Source Processes of Intermediate-Depth Earthquakes

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Overview of Research

I use Blue Waters to simulate intermediate-depth earthquakes.

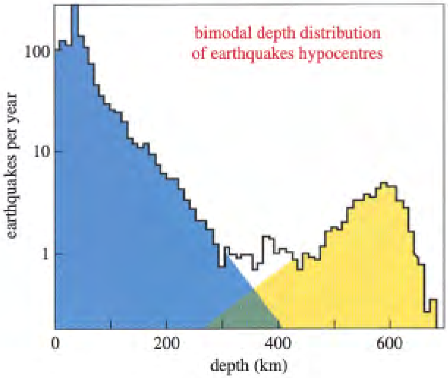

Figure: Green, 2017

Overview of Research

We need a different mechanism to nucleate earthquakes at intermediate depths (7-300 km) because

- pressure is very high (need to overcome high frictional strength!)
- temperature is very high (flow stress is low...we expect ductile deformation)

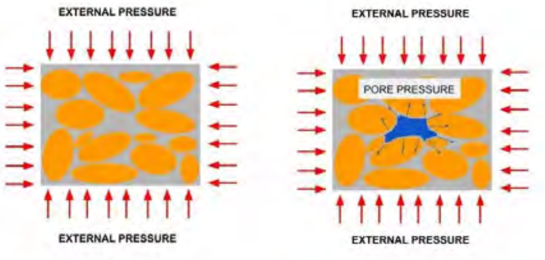

Figure: Berkeley Science Review

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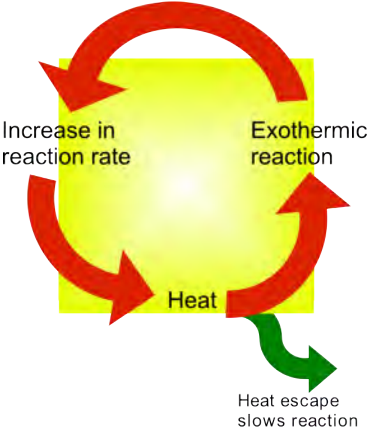


Key Challenges

- Data for intermediate-depth earthquakes is scant in comparison to other earthquakes.
- Hence, solution to the inverse problem is non-unique
- Proper physical model does not exist! Data inversion usually performed assuming behavior similar to shallow earthquakes.

Idea

How can we incorporate hypotheses about intermediate-depth earthquake nucleation into numerical modelling and tie these to data?

Key Challenges

We are also interested in how these earthquakes behave from small to large scales - a change in this behavior would represent a departure from shallow earthquakes.

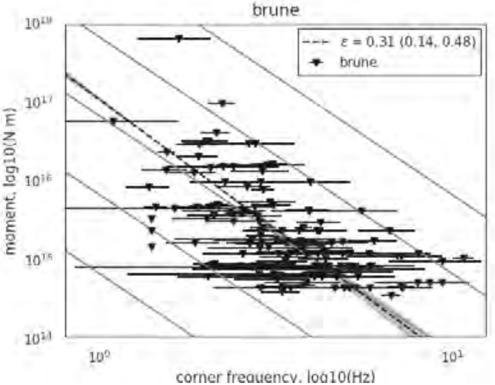


Figure: Chu et al., 2019

Why it matters

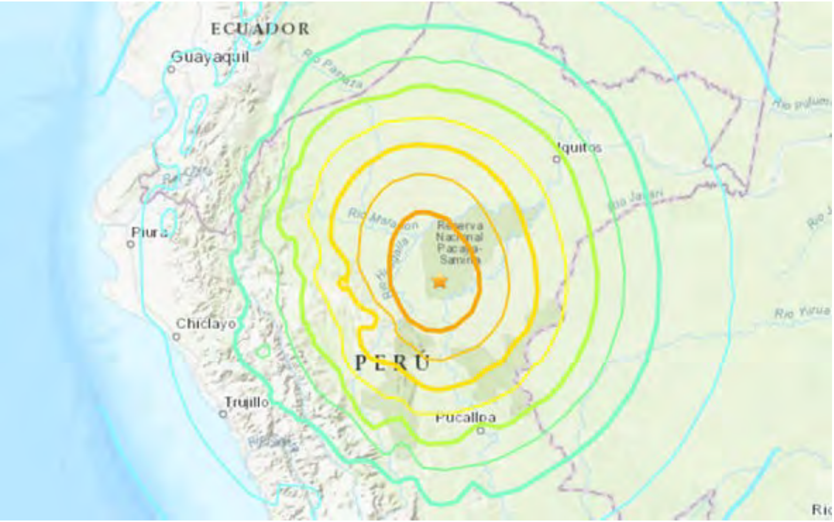


Figure: M8.0 Peru 05/26/2019, USGS ShakeMap

Why it matters

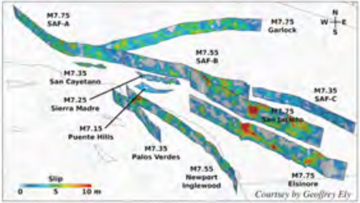
- Not occurring on known faults! Reccurrence/location?
- Earthquake *s*pectral models key to understanding ground motion for structural engineering

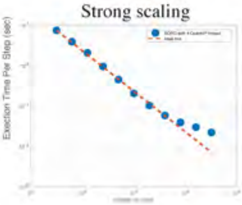
Blue Waters can help!

