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Quasi-real-time on-fault heterogeneous slip distributions for tsunami early warning purposes

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The study presented here takes the move from two well-known premises in tsunami science: the slip distribution on earthquake faults is heterogeneous and, in the case of tsunamigenic earthquakes, slip heterogeneity influences significantly the distribution of tsunami run-ups, especially for near-field areas. In the perspective of tsunami early warning, a crucial issue is to obtain a reasonable slip distribution within a time significantly shorter than the time taken by the waves to impact the nearest coastlines.

When an earthquake occurs, the only information that becomes available after a few minutes concerns the location of the earthquake and its magnitude. The first finite-fault models (FFM), based on seismic/geodetic data inversion, become available several hours or even days after the earthquake origin time. In the case of tsunamigenic earthquakes, tsunami waveforms useful for inversion become available after the tsunami passage at the recording stations. From the warning perspective, the time to get FFM representations is therefore too long for the near-source coastal areas.

We propose and describe a strategy whose goal is to derive in quasi-real-time a reasonable representation of the heterogeneous slip distribution on the fault responsible for a given tsunamigenic earthquake and to forecast the run-up distribution along the nearest coastlines. The strategy is illustrated in its application to the 16 September 2015 Illapel (Chile) tsunamigenic earthquake.

Realistically, the hypocentre location and the magnitude of the event can be available within two-three minutes. Knowing the hypocentre location permits us to place the fault plane in a definite geographical reference, while the knowledge of magnitude allows to derive the fault dimension and the slip model. A key point here is that we can derive slip models only knowing the magnitude and the location of the hypocenter. Among these models, we adopt simple 2D Gaussian Distributions (GDs), representing the main asperity, whose parameters can be deduced from properly defined regression laws. The 2D-GD simple representation takes a very short time to be derived. To complete the characterization of the tsunamigenic source, focal parameters can be safely derived from seismological databases, while the position of the fault represents a trickier point, as the fault plane is not necessarily centered at the earthquake hypocentre. To take this uncertainty into account, as a first approach three faults for each slip model are considered: 1) a plane centered on the hypocentre, 2) a fault shifted northwards, 3) a fault shifted southwards.

We run tsunami simulations for each adopted slip distribution and for each fault position, and compare the results against the available observed tide-gauge and run-up data in the near-field. We compare the performance of our 2D-GD models with respect to the finite-fault models retrieved from inversion procedures, published months after the 2015 event. We demonstrate that the 2D-GD method performs very satisfactorily in comparison to more refined, non-real-time published FFMs and hence permits to produce reliable real-time tsunami simulations very quickly and can be used as an experimental procedure in the frame of operational tsunami warning systems.