T51J-0331

Seasonal modulation of deep slow-slip and earthquakes on the Main Himalayan Thrust

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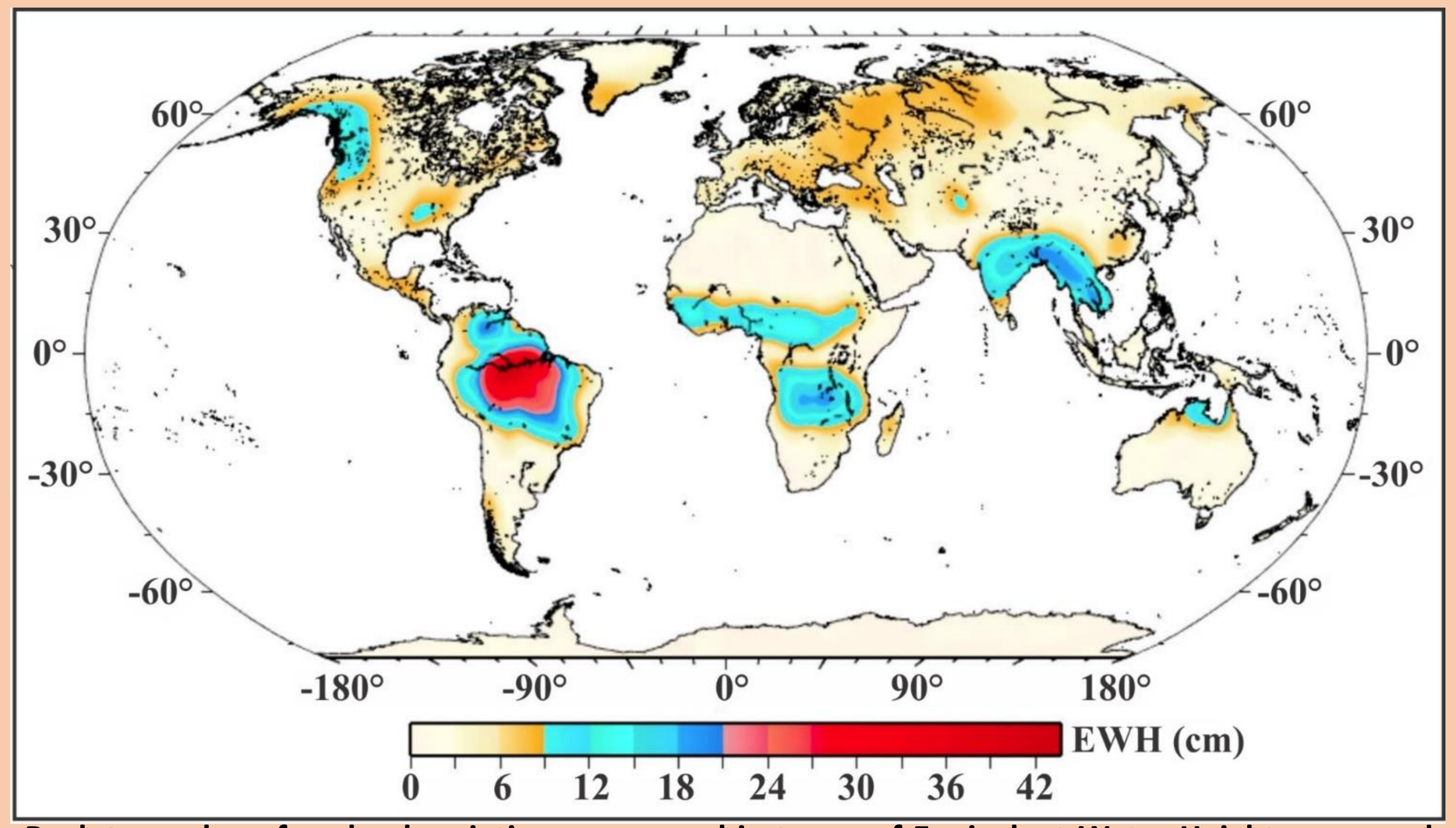
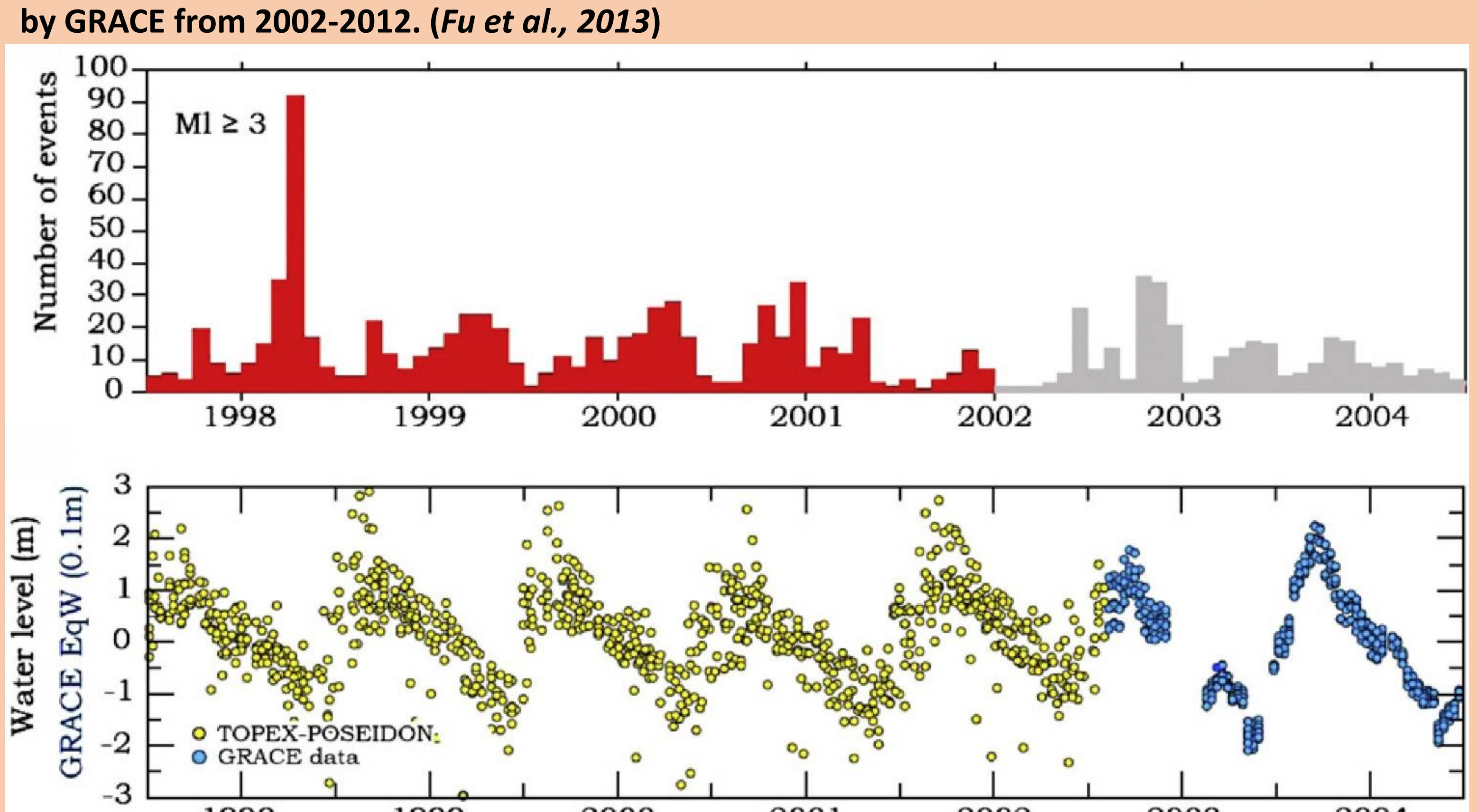
Summary Apart from tectonic processes, large scale seasonal mass movements (or non-tectonic processes) can also cause periodic crustal deformations and seismicity modulation. This work reveals the influence of seasonal hydrological loading cycles on tectonic deformation of the Himalayan plate boundary region, which is quantified using continuous Global Positioning System measurements and satellite data from the Gravity Recovery and Climate Experiment. We suggest that periodic hydrological load oscillation causes stress change on the base of seismogenic zone of the megathrust. This process modulates mid-crustal ramp associated micro-seismicity and influences the timing of Central Himalayan earthquakes.

