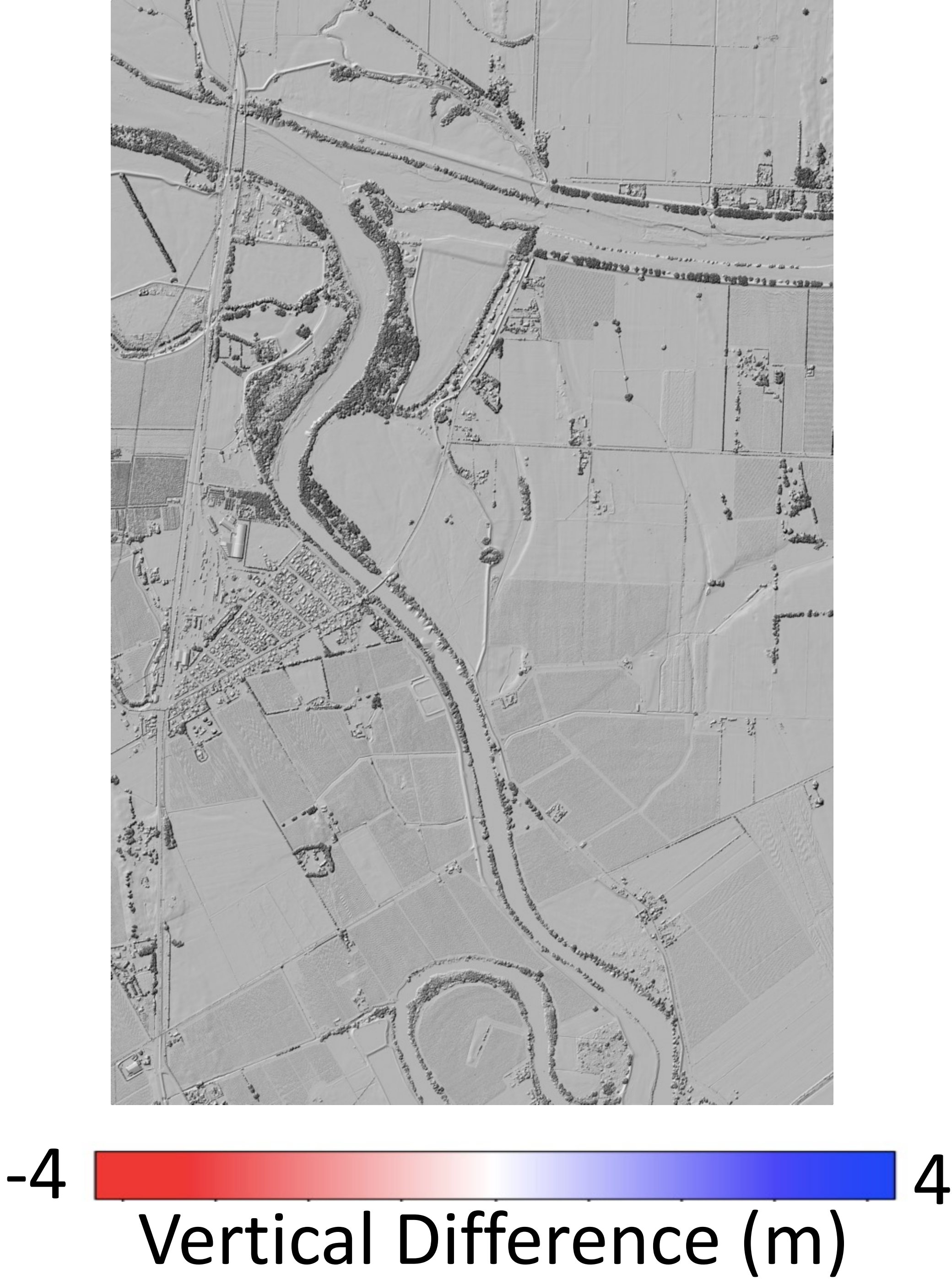
Topographic Differencing

AGIC 2022



Demo for differencing

Interesting areas:

Vertical differencing: Wax Lake Delta (Louisiana), Leaf-on to leaf-off (Central and Eastern Penn), river erosion (Blenheim, North Island, NZ), earthquakes (Mexicali, Ridgecrest- eastern Cal), Urban growth (Salt Lake City, Wellington), volcanoes (Hawaii)

3D differencing: Earthquake (Kumamoto, Japan), landslide (Slumgullion, Colorado), sand dunes (White Sand, New Mexico)

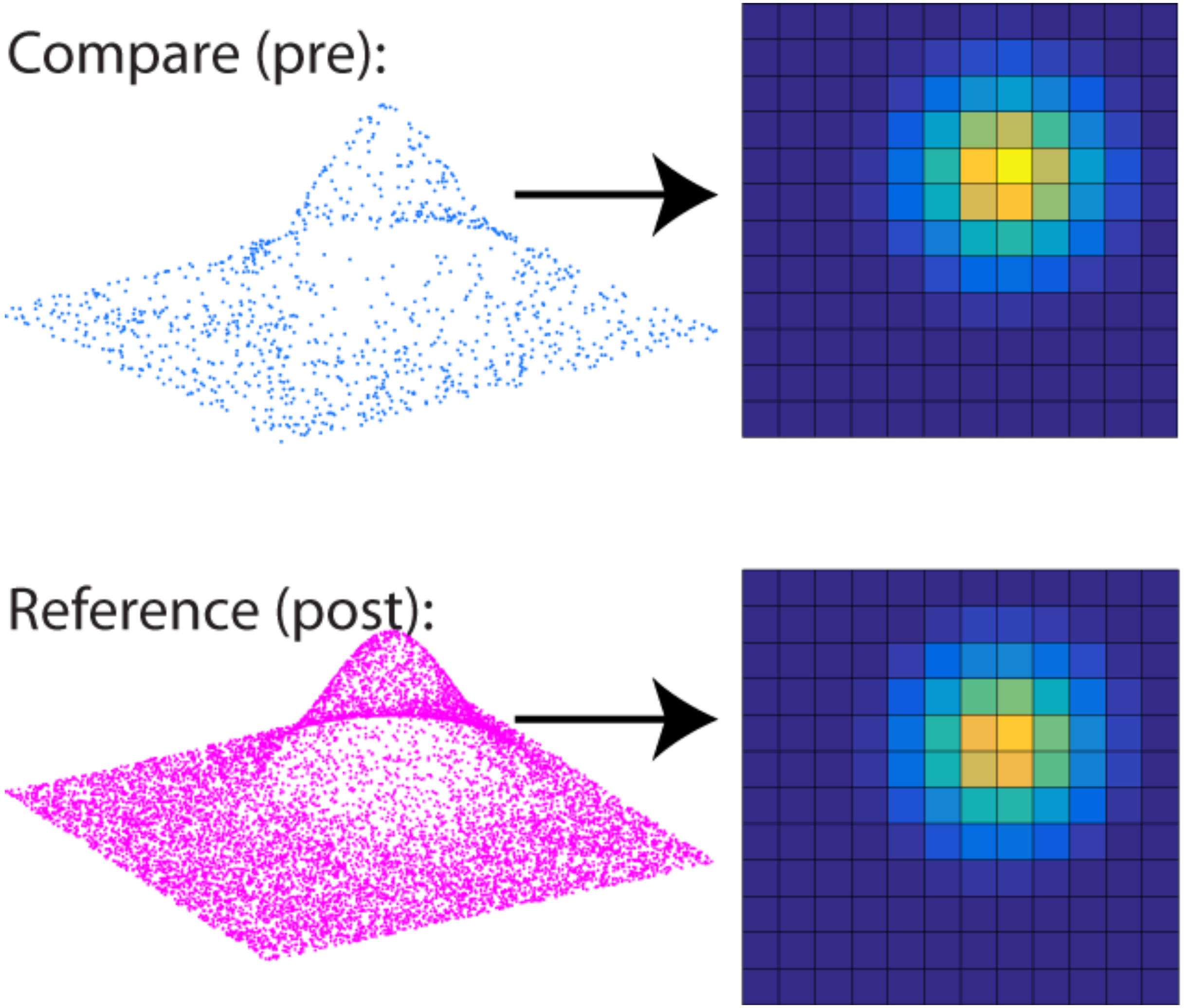
PLEASE: Maximum points per processing jobs during the class today

Vertical differencing: 25 million

3D differencing: 10 million

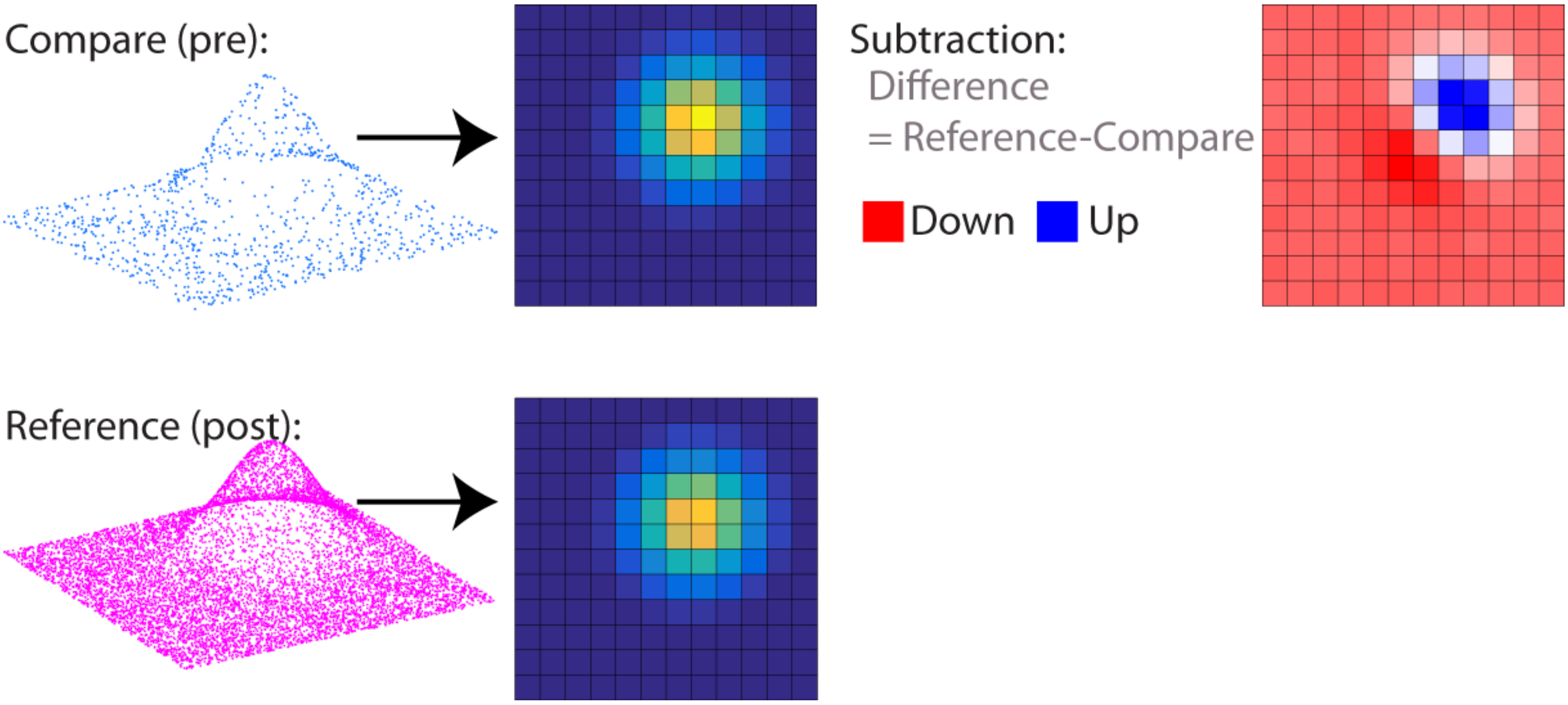
After the class, feel free to process much larger datasets

Vertical topographic differencing



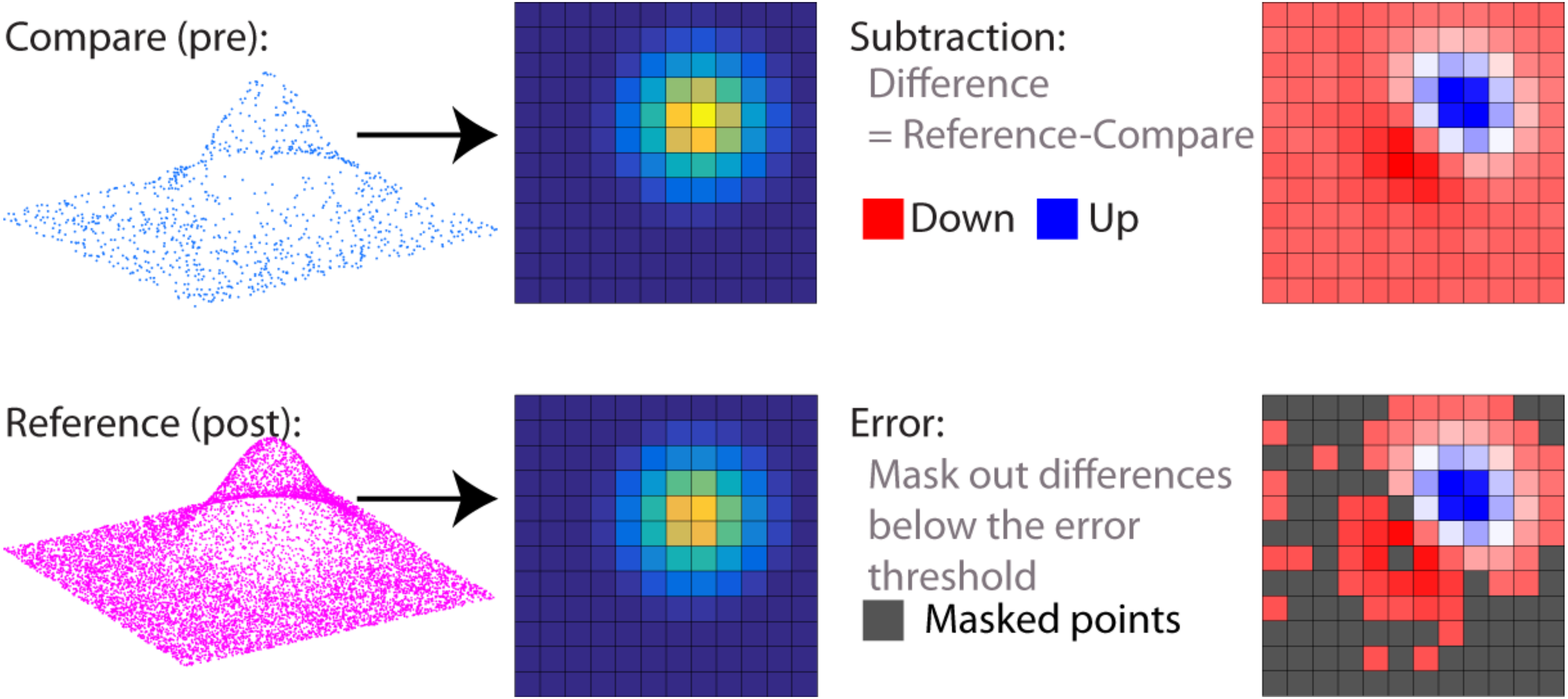
Identical grid for pre and post event topography

