DETAILED MONITORING AND CHARACTERIZATION OF LANDSLIDE DISPLACEMENTS

SPR807: Coastal landslide and sea cliff retreat monitoring for climate change adaption and targeted risk assessment

OSU: Andrew Senogles, Michael J. Olsen, Ben Leshchinsky,
DOGAMI: Jonathan Allen
ODOT: Curran Mohney, Kira Glover-Cutter, Geoff Crook

Oregon Department of Transportation

Oregon State University

Oregon Department of Geology and Mineral Industries 1937

DISCLAIMER

I have financial interests in the company EzDataMD LLC, and commercialization of technology involving point cloud data processing. The conduct, outcomes, or reporting of this research could benefit EzDataMD LLC and could potentially benefit me.

Landslides + Infrastructure = Bad News

Oregon State University
College of Engineering

Dealing with the consequences: Locals, businesses and hospitals facing challenges due to U.S. 101 landslide

[1] KDRV

Repairs continue at Hooskanaden slide area: $1.12 million already spent on disaster

ODOT considers options for a permanent solution

[2] Bandon Western World

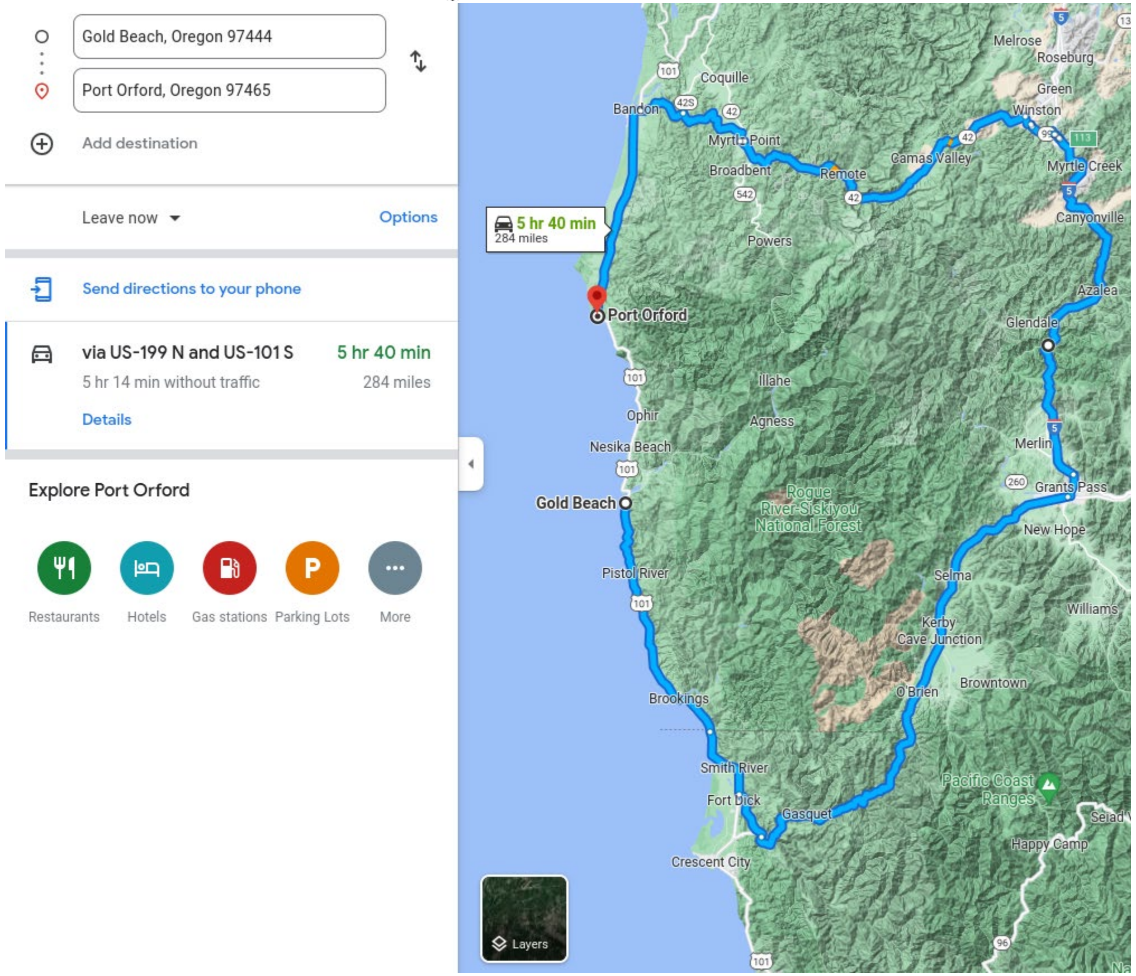
Efforts to stop landslides on U.S. 20 have failed, leaving completion of Oregon's largest road contract in question

[3] The Oregonian

A Recipe for Climate Disaster

Extreme rain, rising sea levels, and more frequent wildfires are all making landslides more likely.

[4] The Atlantic



Heavy rain accelerates damage to Highway 101 north of Newport

FEBRUARY 1, 2024

[4] Yachats News

Monitoring is Essential

- Scientific/Fundamental
  - understand natural processes
  - test hypothesis
  - calibrate models
- Engineering/Practical
  - maintenance
  - risk assessment
  - planning future development

SPR 807Monitoring

- Five sites along Hwy 101.
- Seven-year study period
  - Started Fall 2016
  - Ending Spring 2023
  - Isolate long term trends.
- TLS (terrestrial laser scanning), UAS photogrammetric & UAS lidar surveys.
  - Bi-annual surveys in fall and spring.
- Site instrumentation
  - MeMs & piezometers were installed in six locations.
  - In-Situ GNSS

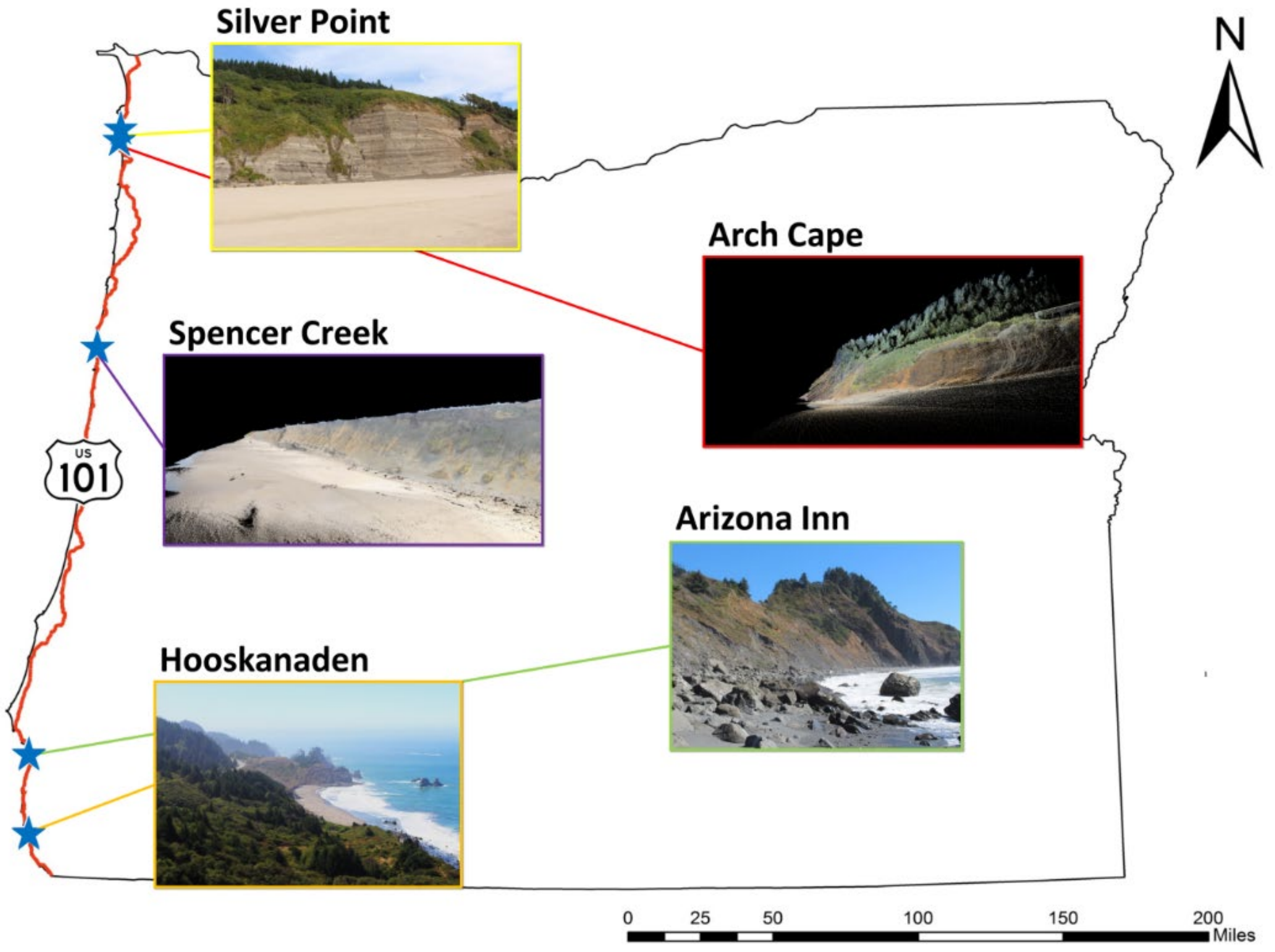
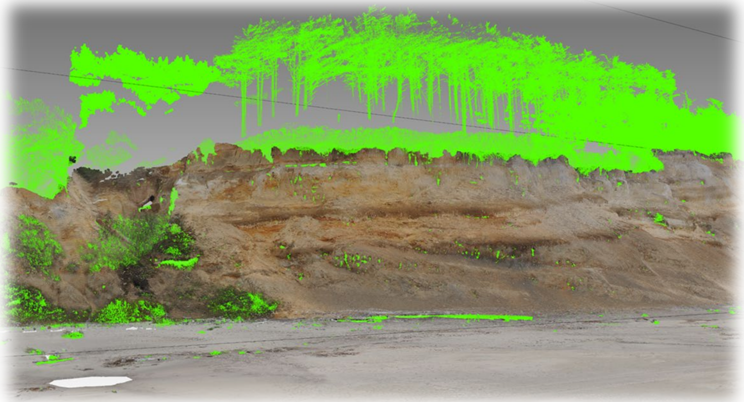


Figure 1: Map of the sites chosen along Hwy 101.

