Progress Report: Improving Estimates of the Southern San Andreas Fault Rupture History: More Data and New Methods

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Demands for supporting the Working Group on California Earthquake Probabilities required an unexpected amount of time. Summary of work completed:

1. Calculated recurrence parameters and probabilities for southern San Andreas fault (SSAF) sites with paleoseismic event dates. Estimates included paleoseismic dating uncertainty directly into the parameter estimates. These inputs were used by the Working Group. Contributed as co-author to Appendix B of the UCERF report.

2. Contributed paleoseismically informed rupture scenarios for the SSAF. Scenarios include quantitative estimates of segment involvement. The WGCEP characterization of the southern SAF in Appendix E of the UCERF 2 report derives in significant measure from this work.

3. Completed a manuscript, in press with BSSA, on linking paleoseismic evidence and developing rupture scenarios for the SSAF.

4. Developed a means to estimate event date pdfs for information indicating N events in M years.

5. Integrated the information of 4 events since ~AD 1420 of the Frazier Mountain record into southern SAF scenarios. Results indicate that the 1857 rupture was probably a representative earthquake that could occur 60 to 80% of the time.

Using Earthquakes Without Dates

Paleoearthquake series with bounding dates (time-bounded series) contain information useful to constrain fault rupture scenarios. Criteria for usefulness are that the interval be usefully bounded and complete:

Usefully Bounded: Dates bounding the interval define the time interval sufficiently that a correlation with adjoining sites may be admitted or rejected. Definite dates would typically qualify; inequality constraints such as “before AD 1200” typically would not.

Complete: The number of ground ruptures in the time interval is known and greater or lesser numbers of events are considered unlikely.

Approximations to both criteria are inevitable and must be considered on a case-by-case basis.

The preliminary Frazier Mountain paleoseismic record (Scharer pers. comm., 2007) is an example of a usefully bounded, probably complete record. In this case, preliminary dating results indicate four events counting 1857 ruptured the ground at Frazier Mountain since ~1420. The useful information in this record includes the number of events in the interval and, with less certainty, the average slip per event. At Frazier Mountain an average slip rate of 34 mm/yr * 588 yrs = 20 meters of total slip. In this total strain estimate we assume that the slip released in the oldest event is approximately replaced by strain accumulated since the most recent event in 1857. For the 1857 and three previous earthquakes to account for ~20 meters of slip, most and probably all would be considered significant events were they to occur today. In the above discussion, uncertainties in dating, slip rate could be included, but they would have little or no practical effect. This is because scenarios are evaluated on the basis of sums in the form of average time congruence or summed displacement (or both) over all ruptures (Biasi and Weldon, 2009). Uncertainties in the definition of one or a few ruptures have no separable expression in the scenarios in which they occur.

We developed a new means that allows us to construct event date pdfs with the limited information of the number of events in an interval. To proceed, we assume uniform prior event date distributions on the interval, here from AD 1420 to 1850. Ordering of the events is then applied as a Bayesian constraint. This leads to the results in Figure 1a. Ordering among events separates the mean date estimates for the penultimate and fourth events by over 200 years. A hypothetical case with five events in ~1350 to 1857 AD is shown in Figure 1b. Note that while the information of ordering among events separates event mean dates, it does not eliminate possible outcomes such as short interseismic intervals, but only reduces their probability consistent with the prior uniform distributions. If more information about the dating is available (e.g. “the oldest event is near the oldest age constraint”), then the uniform prior distribution could be revisited.

Event date pdfs from time-bounded records may be used directly to improve rupture scenarios. Event pdfs are added just like other paleoseismic chronologies to the “pearl-stringing” algorithm (Biasi and Weldon, 2009). To add the Frazier Mountain data, three ruptures before 1857 are available for “stringing”. A representative good fitting scenario from a pool of 500 is shown in Figure 2. Symbol “FR” is located at the milepost of the Frazier Mountain site. An “earthquake-free” period before the fourth earthquake and after AD 1300 is used (green line centered on FR), to approximately account for time in the trenches below the fourth earthquake in which no fifth earthquake was noted. This scenario uses the more recent event dates developed for the Bidart site in the Carrizo Plain (Aksiz et al., 2008; site at “CP” label, Figure 2) in which the most recent five events occur since the mid-1200’s. Other site chronologies are as in Weldon et al. (2008).

