Using Earthquake Simulators for Earthquake Forecasting and Their Testing in CSEP

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ViscoSim
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Physics Based Earthquake Simulators

- To understand hazard better, we desire a statistical description of earthquakes for thousands of years
  - Instrumental, historic, and paleoseismic records are too short and/or too incomplete
- Earthquake simulators can generate long histories
- How can these be used to forecast earthquakes and how can these forecasts be tested in CSEP?

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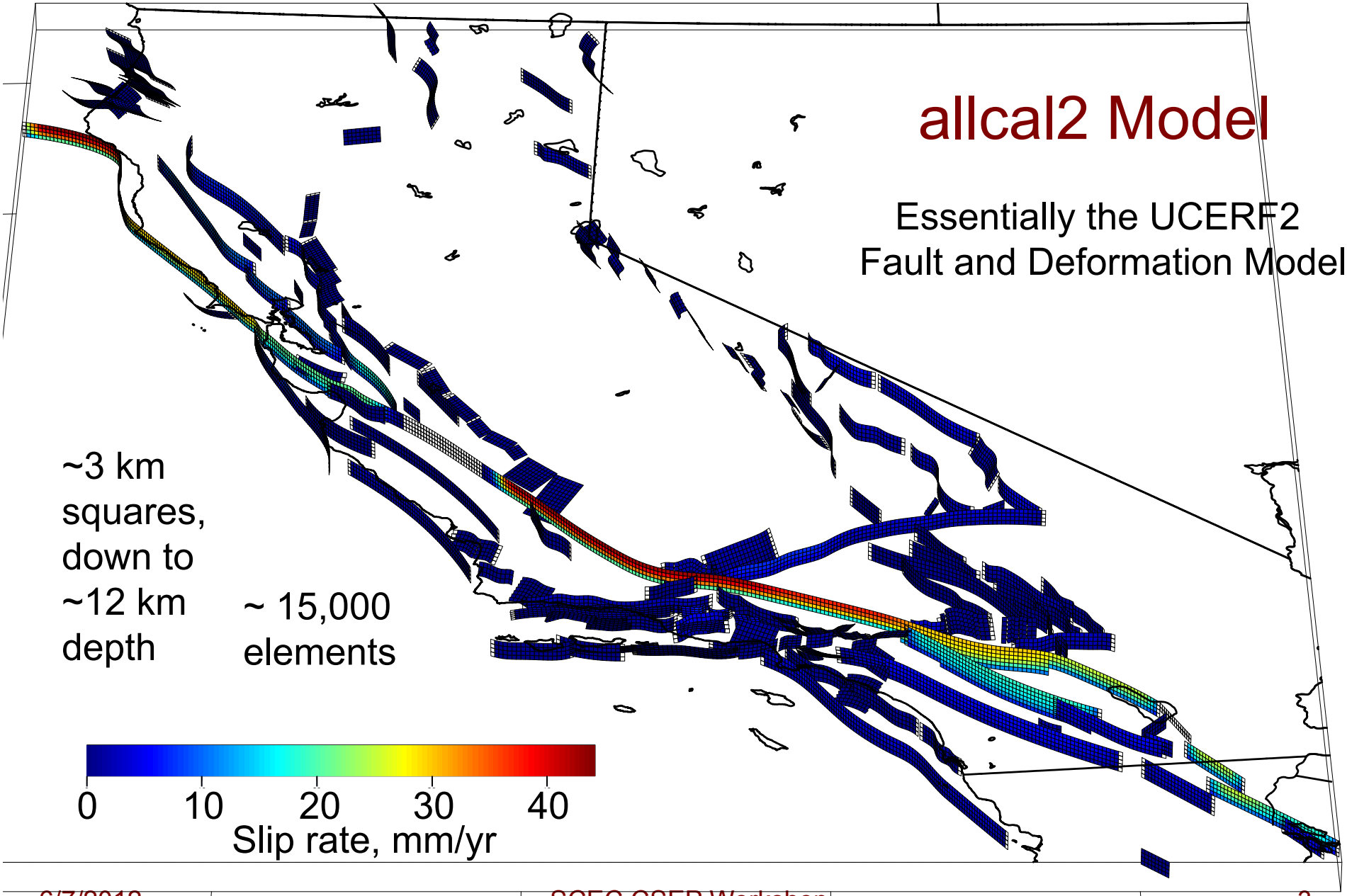
- Brief summary of results from four All California models:
  - ALLCAL (UCSC), VIRTCAL (UCD), RSQSim (UCR), ViscoSim (USGS)
- We have a public web site at

