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Spatiotemporal evolution of deep seismicity beneath the central Himalayas

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Background information

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Intermediate depth earthquakes (40-100 km) have been identified beneath the central section of the Himalayan orogen since the 1980s (*e.g., Chen et al., 1981, 1983*).

Studies related to these events (*e.g., Chen et al., 1983; Jackson, 2002*) have improved the current understanding of the rheology of the continental lithosphere. Eclogitization processes have been linked to the existence of these events (e.g., *Jackson et al., 2004, Hetényi et al., 2007, Alvizuri and Hetényi, 2019*).

Current knowledge of the seismicity characteristics and evolution of these events are limited. Regional seismicity studies have mostly focused on shallow seismicity (*e.g., Pandey et al., 1995, 1999; Monsalve et al., 2006*).

Here, we compile a **high-quality earthquake catalog** to examine the temporal evolution of seismicity and provide improved insights into the processes and mechanisms that control seismogenesis at depths near the roots of the central Himalayan orogen.

Map of seismic sites

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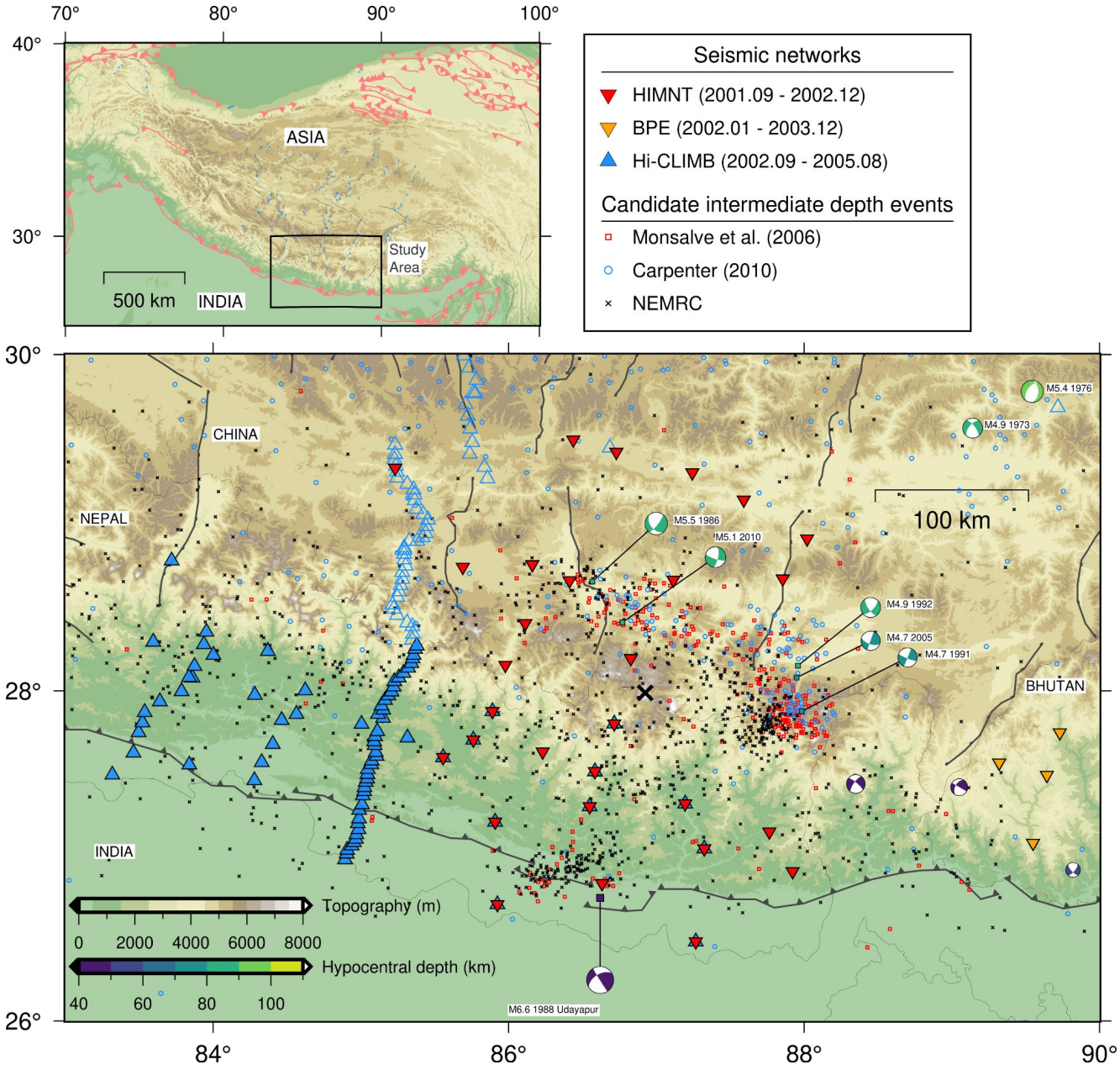

We start with candidate events from existing catalogs.

We complement with additional earthquakes using automatic earthquake detection (i.e., *EQTransformer*) and matched-filter detection (i.e., *EQcorrscan*) methods.

We estimate local magnitudes in a consistent way (formula of *Adhikari et al. 2015*).

Figure 1. Distribution of seismic networks operating in the Himalayas between late 2001 and mid 2013. Red and blue inverted triangles show the HIMNT and BPE seismic sites, respectively. Blue triangles depict Hi-CLIMB. Black cross indicates the location of M. Everest. Focal mechanism solutions are obtained from previous studies and Global CMT catalog.

Map of intermediate depth seismicity

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We detect ~1,000 potential intermediate depth earthquake. We locate events using *NonLinLoc* and a 1D velocity model.

Quality control:
1) At least eight phases (at least two of which are S picks); 2) RMS value smaller than 1.0; 3) Distance to closest station smaller than earthquake's hypocentral depth.

After applying quality criteria we retain **414 high-quality locations.**

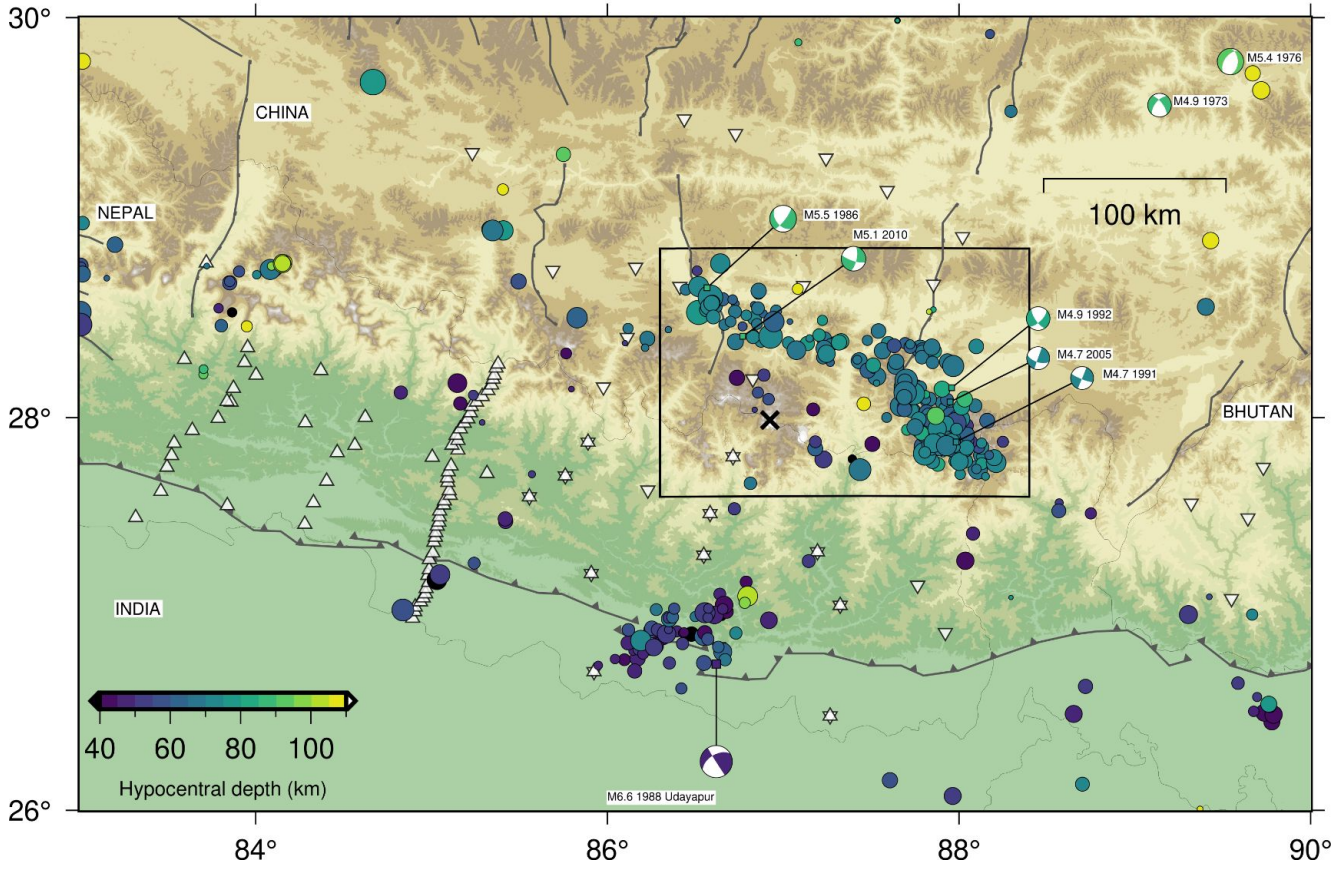

Figure 2. Epicenters of **414** high-quality intermediate depth earthquake locations. We use NonLinLoc and a 1D velocity model.

