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Anisotropic strength of fault zones suggested from geodesy and seismic imaging: Example from the Main Himalayan Thrust

Keywords: Fault structure, fault strength, coseismic deformation, receiver functions, anisotropy

Category: SDOT

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1. Abstract

Combine InSAR, GPS, seismic observations to image structure and behavior of Main Himalayan thrust fault (MHT) near 2015 M7.8 Gorkha event

Data: Geodesy - coseismic InSAR tracks, GPS offsets; Seismology - azimuthal analysis of receiver functions (RF), HICLIMB, NAMASTE, HIMNT experiments

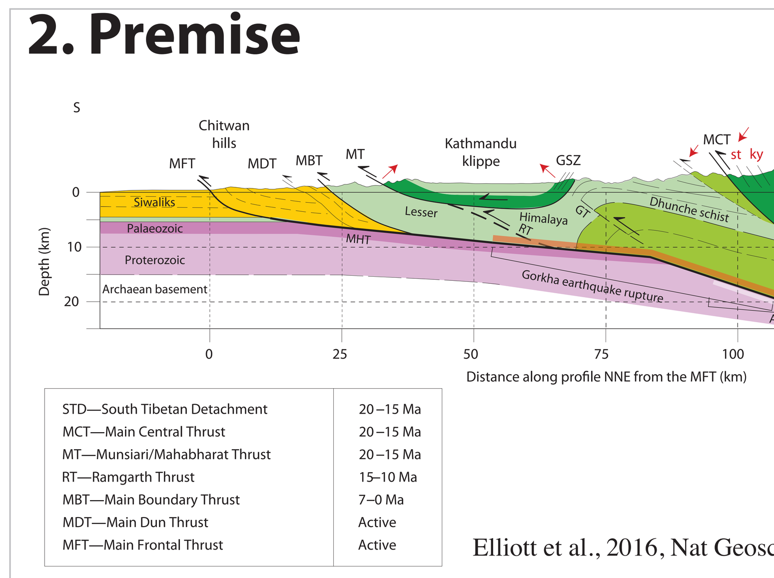
Question: Previously proposed low-velocity layer at MHT - implies weak layer. May also be anisotropic (RF)

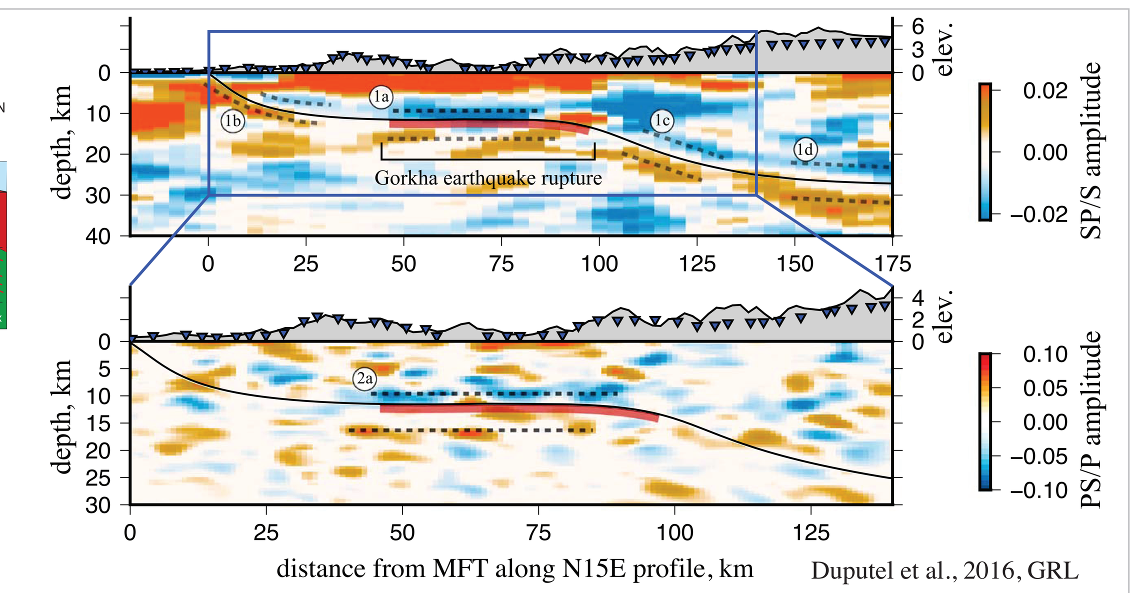
Results: Geodetic data better fit with oriented strength heterogeneity within the low-velocity layer (i.e., strength anisotropy) compared to homogeneous or layered rigidity structure. Systematically unable to fit vertical/line-of-sight and horizontal displacements unless varying rigidity of the fault layer. Vertical and line-of-sight displacements better fit with lower rigidity, horizontal with higher.

