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3D linked subduction, dynamic rupture, tsunami and inundation modeling

(Wirp et al. Front. Earth Sci., 2020)

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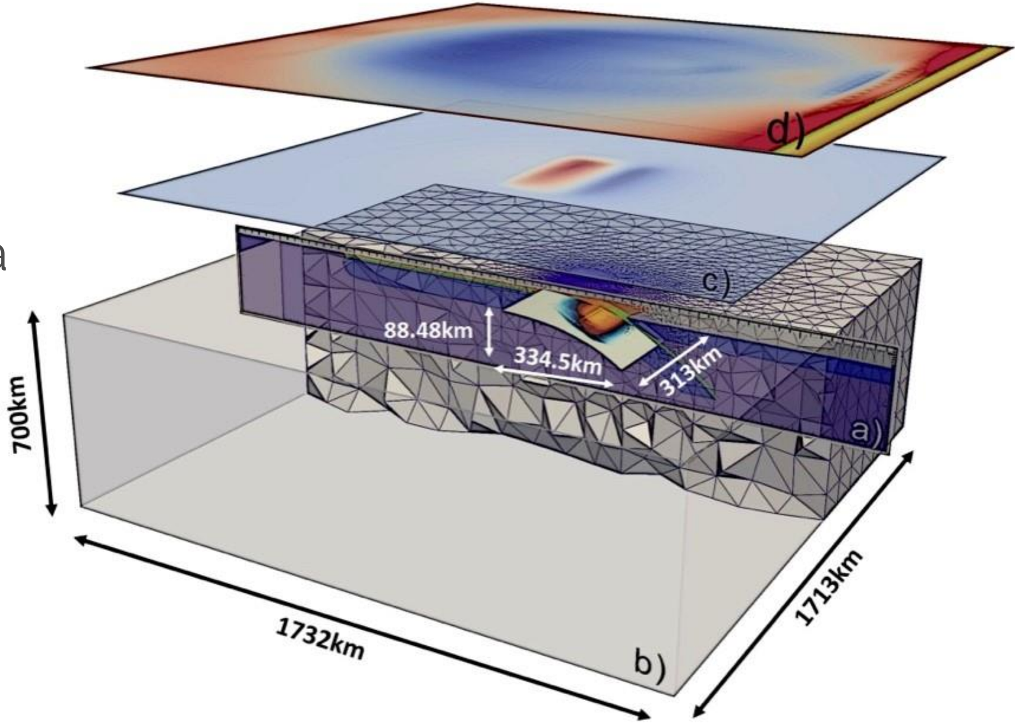
Linking steps

a) **Seismo-thermal-mechanical** model captures geodynamics and seismic cycle *(van Zelst et al., 2019)*

b) **Dynamic rupture modeling** of a single earthquake

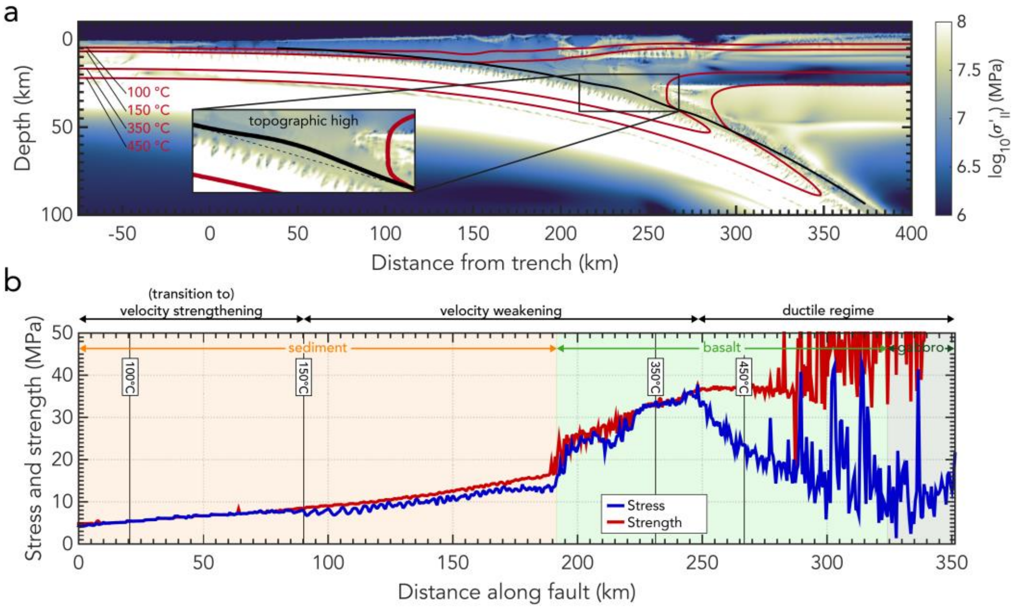
c) Time-depentend co-seismic **seafloor displacement**

