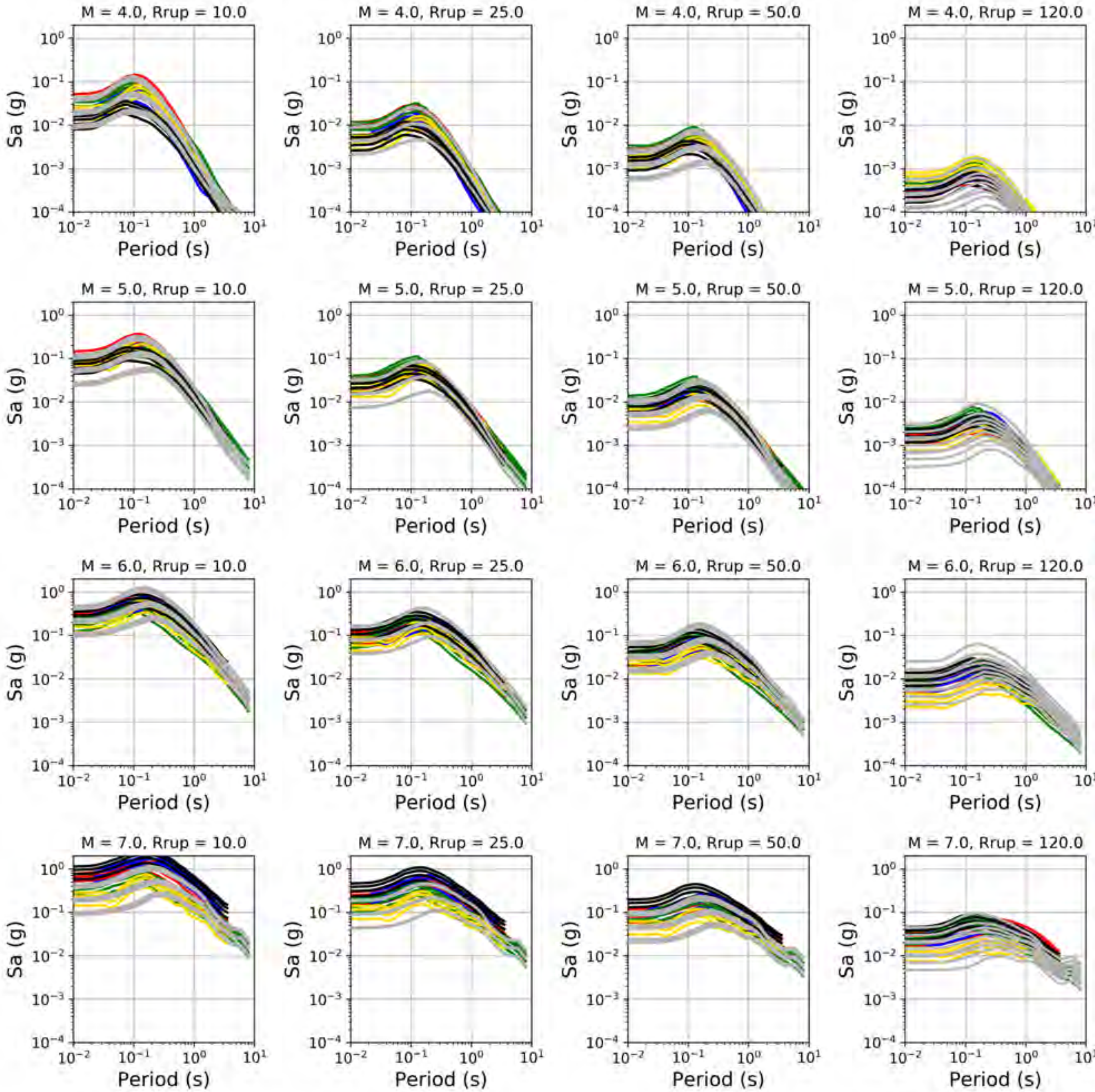


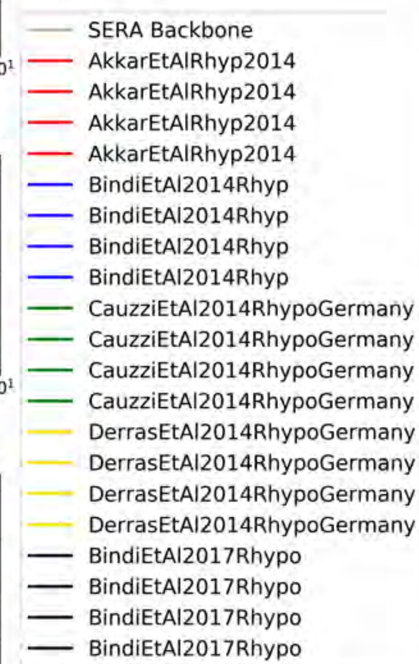
$\varepsilon \approx 1.732$ (Miller & Rice, 1983)

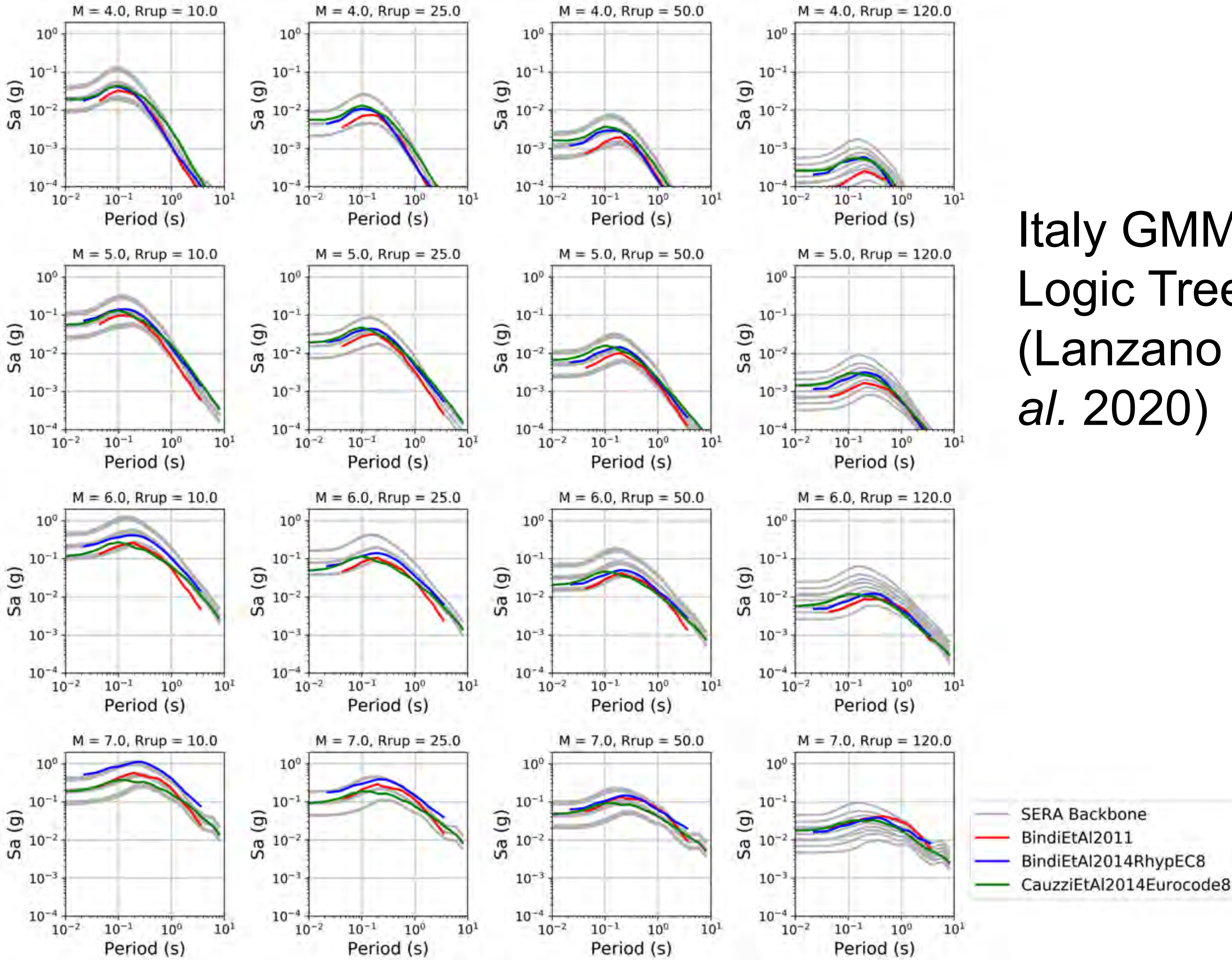

M = 4.0, Rrup = 5.0
M = 4.0, Rrup = 50.0
M = 4.0, Rrup = 120.0
M = 5.5, Rrup = 5.0
M = 5.5, Rrup = 50.0
M = 5.5, Rrup = 120.0
M = 7.0, Rrup = 5.0
M = 7.0, Rrup = 50.0
M = 7.0, Rrup = 120.0
Sa (g)
Period (s)
AkkarEtAlRjb2014
BindiEtAl2014Rjb
DerrasEtAl2014


M = 4.0, Rrup = 5.0
M = 4.0, Rrup = 50.0
M = 4.0, Rrup = 120.0
M = 5.5, Rrup = 5.0
M = 5.5, Rrup = 50.0
M = 5.5, Rrup = 120.0
M = 7.0, Rrup = 5.0
M = 7.0, Rrup = 50.0
M = 7.0, Rrup = 120.0
Sa (g)
Period (s)
AkkarBommer2010
ZhaoEtAl2006Asc
CauzziFaccioli2008
ChiouYoungs2008
Campbell2003SHARE
ToroEtAl2002SHARE

Germany GMM Logic Tree (Grünthal *et al.* 2018)

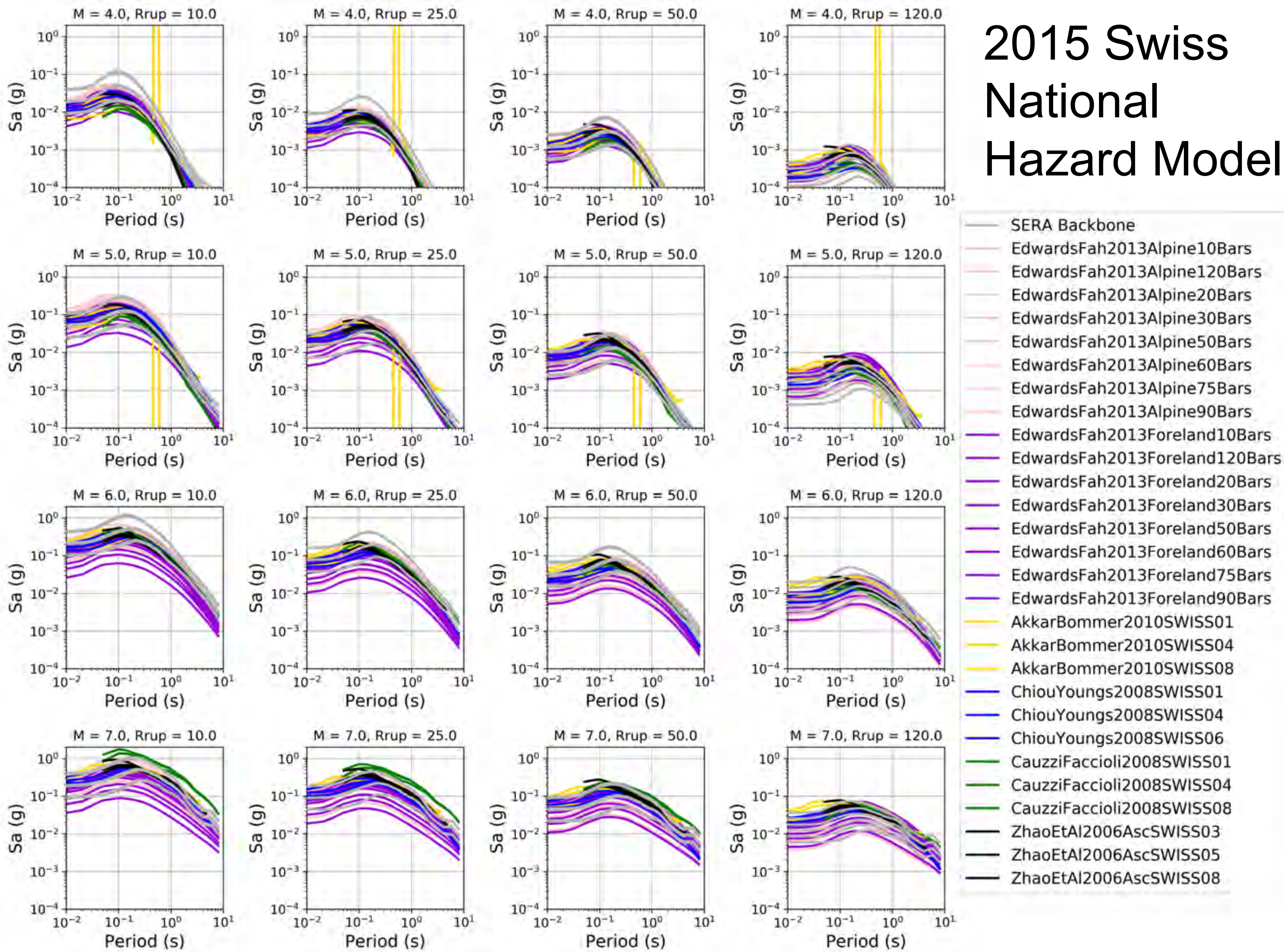




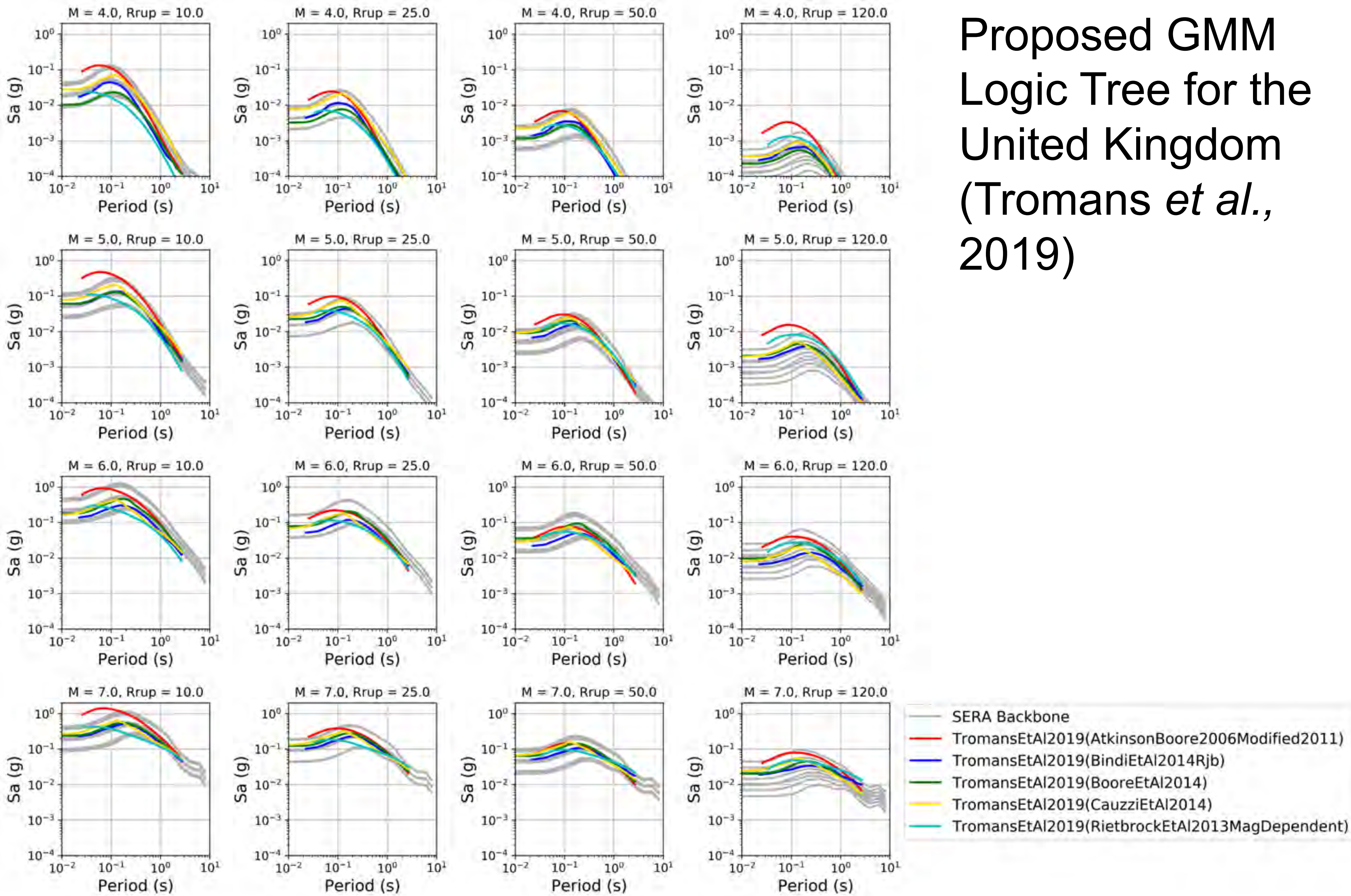


Italy GMM Logic Tree (Lanzano *et al.* 2020)

2015 Swiss National Hazard Model



Proposed GMM Logic Tree for the United Kingdom (Tromans *et al.*, 2019)



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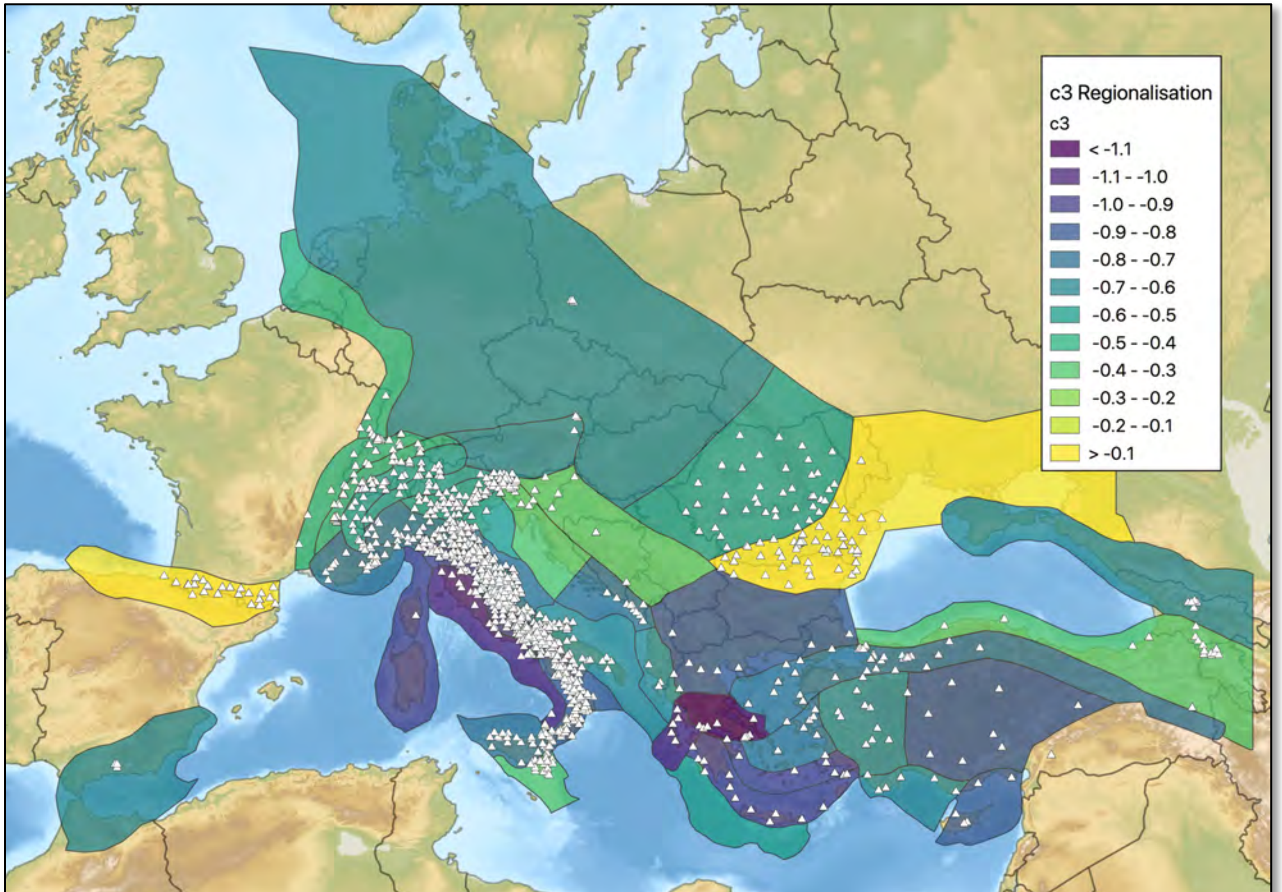
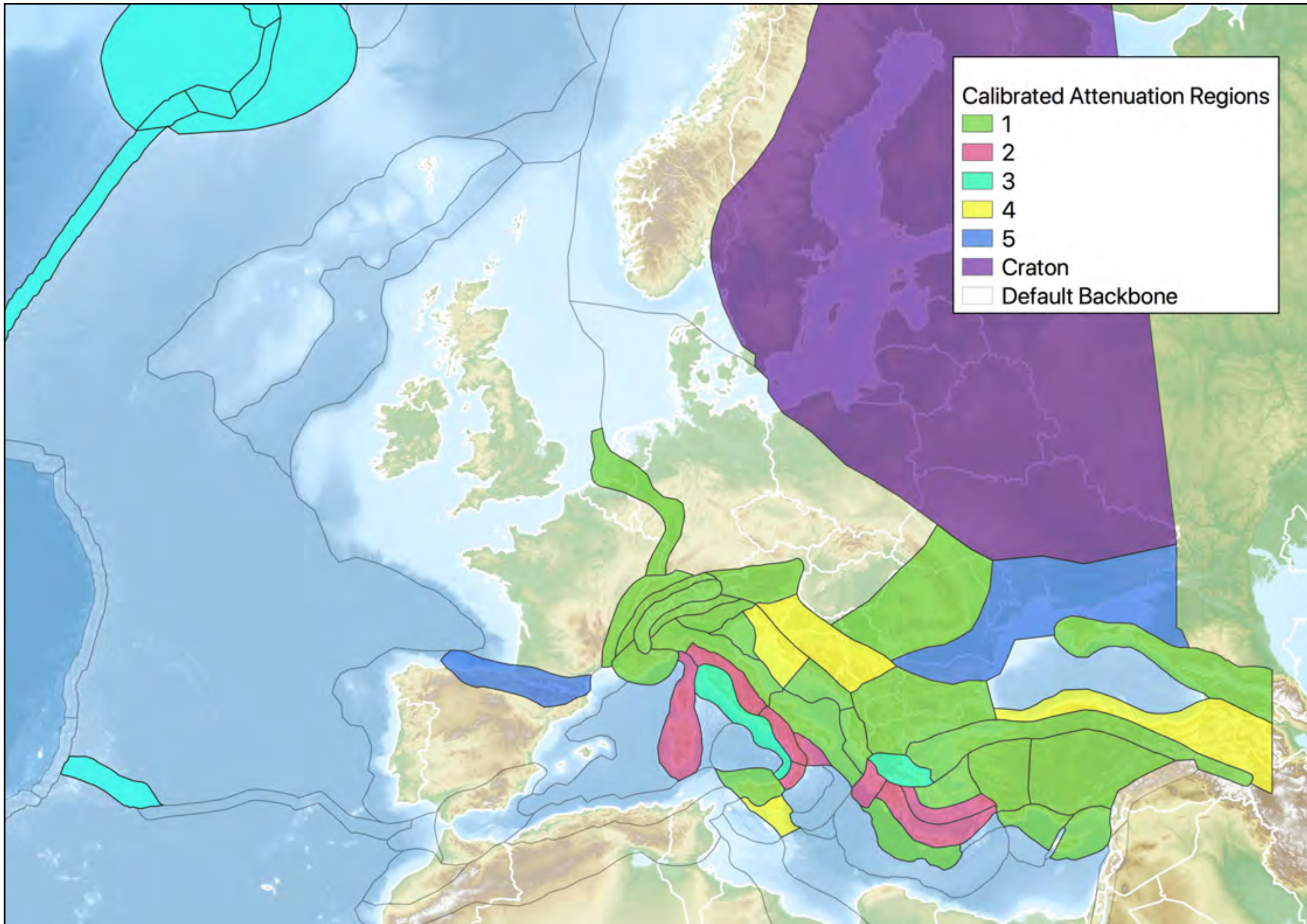
Regional Calibrations – Anelastic Attenuation



For local-scale PSHA $\delta c_3(T)$ and its standard error could be adopted directly

For regional scale PSHA applying a different logic tree for each of the 37 zones is impractical!

Regionalising the GMPE using Data



Hierarchical clustering of $c_3(T)$ identifies regions with similar period-dependent trends in c_3

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T)
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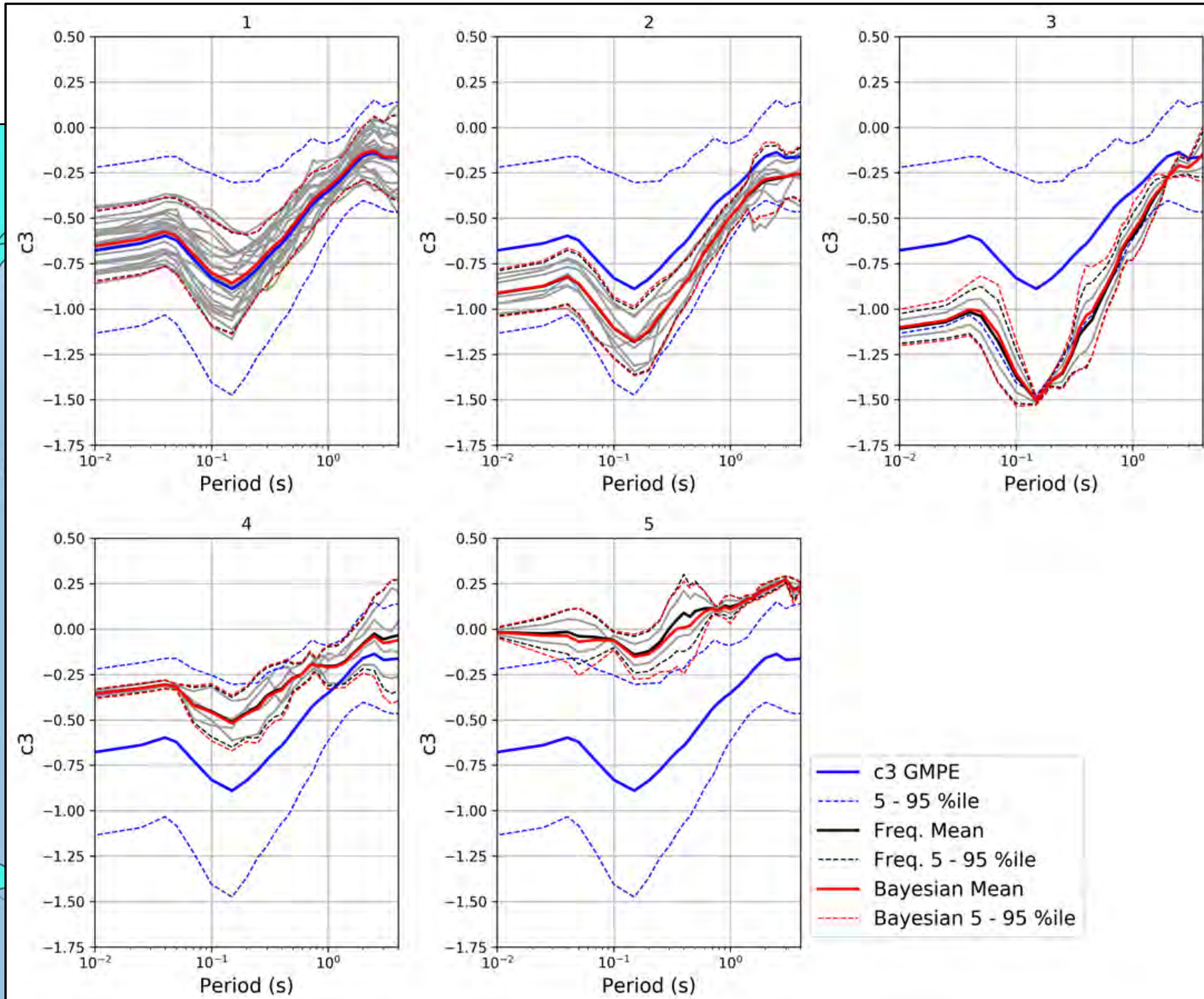
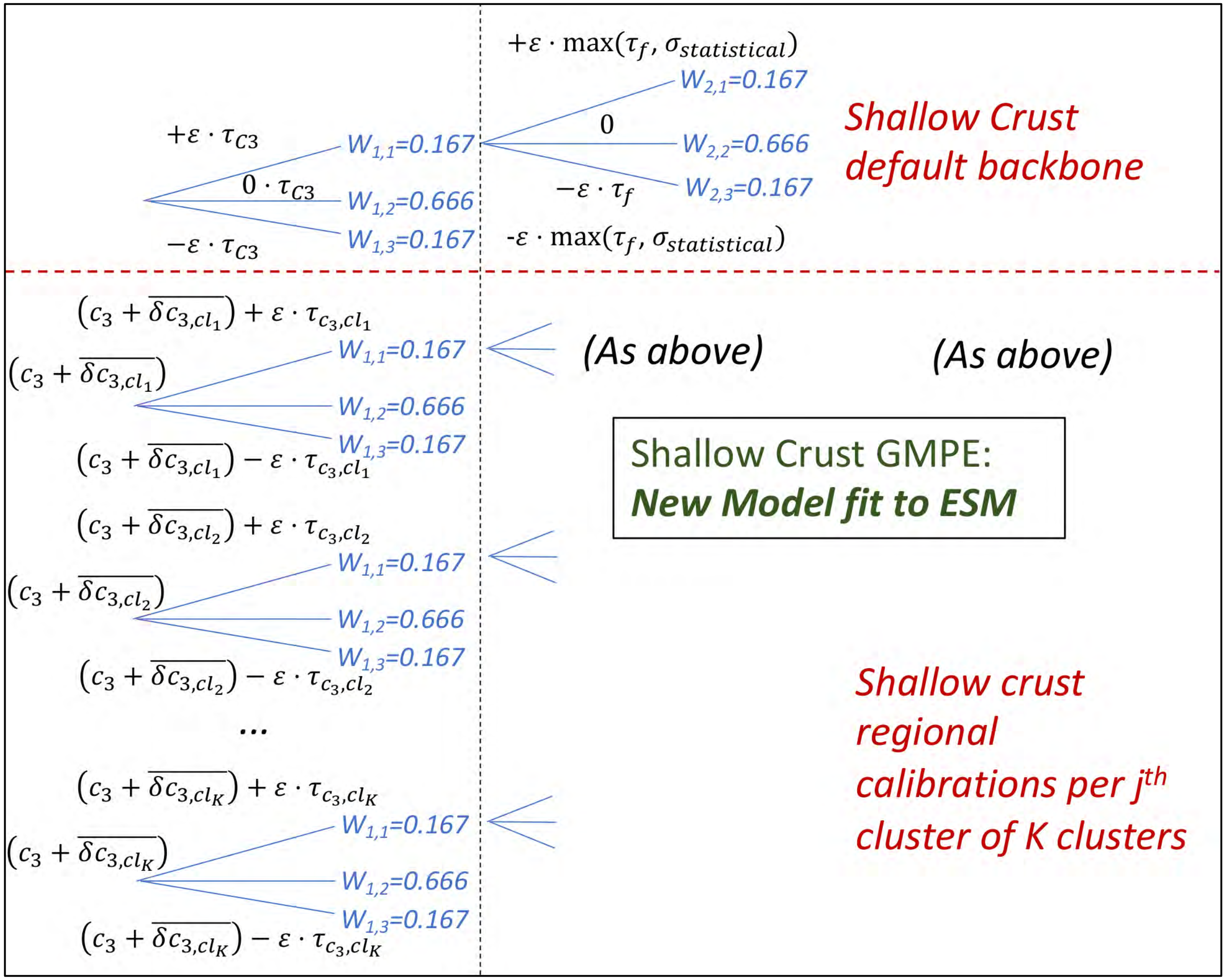
pendent
nds in c_3

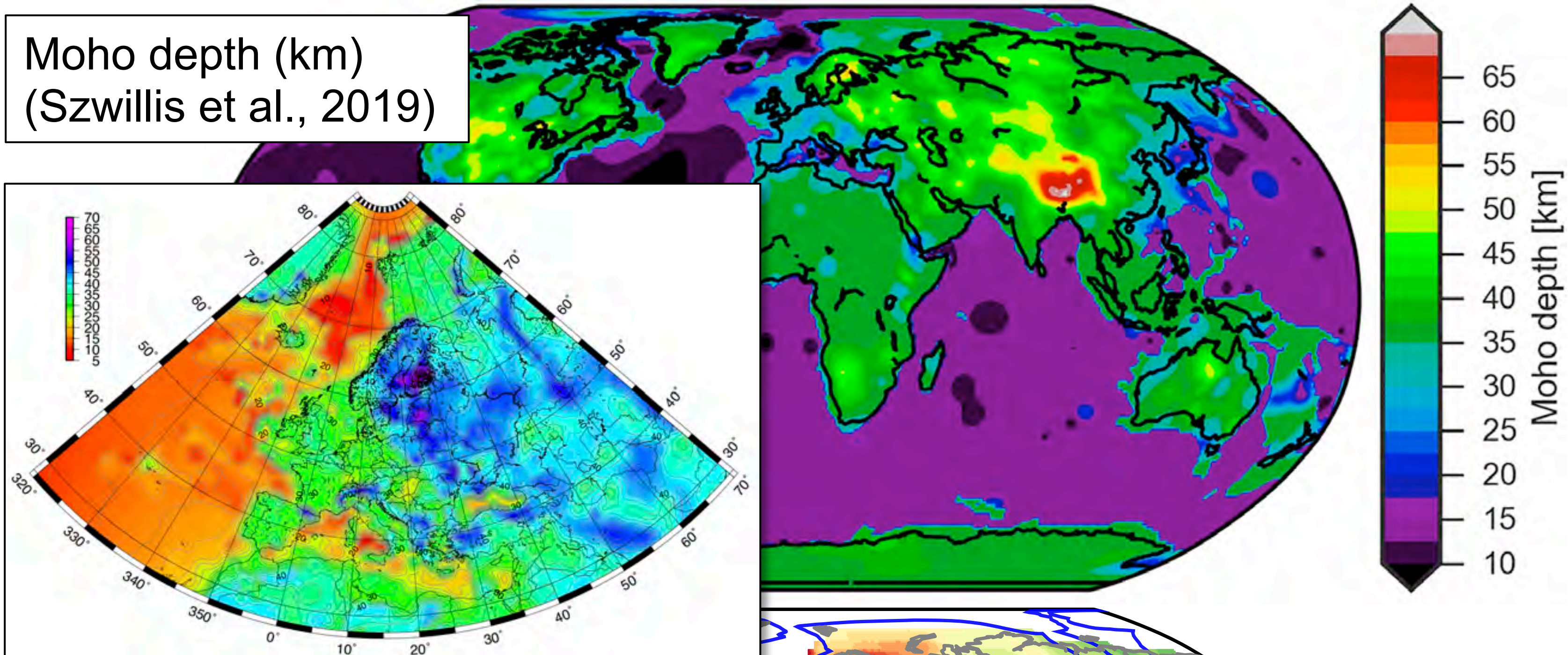


Shallow Crustal Backbone

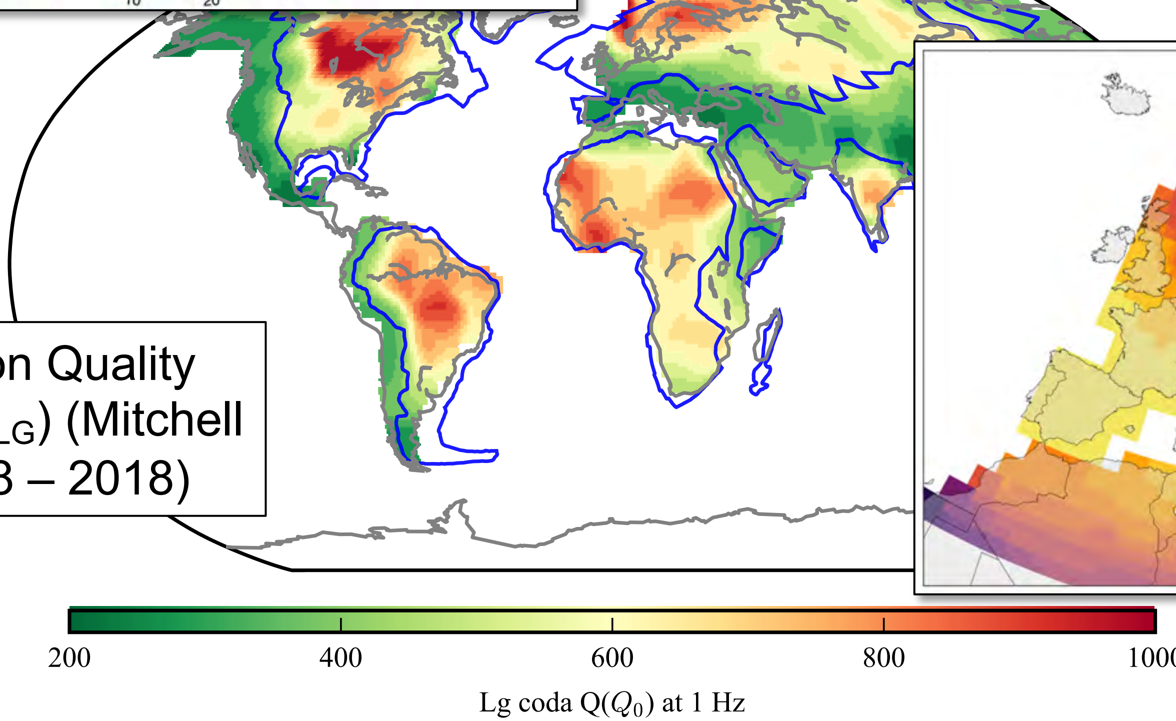


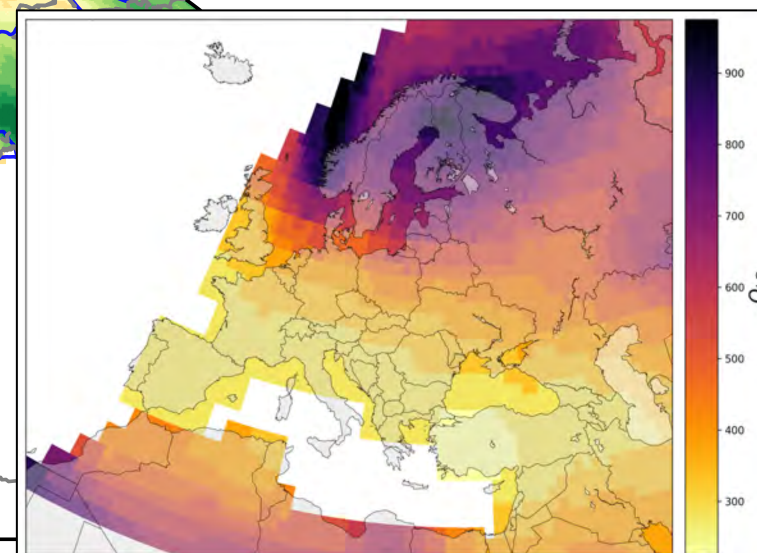
But … not all seismicity in Europe is from active shallow crustal regions!

Moho depth (km)
(Szwillis et al., 2019)



Grad *et al.* (2007)





Attenuation Quality Factor (Q_{LG}) (Mitchell et al. 2008 – 2018)

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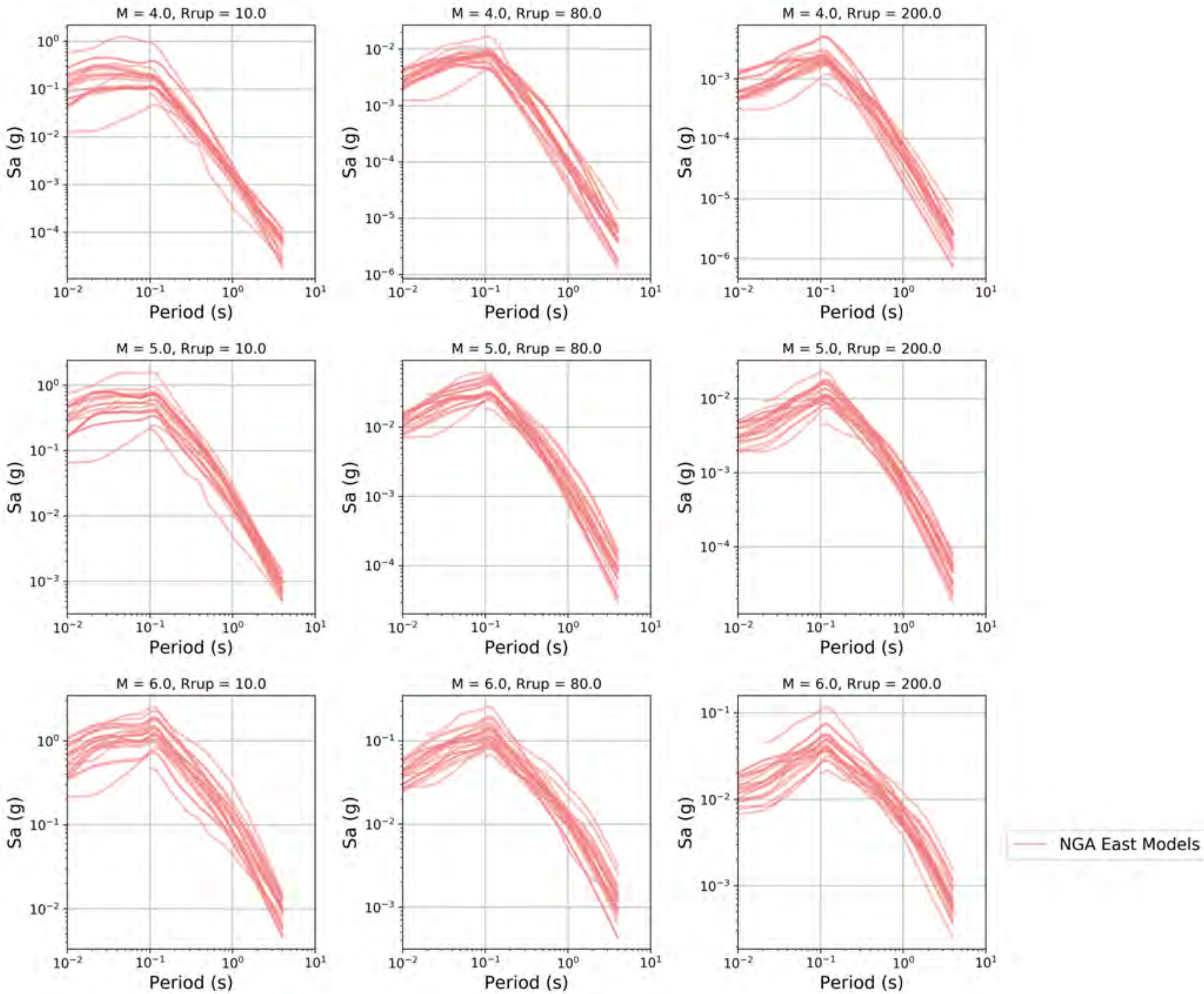
NGA East: Key to a Stable Craton GMM

- ***Key Assumption 1:*** GMMs calibrated for Cental & Eastern US (NGA East, 2015 – PEER 2015/04, PEER 2015/08) are suitable for application *only* in the stable craton of Europe

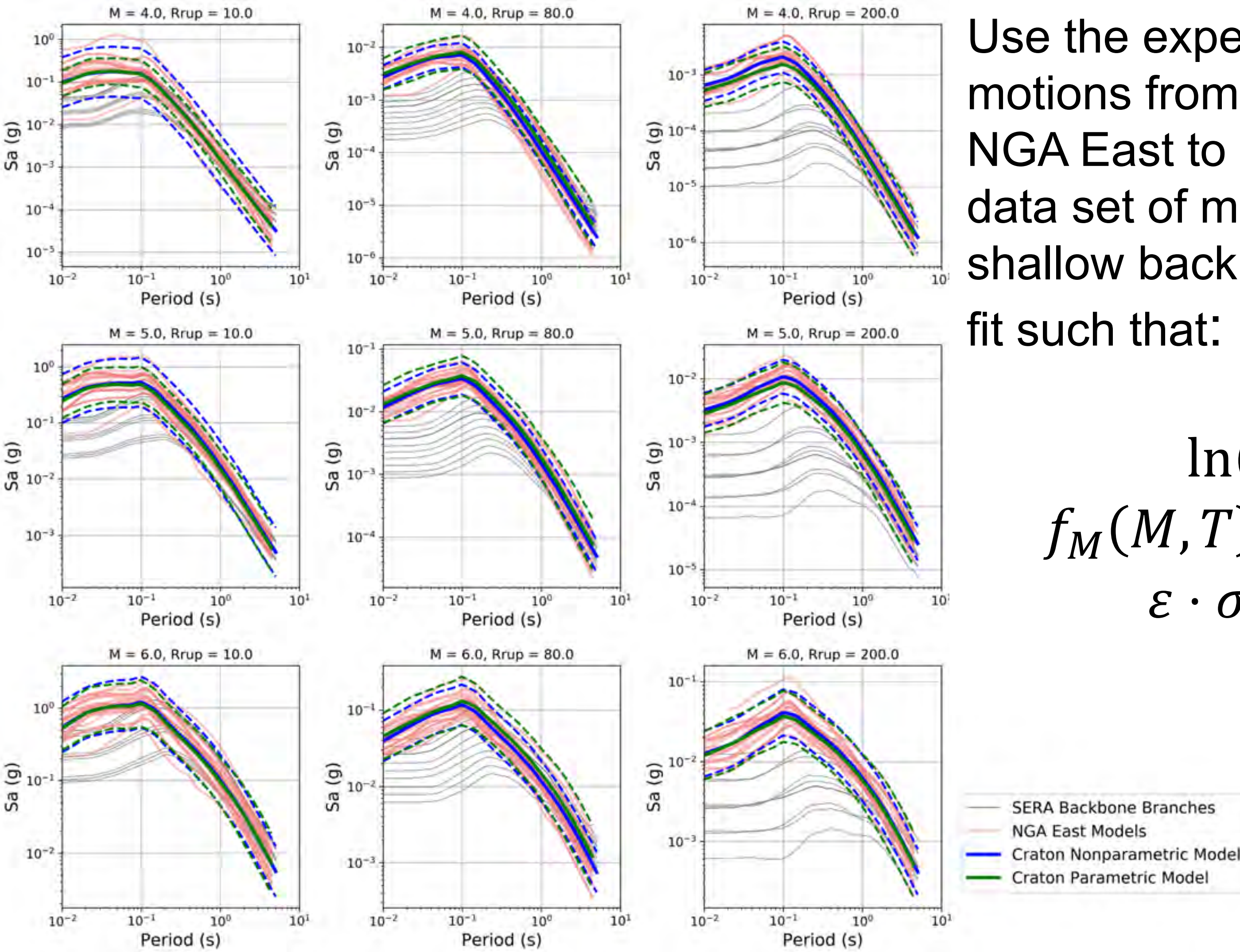
- ***Key Assumption 2:*** The suite of 20 NGA East Models (also include Pezeschk *et al.*, 2011) is representative of the range of possible median ground motions, and no *individual NGA East GMPE is weighted higher than any other*

- ***Key Assumption 3:*** NGA East models originally calibrated for very hard rock (V_{S30} 3000 m/s). For current purpose these are rendered to 800 m/s using the NGA East Site amplification models of Stewart *et al*. (2017) and Hashash *et al*. (2017)

NGA East Models



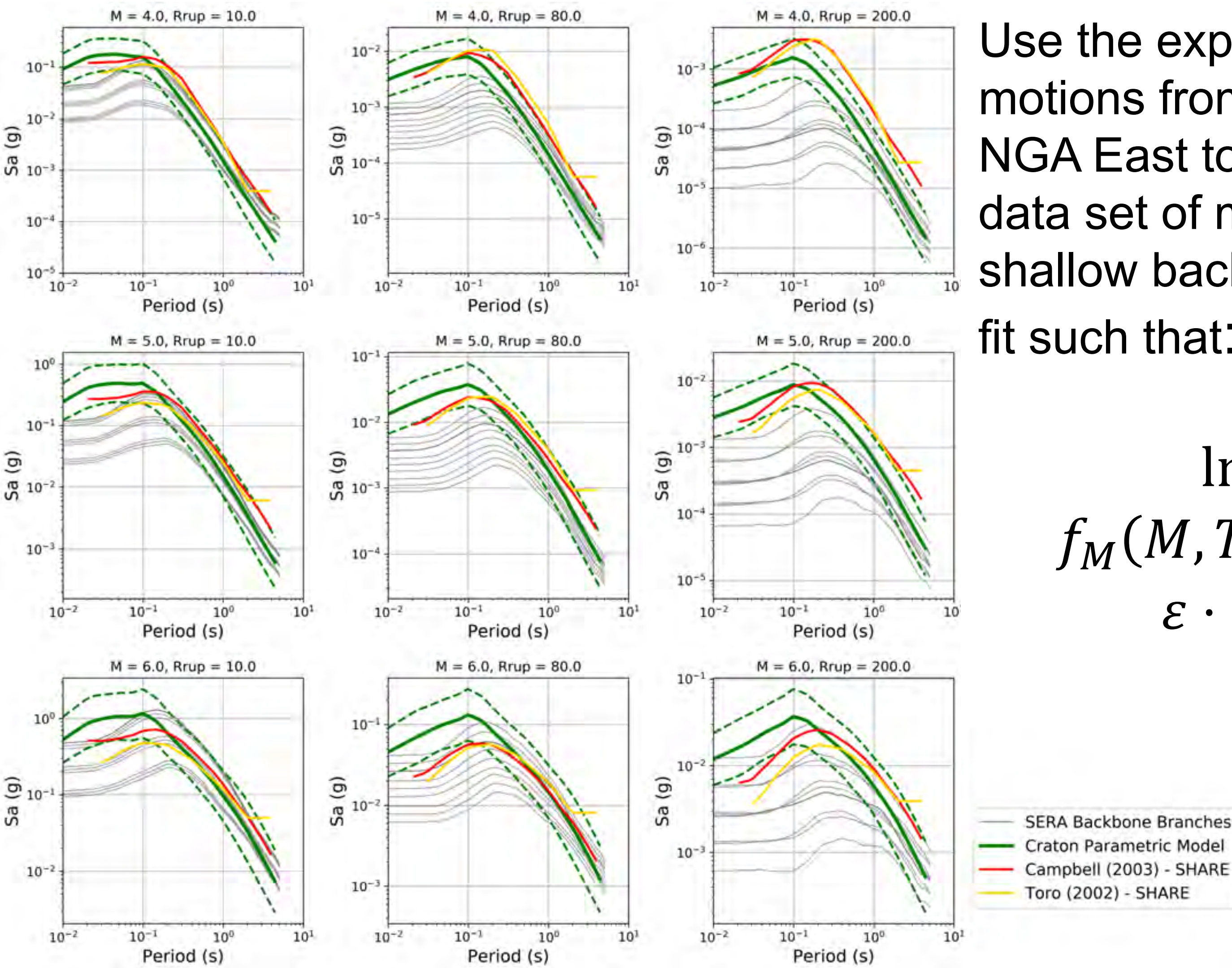
Parametric Craton Model



Use the expected ground motions from all models in the NGA East to generate a synthetic data set of motions to which the shallow backbone GMPE can be fit such that:

$$\ln(M,R,T) = f_M(M,T) + f_R(M,R,T) + \varepsilon \cdot \sigma_{statistical}(T)$$

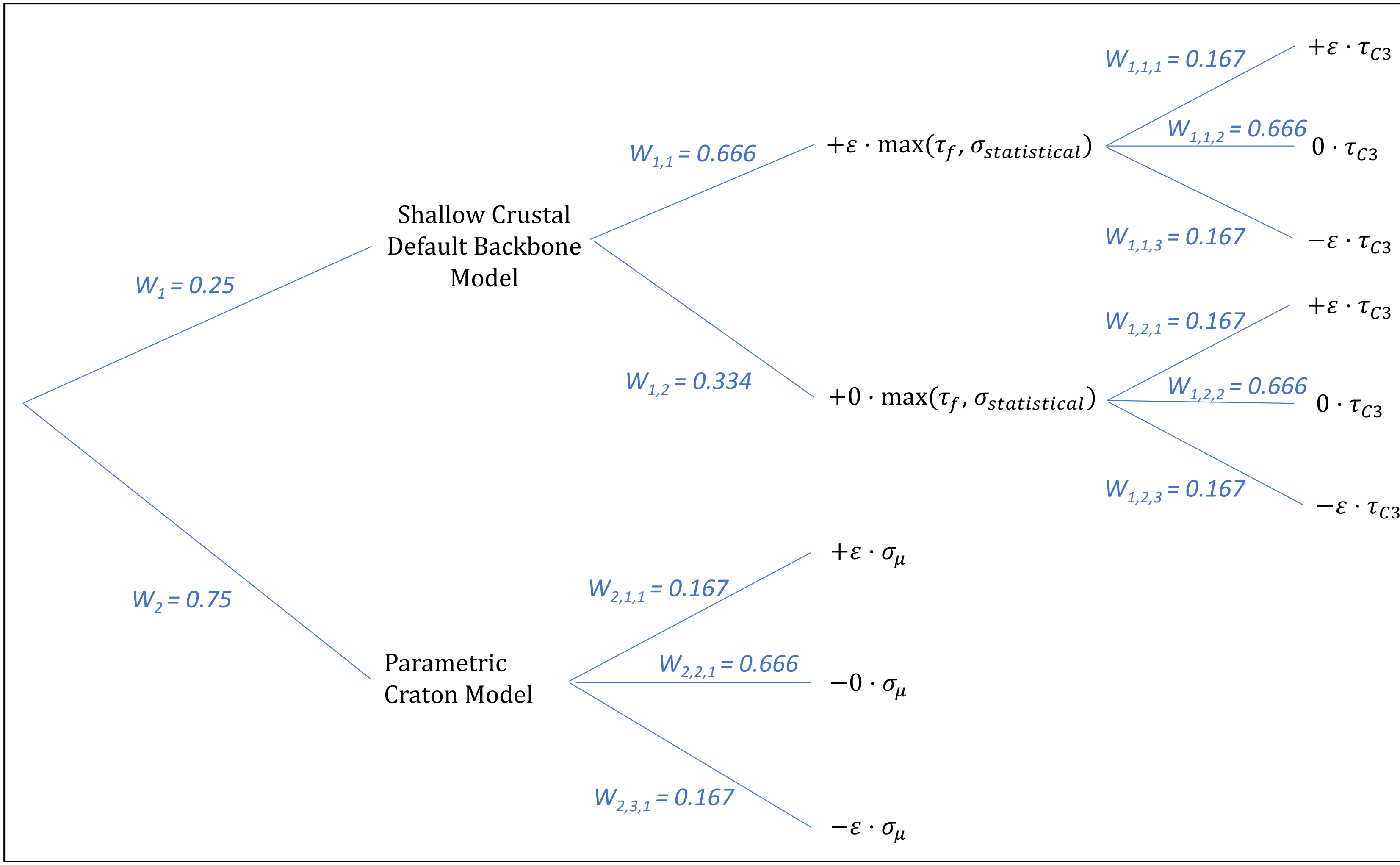
Parametric Craton Model



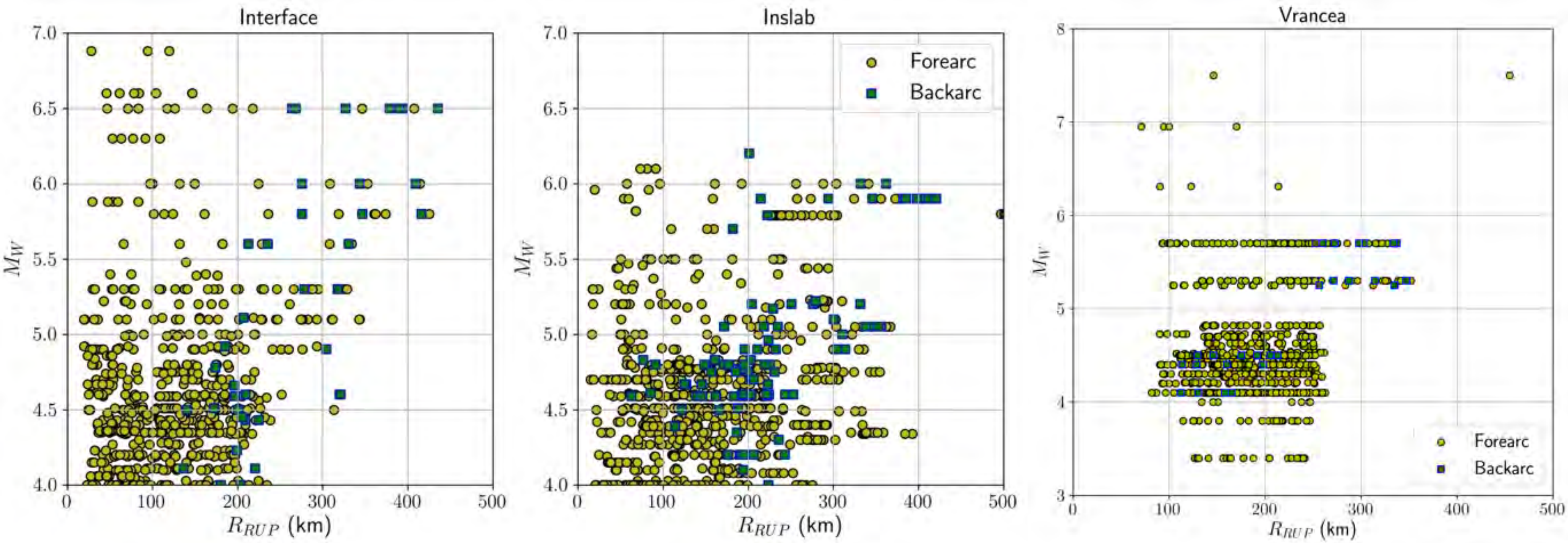
Use the expected ground motions from all models in the NGA East to generate a synthetic data set of motions to which the shallow backbone GMPE can be fit such that:

$$\ln(M, R, T) = f_M(M, T) + f_R(M, R, T) + \varepsilon \cdot \sigma_{statistical}(T)$$

Craton Ground Motion Logic Tree

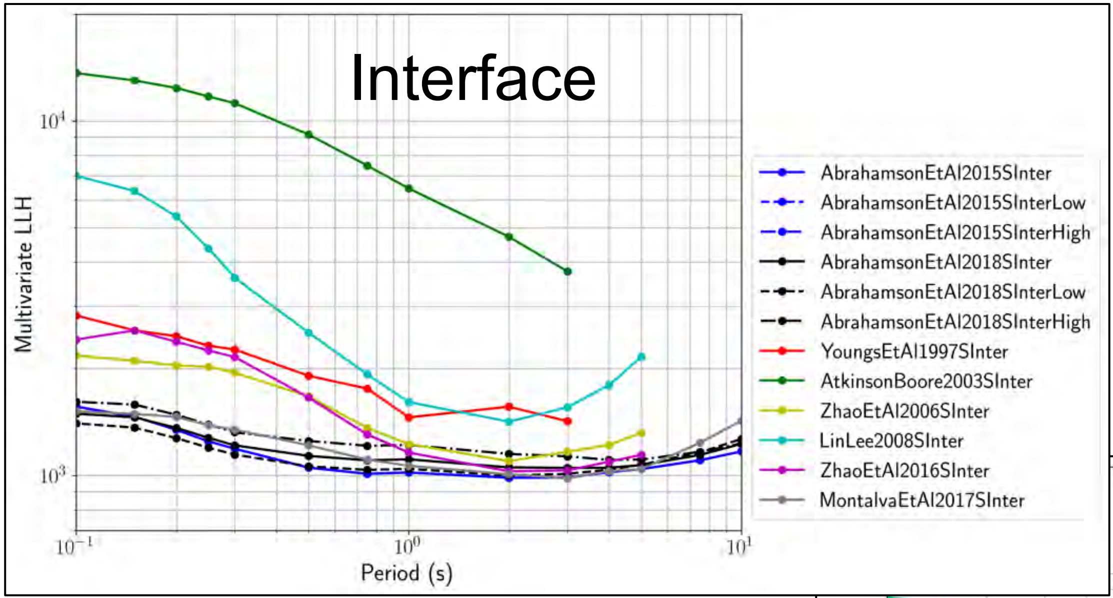


Subduction & Vrancea Events in ESM



- Subduction events classified from ESM via a fuzzy classifier
- Vrancea deep source events identified by hand
- All records from events with M_W < 4 excluded

Comparisons of Subduction GMMs Against ESM Data

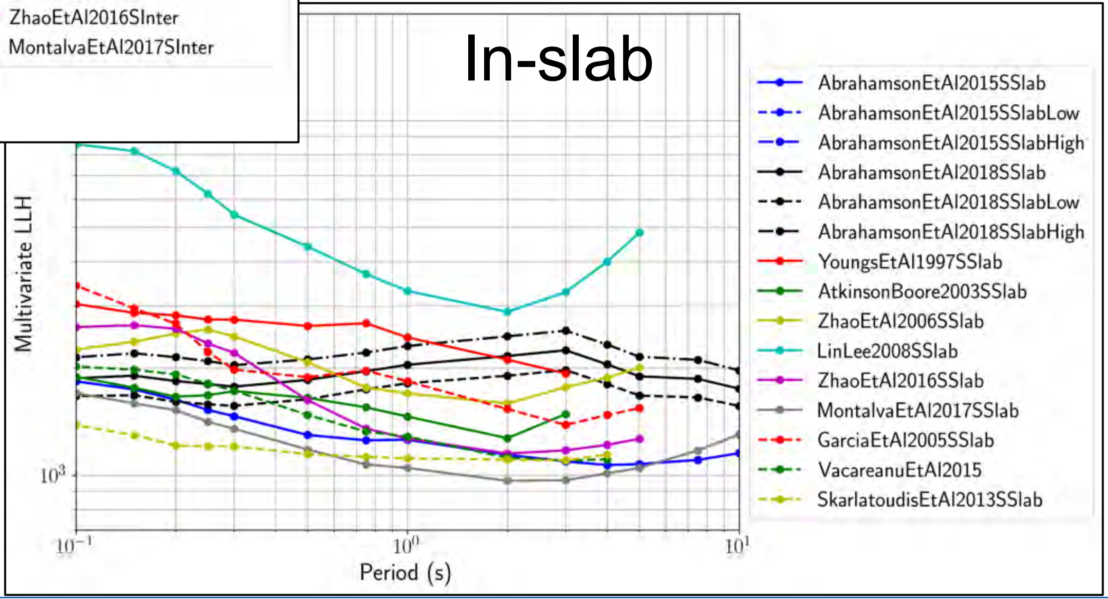


Interface:

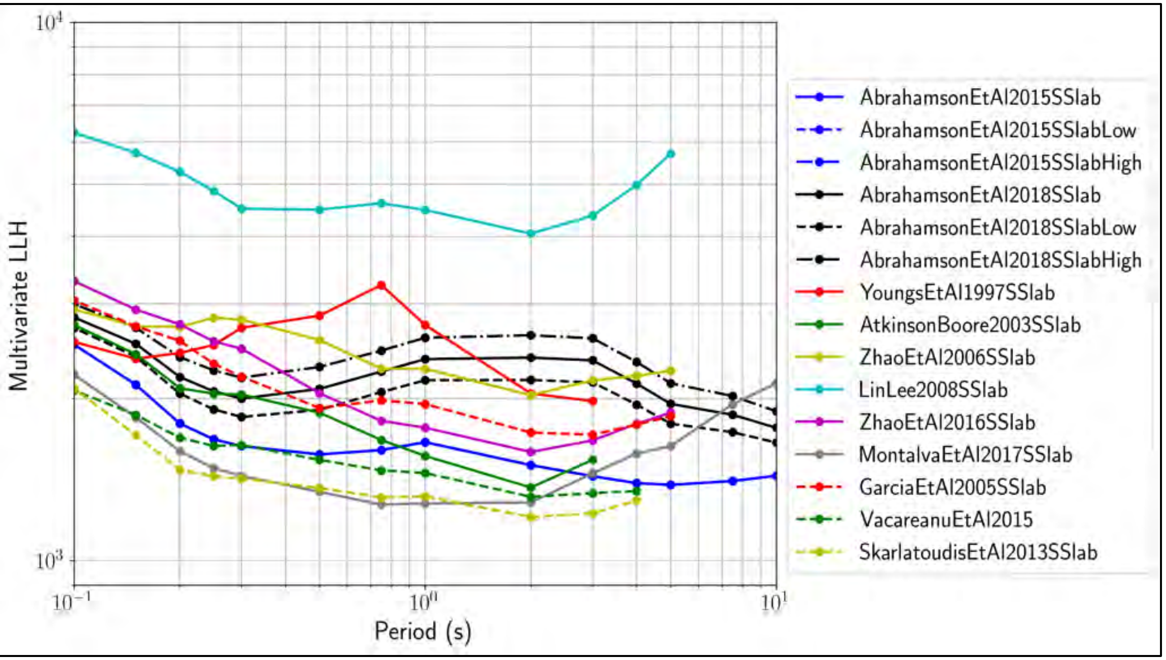
Abrahamson et al. (2016) “BC Hydro” gives lowest Multivariate log-likelihood (LLH) across the full spectrum

Inslab:

BC Hydro (2016) generally good (as is Montalva et al., 2017). Skarlatoudis et al., (2013) gives the lowest LLH at short periods



Comparisons of Subduction GMMs Against ESM Data

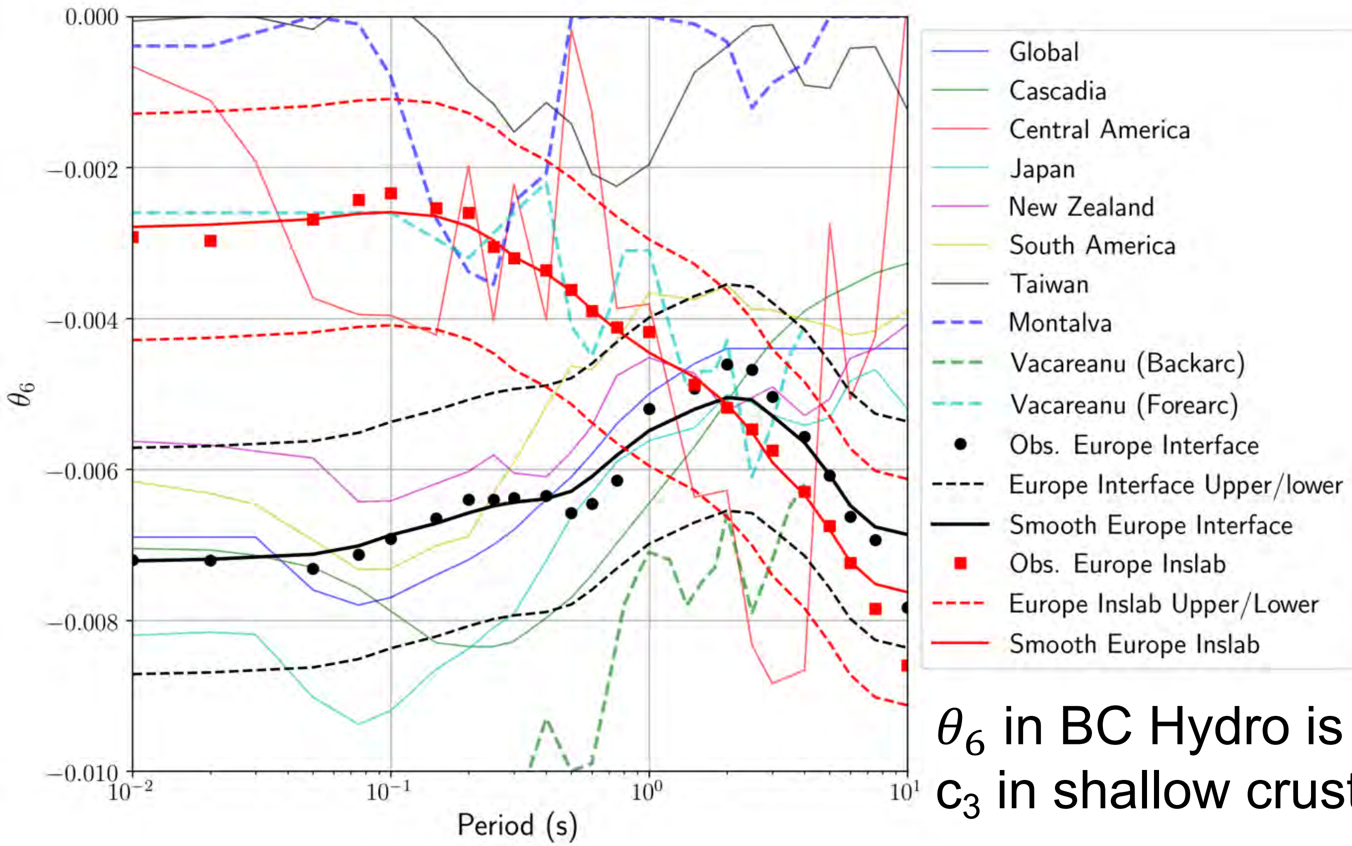


Vrancea Deep Source

BC Hydro (2016) *among* the better performing, and Vacareanu *et al.* (2015) is similar.

