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Comment on "Tidal synchronicity of the 26 December 2004 Sumatran earthquake and its aftershocks" by R. G. M. Crockett et al.

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[1] *Crockett et al.* [2006] report a striking coincidence of some of the larger recent earthquakes around the Sunda/Andaman/Java trench regions with the times of the full and new moon. However, it may be worth noting that the results contradict nearly all previous studies and theoretical expectations, and the statistics invoked have some problems.

[2] Two flavors of earthquake-tide correlations have been sought, with either the diurnal stress variations or the biweekly modulations in the amplitude of the stress envelope. A correlation with both tidal periods has occasionally been noted in the case of seismicity just below the ocean floor at mid-ocean ridges, but in each reported case the correlation with biweekly tides was much weaker than the correlation with diurnal tides [*Wilcock*, 2001; *Tolstoy et al.*, 2002]. Extensive data on global tectonic earthquakes have sometimes shown evidence of a correlation with diurnal tides [*Tanaka et al.*, 2002, *Tsuruoka et al.*, 1995], especially in the case of the strongest tides [*Cochran et al.*, 2004]. However, none of the studies report seeing a correlation with the biweekly tide. Even regional studies of far larger sets of earthquakes in the San Francisco Bay Area [*McNutt and Heaton*, 1981; *Kennedy et al.*, 2004] and the Pacific Northwest [*Kennedy et al.*, 2004] find no measurable correlation. As stated by *Hartzell and Heaton* [1989], the difference in the amplitude of the biweekly tidal stress envelope is much smaller than the diurnal peak-to-peak stress variation, with diurnal stress variation being over 5 times larger than the biweekly variation. Along the same vein, theoretical studies predict a correlation with the diurnal but not biweekly tides due to the small overall amplitude variation of biweekly tides [*Dieterich*, 1987].

[3] *Crockett et al.* [2006] base their conclusions on a comparison with the lunar phase only; however, it has been well documented, for example in a review by *Emter* [1997], that the tidal time series must be computed in relation to the focal mechanism to derive a useful correlation. In addition, *Crockett et al.* [2006] do not include the ocean tide component of the tidal stress in their correlation even though the ocean tide component is often an order of magnitude larger than the solid earth tide in subduction zone (coastal) environments. Depth matters as well; for example, *Tsuruoka et al.* [1995] show that tides calculated at the surface can be opposite in phase to tidal time series at hypocentral depths when ocean loading is taken into account.

[4] Perhaps most importantly, the statistics employed by *Crockett et al.* [2006] are somewhat problematic. Schuster's test is only valid for independent datasets in which events occur at random. This test can produce a false positive result if the data set is not random and so should not be used for statistical tests on catalogs that include aftershocks. Therefore, the statistics given by *Crockett et al.* [2006] for the raw (clustered) catalog are invalid. Specifically, in the clustered catalog, the times of aftershocks of the M9.3 megathrust dominate the sample, and they are not uncorrelated in time. Rather they tend to occur just after the mainshock, as aftershocks are prone to do.

[5] The most compelling statistic of *Crockett et al.* [2006] is the one derived from 13/14 declustered events happening near the quadrants of either the full or new moons. An only 1-in-a-100 chance of finding the result at random is cited, but the paper documentation suggests the degrees of free-

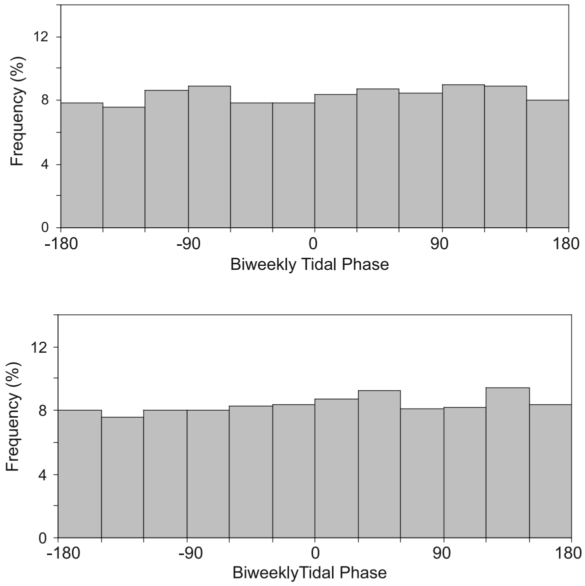

Figure 1. Histogram of frequency of thrust earthquakes versus tidal phase for biweekly (top) normal stress and (bottom) shear stress time series. The tidal phase range acting to encourage failure is between −90° and 90°, when normal stress is reduced and shear stress is in the direction of slip.