d) Non-linear **hydrostatic tsunami propagation & inundation model**



Workflow adapted from Madden et al. 2020

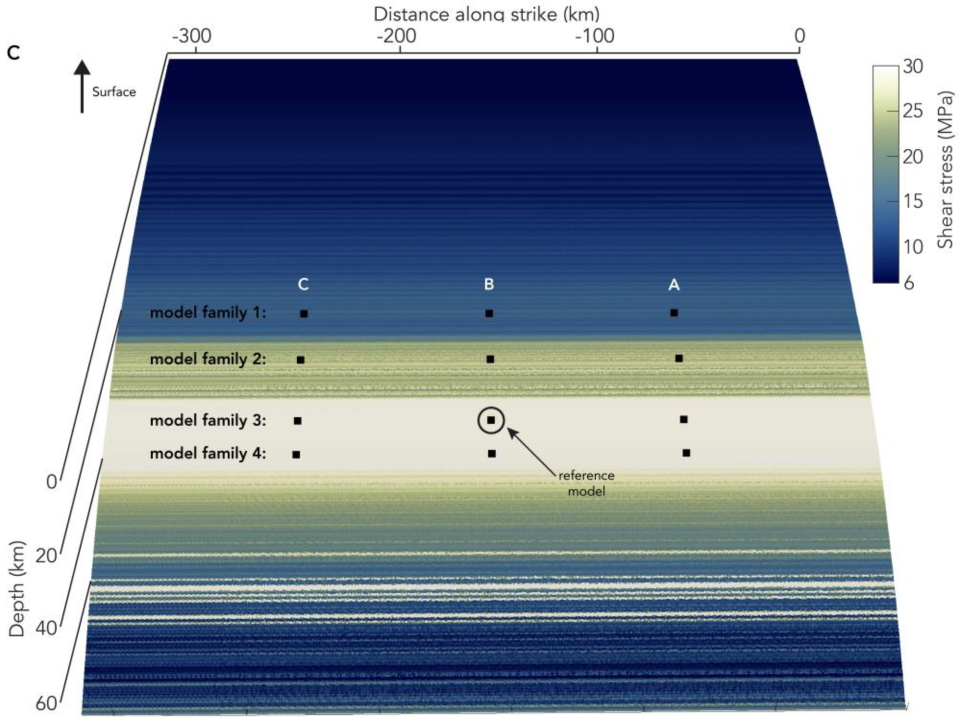
Initial earthquake conditions



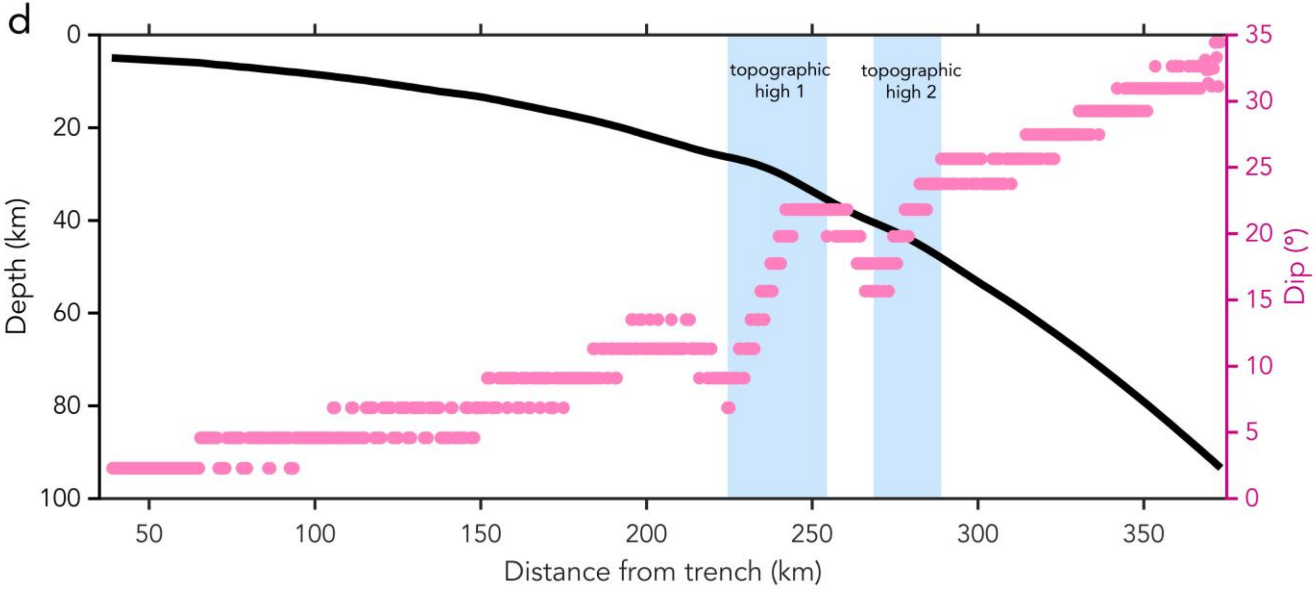
- Fault geometry evolves during long-term subduction process *(van Zelst et al., 2019)*
- Stresses and strength on the fault show potential "points of failure"
- Hypocenter choosen at failure locations

