State-of-the-art of databases and catalogues including the TSUMAPS-NEAM Project

Roberto Basili

Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy

Acknowledgments: colleagues and friends who participated in EC projects SHARE, ASTARTE, TSUMAPS-NEAM, SERA, EPOS-IP, EPOS TCS Seismology and TCS Tsunami, EFEHR, Geo-Inquire and other projects and initiatives

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Outline

- Principles of open science and data-quality assurance
- Tsunami hazard (NEAMTHM18)
- Earthquake catalogues
- Seismogenic fault databases
- Epistemic Uncertainty
- Focus on the Hellenic Arc
- Focus on the Azores-Gibraltar Fault Zone
- Outlook on fault-source characterization

Principles of Open Science

Open Science demands transparency. Data sharing is crucial, not just for protocol, but as a "trust marker." This openness signals a willingness to be scrutinized by peers, building trust among scientists, the public, industry, and funders.

EPOS
EUROPEAN PLATE OBSERVING SYSTEM

TCS Seismology

TCS Tsunami

Orfeus

EFEHR

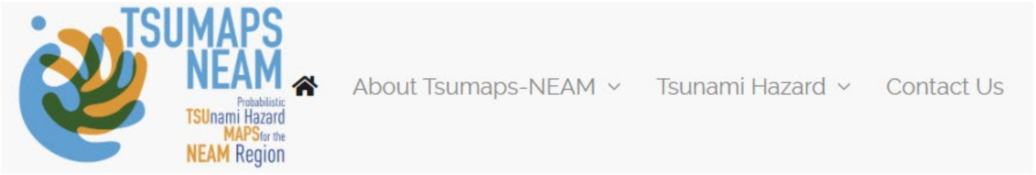
CSEM EMSC

Common data-quality definitions

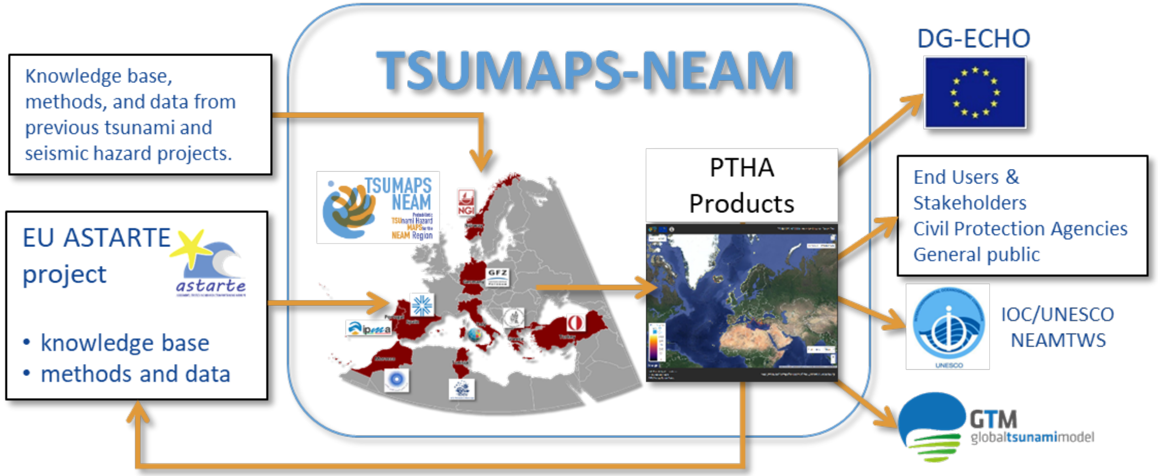
Authors	Year	Data Quality Definition
Wang and Strong	1996	"data that are fit for use by data consumers." (Wang & Strong, 1996, p. 6)
Redman	2001	"Data are of high quality if they are fit for their intended uses in operations, decision making, and planning. Data are fit for use if they are free of defects and possess desired features." (Redman, 2001, p. 74)
Kahn, Strong, and Wang	2002	"conformance to specifications" and "meeting or exceeding consumer expectations" (Kahn et al., 2002, p. 185)
Olson	2003	"[…] data has quality if it satisfies the requirements of its intended use." (Olson, 2003, p. 24)

Tsunami hazard (NEAMTHM18)

https://tsumaps-neam.eu/neamthm18/



Funded by European Union Humanitarian Aid and Civil Protection



NEAMTHM18 Portfolio

Hazard curves were calculated at **2,343 POIs** (North-Eastern Atlantic: 1,076; Mediterranean Sea: 1,130; Black Sea: 137) at an average spacing of **~20 km**.

For each curve, values for **mean, 2nd, 16th, 50th, 84th**, and **98th** percentiles.

Probability maps for **MIH 1, 2, 5, 10, 20** meters;

Hazard maps for **ARP 500, 1000, 2500, 5000, 10000** years

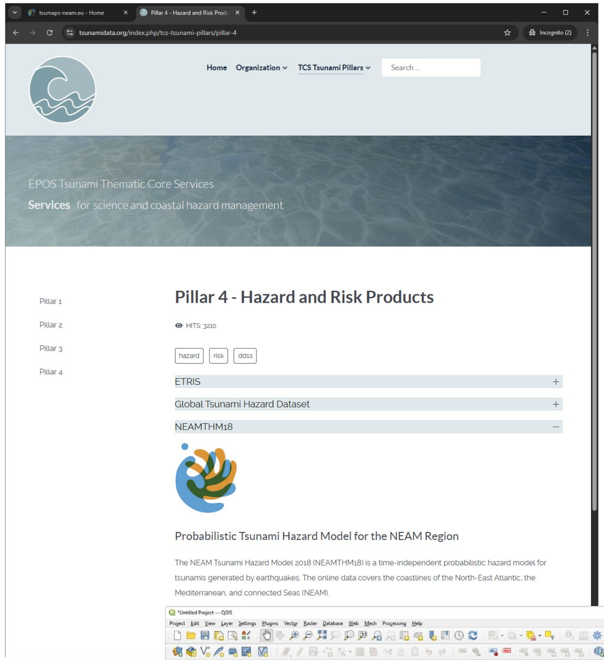
Map displays for **mean, 2nd, 16th, 50th, 84th** and **98th** percentiles.

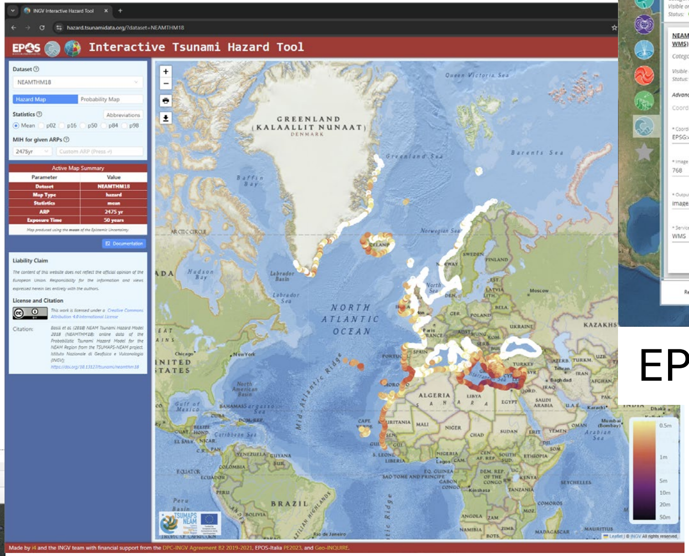
Interactive Hazard Map and Curve **Tool**

Comprehensive **Documentation** with two review reports (352 pp.)

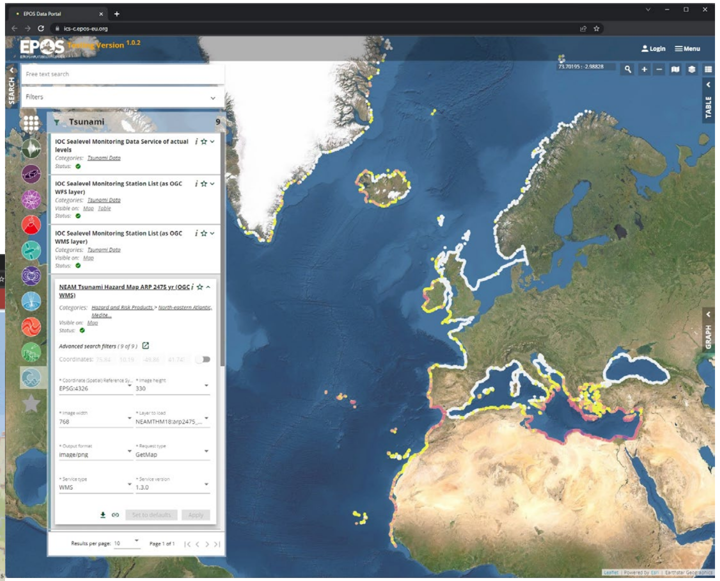
Summary **Article** Basili et al. (2021, https://doi.org/10.3389/feart.2020.616594) and several other **publications** (https://tsumaps-neam.eu/tsunami-hazard/publications)

Improved access to NEAMTHM18

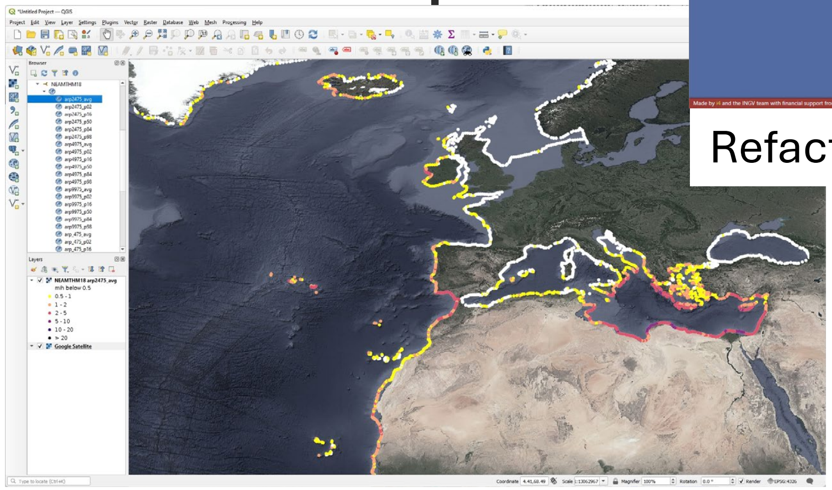




Refactored Interactive web mapper



EPOS Integrated Core Service GUI



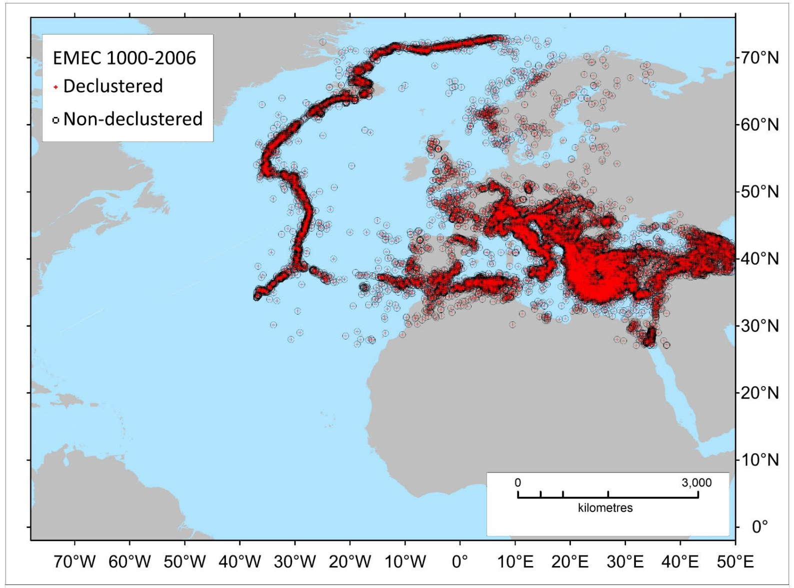
OGC web services on your desktop GIS

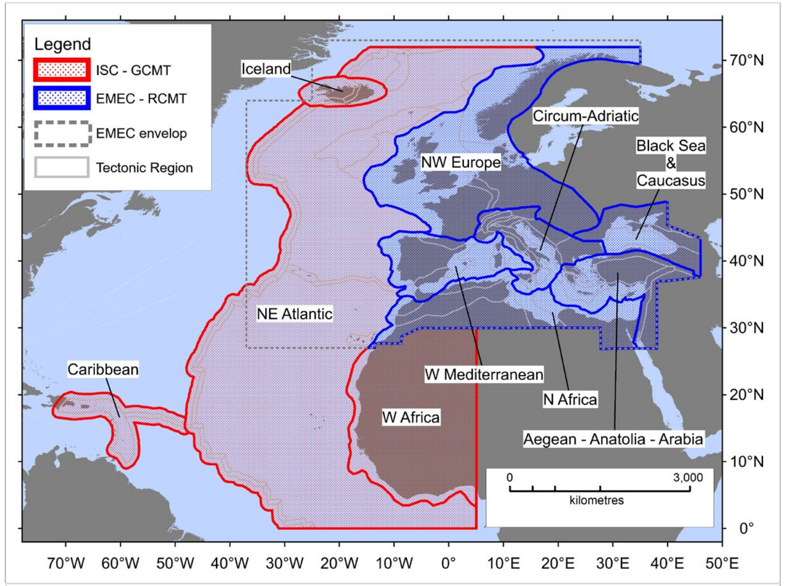
The workflow for local inundation mapping is currently distributed as Trans-National Access in Geo-INQUIRE

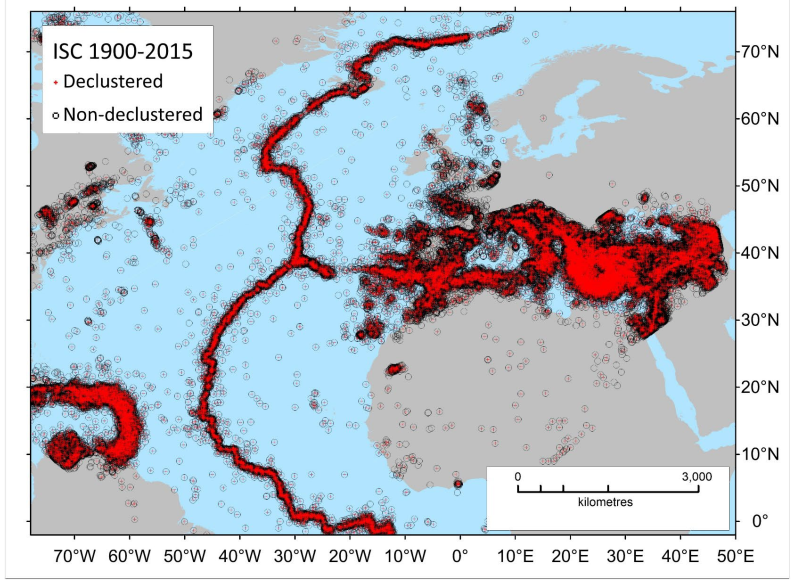
Geo-INQUIRE

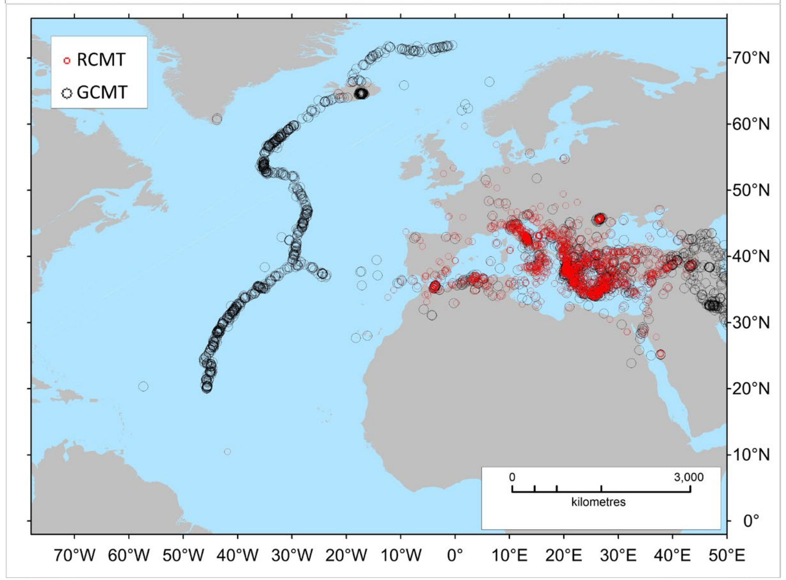
ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

