Bluff erosion along the east shore of Lake Michigan: Synergy between water levels and lithology

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Abstract

Along the east coast of Lake Michigan, shallow to intermediate depth landslides are influenced by lake water levels, bluff ground water saturation, and lithology. The bluffs are composed of unconsolidated glacial tills interbedded with / overlain by glaciodeltaic sand and lacustrine silt and clay. These bluffs are experiencing toe erosion due to lake level rise, surface erosion, creeping, and slumping due to water runoff and seepage. Lake Michigan water levels rose after 2013 following a below average period (˜1999-2013), peaking at record levels in 2019-2020 before falling slightly in 2021. This rise accelerated bluff toe erosion, and longshore currents rapidly removed the sediment and redistributed it along the coast. Recent bluff failures have brought media attention due to real estate and roadway losses. Many property owners have chosen to armor the shoreline to prevent further erosion. This study is focused on 3 sites: (1). a 1.9 km stretch along Lakeshore Dr. in St. Joseph (SJo), MI; (2). a 2 km stretch of subdivisions centered on Miami Park (MP), MI; and {3). a 1 km stretch of natural vegetated area north of a water reservoir near Ludington (LU), MI. All sites have active groundwater seepage at clay layer contacts on the bluff faces. Nadir and obliques photos obtained in July 2019 and 2021 using Unmanned Aerial Systems (UAS) have shown that all sites experienced erosion, landslides, and bluff top retreat. SJo site has dense vegetation on the bluff face but recent failures have removed vegetation and sediment along the face slope. MP area experienced significant bluff retreat, despite toe armoring with large boulders along several sections. At a Nature Preserve (MP), the bluff top retreated as much as 5-10m, with loss of vegetation on the bluff face and multiple landslides. LU area had several landslides resulting in both vegetation and land surface loss. From 2019 to2021, the LU area experienced 177,000 ± 2300 m^3 of erosion, which indicates a rate of erosion three times the erosion rate calculated for 2012-2019 (190,000 ± 14,000 m^3). More than 5m of glaciodeltaic sand were lost during 2019-2021 around a water seep above lacustrine clay with marginal accumulation at the bluff toe, whereas during 2012-2019 toe erosion removed >10m underneath that location, with ˜5m loss normal to the face.

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EP-22A-02

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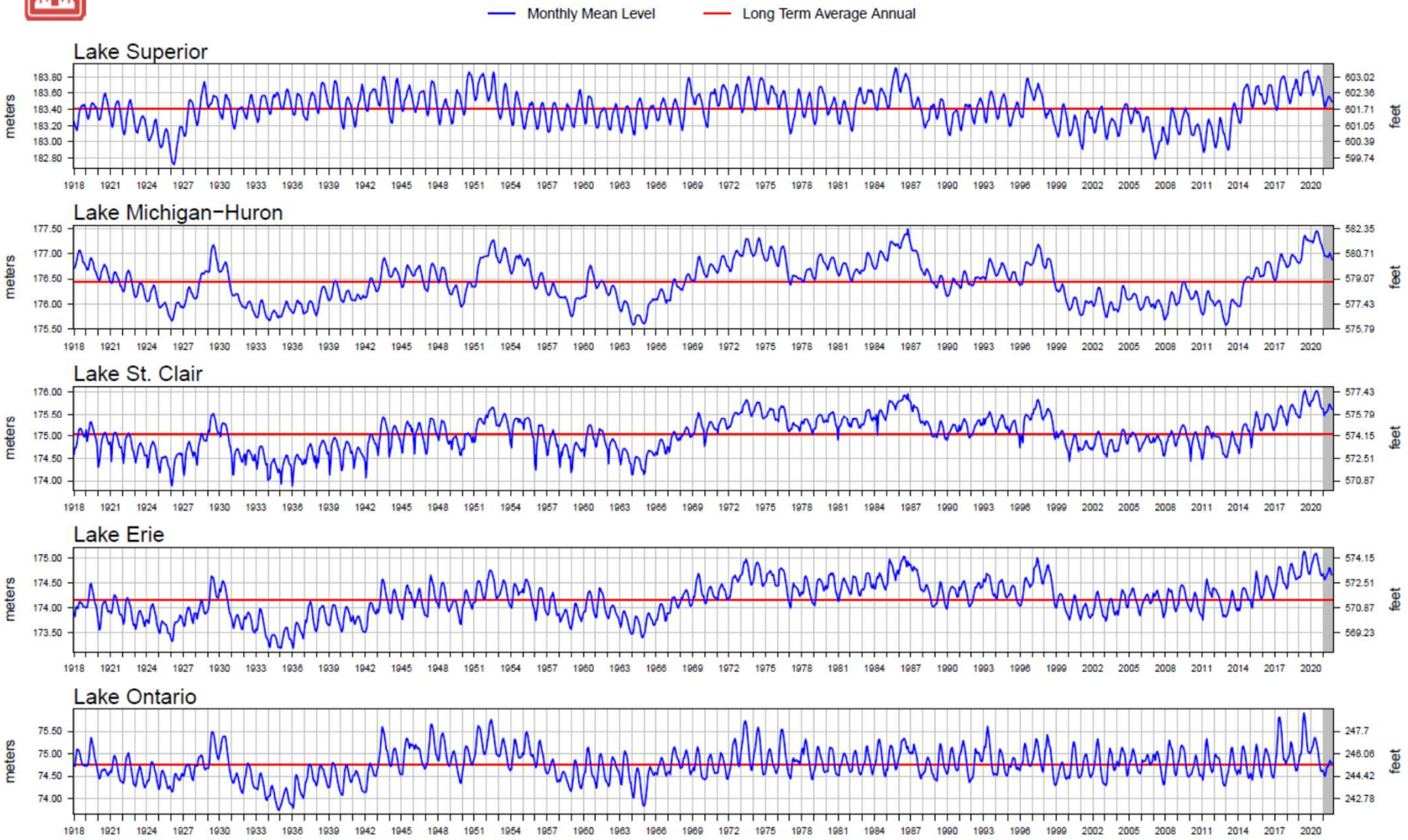
[3] Michigan Geological Survey

July 2017

Sept 2019

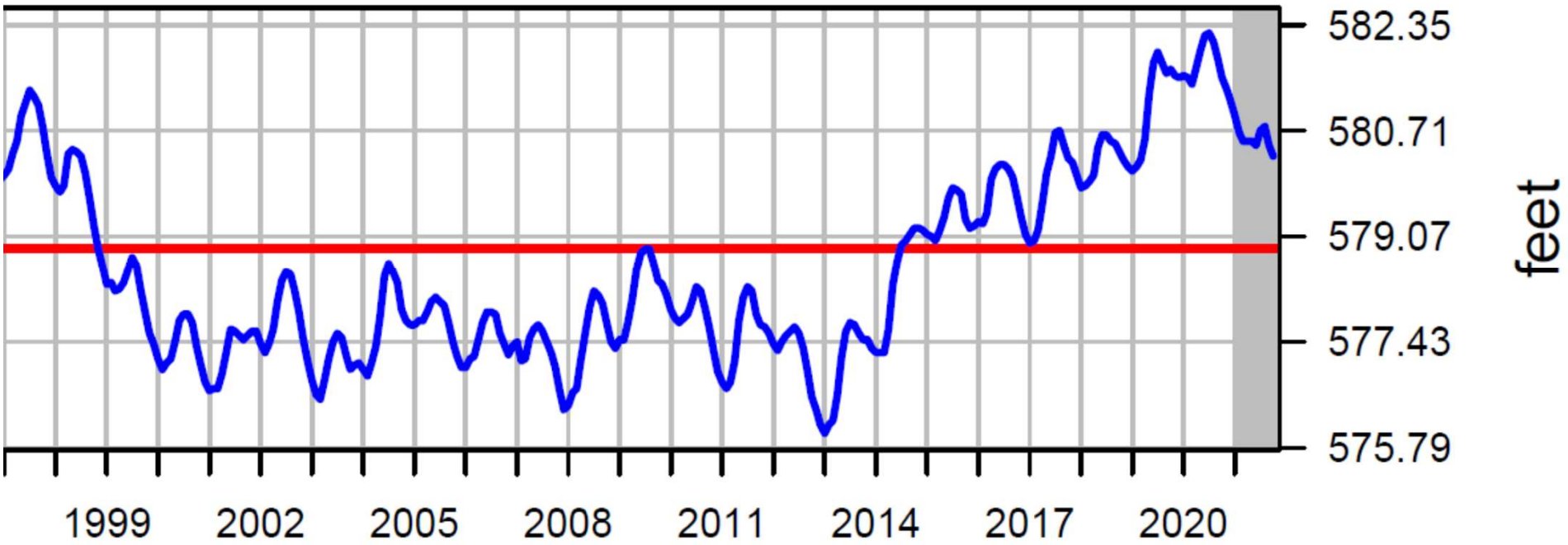
Great Lakes Water Levels (1918−2021)

