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Rapid earthquake source characterization in the context of tsunami early warning

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It is well known that for earthquake-generated tsunamis impacting near-field coastlines the focal mechanism, the position of the fault with respect to the coastline and the on fault slip distribution are key factors in determining the efficiency of the generation process and the distribution of the maximum run-up and inundation along the nearby coasts. The time needed to obtain the aforementioned information from the analysis of seismic records is usually too long compared to the time required to issue a timely tsunami warning/alert to the nearest coastlines. In the context of tsunami early warning systems, a big challenge is hence to be able to define 1) the relative position of the hypocenter and of the fault and 2) the earthquake focal mechanism, based only on the preliminary earthquake localization and magnitude estimation, which are made available by seismic networks soon after the earthquake occurs.

In this study, the intrinsic unpredictability of the position of the hypocenter on the fault plane is studied through a probabilistic approach based on the analysis of two finite fault model datasets (SRCMOD and USGS) and by limiting the analysis to moderate-to-large shallow earthquakes (Mw 6 and depth 50 km). After a proper homogenization procedure needed to define a common geometry for all samples in the two datasets, the hypocentral positions are fitted with different probability density functions (PDFs) separately in the along-dip and along-strike directions.

Regarding the focal mechanism determination, different approaches have been tested: the most successful is restricted to subduction-type earthquakes. It defines average values and uncertainties for strike, dip and rake angles based on a combination of a proper zonation of the main tsunamigenic subduction areas worldwide and of subduction zone geometries available from publicdatabases.

The general workflow that we propose can be schematically outlined as follows. Once an earthquake occurs and the magnitude and hypocentral solutions are made available by seismic networks, it is possible to assign the focal mechanism by selecting the characteristic values for strike, dip and rake of the zone where the hypocenter falls into. Fault length and width, as well as the slip distribution on the fault plane, are computed through regression laws against magnitude proposed by previous studies. The resulting rectangular fault plane can be discretized into a matrix of subfaults: the position of the center of each subfault can be considered as a “realization” of the hypocenter position, which can then be assigned a probability. In this way, we can define a number of earthquake fault scenarios, each of which is assigned a probability, and we can run tsunami numerical simulations for each scenario to quantify the classical observables, such as water elevation time series in selected offshore/coastal tide-gauges, flow depth, run-up, inundation distance. The final results can be provided as probabilistic distributions of the different observables.

The general approach, which is still in a proof-of-concept stage, is applied to the 16 September 2015 Illapel (Chile) tsunamigenic earthquake (Mw = 8.2). The comparison with the available tsunami observations is discussed with special attention devoted to the early-warning perspective.