Operational earthquake forecasting during the M6.4 Searles Valley and M7.1 Ridgecrest sequence using the UCERF3-ETAS model—evaluation and lessons learned

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Background

By 11:07 am on July 4, 2019 (33 minutes after the M6.4 Searles Valley earthquake), the first UCERF3-ETAS aftershock simulations were running at the University of Southern California's High-Performance Computing Center. UCERF3-ETAS (Field et al., 2017), an extension to the Third Uniform California Earthquake Rupture Forecast, is the first comprehensive fault-based epidemic-type aftershock sequence model. It produces ensemble simulations of aftershock sequences both on and between explicitly modeled UCERF3 faults to answer a key question in earthquake forecasting: What are the chances that an earthquake that just occurred will turn out to be the foreshock of an even bigger event? At 11:39 am, the first results were posted to the Southern California Earthquake Center's scientific response coordination page: the UCERF3-ETAS model predicted a 3% chance of triggering an aftershock larger than M6.4 within the first week.

Such an event occurred 34 hours later, this time a much more powerful (M7.1) earthquake. Aftershock probabilities were recalculated and provided to the U.S. Geological Survey and the California Earthquake Prediction Evaluation Council (CEPEC) for use in assessing the probabilities of a larger shock. As seismic activity propagated southeastward to the Garlock Fault, a particular concern was the possibility that the Ridgecrest sequence could trigger a large earthquake on this major fault. Standard short-term forecasting models in current use by the USGS and CEPEC do not explicitly consider the proximity of seismic activity to major faults like the Garlock. In contrast, the UCERF3-ETAS model has been explicitly designed to produce such probabilities.

Development of the UCERF3-ETAS code base during the past year allowed us to rapidly prepare Ridgecrest simulations. Moreover, new tools were quickly developed in the weeks following the M7.1 event, including the incorporation of 3-D finite rupture models, which allowed us to account explicitly for the distance between the observed rupture surfaces and neighboring faults. As various finite fault models were generated, sensitivity to rupture geometry became apparent, though the differences between all of the finite sources are much smaller than the difference between using our best finite source and point source. This suggests that, while sensitivities exist, inclusion of an uncertain finite source is still preferred over a point source model.

M7.1 Preferred Model Results (Finite Source)

A detailed finite rupture geometry was posted ComCat on Thursday, July 11, at 6:32 pm. This geometry was developed through analysis of coseismic deformation from INSAR. We developed the capability to scrape these sources for use in UCERF3-ETAS simulations on Tuesday, July 16, and have used that rupture geometry as our preferred model since.

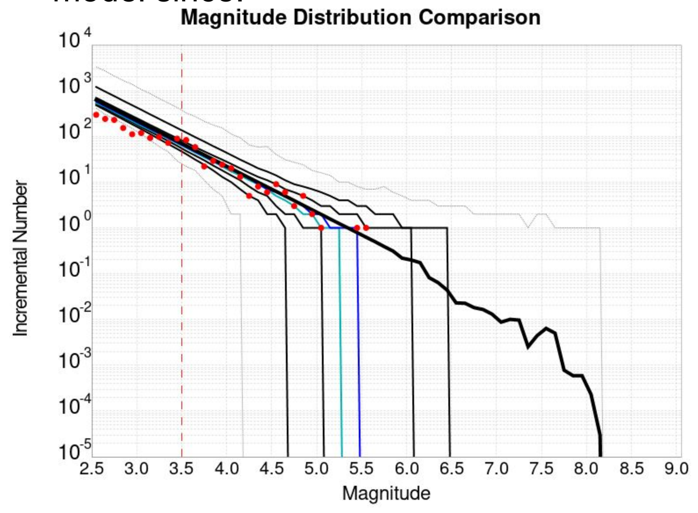


Figure 1: Magnitude-Number Comparison
Comparison of UCERF3-ETAS preferred model predicted incremental magnitude number distribution (solid lines) and actual aftershocks reported by ComCat (M7.1). Simulation mean expectation is plotted with a thick black line, median in blue, percentiles as thin black lines.

