Committee on Earth Observation Satellites

Landslide Disaster Working Group Pilot:

March 16th, 2017, Rome
WGDisaster Meeting #7

Co-leads of landslide pilot

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

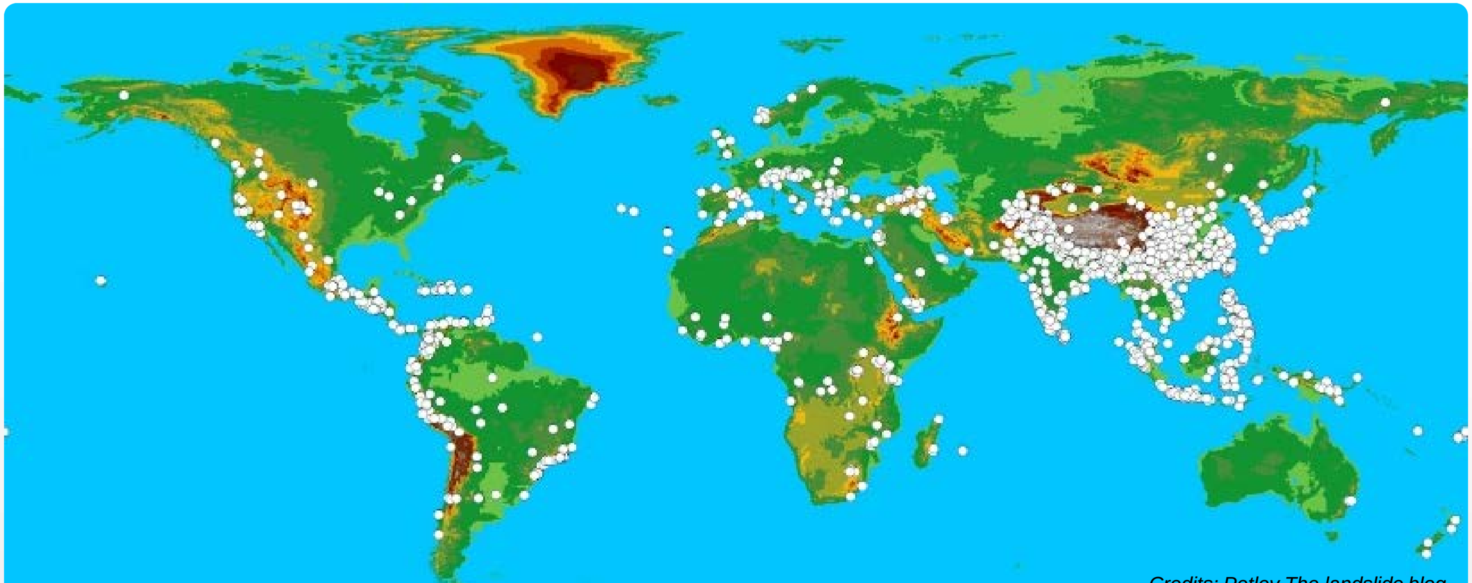
Dr. Jonathan Godt, Landslide Hazards Coordinator, U.S. Geological Survey, Colorado, USA

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

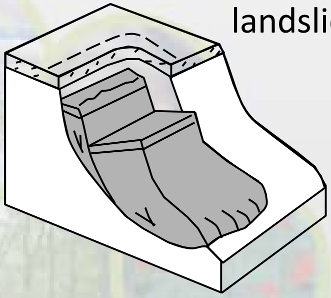
Dr. Sigrid Roessner, GFZ German Research Centre for Geosciences, Germany

Landslides – global fatal hazard

Fatal landslides 2002-2012 ca. 90,000 fatalities



Credits: Petley The landslide blog



Credits: USGS The landslide handbook

UN-Spider Data application guidelines:
http://www.un-spider.org/links-and-resources/data-sources/daotm-landslides

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. 25,000 landslides

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


Credits: Onlinekhabar

Nepal: Bhote Koshi July 2016
http://english.onlinekhabar.com/2016/07/08/381114


Credits: Tsou Univ. Kyoto

Taiwan: fotos before and after typhoon

Long-term large-area landslide monitoring in Kyrgyzstan

Area of intense and constant landslide activity (>10,000km²)

Fatalities and destroyed infrastructure each year

Big need for systematic and continuous process analysis over time and space – monitoring

Credits: Robert Behling, GFZ Potsdam

Credits: MES, Kyrgyzstan

Constant seasonal landslide activity

Constantly ongoing activity without major triggering events

e.g. 27.04.2016 failure: 1 victim

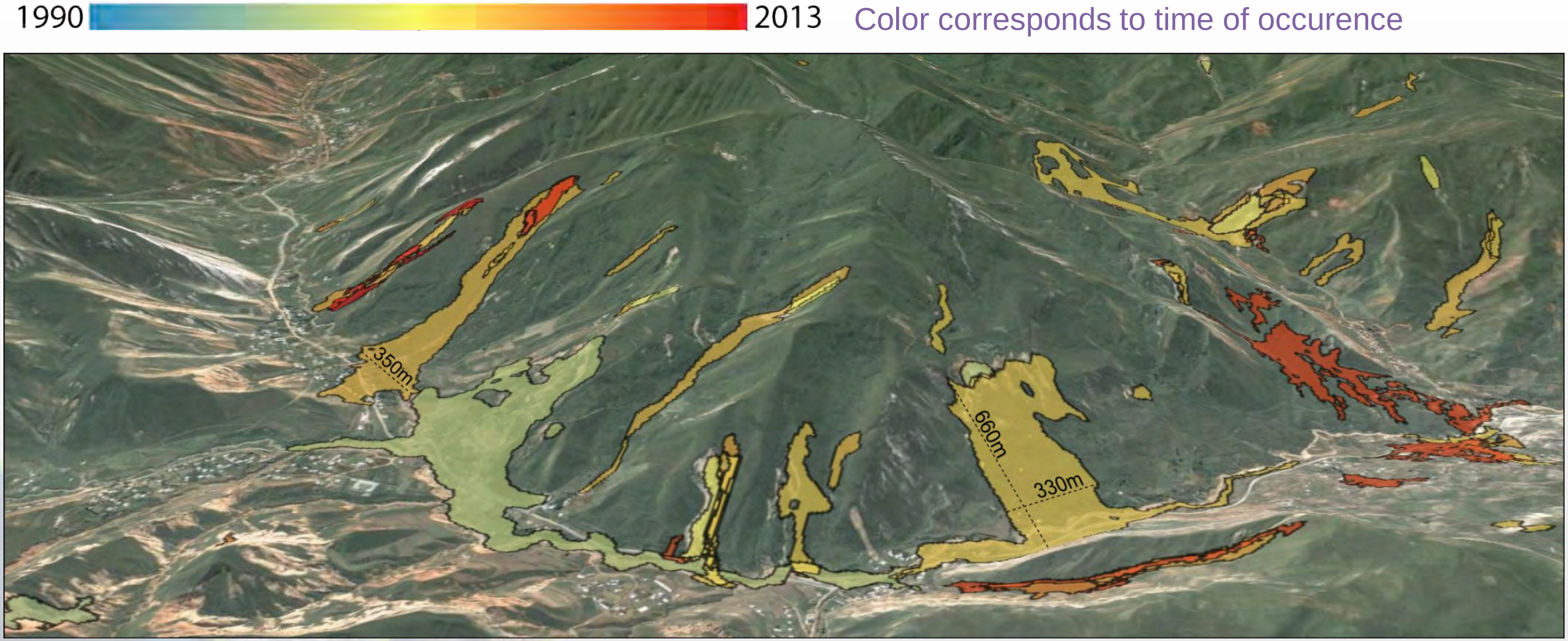
Total of two failures: 1st 0.1km³, 2nd 1.6km³

Featured in AGU landslide blog
http://blogs.agu.org/ - Landslide Kyrgyzstan
Link to video documenting landslide failure
https://youtu.be/mB6x18IzUJA

Foto: Drone image taken by GFZ Potsdam (October 2016)

Video: landslide failure 27.04.16

Long-term Landslide Mapping
object-based multi-temporal detection



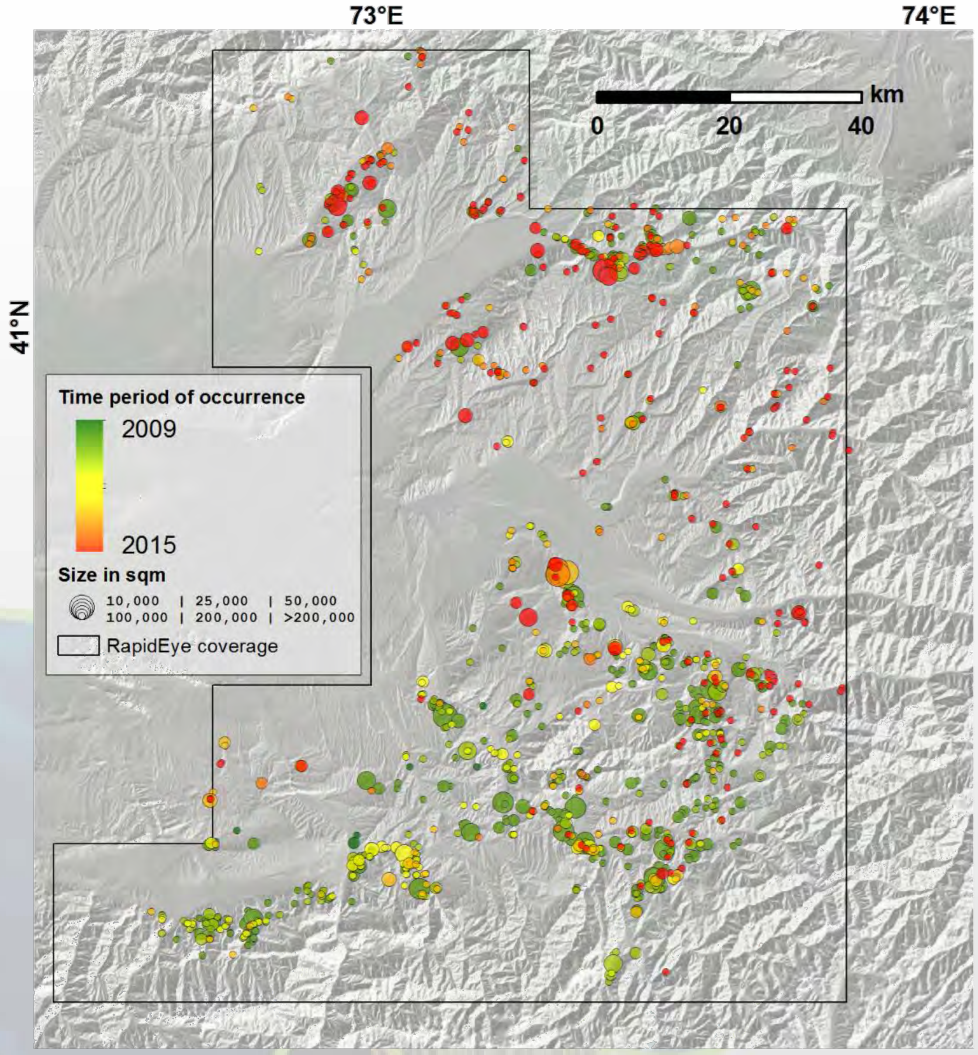
Color corresponds to time of occurence

Automated Approach identifies landslides:

- of different shapes, sizes, lithology, activity stage (fresh, reactivation)
- of multiple activations (enlargements, secondary movements)

Behling, R., Roessner, S., et al., 2016. Derivation of long-term spatiotemporal landslide activity - A multi-sensor time series approach. *Remote Sensing of Environment,* 186, 88–104.

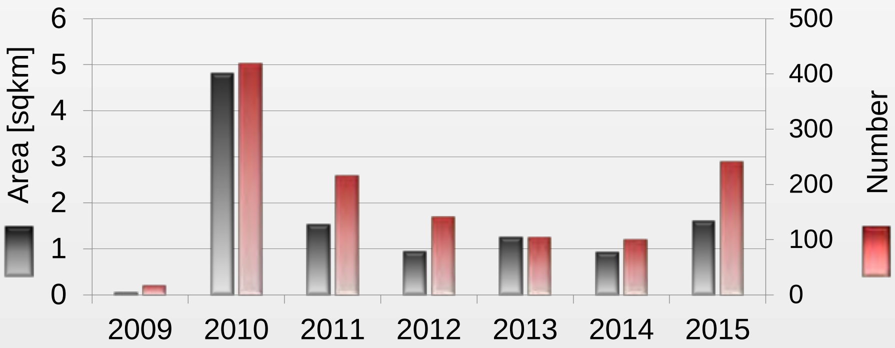
Automated Regular Monitoring of Landslides over Large Areas



Kyrgyzstan: 12,000 km² area

Time period: 2009 - 2015

- 1022 RapidEye datasets (RESA program)
  - intervals up to several days
- 1239 landslides (~90 reported by authorities)
- 100 sqm – 0.75 sqkm, 11 km² total
- Clear short-term spatiotemporal variations

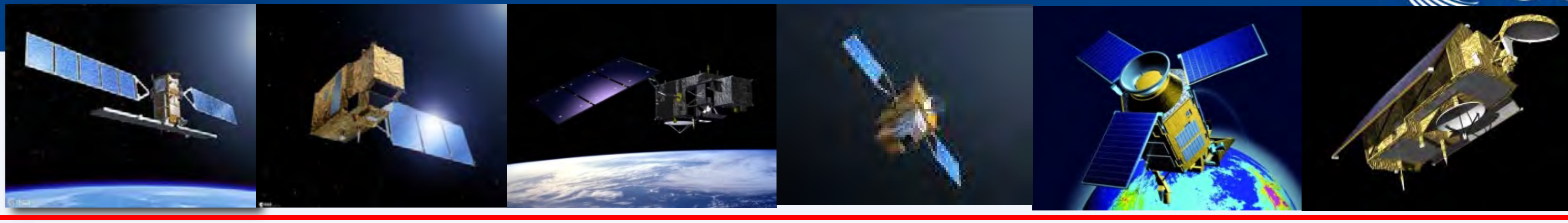


- continuous landslide activity without any major trigger - need for regular monitoring

Behling, R., Roessner, S., et al., 2014. Automated Spatiotemporal Landslide Mapping over Large Areas Using RapidEye Time Series Data. *Remote Sensing*, 9, 8026-8055.

Behling, R., Roessner, S., et al., 2014. Robust Automated Image Co-Registration of Optical Multi-Sensor Time Series Data: Database Generation for Multi-Temporal Landslide Detection. *Remote Sensing*, 6, 2572-2600.

Copernicus Space Component: Sentinel* Missions



S1A/B: Radar Mission — 1A LAUNCHED 3 APRIL 2014 — 1B LAUNCHED 22 APRIL 2016

S2A/B: High Resolution Optical Mission — 2A LAUNCHED 23 JUNE 2015 — 2B LAUNCHED 7 MARCH 2017

S3A/B: Medium Resolution Imaging and Altimetry Mission

S4A/B: Geostationary Atmospheric Chemistry Mission

S5P: Low Earth Orbit Atmospheric Chemistry Precursor Mission

S5A/B/C: Low Earth Orbit Atmospheric Chemistry Mission

Jason-CS A/B: Altimetry Mission

Landslides 2016 - Sentinel-2A

Status for Landslide WG

- **November 2015:** Landslide Pilot conditionally endorsed by plenary
- **December 2015**: Convened first Disaster Landslide Pilot meeting (virtual)
- **January-Feb 2016**: Conducted survey of participants to define expertise, interests, and areas of focus
- **March 2016:** Introduction of potential Landslide Pilot at CEOS #5 meeting in Bonn, Germany
- **April 2016**: In person meeting of pilot participants in Vienna, Austria
- **July 2016**: Drafted CEOS DRM Landslide Pilot Plan and further defined study areas and co-leads
- **August 2016**: Co-lead meeting to discuss further development of study areas and Landslide Pilot Plan
- **September 2016**: Propose plan to CEOS Disaster WG for approval as 4th disaster pilot
- **September 2016**: Establish the Landslide Pilot web presence on CEOS.ORG with a summary of goals, objectives and participants
- **October 2016:** Confirm Landslide Pilot implementation plan and data acquisition strategy
- **November 2016:** Presentation of landslide pilot in CEOS plenary
- **January 2017**: Planning of data acquisitions for Nepal and Pacific Northwest

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)**

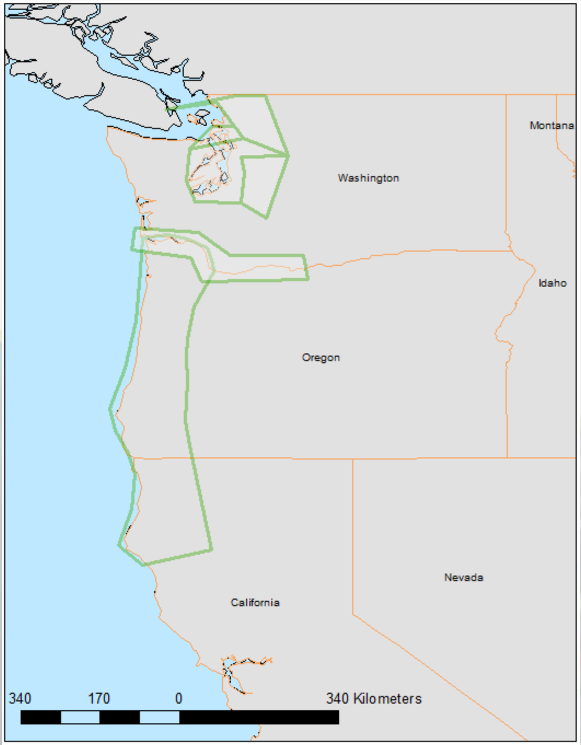
Proposed key user communities

- **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.

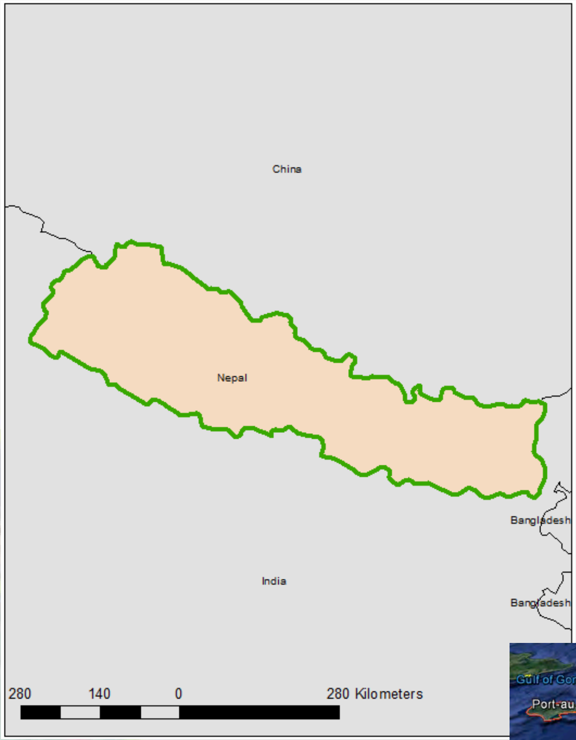
Target areas for Landslide Pilot EO data

The Landslide Pilot will focus on two primary regions (Nepal and the Pacific Northwes, USA) and four experimental regions (Southeast Alaska, China, Caribbean, Peru).