NEAMTHM18 seismic sources: input data (earthquake catalogs)





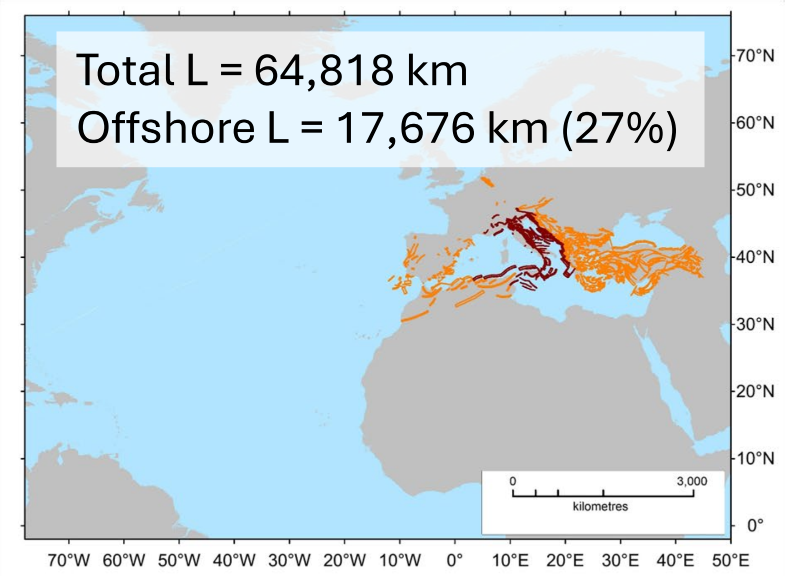




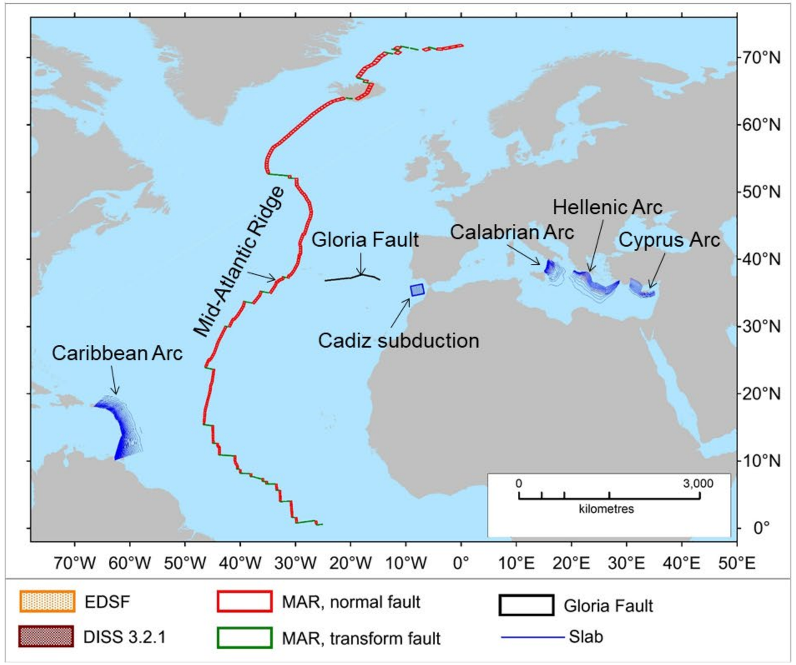
- SHEEC-EMEC time span 1000-2006 (Stucchi et al., 2012; Grünthal & Wahlström, 2012)
- ISC (ISC, 2016) time span 1900-2015
- GCMT (Dziewonski et al., 1981; Ekström et al., 2012)
- RCMT (Pondrelli & Salimbeni, 2015)

NEAMTHM18 seismic sources: input data (fault databases)

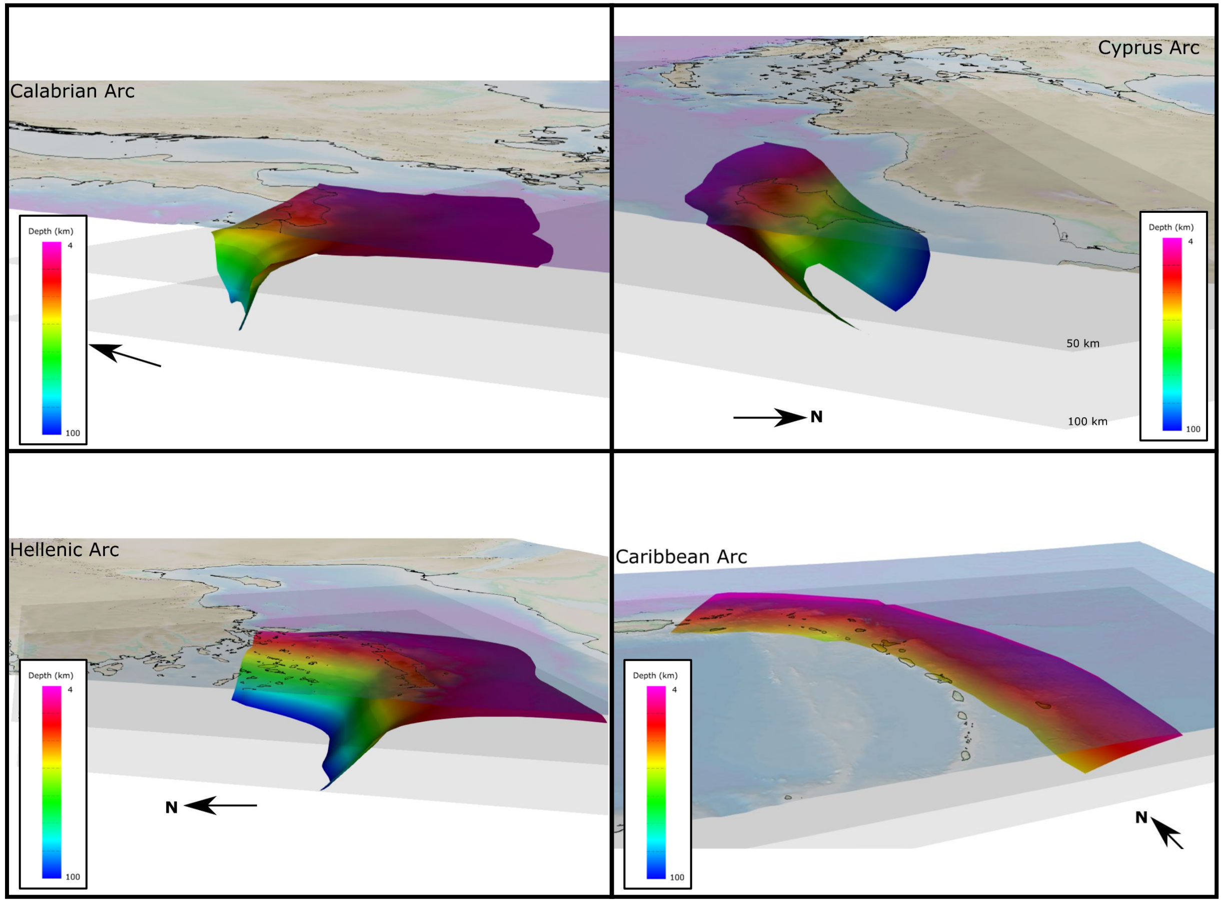
Crustal faults



Slabs and main plate boundaries



Slab complex 3D geometries

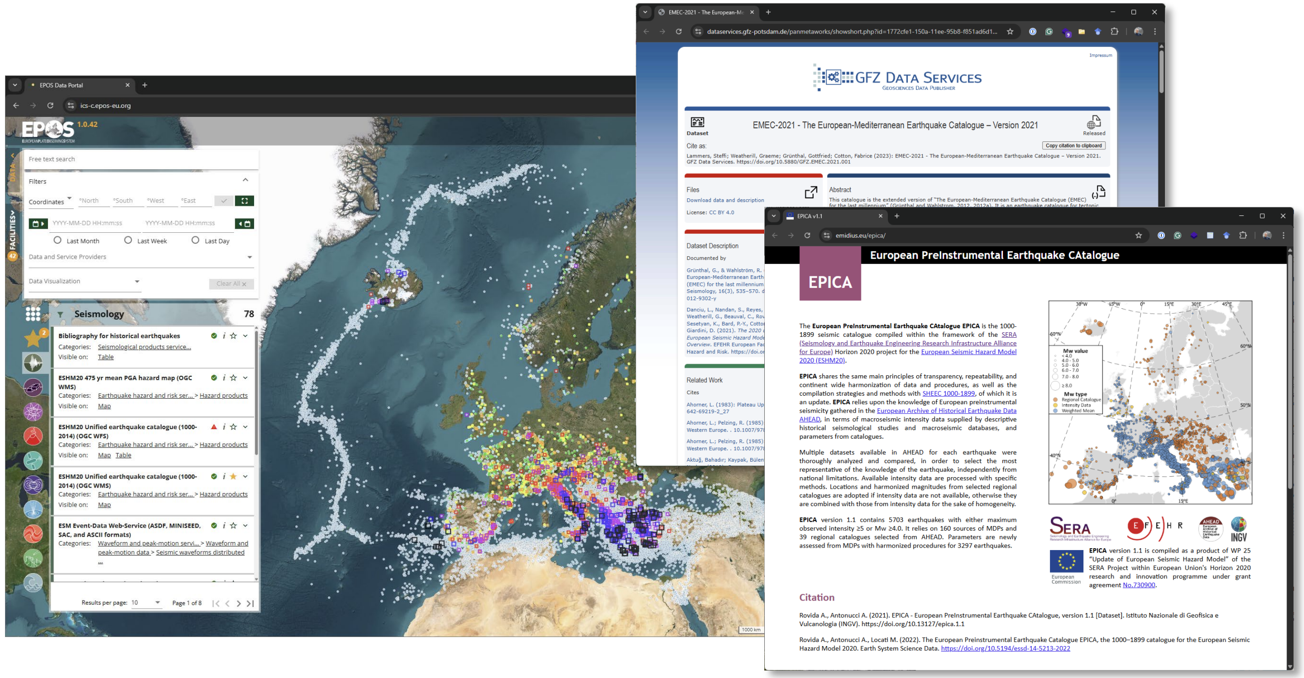


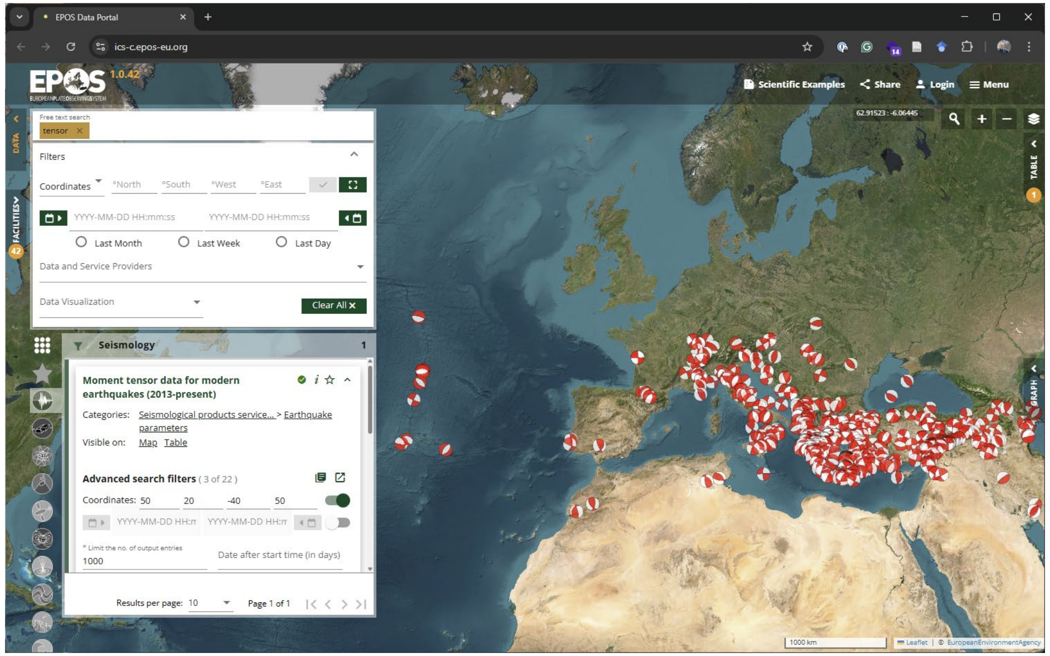
- EDSF (Basili et al., 2013)
- DISS 3.2.1 (DISS WG, 2018)

- PB2002 Bird (2003)
- SLAB 2.0 (Hayes et al., 2018)
- CAS (Maesano et al., 2017)

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Earthquake catalogues





EPICA version 1.1 contains 5703 earthquakes from 1000 to 1899 CE with either maximum observed intensity ≥5 or Mw ≥4.0.

Rovida, A., & Antonucci, A. (2021). EPICA - European PreInstrumental Earthquake CAtalogue, version 1.1

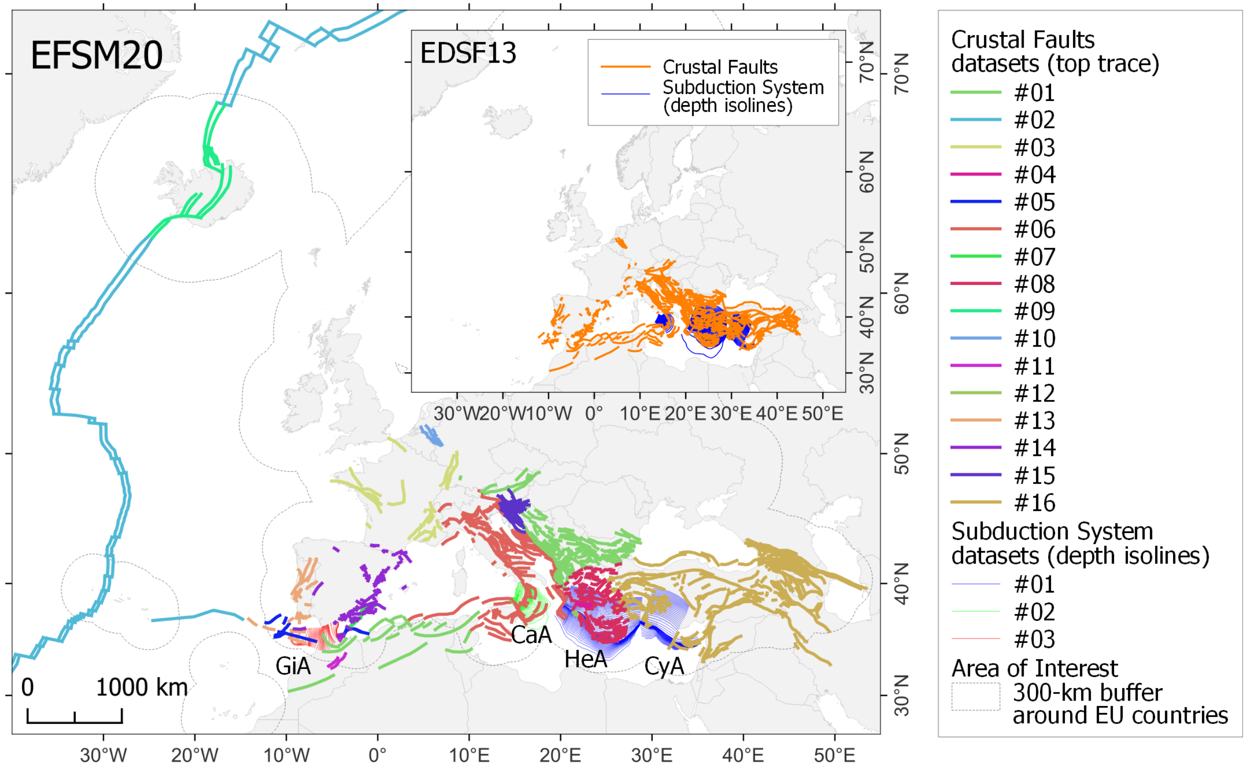
EMEC 2021 contains 71271 earthquakes from 1000 to 2021 CE with a uniform magnitude Mw ≥ 3.5.