Monitoring Workflow

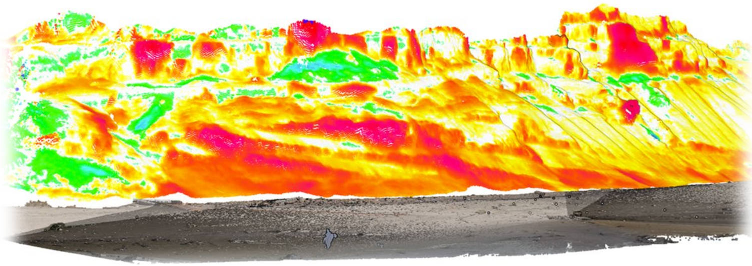
Oregon State University
College of Engineering



Data Collection

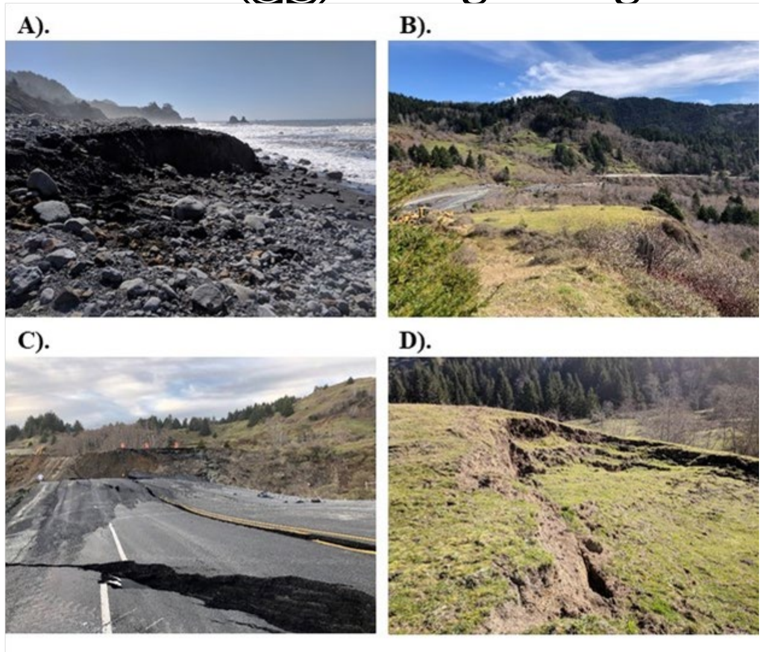
Processing & Analysis

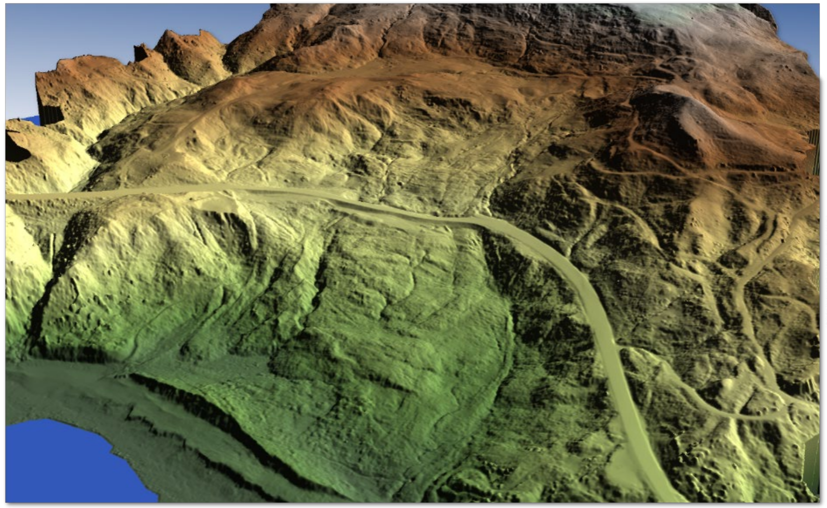
In-Situ

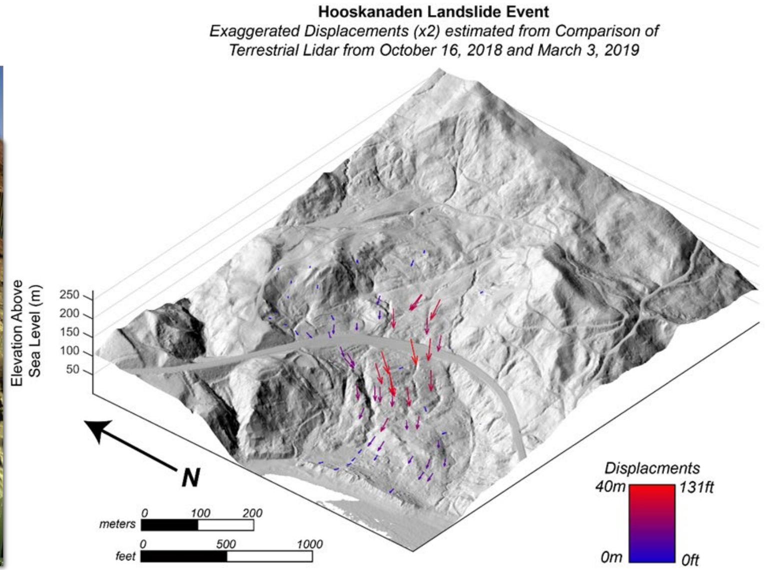


Hooskanaden

- Fastest moving landslide of all the sites.
  - Hard to measure erosion/displacement using conventional change detection methods.
- Inclinometers failed within a couple months.
- Large Failure in February 2019.
  - 40 m movement
  - Crept at rates of decimeters per hour for a few days







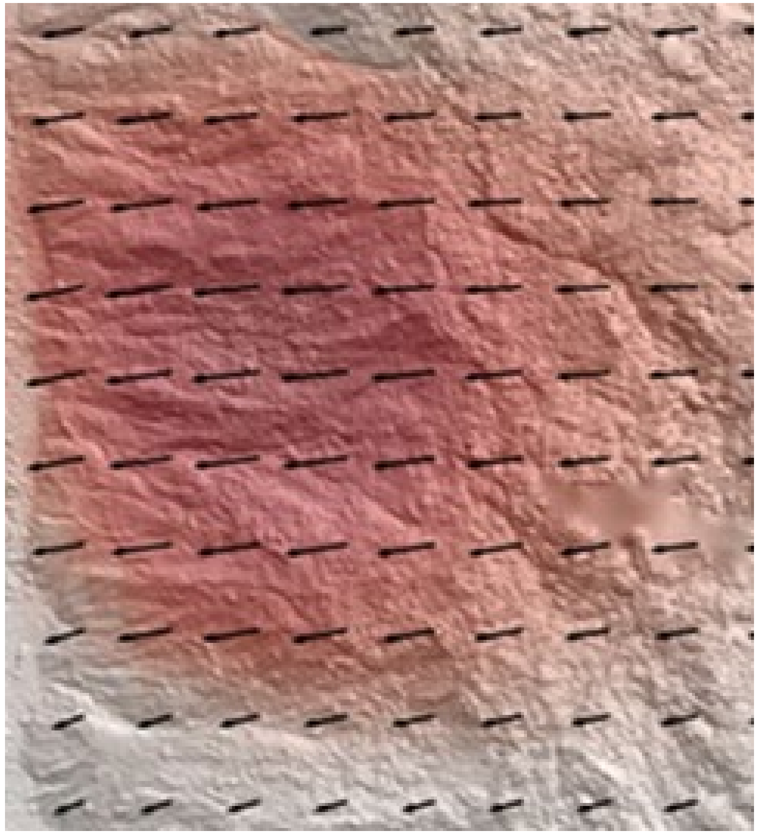
Part I.

SlideSIM: SlideSim: 3D Landslide Displacement Monitoring through a Physics-Based Simulation Approach to Self-Supervised Learning

LADI: Landslide Displacement Interpolation Through a Spatial-Temporal Kalman FIlter

SlideSim Goals:

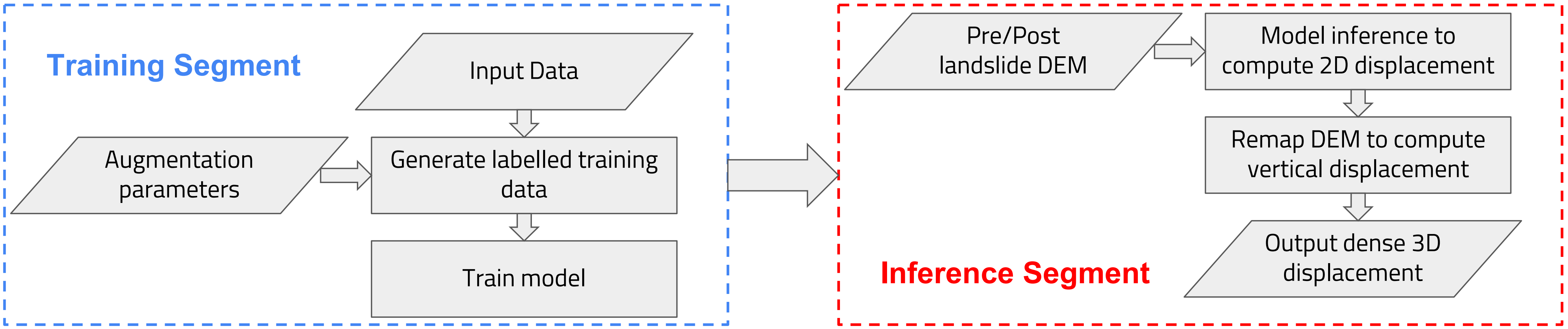
1. Simple input (sequential DEMs)
2. Capable of producing 3D dense displacement data
3. Easy to use across varying sites/conditions
4. Little requirement for manual tuning/manipulation
5. Flexible input data source (lidar, photogrammetric, etc)

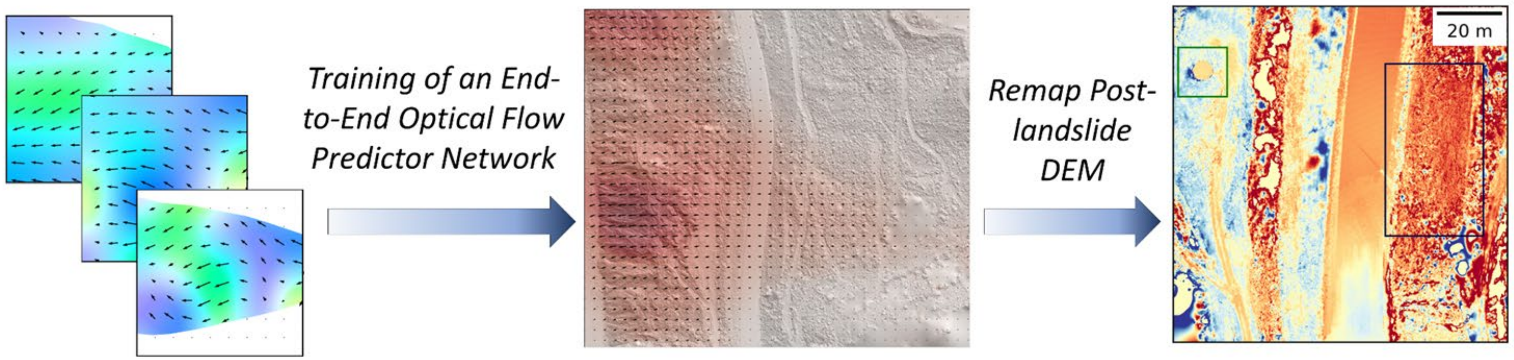


Senogles, Andrew, Michael J. Olsen, and Ben Leshchinsky. 2022. "SlideSim: 3D Landslide Displacement Monitoring through a Physics-Based Simulation Approach to Self-Supervised Learning" *Remote Sensing* 14, no. 11: 2644. https://doi.org/10.3390/rs14112644