On fault stresses in 3D

- We copy all material properties to the 3rd dimension
- 4 model families with hypocenters at 25, 30, 40 and 45km depth
- Lateral hypocenter variation to 25% and 75% of the fault
- 1 reference model 3B



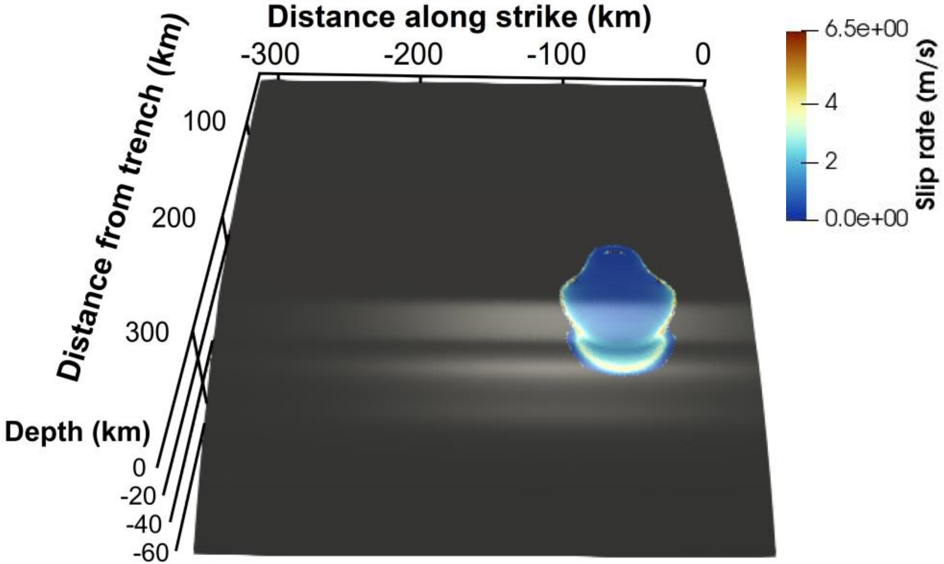
Fault geometry in 2D



- 2 sharp increases in fault dip
  - between 225 and 255km
  - between 270 and 290km
- Represent 2 **topographic highs** on the fault

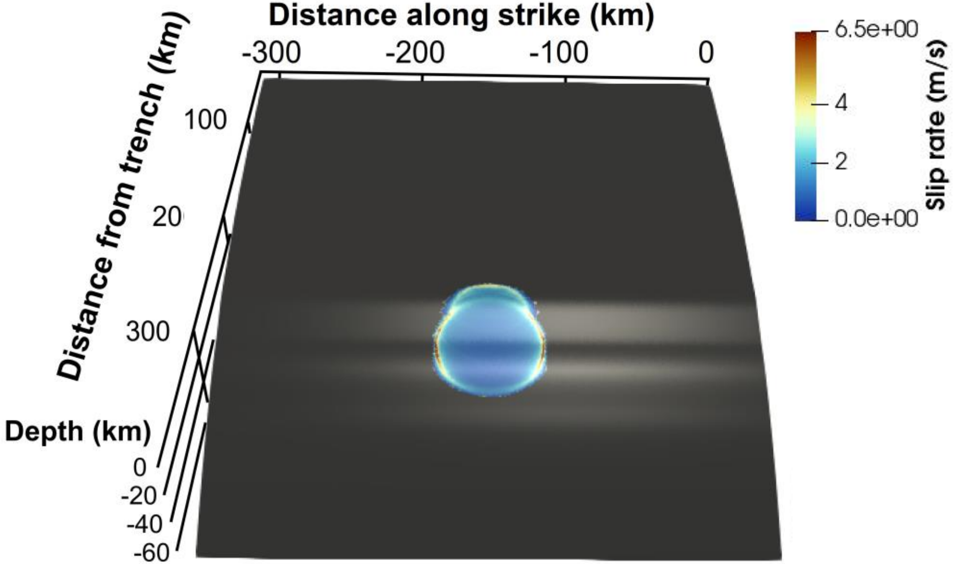
On-fault rupture evolution

- For shallow hypocenter we observe supershear evolution in **downdip** direction



