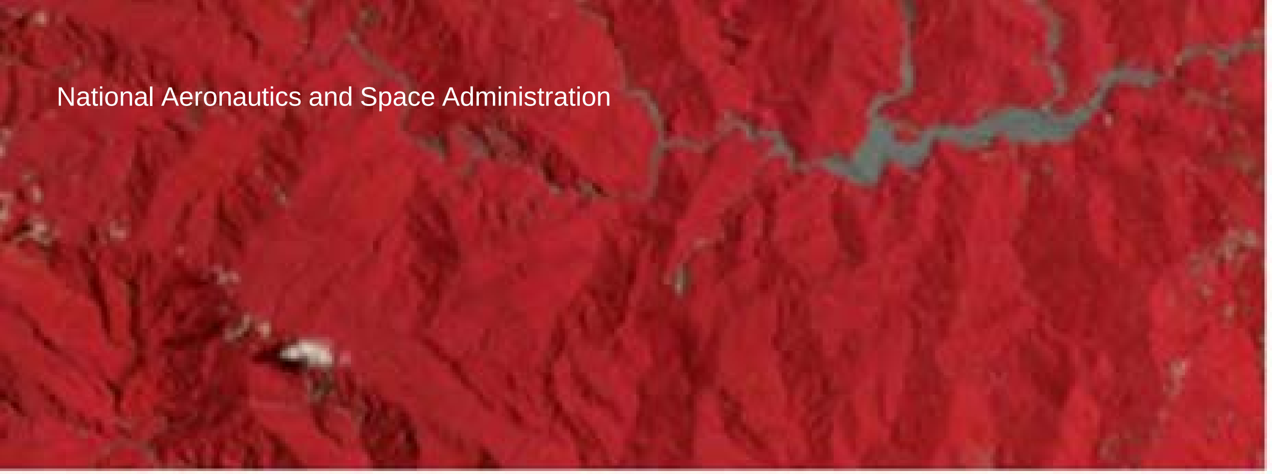
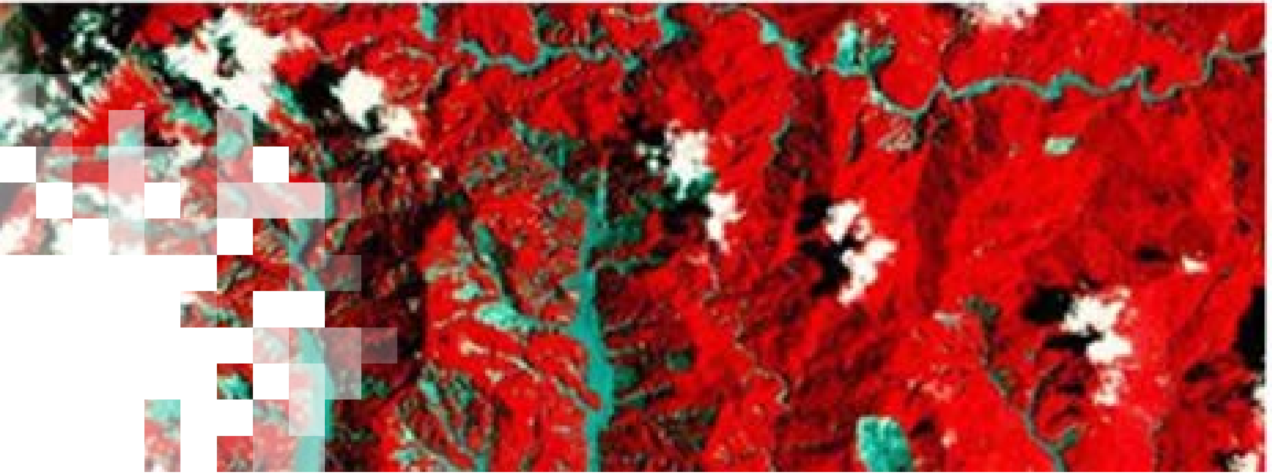
National Aeronautics and Space Administration





Landslide Monitoring and Risk Assessment Using NASA Earth System Data

Part 1: Remote Sensing for Landslide Science and Disaster Planning

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

March 11, 2025

About ARSET

- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**

- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

AGRICULTURE
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About ARSET Trainings

- Cost-free
- Online or in-person
- Bilingual and multilingual options
- Only use open-source software and data
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- Live and instructor-led or asynchronous and self-paced

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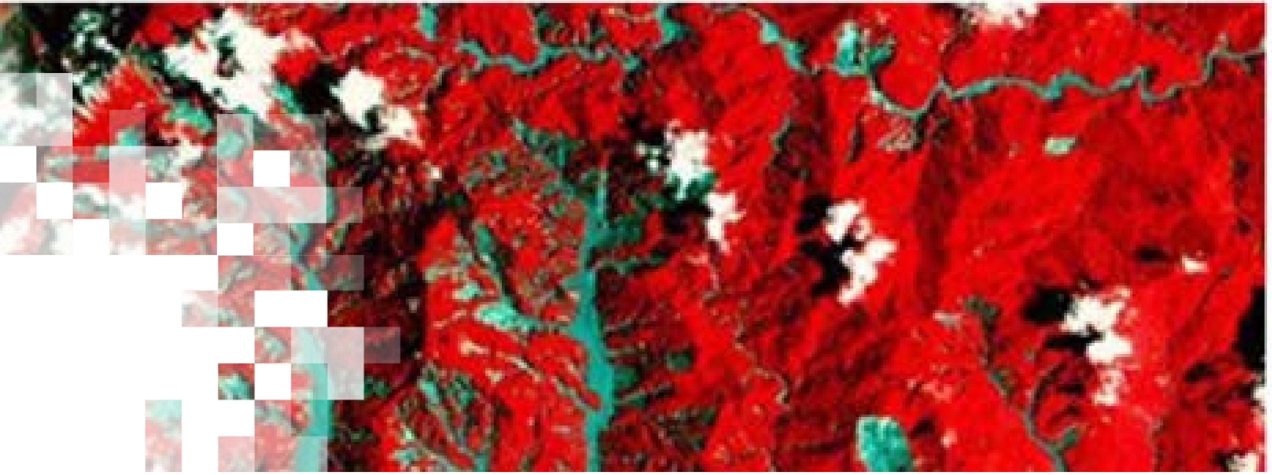



Landslide Monitoring and Risk Assessment Using NASA Earth System Data Overview

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 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

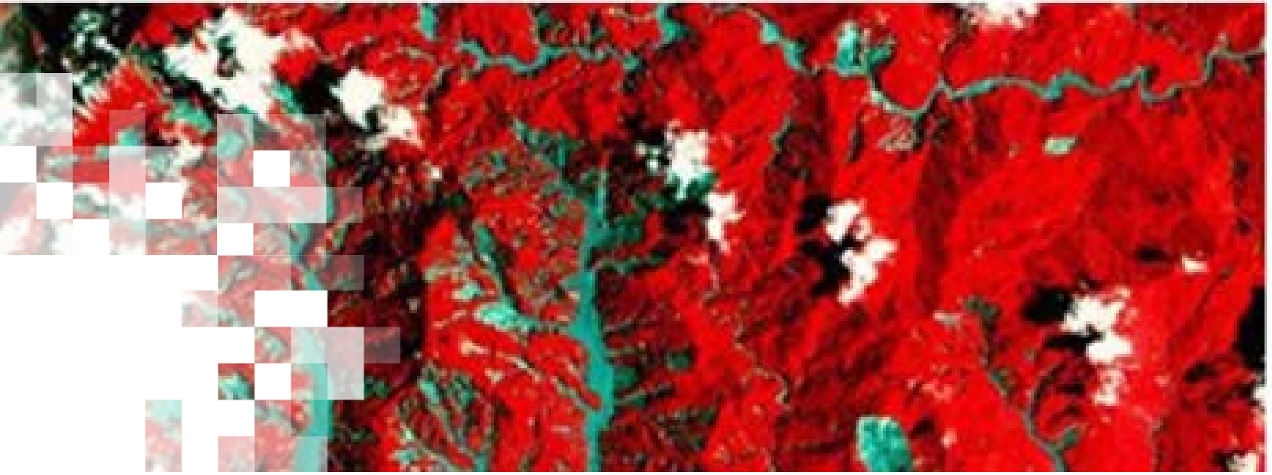
Remote Sensing and Landslide Susceptibility

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 1: Remote Sensing for Landslide Science and Disaster Planning

Part 1 Objectives

By the end of Part 1, 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.

How to Ask Questions

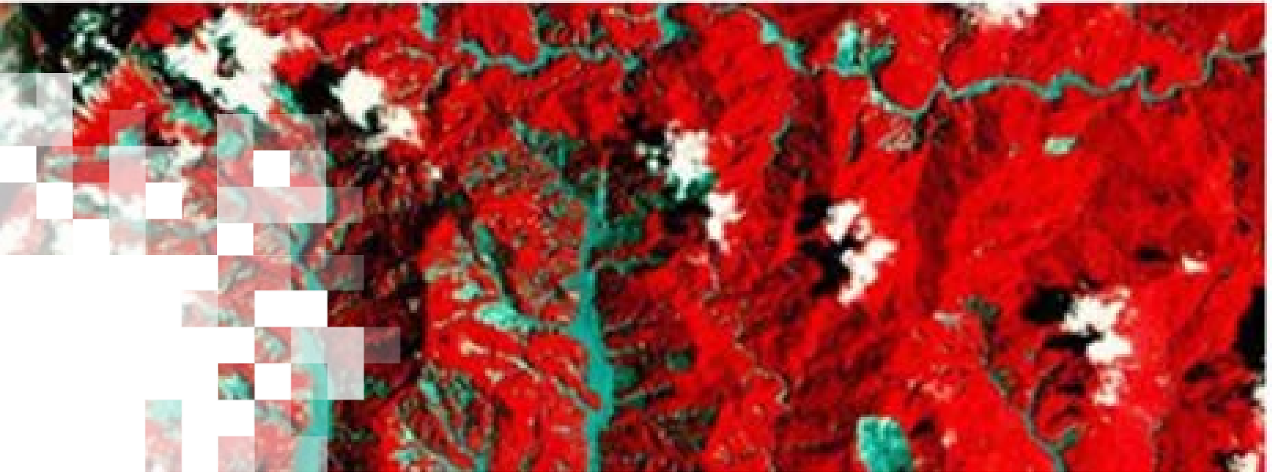
- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session.
- The remainder of the questions will be answered in the Q&A document, which will be posted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

Part 1 – Trainer

Dr. Robert Emberson

Associate Program Manager/Disasters

UMBC


Section 1: Core Concepts

Section 1: Core Concepts

What is a landslide?

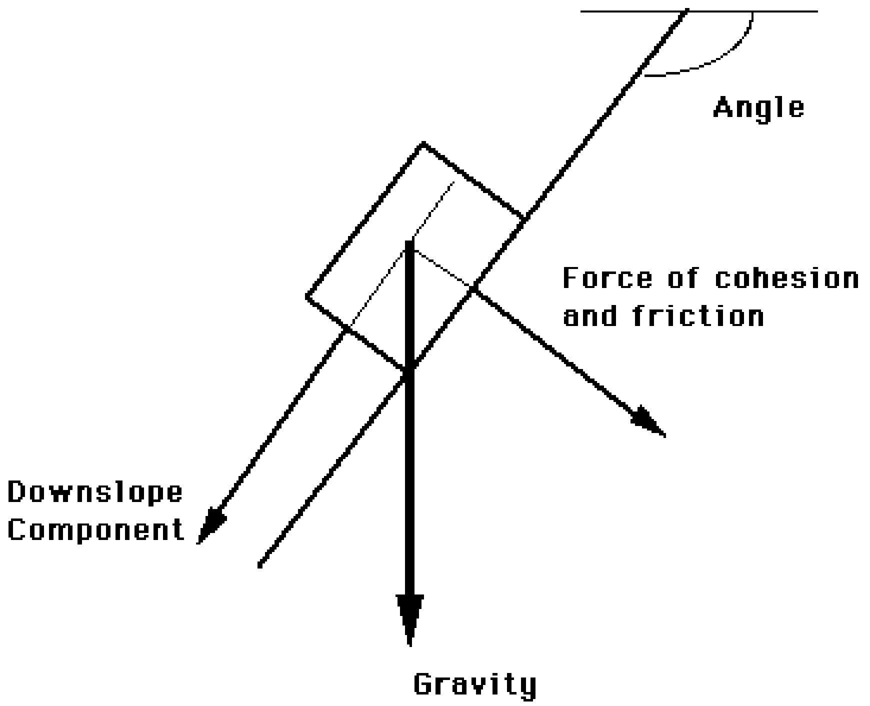
- A landslide is defined as the movement of a mass of rock, debris, or earth down a slope.
- Down-slope movement can be in the form of falls, topples, slides, spreads, and flows.
- Landslides can vary in size from individual rocks and boulders to hillslope-sized failures with cubic kilometers of mobilized material.
- The term landslide encompasses dynamic processes ranging from localized rock falls to highly mobile and fluidized debris flows.

Credit: Robert Emberson

Section 1: Core Concepts

What causes landslides?

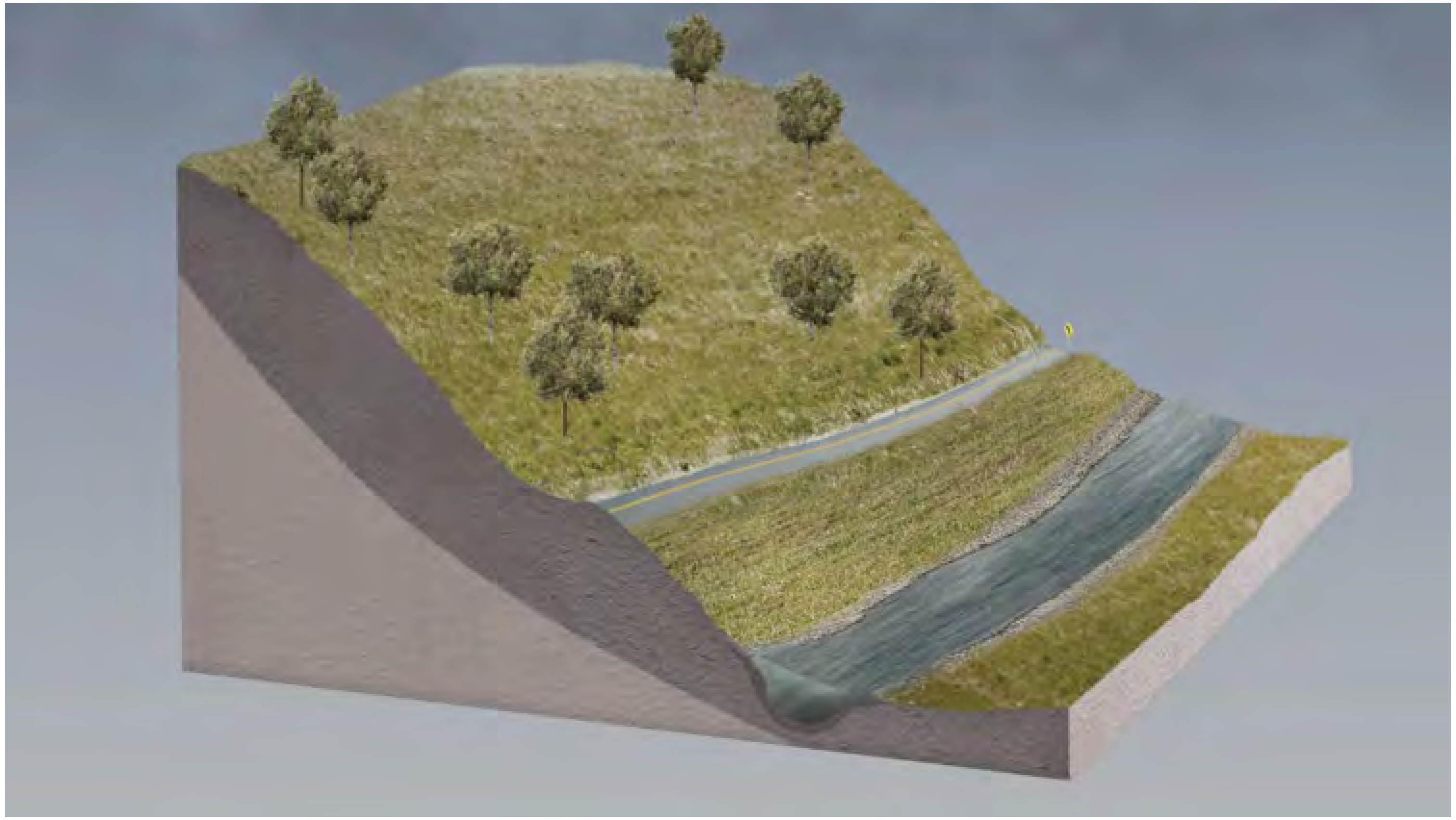
- Gravitational failure occurs when the downslope component of the gravitational force on a body of material exceeds the forces of cohesion and friction that resist movement.
- An important concept is the **failure plane** – the surface upon which landslides move. This can be a complex surface.
- Long term factors contribute to the overall balance of forces, but typically short-term dynamic **triggers** create changes in the force balance and lead to failure.



