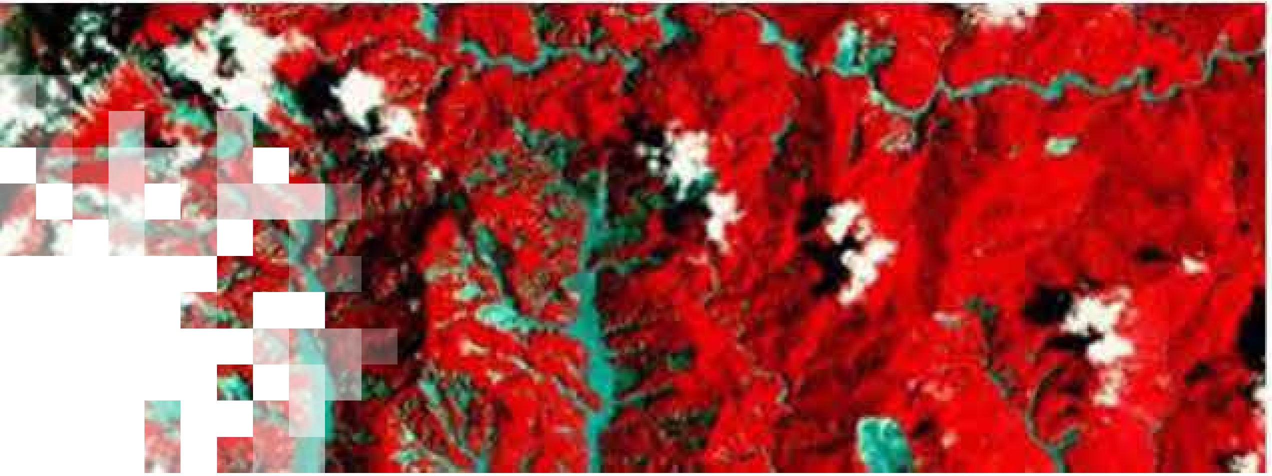
National Aeronautics and Space Administration

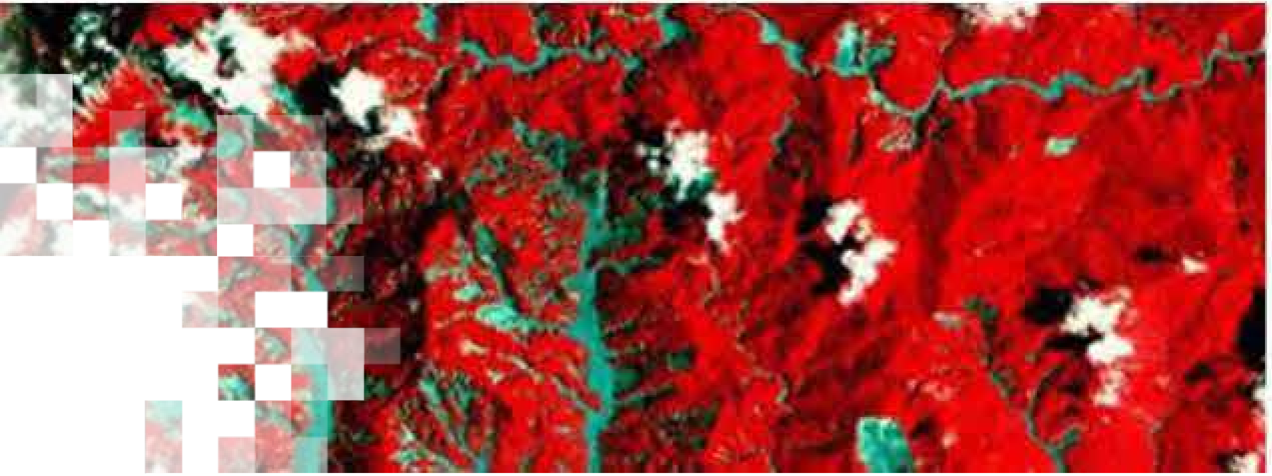


Landslide Monitoring and Risk Assessment Using NASA Earth System Data

Part 3: Remote Sensing and Landslide Susceptibility

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

March 18, 2025


Landslide Monitoring and Risk Assessment Using NASA Earth System Data

Overview

Training Outline

Part 1	Part 2	**Part 3**
Remote Sensing for Landslide Science and Disaster Planning	Mapping Landslide Occurrence Using Earth Observations	**Remote Sensing and Landslide Susceptibility**
March 11, 2025	March 13, 2025	**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.

Prerequisite

- Fundamentals of Remote Sensing

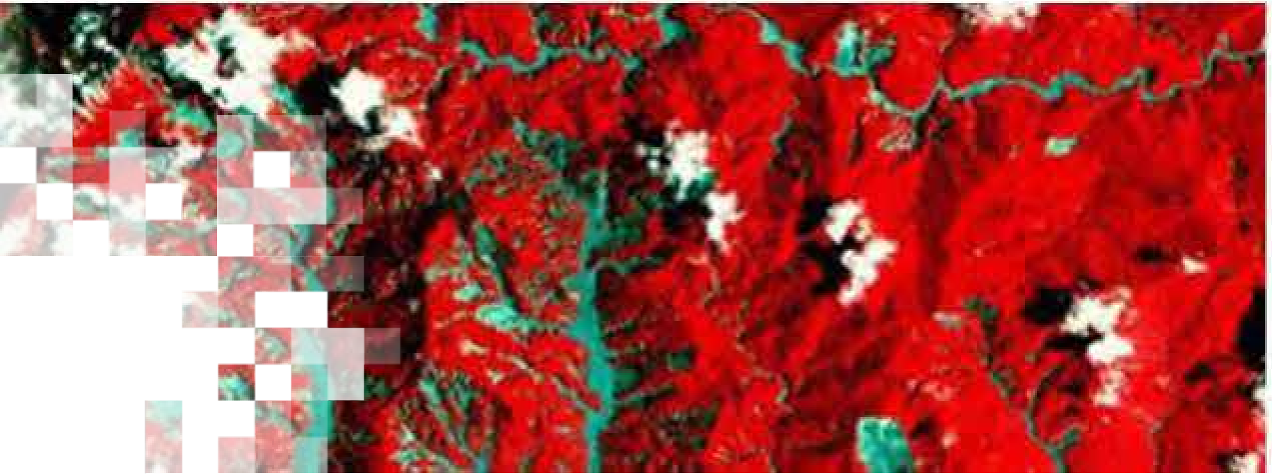
How to Ask Questions

- 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.

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.



Landslide Monitoring and Risk Assessment Using NASA Earth System Data

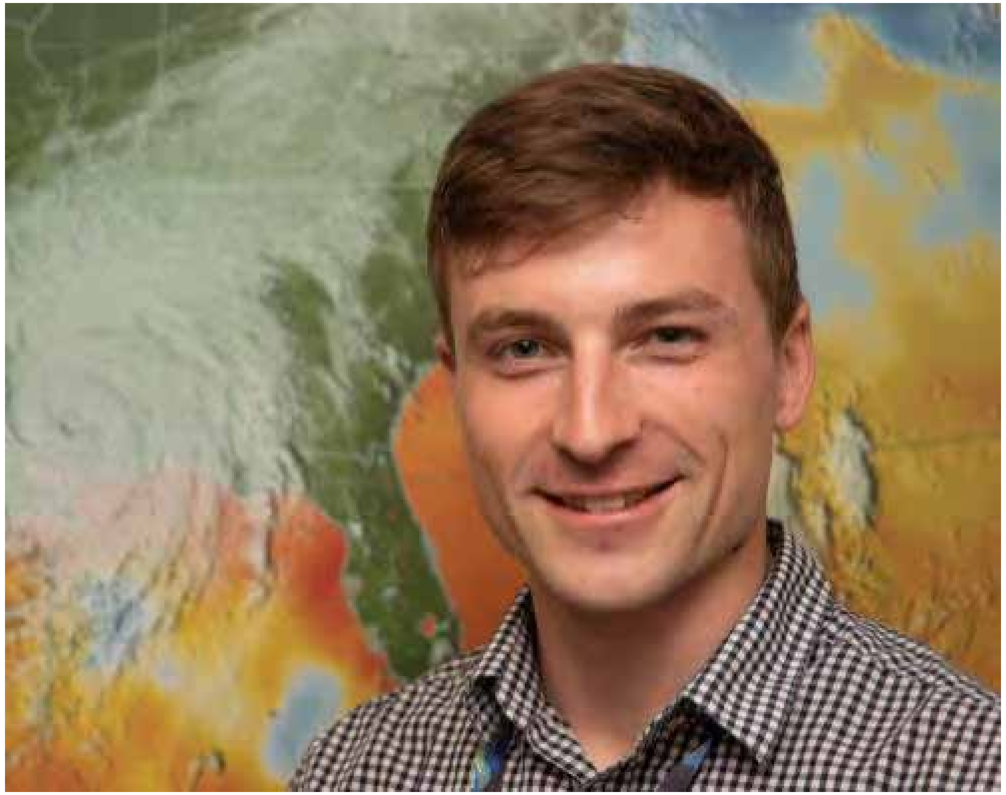
Part 3: Remote sensing and landslide susceptibility

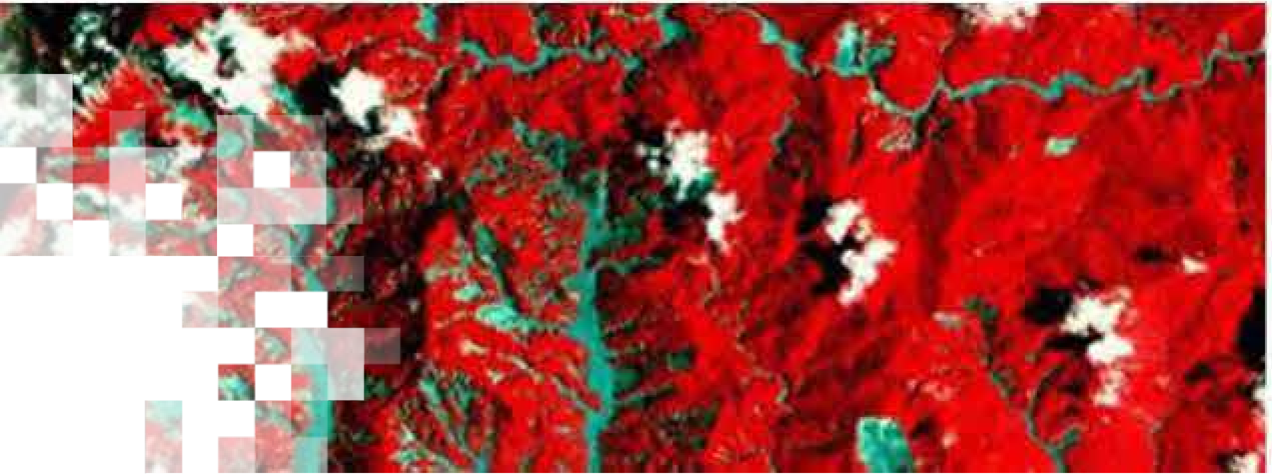
Part 3 – Trainer

Dr. Robert Emberson

Associate Program Manager/Disasters

UMBC





Section 1: Landslide Susceptibility

Section 1: Landslide Susceptibility

Defining Landslide Susceptibility

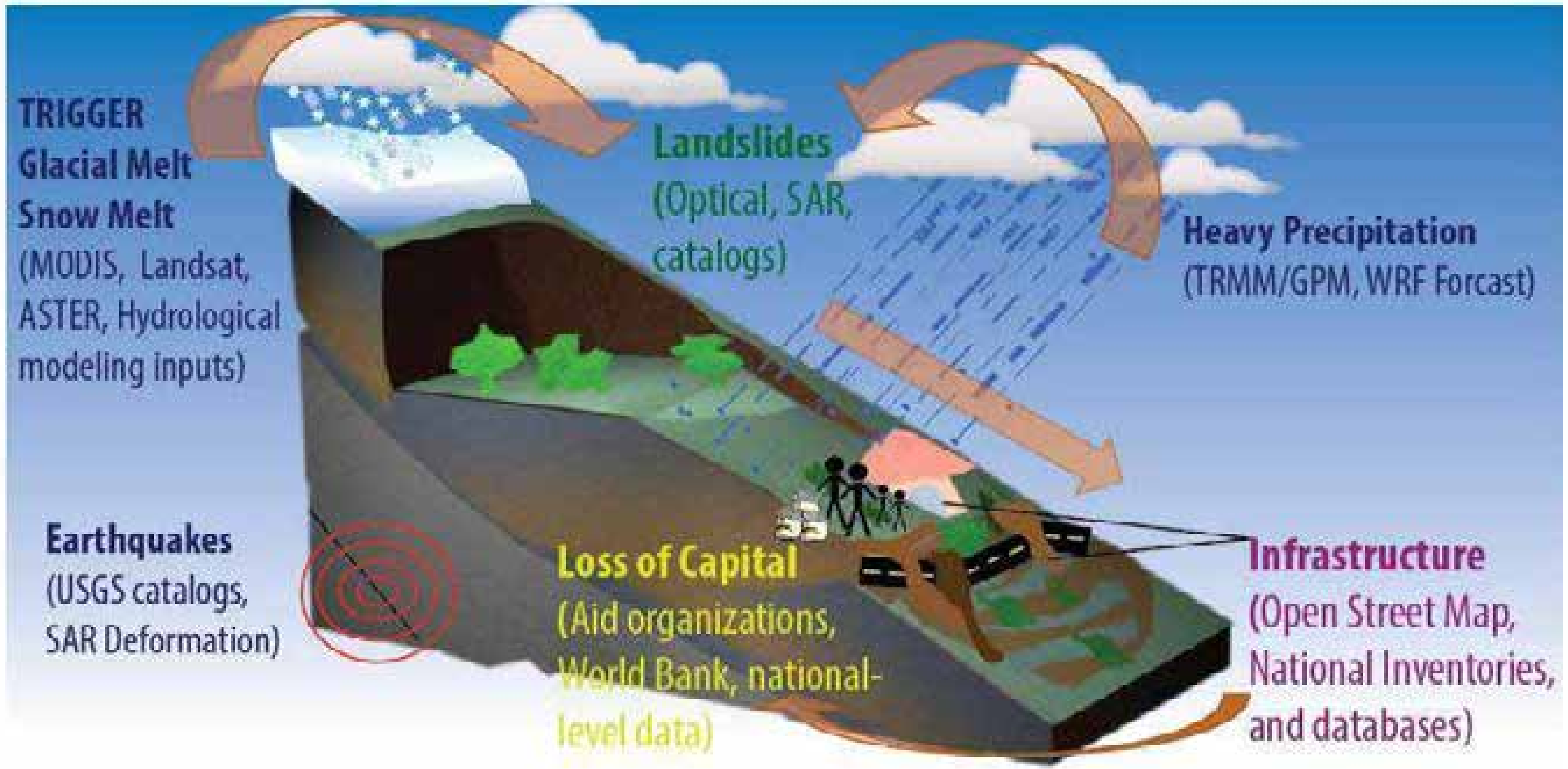
Reichenbach et al. (2018): "Landslide susceptibility… [is the] likelihood of a landslide occurring in an area on the basis of the local terrain and environmental conditions"

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 1: Landslide Susceptibility

Defining Landslide Susceptibility

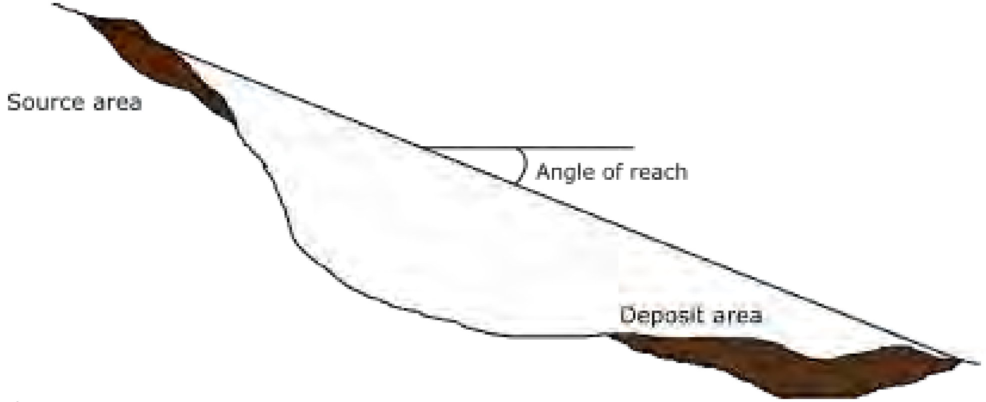
- Triggers (earthquakes, heavy rainfall, snow melt) do not determine susceptibility.
- Which factors affect susceptibility, and how can we observe them?



Section 1: Landslide Susceptibility

Defining Landslide Susceptibility

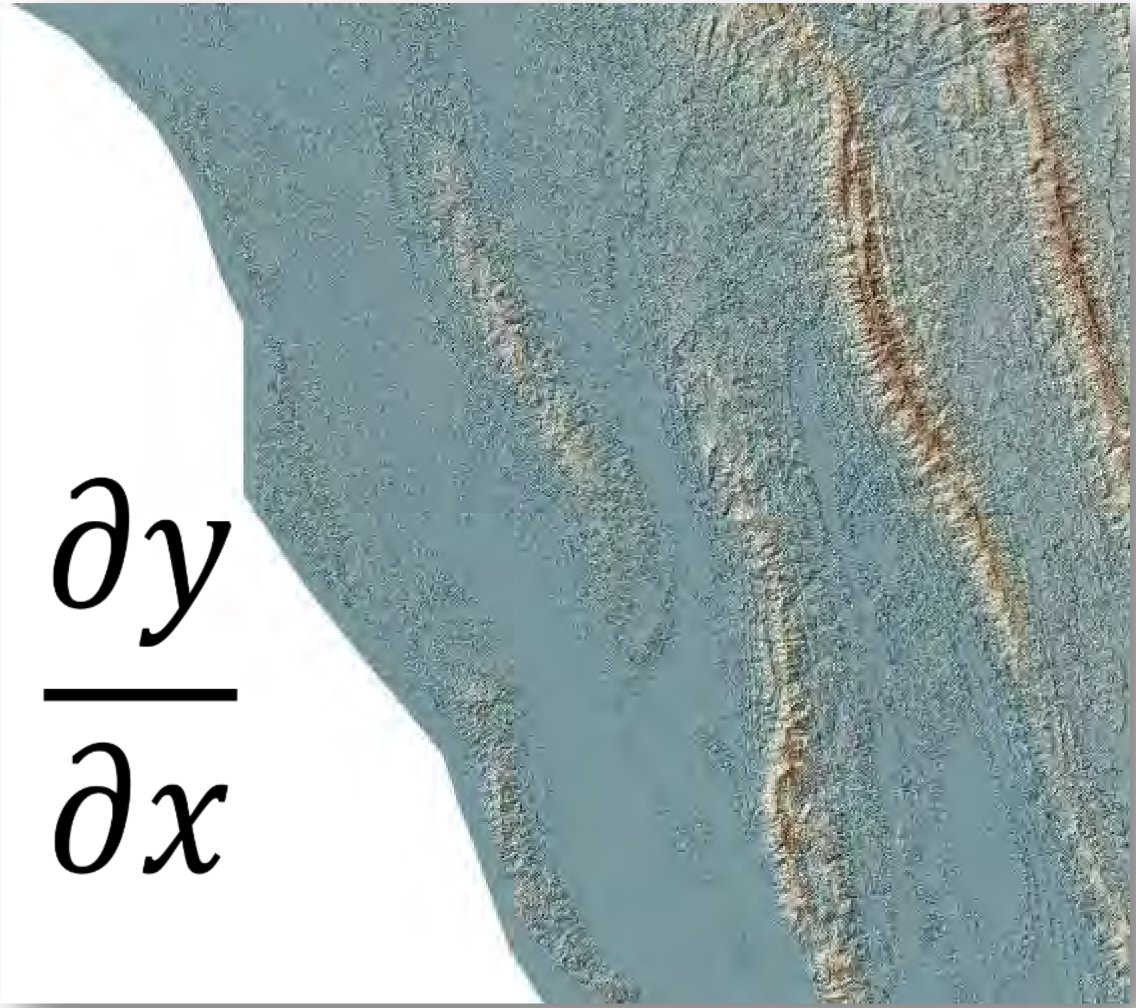
- Important to consider the differences in location of landslide source and impact.
- Susceptibility describes the areas landslides are likely to **originate**.
- Hazard and impact analysis should consider the potential runout areas and overall impact.
- Implications for inputs to susceptibility models.