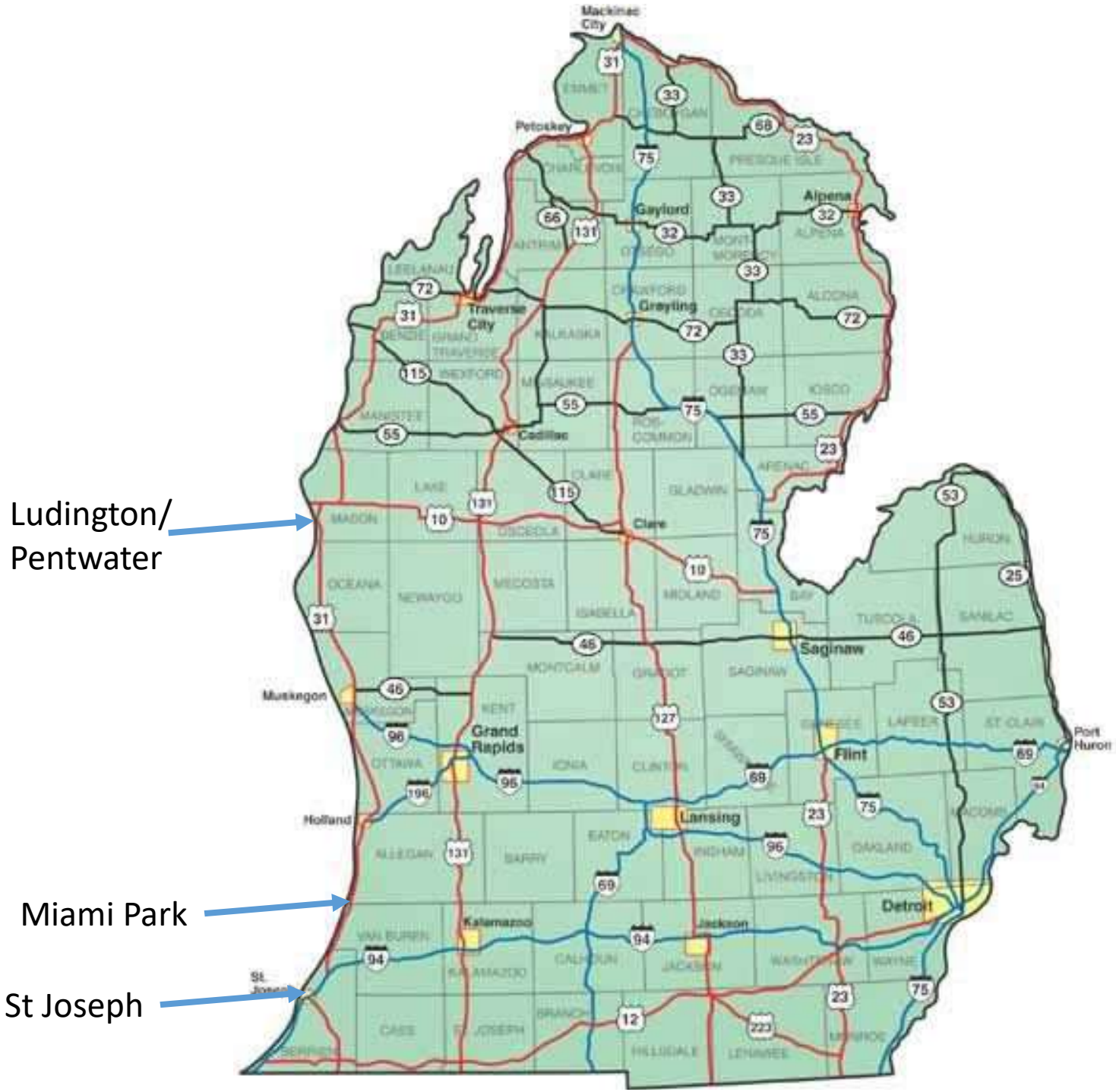


The monthly average levels are based on a network of water level gages located around the lakes.
Elevations are referenced to the International Great Lakes Datum (1985).

Water levels have been coordinated through 2020. Values highlighted in gray are provisional.

Lake Michigan-Huron Water Levels




Ludington/
Pentwater
Miami Park
St Joseph
Mackinac City
Petoskey
Gaylord
Alpena
Traverse City
Greyling
Cadillac
Clare
Saginaw
Muskegon
Grand Rapids
Flint
Port Huron
Holland
Lansing
Kalamazoo
Jackson
Detroit

SfM (Structure from Motion)

