Future Use of NASA Airborne Platforms to Advance Earth Science Priorities

Surface dynamics, geological hazards, and disasters

Montecito, California 2018,
debris flows after a fire
SOURCE: USGS

July 29, 2020

William E. Dietrich
Department of Earth and Planetary Science
University of California, Berkeley

Four common goals of Surface Dynamics, Geological Hazards, and Disaster research:

General remote sensing data goals

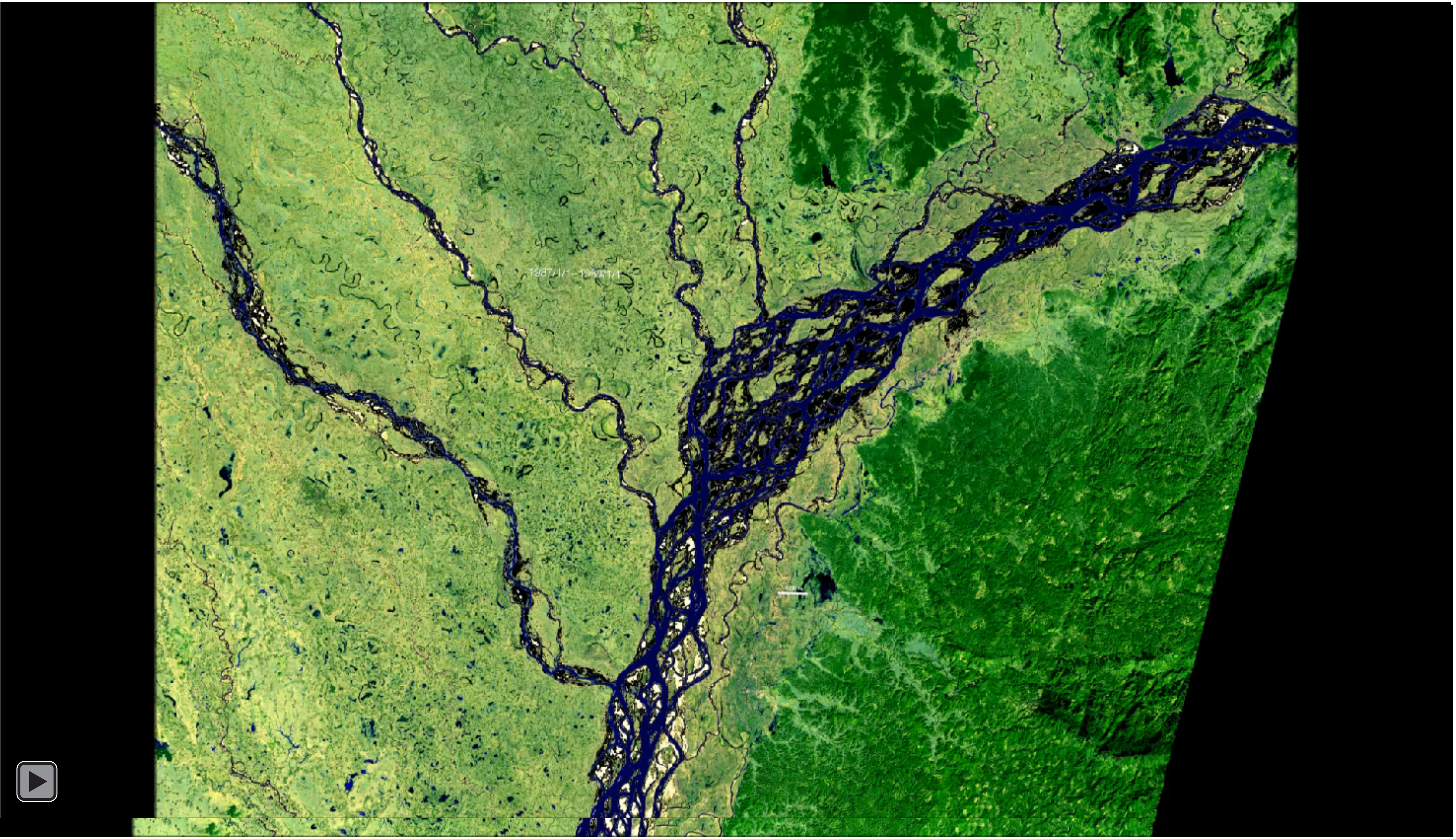
1. High spatial resolution and repeat surveys (regularly and event response)
2. Global coverage

Application

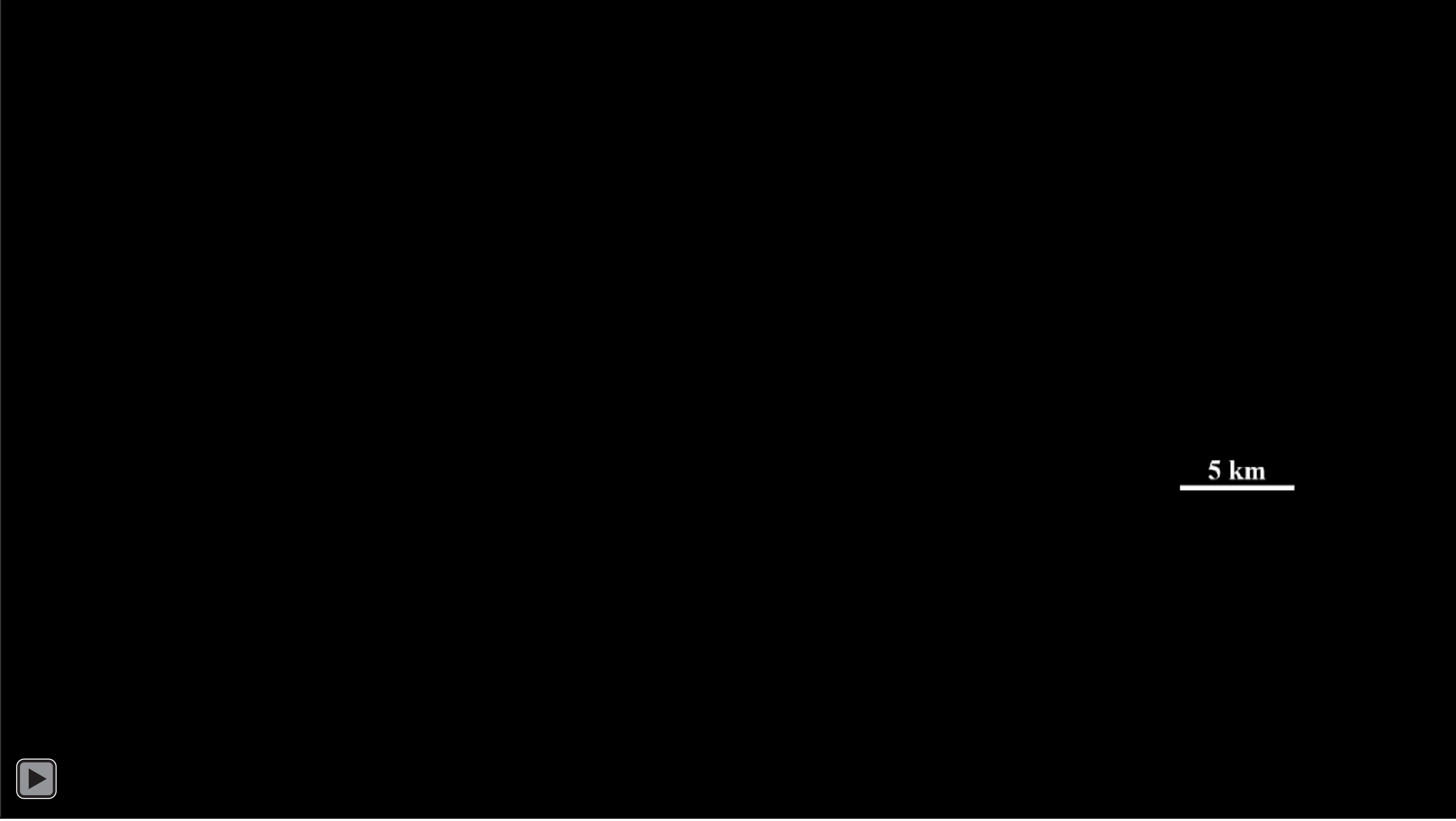
1. Document and predict rapidly changing landscapes
2. Forecast hazards/disasters

High resolution data and repeat surveys that reveal dynamics are key to understanding process.

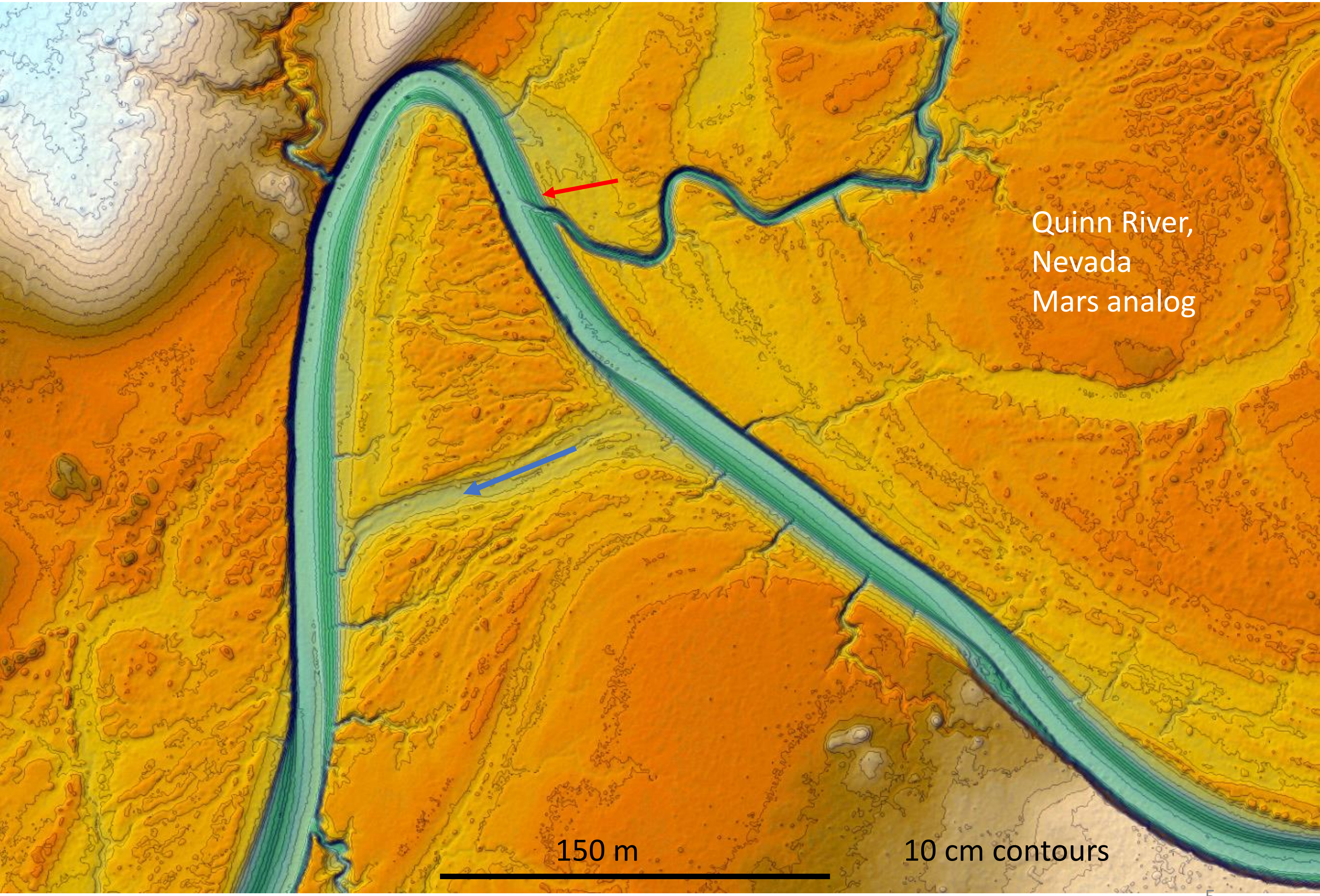
Large scale change is the sum of local actions



30 years of Landsat imagery of the Brahmaputra River
Source: Alexander Bryk

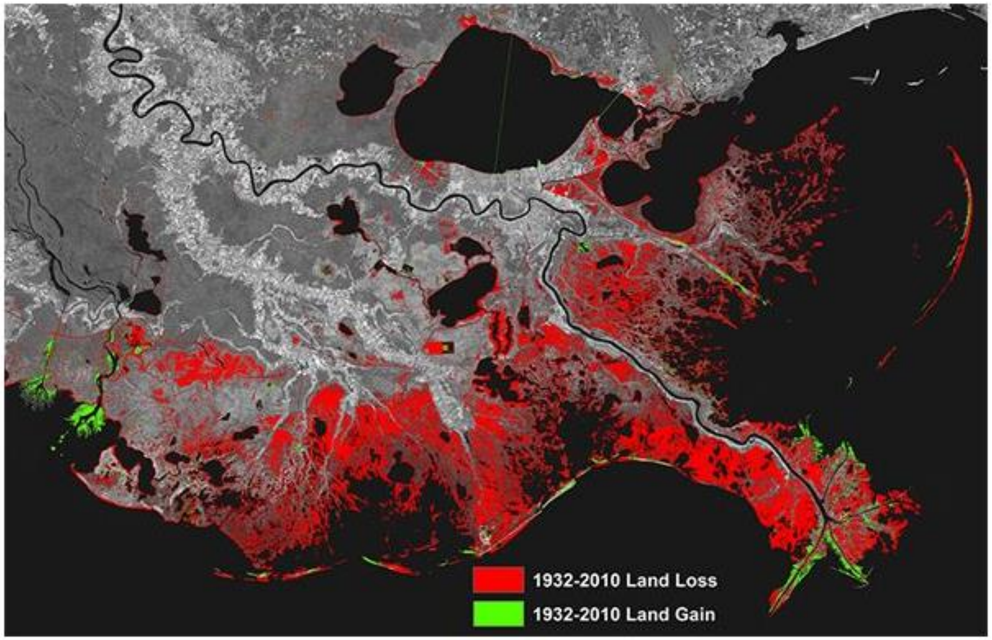


30 years of Landsat imagery of the Ucayali River, Peru
Source: Alexander Bryk



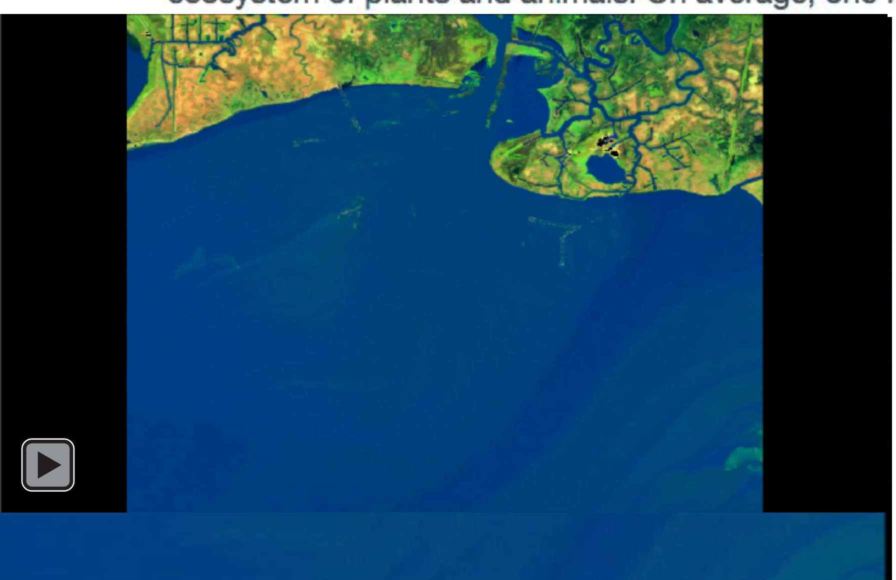
NCALM Lidar

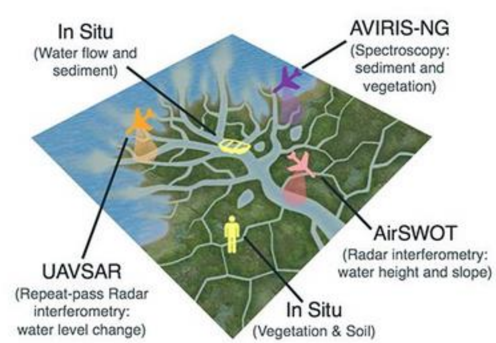
The Delta-X mission studies the Mississippi River Delta, the most famous river delta in the United States and the 7th largest river delta on Earth.



