Using Corals to Investigate the Seismic Cycle in the Banyak Islands, Indonesia

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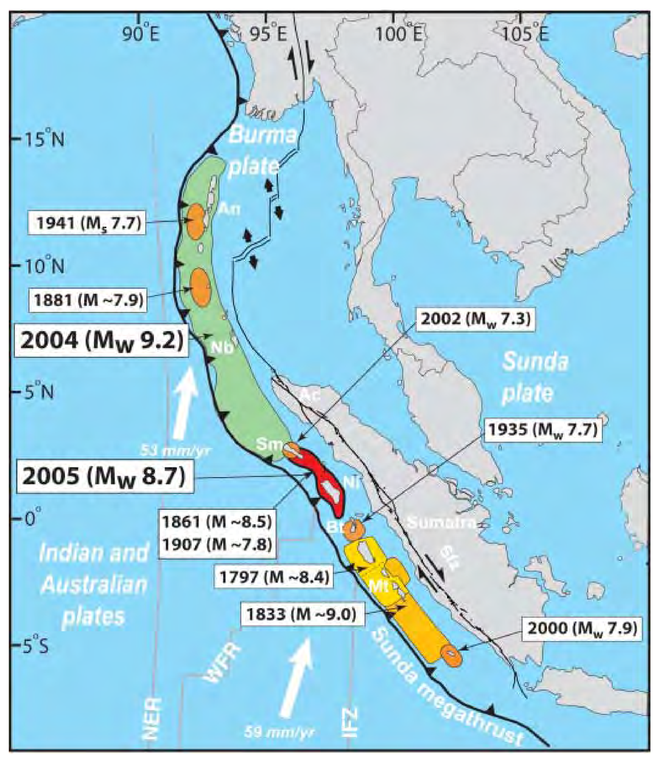
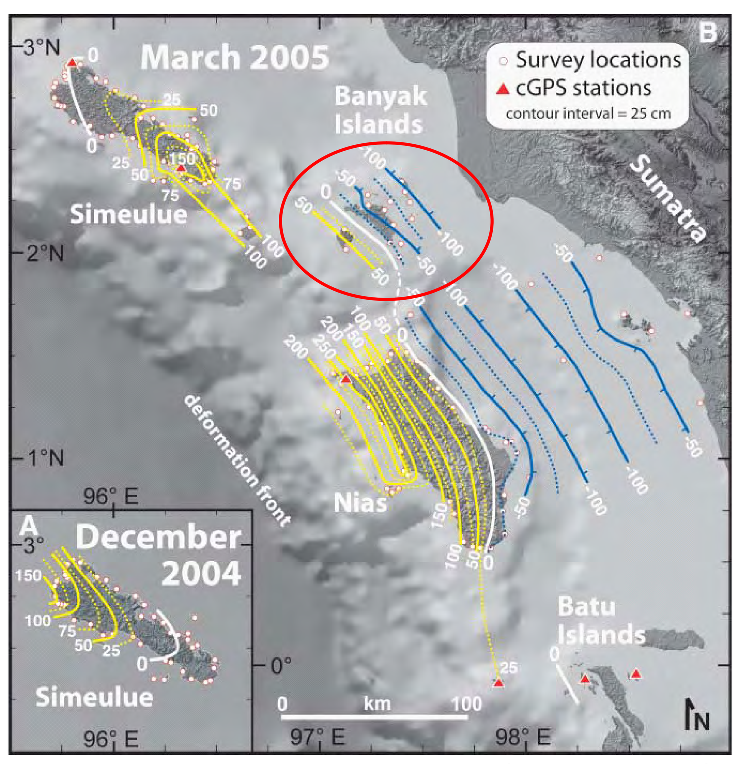
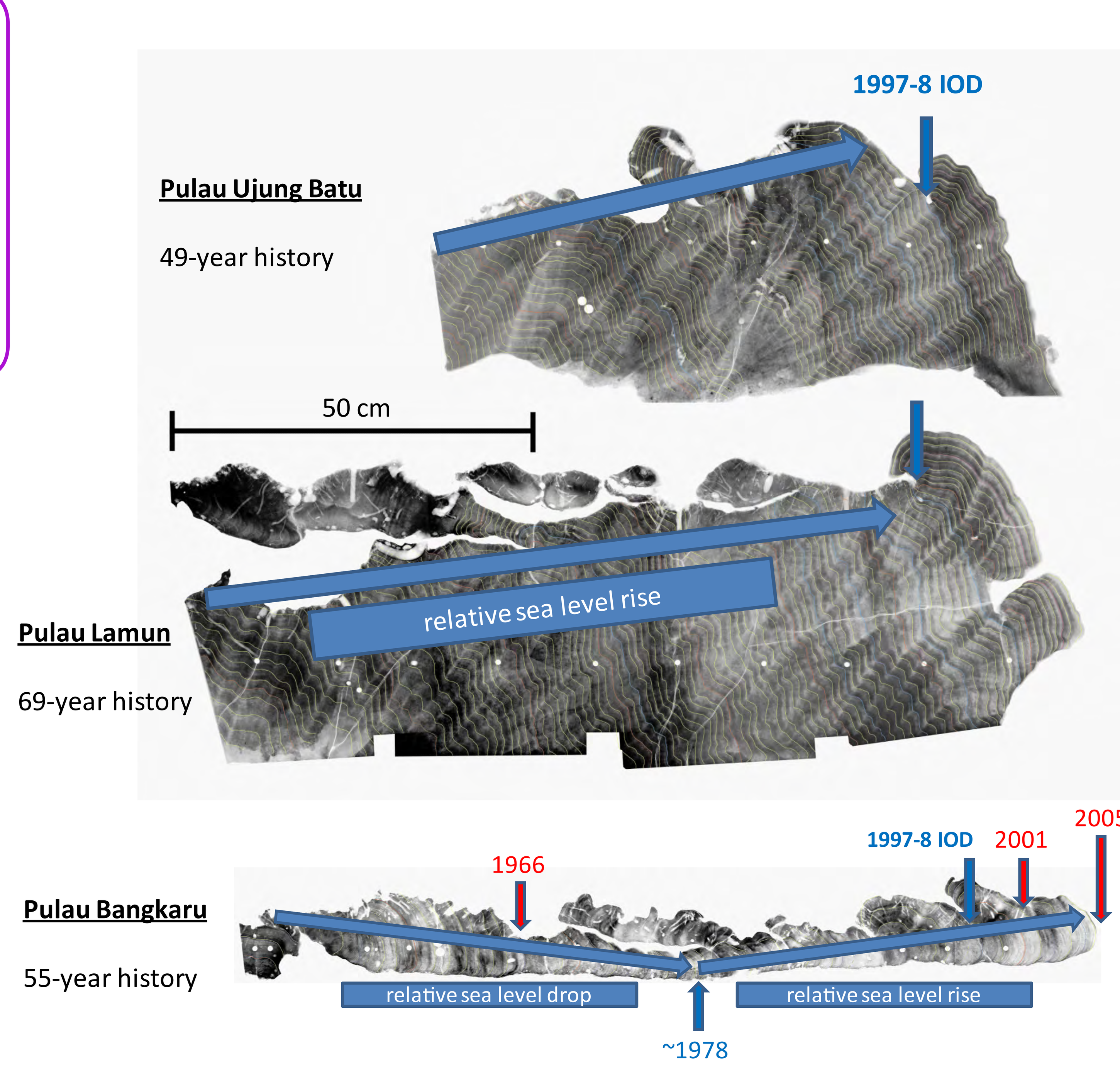
The Banyak Islands

