Simulation of Translational and Rotational ground motions

A Short Presentation

Presented by
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Post-doctoral Research Associate
Institute of Geophysics
University of Hamburg, Germany

May 27, 2022

The Seismic Source

- The characteristics of seismic waves depend on:
  1. Earthquake source
  2. Medium of wave propagation
  3. Boundary conditions

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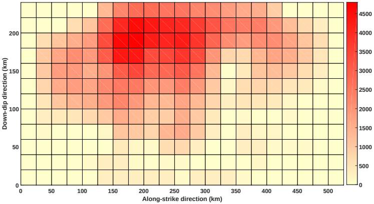

Tohoku (2011) source model

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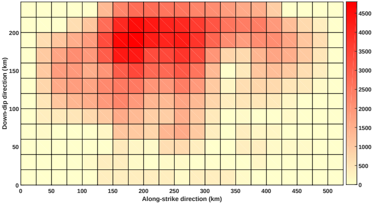
  - Seismic sources are represented as rectangular regions with slip distributed over the surface of the fault plane
  - Extreme slips are observed near the hypocenter and are responsible for the peak amplitude observed in simulated ground motions



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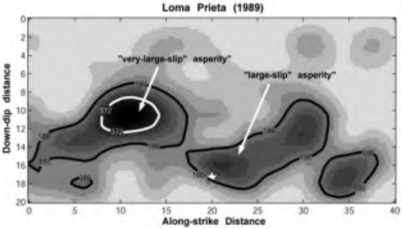
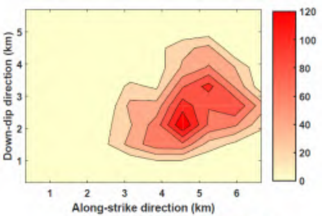
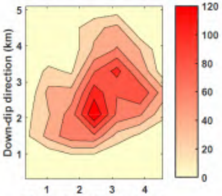


Asperities in literature (Mai et al.,(2005))

The Seismic Source
Regions of SMG in rupture model

- Effective Dimensions
  - Effective slip dimensions are defined such that, each sub-fault of the effective slip contributes to 90% of total cumulative energy





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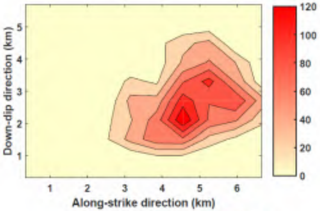
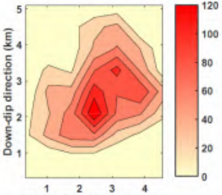
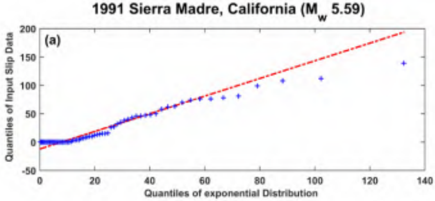




- Regions of Strong Motion Generation
  - Q-Q plot shows that higher values of slip tend to deviate from standard exponential distribution.



Q-Q plot for 1991 Sierra Madre earthquake

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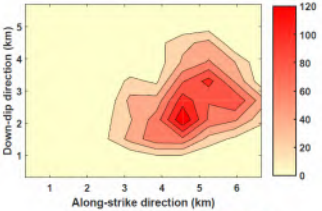

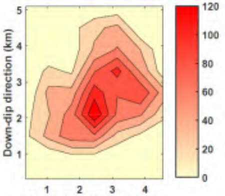

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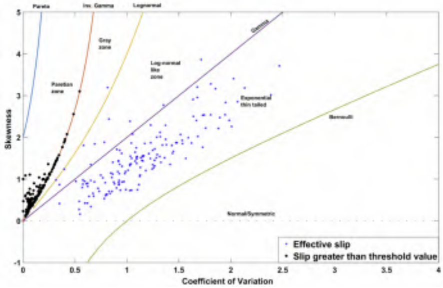

CV-Skewness plot

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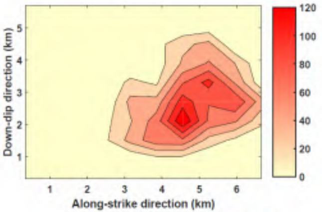
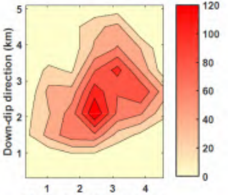
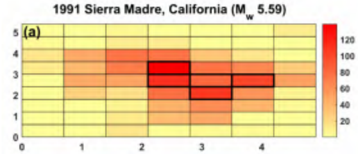