  http://scec.usc.edu/research/eqsims/

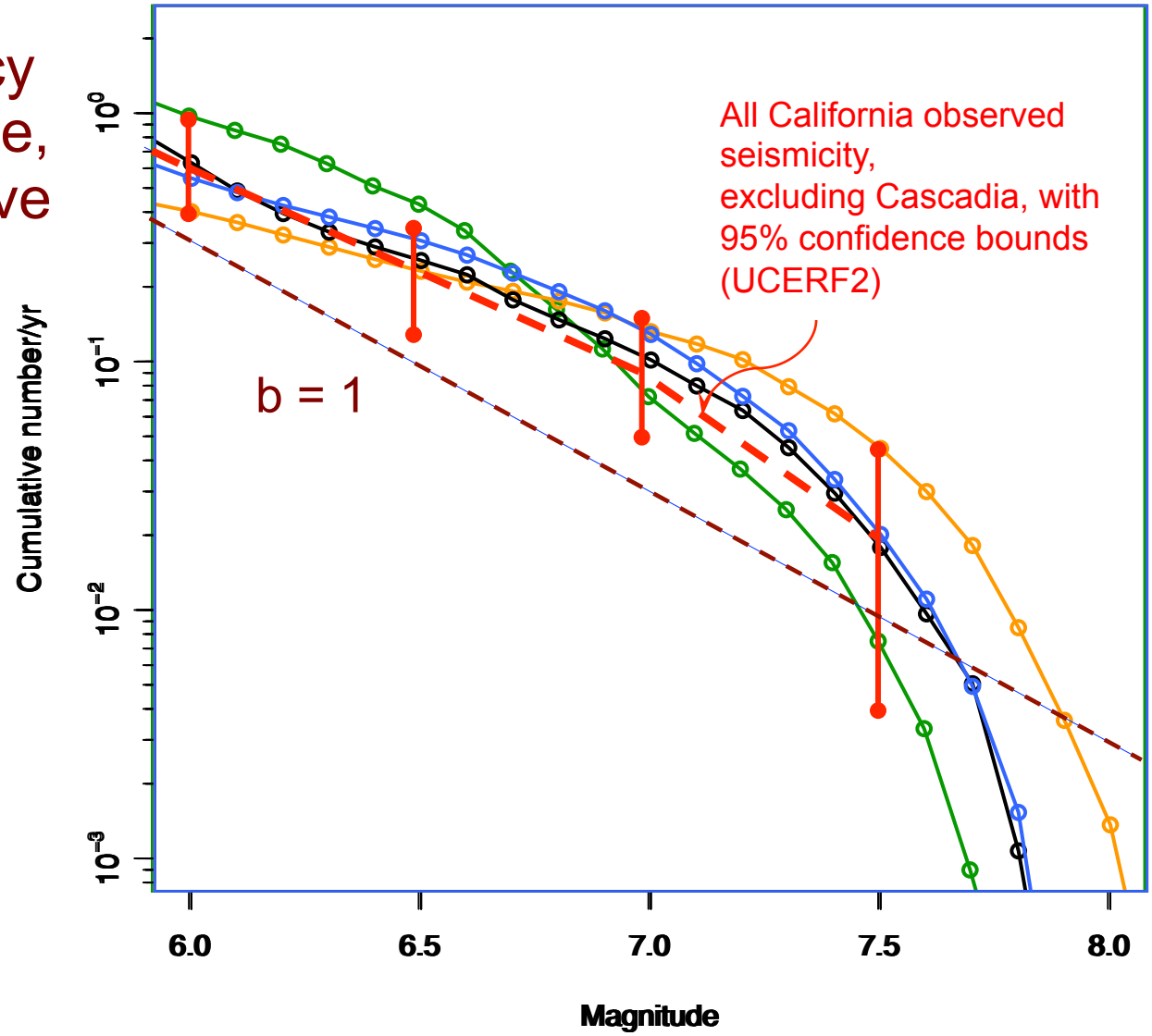
allcal2 Model

Essentially the UCERF2
Fault and Deformation Model



Our Entire California Fault System

Frequency Magnitude, Cumulative



ALLCAL

VIRTCAL

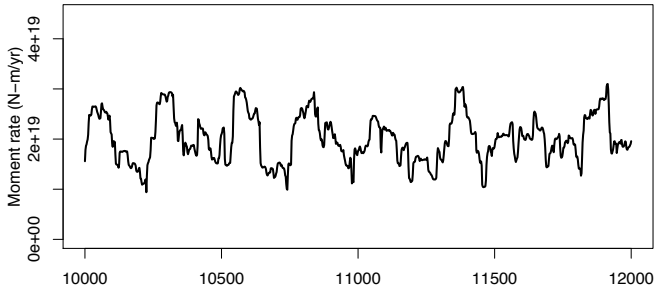
RSQSim

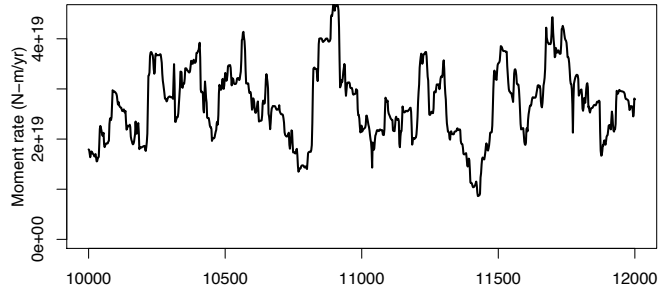
ViscoSim

allcal2

Moment and Event Rates – 100 yr moving averages

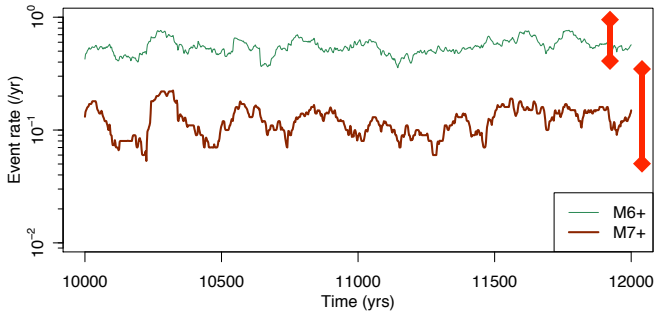
Red bars show observed 95 % confidence intervals for M6+ and M7+ from UCERF2

