Committee on Earth Observation Satellites

Landslide Pilot Working Group Presentation

September 5th, 2017

Co-leads of landslide pilot

Dr. Dalia Kirschbaum, NASA Goddard Space Flight Center, Maryland, USA

Dr. Jonathan Godt, Landslide Hazards Coordinator, U.S. Geological Survey, Colorado, USA

Dr. Jean-Philippe Malet, School and Observatory of Earth Sciences, University of Strasbourg, France

Dr. Sigrid Roessner, GFZ German Research Centre for Geosciences, Germany

Landslides in multi-hazard environments

Earthquakes — **Major triggers** — **Hydrometeorologic extremes (e.g. typhoon)**

New Zealand: 2016 (7.8Mw) ca. 6,000 landslides
Nepal: 2015 (7.8Mw) ca. 20,000 landslides

Taiwan: 2009 Typhoon Morakot: ca. 20,000 landslides

Nepal: Bhote Koshi (drone image month after EQ)

Taiwan: fotos before and after

Status for Landslide WG

- **January 2017**: Planning of data acquisitions for Nepal and Pacific Northwest
- **January 2017**: Begin licensing agreement processes and querying of data requests from the group
- **April 2017**: Landslide pilot meeting at the European Geological Society Annual meeting and presentation in Remote Sensing of Landslides session
- **July 2017**: Completed most licensing agreements and data request submissions to space agencies
- **August 2017**: Continuing to request data for main pilot areas

Landslides Pilot: Main Goals

To demonstrate the **effective exploitation** of Earth observations (EO) data and technologies to **detect, map and monitor landslides and landslide prone hillsides**, in different physiographic and climatic regions.

To apply satellite EO across the **cycle of landslide disaster risk management**, including preparedness, situational awareness, response and recovery with a distinct multi-hazard focus on cascading impacts and risks.

Pilot Objectives

A. **Establish effective practices** for merging different Earth Observation data (e.g. optical and radar) to better monitor and map landslide activity over time and space.
B. Demonstrate how landslide products, models, and services can **support disaster risk management** for multi-hazard and cascading landslide events.
C. **Engage and partner with data brokers and end users** to understand requirements and user expectations and get feedback through the activities described in objectives 1-2.

Key Pilot Outputs & Deliverables

- Report on recommended practices for the combined exploitation of SAR and Optical imagery and technologies for landslide detection, mapping and monitoring". **(Objective A**)

- Report on effective methodologies and strategies for considering multi-hazard and cascading aspect of landslides through multi-temporal landslide mapping from multiple triggers (leveraging information/interactions with the volcano, flood and earthquake pilots) **(Objective A-C)**

- Landslide event inventory and activity (monitoring) maps produced using optical and SAR imagery and technologies, and their combination, for selected case studies / geographical areas. **(Objectives B-C)**

- Report on end user engagement strategies and characterize enablers, challenges, barriers to effective transfer of information, knowledge and technologies. **(Objective D)**

Proposed key user communities

- **Users**: national, regional and local governments, civil protection agencies, meteorological and geological services, land use planning decision makers, disaster risk reduction specialists with NGOs and international organisations, industry (including e.g., insurance, transport, forestry sectors).
- **Practitioners**: landslide modelers, scientists and engineers in hydrology, water and environment ministries, meteorological and geological services, satellite data providers, volcano observatories, and value added service companies.
- **Institutional bodies responsible for communication of risk** (gap between technical level and shared information with communities): research institutions with operational responsibilities.
- **General public**: landslide event information for some of the case studies will be made available to the general public for increased awareness of these hazards and remote sensing capabilities, although the main focus of the pilot is on specialized users.

Proposed regional study leads

Region	*Regional Point of Contact*
Nepal	**Nick Rosser, Sigrid Roessner, Dalia Kirschbaum**
Pacific Northwest, US	**Jonathan Godt, Dalia Kirschbaum**
Southeast Alaska	***Marten Geertsema***
Peru	***Jeff Kargel***
Caribbean (Cuba/Lesser Antilles)	***Enrique Castellanos, Jean-Philippe Malet***
China	***Zeng-Guang Zhou (TBD)***
Indonesia	***TBD***

Other areas of interest to community:

- Eastern Africa (POC Olivier Dewitte)

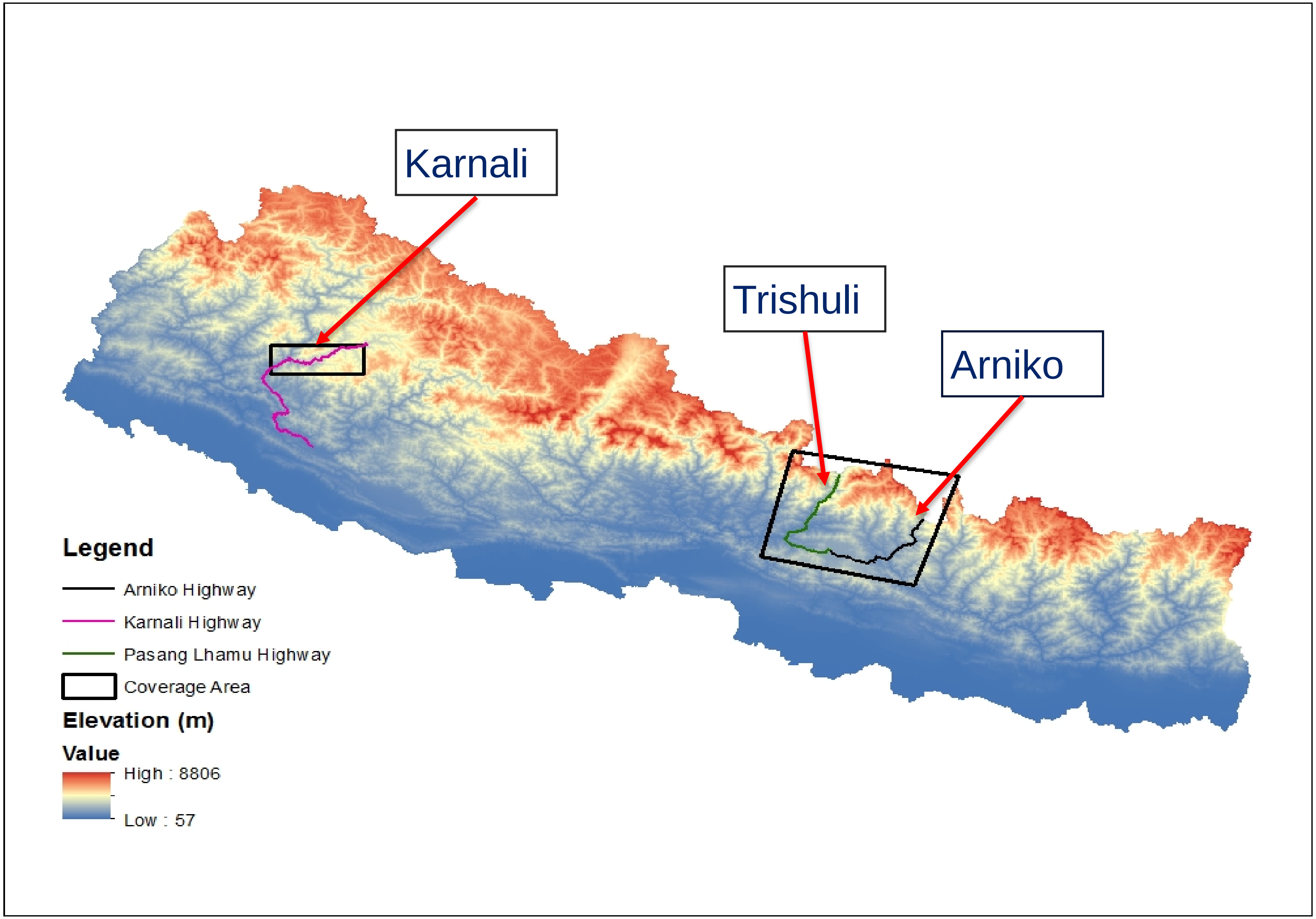
How data will be exploited

Geographic Area	Products	Value Added Partners
Nepal	Landslide monitoring and deformation analysis, multi-temporal landslide inventories, magnitude-frequency analysis of landslide occurrence, multi-temporal landslide hazard analysis	ICIMOD, Nepal Govt. Ministries, World Bank, Red Cross, US Army Corp of Engineers
Pacific Northwest, US	Landslide monitoring and deformation mapping, historical analysis and multi-temporal mapping	Washington and Oregon Departments of Transportation, National Parks Service, National Forest Service, FEMA, USGS
SE Alaska	Identify timing of rock avalanches and detection of precursory deformation	USGS and U.S. National Park Service
China	Technologies of spatial-temporal detection of landslides; Spatial-temporal mapping of earthquake-induced landslides	IMHE/CAS (Institute of Mountain Hazards and Environment, Chinese Academy of Sciences).
Haiti and Lesser Antilles	Multi-temporal landslide maps, Landslide monitoring and deformation mapping Methodological developments for automated processing of time series (GEP platform, other calculation). Frequency-magnitude relationships with triggers. Haiti and Lesser Volcanic Arc	CNES (Kal-Haiti), CNIGS, CIAT and UEH (Haiti) Permanent Risk Observatory of Guadeloupe and Martinique
Peru	*In development*	
Indonesia	*In development*	

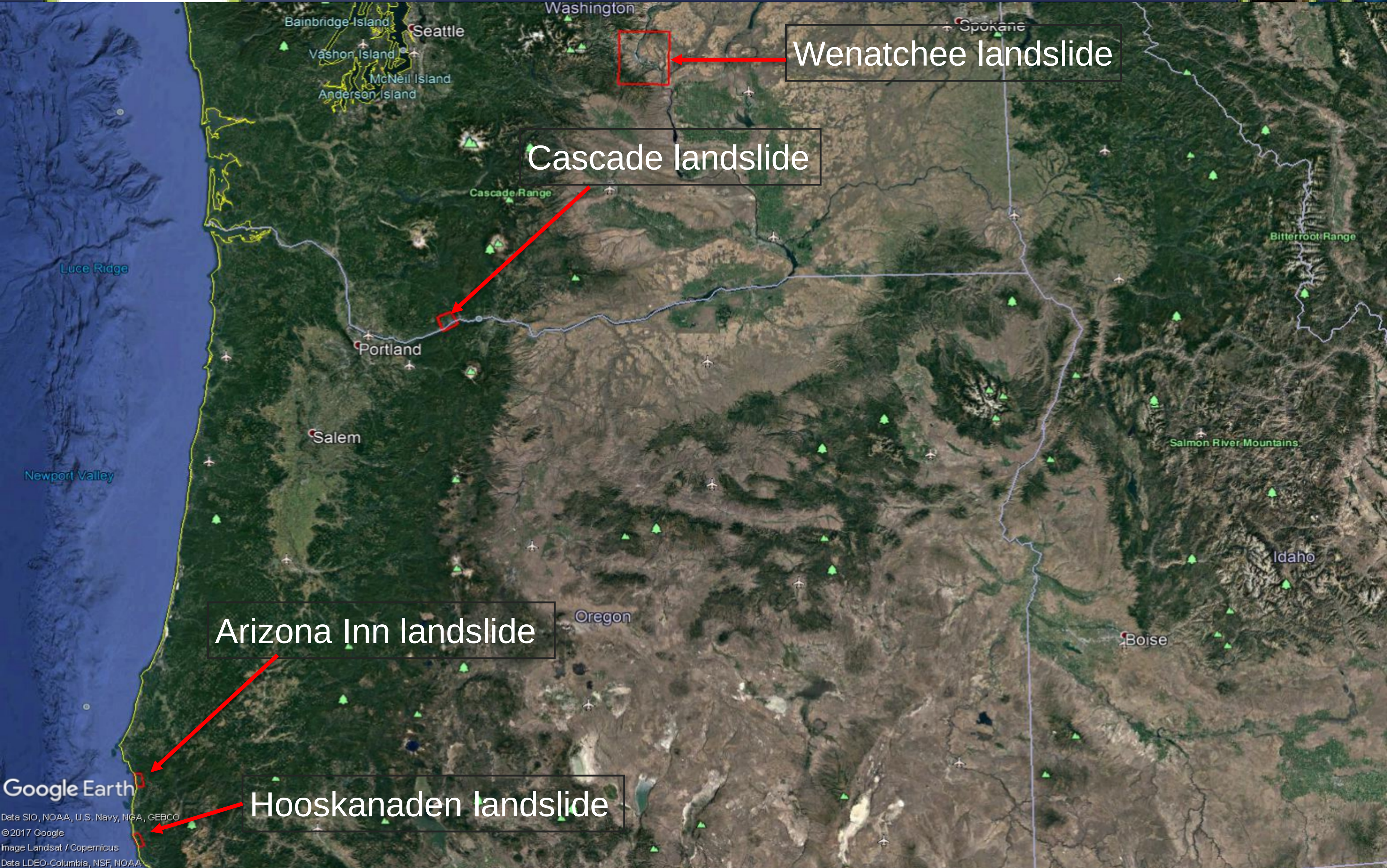
Data requests/region

	Total quota	Nepal		Pacific Northwest	
	All years	New	Archived	New	Archived
SPOT (archive only)	Not (presently) available		60		60
Pleiades	100	25	25	25	25
ALOS-2 / PALSAR-2		100	50	100	
Radarsat-2	110		60		50
Cosmo Sky-Med	?	150	150	100	50
TerraSAR-X (StripMap)	?	100	all archived datasets	50	
TerraSAR-X (Spotlight)	?	100			

Nepal data request areas



PNW data request areas



DLR/TerraSAR-X

- PI: Sigrid Roessner
- Nepal: Tasking requested submitted for Trishuli and Arniko highways. (GFZ Postdam)
- PNW: Tasking request submitted for 3 landslide areas. (Oregon State University and Southern Methodist University)
- **Status**: Confirming requested areas in Nepal and PNW

CSA/Radarsat-2

PI: Jean Philippe Malet

Status: Agreements have been signed and SOAR Geohazard proposal has been accepted by CSA. Access to acquisition planning tool has been established.

