Tsunami generation due to supershear earthquakes: a case study

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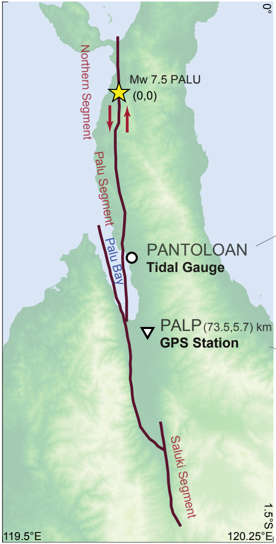
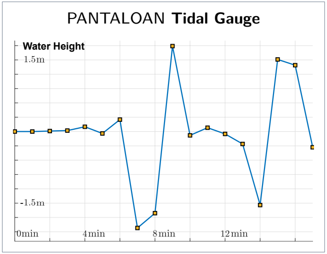
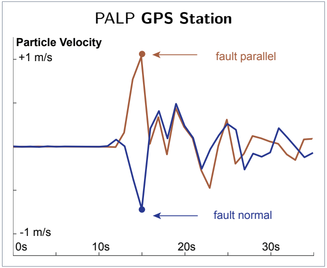
The 2018 Sulawesi earthquake and Palu bay tsunami



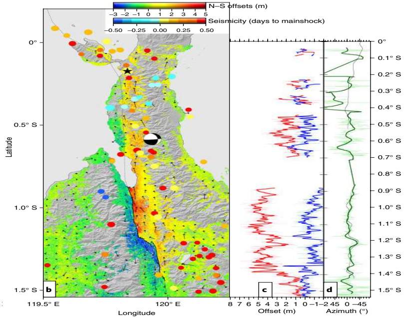




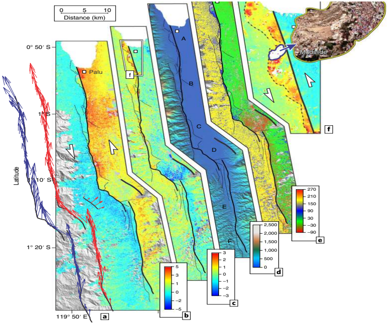
Far field evidence of a supershear rupture at Palu

- Supershear speed inferred from short-duration of moment release, smoothness of fault geometry and lack of significant aftershocks

Geodetic data



Rupture speed between 4.3 and 5.2km/s

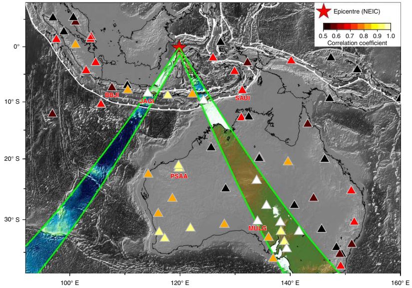


A Socquet, J Hollingsworth, E Pathier, M Bouchon, *Nature Geoscience* (2019)

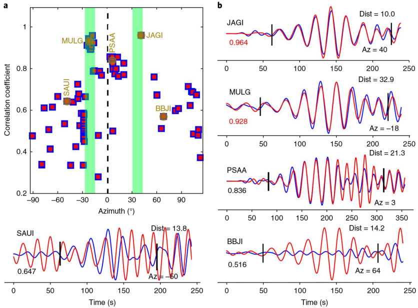
Far field evidence of a supershear rupture at Palu

- Supershear speed inferred from back-projection of teleseismic data and from far-field Rayleigh mach waves

Teleseismic data



Rupture speed of 4.1km/s

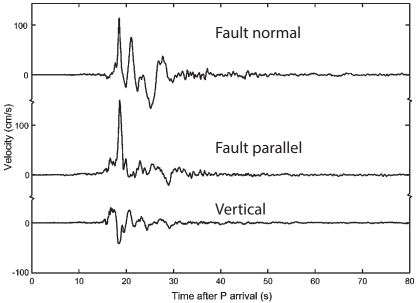


H Bao, JP Ampuero, L Meng, EJ Fielding, C Liang, CWD Milliner, T Feng, H Huang, *Nature Geoscience* (2019)