Millions of people live on the Mississippi Delta, along with a unique ecosystem of plants and animals. On average, one football field of

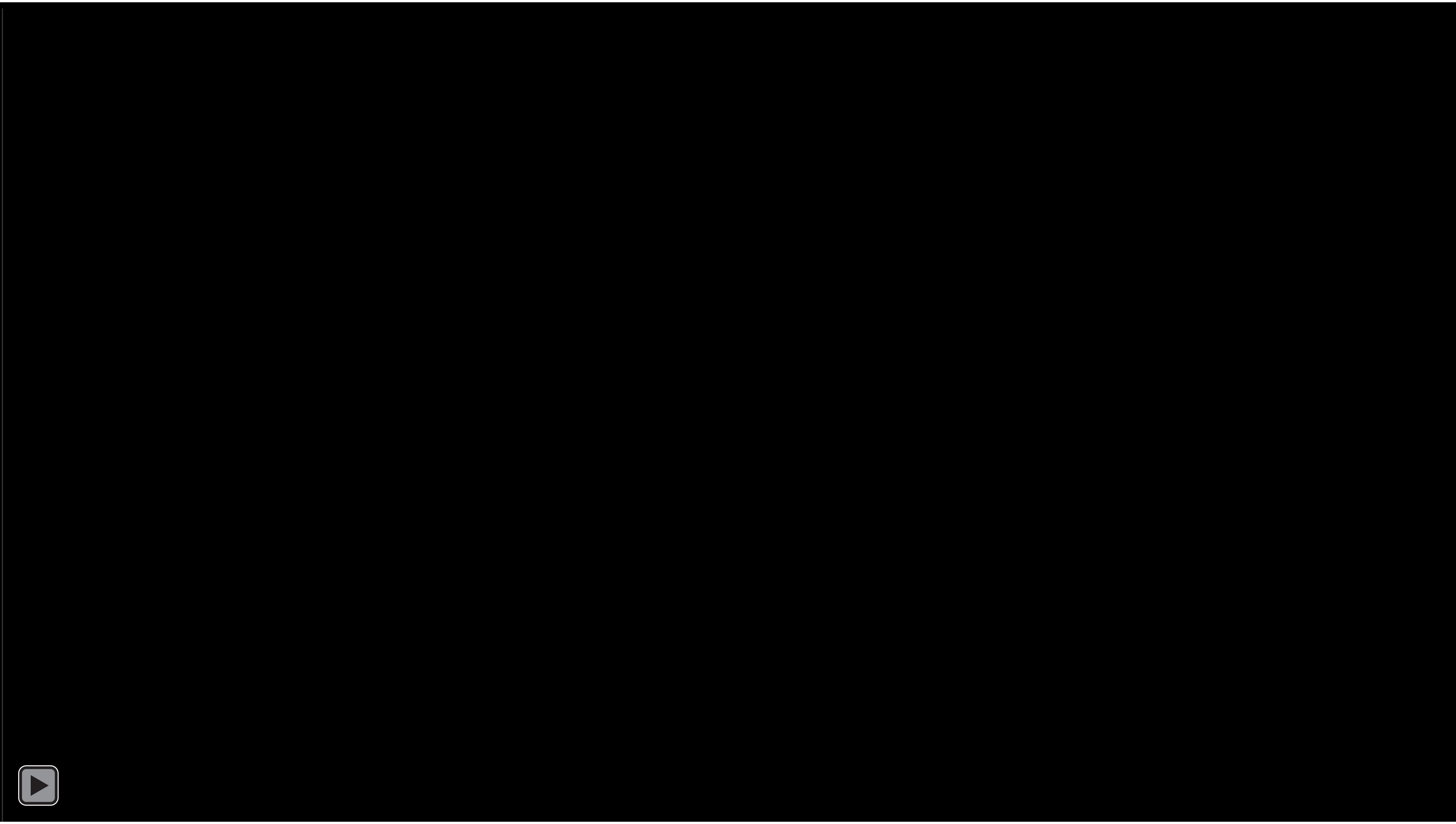
Delta-X



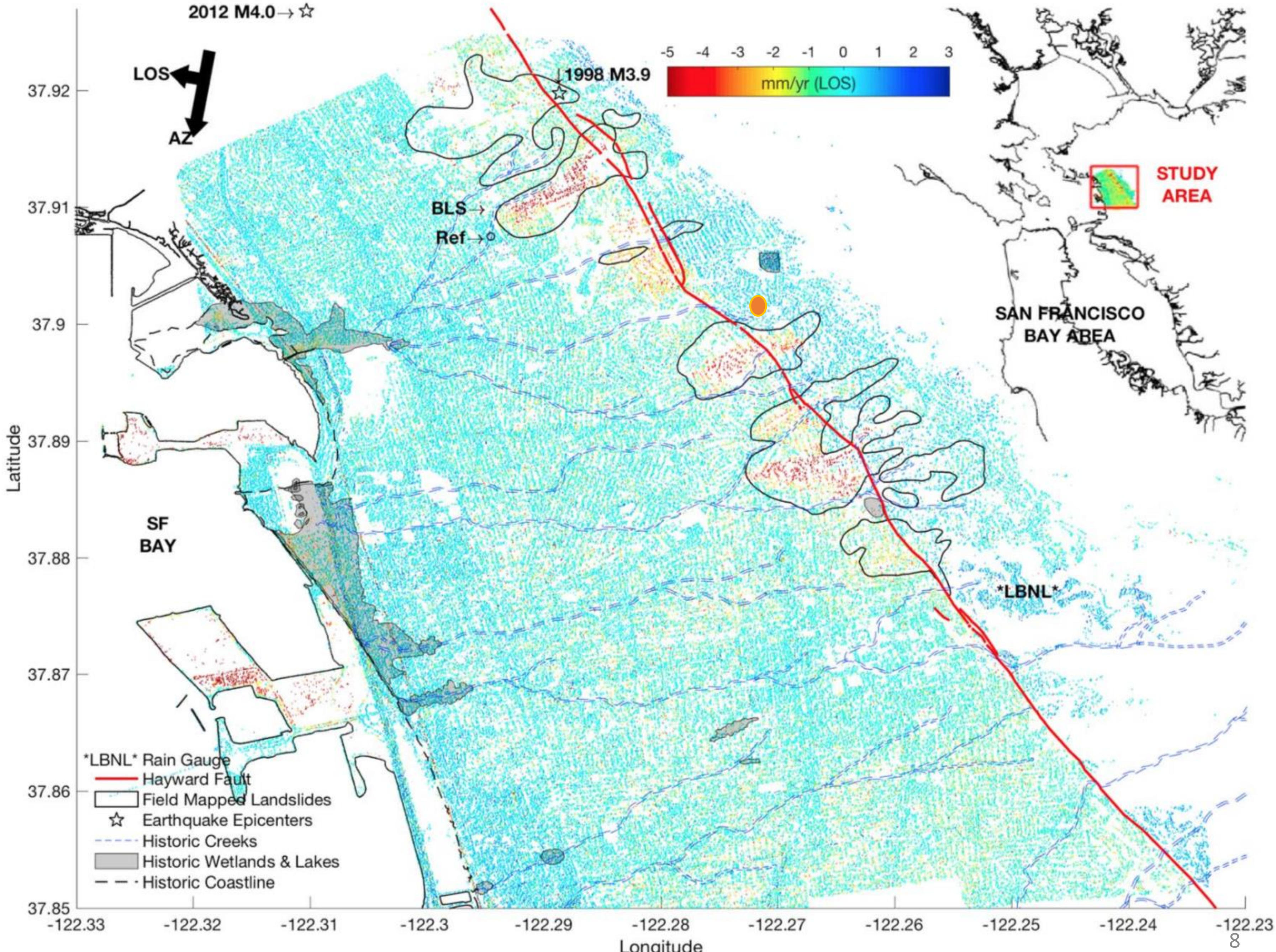


- An **airborne campaign** with three instruments: UAVSAR, AVIRIS, and AirSWOT
- A **field campaign** with boats and boots on the ground to take measurements

Funded by the Earth Venture Suborbital (EVS-3) program, Delta-X's 5-year mission will operate from 2019–2023.

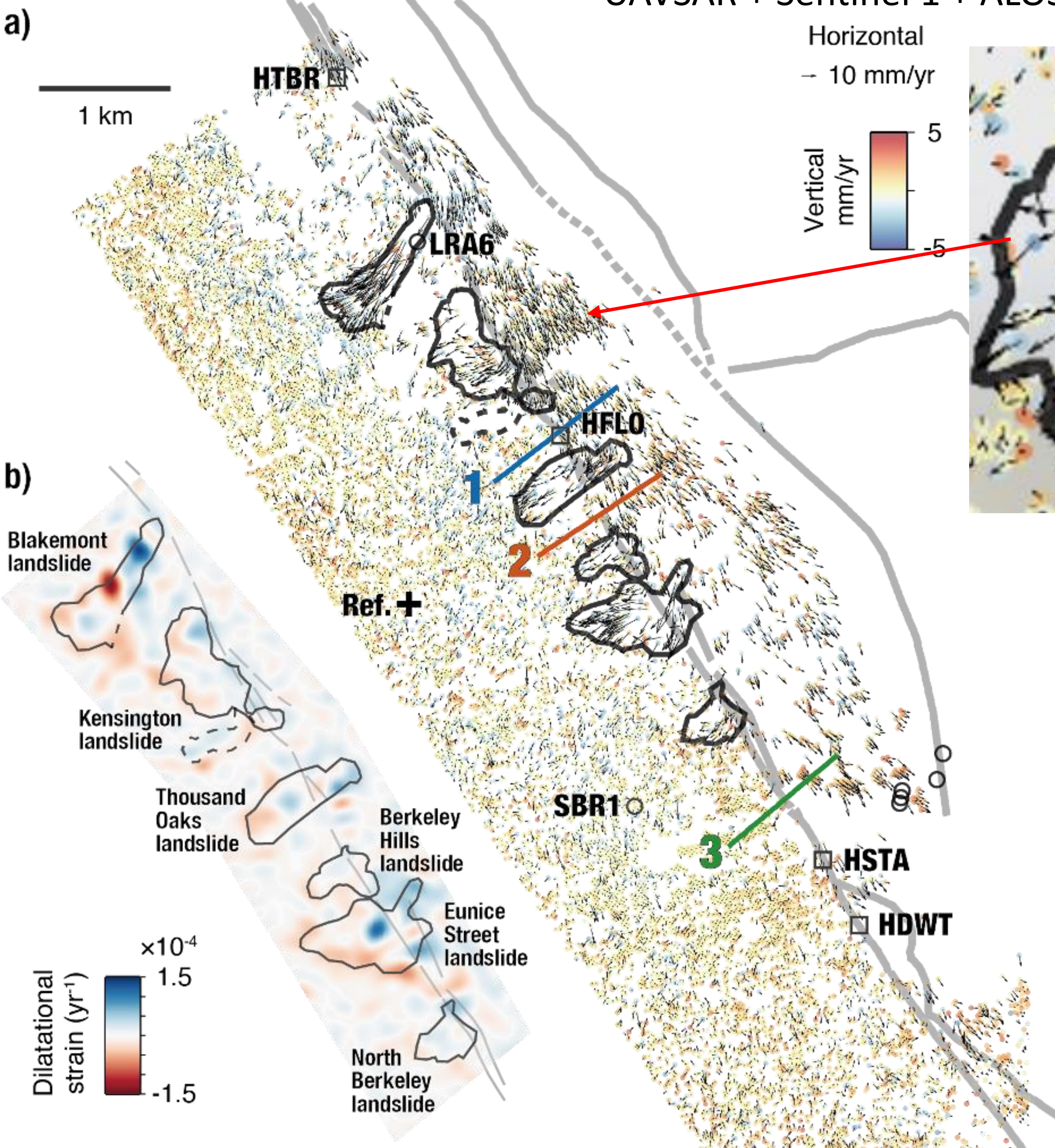


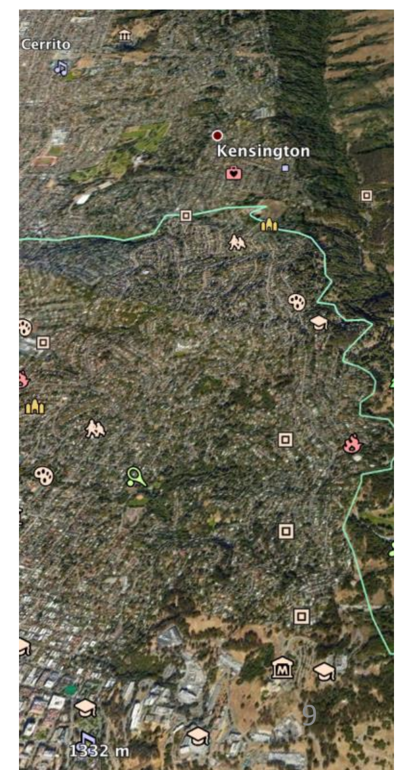
30 years of Landsat imagery in Denali National Park
Source: Alexander Bryk