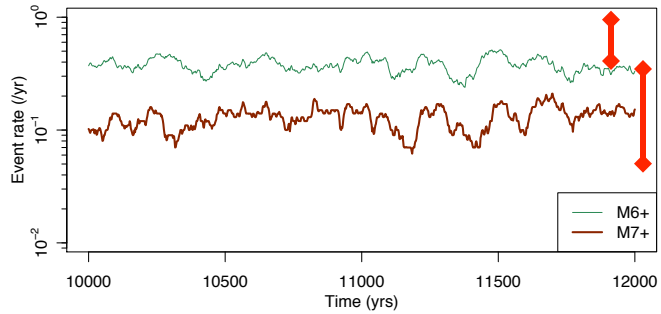




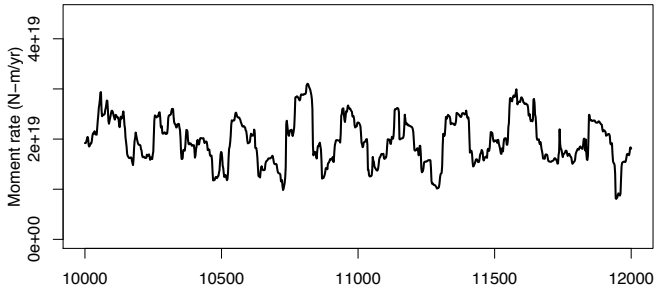
ALLCAL

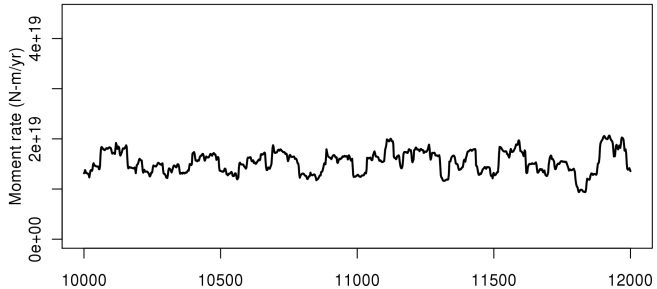
VIRTCAL





100 year averages of moment and M7 event rates vary by factor of 3

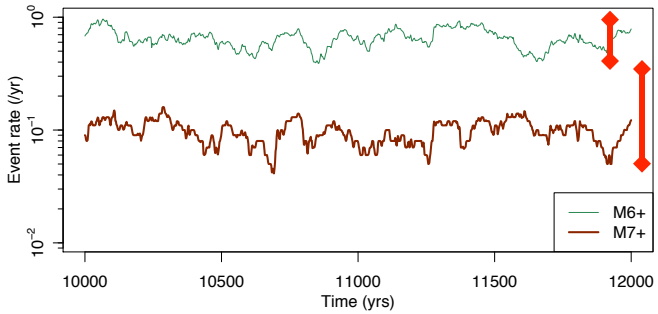


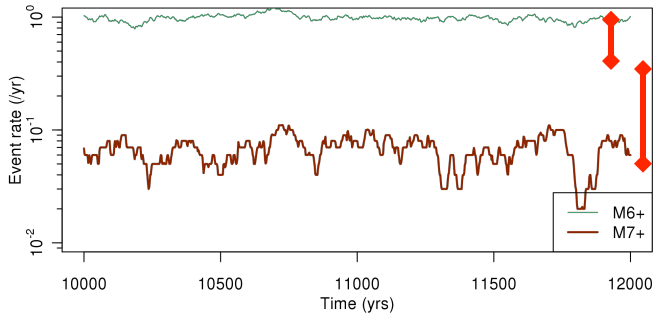


200 yr intervals can be found that differ significantly from other 200 yr intervals

RSQSim

ViscoSim



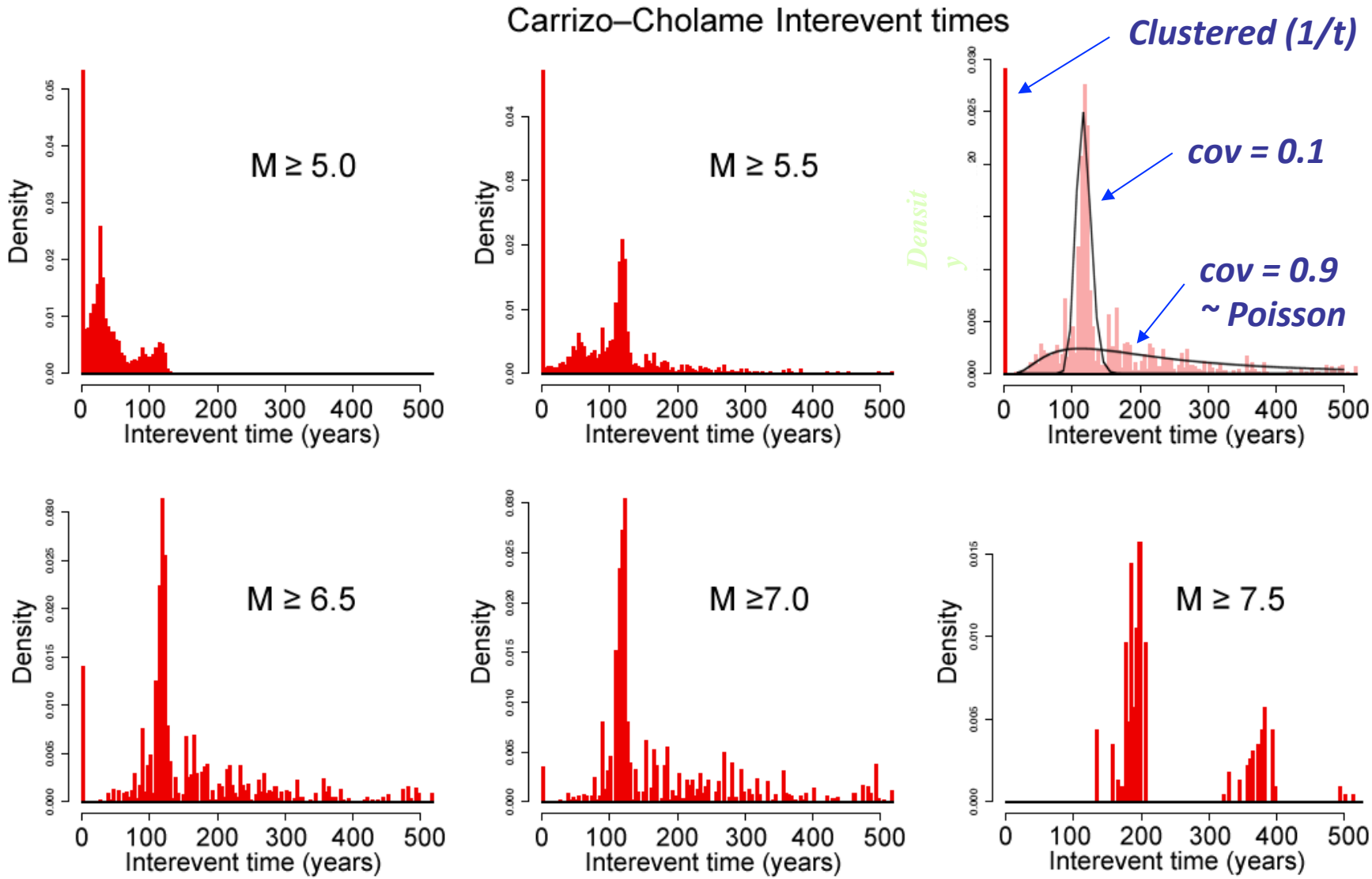


How to Deal with Off Fault Seismicity?