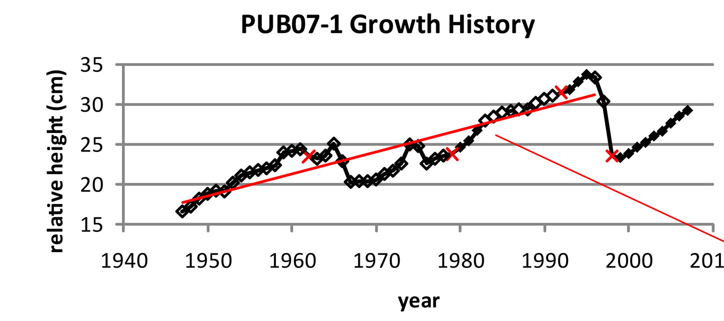
The Sumatran subduction zone is an ideal natural laboratory for studying the seismic cycle due to its recent sequence of great earthquakes, a cGPS network with some stations in operation since 2002, and islands that provide a basis for coral-based and instrument-based geodesy above the seismogenic part of the megathrust. The Banyak Islands span the coseismic hinge line between uplift and subsidence in the 2005 Nias-Simeulue earthquake, and are therefore most sensitive to behavior of the megathrust near the down-dip limit of coseismic slip.

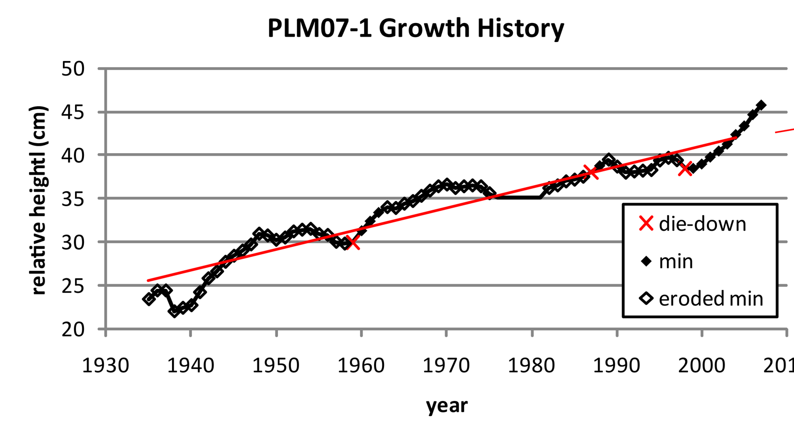


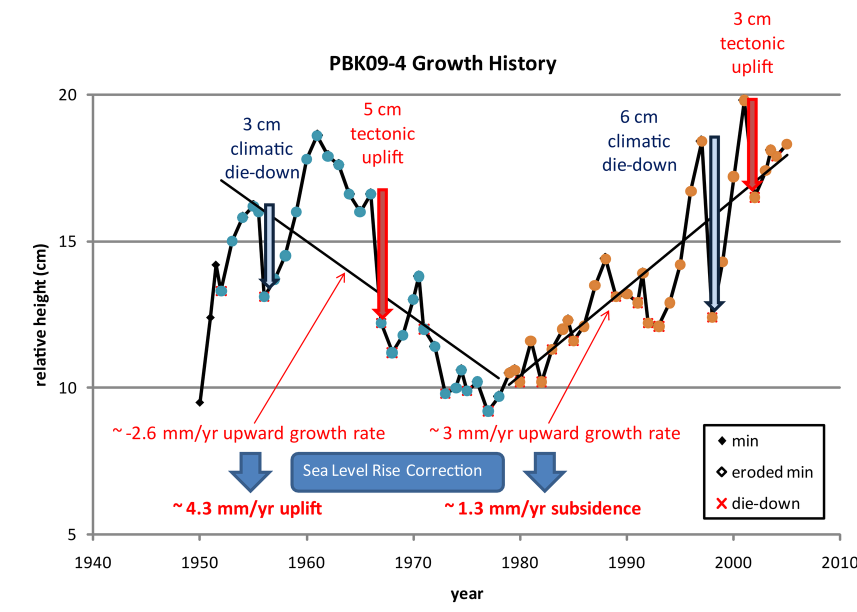


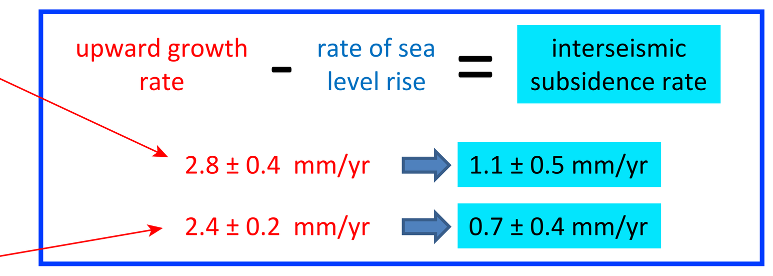
(Briggs et al. 2006)











