How much does geometry of seismic sources matter in tsunami modeling? A sensitivity analysis for the Calabrian subduction interface

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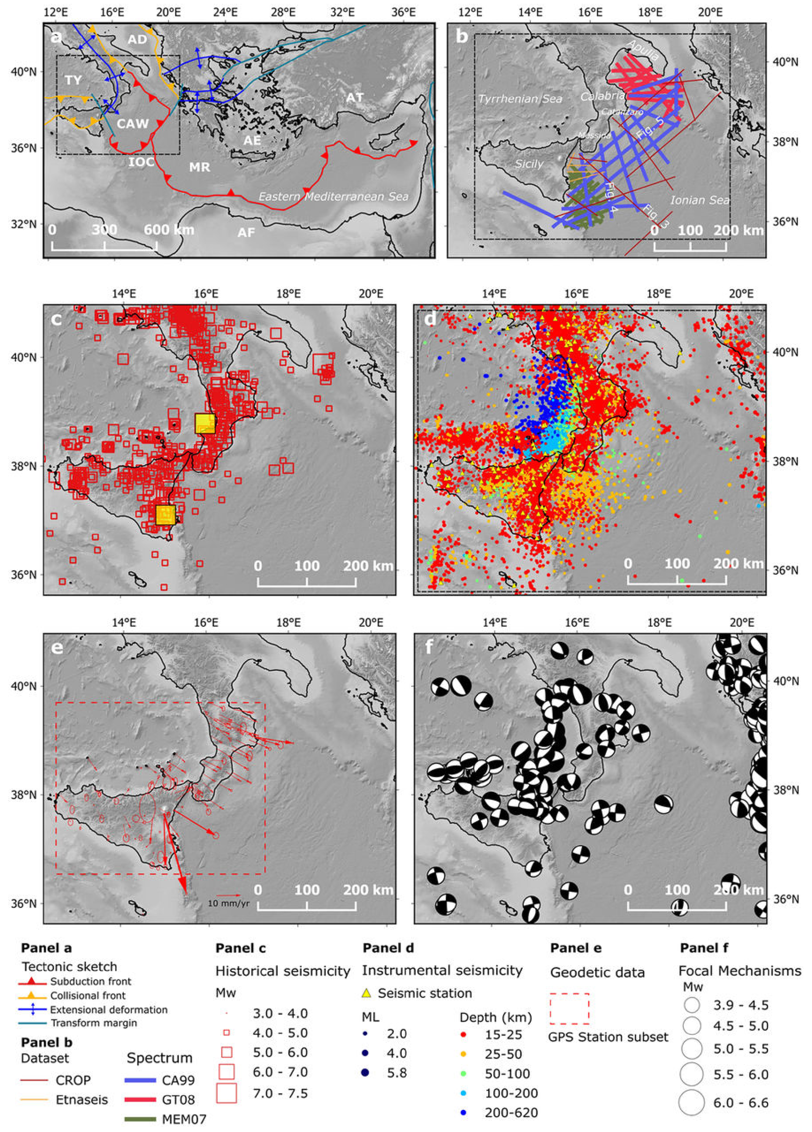
Abstract

The geometry of seismogenic sources could be one of the most important factors concurring to control the generation and the propagation of earthquake-generated tsunamis and their effects on the coasts. Since the majority of potentially tsunamigenic earthquakes occur offshore, the corresponding faults are generally poorly constrained and, consequently, their geometry is often oversimplified as a planar fault. The rupture area of mega-thrust earthquakes in subduction zones, where most of the greatest tsunamis have occurred, extends for tens to hundreds of kilometers both down dip and along strike, and generally deviates from the planar geometry. Therefore, the larger the earthquake size is, the weaker the planar fault assumption become.