Image Quotas:

Nepal: 60 archived

PNW: 50 archived

ASI/COSMO-SkyMed

PI: Signatory PI is likely Sigrid Roessner (will be submitted on September).

Status: All the signatures of the participants have been collected. Detailed proposal will be submitted on September to establish the quota.

CNES - Pleiades/SPOT

Pleiades

Status: Received approval from CNES for images, working to sign the Specific user Agreement. A total of 40,000 km^2 can be requested within 3 year pilot. Agreements for specific data requests need to be confirmed with participants in CEOS landslide pilot

Nepal: Archived imagery request for Karnali, Arniko and Pasang Lhamu highway

PNW: Archived and tasking request for Arizona Inn and Hooskanaden landslides (Oregon State University)

SPOT

Most of the image request came for SPOT 6/7 which is not available from CEOS. CNES suggested and alternative way for requesting data through GEOSUD with Jean Philippe Malet as PI.

Status: Waiting for information from Jean-Philippe Malet

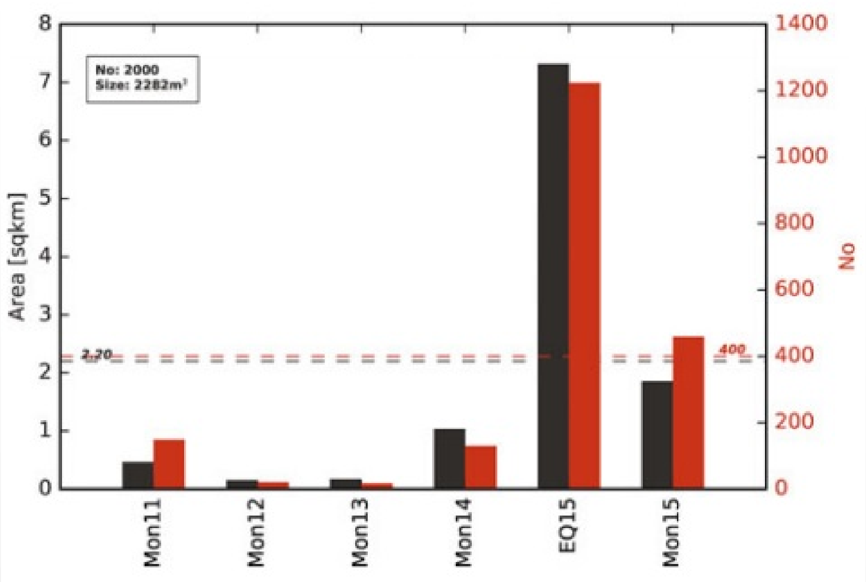
Suggested rapid response for landslide disasters

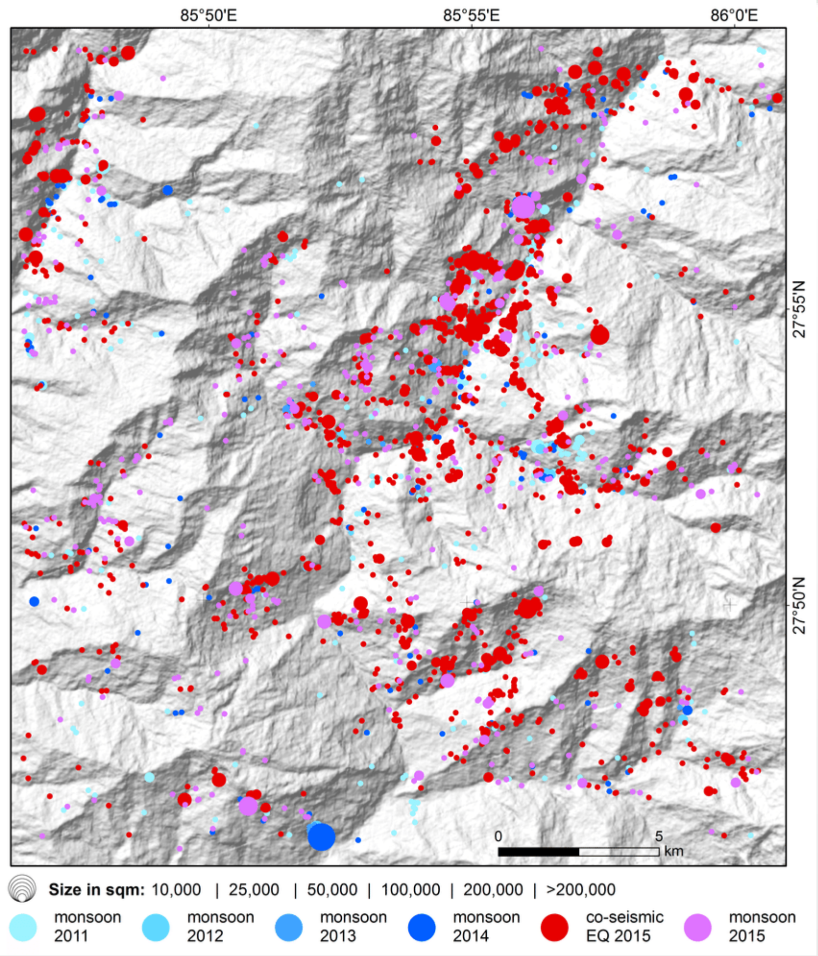
- Disaster occurs
- Co-leads have a coordination e-mail to determine next steps
- Send out CEOS Landslide WG e-mail
  - Determine potential end user group to be recipient of information
  - Determine core response group from CEOS group
- Establish frequency of coordinating calls and create lead for engaging with end users
- Determine data availability from disaster charter
- Request additional tasking from CEOS (coordinating with other pilots if relevant)

Recent research activities

- Research activities focused on application of remote sensing data products utilizing either publically available data or scenes obtained through an alternative agreements

Multi-temporal monsoonal landslide along Pasang Lhamu Highway, Nepal





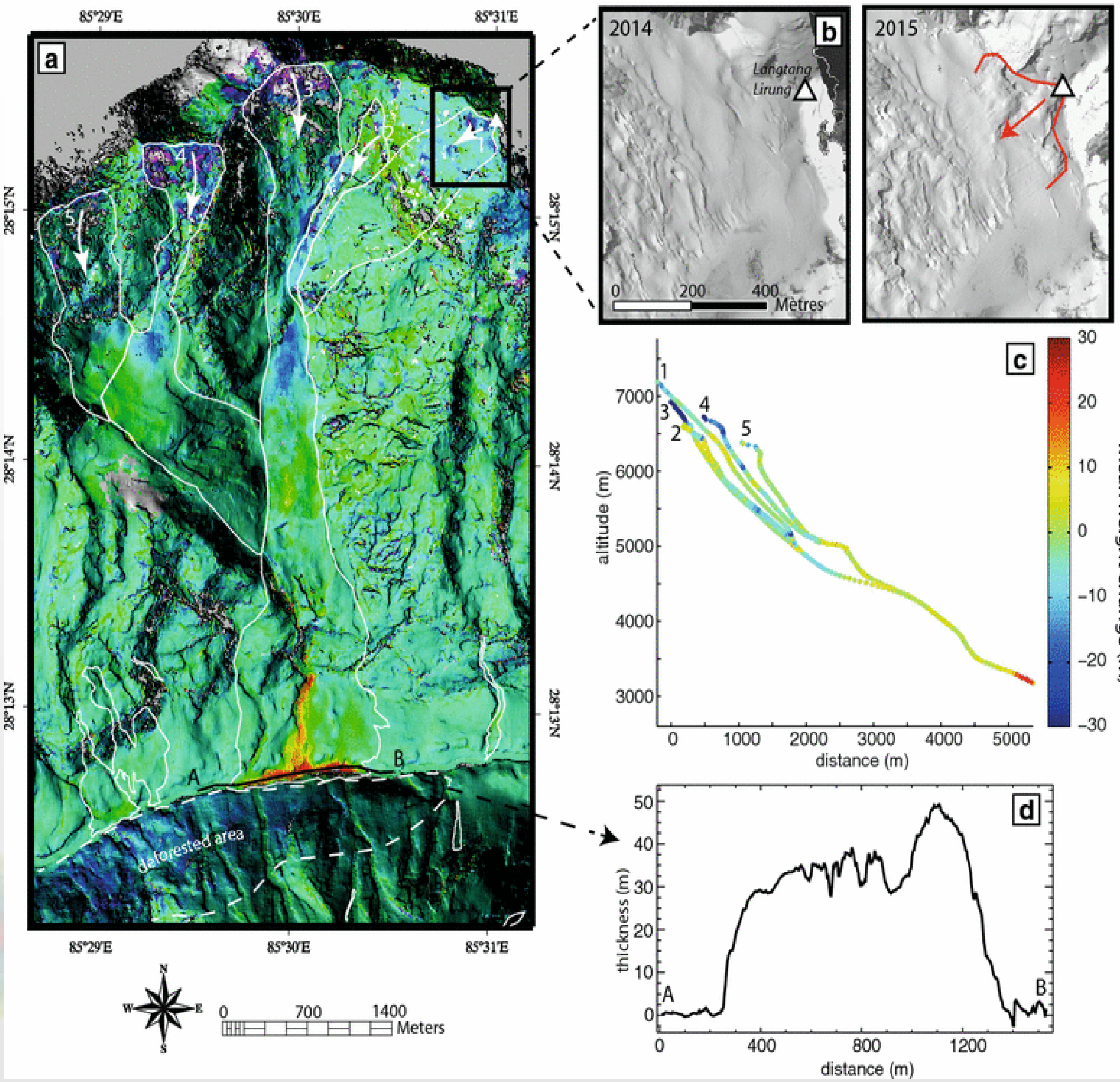
- Multi temporal monsoonal landslide inventory (2011 – 2015) derived from a time series of 13 Rapideye Level 3A data.
- 2000 landslides with sizes ranging from 200 m^2 to 0.76 km^2 affecting a total area of 10.9 km^2.
- 1224 landslides triggered by 2015 Gorkha earthquake.

Behling and Roessner (2017)

Landslide triggered by Gorkha Earthquake (Langtang, Nepal)

- 160 landslide identified using DSM prepared using SPOT 6/7 stereo pairs.

- Main debris avalanches accumulated
  6.95 × 106 m3 of deposits in the valley with thicknesses reaching 60 m, and
  9.66 × 106 m3 in the glaciated part above 5000 m asl.

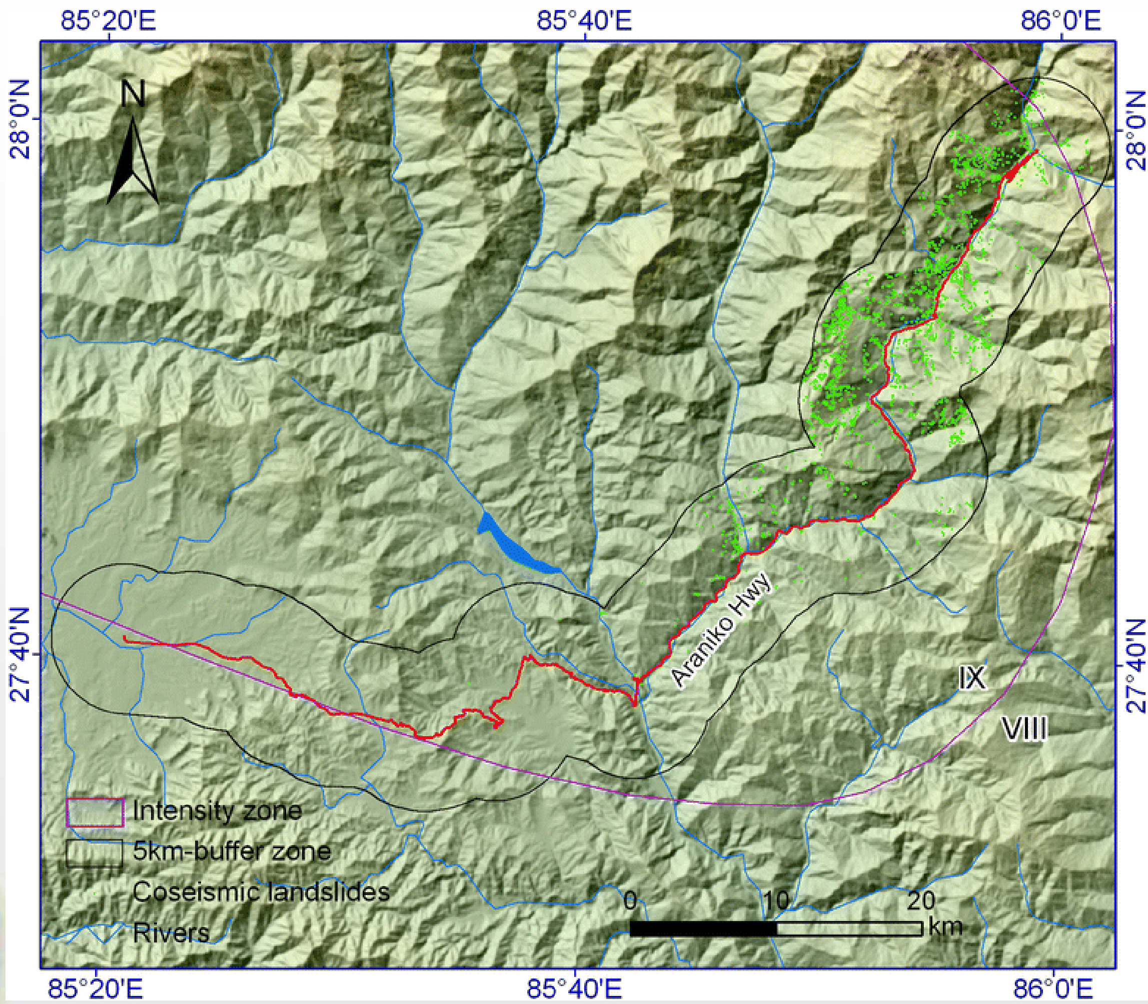


Lacroix (2017)

Landslide Damage along Arniko Highway during Gorkha earthquake, 2015.

- Landslide inventory prepared using VHR satellite imagery and field visit (all derived from Google Earth Platform).