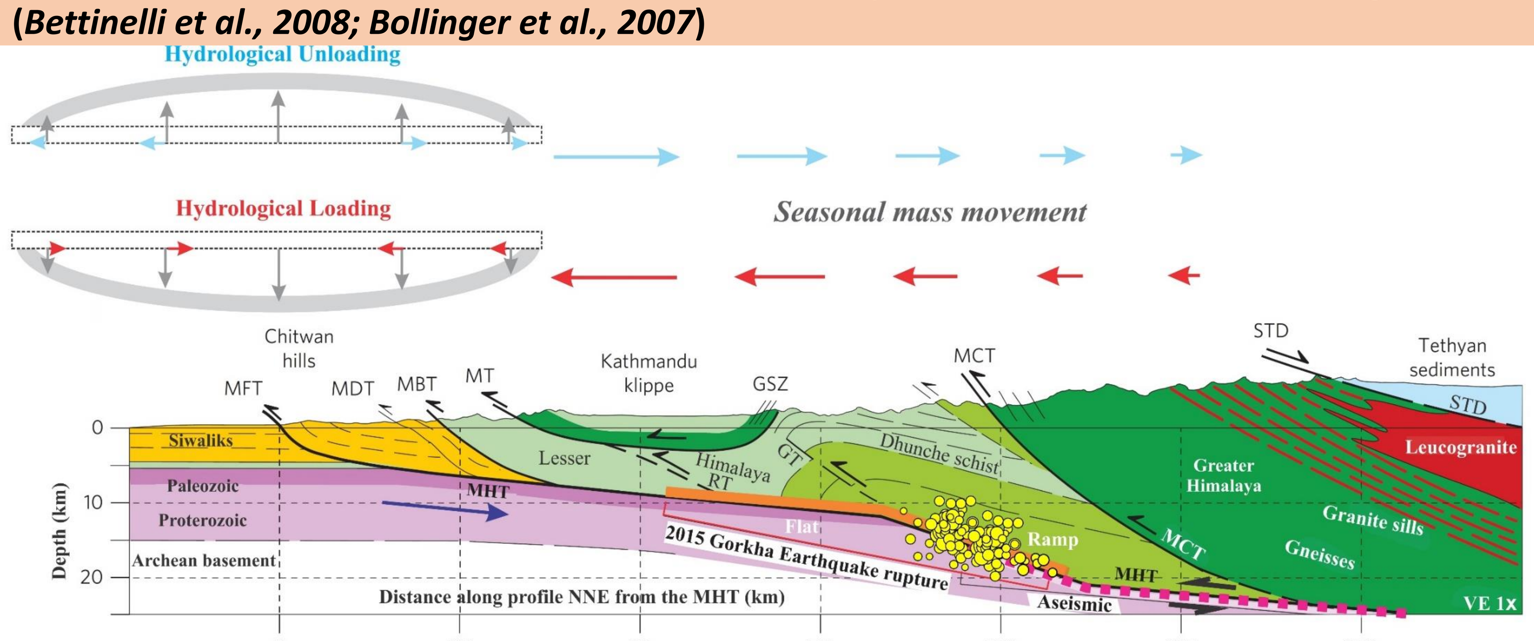
Literature Reviews and Evidences of Seasonal Deformation



Peak to peak surface load variations expressed in terms of Equivalent Water Height measured by GRACE from 2002-2012. (*Fu et al., 2013*)



Correlation between seasonal variation of seismicity and water level in the Ganges basin. (*Bettinelli et al., 2008; Bollinger et al., 2007*)

