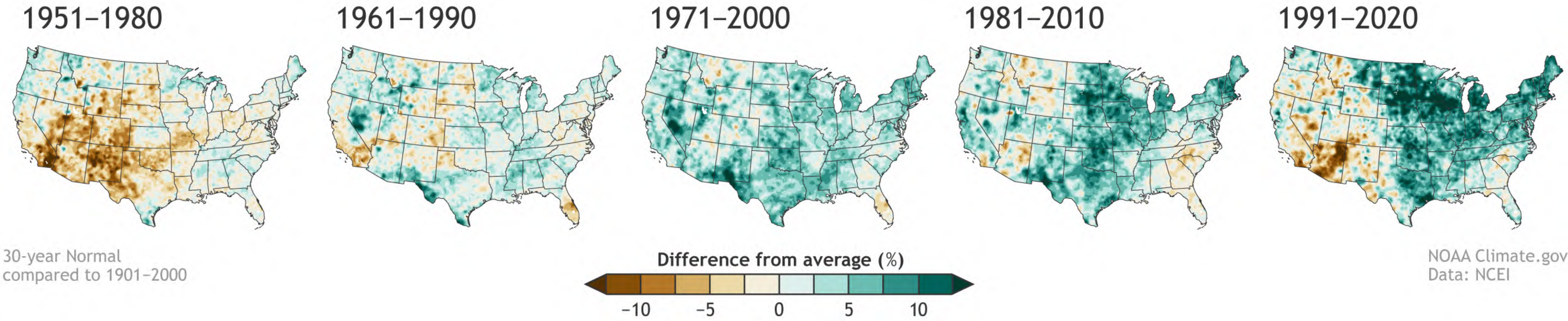
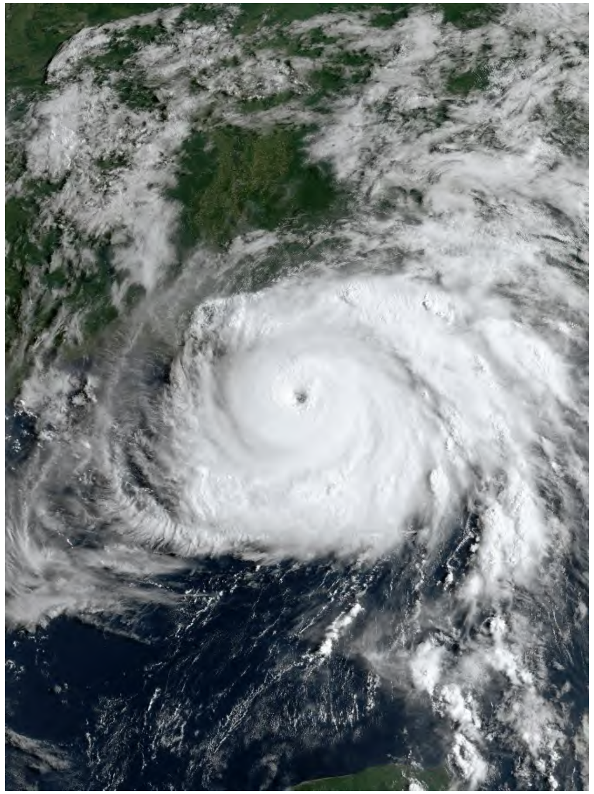



# Highway Slope Monitoring using 3D Laser Scanning at Different Seasons

AQM Zohuruzzaman, David P. Wamai, Weicong Feng, Sadik Khan, **Austin R.J. Downey**, Jie Wei, Erik Blasch, Paul T. Schrader

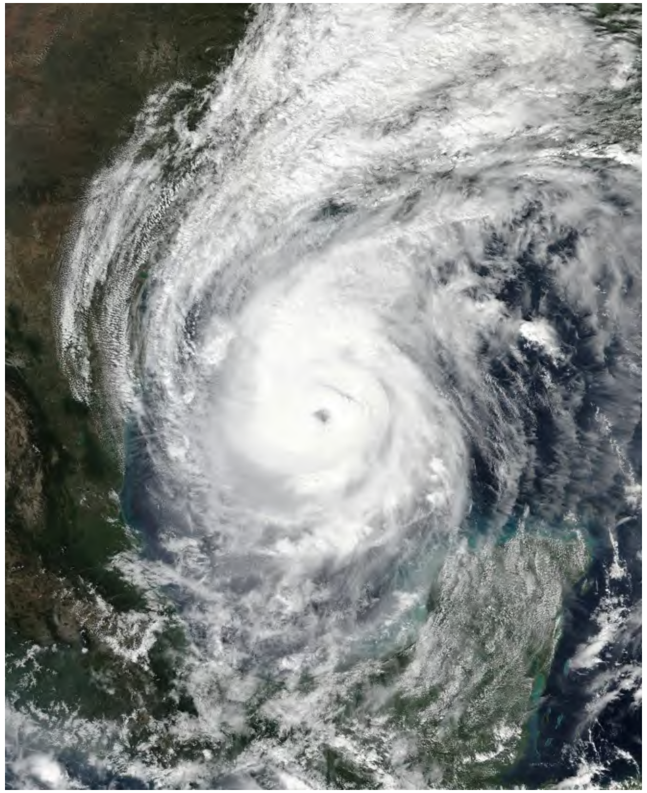
UNIVERSITY OF South Carolina
JSU 1877 JACKSON STATE UNIVERSITY®
CUNY THE CITY UNIVERSITY OF NEW YORK
AFRL THE AIR FORCE RESEARCH LABORATORY LEAD | DISCOVER | DEVELOP | DELIVER