Searching for unmistakable signatures in the near field

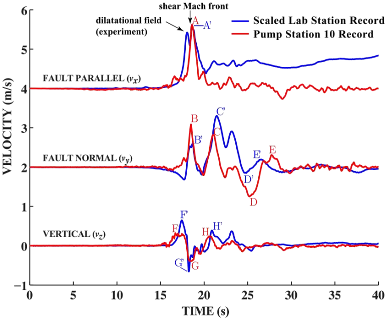
- Trailing Rayleigh wave
- Fault parallel velocity > fault normal
- Dilatational field

2002 Denali **accelerometer data** (PS10, 250Hz)



📖 WL Ellsworth, M Celebi, JR Evans, EG Jensen, R Kayen, MC Metz, DJ Nyman, JW Roddick, P Spudich, CD Stephens, *Earthquake Spectra* (2004)

2002 Denali **lab experiments**



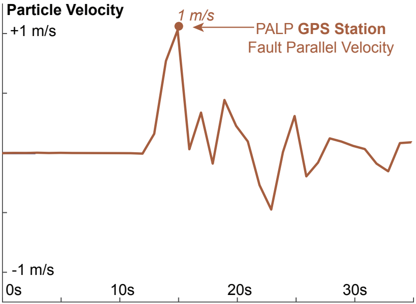
📖 M Mello, HS Bhat, AJ Rosakis, H Kanamori, *Earth and Planetary Science Letters* (2014)

📖 E Dunham & R Archuleta, *Bulletin of the Siesmological Society of America* (2004)

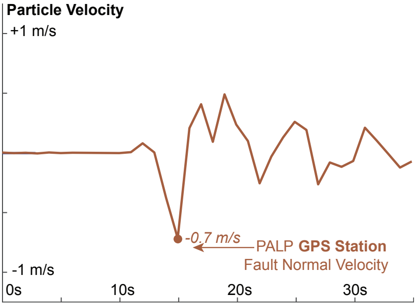
First near field evidence of a supershear rupture at Palu

- Trailing Rayleigh wave
- **Fault parallel velocity > fault normal**
- Dilatational field