RFs show degree-1 backazimuth patterns with polarity reversals and negligible moveout, matched with intermediate to steeply north-dipping foliation within the layer. Some isotropic low-velocity contribution from layer, but dip too shallow to explain signal - need anisotropy.

Interpretation: Significant fabric develops within sediments carried on the underthrusting Indian plate, creating an **anisotropic strength** profile that affects seismic observations as well as geodetic observations, modeling, and inversions. The isotropic assumption may therefore lead to bias in fault observations from both fields.

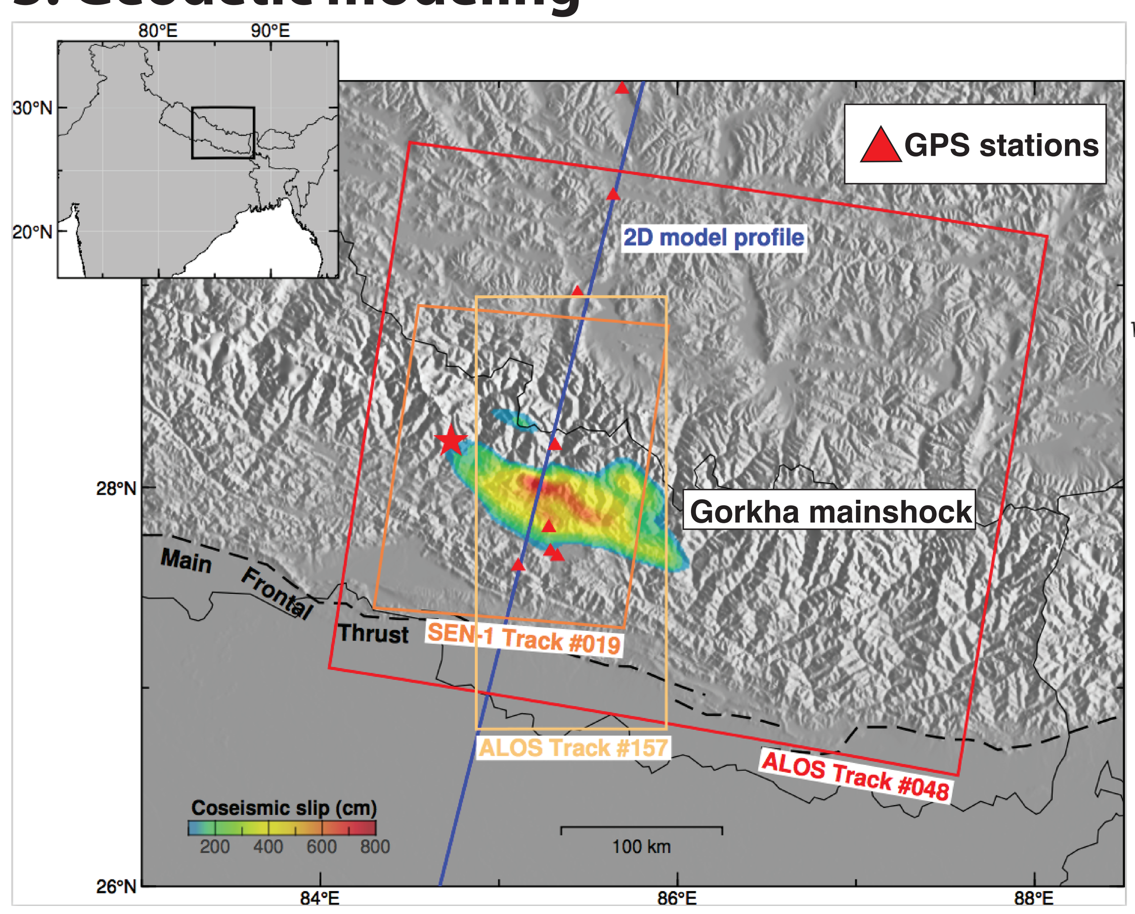
2. Premise



