3D Scattering and Absorption Imaging of the Jammu-Kashmir Himalaya

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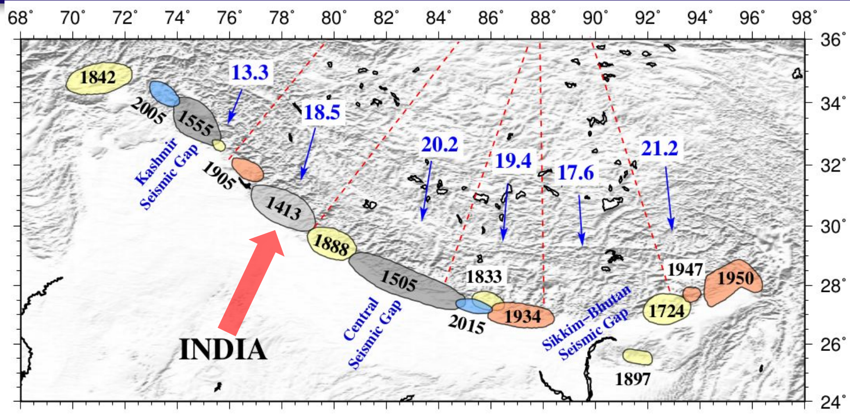
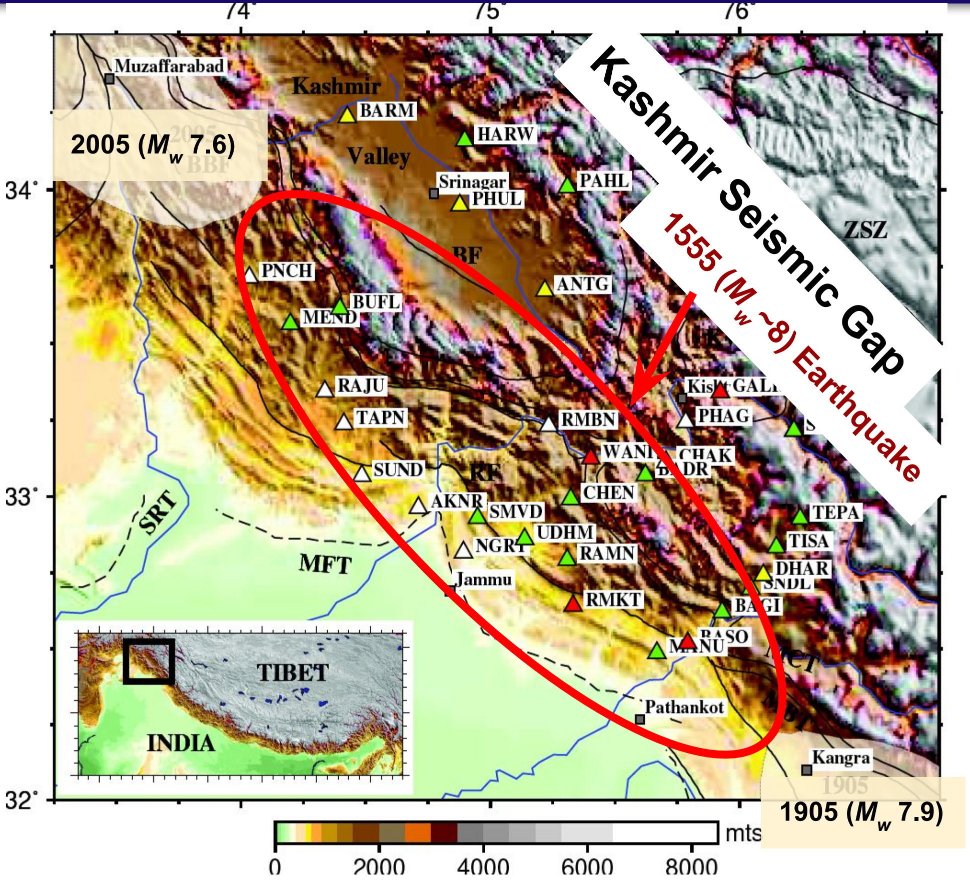
Introduction (The Kashmir ‘Seismic Gap’ & JAKSNET)



Stevens & Avouac (2015), *Bilham* (2019)

- Kashmir Seismic Gap - Meisoseismal zone of the 1555 major-to-great earthquake (Mw ~8)
- Arc normal convergence rate (GPS): ~11 mm/yr
- Slip accumulated: ~5 m (over 467 years)
- Potential to drive magnitude ~8 earthquake *(assuming a rupture of the entire gap 250x100 km^2)*
- Hence, the need for better attenuation models to quantify ground shaking from future earthquakes.



