Estimates of afterslip for large earthquakes using normal-mode data

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For our understanding of scaling of earthquake source, accurate estimates of the moment of an earthquake and its source duration are essential. However, the analysis of normal mode data for recent large earthquakes indicates that many published solutions, especially the Global Centroid Moment Tensor solutions (hereafter GCMT), require additional slip (afterslip) in order to explain the normal-mode amplitude data. Therefore, the GCMT solutions alone may not represent the whole picture of source process, at least for large events. I will make this case by using examples from the 2004 Sumatran-Andaman event ($M_w = 9.1 - 9.3$) and the Chilean event (Bio-Bio), on 27 February, 2010 ($M_w = 8.8$).

For normal mode data, one of the useful parameters for source study is the modal amplitude vs. frequency variations. If we calculate modal amplitudes of large earthquakes for published GCMT solutions, modal amplitudes for data below 1 mHz (millihertz) are typically much larger than theoretical estimates. In the case of the Sumatran event, the ratio of data to theoretical value for ${}_0S_2$ (0.3 mHz) is about 2-3 (2.5 in Stein and Okal, 2005). In fact, a sequence of modes up to about 2 mHz shows statistically significant deviations from 1 for the modal-amplitude ratio. The fact that this ratio systematically approaches 1 at about 2 mHz is not surprising as the GCMT solution is typically determined with surface waves at about 2-3 mHz and above.

I will show that this deviation for the amplitude ratio (from 1) was also seen for the Chilean earthquake data in 2010, although the ratio for ${}_0S_2$ is about 1.4 and amplitude ratios systematically approaches 1 for higher-frequency modes. Therefore, the deviation is much smaller than the Sumatran event but it shows that the GCMT solution does not reflect the true size of this earthquake.

I set up a simple parameter search scheme to find a best fitting solution by introducing an additional slip to the GCMT solution. Two parameters are the (additional) moment and its source duration (rise time). For the Chilean (Biobio) event, my best solution requires an additional moment of 24 percent that occurred over 110 seconds. The GCMT solution plus this afterslip fit all modal data below 2 mHz quite well. This afterslip is not necessarily a slow event as the GCMT solution for this event was $M_o = 1.84 \times 10^{29}$ (dyne-cm) with source duration of 121 seconds.

I will discuss the details on these estimates, particularly focussing on resolvability of each parameter as well as trade-offs among parameters.