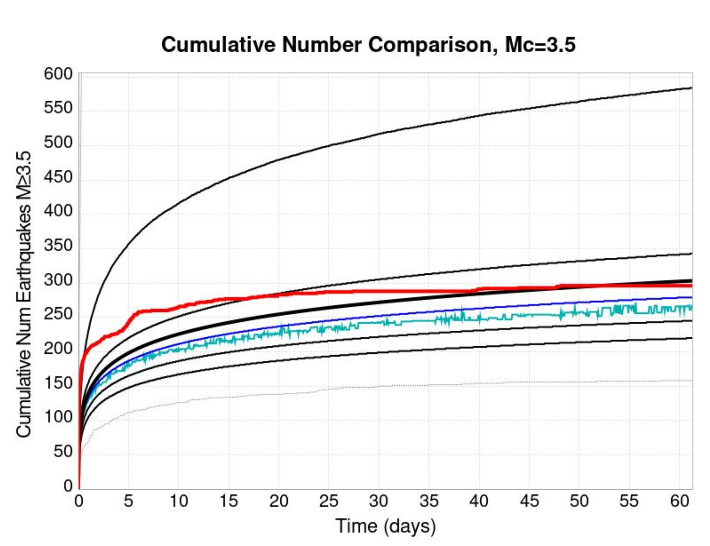


Figure 2: Cumulative Number M≥3.5 Comparison
Comparison of UCERF3-ETAS cumulative number of M≥3.5 events as a function of time with ComCat data. While the actual sequence has a different shape (higher mainshock productivity, lower aftershock productivity), the overall fit after 2 months is good.

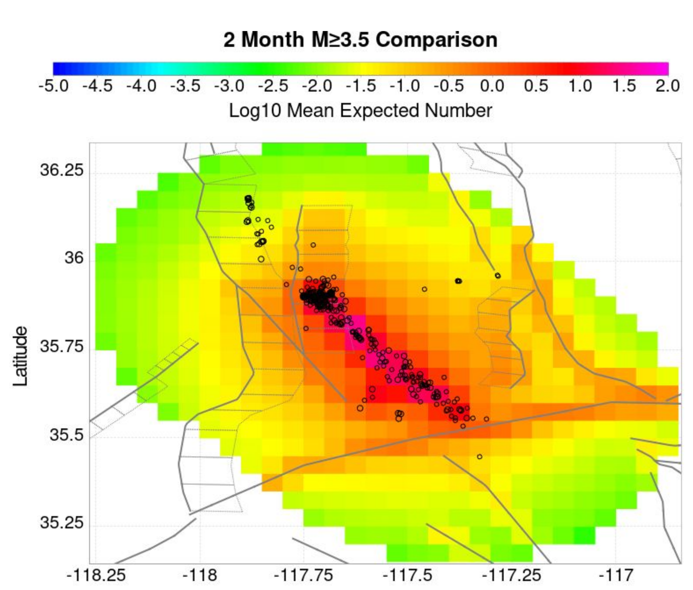


Figure 3: Spatial Distribution of M≥3.5 Events
Comparison of UCERF3-ETAS preferred model predicted spatial distribution of M≥3.5 aftershocks with ComCat data (black circles). Probabilities are highest along the input rupture surface, and near previously mapped active neighboring faults.

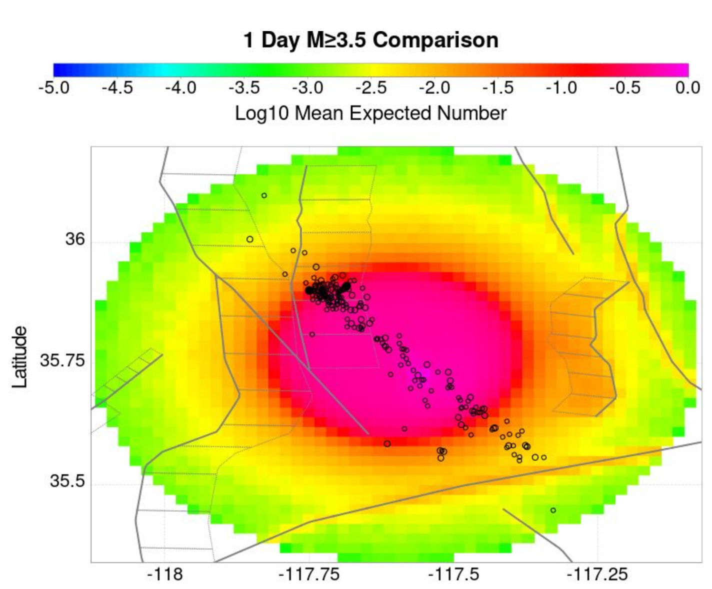


Figure 4: Point Source Spatial Distribution
Same as Figure 3, except with a point source rupture model instead of the finite rupture source. Failure to include the finite source model results in a generic, spherical falloff from the epicenter (though probabilities are higher in the vicinity of previously mapped faults).