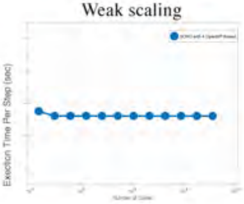
We can use dynamic rupture models to study larger intermediate depth earthquakes with more realistic physical models.

Code Details

- We used SORD (support-operator rupture dynamics), a staggered-grid split-node code as detailed in Ely, Day and Minter (GJI 2009).
- SORD has been modified by Yongfei Wang also to include hybrid OpenMP/MPI (new on Blue Waters)







Results

Dynamic simulation of the 145 km deep, 2006 Oita-Chubu event, M 6.4

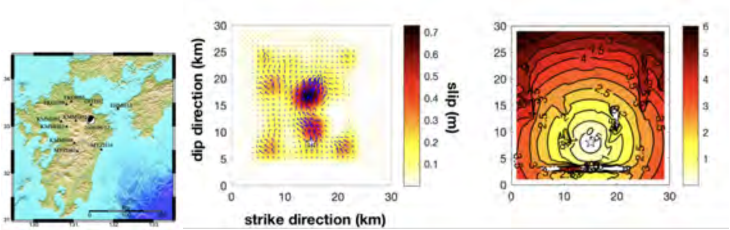


Figure: Map from Nagumo and Sasatani (2006), RHS shows final slip vectors and slip contours over time

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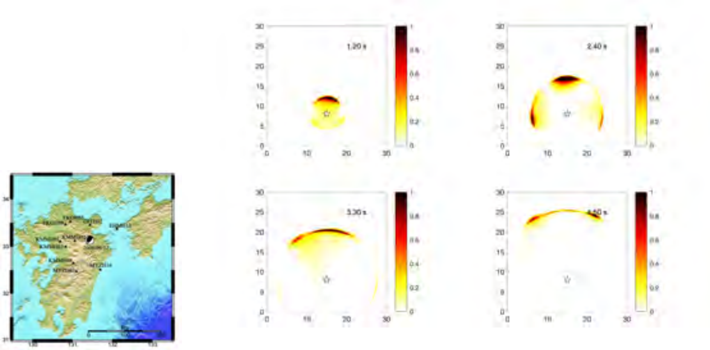


Figure: Map from Nagumo and Sasatani (2006), RHS shows snapshots of slip.

But could be improved

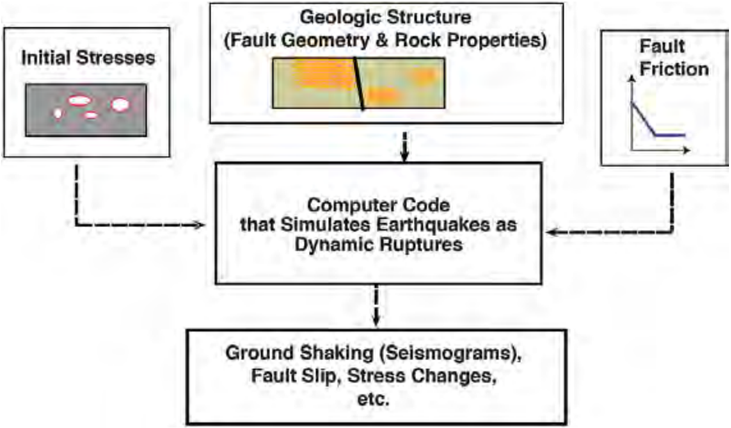
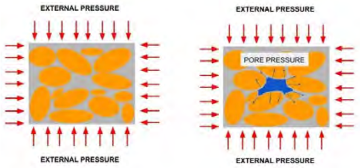
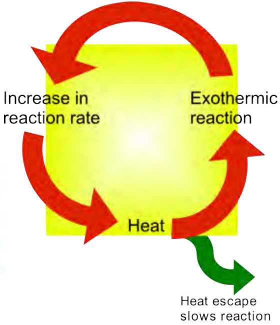


Figure: Harris, et al., SRL 2018

Remember these proposed mechanisms?





