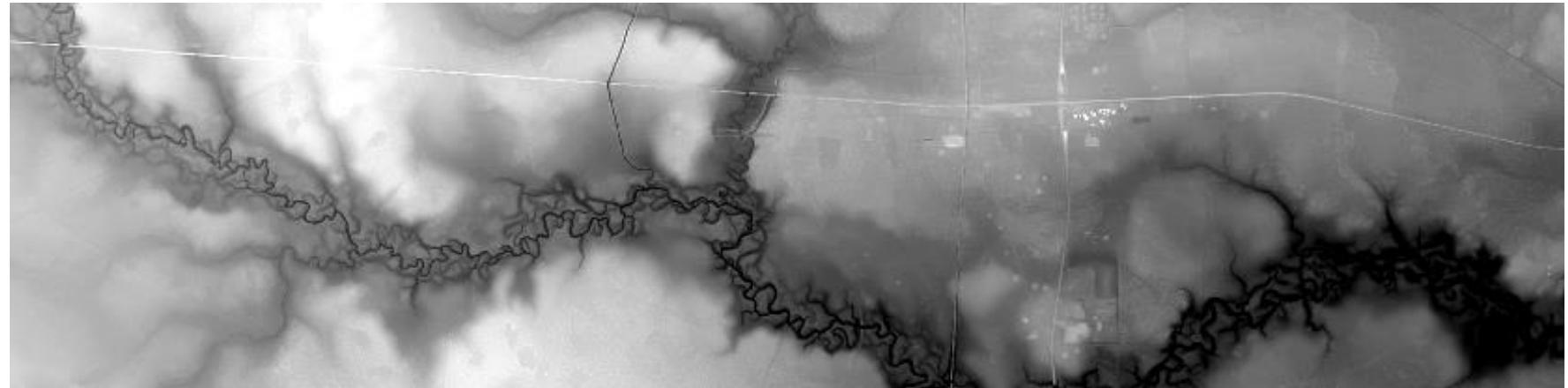


- High-resolution topographic (HRT) data is becoming more easily accessible and prevalent, and is rapidly advancing our understanding of myriad surface and ecological processes. Landscape connectivity is the framework that describes the routing of fluids, sediments, and solutes across a landscape and is a primary control on geomorphology and ecology. Connectivity is not a static parameter, but rather a continuum that dynamically evolves on a range of temporal and spatial scales, and the observation of which is highly dependent on the available methodology. In this clinic we showcase the utility of HRT for the observation and characterization of landscapes and compare results with those of coarser spatial resolution data-sets. We highlight the potential for integrating HRT observations and parameters such as vegetation density, surface relief, and local slope variability with numerical surface process models. Participants will gain an understanding of the basics of HRT, data availability and basic analysis, and the use of HRT parameters in modeling.

Exploring surface processes and landscape connectivity through high-resolution topography: integration of high resolution data in numerical modeling

John Swartz
Paola Passalacqua
Nancy Glenn
Chris Crosby
5/20/2020



Advancing the Analysis of High Resolution Topography



EARTH CUBE
TRANSFORMING GEOSCIENCES RESEARCH



The University of Texas at Austin
Civil, Architectural and
Environmental Engineering

PassaH2O Group



CSDMS
community surface
dynamics modeling system

Advancing the Analysis of High Resolution Topography: A²HRT



John Swartz
UT/BSU



Paola Passalacqua
UT



Nancy Glenn
UNSW/BSU



Chris Crosby
OpenTopography/
UNAVCO

Earthcube sponsored Research Coordination Network (RCN)

Focused on assessing current state of HRT and developing best practices, linkages between models and observations, and community

Want to be involved?

Working group on data-model integration

Summer learning series

Contact us! Or me, specifically

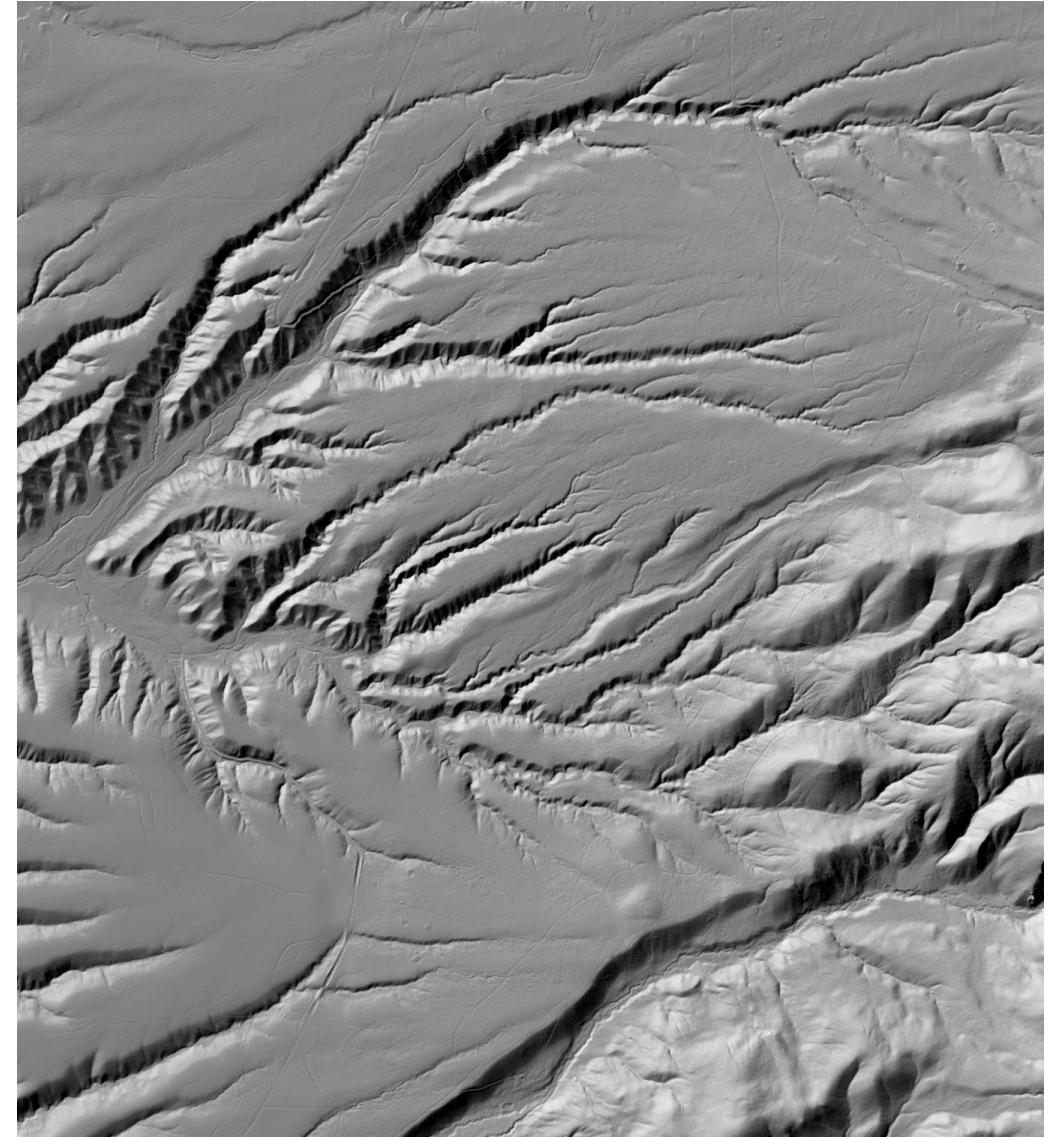


CSDMS 2020 Overview

1. Introduction to High-resolution topography, applications, and connectivity
2. Hands-on: Basic raster and terrain analysis
3. Use of high-resolution data in modeling
4. Hands-on: Hydrodynamic modeling with ANUGA
5. Discussion

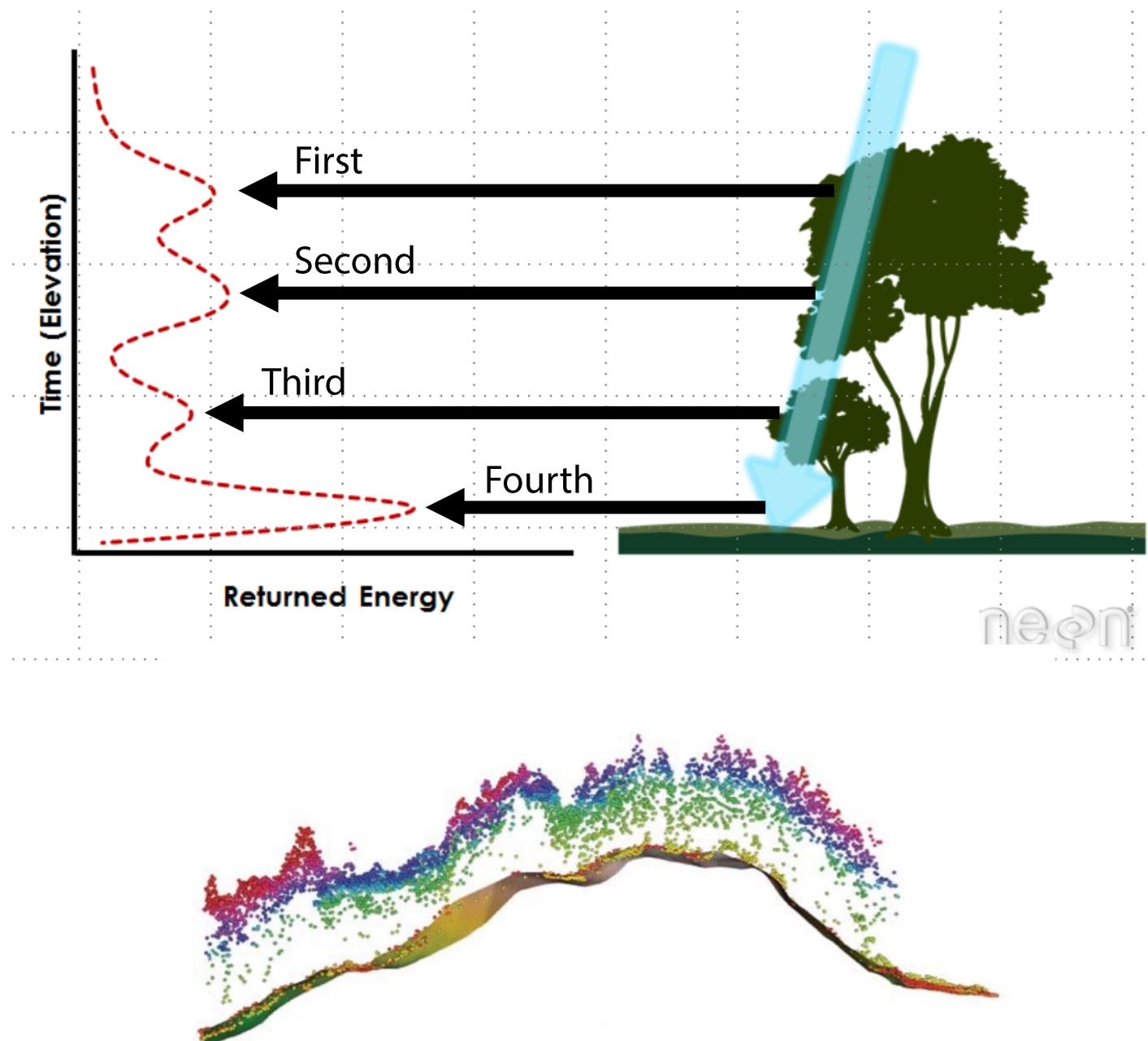
1. What is high-resolution topography (HRT)?

- Technology that can acquire meter to sub-meter scale datasets
 - Lidar (ALS or TLS)
 - Photogrammetry (e.g. drone Structure-from-Motion)
 - Synthetic aperture radar (SAR)
 - Multi-beam bathymetry
- Provide accurate characterization of small-scale processes and structure
- Challenges in data handling and computation

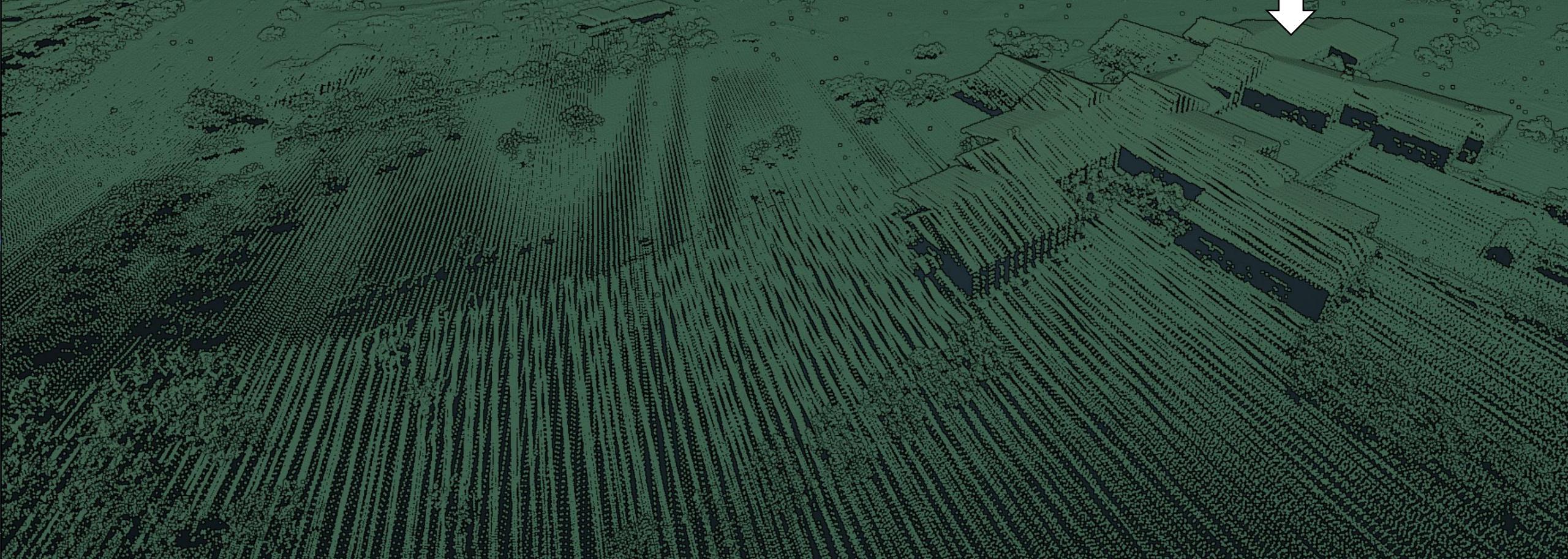


Lidar basics

- Measure distance from laser two-way travel time
 - Can be spaceborne, airborne, or terrestrial
- Vertical accuracy typically in the 5-15cm range
- Horizontal accuracy from 20cm-1m depending on point density
- Lidar quality can be highly variable!
 - E.g. Location uncertainty, terrain slope, vegetation density, flight swath offset, etc
 - **Processing is a critical step!**

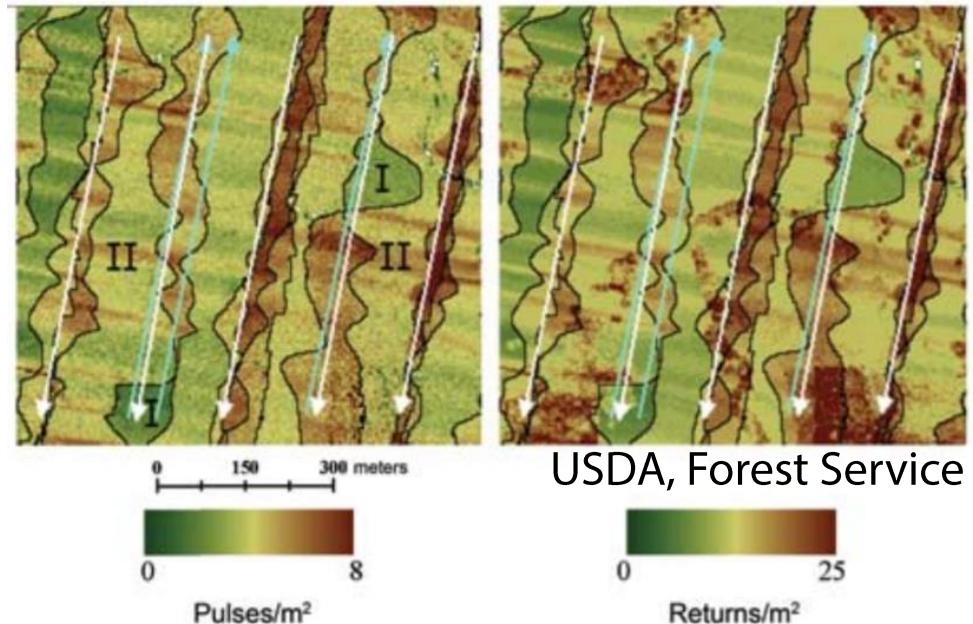


USDA Forest Service

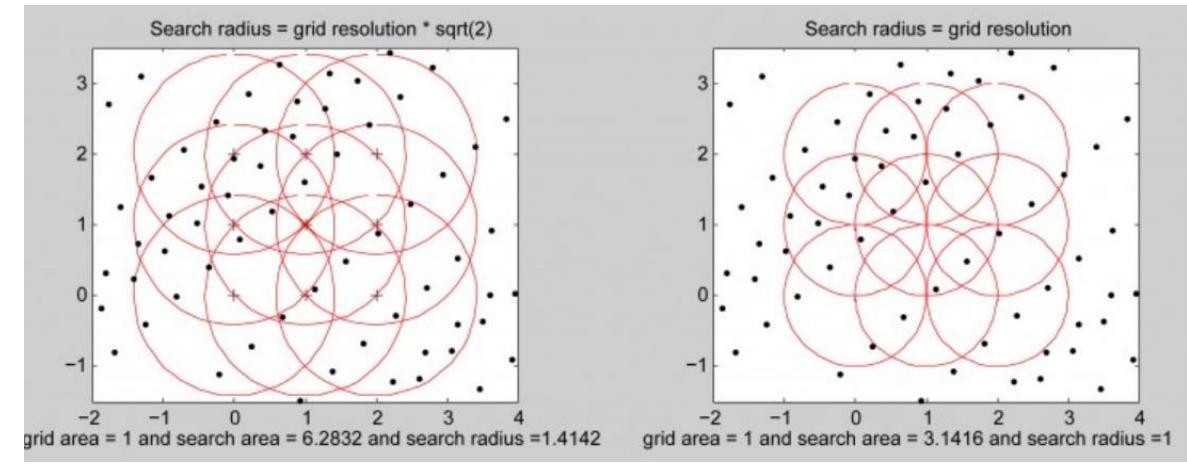


Point clouds to gridded rasters

1. Acquire and QC survey

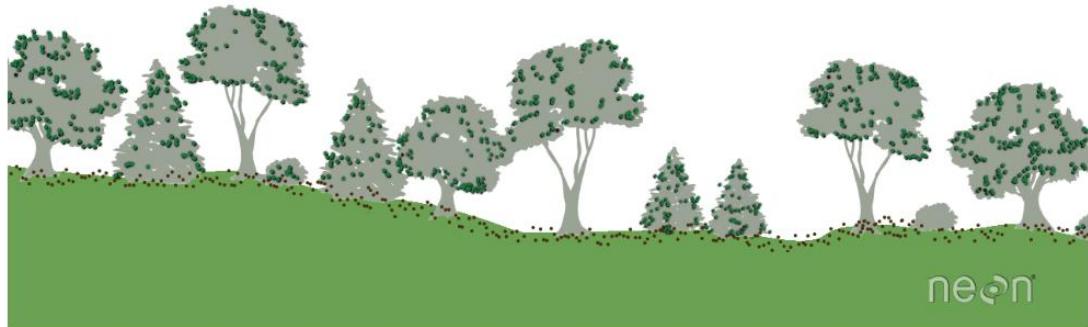


3. Grid points based on return density

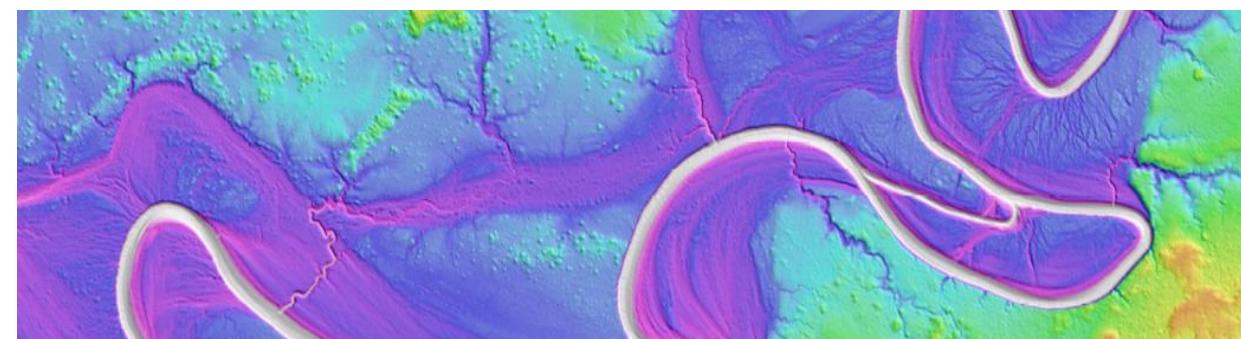


Points2Grid, OpenTopography

2. Classify returns (e.g. ground, vegetation)



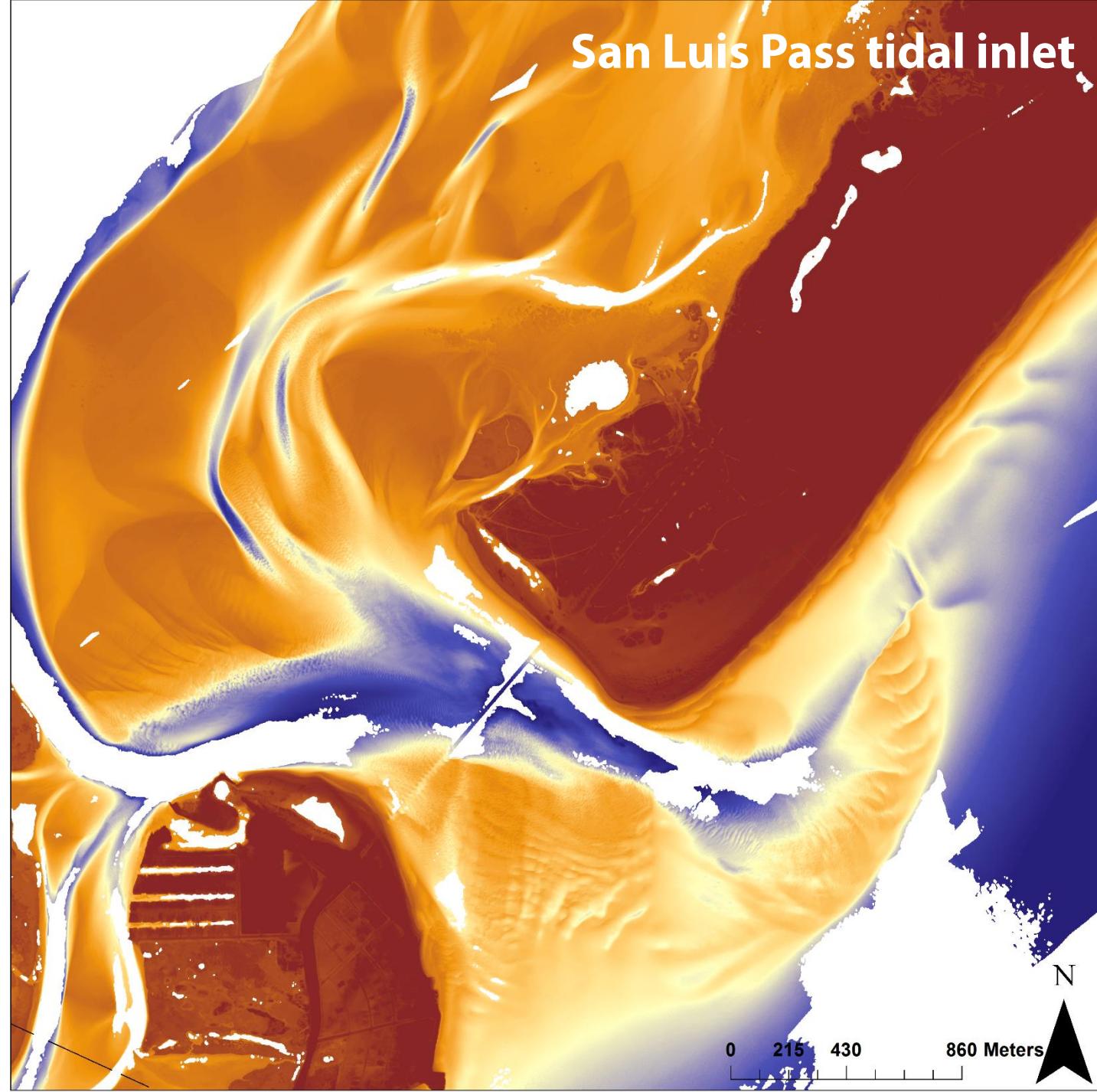
4. Enjoy your new raster!