Map of intermediate depth seismicity

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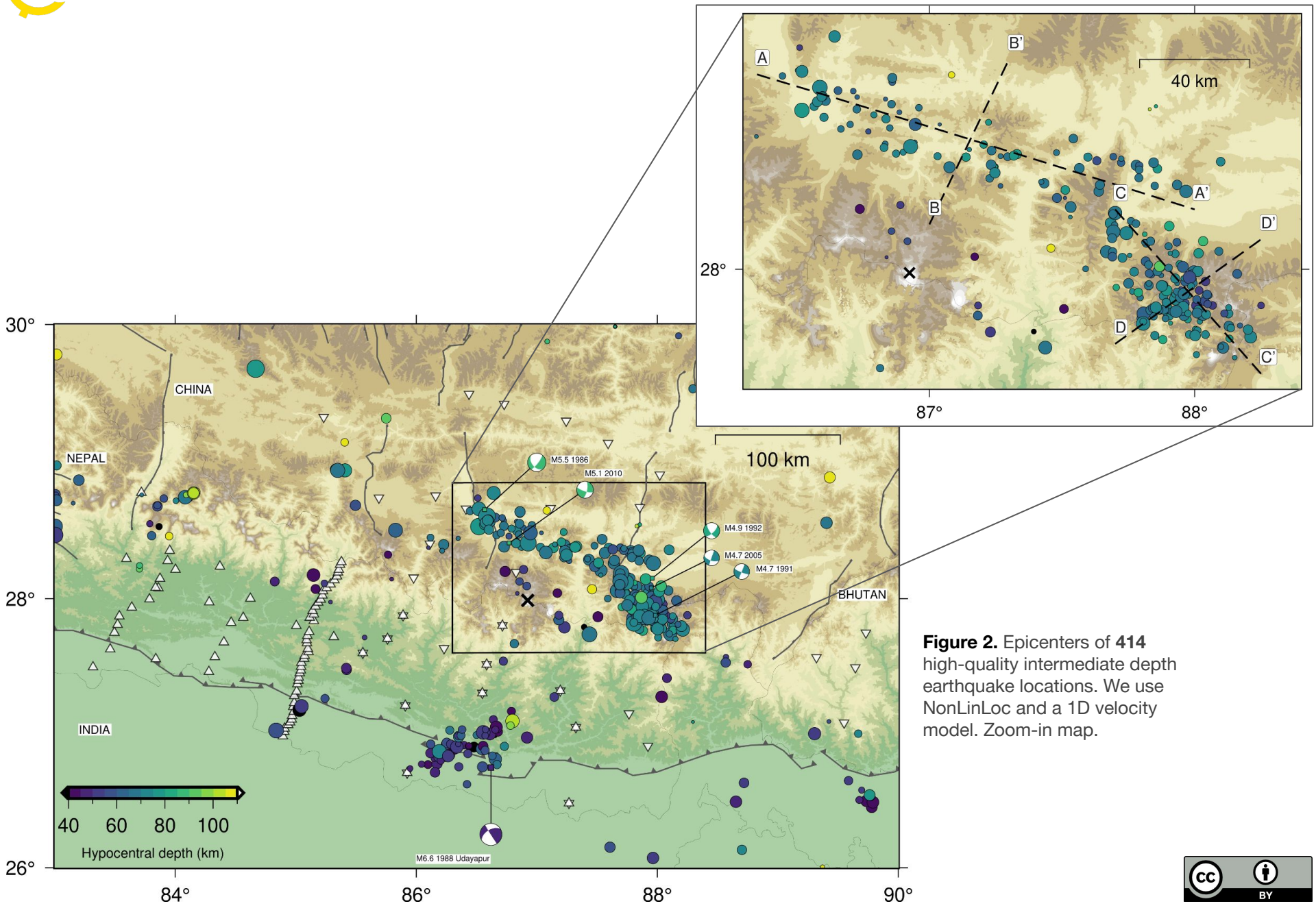

Figure 2. Epicenters of **414** high-quality intermediate depth earthquake locations. We use NonLinLoc and a 1D velocity model. Zoom-in map.

Spatial distribution of seismicity

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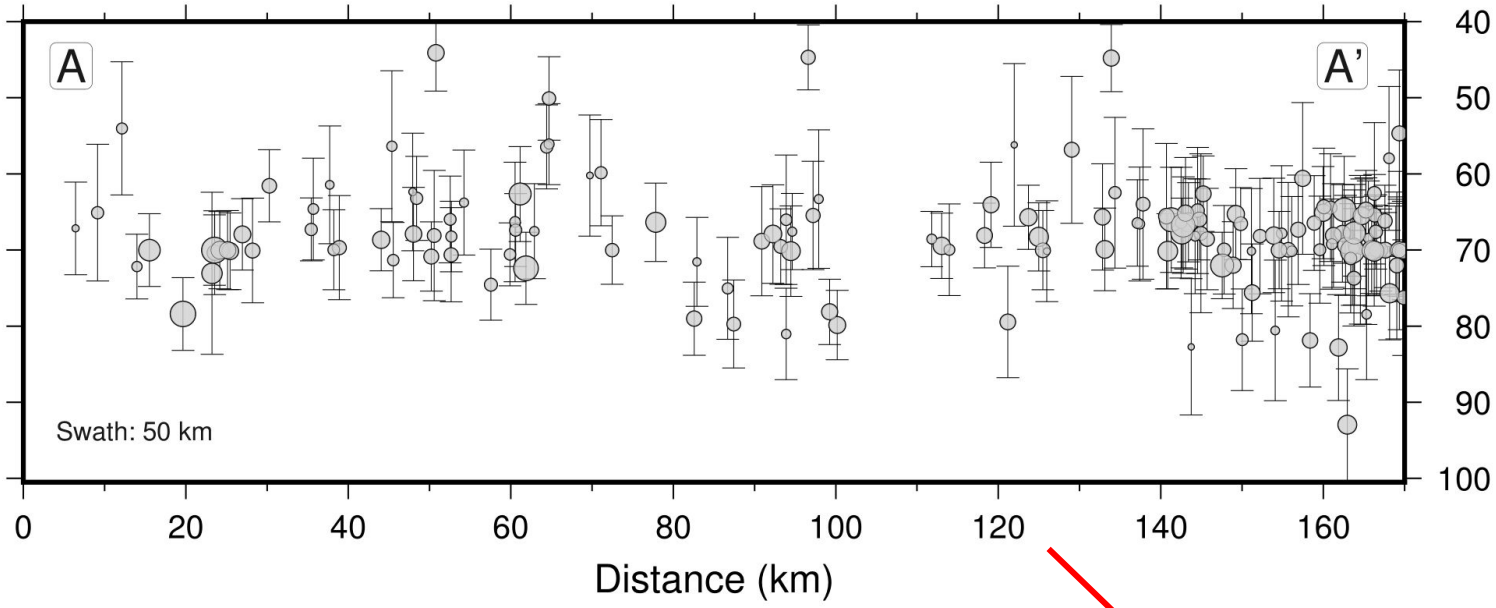
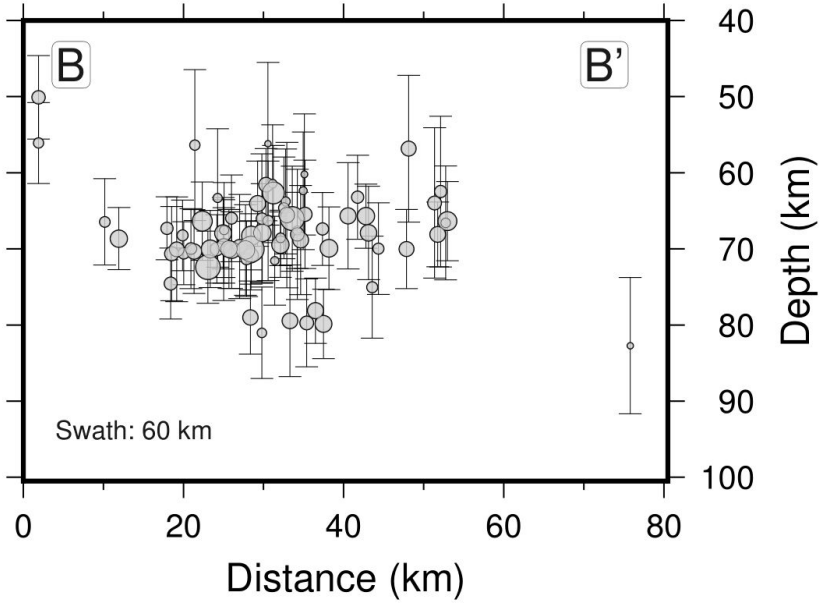


Seismic deformation here takes place within a ~20-30 km wide and ~12 km long zone.