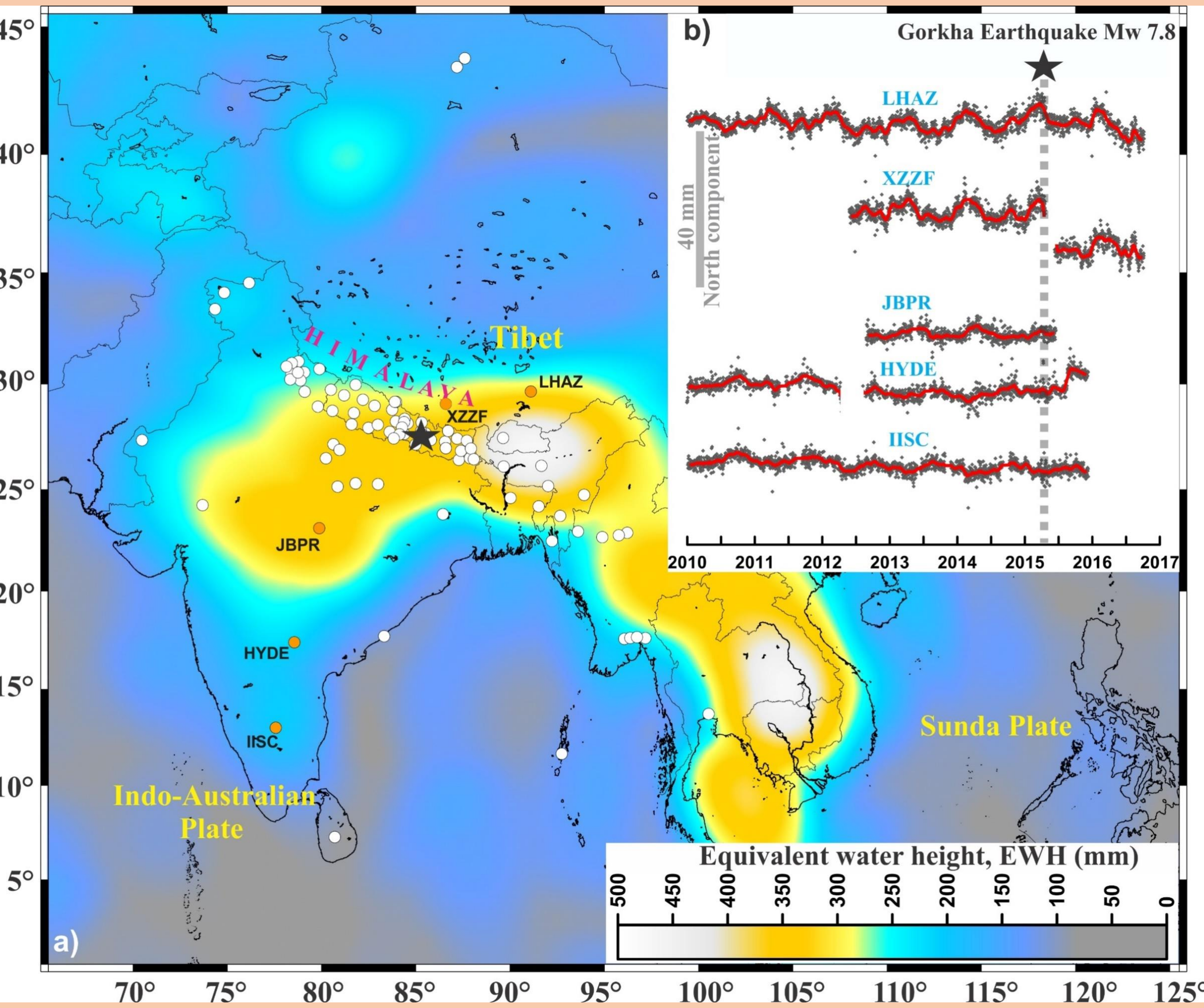


Conceptual model describing the effect of the hydrological mass oscillation (loading/unloading) along the North–South profile of Nepal-Himalaya region. (modified from *Elliott et al., 2016*)