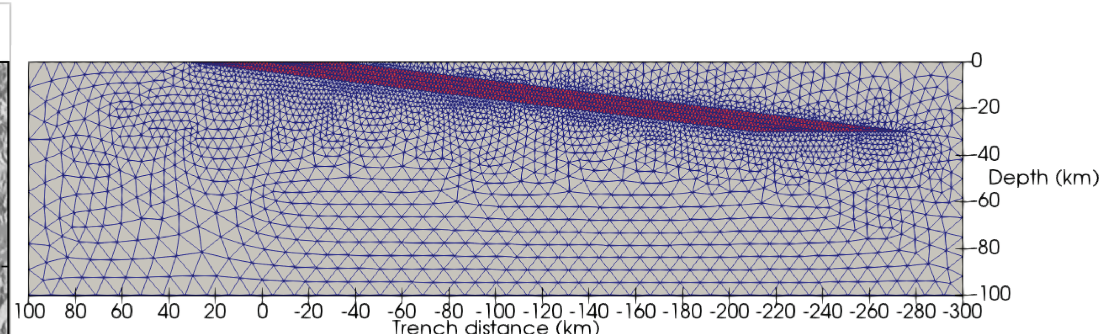


Structural imaging: Low velocity layer (LVL) atop the underthrusting Indian plate. Low velocity = weak layer.
1. How does this affect coseismic displacement?
2. Is this layer anisotropic?
Tackle with geodetic modeling and receiver functions.

3. Geodetic modeling



GPS: Yadav et al., 2017; displacement: Elliott et al., 2016, Nat Geosci; topography: ETOPO1; epicenter: USGS

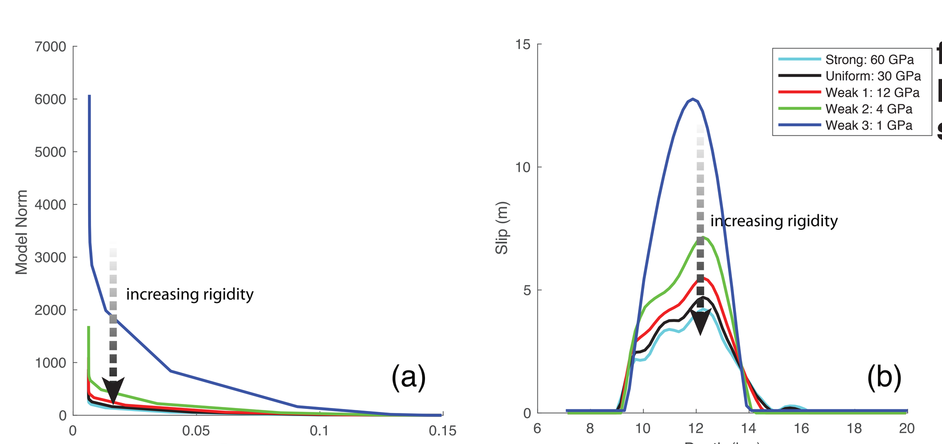


Model: Red - fault layer above slip surface, FEM mesh; vary fault layer strength (8 km thick, 7° dip)

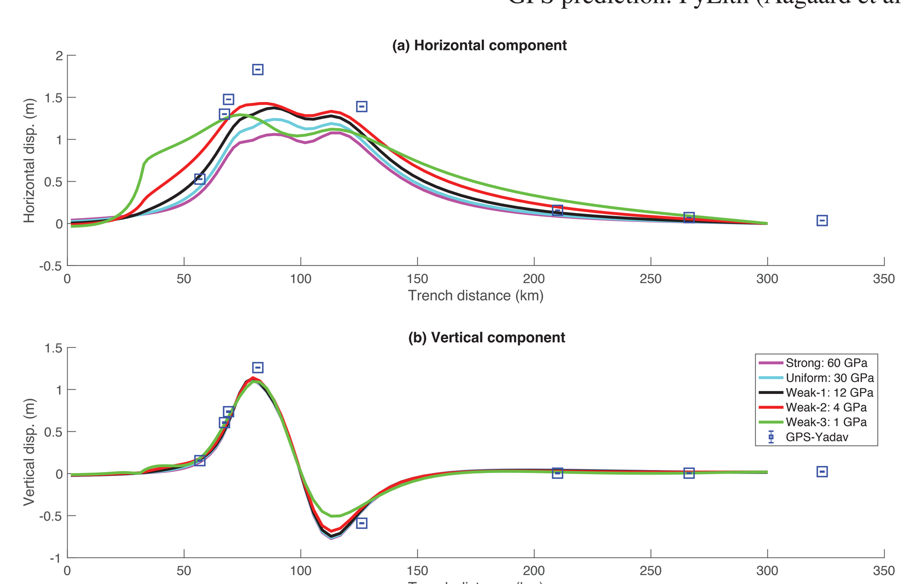
Data: mainshock coseismic displacement 3 InSAR tracks 8 GPS stations