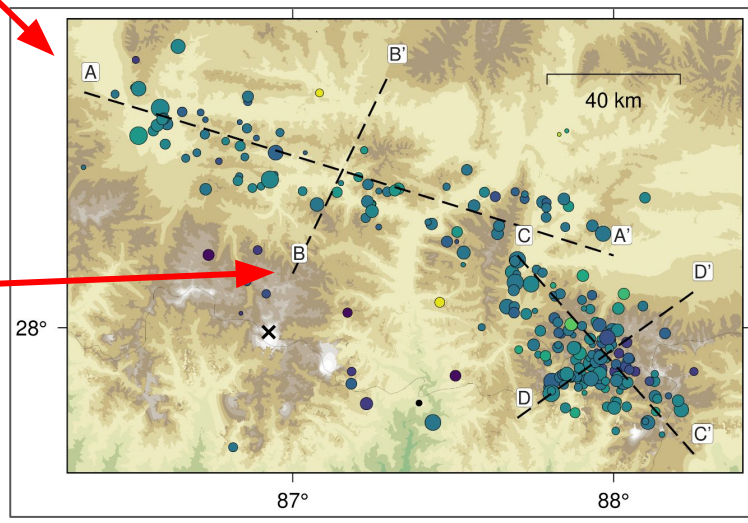


Figure 3. Vertical cross-sections A-A' and B-B' of earthquake hypocenters and depth uncertainties (vertical bars).

Spatial distribution of seismicity

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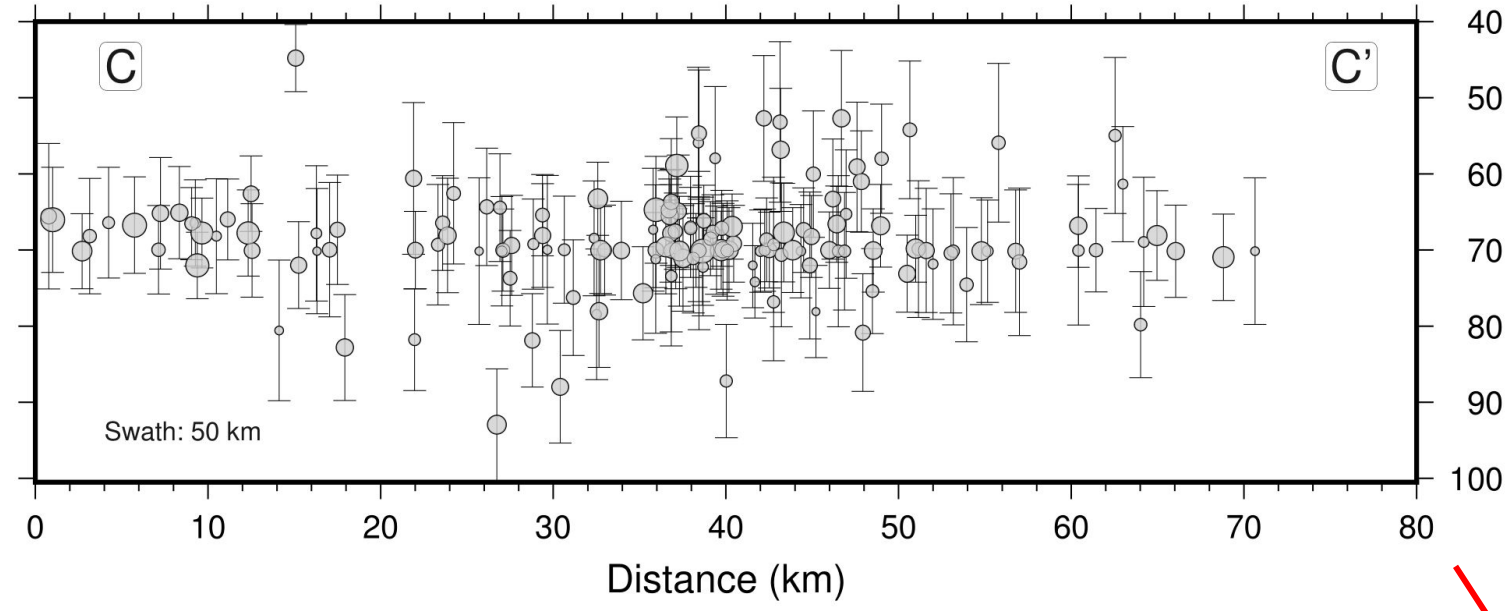
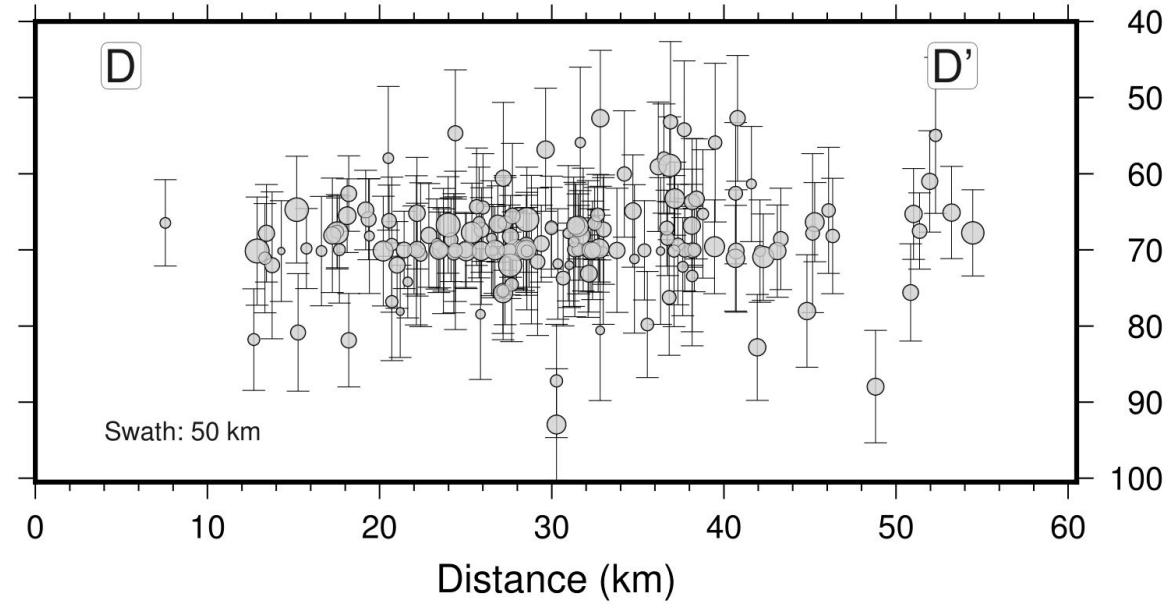


Seismic deformation here takes place within a ~30 km wide and ~15-20 km long zone.



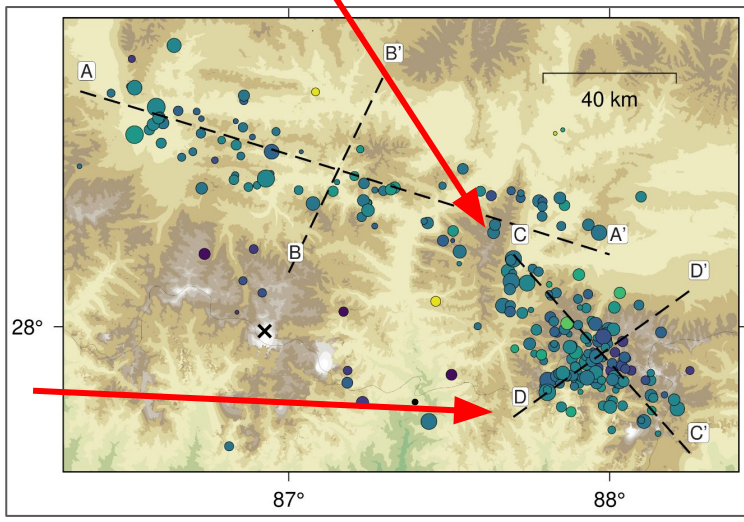


Figure 4. Vertical cross-sections C-C and D-D' of earthquake hypocenters and depth uncertainties (vertical bars).