(Sharma et al. 2020, SRL & Mitra et al. 2023, JGR)

3D Attenuation

S-WAVE ATTENUATION → **CODA NORMALIZATION** (Del Pezzo et al. (2006), De Siena et al. (2014), Prudencio et al. (2015))

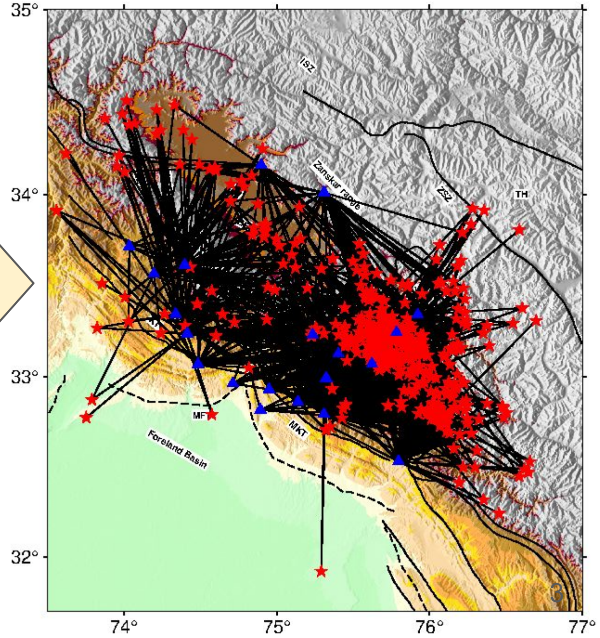
INTRINSIC ATTENUATION → **CODA Q METHOD** (Aki & Chouet (1975), Sato et al. (2012), De Siena et al. (2017))

SCATTERING ATTENUATION → **PEAK DELAY METHOD** (Takahashi et al. (2007), Calvet et al. (2015))

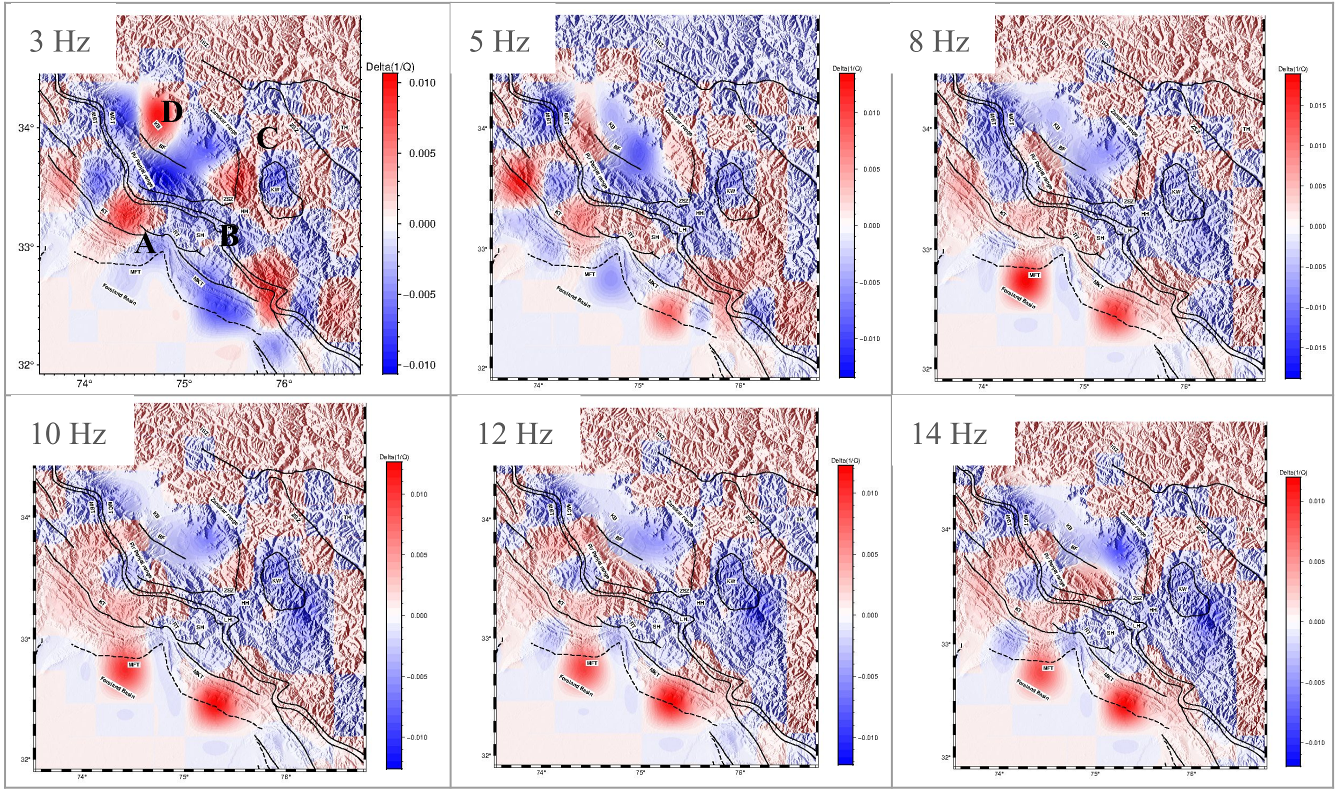
MuRAT

(De Siena et al. (2014))

→ Final dataset comprising 525 earthquakes, with 1750 ray-paths (obtained from non-linear earthquake relocation, Shamim et al. 2024, GRL).