# Recent Hurricanes in The Gulf of Mexico

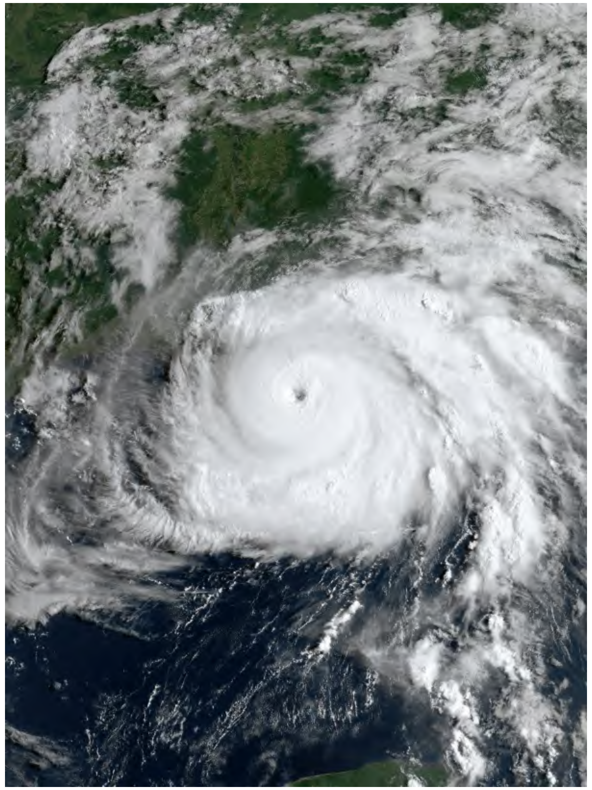


**Hurricane Harvey**
Category: 4
Year: 2017
Affected States: Texas, Louisiana
Damage: $125 Billion

**Hurricane Laura**
Category: 4
Year: 2020
Affected States: Louisiana
Damage: $19.1 Billion



**Hurricane Delta**
Category: 4
Year: 2020
Affected States: Louisiana, Texas
Damage: $3.09 Billion



**Hurricane Ida**
Category: 4
Year: 2021
Affected States: Louisiana, Northeastern USA
Damage: $65.25 Billion

# Climate Change

The New York Times

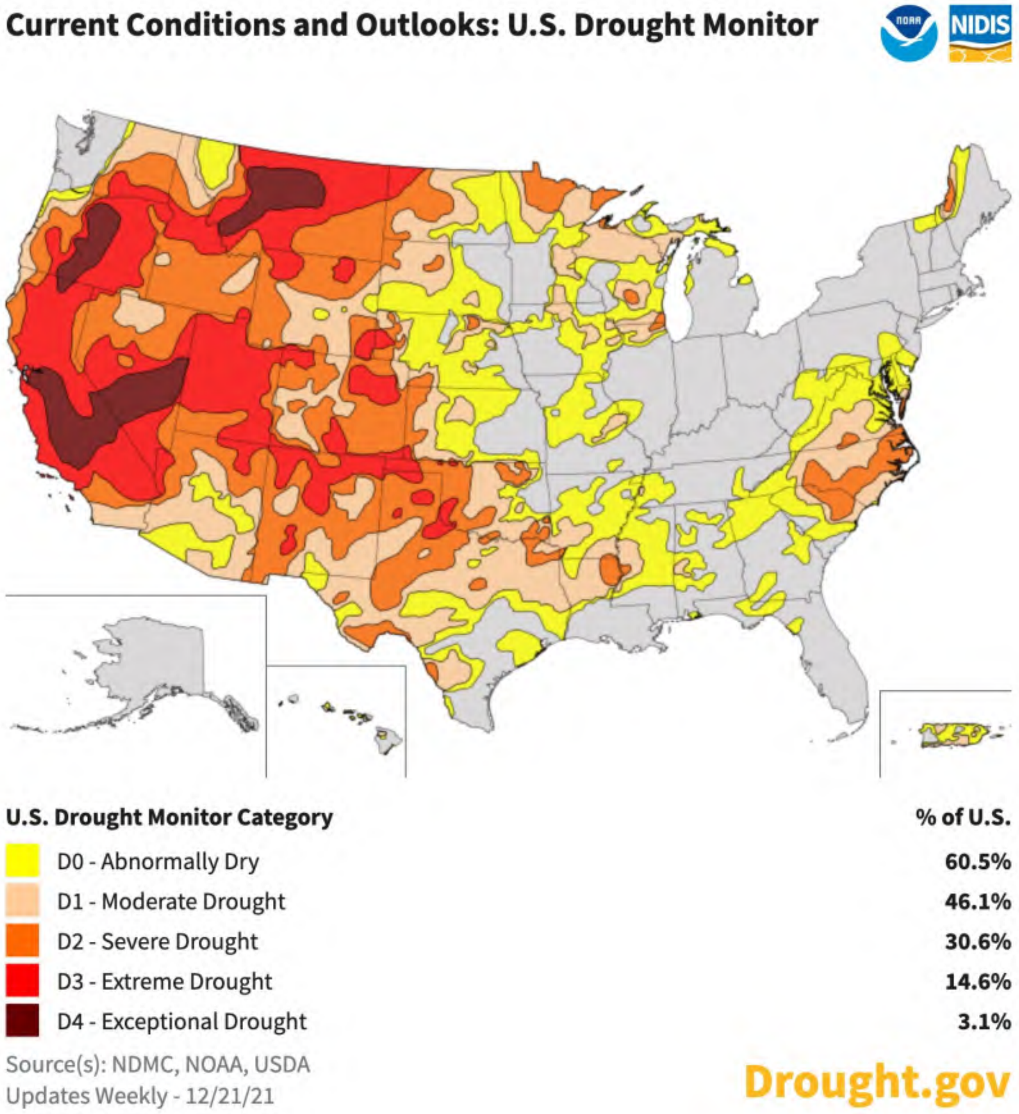
These Maps Tell the Story of Two Americas: One Parched, One Soaked

By Aatish Bhatia and Nadja Popovich Aug. 24, 2021

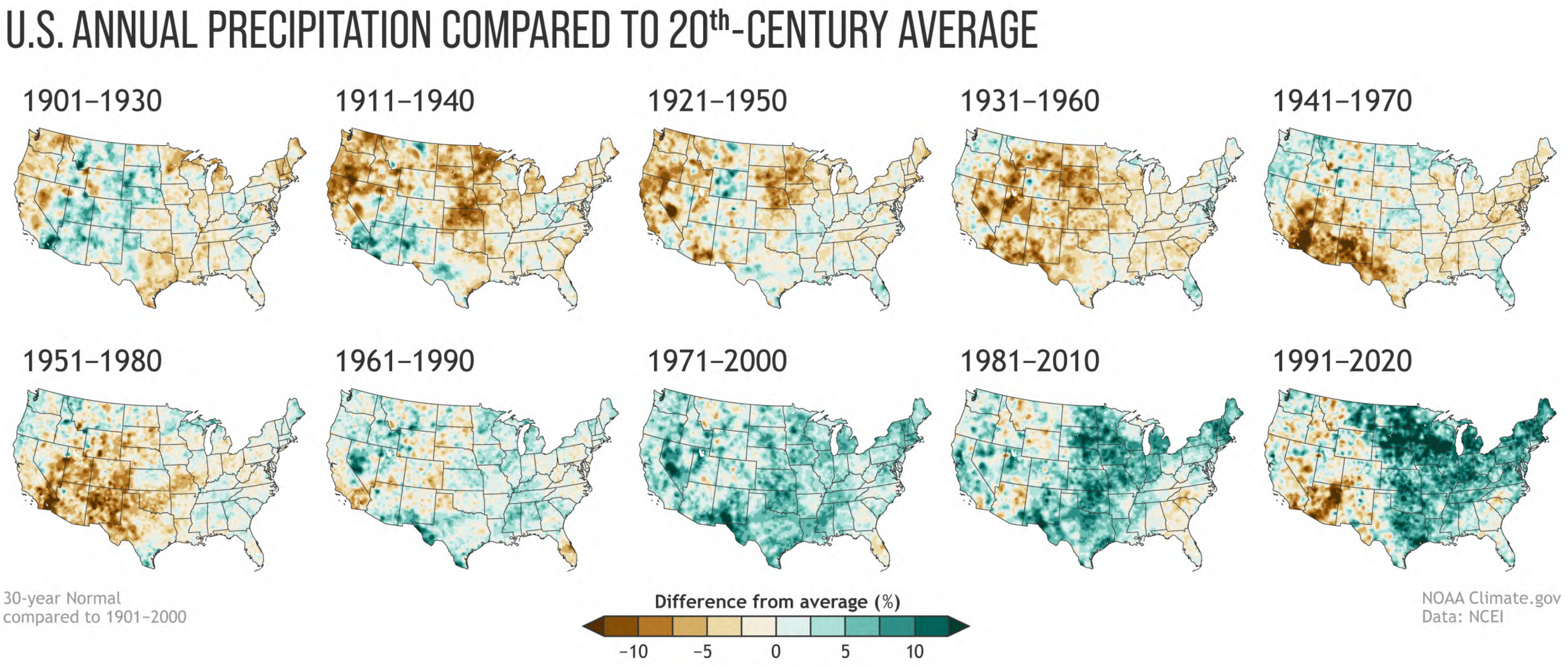
The country, like most of the world, is becoming both drier and wetter in the era of climate change. It depends where you live.