In this work, we present a sensitivity analysis aimed to explore the effects on modeled tsunamis generated by seismic sources with different degrees of geometric complexities. We focused on the Calabrian subduction zone, located in the Mediterranean Sea, which is characterized by the convergence between the African and European plates, with rates of up to 5 mm/yr. This subduction zone has been considered to have generated some past large earthquakes and tsunamis, despite it shows only in-slab significant seismic activity below 40 km depth and no relevant seismicity in the shallower portion of the interface. Our analysis is performed by defining and modeling an exhaustive set of tsunami scenarios located in the Calabrian subduction and using different models of the subduction interface with increasing geometrical complexity, from a planar surface to a highly detailed 3D surface. The latter was obtained from the interpretation of a dense network of seismic reflection profiles coupled with the analysis of the seismicity distribution. The more relevant effects due to the inclusion of 3D complexities in the seismic source geometry are finally highlighted in terms of the resulting tsunami impact.

Calabrian Arc geology and data



Tectonic and geologic data used to study the Calabrian Arc subduction zone.

Panel a – Tectonic sketch of the Eastern Mediterranean region; AF: African plate, AE: Aegean plate, AT: Anatolian plate, EU: Eurasian plate, AD: Adria microplate, CAW: Cabrian accretionary wedge; IOC: Ionian oceanic crust, MR: Mediterranean ridge, TY: Tyrrhenian Sea. The dashed rectangle shows location of Panel b.

Panel b - Dataset used in this work. Seismic profiles from: CROP Project (http://www.crop.cnr.it/front-page_EN), Spectrum (http://www.spectrumgeo.com/ provided under confidentiality agreement CA60), Etnaseis survey.

Panel c – Historical seismicity from CPTI15.

Panel d – Instrumental seismicity from the Italian Seismological Instrumental and Parametric Database, earthquake plotted are recorded in the time period 2005–2016.

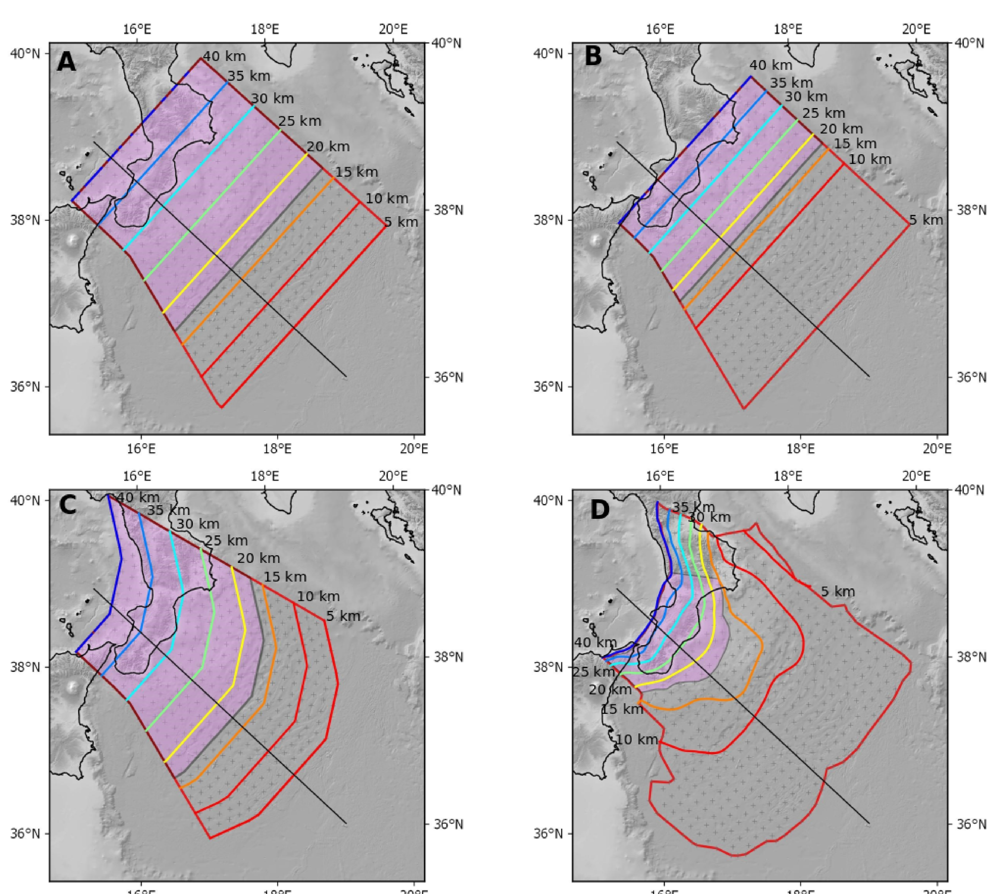
Panel e – Velocity field from continuous GPS station in the 1998–2009 time span for Sicily and Calabria plotted with a fixed Africa ref. Velocity ellipses represent 1-sigma confidence errors.