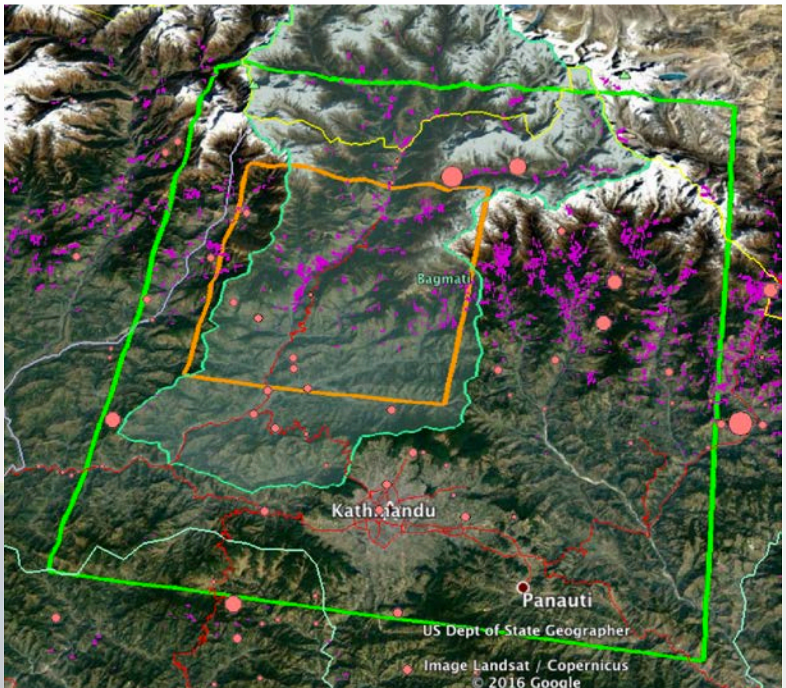
- 35 coseismic landslides damaged the Arniko Highway along a total length 1,415 m. The total volume of them was estimated to be 0.37 million m3

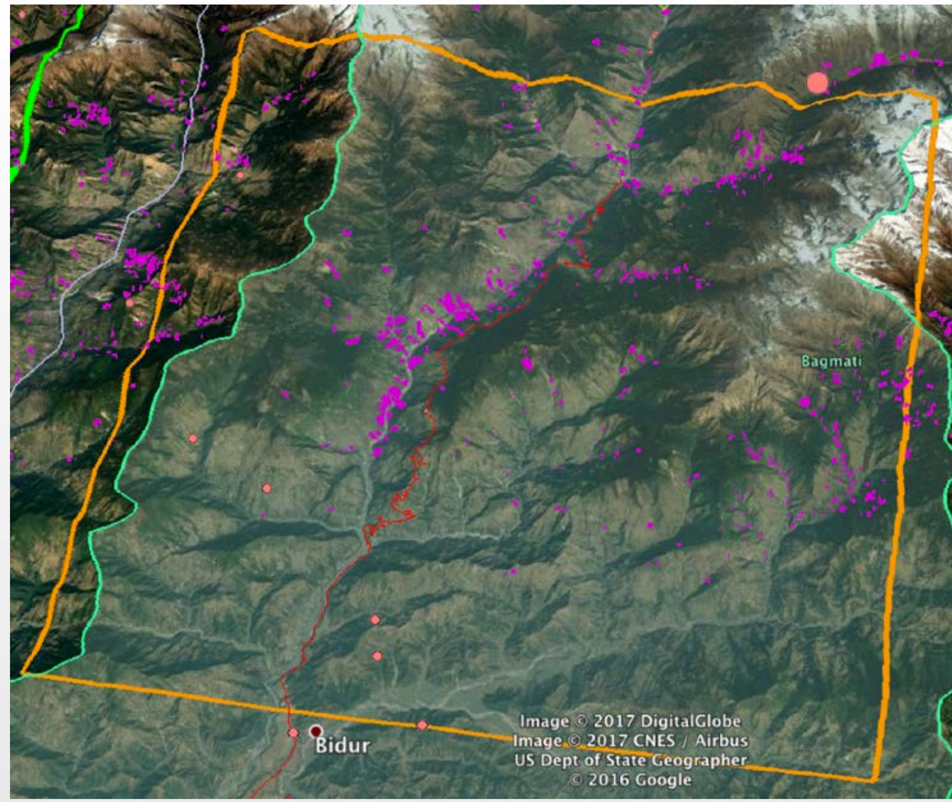


Xu et al (2017)

SAR feasibility for Landslide mapping in Langtang valley, along Trishuli highway

Zoom over **focus area** = **Orange**





Green poly = Trishuli basin (Kyle study Area)
Bordeaux = Roads
Red circle / magenta lines = landslides

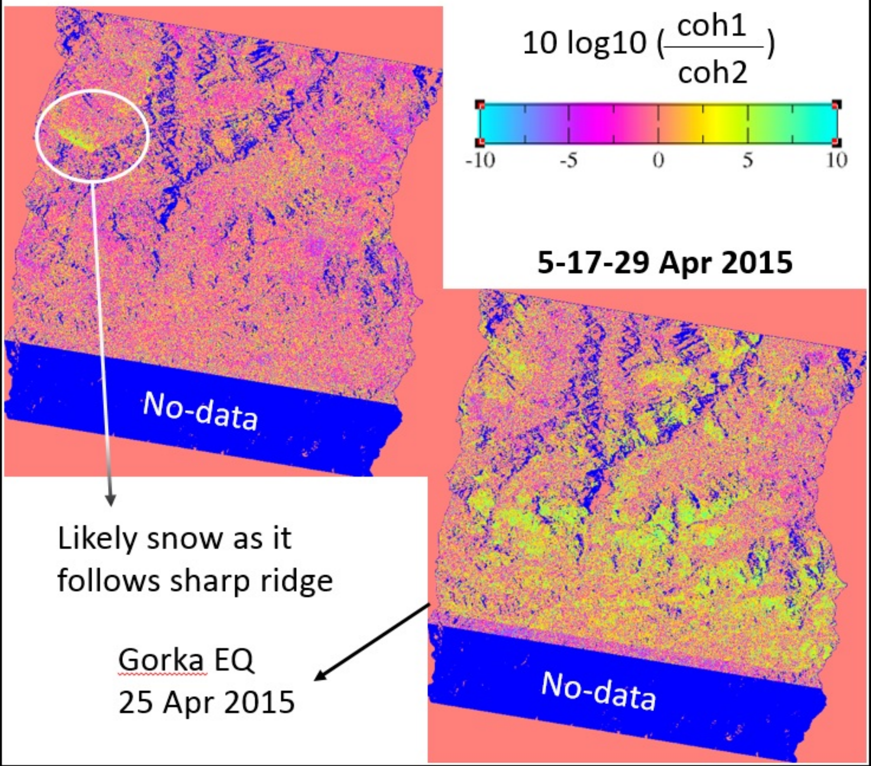
Bekaert, JPL

Coherence-Index (April-November)

Coherence-Index (April-November)

7-19-31 Oct 2014

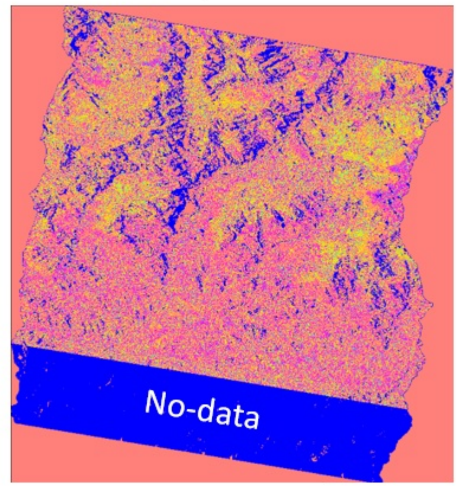
5-17-29 Apr 2015



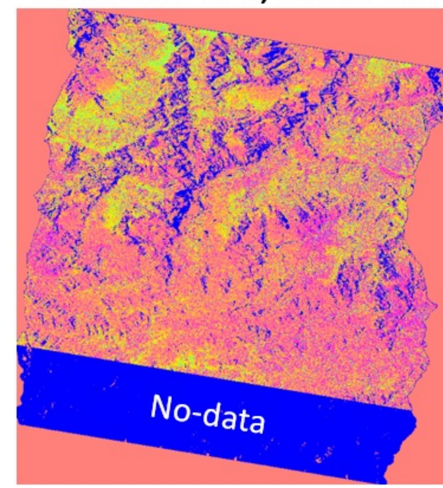
Not considered but examples of Winter/spring

Clearly see effects of decorrelation for winter images

19-31 Oct, 12 Nov 2014



19-31 Dec 2016, 12 Jan 2017



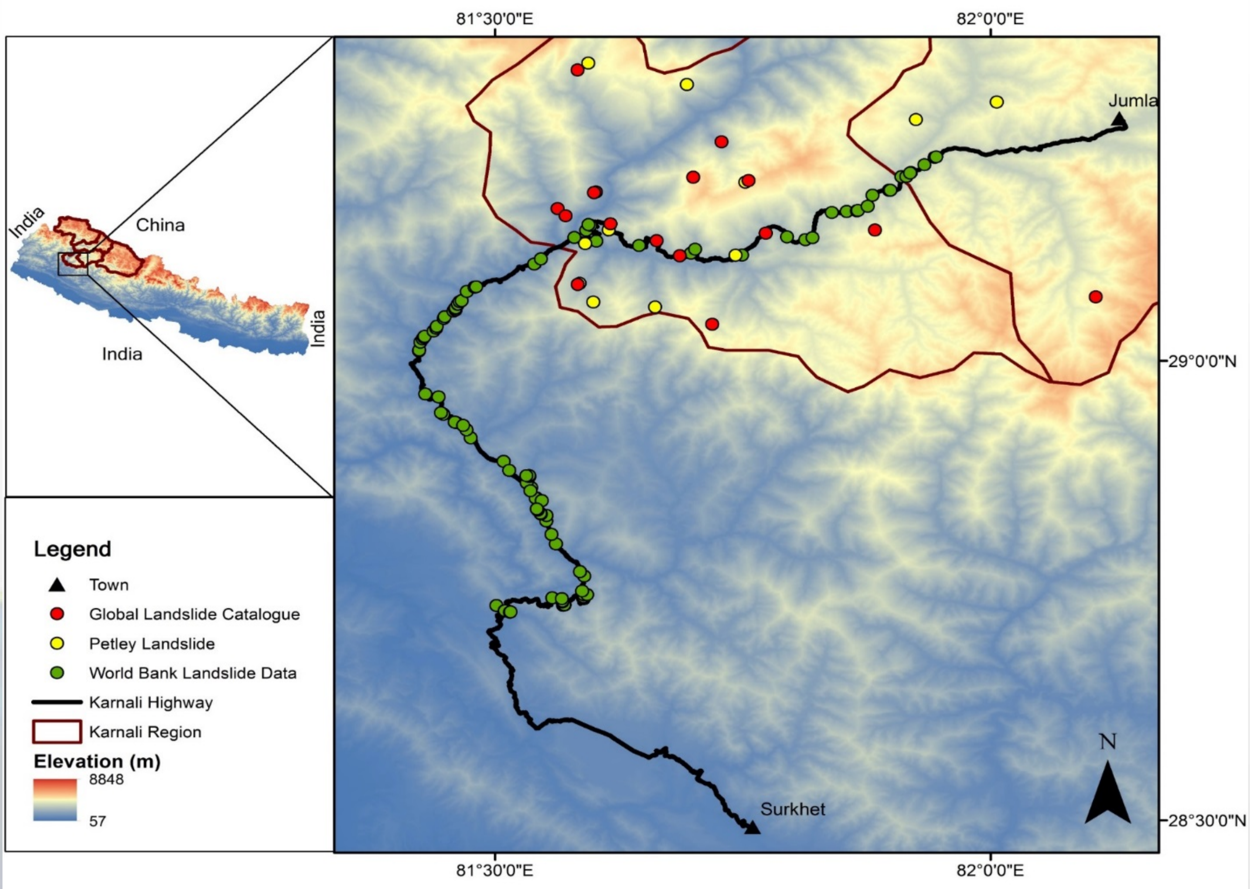
Next steps:
- Overlay in GIS tool
- Binary map => Thresholding (not really objective)
- Try other metrics: e.g. coherence NDVI / amplitude
- Compare Gorka EQ with reported damage maps

>0 coh_t2 is lower than coh_t1 (e.g. snow/rain/landslide event between acquisition 2 and 3)

<0 coh_t1 is higher than coh_t1 (e.g. event could be between acquisition 1 and 2)

© 2017 California Institute of Technology. Government sponsorship acknowledged.

