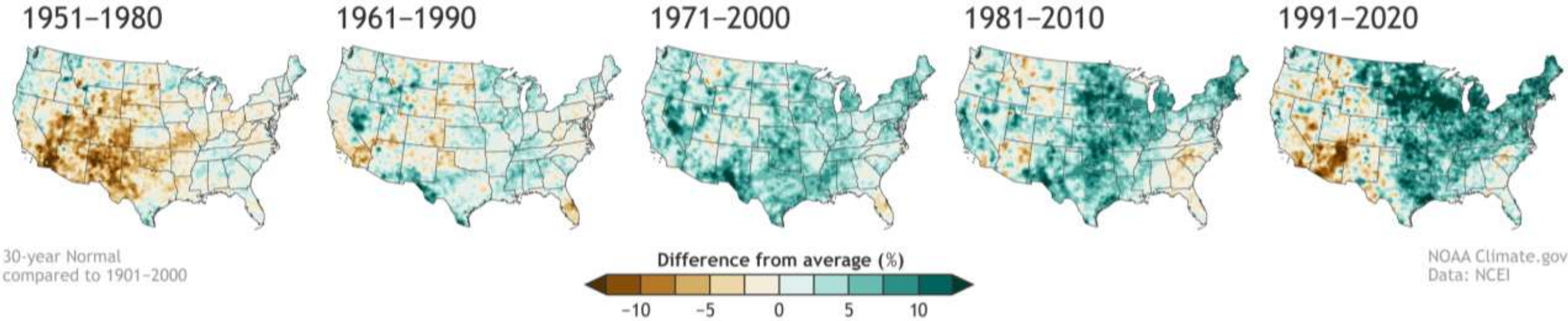



# Earthen Embankment Monitoring using LiDAR data by Randomized Consensus of Topological Data Analysis

Austin R.J. Downey[1], Jie Wei[2], A Q M Zohuruzzaman[3], Paul T. Schrader[4], Sadik Khan[3], Jason Bakos[1]
Weicong Feng[2], Erik Blasch[4], and Erika Ardiles-Cruz[4]

1 University of South Carolina 2 The City College of New York 3 Jackson State University 4 AFRL The Air Force Research Laboratory

# Recent Hurricanes in The Gulf of Mexico

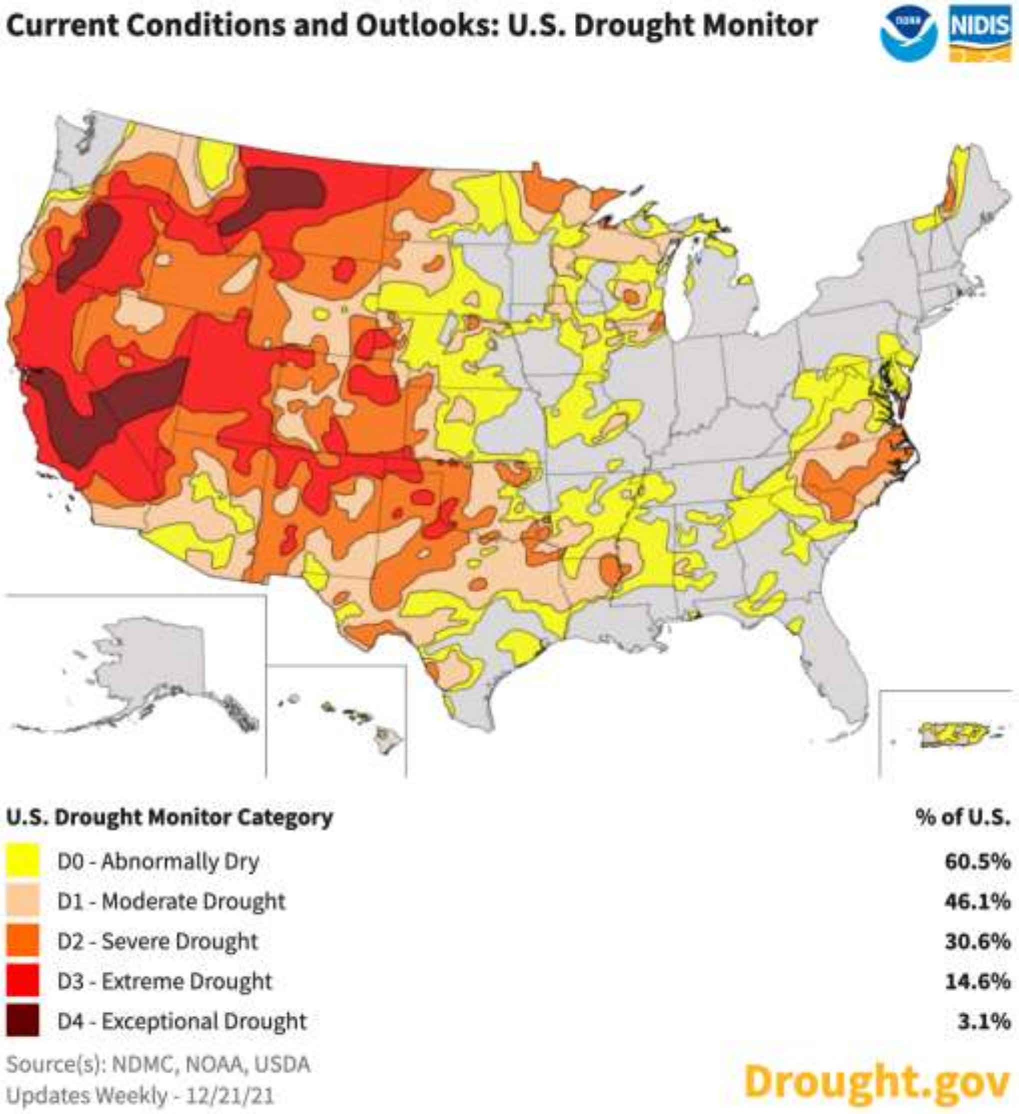
**Hurricane Harvey**
Category: 4
Year: 2017
Affected States: Texas, Louisiana
Damage: $125 Billion

