UNIVERSITETET I OSLO

GEO3460 – Geografiske informasjonssystemer (GIS) og geografisk datainnsamling – vår 2025

GEO3460 - Geographical Information Systems (GIS) and Geographical Data Acquisition - spring 2025

DEM generation and visualization

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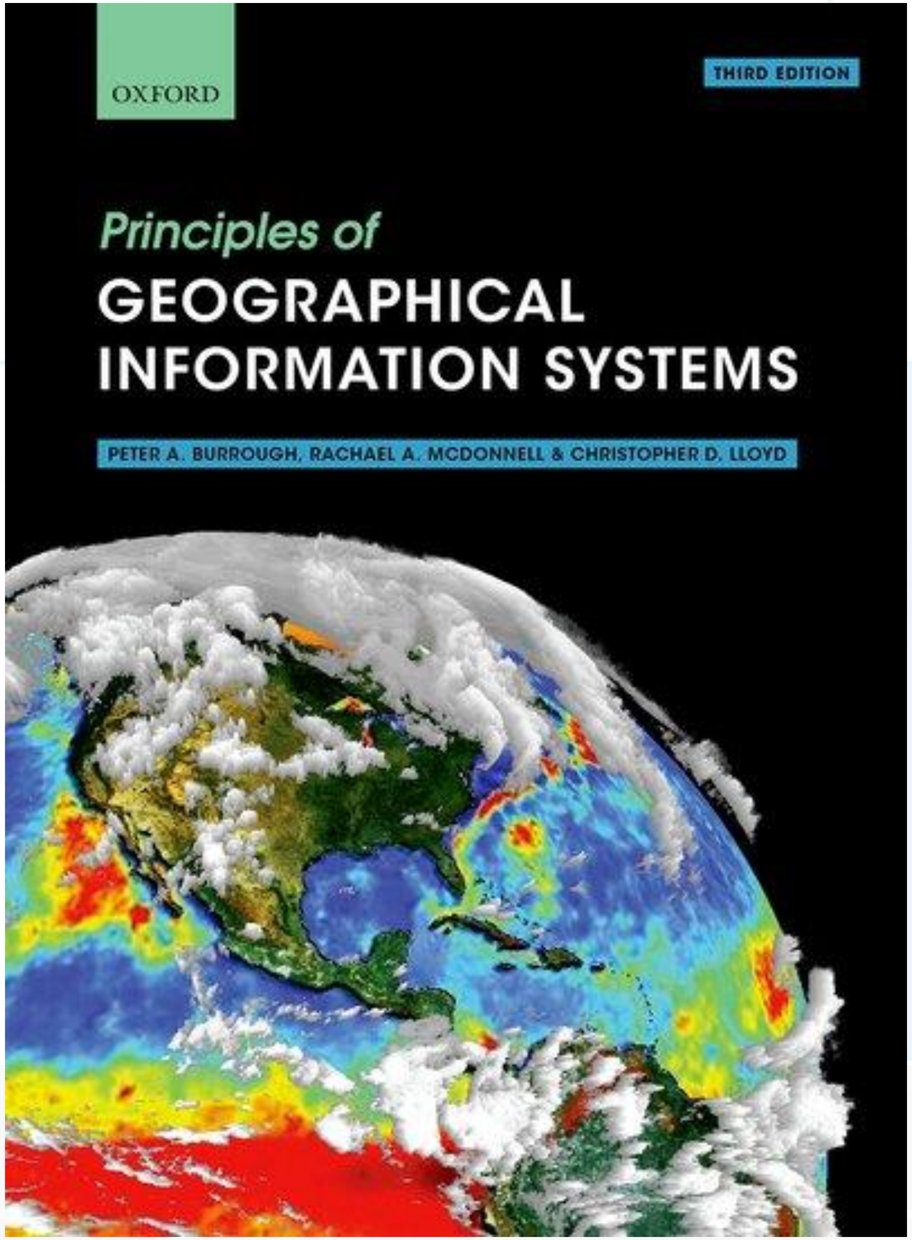
Based on the lectures by Dr. Livia Piermattei



- Reference text book:

"*Geographical information systems*" (not available online)

  - Chapter 11

Learning Objectives

1

Elevation data
- Definition
- DEM data structure
- Contour line, TIN, raster

2

Elevation data source:
- Remote sensing
- Photogrammetry
- Las file
- DEM generation

3

DEM visualization
- Hillshade
- Example

Today's topics

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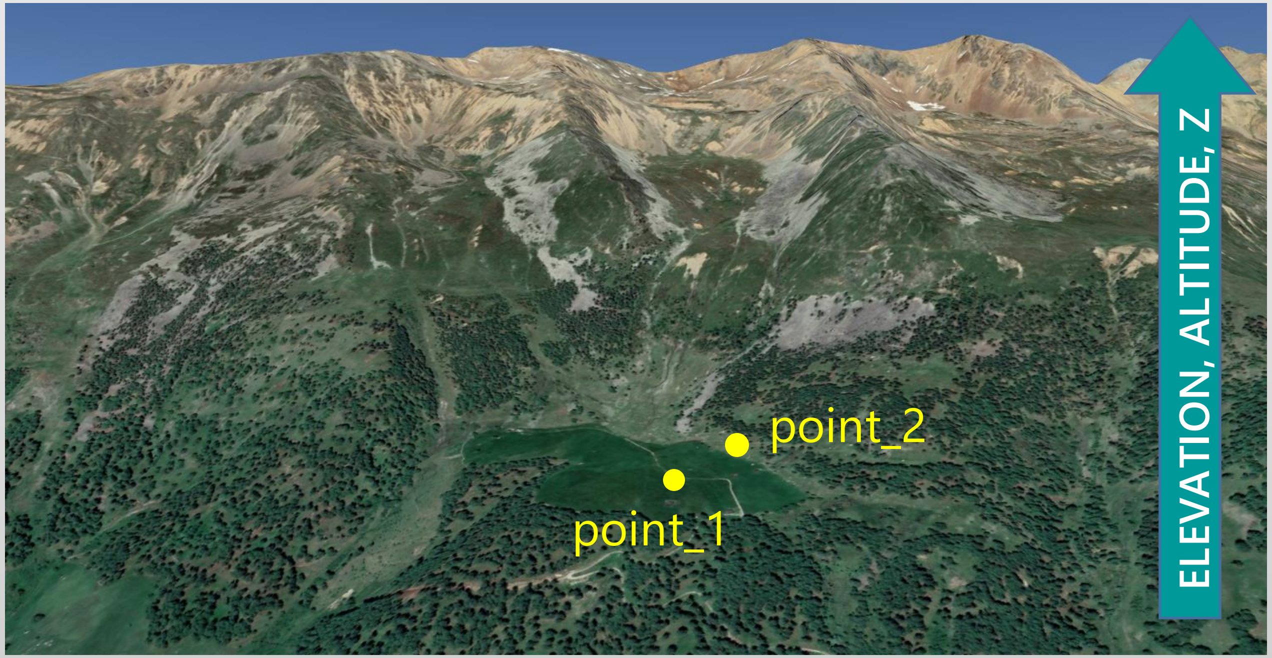
Today's topics