Model name	Shear modulus (GPa)	Youngs modulus (GPa)	Poisson's ratio	Vs (m/s)	Vp (m/s)	Vp/Vs
Strong	60	150	0.25	4899.0	8485.3	1.73
Uniform	30	75	0.25	3464.1	6000	1.73
Weak-1	12.0	30.0	0.25	2449.5	4242.6	1.73
Weak-2	4.0	10.0	0.25	1414.2	2449.5	1.73
Weak-3	1.0	2.5	0.25	632.4555	1095.4	1.73

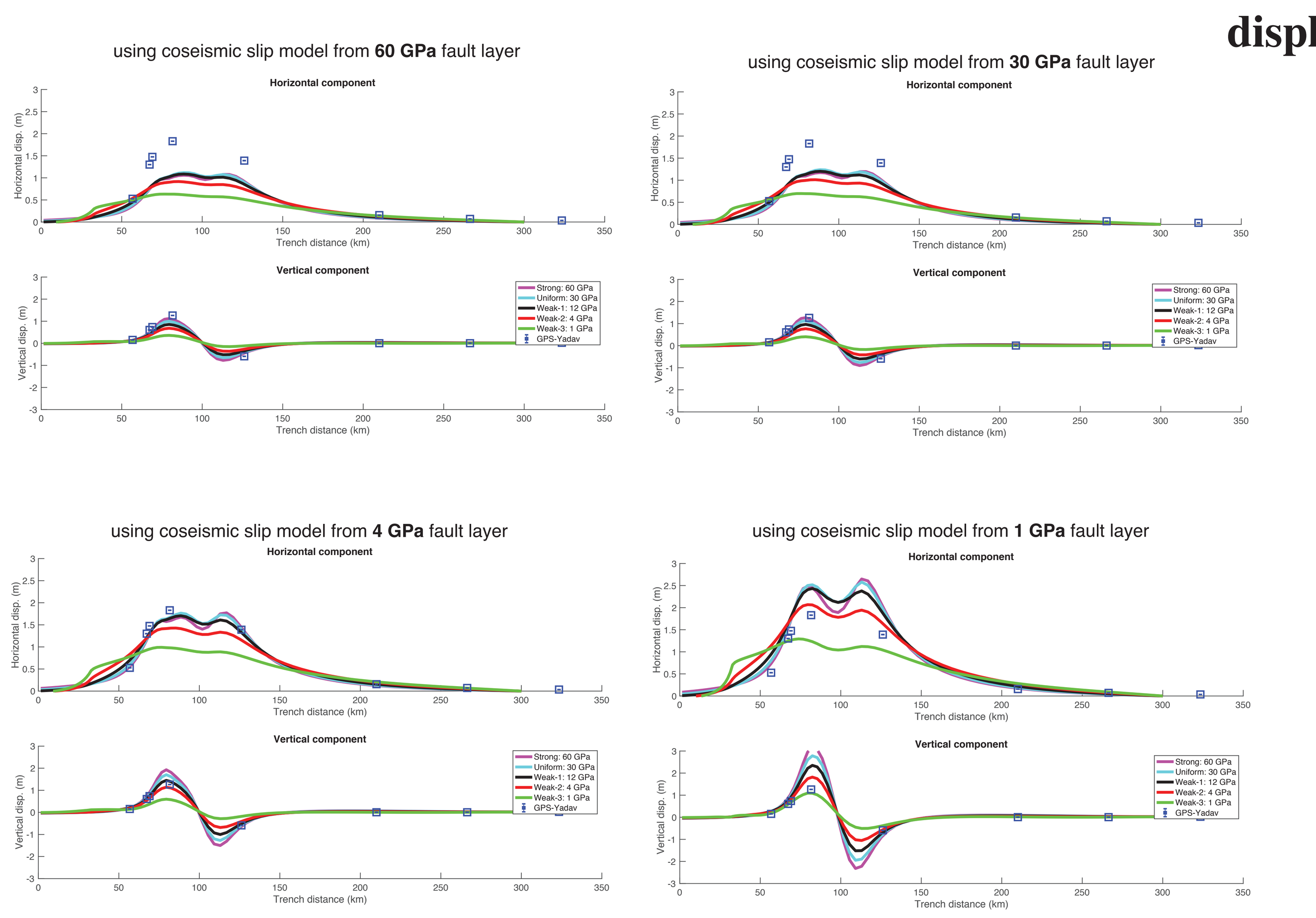
methods: INSAR inversion: Barnhart et al., 2015, SRL; GPS prediction: PyLith (Aagaard et al., 2013)



InSAR line-of-sight (LOS) data: Weaker layer above slip interface predicts more coseismic slip.

