

A seismogenic modelling approach for rift-basin fault systems in slow-deforming regions: application to the western margin of the Valencia Trough



1. INTRODUCTION

Seismic hazard assessment is crucial for the design of critical facilities (such as nuclear power plants), whose damage could lead to severe consequences. The design of such facilities typically requires the definition of seismic actions associated with return periods on the order of 10.000 years. Earthquakes with such low frequency are well documented in fast deforming regions, where paleoseismic records commonly encompass several seismic cycles. In contrast, in slow deforming regions, the scarcity of seismic data hinders the identification of active faults.

Despite their importance, the incorporation of faults into seismic hazard models remains challenging, particularly in low strain regions such as the western margin of the Valencia Trough. This region in northeastern Iberia (Fig. 1) corresponds to a passive margin characterized by a basin-and-range structure, bounded by multiple NNE–SSW-oriented normal faults formed during the Neogene during the Quaternary. The seismogenic activity of some of these faults during the Quaternary has been demonstrated by previous studies [1].

The main faults in the region are usually associated with mountain fronts. However, we are currently studying some newly discovered faults crosscutting Pleistocene alluvial fans, by means of geomorphology, geophysics, paleoseismology and geochronology in order to unravel their seismogenic behaviour. The possible contribution of these recently discovered active faults into the seismic hazard of the region still needs to be investigated.

For more information about these new seismogenic sources, see vPoster Vp.99, Session VP530 ("Constraining Late Pleistocene to Holocene seismic fault activity in NE Iberia: The value of integrating complementary techniques in a low-strain region")

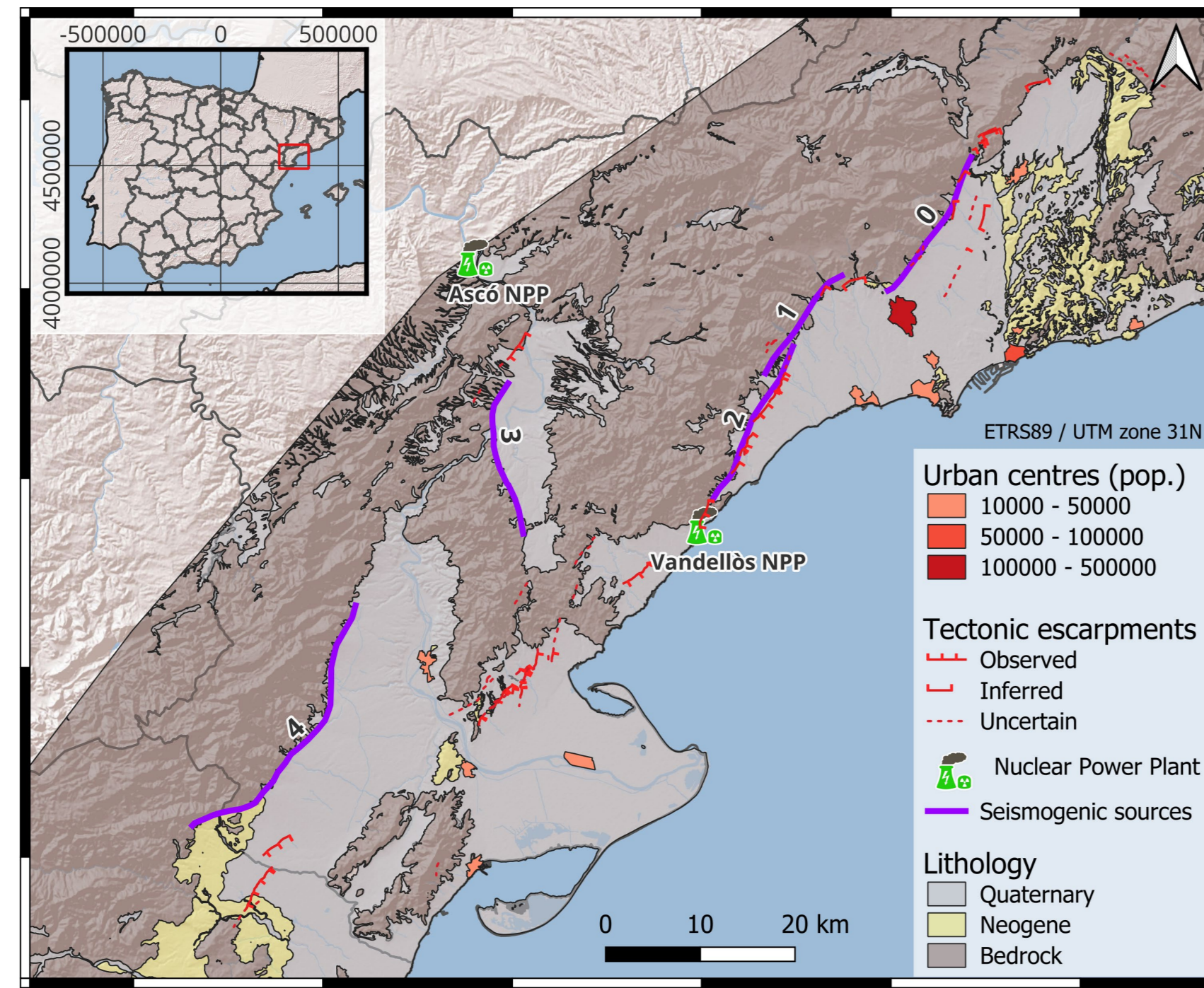
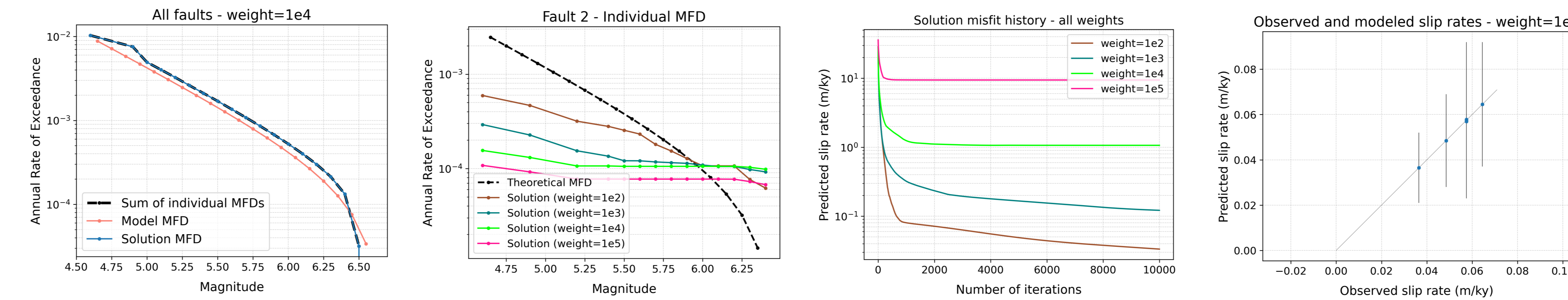


