The June, 2005 Anza/Yucaipa Southern California Earthquake Sequence: Distant Triggering by Moderate Mainshocks

For more information on the Anza sequences see the Scripps website by Kris Walker, Debi Kilb, and Guoqing Lin

http://eqinfo.ucsd.edu/~dkilb/anza_2001_2005.html

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On June 12, 2005, a M_W 5.2 earthquake occurred on the San Jacinto fault system near the town of Anza and was felt throughout Southern California. Two subsequent events appeared unusual. The first was an elongated cluster of aftershocks along the San Jacinto Fault zone. This raised early speculation that aftershocks were triggered by an aseismic creep event along the San Jacinto. A creep event at depth has now been observed, with an estimated moment equivalent to that of an M 5.0 earthquake (Agnew and Wyatt, 2005). Whether or not this creep event is unusual, and thus whether it could have created an unusual aftershock sequence, is not known, as a lack of instrumentation elsewhere has prevented similar observation. Aseismic afterslip at the surface is routinely observed, and aseismic slip below the surface was inferred after Loma Prieta (Segall et al. 2000). An alternative explanation for the elongated sequence is that aftershock sequences are always this long -- they just usually cannot be observed. The Anza mainshock occured in the middle of the densely instrumented Anza seismic array, which detected a high percentage of small earthquakes. A close look at the data and simulations support this hypothesis.

The other potentially unusual event was the occurrence of a M_W 4.9 earthquake 4 days after the Anza mainshock, 72 km away. There is less than a 2% probability that this earthquake was a random event; over the past five years (2000-2005) there have been only 8 M > 4.9 earthquakes in Southern California. Is it plausible that a M 5.2 earthquake could have triggered another earthquake over 70 km away? Static stress changes are negligible at such distances, but dynamic stress changes are not. Using M 5-6 mainshocks from throughout California, we demonstrate that triggering can occur out to several hundred kilometers at high statistical significance, corroborating clustering statistics by Ebel and Kafka (2002). On average, at distances over 70 km, within a time period of 4 days, we expect a M 5.2 earthquake to trigger a M > 4 earthquake about 21% of the time and to trigger a M > 4.9 earthquake about 3% of the time.

References

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Aftershock sequence of the 12 June MW 5.2 Anza

Observations

Fault length of Anza 2005 mainshock: ~ 4 km

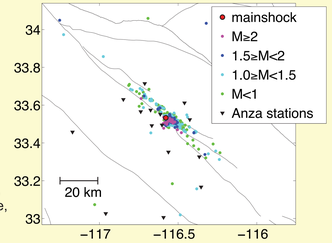
Expected aftershock sequence length:~ 4 - 8 km

Observed aftershock sequence length: ~ 50 km

The silent slip hypothesis: A long aseismic slip event triggered the aftershocks

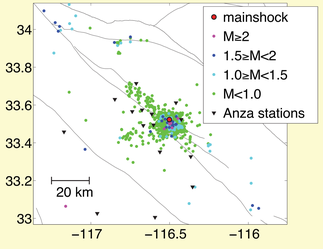
The network hypothesis: Aftershock sequences are often this long. Extraordinarily good seismic station coverage (the Anza network) simply allowed us to see many more small aftershocks than usual. Note how the aftershocks are bounded by the Anza stations, and how the M > 1.5 earthquakes, the smallest we would usually see, define a normal aftershock zone **(RIGHT)**.

First four days of Anza 2005 aftershocks



Southern California Seismographic Network Catalog

First four days of Anza 2001 aftershocks



Anza Seismic Network Catalog

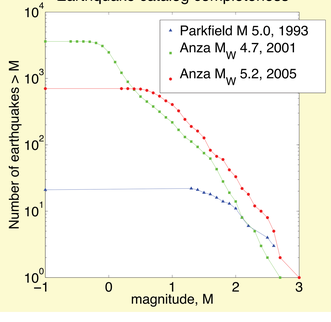
Evidence for the network hypothesis, I:

The Anza network catalog contains a similarly extended aftershock sequence for the M_W 4.7 2001 Anza earthquake, which nucleated 6 km to the SE. Note again how the extended aftershock sequence is bounded by the Anza seismic network, and how, if only the larger aftershocks could be seen, the extent of the sequence would appear to be much smaller (LEFT).

Evidence for the network hypothesis, II:

The Anza network clearly provides better detection of small aftershocks than is normally seen in California. Even the Parkfield network, which is also well instrumented, has not recorded as many aftershocks. At RIGHT are magnitude frequency plots for the aftershocks of the 2005 Anza earthquake (in red) from the SCSN catalog, aftershocks of the 2001 Anza earthquake (in green) from the Anza catalog, and aftershocks of the1993 M 5 Parkfield earthquake (in blue) from the Northern California Seismic Network catalog. The sequence with the best small earthquake detection (Anza 2001) also covers the most area (ABOVE).