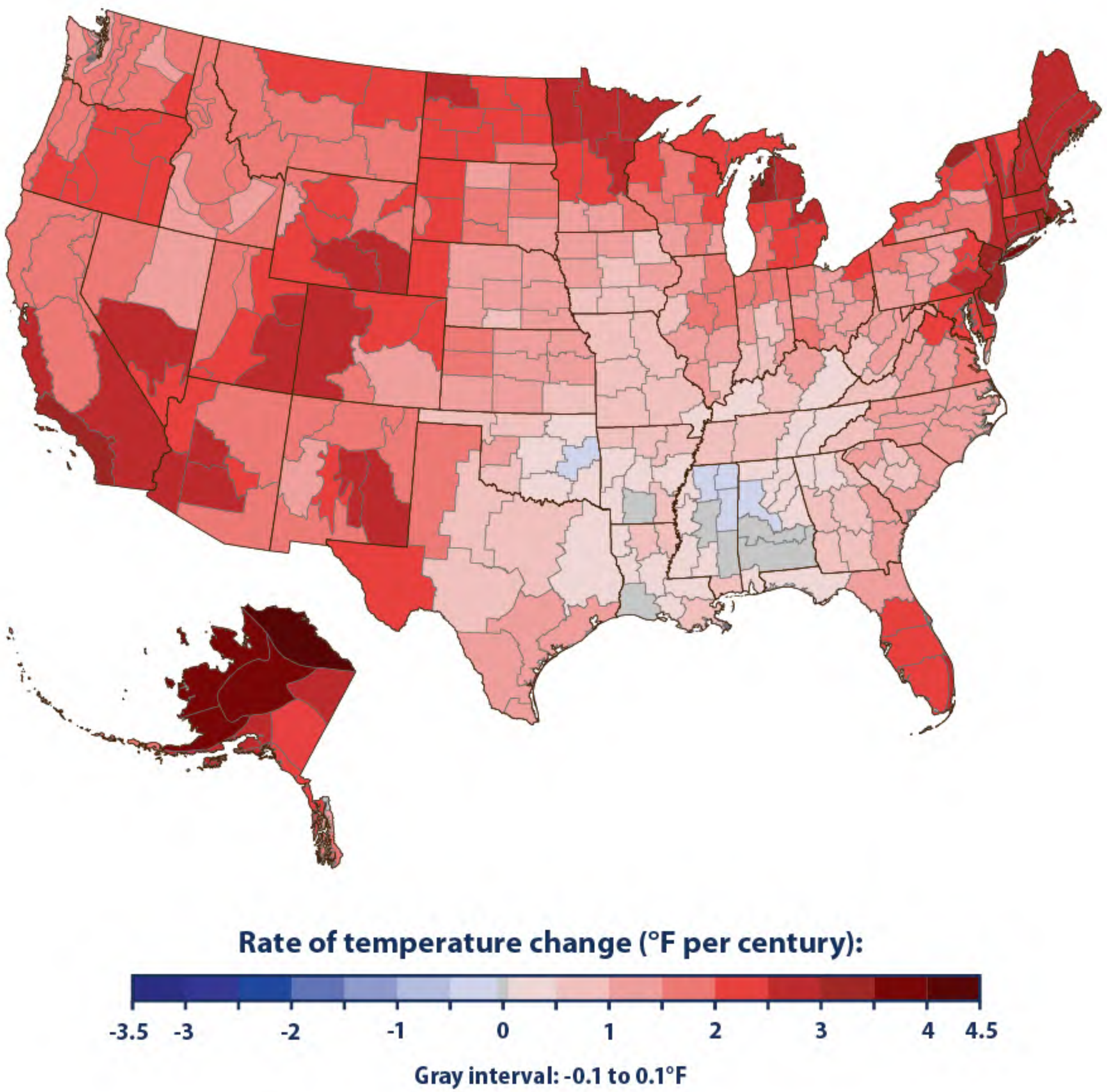
Source: NOAA's National Centers for Environmental Information