Section 1: Landslide Susceptibility

Relevant Factors and Associated Satellite Datasets

- Topographic factors are critical to determine landslide susceptibility.
- Relevant factors include:
  - Slope



$$\frac{\partial y}{\partial x}$$

Section 1: Landslide Susceptibility

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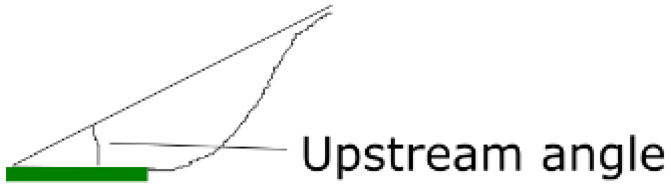
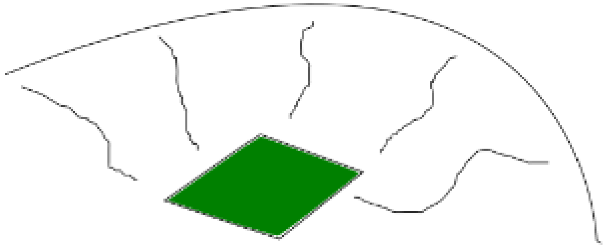
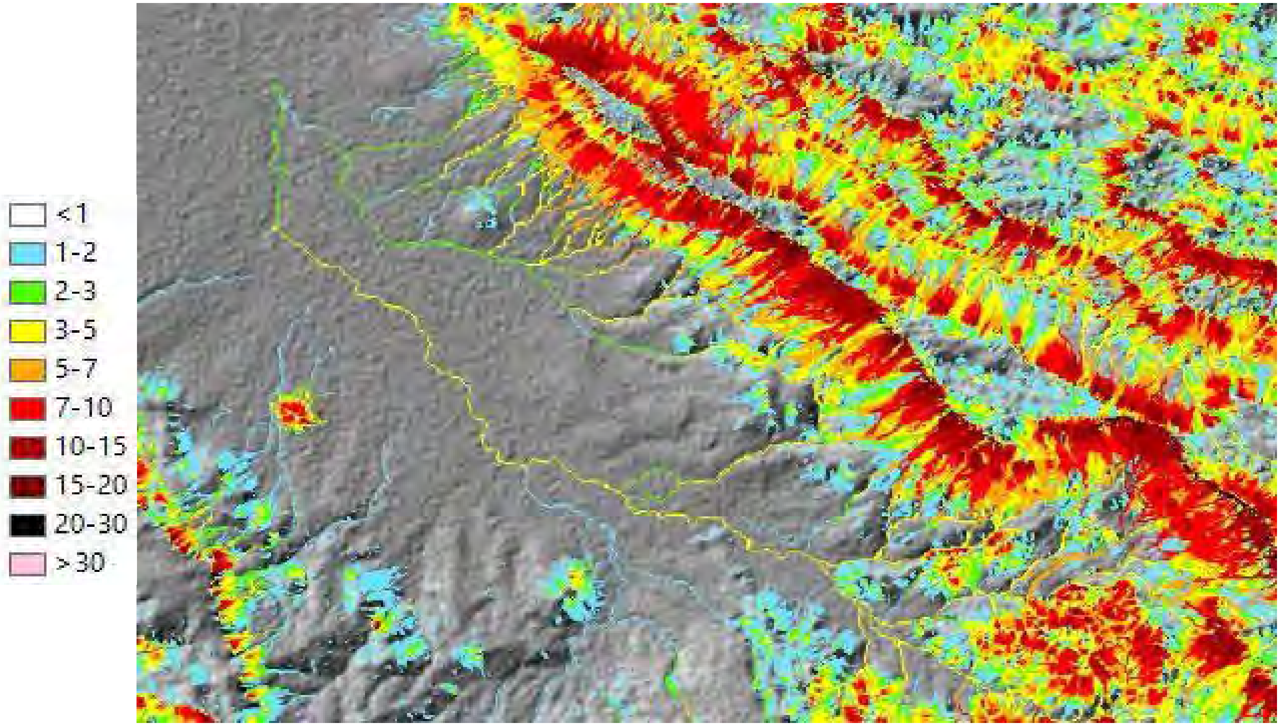
  - Slope
  - Average upstream slope





Calculate for each cell draining into a given cell

Average Upstream Angle Example – Mt Elgon, Kenya



Section 1: Landslide Susceptibility

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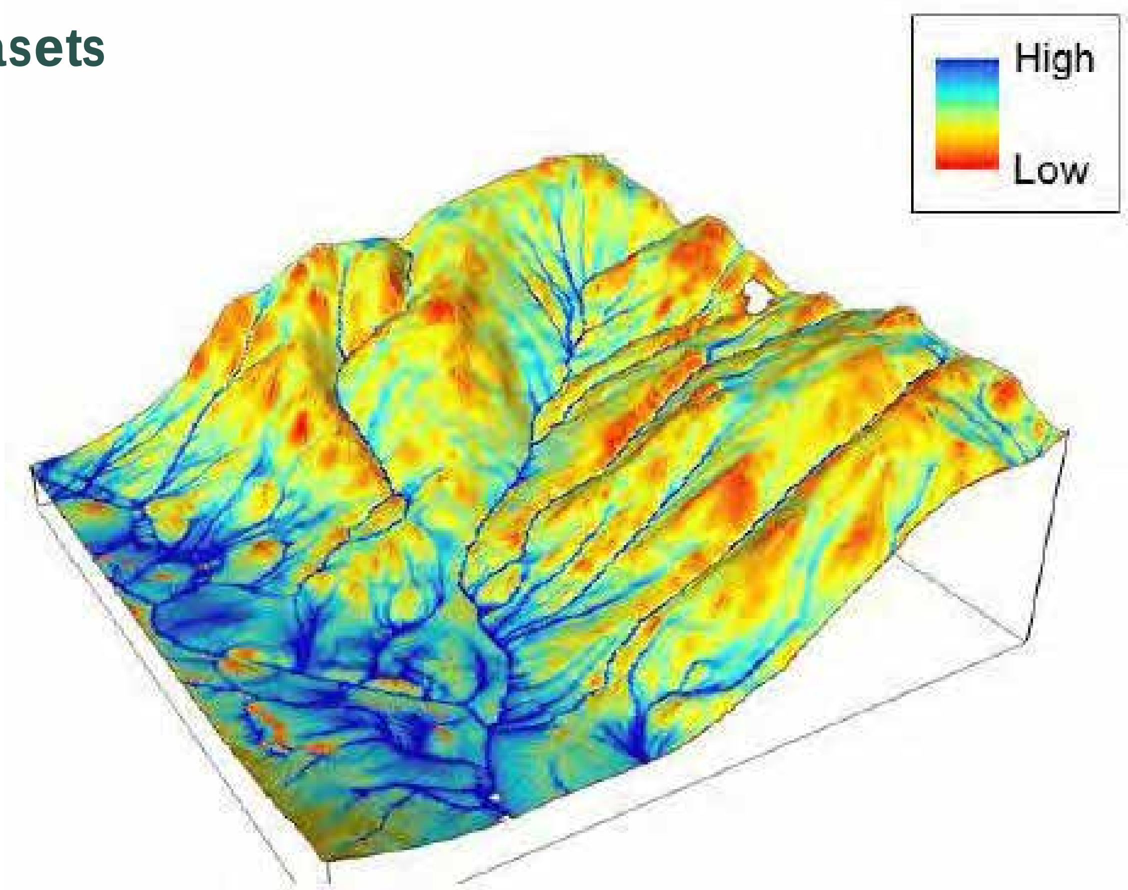
  - Compound Topographic Index / Wetness Index



CTI = ln(a/tan b)

a: flow accumulation; b: local slope in radians

Section 1: Landslide Susceptibility

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  - Compound Topographic Index / Wetness Index
  - Topographic Roughness / Ruggedness

Credit: Robert Emberson

TRI = root mean squared difference in elevation between a central pixel and each of its eight neighboring pixels.

Section 1: Landslide Susceptibility

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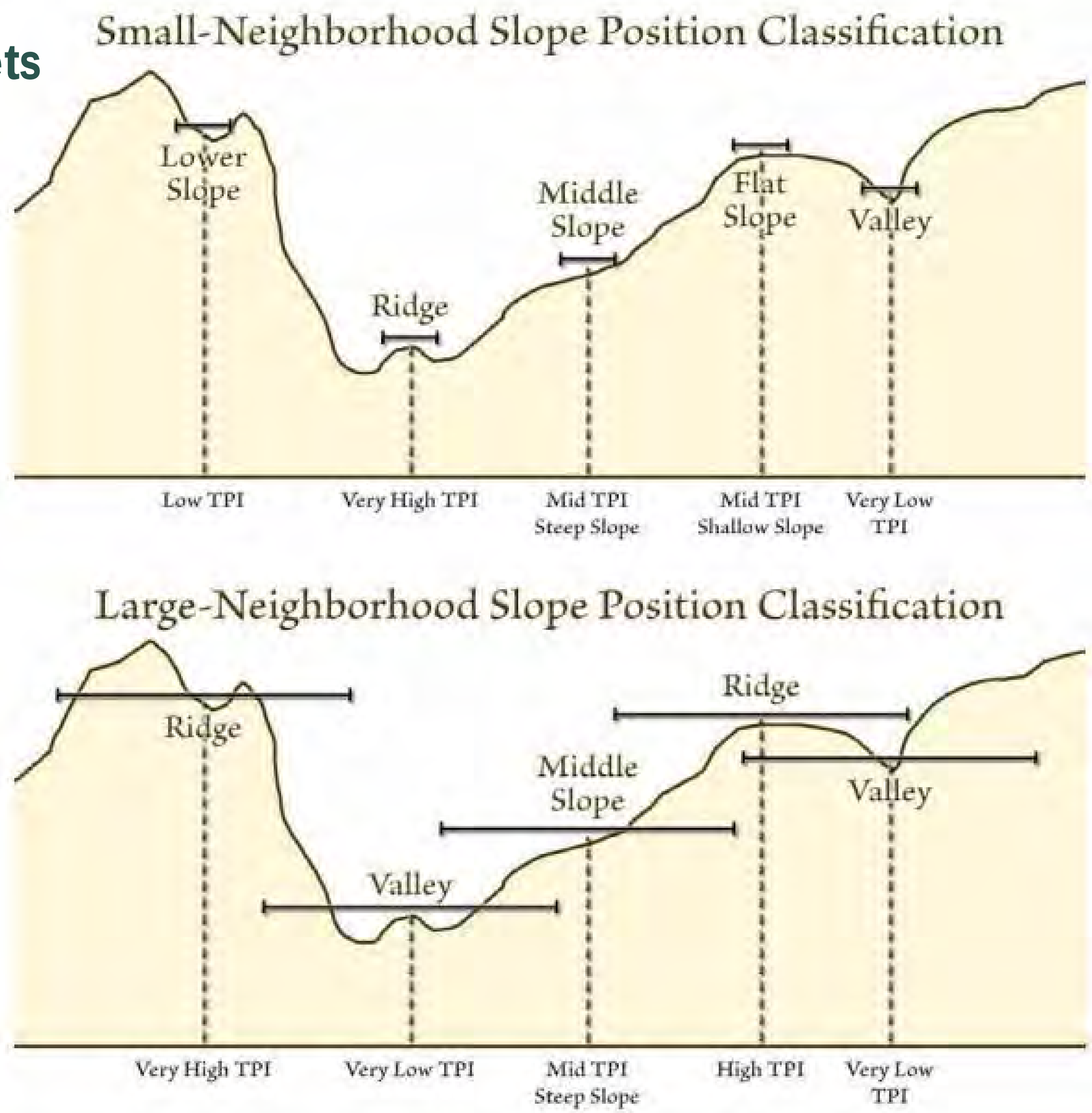
  - Topographic Position



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  - Topographic Position
  - Others (curvature, aspect)

Section 1: Landslide Susceptibility

Relevant Factors and Associated Satellite Datasets

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- Relevant factors inc
  - Slope
  - Average upstre
  - Compound Top Wetness Index
  - Topographic Ro Ruggedness
  - Topographic Po
  - Others (curvatu

NASA DEM data highly relevant; available via Land Processes DAAC.

Other DEM data could include high-resolution datasets.

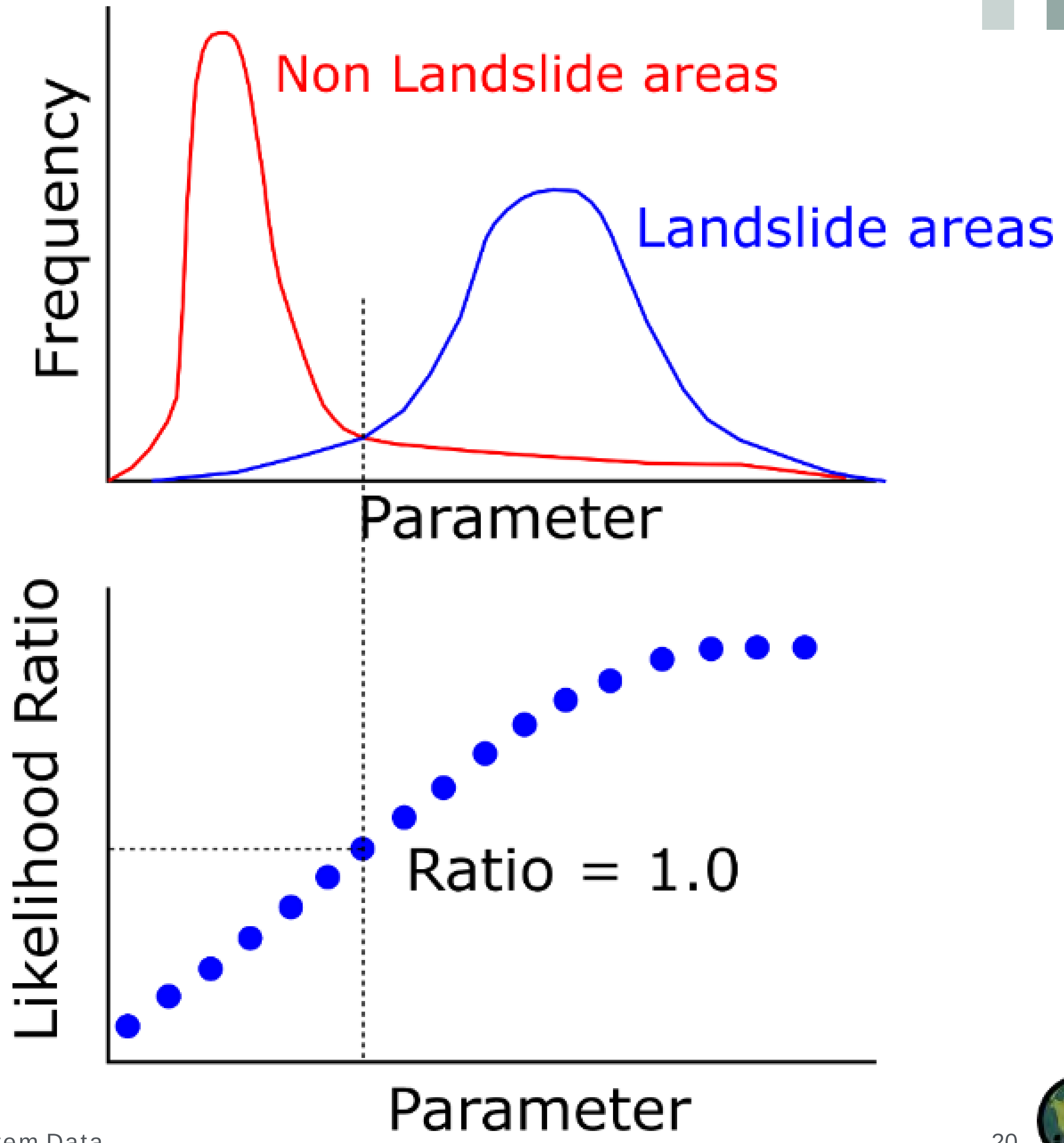
OpenTopography is an excellent resource.

Section 1: Landslide Susceptibility

Analyzing Landslide Locations in DEM Data

The pixels associated with landslides can be compared with non-landslide pixels in a study area to show relative frequency of landsliding.

Often distinct source and runout area relationships.



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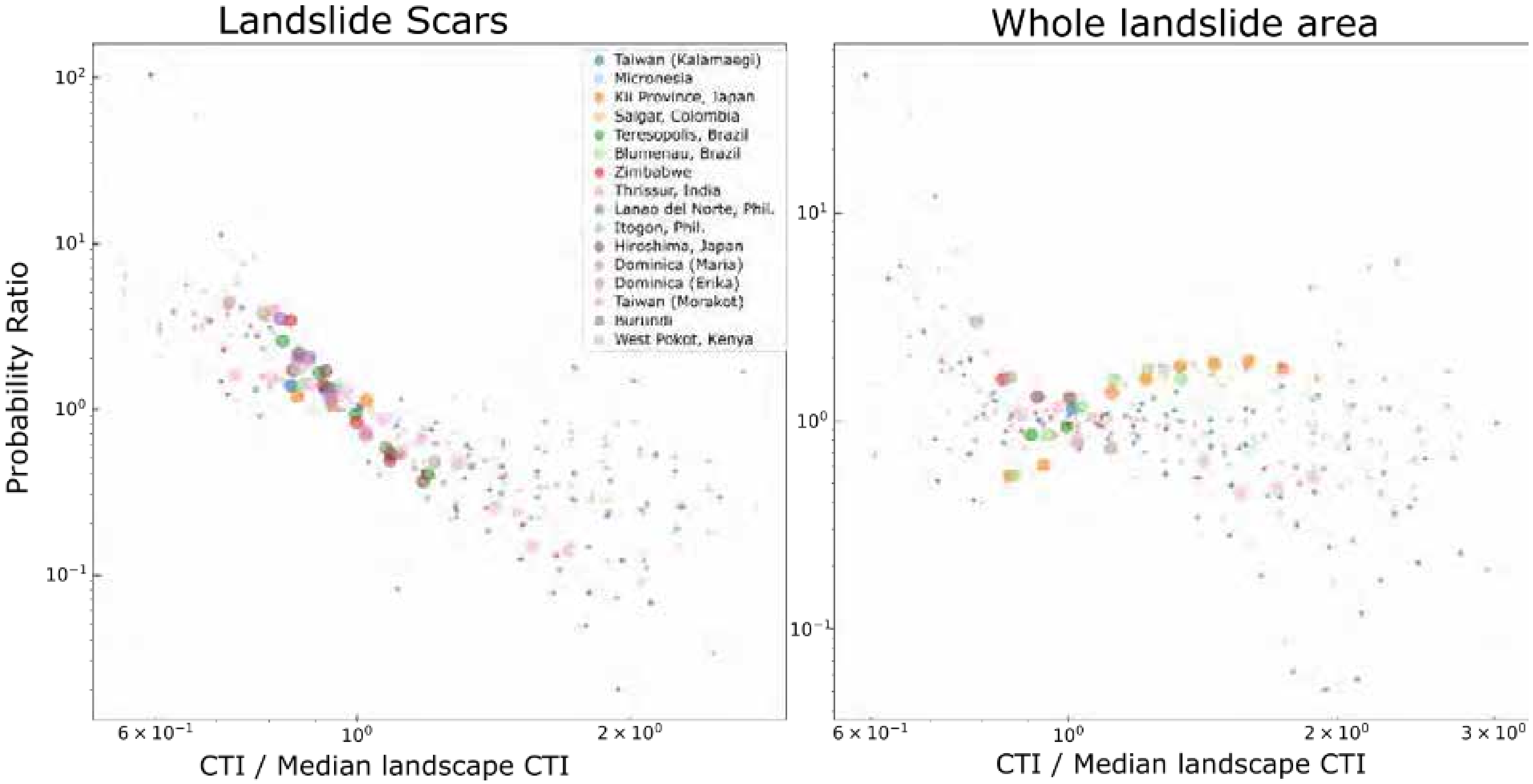

Section 1: Landslide Susceptibility

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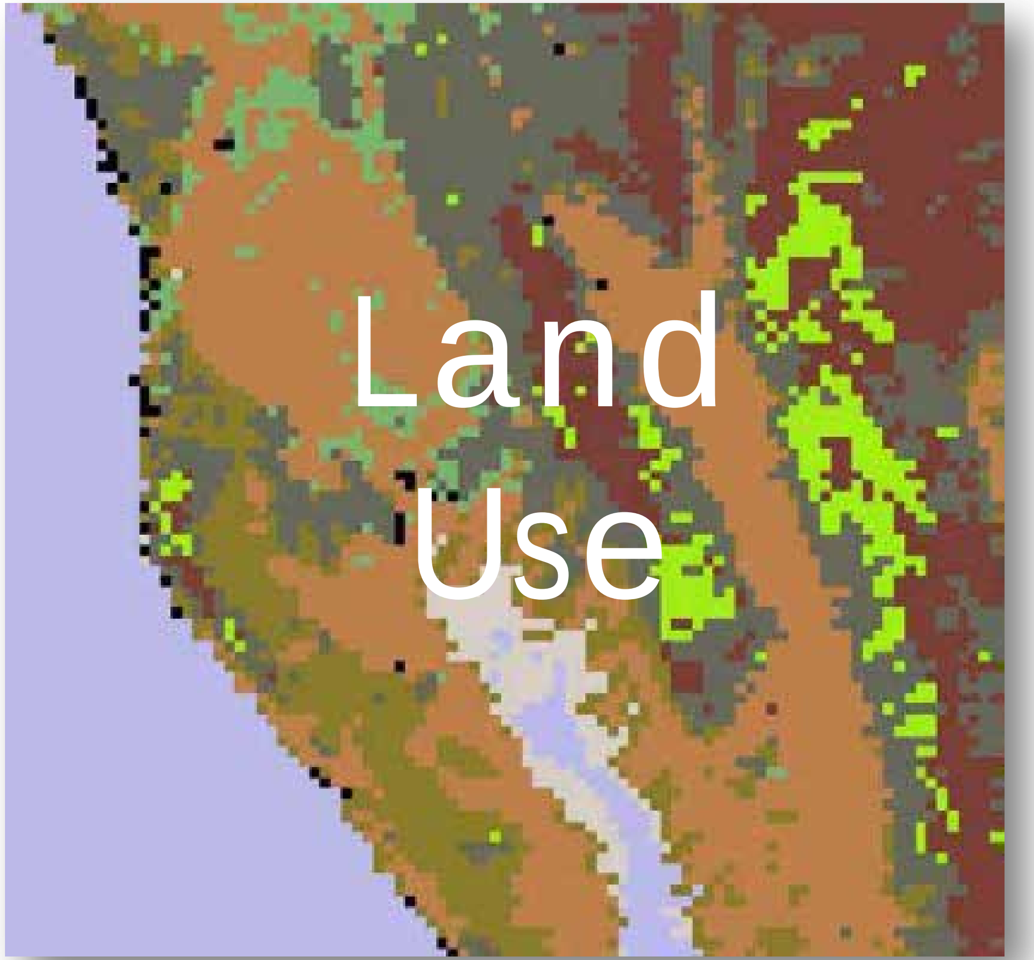


Typical datasets include MODIS, Landsat, Sentinel data.

