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Discussions

Interactive comment on "Discrete element modeling of a subduction zone with a seafloor irregularity and its impact on the seismic cycle" *by* Liqing Jiao et al.

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"This manuscript uses a DEM subduction zone to investigate the role of seafloor geometry in the seismic cycle. This type of modeling is useful for improving our understanding of the mechanisms that control size, timing, and location of large megathrust earthquakes. The discrete element approach used in this study offers a promising avenue toward linking seismic observations with physical processes driven by fault geometry. However, the novel contributions of this particular study are not obvious. The study reproduces observed behavior but does not offer significant new insight into the mechanisms that control the observations. I suggest that the simulation

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results should be compared to a reference model without a subducting seamount. This information can be used to more robustly demonstrate the role of geometry on the seismic cycle.”

Thanks for the comments! Our models first confirm the importance seafloor irregularity on the generation of megathrust events. We then concludes our models fit observations, including paleseismic records, spatial patterns of seismicity in a subduction system (such as seismicity along megathrust, splay fault, and back prism zone). Our model also explains seismogenic domains along the megathrust identified from the seismic observations by Lay et al. (2012). In addition to confirming the feasibility of this model by comparing with observations, the outcomes of this model (e.g., earthquake cycle with uncertainty, triggering interaction between megathrust and splay fault) could also contribute crucial parameters for subsequent probabilistic seismic or tsunami hazard assessments for a subduction zone system. Besides, we followed this comment and added a model test without seamount in the supplementary material to compare. This case, however, cannot explain the megathrust events and confirms the importance seafloor irregularity on the generation of megathrust events.

“Furthermore, a suite of simulations can be run to test the role of different geometries on seismic behavior.”

I do agree that the different geometry could affect on the seismic behavior. But, in our modeling, the geometry is based on the seismic observations, which is the real geometry in the Sumatran subduction zone. We prefer to make this part as our future work.

“In line 130, Is the regeneration of particle bonds appropriate for a deforming fault gouge? Loss of cohesion in the damage zone might be better captured by withholding bond generation or regenerating bonds at lower strength.”

Yes, the regeneration of particle bonds represents the fault strength which is mainly on the deforming fault gouge. Although lots of cohesion in the damage zone might be better captured by the bond generations, such setting, however, requires computation resource.

“In line 145. The mean radius of elements is 1km. Are the elements heterogeneous in size? If so, what are the range of particle radii used? Somewhere, there should be a discussion of the implication of using particles that are 1km in radius. The roughness that results from large particles would influence the slip behavior along the fault. How would using smaller elements alter the observations? What about the grain size distribution? There are essentially two scales of geometry here. First, stress heterogeneity set up by particle to particle asperities (km-scale). Second, the stress concentration set up by the imposed seamount (39km wide, 6km high). I suggest discussing more of the first to understand the role of particle roughness on seismic cycle.”

Yes, the elements are heterogeneous in size. The ratio of largest to smallest elements is 1.86, shown in the Table 1. The grain size distribution is normal distribution. Using this distribution is to avoid extra-large or -small particles inside the model. Although particle roughness could affect on the seismic cycles, this study does not consider the effect of the particle roughness. Here are two reasons: 1. The seamount geometry has been confirmed (by a deep seismic reflection survey according to Singh et al., 2011). It should be the main factor controlling the seismic cycle in the subduction zone. 2. We did not focus on the research of the particle roughness, since we have combined it with the other physical parameters. The particle roughness and the physical property together work on the seismic cycle along the interface between the slab and the overriding plate. In a macro-scale, these parameters work together to control the seismic cycle, which is comparable to the observations.

"The model is initialized with the seamount already subducted. The deformation that would have been associated with its emplacement is not captured here. The deformation associated with prior seamount subduction would presumably alter the timing and location of the splay faults. See [1]."

Yes, when the seamount subducting, it could generate other splay faults at different places, which could explain existing splay faults there. Note that without other irregularities, these splay faults are difficult to be re-activated. In our model, we did not consider the pre-existing splay fault, the seamount deformation just generates the splay fault inside the intact overriding plate. As we see here, if the seamount is located at the shallow depth, the splay fault might not happen or happen at other places. But, in the recent seismic record, some earthquakes occur out of the seismic sequence along the interface and are just above the seamount, which should be related to the splay fault propagation.

"Line 197. The rebound tends to reset the state of stress with respect to what? How is this quantified?"

The rebound tends to reset the state of stress with respect to the stress state before the rebound happened. The rebound behavior is quantified by the rock behavior. The natural rebound behavior of the entire slab in the subduction zone is difficult to be tested or quantified by the experiments in the lab. We just compare the modeling results to the observations, which is represented by the seismic cycle behavior.