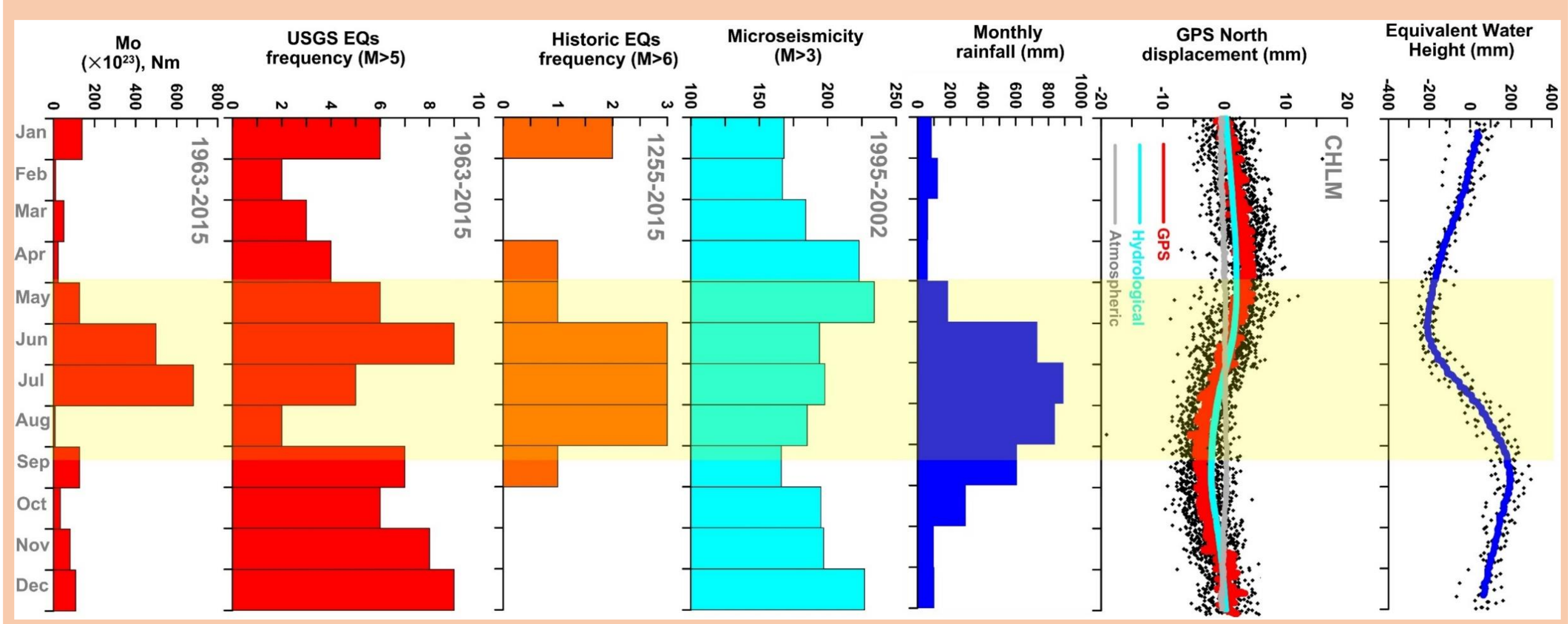
Key Questions

1. Why Himalayan mid-crustal ramp is more sensitive to seismicity modulation and nucleation of Central Himalayan earthquakes?
2. Is there an interplay between tectonic and non-tectonic deformation along the Himalayan plate boundary region?
3. Any evidence of slow-slip along the Himalayan plate boundary?

Observations



Peak to peak hydrological load over Southeast Asia derived from GRACE observation for the time period 2002-2012. Geodetic networks from Nepal (http://www.tectonics.caltech), Kumaun-Garhwal Himalaya (CSIR-NGRI, Hyderabad, India), UNAVCO and China (ftp://ftp.cgps.ac.cn/) are used to quantify the seasonal deformation.

