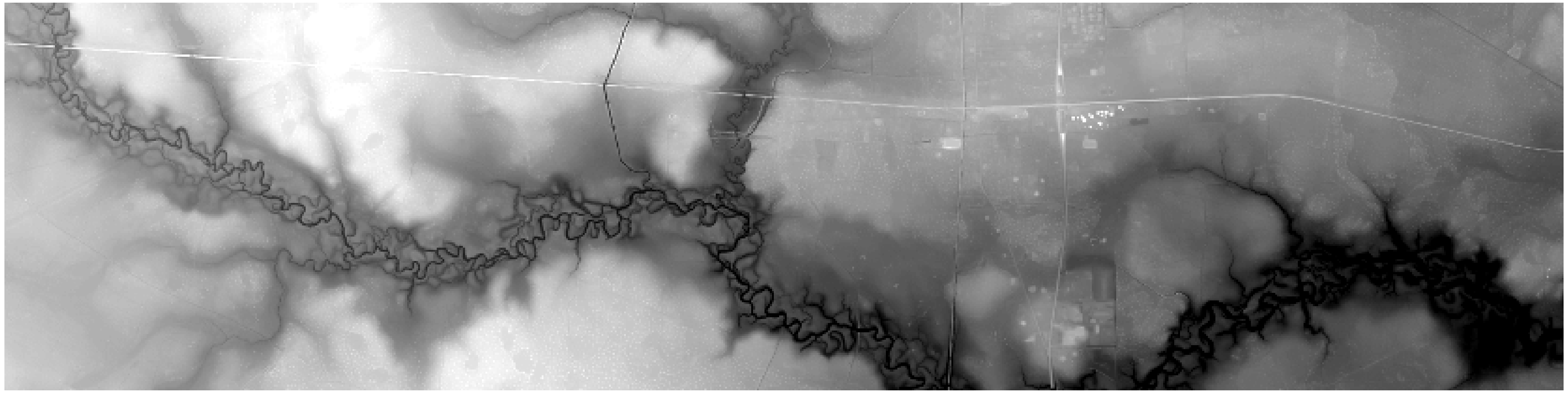
Exploring surface processes and landscape connectivity through high-resolution topography: integration of high resolution data in numerical modeling

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



Advancing the Analysis of High Resolution Topography

EarthCube
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NSF

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**

CSDMS
community surface dynamics modeling system


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

NSF

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

OpenTopography
High-Resolution Topography Data and Tools

BOISE STATE UNIVERSITY

UNSW SYDNEY

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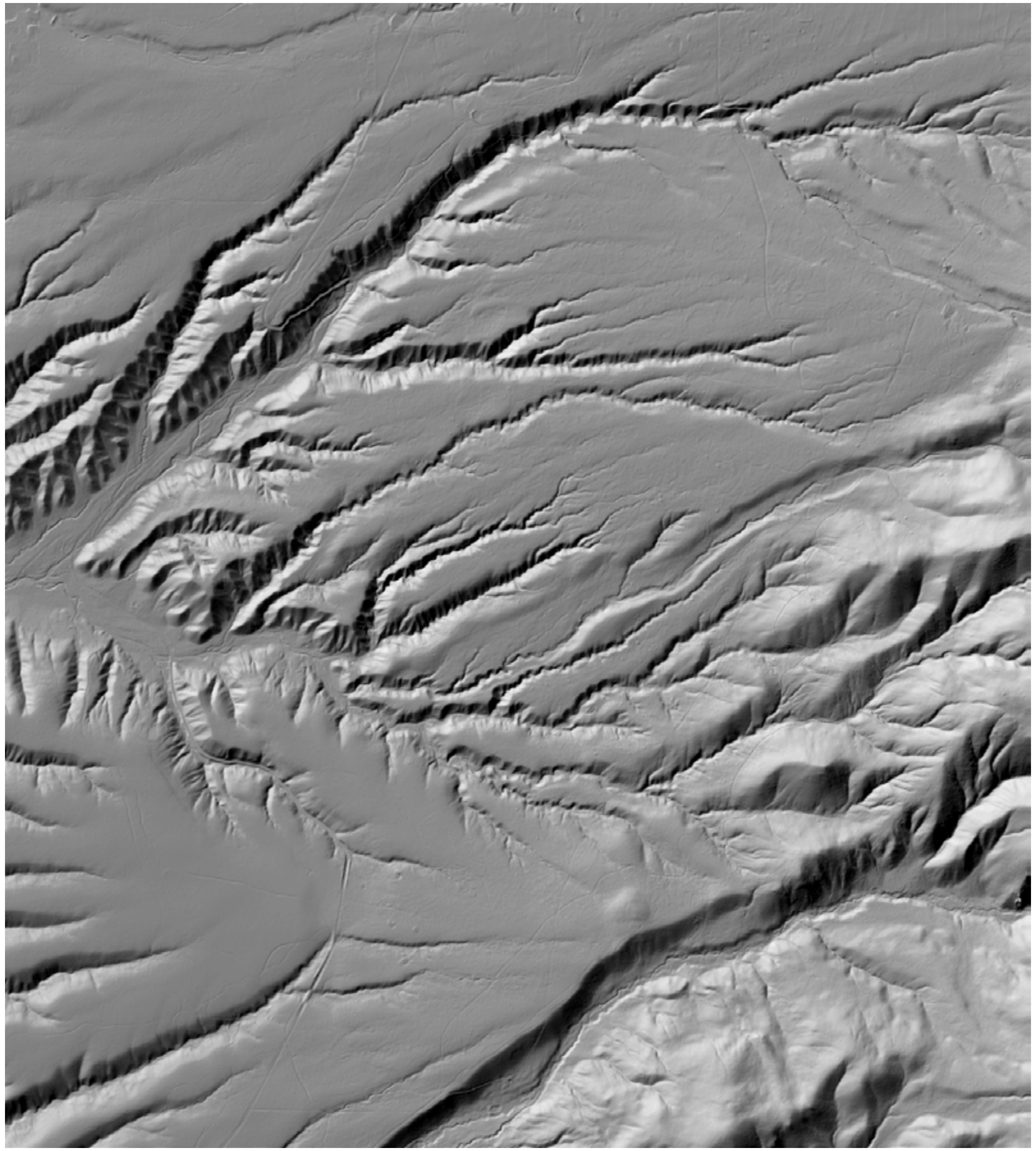
CSDMS 2020 Overview

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

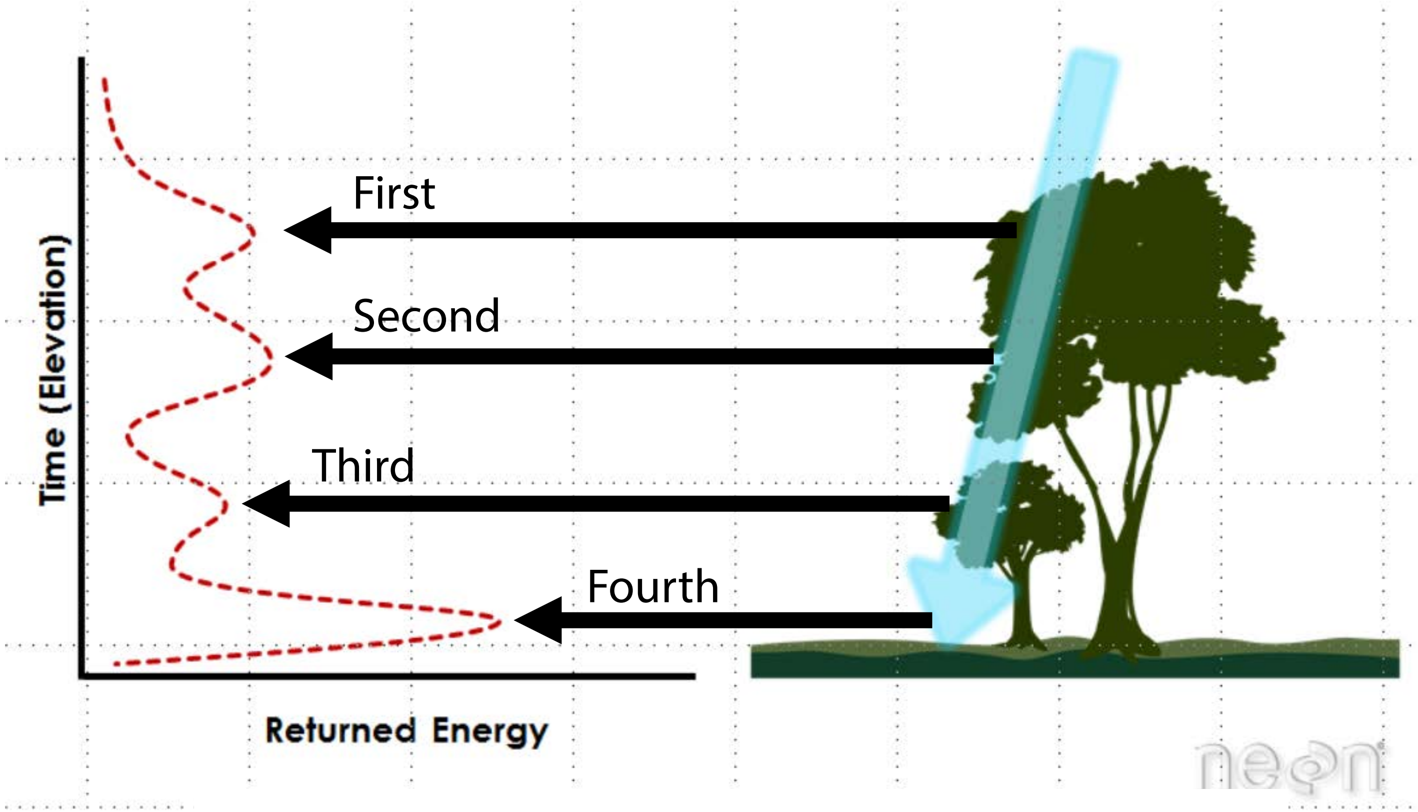
1. What is high-resolution topography (HRT)?

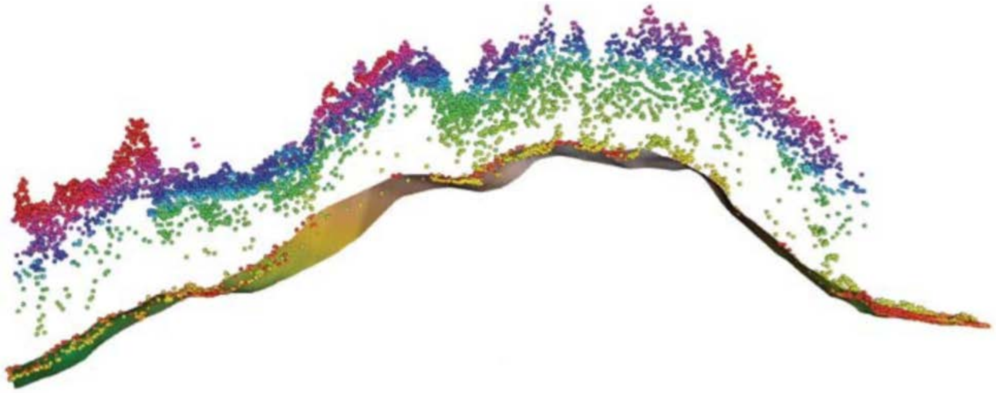
- Technology that can acquire meter to sub-meter scale datasets
  - Lidar (ALS or TLS)
  - Photogrammetry (e.g. drone Structure-from-Motion)
  - Synthetic aperture radar (SAR)
  - Multi-beam bathymetry
- Provide accurate characterization of small-scale processes and structure
- Challenges in data handling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



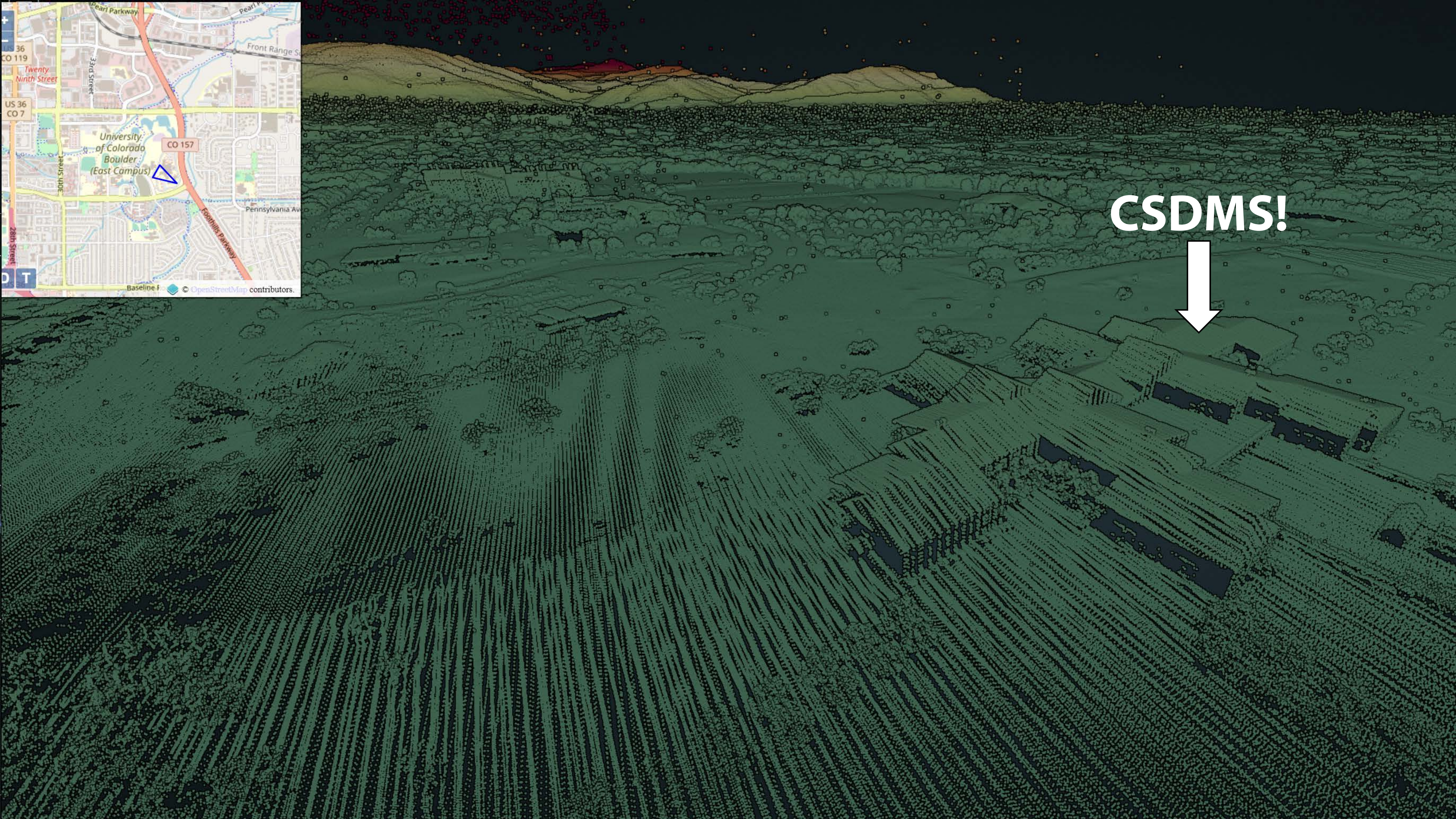
Lidar basics

- 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!**



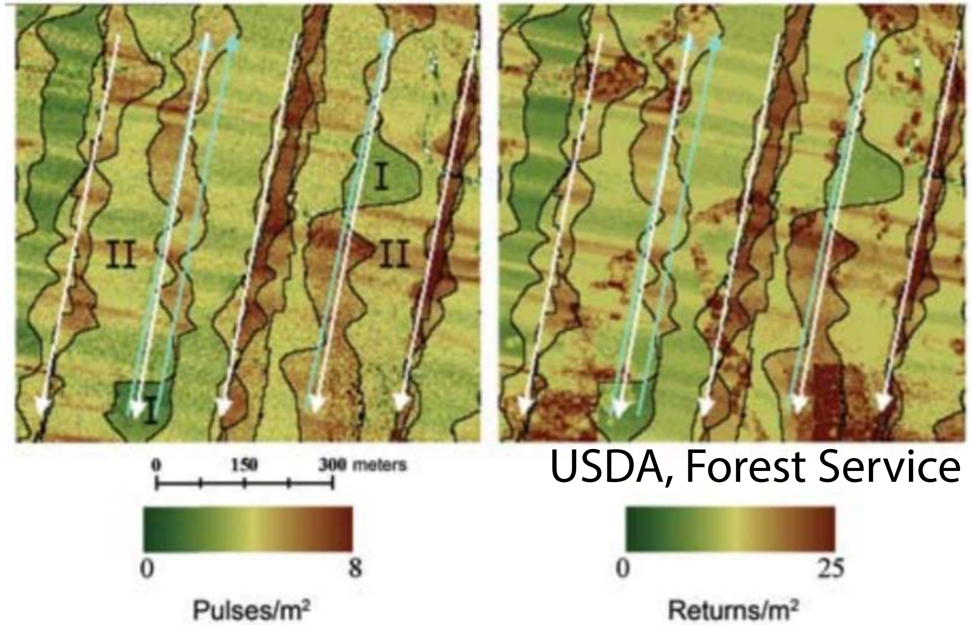


USDA Forest Service


CSDMS!
Pearl Parkway
Front Range
US 36
CO 119
Twenty Ninth Street
33rd Street
US 36
CO 7
University of Colorado Boulder (East Campus)
CO 157
30th Street
Pennsylvania Ave
Foothills Parkway
28th Street
© OpenStreetMap contributors.