Pacific Northwest, USA



Nepal



Experimental Regions

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***

How data will be exploited

Geographic Area	Products	Key users / local 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 Contributions from CEOS Agencies

Mission/Instrument	Agency	New	Archived	Total	Comments
Sentinel-2A / MSI	**ESA**				Available
EO-1 / ALI	**NASA**				Use Archived Imagery
Landsat-8 / OLI	**USGS**				Available
SPOT (archive only)	**CNES**	20	170	190	
Pleiades	**CNES**	100	75	175	
ALOS-2 / PALSAR-2	**JAXA**	400	100	500	
Sentinel-1A / SAR	**ESA**				Available
Sentinel-1B / SAR	**ESA**				Available
Radarsat-2 / SAR-C	**CSA**	105	155	260	
Cosmo Sky-Med / SAR-2000	**ASI**	400	225	625	
TerraSAR-X	**DLR**	460	100	560	

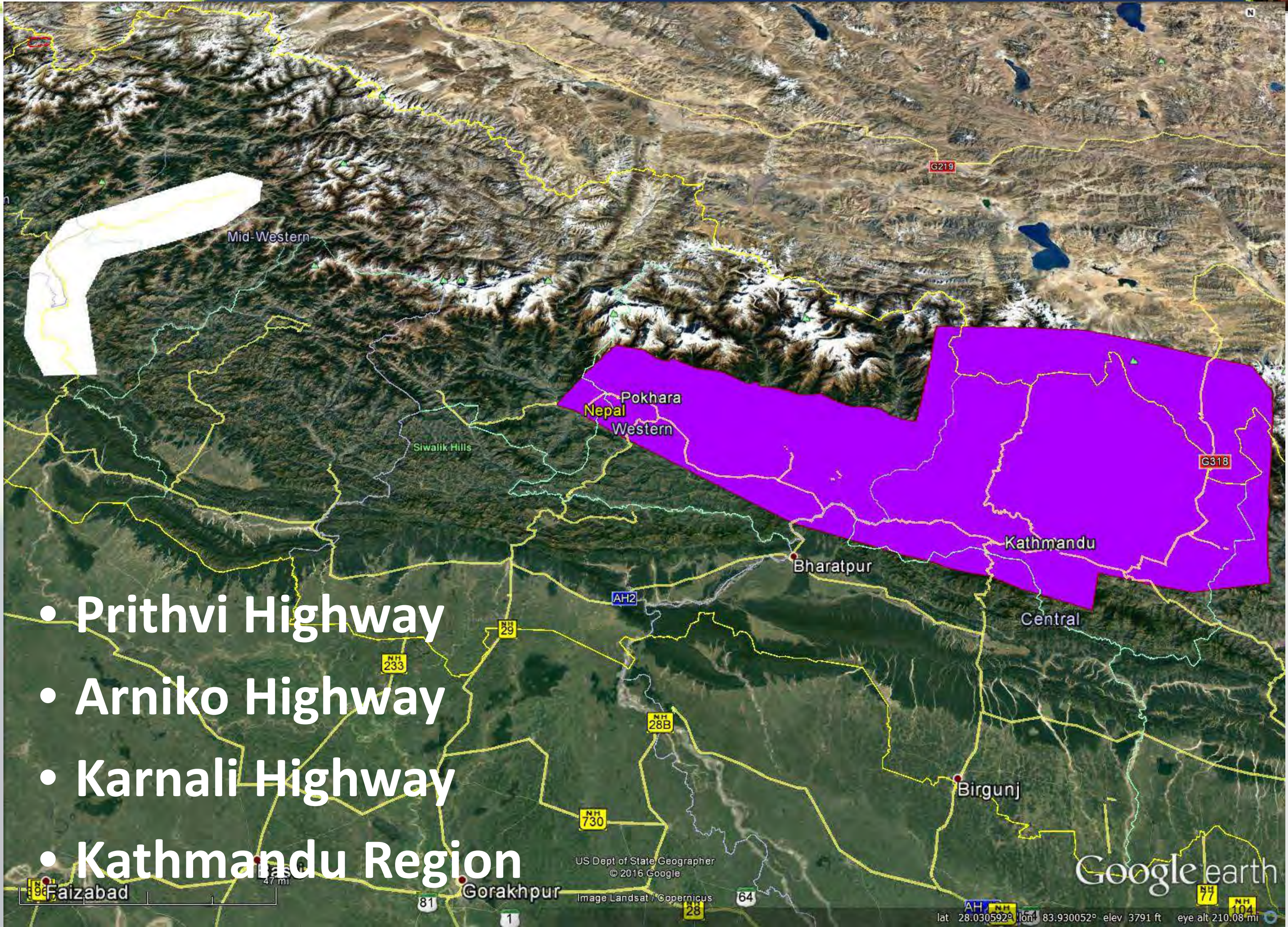
Data requests/region

	Nepal		Pacific Northwest		China		SE Alaska		Peru		Caribbean		Indonesia	
	New	Archived	New	Archived	New	Archived	New	Archived	New	Archived	New	Archived	New	Archived
SPOT (archive only)		60		60	20							50		
Pleiades	25	25	25	25	25	25					25			
ALOS-2 / PALSAR-2	100	50	100		50		25	25	25	25	75		25	
Radarsat-2	30	30		50			25	25			50	50		
Cosmo Sky-Med	150	150	100	50				25					150	
TerraSAR-X (StripMap)	100	all archived datasets	50					50			100		60	
TerraSAR-X (Spotlight)	100						50	50						

Data Request Plan

- Requestor Name, e-mail, affiliation
- Name of Location
- Lat/lon (Decimal Degrees), KML of area is ideal
- Date of request acquisition (or date range preferred)
- Platform/Instrument/Sensor
- Image ID (if available), if stereo images requested, indicate the B/H ratio
- Indicate ability to process raw data
- Brief summary of data usage

Nepal Study area



- Prithvi Highway
- Arniko Highway
- Karnali Highway
- Kathmandu Region

Nepal Study Team

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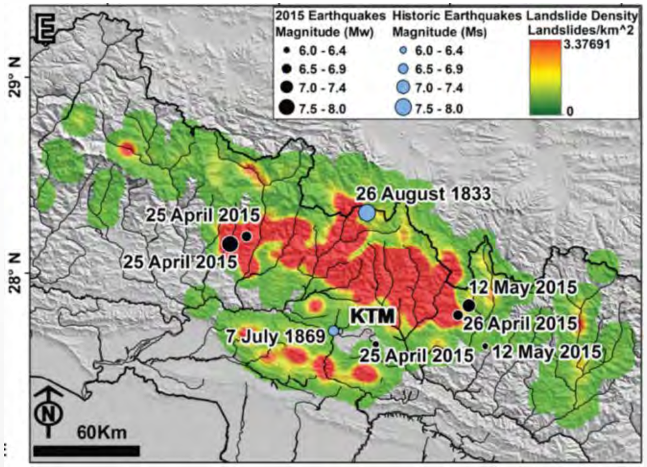
Nepal landslide monitoring

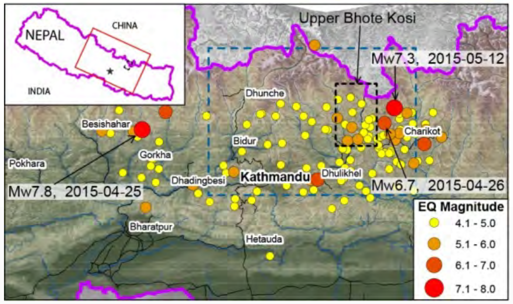
- **Why**: highly active tectonic setting with strong monsoon season that triggers hundreds-thousands of landslides each year. Gorka Earthquake, 2015 caused thousands of landslides that were mapped by many different groups.
- **Who**: Wide range of groups working in this area (Durham University, ITC, USGS, NASA, and other academics, and many more) with a breadth of experience and expertise in this region
- **What**: Engagement with stakeholders and regional experts within the region, leverage data from supersite



Kargel, J. S., et al. 2015, *Science*

Figure 15. Aerial image of the Pisang 2 earth slide along the Marsyangdi River upstream from Pisang village. As of May 30, 2015, this landslide constricted the river with a 350-m-long slackwater lake upstream of the landslide deposit. Maximum width of impoundment in image is approximately 50 m.

Collins and Jibson, Open-File Report 2015-1142



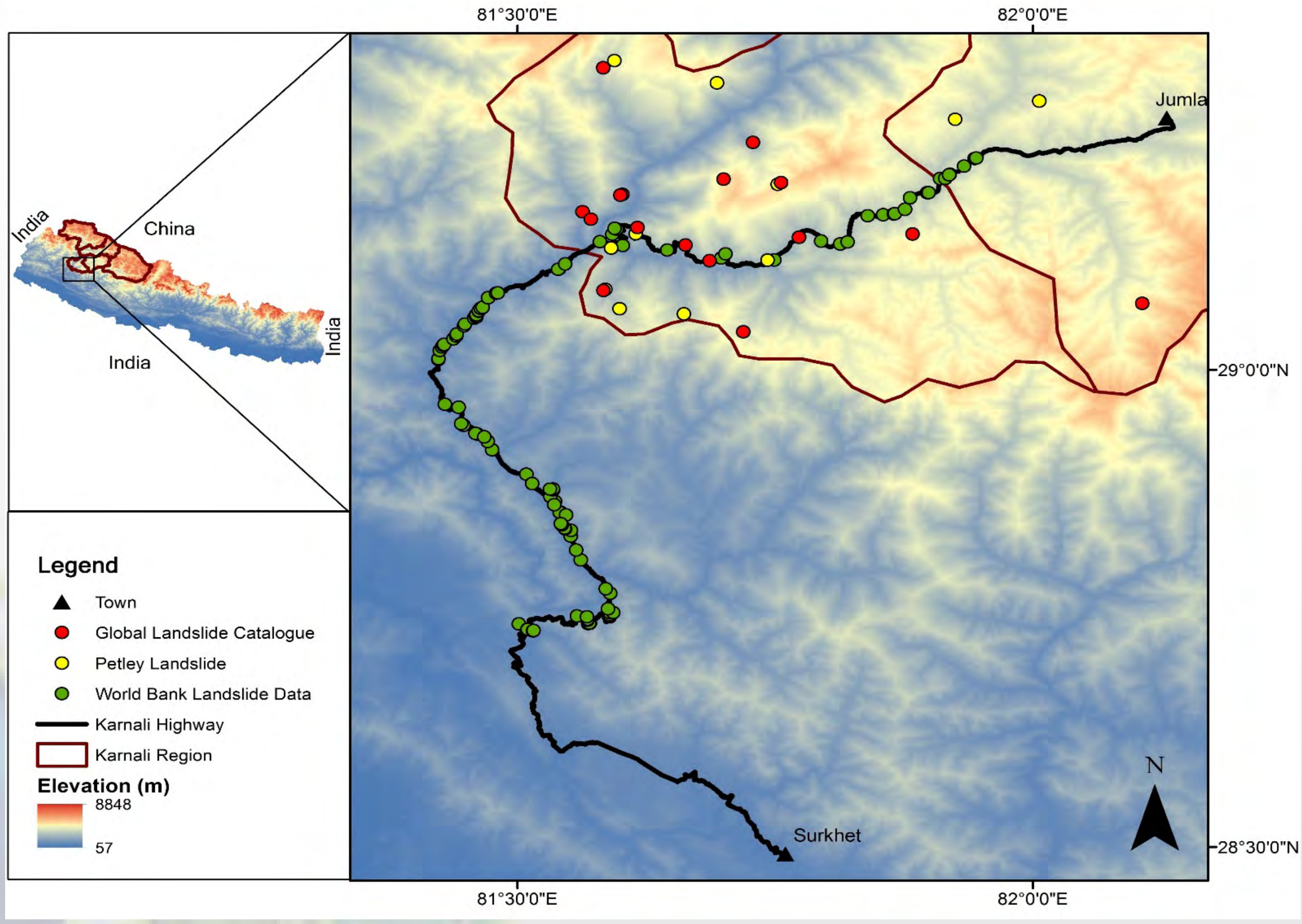
Durham, NSET Nepal, BGS, site monitoring and mapping in Sindhupalchowk, Upper Bhote Kosi, Arniko Highway

GFZ Potsdam: Field based monitoring / remote sensing analysis after Gorkha earth-quake for understanding long-term landsliding and erosion

Karnali Region

- 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.
- Also presents an opportunity to test techniques and lessons learned from The Arniko and Prithivi Highway.
- Will also meet the objective of CEOS to demonstrate the value of satellite EO in context of integrated landslide management practices.

Landslides in Karnali Region



Available EO data

Optical

Data source	Availability	Time	Resoultion
Sentinel 2A	Yes	2015-present	10,20,60 m
Aster	Yes	2000 - present	15,30,90 m
Landsat 8	Yes	2013 - present	15,30 m
SPOT 6-7	Yes	2012,2014 - present	1.5 m
DigitalGlobe	Yes	2007-present	0.5 m

Radar

Data source	Availability	Time	Resolution (No)
Sentinel 1A	Yes	2014 - present	5x20 m (800)
Sentinel 1B	Yes	2016 - present	5x20 m (78)
Radarsat 2	Yes	2008-present	3-100m (319)
TerraSAR X	No		
Cosmo SkyMEd	?		

Nepal 2015 earthquakes - Landslides & residual hazard

c. 25,000 landslides triggered by earthquake sequence

- EQ was equivalent to *c*. 200 years of *normal* annual landslide activity in Nepal
- Predominantly small events: rockfalls, dry debris avalanches, ridgeline failures

Secondary landslide hazard remains high:

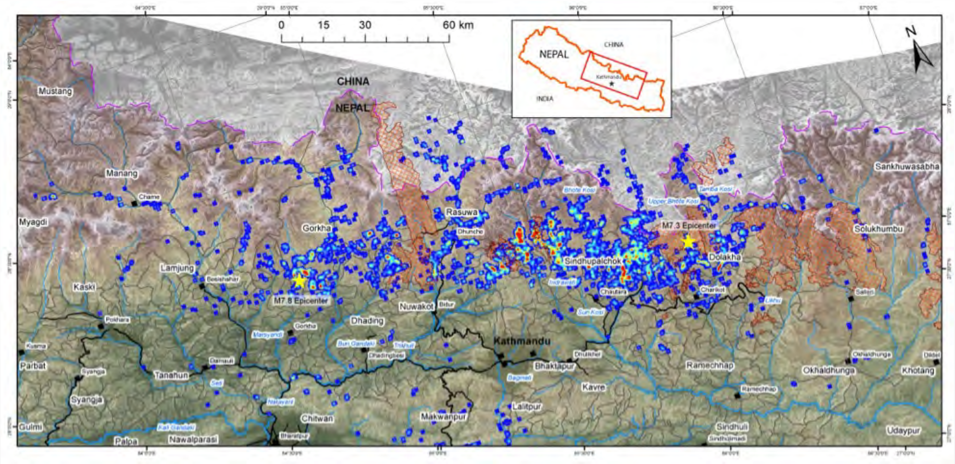
- Incipient landsliding associated with cracked ground
- GLOF (e.g. July ’16) / Landslide dam breach floods observed
- ’15 & ‘16 monsoons were equivalent to *c*. 20 years of normal monsoon-triggered landslide activity

Evolving nature of EQ-triggered landslides:

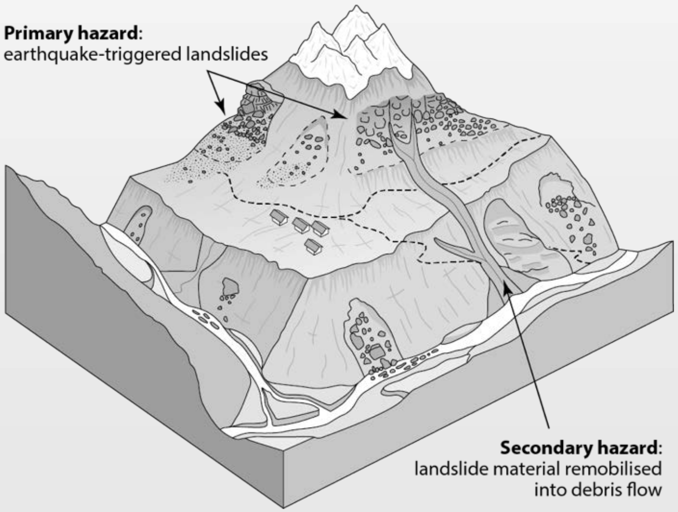
- Landslide number is reducing, but remaining landslides are becoming bigger & are travelling further to valley bottoms

***c*. 400 settlements identified as ‘at risk’** from geohazards by G. of Nepal - National Reconstruction Authority & UNOPS

- Ongoing geohazards assessment is defining future risk management policy for these settlements
- EO data has critical role in supporting this effort



Landslides mapped by DU and BGS in the weeks after the 2015 EQs
Data mapped from optical imagery in Google Crisis, Disaster Charter



