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TRANSPORTATION RESEARCH BOARD

The Ubiquitous Unmanned Aerial Vehicle – UAVs for Infrastructure Monitoring

March 16, 2021

@NASEMTRB
#TRBwebinar

PDH Certification Information:

- 1.5 Professional Development Hour (PDH) – see follow-up email for instructions
- You must attend the entire webinar to be eligible to receive PDH credits
- Questions? Contact Reggie Gillum at RGillum@nas.edu

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Learning Objectives

1. Identify FAA guidelines to safely conduct aerial inspections
2. Discuss applications of UAVs for infrastructure monitoring
3. Discuss importance of using different sensors to collect data

The Ubiquitous Unmanned Aerial Vehicle – UAVs for Geotechnical Infrastructure Monitoring

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Senior Geotechnical Engineer
FHWA – HIBS 20
Washington, DC

Transportation Research Board
The National Academies of Sciences, Engineering, and Medicine
March 16, 2021

Images Source: FHWA

INTRODUCTION

- Unmanned Aerial System (UAS) or drones, are multi-use aircrafts controlled from a *licensed operator* on the ground
- Unmanned Aerial Vehicles (UAV) is one of the technologies listed under *FHWA's initiative Every Day Counts* (EDC) 5
- EDC is a State-based model that identifies and rapidly deploys proven, yet underutilized innovations to:
  - Shorten project delivery
  - Enhance roadway safety
  - Reduce congestion
  - Integrate automation

CO DOT Drone @ Waldo-Canyon Debris flow Catchment Basin
(Source: FHWA)

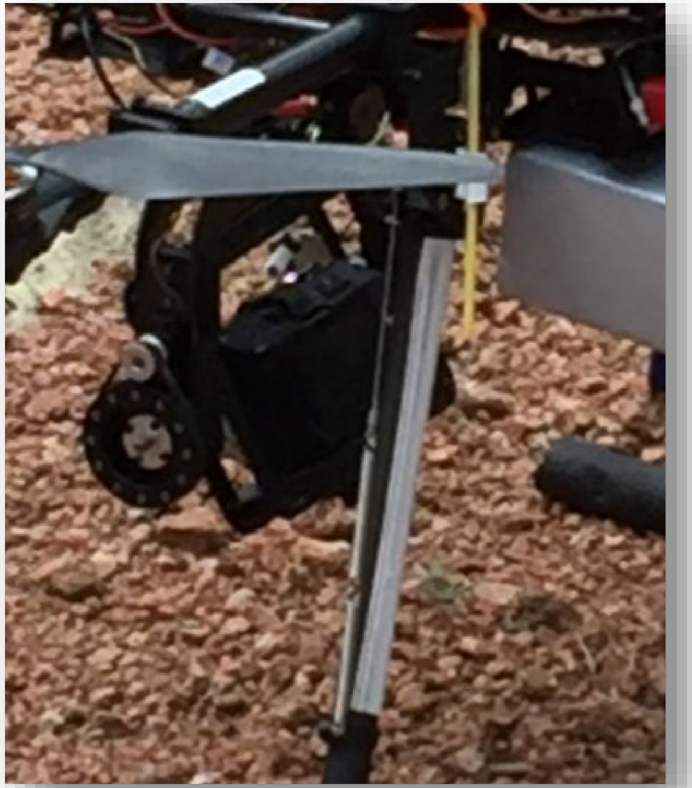
UAS/UAVs Advantages

- Unmanned Aerial Systems (UAS) may improve *safety* and reduce risk to personnel:
  - Inspection and assessment of an active landslide or debris flow
  - Collection of information from steep rock slopes
- UAS may reduce labor and time to collect data (*Efficiency*) (*from days or hours to minutes for some instances*)
- UAS may provide a cost-effective option (*Economy*)
- UAS may capture views and data that may not have been possible (*Accessibility & Perspective*) during traditional inspections of hazard event locations such as landslides, rockfalls, debris flow, etc.

Palmerton, PA
(Source: FHWA)

UAS Mounted Devices for Geotech Applications

- There are several UAS mounted devices for Geotechnical Applications:
  - Thermal Imaging
  - Optical Camera
- UAVs are used with the Structure-from-Motion (SfM) methodology, to create 3D models of a variety of geo-infrastructure.
- UAV light detection and ranging (LiDAR) may offer an advantage in terms of large and uniform ground coverage over different geomorphic environments, higher point density, and ability to penetrate through vegetation to capture points below the canopy.



CO DOT Drone @ Waldo-Canyon Debris flow Catchment Basin
(Source: FHWA)

Speakers Panel

- Updated Federal Aviation Administration Guidelines

Michael O'Shea – Federal Aviation Administration

- Application of UAVs for GEOTECHNICAL INFRASTRUCTURE MONITORING

Dr. Tom Oommen – Michigan Technology University

- UAS Case Studies Applications of Unmanned Aerial Vehicles in Monitoring Geotechnical Assets

Dr. Surya S. Congress – Texas A&M University

Moderator – Khalid Mohamed

Federal Highway Administration

Thank You

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The contents of this presentation do not have the force and effect of law and are not meant to bind the public in any way. This presentation is intended only to provide information to the public regarding existing requirements under the law or agency policies.

Regulatory Requirements for using UAS for Geotechnical Infrastructure Monitoring

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Office of UAS Integration

Program Manager/Public Safety Liaison

What is the FAA's Mission?:

The FAA's continuing mission is to provide the safest, most efficient aerospace system in the world.

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UAS Operations, Registration, and Compliance

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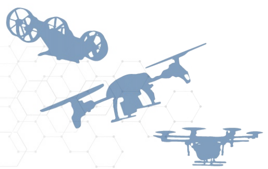
Types of UAS Operations

*Table represents operations that have happened or are possible

	UAS Operating Authority	Aircraft Requirements	Pilot Requirements	Airspace Requirements	Types of Operation
Civil	Part 91	**Section 44807 exemption**	Part 61 airman certificate	Blanket COA or Jurisdictional COA for specific airspace	UAS can be > 55 lbs.
		Experimental Aircraft (Experimental Special Airworthiness Certificate)	Part 61 airman certificate	Standard COA for specific airspace	Research and development, crew training, and market survey
	Part 107	UAS < 55 lbs. Max. Gross Operating Weight	Part 107 remote pilot certificate with small UAS rating	Airspace waiver or authorization for Class B, C, D, E airspace	VLOS, daytime, Class G, 400 ft., not over people (some regulations subject to waiver)
	Section 44809 Exception for Limited Recreational Operations of Unmanned Aircraft		Community-based organization (CBO) standards	Airspace authorization requirement for controlled airspace	CBO safety guidelines and strictly recreational purposes
	Part 135	Section 44807 exemption or certification process	Part 61 airman certificate	Blanket COA or Jurisdictional COA for specific airspace	UAS can be > 55 lbs.
Public	**Public Aircraft Operations**	Self-certification by public agency	Self-certification by public agency	Blanket COA or Standard COA for specific airspace	Public Aircraft Operations (AC 00-1.1B); UAS Test Site operations



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How Will You Operate?

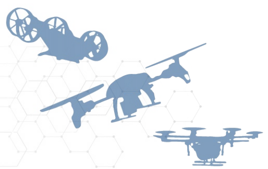
Public (PAO)

Civil (Part 91 or 107)

See AC 00-1.1A,

49 USC §40102(a)(41) and 49 USC §40125

Public Status determined on a per flight basis



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Part 107 Operating Rules

No operations over people

Daylight or civil twilight only

Must yield right-of-way to manned aircraft

One UAS per operator

Visual line-of-sight only

Remote pilot certificate required

Registration required for all UAS

Operations in controlled airspace require authorization

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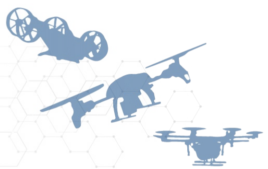
Public Aircraft Operations

Certificate of Authorization (COA)

- **"Public aircraft" means any of the following:**
  - (C) An aircraft owned and operated by the government of a State, the District of Columbia, or a territory or possession of the United States or a political subdivision of one of these governments, except as provided in section 40125(b).
  - (D) An aircraft exclusively leased for at least 90 continuous days by the government of a State, the District of Columbia, or a territory or possession of the United States or a political subdivision of one of these governments, except as provided in section 40125(b).

- **"Civil aircraft" means an aircraft except a public aircraft. The FAA considers all aircraft ops not flown or qualified as a public aircraft operation to be a civil operation, flown under civil rules.**



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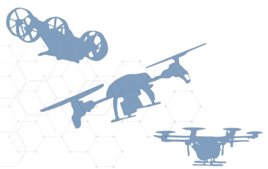
Governmental Function

49 USC 40125

- The term <u>"governmental function"</u> means an activity undertaken by a government, such as national defense, intelligence missions, firefighting, search and rescue, law enforcement (including transport of prisoners, detainees, and illegal aliens), aeronautical research, or biological or geological resource management.

- An aircraft described in subparagraph (A), (B), (C), or (D) of section 40102(a)(41) does not qualify as a public aircraft under such section when the aircraft is used for commercial purposes *(performing a non governmental function)* or to carry an individual other than a crewmember or a qualified non-crewmember.

- <u>*Not all public entity aviation activities meet the qualifications. Just because you are a public entity does not necessarily mean your flight meets the criteria as a governmental function.*</u>



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When do I get to Operate BVLOS?

- All about Safety

- Two Step Process

  - Ops Over People (Part 91 allows in case of life saving emergency)

  - Alternate means of compliance to 91.113 / 107.31

- What is Tactical BVLOS? (ATO AJV)

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Tactical Beyond Visual Line of Sight Waiver

- In July 2021, the FAA unveiled the new Public Safety Tactical Beyond Visual Line of Sight (TBVLOS) waiver for first responders.
- The TBVLOS waiver provides public safety professionals with permission to fly beyond visual line of sight when it counts most – in cases of extreme emergency.
- The UAS can be no further than 1,500 feet from the pilot in command and cannot exceed 50 feet above the obstacle or 400 feet above ground level (AGL).
- Examples: With a TBVLOS, the pilot could fly the UAS behind bridges or walls, over certain rooftops, or around corners.

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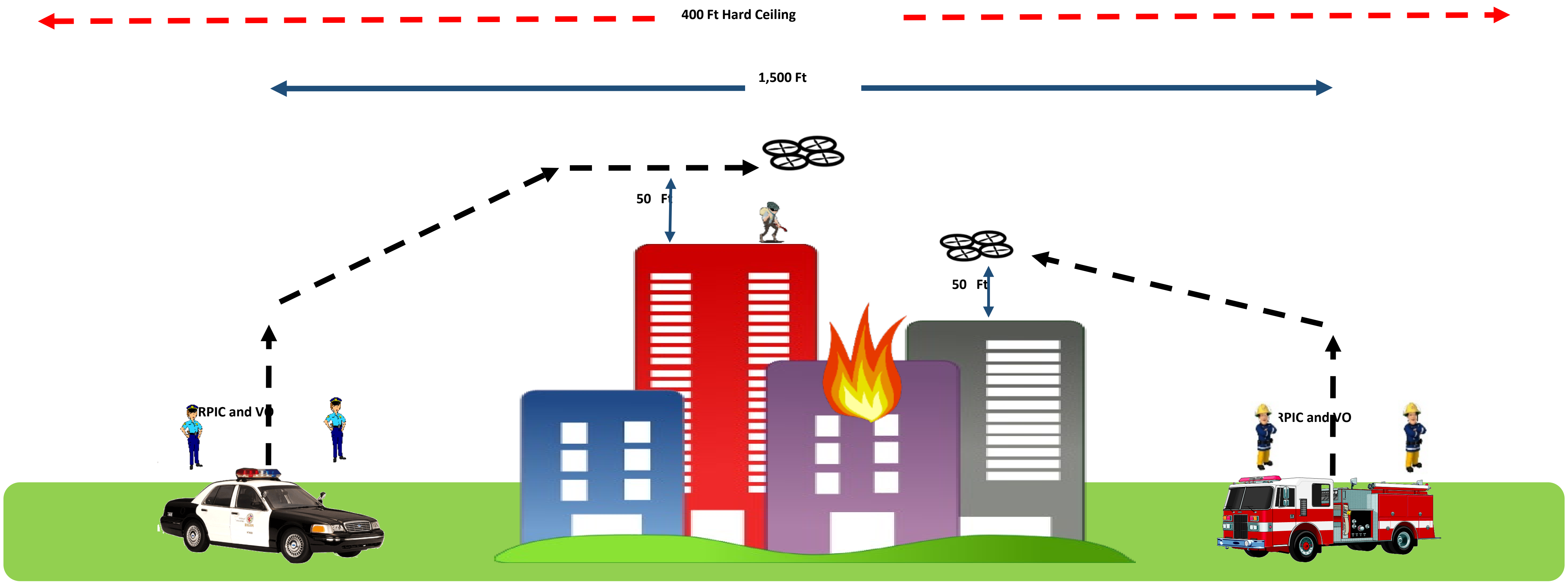
TBVLOS



https://www.faa.gov/uas/public_safety_gov/public_safety_toolkit/media/TBVLOS_Waiver_Final.pdf

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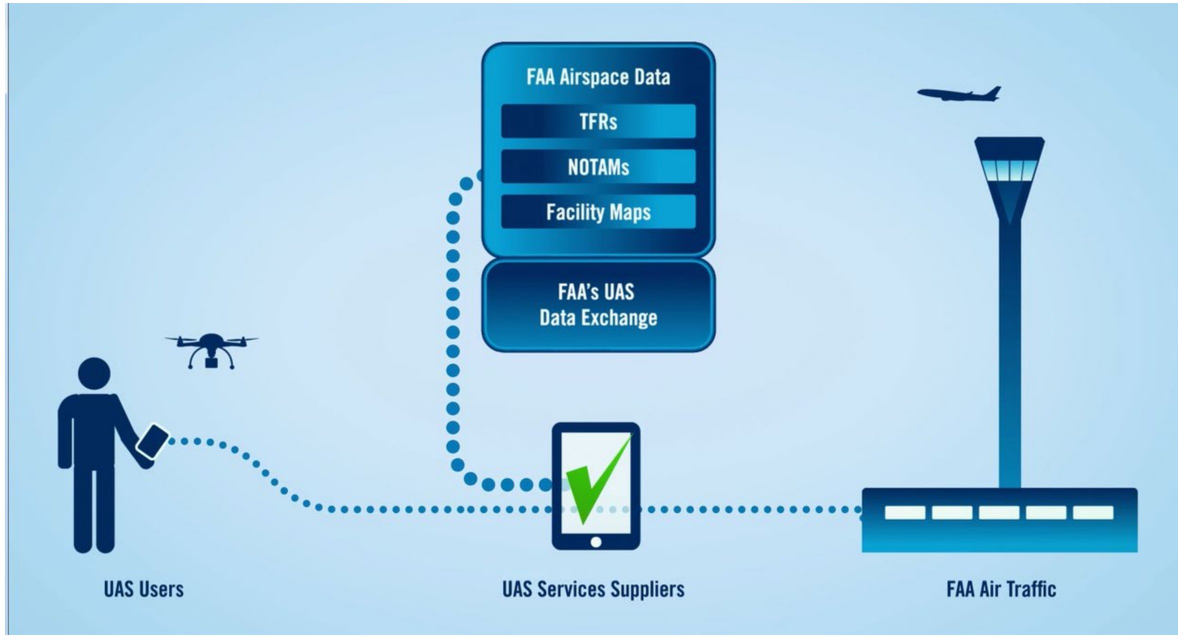
Low Altitude Authorization and Notification Capability (LAANC)