The Interseismic Story

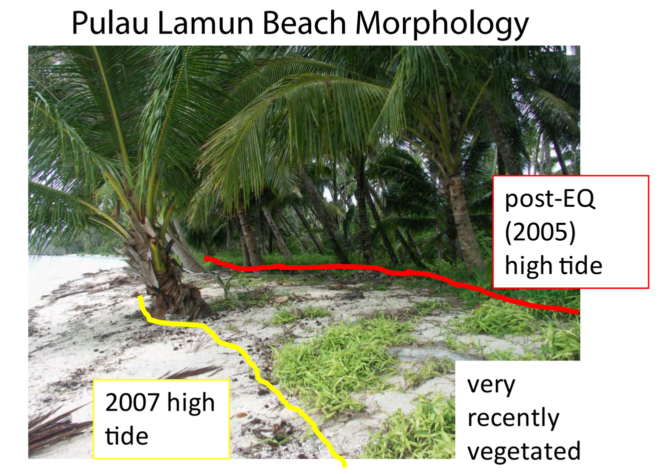
Coral slabs from the two coseismic subsidence sites in the Banyak Islands yielded upward growth rates of 2-3 mm/yr for the half-century prior to the 2005 earthquake. Applying a correction for the average global 20th century sea level rise of 1.7 mm/yr (Church & White, 2006), it can be inferred that during the interseismic period, these sites were subsiding at approximately 1 mm/yr. If the rate of sea level rise off Sumatra is higher than the global average, as suggested by some models, little or no deformation occurred at these sites in the late interseismic period prior to the 2005 earthquake. The coseismic uplift site, Bangkaru, has a very different coral growth history showing periods of both uplift and subsidence in the late interseismic period.