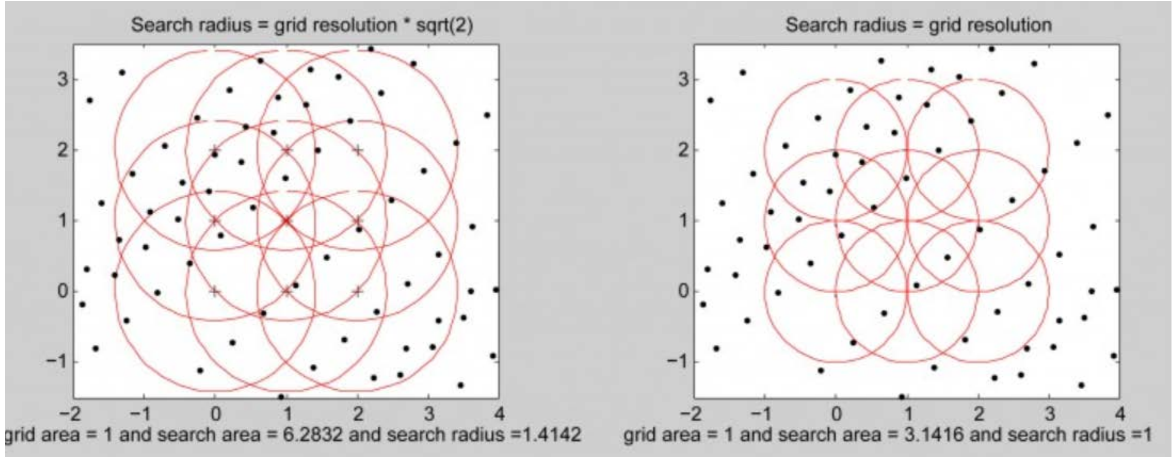
Point clouds to gridded rasters

1. Acquire and QC survey



USDA, Forest Service

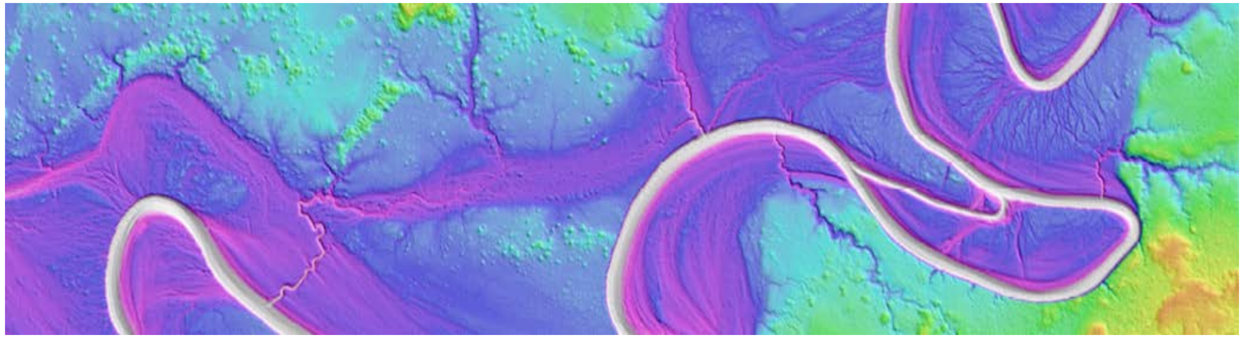
3. Grid points based on return density



Points2Grid, OpenTopography

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

4. Enjoy your new raster!

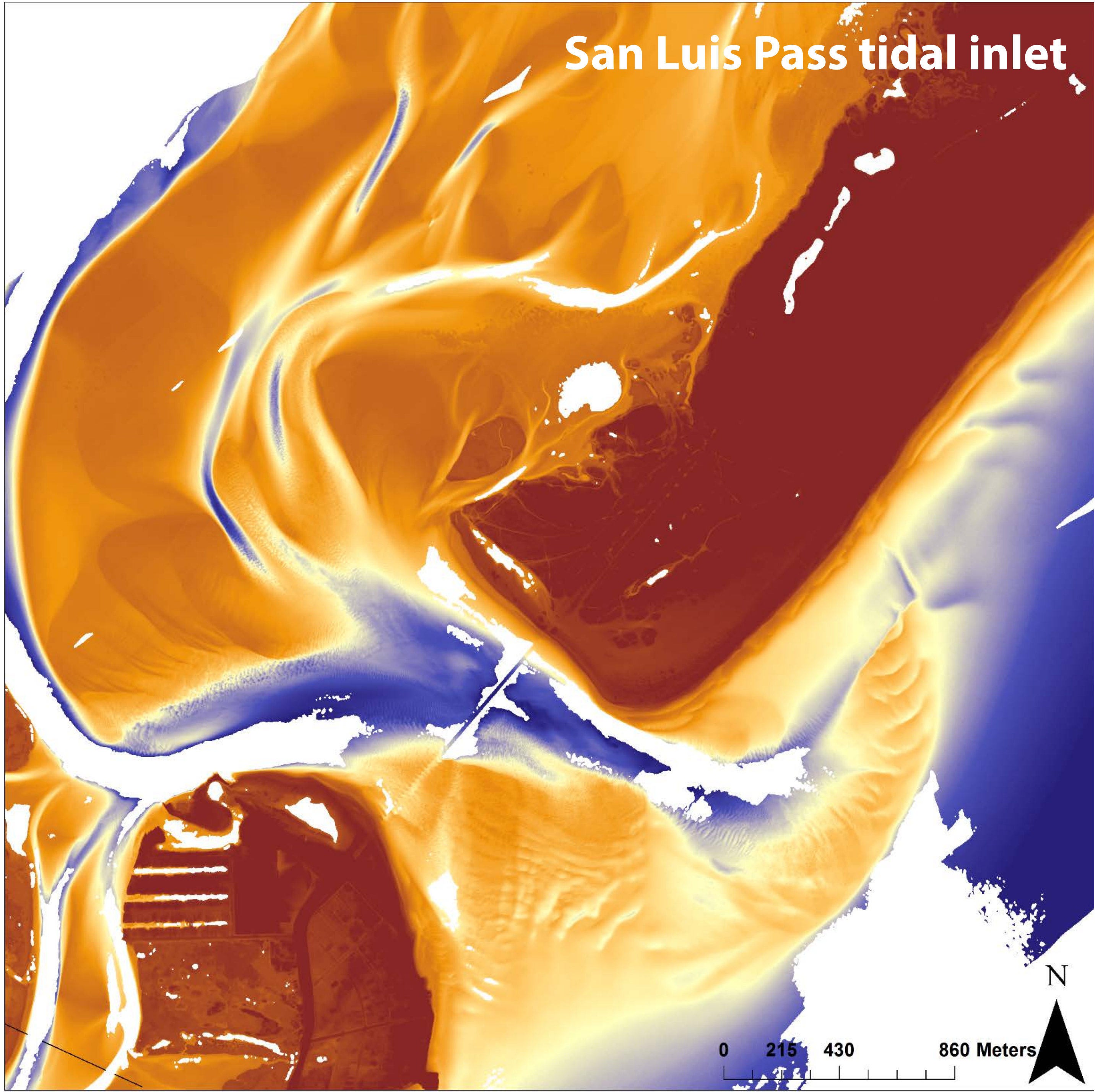


OpenTopography

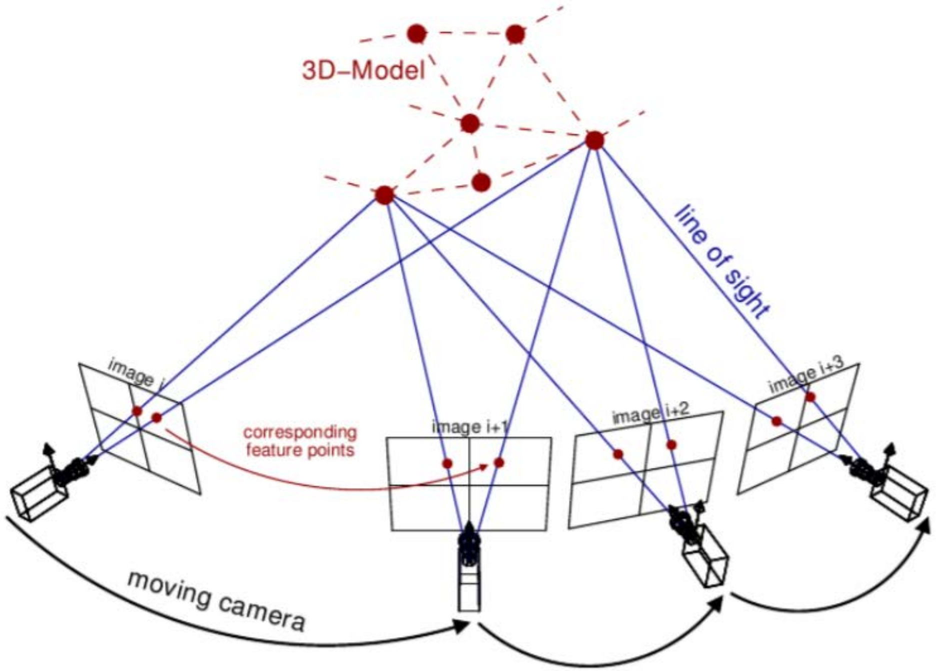
Topobathymetric lidar

- 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

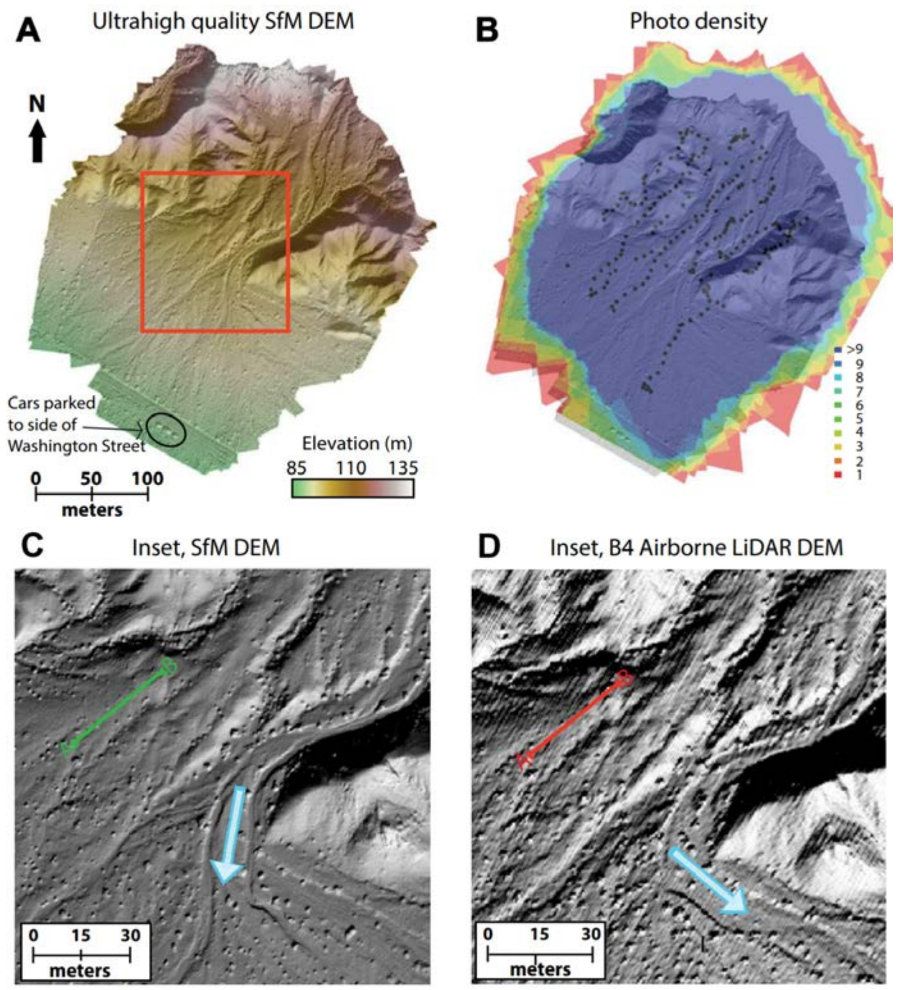


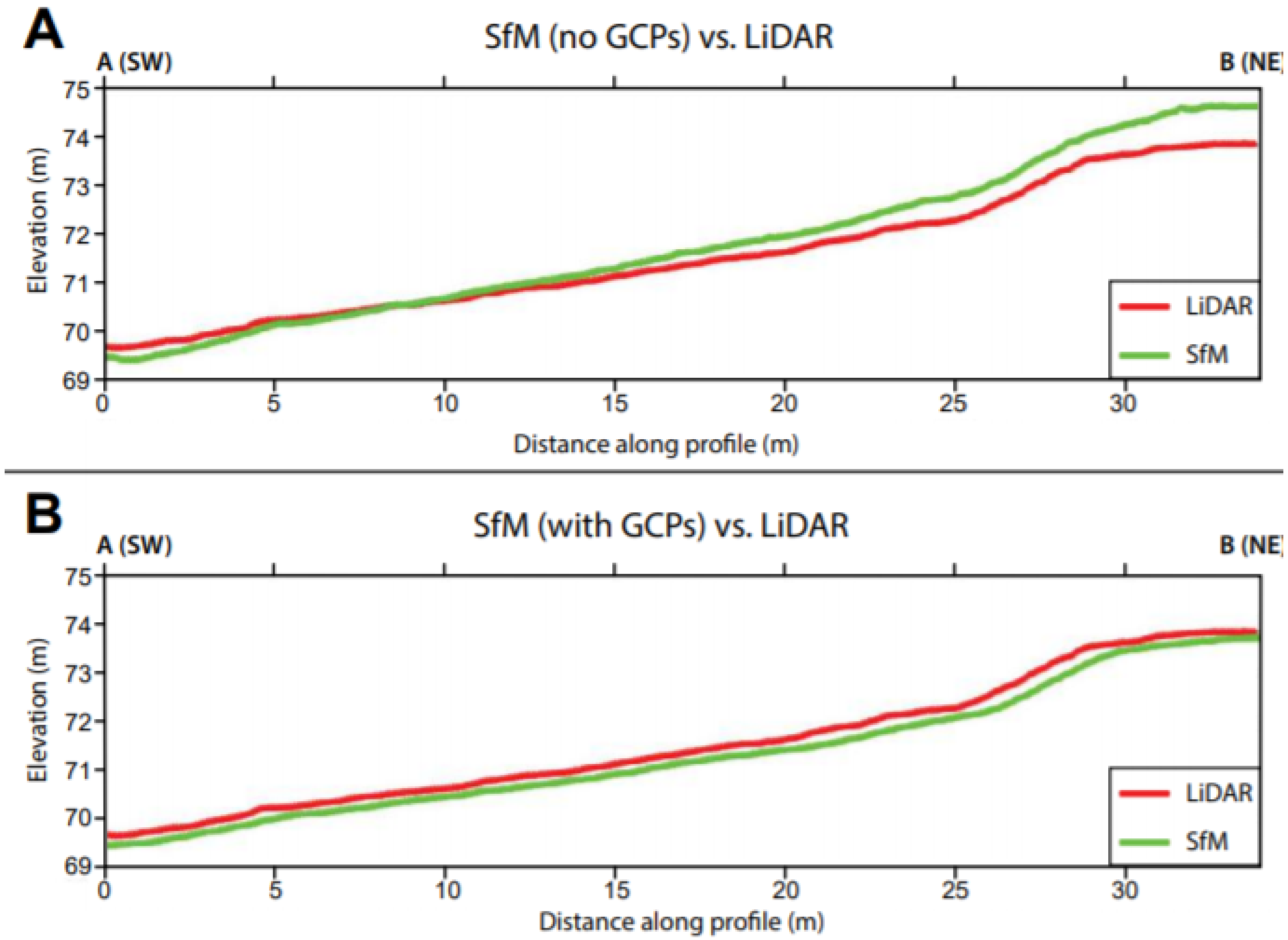
Edwin Nissen, UNAVCO

- 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

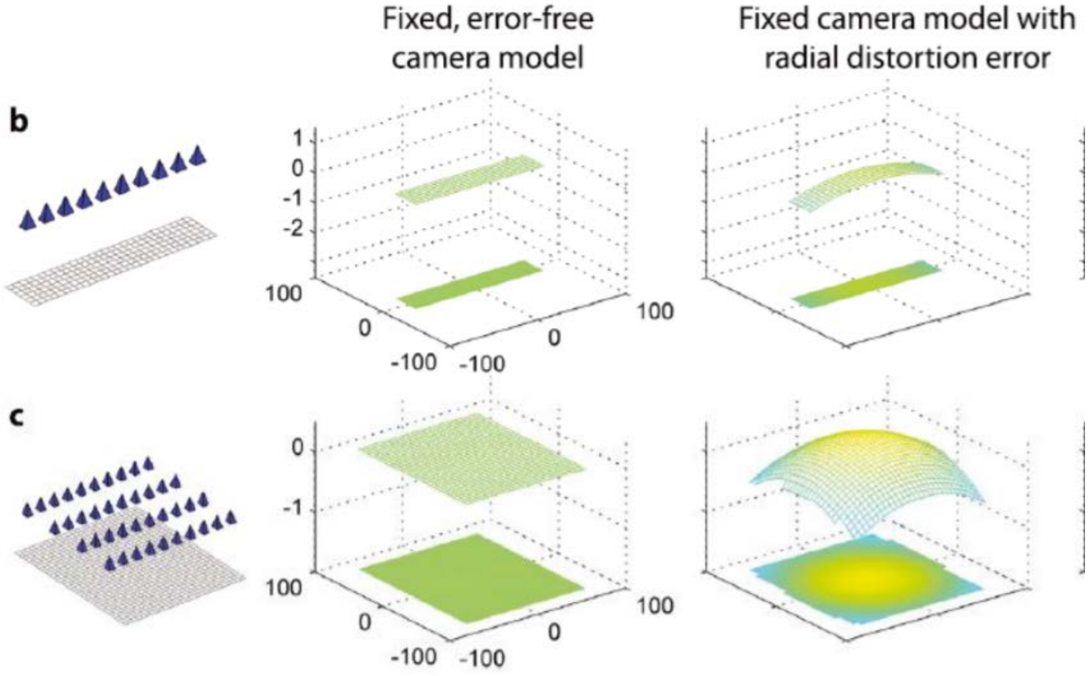


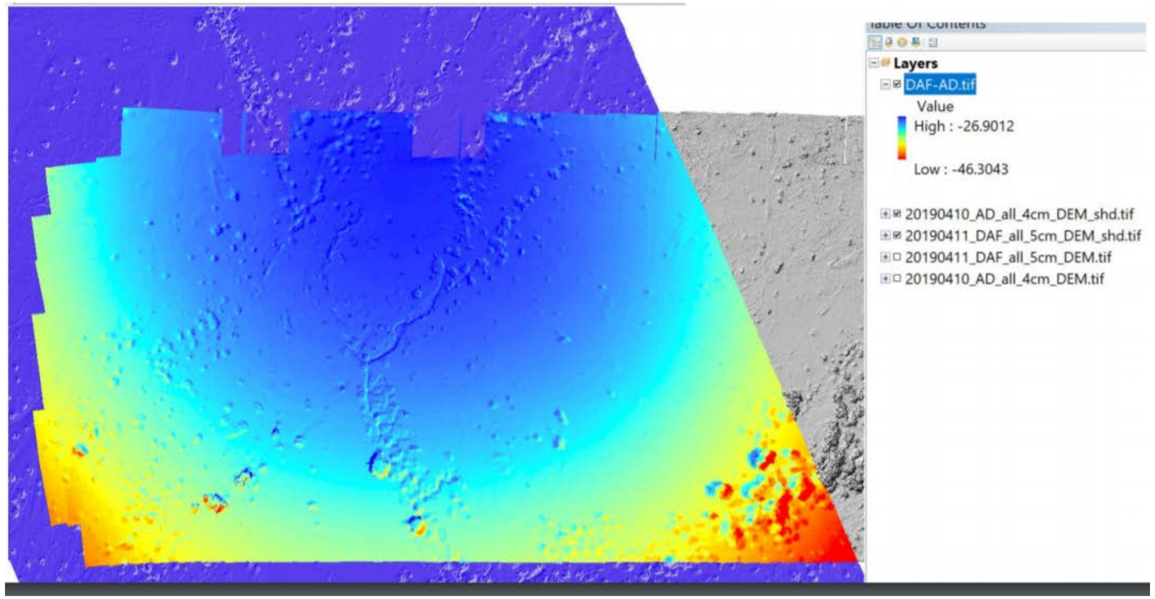


Kendra Johnson et al. (2014). Rapid mapping of ultrafine fault zone topography with structure from motion. *Geosphere*

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!

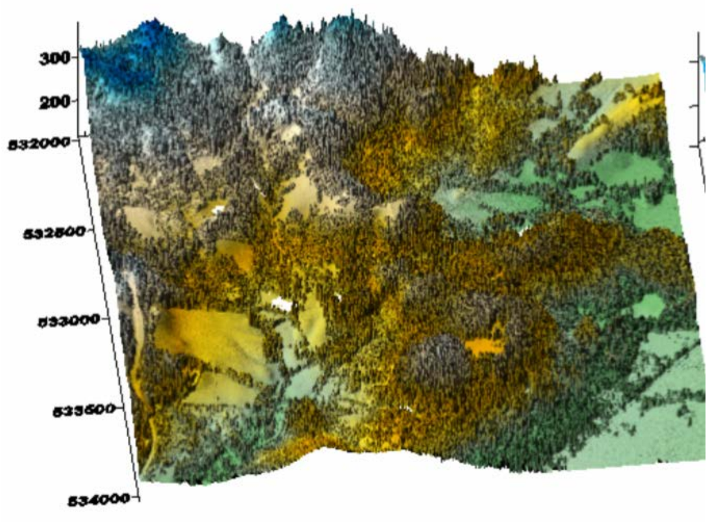


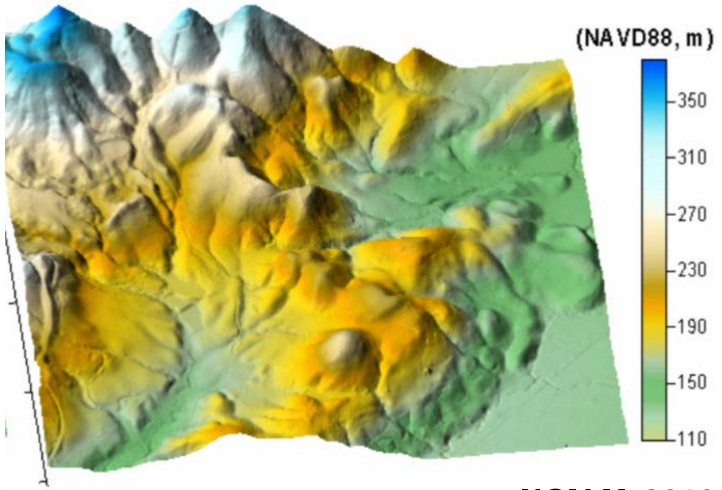


James & Robson (2014), Mitigating systematic error in topographic models derived from UAV and ground-based image networks, Earth Surface Processes and Landforms

Digital terrain and digital surface models

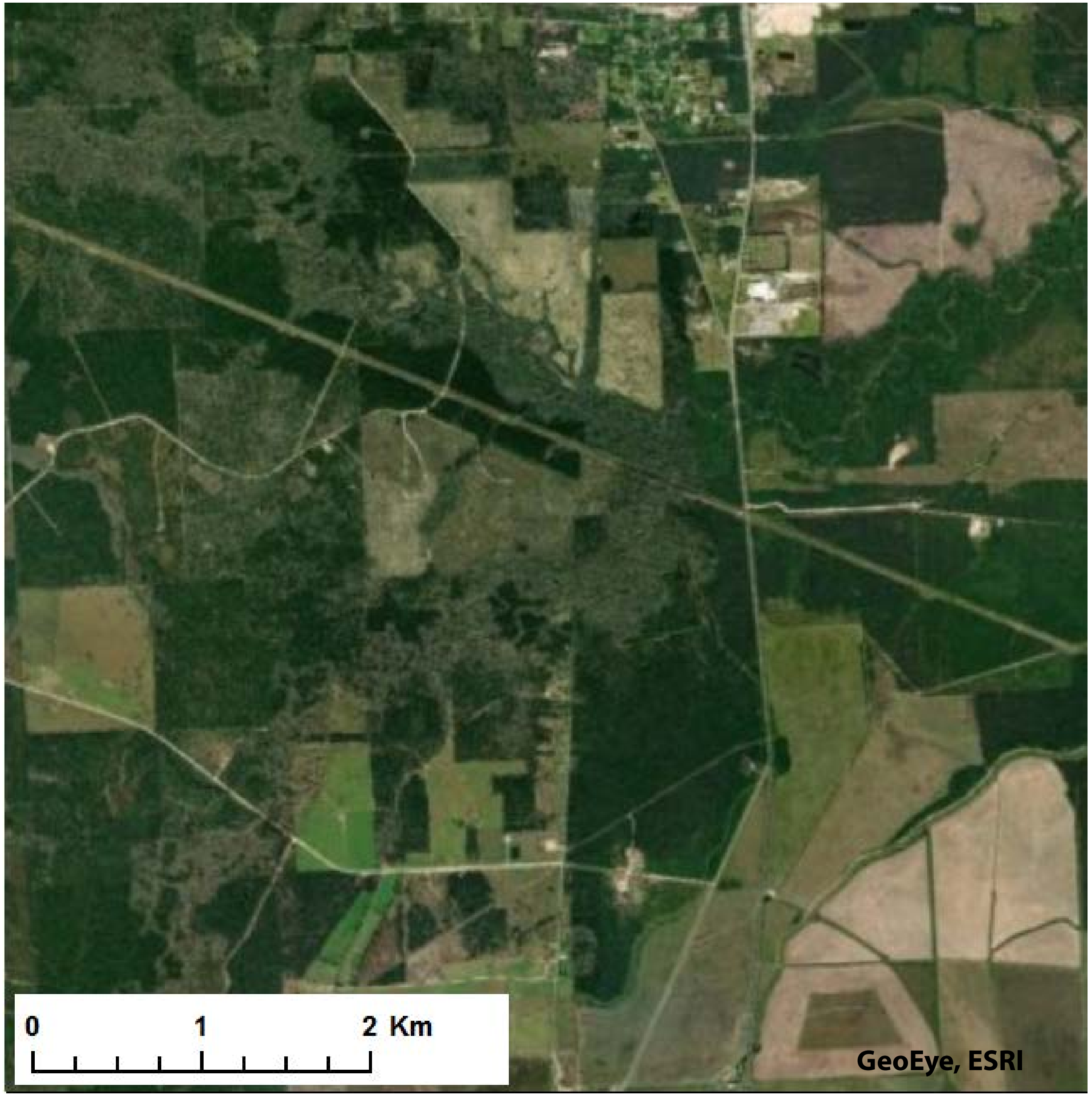
- DTMs and DSMs are the most commonly encountered topography data
- DTM = "bare-earth" surface: the classic lidar derived elevation raster
- DSM= Highest point surface: could be terrain, vegetation, or structures
- Lidar provides ability to create both
- SfM typically limited to DSMs
- Both have utility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

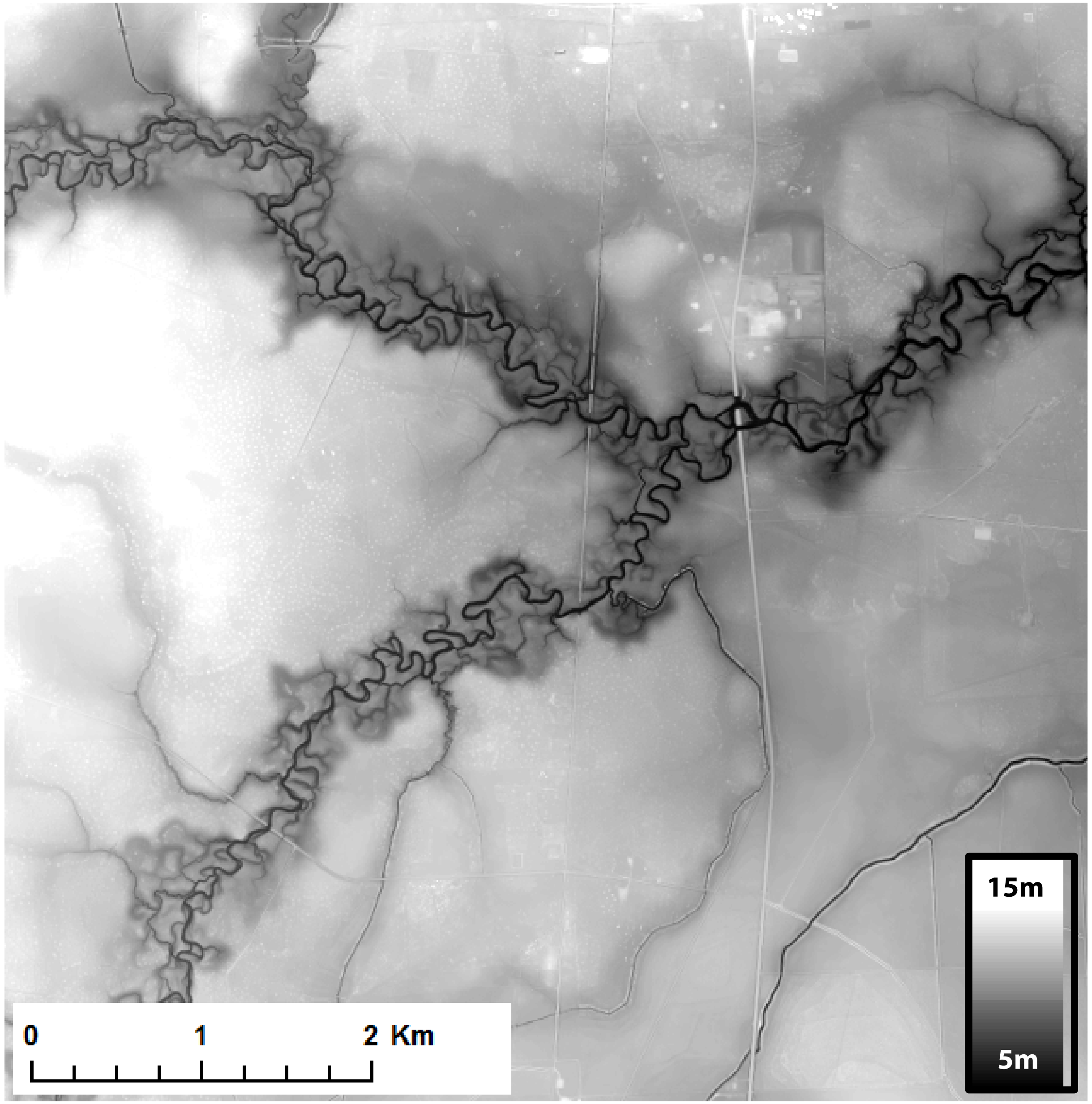




NCALM, 2010

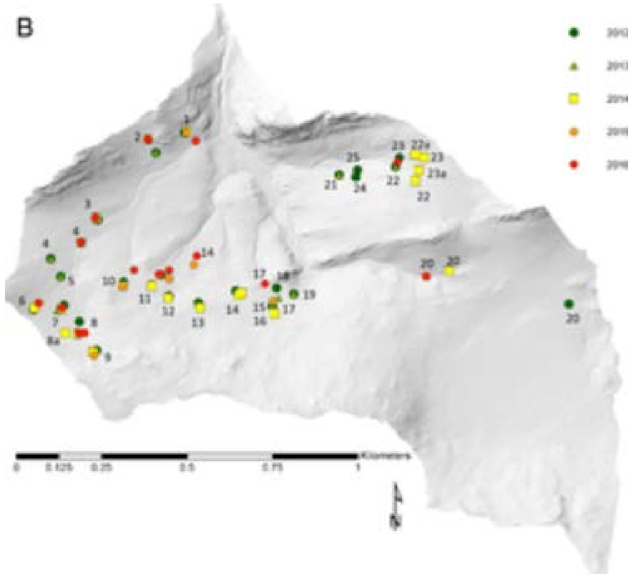
Lidar bare earth digital terrain models (DTMs)