Goals

- Enable efficient notification and authorization services to small UAS operators
- Provide the data exchange framework for UAS traffic management (UTM)

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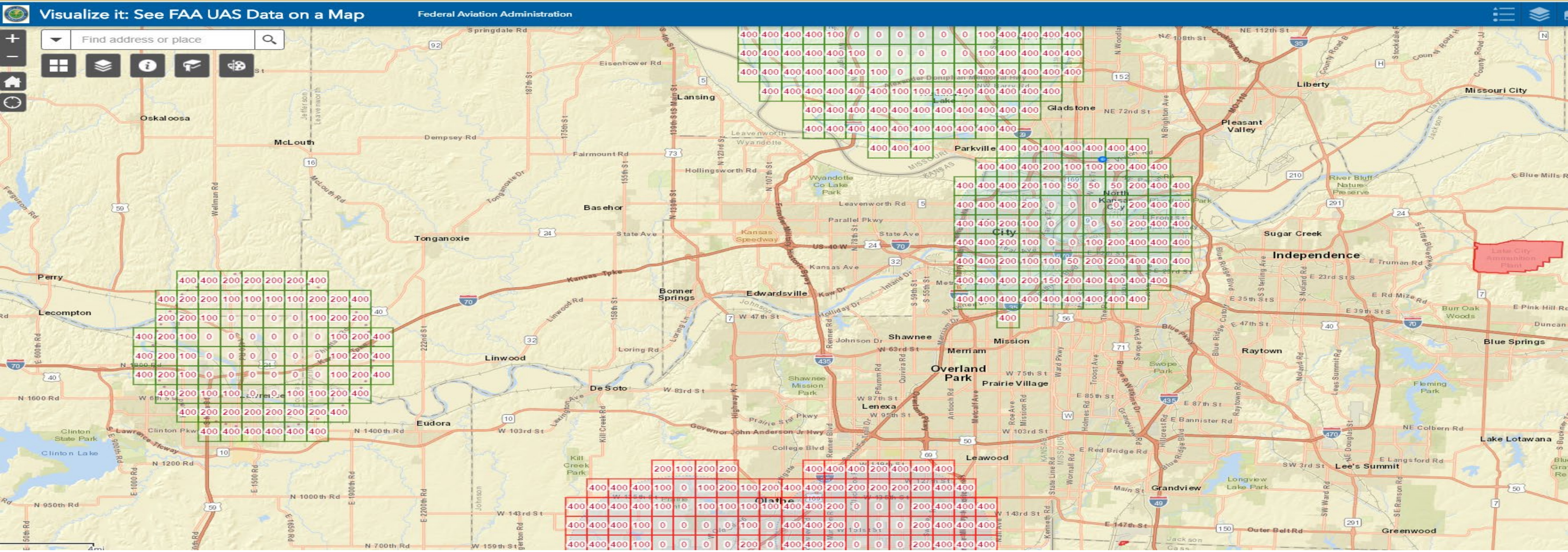
Kansas City Area Airports with LAANC



UAS Overview

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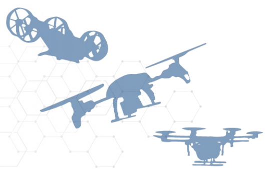
Emergency Public Safety Ops

- Already flying under Part 107 or a COA, but need additional operational provisions? ✔
- Need to fly in a Temporary Flight Restriction (TFR)? ✔
- Need to fly in controlled airspace? ✔

If you checked <u>any</u> of these boxes, call the FAA System Operations Support Center (SOSC) at 202-267-8276

For more info, go here: https://www.faa.gov/uas/getting_started/emergency_approval/



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UAS Laws, Regulations, and Rulemaking

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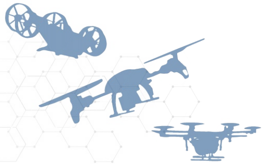
Rulemaking

Name of Rule	Stage	Status
External Marking Requirement for Small Unmanned Aircraft https://www.regulations.gov/docket?D=FAA-2018-1084	Final Rule	In effect
Operations of sUAS Over People/Night/Show RPC **https://www.regulations.gov/document?D=FAA-2018-1087-0001**	NPRM	949 comments - Finalized with rule for Remote ID
Safe and Secure Operations of Small UAS https://www.regulations.gov/docket?D=FAA-2018-1086	ANPRM	1842 comments
Remote Identification https://www.regulations.gov/document?D=FAA-2019-1100-0001	NPRM	In process, 53,040 comments
UAS Flight Restrictions Near Critical Infrastructure	Draft NPRM	Published for comment in the near future
Modernization of the Special Airworthiness Certification (MOSAIC)	Draft NPRM	Development is underway



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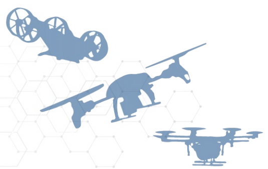
Rulemaking: RID/OOP/NO

Remote Identification (ID) Overview

- The Remote Identification of Unmanned Aircraft Final Rule is the next incremental step towards further integration of Unmanned Aircraft (UA) in the National Airspace System.
- In its most basic form, remote identification can be described as a “digital license plate” for UA. Except instead of ‘registration’, you will get aircraft serial number.
- Remote ID is necessary to address aviation safety and security issues regarding UA operations in the National Airspace System, and is an essential building block toward safely allowing more complex UA operations.



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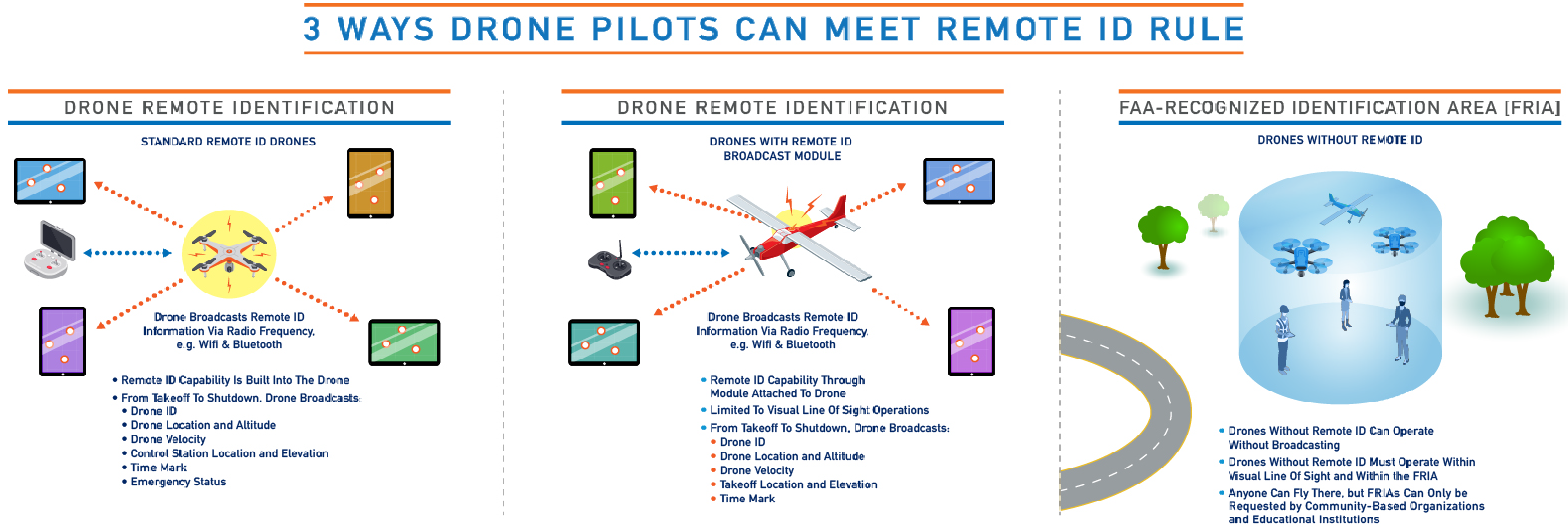
Rulemaking: RID/OOP/NO



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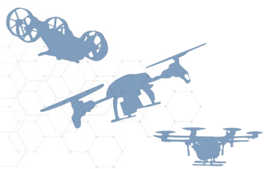
Rulemaking: RID/OOP/NO

Current Rules Schedule:

Final Rule posting on FAA.gov	**December 28, 2020**
RID and OPP Final Rule published in Federal Register	January 15, 2021
RID and OPP Final Rule Effective Date	**April 21, 2021**
Recurrent Training Available/Effective On-line	April 06, 2021 (can't exercise night privilege until effective date of rule @ 04/21/2021)
Night Waivers Sunset	May 17, 2021
RID UAS Mfg/Production Compliance Date	September 16, 2022
FAA accepting FRIA applications	September 16, 2022 (Publication Date 01/15/2021 + 20 Months)
RID Operational Compliance Date	September 16, 2023



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Rulemaking: RID/OOP/NO

Operations Over People/Night Operations

- Part 107 did not permit small unmanned aircraft operations over people without a waiver. The rule will modify part 107 to permit routine operations of small unmanned aircraft over people.
  - 4 Categories
  - Cats 2/3/4 Does not contain any exposed rotating parts that could lacerate human skin upon impact with a human being.
  - Specific considerations for operations over moving vehicles (sustained flight)
- Part 107 did not permit small unmanned aircraft operations at night without a waiver. The rule will modify part 107 to permit routine operations of small unmanned aircraft at night.
  - Anti-collision lights that can be seen for 3 statute miles and have a flash rate sufficient to avoid a collision.
  - Must be operational prior and during flight

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UAS Resources and Useful Information

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Pilot Responsibility - Public Aircraft

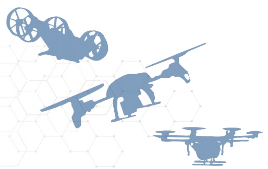
14 CFR 91.3

§91.3 Responsibility and authority of the pilot in command.

(a) The pilot in command of an aircraft is directly responsible for, and is the final authority as to, the operation of that aircraft.

(b) In an in-flight emergency requiring immediate action, the pilot in command may deviate from any rule of this part to the extent required to meet that emergency.

(c) Each pilot in command who deviates from a rule under paragraph (b) of this section shall, upon the request of the Administrator, send a written report of that deviation to the Administrator.



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Pilot Responsibility –Civil (Part 107)

14 CFR107.19 Remote pilot in command.

(a) A remote pilot in command must be designated before or during the flight of the small unmanned aircraft.

(b) The remote pilot in command is directly responsible for and is the final authority as to the operation of the small unmanned aircraft system.

(c) The remote pilot in command must ensure that the small unmanned aircraft will pose no undue hazard to other people, other aircraft, or other property in the event of a loss of control of the aircraft for any reason.

(d) The remote pilot in command must ensure that the small UAS operation complies with all applicable regulations of this chapter.

(e) The remote pilot in command must have the ability to direct the small unmanned aircraft to ensure compliance with the applicable provisions of this chapter.

Probable Cause: Contributing to the accident were an organizational culture that prioritized mission execution over aviation safety and the pilot's fatigue, self-induced pressure to conduct the flight, and situational stress.
https://www.ntsb.gov/investigations/AccidentReports/Pages/AAR1104.aspx

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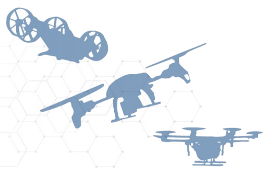
Reporting Unsafe UAS Activity

- **While flying or at the airport:**
  - Report the sighting to Air Traffic Control
    - Note the location, altitude, and characteristics of the aircraft
- **Anywhere else:**
  - Call local law enforcement
    - The FAA has published guidance for law enforcement to help them respond to unsafe UAS activity
- **Be as detailed & specific as possible**
  - Location, altitude, direction, pictures, videos, etc.



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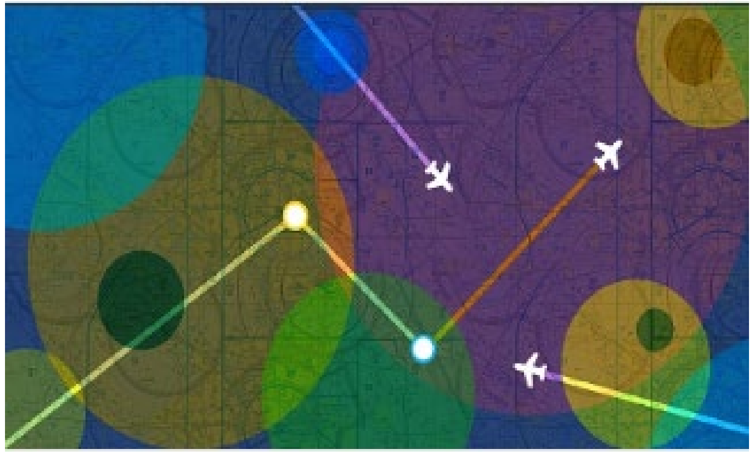
UAS Security Sensitive Restrictions

- 300+ restrictions over sensitive facilities, including military sites, national landmarks, federal prisons, and other sites
- Existing authority from Title 14 CFR 99.7
- Must contact facility, and if in controlled airspace, the FAA, to operate over sites

➢ Interactive map and a list of facilities are available: https://uas-faa.opendata.arcgis.com

- Existing restricted airspace remains in effect



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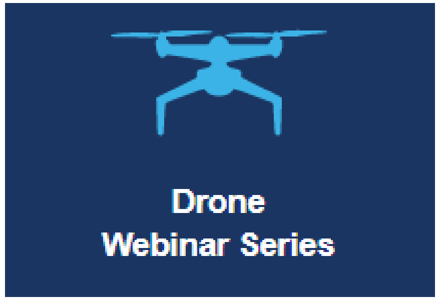
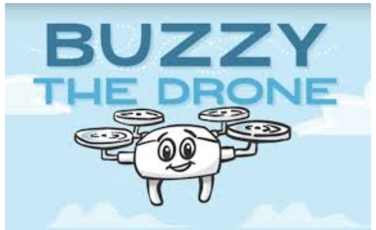
Education and Public Outreach