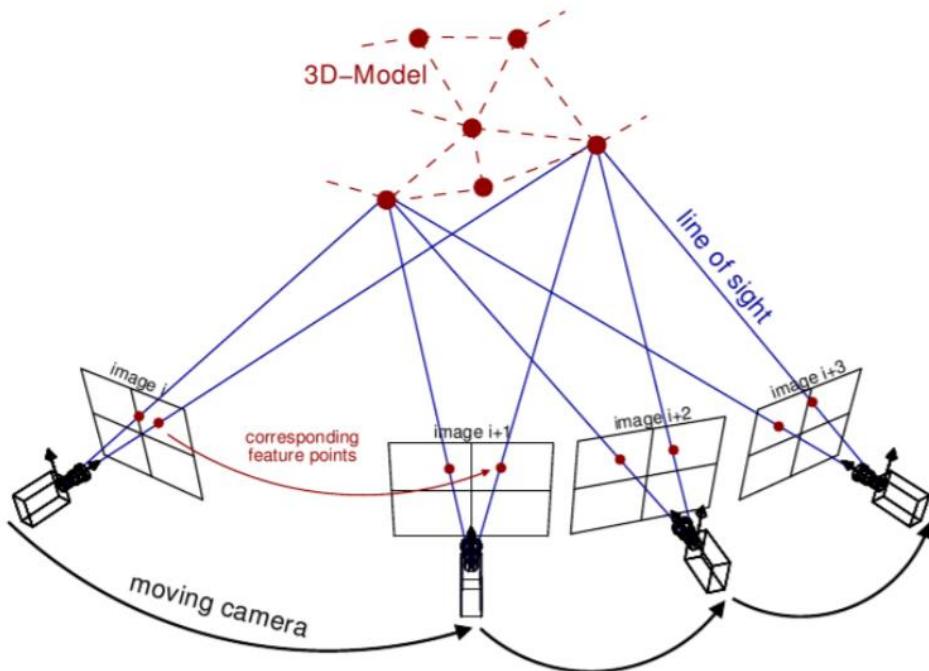
OpenTopography

Topobathymetric lidar

- Specific high-energy lidar systems can image subaqueous environments, given ideal water conditions
- Allow for investigation of subaerial and subaqueous environments at same time
 - Coastal and fluvial studies greatly benefit



Structure-from-motion photogrammetry

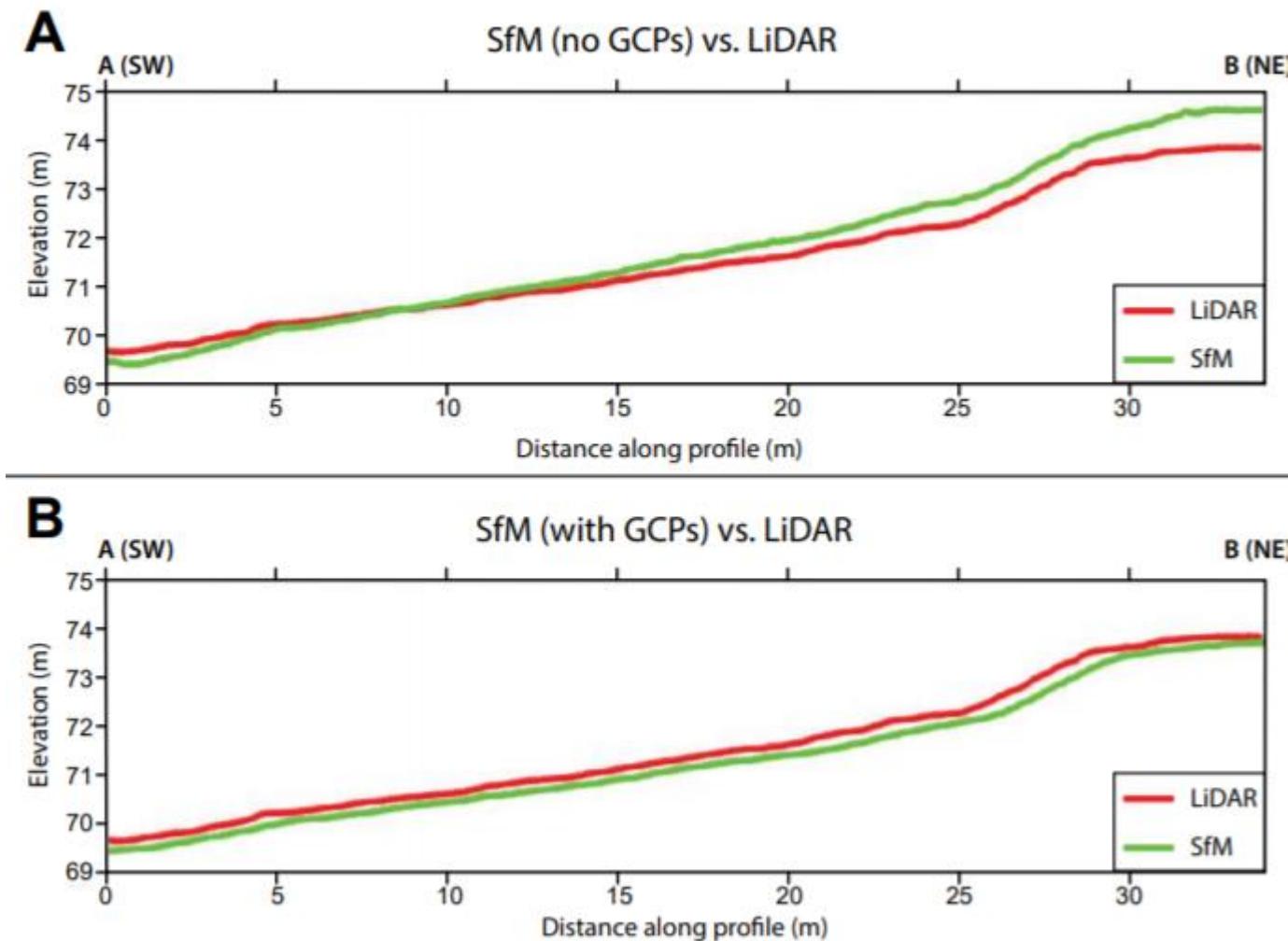
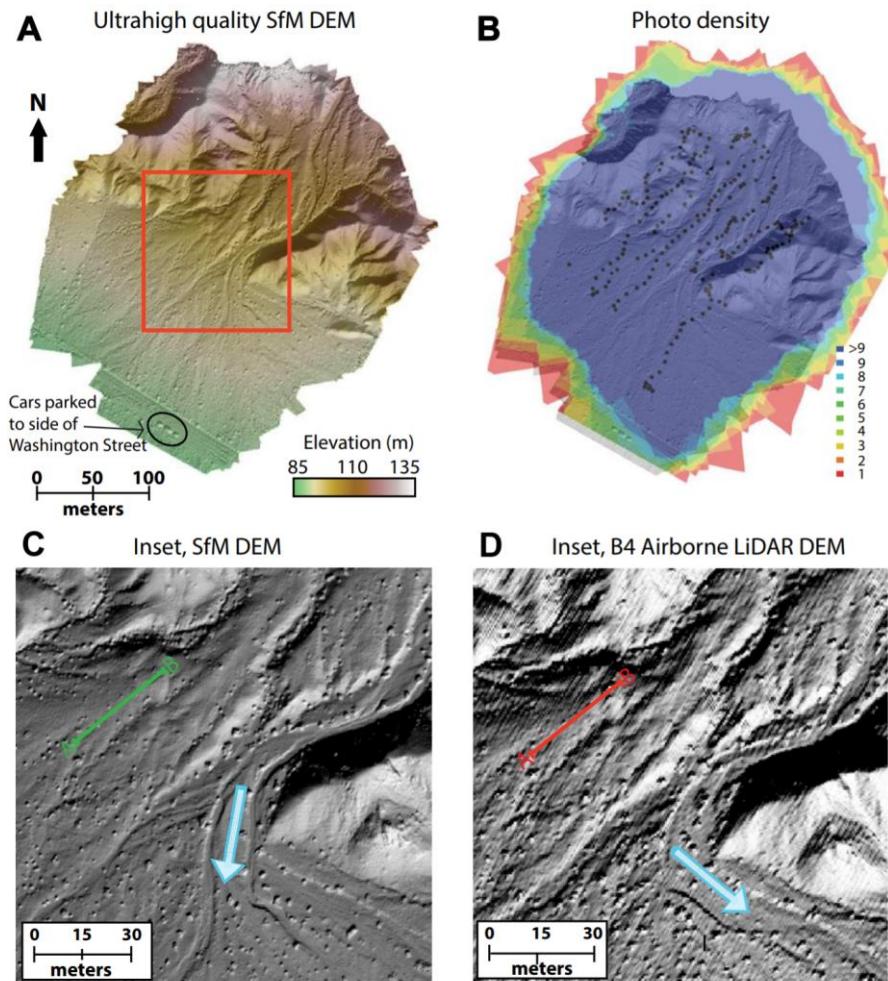


Edwin Nissen, UNAVCO

- Match corresponding scale-invariant features and measure distances between them with offset imagery
- Requires no a priori knowledge of locations or camera angles
- Generate dense point clouds and surface models

**Can be acquired quickly and cheaply
Use has exploded!**

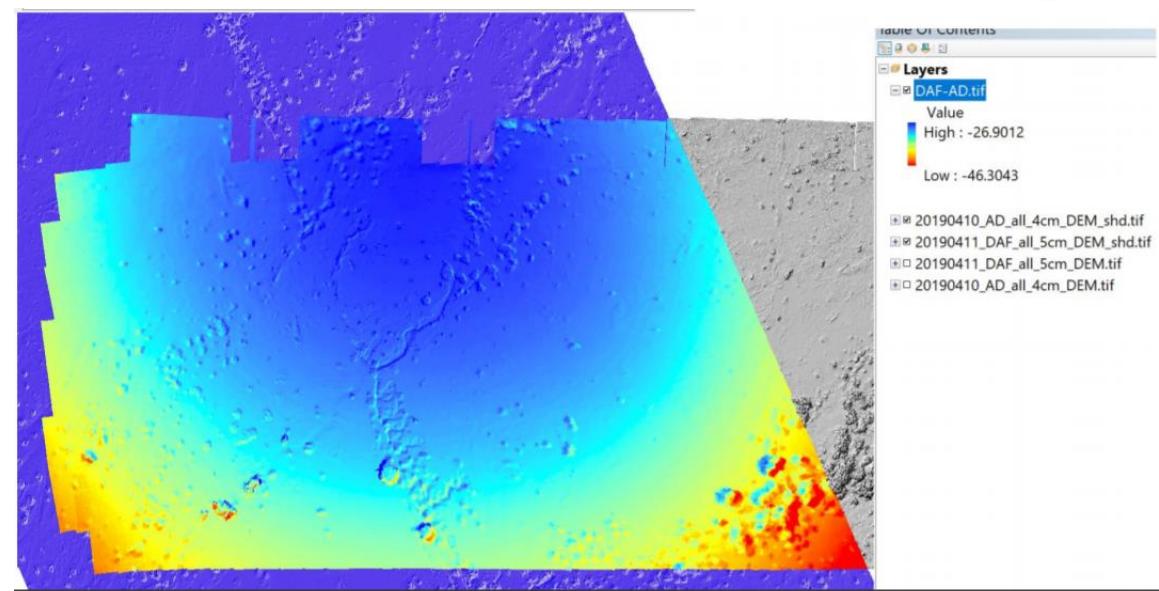
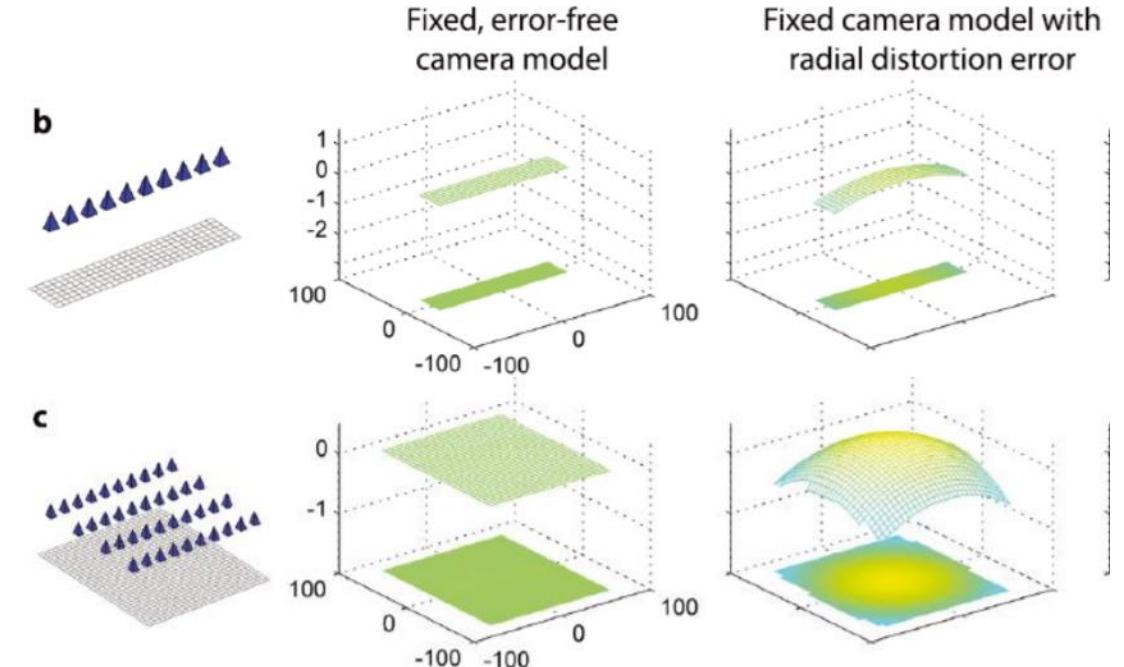
Rapid and inexpensive high-quality 3D models



Kendra Johnson et al. (2014). Rapid mapping of ultrafine fault zone topography with structure from motion. *Geosphere*

Sounds great! What's the catch?

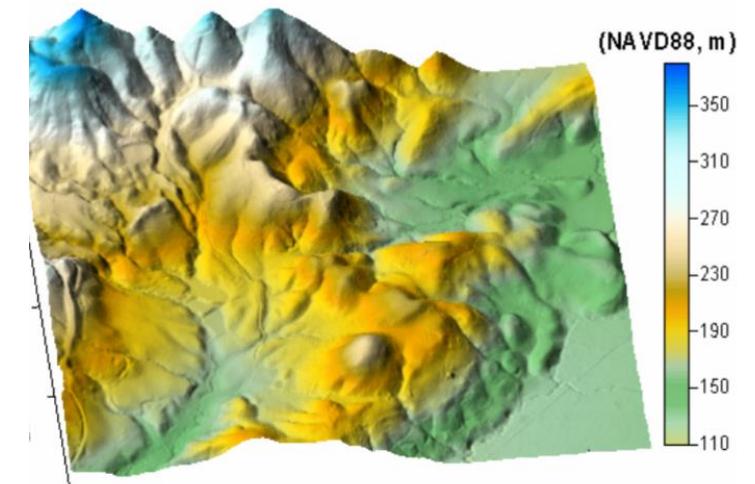
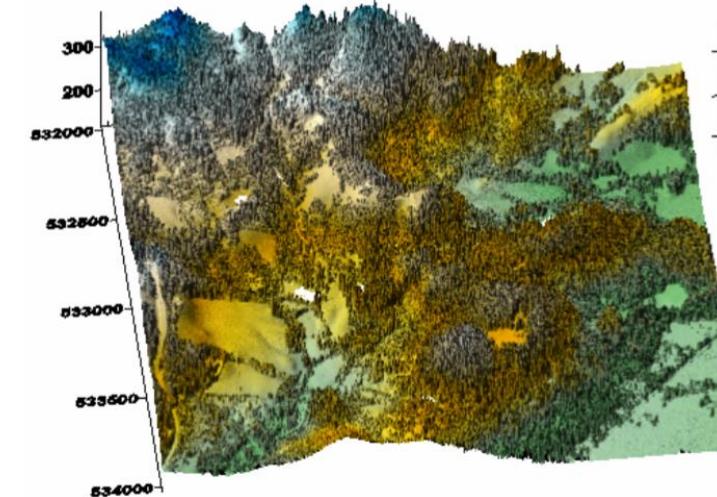
- More difficult to cover large areas
- **Cannot see through vegetation**
 - **Limited to surface topography**
- Lens and camera distortion can be an issue
- Lack of standardization in acquisition, processing, and data quality make comparing repeat surveys a challenge!



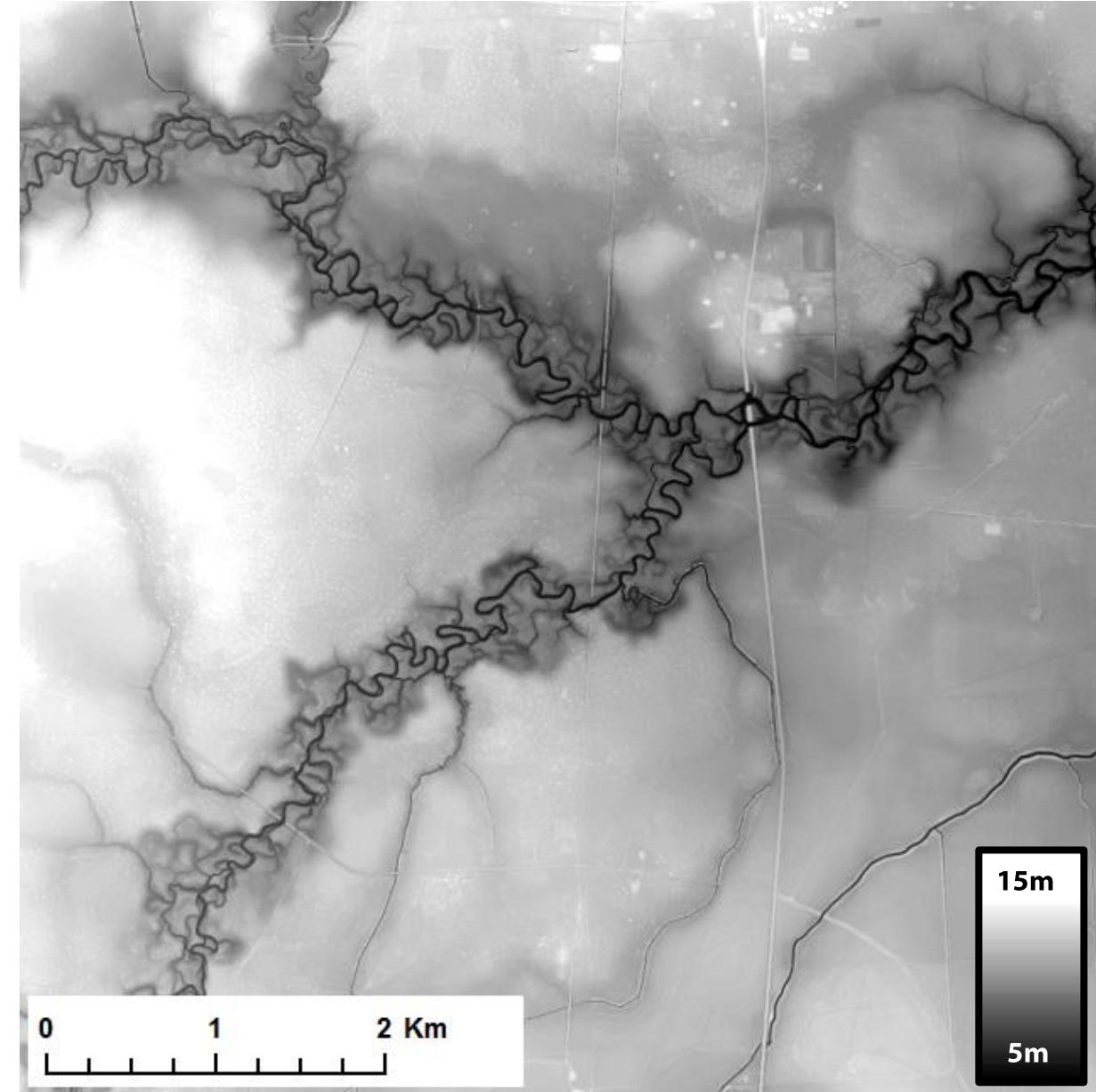
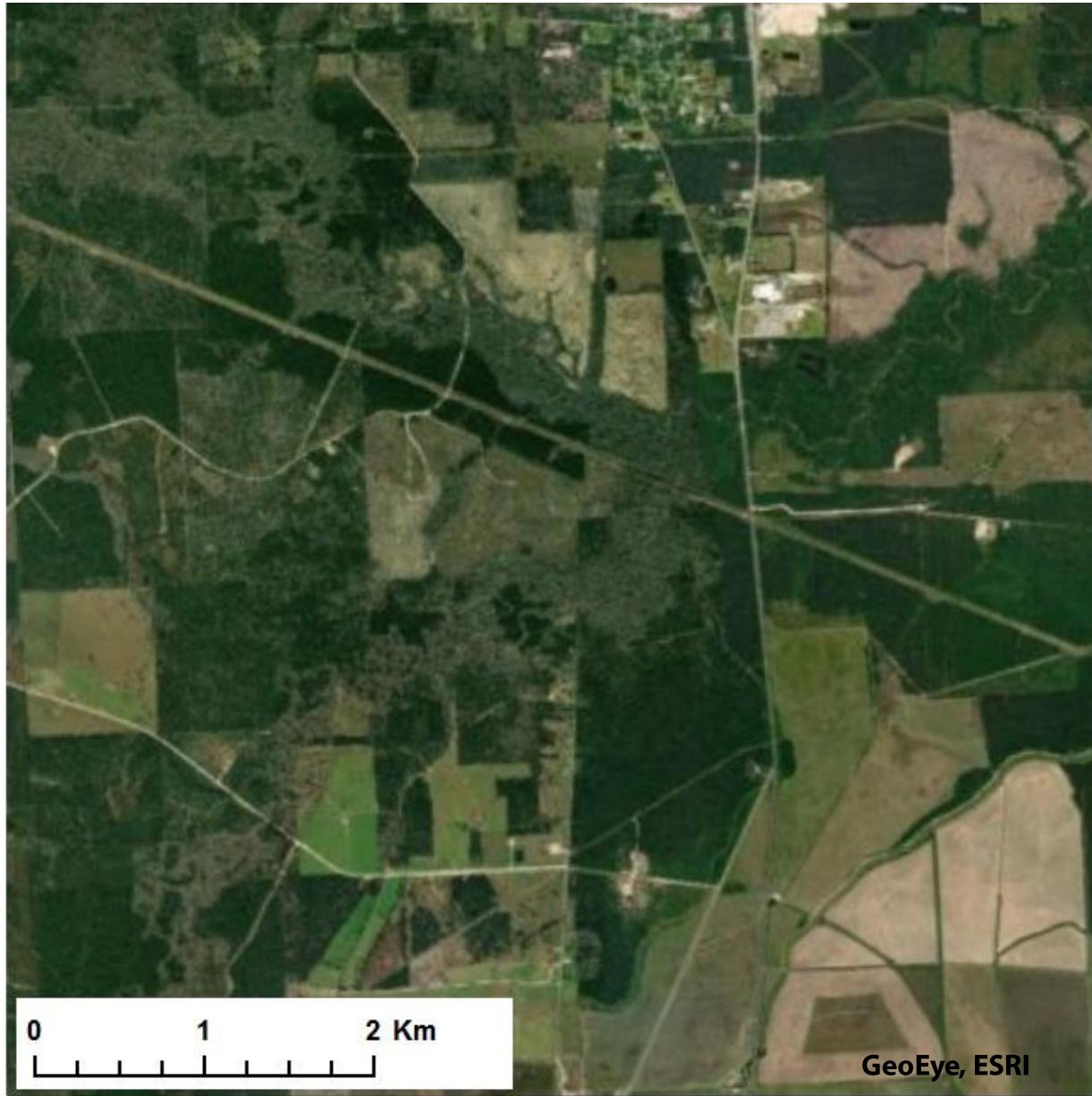
James & Robson (2014), Mitigating systematic error in topographic models derived from UAV and ground-based image networks, Earth Surface Processes and Landforms