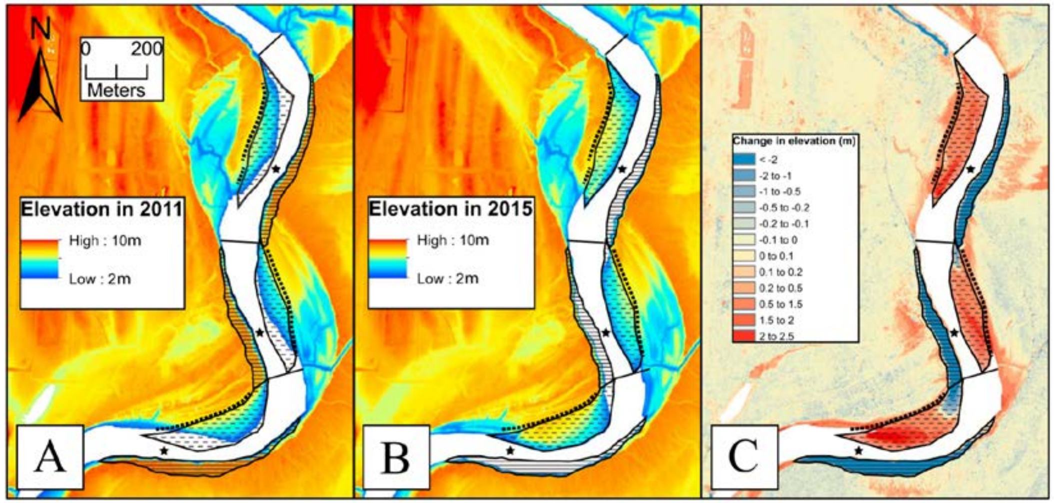


1B. Common applications and uses of HRT

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

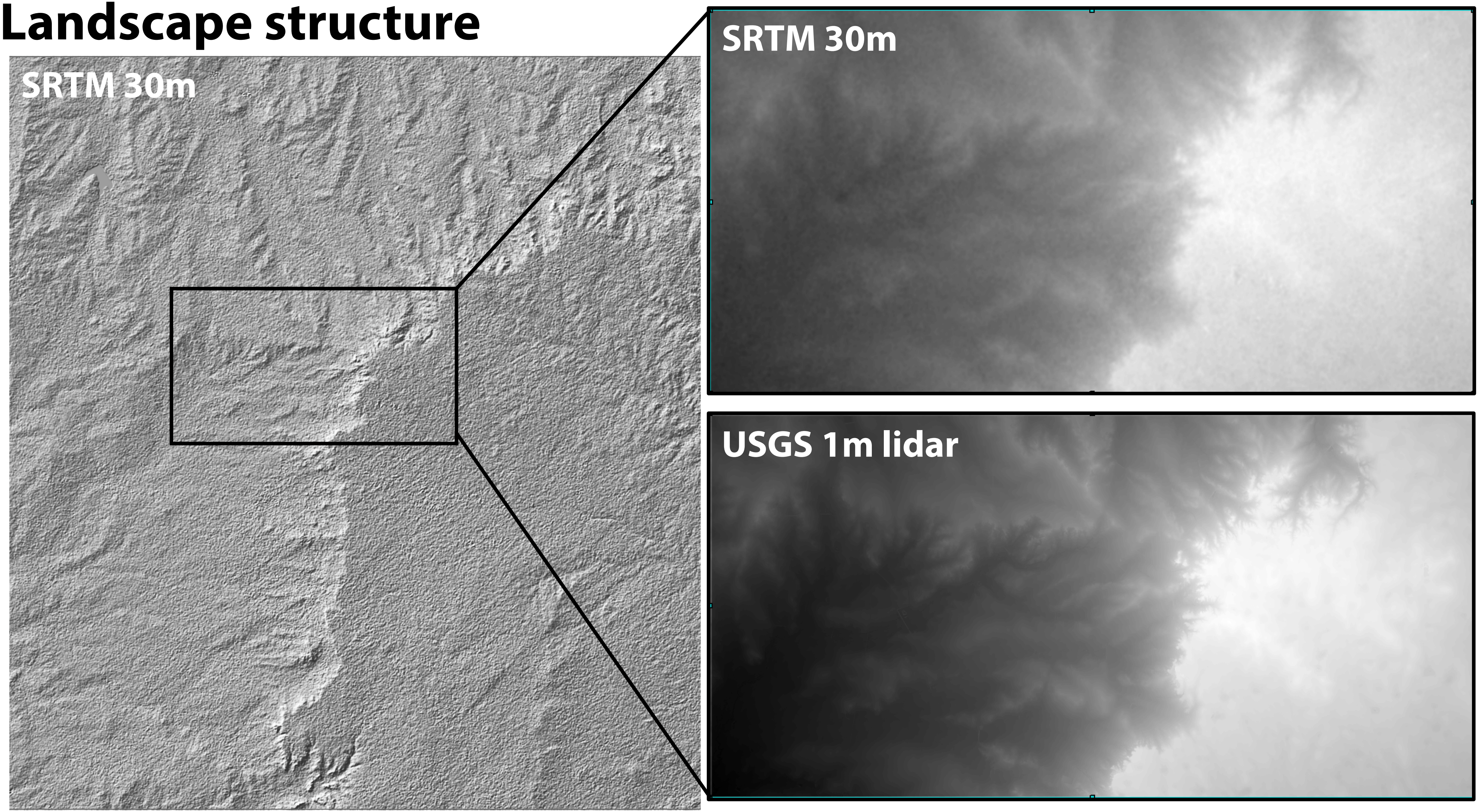


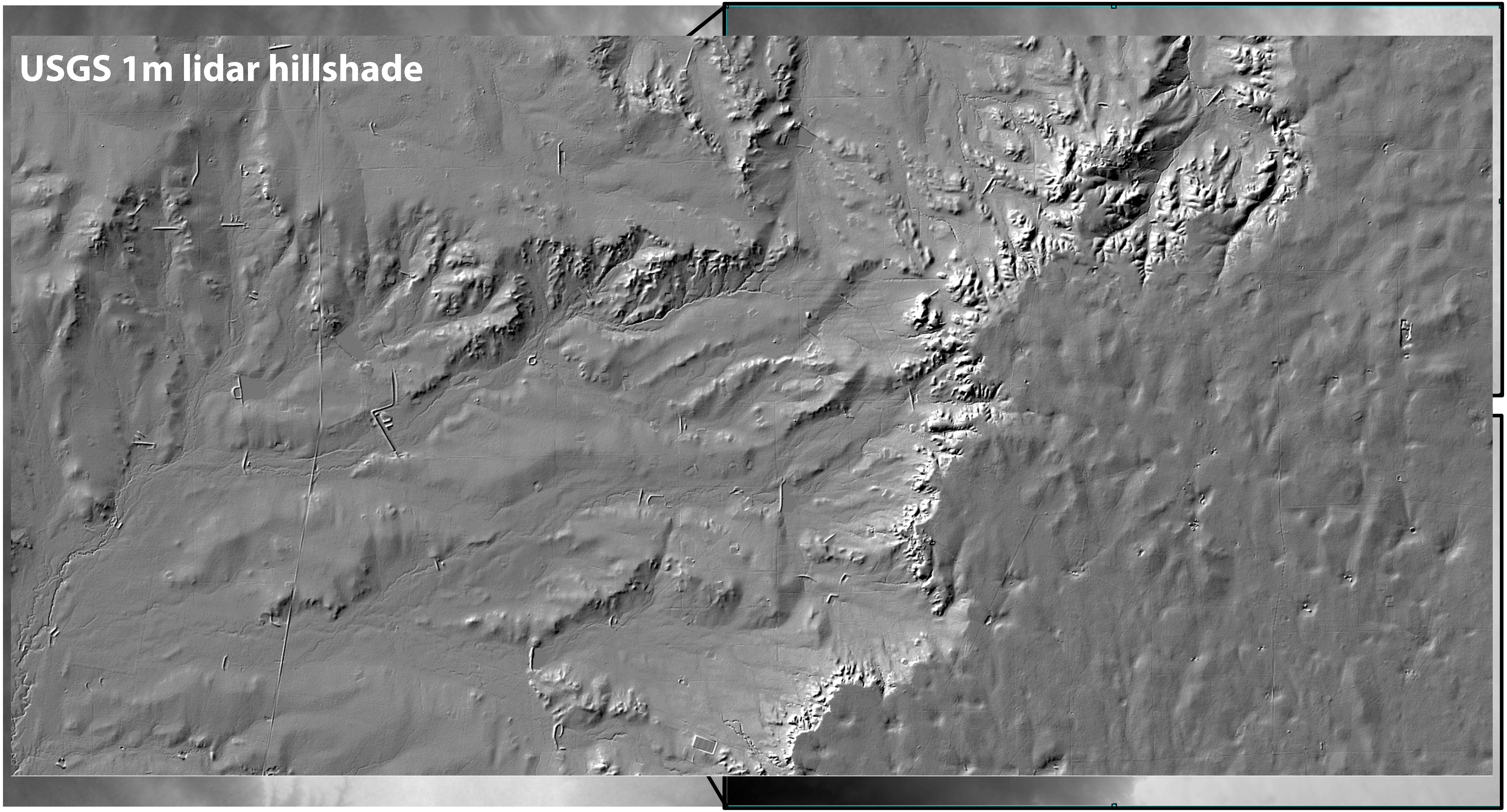
Ellen Wohl and Daniel Scott, 2017. Transience of channel head locations following disturbance. *Earth Surface Processes and Landforms*

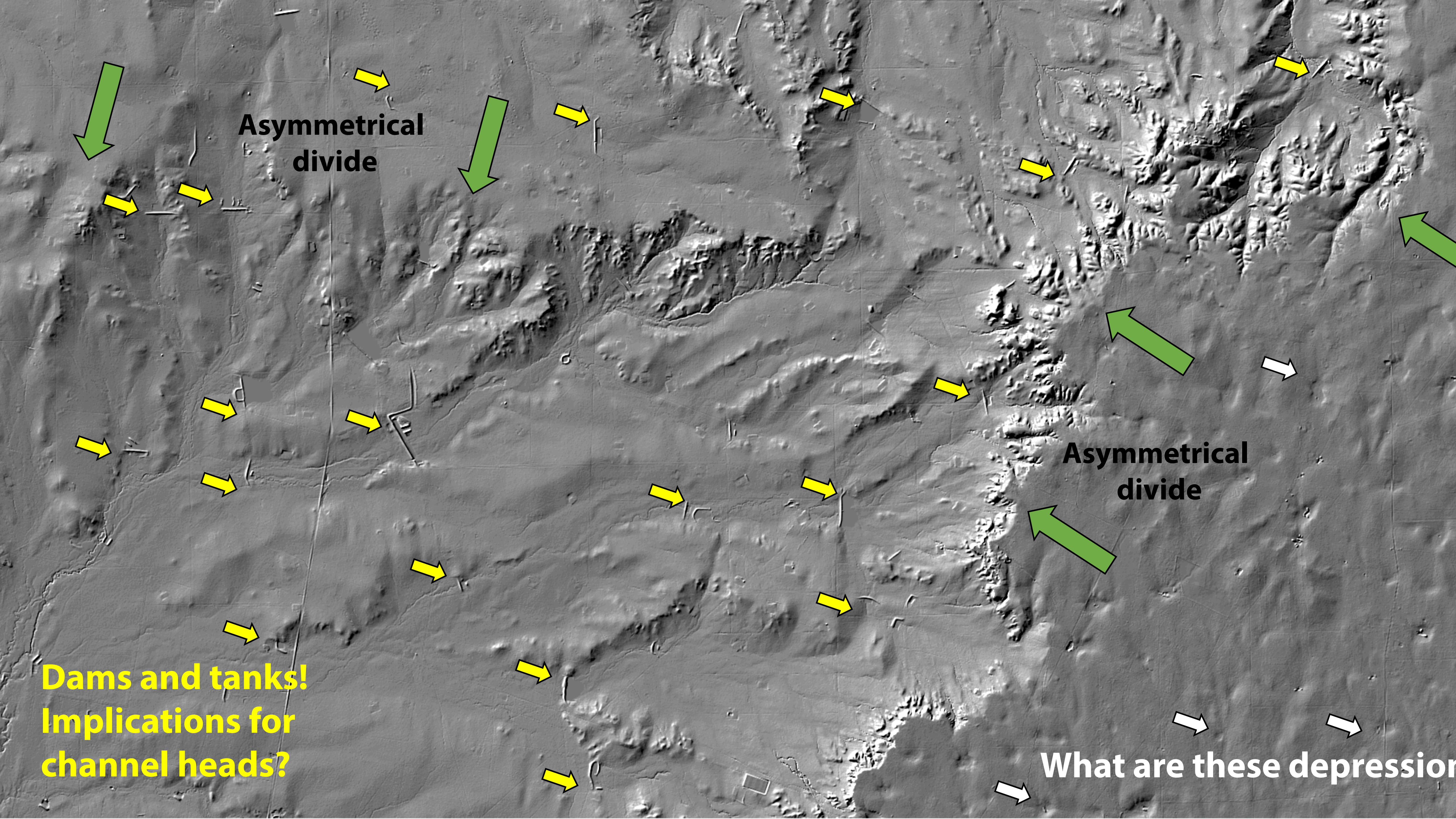


Jasmine Mason and David Mohrig, 2017. Using Time-Lapse Lidar to Quantify River Bend Evolution on the Meandering Coastal Trinity River, Texas, USA. JGR-ES

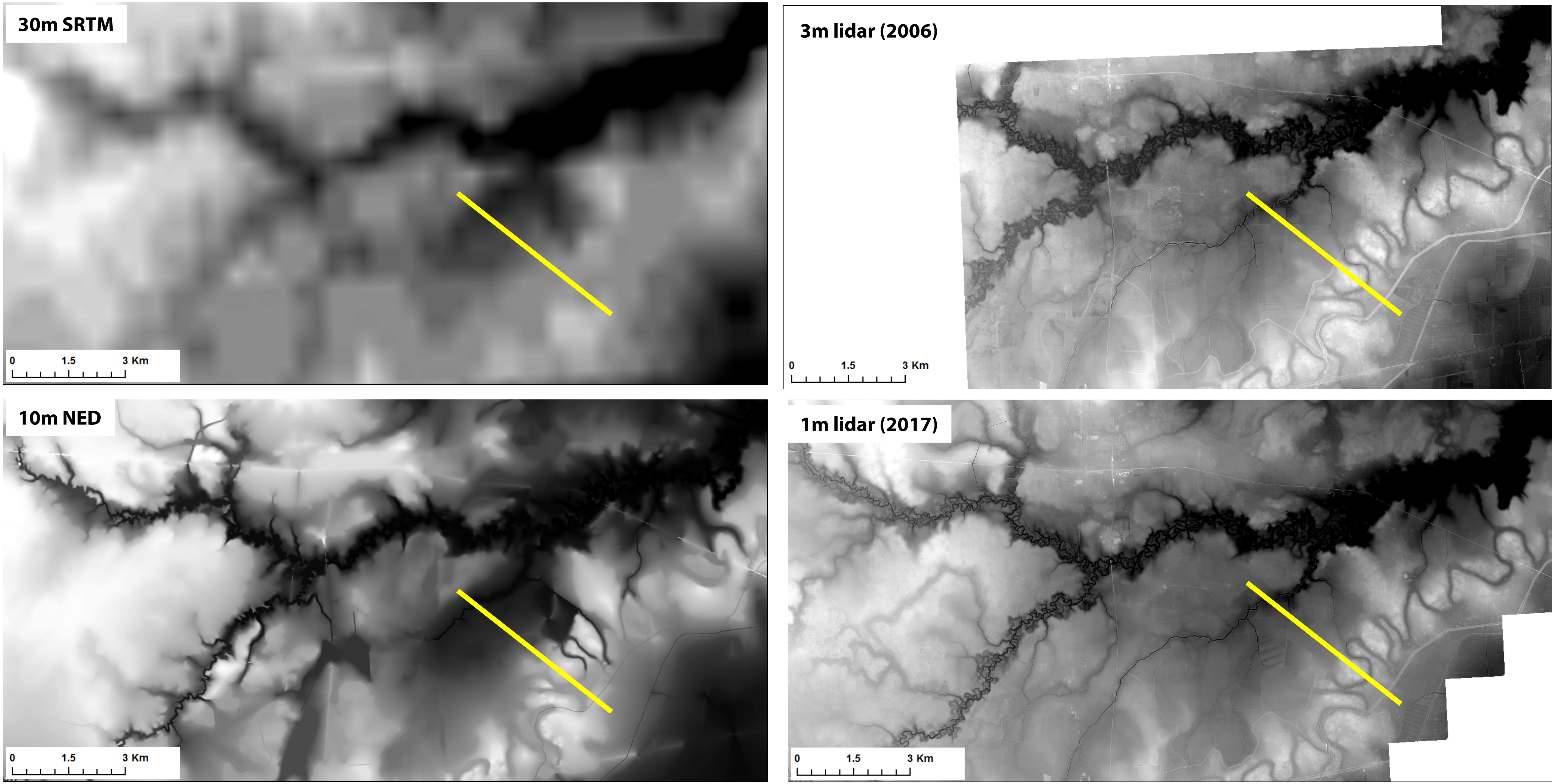
Landscape structure



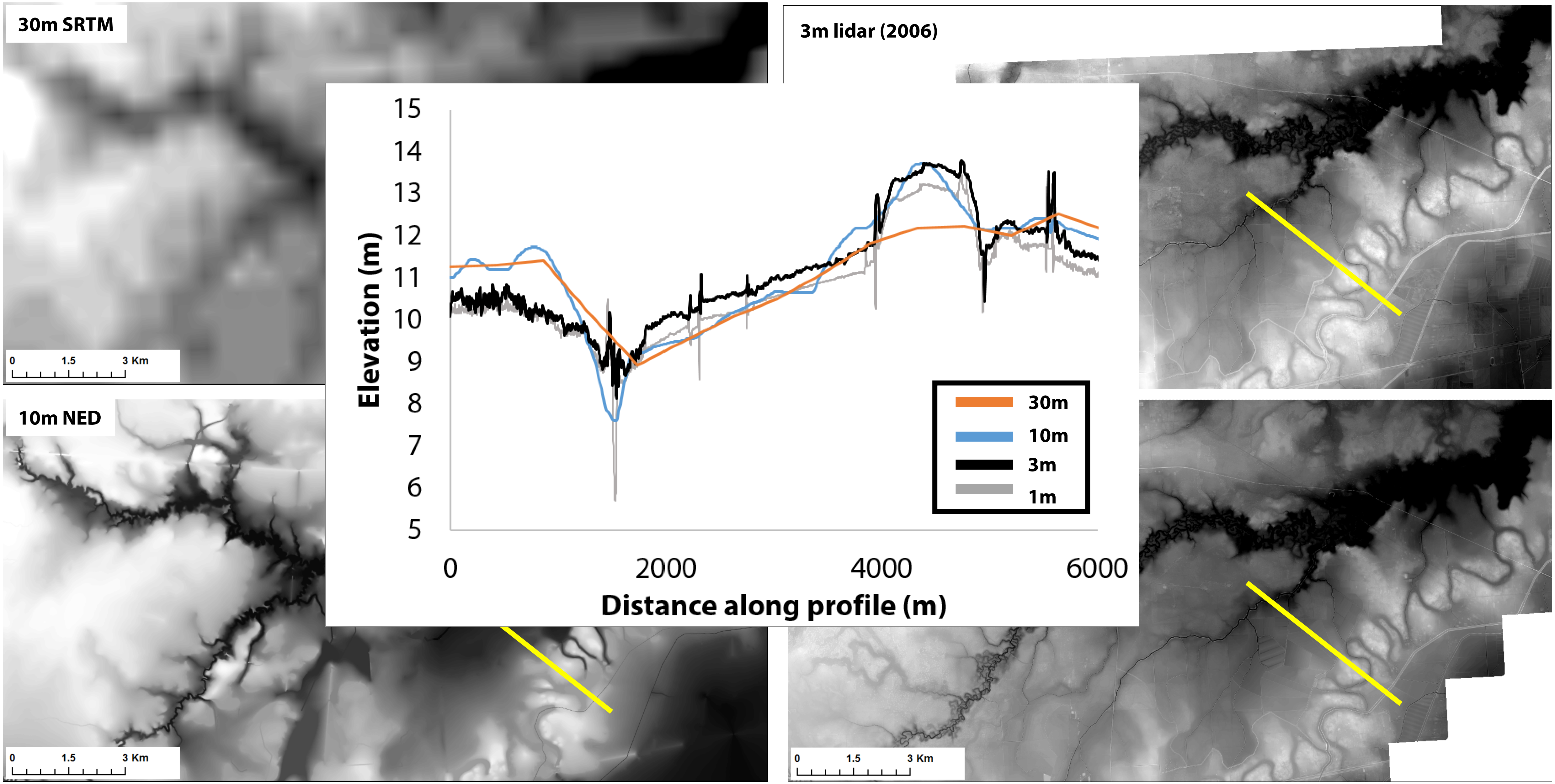

USGS 1m lidar hillshade


Asymmetrical divide
Asymmetrical divide
Dams and tanks! Implications for channel heads?
What are these depressior