Lowest LLH scores go to Montalva *et al.* (2017) and Skarlatoudis *et al.* (2013)

Subduction Logic Tree: 1. Attenuation



Gradient of linear fit to intra-event residuals (θ_6) shown as dots for interface (black) and inslab (red)

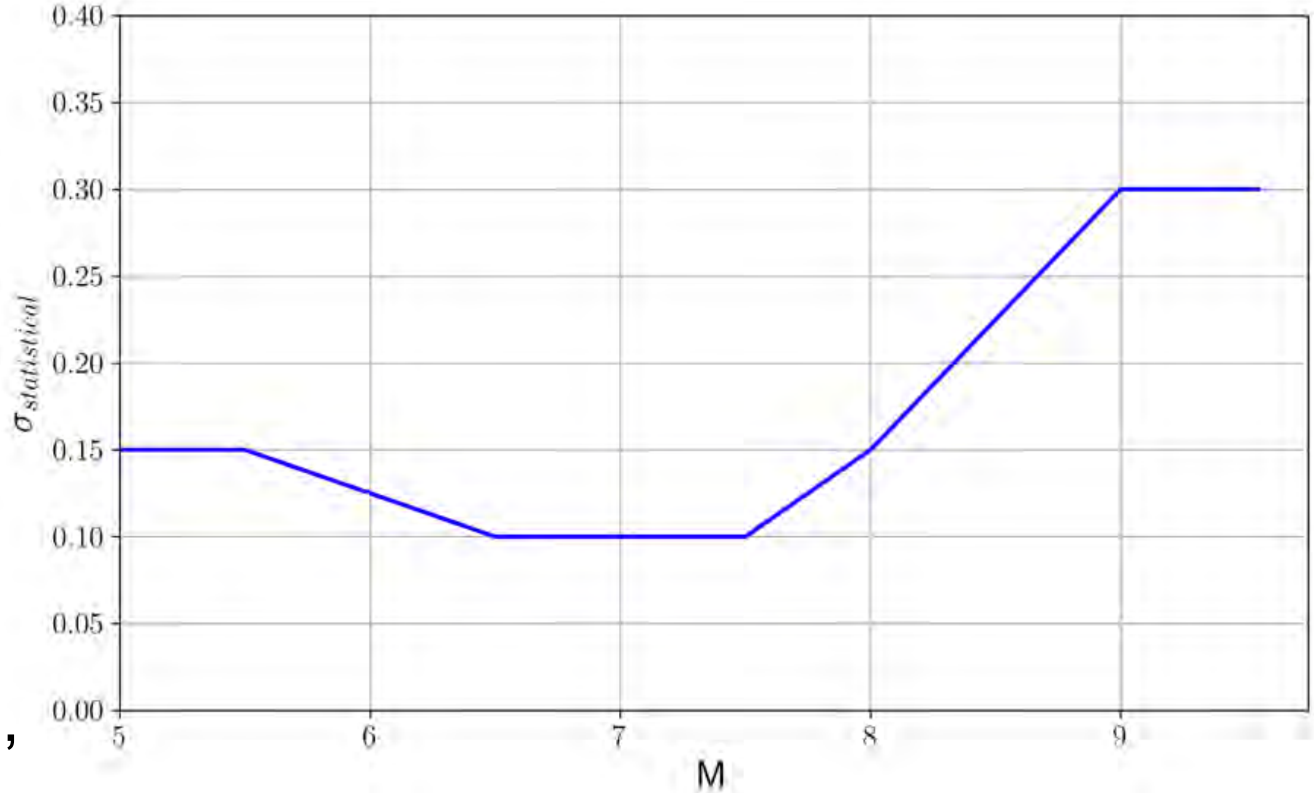
θ_6 in BC Hydro is equivalent to c_3 in shallow crustal GMPE

Adjustment factor of ± 0.0015 applied to the smoothed ESM calibrated θ_6 values envelopes reasonably most of the regional variations in θ_6.

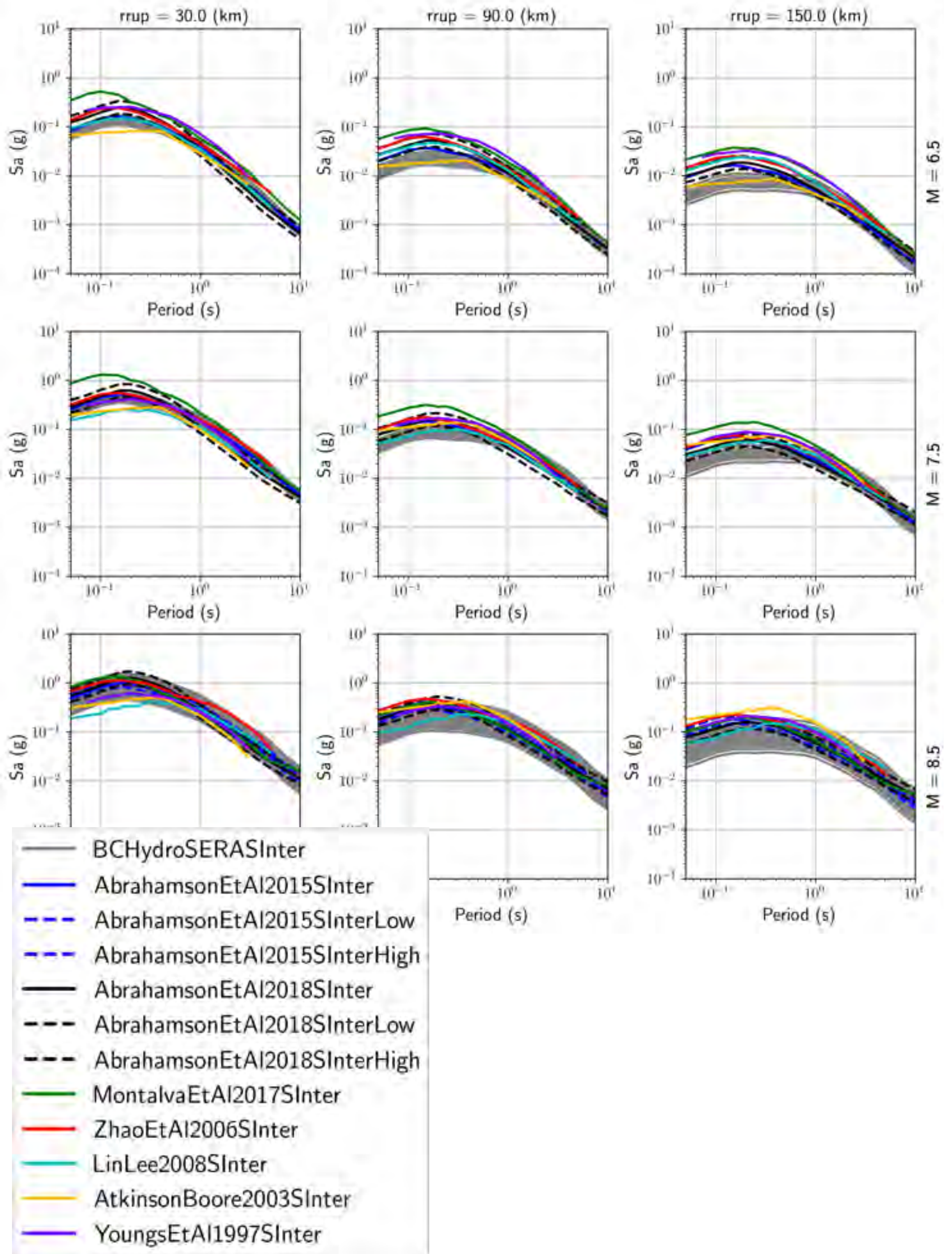
Subduction Logic Tree: $\sigma_{statistical}$

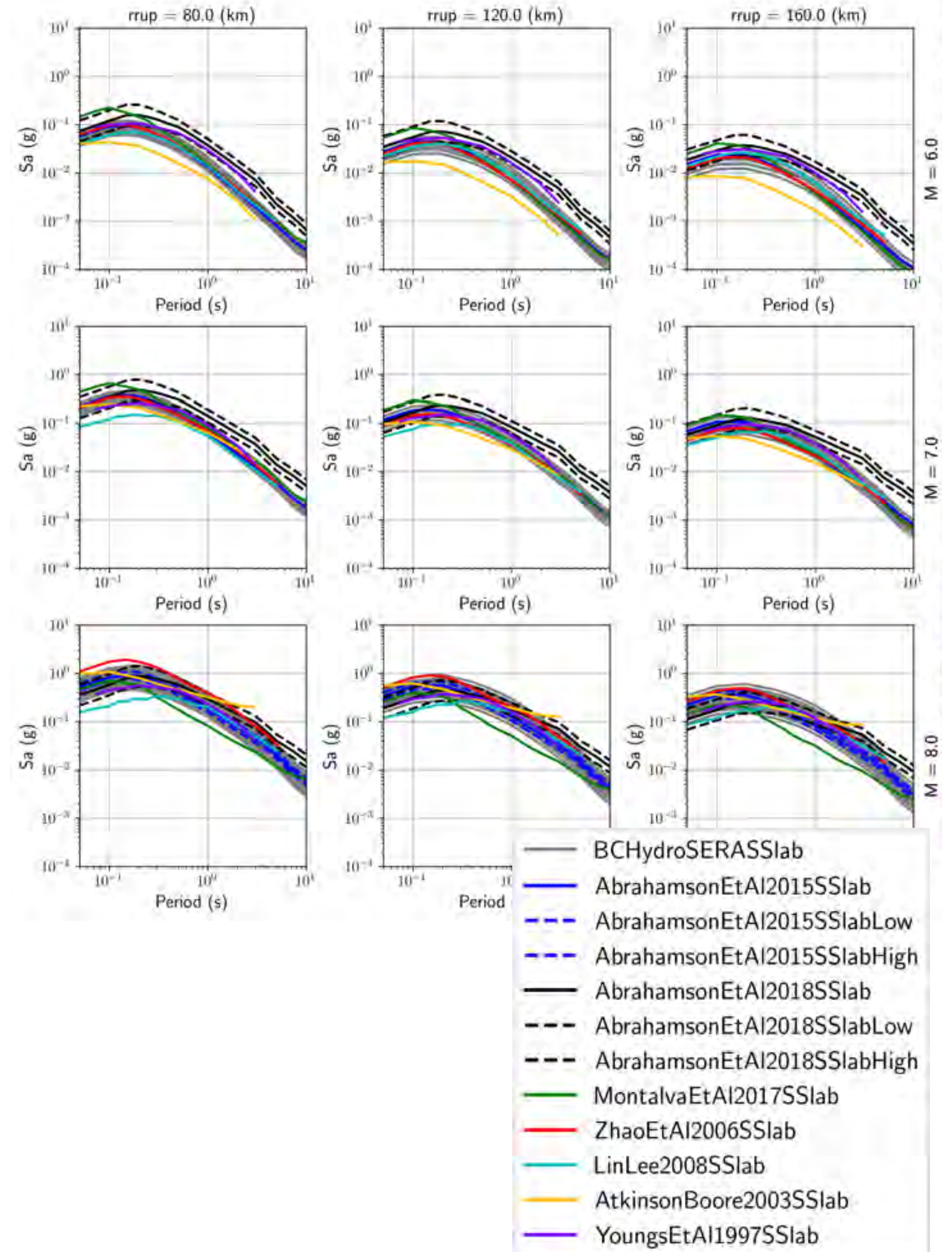
Cannot fit $\sigma_{statistical}$ directly using the Al Atik & Youngs (2014)

Rely on values reported in BC Hydro report (BC Hydro, 2012; Coppersmith et al., 2014)

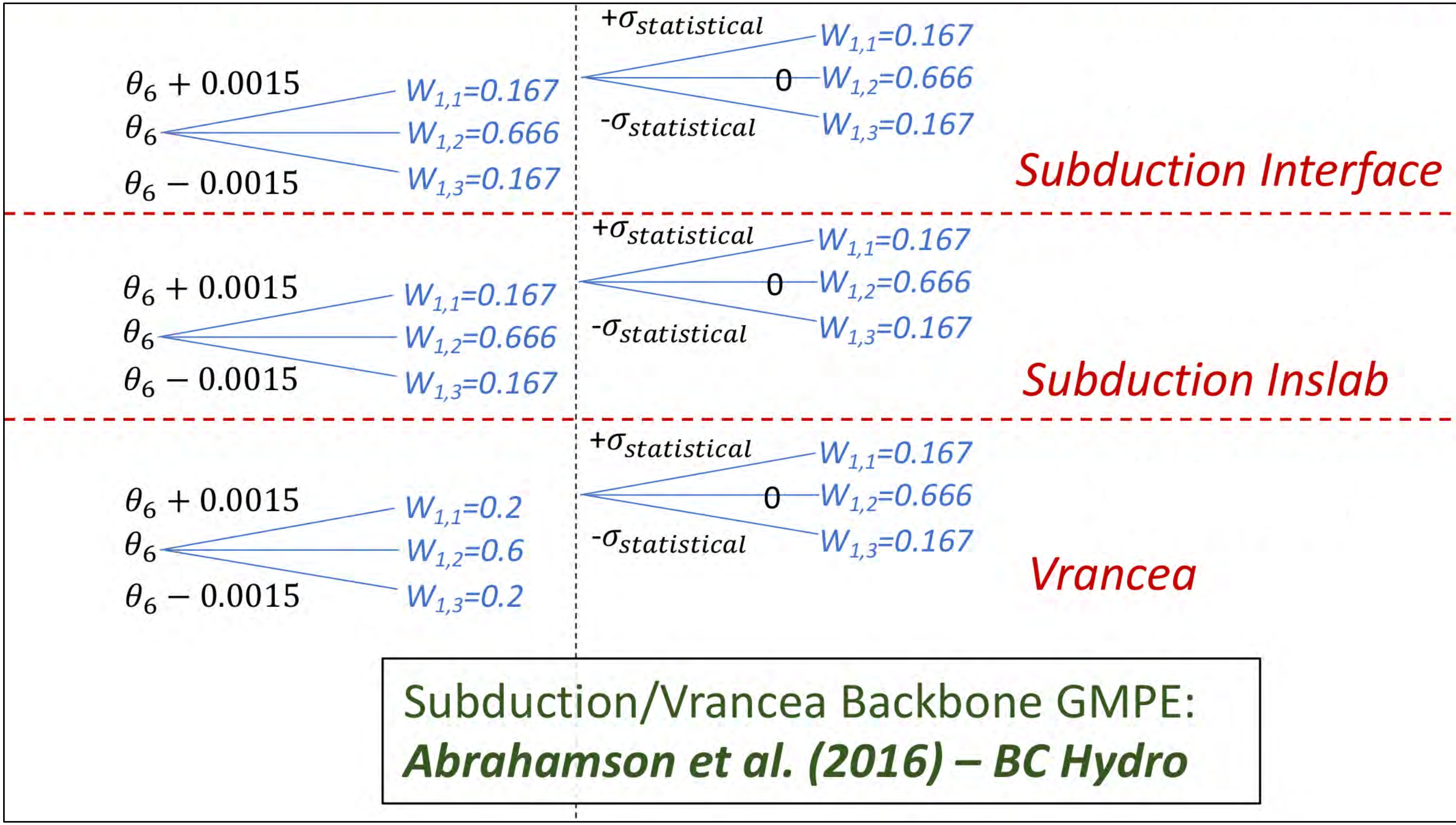


Calibrated to values reported in Hanford Site PSHA given reported composition of BC Hydro data set


rrup = 30.0 (km)
rrup = 90.0 (km)
rrup = 150.0 (km)
M = 6.5
M = 7.5
M = 8.5
Sa (g)
Period (s)
BCHydroSERASInter
AbrahamsonEtAl2015SInter
AbrahamsonEtAl2015SInterLow
AbrahamsonEtAl2015SInterHigh
AbrahamsonEtAl2018SInter
AbrahamsonEtAl2018SInterLow
AbrahamsonEtAl2018SInterHigh
MontalvaEtAl2017SInter
ZhaoEtAl2006SInter
LinLee2008SInter
AtkinsonBoore2003SInter
YoungsEtAl1997SInter


rrup = 80.0 (km)
rrup = 120.0 (km)
rrup = 160.0 (km)
M = 6.0
M = 7.0
M = 8.0
Sa (g)
Period (s)
BCHydroSERASSlab
AbrahamsonEtAl2015SSlab
AbrahamsonEtAl2015SSlabLow
AbrahamsonEtAl2015SSlabHigh
AbrahamsonEtAl2018SSlab
AbrahamsonEtAl2018SSlabLow
AbrahamsonEtAl2018SSlabHigh
MontalvaEtAl2017SSlab
ZhaoEtAl2006SSlab
LinLee2008SSlab
AtkinsonBoore2003SSlab
YoungsEtAl1997SSlab

Subduction Logic Tree



Site Response

ESHM2020 serves two objectives:

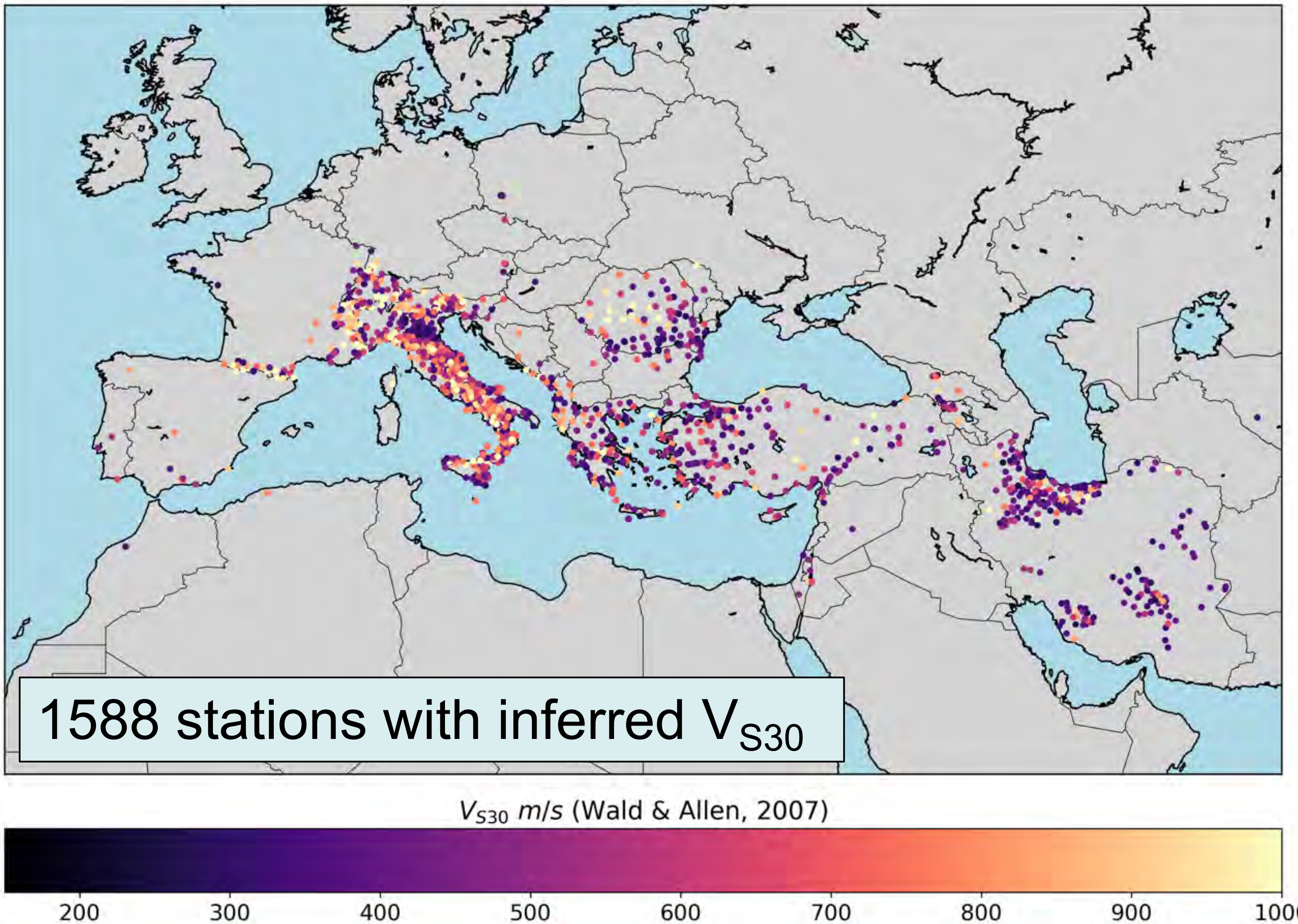
Reference seismic hazard map on EC8 class A (rock - V_{S30} 800 m/s) for compatibilty with Eurocode requirements

- Assumes uniform site condition
- Should assume site condition is known/measured

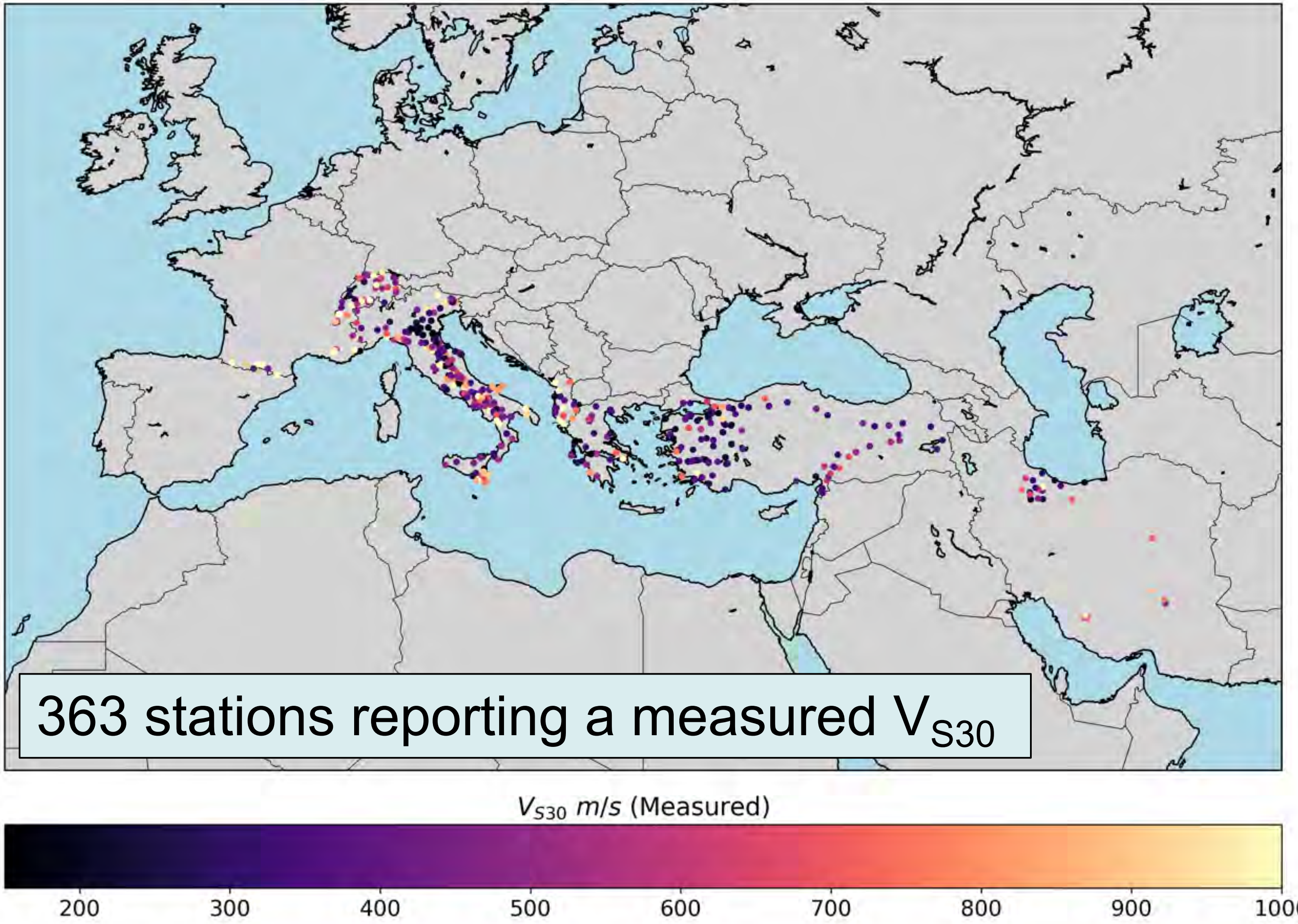
Seismic hazard input for European Risk Model

- Requires site parameterisation at resolution required for risk calculation (30“ – 120“)
- *In most cases* assumes site information inferred via proxy (not measured)
- Two methodologies considered:
  1. V_{S30} inferred from topography
  2. Amplification directly obtained from topography and geology

V_{S30} Coverage in ESM

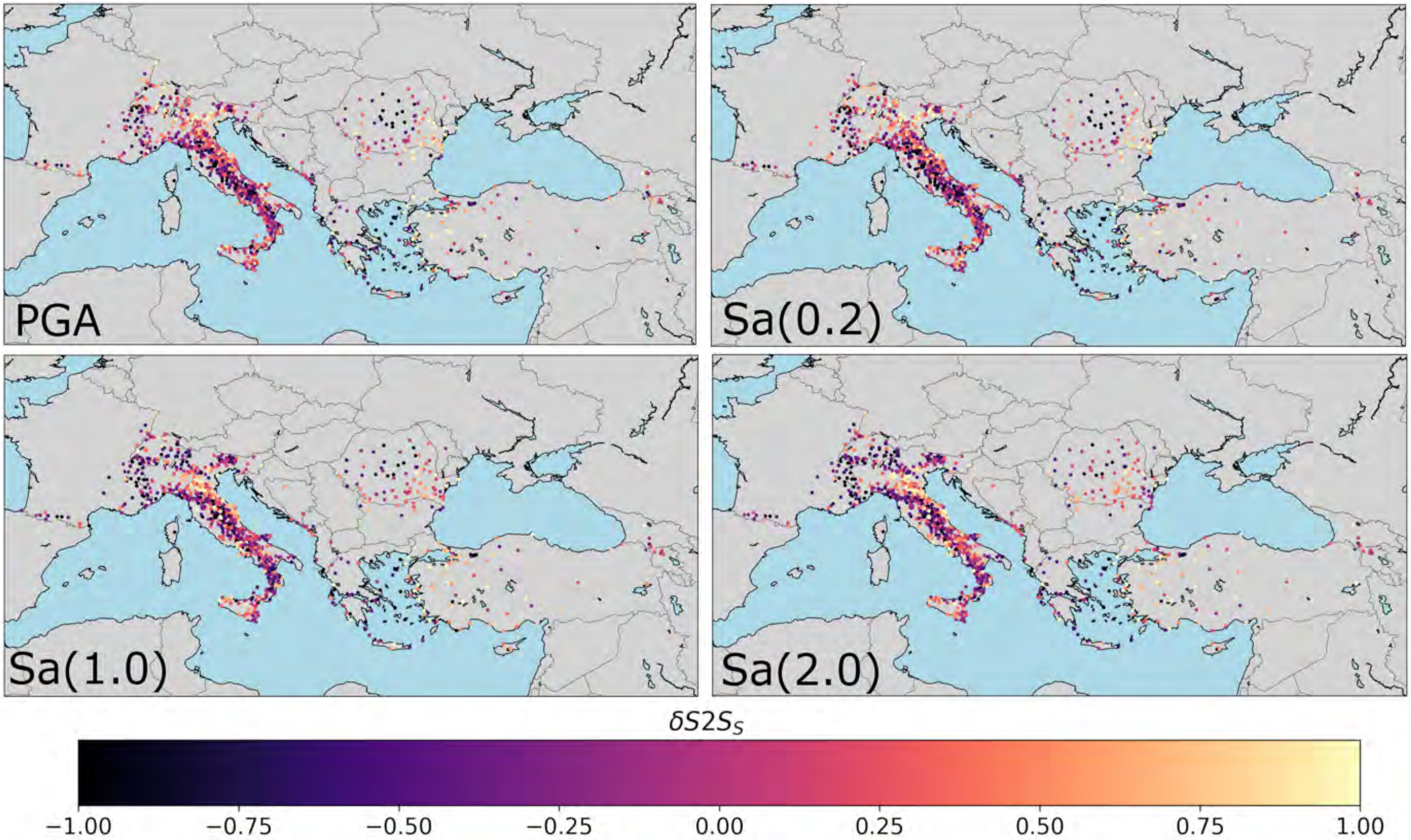


V_{S30} Coverage in ESM



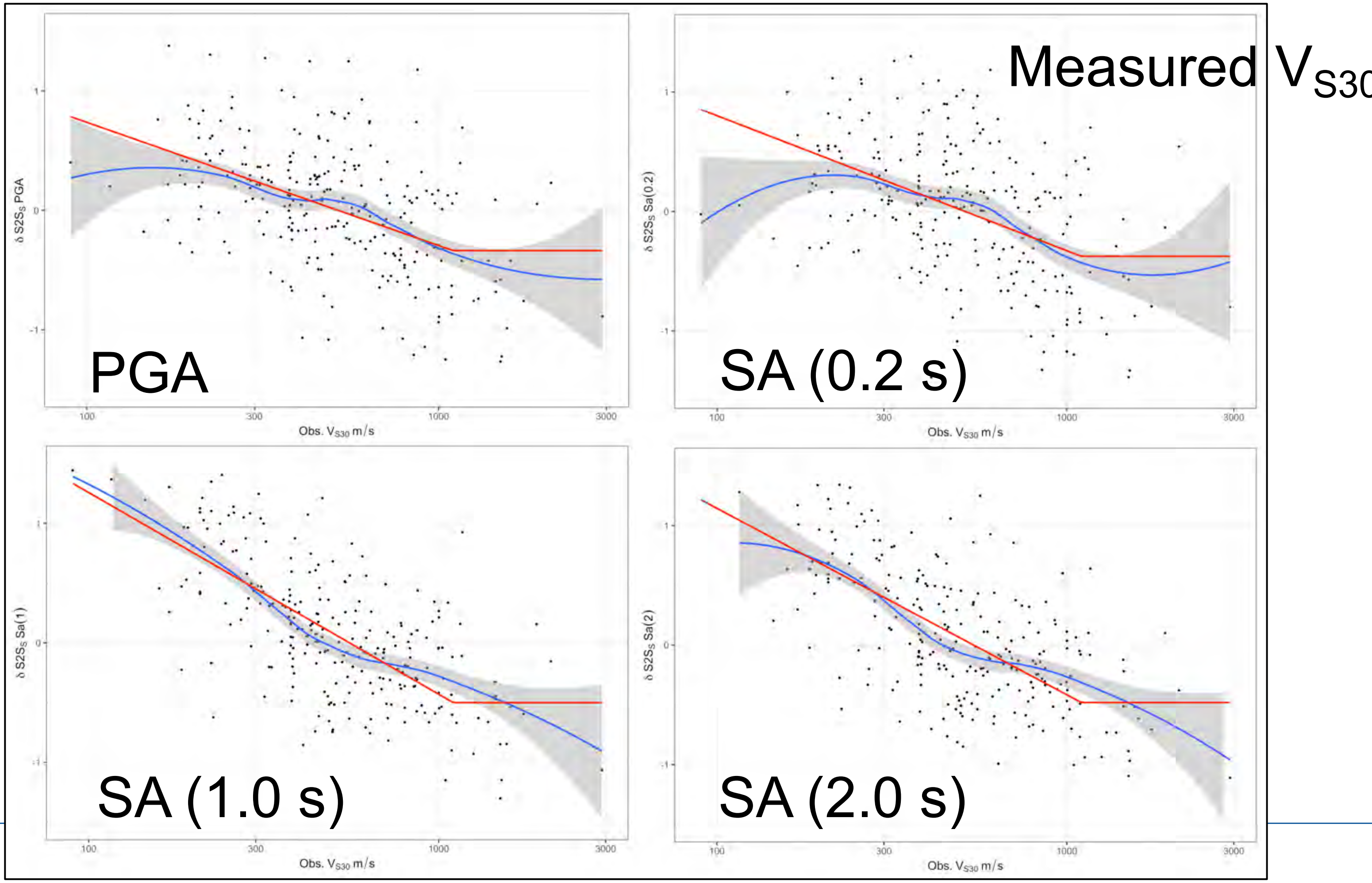
Site Amplification Model

$$ln(\mu) = e_1 + f_R\left(M_W, R_{JB}, h_D\right) + f_M(M_W) + \delta B_f + \delta B_e + \delta S2S_s + \varepsilon$$



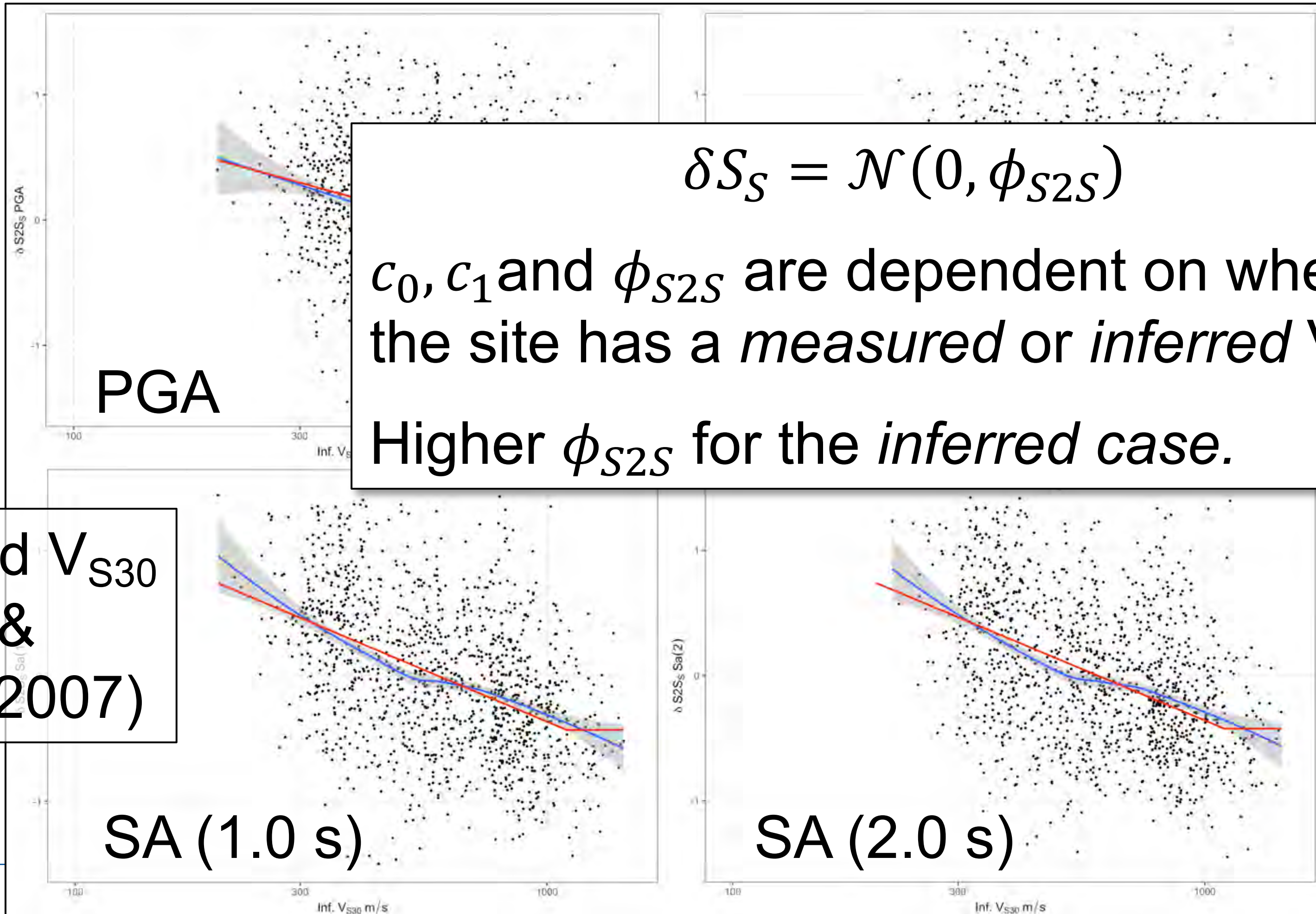
Site Amplification Model

$$\delta S2S_S = \begin{cases} c_1 \ln(V_{S30}/c_0) \\ c_1 \ln(V_C/c_0) \end{cases} + \delta S_S \quad \begin{matrix} for\ V_{S30} \leq V_C \\ for\ V_{S30} > V_C \end{matrix}$$



Site Amplification Model

$$\delta S2S_S = \begin{cases} c_1 \ln(V_{S30}/c_0) & \text{for } V_{S30} \le V_C \\ c_1 \ln(V_C/c_0) & \text{for } V_{S30} > V_C \end{cases} + \delta S_S$$



$$\delta S_S = \mathcal{N}(0, \phi_{S2S})$$

c_0, c_1 and ϕ_{S2S} are dependent on whether the site has a *measured* or *inferred* V_{S30}

Higher ϕ_{S2S} for the *inferred case.*

Inferred V_{S30} (Wald & Allen, 2007)

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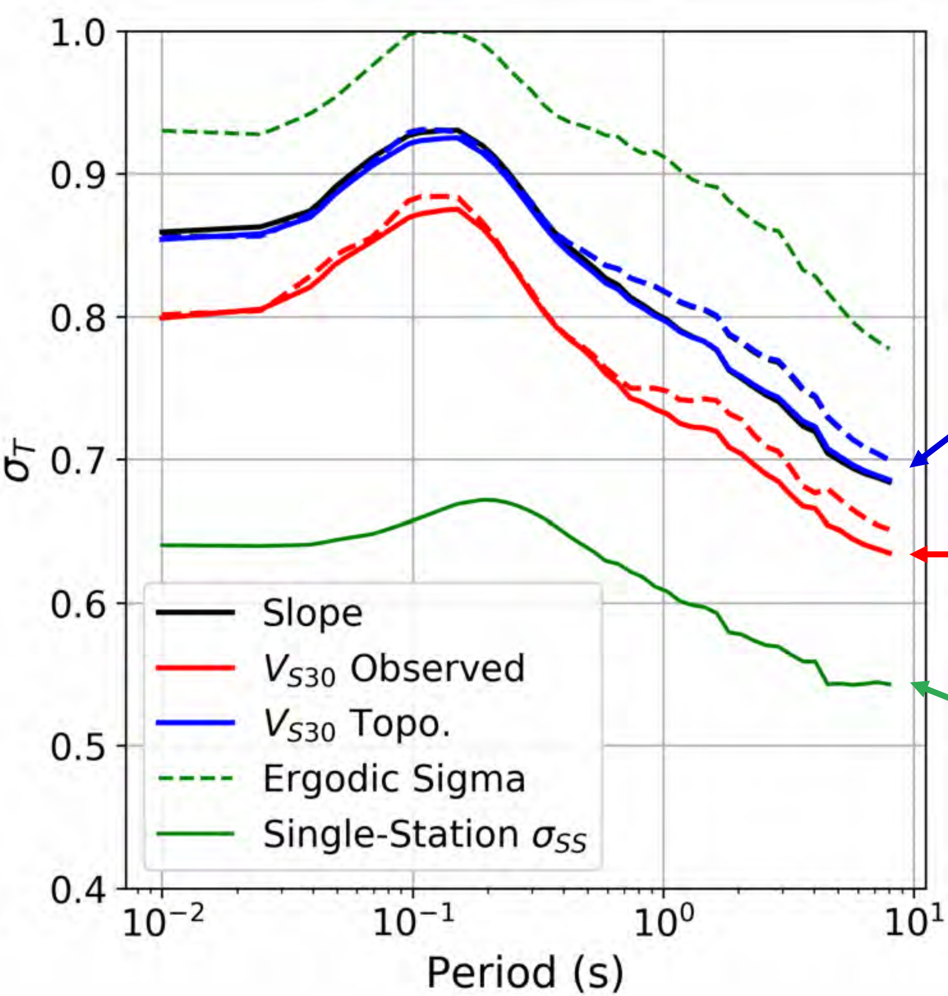
Shallow Ground Motion Aleatory Variability



Inferred site σ_T: used in risk calculations on sites with unknown (inferred) properties

Measured site σ_T: used in hazard calculations on EC8 rock (V_{S30} 800 m/s)

Single-station σ_T: used ***only*** in calculations when site-specific amplification is known and well-calibrated

Summary: What did we change and why?

- *Multi-model* approach replaced with a general (or calibrated) *backbone*
  - *Turn epistemic uncertainties from a problem of model selection to one of characterising what we do and don't actually know about ground motions!*
  - *Uncertainties are now greater in places where we have very little or no strong motion data*
- New ground motion models for shallow crustal earthquakes and for cratonic environments
  - *Much more data from Engineering Strong Motion (ESM) database*
  - *Can be calibrated regionally – more data refines the model locally and reduces uncertainty: a framework for future models?*
  - *Broader band – Sa from 0.01 to 8 s (previously only to 4 s)*

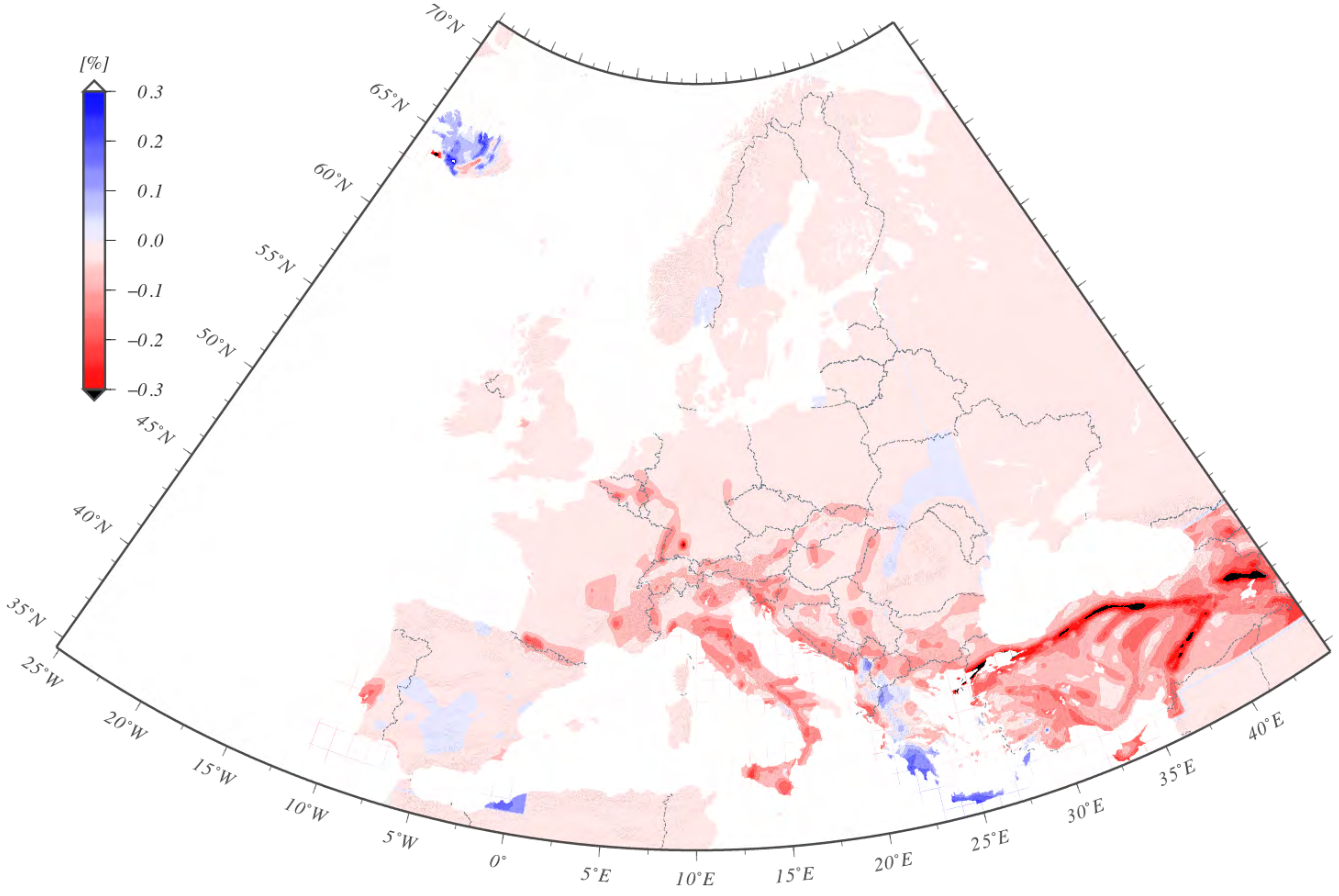
Summary: What did we change and why?

- Subduction and deep seismicity model updated
  - *Recent high quality model (BC Hydro) calibrated to European data*
  - *ESM has a substantial increase in records from these environments*
- Measured/Inferred site categorisation
  - *Uncertainty should be lower (therefore potentially lower hazard) when ground motion conditions (V_{S30}) are known – and higher when they are not!*
- Compatibility with European scale risk calculations
  - *Ground motion and site amplification models permit application and calibration to different site conditions across Europe*
  - *Preliminary comparison with EC8 amplification factors for estimating hazard on soils is encouraging – but more still to do*

THE 2020 EUROPEAN SEISMIC HAZARD MODEL: INTEGRATION, CALCULATION, AND RESULTS

Laurentiu Danciu
Swiss Seismological Service, ETH Zurich

and the SERA JRA3 Working Group: S. Hiemer, S. Nandan , G. Weatherill, R. Basili, A. Rovida, C. Beauval, P-Y Bard, S. Villanova, K. Sesetyan, F. Cotton, S. Wiemer, and D. Giardini



SERA -JRA3/SC8 Meeting October 14th 2019 | Pavia, Italy

SERA
Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe

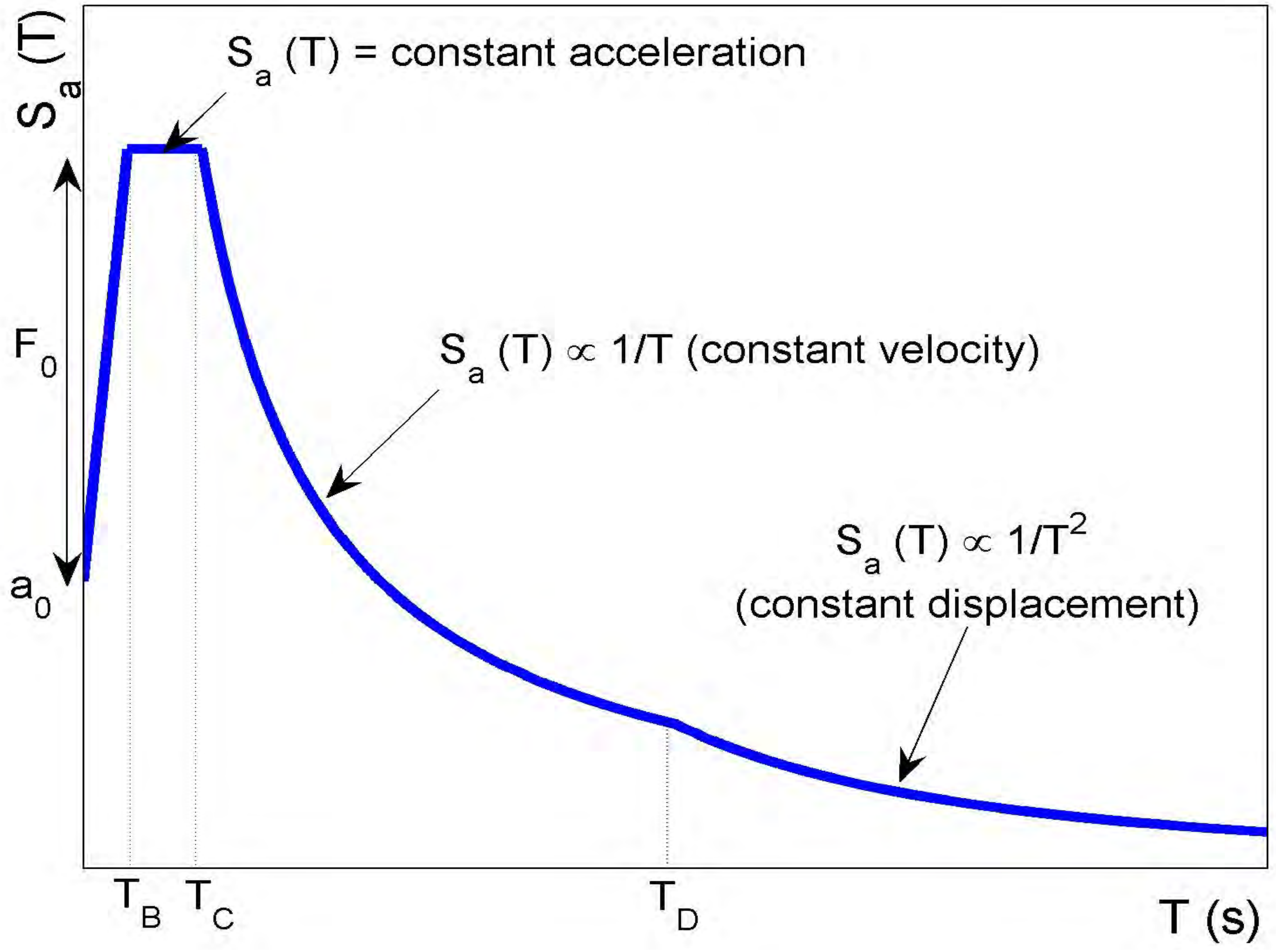
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.

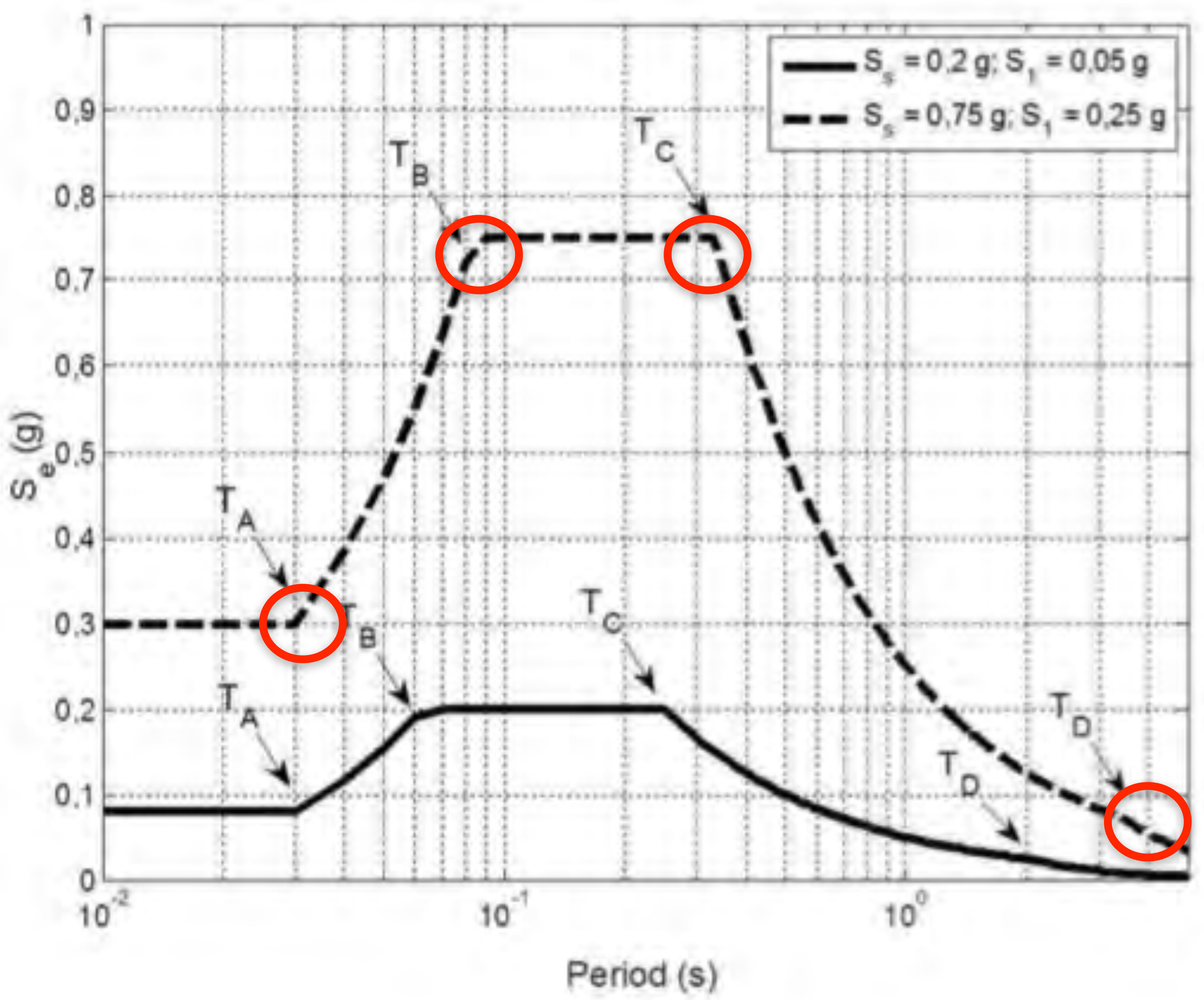
Outline

- ESHM20: Uncertainties and Logic Tree
- ESHM20: OpenQuake Model Implementation
- ESHM20: Preliminary Hazard Results

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.

ESHM20: Update





- **Interaction with CEN/TC250/SC8 and with EC8 PT1 to ensure the consistency of the output specifications with the present code revision activities and effective communication between the SERA team and the decision makers in CEN/TC250/SC8.**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.