Vertical topographic differencing



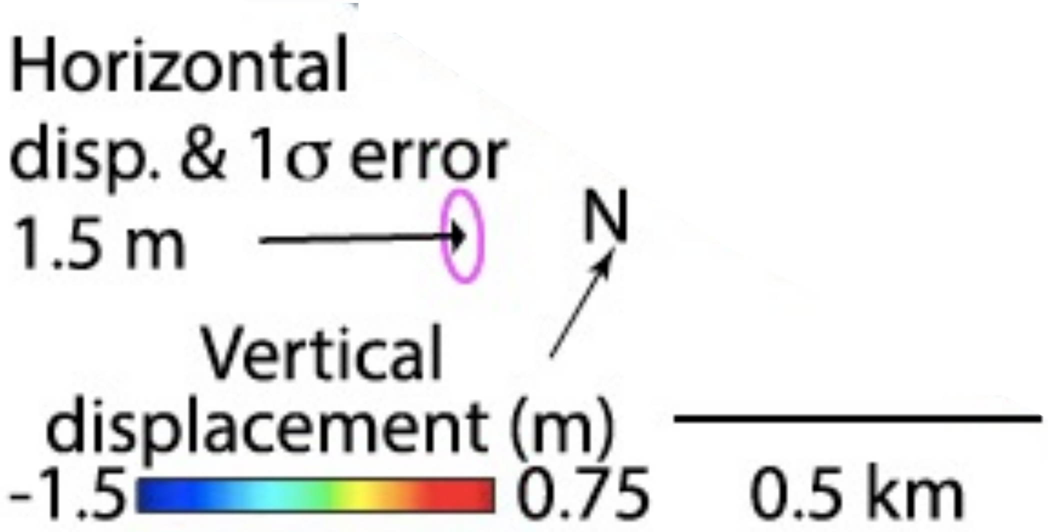
Raster subtraction

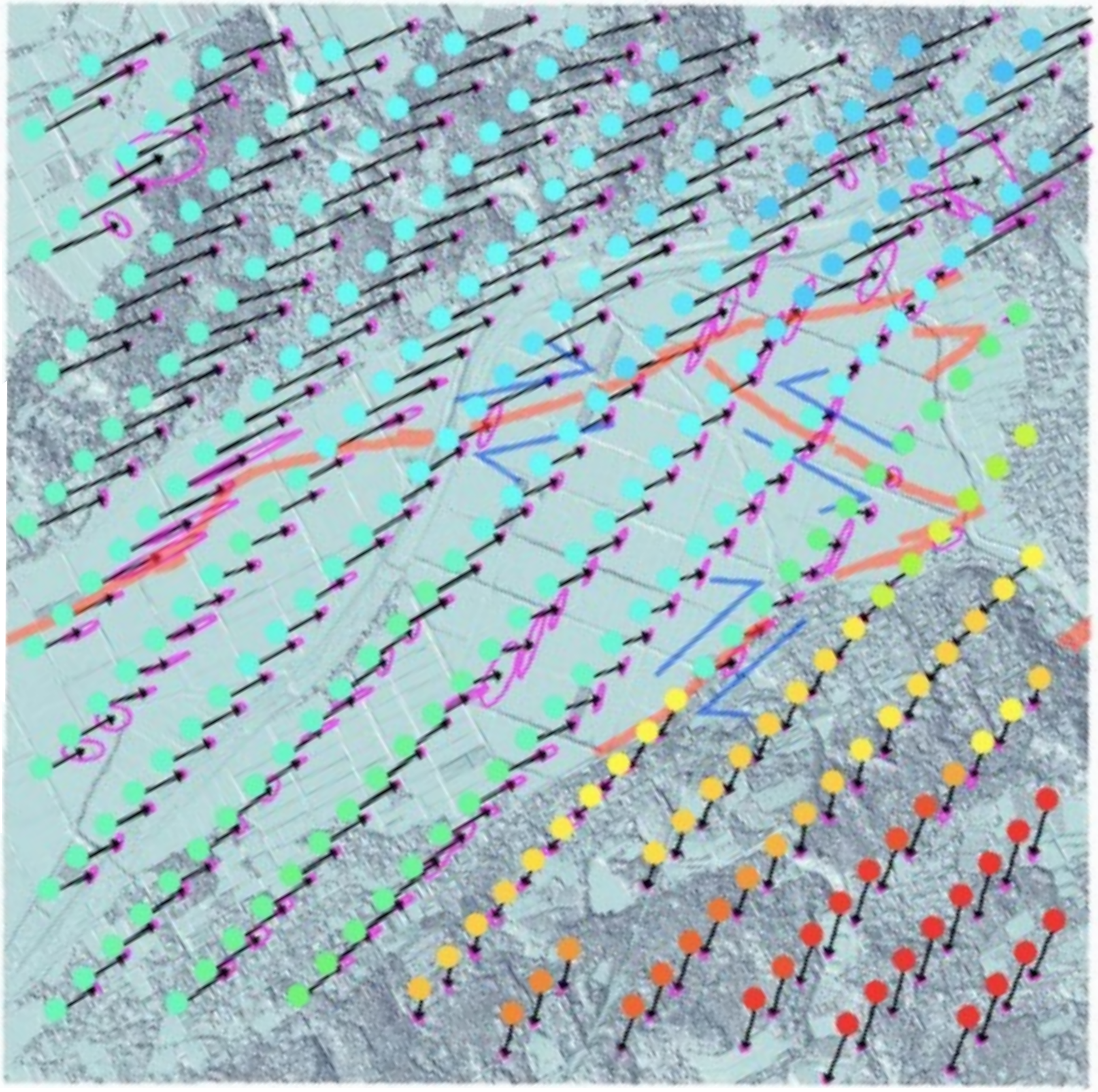
Vertical topographic differencing



Option: mask differences below error threshold

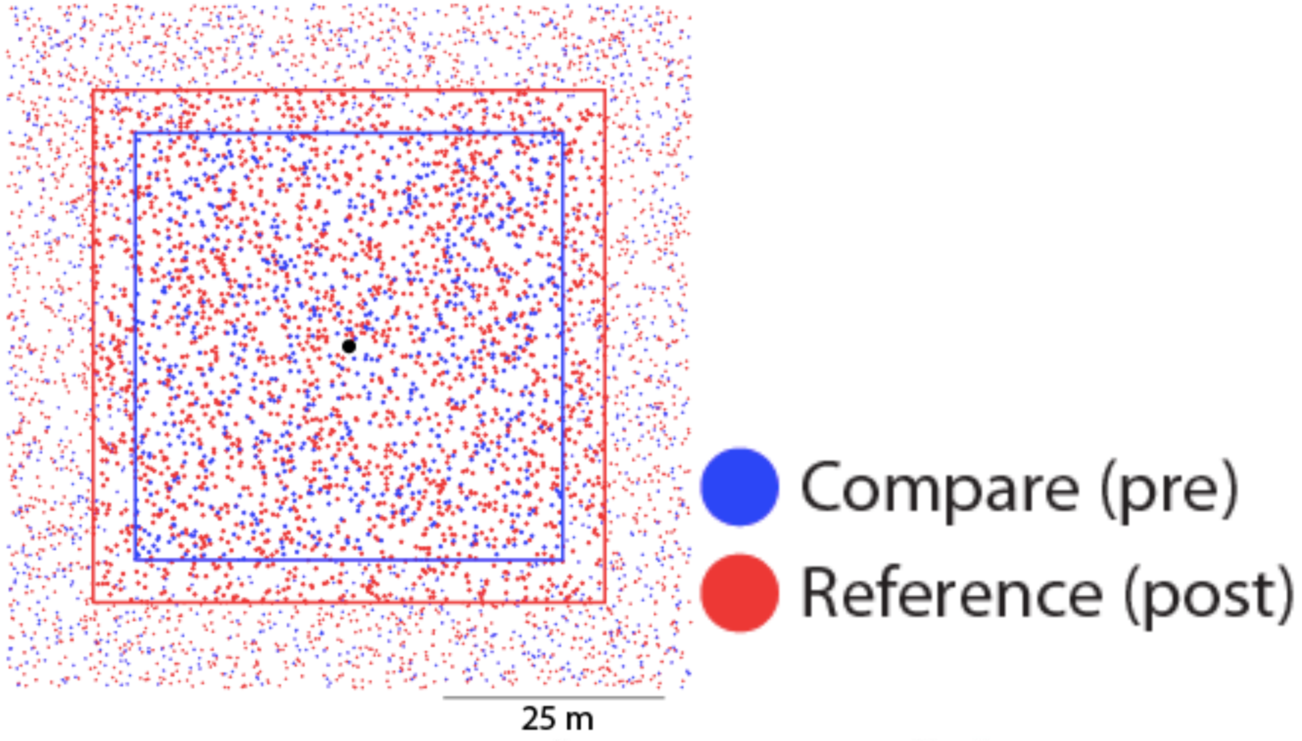
3D Topographic differencing

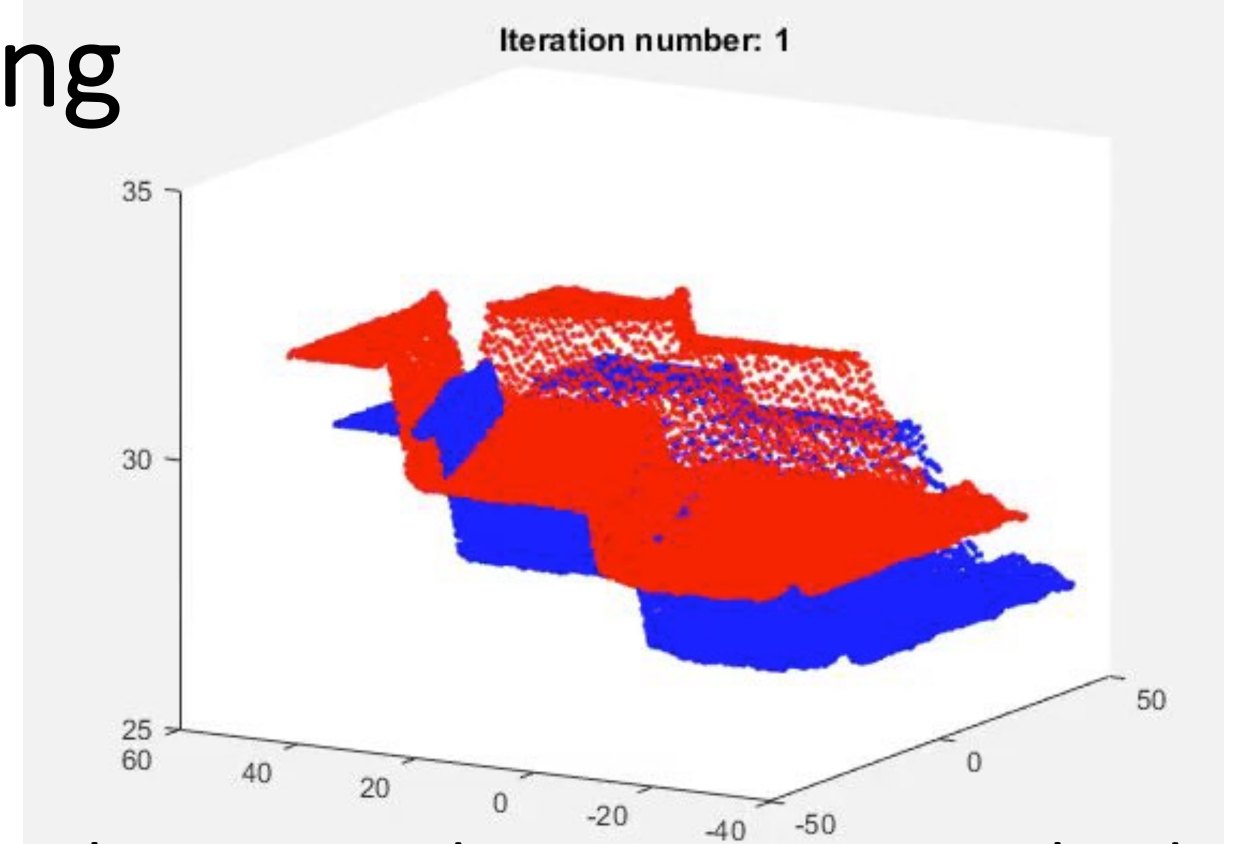




Besl and McKay (1992); Geiger et al., (2012); Nissen et al., (2012; 2014); Scott et al., (2018)

3D Topographic differencing
Iterative Closest Point

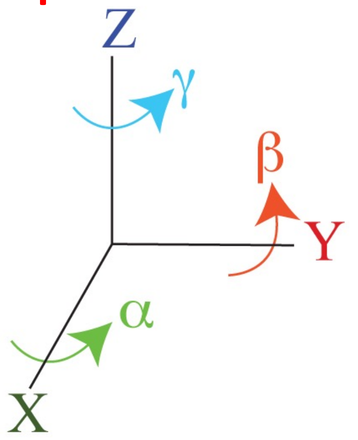




Align pre- and post- event point clouds

$$\text{Deformed point cloud} = \begin{bmatrix} 1 & -\gamma & \beta \\ \gamma & 1 & -\alpha \\ -\beta & \alpha & 1 \end{bmatrix} \begin{bmatrix} \text{Undeformed point cloud} \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix}$$

Rotation Translation



Coordinate system

On-demand differencing

OpenTopography
High-Resolution Topography Data and Tools

Iowa City, Iowa: 2008-2014

-8 0 8
Vertical Difference (m)

What?