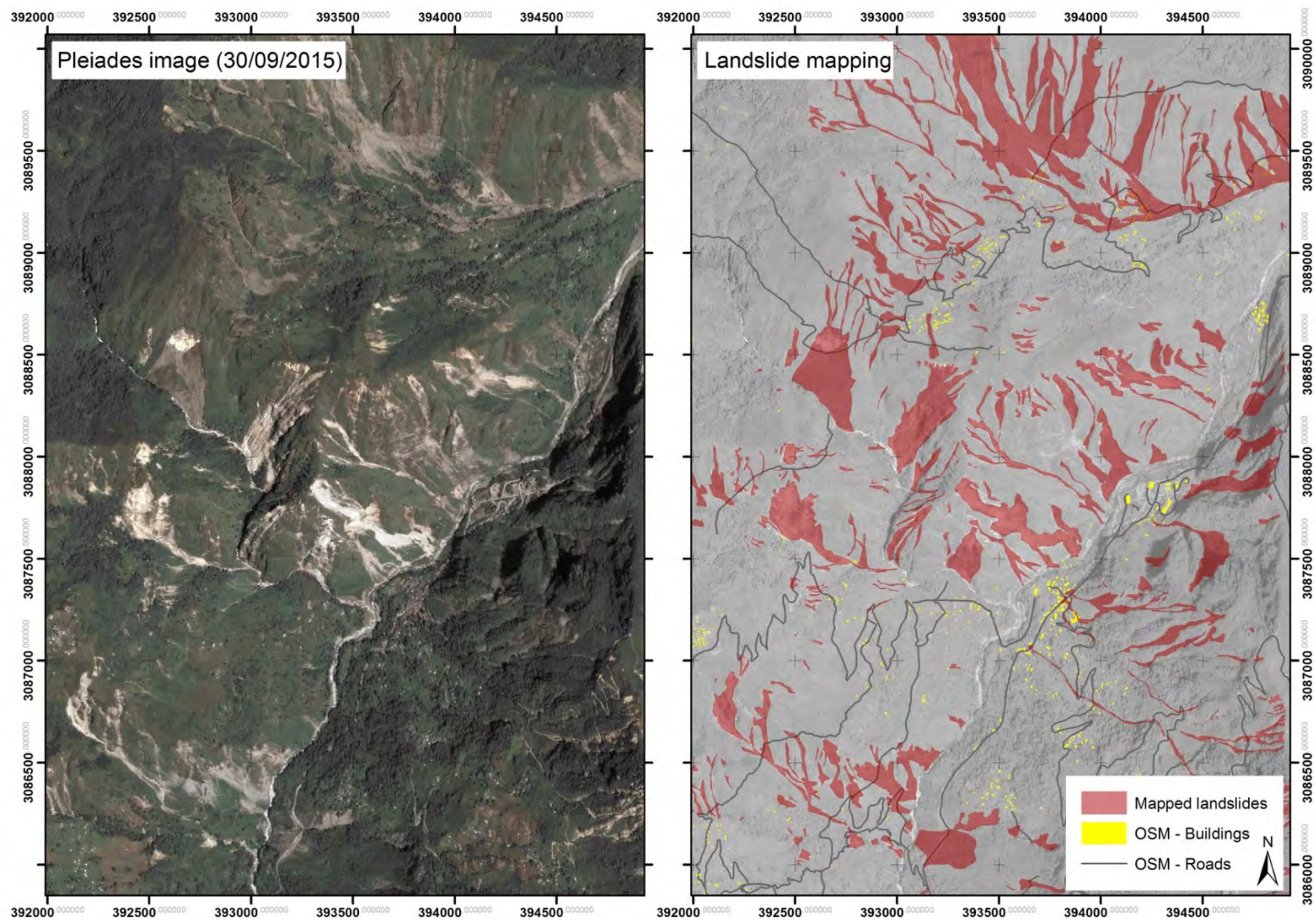
Durham University

Ridgeline landslides – Narathang, Upper Bhote Kosi, Sindhupalchok, February 2017

Rockfall impacts in valleys, Sept' '16

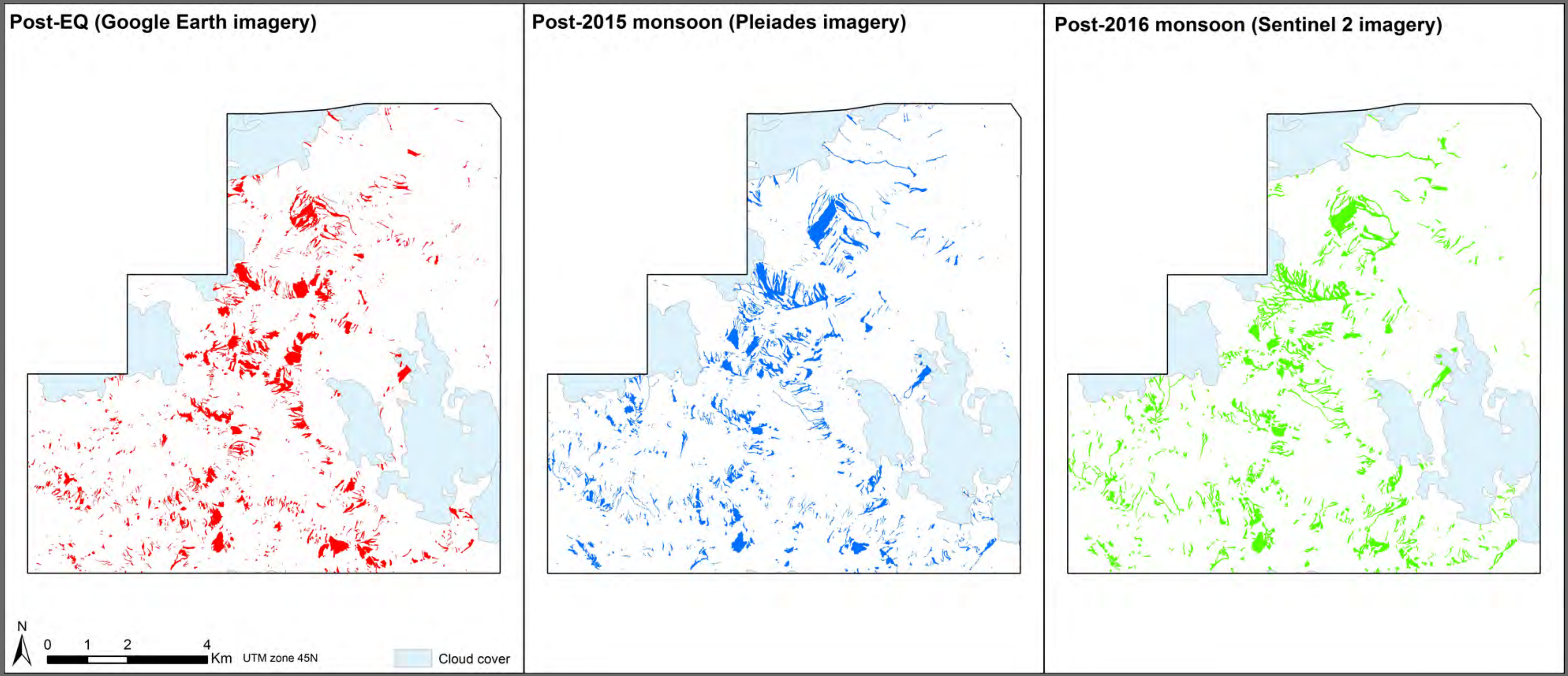
Debris flow deposits in valleys, Phulpin, Feb' '17

Durham University



Durham University

Landslide mapping in the Upper Bhote Kosi Valley



Post earthquake, and post 2015 & 2016 monsoon

Ongoing landslide / EO projects in Nepal @ Durham

- **DFID-SHEAR program:** Monitoring & modelling post-earthquake landslide risk across the 14 earthquake impacted districts, 2017 – 2019
  - Feeds EO-based landslide monitoring & scenario modelling into the Government of Nepal National Reconstruction Program
  - **DATA NEEDS:** High-res optical data for validating sequential mapping from Sentinel across 14 affected districts, including pre- & post-monsoon imagery (SPOT, Pleiades) in test areas (e.g. Upper Bhote Kosi, Trisuli Basin), 2014 – 2019.
- Research Councils UK (NERC) funded: "**Monitoring of post-earthquake damaged slopes**", combining EO mapping with ground based instrumentation
  - http://community.dur.ac.uk/nepal.2015eq
  - **DATA NEEDS:** As above.
- Durham University **AND Doctoral Training Initiative 2016 – 2020**, focusing on landslide risk in Nepal:
  - https://www.dur.ac.uk/ihrr/graduate-study/natural-disasters/and-students/
  - e.g. Project 1: Use of InSAR for mapping and monitoring earthquake-triggered landslides - field study site: Upper Bhote Kosi
  - e.g. Project 2: Modelling the impact on roads on landslide risk in Nepal
  - **DATA NEEDS:** High-resolution DEM from HMA project, plus high-resolution optical data as above, for verification of SAR-based mapping. Access to all SAR data is already in place. Optical data needs as above.
- **Earthquake & landslide scenario modelling** for emergency planning and preparedness
  - Dr Tom Robinson, Addison Wheeler Fellow, Durham University – 2017 – 2020
  - Provides risk planning scenarios for UN Resident Coordinators Office & WFP, Kathmandu
  - **DATA NEEDS:** As above.
- **Earthquakes without Frontiers** (http://ewf.nerc.ac.uk)
  - Large interdisciplinary project on earthquake risk reduction and secondary hazards across
  - Nepal, China, India & Kazakhstan
  - **DATA NEEDS:** As above.

Automated Landslide Mapping 2015
Gorkha earthquake, Nepal

Need for understanding of relationship between short-term earthquake induced landslide activity and long-term inter-seismic landscape response

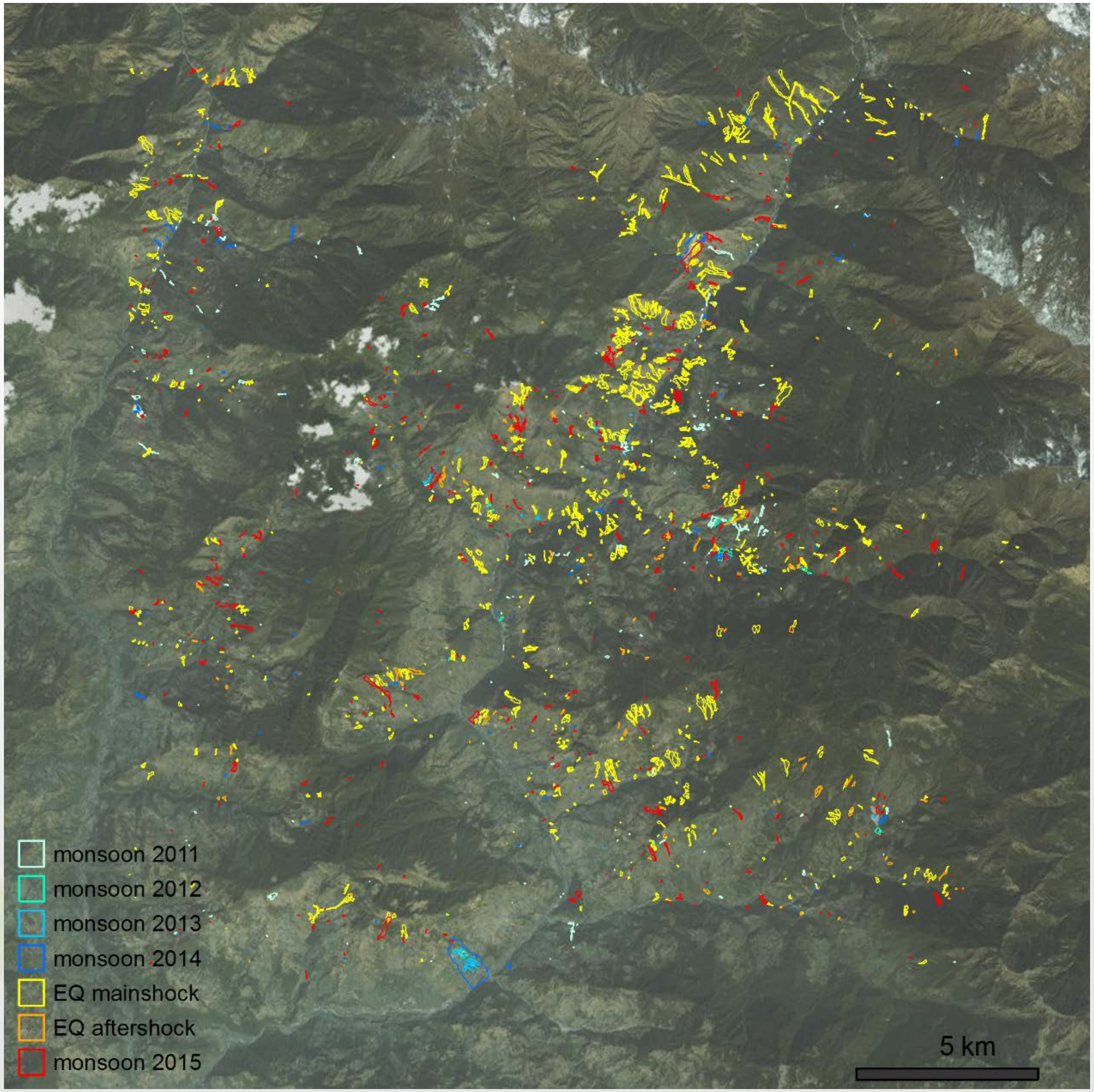
Automated analysis of pilot area (25*25 km) using RapidEye and Landsat data (2011 – 2015)

~2000 total landslides

~1000 co-seismic landslides

~500 landslides during monsoon 2015

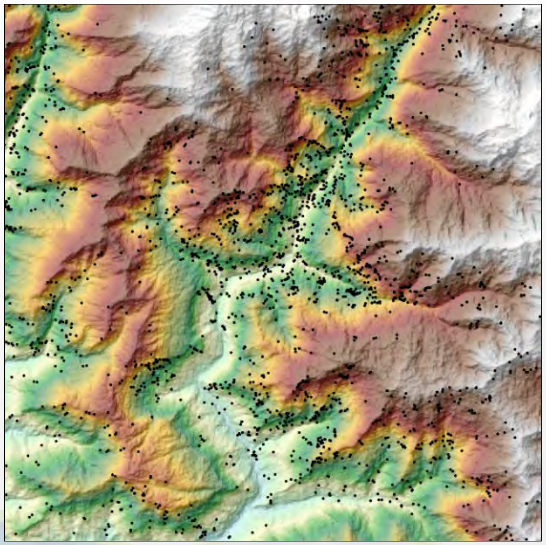
few 100's of landslides before



Robert Behling and Odin Marc, GFZ Potsdam

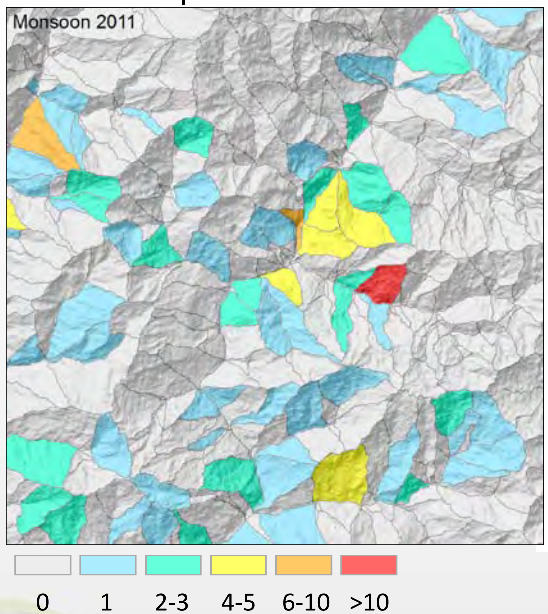
Landslide activity 2011 – 2016 earthquake and monsoon related

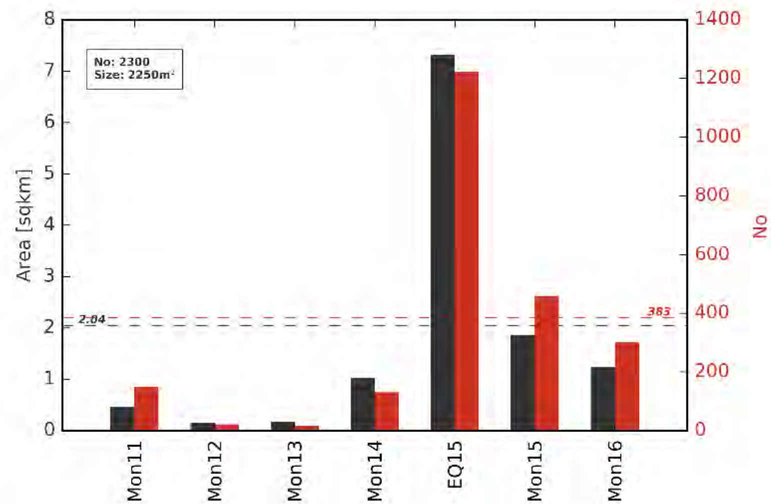
Detected landslides



25x25km

Landslides per terrain unit





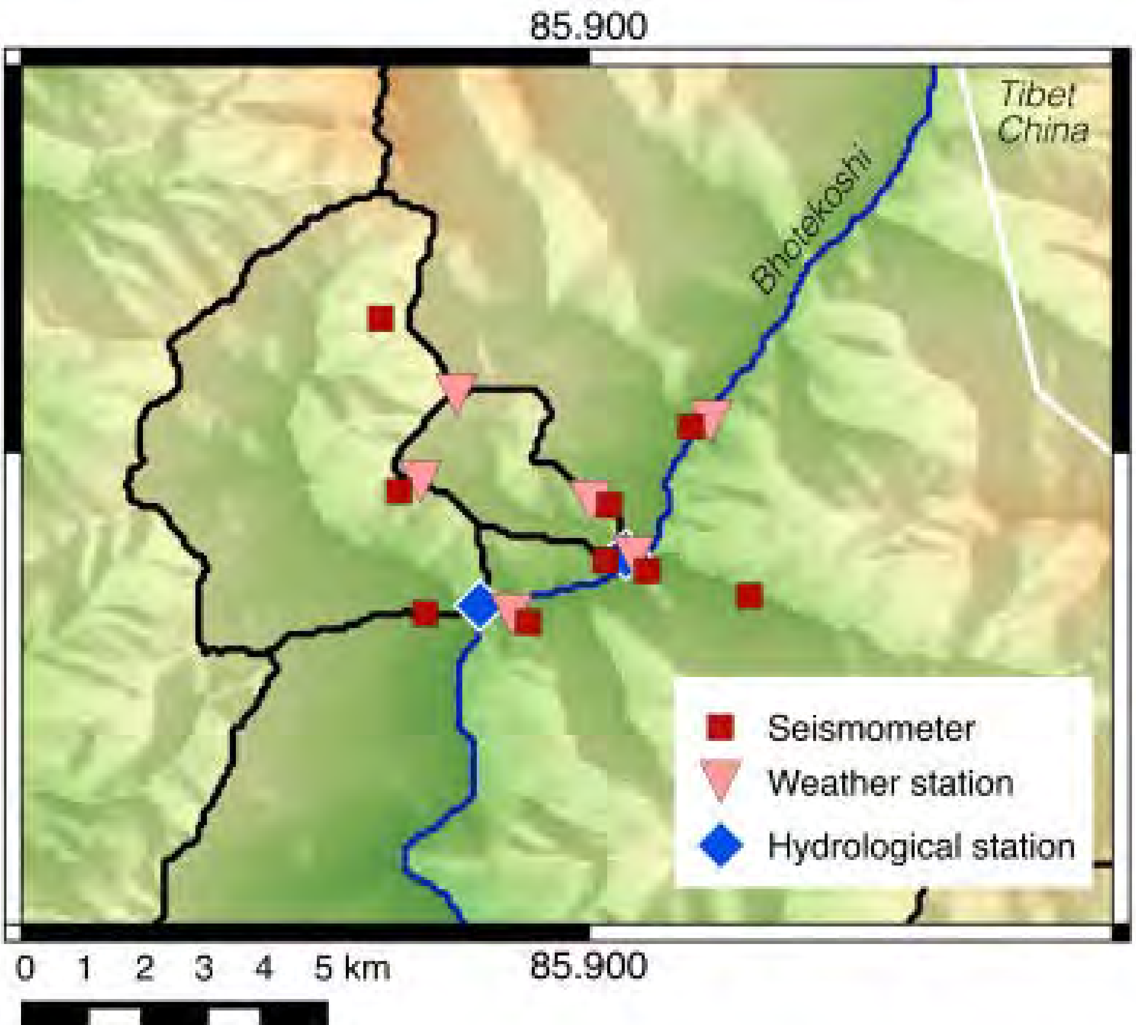
Applied automated approach for pilot area: Upper Bhote Koshi

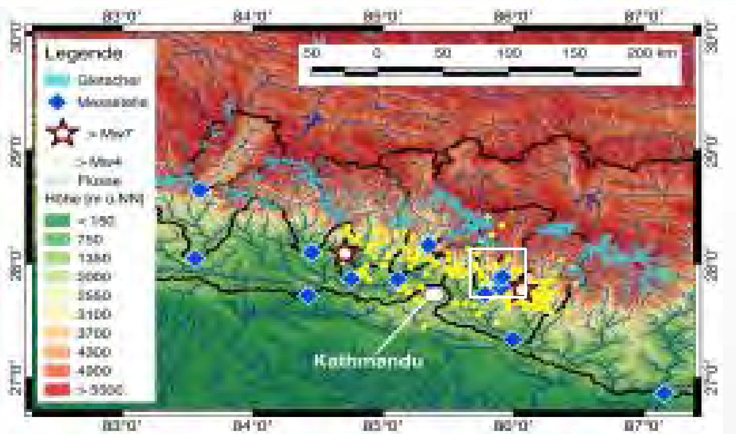
- Proofed principal transferability of developed methodology for long-term monitoring
- Derives impact of the earthquake (co-seismic landslides) in context to the before and after activity.
  => Increased monsoonal landslide rates after earthquake due to widespread substrate weakening
- **Need for integration of radar remote sensing to increase temporal resolution of monitoring (monsoon period) and complement post-failure detection by activation analysis (early warning)**

Robert Behling and Sigrid Roessner, GFZ Potsdam

GFZ ground-based monitoring

Research conducted by Geomorphology Section (5.1) of GFZ Potsdam – led by Prof. Niels Hovius





12 seismic stations
6 weather stations
2 hydrological stations
2 time-lapse cameras
Daily water and suspended sediment sampling

Kristen Cook, GFZ Potsdam

Repeat ground-based monitoring

Repeat terrestrial lidar surveys of landslide deposits in the Bhote Koshi area to track deposit mobility and sediment export

Observations in June 2015, July 2015, October 2015, March 2016, and November 2016

Terrestrial Lidar (Riegl VZ-6000, 6 km range), time-lapse cameras

Relate to observatory data – seismic data, weather, hydrology, suspended sediment flux