Long-term analysis and change detection are relevant considerations.

Section 1: Landslide Susceptibility

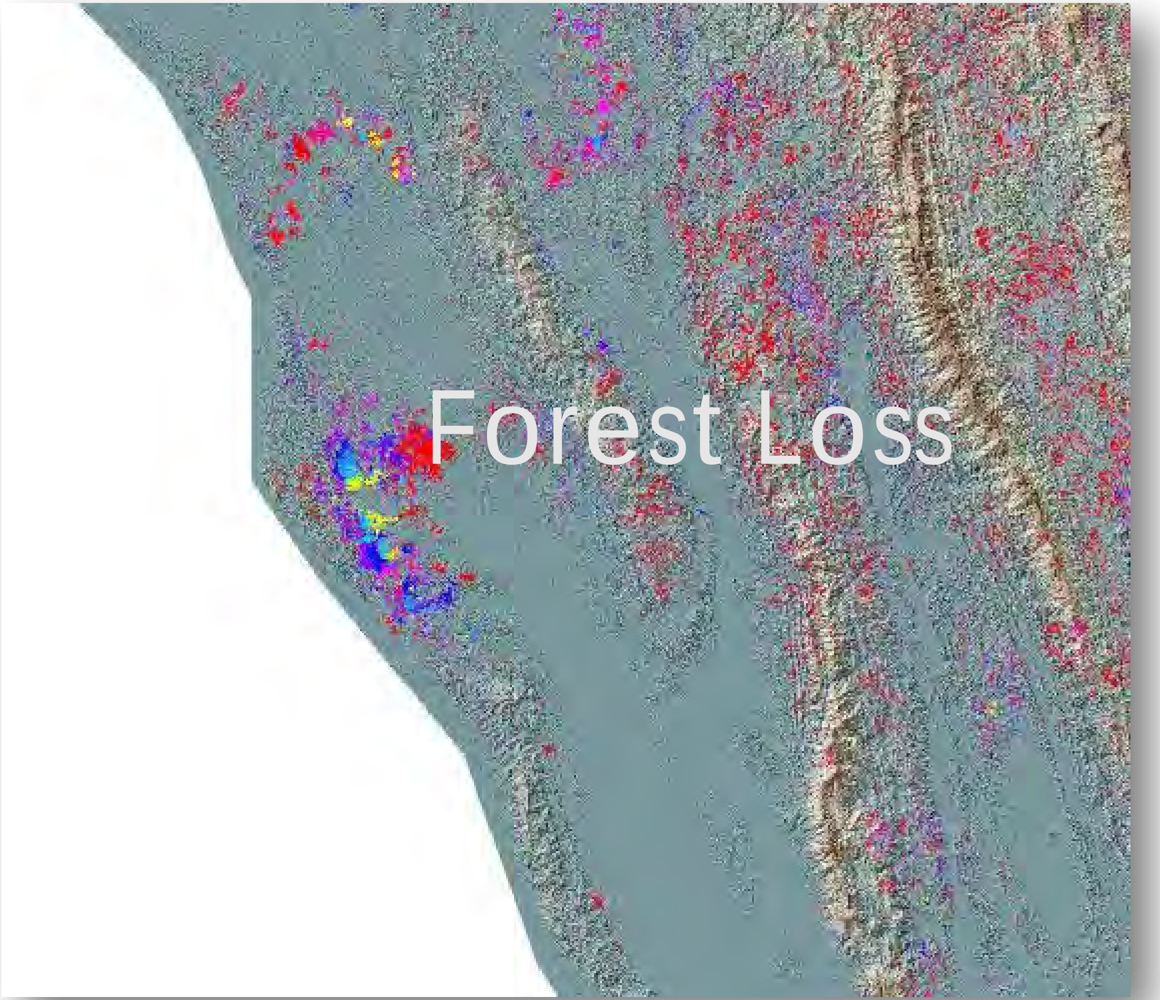
Relevant Factors and Associated Satellite Datasets

ORNL DAAC contains global data for soil thickness and regolith.

Soil type may be an additional consideration.

Section 1: Landslide Susceptibility

Relevant Factors and Associated Satellite Datasets



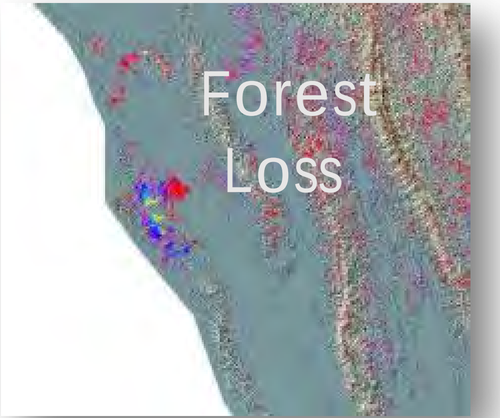
Landsat-derived annual forest loss is a robust analytical tool.

Section 1: Landslide Susceptibility

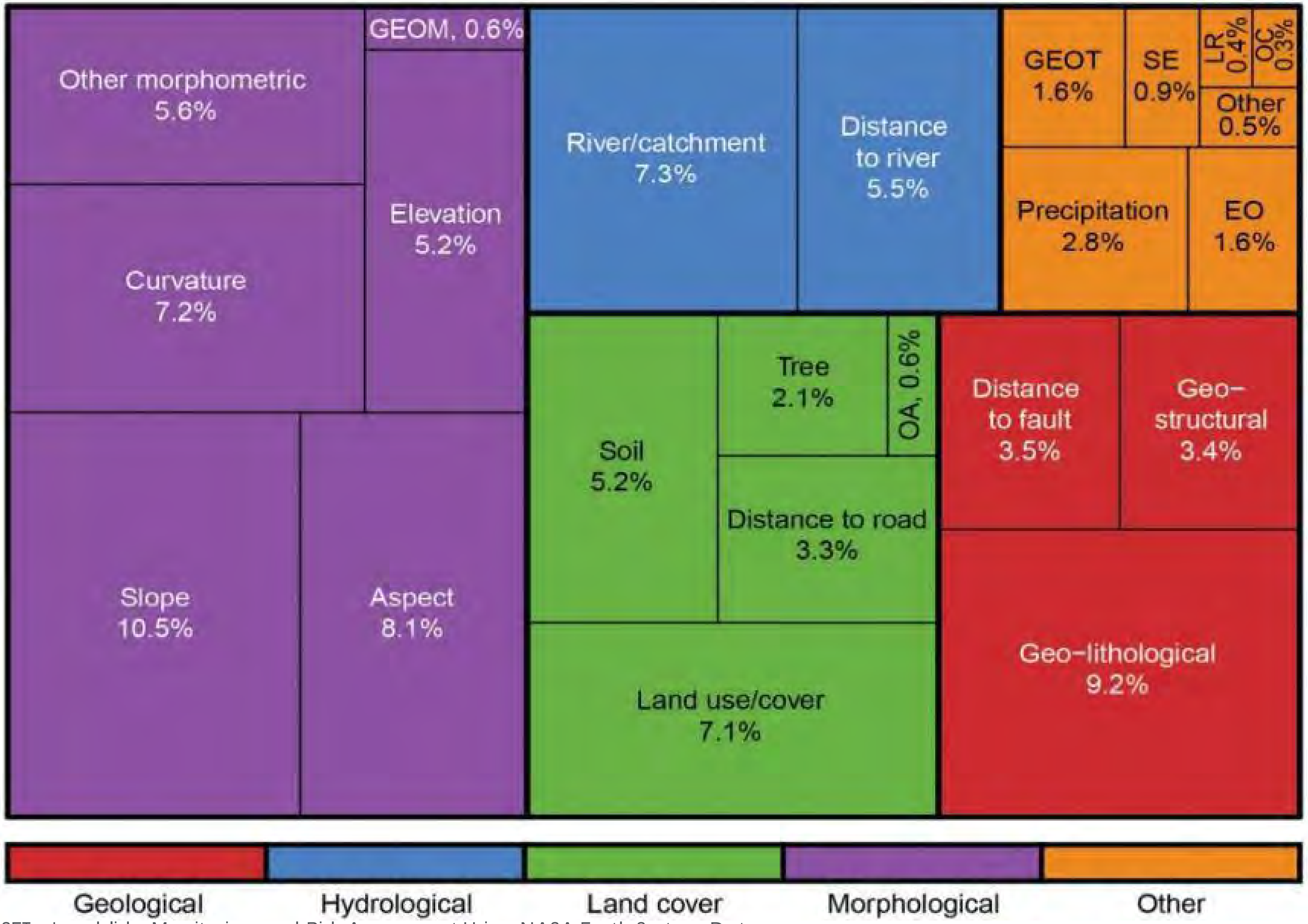
Relevant Factors and Associated Satellite Datasets

Lithology (global model or local)

Faults, geo-structural info also relevant



Section 1: Landslide Susceptibility



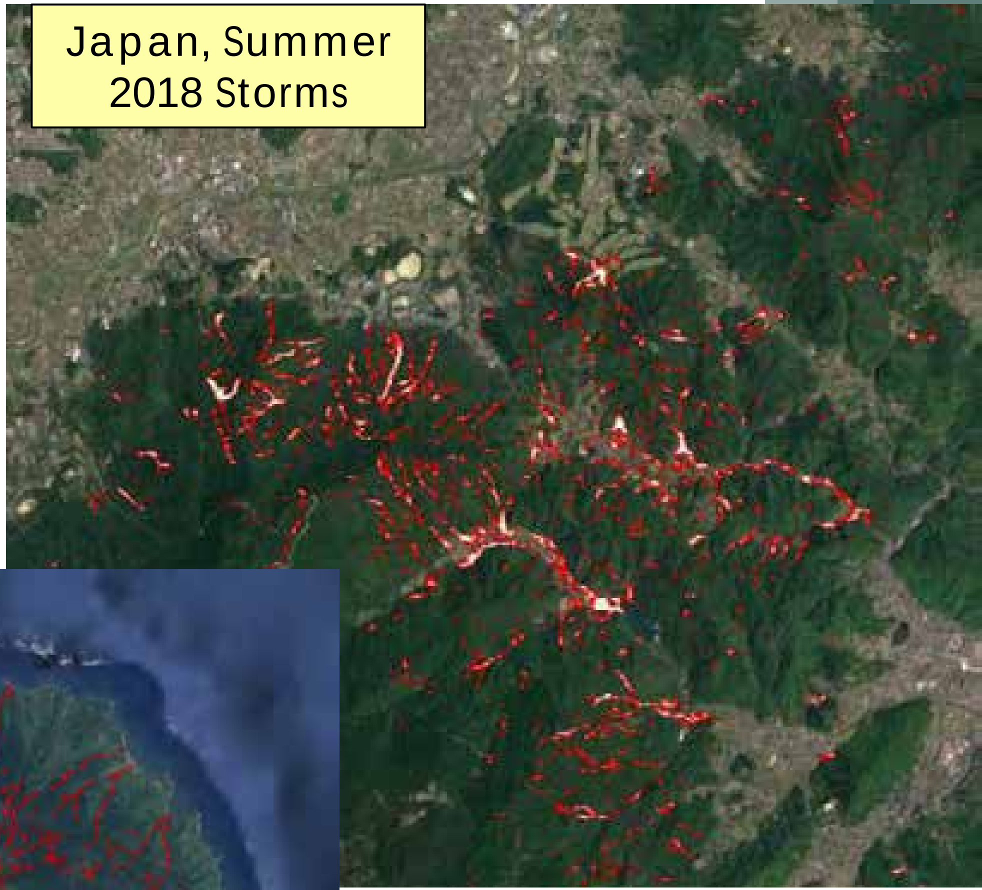
Factors included in landslide susceptibility models.

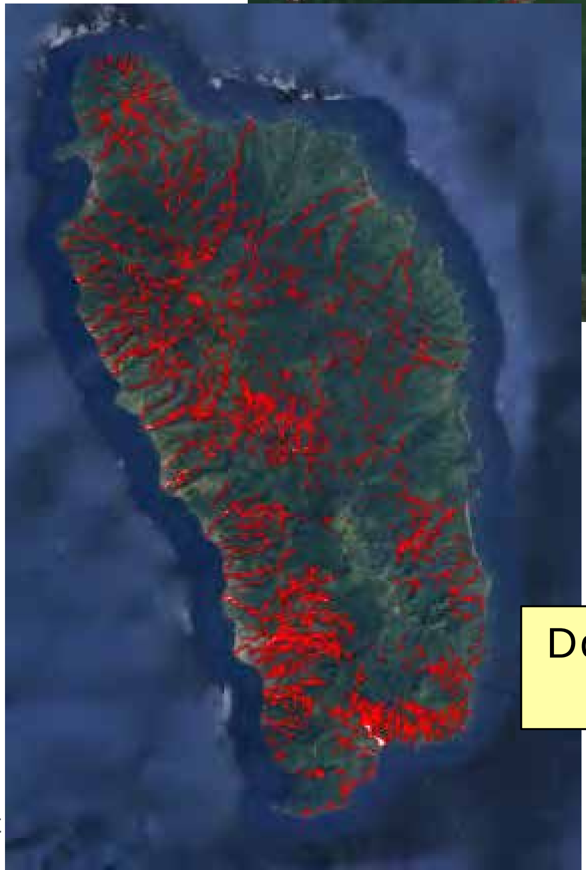
Reichenbach et al. 2018

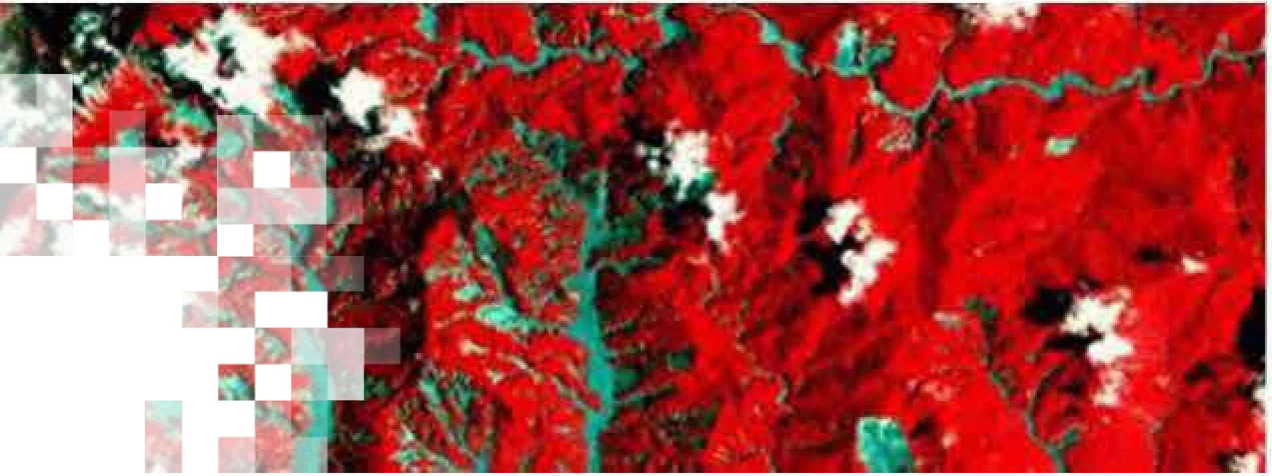
Section 1: Landslide Susceptibility

Statistical- vs Physically- Based Susceptibility Models

- Satellite data is very effective at local, regional and even global scale.
- Analysis of surface data using large landslide inventories permits effective statistical analysis of landslide areas.
- However, most EO data serves only as a proxy for physical reasons why landslides occur; subsurface friction and relevant gravitational forces not typically characterized.
- EO-based models are typically statistical; some localized models using geo-engineering methods may permit physics-based modelling.






Section 2: Constructing Susceptibility Models

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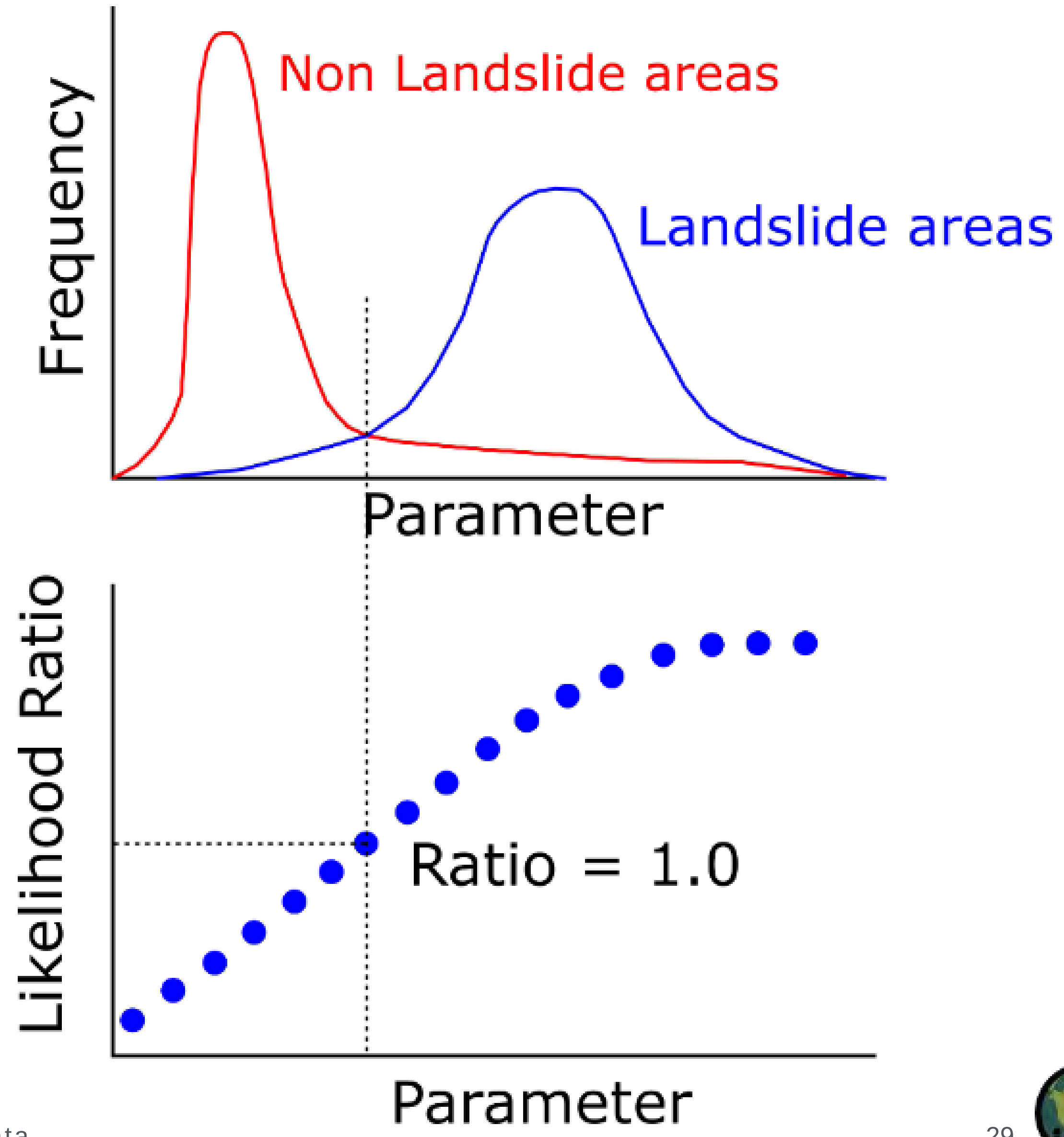
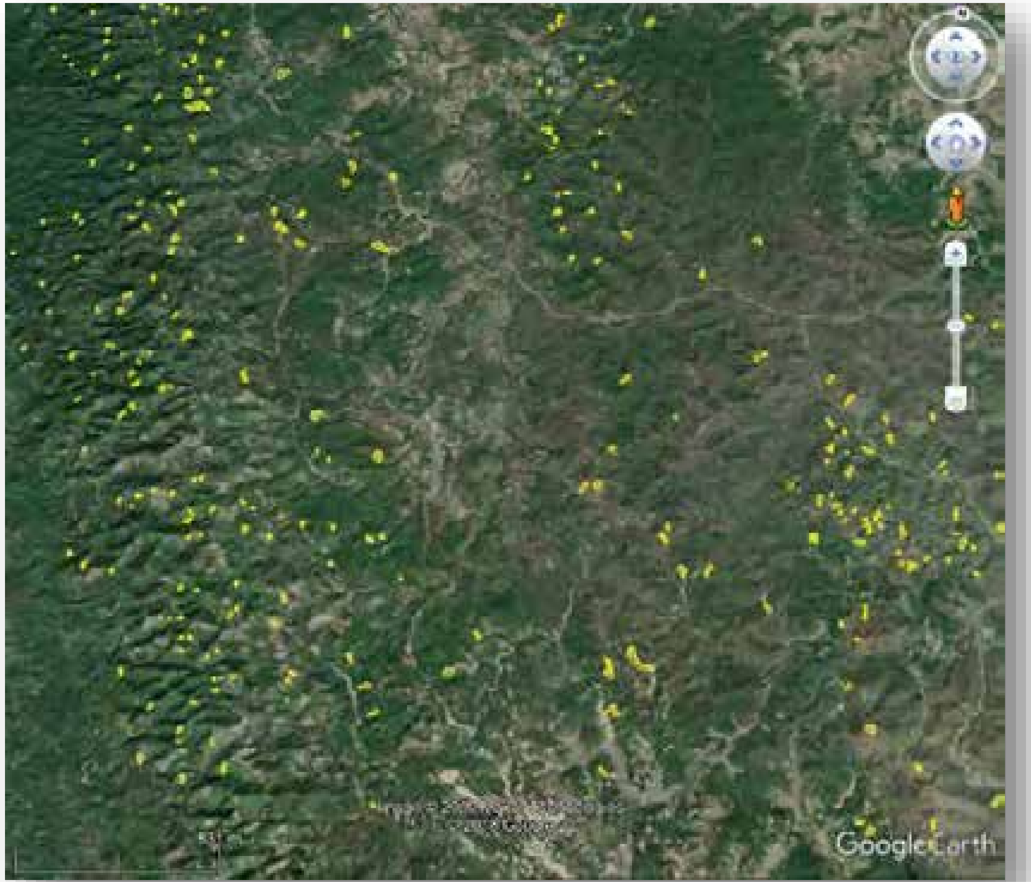
Statistical Inputs and Outputs

- Statistical models use combinations of data associated with susceptibility in combination with training data – typically locations of landslides.
- Relationships are determined between the location of landslides and the input factors.
- These relationships are then generalized and applied to input data, to create an output susceptibility map – a prediction of other locations where landslides are likely to occur.
- Single parameter models are conceptually simple but introducing further parameters can create additional considerations.