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

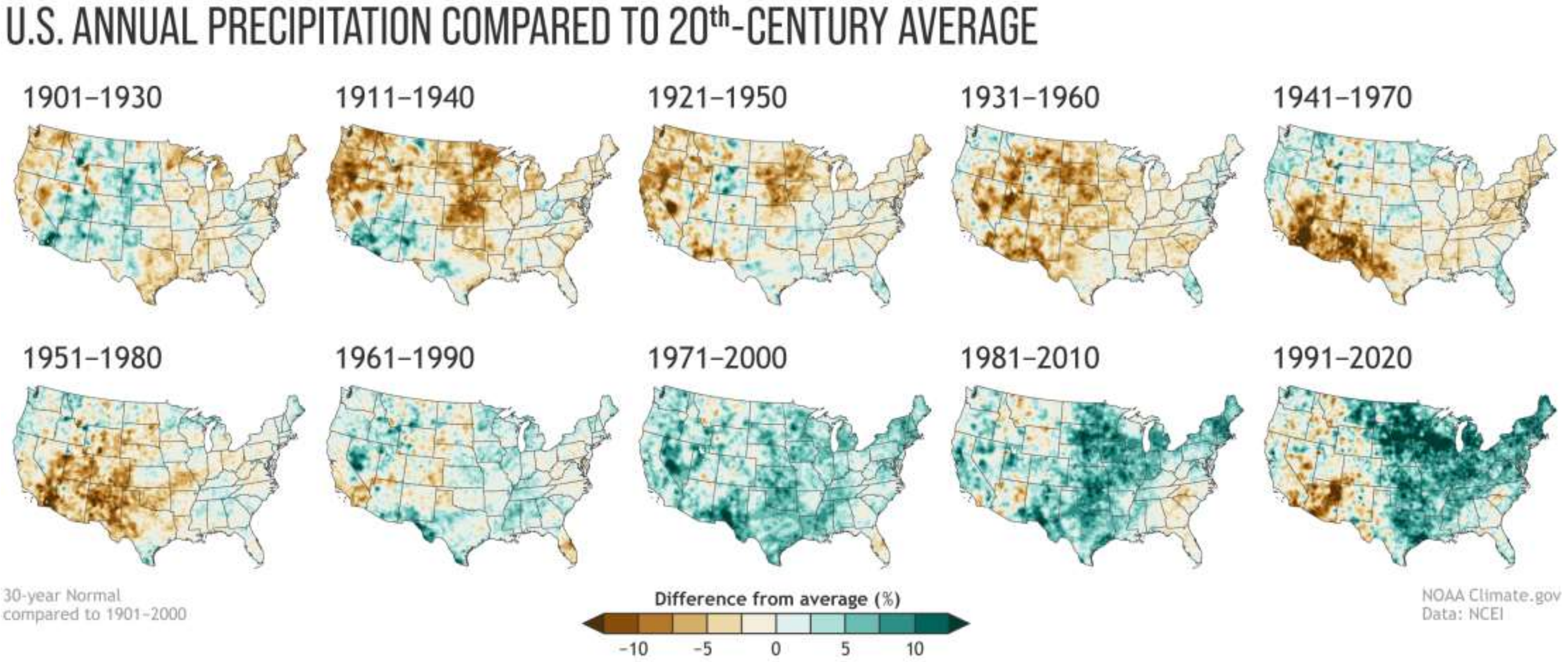
**Hurricane Delta**
Category: 4
Year: 2020
Affected States: Louisiana, Texas
Damage: $3.09 Billion