Section 1: Core Concepts

What causes landslides?

- Water infiltrating into soils and rock can reduce the cohesive and frictional forces in a hillslope.
- **Rainfall-triggered landslides** are a critical part of landslide activity.
- **Water** can further mobilize landslide sediment and drive formation of **debris flows**.

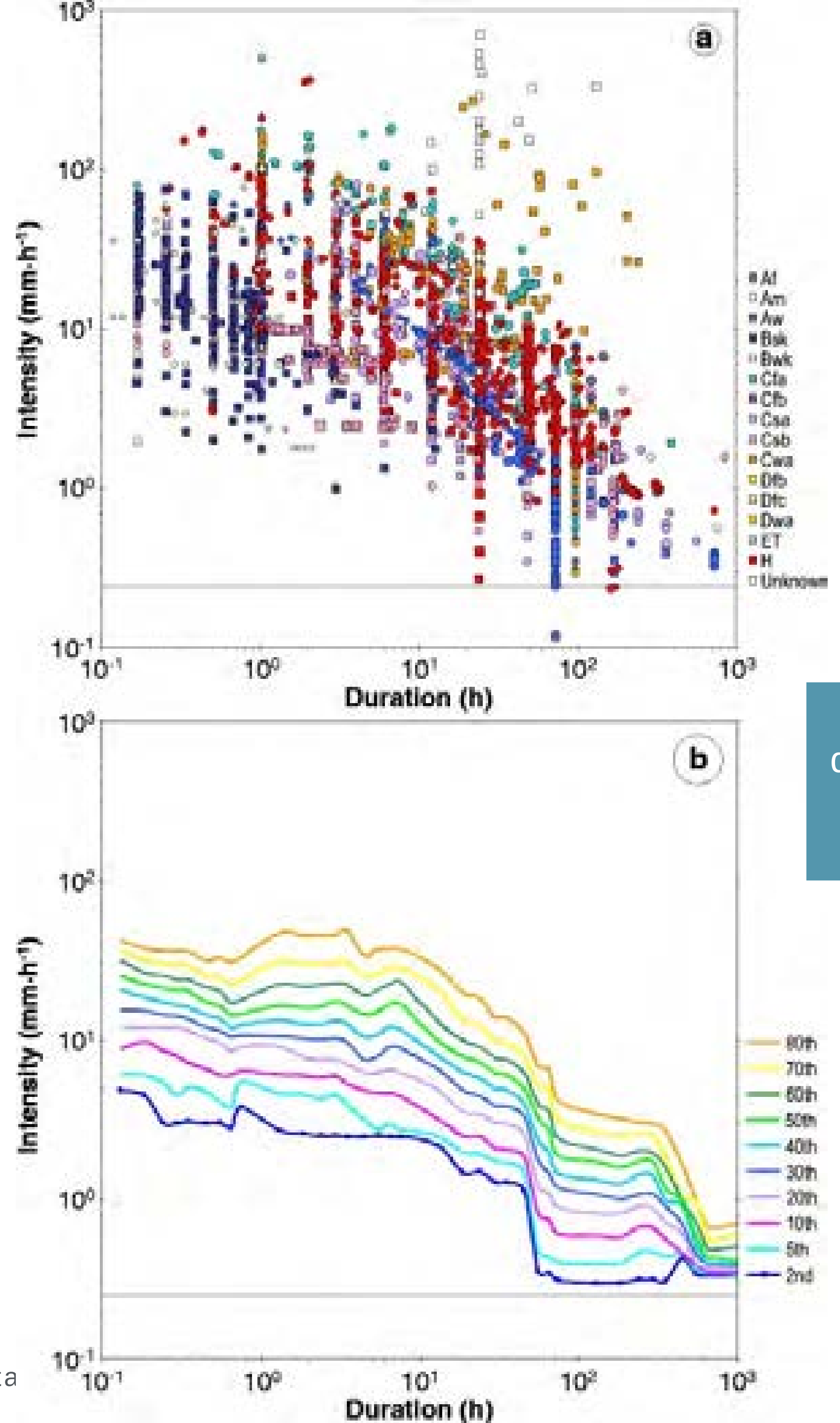


Credit: NASA Scientific Visualization Studio (GSFC)

Section 1: Core Concepts

What causes landslides?

- **Intensity and duration** of rainfall both determine the likely landslide response.
- Extended low-level rainfall events can saturate hillslopes, driving landsliding, while short, intense storms can similarly lead to failure.
- Estimates of thresholds for landsliding must consider both factors.

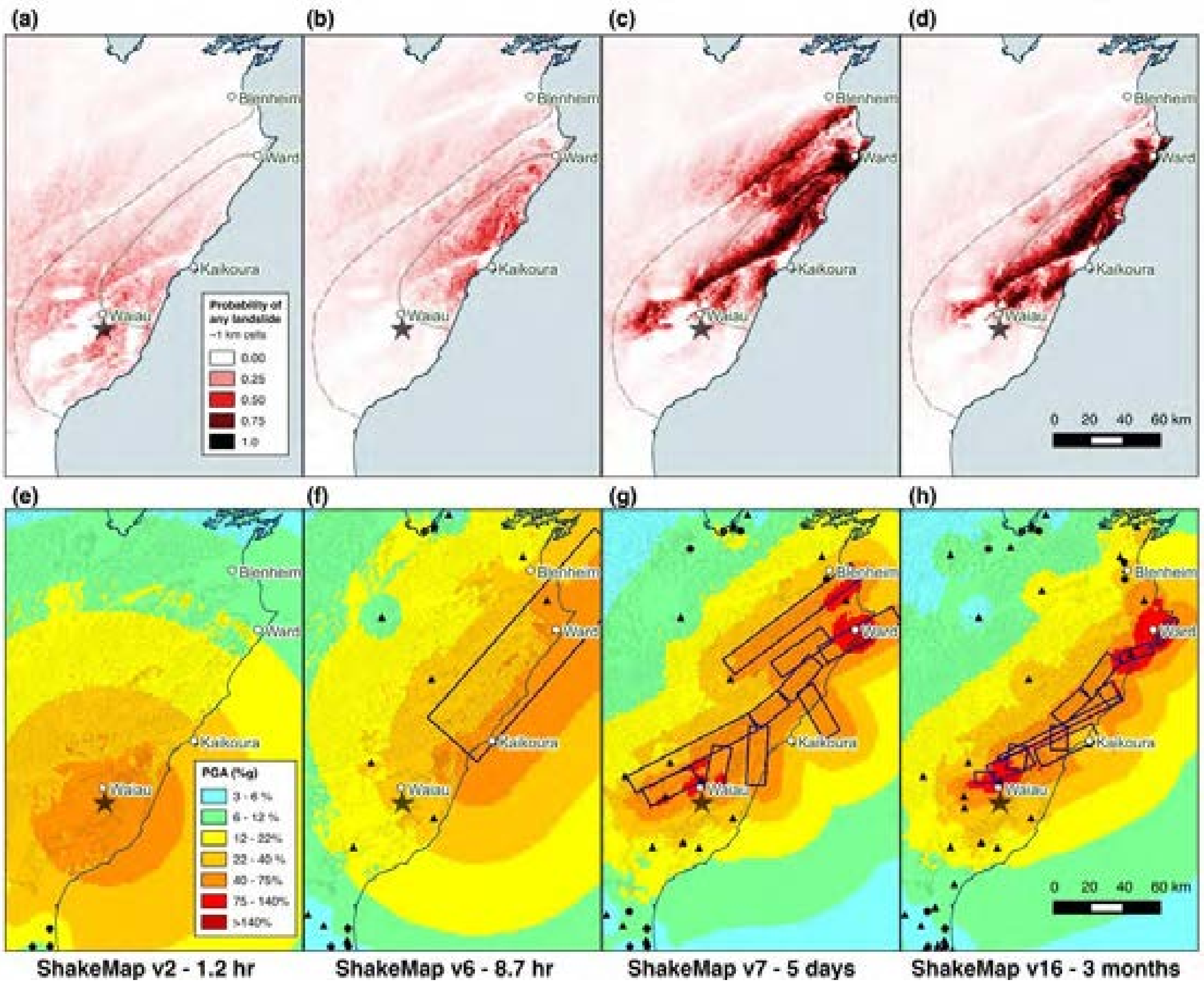


Intensity-duration curves; Guzzetti et al., 2008

Section 1: Core Concepts

What causes landslides?

- **Strong earthquakes** are a significant driver of landslides.
- The depth, intensity, and fault-plane orientation of an earthquake all influence the likely landslide response.
- Seismic shaking is more intense at the peak of hillslopes, whereas fluid saturation increases at lower slopes; leads to a different distribution of landslide location.



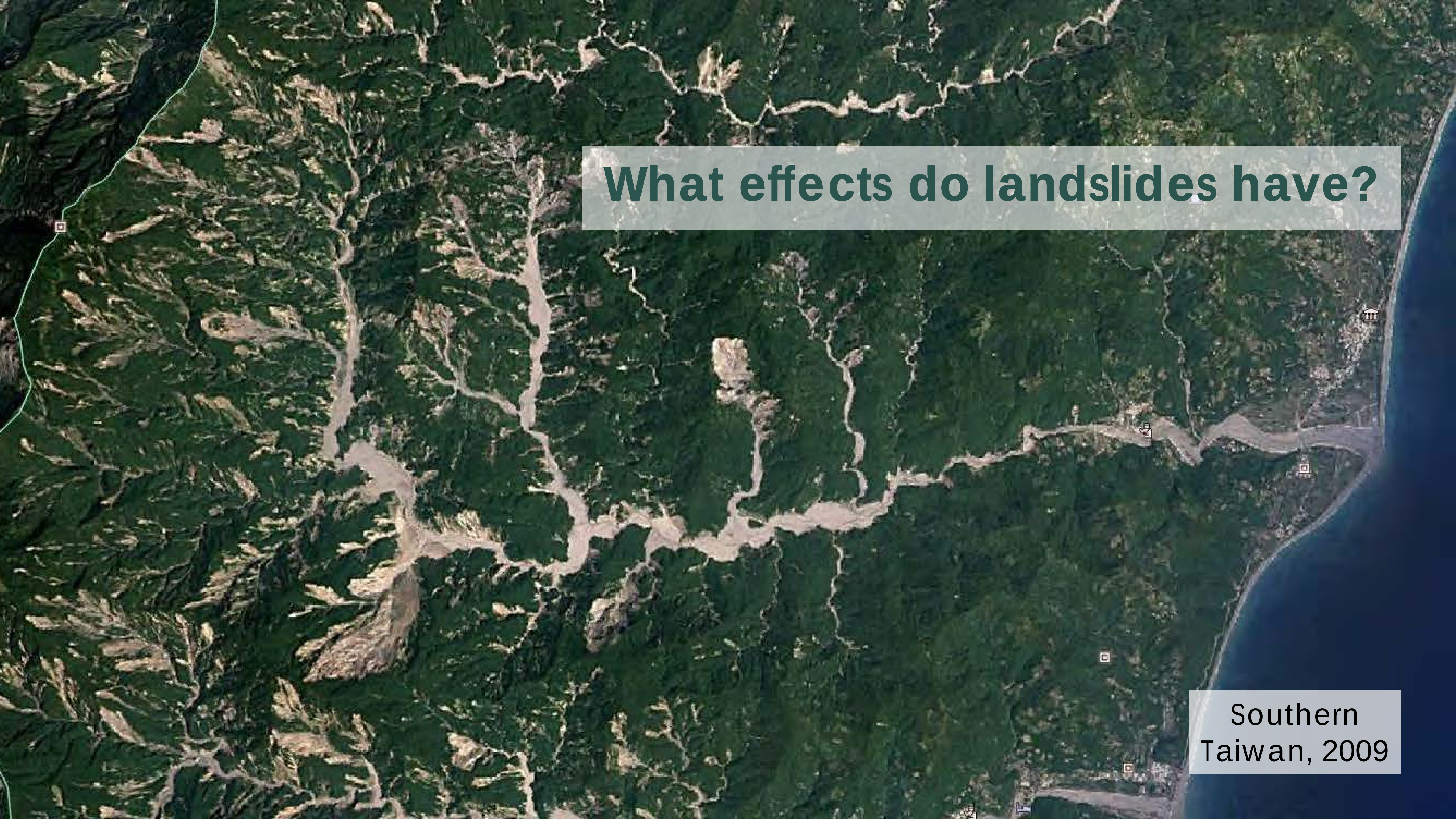
USGS Ground-Failure Landslide Model

Section 1: Core Concepts

What causes landslides?

- Other factors can trigger landslides in some settings.
- Freeze-thaw processes can lead to fracture of rocks and failure.
- Human-driven processes – e.g., deforestation, urbanization, water loading – can be critical
- Volcanoes can trigger devastating landslides like Mount St. Helens (USGS).
- Wave-driven erosion can also play a role.

Credit: USGS


What effects do landslides have?
Southern Taiwan, 2009

Section 1: Core Concepts

What effects do landslides have?

- Landslides in many steep mountain belts are the primary source of sediment erosion and are the engine that drives changes in morphology.

Acquired November 2012, this image shows a sediment plume along Spain's southwestern coast captured by the MODIS instrument.
Credit: NASA

Section 1: Core Concepts

What effects do landslides have?

- **Transported sediment** can influence downstream biochemical processes both onshore and offshore.
- Landslides also act to drive chemical weathering.