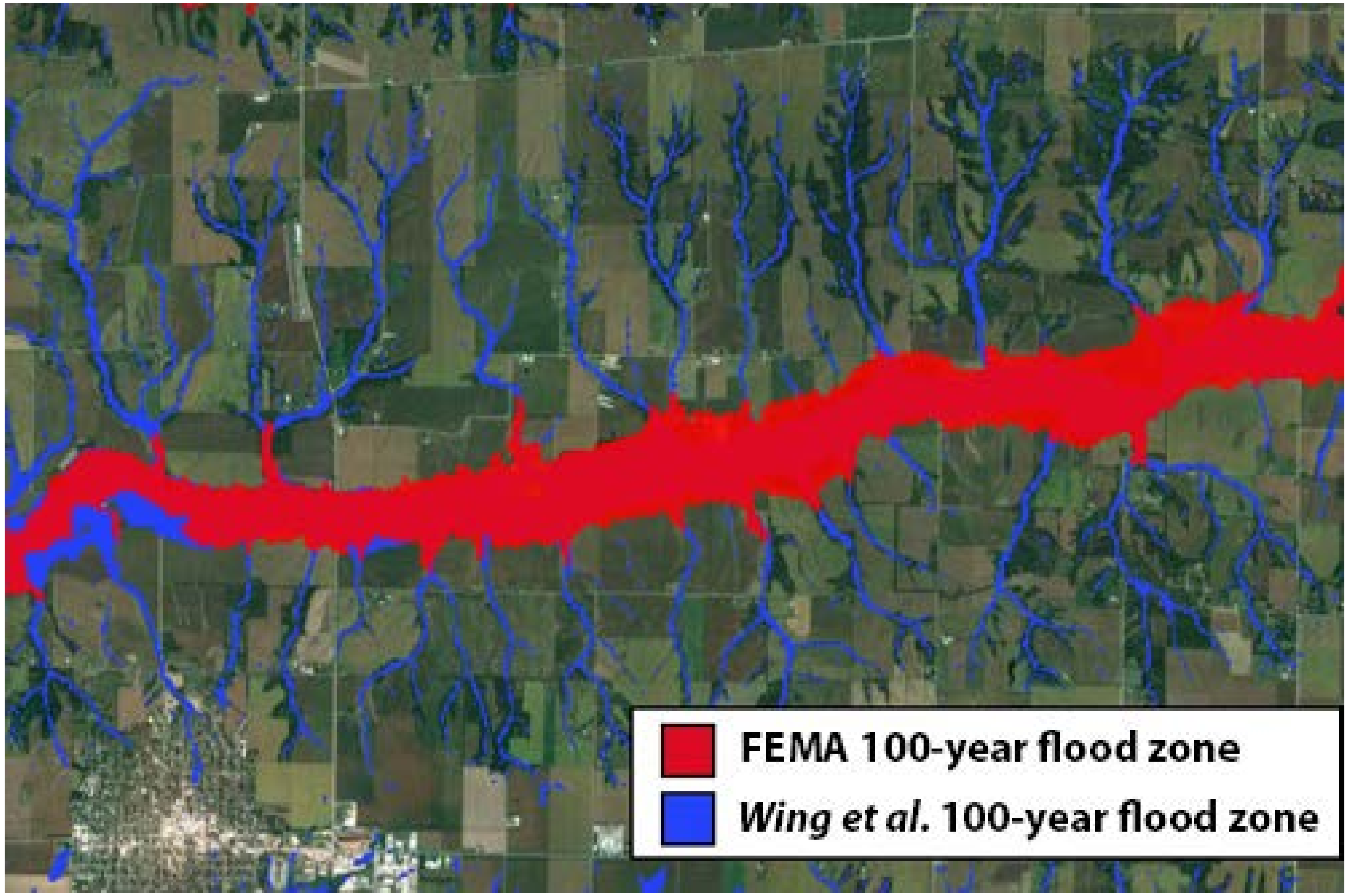
High-resolution topography necessary to resolve networks

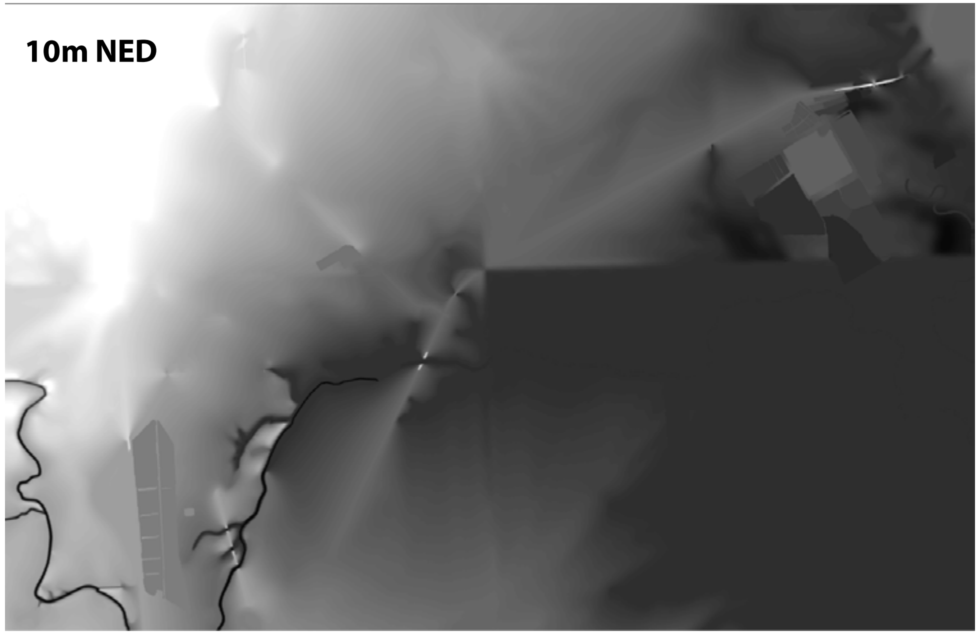


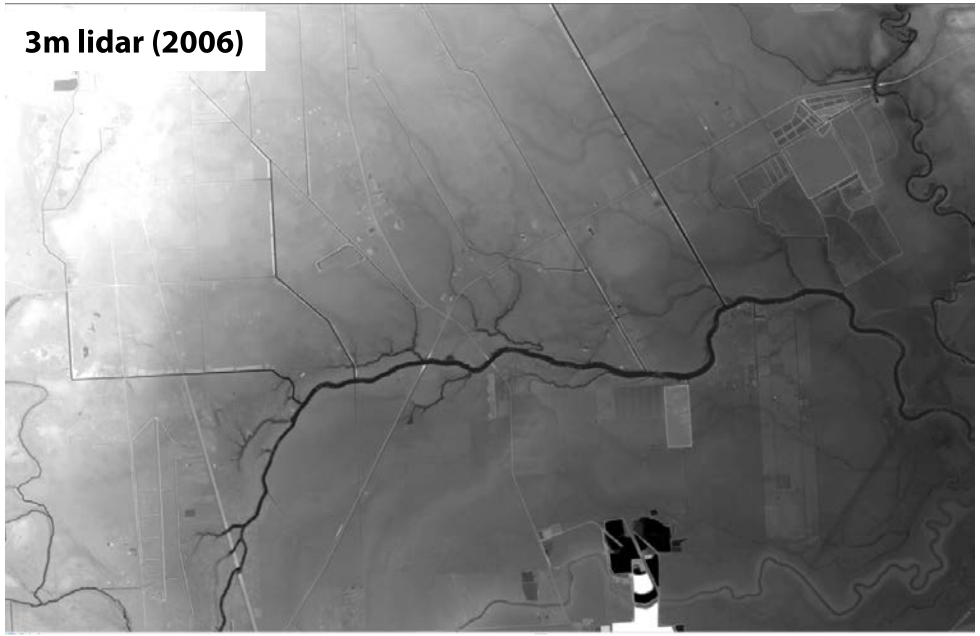
High-resolution topography necessary to resolve networks



Leads to better flood mapping



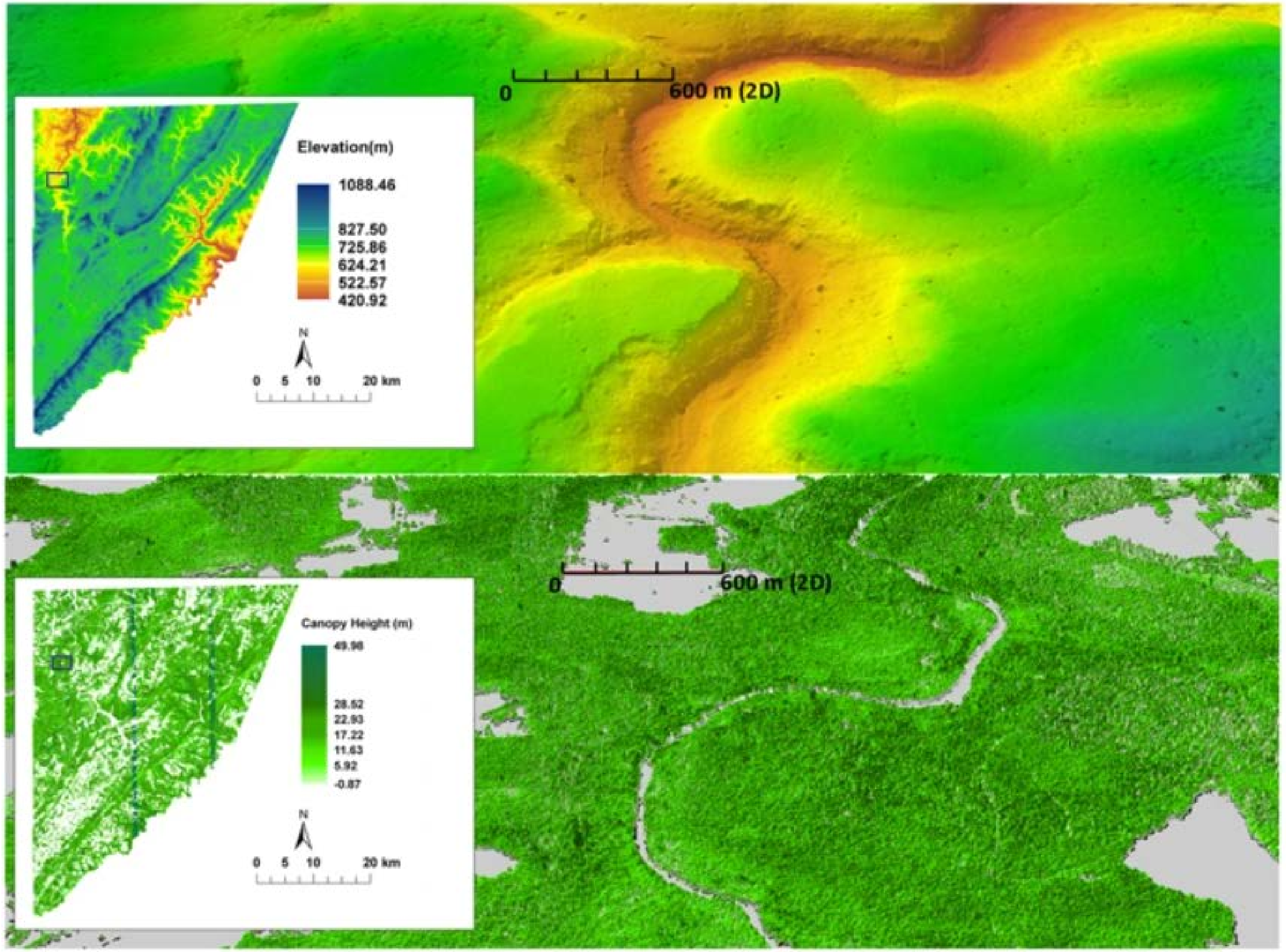




- Better characterization of landscape leads to better recognition of flood risk
- Current mapping potentially underestimates risk for ~30 million people

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

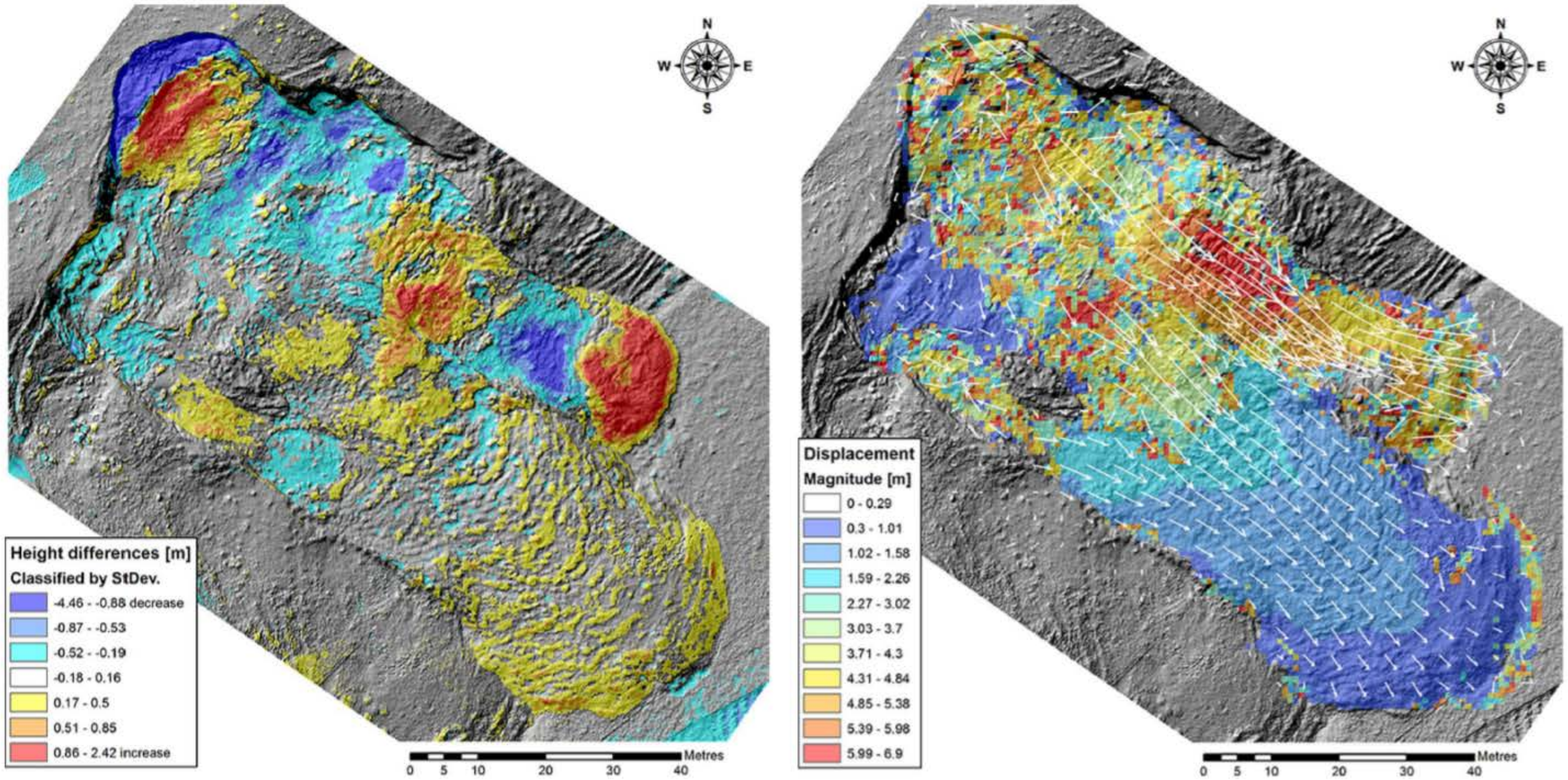


Anu Swatantran et al., 2016. Rapid, High-Resolution Forest Structure and Terrain Mapping over Large Areas using Single Photon Lidar. *Scientific Reports*

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

2. Hands-on with HRT

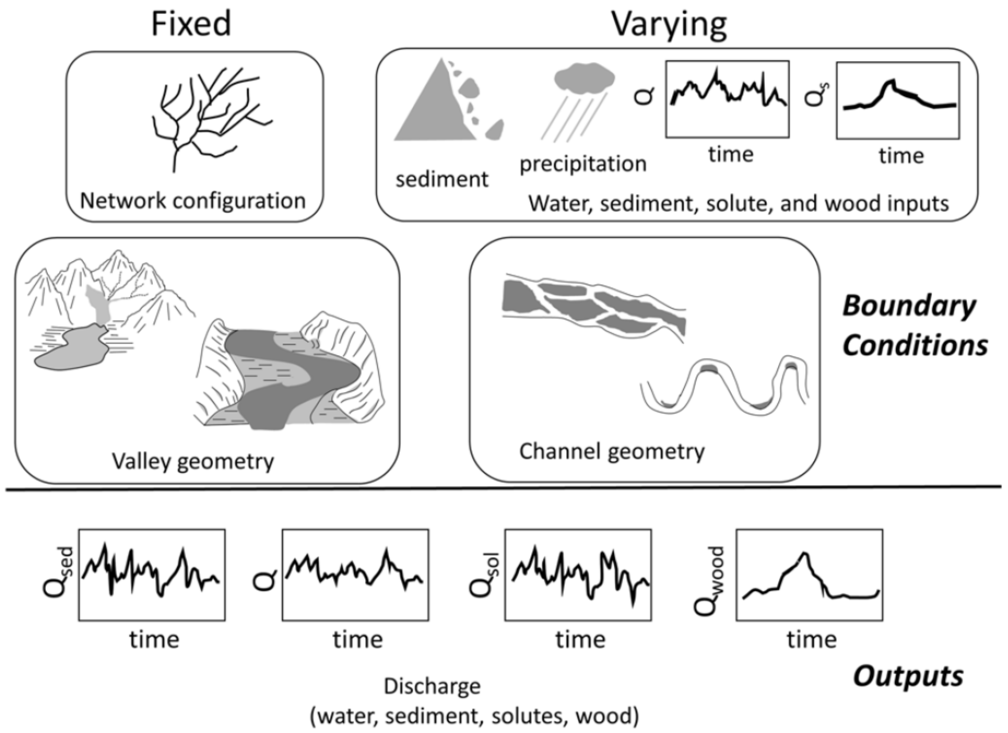
Time to move to the Google co-lab!

- Loading and visualization of raster DEMs with python

- Basic terrain analysis

3. Assessing landscape connectivity

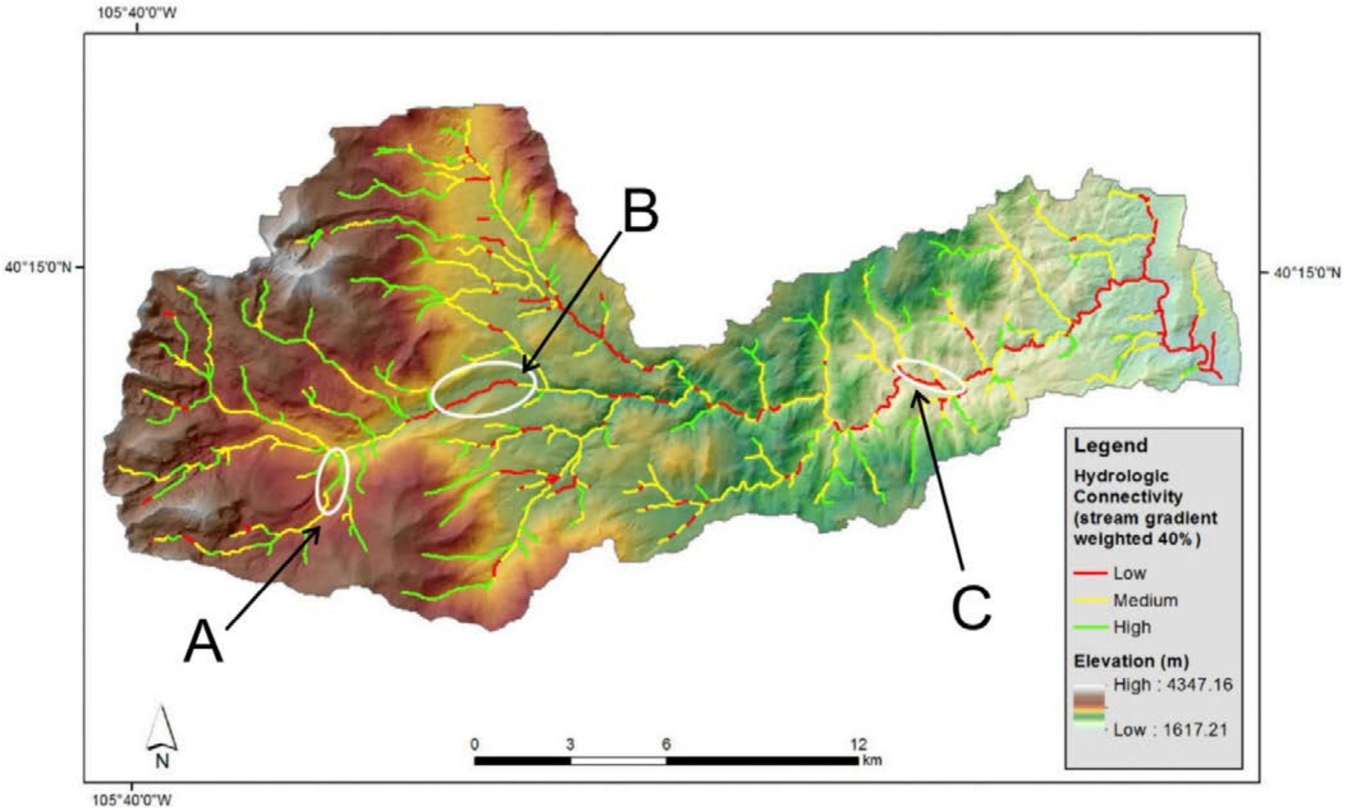
- Focus on hydrologic connectivity
- How does it control processes?
    - Hydrologic connectivity is the framework that sediment, solutes, and biota can move through and influence landscape function and development
- How do different domains interact and on what spatio/temporal scales?
    - E.g. how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



Ellen Wohl, 2018

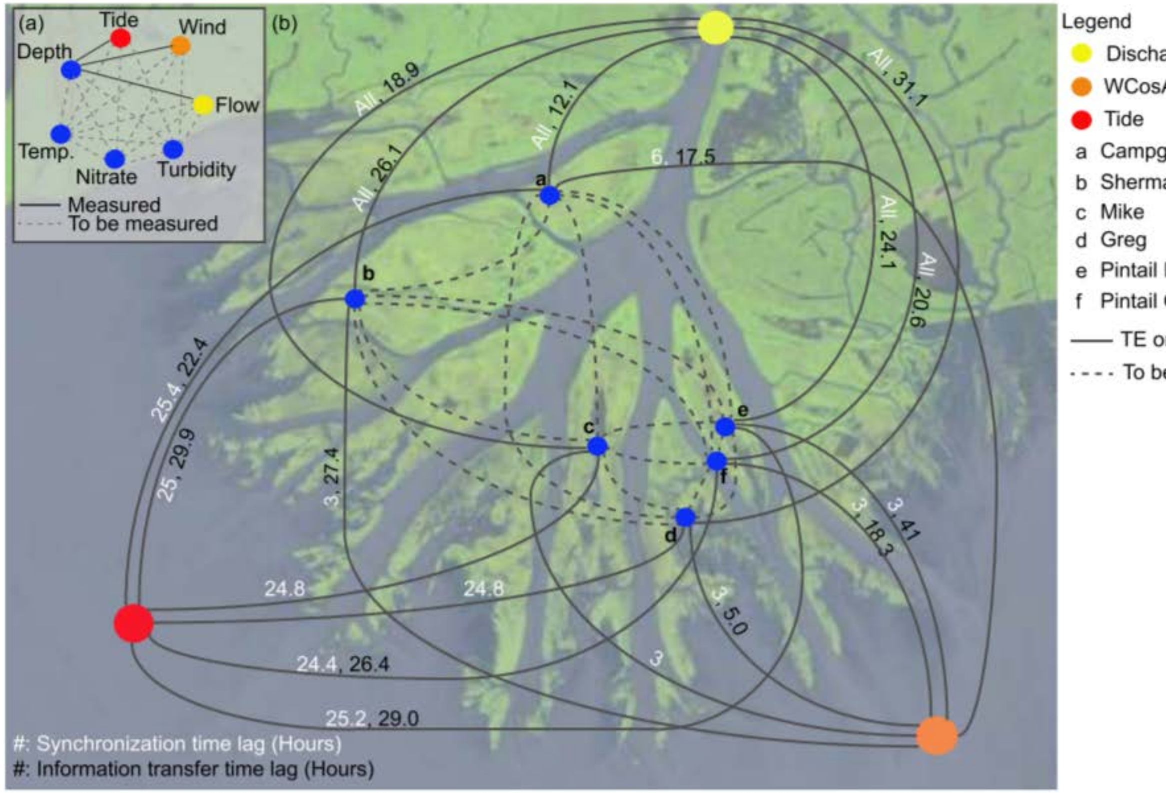
What influences connectivity? (Lots)

