Title of the article

Rebekah Lee

1. Abstract

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2. Introduction

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3. Methods

Herrendörfer et al. [2015] model subduction zones using a two-dimensional numerical model of a simplified and scaled subduction zone to investigate the role of the seimogenic zone downdip width. In this model a rigid plate subducts beneath a visco-elastic wedge at an angle of 10°. The seismogenic zone has velocity weakening properties, whereas the aseismic zone has velocity strengthening properties. The authors use conservative finite differences to solve for conservation of mass (eq. 1) and momentum (eq. 2) under the assumption of incompressibility ($\nabla \cdot \vec{v}$):

$$\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} = 0, \tag{1}$$

$$\frac{\partial \sigma'_{xx}}{\partial x} + \frac{\sigma'_{yy}}{\partial y} - \frac{\partial P}{\partial x} = \rho \frac{Dv_x}{Dt}$$

$$\frac{\partial \sigma'_{yx}}{\partial x} + \frac{\sigma'_{yy}}{\partial y} - \frac{\partial P}{\partial y} = \rho \frac{Dv_y}{Dt} - \rho g \tag{2}$$

where v_x and v_y are horizontal and vertical velocities, σ' is the stress tensor, P is pressure, g is the gravitaional constant and ρ is density. The authors use a constitutive relationship that connects the deviatoric stresses (σ'_{ij}) and strain rates ($\dot{\epsilon}'_{ij}$) applying linear elasticity and Newtonian viscosity: EQN4HERE

where G is shear modulus, η is effective viscosity, $\sigma'_{II} = \sqrt{\sigma'^2_{xx} + \sigma'^2_{xy}}$ is the plastic flow potential, and χ is a plastic multiplier connecting plastic strain rates and stresses.

Flow becomes plastic when the plastic flow potential, σ'_{II} reaches the local pressure-dependent yield strength, σ_{yield}:

$$\sigma'_{II} = \sigma_{yield} = C + \mu_{eff} \cdot P, \tag{3}$$

where C is cohesion and μ_{eff} is the effective friction coefficient. μ_{eff} is strongly rate dependent as it depends on the visco-plastic slip velocity, V_{vp}:

$$\mu_{eff} = \mu_s(1-\gamma) + \mu_s \frac{\gamma}{1 + \frac{V_{vp}}{V_c}}, \tag{4}$$

where γ is amount of weakening ($1 - \frac{\mu_s}{\mu_d}$), μ_s and μ_d are static and dynamic coefficients, respectively, and V_c is characteristic slip velocity.

During plastic deformation elastic strain is zero and the second invariant of deviatoric stresses must be constant. The total strain rate therefore is the sum of the viscous and plastic strain rates, so that the plastic strain is $\dot{\epsilon}'_{II} - \dot{\epsilon}'^{(viscous)}_{II}$ (where $\dot{\epsilon}'_{II} = \sqrt{\dot{\epsilon}'^2_{xx} + \dot{\epsilon}'^2_{xy}}$) and the visco-plastic viscosity is:

$$\eta_{vp} = \eta \frac{\sigma'_{II}}{\eta\chi + \sigma'_{II}}, \tag{5}$$

with

$$\chi = 2(\dot{\epsilon}'_{II} - \dot{\epsilon}'^{(viscous)}_{II}) = 2(\dot{\epsilon}'_{II} - \frac{1}{2\eta}\sigma'_{II}) \tag{6}$$