Panel f – Regional Centroid Moment Tensor solution.

Topo-bathymetric relief (Panels a-f) is obtained from SRTM30_PLUS. Coastlines are from the European Environmental Agency (http://www.eea.europa.eu/)

Figures and captions in this frame from ***Maesano et al., 2017***

Slab interface models



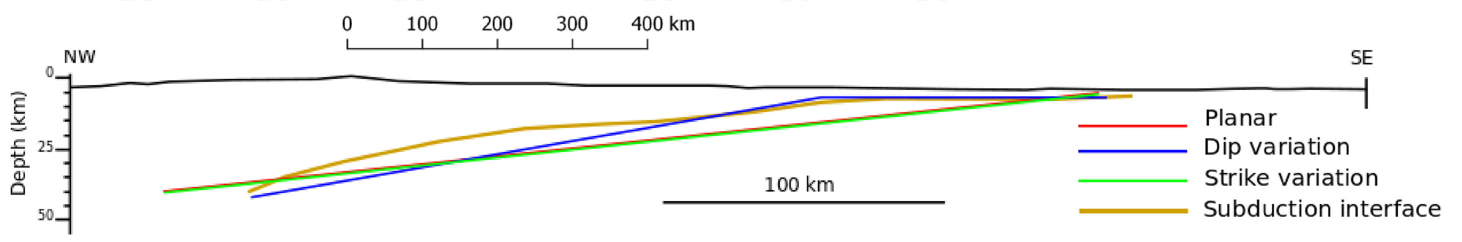
A - Planar
Strike 222°; Dip 6°;
Top: -5 km; Bottom: -40 km

B - Dip variation
Strike 222°; Dip1: 0°; Dip2: 10°;
Top:-6.2 km; Bottom: -40 km

C - Strike variation
Strike: 167°, 192°, 221°, 245° ; Dip: 6°;
Top: -5 km; Bottom: -40 km