Figure 1. Study area. The five faults considered in this study are shown (0: El Camp-1; 1: El Camp-2; 2: El Camp-3; 3: Pla de Burgar; 4: Baix Ebre), from QAFI [2]. The locations of the site-specific studies are also indicated. Newly identified faults under study (not considered in this study) are shown in red.

3. RESULTS

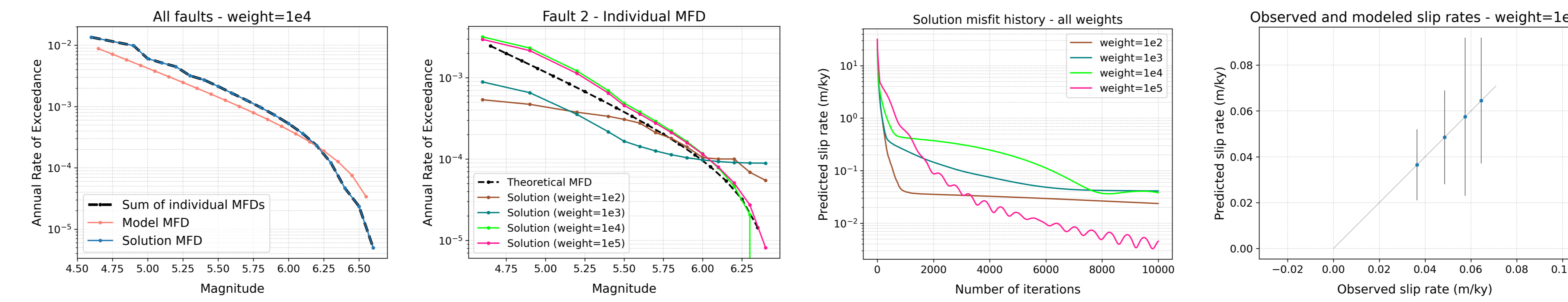
Single-fault ruptures. Fault relative MFDs + Regional MFD relative equations :

Good agreement with the regional MFD, although less satisfactory for some individual faults (fault 2).



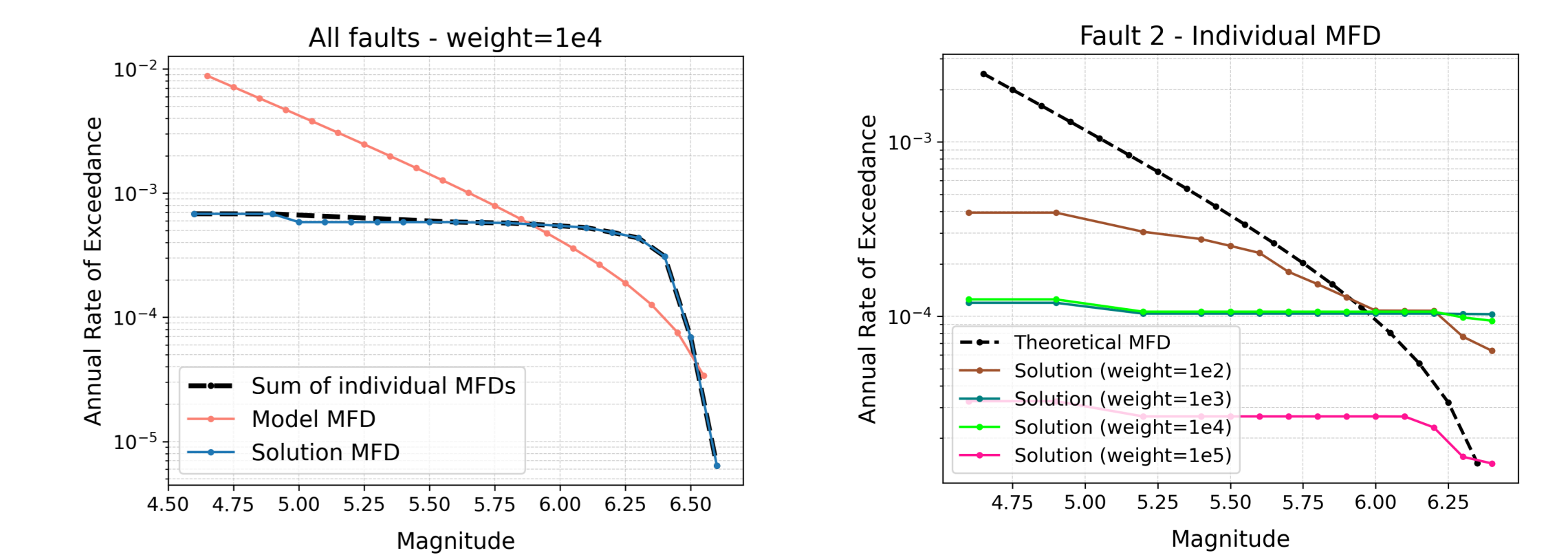
Single-fault ruptures. Only fault relative MFDs:

