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Improving Physics-based Earthquake Forecasting During the 2016-2017 Central Italy Earthquake Sequence

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In the aftermath of a devastating earthquake, the ensuing cascade of aftershocks can turn out to be even more destructive than the mainshock. Operational earthquake forecasting seeks to provide reliable real-time information about the time-dependence of earthquake hazard to the public. Two forecasting approaches tend to be used: statistical modelling, which employs empirical laws to predict the clustering characteristics (e.g. ETAS); and physics-based modelling, that combines the stress transfer hypothesis with rate-and-state friction laws (CRS models). Our work is partly motivated by recent retrospective experiments that reveal the comparable performance of physics-based and statistical forecasts.

Here, we assess the influence of individual CRS model choices driven by real-time conditions, and clarify the effect of input data quality on the predictive skills of CRS forecasts during the 2016-17 Central Italy earthquake cascade. In the first year of the 2016-17 Central Italy sequence 1160 $M \geq 3.0$ events were detected, spreading along a 60-km long normal fault system. Among these, seven $M \geq 5.4$ earthquakes occurred from a few hours to five months after the first Mw 6.0 Amatrice event. We develop seven physics-based models with gradually increasing level of refinement as part of a pseudo-prospective experiment. The preliminary forecasts include data available just a few minutes after each $M \geq 5.4$ event, featuring synthetic source models with empirically determined fault length and fault constitutive parameters from previous regional studies. Increasingly complex models incorporate: (1) optimized rate-state parameters, (2) spatially heterogeneous receiver fault planes, (3) best available slip models, and (4) secondary triggering effects from $M \geq 3.0$ aftershocks.

We evaluate and track models' performance in space and time using CSEP log-likelihood statistics for a 1-year time horizon after the Mw 6.0 Amatrice earthquake and compare against a benchmark ETAS model.

When including refined input data and increasing model complexity, we observe a significant performance improvement of physics-based forecasts. The most enhanced CRS forecasts reach dramatic probability gains per earthquake of up to 1,000 over the preliminary physics-based realizations. The results confirm that CRS models are about as informative as ETAS only when secondary triggering effects are included together with realistic slip models, spatially heterogeneous receiver fault planes and optimized fault constitutive parameters.