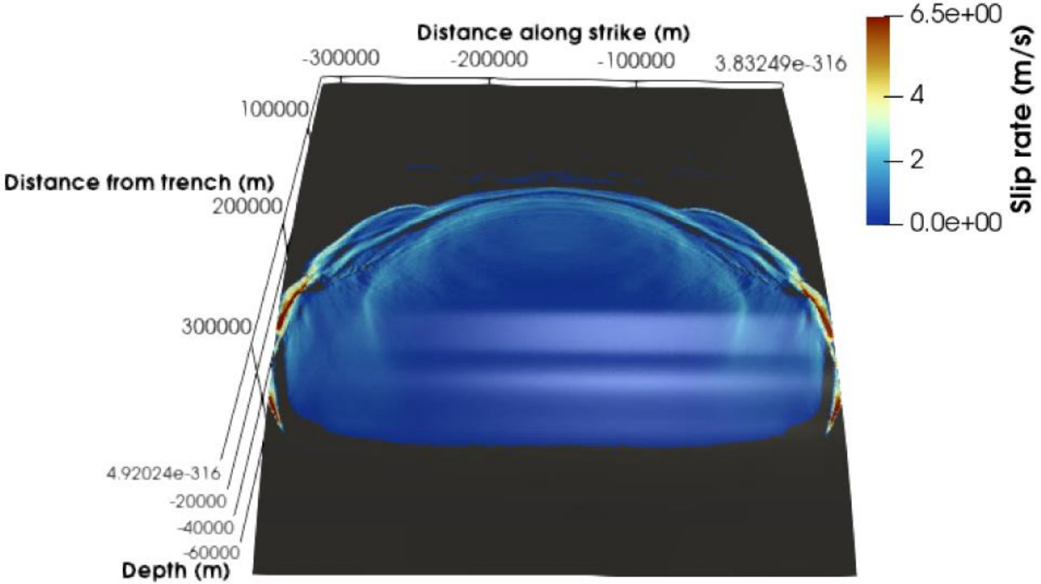
On-fault rupture evolution

- For deeper hypocenter we observe supershear evolution in **updip** direction

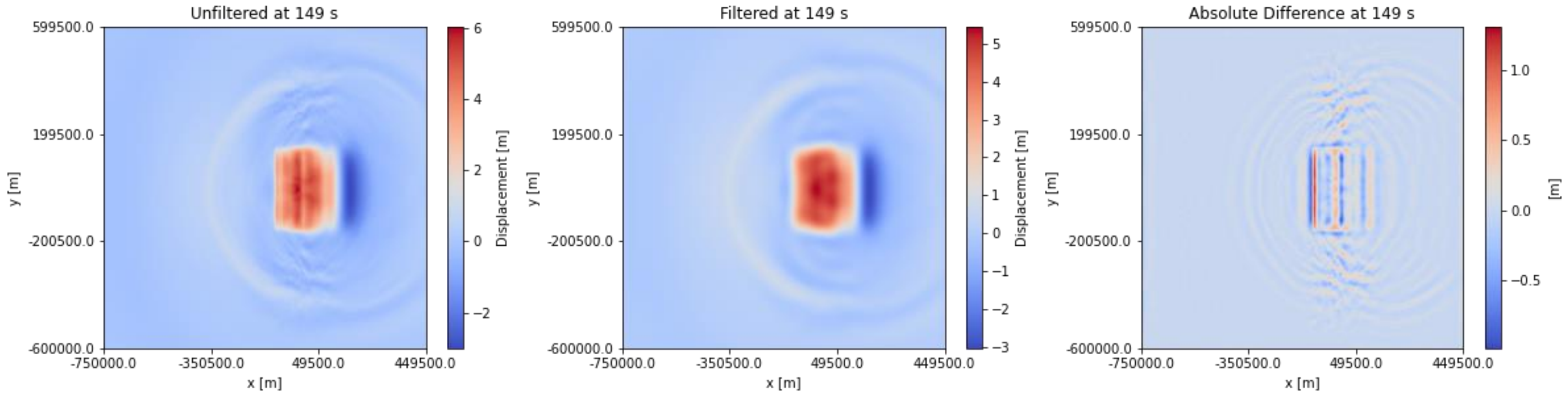


We observe

- Supershear triggered at topographic highs
- Barely a difference in rupture dynamics for different hypocenter depths
- Minor bimaterial effects for lateral varying hypocenter locations



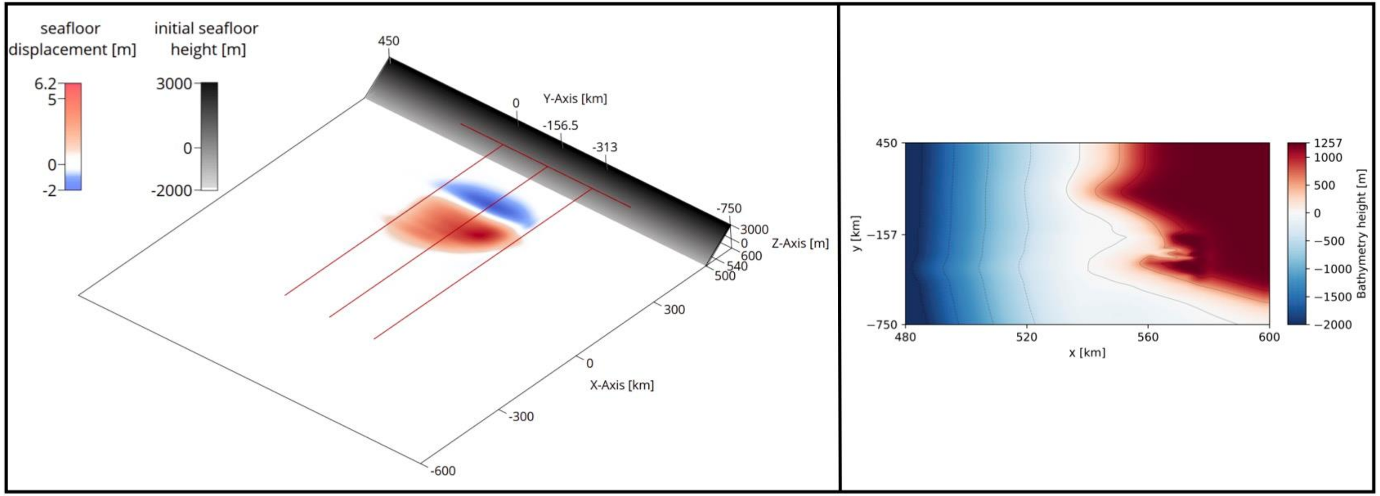
Seafloor displacement is filtered and used as time-dependent input for tsunami model sam(oa)^2-flash



