भारतीय भूवैज्ञानिक सर्वेक्षण

GEOLOGICAL SURVEY OF INDIA

Landslide Susceptibility, Early Warning and Seismic Hazard Zonation

Dr. Saibal Ghosh
Deputy Director General

National Meet on Disaster Management by NRSC, Hyderabad, 27-28 Feb, 2023

Topics to be discussed

- Landslide scenarios
- Landslide Susceptibility Analysis
- Landslide Maps, and Utility
- Regional LEWS Plan and Program
- Earthquake and Seismic Studies
- Way Forward

Landslide-a complex hazard

Profuse loss of resources

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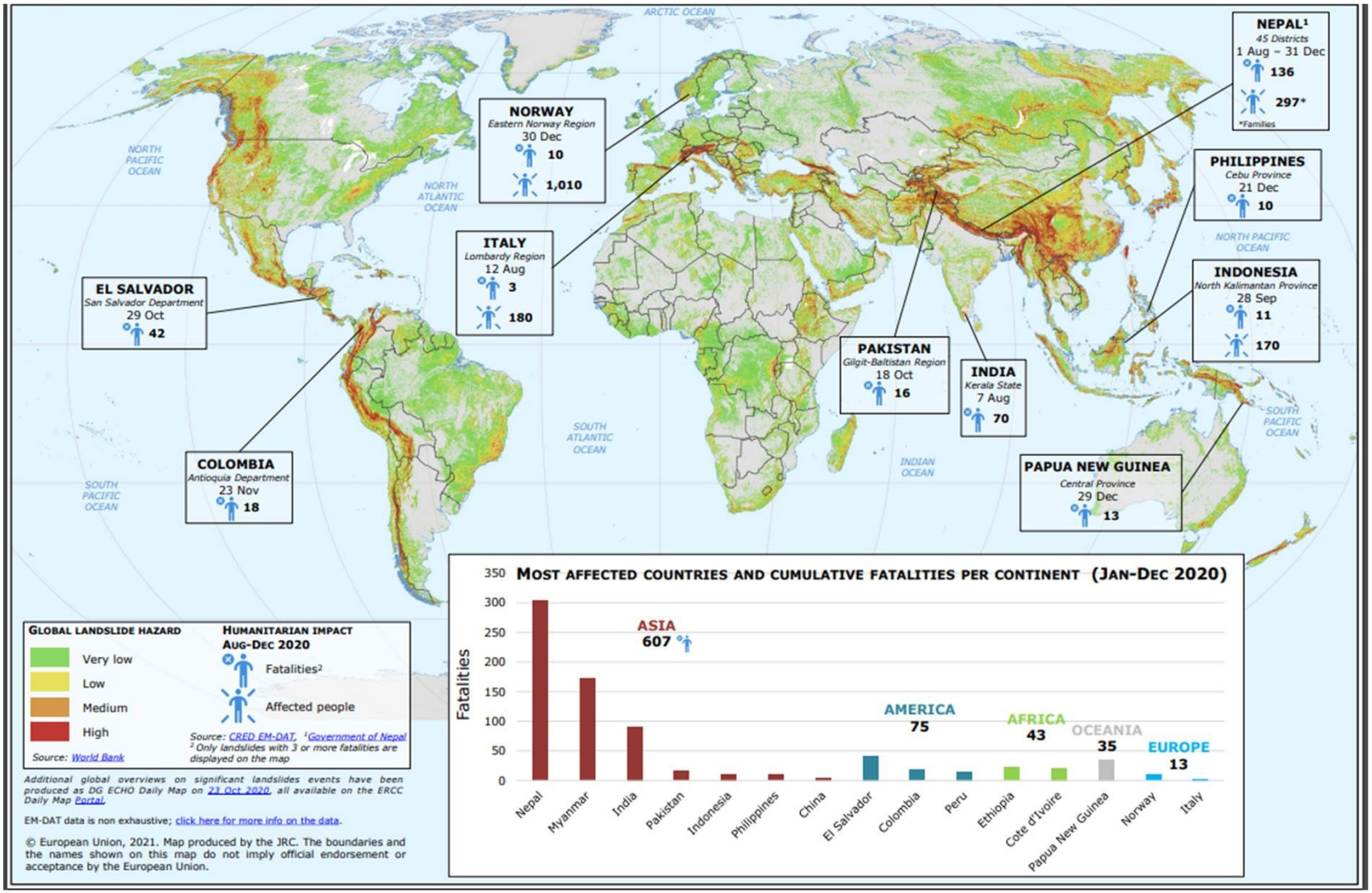
Global Landslide Hazard Map

Olga Petrucci; Sustainability 2022, 14, 9346. https://doi.org/10.3390/su14159346



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Landslide scenario Global -WHO estimates

https://www.who.int/health-topics/landslides#tab=tab_1

4.8 million people affected

Between 1998-2017, landslides affected an estimated 4.8 million people worldwide.

Find out more

18 000 deaths due to landslides

Between 1998-2017, landslides caused more than 18 000 deaths worldwide.

Find out more

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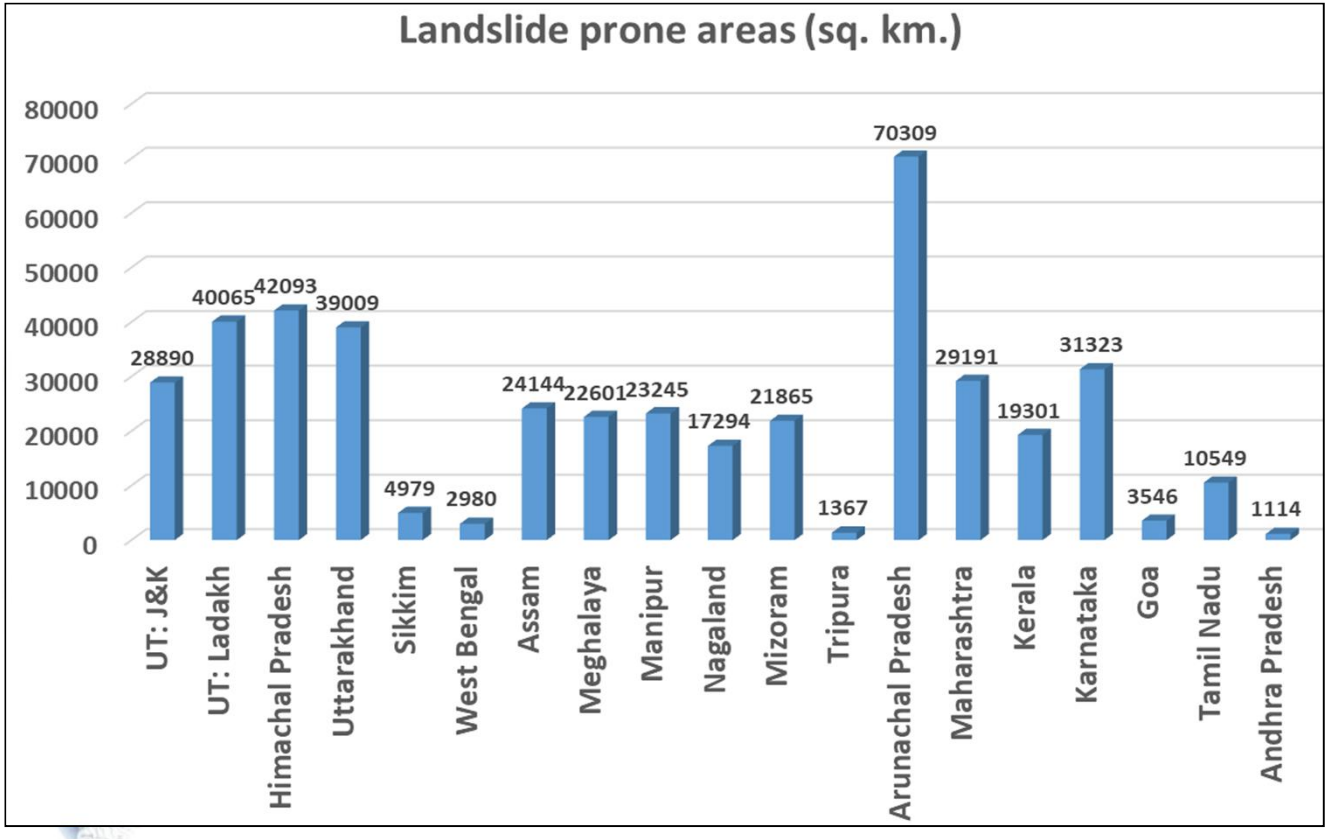
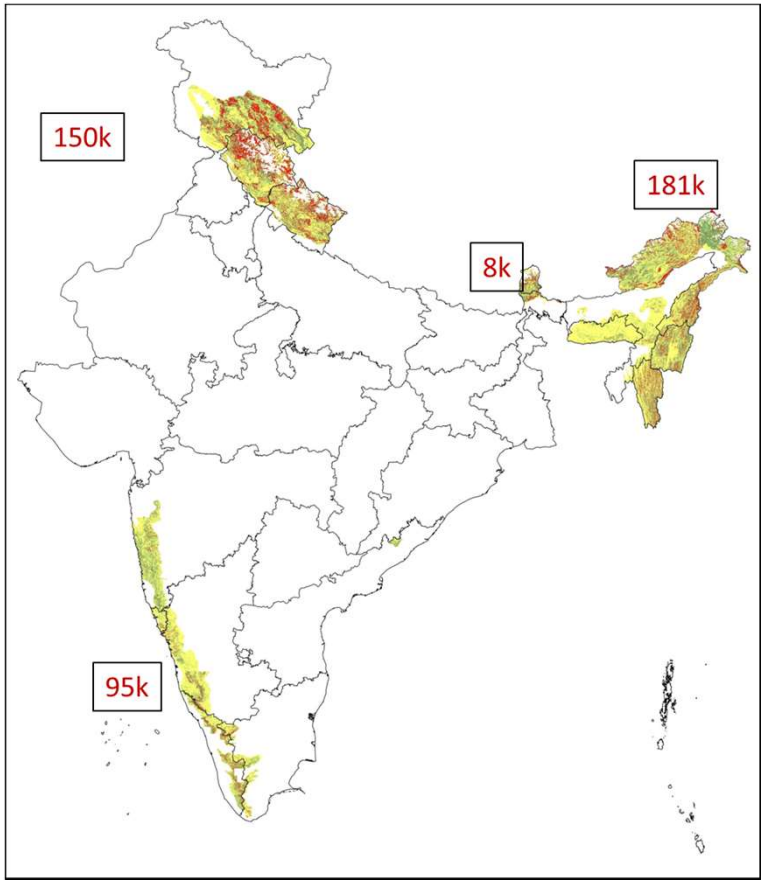
Landslide Scenarios - India

(Froude and Petley, 2018)

1. India is one of the most affected countries for fatal landslides (as revealed after analysing 5,031 fatal landslides worldwide between 2004 and 2016)
2. India registered 10,900 deaths from landslides (18% of the global landslide casualties) between 2004 and 2016.
3. Out of the total global landslides triggered by rainfall, 16% are from India. Of these, 77% of them occurred during the monsoon.
4. Study showed that number of anthropogenically-triggered landslides is increasing in India. About 28% landslides has a relation to construction activity.

Landslide Scenarios - India





- 4.3 lakh sq. km. area is landslide prone (12.6% of the Indian landmass)
- Varied geo-environments & complex failure mechanisms

Landslides inventoried by GSI during 2015-2020

State Name	Number of landslides
Arunachal Pradesh	33
Assam	120
Meghalaya	32
Mizoram	14
Tripura	10
Manipur	20
Nagaland	34
Sikkim	20
Himachal Pradesh	97
Jammu & Kashmir (UT)	169
Uttarakhand	27
Karnataka	194
Tamil Nadu	196
Kerala	2238
Maharashtra	78
West Bengal	374
Total	**3656**

Major fatal landslide events in last three years

Major fatal landslide events triggered by extreme rainfall / cloudburst/ flash floods during 2018-2020 (Total = 25 events); on average ~8 events per year		
S.No.	**State**	**Number of major events**
1	Jammu & Kashmir	5
2	Himachal Pradesh	2
3	Assam	3
4	Karnataka	2
5	Kerala	3
6	Mizoram	2
7	Arunachal Pradesh	1
8	Uttarakhand	3
9	Tripura	1
10	Manipur	1
11	Maharashtra	2

In 2021, we already have 25 major fatal landslide events till September 2021

There has been a 200% increase already in the normal fatal landslide incidents in 2021

Landslide Zoning – Multi-scale & multi-purpose exercise

Purpose		Type of Zoning				Levels of Zoning			Mapping Scale
		Inventory	Susceptibility	Hazard	Risk	Primary	Intermediate	Advanced	
Regional Zoning	Information								1:50,000 and smaller
	Advisory								
	Statutory								
Local Zoning	Information								1:5000 to 1:10,000
	Advisory								
	Statutory								
Site-specific Zoning	Information								1:5000 or larger
	Advisory								
	Statutory								
	Design								

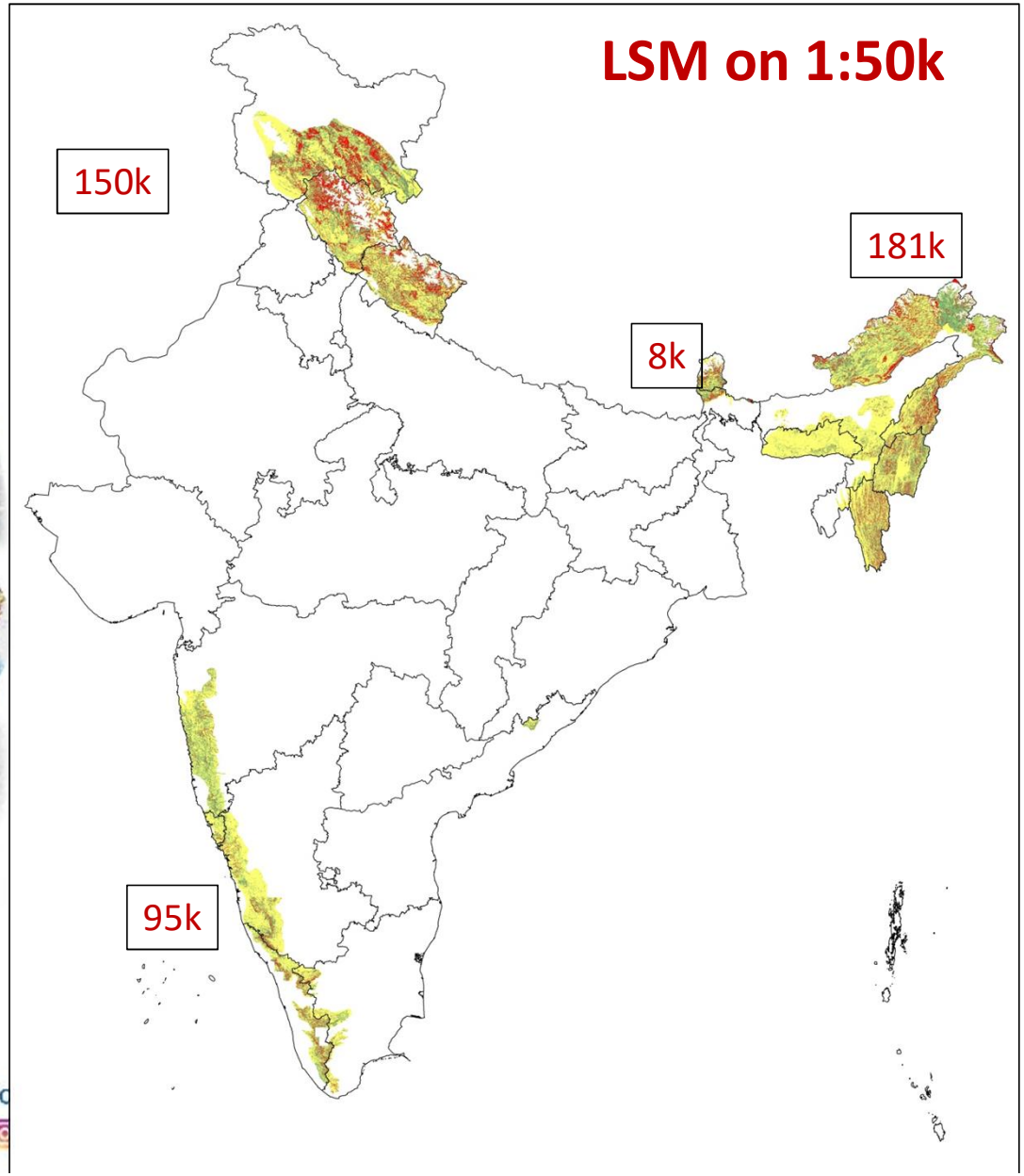




	Applicable
	May be applicable
	Not Recommended
	May not be feasible

- **Purpose**
- **Type**
- **Level**
- **Scale**

After Fell *et al.*, 2008 and van Westen *et al.*, 2008)



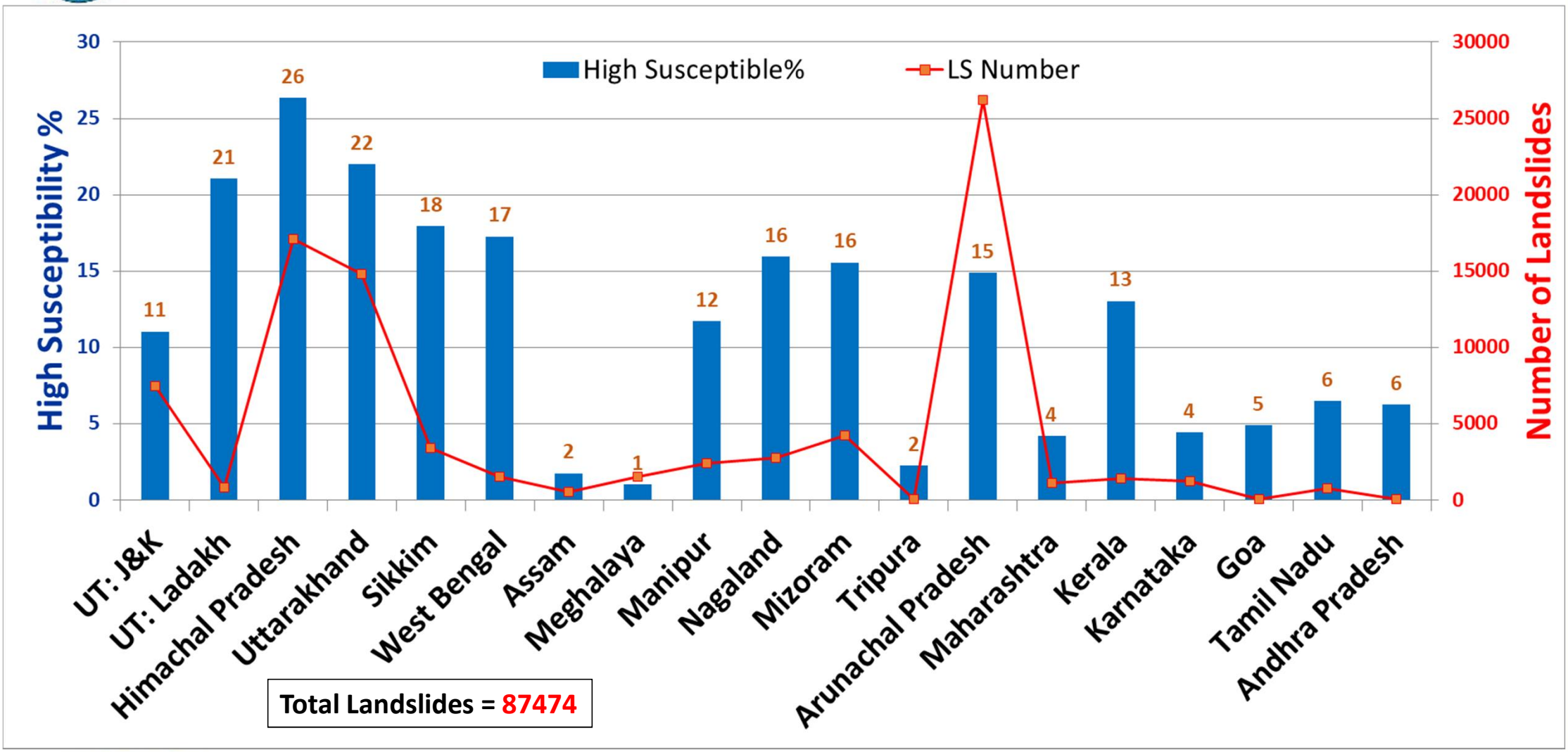
Total NLSM Target = 434 k sq. km; Entire map is already prepared

Scale: 1:50,000

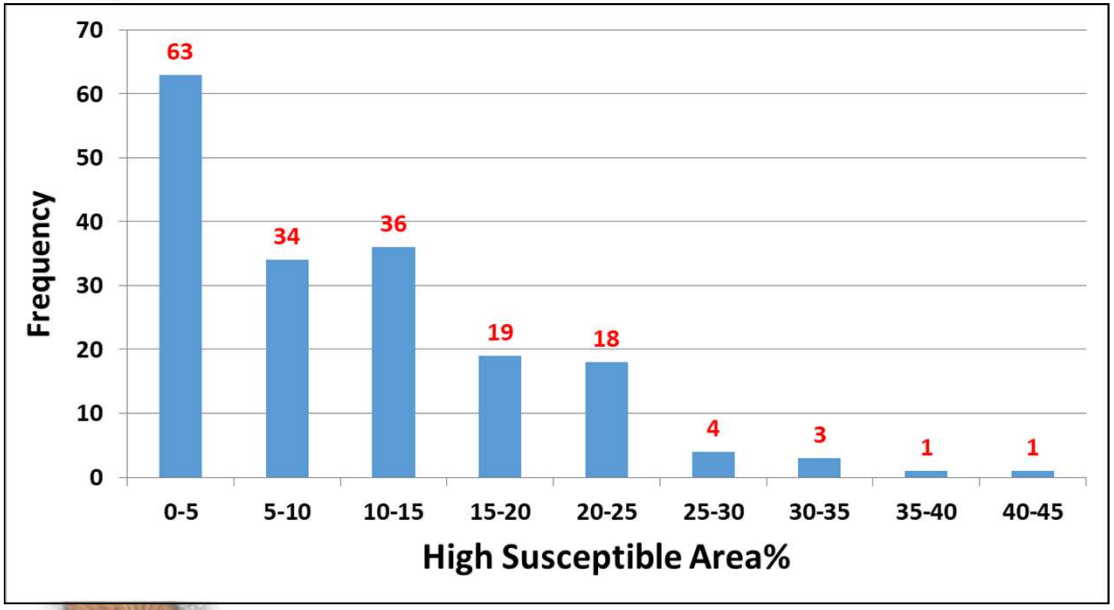
Data uploaded in GSI's Bhukosh Portal (http://bhukosh.gsi.gov.in/Bhukosh/Public) for free download and use by all

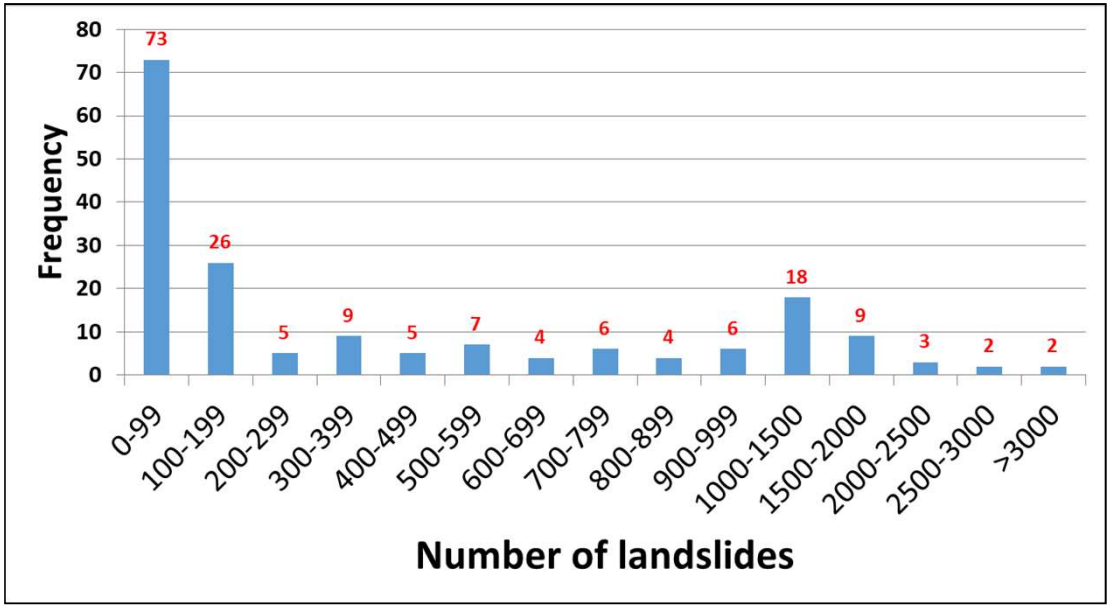
- ✓ NLSM Maps = 363 k sq. km. (~85% of total target)
- ✓ Landslide polygons mapped and uploaded = 61,287 nos.
- ✓ Landslide field-validated with 42 nos field based attributes = 28,831 nos. (~50%)
- ✓ Parts of States: 19;
- ✓ Parts of Districts : 179

Landslide Susceptibility Scenario of India



Utility of the NLSM product

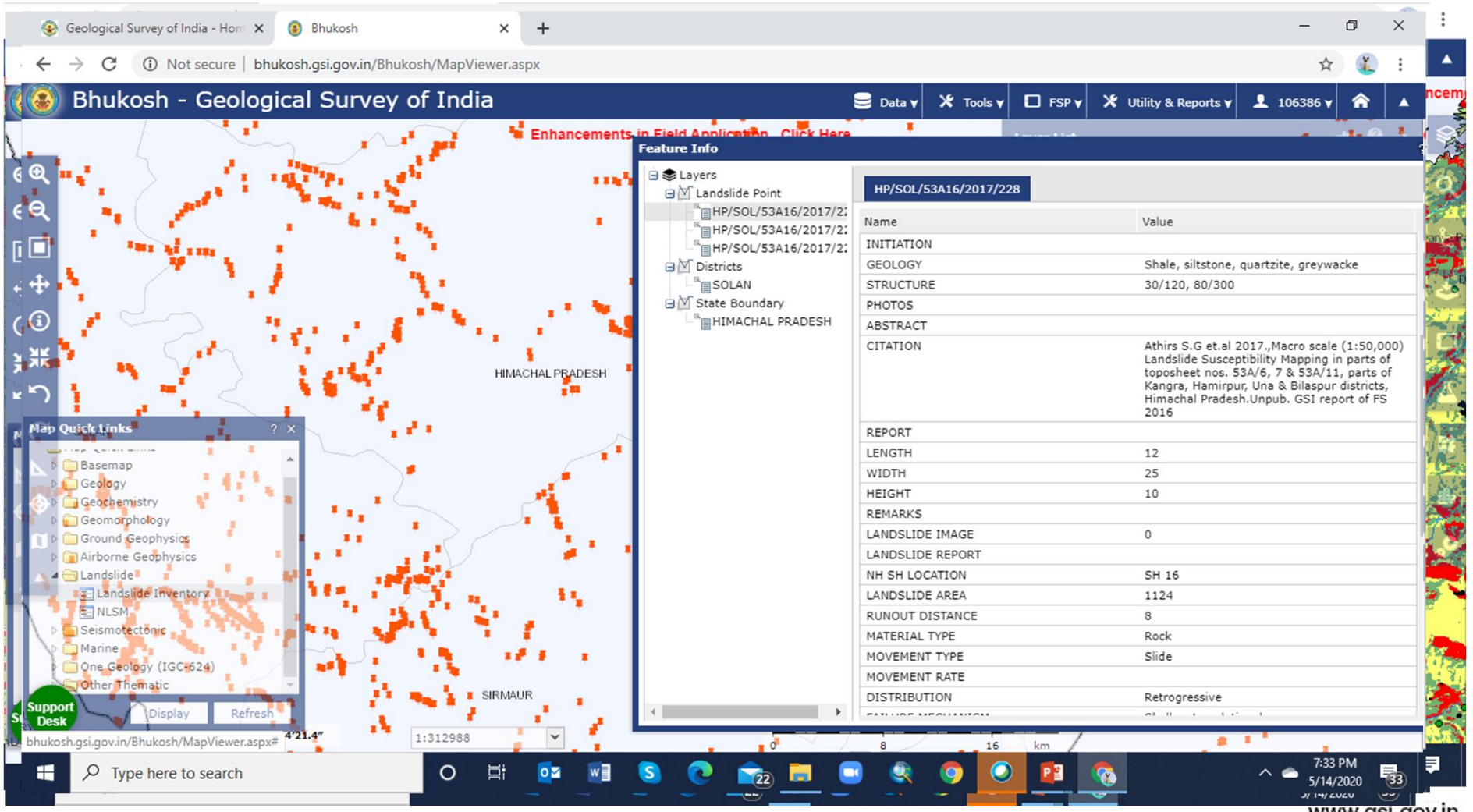




- ❑ Baseline data on susceptibility condition
- ❑ Regional land use planning
- ❑ Ranking of districts for resource allocation (NDMA)
- ❑ Identification of sectors for meso (1:10k) or site specific (1:1000) studies-200sectors
- ❑ Use as base map for Regional Landslide Early Warning System (LEWS)
- ❑ Vulnerability assessment of the exposed elements as a tool for decision support

National geodatabase in public domain

(http://bhukosh.gsi.gov.in/Bhukosh/Public)



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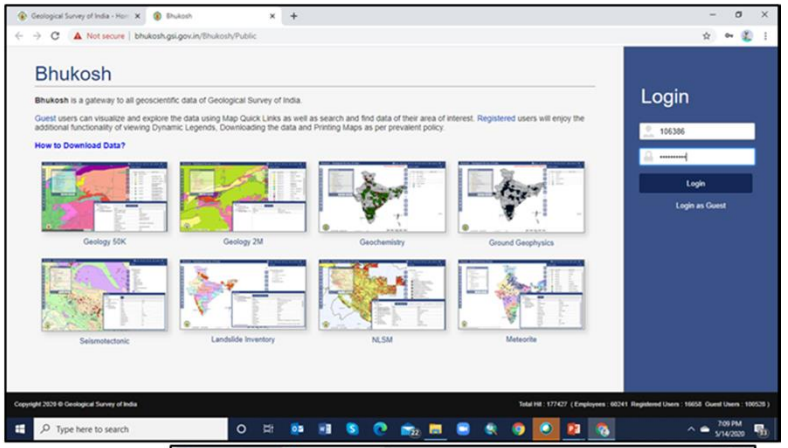
Data dissemination in public domain

(http://bhukosh.gsi.gov.in/Bhukosh/Public)

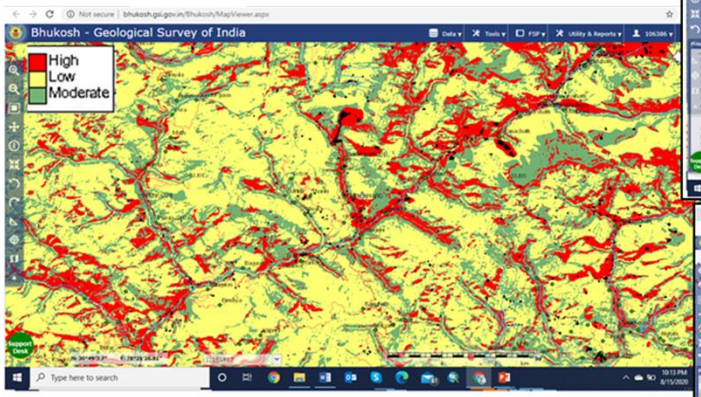
Metrics	Landslide Inventory	NLSM
Total number of download instances	6519	5322
Total no. of unique non-GSI users who downloaded	926	710
Number of different unique affiliations of the non-GSI registered users who downloaded	487	394

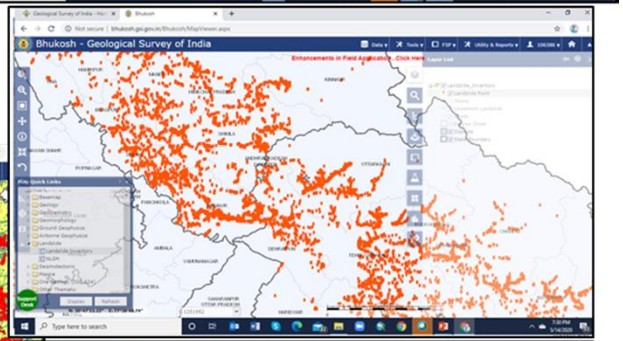


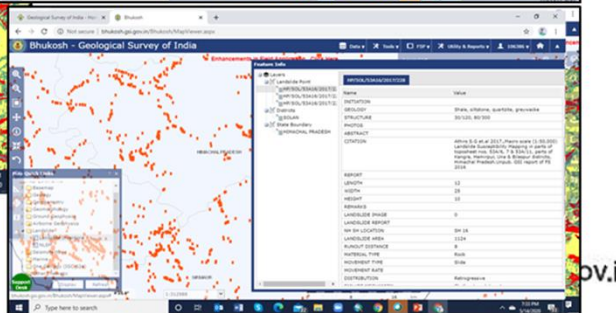
The data is also shared through WMS with NDMA Map Portal

Directly shared

SDMA - West Bengal
SDMA - Sikkim
SDMA – Uttarakhand
SDMA - Himachal Pradesh
SDMA - Kerala
SDMA - Tamil Nadu used in TMSMART APP of State Govt.
SDMA - J&K - Landslide Inventory only
MoRTH - Uttarakhand Map
BMTPC - Landslide Inventory only







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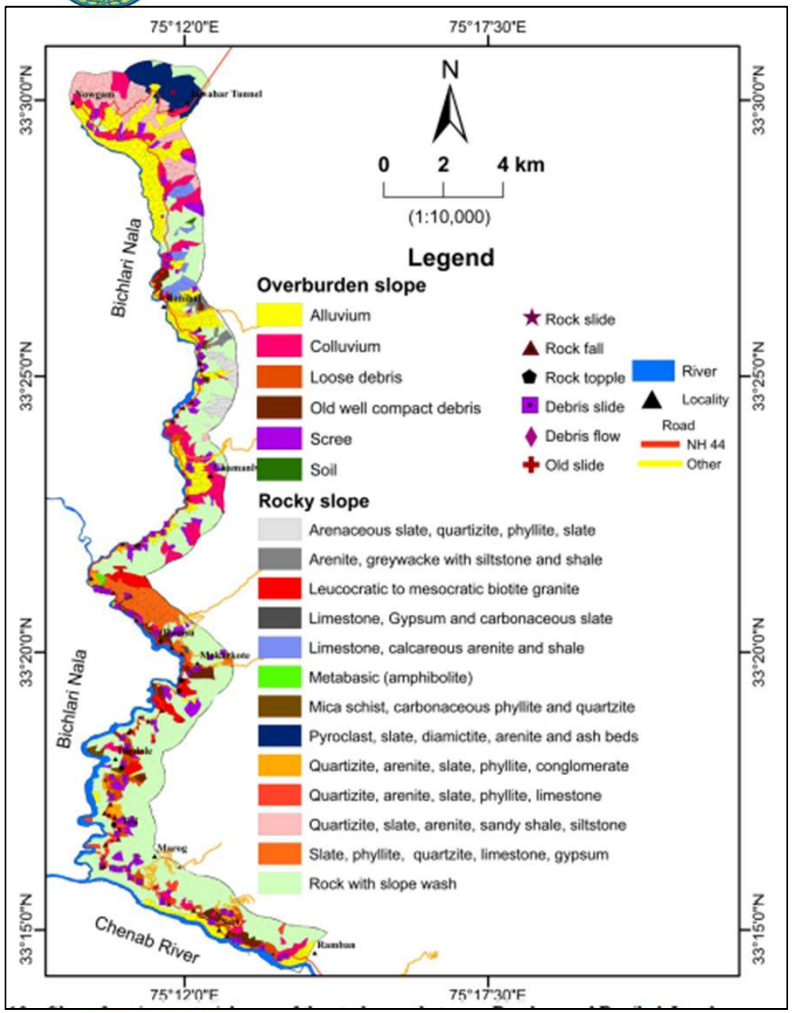
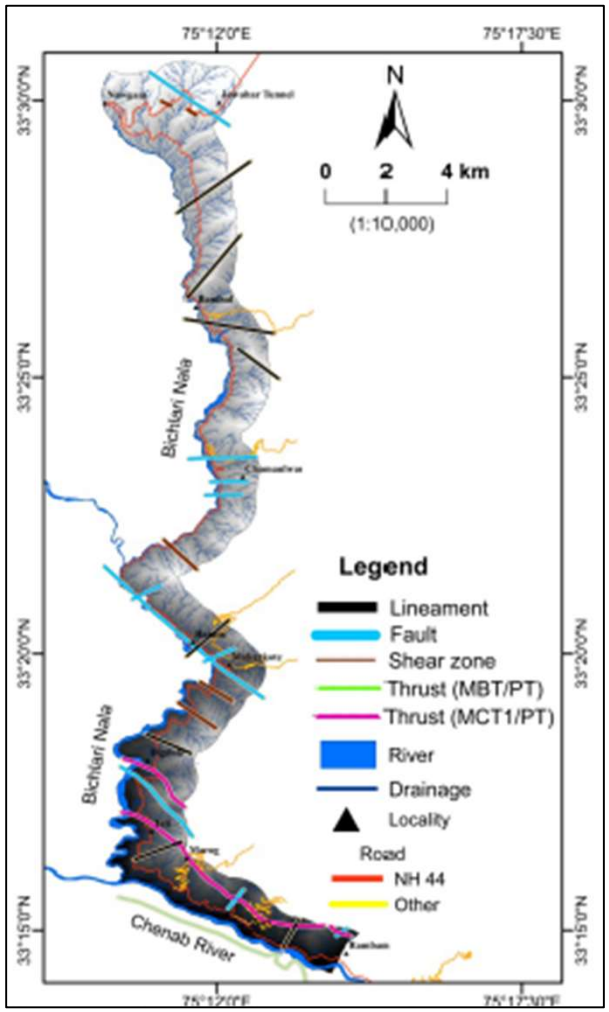
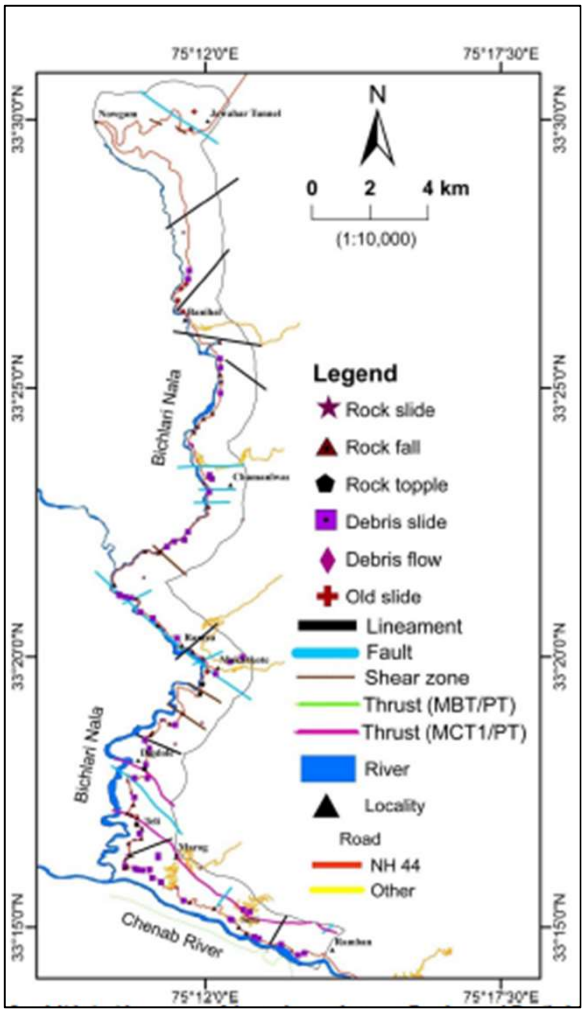
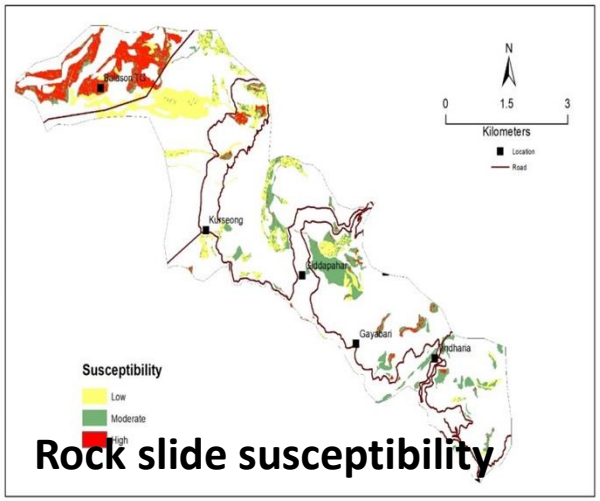
Landslide Susceptibility on 1:10,000 scale



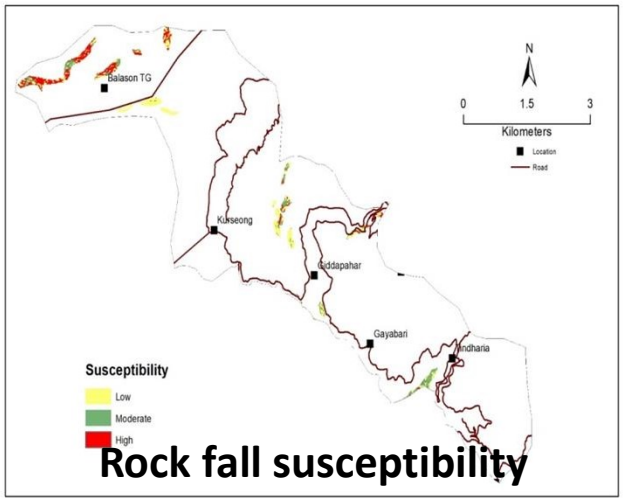




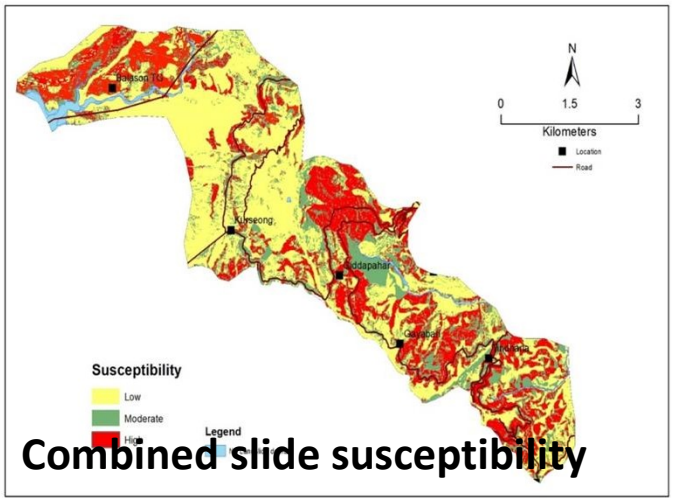
Landslide susceptibility mapping 1:10k (Mesoscale)



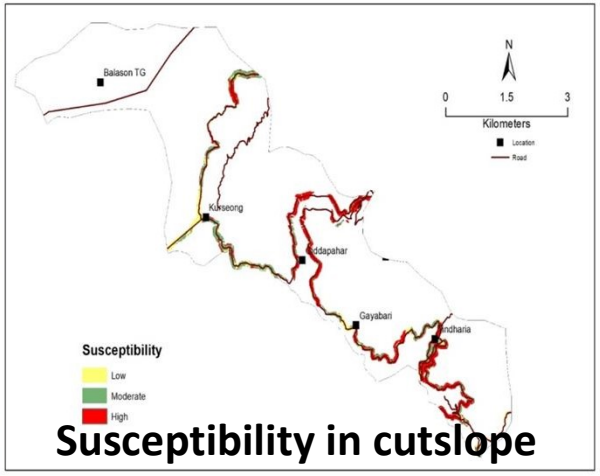
Rock slide susceptibility



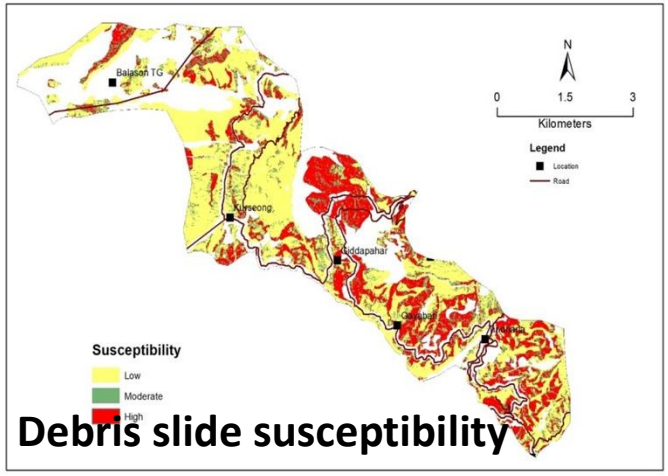
Rock fall susceptibility



Combined slide susceptibility



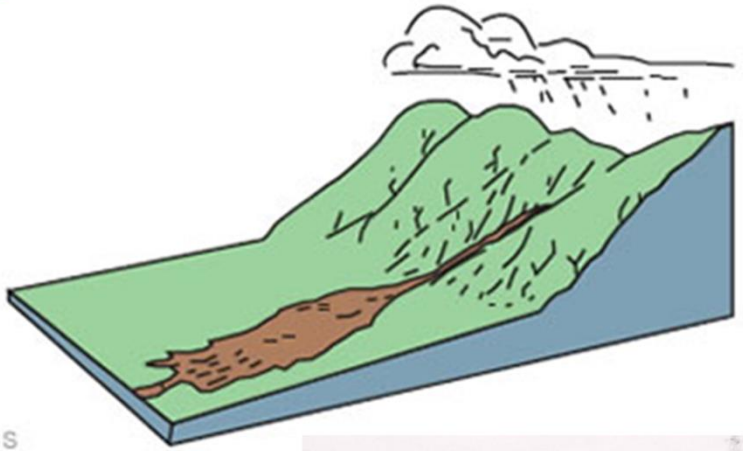
Susceptibility in cutslope



Debris slide susceptibility

Runout???