Results in Figure 2 are representative of the good-fitting scenarios that include the young Carrizo record and the new Frazier event information. This example has an average displacement misfit compared with the WGCEP slip-rate model 2.1 of about 1.9 meters (Figure 2, lower, solid line, is the sum of displacements, compared to predictions of total slip since AD 1100 shown as “X”s.) Four of the most recent five events from Bidart (CP)

rupture correlate with Frazier Mountain ruptures, and three ruptured at least as far as Pallett Creek (PC). It is not clear whether the long-term recurrence rate at Bidart will be so short as implied by the most recent few events, but at present it appears that events may have been relatively larger than would be expected from the recurrence time alone. Scenarios that fit the total displacement prediction ("X"s) well have to account for the total with relatively few earthquakes, based on the paleoseismic record. As a result, we conclude that the present paleoseismic record favors semi-characteristic ruptures, of which 1857 would be a member, approximately 60 to 80 percent of the time.

This conclusion would need to be revisited if more events are identified at Bidart in the post-1100 AD period, or if a much shorter recurrence interval at Frazier Mountain is confirmed. The selection of "good-fitting" scenarios would also change if the average displacement of ruptures does not increase with rupture length. That is, if a long rupture and a short one could equally have large average displacements, then displacement totals could be achieved by short ruptures laid end-to-end. Arguing against this, however, is the fact that many more earthquakes would be needed to maintain the displacement rate on the fault. This would make even less likely the 151-year hiatus since the last significant southern San Andreas fault earthquake.

By way of more general conclusions, results show that spatial sampling is greatly improved by the new Frazier Mountain site. Even preliminary data are helpful. Efforts at Frazier Mountain and elsewhere to fill in between Carrizo and Pallett Creek will improve characterization of the largest ruptures on the southern SAF. Deeper records at Carrizo will also be important to constrain rupture style and timing. Finally, the Average Displacement-Length scaling relationship is important; smaller AD for a given rupture length would admit more good-fitting scenarios and broaden the range of possibilities for the most recent southern SAF history.

Publications:

Dawson, T., Weldon, R., Biasi, G. P. (2007 to WGCEP, final 2008). Appendix B, Recurrence Interval and Event Age Data for Type A Faults, in The Uniform California Earthquake Rupture Forecast, Version 2 (UCERF 2), *California Geological Survey Special Report 203 and USGS Open File Report 2007-1437*, April 2008. Appendix B summaries available recurrence interval and event age data for large faults with paleoseismic data constraining the recurrence interval. Provided the southern San Andreas fault paleoearthquake dates and recurrence interval estimates.

Weldon, R., Biasi, G. P., Wells, C., Dawson, T. (2007 to WGCEP; final 2008). Appendix E, Overview of the Southern San Andreas Fault Model", The Uniform California Earthquake Rupture Forecast, Version 2 (UCERF 2), *California Geological Survey Special Report 203, and USGS Open File Report 2007-1437*, April 2008. Appendix E is an overview of the southern San Andreas fault model used for the UCERF-2. Provided paleoseismic rupture scenarios and activity rates for single and multiple-segment SAF earthquakes.

Scharer, K. M., Weldon, R. J., Fumal, T., Biasi, G. P. (2007). Paleoearthquakes on the southern San Andreas fault, Wrightwood CA, 3000 to 1500 B.C.: a new method for evaluating paleoseismic evidence and earthquake horizons. Bulletin of the Seismological Society of America, 97(4), 1054-1093, doi: 10.1785/0120060137.

Biasi, G. P. and Ray J. Weldon II (in press, scheduled April 2009). San Andreas Fault Rupture Scenarios From Multiple Paleoseismic Records: "Stringing Pearls" Bulletin of the Seismological Society of America, 99.

Captions

Figure 1: (a) New results showing how information of N events in M years is translated into event date pdfs. Here the preliminary Frazier Mountain record indicates four events in the interval ~1420 to 1857. The dashed lines indicate prior date distributions. Posterior date pdfs are solid lines. Dates under event names indicate the prior and order-constrained mean dates. Rough event dates can be valuable for constructing scenarios of SAF rupture. (b) Similar plot, but showing a hypothetical five events in ~1350 to 1857 AD.

Figure 2: Example scenario showing the location and consequences of the preliminary data at Frazier Mountain. In this scenario all four Frazier events correlate with Carrizo events. Displacement summed over all ruptures in the scenario is shown as a solid line in the lower half of the figure. Predicted slip ("X"s) using slip rates from WGCEP model 2.1 and time since AD 1100 are used as a fitting standard. Except for the Coachella section (south of milepost 470) the displacement fit is good, with a mean misfit of 1.9 meters.