Lammers et al. (2023) EMEC-2021 - The European-Mediterranean Earthquake Catalogue – Version 2021

Moment tensor data for modern earthquakes (2013-present), provided by EMSC - European-Mediterranean Seismological Centre – FR

Specifications at https://www.emsc-csem.org/Files/epos/specifications/Specs_MT-WS.pdf

Seismogenic fault databases



1,248 crustal faults spanning a total length of ~95,100 km (42% offshore) and four subduction systems (Gibraltar, Calabrian, Hellenic, and Cyprus Arcs)

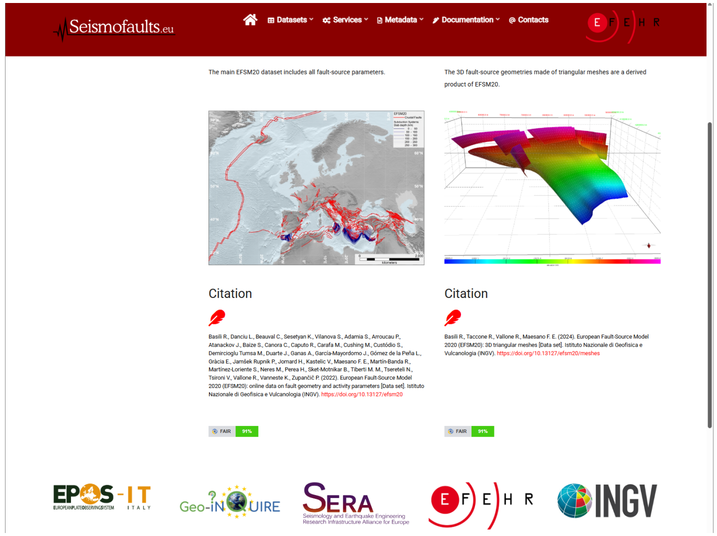
Basili et al. (2022, dataset; 2024, NHESS)

Nat. Hazards Earth Syst. Sci., 24, 3945–3976, 2024
https://doi.org/10.5194/nhess-24-3945-2024

Natural Hazards and Earth System Sciences
Open Access
EGU

The European Fault-Source Model 2020 (EFSM20): geologic input data for the European Seismic Hazard Model 2020

Roberto Basili[1], Laurentiu Danciu[2], Céline Beauval[3], Karin Sesetyan[4], Susana Pires Vilanova[5], Shota Adamia[6], Pierre Arroucau[7], Jure Atanackov[8], Stéphane Baize[9], Carolina Canora[10], Riccardo Caputo[11], Michele Matteo Cosimo Carafa[1], Edward Marc Cushing[9], Susana Custódio[12], Mine Betul Demircioglu Tumsa[13], João C. Duarte[12], Athanassios Ganas[14], Julián García-Mayordomo[15], Laura Gómez de la Peña[16], Eulàlia Gràcia[16], Petra Jamšek Rupnik[8], Hervé Jomard[9], Vanja Kastelic[1], Francesco Emanuele Maesano[1], Raquel Martín-Banda[15], Sara Martínez-Loriente[16], Marta Neres[17,12], Hector Perea[16], Barbara Šket Motnikar[18], Mara Monica Tiberti[1], Nino Tsereteli[6], Varvara Tsironi[14], Roberto Vallone[1], Kris Vanneste[19], Polona Zupančič[18], and Domenico Giardini[20]



https://seismofaults.eu/efsm20

The compilation of EFSM20 relies heavily on publicly available datasets (see tables below) and voluntarily contributed datasets spanning large regions, as well as solicited local contributions in specific areas of interest.

Crustal Faults

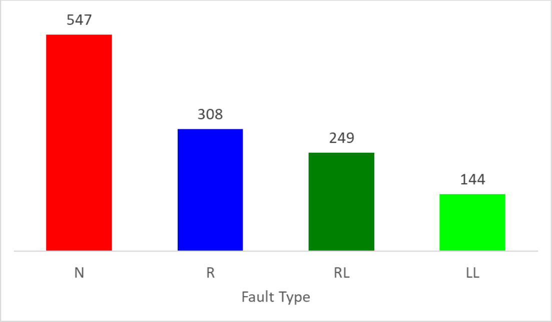
TITLE	REFERENCE	URL	COVERAGE
EDSF 2013	Basili et al. (2013); Giardini et al. (2013)	http://diss.rm.ingv.it/share-edsf/	Europe and Mediterranean
QAFI 3	IGME (2015)	http://info.igme.es/qafi/	Iberia
DISS 3.2.2	DISSWG (2021)	http://diss.rm.ingv.it/diss/	Central Mediterranean
GREDASS 2.0	Caputo & Pavlides (2013)	http://gredass.unife.it/	Aegean
LRGM	Vanneste et al. (2013)	https://doi.org/10.1785/0120120037	Lower Rhine Graben
AFCD	Emre et al. (2018); Demircioğlu et al. (2017)	http://www.mta.gov.tr/eng/maps/active-fault-1250000	Anatolia
EMME FAULT SOURCES	Danciu et al. (2018)	http://www.efehr.org/en/Documentation/specific-hazard-models/middle-east/active-faults/	Middle East
NOAFAULTS 3.0	Ganas et al. (2013)	https://arcg.is/04Haer	Greece
BDFA	Jomard et al. (2017)	https://www.nat-hazards-earth-syst-sci.net/17/1573/2017/	France
SLOVENIAN FAULT SOURCE MODEL	Atanackov et al. (2021)	https://doi.org/10.3389/feart.2021.604388	Slovenia

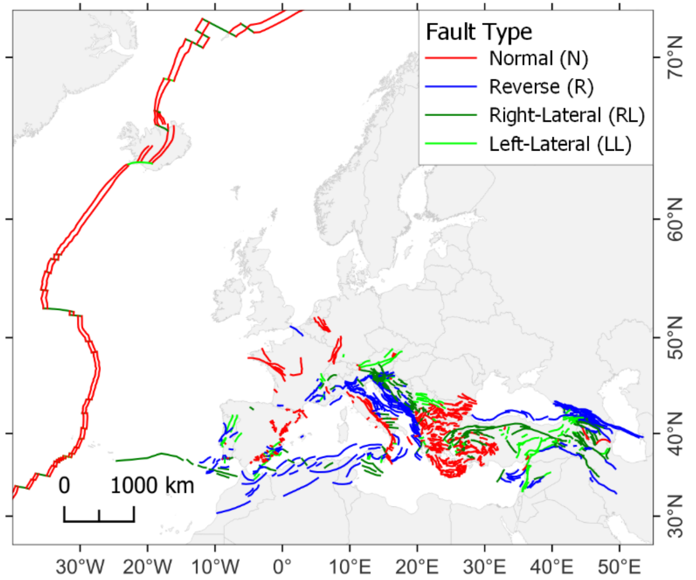
Subduction Systems

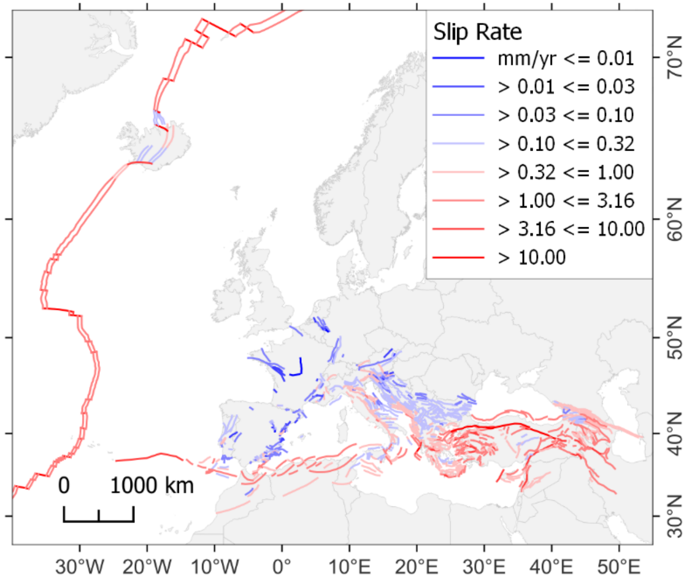
TITLE	REFERENCE	URL	COVERAGE
EDSF 2013	Basili et al. (2013); Giardini et al. (2013)	http://diss.rm.ingv.it/share-edsf/	Central-Eastern Mediterranean
DISS 3.2.1	DISSWG (2018)	http://diss.rm.ingv.it/diss/	Central-Eastern Mediterranean
CALABRIAN ARC MODEL	Maesano et al. (2017)	https://www.nature.com/articles/s41598-017-09074-8	Central Mediterranean
SLAB 2.0	Hayes (2018); Hayes et al. (2018)	https://doi.org/10.5066/F7PV6JNV	World
GEM-FE SICP 2.0	Berryman et al. (2015)	--	World
SUBMAP 4.2	Heuret & Lallemand (2005)	http://submap.gm.univ-montp2.fr/index.php	World
PB2002	Bird et al. (2003)	http://peterbird.name/publications/2003_PB2002/2003_PB2002.htm	World