In a few mouse clicks, users can run differencing calculations on OT

Why?

Standardize approach

Democratize access to tools

Build to Big Data capability

Challenges:

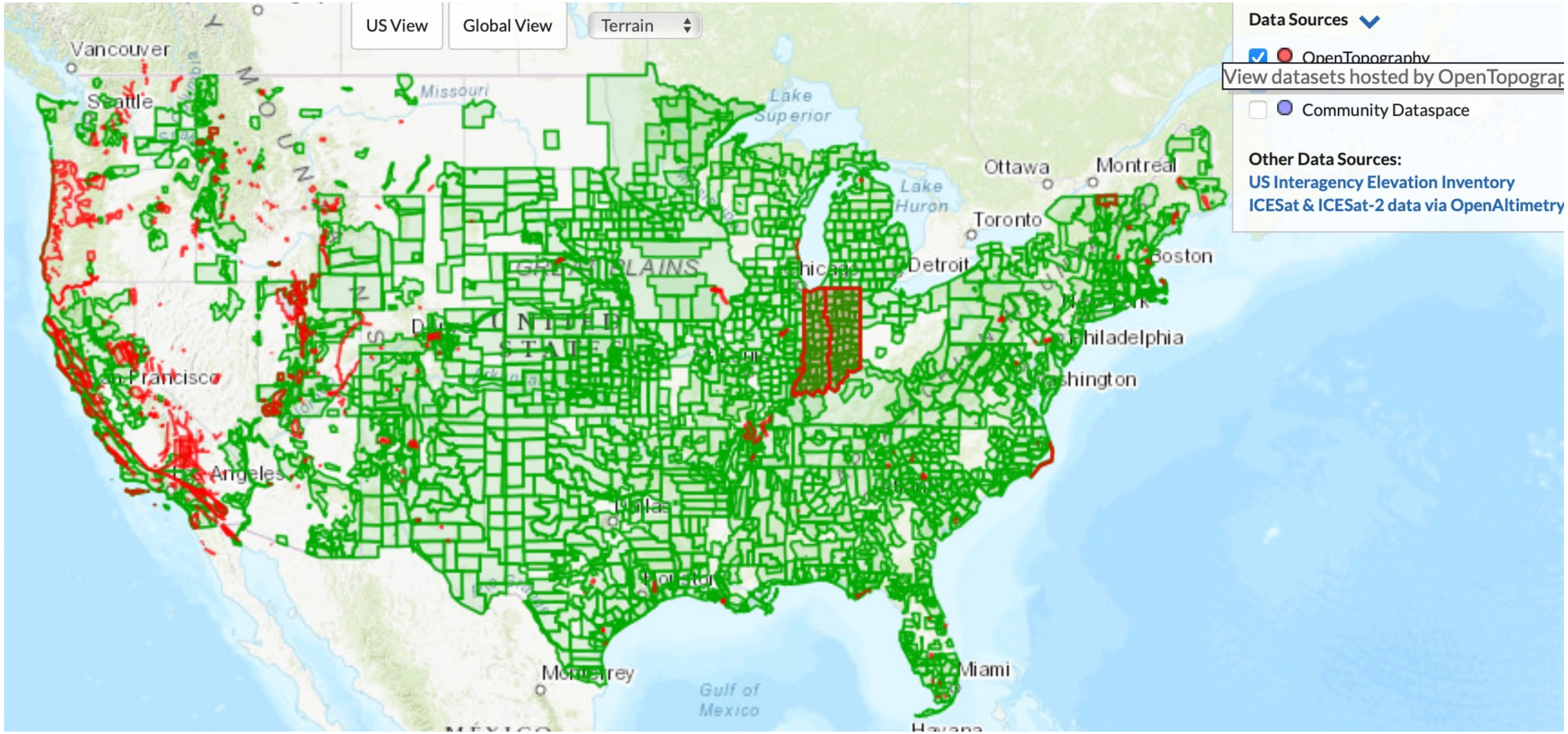
Legacy & Hybrid data

Algorithms: On-demand

Cyber-infrastructure & HPC

Scott, C., Phan, M., Nandigam, V., Crosby, C., Arrowsmith, R. (2021). Measuring change along the Earth's surface: On-Demand vertical and 3D topographic differencing hosted by OpenTopography. *Geosphere*. https://doi.org/10.1130/GES02259.1

Differencing in OpenTopography



Perform differencing on overlapping red datasets

>130 datasets with differencing

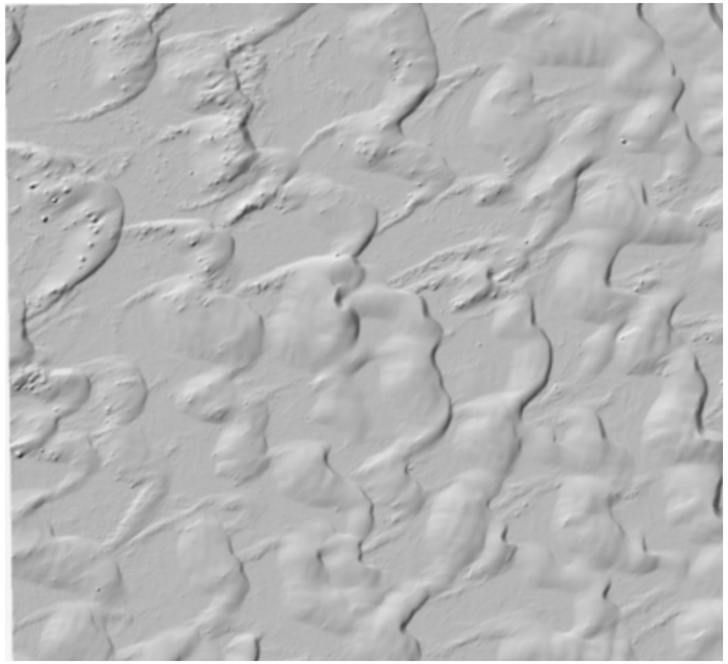
Many in US and NZ

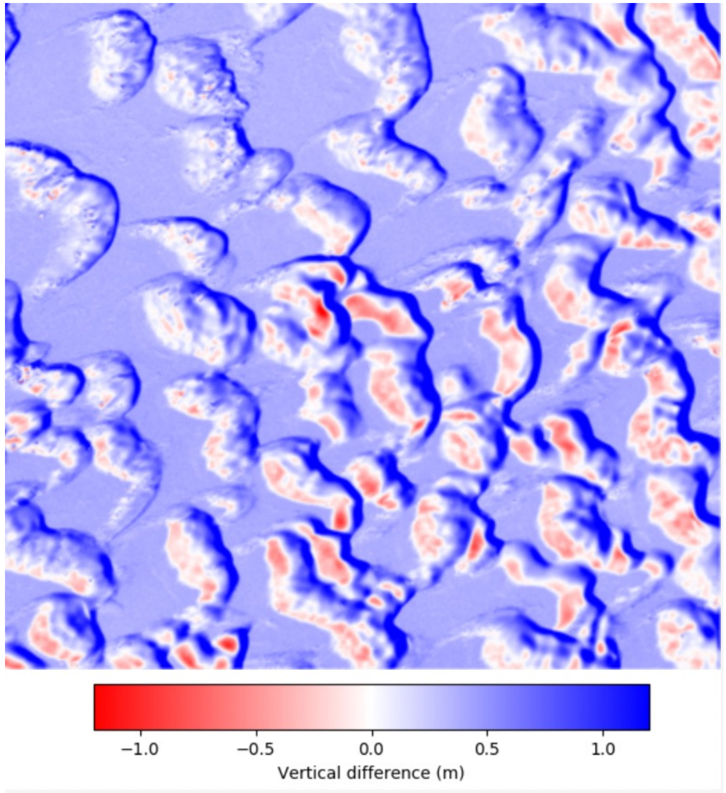
Record many processes

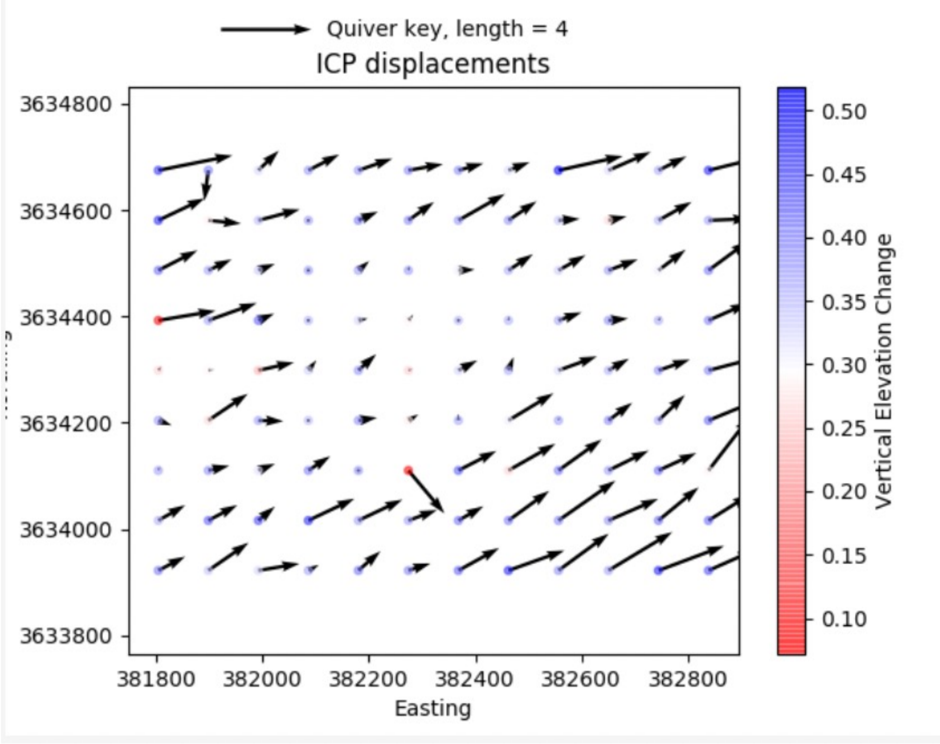
Not (yet) implemented on USGS datasets (green)