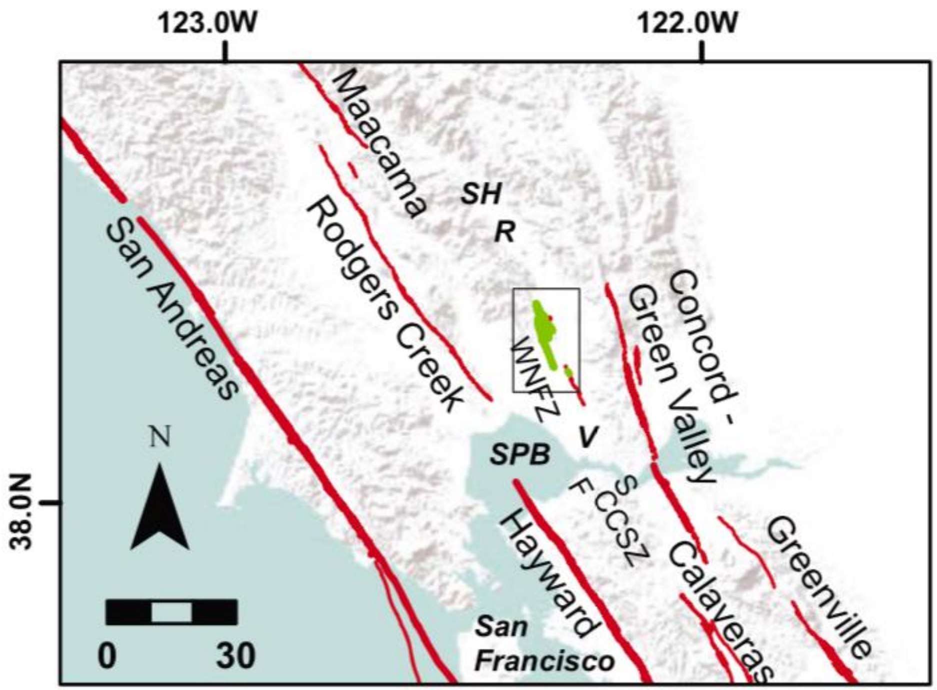
Cohen-Waeber, et al., GRL, 2017

UAVSAR + Sentinel 1 + ALOS-2 stirp





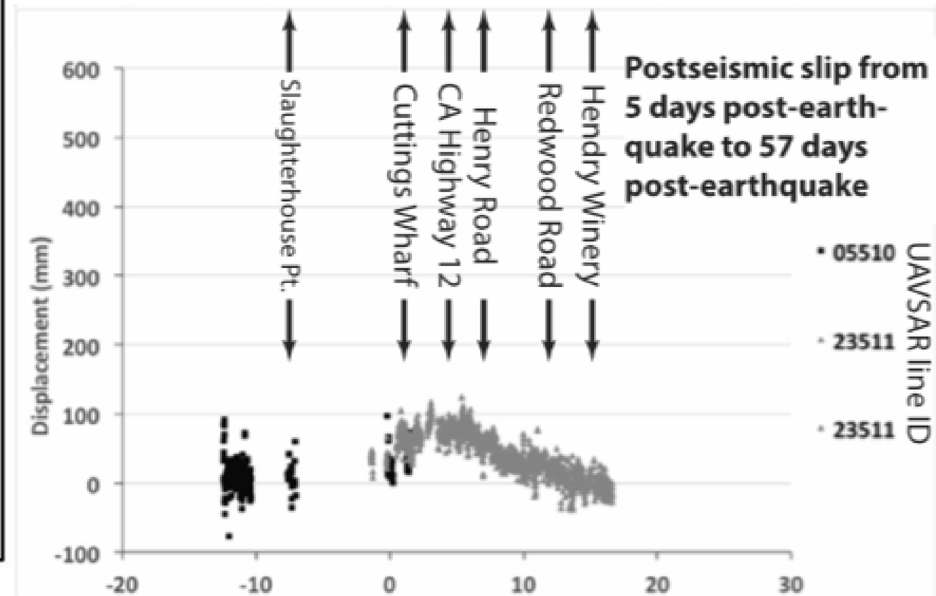
Source: Roland Burgmann

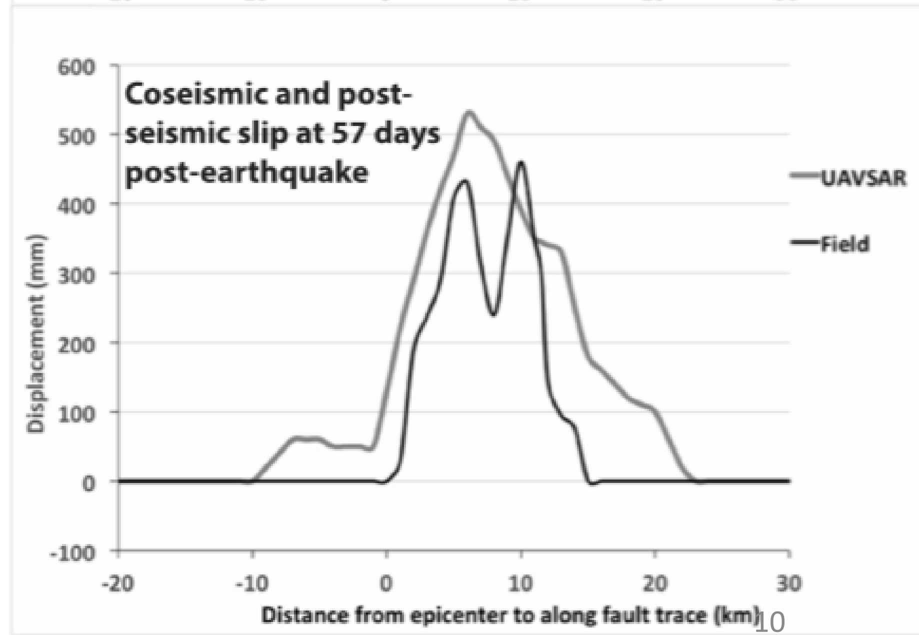


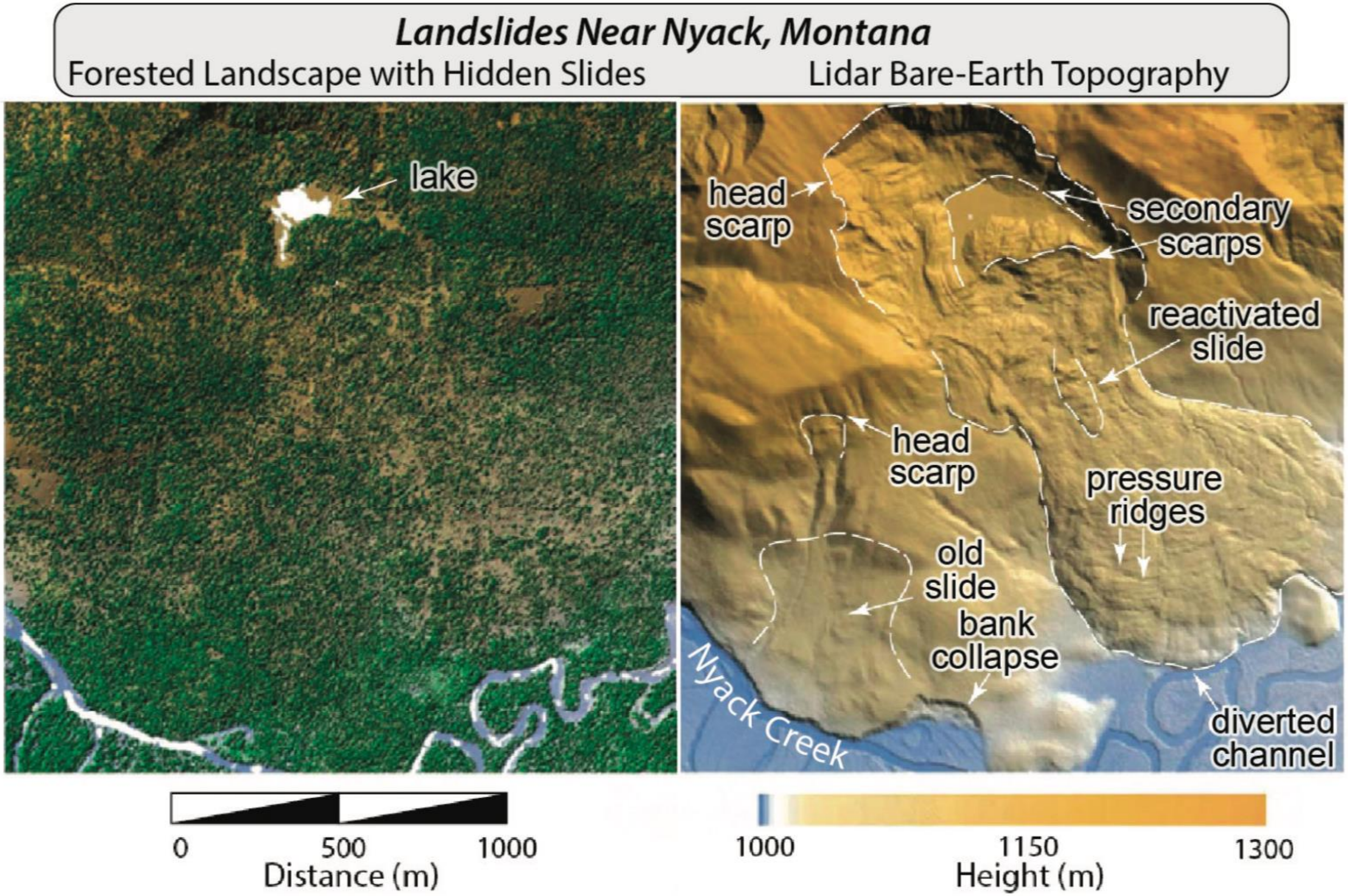
August 24, 2014 , 6.0 magnitude earthquake nucleated at ~8.8 km below surface

Repeat UAVSAR flights reveal a complex rupture pattern and a wide "relaxation" zone; in some areas post seismic slip exceeding coseismic slip amount.

Delong et al., EES, 2016



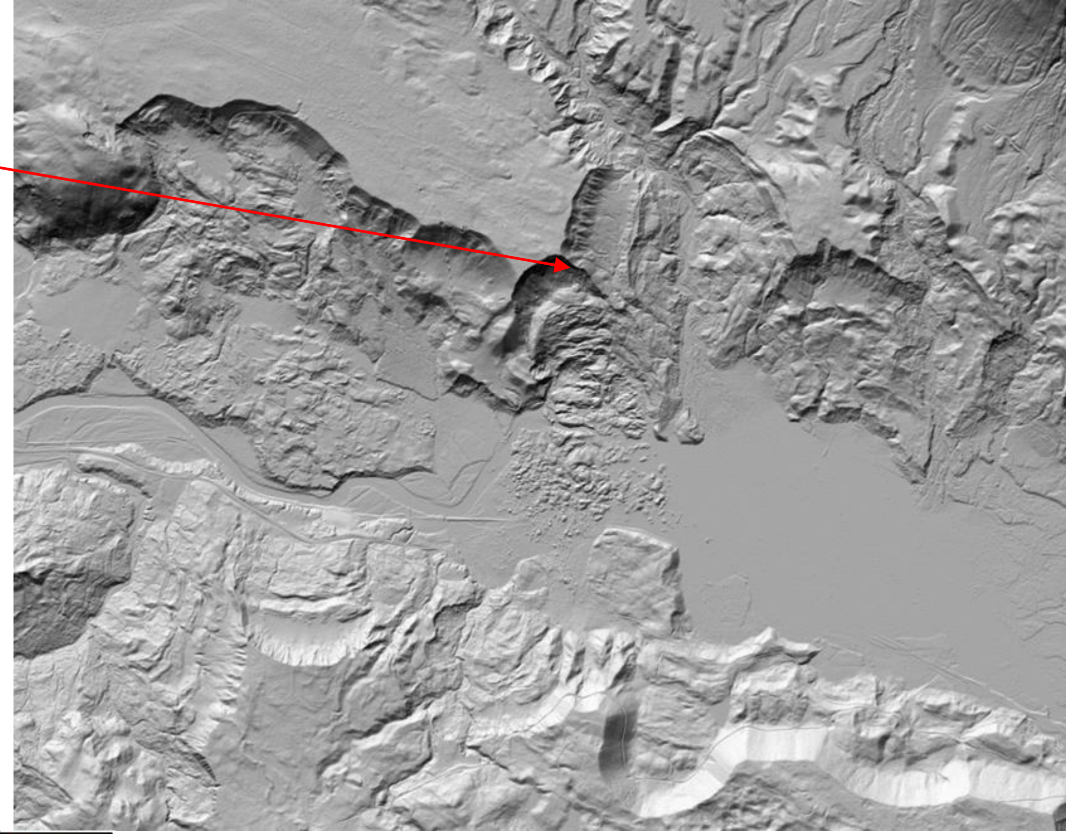


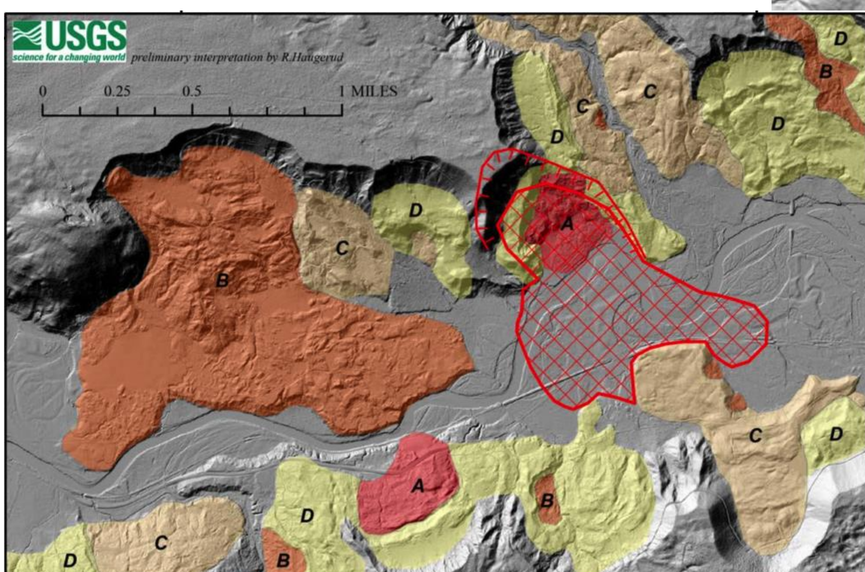


Source: National Center for Airborne Laser Mapping

On March 22, 2014, the Oso landslide in the state of Washington, killed 43 people and caused more than $120 million in economic loss.

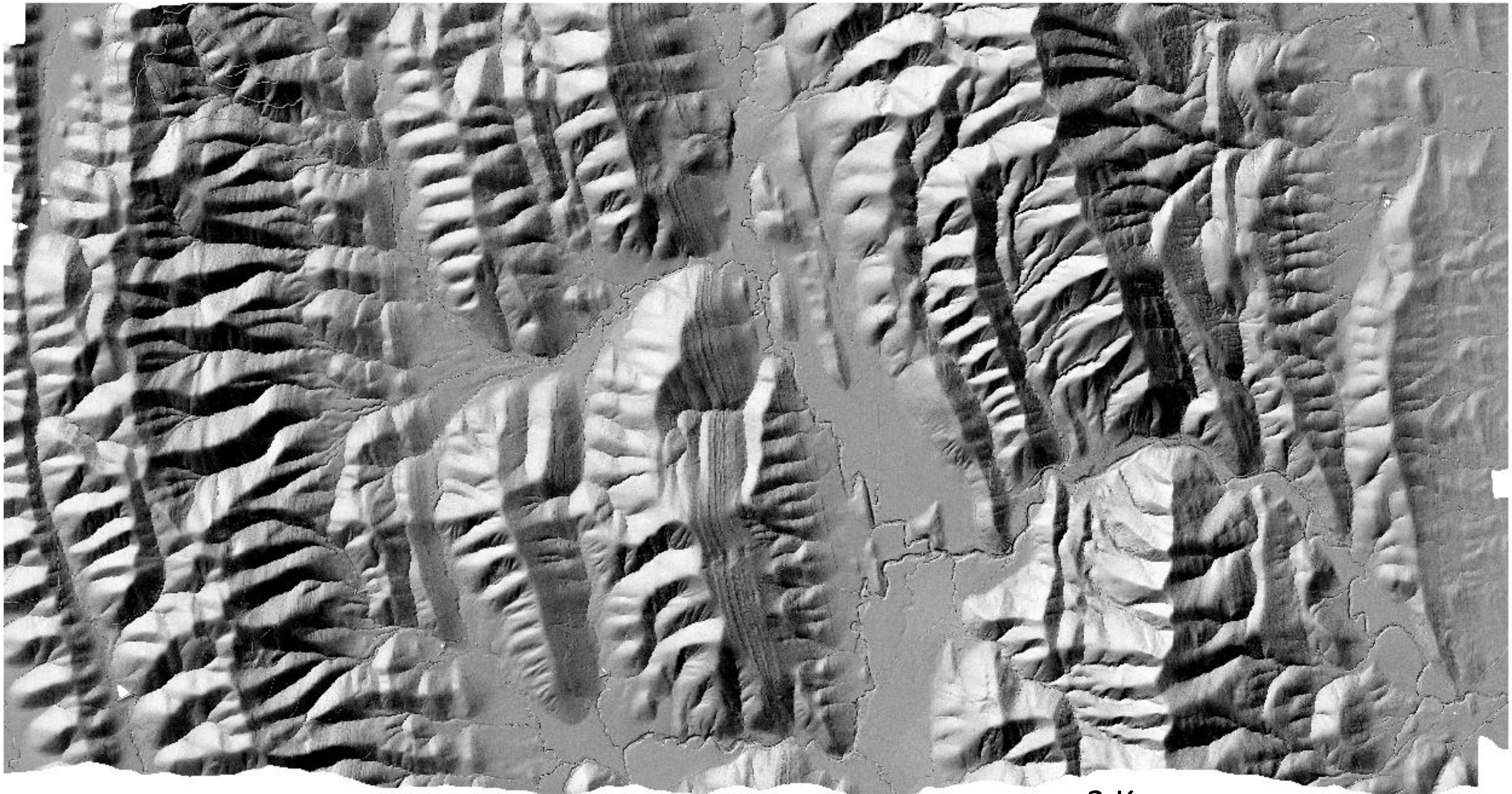
Google Earth view





Bare-earth shaded relief image derived from **airborne lidar** of river valley revealing numerous large-scale landslides (Warttman et al, 2016)