Kristen Cook, GFZ Potsdam

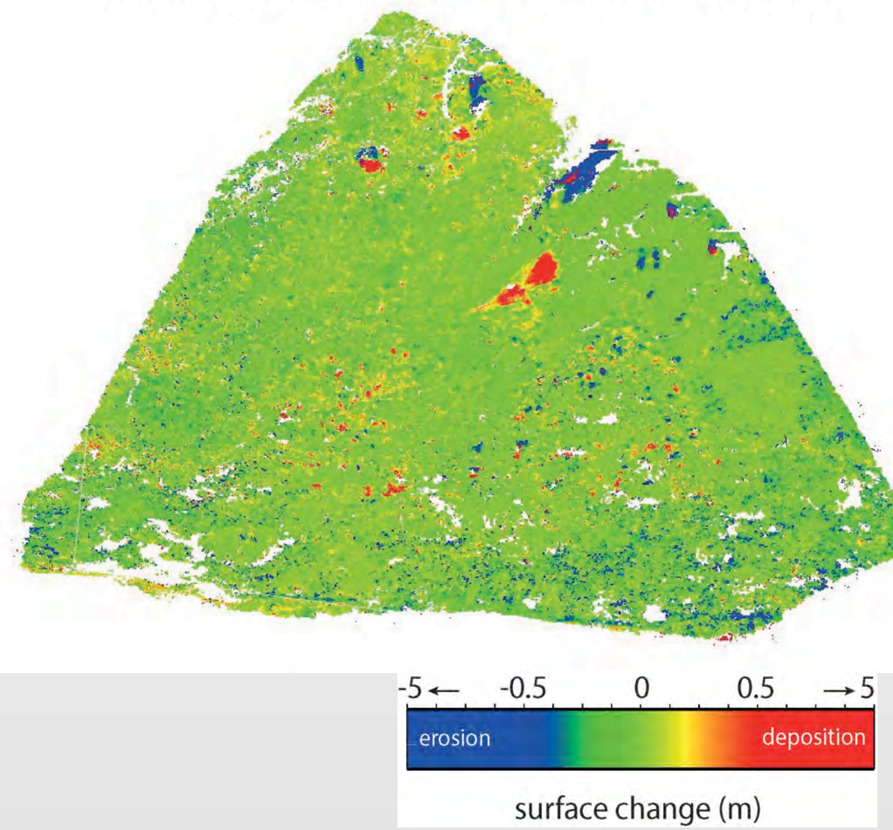
Terrestrial lidar-based monitoring of landslide changes

Surveys generate point clouds with cm to 10s of cm resolution
Measure cloud-cloud changes normal to the surface using M3C2 algorithm (Lague et al., 2013) in CloudCompare

Small unconnected landslide

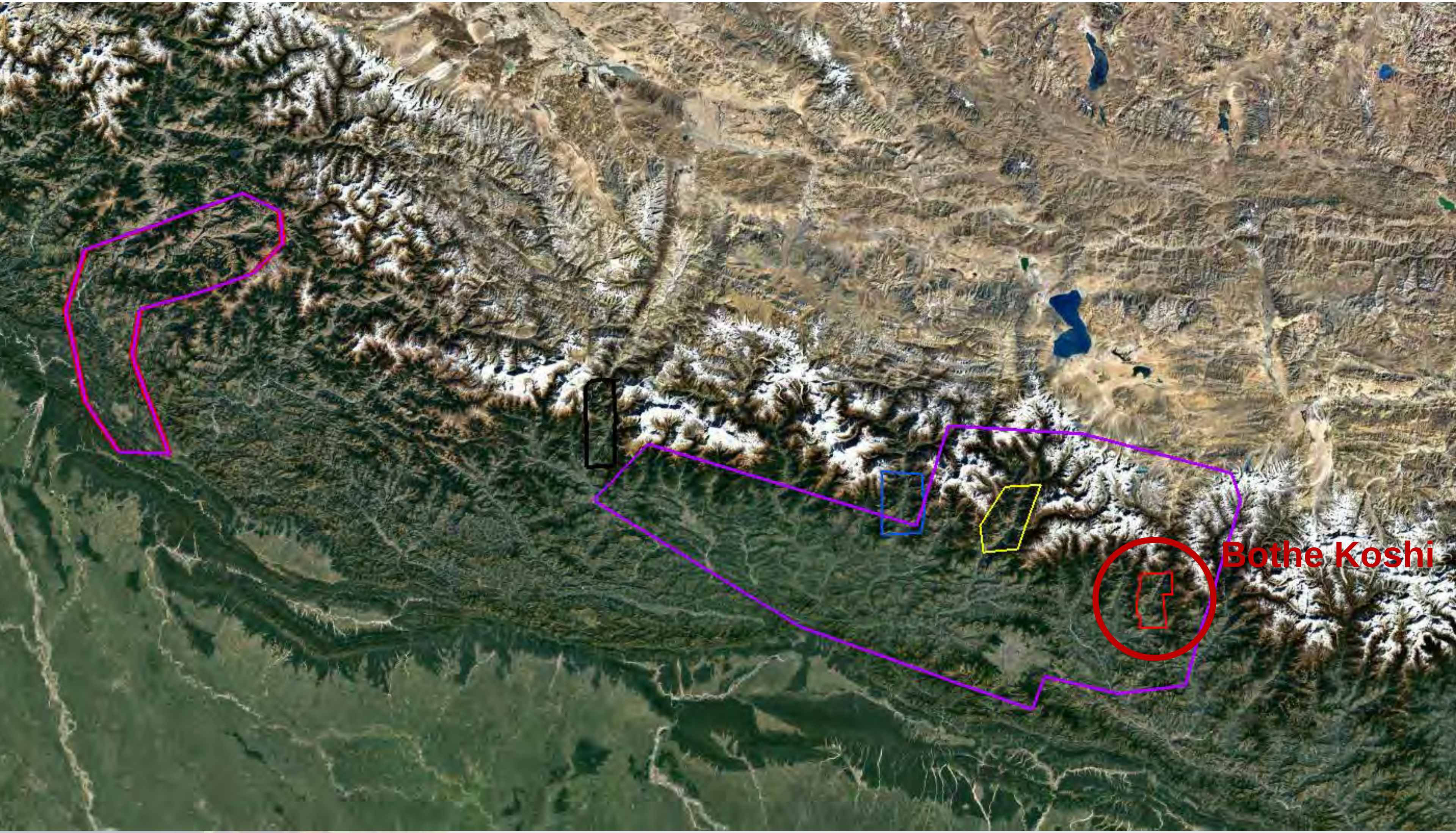
Lidar point cloud, March 2016

Surface change, July 2015 to March 2016



Kristen Cook, GFZ Potsdam

Preliminary selection test regions



Next Steps/Action Items

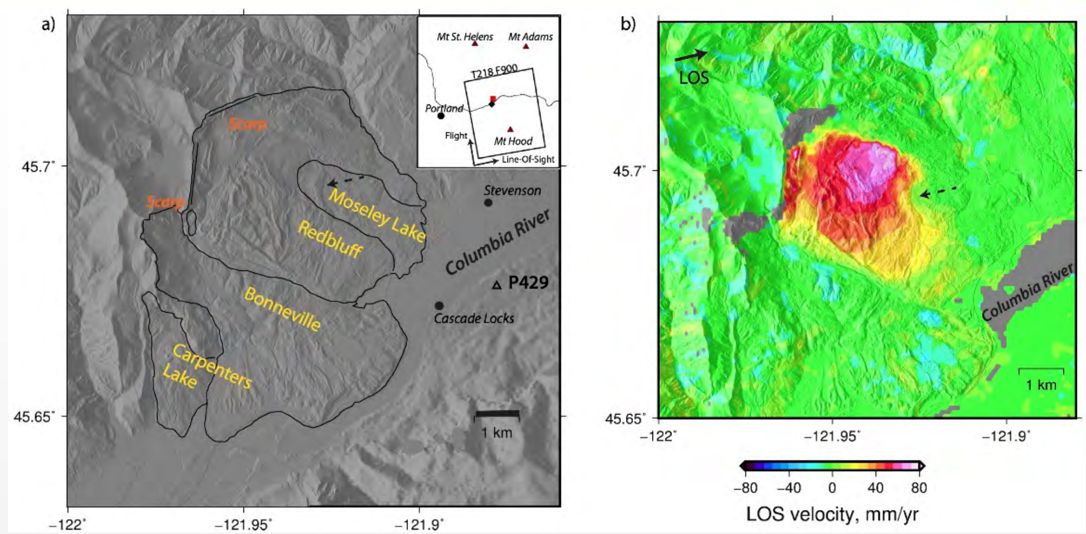
- Establish monthly group meetings for Nepal
- Gaining overview of research conducted by pilot members within different areas in Nepal
- Final agreement on data acquisition strategies
- Specific data requests using data capture sheets
- Test methodologies in study regions to compare and establish best practices for community use
- Begin working towards “Effective Practices in Merging Optical and SAR for landslide mapping and monitoring” - white paper/overview article

PNW Study Region

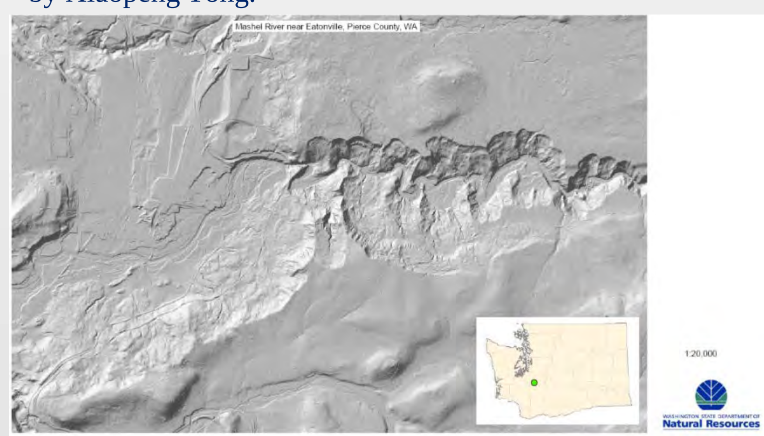
- Western Washington
- Western Oregon
- Northwestern California

Pacific Northwest, USA

- **Why**: Active geomorphologic and tectonic settings with extensive landsliding
- **Who:** There is a breadth of experience from USGS, State Geo Surveys, Research groups, NASA, and others with experience using EO data to both monitor active landslides and conduct multi-temporal landslide mapping
- **What**: several existing activities already underway in this region, including engagement from end users (DOTs, NPS, NFS, etc.)



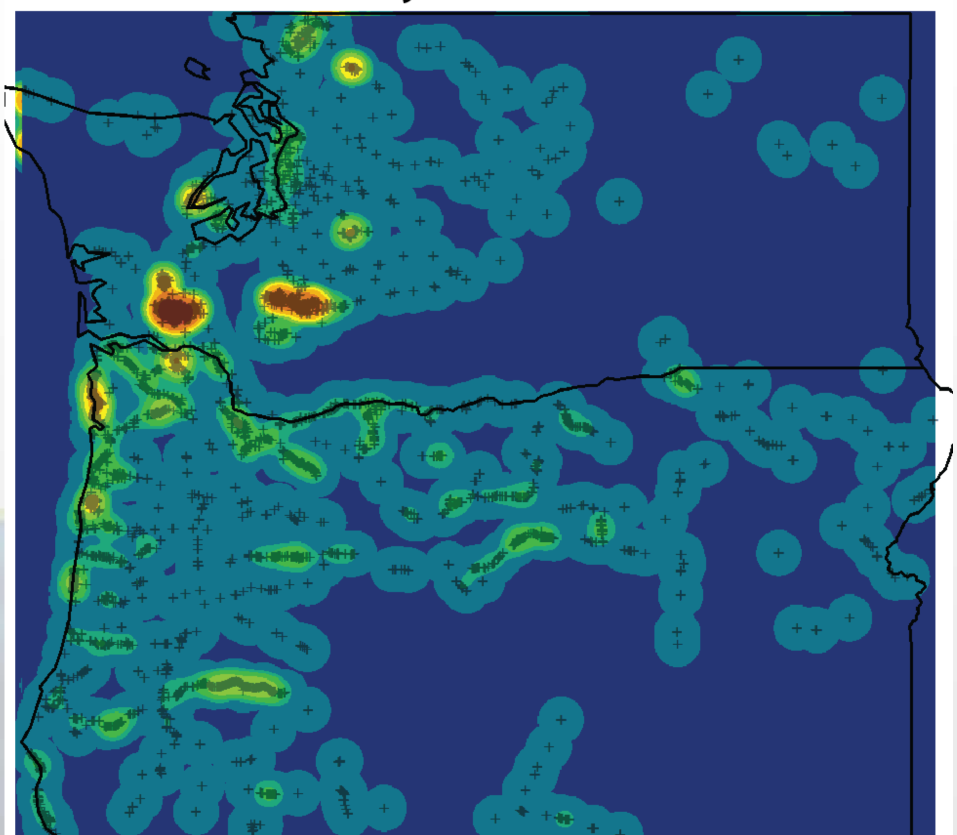
(left) Shaded relief map of the Cascade Landslide Complex located along the Columbia River Gorge from a LiDAR DEM. (right) Average line-of-sight velocity measured by InSAR (ALOS-1) indicating active movement of the Redbluff landslide. Warm colors indicate motion away from the satellite in the look direction (black solid arrow). The background shading is based on the 2m-resolution DEM from LiDAR. Figure prepared by Xiaopeng Tong.



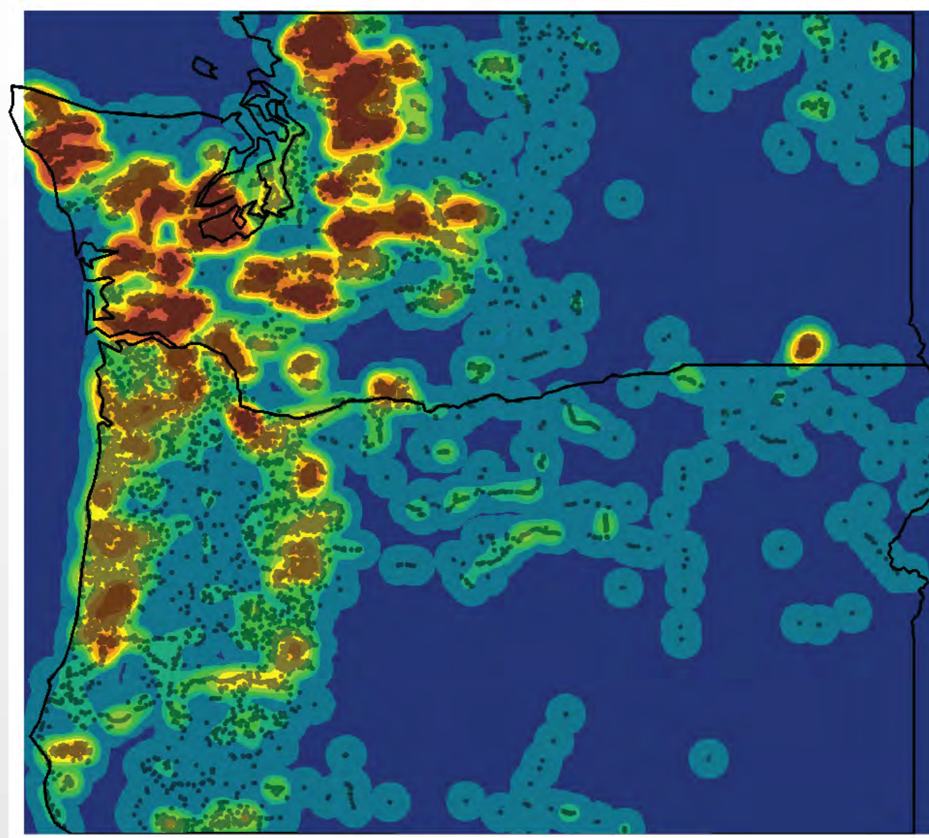
Example of multiple slope movements from the Mashel River near Eatonville, WA. Shaded relief from LiDAR, provided by Washington DNR.

Landslide Inventory

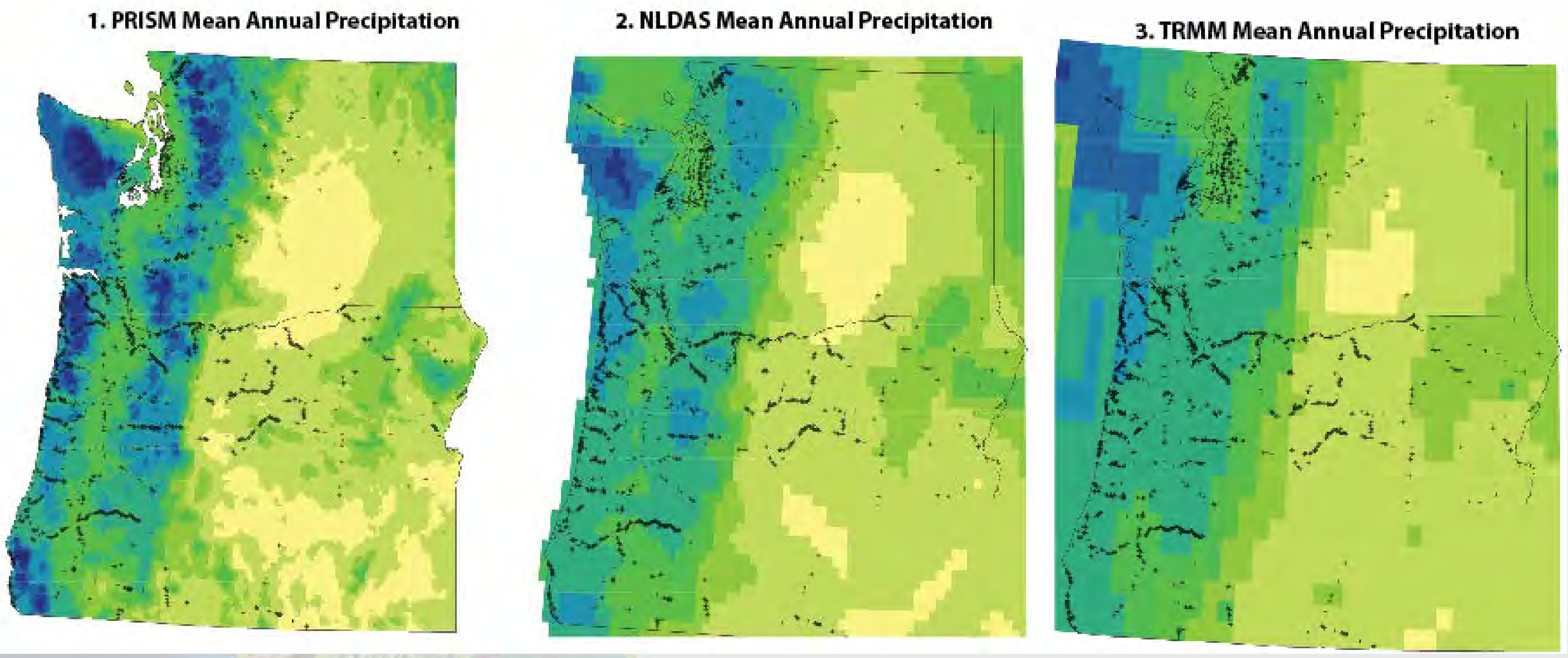
Landslide Density for events with Dates



Landslide Density for all available events



Spatio-temporal Precipitation Patterns



Landslide Model Development

Static Susceptibility

- DEM
- Soil
- Geology

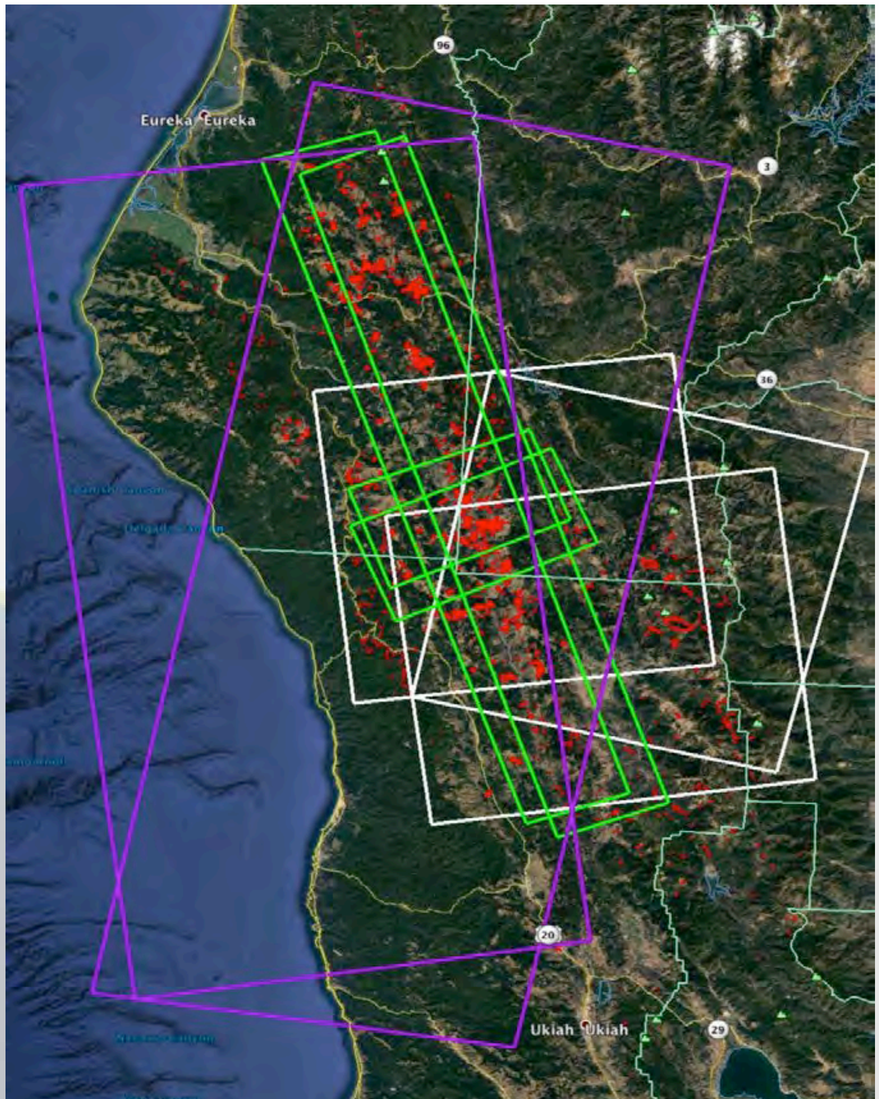
Dynamic seasonal/decadal

- Climate forcings
- Fires (burned area/active)
- Snow/Ice Extent
- Land cover
- Roads
- Population

Dynamic (daily/hourly)

- Precipitation
- Soil Moisture
- Snow Melt
- Temperature
- Seismicity?