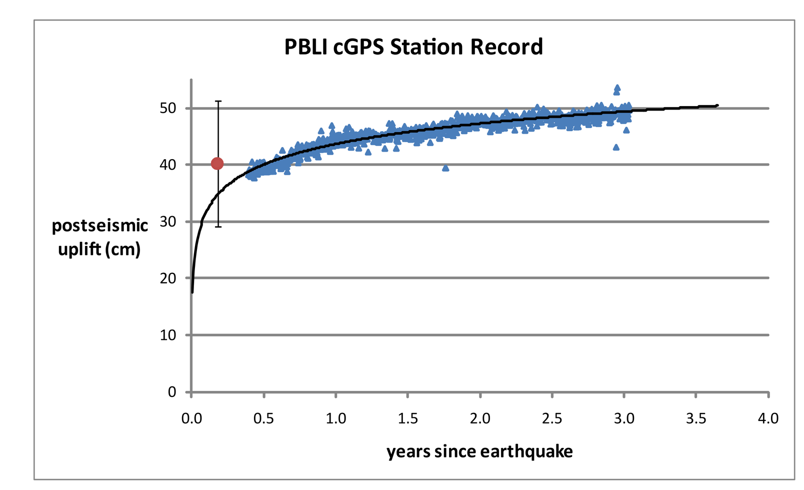
The Postseismic Story

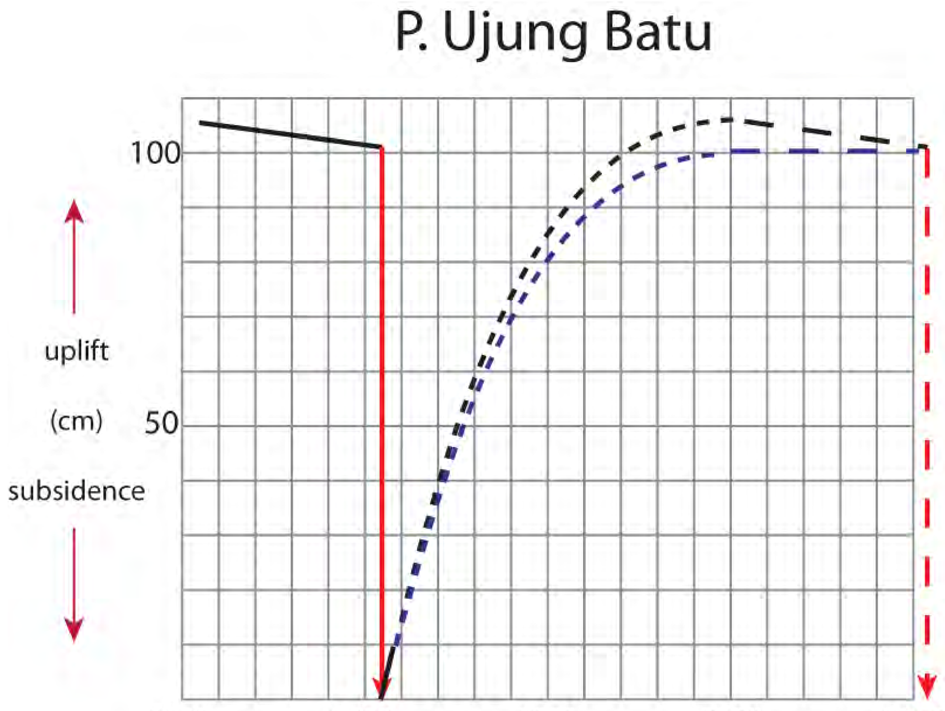
We measured the the net uplift or subsidence that had occurred between the time of our visit to the site (late July 2007) and just prior to the 2005 earthquake, a time interval which includes the coseismic deformation as well as the first 2.3 years of postseismic deformation. The differences between the "net change" values and the coseismic measurements reported by Briggs et al. (2006), corrected for tidal anomalies at the times of the measurements, give the amount of postseismic deformation which occurred in the time interval between the two measurements, May/June 2005 to late July 2007. Small amounts of uplift occured at Ujung Batu and Lamun (which subsided coseismically), while postseismic uplift at the Bangkaru site has equalled or even exceeded the coseismic uplift. While the uncertainty is larger than the measurements at Ujung Batu and Lamun, the PBLI cGPS station near the Ujung Batu site has a record consistent with the postseismic uplift measurement, and beach morphology at the Lamun site also suggests postseismic uplift. A logarithmic fit to the cGPS time series suggests that there may have been as much as 15 cm of postseismic uplift prior to the initial coseismic measurements in May/June 2005. This unknown amount of deformation would add to both the total coseismic subsidence and total postseismic uplift.

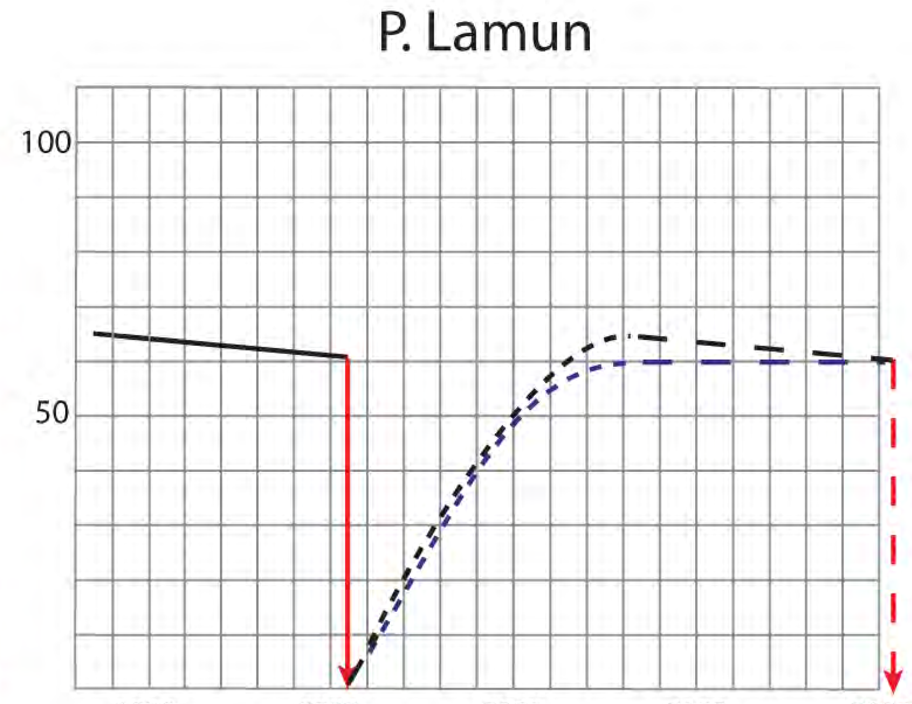
Site	Interseismic	Coseismic	Postseismic (Coral)	Postseismic (Other)
Ujung Batu	-1.1 ± 0.5 mm/yr	~ -100 ± 16 cm	8 ± 11 cm	10 ± 2 cm (cGPS)
Lamun	-0.7 ± 0.4 mm/yr	~ -60 ± 16 cm	3 ± 10 cm	10-15 cm (beach)
Bangkaru	4.3 and -1.3 mm/yr	20 ± 6 cm	23 ± 8 cm	