Crustal Faults

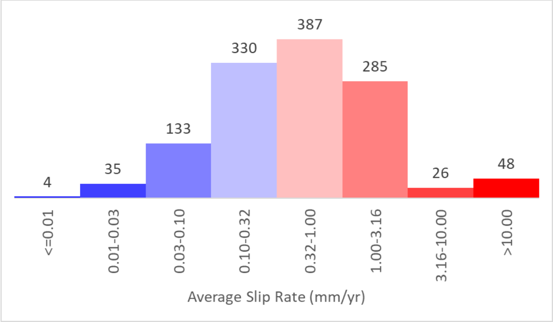
Faulting types



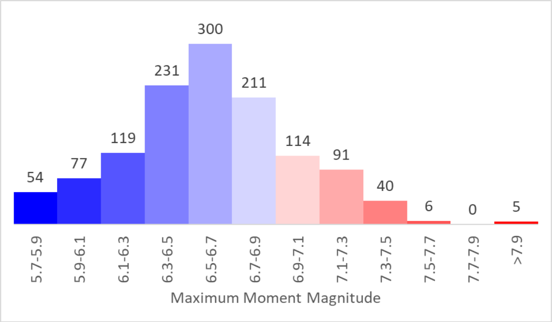


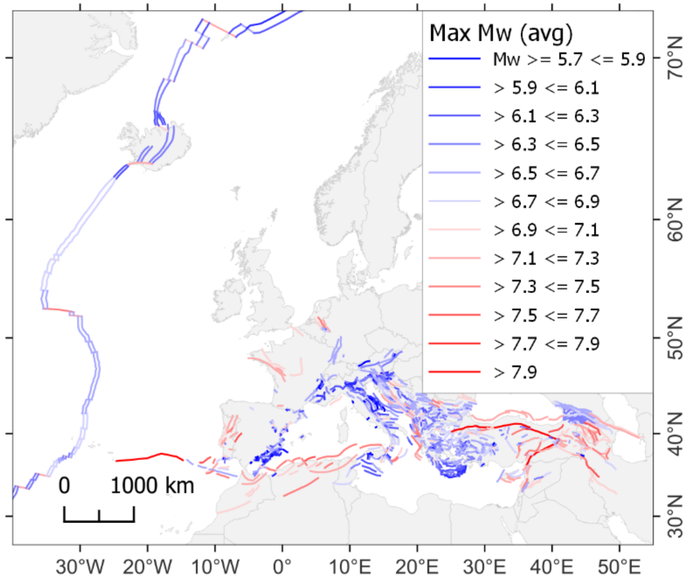


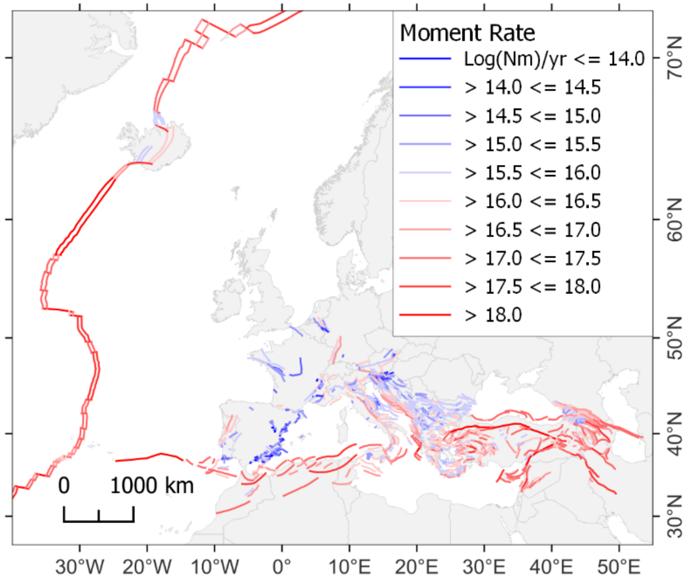
Slip rates



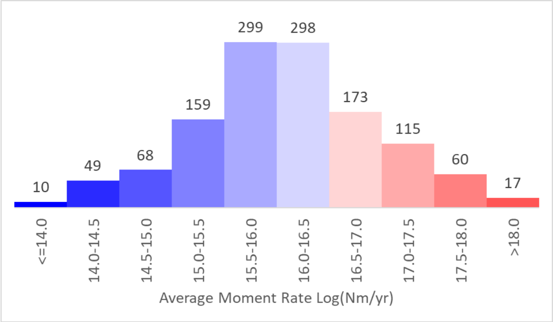
Max Mw



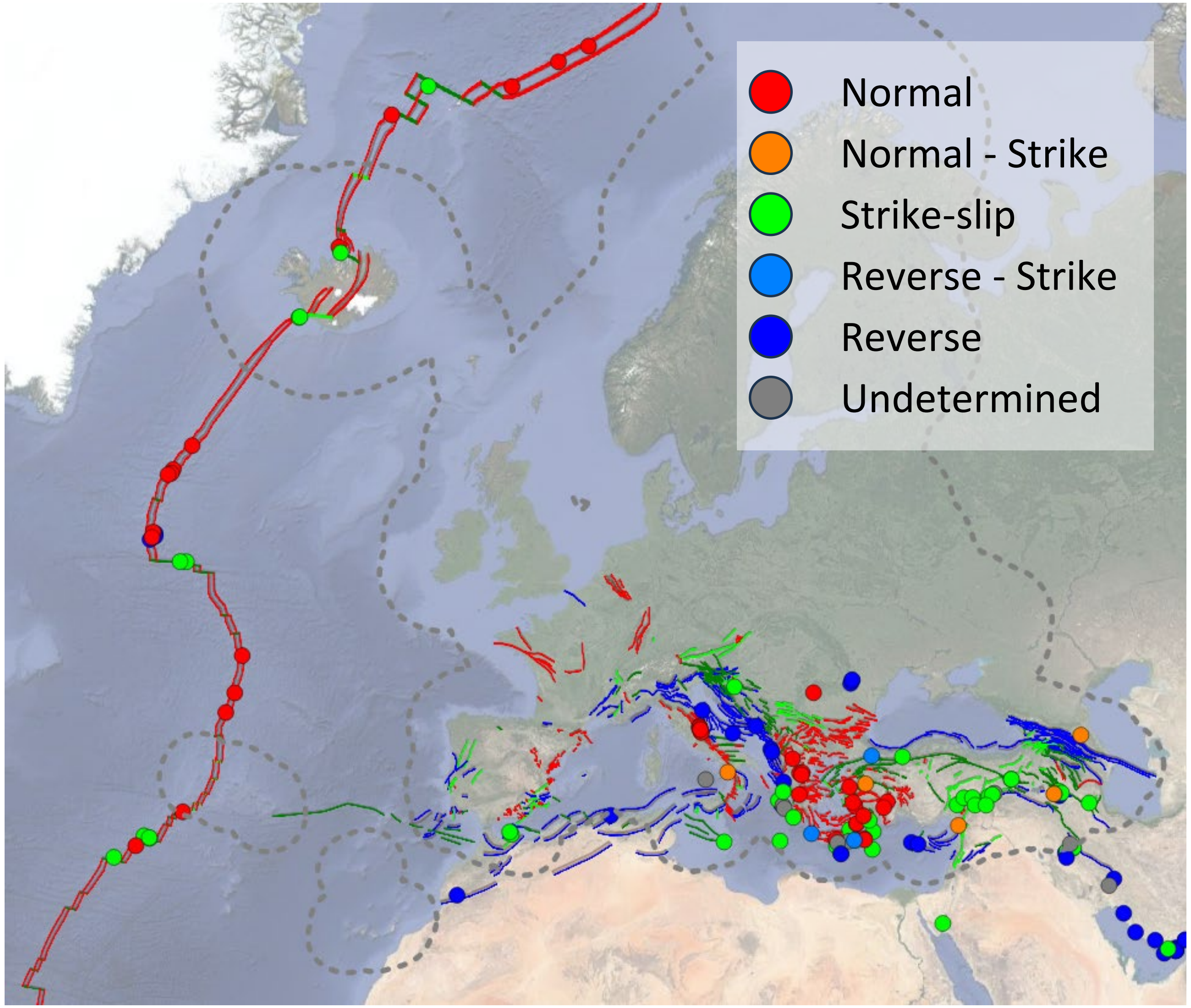


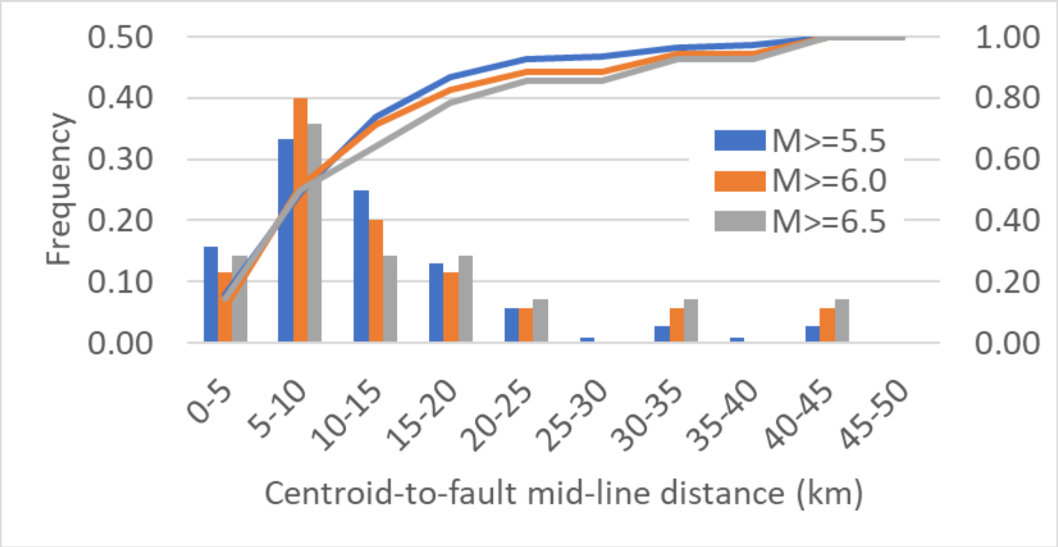


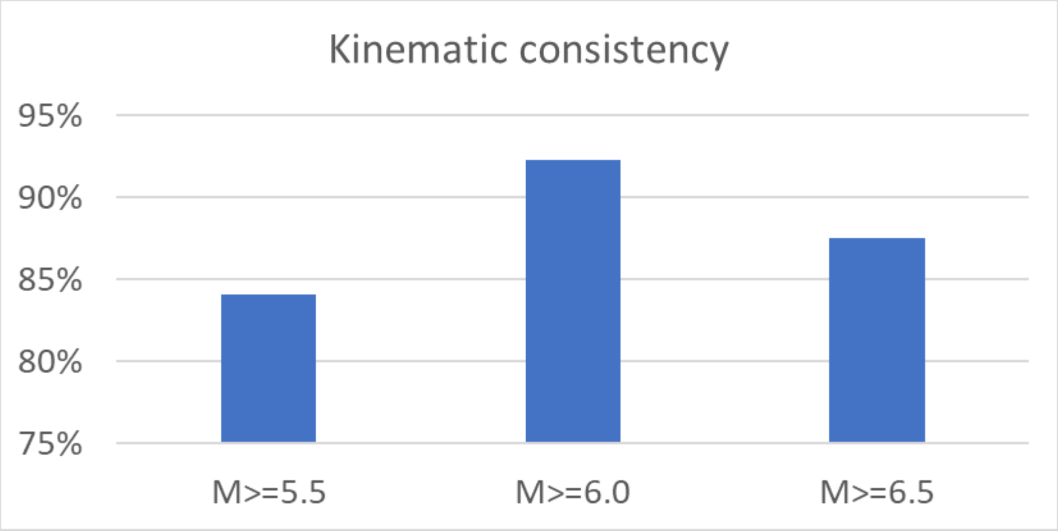
Moment rates (log scale)



Crustal Faults

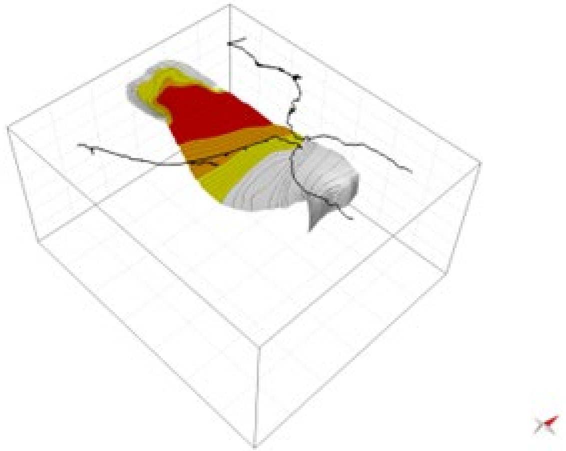




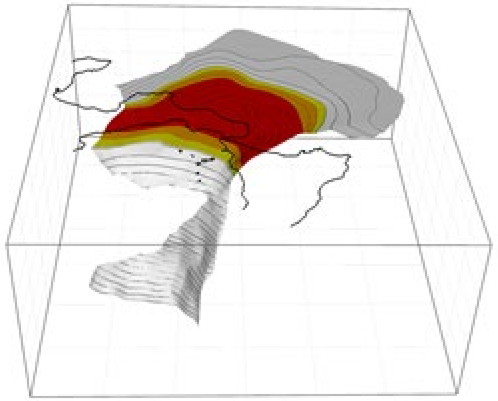


Subduction Interfaces

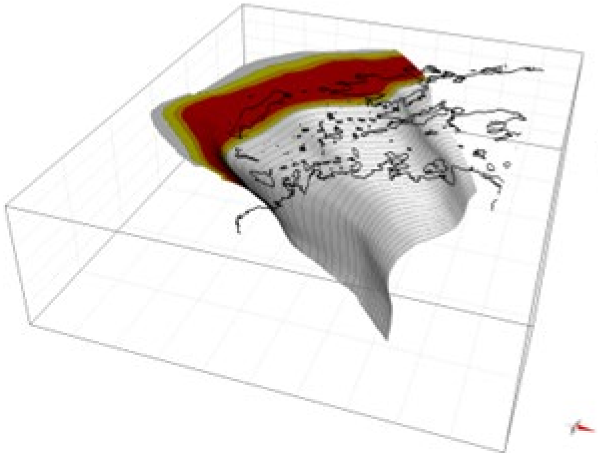
Gibraltar Arc



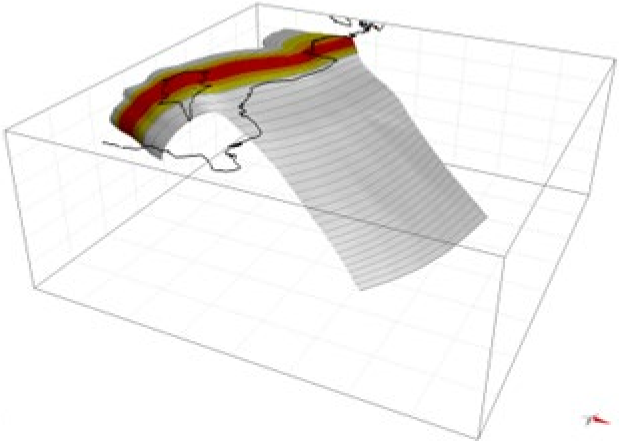
Calabrian Arc

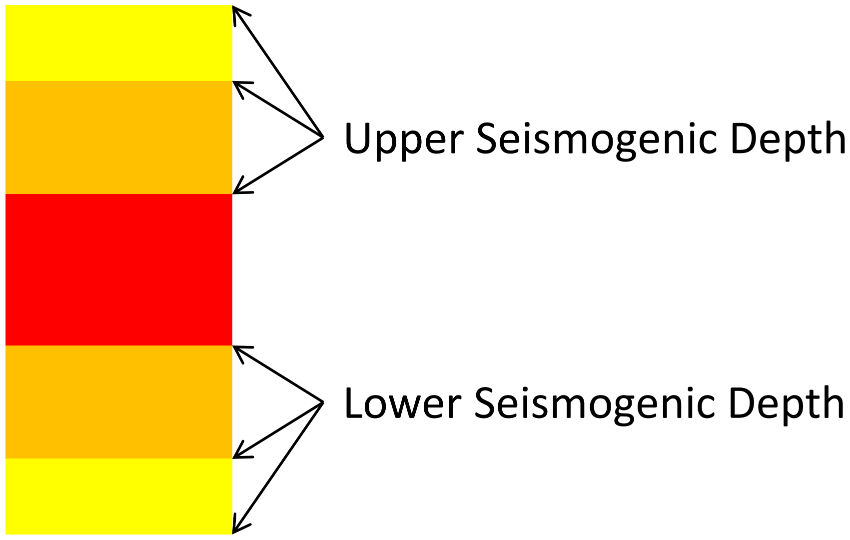


Hellenic Arc

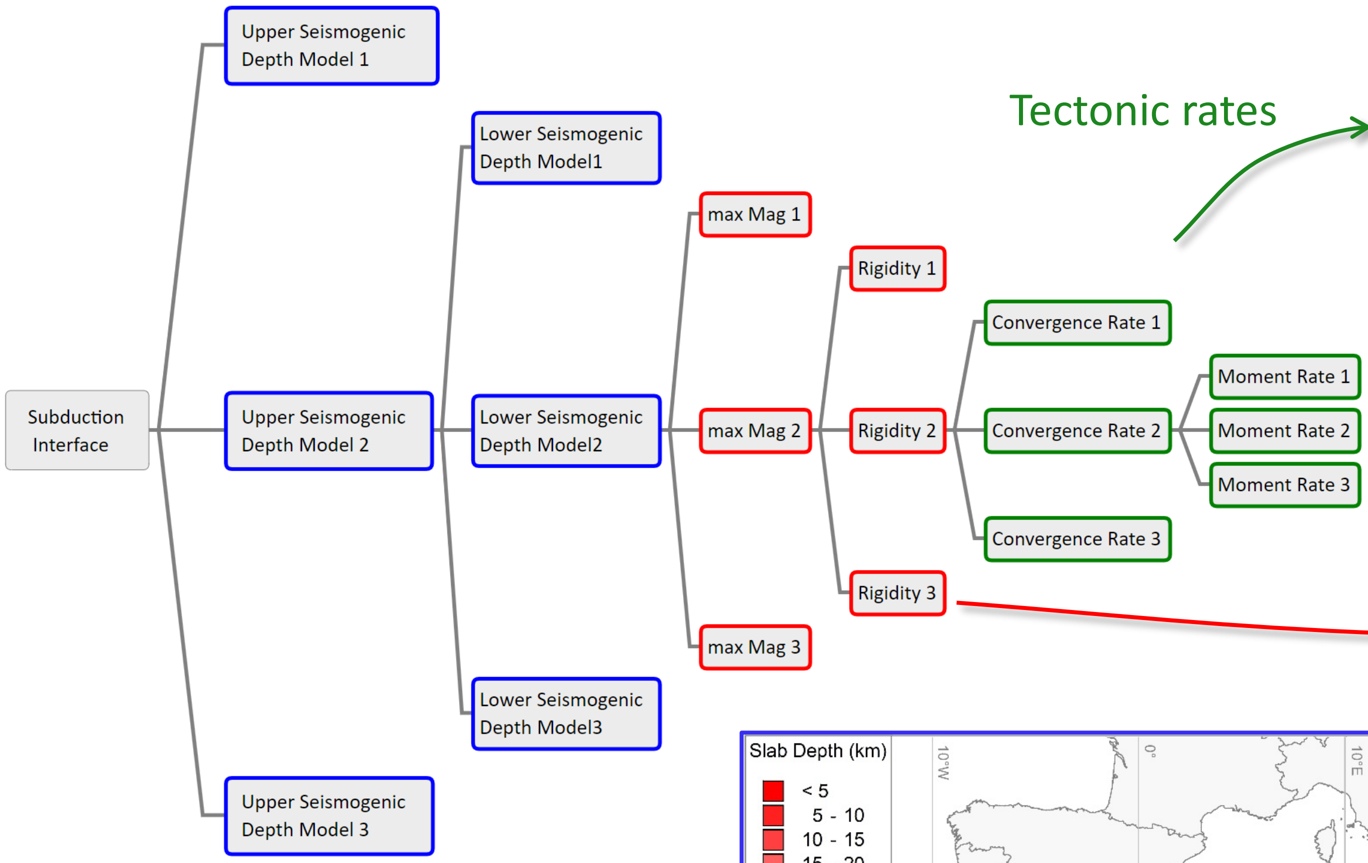


Cyprus Arc

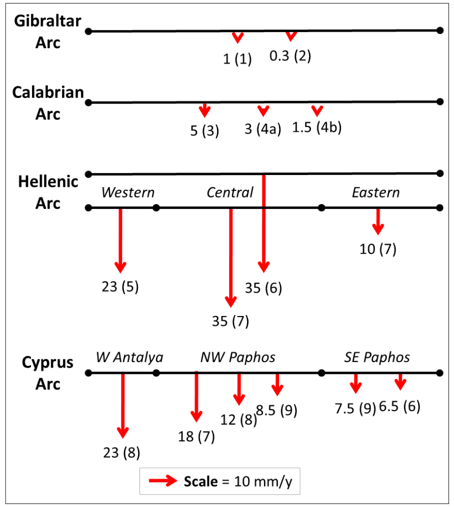




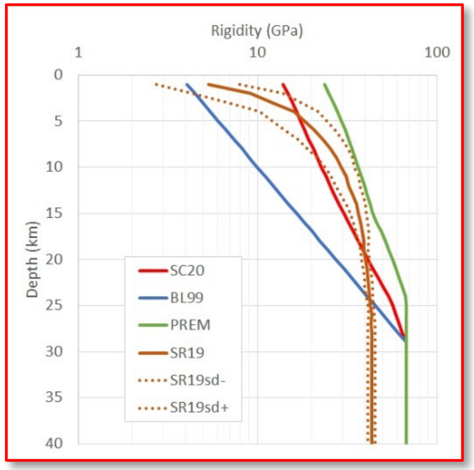
Subduction Interfaces



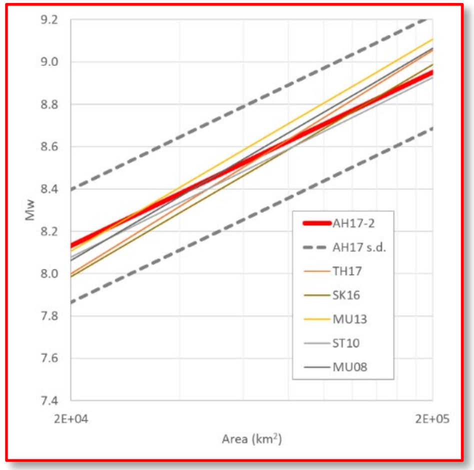
Tectonic rates



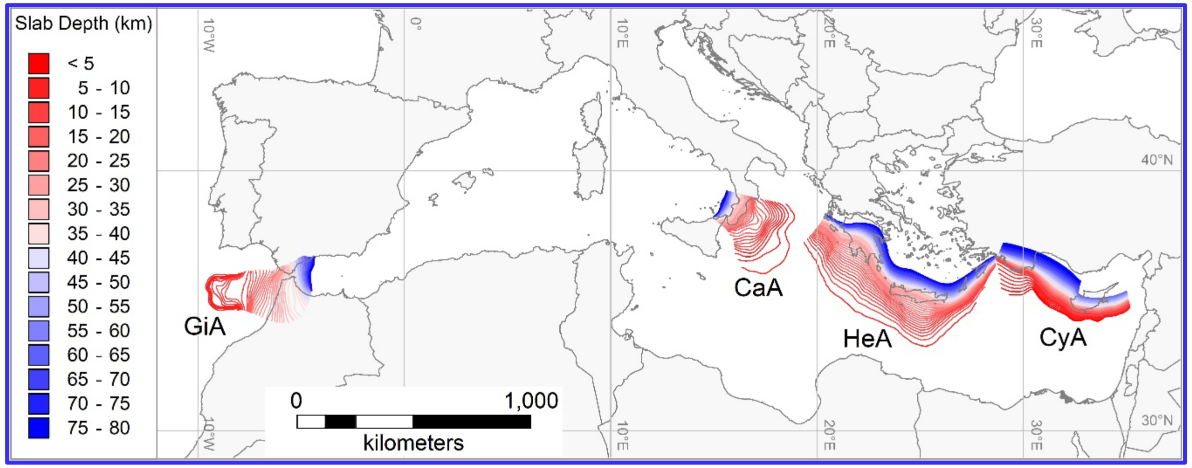
Rigidity



Max Magnitude



Upper and lower seismogenic depths



Epistemic uncertainty

Epistemic uncertainty refers to a lack of knowledge - something we could, in principle, know for sure - in contrast to aleatoric uncertainty "intrinsic randomness" involved in which possible futures will actually occur.