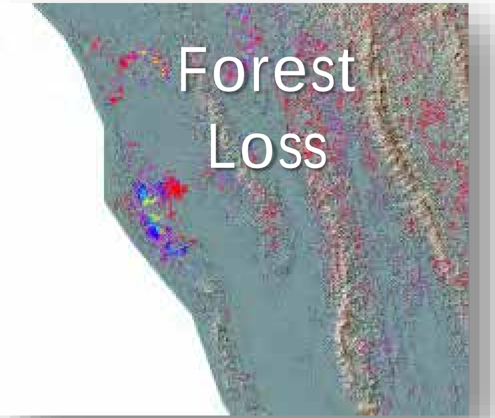


Section 2: Constructing Susceptibility Models

Statistical Inputs and Outputs



Landslide inventory
necessary to calibrate



Section 2: Constructing Susceptibility Models

Landslide Inventory Considerations

- Landslide inventories vary widely.
- Global Landslide Catalog not a 'complete' dataset.
- More local data may be complete.

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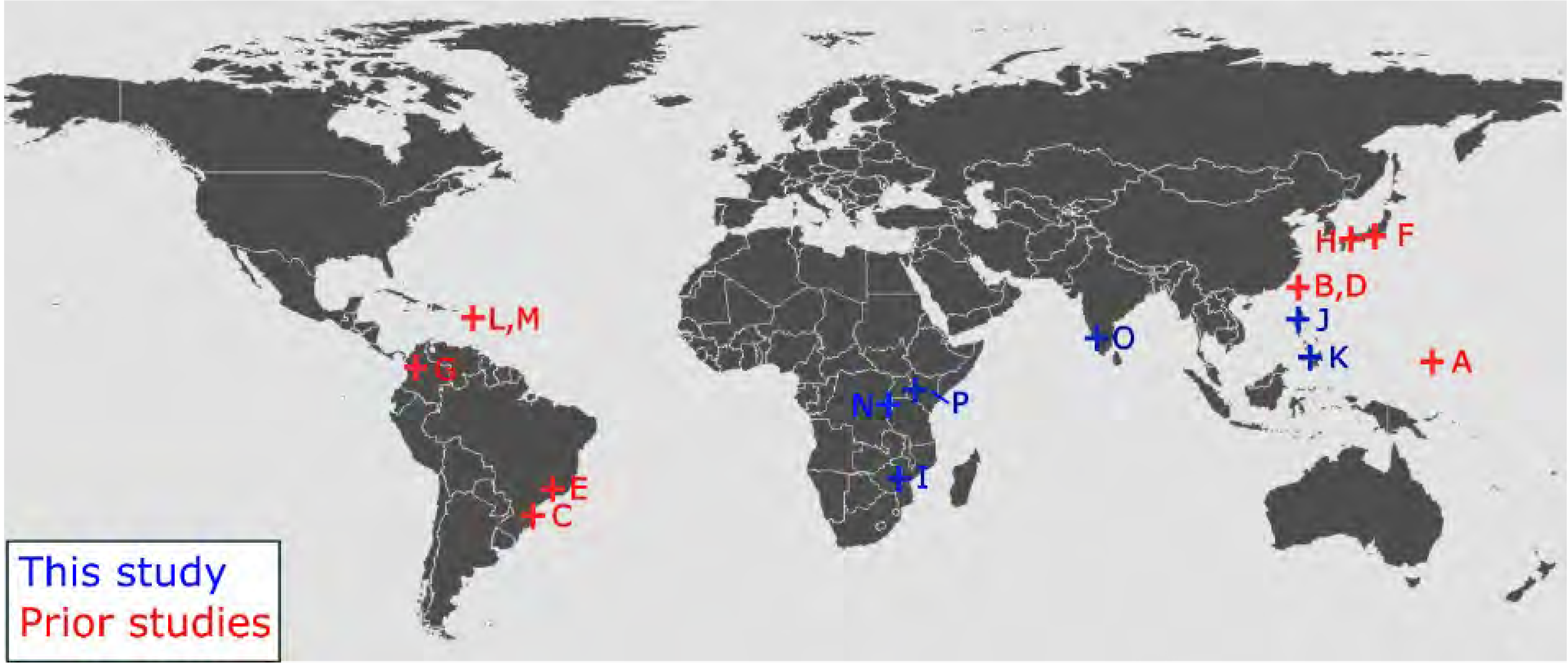

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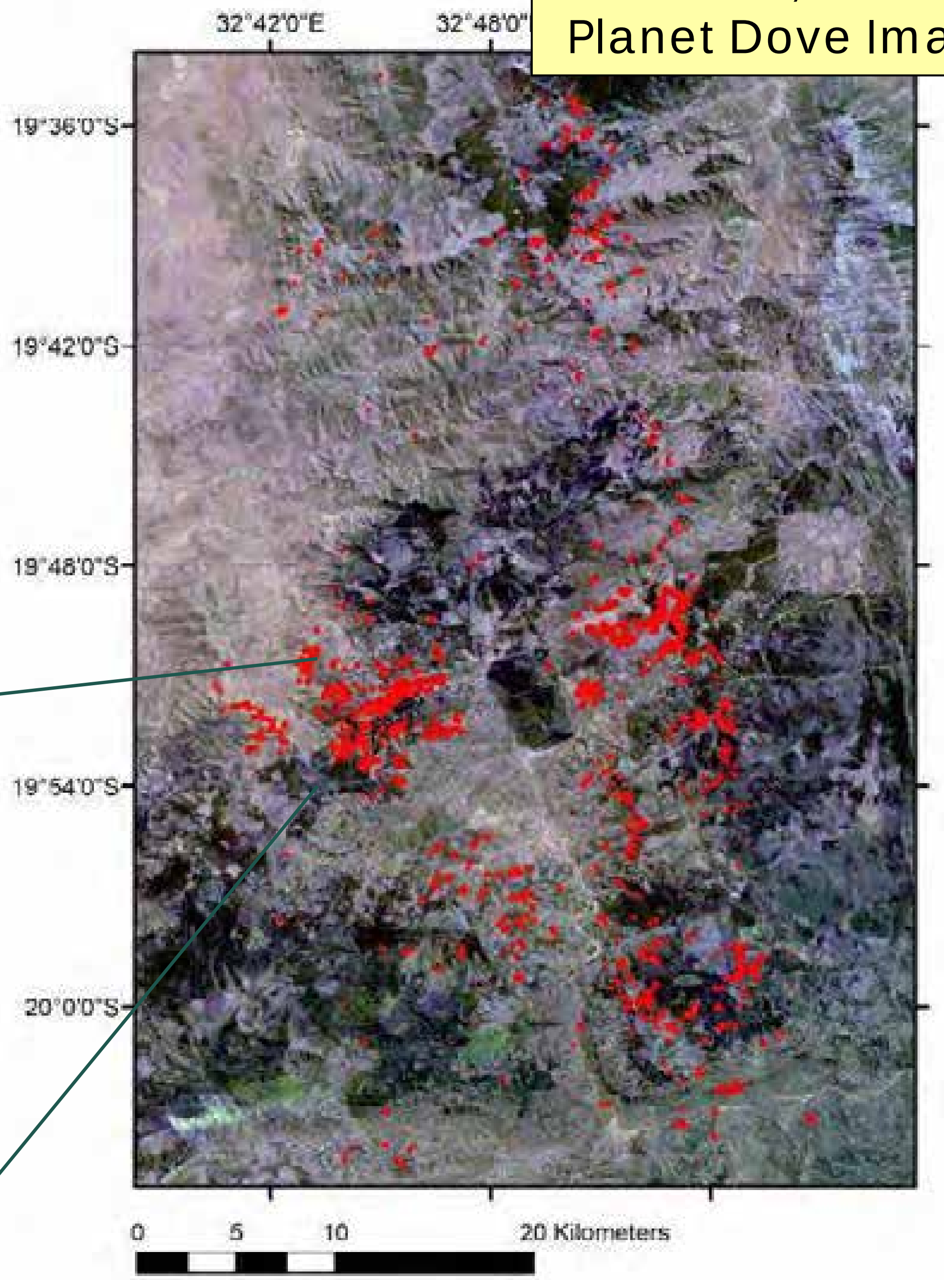
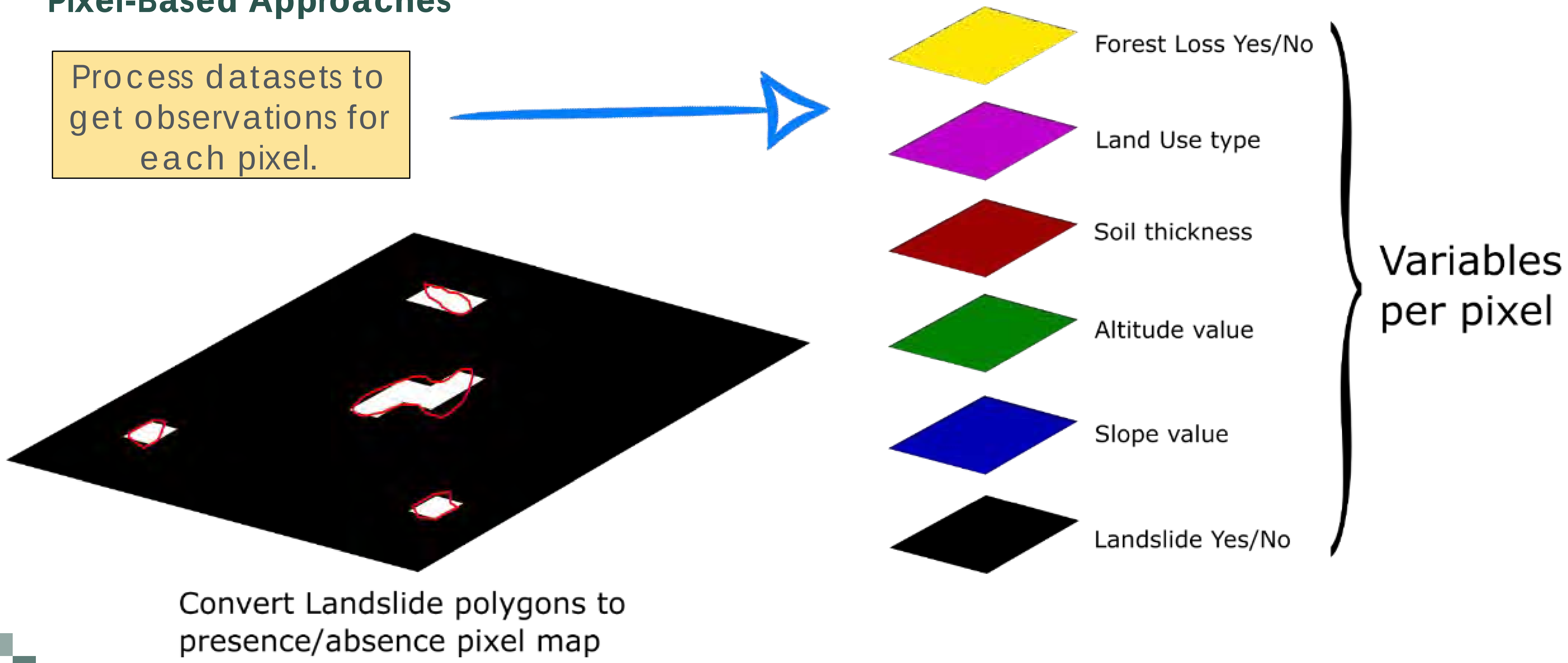


Zimbabwe; Cyclone Idai, 2019
Planet Dove Imagery

Section 2: Constructing Susceptibility Models

Pixel-Based Approaches

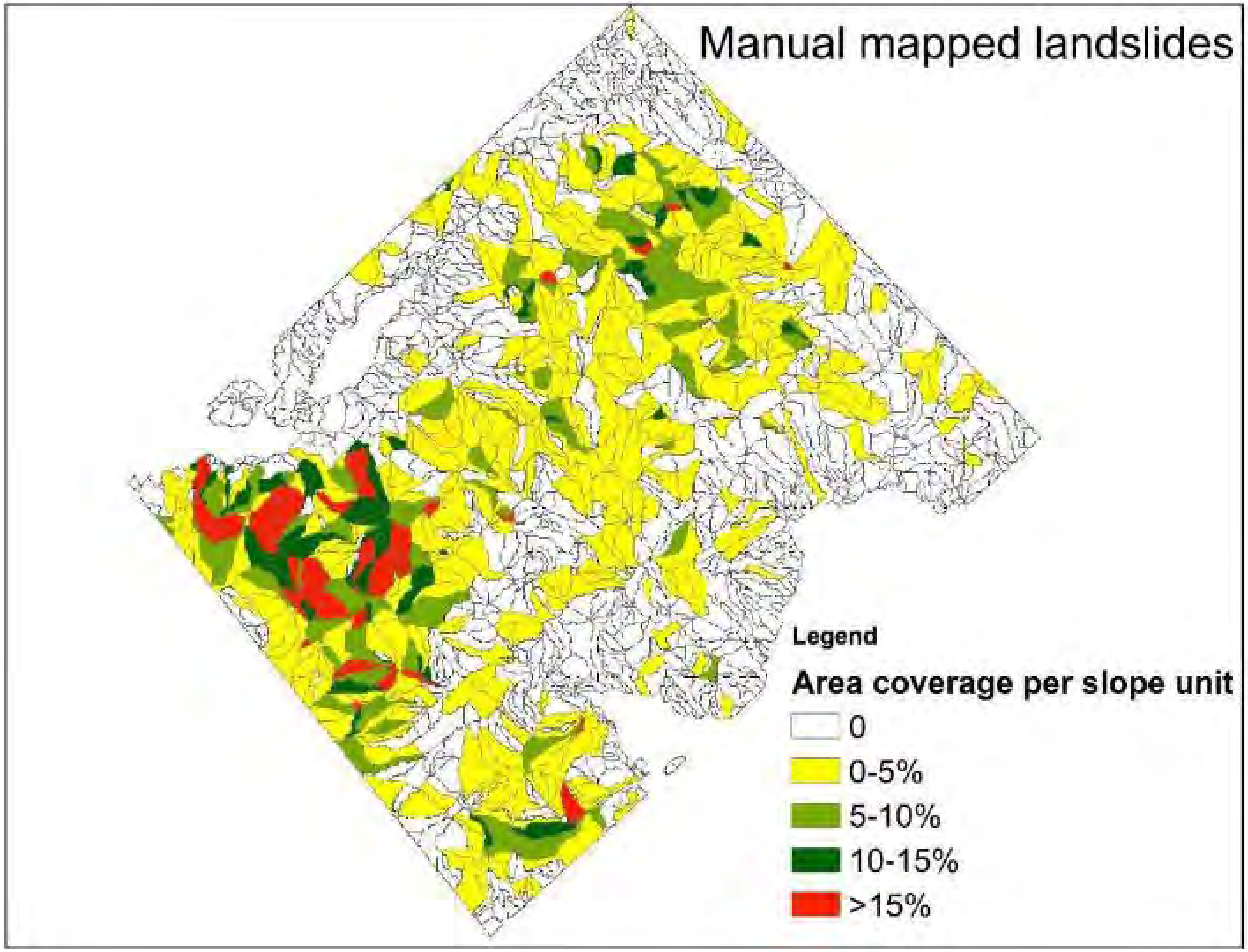
Process datasets to get observations for each pixel.



Section 2: Constructing Susceptibility Models

Slope Unit-Based Approaches

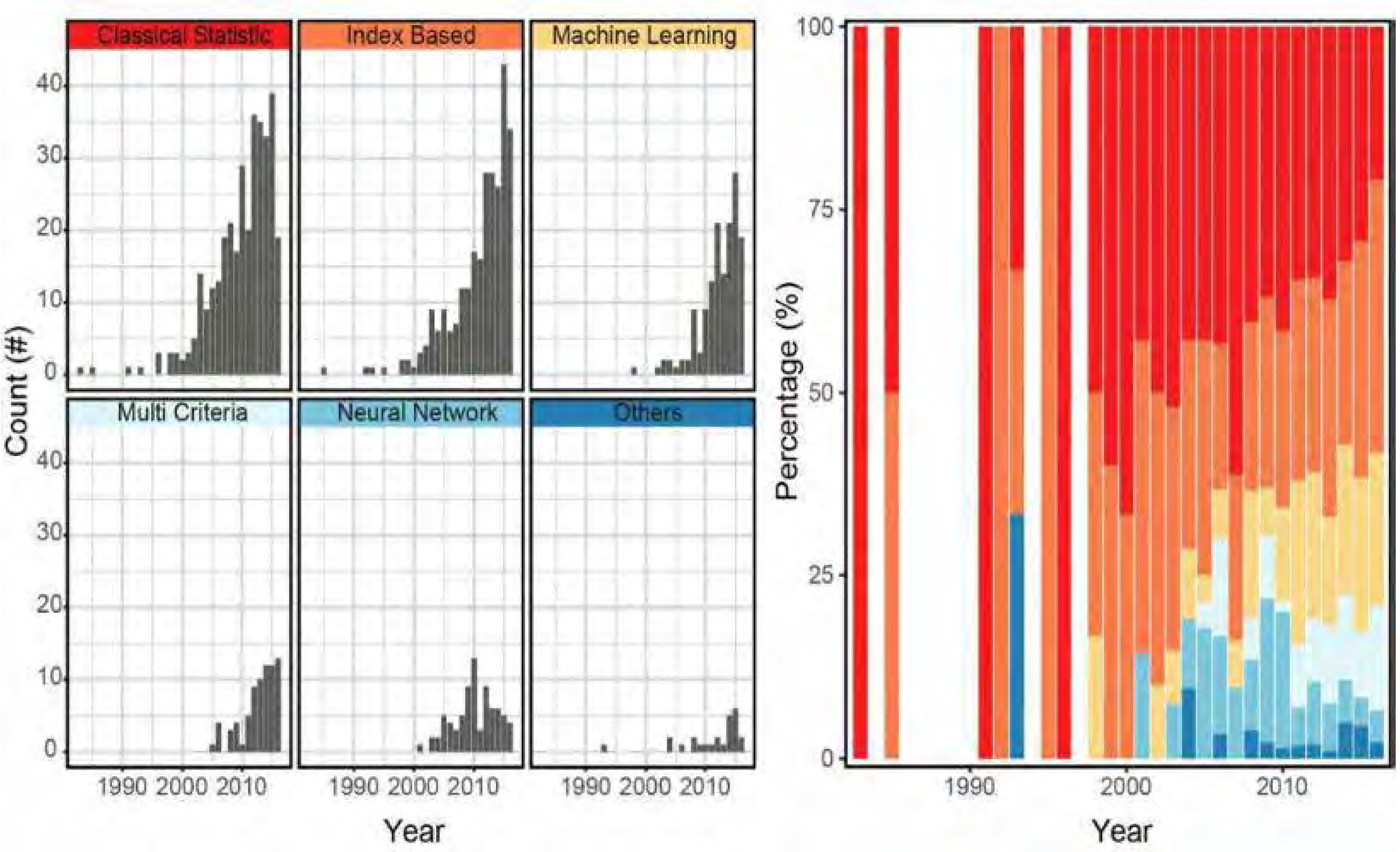
- Collect landslide data and parameter data for hillslope sections
- Can be more accurate and avoids pixels cutting across two valleys
- Found in newer research



Section 2: Constructing Susceptibility Models

Statistical Methods

- Enormous variety of statistical methods employed for susceptibility analysis.
- NASA teams have used classical statistical, machine learning, and neural network approaches to generate susceptibility estimates.
- Each approach has caveats in terms of data.
- Critical rule of thumb: outputs are only as good as inputs.



