Creating DEMs From LiDAR Point Cloud Data

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Digital Elevation Models

- Digital representation of topography / terrain
  - "Raster" format – a grid of squares or "pixels"
  - Continuous surface where Z (elevation) is estimated on a regular X,Y grid
  - "2.5D"

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	0
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Source: http://www.ncgia.ucsb.edu/giscc/extra/e001/e001.html

- Grid resolution is defined by the size in the horizontal dimension of the pixel
  - 1 meter DEM has pixels 1 m x 1m assigned a single elevation value.

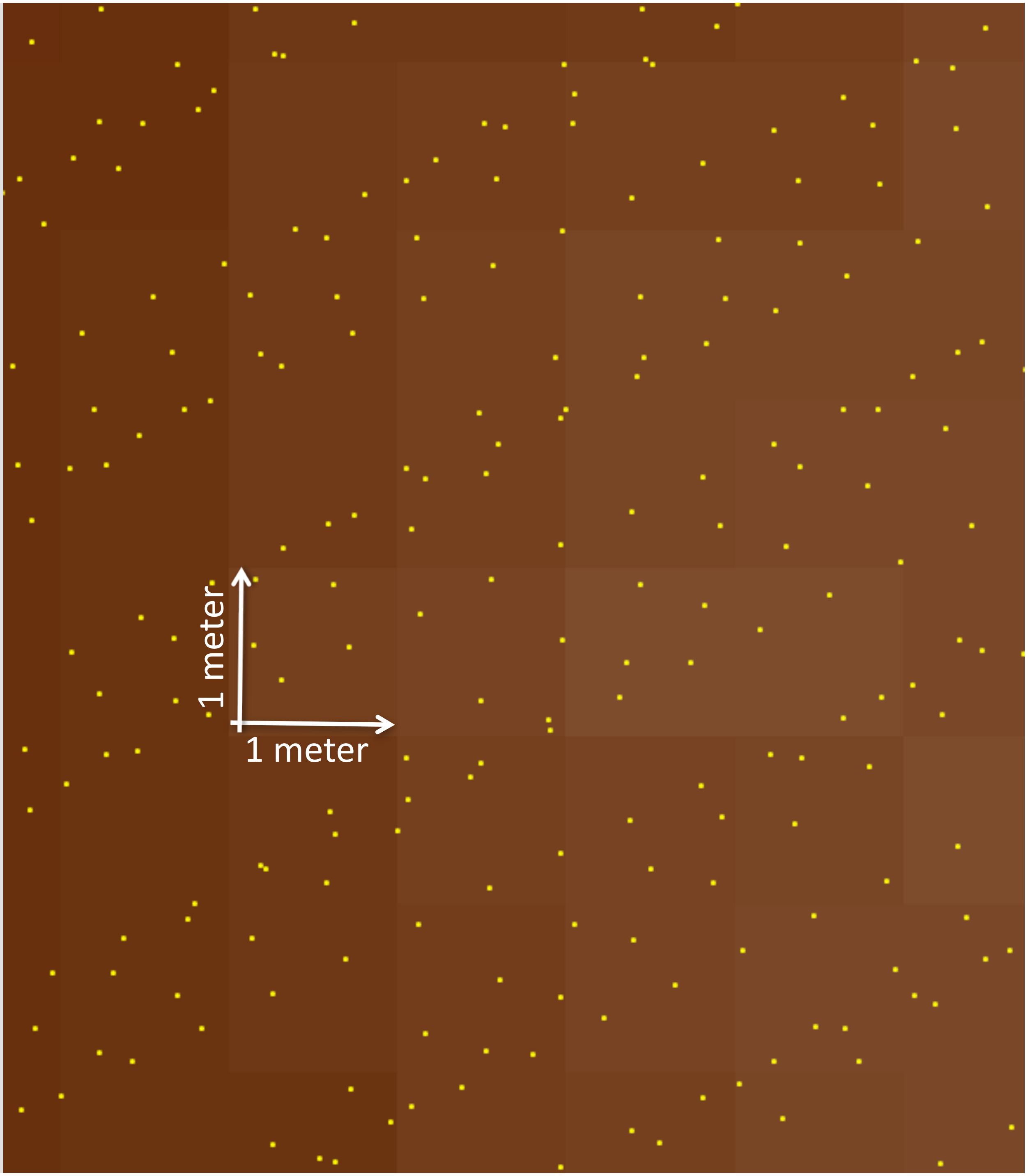
- 1 meter grid

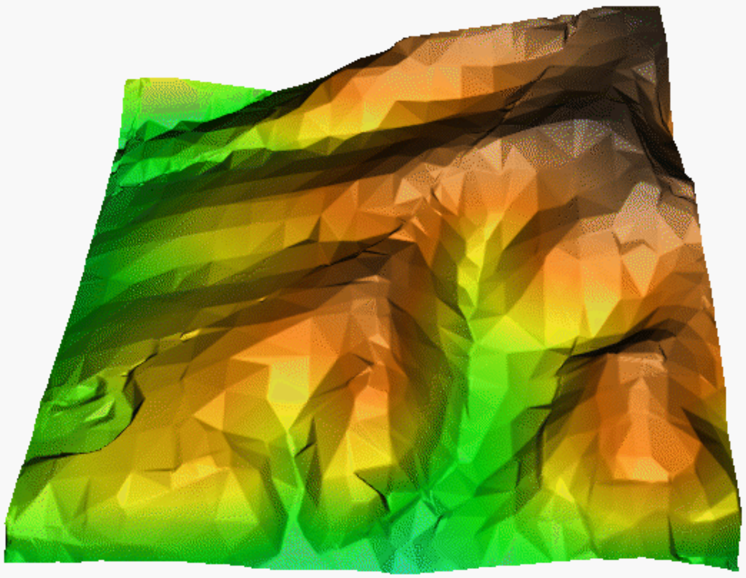
- LiDAR returns from EarthScope data collection

- Example from flat area with little or no vegetation so ground is sampled approx. 5+ times per square meter

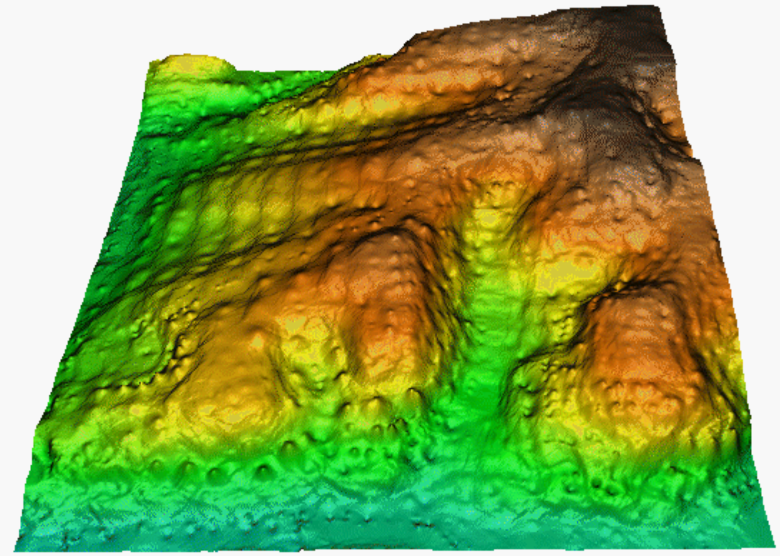
- How do we best fit a continuous surface to these points?

- Ultimately wish to represent irregularly sampled data on a regularized grid.

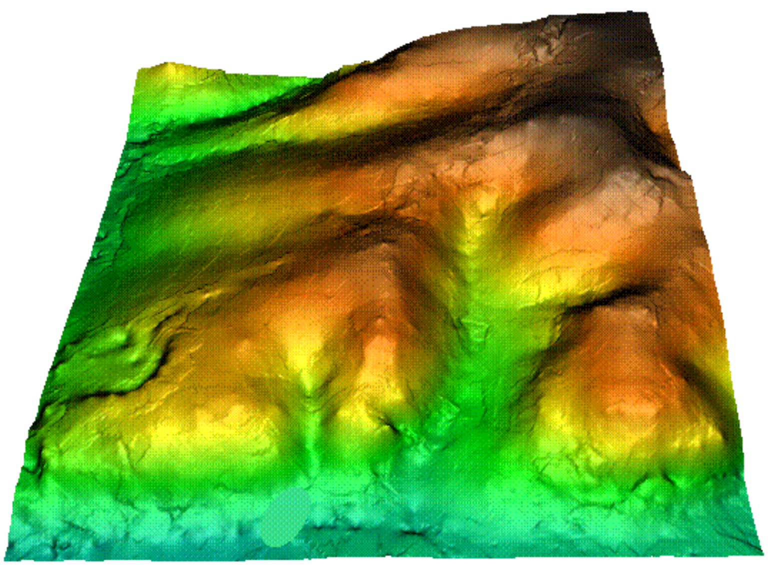




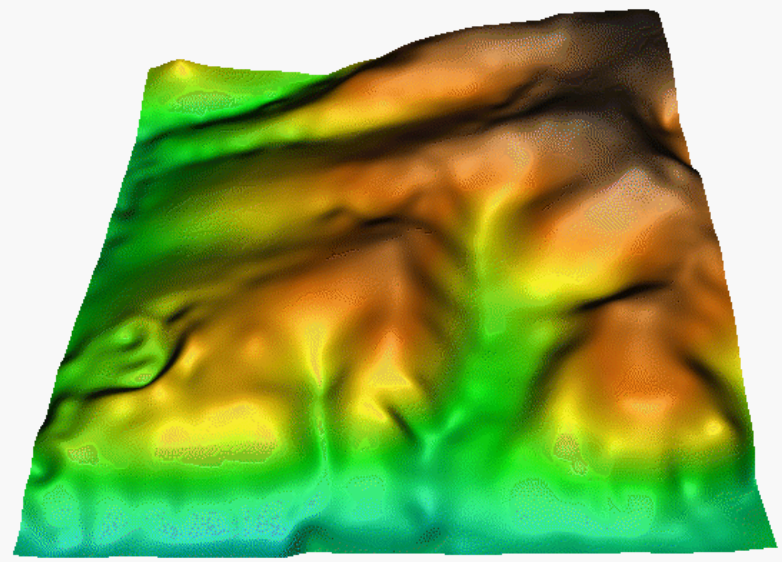
Triangulated Irregular Network (TIN)