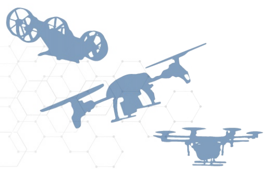
NATIONAL DRONE SAFETY AWARENESS WEEK

KNOW BEFORE YOU FLY

ON-DEMAND WEBINARS	REMOTE IDENTIFICATION	RESEARCH AND DEVELOPMENT	RECREATIONAL FLIERS AND SECTION 349
INTEGRATION PILOT PROGRAM	UAS TRAFFIC MANAGEMENT	BY THE NUMBERS	B4UFLY
LATEST OUTREACH AND EDUCATION MATERIALS	RULEMAKING	PUBLIC SAFETY & GOVERNMENT	LAANC







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New B4UFLY

- **B4UFLY helps recreational flyers know where they can and cannot fly with interactive maps**
  - 2016: B4UFLY launched (FAA's first mobile app)
  - February 2019: FAA partnered with Kittyhawk to improve the B4UFLY user experience
  - July 31, 2019: The new B4UFLY app launched to the public
  - Feb 2021, Web Based Application

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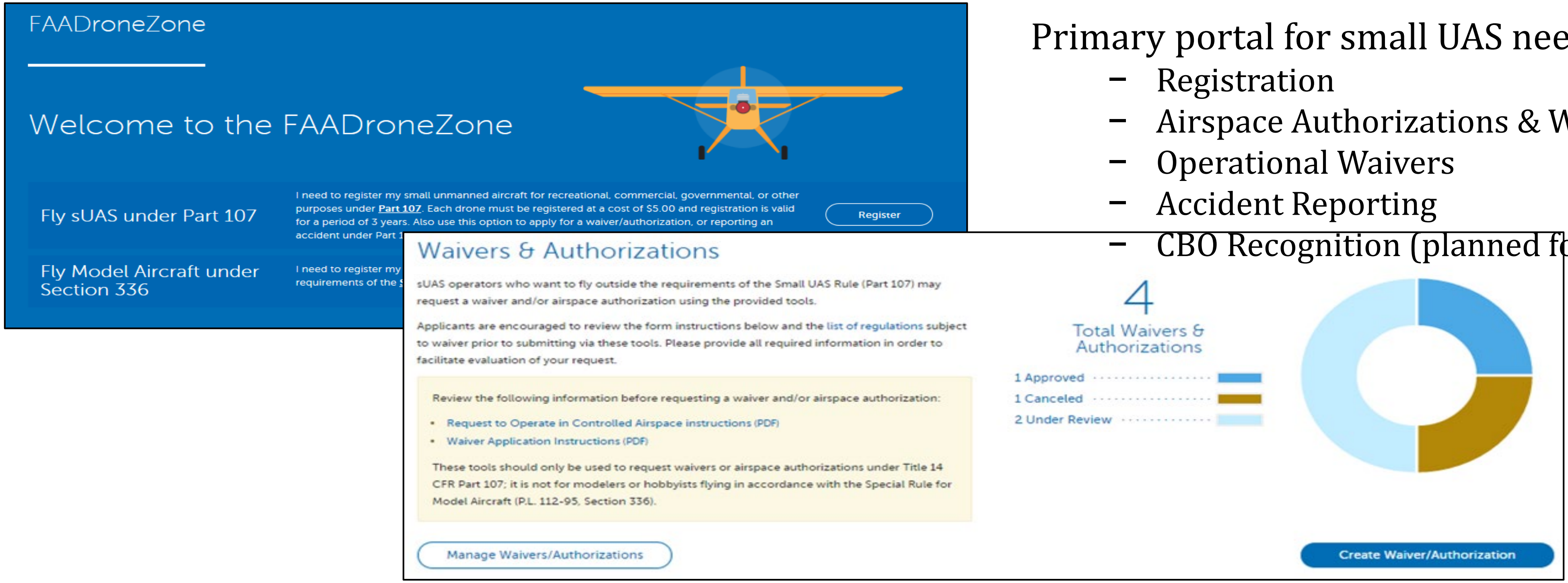
FAA DroneZone



Primary portal for small UAS needs

- Registration
- Airspace Authorizations & Waivers
- Operational Waivers
- Accident Reporting
- CBO Recognition (planned for late 2020)

UAShelp@faa.gov or 844-FLYMYUA

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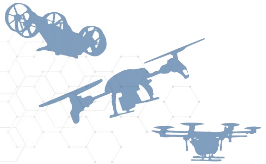
Handy Tools and References

Help with Operations	• **B4UFlyApp:**https://www.faa.gov/uas/recreational_fliers/where_can_i_fly/b4ufly/ • **Part 107 Waivers:** https://faadronezone.faa.gov/#/ • **NOTAM Entry**: https://www.1800wxbrief.com/Website/uoa
Understanding Regulations	• **AC 00-1.1B:** Public Aircraft Operations • **14 CFR Part 107:** Small Unmanned Aircraft Systems • **AC 107-2:** Small Unmanned Aircraft Systems (sUAS) • **Title 49 U.S.C. §§ 40102(a)(41) and 40125**
General Information	• **FAA UAS Webpage: https://www.faa.gov/uas/**
Emergency Operations	• **Sys Ops Sec: (202) 267-8276, 9-ator-hq-sosc@faa.gov** • https://www.faa.gov/uas/getting_started/emergency_approval/



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Questions?

- For questions about operations contact the UAS Support Desk: UAShelp@faa.gov or 844-FLYMYUA

- FAA Aviation Security Law Enforcement Assistance Program: LEAP@faa.gov

- FAA Office of UAS Integration Public Safety Liaison: Mike O'Shea, Program Manager, michael.oshea@faa.gov

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March 16, 2021

APPLICATION OF UAVS FOR GEOTECHNICAL INFRASTRUCTURE MONITORING

Lecture: Sensing Infrastructure Using UAV: Benefits of Multiple Sensors

Instructor: Thomas Oommen; Michigan Technological University

Webinar for the Transportation Research Board

Contact: toommen@mtu.edu

Co-authors: Jordan Ewing Ph. D. Student, Michigan Tech
Colin Brooks, Michigan Tech Research Institute
Rick Dobson, Michigan Tech Research Institute
Rudiger Ecobar Wolf, Michigan Tech

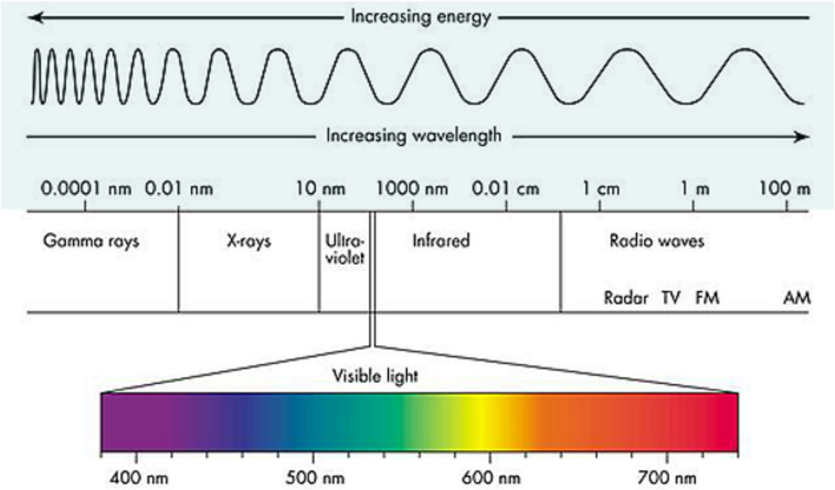
Acknowledgement: This project was funded by the US Department of Transportation (USDOT) through the Office of the Assistant Secretary for Research and Technology, University of Michigan Automotive Research Center, and other private companies.

Disclaimer: The views, opinions, findings, and conclusions reflected in this presentation are the responsibility of the authors only and do not represent the official policy or position of the USDOT/OST-R, or any State or other entity.

Outline | Multi-Sensor

- Optical Sensor
- Hyper-spectral
- Thermal

Thermal & Hyperspectral



Light energy is either reflected, transmitted, or absorbed when interacting with a material

Thermal: 7.5 – 13.5 um

Soil absorbs the energy and is then radiated back out. Provides subsurface data about the material.

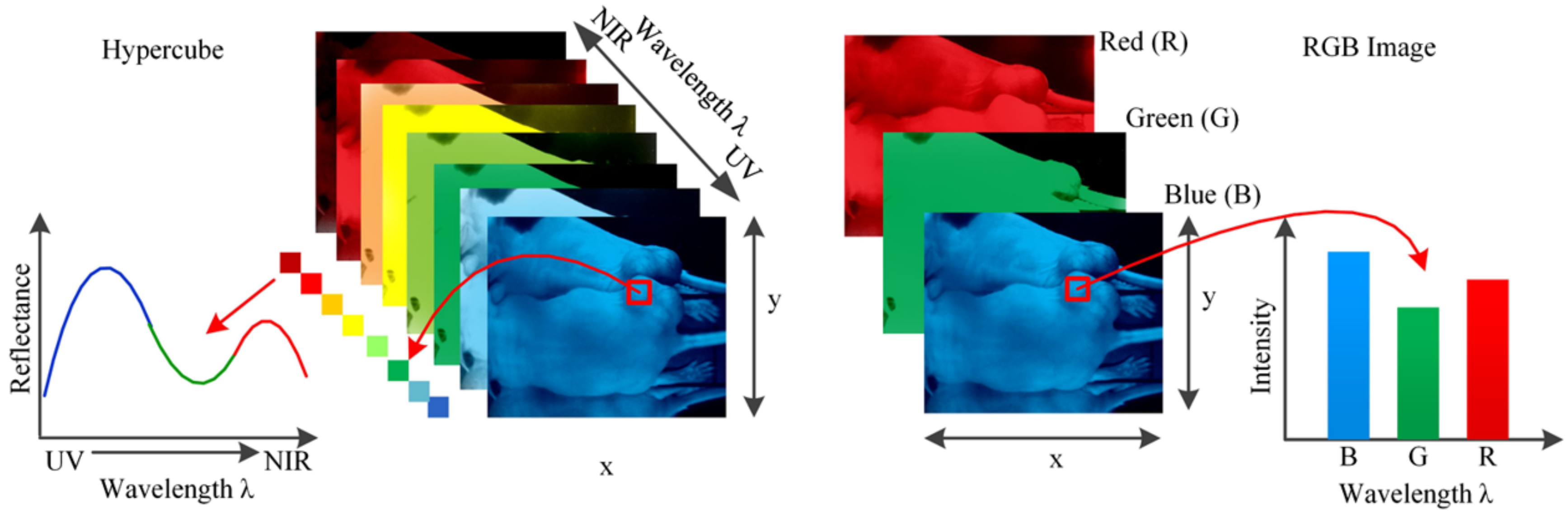
Hyperspectral: 400-1700 nm

Light reflected on the surface gives only surface data to allow for classification of the soils.

Electromagnetic Spectrum

Thermal & Hyperspectral

Remote Sensing: Why Hyperspectral?



- Multispectral: few wide band range that then gets averaged, discrete values for RGB
  - Used for typical camera on your phone
- Hyperspectral: multiple very narrow bands to make a continuous plot
  - Used for mineral mapping, classification, and medical imaging

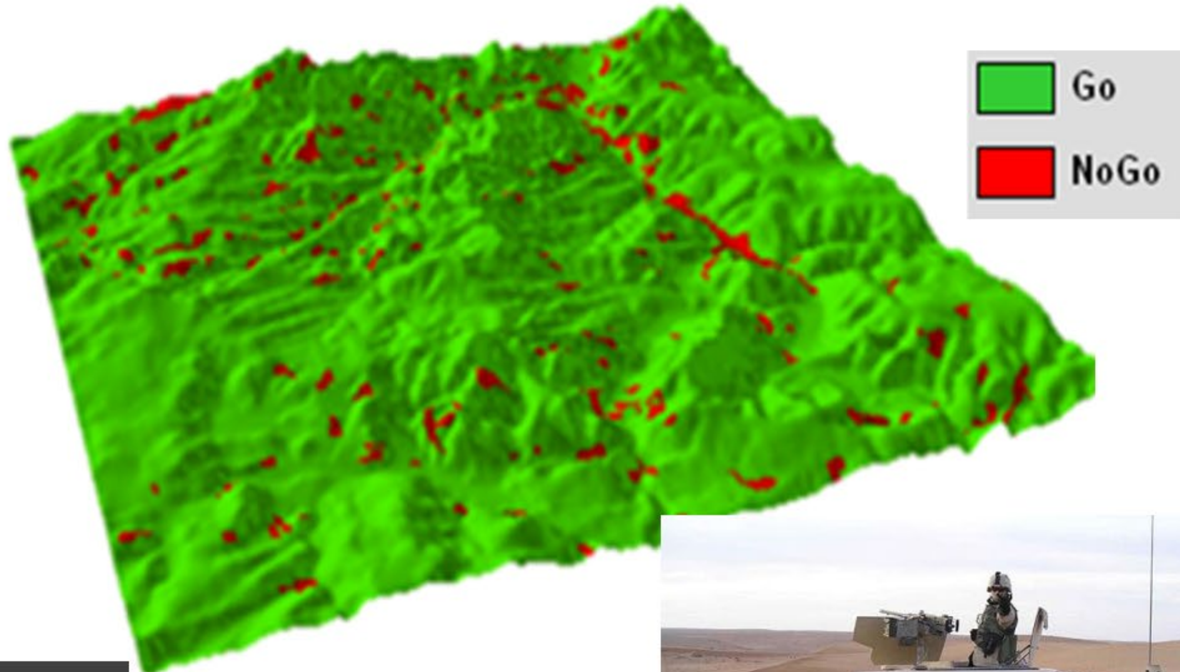
Thermal & Hyperspectral

Thermal Inertia/Apparent Thermal Inertia

- Thermal Inertia: $TI = (k\rho c)^{1/2}$
  - The potential of a material to absorb and store heat (measures a material's resistance to change in temperature)
  - Function of material composition / type
  - k = thermal conductivity, ρ = bulk density of the surface material, c = specific heat
- Apparent Thermal Inertia (ATI): close approximation of Thermal Inertia
  - $ATI = (1 - \alpha)/\Delta T$
    - α = albedo, ΔT = change in temp.