Good agreement for both regional and individual MFDs across all faults.



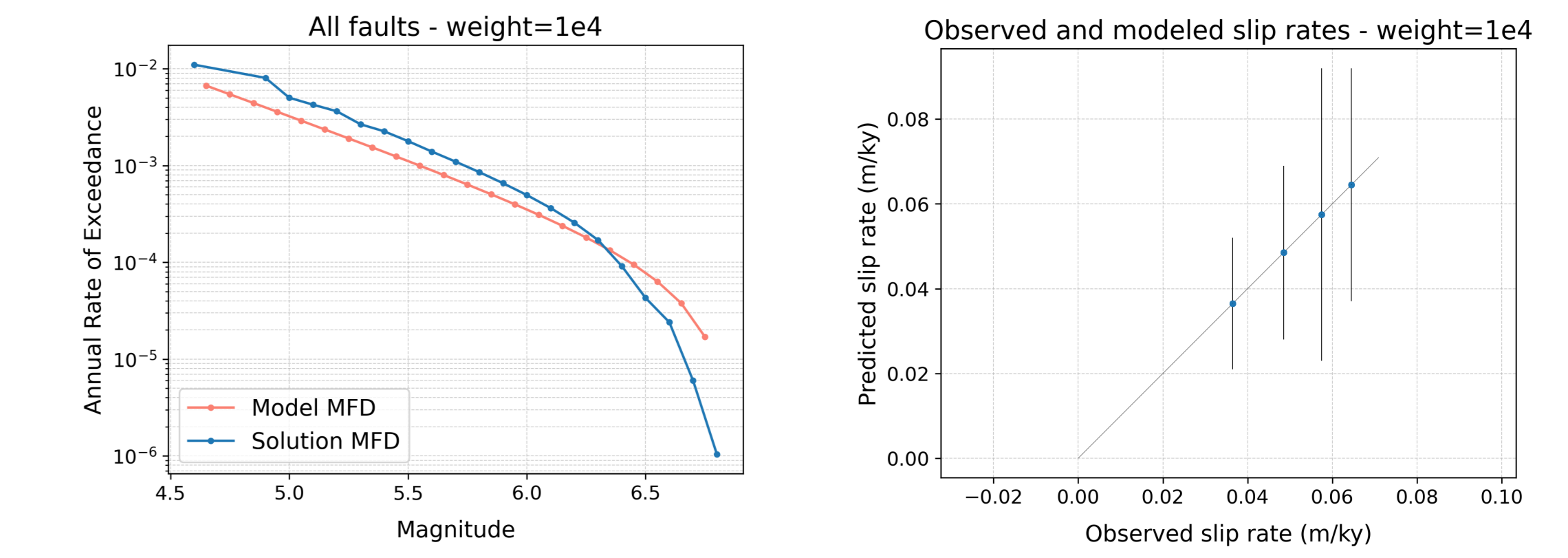
Single-fault ruptures. Fault relative MFDs + Regional MFD relative equations + Model absolute MFD:

An increased number of constraints in the inversion leads MFDs to adopt more characteristic shapes.



Multi-fault ruptures (max jump distance = 15 km). Only Fault relative MFDs:

Satisfactory agreement with regional and individual fault MFDs (only shown regional MFD)



2. METHODS: FERMI

In this study we test the FERMI (Fault nEtwoRks Modelling) approach on 5 faults of this region (based on accessible data through Quaternary Active Faults Database, QAFI) [2] and analyze the resulting seismic hazard for sites located at 2 different distances from the closest fault, respectively.

