

2025 CSEP Workshop Report

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I. Project Overview

A. Abstract

Describe the project objectives, methodology, and results obtained and their significance. If this work is a continuation of a multi-year SCEC-funded project, please include major research findings for all previous years in the abstract. (Maximum 250 words.)

We had requested funds for a one-day workshop before the SCEC annual meeting to stimulate the development and evaluation of physics-based earthquake forecasting along the entire San Andreas plate boundary system. Given international travel limitations, we held a small planning/convening workshop in-person at the 2025 SCEC annual meeting, and unfortunately have not yet been able to hold the planned follow-up community workshop, either in-person or virtually. Challenges included international travel limitations, resources for international participants (considered key for this workshop), coordinating across time zones spanning 21 hours and different leave calendars across hemispheres. This report summarises the planning workshop activities and recent progress of the CSEP community.

B. SCEC Annual Science Highlights

Each year, the *SCEC Science Planning Committee* reviews and summarizes SCEC research accomplishments, and presents the results to the SCEC community and funding agencies. Rank (in order of preference) the sections in which you would like your project results to appear. Choose up to 3 working groups from below and order them according to your preference ranking. The list is pre-populated with the SCEC groups you selected during proposal submission.

- Earthquake Forecasting and Predictability (EFP)
- Seismology
- Research Computing

C. Exemplary Figure

Select one figure from your project report that best exemplifies the significance of the results. The figure may be used in the SCEC Annual Science Highlights and chosen for the cover of the Annual Meeting Proceedings Volume. In the box below, enter the figure number from the project report, figure caption and figure credits. (Maximum 100 words.)

Figure 1: Spatio-temporal evolution of a synthetic UCERF3-ETAS catalog with multiple finite ruptures for 5 April 2010, the day after the 2010 El Mayor Cucapah earthquake. Points with the same color have the same parent. The parent and offspring are color-coded to identify 4 generations. Point size is proportional to magnitude and triangles represent finite ruptures [taken from Serafini et al., 2026, in preparation].

D. SCEC Science Milestones

Select all *SCEC science milestones* this project contributed to.

D2-2; C-1, 2, 3-1; D1-1

E. Intellectual Merit

How does the project contribute to the overall intellectual merit of SCEC? For example: *How does the research contribute to advancing knowledge and understanding in the field and, more specifically, SCEC research objectives? To what extent has the activity developed creative and original concepts?* (Maximum 100 words.)

The workshop contributes to SCEC's goal of advancing the predictability of earthquakes by rigorous testing of models and developing new and improved models. One example of innovation involves the development of new methods to evaluate simulation-based forecasting models.

F. Broader Impacts

How does the project contribute to the broader impacts of SCEC as a whole? For example: *How well has the activity promoted or supported teaching, training, and learning at your institution or across SCEC? If your project included a SCEC intern, what was his/her contribution? How has your project broadened the participation of underrepresented groups? To what extent has the project enhanced the infrastructure for research and education (e.g., facilities, instrumentation, networks, and partnerships)? What are some possible benefits of the activity to society?* (Maximum 100 words.)

CSEP actively promotes open research principles amongst the community, including the publication of reproducibility packages and open-source community-developed software along with training workshops and online and in-person tutorials. These efforts have broadened the participant base and elevated the field's rigor. CSEP's forecast model evaluations provide independent assessments of the kinds of models that international and US government agencies use for public forecasting, thereby building objective confidence in their predictive skills and exposing limitations.

G. Project Participants

What individuals have worked on the project? What organizations have been involved as partners? Were other collaborators or contacts involved? If so, please provide details. (Maximum 100 words.)

The core CSEP group currently involves scientists from the University of Bristol, GFZ Potsdam, SCEC, ETH Zurich and GNS Science (now called Earth Sciences New Zealand). The planning workshop also included researchers from UCLA and the USGS. The workshop was attended by about 15 attendees.