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

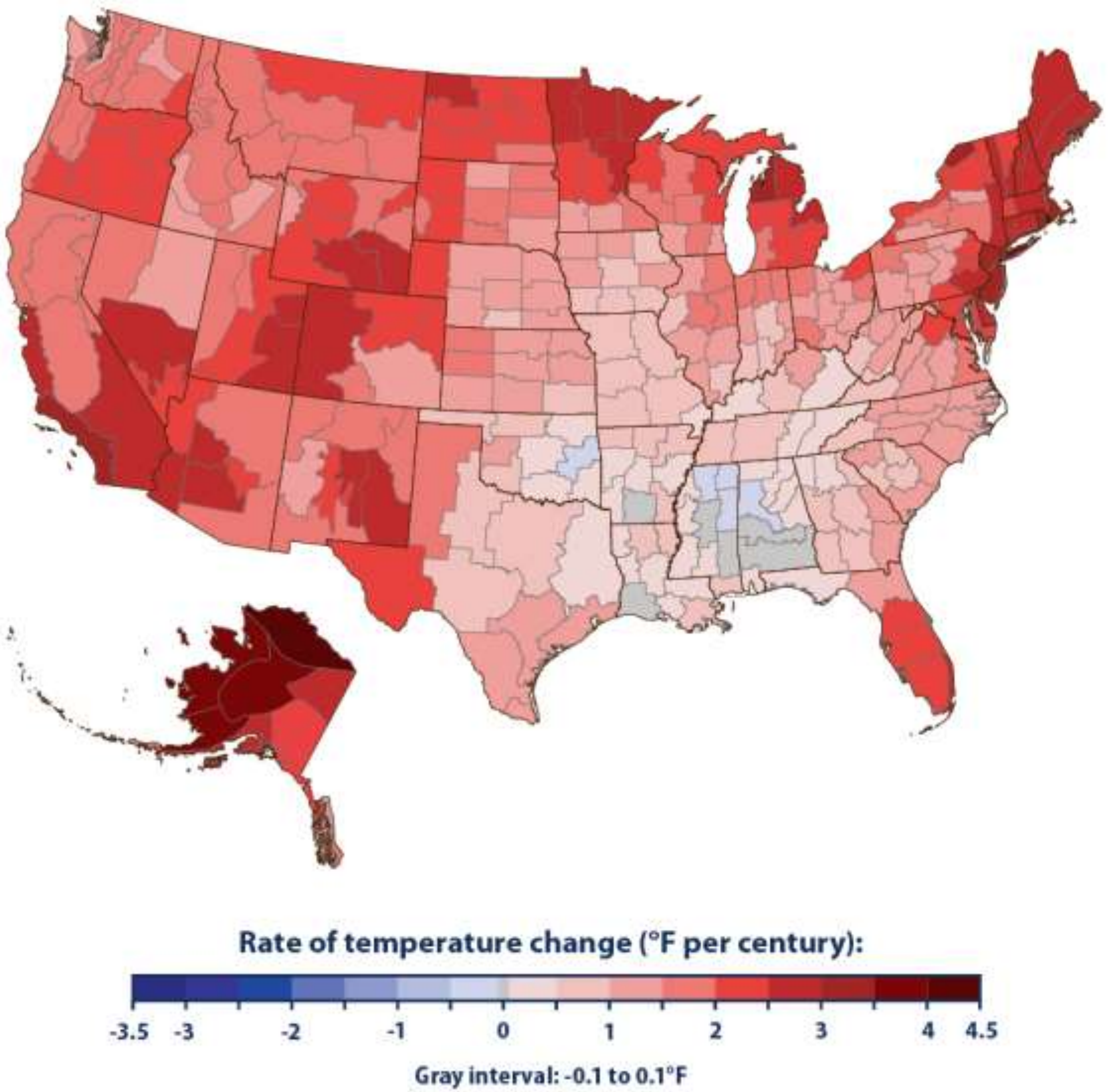
# Climate Change

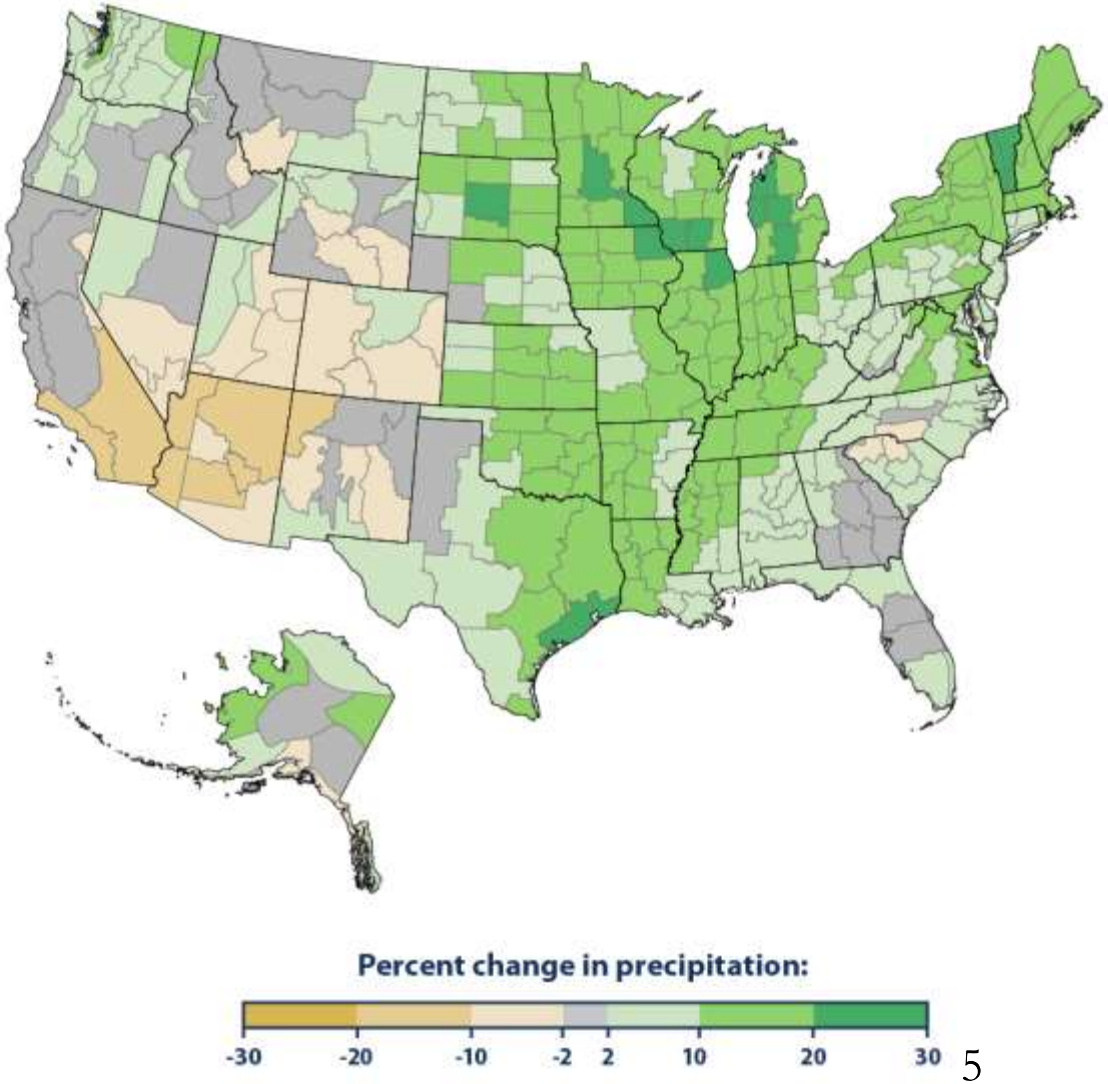



# Changes in Precipitation

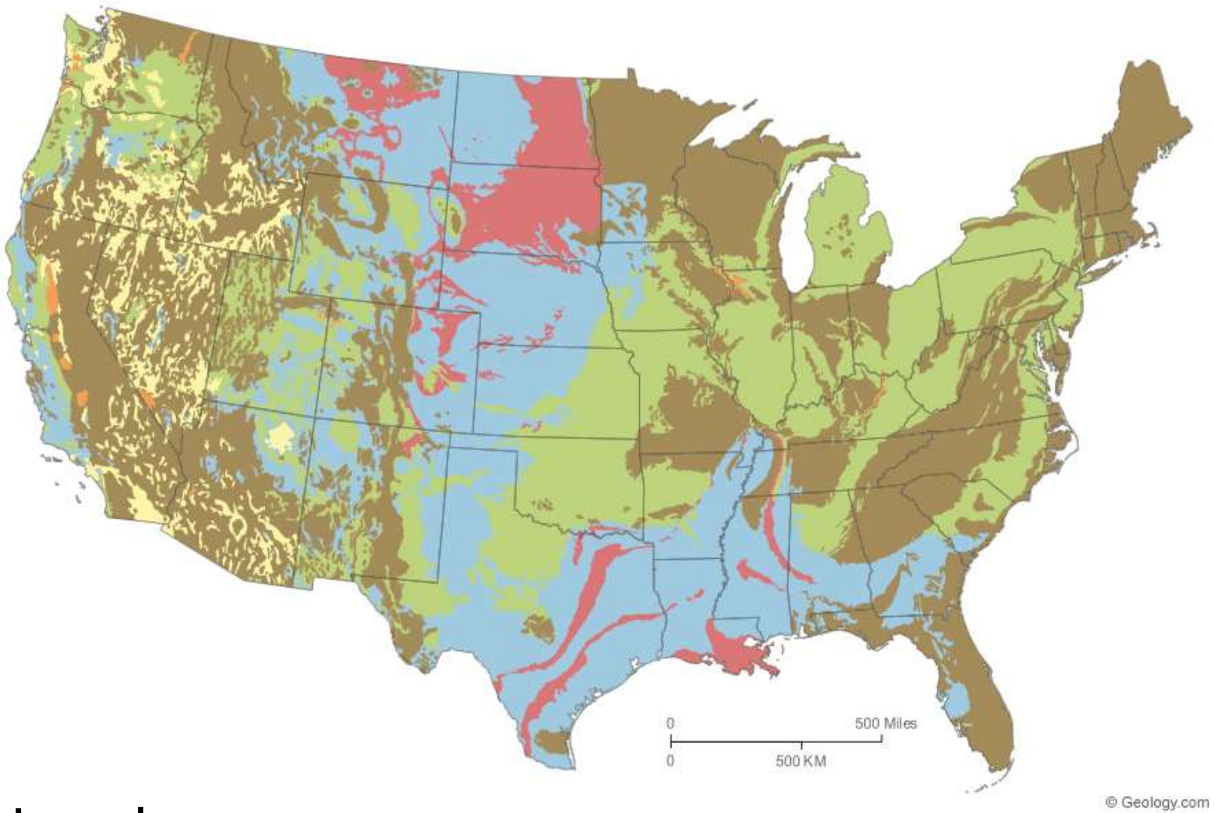