Map of relative age of large landslides: youngest (A) to oldest (D) revealed by the high resolution lidar imagery (Haugerud, 2014



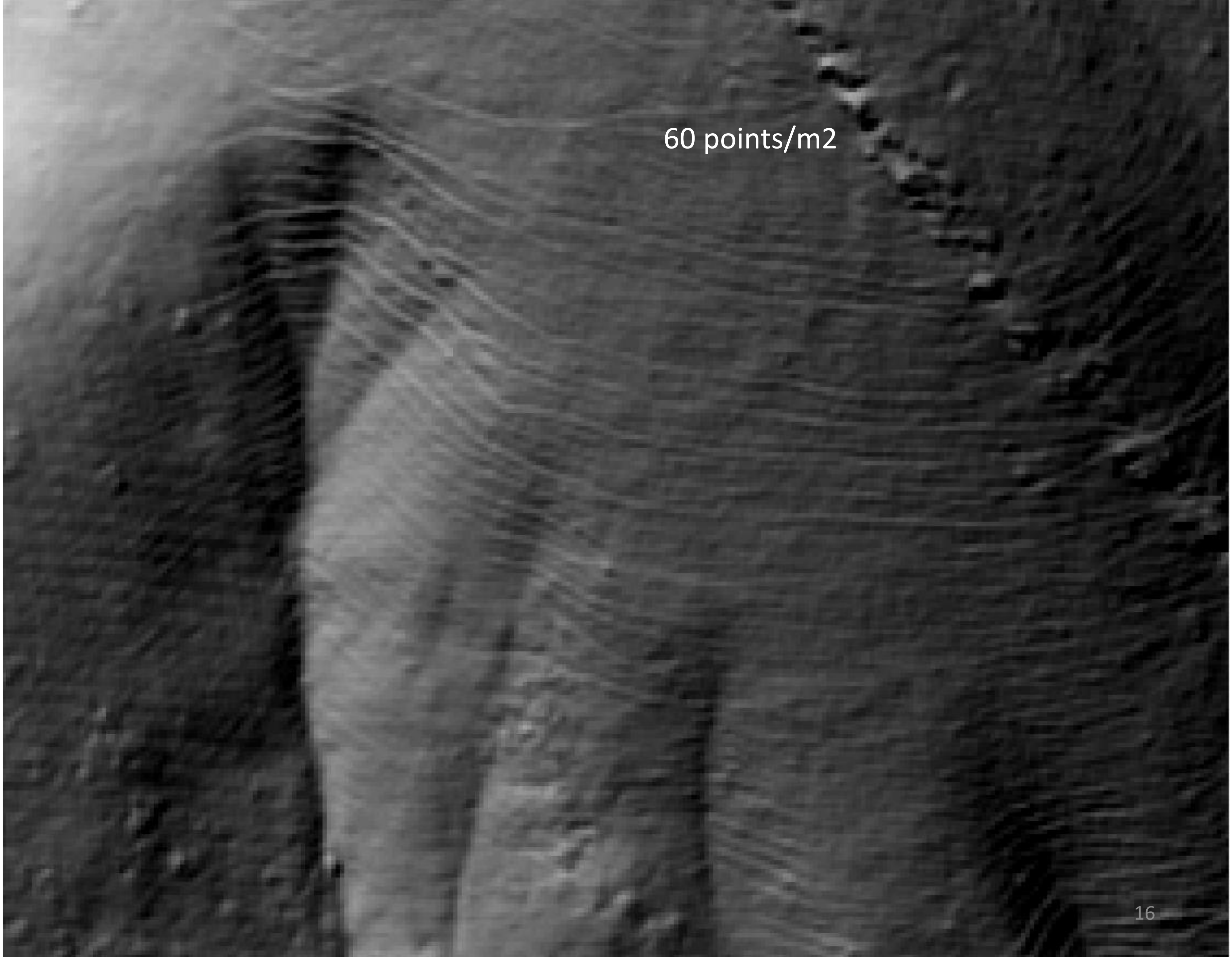
Eastern edge of the California Coast Range
Great Valley Sequence sedimentary rocks

20 points/ m2 NCALM lidar

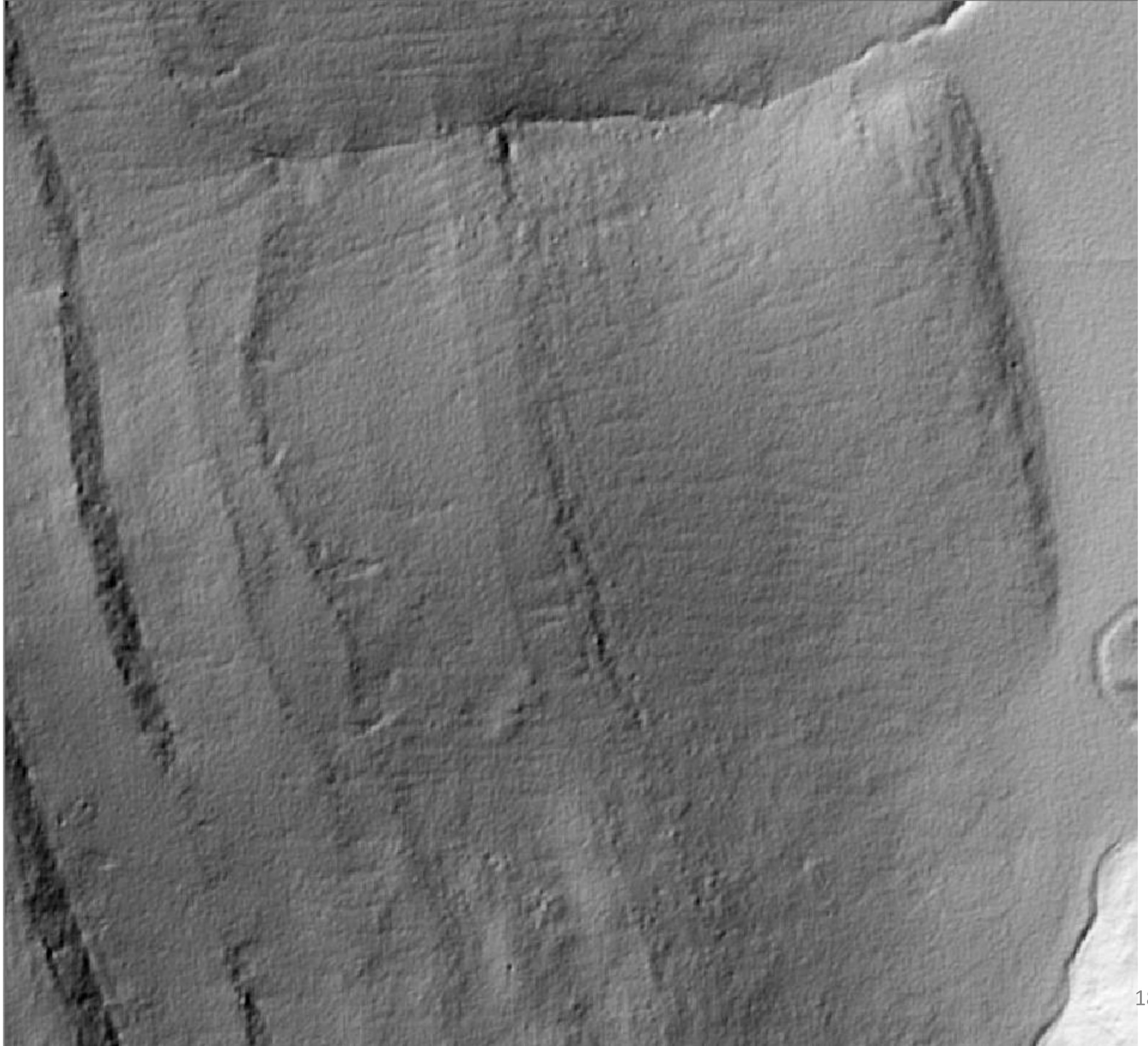
What sets the wavelengths of ridges and valleys?

How do we include rock properties into prediction of landscape evolution models?


20 point/m2

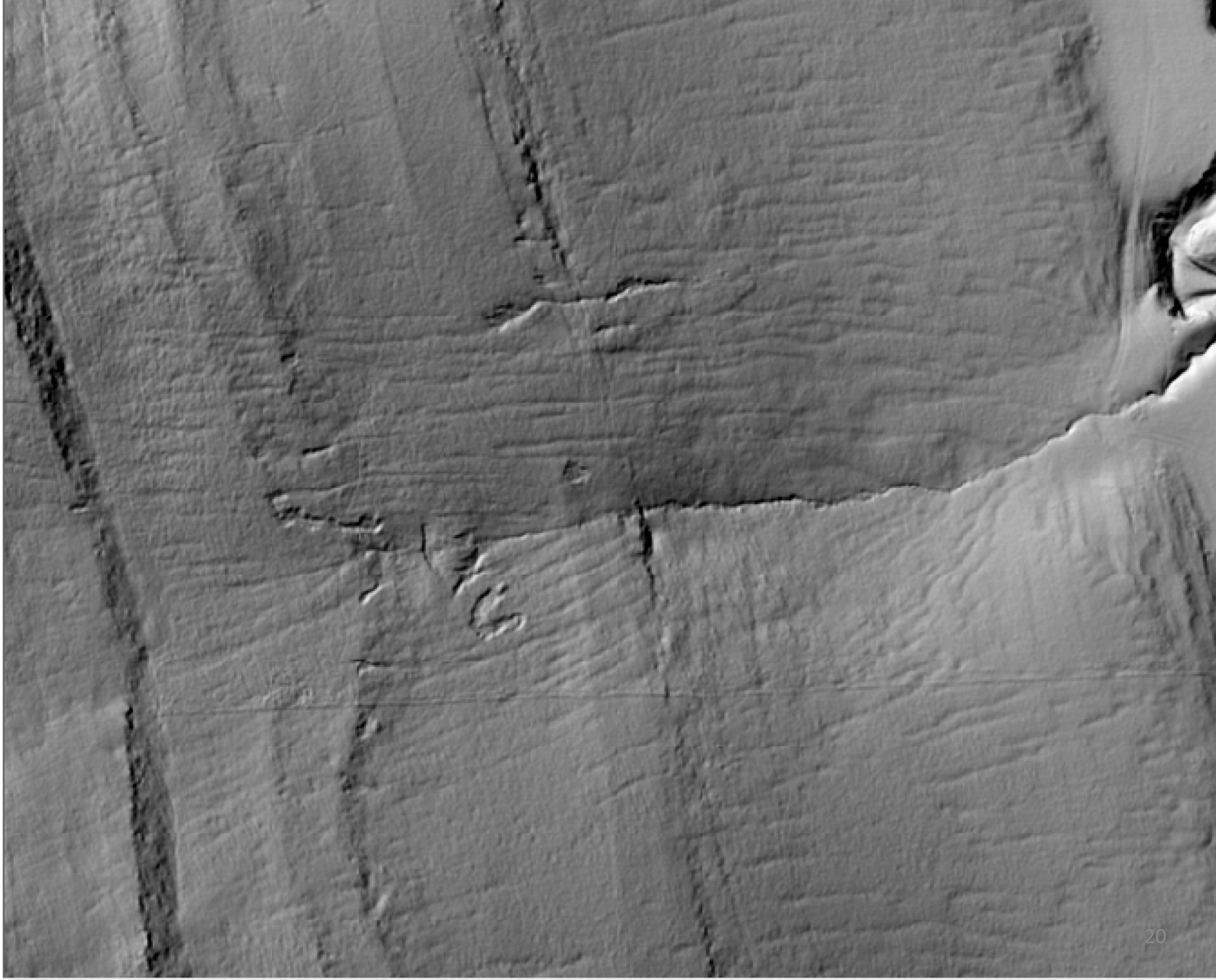

60 points/m2

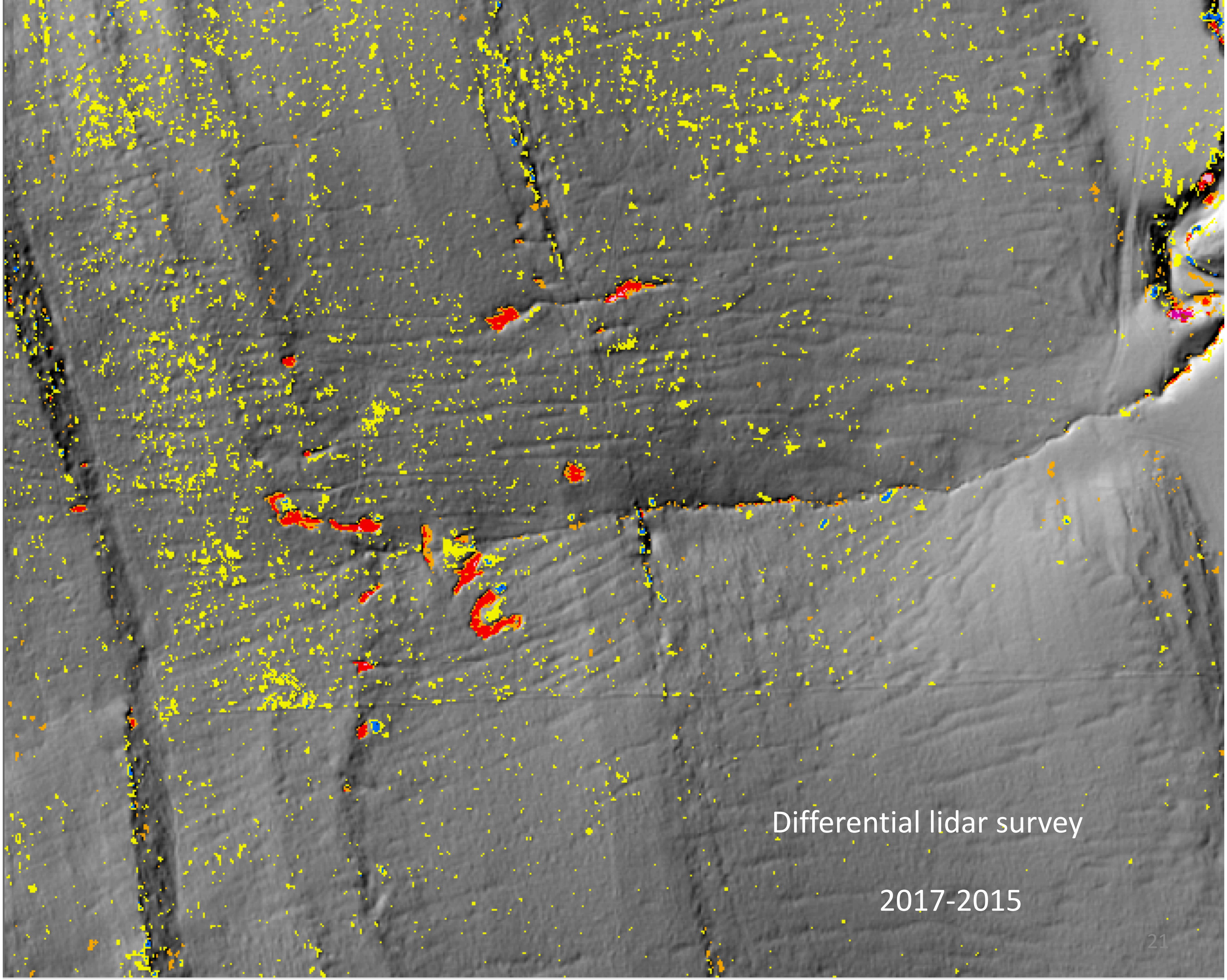

0
2.75
5.5
11
Meters
N



2015

2017




Differential lidar survey
2017-2015

Before fire

January 9, 2018

After fire and storm

15 minute rainstorm of 19 mm
California

20 dead, 296 buildings damaged or destroyed– January 14, 2018. Only 2 caused by fire itself.