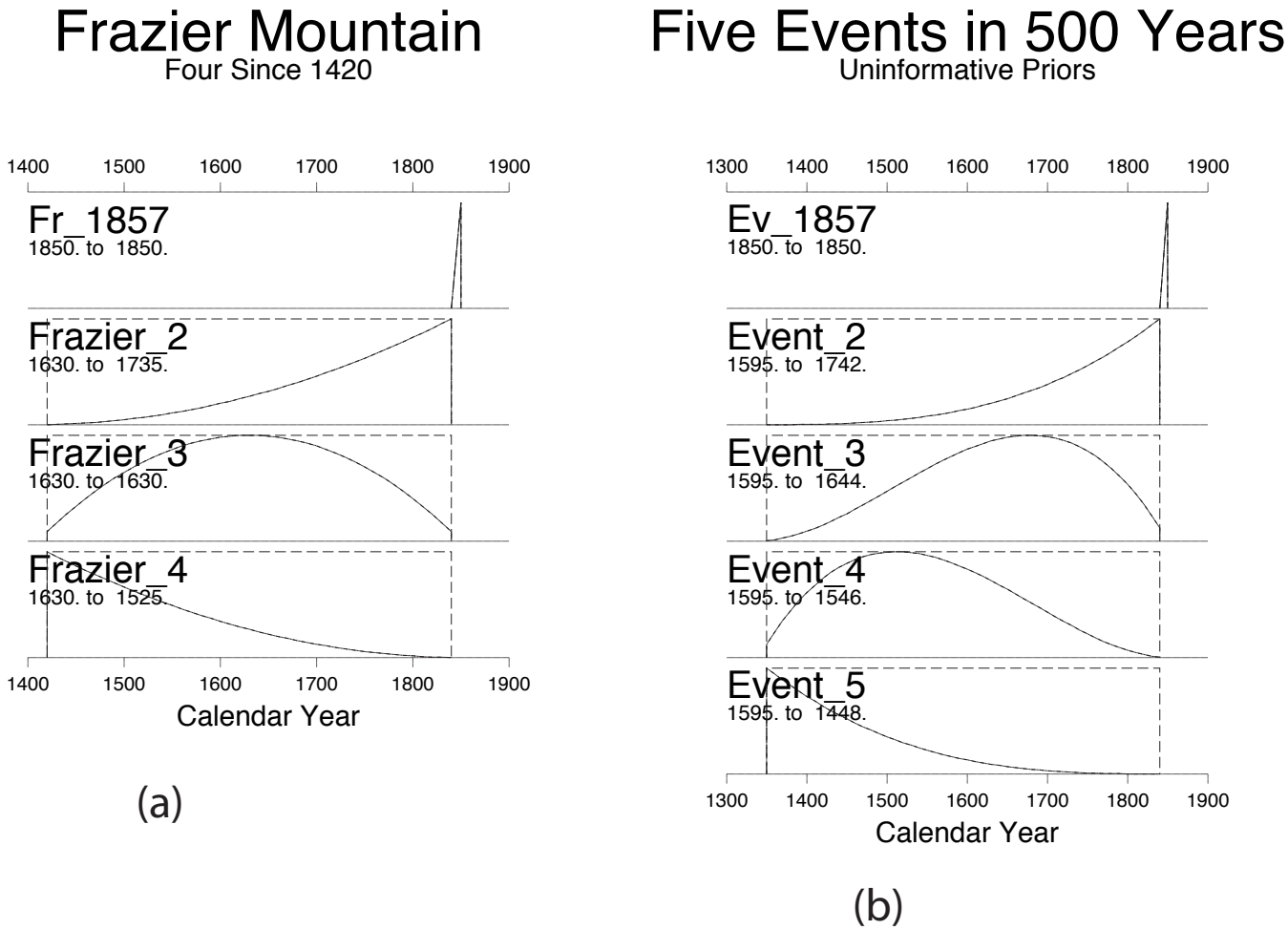
Frazier Mountain
Four Since 1420
1400
1500
1600
1700
1800
1900
Fr_1857
1850. to 1850.
Frazier_2
1630. to 1735.
Frazier_3
1630. to 1630.
Frazier_4
1630. to 1525.
Calendar Year
(a)
Five Events in 500 Years
Uninformative Priors
1300
1400
1500
1600
1700
1800
1900
Ev_1857
1850. to 1850.
Event_2
1595. to 1742.
Event_3
1595. to 1644.
Event_4
1595. to 1546.
Event_5
1595. to 1448.
Calendar Year
(b)

