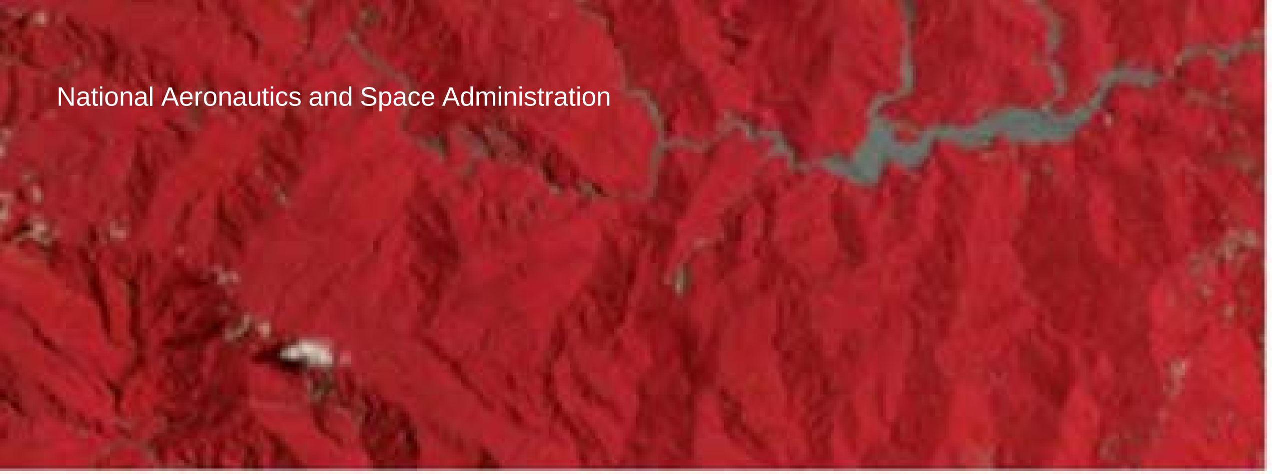
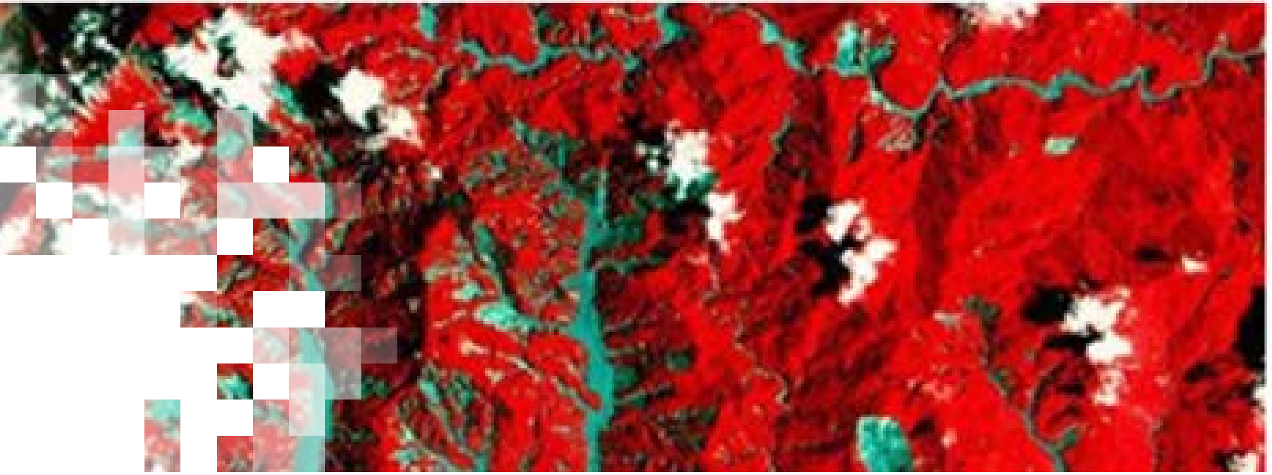
National Aeronautics and Space Administration





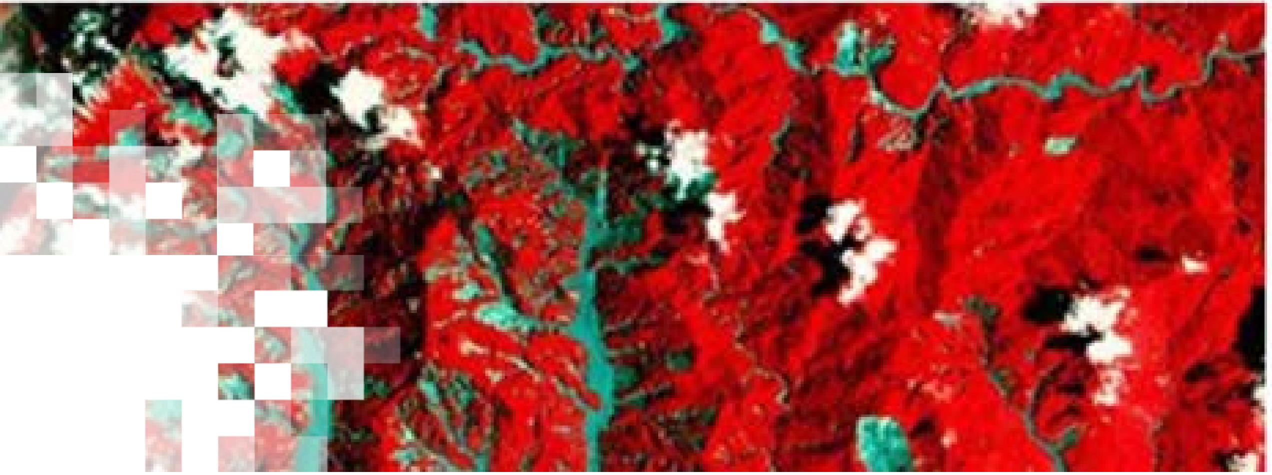
Landslide Monitoring and Risk Assessment Using NASA Earth System Data

Part 2: Mapping Landslide Occurrence Using Earth Observations

Dr. Robert Emberson (Associate Program Manager/Disasters, UMBC)

Dr. Pukar Amatya (Associate Research Scientist, UMBC)

March 13, 2025


Landslide Monitoring and Risk Assessment Using NASA Earth System Data

Overview

Training Learning Objectives

By the end of this training, participants will be able to:

- Identify the core concepts of landslide risk mapping including geophysical and meteorological drivers, and how satellite data can be used for this purpose.
- Select appropriate satellite data and model data to support landslide science and disaster preparedness associated with landslides.
- Recognize how to map where landslides have occurred using optical and radar data and understand how automated tools can be used for this purpose.

Prerequisites

- Fundamentals of Remote Sensing

Training Outline

Part 1

Remote Sensing for Landslide Science and Disaster Planning

March 11, 2025

Part 2

Mapping Landslide Occurrence Using Earth Observations

March 13, 2025

Part 3

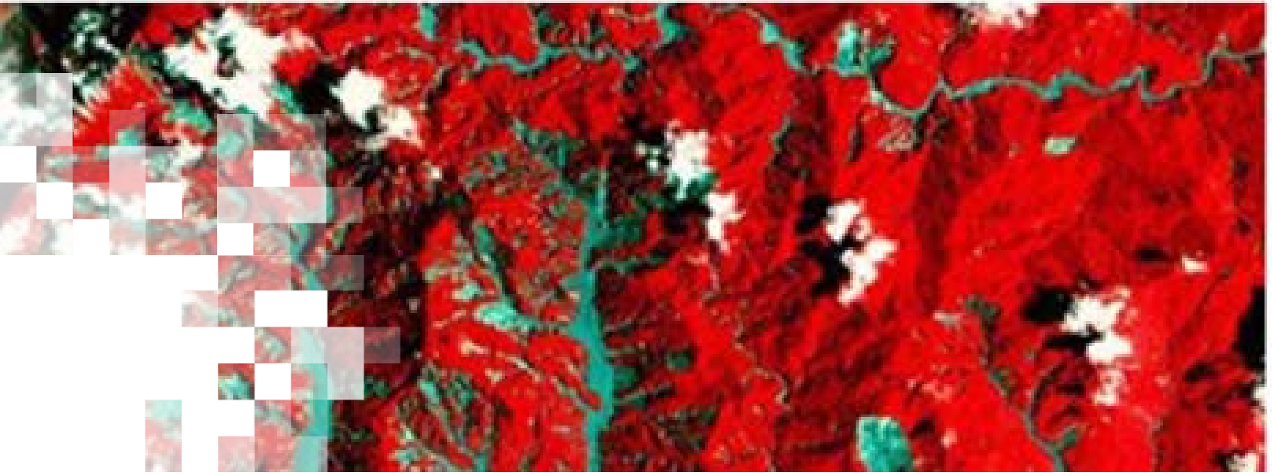
Remote Sensing and Landslide Susceptibility

March 18, 2025

Homework

Opens March 18 – **Due April 1** – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.


Landslide Monitoring and Risk Assessment Using NASA Earth System Data

Part 2: Mapping Landslide Occurrence Using Earth Observations

Part 2 Objectives

By the end of Part 2, participants will be able to:

- Select appropriate satellite data and model data to support landslide science and disaster preparedness associated with landslides.
- Recognize how to map where landslides have occurred using optical and radar data and understand how automated tools can be used for this purpose.

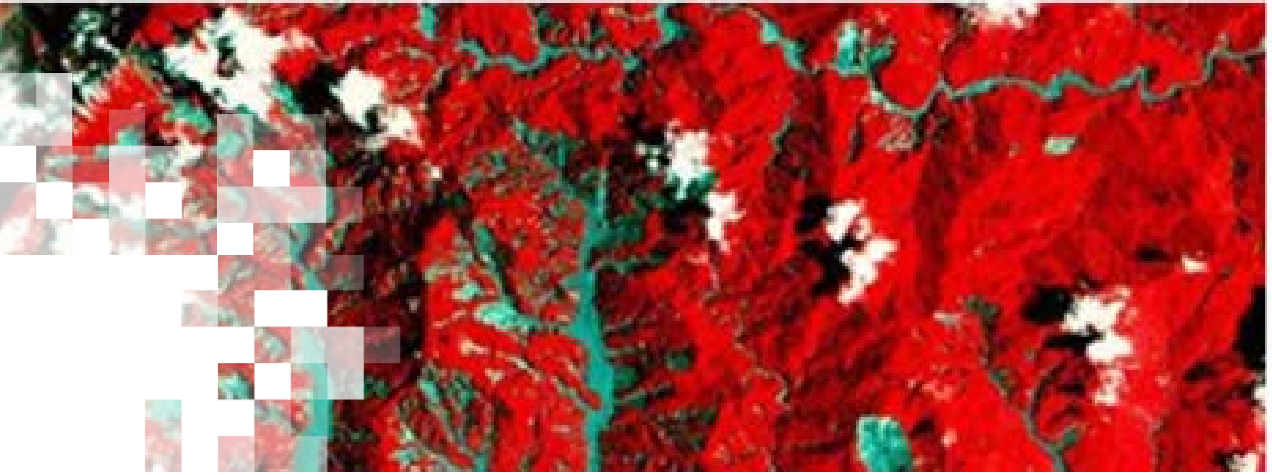
How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

Part 2 – Trainers

Dr. Robert Emberson
Associate Program Manager/Disasters
UMBC

Dr. Pukar Amatya
Associate Research Scientist
UMBC



Section 1: Landslide Mapping Using Satellite Data

Section 1: Landslide Mapping Using Satellite Data

First Steps

- Has a landslide occurred in your area of interest? What is needed for mapping using satellite data?
- Post-event imagery, as close to the event in question as possible; pre-event imagery is beneficial. It is important to ensure these are georeferenced.
- GIS software system
- Additional ancillary data sometimes helpful

Credit: Wikipedia / Woudloper

Section 1: Landslide Mapping Using Satellite Data

What characterizes landslide events?

- Rapid and often devastating movement of material downslope often creates highly visible surface changes.
- Impacts to human systems may be clear.
- An ability to translate two-dimensional observations from orbit into an understanding of what this might mean on the ground is a critical skill to develop.

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Big Sur Landslide (California, USA). Source: John Madonna, AP

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Source: Google Earth Imagery

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Rockfall in Oregon, USA. Source: Oregon DOT

Section 1: Landslide Mapping Using Satellite Data

Outlining Landslides

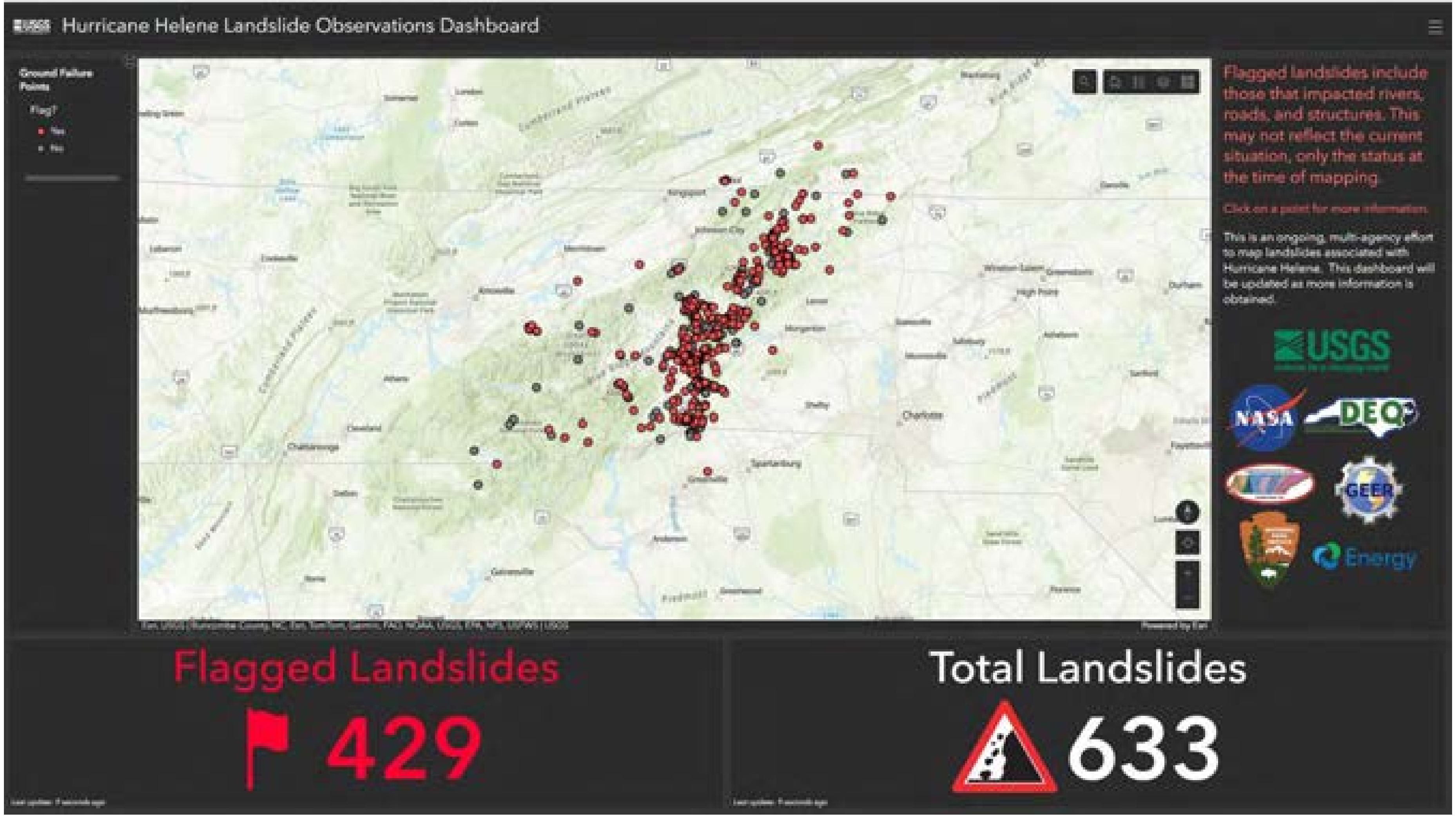
- Once you have identified a landslide on a satellite image, recording the location is the next step.
- GIS tools, including Esri, Google Earth and open-source systems allow drawing shapes around areas.
- This produces a polygon outline of the landslide location.
- Multiple landslides can be merged as a multi-polygon shapefile or geodatabase.