Stream gradient and disruption in mountain catchments



Ellen Wohl, 2017

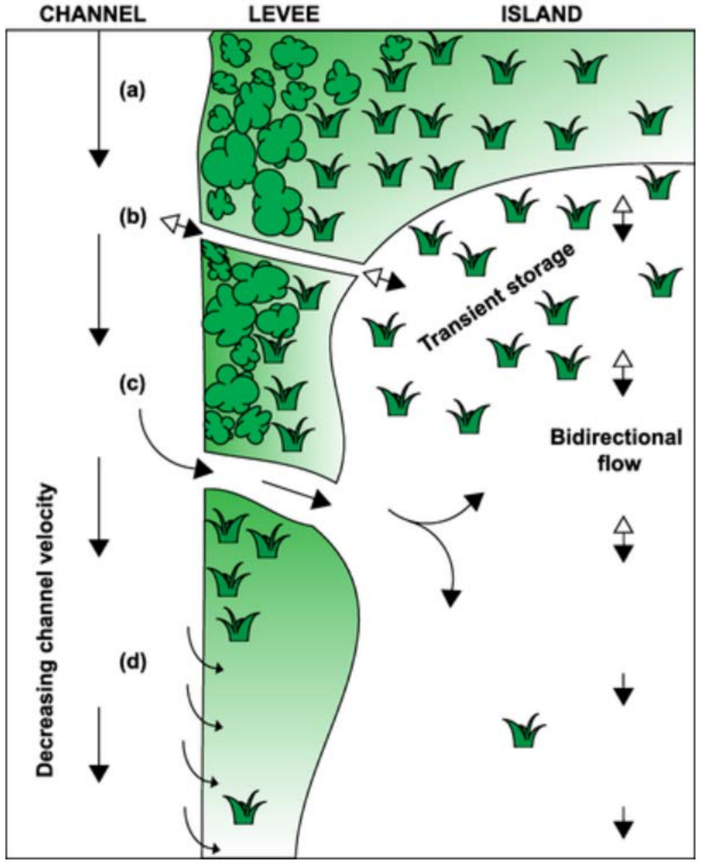
Process coupling in deltaic environments



Alicia Sendrowski and Paola Passalacqua, 2017

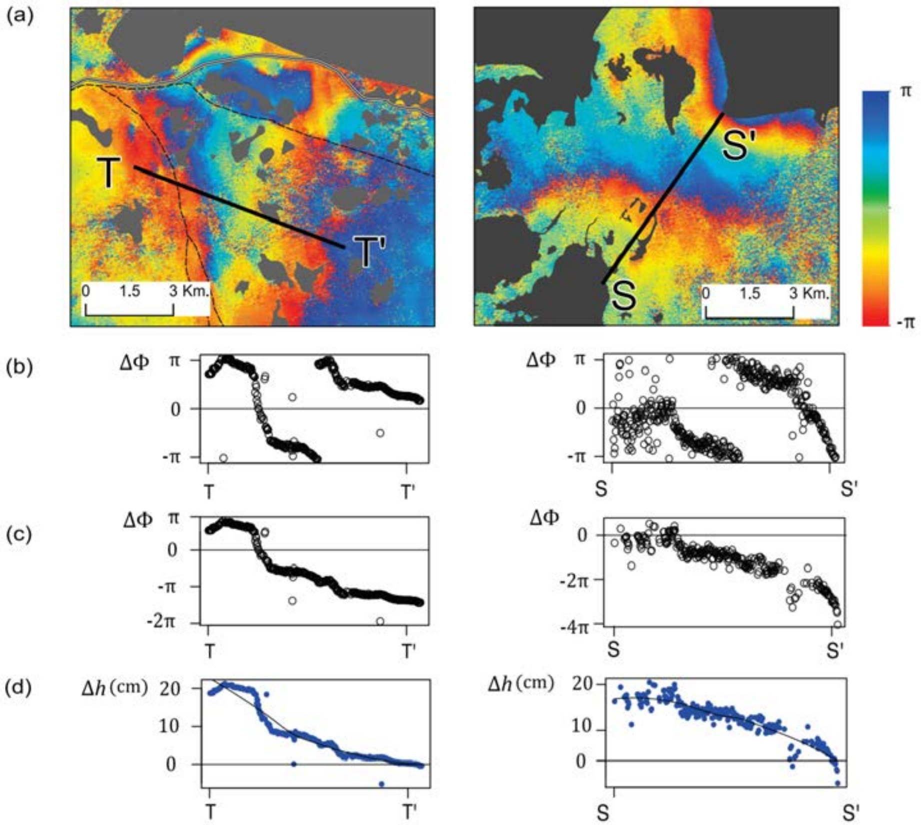
Hydrologic connectivity mediates surface processes and ecological feedbacks

Channel-island processes in deltas



Matt Hiatt et al., 2015

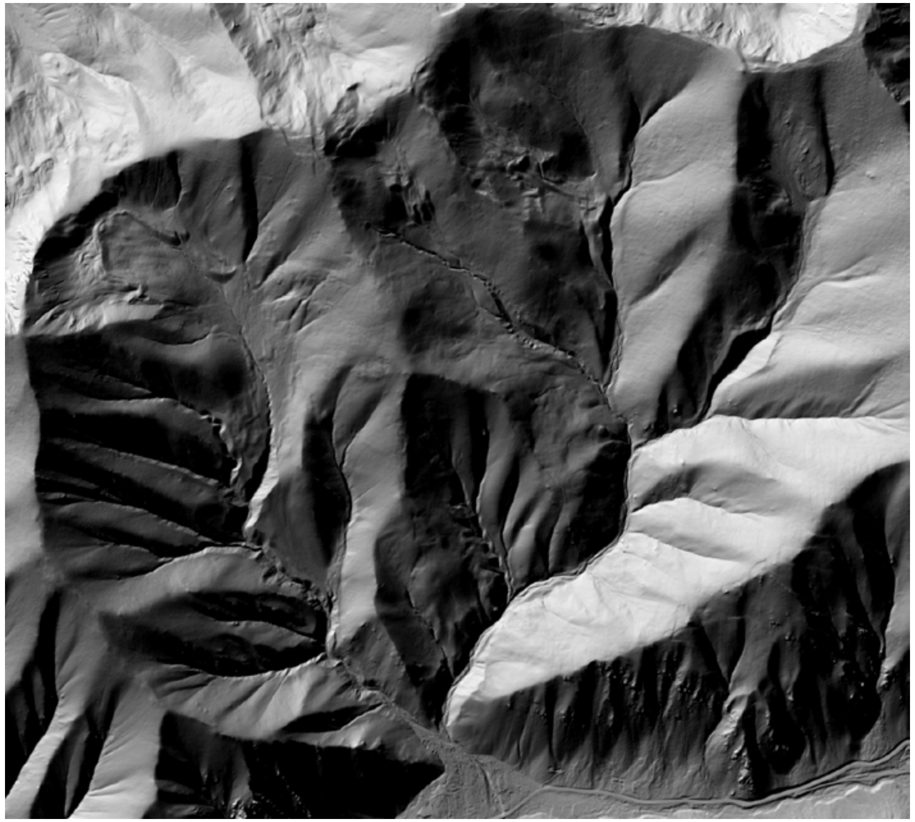
Wetland inundation during high discharge



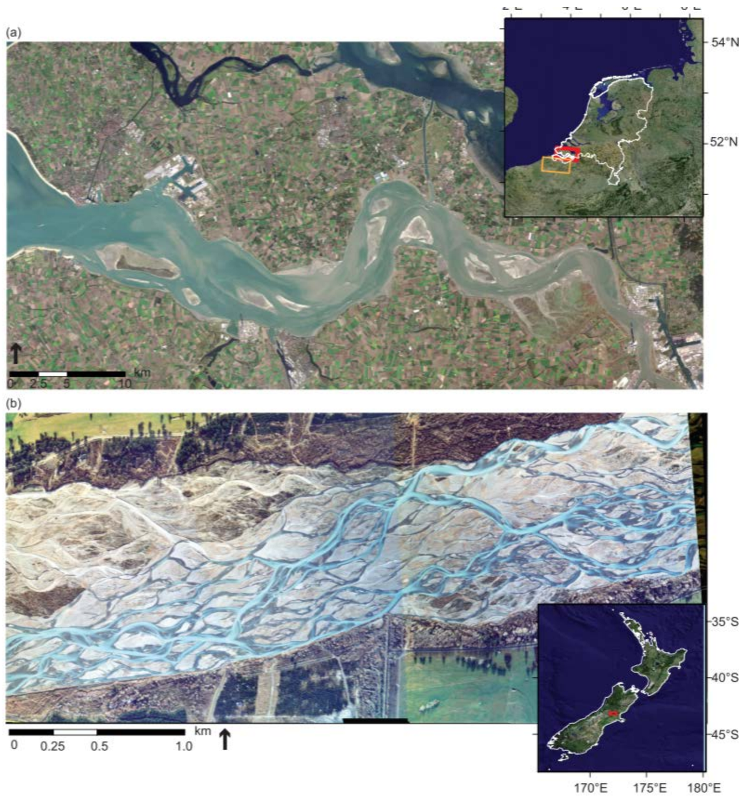
Fernando Jaramillo et al., 2018

Focus on network structure across domains

Dendritic upstream catchments

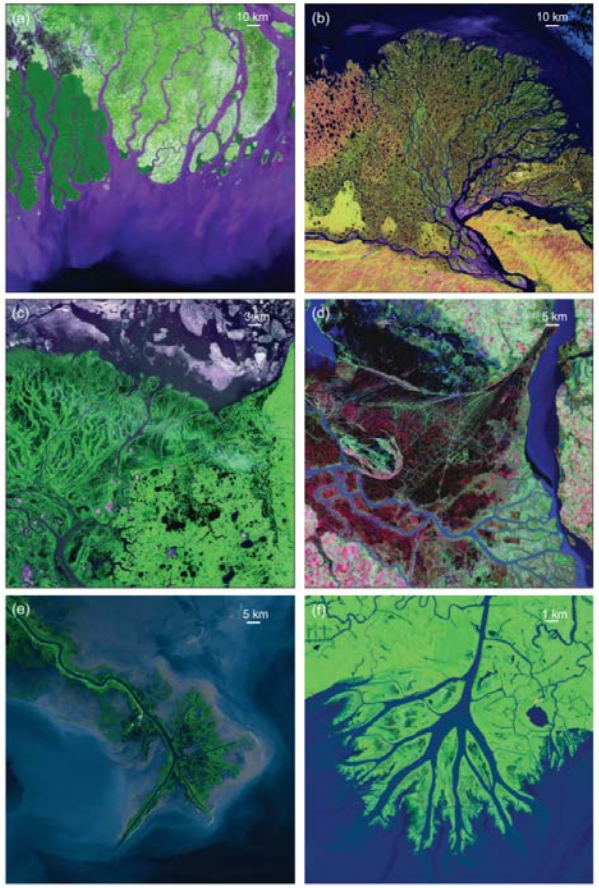


Meandering/braided streams



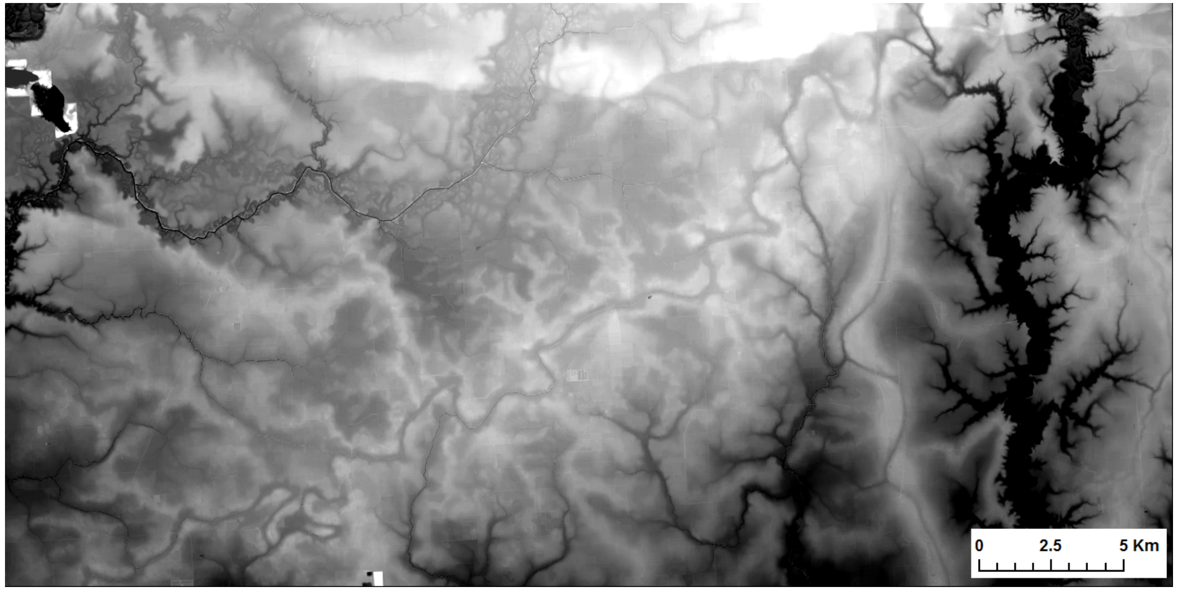
Hiatt et al., 2020

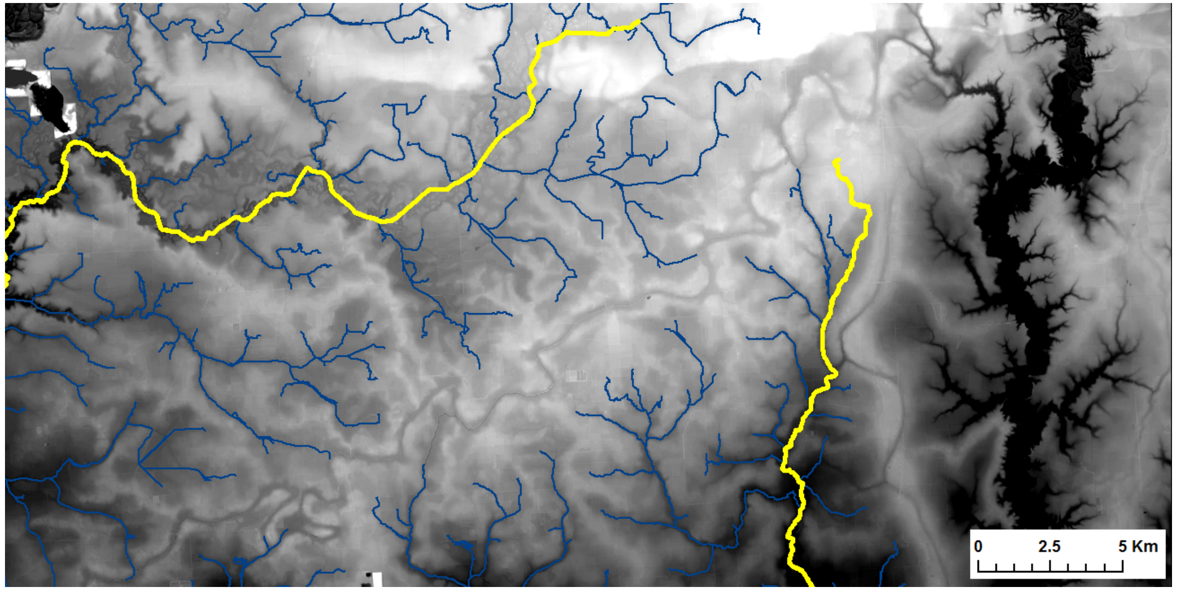
Delta distributaries

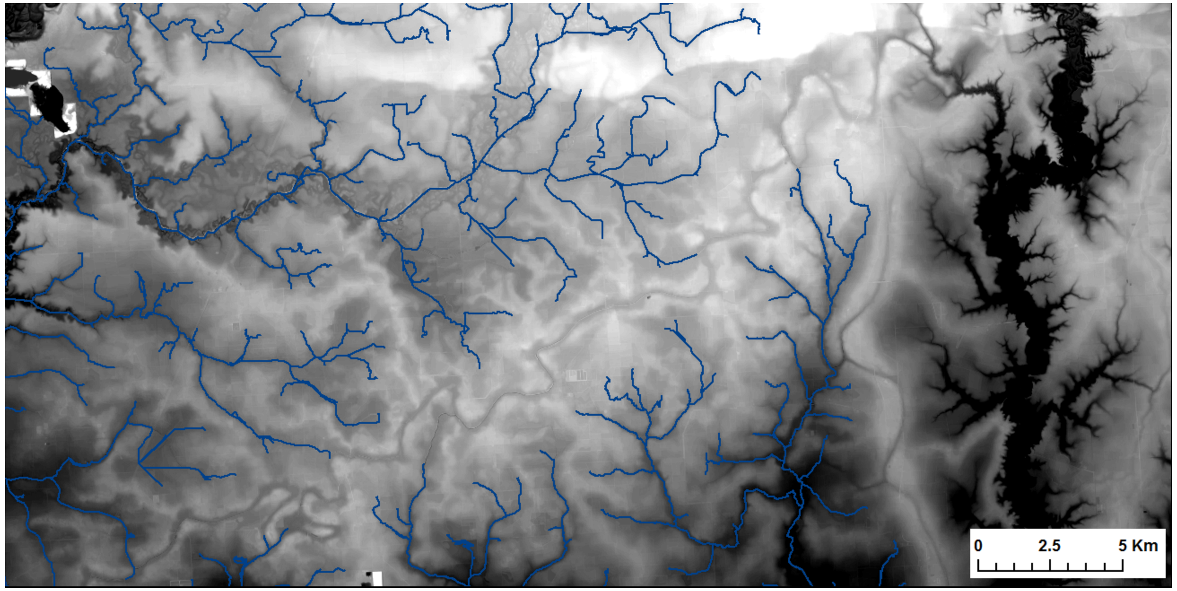


Paola Passalacqua, 2017

Typical channel network extraction and analysis workflow

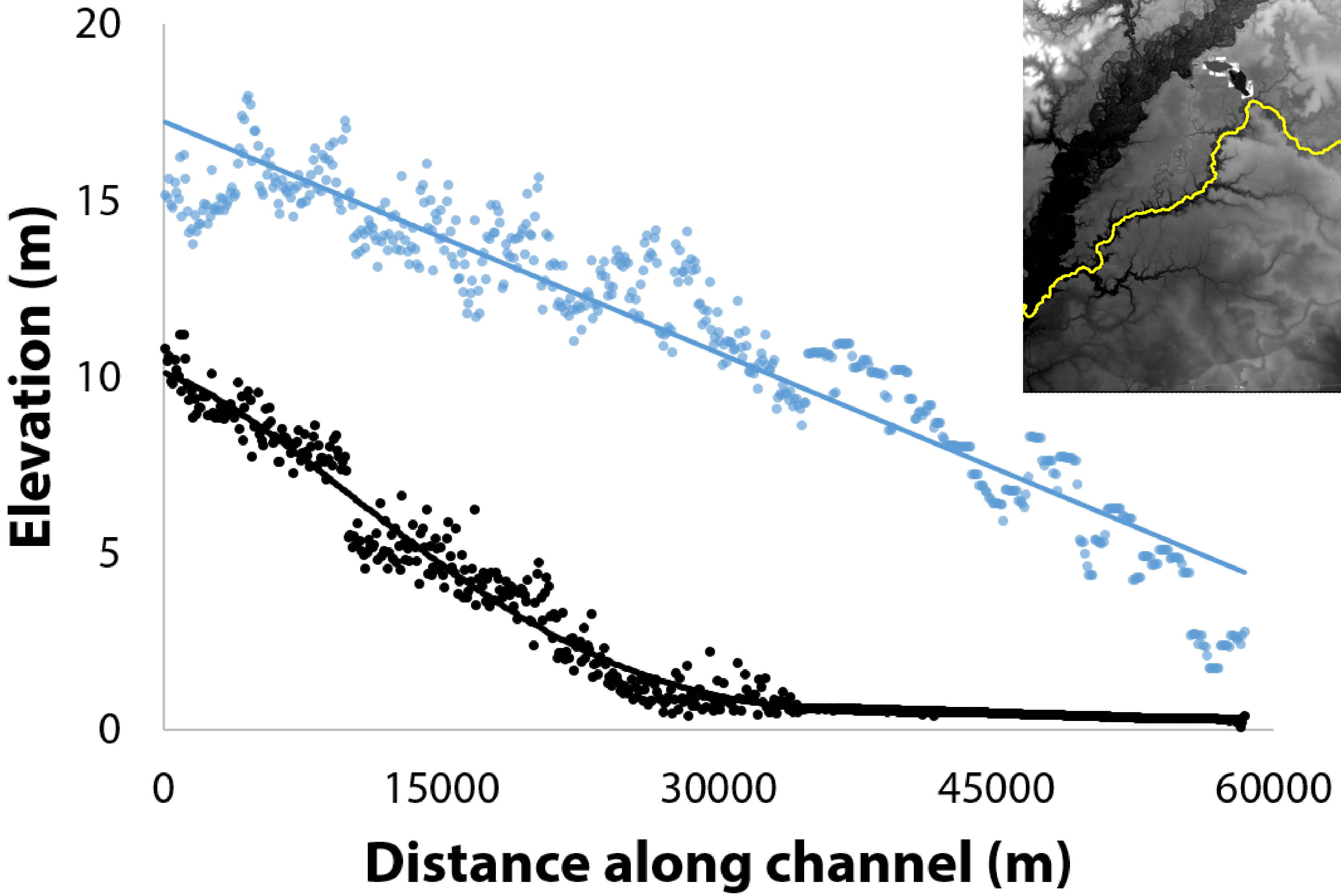


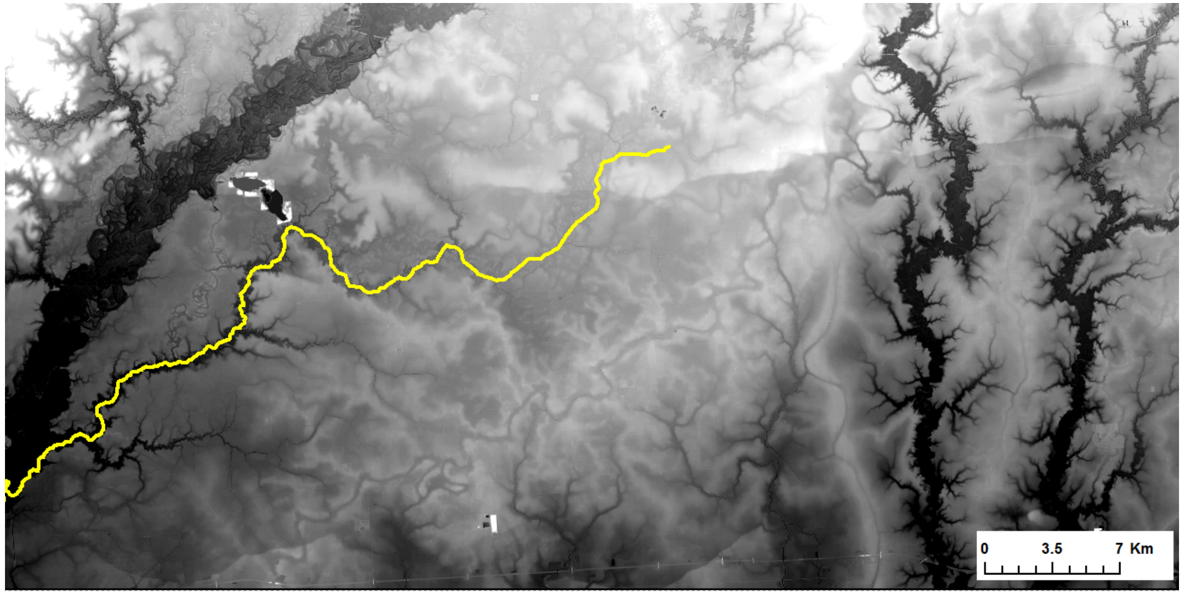




1) Create hydrologically corrected DEM
2) Steepest descent flow routing using minimum contributing area = $0.5km^2$
3) Extract trunk stream profiles and local relief
4) Examine channel heads and divides to understand bounding morphology
5) Extract network metrics (length, area)