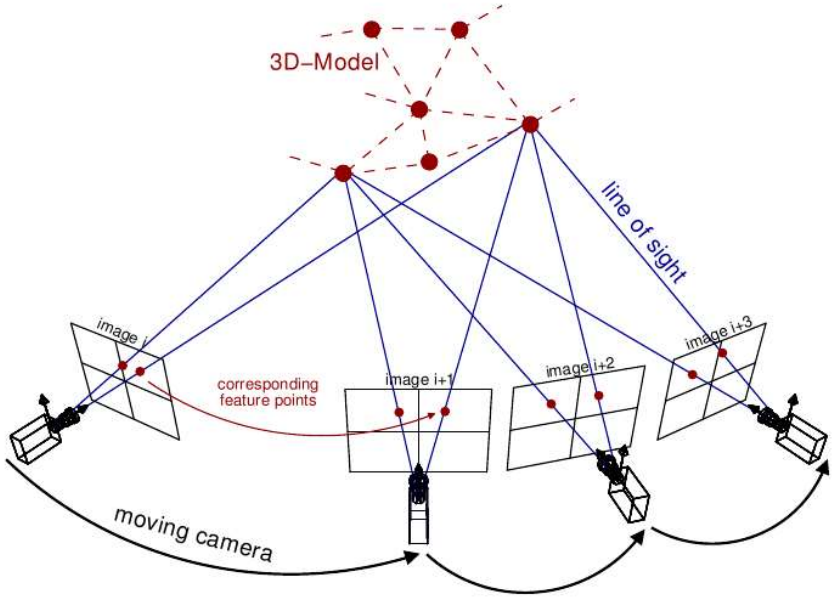


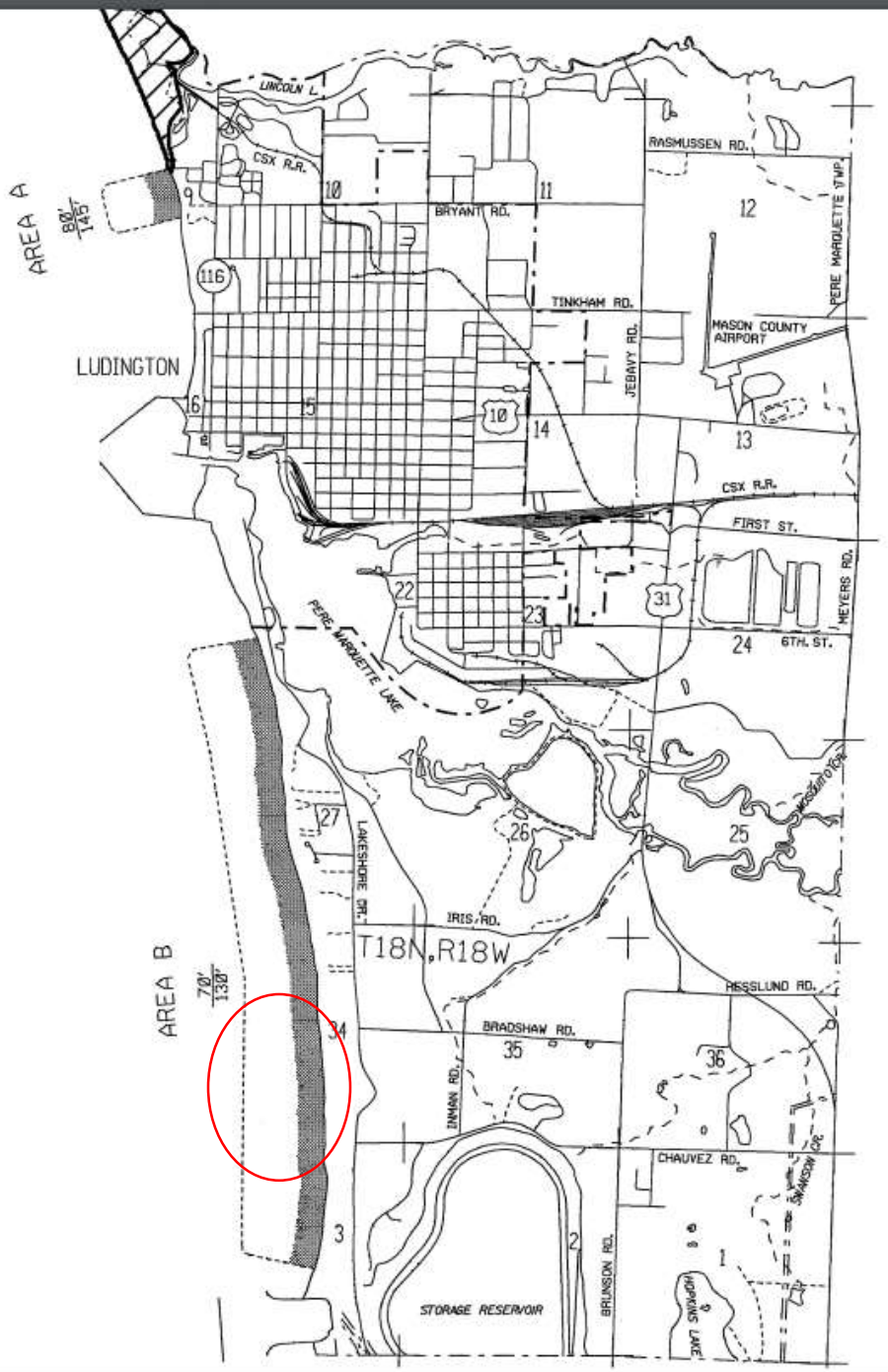
Image Acquisition

- 2017: DJI Phantom 3 Pro (July)
- 2019: DJI Phantom 3 Pro, DJI Mavic Enterprise (July, August, Sept, Oct)
- 2021: DJI Phantom 4 Pro, DJI Mavic Enterprise (July)

- Propeller Ground Control Points (2019,2021)
  - 4 Hour data collection
  - Corrected to CORS network

- Processed in
  - Agisoft
  - Drone Deploy
- Analysis
  - Cloud Compare
  - USGS R routines

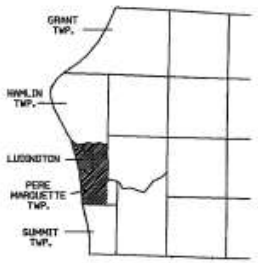
Ludington/
Pentwater



PERE MARQUETTE TOWNSHIP

HIGH RISK EROSION AREAS & CRITICAL DUNE AREAS

MASON COUNTY



HIGH RISK EROSION AREAS

60' 120' THE NUMBER REPRESENTS, IN FEET, THE 30 YEAR PROJECTED RECESSION DISTANCE. THE NUMBER REPRESENTS, IN FEET, THE 60 YEAR PROJECTED RECESSION DISTANCE.

HIGH RISK EROSION AREA (shading alongshore)

THESE AREAS ARE LEGALLY DEFINED BY PART 323, SHORELANDS PROTECTION AND MANAGEMENT, OF THE NATURAL RESOURCE & ENVIRONMENTAL PROTECTION ACT 1994 PA 451 BEING GREAT LAKES SHORELAND AREAS DOCUMENTED TO RECEDE AN AVERAGE OF ONE FOOT OR MORE PER YEAR.

CRITICAL DUNE AREAS

BARRIER DUNES
BARRIER DUNE FORMATIONS DESIGNATED PURSUANT TO PART 353, SAND DUNE PROTECTION & MANAGEMENT, OF THE NATURAL RESOURCE & ENVIRONMENTAL PROTECTION ACT 1994 PA 451.

AREAS NOT INCLUDED IN DESIGNATED BARRIER DUNE FORMATIONS THAT ARE COMPOSED PRIMARILY OF DUNE SAND AND EXHIBIT SEVERAL DUNE-LIKE CHARACTERISTICS.

EXEMPLARY DUNE ASSOCIATED PLANT COMMUNITIES OUTSIDE DESIGNATED DUNE FORMATIONS. MICHIGAN NATURAL FEATURES INVENTORY REFERENCE CODE INDICATED.

SOURCE

STATE OF MICHIGAN RECESSION RATE MAPS & ATLAS OF CRITICAL DUNE AREAS

INFORMATION

MICHIGAN DEPARTMENT OF NATURAL RESOURCES
LAND AND WATER MANAGEMENT DIVISION
P.O. BOX 30458
LANSING, MI 48909-7958
(517) 373-1950