Inverse Distance Weighted (IDW)



Kriging



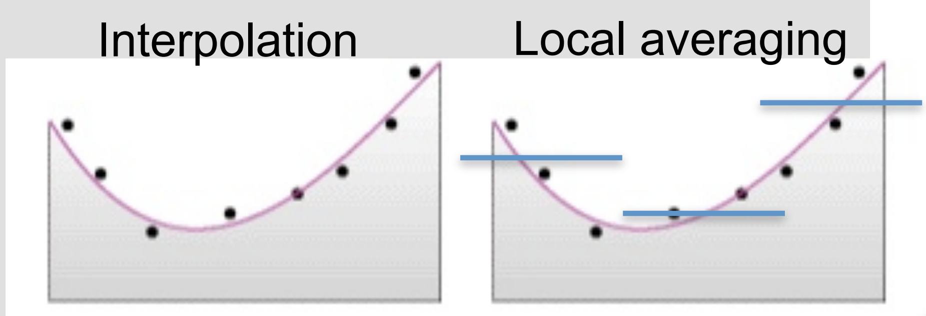
Regularized Spline with Tension and smoothing (RST)

Figure from Helena Mitasova (NCSU): http://skagit.meas.ncsu.edu/~helena/gmslab/index.html

Challenges & Approaches:

- Massive volume of point cloud data that need to be gridded presents unique challenge to many traditional GIS interpolation approaches.
  - Computation time becomes a serious concern

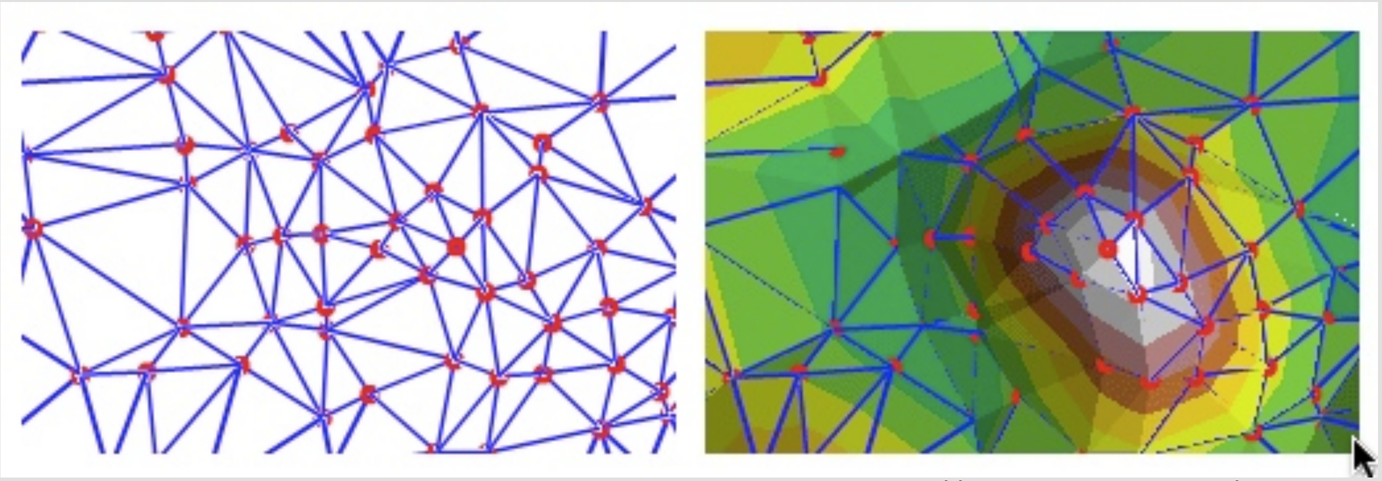
- Global vs Local fit
  - Global fit uses elevations from the whole map area to estimate unknown elevation at the grid node.
    - Ex: Kriging, Trend Surface Analysis, splines
    - Computationally intensive and require segmentation approaches to break input data into pieces which can be processed independently.
    - Often inexact interpolators
      -Surface does not exactly fit all points.
    - Works well in areas where ground is poorly sampled.



http://webhelp.esri.com/

Challenges & Approaches II:

- Triangular Irregular Networks (TIN)
  - Constructed by triangulating a set of points



http://webhelp.esri.com/

  - Linear interpolation where points are fit exactly
  - Computationally efficient
  - Preserve heterogeneity of detail in sampling
  - Vector-based format so conversion to grid is necessary for many types of analysis.

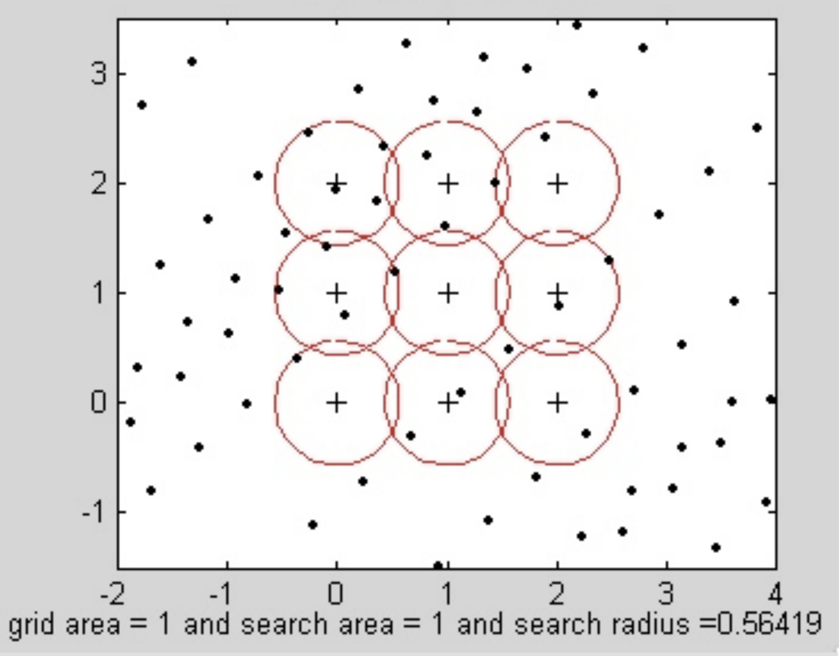
Challenges & Approaches III:

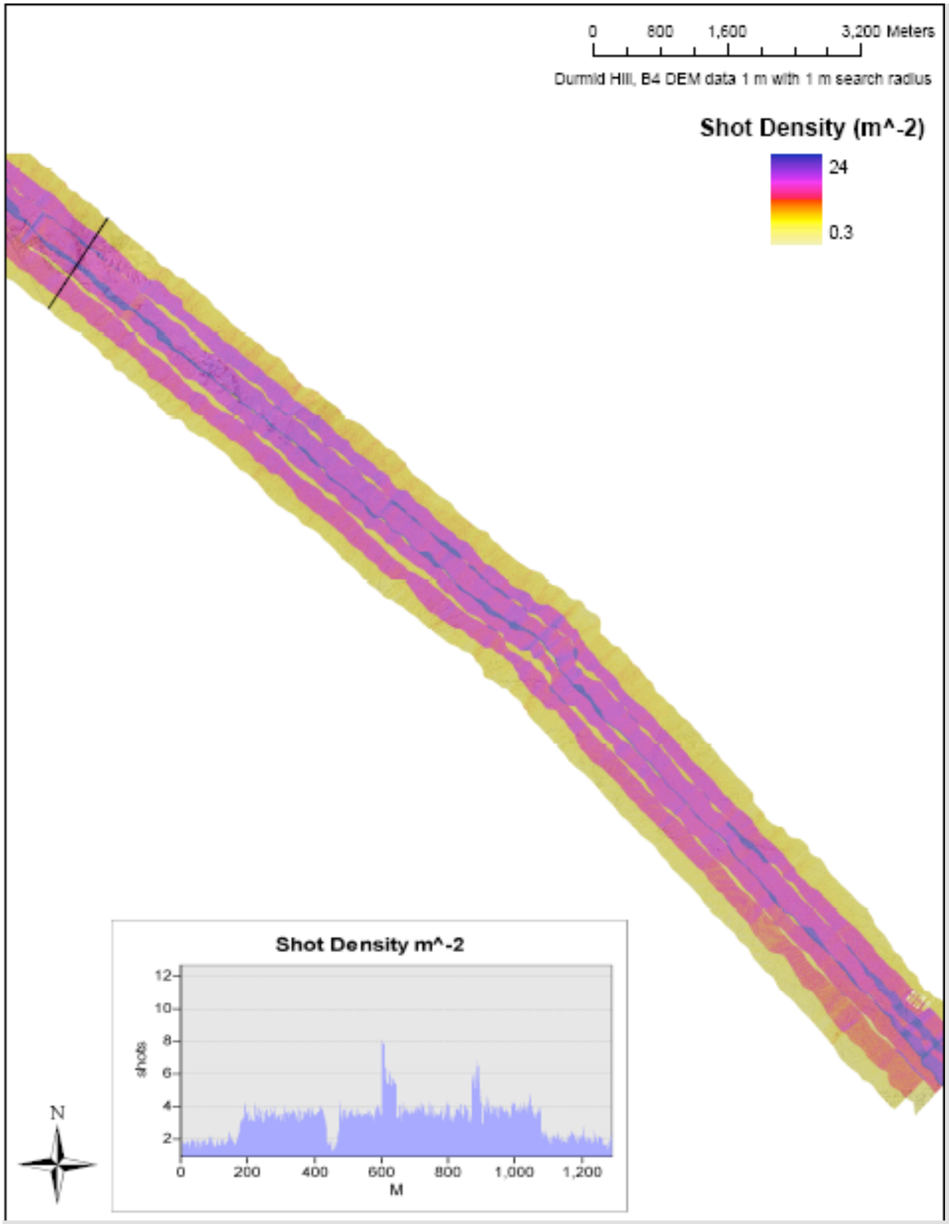
- Global vs Local fit cont.:
  - Local fit only uses elevations immediately surrounding the grid node to estimate elevation.
    - Nearest neighbor, local binning, moving window
    - For all points that fall within the defined search area, apply mathematical function e.g Z_{mean} Z_{min} Z_{max} Z_{idw}