- Regions of Strong Motion Generation
  - Q-Q plot shows that higher values of slip tend to deviate from standard exponential distribution.
  - Finally, we get the regions of SMG



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Regions of SMG in rupture model

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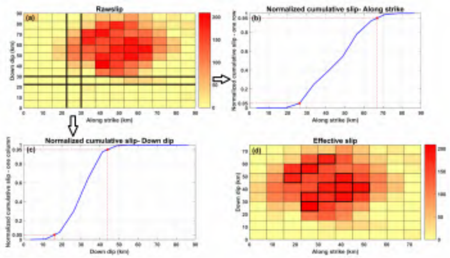

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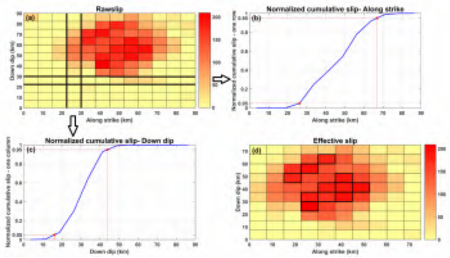

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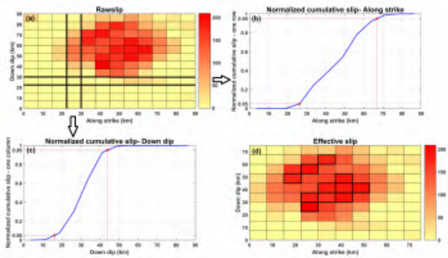

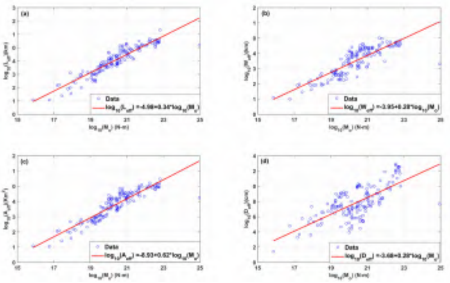

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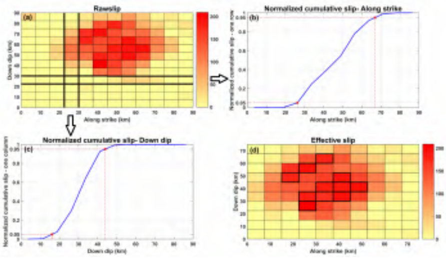

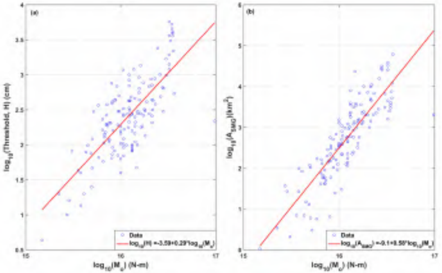

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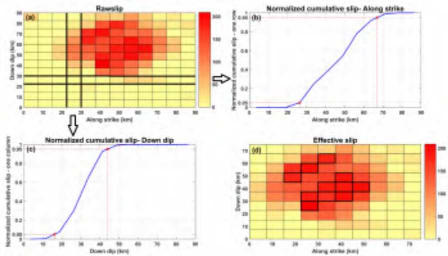

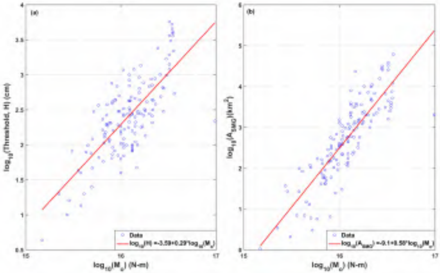

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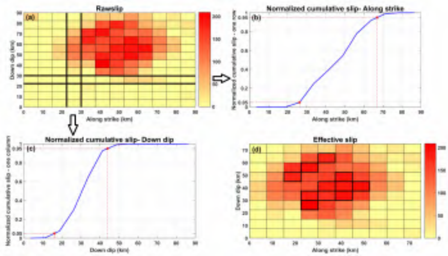

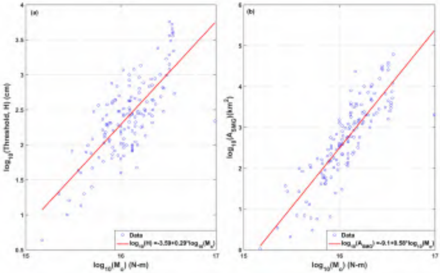

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- These equations can be used to predict the rupture parameters for future earthquake
- DOI: 10.1007/s00024-019-02136-0