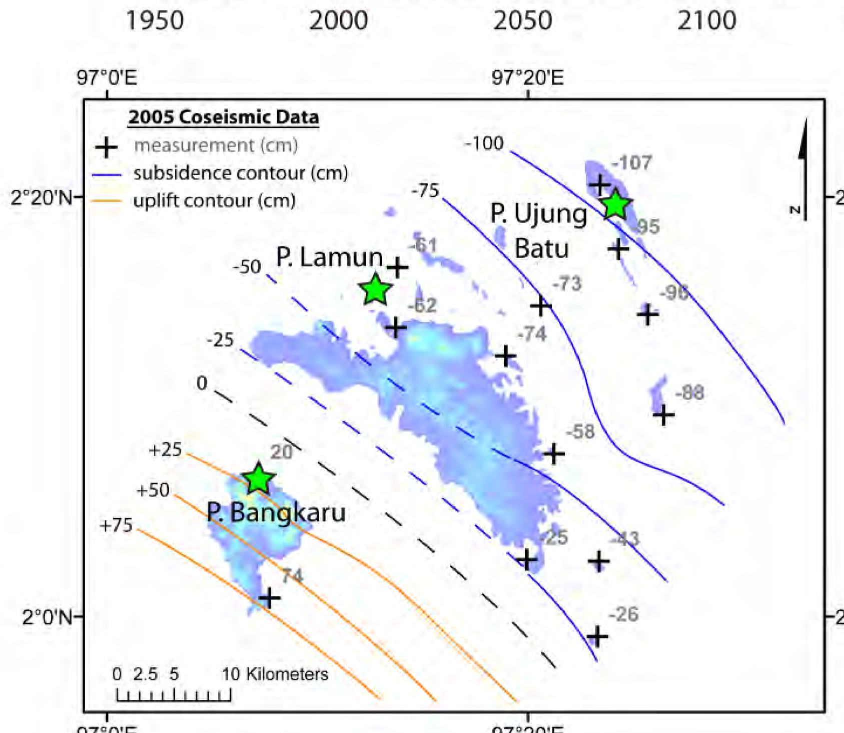
Pulau Lamun Beach Morphology

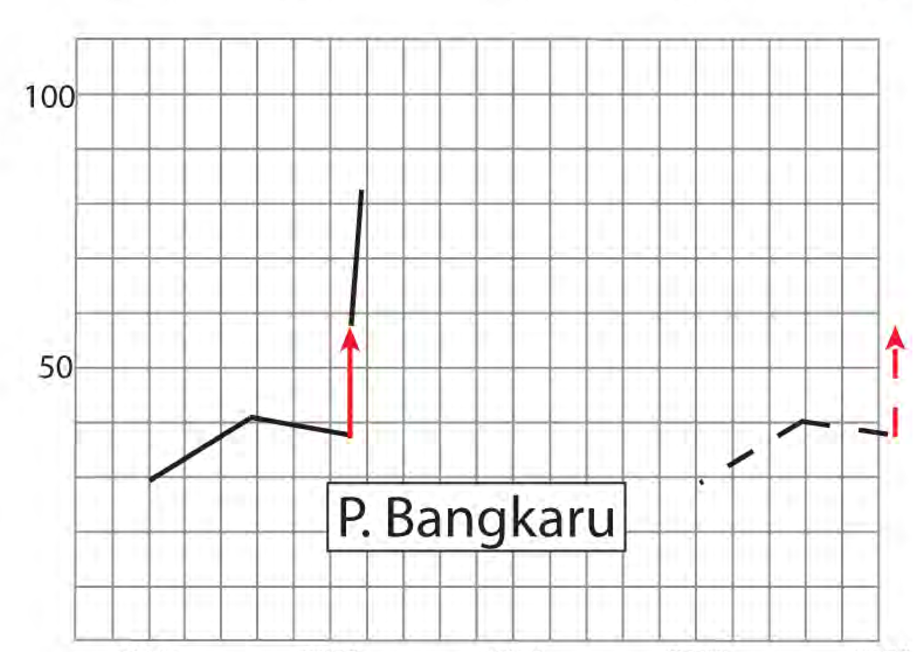










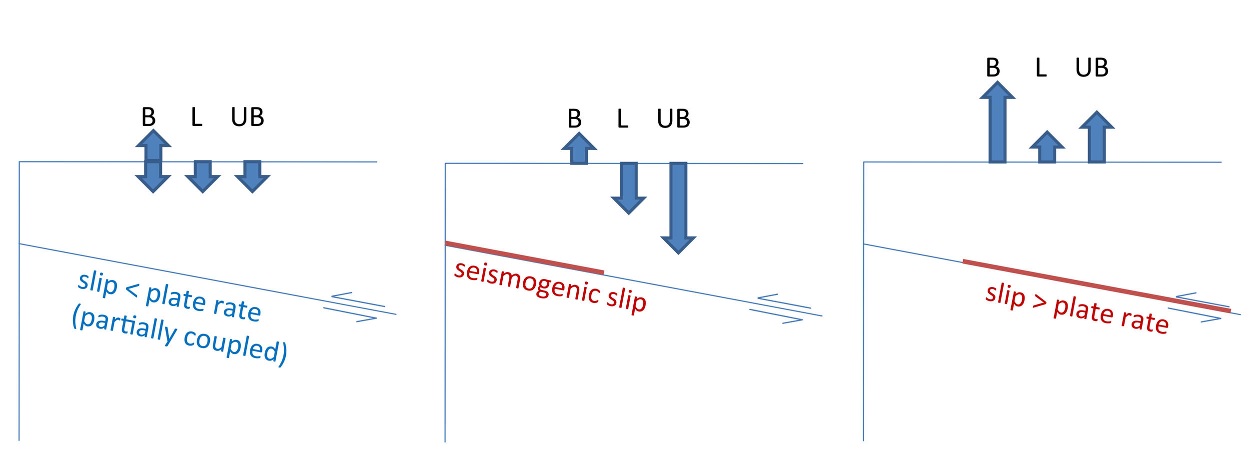


Putting It All Together: Interseismic, Coseismic, and Postseismic Deformation

Solid lines in the "single-sawtooth" plots to the left represent measured deformation in the various phases of the seismic cycle, while dashed lines show hypothesized completions of the seismic cycle using the 150-year interseismic interval suggested by historical records. The 50- to 70-year period of slow subsidence prior to the 2005 earthquake represents a third or more of the interseismic interval. This poses a problem for the "deformation budget," since this motion is actually adding to, rather than recovering, the coseismic subsidence at the Ujung Batu and Lamun sites. The high rates of postseismic uplift observed at both sites are the likely solution to this budget imbalance, suggesting that most of the coseismic subsidence will be recovered in the first 50 years following the 2005 earthquake, with little or no deformation occurring late in the interseismic interval. These fast uplift rates must be sustained for decades in order to completely recover the coseismic subsidence prior to a period of near-zero deformation in the final third of the interseismic interval. In order to overshoot recovery of the 2005 subsidence to provide extra uplift which would then be recovered by slow subsidence in the decades prior to the next earthquake, matching the pre-2005 pattern, fast postseismic uplift rates must be sustained for an even longer period. If these rates are not sustained, a down-dip slip event (either seismic or aseismic) is required to fill the deformation deficit. Alternatively, some amount of permanent deformation may remain, at least over a single seismic cycle. The Bangkaru site is even more puzzling in that uplift has occurred during all three stages of the seismic cycle. In order to balance the deformation budget at this location, the postseismic uplift must eventually cease and give way to subsidence, or an updip slip event must occur. There is some evidence that a tsunamigenic earthquake in 1907 was such an updip slip event. The behavior of the cGPS stations throughout the coming years and decades, as well as future field surveys, will serve to test these hypotheses.

