Comment on “A model of earthquake triggering probabilities and application to dynamic deformations constrained by ground motion observations” by Joan Gomberg and Karen Felzer

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[1] *Felzer and Brodsky* [2006] argued that a uniform power law distance-decay of aftershock density to 50 km from small main shocks provides evidence that aftershocks are triggered by dynamic stress, since static stress would be negligible more than a few kilometers from the main shocks. This study was succeeded by *Gomberg and Felzer* [2008], which extended the analysis. Figure 1 of *Gomberg and Felzer* [2008], reproduced here as Figure 1a, is presented to show that the decay of seismicity density from main shocks “is a constant over distances spanning a fraction of a main shock fault length to hundreds of main shock fault lengths, at least out to absolute distances of 50–100 km” (paragraph 6). *Gomberg and Felzer*’s [2008] Figure 1 caption states that “All aftershocks are M > 2 and occur in the first 5 min after their main shock; the short time window separates aftershocks from unrelated background earthquakes.” But inspection of the *Felzer and Brodsky* [2006] source panels for Figure 1 indicates that the circles are actually the first 2 days of M ≥ 3 aftershocks. Apart from the mislabeling, rescaling the aftershock density from 2 days to 5 min is too uncertain to make the compatibility argument advanced, and the restricted ranges of the two data sets give an appearance of continuity that is inconsistent with the full data.

[2] *Gomberg and Felzer*’s [2008] Figure 1 is shown with the line, shaded rectangles, and labels removed in Figure 1b. The caption to their Figure 1 states that “[t]riangles and circles are for M2–3 and M5–6 main shocks, respectively. Note that we plot only a subset of aftershocks in each magnitude range, retaining only aftershocks of M5–6 main shocks at $r < 3$ km and of M2–3 main shocks at larger distances. This highlights the continuity in densities across the transition from near-field to far-field, which occurs at about $r \approx D \approx 3$ km for the M5–6 main shocks.” This statement is also incorrect; the circles are aftershocks of M5–6 main shocks out to 12 km, and thus the data overlap over 3–12 km, and so cannot highlight the absence of an offset across a 3 km boundary.

[3] As *Gomberg and Felzer* [2008] state, the data in Figure 1 come from *Felzer and Brodsky* [2006]. It appears that Figure 1 combines data from Figure S5 of *Felzer and Brodsky* [2006] (shown here as Figure 1c) with data from Figure S1a from *Felzer and Brodsky* [2006] (shown here as Figure 1d). The points just outside of the selected ranges are inconsistent with the claimed continuity; the data are windowed so that outliers at distances greater than 10 km in Figure S5, and a change in slope of the data between 80 and 100 km in Figure S1, are excluded from *Gomberg and Felzer*’s [2008] Figure 1.

[4] For use in Figure 1 of *Gomberg and Felzer* [2008], the seismicity densities of the M5–6 data need to be rescaled by the aftershock magnitude difference (a factor of about 10 for a Gutenberg-Richter *b* value of 1), the relative number of main shocks in the two data sets (a factor of 821), and the observation that larger main shocks produce more aftershocks (a factor of about 0.001, based on the work by *Felzer et al.* [2004]); together these three factors come to about 8.2. But since aftershock frequency, and thus density, decays rapidly with time, rescaling Figure 1c from 2 days to 5 min also depends on the Omori *c* delay and *p* decay exponent, in which earthquake frequency is proportional to $(c + t)^{-p}$, where *t* is time. Table 3 of *Felzer et al.* [2003] lists a range of observed *c* delays (1 s to 2 h) and *p* exponents (0.75–1.37). The net scaling could thus range over 0.08 to 8.21 (see Table 1 and Figure 1b). *Felzer and Kilb* [2009] use $p = 1.34$ and $c = 2$ h in their simulations for a southern California M = 5.2 main shock, which would result in a factor of 0.16, much smaller than the value of 1.0–1.3 used in their Figure 1. *Kagan and Houston* [2005] find $c = 60$ s, and *Peng et al.* [2007] find a $c = 20$ s, the shortest estimates yet obtained; even for this narrower range, the factor could span 0.66–6.6, too uncertain to argue for continuity in seismicity density decay with distance.

[5] *Gomberg and Felzer* [2011] reveal that only 9 of the 35 M5–6 main shocks that met their stated time and distance selection criteria are shown in Figure 1 (and so this is also true for *Felzer and Brodsky* [2006, Figures 3 and S5]) because the others “did not have well-located and well-defined fault planes.” The exclusion of 80% of the aftershocks (399 out of 503), combined with the absence of identification of main shocks that were selected, makes the M5–6 portion of *Gomberg and Felzer*’s [2008] Figure 1 irreproducible.

[6] *Gomberg and Felzer* [2011] state that unlike the approach in this paper, “the decay rate can be measured