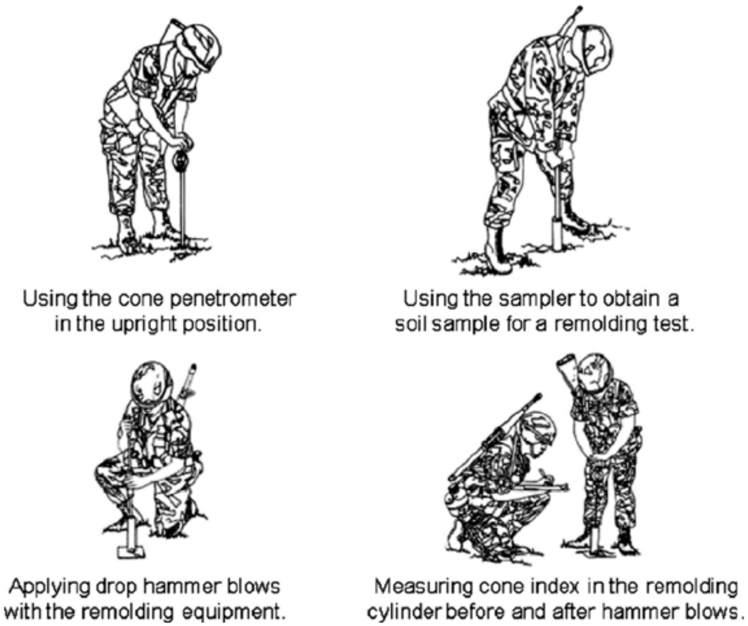
Application| Thermal & Hyperspectral

Go/No Go mobility maps are critical for Army mission planning



- They provide the best route options for which ground forces should maneuver through a terrain
- Ultimately to avoid unwanted traps, attacks, or having the vehicles get stuck due to path conditions

Application| Thermal & Hyperspectral

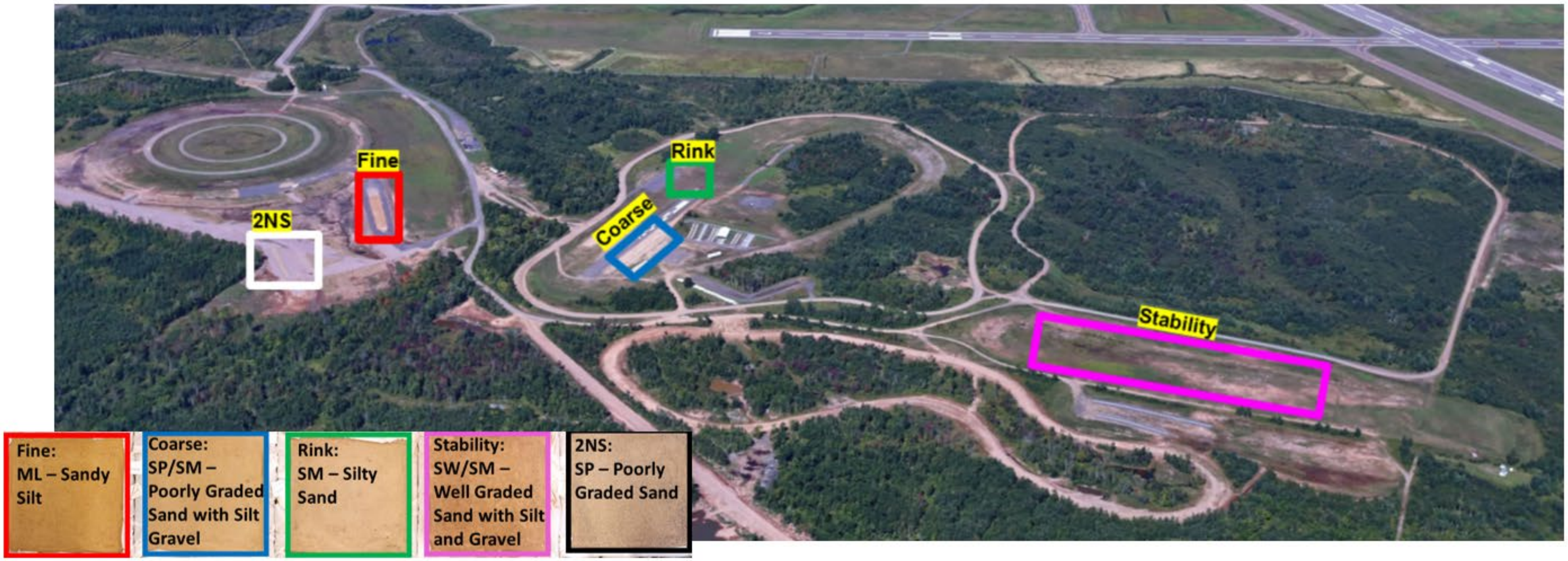


Limitation:

- It relies heavily on in-situ measurements
- In-situ terrain data collection can put the soldiers in harms way

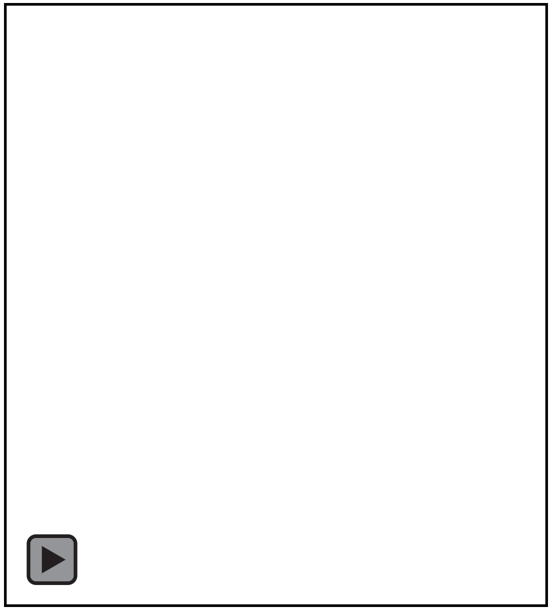
State of the Art: Terrain Strength Characterization

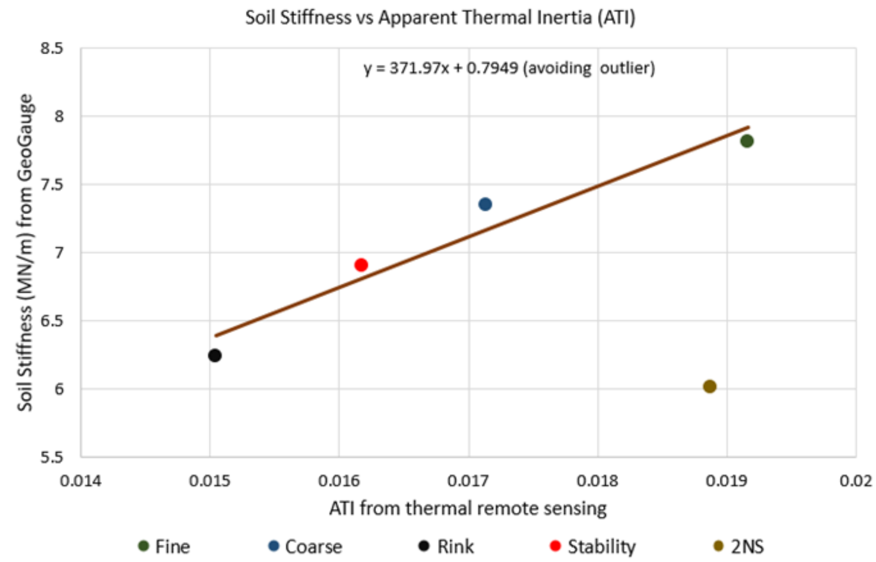
Application| Thermal & Hyperspectral



Keweenaw Research Center

Application| Thermal & Hyperspectral



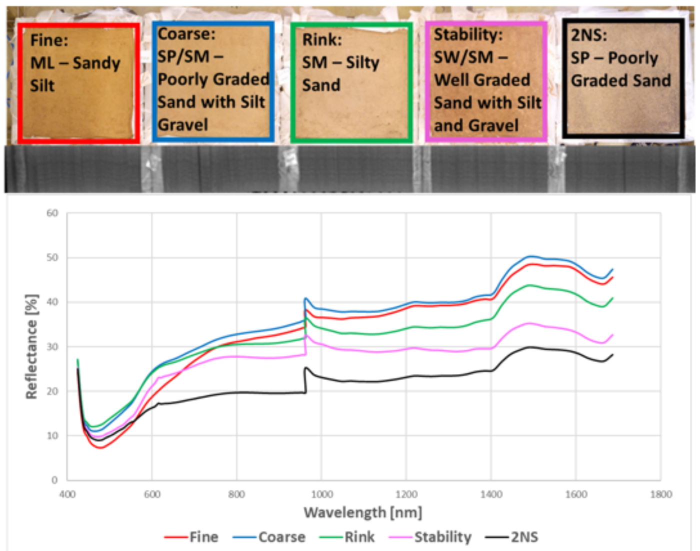


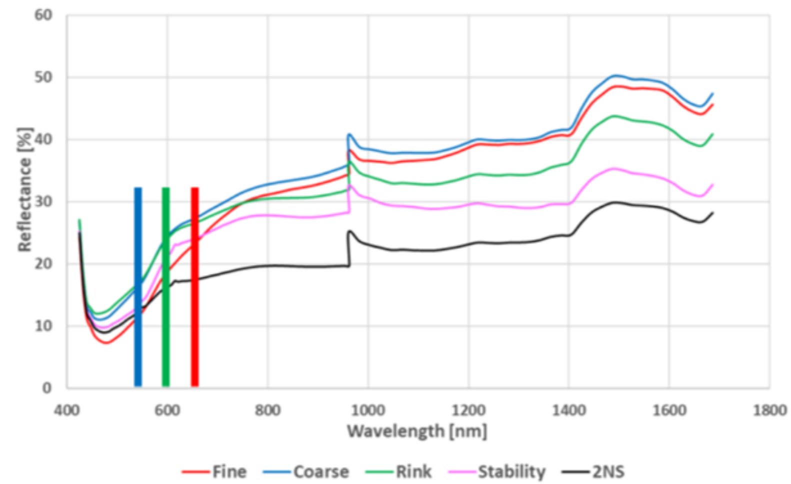
Humboldt: H-4140 GeoGauge

Device was used to collect the stiffness of each soil

Units: [MN/m]

Application| Thermal & Hyperspectral



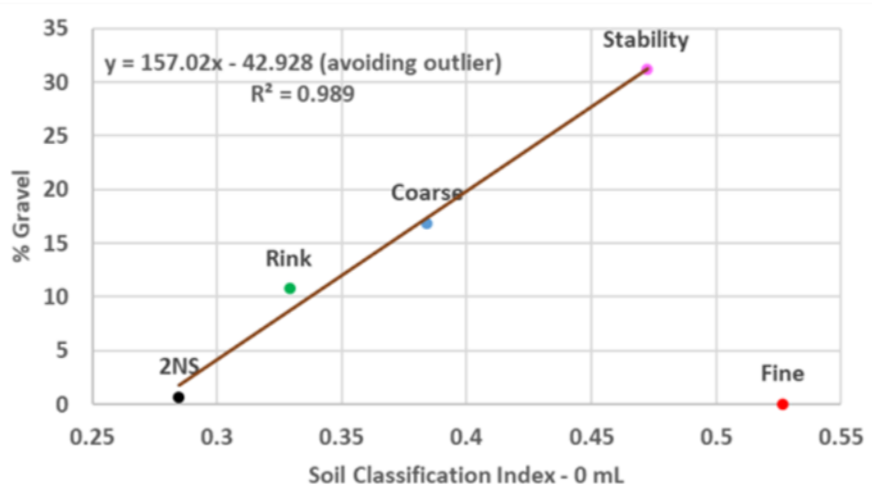


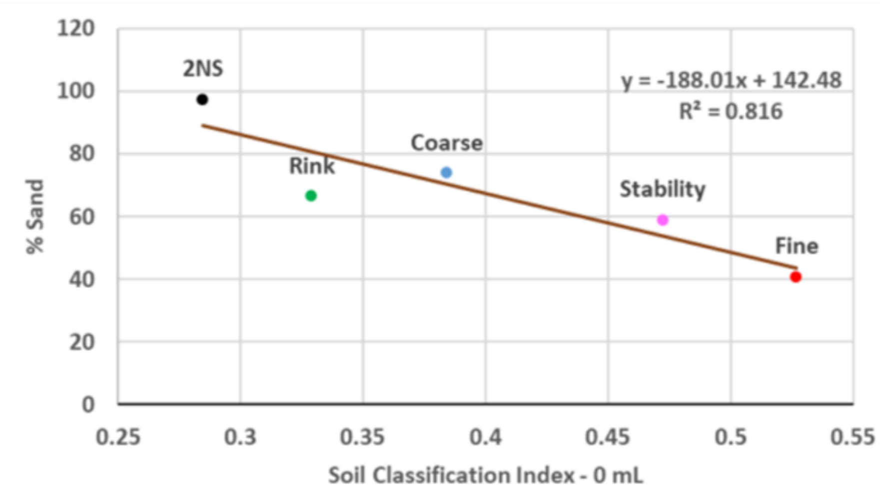
Soil Classification Index = $(R_{650} - R_{550})/R_{600}$