SlideSim Overview

Oregon State University
College of Engineering





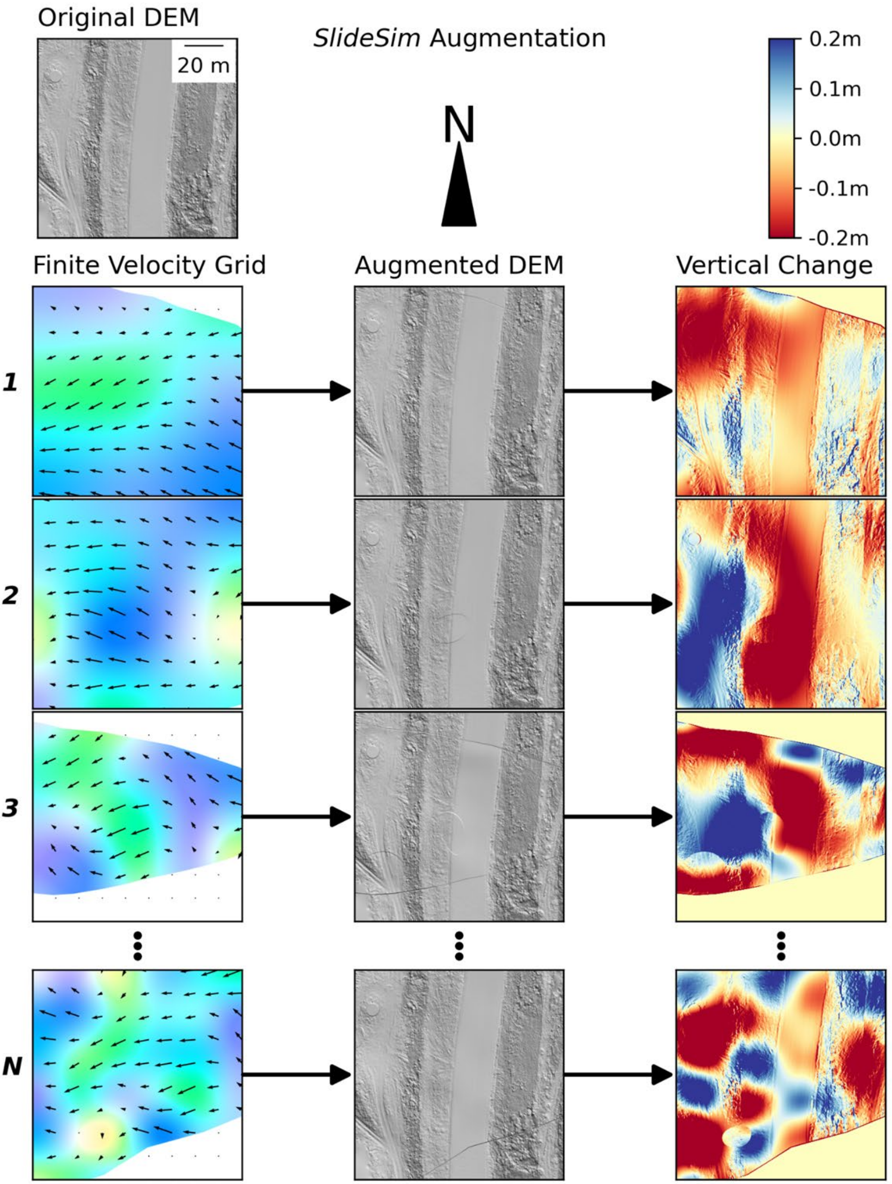
Simulation, Augmentation, and Generation of Synthetic Training Data

Create Horizontal Displacement Grid

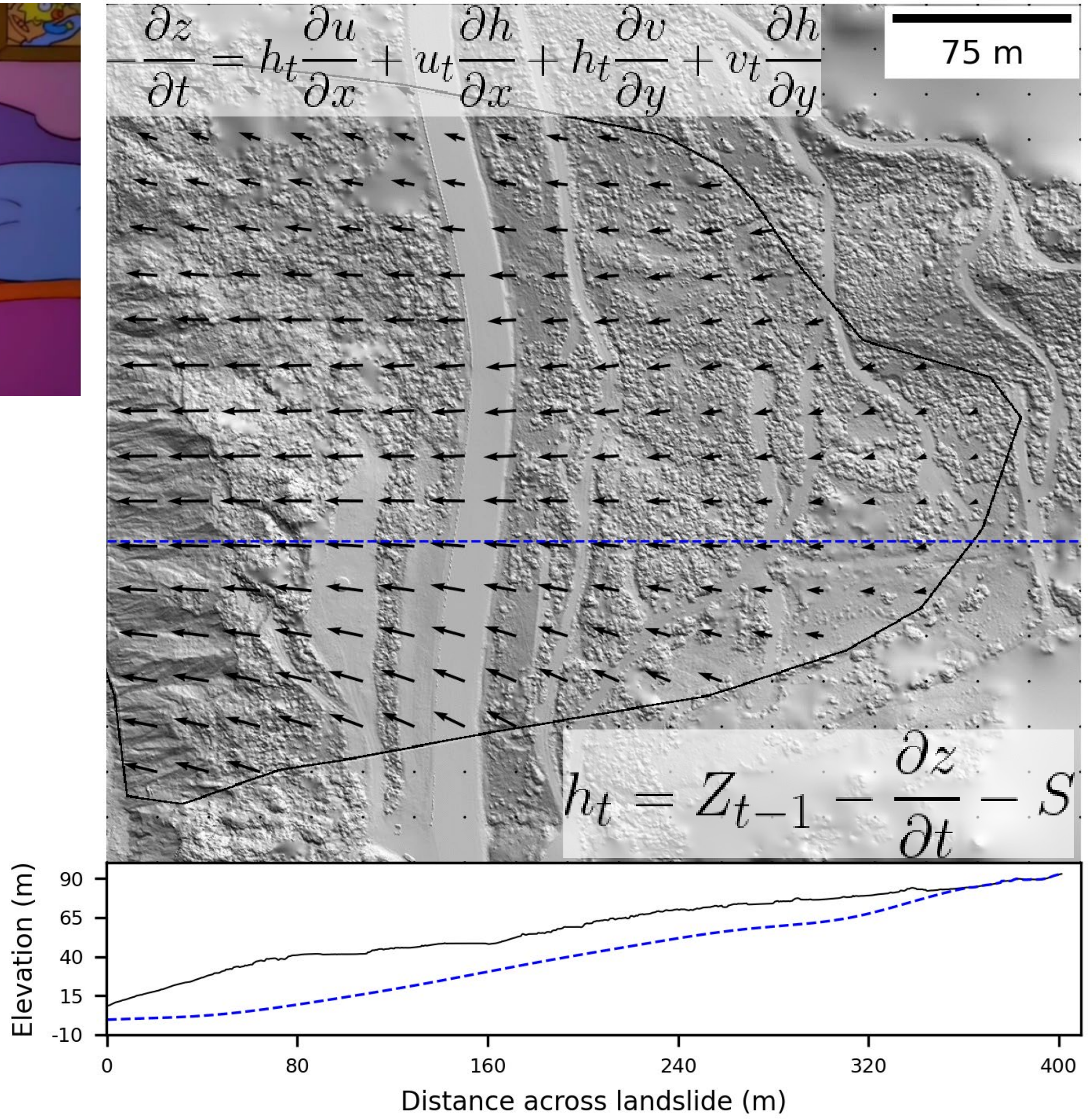
Obtain Corrected Vertical Displacement Grid

Data Augmentation & Conservation of Mass

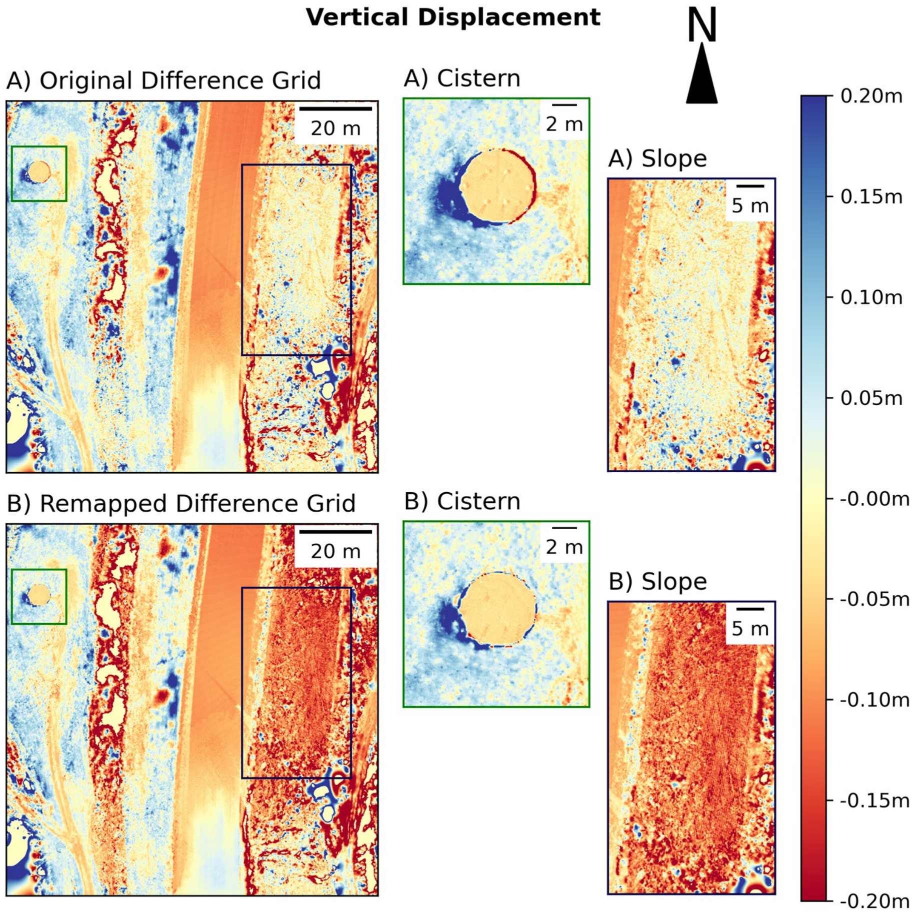
$$N = N_{DEMs} \cdot N_{boundaries} \cdot N_{SSEMs} \cdot N_{vels}$$