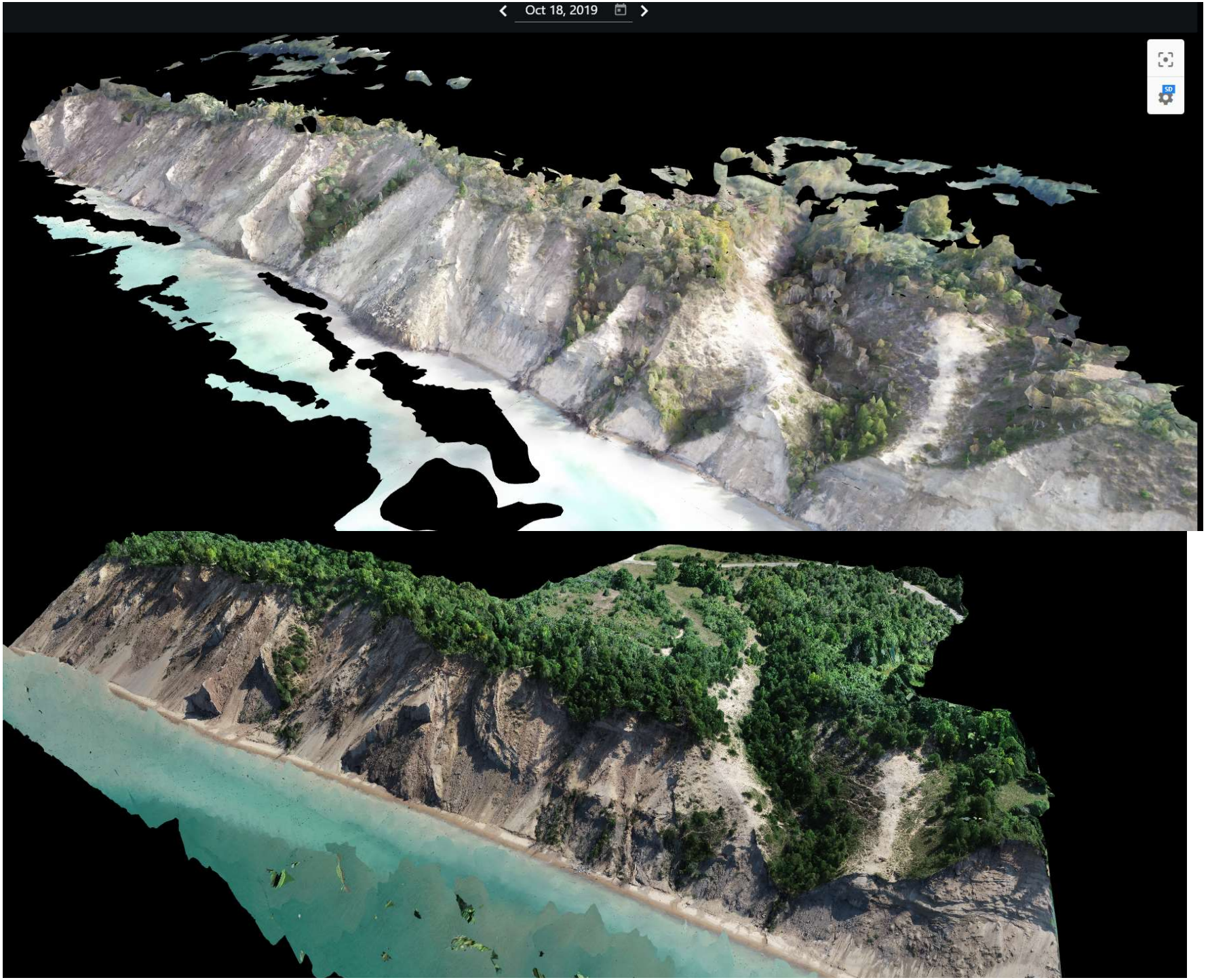
GIS
GREAT LAKES INFORMATION SYSTEM
MICHIGAN DEPARTMENT OF NATURAL RESOURCES
LAND AND WATER MANAGEMENT DIVISION