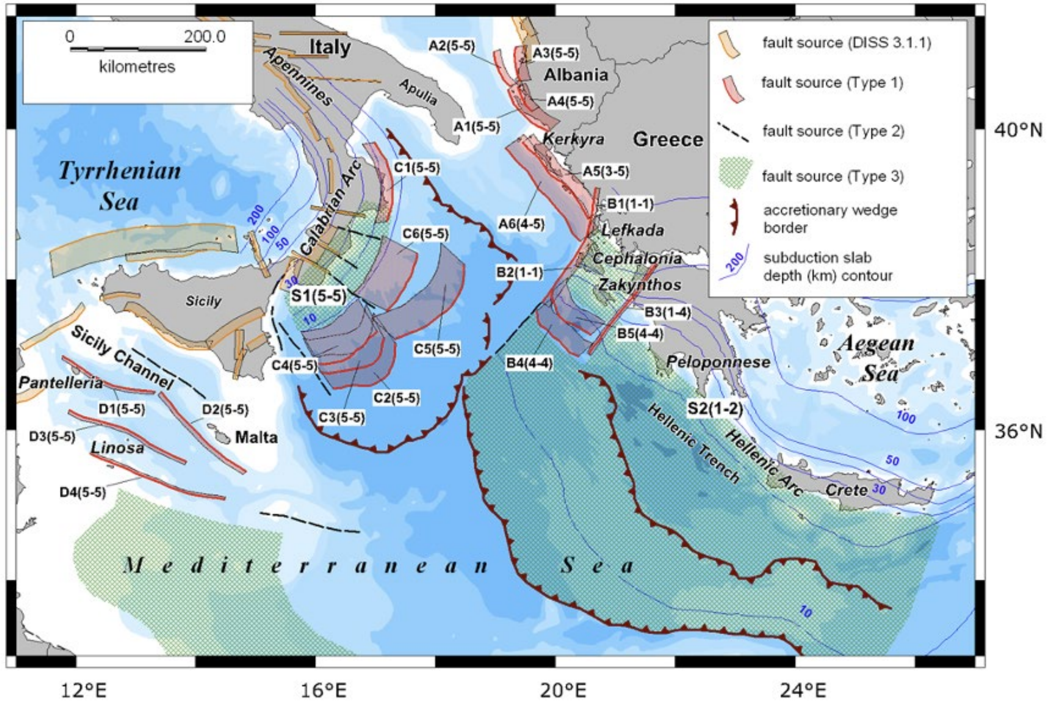
The epistemic uncertainty can be reduced by further observation and refinement.

Epistemic uncertainty

Fault Type 1: coastal and offshore structures that are fully parameterized and their epistemic uncertainty addressed.

Fault Type 2: known offshore structures, or possible continuation of known onshore faults, whose capability of releasing earthquakes of significant magnitude is unknown or not yet investigated.

Fault Type 3: structures located in areas with known or possible seismic/tectonic activity, but where fault identification and mapping has not yet been carried out. This condition may occur for different reasons, e.g., scarcity of geophysical/geological data at the scale of interest, and/or complex fault systems with many structures whose relative importance is difficult to discriminate.



Basili et al. (2013; NHESS)

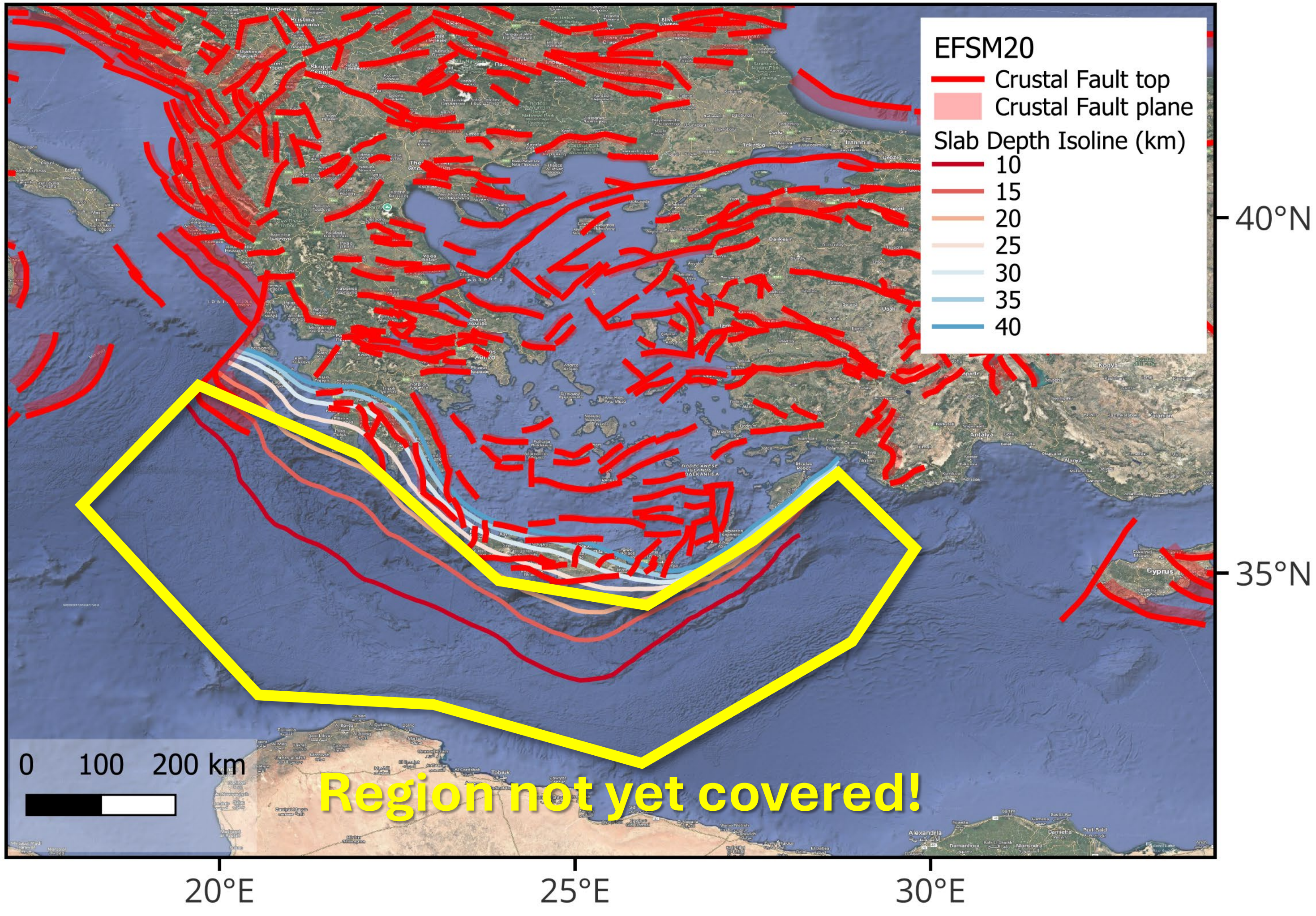
Excerpt from Basili et al. (2024; NHESS)

4 Discussion

4.1 Lessons learned from the compilation and harmonization

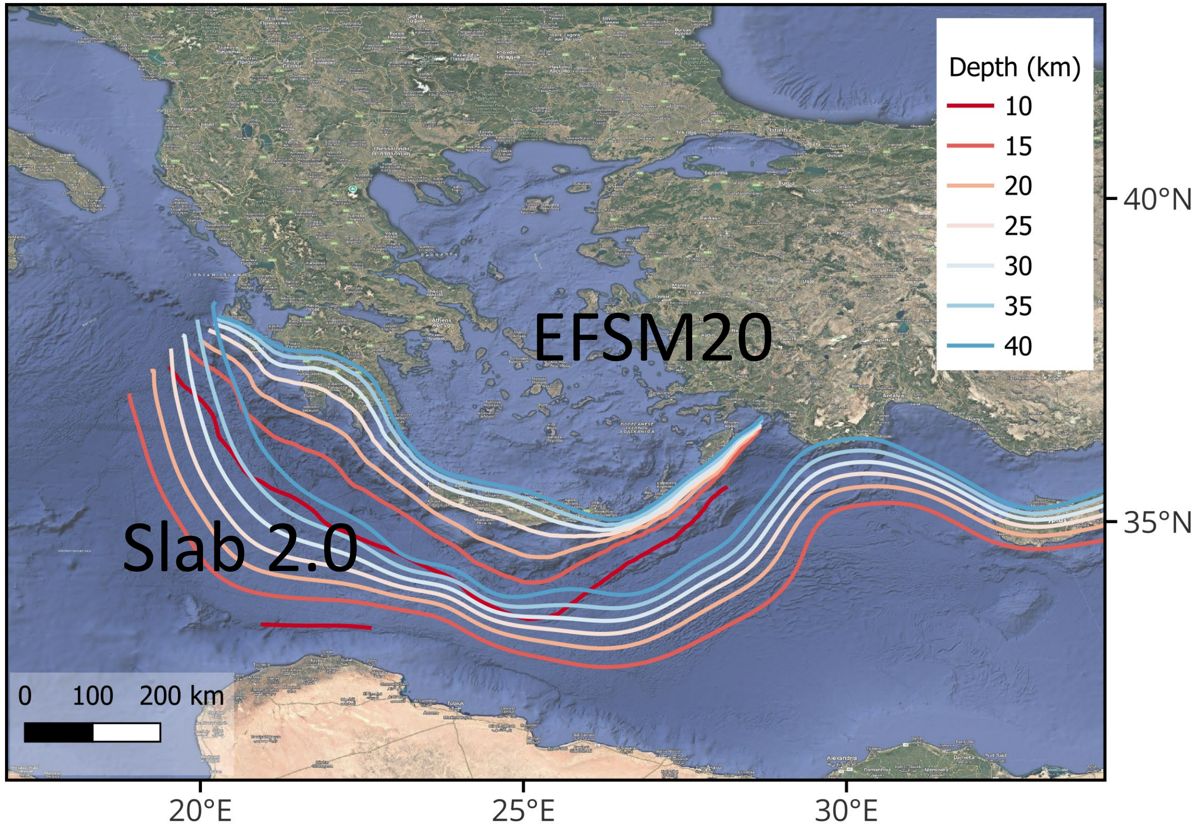
The compilation of EFSM20 represents a substantial update and advancement of EDSF13. **EFSM20** improved along the boundary around the European plate and within the plate interiors, focusing on the region within a 300 km wide buffer around European countries. Within this buffer, the **compilation was simplified in Iceland and certainly lacking in the Azores, mainly due to the complex volcano-tectonic processes and limited knowledge of active structures. Also lacking is the region of the Hellenic Arc and Cyprus Arc accretionary wedge, where seismic sources, such as splay thrust faults and back thrusts, are known to exist, but their systematic mapping would require a dedicated effort** due to the large extent of the region, its offshore location, and complex deformation that characterize accretionary wedges in general, as well as a very broad and fast-growing one in this case (>300 km at 10 mm yr^{-1}) due to the long duration (>35 Myr) of the subduction process (Kastens, 1991).

Focus on the Hellenic Arc

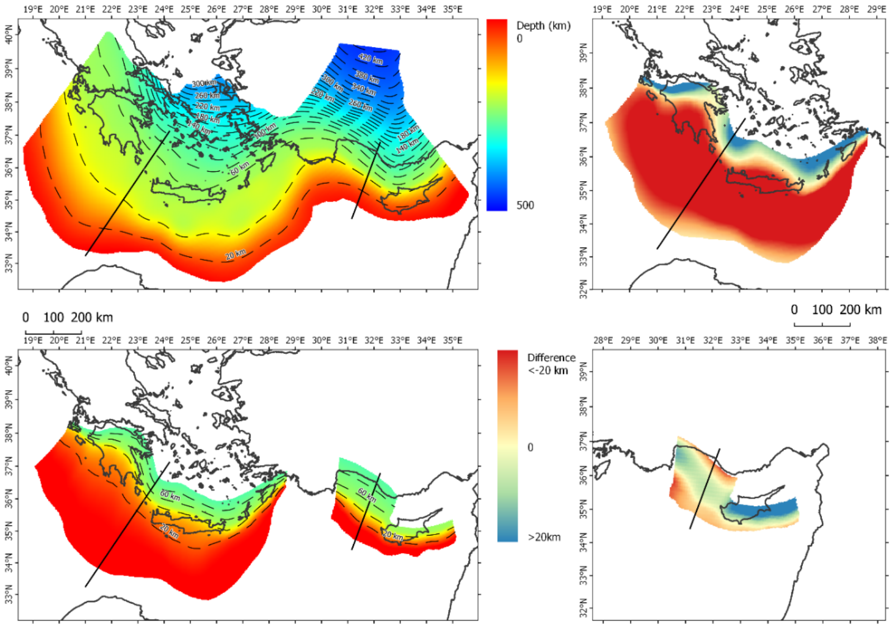


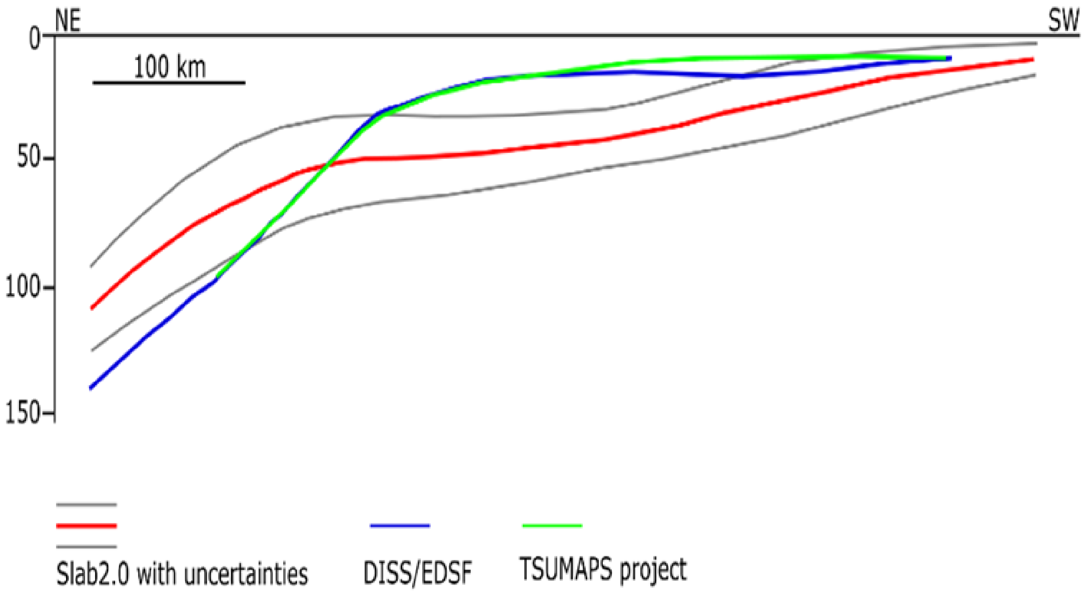
ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Focus on the Hellenic Arc