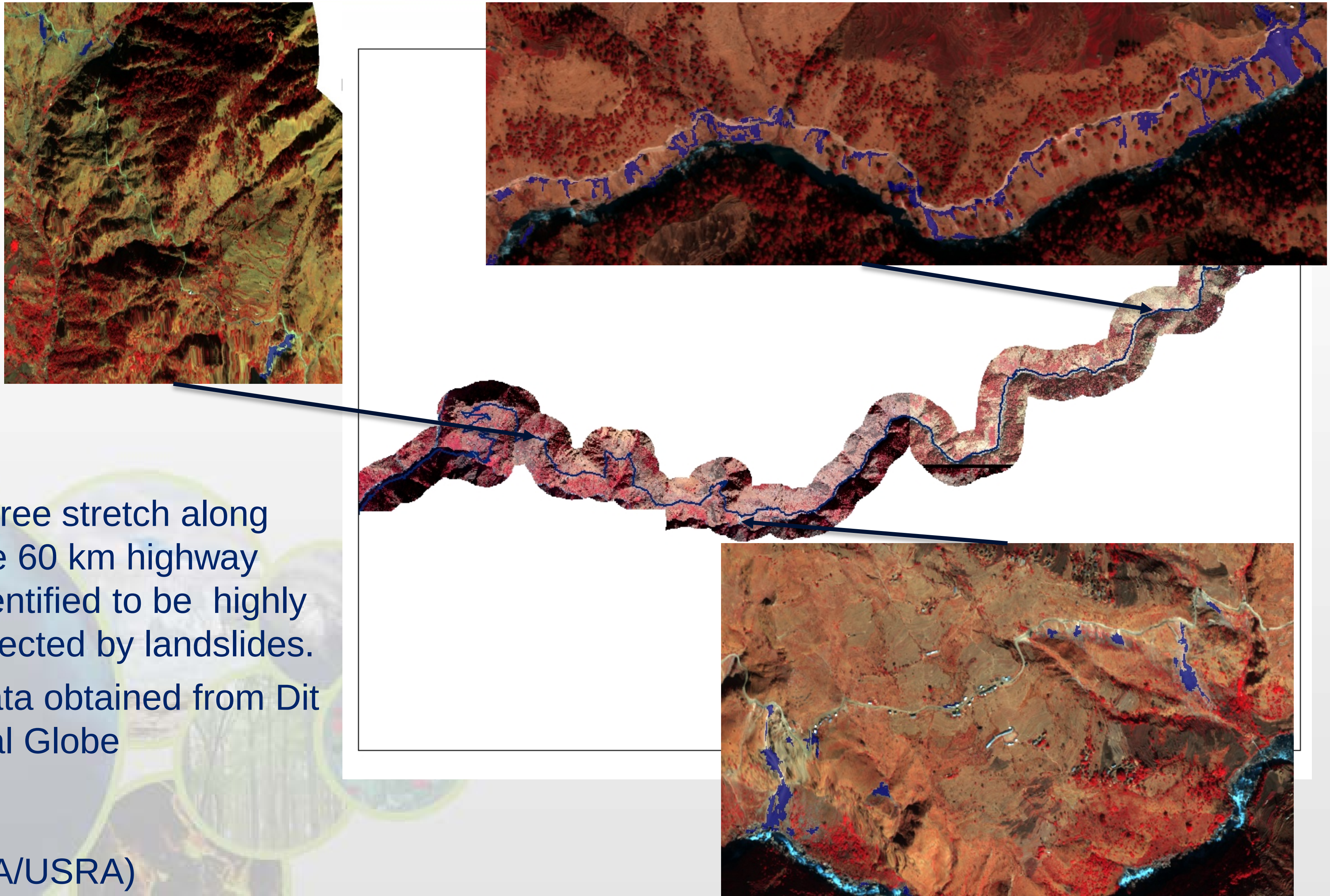
Landslide Mapping in Karnali Region



@KarnaliKo

- One of the poorest and least accessible region.
- The Karnali highway is the only major road network connecting Jumla the capital with Terai region.
- Out of 232 km only 11 km are blacktopped and is considered as one of the most dangerous highways in the world.
- Reports of blockage every year due to landslides ultimately resulting in death of people due to food shortage.
- **This will be the first effort to map landslides in Karnali Highway in collaboration with The World Bank.**

Object oriented analysis based landslide mapping (Karnali Highway, Nepal)



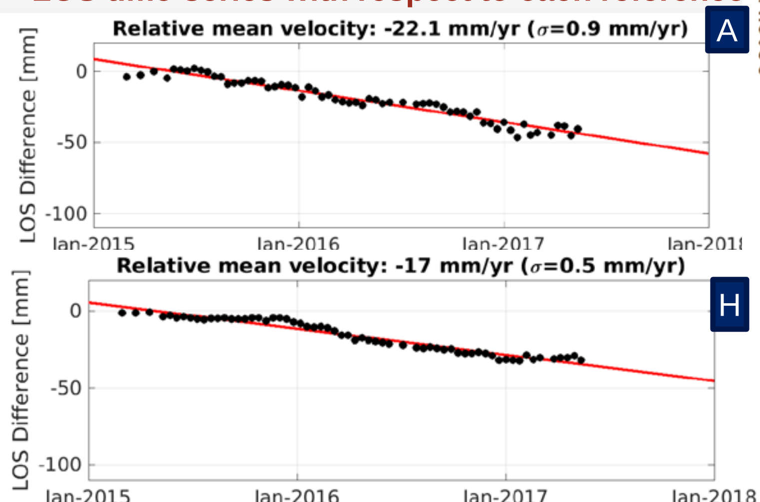
- Three stretch along the 60 km highway identified to be highly affected by landslides.
- Data obtained from Dit igal Globe

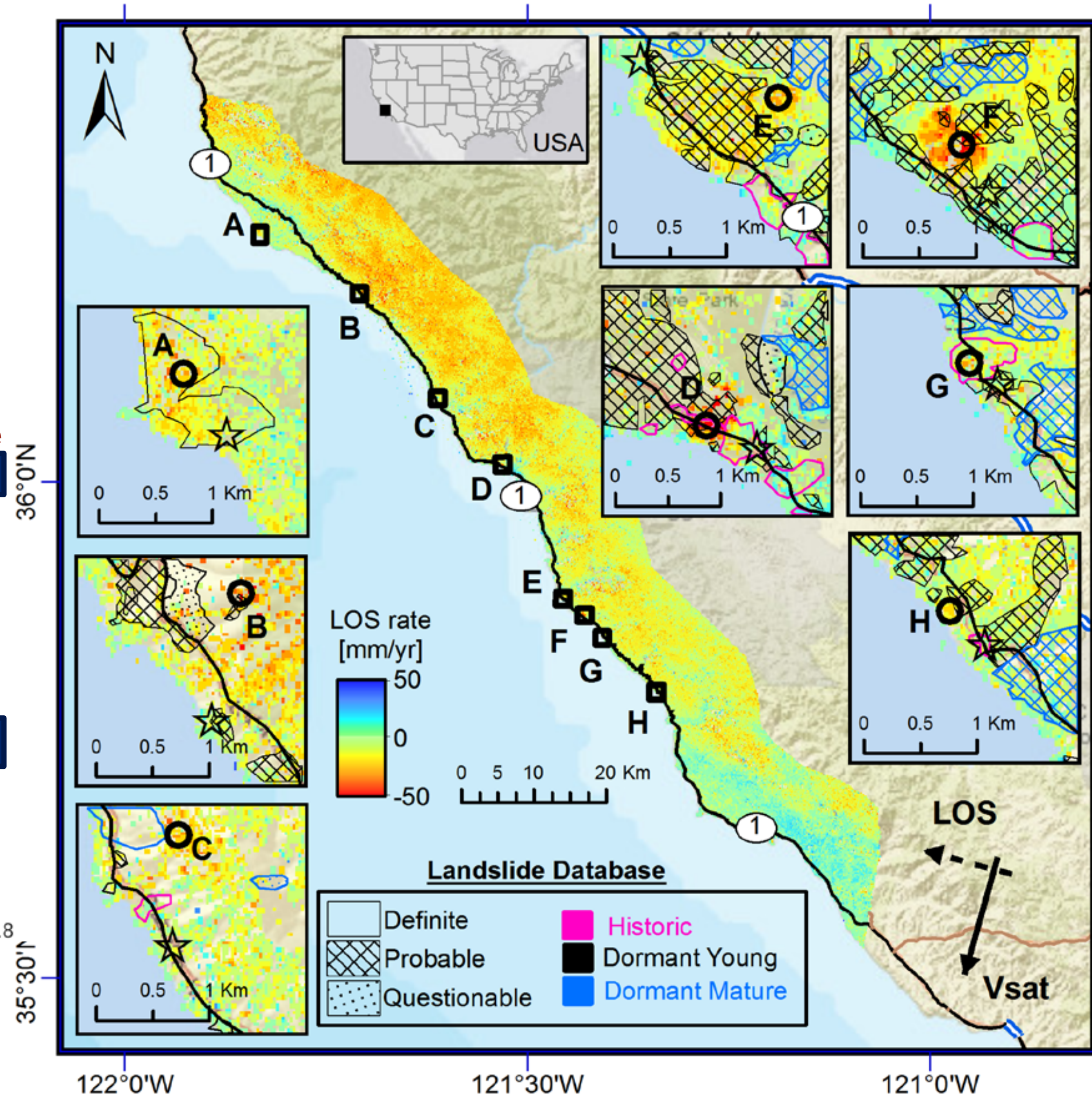
(NASA/USRA)

Time-series InSAR research Demonstration of landslide mapping using Sentinel-1 (PNW, USA)

Map shows average line-of-sight surface displacement rates between Oct 2014-May 2017 using Sentinel 1 SAR data and processed using JPL's ISCE processor and StaMPS time-series package.

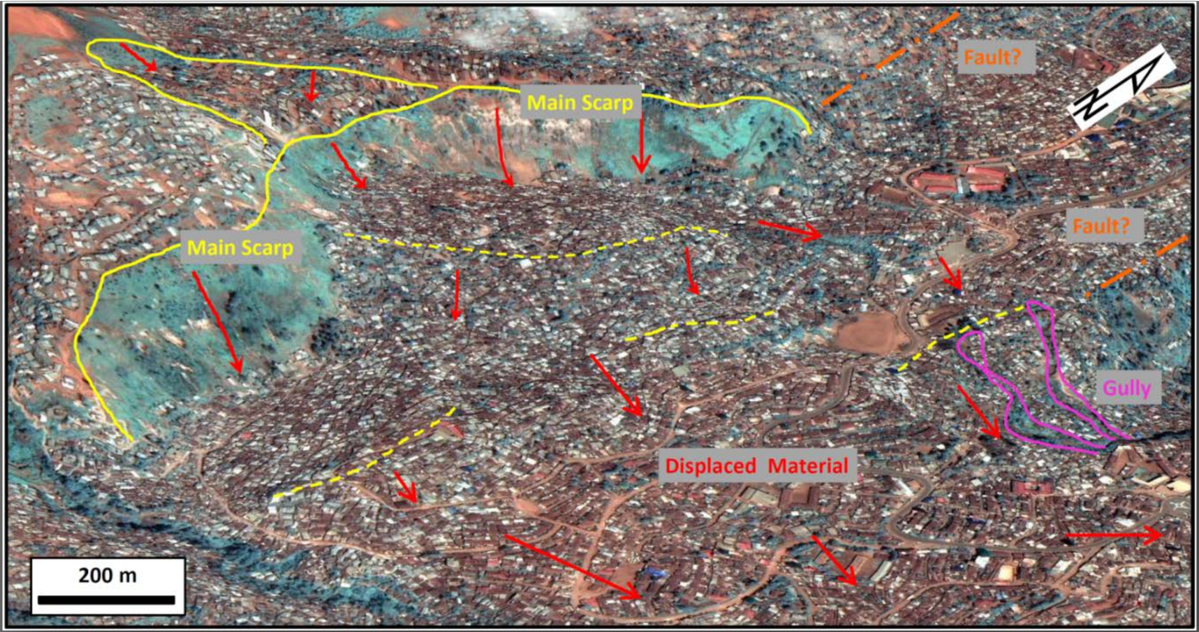
LOS time-series with respect to each reference