Digital terrain and digital surface models

- DTMs and DSMs are the most commonly encountered topography data
- DTM = “bare-earth” surface: the classic lidar derived elevation raster
- DSM= Highest point surface: could be terrain, vegetation, or structures
- Lidar provides ability to create both
- SfM typically limited to DSMs
- Both have utility depending on the science!
 - **Looking at you, geologists**

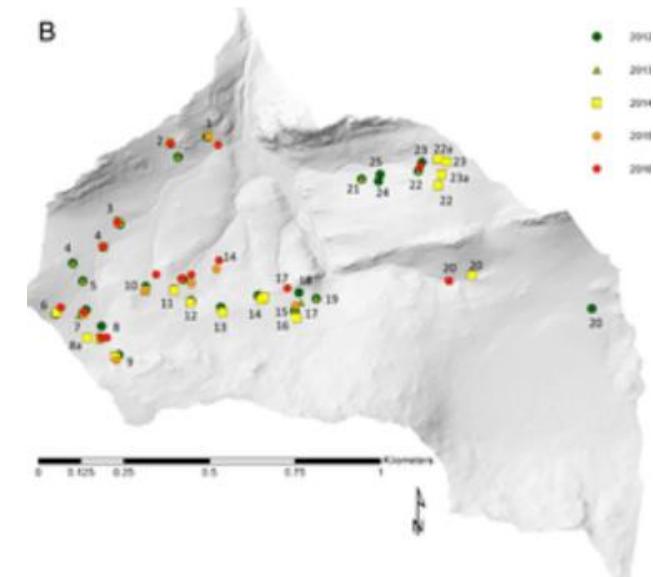


Lidar bare earth digital terrain models (DTMs)

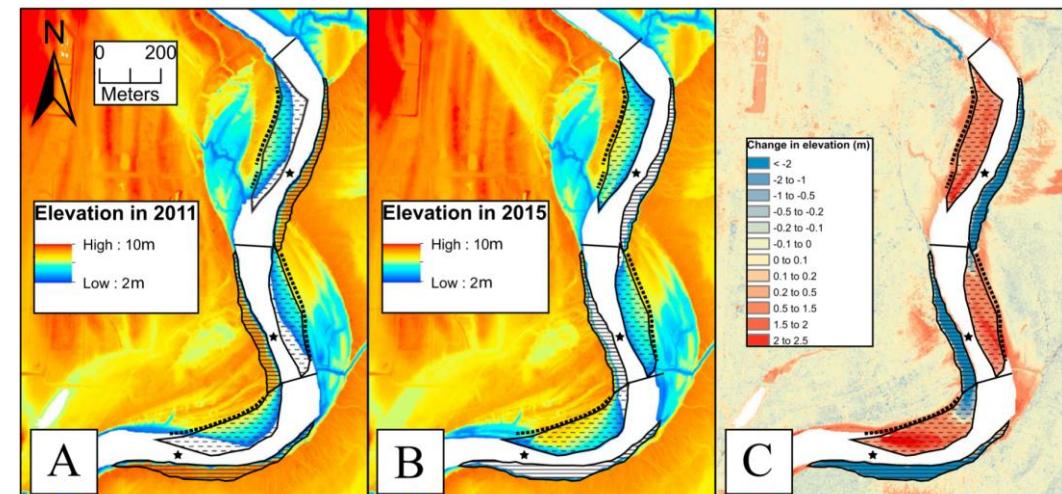


1B. Common applications and uses of HRT

- Landscape structure
- Small-scale processes and surface characteristics
- Inputs to surface process modeling
- Vegetation and canopy structure
- High-precision change detection



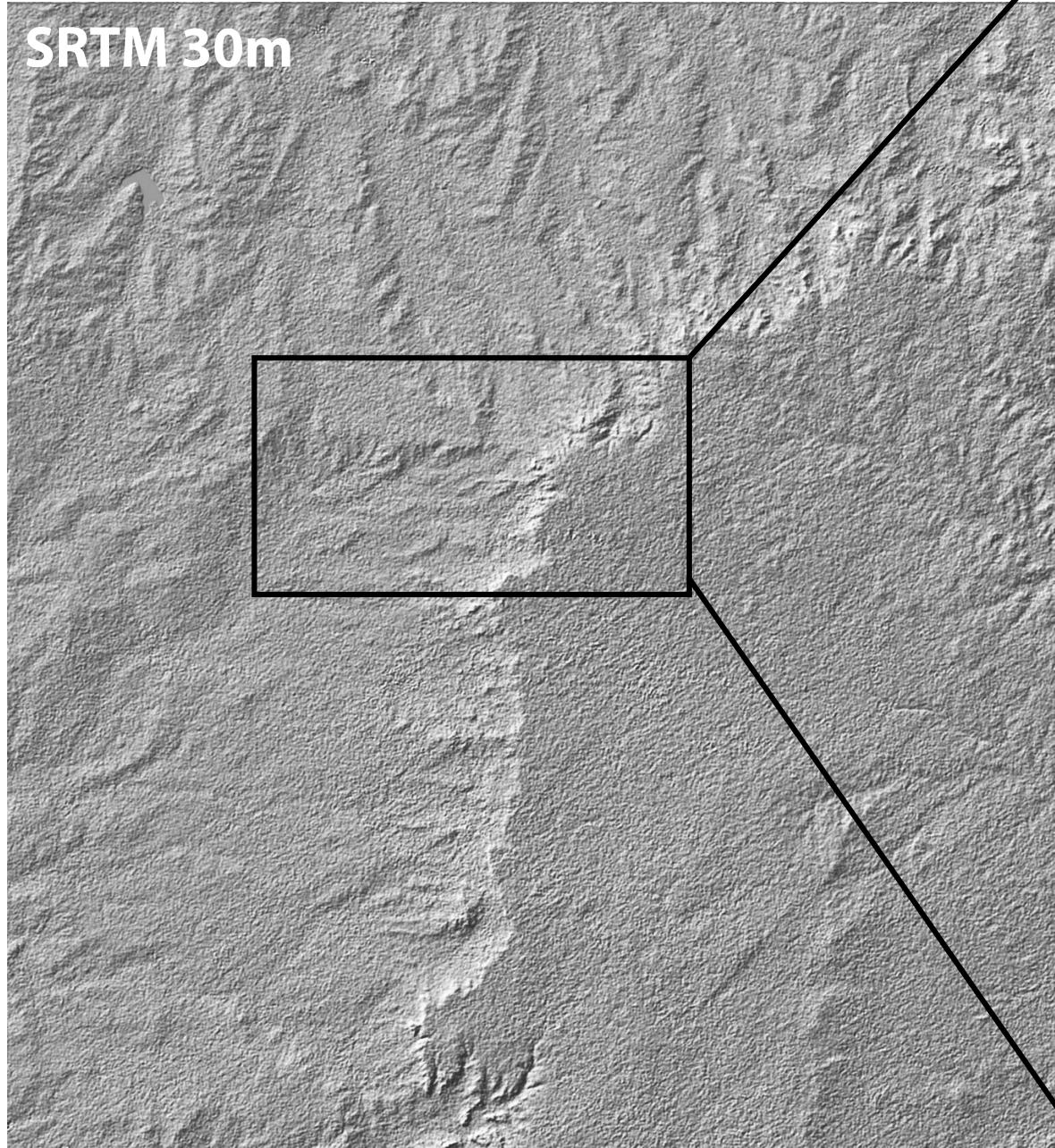
Ellen Wohl and Daniel Scott, 2017. Transience of channel head locations following disturbance. *Earth Surface Processes and Landforms*



Jasmine Mason and David Mohrig, 2017. Using Time-Lapse Lidar to Quantify River Bend Evolution on the Meandering Coastal Trinity River, Texas, USA. *JGR-ES*