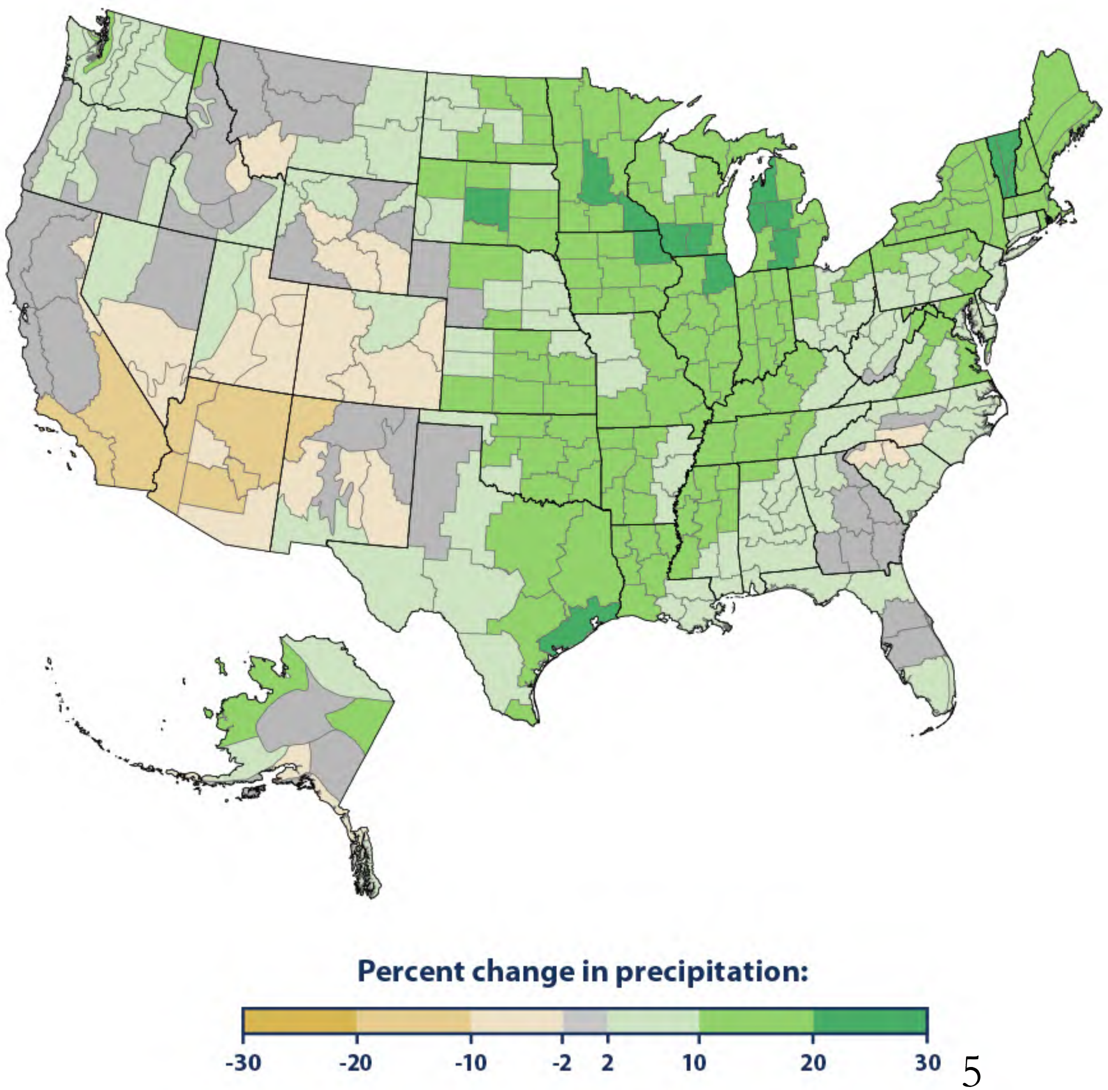


# Changes in Precipitation

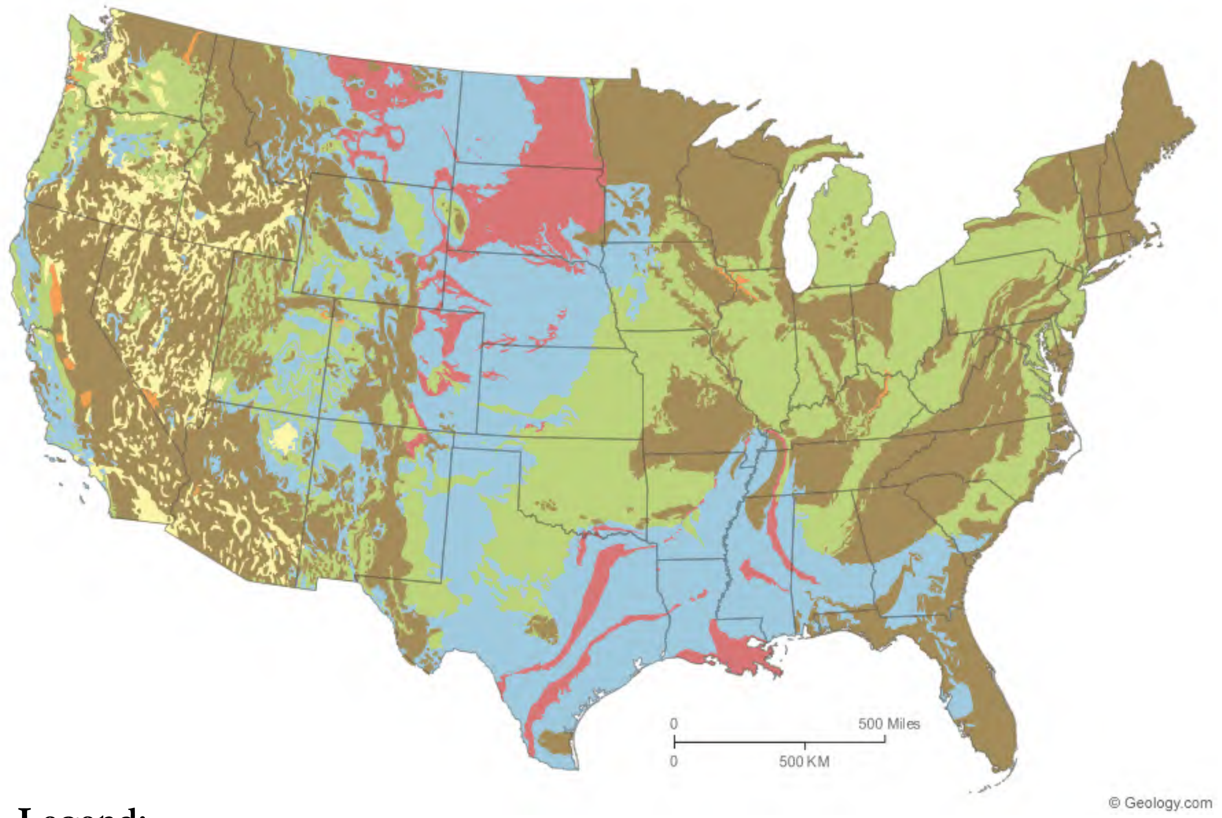


# Temperature and Precipitation Variation Due to Climate Change

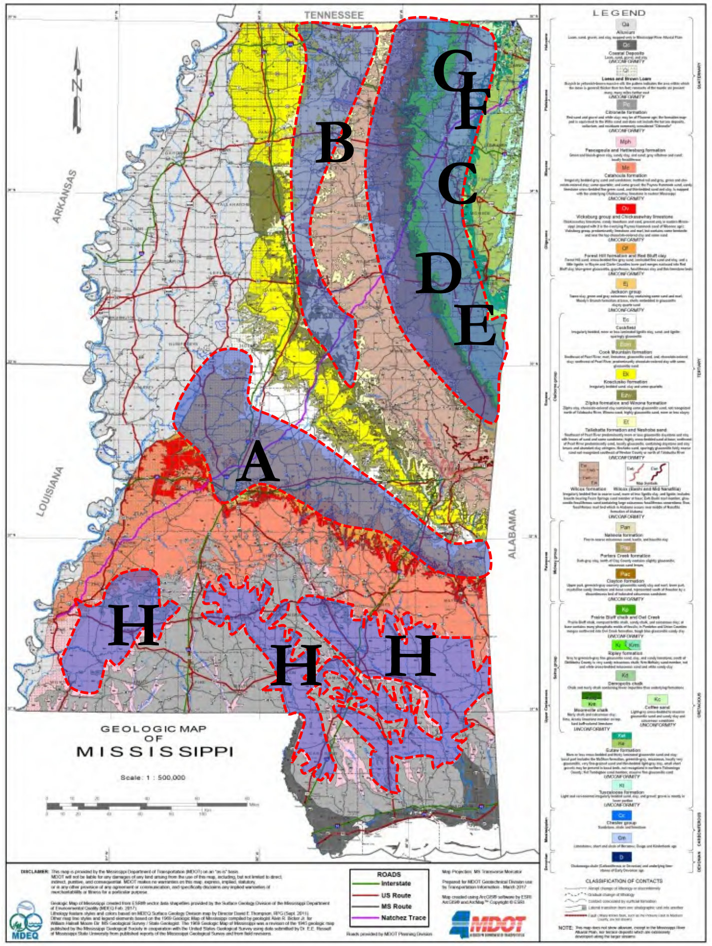


# Expansive Soil




**Legend:**
**Red**: Clay having high swelling potential
**Blue**: Less than 50% of clay contents having high swelling potential
**Orange**: Clay content having slight to moderate swelling potential
**Green**: Less than 50% of clay contents having slight to moderate swelling potential
**Brown**: Little or no swelling clay
**Yellow**: Insufficient data