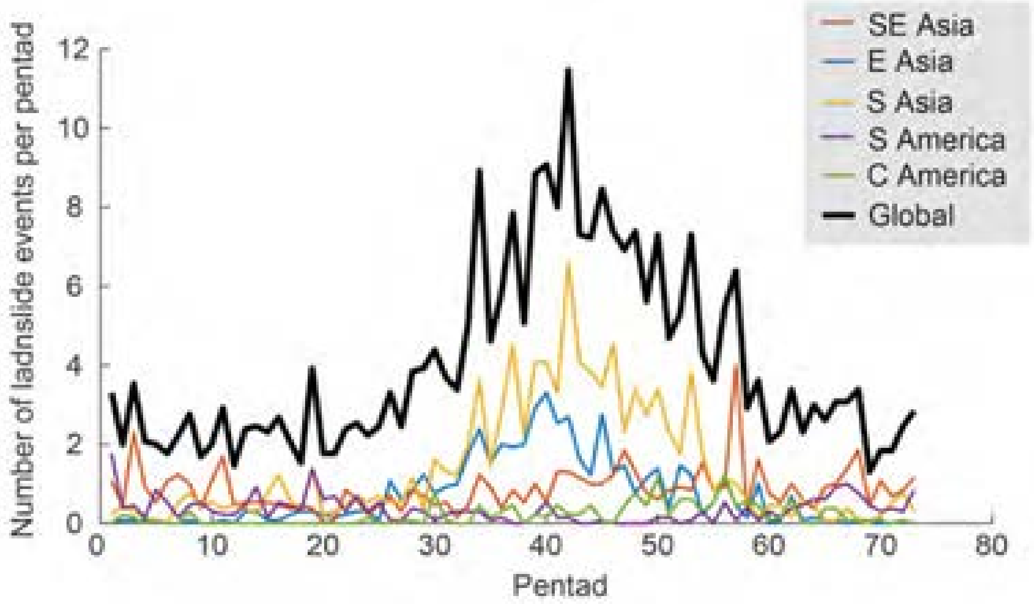
Bacterial communities in water filtering through landslides in Taiwan.
Credit: Robert Emberson

Section 1: Core Concepts

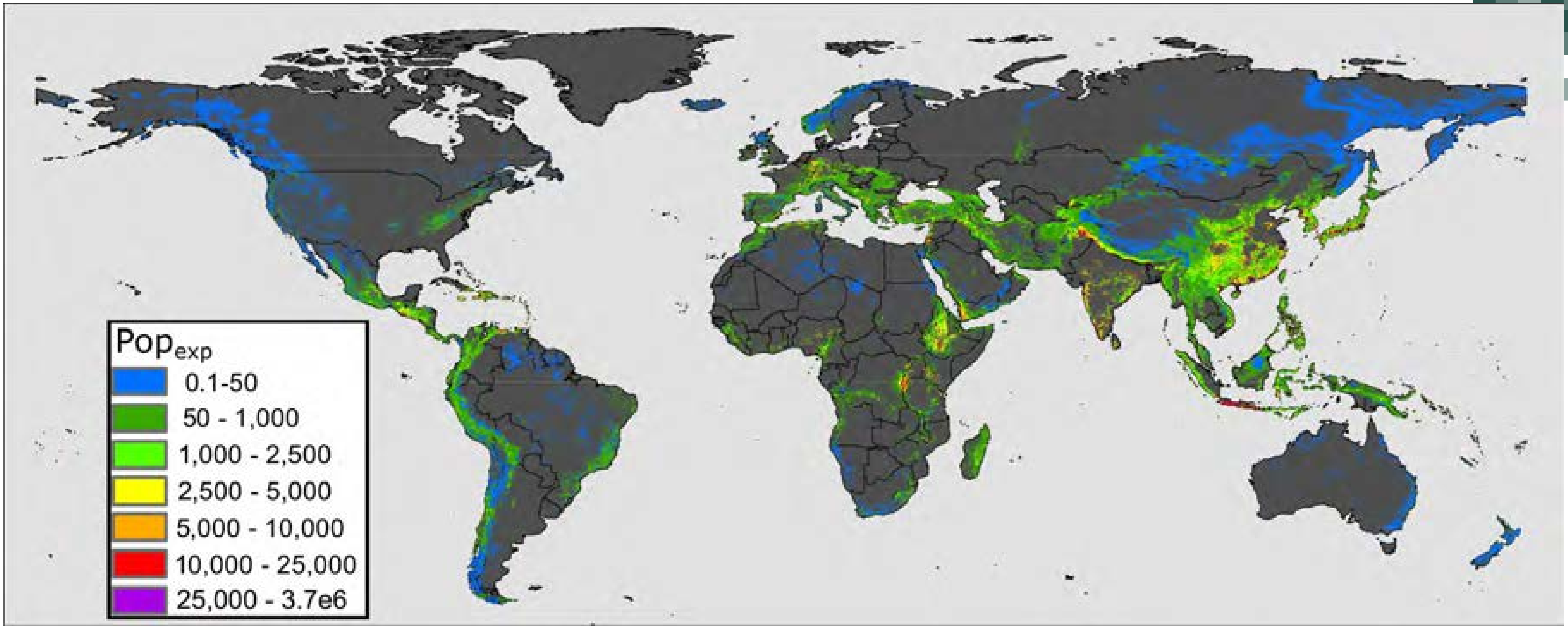
What effects do landslides have?

- Landslides cause thousands of fatalities every year, and billions of dollars of damage.
- **Linear infrastructure** is particularly vulnerable in mountainous regions.
- **Downstream communities** may face elevated debris flow risks for many years after earthquakes.
- **Peri-urban** development is particularly vulnerable.

Credit: Agência Brasil. License: CC BY-SA 3.0



Fatal landslide distribution; Froude & Petley 2018

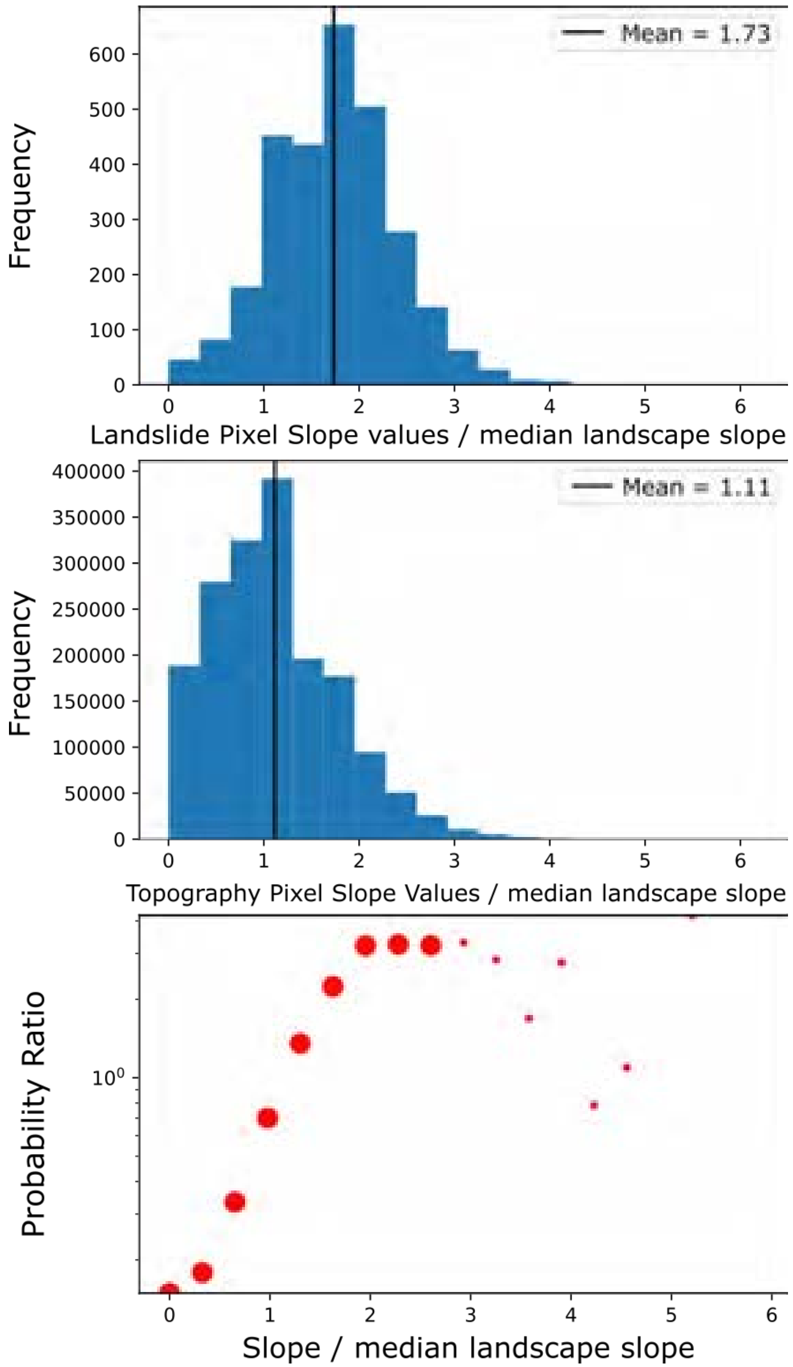


Population Exposure to landslide hazard is widely distributed

Section 1: Core Concepts

What factors influence landslide occurrence?

- Many factors can influence likelihood of landslide occurrence in a given location.
- Topography is typically among the most important elements, with steeper slopes more likely to fail gravitationally.
- Relief, Aspect, Roughness, and Position in landscape (base of slope or top of slope) also influence the likelihood of landsliding.



Slope values for landslides in Zimbabwe, 2019

Section 1: Core Concepts

What factors influence landslide occurrence?

- The **type of material** under gravitational stress also influences landslide potential.
- The **strong bedrock lithologies** like granite can reduce landslide likelihood, with limited failure planes.
- Rock **strata arranged horizontally** – like the Grand Canyon – can also permit steeper slopes to be stable, limiting the influence of topography.

Credit: David Iliff. License: CC BY-SA 3.0

Credit: Murray Foubister. License: CC BY-SA 2.0

Section 1: Core Concepts

What factors influence landslide occurrence?

- The type of land use and particularly the **type and density of vegetation** strongly influences landslide propensity.
- Plants can strongly bind surficial material together and stabilize hillslopes.
- Plants can strongly influence the rate of water infiltration, reducing saturation.
- Conversely, extreme wind can knock down trees and mobilize sediment.

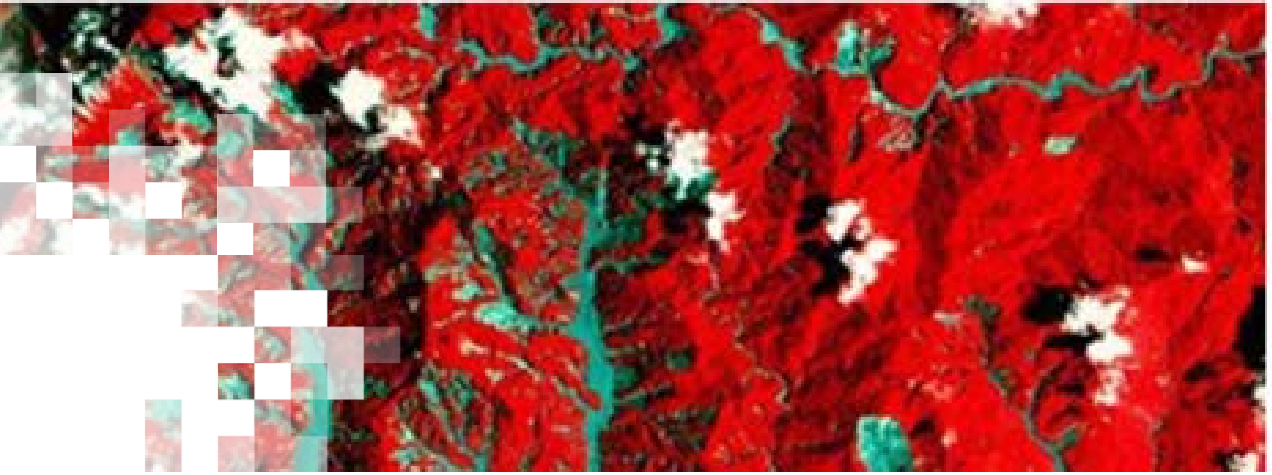
Credit: AnRo0002 (Wikipedia Commons)

Section 1: Core Concepts

Slow Moving Landslides

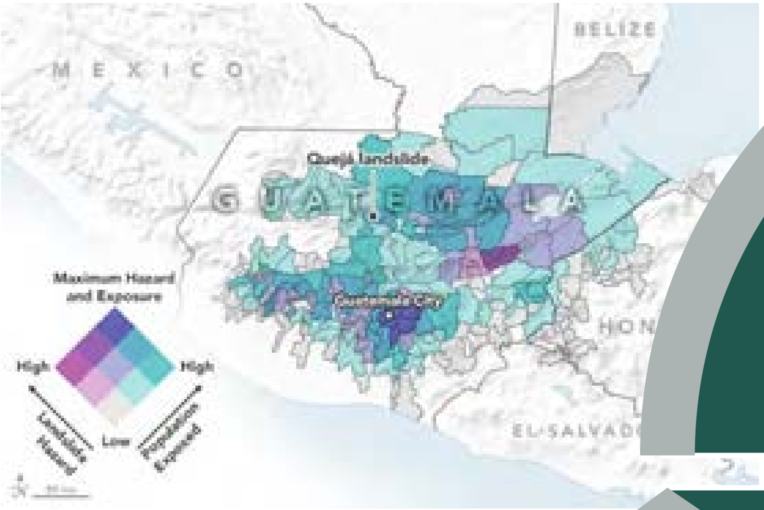
- Many landslides occur catastrophically, with debris flows reaching 35–50mph.
- Some landslides can move very slowly, at rates of mm or cm per year.
- Slow-moving deformation is typically observed in large sediment mantled regions and can disrupt infrastructure.
- These slow-moving landslides can transition to fast motion catastrophic events.

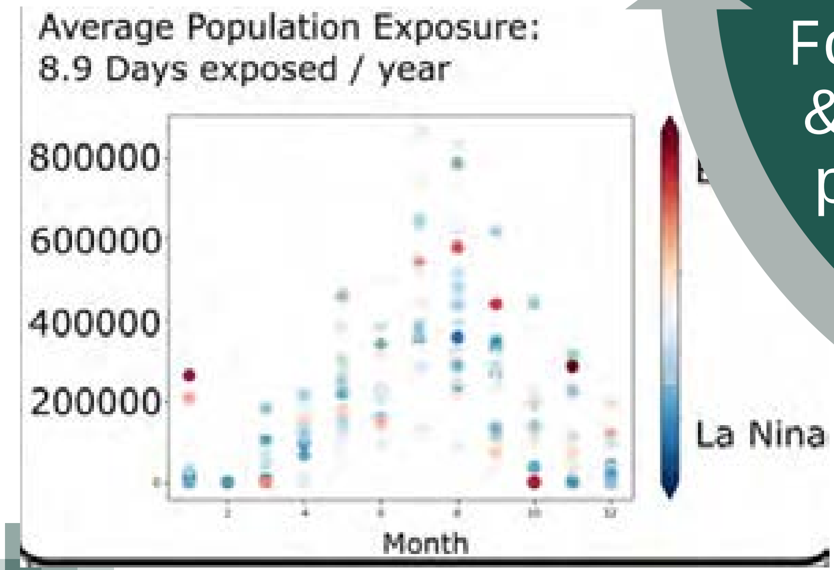
Slow moving landslide impacted road. Credit: YRB North Peace Ltd.