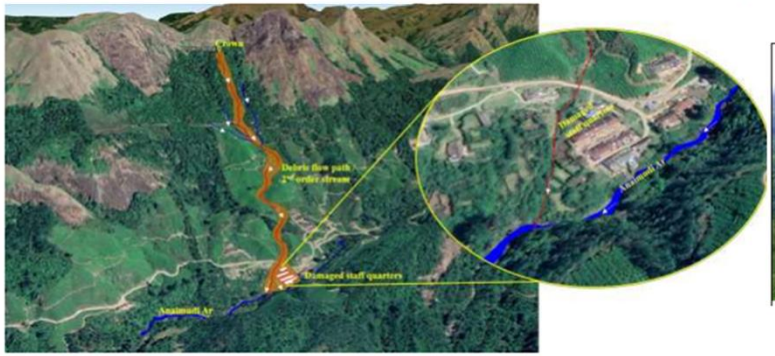
Debris flow Impact Modeling



USGS

Mirik landslide, Darjeeling: In 2015, 19 people died

Malin Landslide, Pune: 2014, 151 people died



Pettimudi Debris Flow, Idukki, Kerala (06.08.2020) 66 people died

Source: SU: Kerala, GSI

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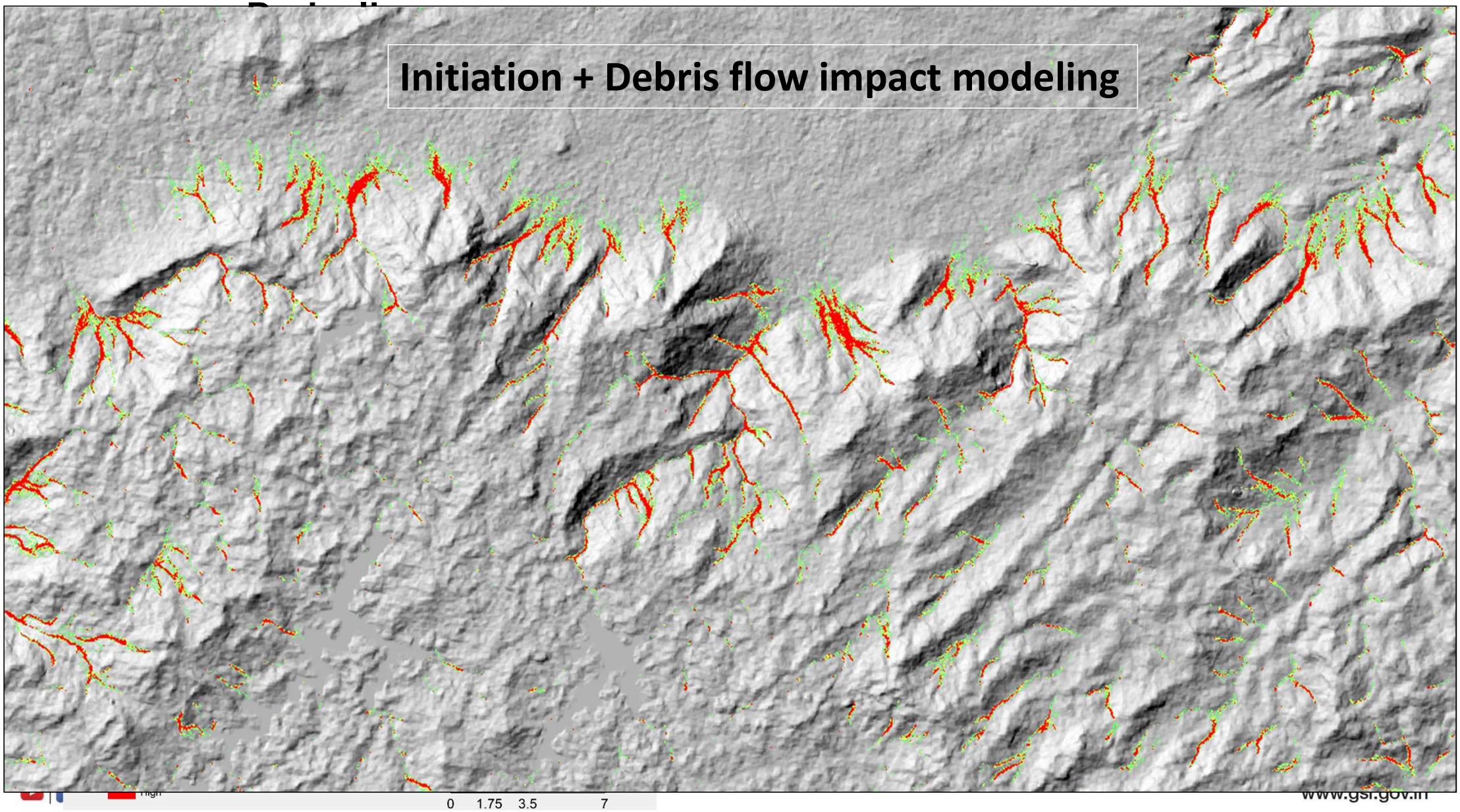
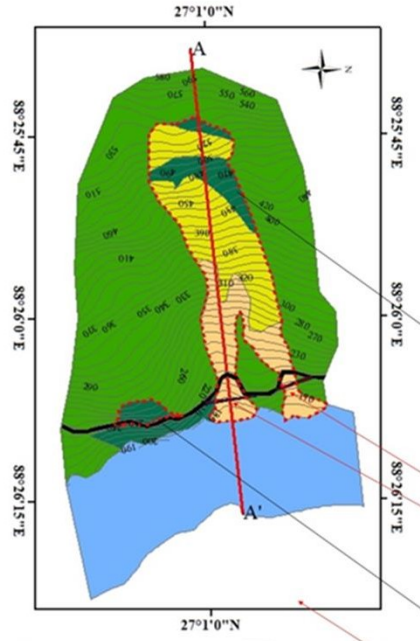
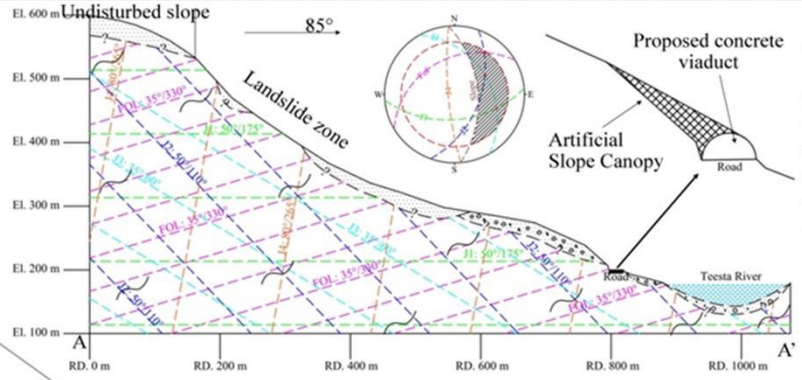

Initiation + Debris flow impact modeling
0 1.75 3.5 7
www.gsi.gov.in

LANDSLIDE MANAGEMENT MAP OF 29TH MILE LANDSLIDE ZONE ALONG NH - 10.

The 29th Mile landslide zone (Latitude: 27.0170°N, Longitude: 88.4349°E), covering a road stretch of approx. 590 m, is the most critical area in in terms of landslide hazard along NH - 10. The area has repeated history of slope failures during monsoons. Highly weathered fragile phyllite is exposed along the road section. Beside foliation, the rock has been traversed by three to four set of joints. At places, the foliation is folded. The rockmass quality is very poor (RMR—19, Class - V). The geoscientific cause of the landslide is presence of very poor quality rockmass and adverse discontinuities' orientation with respect to slope direction giving favourable conditions for planer and wedge failures. During monsoon, two nalas were flowing along the right flank of the landslide.



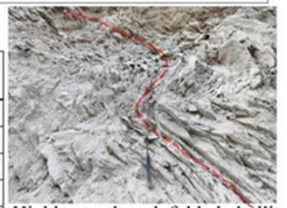
Schematic slope forming material map of the area



chematic geological section along the landslide showing proposed recommendations

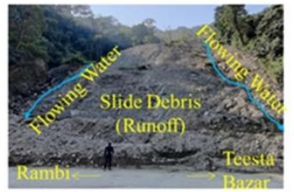
Discontinuity Data

	Dip	Dip Direction
Bedding	35°	330°
J1	50°	175°
J2	50°	110°
J3	35°	160°
J4	80°	265°



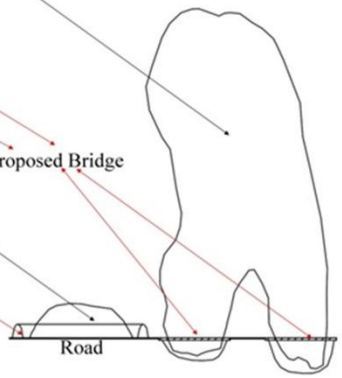
Highly weathered, folded phyllite present along road at rock slide zone

Road stretch of proposed cut and cover section at rock slide zone



Right flank of the slide at road level.

Left flank of the slide at road level



Note:

(i) The geological section is schematic. The discontinuity data are collected from limited observation points along road and extrapolated in the section. Hence, the traces of discontinuity may locally vary.
(ii) For detailed design of the proposed concrete via duct / cut and cover section and bridges over the critical road stretch, large scale geotechnical investigation may be taken up. The alignment has been proposed based on limited field study only.
(iii) The contours and elevations are derived from ALOS PALSAR DEM of 12.5 m resolution.

Recommendation:

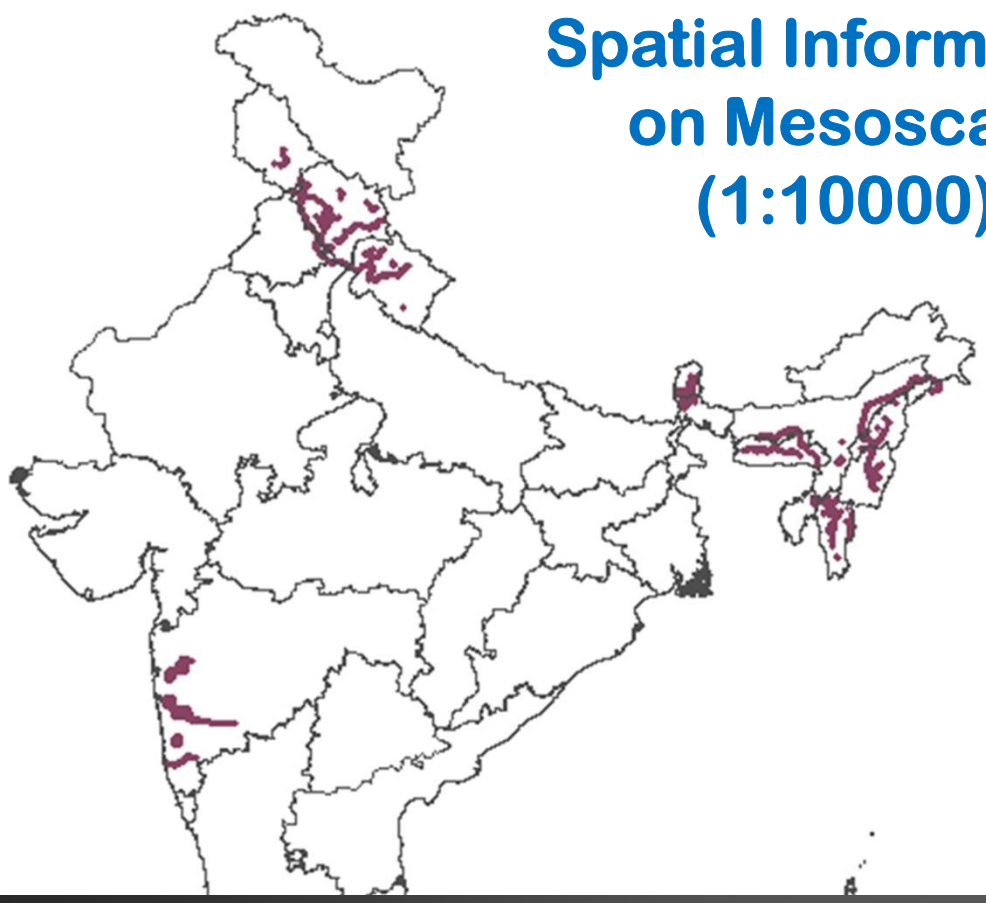
Slope easing with benching. Reinforcement of the slope with combination of grouting, rock anchors / self-drilling anchors (SDA) and wire mesh shotcrete. Drainage holes may be provided in staggered pattern.

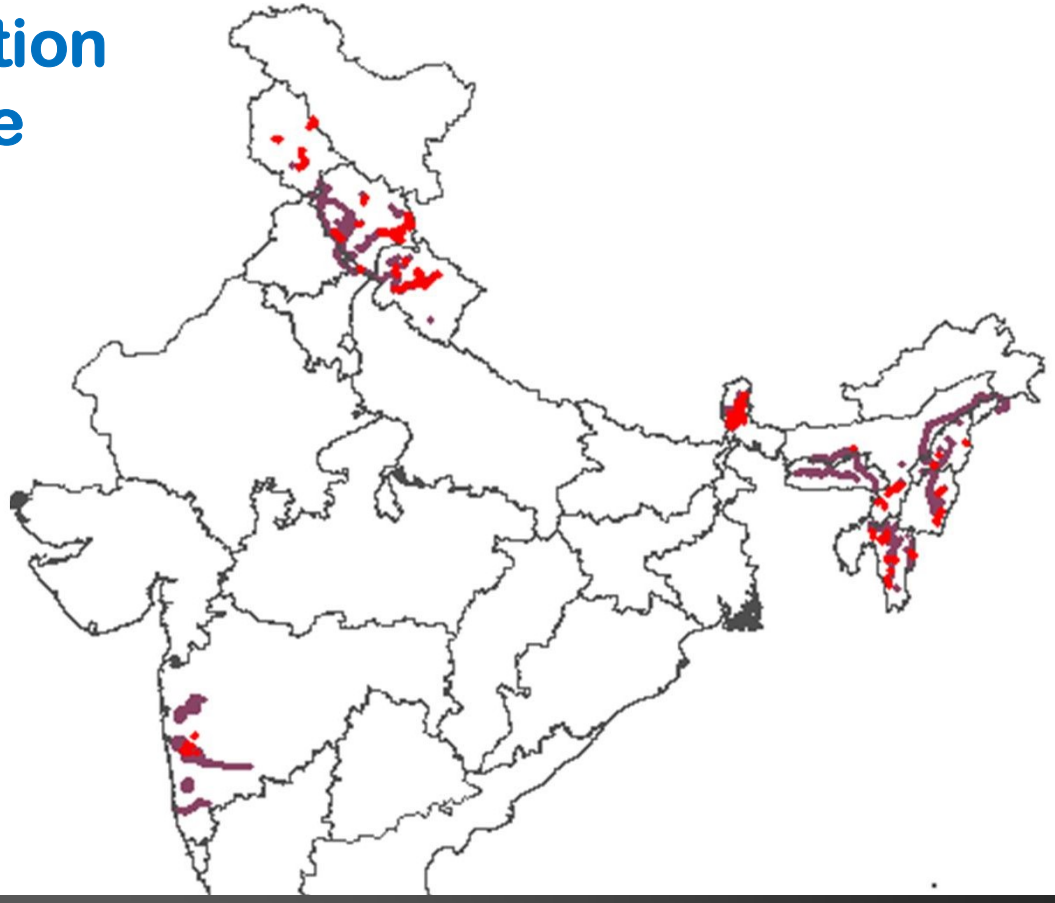
In addition to the conventional recommendations, for smooth movement of traffic, possibilities of construction of a curved concrete via duct / cut and cover section for the entire stretch (approx. 590 m) over the road with backfilled support towards the hill side may be explored.

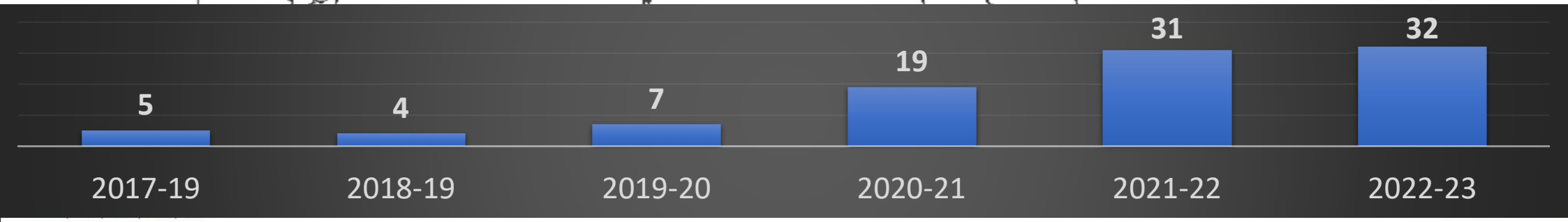
Alternatively, one concrete via duct of approx. 200 m stretch at the small rock slide zone and two bridges of short span (approx. 120 - 130 m) over the runoffs of the big slide may be explored. The rockmass below the road level may be strengthen with consolidation grouting followed by insertion of closely spaced grouted micro plies of suitable length. The well foundation is required for the construction of piers of the bridges.

Prepared by:
Sunandan Basu, Geologist; Suman Saha, Geologist
LS & EG Division, Eastern Region, Geological Survey of India

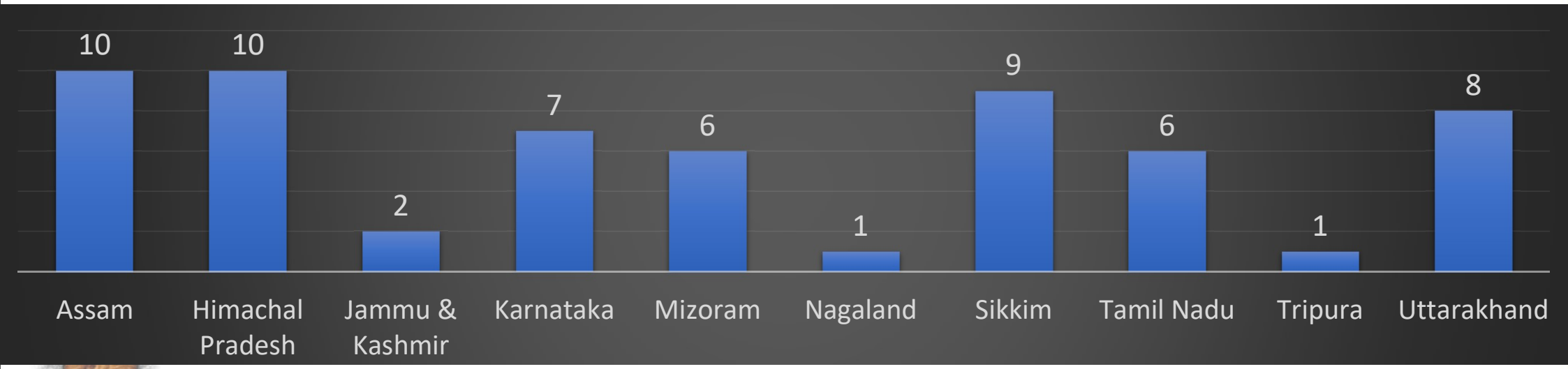
Spatial Information on Mesoscale (1:10000)







Projects taken up on requests from Stakeholders for 1:10k studies

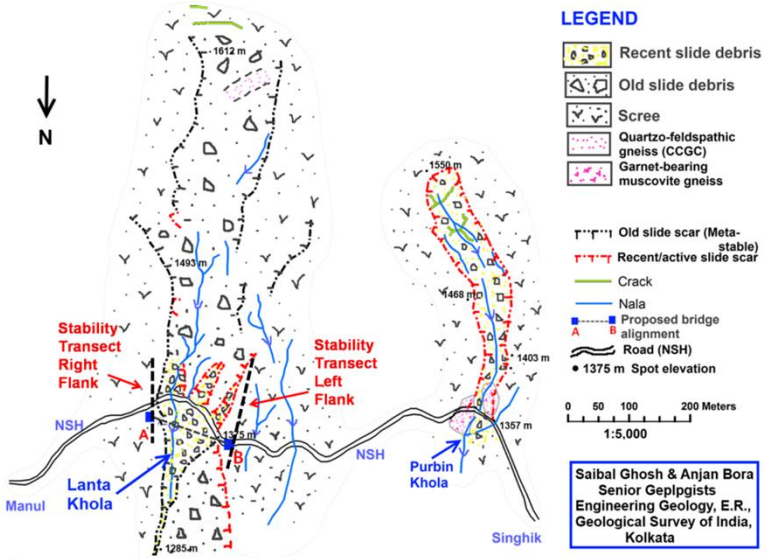


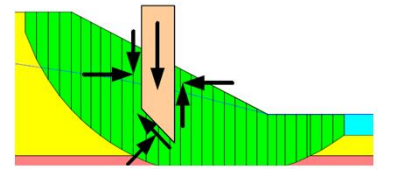
60 nos. 1:10k projects out **98** projects taken up by GSI (61%)

Spatial Information on Site-specific scale (1:1000)

Status of Site Specific scale (1:1000) Investigations of GSI					
	2019-20	2020-21	2021-22	Completed	2022-23
Himachal Pradesh	0	0	0	**3**	10
J&K	2	14	2	**18**	3
Kerala	0	1	0	**1**	0
Meghalaya	1	0	0	**1**	0
Nagaland	0	0	1	**1**	0
Sikkim	0	3	1	**4**	1
Tamil Nadu	0	0	1	**1**	0
Uttarakhand	1	0	0	**1**	0
Total	**4**	**18**	**5**	**30**	**14**

Site specific landslide investigations

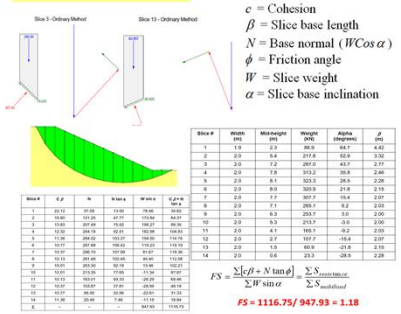




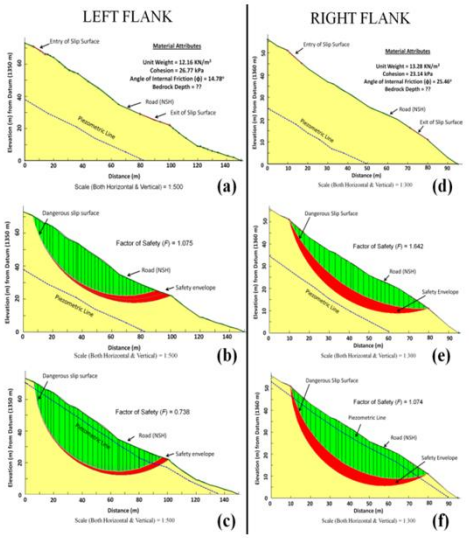
$$FS = \frac{\sum[c\beta + N\tan\phi]}{\sum W\sin\alpha} = \frac{\sum S_{resistance}}{\sum S_{mobilised}}$$

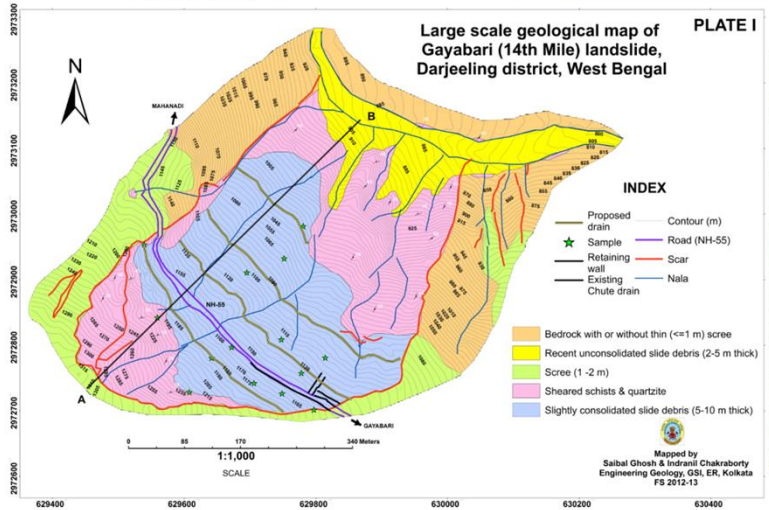
Where:

c = Cohesion
β = Slice base length
N = Base normal ($WCos\,\alpha$)
ϕ = Friction angle
W = Slice weight
α = Slice base inclination



$FS = 1116.75/\ 947.93 = 1.18$





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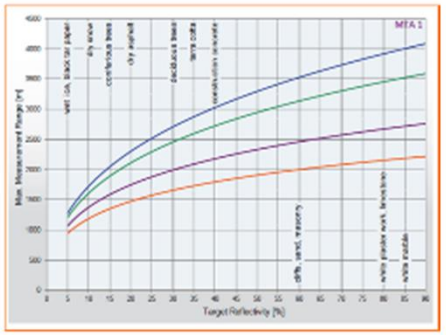
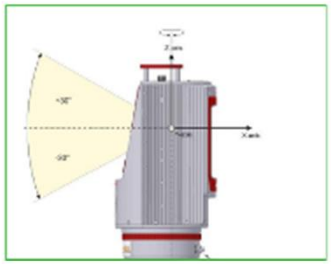
Technology used in Landslide Studies (Site-specific)

Measurement range:

- Medium to long range of 4 km when the surface is completely flat & white.
- In case of 20% reflectivity, range around 1500-2400 m.
- 15 mm accuracy

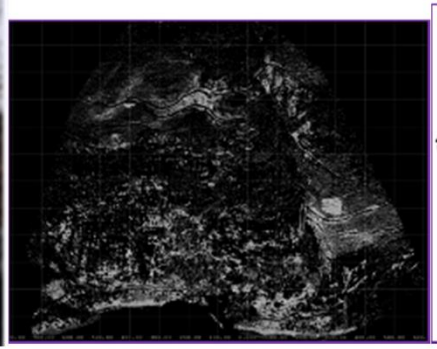




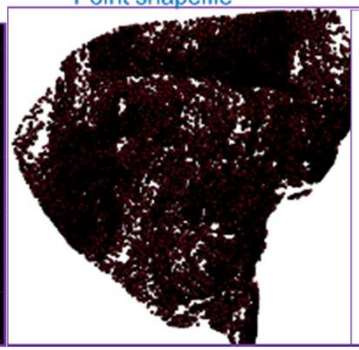
Field of View

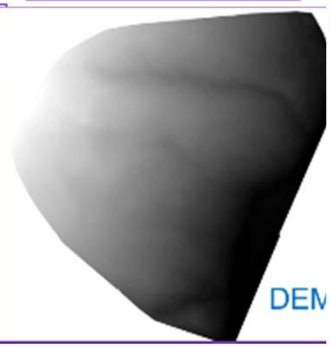
- Vertical: 60 degrees
- Horizontal: 360 degrees

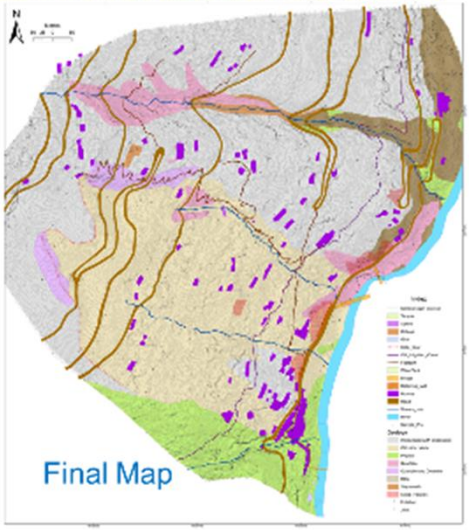
Cleaned scan data



Point shapefile

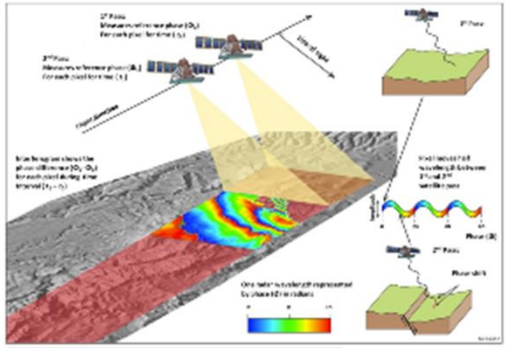


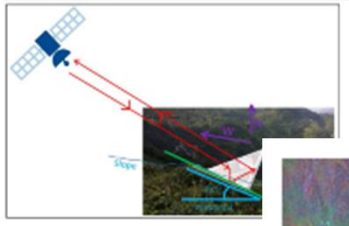




Terrestrial 3D Laser Scanner

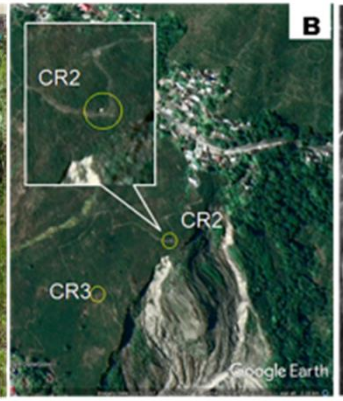
Site specific monitoring

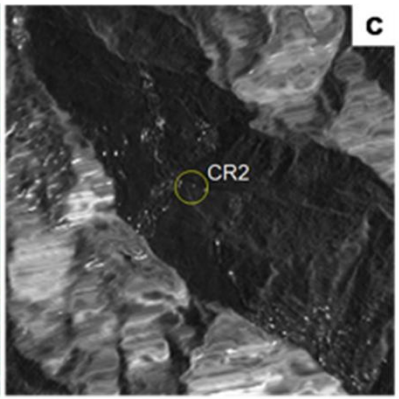


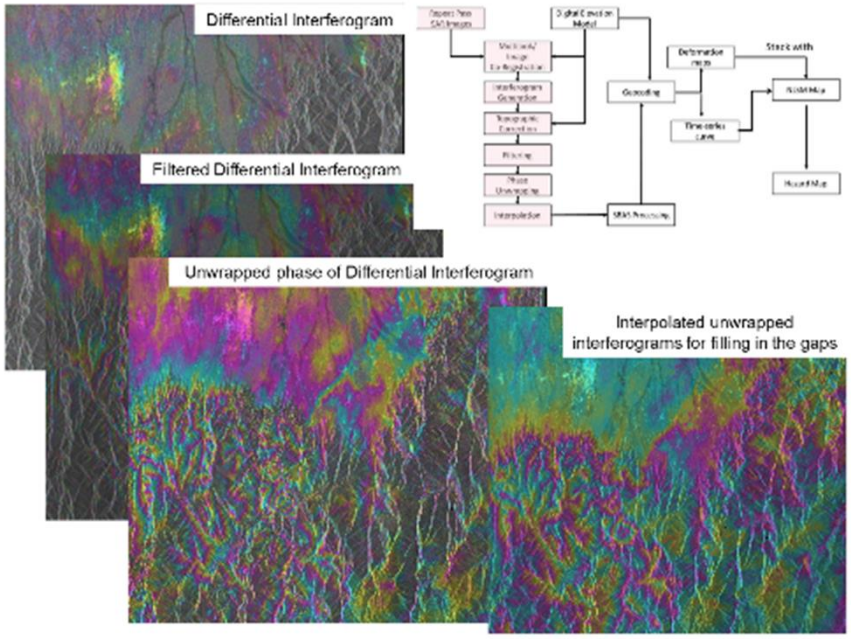


RADARSAT-2

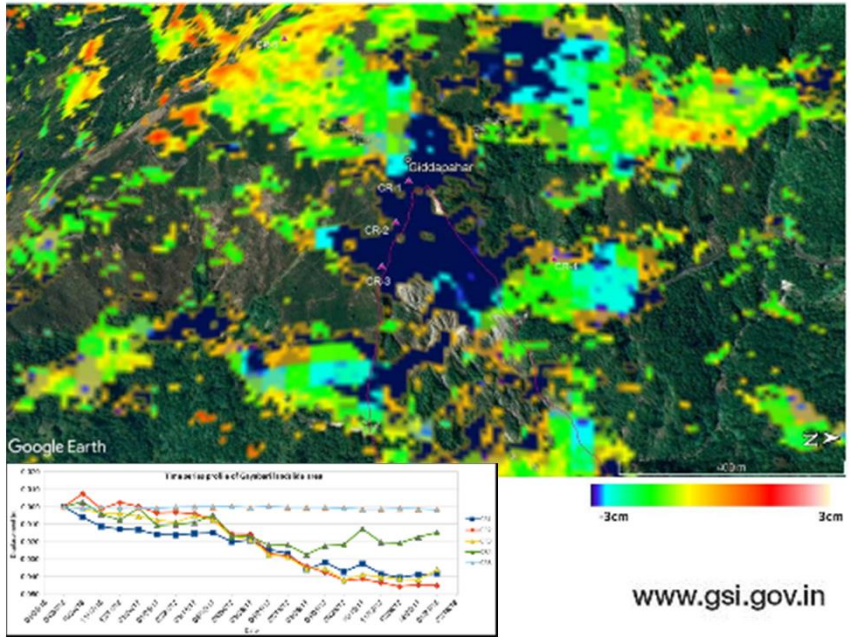
- Extra-Fine, HH Polarization with ascending mode geometry
- Spatial Extent 160 km × 77 km
- Revisit time: 24 days
- Data available from 30.09.16 to 23.01.18 (21 scenes)







LOS surface displacement map



InSAR for monitoring Active Landslides

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Regional LEWS – Background

Developing a **prototype regional landslide early warning system** that combines **meteorological** and **landscape dynamics** information in the **test case areas of Nilgiris District, Tamil Nadu and Darjeeling District, West Bengal.**

Spatial scale: catchment & region.

Temporal scale: daily.

LANDSLIP Consortium

LANDSLIP Research (2017-2022)

Currently the prototype models are under testing at three study sites

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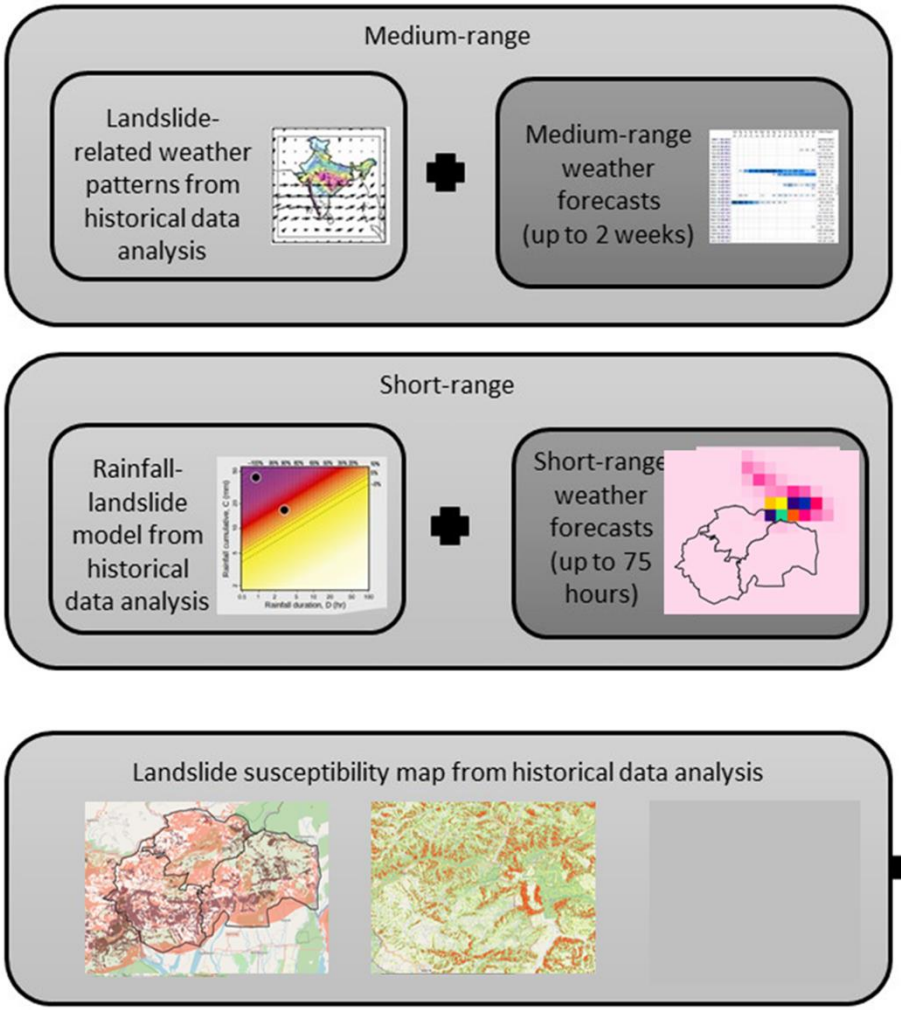
Prototype Regional LEWS



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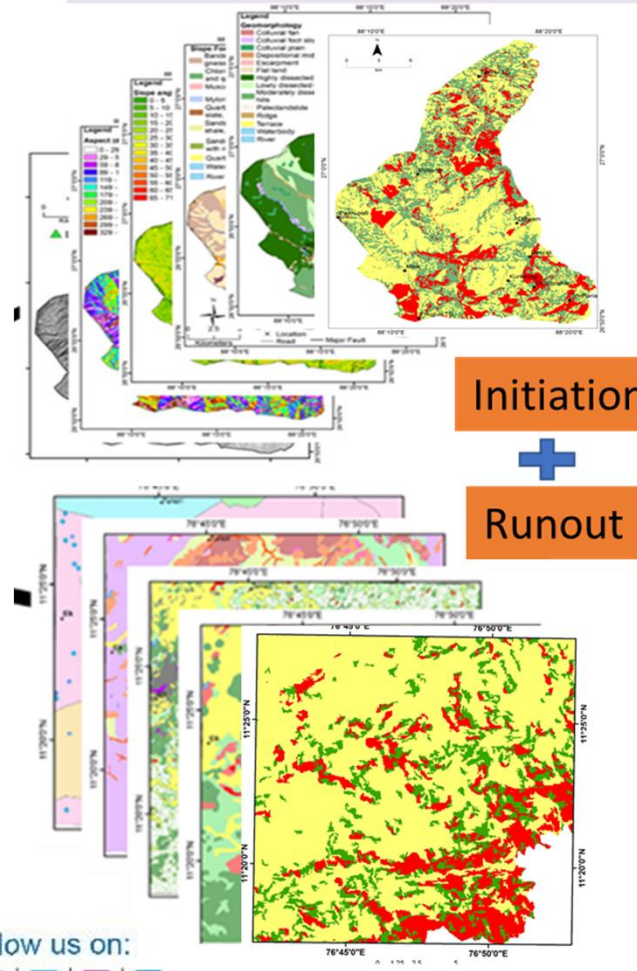
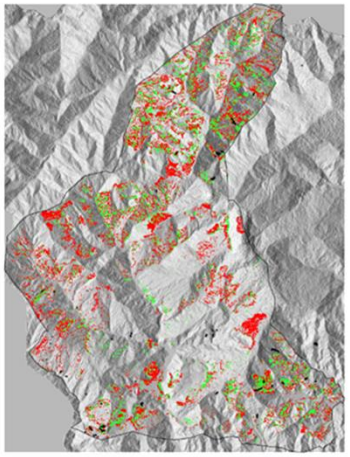
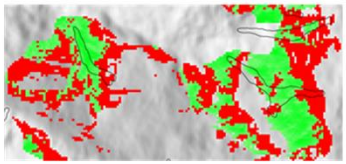
Landscape dynamics



Initiation

Runout

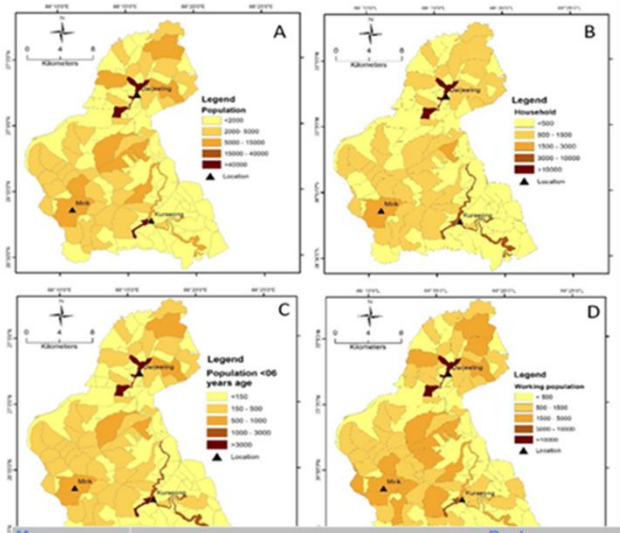




High initiation susceptibility

High runout susceptibility

Combined susc



Mauza	Rank								
	Susceptibility	Total population	Household	Literacy	Population <06 years	Working population	NH & SH	Other roads	Final rank
Sukhiapokhri (CT)	109	1	1	1	1	1	0	1	1
Kurseong	99	2	2	2	2	2	26	11	2
Manjua Forest (Panighata)	65	3	3	3	3	3		44	3
Simana Basti	119	4	4	4	4	4	21	69	4
Giddapahar	83	5	5	5	5	5	25	6	5

Exposure, vulnerability assessment

Risk assessment- Selected top 50 villages

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Daily Forecast Bulletin





Page-1

Date of Issue: 08 June 2021 | Time of Issue: 14:00 IST

SHORT–RANGE FORECAST

Day 1 (valid from 08 June 2021 14:30 to 09 June 2021 14:30 IST)

Day 2 (valid from 09 June 2021 14:30 to 10 June 2021 14:30 IST)

Day 1: • **High possibility of landslide** occurrences in Kalimpong I and Gorubathan blocks. Multiple landslides may occur in the entire two blocks.
• **Moderate possibility of landslide** occurrences in Kalimpong II block in and around Git Dubling Khasmahal, Git Beong Khasmahal, Palla Khasmahal mauzas.

Day 2: • **Moderate possibility of landslide** occurrences in Kalimpong I and Gorubathan block in and around Kalimpong Khashmahal, Mangwa Forest, Riyong Forest, Bhalukhop Khasmahal, Pudung Khasmahal, Birik Forest, Tangta Forest, Chichu Forest, Samsing Khasmahal, Kumai Tea Garden, Paren Forest, Rango Forest, Paten Godak Khasmahal, Eastnar Forest, Pankasari Forest and Gorubathan Khasmahal mauzas.
• **Low possibility of landslide** occurrences in Kalimpong II block, however untreated modified slopes (road/settlement cuts) are prone to failure

Landslide Forecast

Forecast level	Description
Very high	Very high possibility of occurrences of landslides in many locations (widespread).
High	High possibility of occurrences of landslides in one or many locations (localised).
Moderate	Moderate possibility of occurrences of landslides
Low	Low possibility of occurrences of landslides, a few small landslides may occur

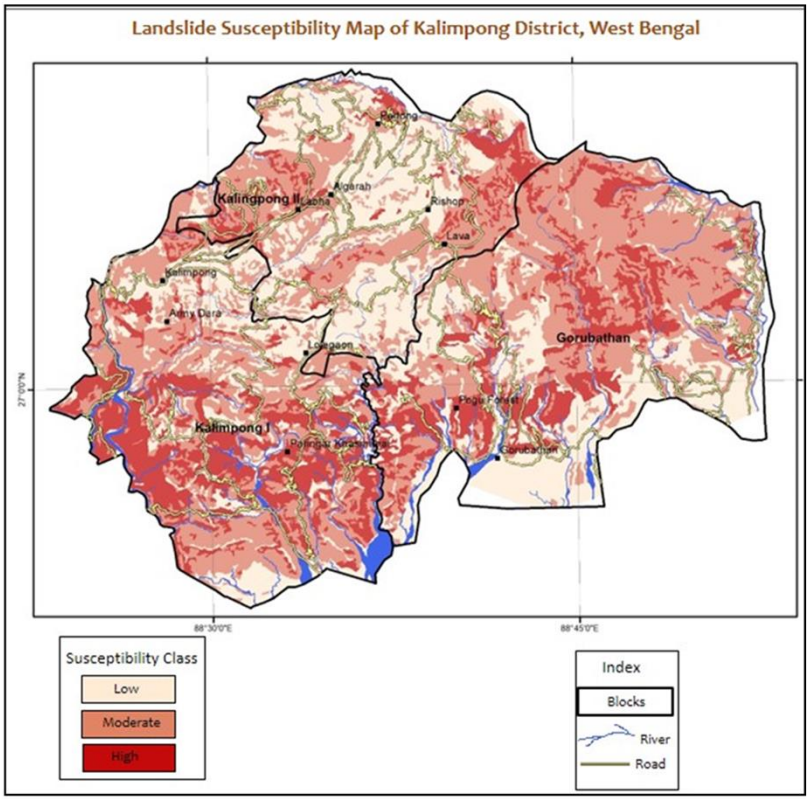
MEDIUM–RANGE FORECAST

Valid from 10 June (14:30 IST) to 22 June 2021 (24:00IST)

The period from 10th June to 17th June there is a **low possibility** of occurrence of a weather pattern that can be associated with occurrence of landslide and after that the possibility will increases to **moderate** till 22nd June 2021.

Page-2

Landslide Susceptibility Map of Kalimpong District, West Bengal



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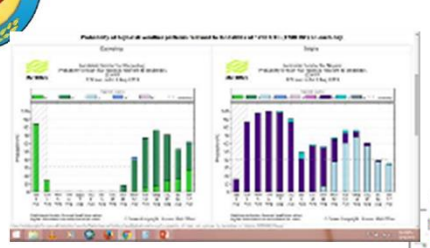
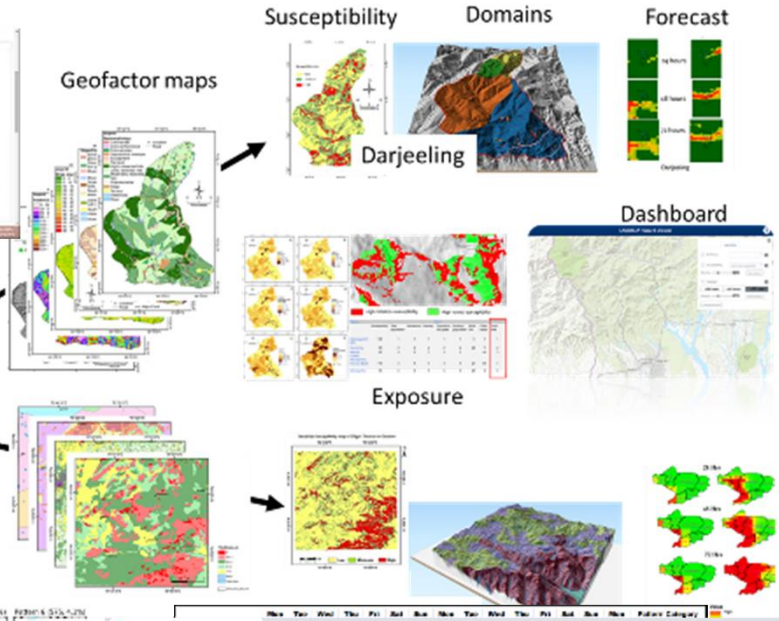
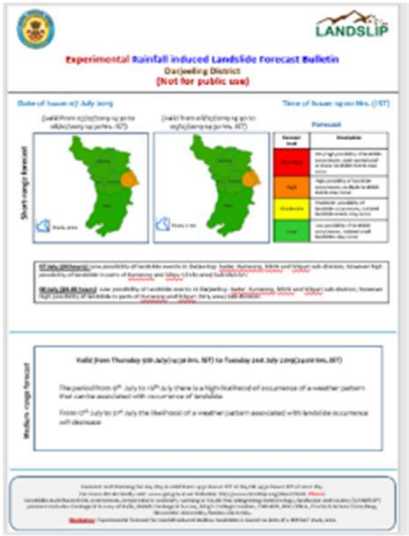
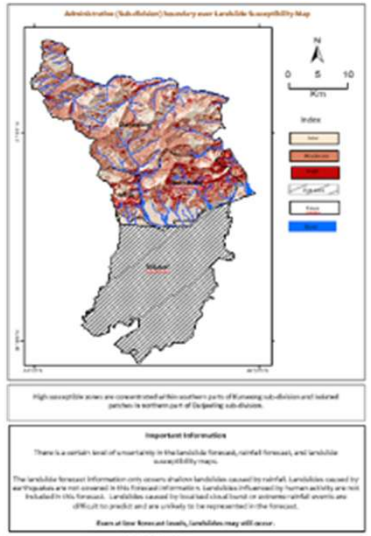
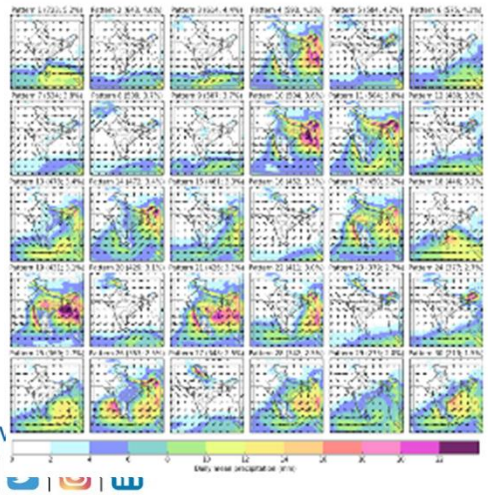
Landslide Early Warning-Regional forecasting

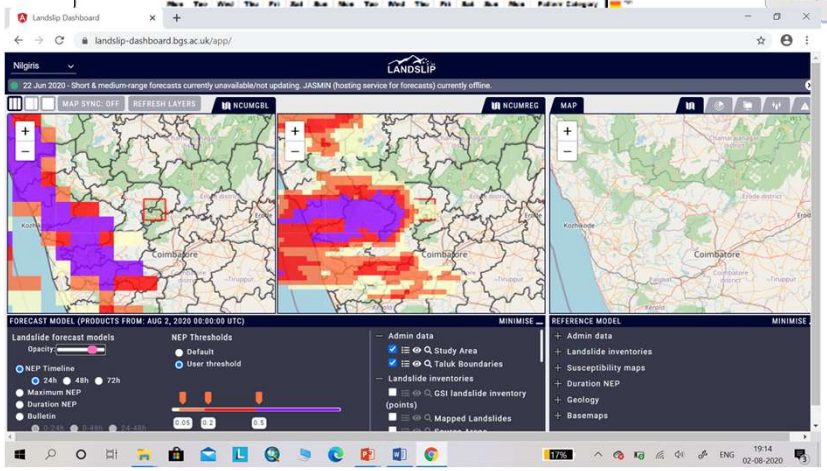












IMD/NCMRWF

Stakeholders NDMA/ SDMA/State Govt.