Landslide Monitoring North California / Eel River



A. Handwerger, M.-H. Huang, E.J. Fielding

SAR coverage

- Purple = Sentinel 1A/B with 6 day minimum acquisition
- White = ALOS2 with 14 day minimum acquisition
- Green = UAVSAR, irregular acquisition interval
- Red polygons = landslide inventory
  (Mackey et al., 2011; Handwerger et al., 2015; Bennett et al., 2016)

Bennett, G. L., Miller, S. R., Roering, J. J., & Schmidt, D. A. (2016). Landslides, threshold slopes, and the survival of relict terrain in the wake of the Mendocino Triple Junction. *Geology*, *44*(5), 363-366.

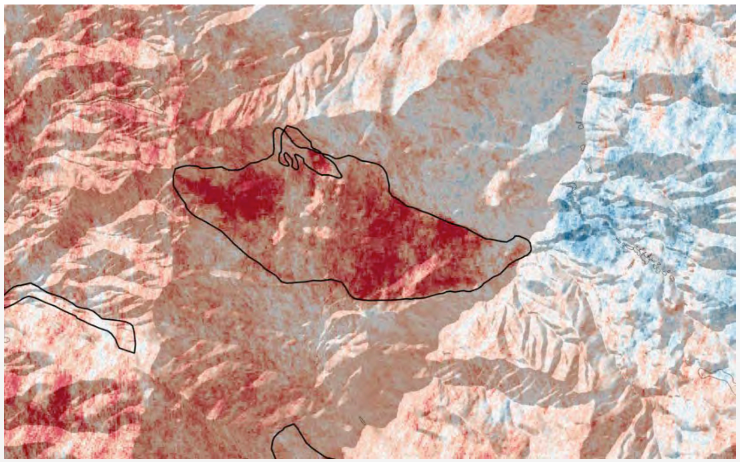
Handwerger, A. L., Roering, J. J., Schmidt, D. A., & Rempel, A. W. (2015). Kinematics of earthflows in the Northern California Coast Ranges using satellite interferometry. *Geomorphology*, *246*, 321-333.

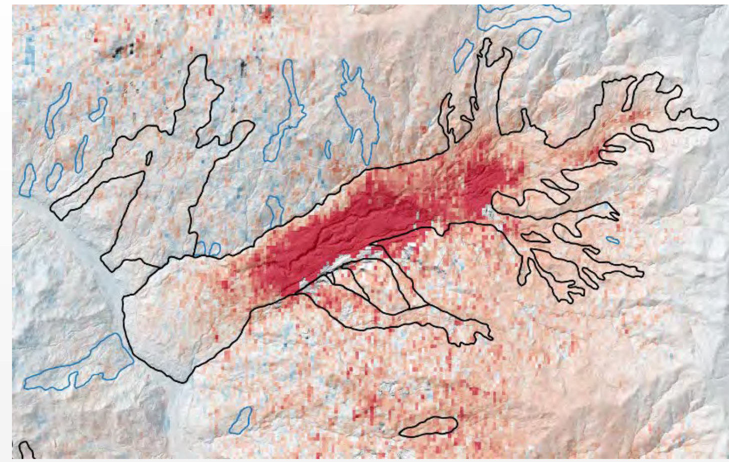
Jet Propulsion Laboratory
California Institute of Technology

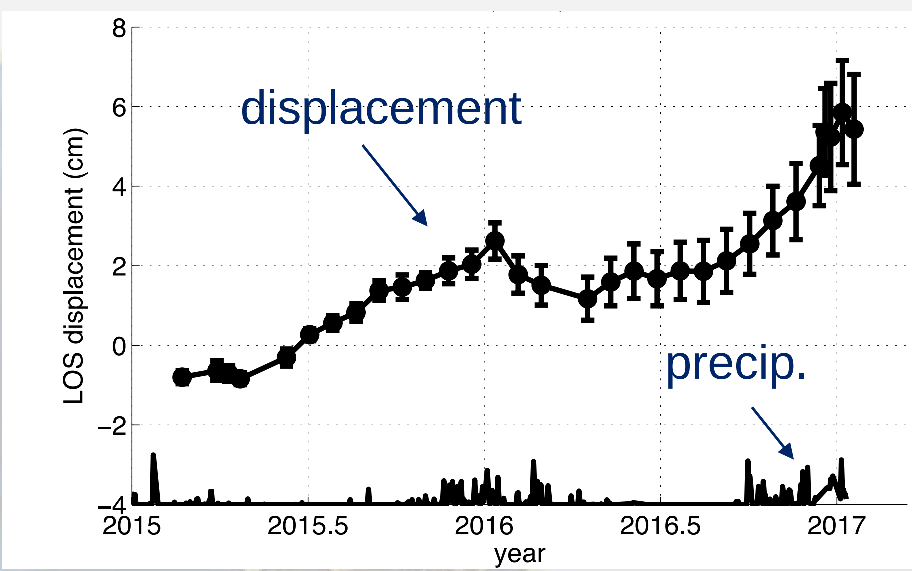
Landslide Monitoring
North California / Eel River

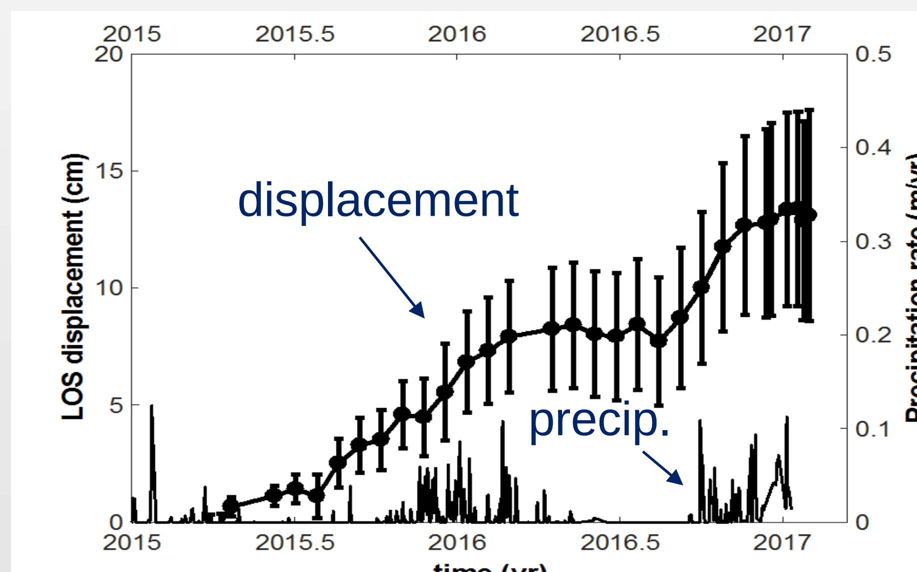
InSAR time series Offset Tracking

A. Handwerger, M.-H. Huang, E.J. Fielding

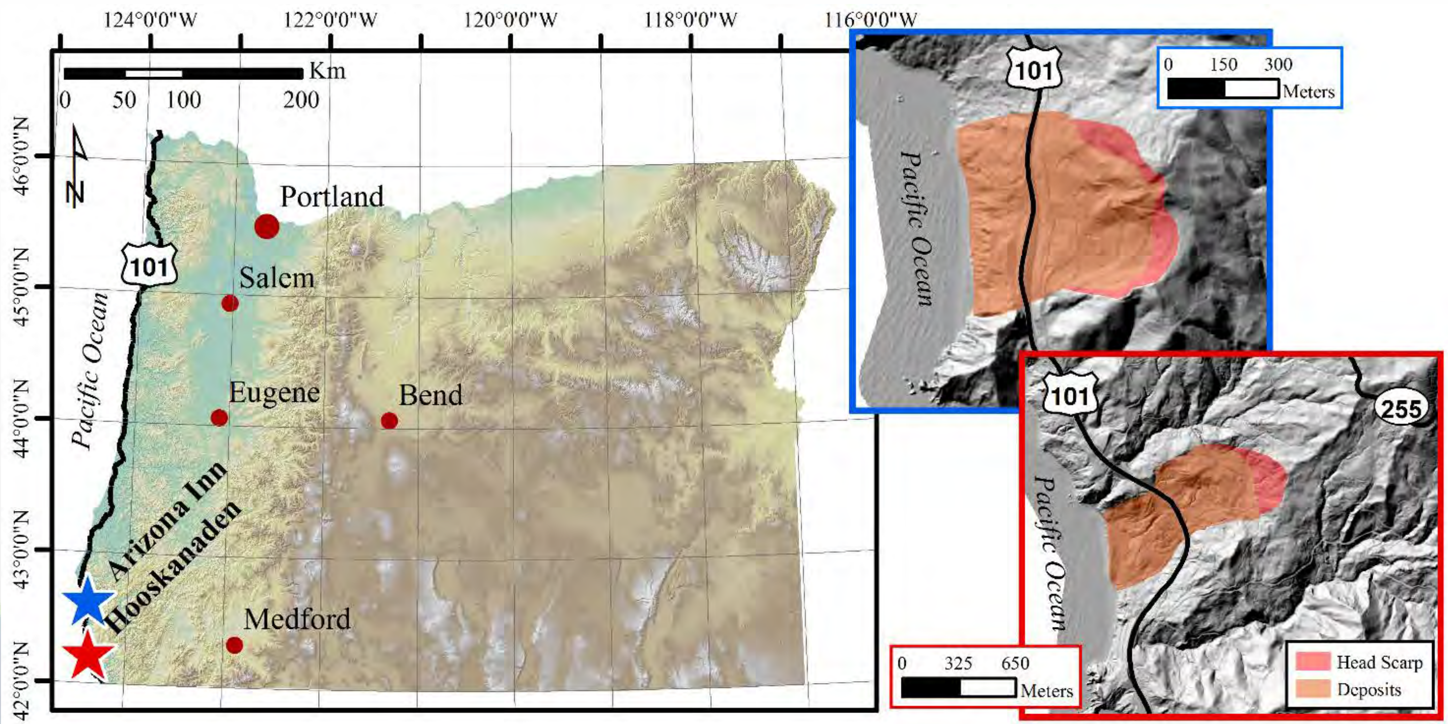








Landslide Monitoring
Oregon Coastal Landslides



Hooskanaden Slide: Large deep seated landslide with earthflow characteristics. West of Highway 101. Exhibits retrogressive creep triggered by coastal bluff erosion. **Location (Lat,Long):** 42.219231°,-124.373142°

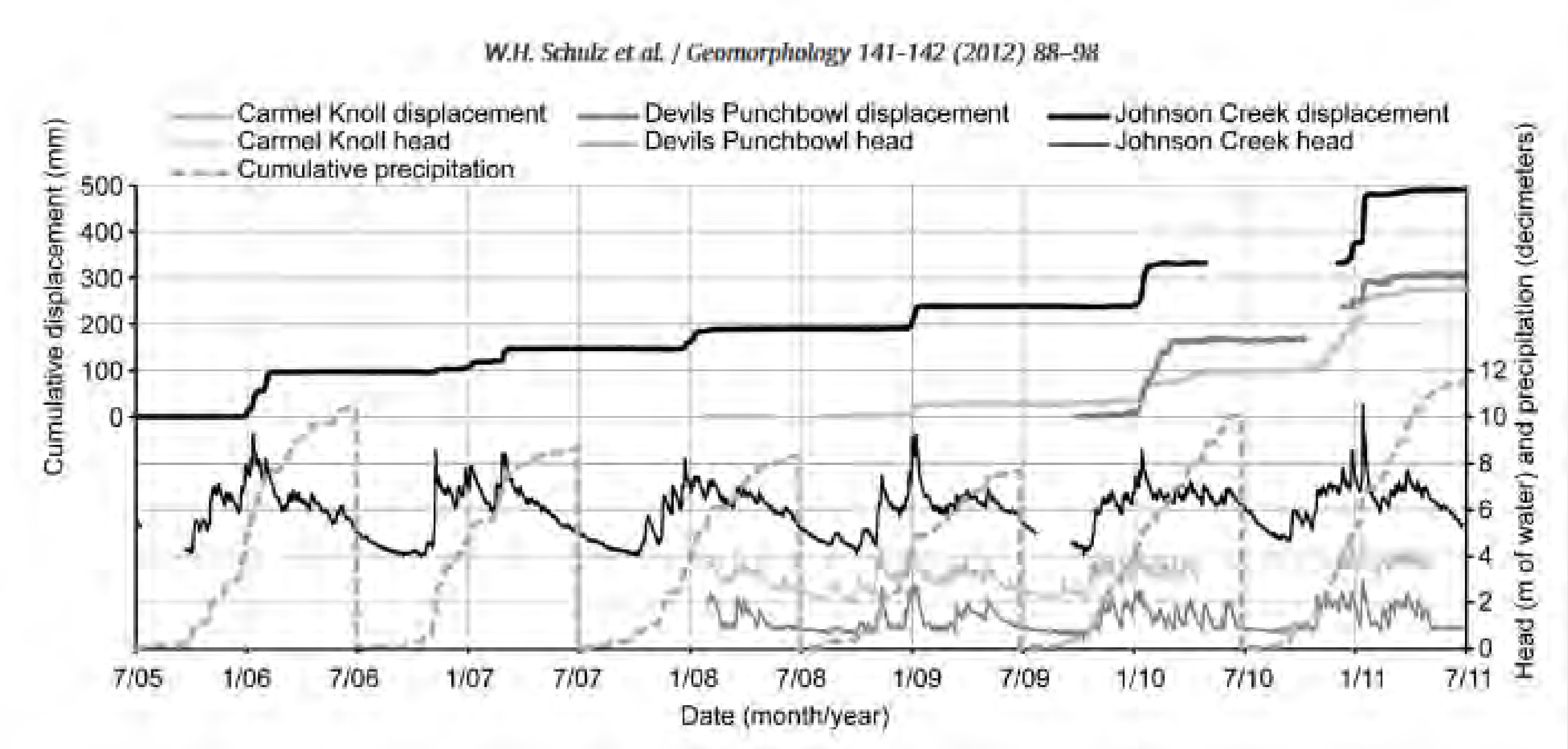
Existing Project: A 7 year (ending 2023) landslide monitoring project for the Oregon Department of Transportation (ODOT). Monitoring efforts include, bi-annual terrestrial laser scanning of the coastal bluff, Highway 101, and regions of the slide mass, as well as, unmanned aircraft system (UAS) imagery acquisition. In addition to surveying, movement and pore water pressure within the Arizona Inn landslide is being monitored with an in-ground MEMS array with piezometers

Oregon Department of Transportation

OSU Oregon State University

Landslide Monitoring
Oregon Coastal Landslides

USGS monitoring at Johnson Creek and Carmel Knoll landslides / Oregon Coast.

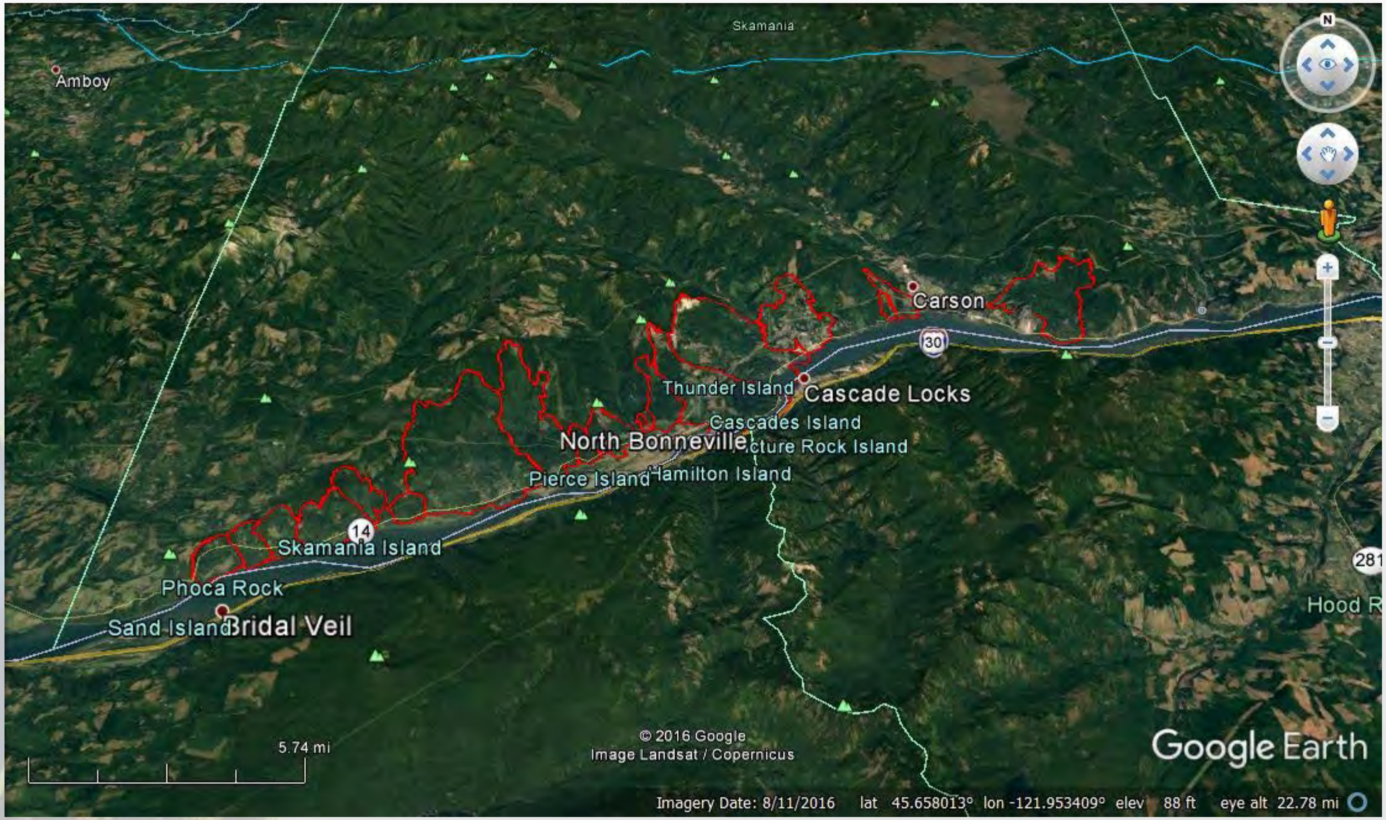


Schulz and Ellis report on Johnson Creek slide in Lincoln County, https://pubs.usgs.gov/of/2007/1127/