Spatiotemporal evolution of seismicity

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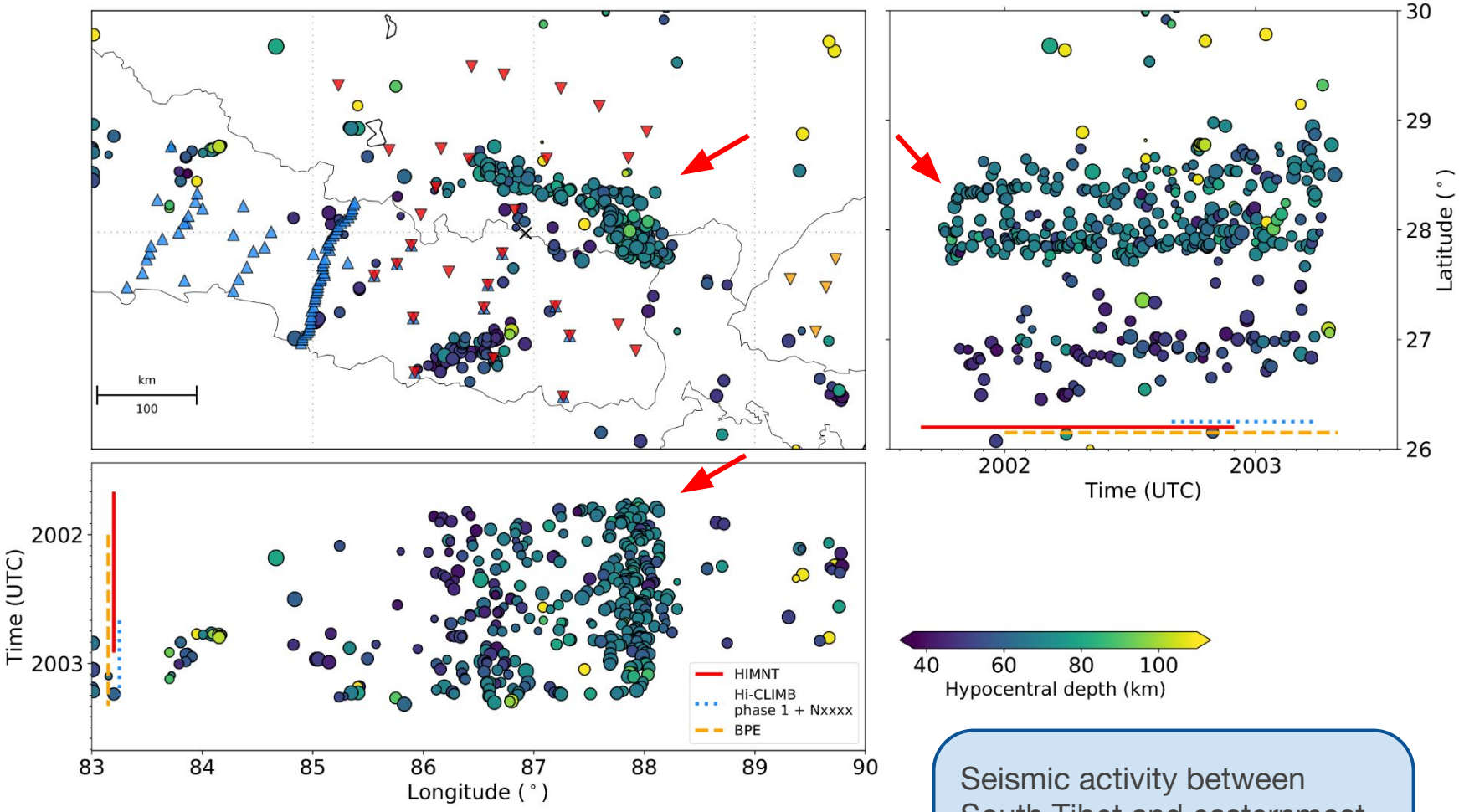


Figure 5. Map showing the locations of the **414 intermediate depth earthquakes** (colored according to their hypocentral depths). Panels on bottom and right show longitude and latitude versus time, respectively.

Seismic activity between South Tibet and easternmost Nepal is continuous throughout the examined time period.

Rate of seismicity

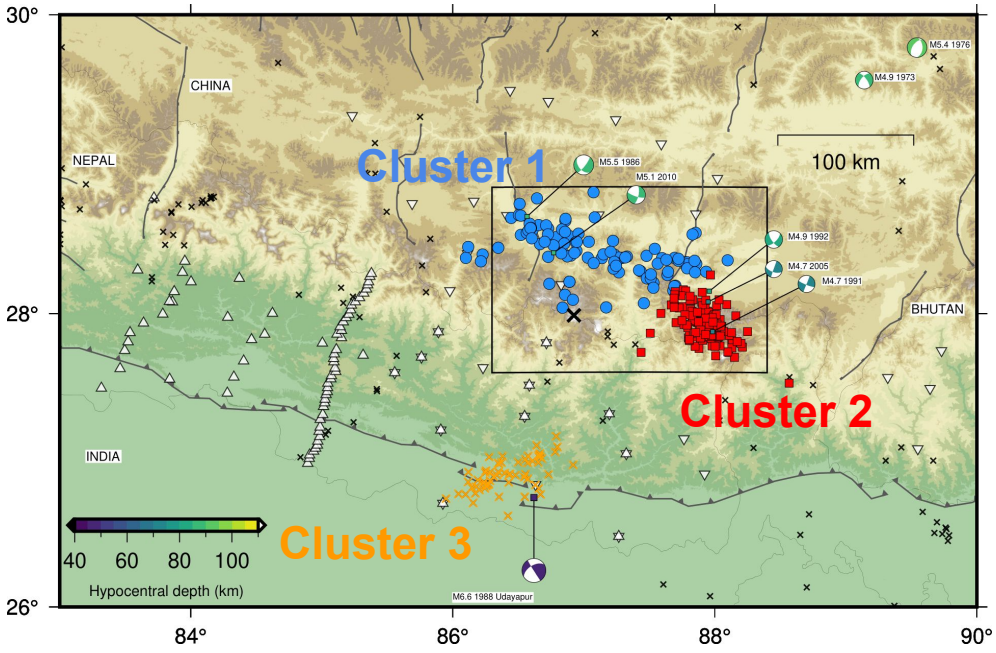


Figure 6. Map of clusters defined according to their spatiotemporal features.

We divide the seismicity into three main clusters given their spatial distributions

Seismicity rates within the clusters are relatively constant.

Cluster 2 presents the highest rates.

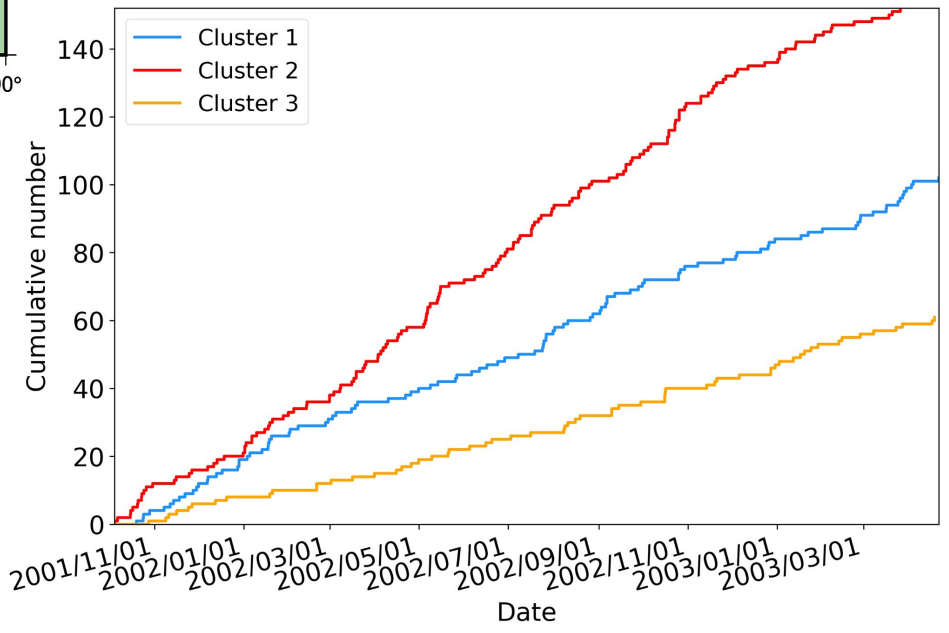
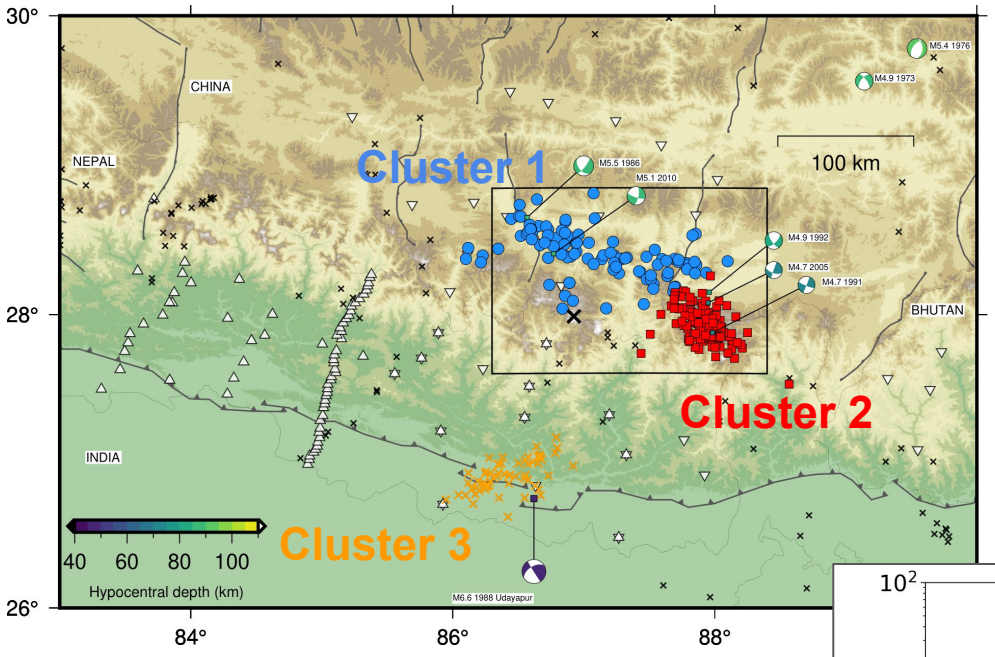