Montecito, California

https://www.humanityroad.org/situation-reports/usa/montecito-mudslides-california

Near Rio de Janeiro, Brazil ~1400 dead January 2011

~200 mm rainfall in ~ 8 hours landslides -> debris flows

Source: Soriano: DOI: 10.2495/DMAN150051

WHEN *Use precipitation forecast with empirical threshold rainfall conditions*

WHERE: *statistically defined potentially unstable areas or mechanistic modeling*

Italy
Brazil
Japan
USA
Taiwan
China
Hong Kong

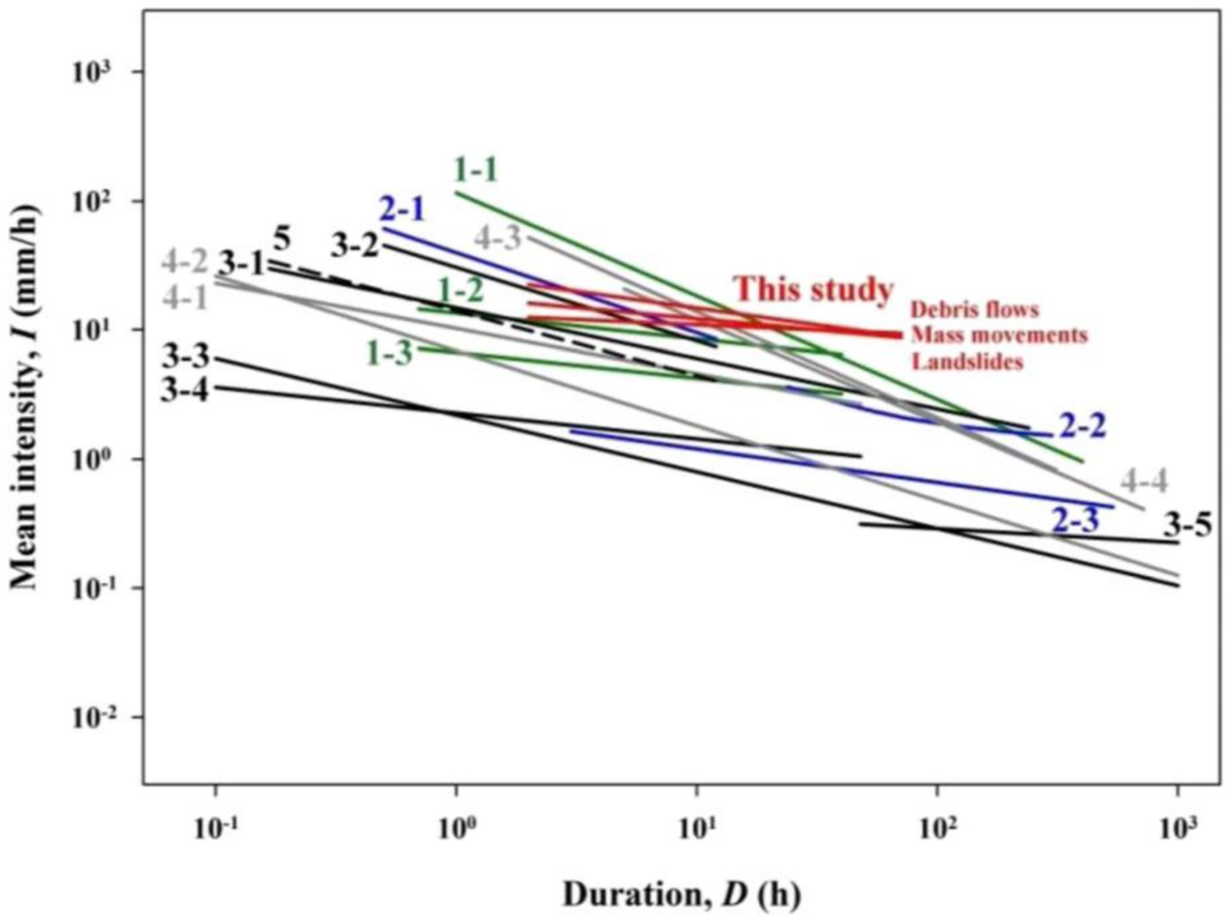
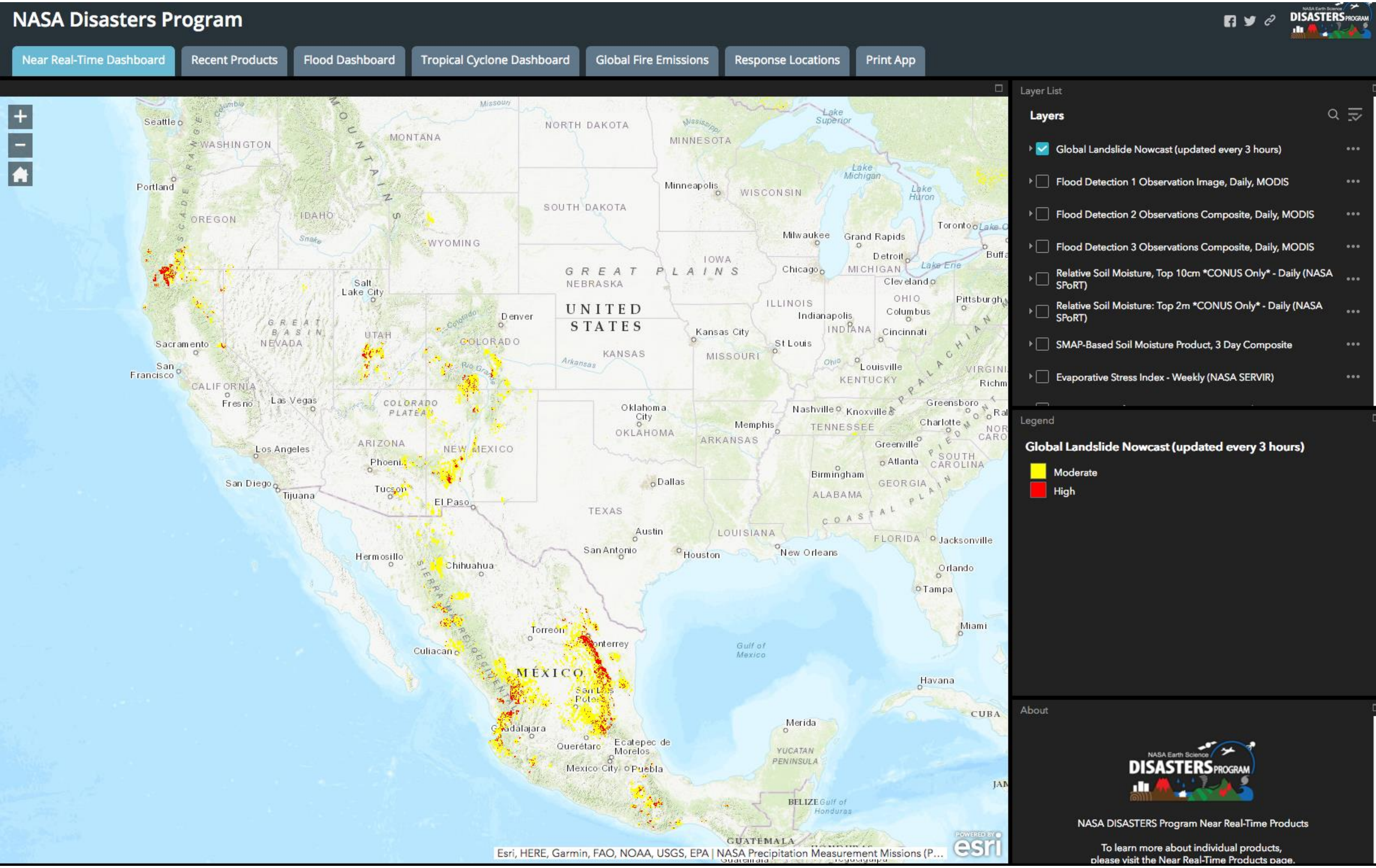


Fig. 6 Comparison of *I–D* thresholds. *Green lines* thresholds for Taiwan. *Blue lines* thresholds for Japan. *Black lines* global thresholds. *Gray lines* thresholds for humid (sub)tropics or Asian monsoon regions. *Dashed line* other regional thresholds. *1-1* Chien-Yuan et al. (2005); *1–2* and *1–3* Jan and Chen (2005); *2–1* and *3–2* Jibson (1989); *2–2* Hong et al. (2005); *2–3* Saito et al. (2010a); *3–1* Caine (1980); *3–3*, *3–4*, and *3–5* Guzzetti et al. (2008); *4–1* and *4–2* Guzzetti et al. (2008), *Cfa* climate of humid subtropical east coast in Köppen's system; *4–3* Larsen and Simon (1993), Puerto Rico; *4–4* Dahal and Hasegawa (2008), Nepal Himalaya; *5* Cannon et al. (2008), Southern California

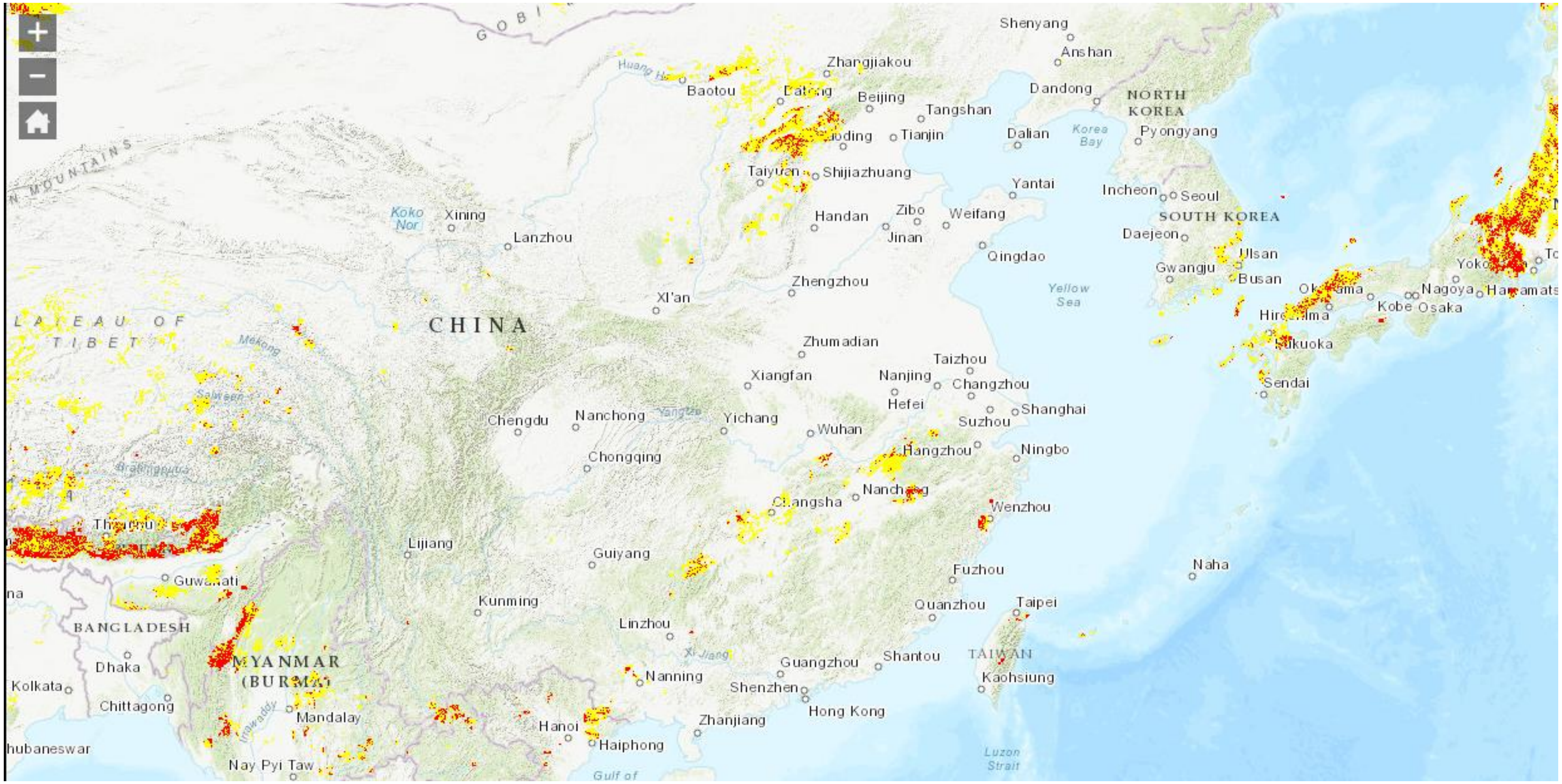
Chen et al., 2015

NASA Global Landslide Nowcast

https://maps.disasters.nasa.gov/arcgis/apps/MapSeries/index.html?appid=ab7723584fe847449faaa2e62d3bef74



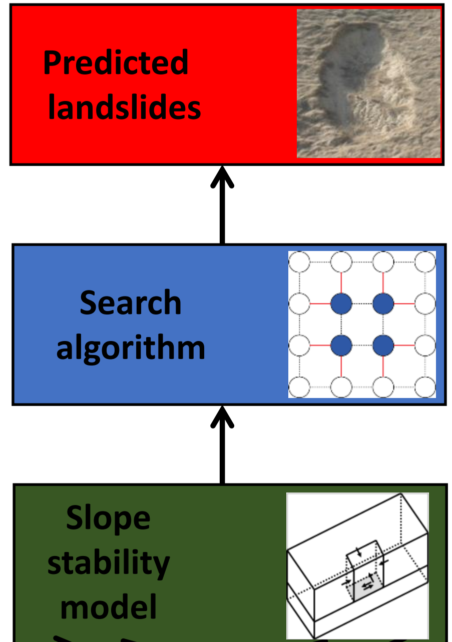
Forecasts of risk of landsliding updated every 3 hours

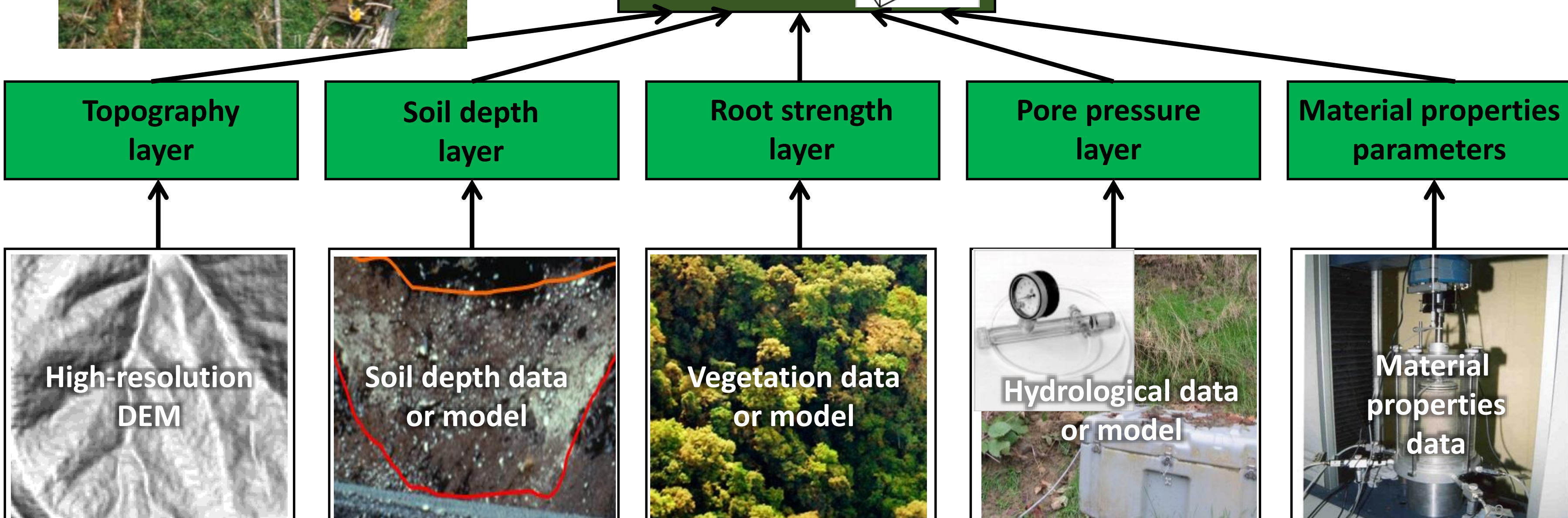


Data on slope, faults, geology, forest loss, and road networks were combined using a heuristic fuzzy approach.