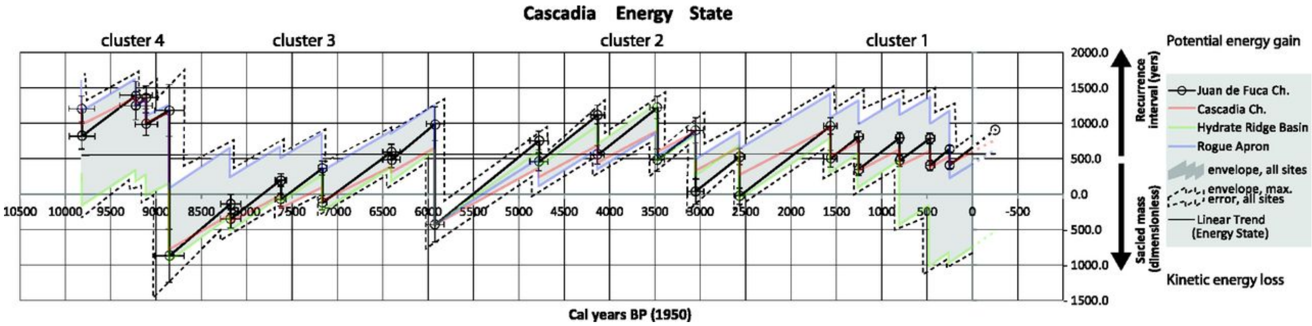

Figure 1. caption here

The authors define subcritical ruptures as events that fail to propagate a long distance out of their nucleation region. Pulse-like ruptures propagate further than subcritical ruptures but have a local duration of coseismic displacements that is short compared to the total rupture duration. In a crack-like rupture most of the rupture area continues to slip until the end of the rupture. See column three of figure 3 for plots of the horizontal velocity through time and distance from backstop for each of the rupture types.

4. Data and Results

The tsunami record near Sendai, Japan shows events in 1896, 1611 and 869. The largest is the 869 even with tsunami penetrating $3-4$ km inland, similar to the 2011 earthquake. There is also evidence for two predecessors with tsunamis reaching the same distance inland as the 869 and 2011 earthquakes. This evidence supports the existence of periodic outsized earthquakes greater than magnitude 9 with a recurrance interval between $800-1200$ years [*Goldfinger et al.*, 2013].

Goldfinger et al. [2013] identify the Cascadia subduction zone as another area likely to produce supercycle earthquakes. They correlate turbidite cores along the subduction zone and find consistency between sites for the same events in terms of mass size.

Figure **1** shows the results from modeling the energy state in the Cascadia subduction zone [*Goldfinger et al.*, 2013].

They identify four clusters from the past 10 thousand years. Cluster four shows an even energy state before falling to a low after a large event. Cluster 3 climbs steadily until falling to a similar low. During this period there are several seismic cycles with relatively low stress drops that do not relieve all of the accumulated strain. A total stress drop finally happens at the end of the cluster with an event much larger than the others within the same cluster. Cluster two differs from the previous in that it does not culminate in an oversized event. Rather, it climbs and then falls over several seismic cycles until it reaches a low energy value about 2500 years BP (1950). The end of the cluster marks a long gap of about 1,000 years of constant increase in energy. Cluster one then slowly decreases the energy state until the A.D. 1700 M_w 9.0 earthquake. [*Goldfinger et al.*, 2013] note that the scale factor is based on the condition of no net energy change over the 10,000 years but that changing this parameter does not change the pattern observed. The authors also note that the seismic coupling coefficient only changes the pattern if the value is allowed to vary between events.