S-Wave Attenuation (~5 km depth)



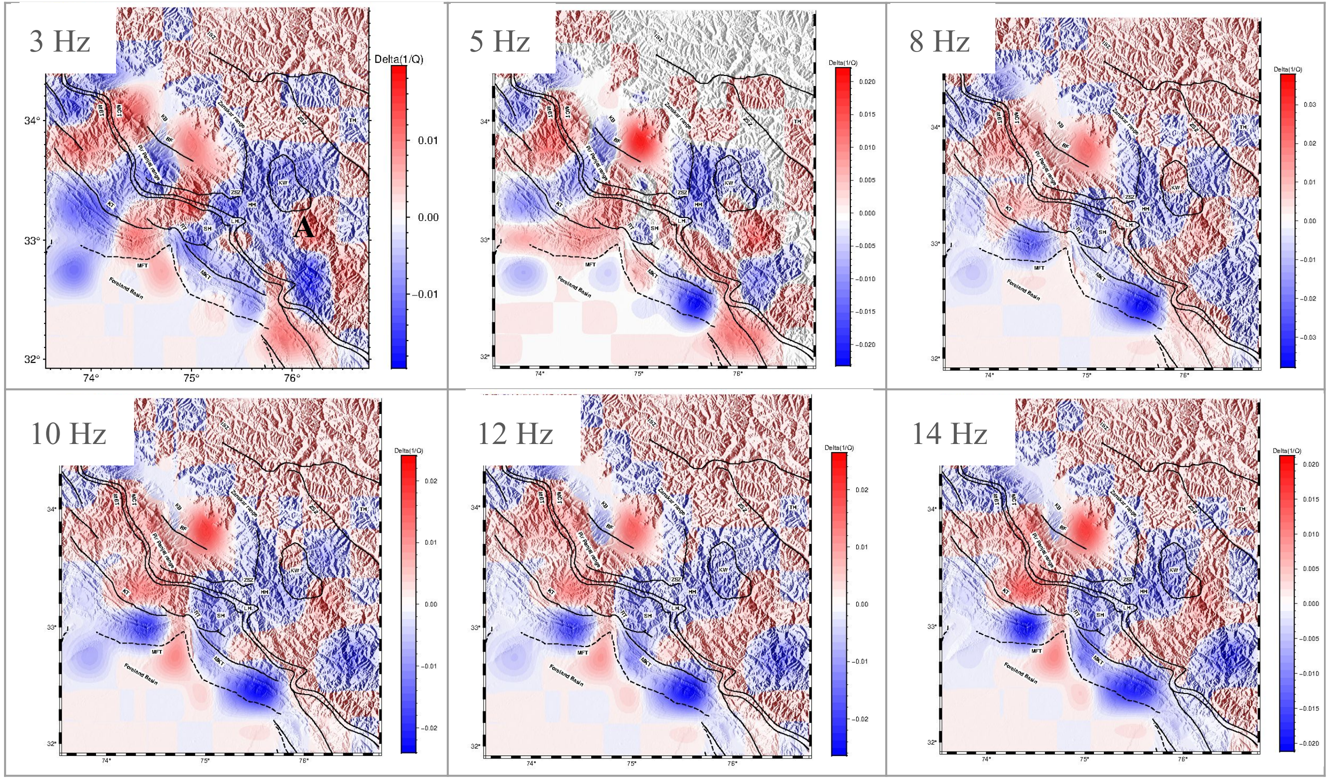
Shiwalik Himalaya (A):
MFT reentrant = low attenuation.
High attenuation zones - NW (Kotli Thrust) & SE (MKT), expand with frequency.

Lesser Himalaya (B):
MBT–MCT reentrant = low attenuation. Flanked by high attenuation NW (Pir Panjal front) & SE (south of Kishtwar Window).

Higher Himalaya & Tethyan (C):
Low frequencies: high attenuation around Kishtwar Window & Zanskar Ranges. ≥8 Hz: high attenuation mainly E of Kashmir Valley & Zanskar. Kishtwar Window = consistently low attenuation.