Figure 7. Cumulative number of events versus date (UTC) for the three clusters.

Temporal behavior of seismicity



Interevent times are generally larger than one day for all clusters.

Cluster 2 shows the smallest values.

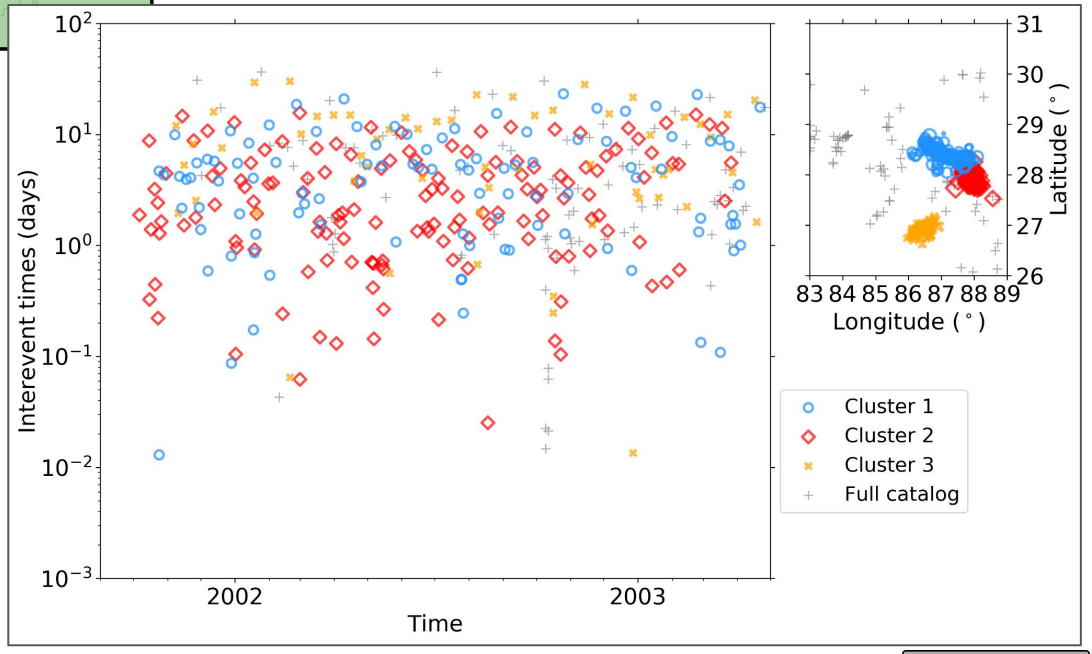


Figure 8. Interevent times of events versus date (UTC) for the three clusters.

Frequency magnitude distribution

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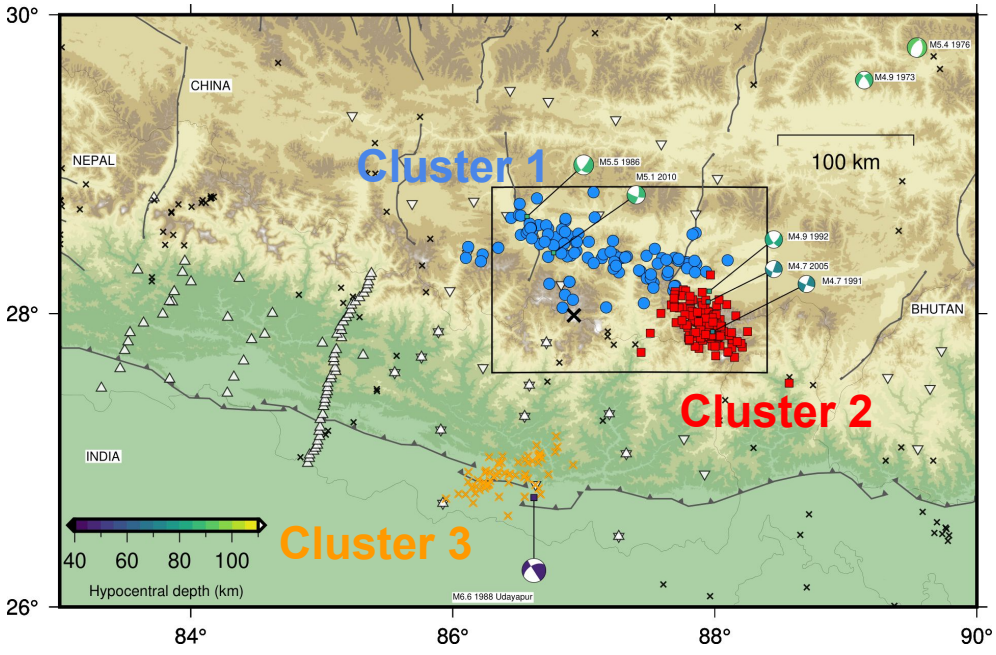