UCERF3-ETAS provides **useful information** about **fault probabilities** after **Ridgecrest**, but can be **sensitive to inputs**

- Assesses probability of Ridgecrest triggering neighboring faults (e.g. Garlock)
- Such probabilities are sensitive to poorly constrained rupture geometry
- Still better to include a poorly constrained rupture surface than completely ignore finite fault extents (if interested in fault probabilities)
- Having a real event (Ridgecrest) was an extremely valuable exercise to learn about these sensitivities, and develop tools to improve response to future events

Timeline

Thursday, July 4, 2019
- 10:33 am: M6.4 Searles Valley Occurred
- 11:07 am: First UCERF3-ETAS simulations running at USC HPC (point sources)
- 11:39 am: Initial results posted to response.scec.org
  - 3% change of M≥6.4 in first week
- 4:02 pm: All 100k simulations finished, results updated

Friday, July 5, 2019
- 8:19 pm: M7.1 Ridgecrest Occurred (initial reported M=6.9)
- 9:11 pm: M6.9 point source simulations running at USC HPC (Kevin unavailable, submitted by Bill Savran)

Saturday, July 6, 2019
- 4:25 am: Point source simulations resubmitted with updated M=7.1
- 9:38 am: Point source M7.1 simulations completed
  - 1% chance of another M≥7.1 in first week
  - 0.46% chance of M≥7 on Garlock Fault in first month
- 10:30 am: CEPEC convenes, considers M7.1 results
- 12:24 pm: UCERF3-ETAS input files and code modified to support arbitrary finite fault surfaces (not on UCERF3 faults)
- 9:12 pm: First finite fault simulations submitted with extents drawn by Ned Field from aftershock sequence
  - 1.92% chance of another M≥7.1 in first week
  - 1.71% chance of M≥7 on Garlock Fault in first month

Tuesday, July 9, 2019
- 11:35 am: ShakeMap planar finite fault source available (V10), based on teleseismic inversion

Thursday, July 11, 2019
- 1:56 pm: UCERF3-ETAS tool developed to fetch events directly from ComCat to configure simulations, specify planar finite fault by strike, dip & length/depth extents
- 5:20 pm: Finite fault simulations with better hand drawn planar source completed
  - 3.95% chance of another M≥7.1 in first week
  - 4.37% chance of M≥7 on Garlock Fault in first month
- 6:32 pm: ShakeMap detailed finite fault source available (V14), based on INSAR

Tuesday, July 16, 2019
- 3:35 pm: UCERF3-ETAS tool updated to fetch complex ShakeMap finite sources from ComCat

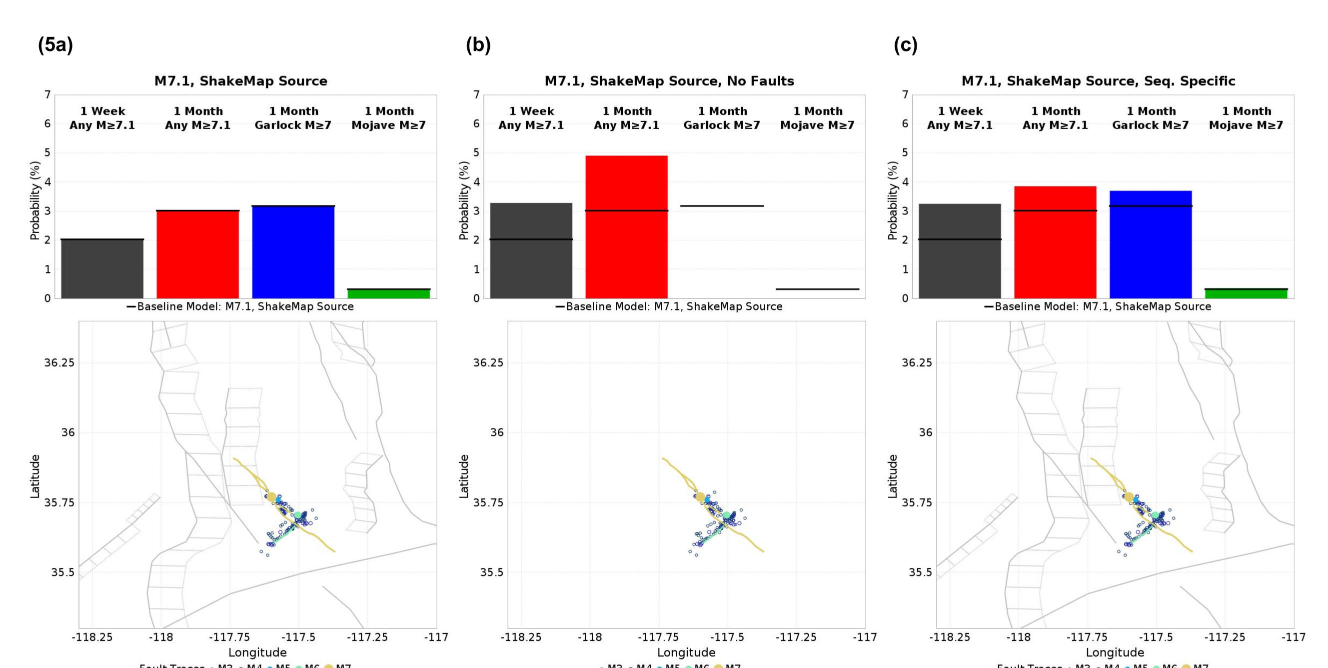
Friday, July 17, 2019
- 12:01 am: Finite fault simulations with complex ShakeMap source (V14) completed
  - 2.99% chance of another M≥7.1 in first week
  - 3.11% chance of M≥7 on Garlock Fault in first month