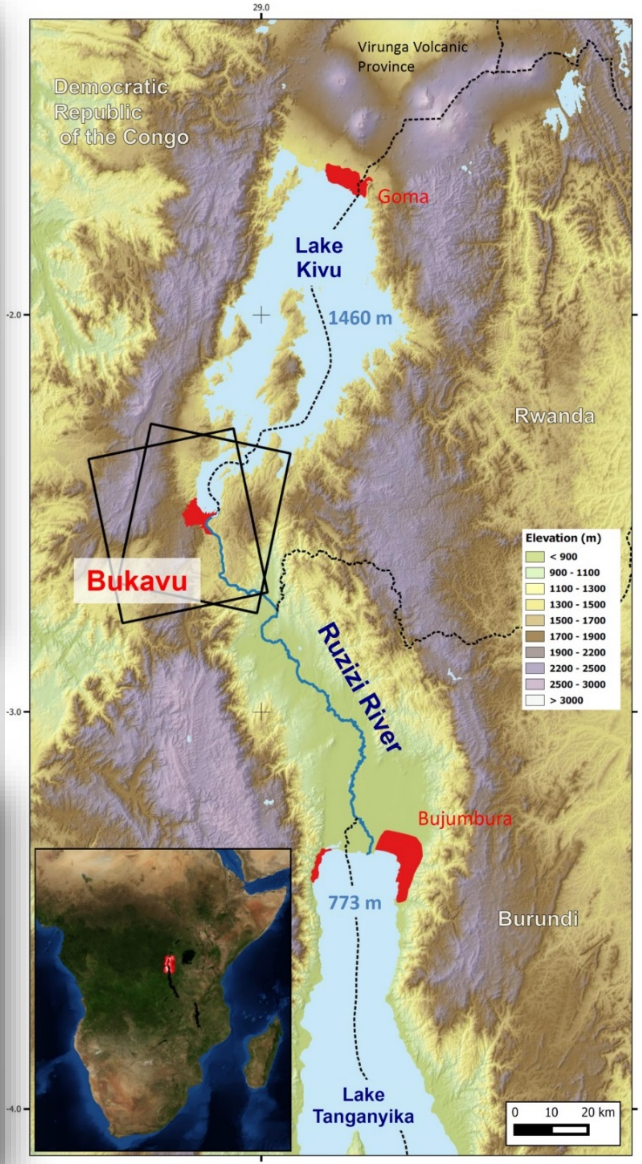




D. Bekaert, P. Agram, and H. Fattahi.
(Jet Propulsion Laboratory, California Institute of Technology)

Bukavu, Africa landslide monitoring

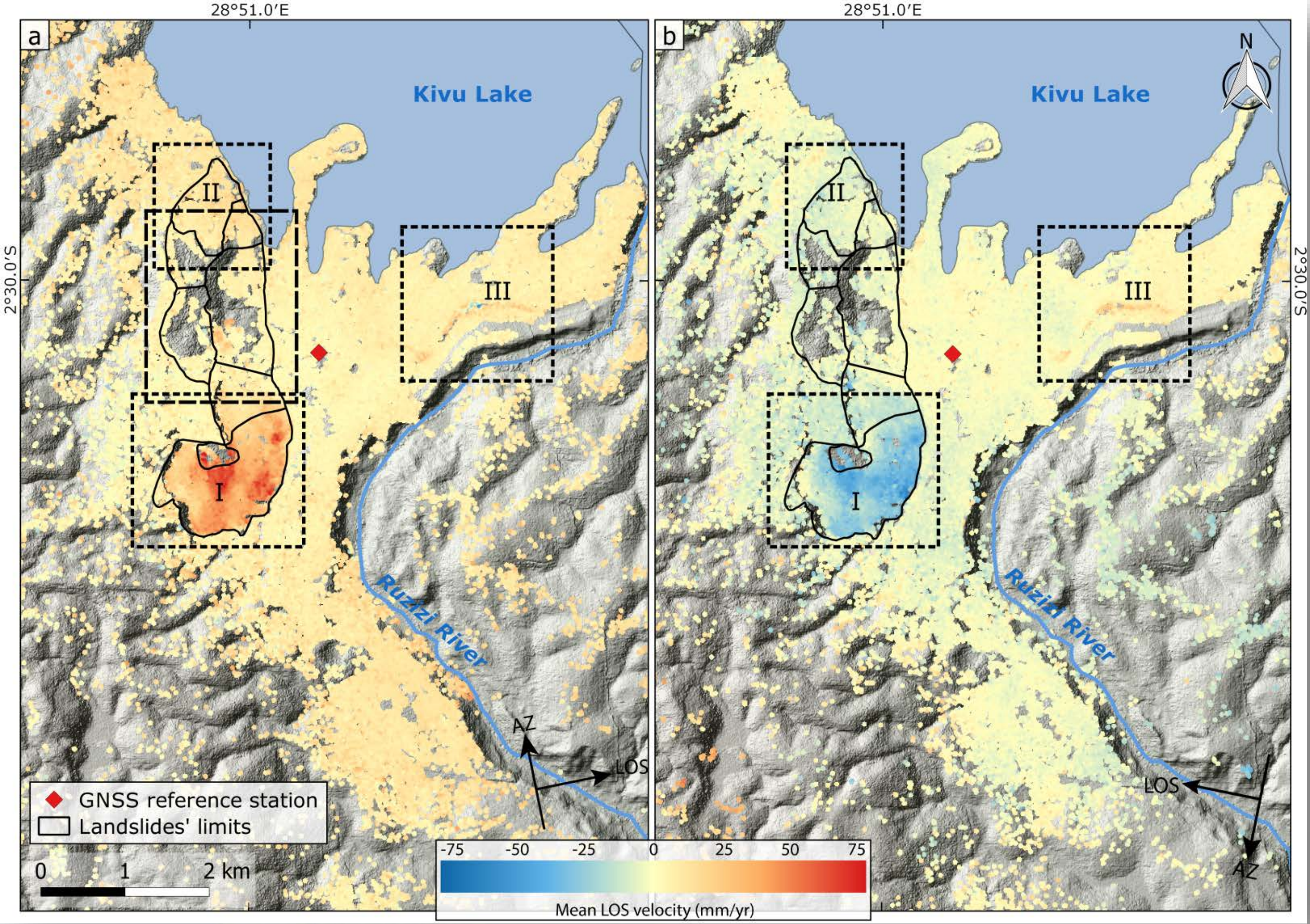




HR Pléiades image draped on 5 m TanDEM-X DEM. This figure focuses on **a large (1.5 km²), deep-seated and slow-moving landslide** (Funu landslide) that affects the densely inhabited (~80 000 inhabitants in the landslide) south-western part of the city of Bukavu.

Dewitte et al. in preparation

InSAR deformation rate maps

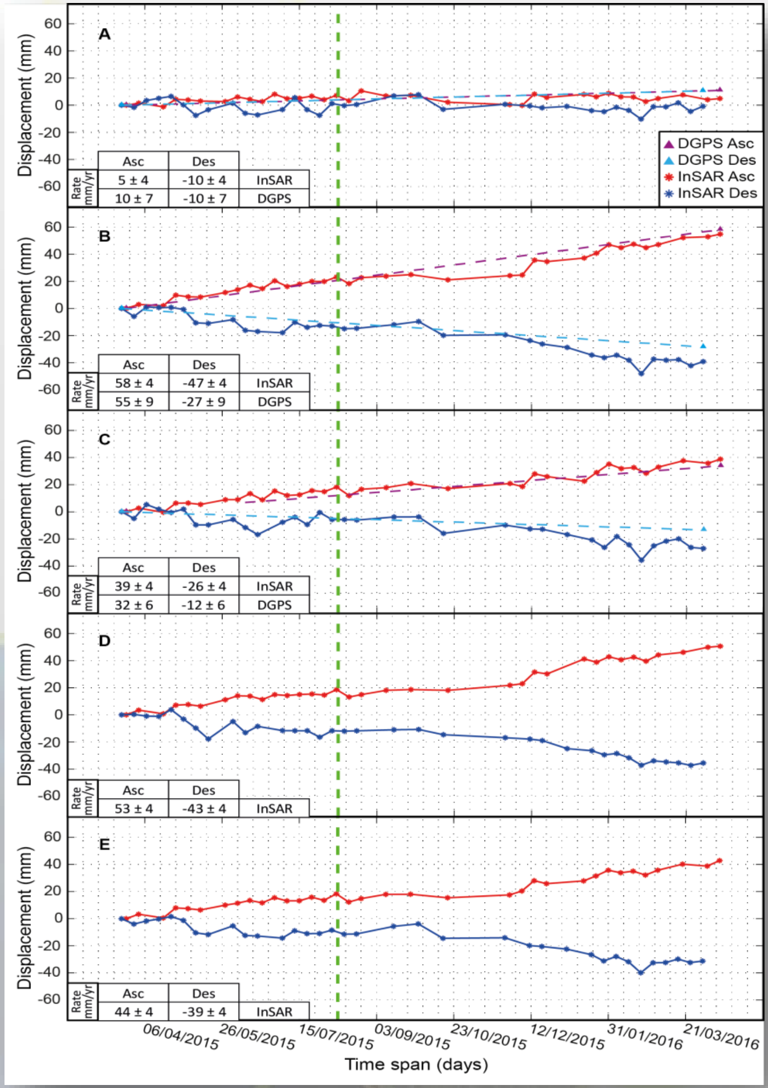


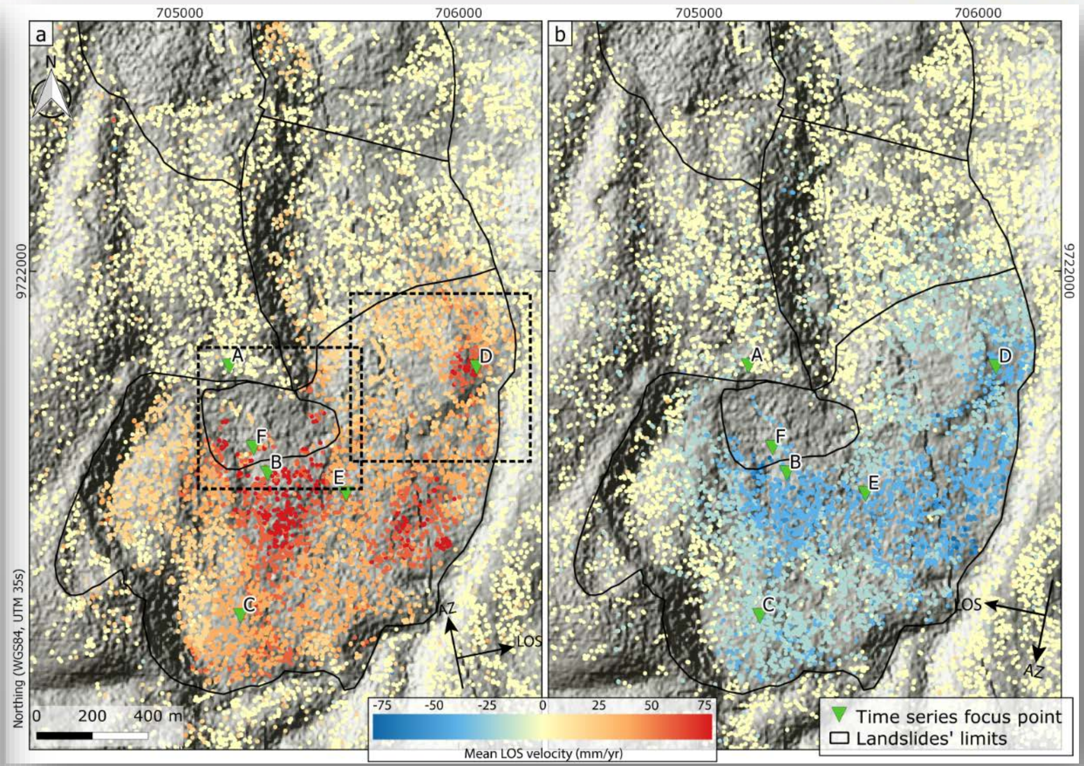
70 CSK images were acquired through the RESIST at a discounted rate through a specific agreement between Belspo (Belgian Science Policy) and A.S.I. - Agenzia Spaziale Italiana. This was possible thanks to the RESIST project which is supported by Belpso and its space program.

InSAR deformation rate maps for the ascending (a) and descending (b) CSK datasets. The combination of the LOS vectors from the ascending and descending datasets shows clearly the **large (1.5 km²), deep-seated and slow-moving landslide** affecting the SW part of the city (I) moving towards the east with an important subsidence component.

Dewitte et al. in preparation

Bukavu ground deformation



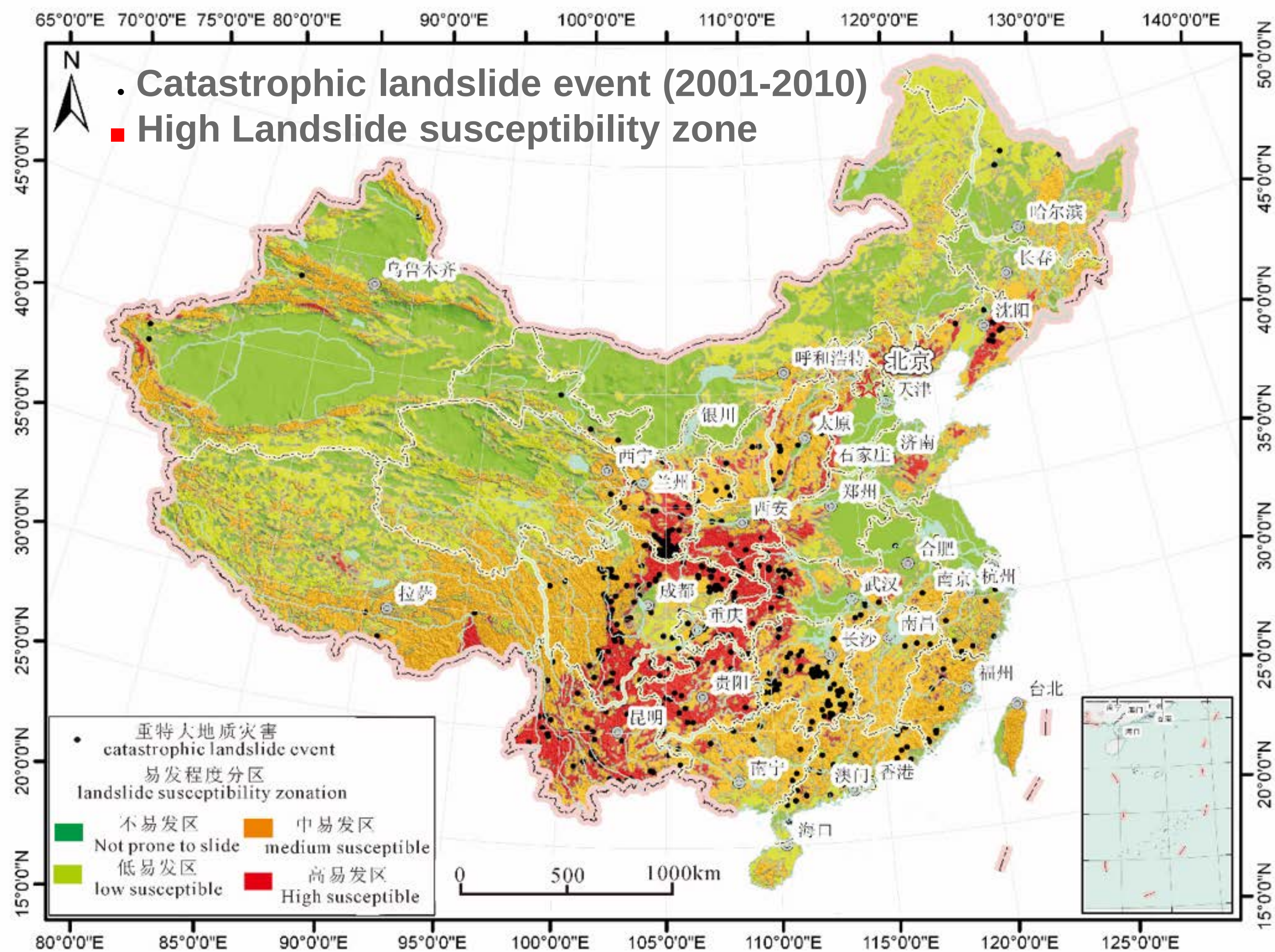


Zoom on Funu landslide (I). Points A to F correspond to the positions where we extract the InSAR displacement time series in Figures 7 and 8 ; the points A, B and C also corresponding to DGPS benchmarks.

Time series of displacement obtained from InSAR on which are overlaid the rates obtained from DGPS measurements when available. The green dashed line corresponds to the Mw 5.8 August 2015 Lwiro Earthquake.