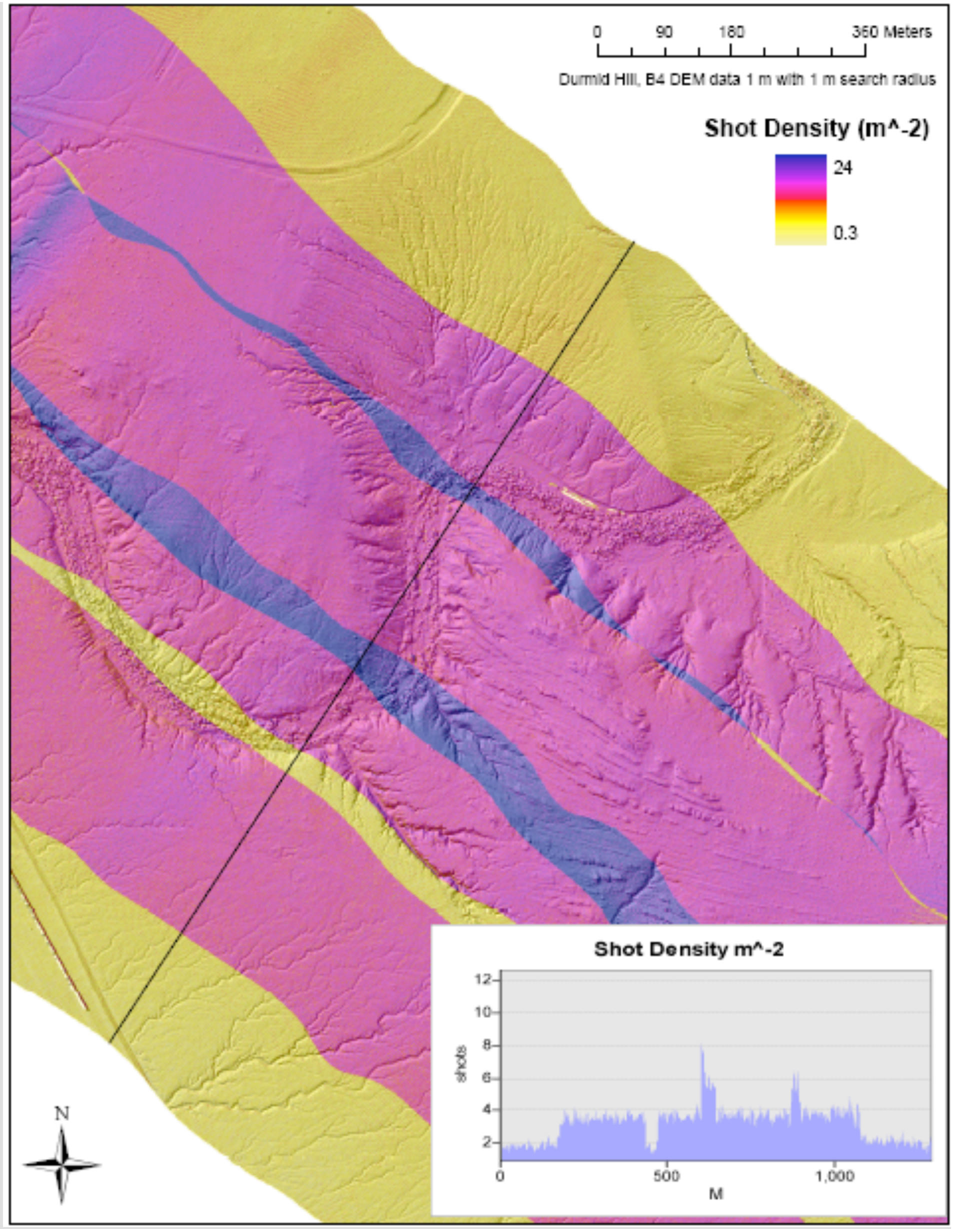
- Computationally efficient
- Not interpolation!
- Works well when:

Sampling density > grid resolution

Ex: sampling density = 5 shots/m^2
grid resolution = 1 m





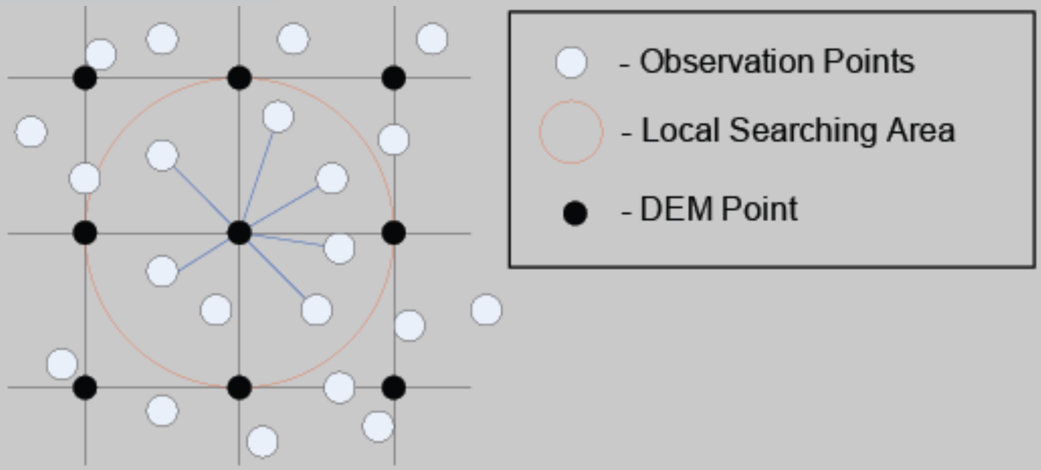


Heterogeneity of surface sampling: B4 shot density maps and profiles

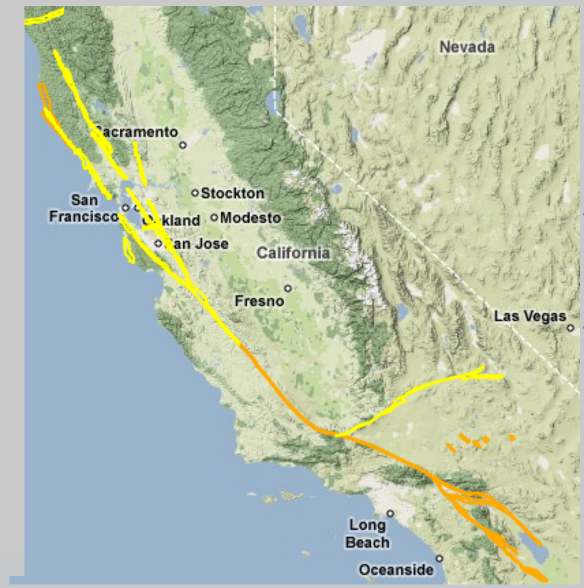
http://lidar.asu.edu/knowledgebase.html

Geoscience/computer science collaboration anecdote: easy high performance implementation of local binning algorithm for Digital Elevation Model computation

Kim, et al., 2006



Local Binning Algorithm



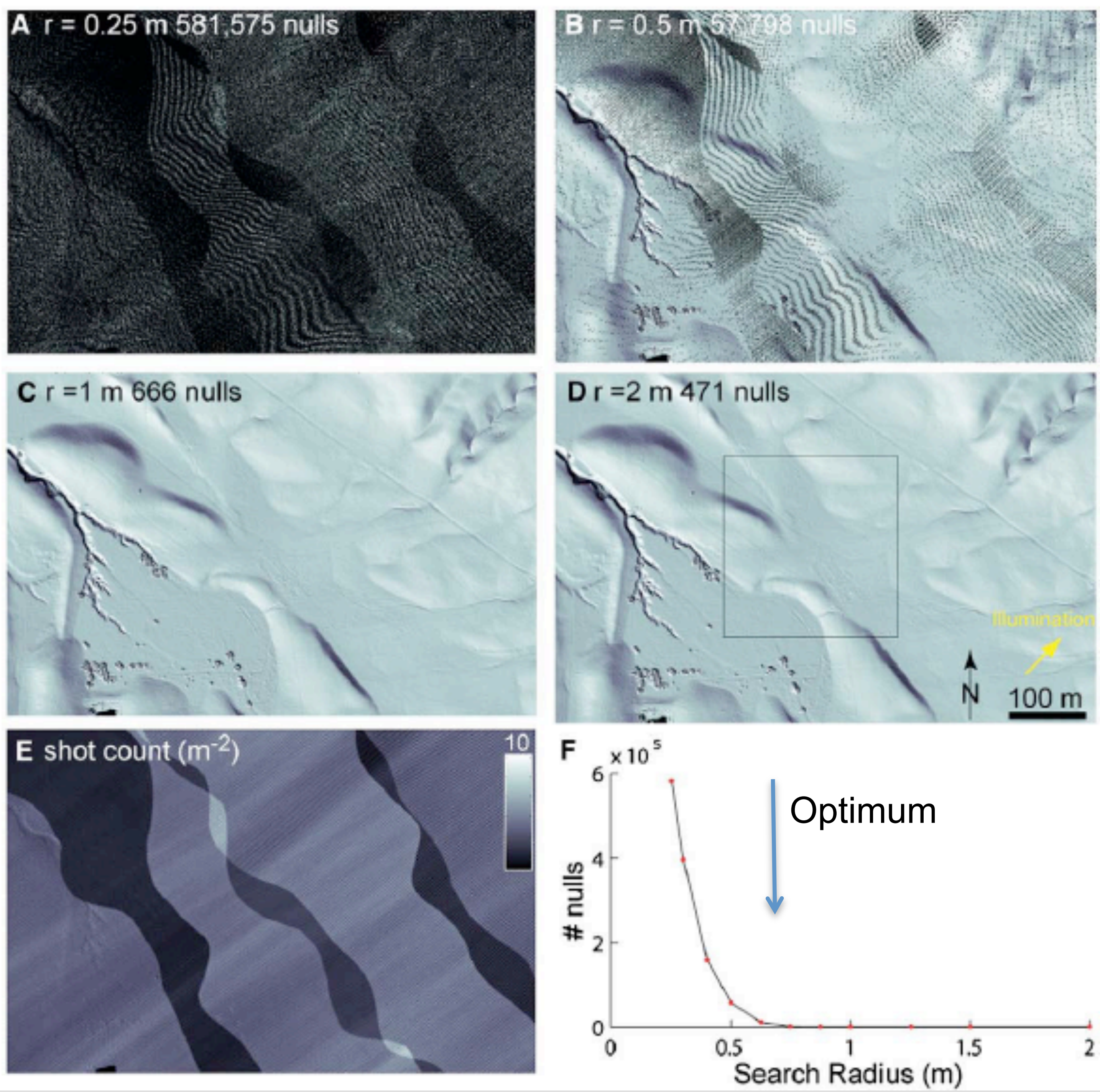
Motivator: lots of new LiDAR data for W. US active faults