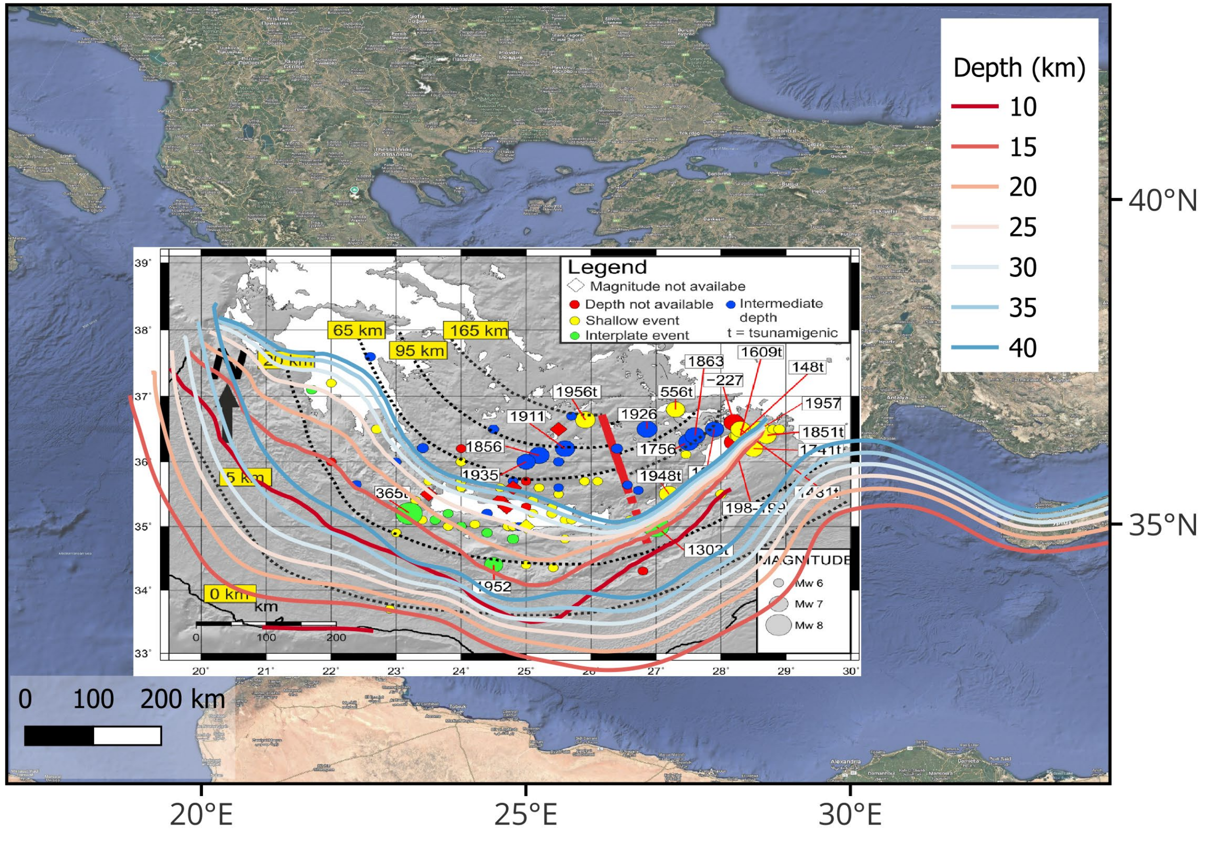


EFSM20: Basili et al. (2024)
Slab 2.0: Hayes et al (2018)

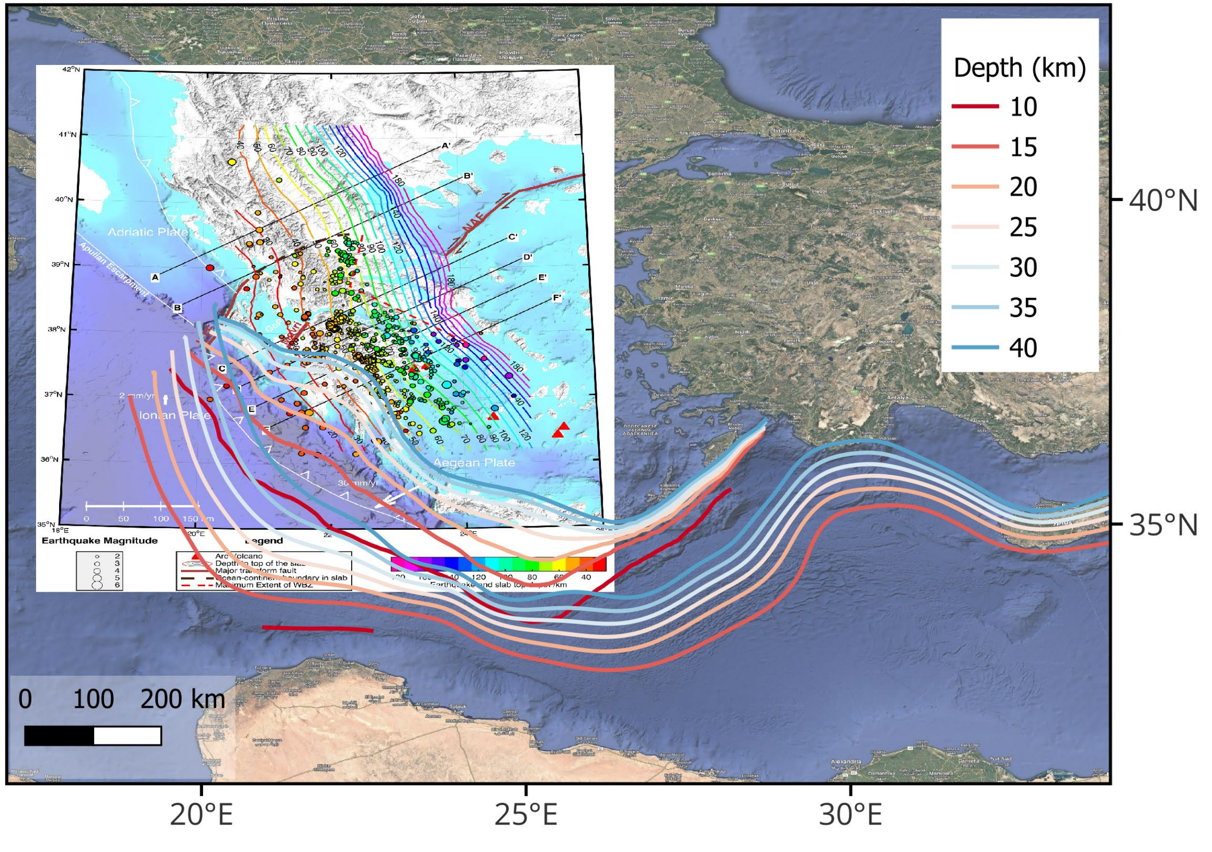




Focus on the Hellenic Arc

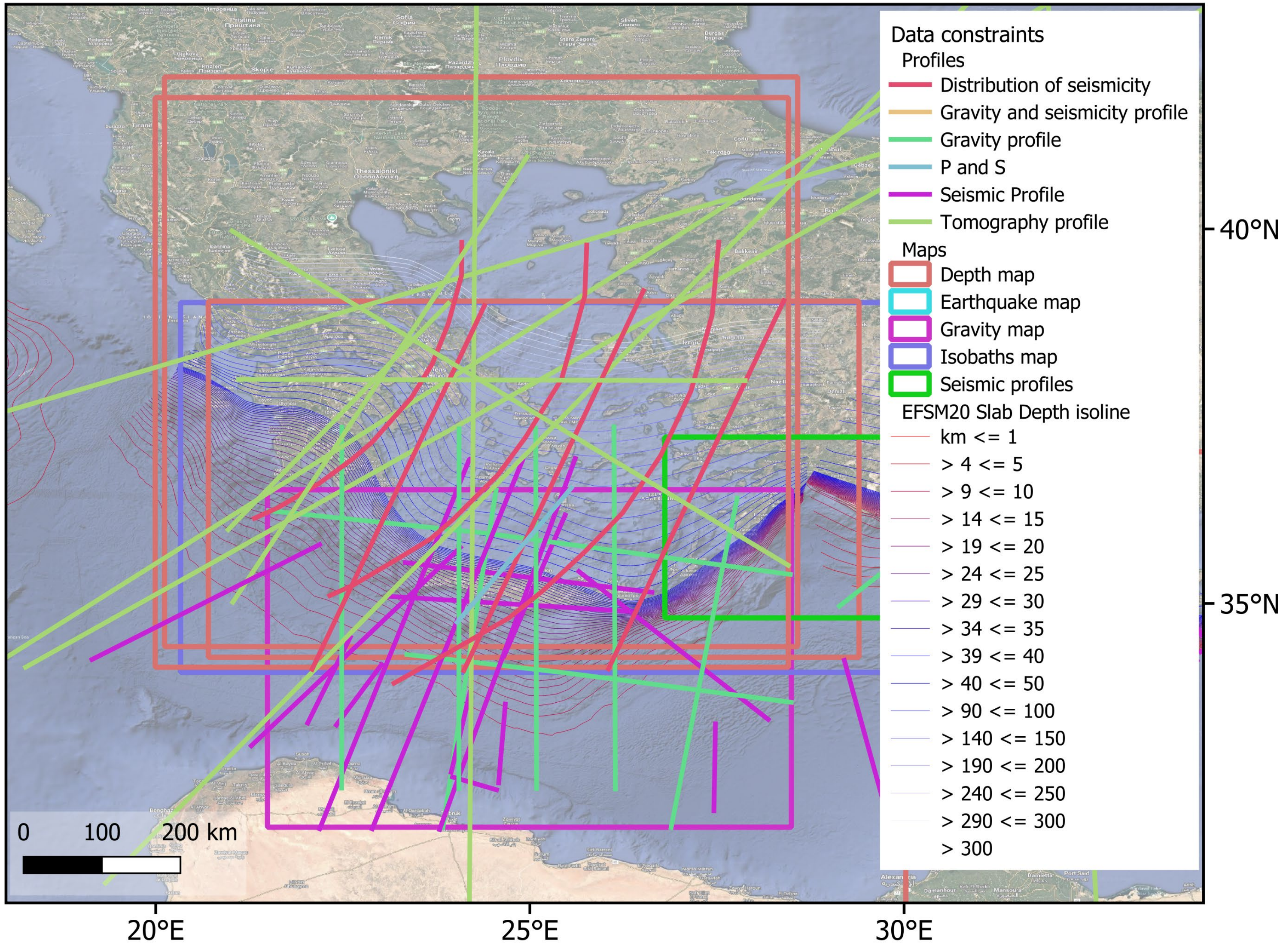


Bocchini et al. (2018, Tectonophysics)



Halpaap et al. (2018, JGR)

Focus on the Hellenic Arc



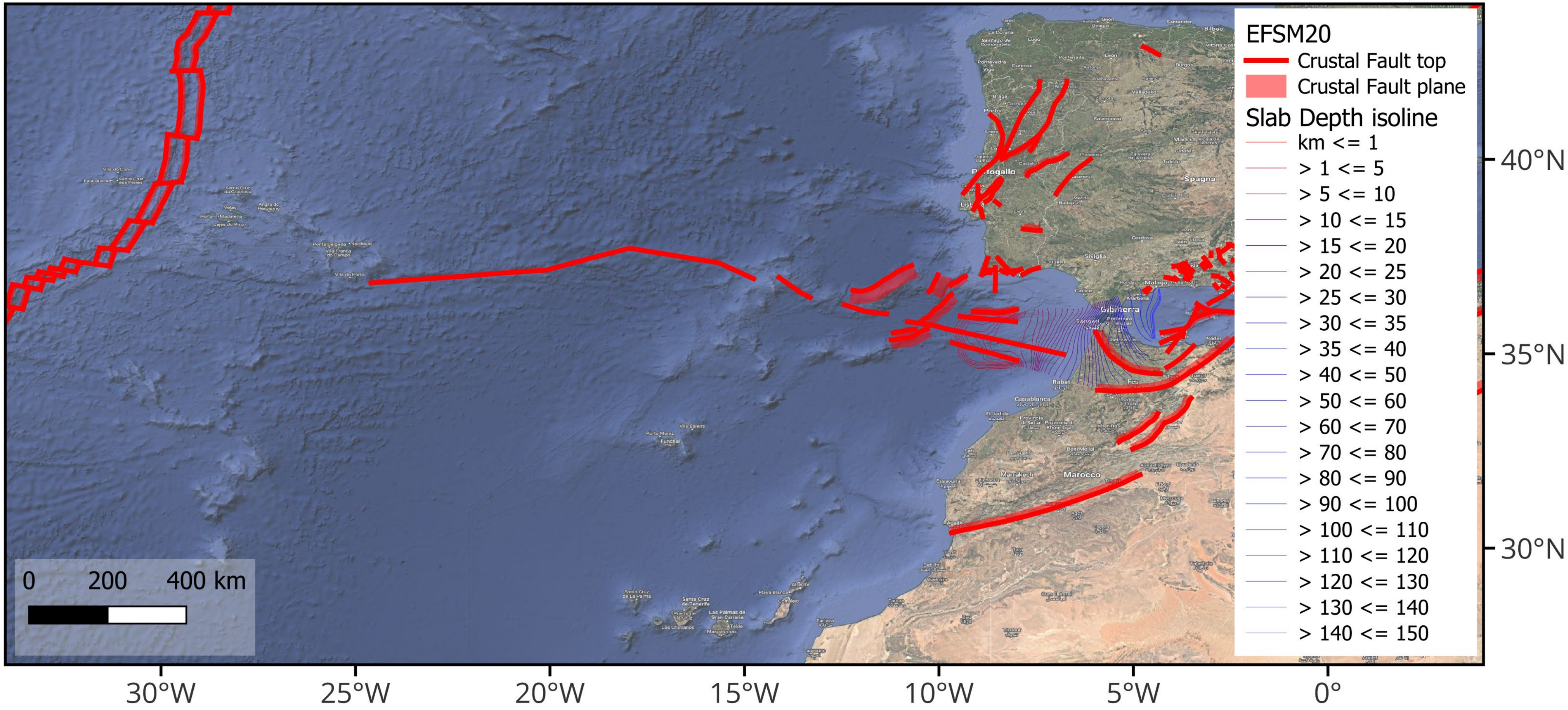
Data used for the EFSM20 version of the Hellenic Arc geometry

Halpaap et al. (2018) use local earthquake tomography and double-difference relocation in conjunction with published images based on scattered teleseismic waves.

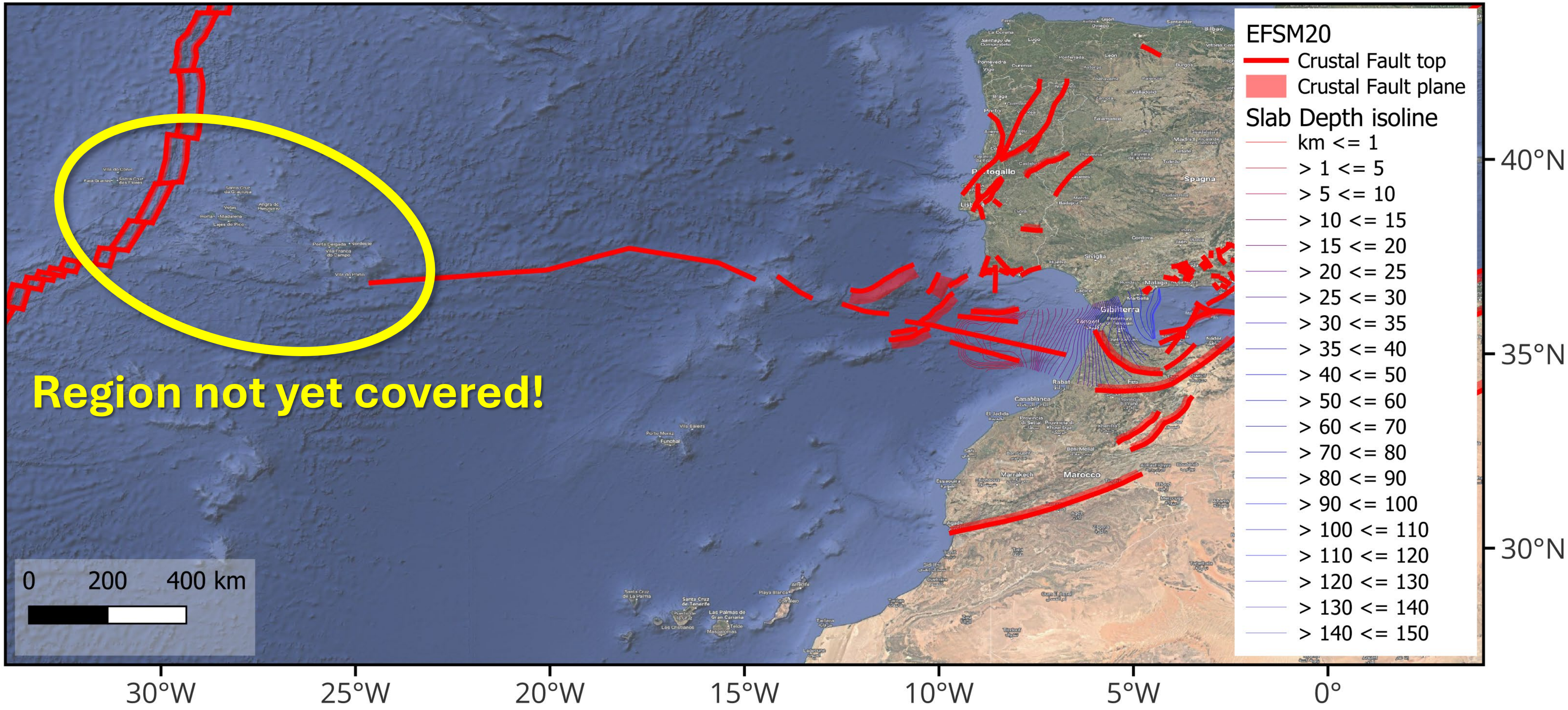
Bocchini et al. (2018) use well-located hypocentres from global and temporary local seismicity catalogs.