Differencing in OpenTopography

OpenTopography
High-Resolution Topography Data and Tools





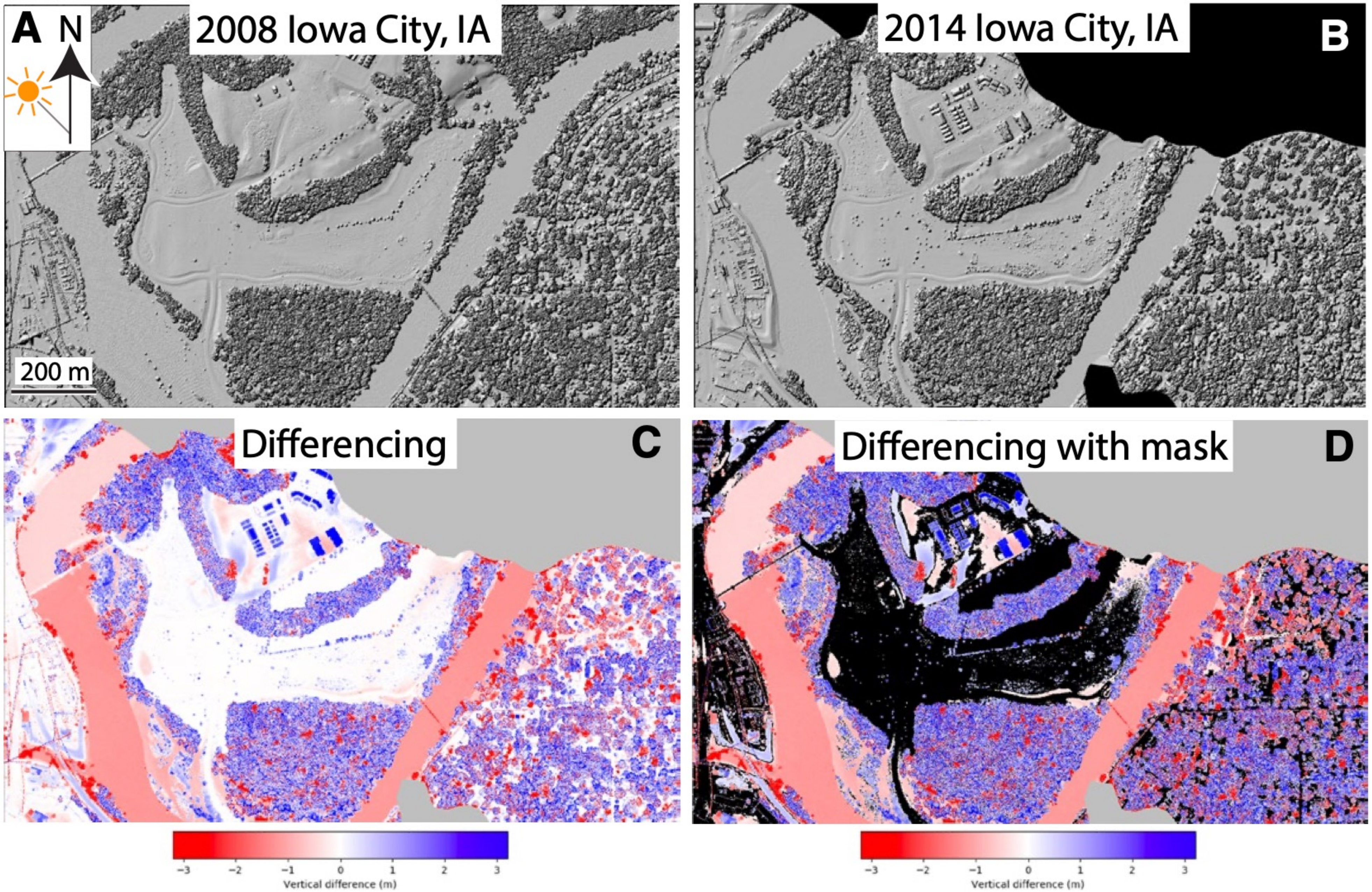


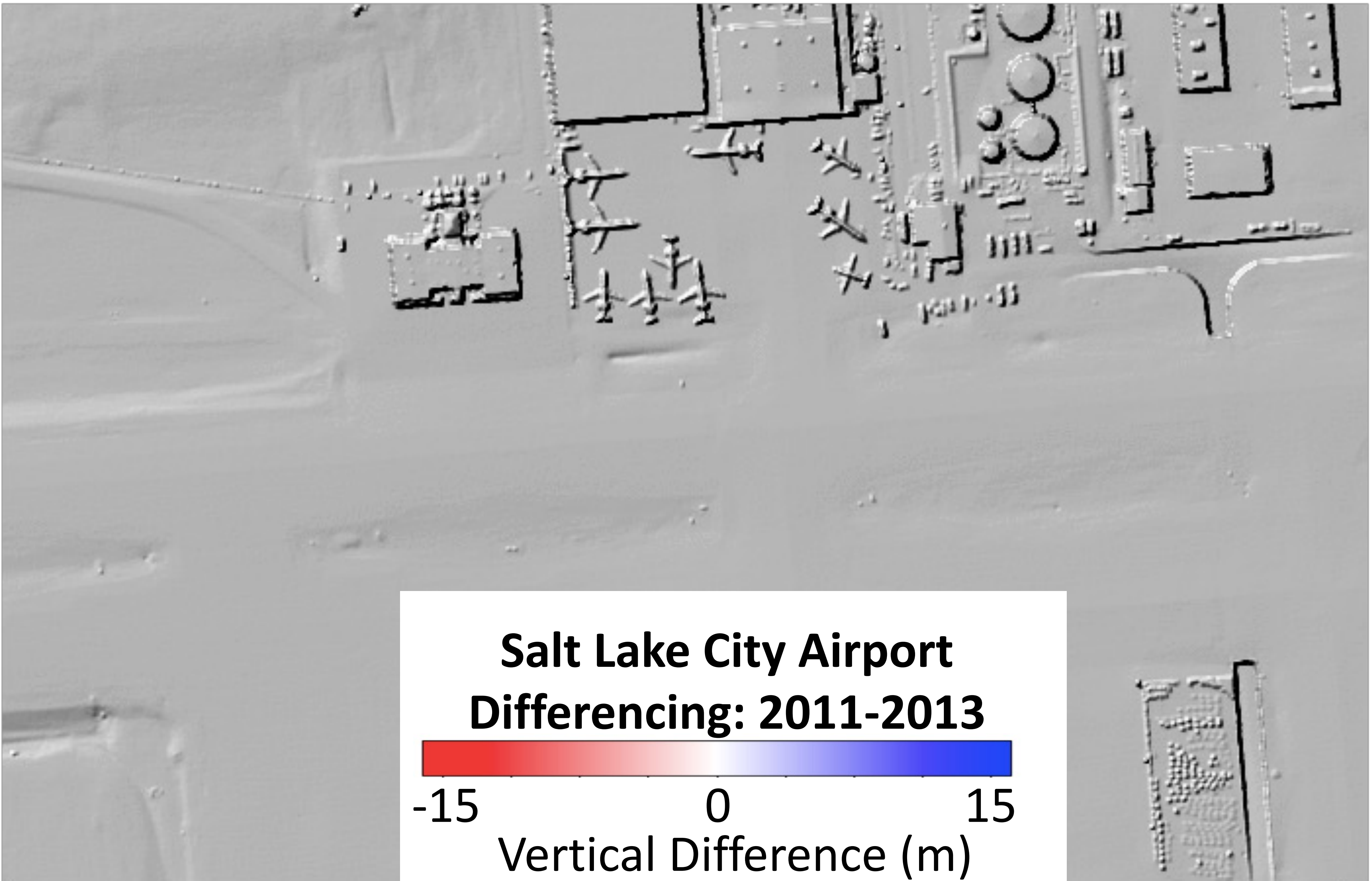
Hillshade

Vertical differencing (52 secs)

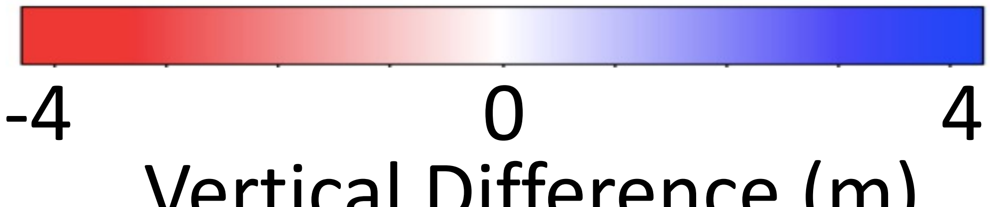
3D differencing (4 mins)

Vertical differencing




Salt Lake City Airport
Differencing: 2011-2013
-15
0
15
Vertical Difference (m)