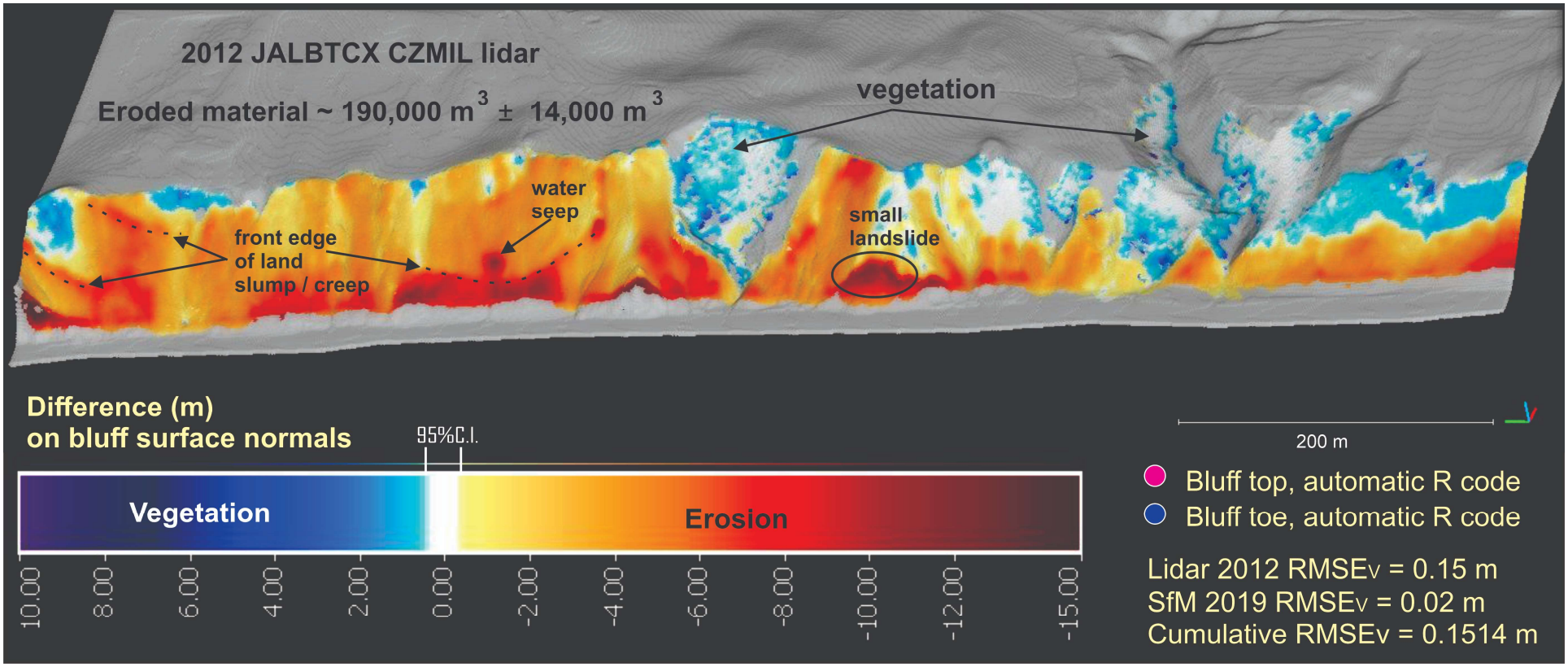
08-24-95

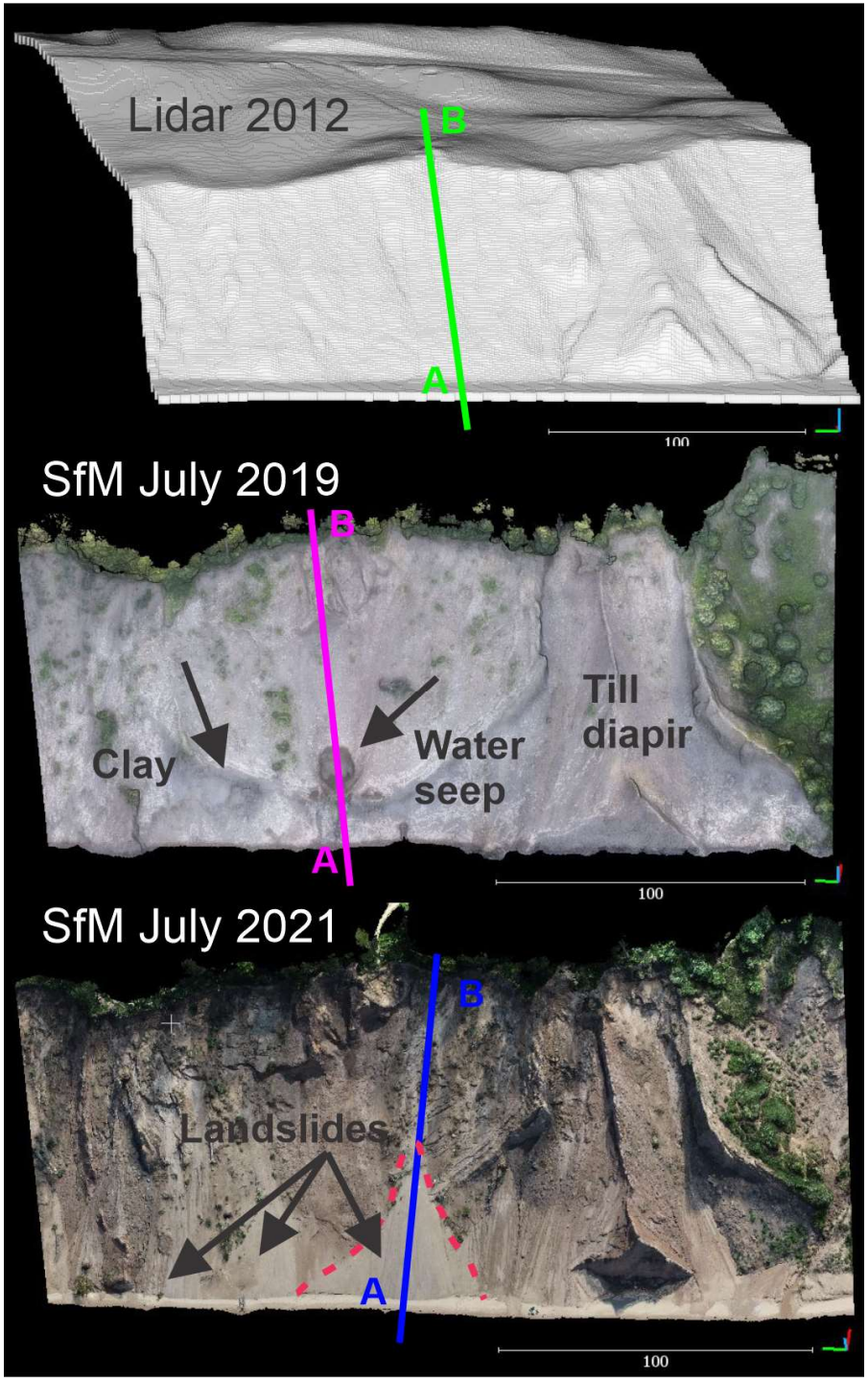
N

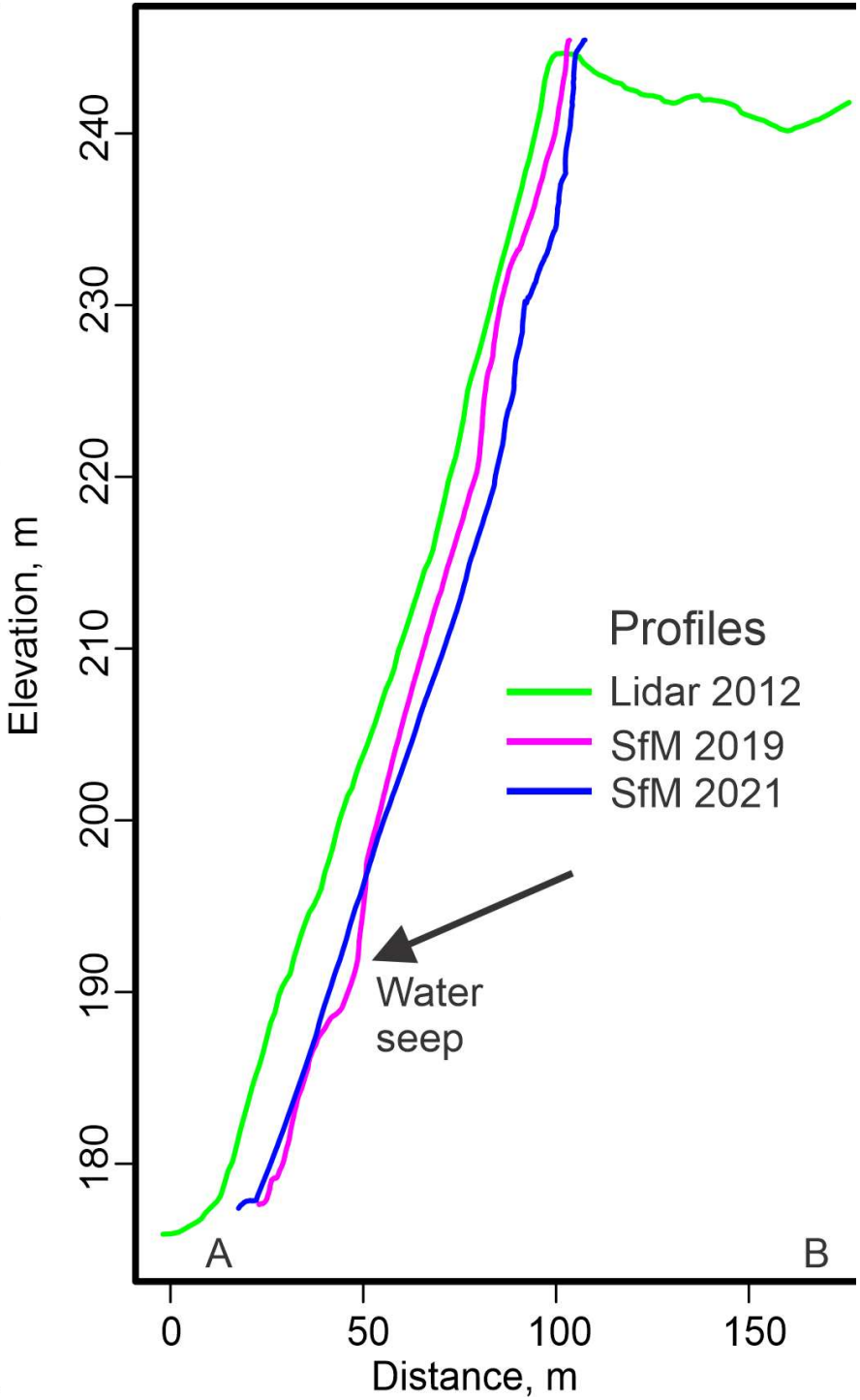
0 2000 4000
FEET

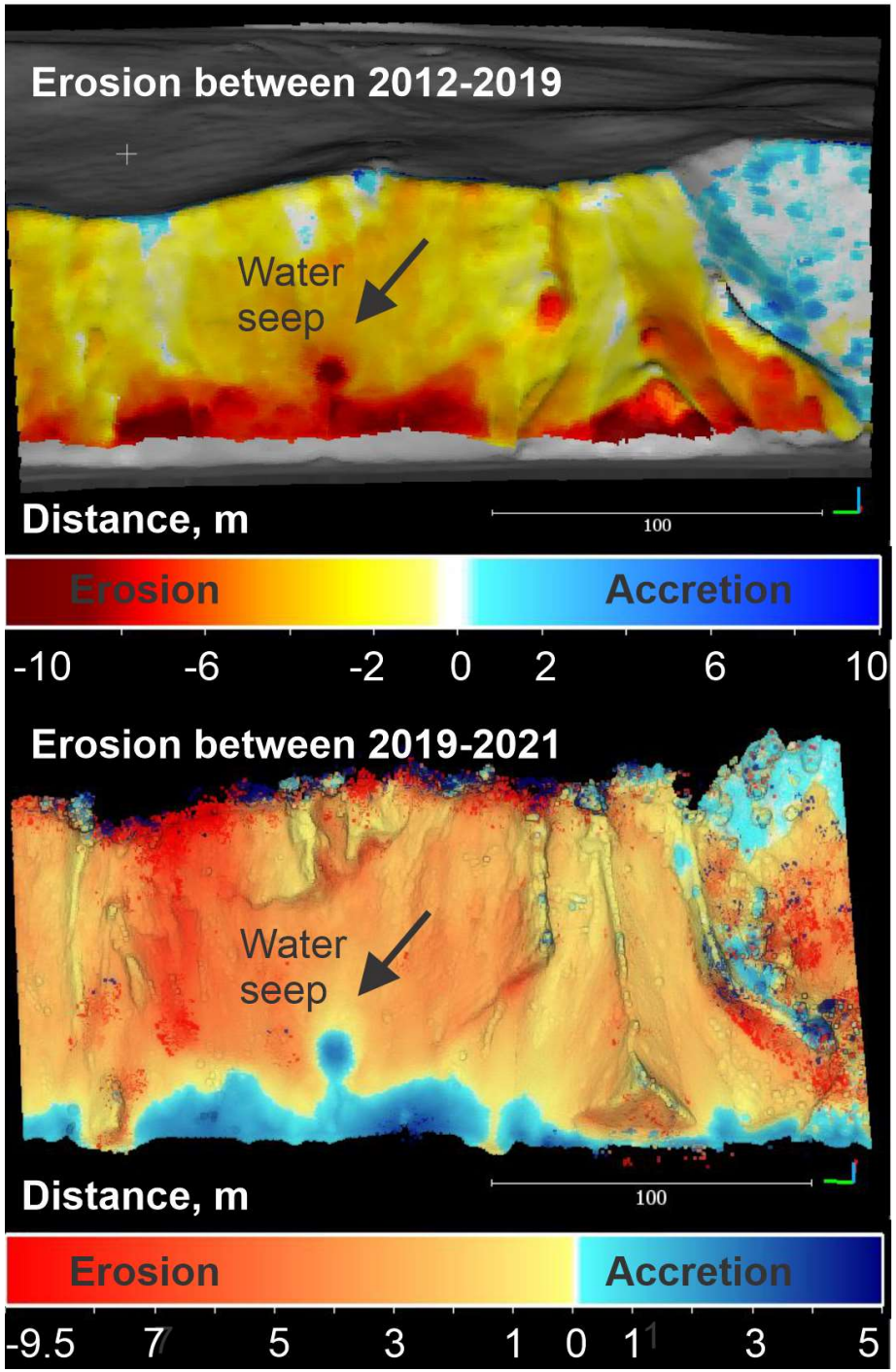
2019 Data Aquisition

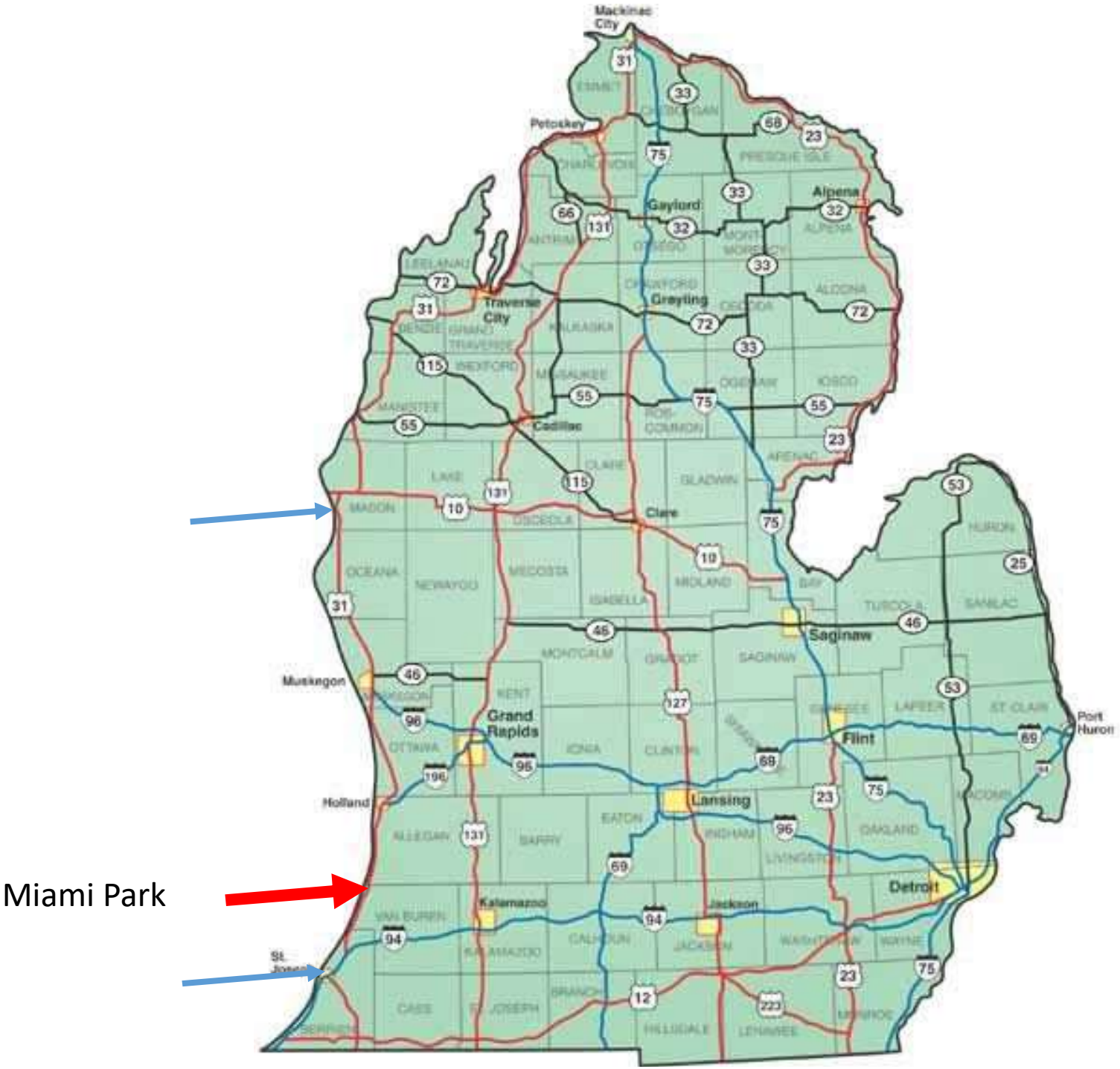

Oct 18, 2019
SD


2012 JALBTCX CZMIL lidar
Eroded material ~ 190,000 m 3 ± 14,000 m 3
vegetation
water seep
front edge of land slump / creep
small landslide
Difference (m) on bluff surface normals
95%C.I.
Vegetation
Erosion
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-15.00
200 m
Bluff top, automatic R code
Bluff toe, automatic R code
Lidar 2012 RMSEv = 0.15 m
SfM 2019 RMSEv = 0.02 m
Cumulative RMSEv = 0.1514 m