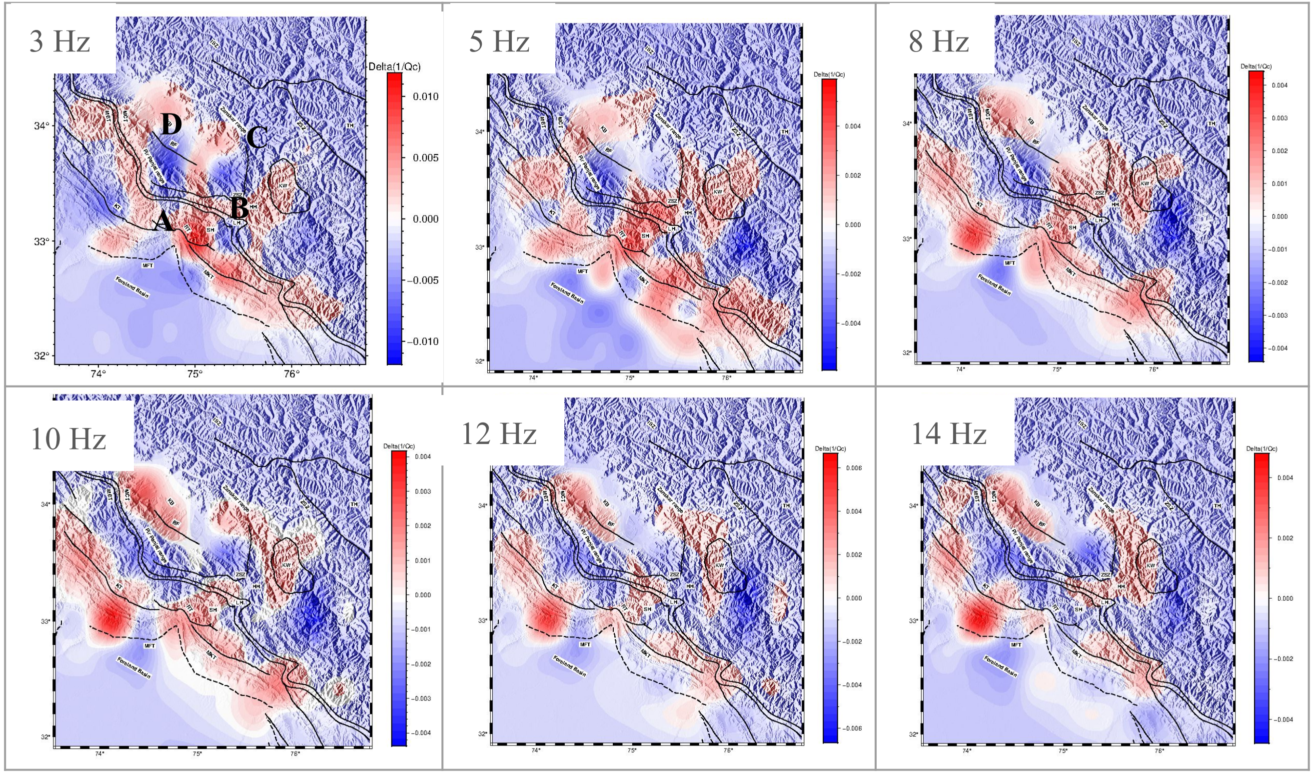
Kashmir Valley (D):
West = higher attenuation, East = lower. With rising frequency, high attenuation shifts SW into Pir Panjal Ranges.

S-Wave Attenuation (~20 km depth)



- This depth samples the Indian middle crust beneath the Foreland Basin, and the Himalayan wedge with the under-thrusting Indian upper crust beneath the Higher Himalaya.
- Similar features as at 5 km depth are observed, with a notable high attenuation southwest of Kishtwar Window **(A)**, linked to structural heterogeneities (e.g., ramps) on the MHT (Shamim et al., 2024, GRL).

Coda-Wave (Intrinsic) Attenuation (~5 km depth)