How to represent topography?



North=Latitude = Y
East =Longitude = X
Elevation = Altitude = Z

point_1 =	point_2 =
423426.532 N	423743.937 N
42098427.234 E	42098937.275 E
294.213 Elevation	296.581 Elevation

How to represent topography?

- ☐ Digital elevation model (DEM)
- ☐ Digital terrain model (DTM)
- ☐ Digital surface model (DSM)

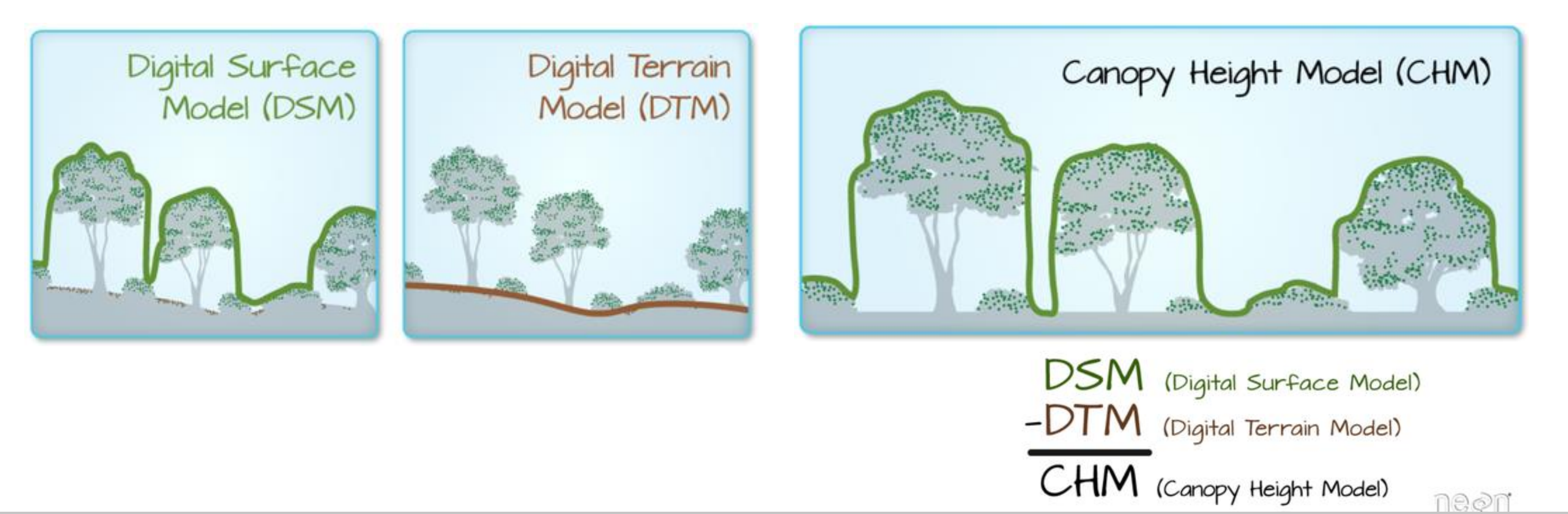
… what does these terms mean?

How to represent topography

- **Digital elevation model (DEM):**
  - A DEM is an elevation model, unmodified from its original data source (such as Lidar, photogrammetry etc.. surface) which could be with or without 'non ground' objects.
- **Digital terrain model (DTM):**
  - DTM is a synonym of bare-earth DEM
- **Digital surface model (DSM→DOM på norsk)**
  - DSM is an elevation model that includes the tops of buildings, trees, powerlines, and any other objects. DSM captures the natural and built features on the Earth's surface.