- On-fault seismicity may not follow Gutenberg-Richter scaling at lower magnitudes
- Could add seismicity on non-modeled, but known faults, and also background seismicity on unmapped faults, to supplement the modeled seismicity
- Such addition may be done in various ways:
  - Introduce background seismicity randomly in time with Gutenberg-Richter scaling, but spatially associated with modeled faults
  - Use the stresses associated with slip on the modeled faults, perhaps rough faults, to cause slip on faults inserted into the model or to cause distributed background seismicity, following rate and state friction predictions

PDFs Can be Obtained from Simulators

Statistics for recurrence of earthquake slip at a specific point from RSQSim



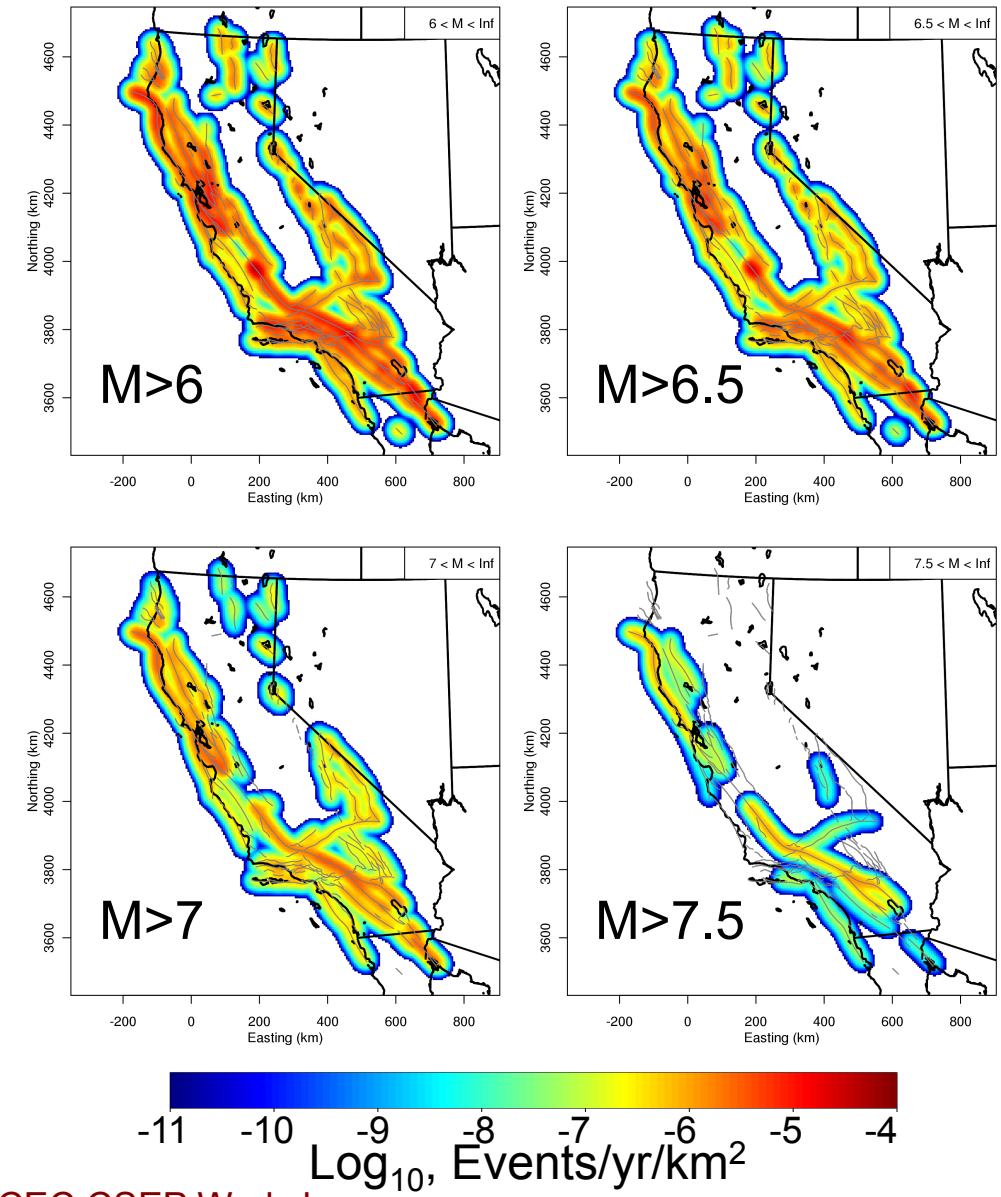
Earthquake Density Rates

Time-Independent Forecasts

These could be tested in CSEP except that the number of M6 events is too small to evaluate in a short time.