Hayes et al. (2018) use earthquake locations, receiver functions, and tomography data.

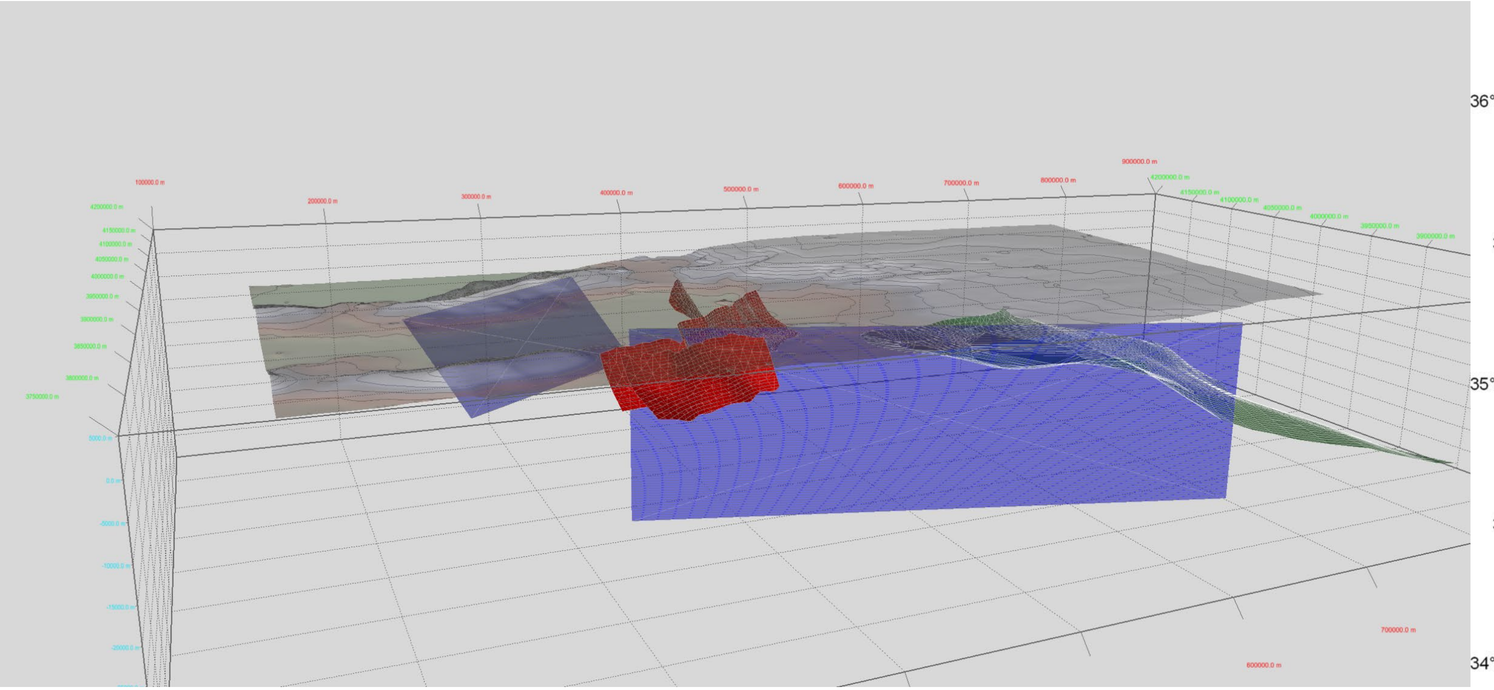
Focus on the Azores-Gibraltar Fault Zone

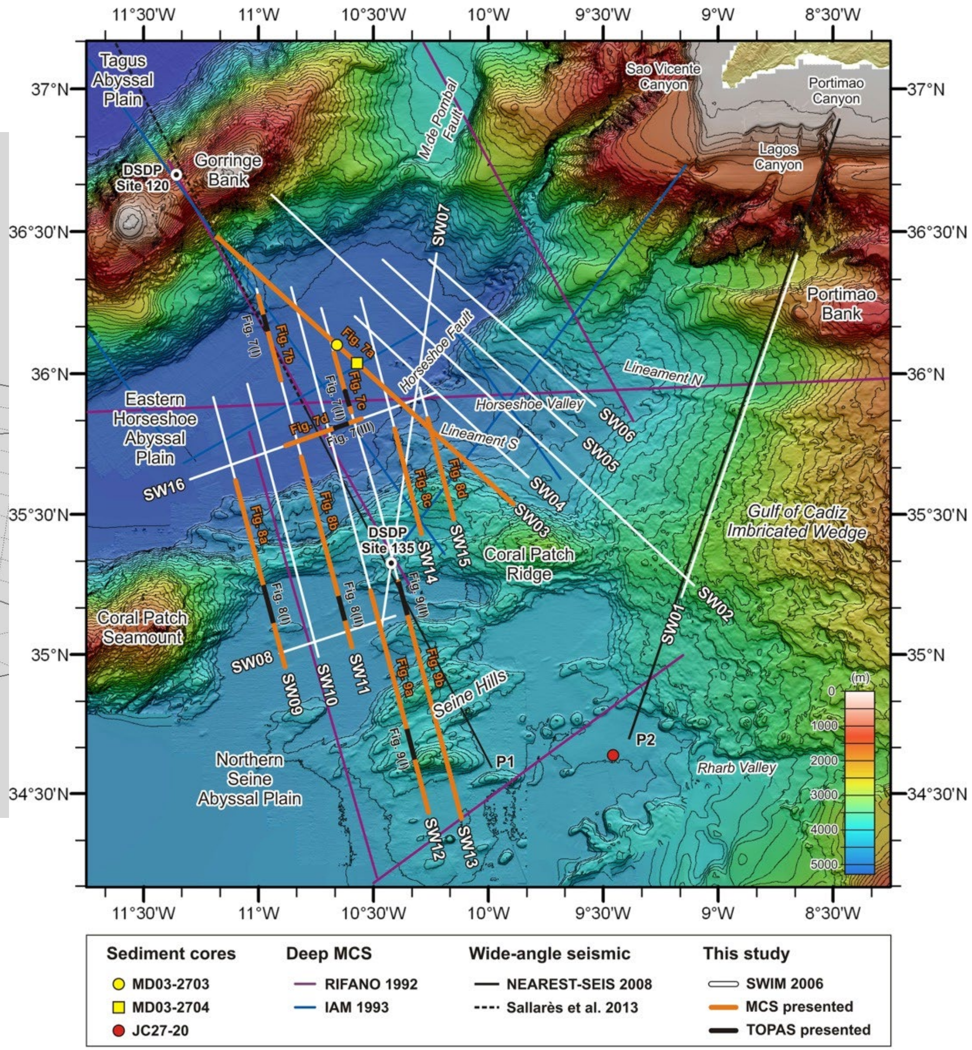


Focus on the Azores-Gibraltar Fault Zone



Focus on the Azores-Gibraltar Fault Zone

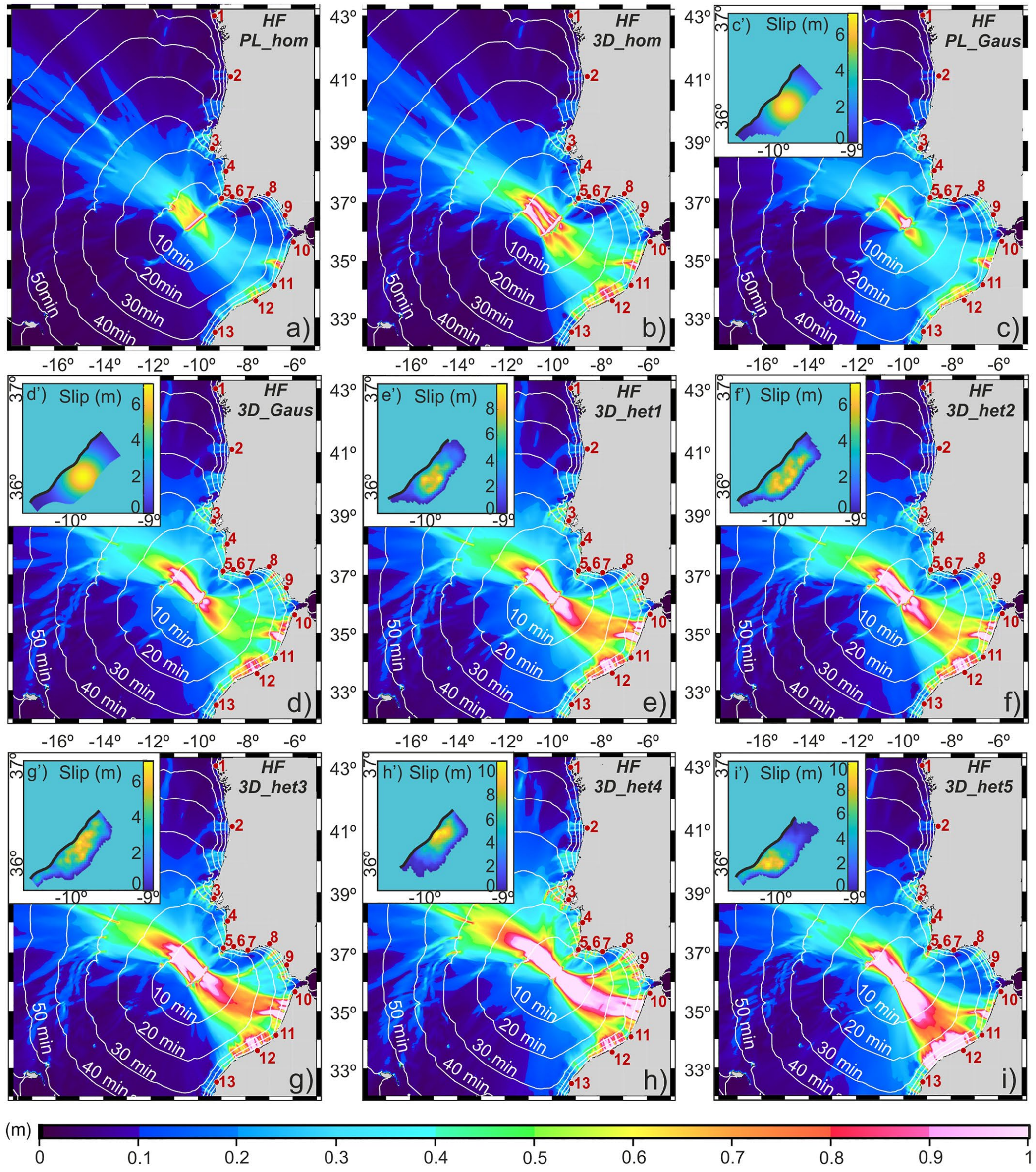




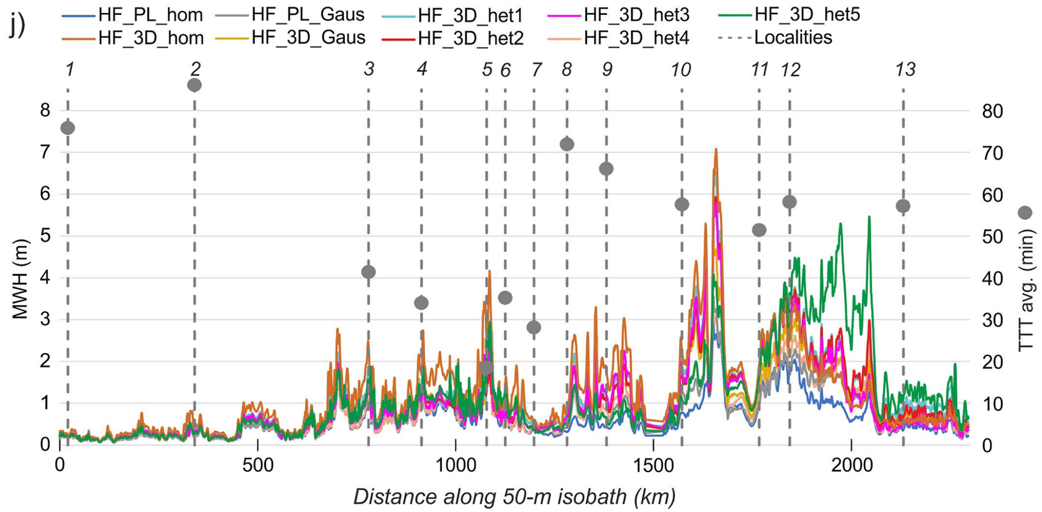
Martínez-Loriente et al. (2013, G3)

Blue: rectangular crustal fault;
Red: 3D complex crustal fault;
Green: 3D complex subduction interface.

Focus on the Azores-Gibraltar Fault Zone



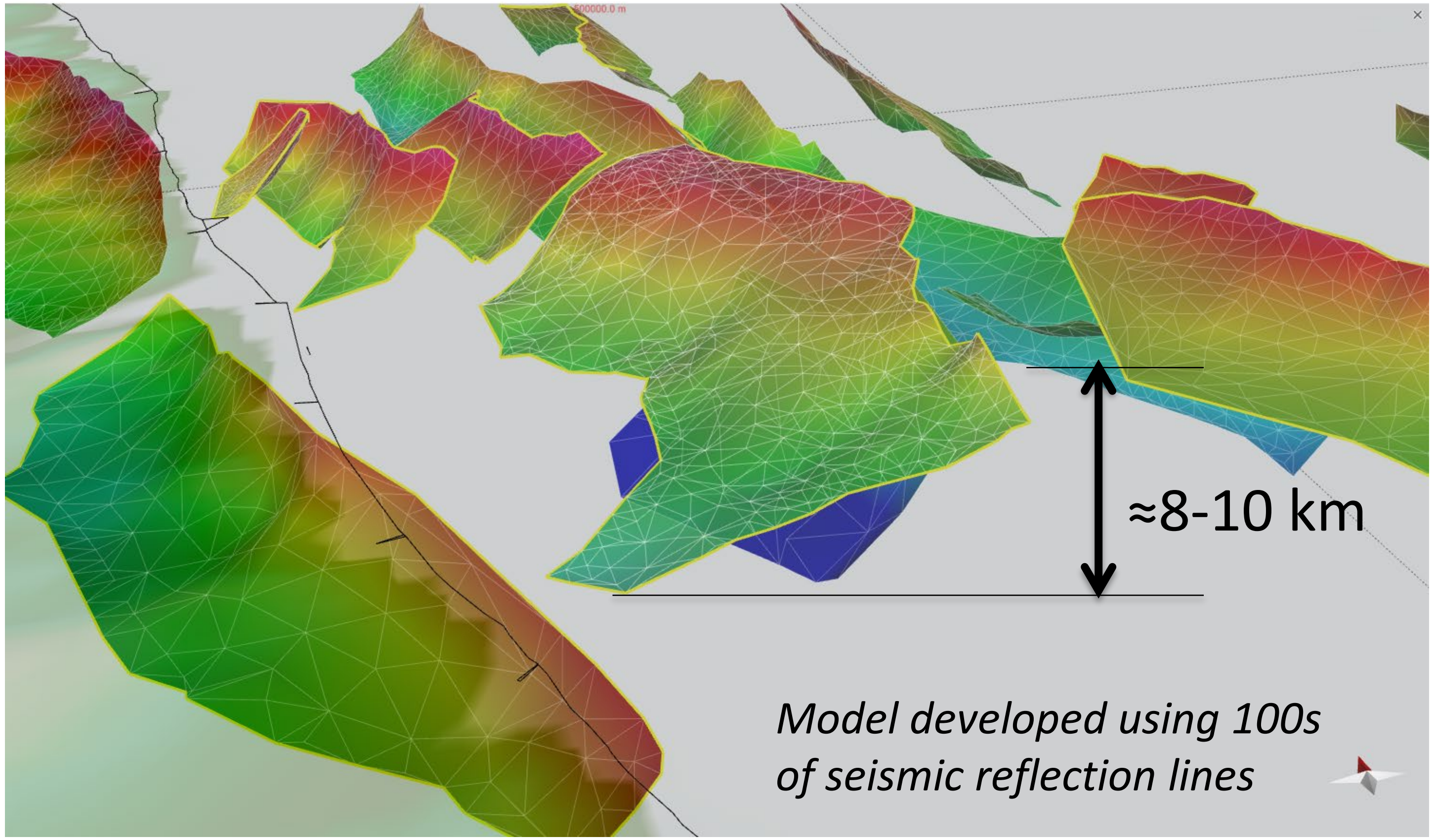
Sensitivity of tsunami scenarios from planar fault to complex fault geometry and homogeneous to heterogeneous slip distributions.