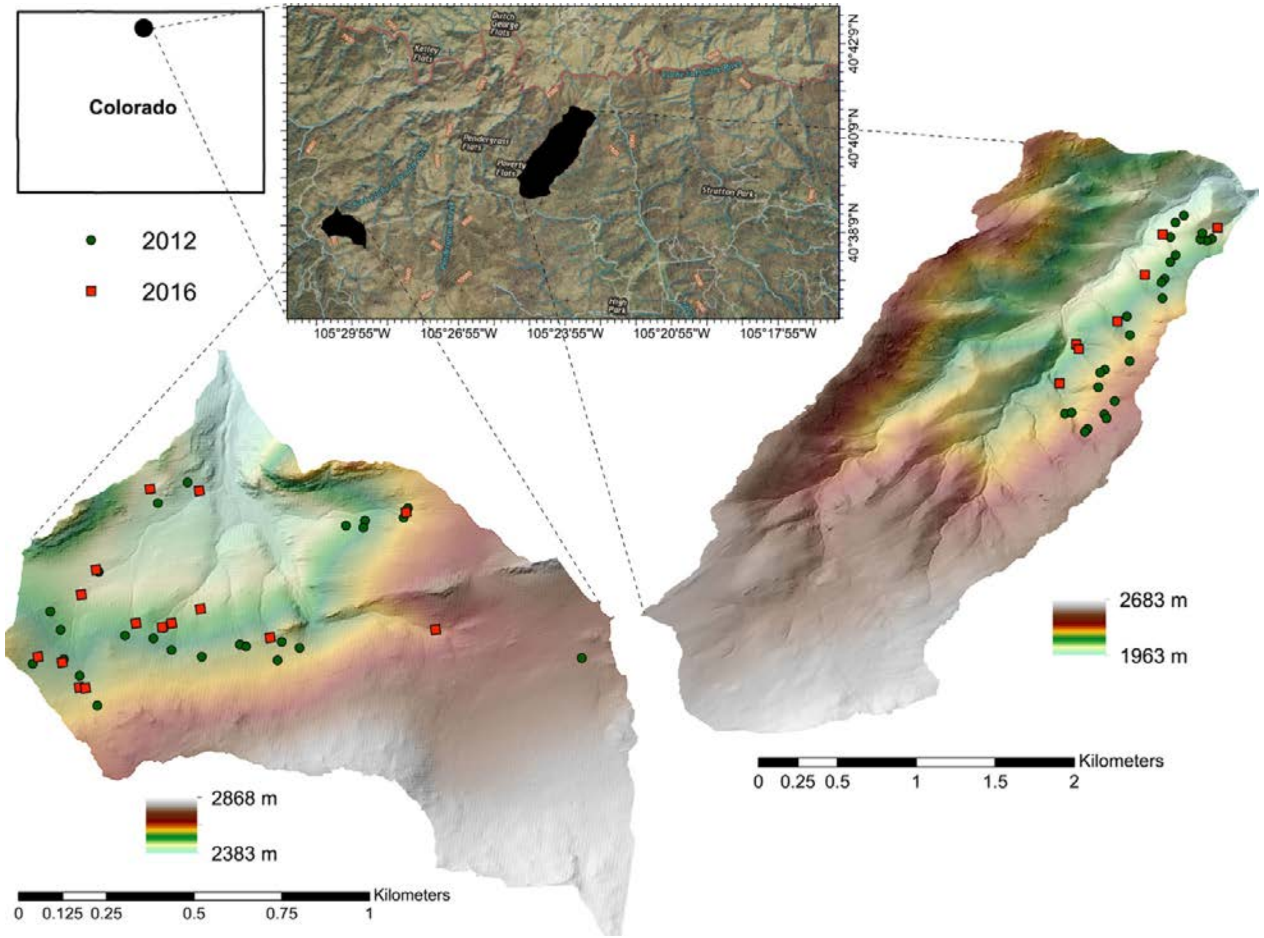
Stream profile and bounding ridge elevations





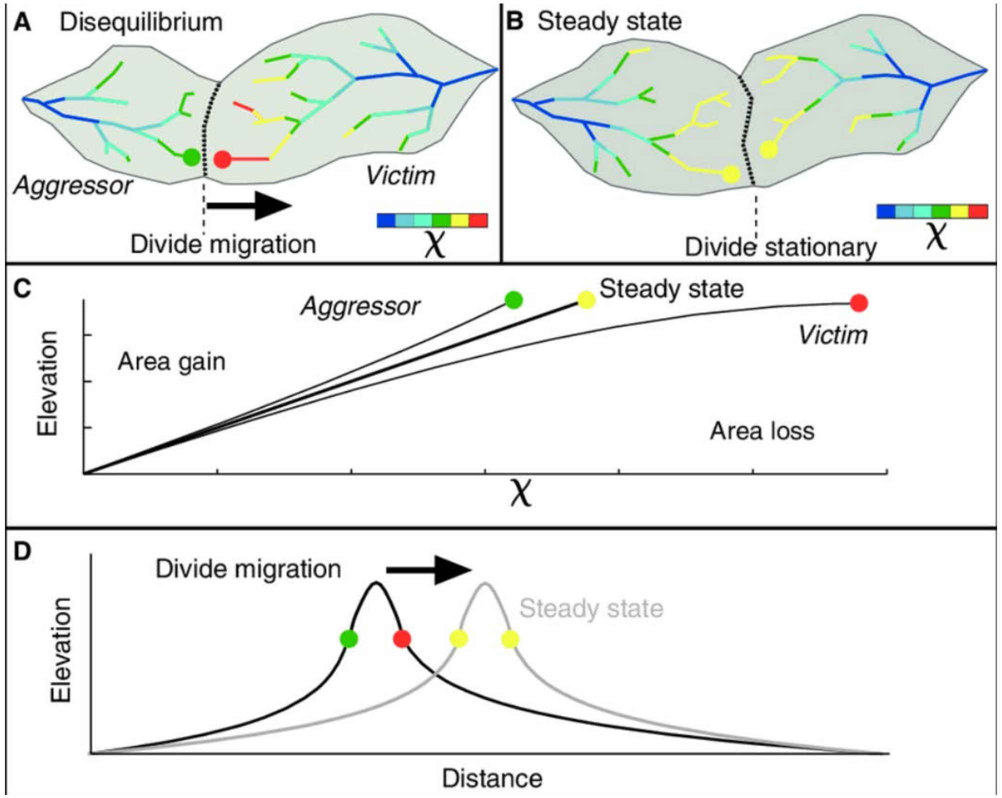
Networks are dynamic in space and time

Channel head number and position post-wildfire



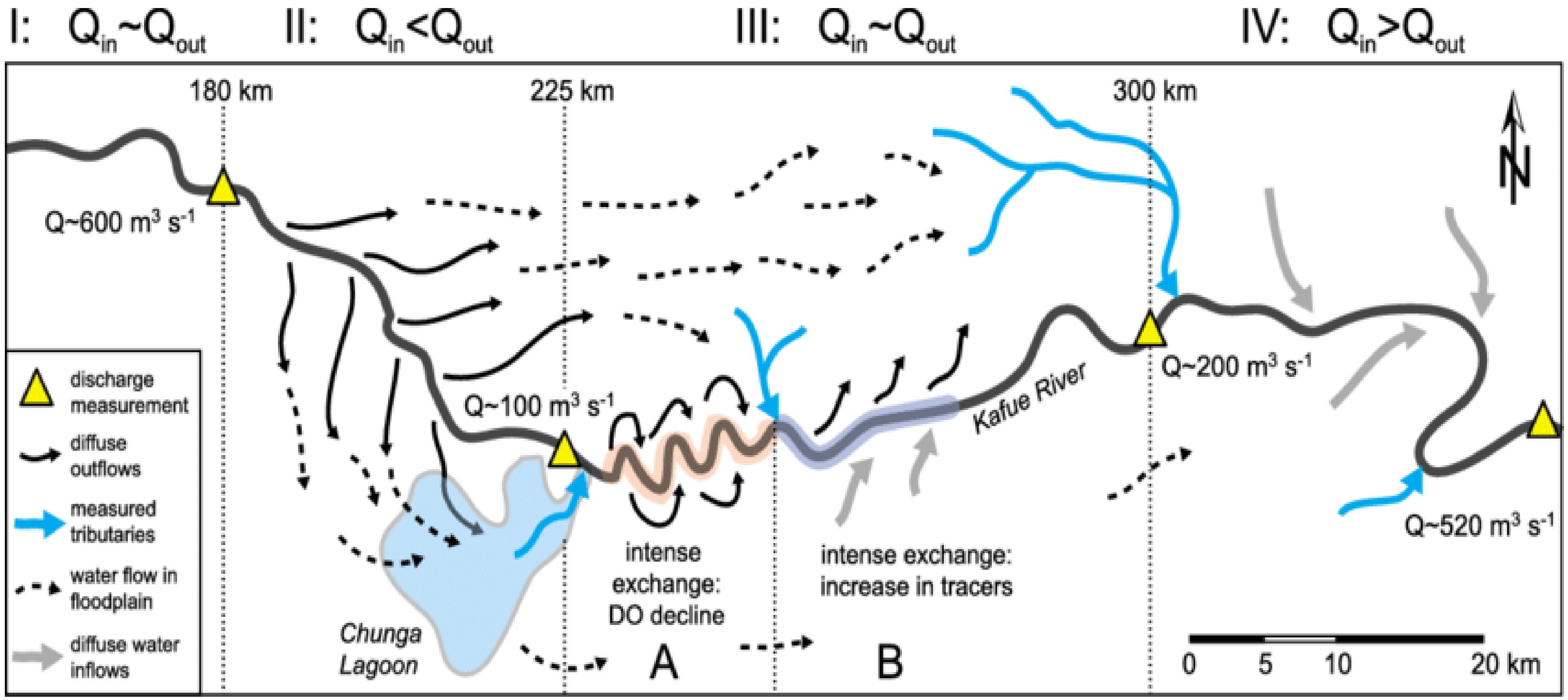
Ellen Wohl and Daniel Scott, 2017

Geologic-scale divide migration and capture



Sean Willet et al., 2014

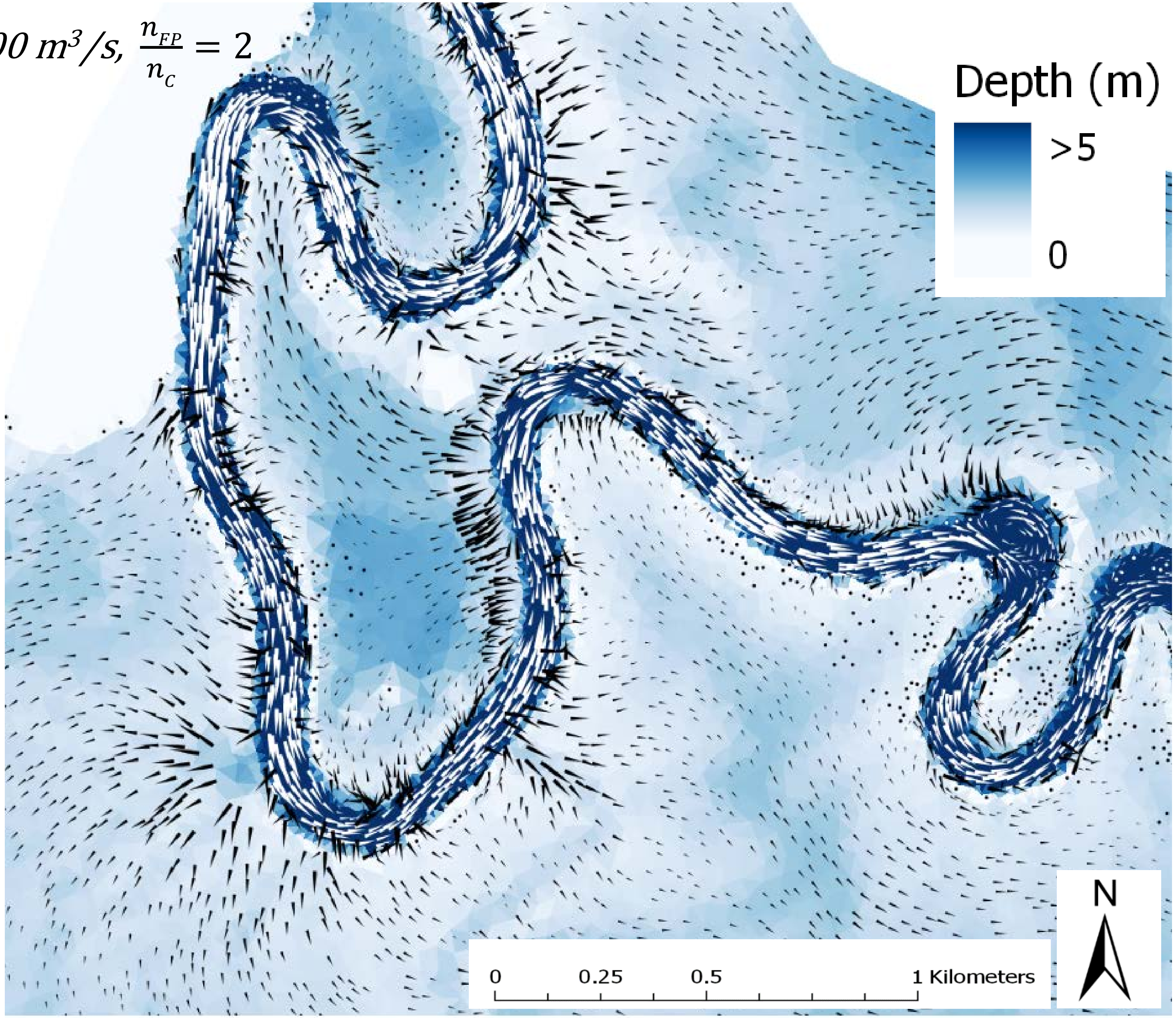
Channel-floodplain connectivity



Source: Zurbrügg et al.(2012)

How is connectivity established? Insights from HRT and Numerical Modeling

$Q = 2500\ m^3/s,\ \frac{n_{FP}}{n_C} = 2$



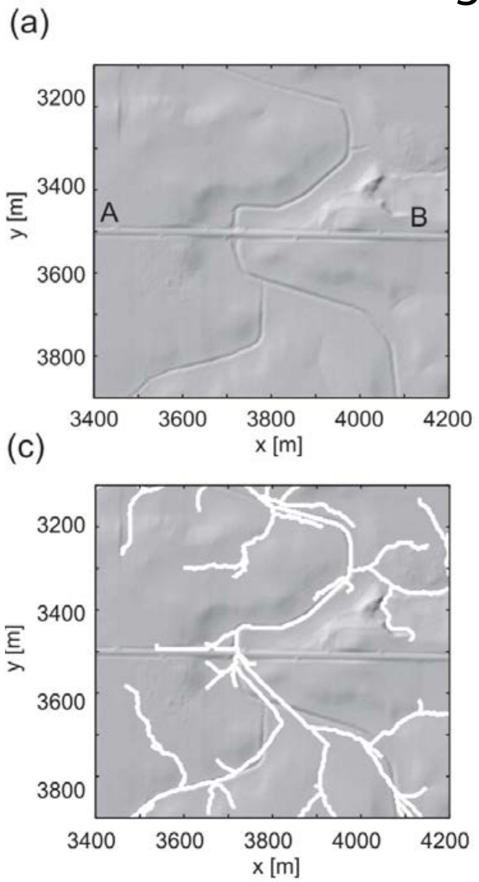
Small-scale topography drives channel-floodplain connectivity

ANUGA modeling results from **Shazzadur Rahman** UT-Austin

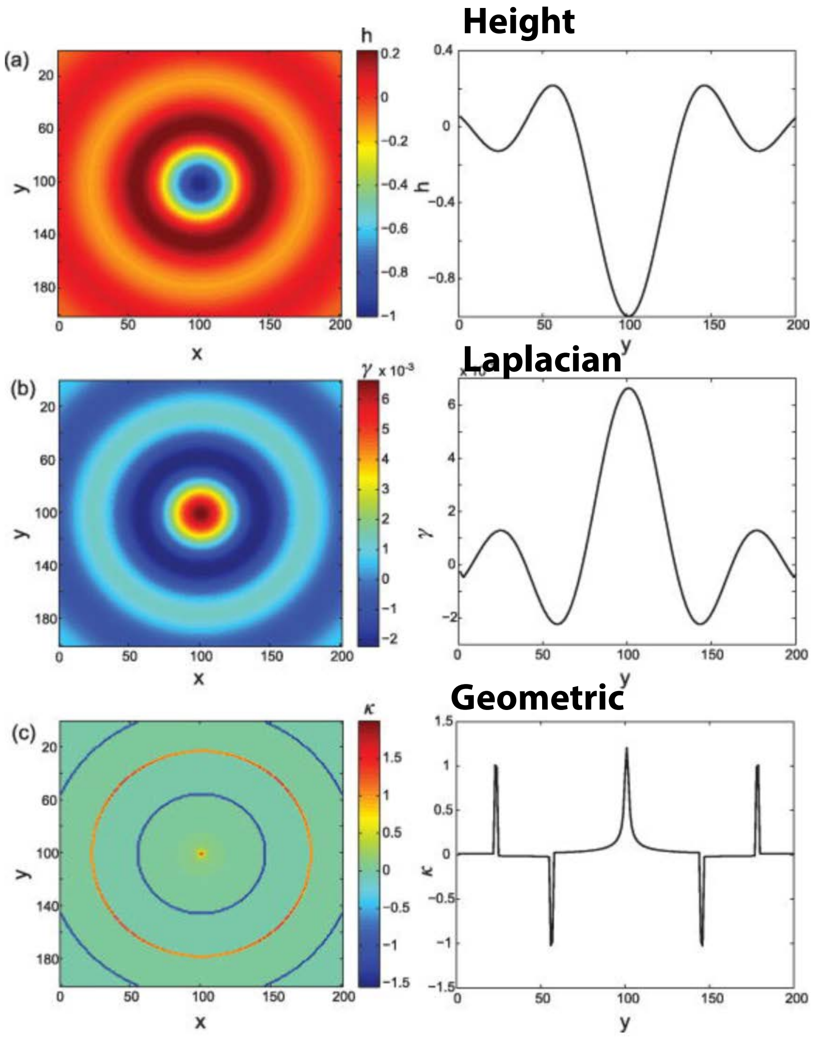
Analyzing channel network structure

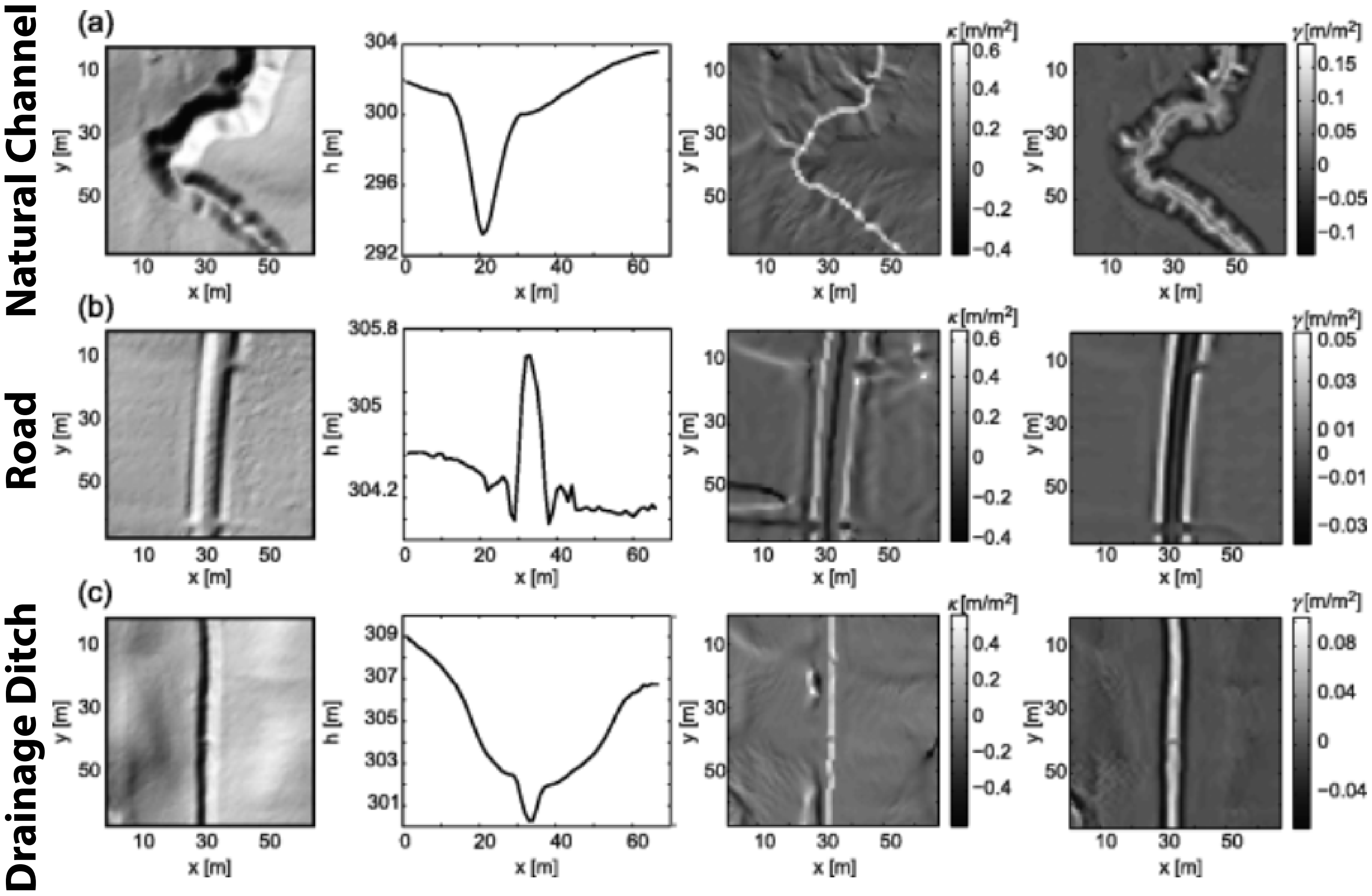
Classic channel network delineation schemes can misplace flowlines based on pit filling and hydro-flattening