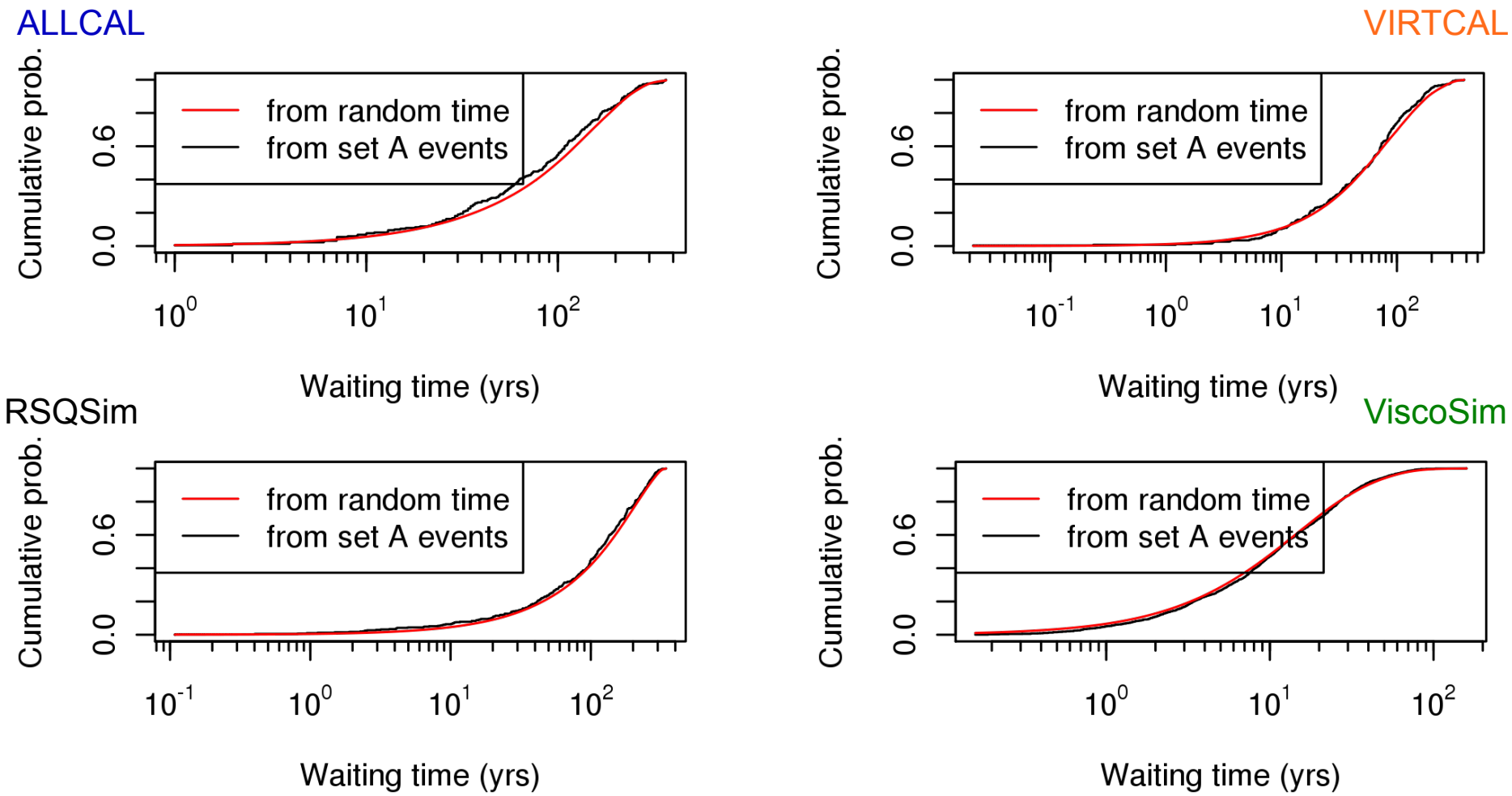
These were computed with 3 km square elements. Once the size is reduced enough, M4 or smaller events could be tested.

ALLCAL

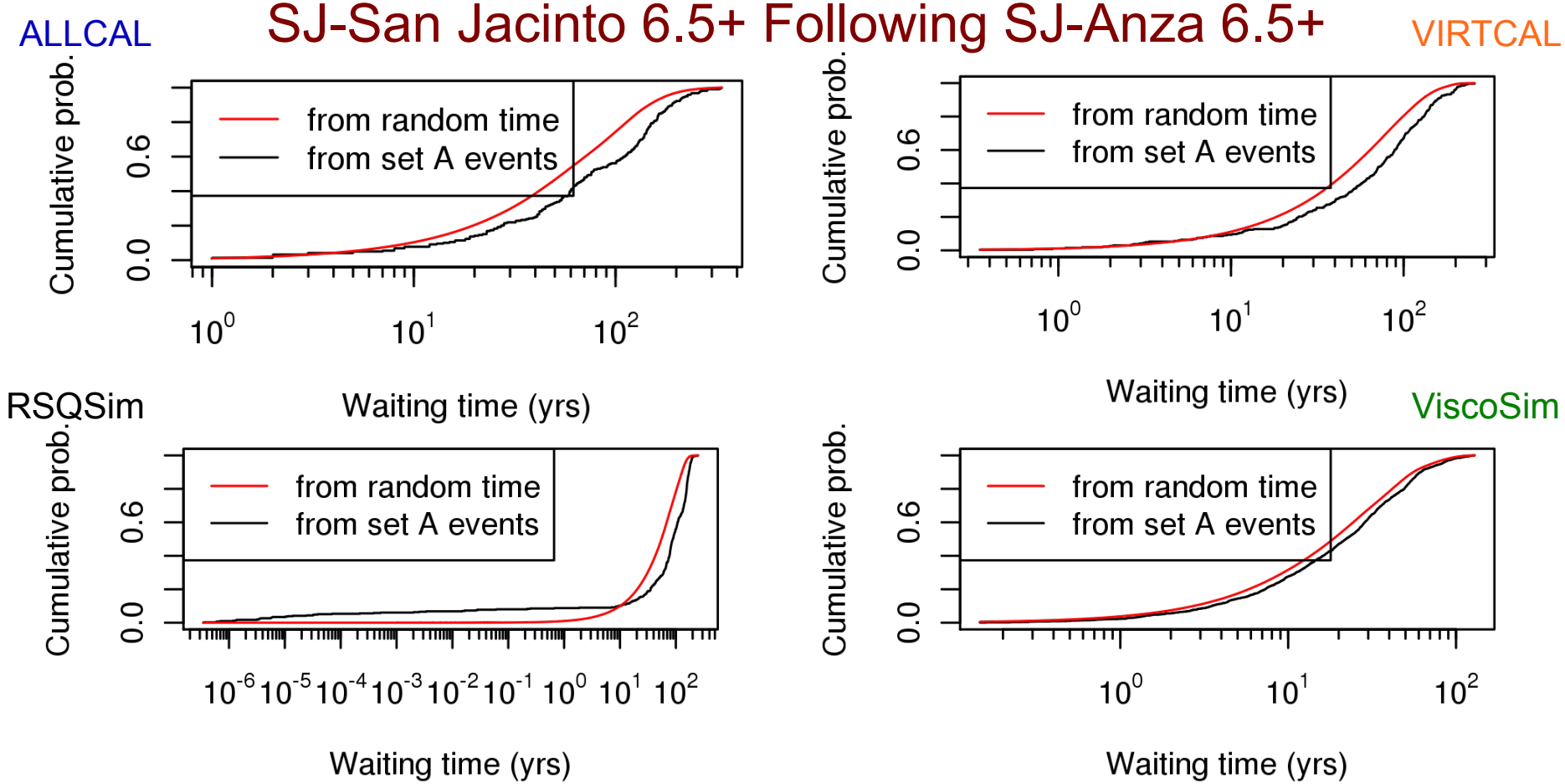


Time-Dependent Forecasts - Conditional Probabilities of One Event Following Another