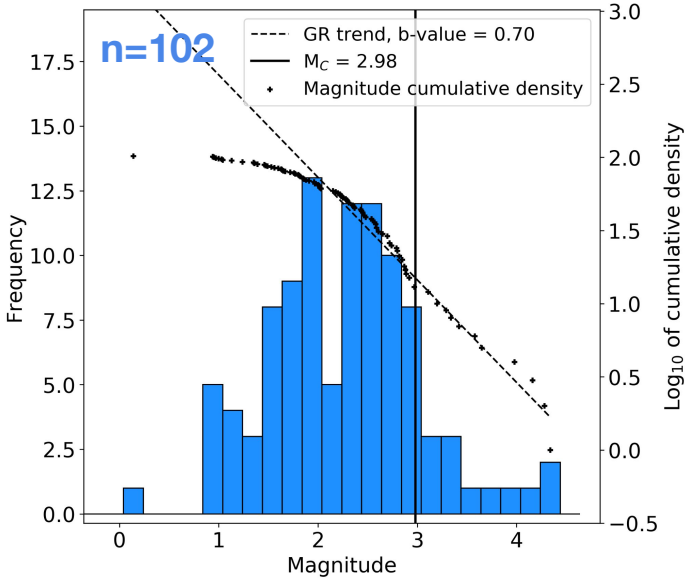

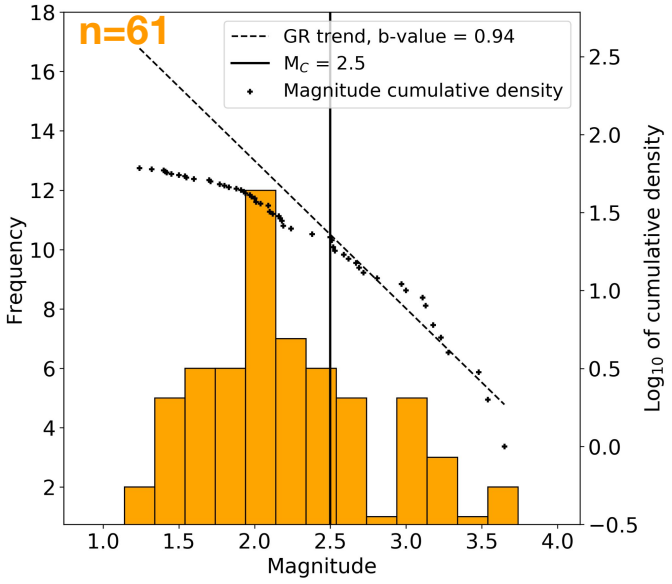

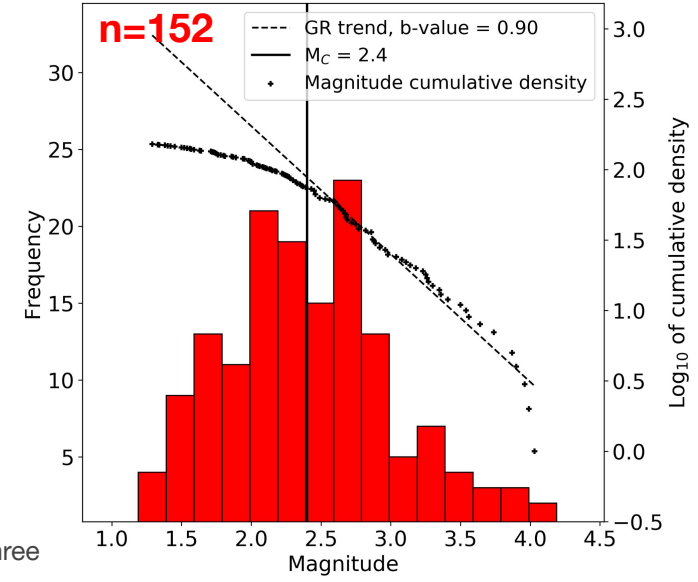

Figure 9. Magnitude frequency distribution of events from the three clusters.

Magnitude vs time distribution

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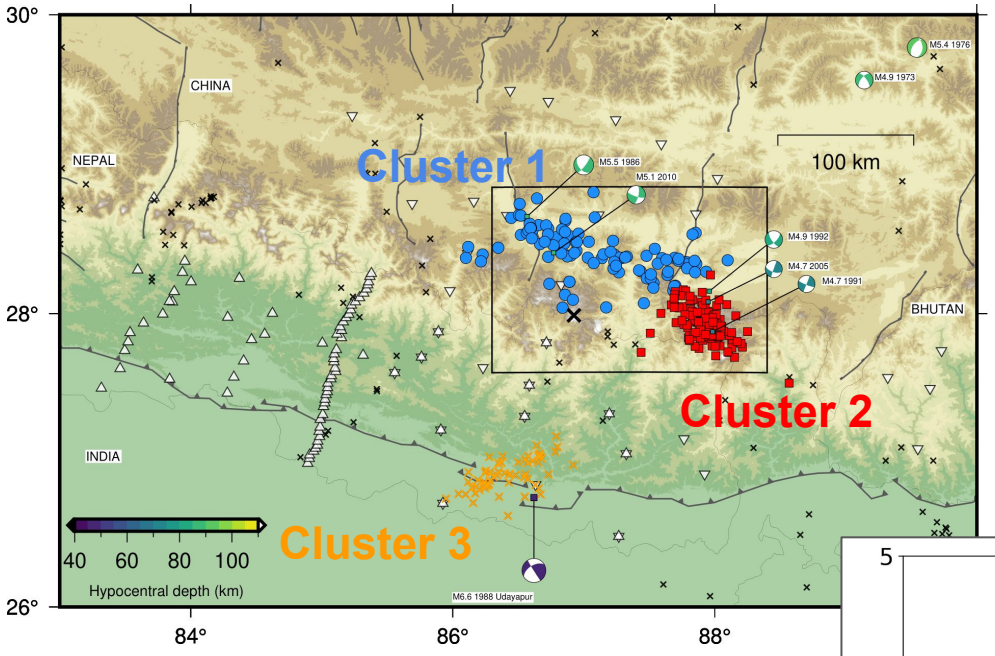

Several M>4.0 events that do not appear to have aftershocks.

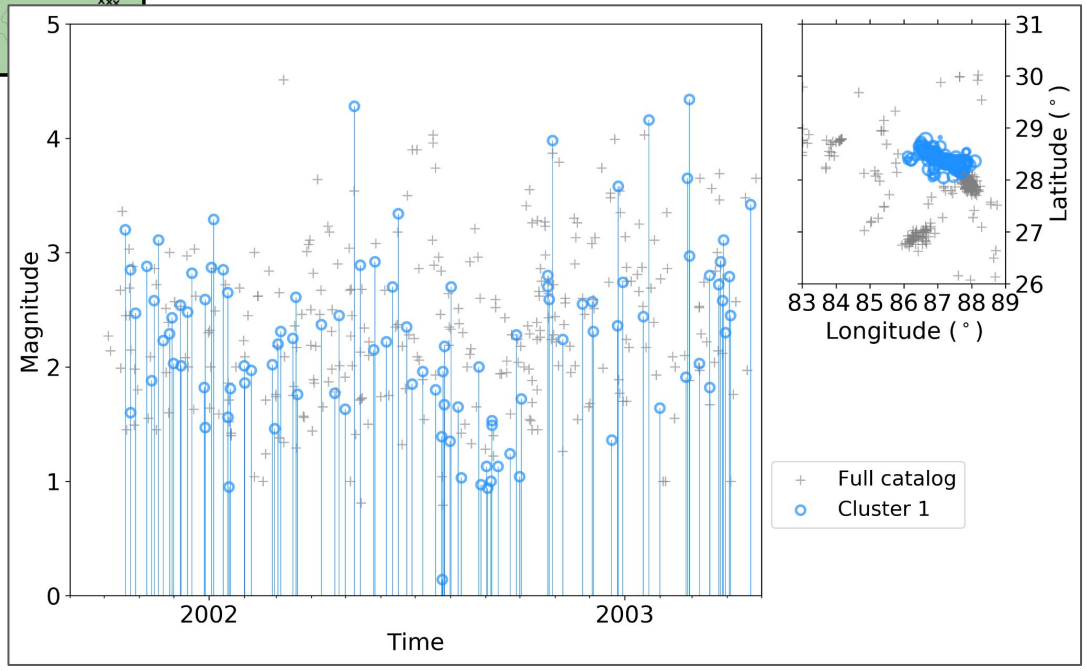

Figure 10. Magnitude vs time plots of events from the three clusters.

Magnitude vs time distribution

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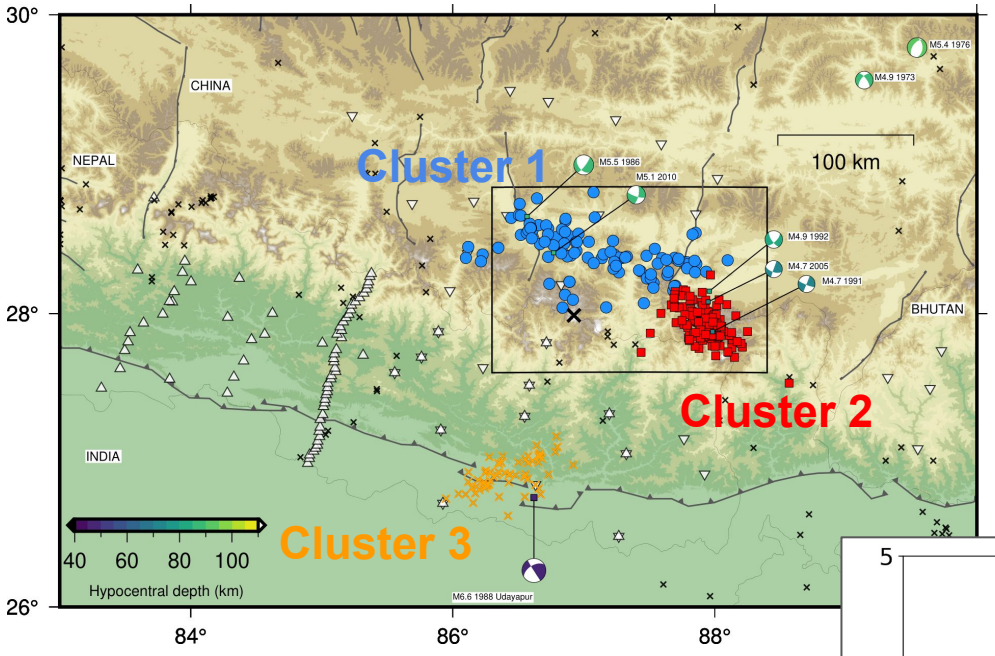
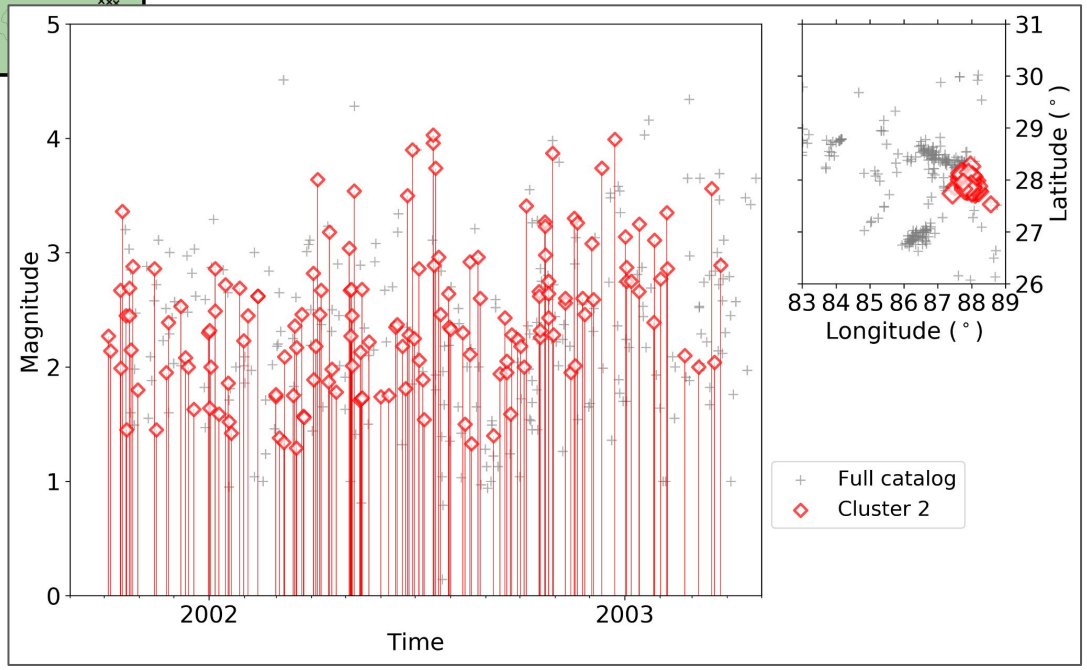