Serra et al. (2021, JGR)

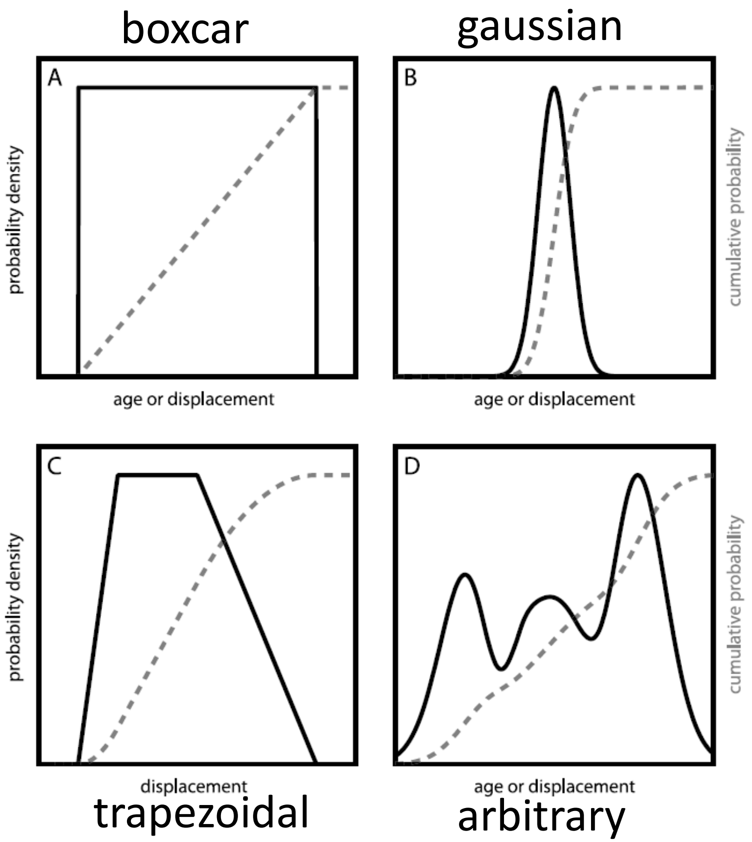
ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

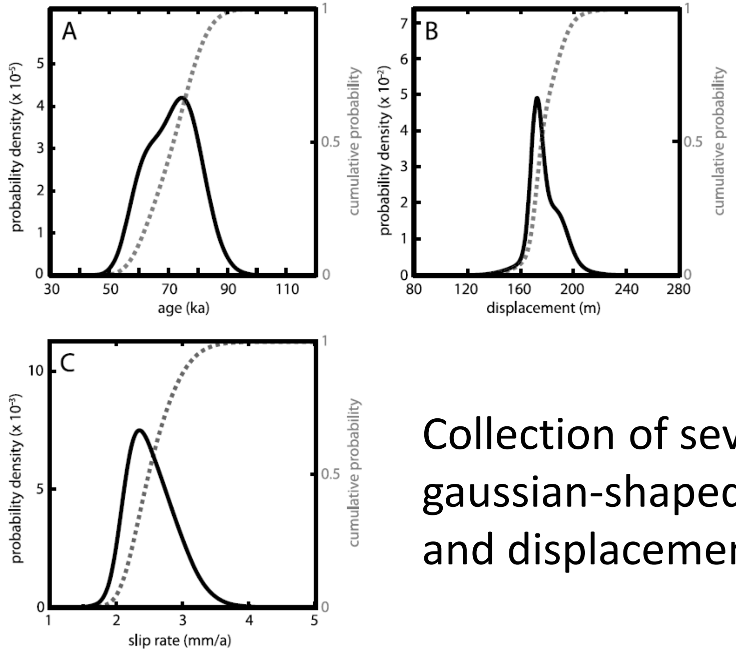
Outlook on fault-sources



3D reconstruction of fault geometry

Outlook on fault-sources



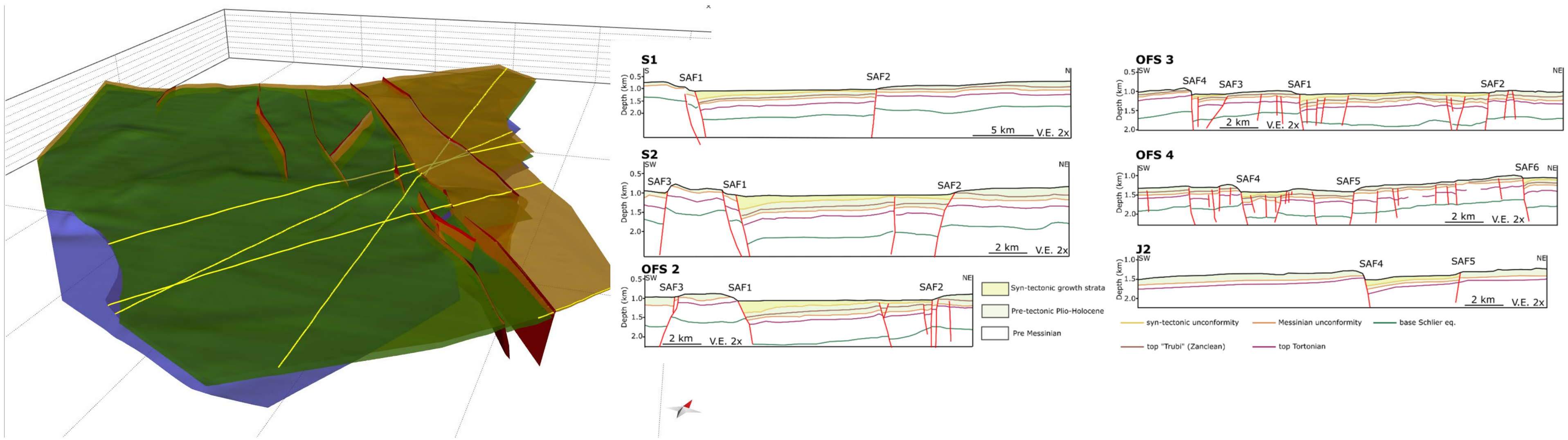


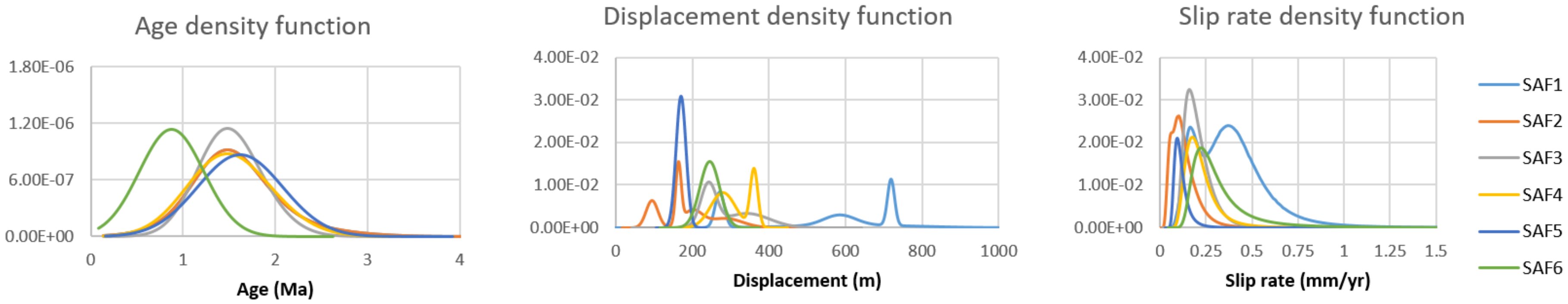
Collection of several gaussian-shaped age and displacement data

Zechar & Frankel, 2009, JGR

Probabilistic reporting of fault slip rates

Outlook on fault-sources





Probabilistic reporting of fault slip rates

Maesano et al. (2020, Tectonics)

Summary points for discussion

- NEAMTHM18 used input datasets considered “fit for the purpose” by the panel of experts and reviewers when it was conceptualized (May 2016).
- Since then, several datasets have been updated/improved. The impact of these updates can only be quantified via disaggregation and sensitivity analyses.
- EPOS provides a framework for distributing “quality-controlled” data produced by the large community with a high level of FAIRness.
- Earthquake catalogs: The instrumental part relies on the collaboration efforts of seismic networks, while the pre-instrumental part relies on macroseismic studies carried out by experts.
- Faults: Most data collection proceeds country by country for practical and organizational reasons. Collaborations are needed to decrease the need for ex-post data harmonization, and efforts are also needed to improve knowledge in the least obvious tectonic regions.
- Fault sources: future trends should focus on 3D fault geometry reconstructions and probabilistic analysis of fault slip rates.

Thank you!

References

- Lammers, S., Weatherill, G., Grünthal, G., & Cotton, F. (2023). EMEC-2021 - The European-Mediterranean Earthquake Catalogue – Version 2021 [Dataset]. GFZ German Research Center for Geosciences. https://doi.org/10.5880/GFZ.EMEC.2021.001
- Rovida, A., & Antonucci, A. (2021). EPICA - European PreInstrumental Earthquake CAtalogue, version 1.1 (Version 1.1) [Dataset]. Istituto Nazionale di Geofisica e Vulcanologia (INGV). https://doi.org/10.13127/EPICA.1.1
- Rovida, A., Antonucci, A., & Locati, M. (2022). The European Preinstrumental Earthquake Catalogue EPICA, the 1000–1899 catalogue for the European Seismic Hazard Model 2020. In Earth System Science Data (Vol. 14, Issue 12, pp. 5213–5231). Copernicus GmbH. https://doi.org/10.5194/essd-14-5213-2022
- Basili, R., Tiberti, M. M., Kastelic, V., Romano, F., Piatanesi, A., Selva, J., & Lorito, S. (2013). Integrating geologic fault data into tsunami hazard studies. In Natural Hazards and Earth System Sciences (Vol. 13, Issue 4, pp. 1025–1050). Copernicus GmbH. https://doi.org/10.5194/nhess-13-1025-2013
- Basili, R., Brizuela, B., Herrero, A., Iqbal, S., Lorito, S., Maesano, F. E., Murphy, S., Perfetti, P., Romano, F., Scala, A., Selva, J., Taroni, M., Thio, H. K., Tiberti, M. M., Tonini, R., Volpe, M., Glimsdal, S., Harbitz, C. B., Løvholt, F., ... Oueslati, F. (2018). NEAM Tsunami Hazard Model 2018 (NEAMTHM18): online data of the Probabilistic Tsunami Hazard Model for the NEAM Region from the TSUMAPS-NEAM project. Istituto Nazionale di Geofisica e Vulcanologia (INGV). https://doi.org/10.13127/TSUNAMI/NEAMTHM18
- Basili, R., Brizuela, B., Herrero, A., Iqbal, S., Lorito, S., Maesano, F. E., Murphy, S., Perfetti, P., Romano, F., Scala, A., Selva, J., Taroni, M., Tiberti, M. M., Thio, H. K., Tonini, R., Volpe, M., Glimsdal, S., Harbitz, C. B., Løvholt, F., ... Zaytsev, A. (2021). The Making of the NEAM Tsunami Hazard Model 2018 (NEAMTHM18). In Frontiers in Earth Science (Vol. 8). Frontiers Media SA. https://doi.org/10.3389/feart.2020.616594
- Basili, R., Danciu, L., Beauval, C., Sesetyan, K., Vilanova, S. P., Adamia, S., Arroucau, P., Atanackov, J., Baize, S., Canora, C., Caputo, R., Carafa, M. M. C., Cushing, E. M., Custódio, S., Demircioglu Tumsa, M. B., Duarte, J. C., Ganas, A., García-Mayordomo, J., Gómez de la Peña, L., ... Zupančič, P. (2022). European Fault-Source Model 2020 (EFSM20): online data on fault geometry and activity parameters [Dataset]. Istituto Nazionale di Geofisica e Vulcanologia (INGV). https://doi.org/10.13127/EFSM20
- Basili, R., Taccone, R. C., Vallone, R., & Maesano, F. E. (2024). European Fault-Source Model 2020 (EFSM20): 3D triangular meshes [Dataset]. Istituto Nazionale di Geofisica e Vulcanologia (INGV). https://doi.org/10.13127/EFSM20/MESHES
- Basili, R., Danciu, L., Beauval, C., Sesetyan, K., Vilanova, S. P., Adamia, S., Arroucau, P., Atanackov, J., Baize, S., Canora, C., Caputo, R., Carafa, M. M. C., Cushing, E. M., Custódio, S., Demircioglu Tumsa, M. B., Duarte, J. C., Ganas, A., García-Mayordomo, J., Gómez de la Peña, L., ... Giardini, D. (2024). The European Fault-Source Model 2020 (EFSM20): geologic input data for the European Seismic Hazard Model 2020. In Natural Hazards and Earth System Sciences (Vol. 24, Issue 11, pp. 3945–3976). Copernicus GmbH. https://doi.org/10.5194/nhess-24-3945-2024
- Bocchini, G. M., Brüstle, A., Becker, D., Meier, T., van Keken, P. E., Ruscic, M., Papadopoulos, G. A., Rische, M., & Friederich, W. (2018). Tearing, segmentation, and backstepping of subduction in the Aegean: New insights from seismicity. In Tectonophysics (Vols. 734–735, pp. 96–118). Elsevier BV. https://doi.org/10.1016/j.tecto.2018.04.002
- Halpaap, F., Rondenay, S., & Ottemöller, L. (2018). Seismicity, Deformation, and Metamorphism in the Western Hellenic Subduction Zone: New Constraints From Tomography. In Journal of Geophysical Research: Solid Earth (Vol. 123, Issue 4, pp. 3000–3026). American Geophysical Union (AGU). https://doi.org/10.1002/2017jb015154
- Hayes, G. P., Moore, G. L., Portner, D. E., Hearne, M., Flamme, H., Furtney, M., & Smoczyk, G. M. (2018). Slab2, a comprehensive subduction zone geometry model. In Science (Vol. 362, Issue 6410, pp. 58–61). American Association for the Advancement of Science (AAAS). https://doi.org/10.1126/science.aat4723
- Serra, C. S., Martínez-Loriente, S., Gràcia, E., Urgeles, R., Gómez de la Peña, L., Maesano, F. E., Basili, R., Volpe, M., Romano, F., Scala, A., Piatanesi, A., & Lorito, S. (2021). Sensitivity of Tsunami Scenarios to Complex Fault Geometry and Heterogeneous Slip Distribution: Case-Studies for SW Iberia and NW Morocco. In Journal of Geophysical Research: Solid Earth (Vol. 126, Issue 10). American Geophysical Union (AGU). https://doi.org/10.1029/2021jb022127
- Martínez-Loriente, S., Gràcia, E., Bartolome, R., Sallarès, V., Connors, C., Perea, H., Lo Iacono, C., Klaeschen, D., Terrinha, P., Dañobeitia, J. J., & Zitellini, N. (2013). Active deformation in old oceanic lithosphere and significance for earthquake hazard: Seismic imaging of the Coral Patch Ridge area and neighboring abyssal plains (SW Iberian Margin). In Geochemistry, Geophysics, Geosystems (Vol. 14, Issue 7, pp. 2206–2231). American Geophysical Union (AGU). https://doi.org/10.1002/ggge.20173
- Zechar, J. D., & Frankel, K. L. (2009). Incorporating and reporting uncertainties in fault slip rates. In Journal of Geophysical Research: Solid Earth (Vol. 114, Issue B12). American Geophysical Union (AGU). https://doi.org/10.1029/2009jb006325
- Maesano, F. E., Volpi, V., Civile, D., Basili, R., Conti, A., Tiberti, M. M., Accettella, D., Conte, R., Zgur, F., & Rossi, G. (2020). Active Extension in a Foreland Trapped Between Two Contractional Chains: The South Apulia Fault System (SAFS). In Tectonics (Vol. 39, Issue 7). American Geophysical Union (AGU). https://doi.org/10.1029/2020tc006116