Reichenbach et al. 2018

Section 2: Constructing Susceptibility Models

Continuous vs Categorical Data

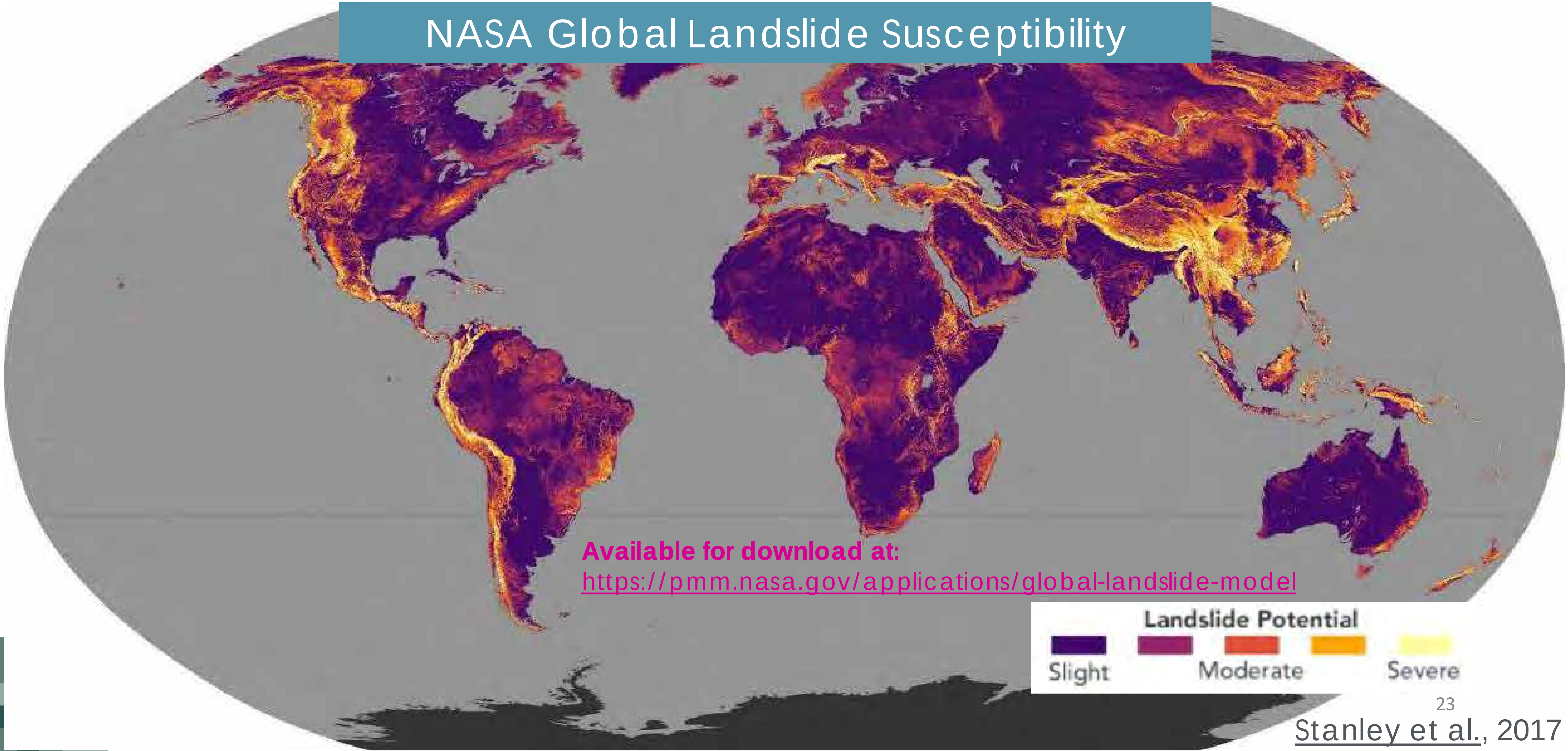
- Statistical Models can incorporate both categorical and continuous data.
- Weighing importance of continuous data is somewhat easier to conceptualize.
- In some statistical models, converting categorical data into continuous data is required for accuracy.

Continuous
- Can take any value in range
- E.g., Slope, Soil Moisture, Rainfall Intensity

Categorical
- Values are classified
- E.g., Land use type, lithology

Section 2: Constructing Susceptibility Models

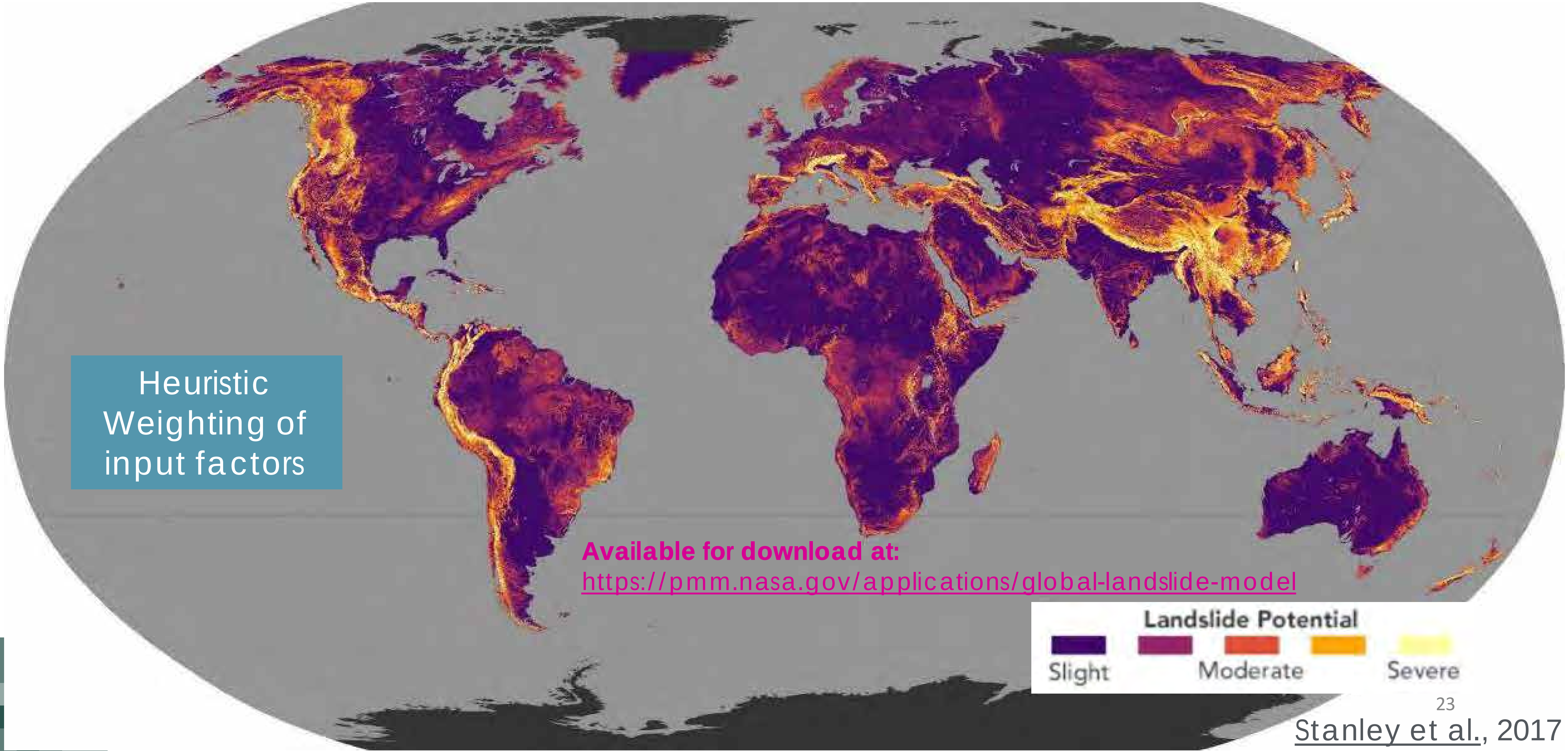
NASA Global Landslide Susceptibility



Available for download at:
https://pmm.nasa.gov/applications/global-landslide-model

Stanley et al., 2017

Section 2: Constructing Susceptibility Models



Heuristic Weighting of input factors

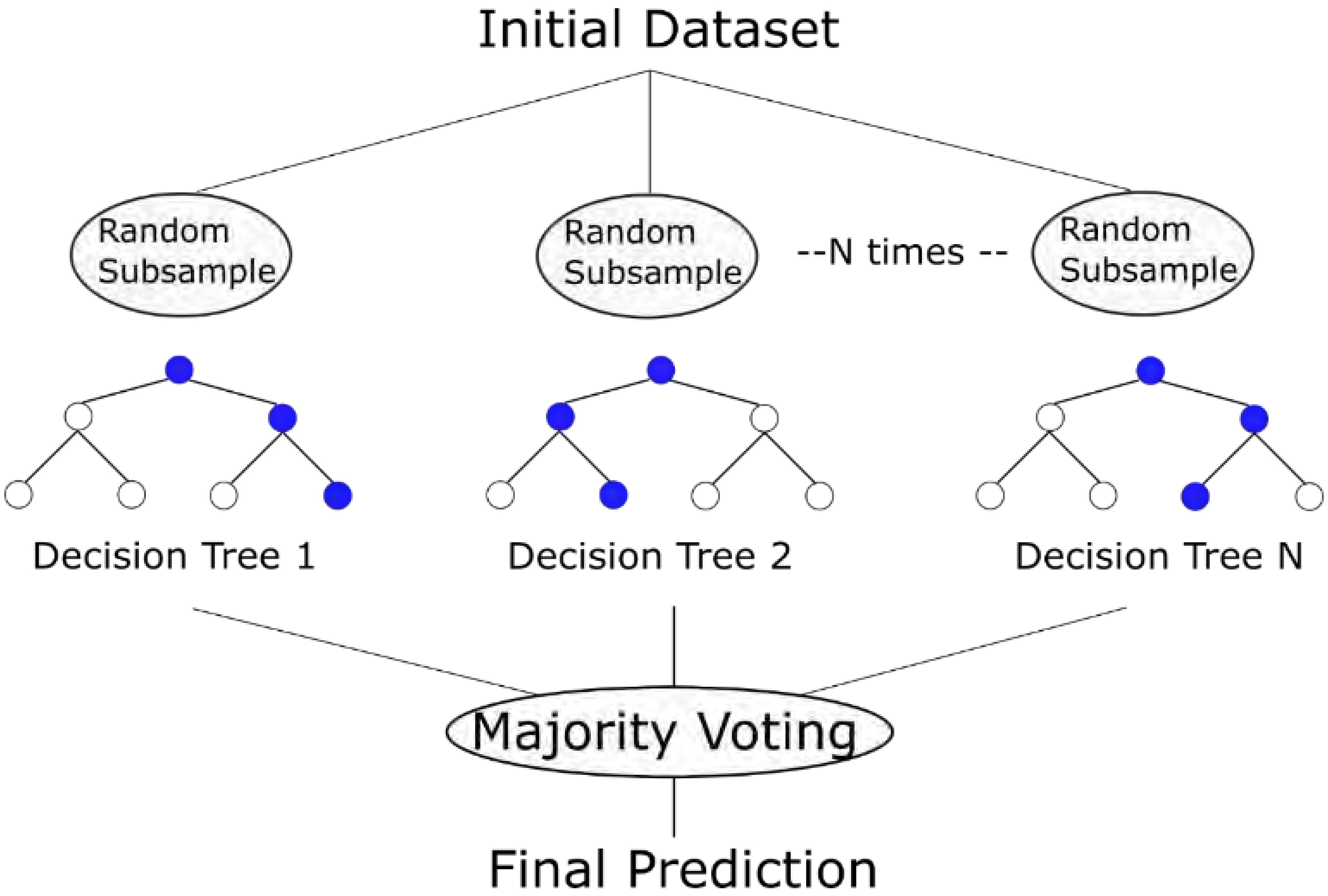
Available for download at:
https://pmm.nasa.gov/applications/global-landslide-model

Stanley et al., 2017

Section 2: Constructing Susceptibility Models

Local / Regional Example

- Open-source data model developed at NASA
- Susceptibility map created using **random forest model**
- Independent of data input & type
- Simplified data processing for diverse end users



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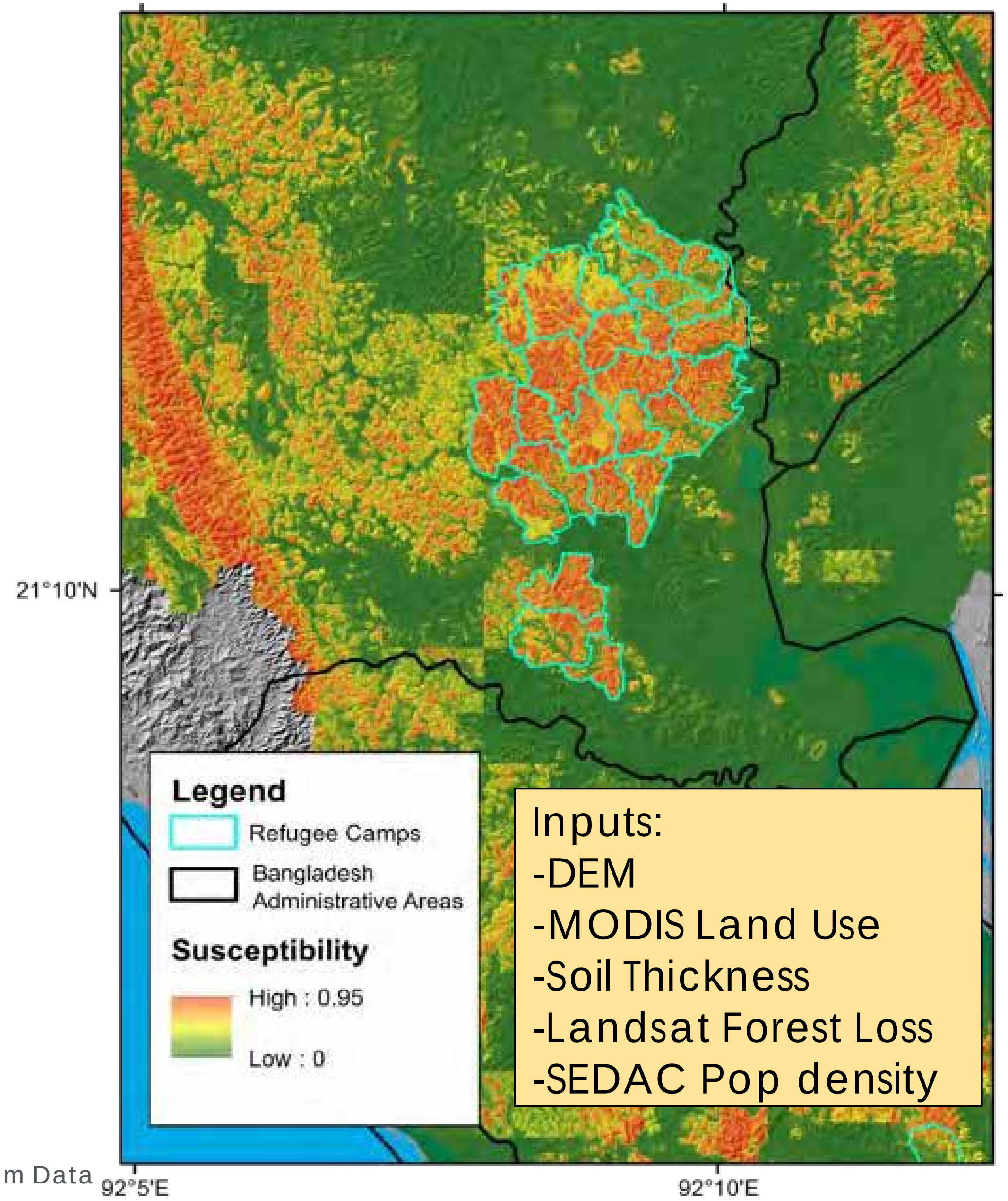

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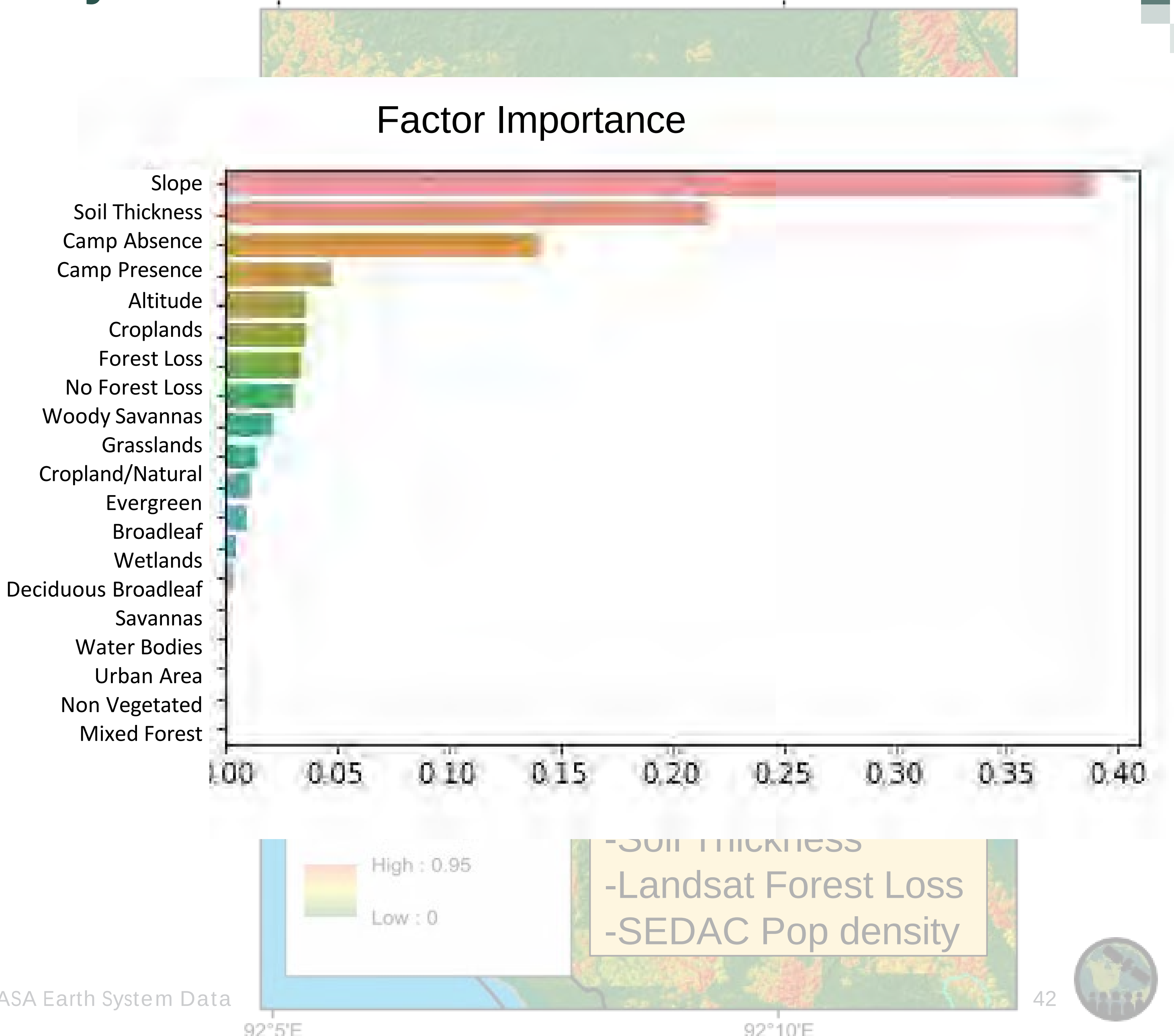
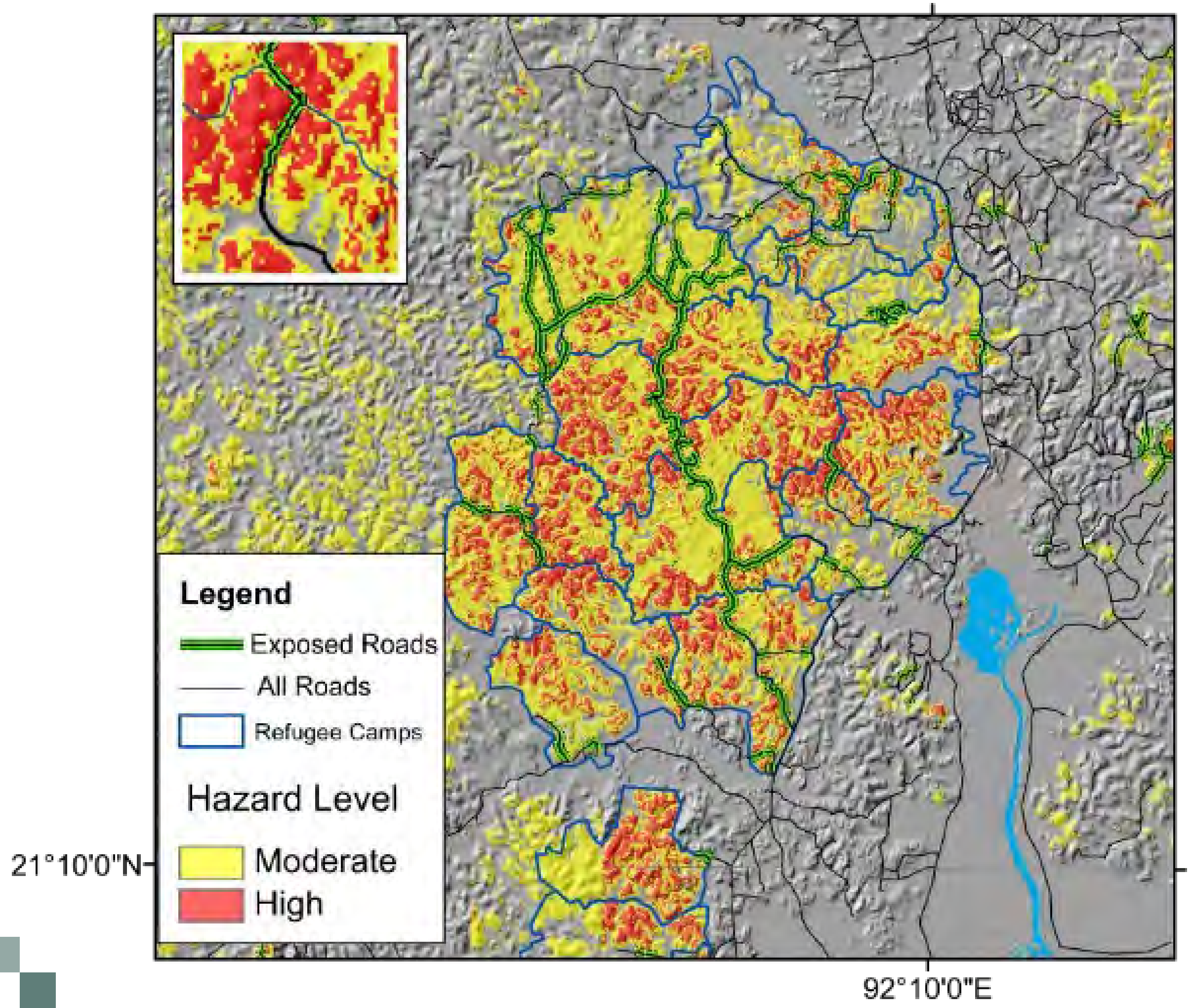