With the local points, five values are computed for each node in a grid:

1) Minimum
2) Maximum
3) Mean
4) Inverse Distance Weighted mean of the local points
5) Density (the number of points in the search area)

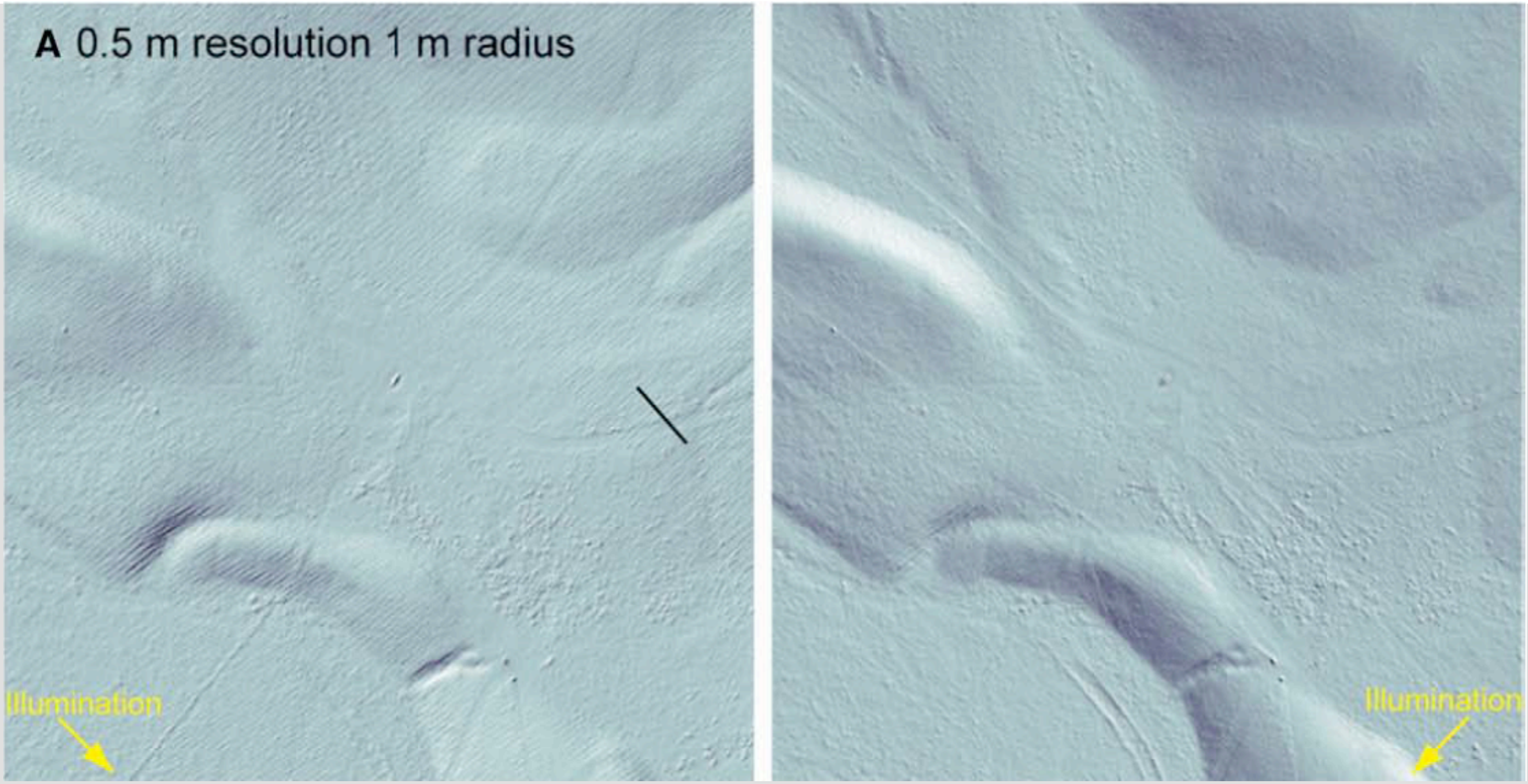
$$Z_{min} = min(Z_l)$$
$$Z_{mean} = mean(Z_l)$$
$$Z_{max} = max(Z_l)$$
$$Z_{IDW} = \frac{\sum_{l=1}^{n} \frac{Z_l}{d_l^p}}{\sum_{l=1}^{n} \frac{1}{d_l^p}}$$

If the number of points in the search radius is 0, the node is assigned a null value. The noble implementation technique can produce a grid containing those five values within O(N) time, where N denotes the size of the point cloud used. In addition, the space cost for this implementation is O(M), where M denotes the size of the grid.



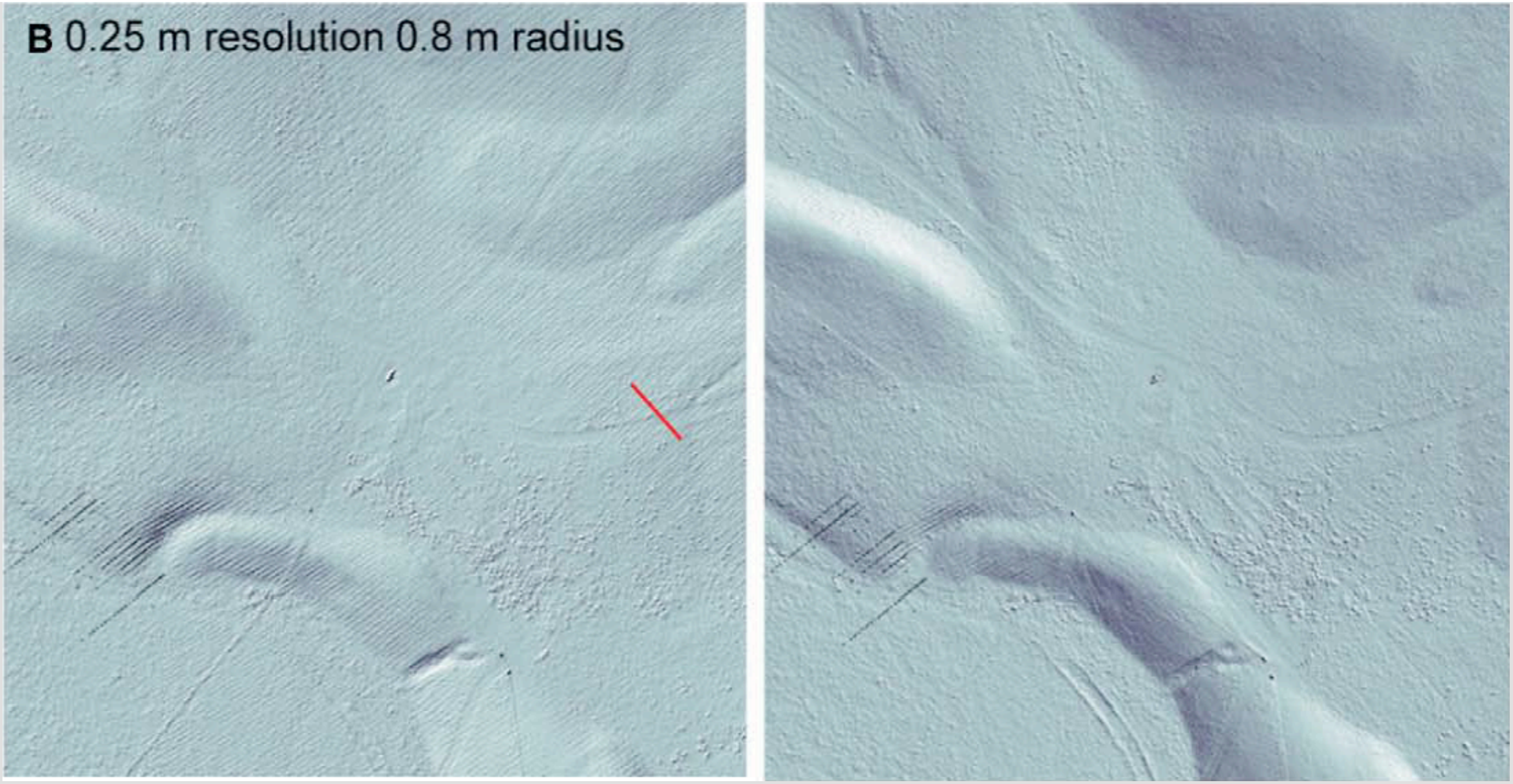
Finding the right search radius for a local binning calculation. Tradeoff of minimizing nulls versus increasing search radius

