2026 SCEC Tandem Training Workshop Report

Modeling the Earthquake Cycle from Faults to Supercomputers

Date: June 22–24, 2026

Location: Martin Johnson House, Scripps Institution of Oceanography, UC San Diego, La Jolla, CA

Conveners: Bar Oryan,Alice-Agnes Gabriel, Dave May, Jeena Yun, and Yohai Magen (Scripps Institution of Oceanography, UC San Diego)

SCEC Award: 26020

Website: www.scec.org/events/2026-tandem-training-workshop

Training materials: https://github.com/TEAR-ERC/tandem-training

Summary

Advances in geodetic, seismic, and geological observations now capture fault slip in far greater detail than was possible only a couple of decades ago, from slow transient deformation to fluid-driven processes and fault zone complexity. Yet the observational record remains incomplete, and observations alone cannot explain the physical processes that govern the seismic cycle. Physics-based models of Sequences of Earthquakes and Aseismic Slip (SEAS) bridge this gap, and next-generation SEAS models can now incorporate the realistic fault geometries, heterogeneous crust, and realistic tectonic loading that observations reveal. These simulations, however, are technically demanding, and many early-career scientists lack opportunities to develop the numerical modeling and high-performance computing (HPC) skills they require. The 2026 SCEC Tandem Training Workshop brought together **39 participants**, primarily in-person graduate students, postdoctoral researchers, and early-career scientists, from **22 institutions in 8 countries** for an intensive 2.5-day, science-driven, hands-on workshop at the Scripps Institution of Oceanography, UC San Diego. Invited talks by Brittany Erickson (University of Oregon), Pierre Romanet (CEREMA/GéoAzur, France), So Ozawa (ERI, University of Tokyo, Japan), and Tom Heaton (Caltech), together with six participant science talks and two poster sessions, connected the training part to the scientific frontiers of earthquake-cycle research. Guided hands-on sessions then trained participants to design, mesh, launch, visualize, and interpret SEAS simulations with Tandem, an open-source HPC code (Uphoff et al., 2023; Gabriel et al., 2026). To make this possible for users at every level, the organizing team built a dedicated computational ecosystem, including HPC access via the Quakeworx Science Gateway, a pre-configured JupyterLab image on the National Data Platform (NPD), and a portable Docker environment, all of which, together with the complete training materials, remain openly available to participants after the workshop. Feedback was strongly positive: the 23 survey responses rated the workshop 4.7/5 for overall value, format, and logistics, and identified the hands-on exercises as the most valuable element.

Motivation and Goals

Natural faults accommodate slip across a wide range of spatial and temporal scales, from months-long aseismic deformation to rapid earthquake ruptures. SEAS simulations (Erickson et al., 2020, 2023;Jiang et al., 2023) connect modern observations of these processes to the underlying physics of the earthquake cycle by modeling how slip accumulates, transfers stress, and drives rupture (Lapusta et al., 2000; Rice, 1993). When coupled with Earth structure datasets such as SCEC's community models, SEAS simulations allow researchers to explore how real fault systems evolve and how their behavior contributes to seismic hazard. Yet many existing SEAS models rely on planar geometries, homogeneous materials, or idealized boundary conditions that fail to represent the complexity revealed by modern observations. Next-generation SEAS models can incorporate realistic fault geometries, heterogeneous crust, and realistic tectonic loading, but these simulations are computationally expensive, and using them requires numerical modeling expertise, proficiency with compilers, and access to HPC resources, capabilities that many early-career researchers have limited opportunities to develop.

The Tandem code was built to address exactly these needs (Uphoff et al., 2023), and this workshop aimed to lower the barriers to its use. Tandem is an open-source HPC code that employs a discontinuous Galerkin discretization on unstructured curvilinear meshes, allowing users to represent curved, dipping, and branching faults, topography, and heterogeneous material structure within a single simulation, and it scales efficiently to as many as 100,000 MPI ranks. Specific goals of the workshop were to (1) expose participants to the frontiers of SEAS research through invited and participant science talks, (2) teach how SEAS models are formulated and what physics they capture, (3) train participants to use Tandem, from constructing and modifying input files and generating meshes to running models on laptops and supercomputers and visualizing and interpreting outputs, (4) provide seamless access to HPC resources , and (5) build a growing community of SEAS modelers prepared to incorporate SCEC datasets and community models into physics-based simulations. These goals directly support SCEC science milestones for developing, maintaining, and training users in community modeling tools (C1,2,3-1), FAIR-aligned workflows (C1-2, C2-2), and integrative earthquake-cycle simulation (C3-1).