Top-down approach

DISTRICT

Taluk/ Block

Village

People Centric L-EWS where community can manage risk by empowering themselves

Bottom-Up approach

Inputs: **Landscape**, **Climate** and **Social** Dynamics

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Tentative plan of Regional Landslide Forecasting timelines

Pre-operational review

States	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
West Bengal														
Tamil Nadu														
Uttarakhand														
Kerala														
Sikkim														
Assam														
Nagaland														
Mizoram														
Meghalaya														
Karnataka														

Developmental phase | Experimental phase | Operational phase

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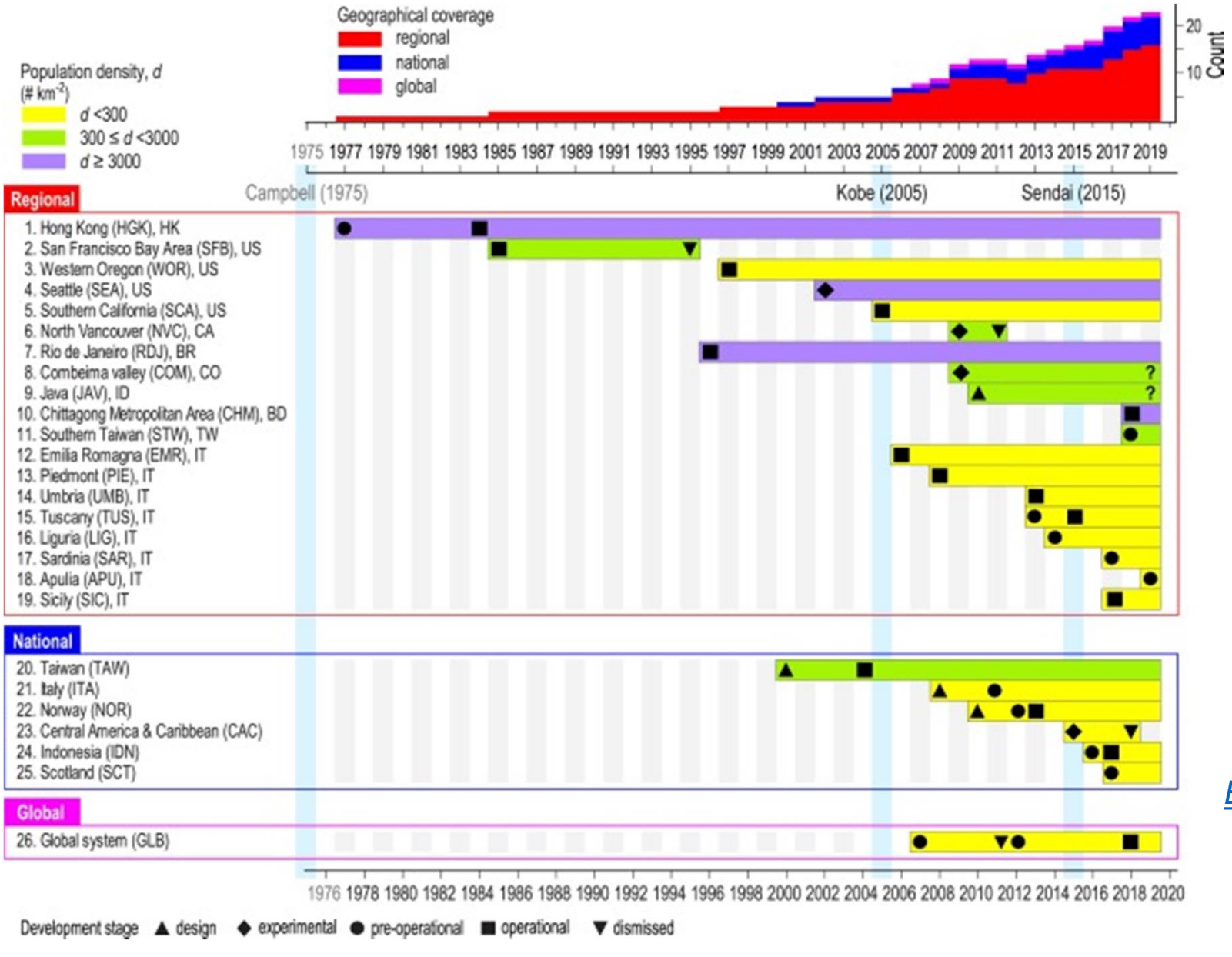
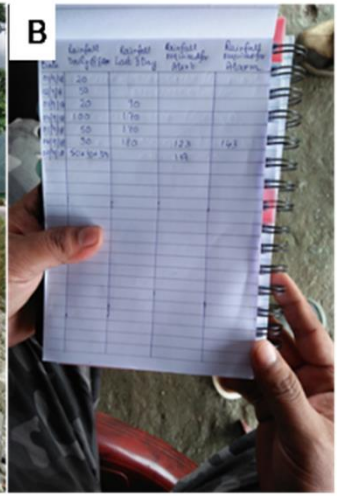


Global best practices

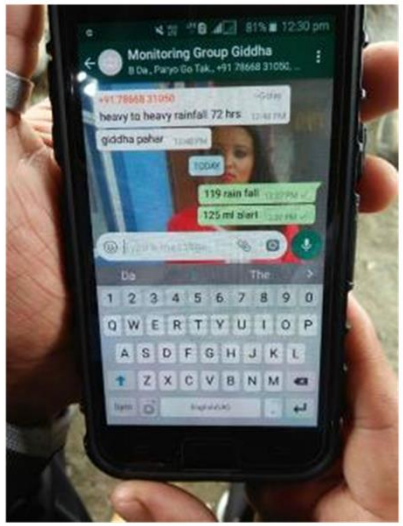
Geographical landslide early warning systems, Guzzetti et al, Earth-Science Reviews Volume 200, January 2020,

Awareness and Community Participation

Risk knowledge



Dissemination and communication



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Nodal agency's journey for 2020 -2030

Integrated in the National Disaster Management Plan of MoM/ GSI

LEWS R&D 10 States	NLFC at GHRM	LSM 10k - 200 sectors by 2027	Site specific -100 sites by 2027	Operationalise LEWS
R&D in progress on in 5 states **(**Uttarakhand, Tamil Nadu, West Bengal, Kerala, and Sikkim) + **5** states (Himachal Pradesh, Assam, Meghalaya, Nagaland, Mizoram, and Karnataka) added in 2022-23	Will be operational by **March 2023**	**LSM 10k – SOP finalised** **57** sector completed **32** taken up 2022-23	**Site specific -30** sites completed; **14** taken up in 2022-23	To be implemented in **phases**; Expected to start by **2025; all 10 states** will be covered by **2030**

Earthquake and Seismic Studies by GSI

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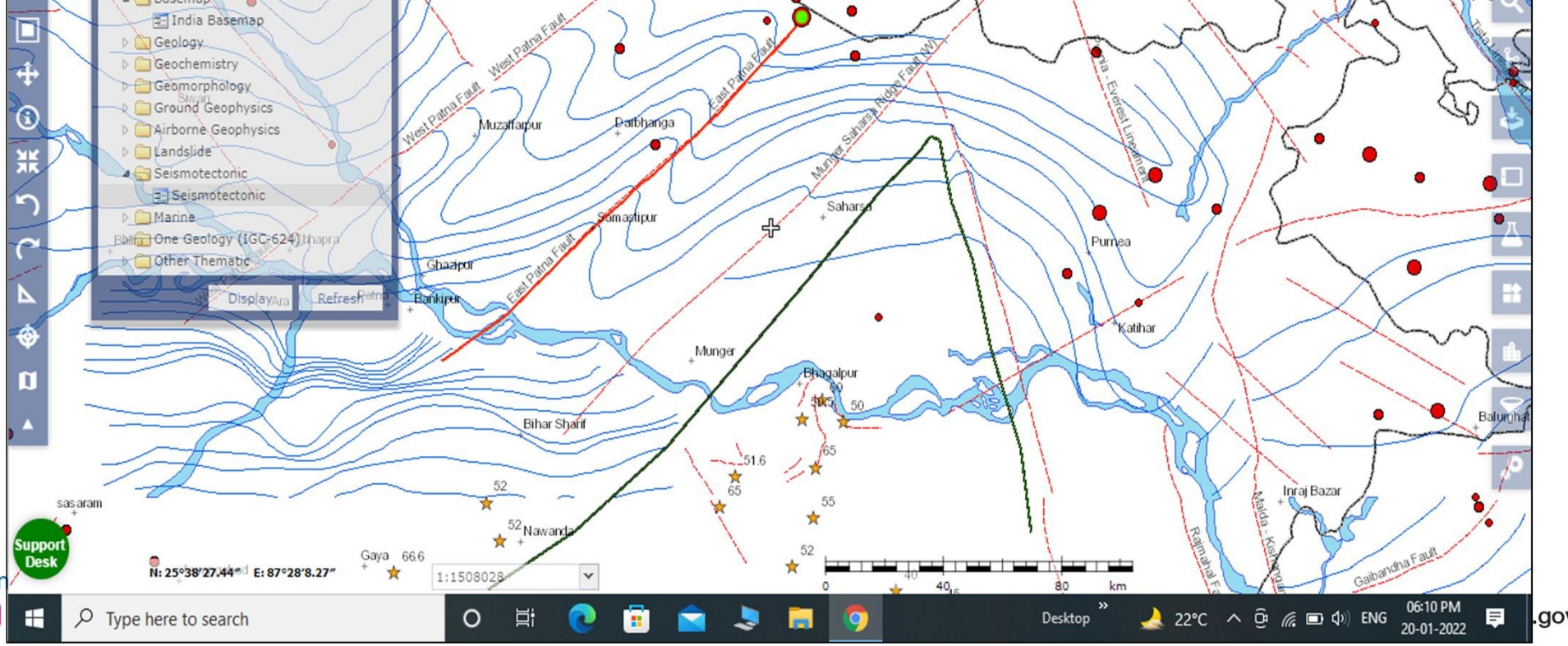
Active Fault Mapping and Seismotectonic Studies



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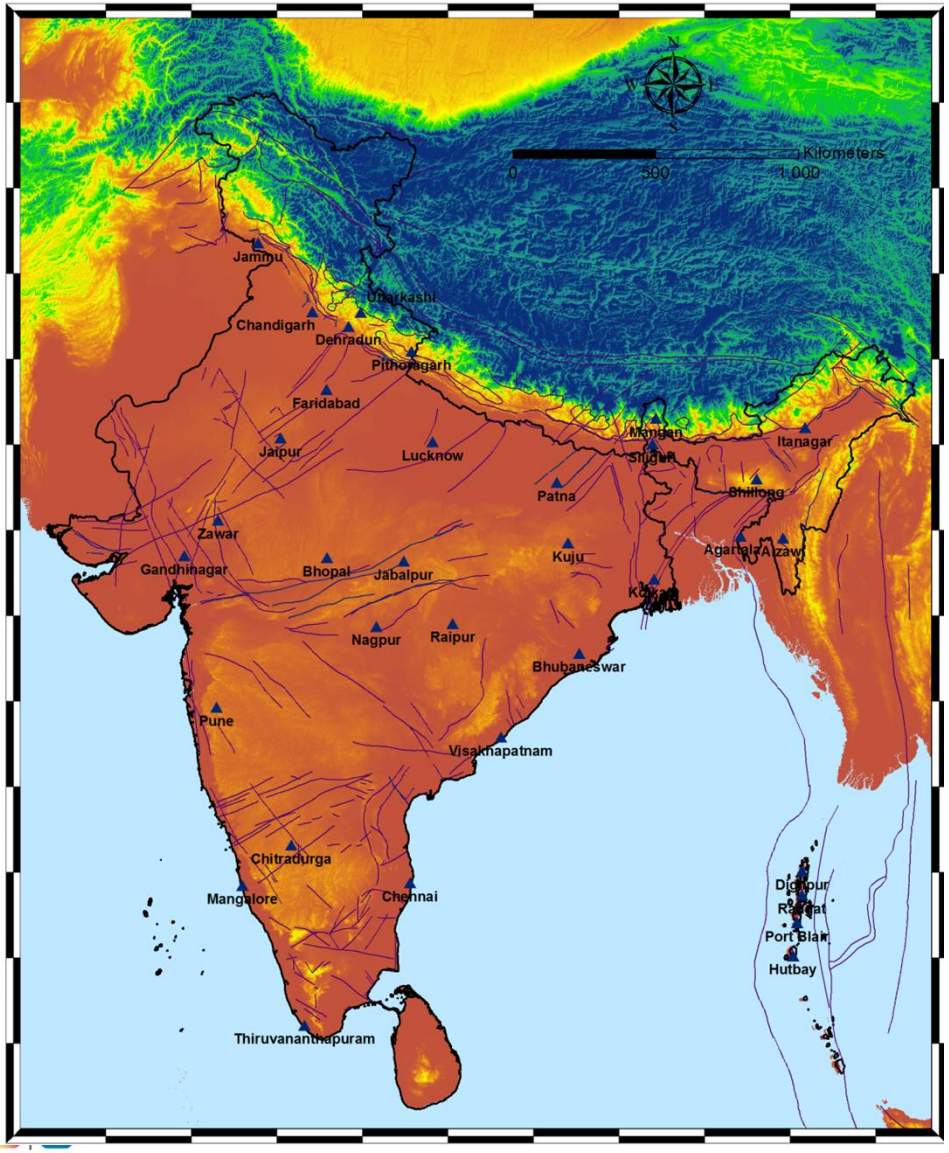
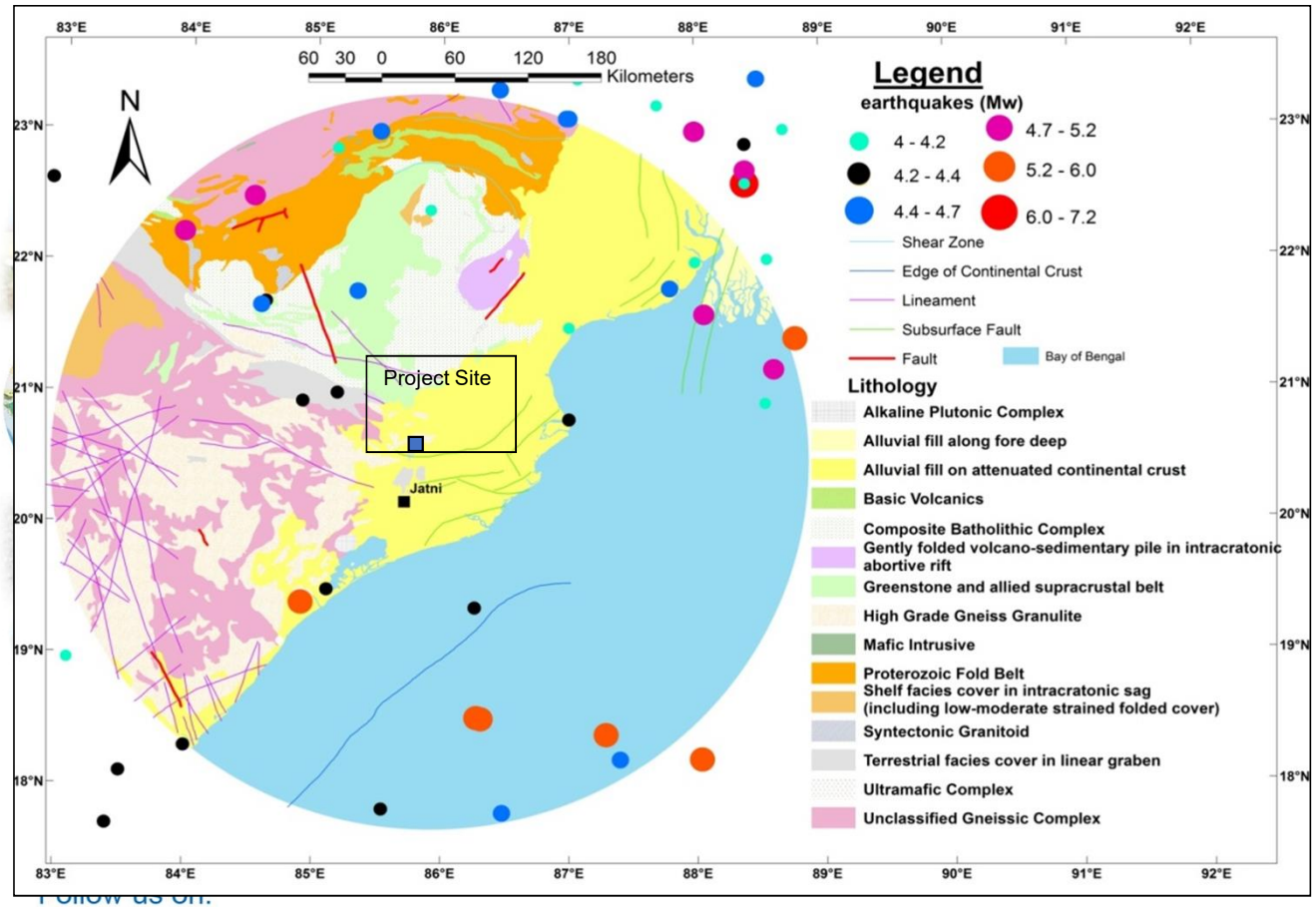
Crustal Deformation Monitoring by Permanent GPS stations



- GSI has 35 permanent GPS stations installed at different parts of the country for monitoring of crustal deformation.
- Along with these permanent stations, campaign mode GPS surveys are carried out for kinematic analysis of active faults.
- GSI has 10 numbers of Seismo geodetic observatories at different parts of the country for recording and analysis of earthquakes.

Seismic Microzonation of Urban Centres

- GSI has completed seismic micro zonation projects of 54 urban centres across the country.
- Micro zonation projects are carried out after receiving requests from State Governments

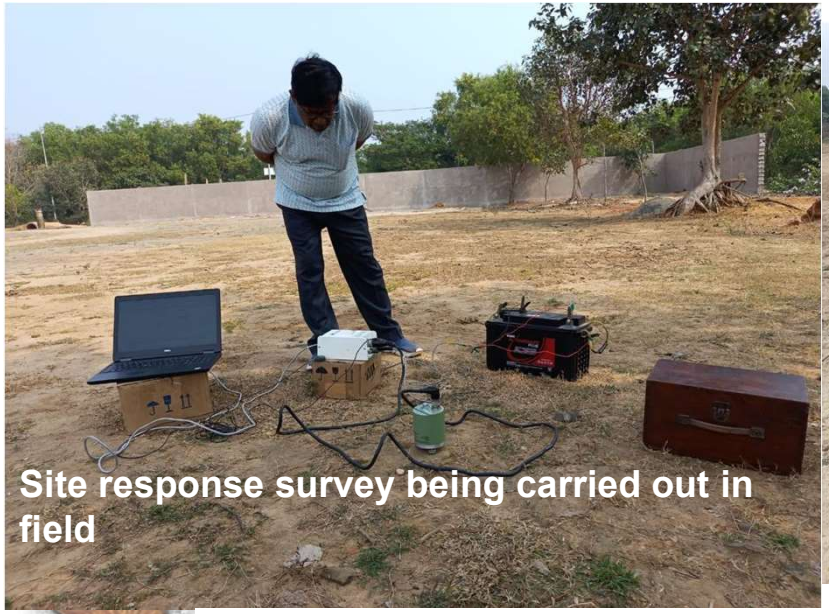


- Seismotectonic analysis around 300 km radius of the Project site with past seismicity data for seismic source Parameters and source characterisation.

- Application of region specific ground motion Attenuation models.

- Probabilistic seismic hazard analysis and preparation of peak ground acceleration map for 10% and 2% probability of exceedance in 50 yrs.

Site response analysis by Geophysical investigation



Site response survey being carried out in field

MASW Survey for shear wave velocity

- Site response survey by using digital seismograph for measuring fundamental frequency and site Amplification factor of different geological units.

- Multi channel Analysis of Surface Waves (MASW) for measuring shear wave velocity (Vs30) of different Geological units up to 30m depth.

- Site classification using the data on the variation of shear wave velocity (Vs30).

Standard Penetration Test for Geotechnical investigation

- SPT at every one meter interval down to a depth of 30 m for detail geotechnical evaluation of the subsurface sediments.

- Geotechnical Parameters like grain size, density, fines content, void ratio and Atterberg limits are analysed.

- Determination of factor of safety against seismically induced Liquefaction susceptibility of the soft sediments to prepare liquefaction potential map

- All geological, geophysical and geotechnical attributes are further integrated by Analytical Hierarchy Process (AHP) to prepare the seismic susceptibility zone map of an area on 1: 25,000 scale.

- The results and outcome of the projects are useful for seismic disaster preparedness and urban planning.

Way Forward for Landslide Hazard Management

- **1:50K LSM** not to be repeated; GSI NLSM data be used as baseline information for **Information and Advisory** only.
- **1:10K LSM** to be taken must be as per the need and priority of the SDMAs, and in consultation with nodal agency (GSI); other agencies to share load with GSI.
- **Regional LEWS** of GSI needs to be prioritized, and Site specific LEWS with low cost instrument be employed only where 1:50K, 1:10K and site specific studies have been completed. CBRI, IIT-Mandi, IIT-Indore, Amrita University etc. be allotted specific terrains.
- **Monitoring using SAR Interferometry** be launched as a National Project using NISAR data for critical sector; **ISRO to be made nodal for this.**
- Site specific landslide mitigation be taken up in line NDMA's existing LRMS Projects; Each State must have State specific TEC which should include GSI, CBRI, IITs, State PWDs, BRO, NHAI etc.
- Implementation of **Land use Zoning Regulations** based on local and site specific landslide zonation (1:10k or larger) maps **be made mandatory in hills/ mountains**

Way Forward for Earthquake Hazard Management

- Recommendations of **Seismic Microzonation studies** be strictly followed on ground
- All major hill towns be covered with **Seismic Microzonation studies**
- **Active Fault Mapping** program be strengthened and prioritized, to be supplemented with adequate MEQ, and Geophysical data;
- **Seismotectonic Atlas of India** be updated on regular basis with new data and information; therefore, sharing of data mutually is extremely important.
- **Permanent GPS station and Seismic Station network** be enlarged and be made denser further; all agencies should work together and freely share these vital data mutually to make a **true and dynamic national seismic database**
- Use of **Earthquake-resistant structures** for settlements are to be implemented mandatorily to save lives in Zone-IV and V areas

Thank You

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Tectonic Geodesy – How better we understand earthquakes now




Vineet Gahalaut
CSIR-NGRI, Hyderabad



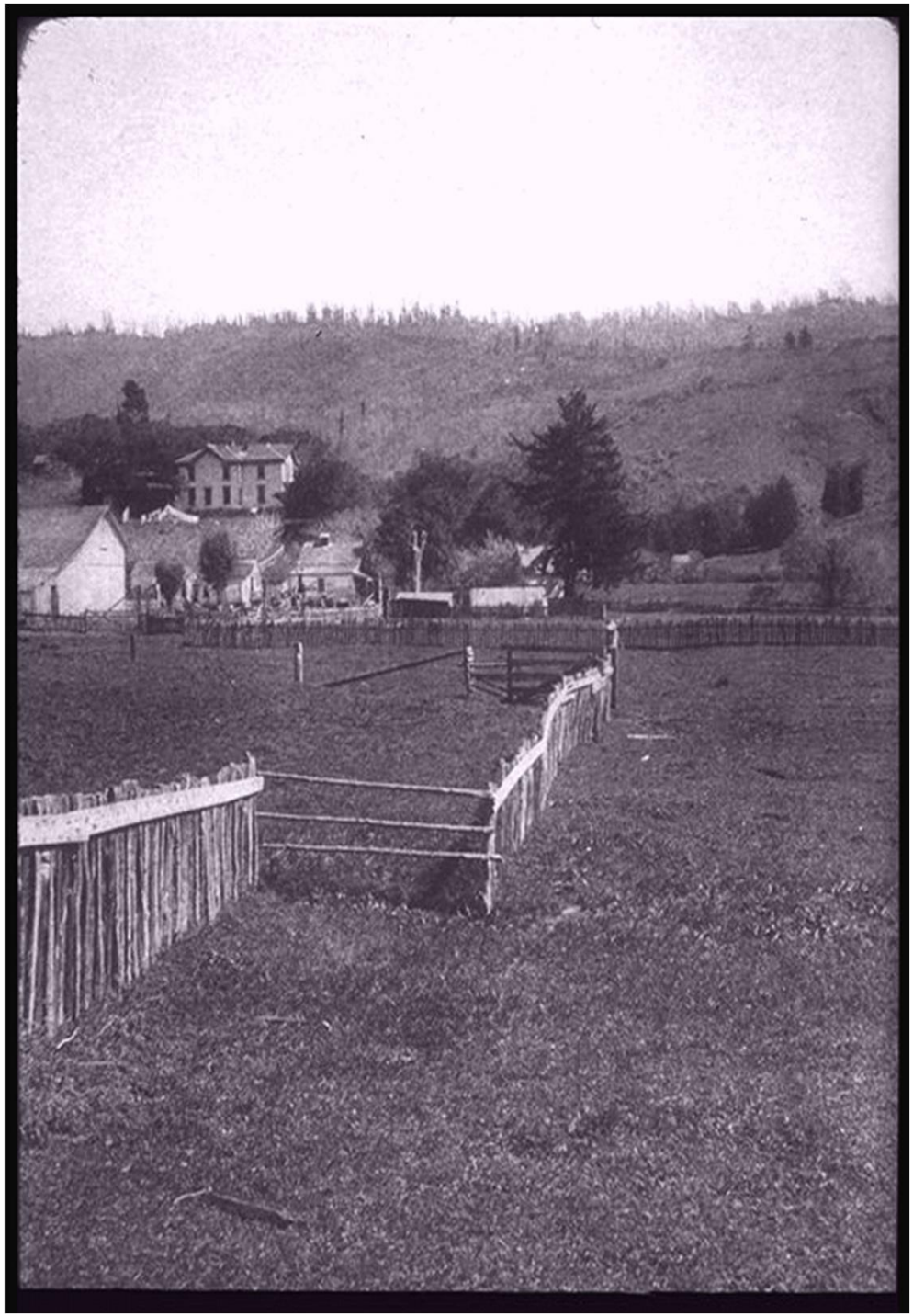

Basic concepts of crustal deformation and earthquake occurrence

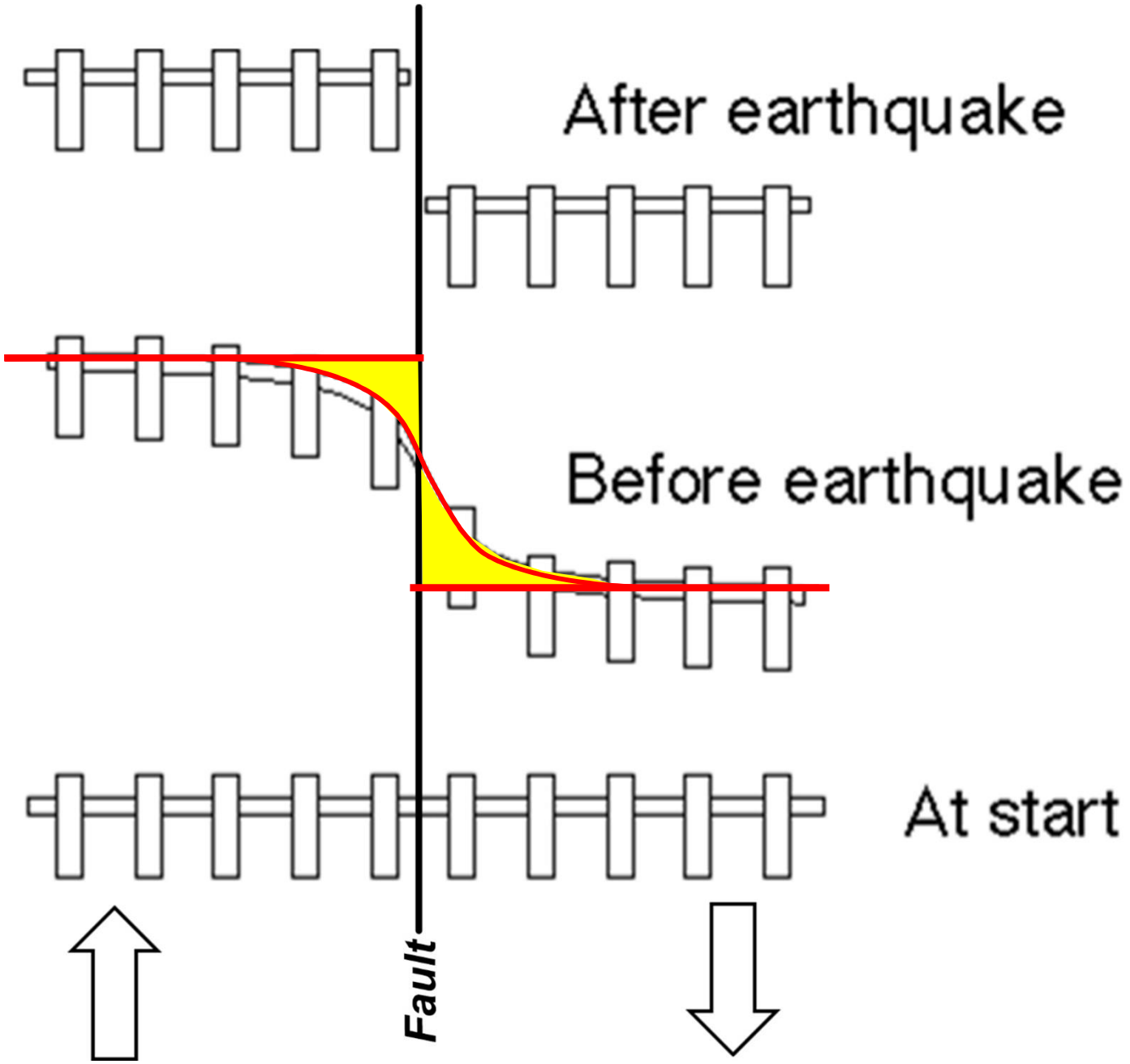
Elastic rebound theory

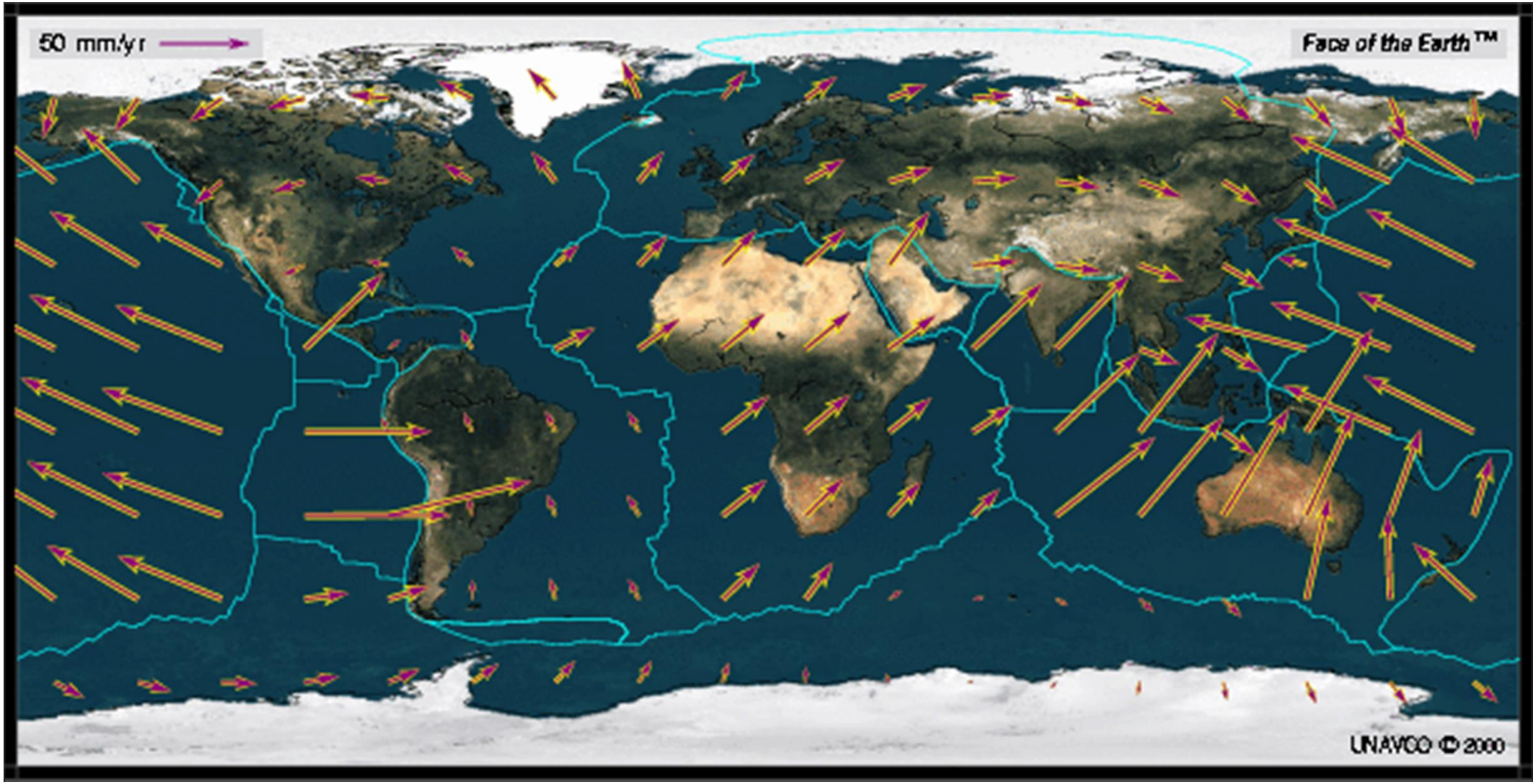
Plate tectonics

Earthquake cycle

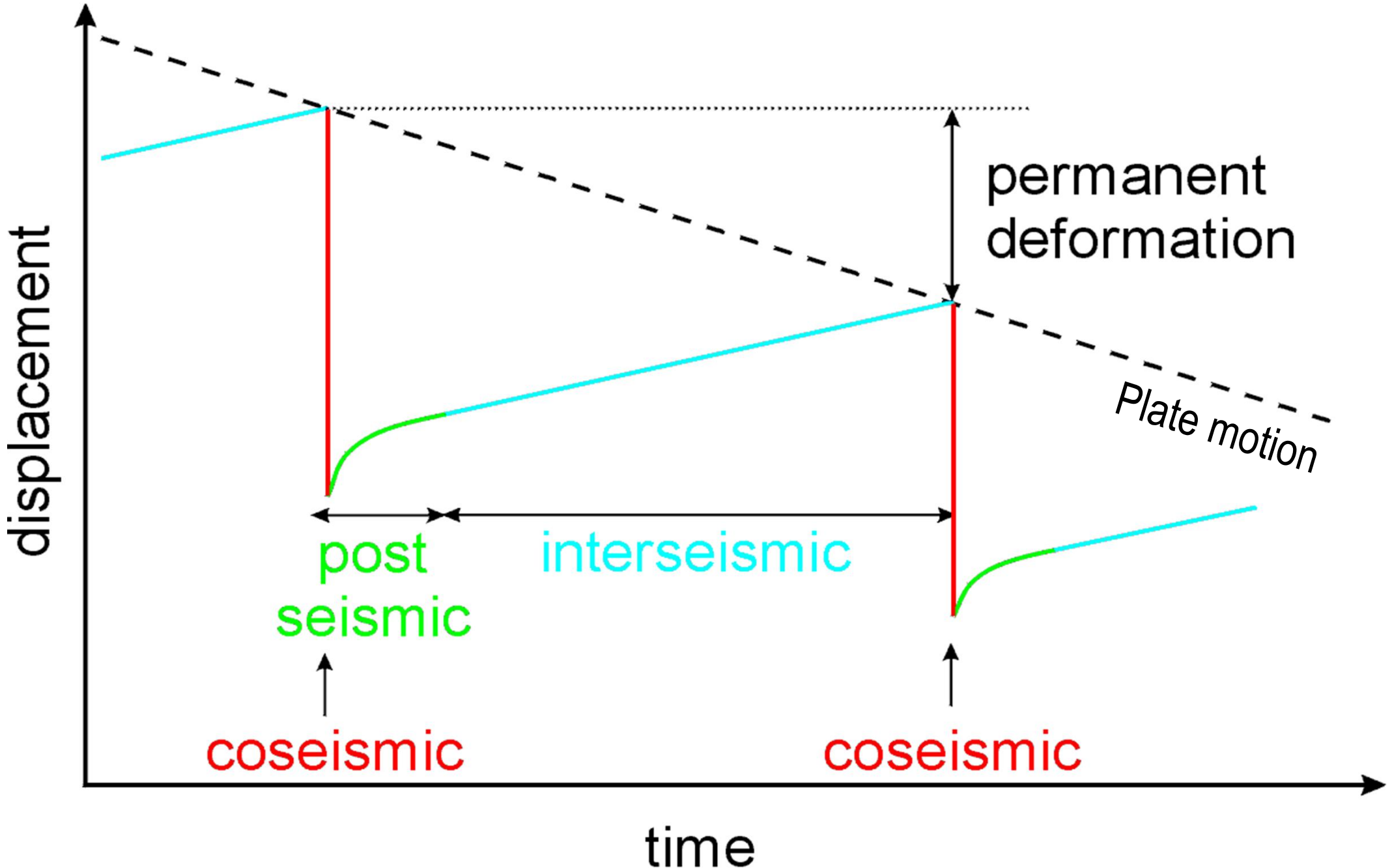
How do earthquakes occur?