Section 2: Constructing Susceptibility Models

Local Susceptibility Analysis

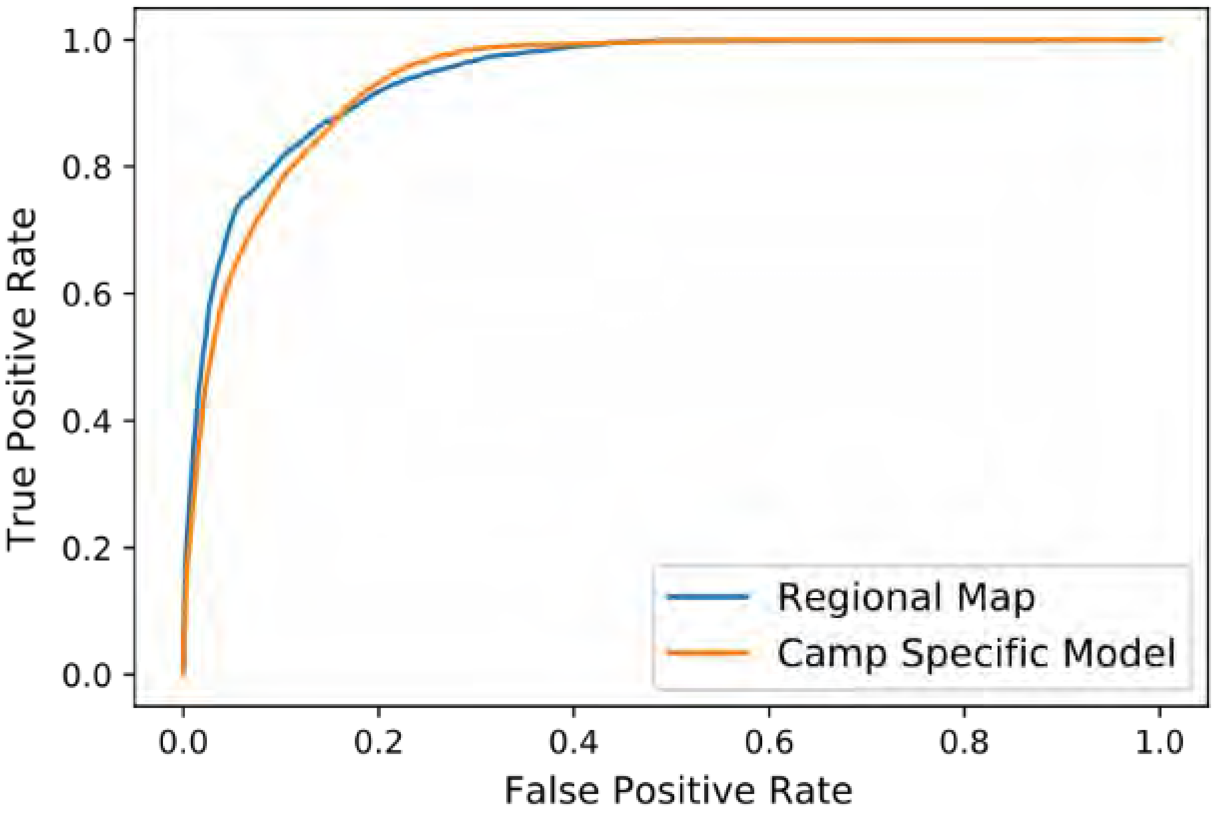


NASA data is used to model the exposure of vulnerable refugees to landslides in the Rohingya refugee camps.

Section 2: Constructing Susceptibility Models

Performance Evaluation

- Variety of methods used to determine accuracy of the model
- Input landslide training data a strong determinant
- **'Test' dataset** should ideally be independent
- Receiver-Operating-Characteristic (ROC) curves widely used
- ROC curves can also be used to build **thresholds**



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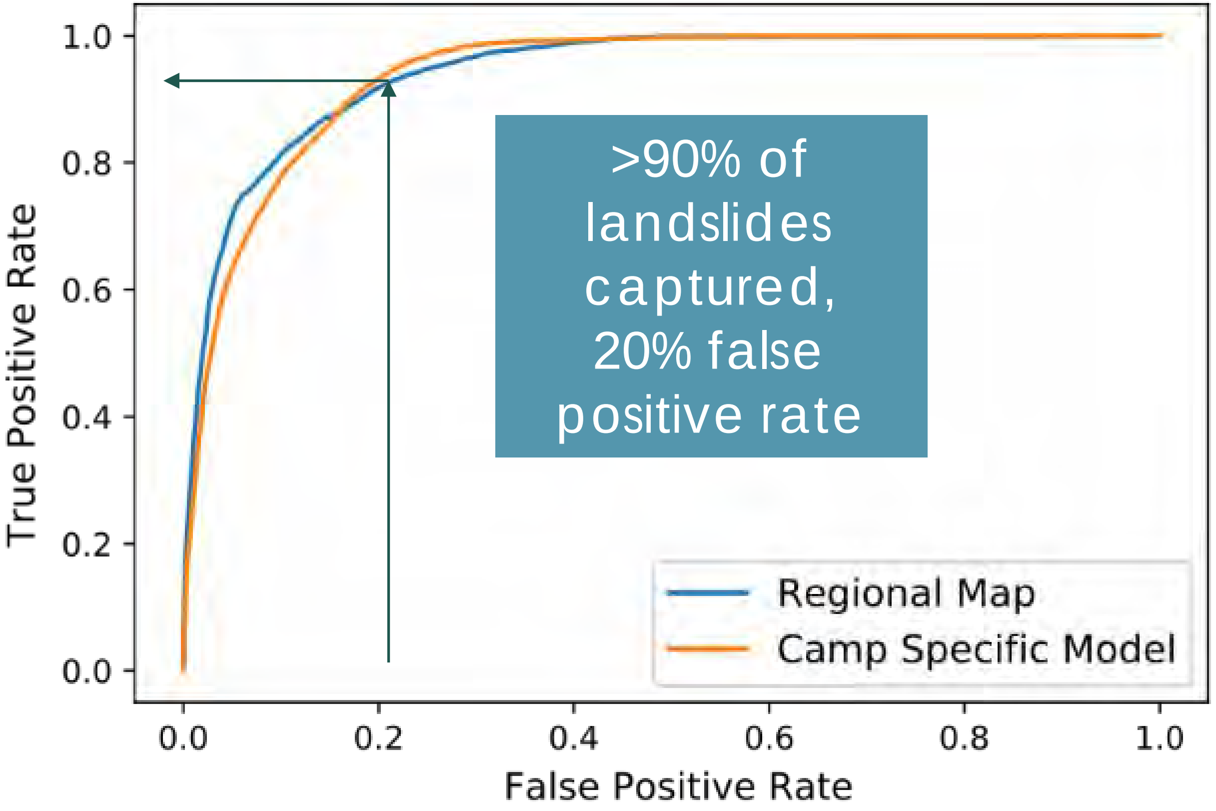
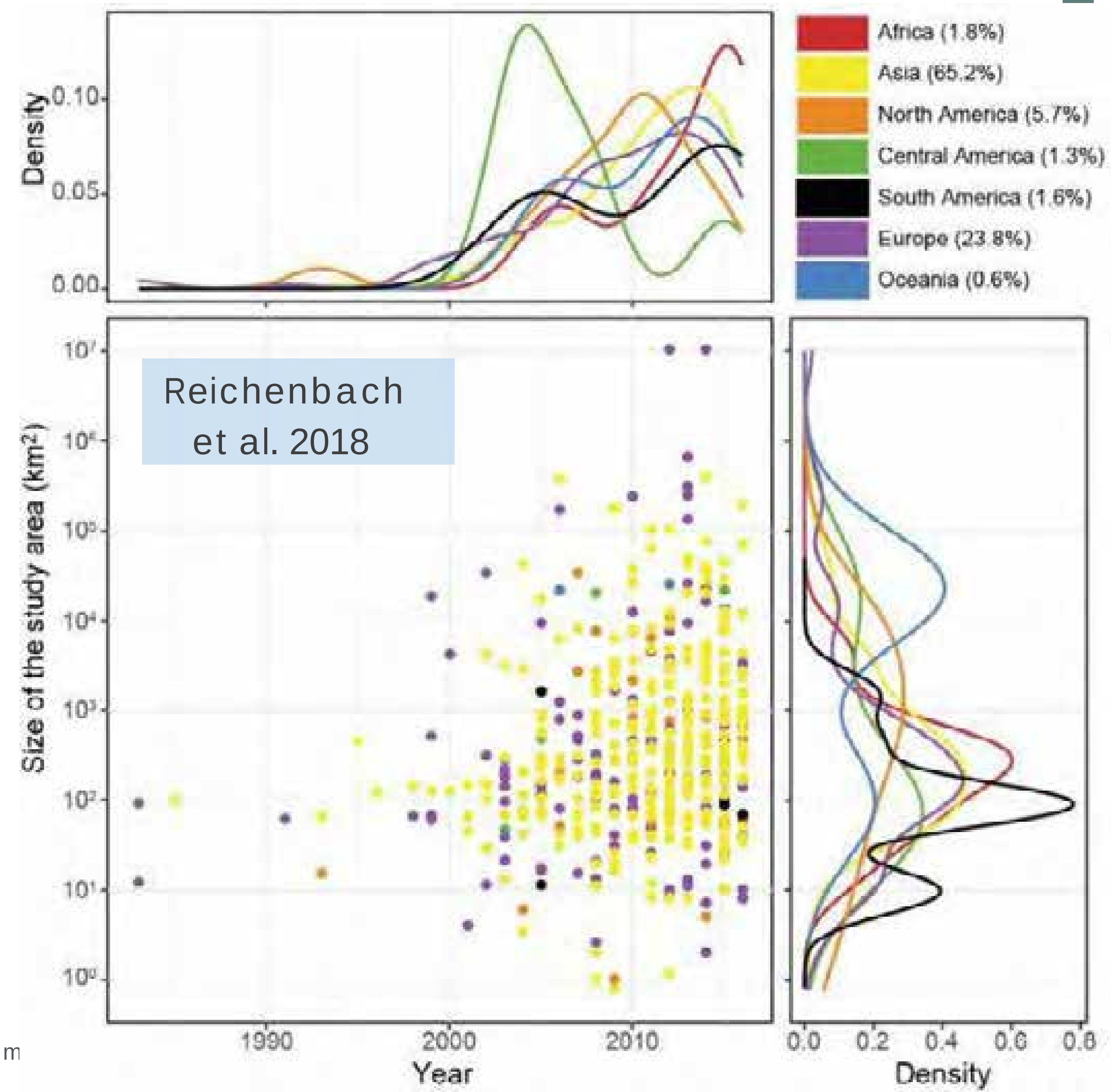


Section 2: Constructing Susceptibility Models

Large Regional Scale?

- Most statistical susceptibility models 10–1000 km^2
- Challenge at large regional scale to obtain complete landslide inventories
- Global scale inventories depend typically on incomplete data, and this must be carefully considered



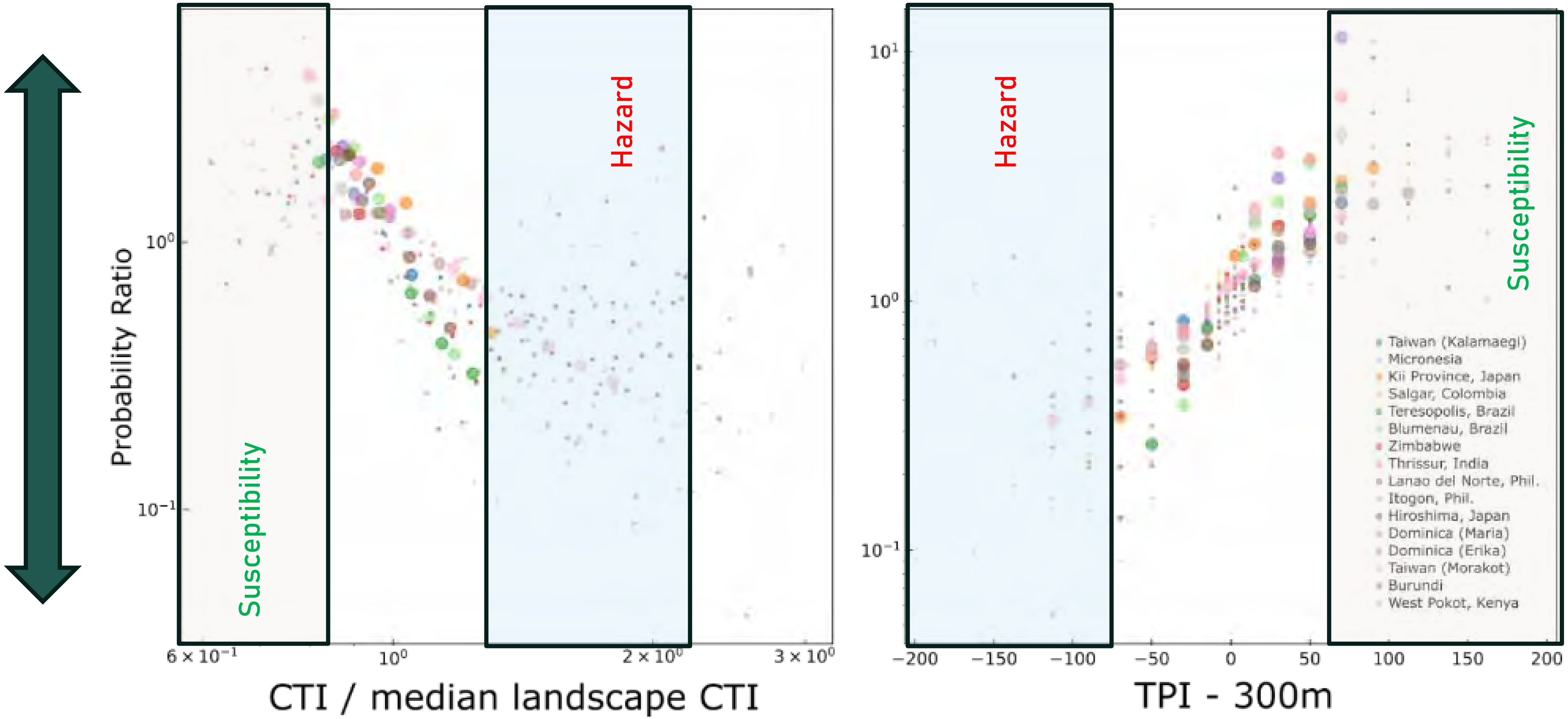
Reichenbach et al. 2018

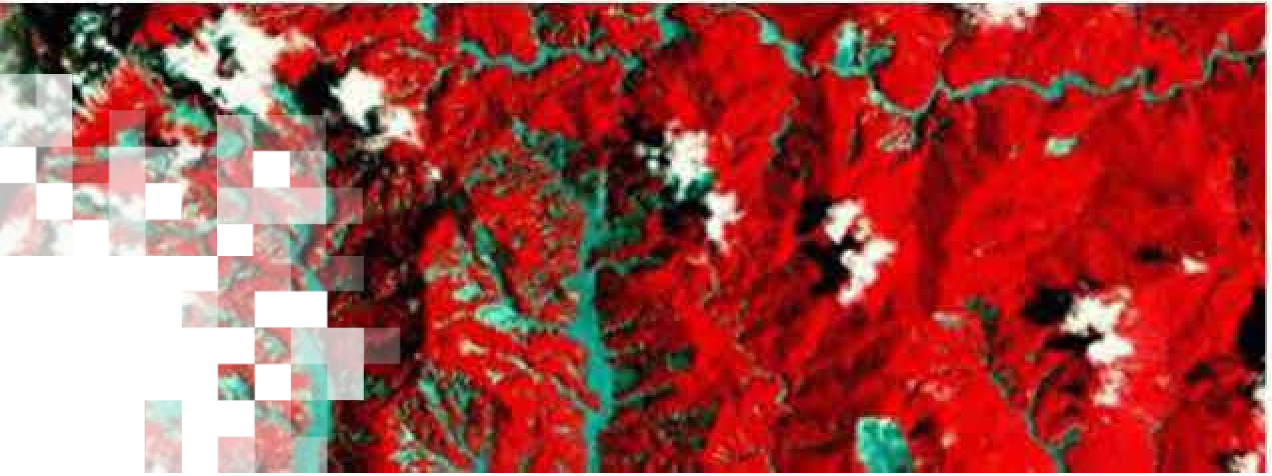
Section 2: Constructing Susceptibility Models

Scars vs Deposits

Scars more likely

Deposits more likely



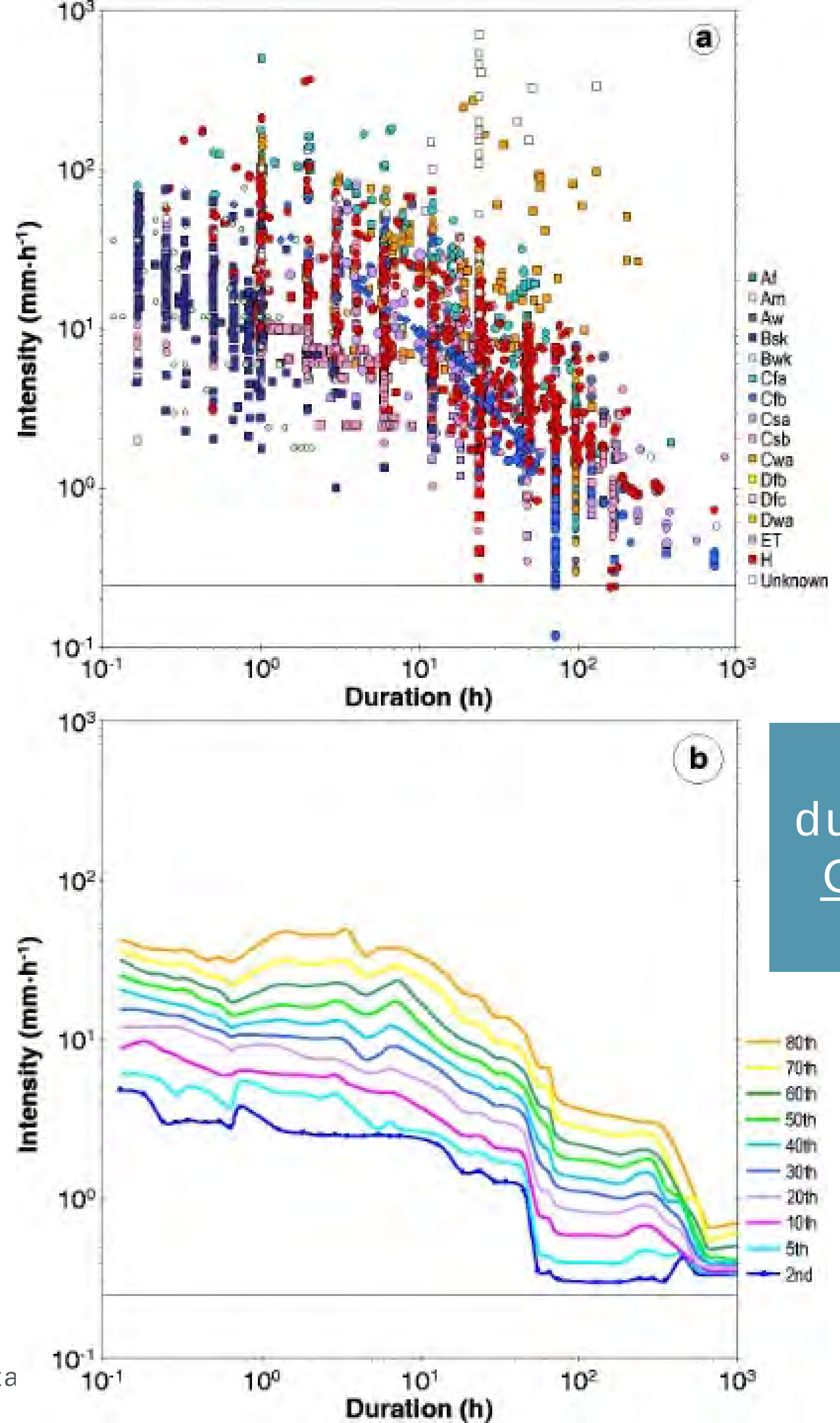


Section 3: Dynamic Hazard Models

Section 3: Dynamic Hazard Models

Rainfall Triggering: Intensity and Duration

- Satellite rainfall data is appropriate for landslide hazard assessment.
- **Intensity and duration** of rainfall both determine the likely landslide response.
- Dynamic statistical models must consider the whole context of recent rainfall history.