→ R_{650}, R_{600}, R_{550} = Reflection value at 650, 600, and 550 nm

Hyperspectral: Soil Classification Index

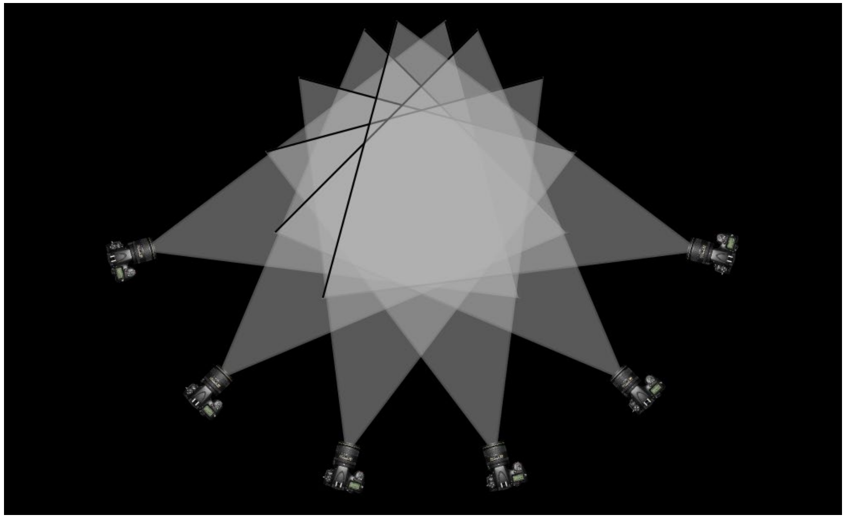
Application | Thermal & Hyperspectral





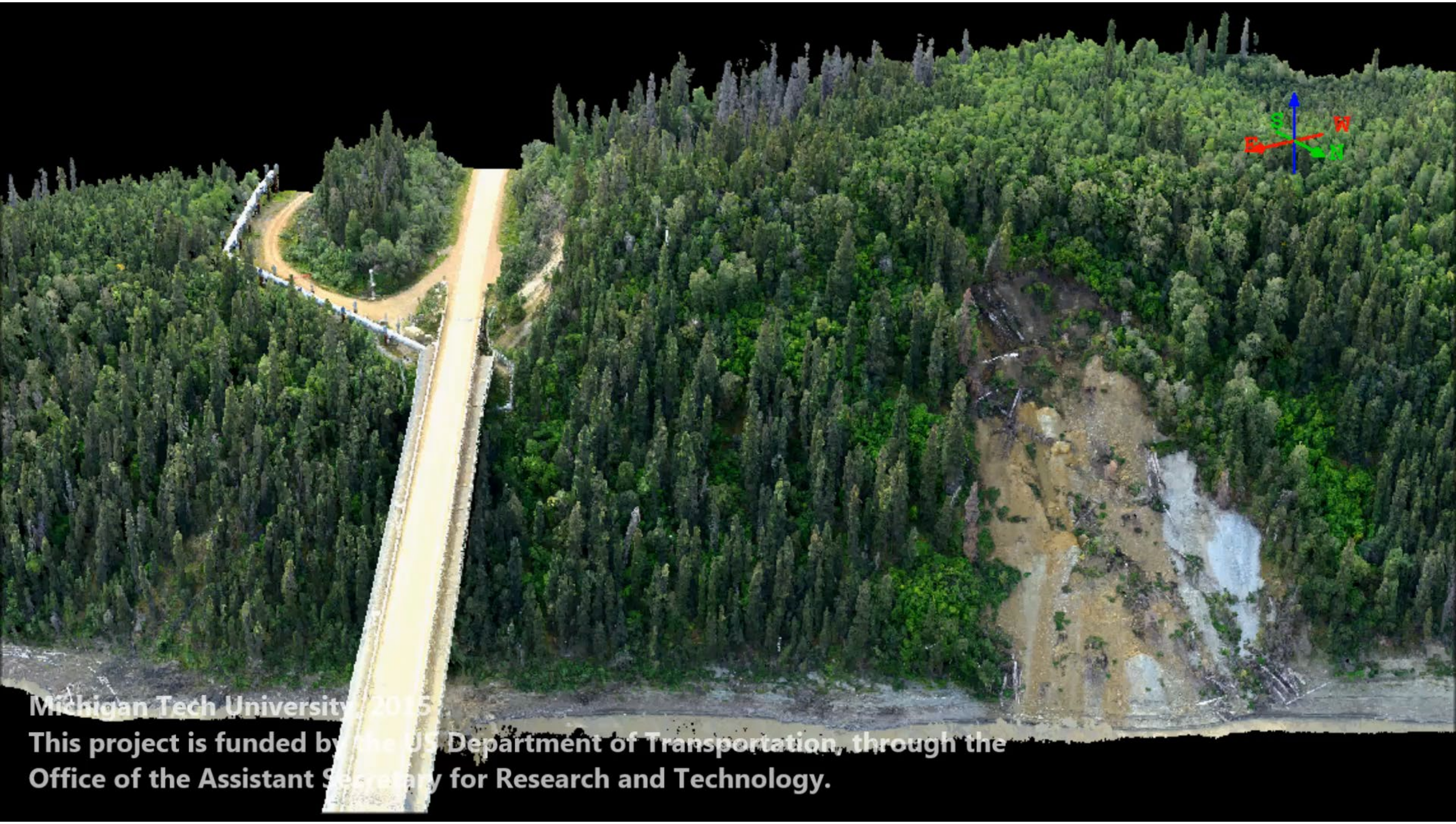
Soil Classification Index: % Gravel & % Sand