Here Calaveras 6.5+ Following SJ-Anza 6.5+: No Causal Effect Expected (namely San Jacinto Fault – Anza Section are A events)

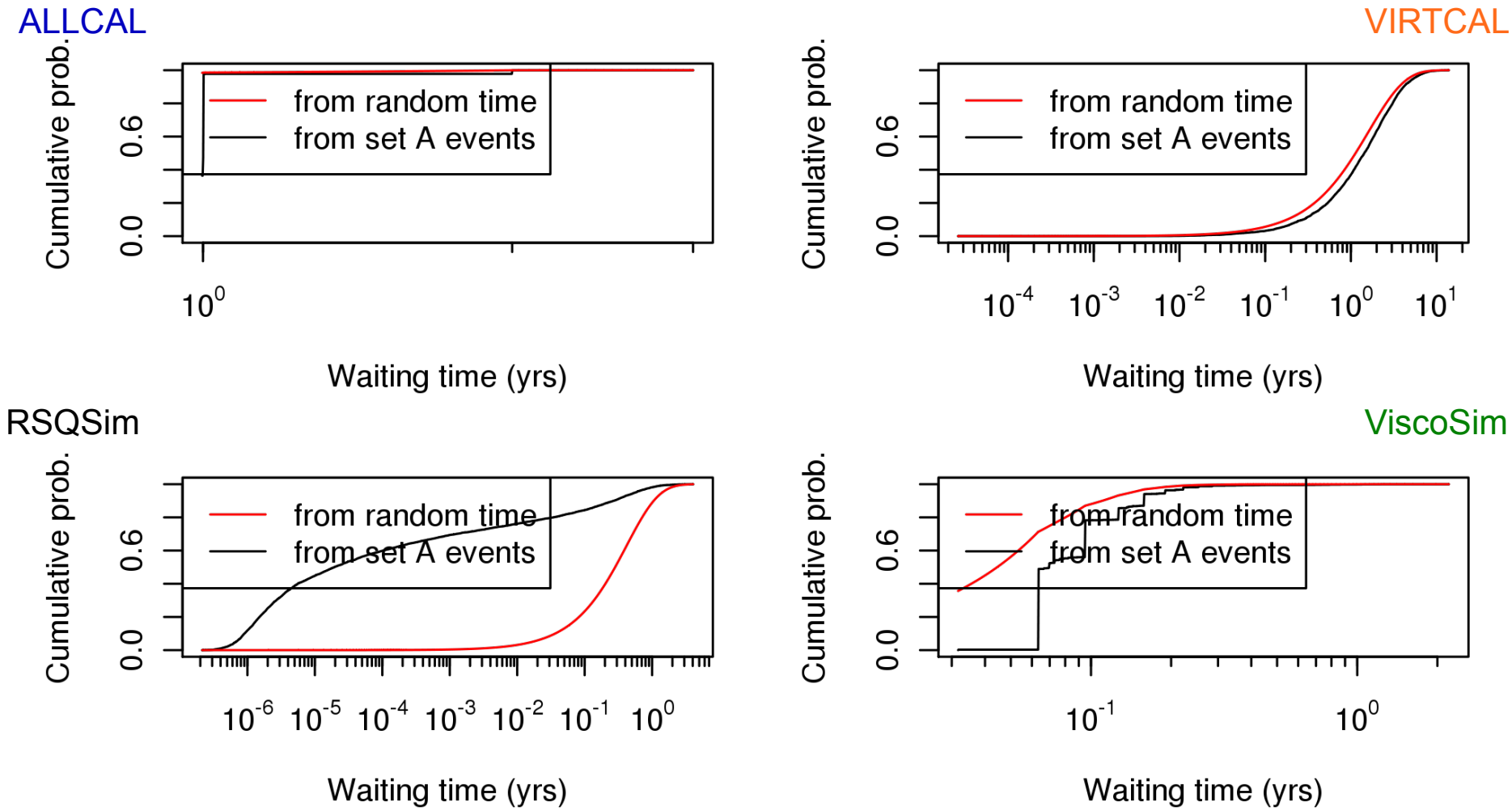


Conditional Probabilities of SJ-San Jacinto 6.5+ Following SJ-Anza 6.5+



Note that for RSQSim, the nonlinear behavior of Rate and State Friction results in increased probability of subsequent M6.5+ events for the 10 years following a M6.5+ event. For all simulators, from 10 to ~200 yrs subsequent events are less likely than for random occurrence.