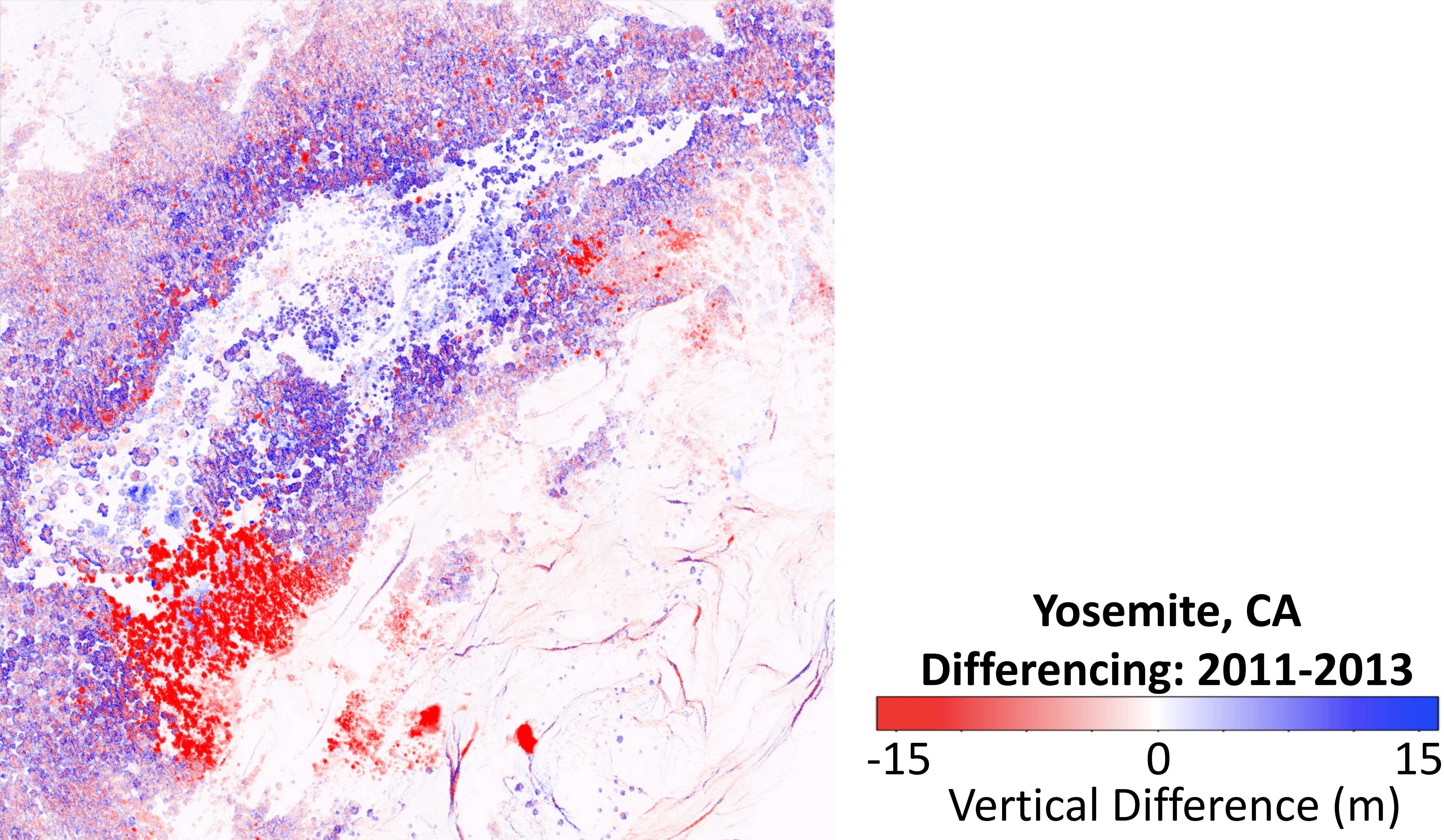
Salt Lake City, Utah



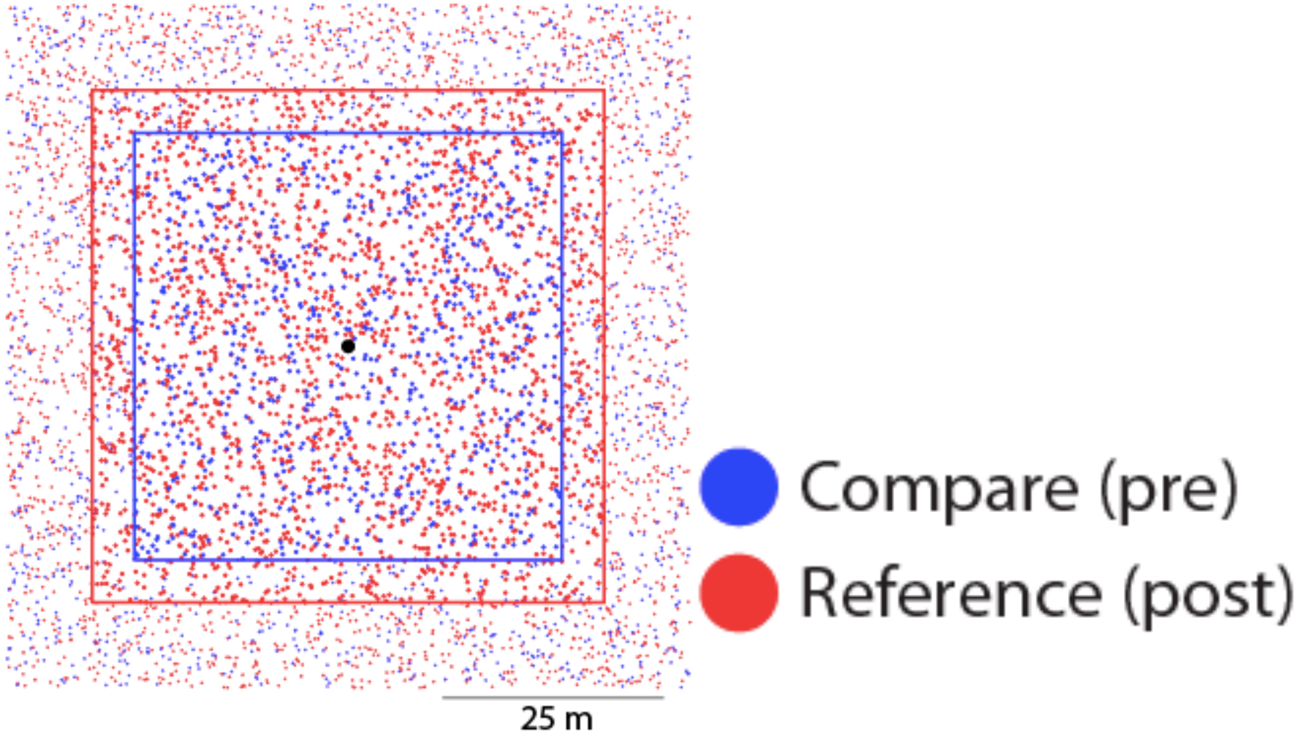
Differencing: Oct 2015- Oct 2017

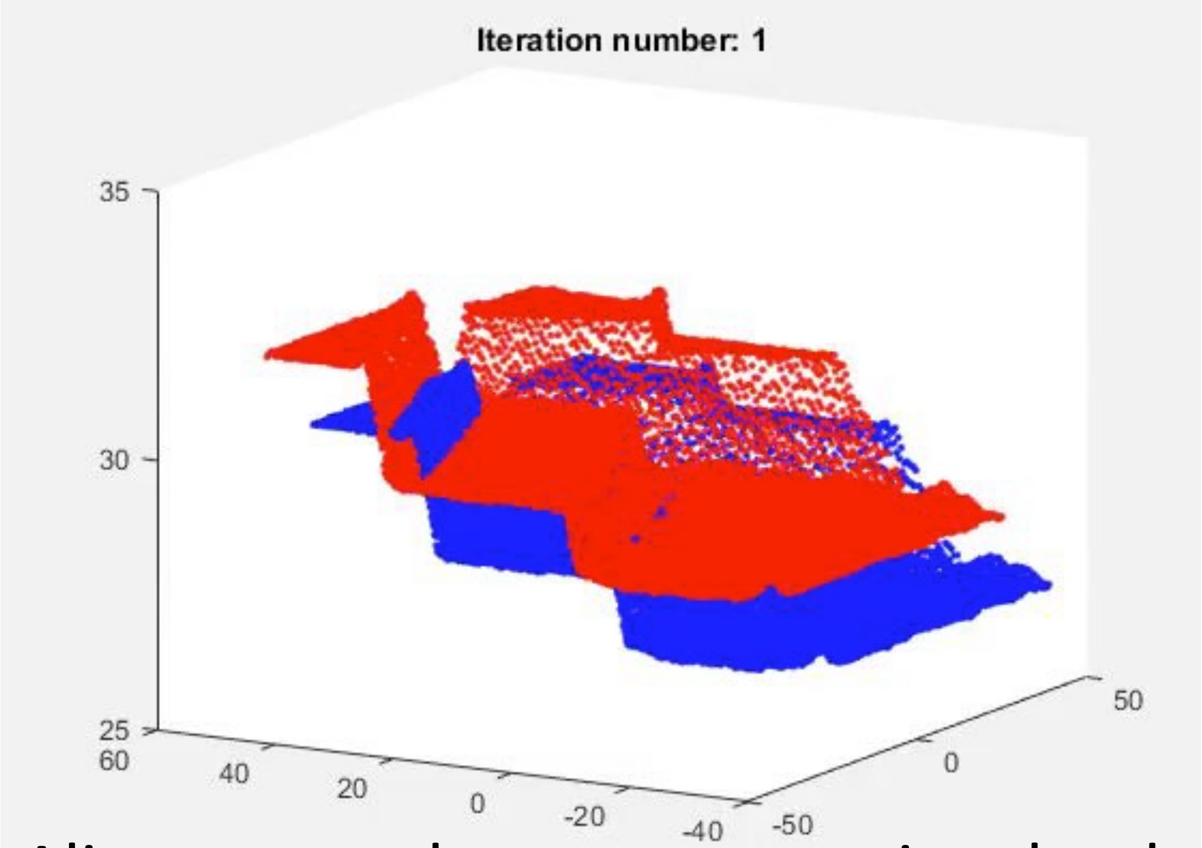
Yosemite, CA

Differencing: 2011-2013



3D Differencing





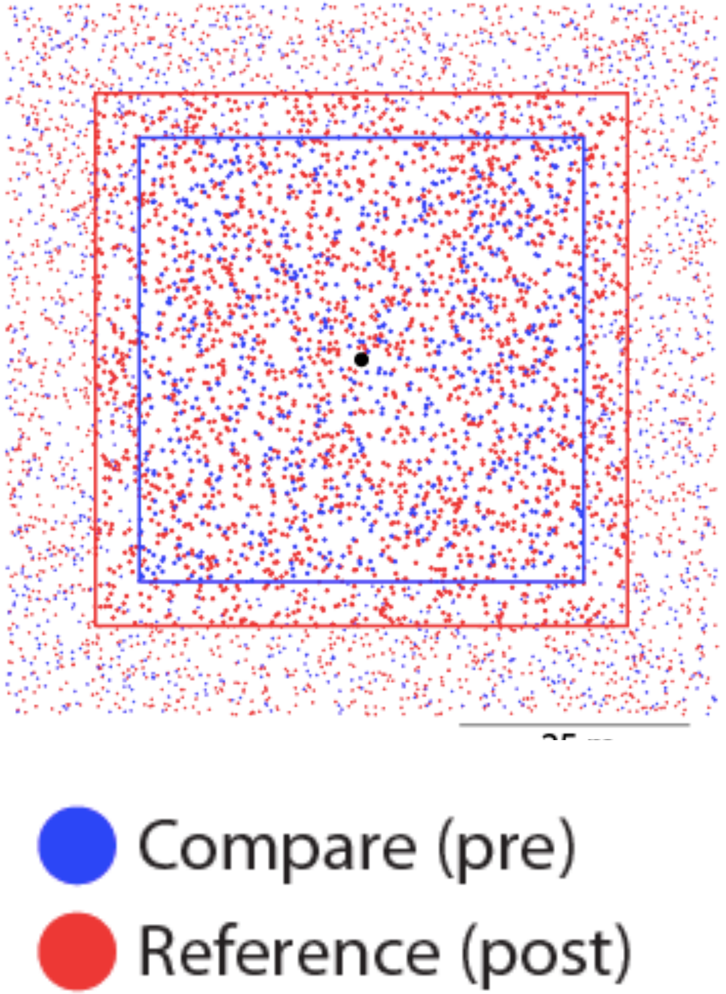
Align pre- and post- event point clouds

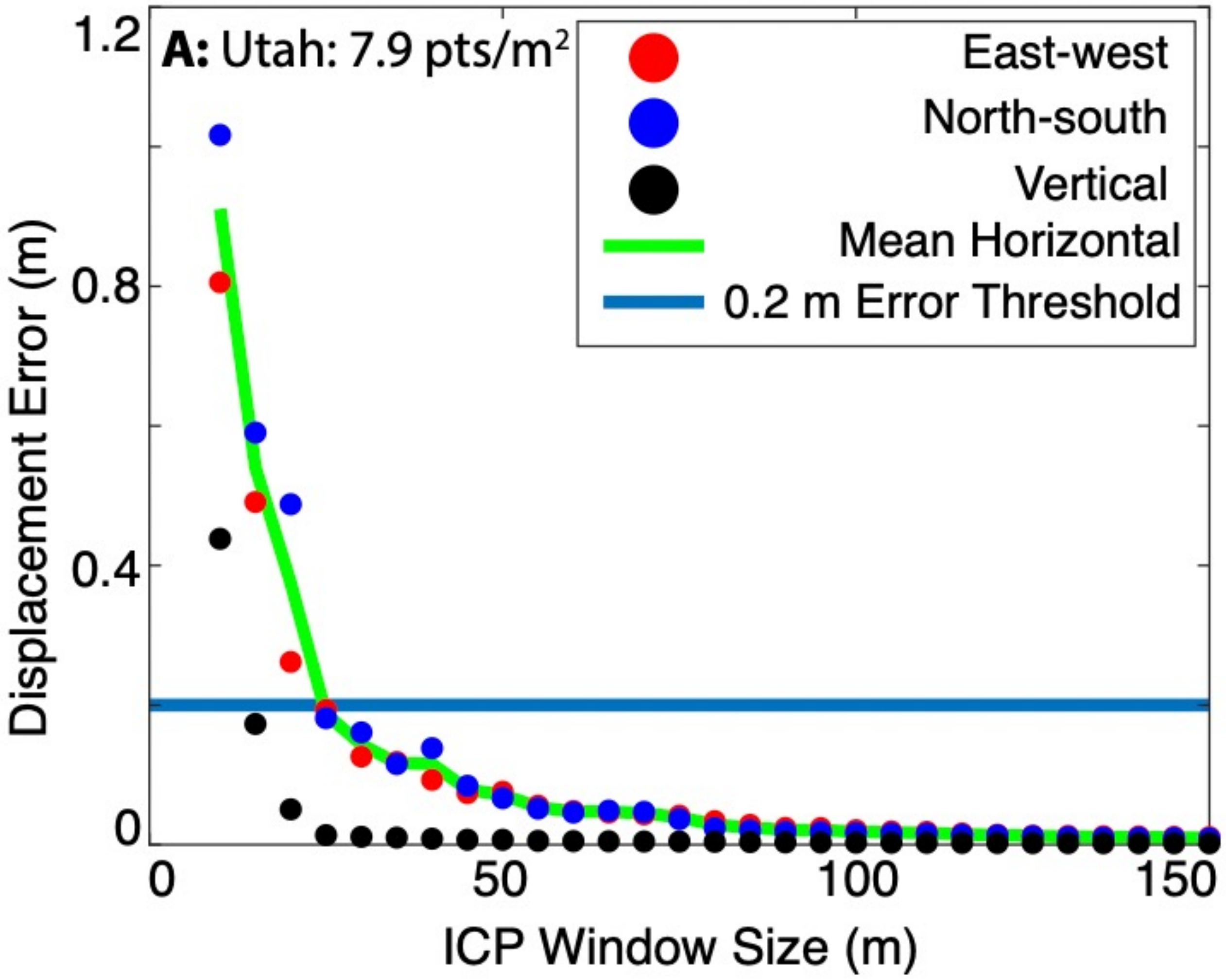
How big should the blue square be?

Too small – Displacements will be noisy

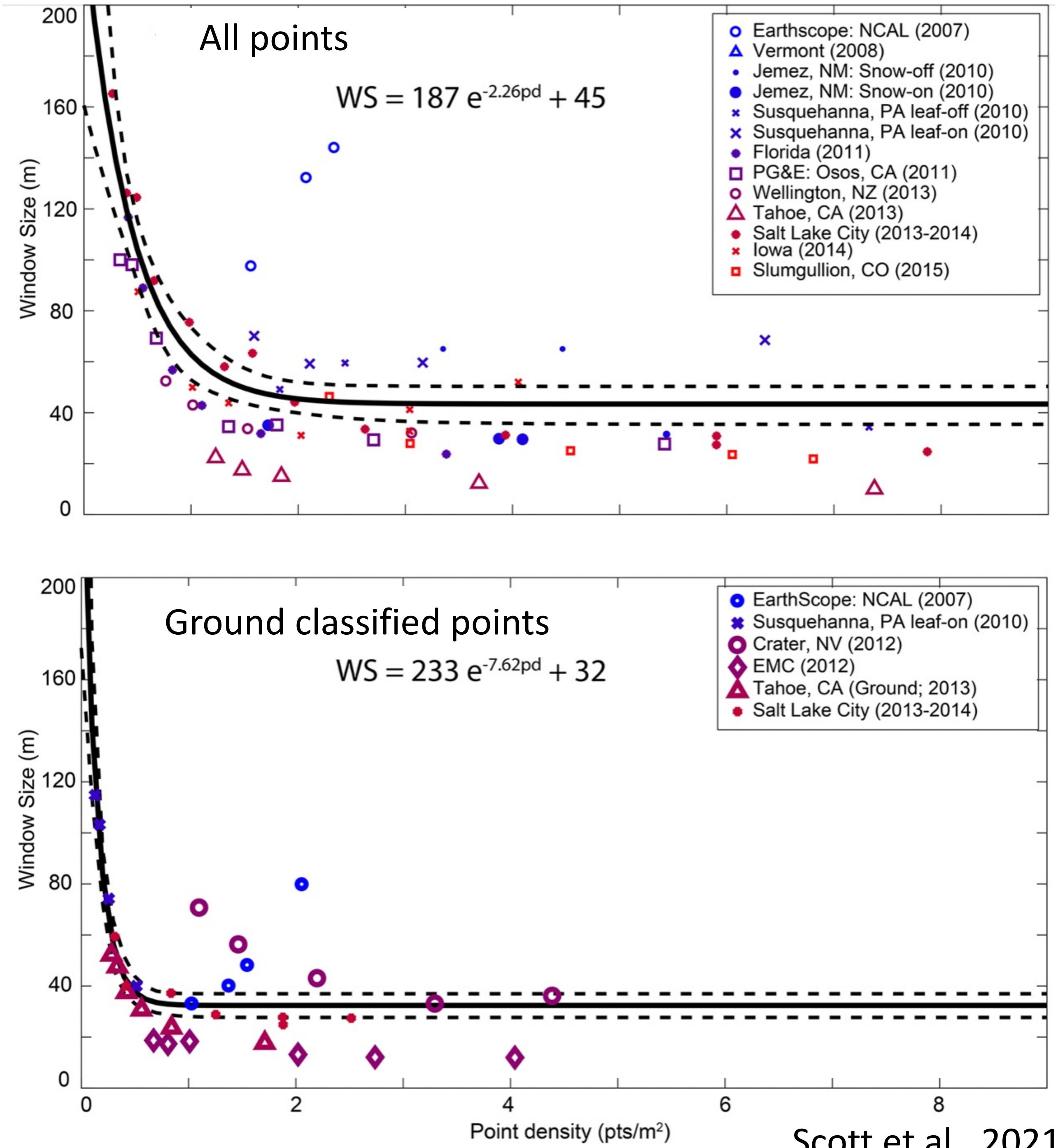
Too big – Missed finer signals that can be resolved