Dewitte et al. in preparation

China Pilot - Landslide Hazards in China



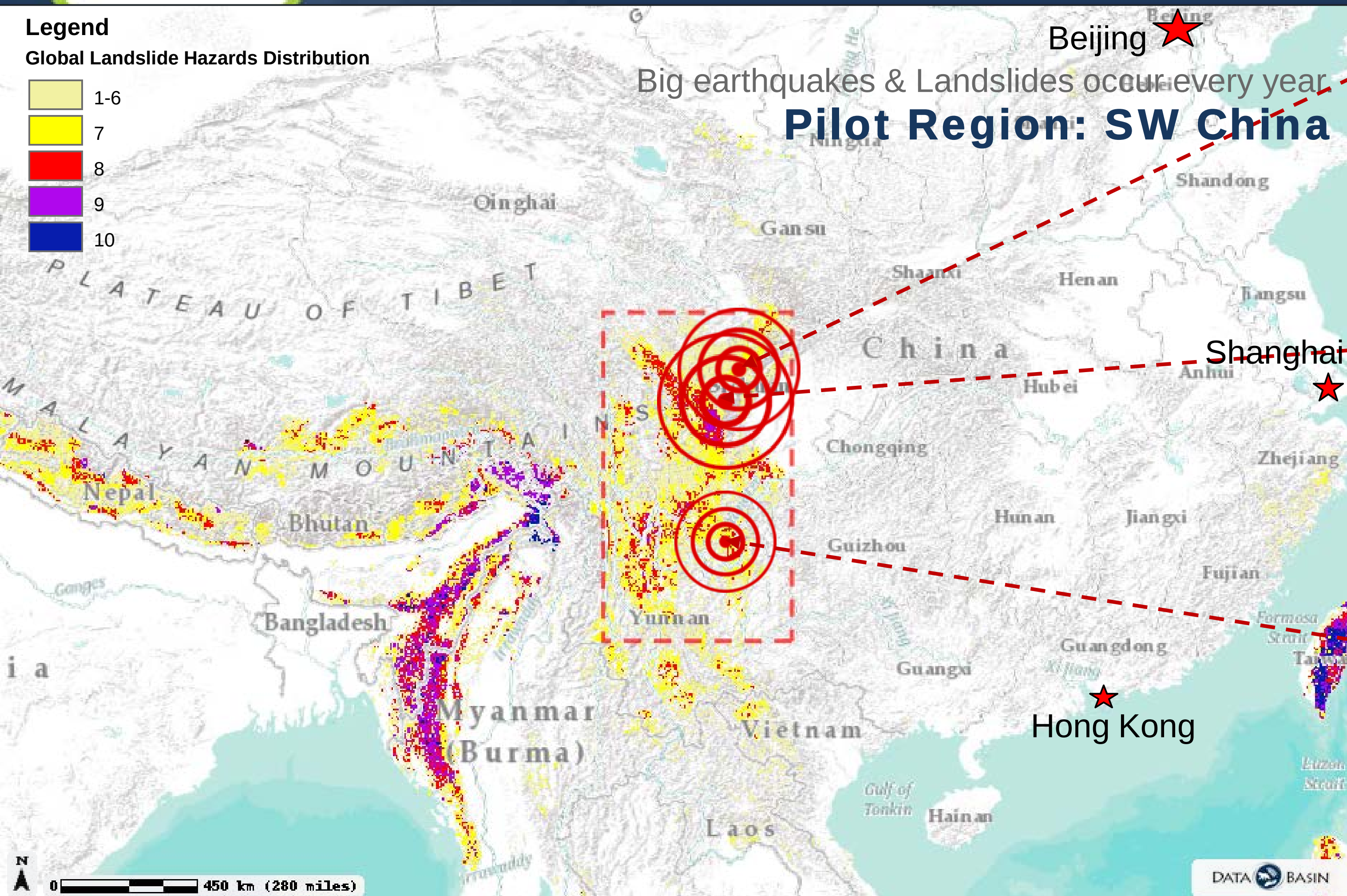
Landslide susceptibility map and catastrophic landslide events during 2001-2010 in China (Jusong Shi et al., 2012)

Threating

- 280,000 potential landslide hazards*
- 10 million people
- 200 billion property

(*China Geological Survey)

China Pilot – Region of Interest



Ms7.0 Earthquake

- **Jiuzhaigou, August 8, 2017**
- **No. of landslides: unknown**
- 617 deaths, 112 missing.

Ms8.0 Earthquake

- **Wenchuan, May 12, 2008**
- **48,000 landslides***
- **70,000 fatalities (20,000 by landslides)**

Ms6.5 Earthquake

- **Ludian, August 3, 2014**
- **1,000+ big landslides**
- Thousands killed in slides

Global Landslide Hazards Distribution

https://databasin.org/datasets/b5c842f4b248464593a7673f5ad7f10f

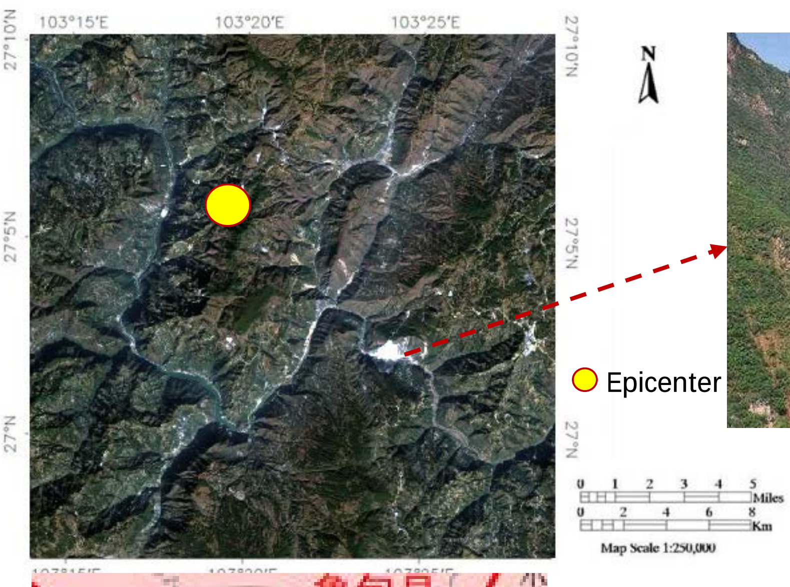
(*Runqiu Huang et al., 2011)

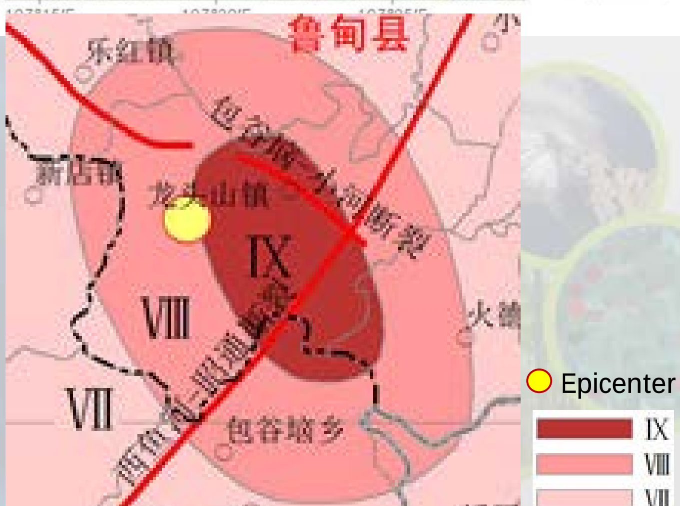
Credits: Center for Hazards and Risk Research (CHRR); Center for International Earth Science Information Network (CIESIN), Columbia University; Norwegian Geotechnical Institute (NGI)

China Pilot – Study Area and Data

Epicentral zone

of Ms6.5 Ludian Earthquake, 2014





Landslides & Barrier Lake

(water level 58m)

Floods

(10+ towns, 30 k㎡ croplands)

Optical Images Time Series

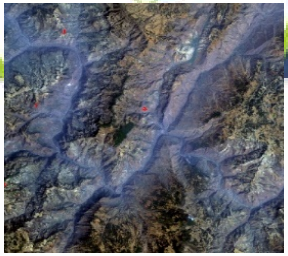
(332 images with 8-30m Res., 2000-2016)

Satellite Sensor	Period	Images No.	Revisit period	Spatial Res.	Country
Landsat TM/ETM+/OLI	2000~	**172**	16 d	15/30 m	USA
GF-1 CCD	2013~	**68**	4 d	2/8/16m	China
HJ-A/B CCD	2008~	**92**	4 d	30 m	China

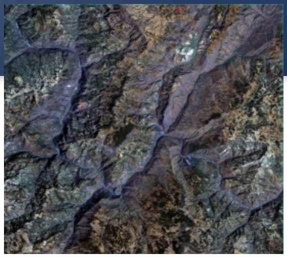
China Pilot – Visually Interpreted Landslides (2000-2015)

Year (Landslides)

● Landslides > 90*120 m²



2000 (6)



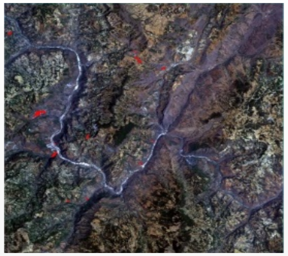
2001 (6)

2002 (12)

2003 (15)

2004 (16)

2005 (12)



2006 (12)

2007 (10)

2008 (17)

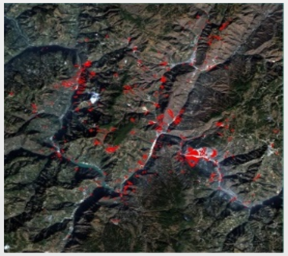
2009 (10)

2010 (14)

2011 (5)

2012 (10)

2013 (7)

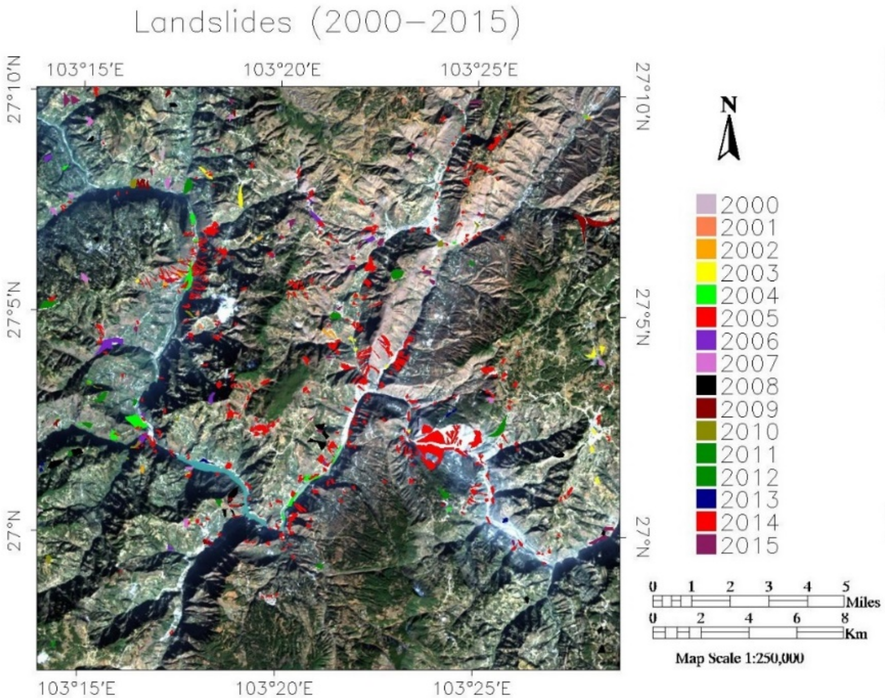


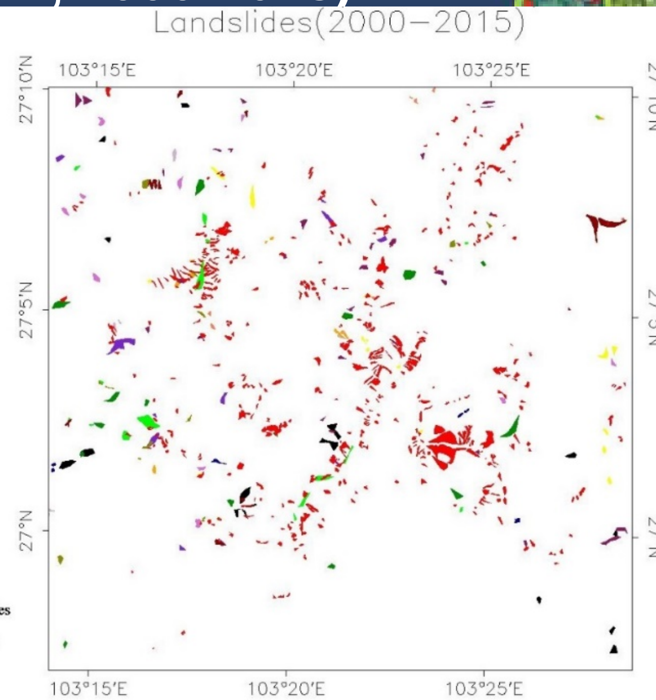
2014 (526)

2015 (28)

Year	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Landslides	*6*	*6*	*12*	*15*	*16*	*12*	*12*	*10*	*17*	*10*	*14*	*5*	*10*	*7*	*526*	*28*
Total Area (km²)	*0.24*	*0.12*	*0.30*	*0.60*	*1.14*	*0.34*	*0.95*	*0.52*	*1.34*	*0.84*	*0.52*	*0.68*	*0.64*	*0.21*	*6.5*	*1.10*

China Pilot – Map of Landslides (> $0.01 km^2$, 2000-2015)

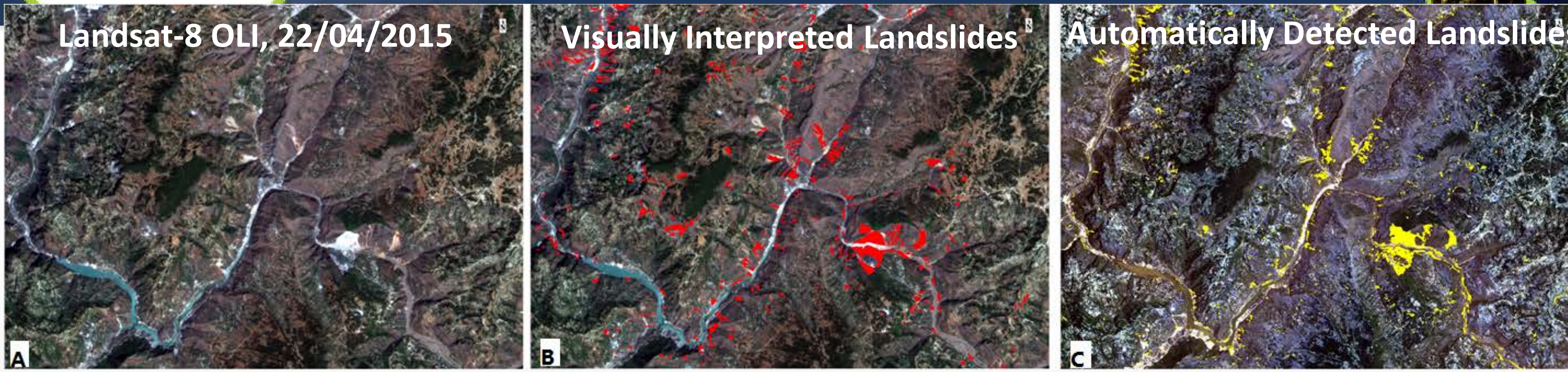




– Landslides occurred every year

– Large amount of huge landslides were induced by earthquake in 2014

China Pilot – Landslide Detection in Multi-temporal Images



Results:

Detect	Interpreted	TP	FN	Producer Accuracy	User Accuracy
1372	1017	872	145	63.56 %	**83.28 %**

- How to detect landslides?