D - Subduction interface
Complex geometry;
Top: -5 km; Bottom: -40 km

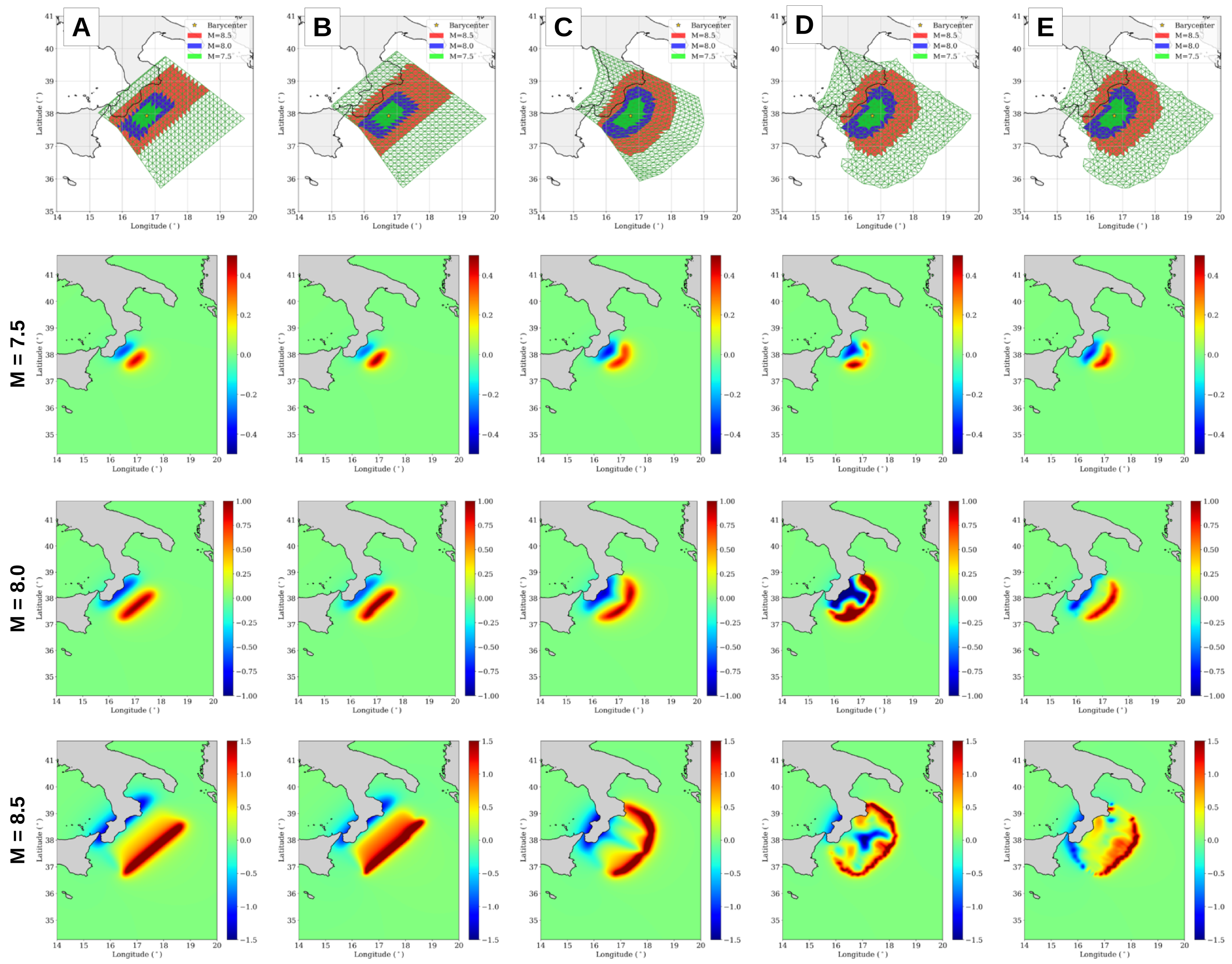
Model D is the final 3D slab interface model obtained in ***Maesano et al., 2017.***



HySEA
TSUMAPS NEAM
Ritmare
La ricerca italiana per il mare

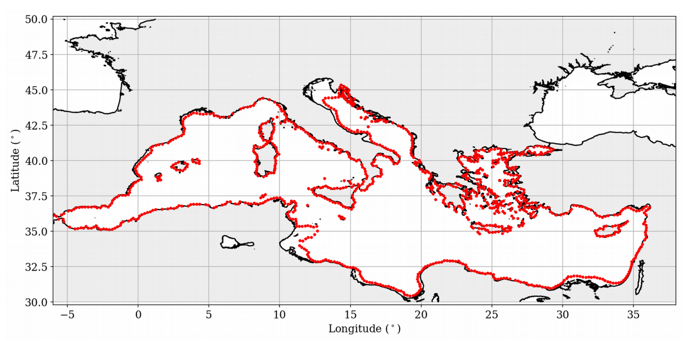
Fault ruptures and tsunami initial conditions