- Apply Fourier filter to separate the significant frequency-wavenumber coefficients of the permanent displacement from the ones of seismic waves
- We erase seismic waves from the seafloor perturbation by designing a kernel to zero out the radial symmetric waves in the frequency-wavenumber representation

Tsunami setup

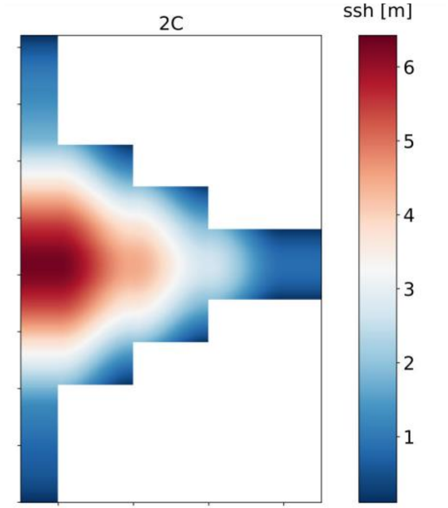
1. Linear sloping beach
   - toe at x = 500 km with an inclination of 5%
   - coastline is located at x = 540 km



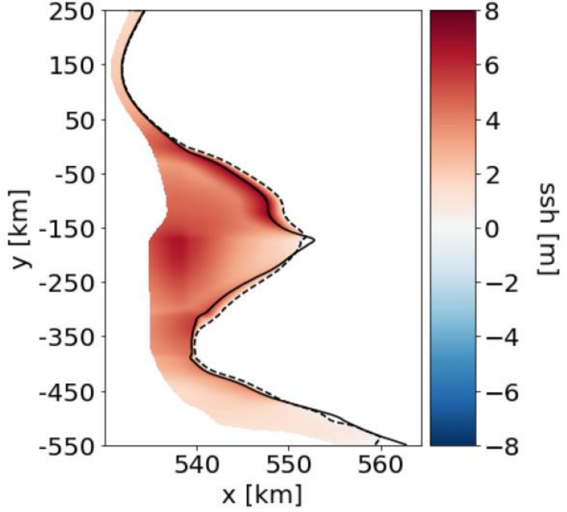
2. Complex beach based on Okushiri geometry

(Yeh et al., 1996)