II. Technical Report

The technical report should describe the project objectives, methodology, and results obtained and their significance. If this work is a continuation of a multi-year SCEC-funded project, please include major research findings for all previous years in the report. (Maximum 5 pages, 1-3 figures with captions, references and publications do not count against limit.)

A. Project Objectives

The planning workshop at the SCEC AM aimed to take stock of new challenges and opportunities in physics-based and empirical earthquake rupture forecasting in the Statewide California Earthquake Center (SCEC). The planning workshop's objectives included learning about recent and ongoing CSEP activities, to gather input for a virtual global workshop on next-generation earthquake forecasting, and to develop future community activities.

B. Methodology

The planning workshop comprised a series of short, invited presentations from researchers from a range of career stages, along with structured discussion time:

Agenda

10:30 Welcome and Introductions [Max Werner]

10:35 Max Werner: Update on CSEP activities

10:45 Luis Vasquez: Assimilation of deterministic multicycle earthquake simulations into probabilistic rupture forecasts

10:55 Francesco Serafini: Time-dependent finite ruptures in UCERF3-ETAS simulations

11:05 Open session: short talks/presentations/opinions

Perspectives from USGS [Ned Field, Kevin Milner, Morgan Page]

Perspectives from New Zealand [Kenny Graham]

Perspectives from SCEC [Ahmed Elbanna, Phil Maechling]

Perspectives from modelers/developers [Rick Schoenberg]

11:30 Discussion

11:45 Future SCEC activities: virtual workshop and team-science activity

C. Results

This section briefly summarises the talks and outcomes of the workshop.

Max Werner provided an overview of recent and ongoing CSEP activities, including research projects and papers, software development, reproducibility packages and training, including via the virtual training organized by Quakeworx.

- CSEP submitted the **floatCSEP** software and documentation for review to the Journal of Open Source Software (JOSS). The review process scrutinises both software and documentation. floatCSEP provides The paper was accepted and was published on 20 February 2026 (Iturrieta et al., 2026)
- CSEP developed **EarthquakeNPP**, benchmark datasets for forecasting with neural point processes. The associated paper has been accepted for publication in the Transaction of Machine Learning Research (Stockman et al., 2026).
- CSEP provided online training of its software pyCSEP during the January 2025 **QuakeWorx cyber-training event**.
- CSEP published the **next-day California forecasting benchmark** paper, comprising over 50,000 forecasts from two dozen models in California between 2007 and 2017 (Serafini et al., 2025).
- Bayona et al. (2026, under review) submitted an evaluation of the models in the benchmark for review, highlighting that **select short-term models are consistent with decadal observations in California**.
- Serafini et al., (2026, in preparation) are evaluating a decade of next-day UCERF3-ETAS simulation-based forecasts against data and the CSEP next-day benchmark. See below and Figure 1.
- Serafini et al. (2026, in revision for GJI) developed new evaluation metrics for magnitude distribution forecasts.

Luis Vazquez presented methods for comparing earthquake rupture forecast models against each other, specifically RSQSim and UCERF3-ETAS. These methods are critical to formal evaluations of the class of rupture-based forecast models. His work was published recently (Vazquez & Jordan, 2025).

Francesco Serafini presented results from a decadal evaluation of the UCERF3-ETAS model in California and against the decadal CSEP California next-day benchmark. Figure 1 illustrates forecasts during the 2010 El Mayor Cucupah sequence.

A series of short presentations and discussions continued these presentations, including by SCEC Director Ahmed Elbanna, USGS researcher Ned Field and UCLA statistician Rick Schoenberg. These culminated in input for a future virtual workshop on next-generation earthquake forecasting, including topics, themes, possible presenters and

future SCEC community activities, including a TAG on physics-based earthquake rupture simulations and forecasting.

Figure 2 illustrates the triggering of finite UCERF3 ruptures as well as (point-wise) ETAS seismicity in one of the synthetic UCERF3-ETAS catalogs for 5 April 2010, i.e. the day after the 2010 El-Mayor Cucapah earthquake. This catalog contains four generations of triggered ruptures, and it illustrates the potential of empirical/stochastic and physics-based rupture simulations for short-term rupture forecasting.