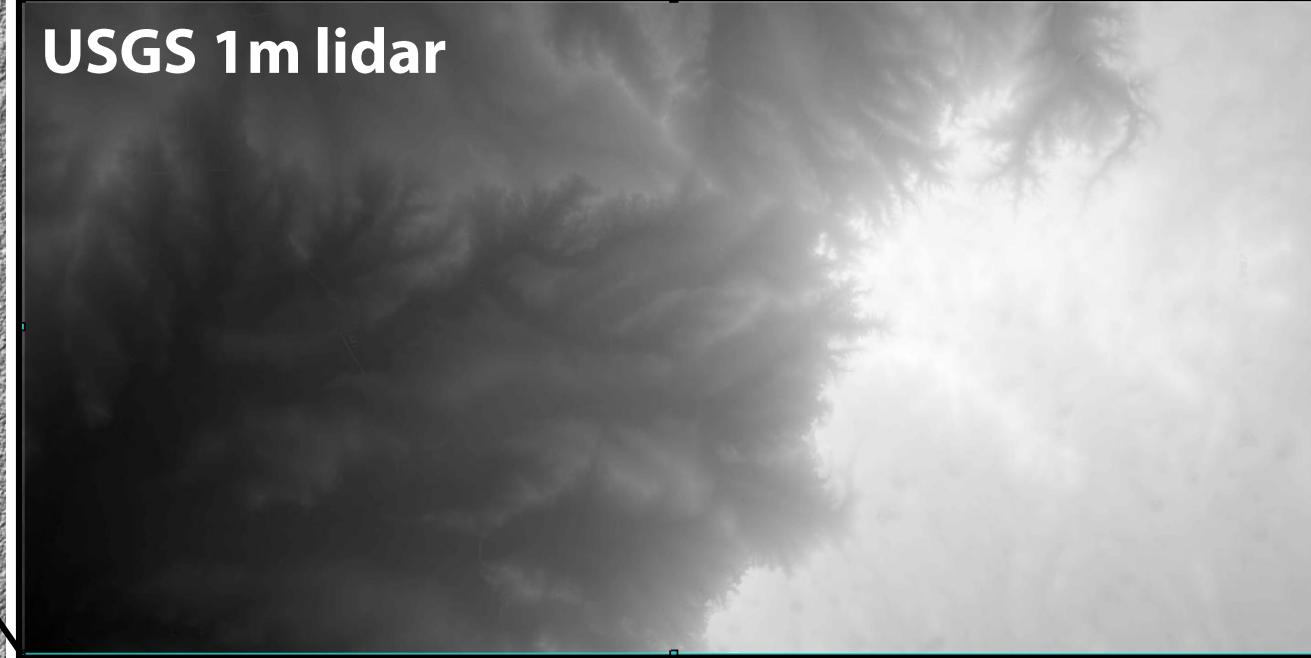
Landscape structure

SRTM 30m

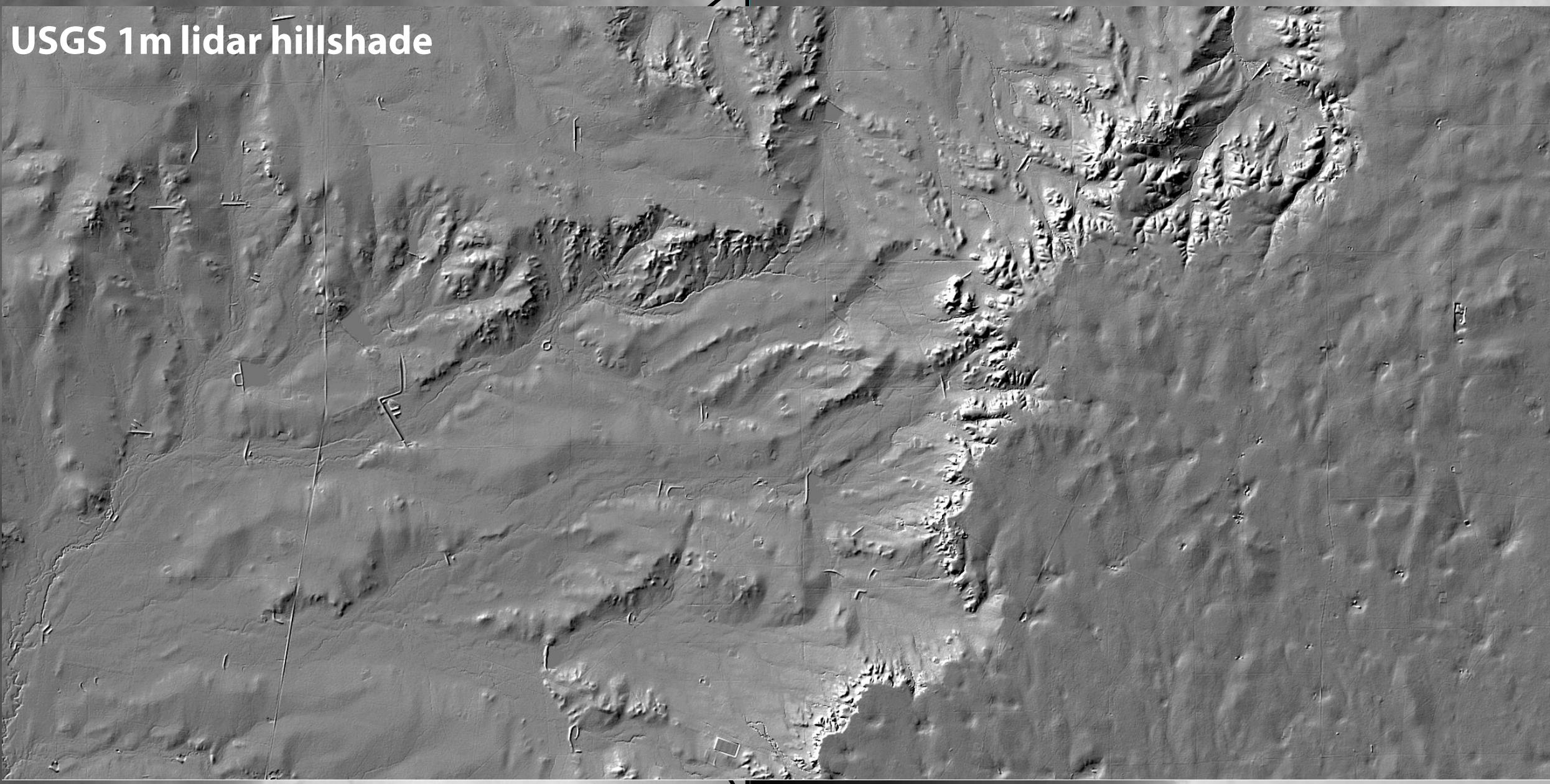


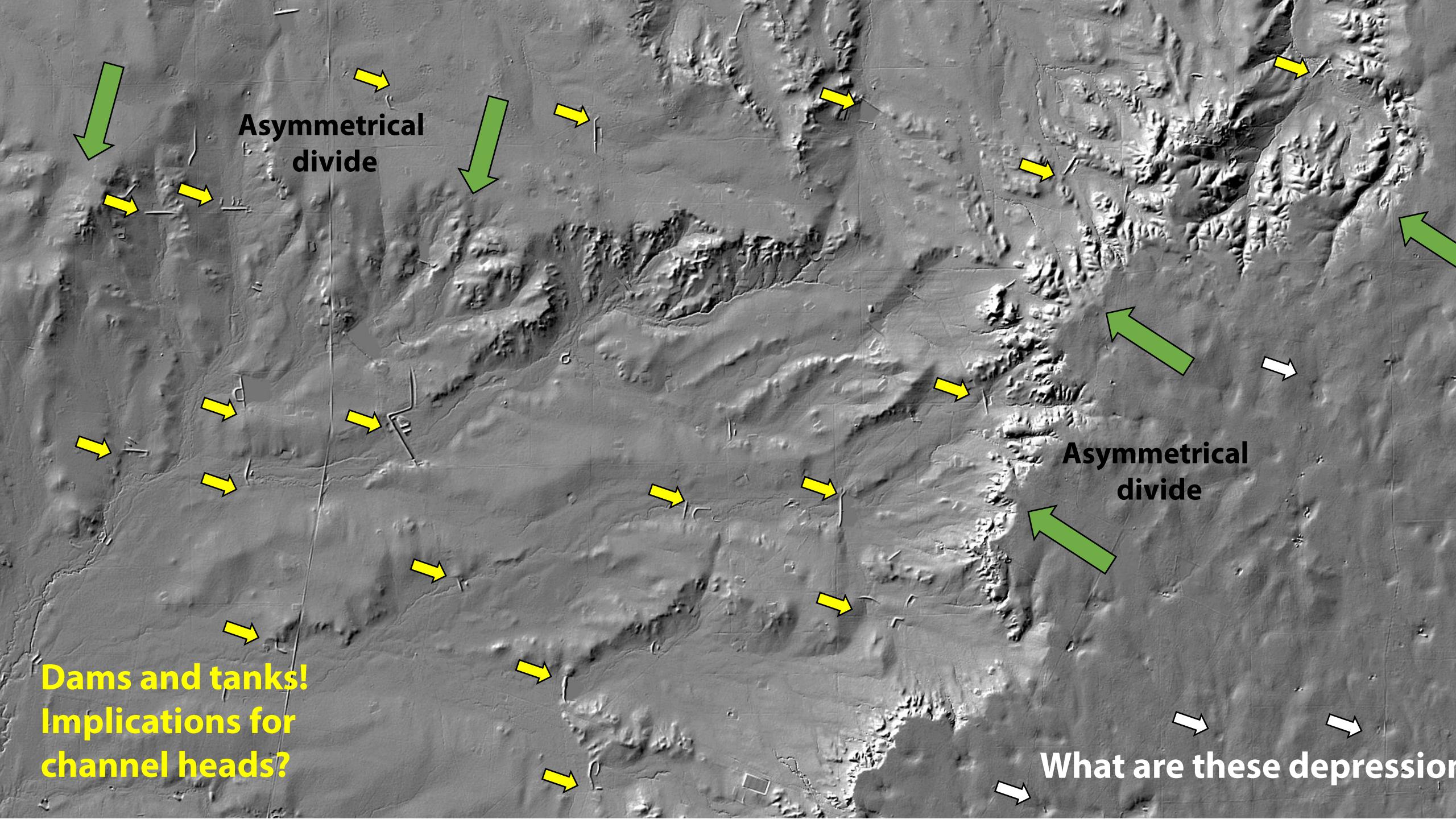
SRTM 30m

USGS 1m lidar



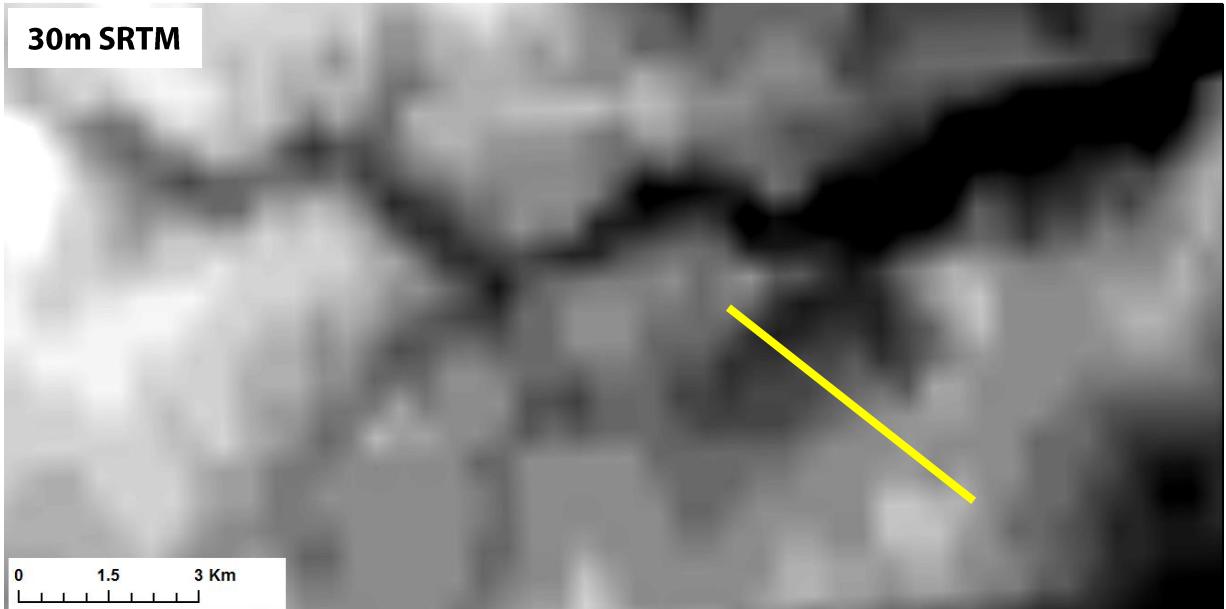
USGS 1m lidar hillshade



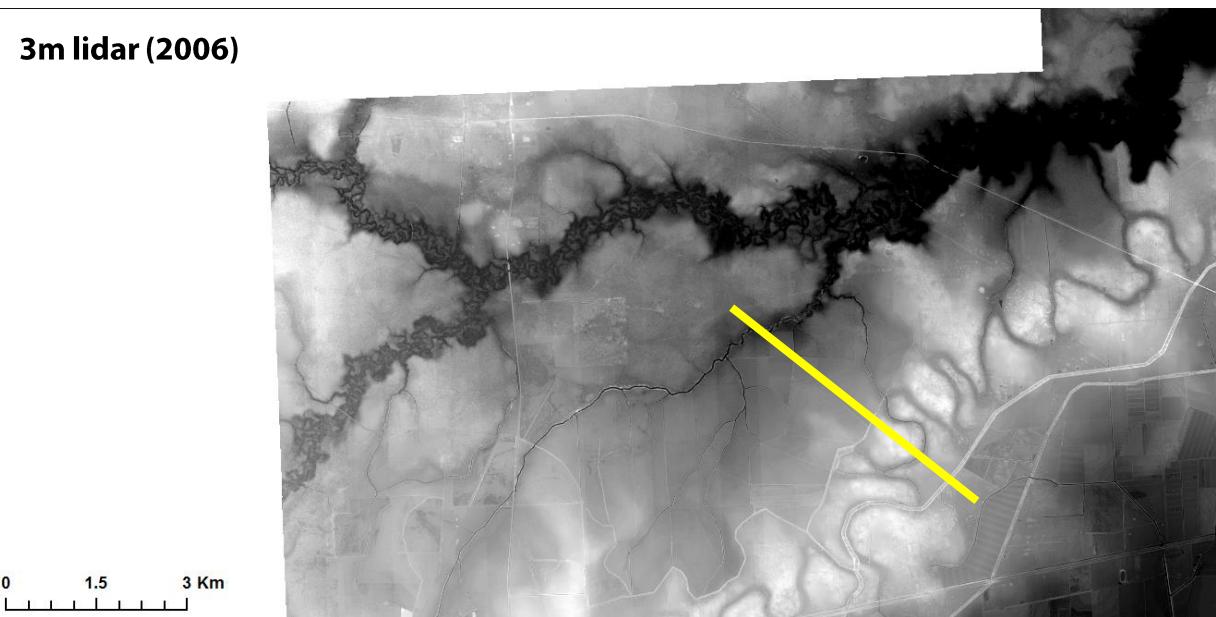


High-resolution topography necessary to resolve networks

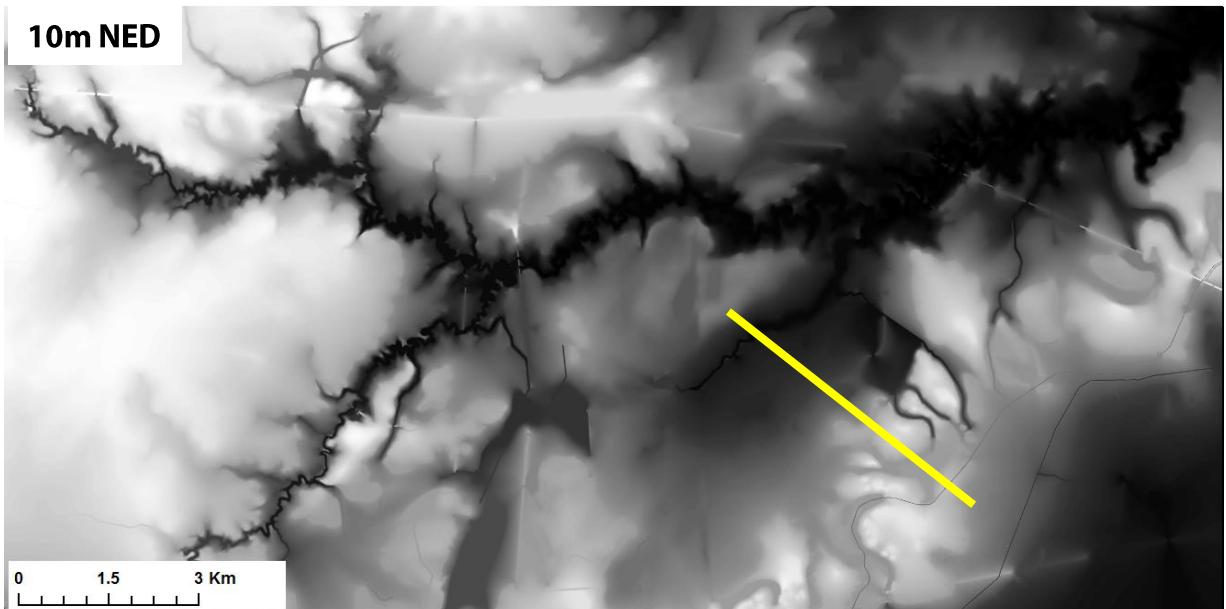
30m SRTM



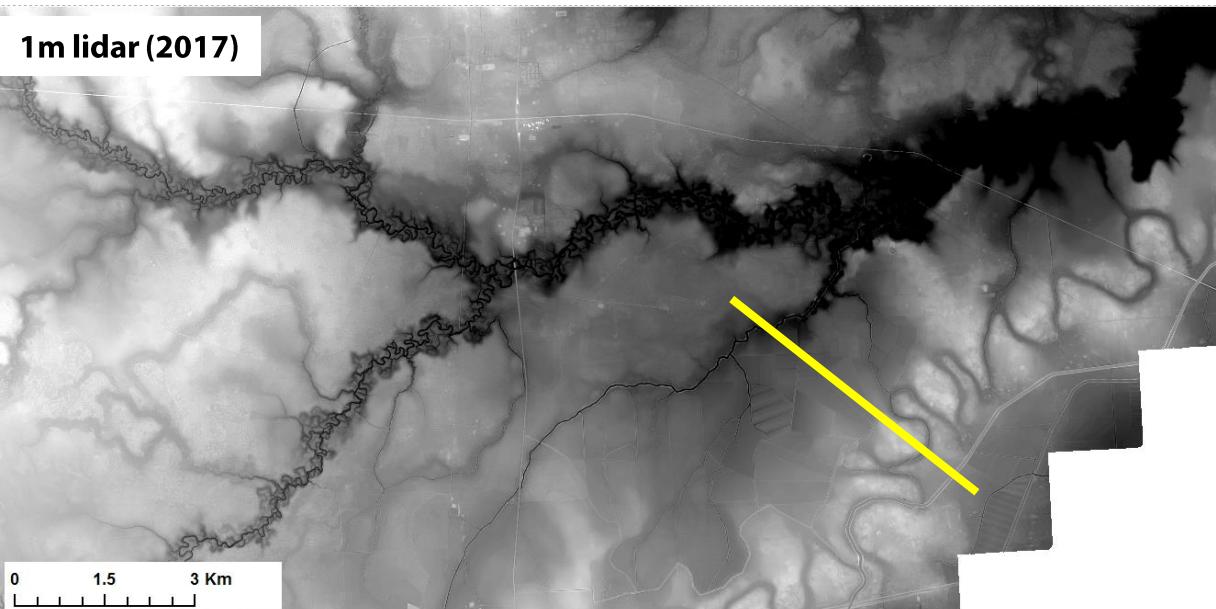
3m lidar (2006)



10m NED

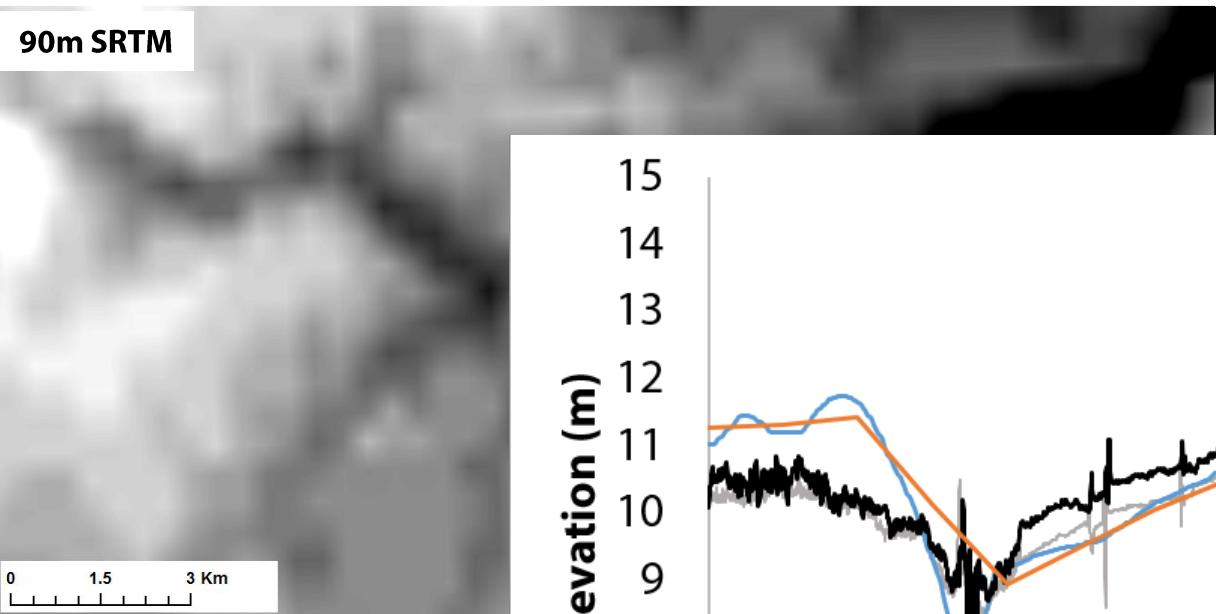


1m lidar (2017)

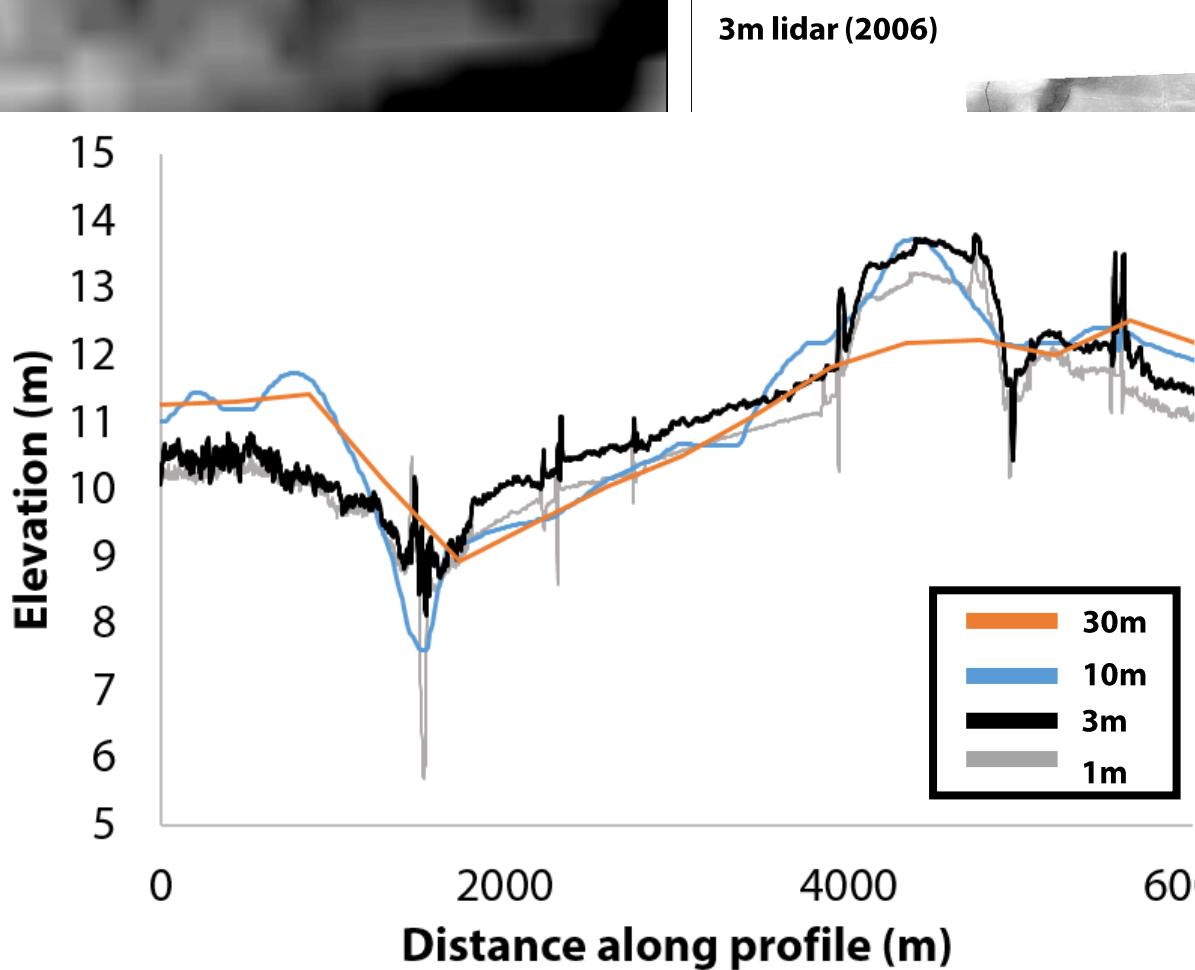
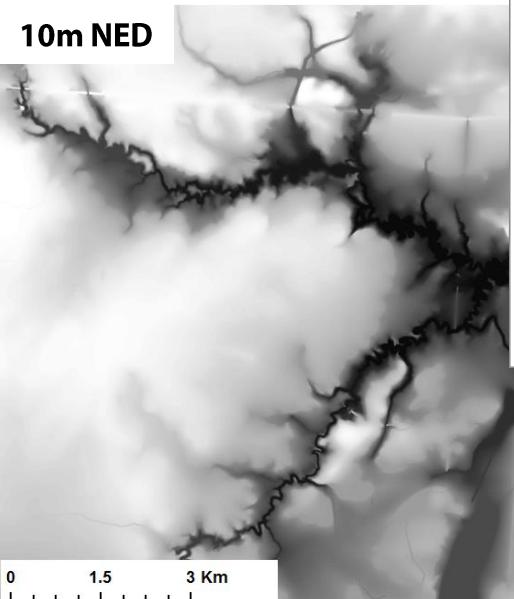


High-resolution topography necessary to resolve networks

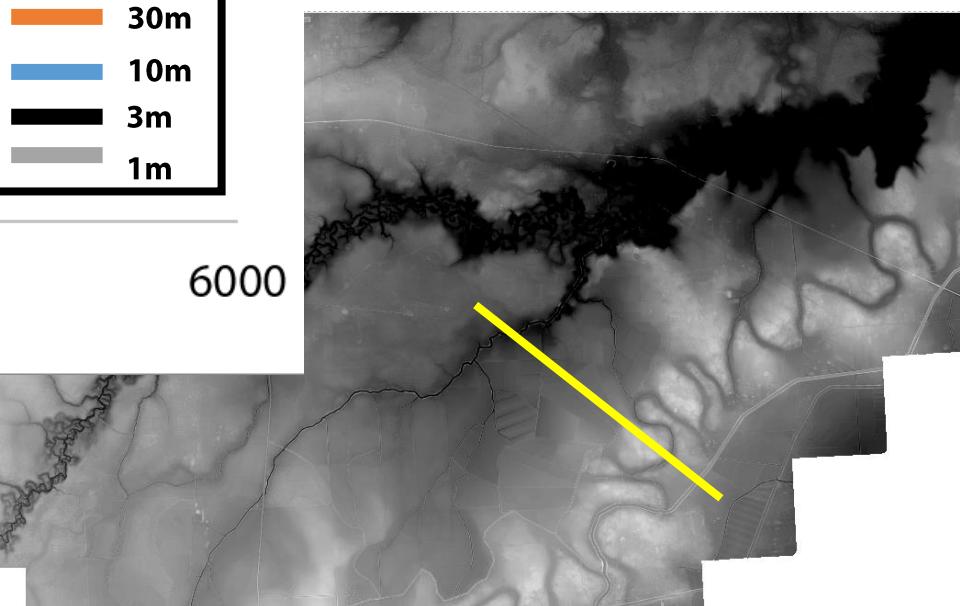
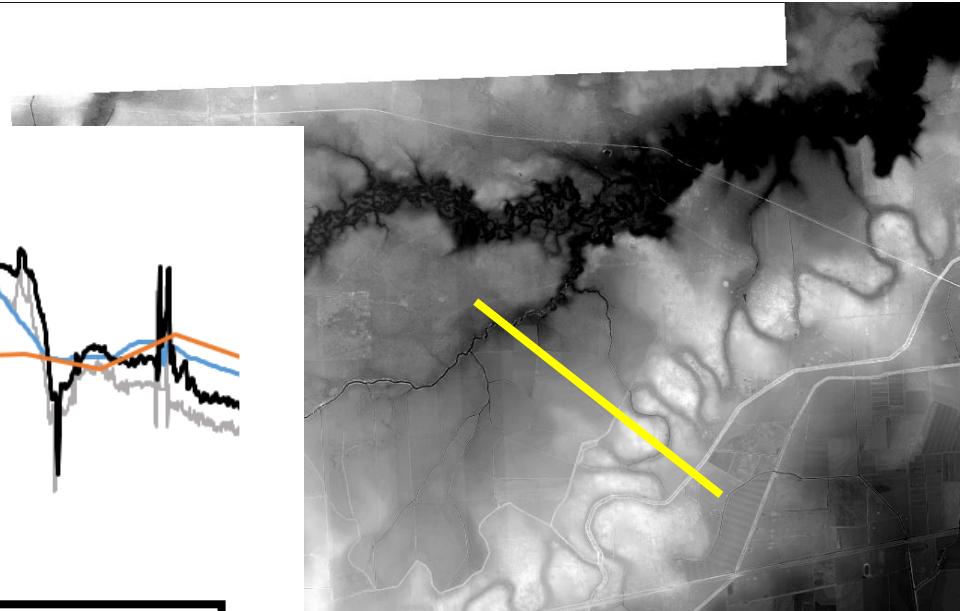
90m SRTM



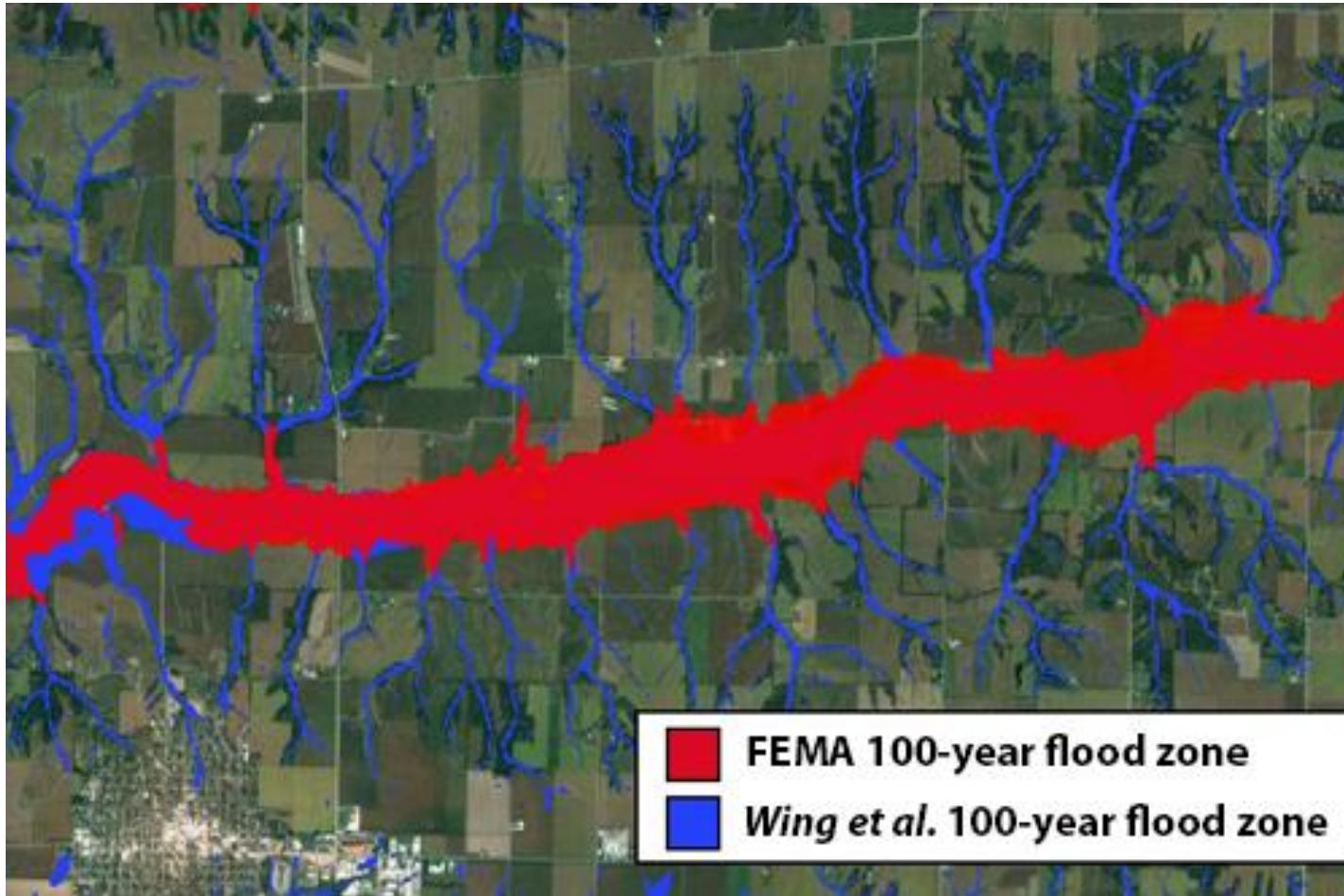
10m NED



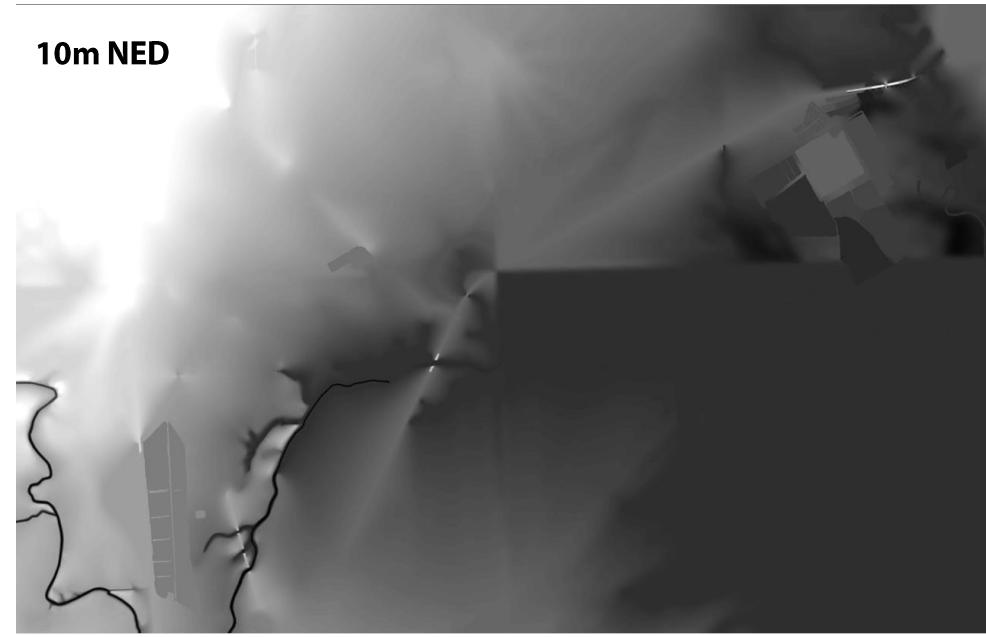
3m lidar (2006)