Program Highlights

The 2.5-day program combined invited and participant science talks, four structured hands-on training sessions, two poster sessions, dedicated open work time, and a guided tour of the San Diego Supercomputer Center (SDSC). The full agenda, poster list, and posted presentation materials are available on the workshop website.

The workshop opened Monday afternoon (June 22) with a science session designed to ground the training in the current frontier of earthquake-cycle research and to show participants, before running their first SEAS simulation, the breadth of science that SEAS simulations enable. The four invited speakers addressed complex physics and geometries in SEAS modeling (Erickson), the theory and simulation of non-planar fault networks (Romanet), fluids and geometrical complexity in the earthquake cycle (Ozawa), and chaotic slip pulses and fractal prestress (Heaton). The slides are available at the workshop website. The first poster session followed.

The following two days interleaved hands-on training with participant science. Session A covered preparing Tandem input files and launching simulations, Session B covered postprocessing and visualizing Tandem output (Figure 1b), Session C covered generating meshes with Gmsh, and Session D covered running and compiling Tandem on HPC systems. Each session paired a short lecture with guided exercises supported by the organizing team of Tandem developers and advanced users. Six participant talks and 23 posters were integrated throughout the program to give early-career participants a platform to present their own research, to connect the training to concrete applications of earthquake-cycle modeling, and to seed collaborations within the emerging user community (Figure 1c). Two open work periods allowed participants to begin developing Tandem models for their own research questions with developers on hand. The SDSC tour (Figure 1d) introduced the Expanse supercomputer on which participants had run their simulations, gave participants an appreciation of the infrastructure and the operational effort behind the HPC centers that make such simulations possible, and included an extended discussion of how researchers can obtain access to national HPC resources through NSF allocation programs.

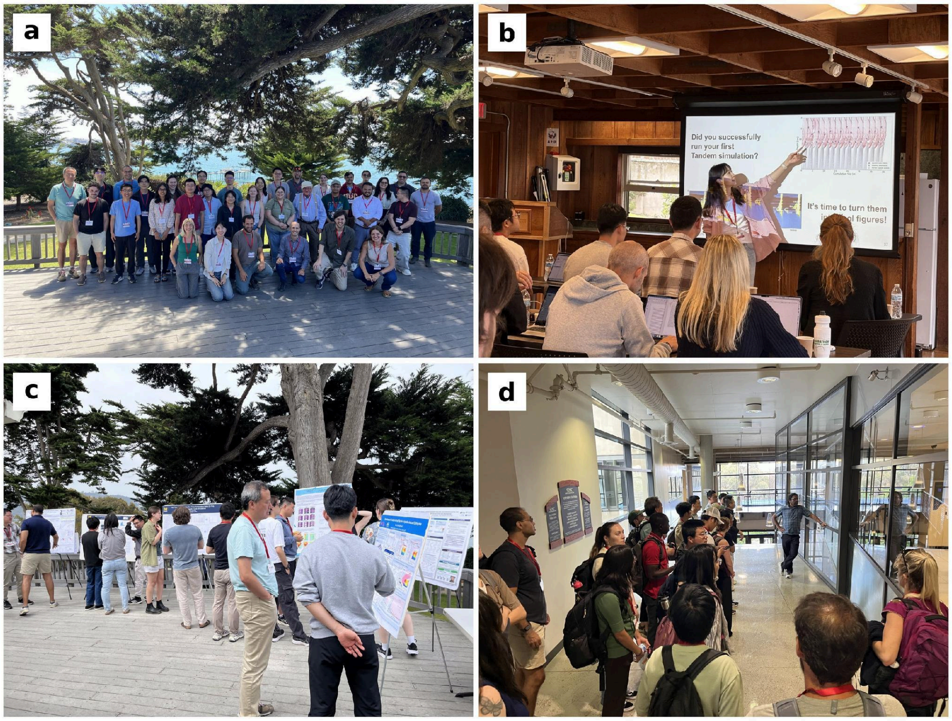

Figure 1. Impressions from the 2026 SCEC Tandem Training Workshop: (a) participants and organizers at the Martin Johnson House, Scripps Institution of Oceanography, (b) a hands-on training session on postprocessing and visualizing Tandem output, (c) the poster session on the Martin Johnson House patio, and (d) the guided tour of the San Diego Supercomputer Center.