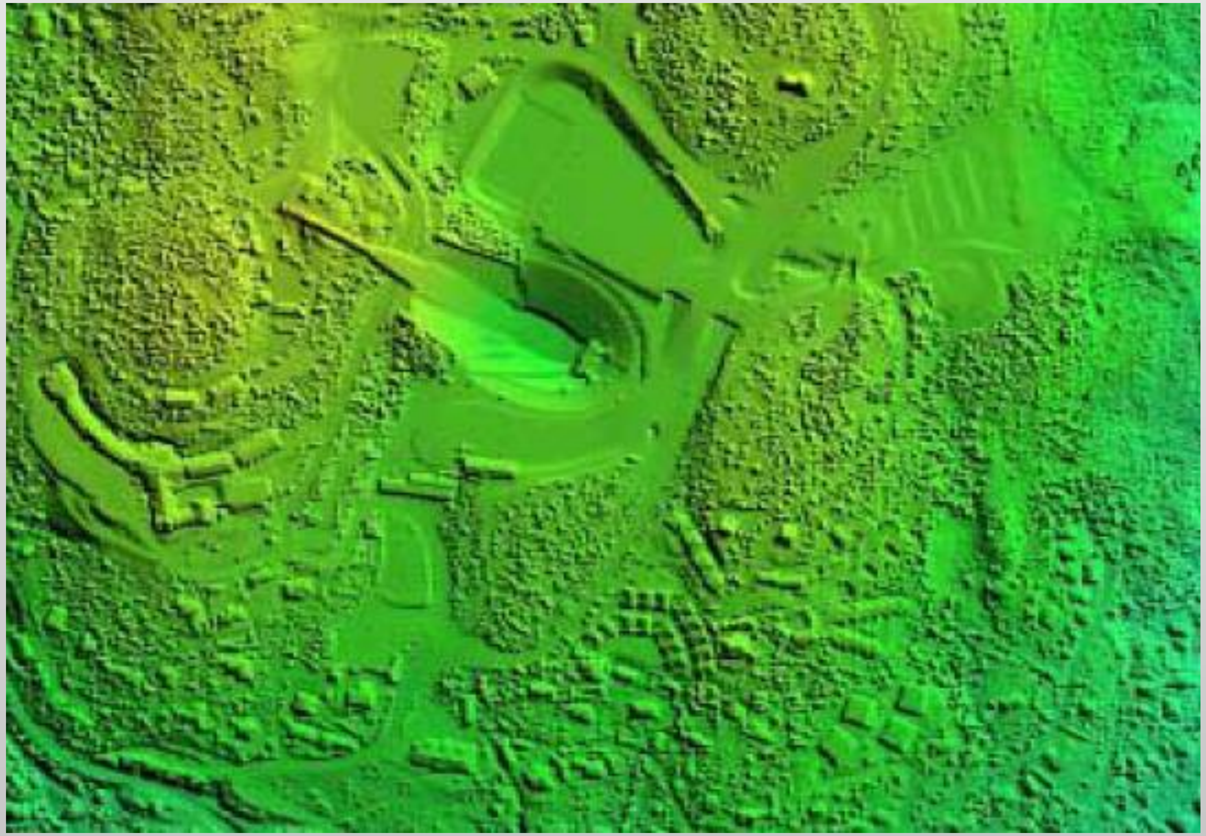
How to represent topography

- **DEM of Difference:** DoD = $DEM_1 - DEM_2$
- **Normalized digital surface model:** nDSM = DSM – DTM
  - In forestry application this is called **canopy height model (CHM)**

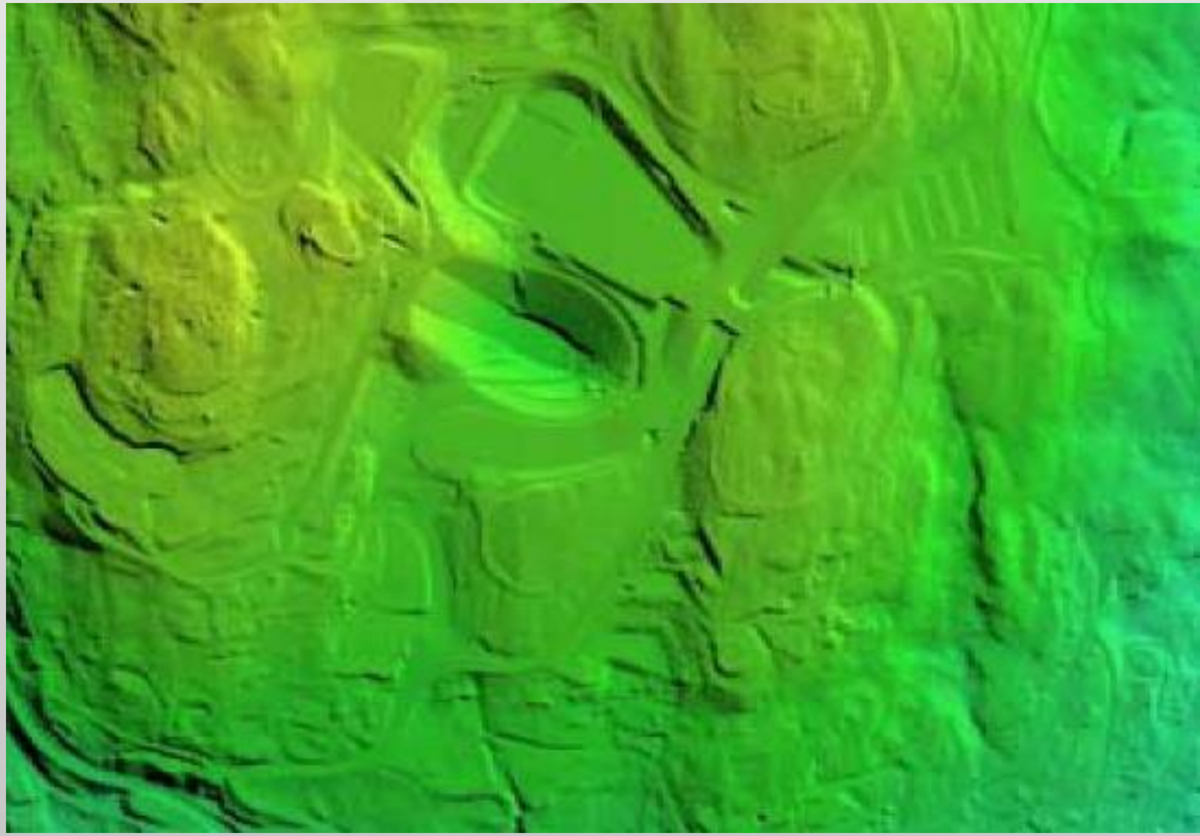


How to represent topography

Digital surface model (DSM)