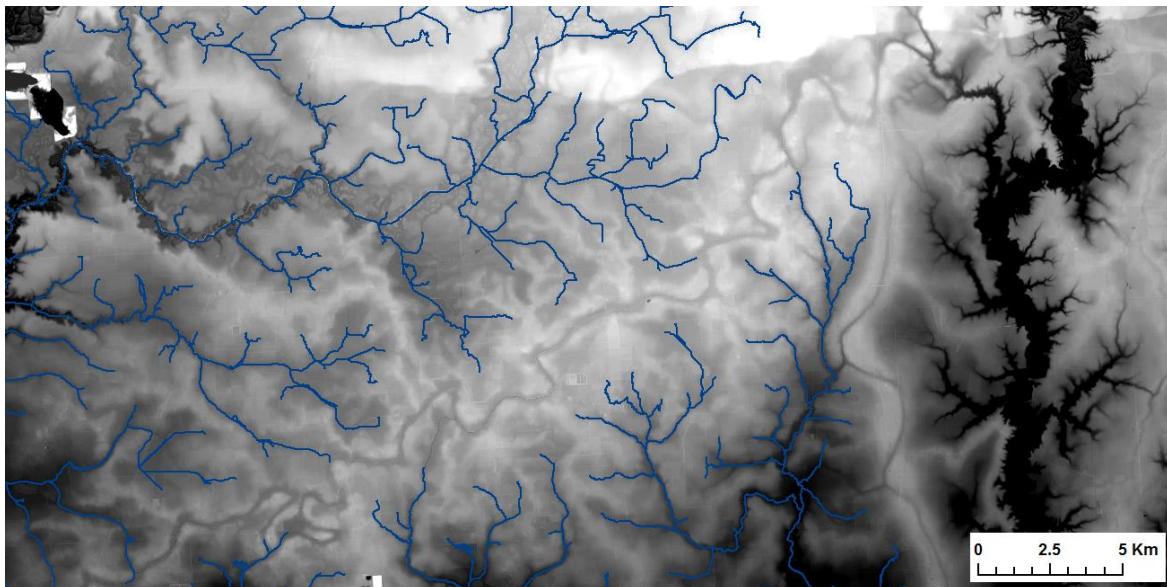
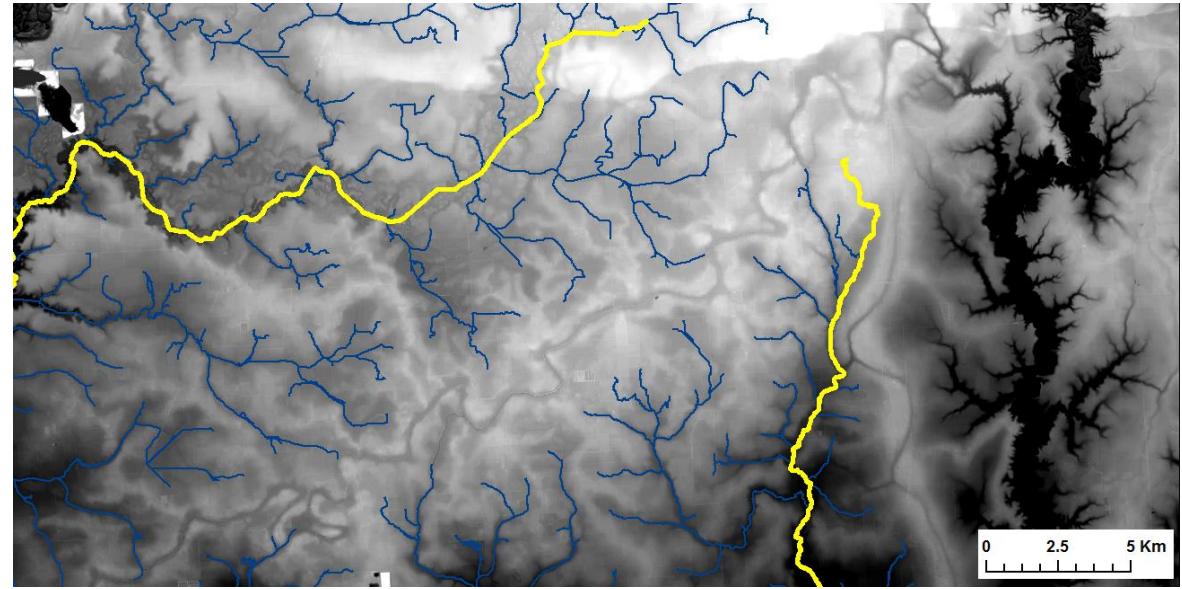
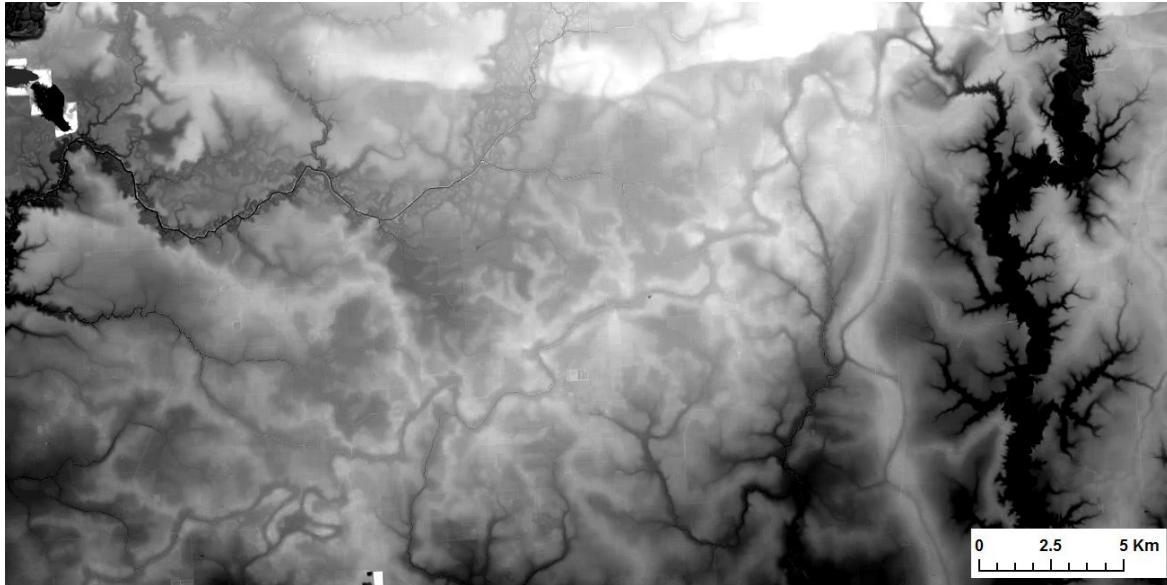
Leads to better flood mapping



- Better characterization of landscape leads to better recognition of flood risk
- Current mapping potentially underestimates risk for ~30 million people

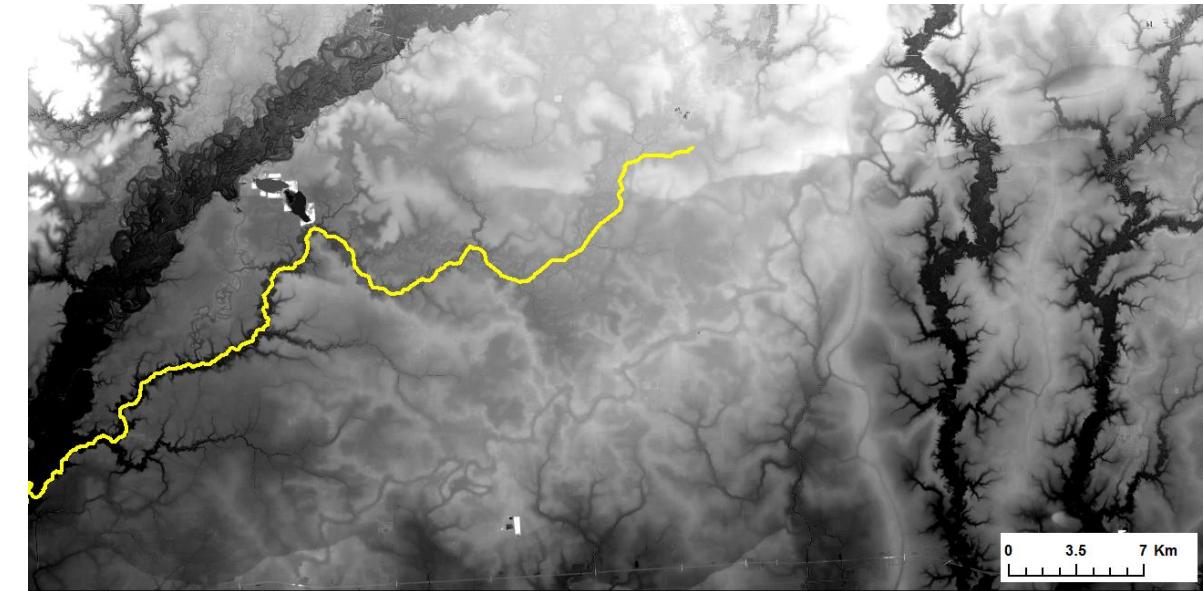
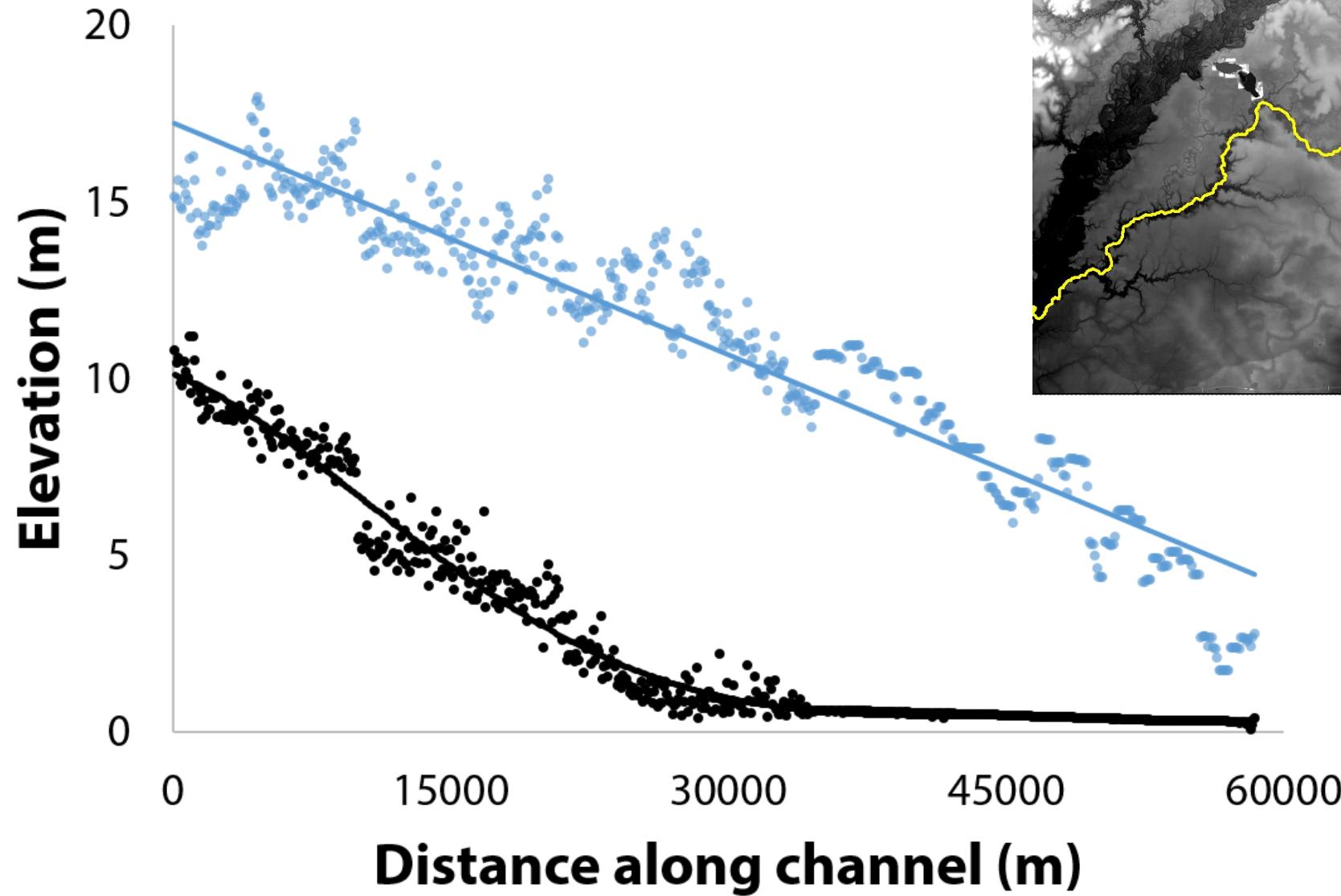


Typical channel network extraction and analysis workflow



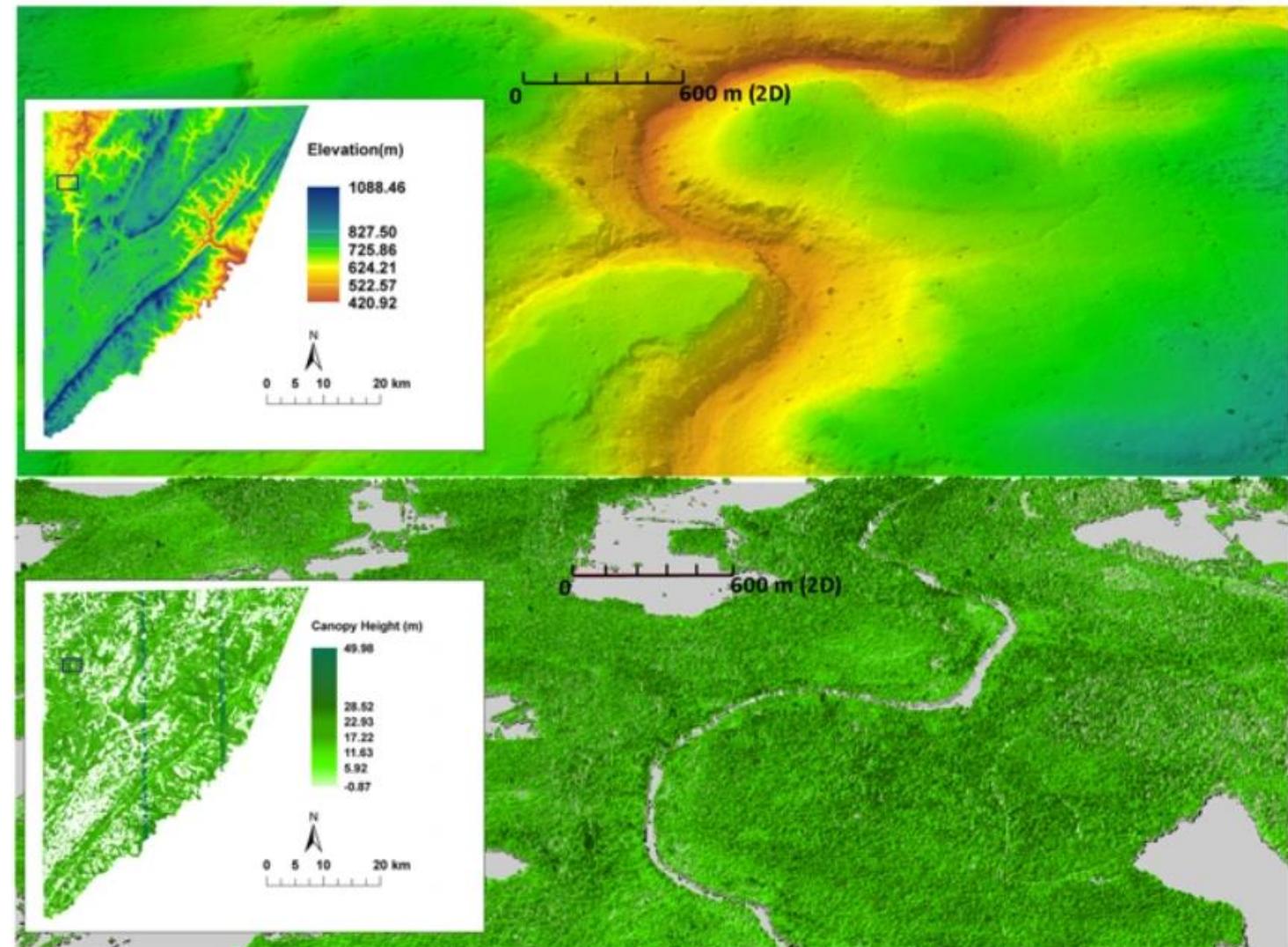
- 1) Create hydrologically corrected DEM
- 2) Steepest descent flow routing using minimum contributing area = 0.5km^2
- 3) Extract trunk stream profiles and local relief
- 4) Examine channel heads and divides to understand bounding morphology
- 5) Extract network metrics (length, area)

Stream profile and bounding ridge elevations



Vegetation and canopy structure

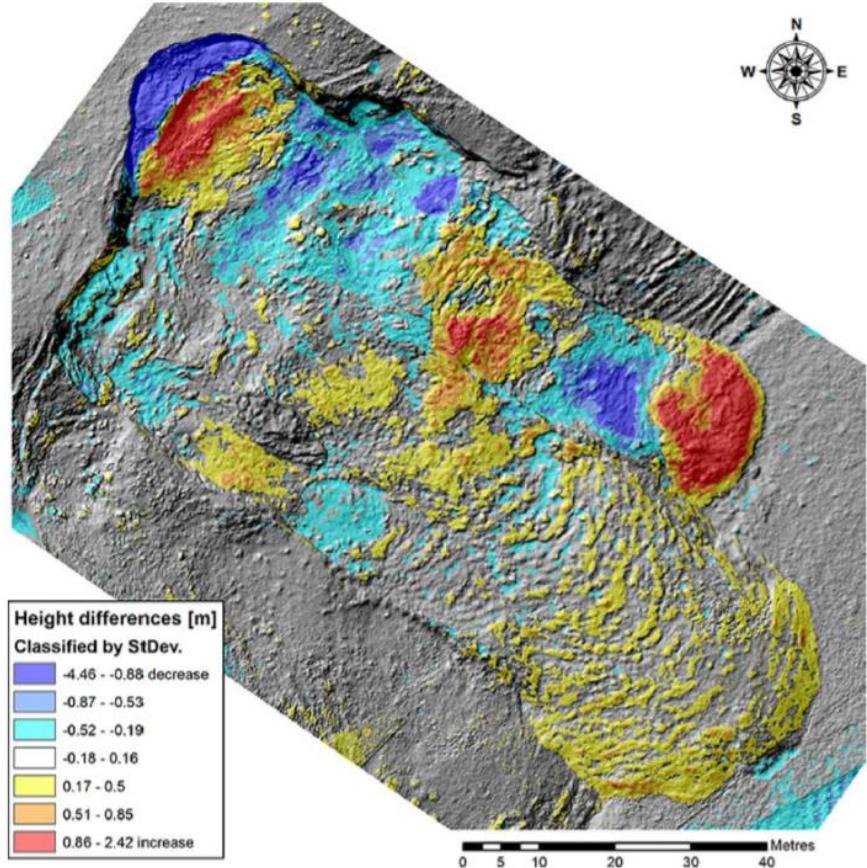
- HRT allows for characterization of vegetation structure, type, and density over topography
- Can relate ecology to underlying landscape structure
- Potential uses for more accurate parameterization of land cover and surface attributes in numerical modeling



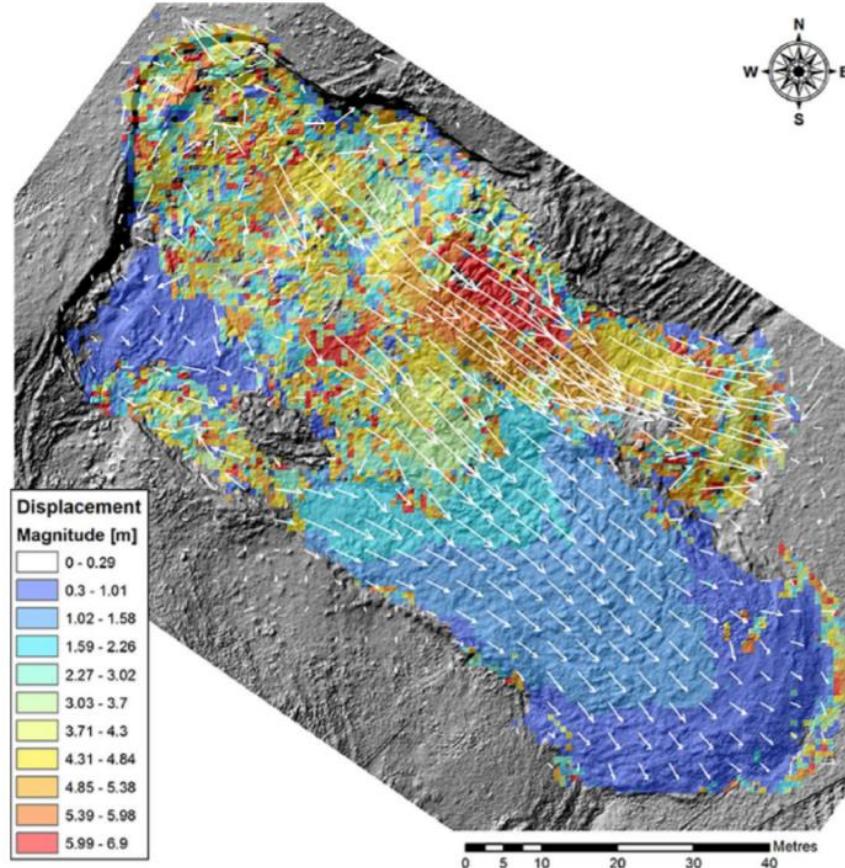
Anu Swatantran et al., 2016. Rapid, High-Resolution Forest Structure and Terrain Mapping over Large Areas using Single Photon Lidar. *Scientific Reports*

Rapid surficial change detection and geohazards

Left. DEM of Difference (DoD) from subtracting elevation grids



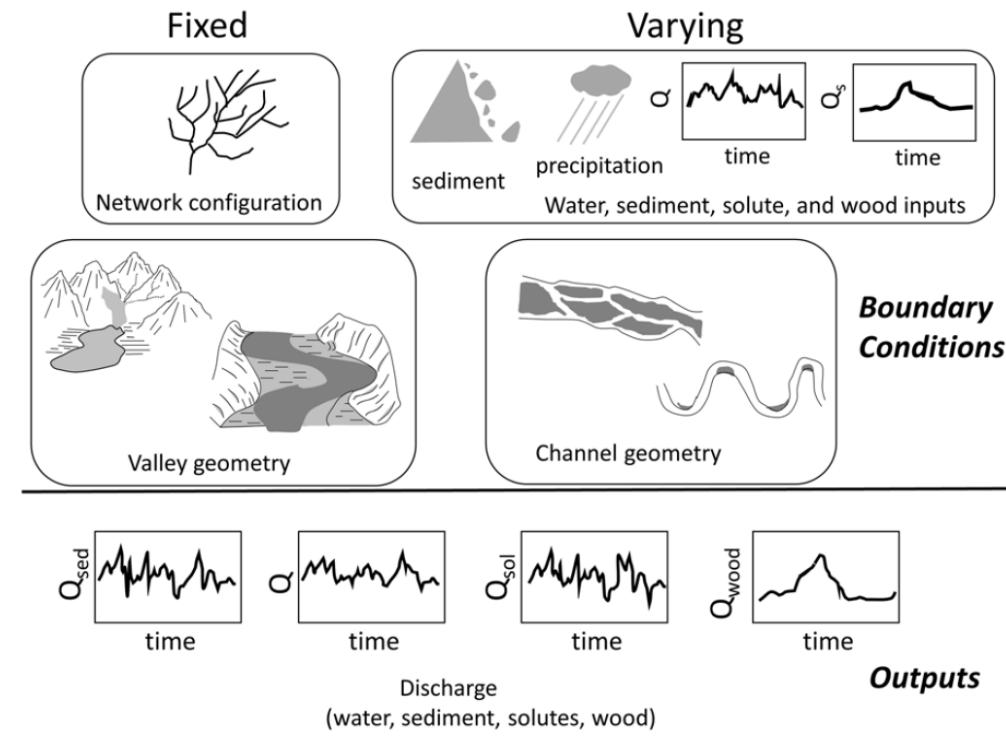
Right. Horizontal displacements from sub-pixel image correlation