Computational Infrastructure, Training Materials, and Documentation

A substantial share of the preparation effort went into two things: training materials written specifically for this workshop, and a computational ecosystem that let every participant run Tandem, a code that ordinarily requires compiling a complex HPC software stack, from the first minutes of the training and keep running following the workshop. We provided the following complementary environments:

- **Quakeworx Science Gateway.** All participants received access to [quakeworx.org]() to run Tandem on the SDSC supercomputer Expanse with up to 65 cores and 120 GB of memory per user, during and after the workshop.
- **National Data Platform (NDP).** With the NDP team at UC San Diego, we built a JupyterLab image with the full Tandem environment pre-installed, deployed through [nationaldataplatform.org]() on the NSF National Research Platform. Each participant could launch a browser-based server with 30 CPU cores, 32 GB of RAM, and 10 GB of persistent storage, and US-affiliated participants retain this free access after the workshop. Computing at this scale would otherwise be costly, and it can carry users through their first independent Tandem models.
- **Tandem Docker container.** A public Docker image (*baroryan/tandem:v1.2.0*) bundles a fully compiled Tandem with JupyterLab on both Apple Silicon and x86 platforms, letting participants run simulations offline on their own laptops and keep the identical environment after the workshop.
- **Tandem UTM virtual machine.** A pre-configured fallback for Apple Silicon Macs that encountered Docker issues, freely available for [download on Zenodo]().

Session D additionally taught participants to compile Tandem from source on external clusters. This layered approach meant that no participant was blocked by computing issues, and the sufficiency of computing resources received the highest survey rating of any category (4.8/5). The hands-on sessions themselves were built on Jupyter notebooks, example input files, and mesh-generation exercises published in the [tandem-training GitHub repository](), complemented by Tandem's online [documentation]() covering installation, input-file formats, and worked examples.

Participants and Selection

The workshop hosted 39 participants (Figure 1a): 37 in person, including the four invited speakers, and 2 who joined the first day remotely, representing 22 institutions in 8 countries. Consistent with the workshop's early-career focus, the cohort consisted primarily of graduate students and postdoctoral researchers, complemented by research scientists and faculty. Selection was rigorous: applications were solicited through the SCEC, SZ4D, CIG, CRESCENT, and Quakeworx mailing lists, and roughly 80 researchers applied, answering questions designed to gauge their motivation for the workshop, the expected benefit to their research and career, and their readiness for its computational components. Selected participants received on-campus room and board at UC San Diego, with partial flight support awarded to the most qualified applicants.

Post-Workshop Survey Results

A post-workshop survey received 23 responses (11 graduate students, 6 postdocs, 4 research scientists, 1 faculty member, and 1 other). Feedback was strongly positive: mean ratings were 4.7/5 for overall engagement and value, 4.7/5 for the effectiveness of the format in promoting learning and networking, 4.7/5 for organization and logistics, and 4.8/5 for the sufficiency of computing resources during hands-on sessions (Figure 2a). Respondents reported a mean confidence of 3.6/5 in using Tandem after the workshop (Figure 2b), an encouraging result given that most arrived with no prior Tandem experience and consistent with the workshop's goal of building a foundation for continued learning rather than producing expert modelers in two days.

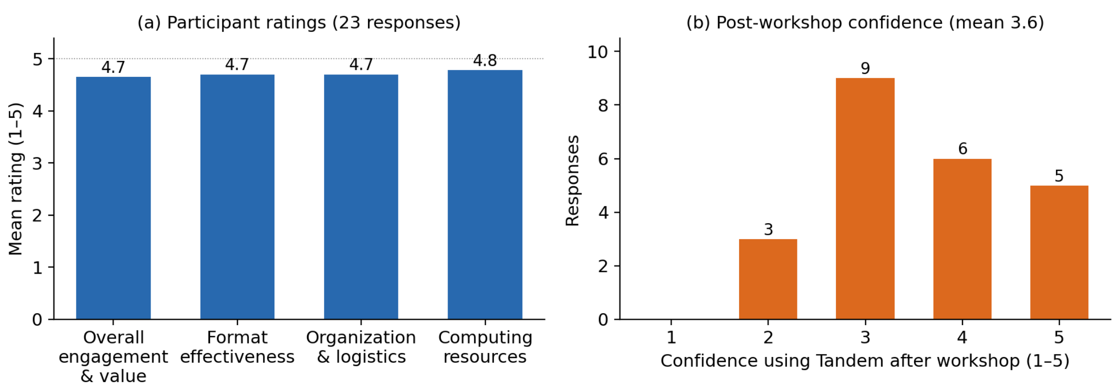

Figure 2. Post-workshop survey results (23 responses). (a) Mean participant ratings of the workshop. (b) Distribution of self-reported confidence using Tandem after the workshop.