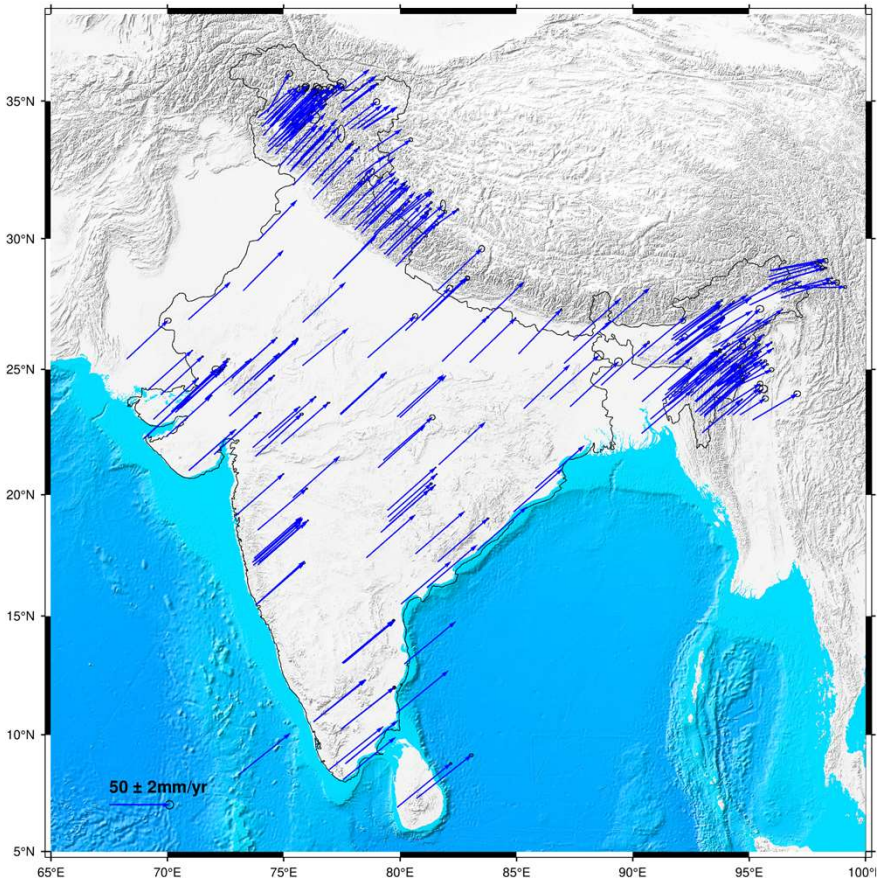

After earthquake
Before earthquake
At start
Fault

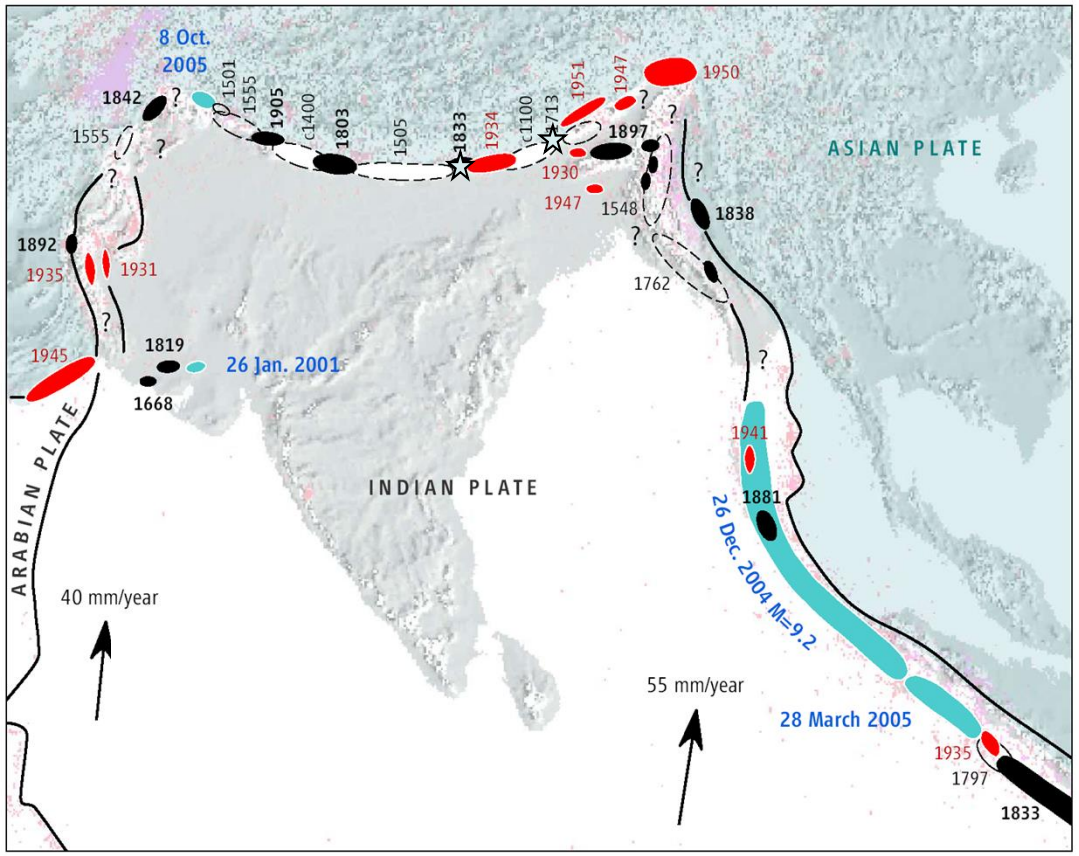

50 mm/yr
Face of the Earth™
UNAVCO © 2000

The earthquake cycle



India plate motion and earthquakes

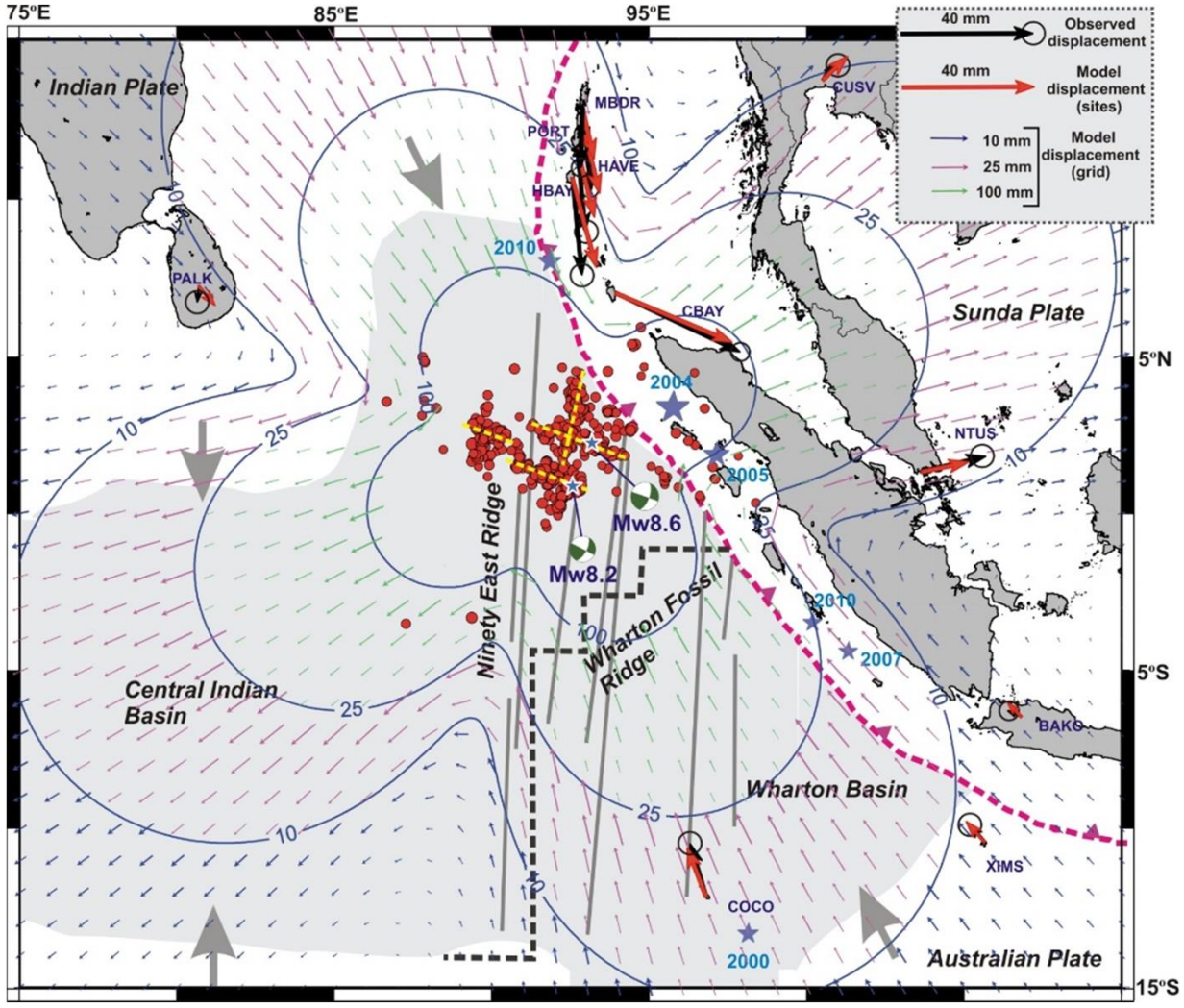


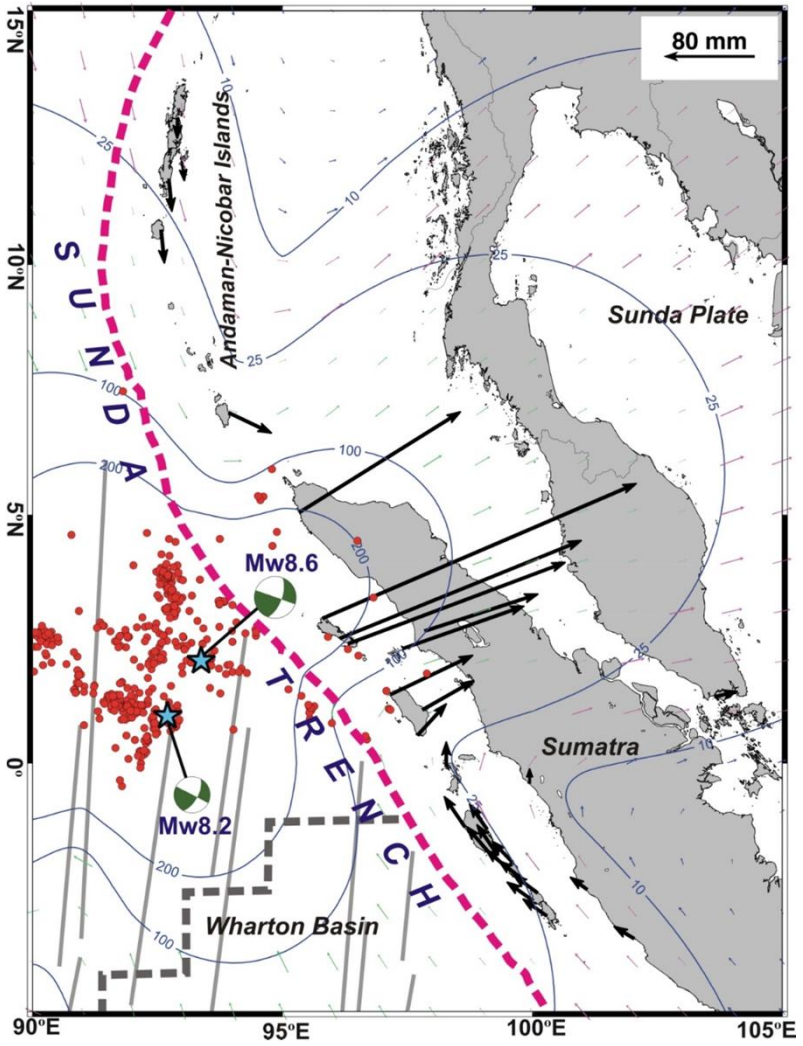


Bilham, 2008

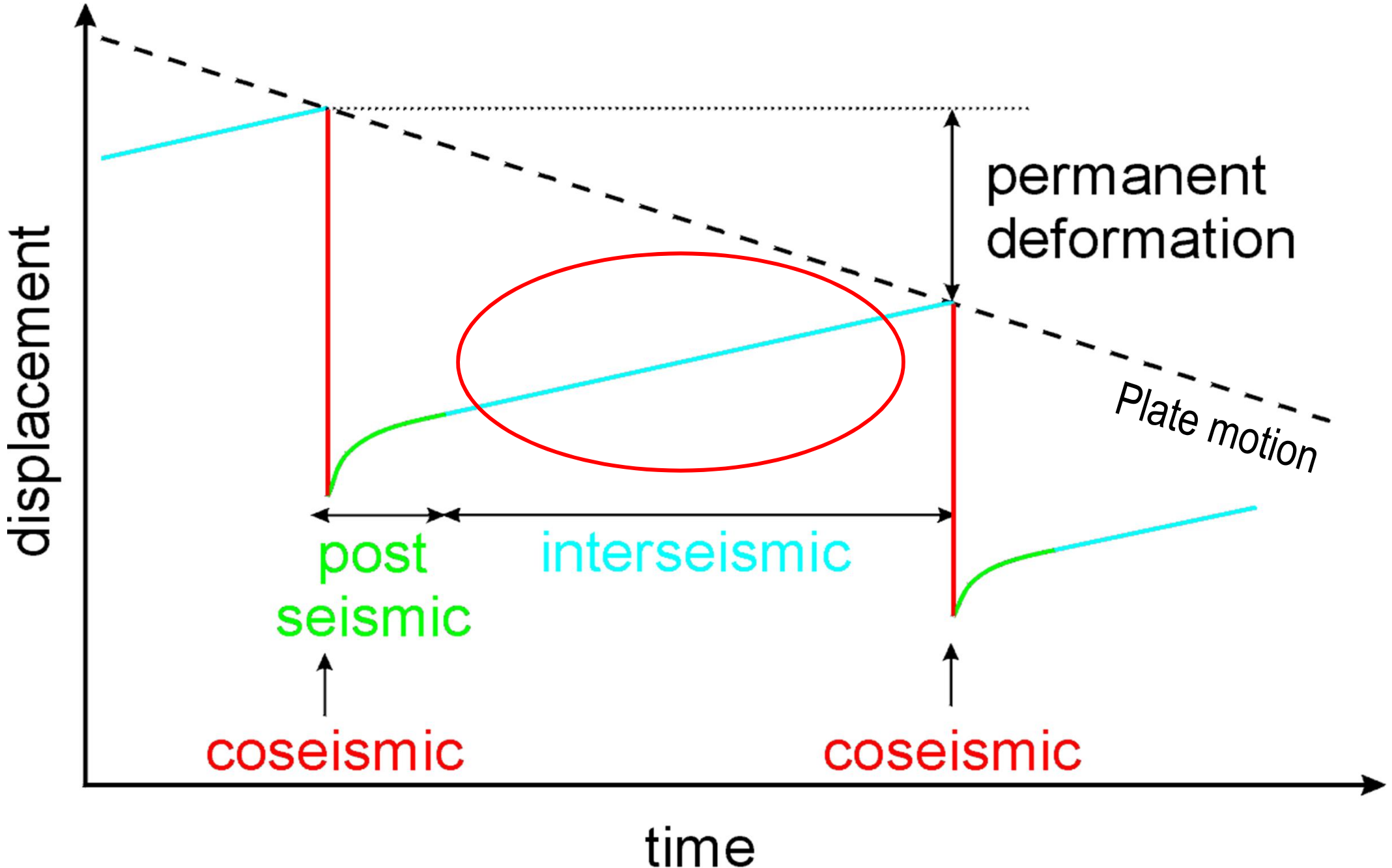
Coseismic offsets and rupture modelling

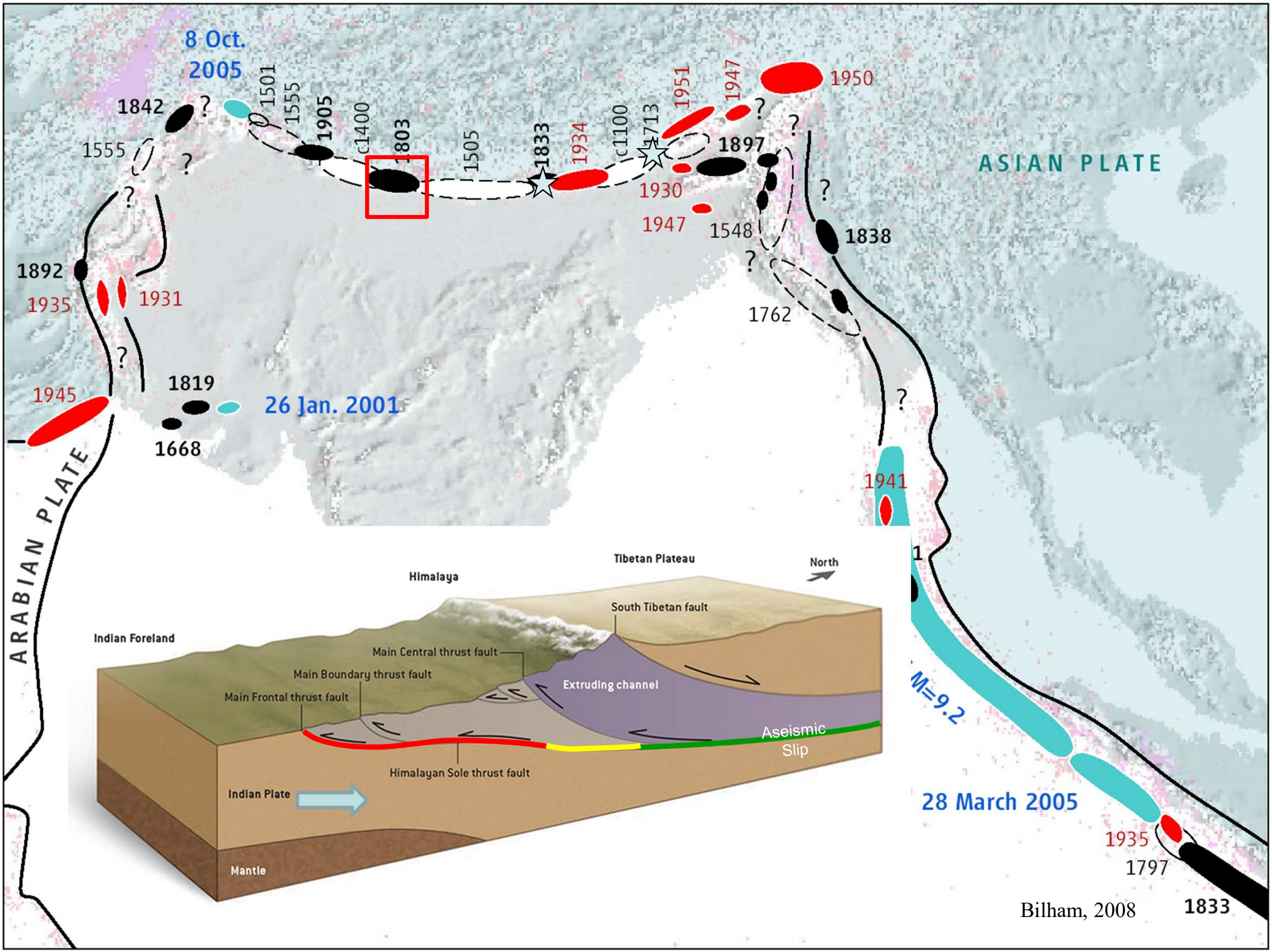
Indian ocean earthquakes (M 8.6 and 8.2)





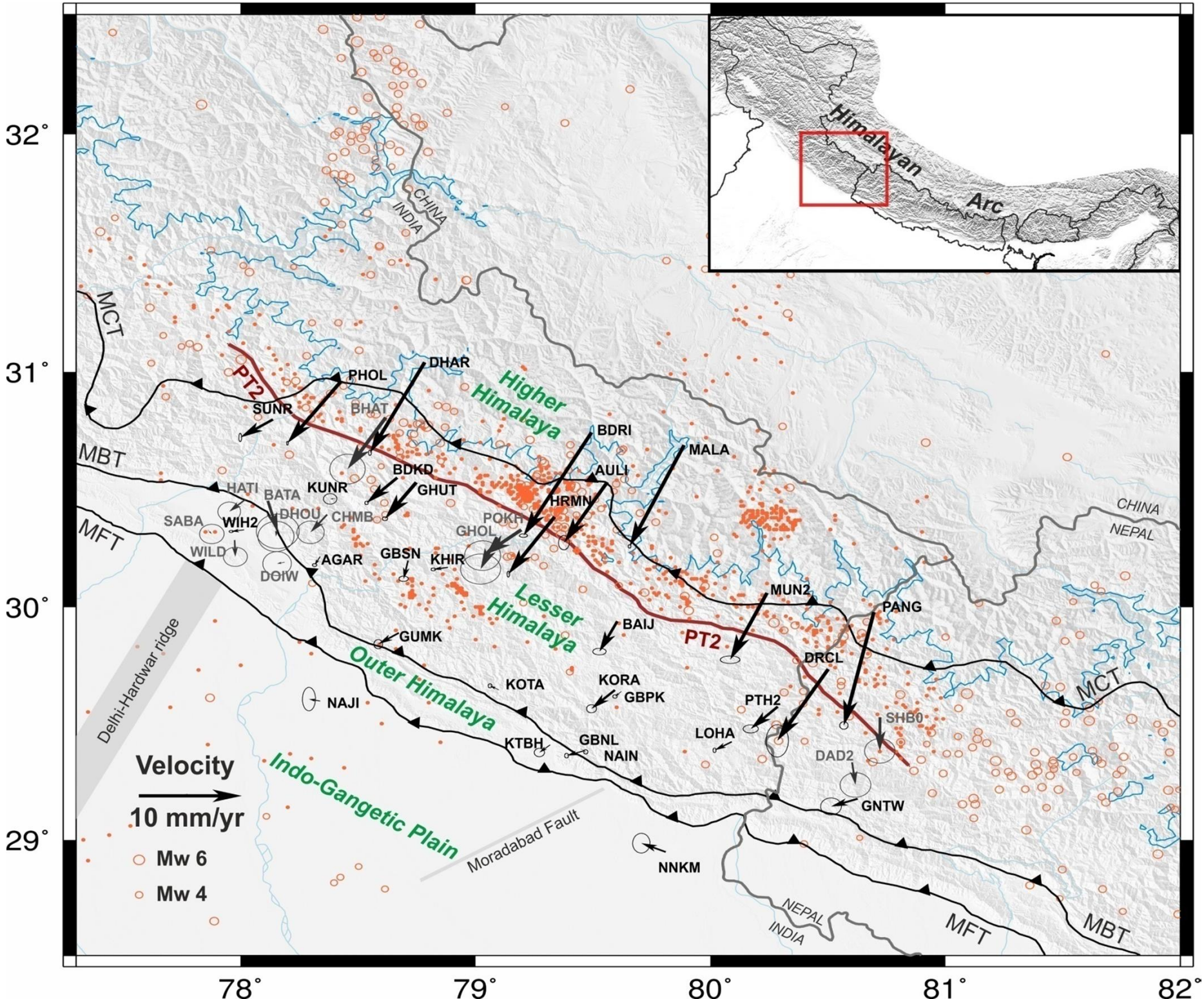
The earthquake cycle

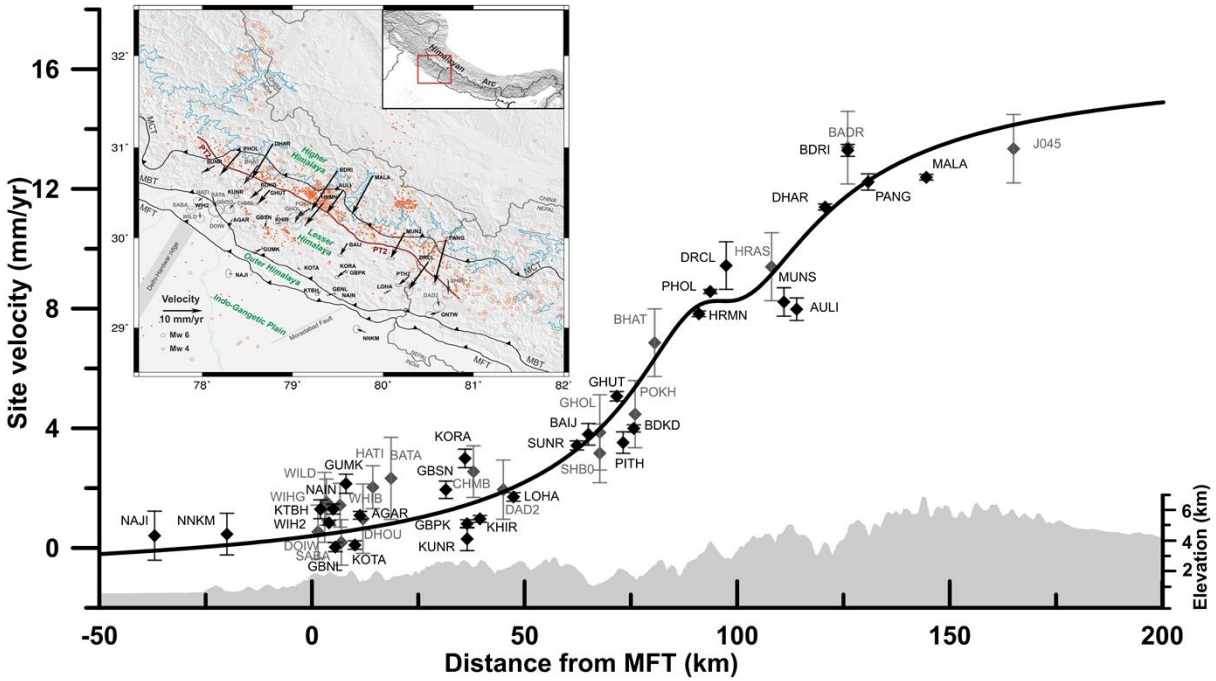


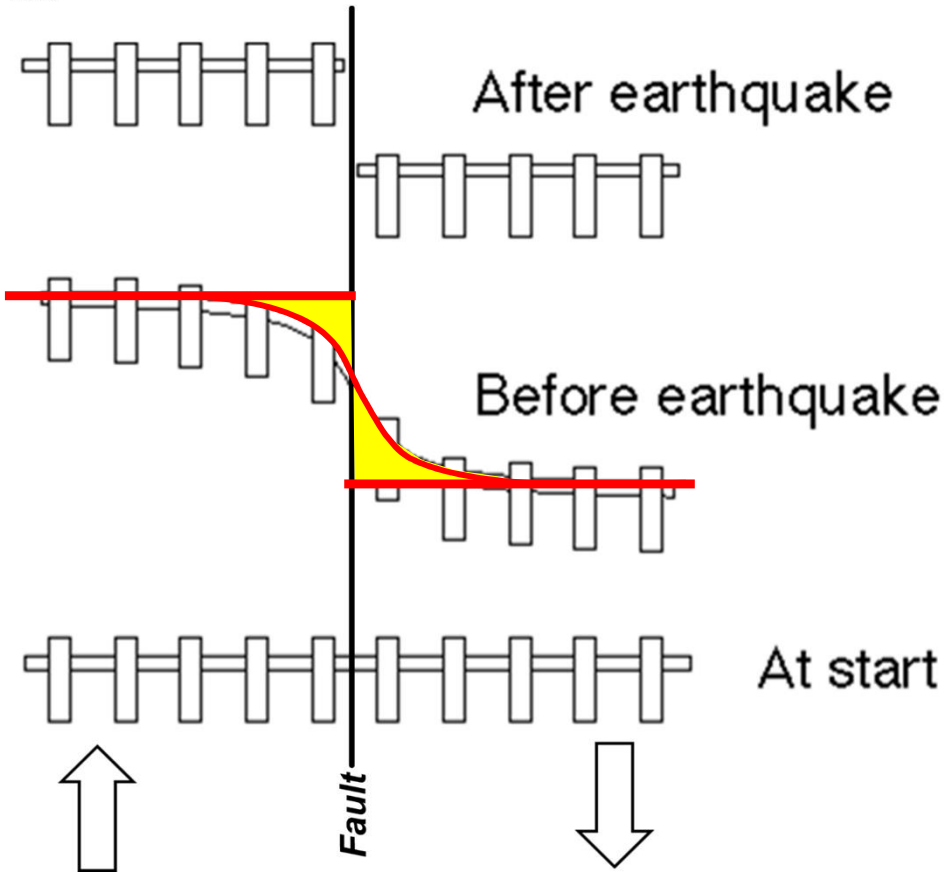

8 Oct.
2005
1842
1555
1501
1555
1905
c1400
1803
1505
1833
1934
c1100
1713
1951
1947
1950
1897
1930
1947
1548
1838
1762
1892
1935
1931
1945
1819
1668
26 Jan. 2001
ARABIAN PLATE
ASIAN PLATE
1941
M=9.2
28 March 2005
1935
1797
1833
Tibetan Plateau
North
Himalaya
South Tibetan fault
Indian Foreland
Main Central thrust fault
Main Boundary thrust fault
Main Frontal thrust fault
Extruding channel
Aseismic
Slip
Himalayan Sole thrust fault
Indian Plate
Mantle

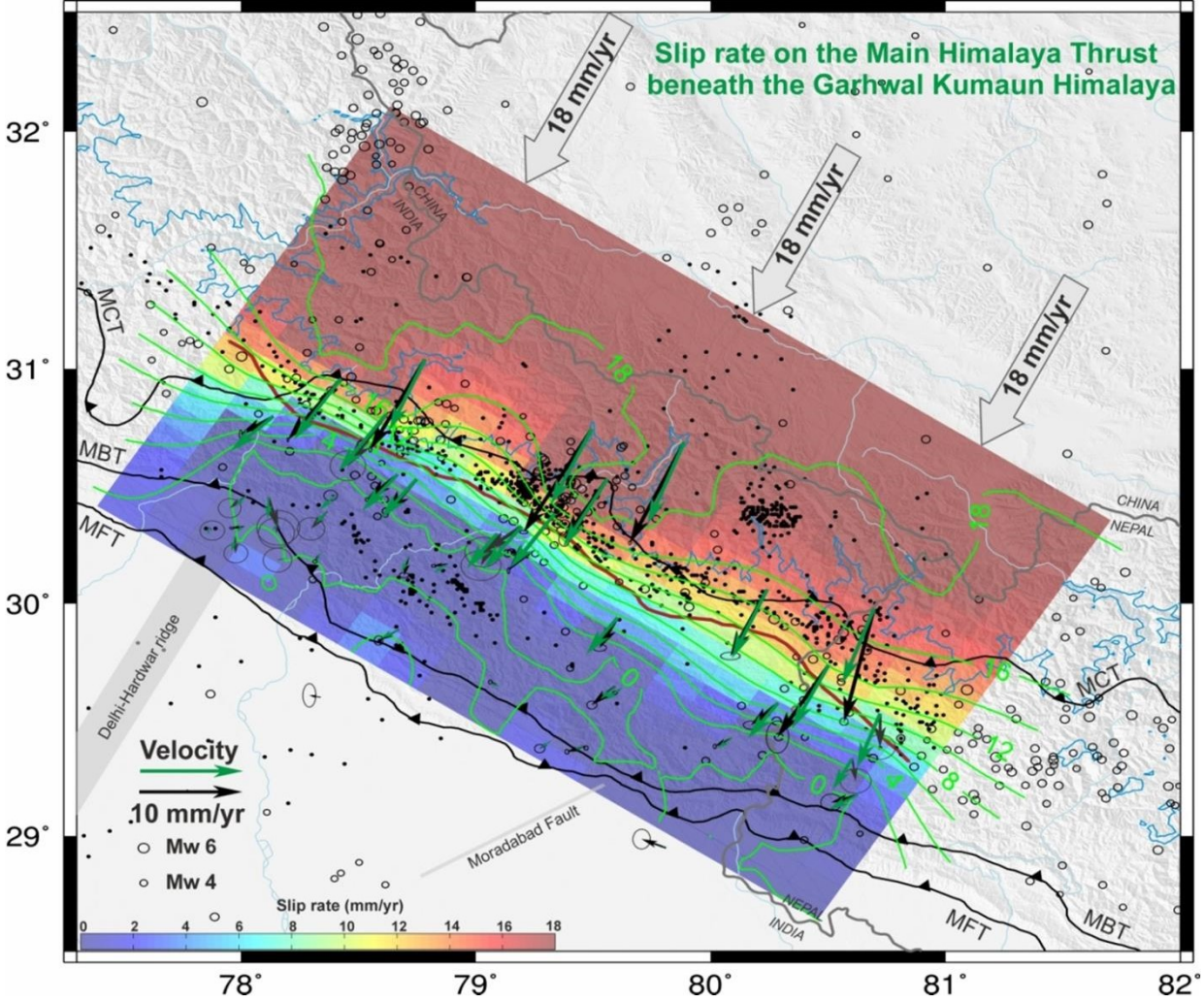
Bilham, 2008


Interplate region
Garhwal Kumaun Himalaya

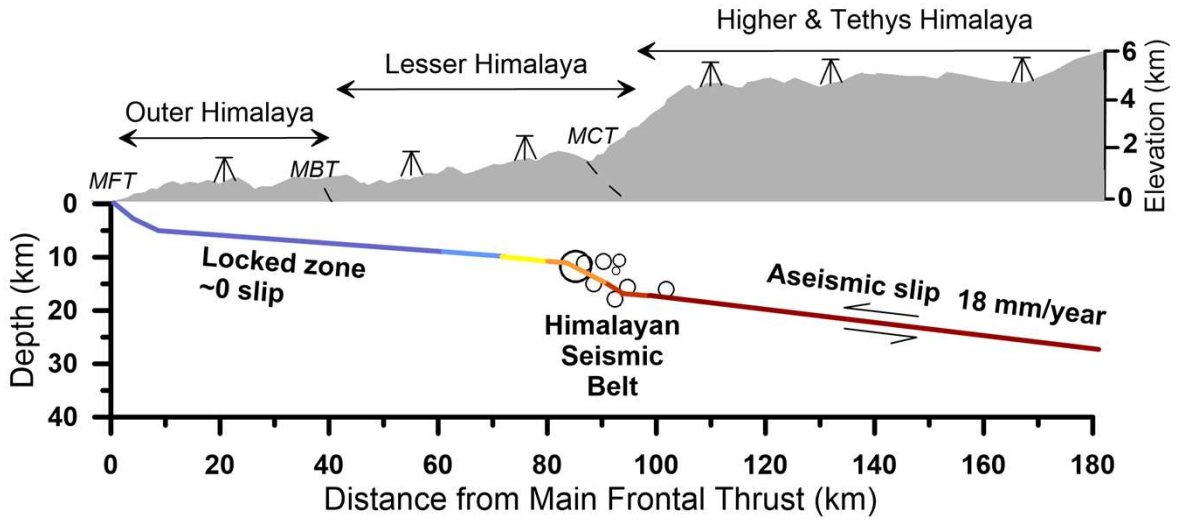

Himalayan
Arc
CHINA
INDIA
MCT
MBT
MFT
PT2
Higher
Himalaya
Lesser
Himalaya
Outer Himalaya
Indo-Gangetic Plain
Delhi-Hardwar ridge
Moradabad Fault
NEPAL
CHINA
NEPAL
INDIA
PHOL
DHAR
SUNR
BHAT
BDRI
MALA
AULI
BDKD
GHUT
KUNR
HRMN
HATI
BATA
DHOU
CHMB
SABA
WIH2
WILD
POKH
GHOL
AGAR
GBSN
KHIR
DOIW
MUN2
PANG
BAIJ
GUMK
DRCL
KOTA
KORA
GBPK
NAJI
PTH2
SHB0
LOHA
KTBH
GBNL
NAIN
DAD2
GNTW
NNKM
Velocity
10 mm/yr
Mw 6
Mw 4
32˚
31˚
30˚
29˚
78˚
79˚
80˚
81˚
82˚

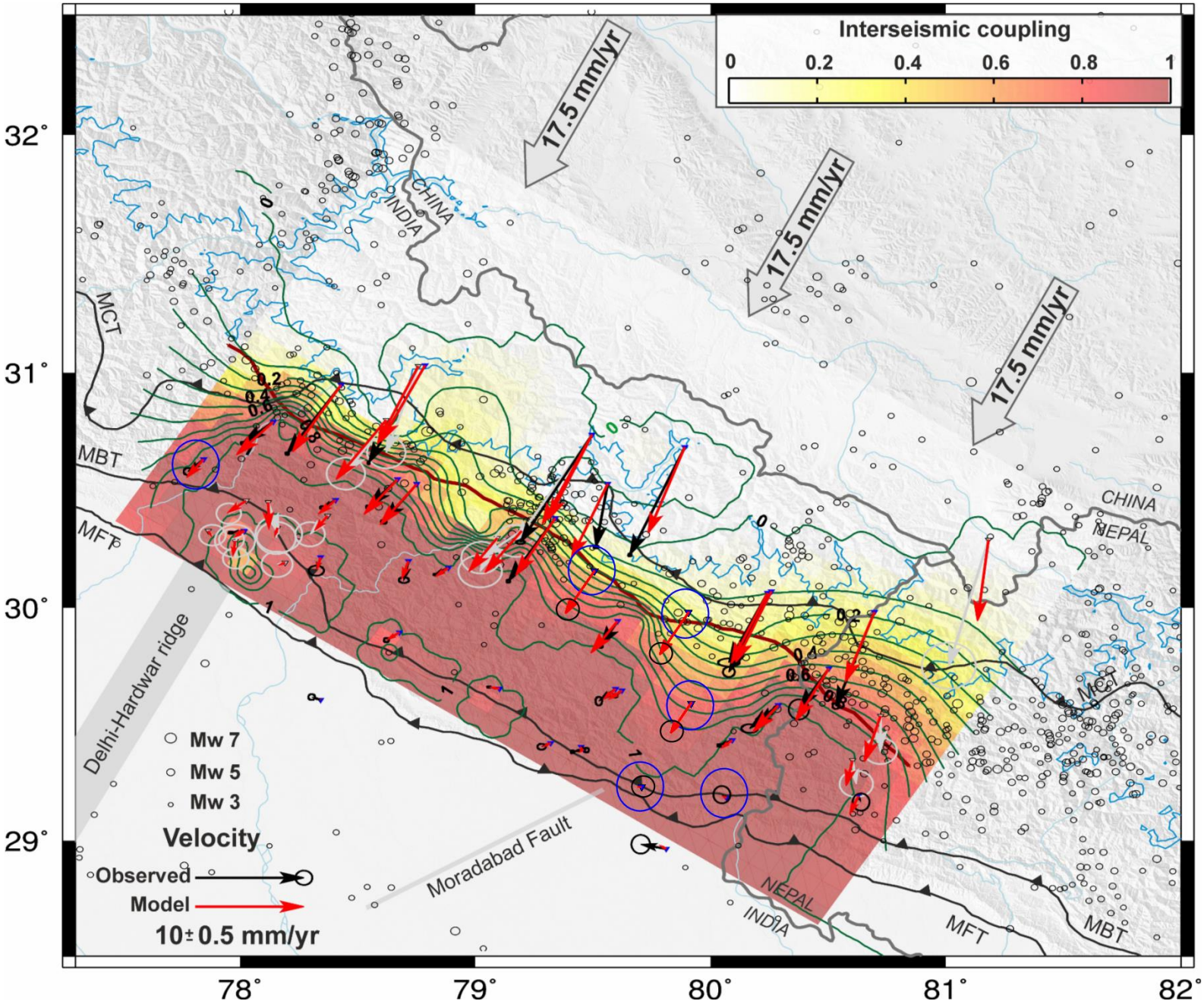

Site velocity (mm/yr)
16
12
8
4
0
-50
0
50
100
150
200
Distance from MFT (km)
Elevation (km)
6
4
2
Velocity
10 mm/yr
Mw 6
Mw 4
Higher Himalaya
Lesser Himalaya
Outer Himalaya
Indo-Gangetic Plain
MBT
MFT
MCT
BADR
BDRI
MALA
J045
DHAR
PANG
DRCL
HRAS
MUNS
PHOL
HRMN
AULI
BHAT
GHUT
POKH
GHOL
BAIJ
BDKD
SUNR
PITH
SHB0
KORA
HATI
BATA
GUMK
GBSN
WILD
CHMB
NAIN
LOHA
WIHG
WHIB
DAD2
KTBH
AGAR
GBPK
KHIR
WIH2
DHOU
KUNR
DOIW
SABA
KOTA
GBNL
NAJI
NNKM


After earthquake
Before earthquake
At start
Fault



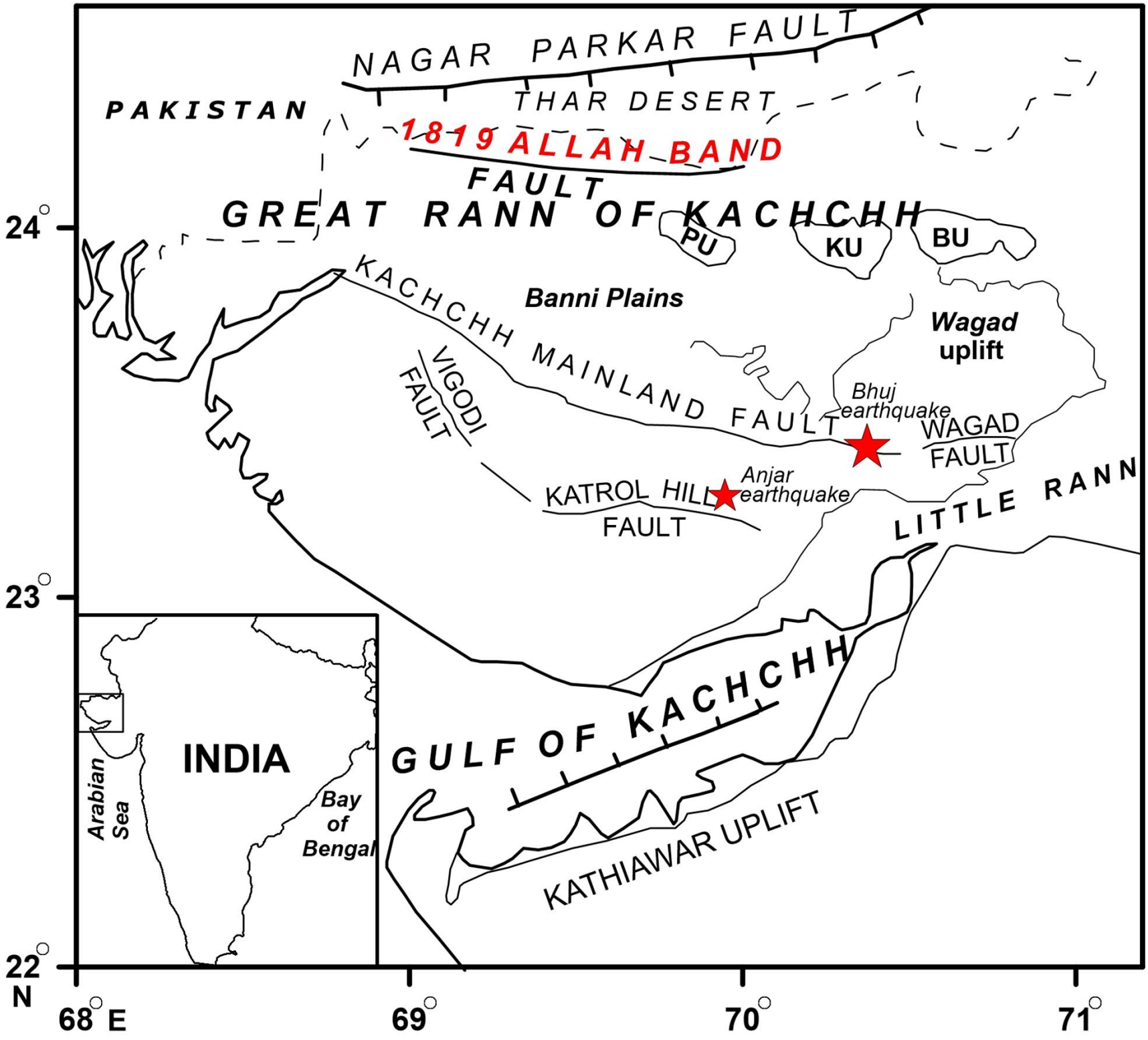
Yadav et al., 2018, EPSL

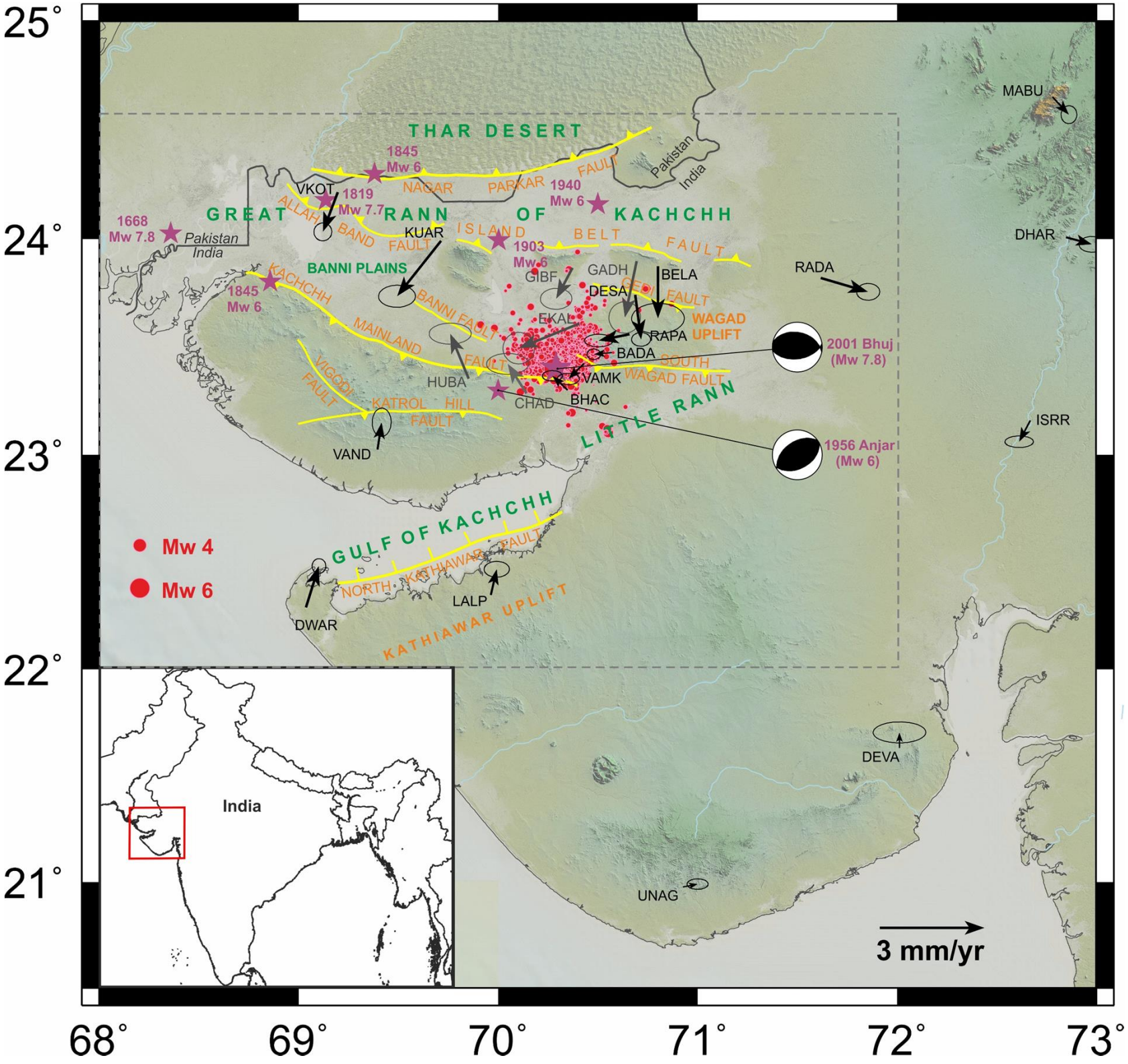


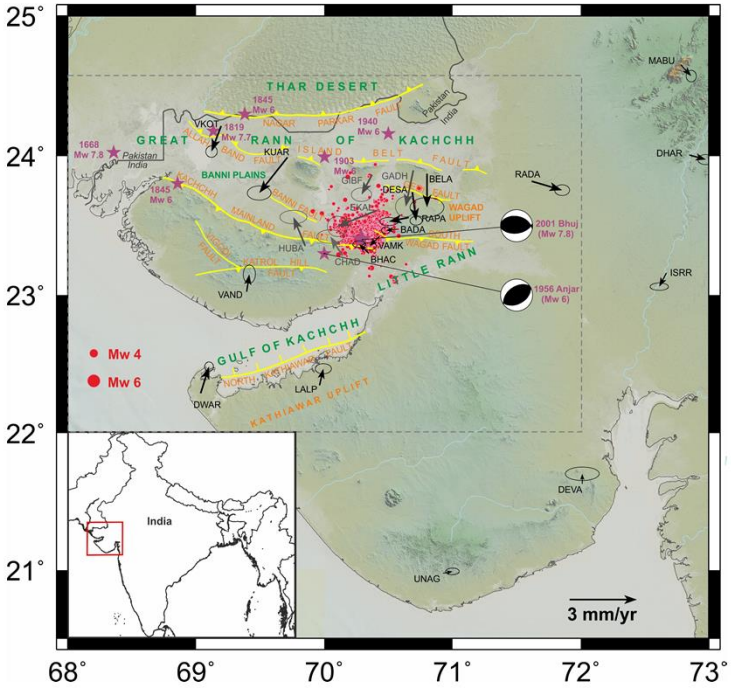


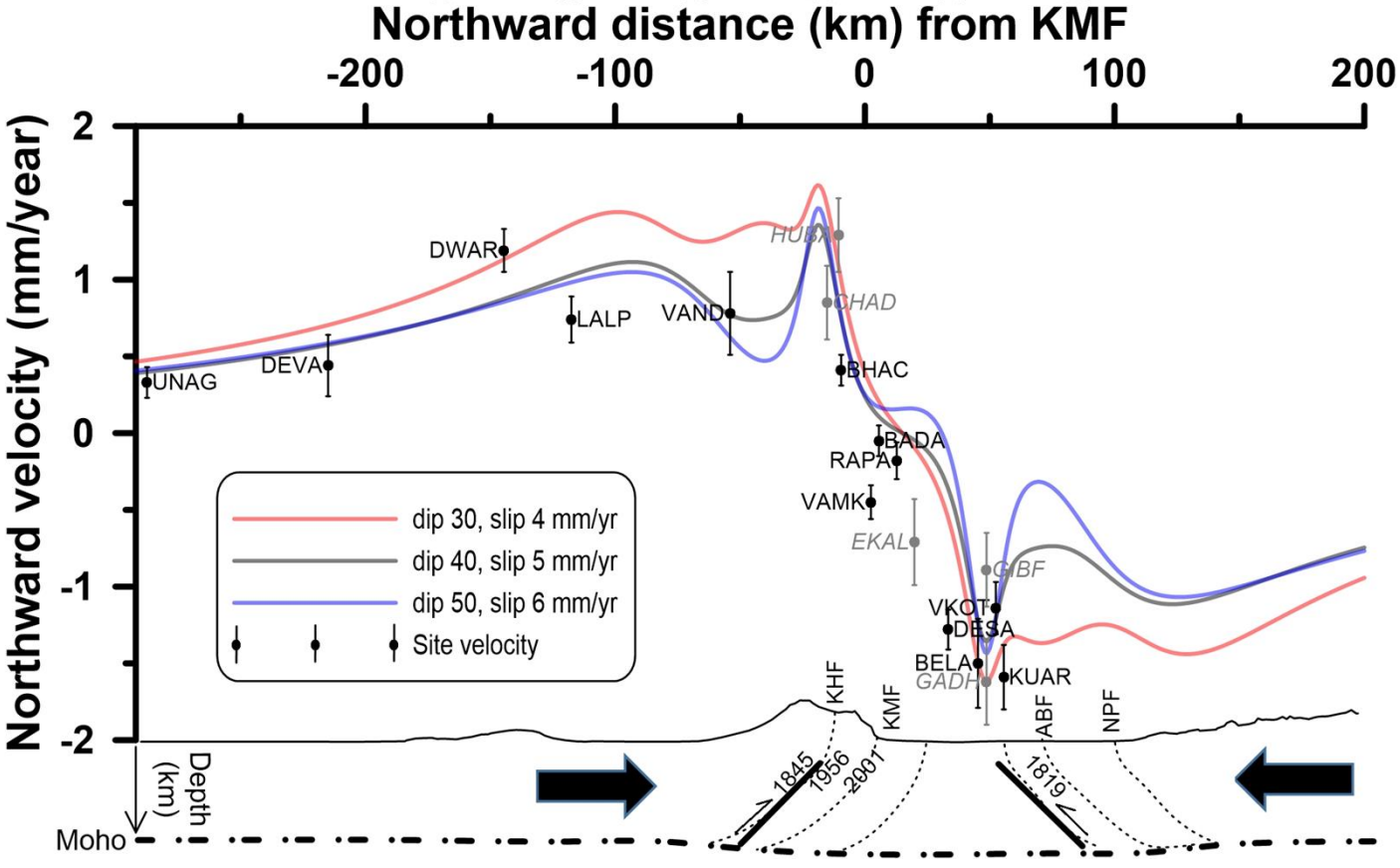
Mondal et al., 2021

and an example from intraplate region: Kuchchh

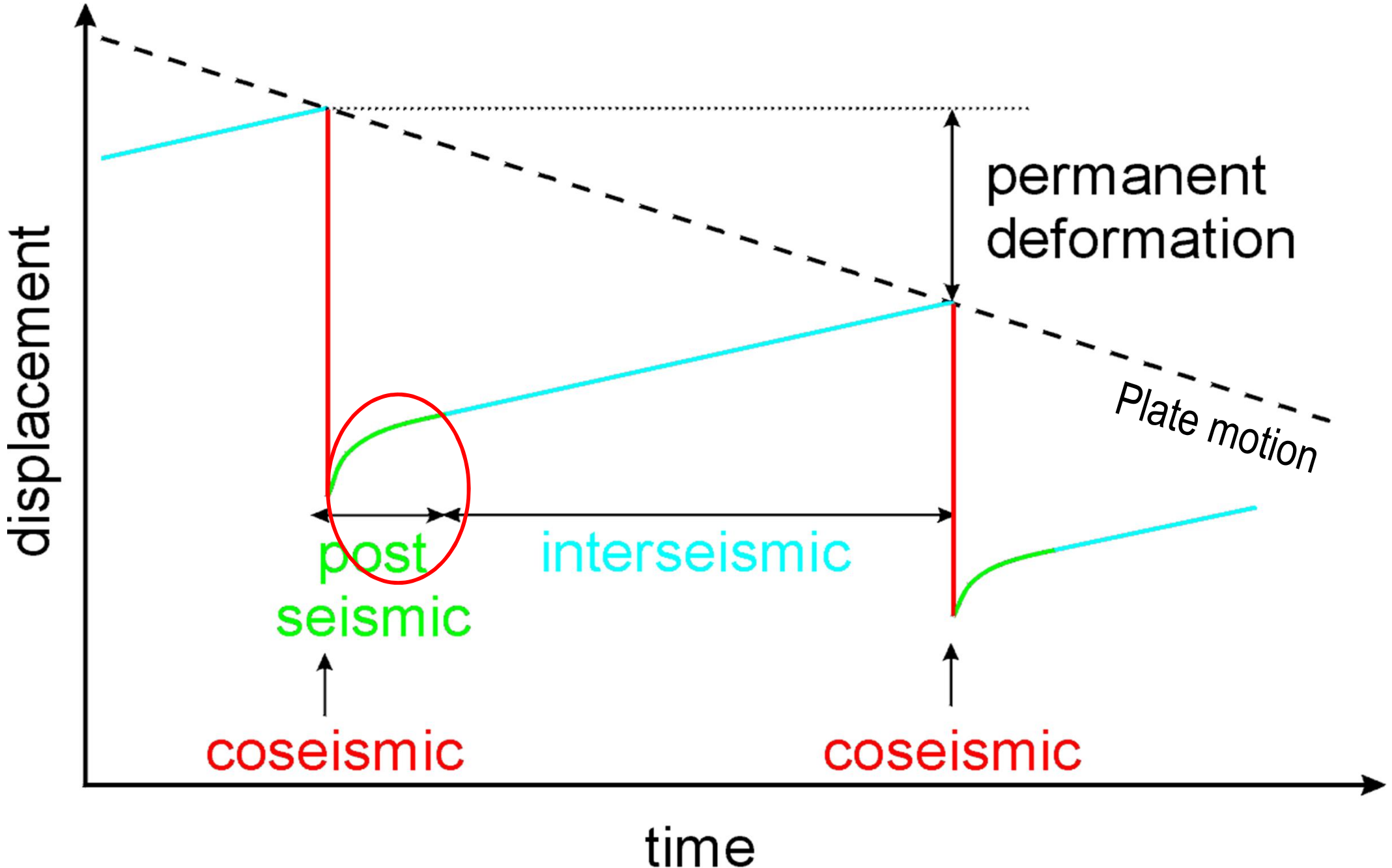

NAGAR PARKAR FAULT
PAKISTAN
THAR DESERT
1819 ALLAH BAND
FAULT
GREAT RANN OF KACHCHH
PU
KU
BU
KACHCHH MAINLAND FAULT
Banni Plains
Wagad
uplift
VIGODI
FAULT
Bhuj
earthquake
WAGAD
FAULT
Anjar
earthquake
KATROL HILL
FAULT
LITTLE RANN
INDIA
Arabian
Sea
Bay
of
Bengal
GULF OF KACHCHH
KATHIAWAR UPLIFT
24°
23°
22°
N
68° E
69°
70°
71°