Landslide in British Columbia, Canada. Source: Planet Imagery

Section 1: Landslide Mapping Using Satellite Data

Points vs Polygons

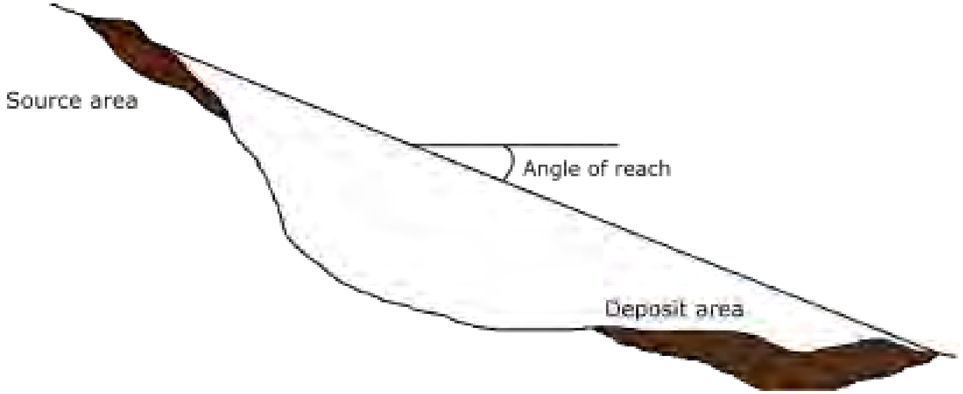
- Although polygons provide more complete analysis of landslide location, points may often be more convenient.
- Faster mapping, less concern about different parts of landslide areas.



Section 1: Landslide Mapping Using Satellite Data

Source and runout zones

- Simplified mapping may combine the source area (or headscarp) of a landslide with the runout and deposit areas.
- Differentiating these zones is important for comparative analysis of susceptibility and hazard – see Part III.
- Manually defining zones of source and deposit is sometimes possible from satellite imagery if separated, but this may be challenging to generalize.
- Long runout events present challenges for mapping; typically, runout into rivers and streams typically not mapped.



Kaikoura Landslide, NZ. Credit: GNS Science

Section 1: Landslide Mapping Using Satellite Data

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Landslides in Southern Taiwan.
Source: Google Earth

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Section 1: Landslide Mapping Using Satellite Data

Source and runout zones

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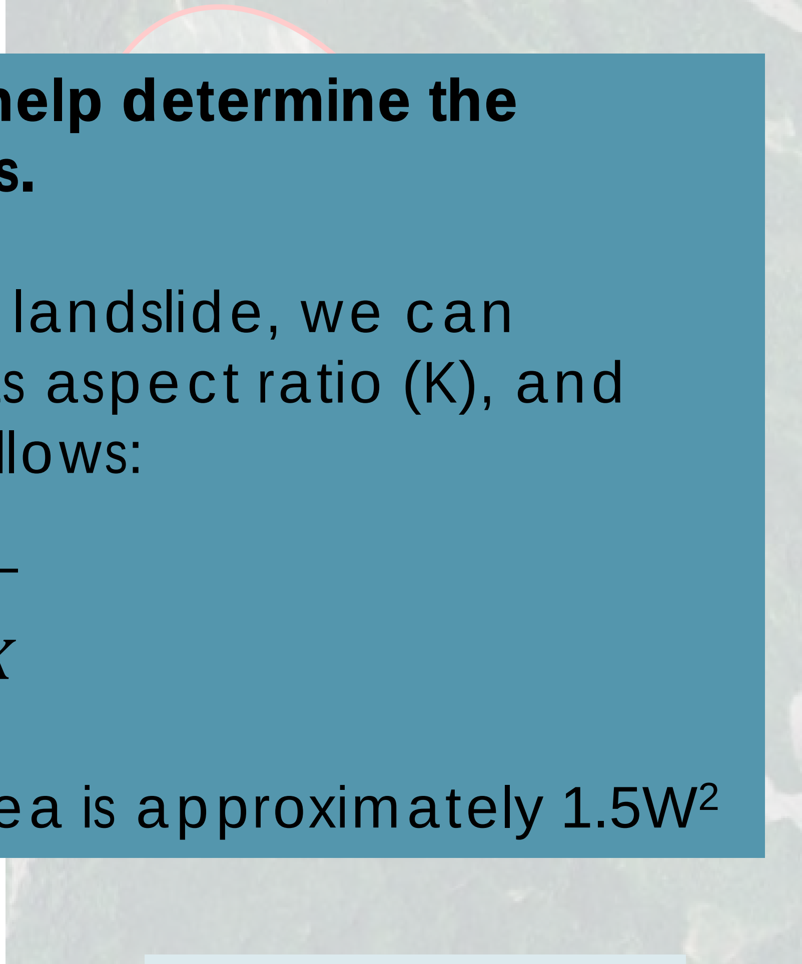
- Differenti compara see Part
- Manually sometim separate generaliz
- Long run typically, mapped.

Some simplified geometric rules can help determine the relative area of landslide source areas.

Using the perimeter and area (A) of a landslide, we can calculate the equivalent ellipse and its aspect ratio (K), and obtain the associated width (W) as follows:

$$W \cong \sqrt{4A/\pi K}$$

Based on global datasets, the scar area is approximately $1.5W^2$

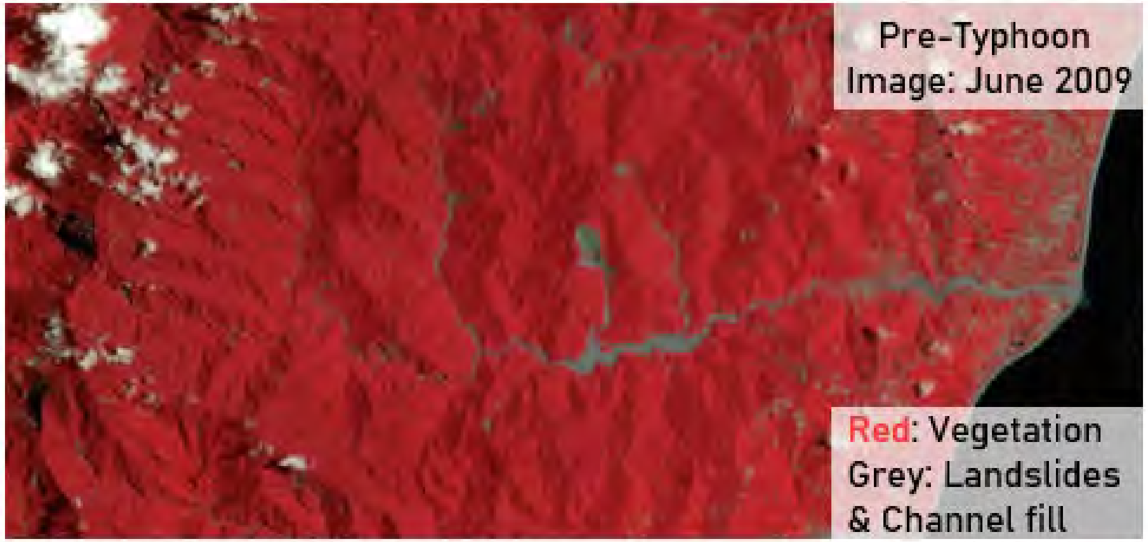


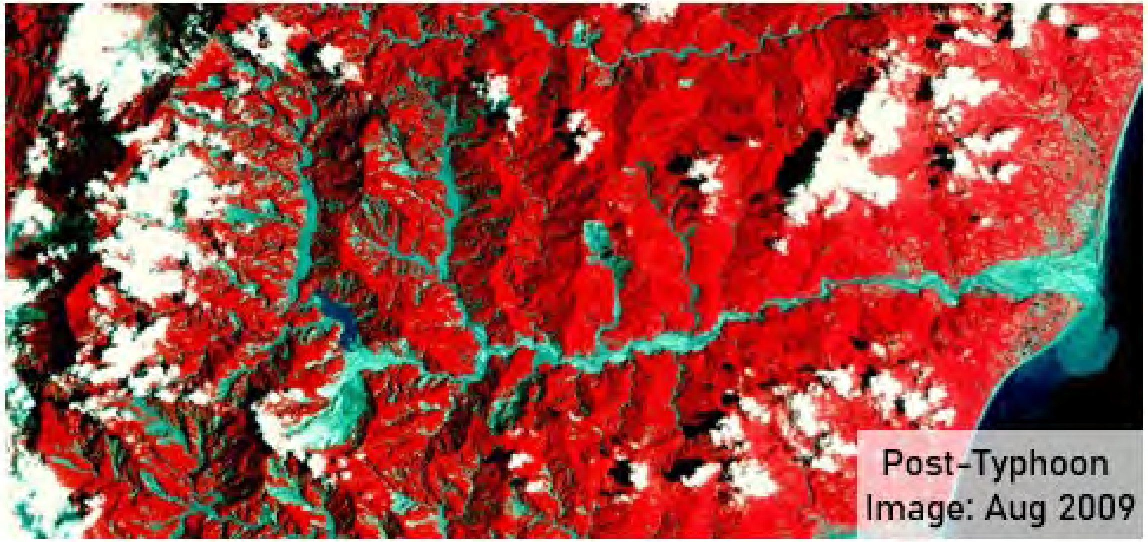
Landslides in Southern Taiwan; Source: Google Earth

Section 1: Landslide Mapping Using Satellite Data

False Color Imagery

- Landslides exposing bedrock may be more visible using different combinations of optical imagery bands.
- Change in vegetation is often employed as this is often more sensitive to surface change.
- NDVI band combination shows clear change for landslides in e.g., Taiwan.



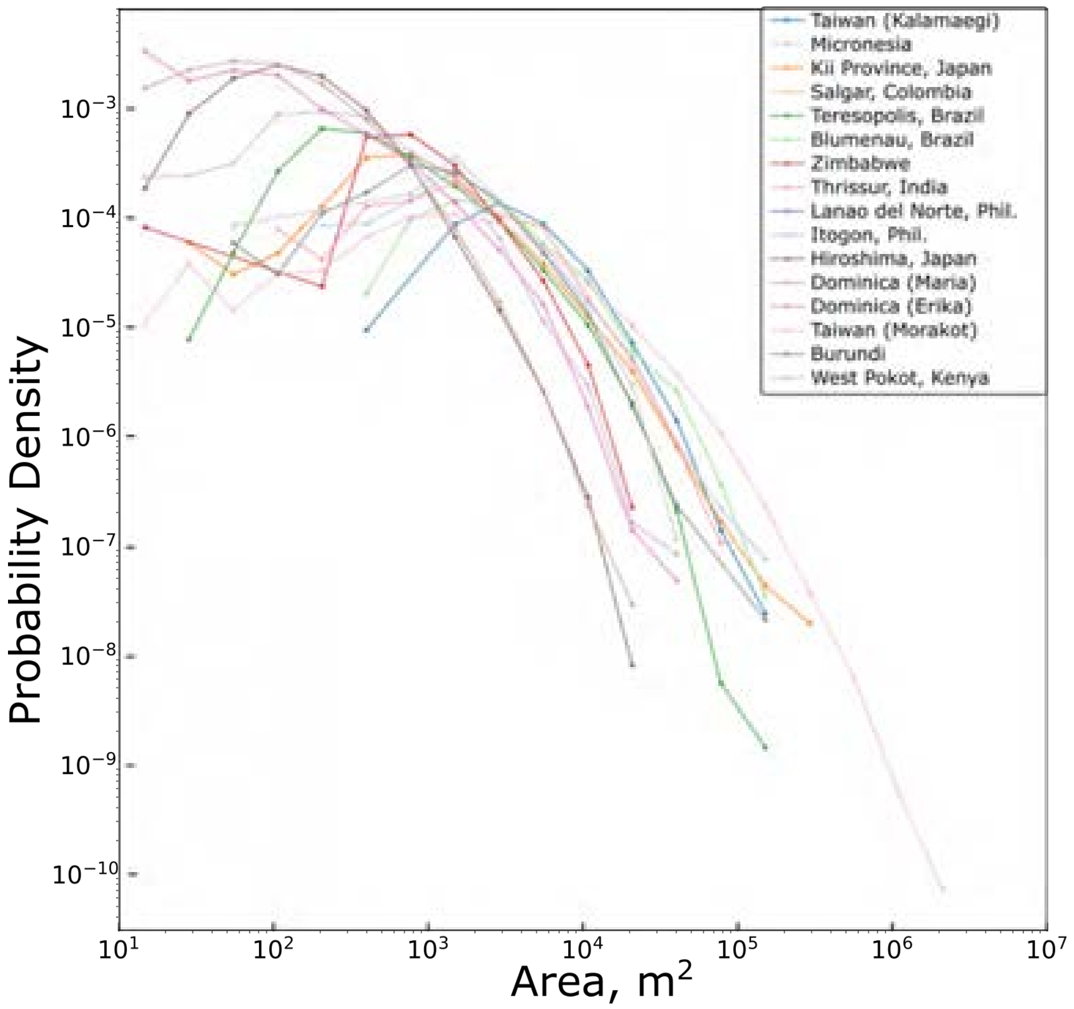


Section 1: Landslide Mapping Using Satellite Data

Relevant imagery resolution

- The number and size of landslides that can be observed strongly depends on the resolution of available imagery.
- An analysis of multiple landslide inventories shows the distribution of landslide area.
- Inventories produced using very high-resolution commercial imagery include significantly higher proportion of small landslides.