# Temperature and Precipitation Variation Due to Climate Change

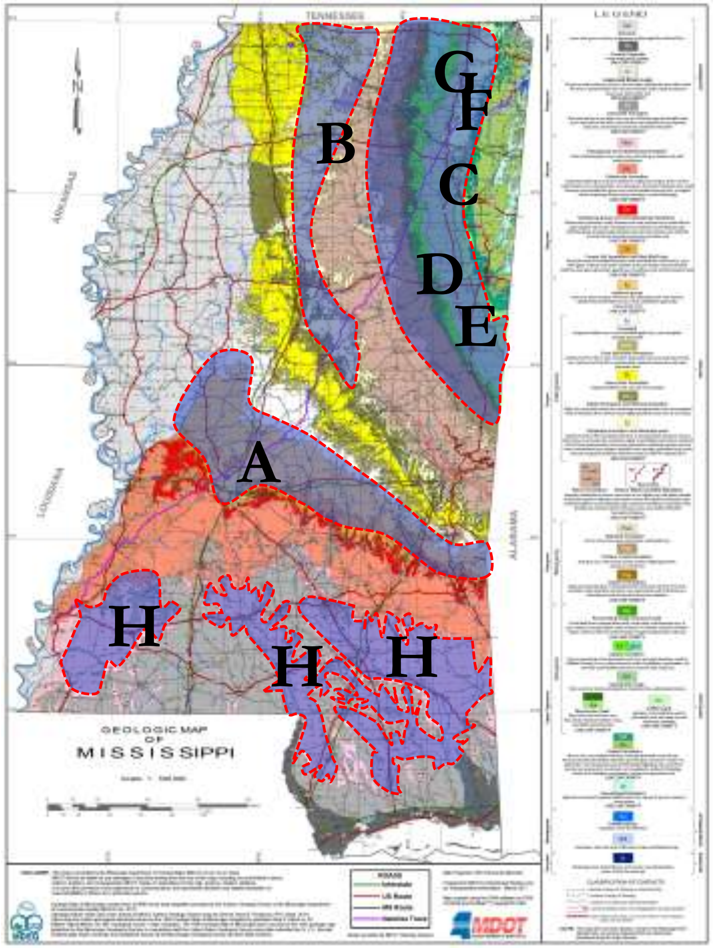


# Expansive Soil




**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