Arrowsmith and Zielke, 2009



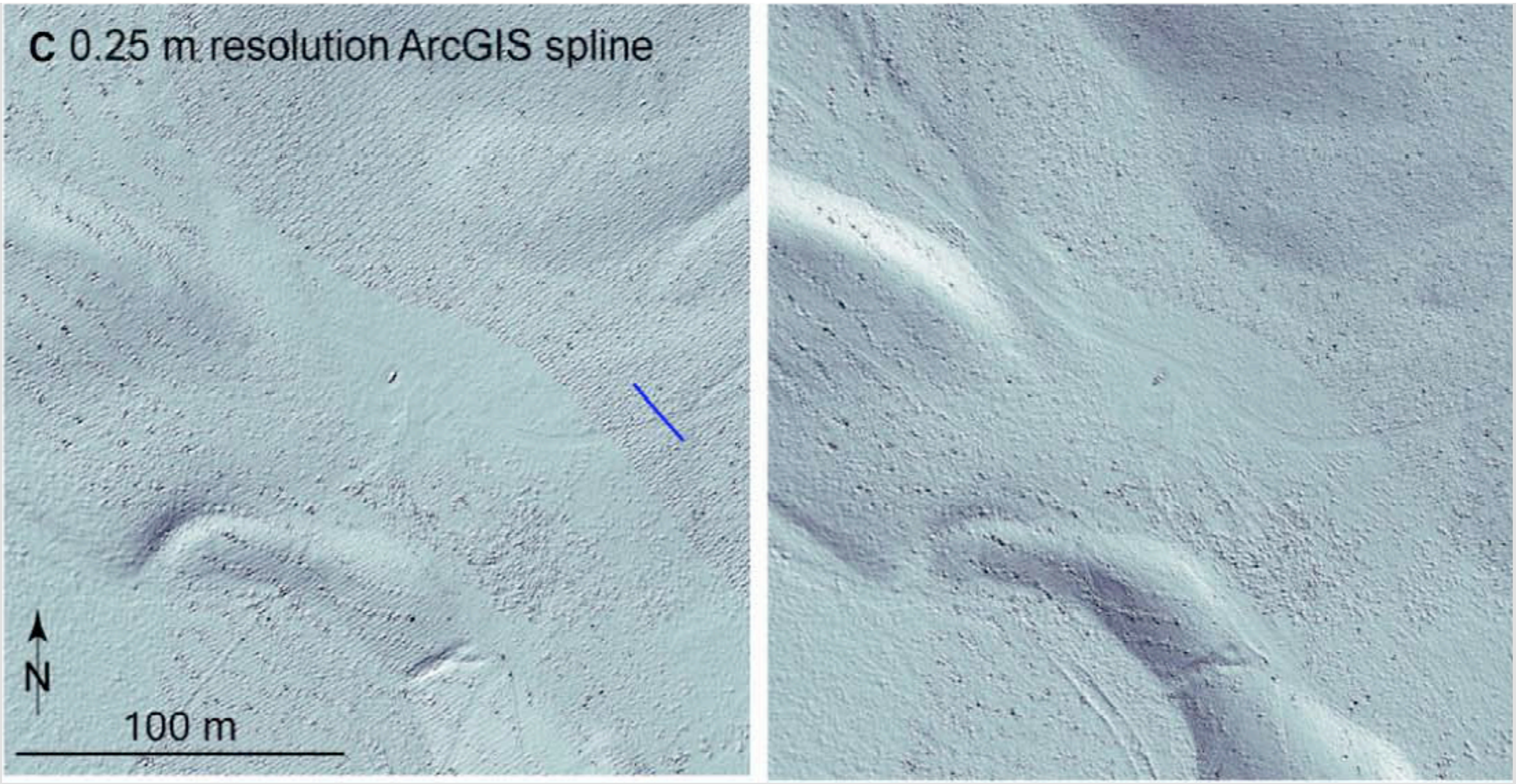
IDW local binning

Arrowsmith and Zielke, 2009



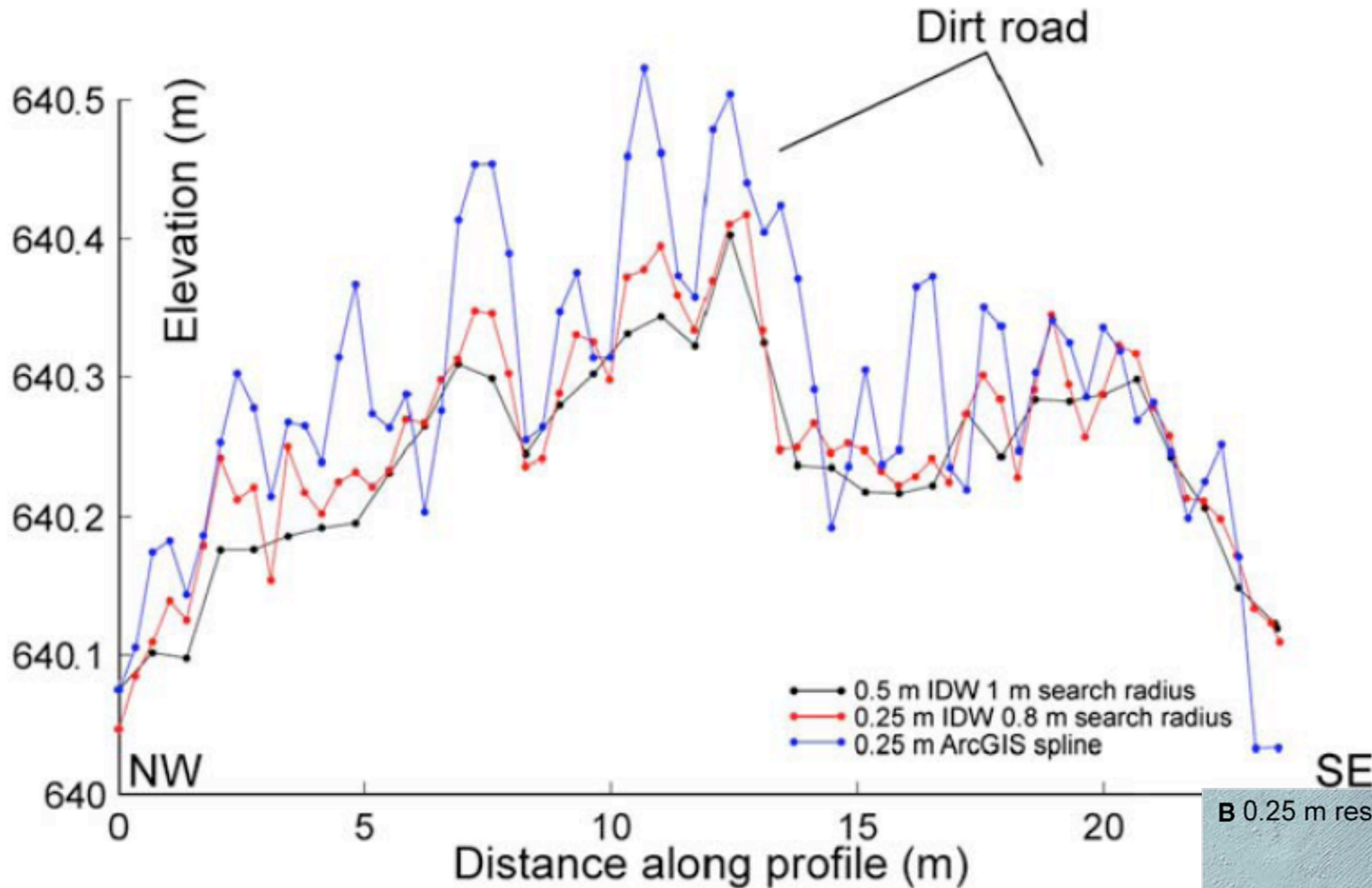
IDW local binning

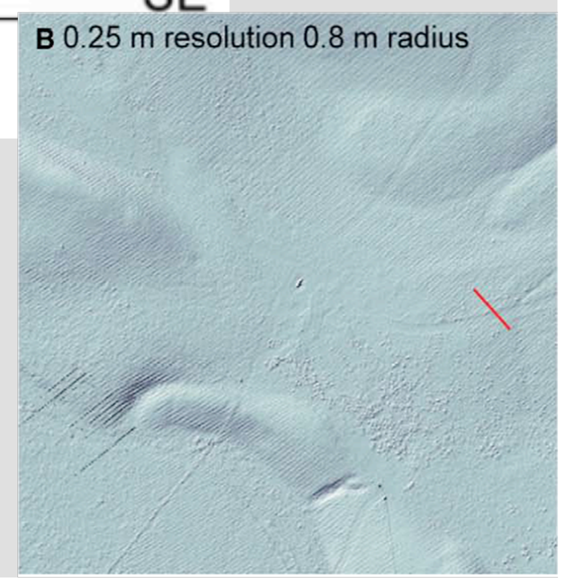
Arrowsmith and Zielke, 2009



ArcGIS interpolation

Arrowsmith and Zielke, 2009

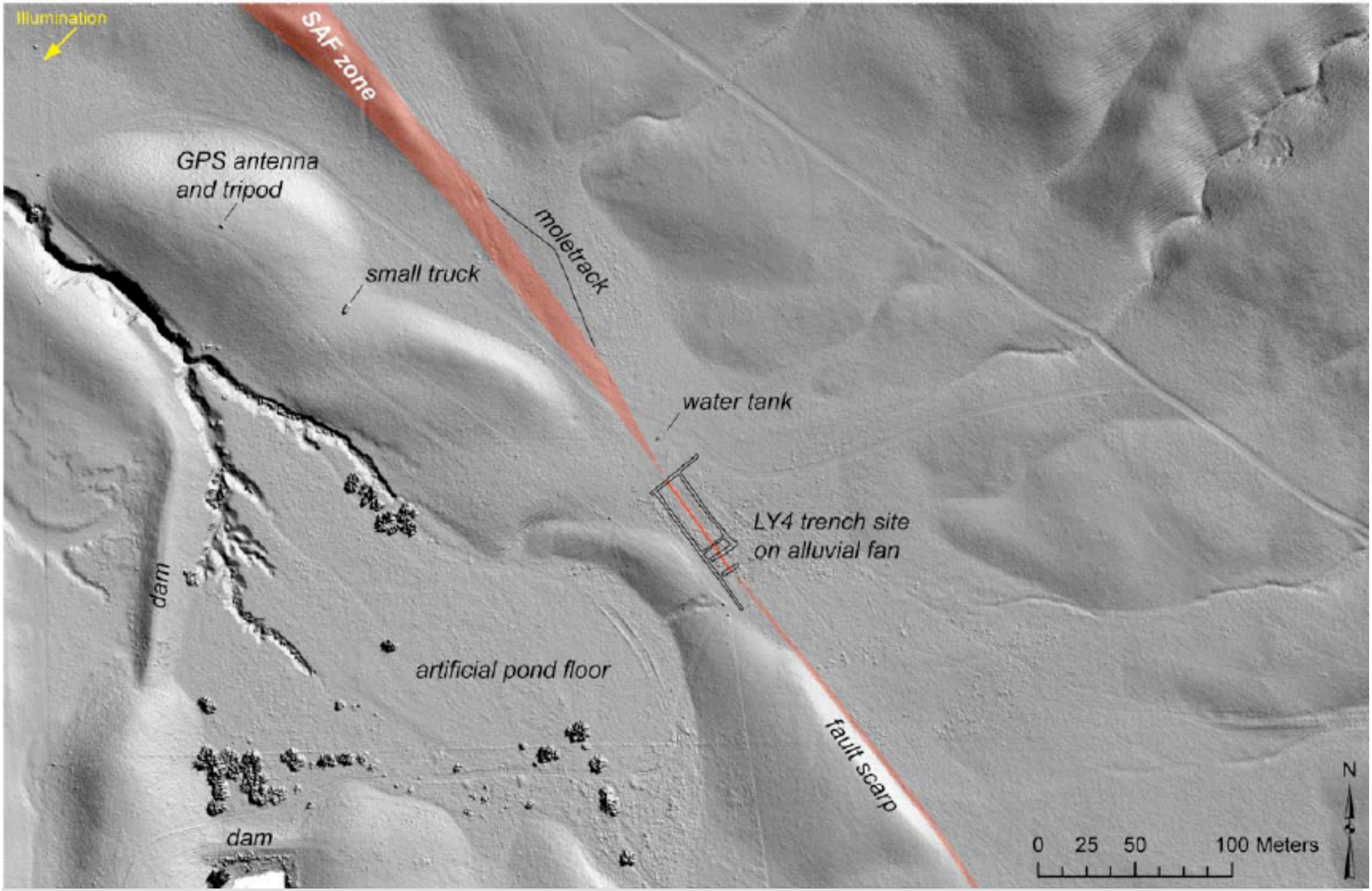




Slicing the different resulting DEMs

-Corduroy