Size Frequency Distribution of Landslide Inventories



Source: Emberson et al., 2022

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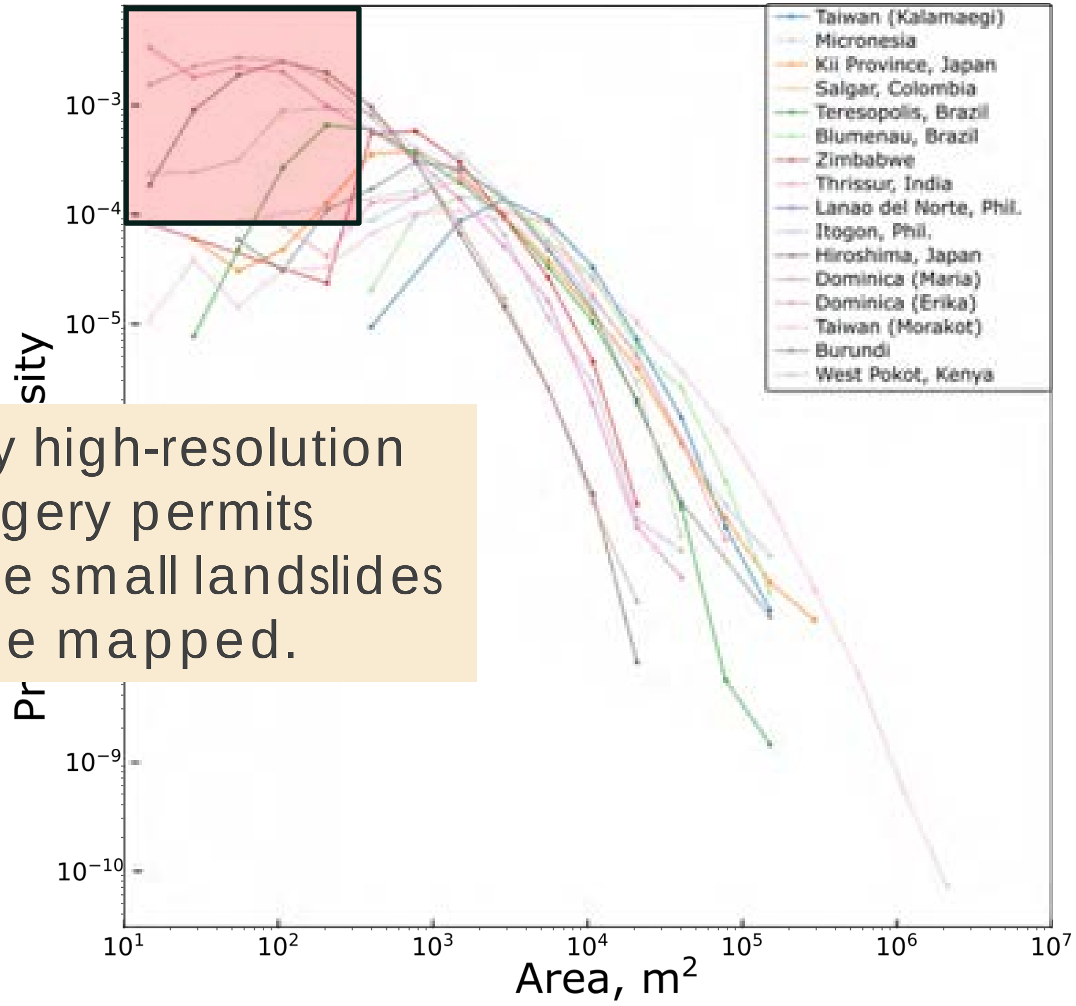


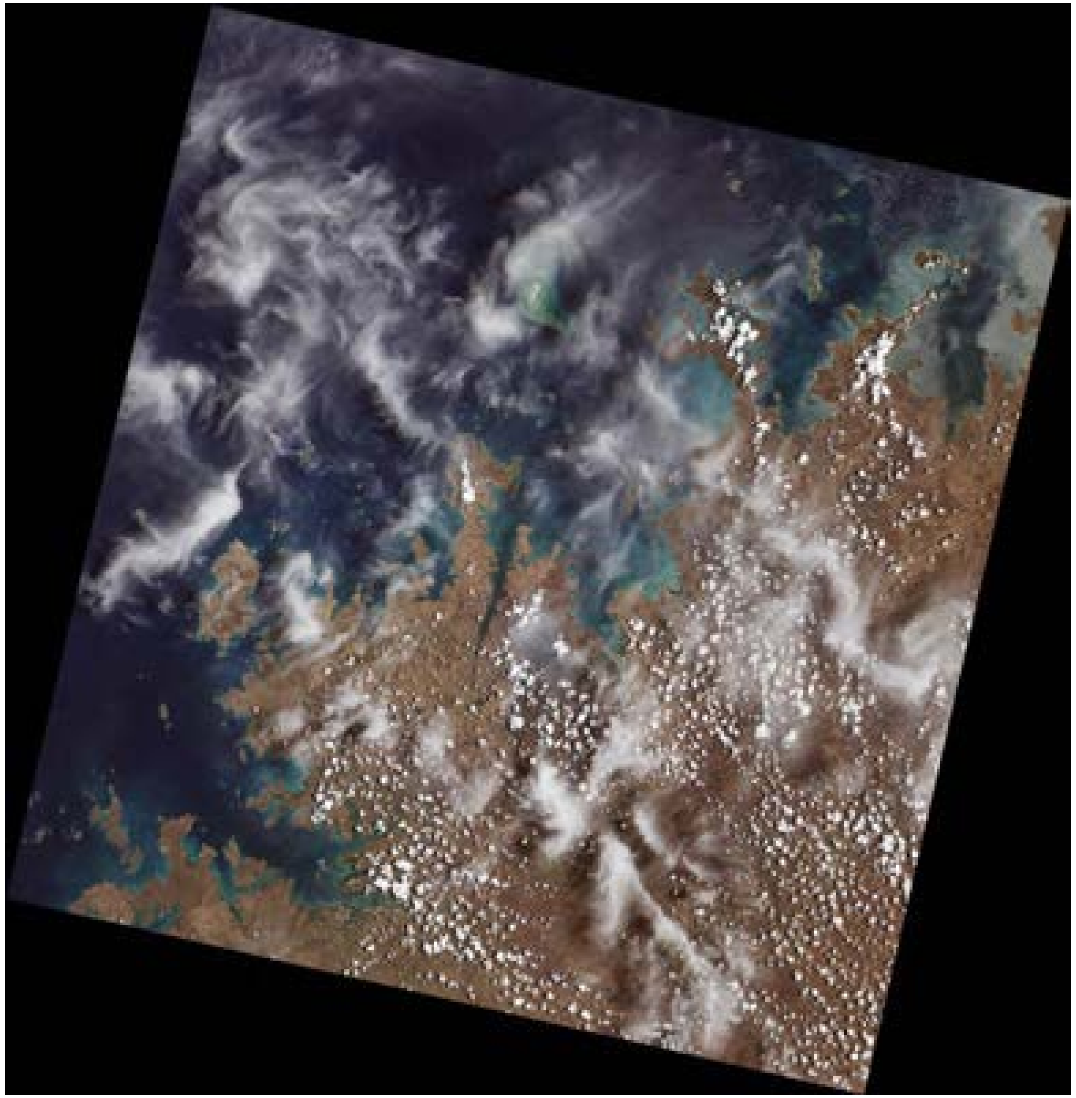
Very high-resolution imagery permits more small landslides to be mapped.

Source: Emberson et al., 2022

Section 1: Landslide Mapping Using Satellite Data

Cloud cover

- Clouds are a significant factor for optical imagery.
- These may strongly mask the areas where landslides occur.
- Preference to seek cloud-free imagery for mapping.
- If this is unavailable, it is important to provide polygon outlines of the cloud locations in the associated inventory to clarify the overall extent of mapping area.



Landsat 9 OLI-2 image of clouds over Northern Australia.
Source: USGS

Section 1: Landslide Mapping Using Satellite Data

Relevant Metadata

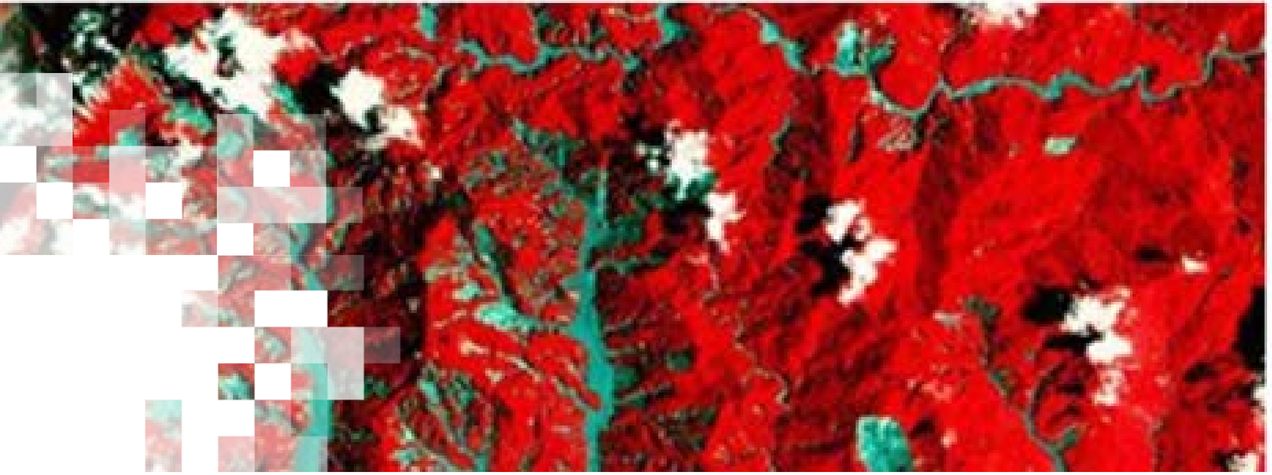
- What is typically needed as associated data for a dataset of mapped landslides?
  - Location
  - Possible triggering event
  - Imagery date(s) – critical to determine if landslides include historic events
  - Imagery source (type of sensor, resolution)
  - Method of mapping (points, polygons, manual or automatic)
  - Person mapping
  - Associated publications
  - Extent of mapping area (including cloud coverage)
  - Type of landslide (rockfall, debris avalanche, etc.)

Section 1: Landslide Mapping Using Satellite Data

New or historic landslides

- After an initial landslide, revegetation can occur over the span of years – decades.
- Older landslides may be invisible as clear scars from optical imagery after revegetation.
- Re-activation of large landslides is common.
- Multi-temporal landslide inventories can provide longer-term analysis.

Landslides in Southern Taiwan—event occurred in 2009; left image 2011, right image 2024


Section 2: Automated Mapping

Section 2: Automatic Mapping

How does automated mapping work?

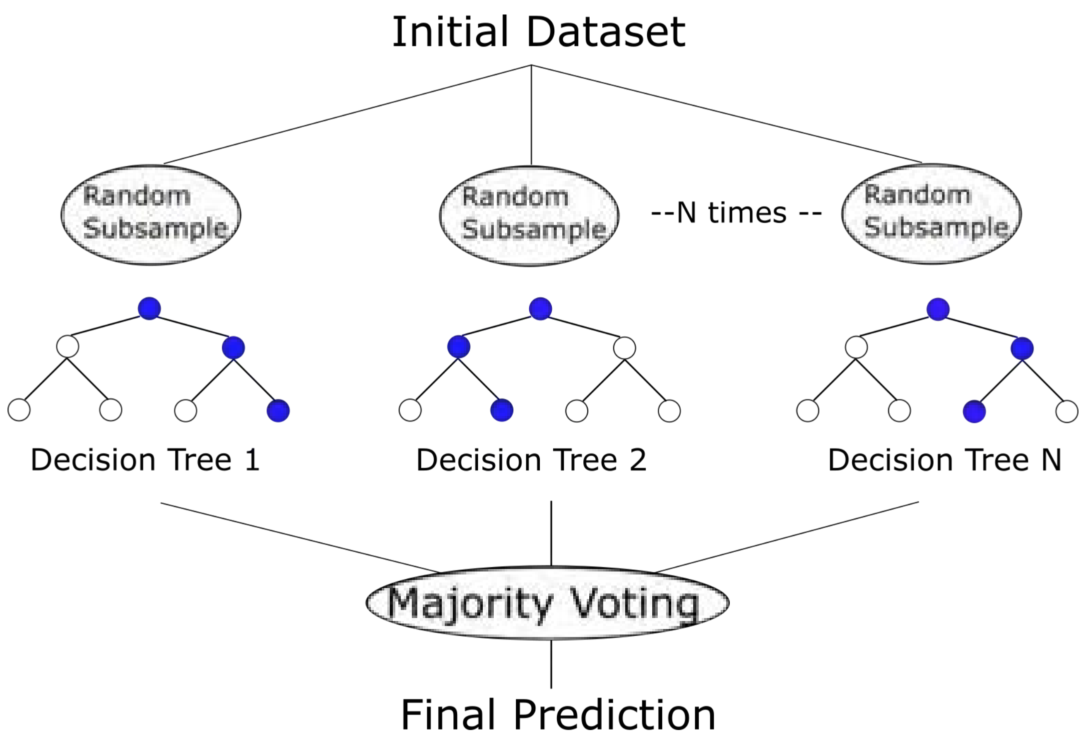
- In some locations, many thousands of landslides may be triggered by a single rainfall event.
- Manual mapping of such events is extremely time consuming, and researchers have sought automatic methods to simplify this process.
- Automatic methods exploit the typical changes in texture, color, and spectral properties of recently disturbed areas.
- Two key approaches: pixel based, and object based.
- Amalgamation is a key issue.

Credit: Google Earth

Section 2: Automatic Mapping

How does automated mapping work?

- To assess changes, training information on landslides is necessary. This typically is made up of manually mapped landslides.
- Most methods typically use prior training data to characterize pixels or objects that are either landslide or non-landslide zones.
- A variety of regression, machine-learning or AI based approaches can then be used to predict other pixels or objects that match the type of input used as training, which is then output as a prediction of likely landslide locations.



Simplified Random Forest Model

Section 2: Automatic Mapping

How does automated mapping work?

1. Pixel-based

- Spectral information from single pixels
- Suffers from salt and pepper effect
- Computationally not expensive

2. Object-based image analysis (OBIA)

- Converts homogenous pixels into objects
- Can incorporate spectral, textural, morphological, geometrical and contextual information
- Computationally expensive

Section 2: Automatic Mapping

Object Based Image Analysis (OBIA)

Two step:

1. Segmentation

Multiresolution segmentation, Mean-Shift segmentation, Watershed segmentation

2. Classification

Ruleset based or machine learning (Random forests, Support Vector Machine etc.)

Most studies based on commercial software

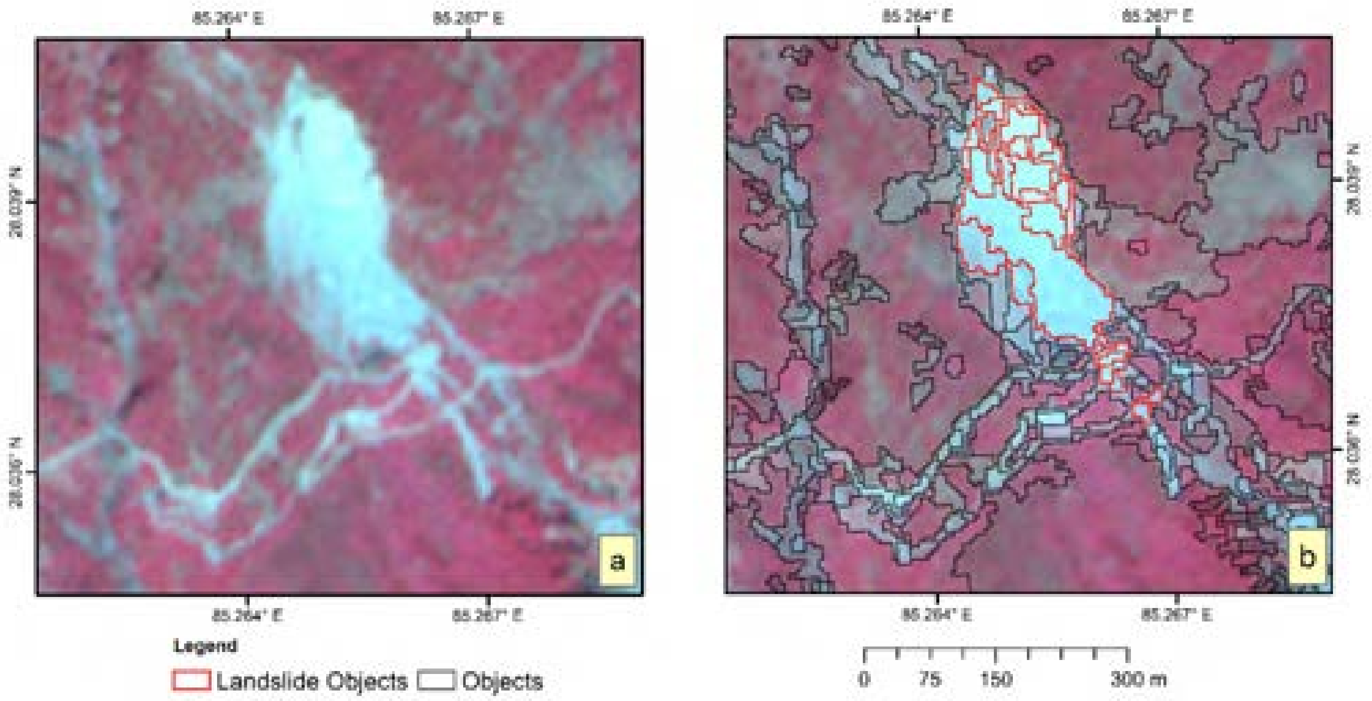


Image ©Planet Labs

Section 2: Automatic Mapping

Semi-Automatic Landslide Detection (SALaD) system

Python packages:

GDAL

Orfeotoolbox (OTB)