Seasurface height linear and complex coast

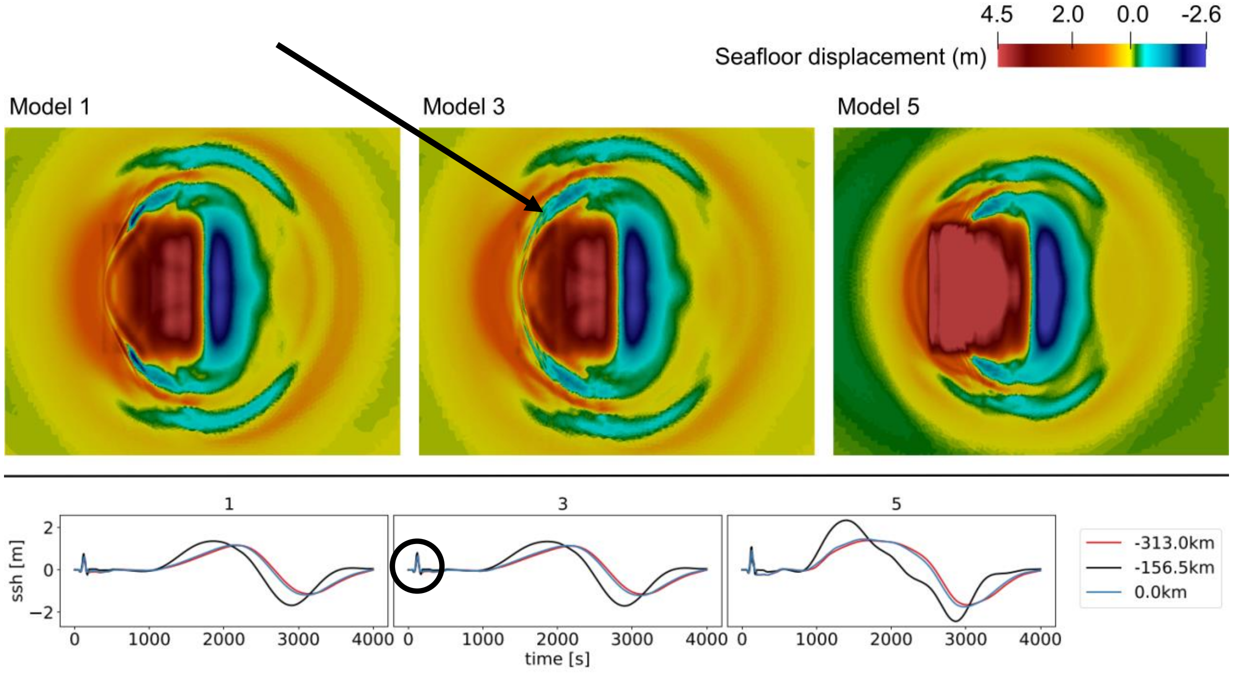


- Linear sloping beach: ssh max. 6.5 meter
- Complex beach geometry: ssh max. ~8 meter



Co-seismic ocean response phases

- Reflect the acoustic, seismic and near-field displacements around the rupture front
- Appear for supershear earthquakes as well as for the “tsunami earthquake”
- Propagate within the DR model and during the dynamic tsunami generation process



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In a next step we

- Increase Poisson's ratio from 0.25 to 0.3

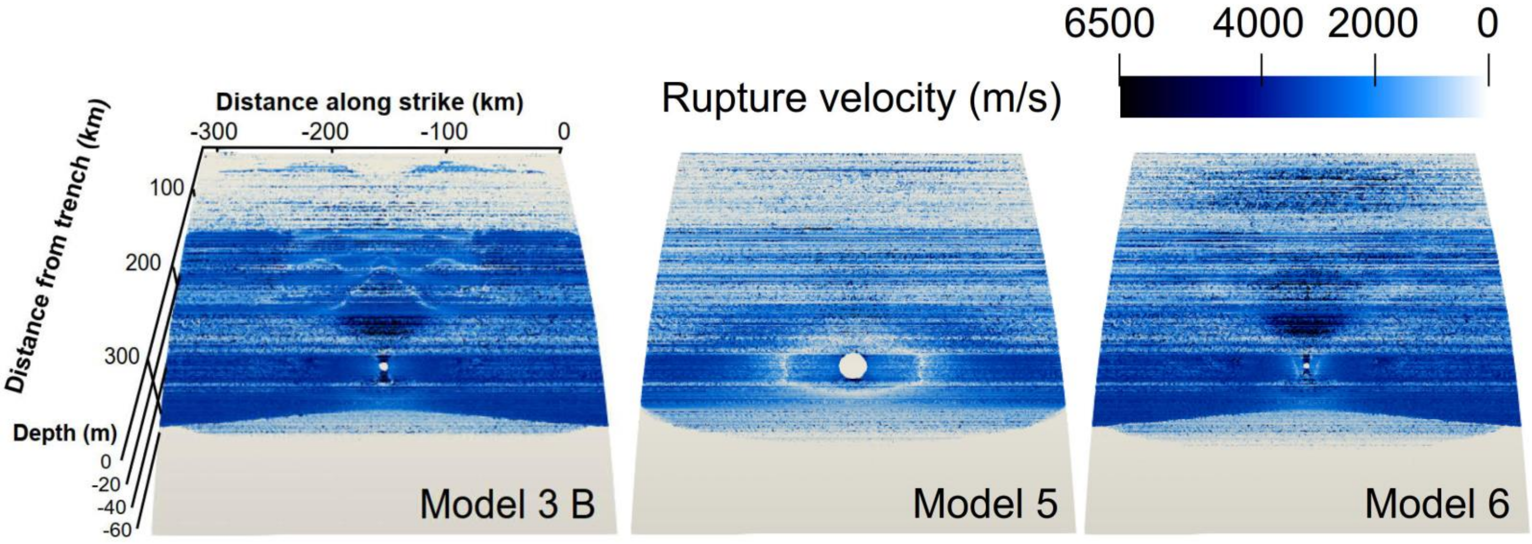
  → model 5

- Triple fracture energy by increasing the critical slip weakening distance Dc from 0.1 to 0.3