Application | Optical



Structure from Motion

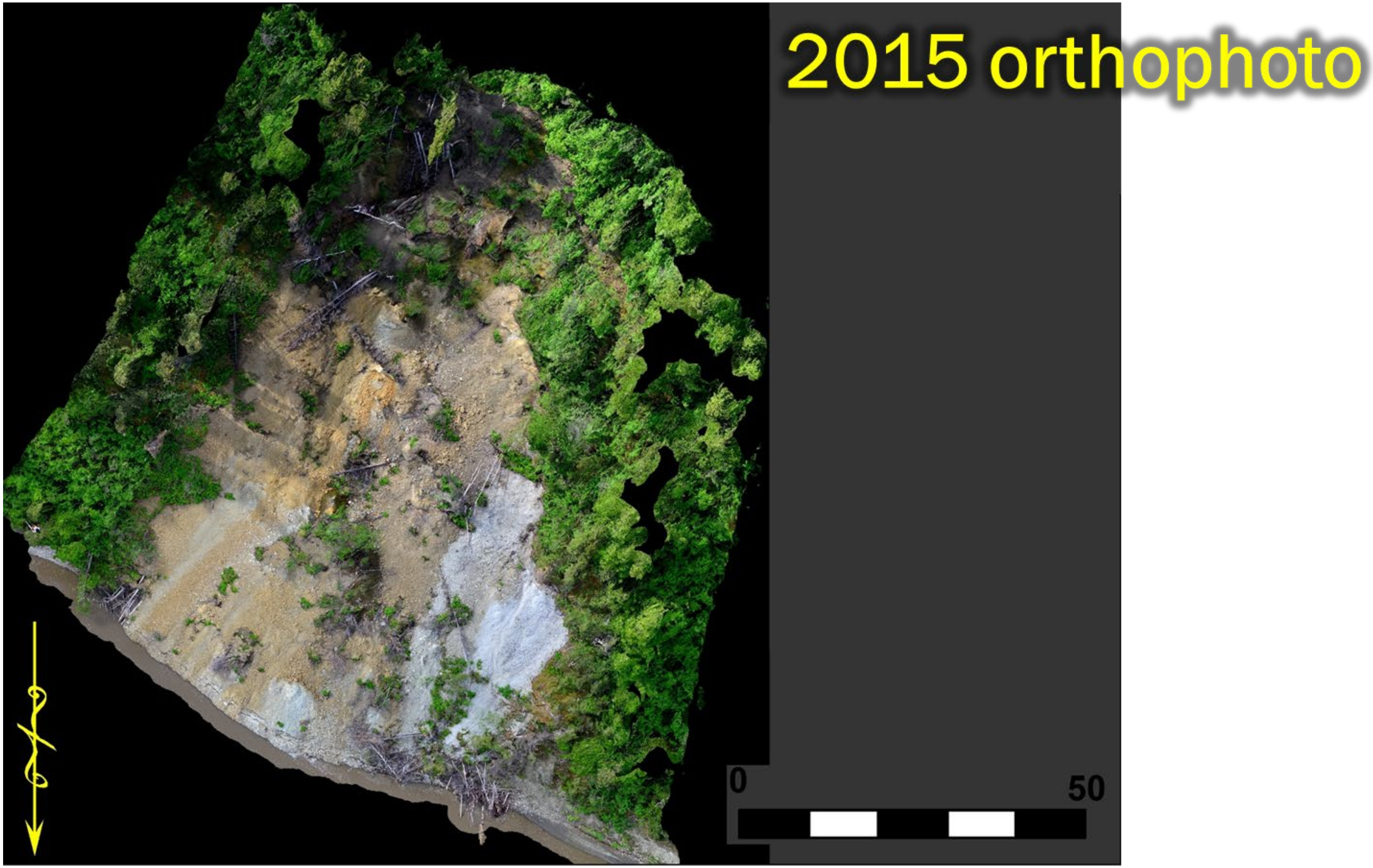
Application | Optical



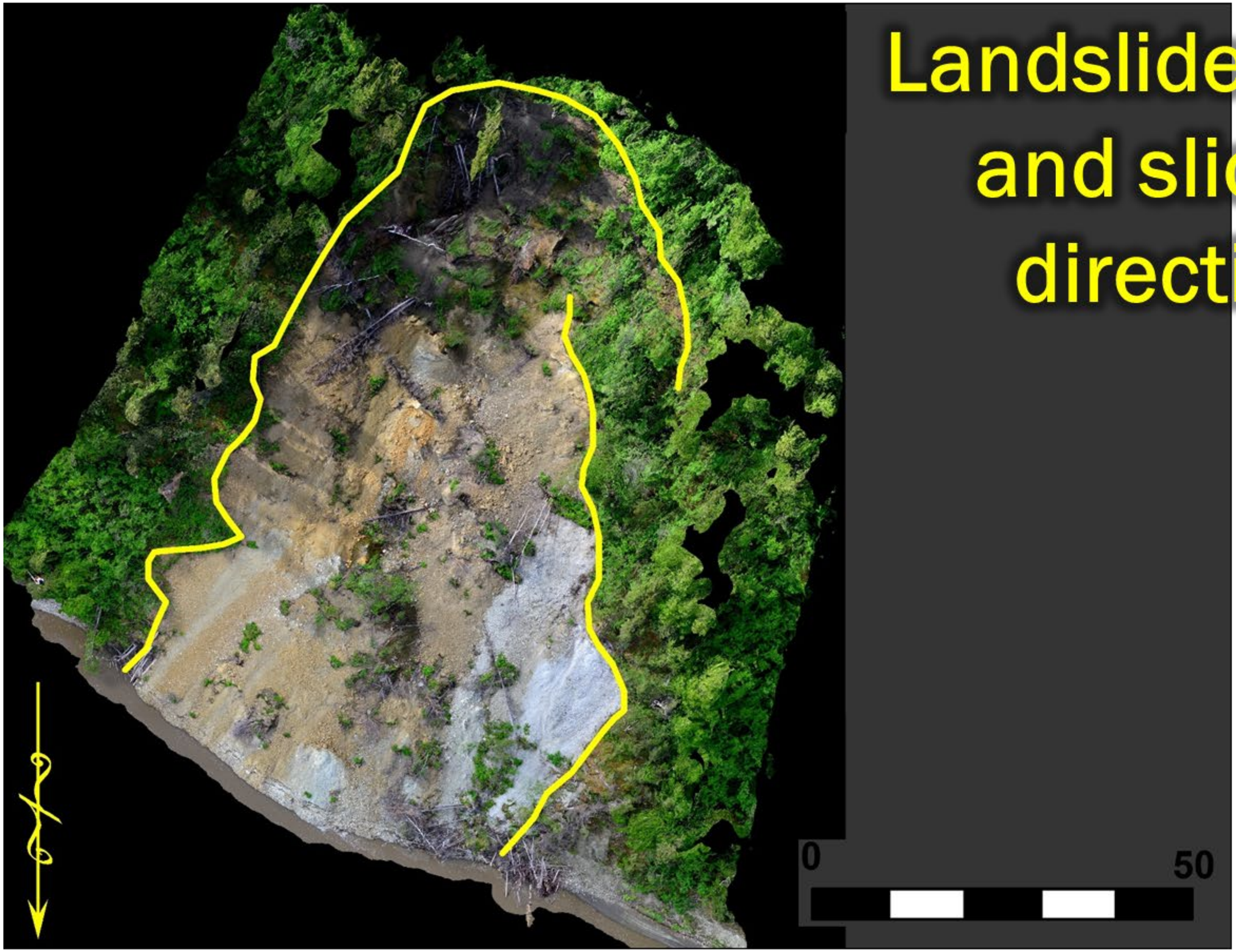
Application| Optical

Application | Optical

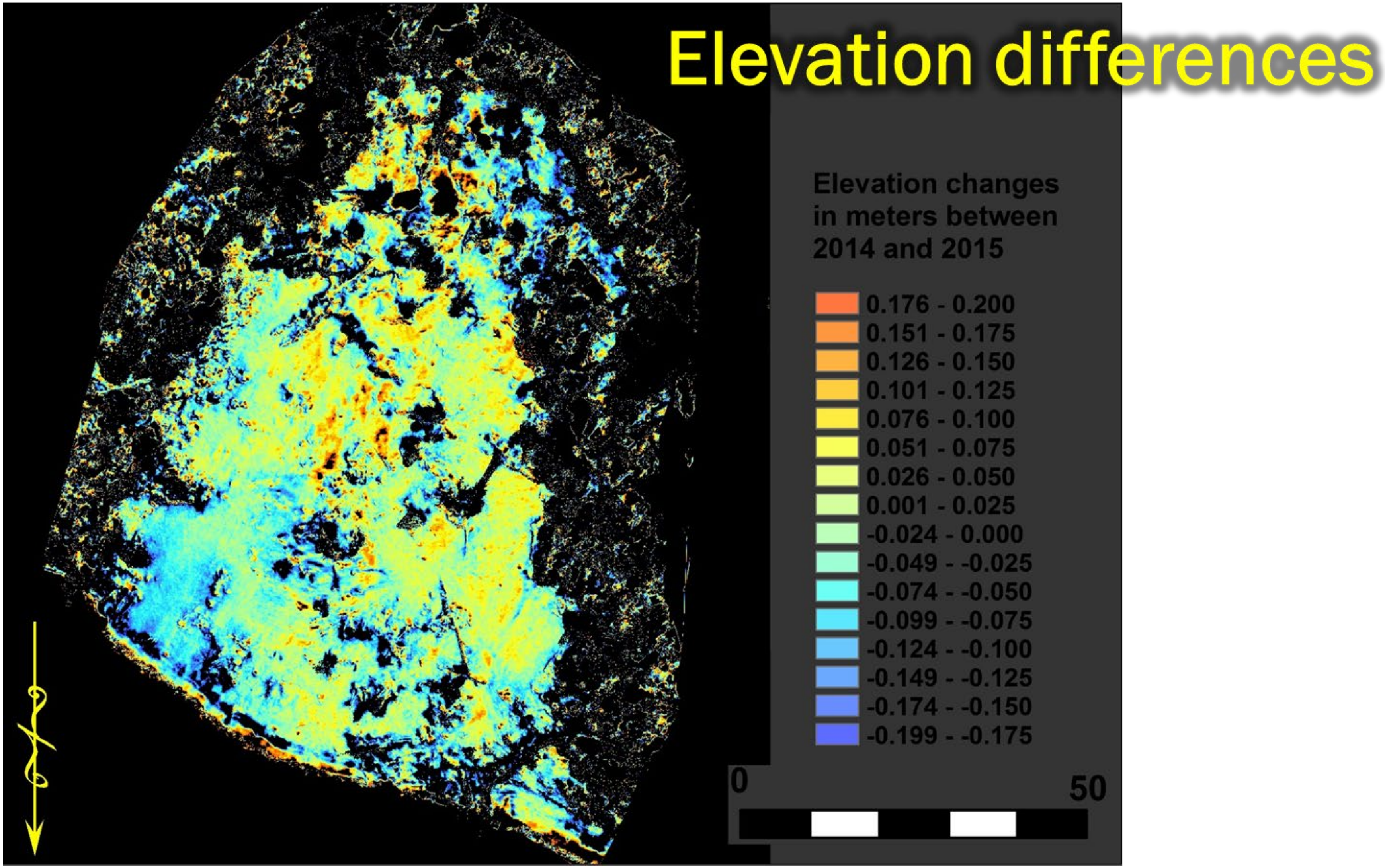
Application| Optical



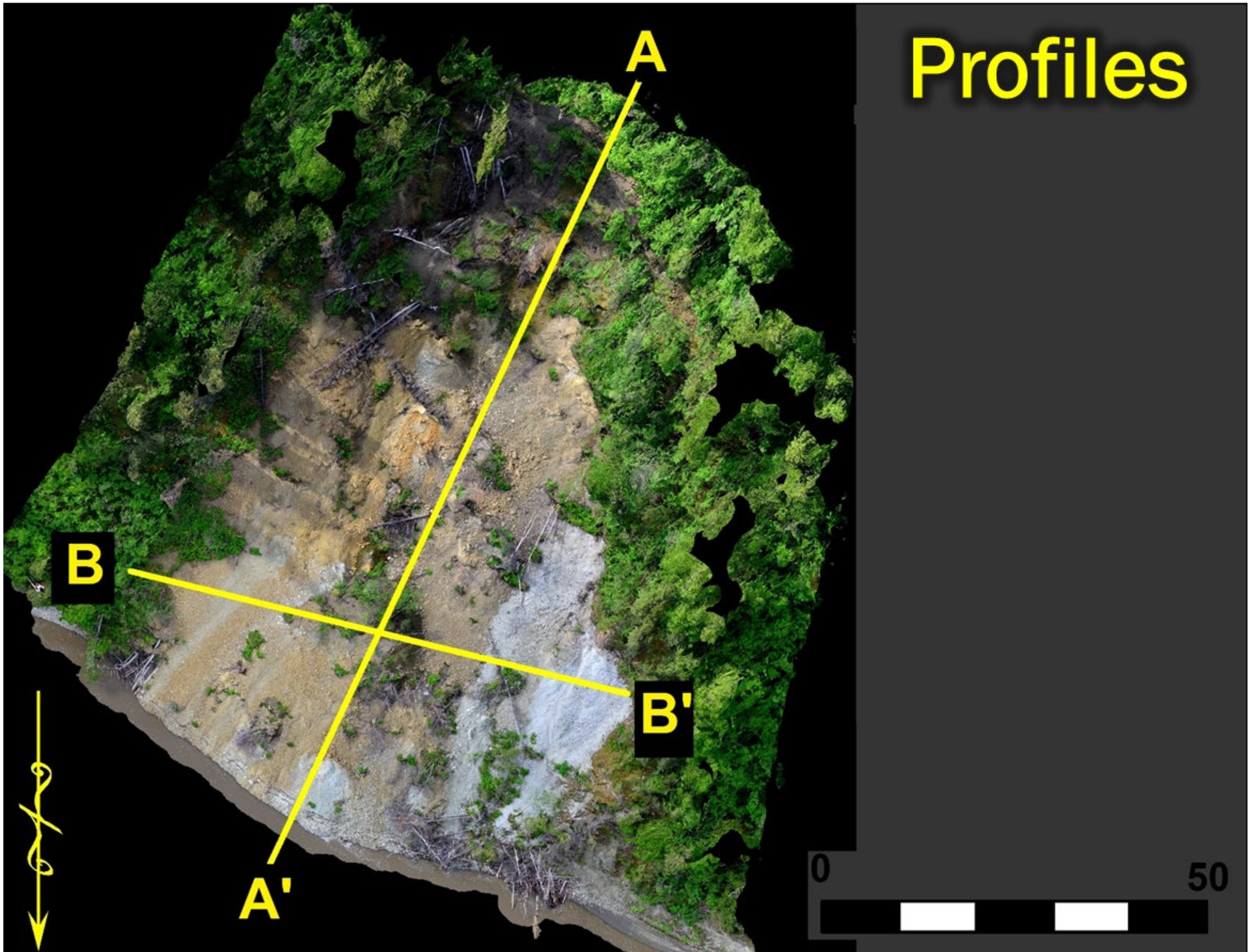
Application | Optical



Application| Optical

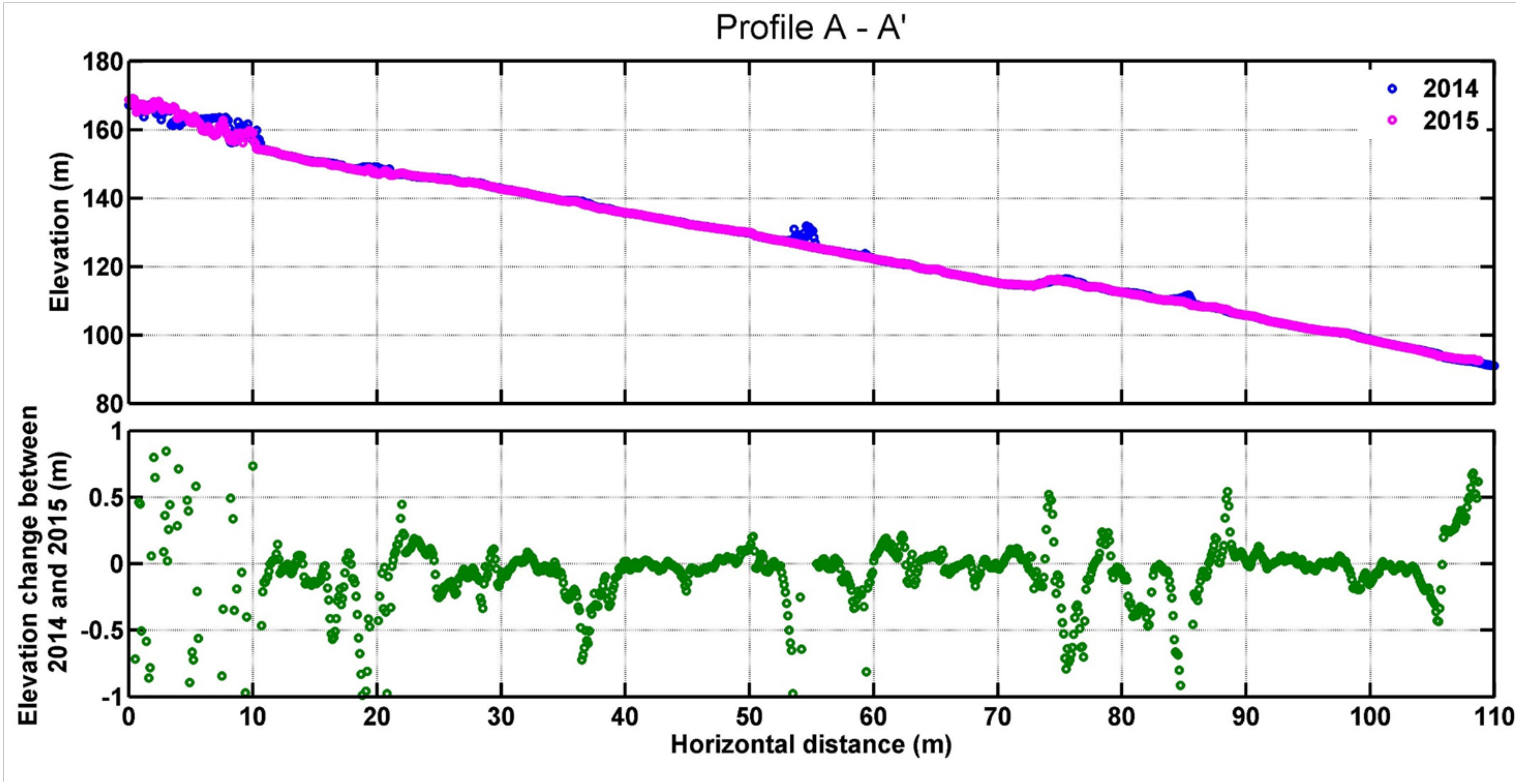


Application | Optical



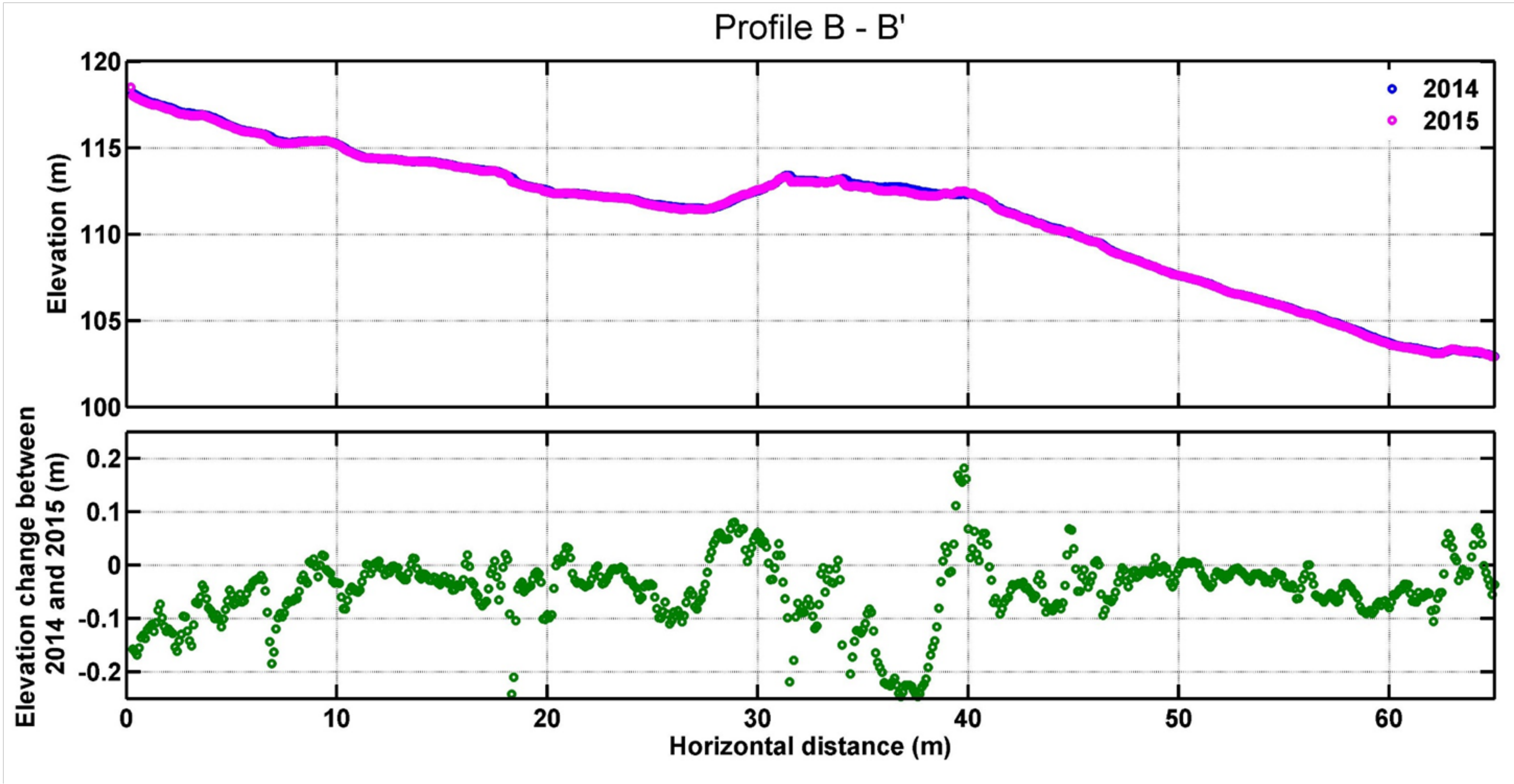
Application| Optical

Profile A – A'



Application| Optical

Profile B – B’



Case Studies: Applications of Unmanned Aerial Vehicles in Monitoring Geotechnical Assets

Surya Sarat Chandra Congress, Ph.D.
Associate Research Scientist

Transportation Research Board
Webinar on The Ubiquitous Unmanned Aerial Vehicle – UAVs for Infrastructure Monitoring
Sponsored By:
Standing Committee on Geotechnical Instrumentation and Modeling (AKG60)

March 16, 2021

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Zachry Department of Civil & Environmental Engineering

Presentation Outline

- Introduction
- Infrastructure Monitoring
- Total Calibration and System Error Analysis
- Monitoring Geotechnical Assets
    - Case Study – I: Expansive Soils
    - Case Study – II: Sulfate Induced Heaving
    - Case Study – III: Disaster Response
    - Case Study – IV: Cut-slope Stability
- Key Observations

Introduction

- 2021 ASCE infrastructure report card
  - 43% of the roadways are in poor condition
  - High-hazard-potential dams have doubled
- Requirement for Inspection tools
  - Proactive monitoring
  - Safe, quick, and cost effective
- Unmanned aerial vehicle systems (UAV or UAS or Drones)
  - Most disruptive technology in human history
  - Billion drones in the world - by the year 2030

Source: ASCE 2021; Inside Robotics

Introduction: Photogrammetry

Photogrammetry is the art and science of making measurements and creating 3-dimensional point clouds from two or more photographs

Smart phone cameras to sensor mounted satellites	Terrestrial and Aerial

Types of Unmanned Aerial Vehicles

Rotary-wing – Lift from the continuous rotation of its blades	Fixed-wing – Single rigid wing across its body

Close Range Photogrammetry (CRP) – <1000 ft radius

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Infrastructure Monitoring

Proactive monitoring

- Preventive maintenance
- Low life cycle cost of infrastructure
- Higher return on investment

Two types of monitoring

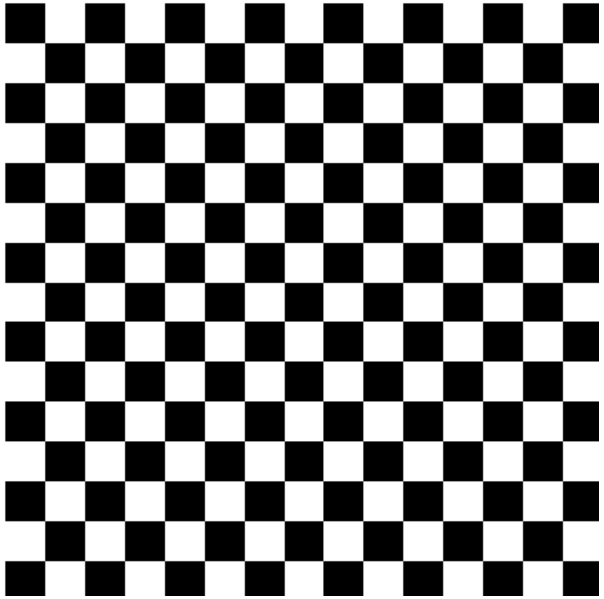
- Qualitative – QA/QC
- Quantitative – Infrastructure Characteristics

3-D Mapping Products

- Dense Point Cloud
- Digital Elevation Model (DEM)
- Orthomosaic

Total Calibration and System Error Analysis

- ❑ Accuracy in geotagging the images
- ❑ Variation in the focal length of camera
- ❑ Thermal effect on lens
- ❑ Analyze resolution and resolving power of the system



Checkerboard

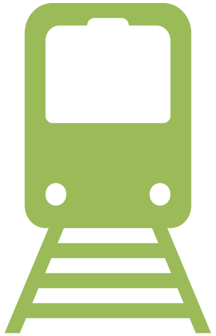
Siemens star

IR thermometer

Infrastructure Asset Monitoring

Pavement Monitoring

- Qualitative – Construction Sequence
- Quantitative – Surficial Distress and Design Features



Rail Corridor Monitoring

- Qualitative – Buckling, vegetation, etc.,
- Quantitative –Cut Slope Stability

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Monitoring Geotechnical Assets