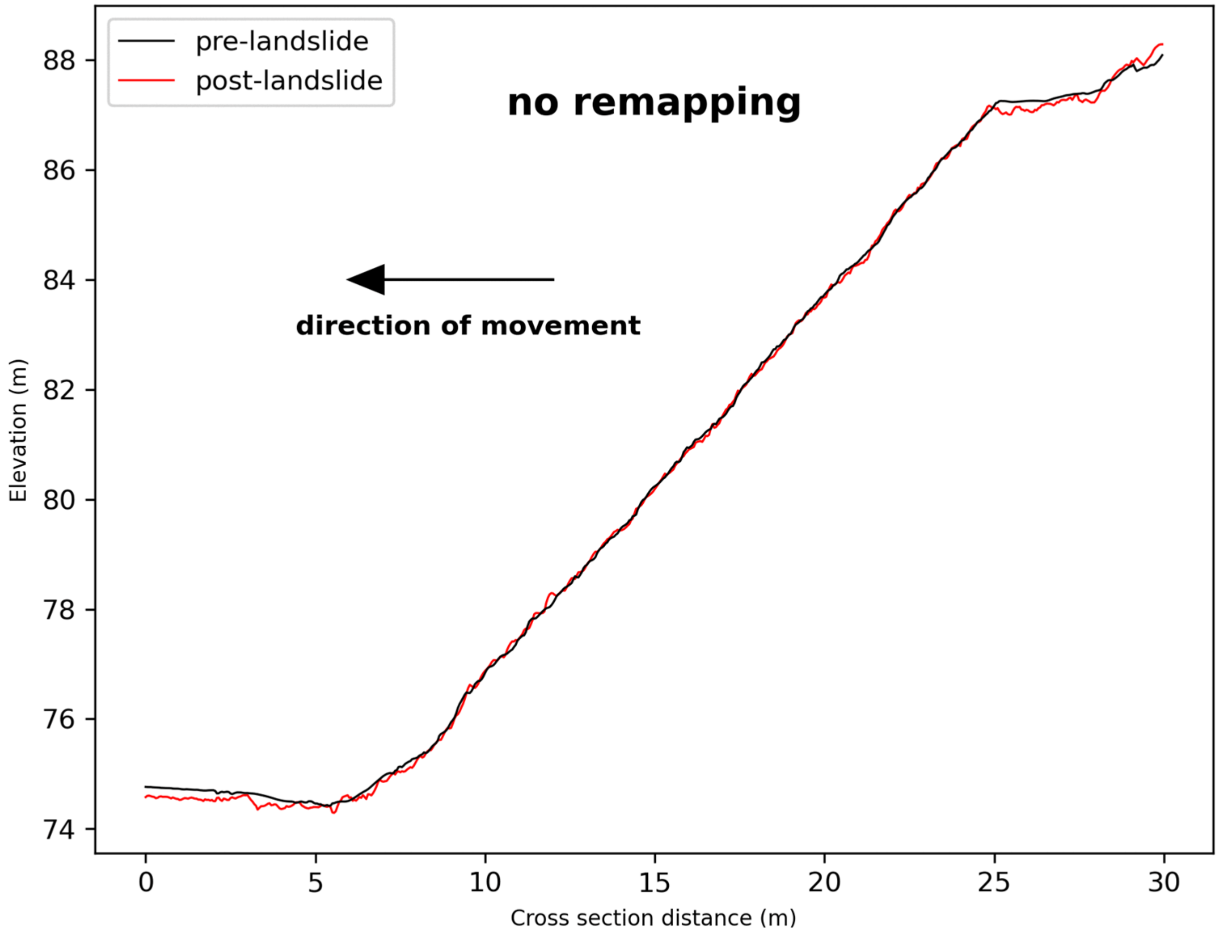


"In this house, we obey the laws of [physics]."
-Homer Simpson



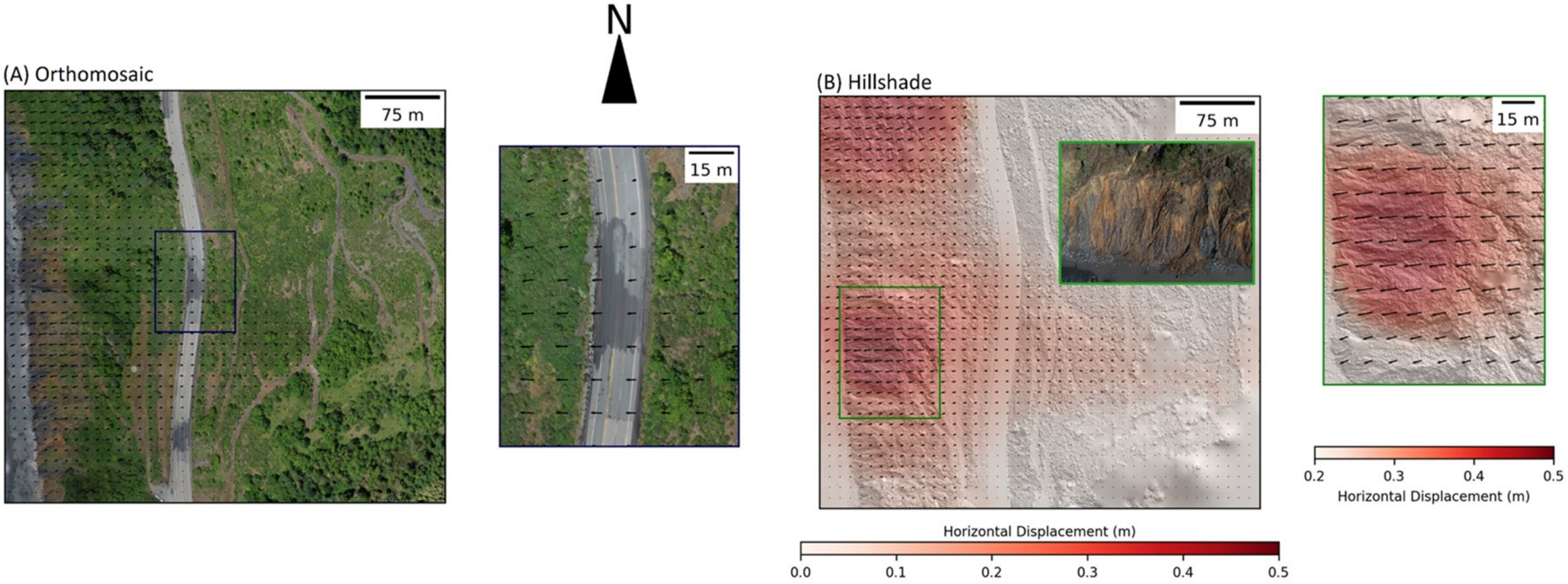
Computing Vertical Displacement



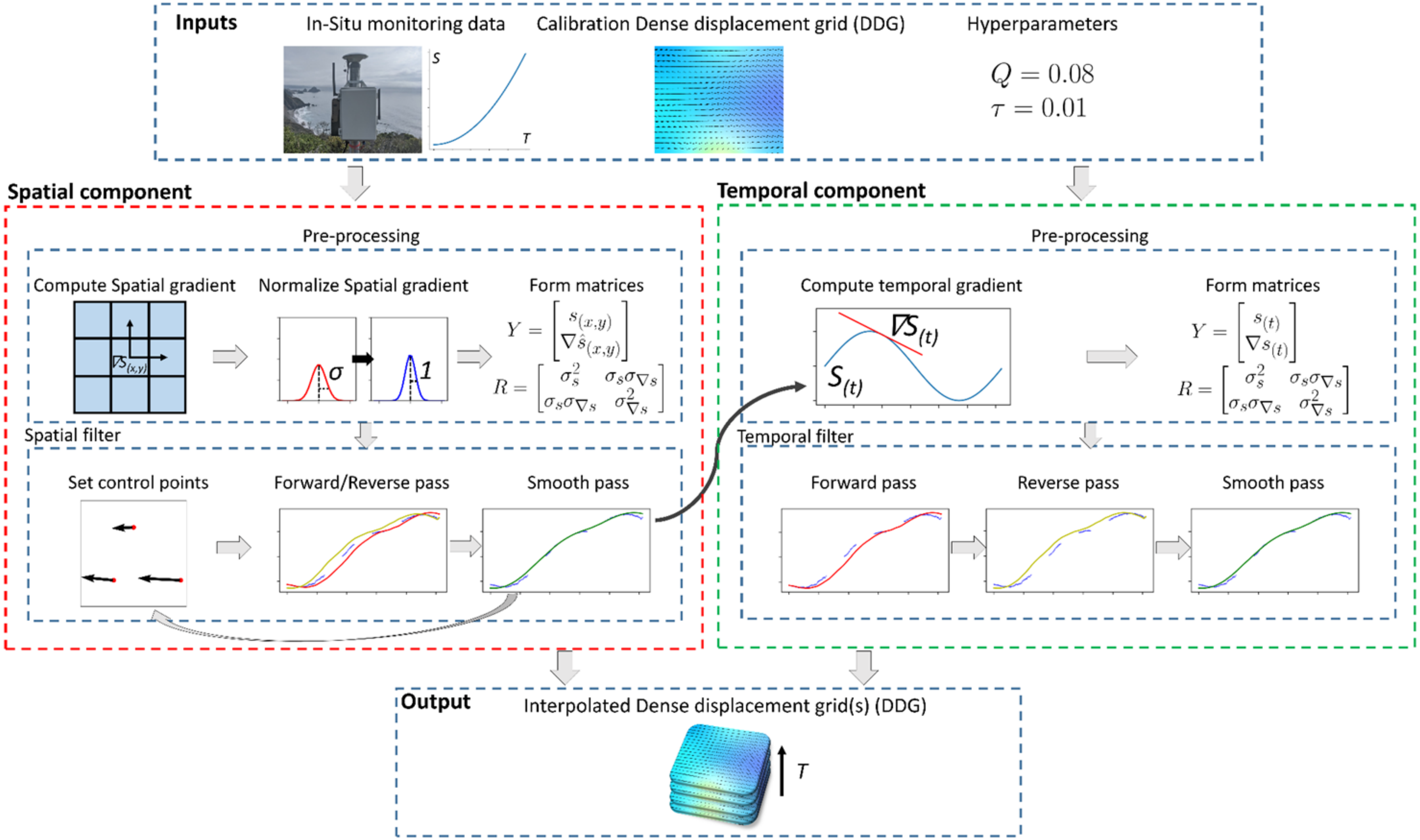


$$DEM_R(x,y) = DEM(x-u(x,y), y-v(x,y))$$

Example Results

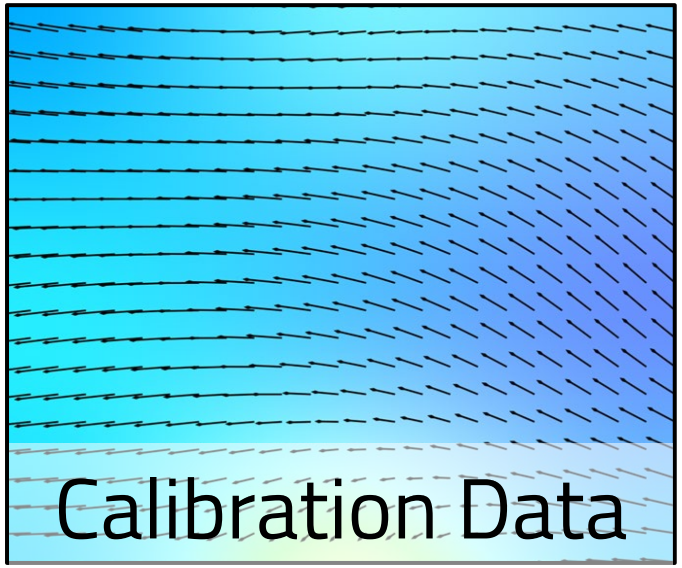


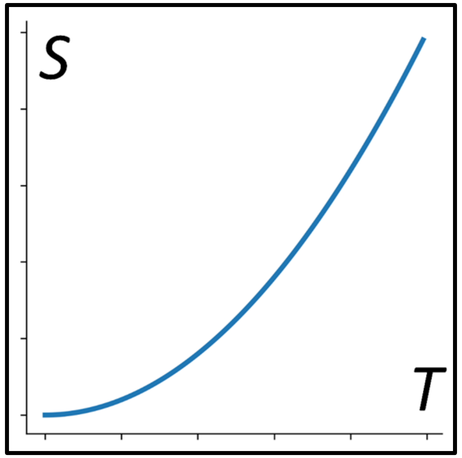
LADI
(LAndslide Displacement Interpolation)