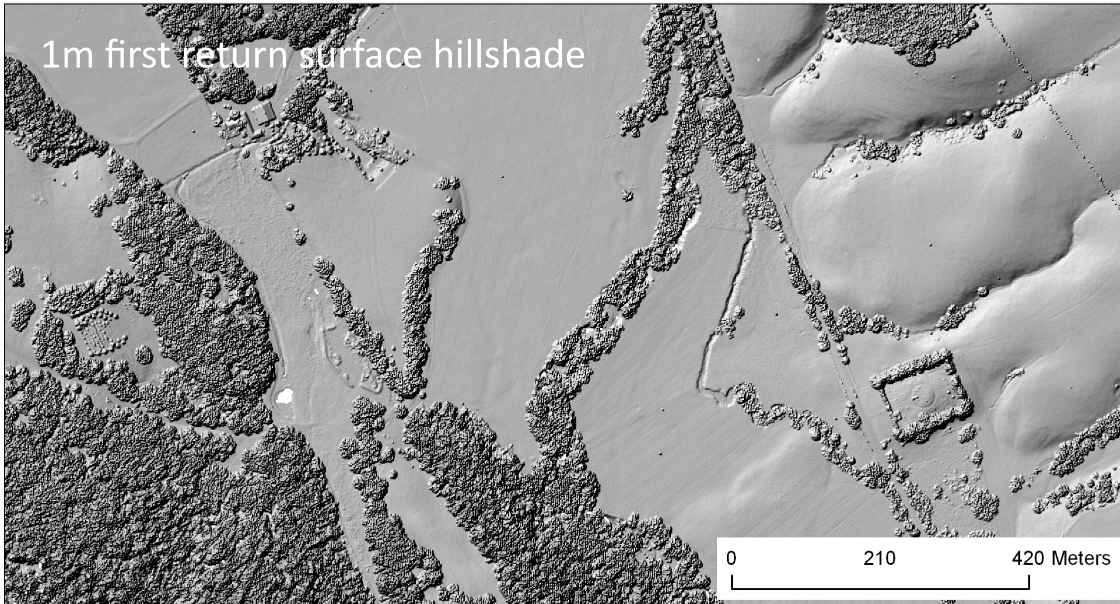
Arrowsmith and Zielke, 2009

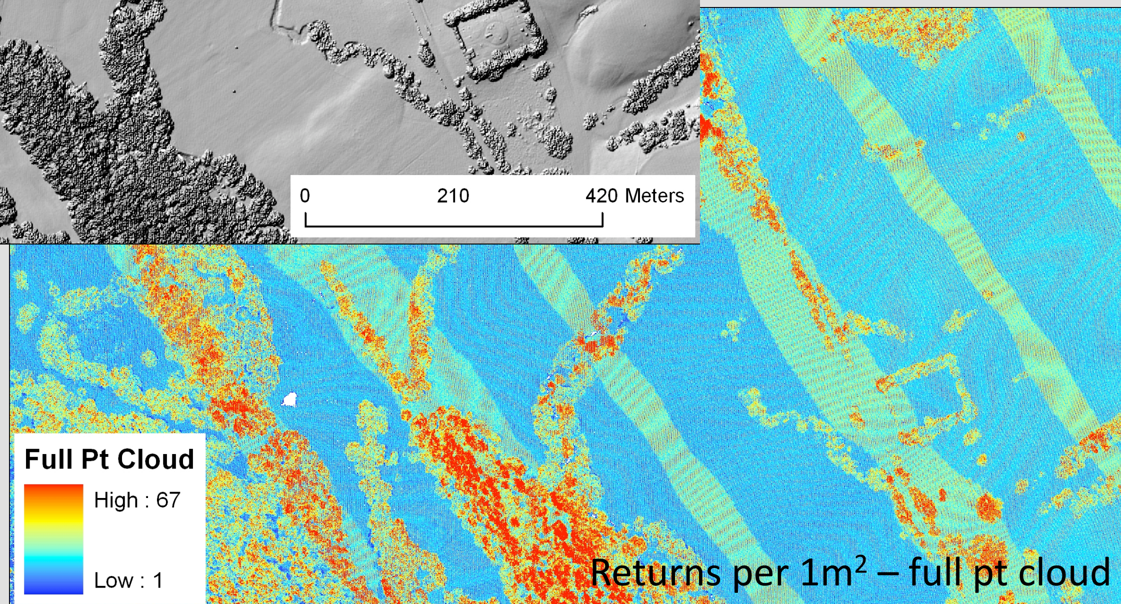


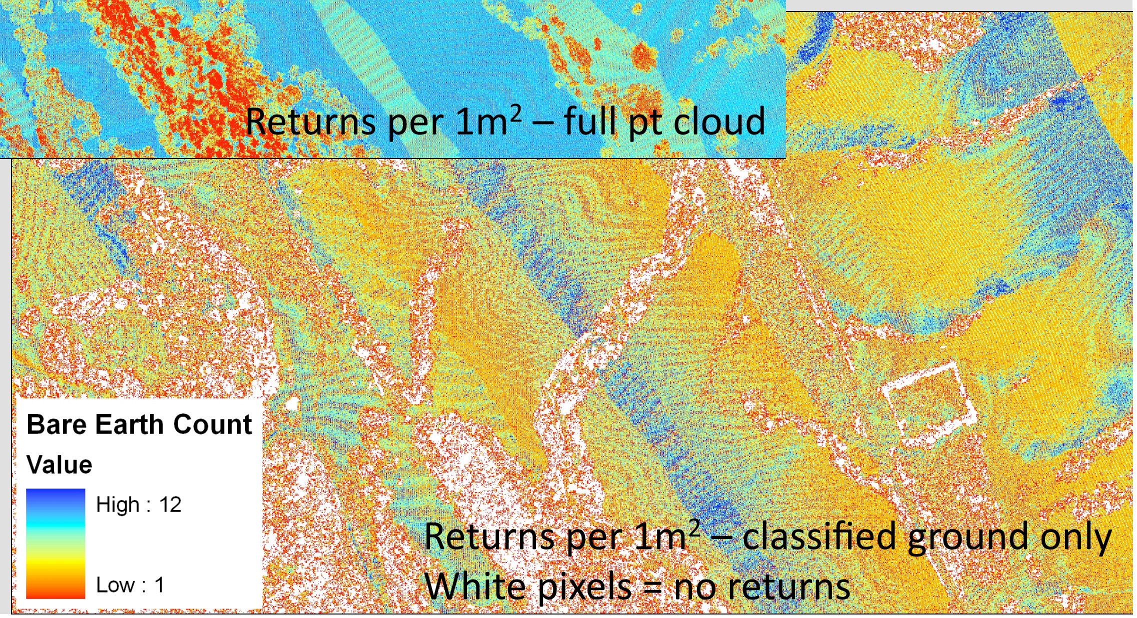
Resulting site map: 0.25 m resolution, 0.8 m search radius

Arrowsmith and Zielke, 2009

Importance of ground return density & DEM resolution

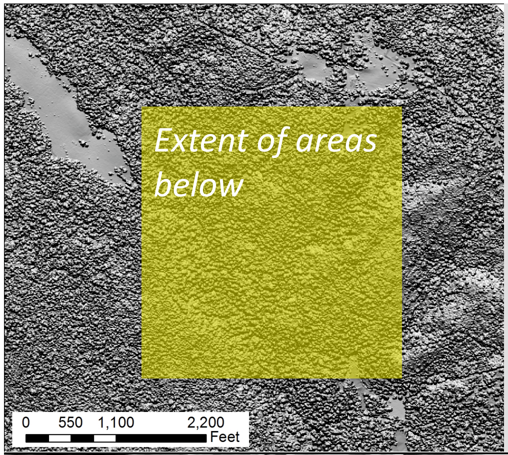






Ground return density may dictate appropriate DEM generation approach.