Ideal window size & displacement error





Use equation to recommend window size

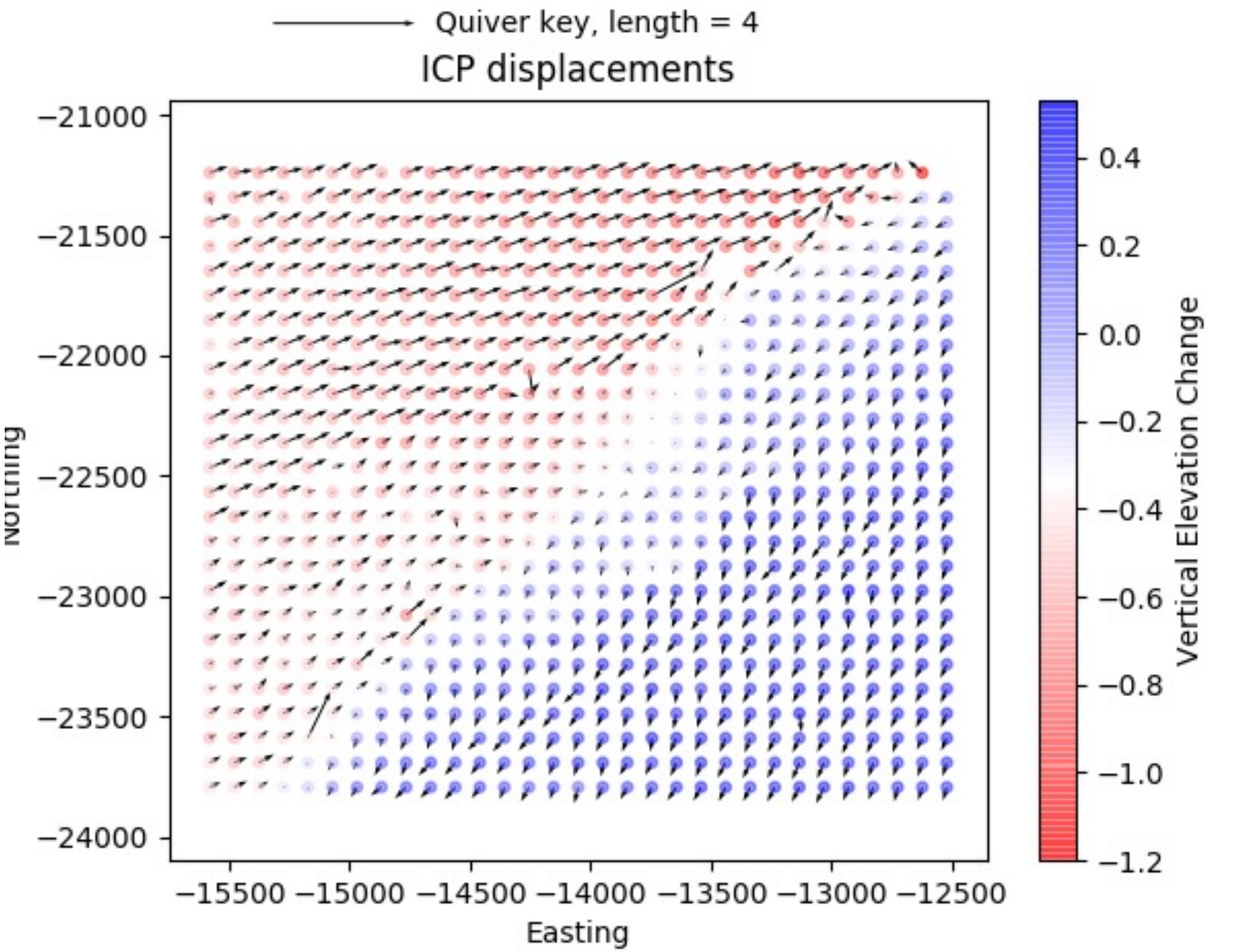


Scott et al., 2021

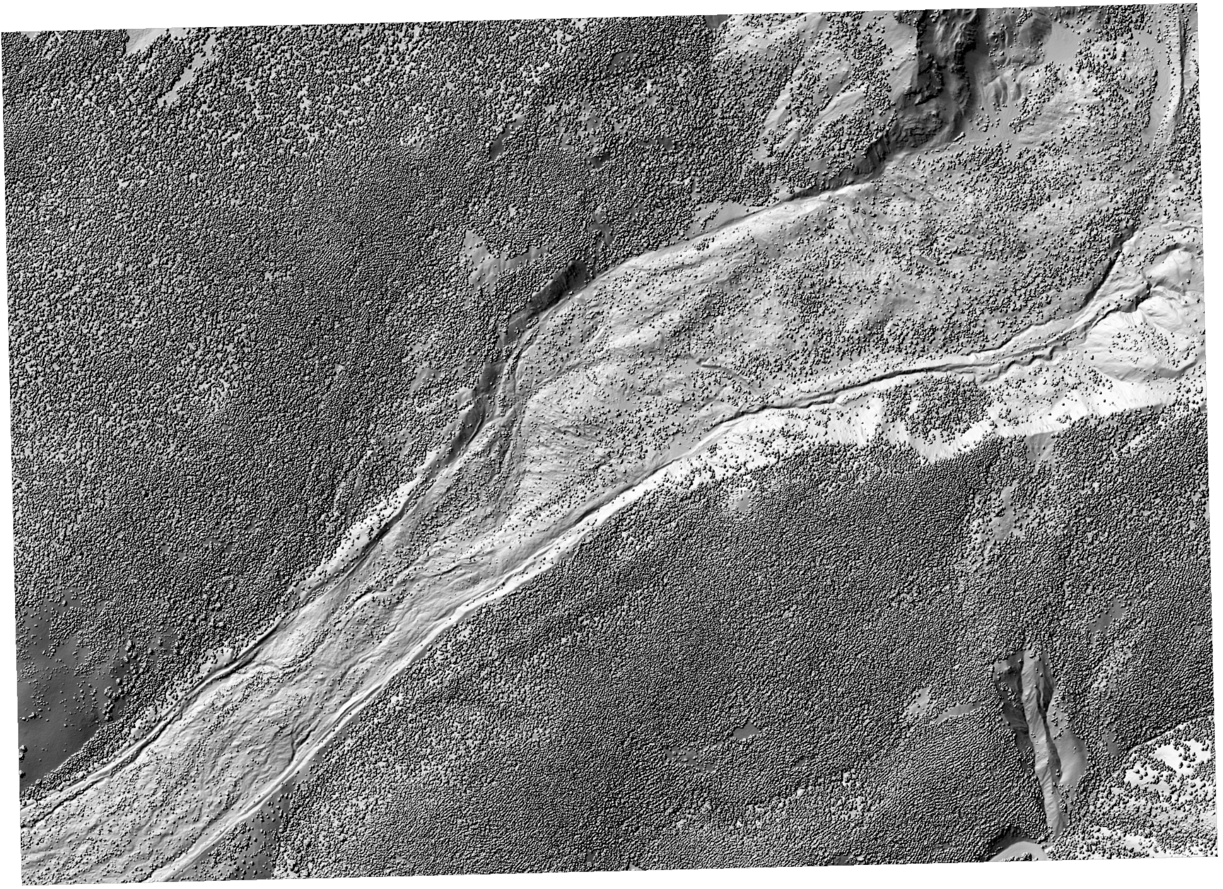
Ideal window size and point density follow an approximate exponential relationship

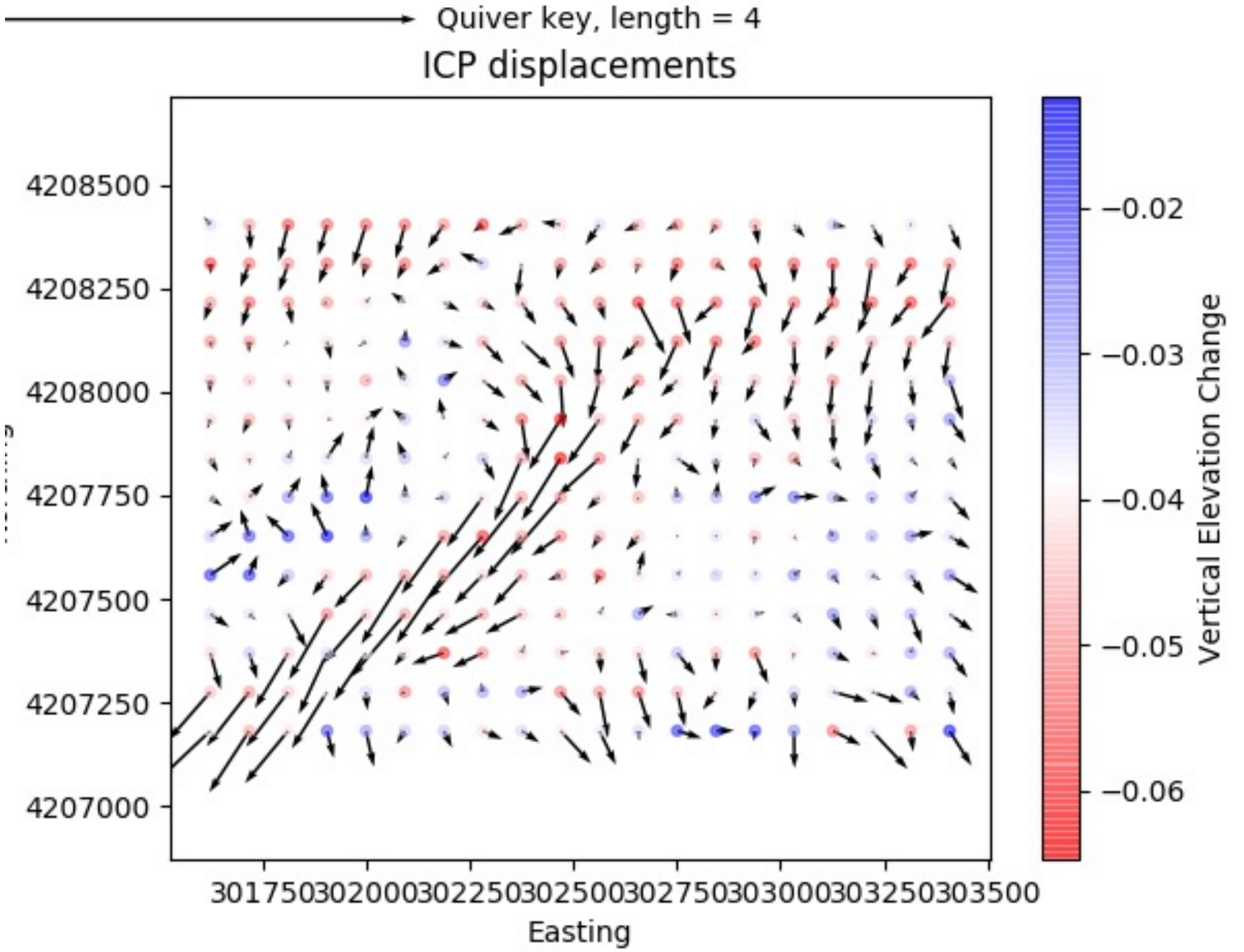
Smaller window size with just ground points. Vegetation generally add noise.

2016 Kumamoto Earthquake, Japan



Slumgullion Landslide, Colorado





Statewide Topographic Differencing of Indiana

Motivation:

Large-scale processing of USGS 3DEP topography

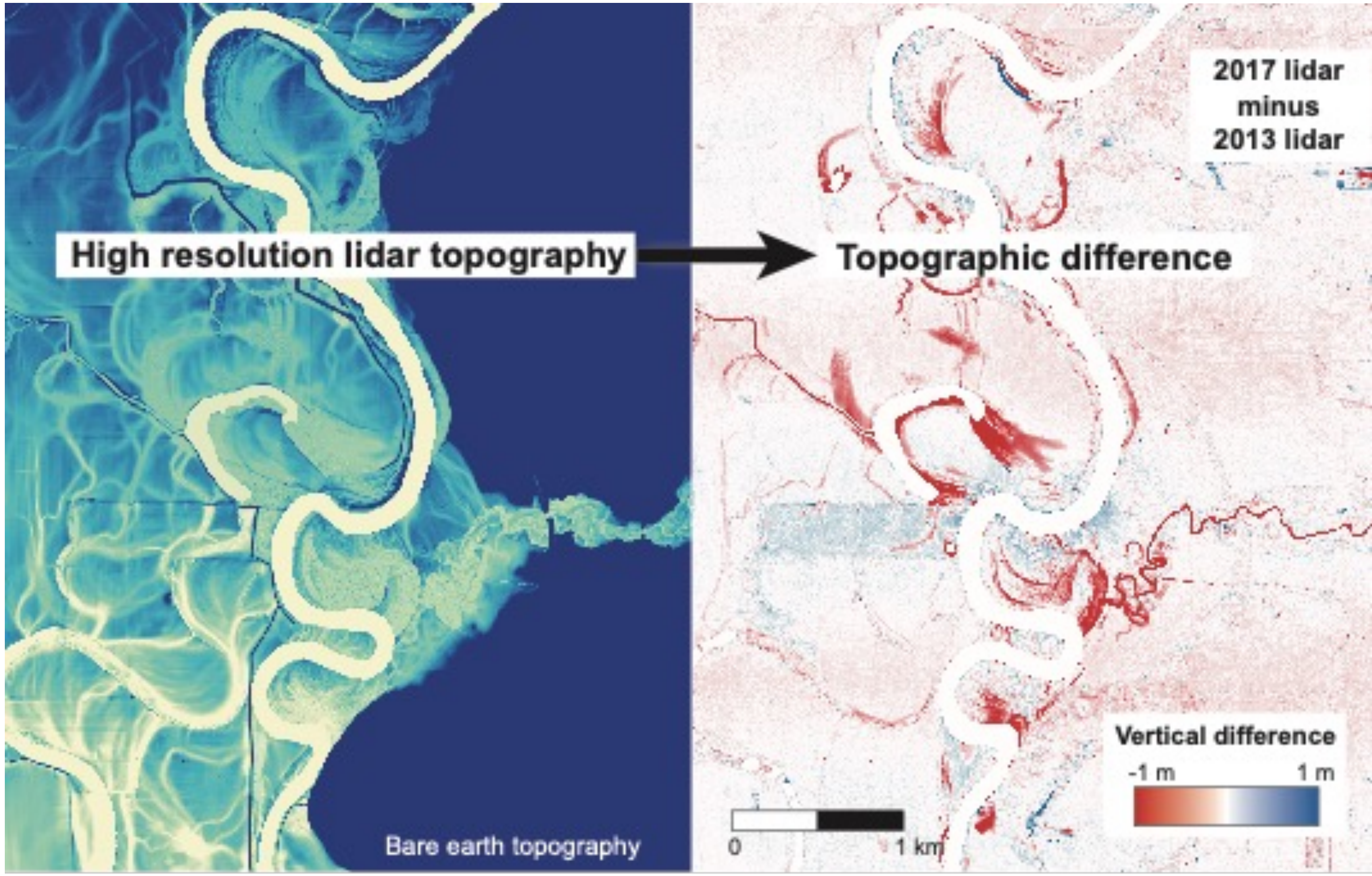
What does a decade of change look like?