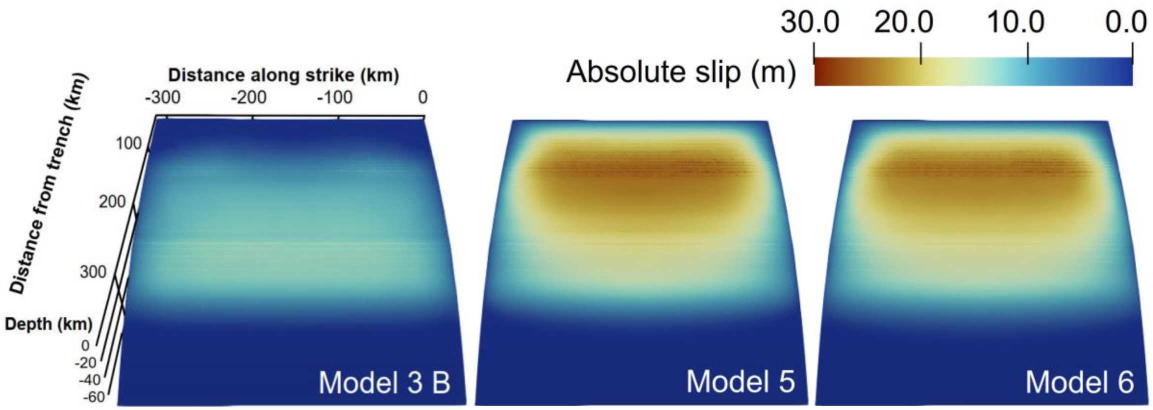
  → model 6

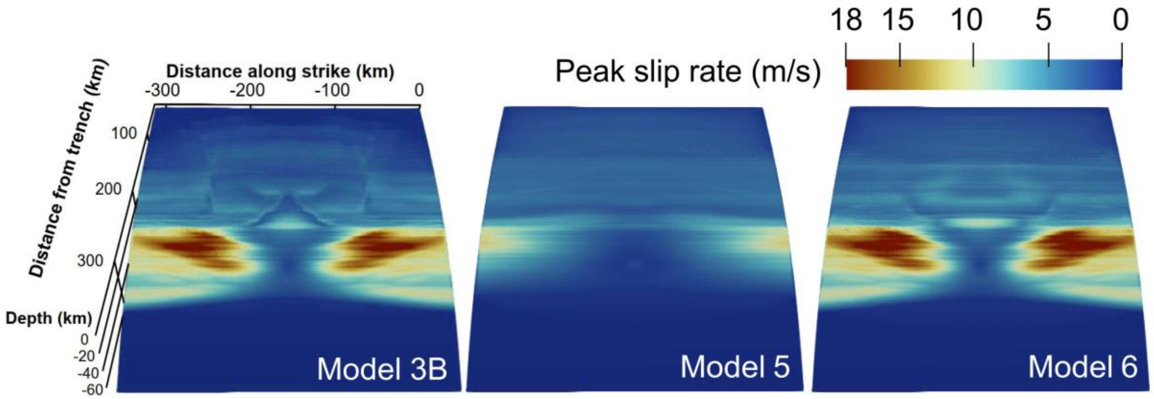
Dynamic Rupture results

- **Model 3B** (reference model, unchanged): supershear in updip direction
- **Model 5** (increased fracture energy): low rupture speed
- **Model 6** (increased Poisson's ratio): supershear in updip direction