Lucieer et al. (2013). Mapping landslide displacements using Structure from Motion (SfM) and image correlation of multi-temporal UAV photography, Progress in Physical Geography

1C. Assessing landscape connectivity

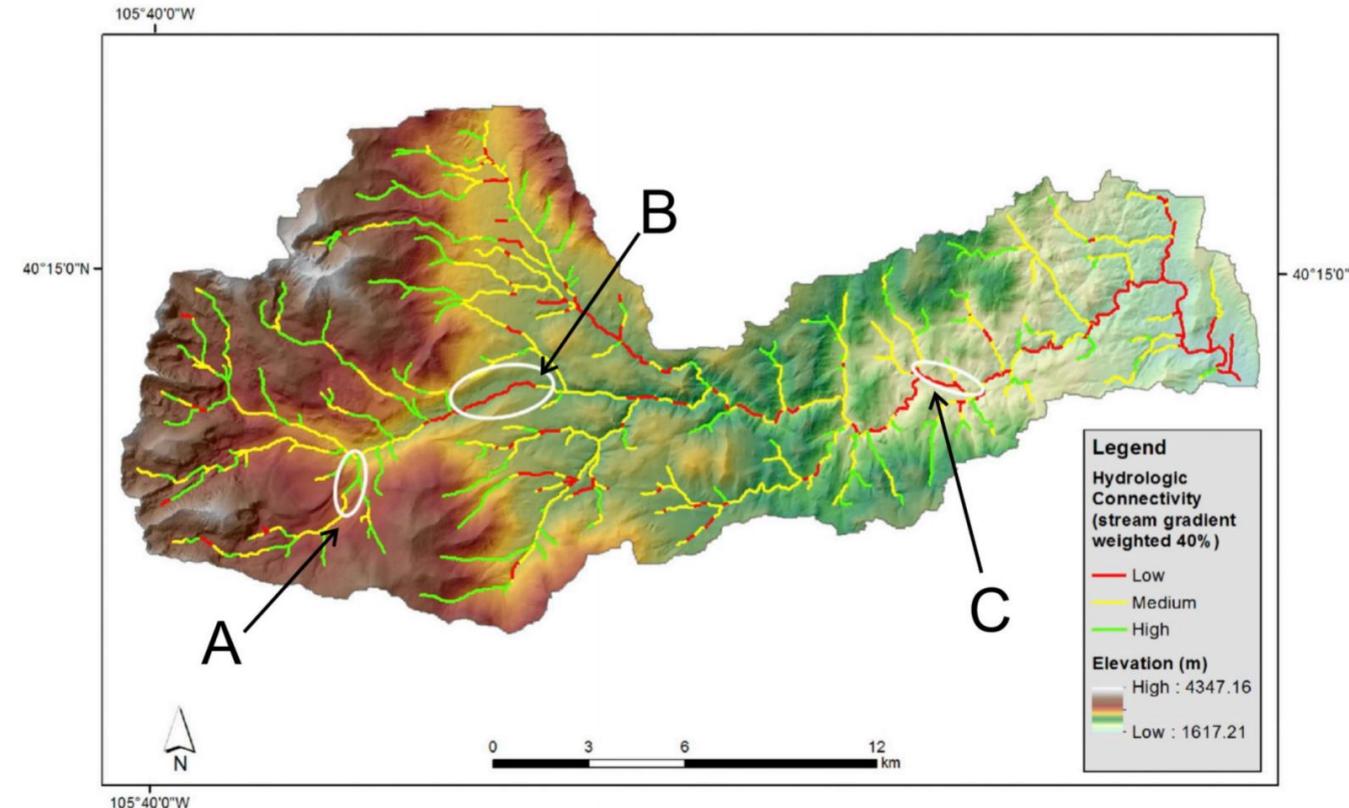
- Focus on hydrologic connectivity
- How does it control processes?
 - Hydrologic connectivity is the framework that sediment, solutes, and biota can move through and influence landscape function and development
- How do different domains interact and on what spatio/temporal scales?
 - E.g. how do rivers couple to their floodplains?
 - How do specific ecological habitats maintain extent, grow, or decline?
 - Patterns and timescales of flux



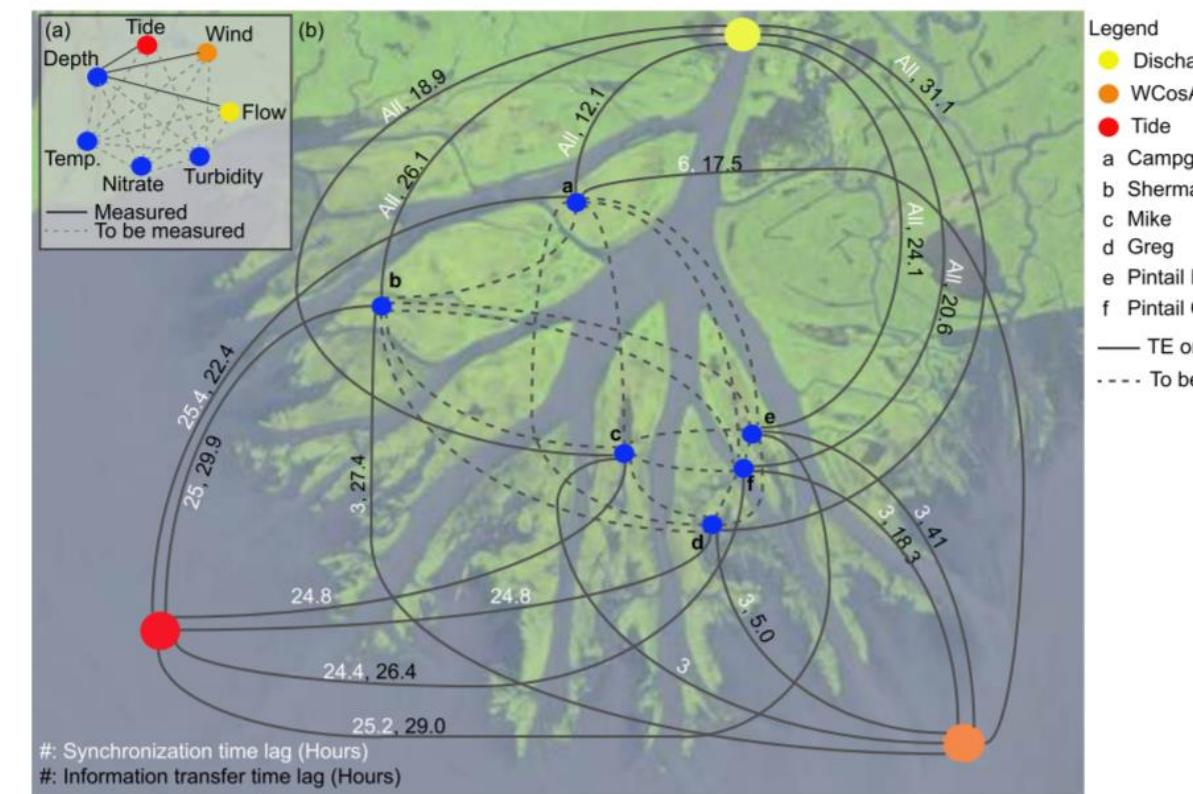
Ellen Wohl, 2018

What influences connectivity? (Lots)

Stream gradient and disruption in mountain catchments



Process coupling in deltaic environments

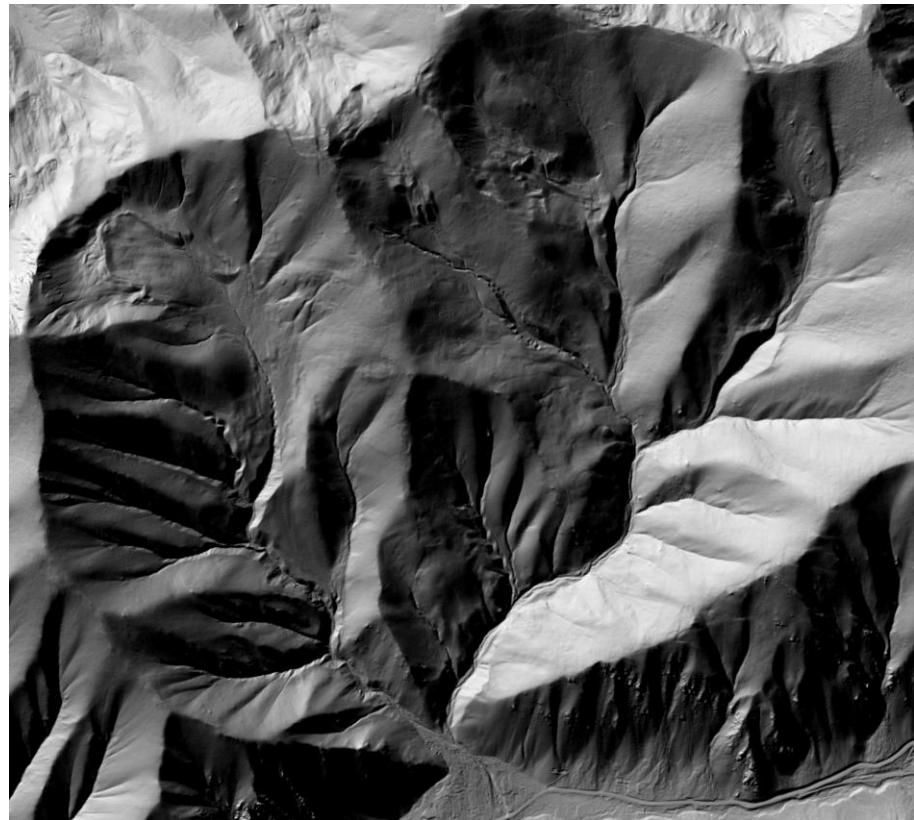


Ellen Wohl, 2017

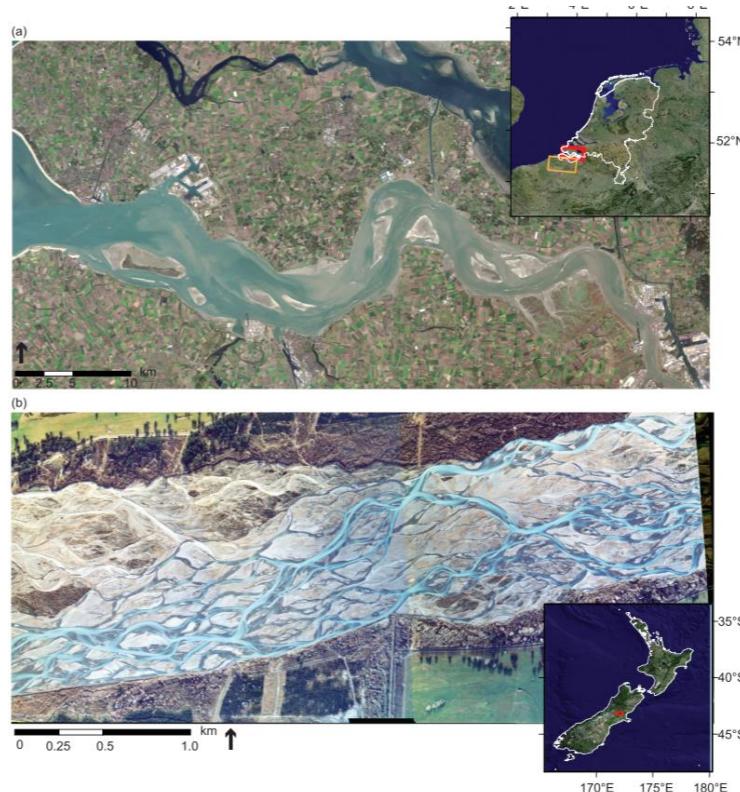
Alicia Sendrowski and Paola Passalacqua, 2017

Focus on network structure across domains

Dendritic upstream catchments

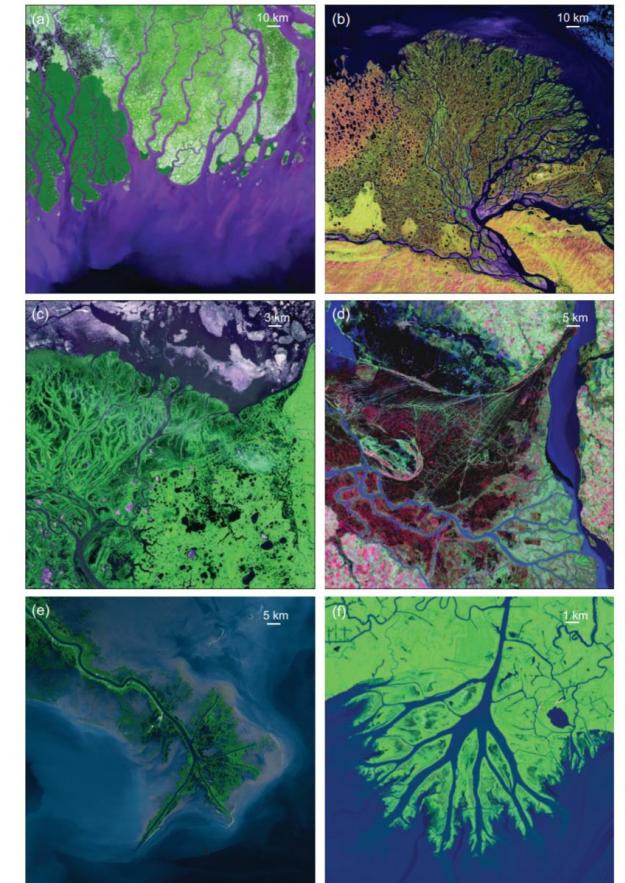


Meandering/braided streams



Hiatt et al., 2020

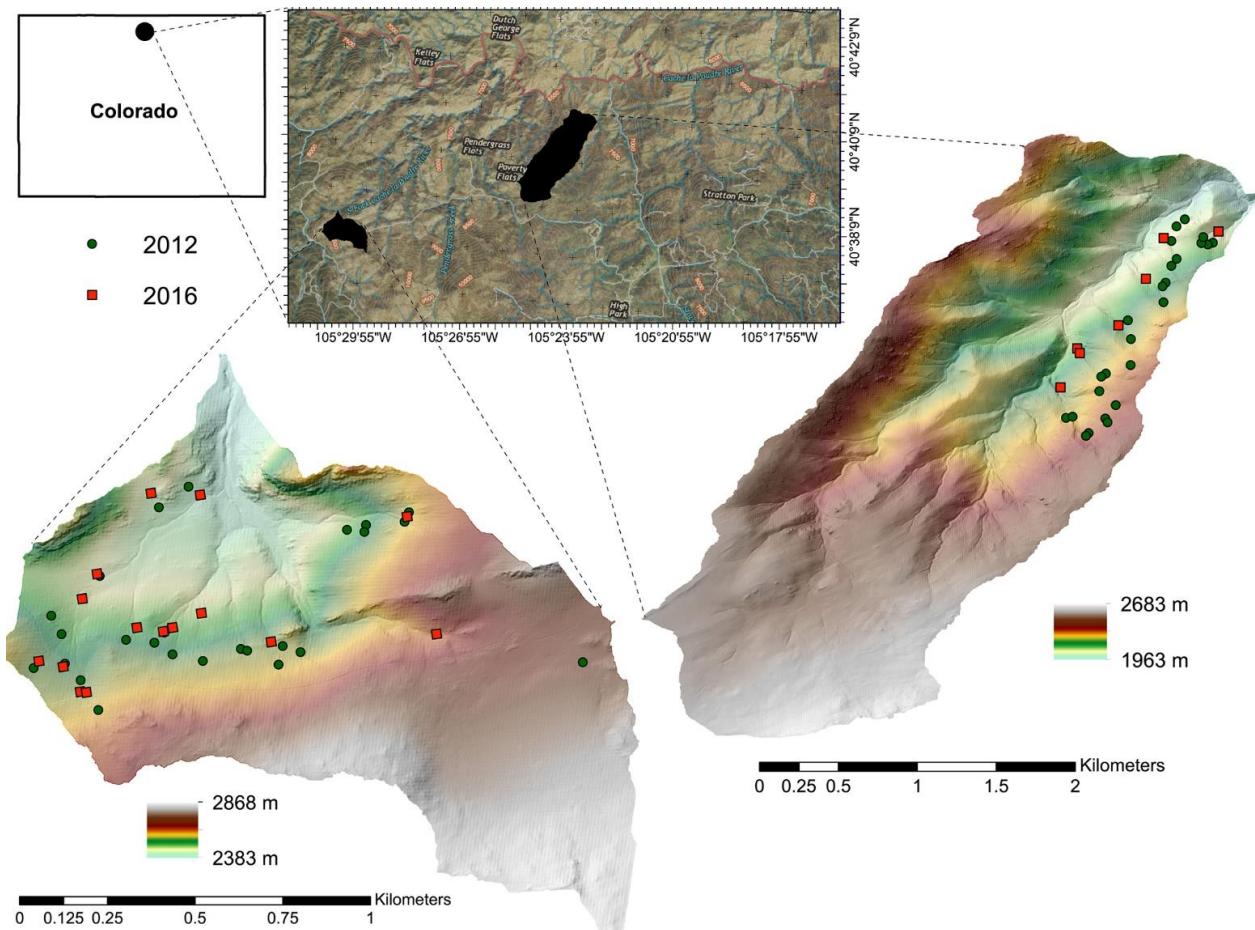
Delta distributaries



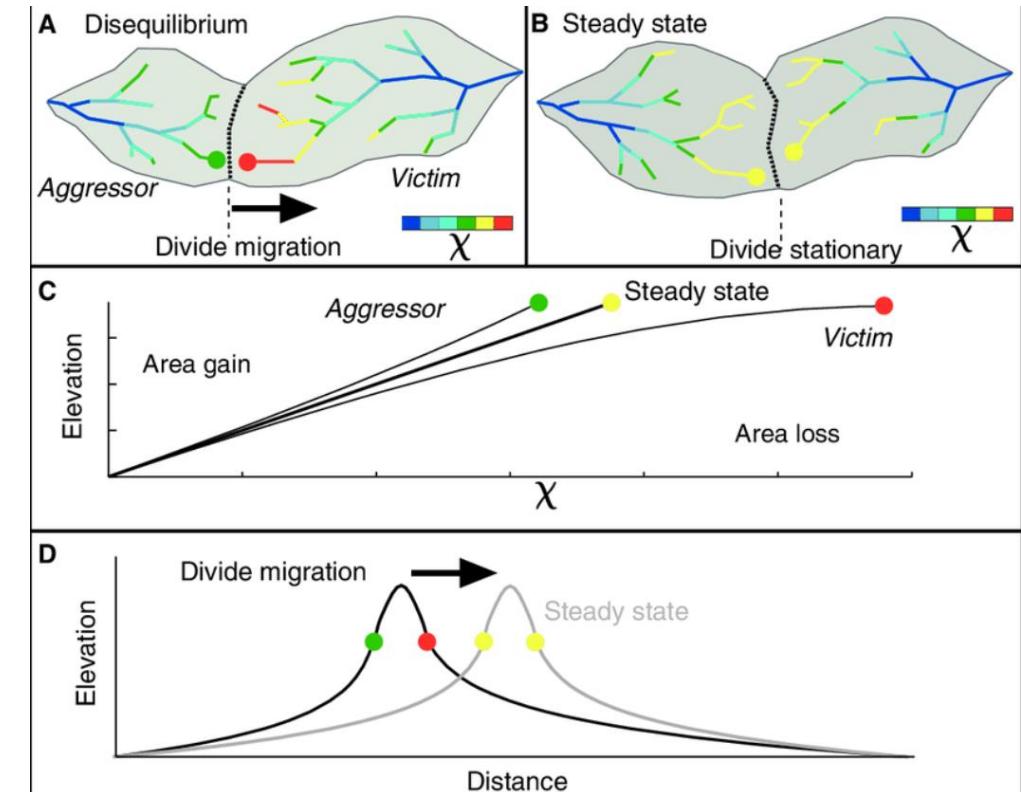
Paola Passalacqua, 2017

Networks are dynamic in space and time

Channel head number and position post-wildfire



Geologic-scale divide migration and capture



Channel-floodplain connectivity

Shazzad!
I'd love one of your figures here

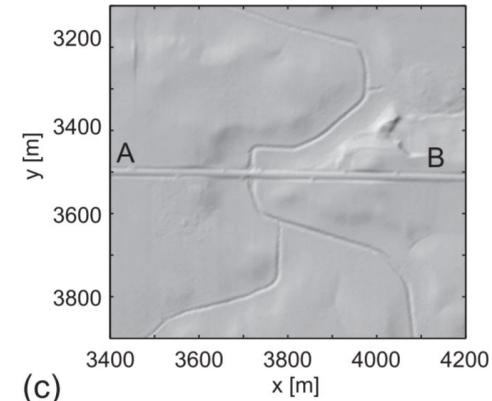
Analyzing channel network structure

Classic channel network delineation schemes can misplace flowlines based on pit filling and hydro-flattening