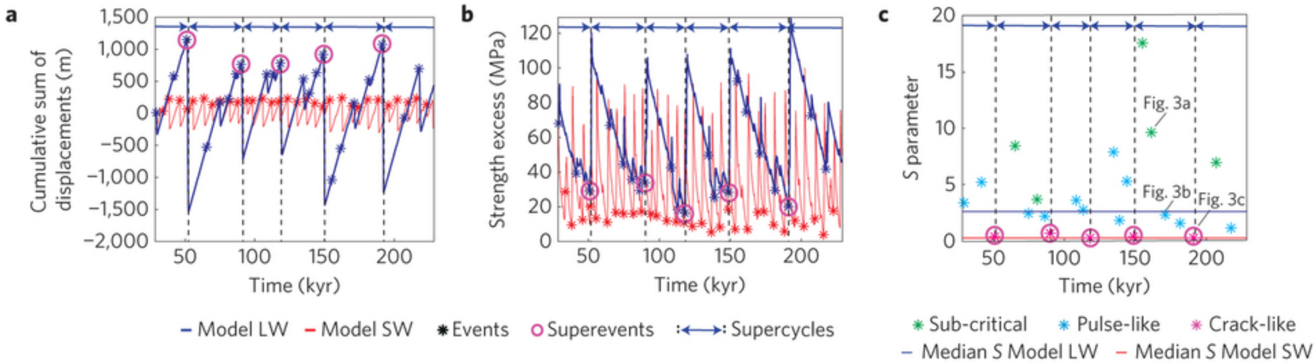

Figure 2. Comparison of characteristics of long (LW) and small (SW) downdip width subduction zone models. Earthquakes indicated by astericks and superevents are circled. Subfigures show cumulative sum over time (**a**) Excess strength (**b**) and S parameter (**b**). S parameter is the ratio of initial strength excess to stress change during an event. Event types are also indicated by color. From *Herrendörfer et al.* [2015].

The four clusters modeled by *Goldfinger et al.* [2013] demonstrate that some events in this subduction zone release energy from previous cycles. This subduction zone is neither slip nor time predictable. Energy release is not tied to recurrance intervals as some events can release energy accumulated from previous seismic cycles. The authors make a few observations relating the energy state to the behavior of the clusters. High energy states results in one very large event, (as in the case of cluster four), or a series of smaller events (as in cluster two). Low energy state results in a long gap in seismicity (cluster 2) or a series of small earthquakes with net energy gain over several cycles (cluster 3).

Figures **2,3** show results from *Herrendörfer et al.* [2015]. Both systems show that events are triggered at low excess stress (Figure **2b**). However, the magnitudes at similar low stresses are much greater for the large width subduction zone, as shown in Figure (**2a**). Large width zones are characterized by supercycles that partially release stress but overall excess strength continues to decrease until at a low level. Figure **3** shows strength excess (shaded green) before and after each of the event types. Subcritical events (a) nucleate close to the downdip limit of the seismogenic zone and transfers stress close to the stopping location (about 125 km from backstop). Pulse-like ruptures (b) nucleate from the downdip limit for short duration and transfer stress updip (about 300 km from backstop). These combine to shift the strain towards the center of the seismogenic zone that eventually results in the crack-like event (c) that ruptures the entire zone.

Herrendörfer et al. [2015] characterize events by an S parameter. The S parameter is a measure of the ratio the inital strength excess and stress change during an event. Figure **2** Large width model is characterized by a higher median S parameter (2.5) compared to the small width model (.25). The average strength excess is increased by increased width and leads to transition from crack-like ruptures of the entire zone to smaller preparatory subcritical and pulse-like ruptures leading up to culminating crack-like rupture.