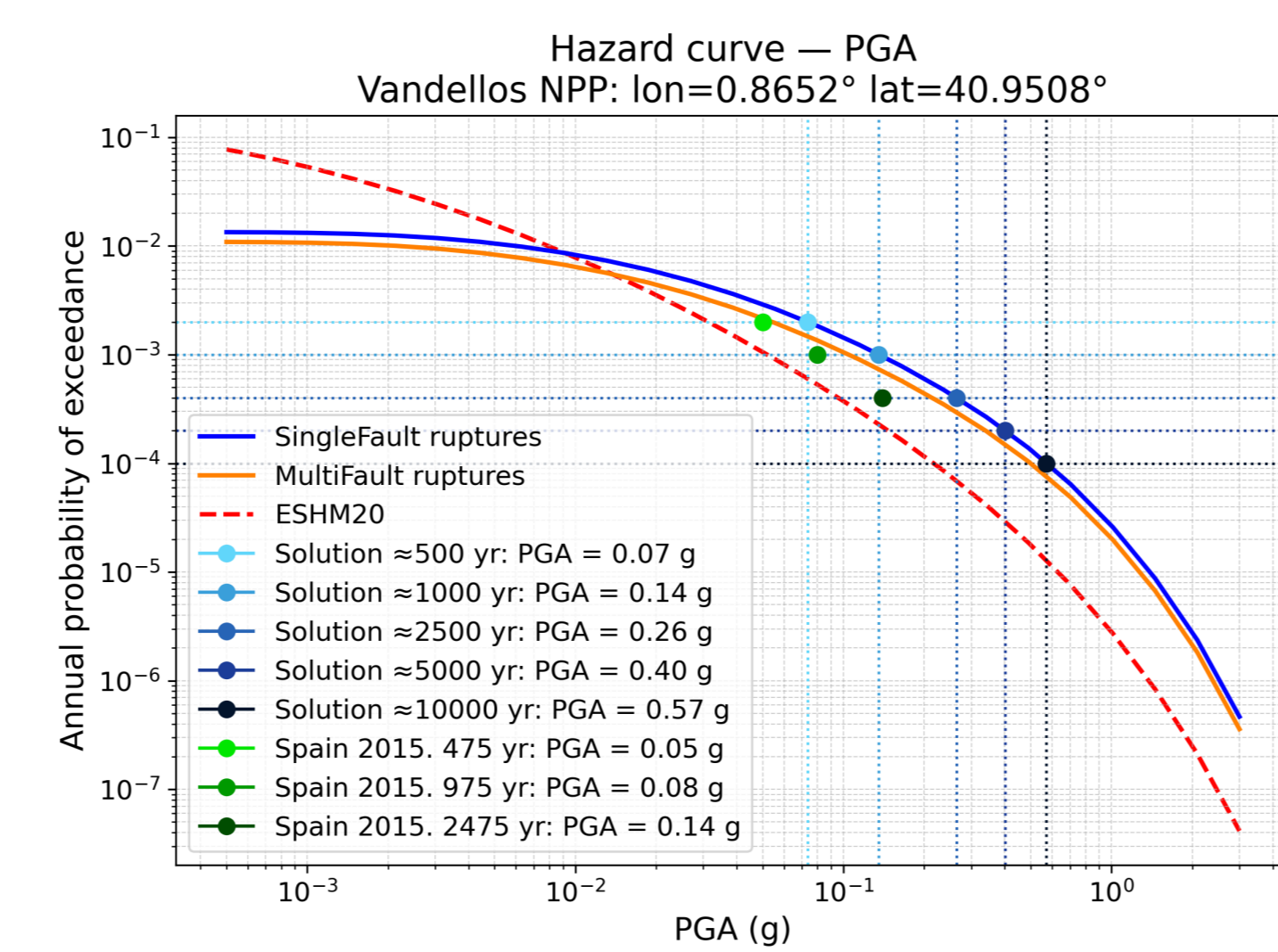
FERMI is a tool that contains GEM's latest solutions for modelling multi-fault ruptures in complex fault systems. It allows creating ruptures in a fault network spanning subfault to multifault scale. The tool is inspired by the OpenSHA tools (e.g. Milner and Field, 2024) [3] and SHERIFS Chartier et al. (2019) [4] approaches to earthquake rupture modelling but with some added flexibility. A fault network is broken into sections of uniform length, where each section becomes a node in a graph. Then, using graph theory, all possible ruptures in the network are defined with an adjacency matrix, where further rupture plausibility constraints can be applied. Ferri can also determine rupture rates through inversion, offering options to fit these rates using slip rates and MFDs, either for individual faults or the entire fault system, with a variety of iterative solver options available.

For FERMI workflow visit: https://gemscientools.github.io/oq-mbtk/contents/fnm_docs/tutorials/atf_ferri_tutorial.html