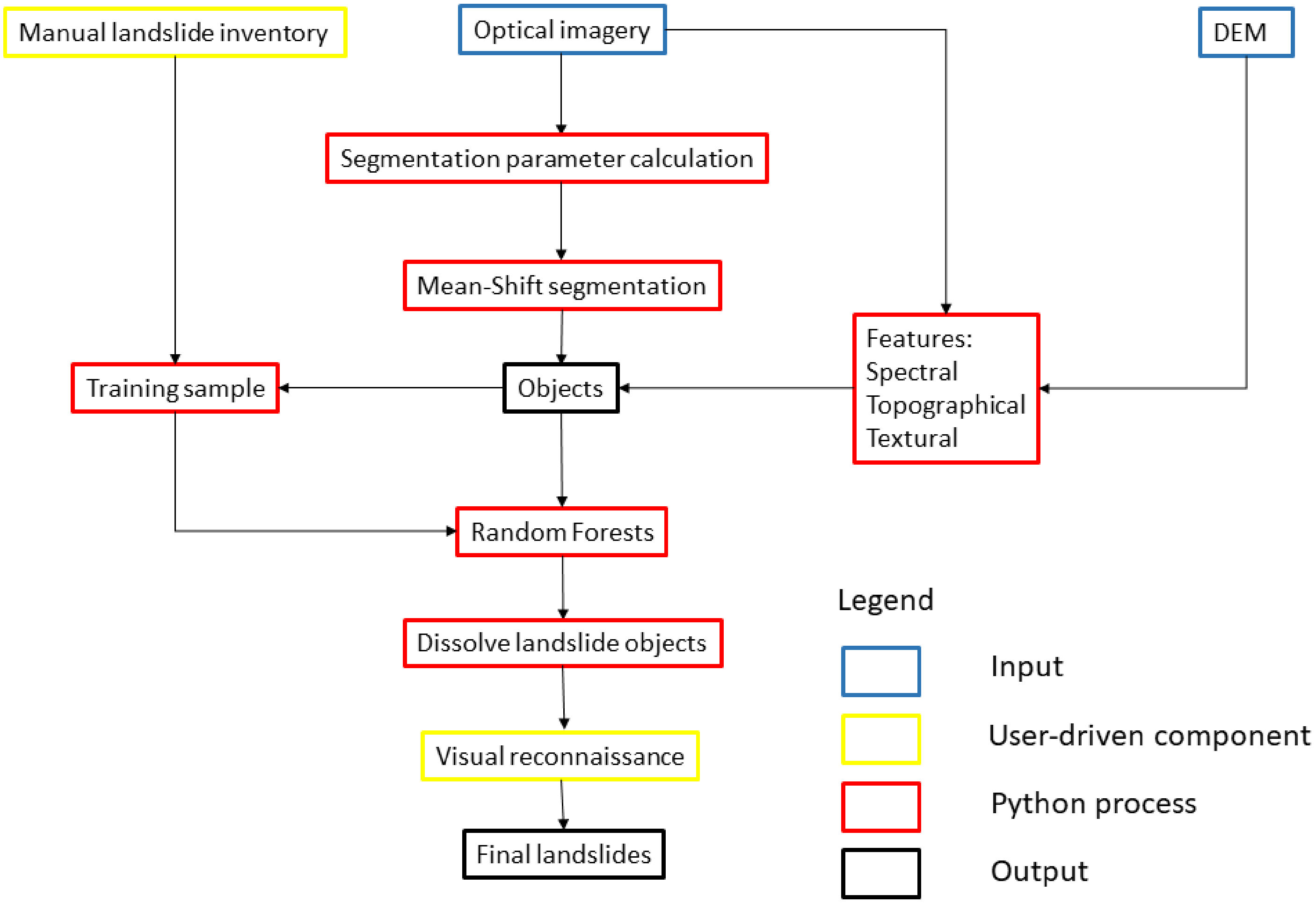
Raster stats

Scikit-Learn

Geopandas

Operating System: Linux or Windows

Currently configured in NCCS ADAPT Linux platform



Amatya et al. (2021) https://github.com/nasa/SALaD

Section 2: Automatic Mapping

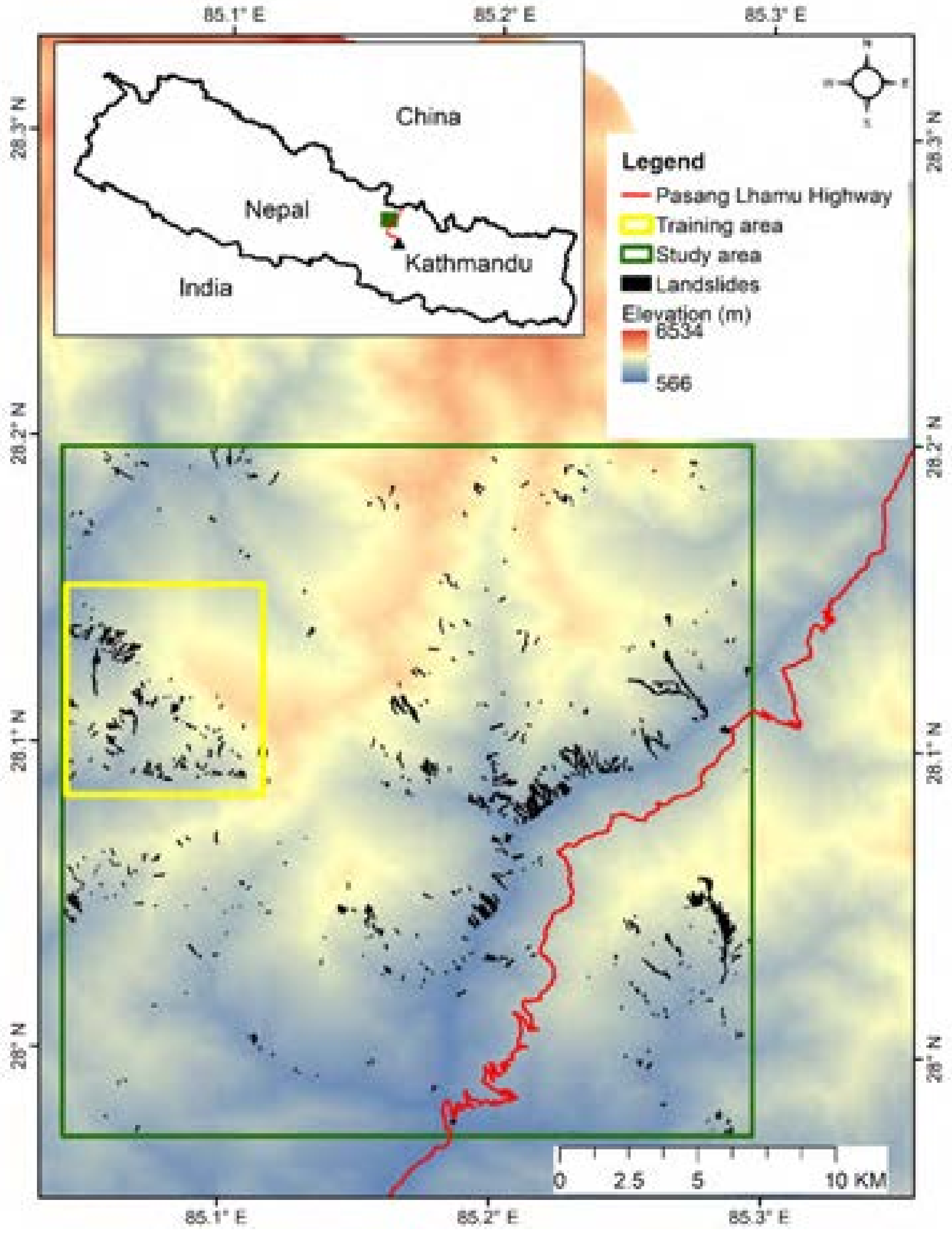
Semi-Automatic Landslide Detection (SALaD) system

Location: Pasang Lhamu Highway, Nepal

Area = 625 km^2

623 landslides manually mapped

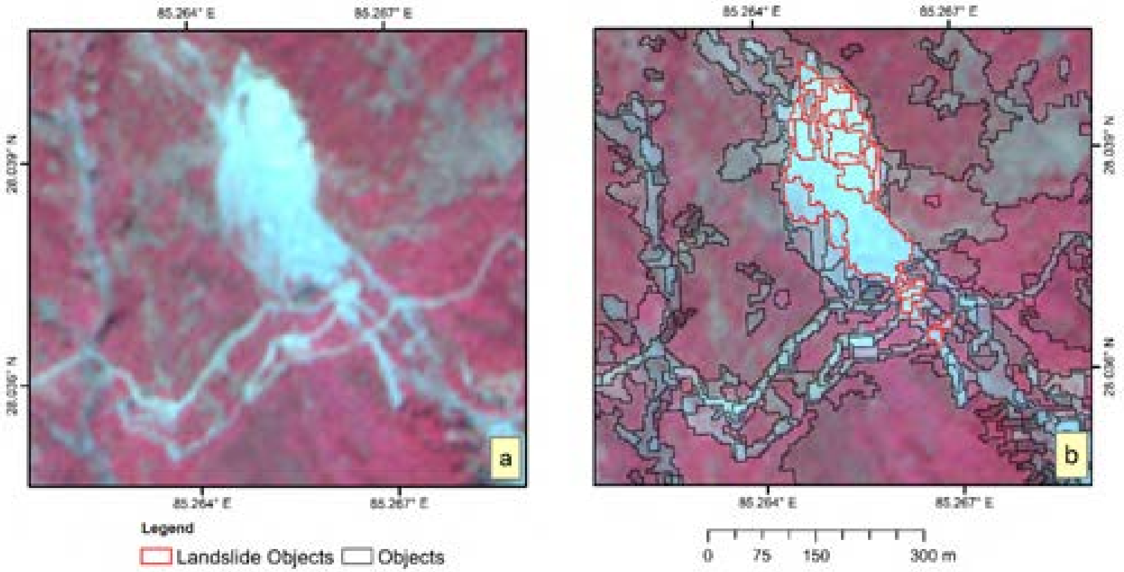
Imagery: RapidEye



Amatya et al. (2021)

Section 2: Automatic Mapping

Semi-Automatic Landslide Detection (SALaD) system



Above: Segmented objects

Below: SALaD detected landslides.

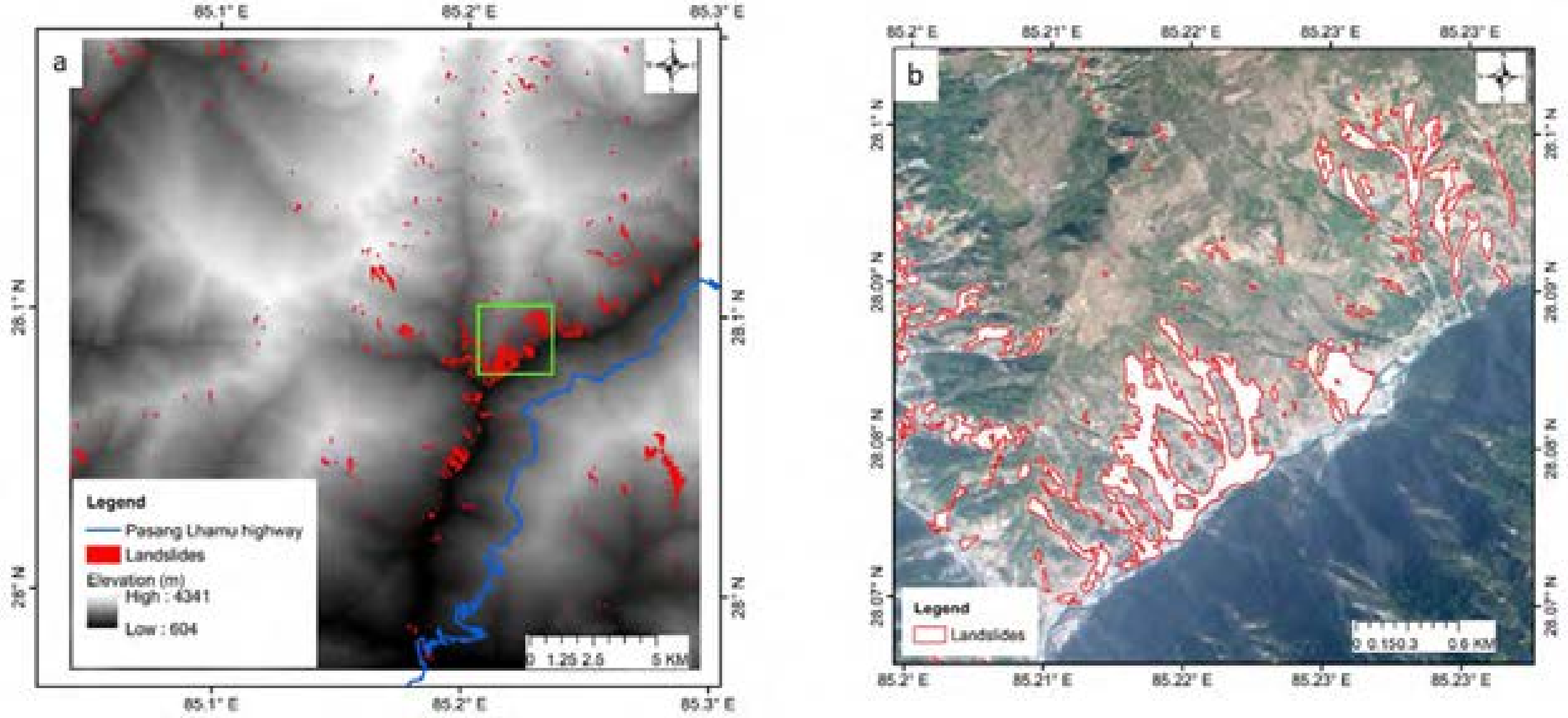
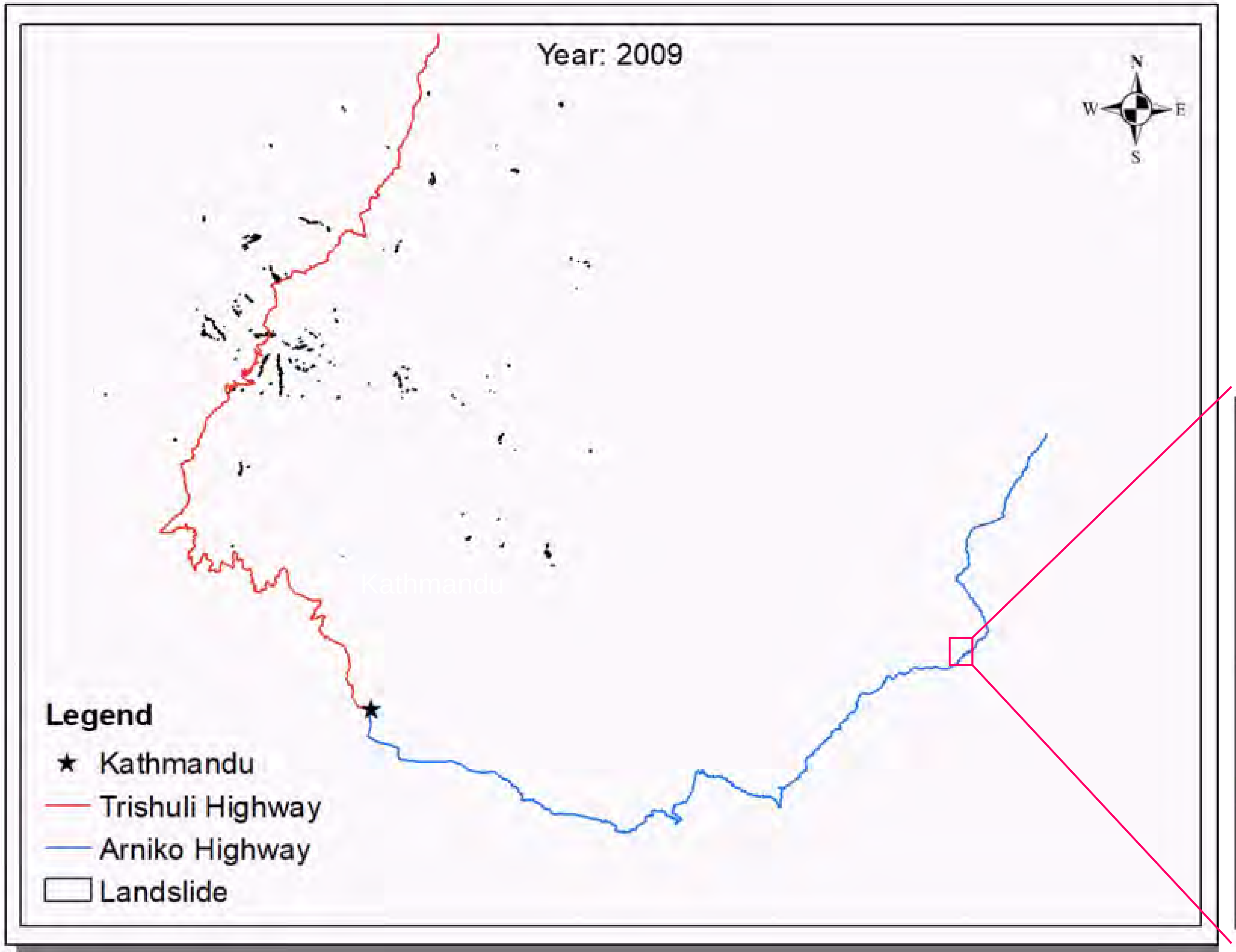