- Case Study – I
  - Expansive Soils – Differential Settlement
  - Qualitative Monitoring
- Case Study – II
  - High Sulfate Soils – Ettringite Induced Heaving (4 in. to 10 in.)
  - Digital Elevation Models and Contours
- Case Study – III
  - Disaster Response
  - Pavement Cracking/ Deformation
- Case Study – IV
  - Rail infrastructure
  - Cut-slope stability

Case Study – I: Site Overview

- **Expansive Soil Subgrade**
  - **Alternate wetting and drying cycles- differential movements of soil and pavement deformations**
- **Major rehabilitation work in 2017**
  - **2 in. (5 cm) thick overlay**
  - **Beginning of 2018 - severe issues including longitudinal cracking and surface depressions**
- **Pavement Design**
  - **Geocell and Recycled Asphalt Pavement (RAP)**

Case Study – I: Qualitative

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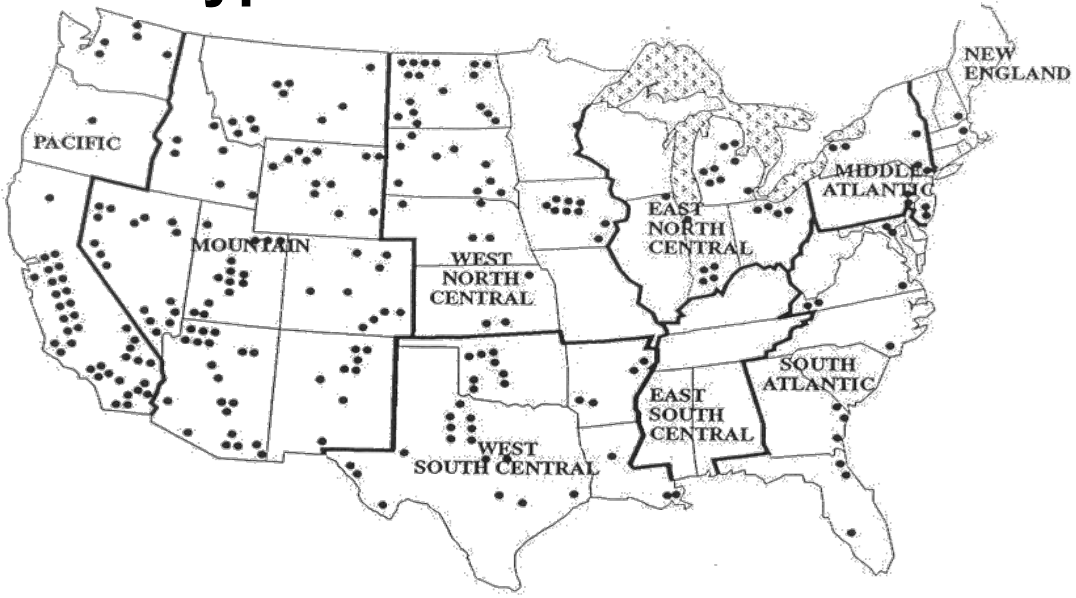
Case Study – II: Site Overview

- Sources of Sulfates in Soil
  - ✓ Gypsum ($CaSO_4.2H_2O$)
  - ✓ Sodium Sulfate (Na_2SO_4)
  - ✓ Magnesium Sulfate ($MgSO_4$)

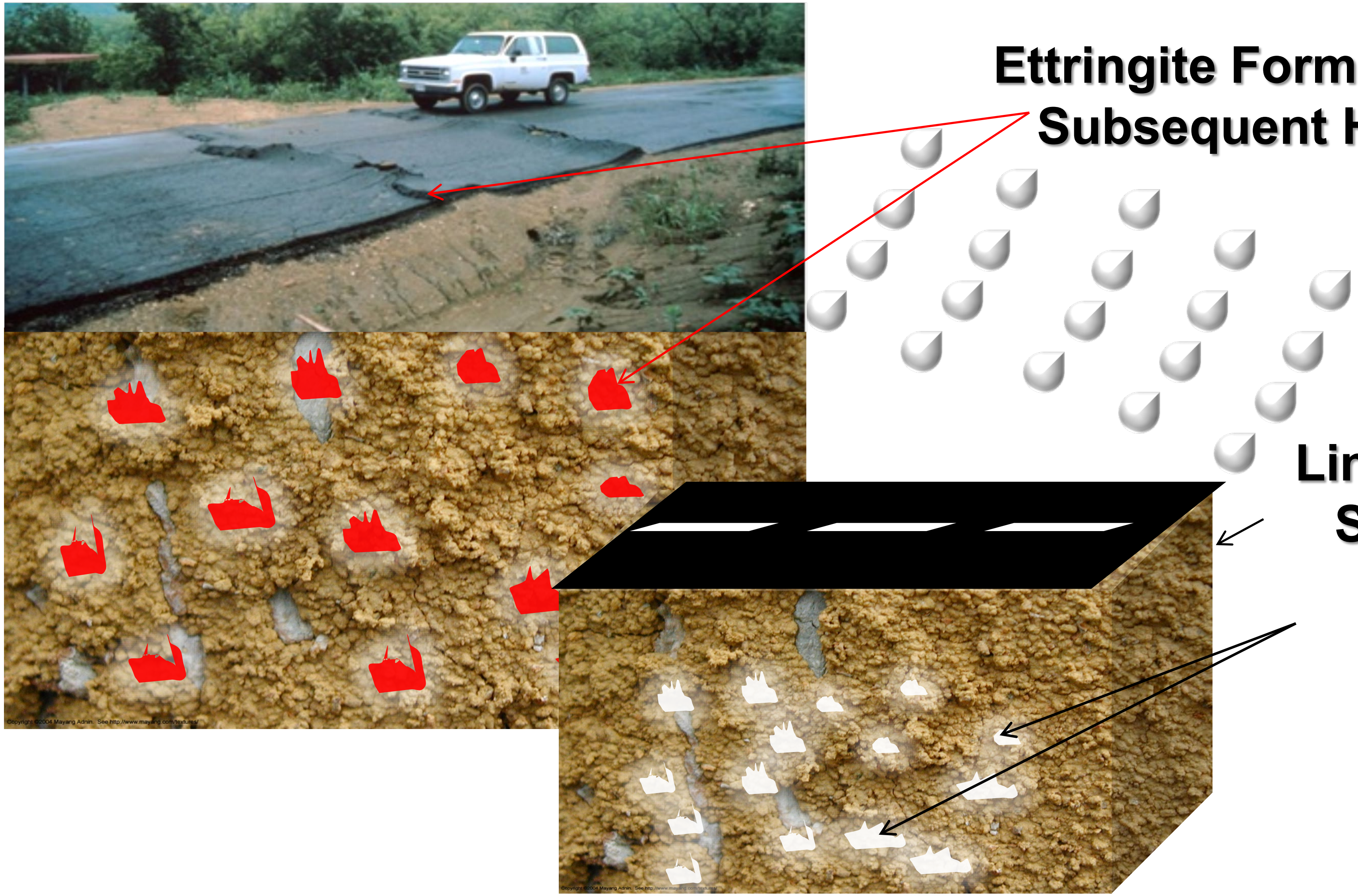
Gypsum in Natural Soils

Distribution of
Gypsum Rich Soils in USA



Calcium Based Treatments of Sulfate Soils: Sulfate-induced Heave - Ettringite Formation
(Mitchell, Hunter, Little and Many Other Researchers)

Sulfate Heaving Phenomenon



Source: Les Perrin

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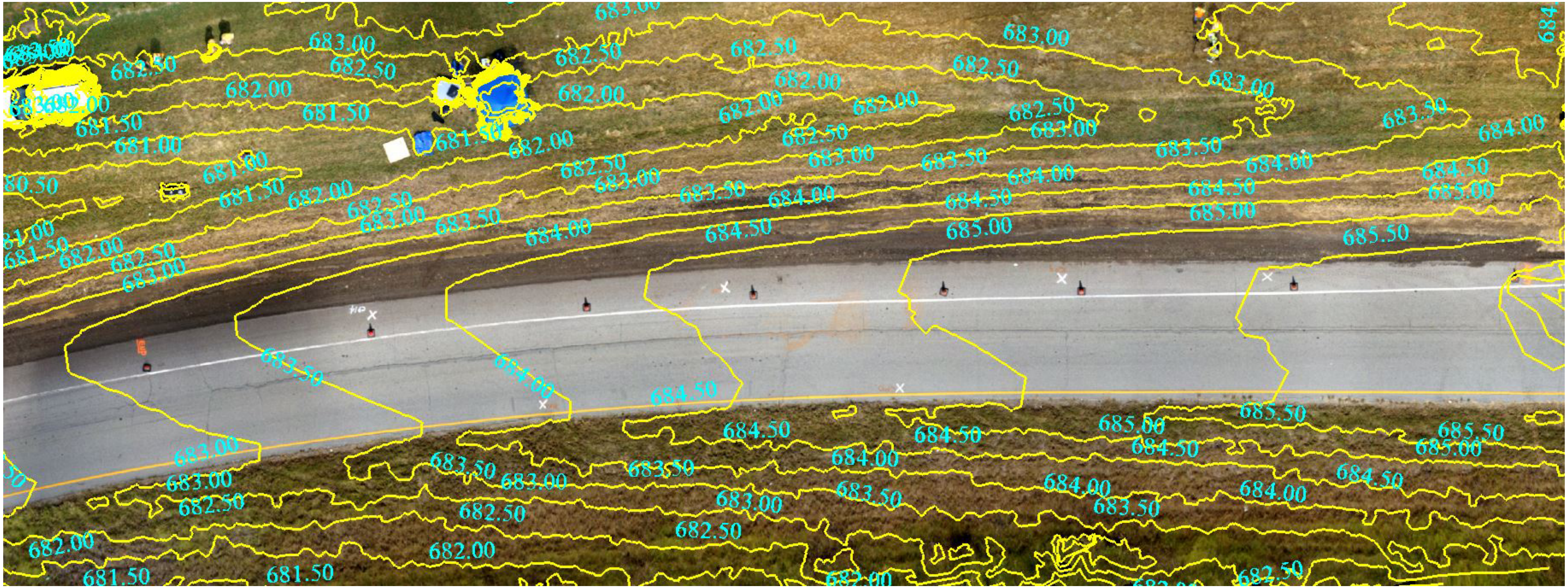
Case Study – II: Sulfate Induced Heaving



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Case Study – III: Site Overview

Case Study – III: Disaster Response

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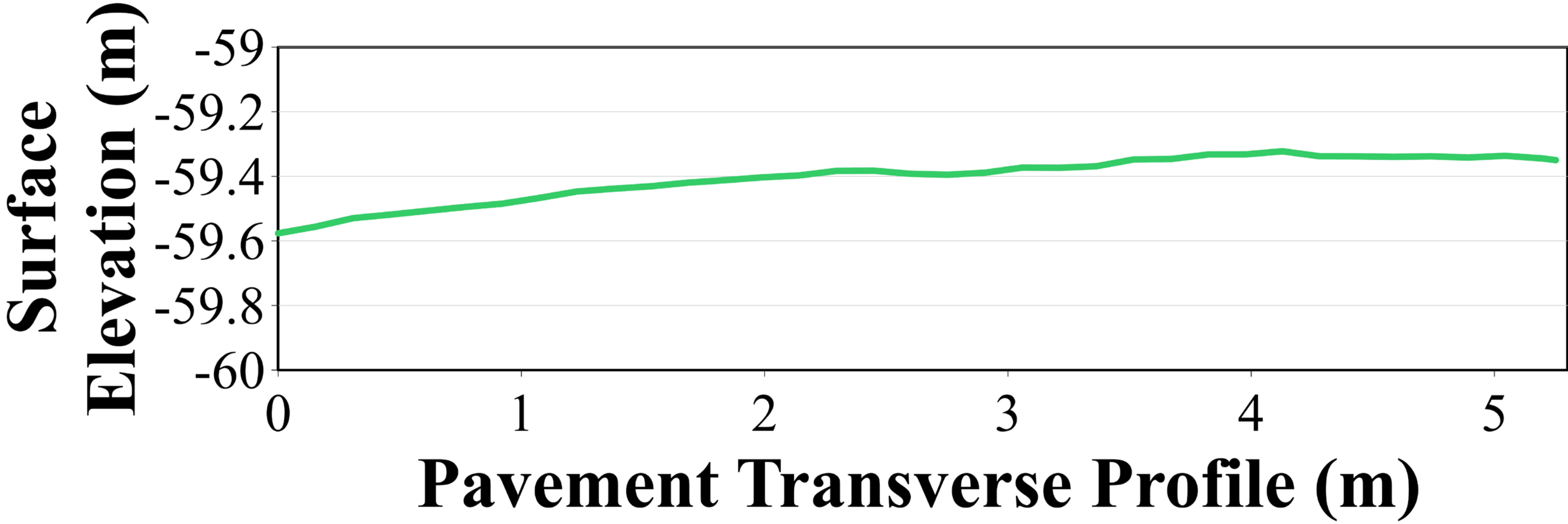
Case Study – III: Disaster Response