Relatively smaller magnitudes compared with Cluster 1.

Magnitude difference between largest event and next largest is less than 0.2 (more swarm-like than mainshock-aftershock type of sequence).



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Magnitude vs time distribution

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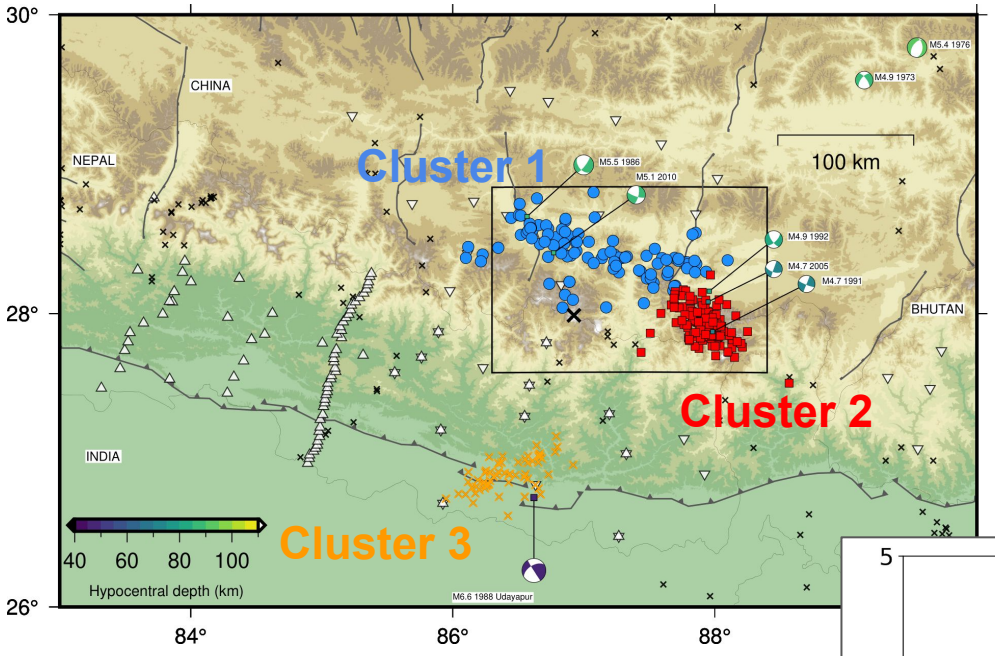

Relatively smaller magnitudes compared to the other two clusters.

Potential sequence related to the intermediate depth M6.6 1988 Udayapur earthquake?

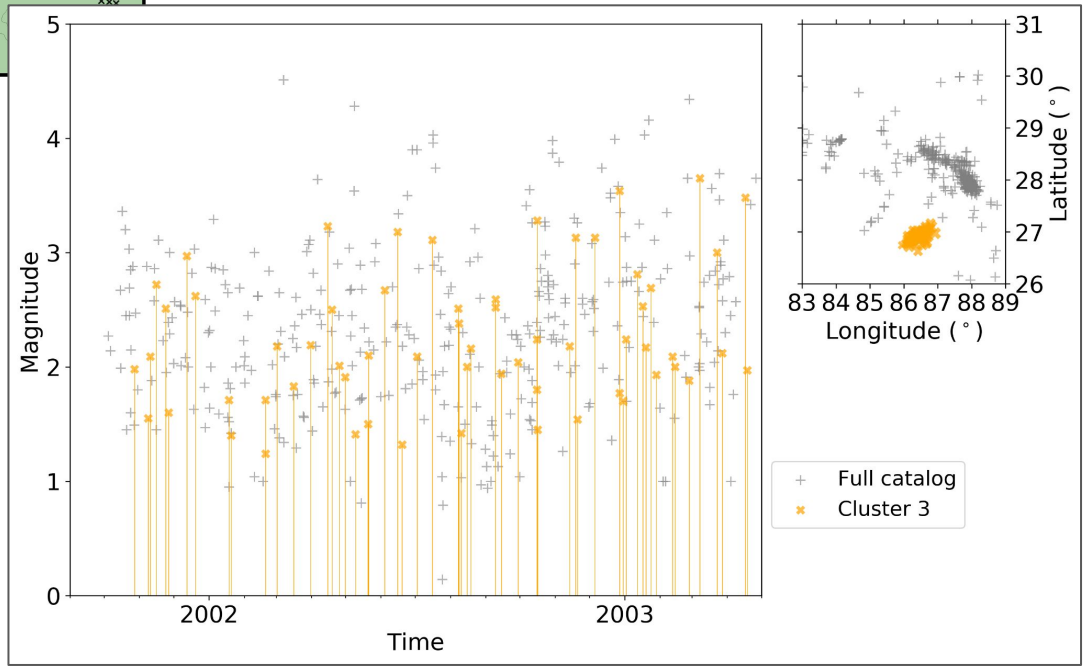

Figure 10. Magnitude vs time plots of events from the three clusters.

Preliminary analysis on migration of seismicity

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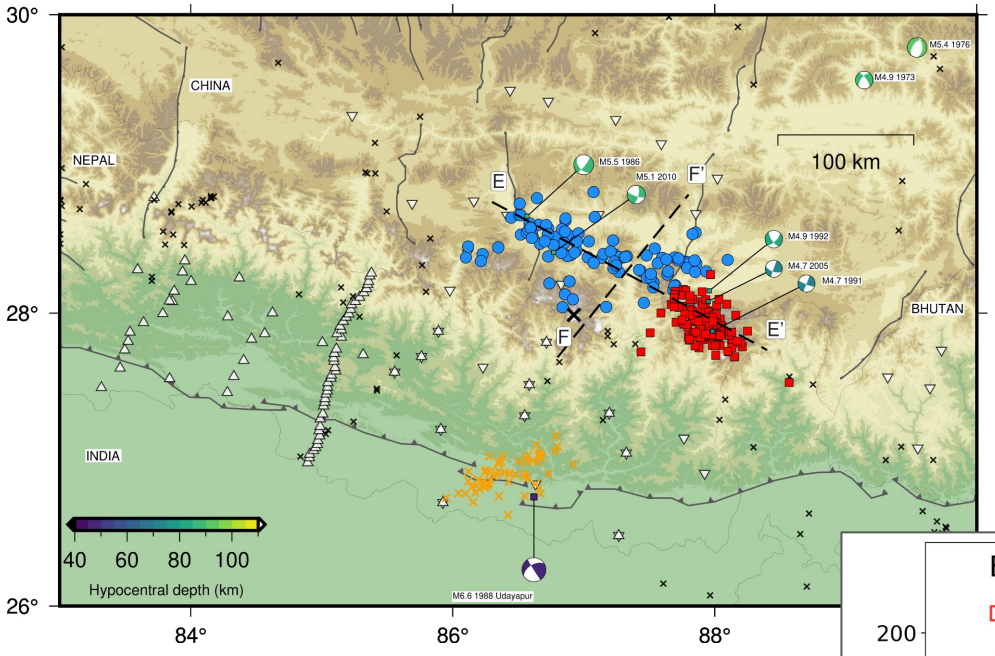

Typically mainshock-aftershock sequences do not exhibit spatial migration.