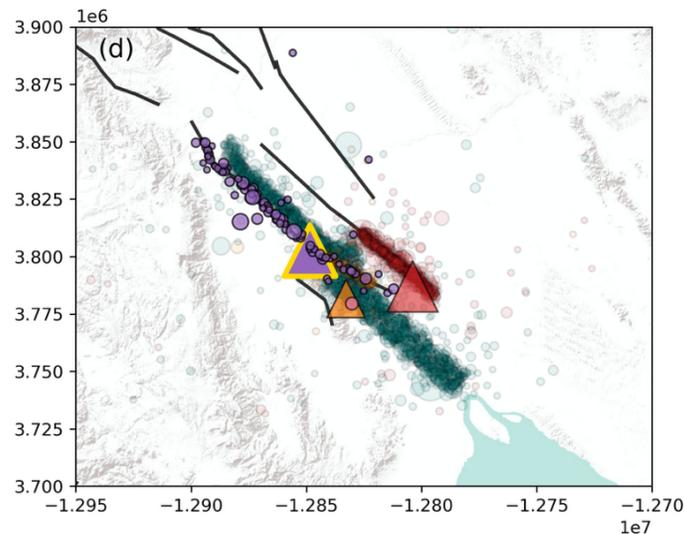


Figure 1: Spatio-temporal evolution of a synthetic UCERF3-ETAS catalog with multiple finite ruptures for 5 April 2010, the day after the 2010 El Mayor Cucapah earthquake. Points with the same color have the same parent. The parent and offspring are color-coded to identify 4 generations. Point size is proportional to magnitude and triangles represent finite ruptures. (Taken from Serafini et al., 2026, in preparation)

D. Significance

This SCEC funded workshop is a focal point of the global CSEP collaboration and operational earthquake forecasting. It brought together SCEC community members, USGS and other national agency personnel and SCEC HQ IT, to discuss the next stages of earthquake forecasting in California and around the globe. Participants debated new frontiers, including rupture forecasting, physics-based models and machine-learning based forecasting. The talks and discussion contribute to the intellectual environment at SCEC, including future proposals and research outputs.

E. References

Bayona, J.A., et al. (2026, under review). Select earthquake forecasting models demonstrate consistency with decadal prospective observations in California. Under review in *Nature Communications*.

Iturrieta, P., Savran, W. H., Herrmann, M., Bayona, J. A., Gerstenberger, M. C., Graham, K., ... & Werner, M. J. (2026). floatCSEP: An application to deploy and conduct reproducible prospective earthquake forecasting experiments. *Journal of Open Source Software*, 11(118), 9408.

Serafini, F., Bayona, J. A., Silva, F., Savran, W., Stockman, S., Maechling, P. J., & Werner, M. J. (2025). A benchmark database of ten years of prospective next-day earthquake forecasts in California from the Collaboratory for the Study of Earthquake Predictability. *Scientific Data*, 12(1), 1501.

Serafini, F. et al. (2026, in revision). Exploring new statistical metrics to evaluate the magnitude distribution of earthquake forecasting models. In revision for *Geophysical Journal International*.

Serafini, F. et al (2026, in preparation). A Decadal Evaluation of UCERF3-ETAS Next-Day Forecasts in California.

Stockman, S., Lawson, D. and Werner, M. J. (2026, accepted in Transaction for Machine Learning Research). EarthquakeNPP: Benchmark datasets for forecasting with neural point processes. *Transaction for Machine Learning Research*. Preprint available from <https://arxiv.org/abs/2410.08226> .

Vazquez, L. A., & Jordan, T. H. (2025). Assimilation of deterministic multicycle earthquake simulations into probabilistic rupture forecasts. *Geophysical Journal International*, 241(2), 1243-1261.