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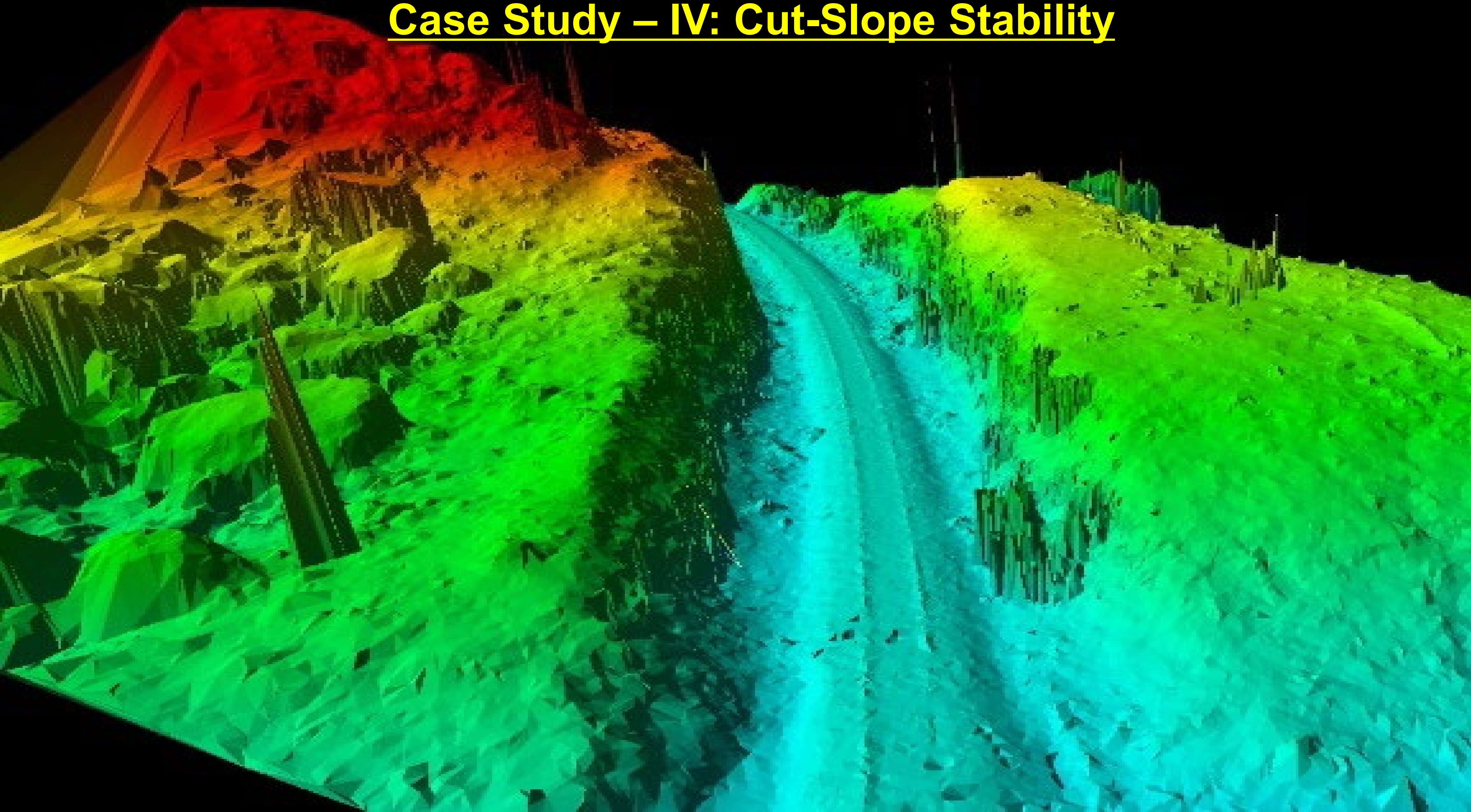
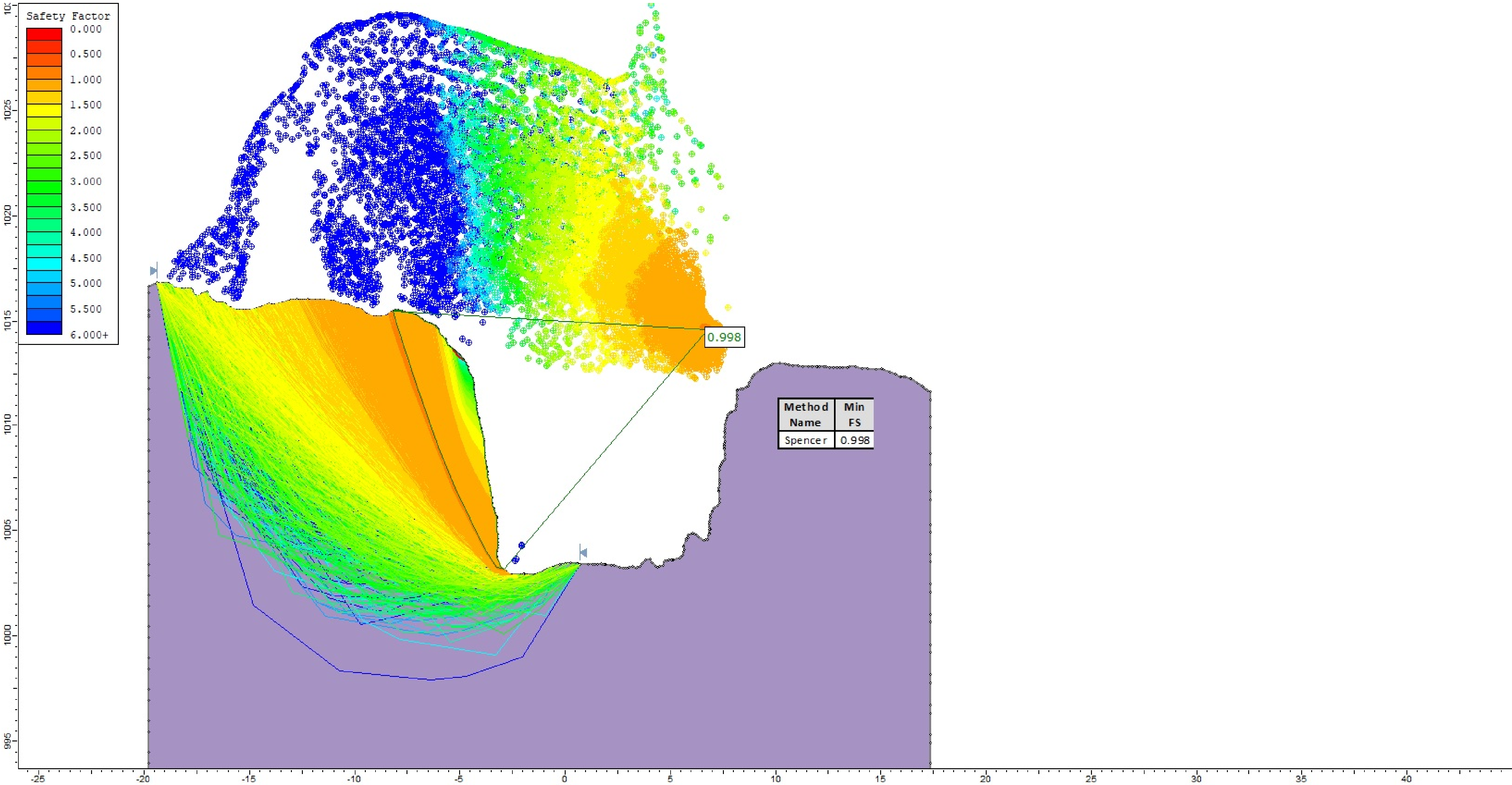
Case Study – IV: Cut-Slope Stability



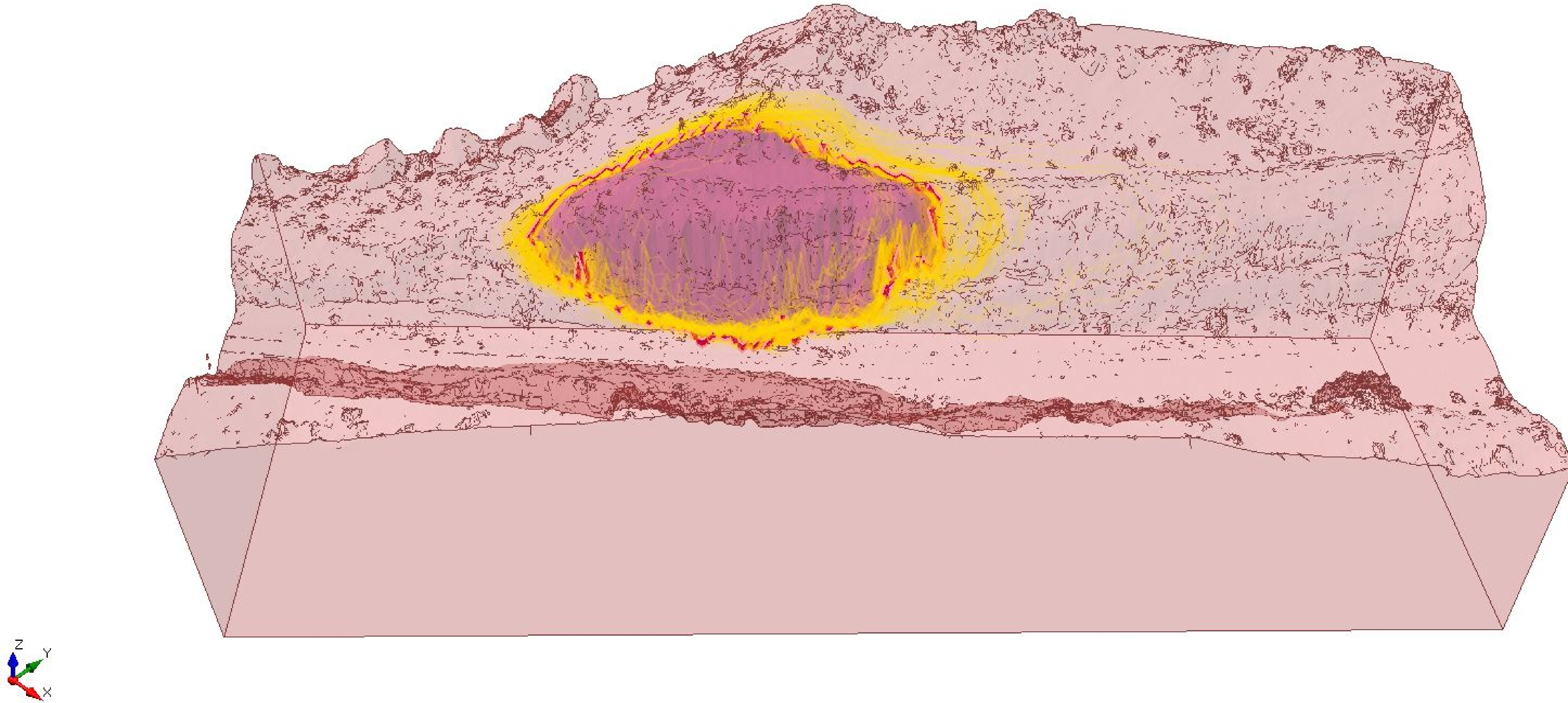
Rail Corridor Monitoring: Quantitative

Rock Cut Area – 2D Slope Stability Analysis

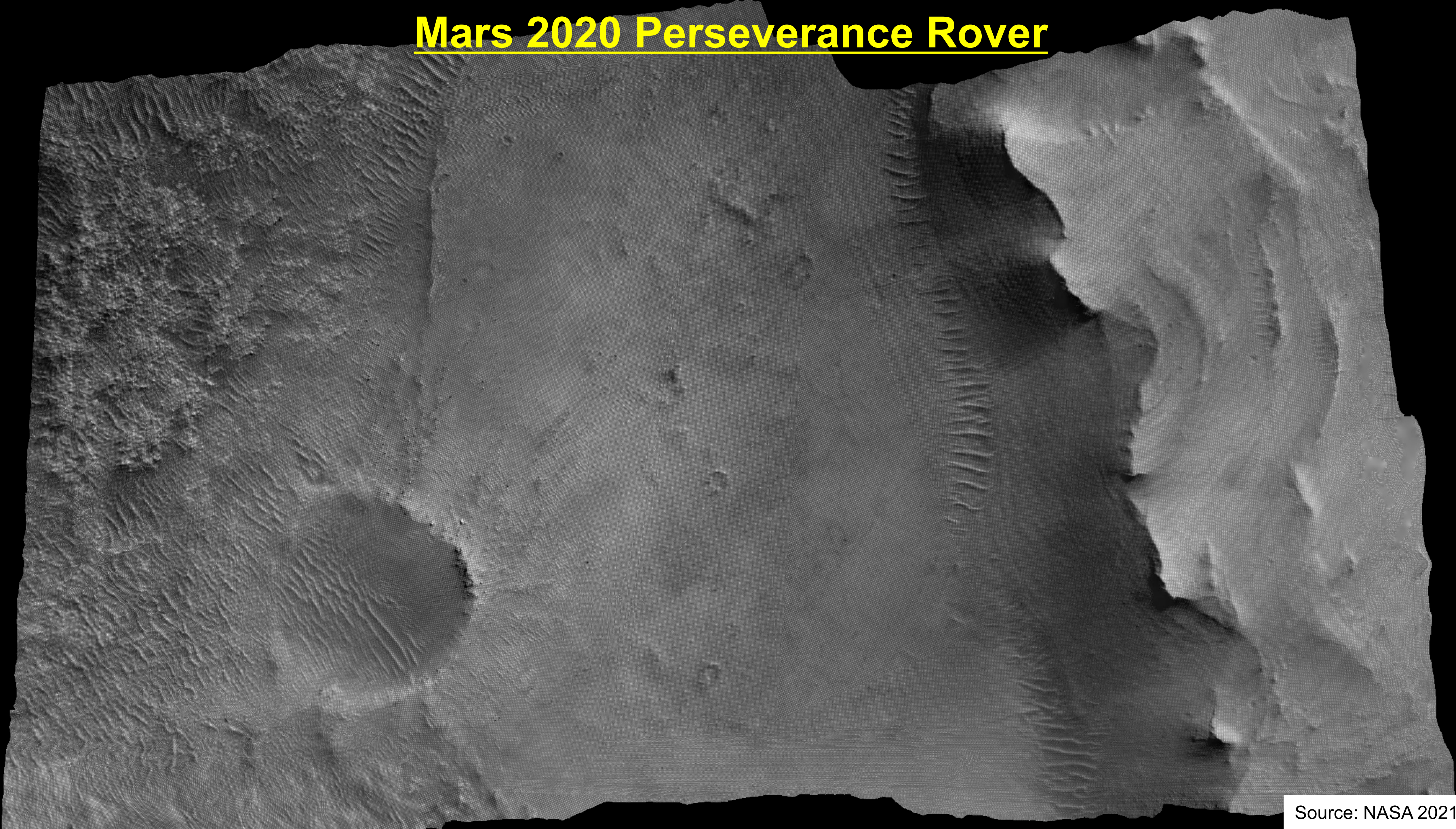


Rail Corridor Monitoring: Quantitative

Rock Cut Area – 3D Slope Stability Analysis



Mars 2020 Perseverance Rover



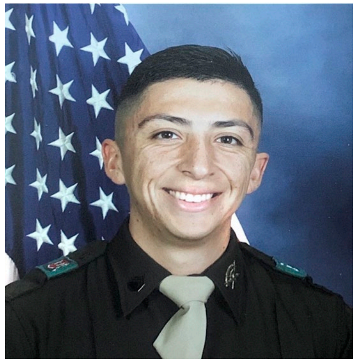
Source: NASA 2021

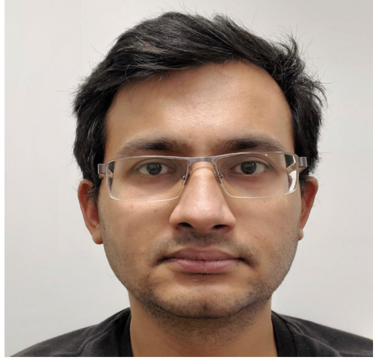
Observations

- **UAVs facilitate remote data collection to evaluate and visualize the condition of infrastructure assets – on Earth or any other planet**
- **Same set of UAV-CRP data models – Different infrastructure attributes**
- **UAVs provide quick results in a safe manner with minimal traffic controls**
- **Results can provide time related infrastructure changes and lead to formulating preventive maintenance plans**
- **Multidisciplinary nature – UAVs, 3D Printing, Machine Learning (ML) & Artificial Intelligence (AI) tools**

Acknowledgments

Dr. Anand J. Puppala and Our Research Team





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➢ Texas Department of Transportation (TxDOT)

➢ Transportation Consortium of South-Central States (Tran-SET) UTC

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Federal Highway Administration

Moderator: Khalid Mohamed

Thomas Oomen, *Michigan State University*

Michael O'Shea, *FAA*

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