Figure 1

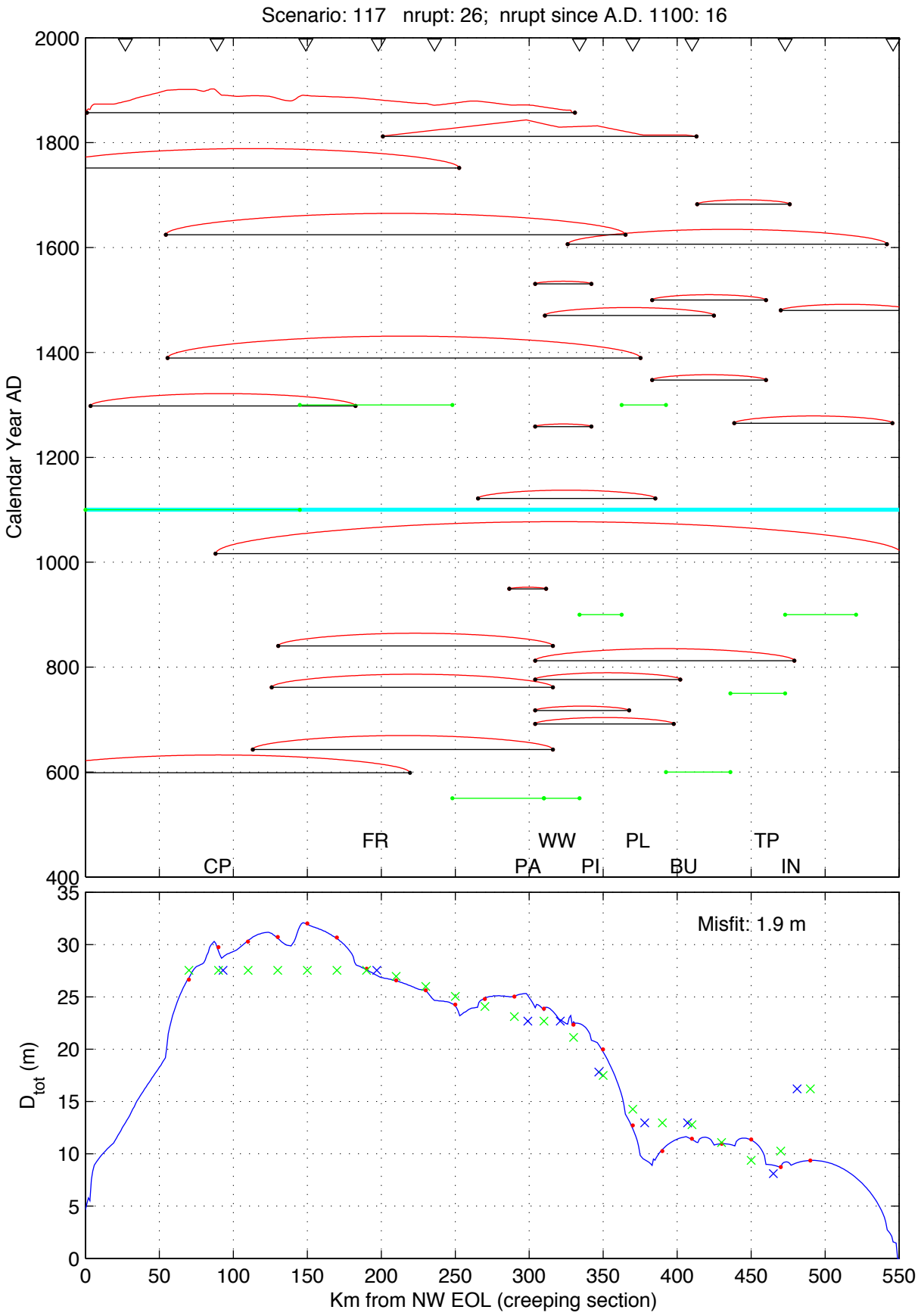
Scenario: 117 nrupt: 26; nrupt since A.D. 1100: 16
Calendar Year AD
2000
1800
1600
1400
1200
1000
800
600
400
CP
FR
PA
WW
PI
PL
BU
TP
IN
Misfit: 1.9 m
D_{tot} (m)
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400
450
500
550
Km from NW EOL (creeping section)

Figure 2