In this initial visual examination, hypocenters appear to migrate unilaterally along E-E' from the southeast to the northwest at rates around ~1-2 km/day.

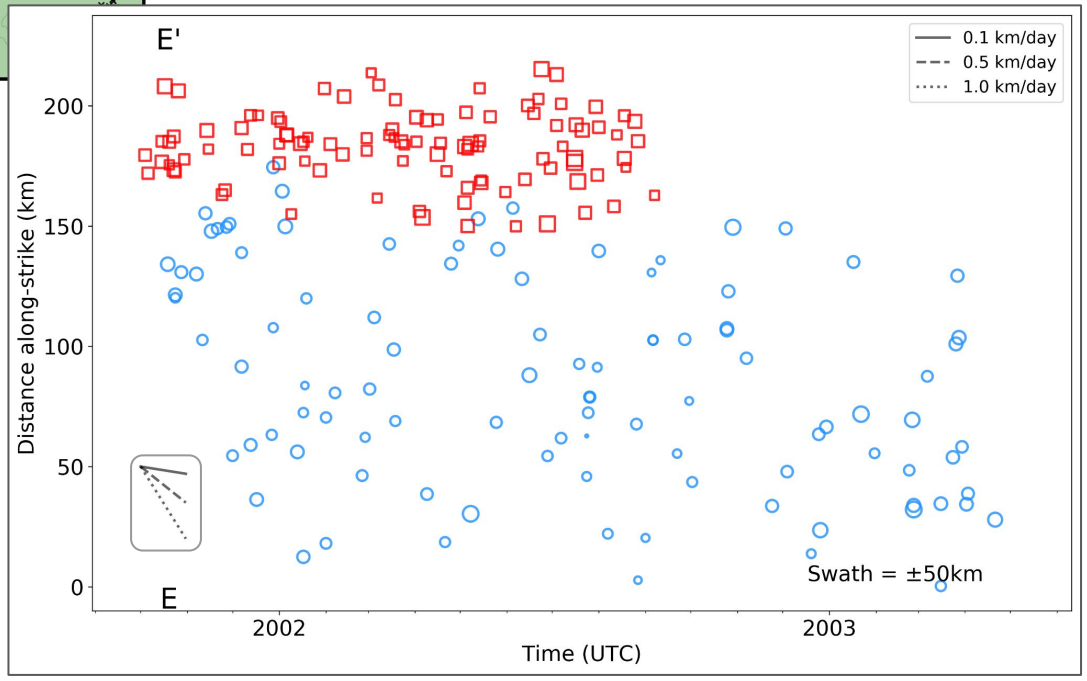

Figure 11. Distance of earthquakes along E-E' versus time.

Preliminary analysis on migration of seismicity

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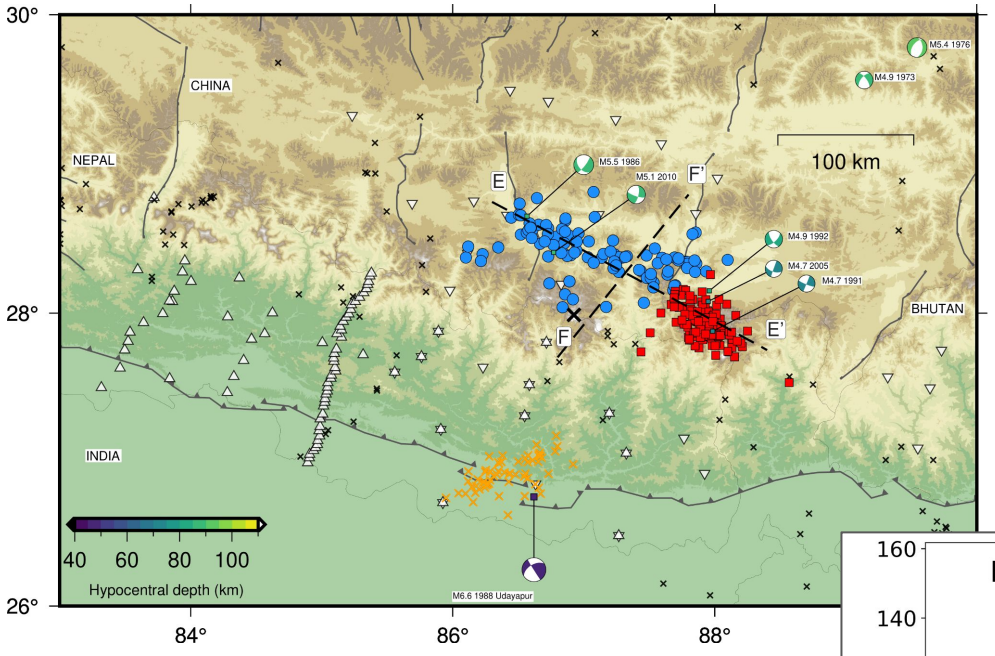

More detailed migration pattern analyses pending...

No obvious rates. Locally appears to be around <~1 km/day.

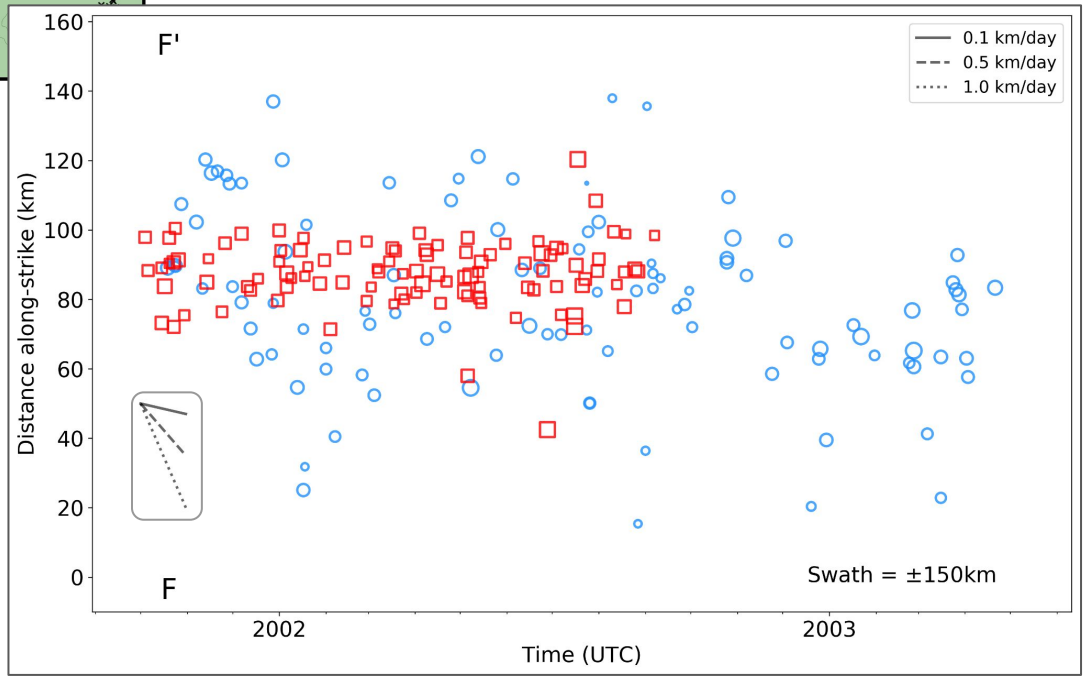

Figure 11. Distance of earthquakes along F-F' versus time.

Contributions and future work

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- We present the longest high-quality catalog of 414 intermediate depth earthquakes that occurred in the central Himalayas between late 2001 and middle 2003.
- We calculate local magnitudes in a consistent way.
- Intermediate depth earthquakes are mainly concentrated on an east-west oriented linear feature in South Tibet adjacent to easternmost Nepal (clusters 1 and 2) at depths between 60 and 80 km (within uncertainties).
- Seismicity there presents the following characteristics:
  - absence of mainshock-aftershock sequences,
  - small largest to next largest magnitude differences,
  - relative constant rates,
  - interevent times mostly >1 day
- These preliminary results suggest that seismicity is more swarm-like in character throughout the examined time period and given the seismic data available.

- We intend to calculate relative earthquake locations (double-difference techniques and waveform cross-correlation to refine the accuracy of the hypocenters).
- We also intend to further examine the migration patterns.
- And finally perform modeling of fluid flow and possible metamorphic reactions (i.e., eclogitization) given these time evolution patterns.