90 m SRTM topographic data

Discrete Landslide Model



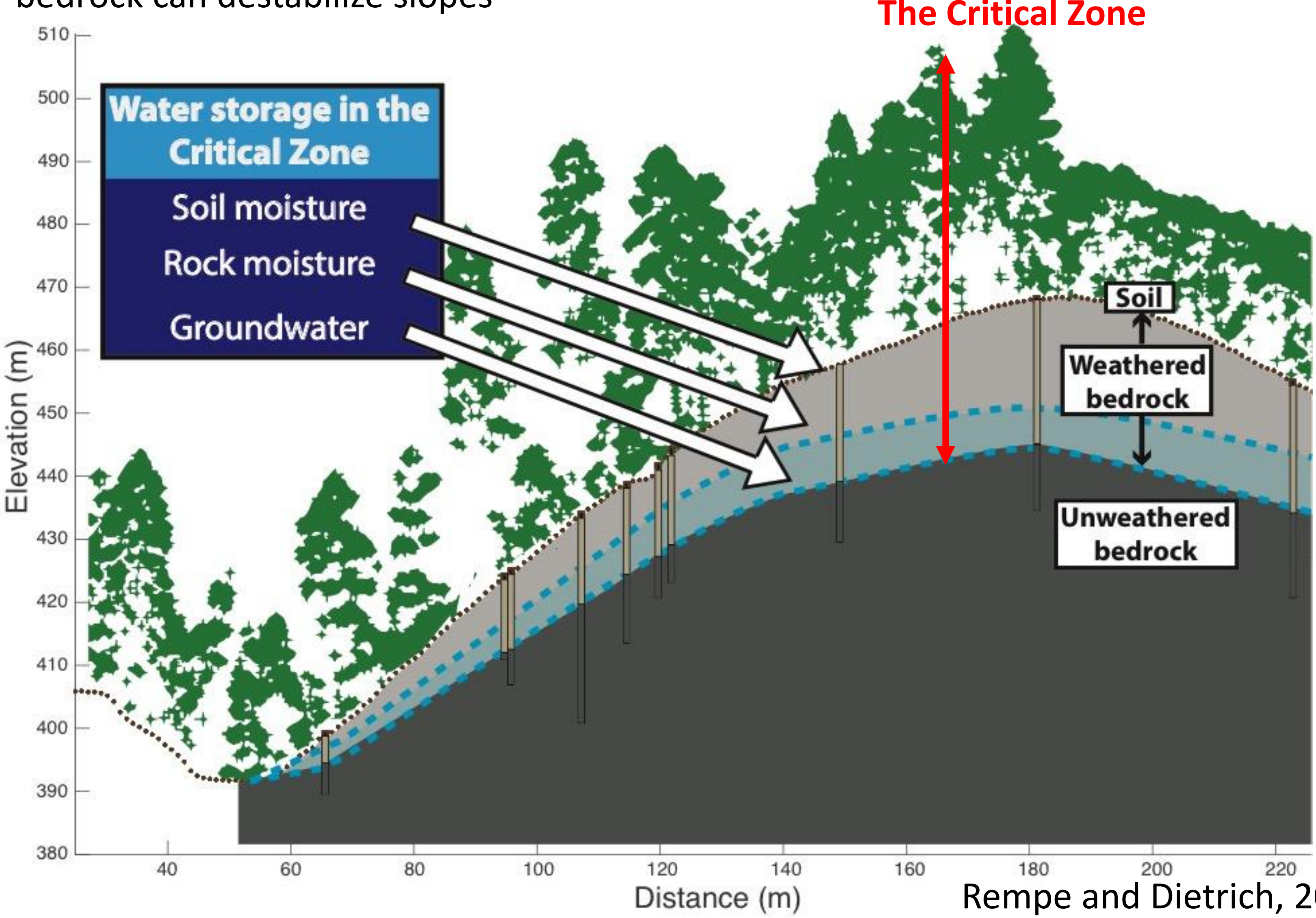


All landslide hazard mapping or prediction models are strongly dependent on the resolution of the topographic data

[Bellugi et al., 2015a,b, JGR

Shallow groundwater developed in weathered bedrock can destabilize slopes

N. California, Mediterranean climate



Rempe and Dietrich, 2018, PNAS

Majority of water used in transpiration by trees is obtained in the rock moisture zone beneath the soil at this site. This moisture storage and use is missing in earth systems models.

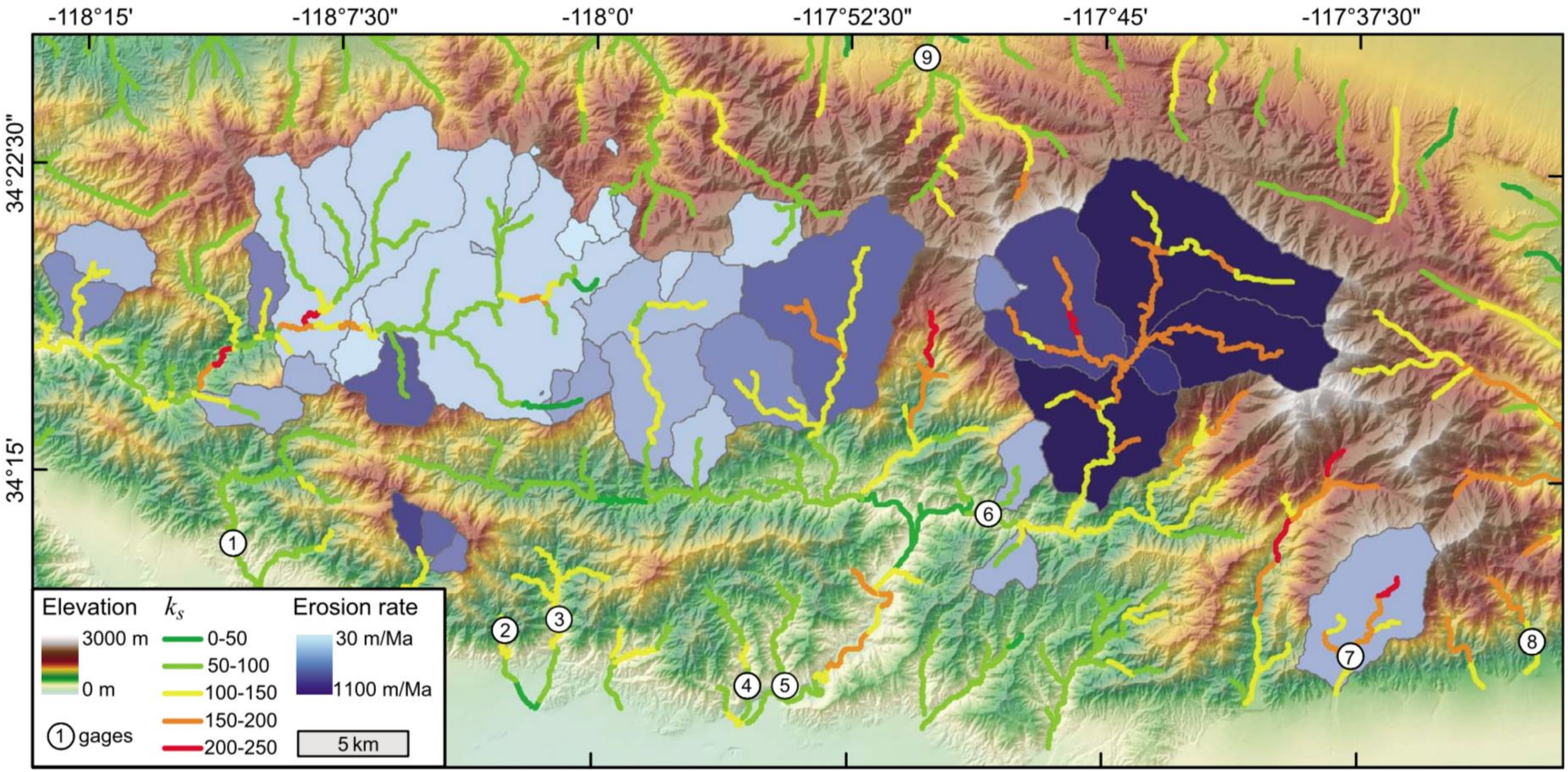
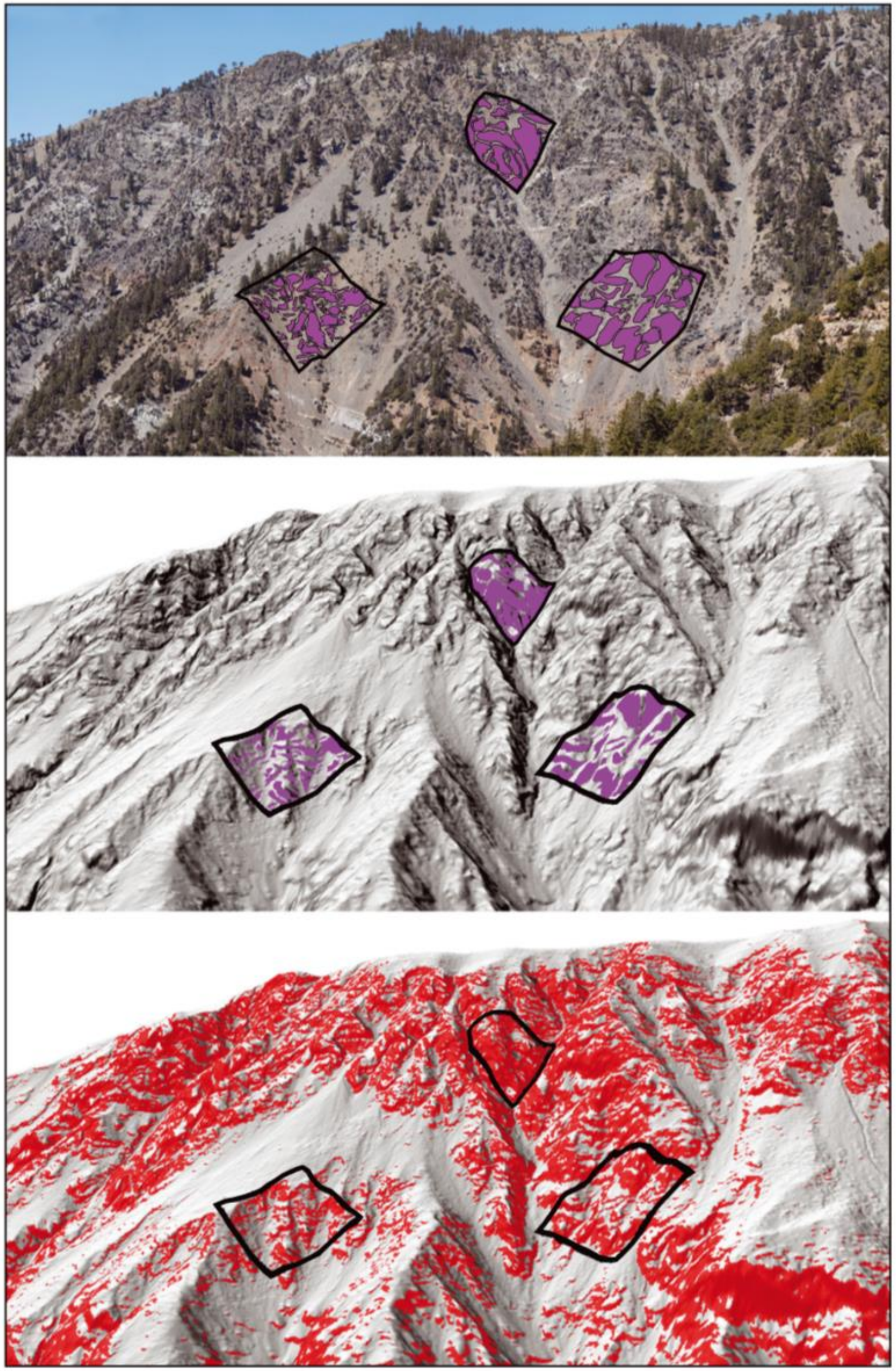


Figure 2. Map of San Gabriel Mountains, California, showing elevation over shaded relief. Catchments

DiBiase and Whipple, JGR, 2011

Cosmogenic radionuclide measurements and thermochronlogy can give us the rate patterns of erosion and uplift to link to topographic expression

How do steep, rocky landscapes work?



High-resolution, repeat coverage lidar gives us access to form and process.

Exposed bedrock (red area)

DiBiase et al., ESPL, 2012

NGEE goal: to enhance representation of arctic ecosystems in earth system models.

Subtle changes in topography (on the scale of 0.5 m) associated with permafrost thaw can lead to new wetlands or lead to gullies and drainage and land drying. This can have a cascading effect through the entire ecosystem, and alter carbon uptake or release to the atmosphere.