Man-made objects can hinder flow accumulation routing

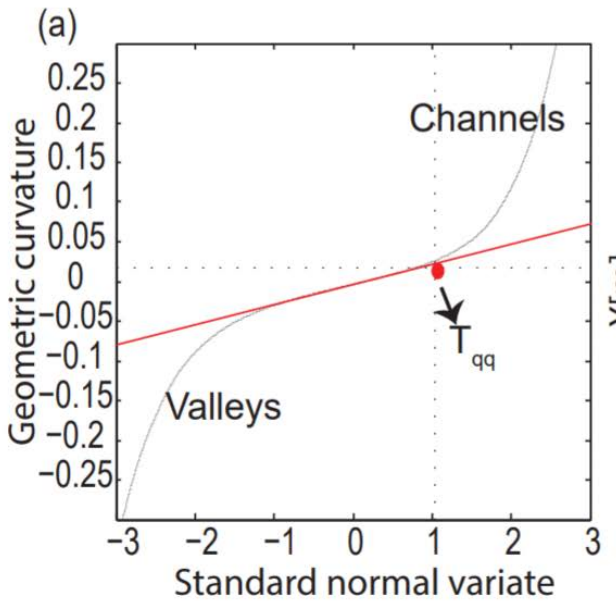


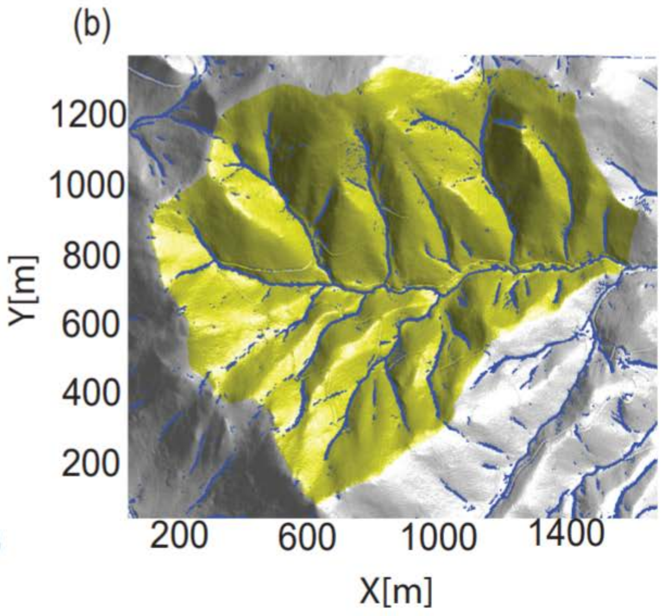
Curvature-based approach: Geonet

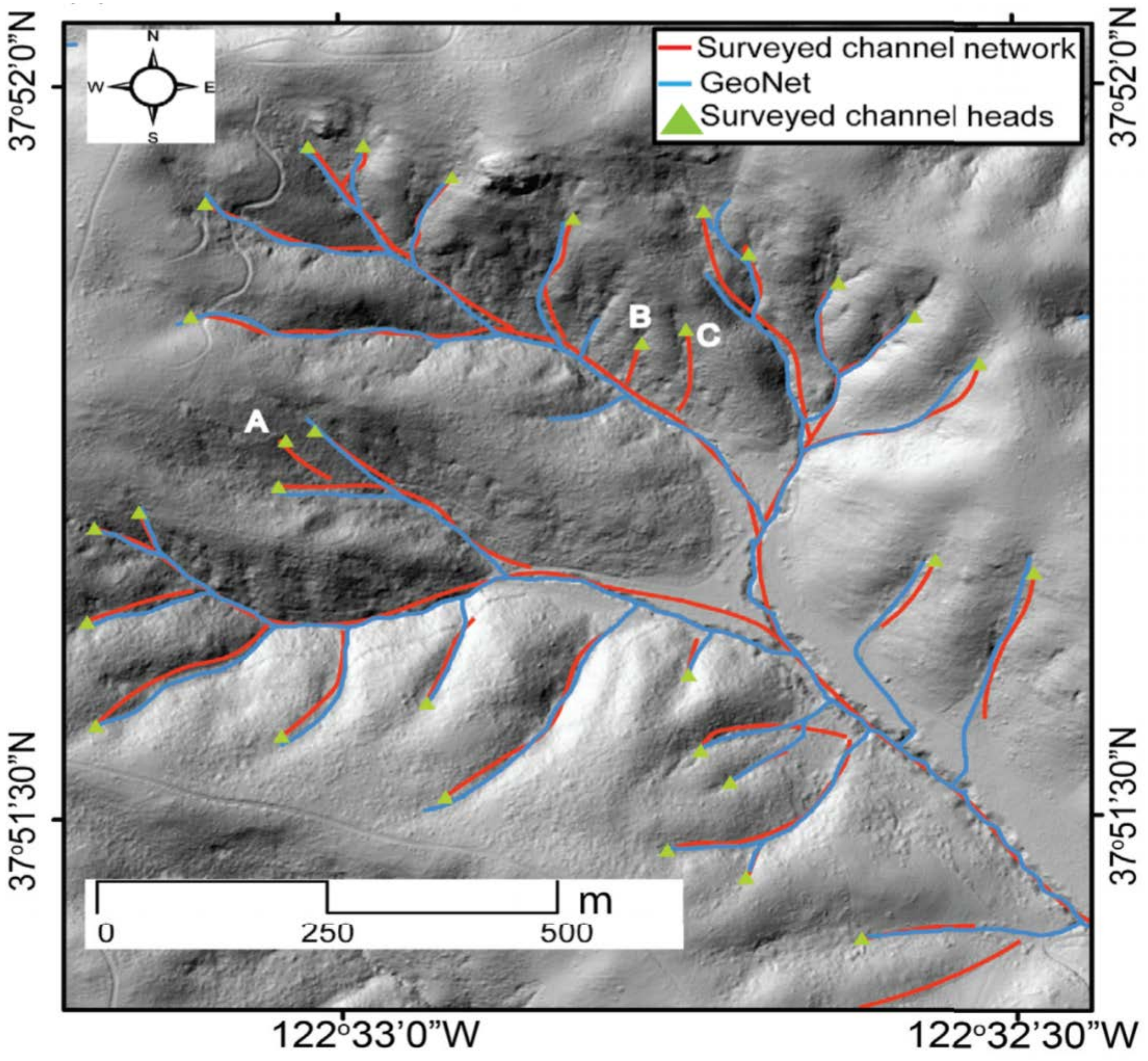




Curvature-based approach: Geonet







4. Hands-on with HRT

Time to move to the Google co-lab!

- Channel network delineation and visualization

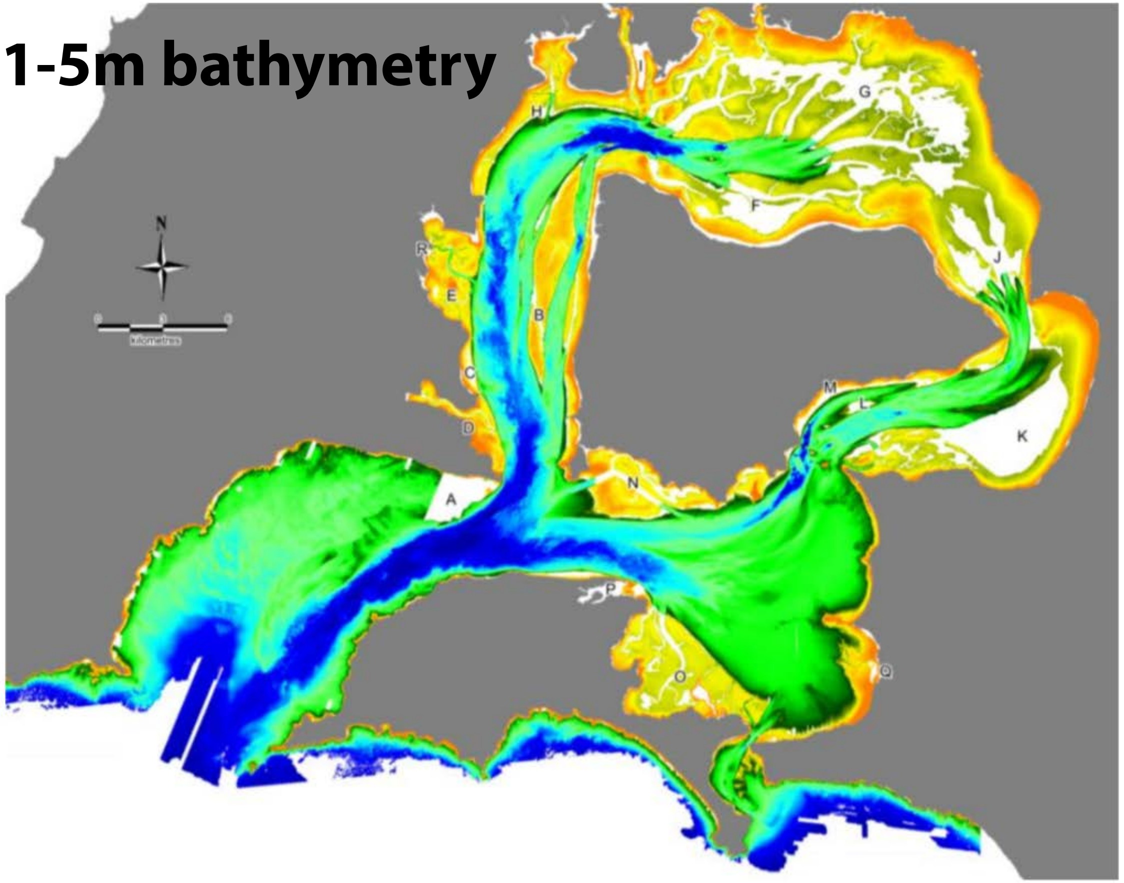
5. Utility of HRT in modeling

- 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!

1-5m bathymetry



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

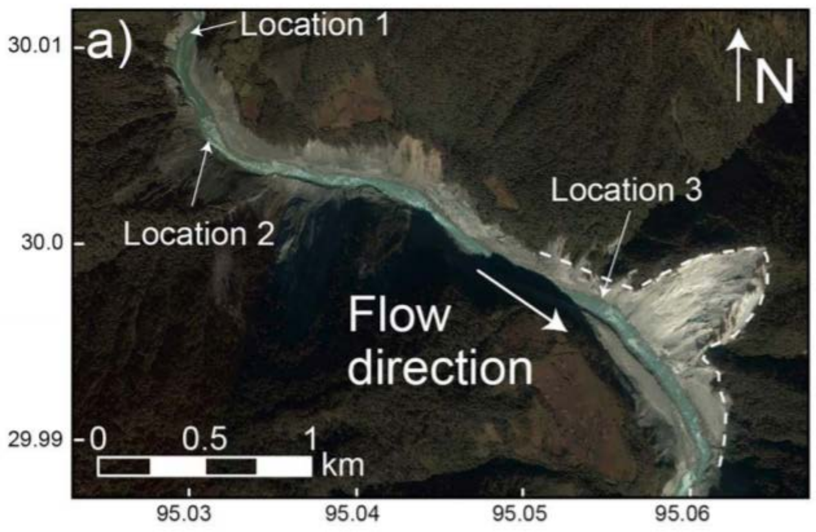
e.g. elevation, surface roughness, vegetation density

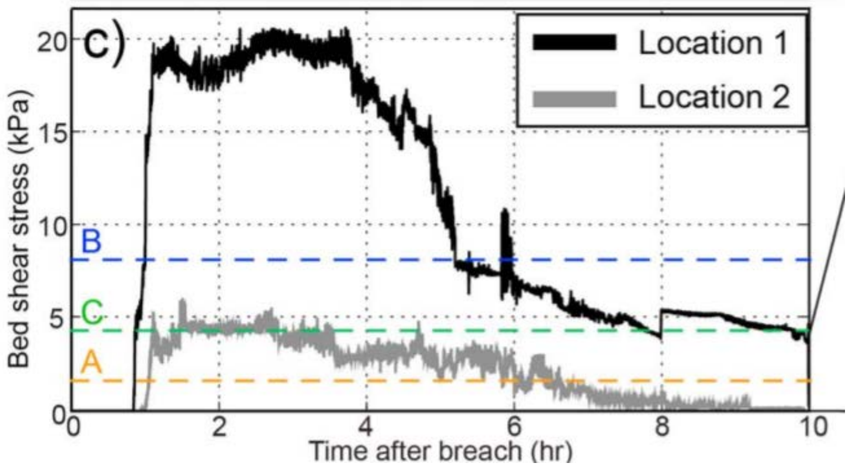
Often disconnect between observations spatial scale and what is computationally possible to handle in a model

C) Validation

How well did our model do?

e.g. topographic differencing, simulated vs. observed flood inundation

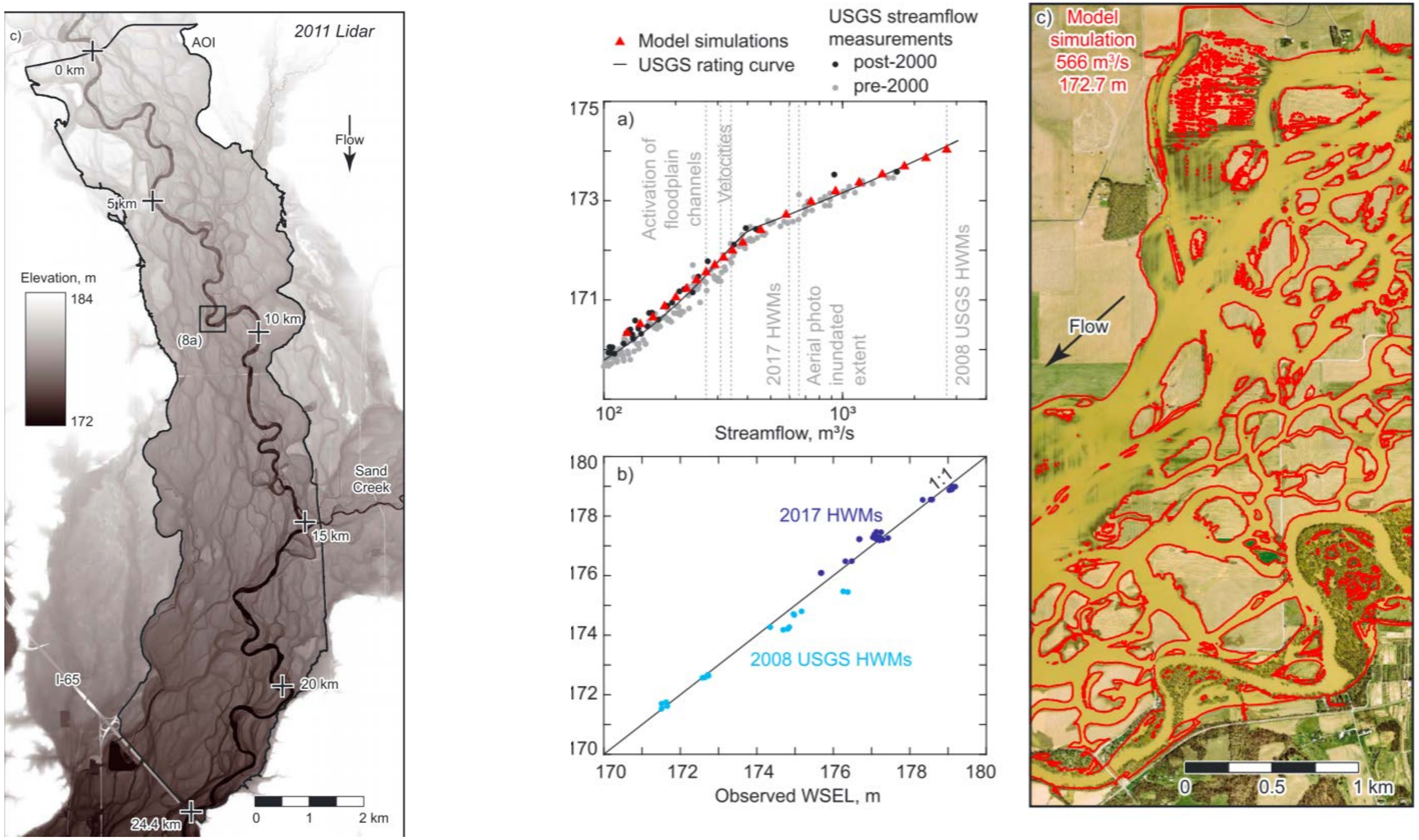




Michael Turzewski et al., 2019. The Geomorphic Impact of Outburst Floods: Integrating Observations and Numerical Simulations of the 2000 Yigong Flood, Eastern Himalaya

Conception: Presence of small-scale features

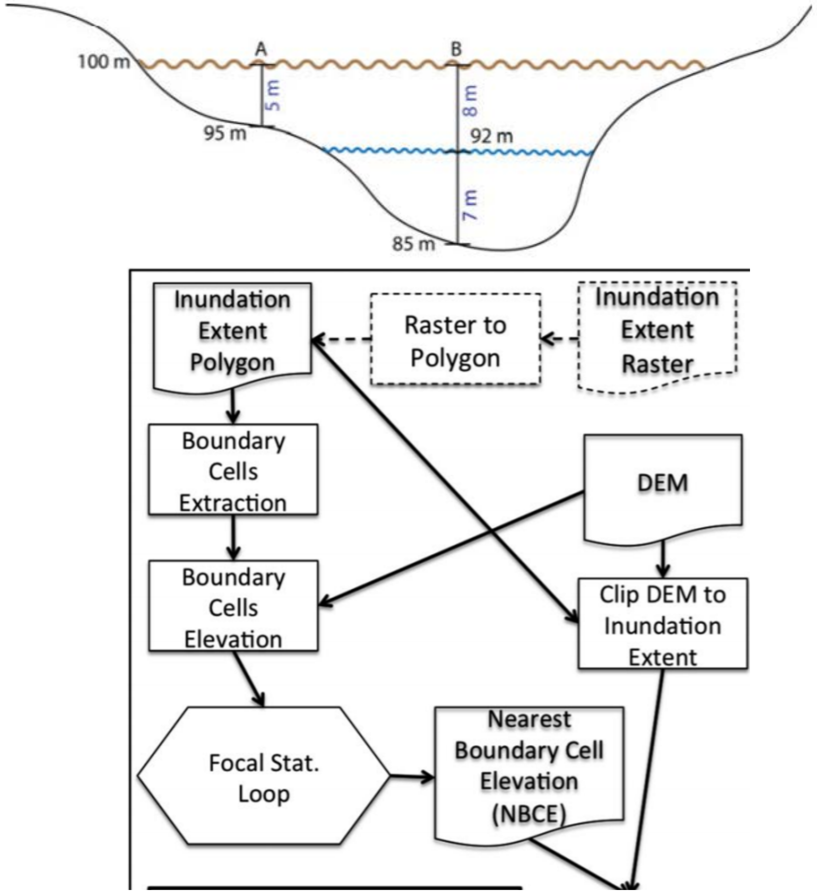
Recognition of low-relief floodplain channels using HRT

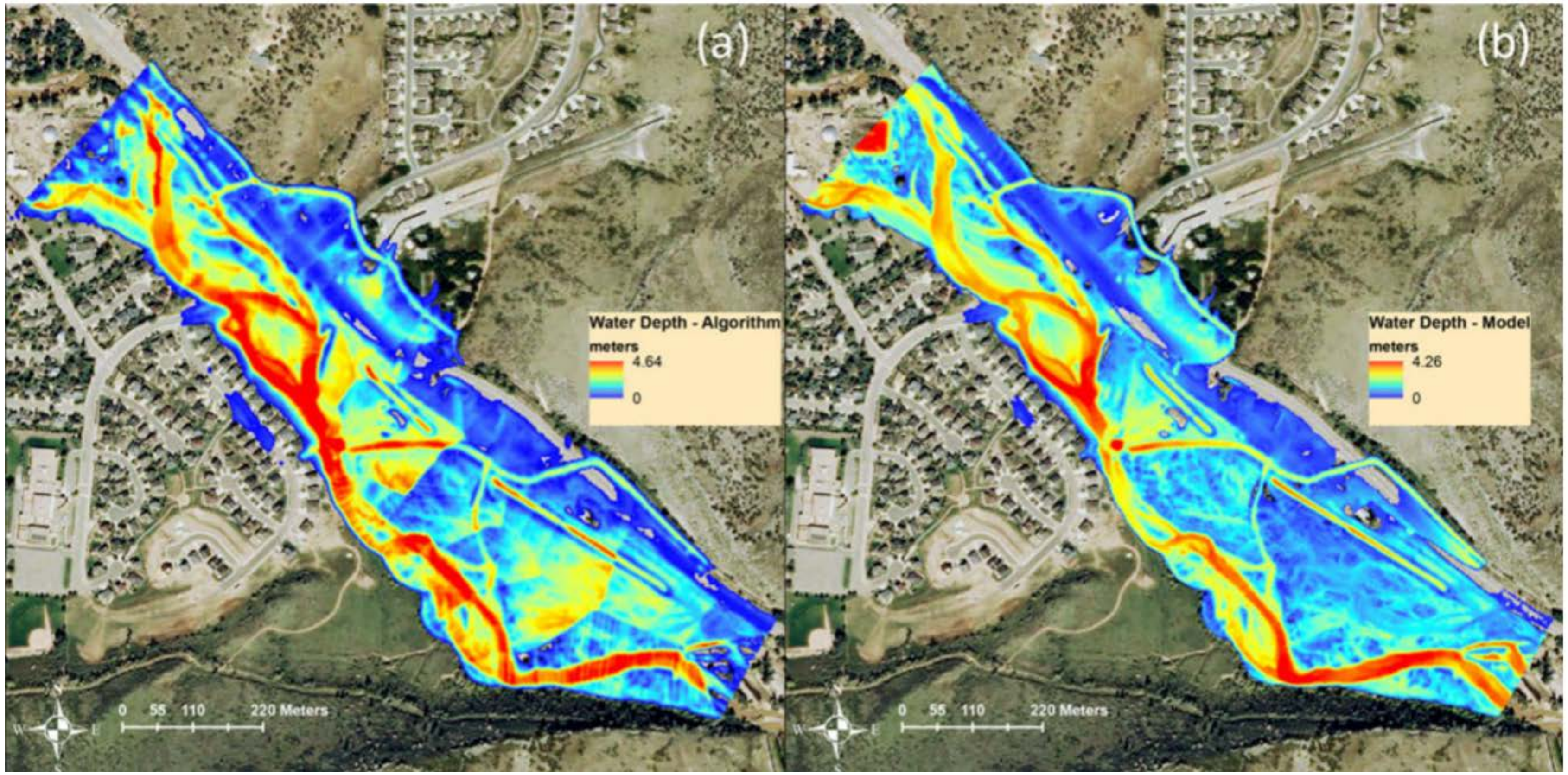


Jonathan Czuba et al., 2019. Dynamics of Surface-Water Connectivity in a Low-Gradient Meandering River Floodplain. WRR

Input: High-resolution boundary conditions

Modeling floodwater depths over 1m stream DEM

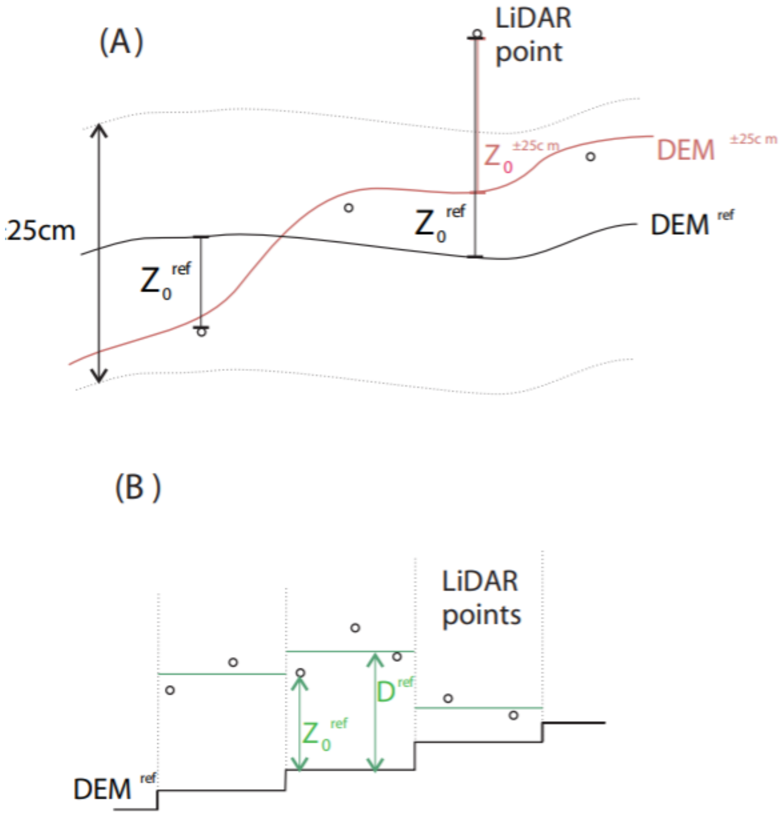


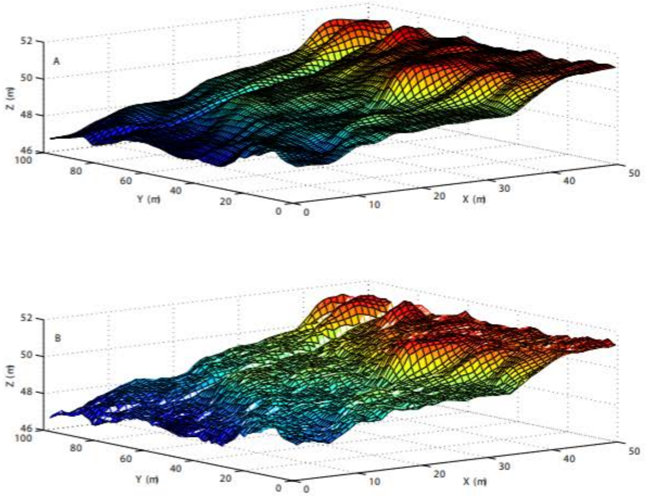


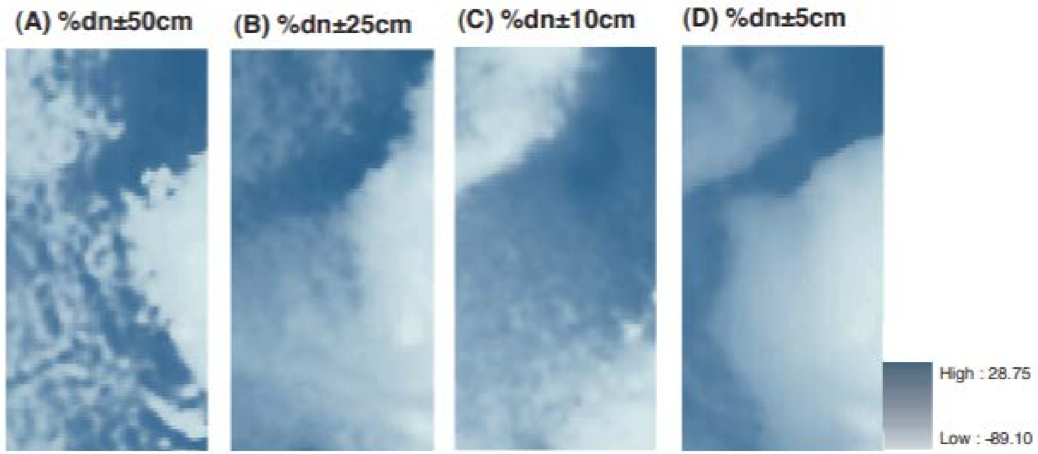
Sagy Cohen et al., 2018. Estimating floodwater depths from flood inundation maps and topography. JAWRA