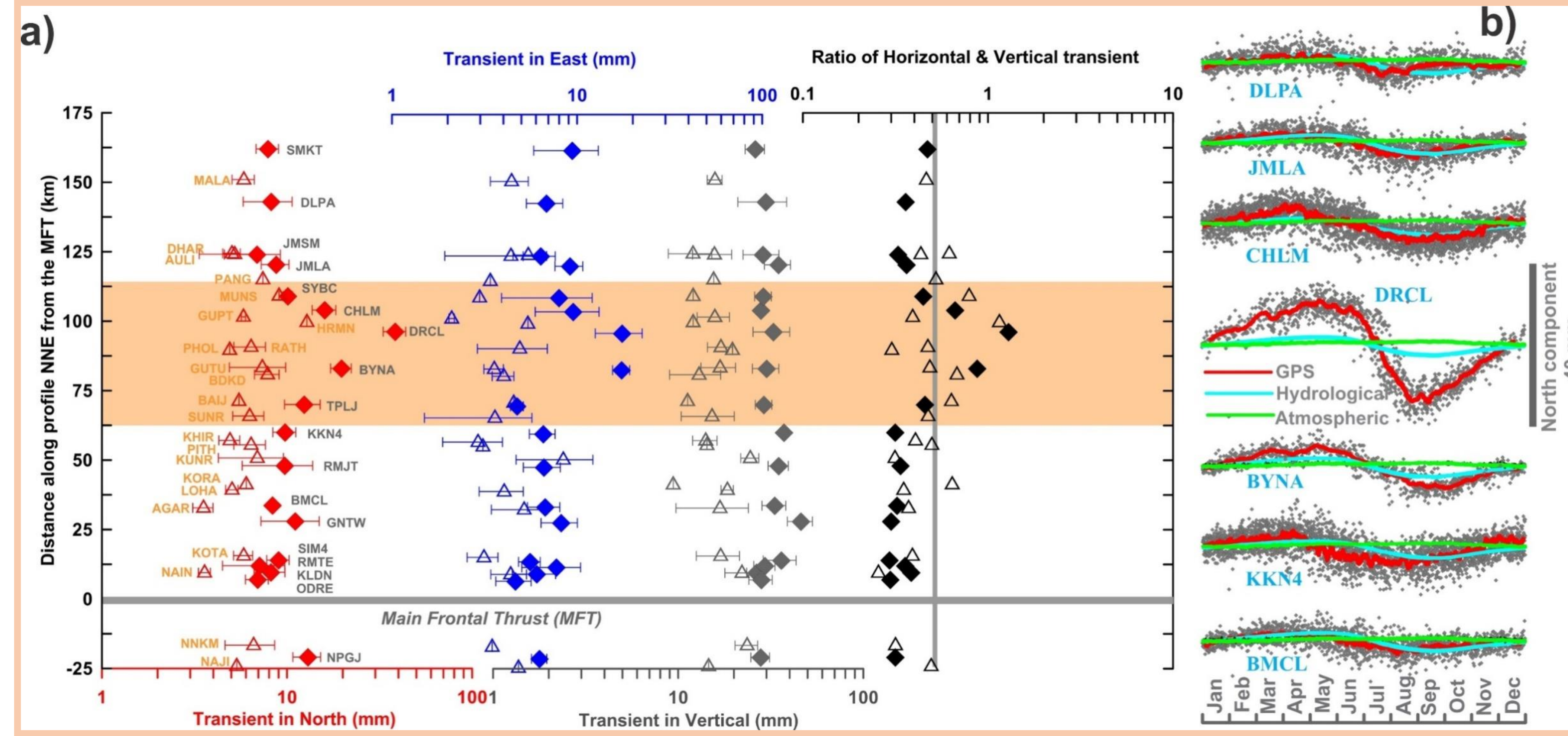


Correlation between equivalent water height (EWH), rainfall, GPS displacement, and seismicity catalogues. GRACE-derived EWH and regional precipitation exhibit strong lag-correlation with the occurrence of historic earthquakes, micro-seismicity, and seismic moments of earthquakes in the USGS catalog.

References: Panda, D., Kundu, B., Gahalaut, V.K., Bürgmann, R., Jha, B., Asaithambi, R., Yadav, R.K., Vissa, N.K. and Bansal, A.K., 2018. Seasonal modulation of deep slow-slip and earthquakes on the Main Himalayan Thrust. *Nature communications* 9(1), 4140.