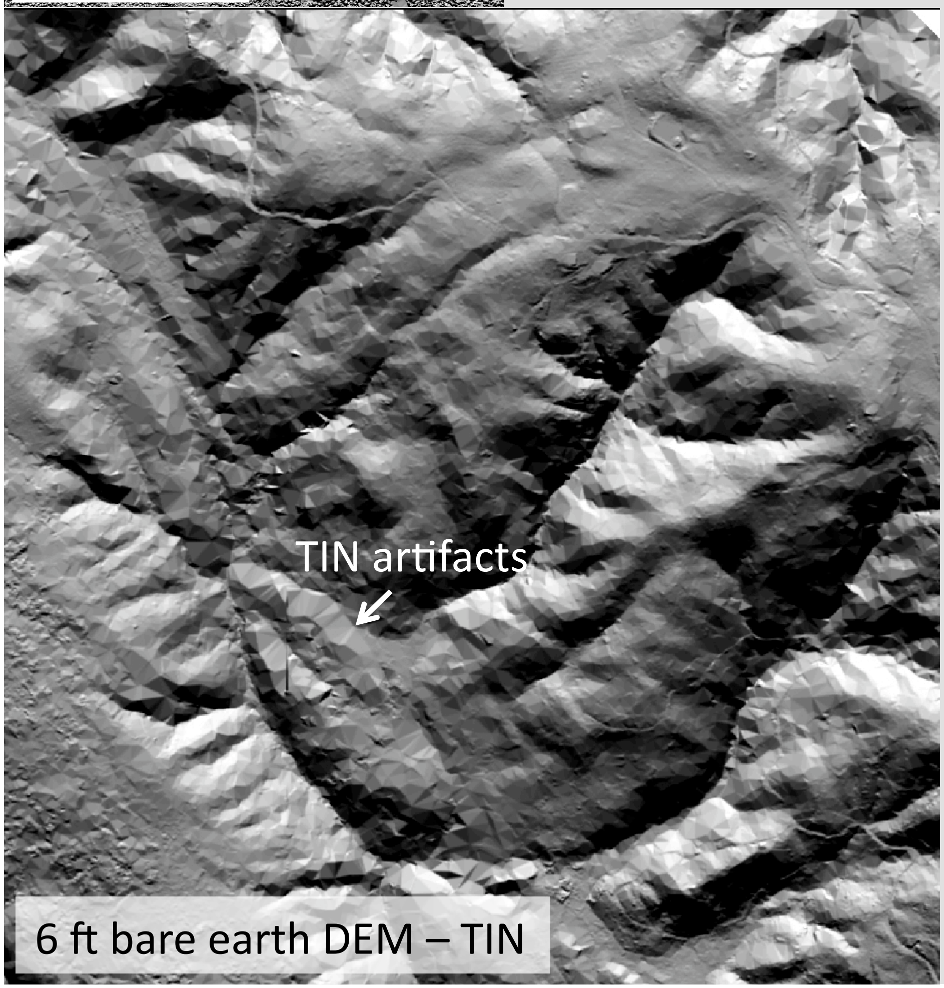
TIN or other non-local interpolator necessary in areas of sparse ground returns (right).

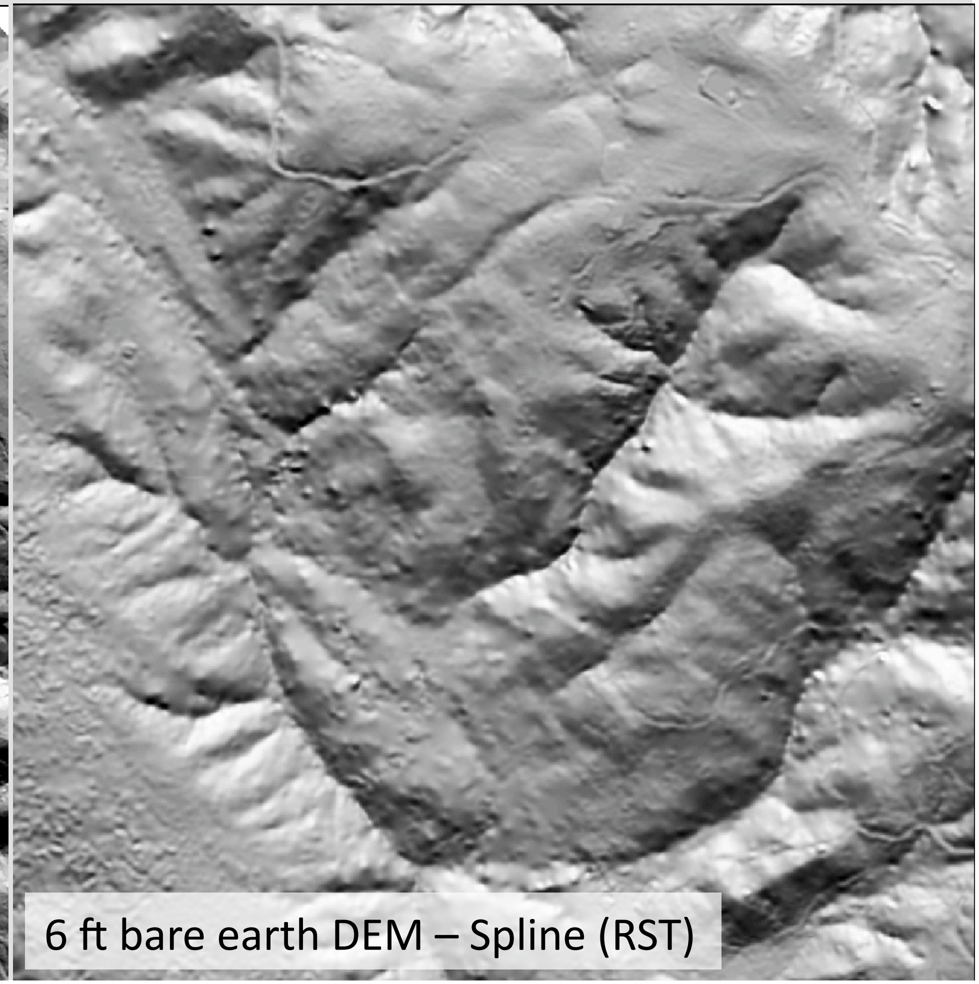


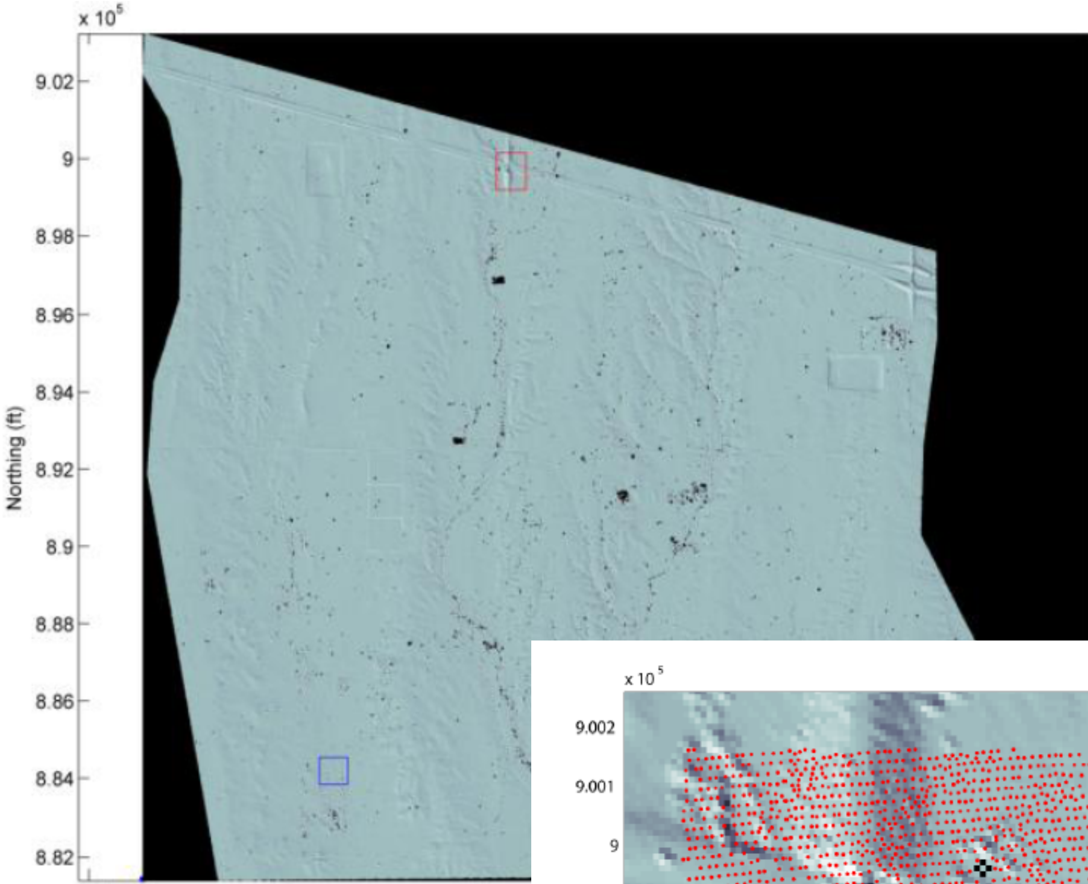
Role of gridding method in areas of low return density:

Do you prefer visible artifacts or smoothed regions where surface is less well constrained?

- Local methods can populate pixels without returns to null (swiss cheese surface – very honest representation of data)
- TIN artifacts in low ground return density
- Spline and Kriging = smoother surface…low return density less clear