Digital terrain model (DTM)



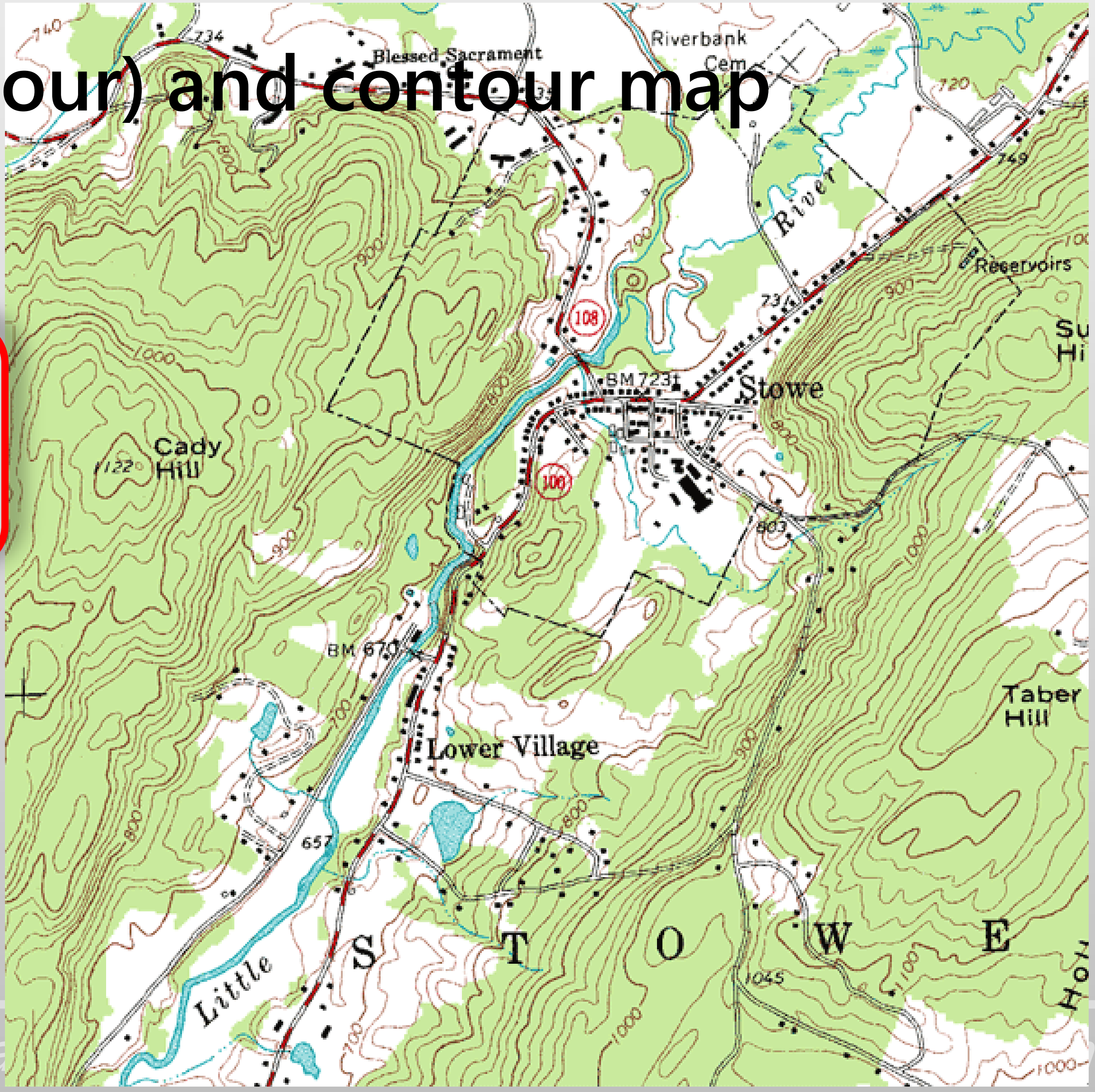
How to represent topography

- **DEM generation (data structure)**
  - **Lines (vector)** – contour map
  - **Raster** –matrix with elevation information
  - **Triangles (vector)** – TIN/Triangulated irregular network

DEM generation

- Lines: contour lines (or contour) and contour map

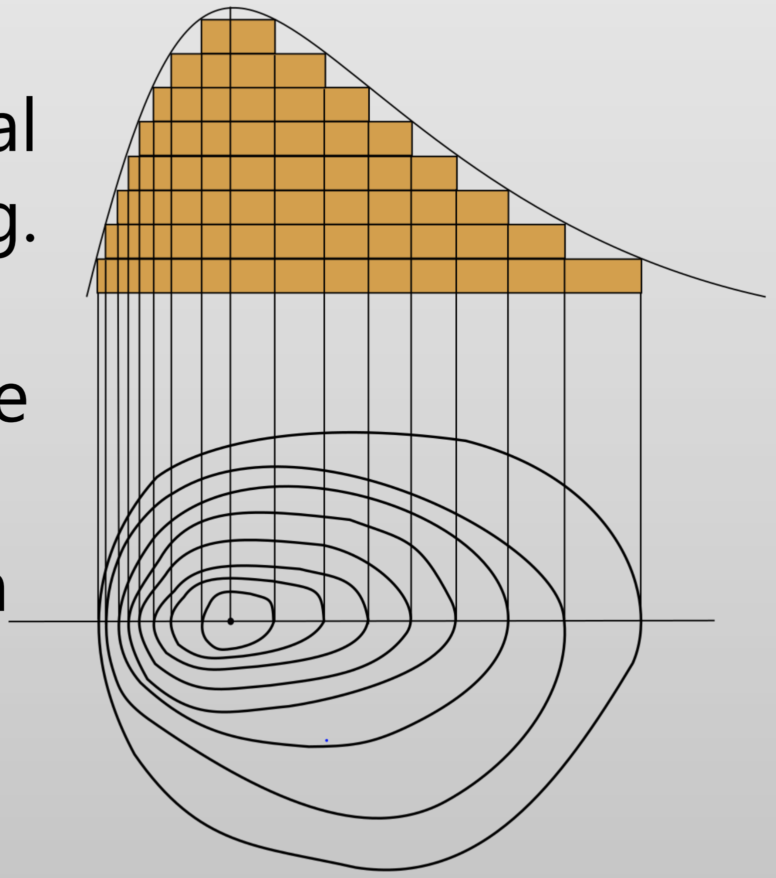
What are all these lines curving all over the place?