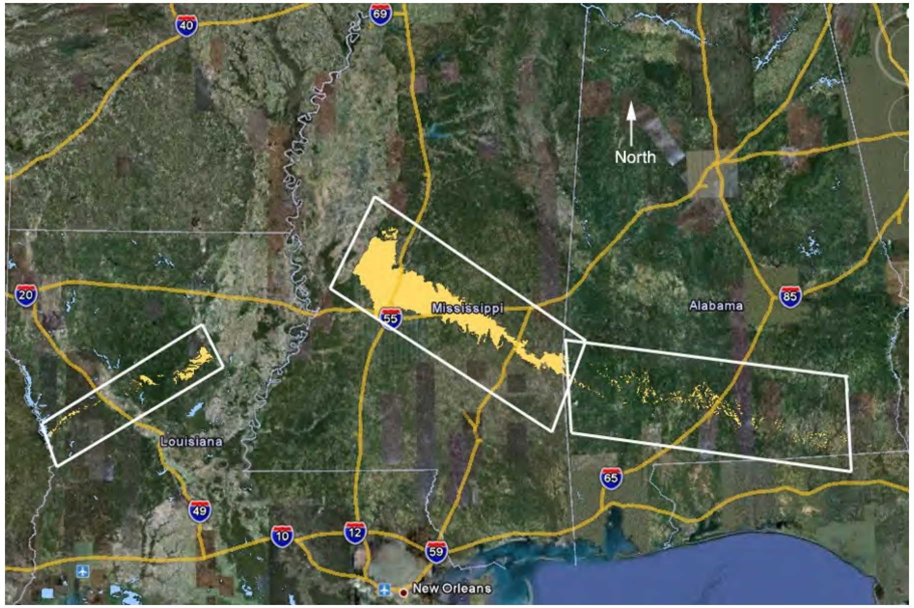



A.Yazoo Clay Formation, B: Porters Creek Clay Formation C: Zilpha Formation, D: Prairie Bluff / Owl Creek Formation, E: Ripley Formation F: Demopolis Chalk Formation, G: Mooreville Chalk Formation H: Hattiesburg/Pascagoula Formation