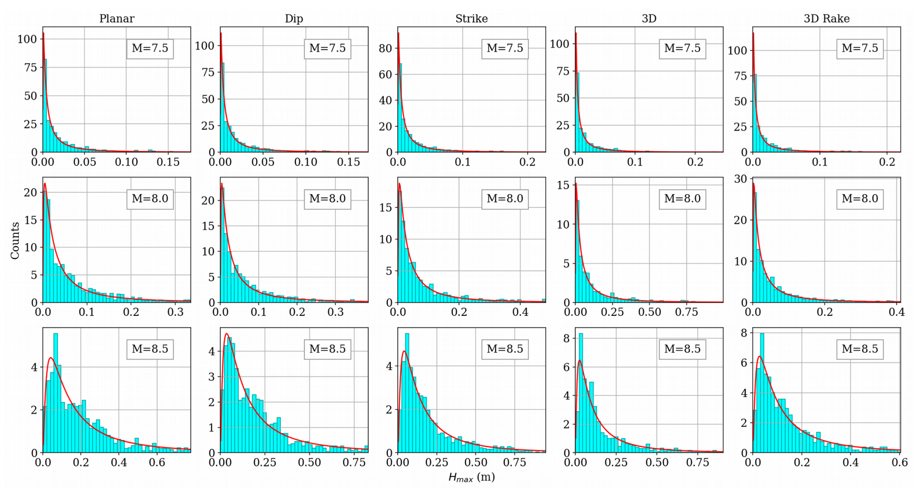
For tsunamis simulated using subduction models A, B, C and D, the **rake angle** is assumed constant for the whole surface (here 90°, often used for thrust mechanisms if more details are unavailable). In addition, we propose an additional **model (E)**, where rake changes and is derived from the tectonic setting of the Calabrian Arc.



Tsunami simulations

Tsunami simulations (8 hrs propagation) performed with HySEA GPU code (De la Asuncion et al., 2013) that solves nonlinear shallow water equations; computational grid has a spatial resolution of 30 arc-sec.; maximum wave heights are recorded at ~13,000 points of interest (average distance of ~2 km) along the 50 m depth isobath (red dots here below)