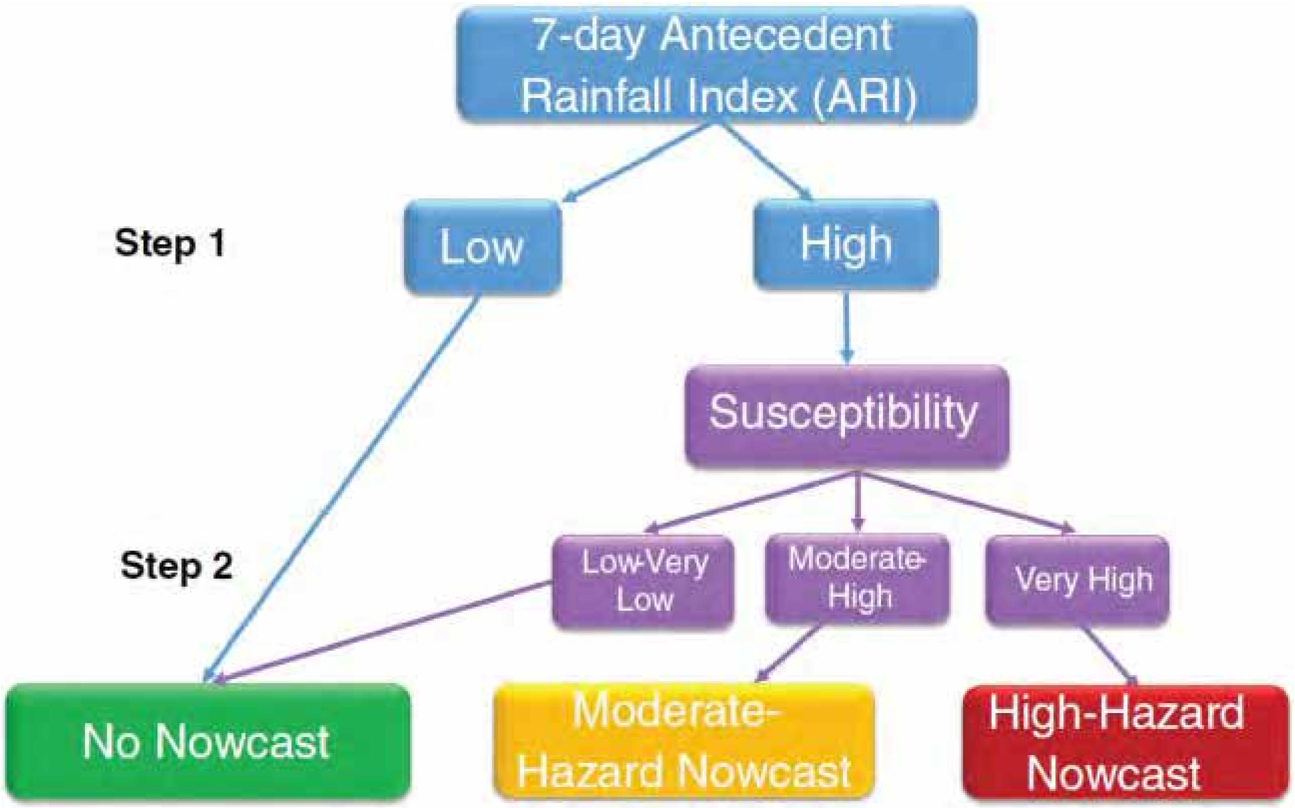


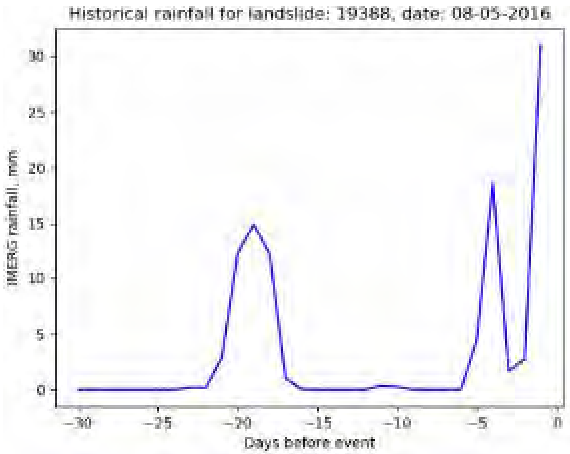
Intensity-duration curves; Guzzetti et al. 2008

Section 3: Dynamic Hazard Models

Landslide Hazard Assessment for Situational Awareness, Version 1

- Simplified NASA Landslide Hazard model used recent rainfall to form 7-day Antecedent Rainfall Index
- Rainfall more strongly weighted the more recently it occurred
- Provided a binary decision-tree method to categorize landslide hazard





Section 3: Dynamic Hazard Models

Landslide Hazard Assessment for Situational Awareness, Version 2

Static Factors
- Topographic variables
- Lithology
- Rock strength

Real-time triggers
- Satellite NRT and antecedent rainfall
- Soil Moisture

Forecast
- Rainfall Forecast
- Soil Moisture Forecast

Near-surface impacts
- Post-fire debris flows
- *Recent seismicity (ongoing)*

Methodology
XGBoost machine-learning model

Trained and evaluated with different types of landslide inventories

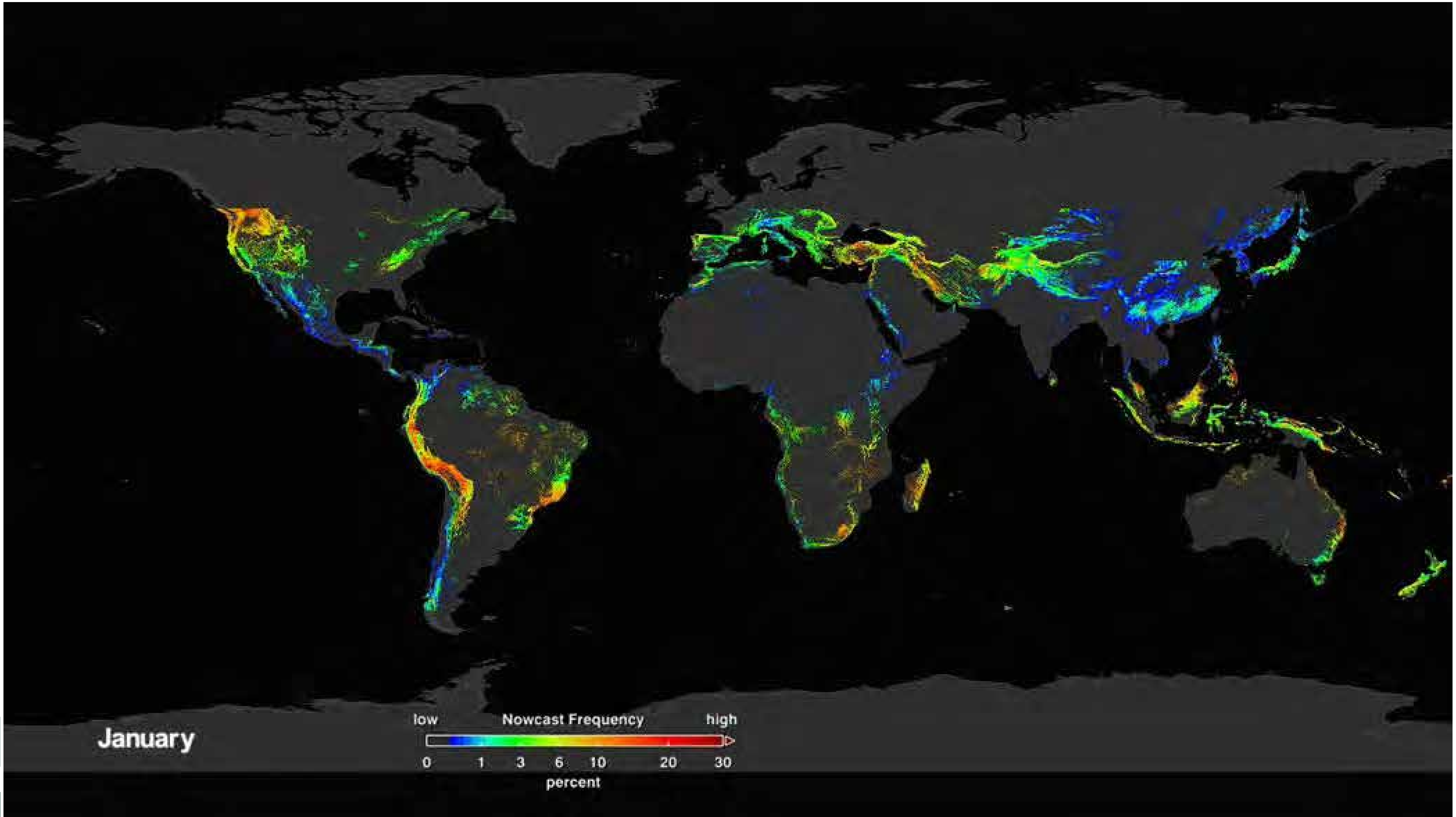
Landslide Nowcast & Forecast:
- Probability of Rainfall-triggered landslides
- Probability of potential landslide information within next several days