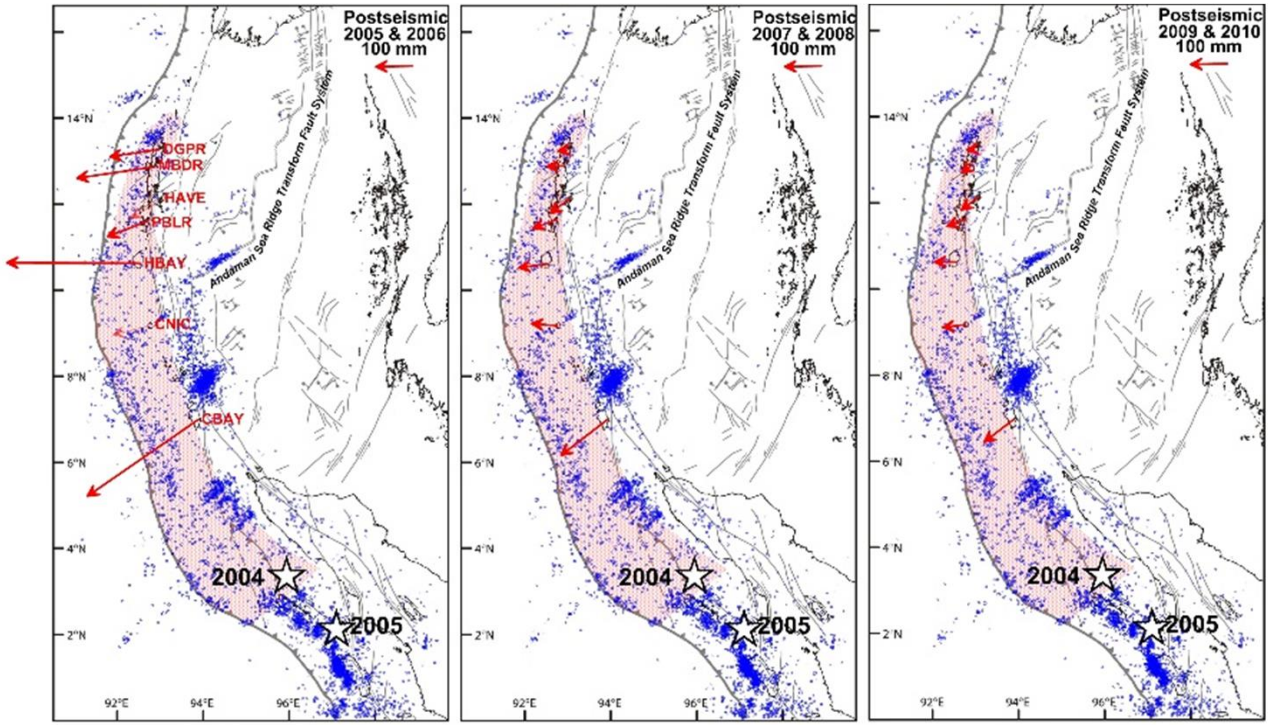

THAR DESERT
GREAT RANN OF KACHCHH
BANNI PLAINS
LITTLE RANN
GULF OF KACHCHH
KATHIAWAR UPLIFT
1845 Mw 6
1819 Mw 7.7
1668 Mw 7.8
1903 Mw 6
1940 Mw 6
1845 Mw 6
2001 Bhuj (Mw 7.8)
1956 Anjar (Mw 6)
Pakistan
India
NAGAR PARKAR FAULT
ALLAR BAND FAULT
ISLAND BELT FAULT
KACHCHH MAINLAND FAULT
BANNI FAULT
GEDI FAULT
WAGAD UPLIFT
WAGAD SOUTH FAULT
VIGODI FAULT
KATROL HILL FAULT
KATHIAWAR NORTH FAULT
VKOT
KUAR
GIBF
GADH
BELA
DESA
EKAL
RAPA
BADA
VAMK
BHAC
CHAD
HUBA
VAND
LALP
DWAR
MABU
DHAR
RADA
ISRR
DEVA
UNAG
Mw 4
Mw 6
3 mm/yr
India
25°
24°
23°
22°
21°
68°
69°
70°
71°
72°
73°

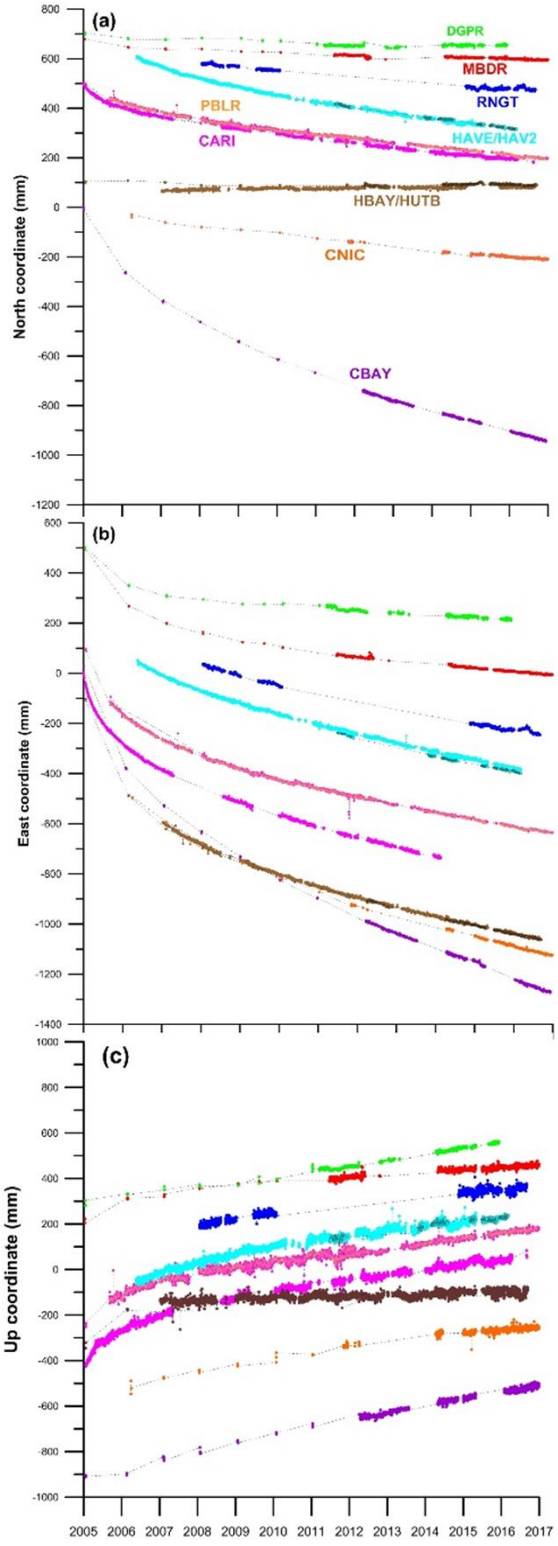

THAR DESERT
GREAT RANN OF KACHCHH
BANNI PLAINS
LITTLE RANN
GULF OF KACHCHH
KATHIAWAR UPLIFT
WAGAD UPLIFT
KUAR
VKOT
GADH
BELA
DESA
EKAL
RAPA
BADA
VAMK
HUBA
CHAD
BHAC
VAND
LALP
DWAR
UNAG
DEVA
RADA
MABU
DHAR
ISRR
2001 Bhuj (Mw 7.8)
1956 Anjar (Mw 6)
1668 Mw 7.8
1819 Mw 7.7
1845 Mw 6
1940 Mw 6
1903 Mw 6
Mw 4
Mw 6
India
Pakistan
3 mm/yr
25˚
24˚
23˚
22˚
21˚
68˚
69˚
70˚
71˚
72˚
73˚


Northward distance (km) from KMF
-200
-100
0
100
200
Northward velocity (mm/year)
2
1
0
-1
-2
DWAR
LALP
VAND
HUBA
CHAD
BHAC
UNAG
DEVA
BADA
RAPA
VAMK
EKAL
GBF
VKOT
DESA
BELA
GADH
KUAR
dip 30, slip 4 mm/yr
dip 40, slip 5 mm/yr
dip 50, slip 6 mm/yr
Site velocity
KHF
KMF
ABF
NPF
1845
1956
2001
1819
Depth (km)
Moho

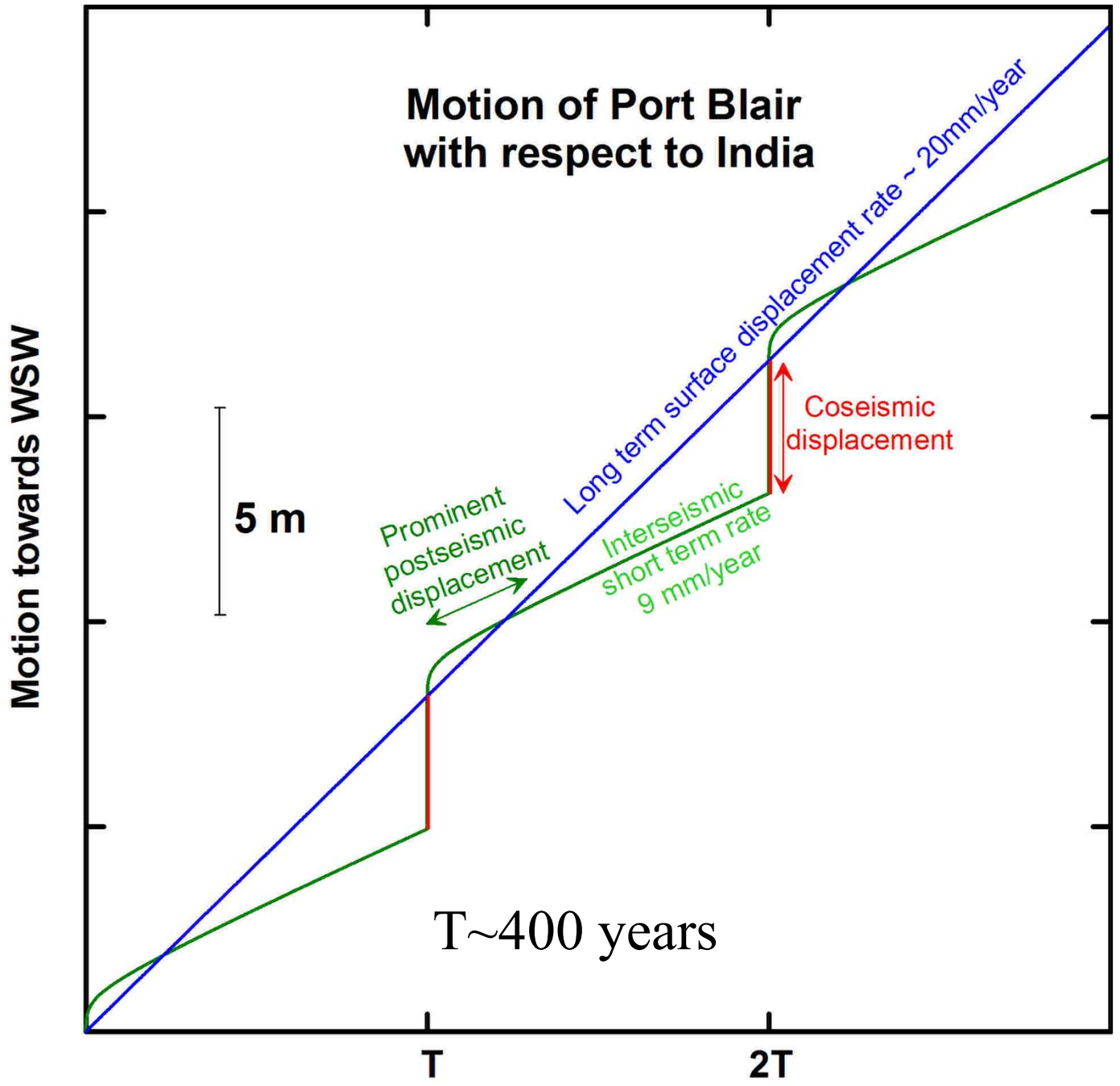
The earthquake cycle

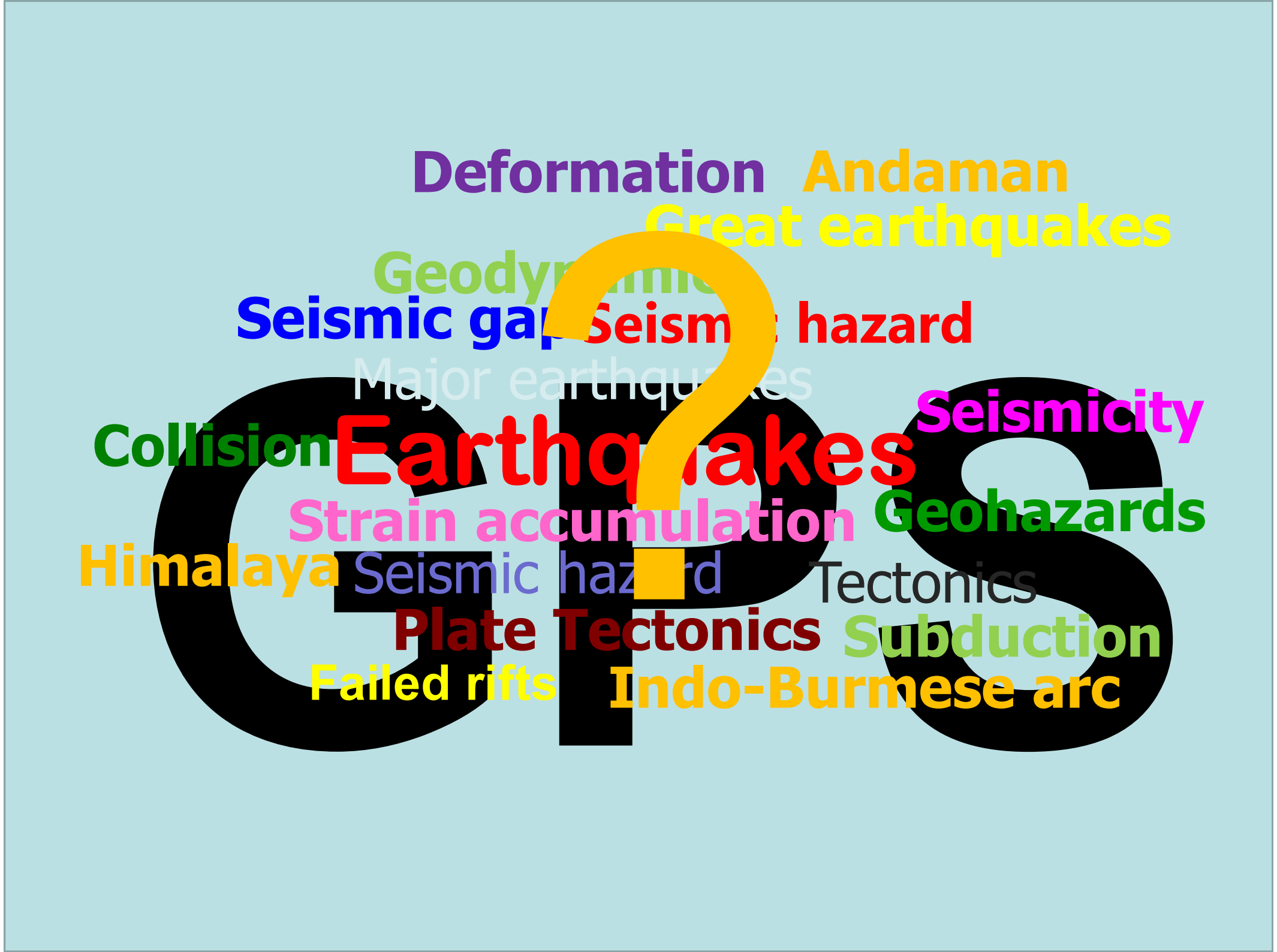



Postseismic
2005 & 2006
100 mm
Postseismic
2007 & 2008
100 mm
Postseismic
2009 & 2010
100 mm
Postseismic
2011 & 2012
100 mm
Postseismic
2013 & 2014
100 mm
Postseismic
2015 & 2016
100 mm
DGPR
MBDR
HAVE
PBLR
HBAY
CNIC
CBAY
Andaman Sea Ridge Transform Fault System
2004
2005


(a)
DGPR
MBDR
RNGT
PBLR
CARI
HAVE/HAV2
HBAY/HUTB
CNIC
CBAY
North coordinate (mm)
(b)
East coordinate (mm)
(c)
Up coordinate (mm)
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

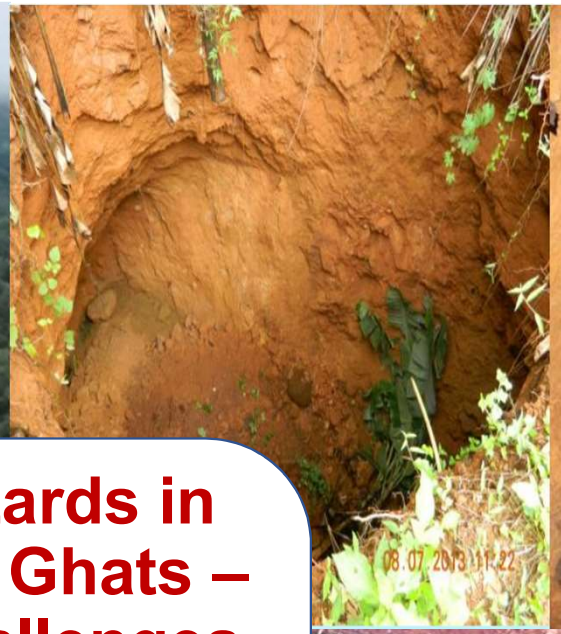
What is the earthquake recurrence interval in the region.

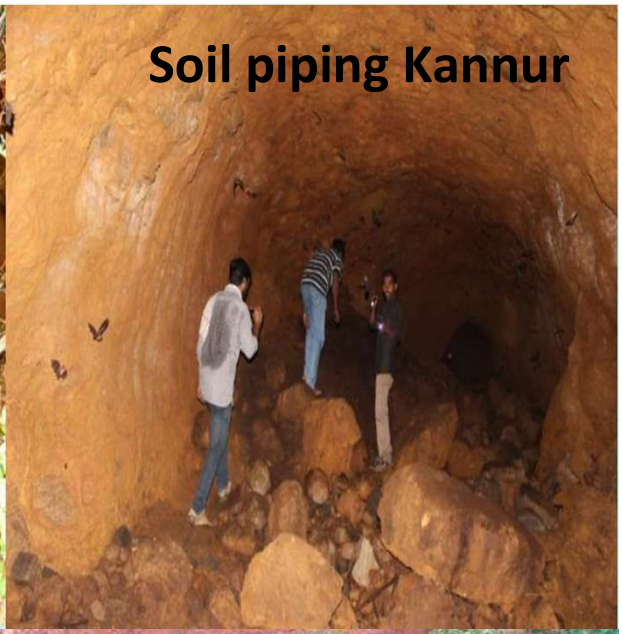



Deformation
Andaman
Great earthquakes
Geodynamic
Seismic gap
Seismic hazard
Major earthquakes
Seismicity
Collision
GPS
Earthquakes
Strain accumulation
Geohazards
Himalaya
Seismic hazard
Tectonics
Plate Tectonics
Subduction
Failed rifts
Indo-Burmese arc

धन्यवाद


рахмат
danke
謝謝
ngiyabonga
spas
teşekkür ederim
Баярлалаа
mersi
kia ora
barka
welalin
tack
mahalo
tapadh leat
спасибо
faafetai lava
vinaka
blagodaram
dank je
misaotra
matondo
paldies
grazzi
спасибі
thank you
gracias
хвала
nanni
nandri
kiitos
dankie
dhanyavad
mauruuru
köszönöm
ačiū
dankon
akun
asante
manana
obrigada
tenki
bedankt
bayarlalaa
gràçie
hvala
murakoze
djiere dieuf
tau
mochchakkeram
enkosi
dziękuję
дякую
mamnun
chokrane
chnorakaloutioun
gratias ago
gràcies
sulpáy
go raibh maith agat
sobodi
děkuji
taiku
obrigado
sukriya
kop khun krap
arigatô
takk
dakujem
trugarez
mèsi
didi madloba
sagolun
ありがとう
tanemirt
grazie
najis tuke
kam sah hamnida
terima kasih
rahmet
rahmat
ευχαριστώ
diolch
dhanyavadagalu
shukriya
mercé
мерси
তোমাকে ধন্যবাদ
감사합니다
xièxie
merci





Geohazards in Western Ghats – New Challenges and Technology Response

Dr. V Nandakumar

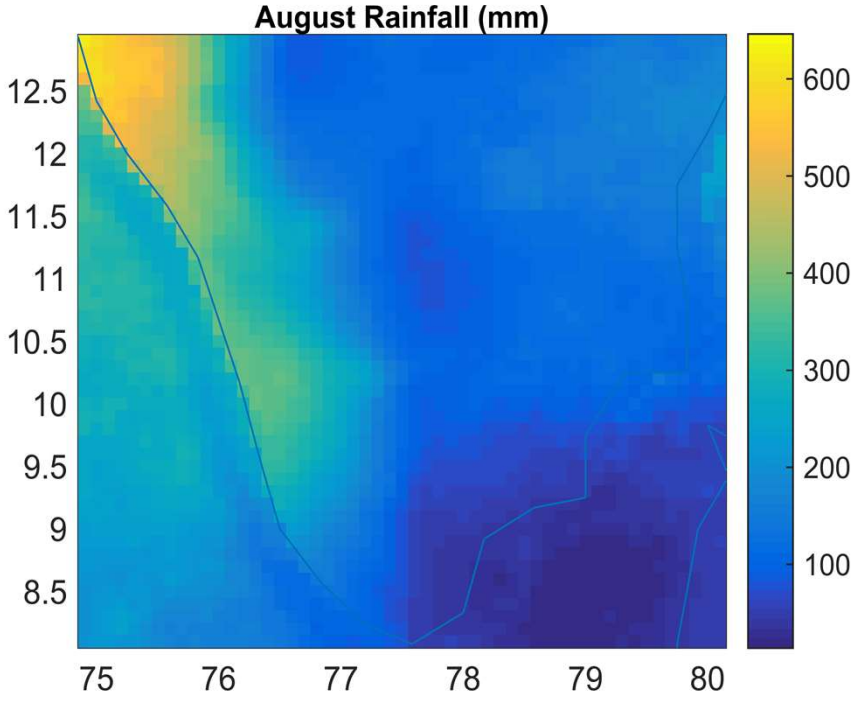
National Center for Earth Science Studies (NCESS), MoES

Thiruvananthapuram

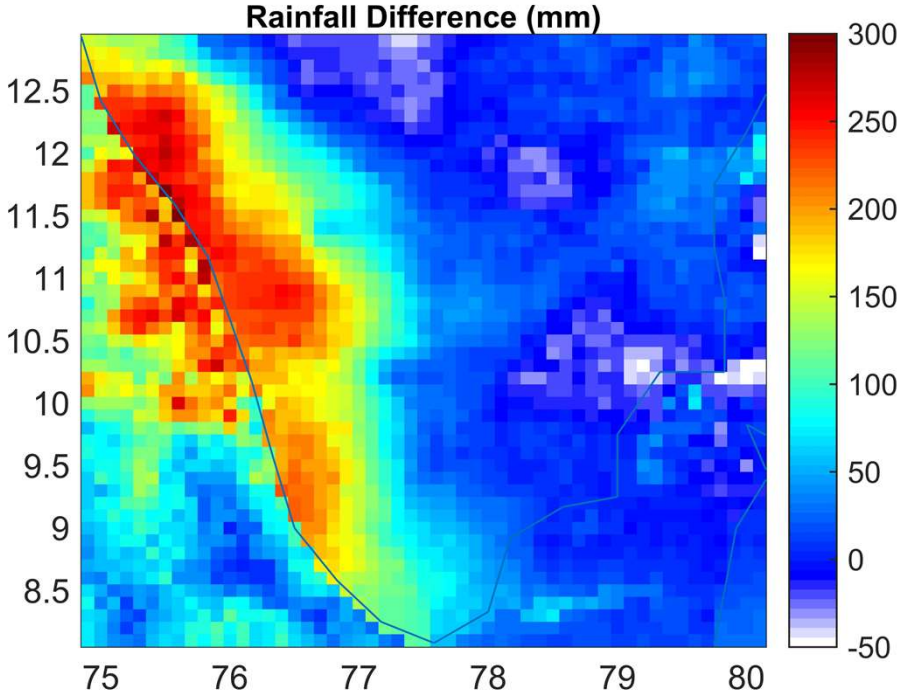
Landslides in WG: Rain as primary trigger

Satellite Gridded rainfall (TRMM,GPM)

Mean Rainfall: 2000 to 2017



Change in recent period August Rainfall: 2018 to 2021

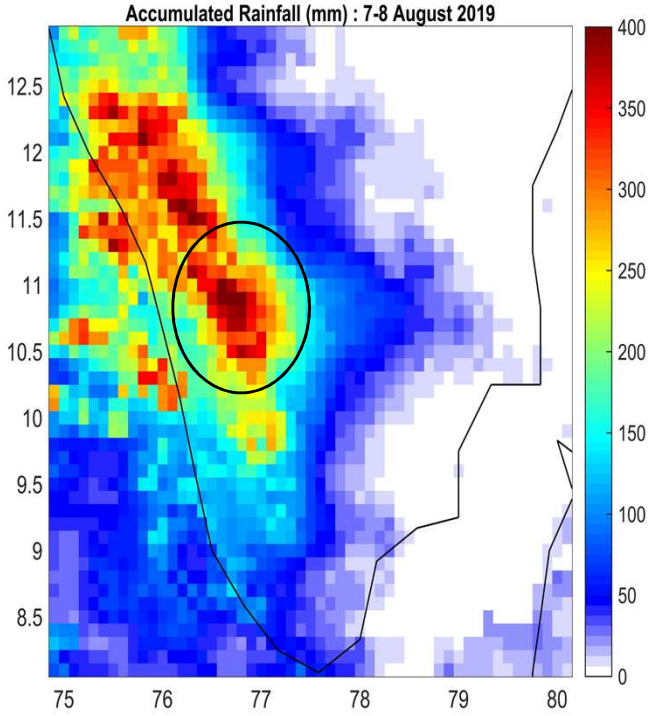


- **Satellite rainfall data are available over hinterlands and complex terrains like WG where weather radar may not be helpful.**
- **TRMM & GPM IMERG satellite rainfall indicate that there is a significant change in accumulated rainfall in August.**
- **Accumulated rainfall in short periods are favorable to land slide, floods and other addon natural hazards.**

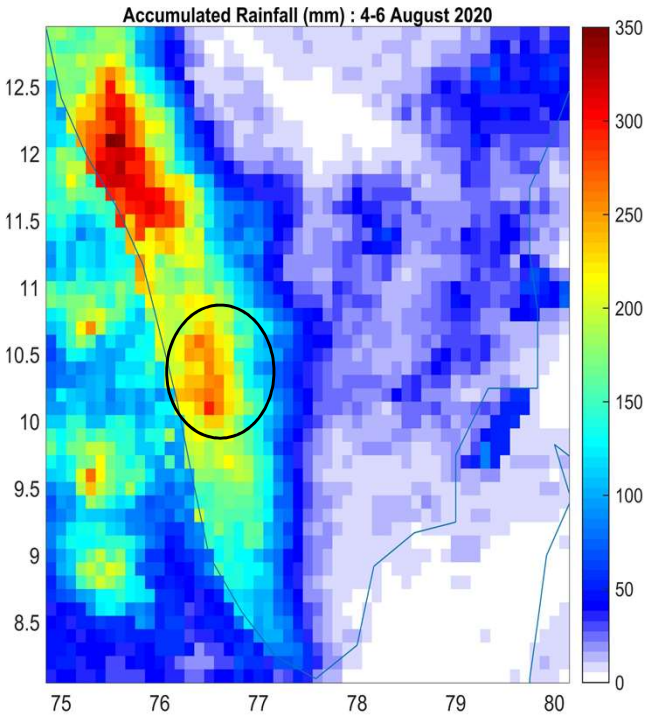
(TRMM: Tropical Rainfall Measuring Mission, GPM: Global Precipitation Measurement; IMERG: Integrated Multi-satellite Retrievals)

Potential Applications of satellite rainfall monitoring

(1) Kavalapara, Nilambur (WG) on 8th August 2019



(2) Pettimudi, Munnar (WG) on 6th August 2020



GPM Satellite observed rainfall indicate heavy precipitation (accumulated rainfall 2-3 days period) > 250 mm during land slides in WG. Accumulated rainfall in short periods were prime reason for the slides. Near Realtime satellite rainfall has potential application for monitoring accumulated precipitation for early warning and evacuations from land slide prone regions

Landslides in WG

Land signals & devastation

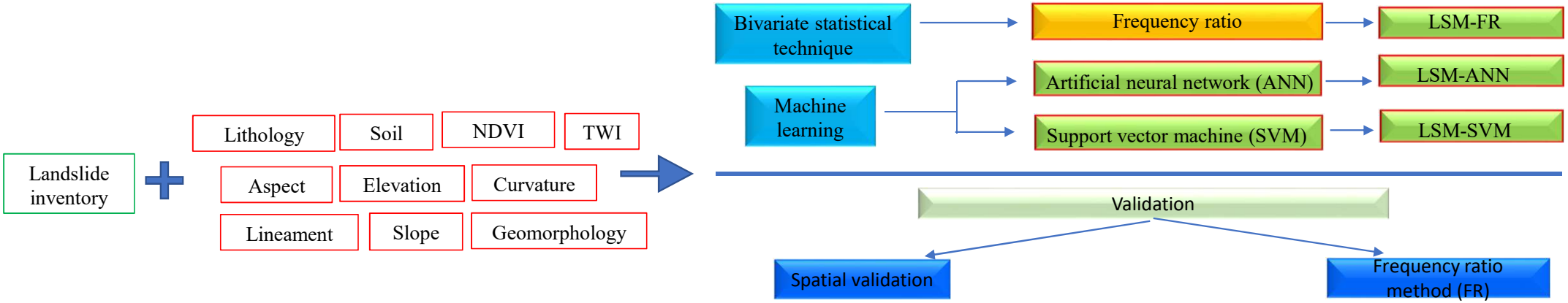
- **Unpresidential catastrophes happened in the highlands of Kerala in the WG during 2018 &2019 events.**
- **Loam and clay loam (Gravel content of 10 to 50%) -*Hill soils* washed away in an unprecedented manner!**
- **Lateral spreads, land subsidence, soil piping and unusual hydrological phenomena observed in WG parts of Kottayam, Idukki, Thrissur, Wayanad, Malappuram and Kannur districts.**
- **Need for adopting modern technologies including machine leaning algorithms for wireless sensor networks (WSN) for real time monitoring and early warning system.**

Between 2019-2022 the number of landslides reported in Kerala state alone is 2239 (GSI).

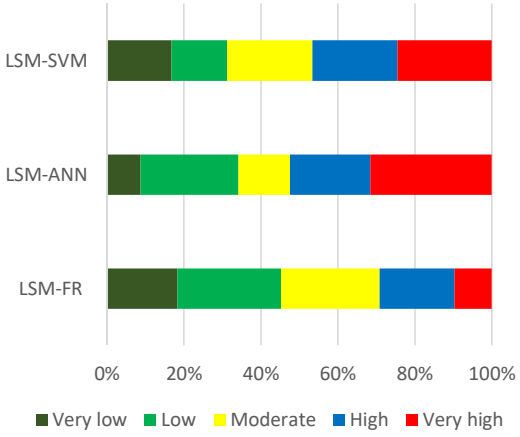
- **Kavalappara : (8-8-2019) – 59 deaths**
- **Puthumala : (8-8-2019) – 17 deaths**
- **Pettimudi : (6-8-2020) – 70 deaths**
- **Kottickal and Kokkayar : (14-10-2021) – 21 deaths**
- **Taliye - (22-07-2021) – 87 deaths**

CARTOSAT- 2E Mx data acquired from NRSC for understanding the areal extent of the debris flow.

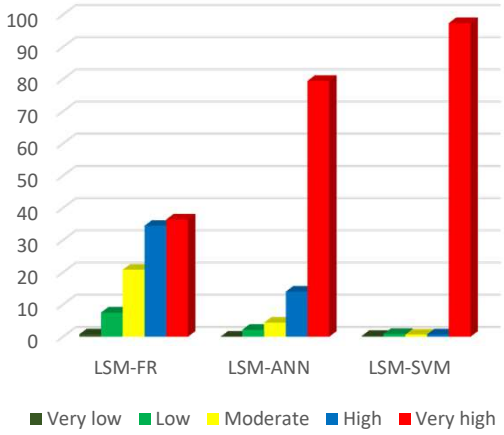
Landslide susceptibility mapping – Methodology



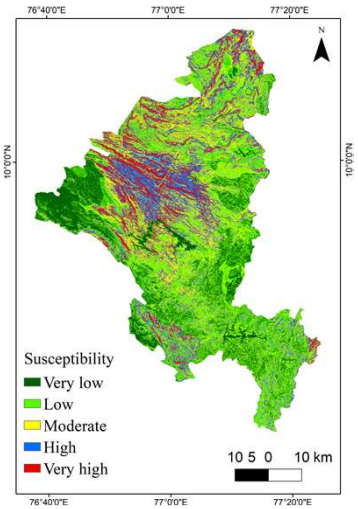
Landslide susceptibility mapping – Validation and result



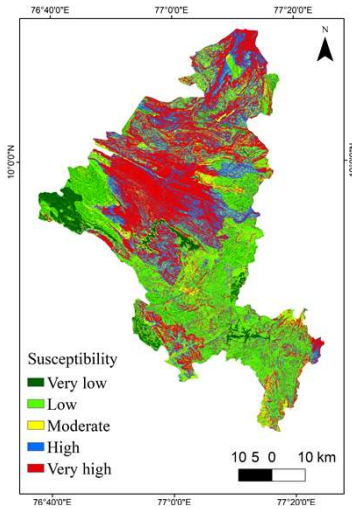
Spatial distribution of susceptibility classes in different maps



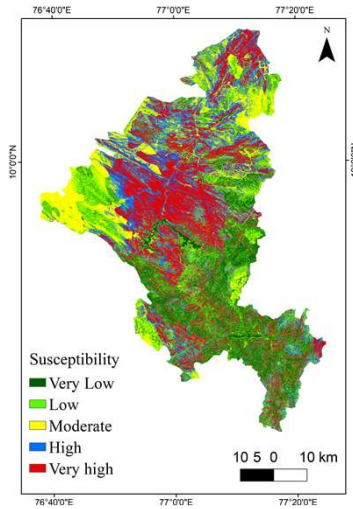
FR assessment of maps



LSM- FR



LSM-ANN

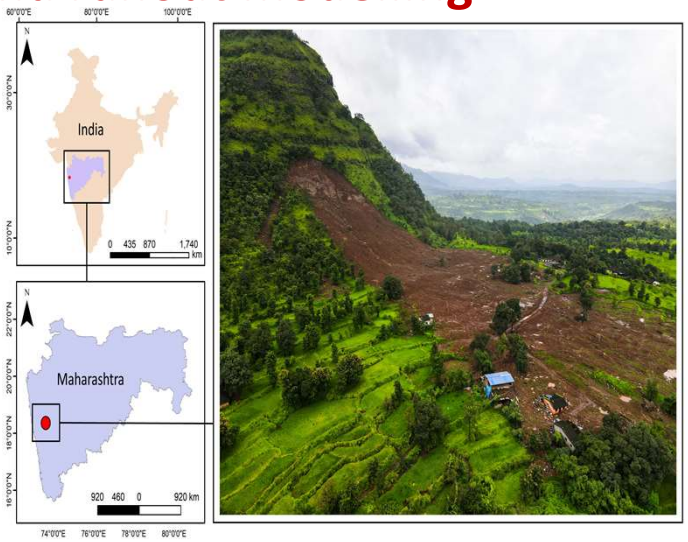


LSM-SVM

Detailed slope stability evaluation and runout modelling

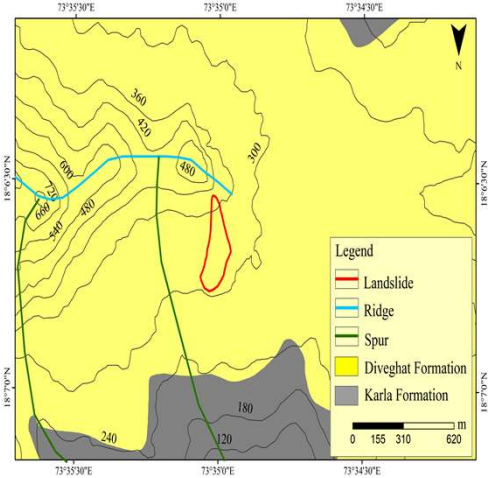
Taliye Landslide **(22 July 2021)**

- Location – Taliye Village, Raigad District, Maharashtra
- Vulnerability - 87 dead, 30 houses, agricultural field
- Morphometry - Crown/ source zone – 15m
  Deposition zone - 230m
  Total runoff - 563m
- Runout modelling – determination of frictional parameters and flow dynamics

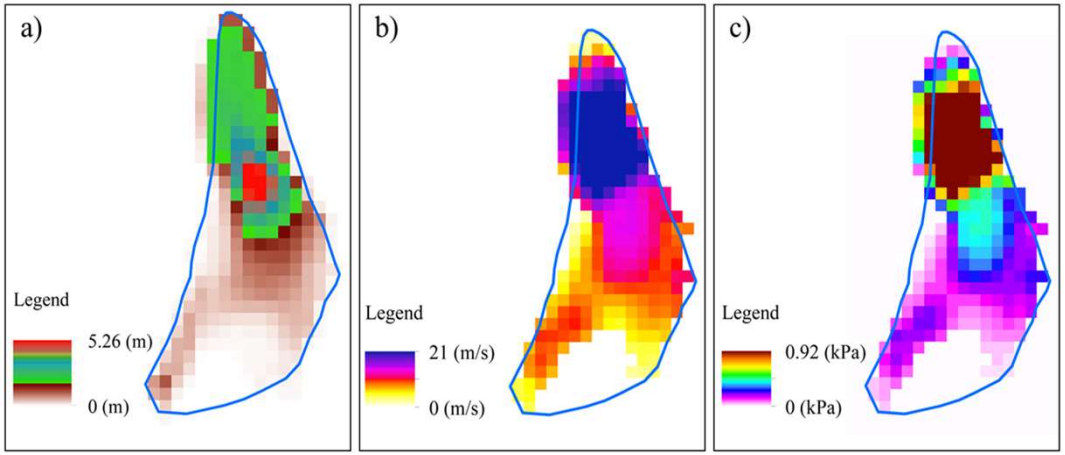


Detailed slope stability evaluation and runout modelling using RAMMS software

- Dry frictional coefficient of 0.06 and turbulent frictional coefficient of 1450 m/s^2 has emerged as the best combination of frictional values
- Type - Unchannelised debris flows
- Causes of failure – Natural & anthropogenic



Landslide location



Flow parameters of debris flow, a) flow height, b) flow velocity and c) flow pressure

Geospatial Landslide Research – A Integrated Approach towards Addressing Landslide hazard in Society

Mapping

- Mobile based spatio-temporal landslide cataloguing involving citizens (**IoT**)
- Satellite based geospatial mapping of landslides for a Nationwide landslide Inventory.m

Monitoring

- Remote Sensing of Landslide Induced surface deformation - National database on DInSAR –(Time series based observation).

Management and dissemination

- UAV for disaster management and recovery
- LiDAR based landslide volume estimation for hydrogeomorphic alterations
- Nationwide Web-GIS based landslide geospatial information/ data dissemination
- Web based awareness and citizen participation on best landslide mitigation practices

Forecast

- Satellite derived rainfall data as threshold for rainfall induced debris flow initiation.
- Ground based SAR interferometry observations to forecast slope failure in specific landslide locations.

Landslide Hazard, Vulnerability & Risk Assessment

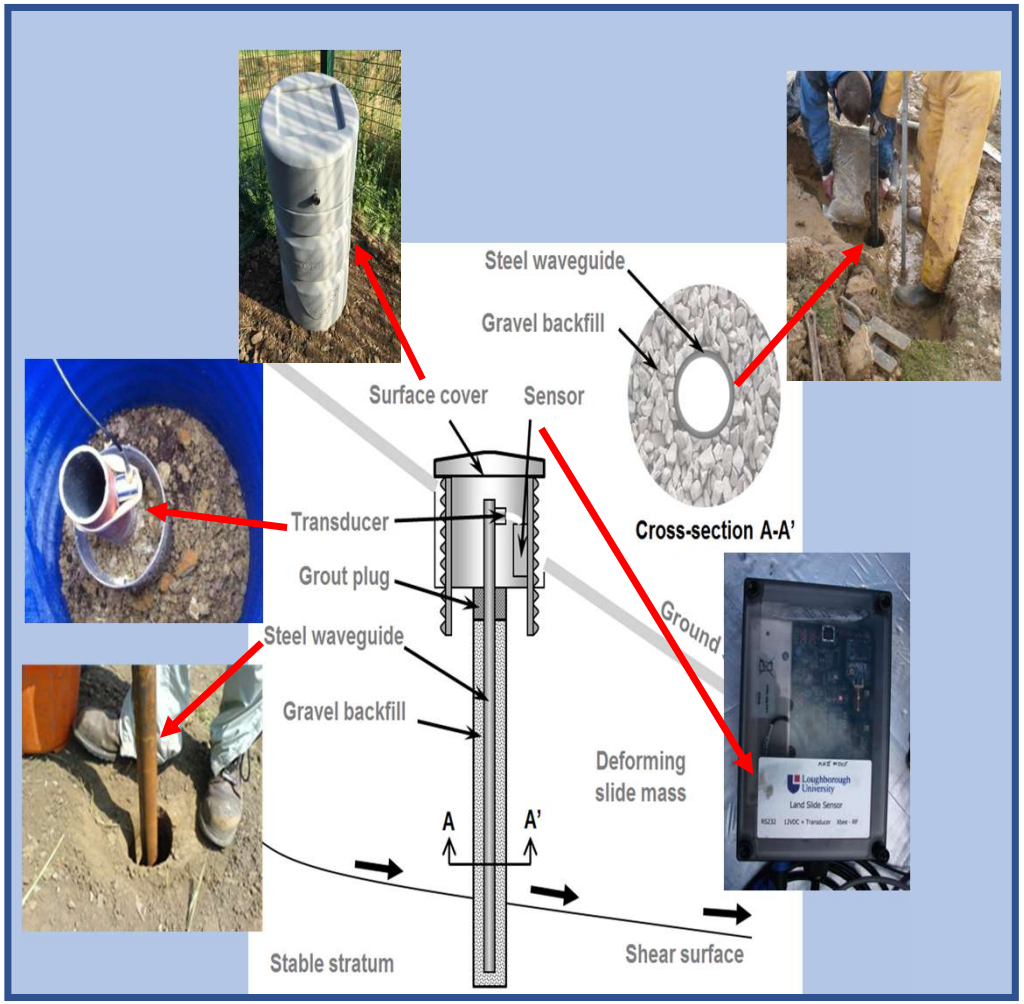
- LHZ/LSZ on **regional scale** has no societal relevance as felt over decades but can be a basic tool.
- Rather **large scale and local scale** LHZ/LSZ should be attempted with RS data and field inputs.
- Susceptibility mapping using AI/Machine learning techniques (ELM, ANN and SVM)
- Should not be restricted to LHZ/LSZ mapping only; Landslide vulnerability and risk assessment must be attempted for urbanized areas in hilly States.

Landslide Early Warning: Rainfall Thresholding

- More research efforts required on rainfall threshold-based landslide early warning for local/catchment scale, not on regional scale:
- Daily rainfall data is available mostly in Indian sub-continent; Hourly data will enhance prediction accuracy
- Historical information on landslide occurrences though available only on date of occurrence; approximate time of occurrence of landslide will supplement hourly rainfall data to enhance prediction accuracy
- Density of rain gauges needs to be improved at least in landslide prone areas to remove the constraints over radius of influence and thereby to improve the prediction accuracy
- Rainfall forecast model to be integrated with the rainfall threshold model for landslide early warning.

Landslide Early Warning: Ground based wireless instrumentation & real-time monitoring

- More research efforts required on active recurring large landslides of societal relevance.
- Development of low-cost sensors including that of AE and their wireless sensor networking systems are quite necessary for the replicability of such monitoring systems. On an experimental basis proven & available AE sensors may be deployed in key areas in Western Ghats.
- Success of the Warning Model depends on the Reliability of the Landslide Model.
- Establishing Early warning systems for debris flow in cooperation with IMD



Land-subsidence due to Soil piping

"Soil Piping" also known as tunnel erosion is the subsurface erosion of soil by percolating waters to produce pipe-like conduits below ground especially in non-lithified earth materials.