A topographic map of Stowe, Vermont with contour lines

DEM generation

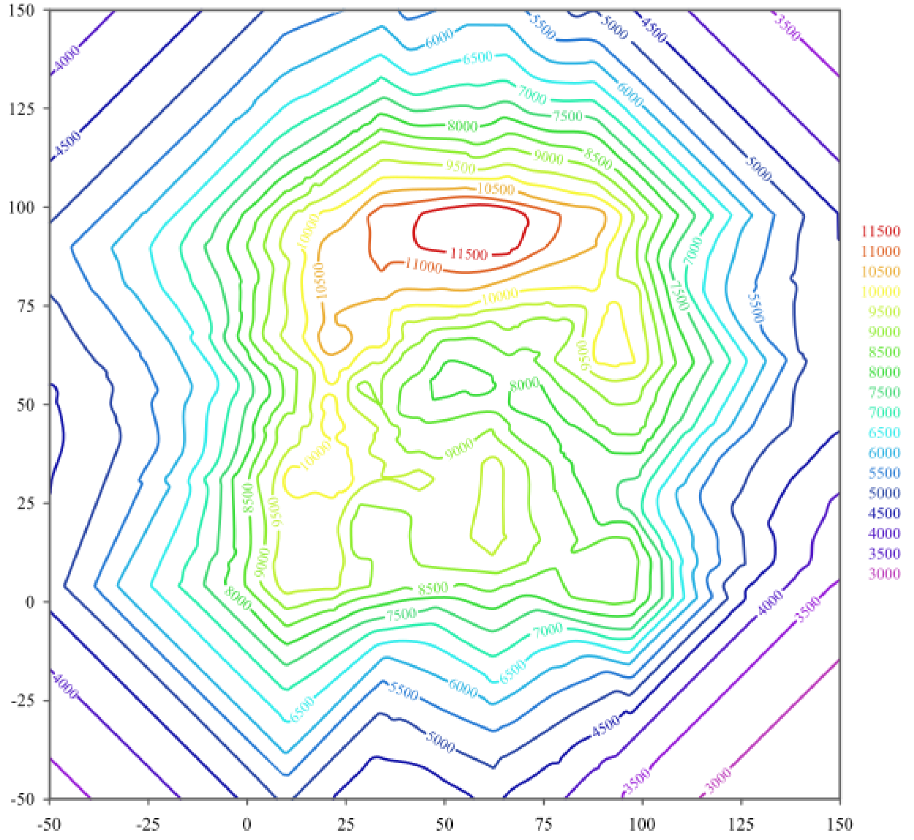
- **Lines: contour lines (or contour) and contour map**
  - Contour lines are vector features
  - Contour line: a line that joins points of equal elevation (height) above a given level, e.g. mean sea level.
    → all the points in the line have equal value
  - A contour map is a map illustrated with contour lines (e.g. topographic map)
  - Limited visualization and analysis possibility