ESHM20: Hazard Calculation Model

Time Independent Hazard Assessment

1. - seismogenic source models

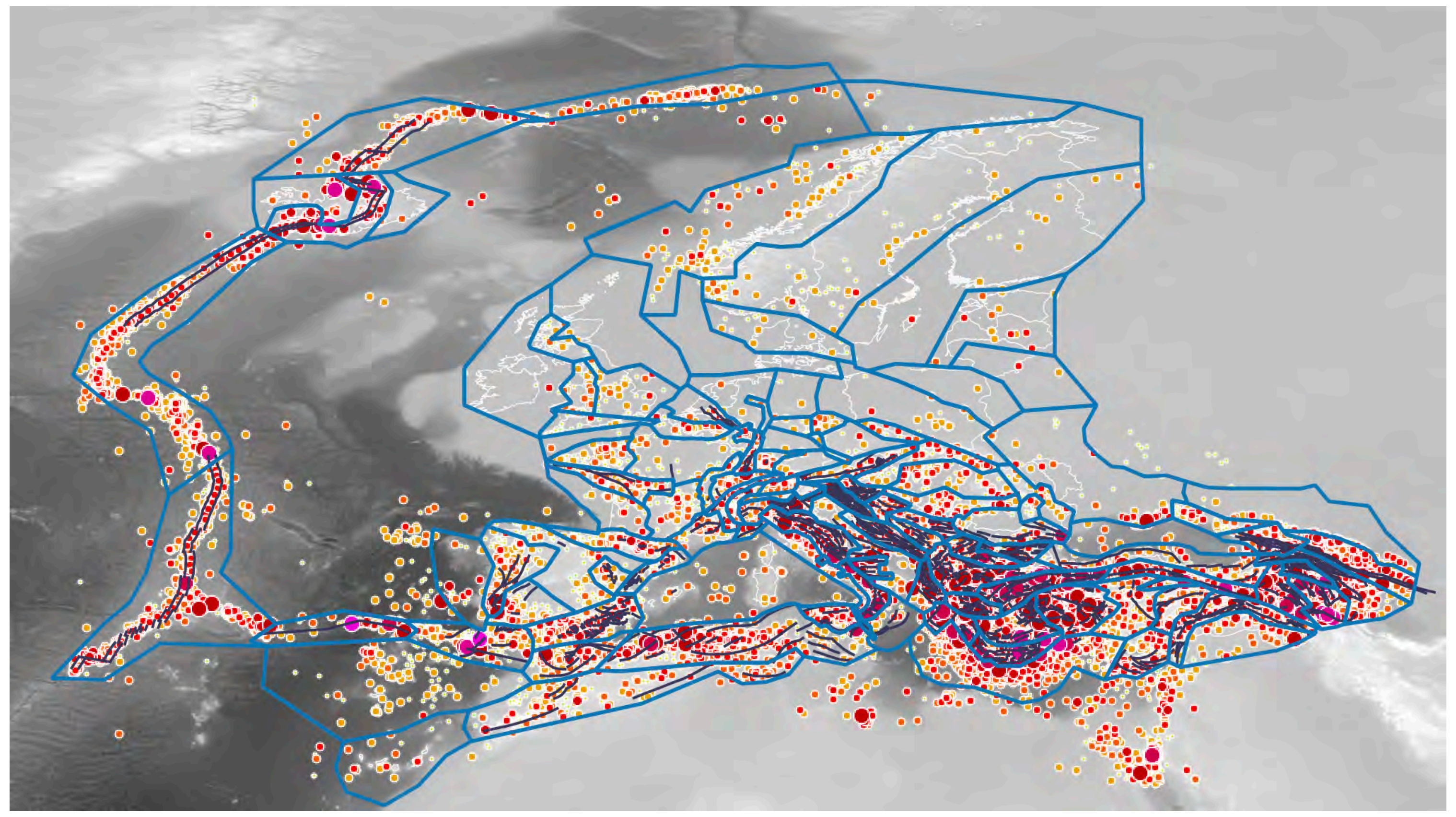
2. - ground motion characteristic model

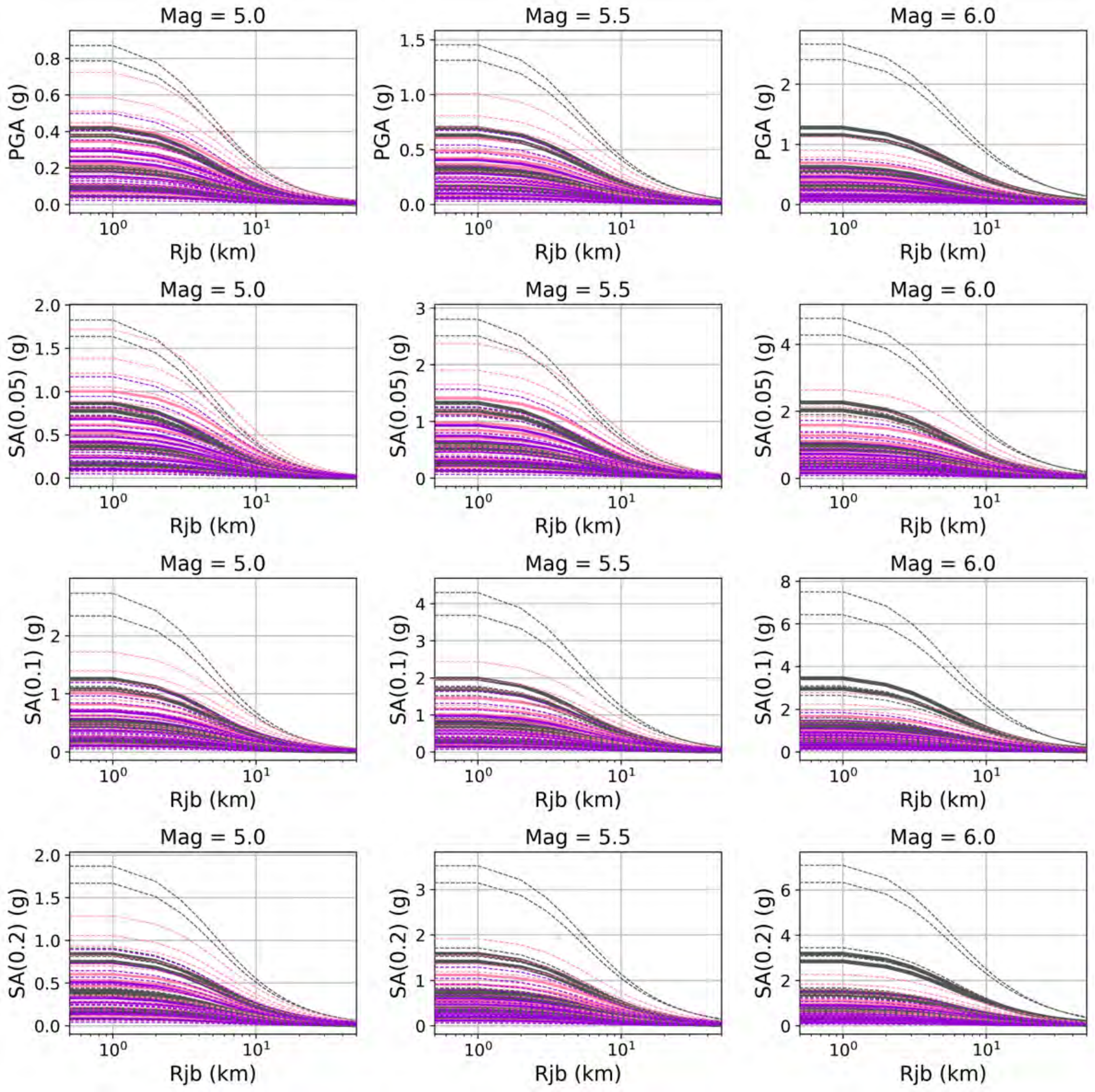
- temporal occurrence of earthquakes is assumed to be described by a Poisonian process characterised by a stationary mean rate of occurrence

  - no aftershocks

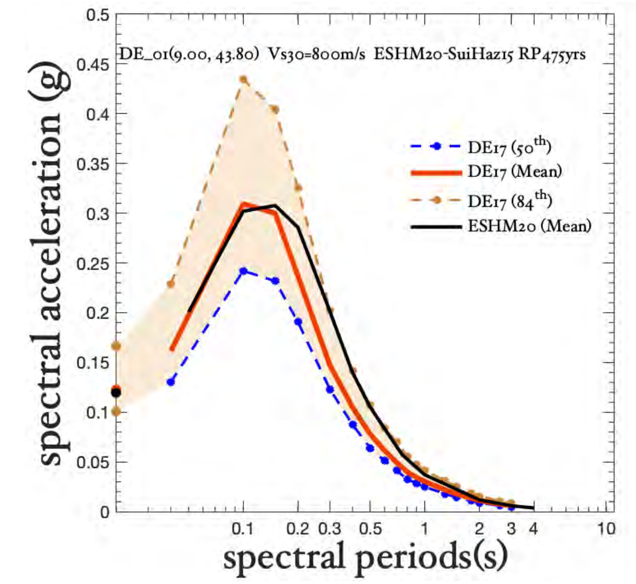
  - no memory between consecutive events

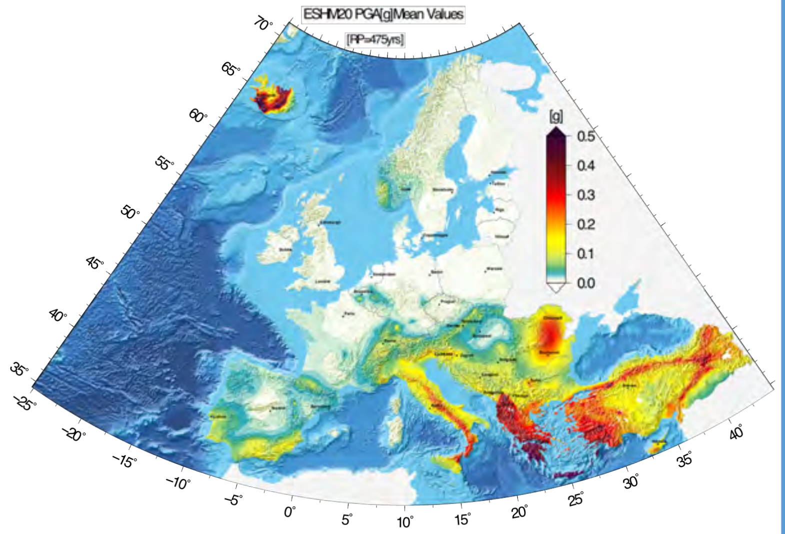
  - no anthropogenic hazard

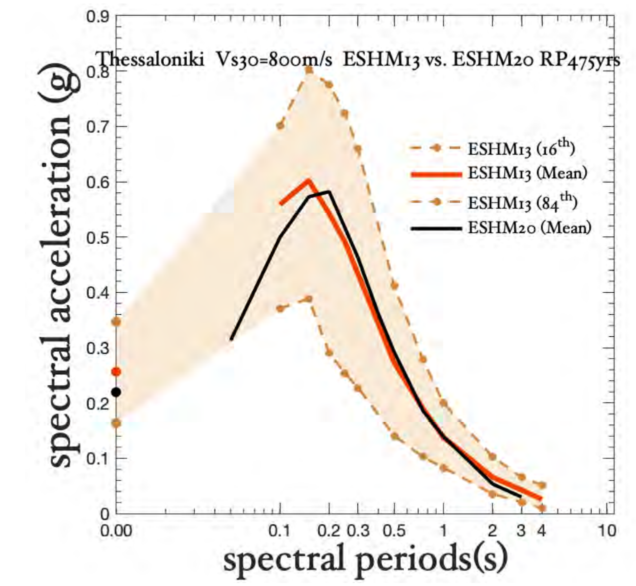




OPENQUAKE
calculate share explore







SERA
Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe

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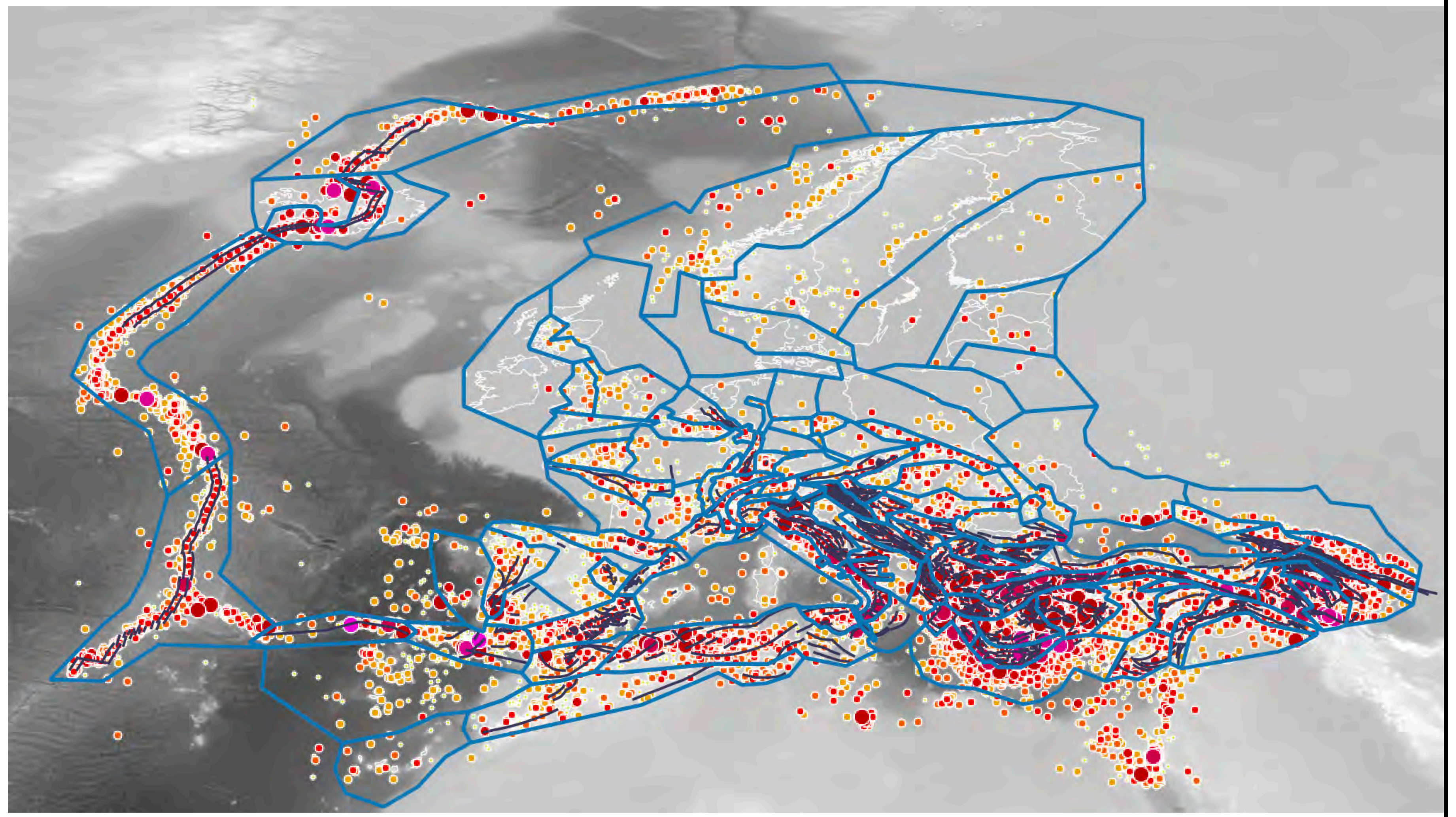
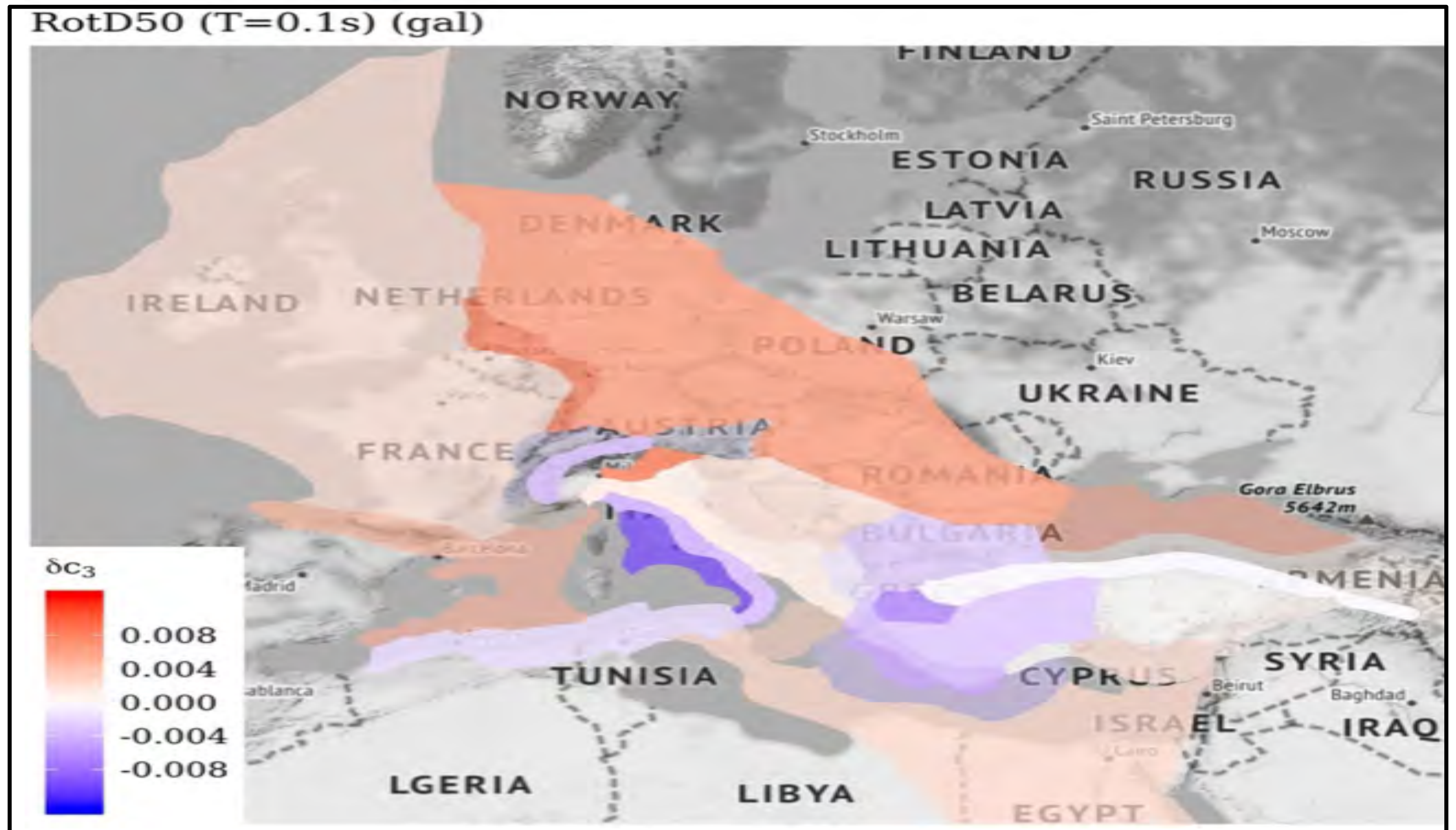
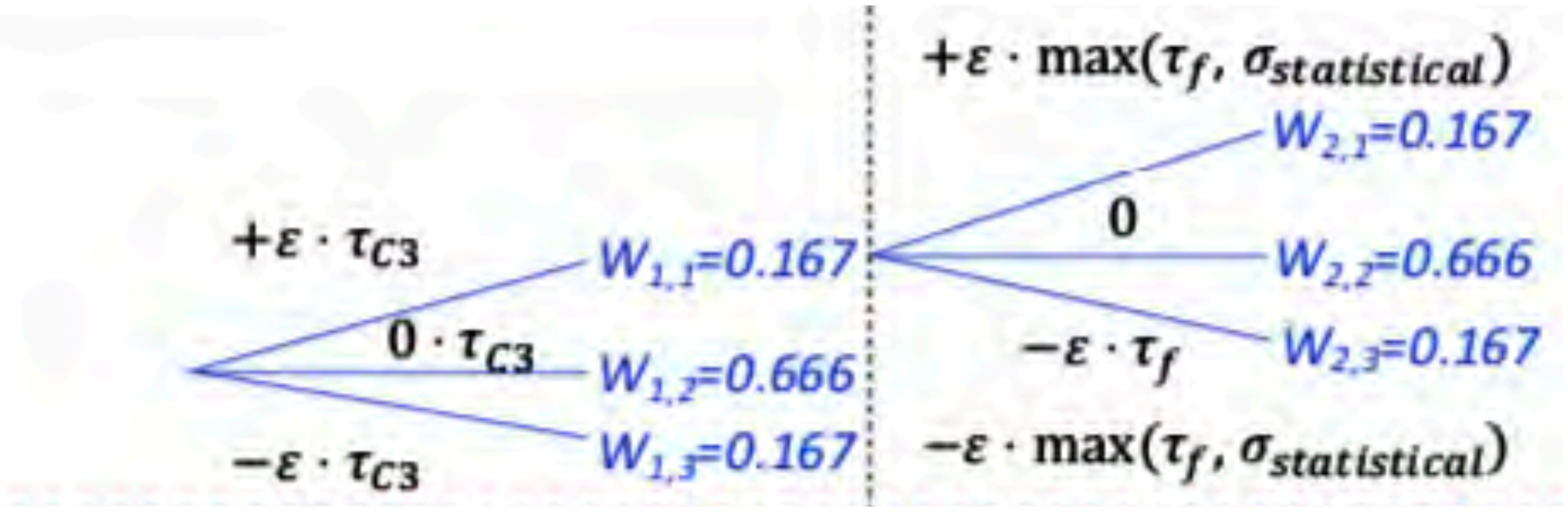
ESHM20 Hazard Calculation Model: Spatial Variability



Seismogenic Source Model





Ground Motion Characteristic Model

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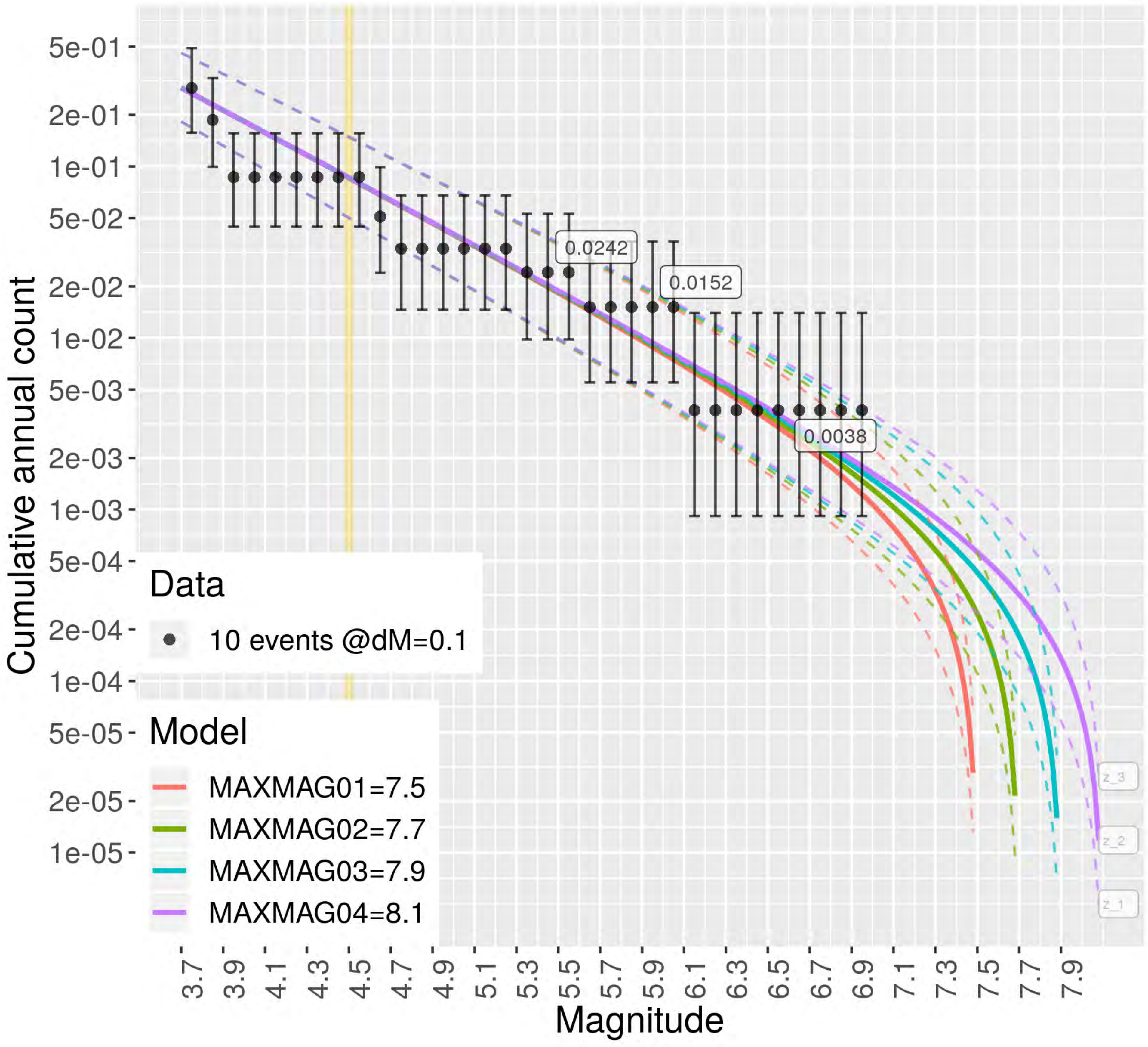
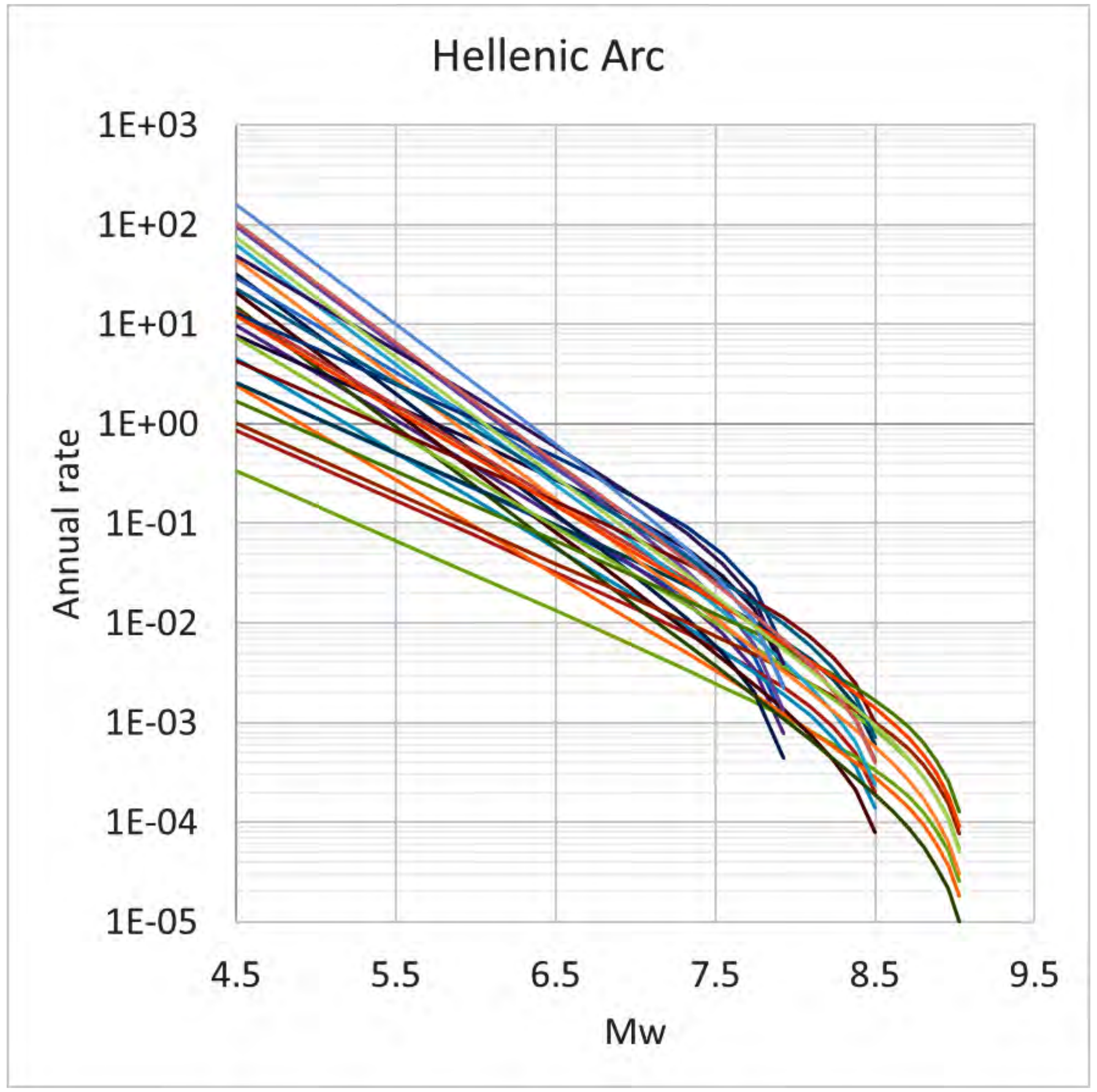
ESHM20 Hazard Calculation Model: Temporal Variability

- represent the centre , the body and the range of the data and assumptions (earthquake catalogue, completeness assessment, declustering, slip-rates to activity rates and maximum magnitude)





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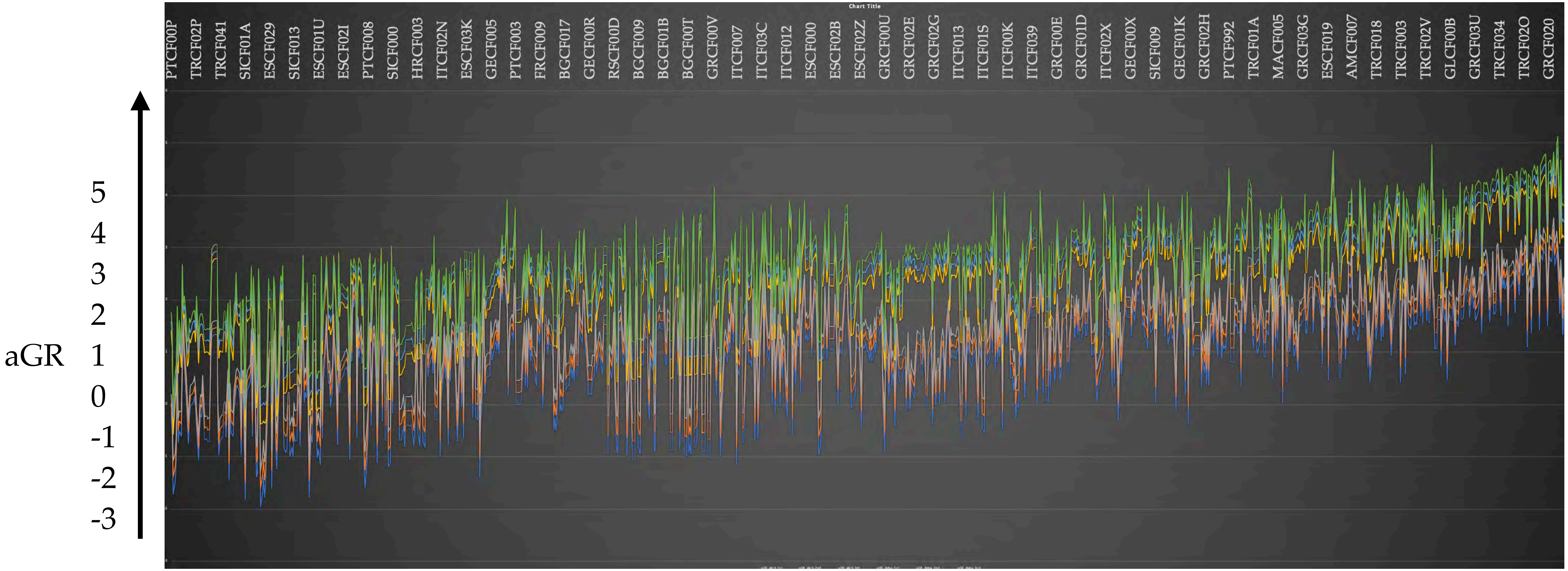
ESHM20 Hazard Calculation Model: Temporal Variability

- represent the centre , the body and the range of the data and assumptions (earthquake catalogue, completeness assessment, declustering, slip-rates to activity rates and maximum magnitude)



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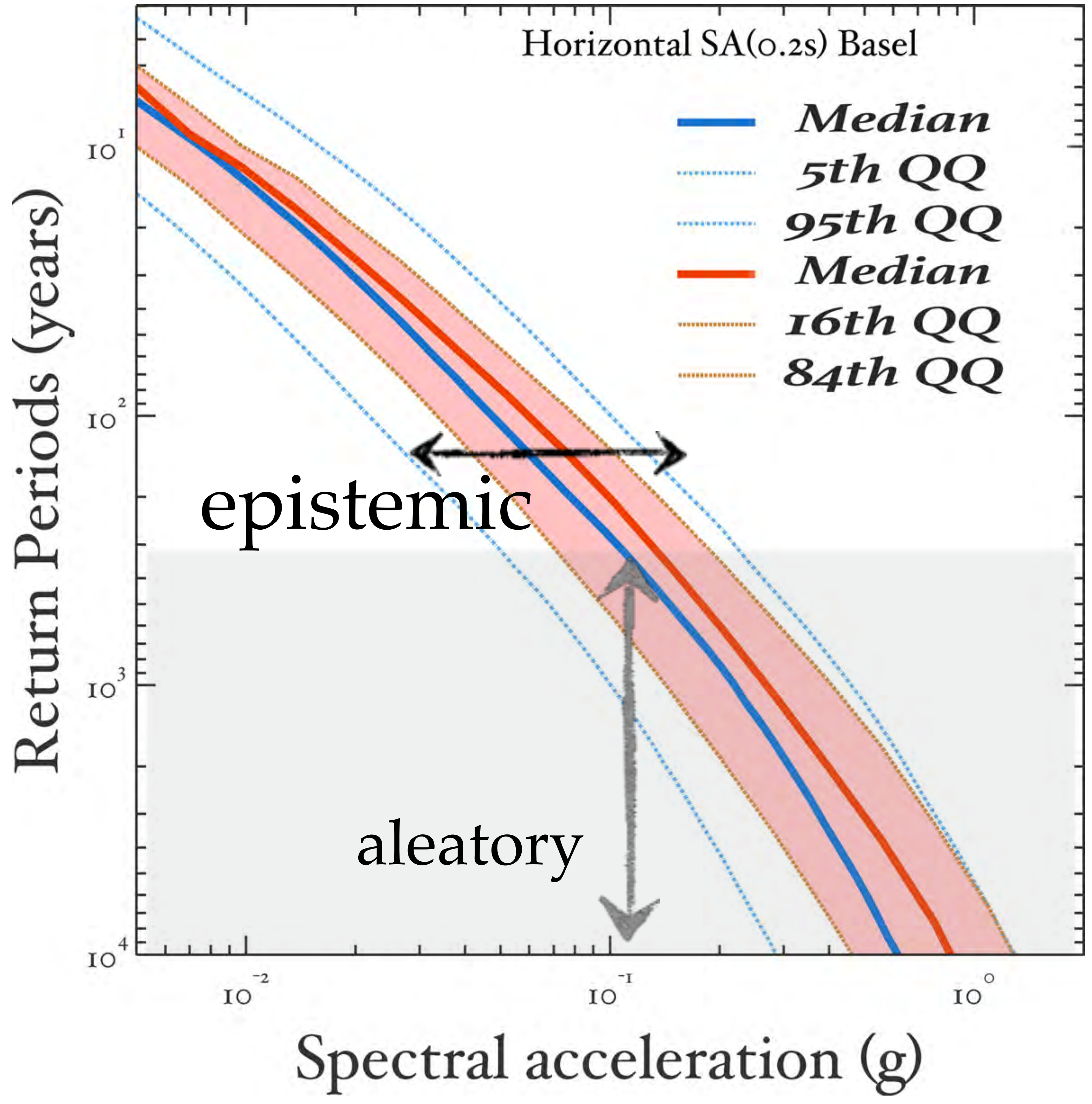
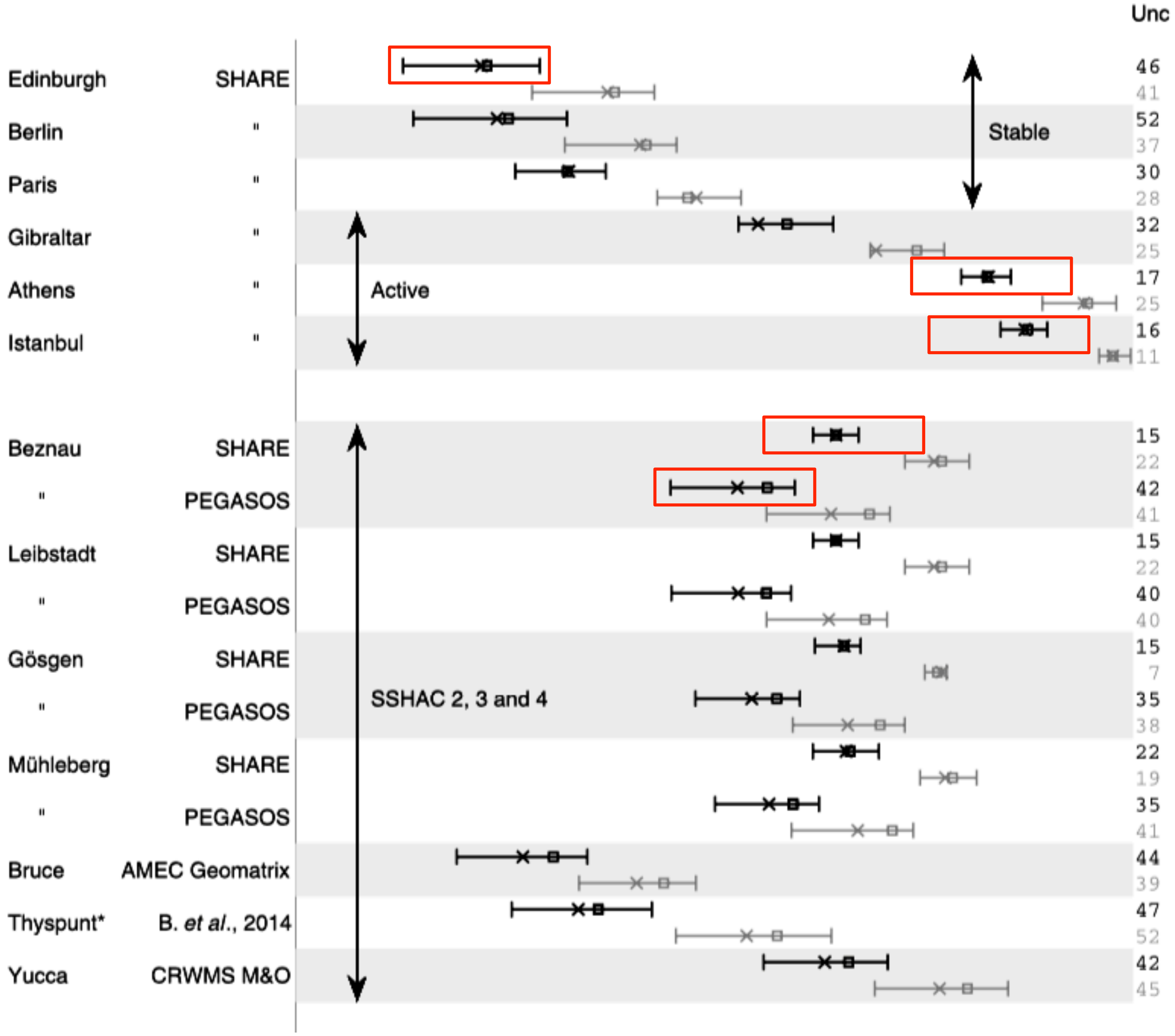
ESHM20 Hazard Calculation Model: Range of Uncertainties





Douglas et al 2014

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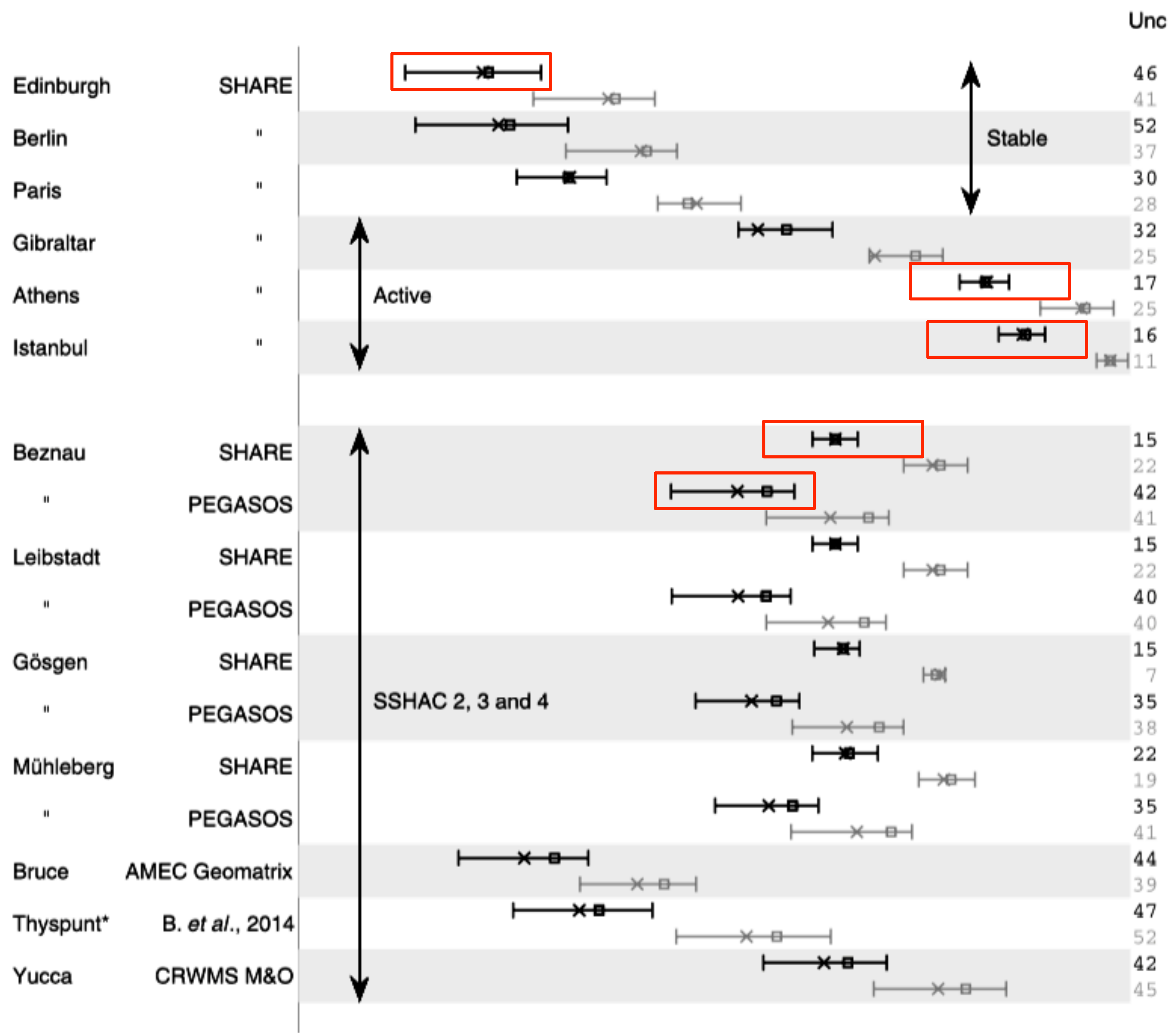
ESHM20Hazard Calculation Model:sampling the logic tree

- **<u>robust</u> <u>mean</u> <u>hazard</u>** and "*good*" quantiles [ESHM13]

- truly exploratory epistemic, with logic tree sampling the full logic tree will result in **<u>accurate mean and robust quantiles</u>** [ESHM20]



The ESHM13 fractals are only due to GMPEs logic tree and weighted mean source models (weighted activity rates, q the summed MFDs and Maximum Magnitudes

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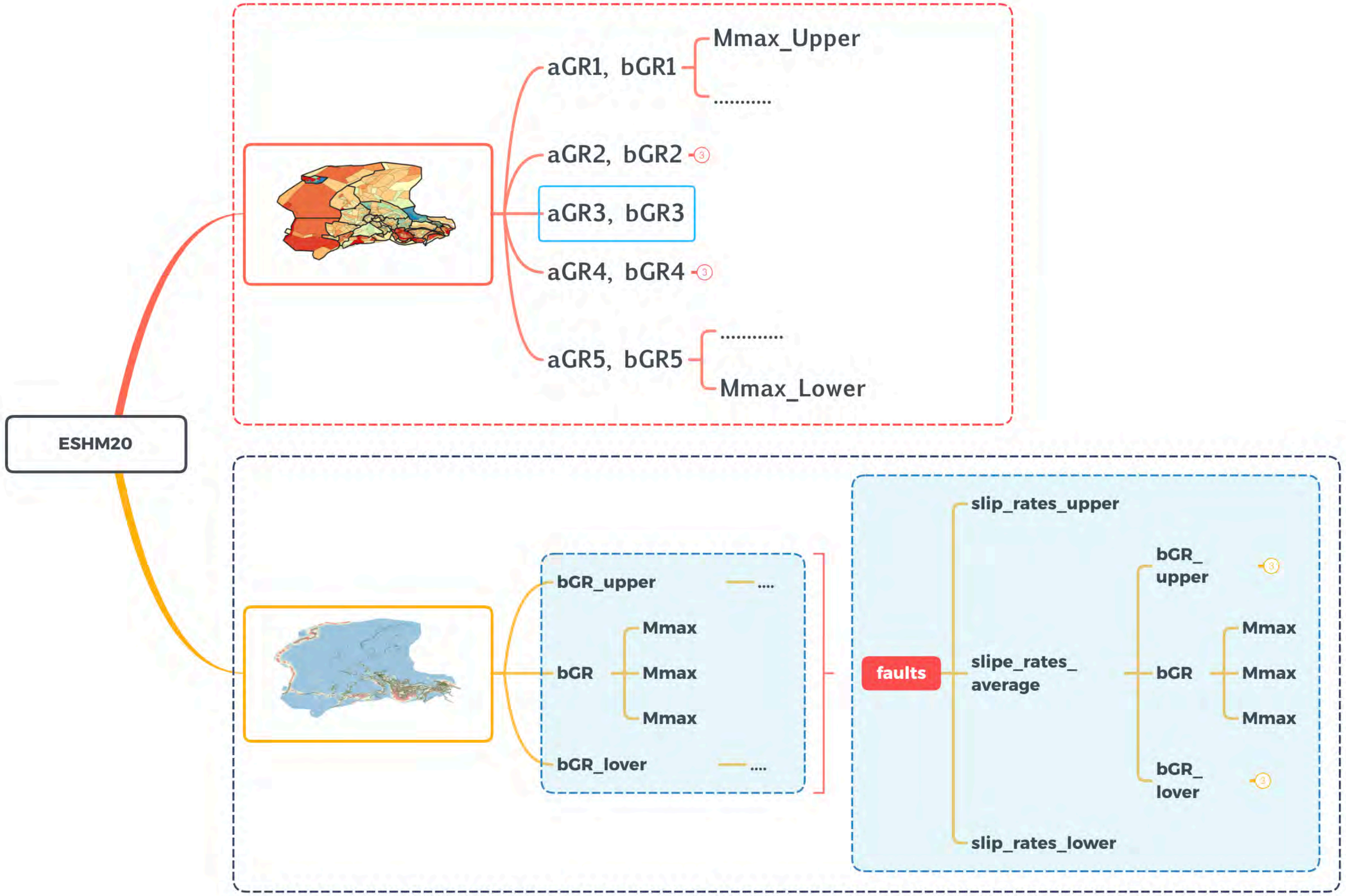
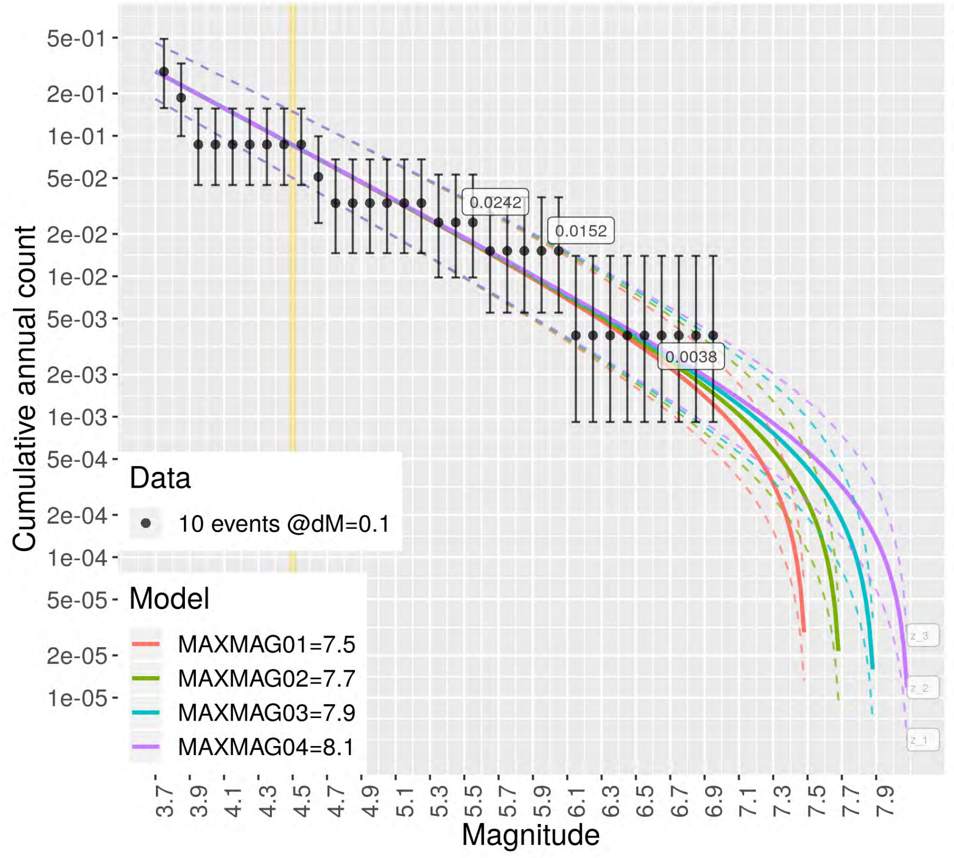
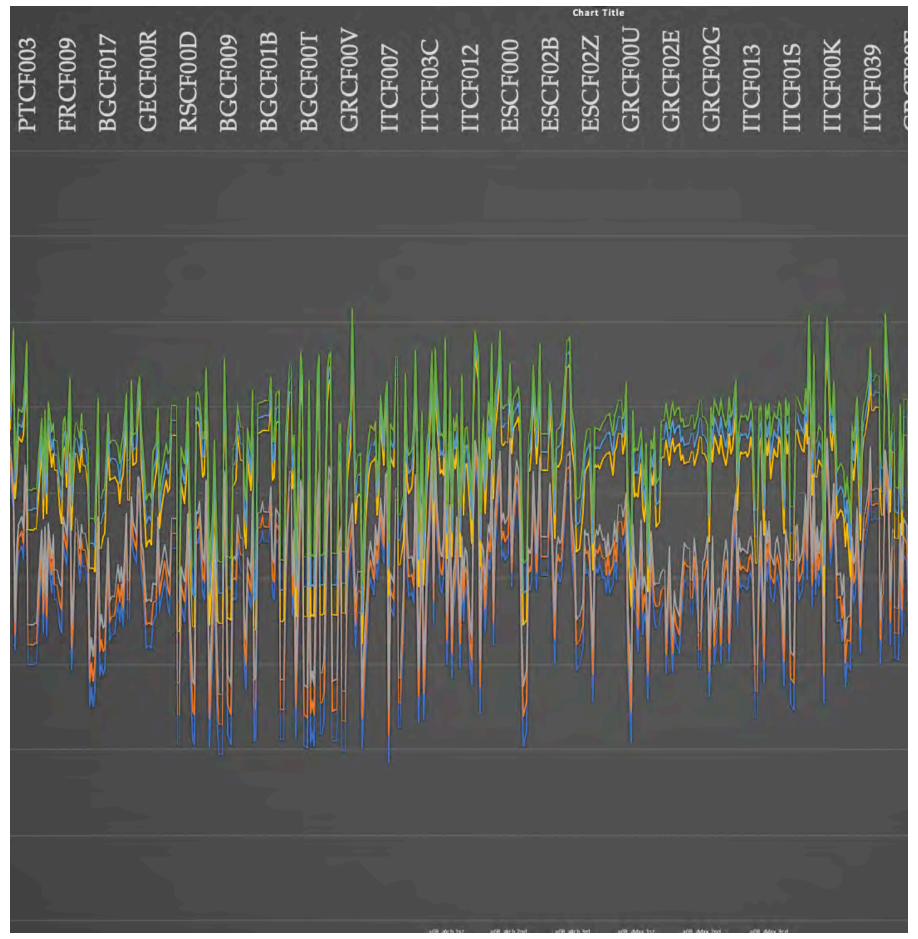
ESHM20: Logic Tree Seismogenic Sources

Capture the inherent uncertainties of the data, information, knowledge as wells as uncertainties model construction (i.e. delineation of areal sources, completeness, declustering, reliability of fault source information)







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ESHM20: Logic Tree Seismogenic Sources

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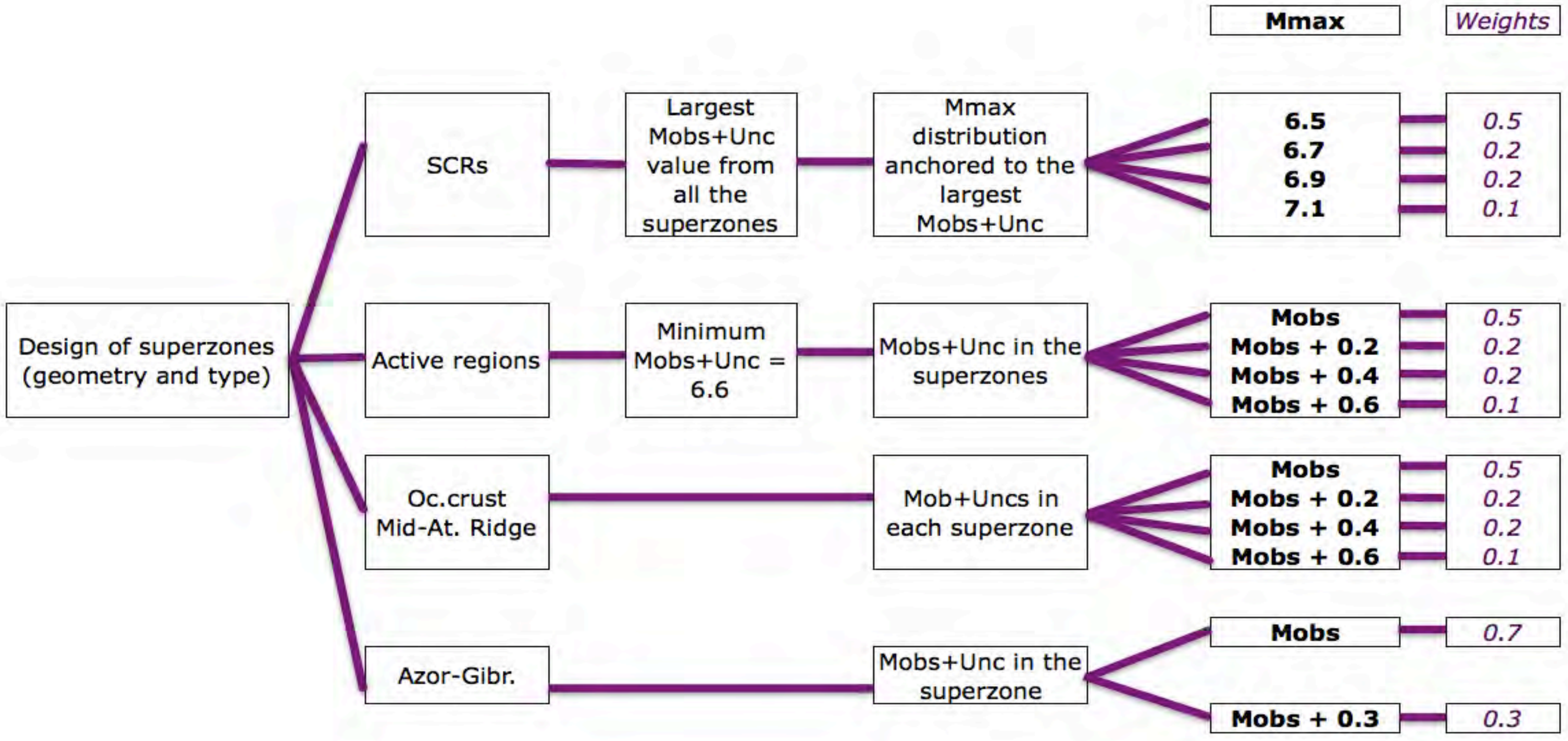

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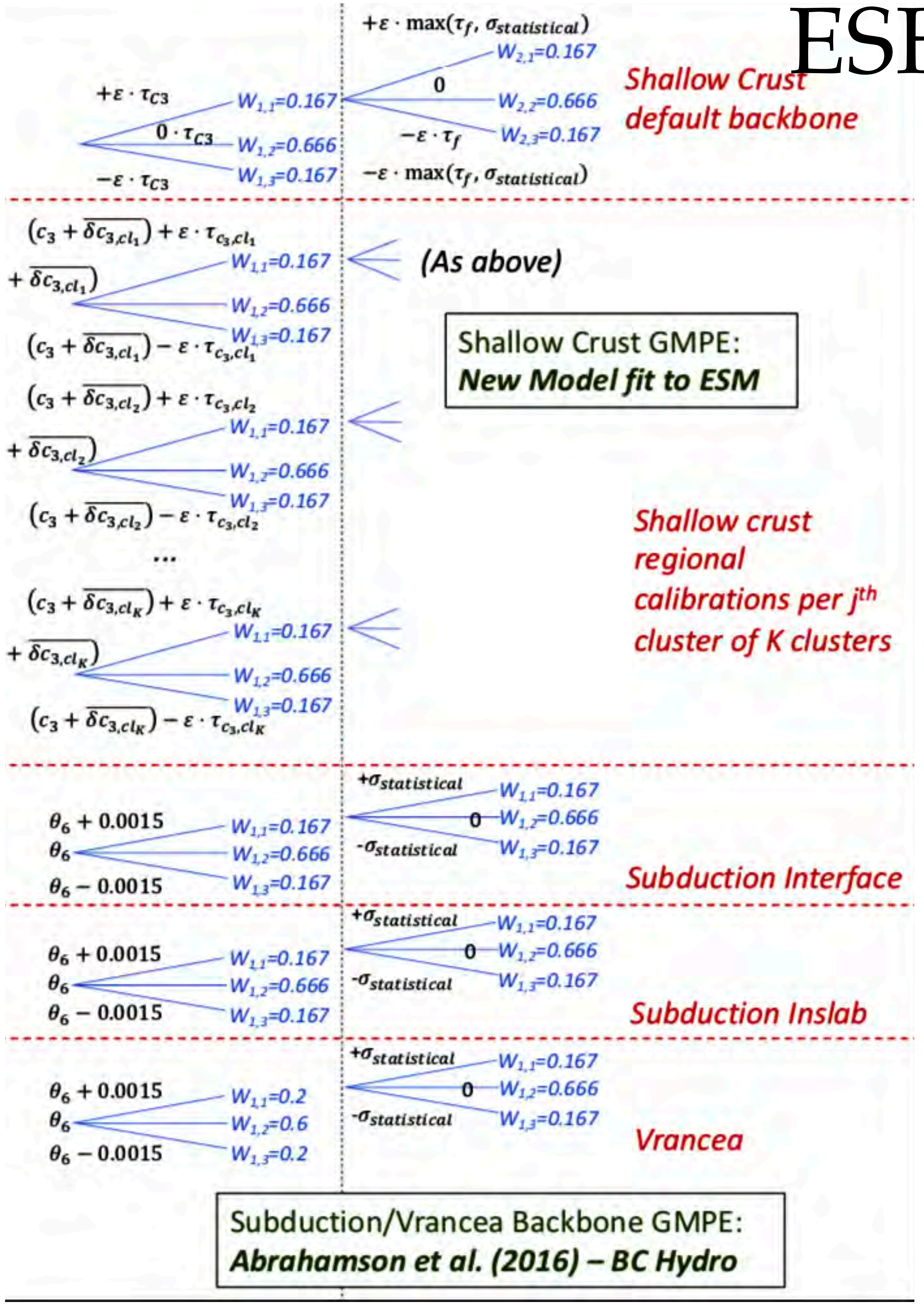
ESHM20: Ground Motion Regionalisation



| G. Weatherill | GFZ Potsdam

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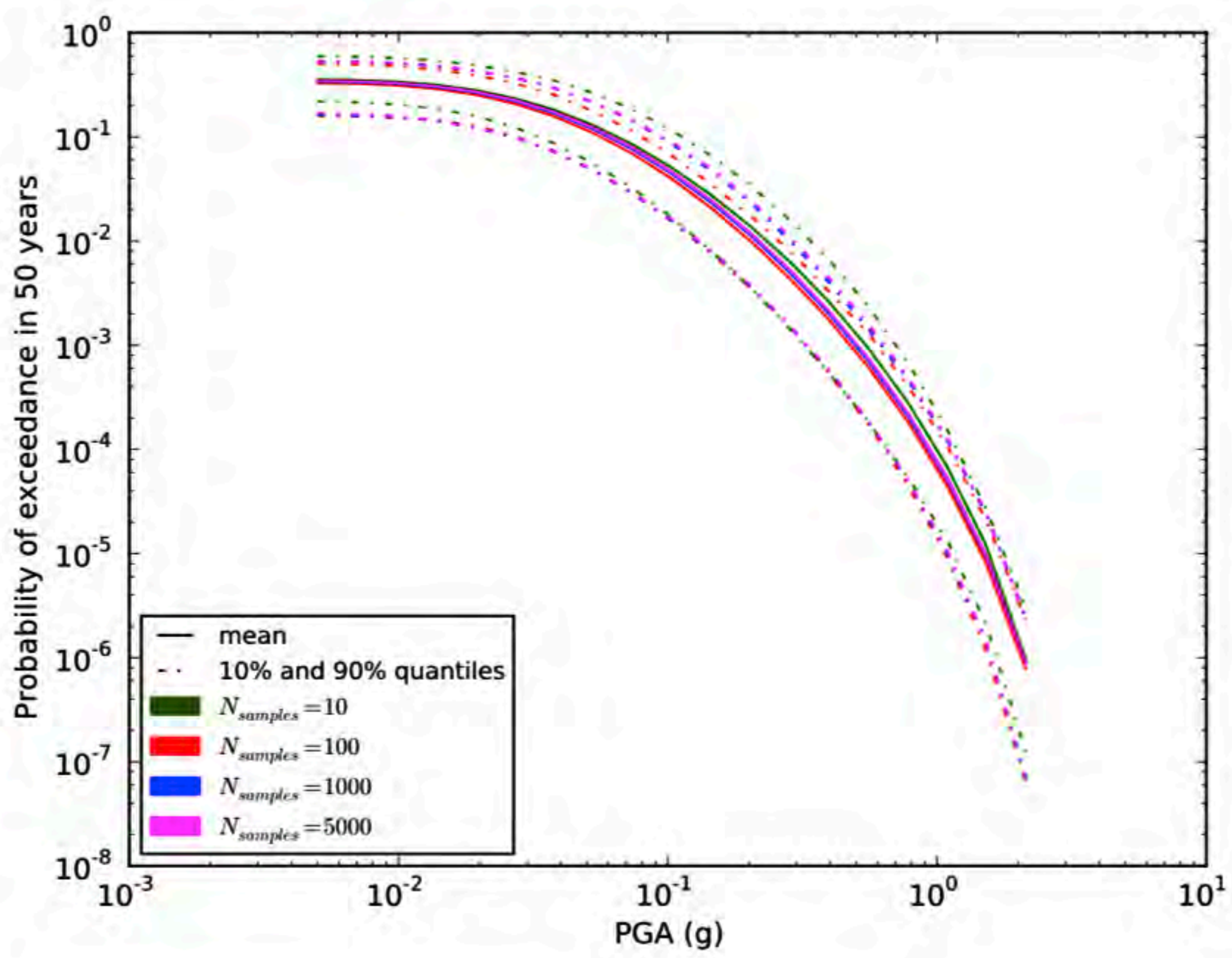
ESHM20Hazard Calculation Model:sampling the logic tree

- **aGR , bGR (3 values)**
- **Maximum Magnitudes (3 to 5 values)**
- **<u>Uncorrelated Uncertainties among sources:</u>**
- N = (# of GR params)^N_sources x (# of maximum magnitudes for each sources)^N_sources
- **N =(5^508)*(5^508) = INF ()**
- **<u>Correlated Uncertainties</u>**
  - End-branches: N_source_models * Activity Rates Params * Maximum Magnitudes
    - 2 source models * 5 [abGRs] * 5 [Maximum Magnitudes] ~**<u>50 end branches</u>**
- Ground Motion Logic Tree multiplies with the End Branches of the Source Models
- Sampling the entire logic tree (5000 ~50000)



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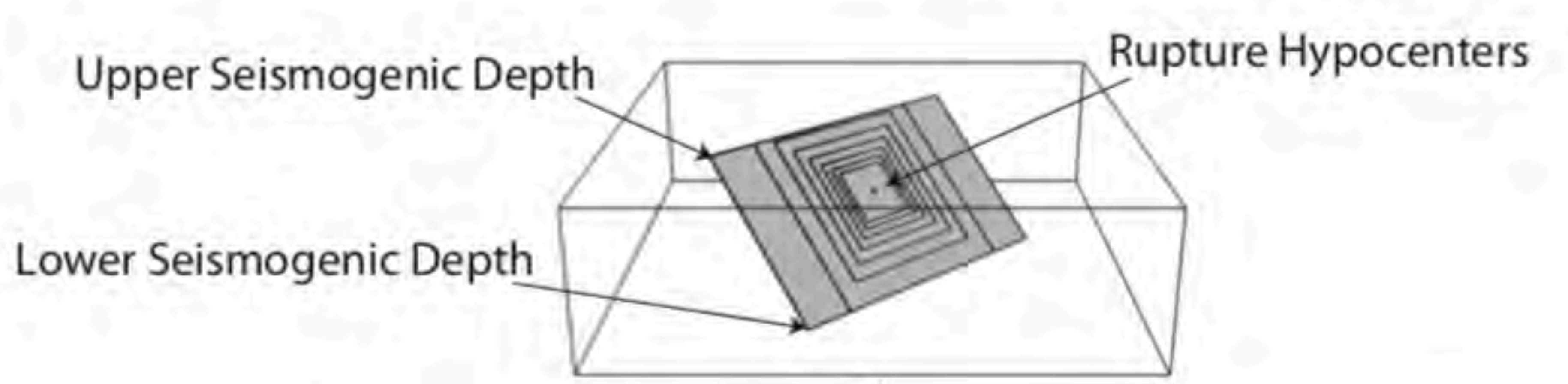
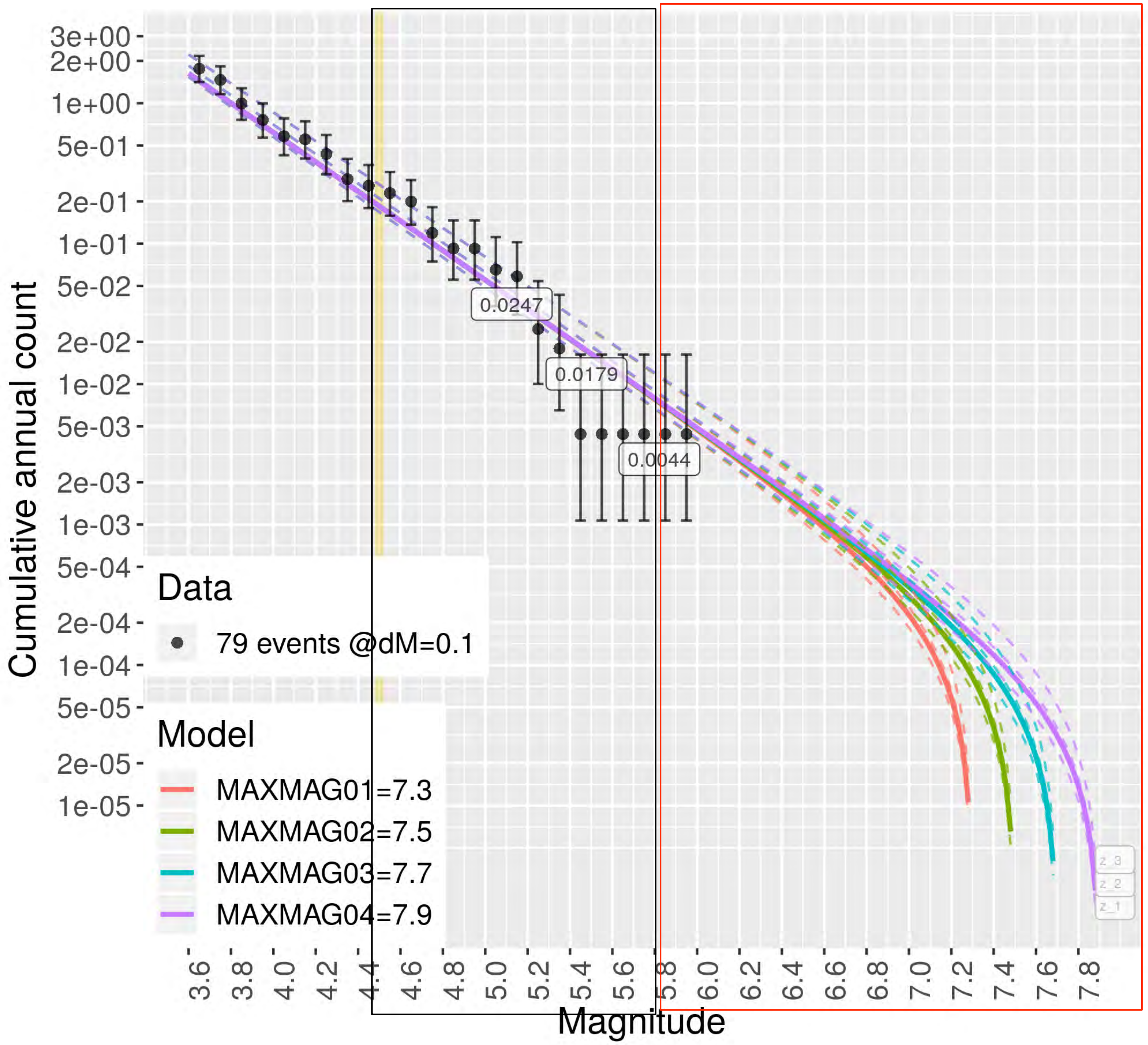
ESHM20Hazard Calculation Model: Point and Area Sources