Modules	Method	Parameters used in this work
Creation of subfaults	Fault traces are expanded down-dip to 3D surfaces, and then broken into smaller, atomic units called 'subfaults' that are capable of independent ruptures. The individual subfault ruptures are the smallest on-fault ruptures in the fault source.	<ul style="list-style-type: none"> Based on 5 faults, 15-30 km length, 12km depth. 2x2 km subfaults have been modeled (equivalent to a M ~4.5 rupture).
Creation of single-fault ruptures	Single-fault ruptures are composed of one or more subfaults. Ruptures with more than one subfault are rectangular groups of contiguous subfaults.	<ul style="list-style-type: none"> Default rupture aspect ratio bounds
Creation of multi-fault ruptures	Multi-fault ruptures are created by joining single-fault ruptures that are separated by a 'jump'. This is done through graph theoretical methods: a N x N distance matrix is created (where N is the number of ruptures) and then this matrix is pared for distances greater than the jump distance, creating an adjacency matrix. Then, all the unique sets of adjacent ruptures is found through a depth-first search algorithm operating on the adjacency matrix. Optional: Plausibility filtering of multi-fault ruptures.	<ul style="list-style-type: none"> Max rupture jump distance considered: 15 km Limiting multi-fault ruptures to be combinations of full-fault single-fault ruptures (rather than all subfault ruptures) Plausibility filtering: not used