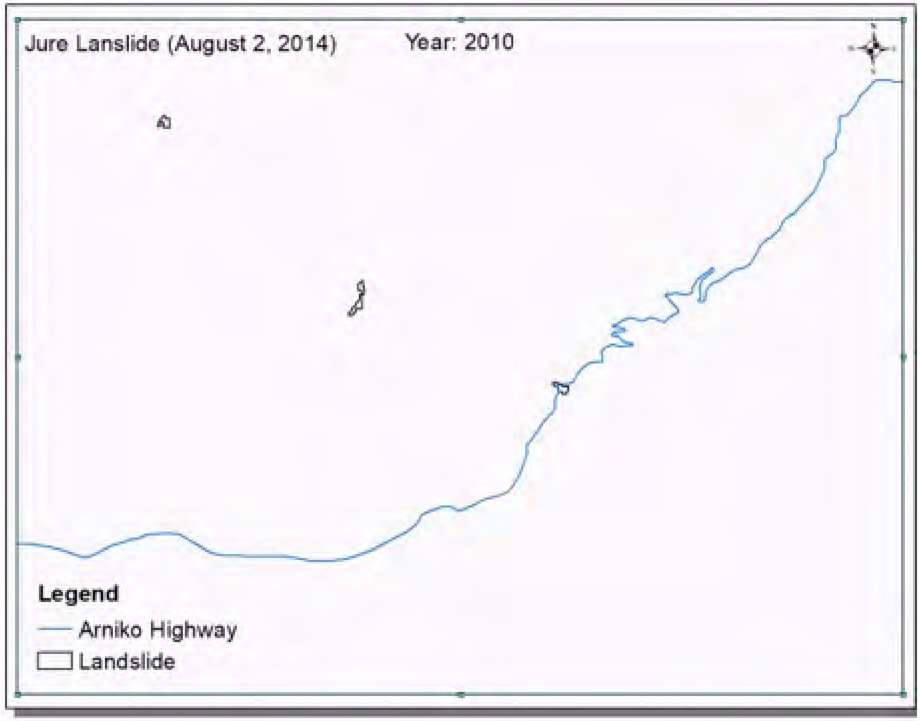
Image ©Planet Labs

Amatya et al. (2021)

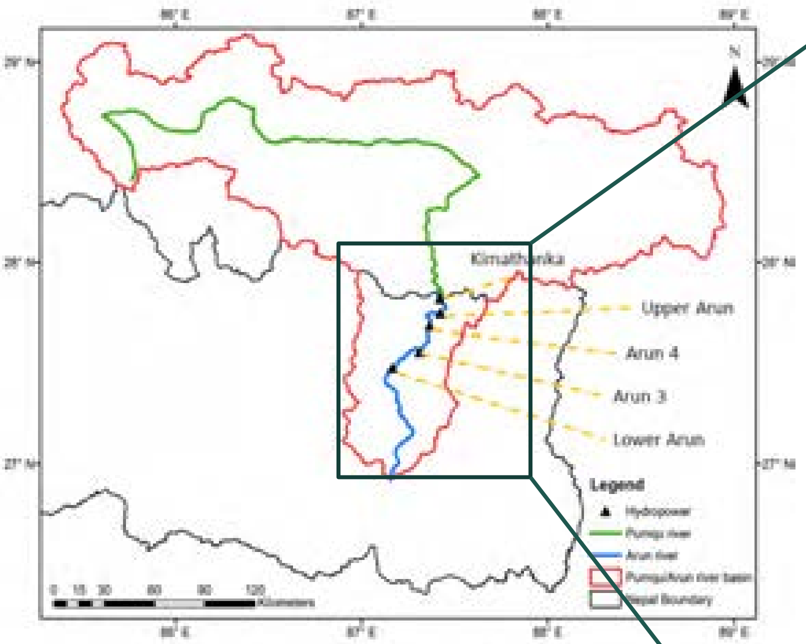
Section 2: Automatic Mapping



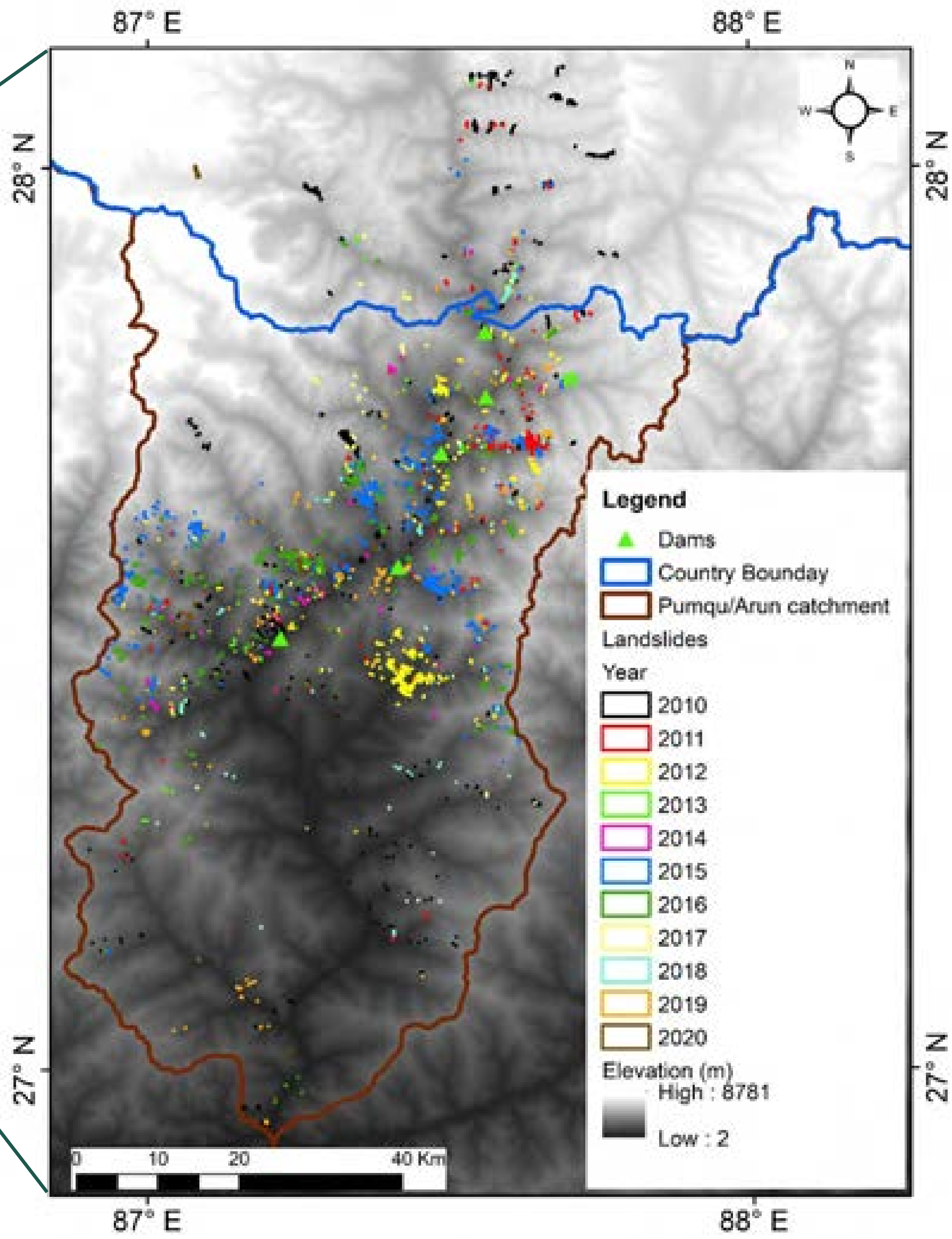
Source: Landsat 8



Section 2: Automatic Mapping

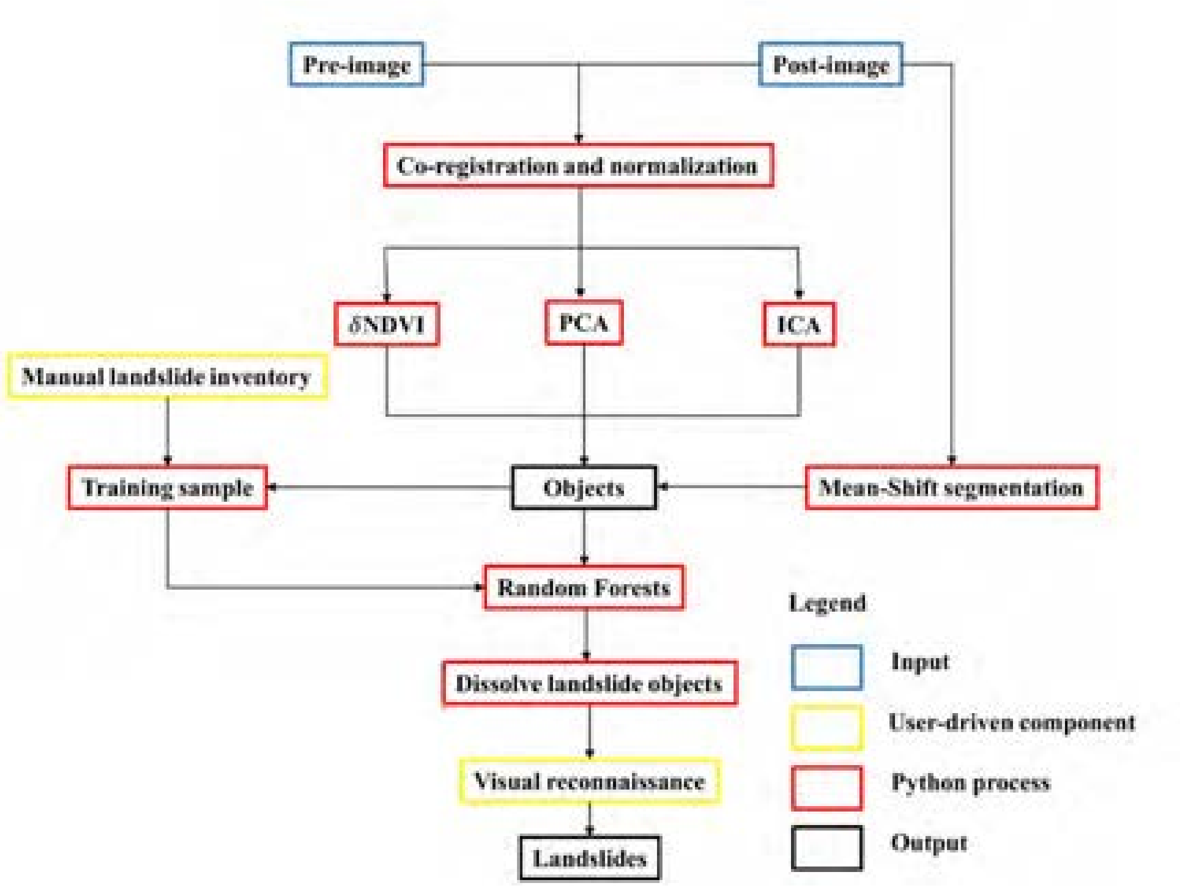


- Years = 2010 – 2020
- Number = 2439
- Minimum size = 97 m^2
- Maximum size = 357089 m^2



Section 2: Automatic Mapping

Semi-Automatic Landslide Detection – Change Detection (SALaD-CD) system



SALaD-CD flowchart (Amatya et al. 2022)

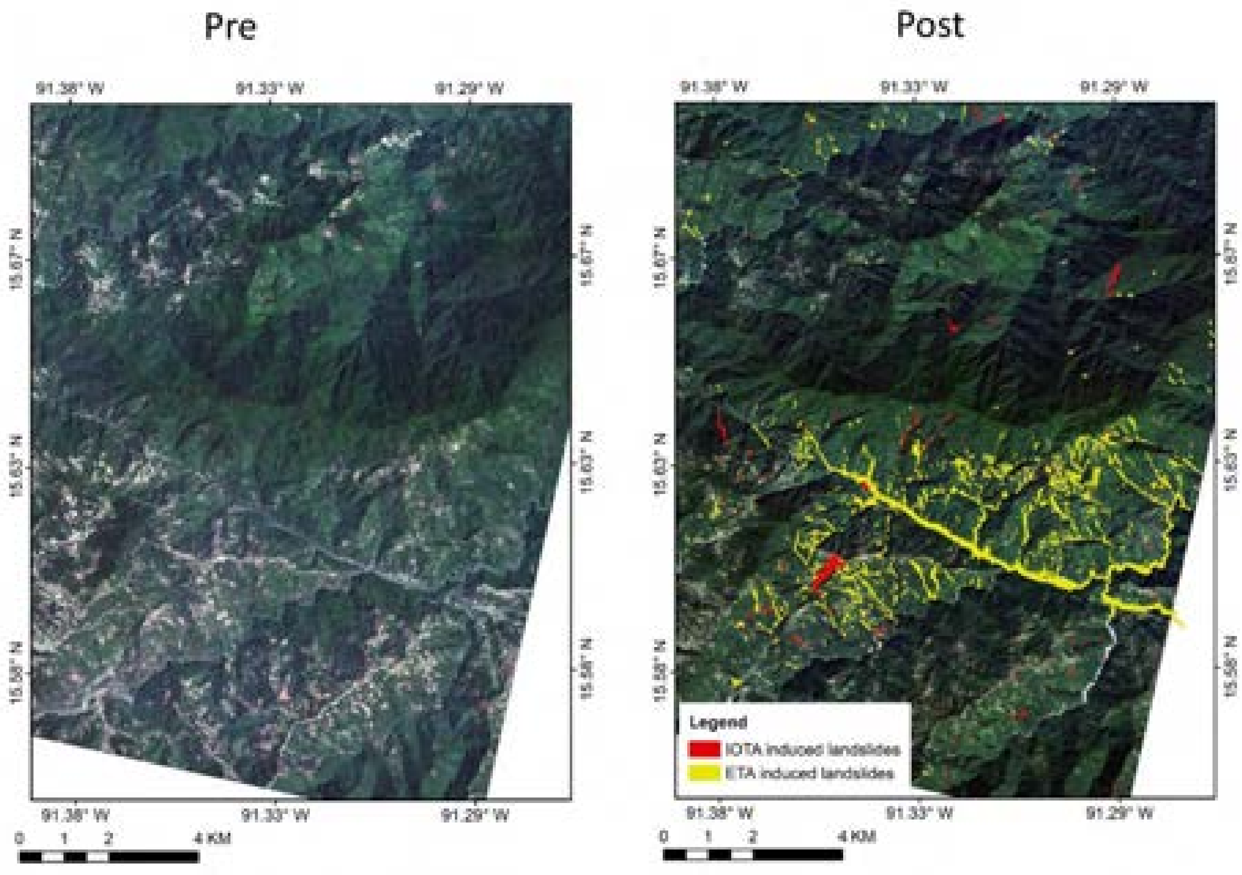
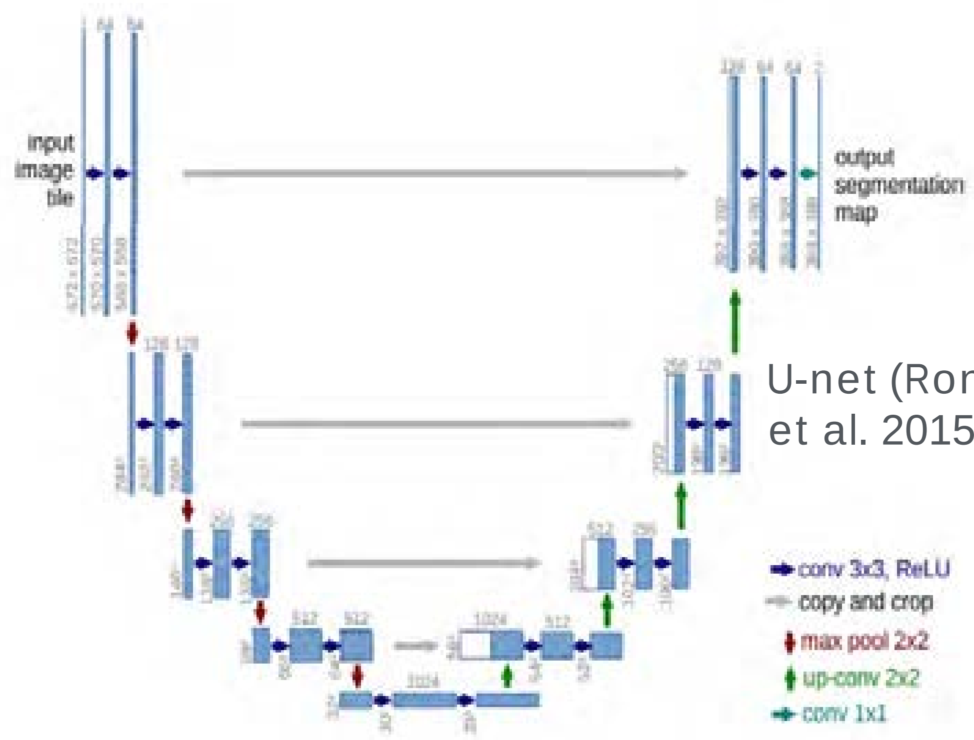