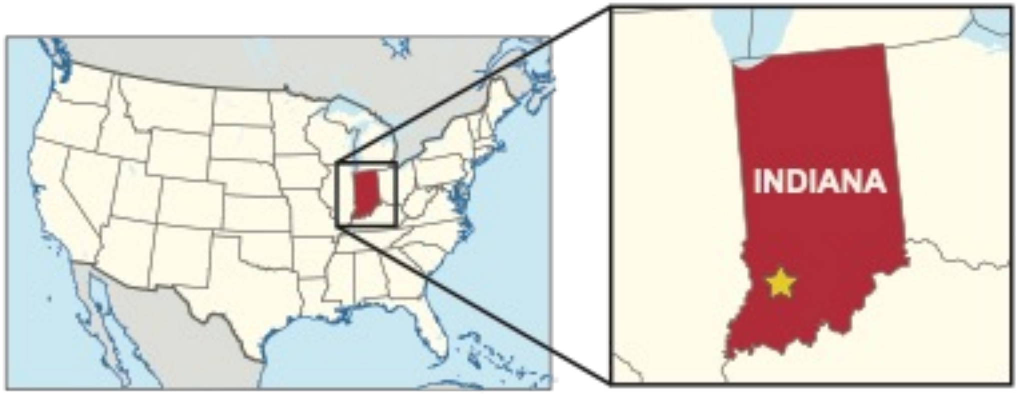
Why Indiana:

Two statewide differencing datasets (including USGS 3DEP)

Anticipated interesting change

Data-hosting partnership between OT and Indiana





Scott, C. P., Beckley, M., Phan, M., Zawacki, E., Crosby, C., Nandigam, V., & Arrowsmith, R. (2022). Statewide USGS 3DEP Lidar Topographic Differencing Applied to Indiana, USA. *Remote Sensing*, *14*(4). https://doi.org/10.3390/rs14040847

Workflow:

Challenges:

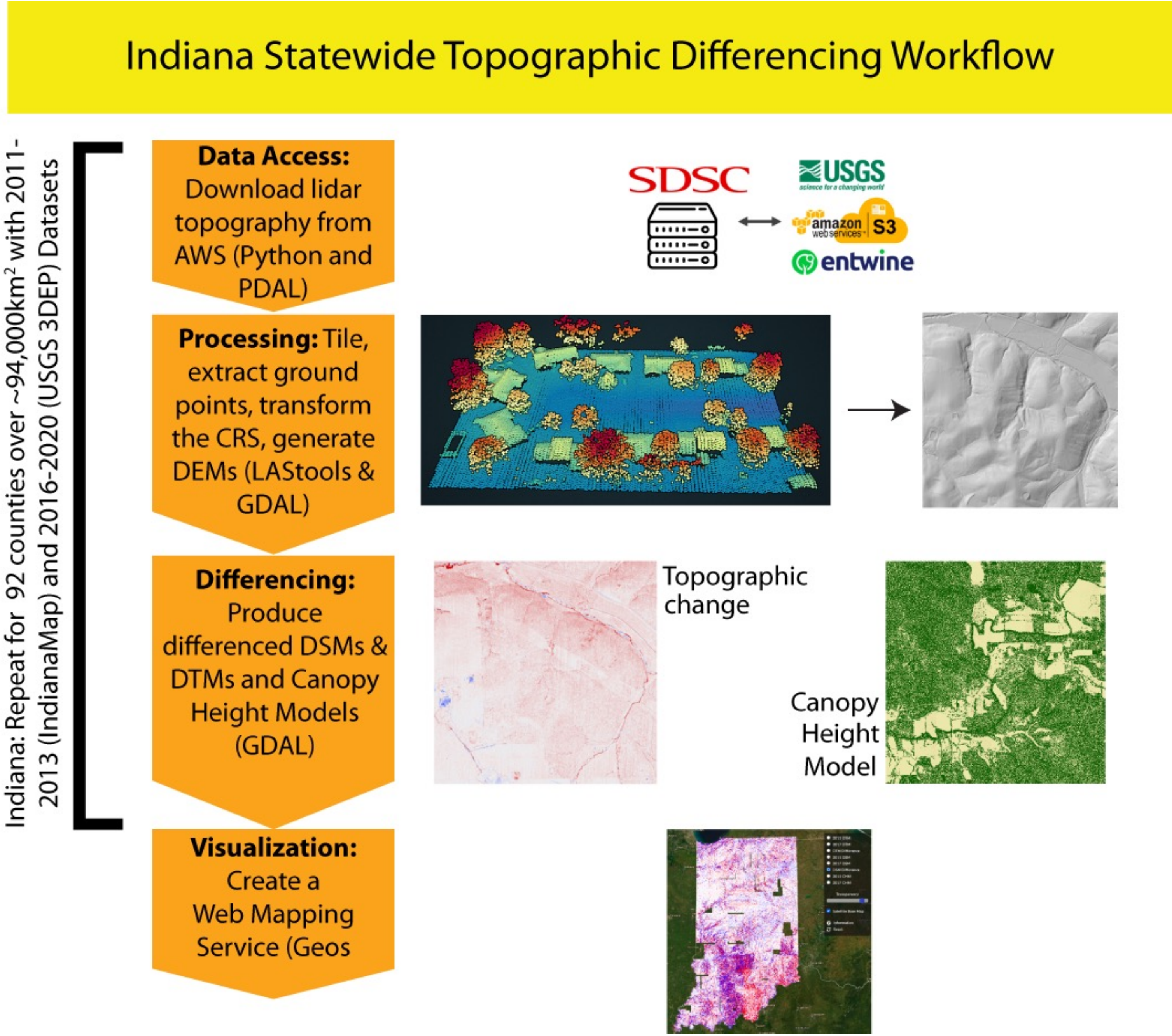
Indiana is 94,000 km^2, ~10^2-10^5 x larger than other differencing studies

Final products are ~4 TB

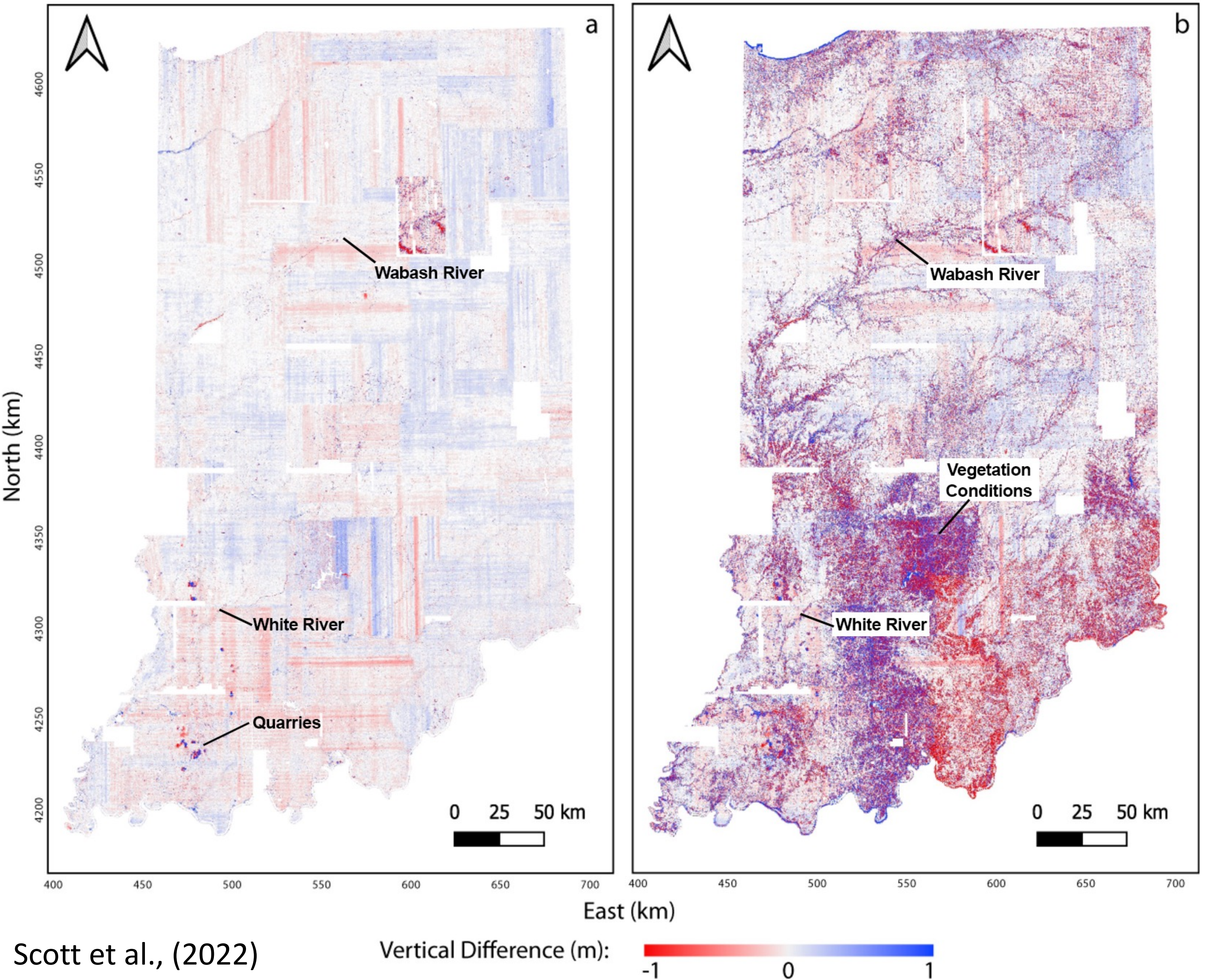
Ensure sufficient memory for intermediate calculations

What are the sources of noise? Should we correct the noise at the state-scale?

Visualize the results?



Scott et al., (2022)



Scott et al., (2022)

IN topographic differencing

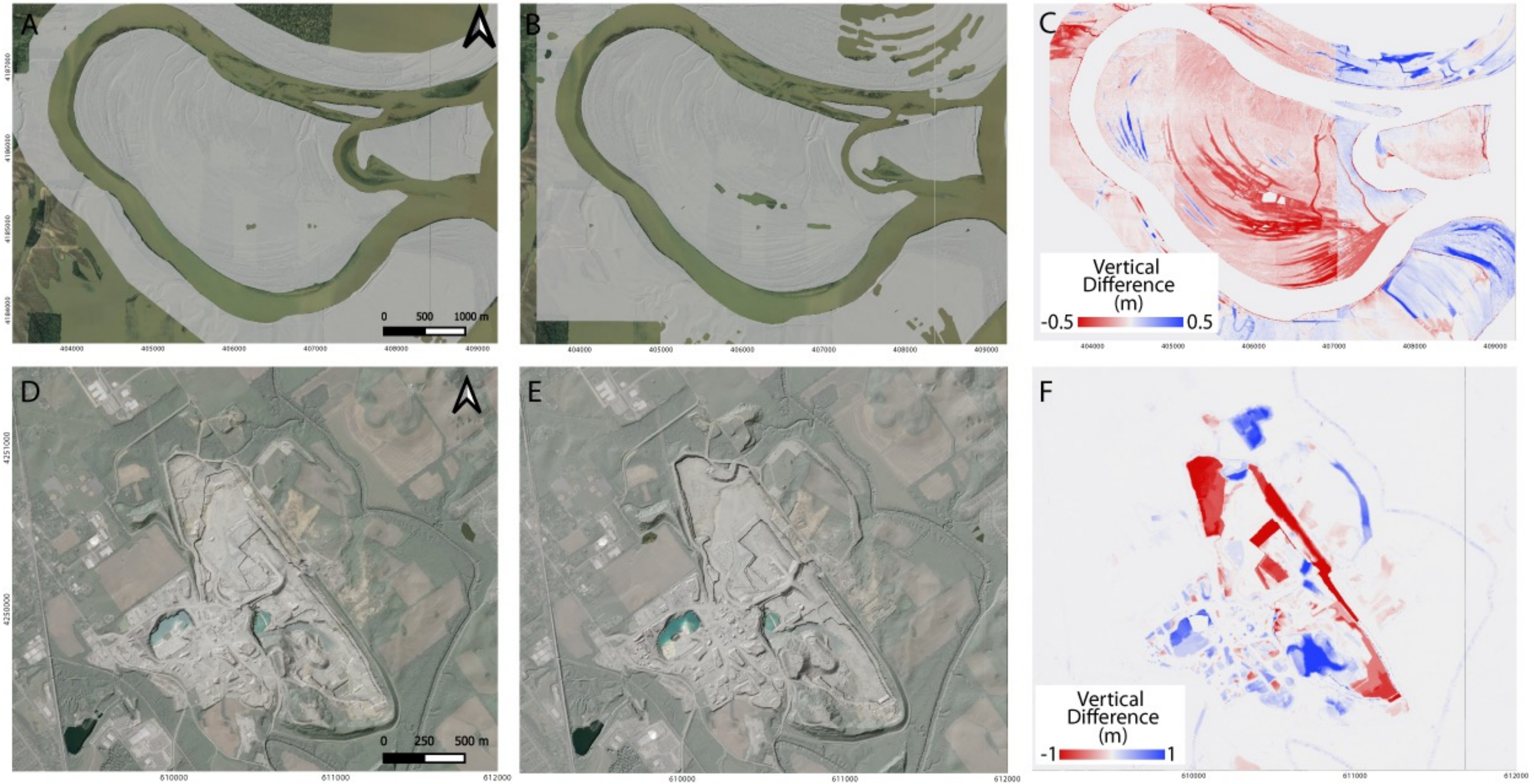
Fluvial and riparian

Vegetation (correlations with season of data acquisition)