# Landslides on Expansive Soil

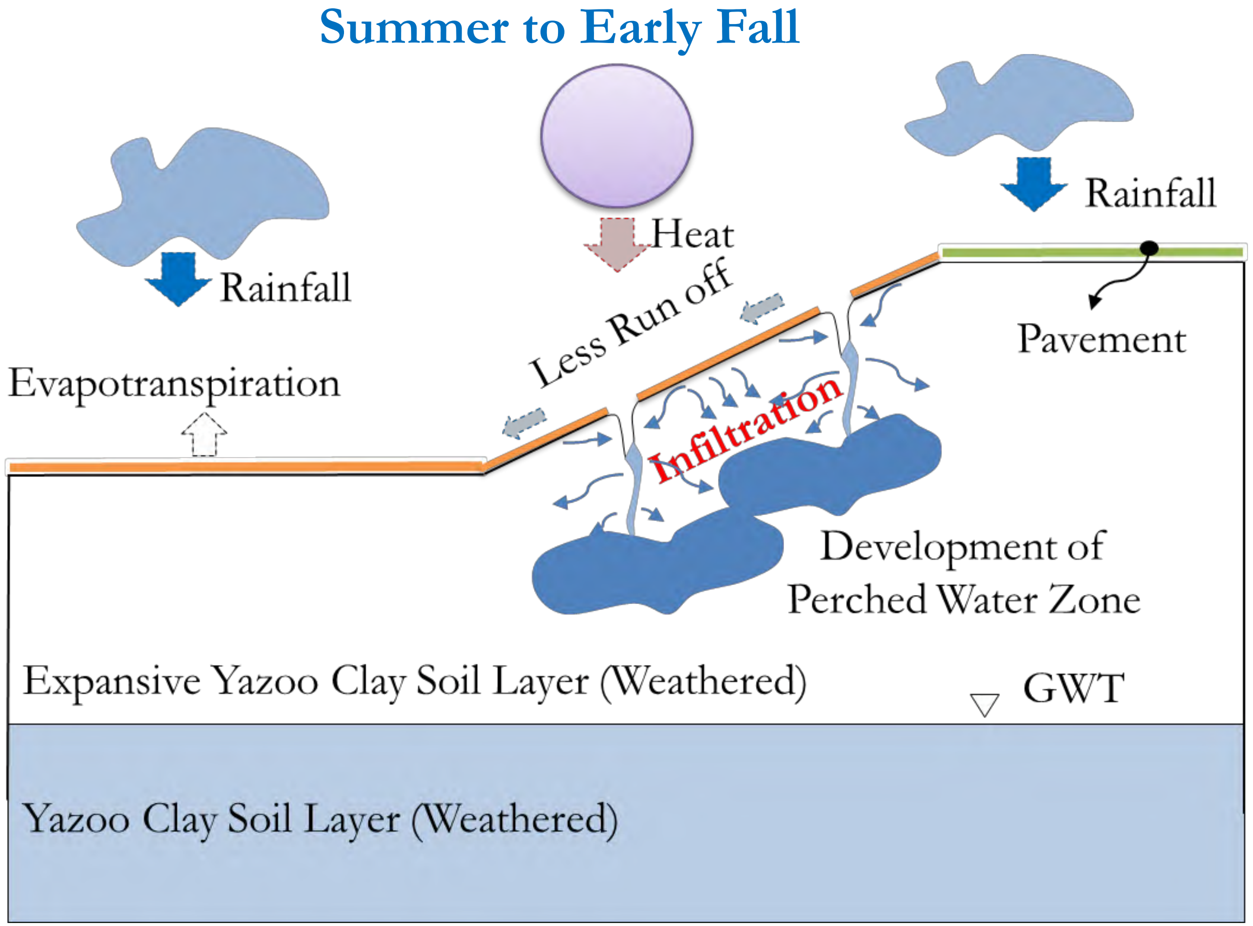
Clinton,
Mississippi
I-20 West

Madison, Mississippi
I55 South exit to
Sowell Road

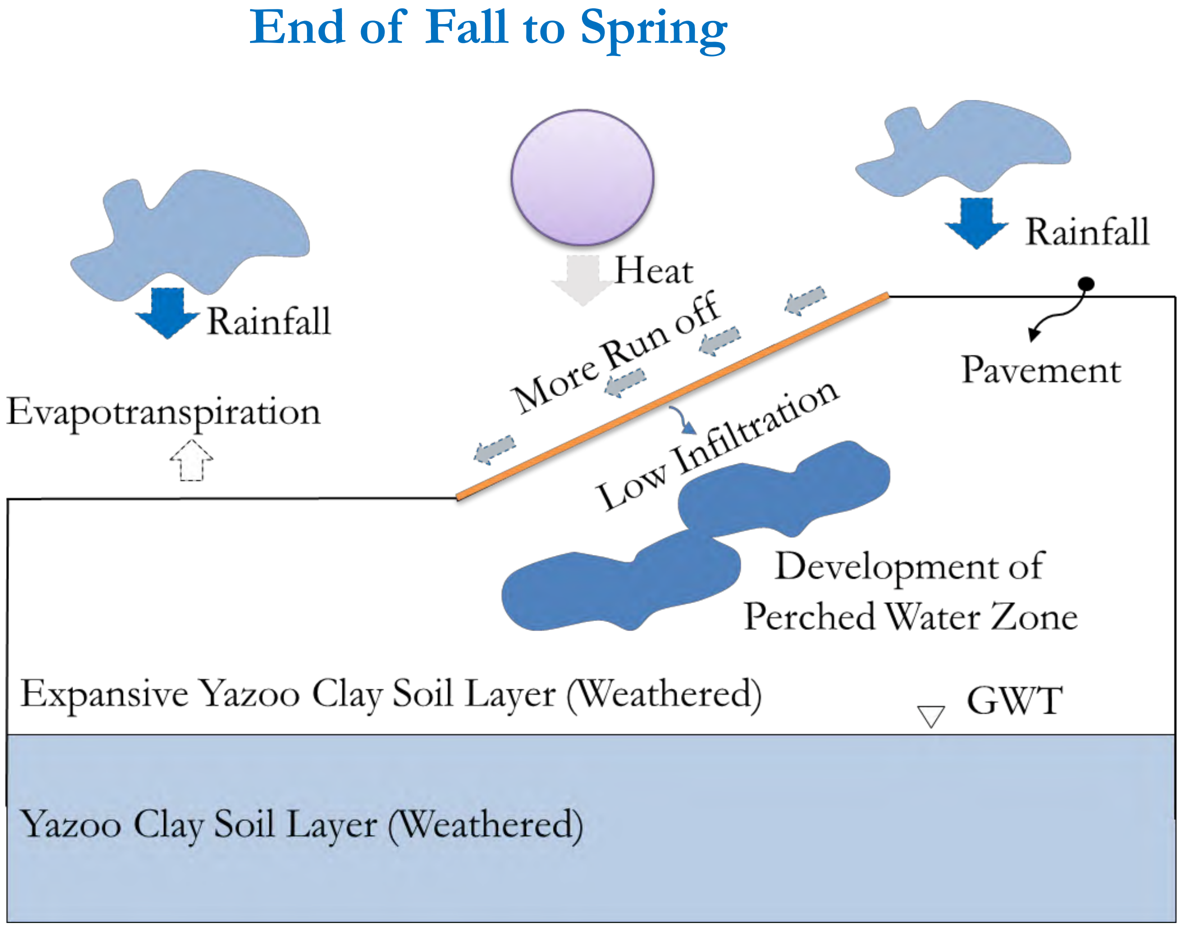



Boundary boxes of the Jackson Formation, including Yazoo clay and its geological equivalents, in Mississippi, Alabama, and Louisiana (after USGS 2010).

# Effect of Climatological Cycles on Landslides

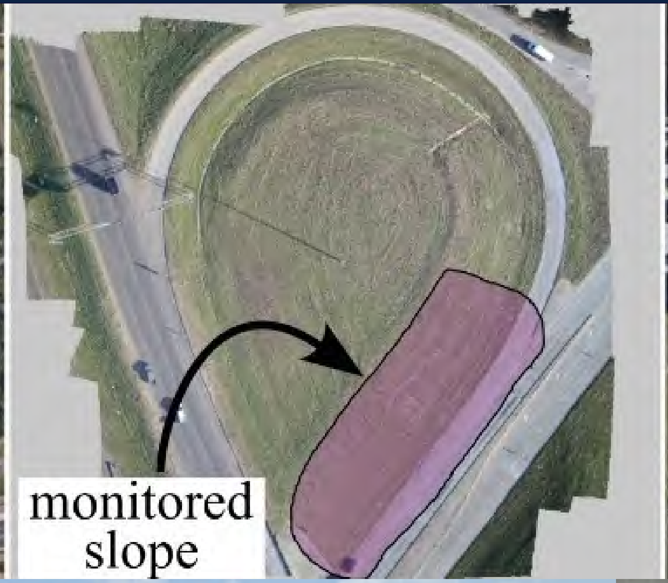



**Presence of desiccation cracks increase vertical permeability which increase infiltration and develop moisture build up**




**As soil gets wet, the desiccation cracks disappear which decrease infiltration. However infiltrated water retained in the slope**

# Monitoring of the Highway Slope Along Terry Road, Jackson, MS



Terrestrial LiDAR

UAV LiDAR

# 3D Point Cloud Surface Topography of the Monitored Embankment

2021 - June

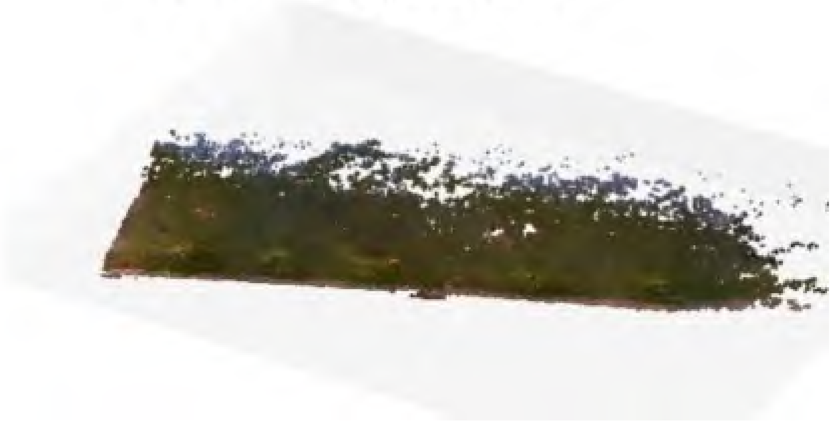
2021 - October

2022 - February

2022 - November

2023 - June

2023 - September



# Computationally Efficient 3-step Plan LiDAR Data Processing

**Step 1: Data Segmentation and Preparation**

- Segment 3D point cloud data into two main regions: road and bank.
- Use normal vectors and curvature values for segmentation.
- Classify points into green (embankment) and blue (road) regions.
- Focus analysis on the bank, filtering out road data.

**Step 2: Curvature Histogram Analysis**

- Compute local Gaussian curvature for each point in the bank.
- Generate a 100-dimensional histogram array representing bank curvature.
- Use Wasserstein distance to compare curvature histograms across different banks.
- This provides a quantitative measure of similarity between bank structures.

**Step 3: Principle Component Analysis (PCA)**

- Conduct PCA on curvature embedding to analyze structural variance within banks.
- Reduce data dimensionality to two principal components.
- Facilitate global visualization and intuitive analysis of data structure.
- Reveal primary modes of variation and identify underlying patterns.