Medium of Wave Propagation
Homogeneous Reduced Micropolar half-space

- The equations of motion for reduced micropolar half space (RMP) are:

$$c_1^2 \nabla\nabla \bullet \vec{u} - c_2^2 \nabla \times \nabla \times \vec{u} + \frac{j w_0^2}{2} \nabla \times \vec{\Theta} - \ddot{\vec{u}} = 0$$

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  - λ is Lame's constant
  - μ is Eringen's shear modulus
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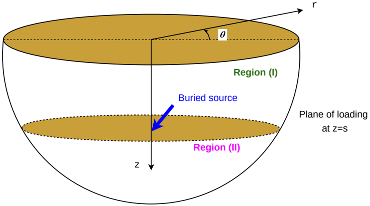

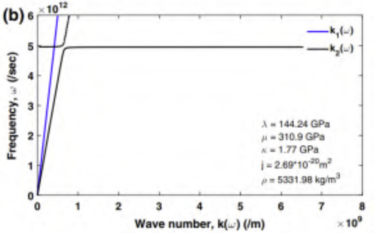

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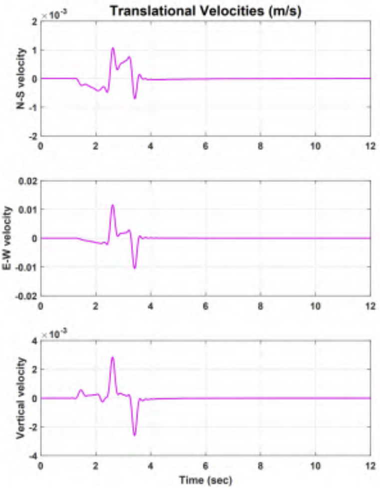
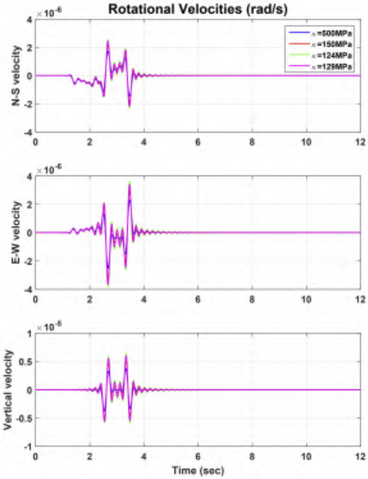


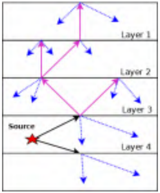
Pure and Applied Geophysics. DOI:10.1007/s00024-019-02225-0



Journal of Seismology. DOI: 10.1007/s10950-021-09983-2

Medium of wave propagation
Layered Reduced Micropolar half-space

- Now, the Earth medium is modelled as layered RMP half-space subjected to earthquake forces.



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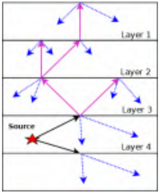
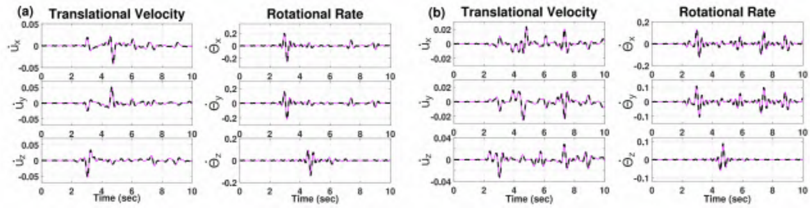
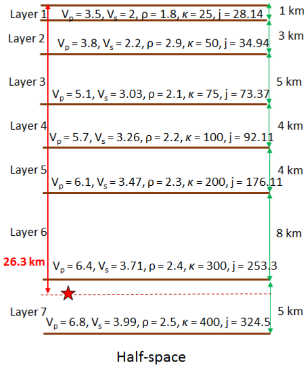
- Now, the Earth medium is modelled as layered RMP half-space subjected to earthquake forces.
- The methodology is first validated with the simulations for a classical elastic medium.