Image ©Planet Labs

Section 2: Automatic Mapping

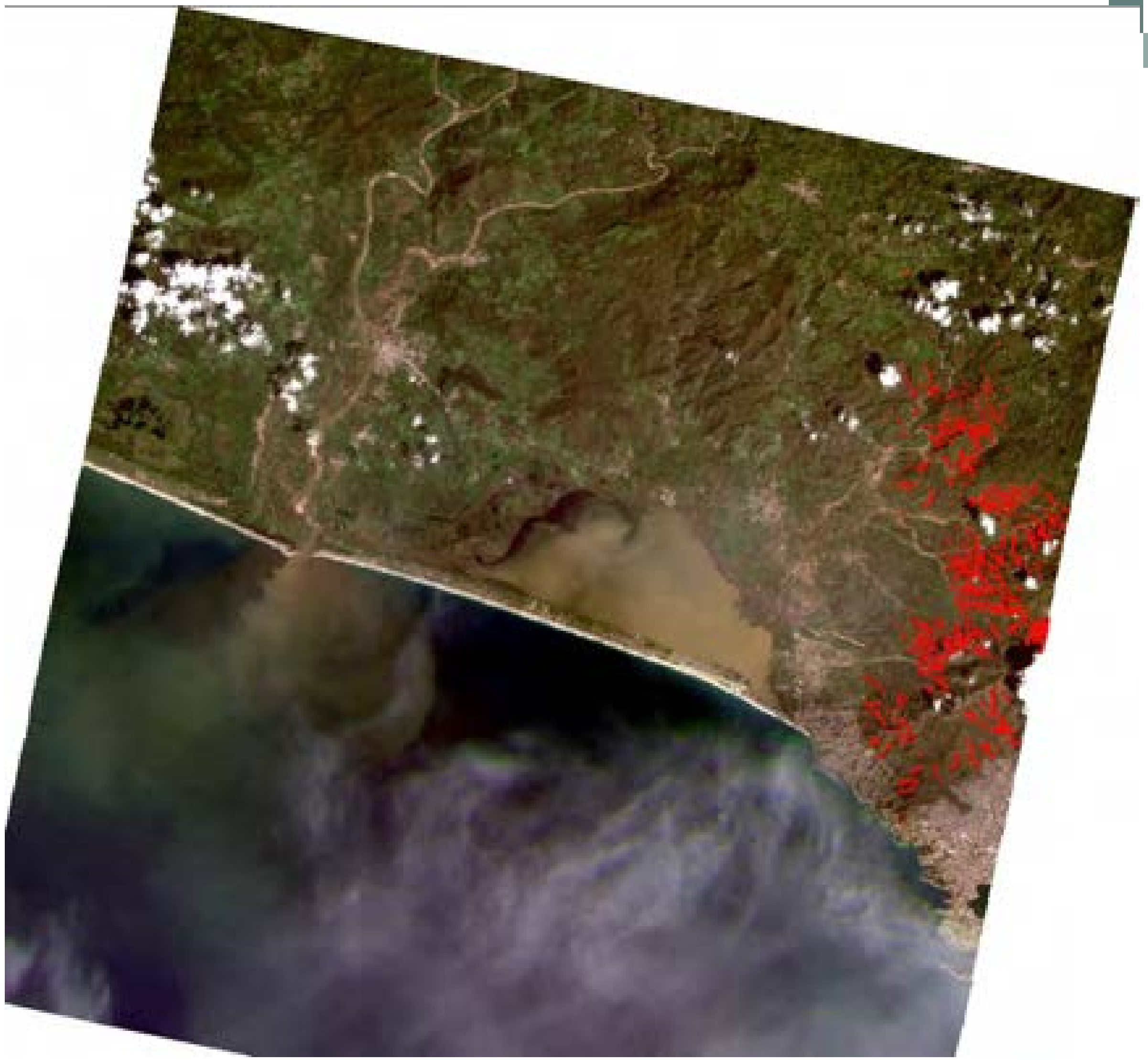
Deep-learning methods



U-net (Ronneberger et al. 2015)

Newly developed U-net method exploits advanced deep learning approaches.

- Faster setup; more reliable and accurate



Landslides

https://maps.disasters.nasa.gov/arcgis/home/item.html?id=78f299478c3746c19642c97ed4977cca

Image ©Planet Labs

Section 2: Automatic Mapping

Additional Considerations

- Training data strongly influences outputs. SALaD-based approaches have been used to map flood damage, relying on change detection.
- DEM inputs – including slope estimates – may be helpful to mask low-elevation flood inundation from landslide results.
- Areas without significant textural, color or spectrographic change may be challenging; this includes desert regions and reactivated landslides.

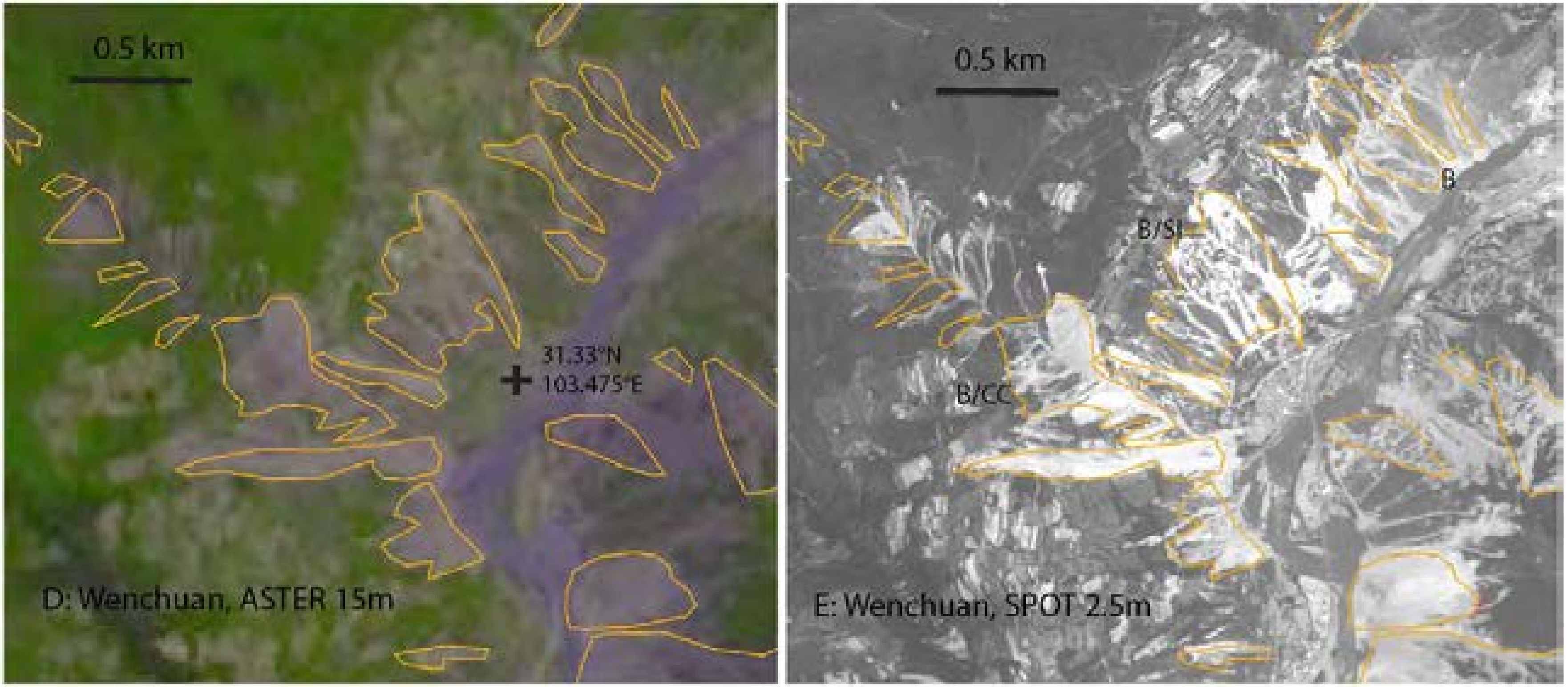
Image ©Planet Labs

Flood damage

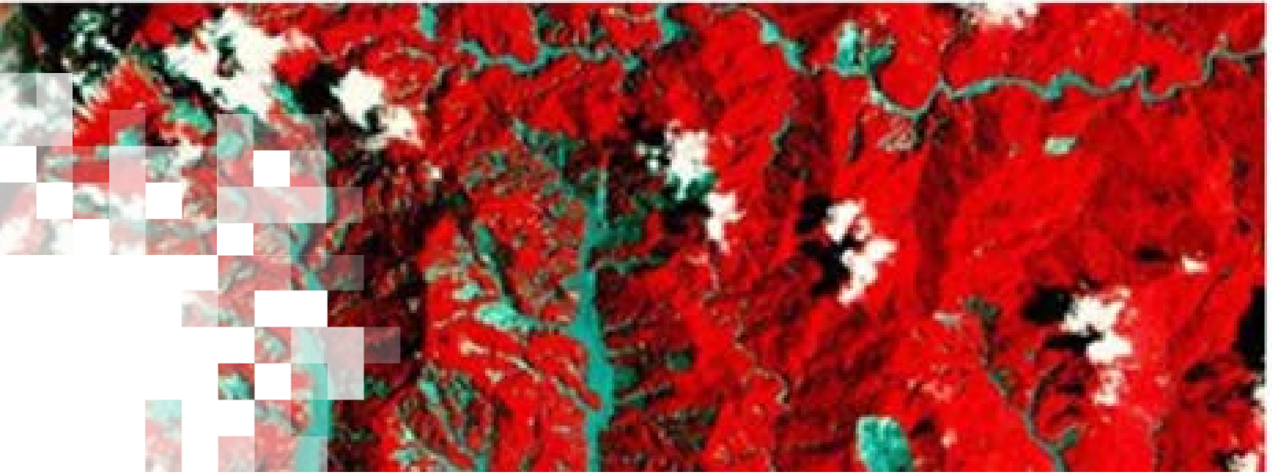
Section 2: Automatic Mapping

Amalgamation

- Automatic mapping is liable to merge individual landslides together, leading to amalgamation problems.
- Although effect on overall estimate of landslide area may be limited, this can strongly influence any derived analysis including runout.



Landslides mapped using low-resolution imagery may lead to amalgamated polygons (left) that do not reflect the reality (right). Images from Wenchuan earthquake region, Marc et al. 2015

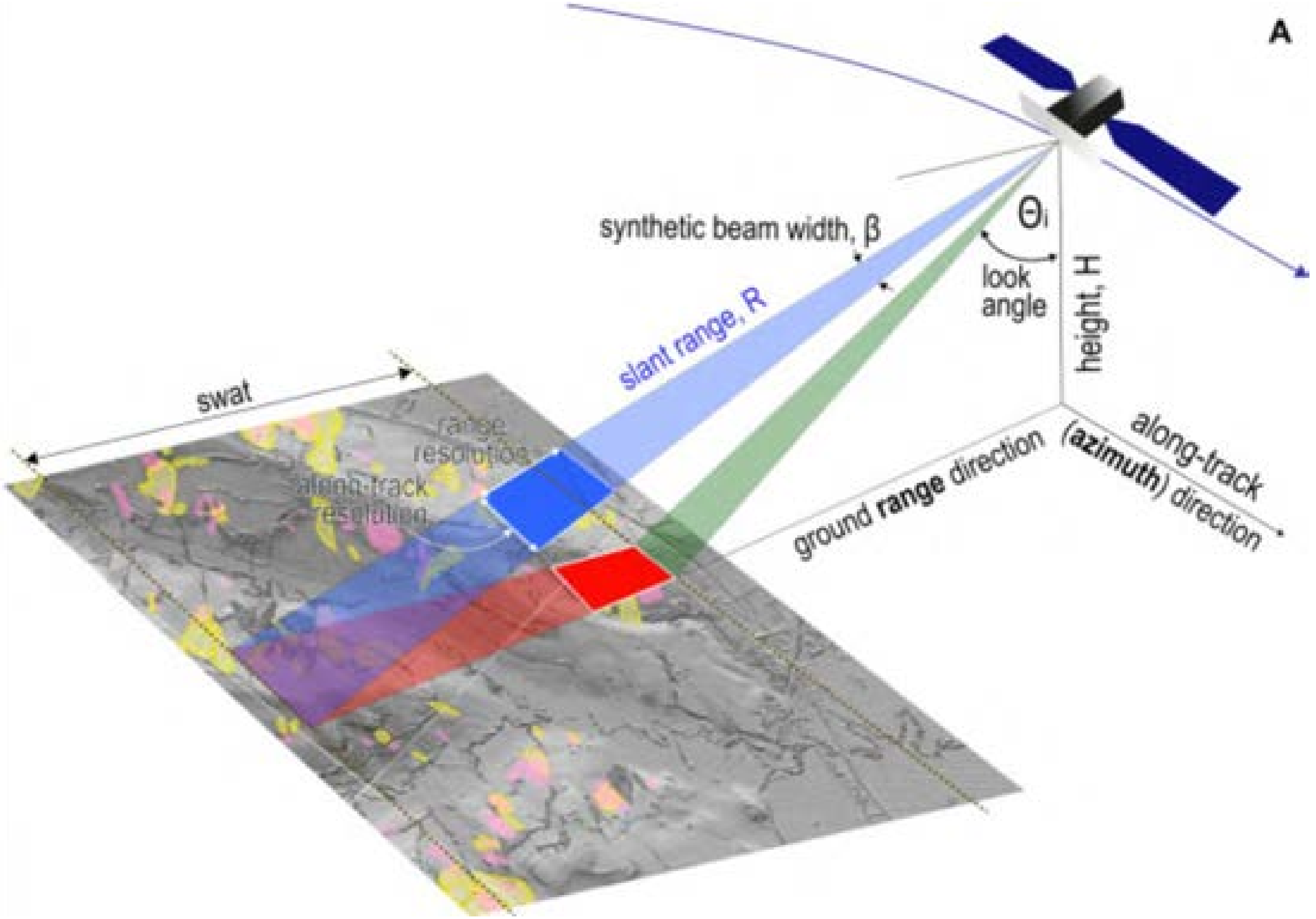


Section 3: Non-optical detection

Section 3: Non-optical detection

SAR analysis

- SAR uses Radar data to image the surface of the Earth.
- Although simple in principle, there are many factors that influence landslide detection.
- Foreshortening, layover, and shadow effects are critical in high relief terrain, where landslides occur.