2018 Palu GPS fault parallel data (PALP, 1Hz)

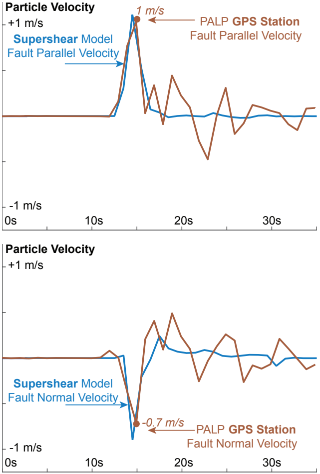


2018 Palu GPS fault normal data (PALP, 1Hz)

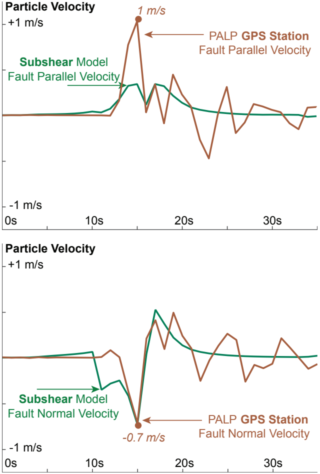


Further verification via dynamic rupture models

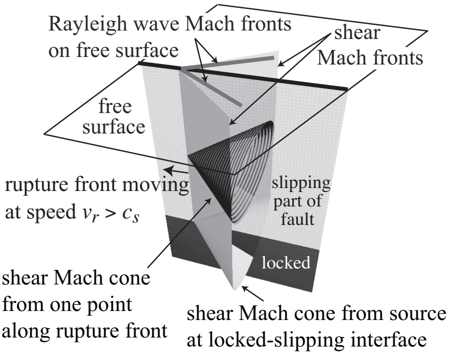
Supershear rupture $(1.6c_s)$

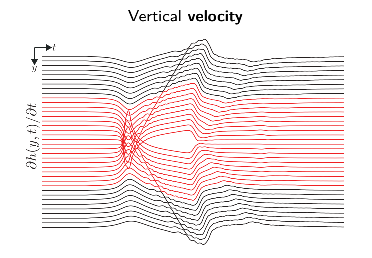


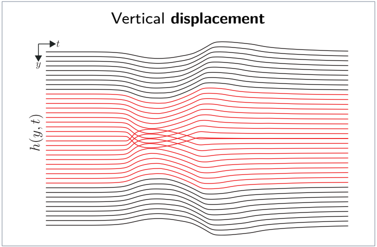
Subshear rupture $(0.8c_s)$



A few words on supershear theory



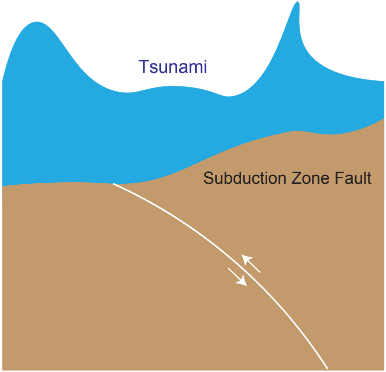




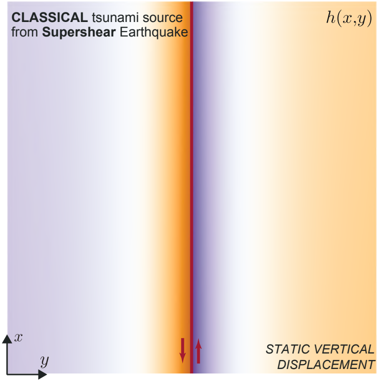
EM Dunham & HS Bhat, *Journal of Geophysical Research* (2008)

Classical displacement-based tsunami models

Vertical bathymetry displacement

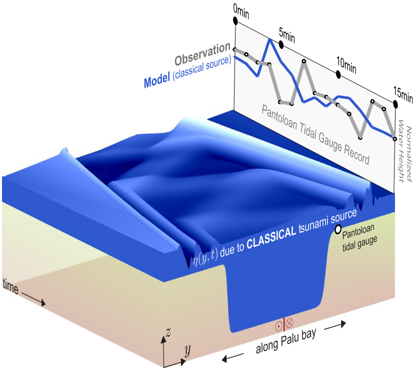


No Mach signatures

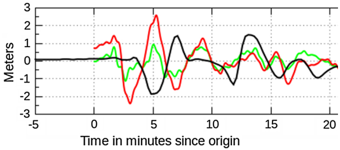


Classical displacement-based models applied to Palu

1D bathymetry (**static displacement**)

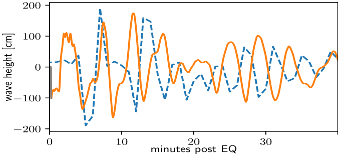


2D bathymetry (**static displacement**)



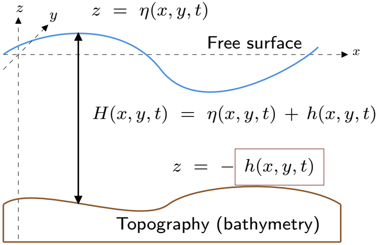
A Jamelot, A Gailler, Ph Heinrich, A Vallage, J Champenois, *Pure and Applied Geophysics* (2019)

2D bathymetry (**time-dependent displacement**)



T Ulrich, S Vater, EH Madden, J Behrens, Y Van Dinther, I Van Zelst, EJ Fielding, C Liang, A-A Gabriel, *Pure and Applied Geophysics* (2019)

Incorporating dynamic ground motion



$\mathbf{u}$:= velocity

H := total height

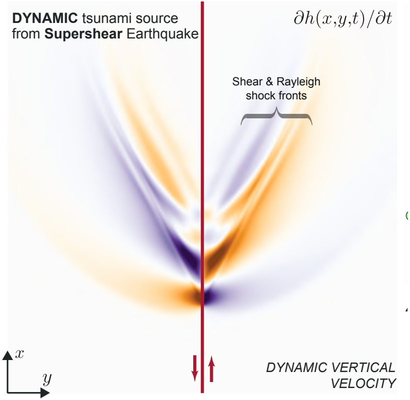
η := height from free surface

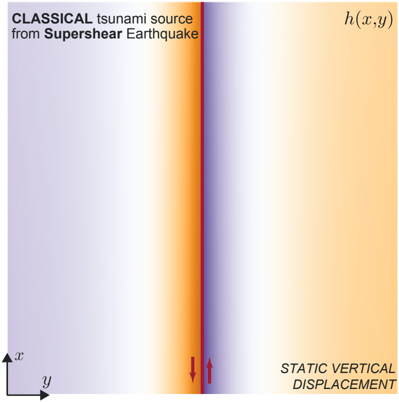
h := bathymetry height (rest + source)

g := gravitational constant (9.8m/s^2)