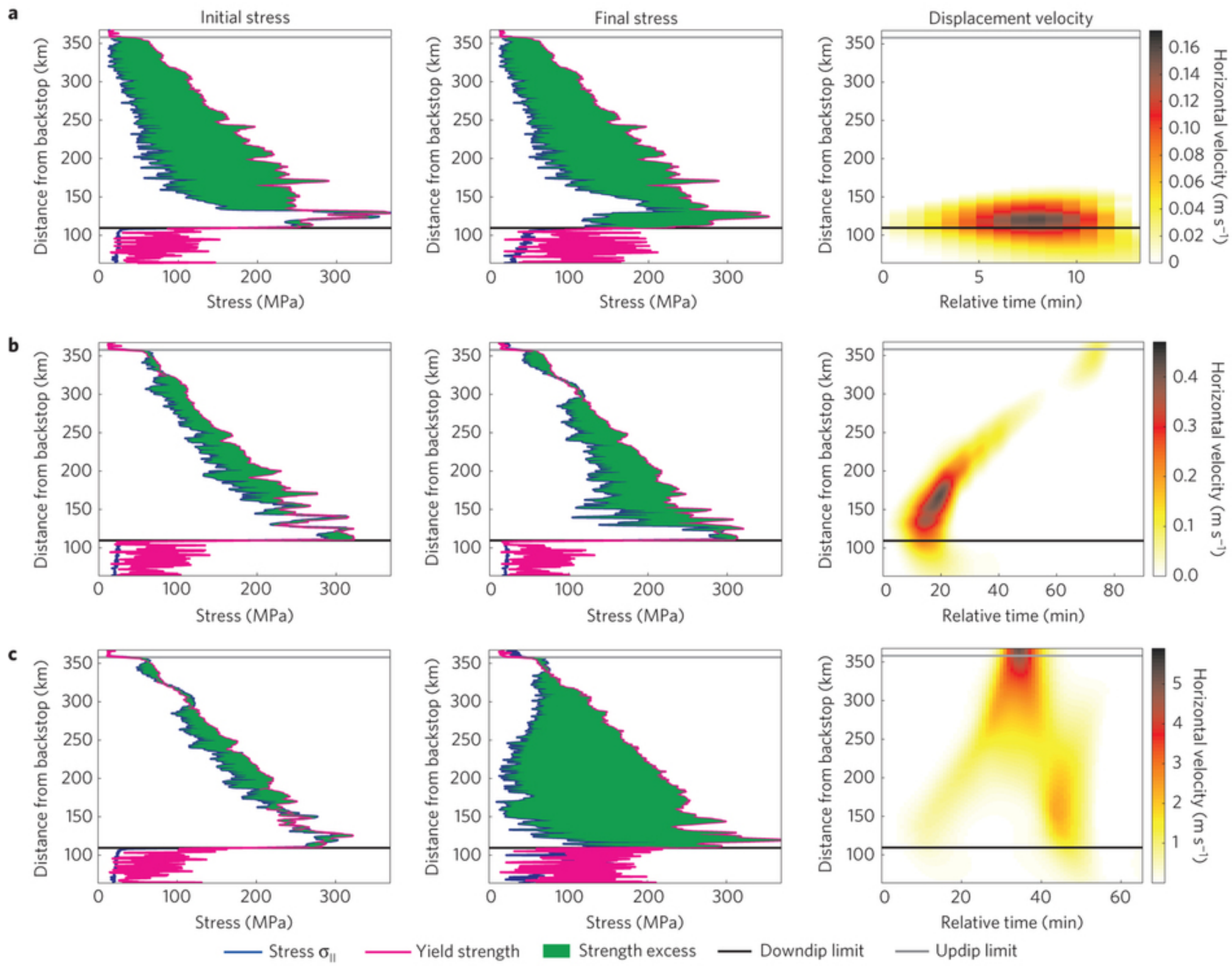

Figure 3. caption

5. Conclusion

Examining the geologic record can give us a good indication of whether or not a subduction zone has produced oversized events in the past. This records include paleoseimic eveidence and tsunami observations and turbidite deposits when they can be attributed to shaking. As the data from the Cascadias demonstrates, there is no simply relationship to predict the size of earthquakes in subduction zones. For example, because supercycles use energy from previous seismic cycles, convergent rate is an unreliable predictor as some earthquakes may not result in a complete stress drop over the area of the fault.

References

Goldfinger, C., Y. Ikeda, R. S. Yeats, and J. Ren (2013), Superquakes and Supercycles, *Seismological Research Letters*, *84*(1), 24–32, doi:10.1785/0220110135.

Herrendörfer, R., Y. van Dinther, T. Gerya, and L. A. Dalguer (2015), Earthquake supercycle in subduction zones controlled by the width of the seismogenic zone, *Nature Geoscience*, *8*(6), 471–474, doi:10.1038/ngeo2427.