Dynamic Rupture results

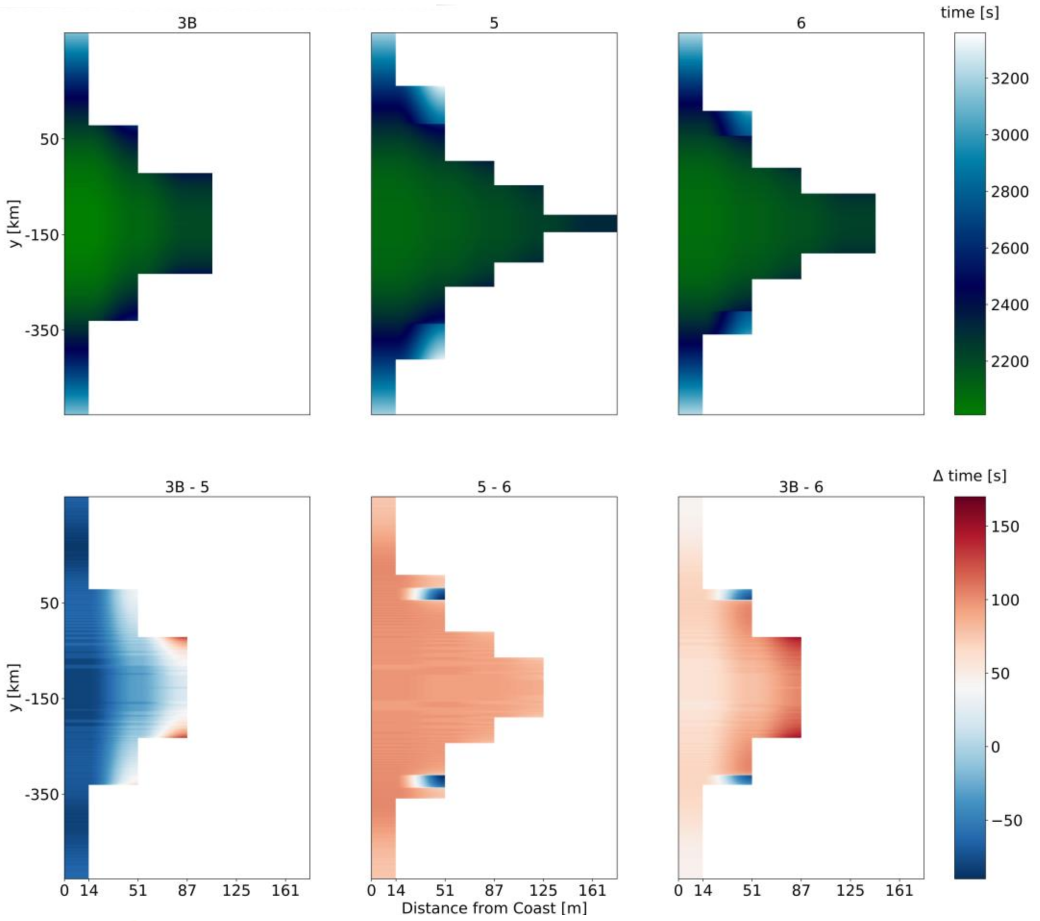




- Model 3B: high peak slip rate and low final slip
- Model 5: low peak slip rate and highest amount of shallow slip
- Model 6: high peak slip rate and large amount of shallow slip

Inundation results at the coast

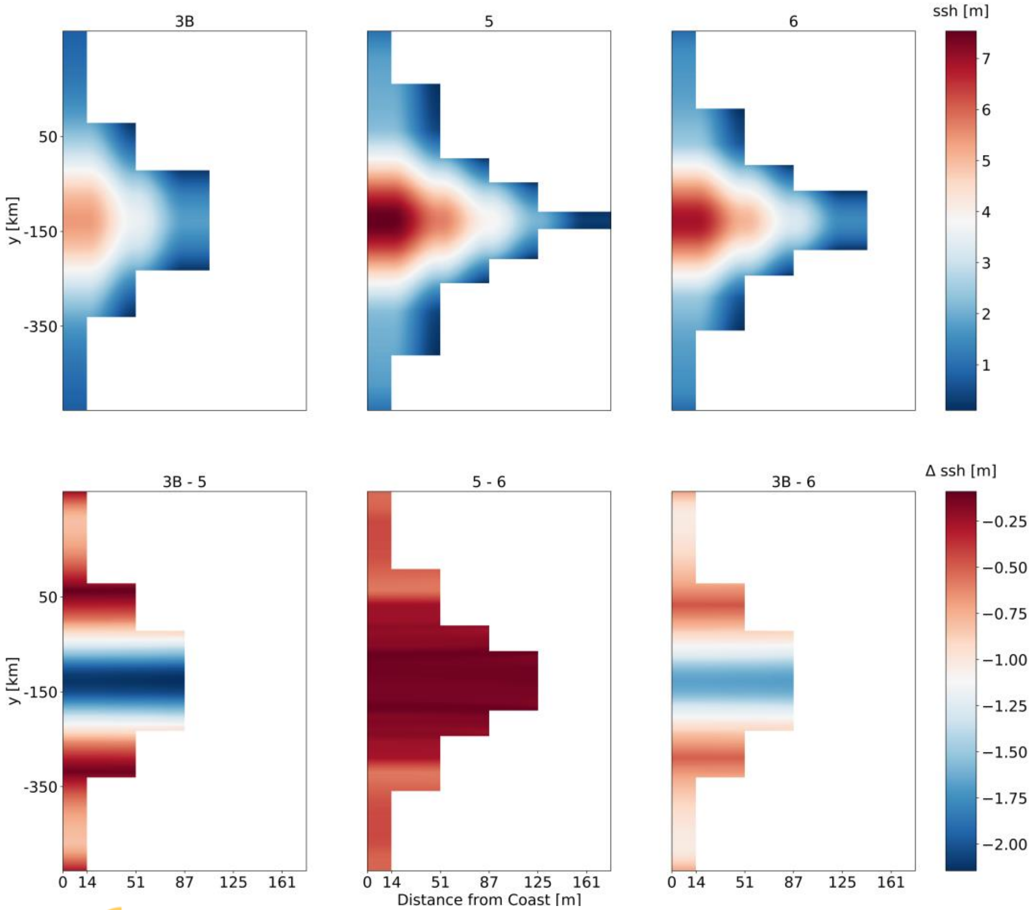
- Latest arrival and greatest inundation area for model 5
- Similar arrival time for model 3B and 6



Seasurface height at the coast

- Highest sea surface height for model 5, ~7.5 meter
- Ssh of model 6 ~0.25m lower
- Lowest sea surface height for reference model 3B, ~5.5 meter

→ **Model 5: Tsunami model**



Summary

- Supershear is triggered at topographic highs
- Barely a difference in rupture dynamics for different hypocenter depths
- Minor bimaterial effects
- Higher Poisson's ratio facilitates slip and leads to higher seafloor uplift and greater tsunami amplitude
- Higher fracture energy → tsunami earthquake with low rupture velocity, high amount of shallow slip and greatest tsunami

(Wirp et al., Front. Earth Sci. 2020)

Future worst-case DR-tsunami scenarios should include

Complex coastline
Earthquake with low rupture speed and accumulated shallow slip
Seafloor bathymetry to account for shoaling effect