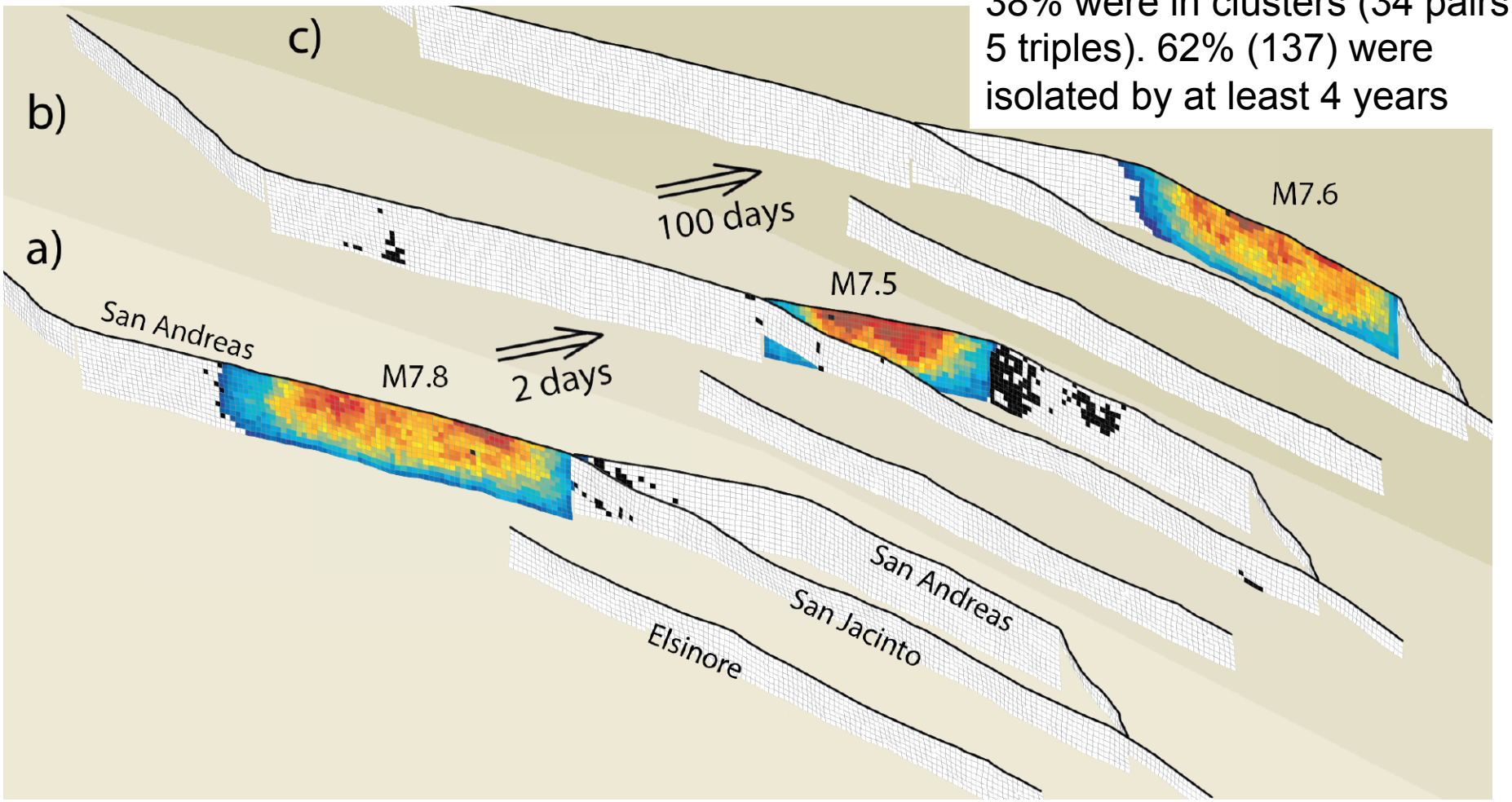
Conditional Probabilities of M5 Following M7



Note that RSQSim shows aftershocks due to Rate and State Friction

Time-Dependent Behavior in RSQSim

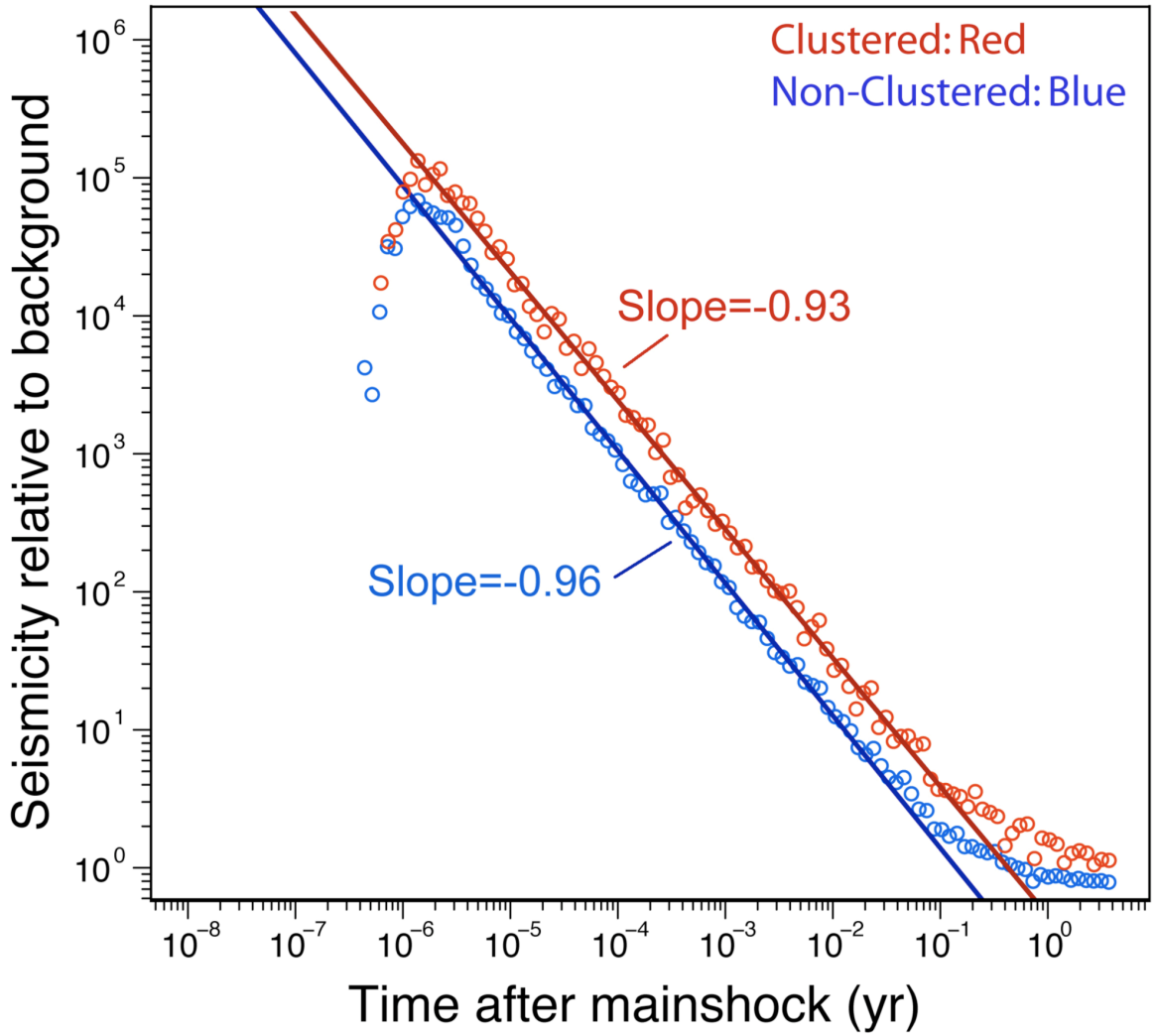
220 events > M 7: Within 4 yrs., one or more additional M7 events occurred. 38% were in clusters (34 pairs; 5 triples). 62% (137) were isolated by at least 4 years