Rupture rate inversion	Determine the annual occurrence rates of each rupture, through an inversion of geological and seismological constraints, such as fault slip rates and magnitude-frequency distributions. This happens through the creation of a system of linear equations which represent the constraints, that is solved using a non-negative least-squares solver developed for this application.	<ul style="list-style-type: none"> Seismic fraction: 1.0, Fault MFD b-value: 0.89, Regional MFD b-value: 0.89 fit MFD to the total moment rate of the faults
Solving for the rupture rates	Based on a non-negative projected-gradient weighted least-squares solver, which is an iterative method that offers rapid convergence. There are a variety of data types and constraints that can be used to solve for the rupture rates: <ul style="list-style-type: none"> -Absolute: an MFD, which has absolute rates (frequencies) for each magnitude bin. -Relative: only the shape (the relative rates) of the MFD is used, i.e. there is a b-value but no a-value An err vector of weights, is derived from the uncertainties for the slip rates, and more arbitrary weights for the bin rates and other constraints.	<ul style="list-style-type: none"> Magnitude-frequency (MFD) constraints for all of the faults involved as well as for the region. Constraints tested in this study: <ul style="list-style-type: none"> -Combinations using Absolute and Relative regional MFDs. -Explored different weights -Truncated Gutenberg-Richter MFDs Tested 10000 iterations
Writing OQ inputs	The rupture rates are saved as an OpenQuake fault source.	

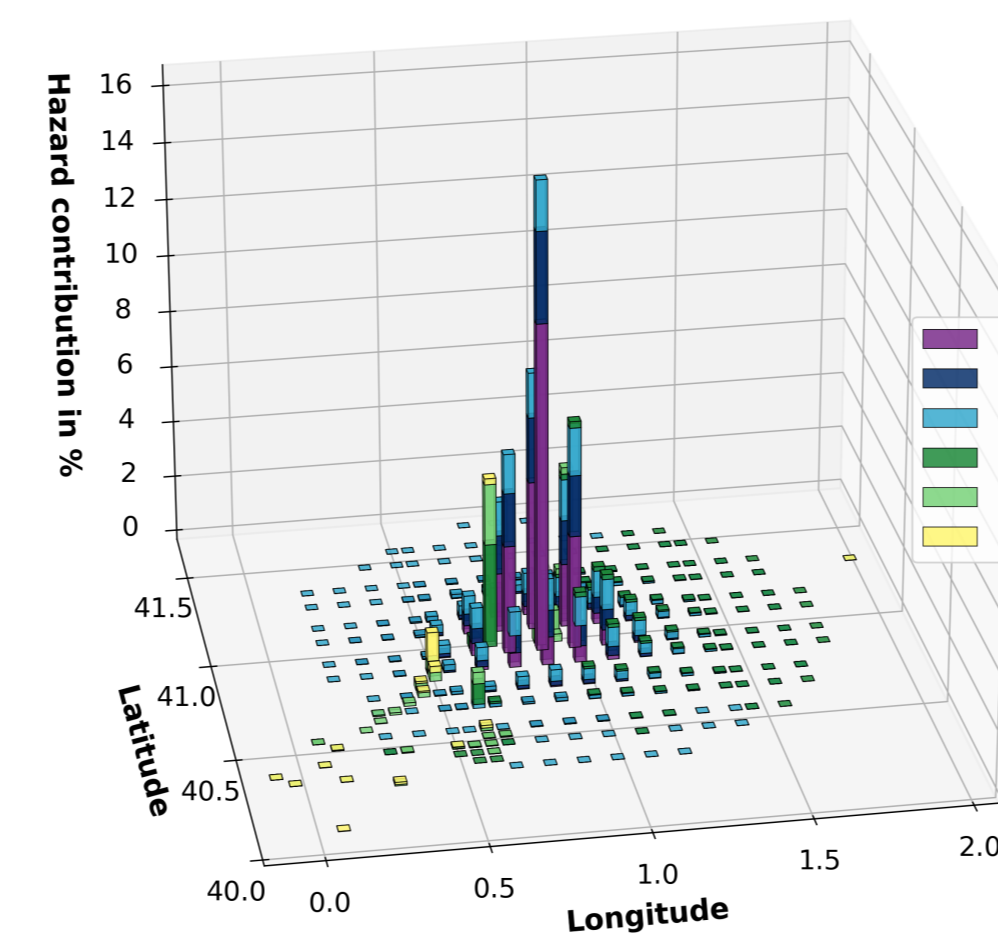
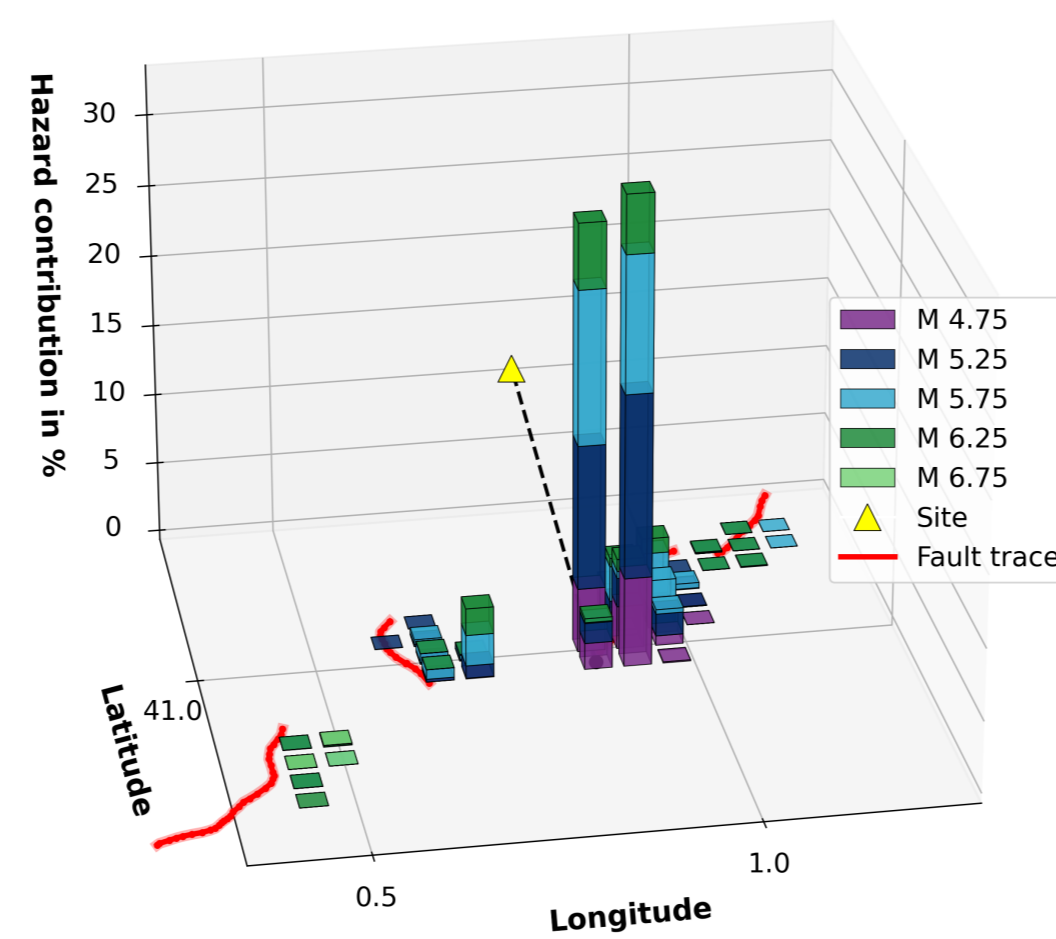
4. DISCUSSION