- Poin Sources vs Extensive Ruptures
- Threshold Magnitude = 5.8Mw
- Each source is described by two MFDs
  - One MFD: Mmin to Threshold Magnitude(5.8)
  - Second MFD: Threshold Magnitude to Maximum Magnitude
- **~18M extensive ruptures** for the area and gridded seismicity model



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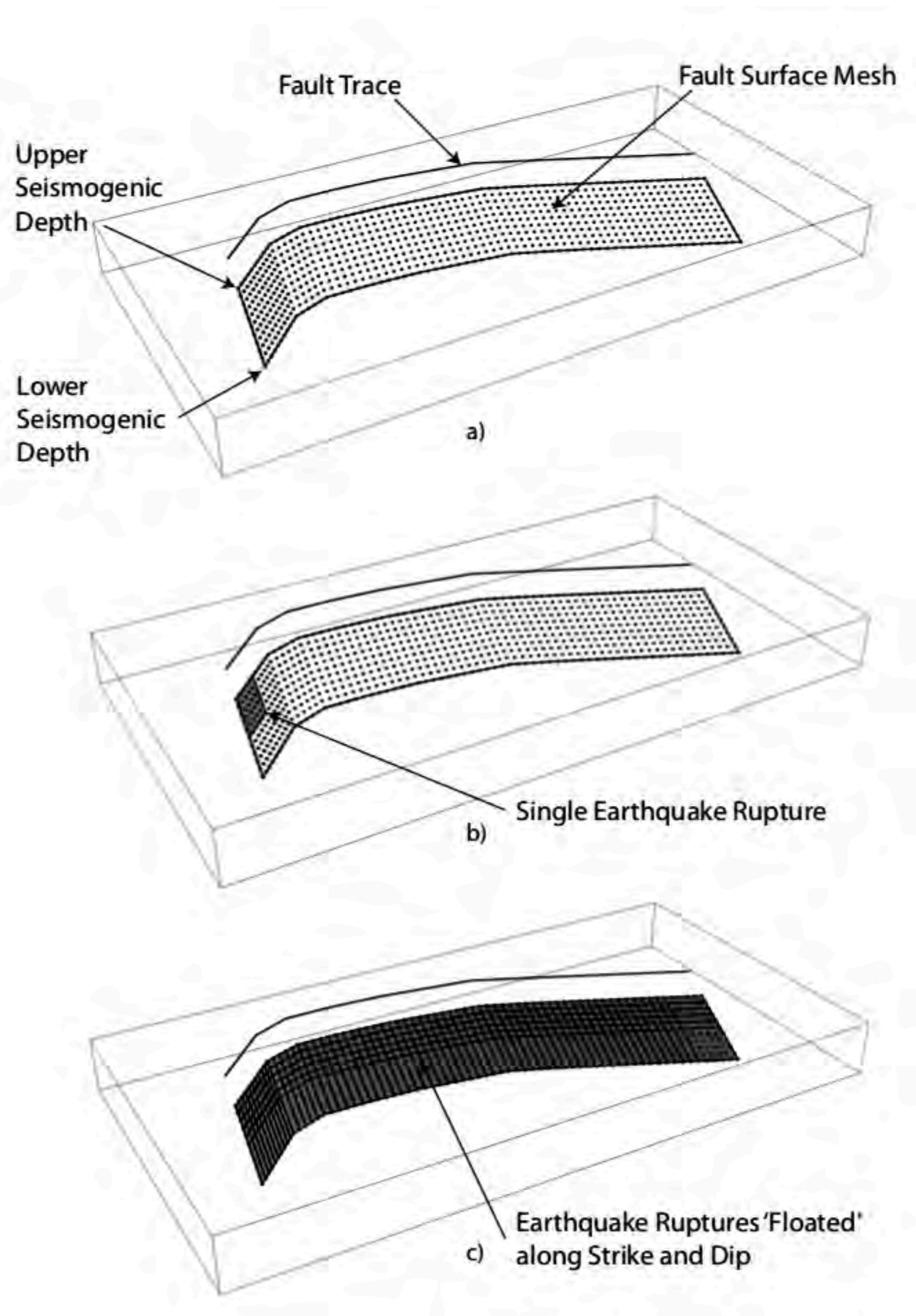
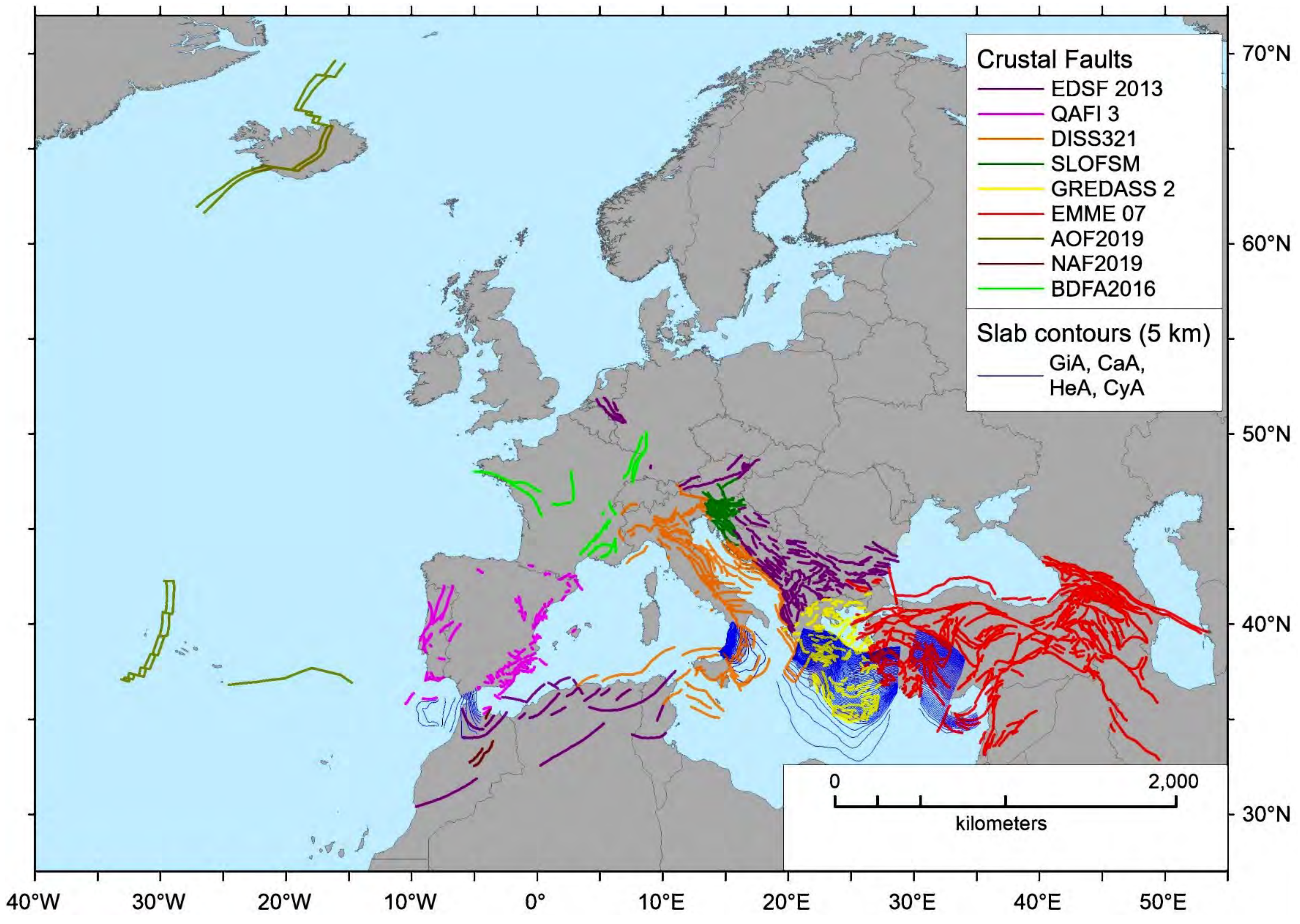
ESHM20Hazard Calculation Model: Source Modes Representation





GEM (2019). The OpenQuake-engine User Manual. Global Earthquake Model (GEM) Open- Quake Manual for Engine version 3.7.0.

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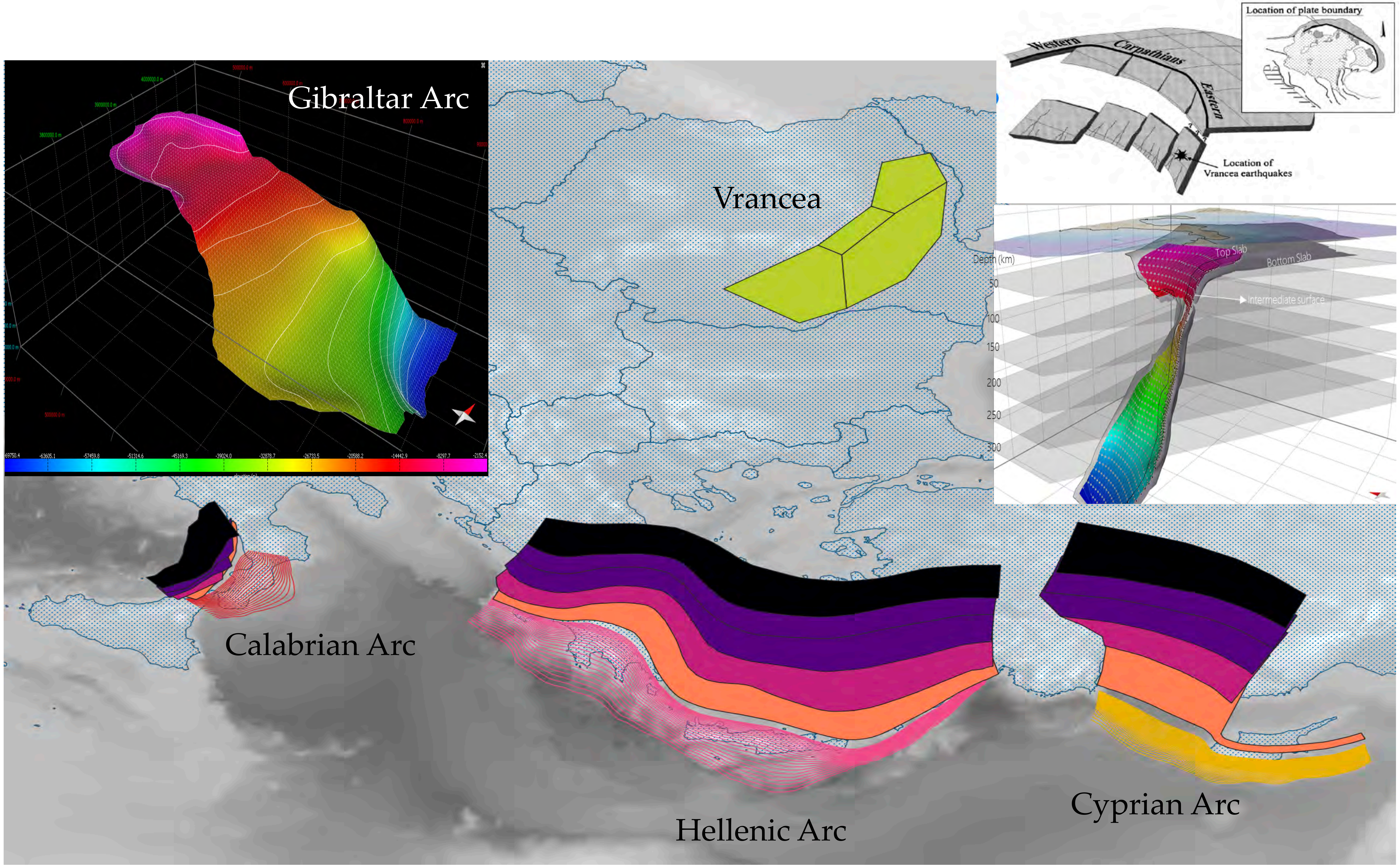
ESHM20Hazard Calculation Model: Source Modes Representation



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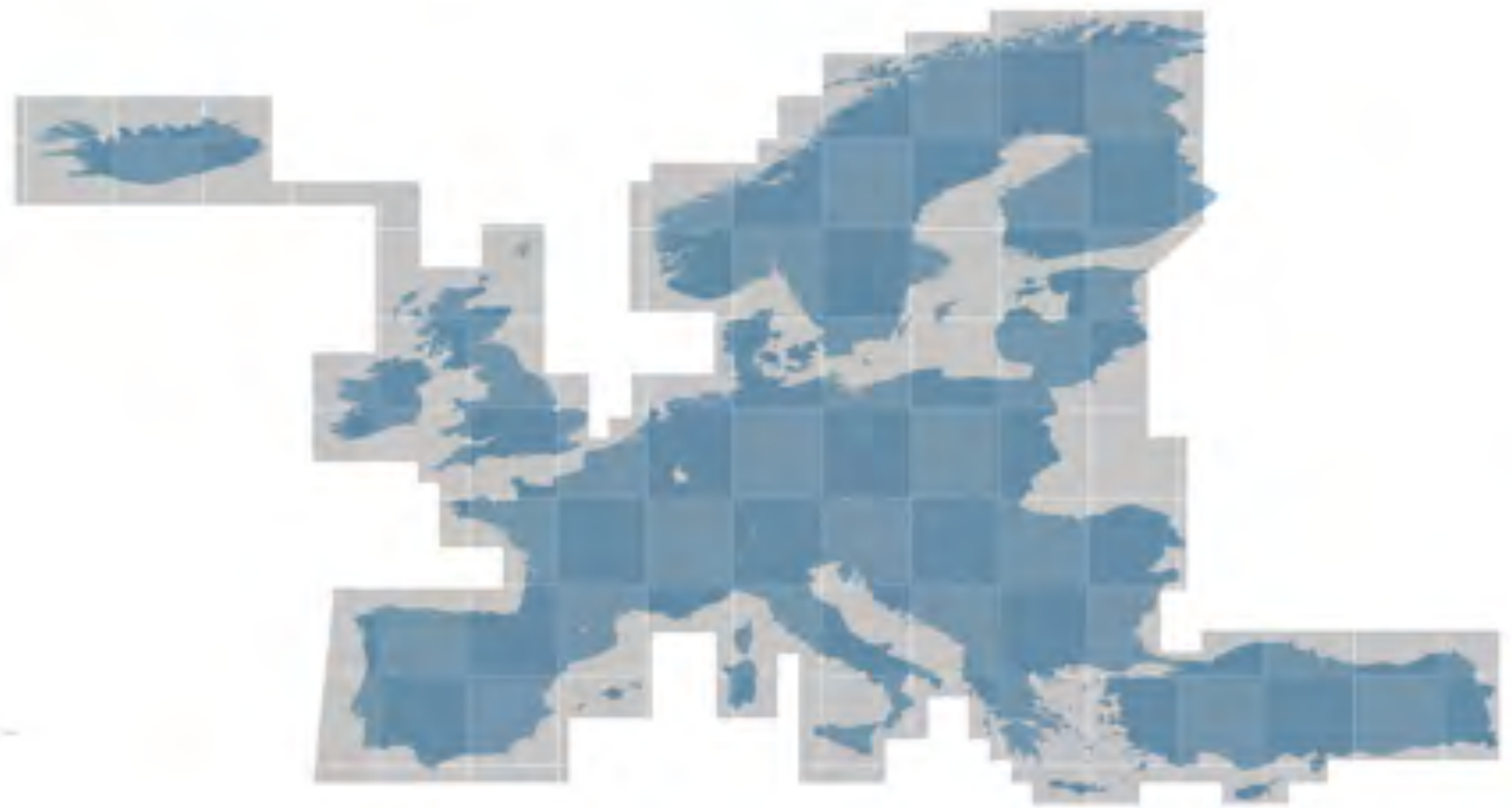
ESHM20Hazard Calculation Model: Settings

- rupture mesh spacing = 1
- complex fault mesh spacing = 10
- width of mfd bin = 0.2
- area source discretization = 10.0
- reference Vs30 value = 800.0
- intensity_measure_types_and_levels = PGA, SA(0.05 to 8.0s)
- truncation_level = 3
- maximum integration distance =
  - Shallow Crust': 200 km
  - Deep Seismicity: 500 km
  - Subduction Interface: 350 km
  - 'default': 150 km
- Output:
  - mean_hazard_curves = true
  - uniform_hazard_spectra = true
  - hazard_maps = true
- quantile_hazard_curves = 0.05 0.16 0.50 0.84 0.95
- poes = 0.10 0.02 0.05 0.01



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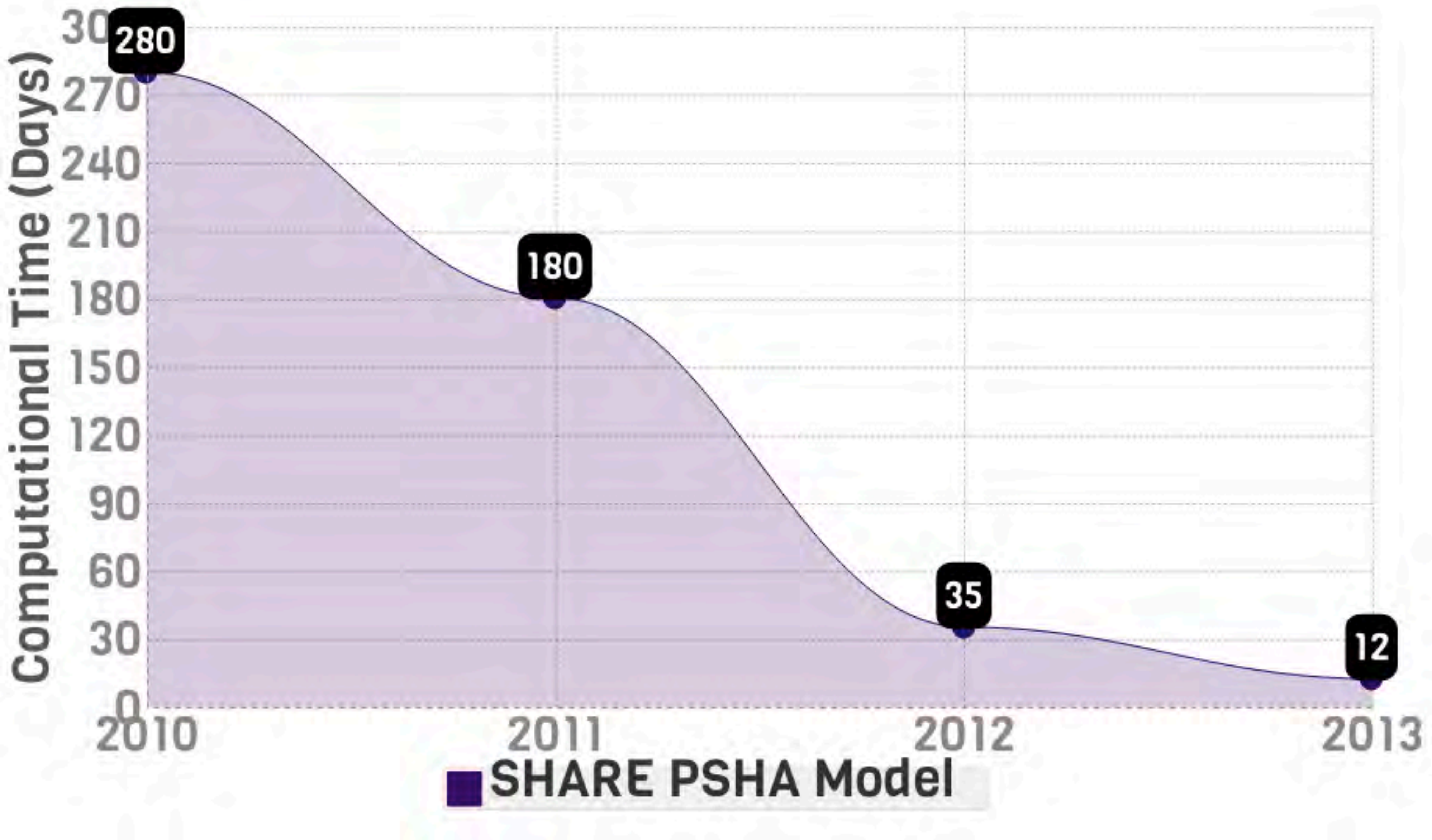
Model Integration: Computational Power



- Compromise between wanting to capture as much **local variation** as possible and actually keeping the **calculation manageable**
- 5 clusters + craton + general backbone + subduction interface + inslab + Vrancea
- each with **9 branches** gives **400k** end branches on GMPE alone multiplies
- ~**50** branches for Seismogenic Source Models
- Total Logic Tree End-Branches: **20M**

32 nodes / 16 CPUs / 512 cores / 1 TB RAM

GLOBAL EARTHQUAKE MODEL
working together to assess risk

A big thank you for outstanding and long term support of GEM IT & Scientific teams

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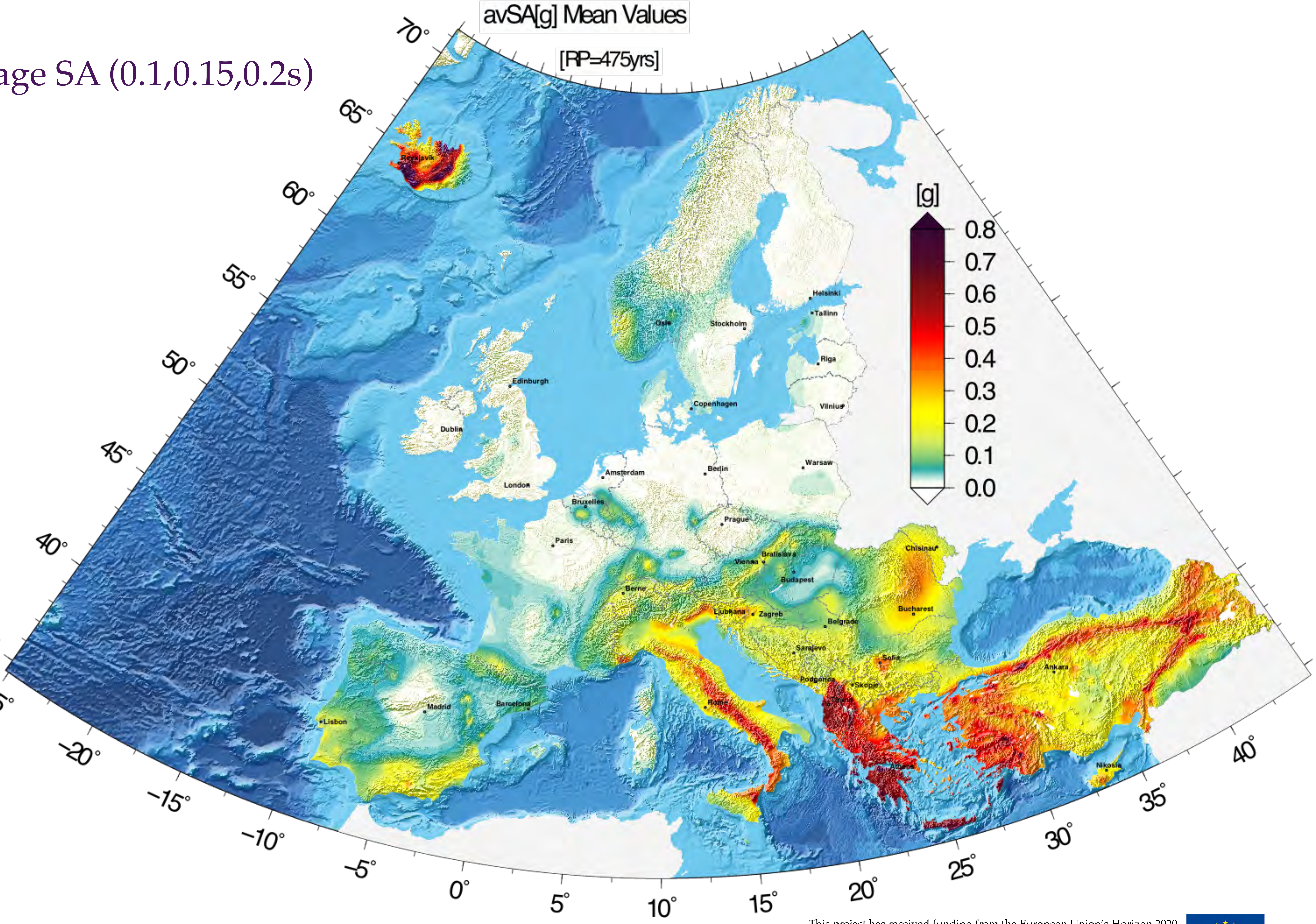
ESHM20: Output and Results

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 730900.

ESHM20: Average SA (0.1,0.15,0.2s) RP=475yrs



SERA
Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe

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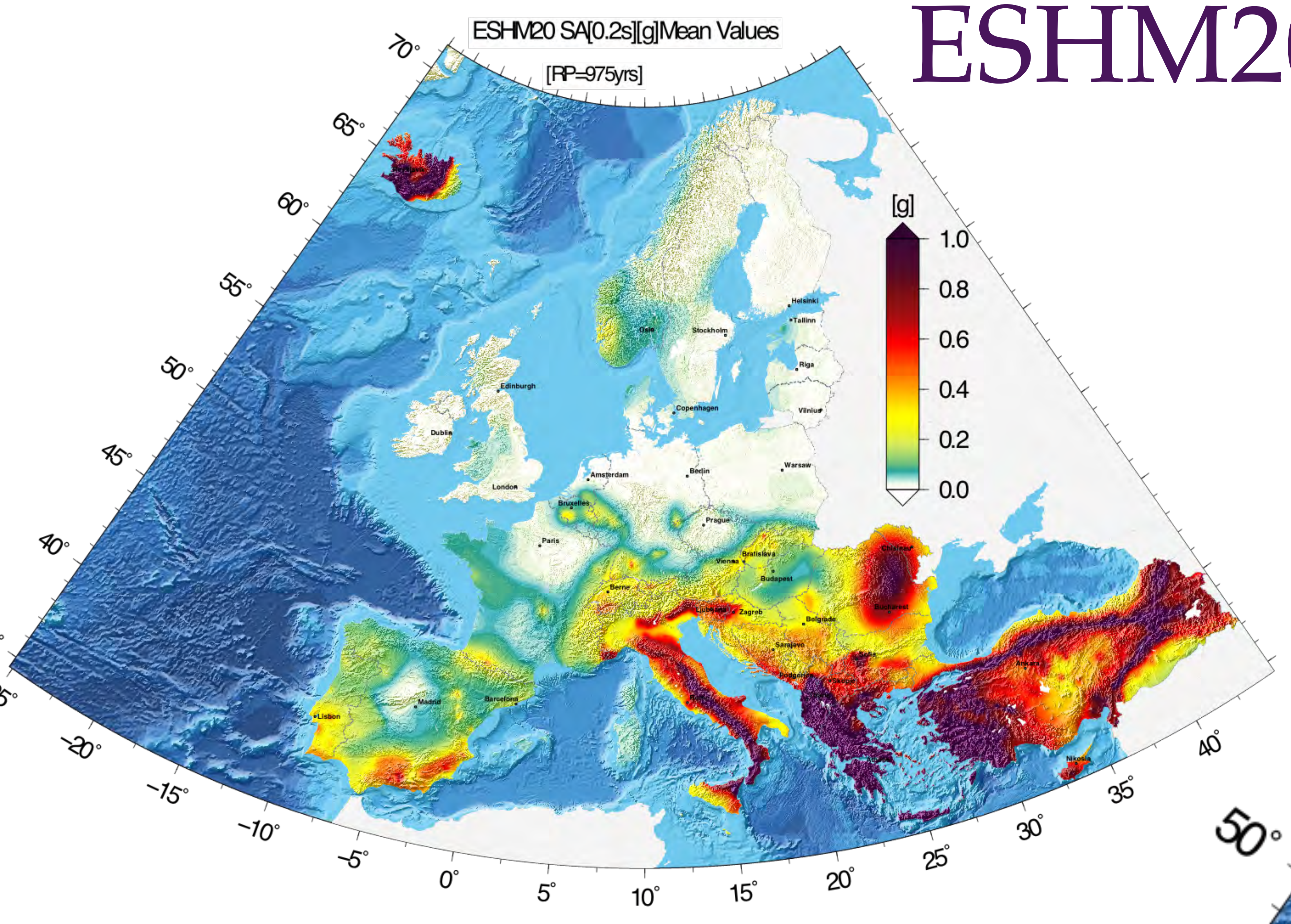
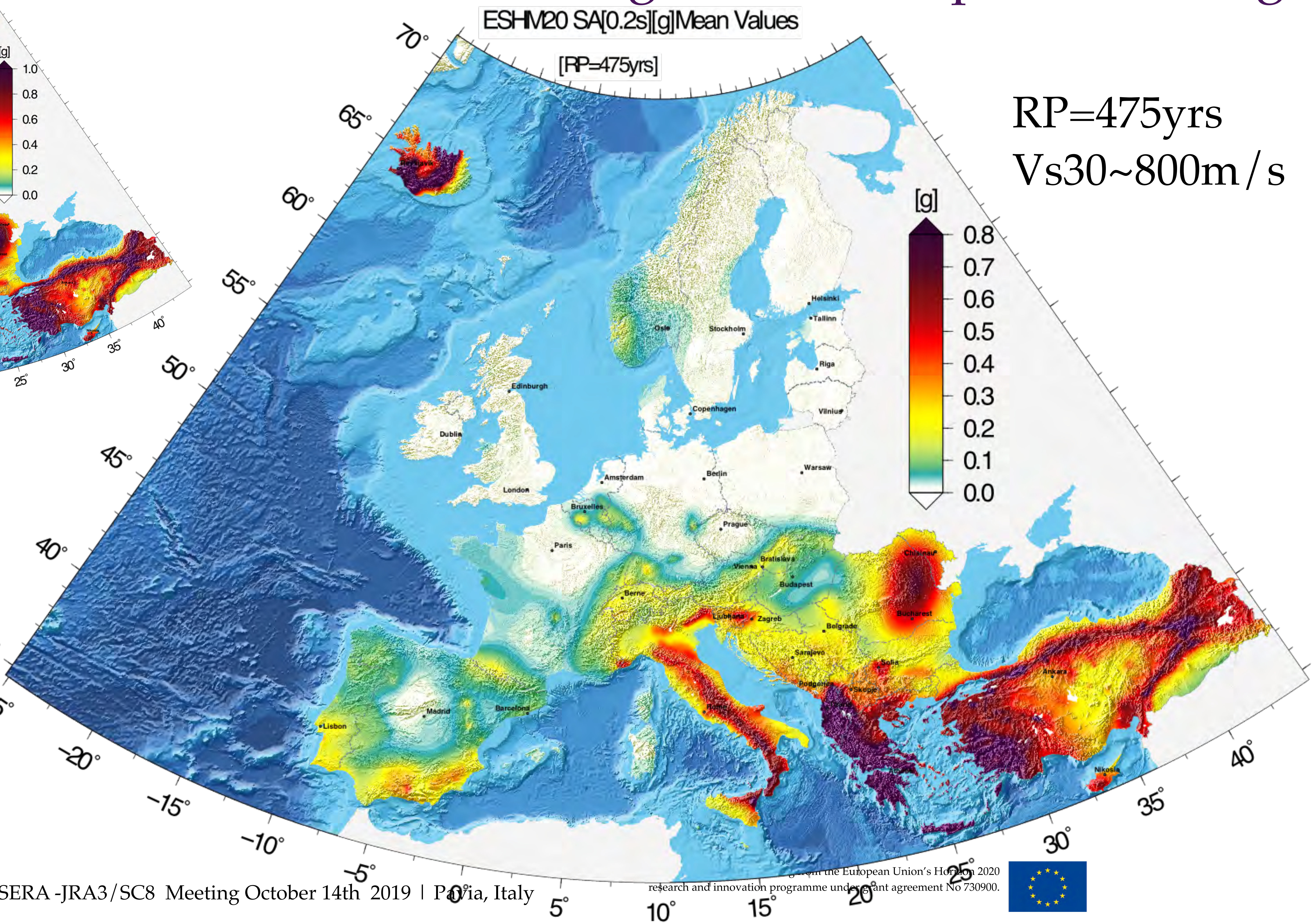
ESHM20: Ground Shaking Hazard Maps: SA[0.2s][g]



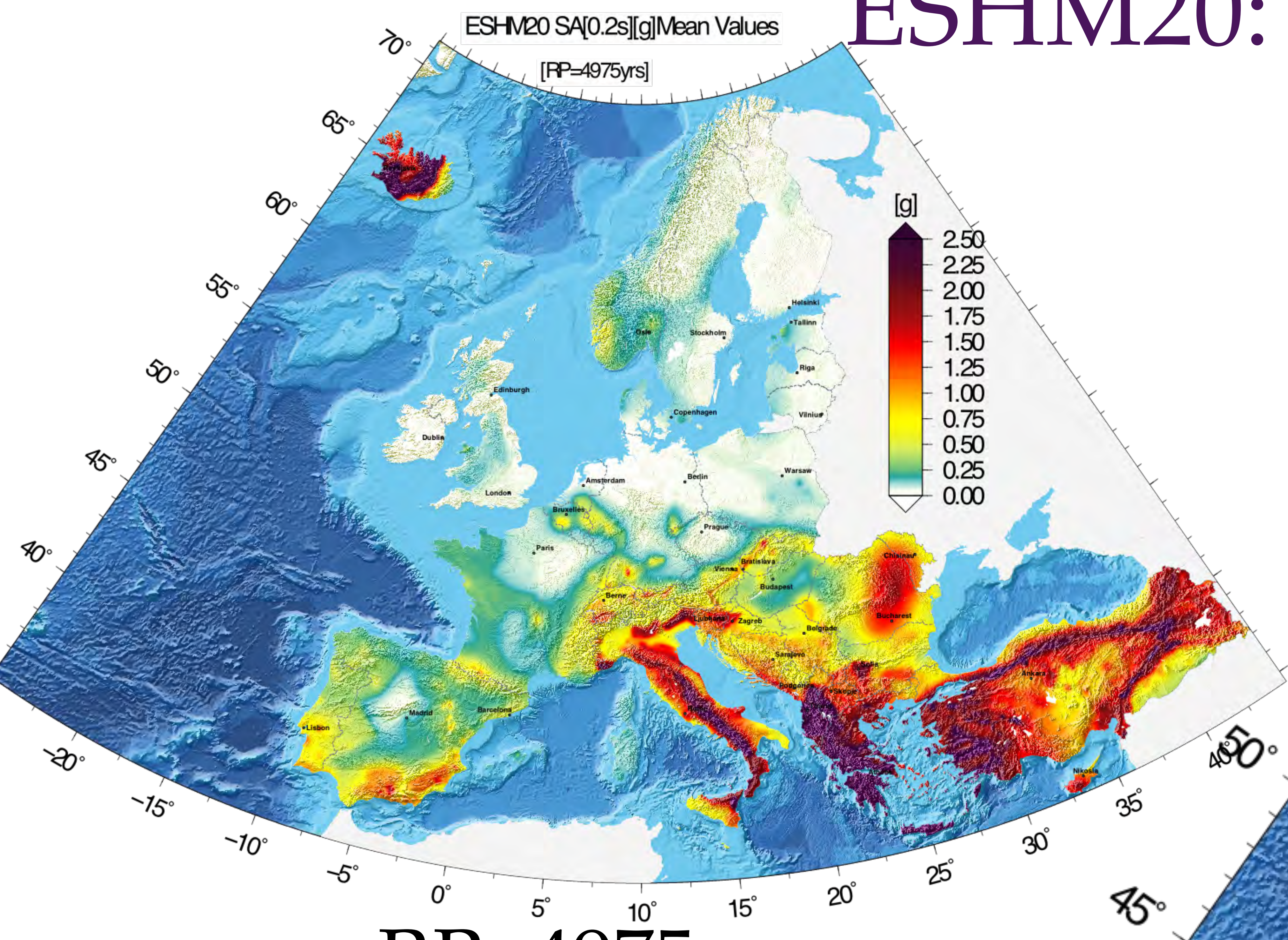
RP=975yrs



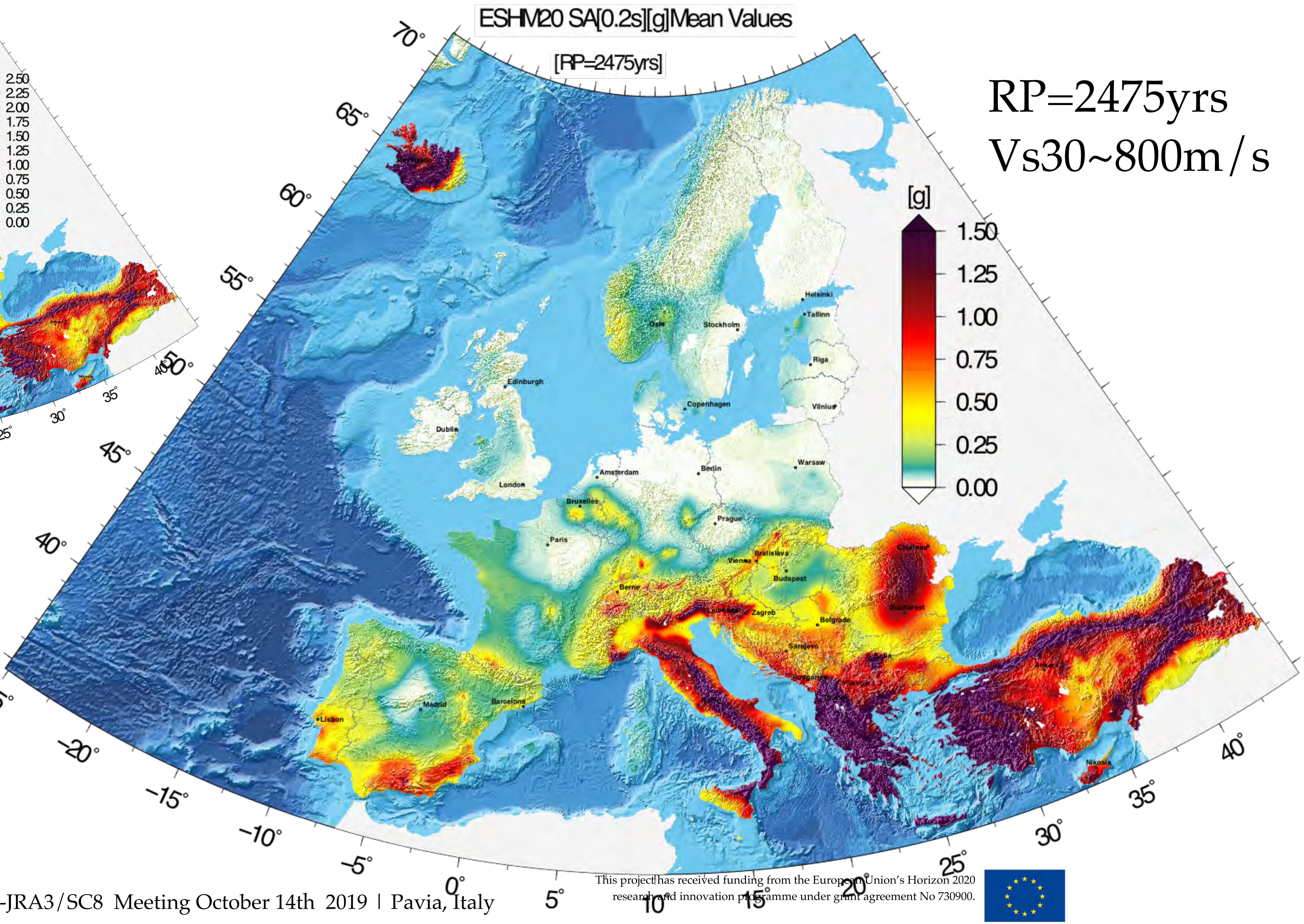
RP=475yrs
Vs30~800m/s

... the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.

ESHM20: Ground Shaking Hazard Maps: SA[0.2s][g]



RP=4975yrs



RP=2475yrs
Vs30~800m/s

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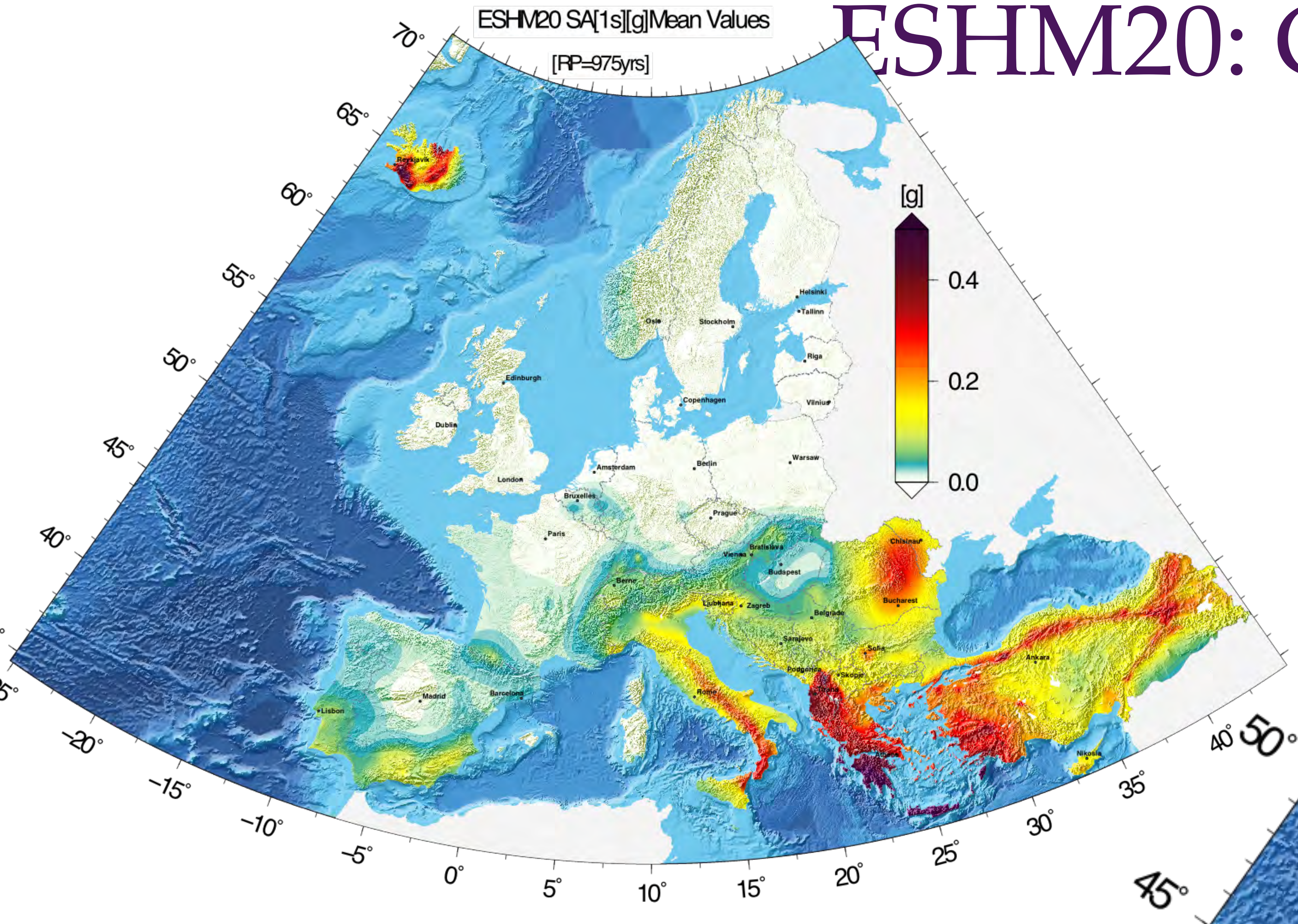
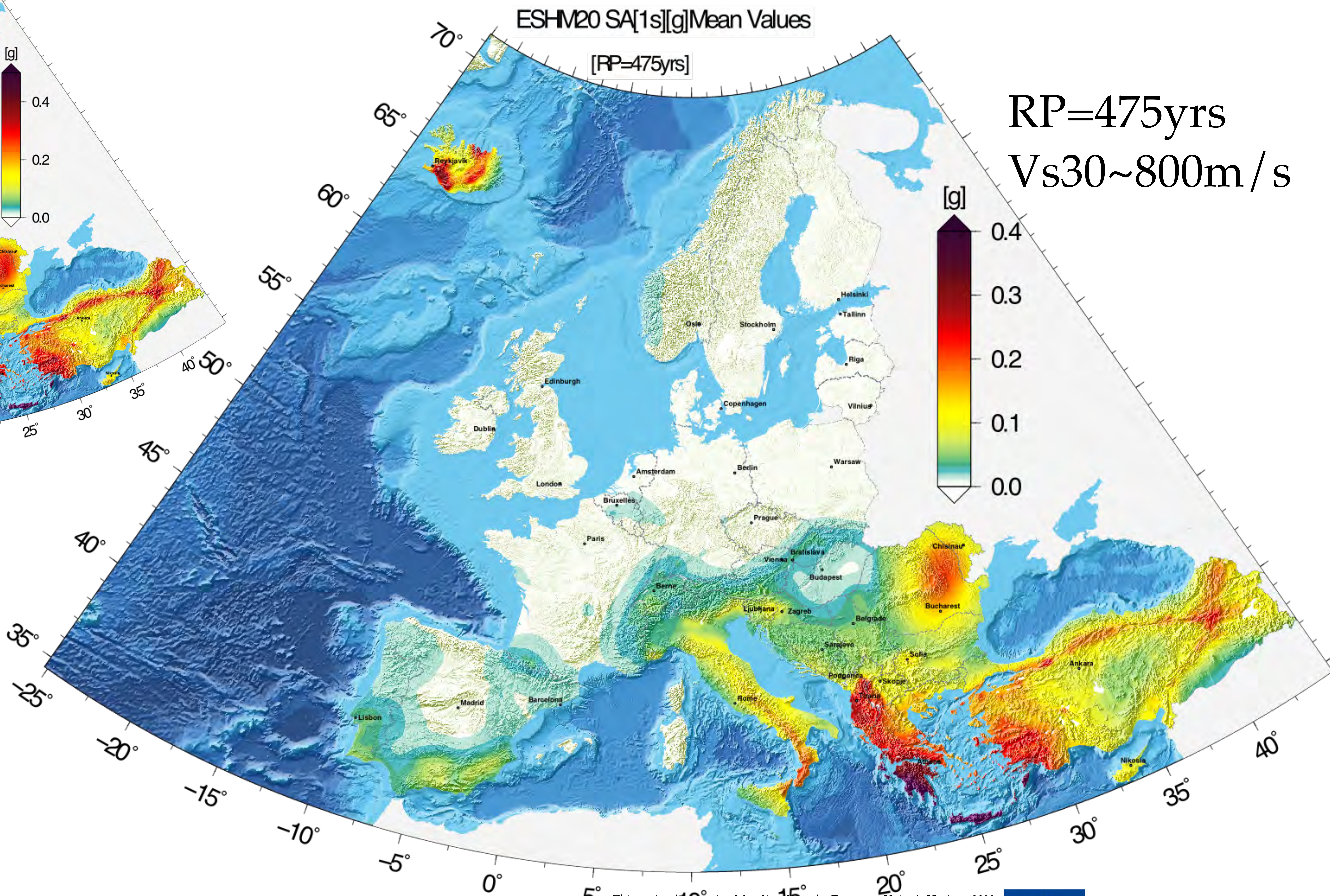
ESHM20: Ground Shaking Hazard Maps: SA[1.0s][g]



RP=975yrs



RP=475yrs
Vs30~800m/s

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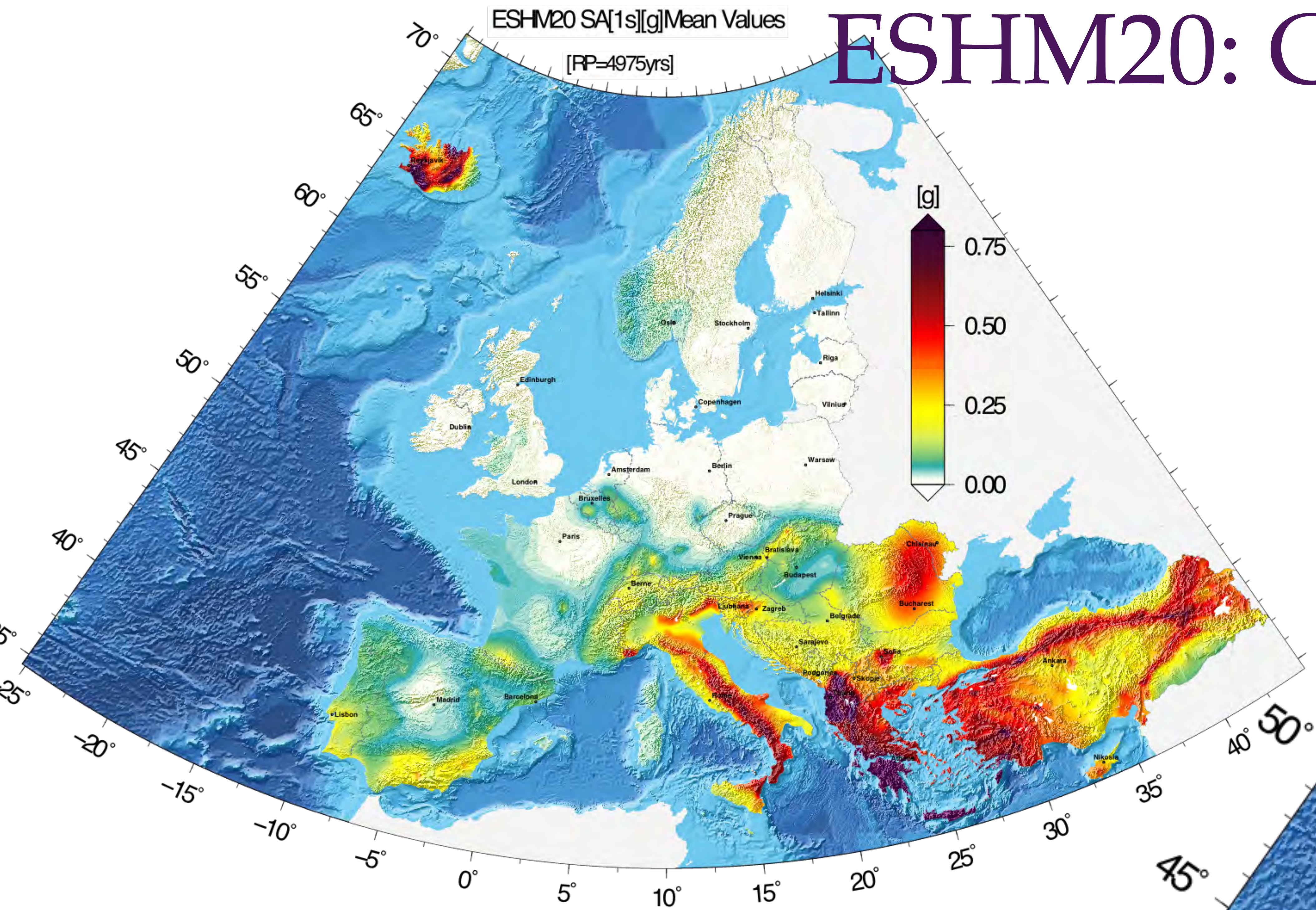
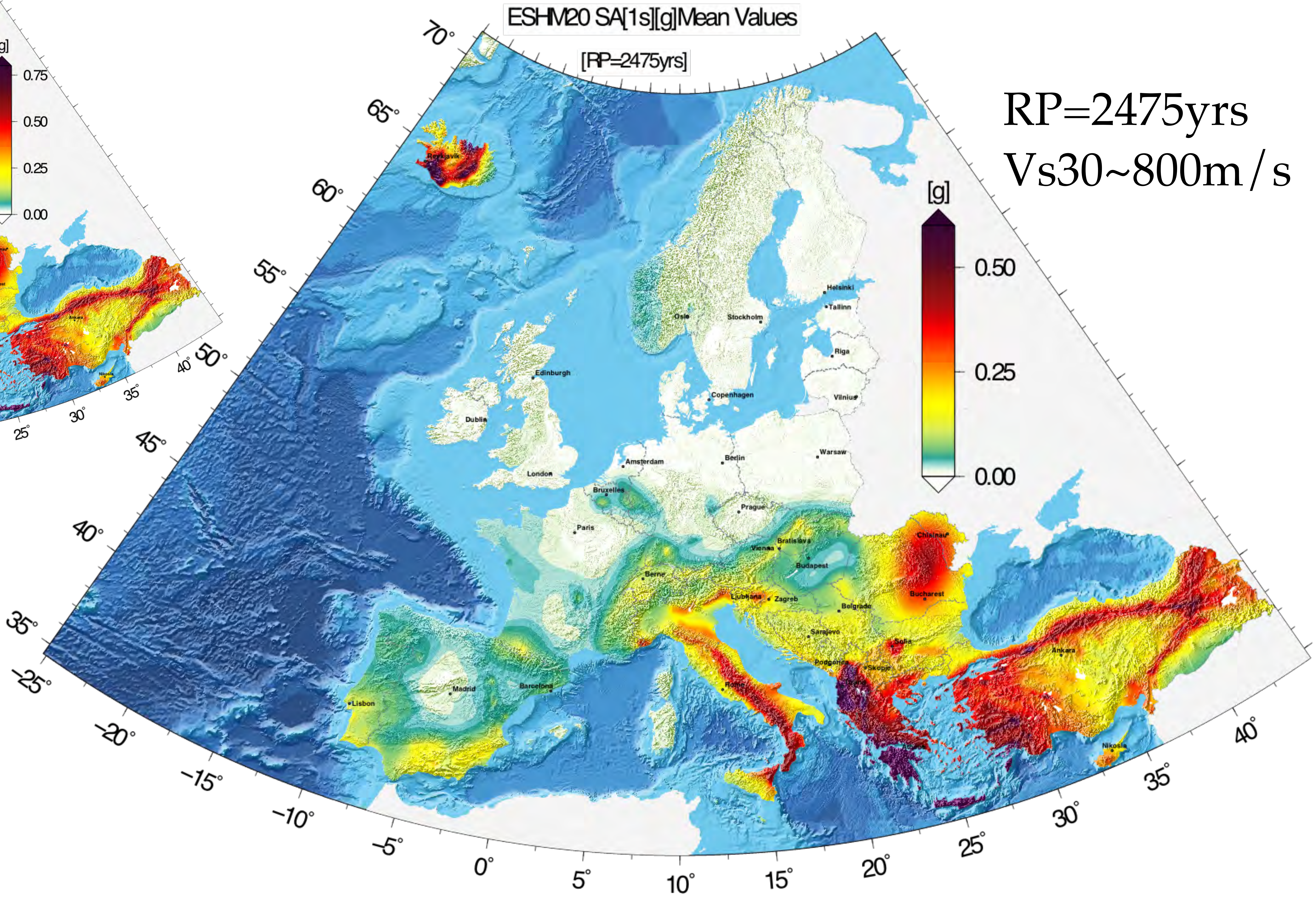
ESHM20: Ground Shaking Hazard Maps: SA[1.0s][g]



RP=4975yrs



RP=2475yrs
Vs30~800m/s

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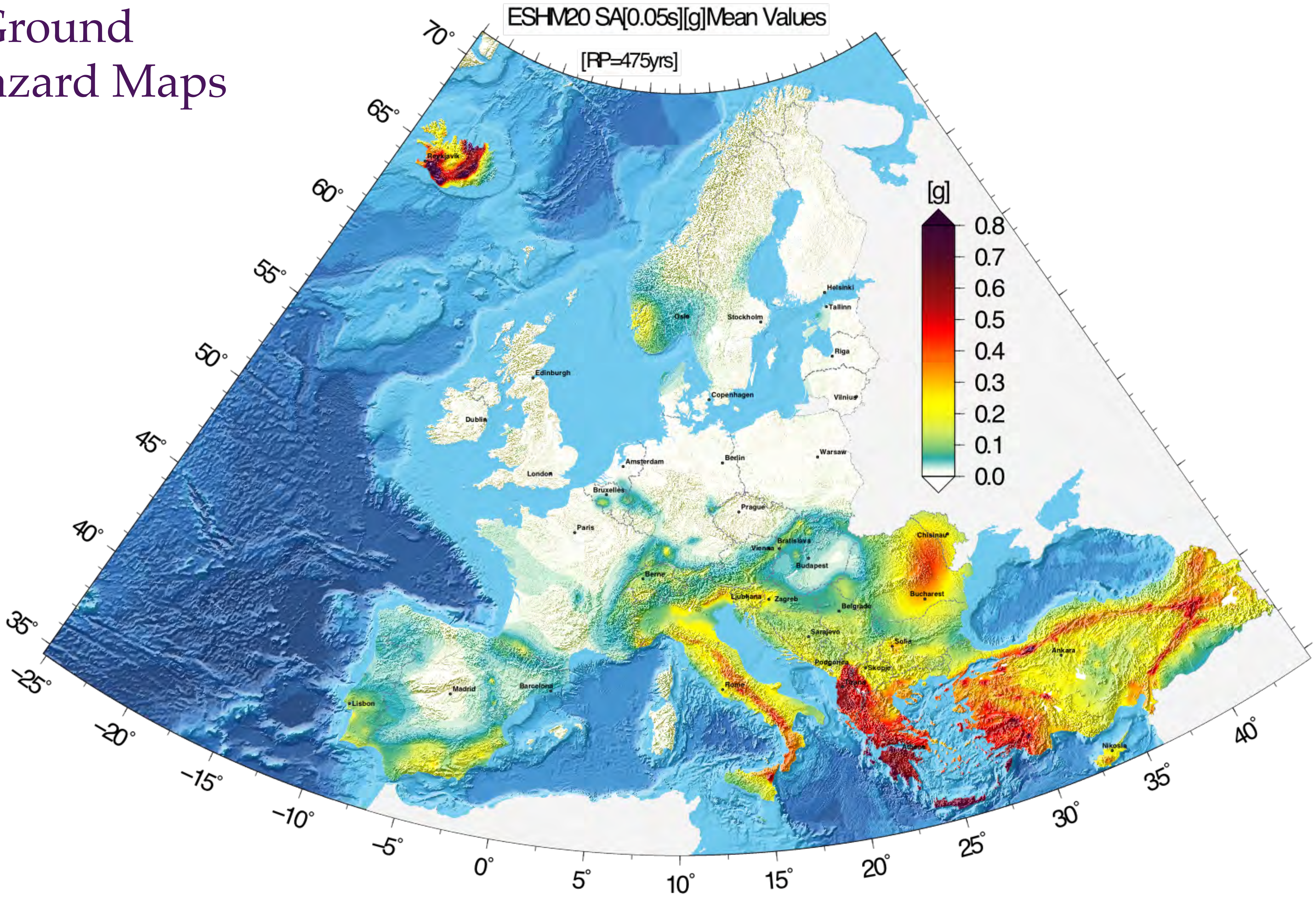
ESHM20: Ground Shaking Hazard Maps



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ESHM20 : Comparison

- ESHM13
- SuiHaz15 (Wiemer Et al 2016)
- DE17 (Grunthal et al 2017)
- Turkey (Sesetyan et al 2018)
- Spain (María Belén Benito Oterino, et al2017)
- UK (Ilaria Musca, et al2019)

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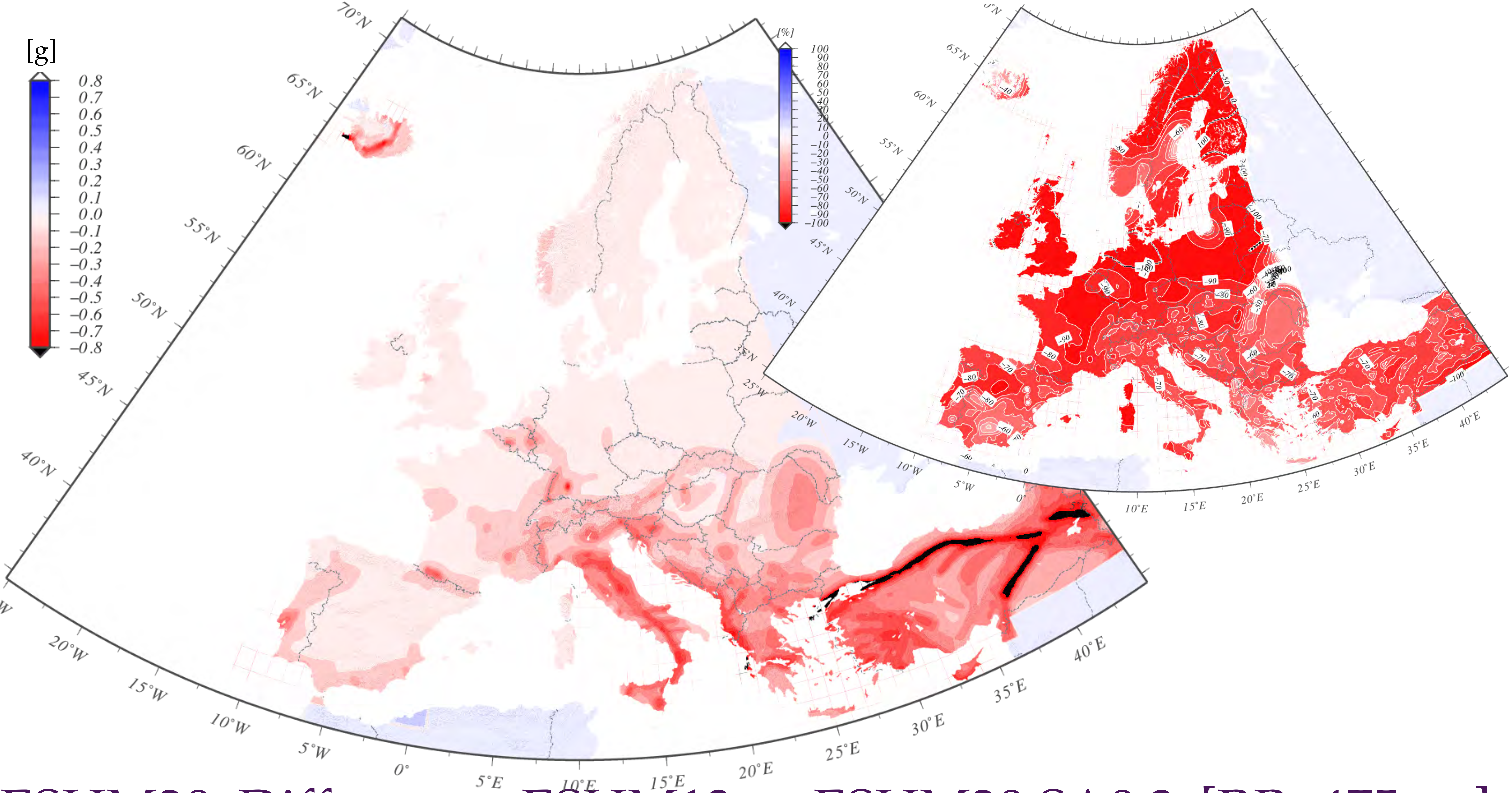