Implications for Fault Interface Behavior

Late in the interseismic period, the slow subsidence at two sites and little net deformation at the third suggests that the plate interface is at least partially coupled below this region, farther down-dip than the coseismic rupture propagated. Coseismic slip on the megathrust was concentrated up-dip of the part of the fault below the islands, as evidenced by the location of the hinge line between the uplift of Bangkaru and the subsidence of the eastern islands. In the postseismic phase, the fault patch below the Banyak Islands must be slipping at rates considerably faster than the rate of tectonic loading to produce such rapid uplift. This slip pattern probably occurs because the Banyak Islands are situated above the down-dip edge of an asperity on the megathrust which forms the seismogenic area. The seismic rupture of this asperity releases the surrounding fault plane (where slip is somewhat inhibited in the interseismic period due to the adjacent locked asperity). This area slips postseismically, eventually matching the coseismic slip which occurred on the asperity. However, because the asperity is again locked, over the course of the interseismic period the slip rate of the region surrounding the asperity eventually decreases below the plate tectonic rate.



Future Possibilities

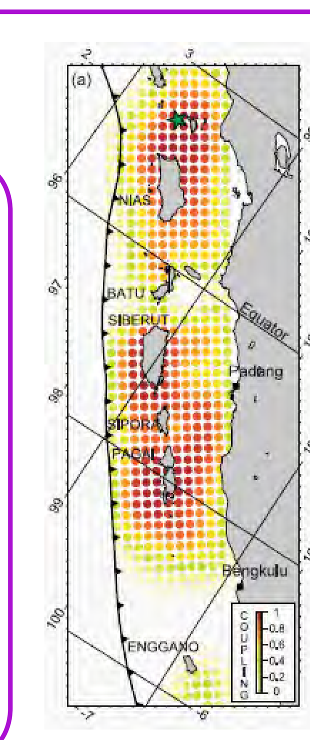
- Install a cGPS station on Bangkaru

- Compare measurements with predictions of interseismic coupling model

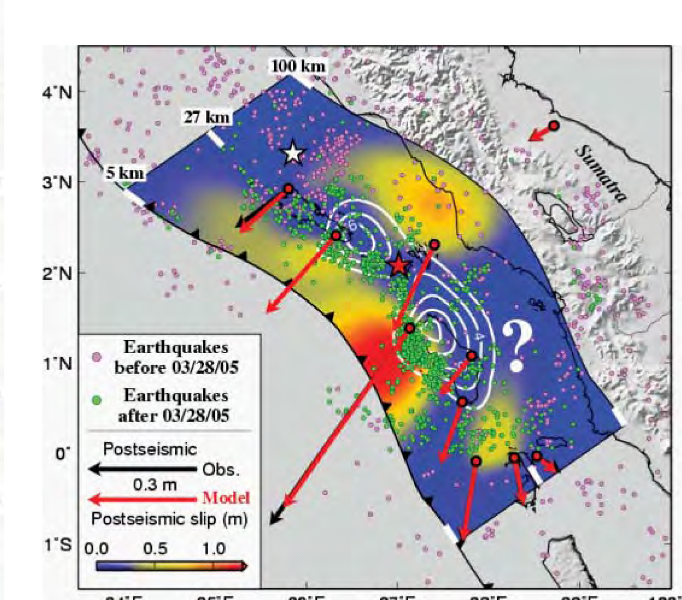
- Compare measurements with temporal forecast of postseismic slip model

- Incorporate new measurements into quantitative models

- More precise corrections using regionally specific, non-constant rates of sea level rise



(Chlieh et al. 2008)



(Hsu et al. 2006)