Vandellòs NPP ~2 km to El Camp fault (Fault n°2)

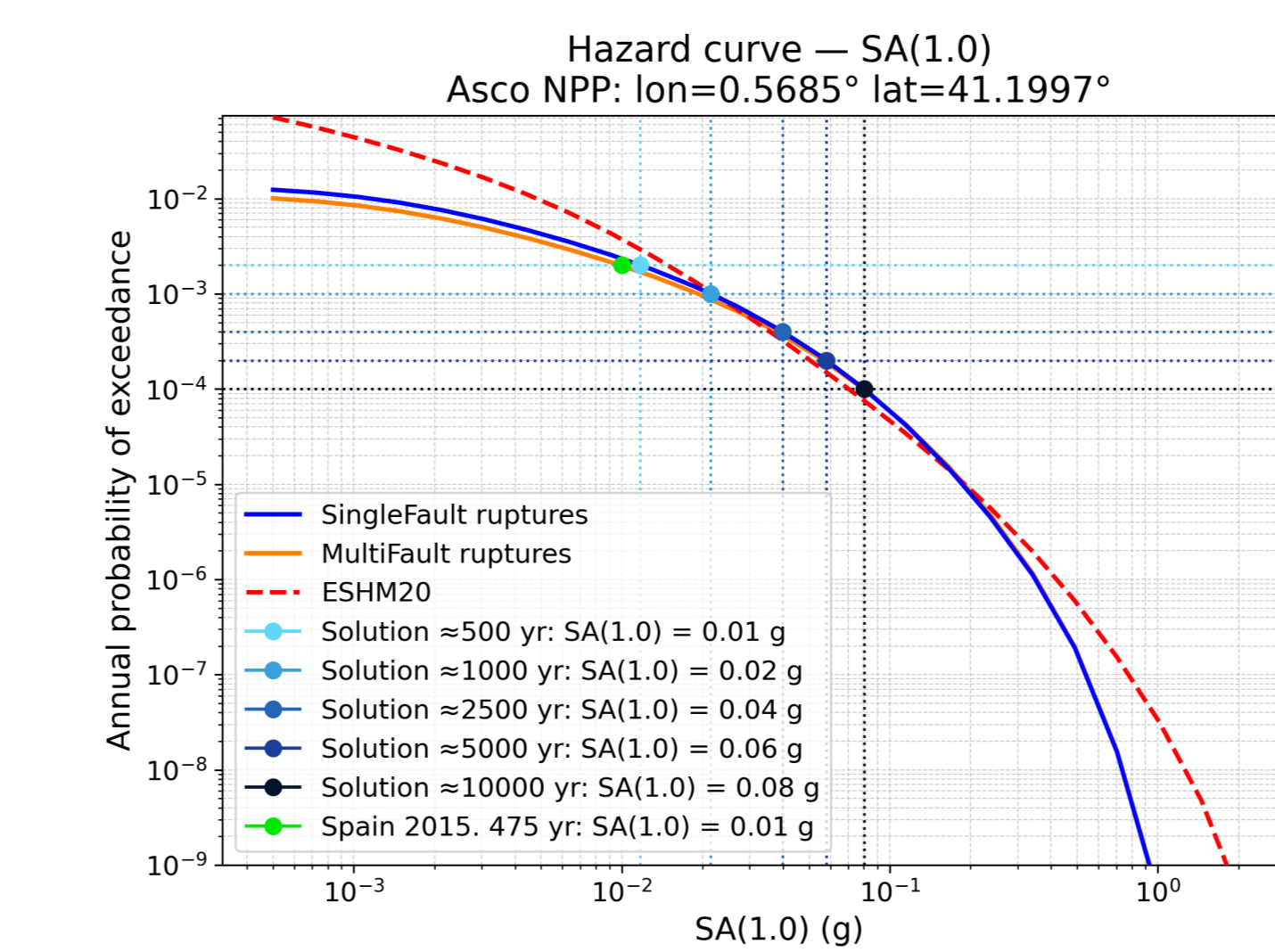


Seismic Hazard Disaggregation - PGA
PoE = 0.01% per year (RT = 10000 years)
Vandellòs NPP
From FERMI solution. Single fault ruptures

Seismic Hazard Disaggregation - PGA
PoE = 0.01% per year (RT = 10000 years)
Vandellòs NPP
From ESHM20 solution. On-fault M ≥ 6.5