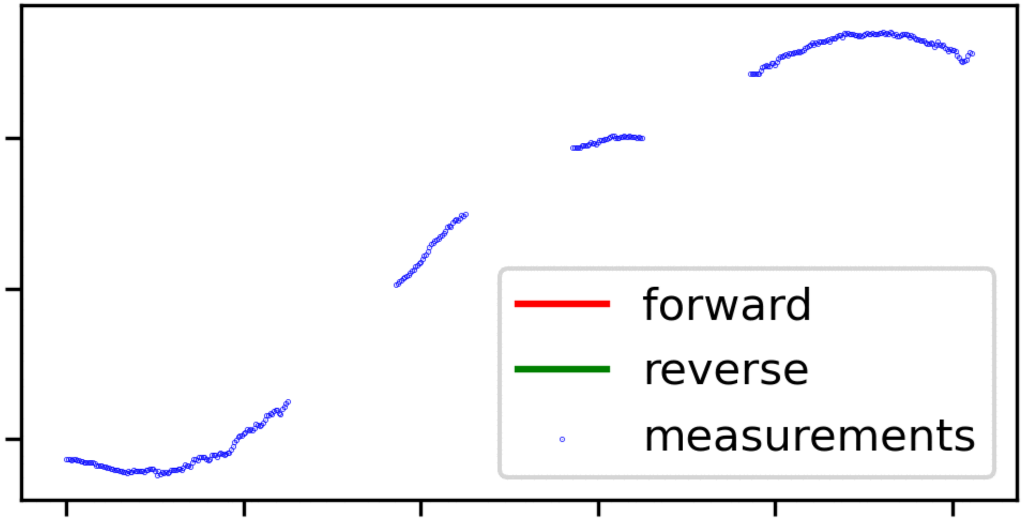
Input Data

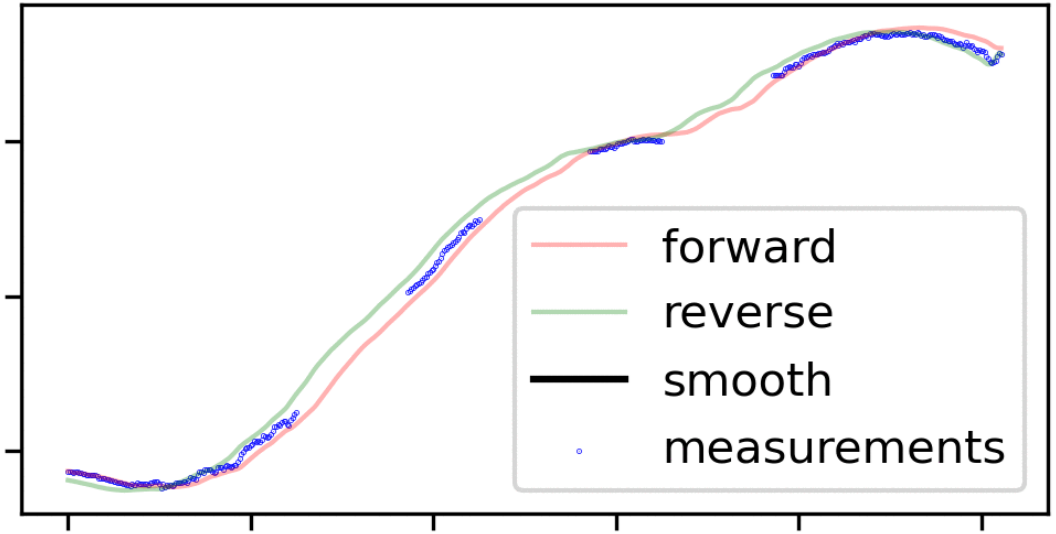
Oregon State University
College of Engineering





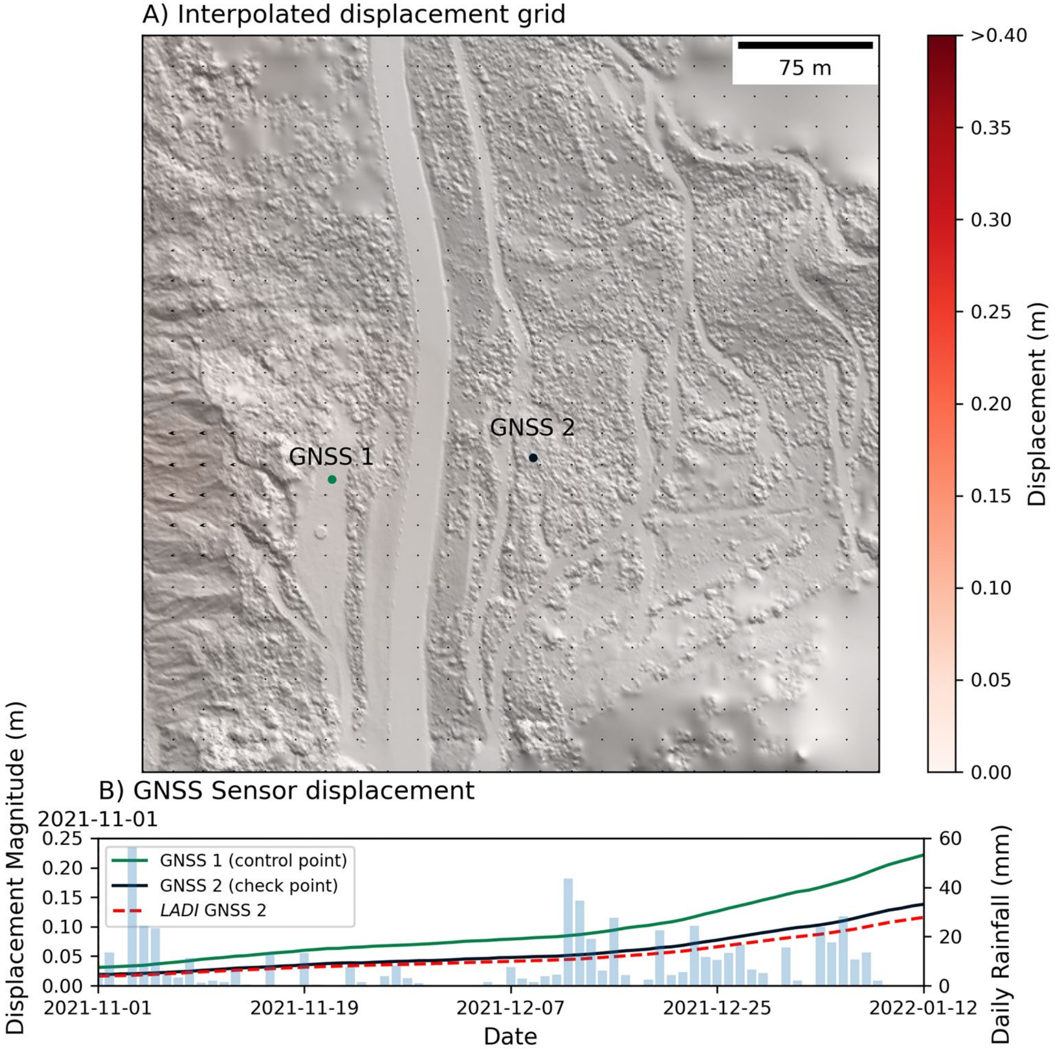
Kalman Smoothing





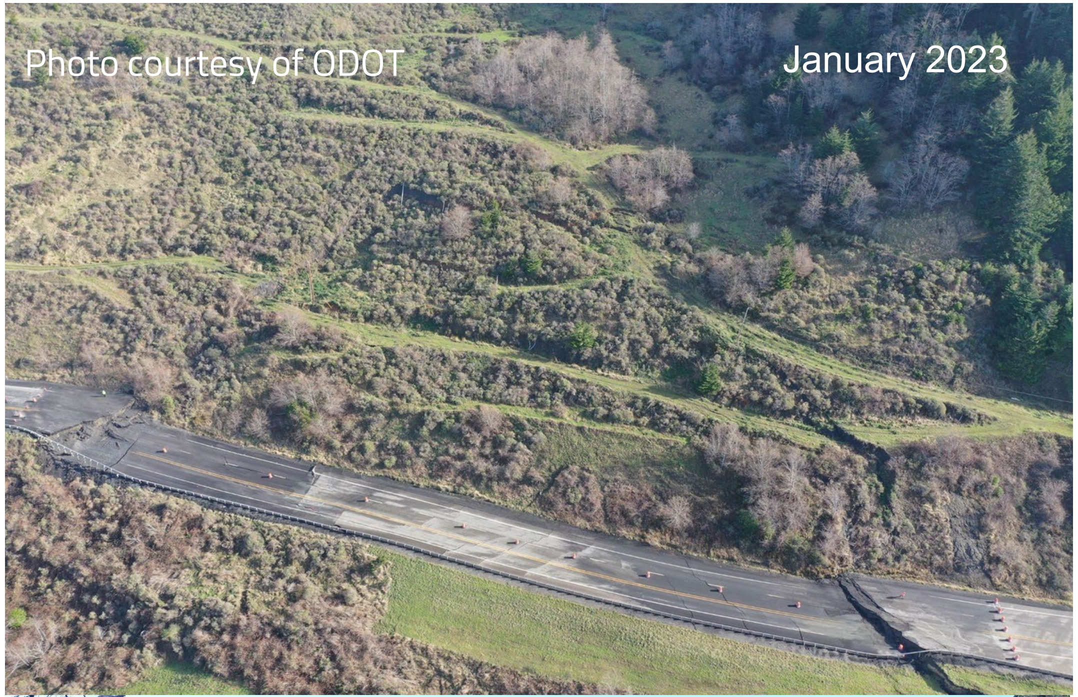
Spatio-temporal Interpolation

- 73 day sequence
- Single Control point
- Validation Control Point
  - RMS = 0.01m
  - R^2 = 0.75