Exposure Model
Population
Roads
Infrastructure

Stanley et al. 2021

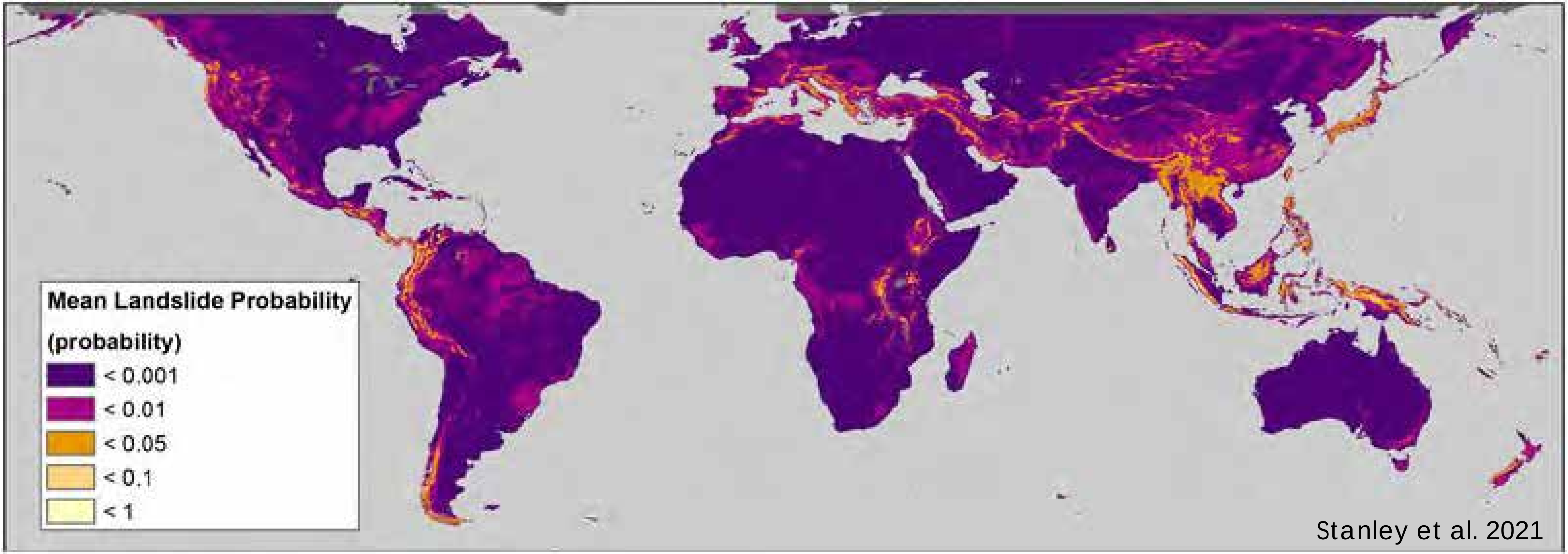
Section 3: Dynamic Hazard Models

Global, Dynamic Landslide Hazard



Section 3: Dynamic Hazard Models

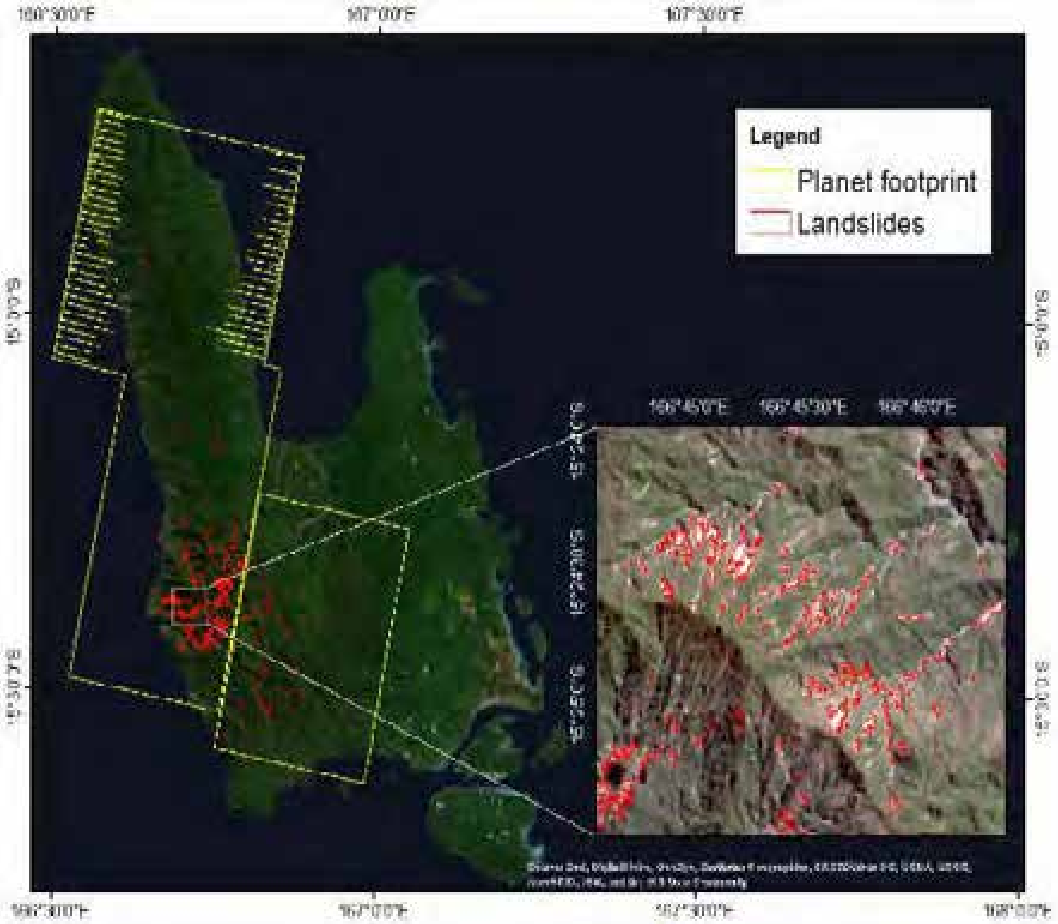
Long-Term Average Landslide Hazard

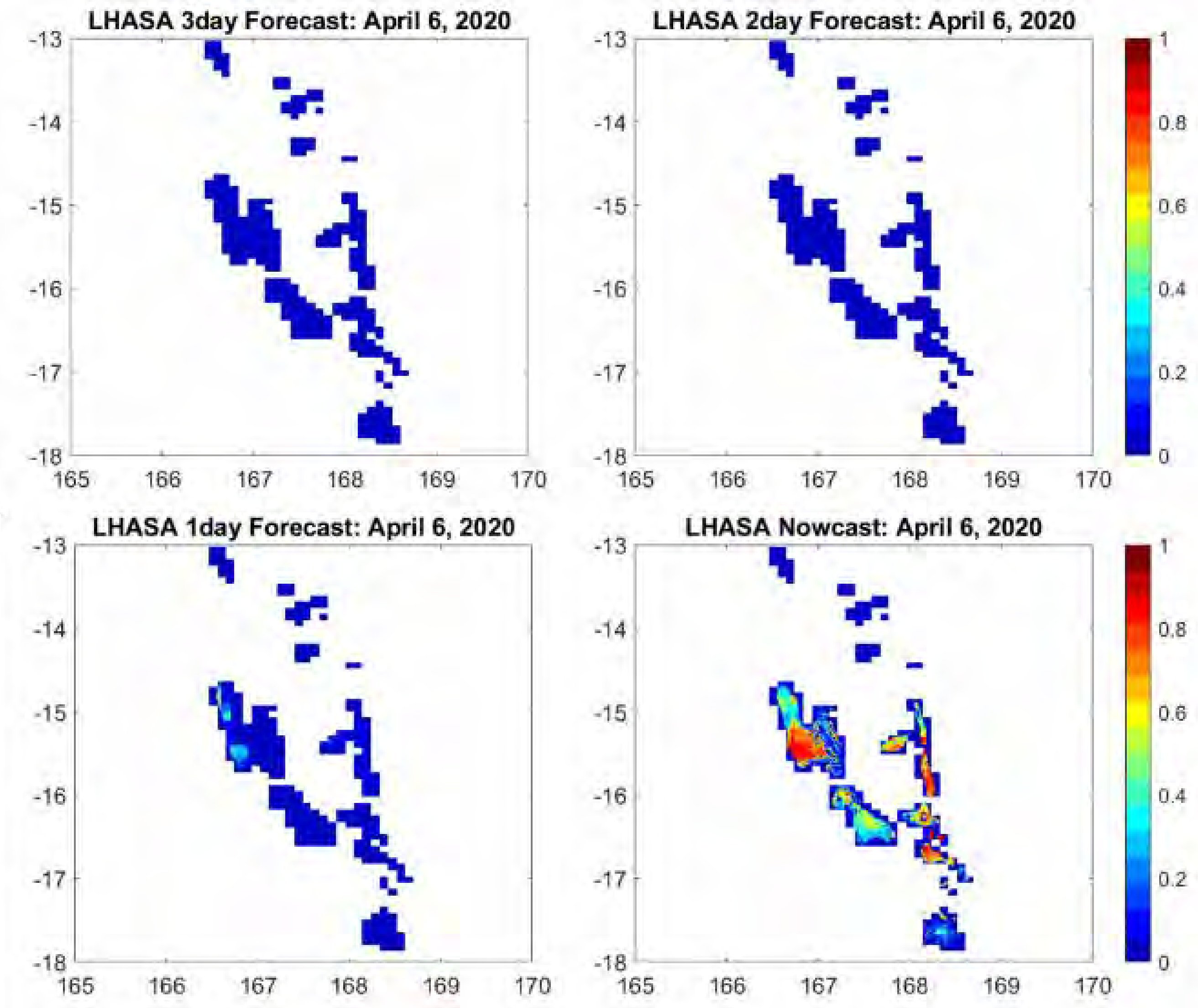


The mean prediction over the time period May 1, 2015, to April 30, 2020

Section 3: Dynamic Hazard Models

LHASA 2 Outputs Assessed

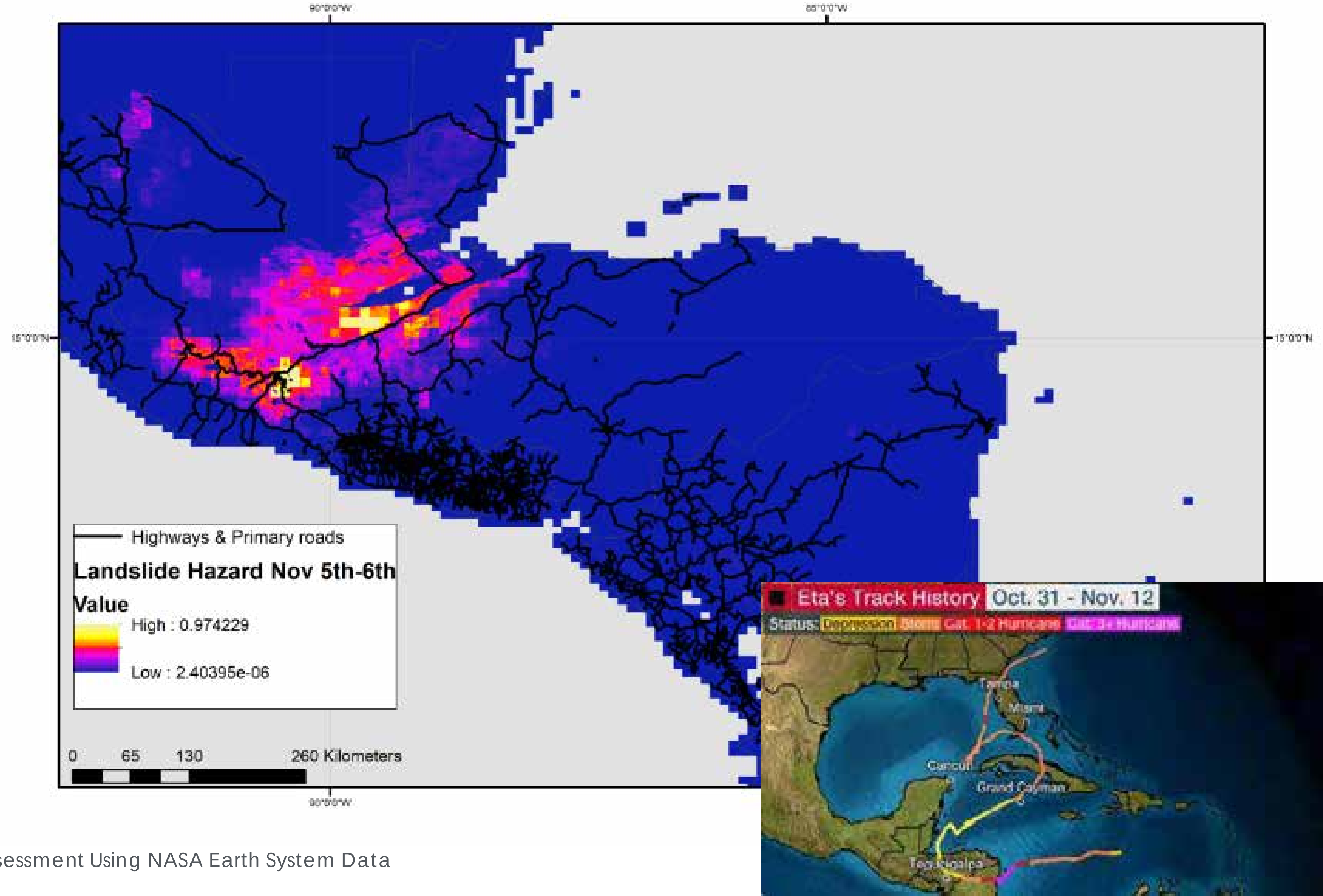




Section 3: Dynamic Hazard Models

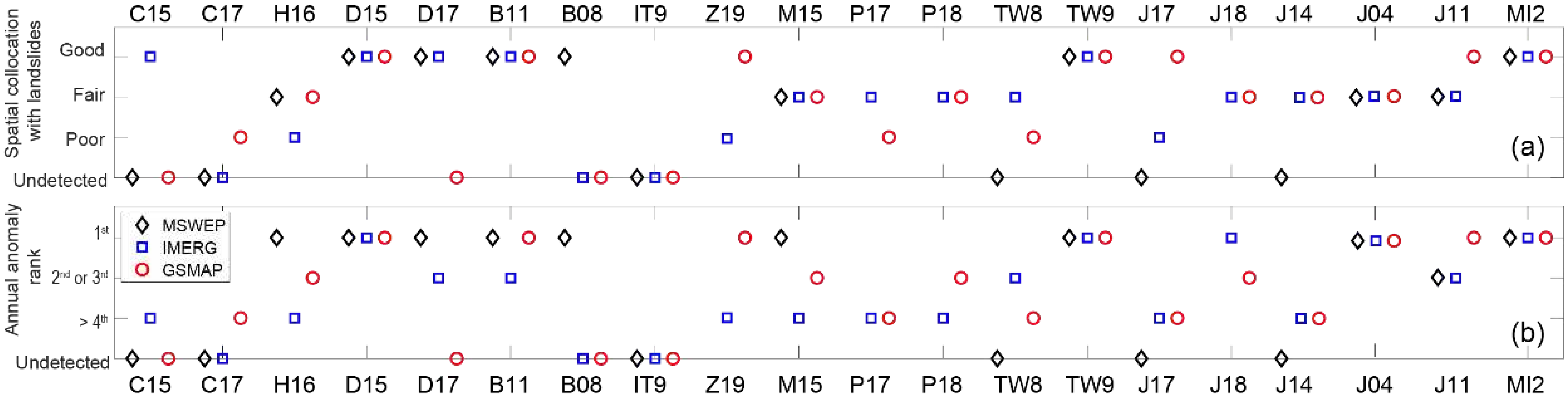
LHASA 2 Outputs Assessed

- Hurricane Eta, 2020
- Killed at least 175 people
- Significant concern about landslides and debris flows in mountainous regions
- LHASA 2.0 Outputs demonstrated strong predictive skill in critical locations



Section 3: Dynamic Hazard Models

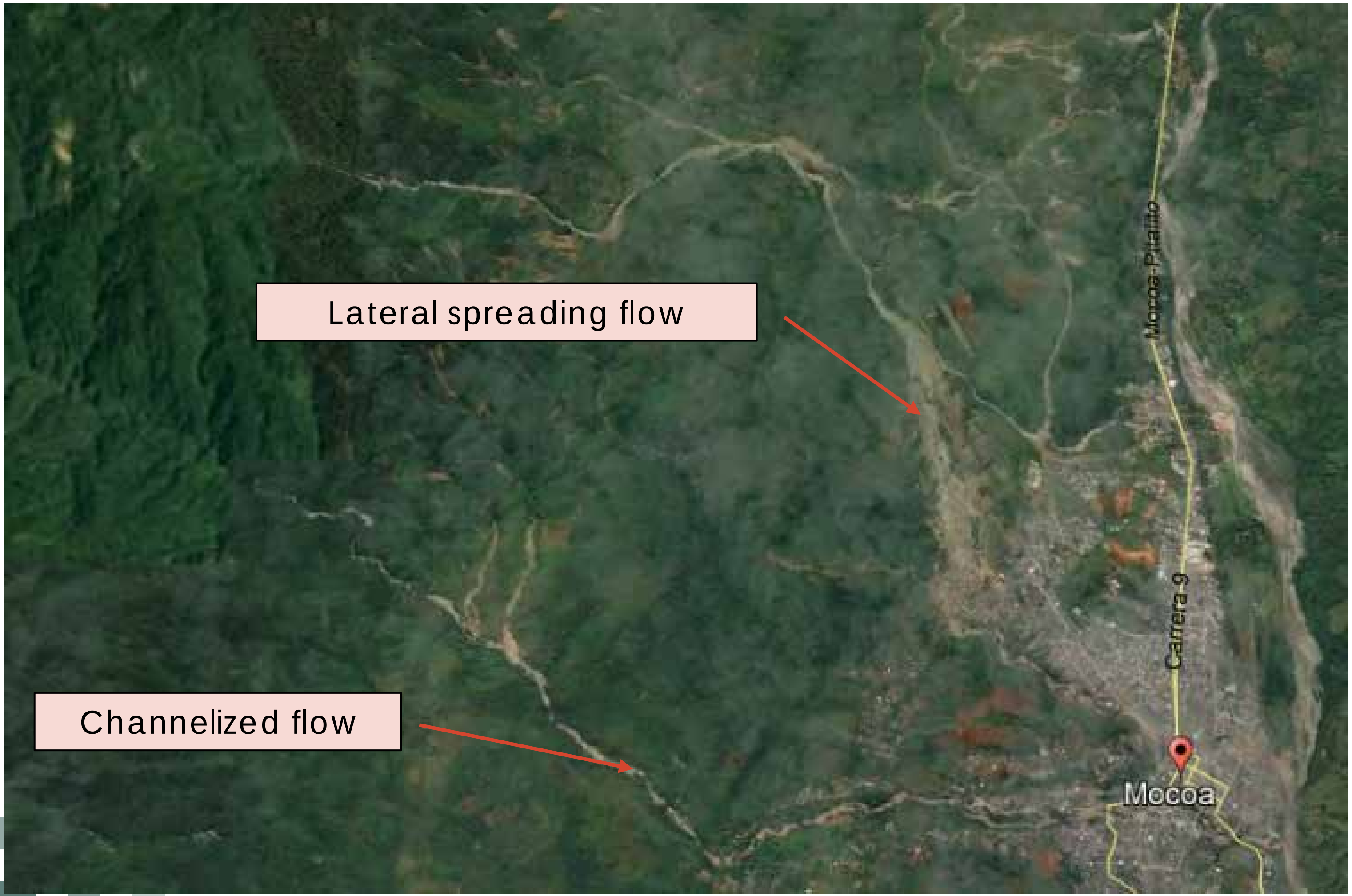
Testing Different Satellite Rainfall Products



Satellite rainfall products do not perfectly predict landslide location, and inconsistency between products. Marc et al. 2021

Section 3: Dynamic Hazard Models

Understanding Runout

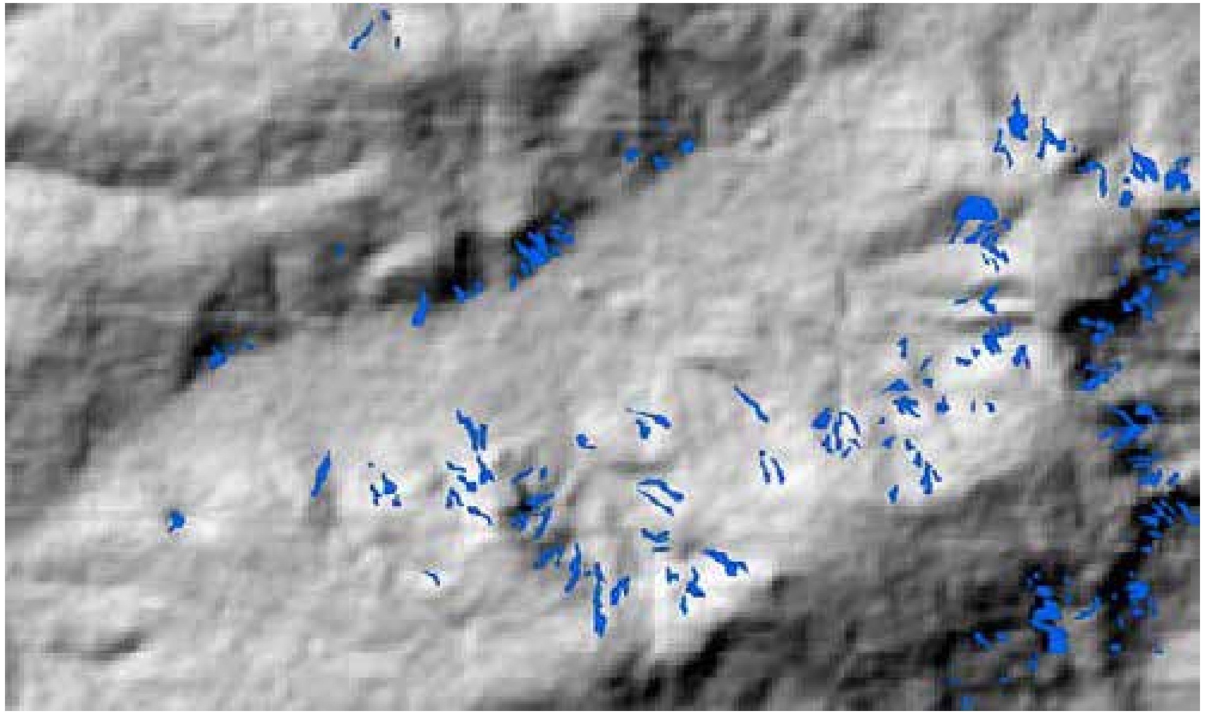


Aerial image of the aftermath of the Mocoa debris flow in Colombia. Credit: [Fox6]

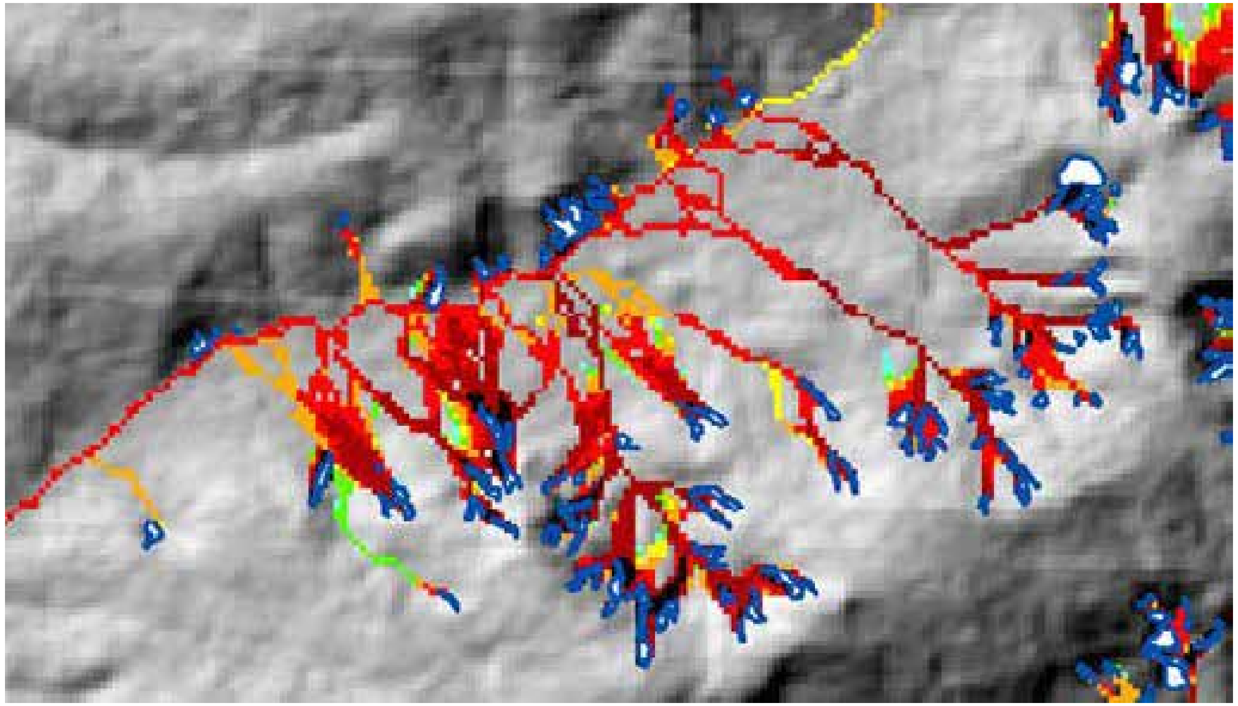
Section 3: Dynamic Hazard Models

Understanding Runout

- Typical runout models are computationally expensive and require extensive input information.
- Further research is needed to develop simplified, generalizable models using satellite data.



Landslide Shapefile



Runout prediction based on landslide volume

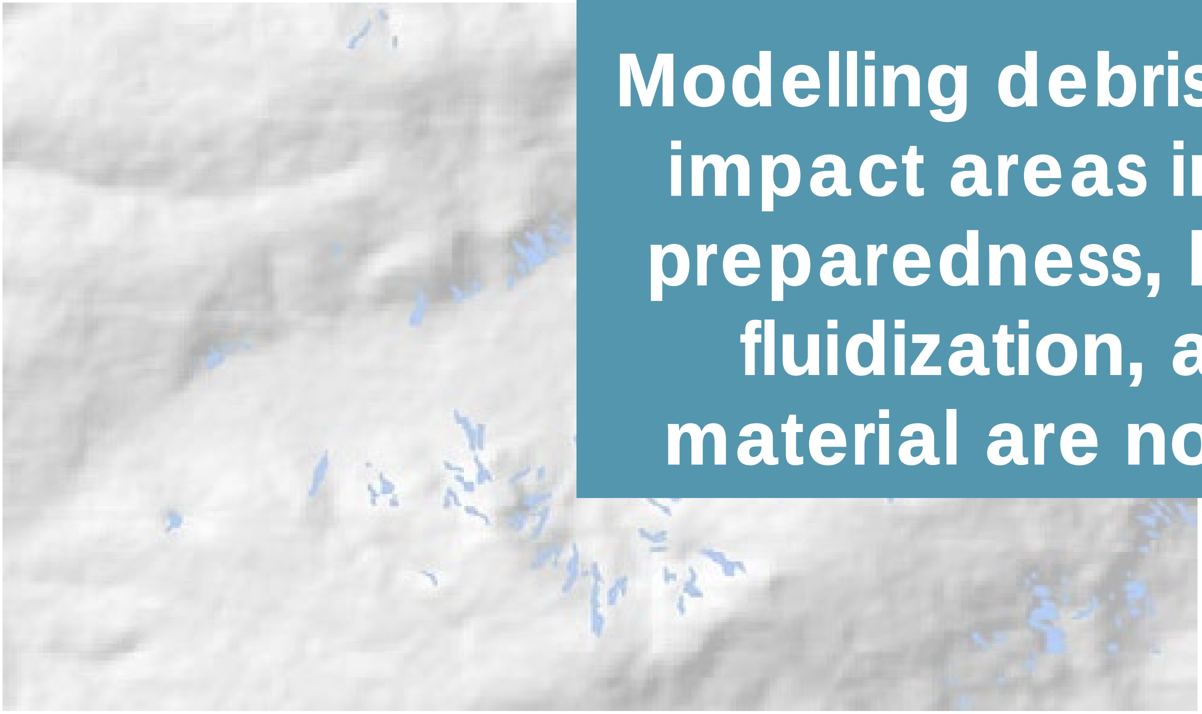
Section 3: Dynamic Hazard Models

Understanding Runout

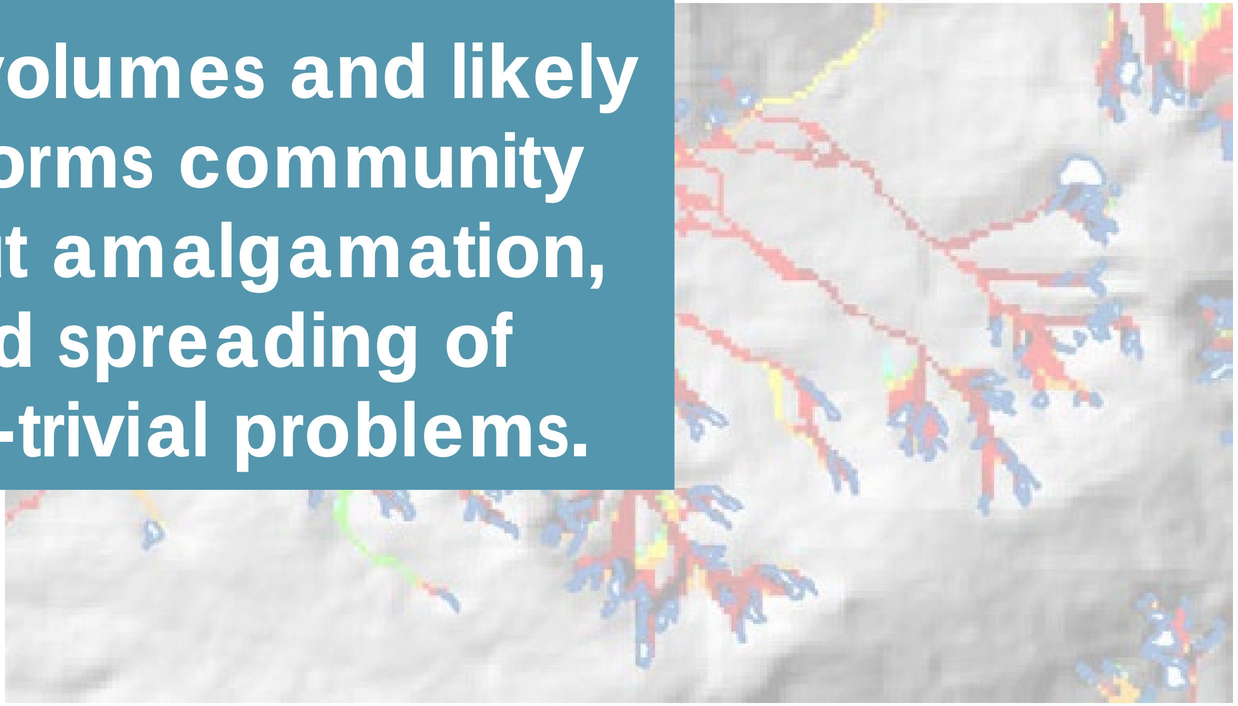
- Typical runout mod … put information.
- Further research is … atellite data.

Predicting runout zones is a key topic for future study.

Modelling debris volumes and likely impact areas informs community preparedness, but amalgamation, fluidization, and spreading of material are non-trivial problems.



Landslide Shapefile



Runout prediction based on landslide volume

Resources

- USGS Landslide Handbook
- ARSET SAR training
- ARSET Hyperspectral training
- NASA Landslides Research
- NASA Disasters Program
- NASA Landslides Guide to field mapping landslides
- NASA SALaD Github
- SAR Handbook
- LPDAAC DEM data
- OpenTopography
- Soil thickness data (ORNL DAAC)

Part 3 Summary

- Landslide susceptibility describes the areas landslides are likely to originate.
- Topographic factors are critical to determine landslide susceptibility.
- NASA DAACs provide datasets (e.g., DEMs, land use/land cover, soil thickness, soil moisture, forest cover, precipitation, etc.) for modeling landslide susceptibility.
- EO-based models are typically statistical; statistical models use combinations of data associated with susceptibility in combination with training data – typically locations (i.e., inventories) of landslides.
- Landslide inventories are necessary to calibrate and construct susceptibility models.
- NASA teams have used classical statistical, machine learning, and neural network approaches to generate susceptibility models.
- A variety of methods are used to determine accuracy of the model.
- Dynamic statistical models must consider the whole context of recent rainfall history (intensity & duration).
- NASA's global Landslide Hazard Assessment for Situational Awareness version 2 (LHASA 2.0) maps areas of potential landslide hazard in real time.

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!