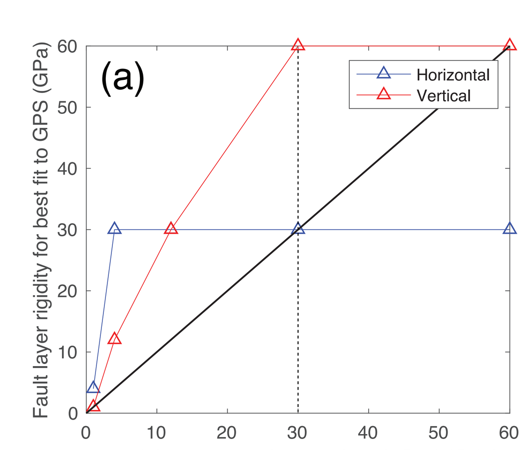


InSAR inversion underpredicts horizontal GPS displacements; better fit with weaker fault layer.

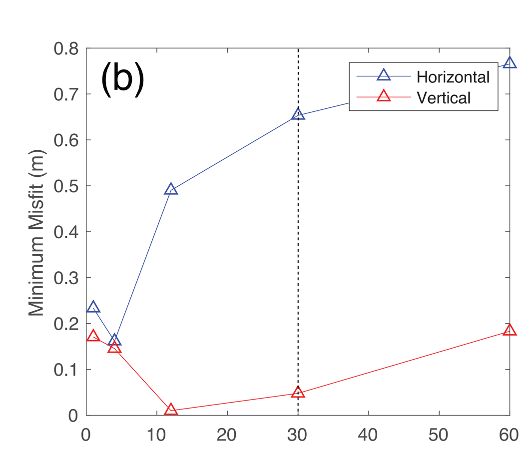


Quasi-anisotropic modeling:
1. invert for slip model using InSAR LOS and different fault layer rigidities
2. predict GPS displacements using each slip model and different layer rigidities

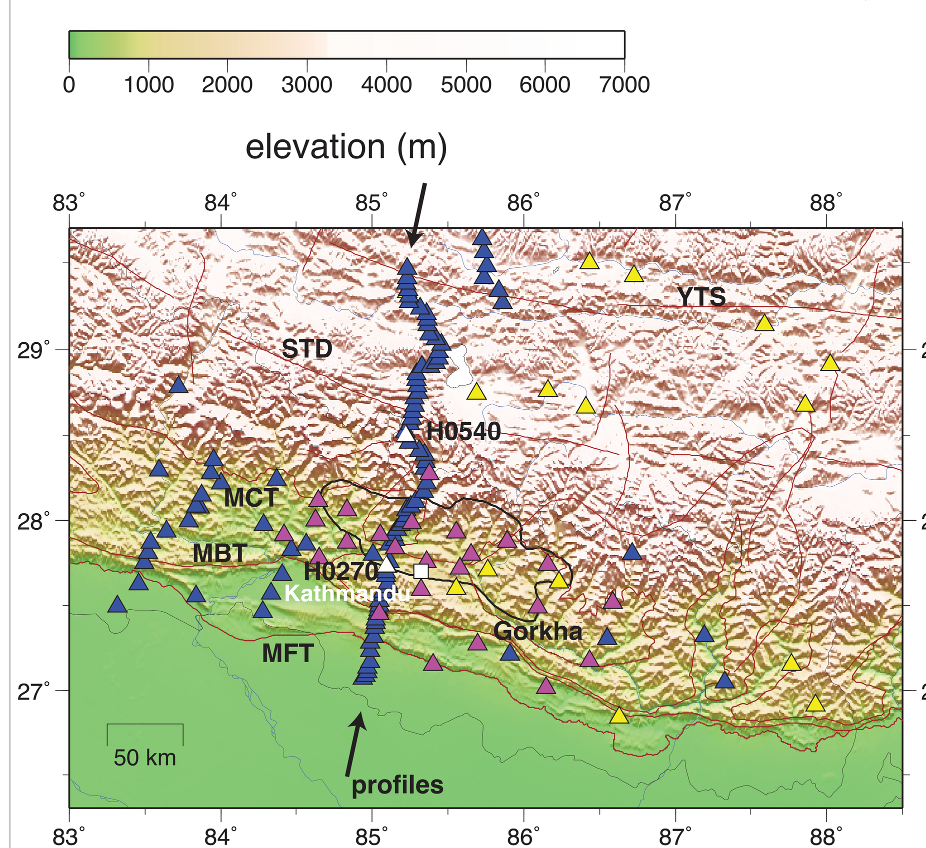
Best-fit model for GPS using each InSAR slip model: Above diagonal (GPS prefers stronger layer)