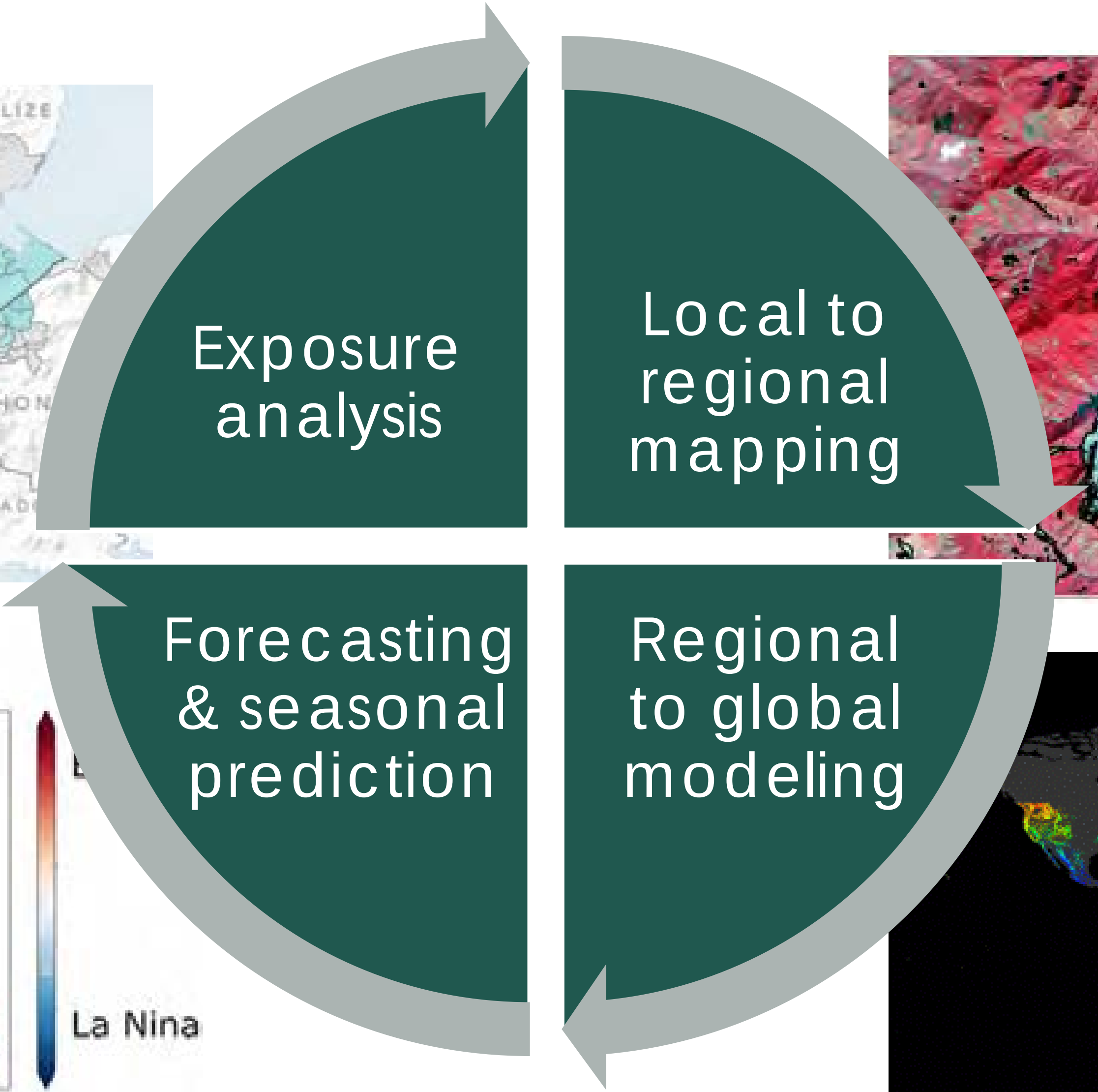


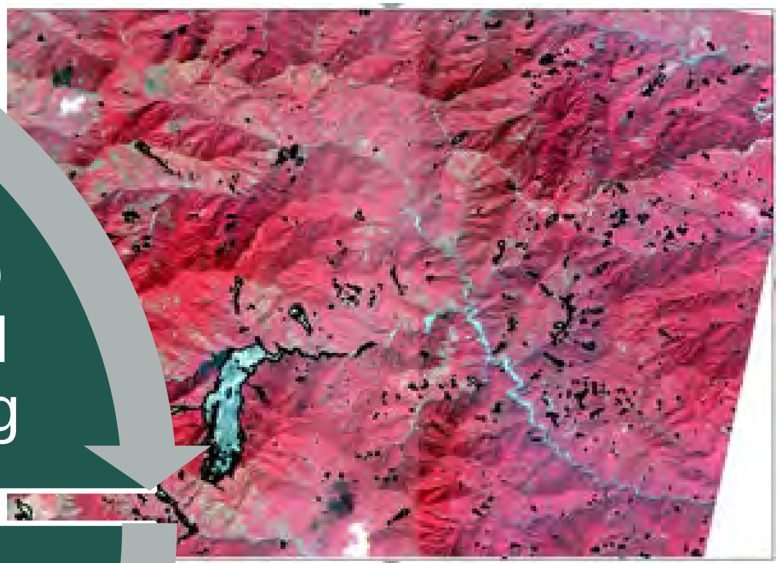
Section 2: Satellite Observations of Landslides

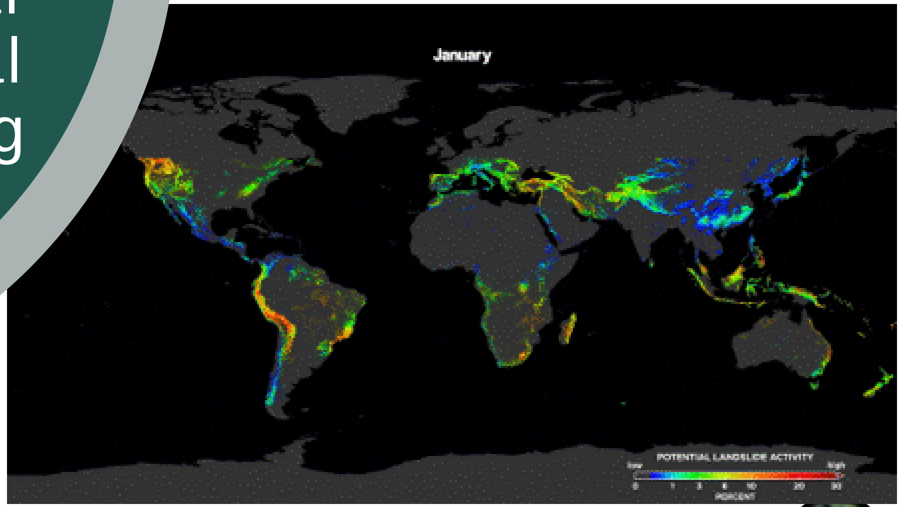
NASA Disasters Data to Inform Landslide Science











Section 2: Satellite Observations of Landslides

Types of Missions: Observing landslide events

- Optical data has for decades formed the primary tool for landslide modelling.
- Optical satellites like Landsat series and Sentinel-2 have provided large-scale assessment with long archives at moderate resolution.
- Newer systems permit higher resolution (temporal and spatial) analysis.
- Cloud cover remains a significant challenge.
- Multiple spectral bands allow for analysis of higher-contrast data including NDVI.

Landslides mapped in British Columbia on October 30, 2021.
Credit: Planet Labs

Section 2: Satellite Observations of Landslides

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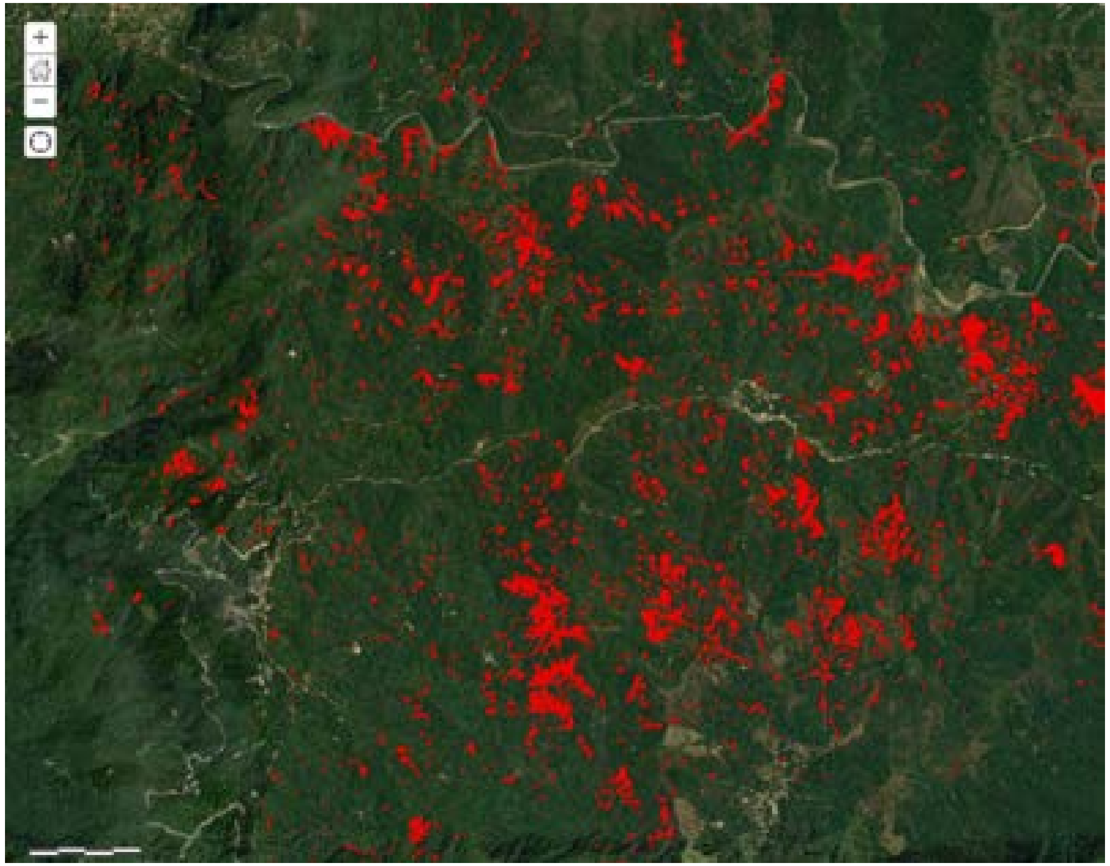

Large landslide inventory mapped using Landsat imagery.

Section 2: Satellite Observations of Landslides

Types of Sensors: Observing landslide events

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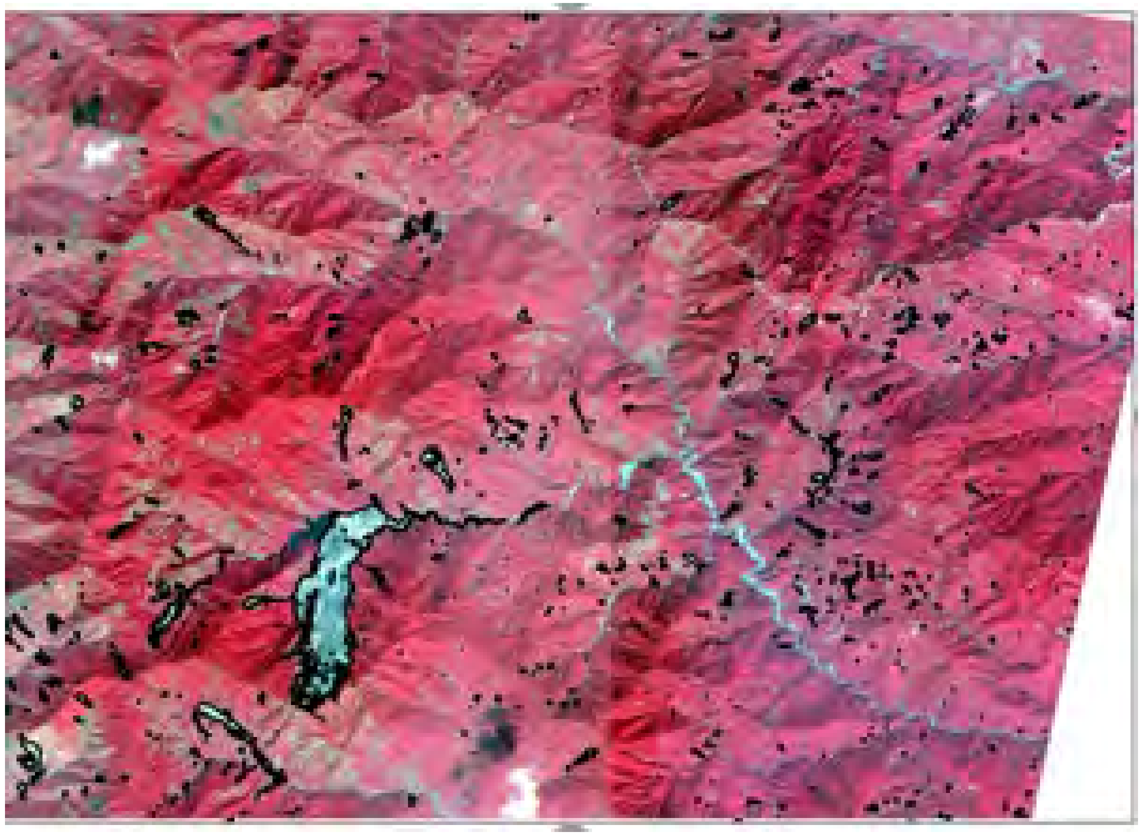
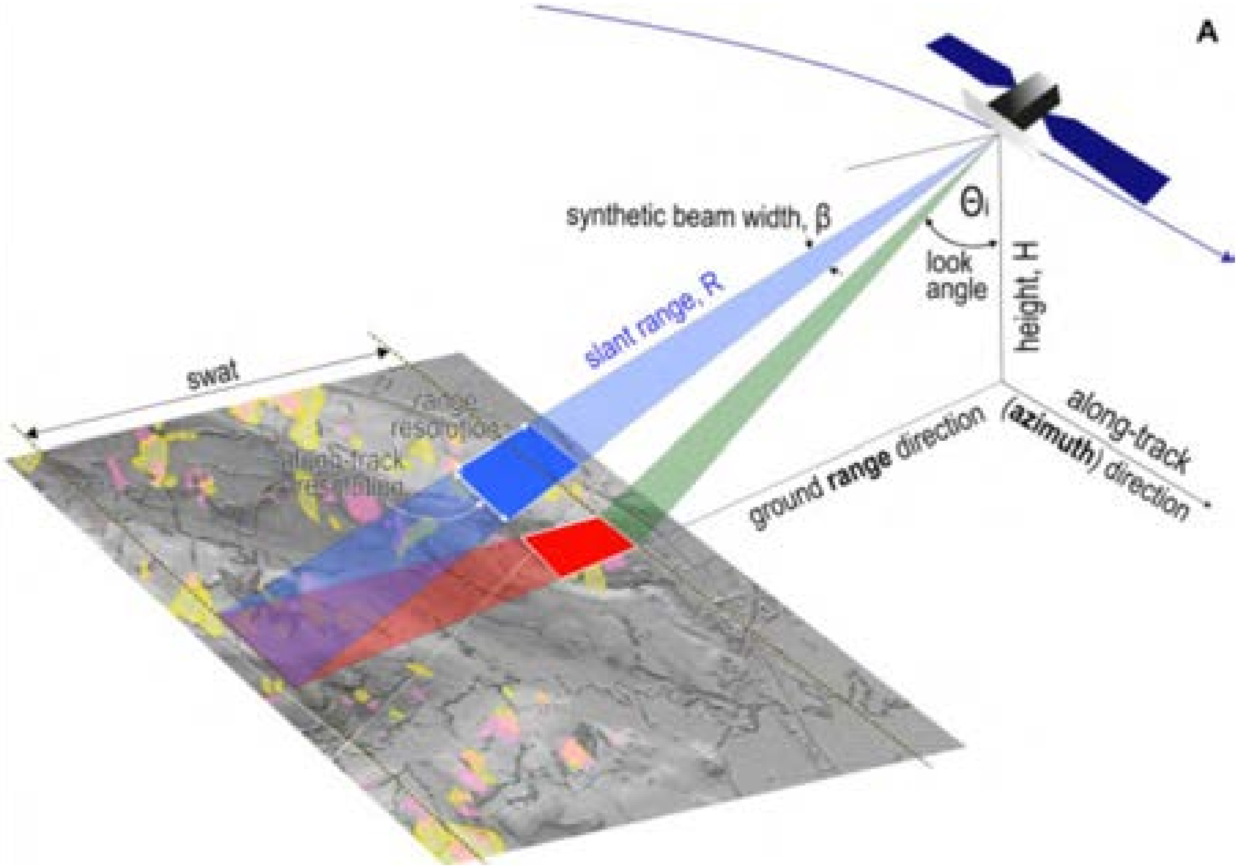


Landslides highlighted using Normalized Difference Vegetation Index (NDVI)

Section 2: Satellite Observations of Landslides

Types of Sensors: Observing landslide events

- Synthetic Aperture Radar (SAR) uses pulses of Radio waves to create 2- or 3-dimensional pictures of the surface.
- Satellites like ALOS-2, Sentinel-1, and the upcoming NASA-ISRO NISAR mission use this method.
- Landslide detection is typically carried out using change detection from pre- and post-event SAR imagery.
- Some methods use changes in the coherence of the SAR signal, while others use amplitude-based approaches.
- Not limited by clouds.
- Additional ARSET training available.



SAR-Landslides Schematic: Mondini et al. 2021

Section 2: Satellite Observations of Landslides

Types of Sensors: Observing Landslide Events

- Several other systems exist to observe landslides remotely.
- Aerial photography is often a primary source of information, either from manned aircraft or unmanned aircraft system (UAS).
- LIDAR (laser imaging, detection, and ranging) has been extensively used to map landscapes to pick out landslides (AGS).
- The atypical 'hummocky' texture of landslide deposits is often a signature.
- New hyperspectral analysis can also benefit landslide science.