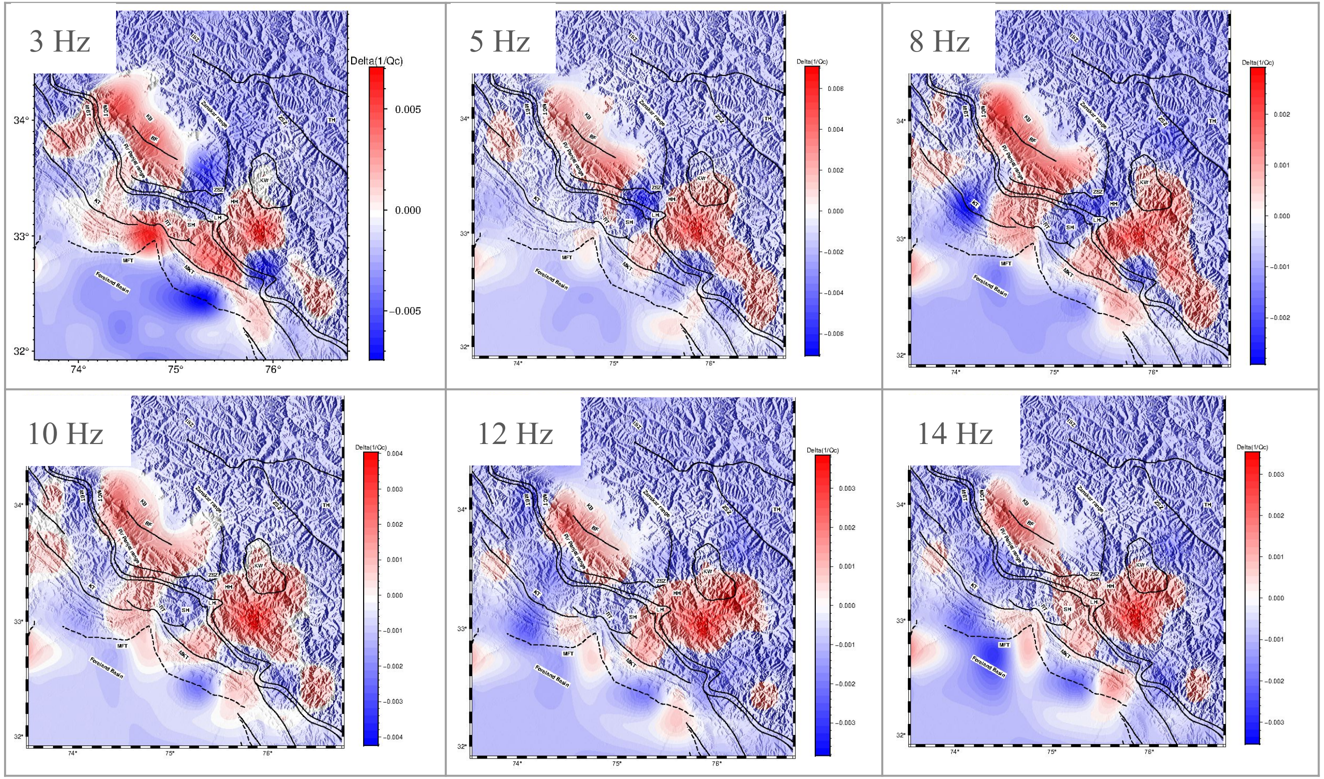
Shiwalik Himalaya **(A):**
Two strong absorption patches at low freq.

Lesser to Higher Himalaya **(B):**
Broad low anomaly SE from the MFT reentrant extends northward, becomes fragmented at higher freq.
Persistent high absorption SW of Kishtwar Window → skirting Zanskar Shear Zone.

Zanskar Region **(B, C):**
3 Hz: mostly low absorption.
Higher freq: high absorption patches shifts eastward into Kishtwar Window.

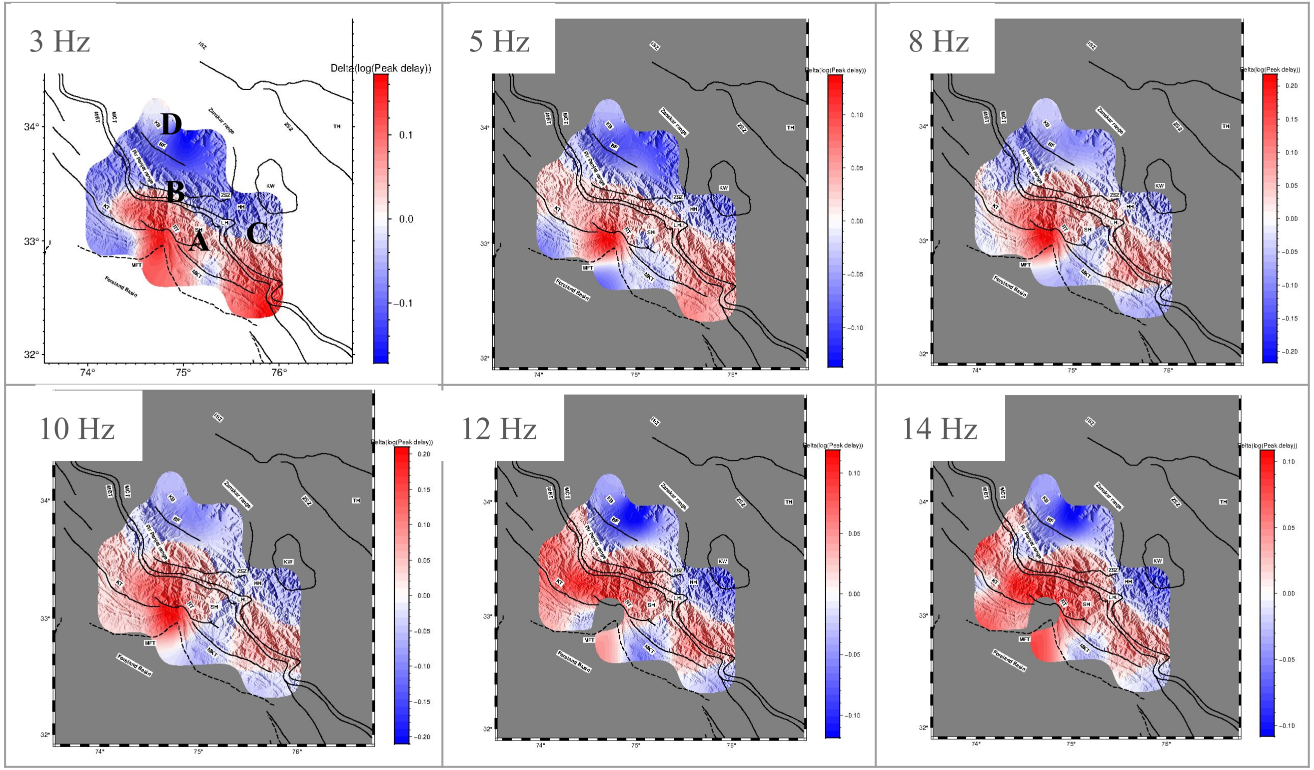
Kashmir Valley **(D):**
West = high absorption; East = low.
Only at 3 Hz: high absorption band along eastern fringe.
Higher freq: western anomaly localizes to SW portion of the valley, low absorption in Pir Panjal.