# Step 1: Data Segmentation and Preparation

Step 1 Operations

- Segment 3D point cloud data into two main regions: road and bank.
- Use normal vectors and curvature values for segmentation.
- Classify points into green (embankment) and blue (road) regions.
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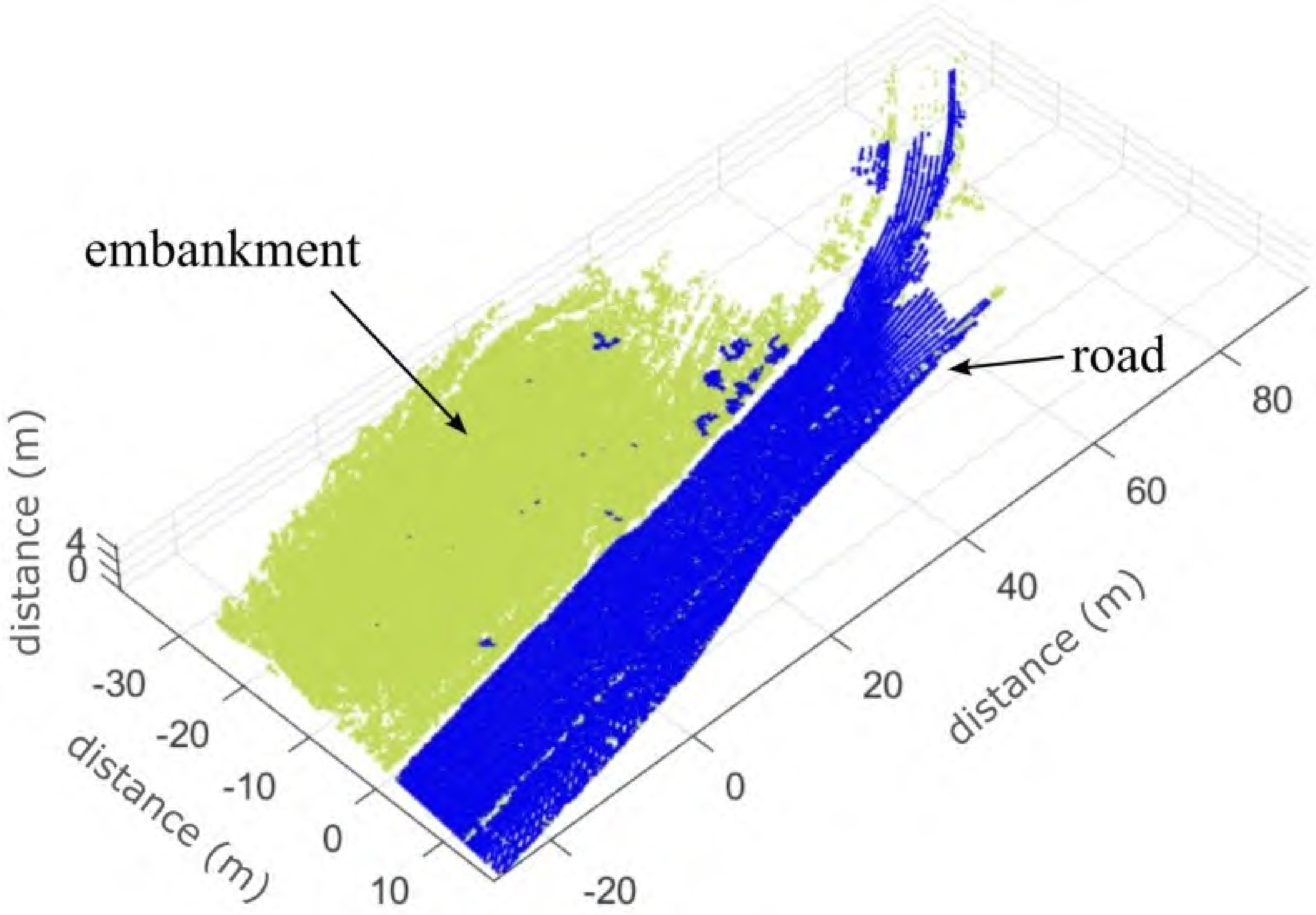
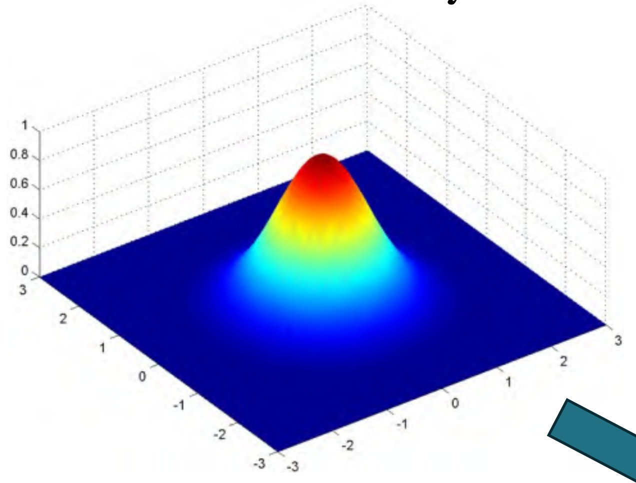


# Step 2: Curvature Histogram Analysis

Step 2 Operations

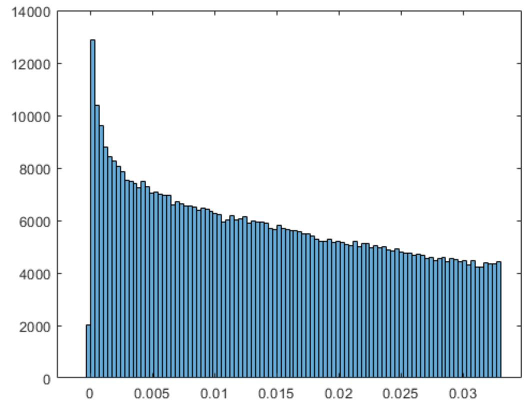
- Compute local Gaussian curvature for each point in the bank.
- Generate a 100-dimensional histogram array representing bank curvature.
- Use Wasserstein distance to compare curvature histograms across different banks.
- This provides a quantitative measure of similarity between bank structures.