Aerial image of the aftermath of the Mocoa debris flow in Colombia. Credit: Fox6

Section 2: Satellite Observations of Landslides

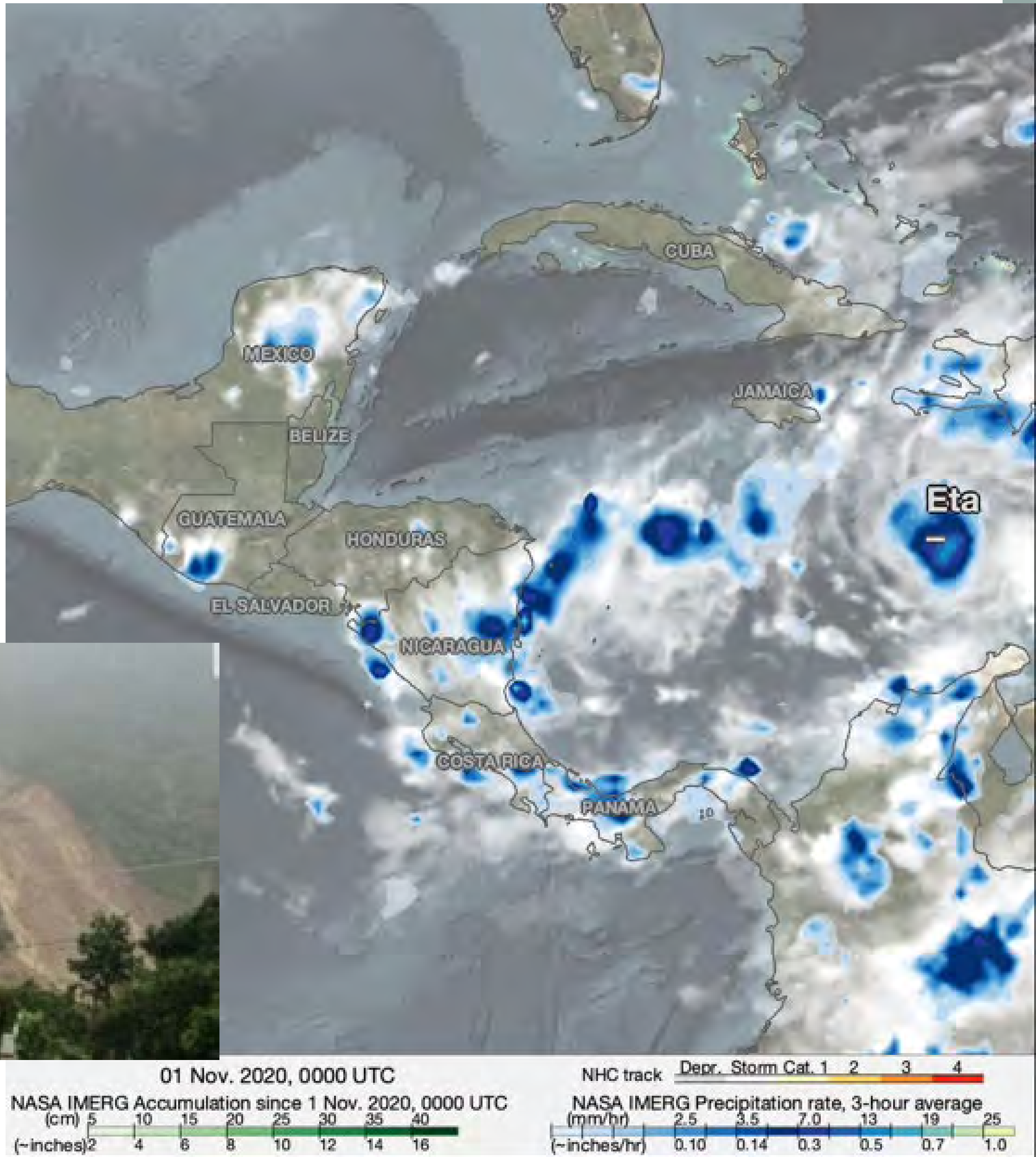
Key Parameters

Resolution	• Higher resolution (spatial & temporal) can increase accuracy of landslide detection • Reduces potential for amalgamation • Tradeoff between image footprint and resolution
Latency	• Low Latency data often extremely important for emergency response analysis • In areas where cloud cover is frequent, repeated low-latency imagery may improve coverage
Spectral bands	• Pre- and post-event analysis benefits from the same spectral bands • Landslides typically remove vegetation, so bands sensitive to biomass are likely beneficial

Section 2: Satellite Observations of Landslides

Observations of landslide triggering factors

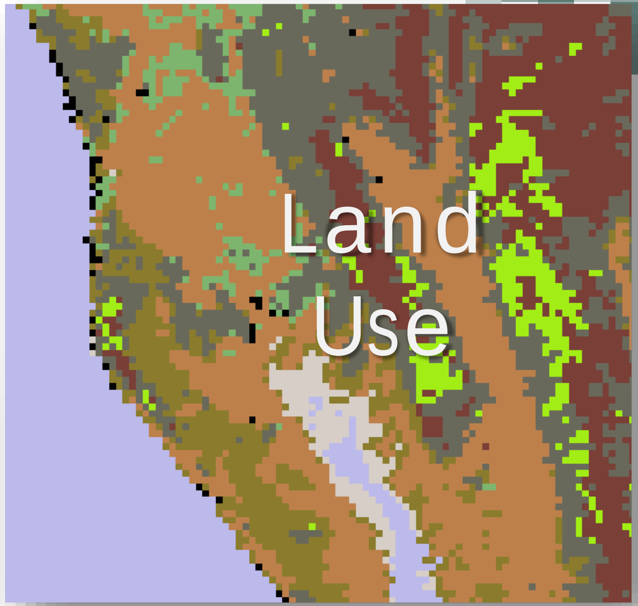
- Satellite observations of rainfall can be critical to assessing landslide triggering conditions.
- NASA's GPM data has proven beneficial for triggering conditions.
- Soil moisture, measured by systems like NASA's SMAP satellite, also helps analyze precursory conditions.
- Characterizing earthquake triggers is typically conducted using terrestrial seismometers, but post-earthquake assessment relies on SAR and optical data.

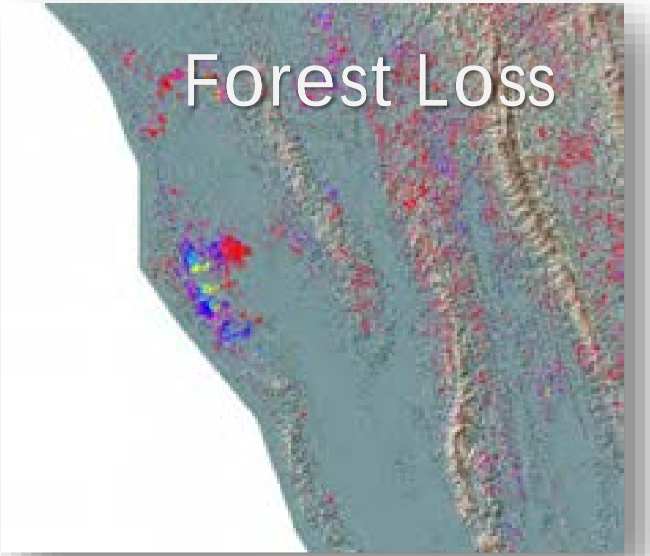


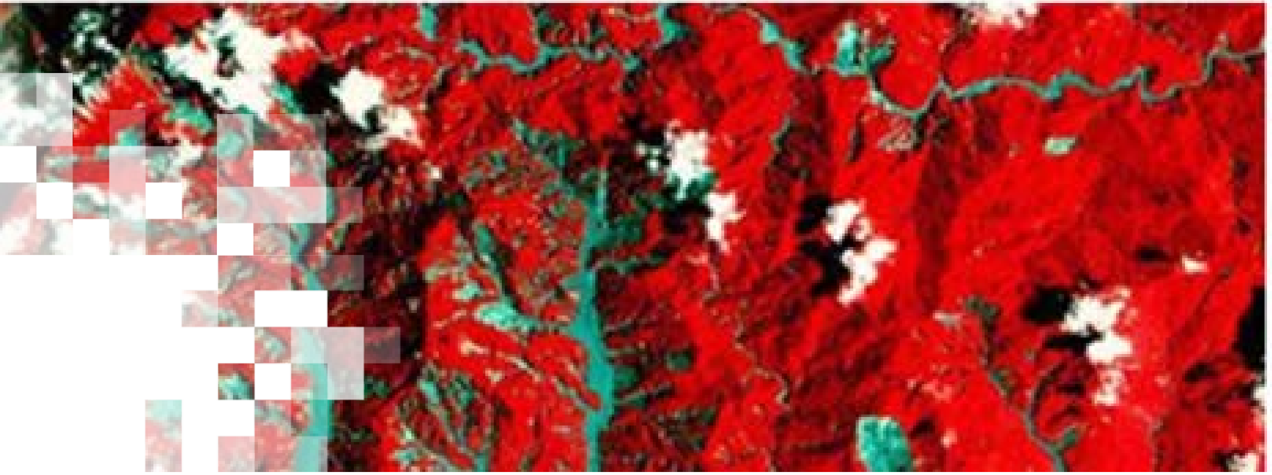
Section 2: Satellite Observations of Landslides

Datasets relevant to characterizing static factors

- Wide variety of satellite-derived datasets can be used to help characterize landslide locations.
- Land use – e.g., MODIS or Sentinel datasets – are critical components.
- Loss of vegetation using Landsat-derived data has been widely incorporated into landslide analyses.
- DEMs form a fundamental component of landslide science, ranging from global SRTM data to higher resolution local data built from LIDAR scanning.
- Wide variety of data resolution and observation time requires care when combining.







Section 3: Ancillary data

Section 3: Ancillary Data

Definitions

- Ward et al. (2020): "exposure refers to the location of economic assets or people in a hazard-prone area."

SUSCEPTIBILITY:	HAZARD:	EXPOSURE:	VULNERABILITY:	RISK:
Where is the landslide likely?	Where and when is the landslide likely?	Who / what is in the hazard zone?	How likely is damage / injury for exposure level?	Hazard x exposure x vulnerability

Section 3: Ancillary Data

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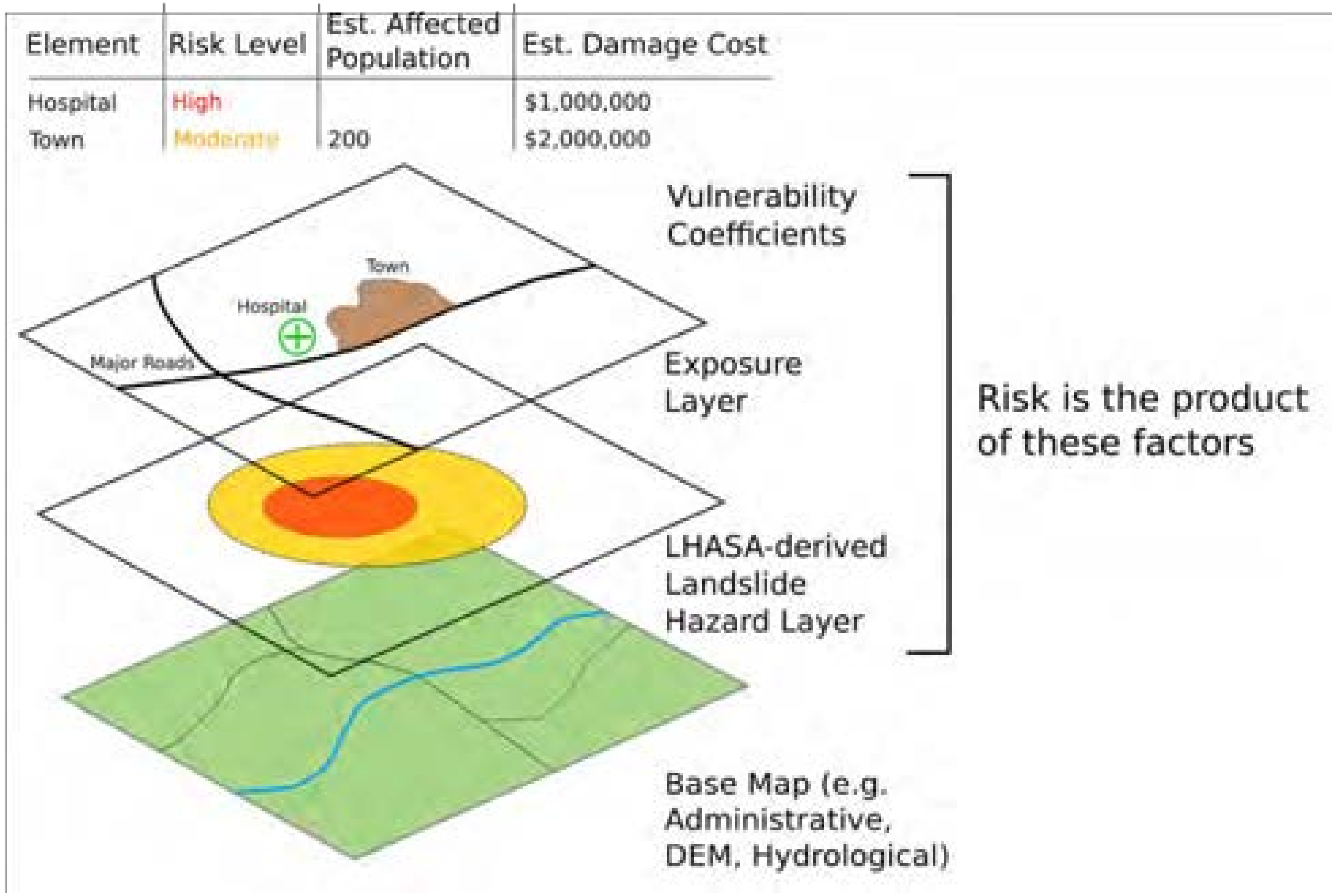
Exposure: Lower level of difficulty

Vulnerability: Significantly greater challenge

Section 3: Ancillary Data

Understanding data combinations

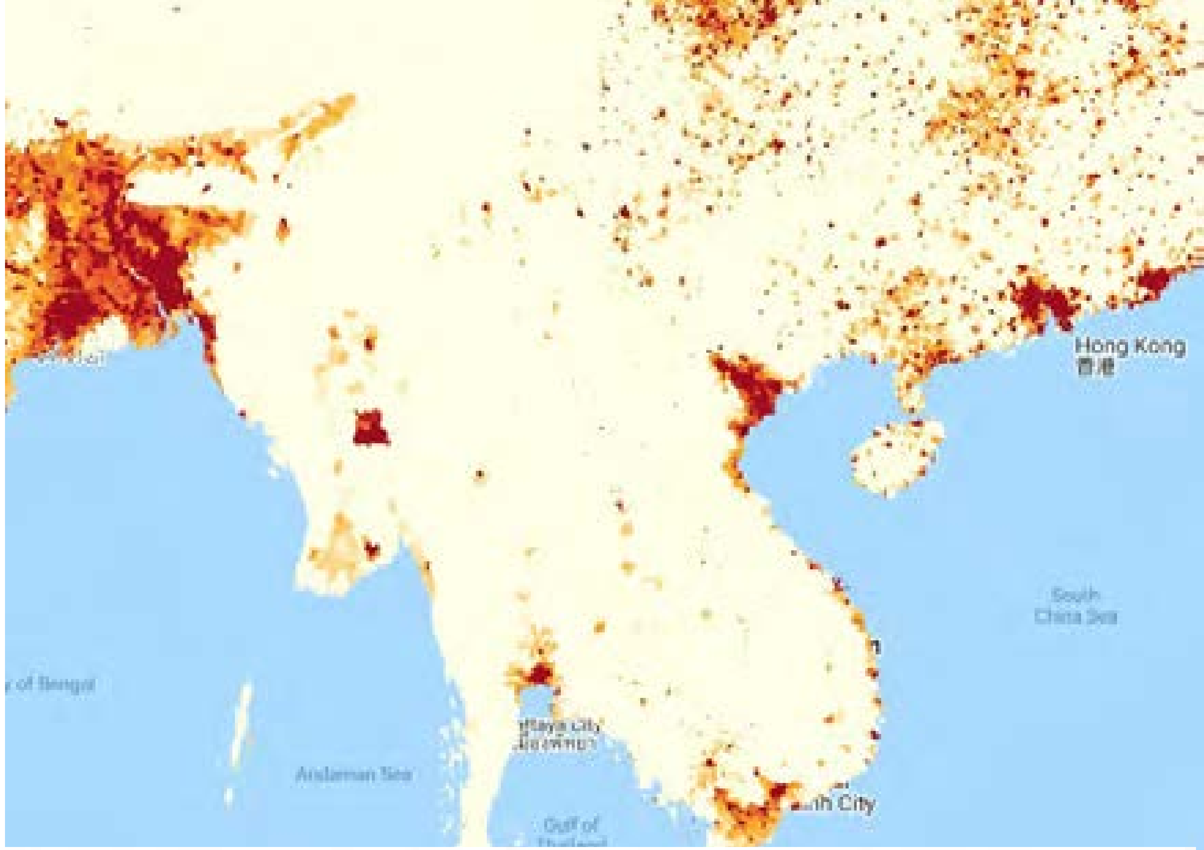
- **Hazard**: e.g., landslide hazard layer. Typically derived from model or observation.
- **Exposure**: Population density, building footprints, key infrastructure. Derived from a variety of input sources.
- **Vulnerability**: Healthcare, demographics, policies designed to mitigate disasters; often qualitative data.