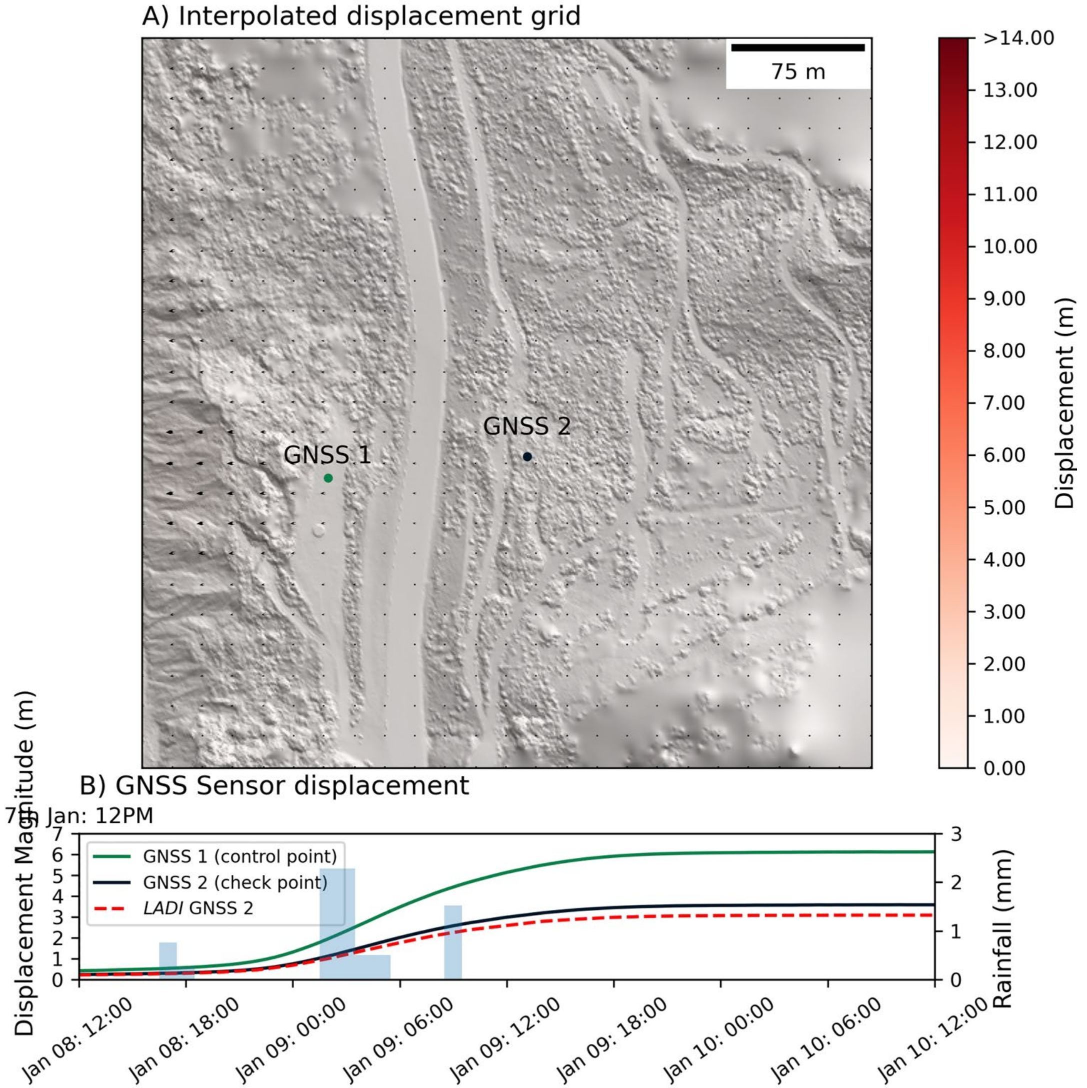


Senogles et al. (Under Review)

Spatio-temporal extrapolation

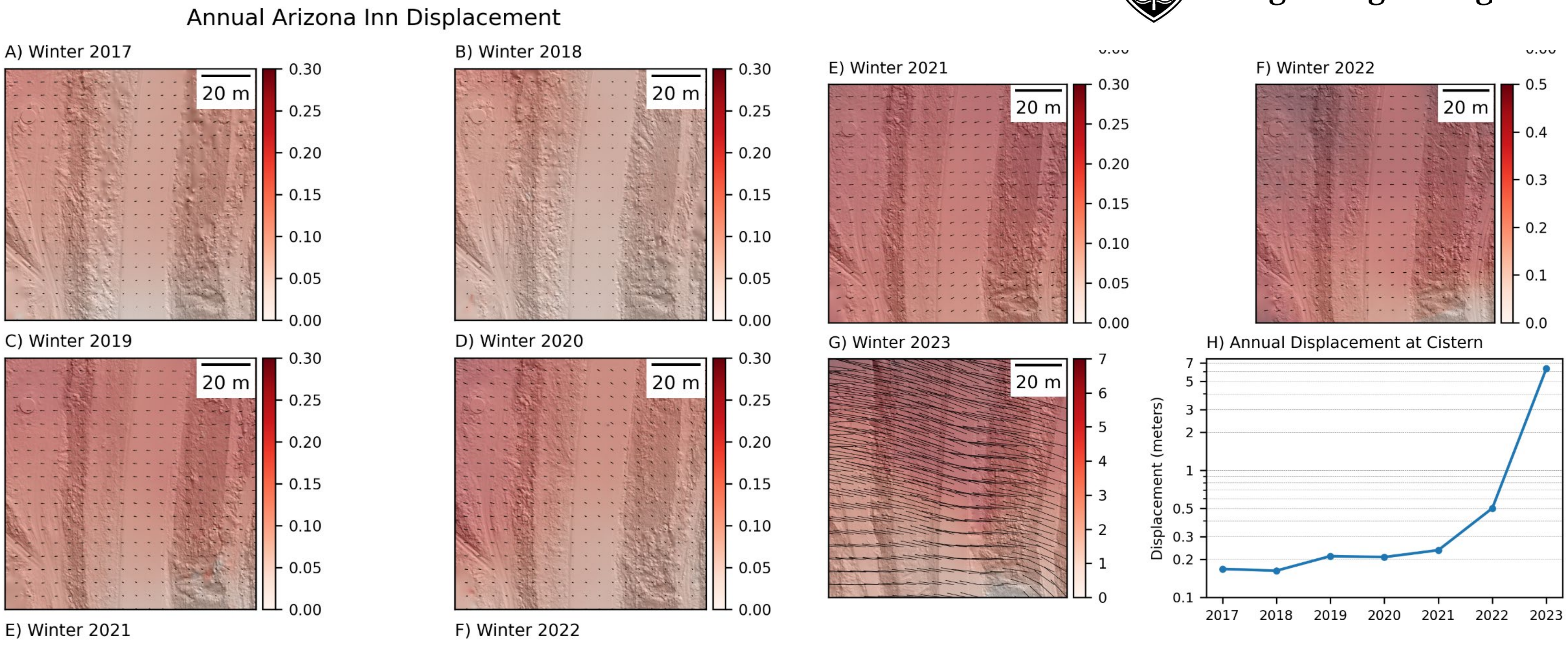


Oregon State University
College of Engineering



Senogles et al. (Under Review)

Arizona Inn history



SlideSim & LADI Summary

1. Novel approaches to 3D landslide displacement monitoring
2. Capable of accurate displacement mapping as shown on real world data
3. Relatively few intuitive parameters
4. Utilizes self-supervised learning, no manual labelling required
5. Robust to input data source and presence of vegetation artifacts
6. Novel method of spatio-temporal interpolation
7. Accurate interpolation with few control points
8. Scalable to large datasets

Part II.

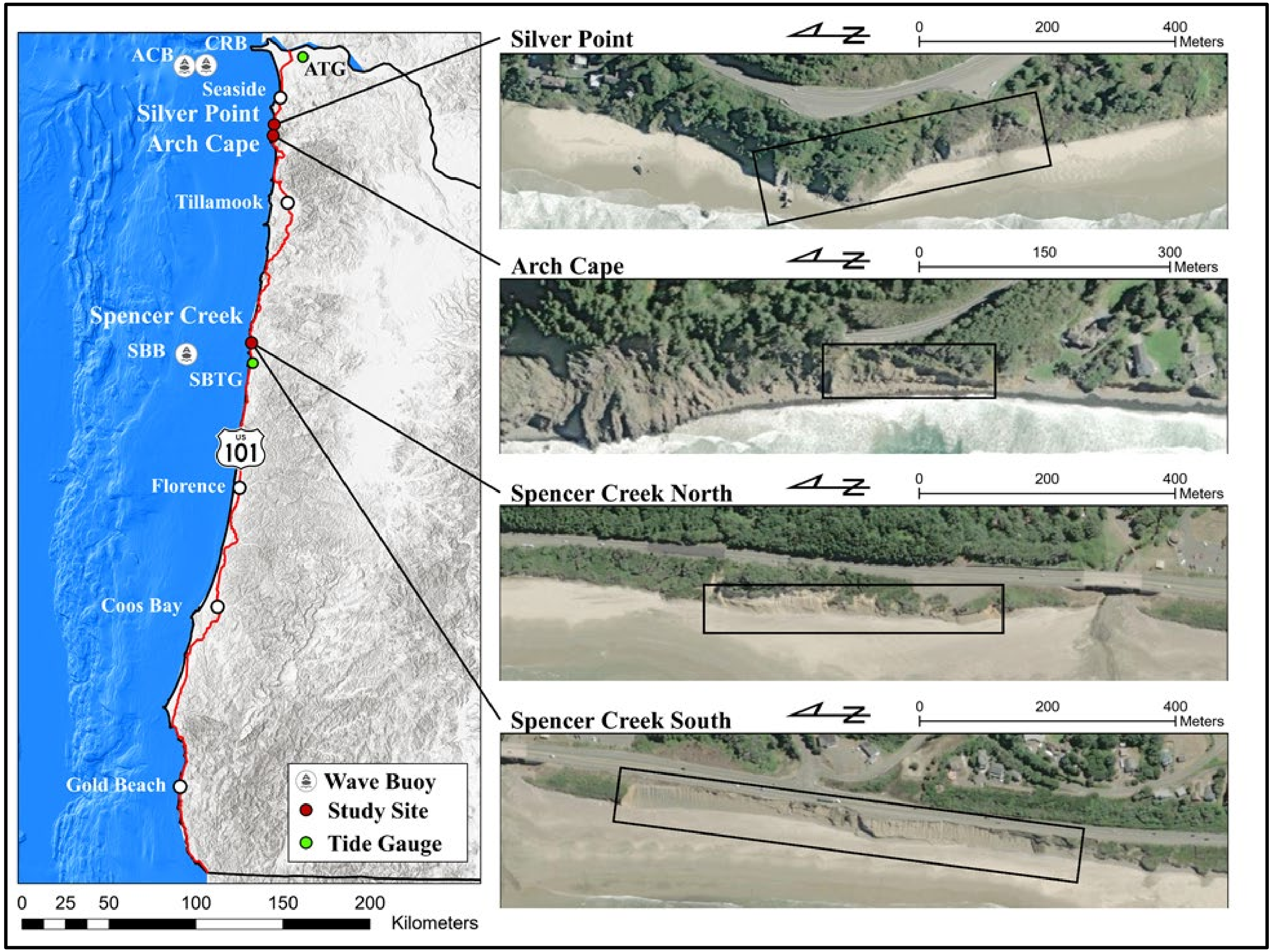
Hyperspatial, Time Series Observations of Morphological and Climatic Processes Driving Sea Cliff Erosion in Oregon, USA

Objectives:

1. Quantify erosion rates
2. Develop an approach to classify erosion into zones
3. Study relationships between erosion and environmental conditions
4. Analyze evolution of erosion and morphology over time
5. Quantify volume-frequency relationships