Coda-Wave (Intrinsic) Attenuation (~20 km depth)



Similar features to those at 5 km depth are observed, with a prominent high absorption patch south of Kishtwar Window **(A)**, associated with structural heterogeneities (e.g., ramps) on the MHT.

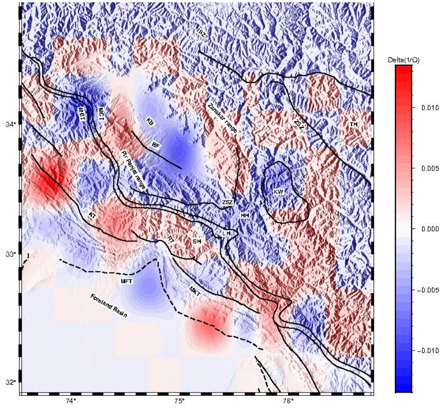
Peak Delay (~5 km depth)



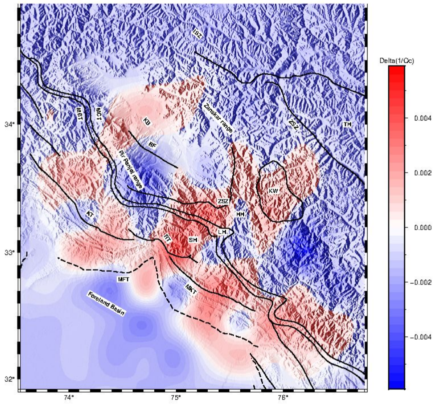
- **High scattering** observed consistently across frequencies, especially in: **Shiwalik Himalaya (A)** near MFT reentrant, areas surrounding the Kotli, Reasi, and MKT thrusts, **most of the Lesser Himalaya.**
- In the **Higher Himalaya**: Scattering localized to **Pir Panjal Range (B)** and south of Kishtwar Window. High scattering zone **south of Kishtwar Window (C)** aligns with clustered seismicity and suggests **structural heterogeneities on the MHT (e.g., ramps).**
- **Kashmir Valley (D)** shows **low scattering** → indicates a **more homogeneous crustal structure despite thin sediment cover.**
- Consistent scattering patterns across frequencies suggest deep-penetrating crustal heterogeneities.

Comparison with V_s Structure

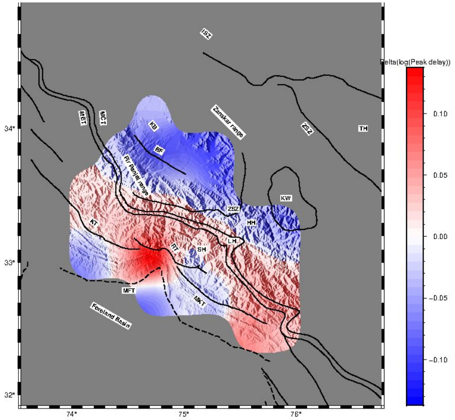
S-wave Attenuation (5Hz)

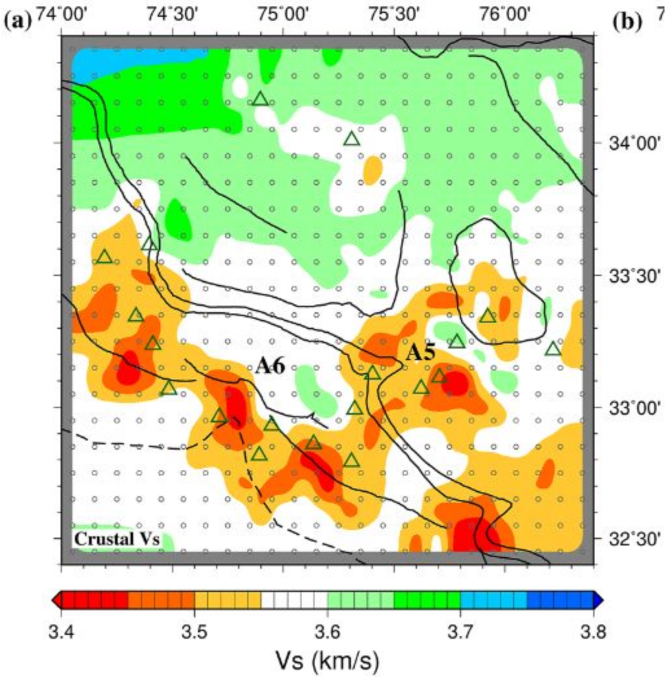


Coda Q (5Hz)