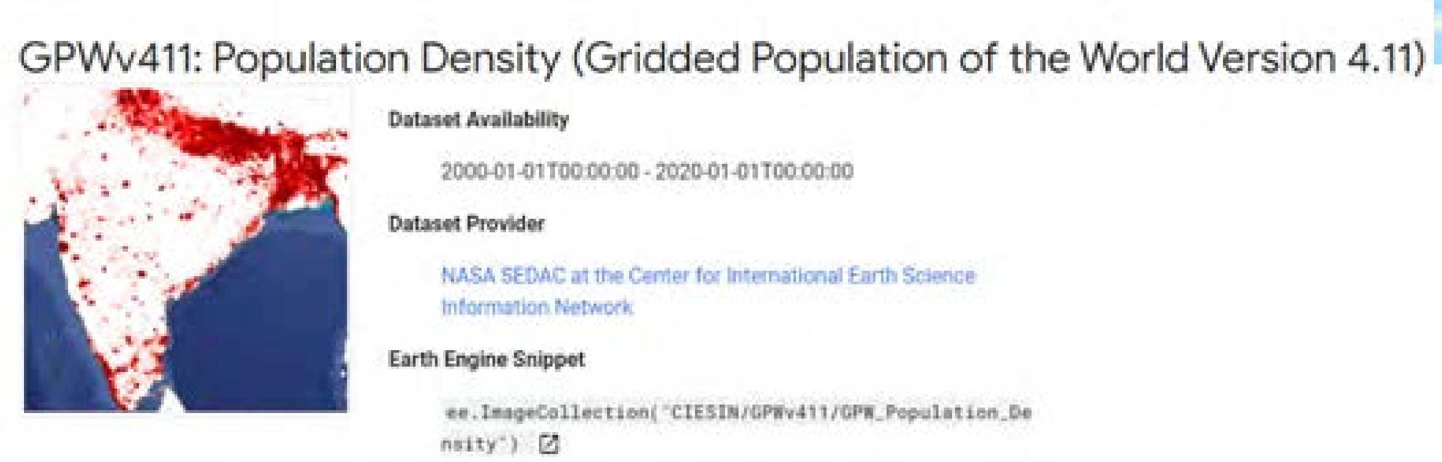


Section 3: Ancillary Data

Global Population Data

- Gridded Population of the World (GPW) is a NASA-sourced dataset available from NASA's Socioeconomic Data and Applications Center (SEDAC)
- Approx. 1 km resolution
- Data from census sources, can impact model output
- Global, 5-time intervals (2000, 2005, 2010, 2015, 2020)

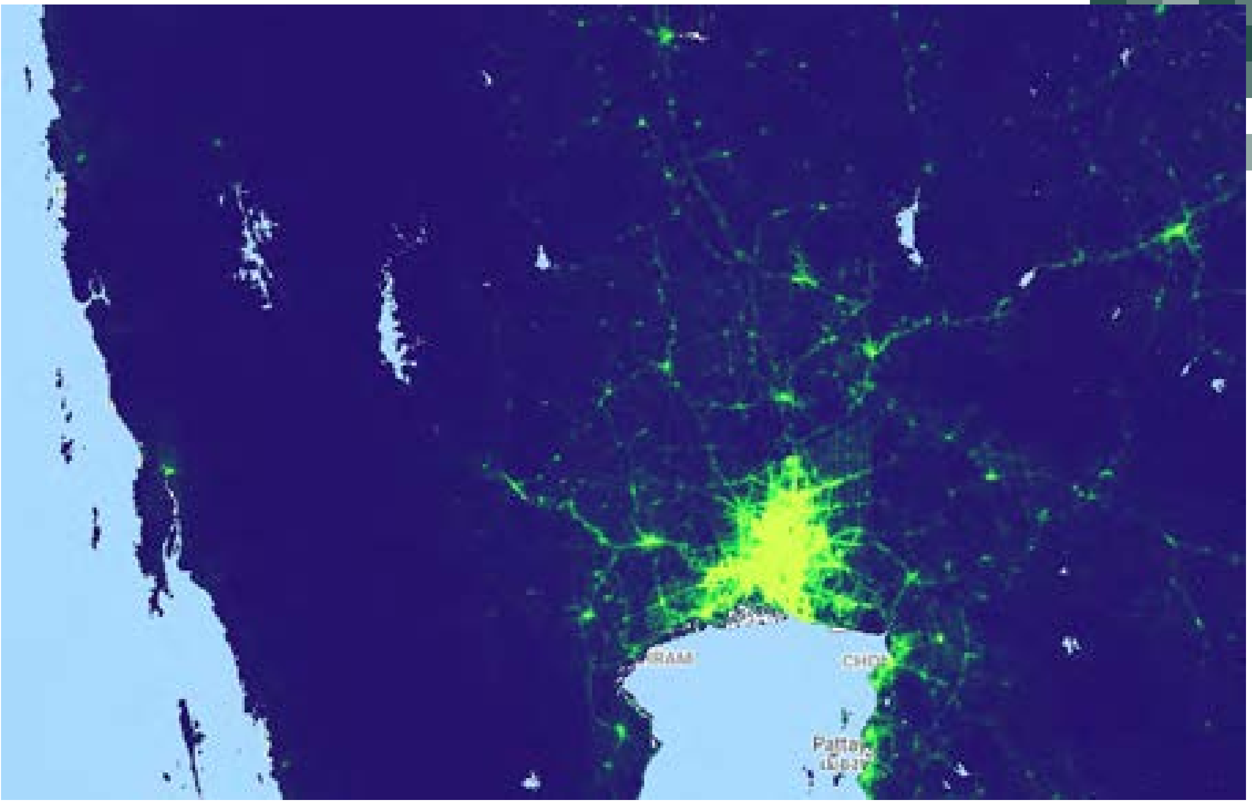




Section 3: Ancillary Data

Global Population Data

- WorldPop is a data-assimilation derived public dataset
- 100 m resolution
- Updated for 2000, merges multiple input streams including satellite and census
- Also includes demographic data



WorldPop Global Project Population Data: Estimated Residential Population per 100x100m Grid Square

Dataset Availability

2000-01-01T00:00:00 - 2021-01-01T00:00:00

Dataset Provider

WorldPop

Earth Engine Snippet

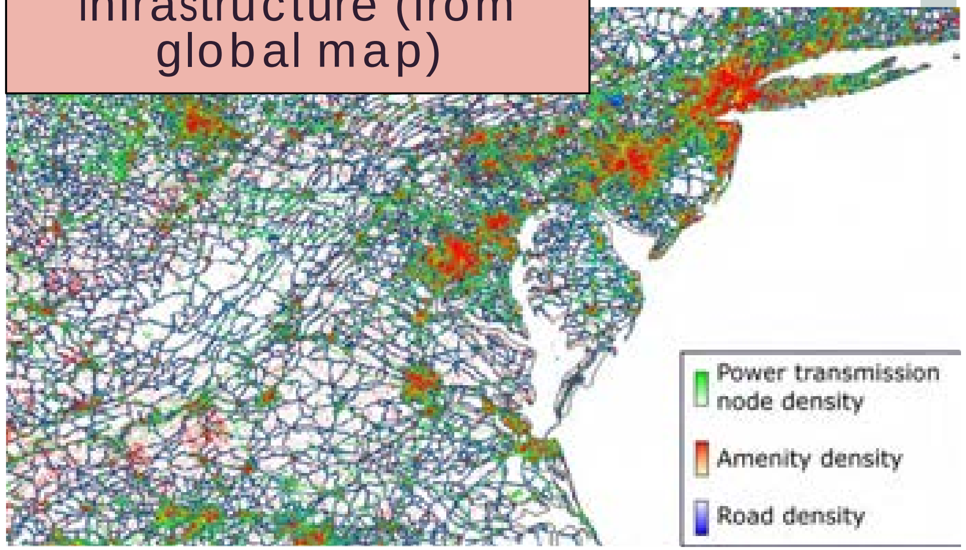
```
ee.ImageCollection("WorldPop/GP/100m/pop")
```

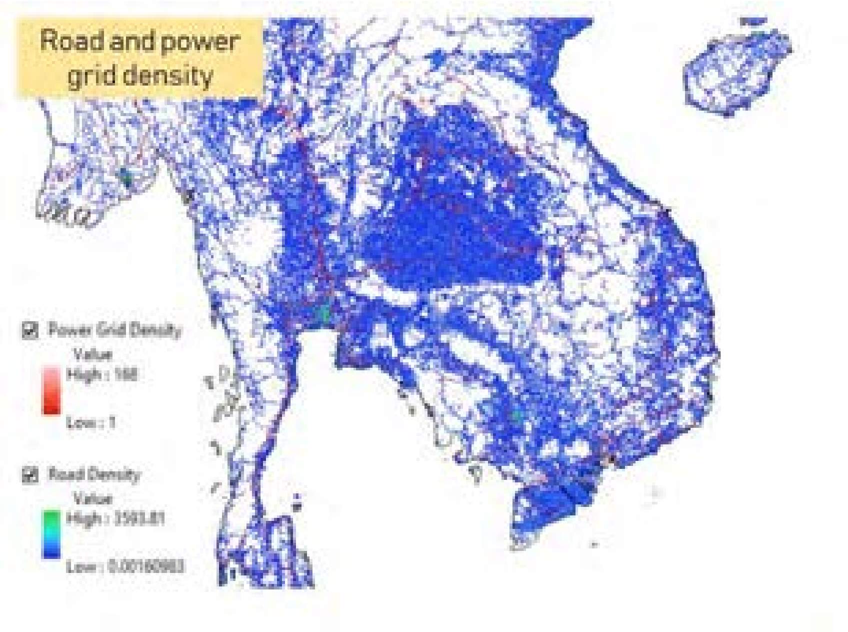
Section 3: Ancillary Data

Infrastructure Data

- Global datasets of infrastructure – buildings, roads, pipelines, and other critical elements – are often large data volumes. Cloud computing is often preferred.
- OpenStreetMap has been used in landslide modelling, as well as more localized datasets.
- Locations of infrastructure elements may be points (0-dimensional), lines (1-dimensional, e.g., roads), polygons (2-dimensional, e.g., building footprints) or rarely objects (3-dimensional).

Example: US East Coast infrastructure (from global map)

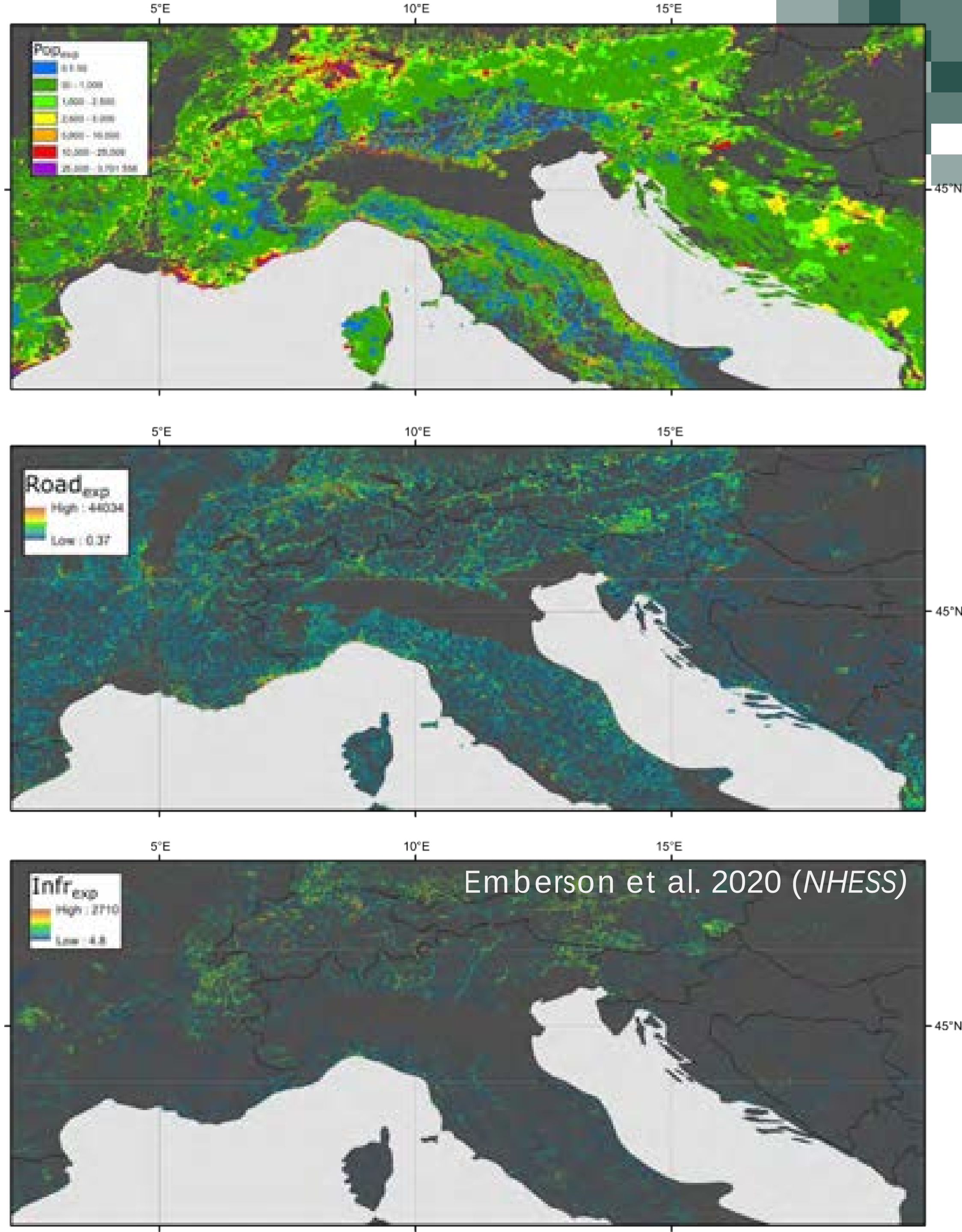




Section 3: Ancillary Data

Raster Based analysis

- Grid, or raster-based assessment of landslide exposure provides analysis at a defined resolution.
- Very useful and effective at large scale—gridded satellite data are highly suitable for this kind of analysis.
- At length scales close to the resolution limit, accuracy and usability may break down.