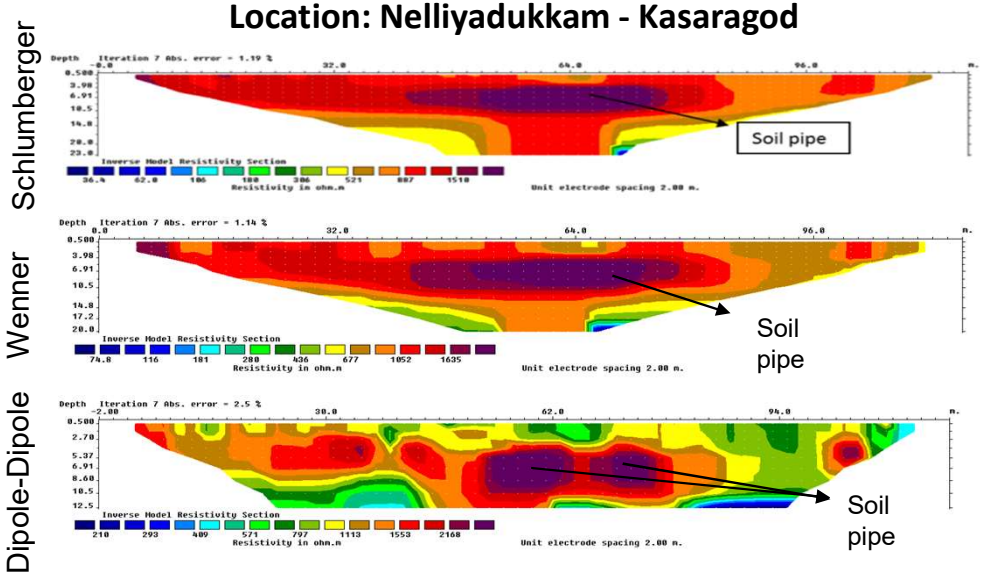
- **They may lie very close to the ground surface or extend several meters below ground.**
- **Once initiated they become cumulative with time, the conduits expand due to subsurface erosion leading to roof collapse and subsidence features on surface.**
- **32 locations from Kannur, Kasaragod, Idukki, Wayanad and Coorg districts studied.**
- **Many landslides and lateral spread are observed to be triggered due to water gushing through such pipes in the highlands.**

➢ **Electrical resistivity tomography considered as a best technique to visualize the spatial and temporal variation in the subsurface structures and physical properties of the soil.**

➢ **Soil pipe usually contains air, water or collapsed soil material. Therefore, it would have the different resistivity from the surrounding bed rock, which can be easily detectable by the resistivity survey.**

Electrical Resistivity Tomography (ERT technique)

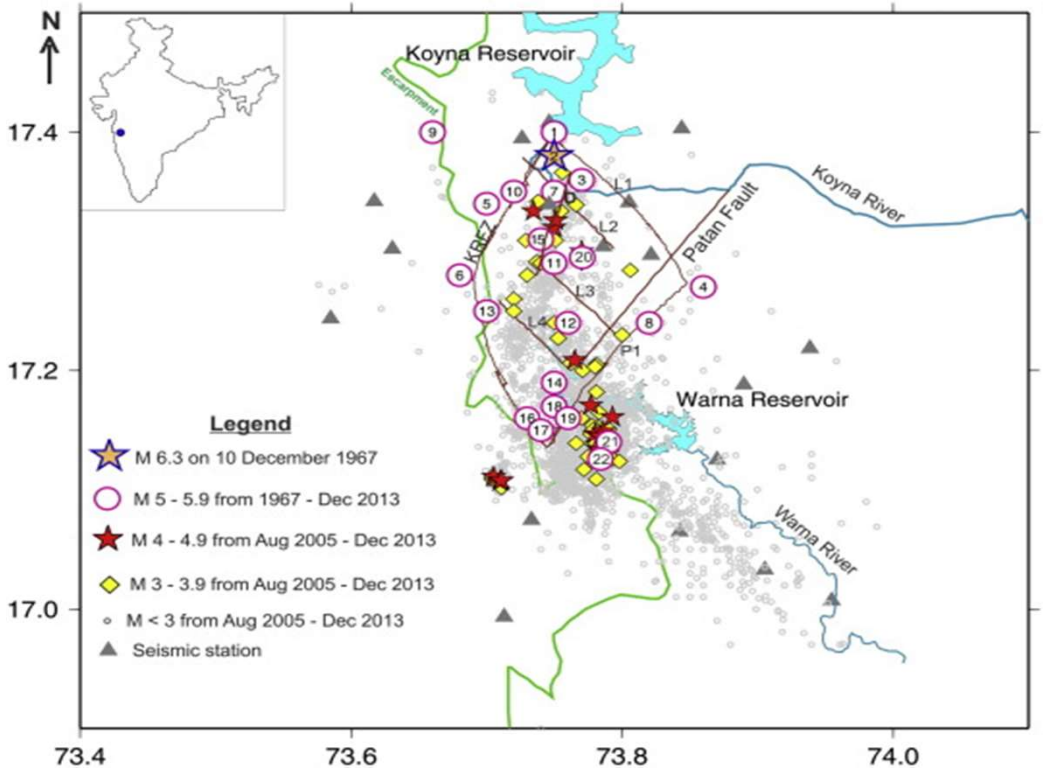
Location: Nelliyadukkam - Kasaragod

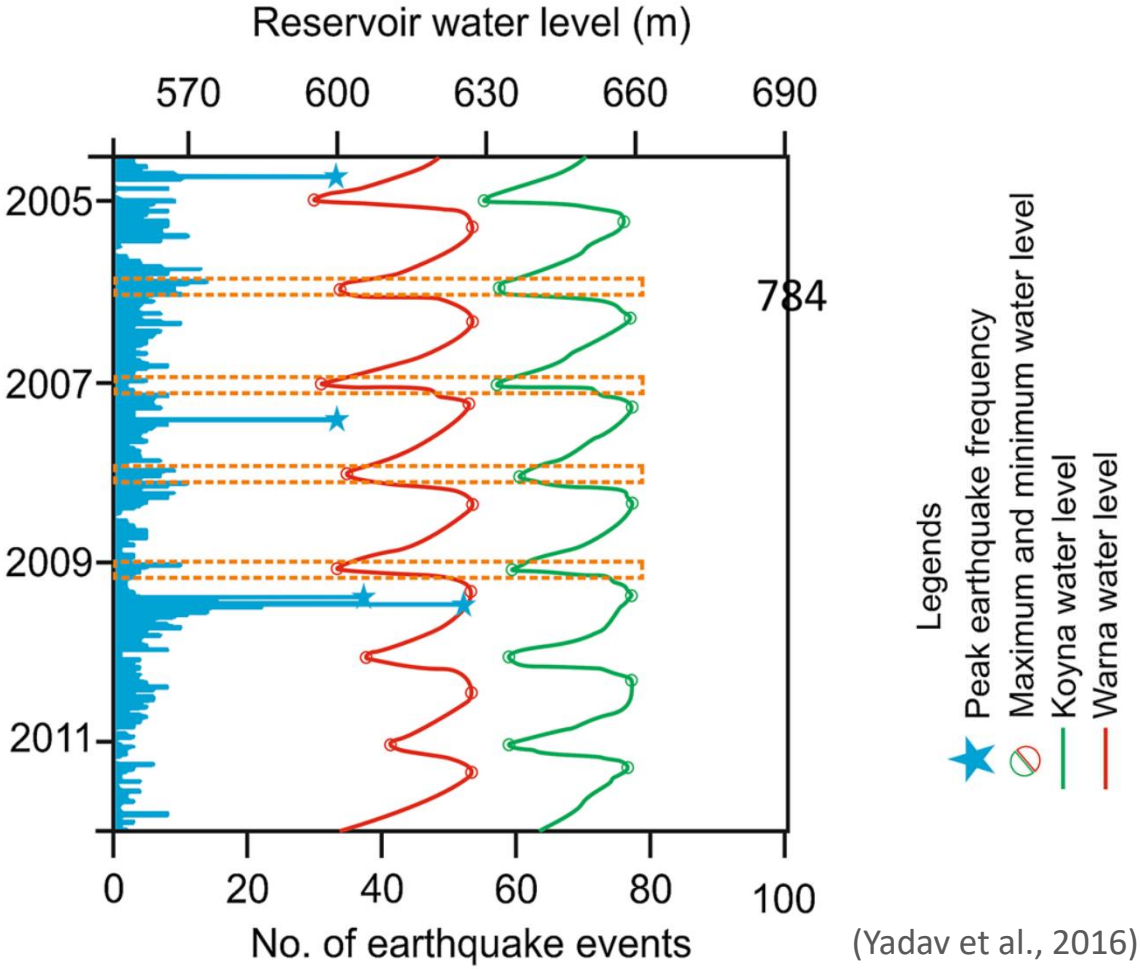


Estimated Depth: 23 m

Intra-Plate Earthquakes along the Western Ghats

Koyna Region



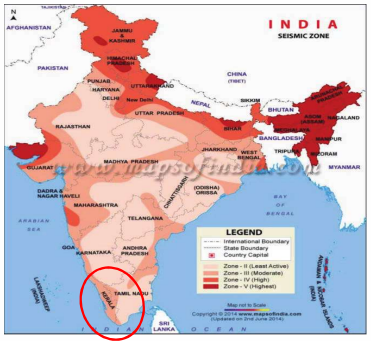


(Yadav et al., 2016)

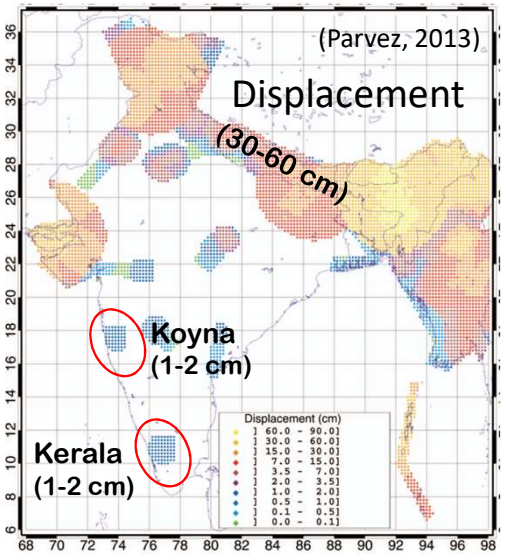
Koyna River Fault Zone
Donachiwada Fault, Patan Fault & L1, L2…NW-SE trending Fractures!

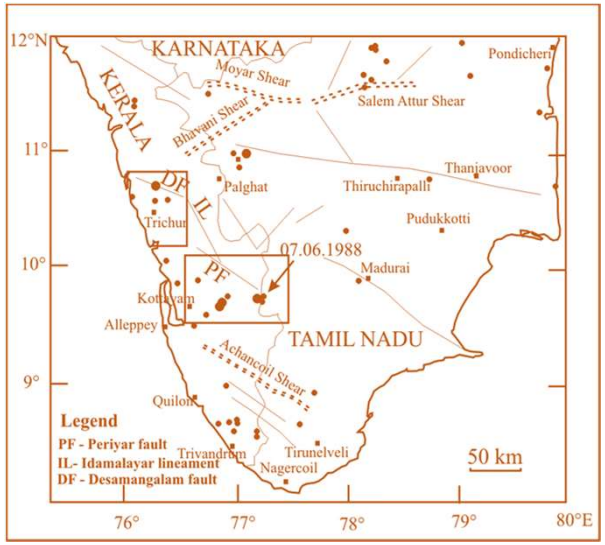
Example for Reservoir Triggered Seismicity – Intra-Plate

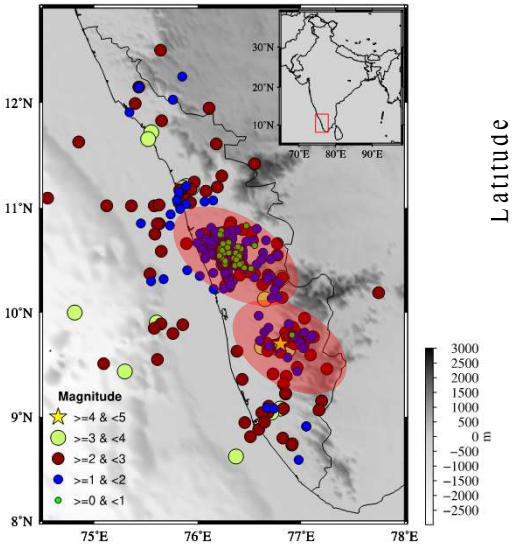
Kerala Region – Seismically Active?

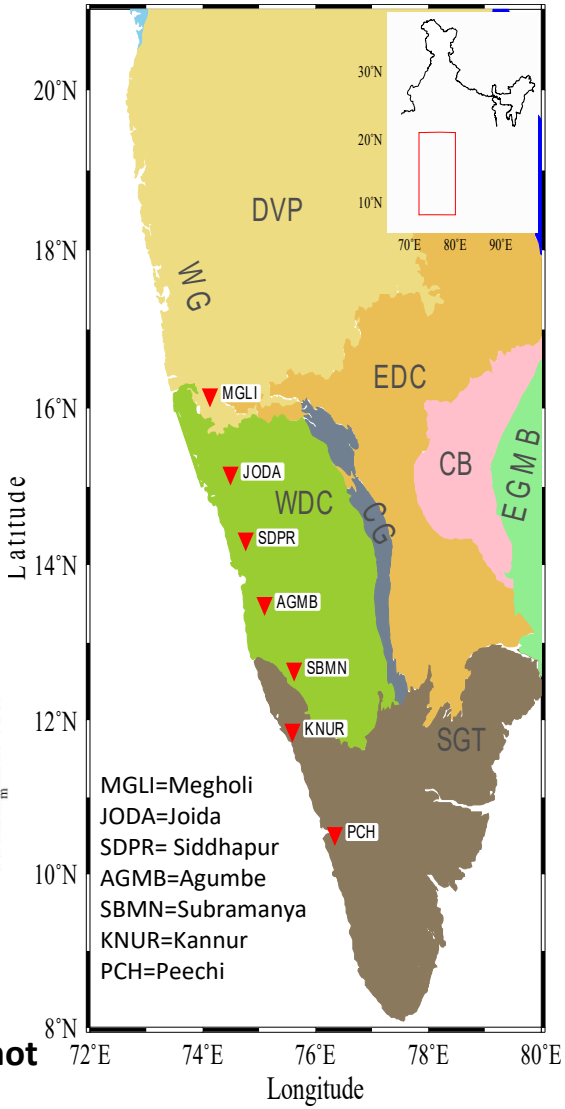


1. **Western terminus of Palghat Gap (Desamangalam Fault - DF)**
2. **Periyar Fault (PF)**



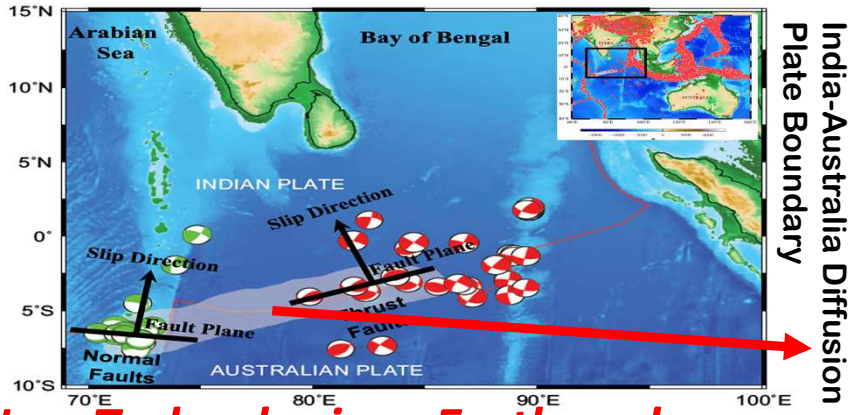






- ❑ **Geologic evaluation in the area of DF suggests it can produce a magnitude greater than 6**
- ❑ **Evidence for repeated activity (PF)**
- ❑ **Earthquake & landslides risk minimization: Required to disclose whether homes are in a fault zone or not**
- ❑ **Natural resources and hazard determination**

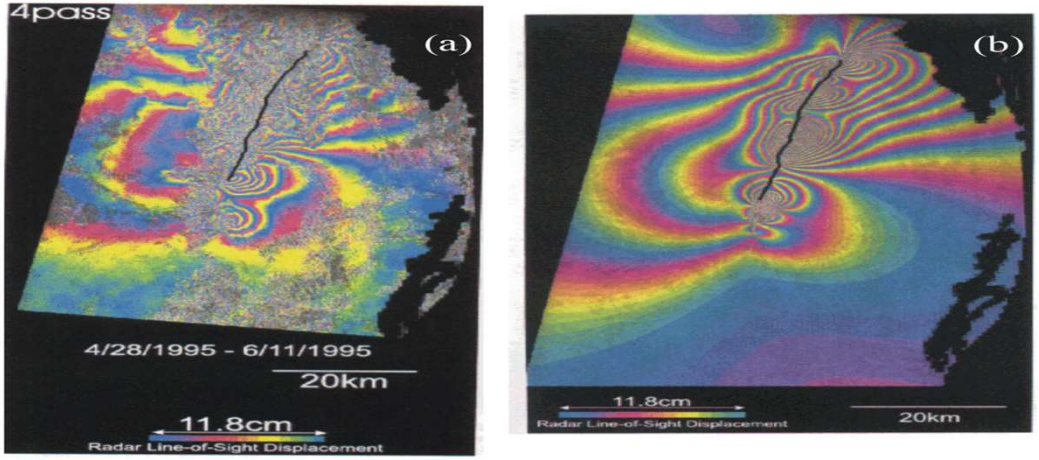
Threat of New Tsunamigenic Zone - Southern India



New Technologies - Earthquakes

InSAR

- The InSAR technique is used to quantify the deformations associated with earthquakes.



Example of ground deformations induced by the Neftegorsk earthquake (M = 7.6, 28 May 1995, Sakhalin, Russia). (a) Radar interferogram. (b) Deformation model prediction.

Implementation of AI/ML

- It is essential to explore the seismological data sets using AI/ML techniques, which will help in understanding the precursory signals, which are hidden in the large data sets.

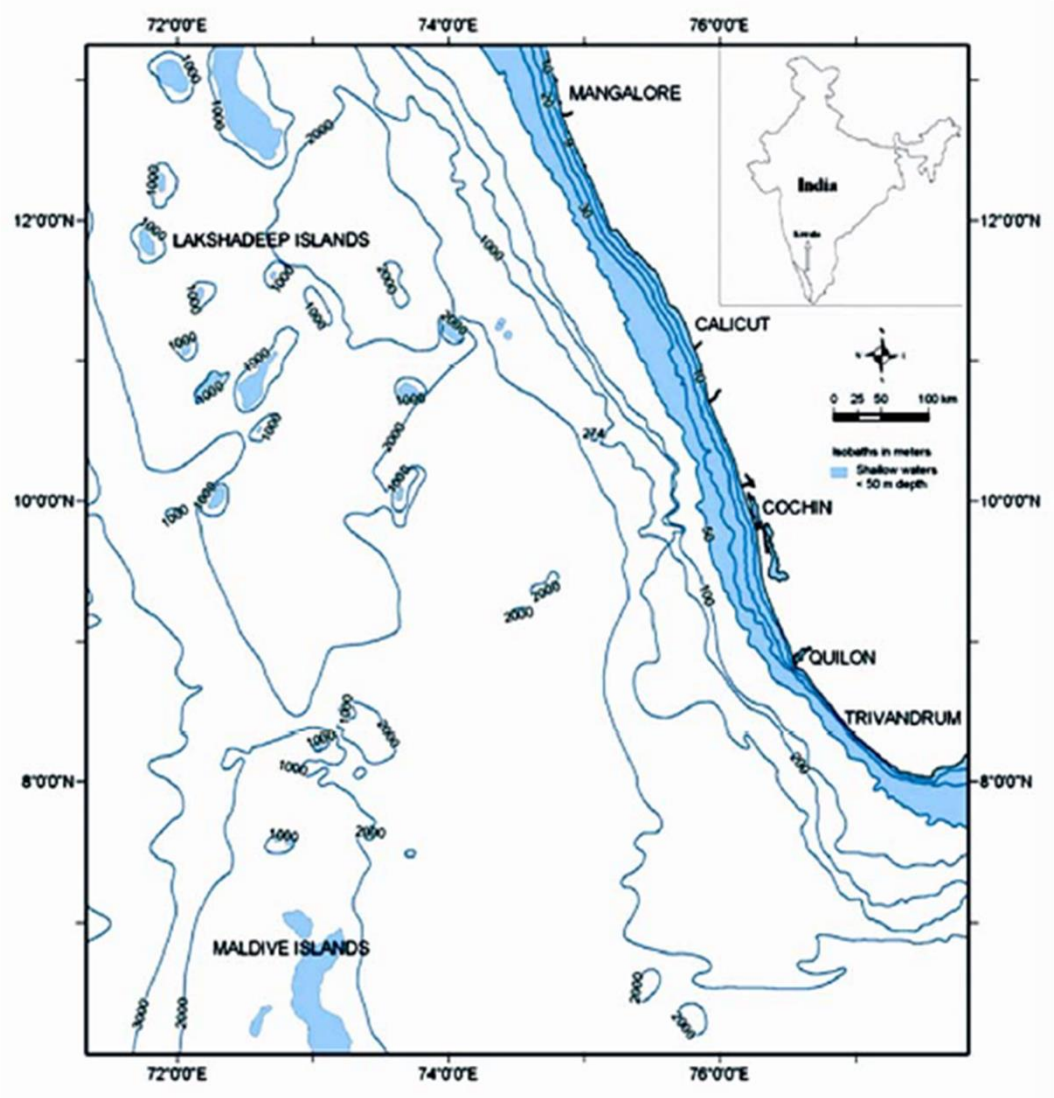
Satellite Data

- Utilization of satellite based data sets along with the seismological data will help to increase the lateral resolution of deformation and in understanding the earthquakes.

The December 2004 Tsunami

- **The 26 December, 2004 Tsunami generated by the M9.3 Sumatra-Andaman earthquake devastated many parts of the Kerala coast, even though they are located in the shadow zone which is part of the SW coast pf India**
- **Nearly 200 people killed and hundreds injured**
- **Coastal length affected : 250 km**
- **Water penetration into mainland : 0.5 to 1.5 km**
- **Average height of Tsunami wave : 3-5m**
- **Human lives lost: Kollam district – 131; Alappuzha district – 35; and Ernakulam – 5**
- **Number of villages affected : 187**
- **Population affected : 1.3 million**
- **Dwelling units lost or damaged : 17,381**

Kerala coast and the southeastern Arabian Sea- the complex bathymetry of the sea due to the Lakshadweep and the Maldives group of Islands

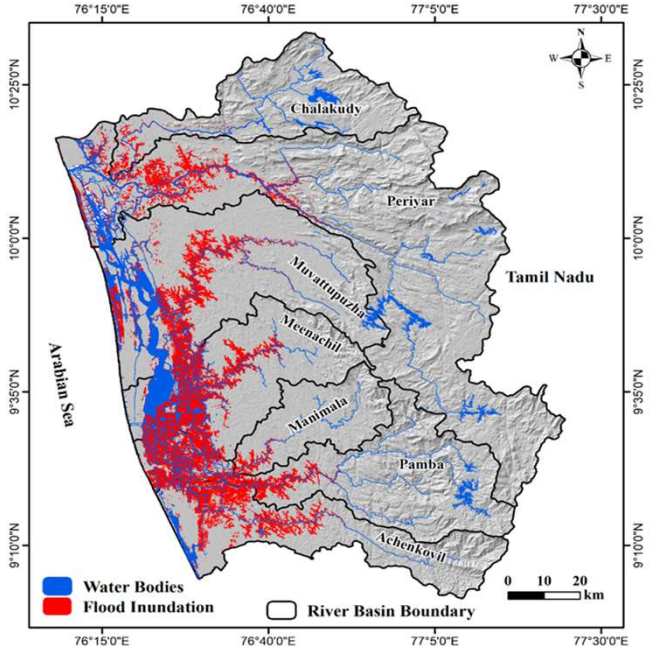


Arrival of 4 sets of waves identified

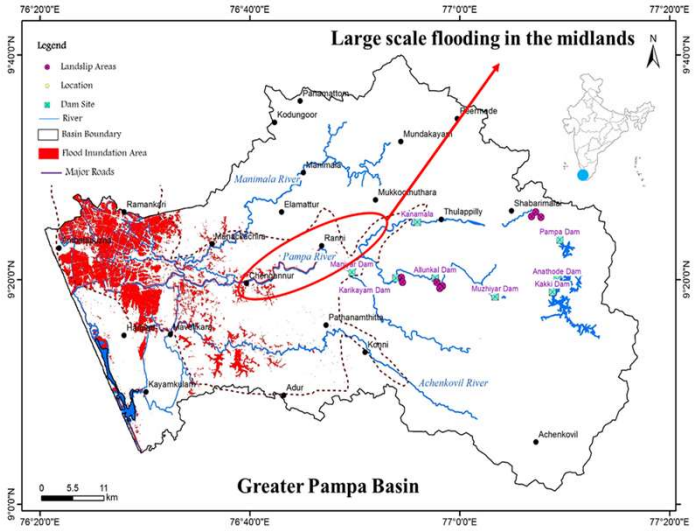
- **First set of waves** - direct waves travelling by multiple paths, subject to all local shallow water effects, such as diffraction, refraction, scattering and local resonances (and dissipation).
- **Second set of waves** -based on the arrival times is explained as reflection from the east side of the Lakshadweep-Maldive Ridge (LMR) and the east coast of Africa
- **Waves that arrived beyond the late hours** of 26th December 2004 cannot be explained as reflected waves , even invoking multiple path hypothesis
- TAD MURTY (Canada) identified a **single crest** (like a solitary wave) whose amplitude was the second highest (after the direct waves) in the tide gauge record at Neendakara, however this was not evident for Cochin. This is attributed to a succession of total internal reflections on the west side of the LMR.

Hydroclimatic Hazards in Western Ghats

The state of Kerala experienced an abnormally heavy rainfall from 1st June 2018 to 19th August 2018 with peak downpour during 15 - 17th August, 2018. As per IMD, Kerala received 2346.6 mm of rainfall during this period as against the expected rainfall of 1649.5 mm. More than 1.08 million people were displaced, 384 deaths were reported, 50,000 houses were partially or wholly damaged in the flood. Flooding events recurred in the subsequent years making flood related hazards an annual event.



Flooding events in the low-lands and midlands of Central Kerala



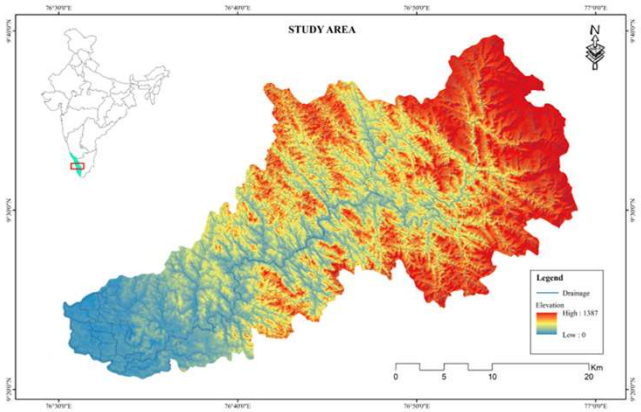
In general, rivers with dams/check dams (Kallada, Pampa, Manimala, Menachil) exhibited higher flood levels than undammed rivers (Ithikkara, Achankovil, Vamanapuram).

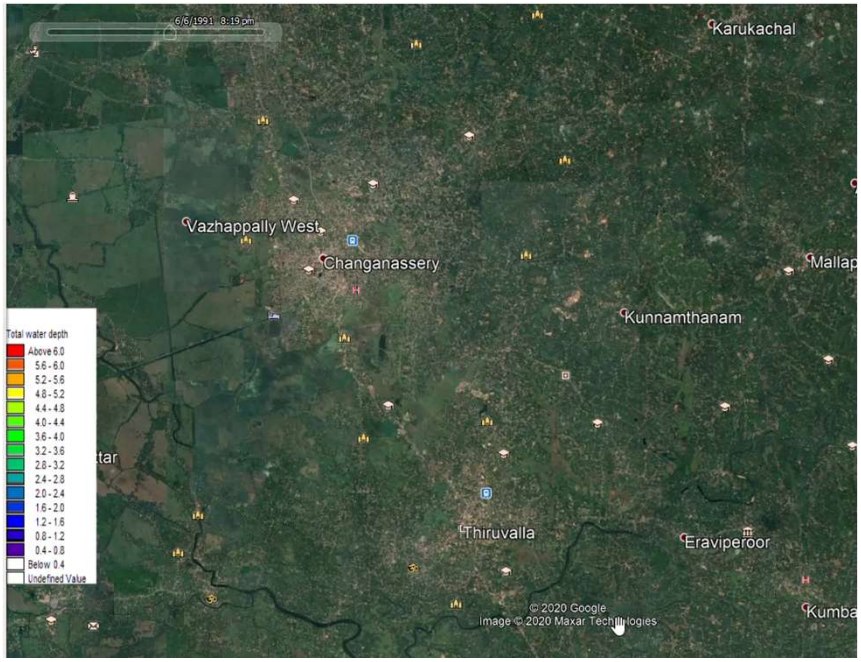
Urban flooding and Riverine Flooding

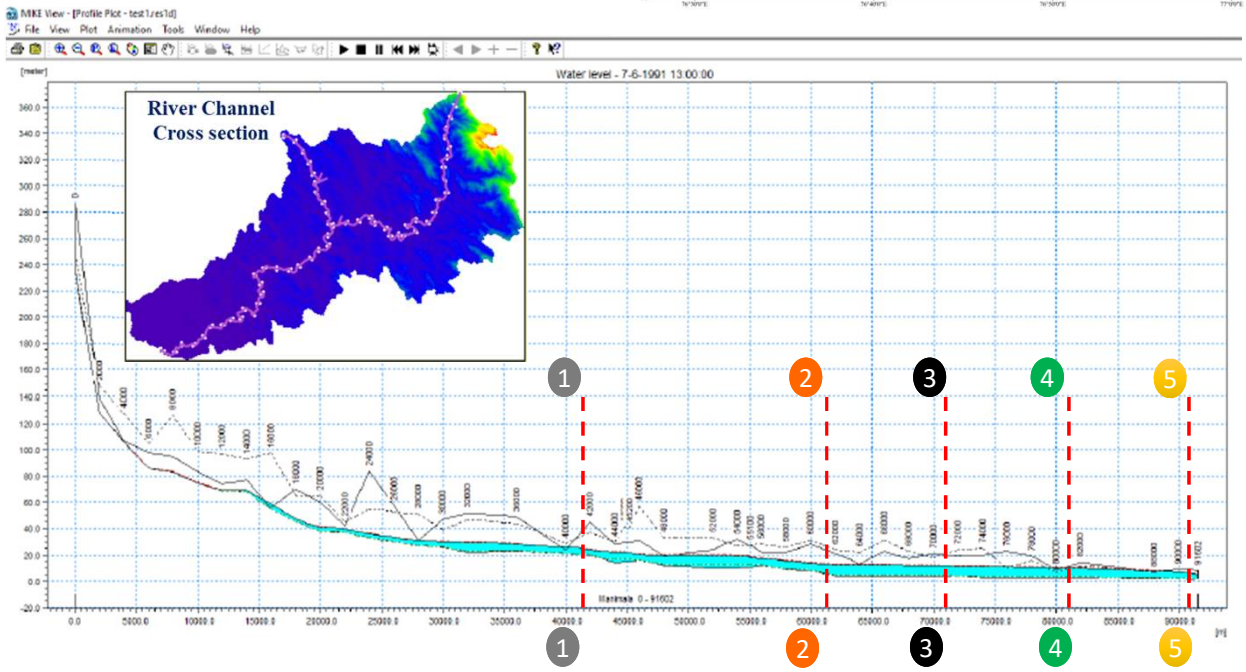
Flood Modelling: Case Study – Manimala River Basin

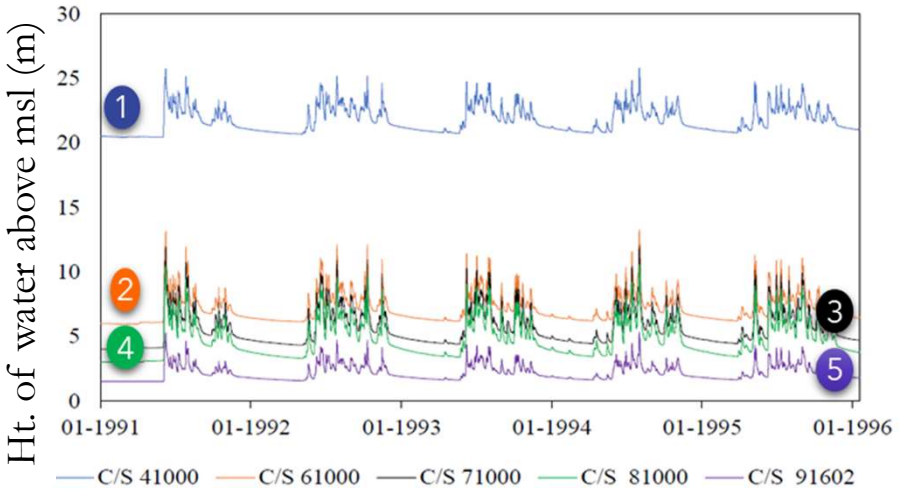
Modelling Tool: MIKE FLOOD

- River channel cross section generated at every 1 km using high resolution (5 m) DEM
- Additional cross sections at engineering structures and branch connections

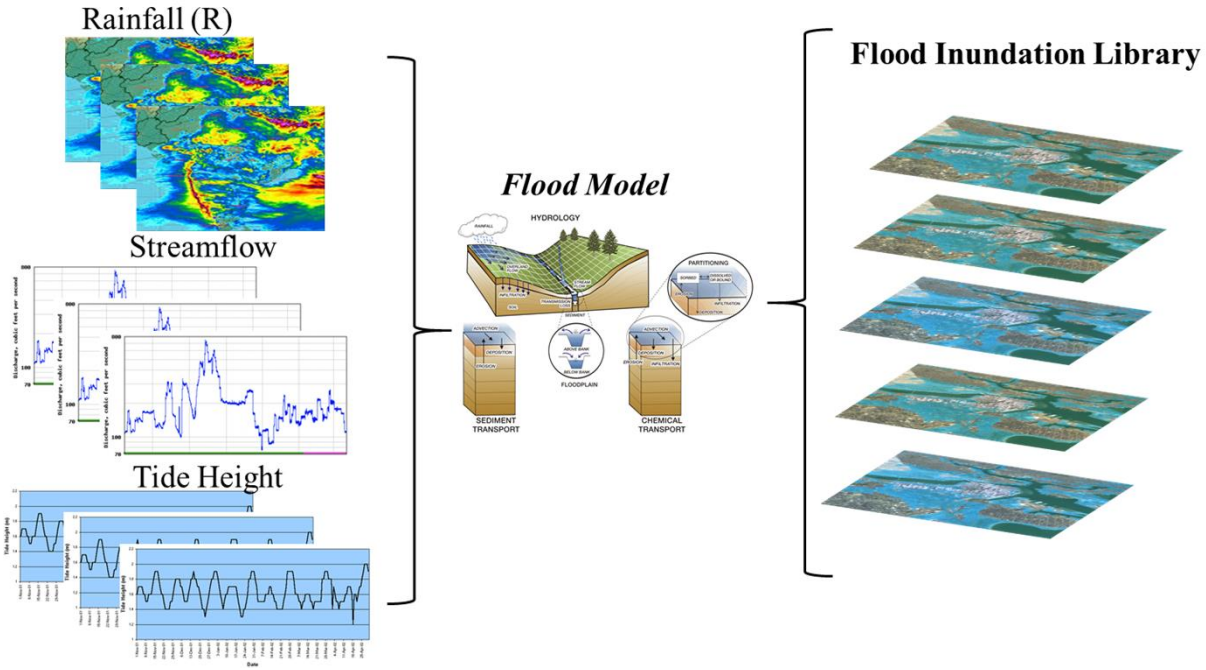






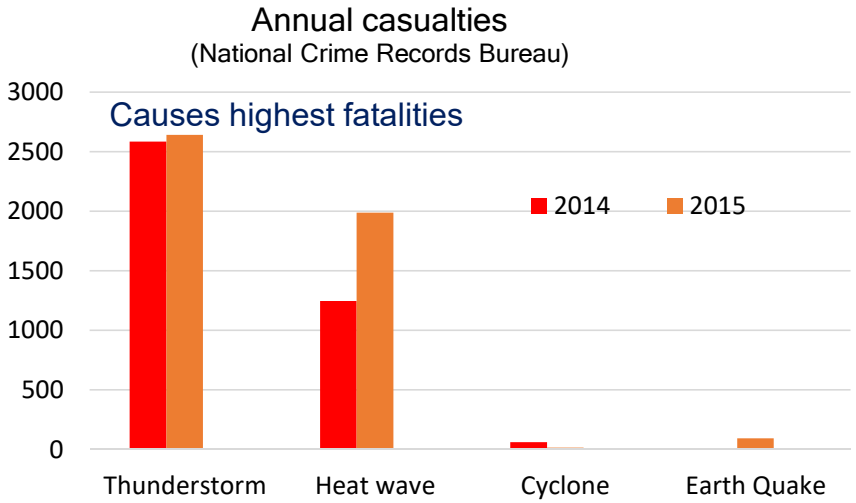


Challenges in flood studies



- **Interstate rivers**
- **Interbasin Water transfer**
- **Intrabasin Water transfer**
- **Dams**
- **Check Dams**
- **Sand Mining - Valley widening and deepening (5-20 cm/year)**
- **Bed materials characteristics/ Sediment dispersal pattern**

Lightning and thunderstorms

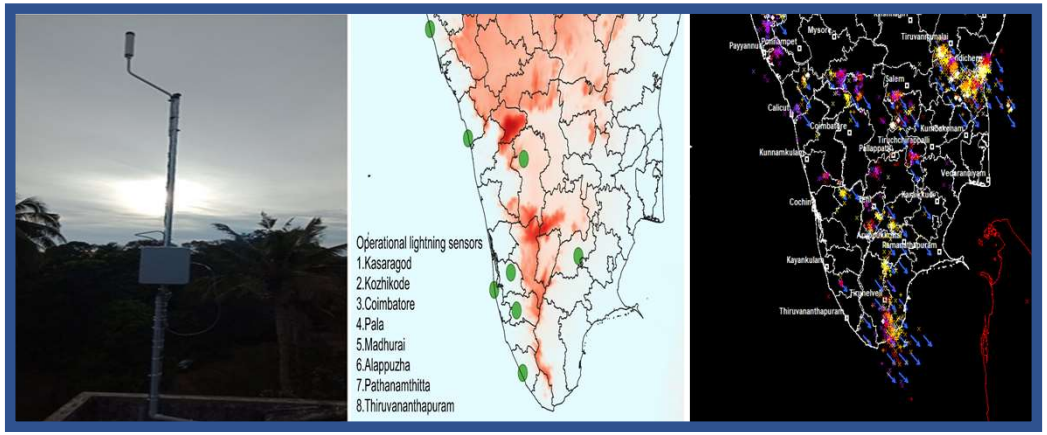


Source: National Crime Records Bureau(NCMRB) [2016]

- **A deadly natural phenomenon, lightning is simply a sudden, electrostatic discharge - a 'spark' or 'flash' as charged atmospheric regions temporarily equalize themselves through this discharge.**
- **Lightning can strike the ground, the air, or inside clouds, but there are roughly 5 to 10 times more cloud flashes than cloud-to-ground flashes.**
- **Among the natural hazards, lightning and thunderstorms caused around 110 deaths in the WG part of Kerala since 2018.**
- **Lightning and thunderstorms can also cause severe damages to agriculture, electric power networks, property and even lead to the occurrence of wildfires.**

NCESS Lightning and thunderstorm research activities

- Provide continuous observation of lightning activities over a region. NCESS is part of Indian lightning detection network and hosting 8 lightning sensors. **(In collaboration with IITM, Pune).**
- Measure spatial and temporal observation of Inter-cloud, cloud to ground lightning and its real time movement.



Field photograph of sensor installation

Sensor Locations

Realtime lightning activity monitoring and tracking

- Sensors (Earth Networks, USA) provide Realtime lightning throughout the peninsular India with 100 m resolution. Detects both cloud to ground and cloud to cloud lightning.
- Sensors help for Realtime monitoring and nowcasting and aviation weather forecasting

THANK YOU

Space data in Landslide and Earthquake Disaster Management

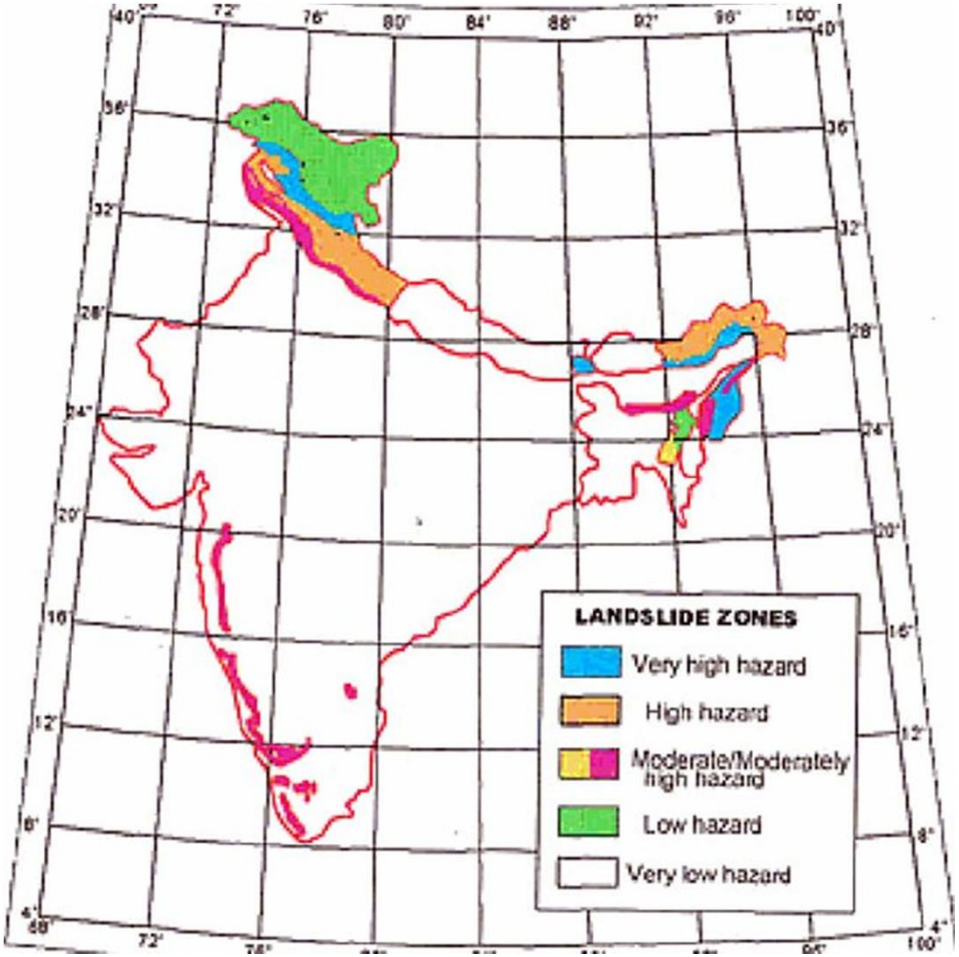
By
Dr. Tapas Ranjan Martha, Scientist-SG
Head, Geohazards and Mineral Exploration Division and
Dy. Project Director, ISRO-DMSP

nrsc

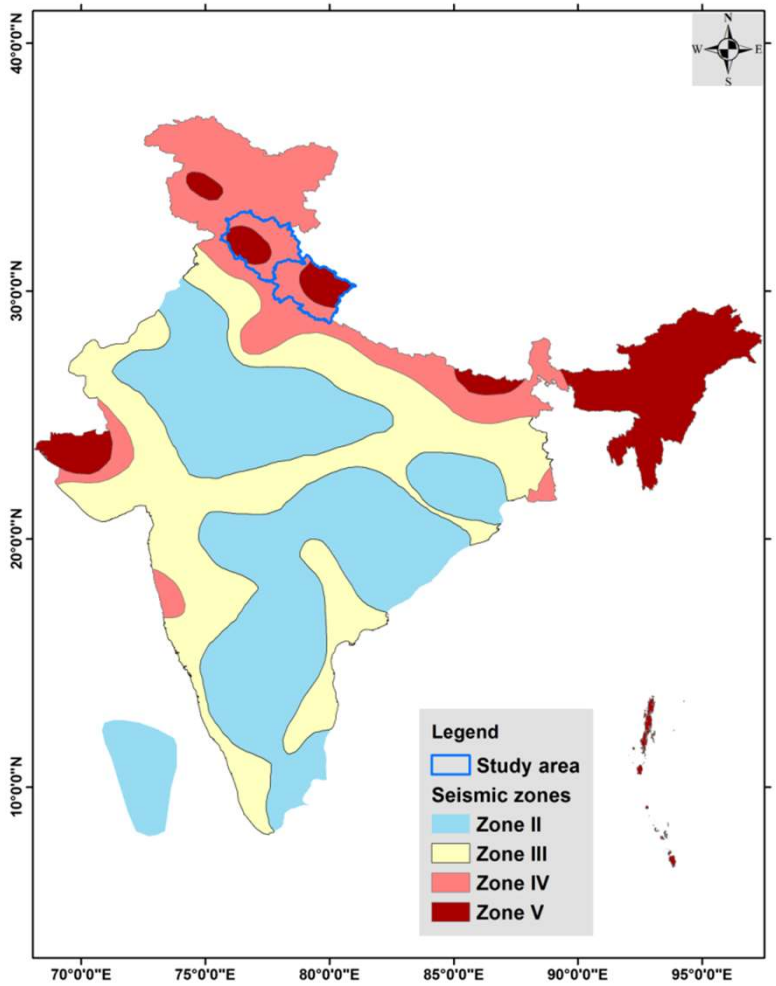
National Remote Sensing Centre
Indian Space Research Organisation
Dept. of Space, Govt. of India
Hyderabad

India on Geohazards

Landslide hazard zonation map of India

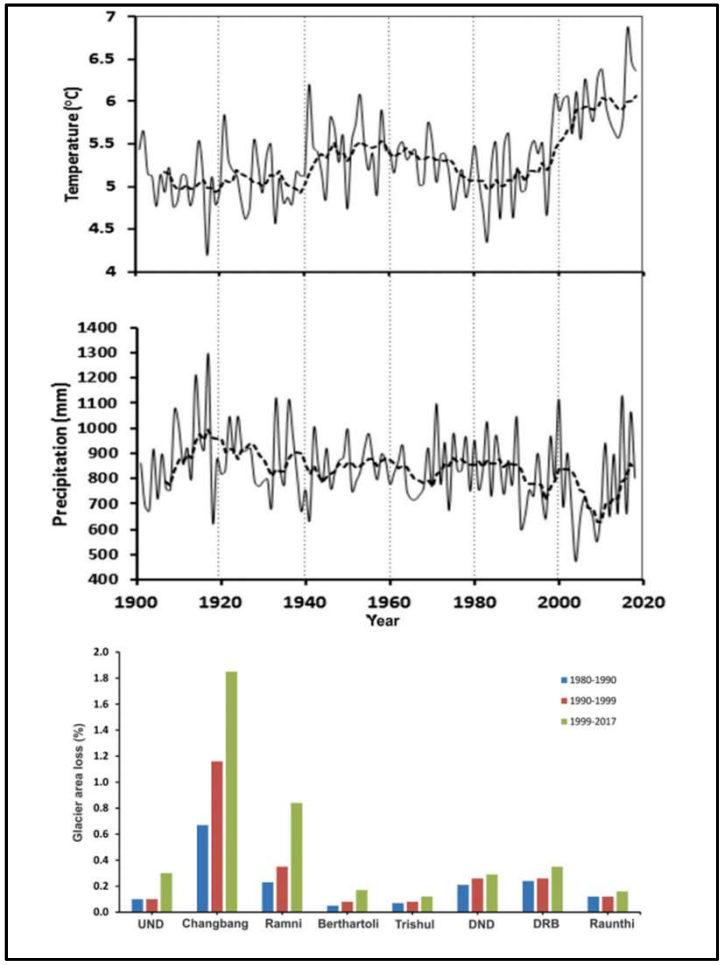


Seismic hazard zonation map of India

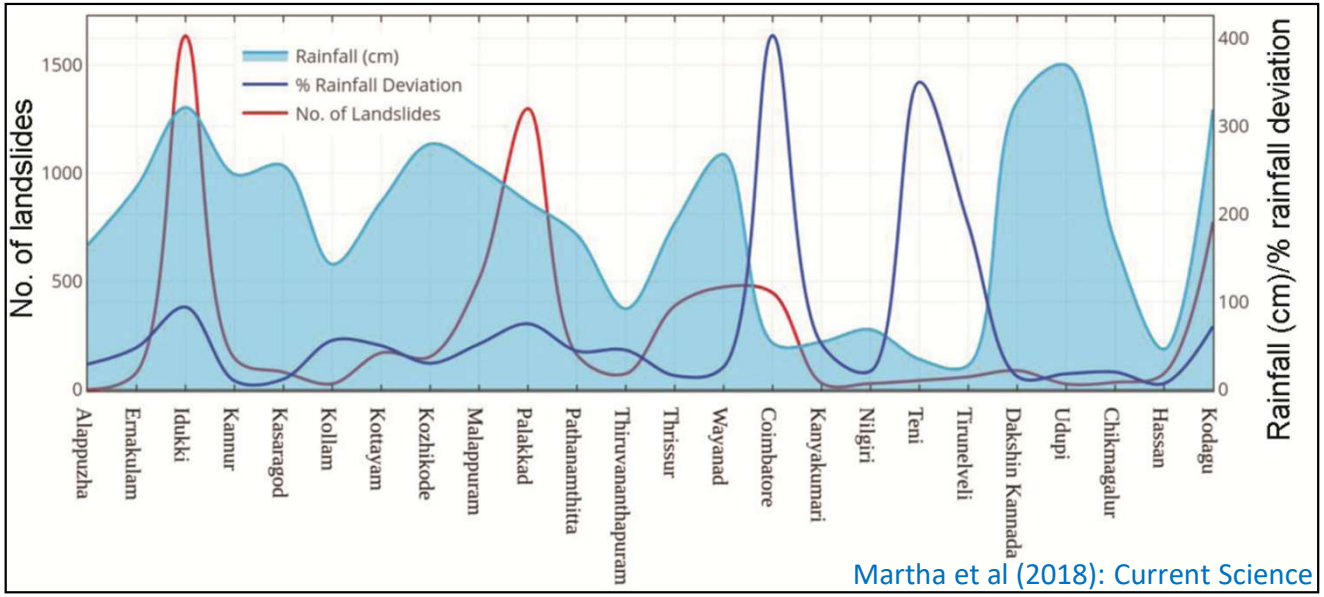


What are drivers of landslides…

Climate Change: Less snow fall, glacier retreat, intense monsoon



Kumar et al (2021): Quaternary international



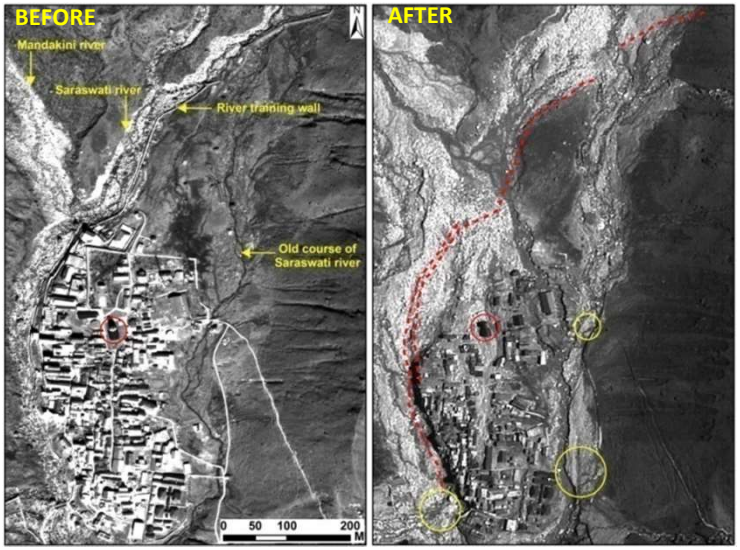
Martha et al (2018): Current Science

Other major causes

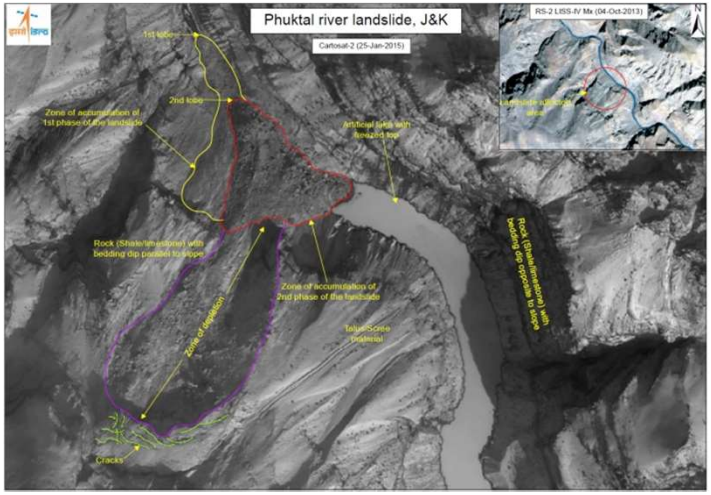
- Geological setup - fragile rocks, tectonic plate boundary and active faults make India more prone landslides and earthquakes
- Anthropogeny – Road expansion, tourism in mountains