"Section 4. The comparison to natural observation is good, but there is a lack of discussion about implications of the results. Furthermore, generalizing the interpretations beyond the Sumatran subduction zone to subduction zones in general would be helpful. The author is very focused on discussing how this resembles one particular

subduction system. The DEM model presented here does not fully capture the physics of the Sumatran subduction zone. The DEM model instead can be used as a tool to investigate the role of seafloor geometry on the seismic cycle in general, rather than attempt to explain the specific behavior at one locality.”
We interpreted the modeling results and compared the results to the Sumatran subduction zone. It might imply the application to other subduction zones. We are aware diversity of subduction zones in respect of slab geometry, irregularity distribution along the slab, slab angle and other contact parameters along the interface. Even though, our model that considers the principal geological features (seafloor irregularity) shows that the distinguished regions comparable to the domains definition from seismic observations in subduction system (Lay et al., 2012).

“The author suggests that seafloor irregularities play a significant role in the seismic cycle. However, with only one simulation, causal links between seamount subduction and the seismic cycle are not robust. This claim must be supported by control simulations. The manuscript would be improved if results of a flat subduction interface were included. Some previous discrete element models [1,2] demonstrate clear earthquake cycles with periodic big events, without including a subducting seamount. Comparison of the results to other models and with a control simulation (subduction with no seamount) would improve the quality of the manuscript.”
We put the simulation case without the seamount in the supplementary material for comparison.

“In line 500. The wording is unclear.”
We revised these sentences and stated that ‘If a rupture in this region does not propagate along the splay fault and arrests at the seamount, it could be associated with small events which would result in slow slips and seismic tremors, corresponding

to the downdip or transitional domain identified by Lay et al. (2012). Thus, the region division along the slab with seamount subduction rigorously matches the domain definition from seismic observations (Lay et al., 2012).'

"In line 531. I think this sentence captures the significant seismic hazard implication for the model and should remain. However in line 535, "in the near future" is defined as less than 100 years or one earthquake cycle. What additional seismic hazard estimation do the results afford, beyond saying that one earthquake will happen within the next earthquake cycle?"
If the recurrence interval and time elapsed since the last event along a megathrust (or an active fault), rupture probability could be quantified through a time-dependent hazard model (e.g., the Brownian passage time model proposed by Ellsworth, 1999). Based on this model, the longer time elapsed since the last event is, a higher rupture probability we expect in the future.

"Line 750. Figure 7. Please include those reference points A to K"
Now Figure 7 have included the reference points.

"Line 770. Figure 9. The time scale over which deformation takes place in these displacement figures needs to be made clear. (a) and (b) are showing cumulative displacement over 80 years while (c) and (d) show displacement during one event only. Figure labels might make this clearer."
The old caption of Figure 9: Fig. 9: Displacements of the overriding plate during the first cycle (80 years), which is identified from Fig. 8c: (a) and (b) are horizontal and vertical components, respectively, before the first big event, (c) and (d) are horizontal and vertical components, respectively, during the first big event, (e) records the

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historical paths of points 1-5 in the first cycle and the vertical light blue line is the occurrence time of the first big event; Representation of Cracks, ST, BT, P1- P5 and conjugate faults are the same as those in Fig. 8. Grey and red arrows show the movement direction of the overriding plates before and after the big event, respectively. The new caption of Figure 9: Fig. 9: Displacements of the overriding plate during the first cycle (80 years), which is identified from Fig. 8c: (a) and (b) are horizontal and vertical components, respectively, before the first big event (72 years; from 200 to 272 years), (c) and (d) are horizontal and vertical components, respectively, during the first big event (8 years; from 272 to 280 years), (e) records the historical paths of points 1-5 in the first cycle and the vertical light blue line is the occurrence time of the first big event; Representation of Cracks, ST, BT, P1-P5 and conjugate faults are the same as those in Fig. 8. Grey and red arrows show the movement direction of the overriding plates before and after the big event, respectively.

“Line 780. Figure 10. Gray lines represent 0.2 year time intervals. During all of the big events, there are many gray lines. This means the fast slip events have durations of over 1 year?”
In the model, we just interpret that the big event occurs in the durations of over 1 year, but we do not know which 0.2 year happens the big event. The deformation is big during this period (over 1 year). So far, since the limit of the DEM method, it is not possible to simulate the precise seismic moment. The precise seismic moment is also controlled by lots of factors, such as local heterogeneities.

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