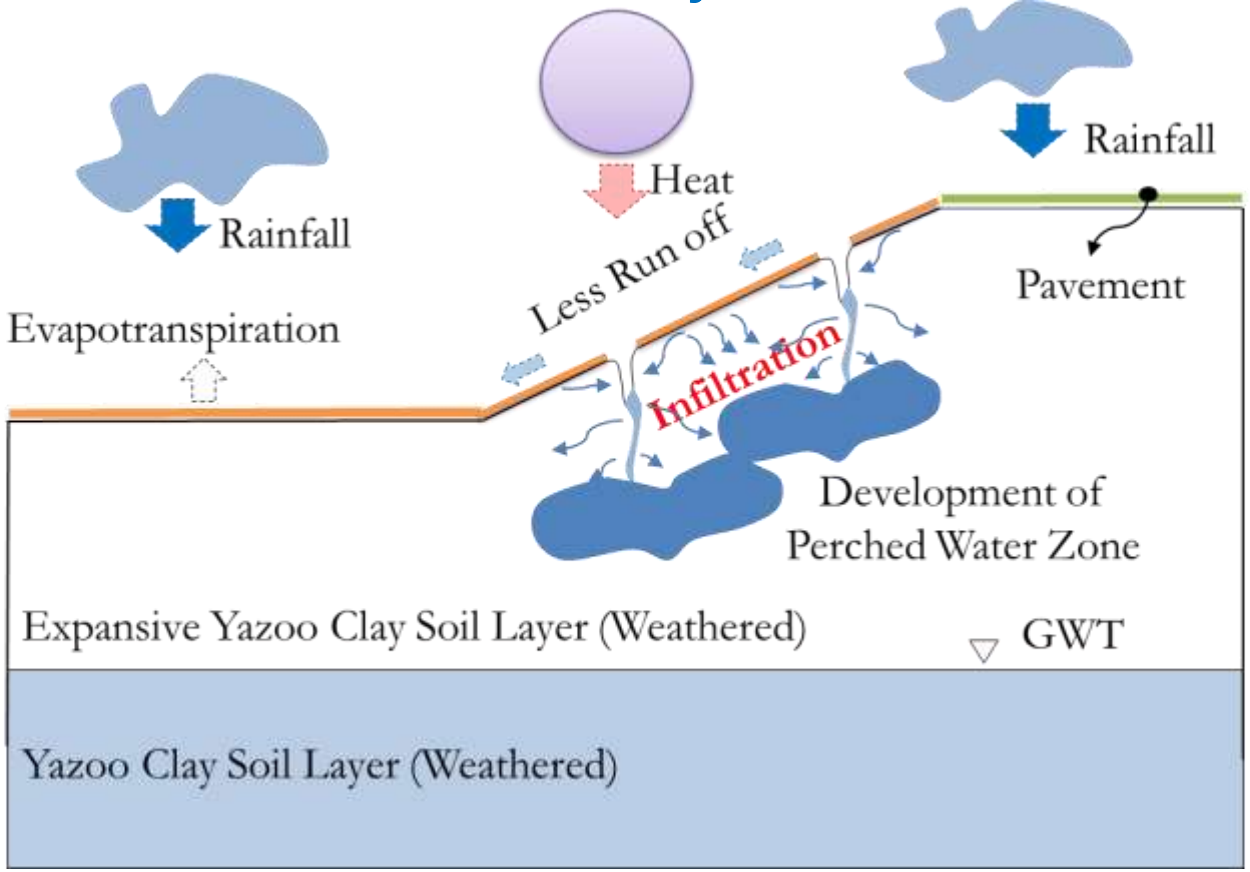
Clinton, Mississippi I-20 West

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).

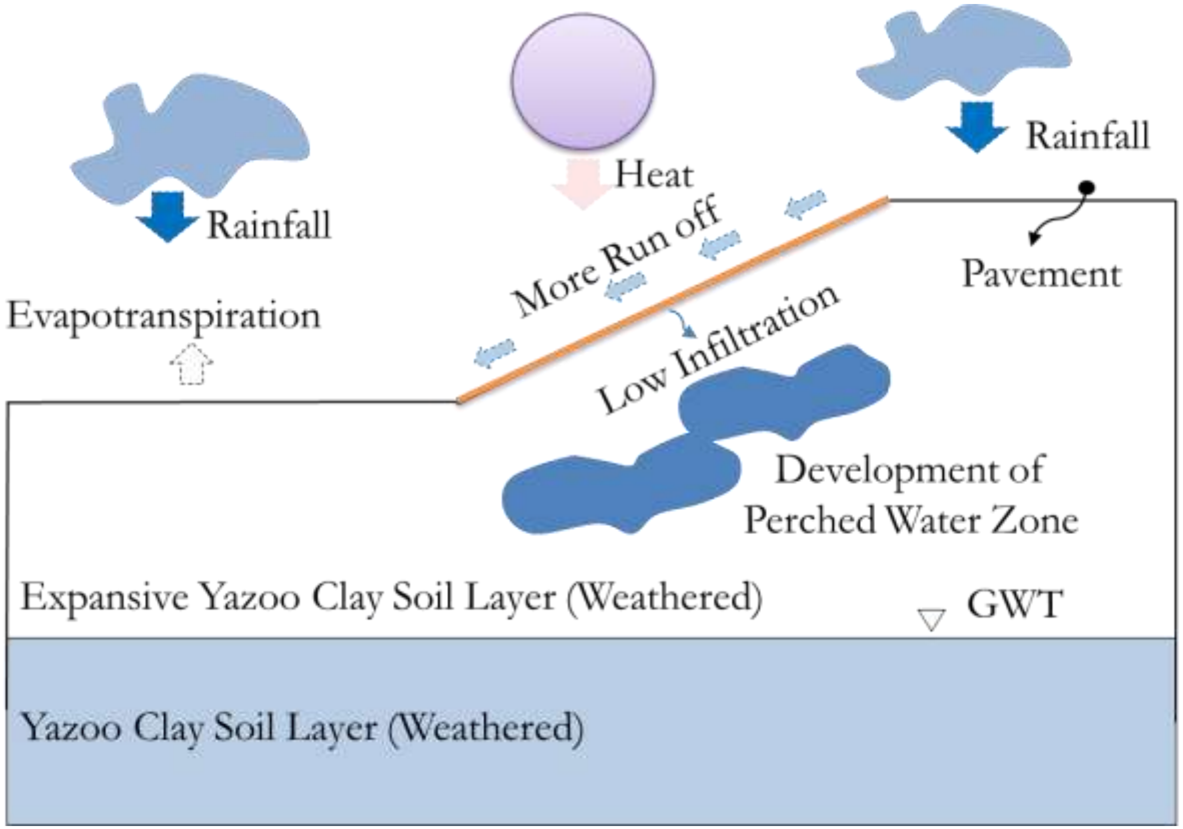
# Effect of Climatological Cycles on Landslides