ESHM20: Differences ESHM13 vs ESHM20 SA0.2s[RP=475yrs]

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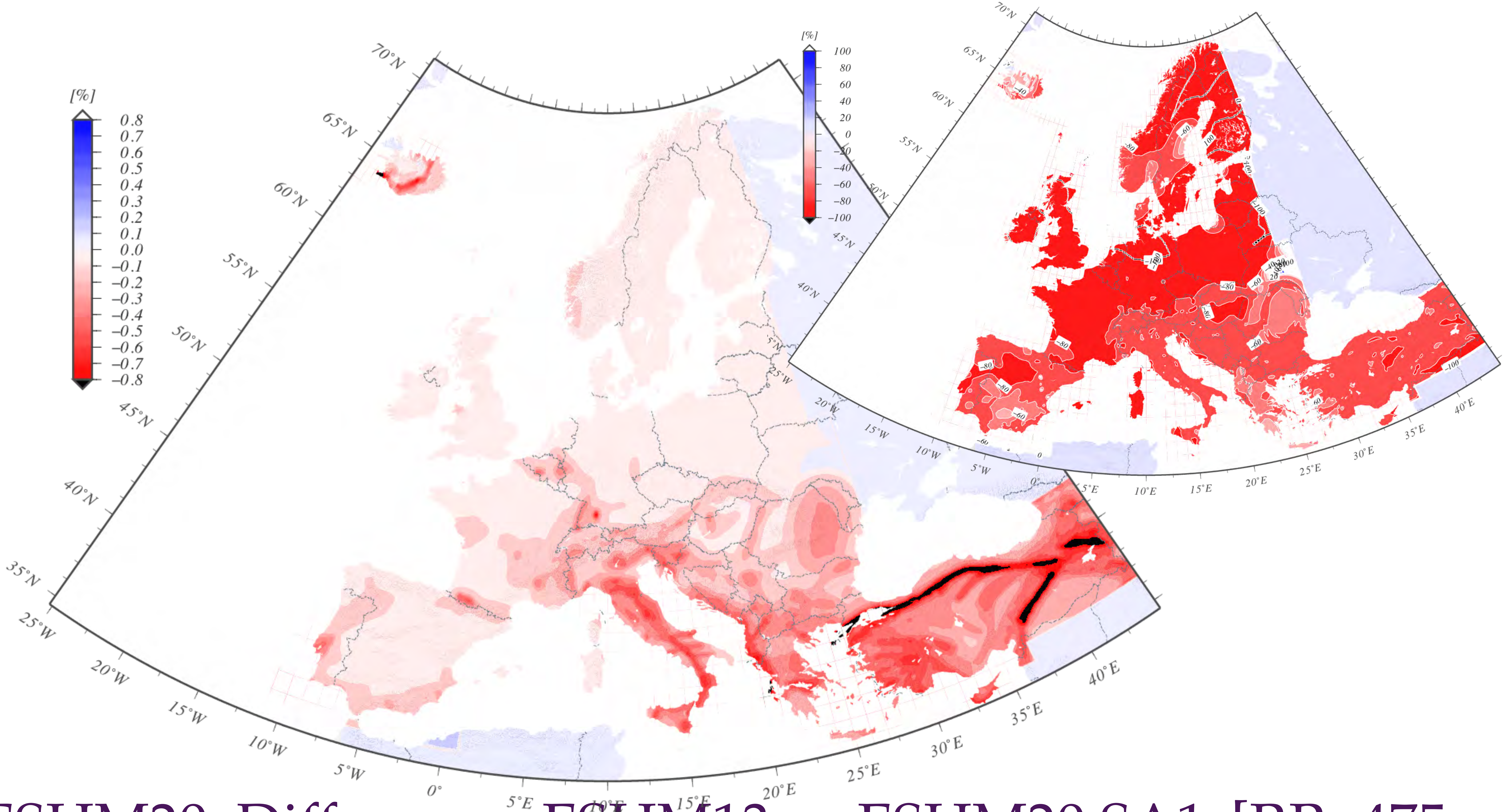

ESHM20: Differences ESHM13 vs ESHM20 SA1s[RP=475yrs]

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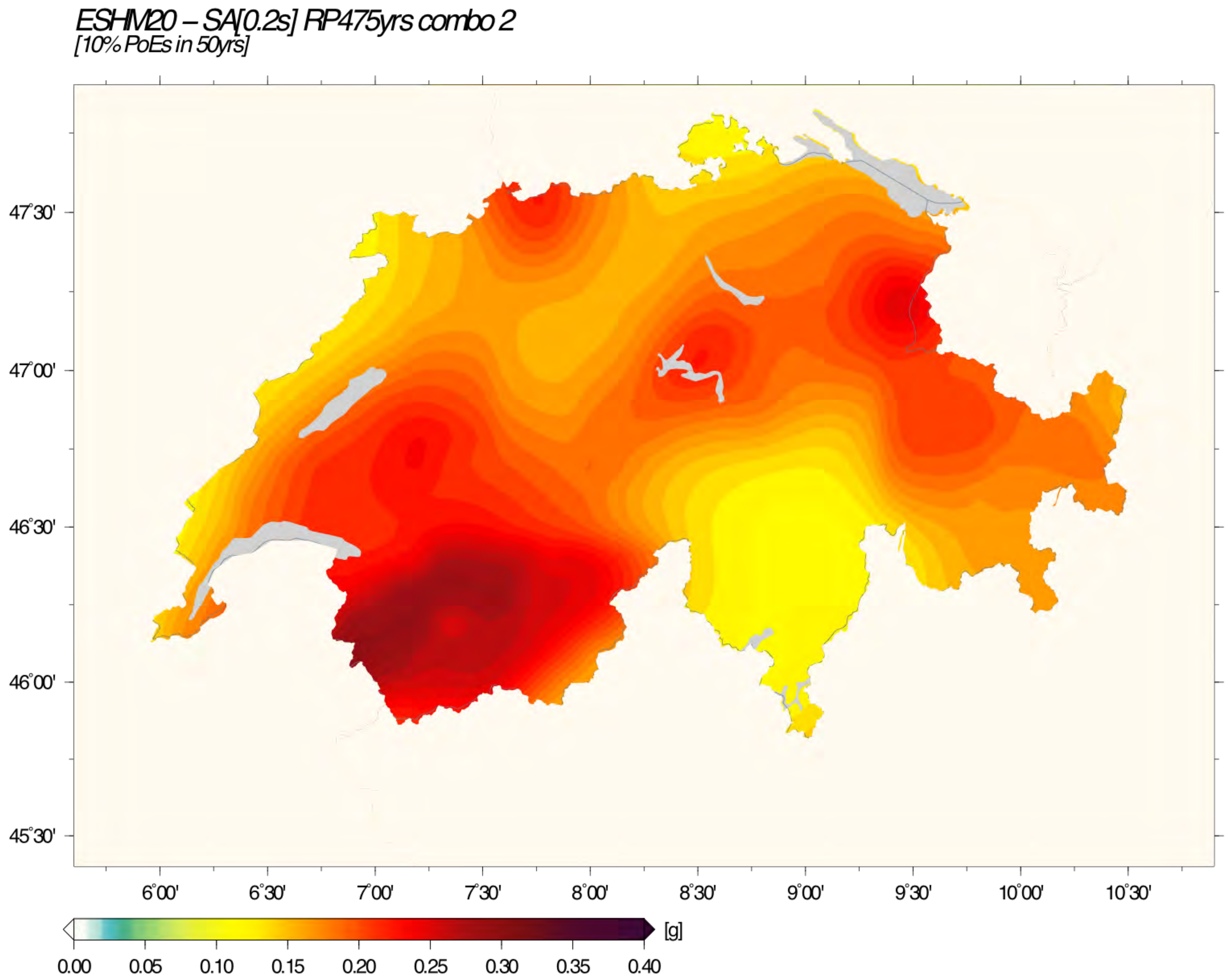

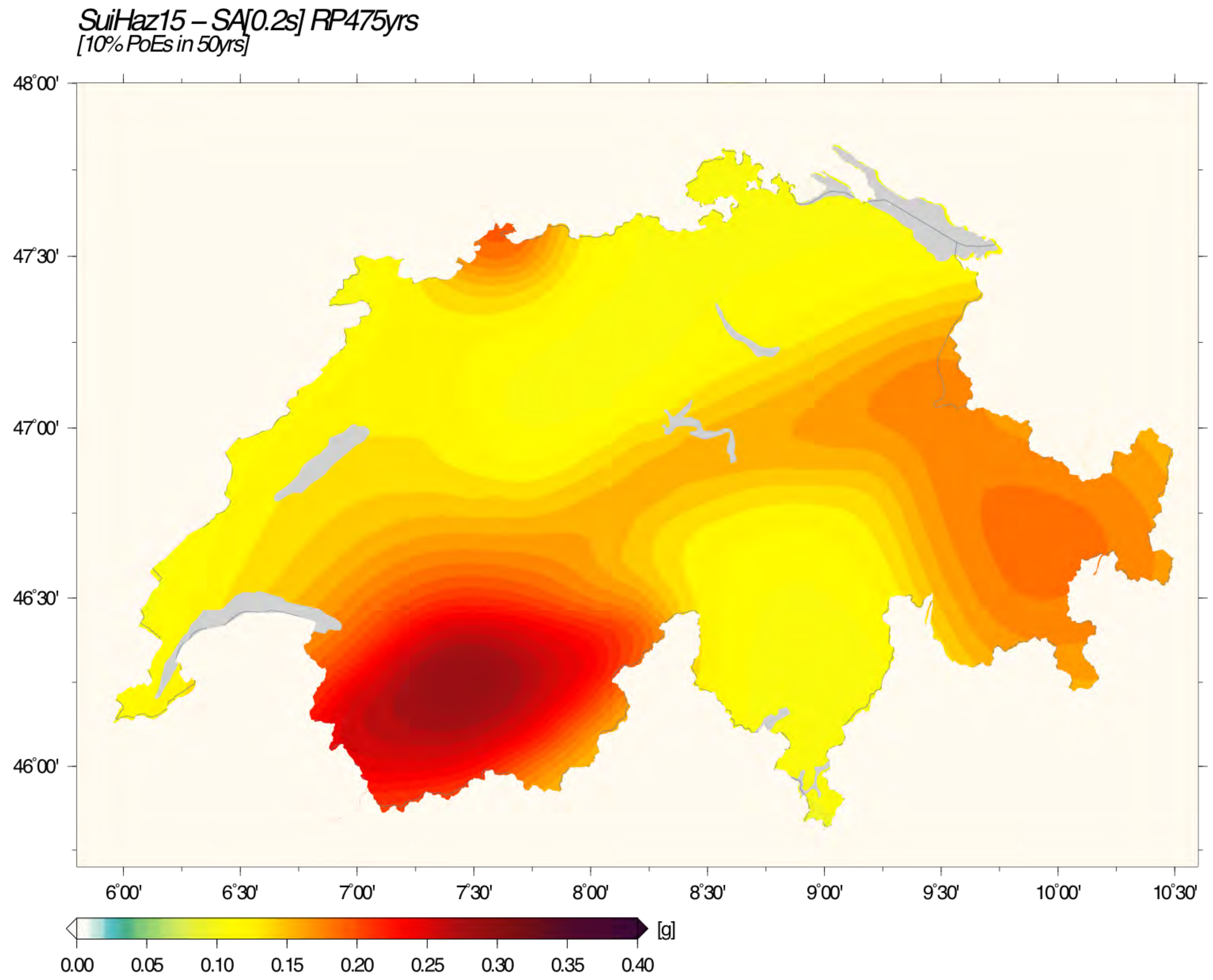

ESHM20 vs SuiHaz2015

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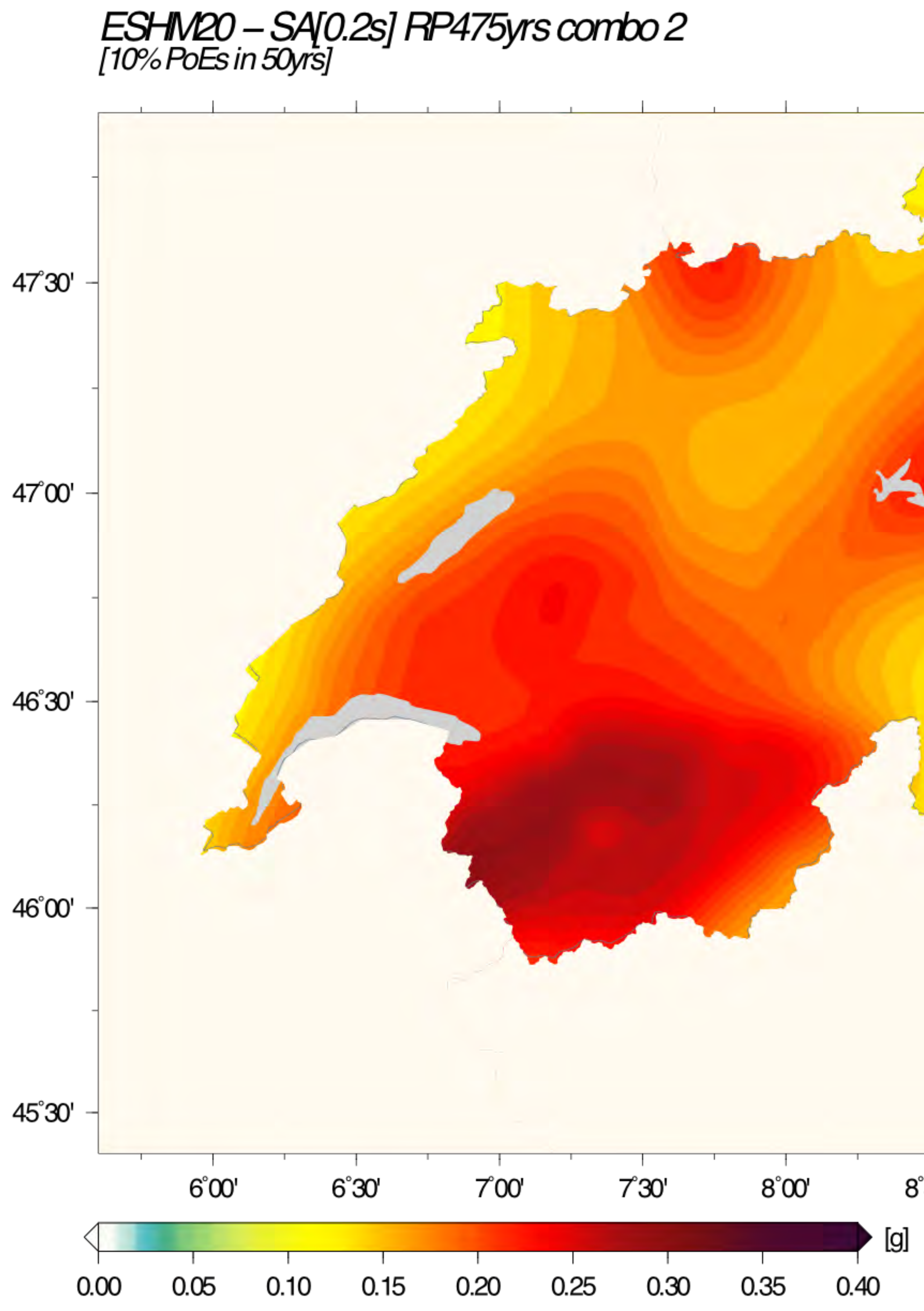
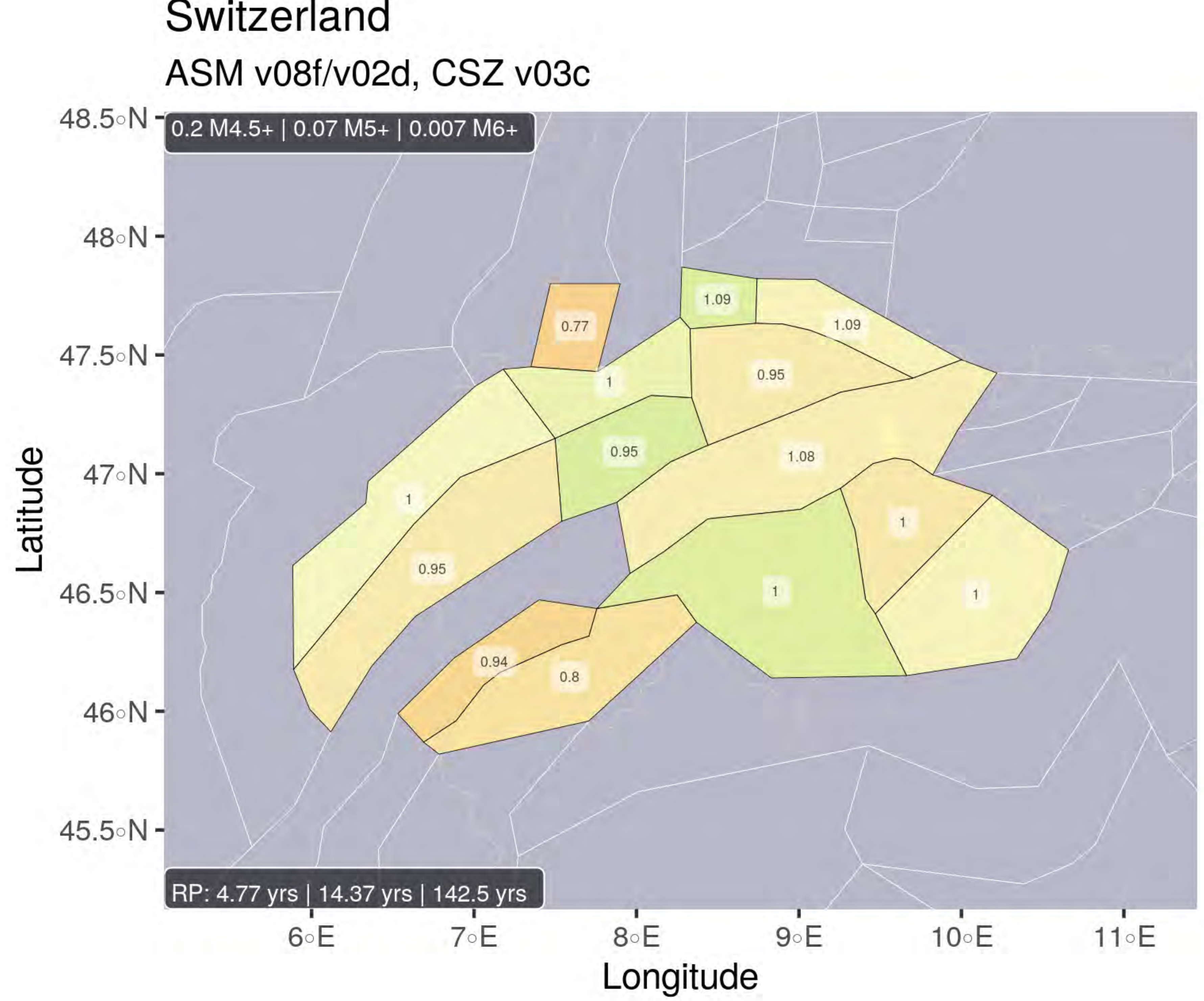
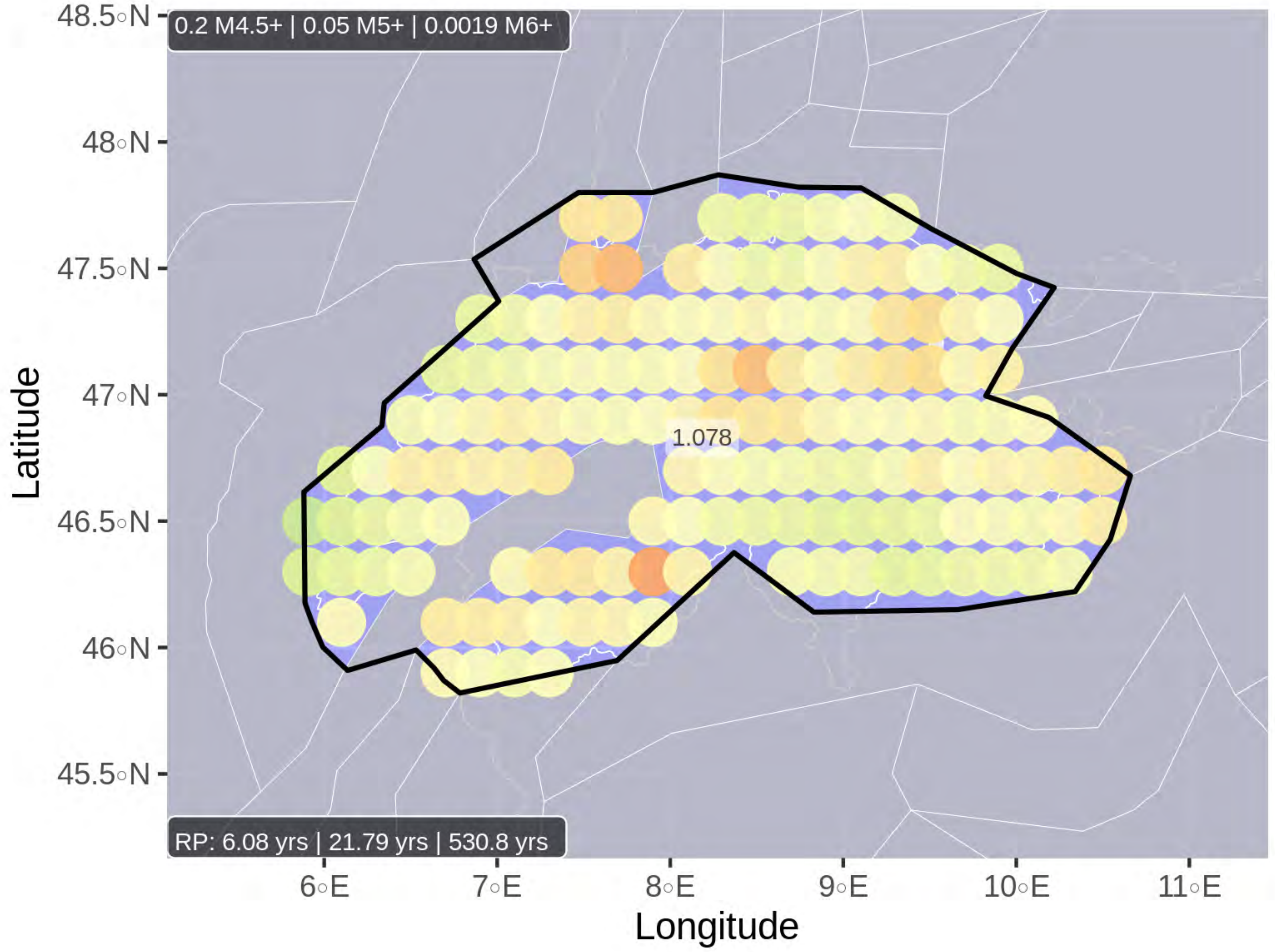
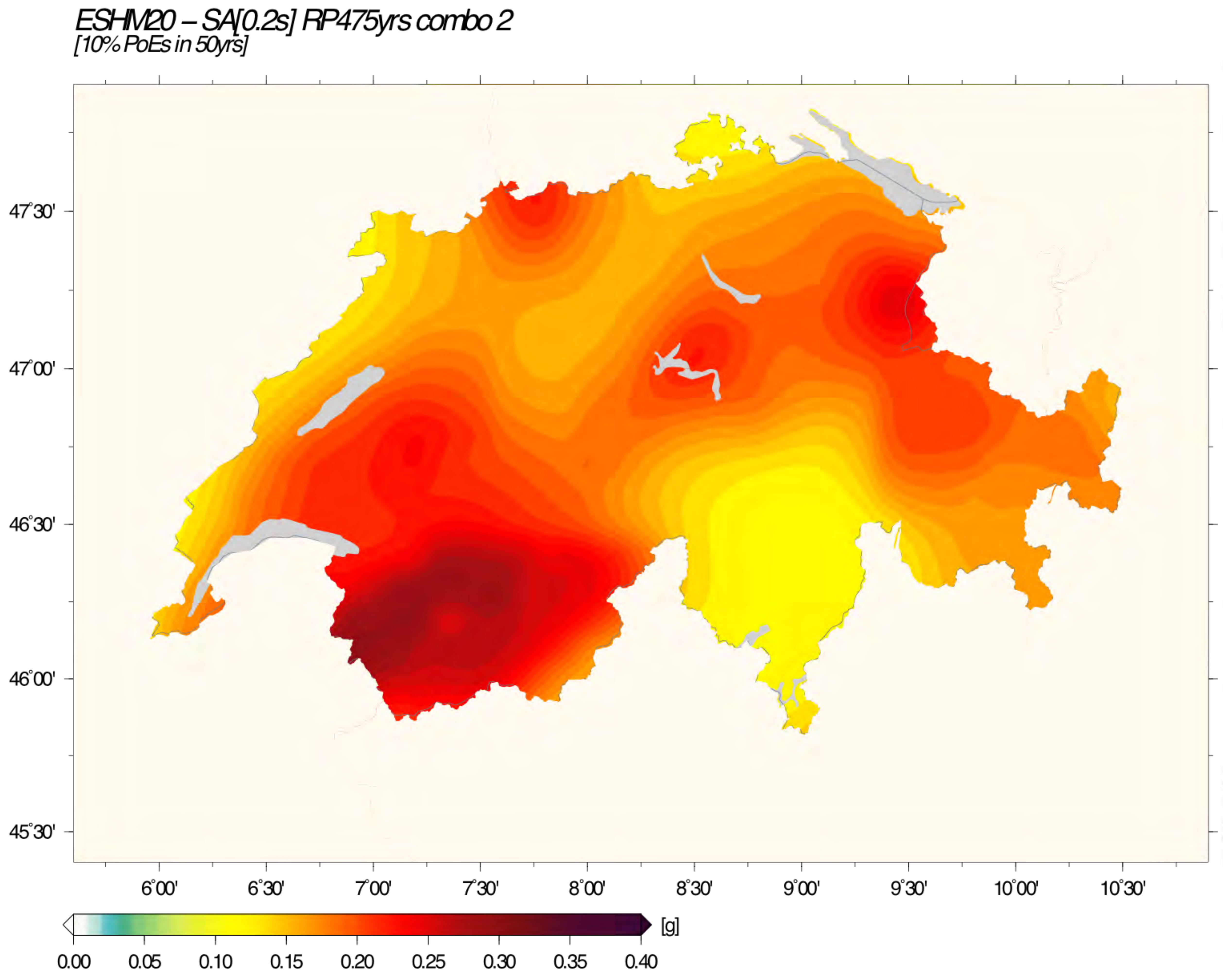
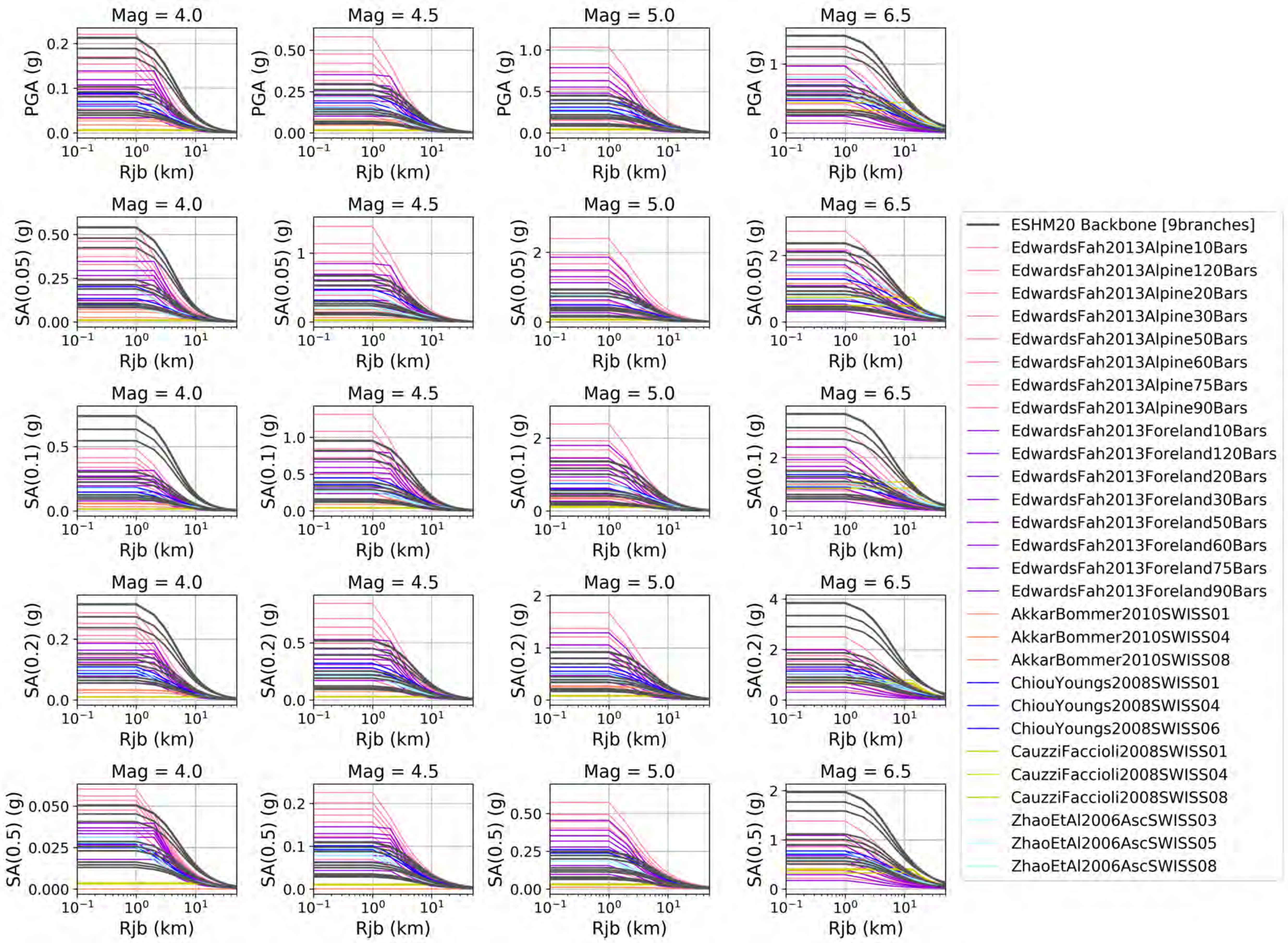






ESHM20 vs SuiHaz2015





ESHM20 vs SuiHaz2015

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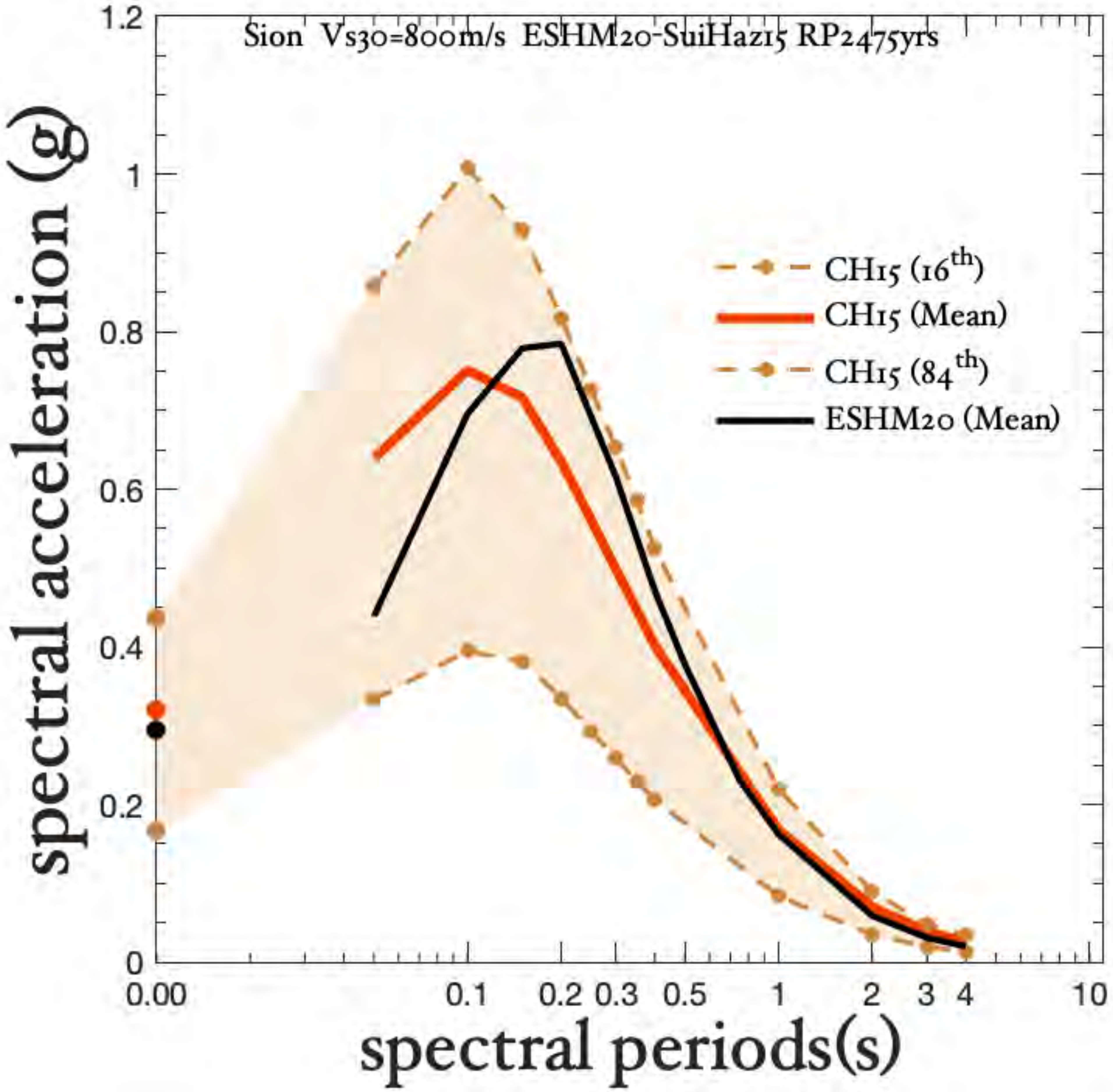

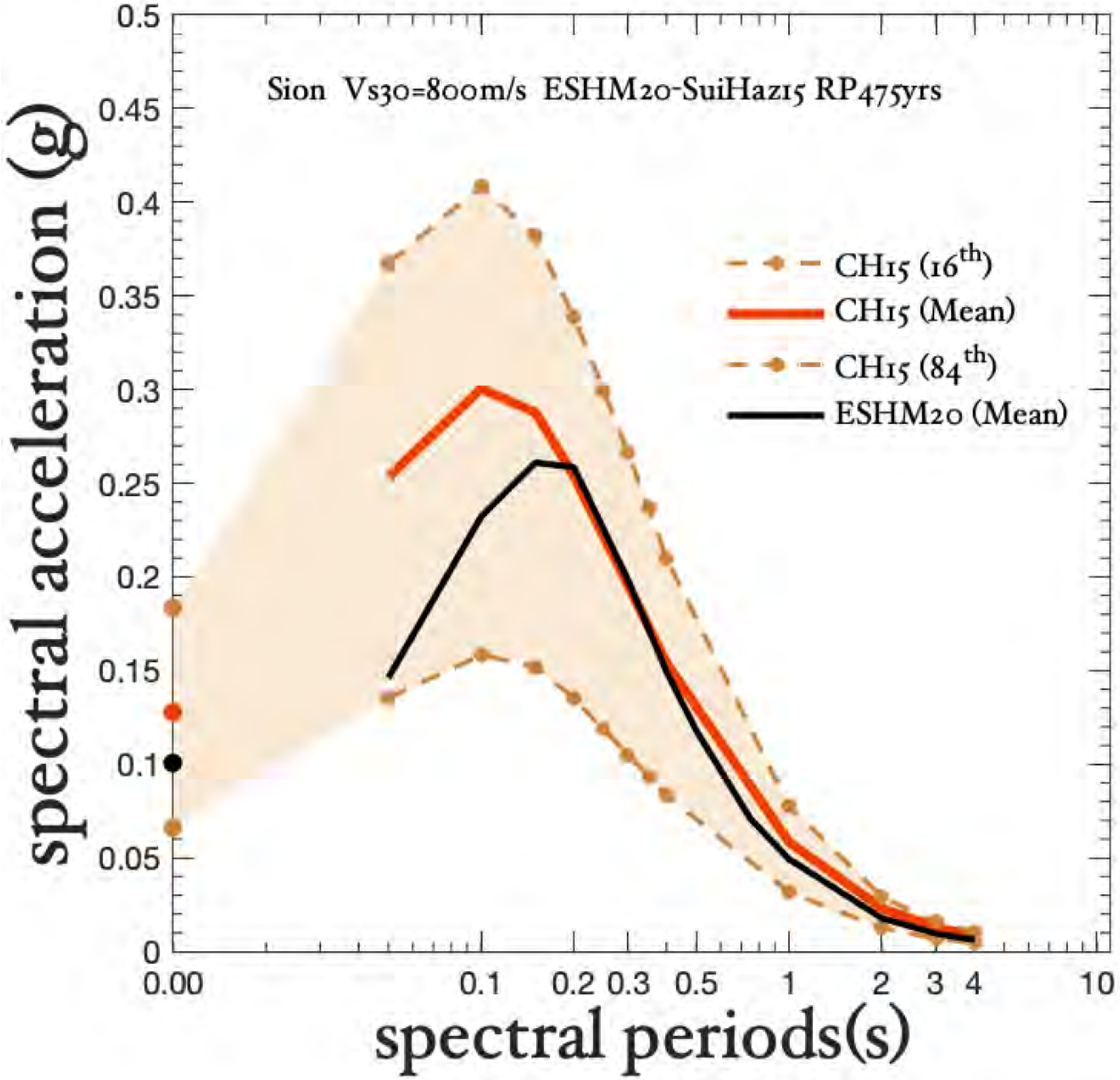

ESHM20 vs SuiHaz2015

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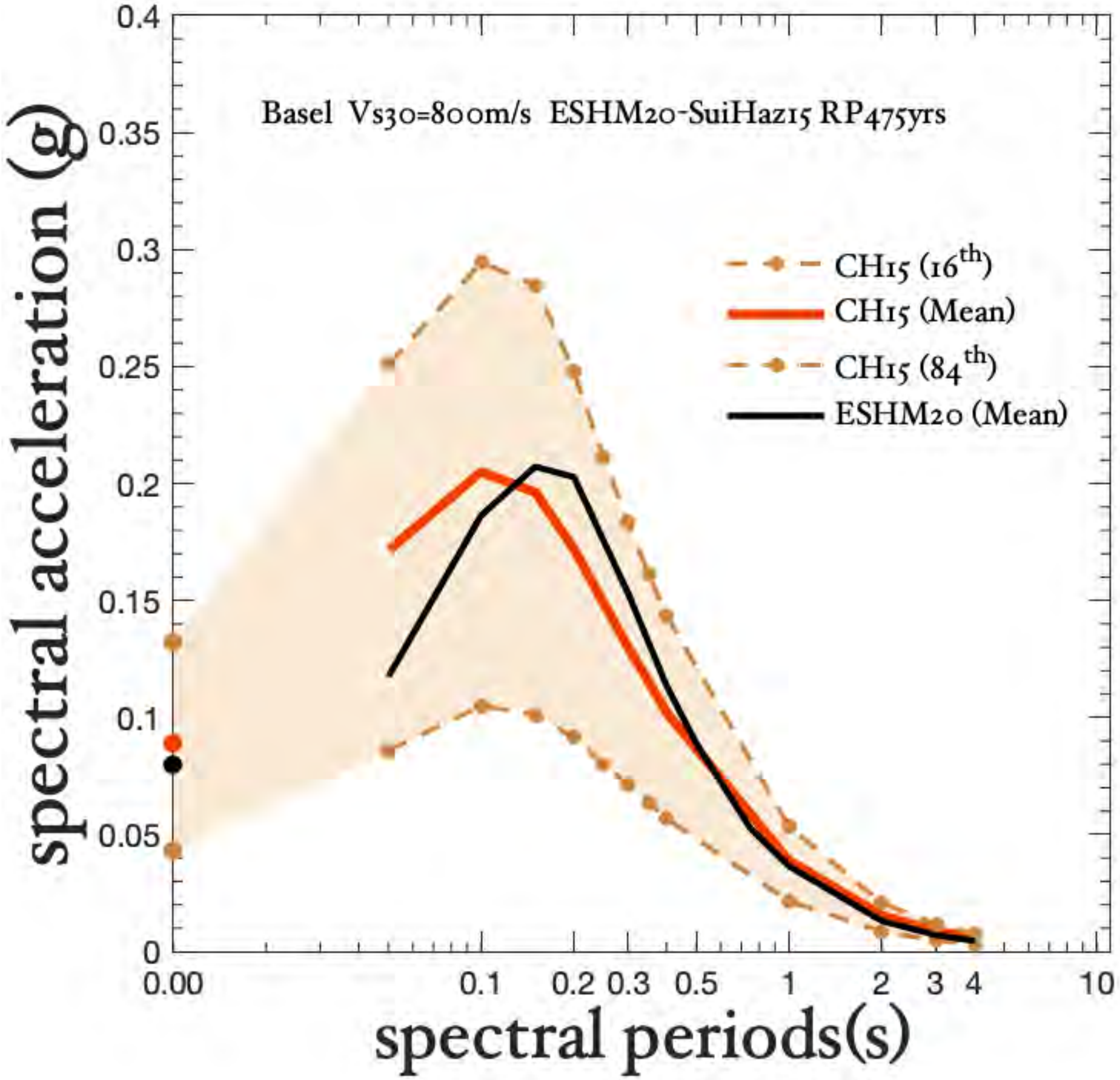

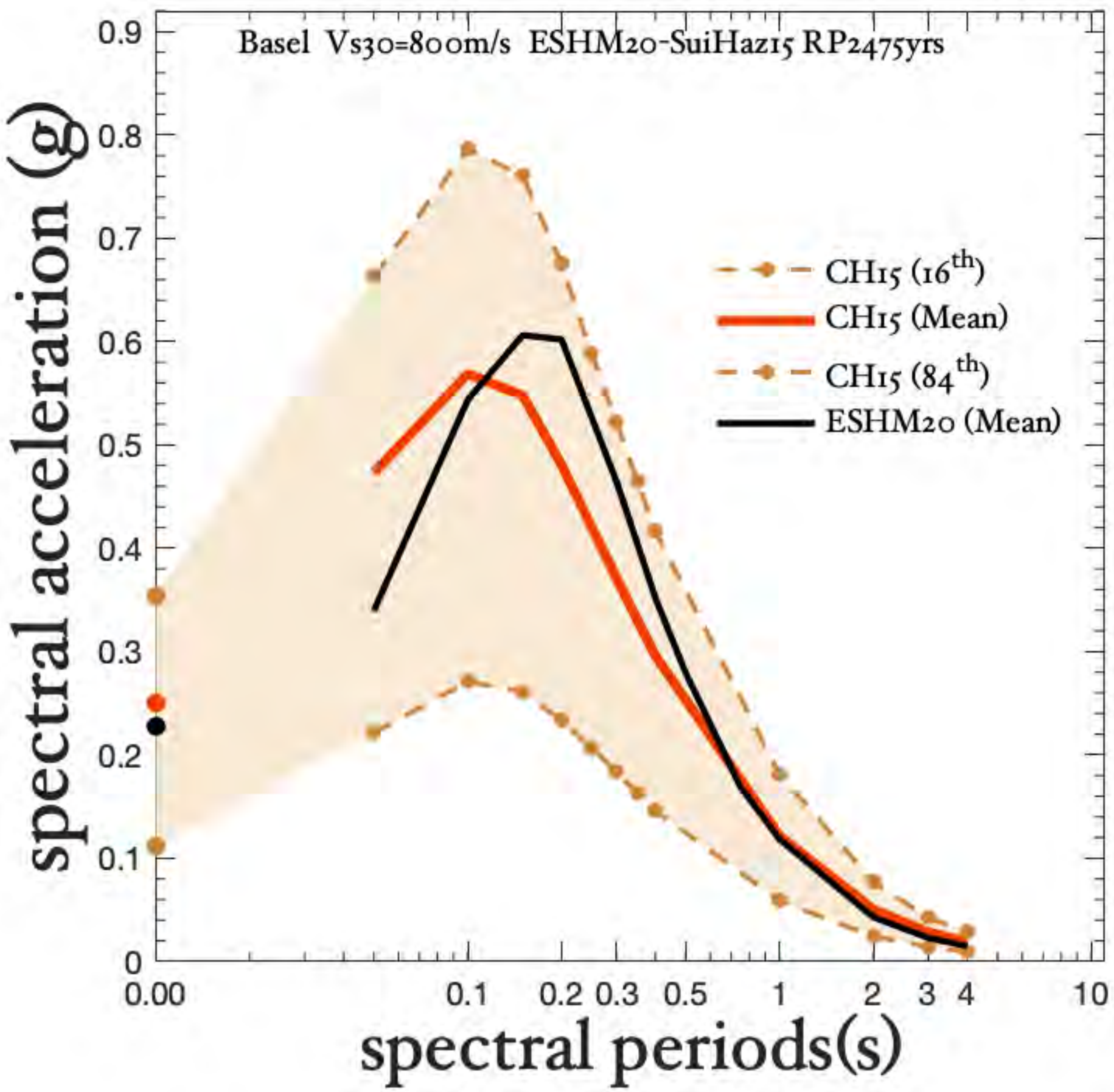

ESHM20 vs SuiHaz2015

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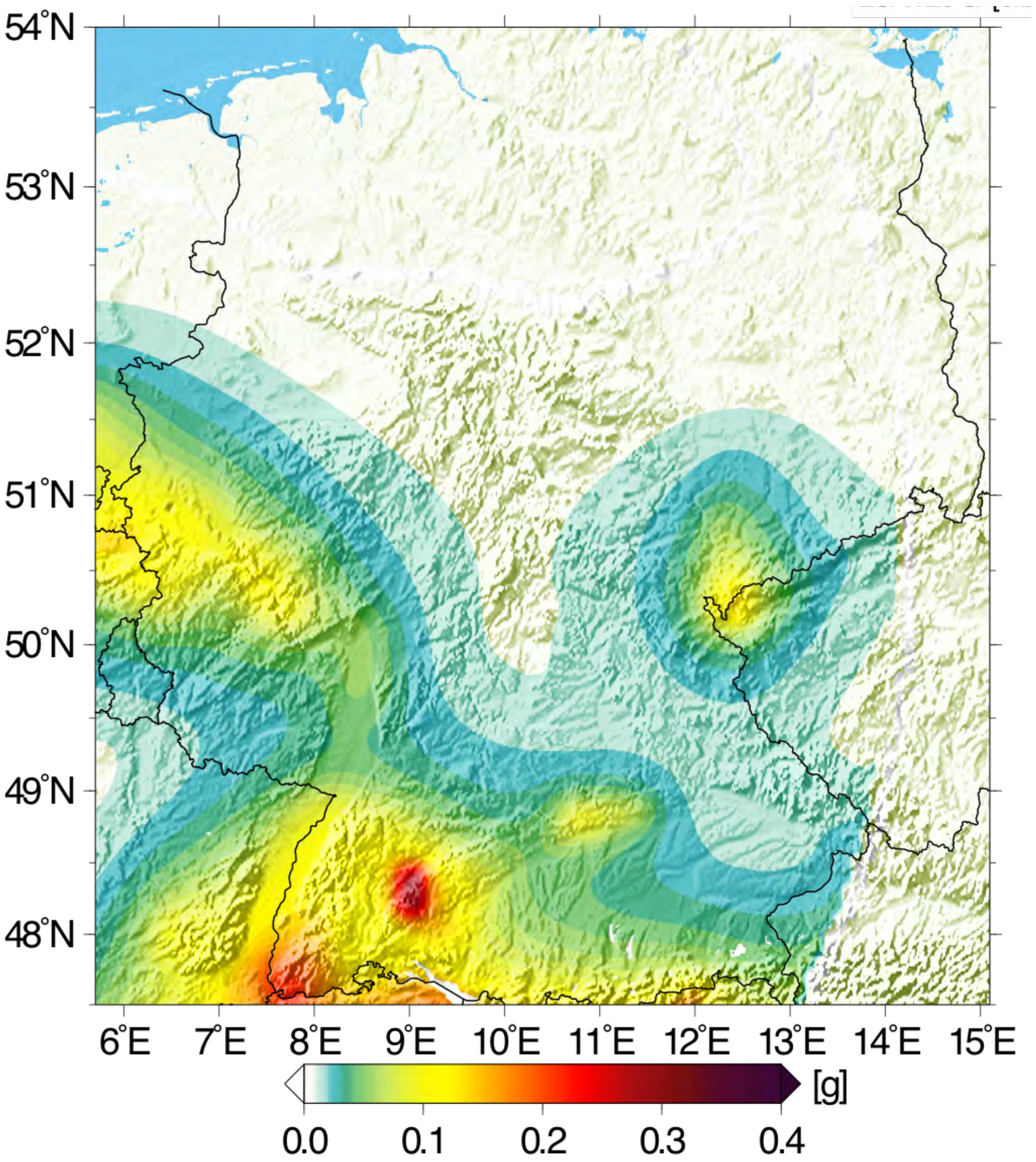

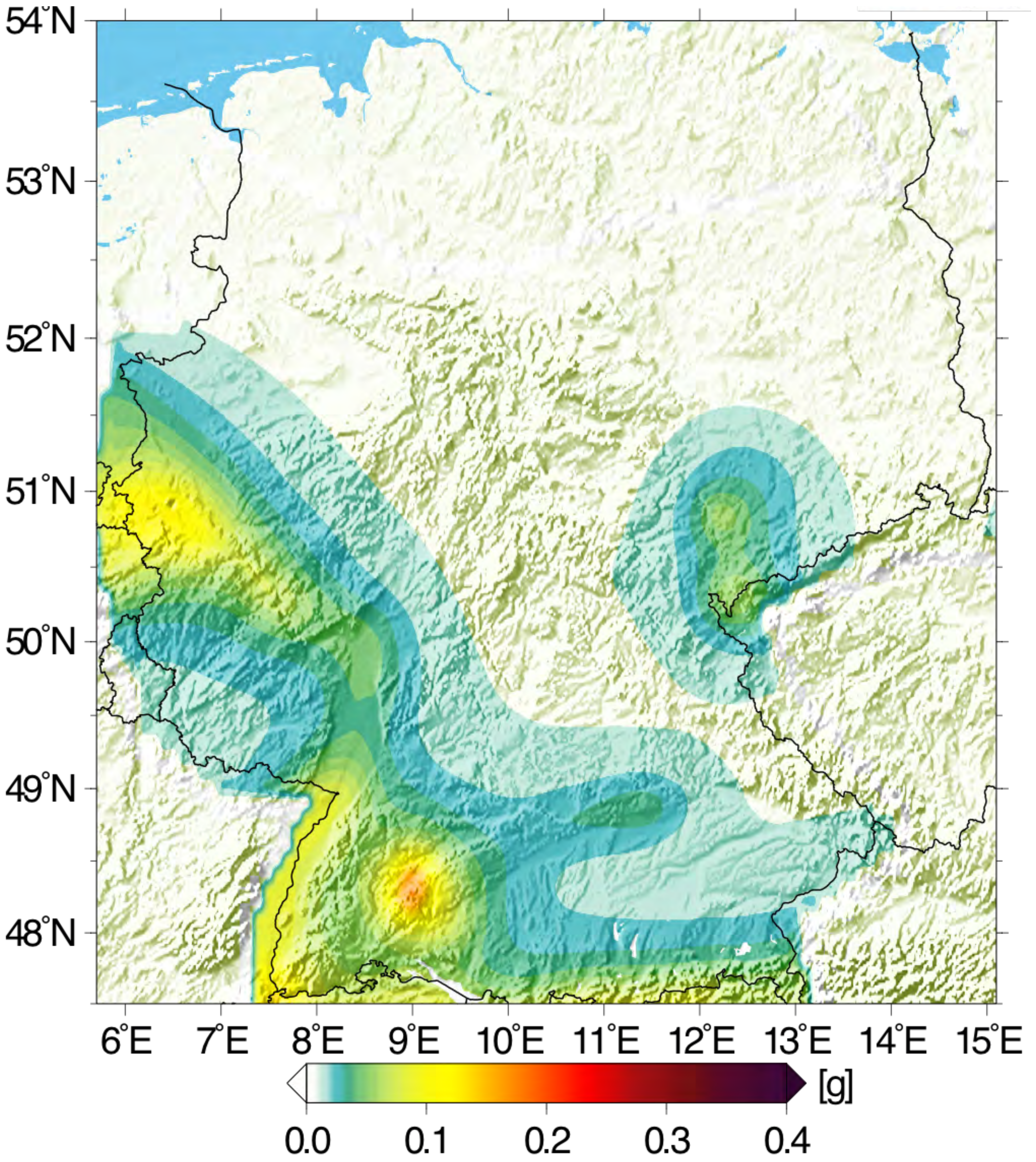

ESHM20 vs DE17(Grunthal el at 2017)

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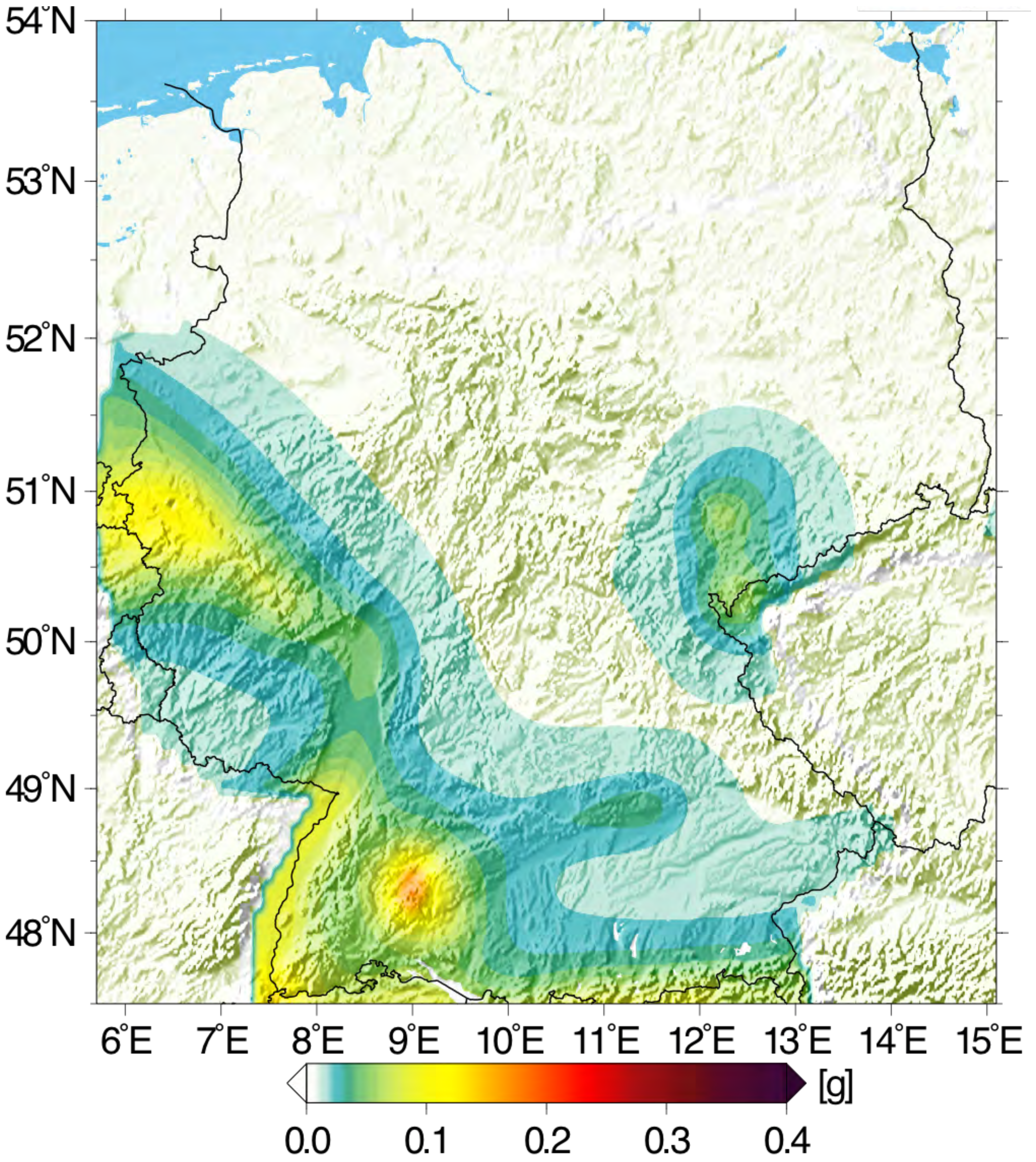

Average SA(0.1, 0.15,0.2s)

ESHM20 vs DE17(Grunthal el at 2017)

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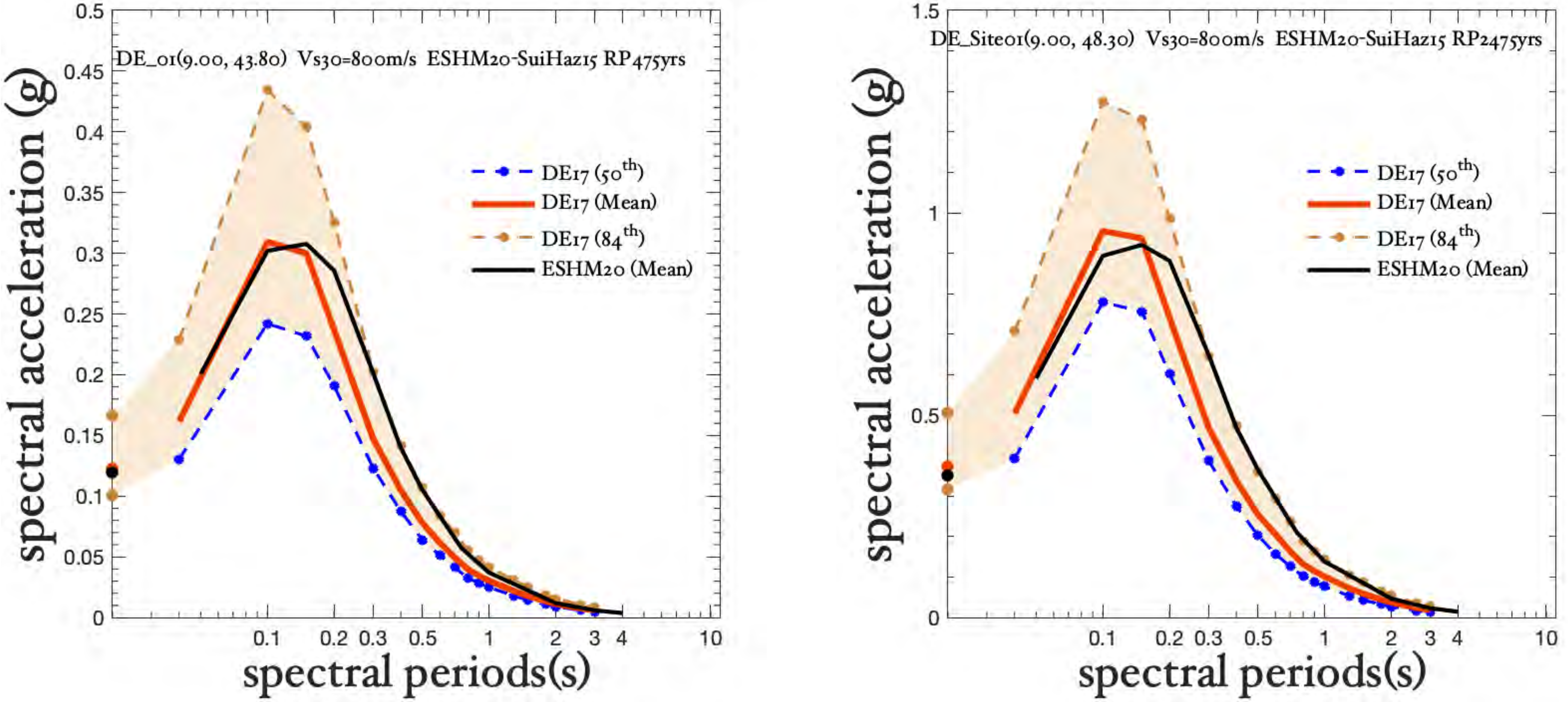
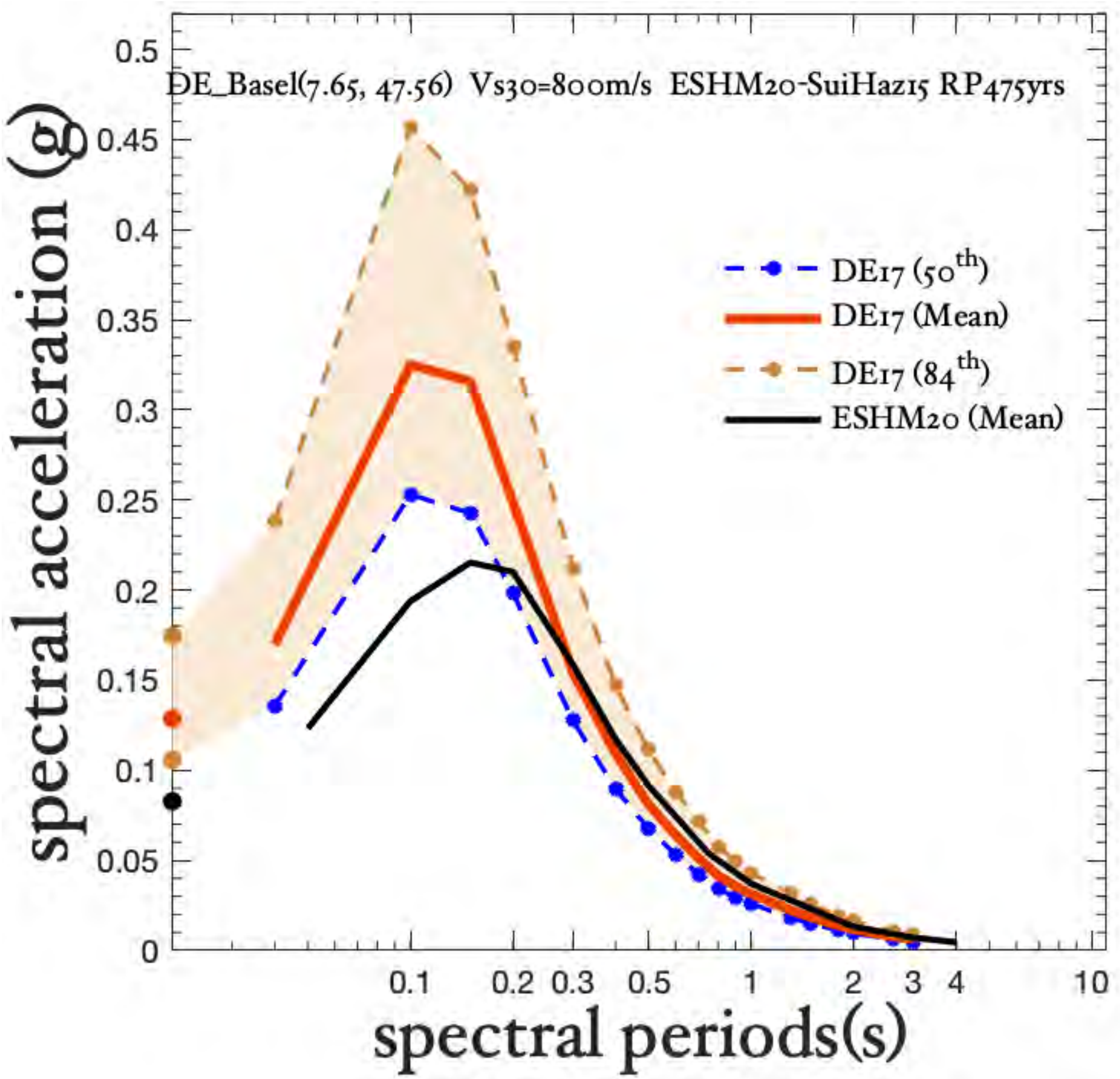
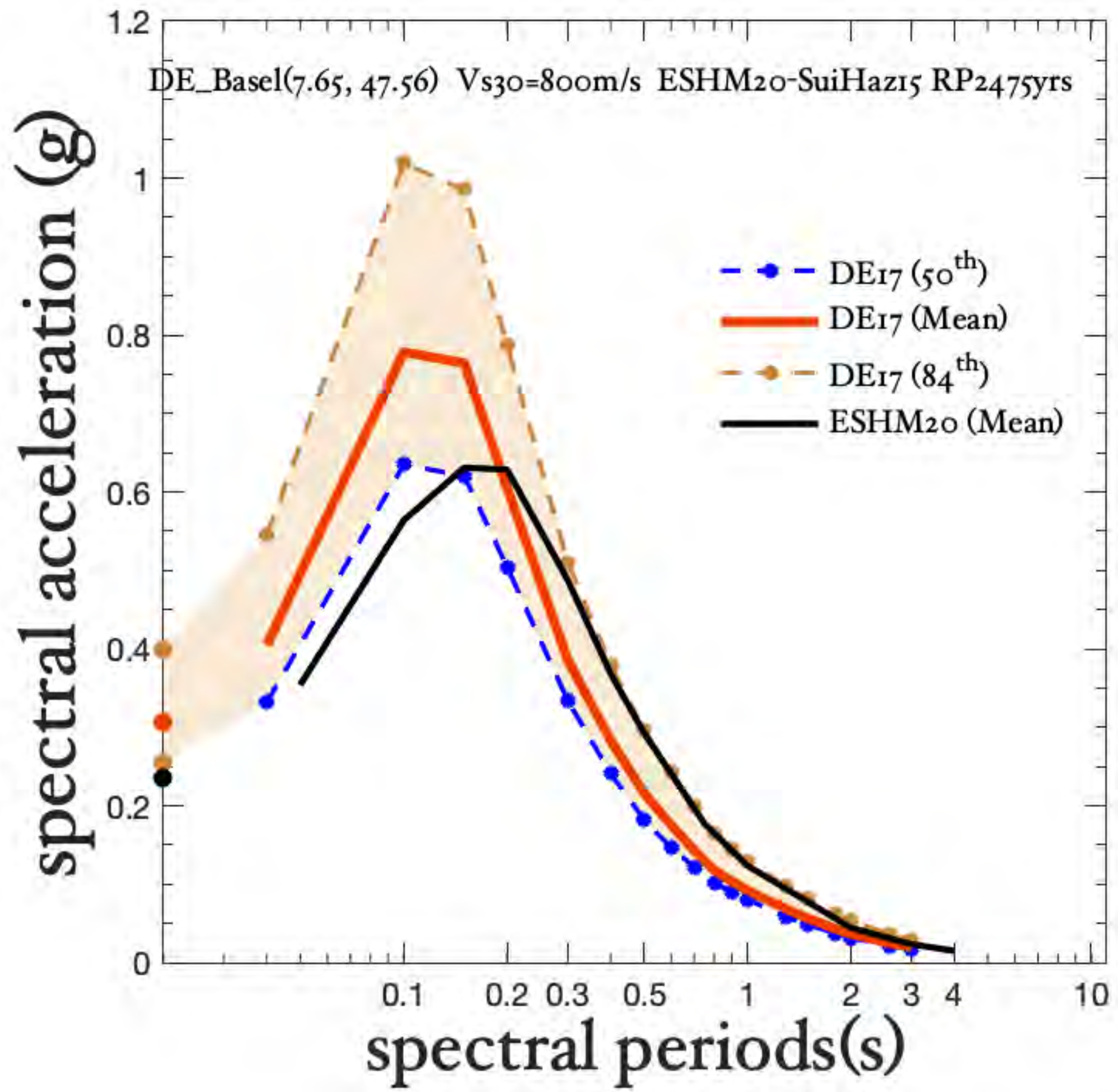


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.