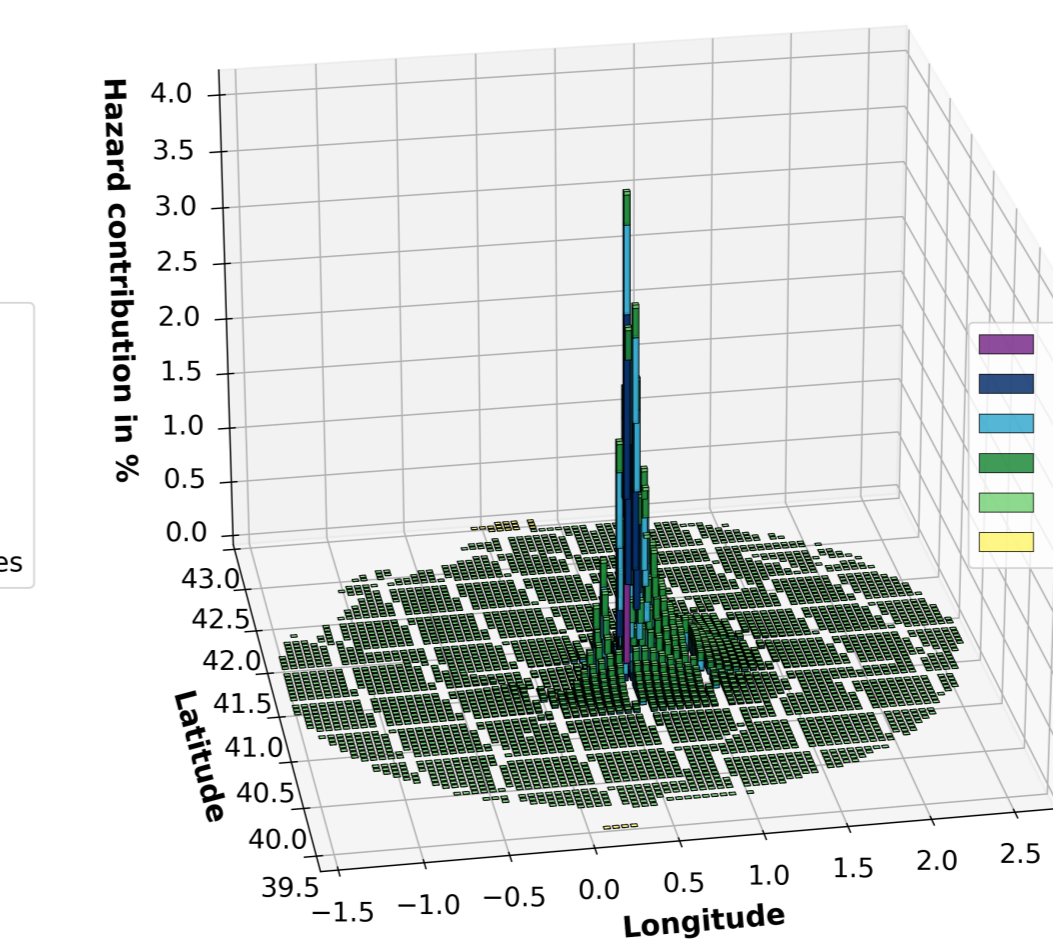
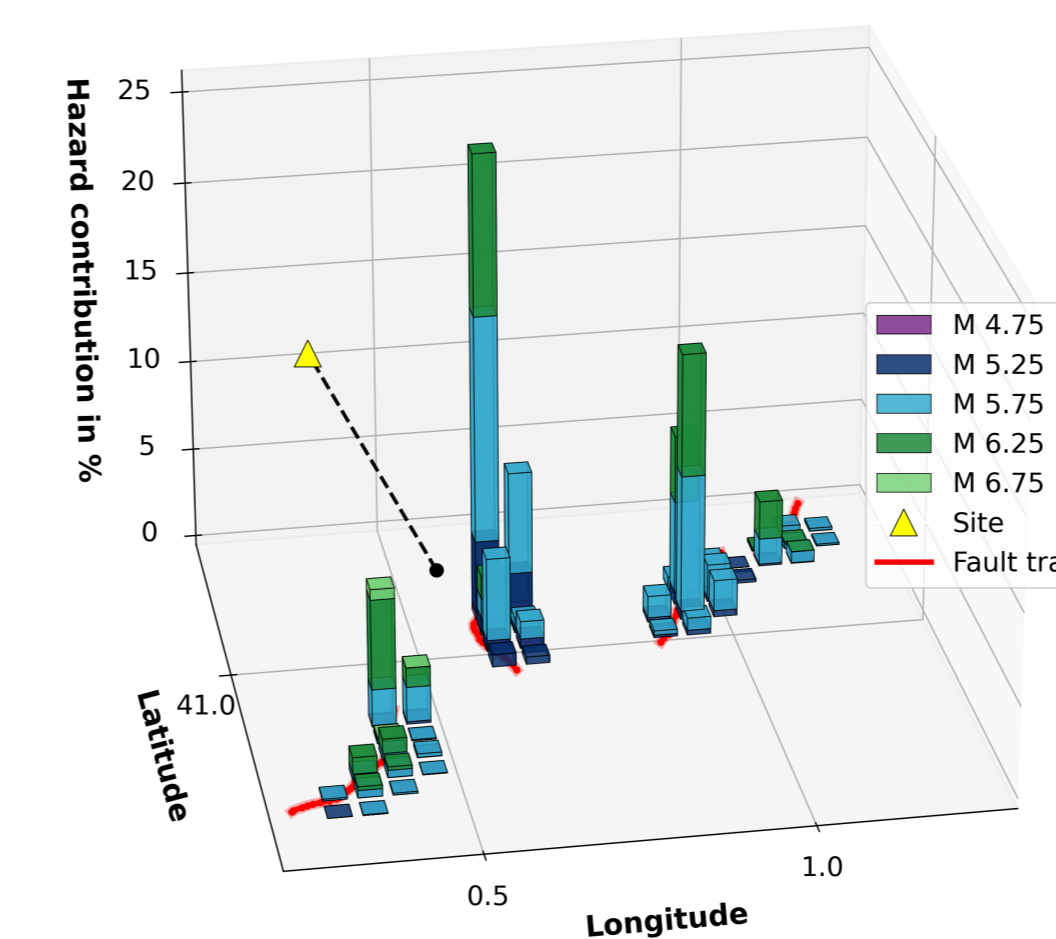


Ascó NPP ~15 km to Pla de Burgar fault (Fault n°3)



Seismic Hazard Disaggregation - SA (1.0)
PoE = 0.01% per year (RT = 10000 years)
Ascó NPP
From FERMI solution. Single fault ruptures

Seismic Hazard Disaggregation - SA (1.0)
PoE = 0.01% per year (RT = 10000 years)
Ascó NPP
From ESHM20 solution. On-fault M ≥ 6.5



5. CONCLUSIONS

In regions characterised by low-slip rate faults, the incorporation of faults into seismic hazard models is primarily relevant in areas surrounding the considered faults. For this reason, site-specific studies may be more appropriate in these contexts to assess the impact of active faults. In such cases, the parametrisation adopted in FERMI becomes particularly important, as it is necessary to ensure that the desired MFDs are obtained for each individual fault, especially for those located near the site of interest. For the five faults investigated in this study, the optimal solution is achieved only by constraining the individual fault MFDs for both single-fault and multi-fault ruptures. However, other parametrisations may be more suitable for fault systems with different characteristics (e.g., longer faults or higher slip rates).

Another important consideration in such slowly deforming regions is the inclusion of faults in seismic hazard models at lower magnitudes, rather than considering them only for M > 6.5. As shown by our disaggregation analyses, in these regions a significant proportion of the hazard associated with faults may arise from small-to-moderate magnitude events. However, this influence is only significant around the considered faults.

Acknowledgements

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References

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 [4] Chartier, T., Scotti, O., and Lyon-Caen, H. SHERIFS: Open-Source Code for Computing Earthquake Rates in Fault Systems and Constructing Hazard Models. *Seismological Research Letters*, 2019. doi: 10.1785/0220180332