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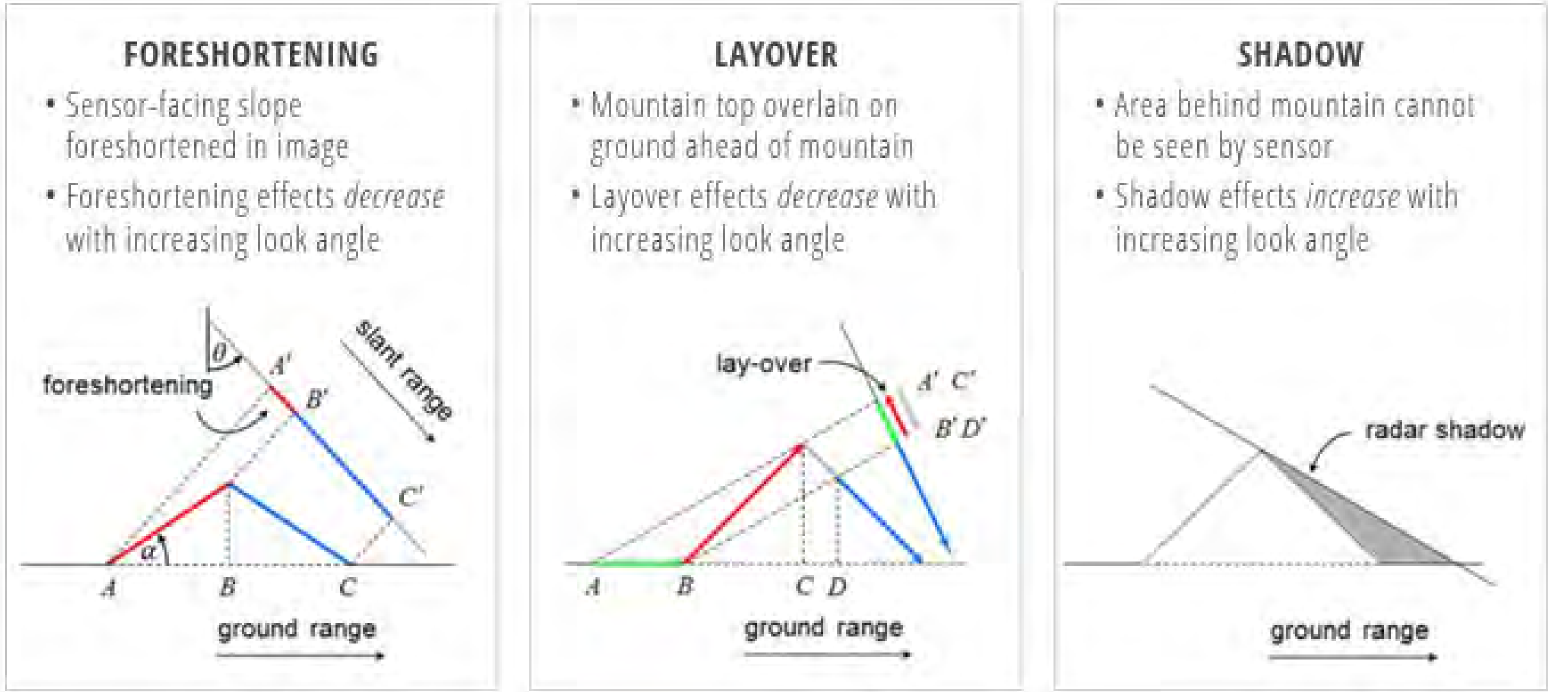

Relief and influence on SAR results. From Meyer et al. 2019

Section 3: Non-optical detection

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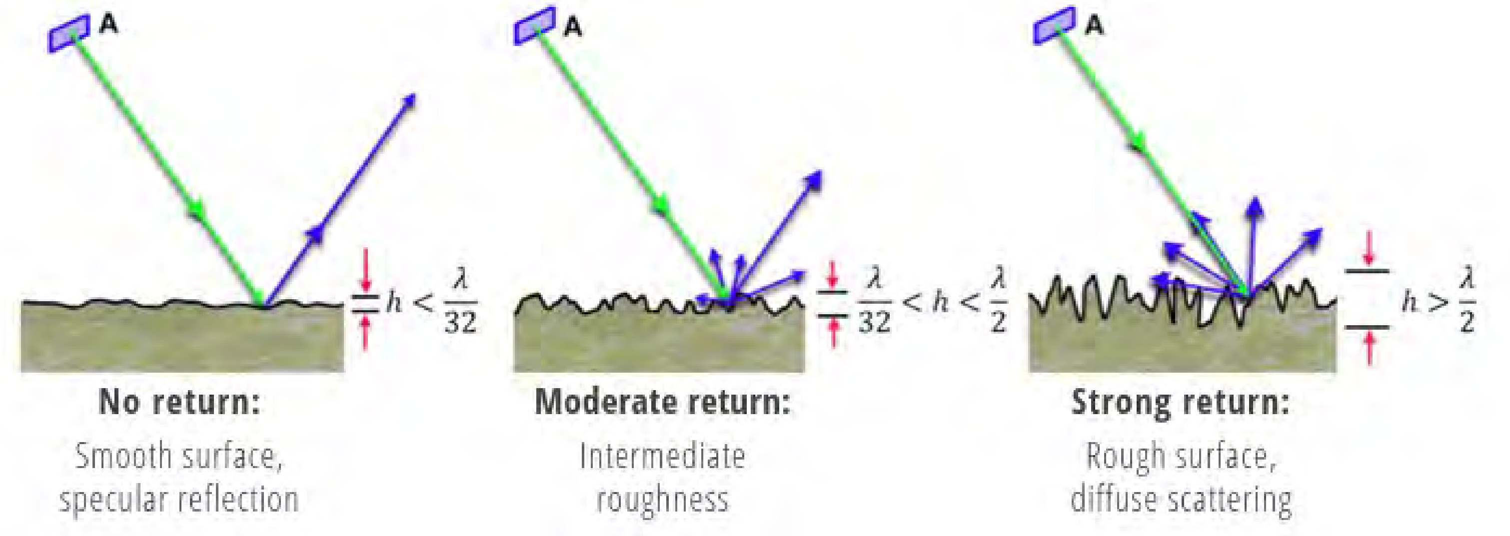
- Foreshortening, layover, and shadow effects are critical in high relief terrain, where landslides occur.
- **The type of surface is also critical to determining the reflection.**



Surface texture and influence on SAR results. From Meyer et al. 2019

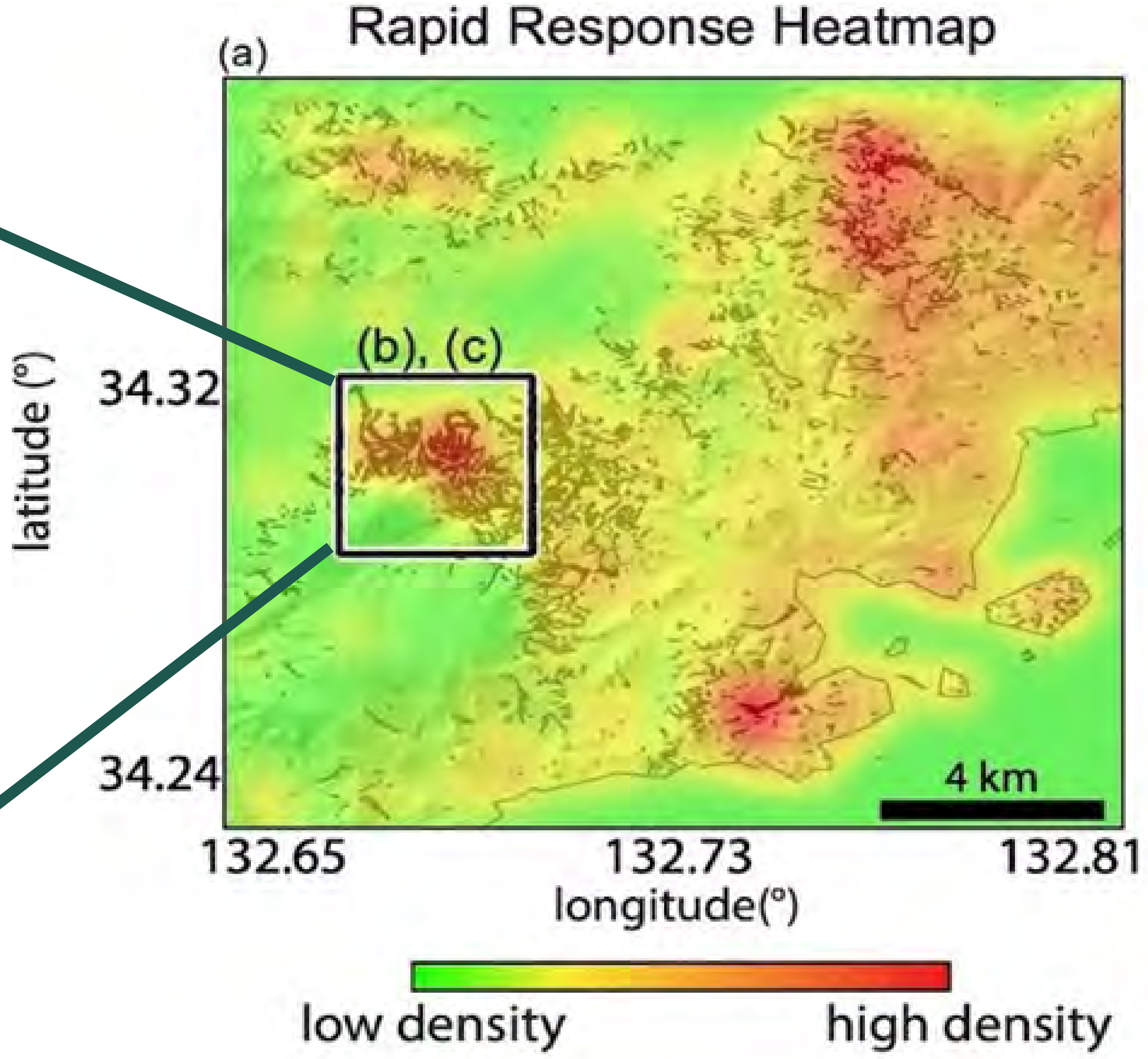
Section 3: Non-optical detection

SAR analysis

- Two key approaches: coherence-based, and amplitude-based. Both use pre- and post-event imagery as comparisons.
- Amplitude based records the overall change in the intensity of the signal return. These have lower sensitivity but have been used recently to explore areas of dense change in landslide volume.
- Coherence based approaches are highly sensitive to changes that would alter the signal of the radar return, including atmospheric influence. Where significant change in surface texture and associated scattering properties occurs as a result of landslides, this can be used for landslide detection.