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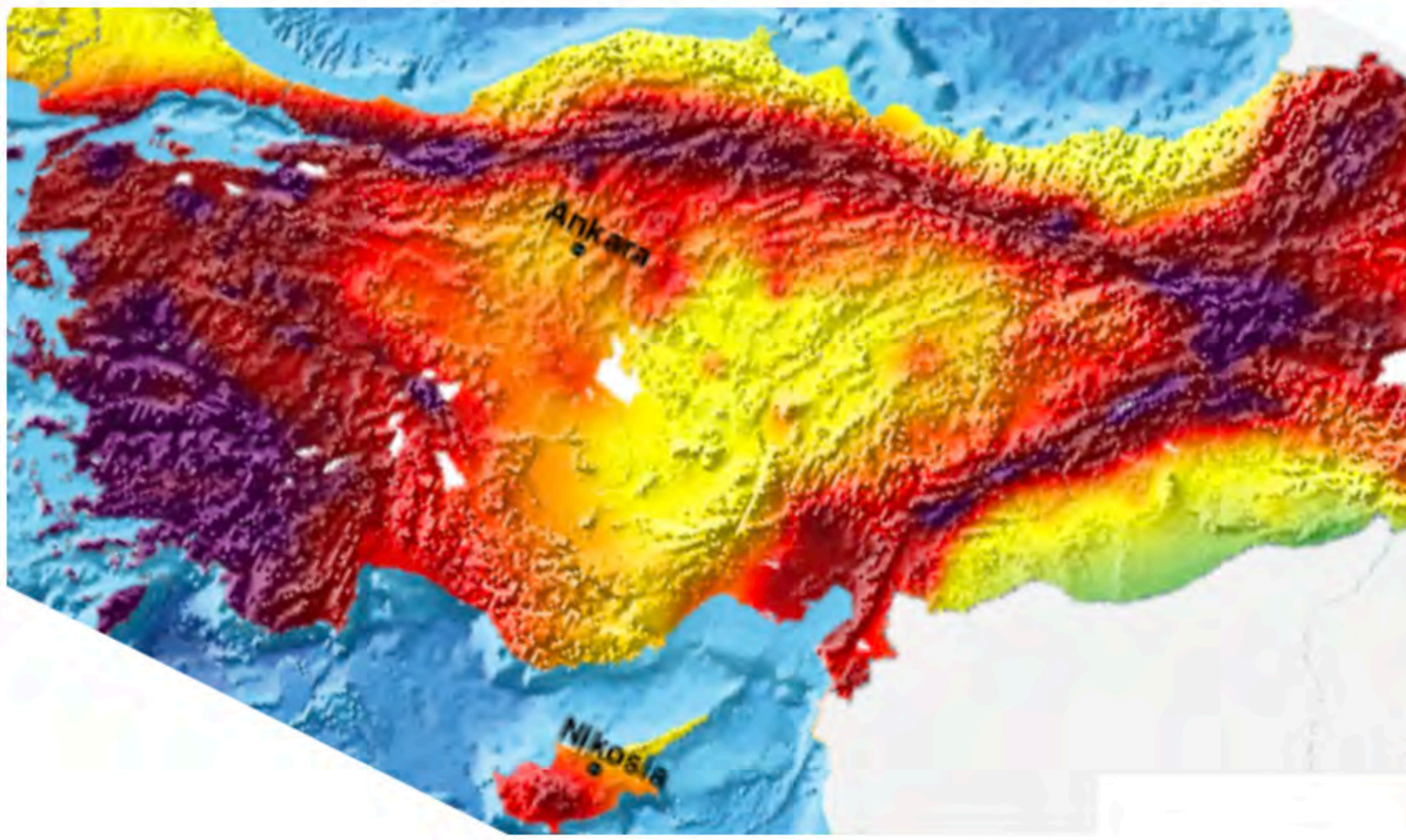
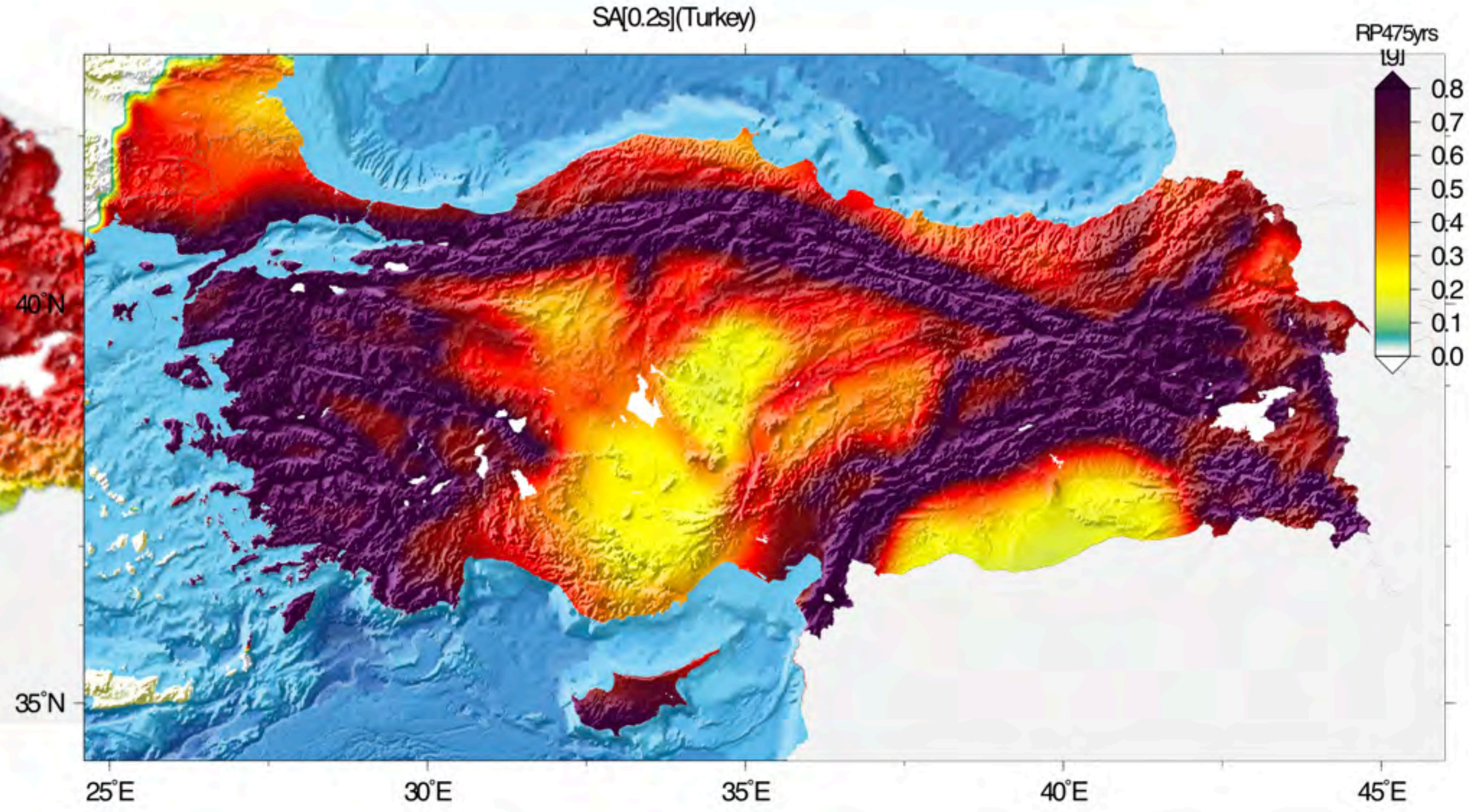
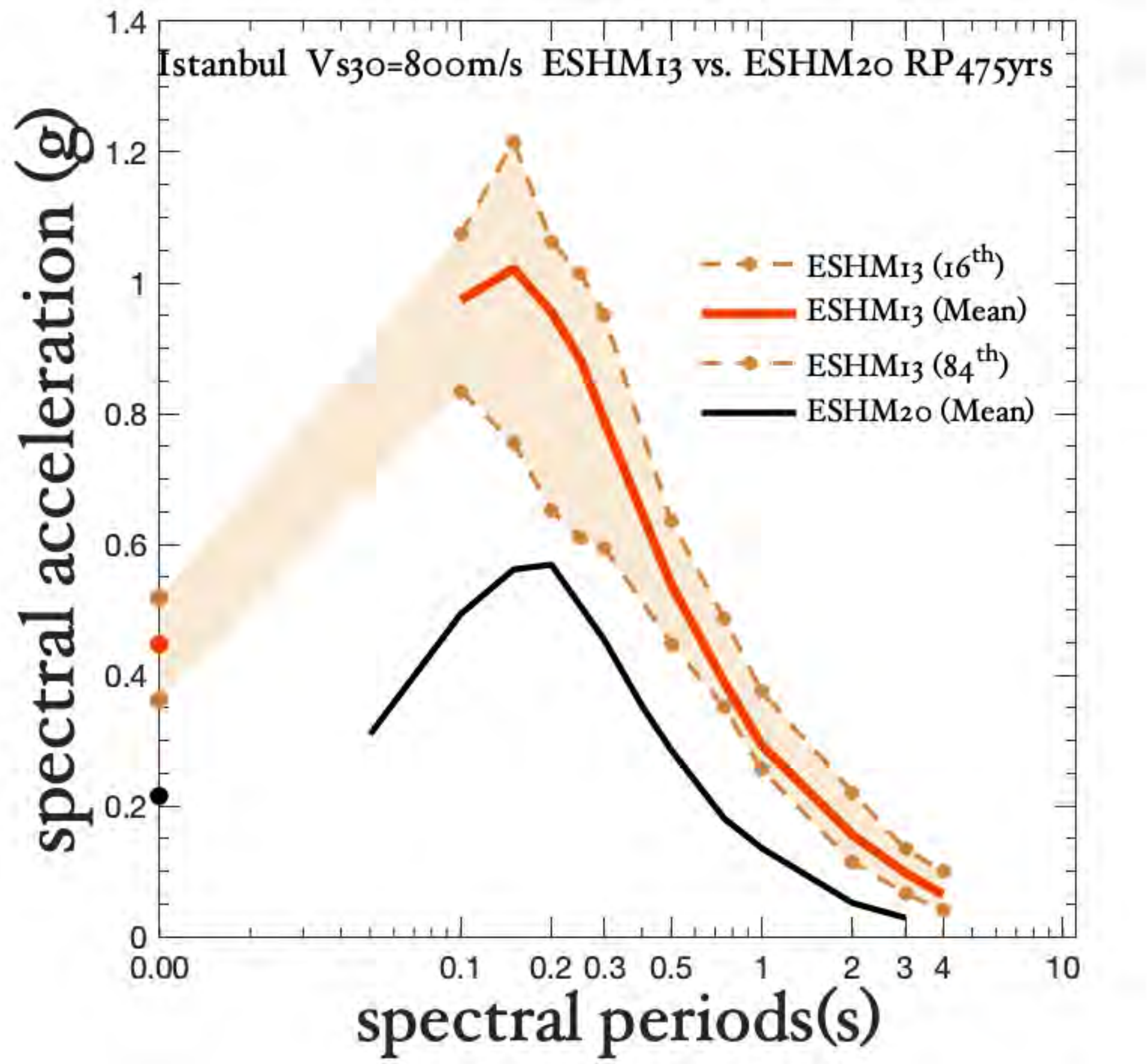
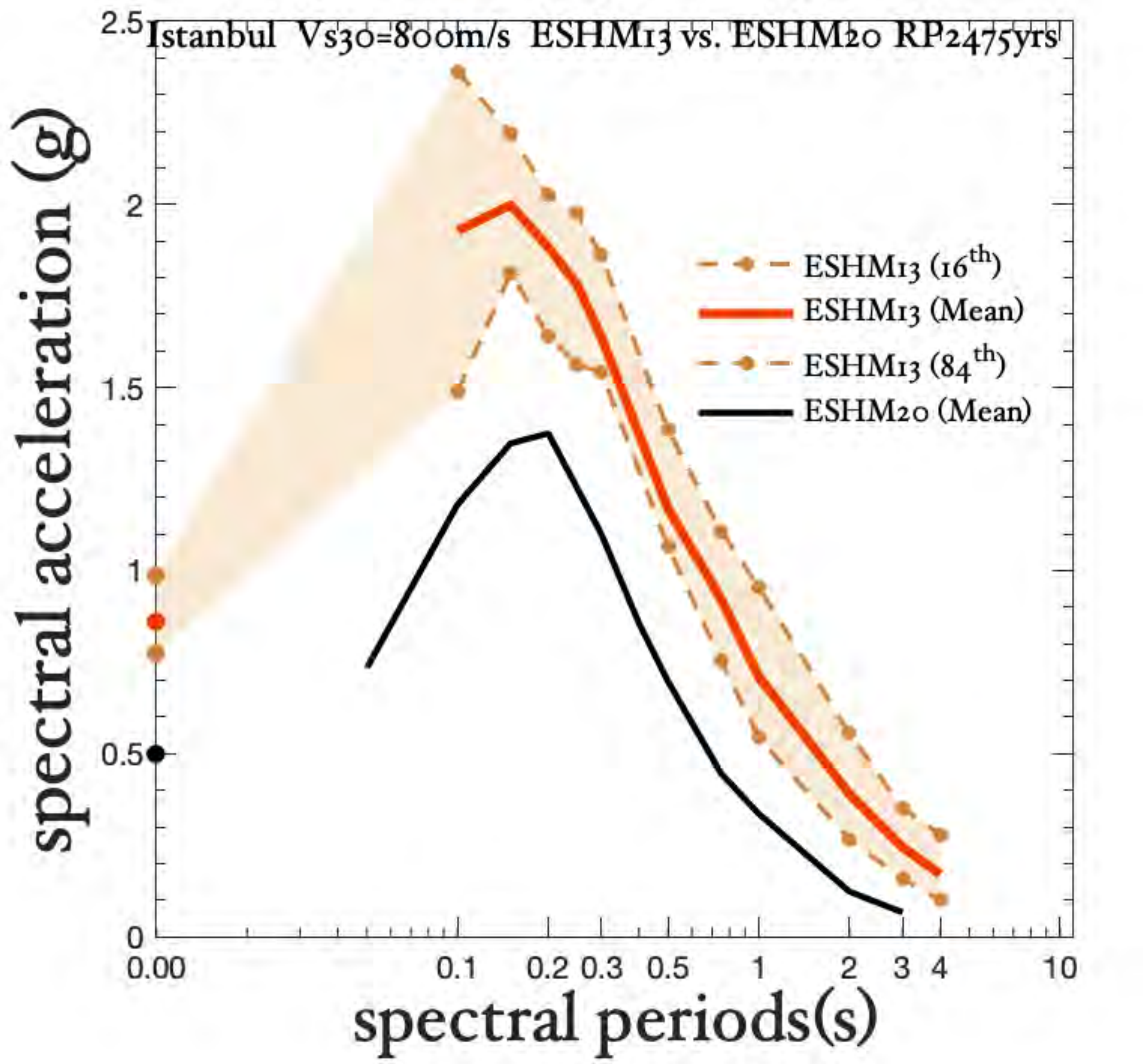




ESHM20 vs TSHM18(Sesetyan el at 2018)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.





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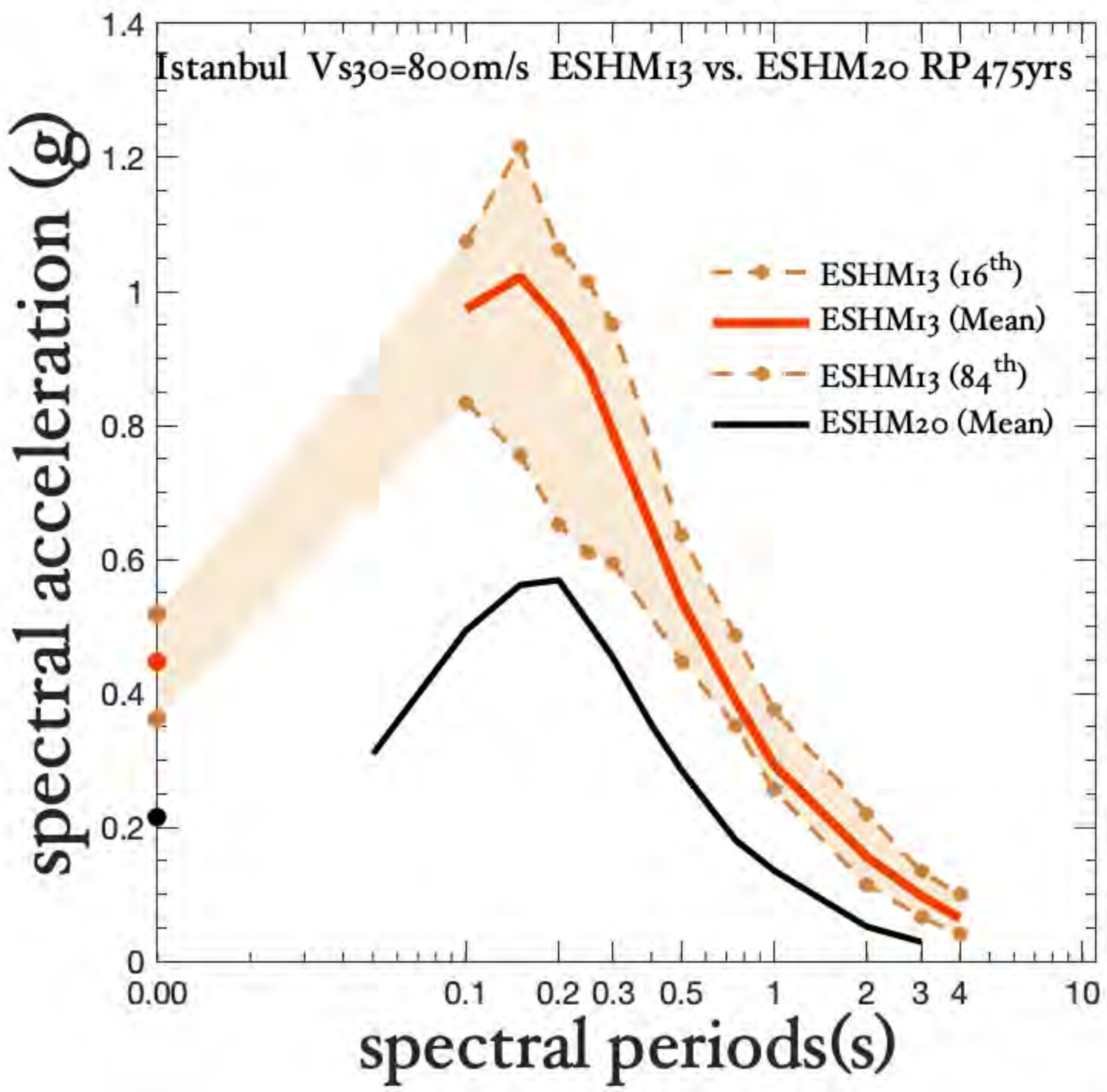
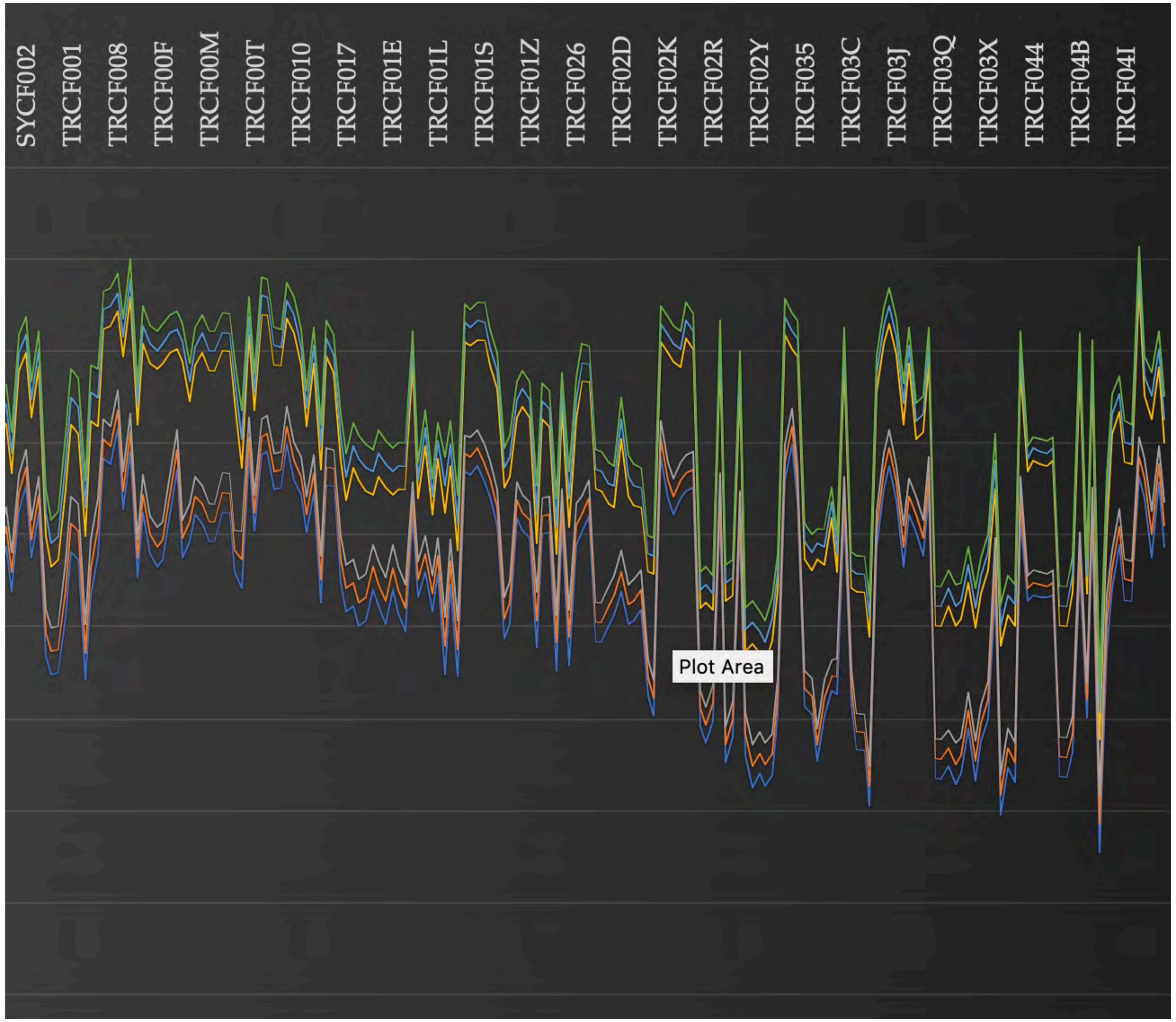




Faults Activity

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.

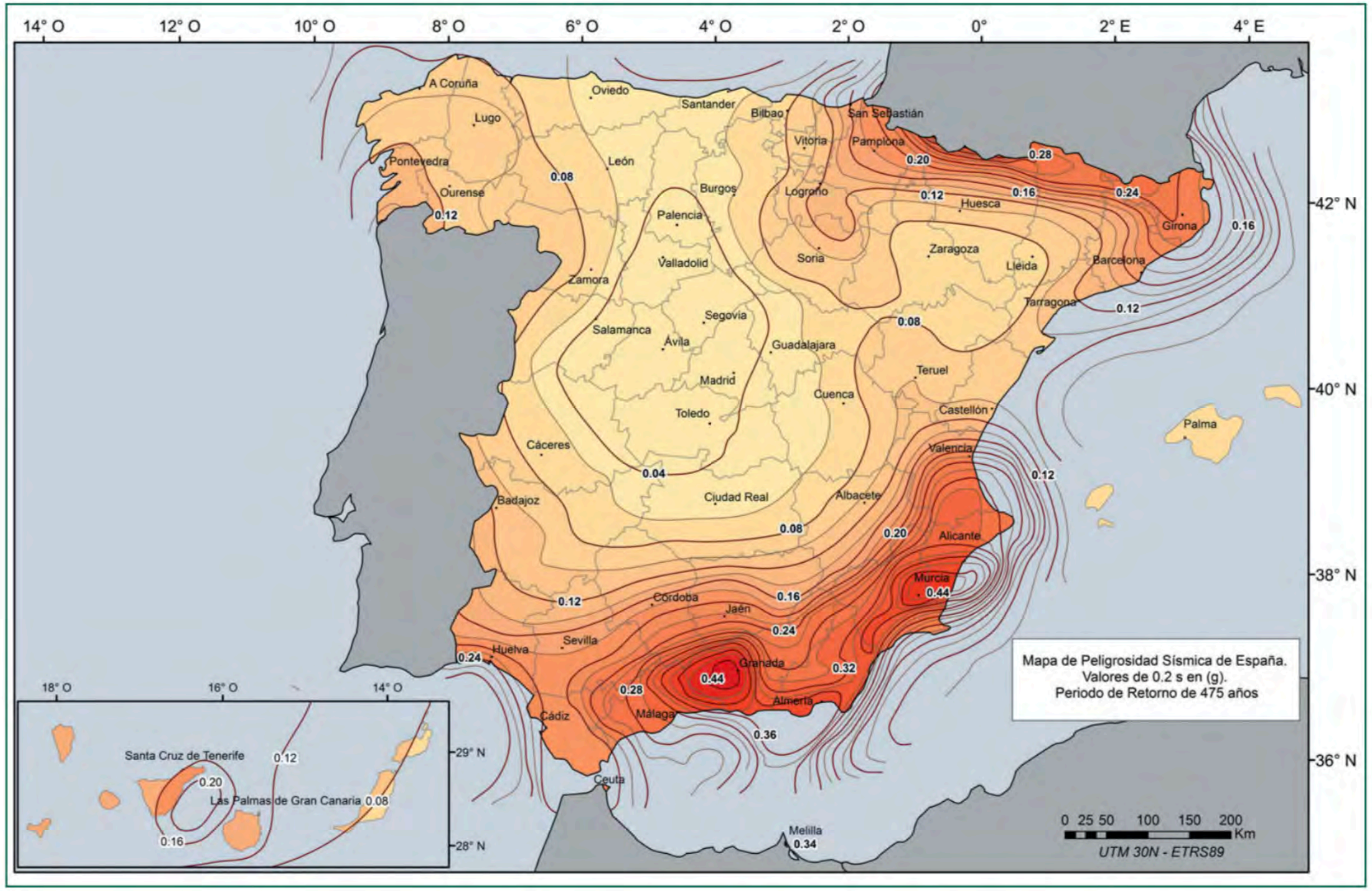
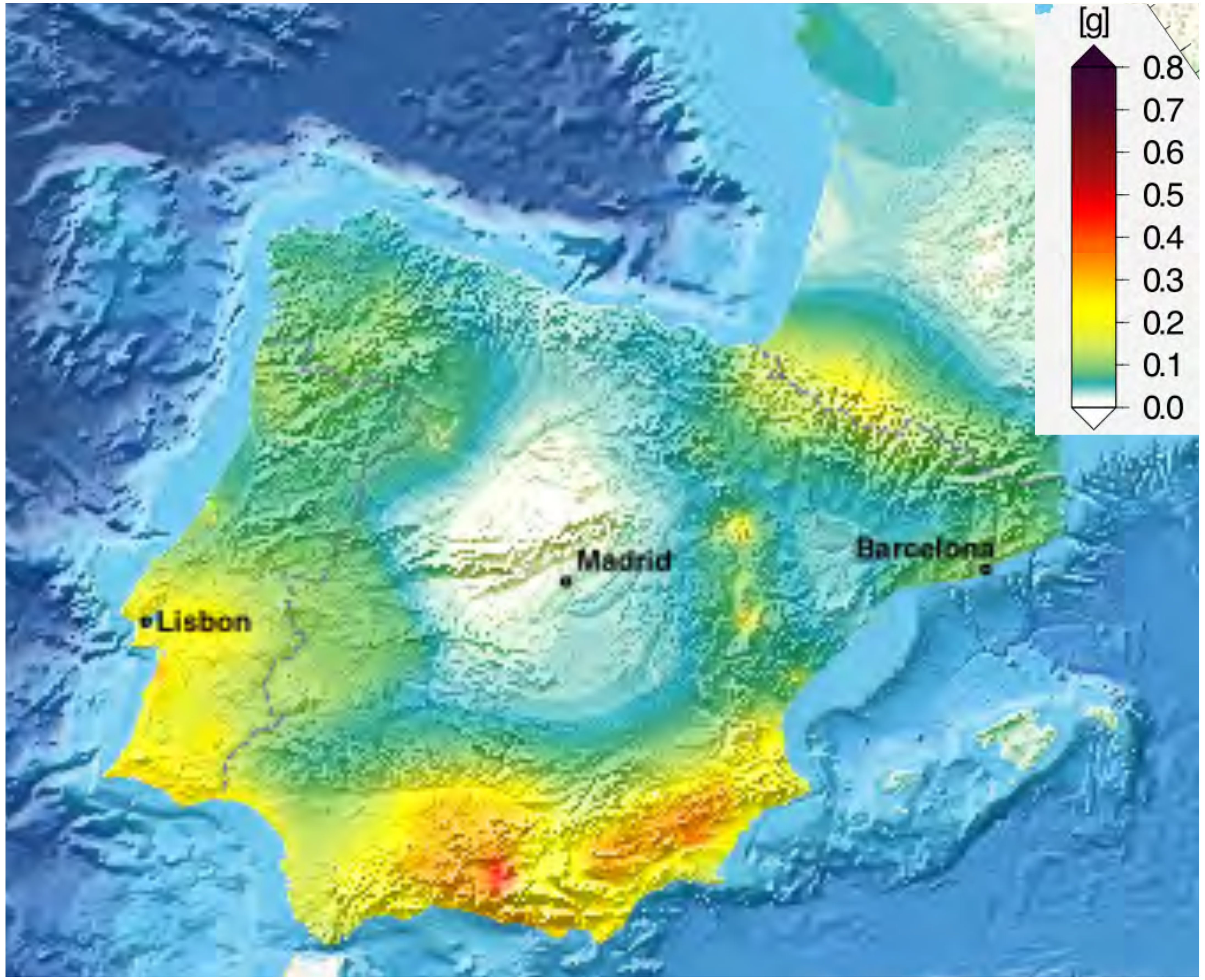


Figura 56. Mapa de aceleración espectral de periodo 0.2 segundos (SA(0.2s) para un periodo de retorno de 475 años.



ESHM20 vs SPAIN12 (María Belén Benito Oterino, et al2017)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.

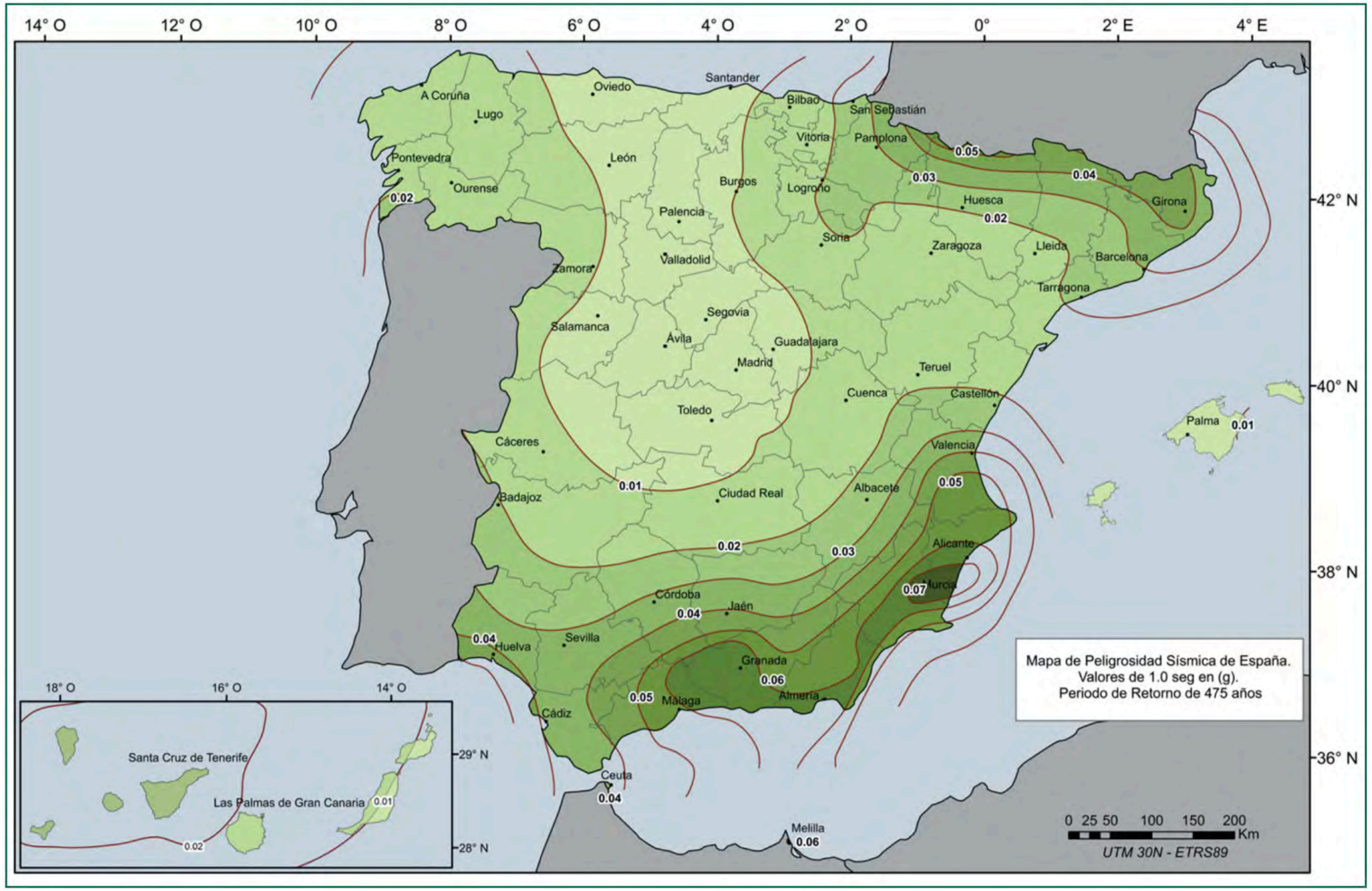
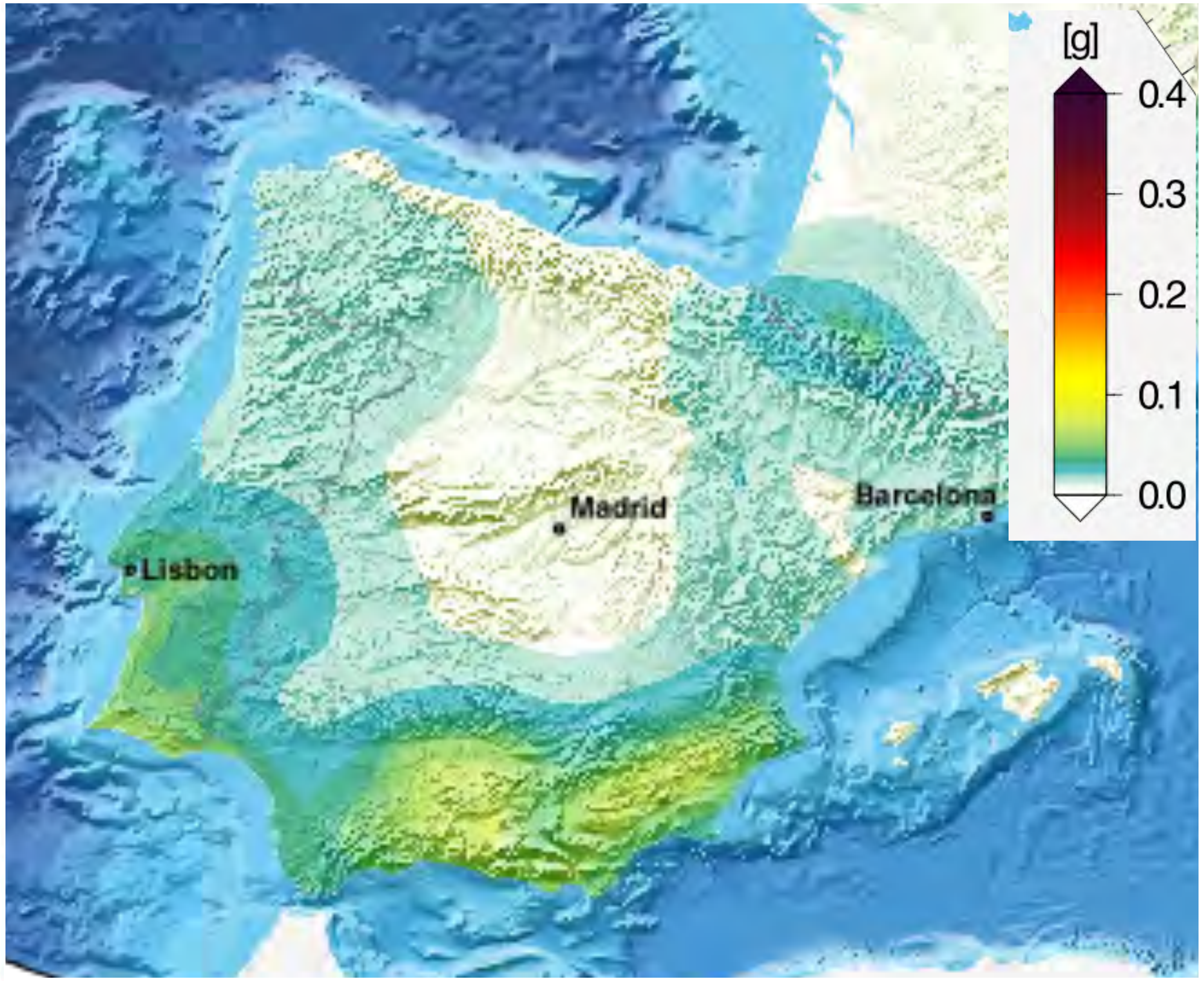
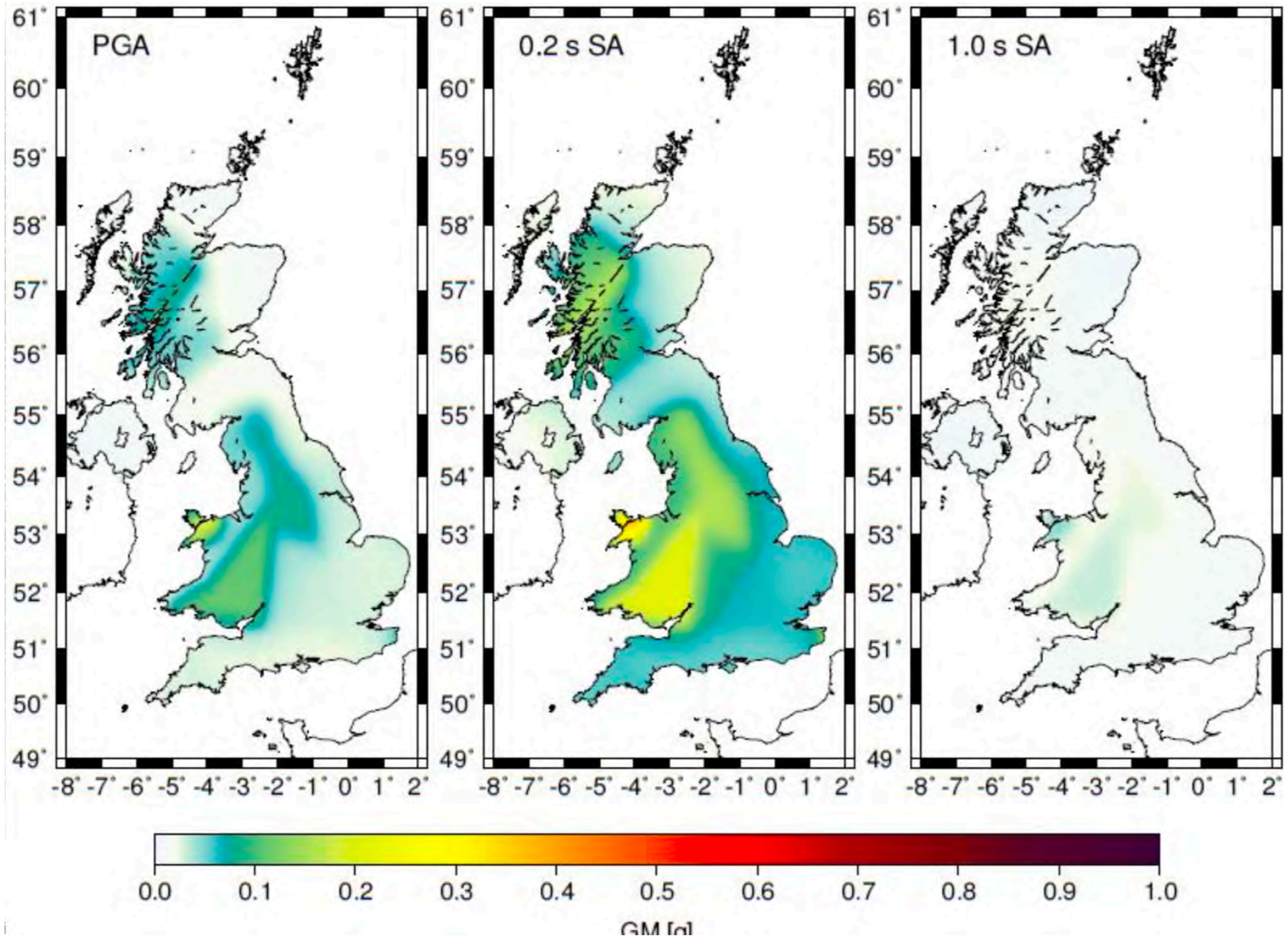


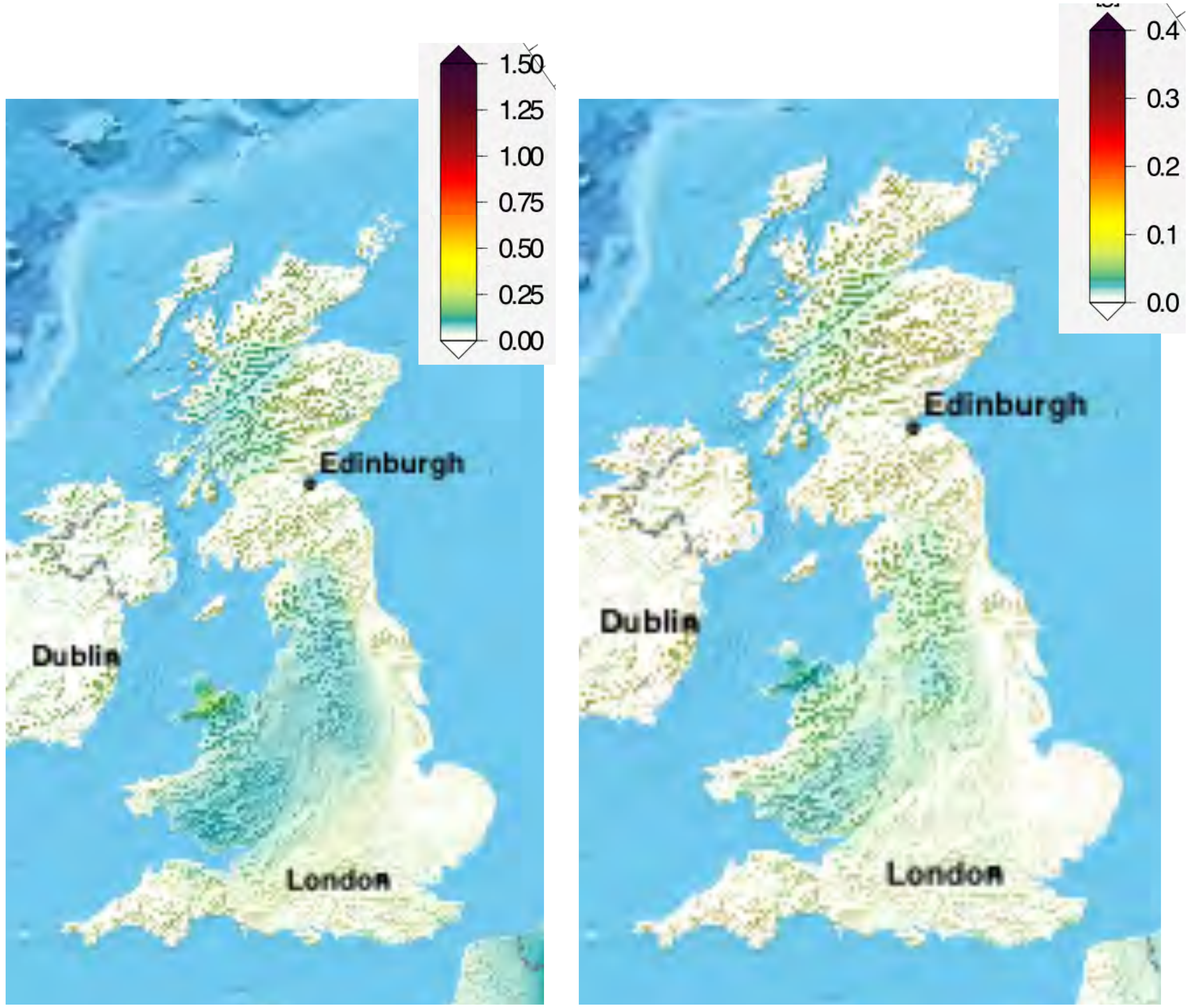
Figura 58. Mapa de aceleración espectral de periodo 1.0 segundos (SA(1.0s) para un periodo de retorno de 475 años.



ESHM20 vs TSHM18(Sesetyan el at 2018)

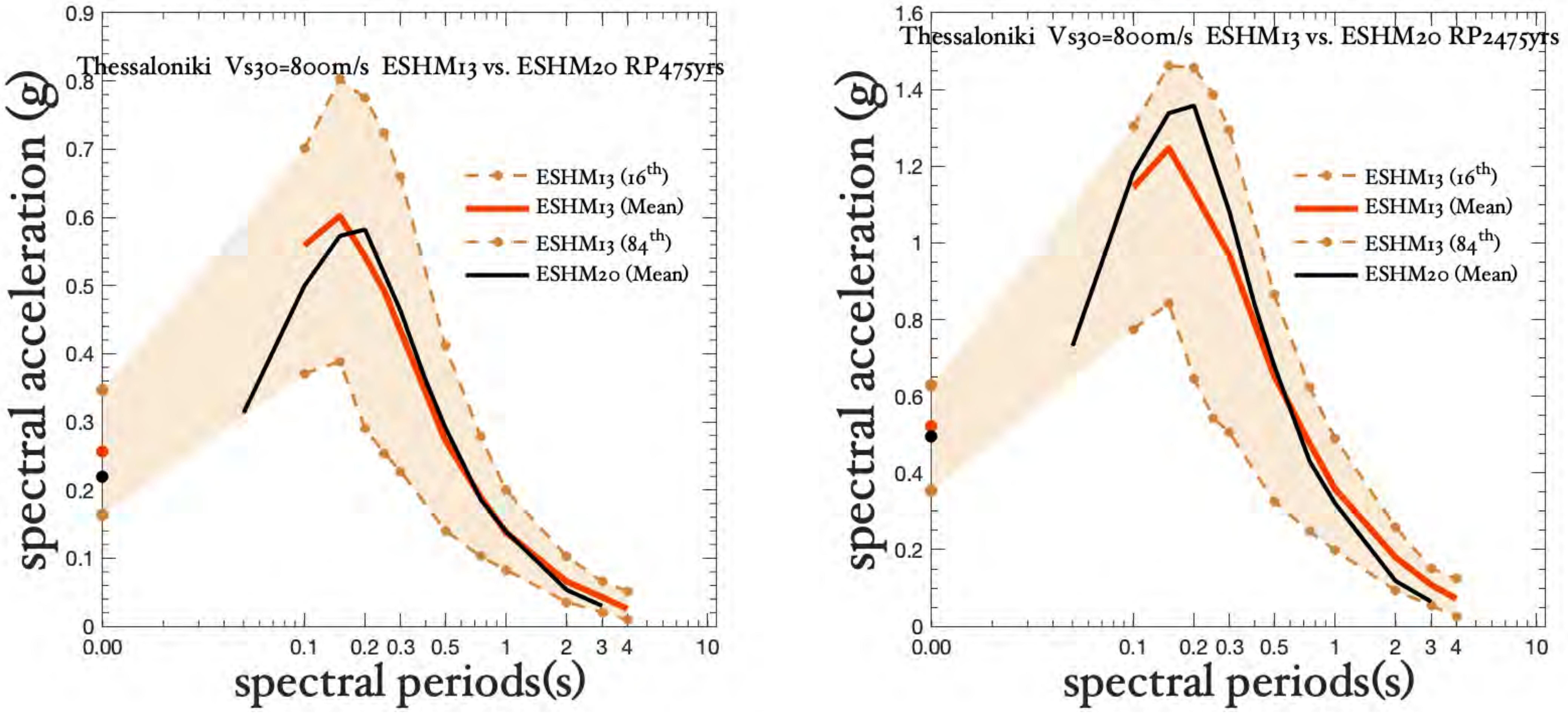
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.



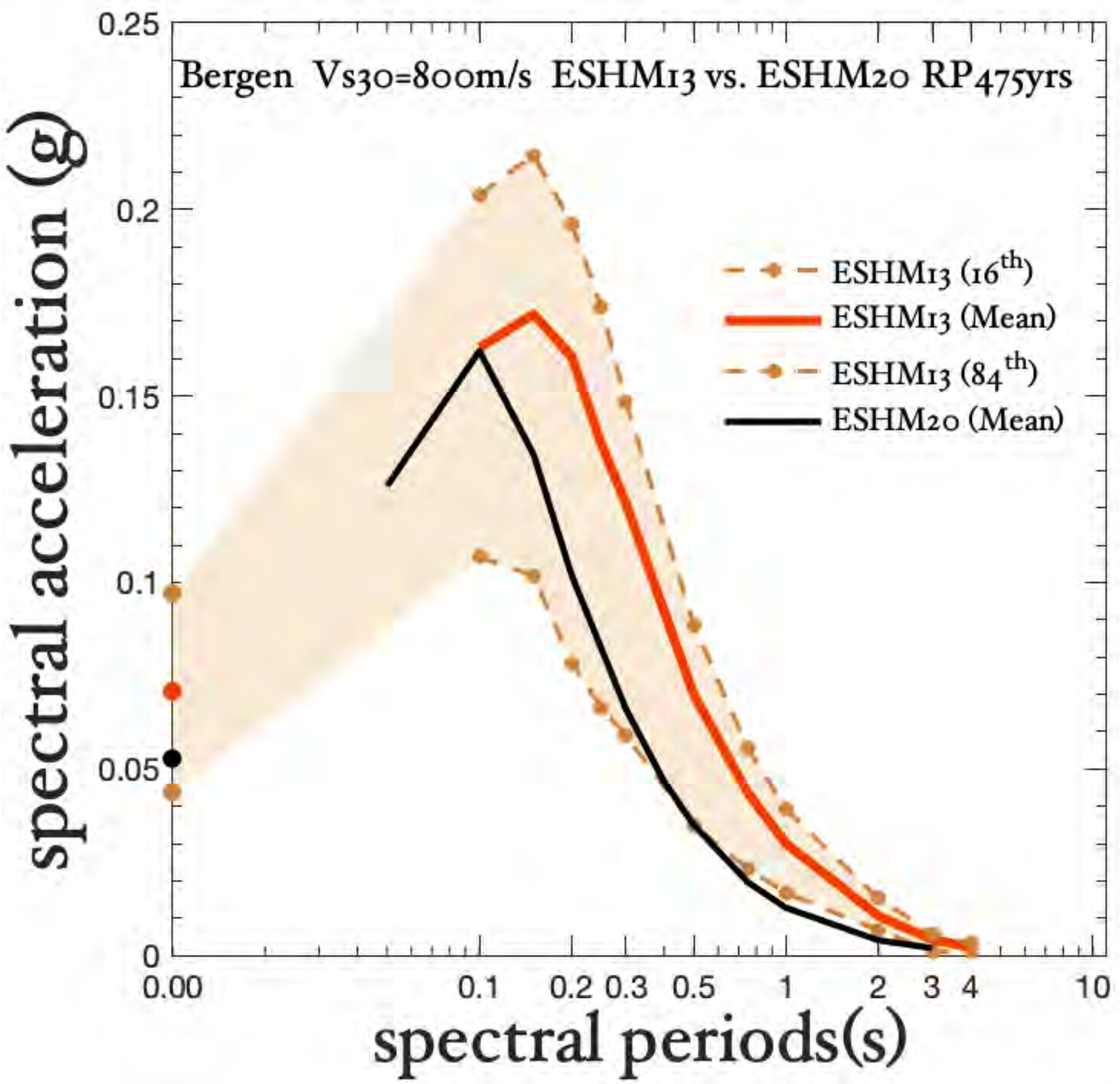


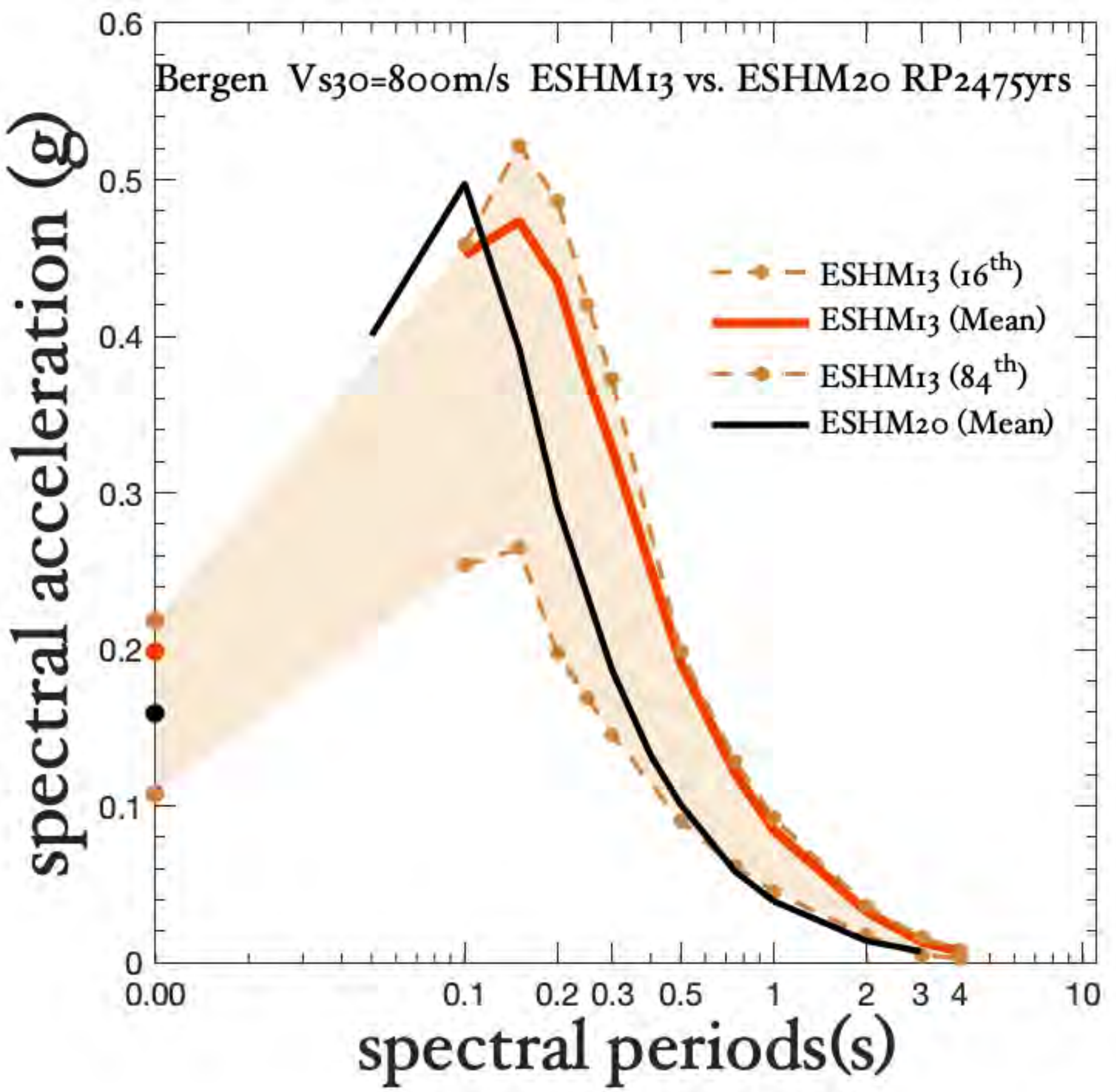
ESHM20 vs National seismic hazard maps for the UK: 2019 update(Ilaria Mosca)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.