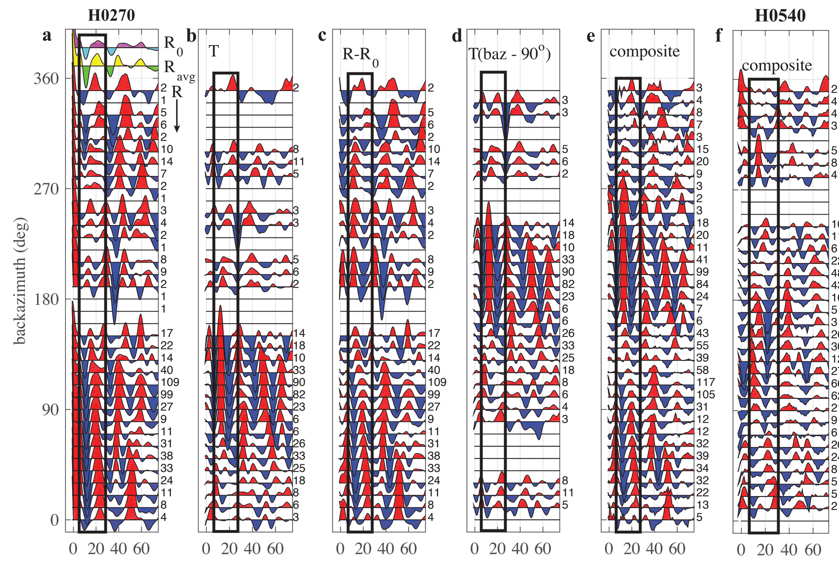
Misfit is lower for weak-layer models; higher for horizontal displacement using slip from stronger models - strength anisotropy



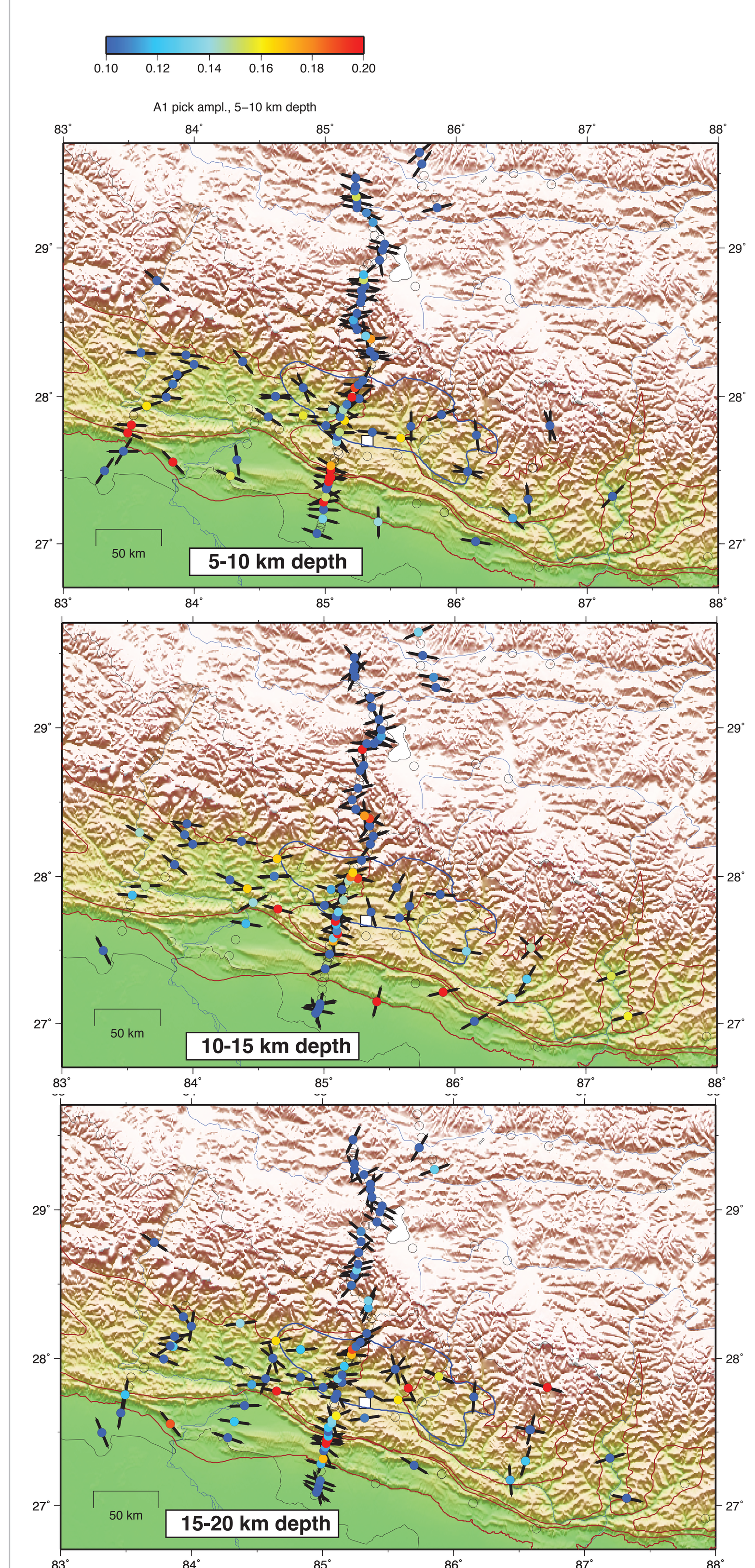
4. Receiver function low-velocity vs. dip/anisotropy