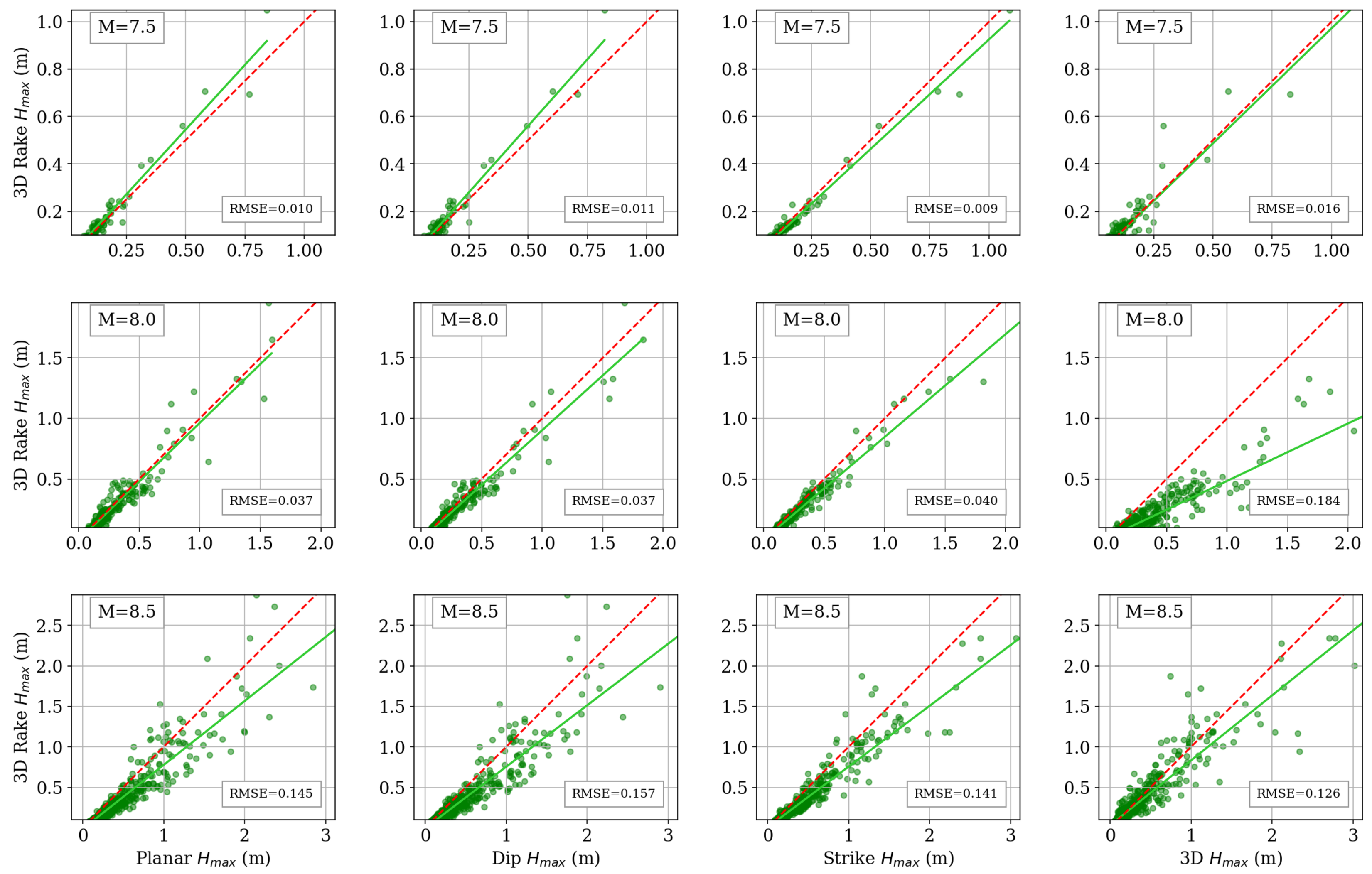




In all tsunami scenarios, maximum wave heights follow a log-normal distribution, as the run-up observations collected in the last decades.

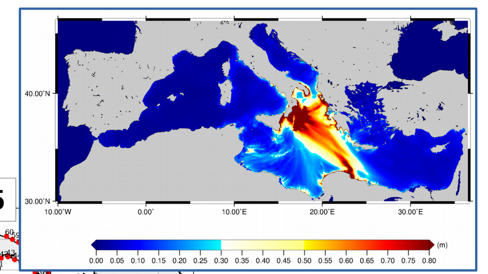
Effects of fault geometry on maximum wave heights

Assuming **model E** as the best model for the Calabrian subduction, maximum wave heights obtained from model E scenarios are compared to the other models. Scatter plots show the differences in terms of dispersion (RMSE) and biases (green line slope). Dispersion increases with larger earthquake magnitudes as well as over-estimation of the simplest models with respect to the assumed best model E. The effect of introducing a rake variability (4th column), constrained by local tectonics, highlights a large source of uncertainty.