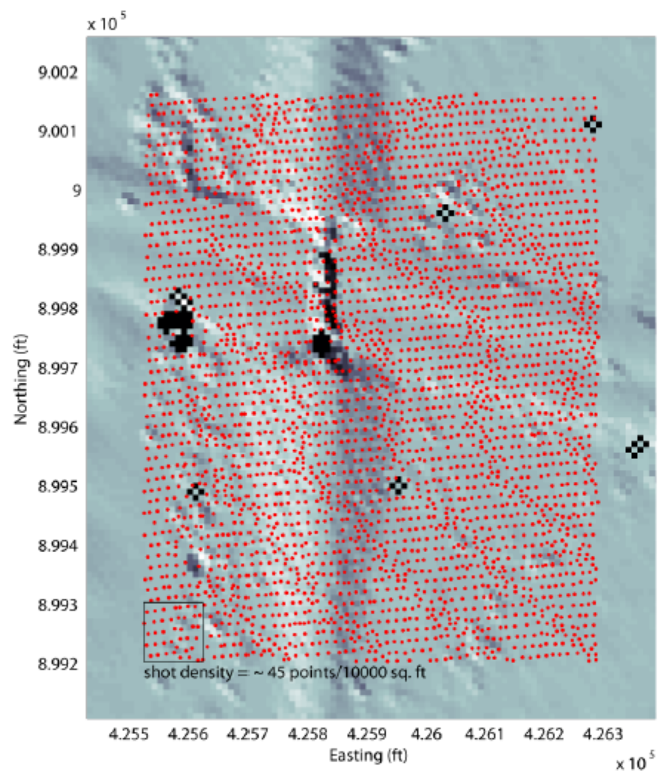


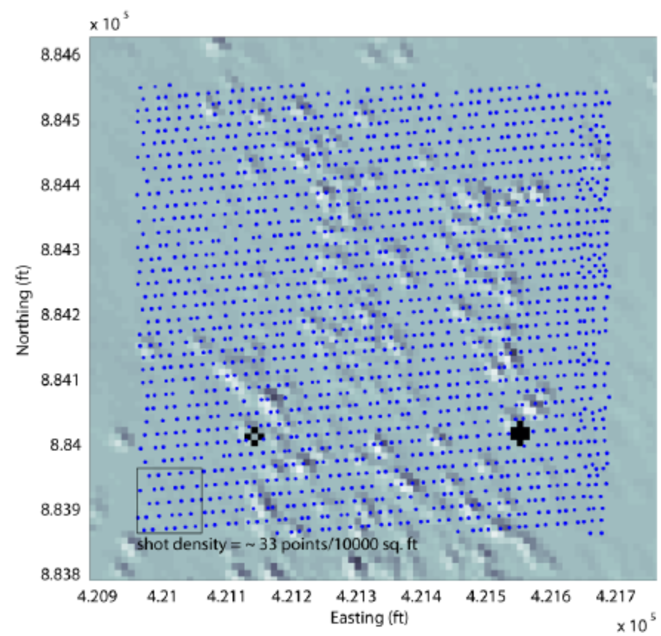


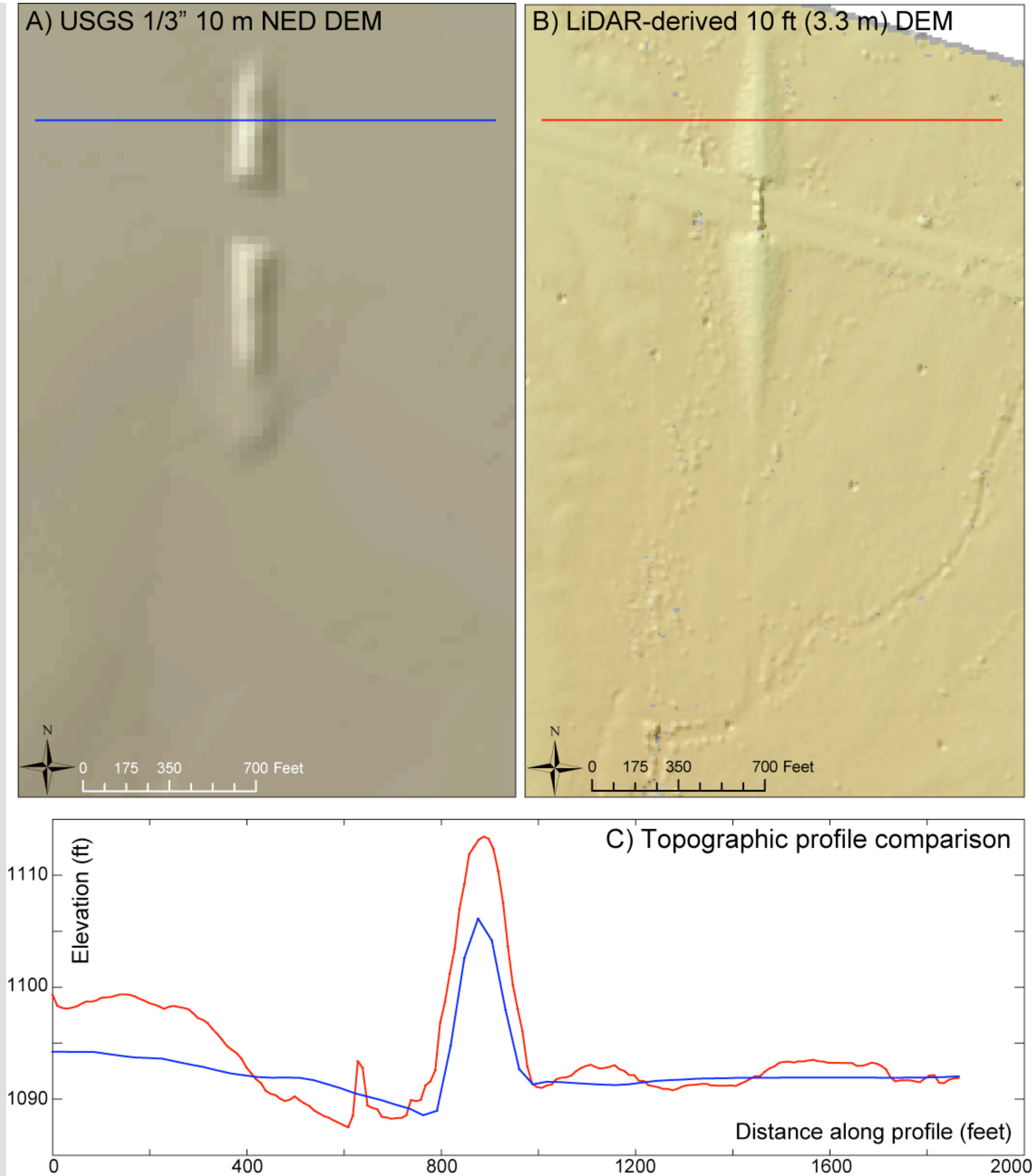


Shot densities

Luke Wash—West Phoenix low quality data



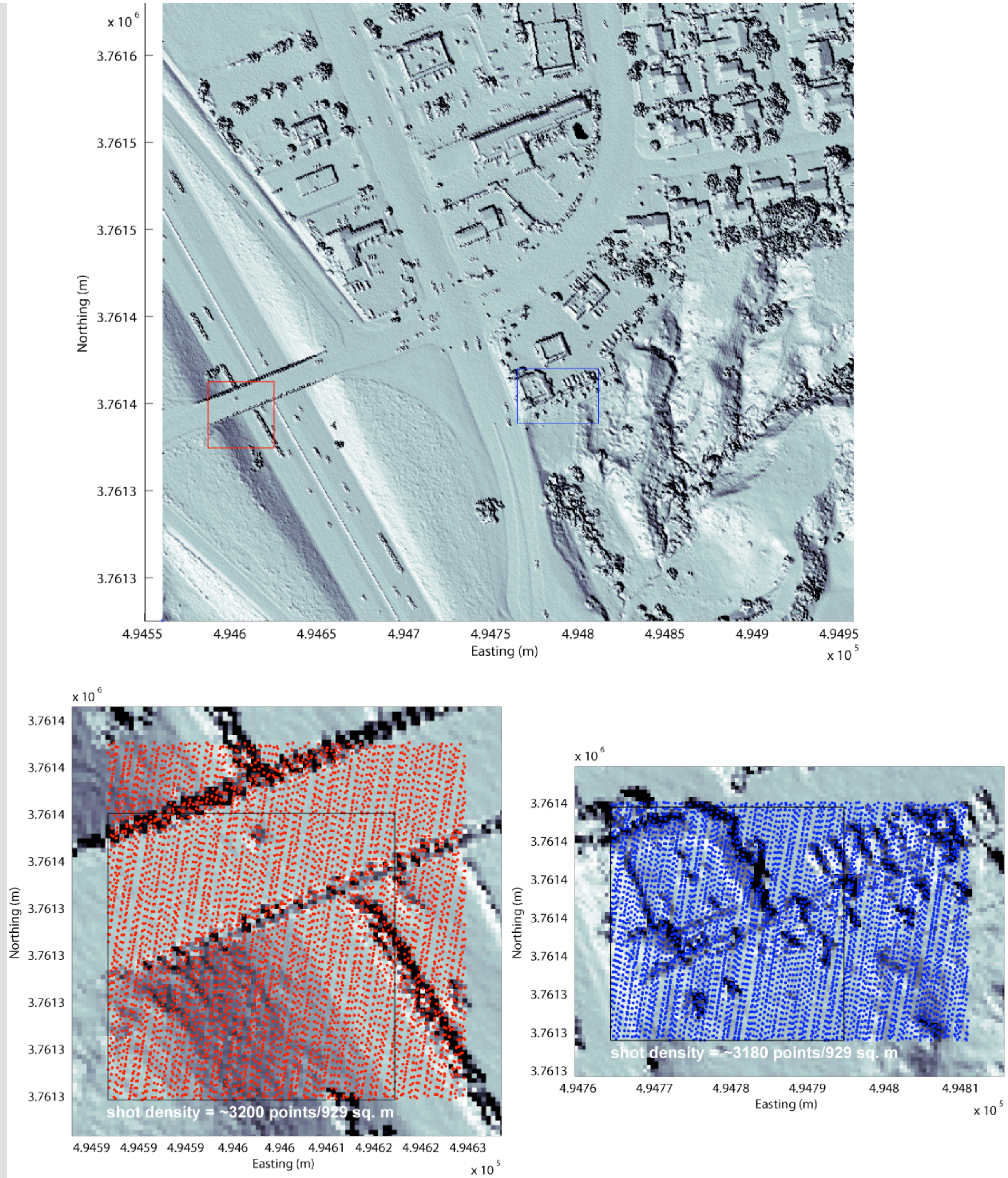




Luke Wash—West Phoenix low quality data

Shot densities

San Bernardino area high quality data (B4)



Other Considerations:

- Application of data:
  - Different applications may warrant different approaches to grid generation
  - e.g. Hydrologic routing vs. geomorphic mapping

- Software and computational resources available

SUMMARY (rules of thumb…):

- In general for LiDAR data, return density is > than grid resolution (i.e. multiple returns per meter)
    - In this case, local gridding approaches can produce accurate DEMs and are computationally efficient.

- When the ground is poorly sampled (typically in areas of dense vegetation and steep topography), it may be necessary to use an interpolation approach such as spline or kriging to fit a surface to fill the gaps and produce a continuous terrain model.

- TINs generally work well in all return densities unless facet artifacts are a problem.

- LiDAR Return densities are very heterogeneous & and it is important to understand your data before beginning to work with them.