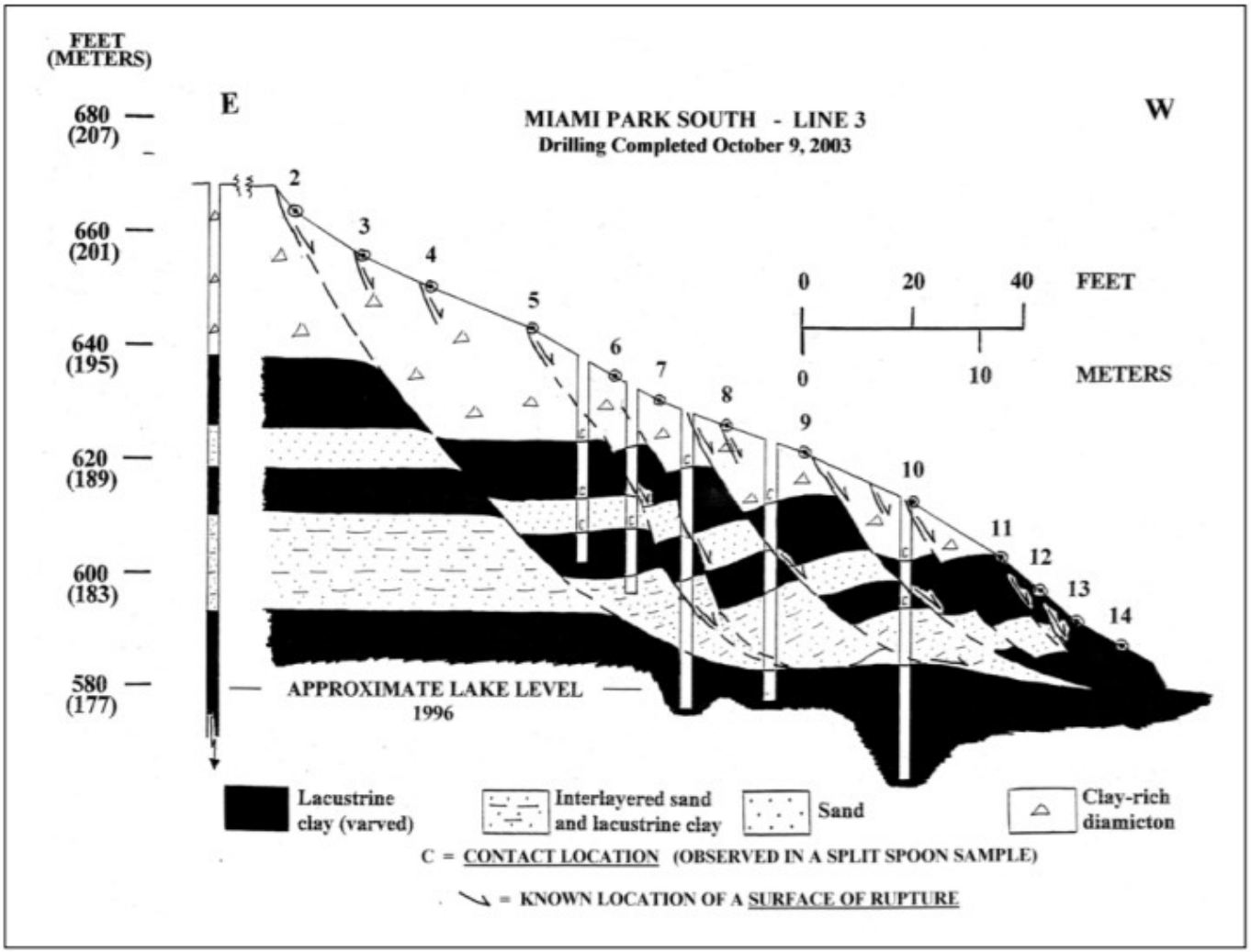

Lidar 2012
B
A
100
SfM July 2019
B
Clay
Water
seep
Till
diapir
A
100
SfM July 2021
B
Landslides
A
100


Elevation, m
180
190
200
210
220
230
240
Profiles
Lidar 2012
SfM 2019
SfM 2021
Water
seep
A
B
0
50
100
150
Distance, m

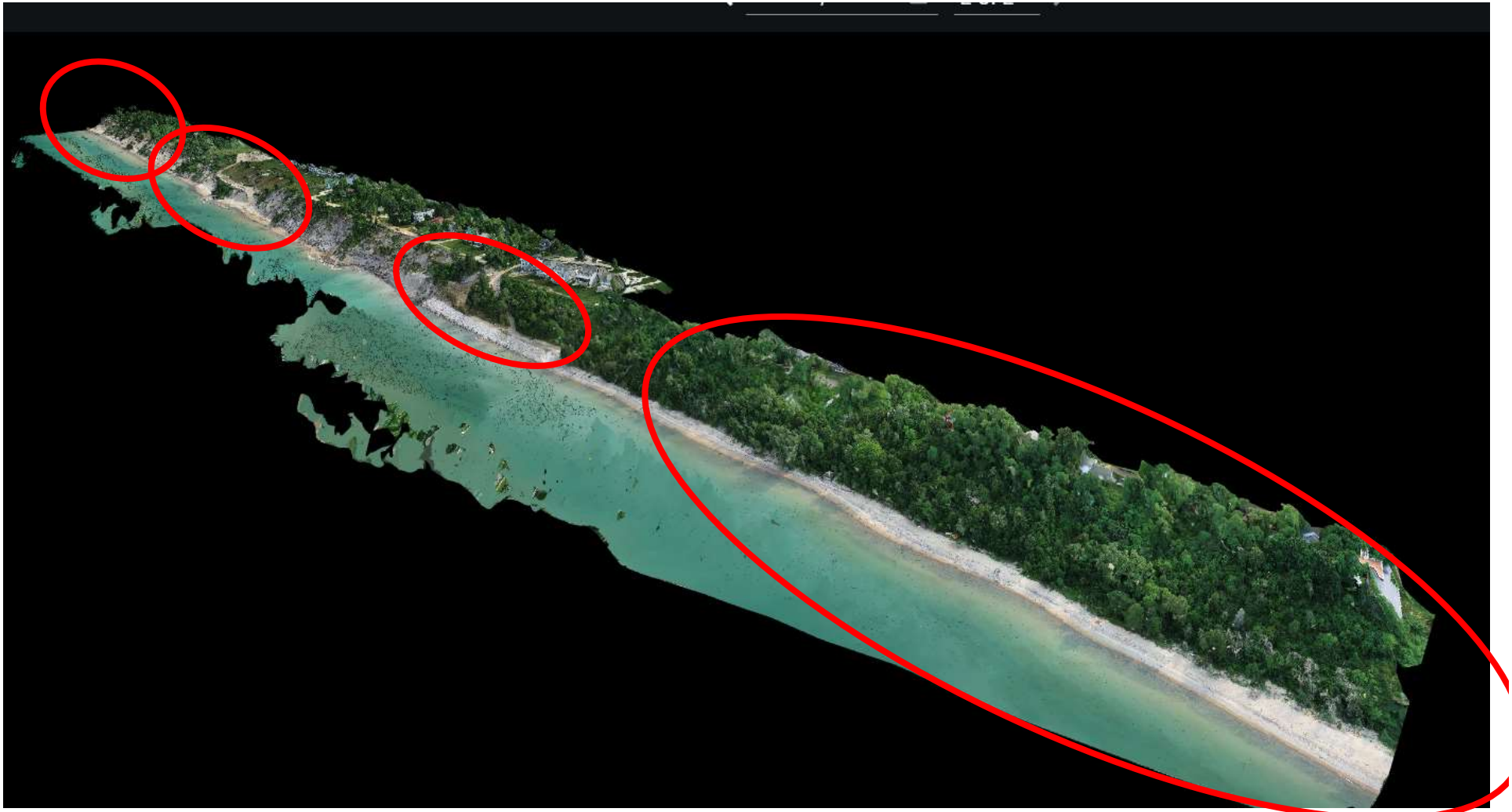

Erosion between 2012-2019
Water seep
Distance, m
100
Erosion
Accretion
-10
-6
-2
0
2
6
10
Erosion between 2019-2021
Water seep
Distance, m
100
Erosion
Accretion
-9.5
7
5
3
1
0
1
3
5