**Curvature Analysis**

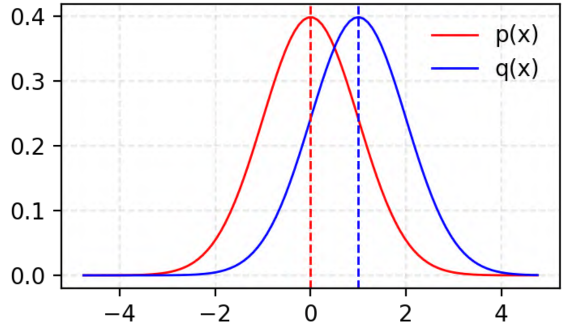




**Histograms**



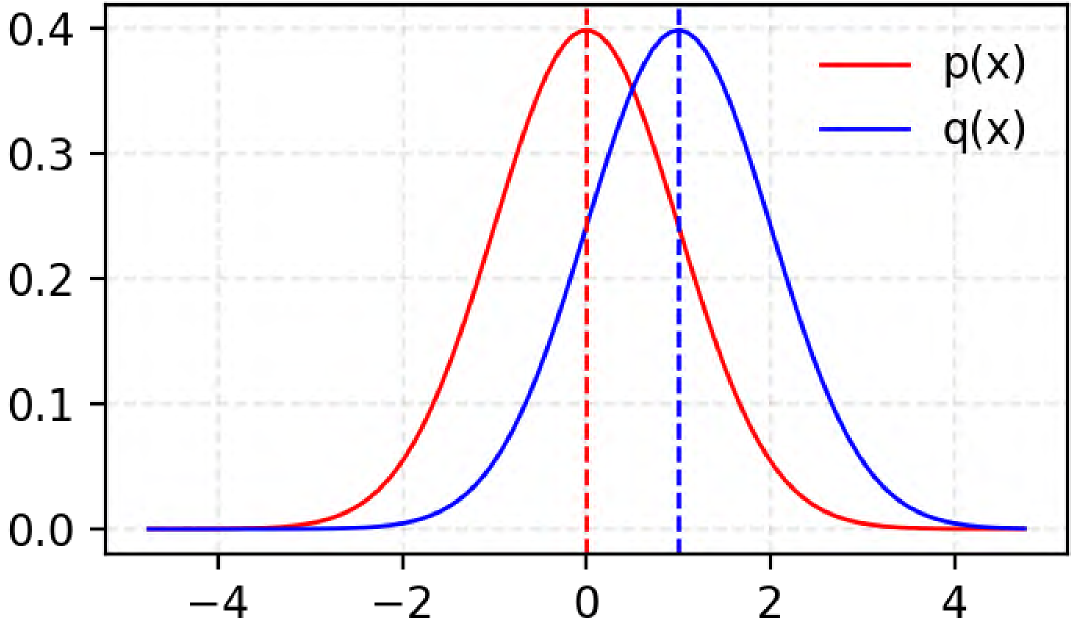

**Wasserstein distance**



# Step 2: Wasserstein Distance (Earth Mover's Distance)

The Wasserstein Distance,

- also called the earth mover's distance, is a metric of the distance function between probability distributions.
- Intuitively, the metric is the minimum "cost" of turning one pile of dirt (probability distributions of histogram) into the other
- It is assumed to be the amount of earth that needs to be moved times the mean distance it has to be moved.
- This provides a quantitative measure of similarity between bank structures.



# Results for Step 2: Wasserstein Distance

Insights from Data

- Wasserstein distance indicates varying degrees of deformation and structural changes across different seasons.
- Significant structural changes observed; average Wasserstein distance for each scan was 152.
- Pronounced Wasserstein distance in June 2023 scan, indicating substantial deformation.
- Reversal in September 2023 with distances between 18 and 98, suggesting seasonal effects rather than geotechnical failure.

**Similarity matrix by Wasserstein distance between the six collected point clouds**.

| | 2021- June | 2021- Oct. | 2022- Feb. | 2022- Nov. | 2023- June | 2023- Sept. |
|---|---|---|---|---|---|---|
| 2021- June | 0 | 24 | 111 | 91 | 381 | 98 |
| 2021- October | | 0 | 112 | 91 | 378 | 98 |
| 2022- February | | | 0 | 29 | 269 | 19 |
| 2022- November | | | | 0 | 290 | 18 |
| 2023-June | | | | | 0 | 282 |
| 2023- September | | | | | | 0 |

# Step 3: Principle Component Analysis (PCA)

Step 3 Operations

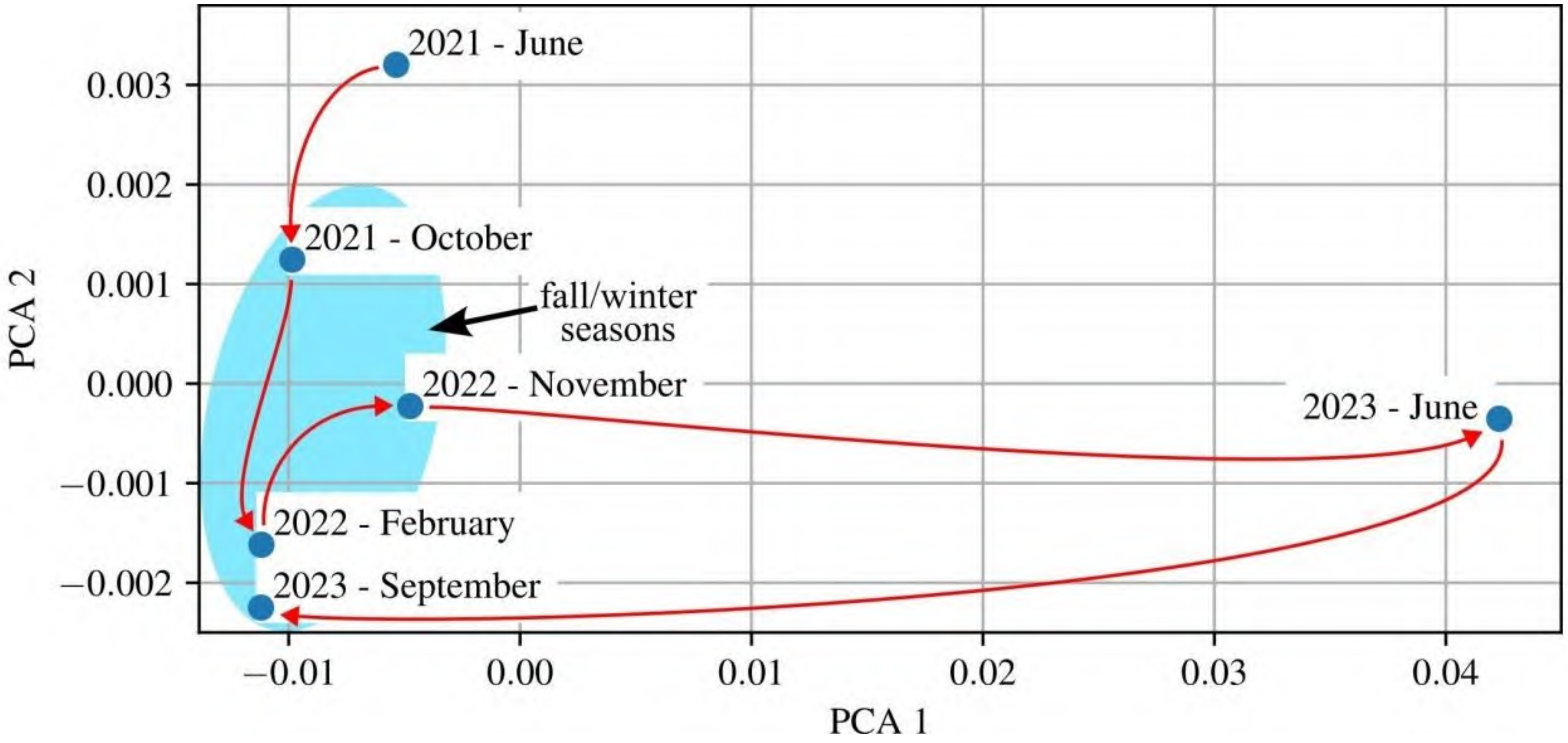
- Conduct PCA on curvature embedding to analyze structural variance within banks.
- Reduce data dimensionality to two principal components.
- Facilitate global visualization and intuitive analysis of data structure.
- Reveal primary modes of variation and identify underlying patterns.


Generic scree plot that is meant to help interpret the PCA and decide how many components to retain.

# Results for Step 3: Principle Component Analysis (PCA)

Insights from Data

- June 2021 and 2023 scans show greatest deviation from this seasonal cluster.
- Suggests a reversion to structural normality post-June 2023



# Thank You

This work is supported by the National Science Foundation Grant numbers 2152896 and 2324052. This work was also partially supported by the Air Force Research Laboratory Faculty Fellowship program which is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation, the United States Air Force, or the US government.

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## Open-source Dataset

GitHub

github.com/ARTS-Laboratory/Dataset-Slope-LiDAR-Embankment-SLidE