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Table 1. Total Number of Earthquakes, Number of Earthquakes in the Encouraging Phase Bin, Number of Excess Events Compared to an Equal Distribution of Events in the Two Bins, Percentage of the Total Events, and Variance

	Total	Number in Encouraging Phase Bin[a]	Excess Events	Percentage of Total	Variance
Normal (all)	2823	1415	3.5	0.124	0.94
Normal (>0.1 bar)	1470	720	−15	−1.02	1.3
Shear (all)	2823	1428	16.5	0.584	0.94
Shear (>0.1 bar)	155	68	−9.5	−6.13	3.99

[a] Number of earthquakes in the encouraging phase bin, −90 to +90.

dom of choosing the time window of interest, the time lag relative to phase of the moon, and the geographic area are not included in the estimate. The rose diagram plots do appear to show a correlation with new and full moon. However, the quadrants were clearly picked to best display the correlation, which similarly invalidates the statistics unless they account for these additional degrees of freedom.

[6] To further investigate with greater resolution the claim by *Crockett et al.* [2006] we examine the correlation of global thrust fault earthquakes with the biweekly tides following our previous study of diurnal tides [*Cochran et al.*, 2004]. From 1977–2000, the Harvard CMT catalog includes 2,823 M5.5+ global thrust earthquake focal mechanisms. For each event we calculate the tidal phase between −180° and 180°; 0° phase is defined to be at the time of maximum stress that promotes failure over the two week period, which is extensional for normal stress and in the direction of slip for shear stress. Tidal stress calculations include both the solid Earth tide and an ocean loading component and the stress is computed with respect to the focal plane at the depth of each earthquake (see *Cochran et al.* [2004] for more details). We search the data for a correlation with the biweekly normal or shear stress tidal phase. Plotted in Figure 1 is the frequency of earthquakes versus the biweekly tidal phase for normal stress and shear stress. Clearly, no strong correlation with the biweekly tides is observed. In addition, we determine the exact number of additional earthquakes (Nex) in the half of the tidal phase that most encourages failure (−90° to +90°) and see a slight increase in the number of earthquakes in the encouraging tidal phase range. The normal stress histogram has 0.12 ± 0.94% more earthquakes and shear stress histogram has 0.584 ± 0.94% more earthquakes that average during times of encouraging tidal stress (Table 1). Therefore, while there is a slight increase in the rate of earthquakes during encouraging tidal phases, neither a comparison with the normal nor shear stress time series gives a statistically significant correlation of earthquake timing with the biweekly tides.

[7] We also examine the subset of events that occur at times of peak biweekly tidal stress amplitudes above 0.1 bar (1e4 Pa) with the assumption that earthquakes are more likely to be triggered by higher stresses. The subset of events with the biweekly normal stress greater than 0.1 bar equals 1470. We find no increase in the number of events in the encouraging phase bin with only 720 earthquakes occurring in this range (Nex = −15). Similarly for the 155 earthquakes that occur when the biweekly shear stress is greater than 0.1 bar, we again find fewer events in the encouraging phase bin (Nex = −9.5). This suggests that it is highly unlikely that there is a marked correlation of earthquake timing with the biweekly tides, even in the cases of fairly high tidal amplitudes (above 0.1 bar). The lack of correlation seen here makes it unlikely that any correlation with the biweekly tide would be resolvable in a much smaller dataset.

[8] So while the results of *Crockett et al.* [2006] are provocative, they are not yet confirmed.

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