Rapid response to landslide disaster

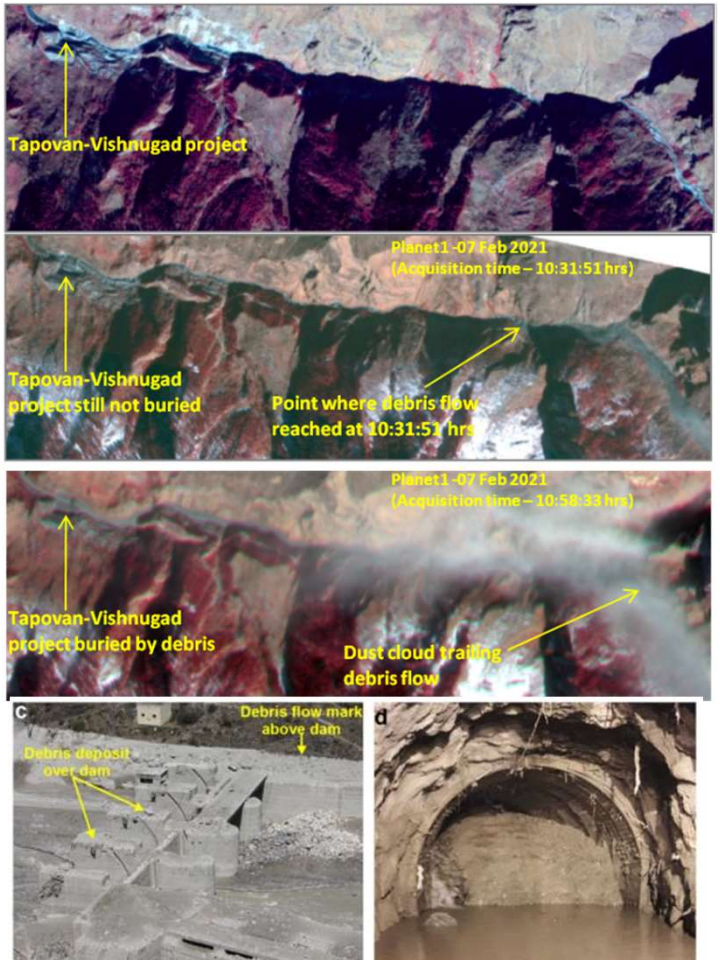
2013 Kedarnath



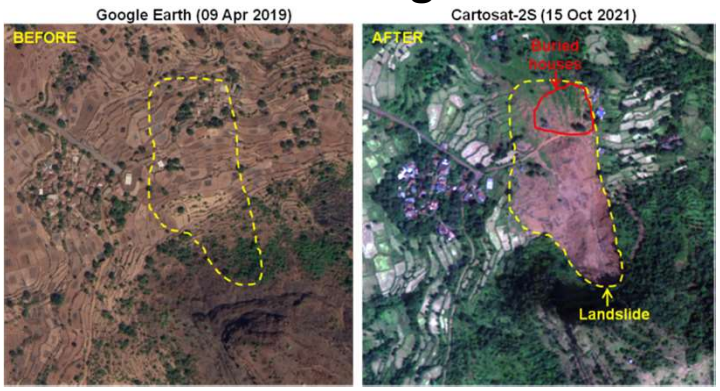
2015 Phuktal river



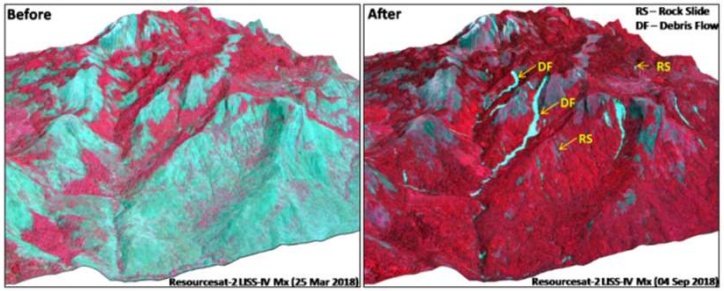
2021 Rishiganga



2021 Raigad

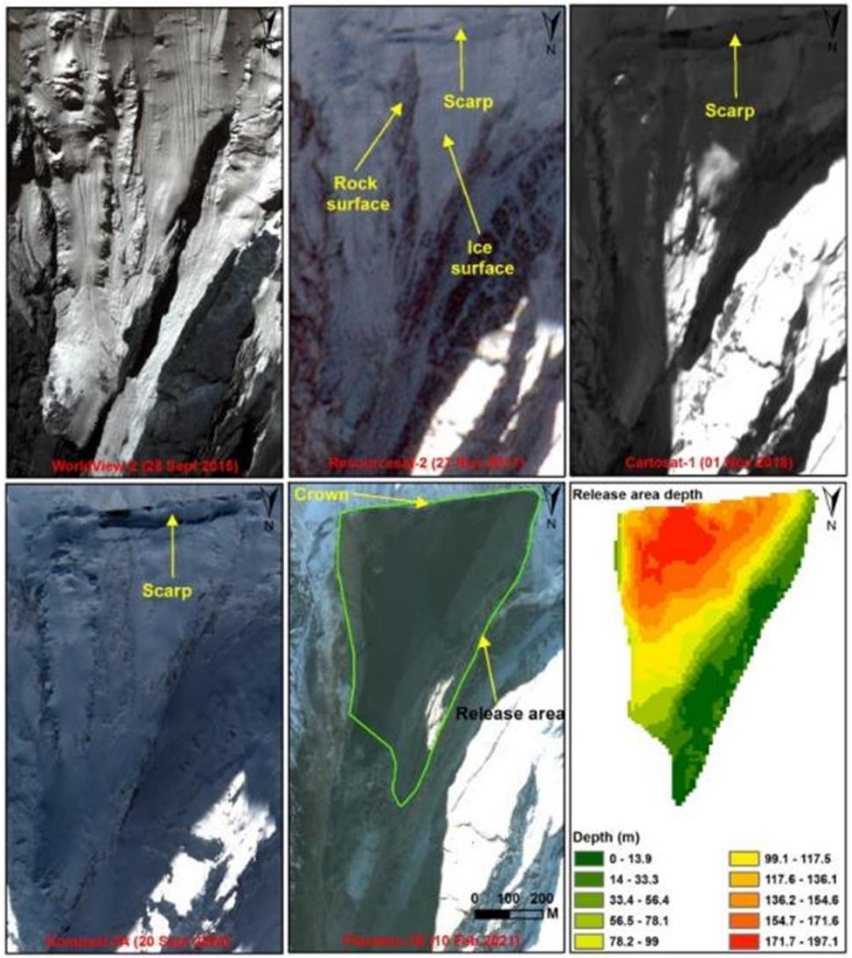


2018 Kerala

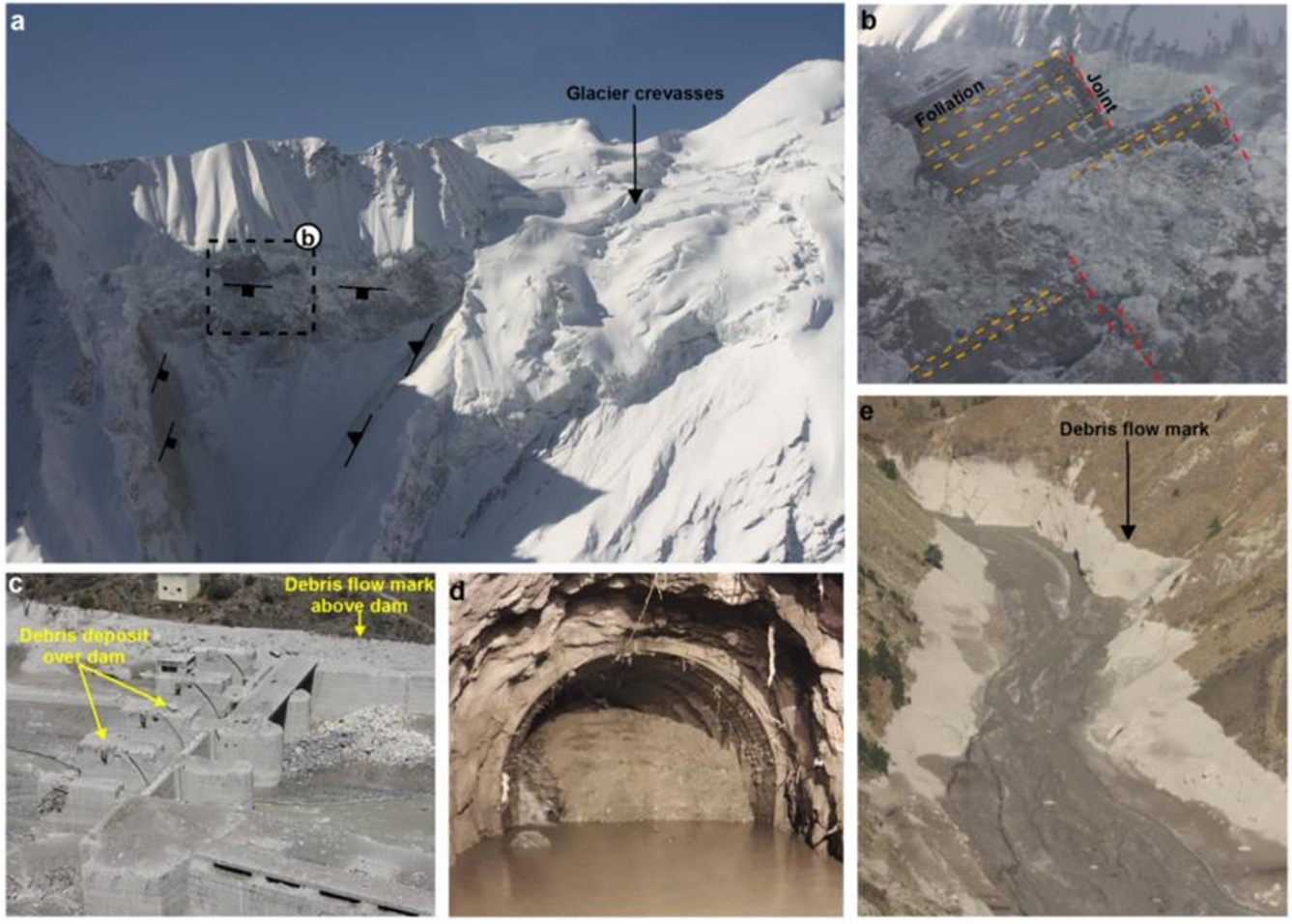


Rishiganga Disaster (07 Feb 2021)

Multi-temporal satellite images

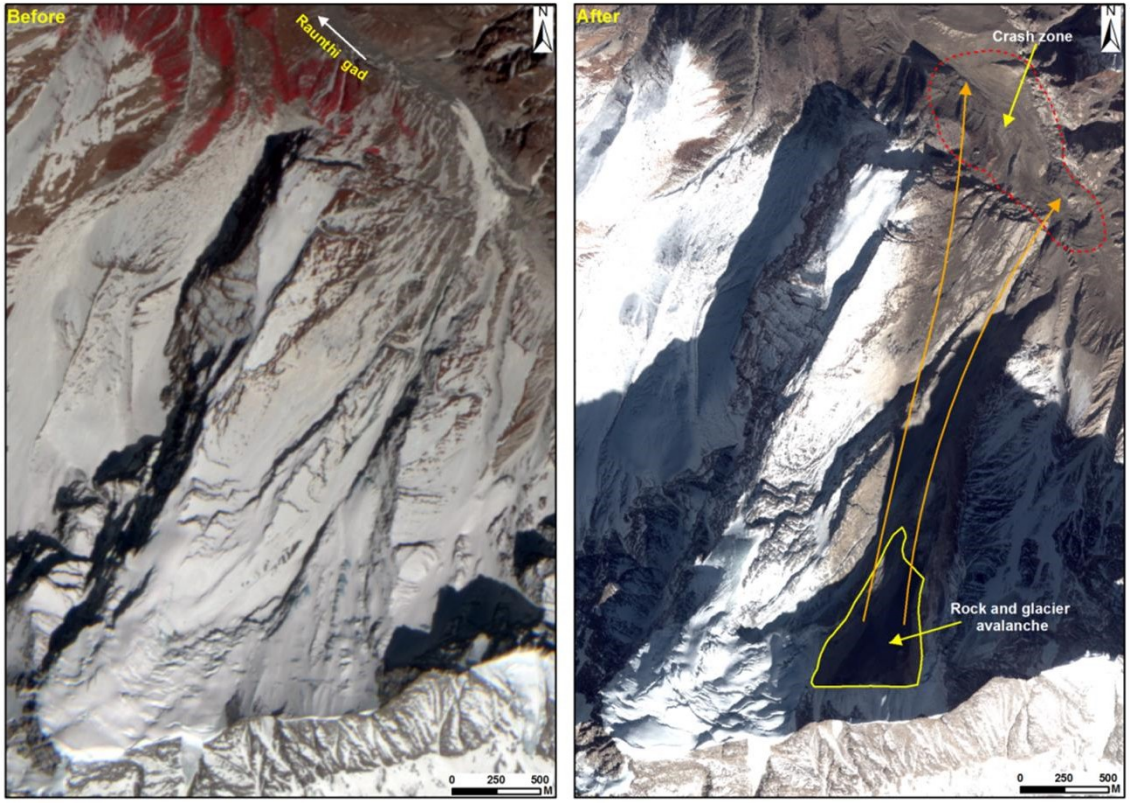


Ground photos

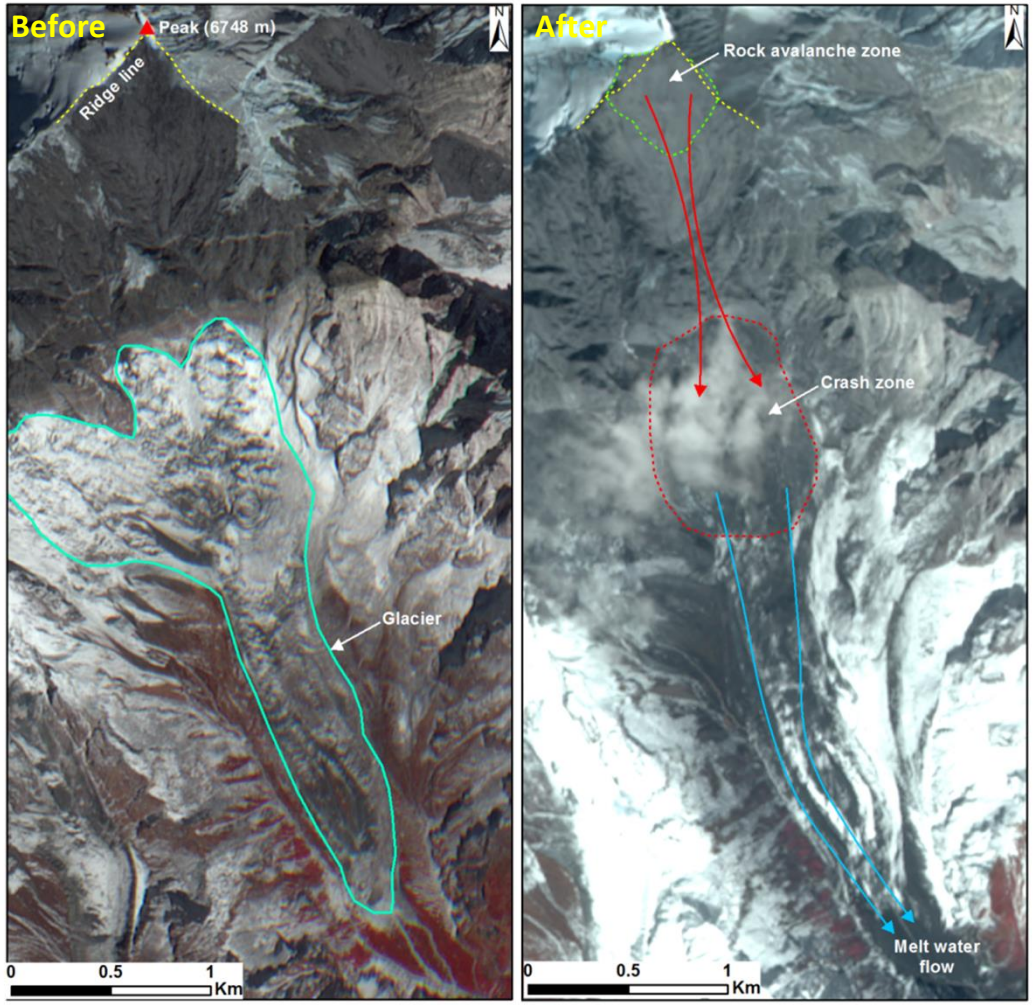


Debris flows in Mountain valleys

Chamoli, Uttarakhand disaster (07 Feb 2021)

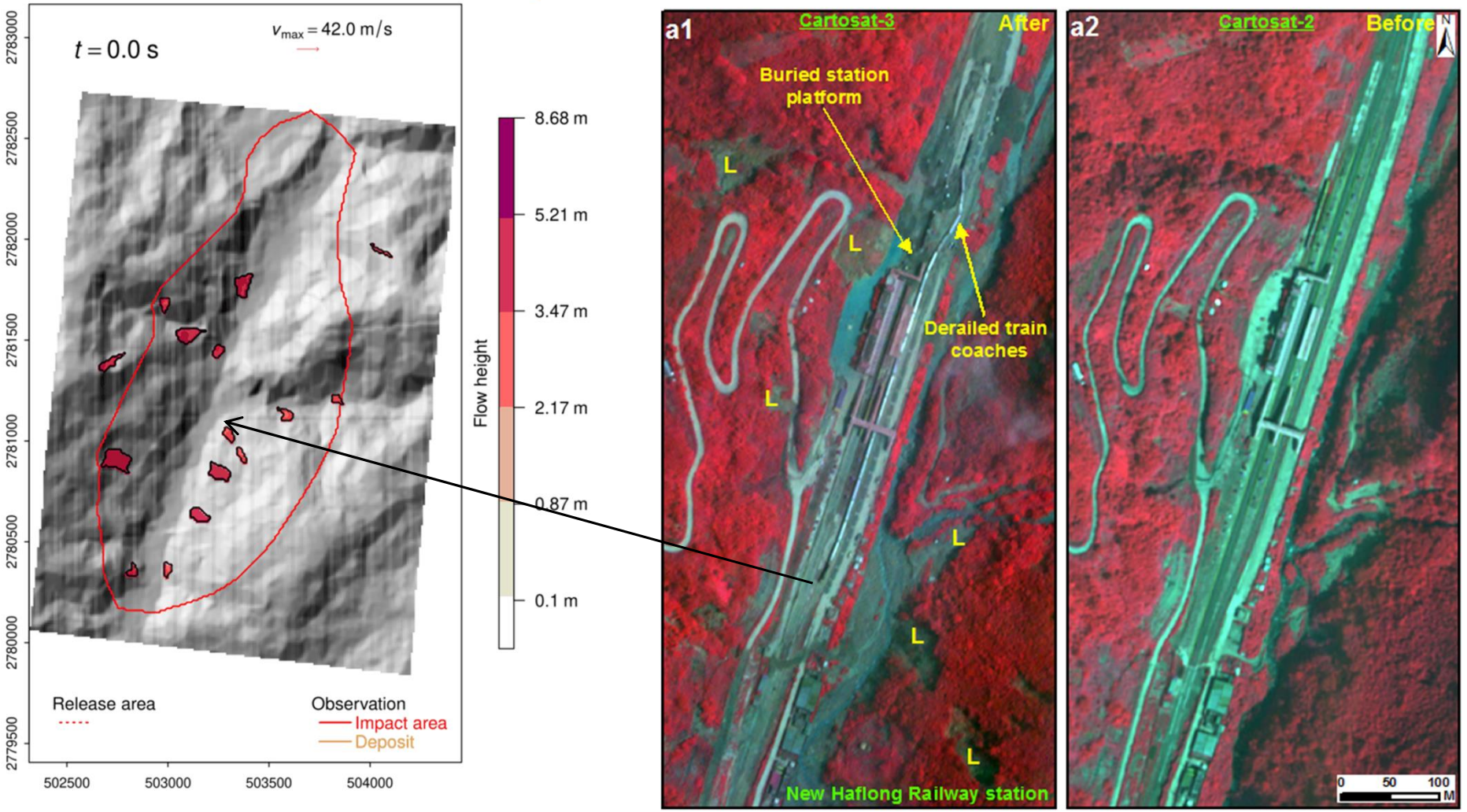


Kameng, Arunachal Pradesh (29 Oct 2021)

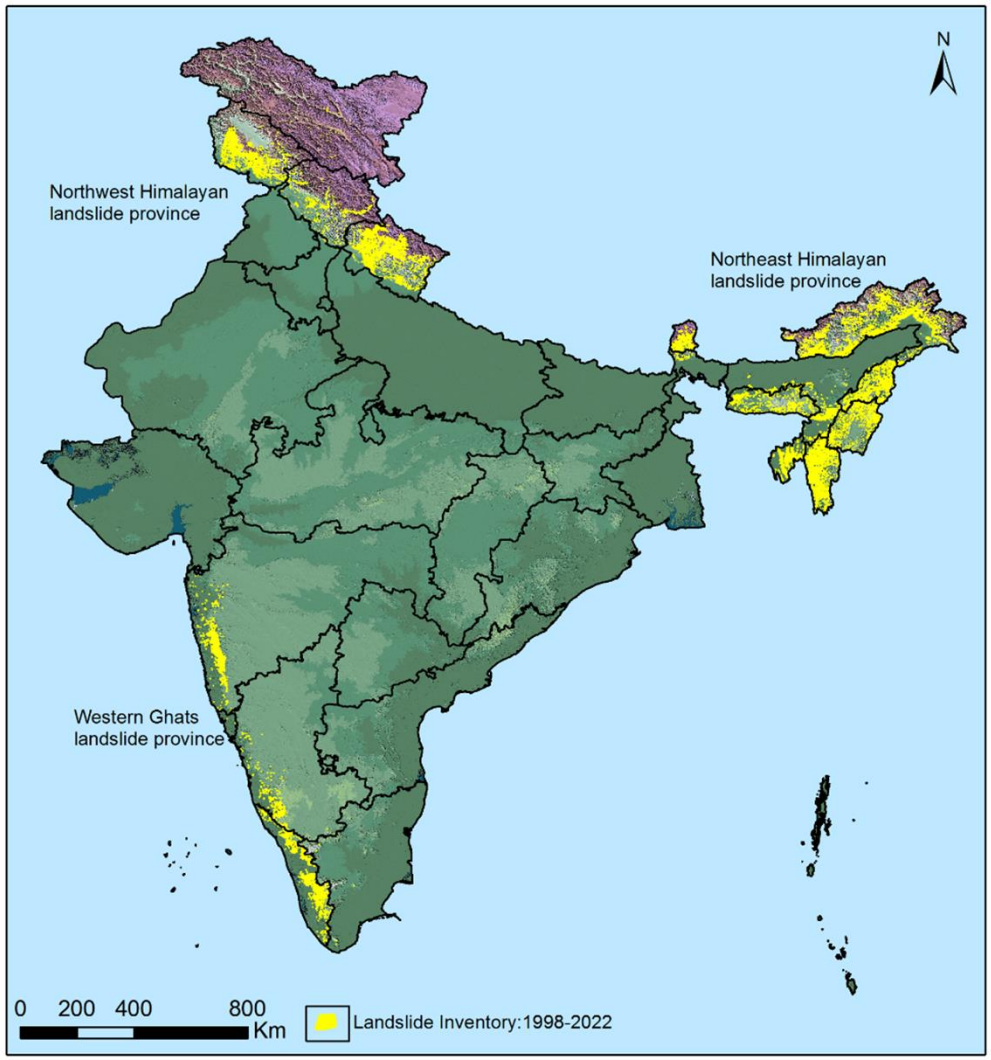


Debris flow in the absence of GLOF and cloudburst.
These are new type events happening in India now.

Debris flow in New Haflong Station, Assam (15 May 2022)

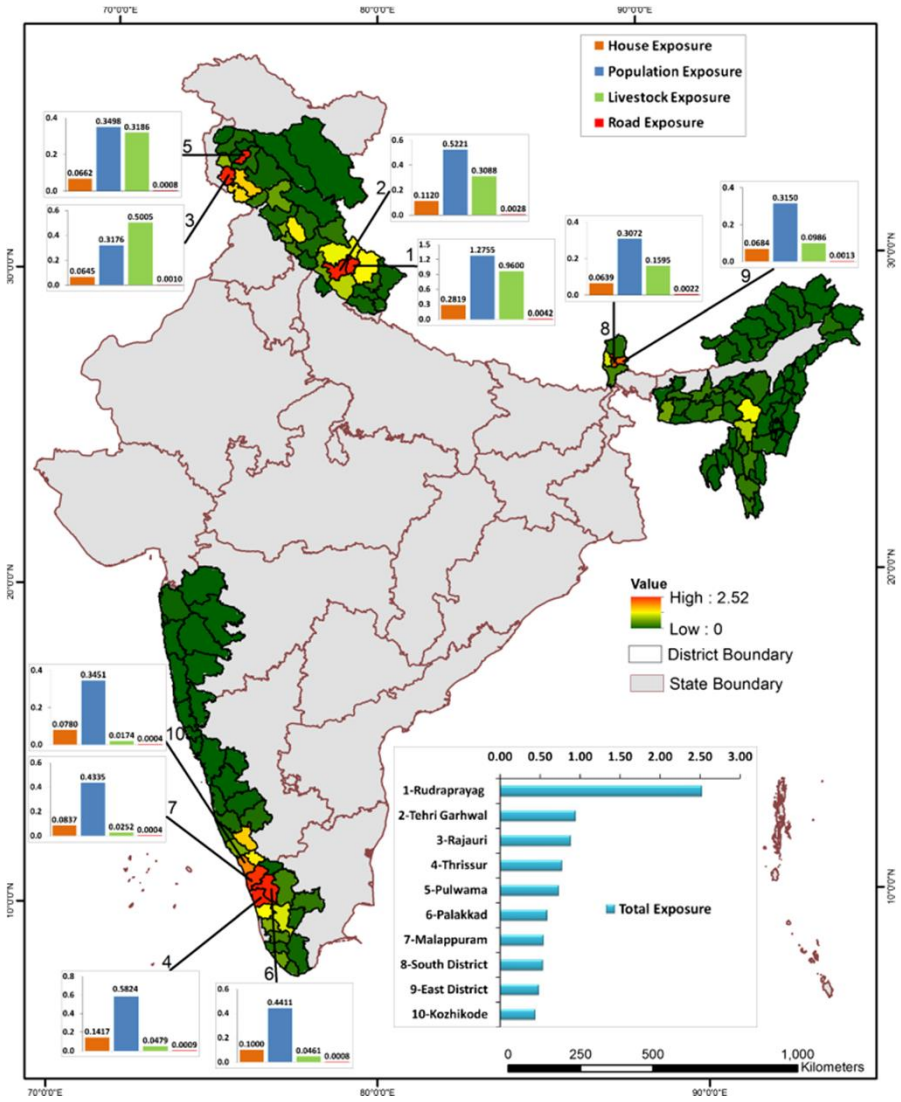


Landslide Inventory of India

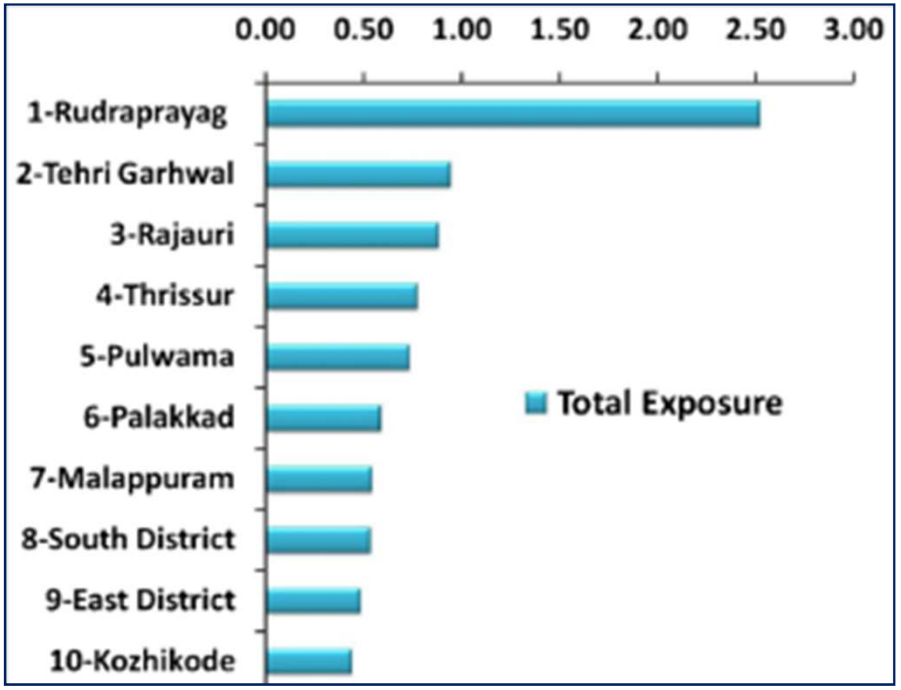


Sl. No.	State/UTs	Monsoon season 2014	Monsoon season 2017	Field-based/year	Event-based / year	Total
1	Jammu and Kashmir	6826	19	434 / 2011	1 / 2015	**7280**
2	Ladakh	23		-	-	**23**
3	Himachal Pradesh	922	172	413 / 1998	1/ 2017 51/2013 2/2021	**1561**
4	Uttarakhand	1593	455	1419 / 1998	32/2003 307/2010 473 / 2012 6610 / 2013 1 / 2017 329/2021 1/2022	**11219**
5	Sikkim	73	79	-	1408 / 2011 8 / 2012 1/ 2016	**1569**
6	West Bengal	24	82	-	66 / 2011	**172**
7	Arunachal Pradesh	2904	4709	-	75 / 2016 1/2021	**7689**
8	Nagaland	54	2071	-	7/2017	**2132**
9	Manipur	379	4559	-	556/2017 1/2022	**5494**
10	Mizoram	1205	2254	-	8926/2017	**12385**
11	Tripura	56	8014	-	-	**8070**
12	Assam	1243	793	-	533/2017 5091/2022	**2569**
13	Meghalaya	2127	512	-	-	**2639**
14	Maharashtra	97	3	-	5012/2021	**5112**
15	Goa	2	1	-	-	**3**
16	Karnataka	82	19	-	993/2018	**1094**
17	Kerala	9	45	-	5191/2018 756/2019 09/2020 29/2021	**6039**
18	Tamil Nadu	79	8	-	603/2018	**690**
19	Haryana	-	100	-	-	**100**
	Total	**17,698**	**23,895**	**2,266**	**37,074**	**80933**

District-wise landslide exposure ranking



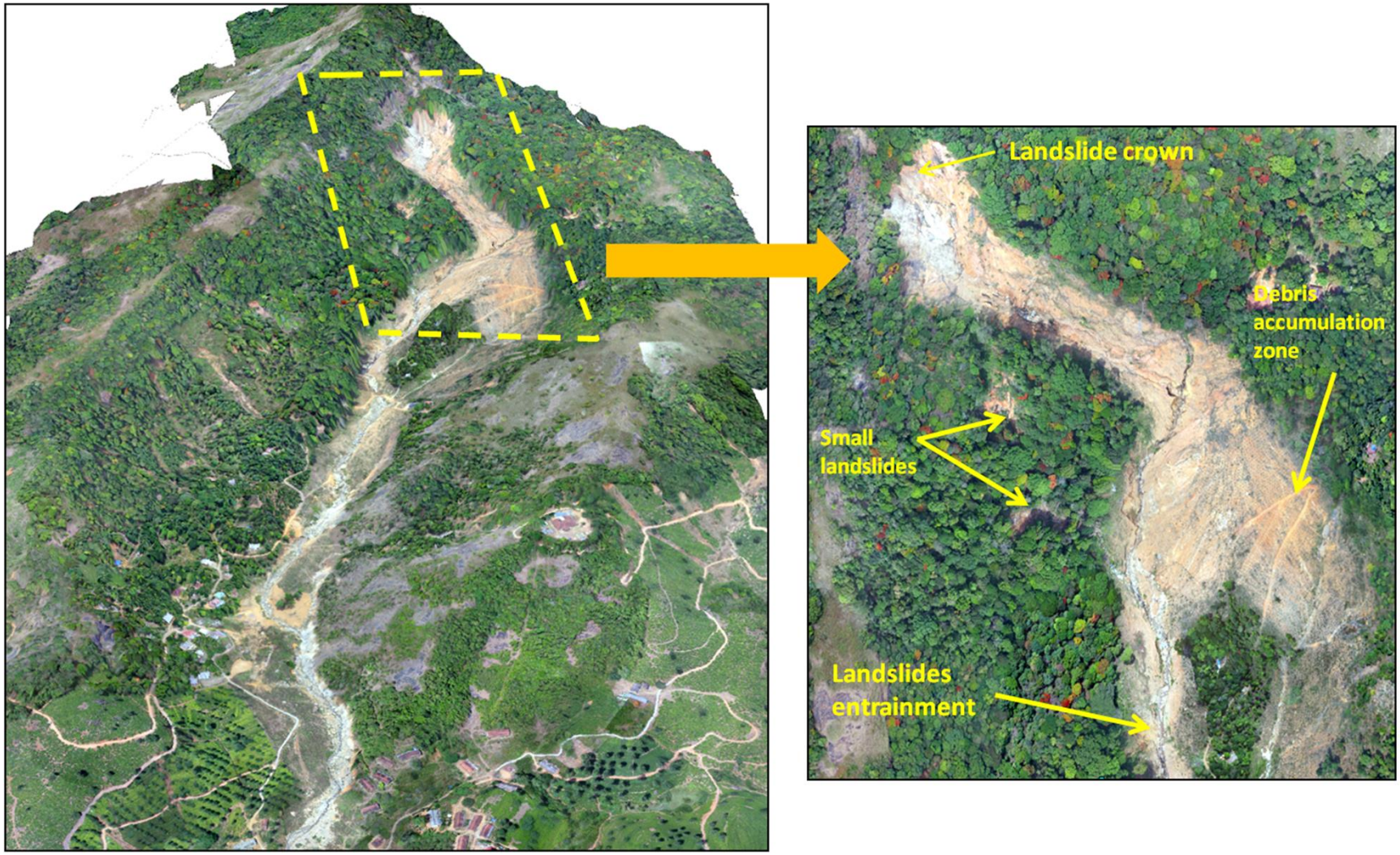
Top 10 landslide prone districts



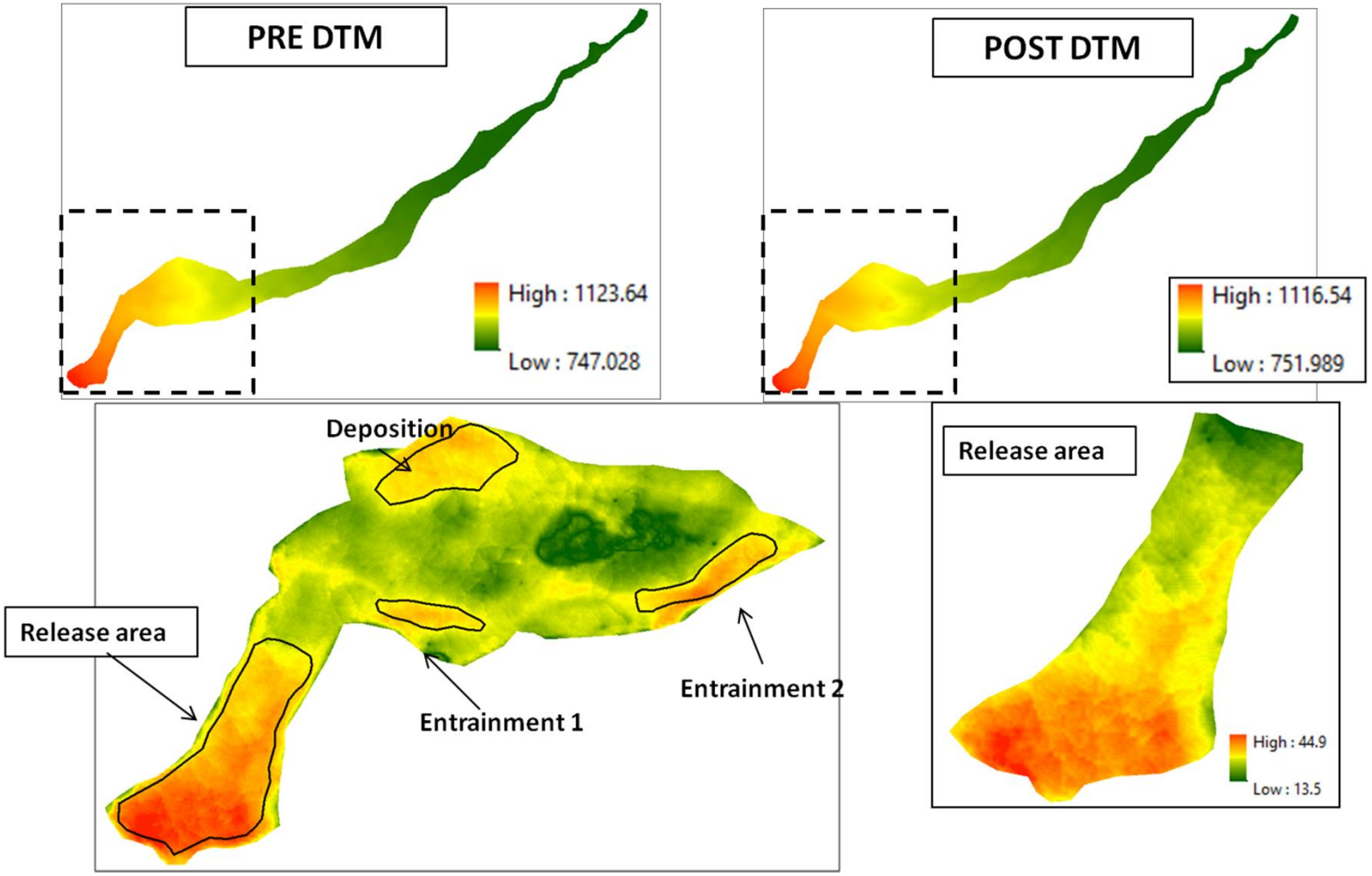
Total 147 districts

Martha et al (2021): Landslides

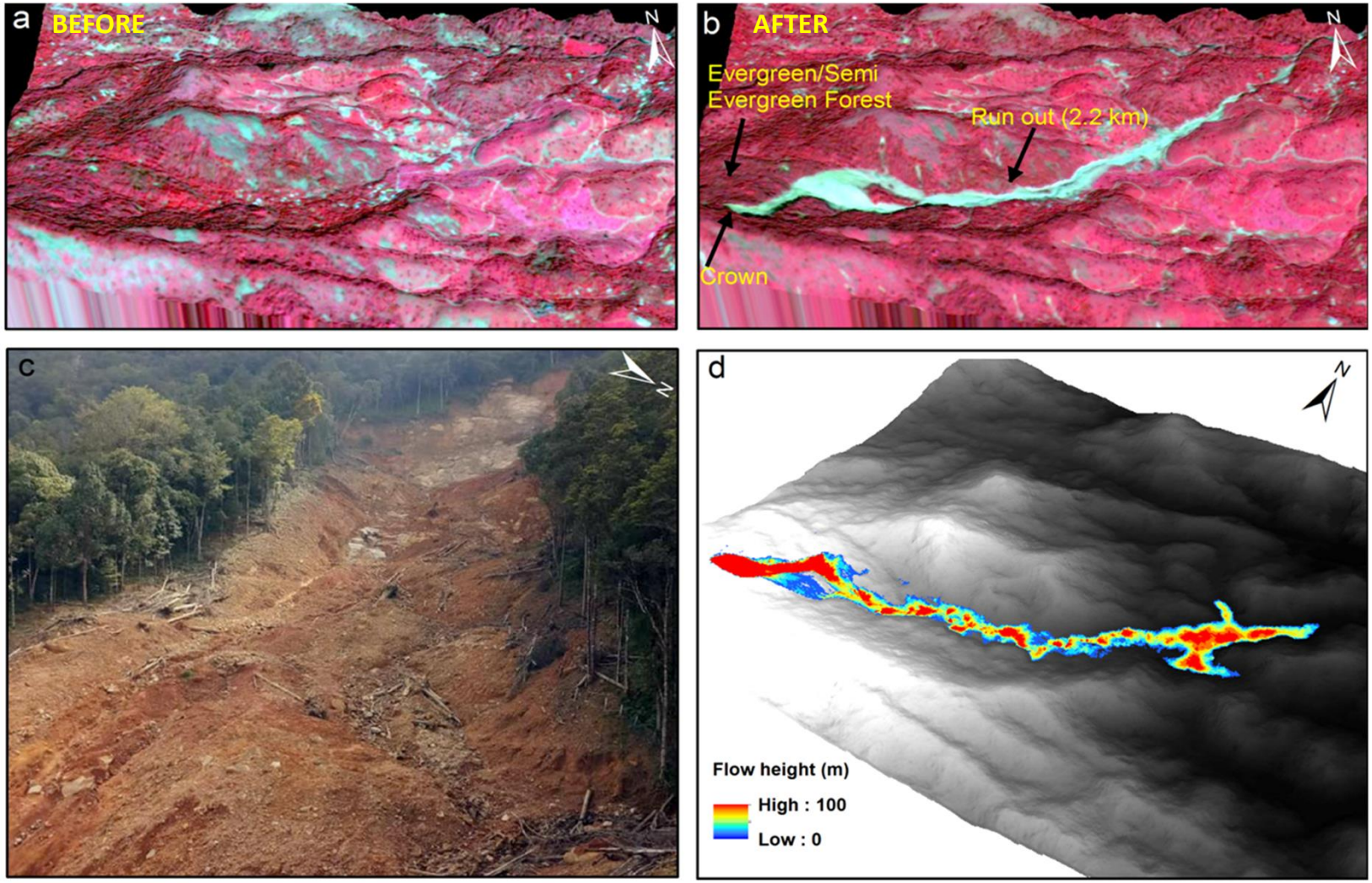
UAV data in Landslide flow modelling



UAV DEM in Landslide flow modelling

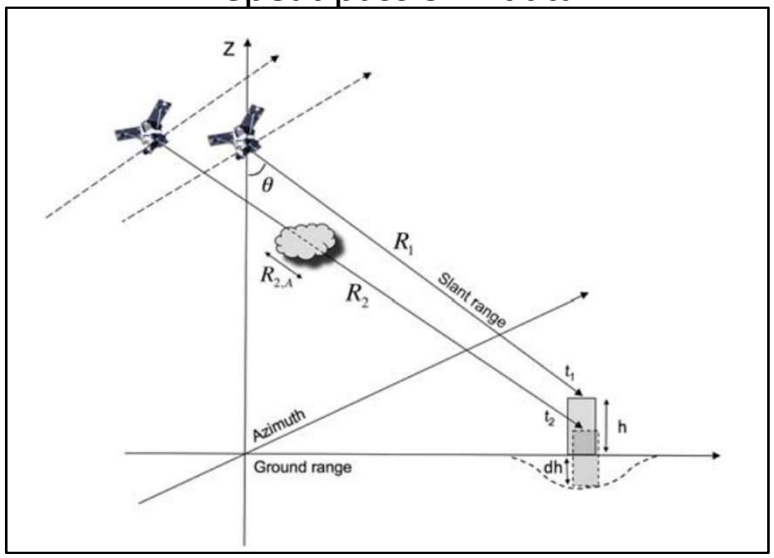


Debris flow modelling



Landslide Kinematics using InSAR

Repeat pass SAR data

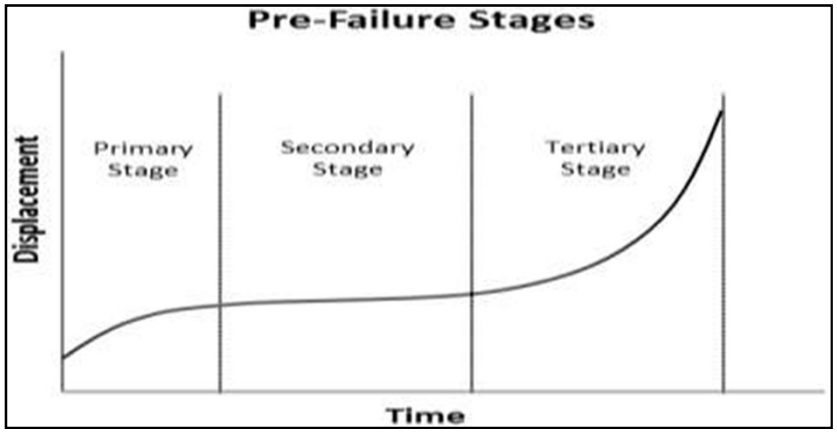


Phase difference (Ø)

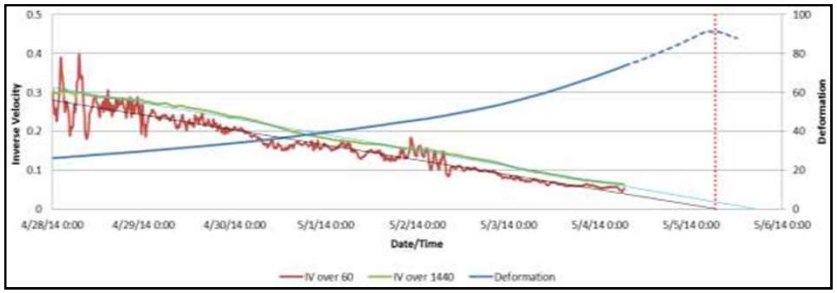
$$\Phi = \frac{4\pi}{\lambda}(dR_T + dR_A + dR_D + dR_N)$$