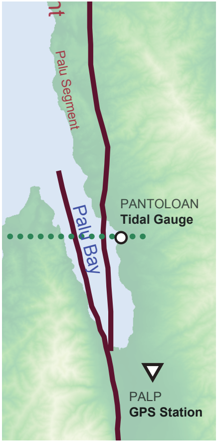
$$\begin{cases} \frac{\partial H}{\partial t} + \nabla \cdot (H\mathbf{u}) = 0 \\ \frac{\partial (H\mathbf{u})}{\partial t} + \nabla \cdot \left(H\mathbf{u} \otimes \mathbf{u} + \frac{1}{2} g H^2 \right) = gH\nabla h \end{cases} \Longleftarrow \begin{array}{c} H(x,y,t) = \eta(x,y,t) + \boxed{h(x,y,t)} \\ \frac{\partial H(x,y,t)}{\partial t} = \frac{\partial \eta(x,y,t)}{\partial t} + \boxed{\frac{\partial h(x,y,t)}{\partial t}} \end{array}$$

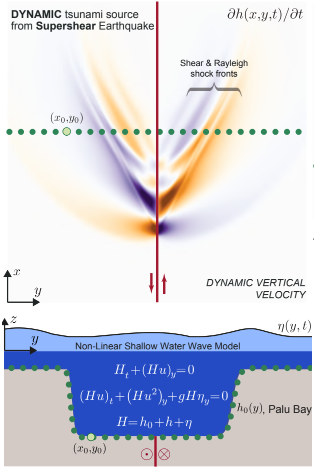
Sourcing with supershear dynamics





Modeling the Palu bay configuration in 1D

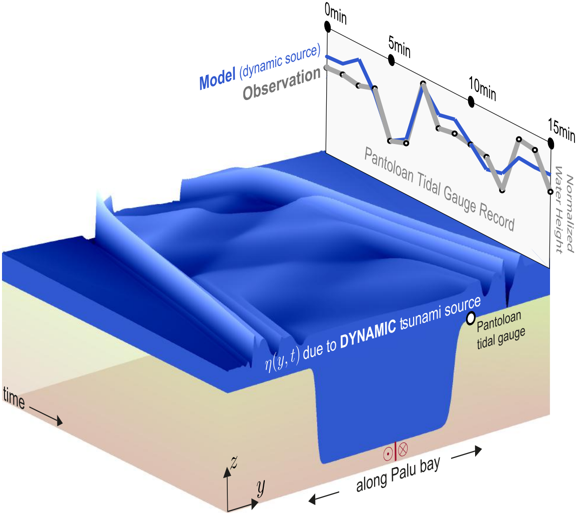


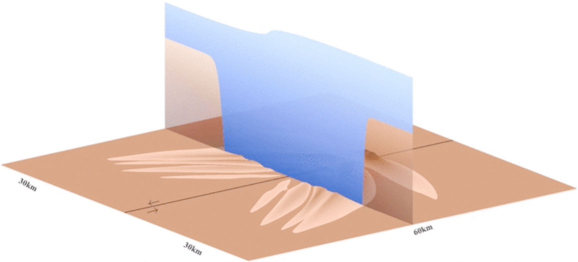


Robust numerical resolution via explicit Fourier continuation:

- F Amlani & NM Pahlevan, *Journal of Computational Physics* (2020)
- F Amlani & OP Bruno, *Journal of Computational Physics* (2016)

Capturing the first motions and arrivals





- The Palu **earthquake went supershear** (*Socquet et al, Bao et al*, this work)
    - The supershear **shock fronts caused the tsunami motion** (this work)
- Palu's **shallow bay amplified the tsunami displacement** (*Ulrich et al, Jamelot et al*, etc.)

Preprint available on **arxiv:1910.14547**