Schulz and others paper on possible earthquake triggering of these slides, http://www.sciencedirect.com/science/article/pii/S0169555X11006404

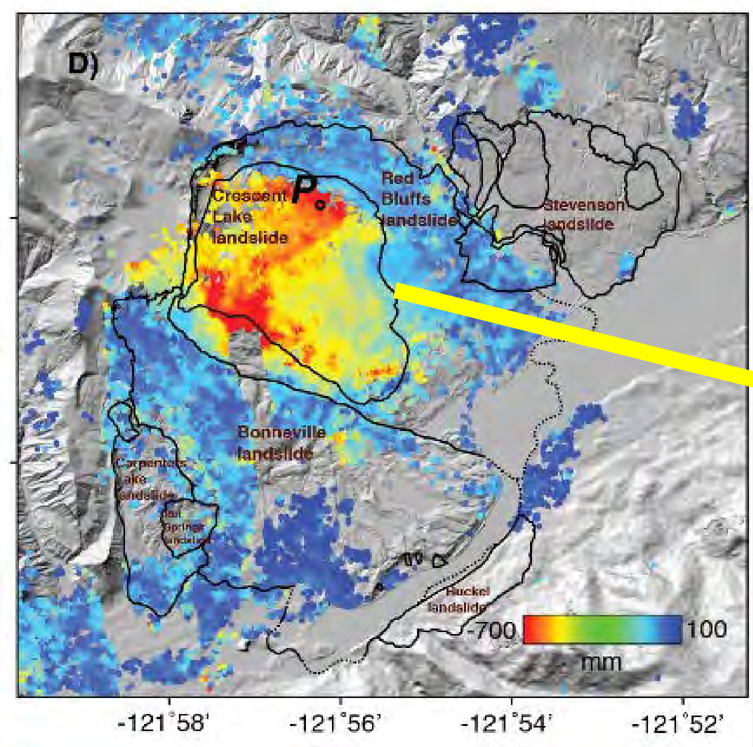
Landslide Monitoring Washington / Columbia River

- Washington DNR is interested in a 40km strip north of the Columbia River and most of the slides are moving in a SSE direction.
- They do not have any movement rate values and are looking to better understand the slow moving landslides in this area

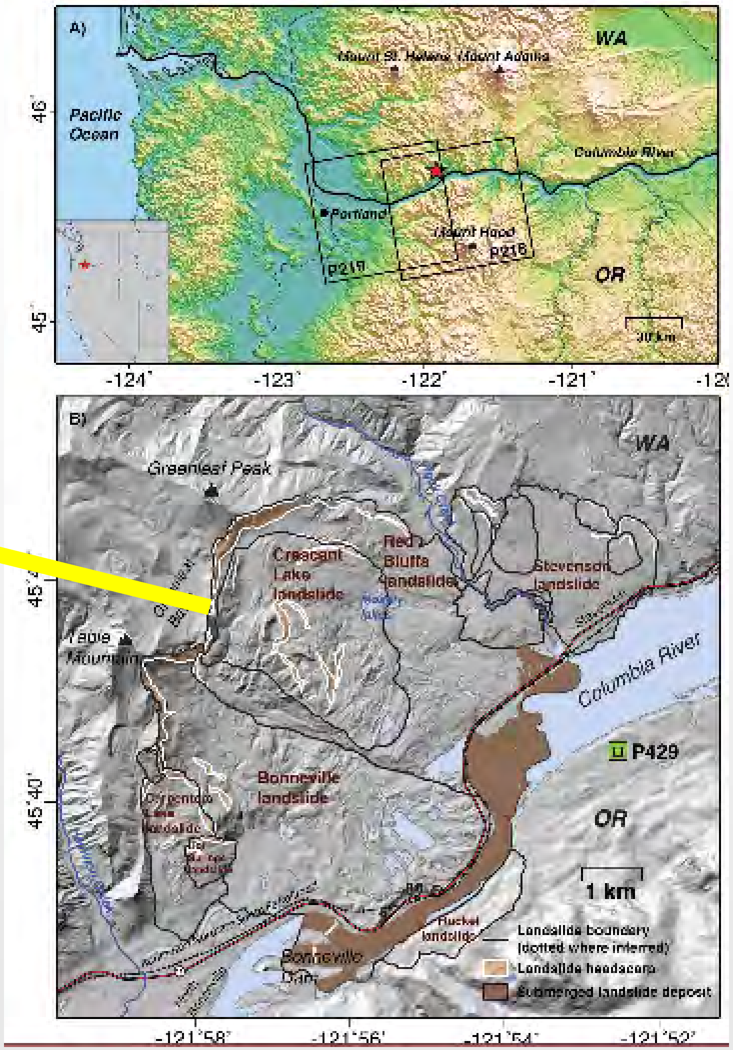


Landslide Monitoring Washington / Columbia River

Previous demonstrations of InSAR movement analyses for Washington State Landslides (Columbia River)



Movement (in mm) of the Crescent Lake Landslide from 2007 to 2011 using InSAR techniques



Source: https://www.smu.edu/-/media/Site/Dedman/Academics/Departments/EarthSciences/PDF/Lu/136_Hu_et_al_InSAR_Cacades_Landslide_Complex_RSE_2016.ashx?la=en

Landslides for local Monitoring and partnership

Name	Affilliation	Country
Alexander Handwerger	JPL	USA
Ziyang Li	Academy of Opto-Electronics,CAS	China
Zeng-Gunag Zhou	CAS, Earth observation Technology Department (ETA) China Space Application Center for Disaster Reduction	China
Matt O'Banion	Oregon State University	USA
Kate Mickelson	Washington Geological Survey	USA
Josh Roering	U Oregon	USA
Ben Leshchinsky	Oregon State	USA
Jonathan Godt	U.S. Geological Survey (USGS)	USA
Eric J. Fielding	NASA/JPL	USA
Stu Frye	NASA/GSFC	USA
Stephen Slaughter	Washington Department of Natural Resources	USA
Pukar Amatya	NASA/GSFC	USA
David Schmidt	U Washington	USA
David Bekaert	NASA JPL	USA
Irina Pavlova	UNESCO	France
Jean-Philippe Malet	CNRS – EOST	France
Andre Stumpf	CNRS – EOST	France

Next steps

Data request plan

- Requestor Name, e-mail, affiliation
- Name of Location
- Lat/lon (Decimal Degrees), KML of area is ideal
- Date of request acquisition (or date range preferred)
- Platform/Instrument/Sensor
- Image ID (if available), if stereo images requested, indicate the B/H ratio
- Indicate ability to process raw data
- Brief summary of data usage

- **Establish monthly group meetings**
- **Consolidate the partnership**
- **Order the data**
- **Begin working** towards “Effective Practices in Merging Optical and SAR for landslide mapping and monitoring” white paper/overview article

Methodology

I. Mapping

- Creating inventories
- Documentation

II. Monitoring

- Routine processing over sample sites

III. EO-based Analysis

- Automatic
- Standardized methods to establish thresholds

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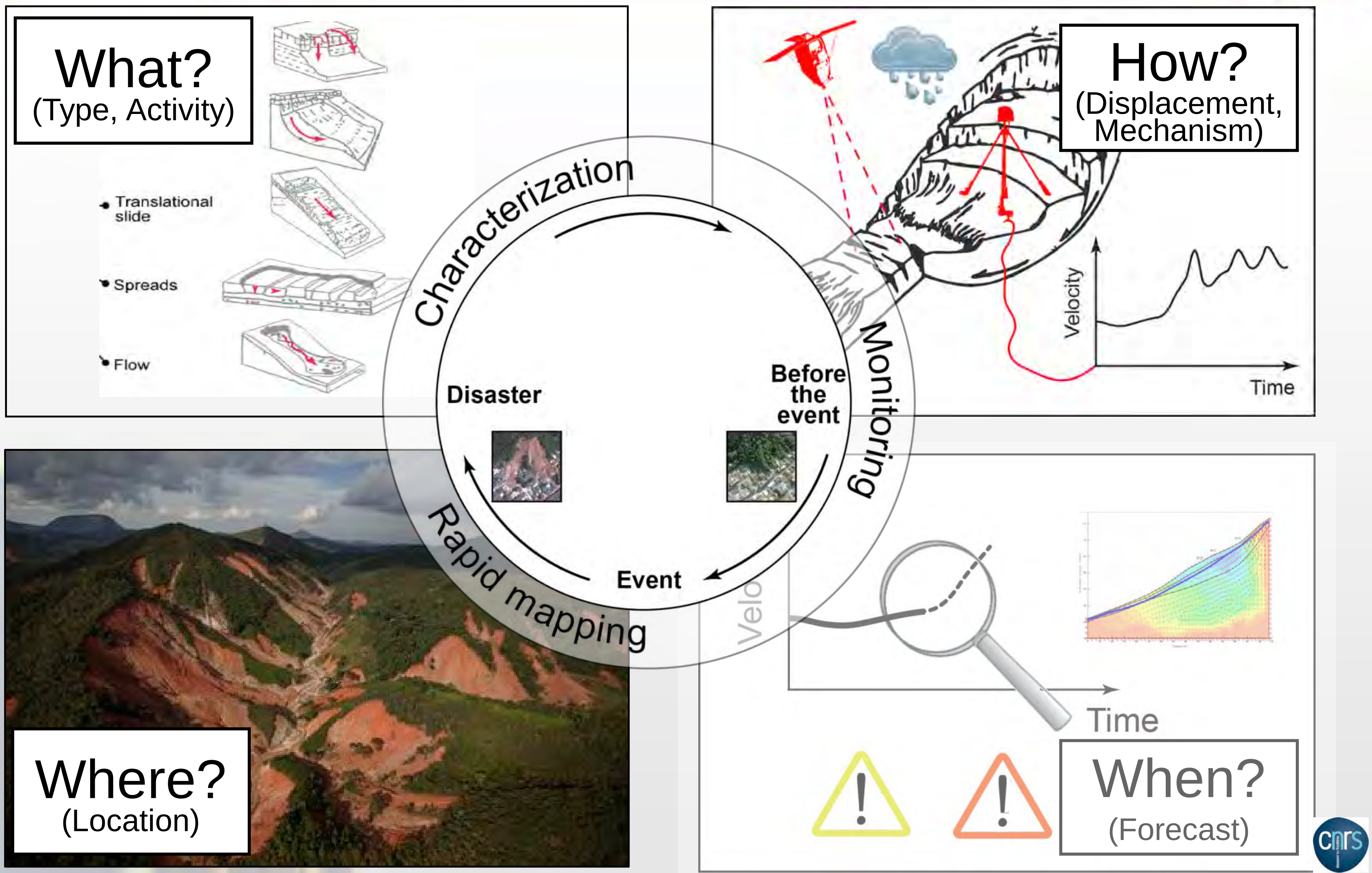
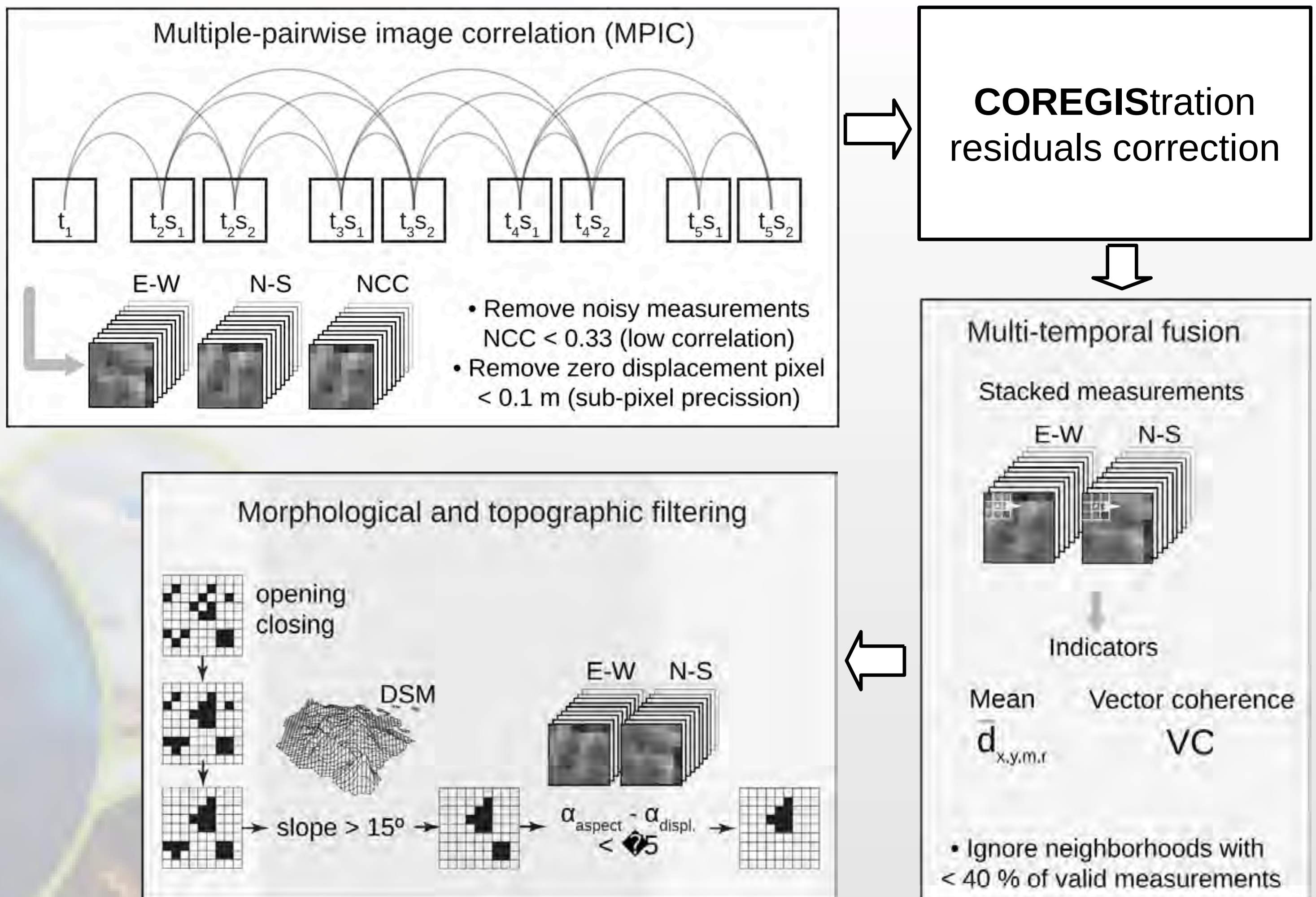
Landslide Remote Sensing



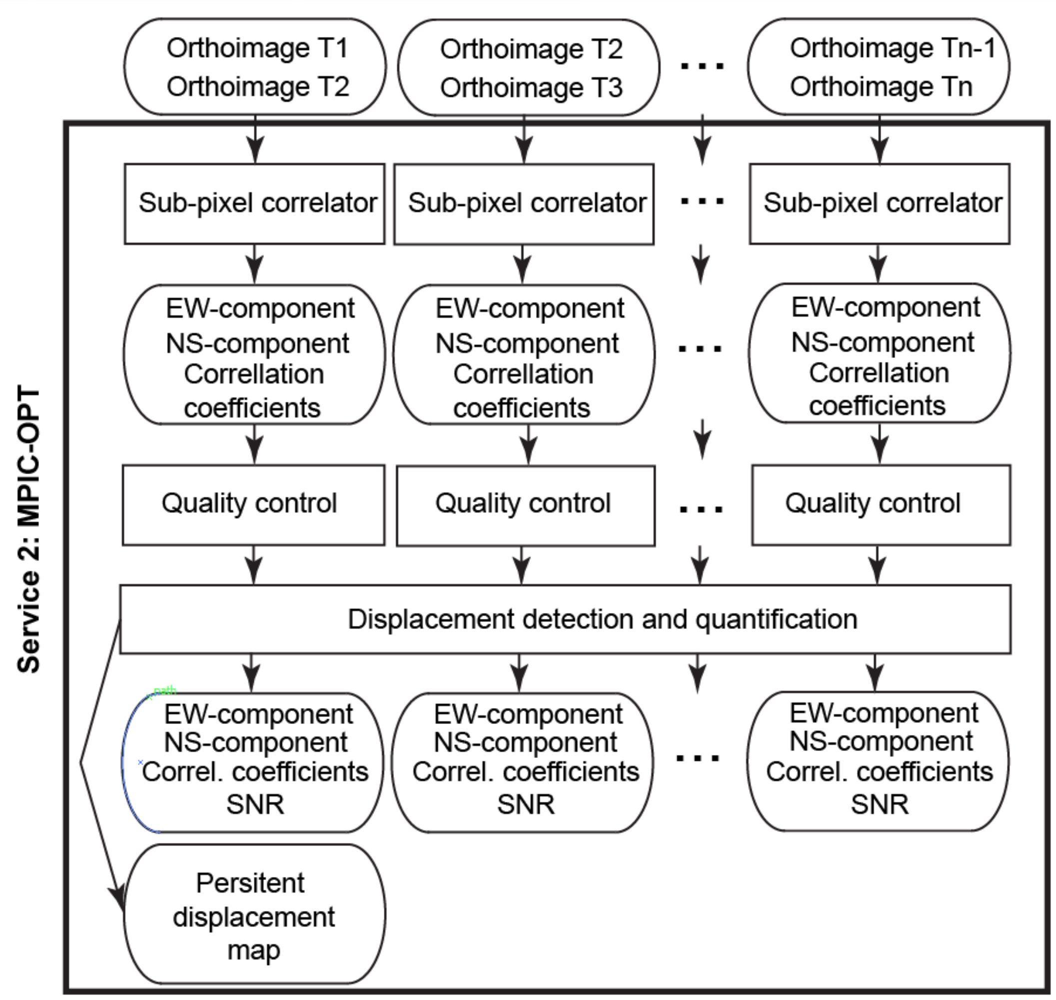
Optical Time Series for Landslide Monitoring

Multiple Pairwise Image Correlation / MPIC-OPT – *Stumpf et al. (2016)*



Optical Time Series for Landslide Monitoring

Multiple Pairwise Image Correlation / MPIC-OPT – *Stumpf et al. (2016)*



- Input: Time series of orthorectified images (e.g. S2, Landsat8, Spot6-7, Pléiades, outputs from service DSM-OPT)
- Output: Surface displacement field (amplitude, direction) + Quality indicators + Landslide activity map (movement/no movement)
- Possibility for on-demand and continuous (e.g. S2) processing (surveillance mode)

Optical Time Series for Landslide Monitoring

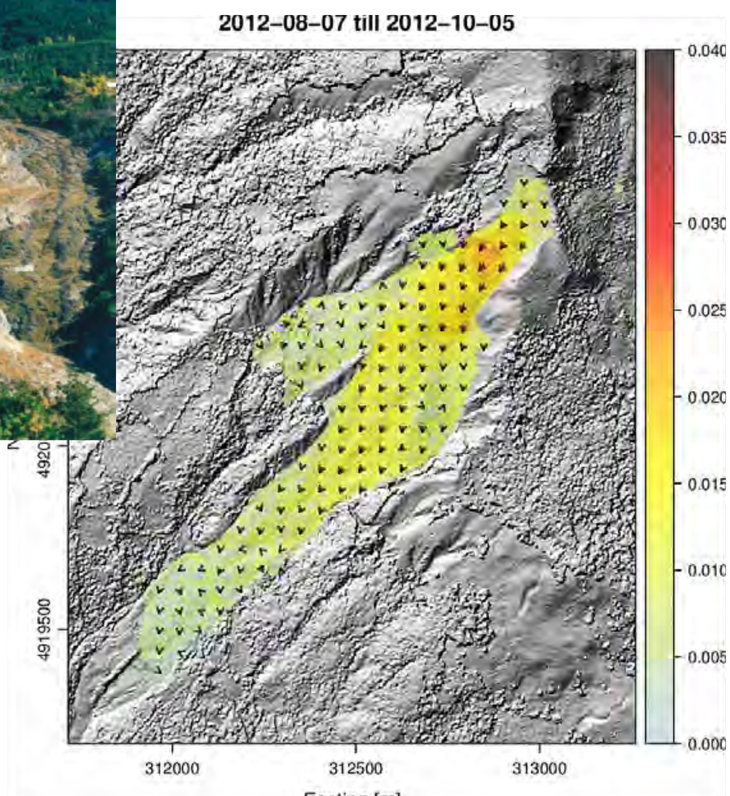
Application of MPIC on Pléiades (0.7 m)