Data Collection

Oregon State University
College of Engineering



7 year semi-annual surveys 2016-2023

PRISM CLIMATE GROUP

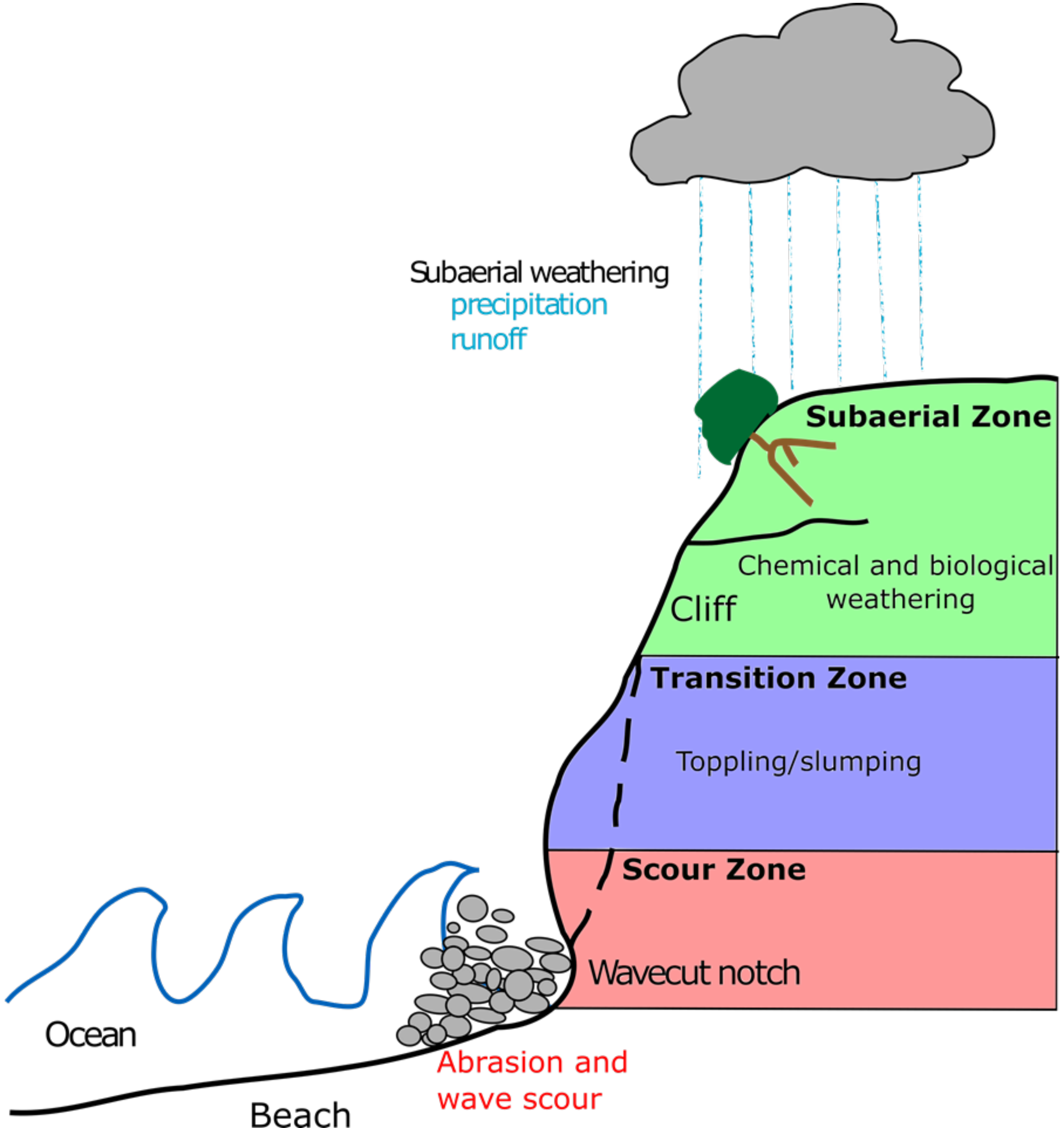
Stonewall Bank Wave Buoy
(photo courtesy of NOAA)

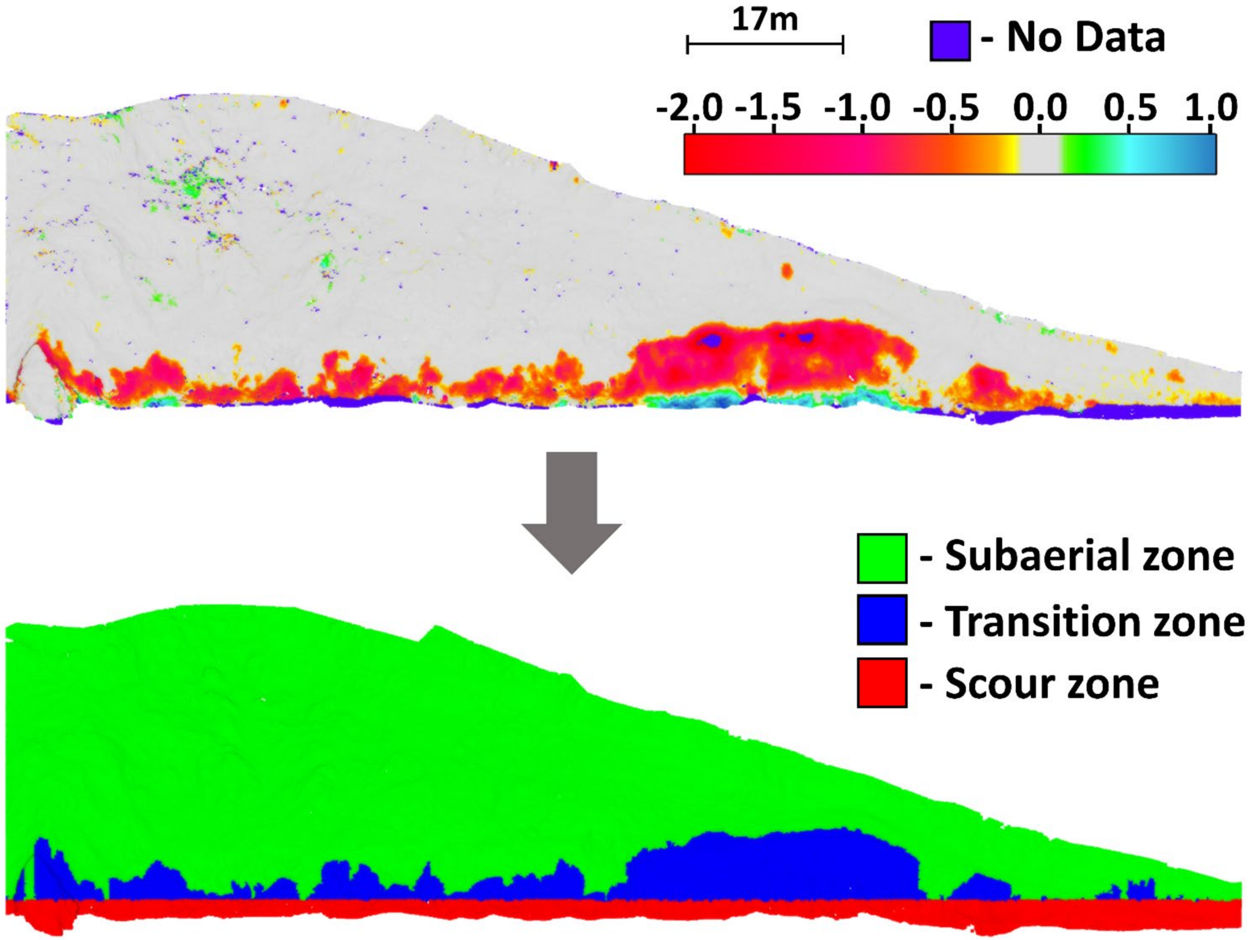
South Beach Tide Gauge
(photo courtesy of NOAA)