ARTICLES
https://doi.org/10.1038/s41561-019-0526-0

nature geoscience

Carbon release through abrupt permafrost thaw

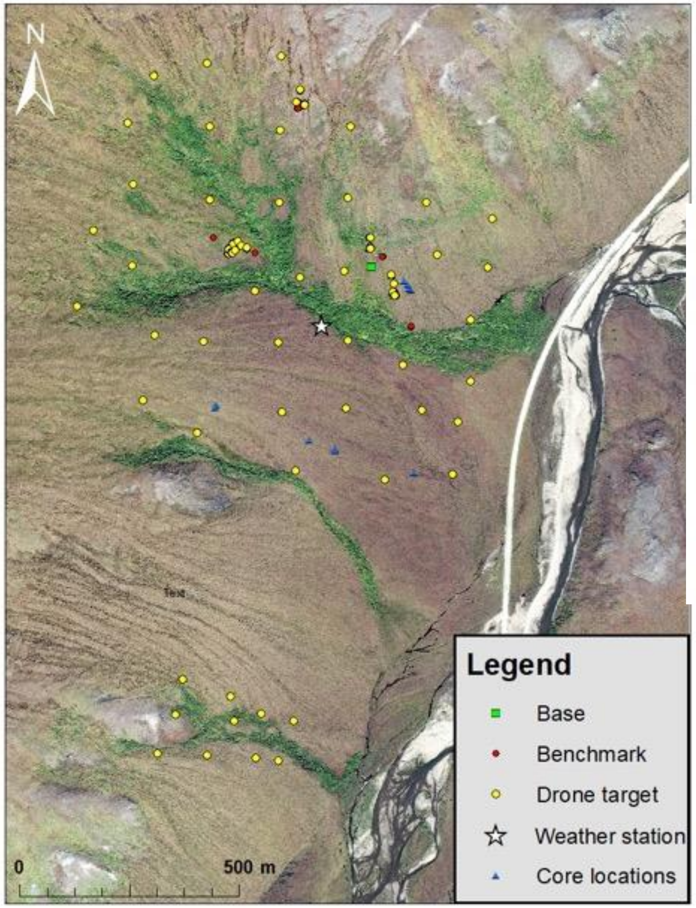
Merritt R. Turetsky[1,2*], Benjamin W. Abbott[3], Miriam C. Jones[4], Katey Walter Anthony[5],

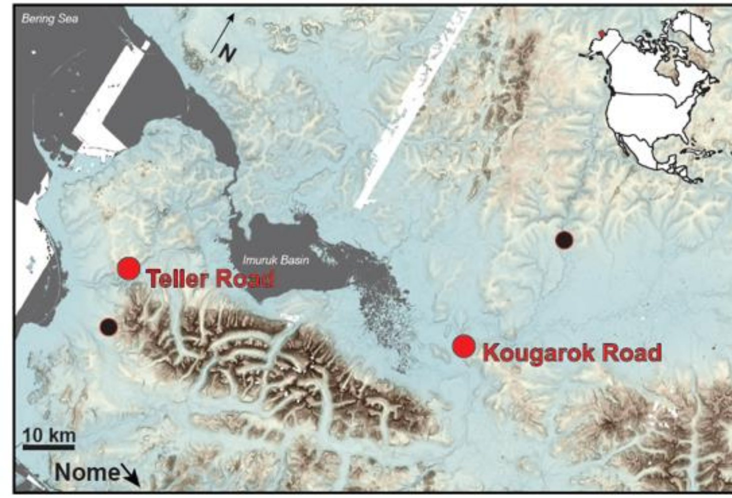
Abrupt thaw will probably occur in <20% of the permafrost zone but could affect half of permafrost carbon through collapsing ground, rapid erosion and landslides.

Active hillslope erosional features will occupy 3% of abrupt thaw terrain by 2300 but emit one-third of abrupt thaw carbon losses.

Active research

Teller (Mile 47)





Landslide and pipe flow erosion

- Soil sampling and coring
- Water sampling
- Differential GPS for soil movement
- UAS LiDAR and imagery
- 14C dating of lobes and hollow fills

Large scale environmental change in the Arctic is the sum of widely distributed small scale process dynamics.

Source: Joel Rowland, LANL

Arctic tundra fires: natural variability and responses to climate change

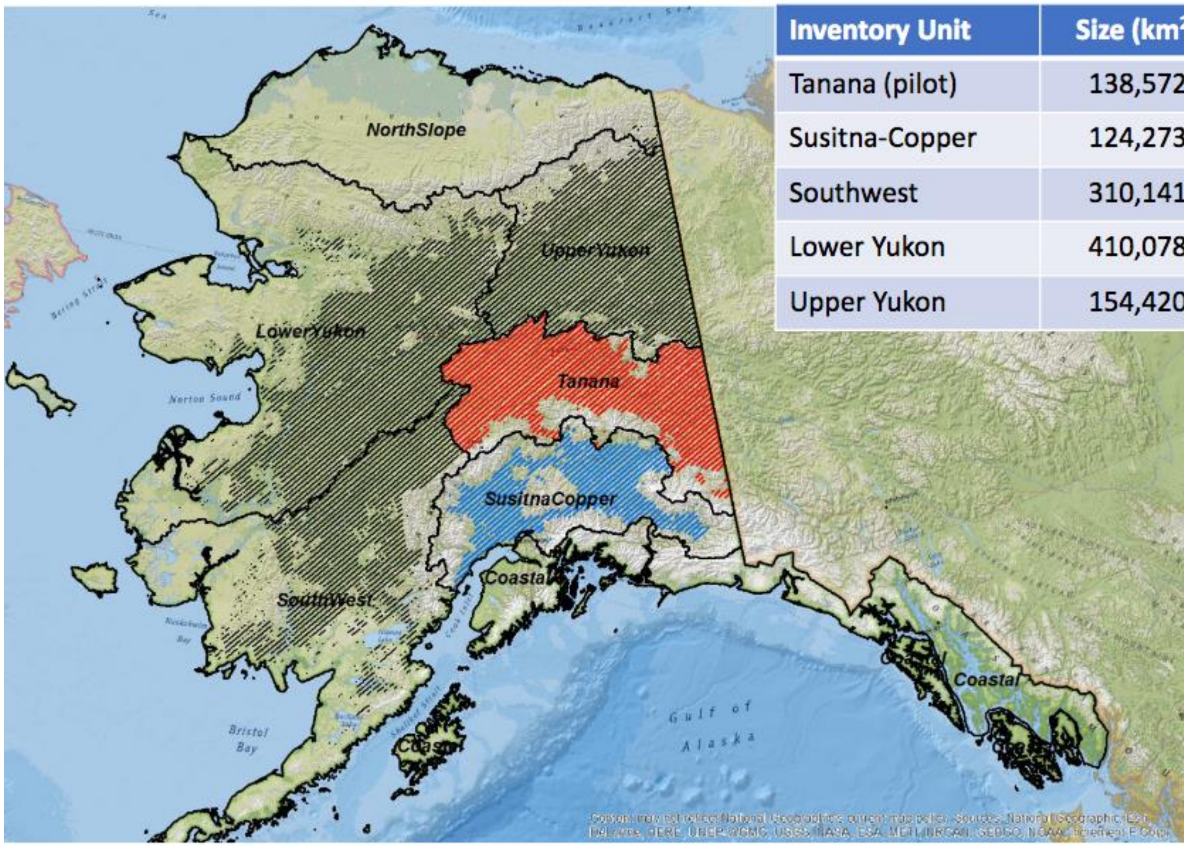
Hu et al.

***Front Ecol Environ* 2015; 13(7): 369–377, doi:10.1890/150063**

Projections based on 21st-century climate scenarios suggest that annual area burned will approximately double in Alaskan tundra by the end of the century.

G-LiHT
Goddard's
Lidar
Hyperspectral
Thermal
3D Imaging of Earth's Biosphere

NASA ABoVE Affiliated Project
funded by
NASA Carbon Monitoring System
NASA Terrestrial Ecology
USFS PNW Research Station



Inventory Unit	Size (km^2)	Reference	Years
Tanana (pilot)	138,572	Arkansas	2014-2018
Susitna-Copper	124,273	Pennsylvania	2018-2020
Southwest	310,141	New Mexico	2020-2022
Lower Yukon	410,078	Montana	2023-2026
Upper Yukon	154,420	Georgia	2027-2029

G-LiHT Sampling transects are spaced 9 km apart to collect multi-sensor data over FIA plots and areas in-between, and both airborne and ground measurements will be used to produce the ***first comprehensive inventory of forests in interior Alaska in >40 years***.

User-friendly L1-L3 data products are shared with the science community through G-LiHT's map-based interface
https://glihtdata.gsfc.nasa.gov/
and soon will be mirrored by LP DAAC.

nature International weekly journal of science

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Huge landslide triggered rare Greenland mega-tsunami

Scientists hope studying last month's deadly event will improve modelling of rockslides that could become more frequent with climate change.

Quirin Schiermeier

27 July 2017 | Corrected: 31 July 2017

Coxe Glacier, another glacier in Barry Arm. (Credit: Frank Kovalchek)

CLIMATE, EARTH SCIENCES, GLACIERHUB BLOG, NATURAL DISASTERS

Alaskan Coast at Risk of Catastrophic Landslide and Mega-Tsunami

BY GRENNAN JOSEPH MILLIKEN | MAY 29, 2020 Commen

Prince William Sound, a major fishing and recreational area on the south coast of Alaska, is at high risk of experiencing a landslide and tsunami of catastrophic proportions, according to a multi-institute group of Alaskan geoscientists.

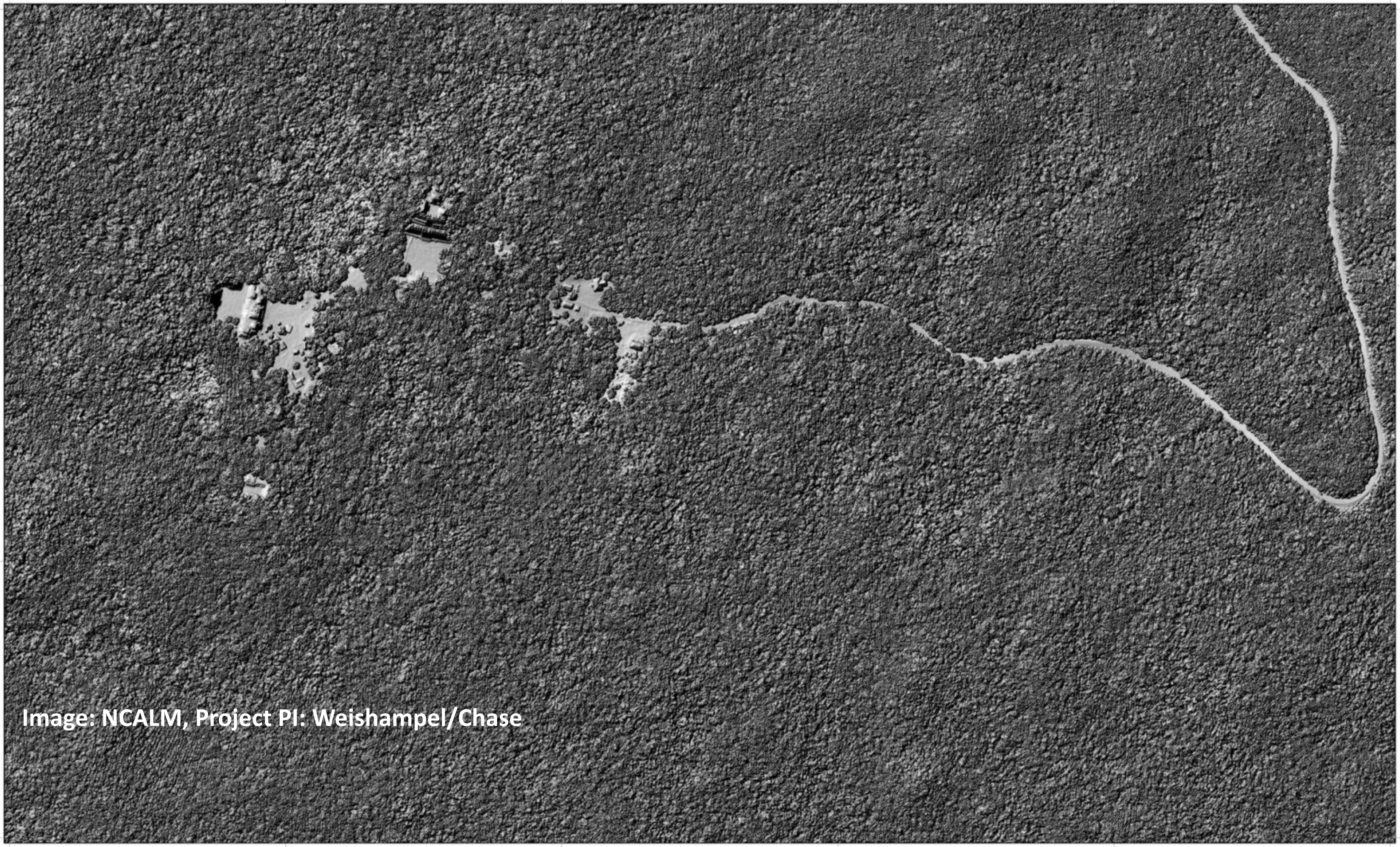
'It Could Happen Anytime': Scientists Warn of Alaska Tsunami Threat

A retreating glacier is increasing the risk of a catastrophic landslide and tsunami within a few decades, researchers say.

landslide-generated tsunamis over 600 feet have occurred in Alaska's Taan Glacier in 2015, and Lituya Bay in 1958, which launched a 1,720-foot wave up the opposite slope of the valley.

NY Times May 15, 2020

2009 Caracol Belize



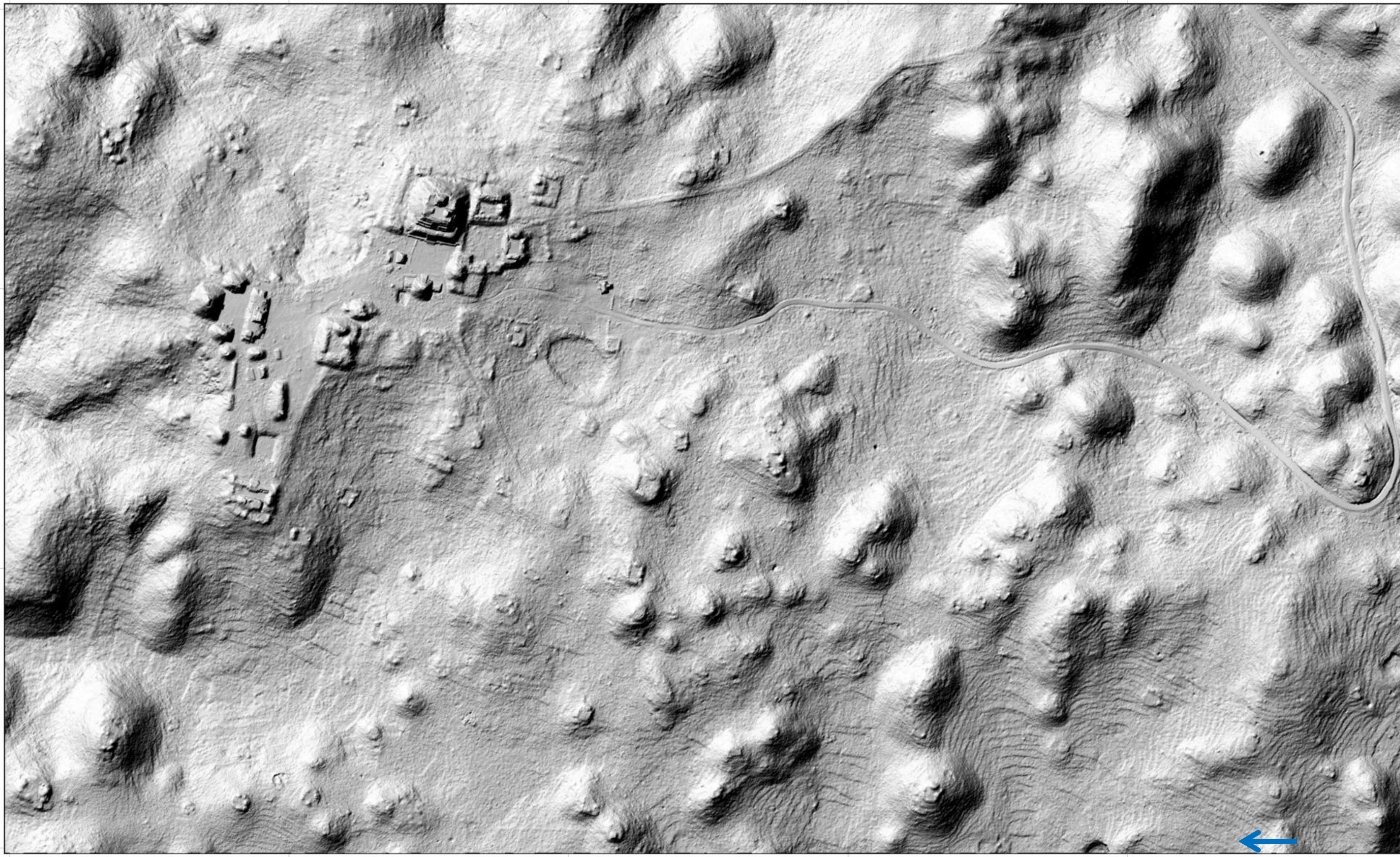


Image: NCALM, Project PI: Weishampel/Chase

PNAS

Geospatial revolution and remote sensing LiDAR in Mesoamerican archaeology

Arlen F. Chase[a,1], Diane Z. Chase[a], Christopher T. Fisher[b], Stephen J. Leisz[b], and John F. Weishampel[c]