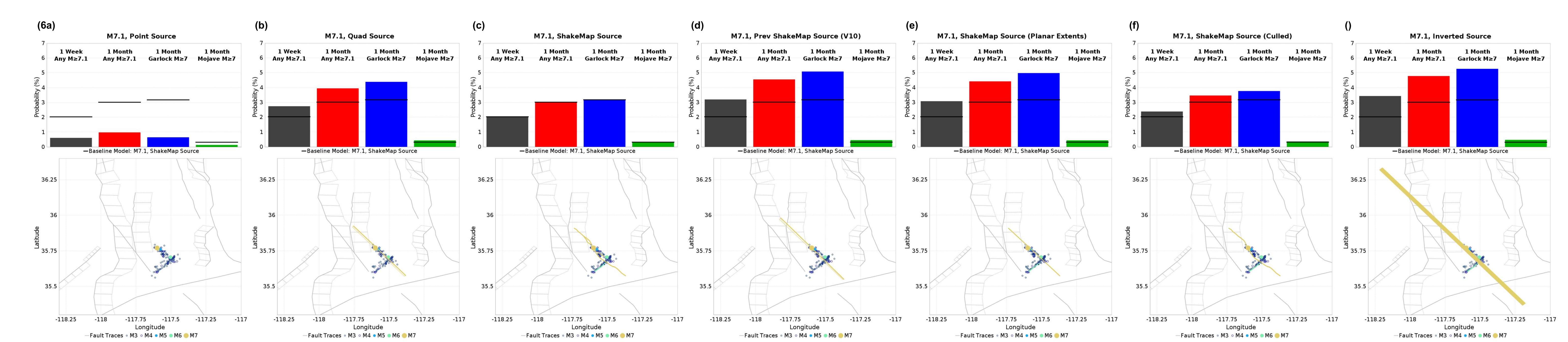
Model Sensitivities

Sensitivity of various probabilities (top panels) to different UCERF3-ETAS configurations. Simulation input fault geometry is shown on the bottom map view panels, with the M7.1 surface in gold. Probabilities from the preferred model (ShakeMap finite source, default parameters) are annotated with a black line.

Figure 5 (right): Sensitivity to different model parameters. Probabilities are higher for this event than for the no-faults version (b). Areas without explicitly mapped faults in regular UCERF3-ETAS are anti-characteristic (as faults are, on average, characteristic and the model must be Gutenberg-Richter statewide), which results in lower probabilities of triggering large ruptures (a) than when faults are excluded. The reverse would be true if the event had occurred on a mapped fault. Results for sequence specific ETAS parameters are shown in (c).

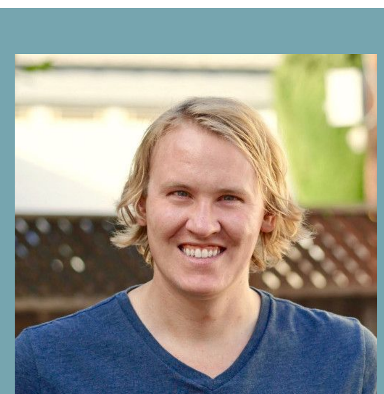
Figure 6 (below): Sensitivity to different input fault geometries. The default model (c) is the ShakeMap finite fault source. Point source (a) simulations have much lower probabilities. Triggering probabilities are sensitive to the distance to faults, and the overall squirliness of the surface. The latter is because surfaces are discretized evenly, with each point on the surface assigned an equal triggering potential, thus more linear sources (with fewer points) give higher probability to the point nearest Garlock. The last panel (g) show the finite source surface from the ComCat USGS finite fault event page, which is overly large and unsuitable for use as input to UCERF3-ETAS.





Questions?

Find this guy or e-mail kmilner@usc.edu



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