Azimuthal RF analysis: Most events from E, azimuthal bias. Here, "LVL" blue arrival; not seen from western azimuths. Strong arrivals on transverse (T) not explained by LVL

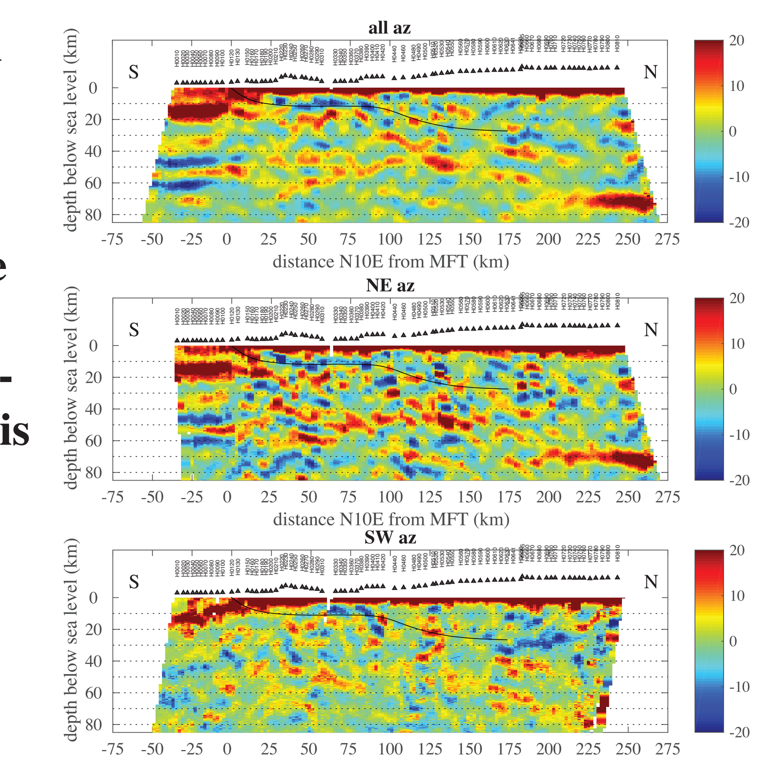


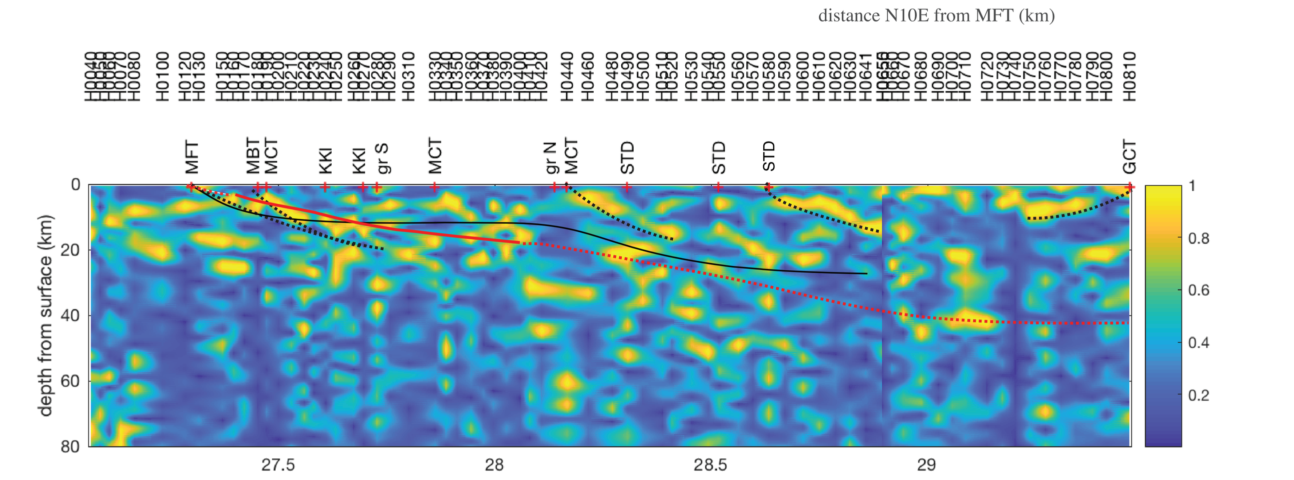
Azimuthal harmonics can be used to find strike, depth, amplitude of conversions from dipping contrasts (isotropic and anisotropic - maps on left).



Strike (bars) and amplitude (color) of A1 arrivals in depth layers. Strikes for larger arrivals tend to be orogen-parallel.

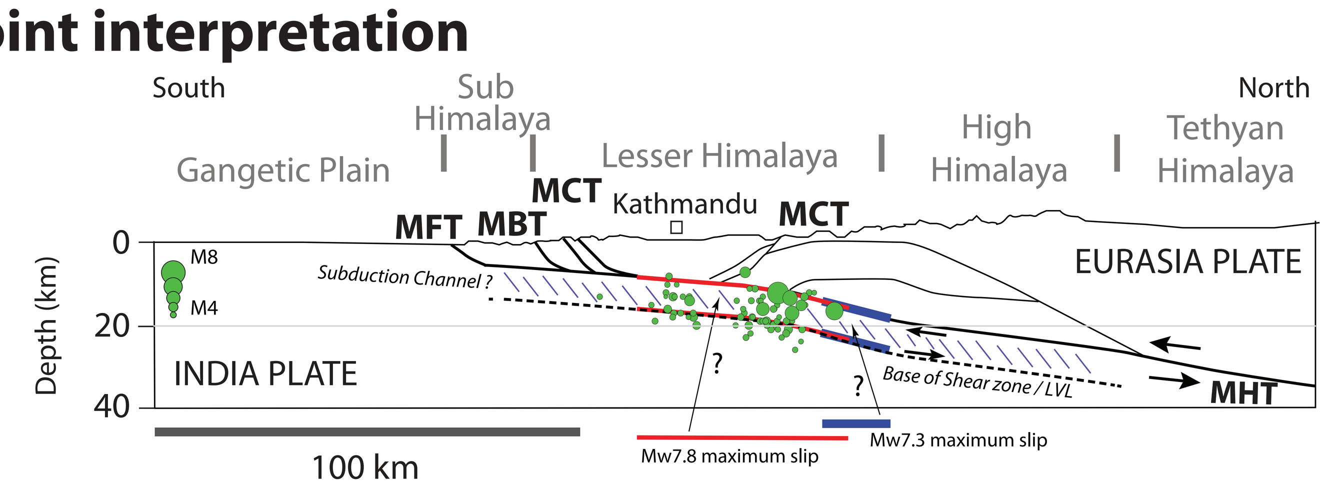
CCP stacks from all (top), updip (middle), downdip (bottom) illumination angles: Possible LVL contribution, but images angle dependent. Black line is Duputel MHT from above





Depth profile of degree-1 harmonic amplitude (A1), trace normalized. Red crosses - faults/structure crossings. Dashed black - interpretation. Solid black - Duputel et al. 2016, red - Schulte-Pelkum et al., 2005 MHT.

5. Joint interpretation



Geodetic and seismic observations could be explained by steeply dipping fabric in MHT layer as proposed by McNamara et al. 2016