Input: Sub-grid attribute parameterization

Distributed roughness coefficients from lidar point clouds



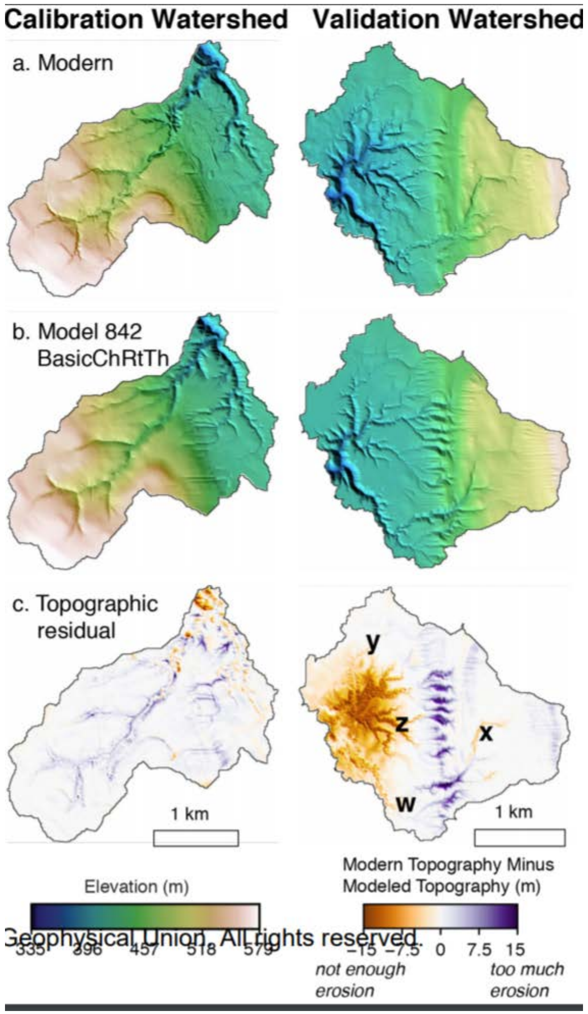


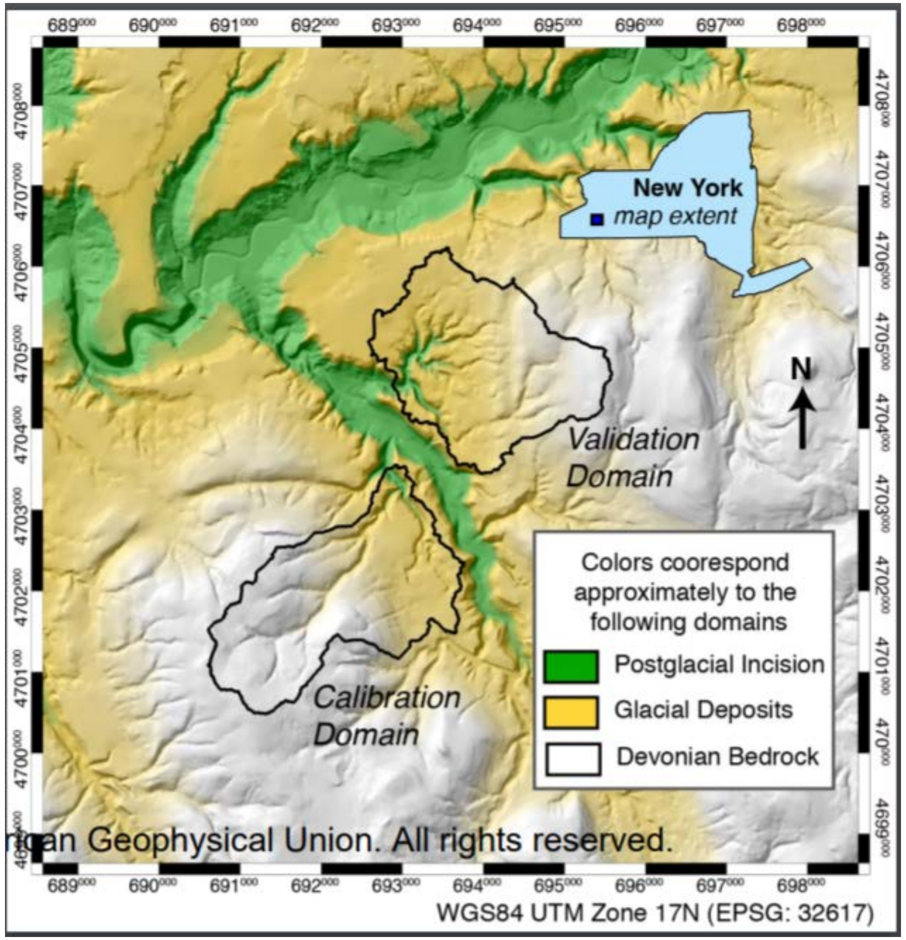


Angeles Casas et al., 2010. A method for parameterizing roughness and topographic sub-grid scale effects in hydraulic modeling from lidar data. HESS

Validation: Testing modeling domains

Model selection for long-term landscape evolution

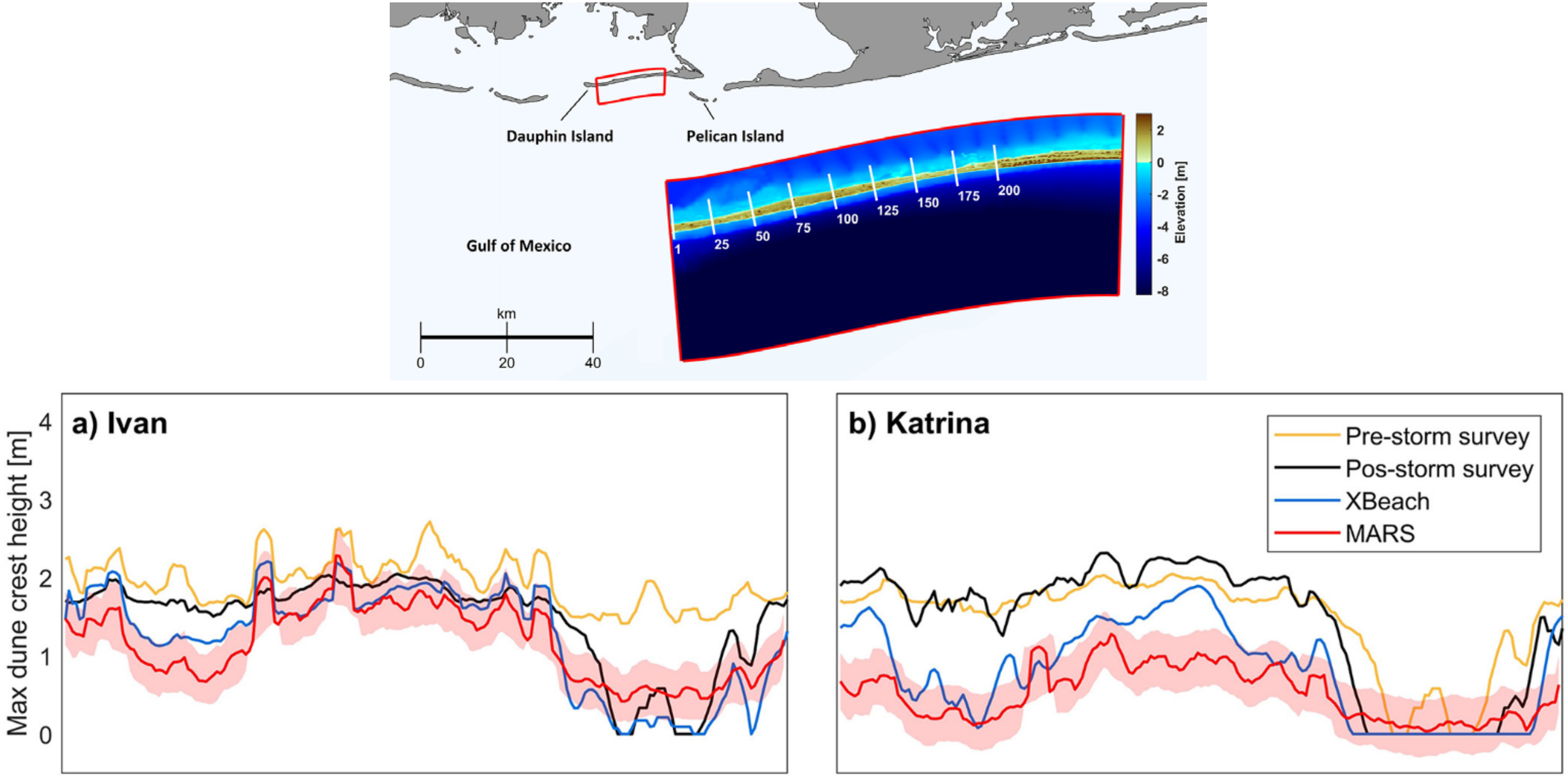




Katherine Barnhart et al., 2020. Inverting topography for landscape evolution model process representation: Part 2, calibration and validation

Validation: Direct comparison of modeled change

Tropical storm induced barrier island erosion

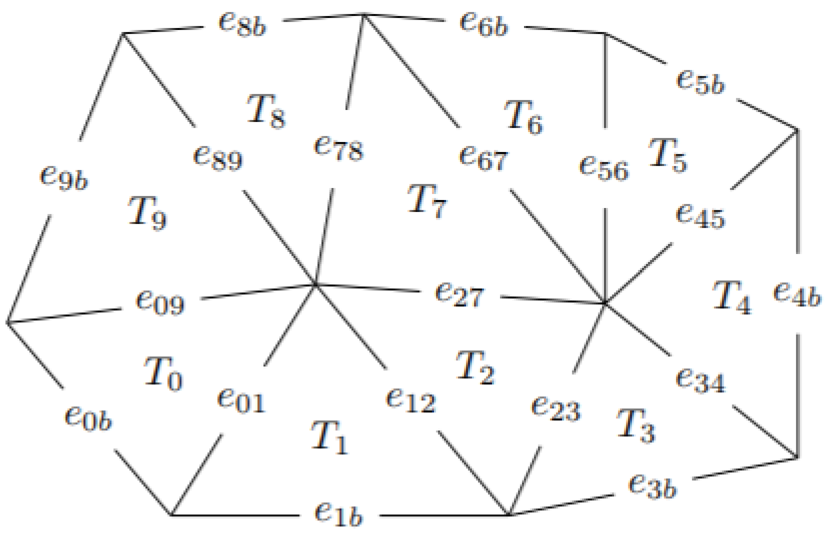


Santos et al., 2019. Combining Numerical and Statistical Models to Predict Storm-Induced Dune Erosion. JGR-ES

Illustration of modeling workflow: ANUGA!

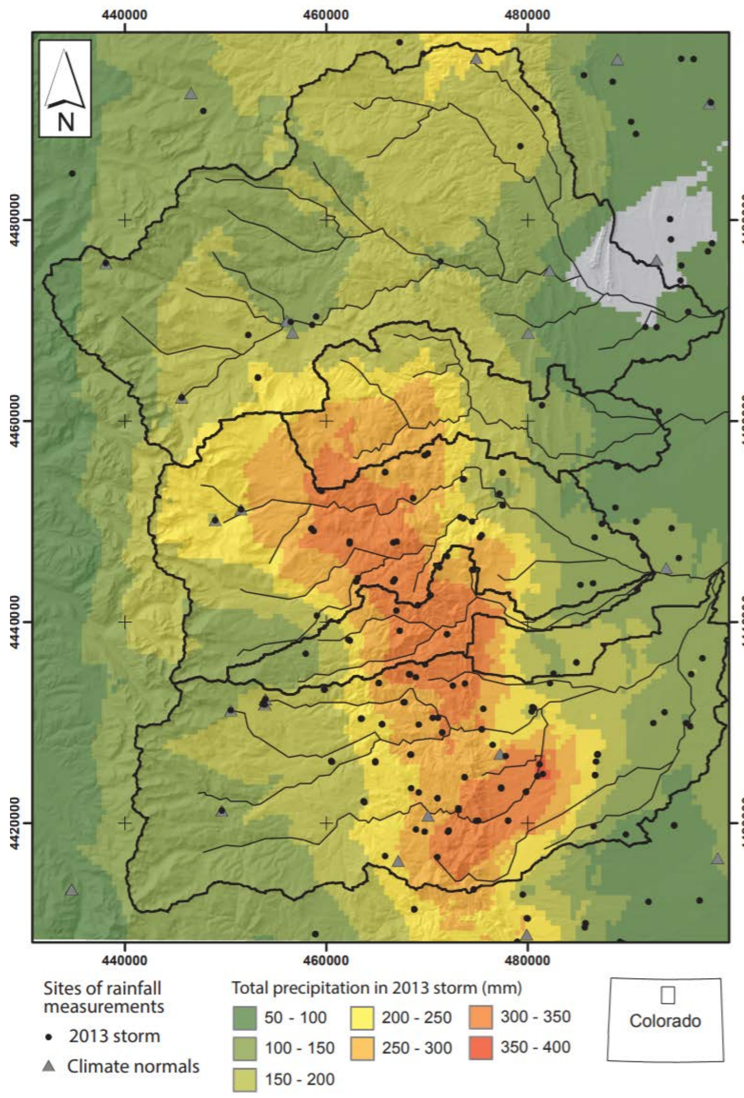
Hydrodynamic modeling code from the **A**ustralian **N**ational **U**niversity and **G**eoscience **A**ustralia

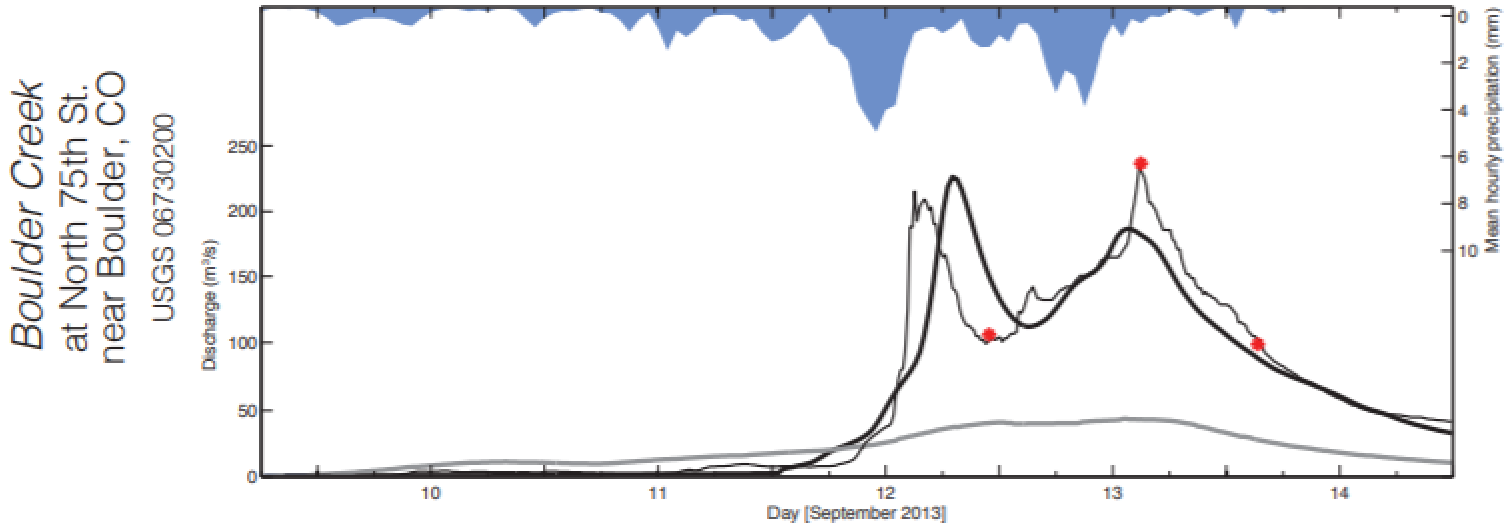
- Open-source solver for depth-integrated, finite-volume 2D shallow water equations
- Originally developed for tsunami inundation modeling, more recently adapted and employed for flood and sediment transport modeling
- Uses an unstructured triangular mesh that allows for multiple resolution and parameter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



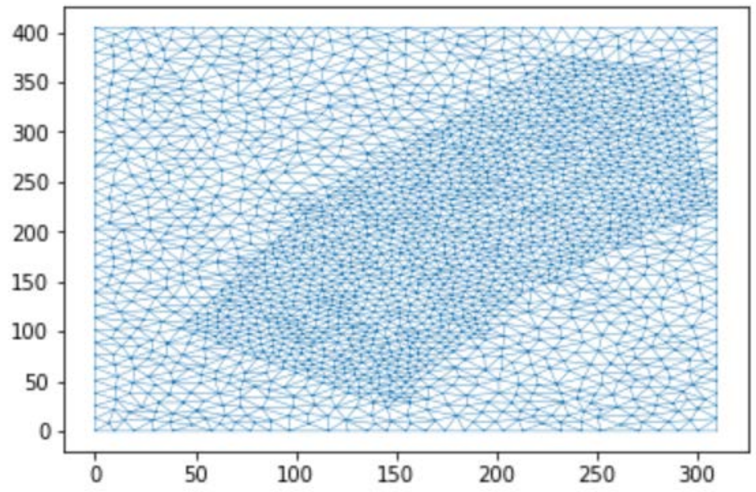


Mariela Perignon, 2014. PhD Dissertation

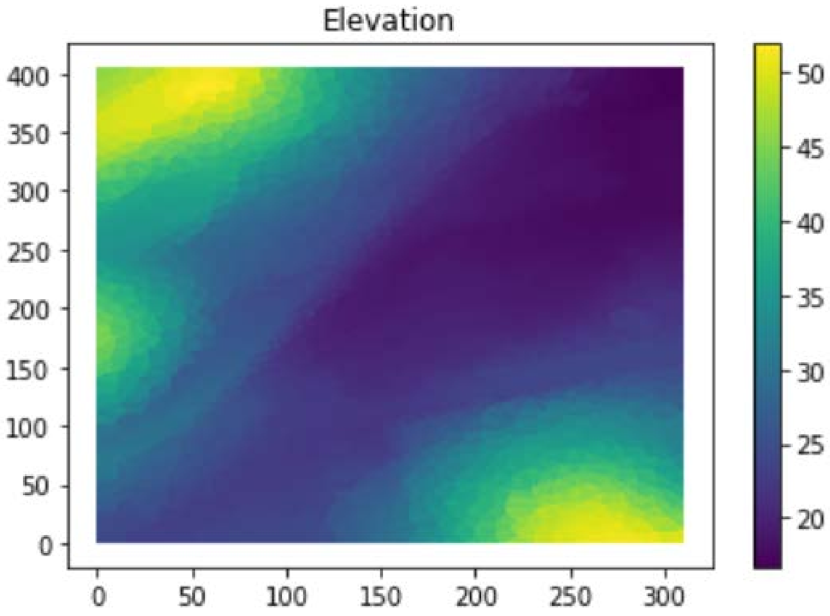
ANUGA model domain setup

- 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

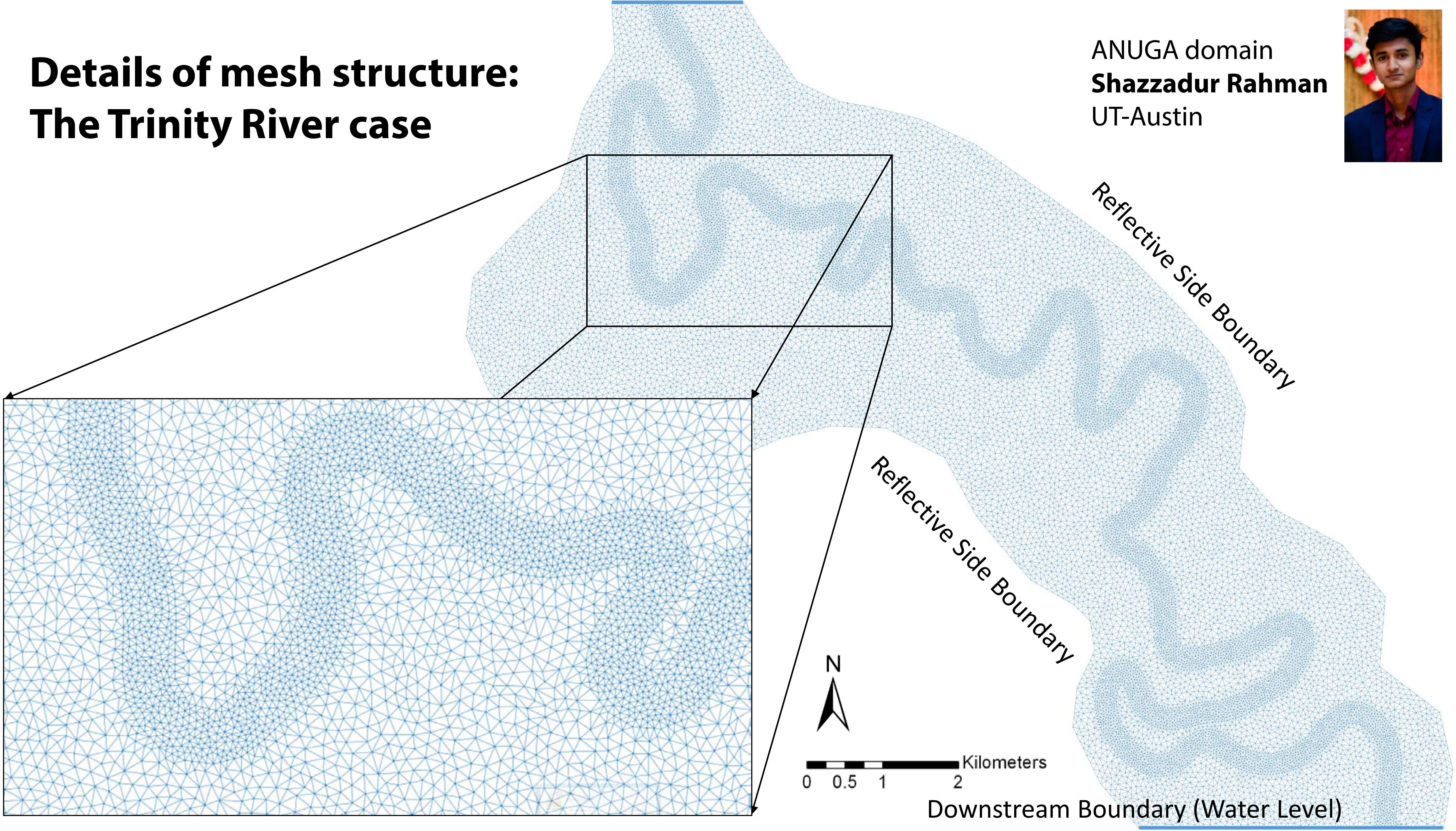


Base resolution = 80 m^2 Channel resolution = 25 m^2



Mesh populated with elevation from DEM

Details of mesh structure: The Trinity River case



ANUGA domain

Shazzadur Rahman
UT-Austin

6. 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?