## Summer to Early Fall



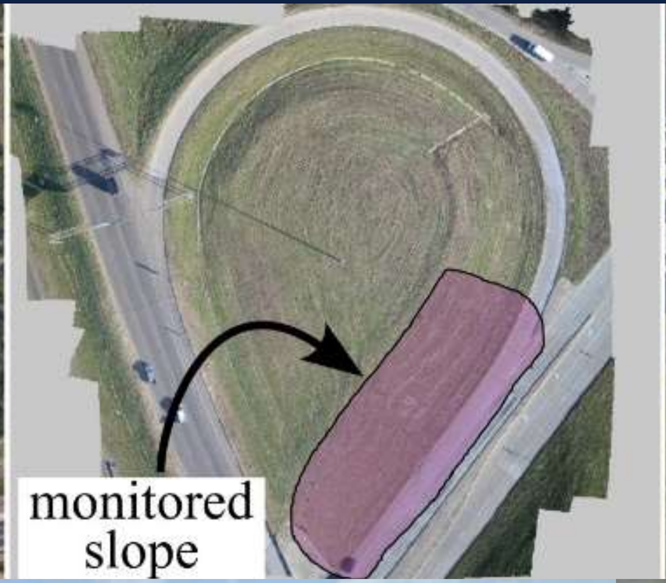

**The presence of desiccation cracks increases vertical permeability which increases infiltration and develops moisture build-up**

