# Community Models in the Next Earthquake Science Center

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## 1. Introduction to Community Models: Examples from SCEC

For nearly 30 years, the Southern California Earthquake Center (SCEC) has been coordinating research on fundamental earthquake science problems involving the physics of fault loading between earthquakes, propagation of large earthquake ruptures, and strong ground motions. Extensive observational datasets must provide the foundation for this science. For example, many SCEC scientists develop detailed computational models of earthquake processes – but regardless of their size and technical sophistication, these models cannot provide useful knowledge if they are not constrained by geophysical and geological observations.

Creating, synthesizing, refining, and disseminating such datasets (in the form of community models) has long been a centerpiece of the SCEC collaboration. We write this document in order to share, based on our collective experience, some ideas on community modeling needs for the next earthquake center. We emphasize that ***due to the sheer volume and diversity of data required to create and constrain modern physics-based simulations, community models must play a key role in the advancement of earthquake science and should have a strong presence in the next earthquake center*.**

The SCEC CXM working group currently oversees the development and refinement of, and provides infrastructure for, six community models:

1. Community Velocity Model (CVM)
2. Community Fault Model (CFM)
3. Community Geodetic Model (CGM)
4. Community Stress Model (CSM)
5. Community Rheology Model (CRM)
6. Community Thermal Model (CTM)

The two most mature of these are the CVM and the CFM, whose initial versions were created in 1998 and 2002, respectively. The CFM provides geometric descriptions of active southern California fault systems and the CVM comprises 3D seismic velocity, density, and elastic property data. Both of these community resources have been used to populate sophisticated numerical models of rupture propagation and strong ground motions for large California earthquakes (e.g. CyberShake), which are used by engineers to improve resilience of buildings and other structures. During SCEC4 (2012-2017), two additional community models quantifying lithospheric stresses and surface deformation patterns (the CSM and the CGM) were launched to inform studies of physics-based seismic hazard and plate-boundary deformation. The two newest community models describing mechanical properties and thermal state of the lithosphere (the CRM and the CTM) are currently in development. The newer CXMs, together with the continually-updated mature models, provide improved observational bases for next-generation earthquake rupture simulations, earthquake cycle deformation models, and model-based predictions strong ground motions.

## 2. The SCEC CXM Collaboration: A Paradigm for the Next Earthquake Center

For the next earthquake science center, creating and disseminating community models will require close collaboration between scientists and IT experts. SCEC has a long history of fostering these collaborations as well as serving suites of detailed, state of the art, and broadly accessible community modeling resources. This collaborative effort has accelerated in recent years, but it remains far from complete. We believe that the next earthquake center should build on the existing CXM resources and leverage the expertise of the SCEC community. Abandoning these valuable resources would represent a great loss to

the earthquake science community and to society in general. In the following sections, we highlight what we consider to be key needs for community modeling in the next earthquake center.

## 2.1. Provide Perpetual Support for Refinement of Models

No community model is ever truly finished – each must continually undergo testing and revision as more data become available and uncertainties become clear. The next earthquake science center should provide consistent and ongoing support for community models to enable the inclusion and assessment of ever-growing, improving, and diversifying datasets. Development of new community models may be required as well.

During SCEC5 (2017-2022), our community has continued to refine and update the four community models introduced prior to 2017 while developing and beginning to populate the two new CXMs. SCEC does not directly employ a large pool of permanent research scientists taking on these tasks: most of the CXM work is accomplished by individual researchers at various institutions working together within a collaborative framework. The CXM working group is led by three volunteers (the authors of this white paper), who also serve on the SCEC Planning Committee. Representatives for each of the six CXMs determine the needs of each CXM and share this information with us as we draft the annual science plan and request for proposals (RFP). The RFP coordinates research efforts related to the individual community models and alerts the SCEC community to topics in need of attention. Scientists who propose research responding to these needs are more likely to be funded, so careful drafting of the RFP guides and expands our collaboration and helps the SCEC collaboration meet its goals.

This collaboration scheme for community model development and maintenance is proven, inclusive, and cost-effective. The next earthquake science center should make use of a similar approach.