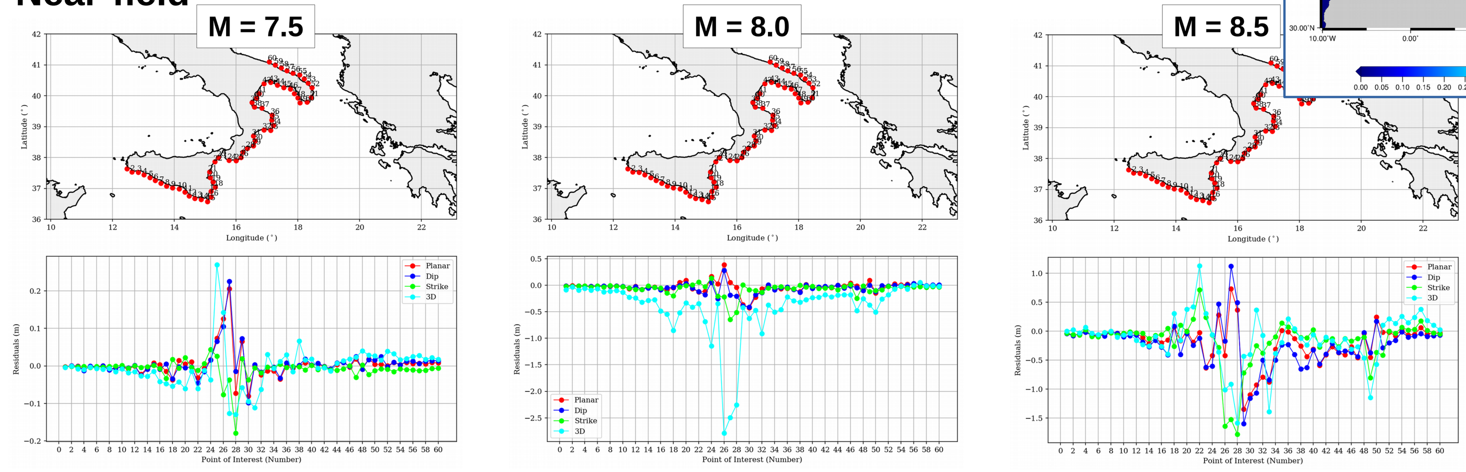


Effects of fault geometry on maximum wave heights along the coastline

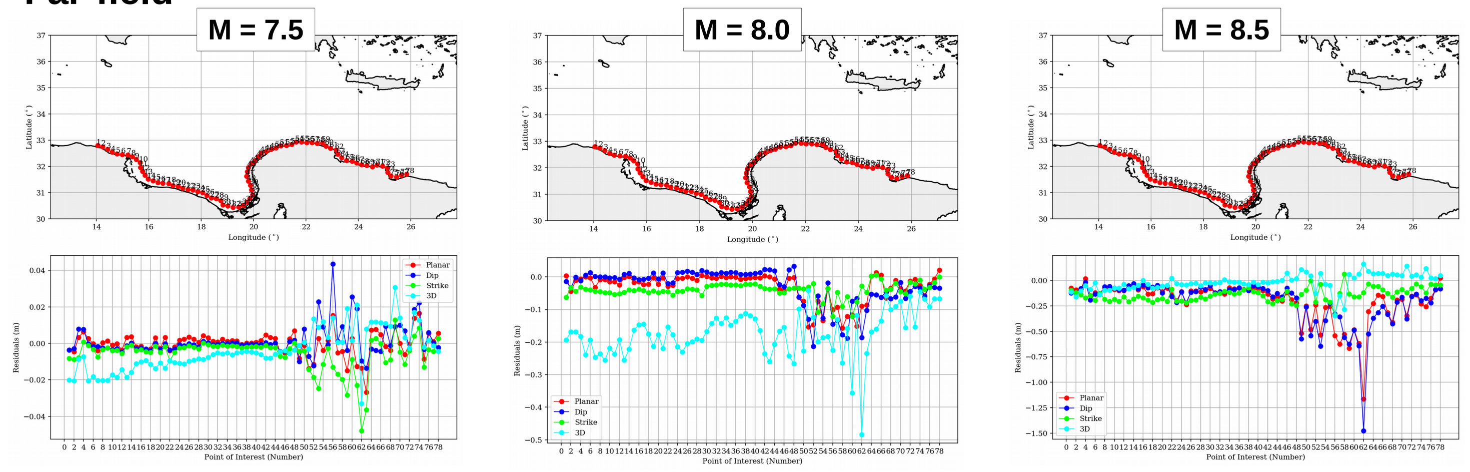
Differences between the best model **model E** and the other models are shown separately for near field and far field, selecting the areas where the higher tsunami impact is expected. Effects due to rake (**cyan line**) highlight important changes even far away from the most affected areas