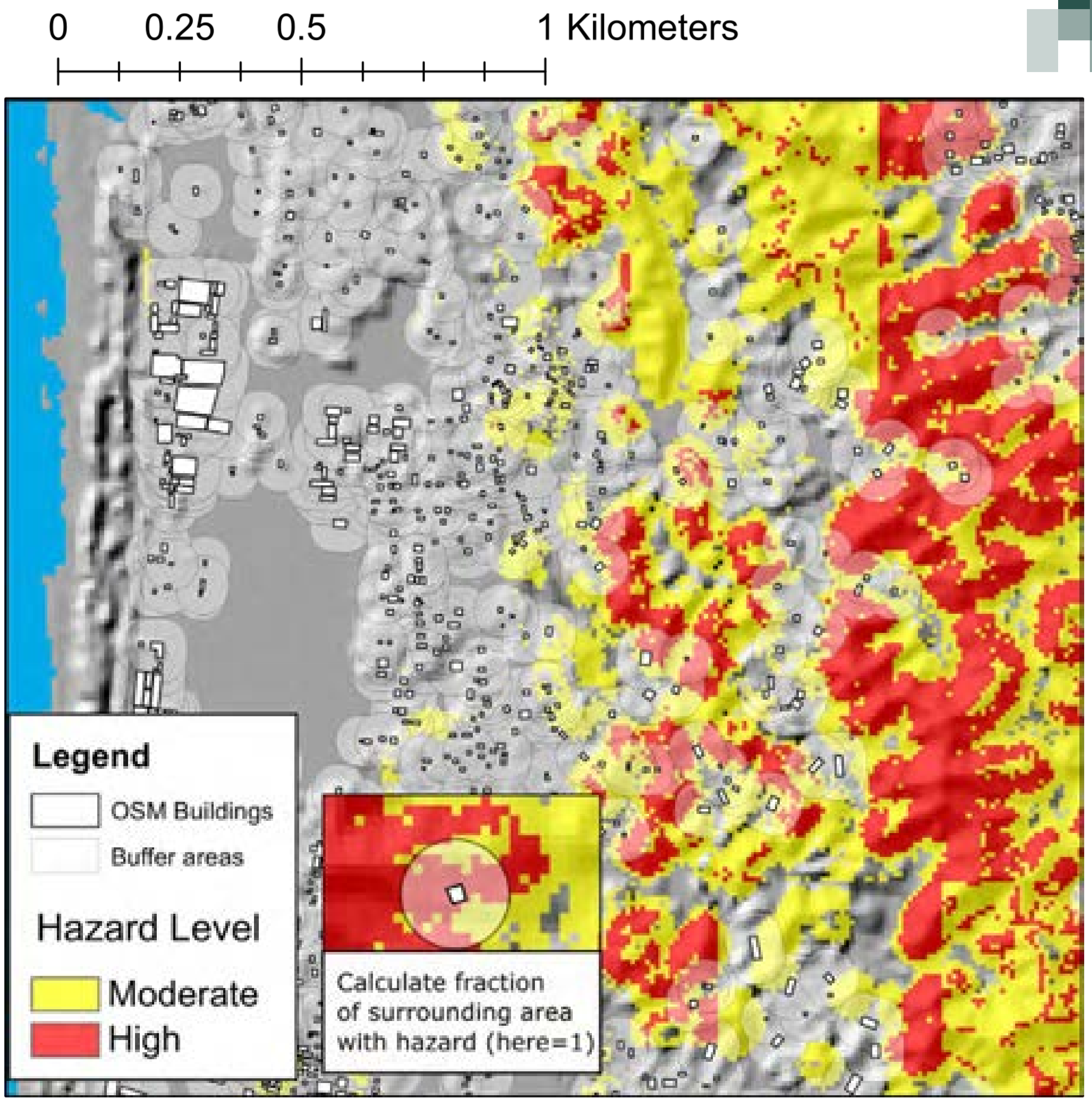


Emberson et al. 2020 (*NHESS*)

Section 3: Ancillary Data

Vector Based analysis

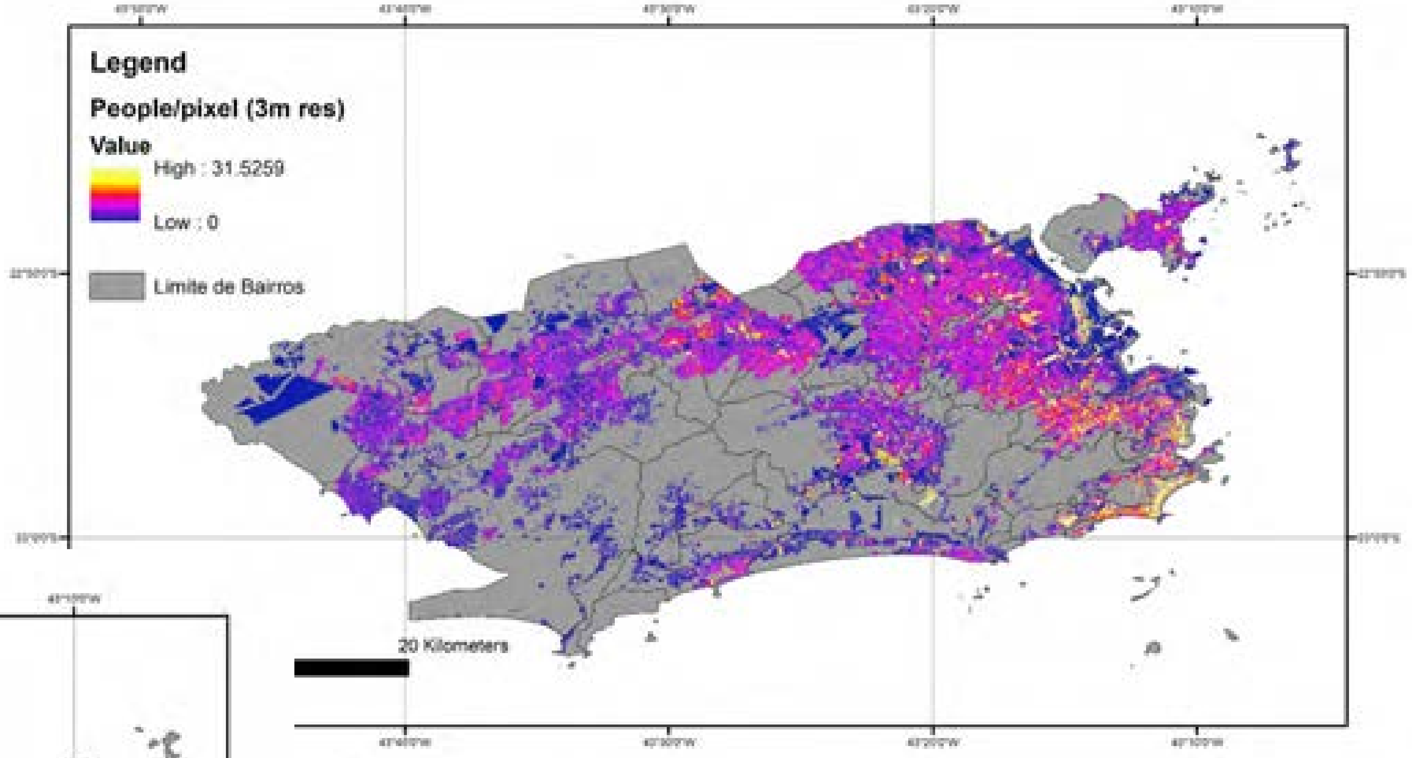
- Vector based analysis can be scale-invariant and can be highly relevant locally.
- Permits intercomparison of individual infrastructure elements.
- Important to note that resolution of input hazard layers may have strong bearing on output reliability.
- High resolution analysis should also consider source vs runout zone of landslides.



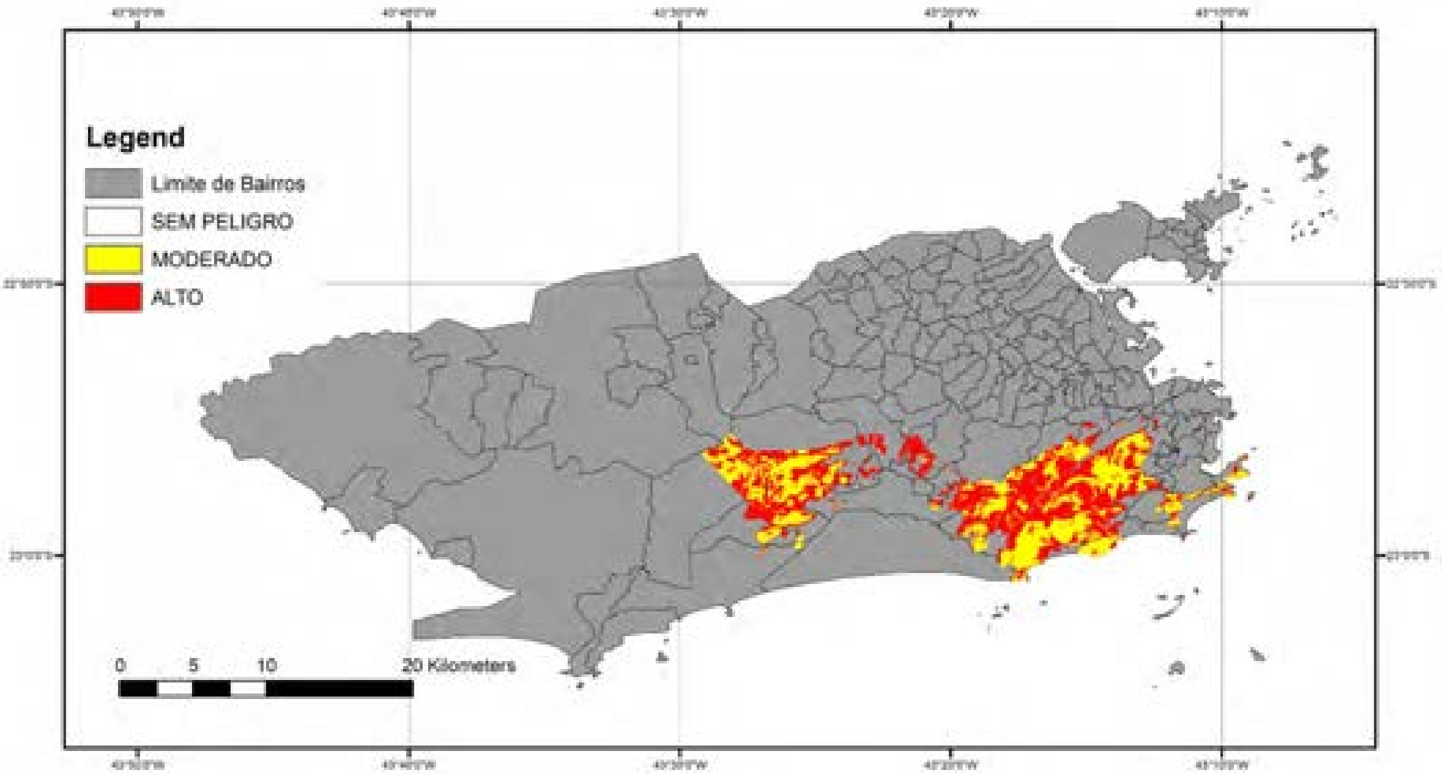
Section 3: Ancillary Data

Putting it all together

- Using an example from Brazil, we can explore how to combine different datasets.



Above: Population Density at 3m resolution



Left: Example Hazard output / LHASA Rio

Section 3: Ancillary Data

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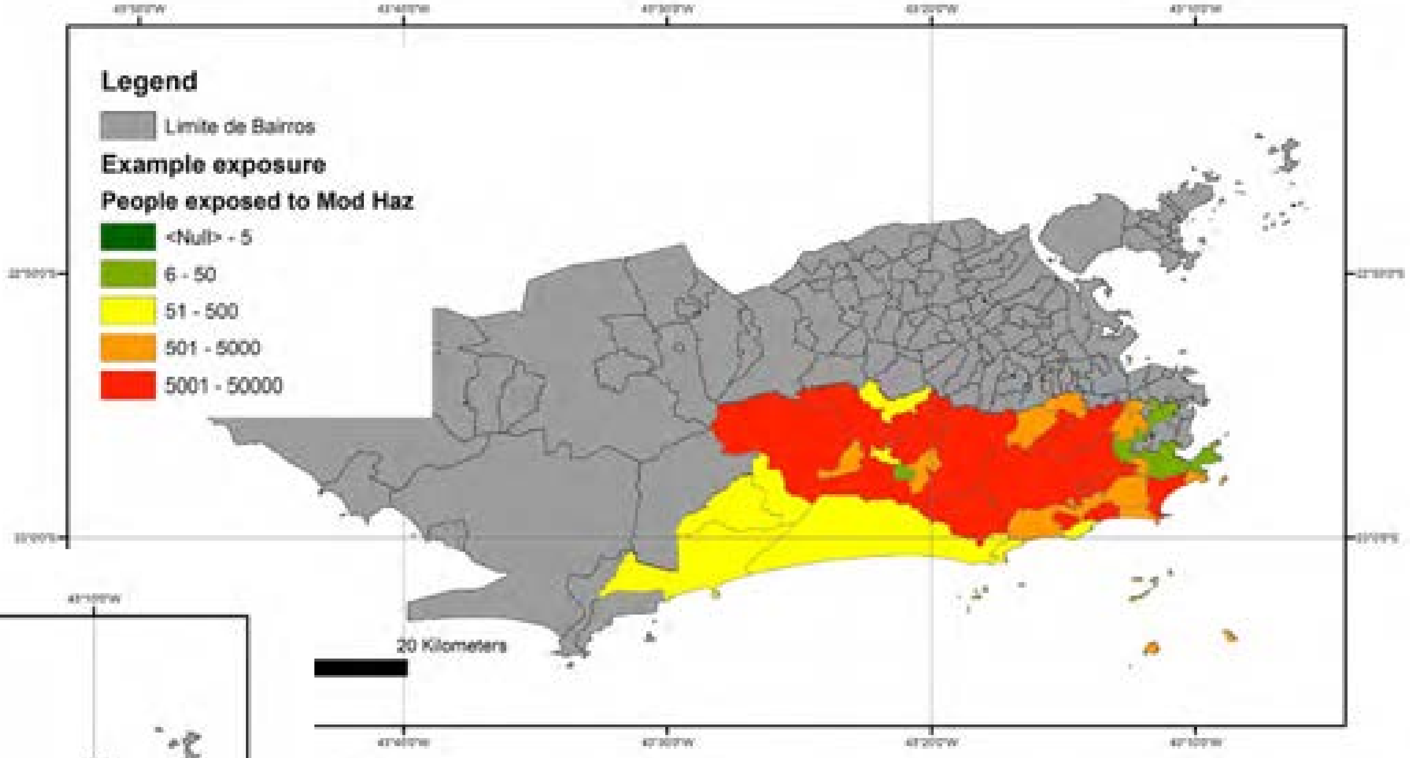
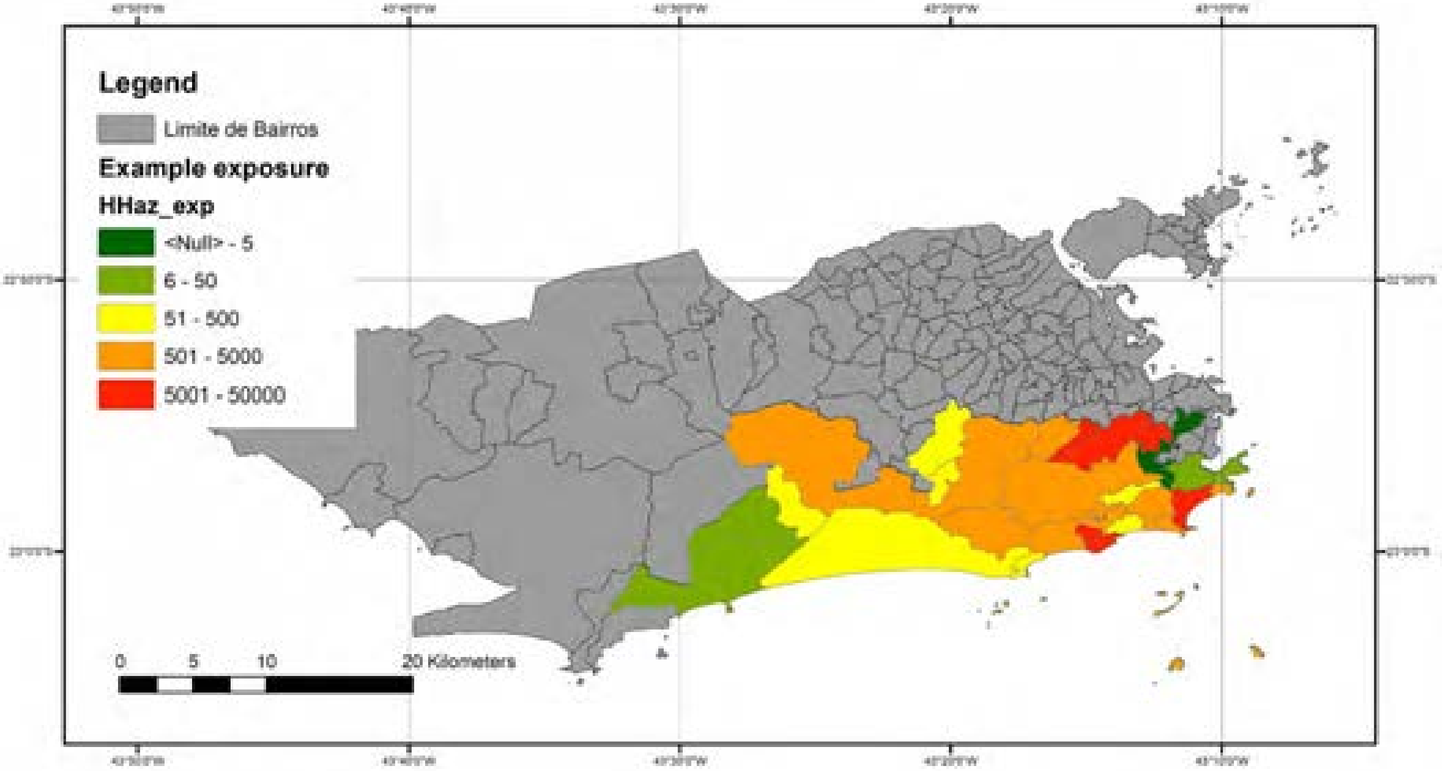