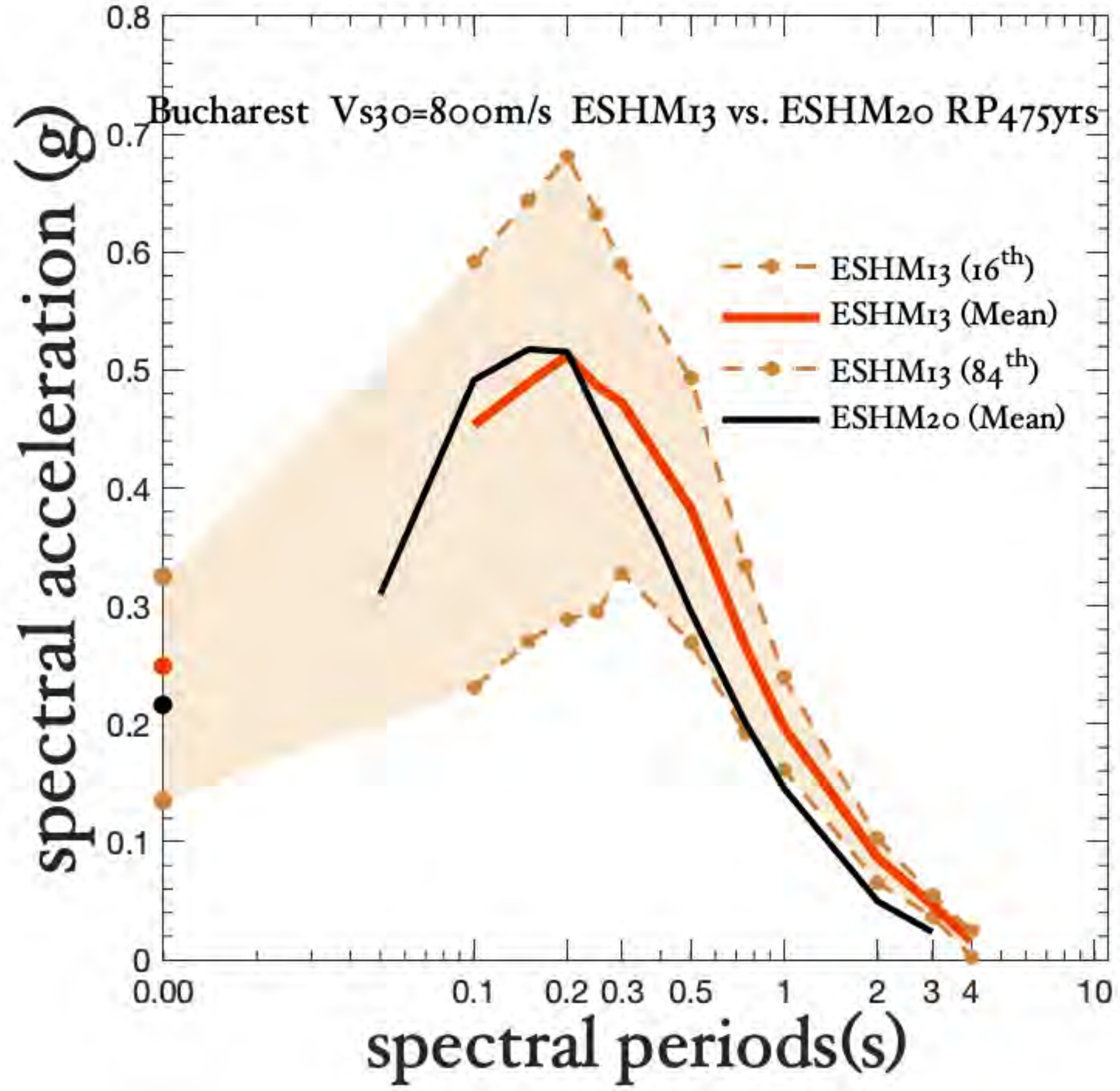


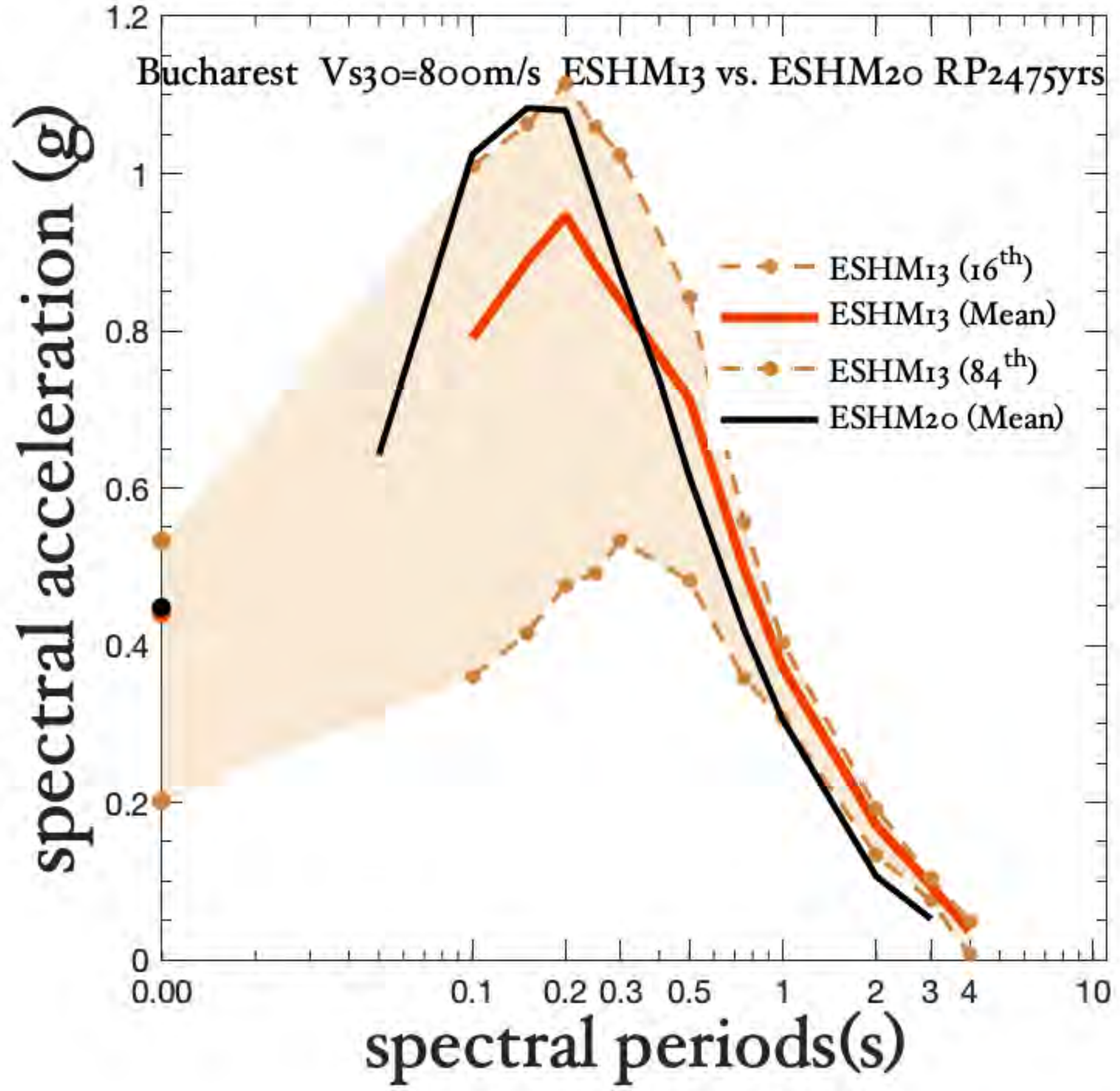
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.





This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.





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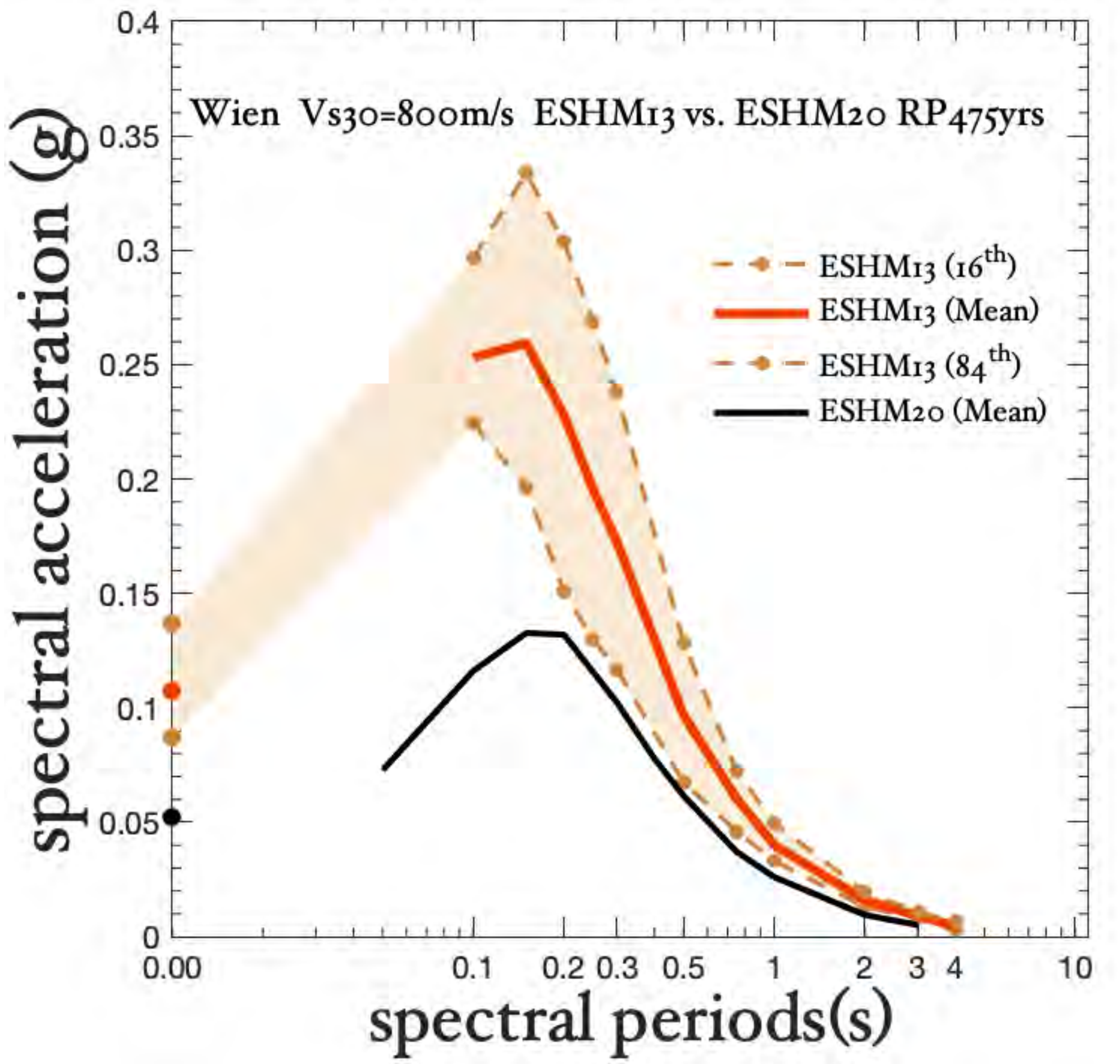
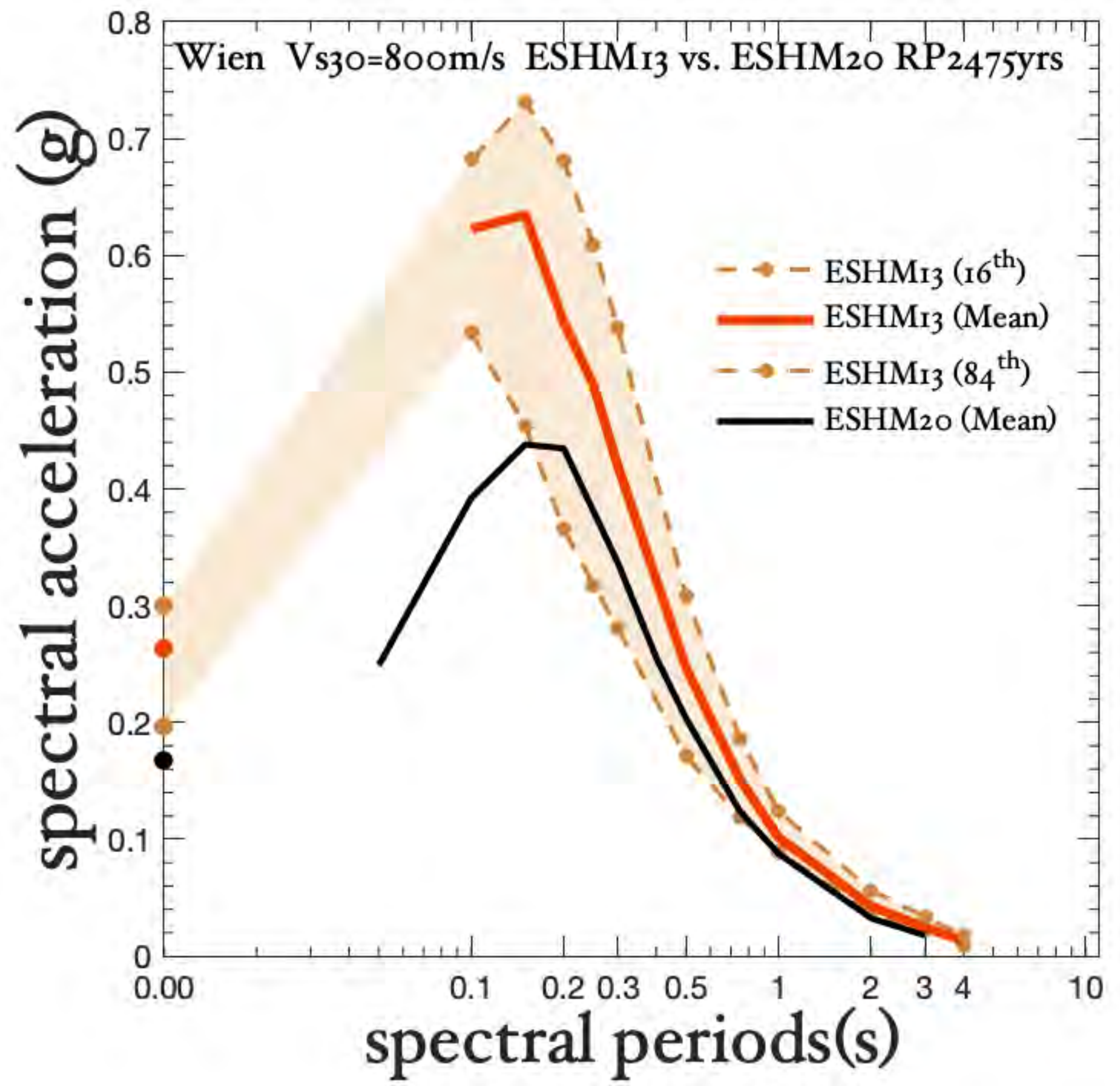
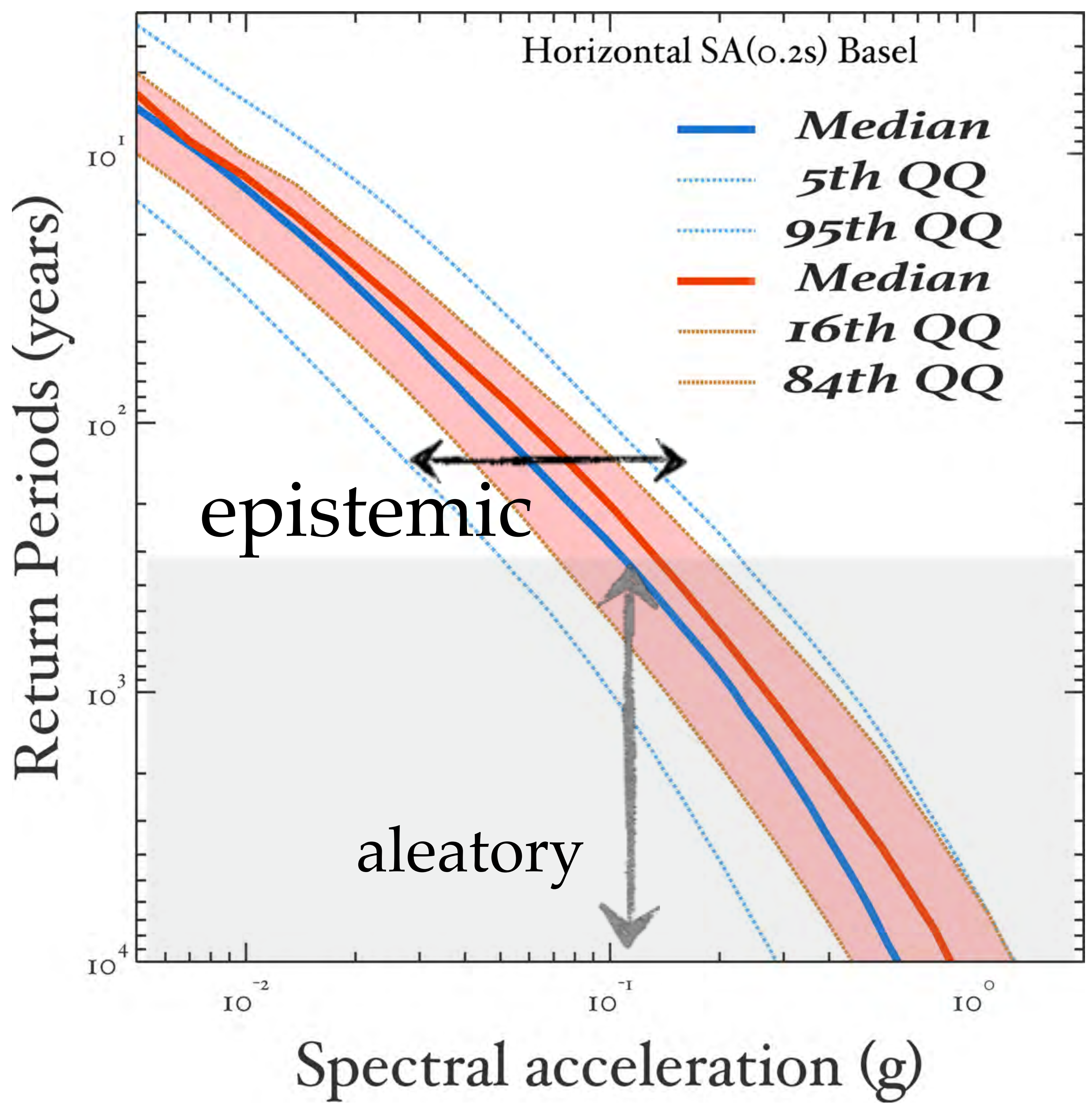
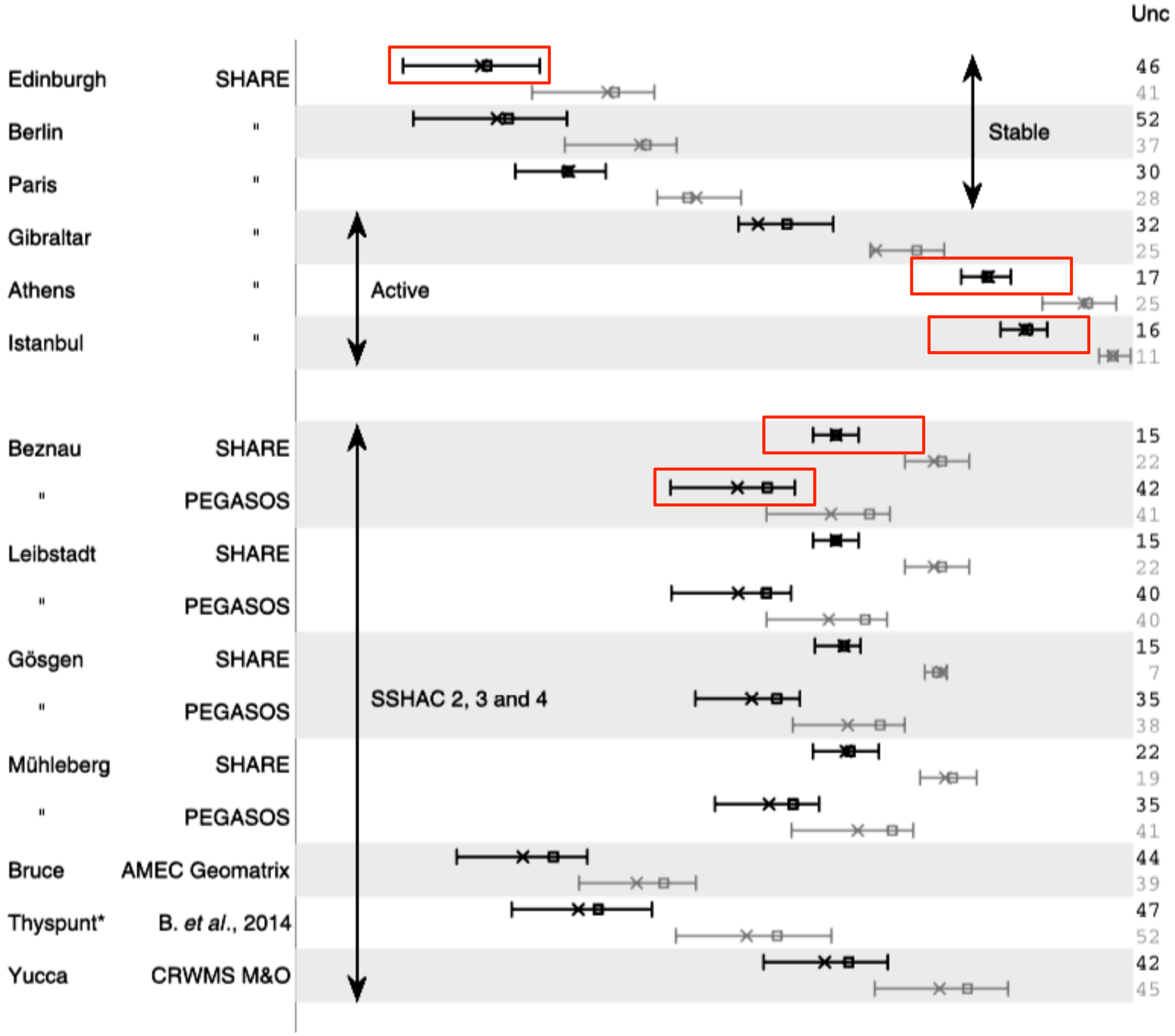




This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.

ESHM20 Hazard Calculation Model: Range of Uncertainties

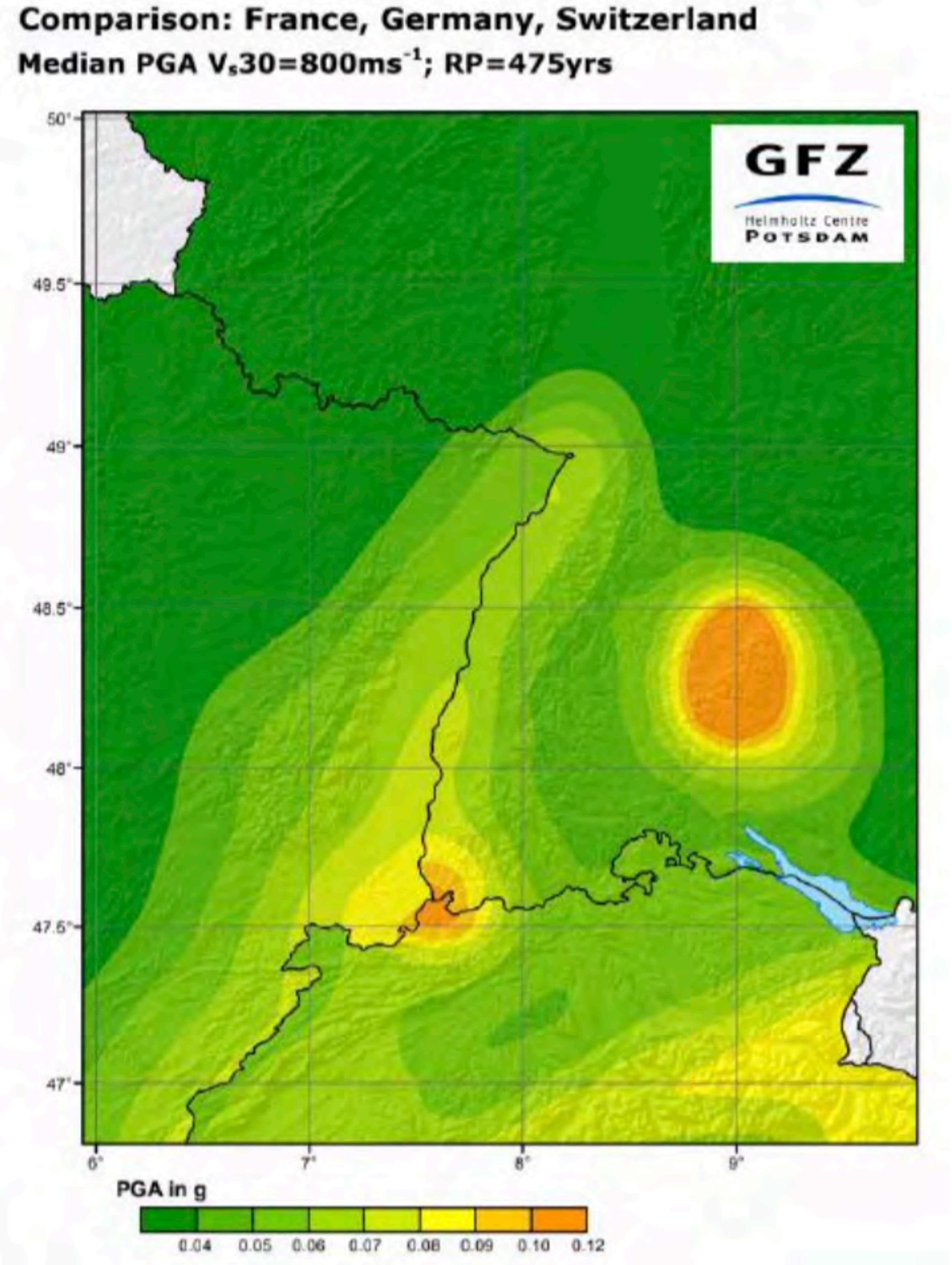


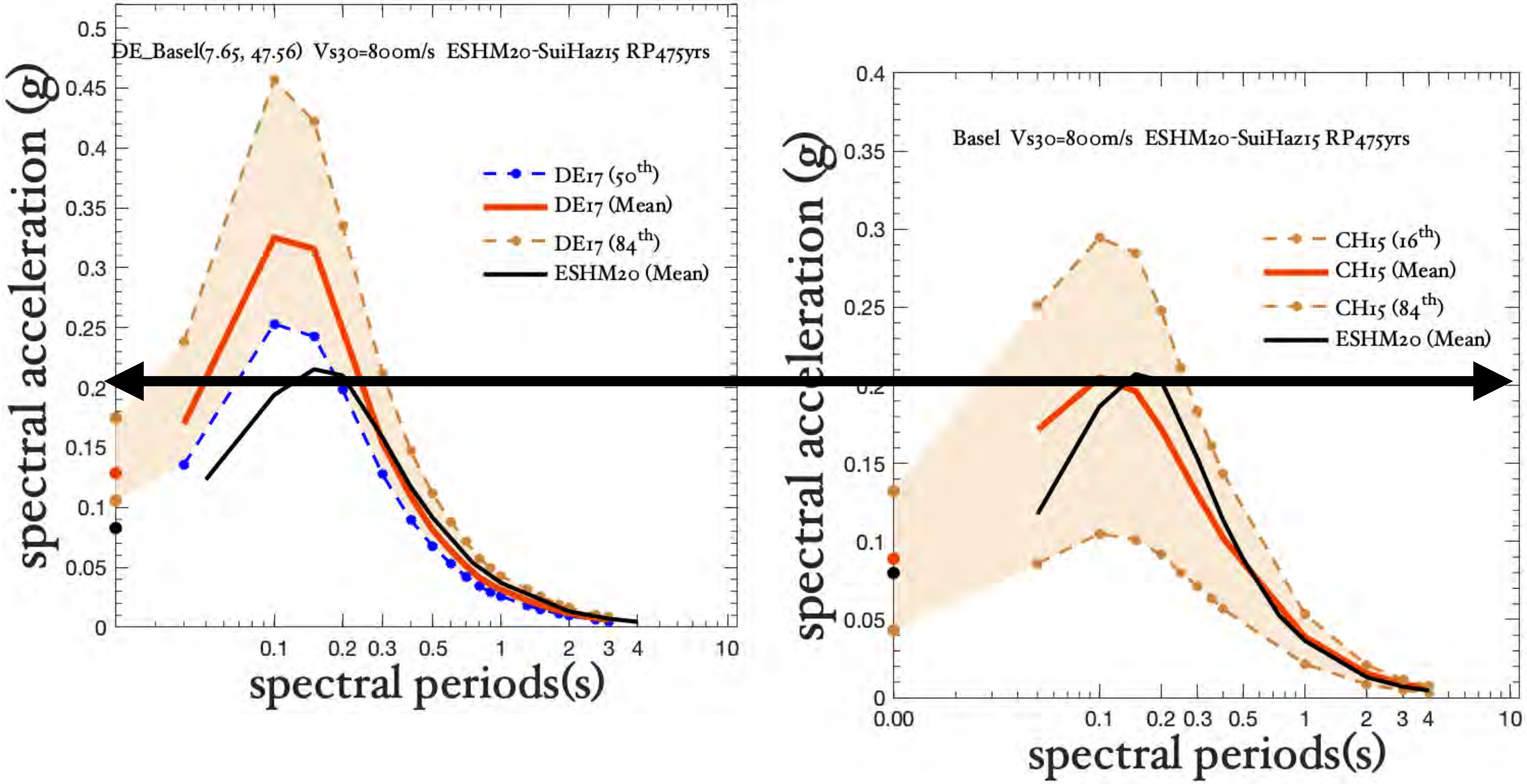


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.

ESHM20: Cross Border Harmonisation -

- Map harmonised between Germany-France-Switzerland





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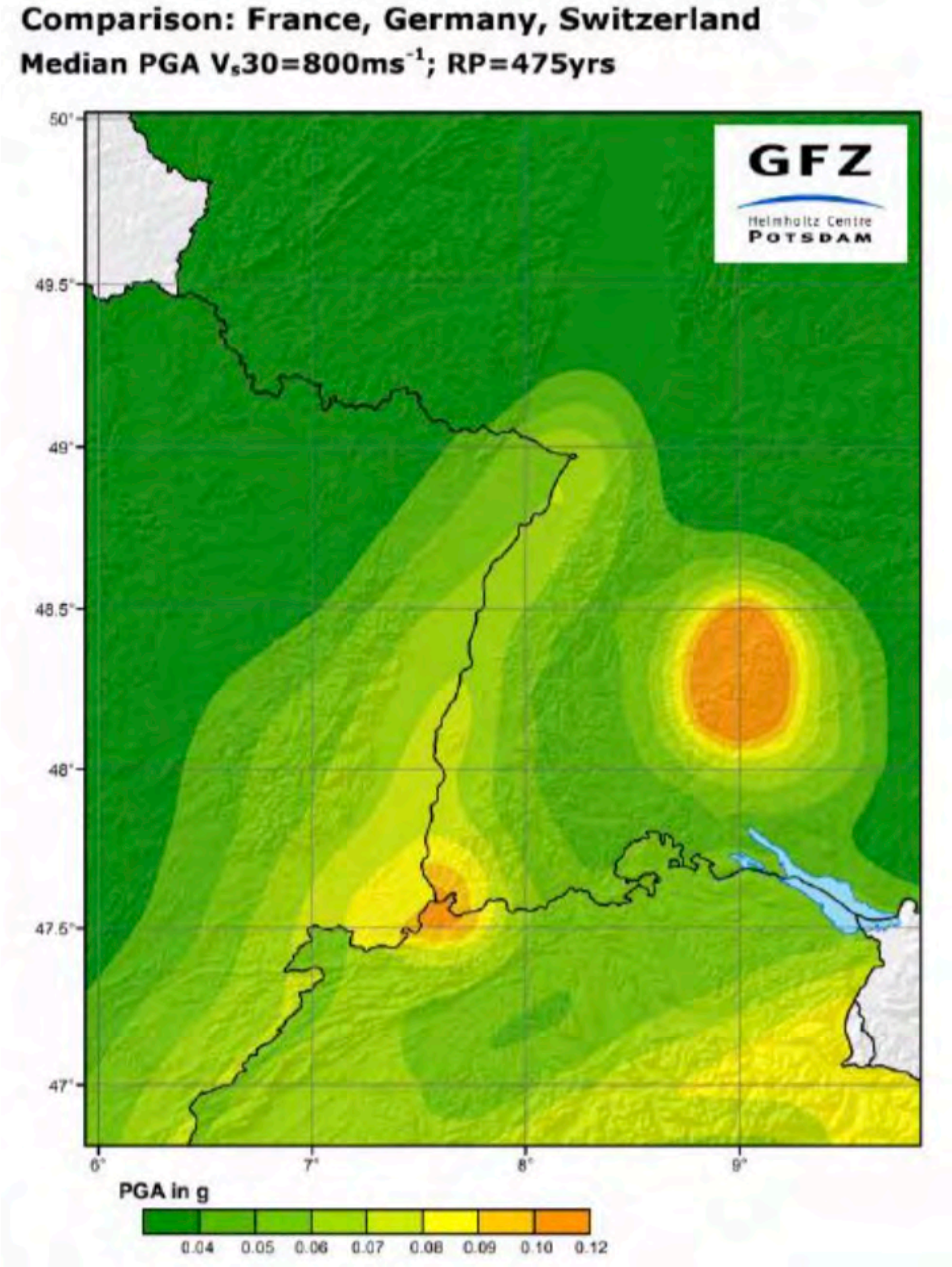
ESHM20: Cross Border Harmonisation -

- Map harmonised between Germany-France-Switzerland



ESHM20 - is the **harmonised** the seismic hazard model at European Level

- different datasets, mainly the earthquake catalogue or different choices of the ground motion models than those at the national models

What are the **implication** of the updated probabilistic seismic hazard estimates in Europe

- Seismic design codes (national zonation and annexes, anchoring values and shape of design spectra)
- Risk assessment (urban or rural, damage distribution, economic losses)
- Safety assessment of critical infrastructures
- Other (…)

Hazard map in France (Drouet et al. in rev.) German hazard Model (Grünthal et al 2017)
Swiss hazard Model (Wiemer at al, 2015)

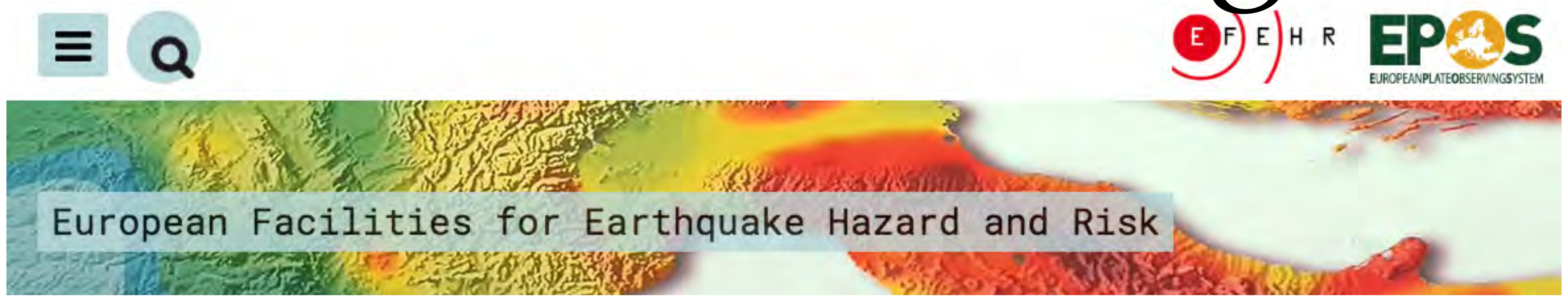
Courtesy to P. Traversa (EDF) , and S. Mak (GFZ) SIGMA2

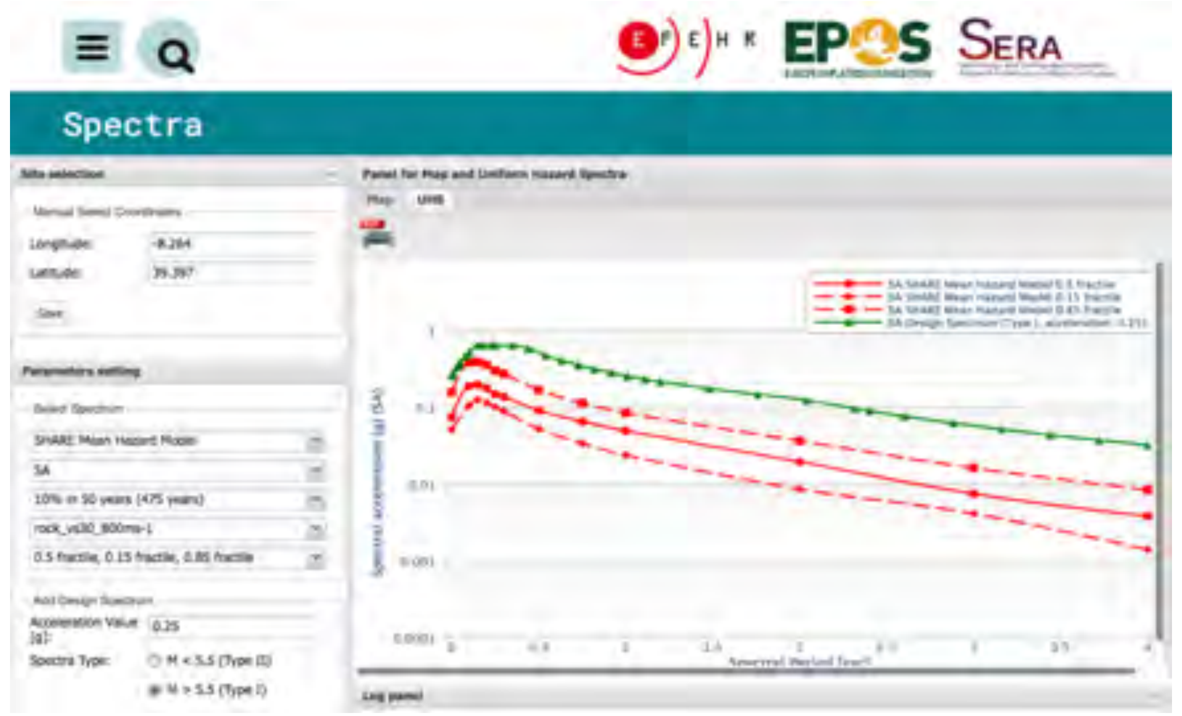
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730900.

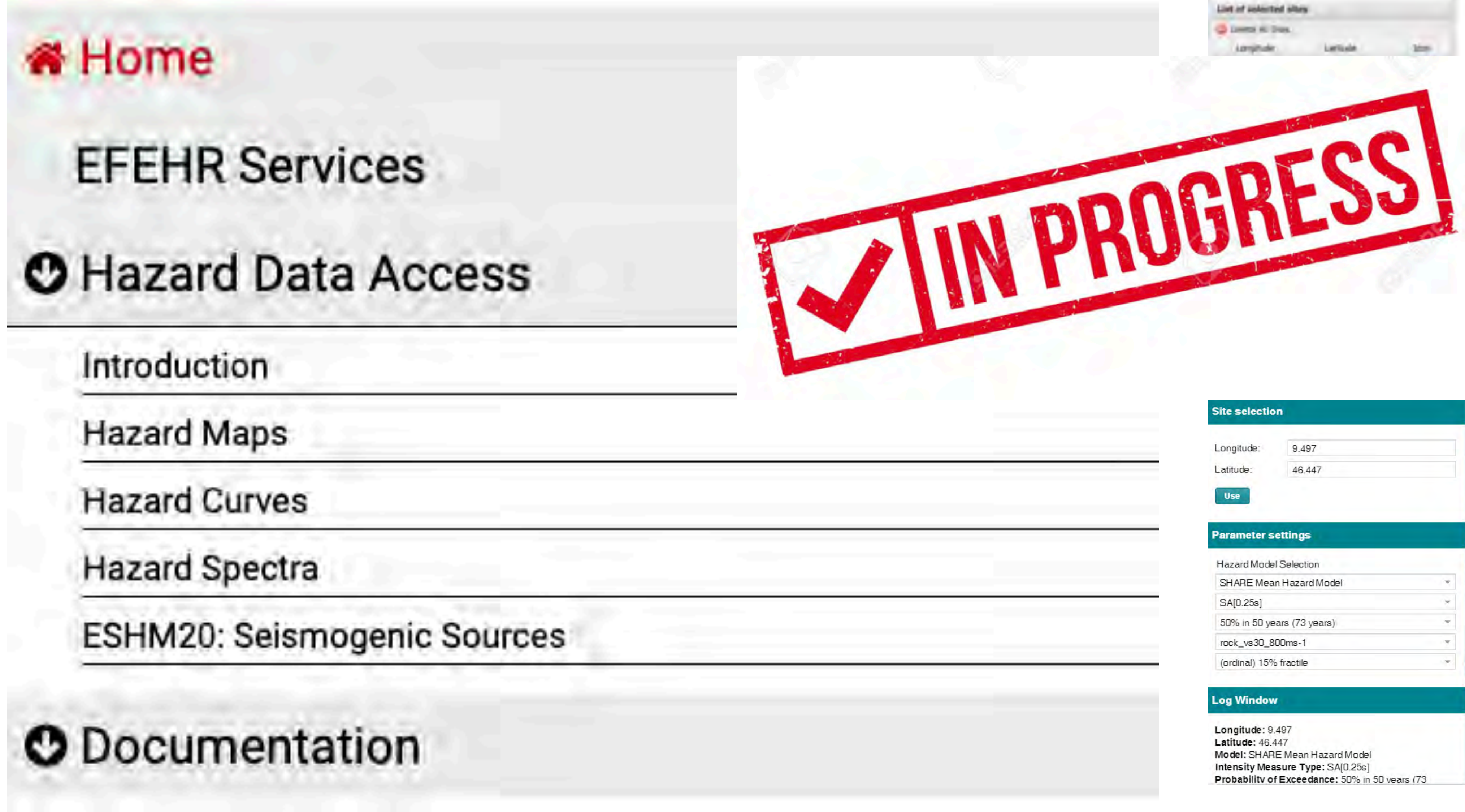
ESHM20: Next Steps

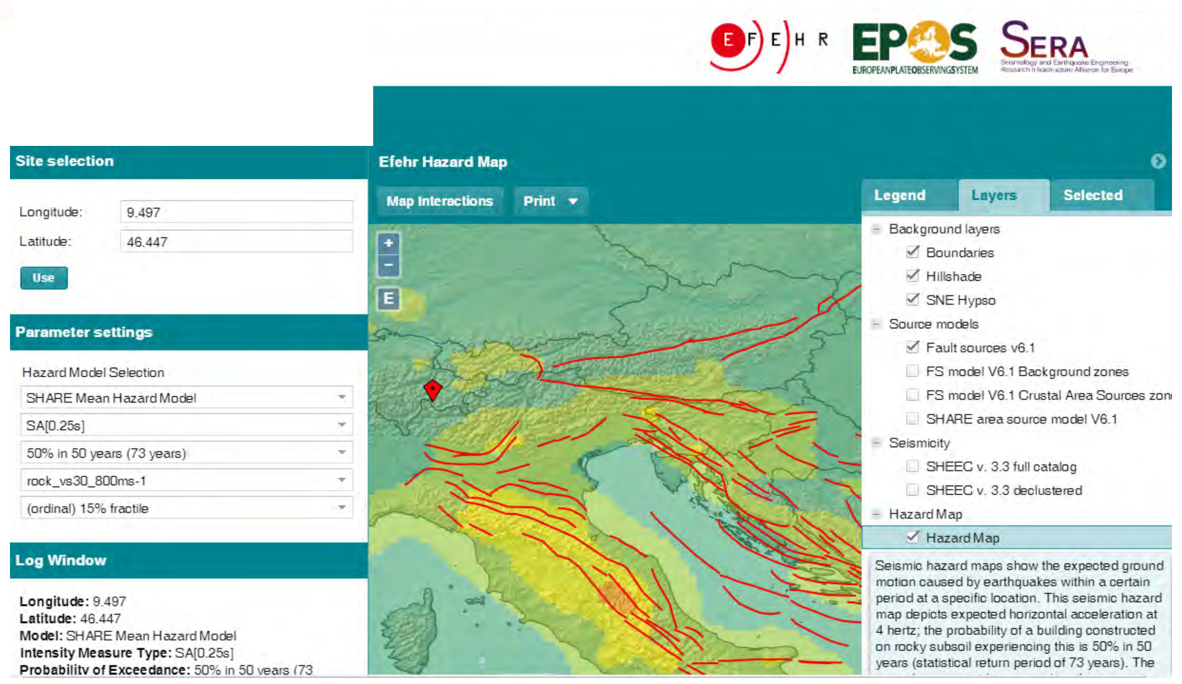
www.efehr.org

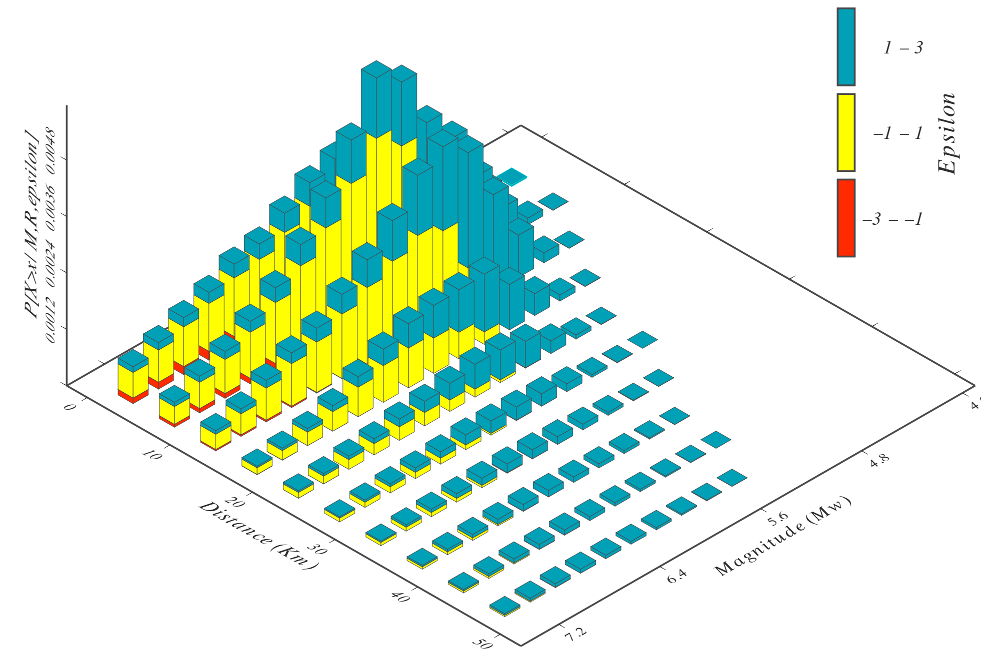
- **Final Calculation [February 2020]**
- **ESHM20 output and products [March 2020]**
- **ESHM20 — Release Model [April 2020]**











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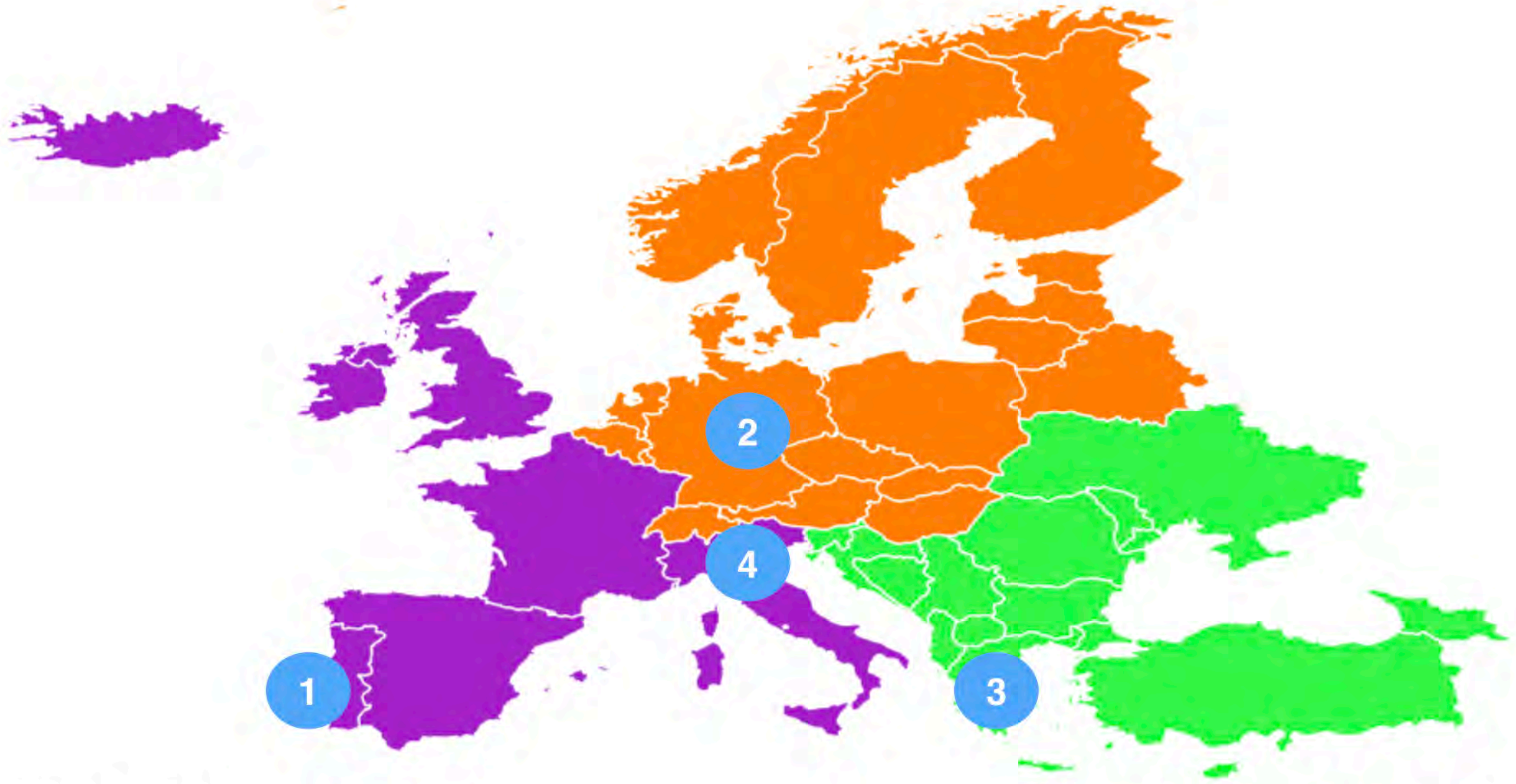
ESHM20: Next Steps

- Update and Finalise (input datasets, seismogenic sources)
- Finalise the seismic hazard calculation to consider the entire logic tree [October]
- Sensitivity Analysis [March 2020]
- Procedure of defining the average SA
- Online access to preliminary data (End October)
- Comparison with National Models [November 2019]
- Send to national experts for review and feedback [end November 2019]
- Receive & Implement Feedback ESHM20-Alpha Model[January -February 2020]



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SERA- Project JRA3: status of activities

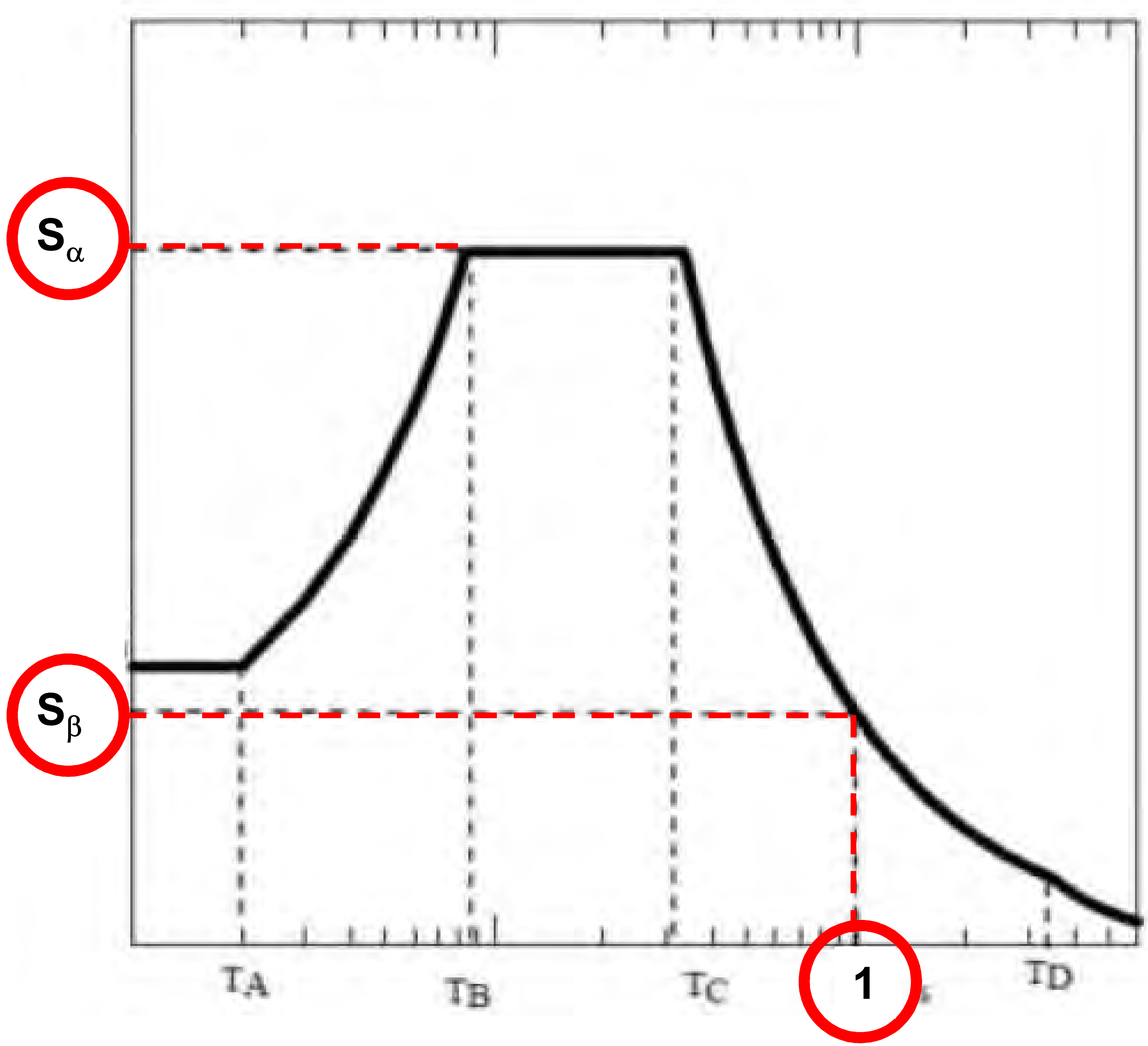
ESHM20 *alpha version* **(Pavia Version October 2019)**	**ESHM20** *Beta version* **(March 2020)**	**ESHM20** *Final version* **(Summer 2020)**
Updated and Cross Border Harmonised Input Catalogues	Revised Input Datasets: faults, Earthquake catalogue (if needed)	Final Input Datasets
Cross Border Harmonised Seismogenic Sources	Consolidated Seismogenic Sources and Ground Motion Models	Final Seismogenic Sources and Ground Motion Models
Newly developed Ground Motion Models		
Output: Informative, not for distribution, not for use	Outputs not for distribution, for use within the scientifical and technical community, SC8 working group, national experts	Main Products released to SC8 commitee Outputs free for distribution and use

SERA-SC8 Workshop, Pavia, 14 October 2019

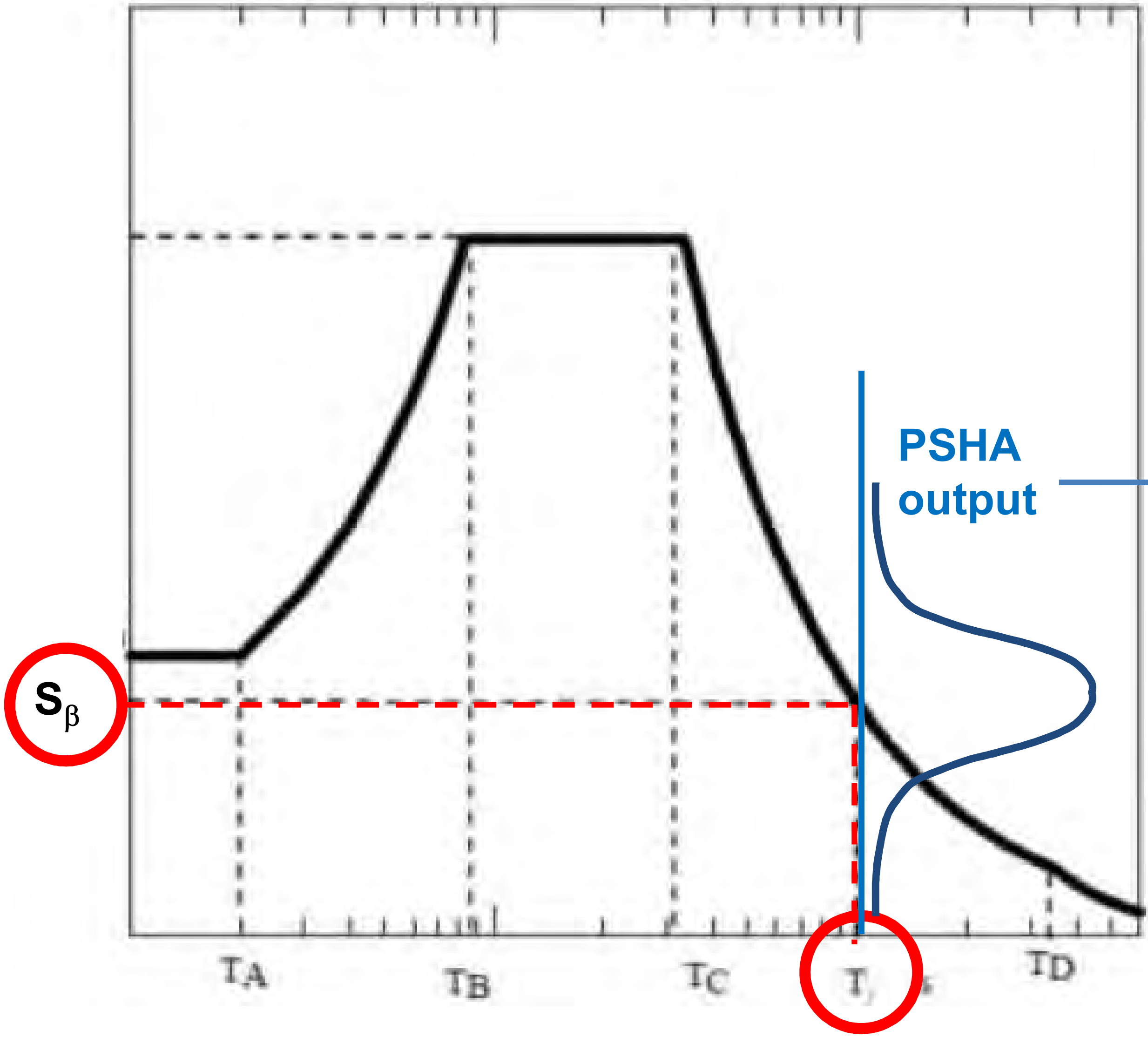
SC8 objective of seismic hazard maps in a possible EC8 informative annex

Pierre Labbé

Standard spectral shape



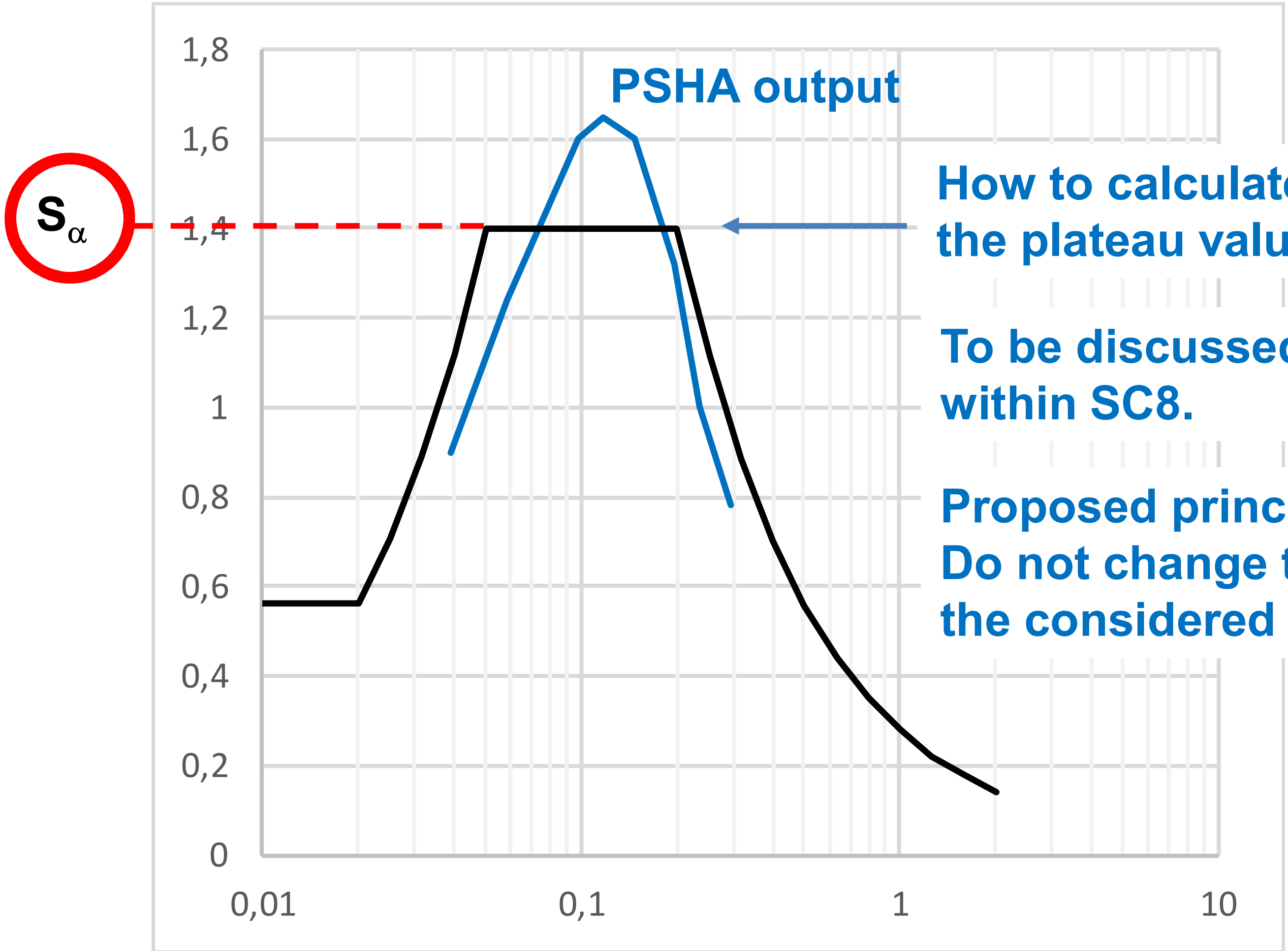
From PSHA to S_α and S_β



Mapped value

To be discussed within SC8 and with SC0

From PSHA to S_α and S_β



How to calculate the plateau value ?

To be discussed within SC8.

Proposed principle:
Do not change the signal energy in the considered range of periods.

From PSHA to S_α and S_β

- Data at the disposal of SC8 members ?
- Way to access it?
- Contact person?
- Further steps towards an S_α map?

EFEHR

EPOS EUROPEAN PLATE OBSERVING SYSTEM

SERA Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe

European Seismic Risk Model 2020 (ESRM20)

SERA-SC8 Meeting, Pavia, 14th October 2019

Helen Crowley, EUCENTRE, helen.crowley@eucentre.it

EUCENTRE FOR YOUR SAFETY.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 730900.

European Seismic Risk Model

Another requirement of the European Seismic Hazard Model (ESHM20) is to provide input to the European Seismic Risk Model (ESRM20) which is being developed in the SERA project.

SERA European Seismic Risk ESRM20

ESHM20 source model logic tree

ESHM20 GMPE logic tree

Geology/topography-based amplification

SERA European exposure model v1.0

SERA vulnerability models v1.0

How do we estimate shaking at surface?