## 2.2. Provide Resources for Hosting/Serving Complex Community Models

As the CXMs have grown in size and complexity and their user bases have expanded, SCEC has begun to face a new challenge: how to efficiently host and serve large CXM datasets over the long term in a way that is user-friendly, supports reproducibility, is consistent with documentation and open science and open data requirements of scientific journals and Federal agencies, and is possible on a limited budget. In recent years, datasets and community models have expanded exponentially in size, and the task of serving these models has required increased IT infrastructure and support. Despite the limited resources, SCEC has kept up with the demand, but as these models expand geographically and increase in complexity, IT needs will become paramount. From our experience, it is critical that the next earthquake science center provide significant, dedicated IT support for community models and data archiving/sharing.

The CXM working group helps facilitate collaboration between scientists and IT experts, and we recommend a similar working group be part of the next earthquake science center as well. This working group serves as a link between the broader SCEC community and the SCEC IT and web development teams. Our role is to understand and clarify the CXM-related IT needs of the SCEC community, and define specific web and software development tasks that address these needs.

Under this framework we have developed and improved software tools for querying individual community models, created a uniform template for CXM websites (including metadata), provided model citation guidance, and created a CXM homepage with links to individual community model webpages to centralize and facilitate data discovery. At the beginning of SCEC5, nearly all of the community models were hosted at individual investigators' personal websites. Since then, they have been migrated progressively to the scec.org domain, and we are working to get DOI's and permanent hosting for these valuable resources. One example of CXM deliverables featuring improved accessibility is the 2019 release of the CFM web-

based viewer and search tool for the CFM. This tool enables SCEC researchers who do not have access to CAD software to directly view, search, and download the CFM.

SCEC IT infrastructure improvements also enable the SCEC community to respond rapidly to new events. In immediate response to the 2019 M6.4 and M7.1 Ridgecrest, California earthquake sequence, SCEC researchers developed new, preliminary 3D source fault representations, which include the Eastern and Southern Little Lake faults as part of the regional Little Lake fault zone. The IT infrastructure for the CFM allowed these preliminary 3D fault representations to be quickly available as triangulated surface representations for download through the CFM web viewer.

### 2.3. Provide Support for Community Modeling Workshops

Community models are of little use if scientists do not know how to make use of the model data and contribute new and relevant data. To address this, SCEC has funded and provided logistical support for several workshops per year to foster collaborative development and diverse usage of CXMs. At these workshops, CXM developers and other members of the SCEC community share updates on CXMs with potential users and contributors. Feedback and guidance on CXM development and IT needs are solicited, and attendees present examples of CXM-enabled science. Workshops have been led by various members of the SCEC community, though for coordination purposes, at least one CXM group leader attends each workshop. We emphasize the importance of holding in-person workshops to widen the use of community models, and to tailor these models to the needs of the research community.

### 2.4. Build on Existing CXMs, but Expand the Geographic Focus

SCEC was originally designed with a regional focus, optimizing the use of limited resources to make significant scientific strides in a particularly strategic geographical location, Southern California. However, it is clear that Southern California is not an isolated geologic system – and that the geographic extent of the next earthquake science center should be informed by the distribution of fault systems, not political boundaries. If the next earthquake science center targets southern California, geophysical data from the southern extension of the San Andreas fault system in northern Mexico, Central and Northern California, and the offshore region will be required to address system-level earthquake science in this region. For example, the M7.2 El Mayor earthquake occurred in northern Mexico, just outside the nominal SCEC region. This limited the data available to study this event and its influence on seismic hazard in southern California, as most of the continually-operating instrumentation was located north of the Mexican border.

SCEC has developed a knowledge base and toolkits that make it possible to construct complex and testable community models that instruct regional earthquake studies. It would be beneficial for any earthquake center to take advantage of this expertise gained from nearly 30 years of experience. SCEC has already started to incorporate adjacent areas into some models, in particular the CTM, CRM, and CVM. If the next earthquake center is to address southern California seismic hazard as part of its mission, it should continue these efforts, and expand the geographical extent of all of the community models.

## 3. Conclusion

SCEC has been producing cutting-edge community models to support earthquake science for nearly three decades. This endeavor provides a template for efficient and sustained scientific collaboration, and has resulted in critical data support for accelerating advances in earthquake science. If the next earthquake science center is to address California (and/or the western U.S.), sustaining the existing SCEC community models and expanding them to cover the entire San Andreas system will pay dividends to the research community and the public for decades to come.