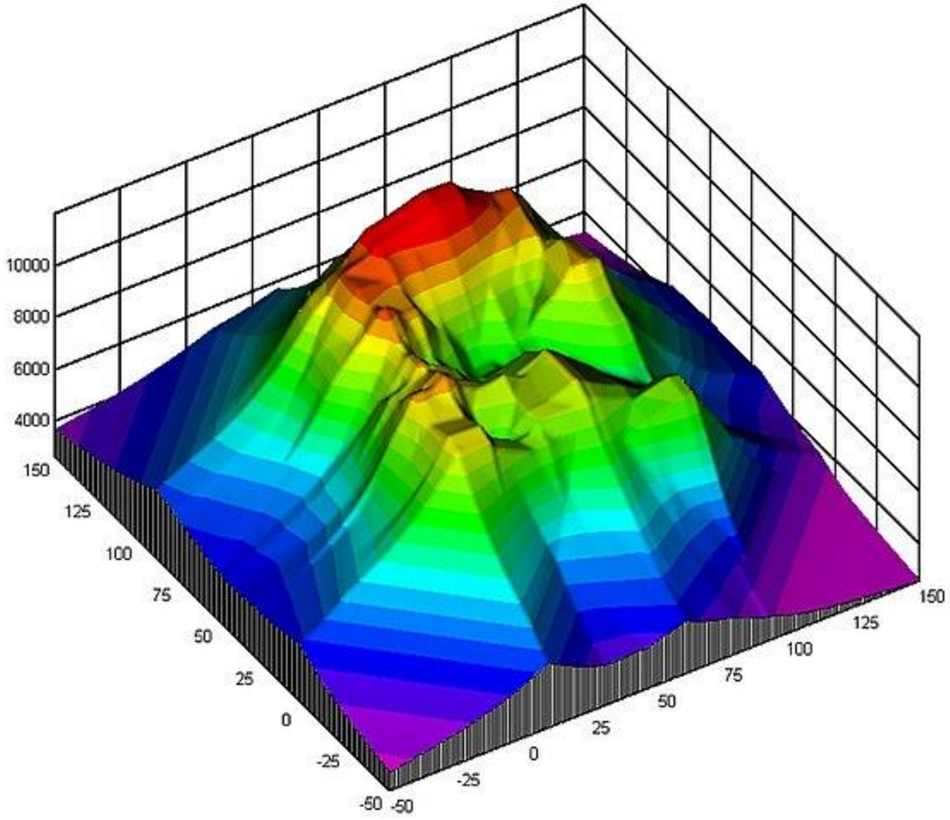
DEM generation

- Lines: contour lines (or contour) and contour map

A 2D contour graph of the 3D surface

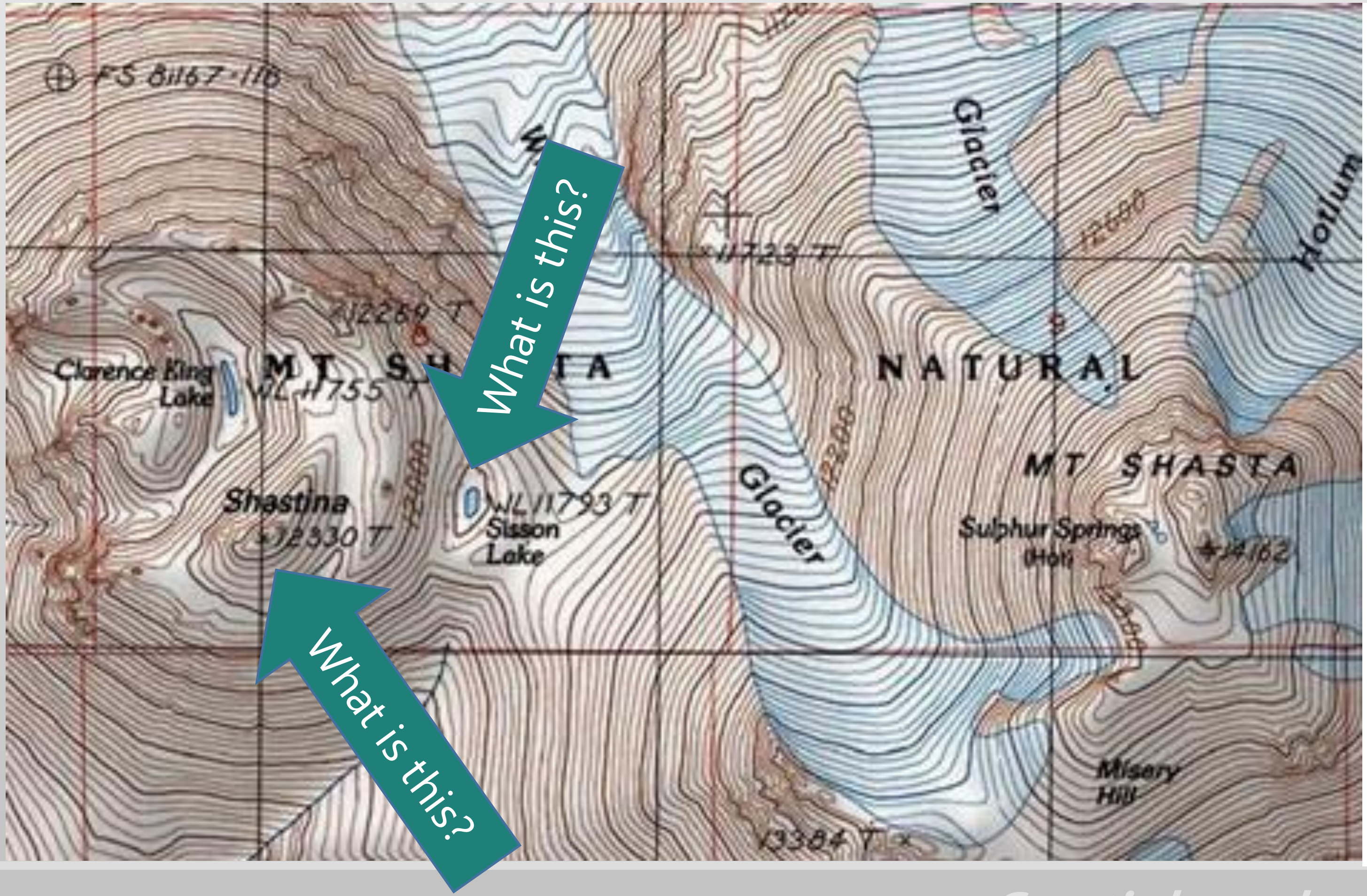


A three-dimensional (3D) surface