(Phase difference is used to measure ground motion)

Creep Theory

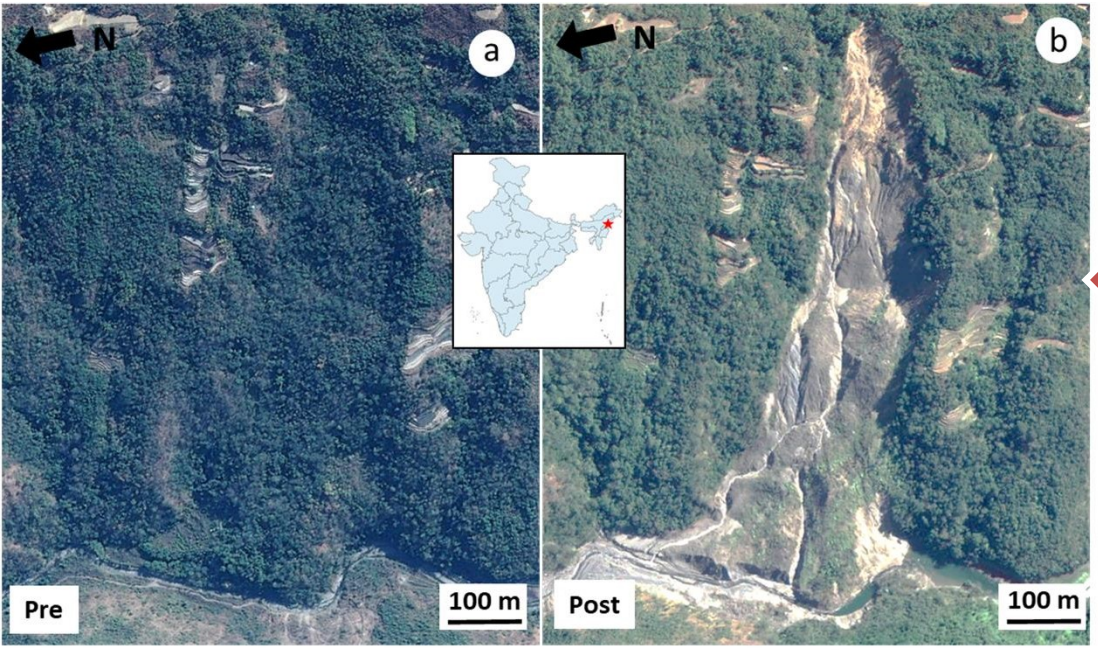


Fukuzono method



Landslide failure prediction in H.P. and Nagaland

nrsc



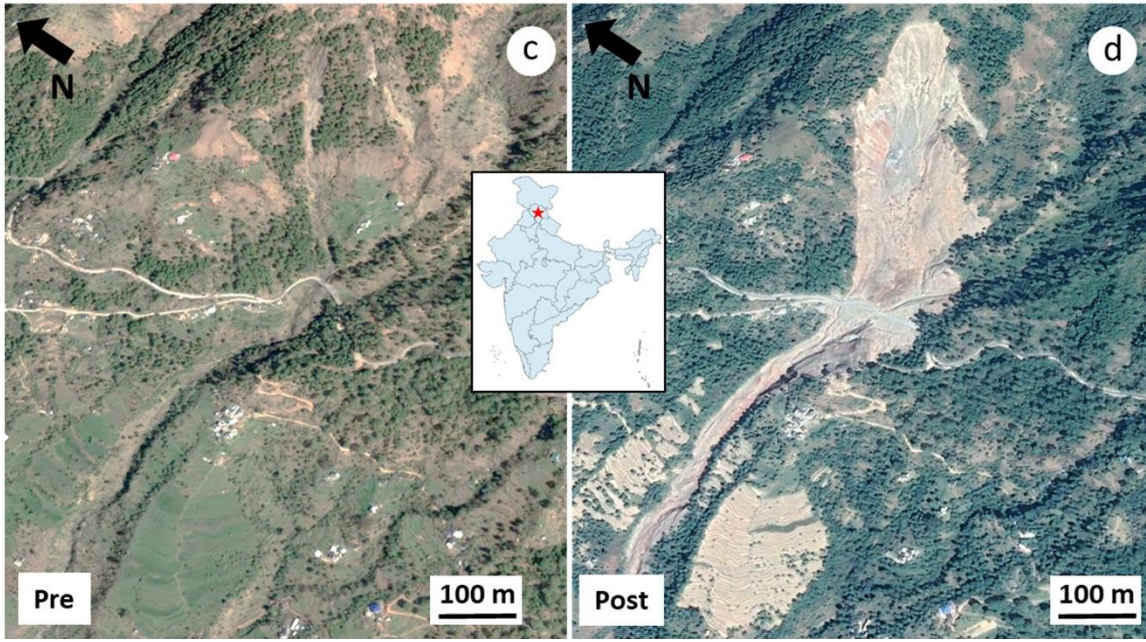
STUDY AREA 1

The Kikruma landslide is located at 25° 36’ 15.5 ° N and 94° 13’ 19.5” E

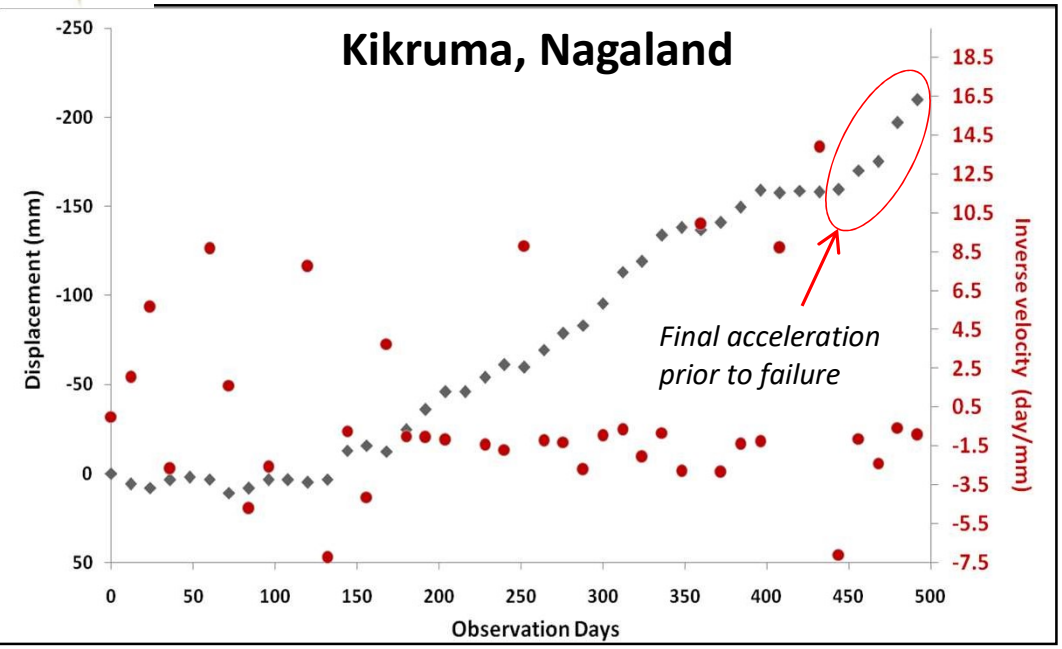
Failure date: 29 July 2018

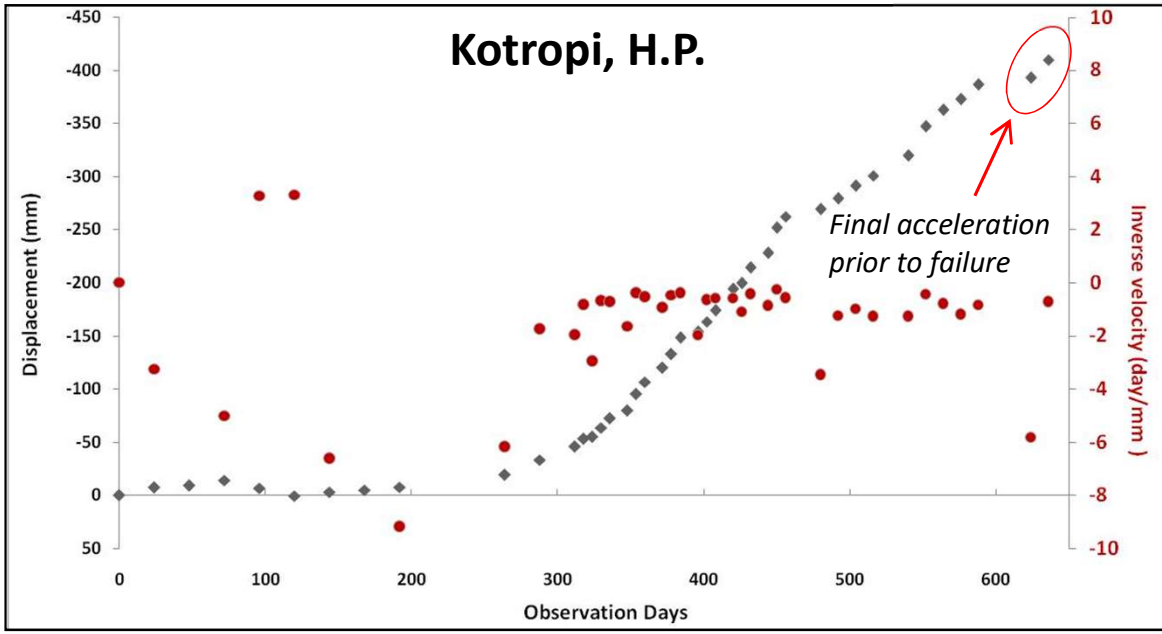
STUDY AREA 2

- The Kotropi landslide is located at 31° 54’ 43.6” N and 76 °53’ 16.4” E
- Failure date: 13 August 2017



Landslide Kinematics and failure prediction





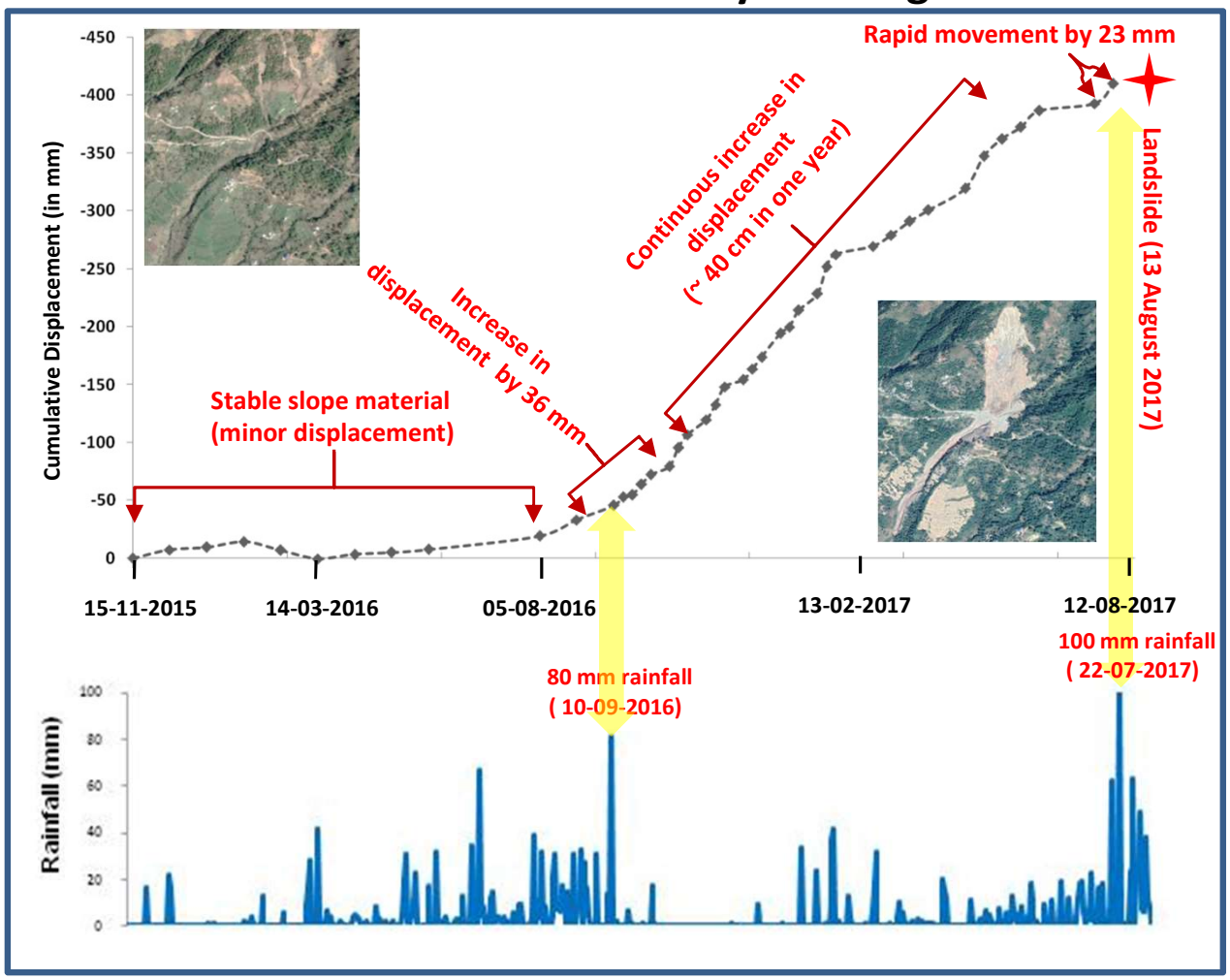
→ Trend of the time series is analysed to identify the locations on the slope where the material is accelerating and thus will lead to eventual failure during an effective trigger

→Kikruma: final instability on observation day number 444 (corresponding to 8th June 2018)
60 days prior to failure

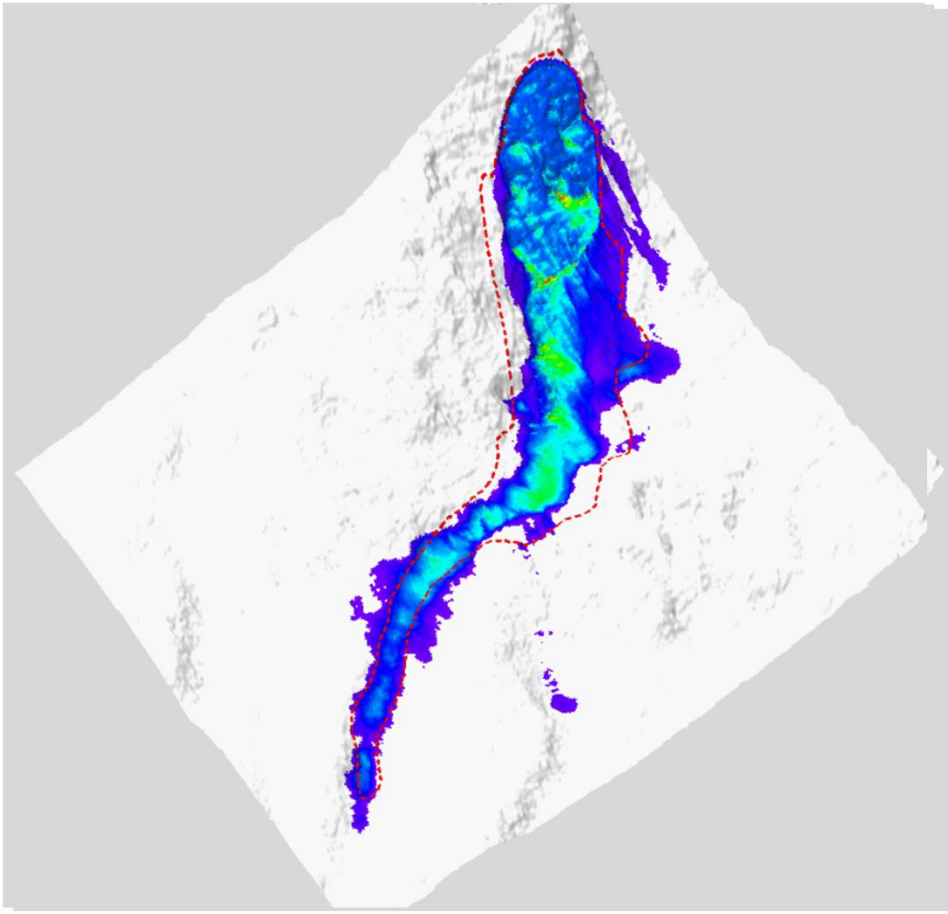
→Kotropi: final instability on observation day number 624 (corresponding to 31 July 2017)
24 days prior to failure

MOVING FORWARD : FAILURE TO FLOW

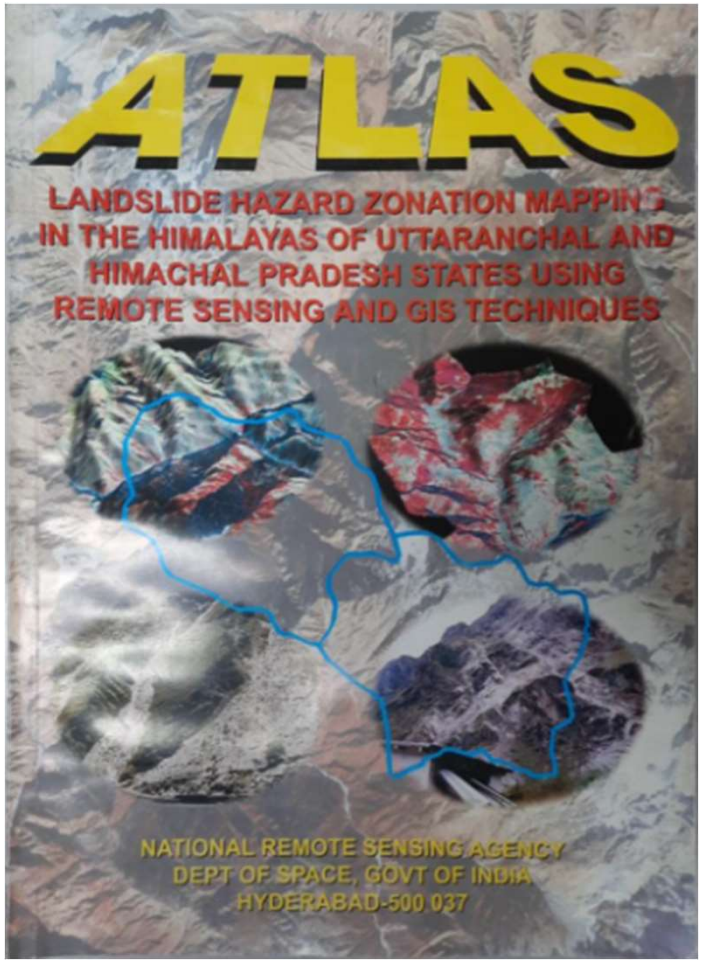
InSAR for landslide early warning



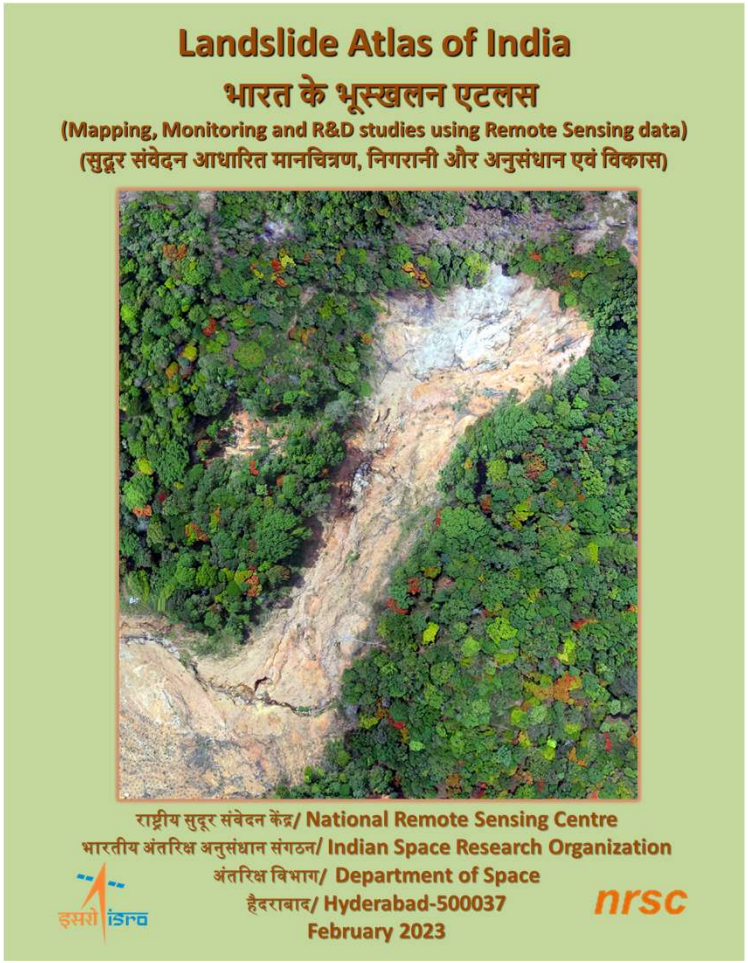
Landslide Flow Simulation



Landslide Atlases by NRSC-ISRO



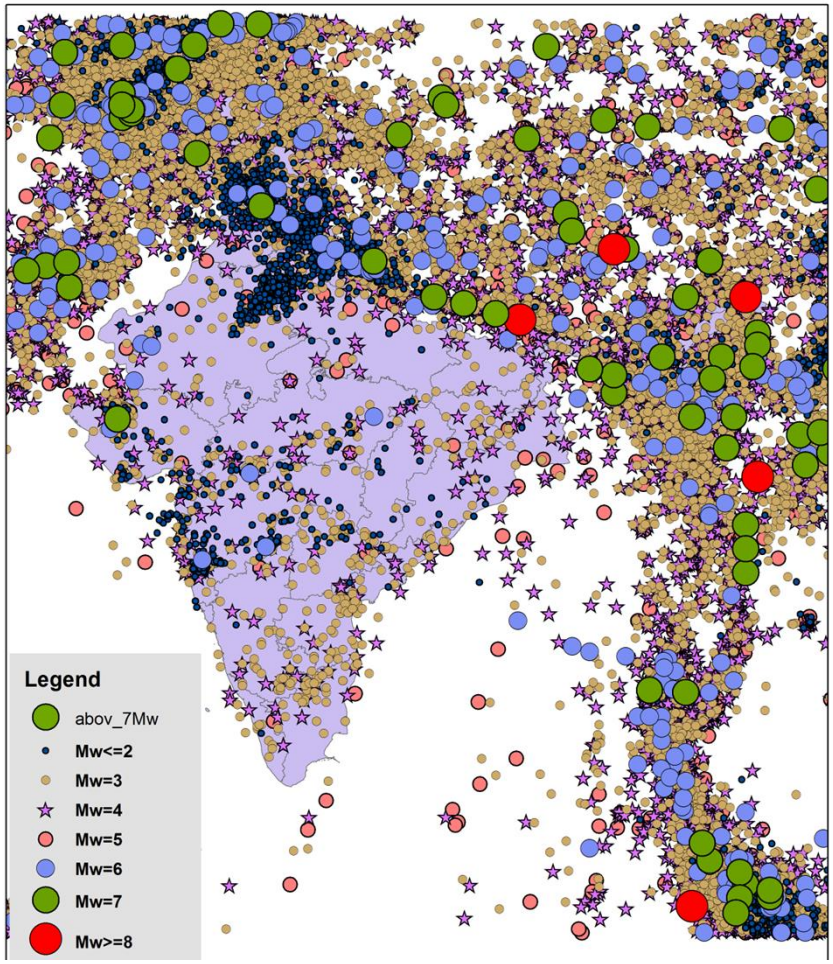
Landslide susceptibility and management maps on 1:25K scale



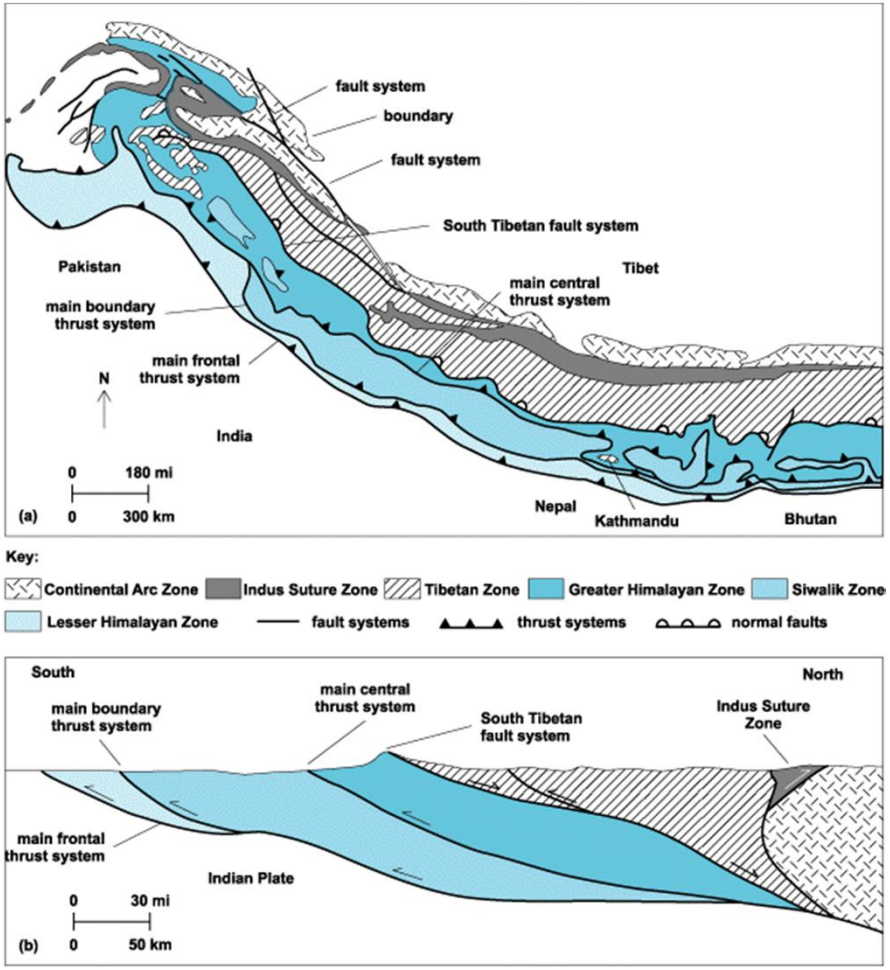
Landslide Inventory, Risk exposure and R&D studies

Earthquakes

Seismicity in the Himalayan Arc



Tectonics of Himalaya

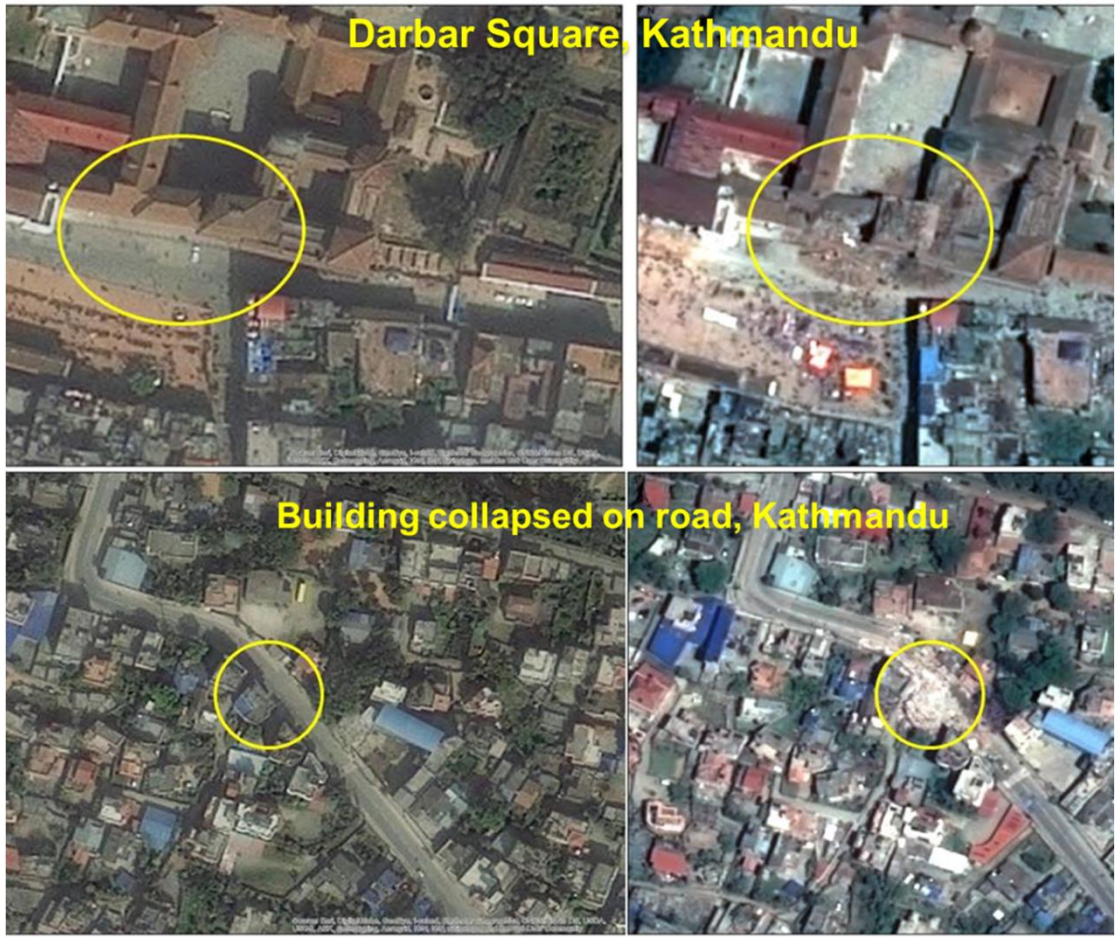


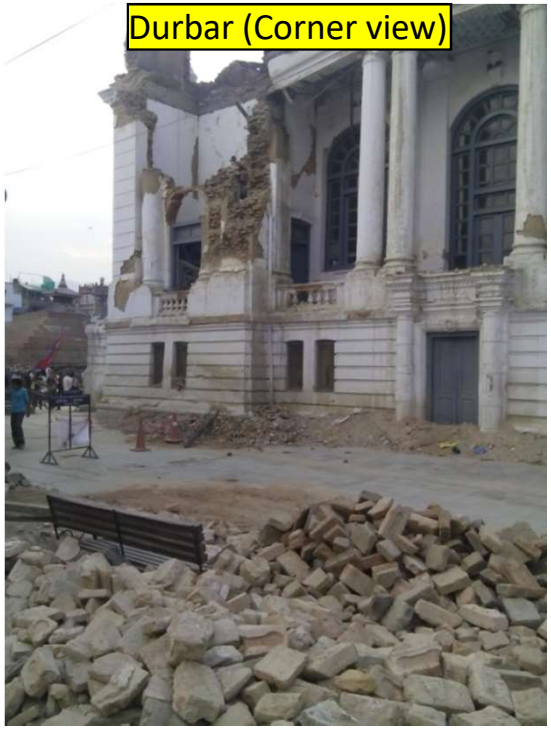
Rapid Response to Nepal Earthquake (25 Apr 2015)

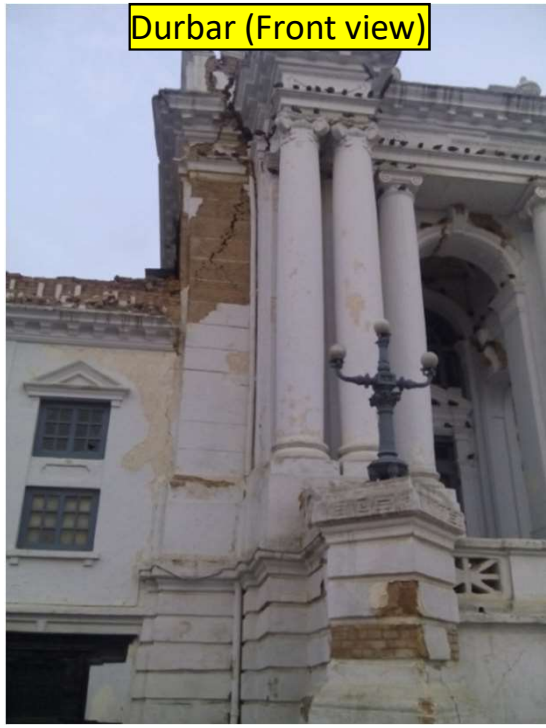
nrsc

Before

After

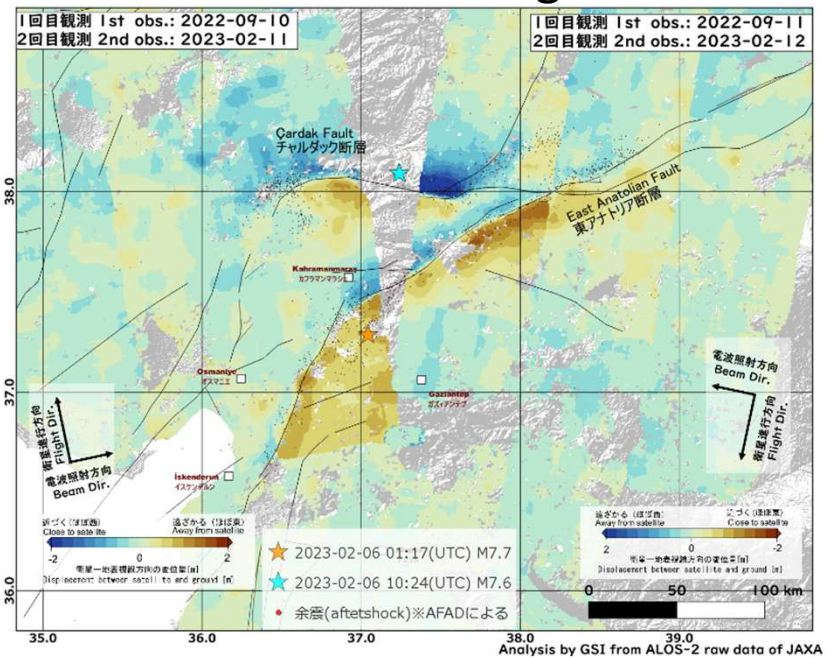






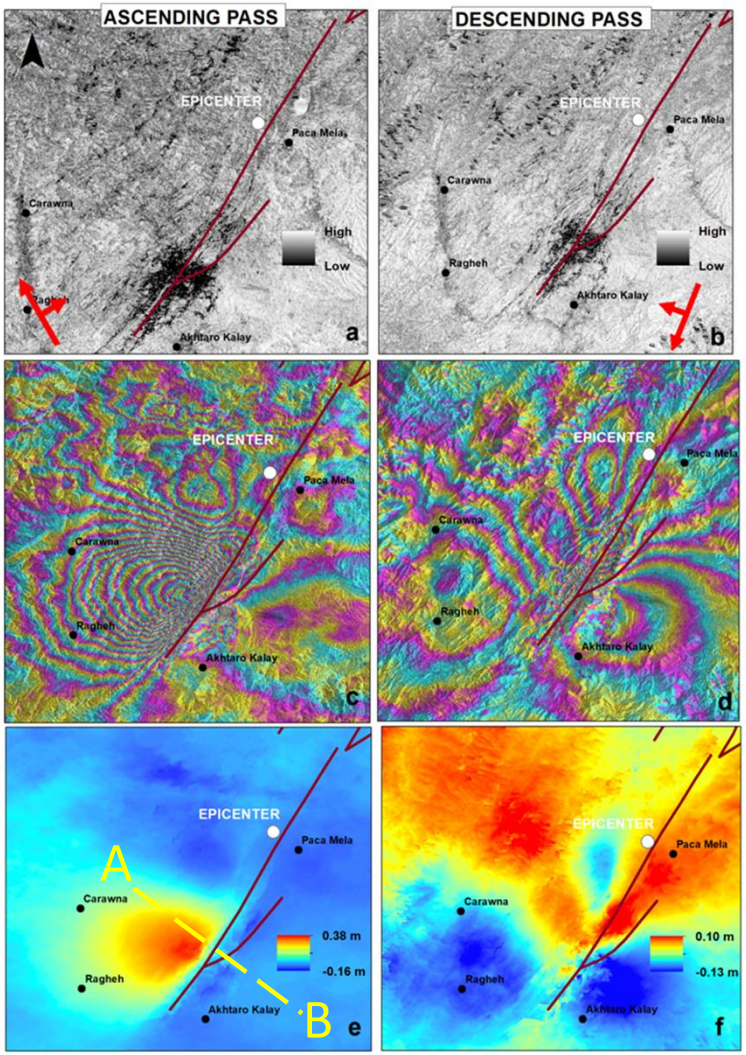
Rapid Response to Turkey Earthquake (06 Feb 2023)

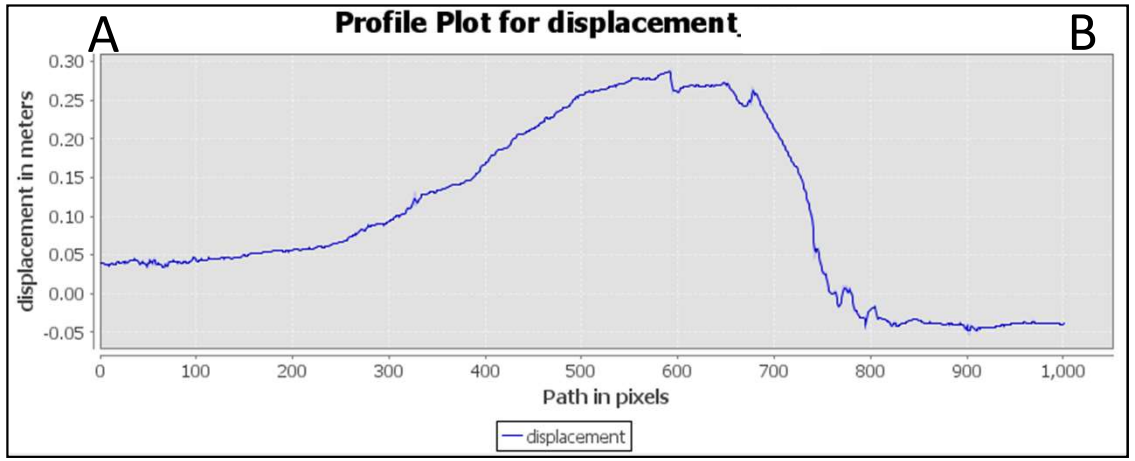
Ground motion along the fault



Analysis by GSI from ALOS-2 raw data of JAXA

Afghanistan Earthquake (21 June 2022)



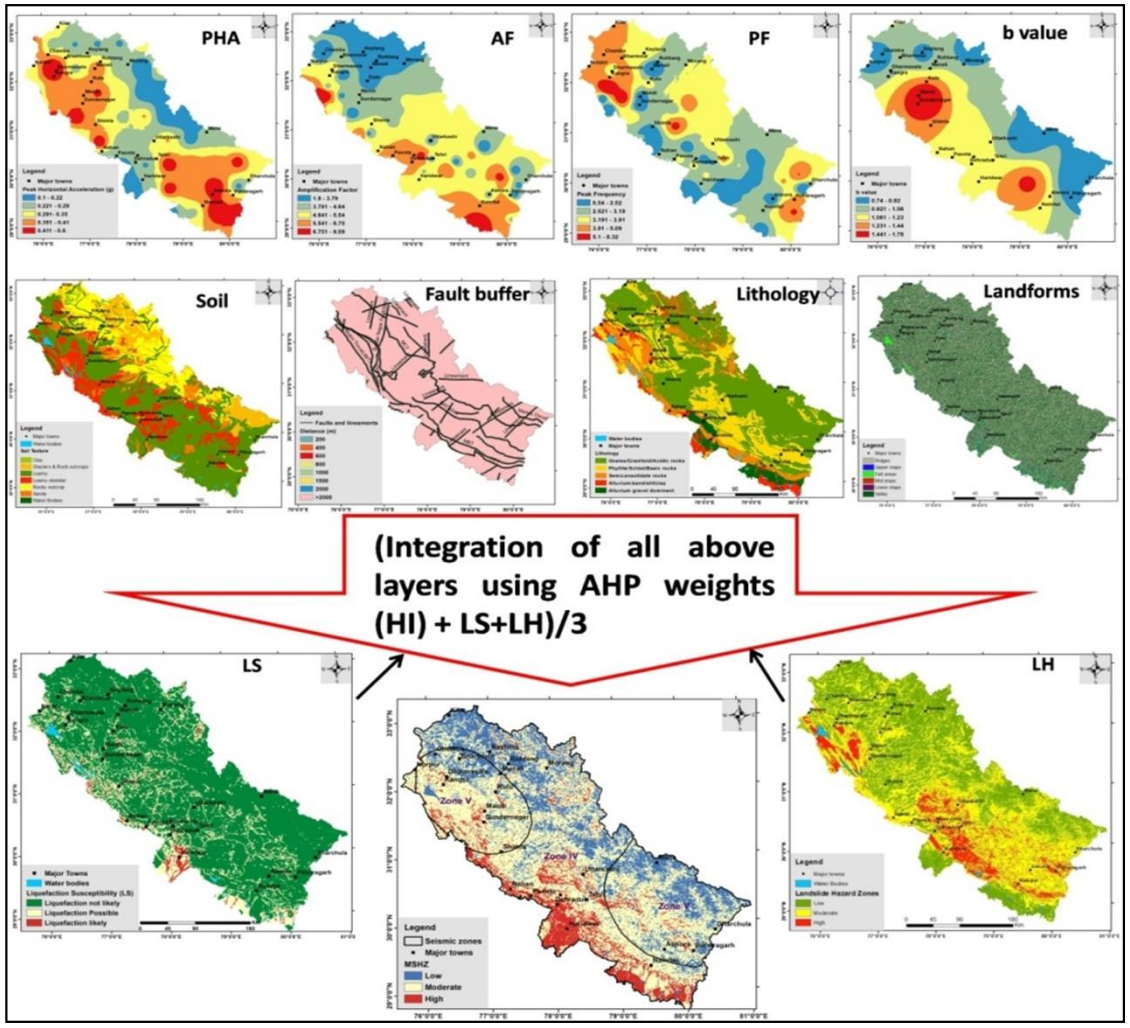


→ DInSAR analysis showed that the earthquake produced up to ~30 cm of upliftment along LoS.

→It has occurred along the eastern side of the north-northeast–south-southwest trending **North Waziristan-Bannu** thrust fault zone.

→The fault appears to be NE-SW trending dextral strike slip with transpressional movement.

Seismic hazard zonation

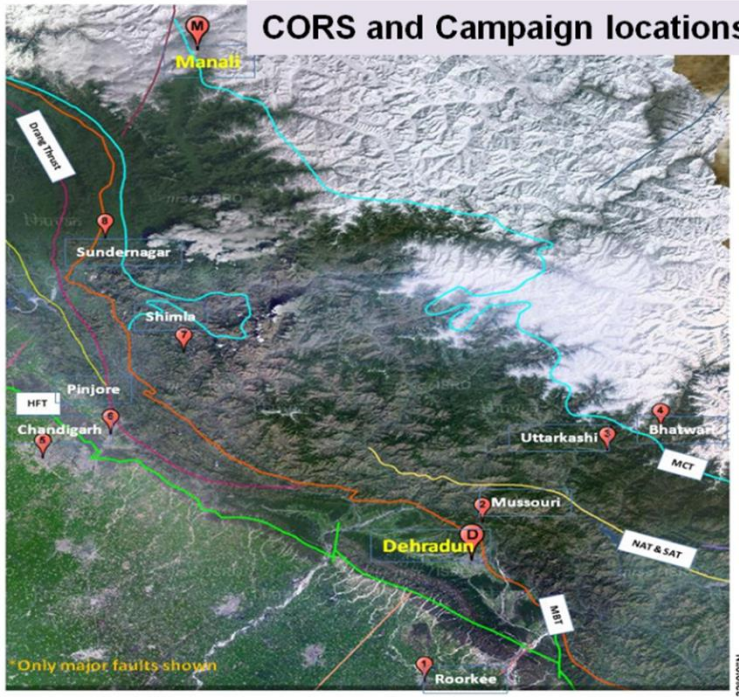


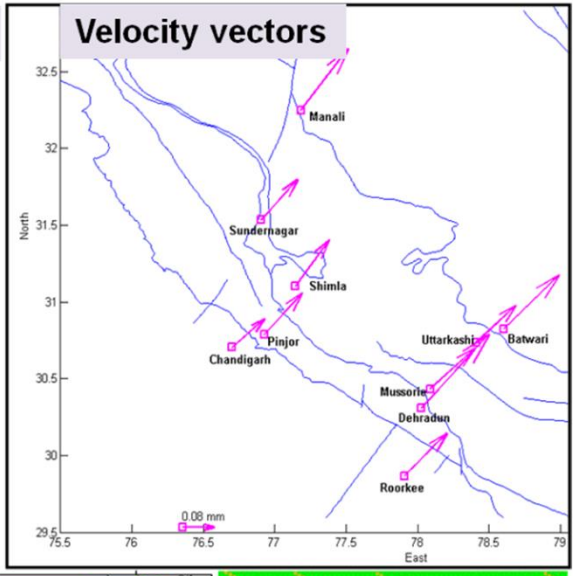
	PGA	AF	PF	Soil	Faults	Landforms	Lithology	Slope
PGA	1	1	2	3	4	5	6	7
AF	1	1	2	2	3	5	6	7
PF	1/2	1/2	1	2	3	5	7	9
Soil	1/3	1/2	1/2	1	2	3	5	7
Faults	1/4	1/3	1/3	1/2	1	2	3	5
Landforms	1/5	1/5	1/5	1/3	1/2	1	2	3
Lithology	1/6	1/6	1/7	1/5	1/3	1/2	1	2
Slope	1/7	1/7	1/9	1/7	1/5	1/3	1/2	1

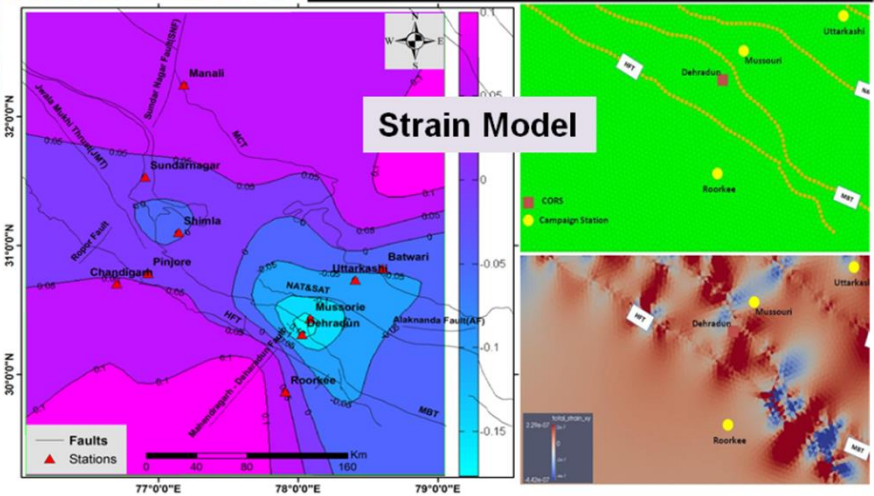
- Induced parameters were considered and this makes it a useful product
- Dynamic parameters need to be considered

Pudi et al. (2021): Env. Earth Science

Geodynamics and CORS







Phase 1

→ **2 C**ontinuous **O**perating **R**eference **S**tations

→ **8 Campaign Mode Sites**

→ Velocity vectors estimated from GNSS

→ 2D Strain modeling from velocity vectors

Team

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Aishwarya Nanda

Thank you