Hands-on exercises were the element most frequently cited as contributing to learning (22 of 23 respondents), followed by participant talks (19) and formal presentations (18) (Figure 3a). Among the hands-on components, preparing input files and launching simulations (20), postprocessing and visualization (17), and mesh generation with Gmsh (17) were rated most useful. Asked what would help them continue using Tandem, respondents most often selected more example problems (15), a community Slack/email list (11), more help interpreting outputs (10), more recorded tutorials (10), and more help with mesh generation (10) (Figure 3b). Respondents described concrete plans to apply the training to their own research, including SEAS modeling of the Indo-Burma subduction zone, the Alpine Fault, shallow slow slip events, intraplate earthquake swarms, fault behavior under varying stressing rates, and benchmarking against in-house simulation codes. Suggestions for improvement centered on allowing more time for the HPC compilation session and the open model-development periods.

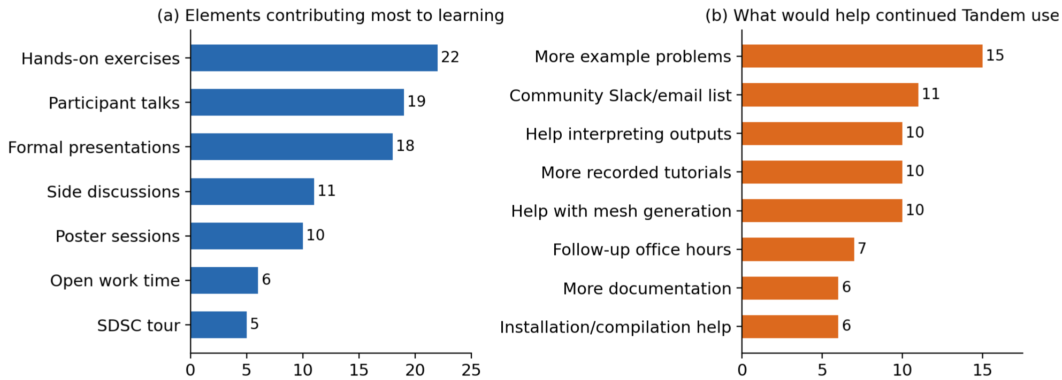

Figure 3. (a) Workshop elements participants cited as contributing most to their learning. (b) Resources participants identified as most helpful for continued Tandem use after the workshop.

Lessons Learned: Shaping the Next Tandem Training

The questionnaire responses, together with the organizing team's own observations, point to concrete ways to make future Tandem training even more effective, and we plan to adapt future workshops accordingly. Several respondents noted that the sessions were compact and fast-paced, and the most common requests were for more example problems and more support in interpreting outputs.

In response, the next workshop will feature more, but shorter, training sessions, each focused on a narrower topic and each devoting an even larger fraction of its time to hands-on work. The training will also follow a clearer simple-to-advanced progression: the first training day will focus exclusively on simple models, covering (1) running a first simulation, (2) understanding and setting up the physics, and (3) simple mesh generation, while the second day will build on that foundation with (4) advanced plotting, (5) advanced meshing, and (6) running Tandem on HPC systems. Finally, the exercises will be supplemented by a larger library of worked examples.

Outcomes and Community Impact

The workshop trained a new international cohort of early-career researchers to design, run, and interpret SEAS simulations with Tandem on platforms ranging from their own laptops to national supercomputing resources, directly building community capacity for physics-based earthquake-cycle modeling in support of SCEC's science priorities. All training materials and computational environments built for the workshop remain freely available to participants for their own research. Several participants left with prototype models for their own study regions developed during the open work sessions, and multiple respondents expressed interest in joint research projects, shared resource repositories, and contributions to the Tandem code base.

Guided by participant feedback, we may establish a community communication channel (a Tandem mailing list was already seeded with addresses collected in the survey), expand the library of documented example problems and output-interpretation documentation, record tutorials for asynchronous use, and hold periodic follow-up office hours. The strong demand, roughly 80 applications for the available seats, and the positive participant response all support future Tandem workshops and a growing SEAS modeling community.

References

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