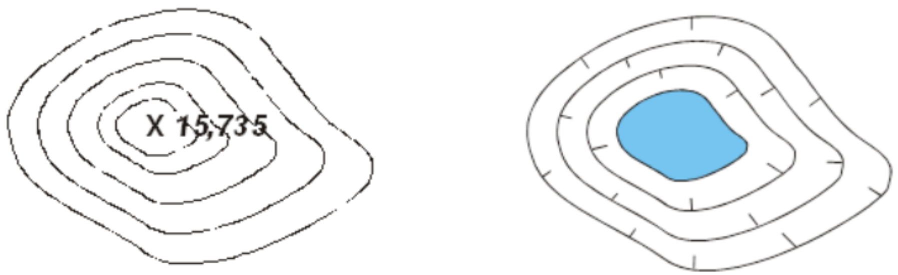


DEM generation

- Lines: contour lines (or contour) and contour map



How interpret contour map

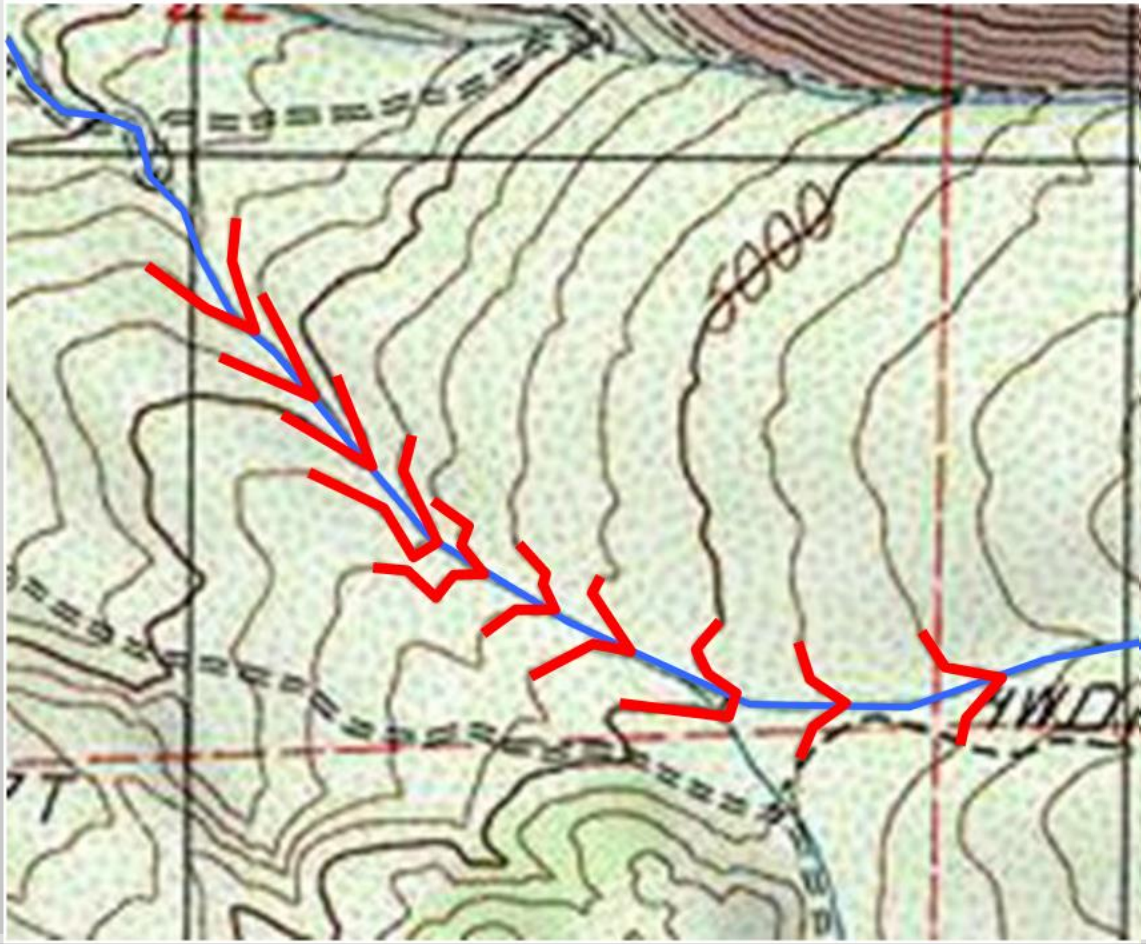


This is a hilltop

This is a pit.
It might even be a volcanic crater.