There were 72 aftershocks in the 2-day interval between the M7.8 and M7.5 events and 183 aftershocks in the 100-day interval between the M7.5 and M7.6 events.

Time-Dependent Forecasts from RSQSim

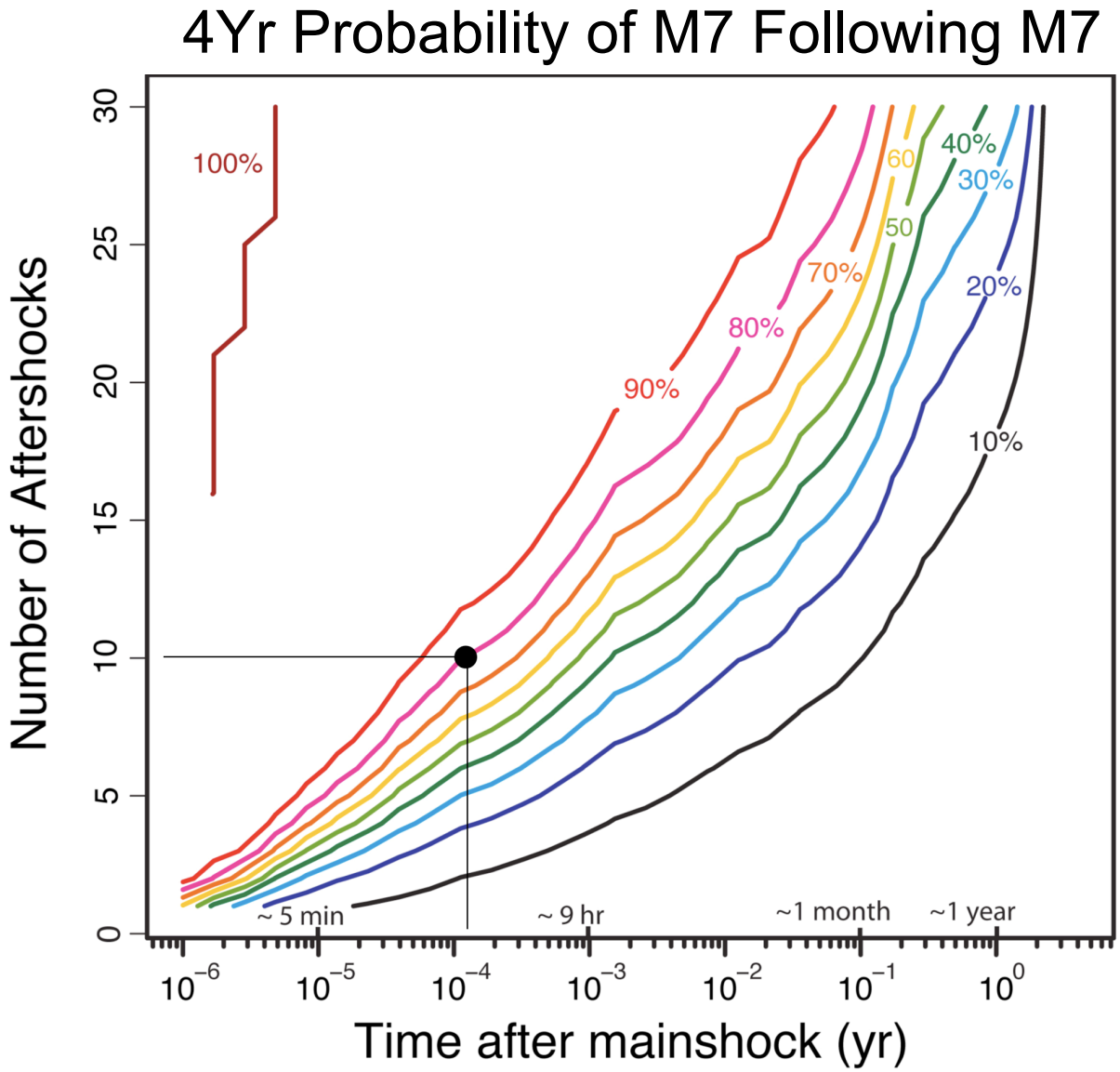
Increased Aftershocks For Clustered EQs



So the productivity of the aftershock sequence is connected to the occurrence of subsequent events.

Perhaps it is a measure of the stress state after the mainshock.

Time-Dependent Forecasts from RSQSim



So one can forecast the probability of occurrence of a subsequent event, based on the productivity of the aftershock sequence.

For example, if 10 aftershocks occur within 1 hour, there is 80% probability of another M7 within 4 years.

This is for 4 years after first M7 and for M7, but can do for other times and magnitudes.

Conclusions

- Many probabilities can be determined for simulators for which insufficient data on actual earthquake exists
- They can produce time-independent and time-dependent earthquake forecasts
- These could be formulated so as to be tested in CSEP
- Testing them beyond the temporal and magnitude range that is assessable in moderately sort term tests would be hard
- If confidence in them can be gained for smaller, more frequent earthquakes, then we should feel better about using them for longer time spans and larger events