Intermediate-depth earthquakes have been hypothesized to display different physics...

$$f(D) = \begin{cases} \mu_s - (\mu_s - \mu_d) D/D_c & D \leq D_c \\ \mu_d & D > D_c \end{cases} \quad (1)$$

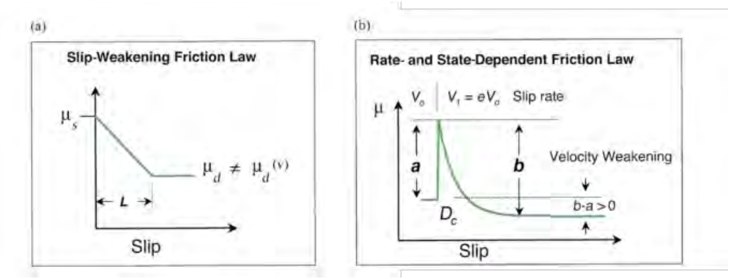


Figure: Marone and Saffer

This means different friction laws

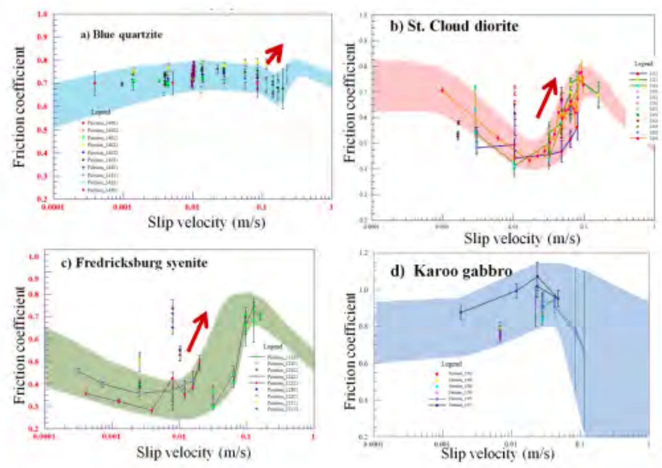


Figure: Liao and Reches, 2013

Some are harder to compute than others

We can solve two coupled PDEs at each node, and time step

$$\frac{\partial T}{\partial t} = \alpha_{th} \frac{\partial^2 T}{\partial z^2} + \frac{\omega(z, t)}{\rho c} \tag{2}$$

$$\frac{\partial p}{\partial t} = \alpha_{hy} \frac{\partial^2 p}{\partial z^2} + \Lambda \frac{\partial T}{\partial t} \tag{3}$$

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$$\frac{\partial T}{\partial t} = \alpha_{th} \frac{\partial^2 T}{\partial z^2} + \frac{\omega(z,t)}{\rho c} \tag{4}$$

$$\frac{\partial p}{\partial t} = \alpha_{hy} \frac{\partial^2 p}{\partial z^2} + \Lambda \frac{\partial T}{\partial t} \tag{5}$$

but it's possible to approximate the old friction law nonlinearly...

$$D_c = \frac{4\rho c}{\sqrt{\pi}\Lambda f}(\sqrt{\alpha_{hy} t} + \sqrt{\alpha_{th} t}) \tag{6}$$

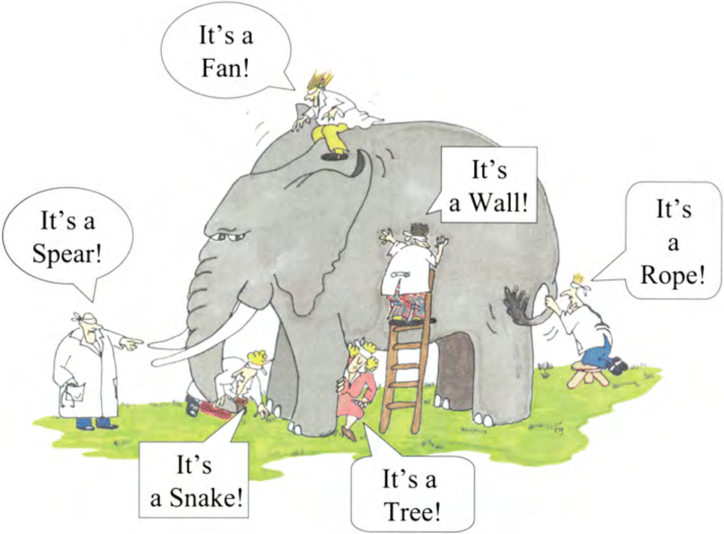

Figure: Google Images

Summary

- We used Blue Waters to simulate a large intermediate depth earthquake (M6.5), with a complicated rupture
- We are implementing alternative friction laws in our model, to better approximate the mechanics hypothesized for intermediate-depth earthquakes
- Blue Waters allows us to study larger intermediate-depth earthquakes, with better incorporation of physics
- We also hope to extend this analysis to more intermediate-depth earthquakes

Acknowledgements

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