Medium of Wave Propagation
Layered Reduced Micropolar half-space

- For $6M_w$ 2012 Wutai, Taiwan earthquake with focal depth of $26.3km$ and radial distance $161km$



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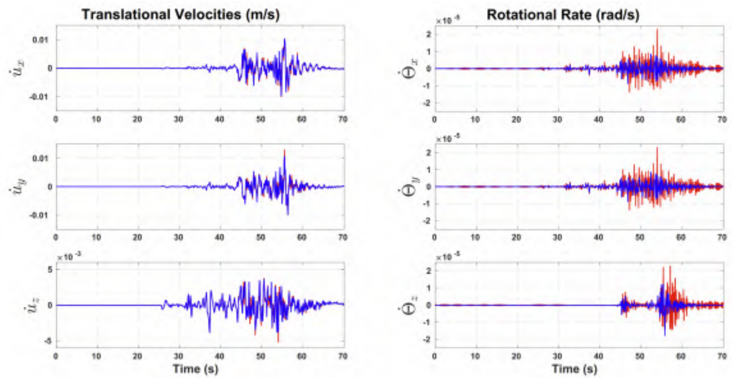
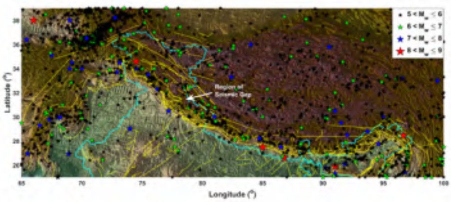


- The simulated peak rotation about vertical axis ($5.5 \times 10^{-5} rad/s$) is in close match with the recorded peak rotation of $5 \times 10^{-5} rad/s$
- Published in: JGR: Solid Earth (DOI: 10.1029/2020JB020931)

Boundary conditions

Amplification of ground motions due to topography

- What will be the effect of 3D Himalayan topography subjected to P, SV and SH waves together??
- It is difficult to incorporate complex topography like the Himalayas in analytical simulation approaches



Past earthquakes in northern India

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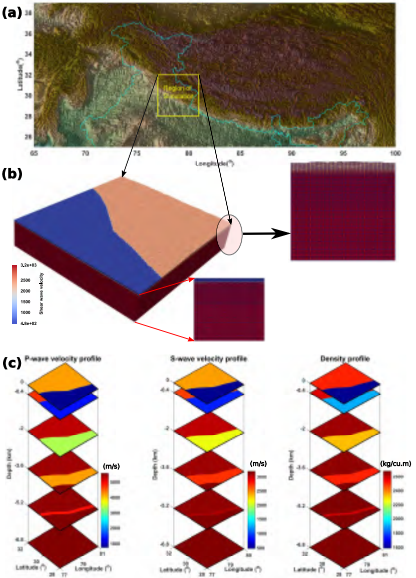

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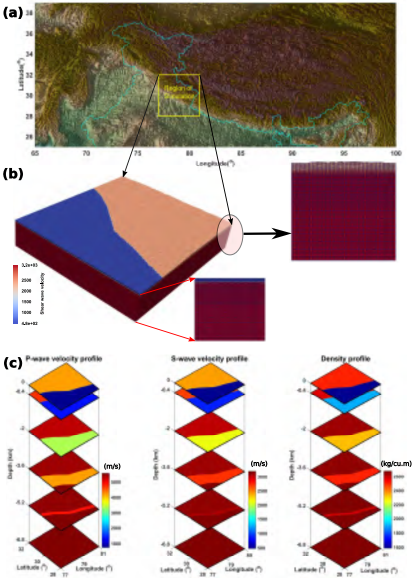
- The region under consideration consists of both the Himalayas and the Indo-Ganga basin
- The model incorporates topography and three dimensional material properties for the Himalayas and the Indo-Ganga basin



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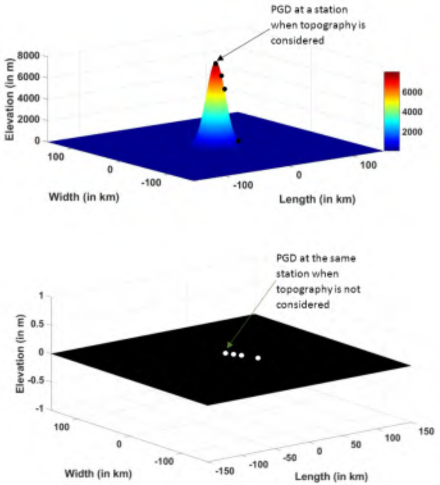

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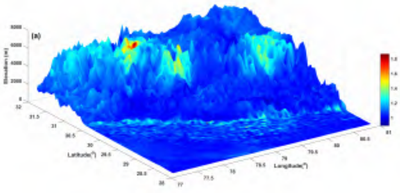
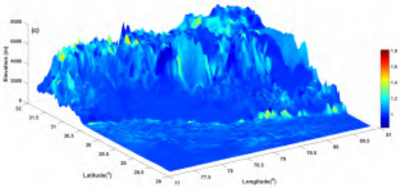


Horizontal direction



Vertical direction

Boundary conditions
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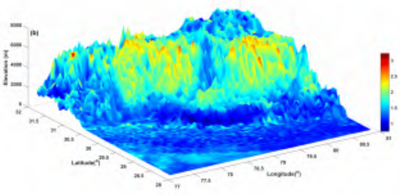
- Amplification observed in the horizontal and vertical direction for
  1. Ground displacement
  2. Ground velocity
- Regression analysis is carried out to determine the variation of these amplification ratios wrt to elevation.