French Alps – Slow-moving landslides

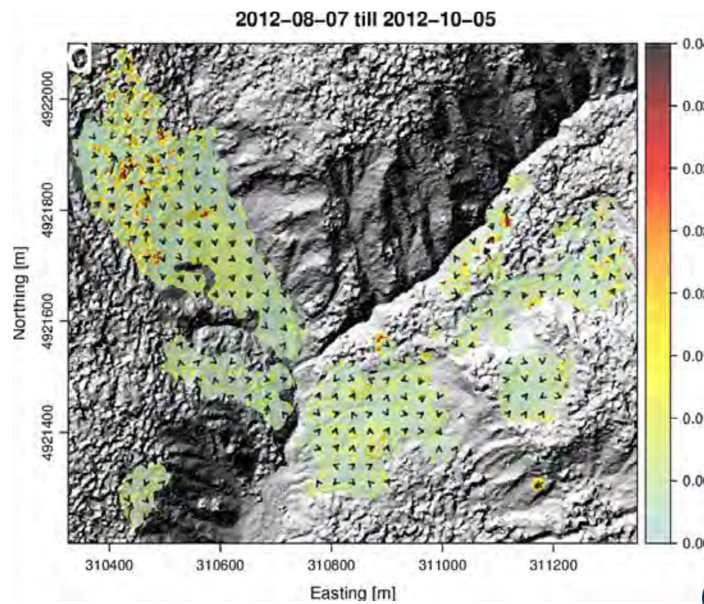
MPIC of 9 Pléiades images (18 pairs):
- local workstation 8 cores: 14 days
- HPC: 4 nodes of 16 cores: 22h

Stumpf et al. (2016)

La Valette landslide



Riou-Bourdoux landslide

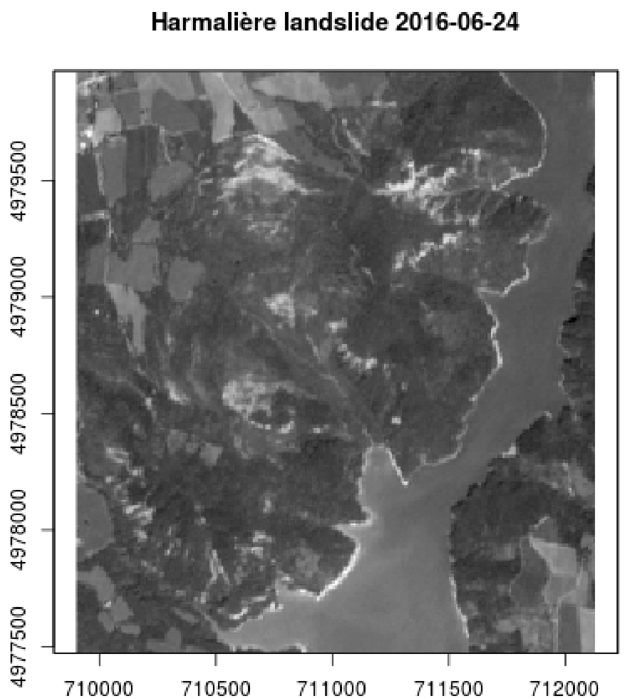


Optical Time Series for Landslide Monitoring

Application of MPIC on S2 (10 m)

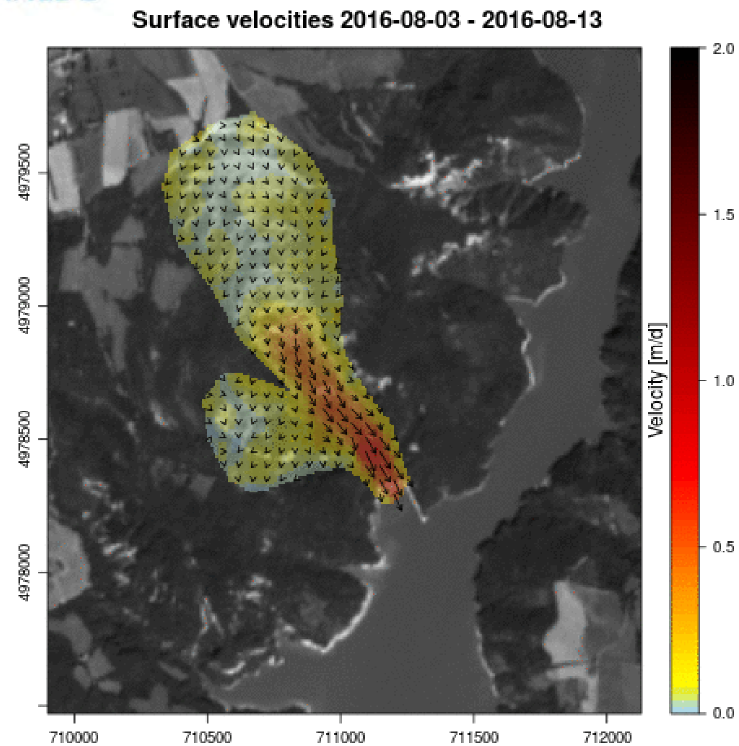
French Alps – Acceleration of large landslides

MPIC of 6 S2 images (12 pairs):
- Use of S2 green band (560 nm)
- More atmospheric scattering in the blue band (490 nm)



SENTINEL 2

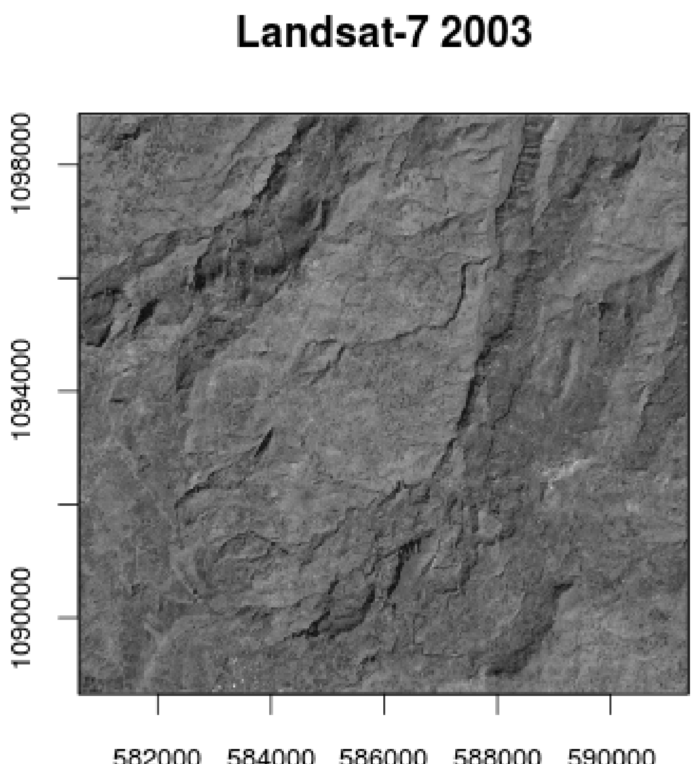
Harmalière landslide (acceleration in July/Aug. 2016)

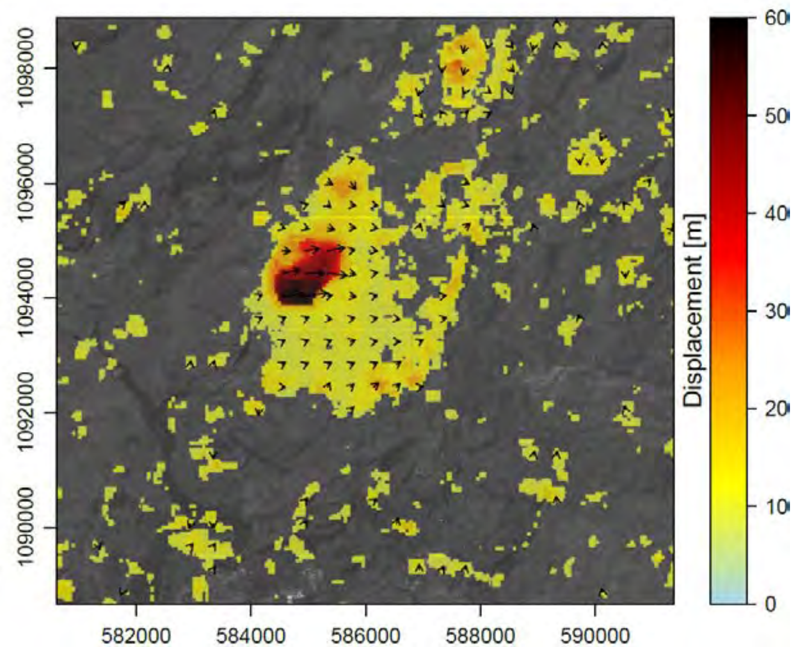


Optical Time Series for Landslide Monitoring

Application of MPIC on S2/Landsat7 (10 m) – Exploitation of multi-sensor archives

Ethiopia – Historical movement of the Debre Sine landslide



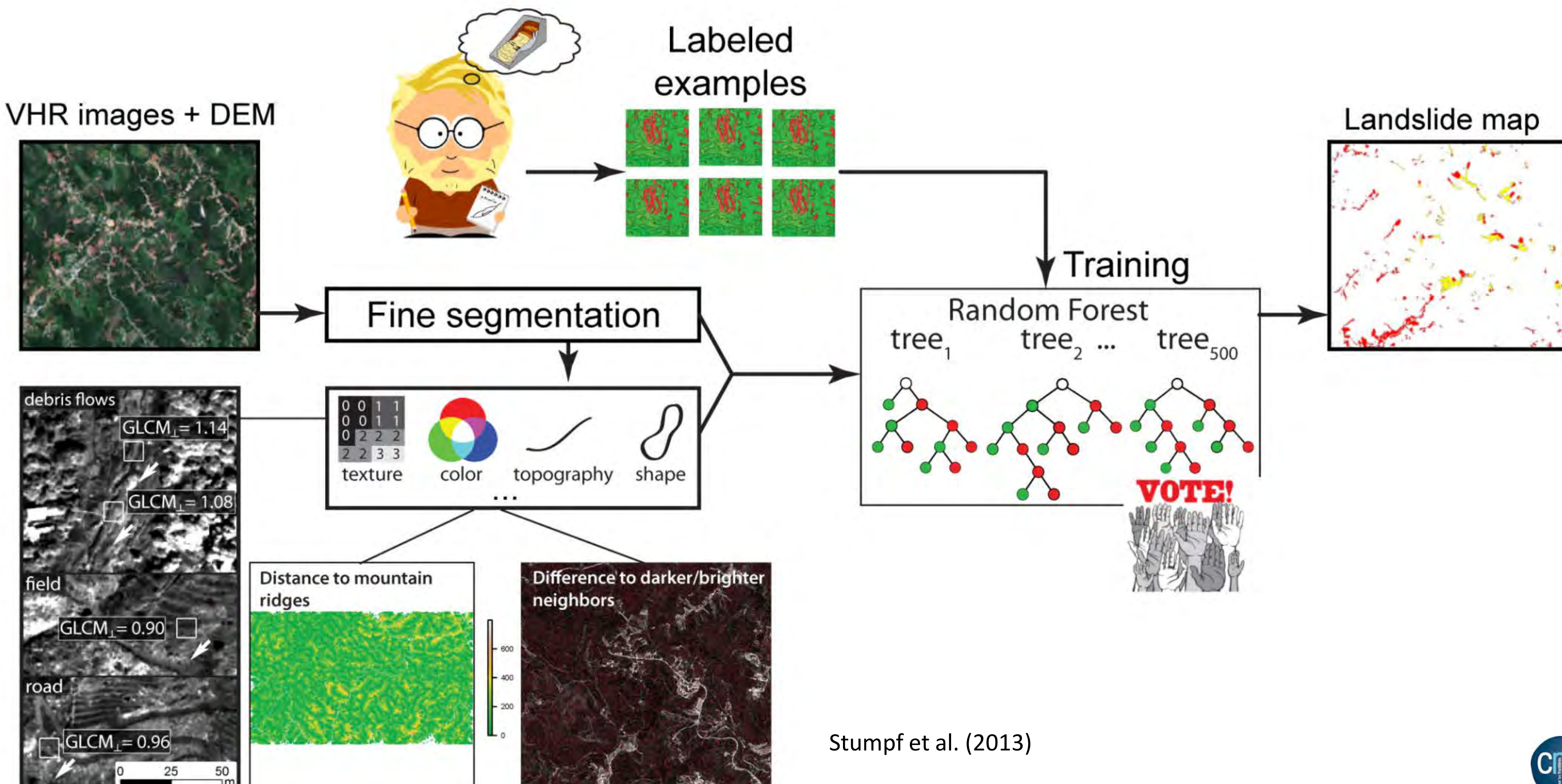


Motion field of the Debre-Sina landslide (Ethiopia): 2003–2016 derived from a combination of L7/S2

Optical Images for Landslide Detection and Mapping

AELIM – Automatic Event Landsilde Inventory Mapping

A generic chain for landslide mapping (rapid mapping, long-term inventory) based on pre/post-event images: methodological framework



Stumpf et al. (2013)

Optical Images for Landslide Detection and Mapping

AELIM – Automatic Event Landsilde Inventory Mapping

Current Implementation on IT infrastructures

Python & Co implementation

- Automatic ingestion of standard formats (currently S-2 L1C, L-8 L1T)
- Automatic coregistration (based on COREGIS)
- Generation of cloud masks (fmask), optional NDVI mask
- Automatic download and resampling of SRTM 30 m
- Segmentation (Large scale region merging, Lasalle et al. 2014)
- Feature extraction: Change vectors, band values and variance, Terrain-steered GLCM texture features, Terrain morphometry, Polygon morphometrics
- Random Forest Classifier, User provides samples as SHP-file
- Approx. 3h to process a full S-2 tile > 110*110 km

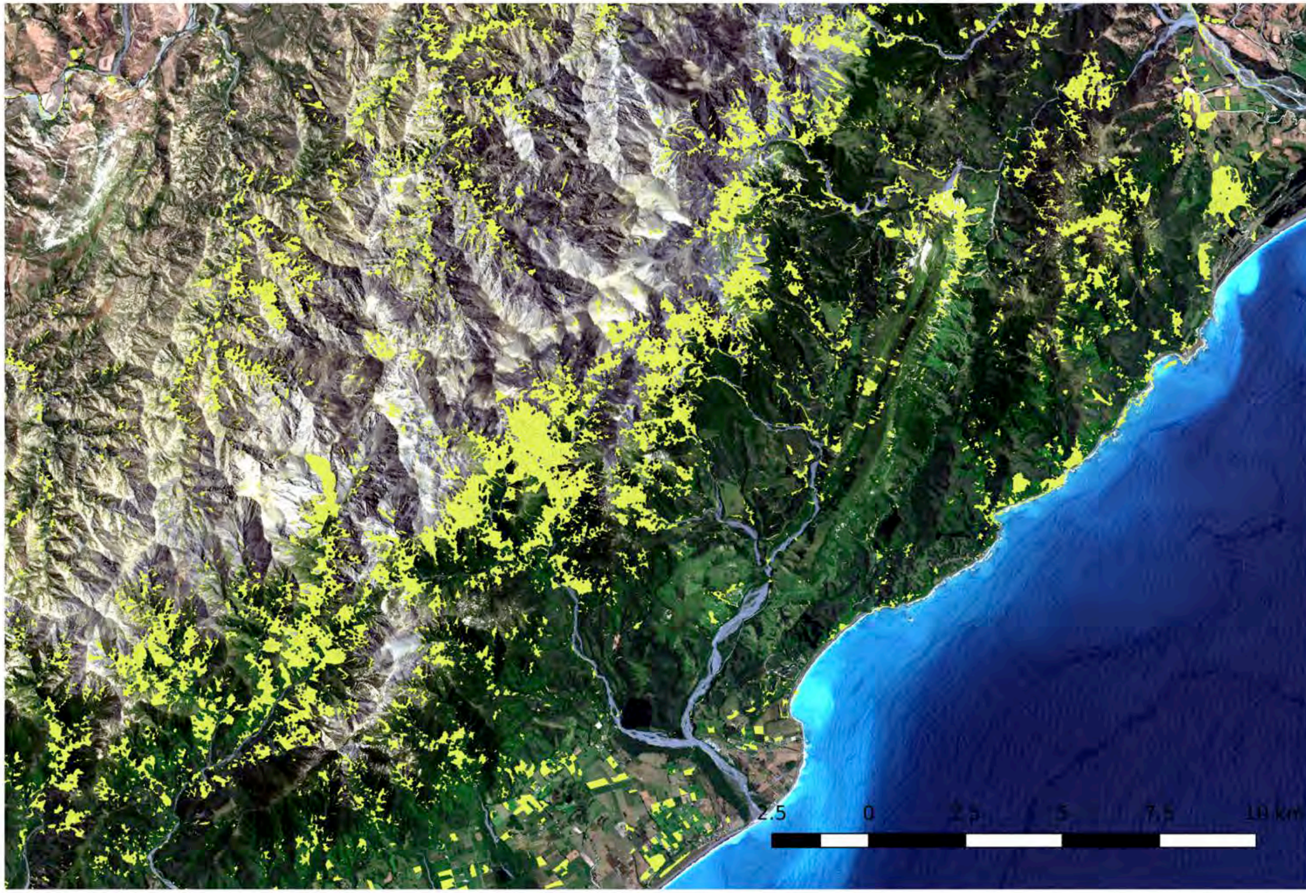
Python 3 OpenCV GDAL H_2O R

Optical Images for Landslide Detection and Mapping

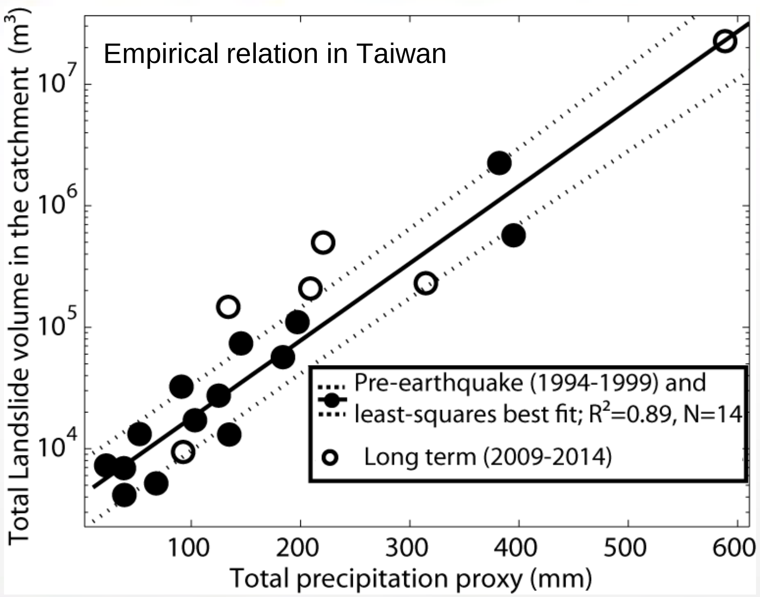
- Test cases
- New-Zealand
- Columbia
- Taiwan
- Nepal (ingestion of Pléiades and Spot6/7 underway)
- Caribean (Haiti, Cuba)
- Ethiopia

Kaikoura earthquake area 2015/12

Kaikoura earthquake – potential landslides (pre-classification)