  Dynamics of Vegetation cover pre- &post- landslides.

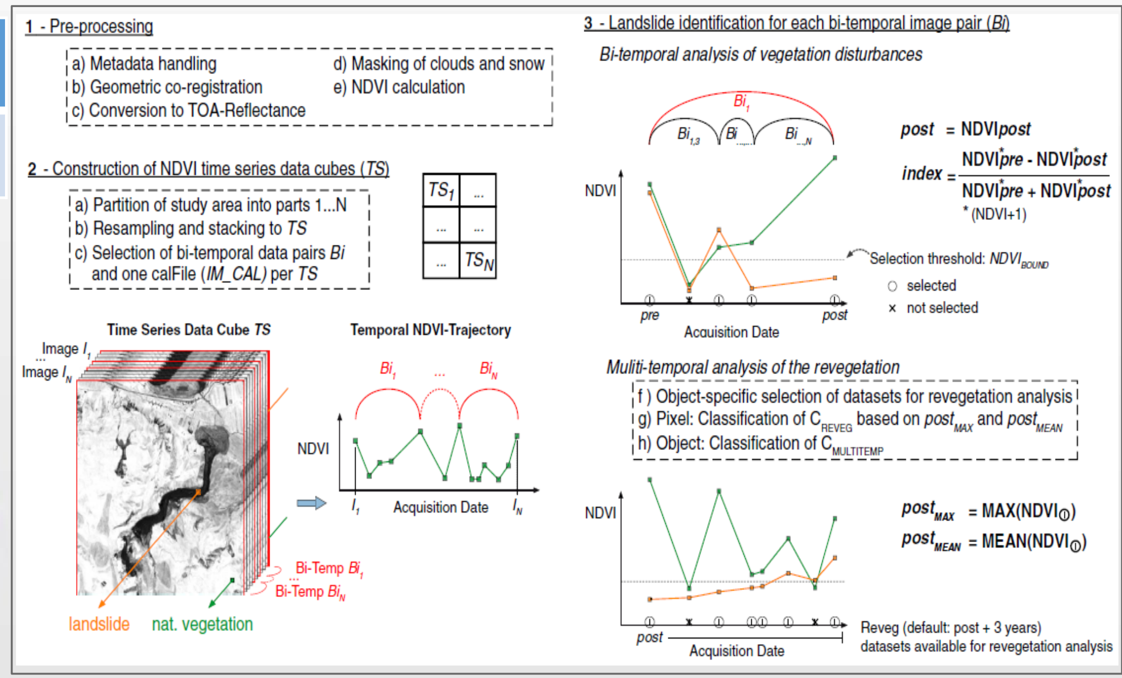
- What are false landslides?

  New roads and quarries.

- What are missing landslides?

  Shallow slopes with little vegetation.

Method used:



R. Behling, S. Roessner, D. Golovko, et al., “Derivation of long-term spatiotemporal landslide activity—A multi-sensor time series approach,” Remote Sensing of Environment (**2016**).

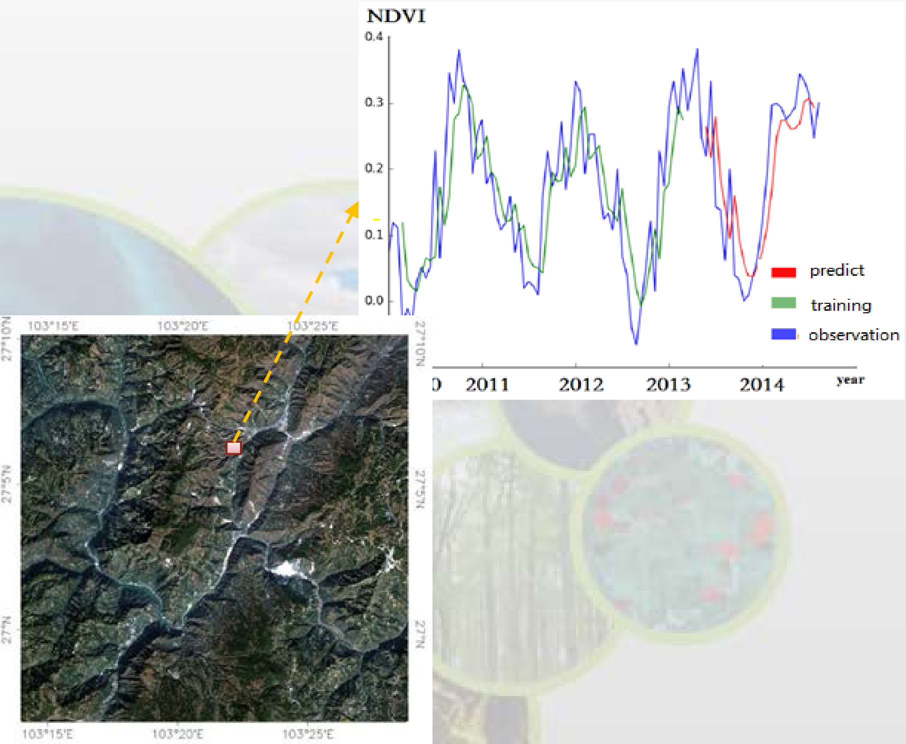
China Pilot – What's next

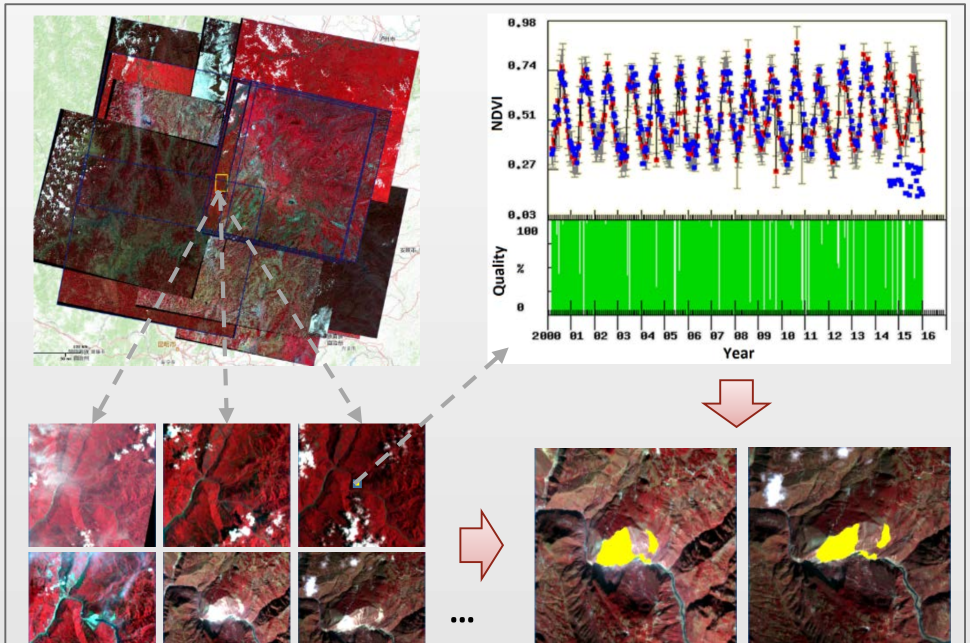
- Objective A:

Develop more effective multi-temporal methods for merging multi-source optical satellite images to better detect historical landslides on a quarterly to monthly basis.

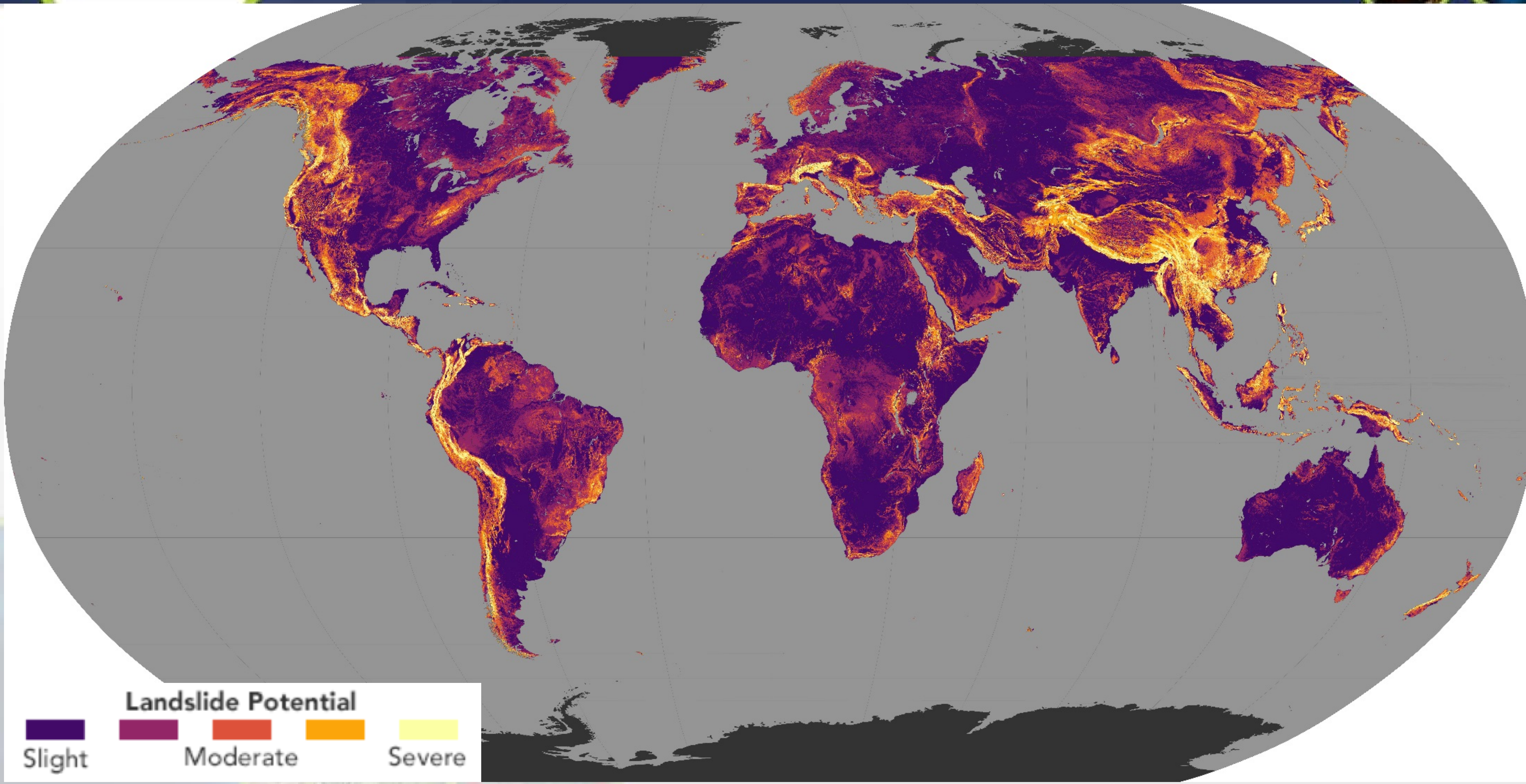
- Objective B:

Develop Machine Learning-based methods for understanding patterns in images time series to rapidly detect new landslides in new available satellite images.