Peak Delay (5Hz)





(Mitra et al. 2023, JGR)

Lower V_s sediments/metasediments of Shiwalik, Lesser Himalaya, and structural heterogeneity south of Kishtwar Window (associated with MHT frontal/lateral ramps) closely align with the high attenuation/scattering anomalies.

Conclusions

- Strong absorption and scattering across the Jammu & Kashmir Himalaya, highlighting crustal complexity.
- **Higher Himalaya**: Low attenuation, but lateral variations near Kishtwar Window suggest unique structural zones.
- **Kishtwar Region**: High absorption linked to Lesser Himalayan metasediments and active MHT frontal/laetralramps. High absorption and scattering correspond to active, deformed areas near MHT, including regions with locked-to-creep transition.
- **Kashmir Valley**: Varying absorption — west (high), east (low) — reflecting sedimentary thickness variations.
- **Zanskar & Pir Panjal Ranges**: Intermittent high attenuation at different frequencies, indicating complex structural heterogeneities.
- **Shiwalik & Lesser Himalayas**: Fluid-saturated sediments and metasediments show high attenuation and absorption due to fractures.
- Lateral variation in attenuation likely influenced by changes in crustal thickness and the depth of the MHT. Compositional and structural factors, like the MHT's frontal ramps, contribute to regional variations.

Future Directions:

- Further studies on thermal/heat-flow properties needed for deeper insights into geodynamics.
- Improved seismic hazard models crucial for mitigating earthquake risks, especially with urbanization in high-risk zones.