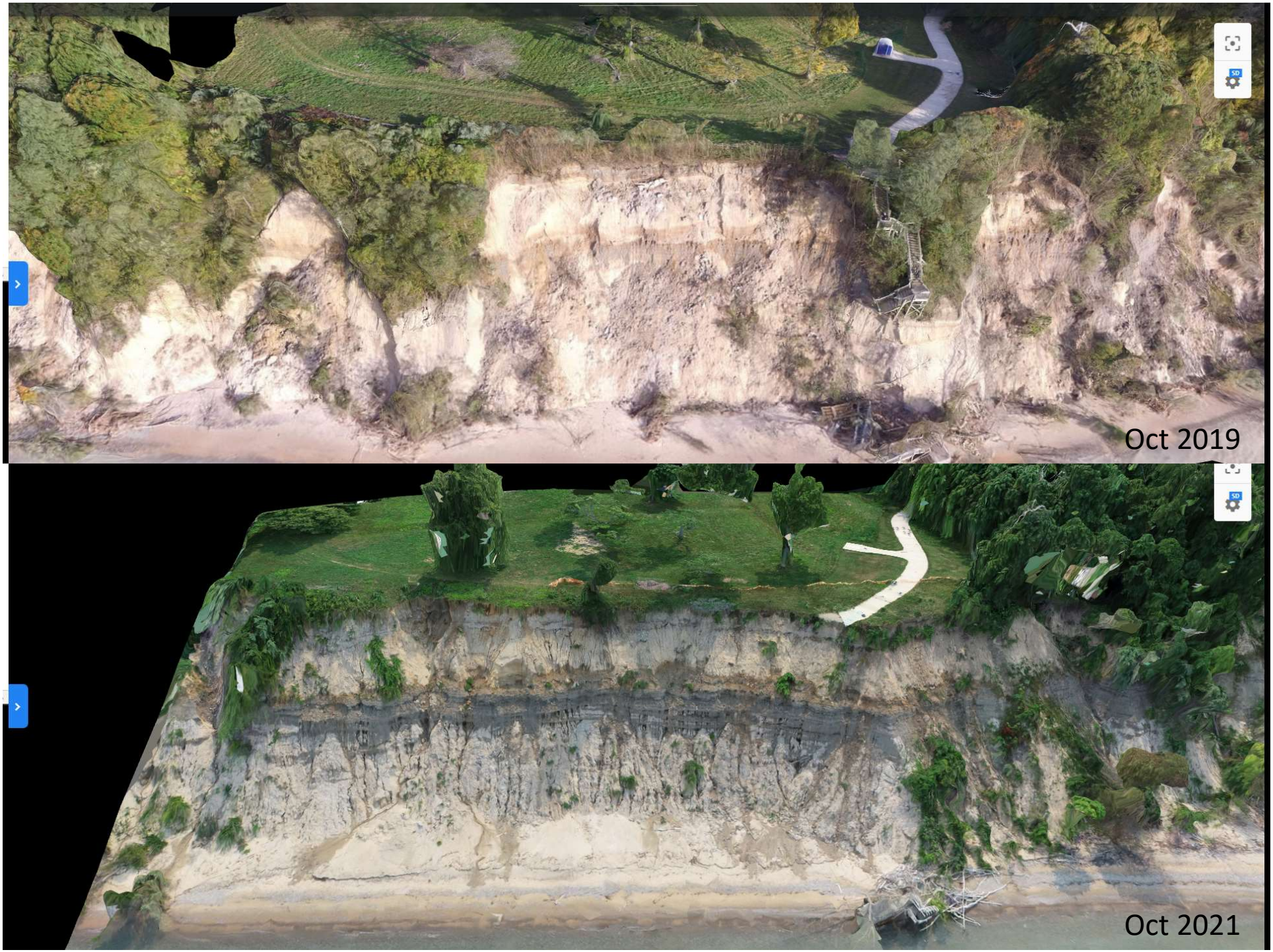

Mackinac City
Petoskey
Gaylord
Alpena
Traverse City
Grayling
Cadillac
Clare
Saginaw
Muskegon
Grand Rapids
Flint
Port Huron
Holland
Lansing
Kalamazoo
Jackson
Detroit
Miami Park

Miami Park, MI



(Glynn et al, 2012)




Oct 2019
Oct 2021

July 2017

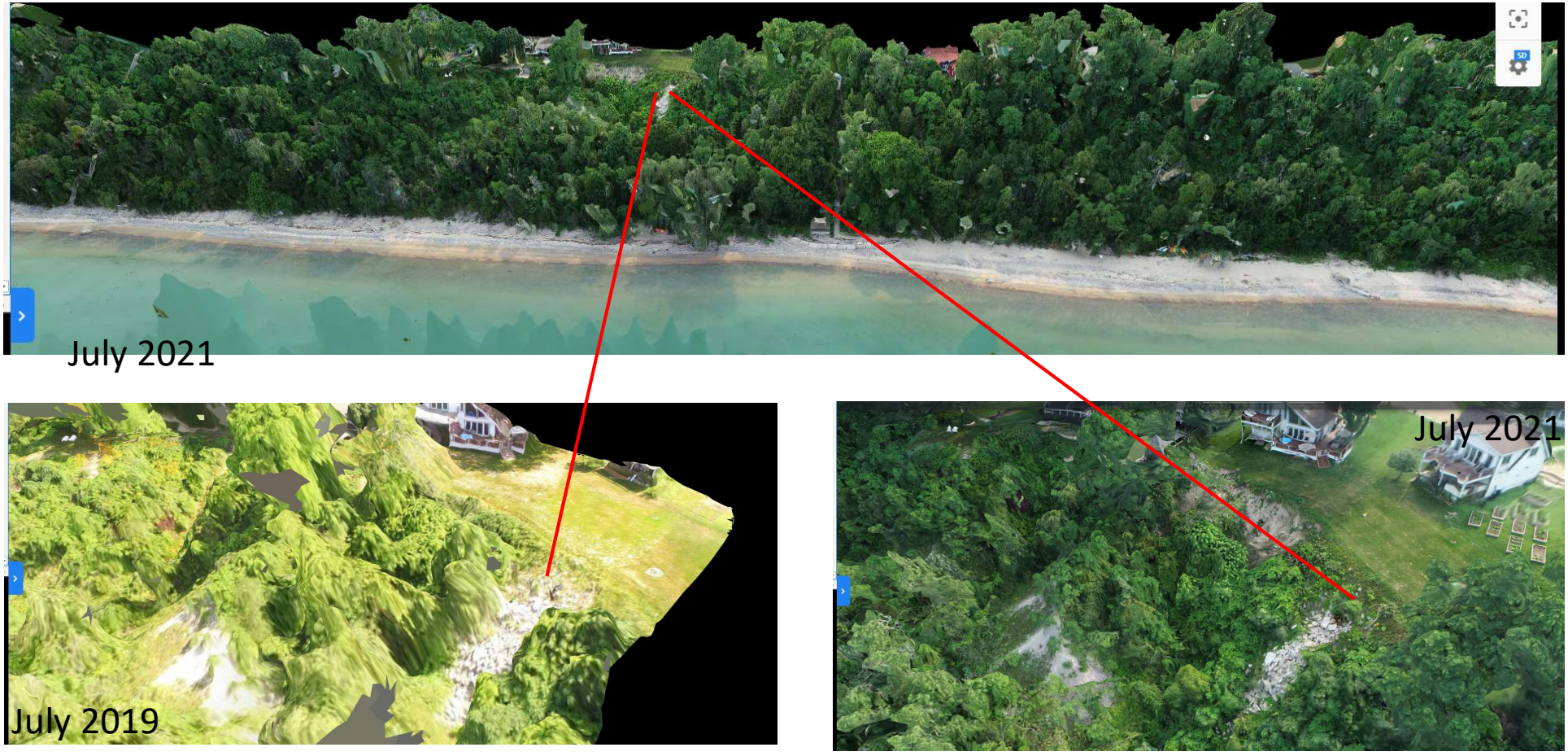
July 2019

Oct 2019

July 2021

July 2017

Sept 2019


July 2021
July 2019
July 2021


Mackinac City
Petoskey
Gaylord
Alpena
Traverse City
Grayling
Cadillac
Clare
Saginaw
Muskegon
Grand Rapids
Flint
Port Huron
Holland
Lansing
Kalamazoo
Jackson
Detroit
St Joseph

St. Joseph, MI

Conclusions

- UAV SfM highly effective in examining specific bluff failure locations
- High Lake levels removed large amounts of material at base of bluff
- Following toe removal, in-bluff characteristics impact how bluff continues to respond
  - Seeps
  - Impermeable layers
  - Sewage drainage (septic vs treatment plant away from bluff)
  - Saturation/ pore pressure

Acknowledgements

- Field Assistance
  - Garrett Link
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  - Guzalay Sataer
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  - Yanni Philopoulos
  - Sarah Kuntzman
  - Sarah Hayes
  - Matthew Bell
  - Muthanna Yaqoob
  - Evangelina Murgia

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