## End of Fall to Spring




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

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

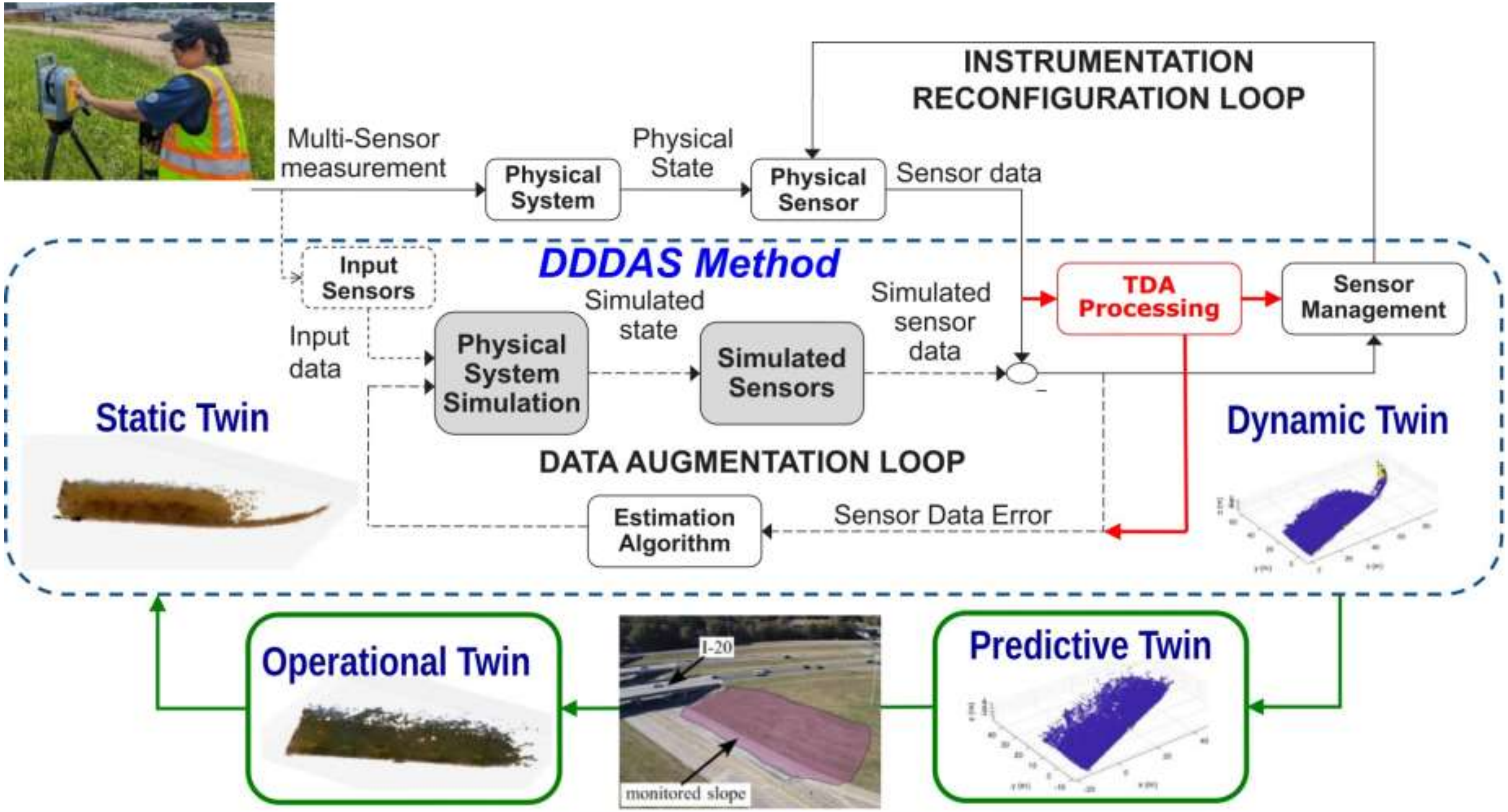


Terrestrial LiDAR

UAV LiDAR

# 3D Point Cloud Surface Topography of the Monitored Embankment

# Dynamic Data-Driven Applications Systems Framework

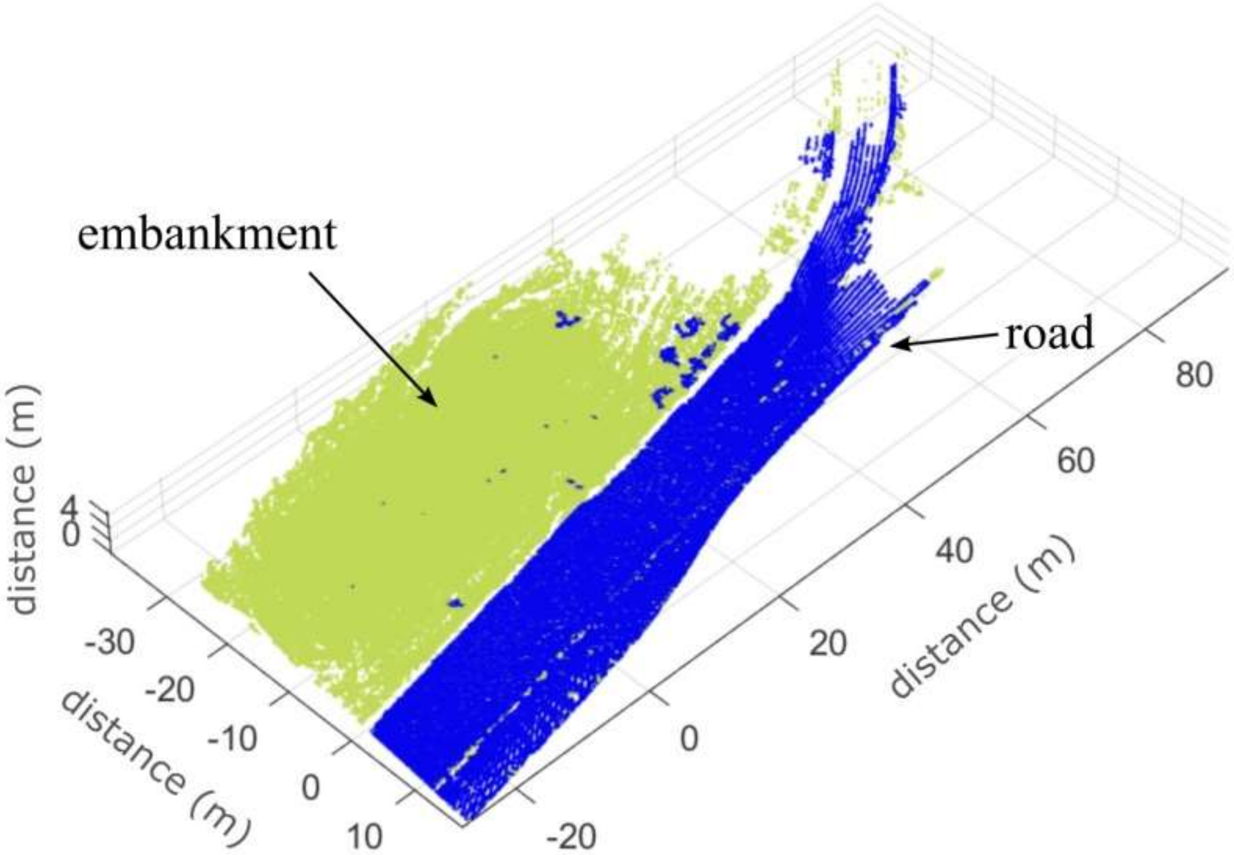



DDDAS framework to enable dynamically optimized 3D LiDAR sensing and TDA-based data processing for enhanced and efficient monitoring of earthen embankments

# Data Segmentation and Preparation

Segment 3D point cloud data into two main regions: road and bank.

- **Method:** Use normal vectors and Gaussian curvature values for region segmentation.
- **Classification:** Classify points into green (embankment, Target of Interest) and blue (road) regions.
- **Purpose:** Focus analysis on the bank, filtering out road data for effective TDA evaluation, a global analysis approach.

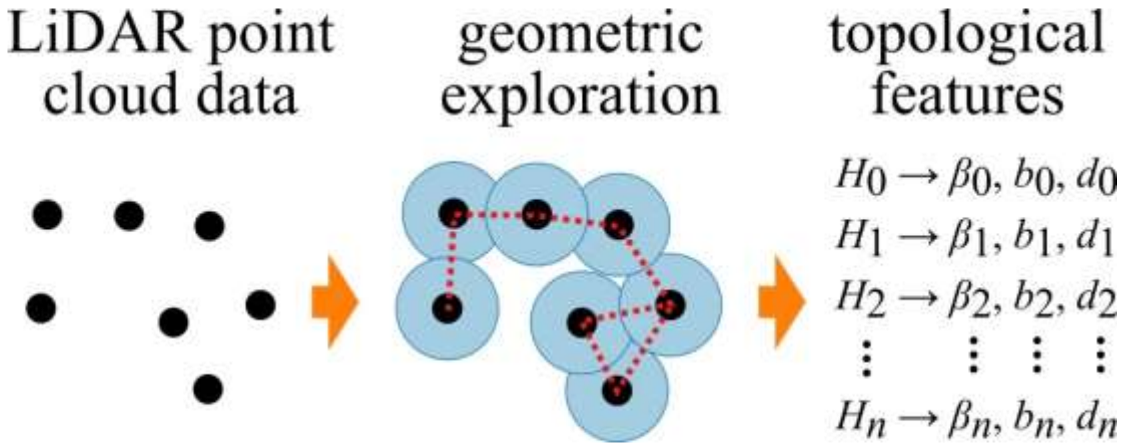



Segmented 3D point cloud data into road and bank regions.