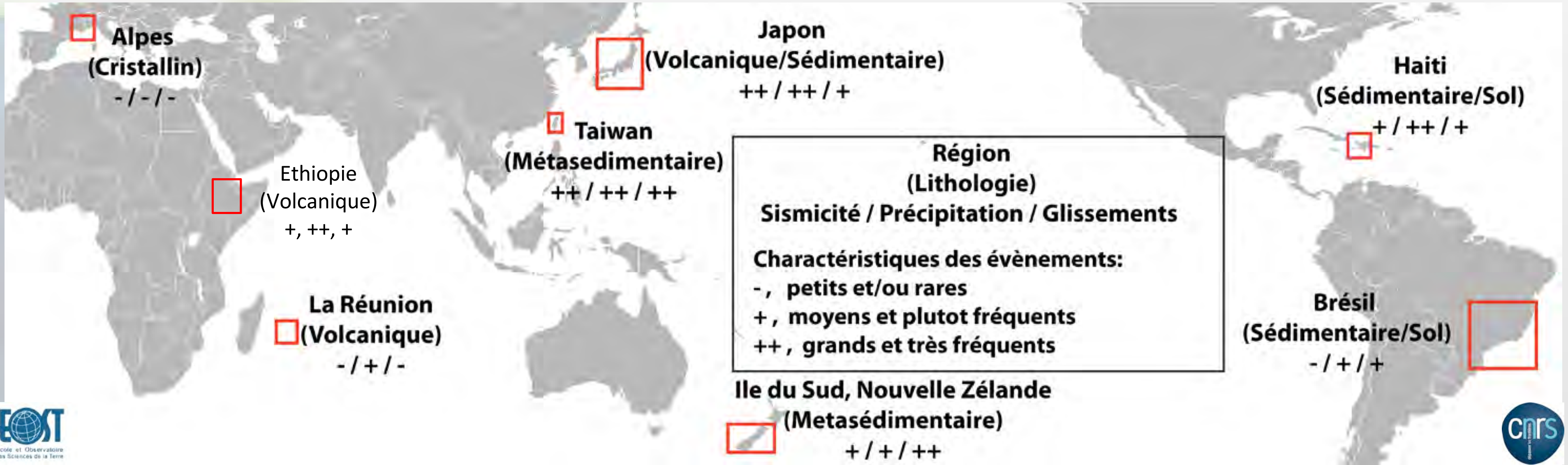
Generalizing the creation of EO-based inventories after major triggering events



Systematizing the creation of EO-based landslide inventory after major triggering events (ETQ > threshold M_L; rainfall event > XX mm) at the global scale
Document the triggering event (seismology, EO-based rainfall estimate using GPM)

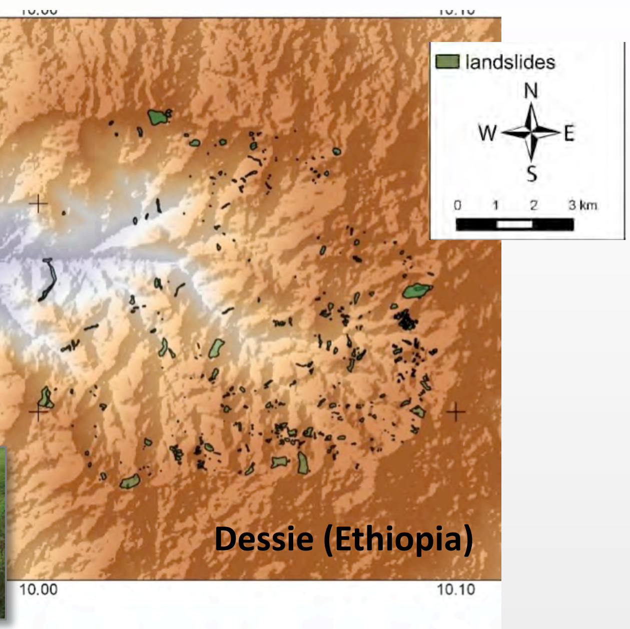
→ Create scaling laws relating landslide intensity to the triggering events

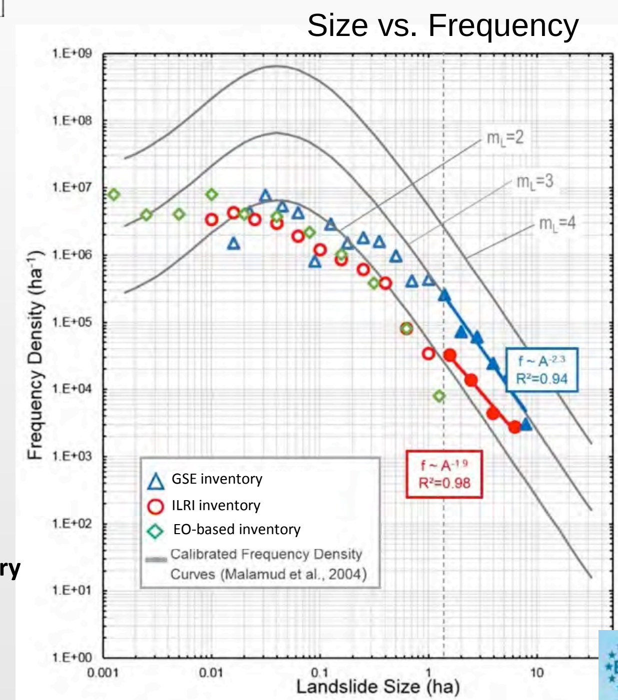
→ CNES project: Post-doc project of Odin Marc at CNRS/EOST



Optical Images for Landslide Detection and Mapping

(Malet et al., subm)





◇ **EO-based inventory**

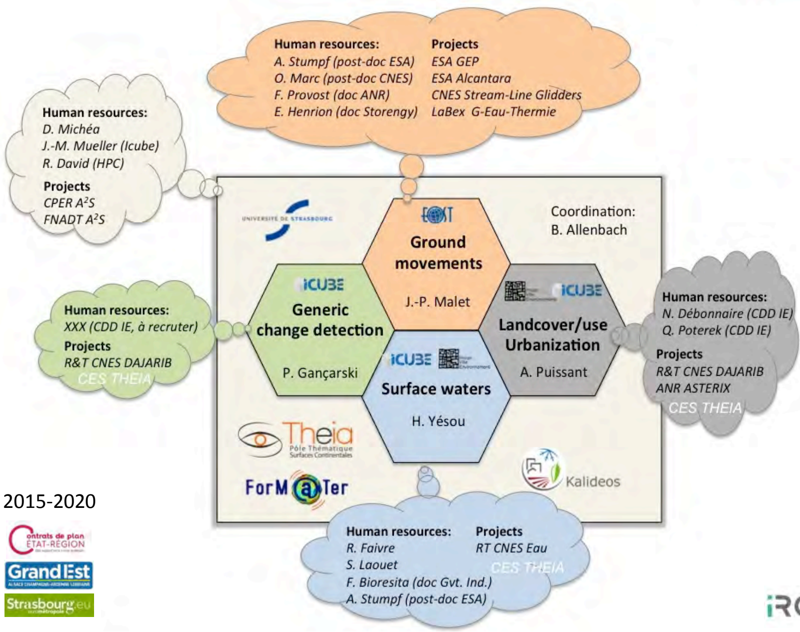
△ **GSE inventory**

○ **ILRI inventory**

A HPC-based processing infrastructure

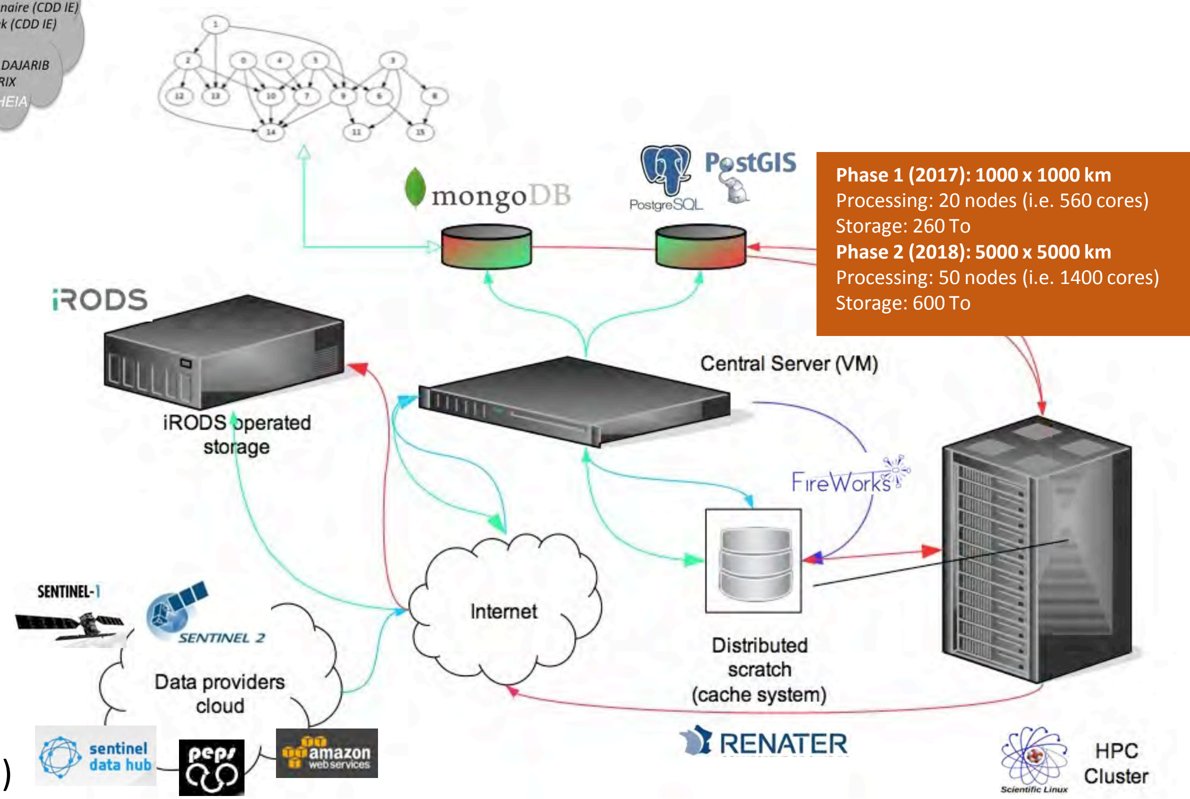
A^2S – University of Strasbourg

ALSACE AVAL SENTINELLE



2015-2020

Phase 1 (2017): 1000 x 1000 km
Processing: 20 nodes (i.e. 560 cores)
Storage: 260 To
Phase 2 (2018): 5000 x 5000 km
Processing: 50 nodes (i.e. 1400 cores)
Storage: 600 To



D. Michéa (Unistra – Icube / EOST / LIVE)

Open Group Discussions

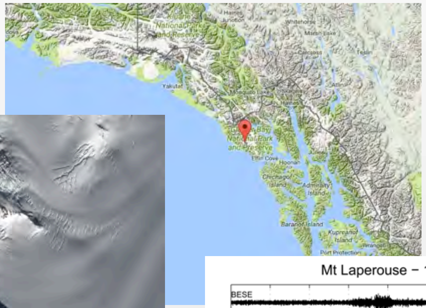
- How should this group operate during Landslide disasters in terms of response?
- What should be our end deliverables?
  - Journal Special Issue?
  - High visibility white paper/joint article?
  - Book?
- Impediments to data requesting and access?
  - Processing?
  - Support?

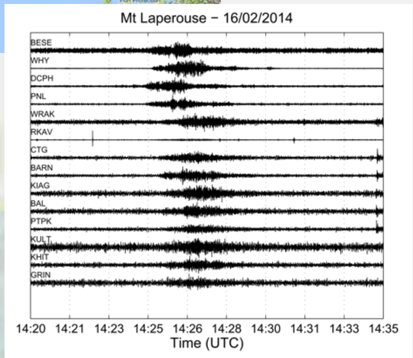
Experimental Regions

Southeast Alaska

- Slow-moving landslides
- Heterogeneous landslide triggers
- Active projects
- End users: National Forest Service, USGS

Sitka, Alaska landslide, August, 2015, James Poulson/The Daily Sitka Sentinel via AP





Mont La Pérouse rockslide, 2014/0216(Glacier Bay National Park). Optical imagery (Pléiades) and seismic signals (Starck, Ekström & Hibert; Univ. Columbia and Univ. Strasbourg)

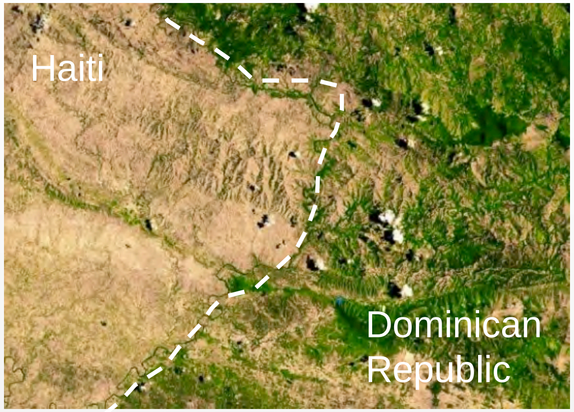
- Very large rockslides
- Detection and characterization by coupling Earth Observation and seismology
- Active projects (LDO/Columbia NY, EOST/Univ. Strasbourg)

Experimental Regions

The Caribbean: Cuba, Haiti and French Antillas

- Tropical climate, active tectonic region and diverse geomorphologic settings
- Rainfall, Earthquake and Anthropogenic induced failures
- Active engagement from Ministry of Energy and Mines (Cuba), CNIGS (Haiti) and CNRS (French Antillas)
- Active projects (Univ. of Strasbourg, CNES KAL-HAITI)
- Also an experimental region of other Disaster Pilots (floods, volcanoes)

Effects of deforestation on landslide susceptibility



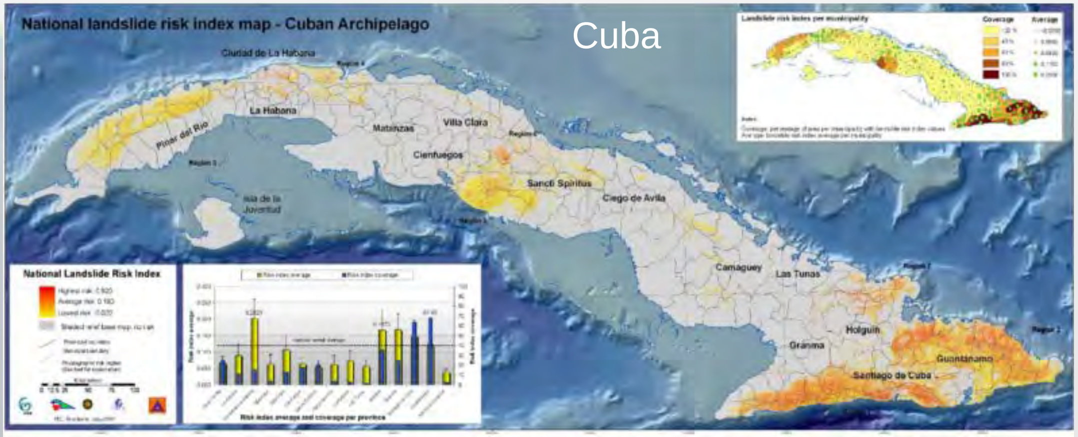


Fig. 8 Final landslide risk index map, as presented to the National Civil Defence authorities. *Inset map* in the *upper right corner* indicates the landslide risk index per municipality, both as the percentage of area with landslide risk index larger than 0 (coverage) as well as the average landslide risk index. The *barchart* shows the landslide risk index values per province

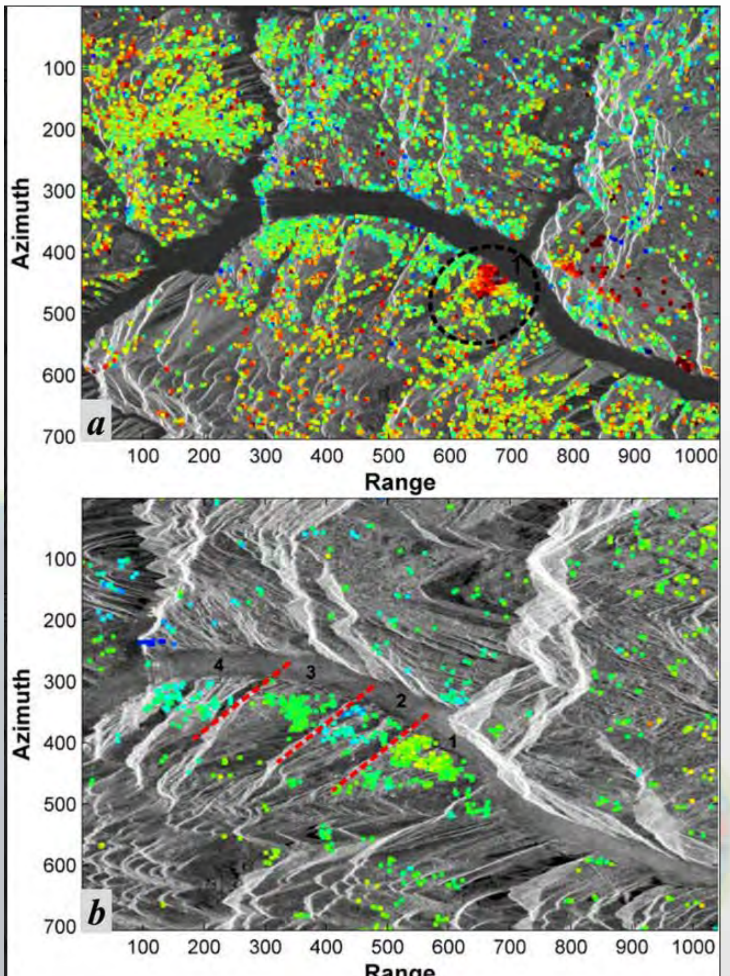
Castellanos & Van Westen (2008)

Landslide dam (Jacmel, Haiti) triggered by the 2010 ETQ

Mudslide (Haiti) triggered by storm Erika (2015)

Experimental Areas

China

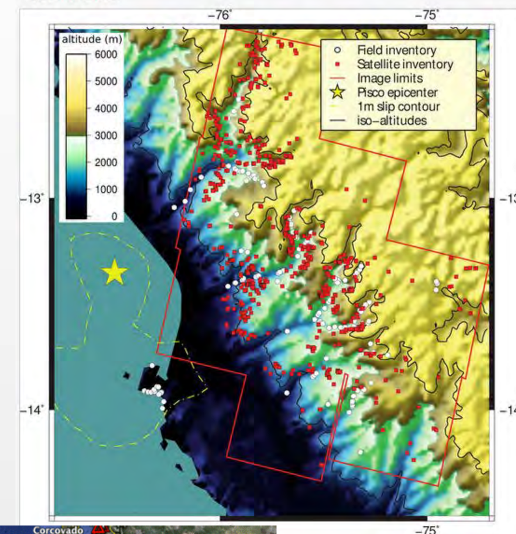


Deformation velocities at PS points in Badong identified by PS-InSAR: (a) from Advanced Land Observing Satellite (ALOS) Phased Array L-band Synthetic Aperture Radar (PALSAR) data; (b) from Environmental Satellite (ENVISAT) Advanced Synthetic Aperture Radar (ASAR) ascending data; and (c) from ENVISAT ASAR descending data. The numbered circles outline the two active landslides. The number 1 in (a) refers to the Huangtupo landslide. The red lines in (b) divided the southern riverbank into several significant deformation zones. The red star in (c) indicates the location of the reference point.

Tantianuparp, P., X. Shi, L. Zhang, T. Balz, and M. Liao, 2013: Characterization of Landslide Deformations in Three Gorges Area Using Multiple InSAR Data Stacks. *Remote Sens.*, **5**, doi:10.3390/rs5062704.

Peru

Figure 10. Field (white circle) and remotely-sensed (red square) landslide inventories. The 1 m contour of slip distribution on the fault during the Pisco earthquake is shown with dashed dot yellow line. The red contour is the coverage of the SPOT5 images. Iso-altitudes are lined in black at 1,000 m and 4,000 m levels.



Lacroix, P., B. Zavala, E. Berthier, and L. Audin, 2013: Supervised Method of Landslide Inventory Using Panchromatic SPOT5 Images and Application to the Earthquake-Triggered Landslides of Pisco (Peru, 2007, Mw8.0). *Remote Sens.*, **5**, doi:10.3390/rs5062590.

Thank you for your attention

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- **Sigrid Roessner, roessner@gfz-potsdam.de**
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