Near-field

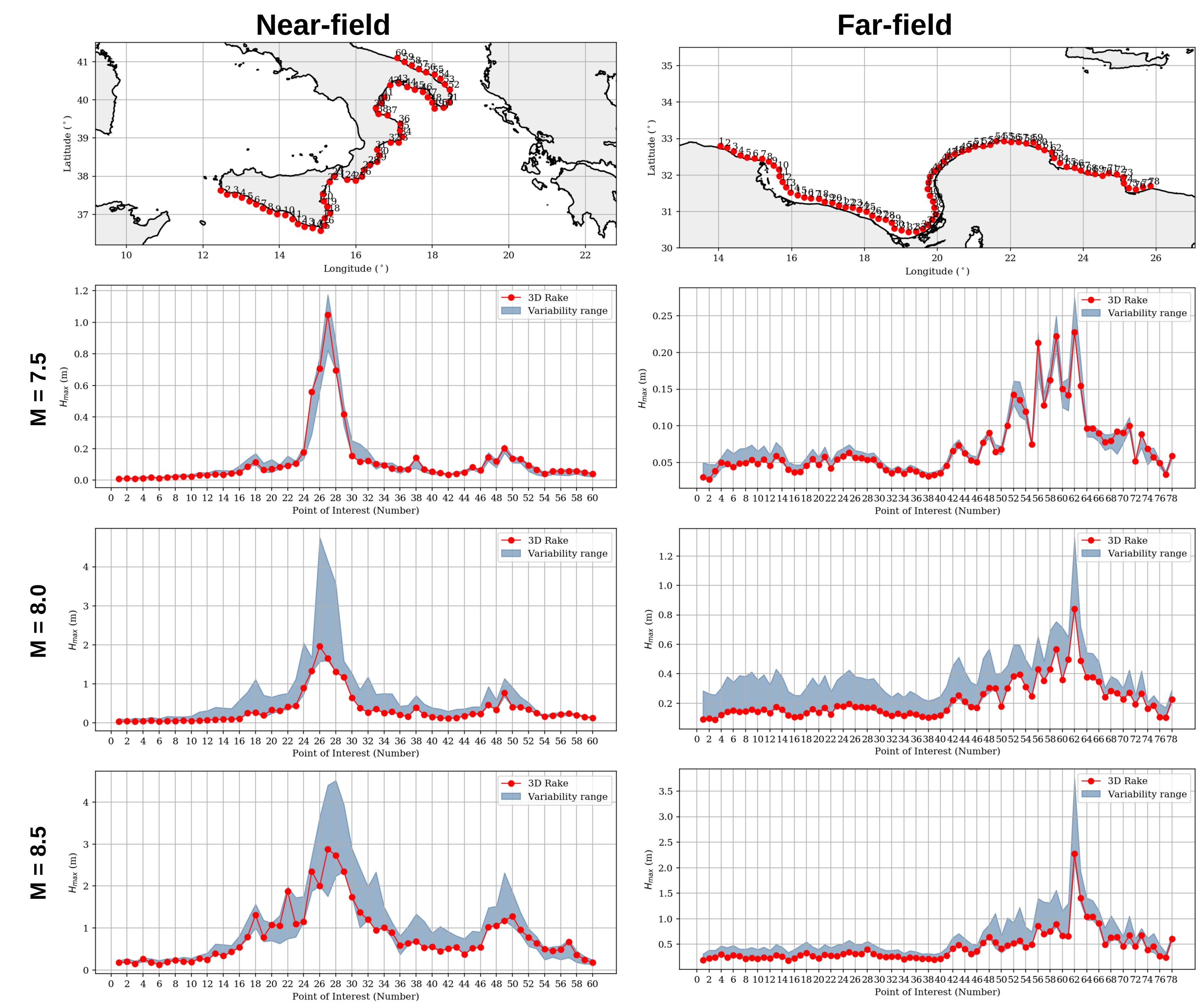


Far-field



Variability of maximum wave heights along coastline

Maximum and minimum wave heights for each point of interest **(blue areas)** versus the results obtained using the assumed best **model E (red line).**



Conclusions

Although still qualitative, for the limited number of tsunami scenarios explored so far, the presented analysis highlights that:

- Different fault geometries have relevant effects on tsunami maximum wave heights amplitudes and their spatial distribution
- Simplest slab models tend to overestimate tsunami effects, especially, for larger magnitudes
- Assumptions on rake can significantly affect maximum wave heights in both the far and near field
- All the factors described above can have important implications for tsunami hazard assessment

References

de la Asunción, M., Castro, M. J., Fernández-Nieto, E. D., Man- tas, J. M., Ortega Acosta, S.,González Vida, J. M. (2013) Efficient GPU implementation of a two waves TVD-WAF method for the two-dimensional one layer shallow water system on structured meshes, Comput. Fluids, 80, 441–452

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