# Topological Data Analysis (TDA)

Overview: Captures local & global patterns in 3D LiDAR data.

- **Key Method:** Persistent Homology (PH) quantifies complex structures.
- **Applications:** Ideal for infrastructure monitoring.
- **Challenge:** High computational cost $O(n^3)$ by using Vietoris-Rips Persistence (VRP) algorithm.
- **Solution:** RANSAC (Random Sampling Consensus) Random sampling reduces compute time, and consensus to maintains data integrity.

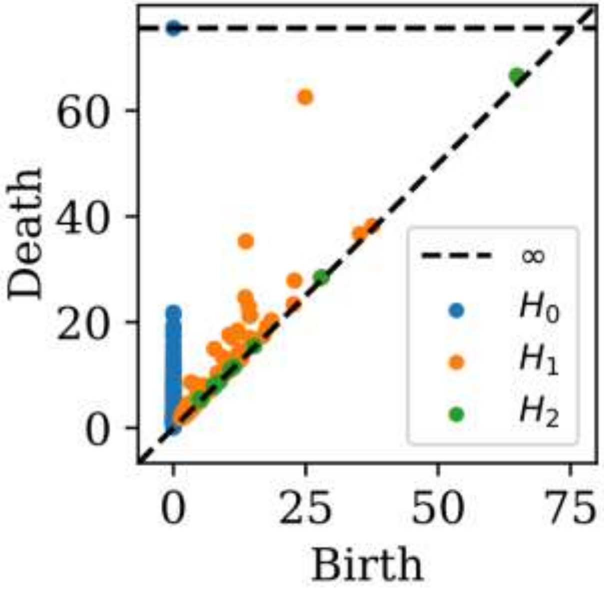



General TDA workflow for spatial data converted to features.

# RANSAC (RANdom SAmple Consensus)-TDA

RANSAC-TDA Approach

- **Objective:** Reduce TDA computing load on large 3D point clouds.
- **Method:** Random sampling of 5,000 points; median of 10 repetitions for stability.
- **Metrics:** Persistence Entropy (PE) for H0 and H1.
- **Advantages:** Efficient computation, effective for large datasets.




Persistence diagram

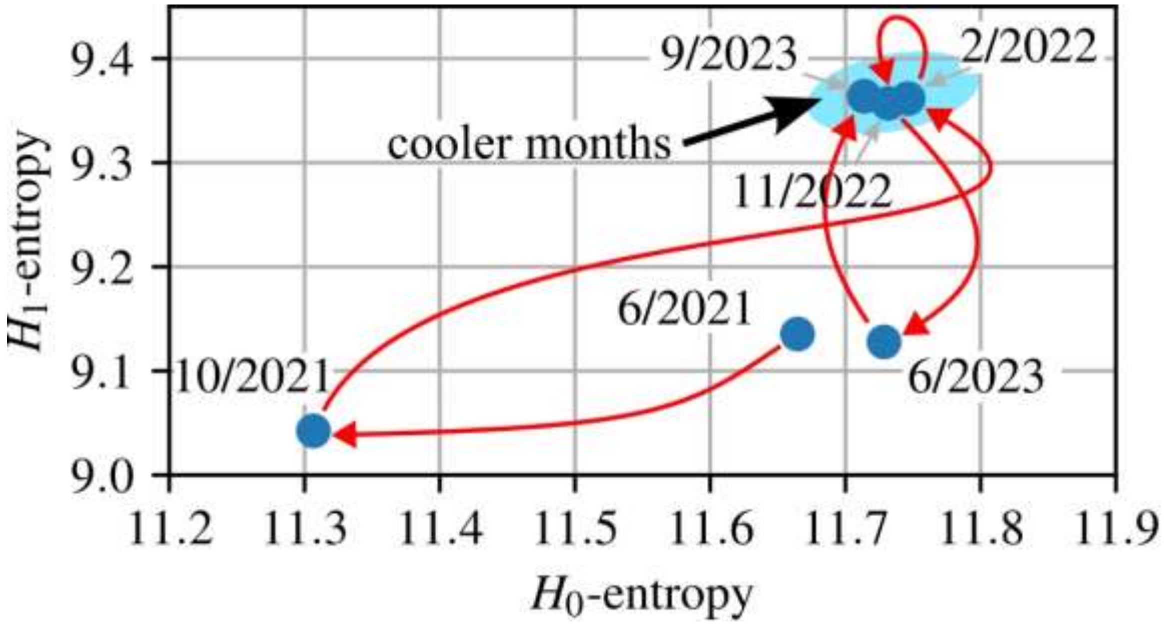
```
procedure RANSAC-TDA(n)
    for K times do
        Randomly sample a subset m_i of 5000 points from point cloud n
        Compute v_i = PE(m_i)
    end for
    return median(v_i)
end procedure
```

Pseudo code for the proposed RANSAC-TDA methodology

# Results for Step 2: Wasserstein Distance

Dataset & RANSAC-TDA Results

- **SLiDE Dataset**: LiDAR scans (June 2021 - Sept 2023) with 20M points each.
- **Challenge**: High computation demand for TDA.
- **RANSAC-TDA Findings**:
  - **PE Analysis**: Detected slope deformations (H0, H1 metrics).
  - **Seasonal Trends**: June 2023 showed moisture-related heaving; baseline return in cooler months.
- **Insights**: High sensitivity and efficient computation, with 69 sec per run.




Results for the TDA analysis in the H1 and H2 plane where the red arrow denotes the passage of time.

# Thank You

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## Open-source Dataset

GitHub

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