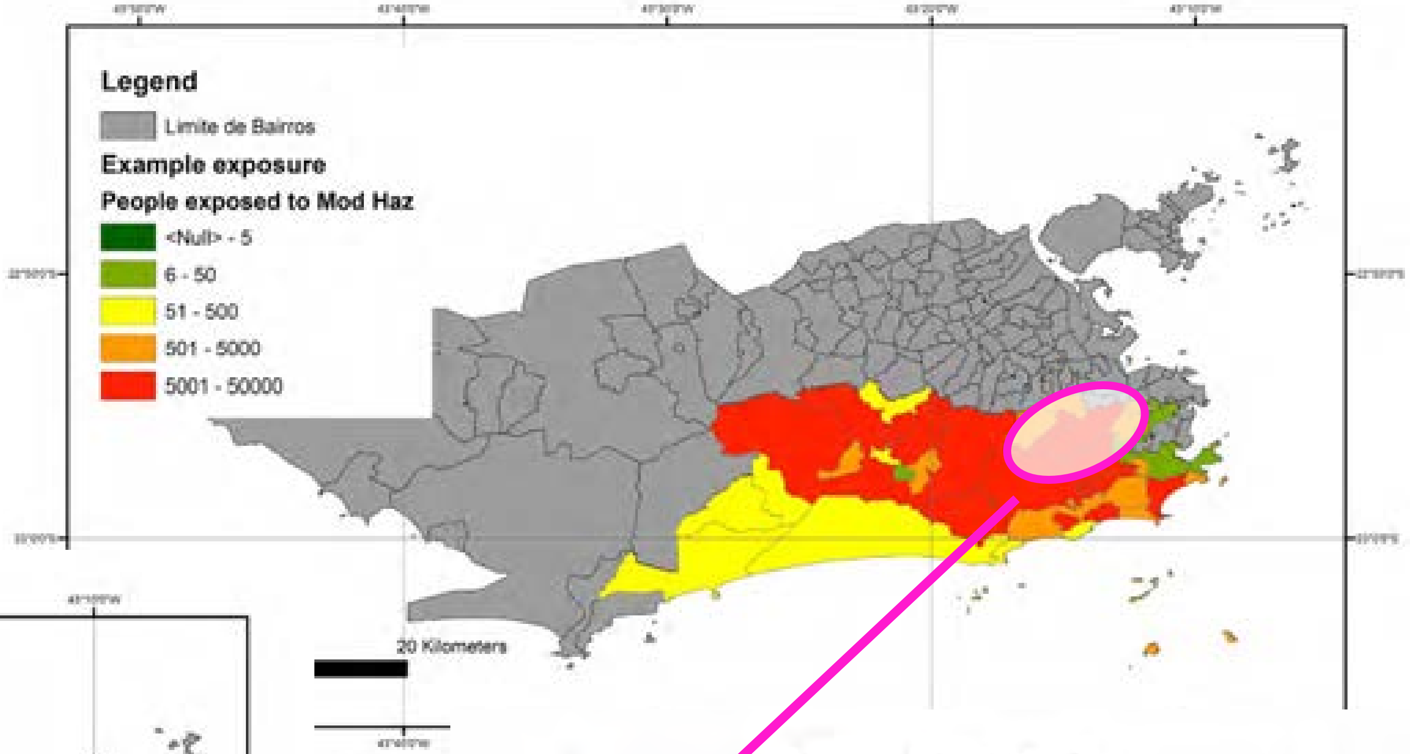
Above: Population exposure to moderate hazard

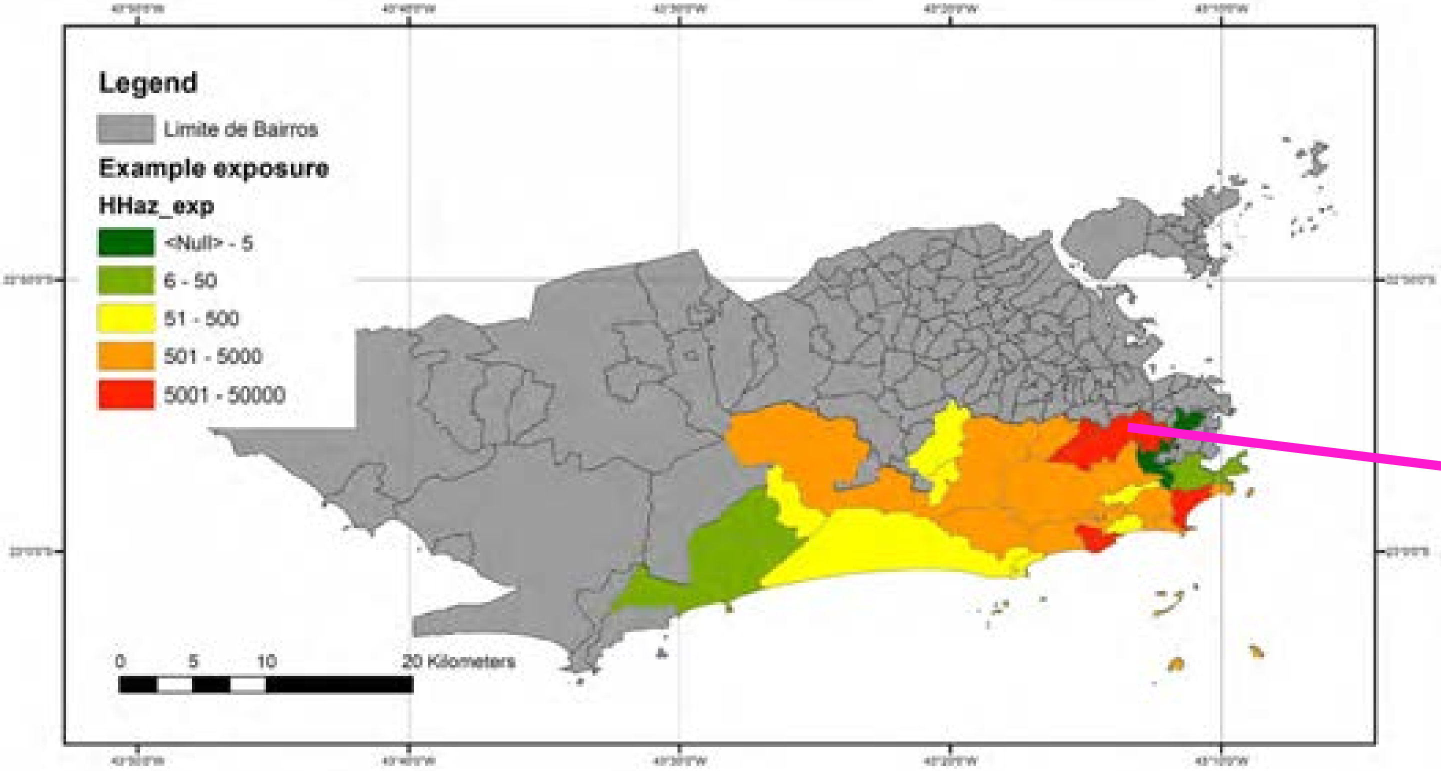
Left: Population exposure to high hazard

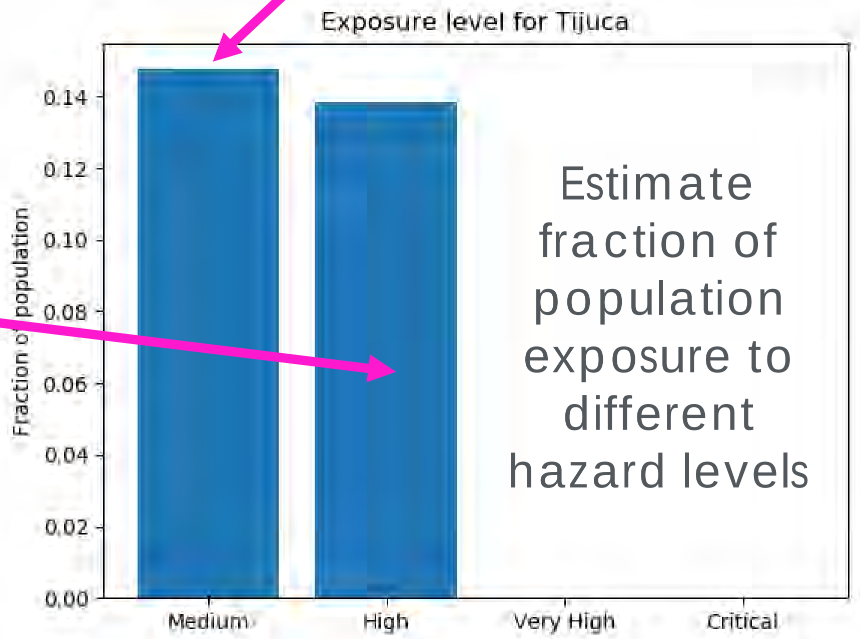
Section 3: Ancillary Data

Putting it all together

- Using an example from Brazil, we can explore how to combine different datasets.



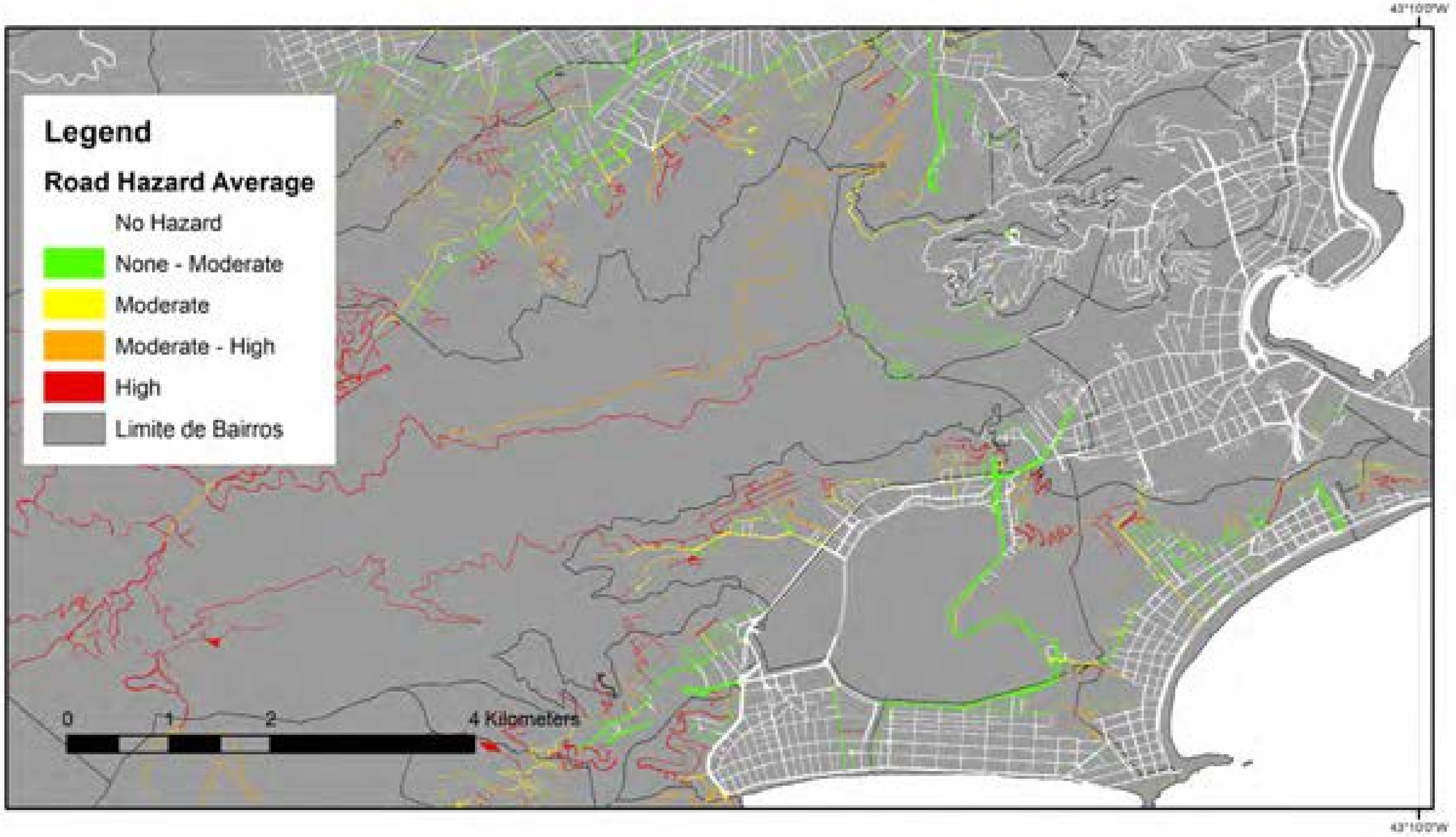




Section 3: Ancillary Data

Putting it all together

- Even with qualitative hazard data, we can combine this with road data to consider which routes through the city may be most exposed to landslide hazard.
- This information can help guide emergency planning processes.



What's Next?

- Understanding how to delineate and map landslides, manually and automatically
- Developing a deeper understanding of satellite data for landslide observation
- Building landslide susceptibility models using satellite data
- Incorporating triggering data to build hazard models

Resources

- USGS Landslide Handbook
- ARSET SAR training
- ARSET Hyperspectral training
- NASA Landslides Research
- NASA Disasters Program

Part 1 Summary

- The term landslide encompasses dynamic processes ranging from localized rock falls to highly mobile and fluidized debris flows.
- Rainfall-triggered landslides are a critical part of landslide activity.
- Earthquakes, freeze-thaw processes, human-driven processes (deforestation & urbanization), volcanoes, and wave-driven erosion can also drive landslide activity.
- Topography is among the most important elements influencing the likelihood of landslide occurrence.
- Remote sensing observations (optical and radar) are critical for the global monitoring, assessment, and response to landslide events.
- Several remote sensing parameters (spatial, temporal, and spectral) are key for satellite observations of landslides.
- Combining ancillary data (population, infrastructure, etc.) with satellite observations allows scientists to model landslide risk at the global scale.

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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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!