Change Detection

Oregon State University
College of Engineering

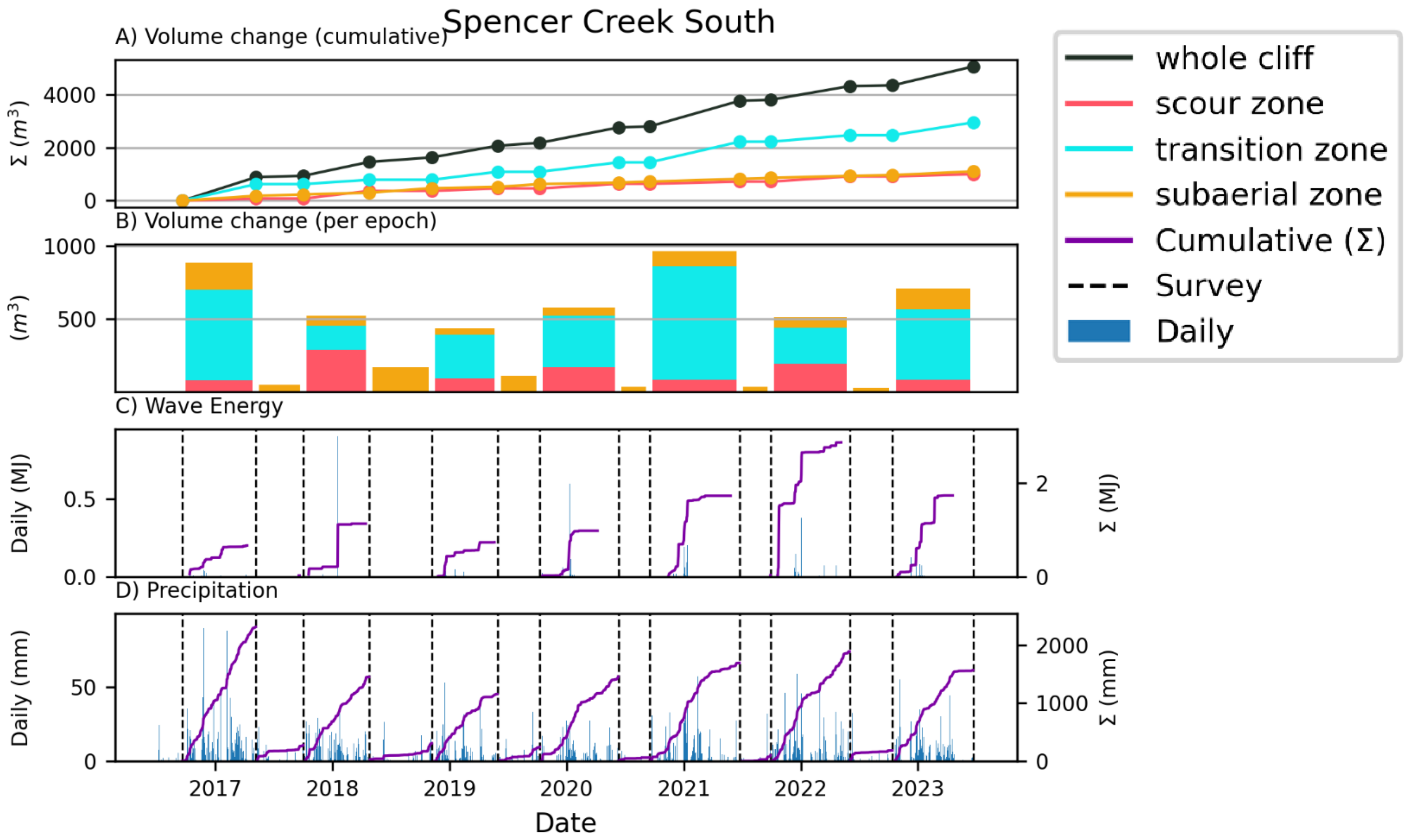
Erosion Zone Classifier





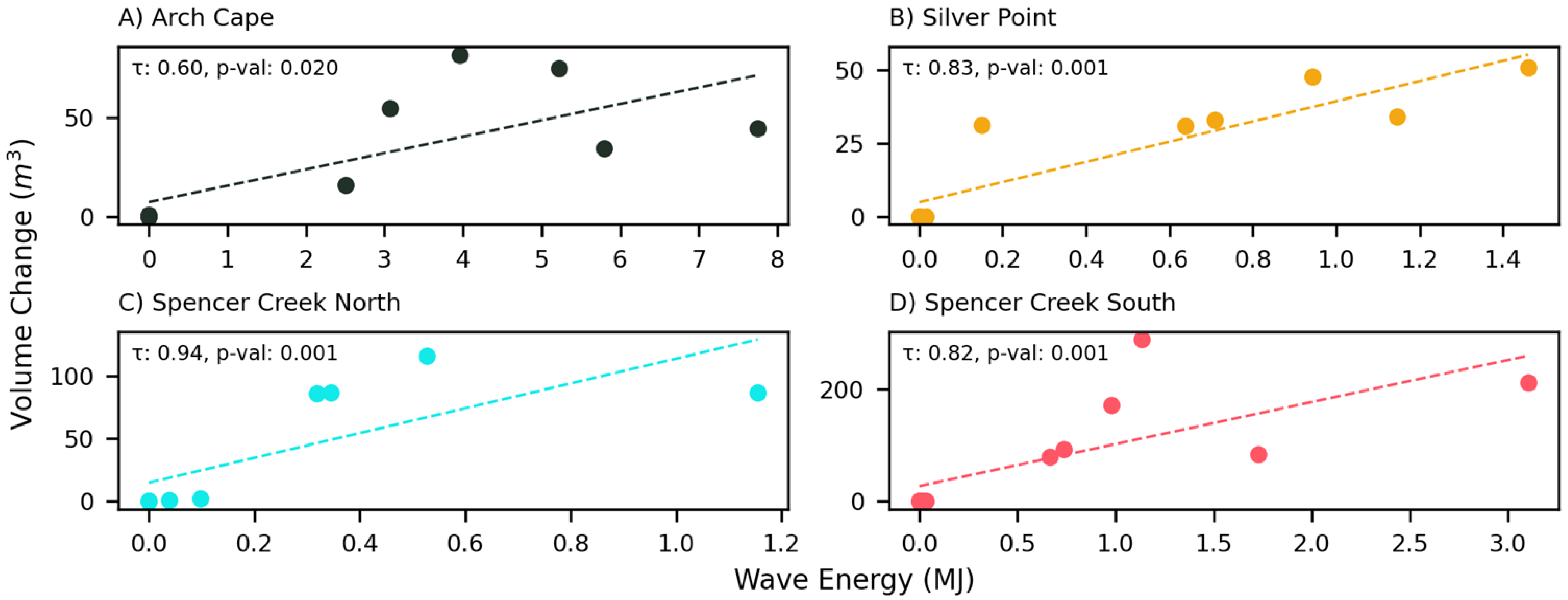
Conditions Over Time

Oregon State University
College of Engineering



Wave Energy vs Scour Zone

Oregon State University
College of Engineering



Volume - Frequency

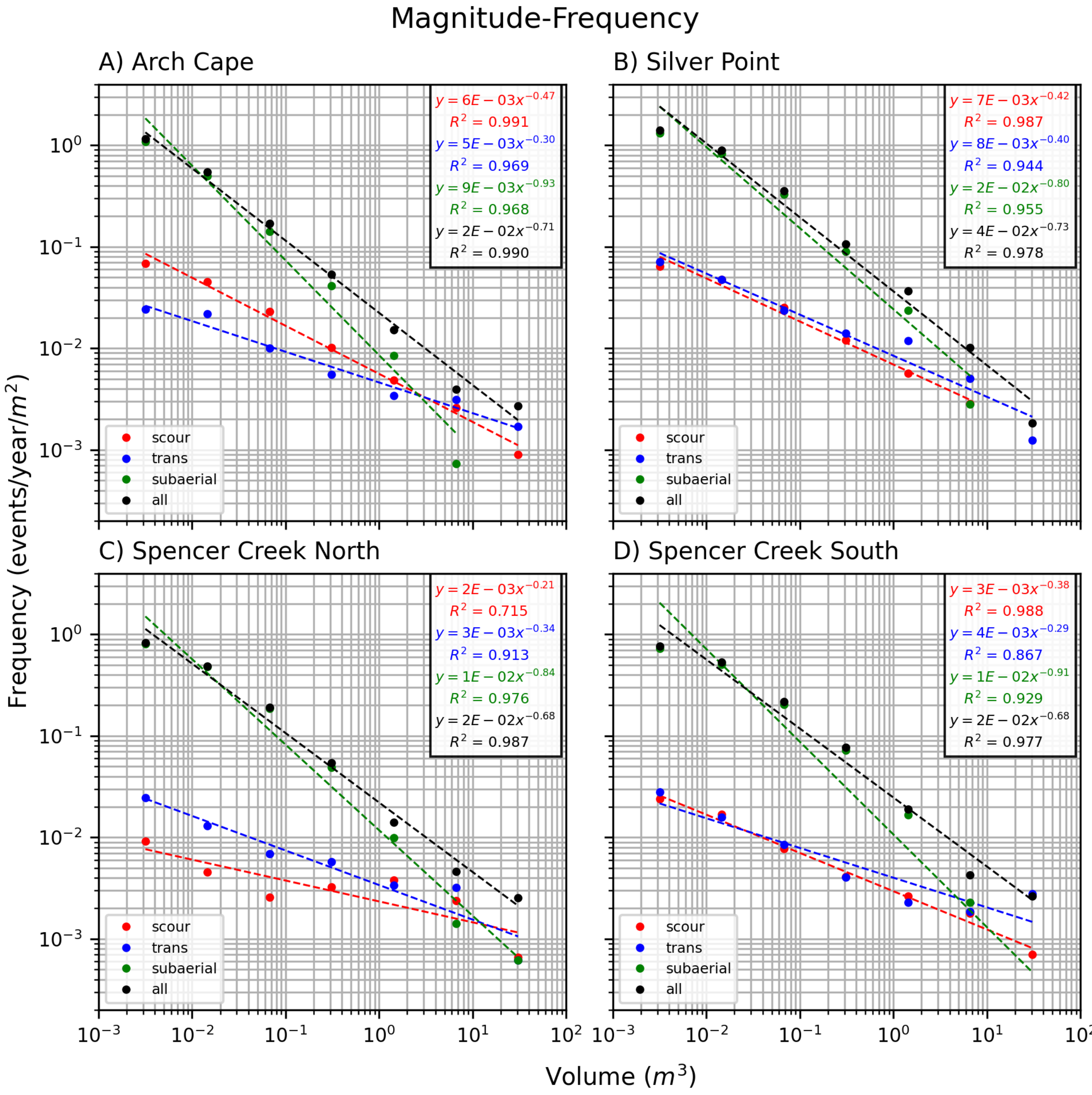
Oregon State University College of Engineering

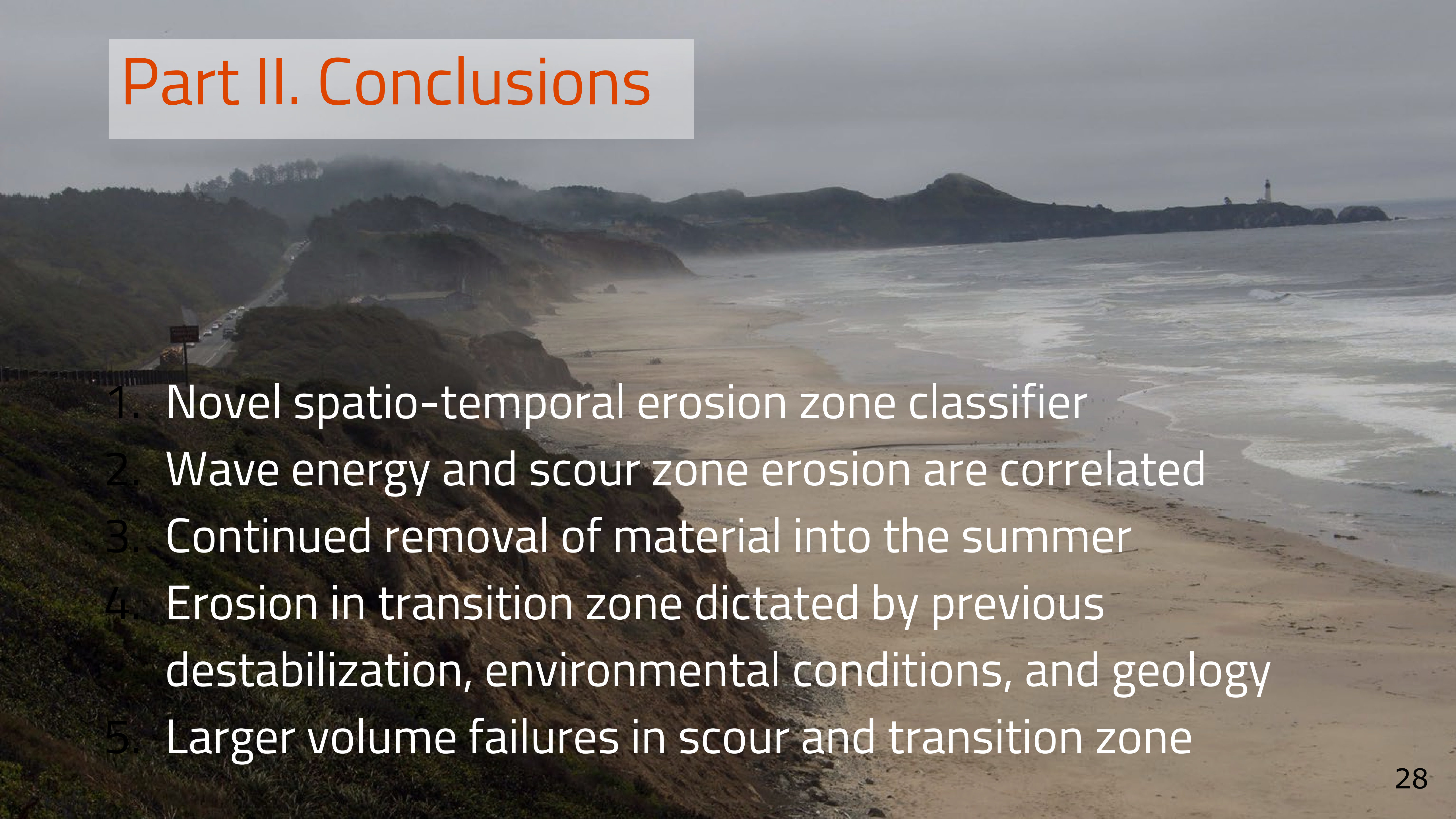
Scour β = -0.37 (-0.18 to -0.45)

Transition β = -0.33 (-0.26 to -0.40)

Subaerial β = -0.87 (-0.80 to -0.90)

Meta β = -0.71 (-0.20 to -1.40)





Part II. Conclusions

1. Novel spatio-temporal erosion zone classifier
2. Wave energy and scour zone erosion are correlated
3. Continued removal of material into the summer
4. Erosion in transition zone dictated by previous destabilization, environmental conditions, and geology
5. Larger volume failures in scour and transition zone

Acknowledgements

- Ben Leshchinsky
- Jon Allan
- Curran Mohney
- Kira Glover-Cutter
- Geoff Crook
- Andrew Senogles
- Matt O'Banion
- Michael Bunn
- Bryce Berrett
- Erik Fulmer

- Fatih Sen
- Dae Kun Kang
- Maria Krivova
- Joanie Hermann
- Bipin Peethambaran
- Stefano Alberti
- Eve Lathrop
- Kat Holtan
- Peyton Pressler
- Ezra Che
- Sahar Kamalou

- David Abiola
- Marian Jamieson
- Sanjaya Paudel
- Mohsen Arjmand
- Ezra Stockton
- Caleb Ogbeta
- Nick Mathews
- Mahyar Sharifi-Mood
- Farid Javadnejad
- Richie Slocum
- Chase Simpson
- And more.....