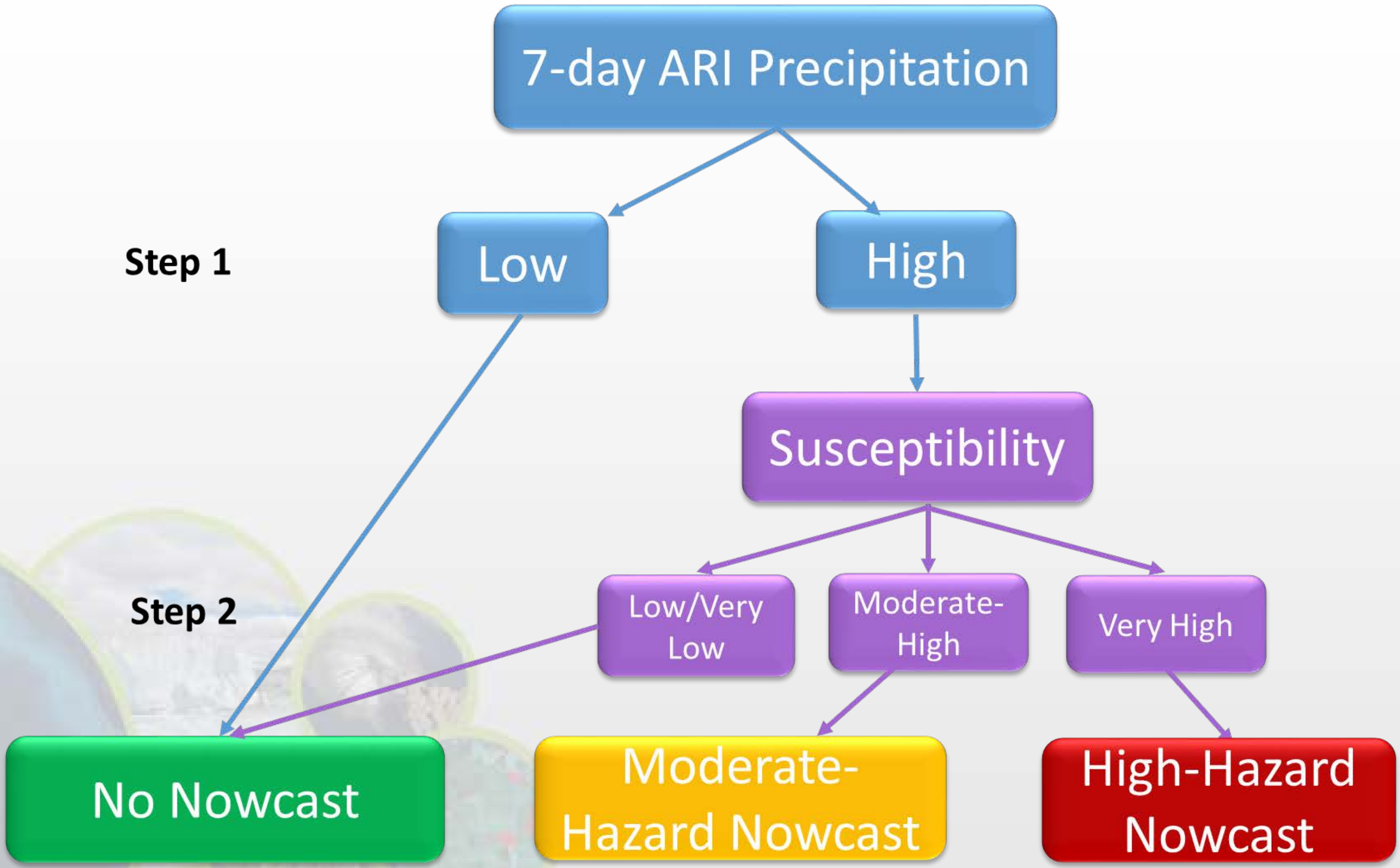


Global Landslide Efforts



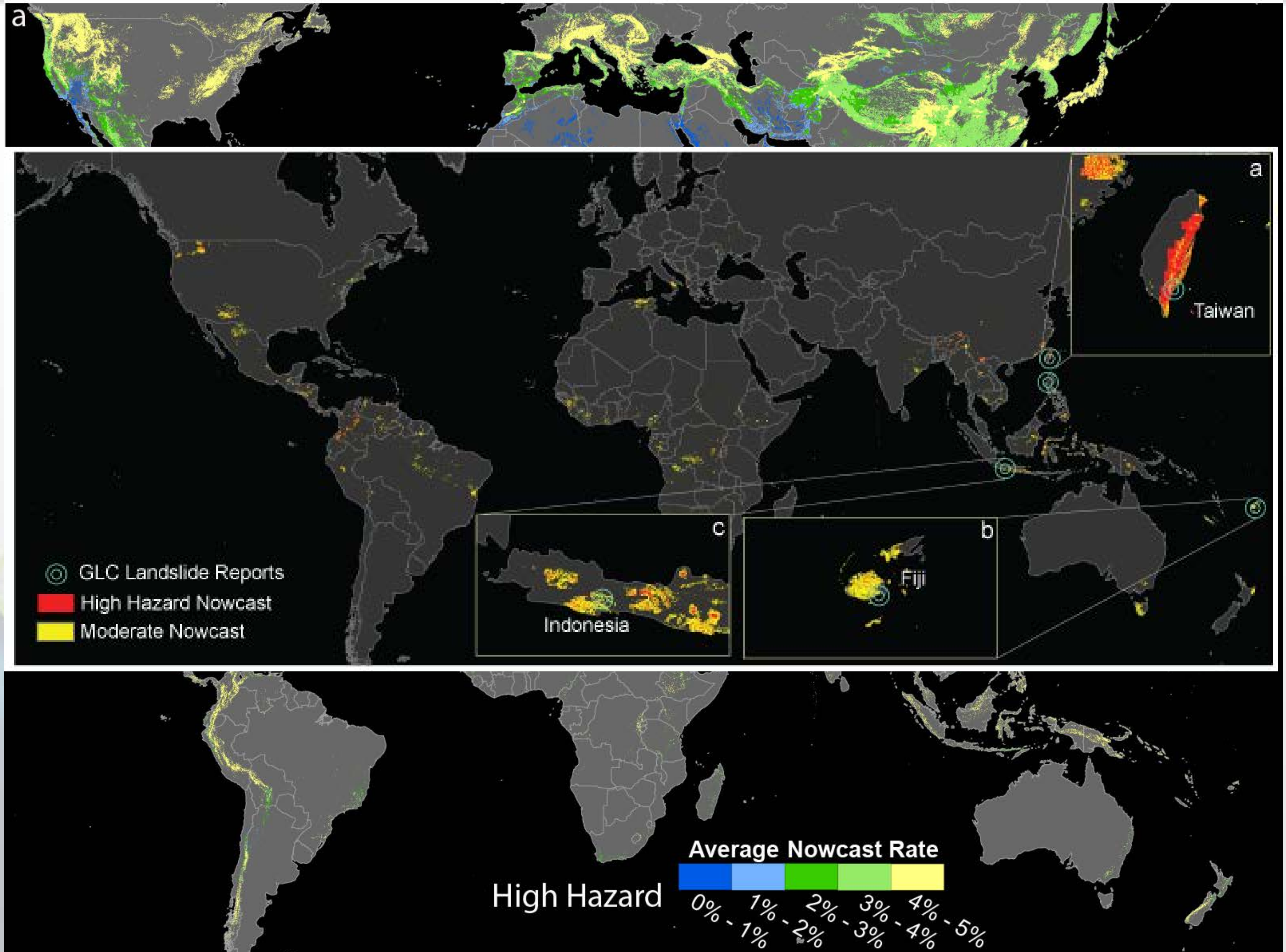
Global landslide susceptibility using slope, forest cover change, soils, geology, and distance to roads. Stanley and Kirschbaum (2017)

Landslide Hazard Assessment for Situational Awareness

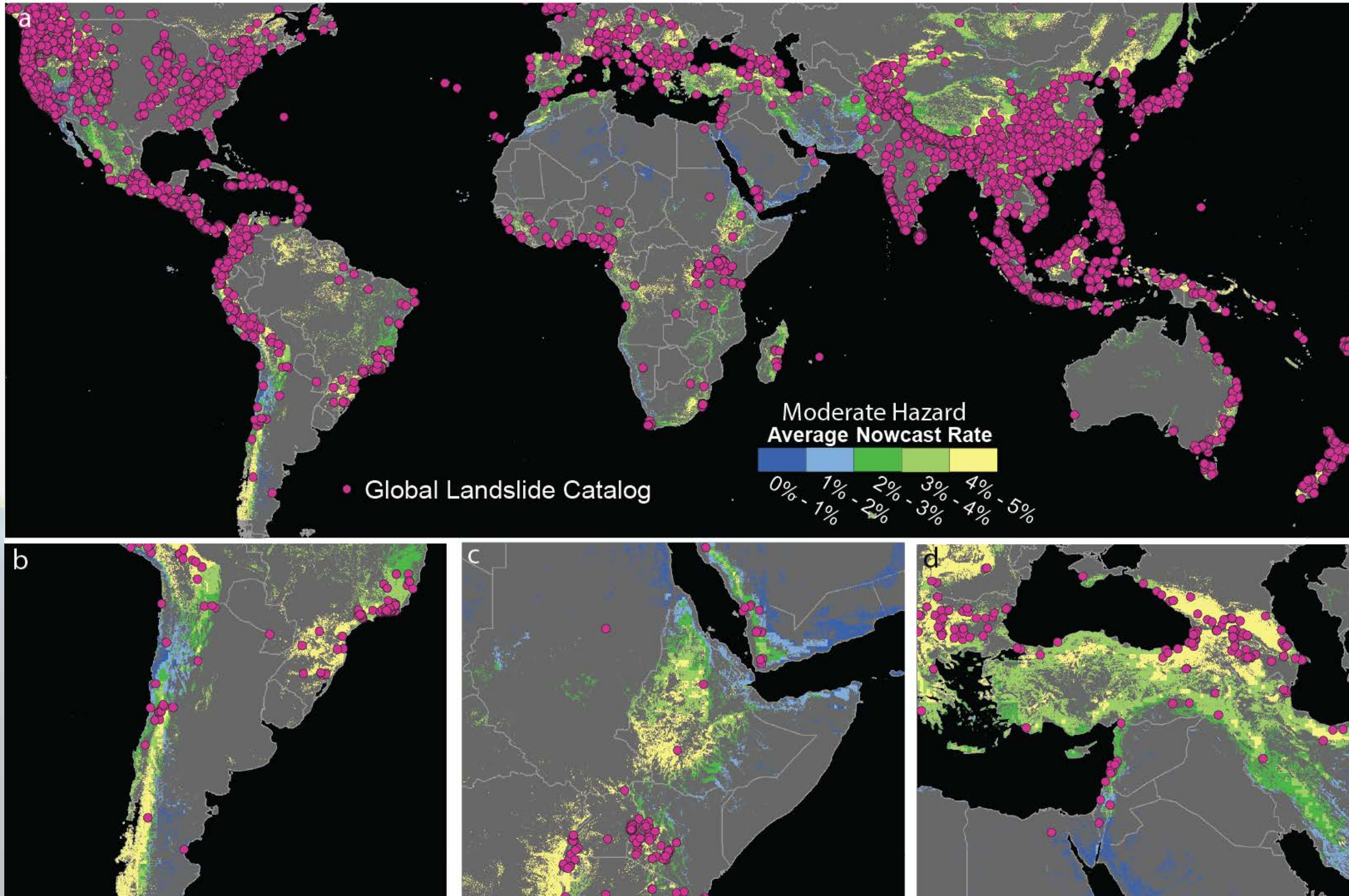


Kirschbaum and Stanley, in prep

Global landslide Nowcasts



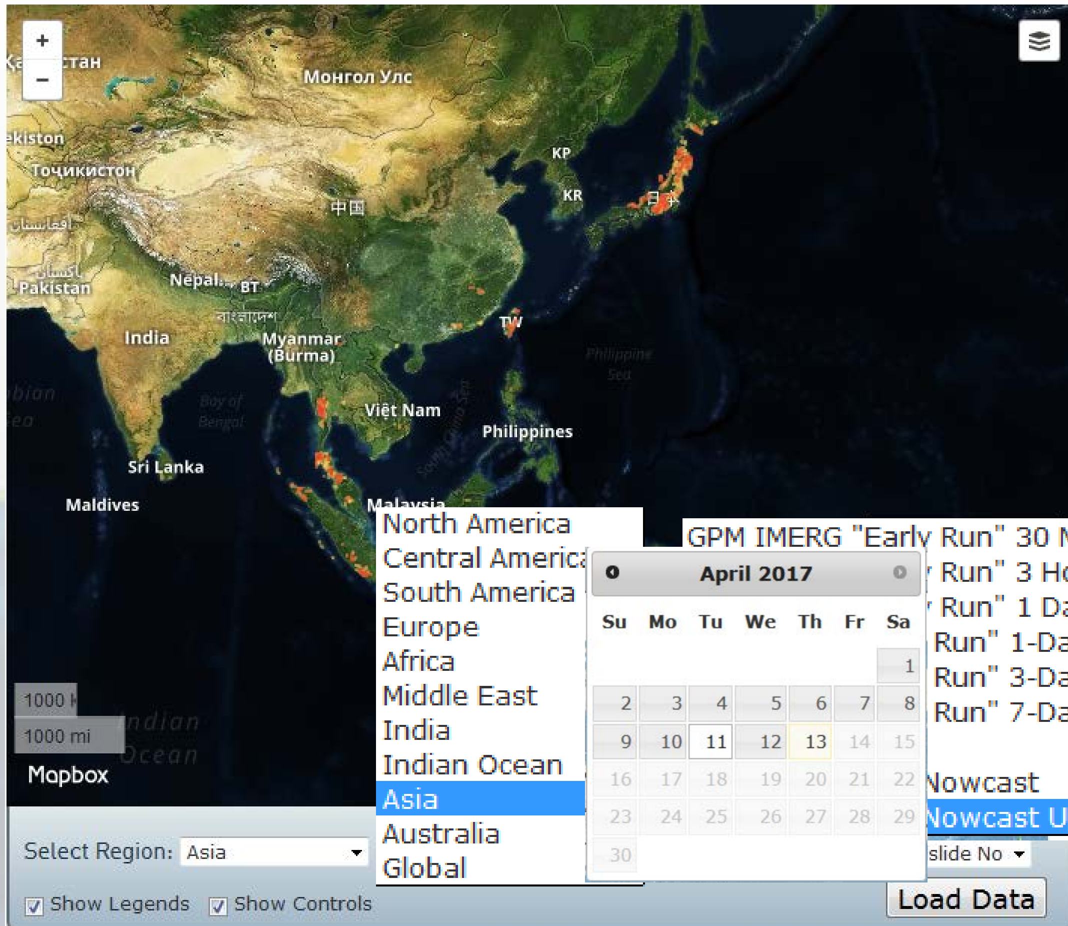
Kirschbaum and Stanley, in prep


a
Moderate Hazard
Average Nowcast Rate
0% - 1%
1% - 2%
2% - 3%
3% - 4%
4% - 5%
Global Landslide Catalog
b
c
d

Data access

https://pmm.nasa.gov/precip-apps

- Landside information can be accessed through an interactive, online viewer
- Export landslide nowcasts, IMERG precipitation, and flood nowcast
- This is a prototype system and we are working on continued validation and related publication.



Download:

- topojson.gz
- geotiff

Export:

- geojson
- arcjson
- shp.tgz

Final Remarks

Operational Take-aways

- Working through the data access pipeline has taken a long time, but we hope to begin receiving data within the month
- A large impediment in the process has been the ability to sign agreements from another government agency
- There is interest and there are opportunities to leverage the Landslide pilot for rapid assessment post-disaster; however, there have not yet been many examples (Sierra Leone is a recent one where Lorant was involved with Jean-Philippe Malet)

Science Take-aways

- Cutting edge research on the potential for exploiting SAR imagery for landslide detection and monitoring in complex terrain with dense or seasonal vegetation (such as in Nepal) is ongoing, but decorrelation remains a major issue in this region. The majority of the community is still reliant on optical or multi-spectral imagery.
- The pilot is keenly interested in gaining access to SPOT data, if possible, to expand the multi-temporal landslide mapping capabilities, particularly over Nepal