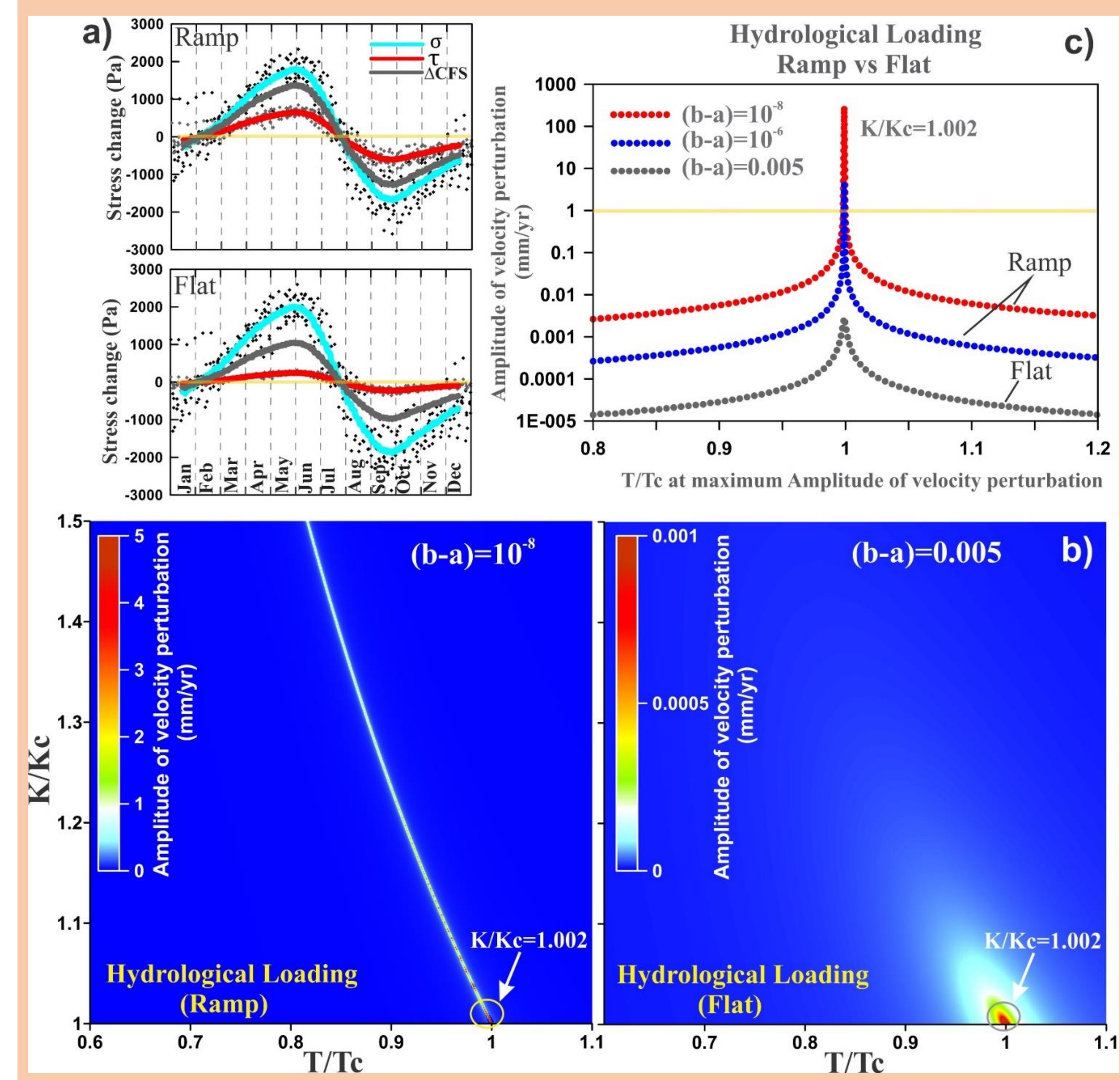
Kundu, B., Vissa, N.K., Panda, D., Jha, B., Asaithambi, R., Tyagi, B. and Mukherjee, S., 2017. Influence of a meteorological cycle in mid-crustal seismicity of the Nepal Himalaya. *Journal of Asian Earth Sciences*, 146, 317-325.

Seasonal Transient Estimation and Hydrological Model



Evidence of seasonal transient deformation and hydrological modelling of GPS displacements across the Nepal and Kumaun-Garhwal Himalaya.