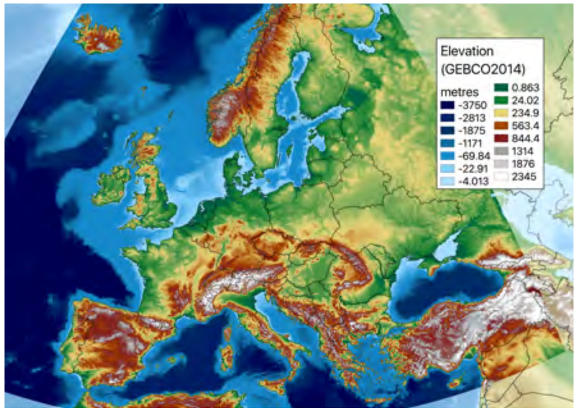
Geology/topography-based amplification

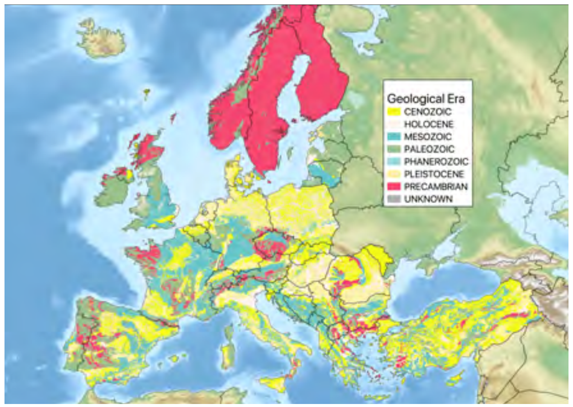
$$\ln(PSA,T) = f_R\left(M_W, R_{JB}, h, T\right) + f_M(M_W,T) + \delta B_e(T) + \delta S2S_S(T) + \delta WS_{e,s}(T)$$

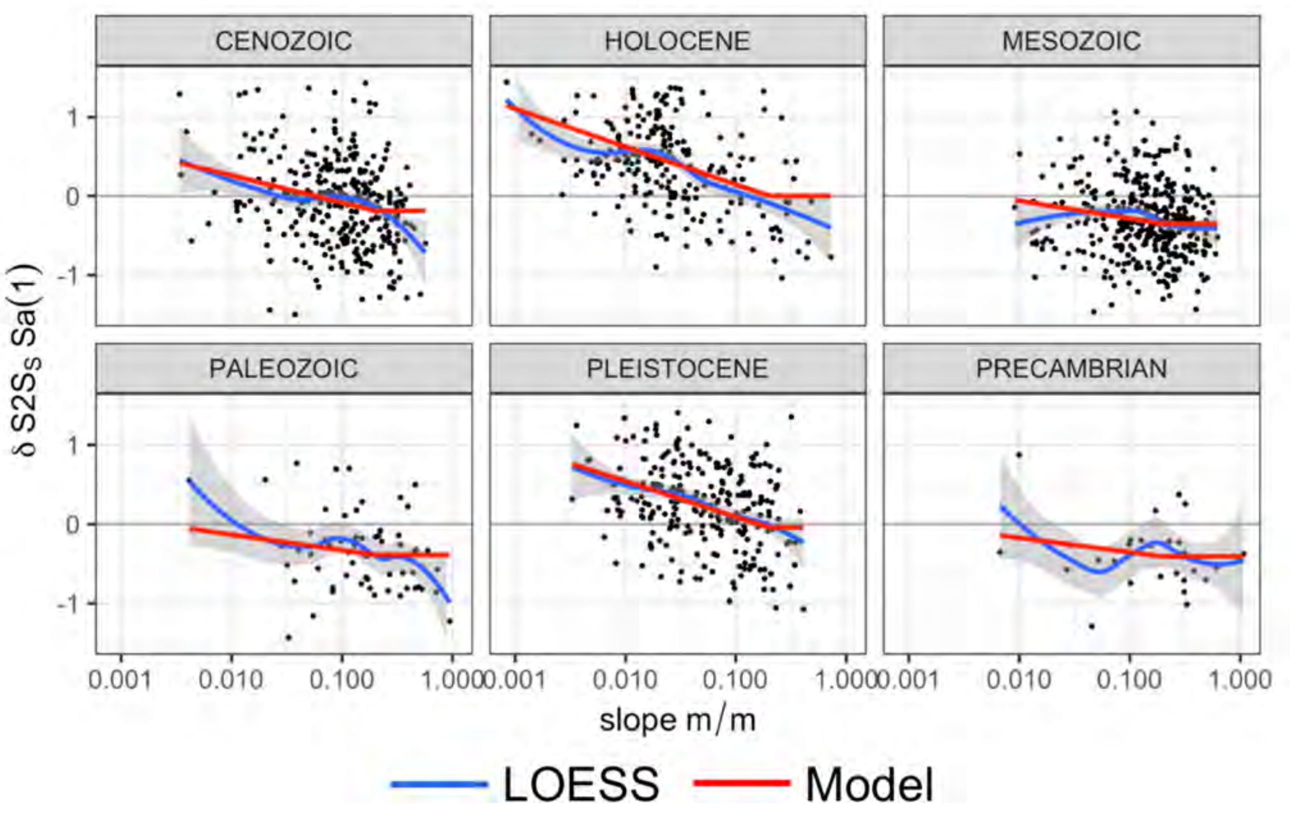
$$\sigma_T^2 = \tau^2 + \phi_0^2 + \phi_{S2S}^2$$

Linear site amplification term, function of slope and geology

$$\delta_{S2S}(T) = \begin{cases} (c_1|geology) \cdot \ln\left(\frac{slope}{c_2|geology}\right) + \varepsilon\sigma_s & for\ slope < x_c \\ (c_1|geology) \cdot \ln\left(\frac{x_c}{c_2|geology}\right) + \varepsilon\sigma_s & for\ slope \geq x_c \end{cases}$$







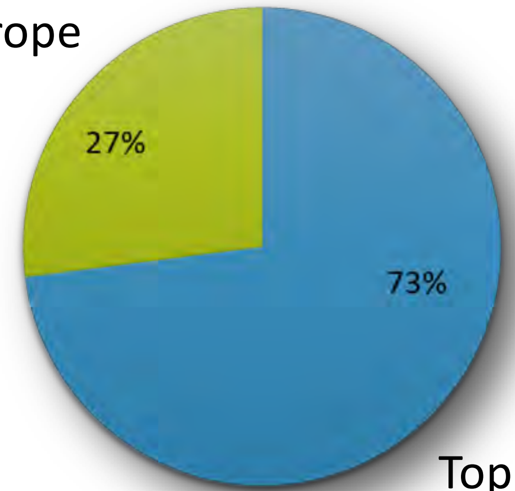
Courtesy of Graeme Weatherill

How many buildings do we have and where?

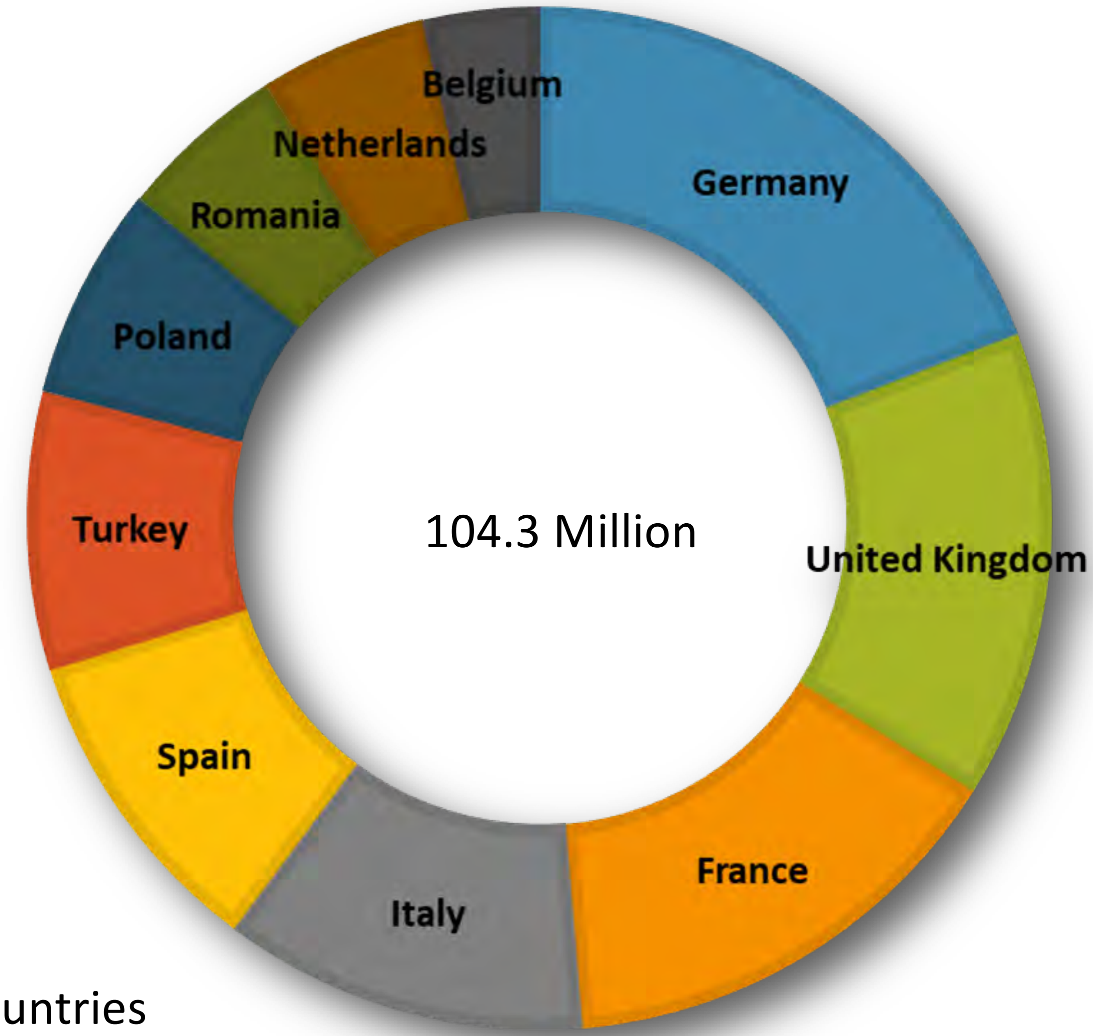
SERA European exposure model v0.2

Total buildings: 142.8 Million

Rest of Europe



Top 10 countries

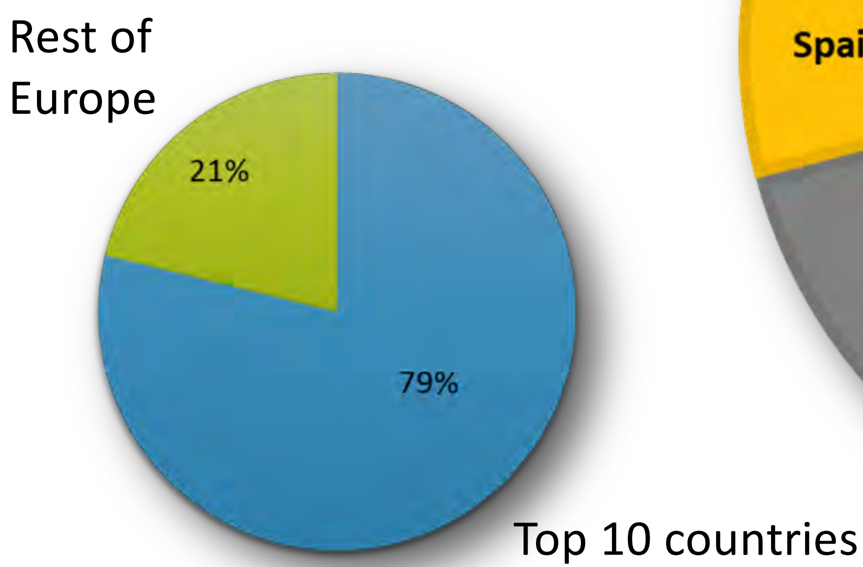


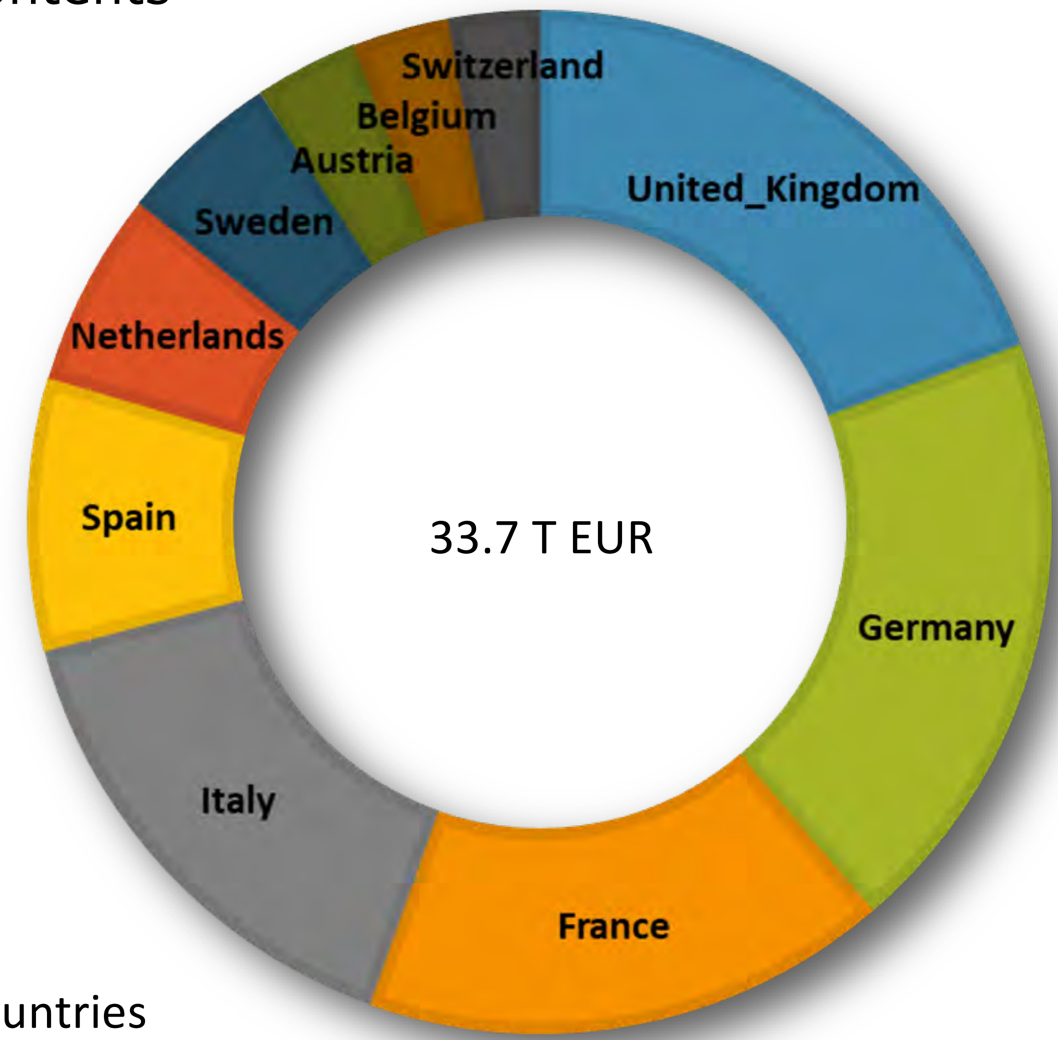
How much value do they have and where?

SERA European exposure model v0.2

Value = replacement cost of structural elements, non-structural elements + contents

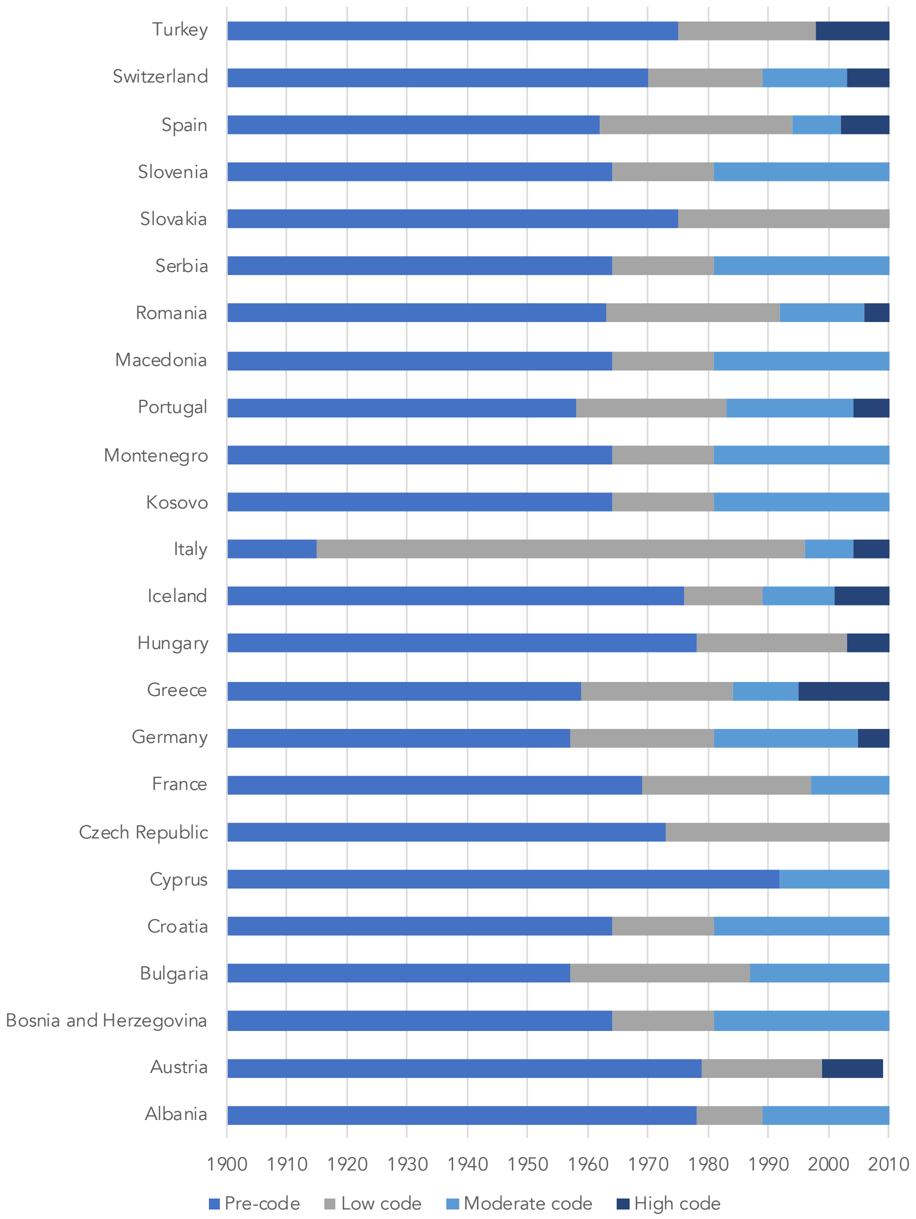
Total value: 42.7 T EUR

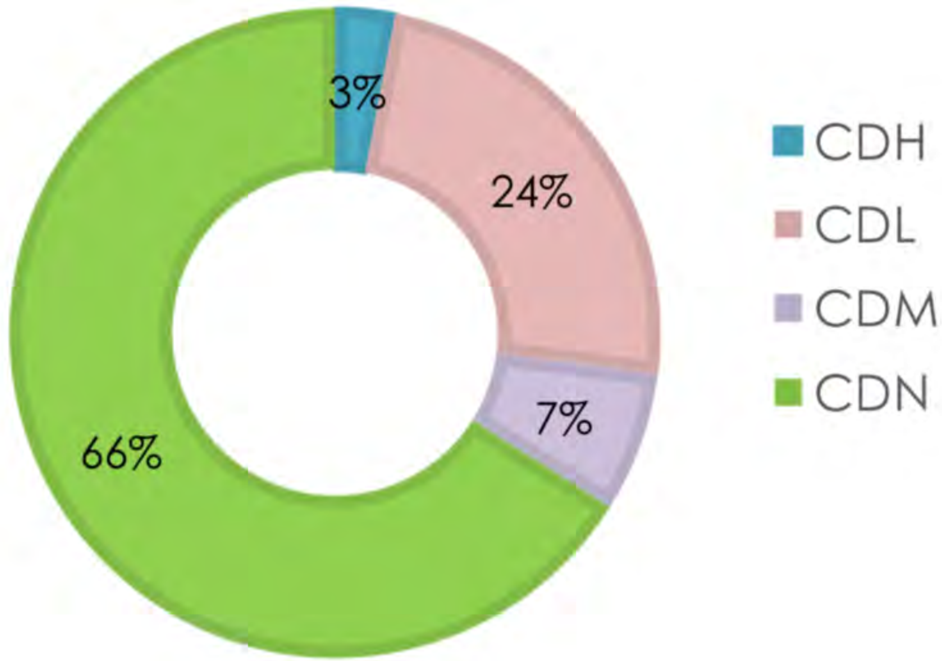




What is the level of seismic design in Europe?

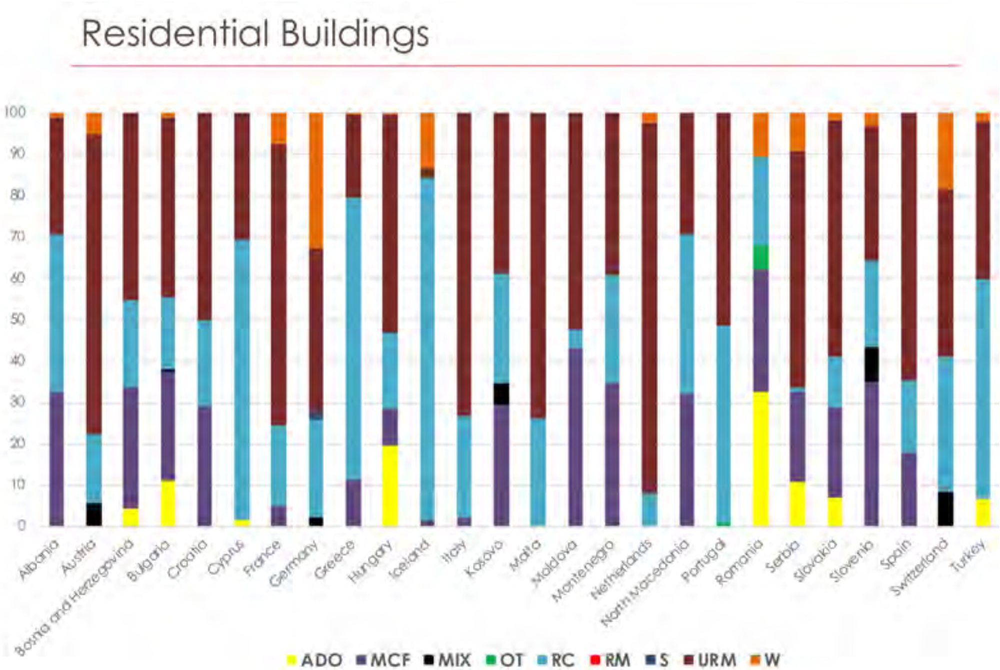
SERA European exposure model v0.2

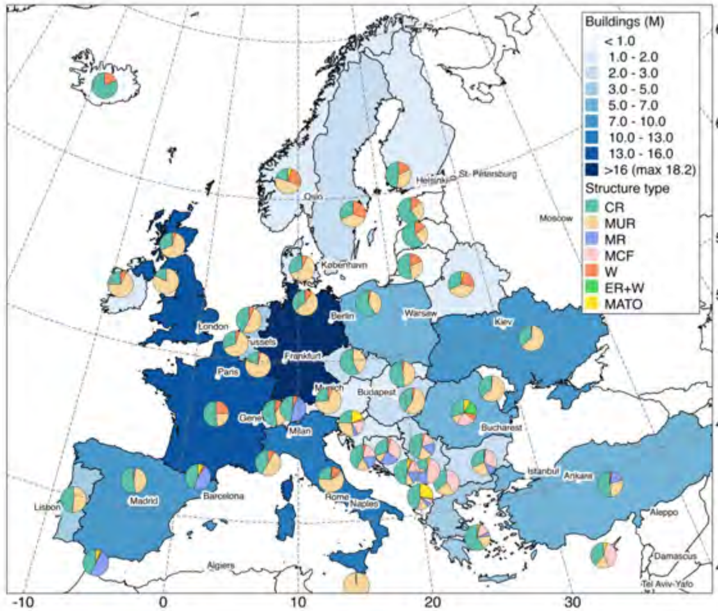


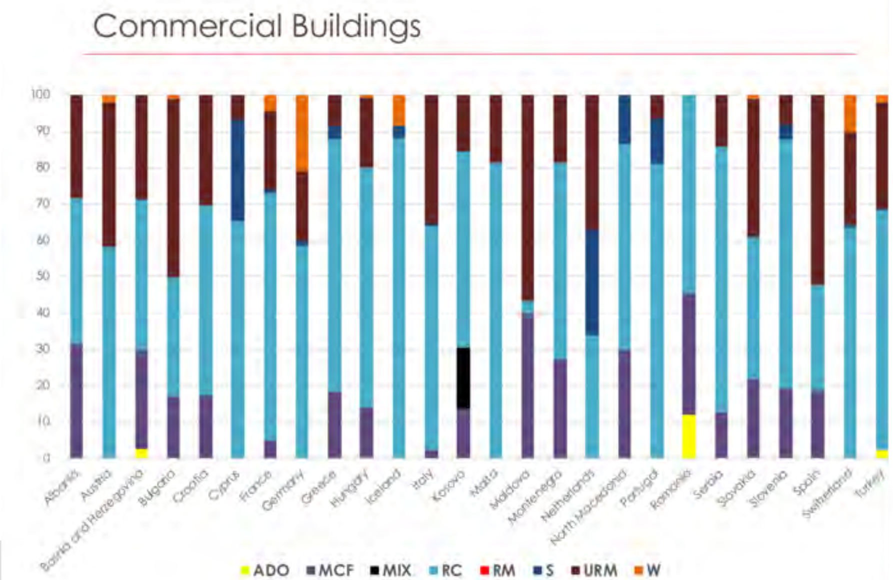


How do the building classes vary?

SERA European exposure model v0.2



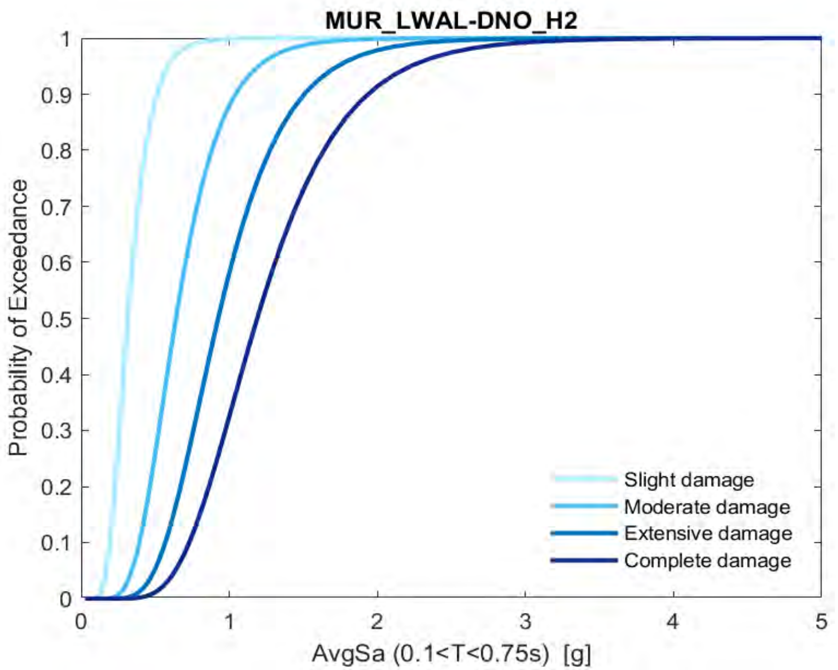




How do we model loss given ground shaking?

SERA vulnerability models

Fragility functions
(from nonlinear dynamic analysis of simplified building models)

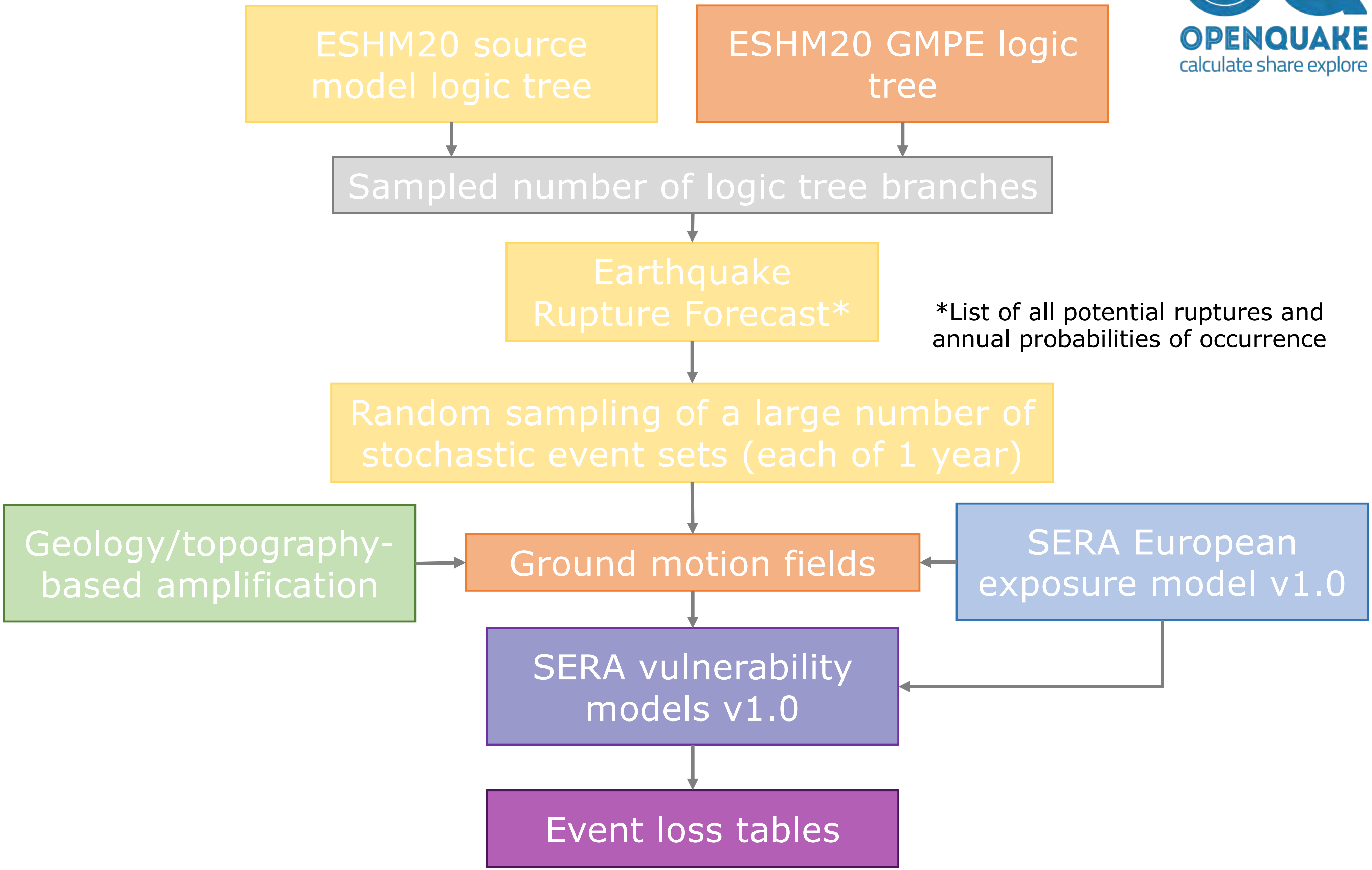


Damage – loss models

DAMAGE STATE	MEAN LOSS RATIO [%]
Slight damage (DS1)	5
Moderate damage (DS2)	20
Extensive damage (DS3)	60
Complete damage (DS4)	100

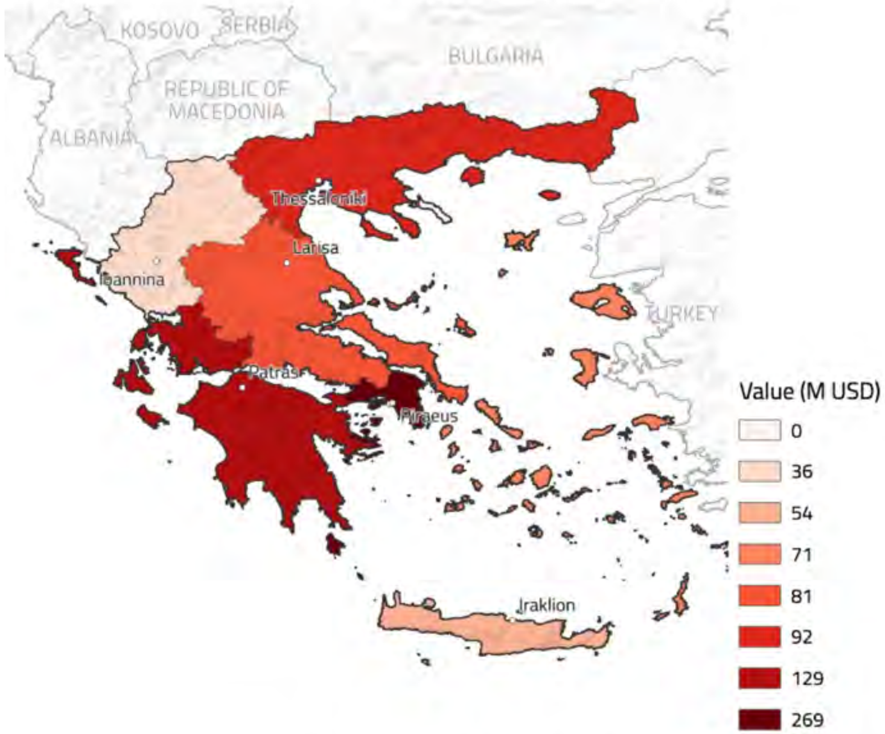
DAMAGE STATE	Probability of collapse | DS4	Fatality ratio | collapse
Complete damage (DS4)	e.g. 0.2	e.g. 0.05

Stochastic Event-based Risk Calculation

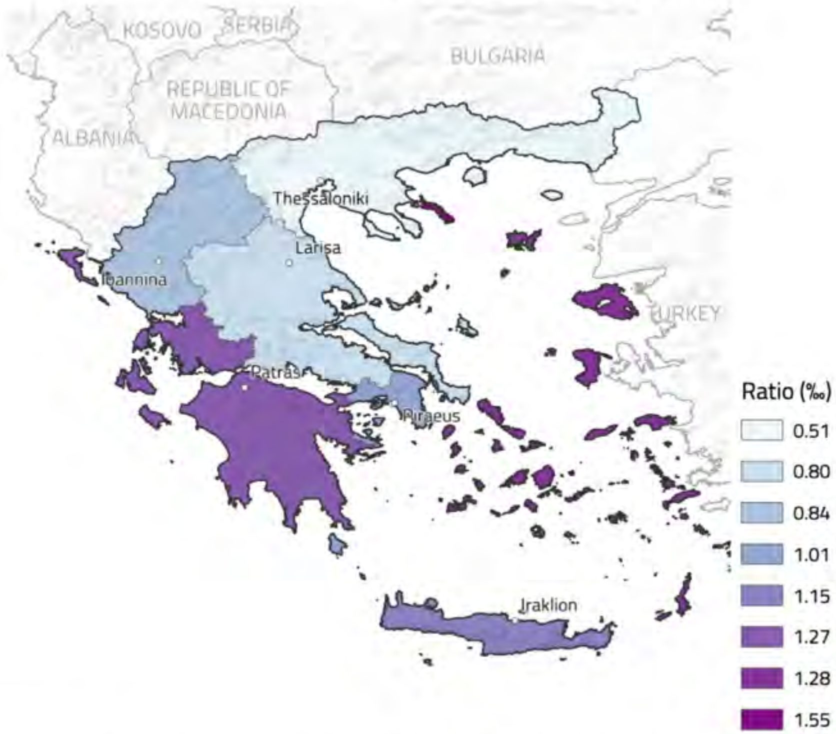


Stochastic Event-based Risk Calculation

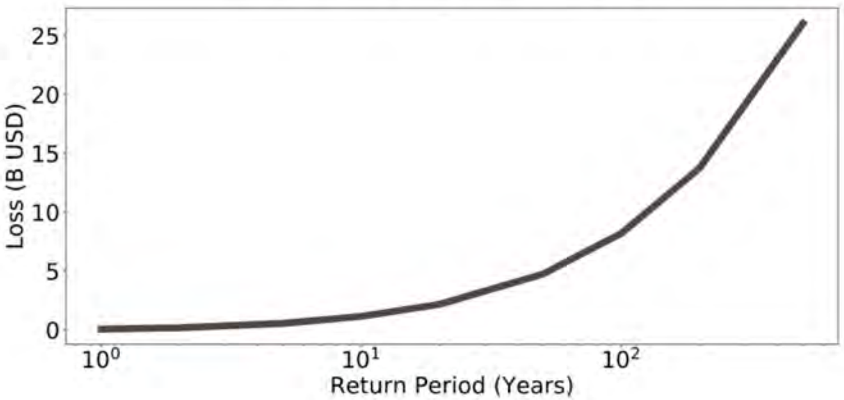
Average Annual Losses



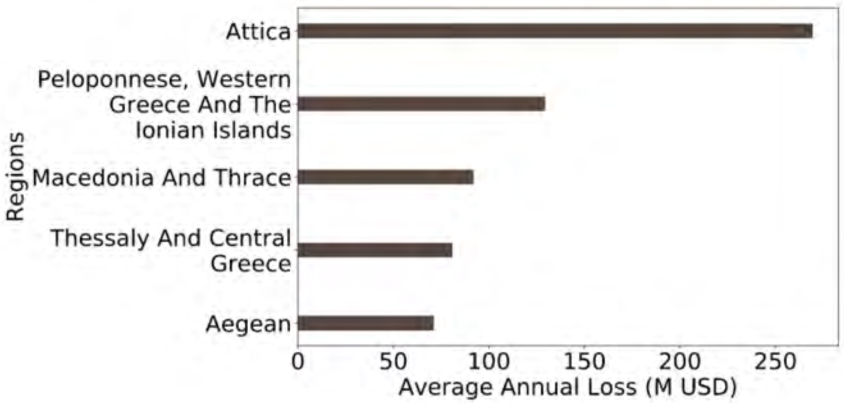
Average Annual Loss Ratios



Loss Exceedance Curve



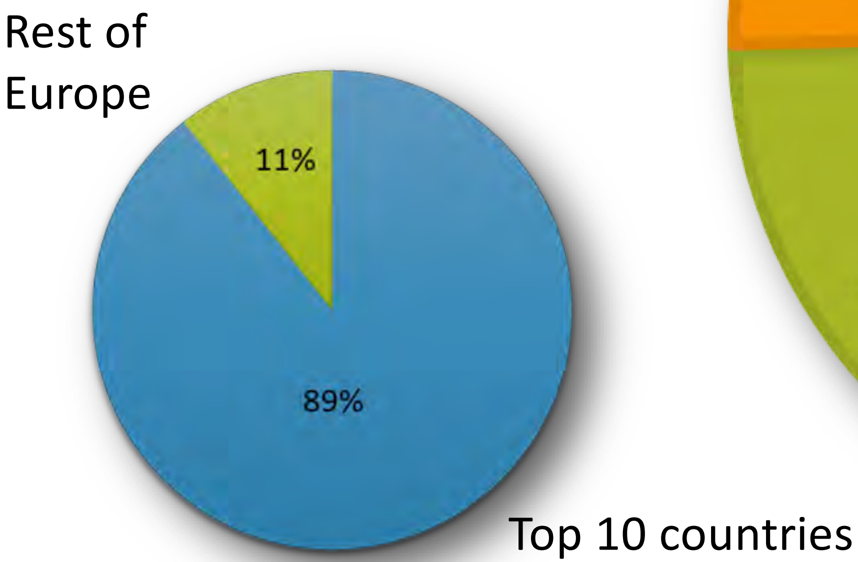
Regions of Highest Earthquake Risk

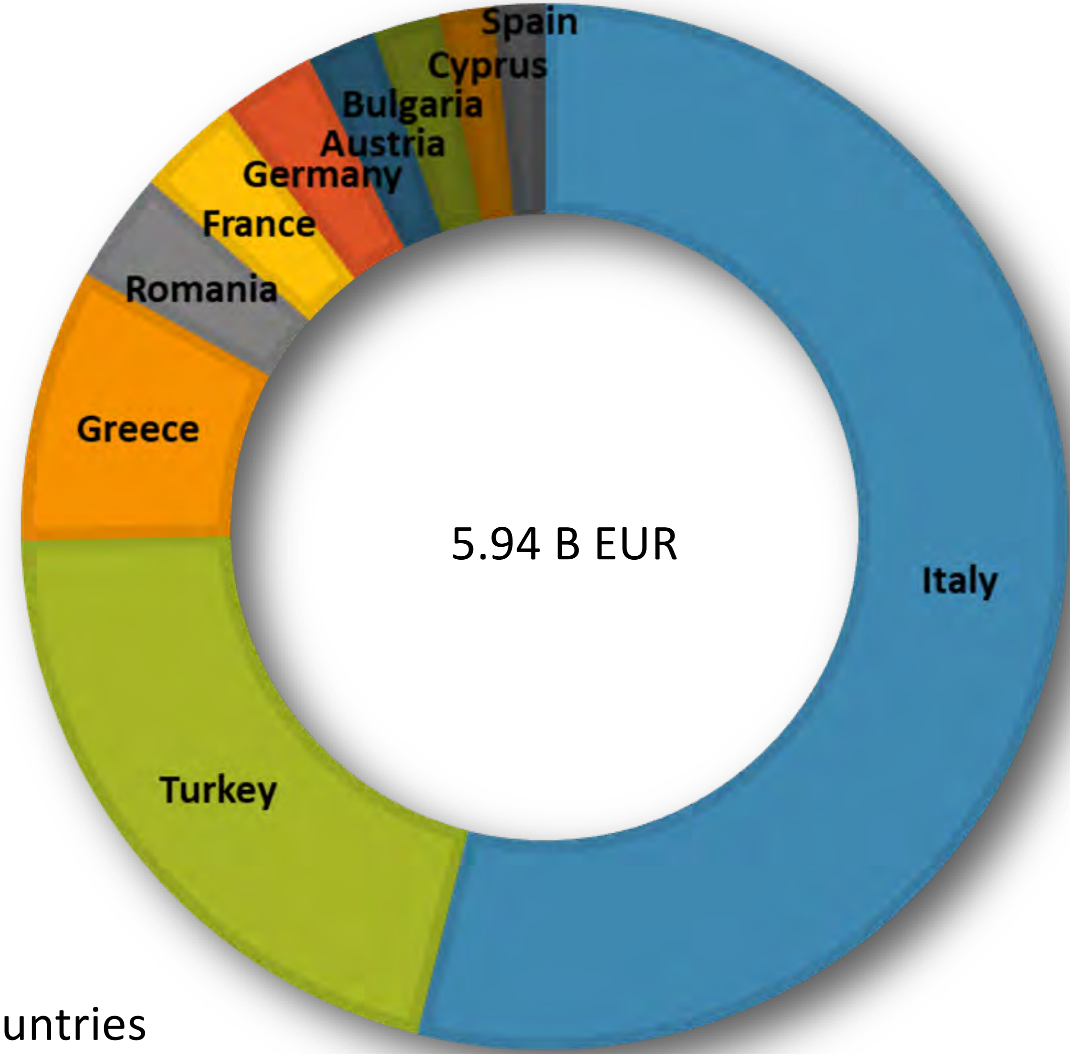


Average annual economic losses

SERA European Risk
v0.2

Total average annual loss:
6.65 B EUR

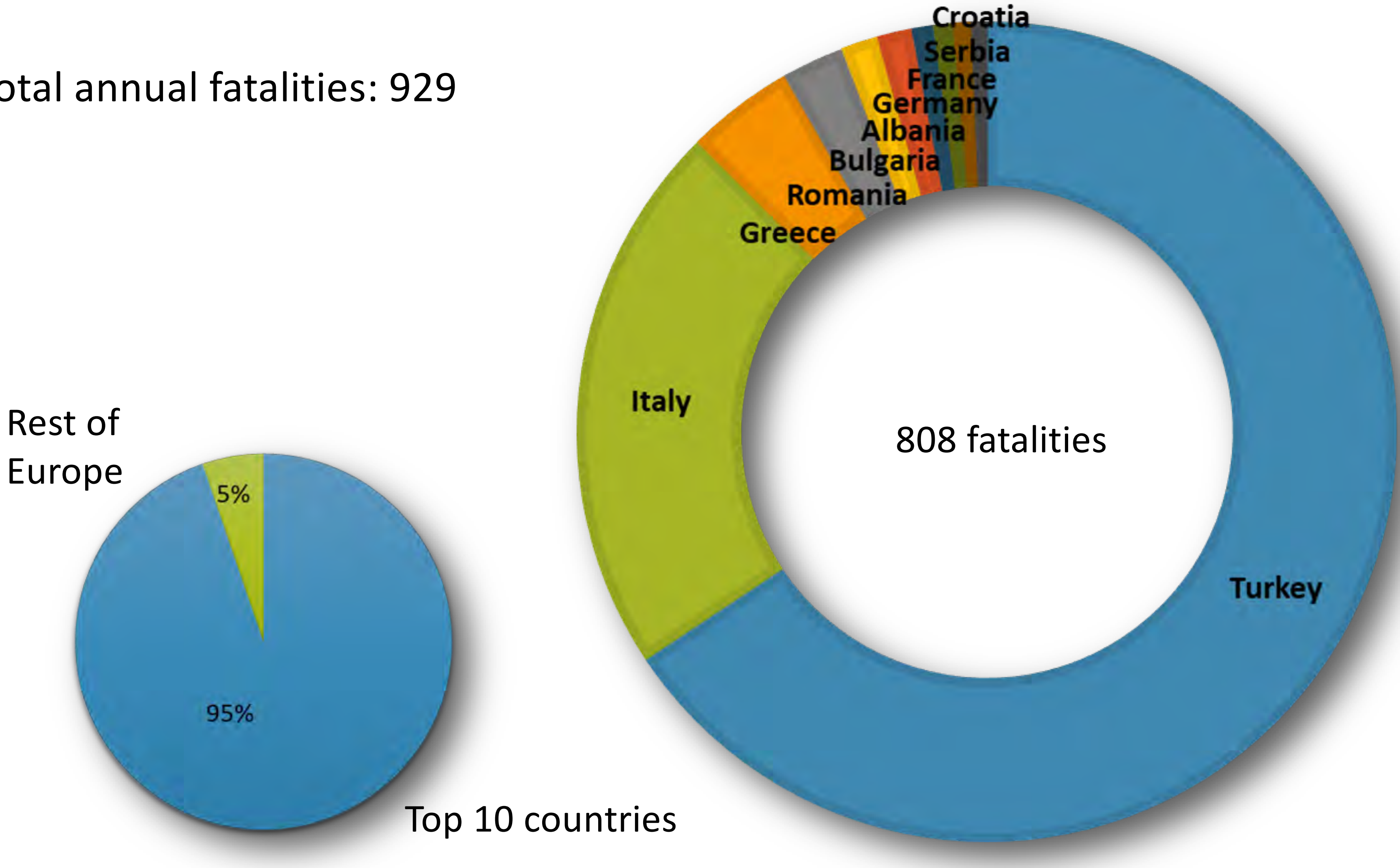




Average annual fatalities

SERA European Risk v0.2

Total annual fatalities: 929



Verification of average annual fatalities

SERA European Risk v0.2

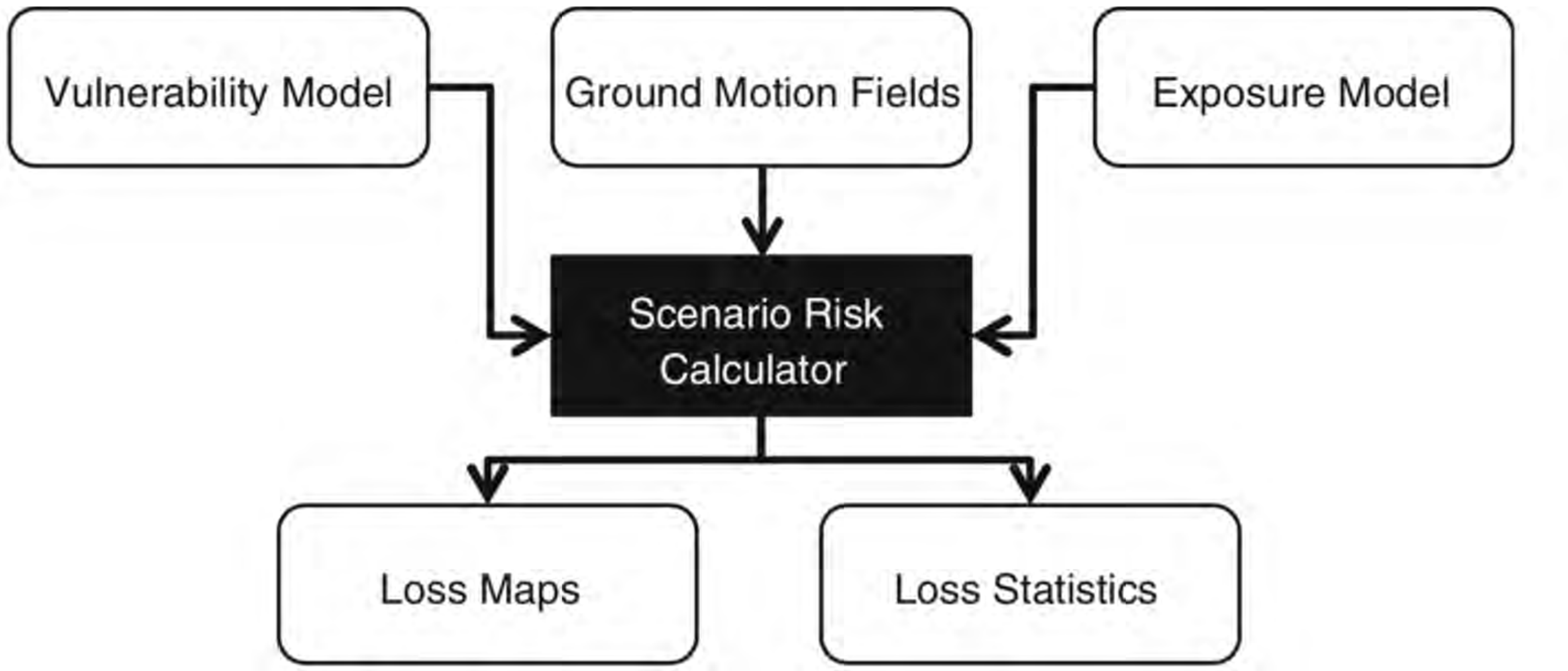
CRED EM-DAT (International Disaster Database)

33482 fatalities / 39 years = 858 / yr

Year	Occurrence	Total deaths	Injured	Affected	Homeless	Total affected	Total damage ('000 $)
1980	5	4846	8417	426300	0	434717	20005000
1981	5	36	450	80750	0	81200	900000
1982	4	1	5	7050	5000	12055	35000
1983	5	14	67	21480	15000	36547	50000
1984	4	4	385	5000	24300	29685	0
1985	3	29	96	9686	0	9782	0
1986	4	26	918	270000	7500	278418	1475000
1988	3	25000	12025	1100690	530000	1642715	14000000
1989	1	274	51	12000	0	12051	24800
1990	11	[illegible]7	985	0	27000	27985	500000
1991	6	274	1505	96845	164000	262350	1700000
1992	3	[illegible]	45	1500	0	1545	150000
1993	2	[illegible]	21	2100	0	2121	0
1994	1	[illegible]	242	0	2100	2342	0
1995	3	2041	910	22500	6300	29710	936800
1996	2	0	0	1500	2000	3500	0
1997	1	14	100	0	38000	38100	4524900
1998	5	10	105	3000	1700	4805	72000
	112	33482	31635	2355786	951837	3339258	75756536

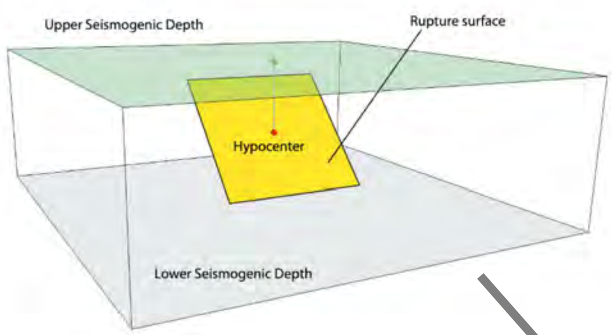
Verification of exposure and vulnerability

OpenQuake-engine Scenario Damage/Risk Calculator

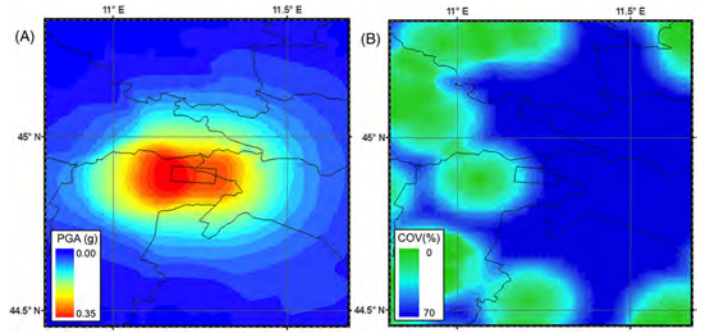


Verification of exposure and vulnerability

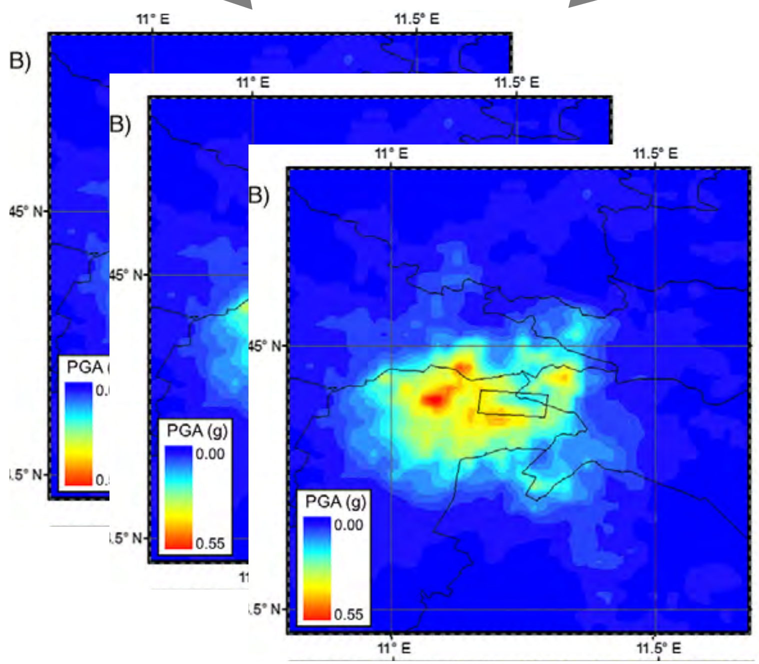
User-defined rupture

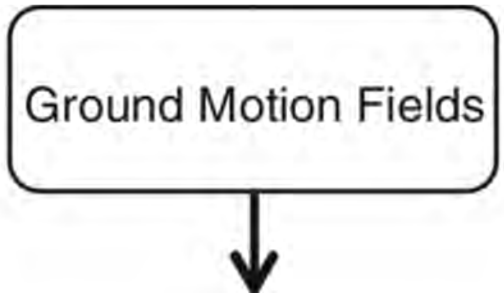


USGS ShakeMap format



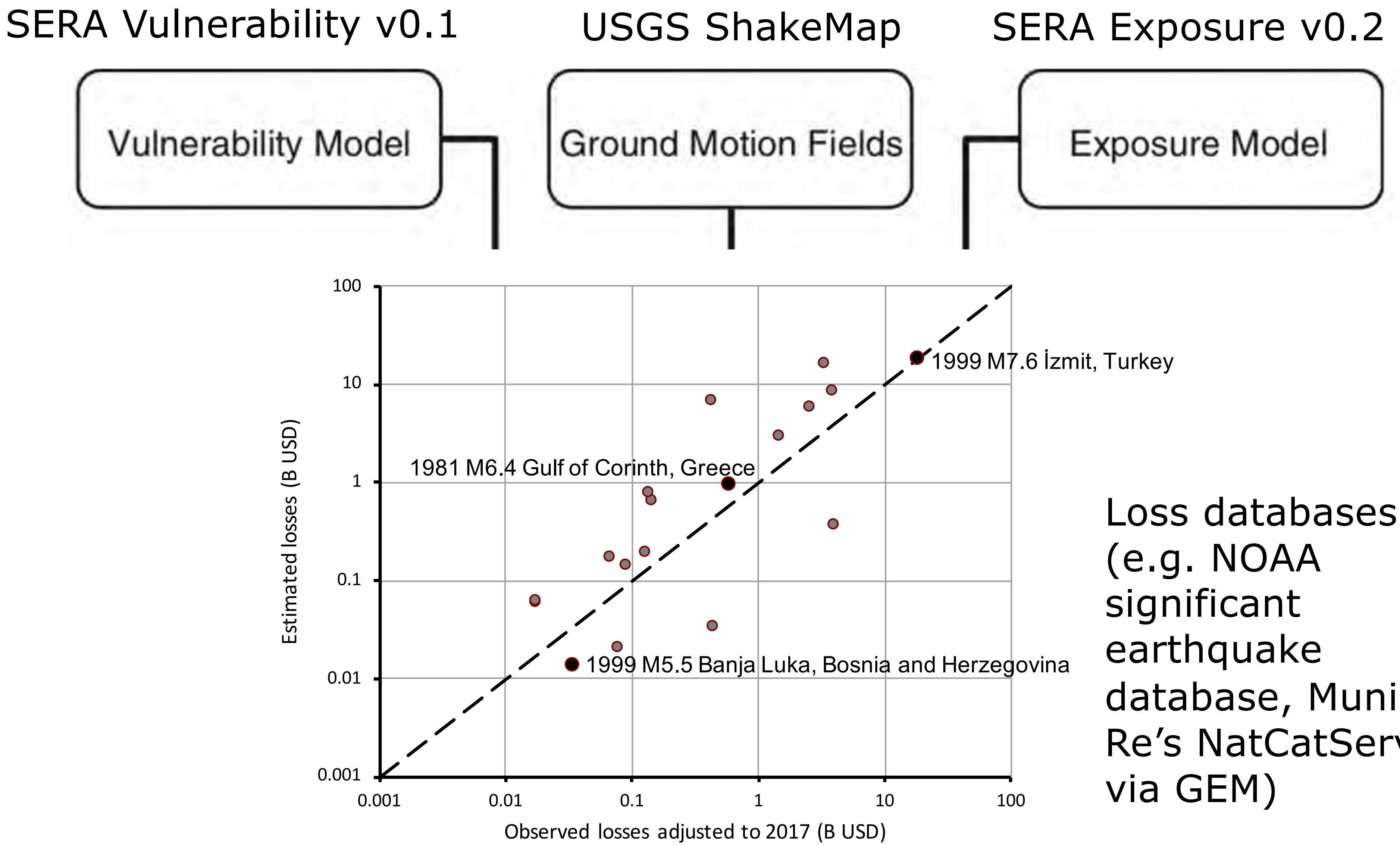
Median CoV





Verification of exposure and vulnerability

SERA European Risk v0.2



Loss databases (e.g. NOAA significant earthquake database, Munich Re's NatCatService via GEM)

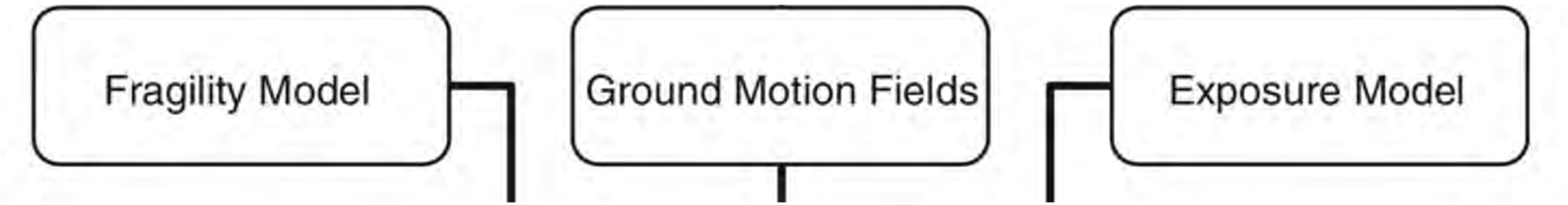
Verification of exposure and vulnerability

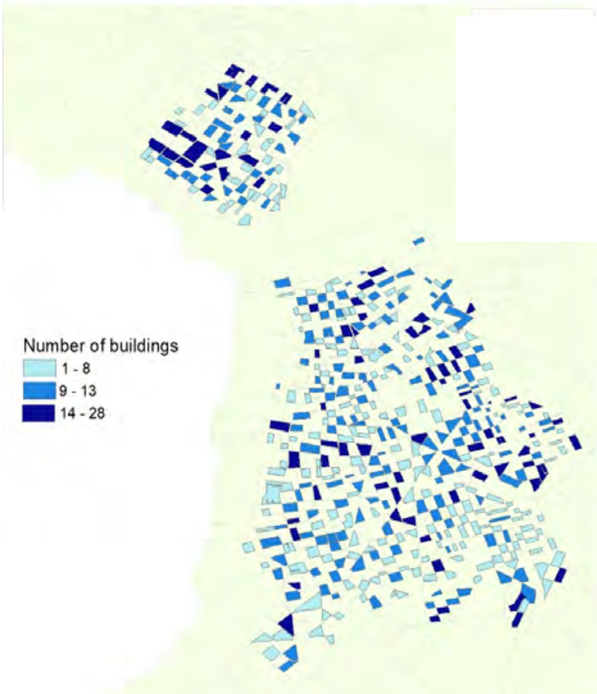
SERA European Risk v0.2

SERA Vulnerability v0.1

USGS ShakeMap or Rupture

Thessaloniki, 1978



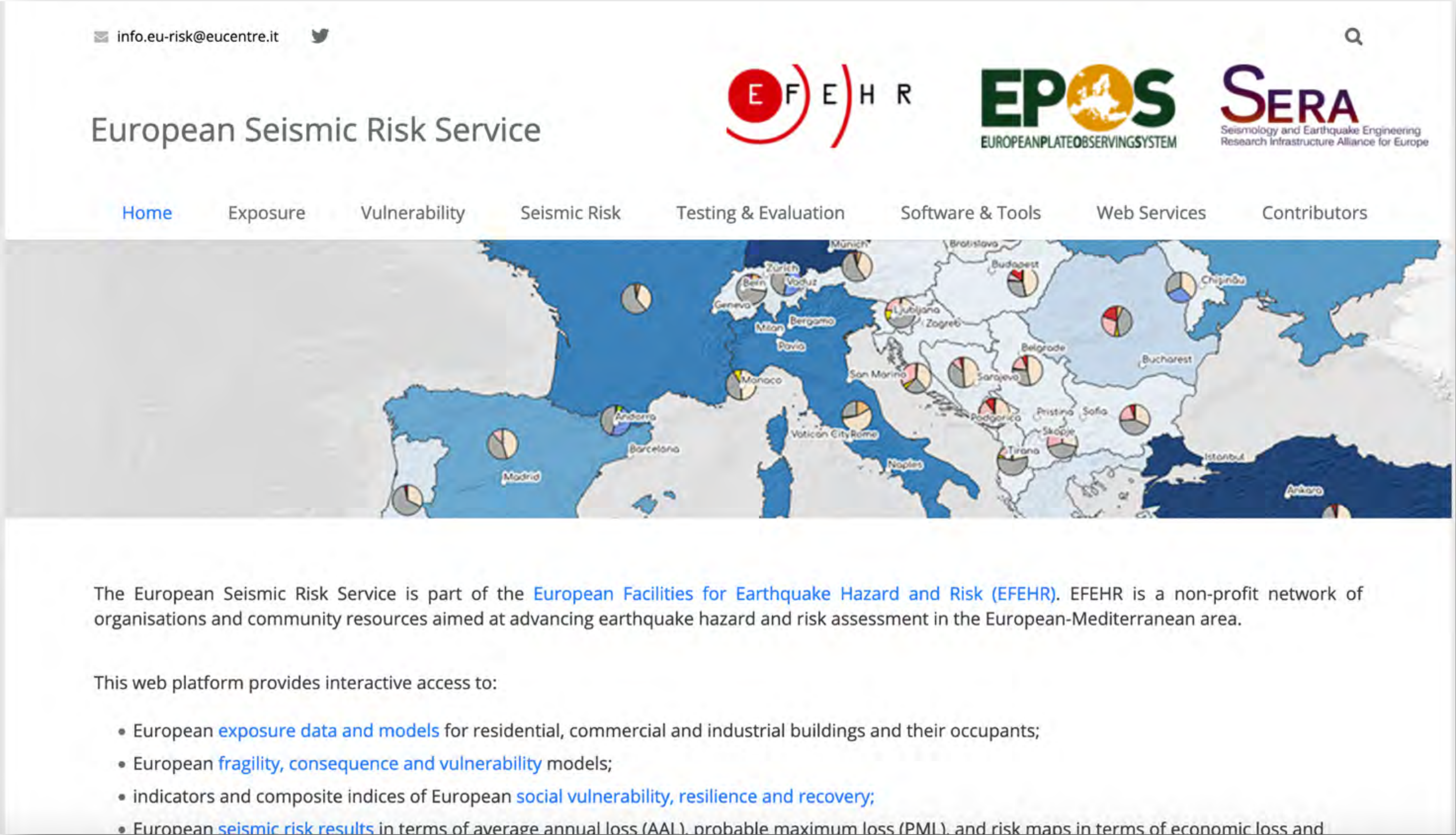


Damage State	Colour Tag	Observed damage (Kappos et al. 2008)	Scenario with fault rupture model	Scenario with USGS ShakeMap
No damage + slight	Green	75 %	76 %	92 %
Moderate + extensive	Yellow	19 %	16 %	7 %
Complete	Red	6 %	8 %	1 %

European Seismic Risk Service

https://eu-risk.eucentre.it

Users/Stakeholders



European Seismic Risk Service

https://eu-risk.eucentre.it

Users/Stakeholders

Interactive European Physical Seismic Risk Viewer

European Seismic Risk Model v1.0:

- ESHM20 model
- European site model
- Exposure models (country by country)
- Vulnerability model
- Risk maps/layers

Questions?

https://eu-risk.eucentre.it

info.eu-risk@eucentre.it

@EFEHR_risk

https://sites.google.com/eucentre.it/european-seismic-risk-model/workshop-presentations

Contact
SERA Project Office | ETH Department of Earth Sciences | Sonneggstr. 5, NO H-floor, CH-8092 Zurich | sera_office@erdw.ethz.ch | +41 44 632 9690