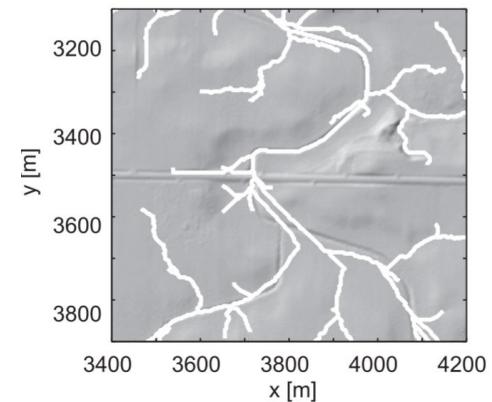


Man-made objects can hinder flow accumulation routing

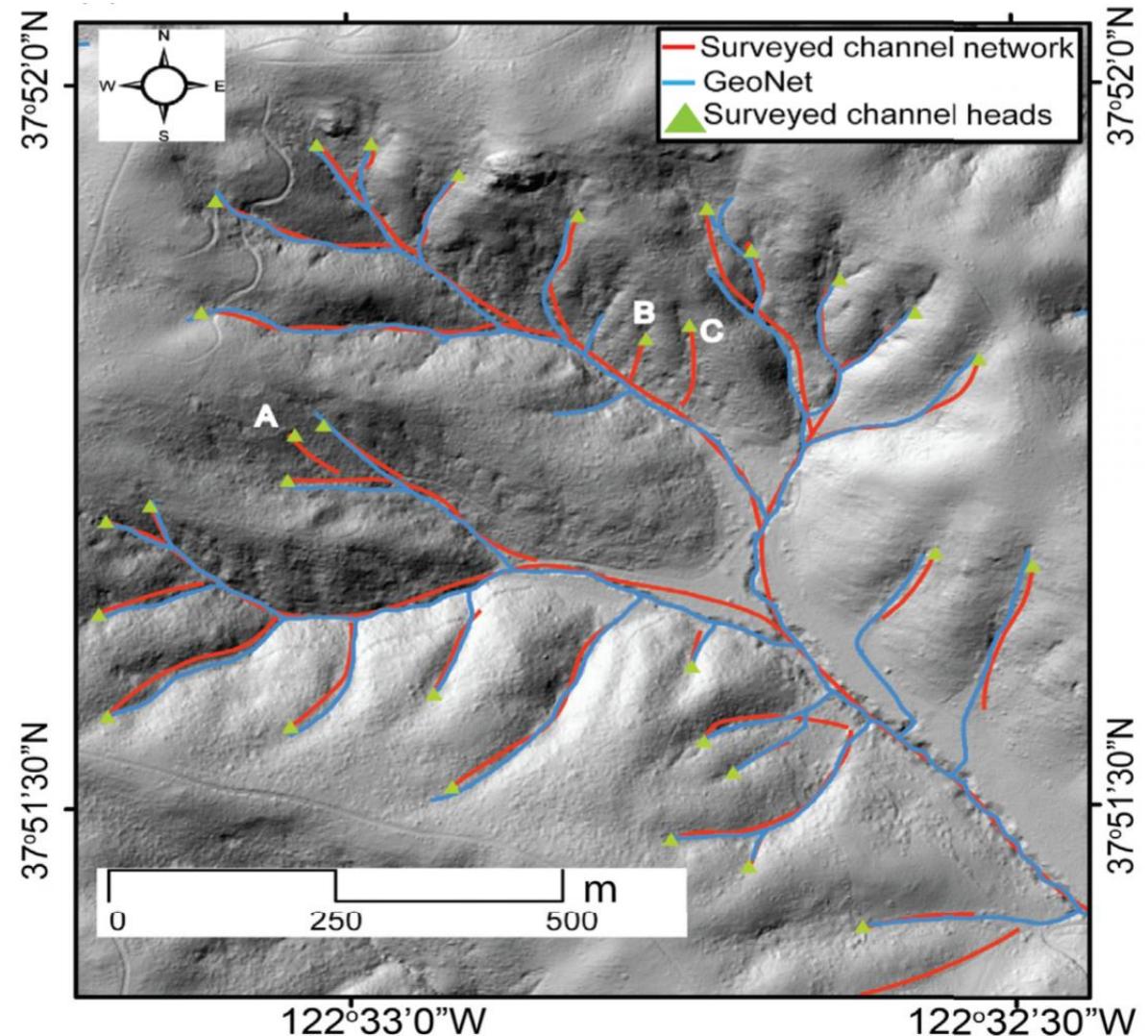
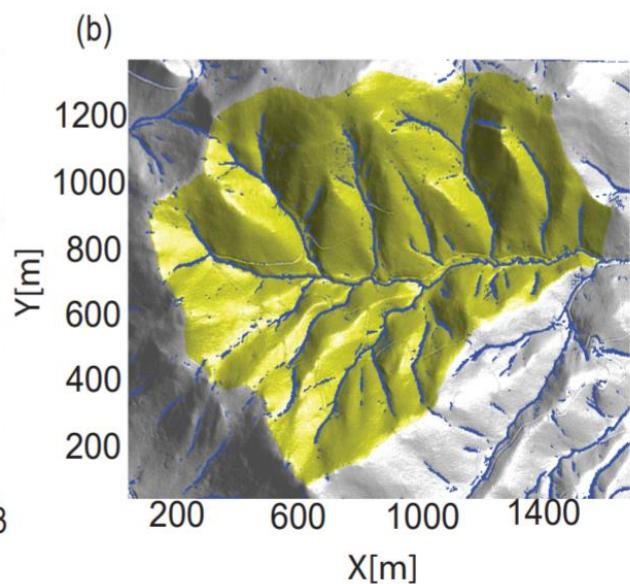
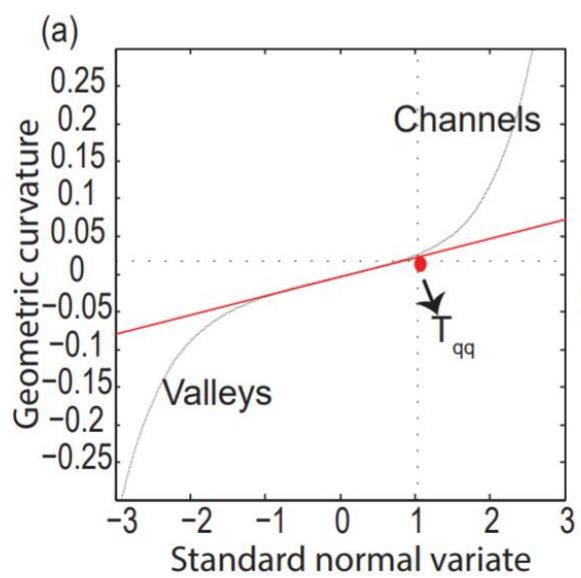
(a)



(c)



Curvature-based approach: Geonet



**NEED TO INSERT SKELETONS FROM MOUNTAINS
AND FLOODPLAINS**

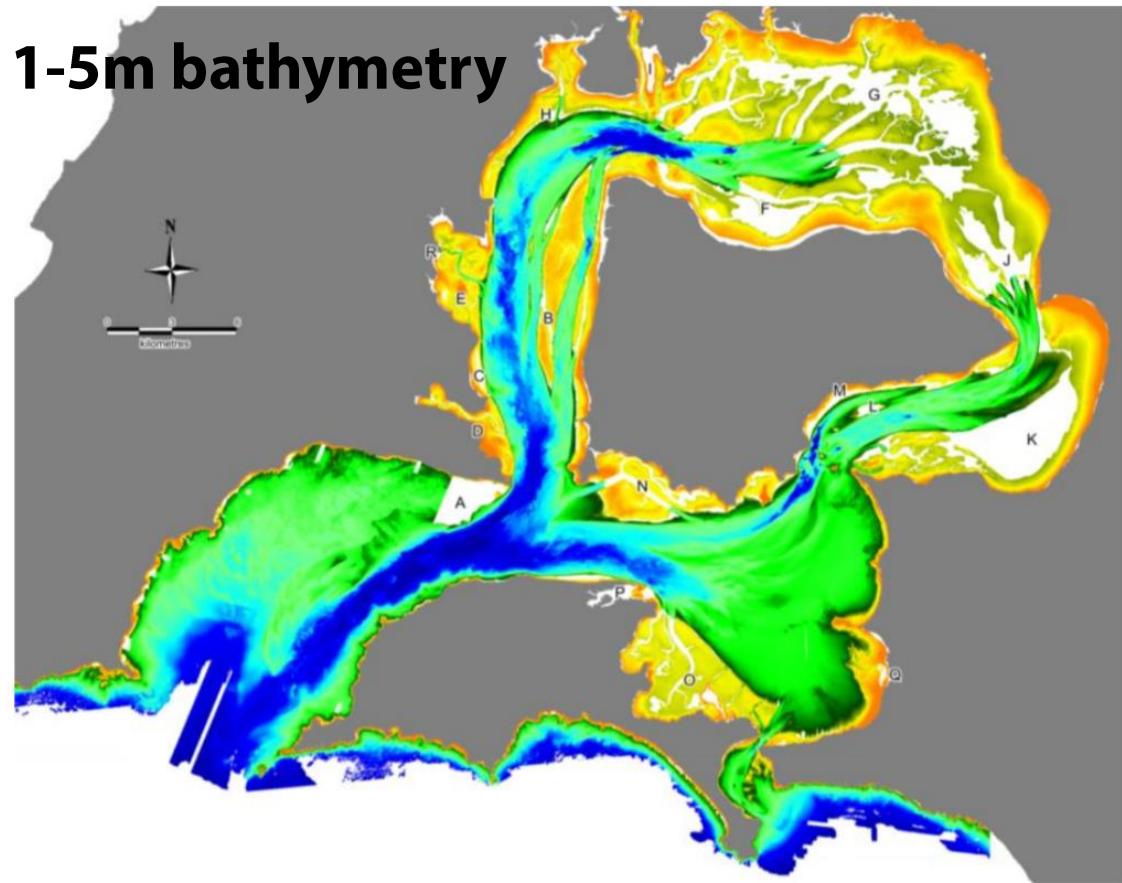
2. Hands-on with HRT

Time to move to the Google co-lab!

- Loading and visualization of raster DEMs with python
- Basic terrain analysis
- Channel network delineation and visualization
- Change detection

3. Utility of HRT in modeling

- Availability of HRT provides opportunity for better integration and validation of numerical modeling and forecasting
- But also challenges!
 - Computation
 - **Just because something is high-resolution, is it useful?**
- Better coordination between “Data” and “modeling” communities is necessary
 - Hence the RCN!



Modeling domain

Table 1. Comparison of the MIKE 21 FM, Delft3D and Delft3D FM model domain resolutions.

Region	MIKE 21 FM	Delft3D	Delft3D FM
Offshore	600 – 1000 m	350 – 1000 m	500 – 1250 m
Western Port	50 – 250 m	50 – 300 m	50 – 300 m
Navigation Channel and Port Area	50 – 100 m	50 – 150 m	50 – 150 m

Symonds et al., 2016. Comparison between MIKE21FM, DELFT3D, and Delft3D Flow models of Western Port Bay, Australia. Coastal Engineering 2016

How is high-resolution data used in modeling?

A) Ideation

Allows for observation of phenomena, processes, or features that lead to formulation of a question tested by modeling

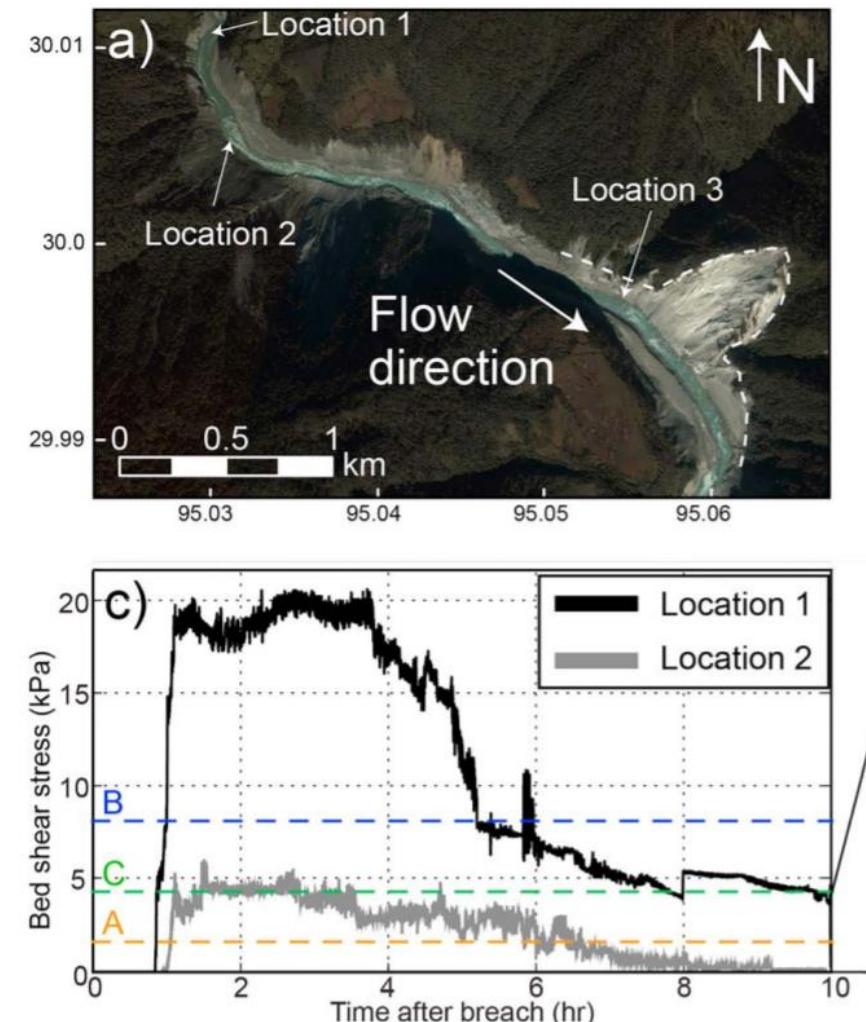
B) Model input

Direct inputs used for running a model
e.g. elevation, surface roughness, vegetation density

Often disconnect between observations spatial scale and what is computationally possible to handle in a model

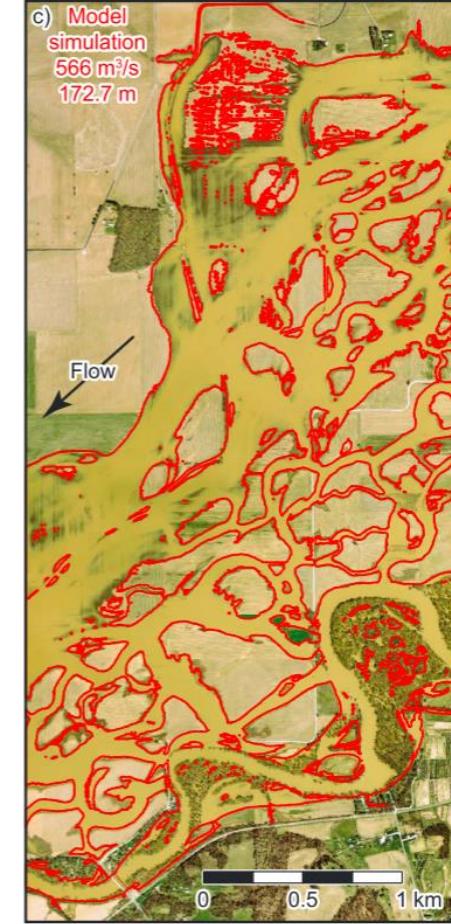
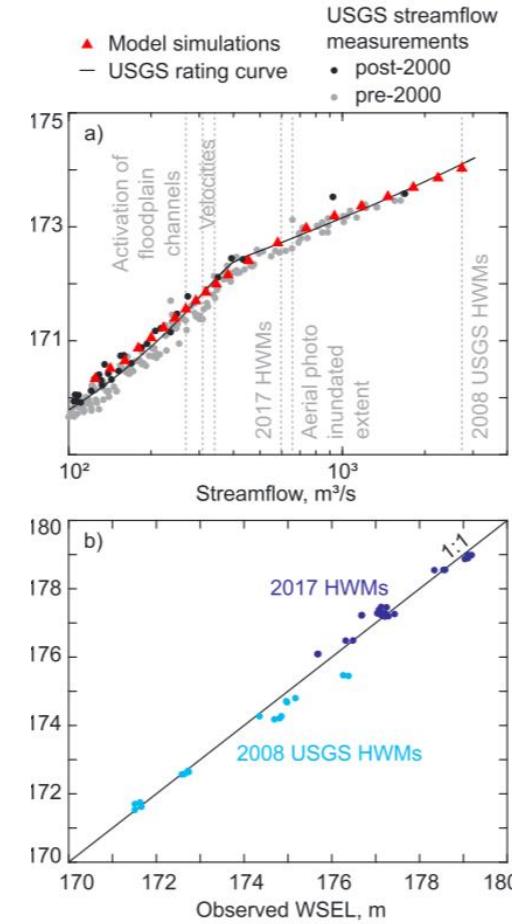
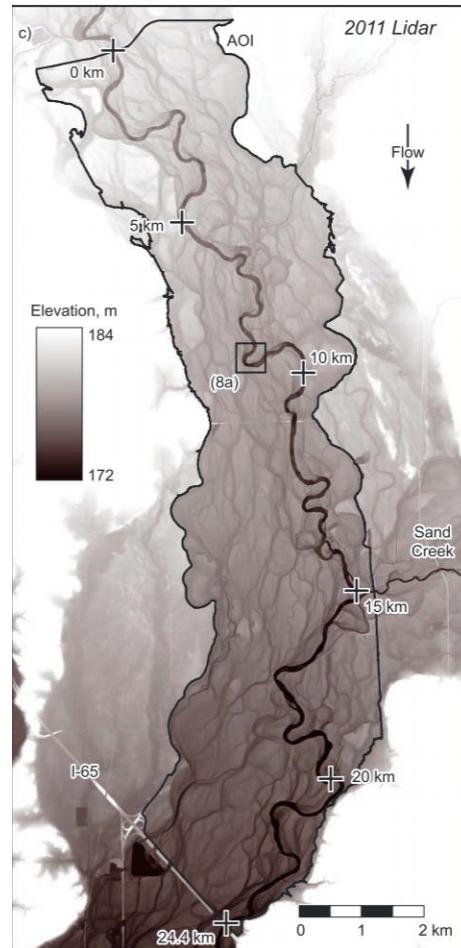
C) Validation

How well did our model do?
e.g. topographic differencing, simulated vs. observed flood inundation



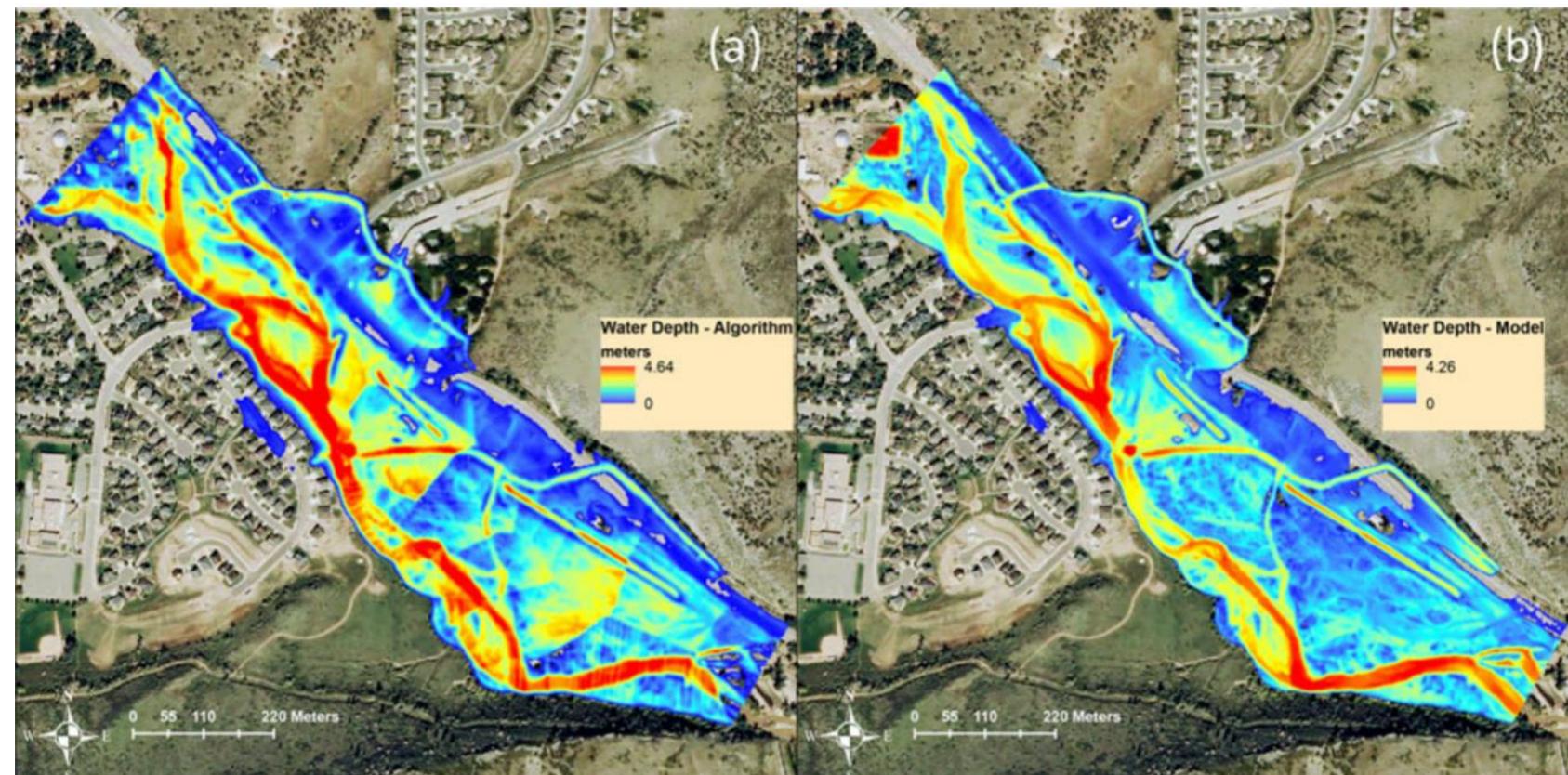
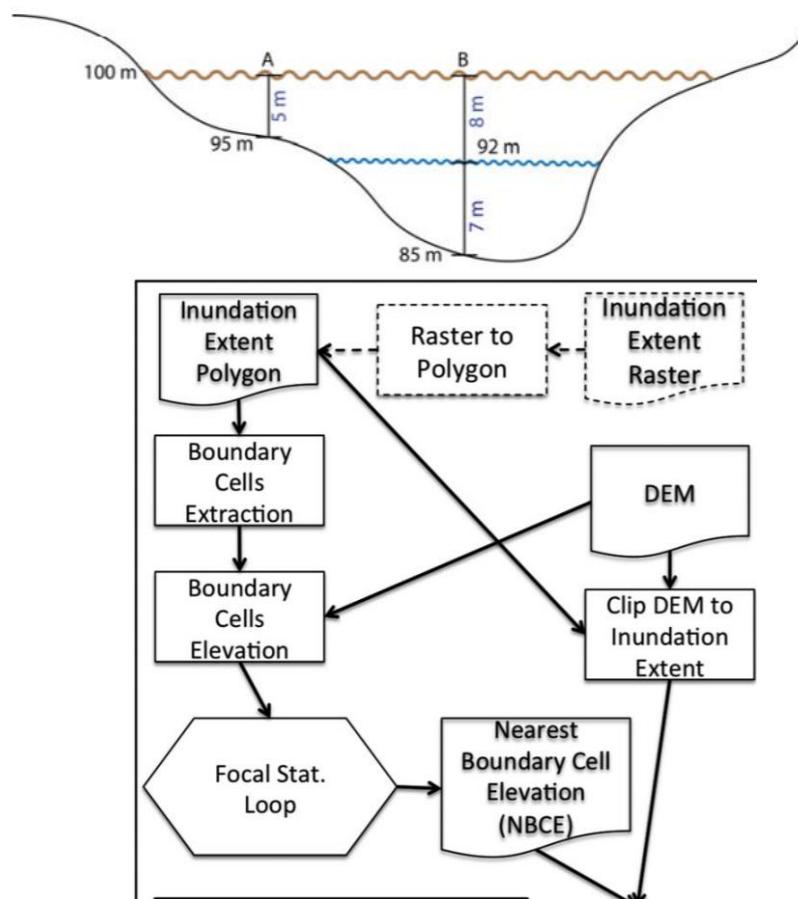
Concept: Presence of small-scale features