Quarries and mining

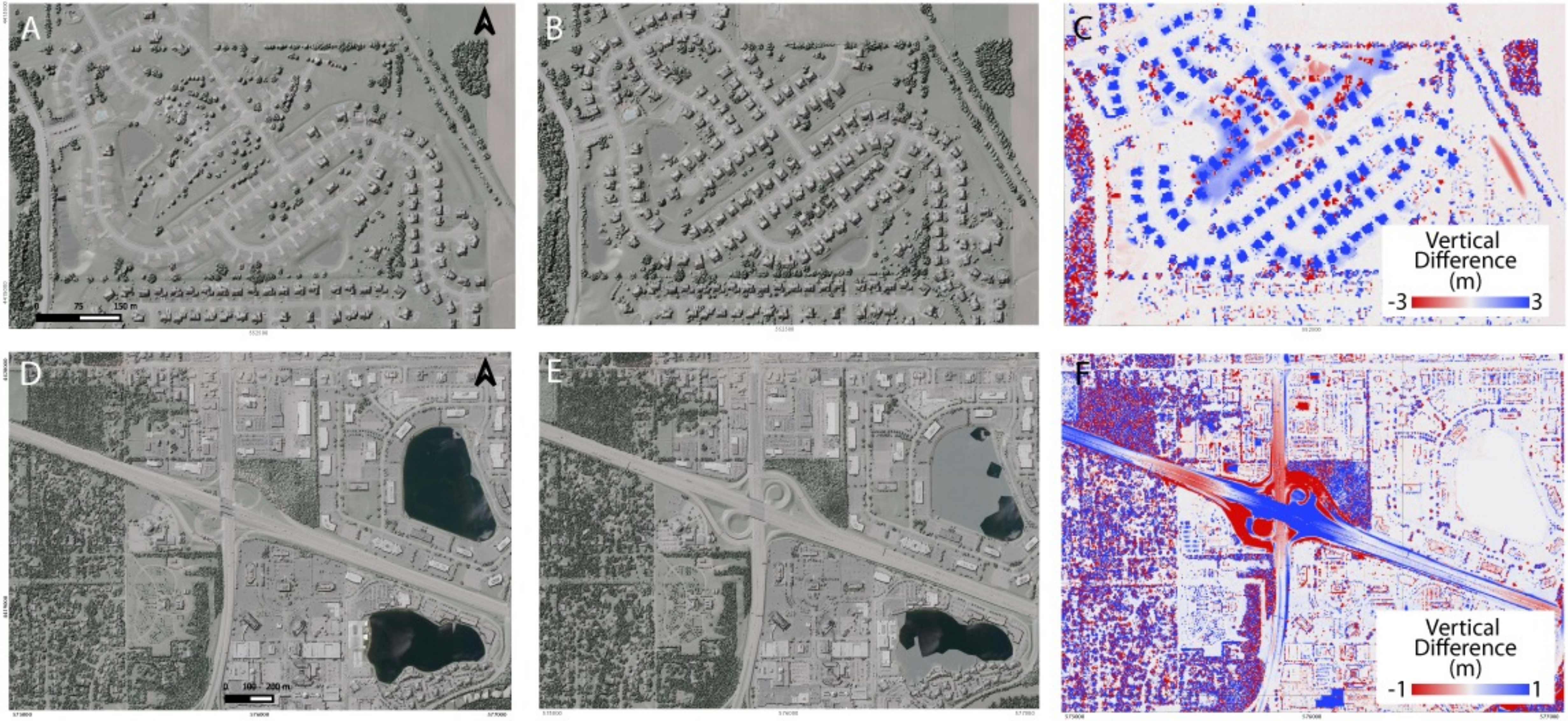
Flight alignment errors

Fluvial processes and quarry



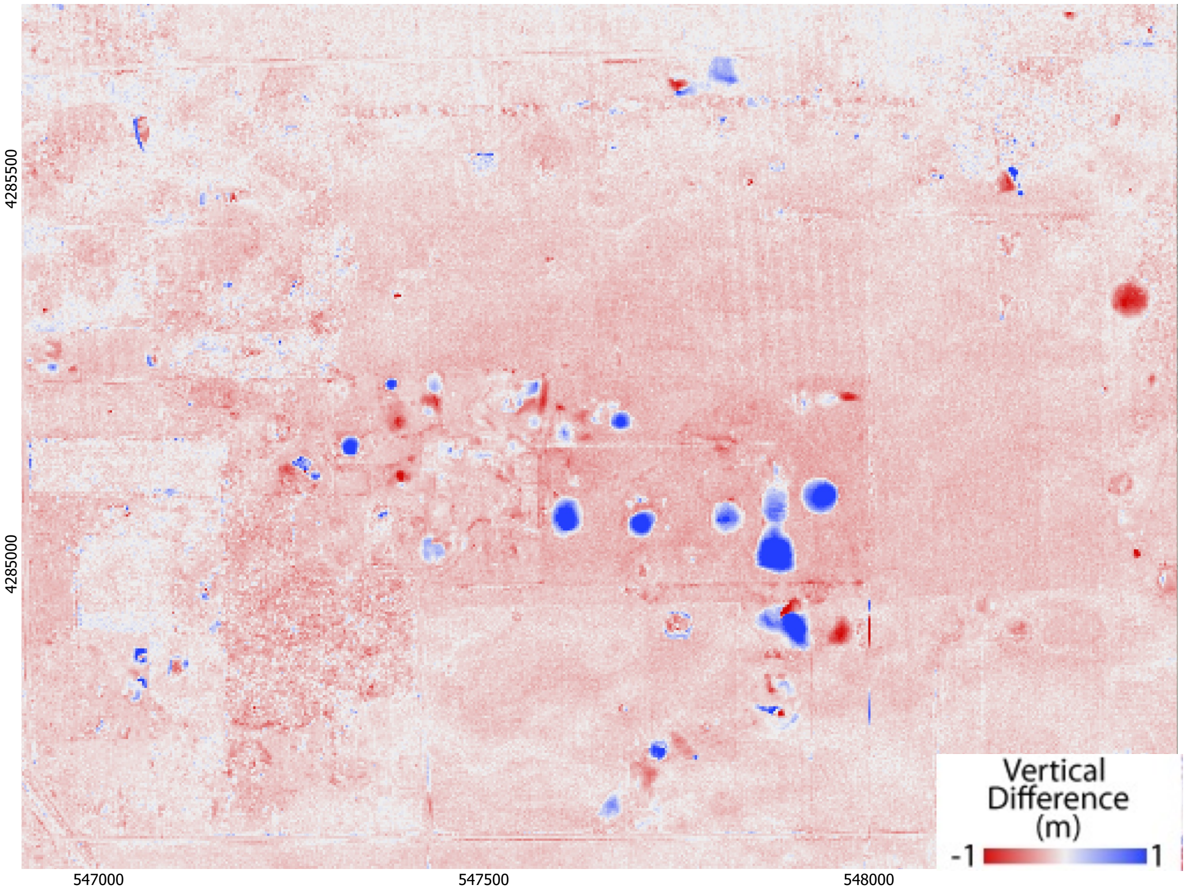
Scott et al., (2022)

Construction in Indianapolis



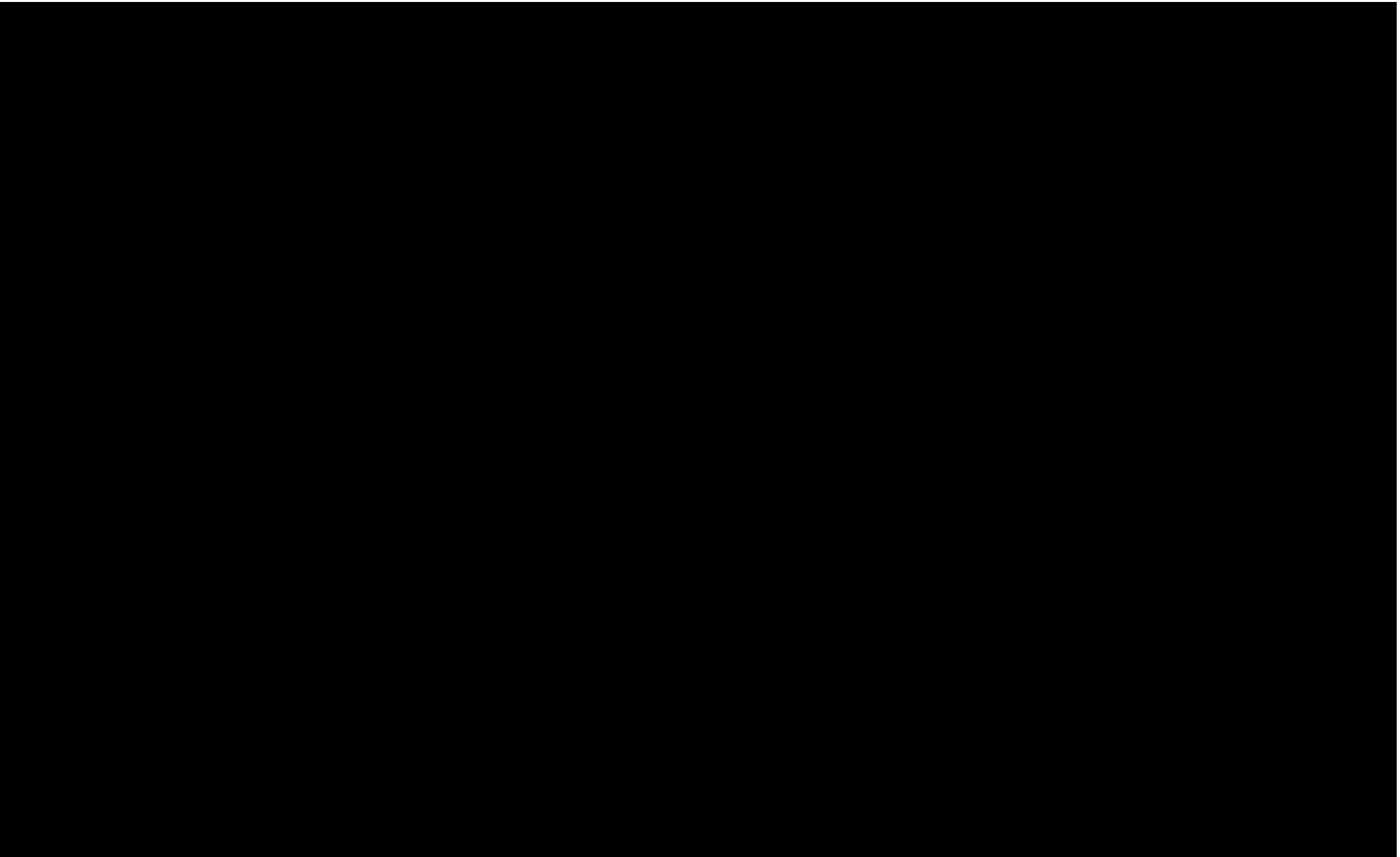
Scott et al., (2022)

Sinkholes



Scott et al., (2022)

Visualize: https://portal.opentopography.org/indiana



The Impact of Open Access Lidar Topography

OpenTopography's partnership with Indiana provides open and web-based access to statewide lidar topography and the framework for the first map of statewide topographic change

https://lidarmag.com/2022/07/26/the-impact-of-open-access-lidar-topography/

Software Contribution

GEOSPHERE

GEOSPHERE, v. 17, no. 4

https://doi.org/10.1130/GES02259.1

12 figures; 2 tables

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Measuring change at Earth's surface: On-demand vertical and three-dimensional topographic differencing implemented in OpenTopography

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ABSTRACT

Topographic differencing measures landscape change by comparing multitemporal high-resolution topography data sets. Here, we focused on two types of topographic differencing: (1) Vertical differencing is the subtraction of digital elevation models (DEMs) that span an event of interest. (2) Three-dimensional (3-D) differencing measures surface change by registering point clouds with a rigid deformation. We recently released topographic differencing in OpenTopography where users perform on-demand vertical and 3-D differencing via an online interface. OpenTopography is a U.S. National Science Foundation–funded facility that provides access to topographic data and processing tools. While topographic differencing has been applied in numerous research studies, the lack of standardization, particularly of 3-D differencing, requires the customization of processing for individual data sets and hinders the community's ability to efficiently perform differencing on the growing archive of topography data. Our paper focuses on streamlined techniques with which to efficiently difference data sets with varying spatial resolution and sensor type (i.e., optical vs. light detection and ranging [lidar]) and over variable landscapes. To optimize on-demand differencing, we considered algorithm choice and displacement resolution. The optimal resolution is controlled by point density, landscape characteristics (e.g., leaf-on vs. leaf-off), and data set quality. We provide processing options derived from metadata that allow users to produce optimal high-quality results, while experienced users can fine tune the parameters to suit their needs. We anticipate that the differencing tool will expand access to this state-of-the-art technology, will be a valuable educational tool, and will serve as a template for differencing the growing number of multitemporal topography data sets.

INTRODUCTION

Topographic differencing measures landscape change from urban growth, flooding (Wheaton et al., 2009; Izumida et al., 2017), coastal processes (Brock et al., 2001; Bull et al., 2010), earthquakes and creeping faults (Oskin et al., 2012; Nissen et al., 2012, 2014; Clark et al., 2017; Scott et al., 2018a; Wedmore et al., 2019; Barnhart et al., 2019; Scott et al., 2020), volcanic eruptions (Albino et al., 2015), and landslides (Lucieer et al., 2014), among other events. Interest in this technique is growing as more regions are surveyed with multitemporal topography data. Vertical differencing is the subtraction of raster-based digital elevation models (DEMs) and can be performed on original raster topography or grids generated from point cloud data, as shown in Figure 1. Three-dimensional (3-D) differencing resolves the best rigid deformation during an event of interest and is performed with a windowed implementation of the iterative closest point (ICP) algorithm (Besl and McKay, 1992; Chen and Medioni, 1992), as illustrated in Figure 2.

The 3-D differencing method, in particular, often requires an expert to dedicate substantial effort to customize processing, and there is little standard methodology or documentation available. As multitemporal topography coverage increases, more data types with variable characteristics are differenced, and results are used to respond to natural disasters and study phenomena altering Earth's surface. In this paper, we describe our implementation of on-demand vertical and 3-D differencing on topography data available via OpenTopography (opentopography.org). A major challenge in 3-D differencing is to select the appropriate differencing algorithm and the resolution of derived displacements, which depend on data resolution, noise, and landscape characteristics. We compared several differencing algorithms and incorporated metadata (e.g., point density) into the default processing settings. Our workflow quickly produces quality differencing results and offers default options that can be further tailored for individual data sets by more advanced users. Deployment of these tools in OpenTopography expands access to state-of-the-art technology for scientists, geospatial professionals, and students. Additionally, our tools can become a reference that contributes to the standardization of topographic differencing, which is lacking in the geosciences.

OpenTopography is a U.S. National Science Foundation–funded facility that enables discovery and access of high-resolution topography data sets and provides on-demand processing tools. OpenTopography is built on a scalable-system–oriented architecture that supports a range of downstream processing tools that derive common science products from hosted raw data (Krishnan et al., 2011). As of October 2020, the 341 point cloud data sets hosted by OpenTopography cover more than

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OpenAccess Academic Publication

Link: https://doi.org/10.1130/GES02259.1

Resources:
https://opentopography.org/learn/differencing

Blog posts

Recorded presentations

Github repository for vertical and 3D differencing

Undergraduate-level lab on 3D differencing