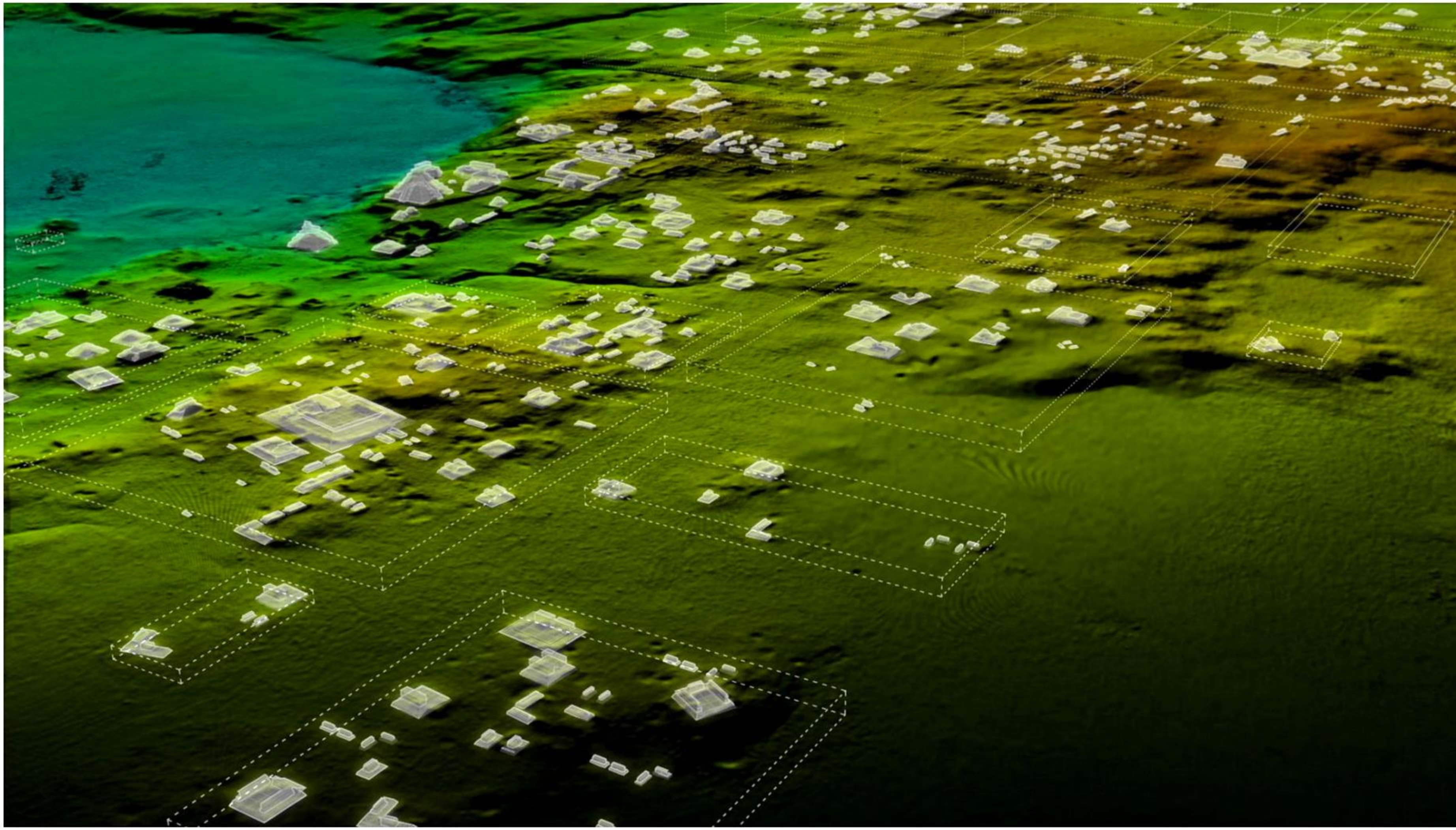
Departments of [a]Anthropology and [c]Biology, University of Central Florida, Orlando, FL 32816; and [b]Department of Anthropology, Colorado State University, Fort Collins, CO 80523

Edited by Jeremy A. Sabloff, Santa Fe Institute, Santa Fe, NM, and approved June 25, 2012 (received for review March 28, 2012)

The application of light detection and ranging (LiDAR), a laser-

settlements, thus permitting the scientific detailing of relationships

Laser Scans Reveal Maya "Megalopolis" Below Guatemalan Jungle (National Geographic)



Laser scans revealed more than 60,000 previously unknown Maya structures that were part of a vast network of cities, fortifications, farms, and highways.

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Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space (2018)

QUESTION S-1. How can large-scale **geological hazards** be accurately **forecast** in a socially relevant time frame?	**S-1a. Measure** the pre-, syn-, and post-eruption surface deformation and products of Earth's entire active land **volcano** inventory with a time scale of days to weeks.
	S-1b. Measure and forecast interseismic, preseismic, coseismic, and postseismic activity over tectonically active areas on time scales ranging from hours to decades.
	S-1c. Forecast and monitor **landslides**, especially those near population centers.
	S-1d. Forecast, model, and measure tsunami generation, propagation, and run-up for major seafloor events.

QUESTION S-2. How do **geological disasters** directly impact the Earth system and society following an event?	**S-2a. Rapidly capture the transient processes following disasters for improved predictive modeling**, as well as response and mitigation through optimal retasking and analysis of space data.
	S-2b. Assess **surface deformation (<10 mm)**, extent of **surface change (<100 m spatial resolution**) and **atmospheric** contamination, and the **composition and temperature** of **volcanic products following a volcanic eruption** (hourly to daily temporal sampling).
	S-2c. Assess co- and postseismic ground deformation (spatial resolution of 100 m and an accuracy of 10 mm) and damage to infrastructure following an **earthquake**.

QUESTION S-3. How will **local sea level** change along coastlines around the world in the next decade to century?	**S-3a.** Quantify the rates of sea-level change and its driving processes at **global, regional, and local** scales, with uncertainty <0.1 mm/yr for global mean sea-level equivalent and <0.5 mm/yr sea-level equivalent at resolution of 10 km.
	S-3b. Determine **vertical motion** of land along coastlines, at uncertainty <1 mm/yr .

QUESTION S-4. What processes and interactions determine the **rates of landscape change**?	**S-4a.** Quantify **global, decadal** landscape change produced by abrupt events and by continuous reshaping of Earth's surface from surface processes, tectonics, and societal activity.
	S4b. Quantify **weather events, surface hydrology, and changes in ice/water content** of near-surface materials that produce landscape change.
	S4c. Quantify **ecosystem response to and causes** of landscape change.

QUESTION S-6. How much **water** is traveling **deep underground** and how does it affect geological processes and water supplies?	**S-6a.** Determine the **fluid pressures, storage**, and flow in confined aquifers at spatial resolution of 100 m and pressure of 1 kPa (0.1 m head).
	S-6b. Measure **all significant fluxes in and out** of the groundwater system across the recharge area.
	S-6c. Determine the **transport and storage** properties in situ within a factor of 3 for shallow aquifers and an order of magnitude for deeper systems.
	S-6d. Determine the impact of water-related human activities and natural water flow on **earthquakes**.

QUESTION S-7. How do we improve discovery and management of **energy, mineral, and soil resources**?	**S-7a. Map topography**, surface mineralogic composition and distribution, thermal properties, soil properties/water content, and solar irradiance for improved development and management of energy, mineral, **agricultural, and natural resources**.

Mass Change	*Large-scale Earth dynamics* measured by the changing mass distribution within and between the Earth's atmosphere, oceans, groundwater, and ice sheets	Spacecraft ranging measurement of gravity anomaly	Designated
Surface Biology and Geology	*Earth surface geology and biology,* ground/water temperature, snow reflectivity, active geologic processes, vegetation traits, and algal biomass	Hyperspectral imagery in the visible and shortwave infrared (IR), multi- or hyperspectral imagery in the thermal IR	Designated
Surface Deformation and Change	*Earth surface dynamics* from earthquakes and landslides to ice sheets and	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	Designated *committed group of observations*

Ice Elevation	*Global ice characterization* including elevation change of land ice to assess sea-level contributions and freeboard height of sea ice to assess sea ice/ocean/atmosphere interaction	Lidar	Explorer

Snow Depth and Snow Water Equivalent	*Snow depth and snow water equivalent*, including high spatial resolution in mountain areas	Radar (Ka/Ku band) altimeter; or lidar*	Explorer
Terrestrial Ecosystem Structure	*3D structure of terrestrial ecosystem* including forest canopy and aboveground biomass and changes in aboveground carbon stock from processes such as deforestation and forest degradation	Lidar	Explorer *a competed group*

Surface Topography and Vegetation	*High-resolution global topography*, including bare surface land topography, ice topography, vegetation structure, and shallow water bathymetry	Radar or lidar	Incubation *intended to accelerate readiness of high-priority observables not yet feasible for cost-effective flight implementation.*

"Satellite-derived high-resolution lidar to obtain high-resolution (1 to 5 m spatial resolution) bare- earth topography globally remains a top priority, but is not yet technically feasible. "

The **NASA Surface Topography and Vegetation (STV) Incubation Study** held its first community workshop on Thursday July 9, 2020. The STV incubation study is being conducted by an STV team at the request of NASA in response to recommendations made in the 2017- 2027 Earth Science Decadal Survey

https://science.nasa.gov/earth-science/decadal-stv/workshop

A Vision for NSF Earth Sciences 2020–2030

EARTH IN TIME

A Decadal Survey for NSF's Division of Earth Sciences

What is an earthquake?
Earthquake rupture is complex, and the deformation of the Earth occurs over a spectrum of rates and in a variety of styles, leading Earth scientists to reconsider the very nature of earthquakes and the dynamics that drive them.

What drives volcanism?
Volcanic eruptions have major effects on people, the atmosphere, the hydrosphere, and the Earth itself, creating an urgent need for fundamental research on how magma forms, rises, and erupts in different settings around the world and how these systems have operated throughout geologic time.

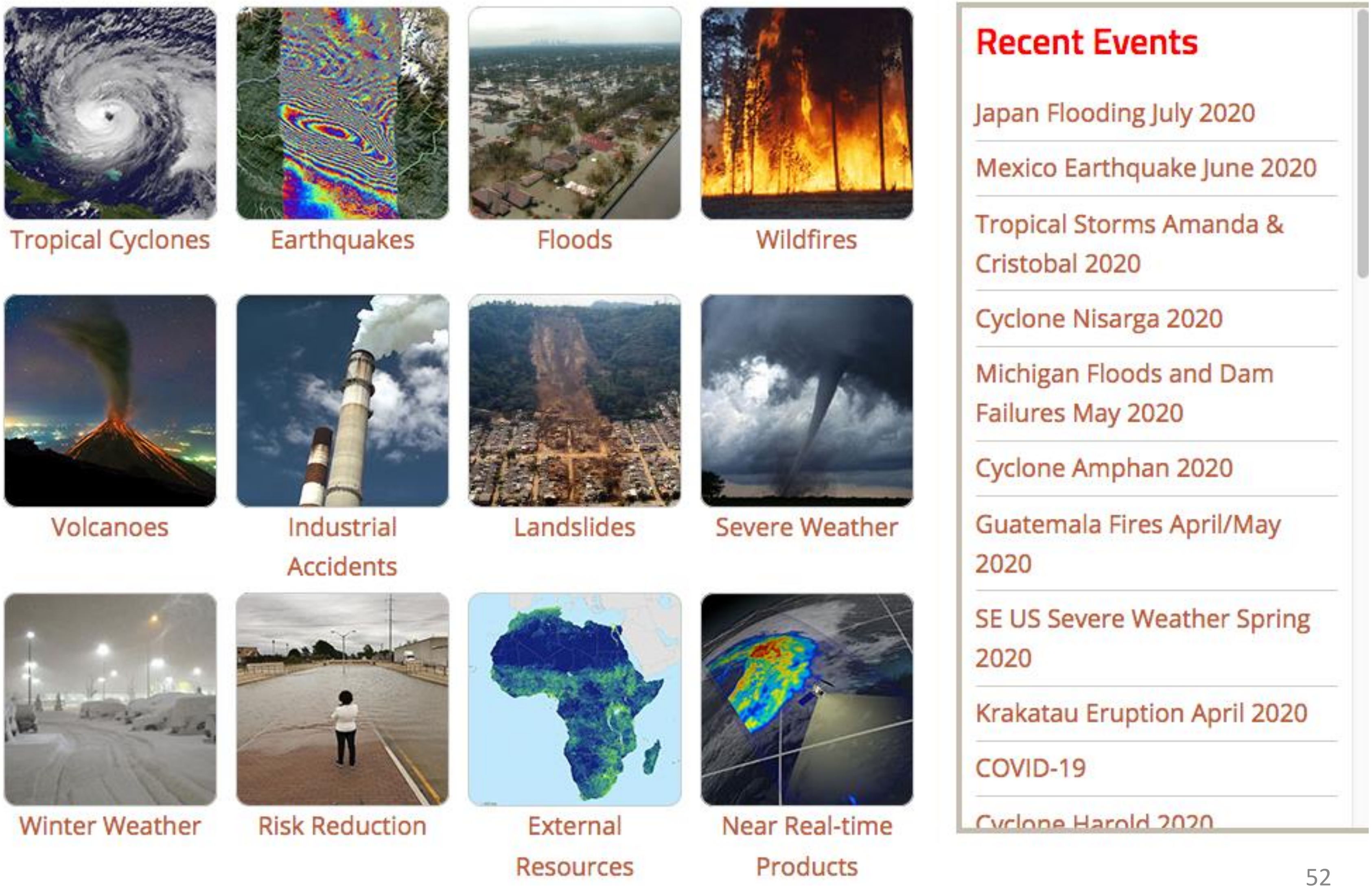
What are the causes and consequences of topographic change?
New technology for measuring topography over geologic to human timescales now makes it possible to address scientific questions linking the deep and surface Earth and urgent societal challenges related to geologic hazards, resources, and climate change.

How does the critical zone influence climate?
The reactive skin of the terrestrial Earth influences moisture, groundwater, energy, and gas exchanges between the land and atmosphere, and its influence on climate is therefore a vital component of understanding the Earth system and how it has responded and will respond to global change.

How is Earth's water cycle changing?
Understanding current and future changes to the water cycle requires fundamental knowledge of the hydro-terrestrial system and how the water cycle interacts with other physical, biological, and chemical processes.

How can Earth science research reduce the risk and toll of geohazards?
A predictive and quantitative understanding of geohazards is essential to reduce risk and impacts and to save lives and infrastructure.

NASA Earth Science Disasters program
https://disasters.nasa.gov/home



Four common goals:

General remote sensing data goals

1. High spatial resolution and repeat surveys (regularly and event response) (~***1 m spatial resolution***)
2. Global coverage

Application

1. Documentation and prediction of rapidly changing landscapes
2. Forecast of hazards/disasters

High resolution data and repeat surveys that reveal dynamics are key to understanding process.

Large scale change is the sum of local actions

Most widely used NASA airborne facilities for earth surface dynamics

Airborne Topographic Mapper has flown Greenland every year since 1993. IceBridge campaign

G-LiHT (lidar, hyperspectral, thermal) system is focused on documenting vegetation in Alaska as part of the ABoVE program

No other dedicated NASA facility for high resolution topographic mapping from airborne lidar

NCALM NSF THE NATIONAL CENTER FOR AIRBORNE LASER MAPPING

UNIVERSITY of HOUSTON

Berkeley University of California

NSF supported facility operating since 2003

Could larger platforms carry multiple instruments?

NASA Surface Topography and Vegetation (STV) Incubation Study will be focused on the challenges of high resolution, repeat surveys and global coverage