Section 3: Non-optical detection

SAR amplitude-based change detection method in Google Earth



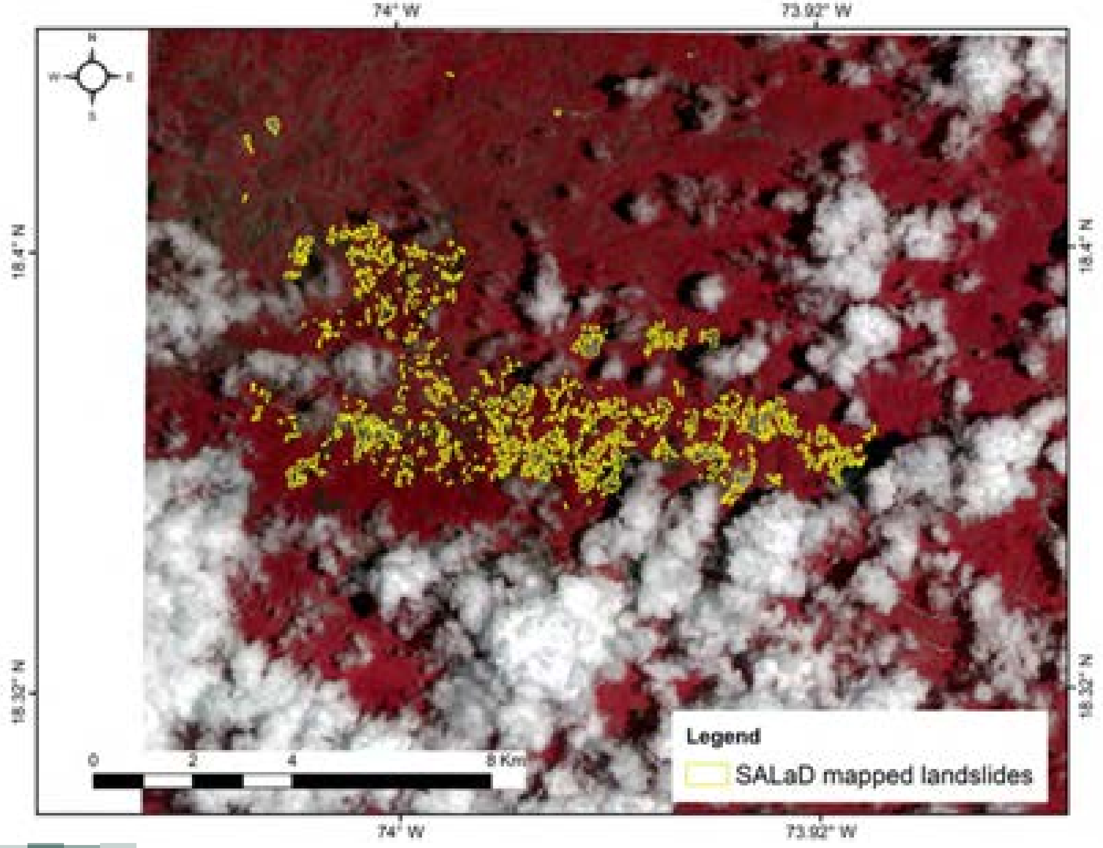
Hiroshima, Japan,
28 June – 8 July 2018

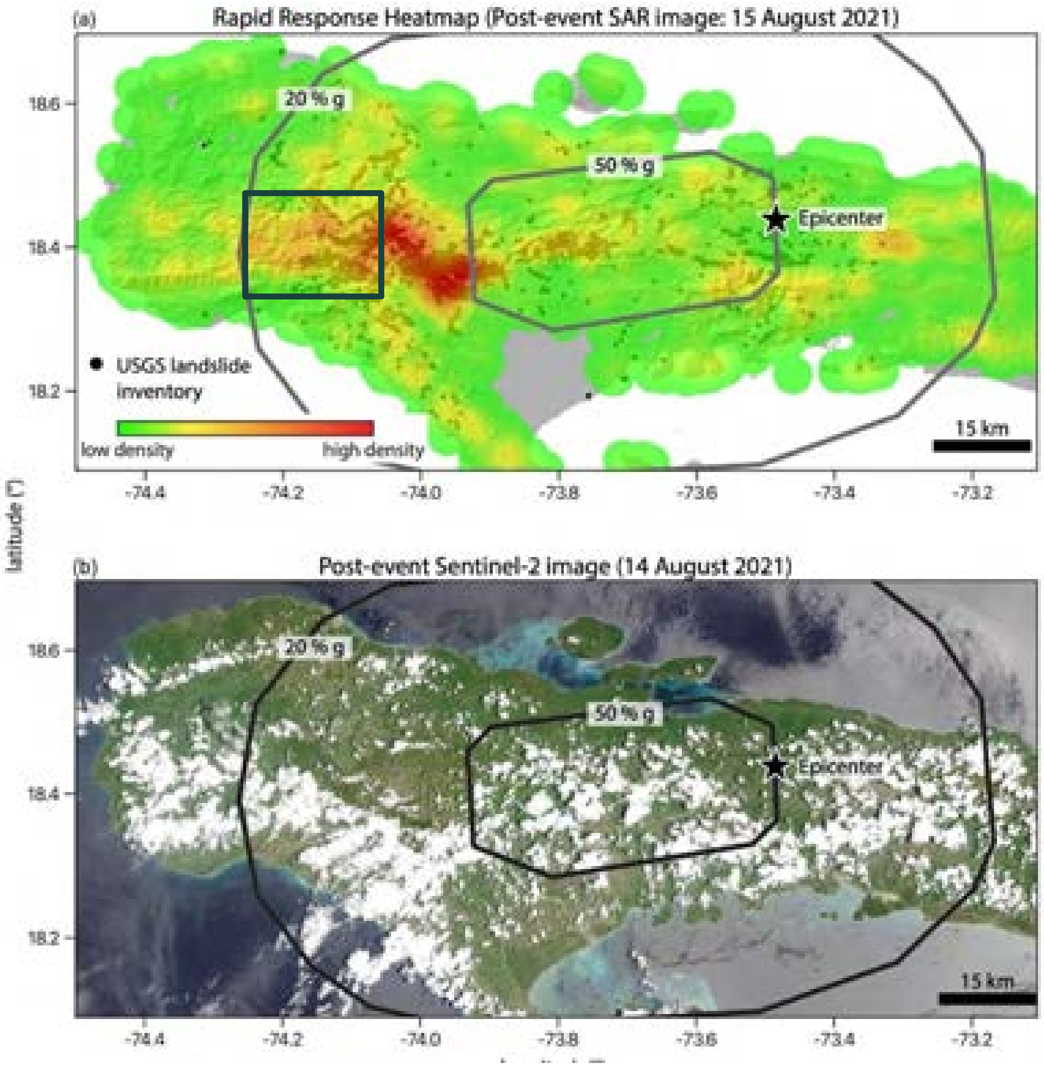
Alexander Handwerger (JPL) and Mong-Han Huang (Univ. Maryland)

Section 3: Non-optical detection

2021 Haiti Earthquake and Landslide Mapping

Robust and rapid method that can penetrate clouds





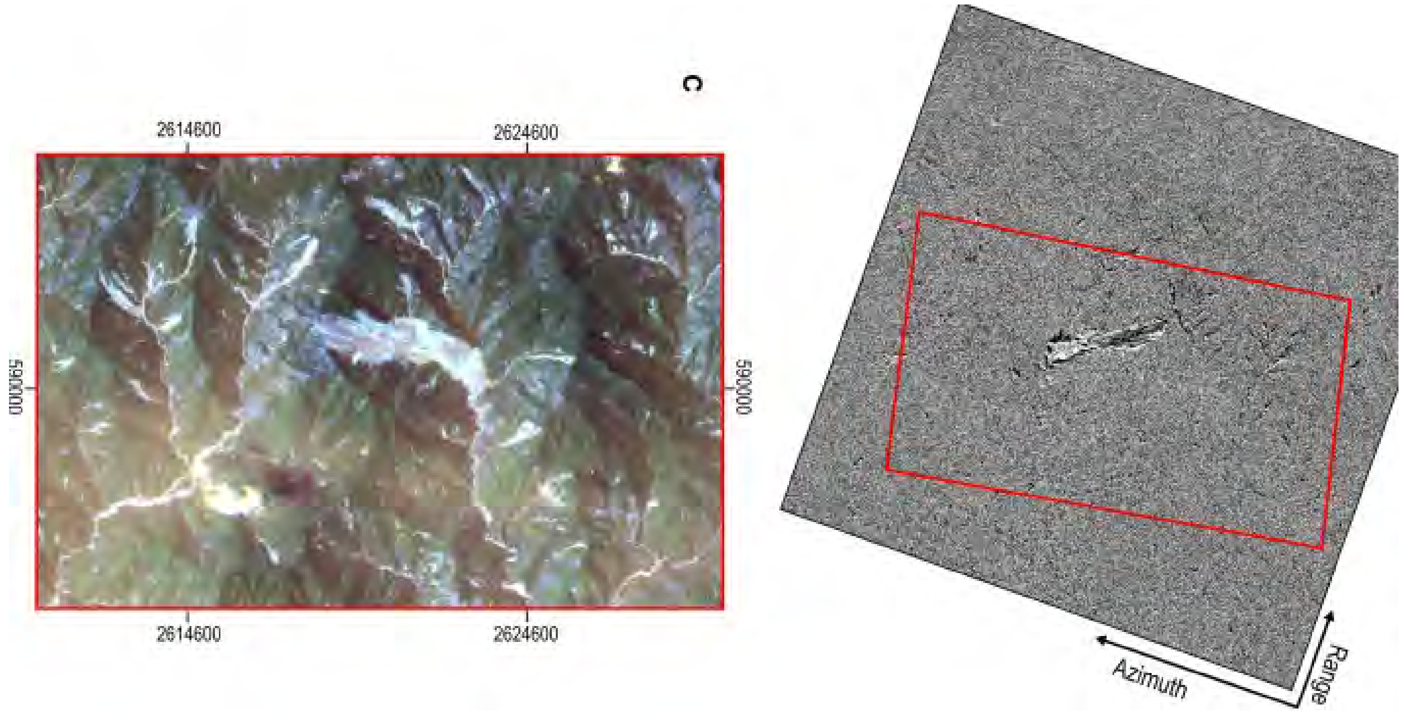
Handwerger et al., 2021

https://nhess.copernicus.org/preprints/nhess-2021-283/

Section 3: Non-optical detection

SAR Coherence based approaches

- Changes in the coherence between two SAR images has been exploited more recently as a method to detect landslides.
- In some cases (see right) this can highlight landslides quite clearly, but in other areas results can be challenging.
- In areas prone to decorrelation of SAR data (e.g., forests) coherence change may have low detection ability.

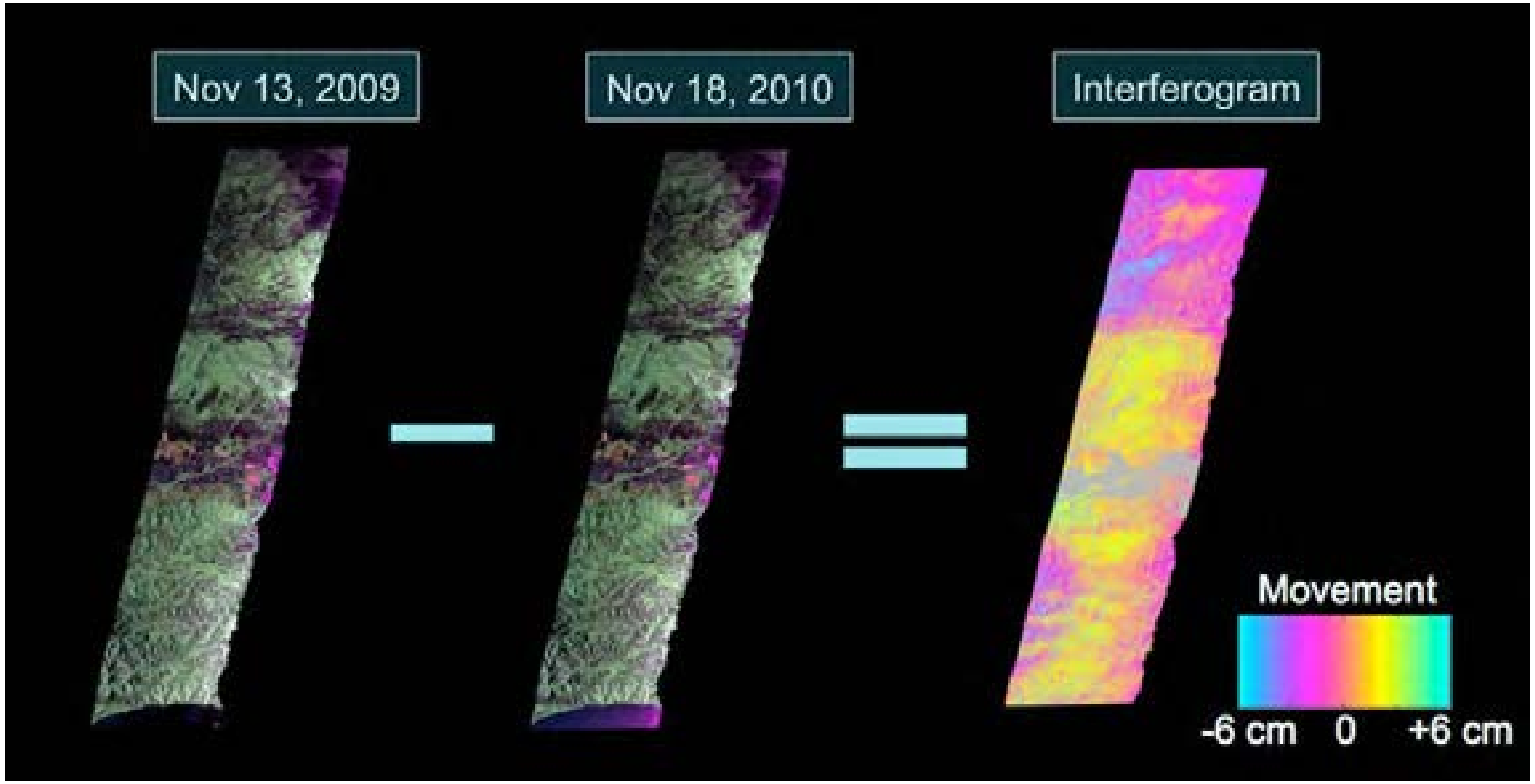


Change in coherence highlighting a large landslide in Myanmar.
Source: Mondini 2021

Section 3: Non-optical detection

InSAR Based approaches

- Interferometric SAR (InSAR) uses two or more images to reveal surface motion.
- This requires extensive preliminary correction but can be used to detect slow moving landslides.
- Generally, requires coherent surfaces to work effectively.



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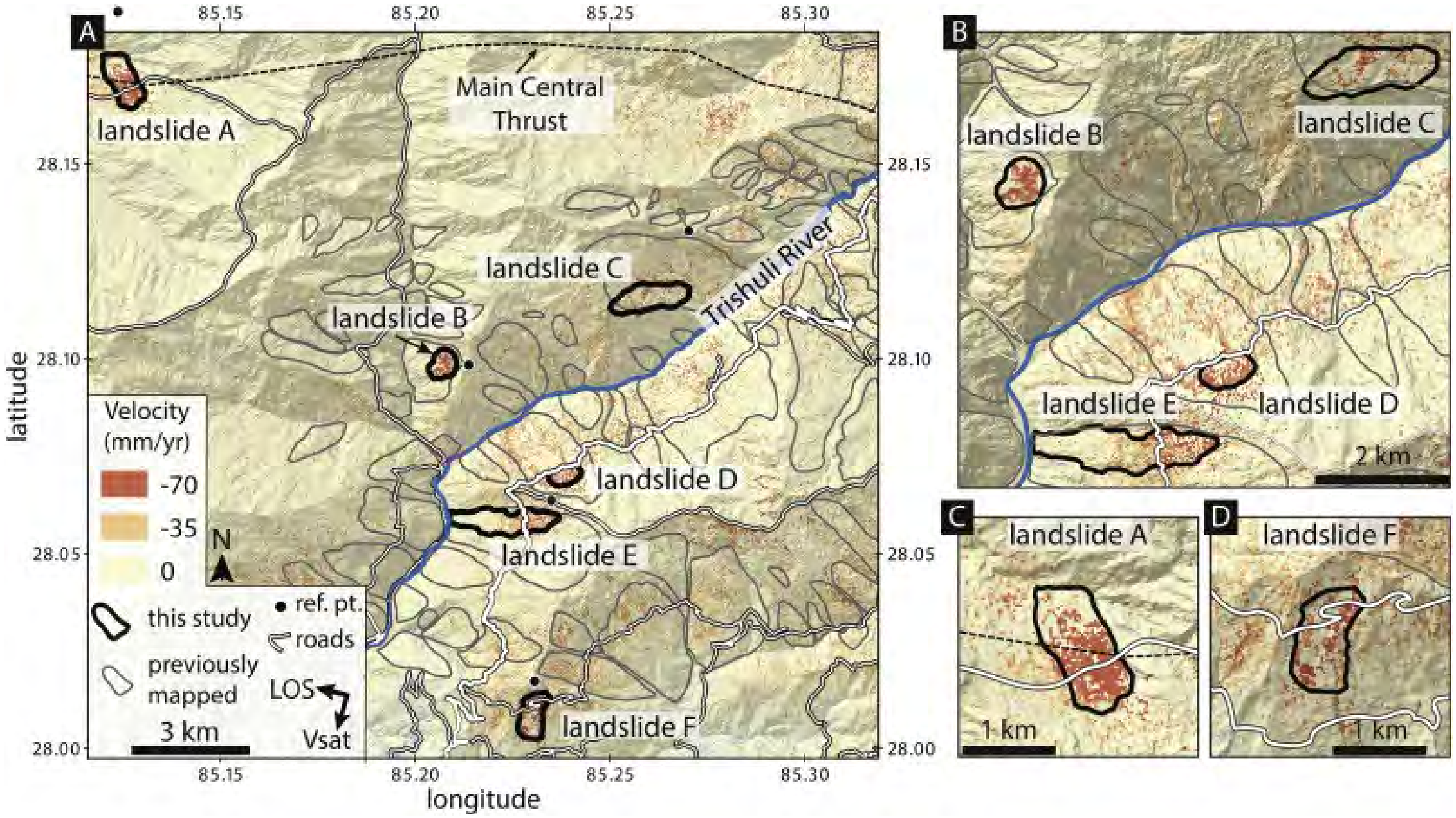

InSAR based analysis of slow-moving landslides in Nepal. Source: Bekaert et al. 2020.

What's Next?

- Building landslide susceptibility models using satellite data
- Incorporating triggering data to build hazard models
- Putting all the pieces together: understanding hazard, exposure, and impact

Resources

- ARSET SAR training
- NASA SALaD Github
- NASA Disasters Program
- NASA Landslides Research
- USGS Landslide Handbook
- ARSET Hyperspectral training
- NASA Landslides Guide to field mapping landslides

Part 2 Summary

- An ability to translate two-dimensional observations from orbit into situational awareness on the ground is a critical skill to develop for landslide mapping.
- Differentiating the source area (or headscarp) of a landslide with the runout and deposit areas is important for comparative analysis of susceptibility and hazard.
- The number and size of landslides that can be observed strongly depends on the resolution of available imagery.
- Relevant metadata is needed when mapping landslides.
- Multi-temporal landslide inventories can provide longer-term analysis.
- Automatic methods for mapping landslides (pixel based and object based) exploit the typical changes in texture, color, and spectral properties of recently disturbed areas.
- Automatic methods use a variety of regression, machine-learning or AI based approaches that can then be used to predict other pixels or objects that match the type of input used as training, which is then output as a prediction of likely landslide locations—training data strongly influences outputs.
- SAR-based landslide mapping uses two key approaches: coherence-based and amplitude-based.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 18 March 2025
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 1 April 2025**

- **Certificate of Completion:**
  - Attend all three live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

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- ARSET YouTube

Visit our Sister Programs:

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- SERVIR

Questions?

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.

Credit: USGS

Thank You!