Earthquake catalog completeness



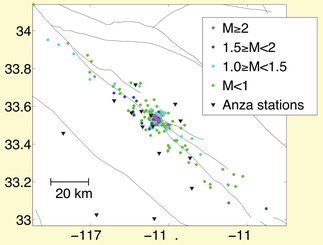
Simulations

Evidence for the network hypothesis, III:

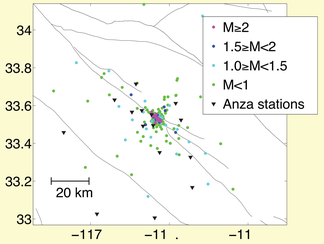
Felzer and Brodsky (2005) found an empirical relationship for how M>2 aftershock decay with distance from M 2 -4 Southern California mainshocks. Using the parameters from their data set, we project what an aftershock sequence of an M 5.2 mainshock would look like if we could see down to M 0.5 (the smallest aftershocks seen in the 2005 Anza aftershock sequence.) The simulated aftershock sequences cover a wide area.

In the top simulation aftershocks are only allowed to occur within 10 km of the SJF; in the bottom plot aftershocks may occur anywheres.

Simulation, Aftershocks ± 10 km of SJF

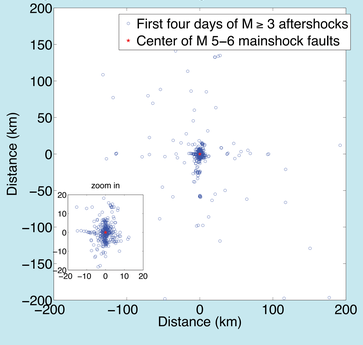


Simulation, Random receiver faults



Triggering of the Yucaipa earthquake

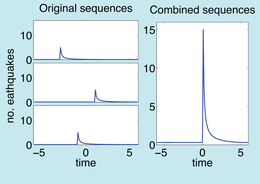
The 33 mainshock and aftershock sequences are plotted together, centered at the origin



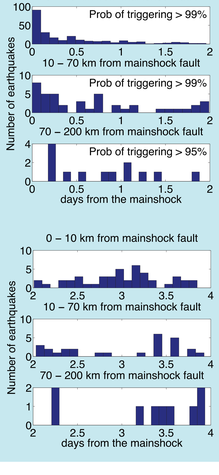
Data Set

To investigate whether the 2005 M_W 5.2 Anza mainshock could have triggered the M_W 4.9 Yucaipa earthquake over a distance of 70 km, we test for statistical evidence that M 5-6 earthquakes are capable of triggering at distances this large. For our data set we use 33 M 5-6 mainshocks from throughout California, from 1984-2004. These mainshocks were chosen because they were not preceded by larger mainshocks within at least 25 days and 500 km, and because they had clear fault plane solutions.

The 33 aftershock sequences were combined in time and space by rotating all of the fault planes to N-S strike and 90 degree dip, and then co-locating the centers of the mainshock faults in space (LEFT) and time (schematic at RIGHT). The combined aftershock sequences are then inspected for triggering at different distances by looking for a peak in seismicity right after the mainshocks (see BELOW LEFT).



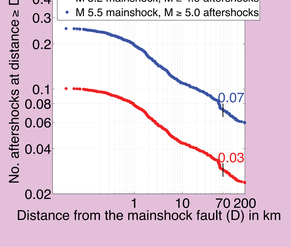
Statistical Analysis



We make histograms of the timing of earthquakes at different distances from the M 5-6 mainshocks. Aftershock triggering is characterized by a heightened rate right after the mainshock (at time zero) followed by a decay. We test for statistical signifcance of a decay by measuring the correlation coefficient of the number of earthquakes vs. time. The more significant (and negative) this coefficient is, the higher the probability of triggering. The temporal decay of seismicity is most obvious for the closest distance range (0-10 km), but is still more than 95% signifcant at dstances > 70 km (the range at which the Yucaipa earthquake was triggered) (LEFT, TOP).

As a control case we also look at the temporal distribution of earthquakes occurring 2-4 days after the mainshocks. If we are looking at aftershock triggering these earthquakes should also be decaying with time, but since they are further from the time of the mainshocks, the effect should be much more subdued. In this case decay is very difficult to detect, and is not statistically significant (LEFT, BOTTOM).

Conclusions

We find evidence that the spatially extended aftershock sequence of the Anza earthquake simply represents a normal aftershock sequence recorded extraordinarily well by the dense Anza seismic network. Extrapolation from measurements of larger aftershocks throughout California indicate that the aftershock sequence of an M 5.2 earthquake should appear at least 50 km long if many aftershocks M 0.5 to 1.5 can be recorded. The extraordinary ability to see small aftershocks at Anza validates this extrapolation and the Felzer and Brodsky (2005) aftershock model.

We cannot prove whether the M 4.9 Yucaipa earthquake, occuring 4.2 days and 70 km from the Anza mainshock, was triggered by the Anza earthquake. By combining the aftershock sequences of other M 5-6 California earthquakes, however, we find statistical evidence that triggering at distances over 70 km does occasionally occur. From the combined aftershock sequences of 33 M 5-6 earthquakes we plot empirical curves of how many aftershocks occur at different distances per mainshock, within a 4 day time period (RIGHT). Curves are based on measurements made for M>3 aftershocks, corrected to different aftershock and mainshock magnitudes via empirical scaling relationships (see Felzer et al., 2004). The results indicate that the Anza earthquake had an a priori 3% probability of triggering a M 4.9 at Yucaipa -- small, but not insignificant.