Recognition of low-relief floodplain channels using HRT



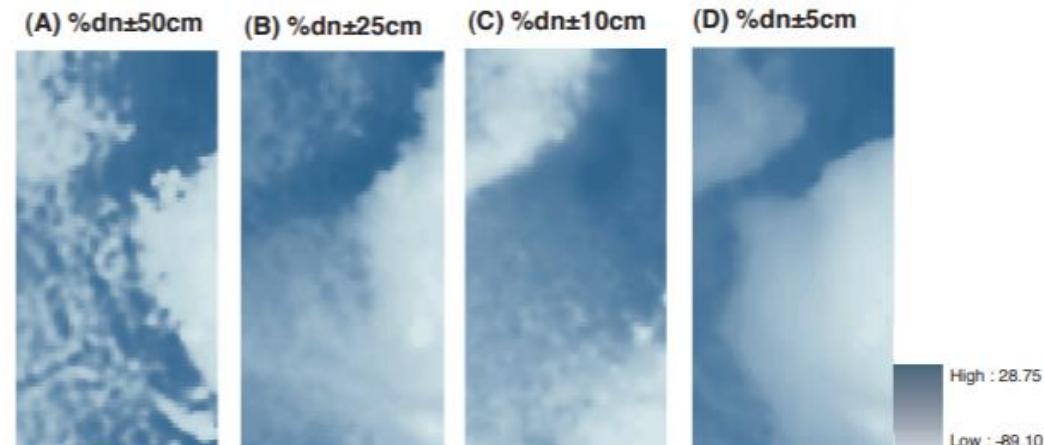
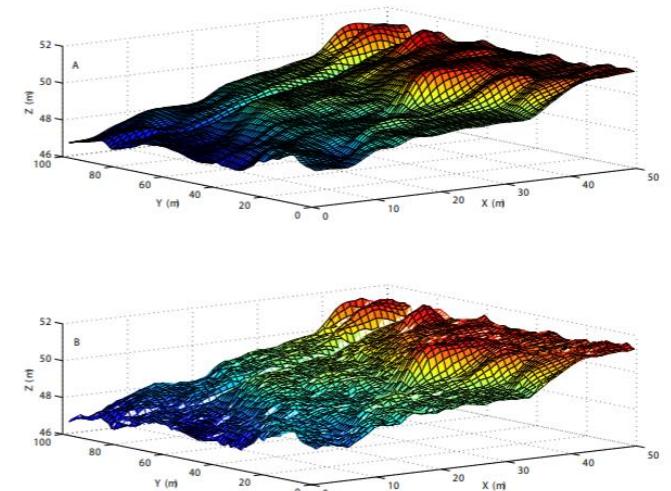
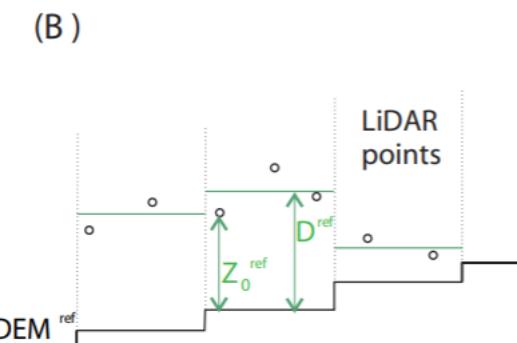
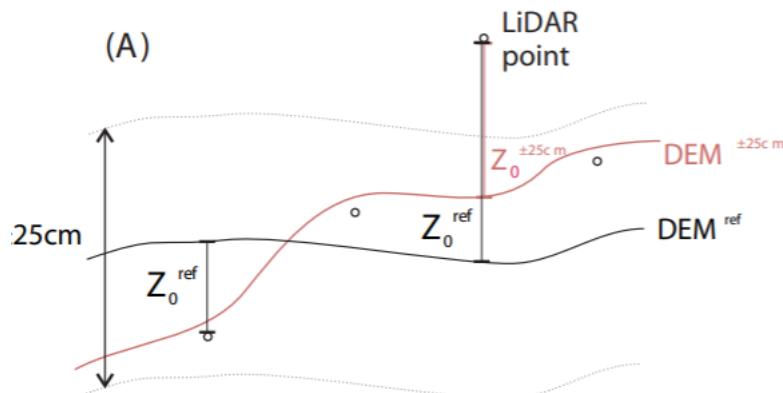
Input: High-resolution boundary conditions

Modeling floodwater depths over 1m stream DEM



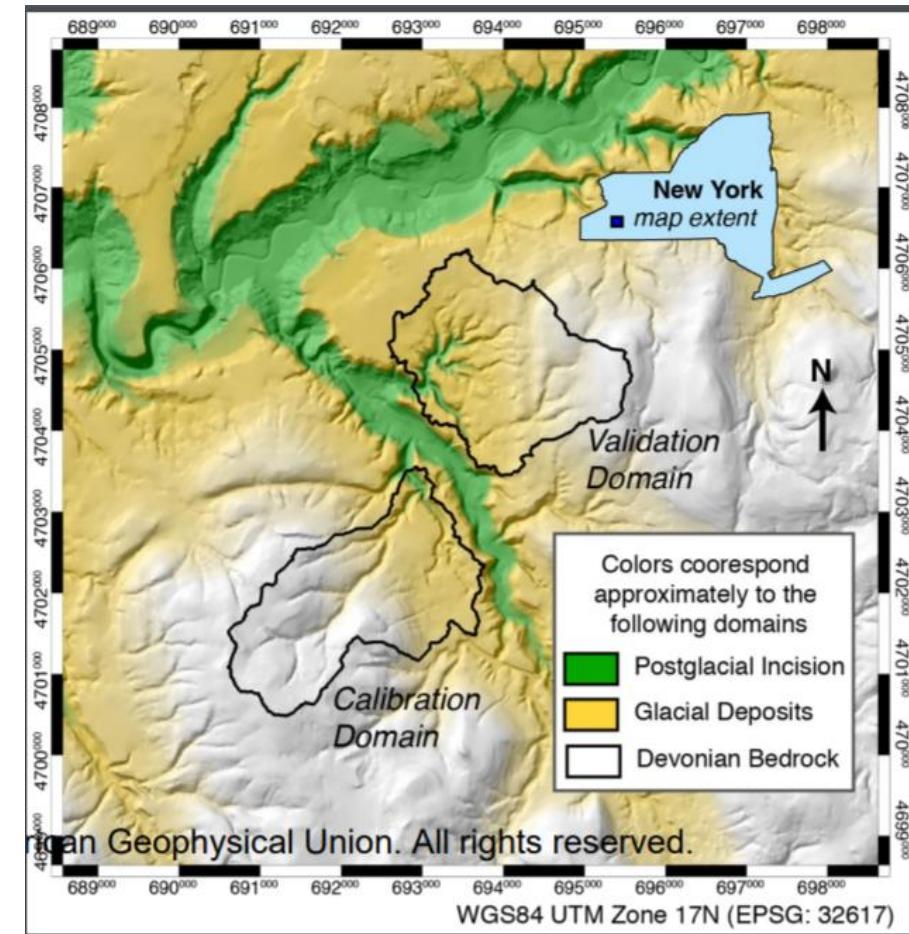
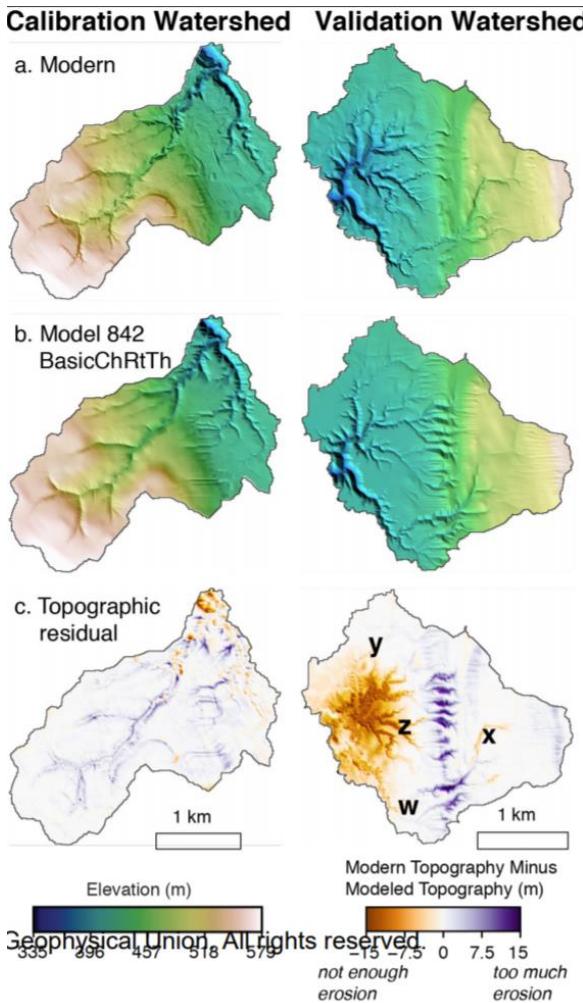
Input: Sub-grid attribute parameterization

Distributed roughness coefficients from lidar point clouds



Validation: Testing modeling domains

Model selection for long-term landscape evolution



Validation: Direct comparison of modeled change

Tropical storm induced barrier island erosion

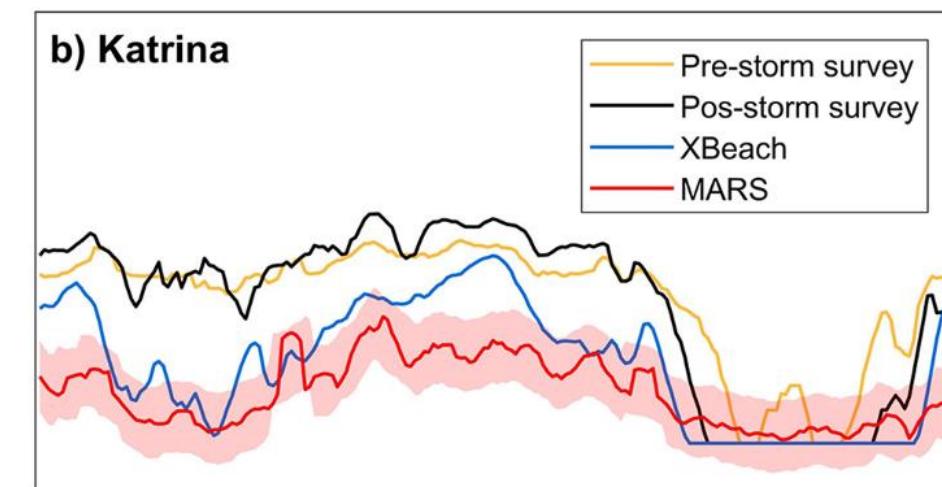
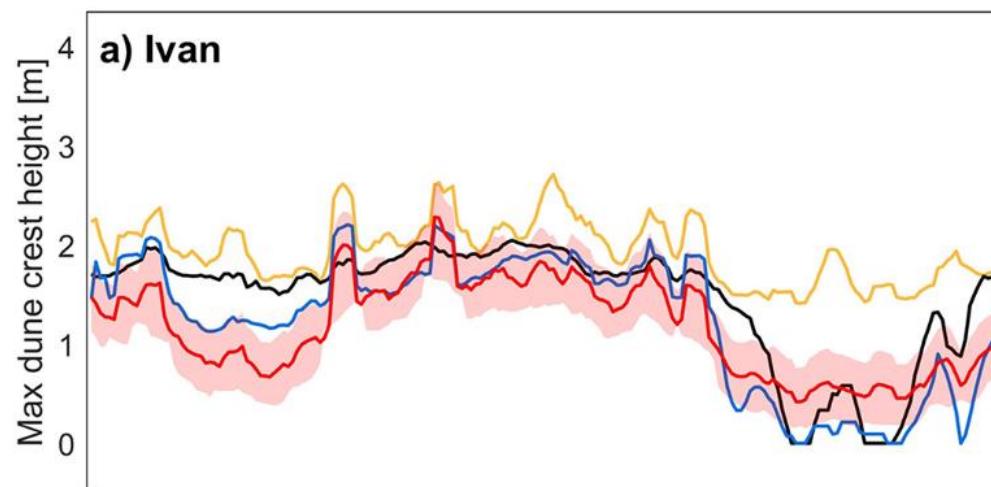
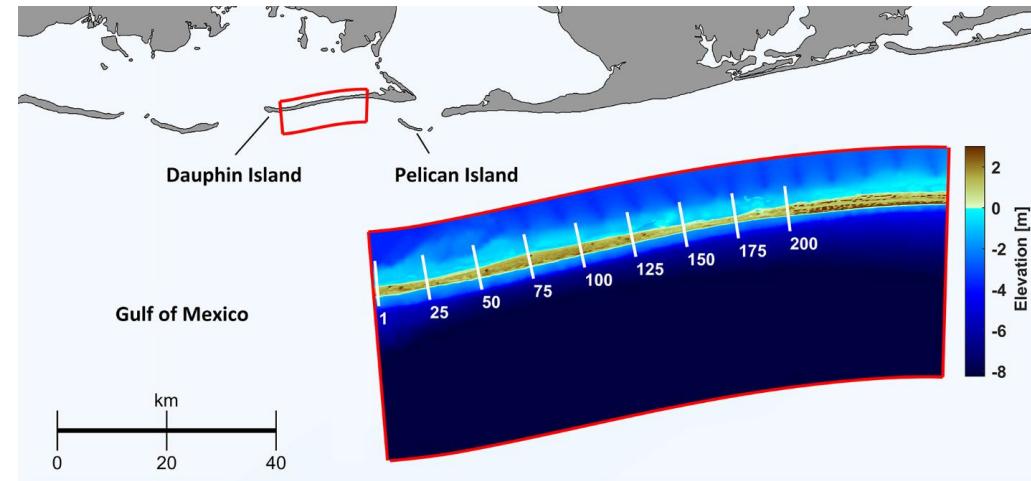
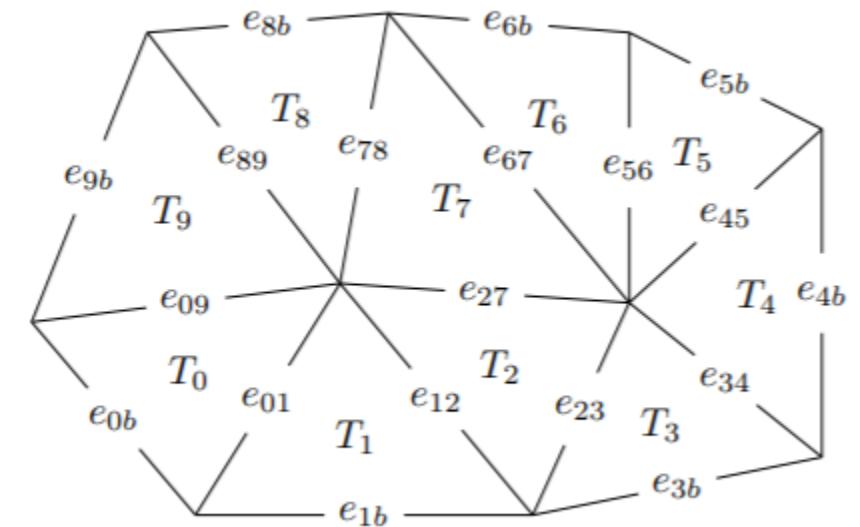


Illustration of modeling workflow: ANUGA!

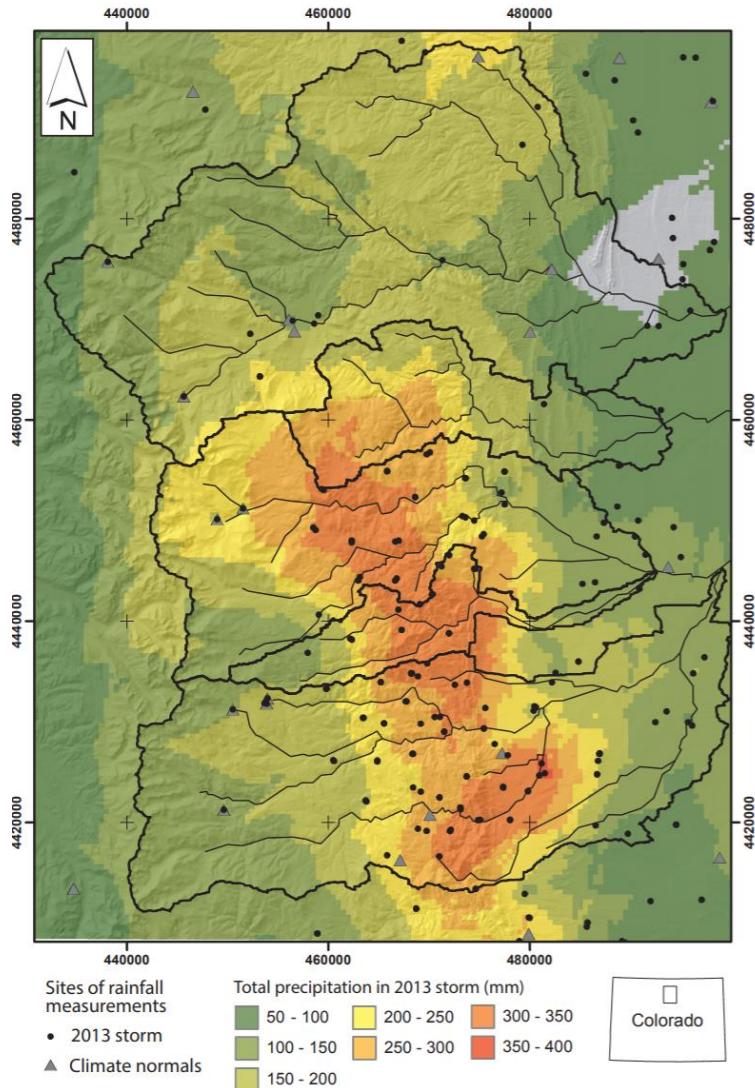
Hydrodynamic modeling code from the **A**ustralian **N**ational **U**niversity and **G**eoscience **A**ustralia

- Open-source solver for depth-integrated, finite-volume 2D shallow water equations
- Originally developed for tsunami inundation modeling, more recently adapted and employed for flood and sediment transport modeling
- Uses an unstructured triangular mesh that allows for multiple resolution and parameter domains within a larger extent

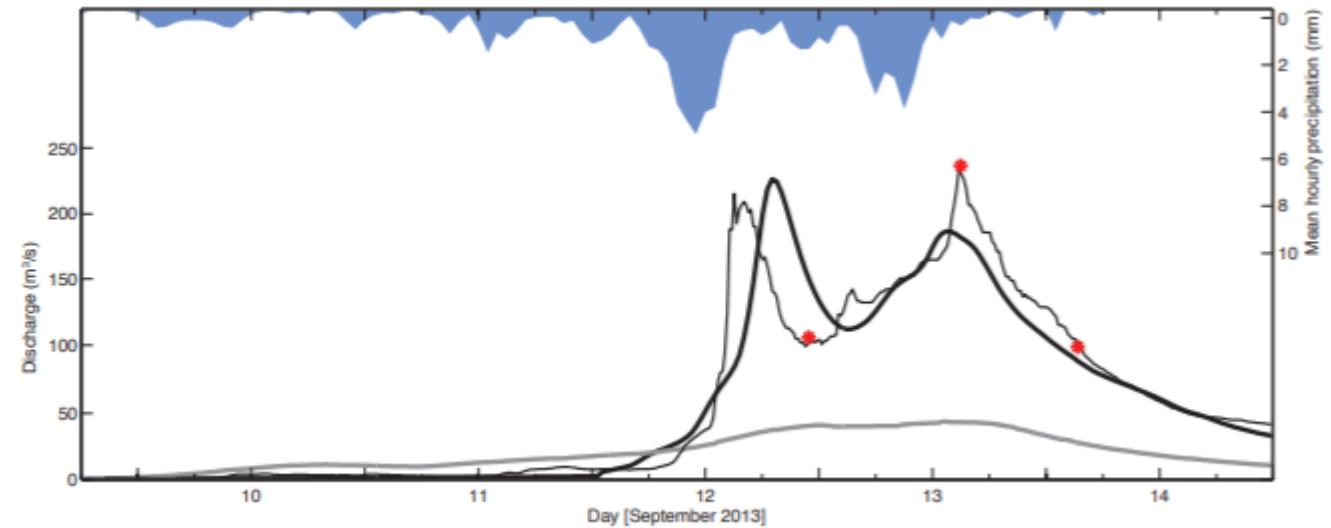


Water depth h , x -momentum uh , and y -momentum vh are conserved within each volume

Use in flood modeling: 2013 Front Range flooding



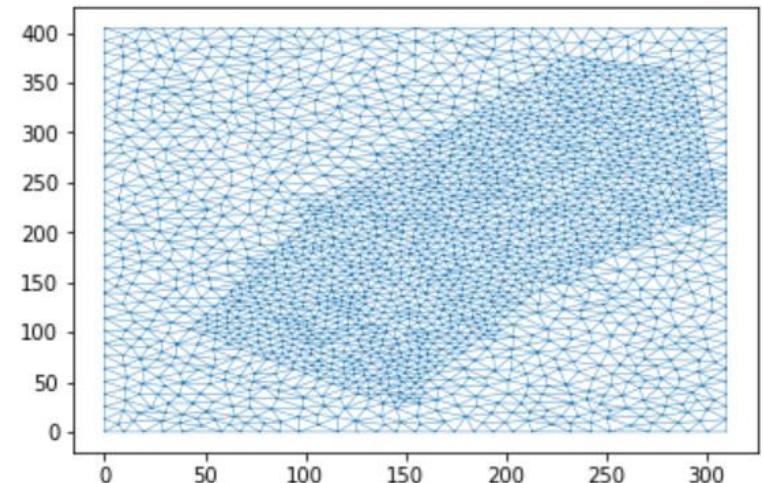
Boulder Creek
at North 75th St.
near Boulder, CO
USGS 06730200



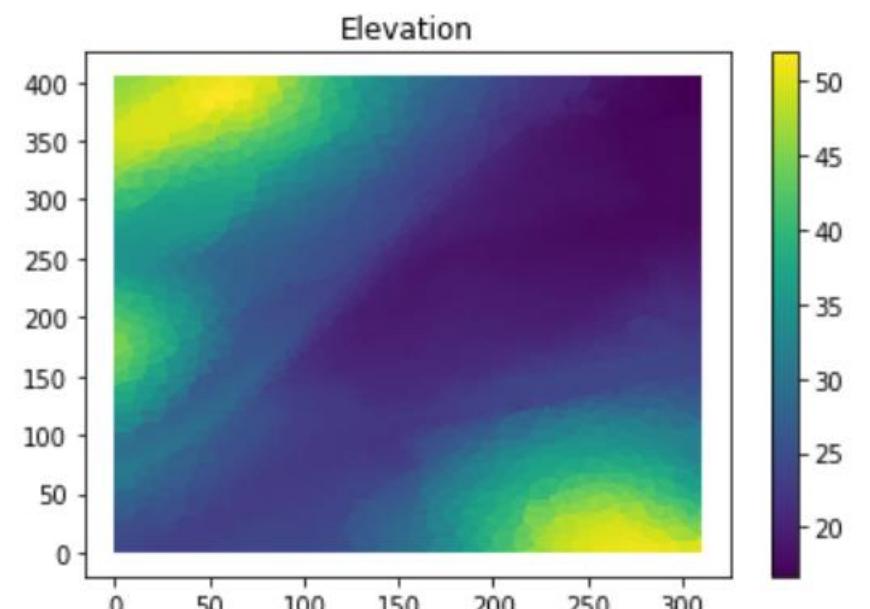
ANUGA model domain setup

- Specify an overall domain and internal sub-regions
- Choose resolution of mesh for each region
 - Resolution represents the maximum allowed area of each triangular node, they may be smaller
- Select Manning's friction co-efficient for each region
- Specify boundary conditions of domain
 - Reflective, transmissive, or fixed stage
- Set-up an inlet flow condition with a constant or time varying discharge
- Evolve the model!

Example from Stephen Roberts and the Meriwether validation test



Base resolution = 80 m^2 Channel resolution = 25 m^2



Mesh populated with elevation from DEM

4. Hands-on with ANUGA

Time to move to the Google co-lab!

- Load in data and boundary polygons
- Create mesh and populate
- Choose inflow conditions
- Evolve!

5. Discussion and thank you!

How do you use topography data?

How do you use modeling?

How do we decide when HRT is necessary?

What should the field and community be doing?

What are the big opportunities or questions?