Acknowledgements

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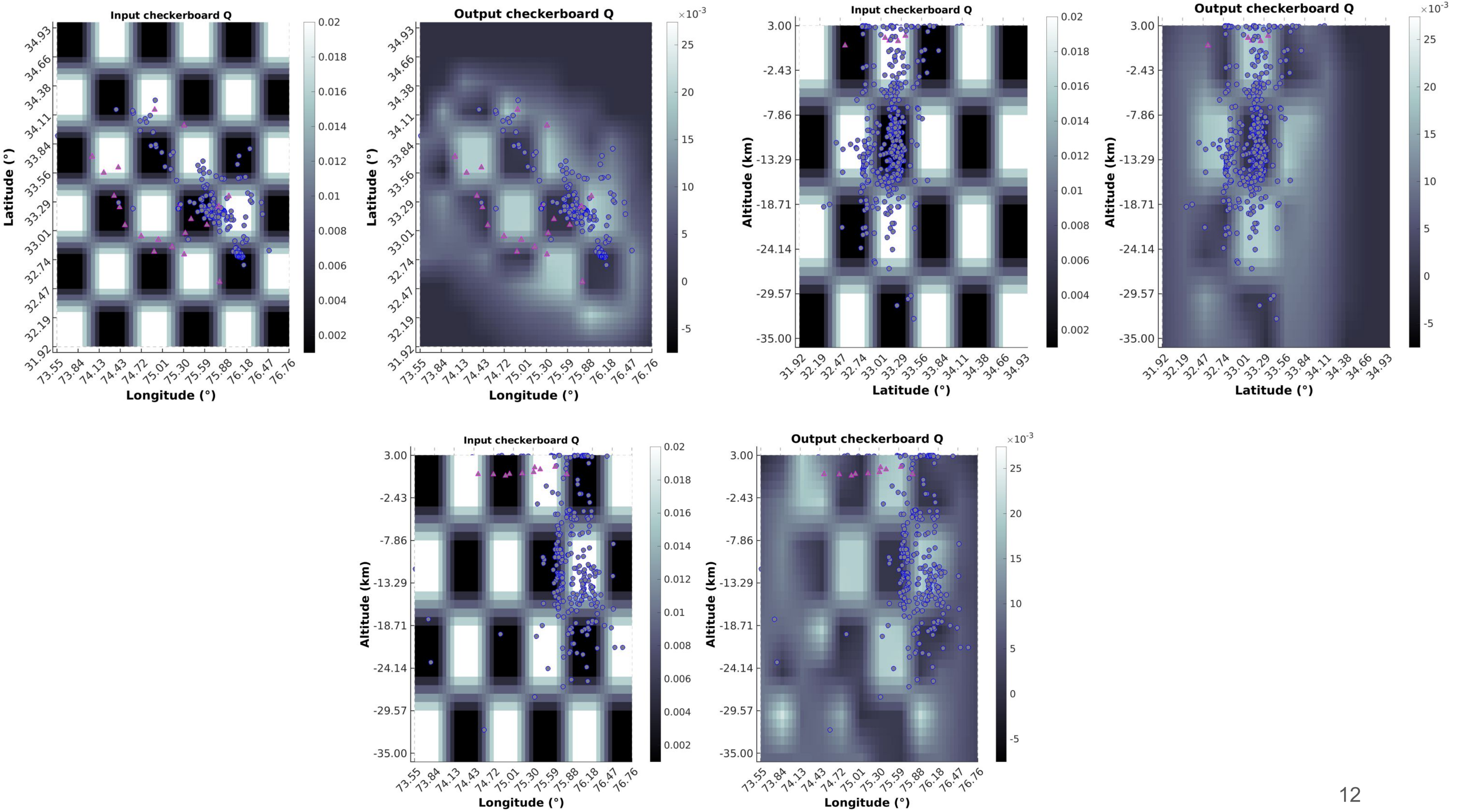
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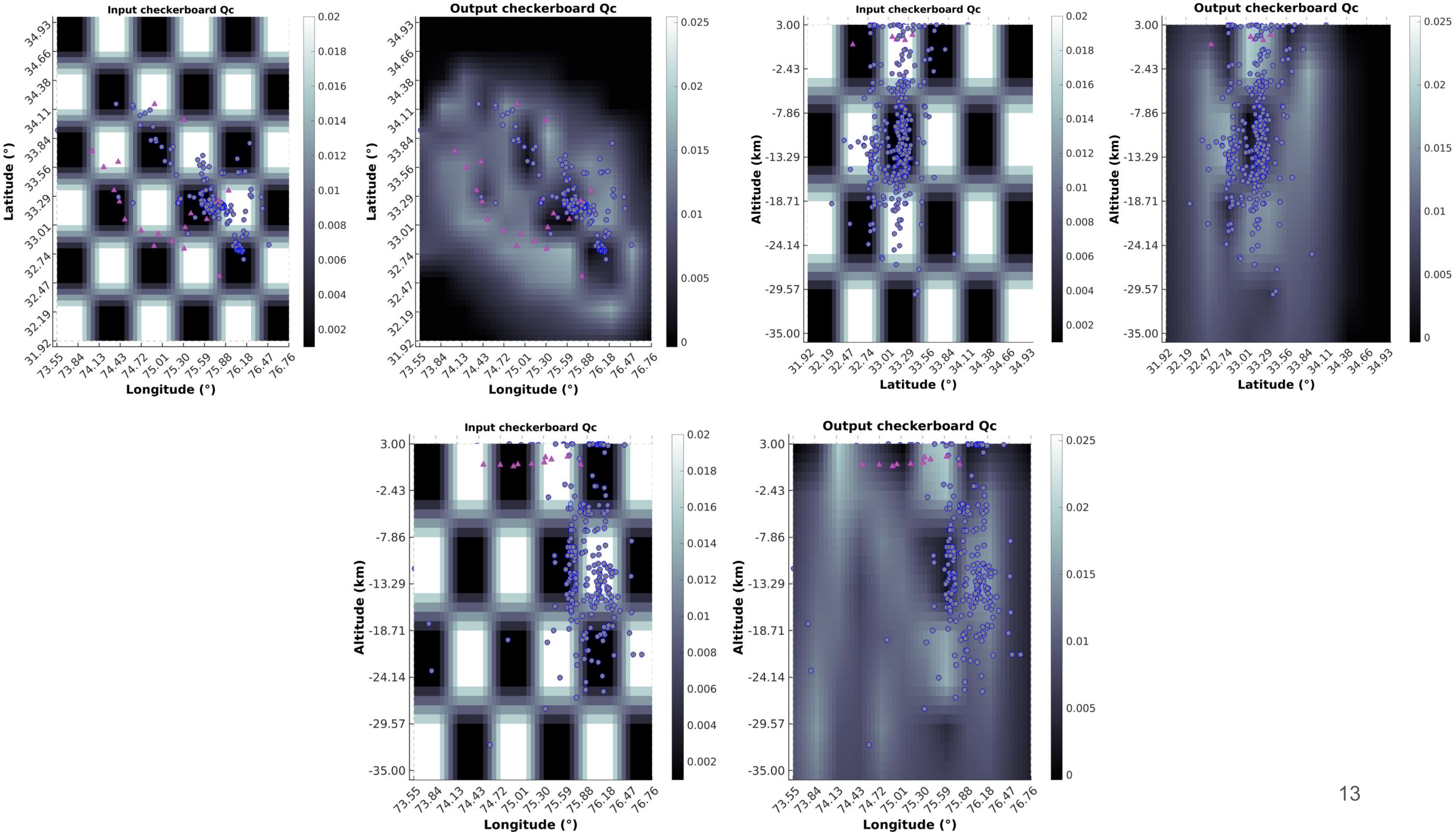
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