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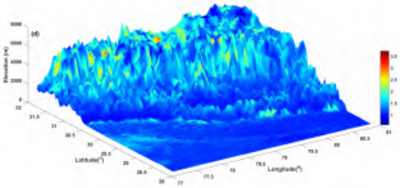


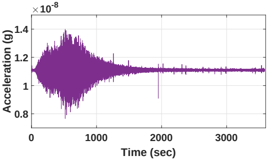
Vertical direction

- Published in: AJGS

Quakes just on Earth??

Ground motion simulations on other planets

- Planetary explorations have shown seismic activities on Mars and Moon.



Ground motion recorded on Moon

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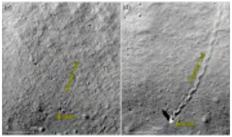

Boulder trails marked on Satellite images (Kumar et al., (2016))

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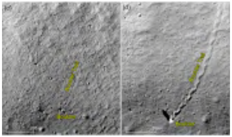
- By static analysis, the minimum PGA required to topple a body is equal to its aspect ratio B/H



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- In the absence of recorded data, seismic activity is understood by the overturning of boulders when subjected to ground motions
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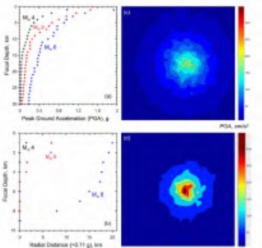
- On Mars, high frequency ground motions are simulated using stochastic seismological model to:
  1. estimate PGA
  2. the radius upto which boulder toppling can be encountered



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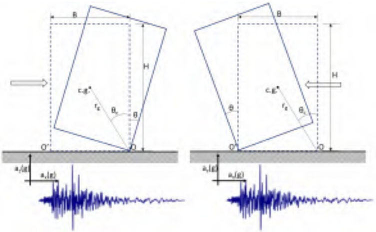

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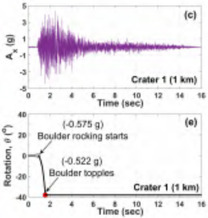
- So, on Moon, ground motions are simulated and dynamic analysis for boulder toppling is carried out



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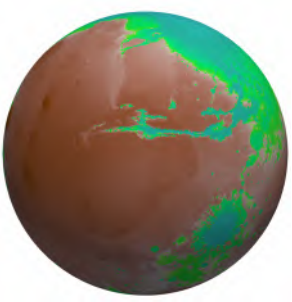

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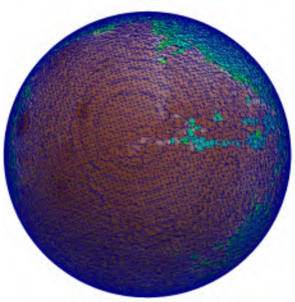

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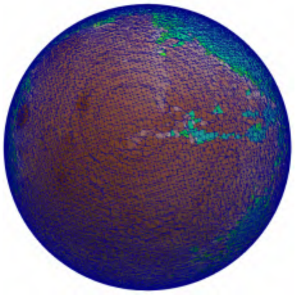

Globe model of Mars

- The developed finite element model incorporates
  1. topography
  2. 3D material properties
  3. multiple orbit waves

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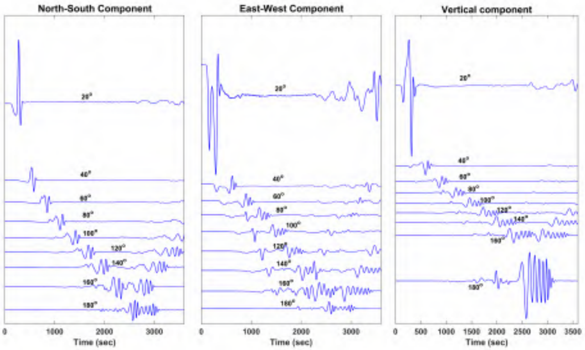
- Published in EPSL and GRL



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- **COMPLEX TOPOGRAPHY**
  - Ground displacements and velocities are amplified due to the presence of Himalayan topography. So, it is important to consider the topography of a region to obtain ground motions

Thank you for your attention!

Questions??

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