Modeling earthquake source processes: from tectonics to dynamic rupture

Executive summary

Modeling earthquake source processes is a vibrant multi-physics, multi-scale, societally important endeavor that tightly links several geoscience disciplines – seismology, geodesy, geology, tectonophysics, hydrology - with numerical computing, data science, machine learning, applied mathematics, continuum mechanics, tribology, materials science, and engineering.

Due to significant recent advances in modeling approaches, observational capabilities, and laboratory experimentation, the field is positioned for rapid future progress towards physics-based, predictive modeling at the societal scales of interest, including scenarios of large destructive earthquakes, prediction of strong ground motion, physics-based estimates of long-term seismic hazard, and potential for induced seismicity. Such progress would be especially timely given considerable natural hazard in several regions of the United States, including California and Pacific Northwest, as well as rapidly accelerating, energy-related industrial activities throughout the world that may cause damaging earthquakes in regions ill-prepared for them.

This report highlights the wide range of relevant scales and processes, articulates the resulting multidisciplinary modeling challenges, emphasizes the need for integrative modeling, and suggests community initiatives that would catalyze future progress. The main cross-cutting themes are the potentially dominating role of fluids - both naturally occurring and added by anthropogenic activities - in the faulting processes in the crust; the effects of inelastic processes and structural complexity of the lithosphere; and the role of shear heating, chemical reactions, and thermomechanical coupling. Of particular importance for future progress is the identified need of rigorously capturing the effects of smaller-scale processes - which may be dominating in earthquake source problems due to extreme multi-scale localization of relevant structures - on the larger-scale phenomena of societal interest, such as destructive earthquakes and induced seismicity.

Future advances would be facilitated by catalyzing community initiatives, such as a systematic community-wide modeling effort to conquer the multi-scale nature of the problem through development of scale-appropriate constitutive laws and integration of earthquake source software solutions; a community effort to harness machine learning and data mining tools to improve observational and modeling inferences; capitalizing on energy-harvesting activities as ongoing field experiments; validation of the developed modeling by a controlled field experiment and well-instrumented laboratory experiments; and contributing physics-based modeling insight into the early warning system that is being implemented on the west coast of the United States. The needed improvements in imaging the earthquake source would rely on intensifying the existing disciplinary and community efforts on novel and dense observational networks, geological studies and fault-zone drilling, and laboratory experimentation.

The overarching modeling challenges relevant to geosciences as a whole include capturing effects of smaller-scale processes on larger-scale phenomena of interest in tractable and scientifically justifiable ways; using multiple types of observables of different precision to constrain multi-scale and multi-physics modeling; and significant software engineering developments needed to benefit from the evolving supercomputing infrastructure. Overall progress would be promoted by funding programs to support open-source code development in collaboration with computer scientists and software engineers; expanding access to supercomputing and storage resources; and educational programs for junior geoscience researchers to learn best modeling and programming practices.

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This report is based on the presentations and discussions at the Workshop on “Modeling Earthquake Source Processes: from Tectonics to Dynamic Rupture” held on October 8-10, 2018 in Pasadena, California, and attended, in person and remotely, by ~140 members of the community (Appendix A).

The Workshop was facilitated by the Local Organizing Committee:
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The Workshop was sponsored by the National Science Foundation (NSF) and additionally supported by the Southern California Science Center (SCEC) and the Seismological Laboratory at the California Institute of Technology.

This final report is being submitted to the NSF and other federal agencies.

Preferred citation
Lapusta, N. et al., 2019, Modeling Earthquake Source Processes: from Tectonics to Dynamic Rupture, Report to the National Science Foundation.

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