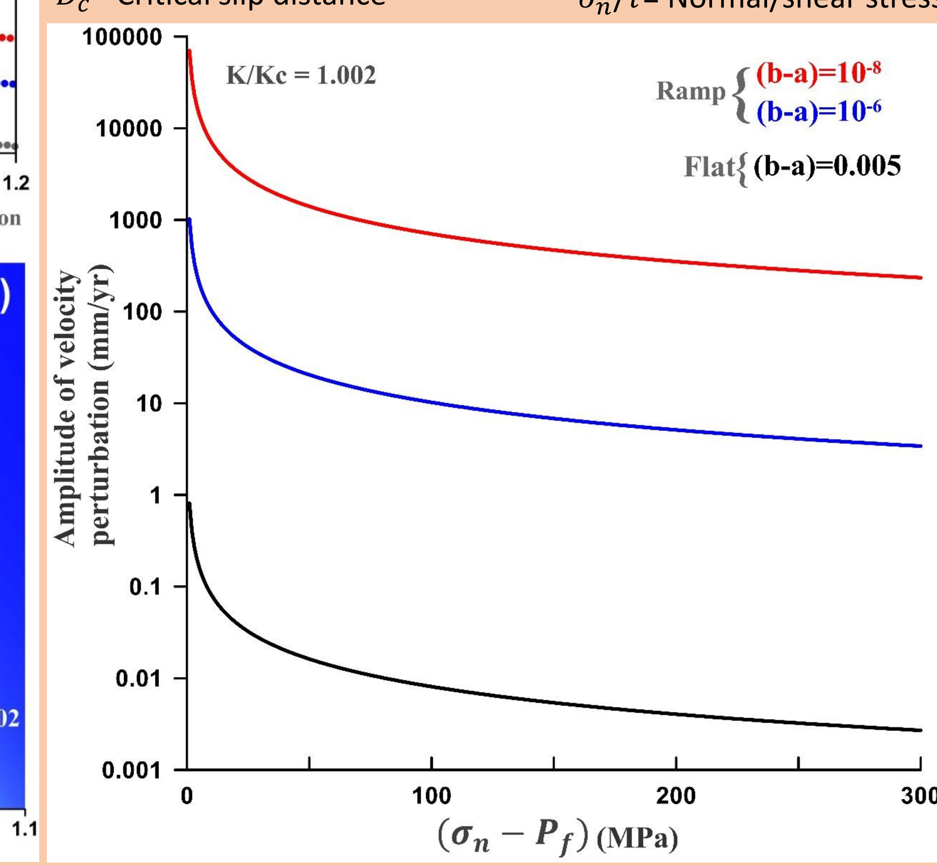
Fault Resonance Model



$$\tilde{V} = qV_{rpm}\frac{q[\widetilde{\sigma_n}(\mu_{ss}-\alpha)-\tilde{\tau}] - i(\widetilde{\sigma_n}-\tilde{\tau})}{(kD_c - a\sigma_n q^2) + iqD_c(k-k_c)}$$

Perfettini et al., (2001)

$\tilde{V}$ = Slip velocity perturbation
V_{rpm} = Relative plate motion velocity
D_c = Critical slip distance
μ_{ss} = Steady state friction
k_c = Critical stiffness
$\widetilde{\sigma_n}/\tilde{\tau}$ = Normal/shear stress



Hydrological load-induced Himalayan fault resonance and effect of fluid pressure on resonance process.

Conclusions

1. Hydrological load over Southeast Asia and Himalayan arc region modulates mid-crustal seismicity and influences central Himalayan earthquakes.
2. Abnormally higher transient in cGPS displacement (that indicate changes in aseismic slip rate i.e., deep slow slips) at the base of the Himalayan seismogenic zone (i.e., on the mid-crustal ramp) can be explained by fault resonance process.
3. Peak in seasonal stress perturbations on the MHT is consistent with the slow-slip acceleration which drives seismicity in the hanging wall on the MHT.

Future Research

- Tectonic vs non-tectonic deformation process can be tested for other plate boundary (e.g., Indo-Burmese Arc, Alaska-Aleutian megathrust zone, Alpine fault) and plate interior (e.g., Koyna-Warna deformation zone, New Madrid Seismic Zone) regions.