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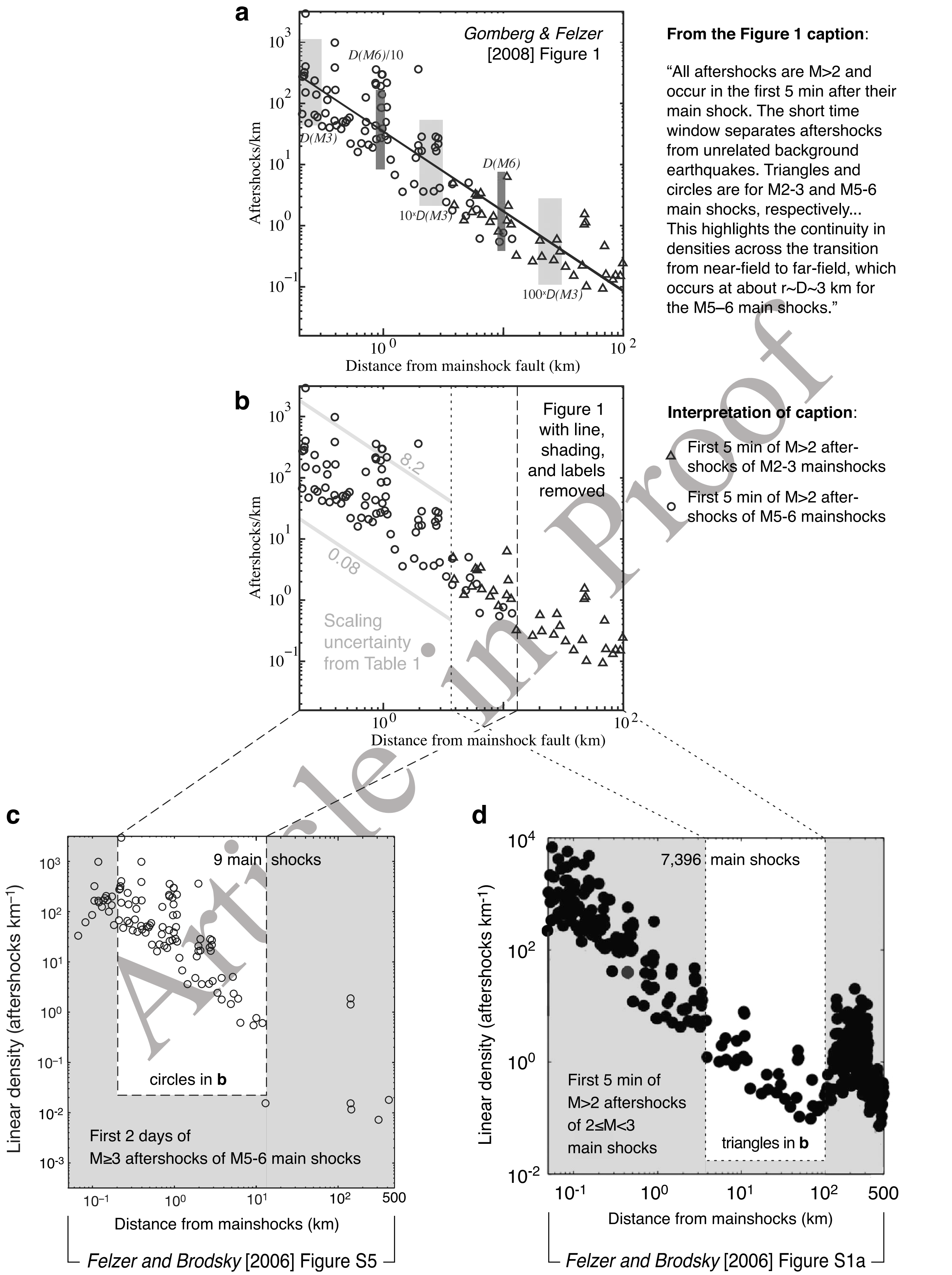

Figure 1. (a) Figure 1 from *Gomberg and Felzer* [2008]; (b) the rescaling uncertainty of the M5–6 data from Table 1. (c and d) from *Felzer and Brodsky* [2006], screened and annotated to show which portions of the data are used in Figure 1 of *Gomberg and Felzer* [2008].

Table 1. Required Rescaling for Figure 1 of *Gomberg and Felzer* [2008]

Parameter	Data Used	Converted to	Conversion Factor
Aftershock magnitude	M ≥ 3	M ≥ 2	~10
Number of main shocks	9	7,396	821
Main shock magnitude	M5–6	M2–3	~0.001
Period (depends on Omori *c* and *p*)	2 day	5 min	~0.01–1.0
Seismicity density rescaling[a]			0.08–8.2

[a]Seismicity density rescaling equals aftershock magnitude times number of main shocks time main shock magnitude time period.

directly from the data," but this is not what they do. First, they use the 399 aftershocks that they rejected from Figure 1, and find that out of the 503 recorded in the first 2 days, 13 struck in the first 5 min. Then, they multiply 13 by 3.8 because of early aftershock incompleteness, and thus claim "that there were likely really a total of ~50 M ≥ 3 aftershocks in the first 5 min." While they use an estimate for the magnitude of completeness as a function of time since the main shock from *Helmstetter et al.* [2005] to estimate the number of missed aftershocks, this must be coupled with Omori *p* and *c* parameters to arrive at a multiplier, which according to *Felzer et al.* [2003] are highly uncertain. They do not state what Omori parameters they used, and their 95% confidence intervals on the scaling factor do not consider any contribution of the multiplier, rendering it a severe underestimate.

[7] Finally, in the last three paragraphs of *Gomberg and Felzer* [2011], they claim to reproduce the calculations made for period in Table 1, but they use a narrower range of Omori parameter uncertainty than is found by *Felzer et al.* [2003]. They advocate for a 1.3 (−0.3 ± 0.4) scaling factor but do not correct their Figure 1. They also claim that "only total aftershock sequence parameters appropriate to early times after the main shock should be used." This contradicts the central contention of *Felzer and Brodsky* [2006] that all events within the first 5 min (or 2 days) are direct aftershocks of their main shocks, which is why Felzer and Brodsky take the triggering distance to be the main shock–aftershock separation, not the closest distance between two aftershocks. If, instead, the published uncertainties are honored, the 5 min and 2 day data sets are too incompatible to be described by *Gomberg and Felzer* [2008] as continuous.

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