DEM generation

- Lines: contour lines (or contour) and contour map



How interpret contour map

The blue line is the river and the "v" lines indicate steep slope

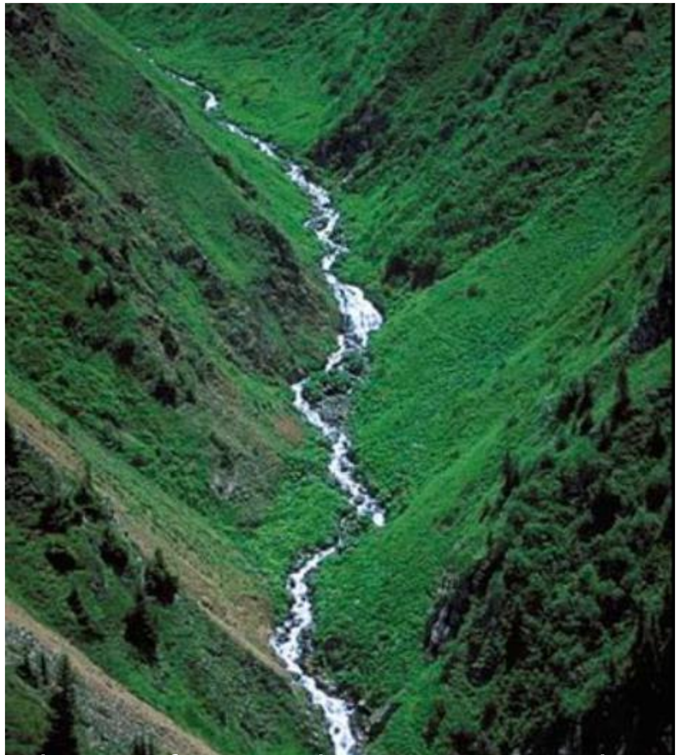


Photo of a river between step slope

DEM generation

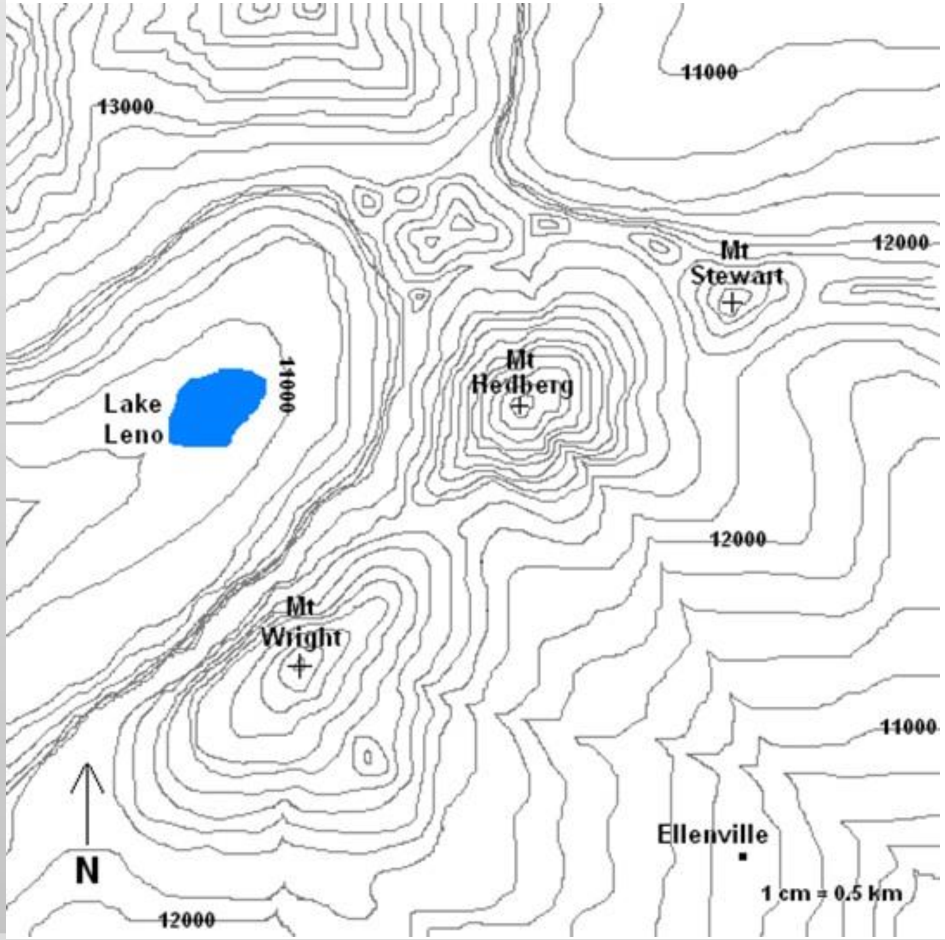
- Lines: contour lines (or contour) and contour map

<u>How interpret contour map</u>

The numbers on some of the lines indicate elevation / altitude / height above sea level

DEM generation

- Lines: contour lines (or contour) and contour map

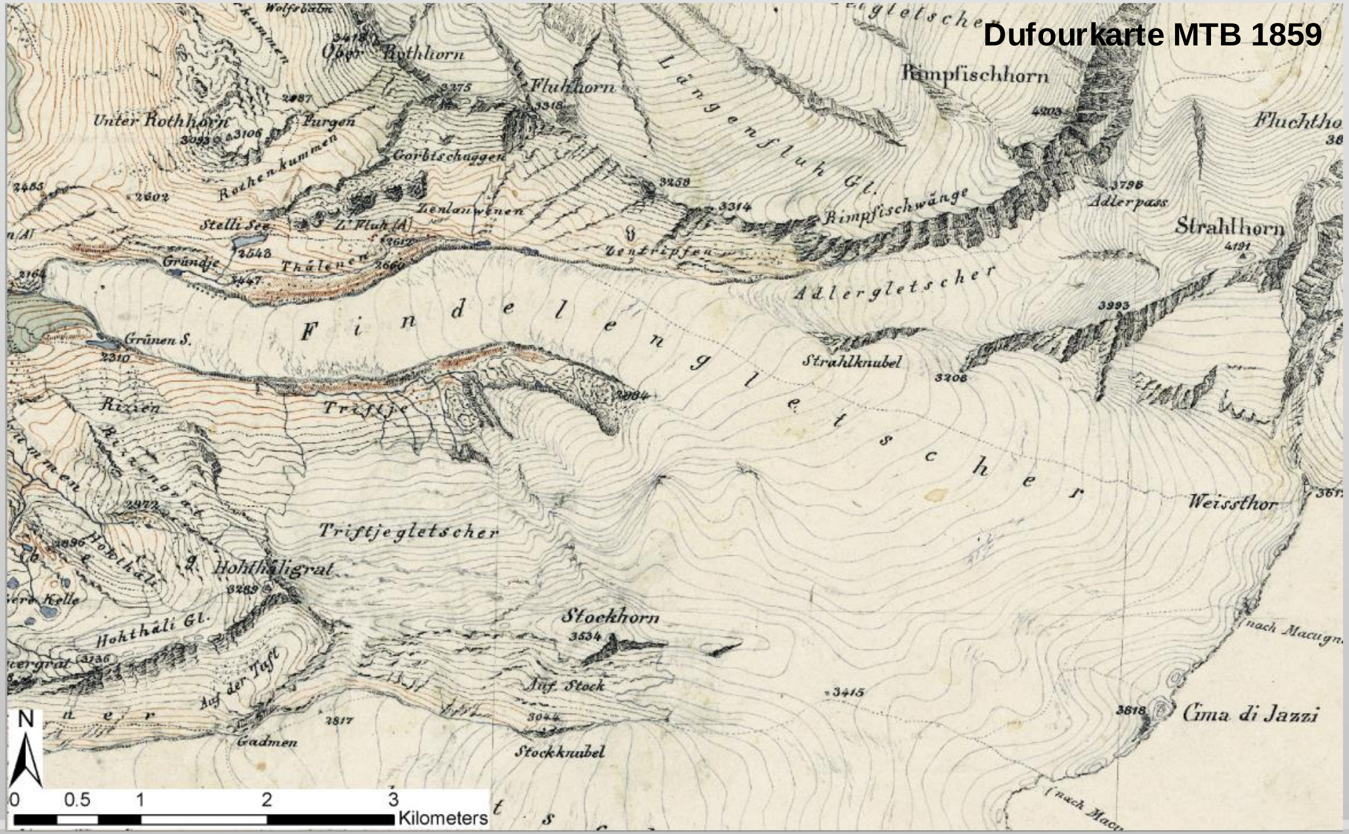


How interpret contour map

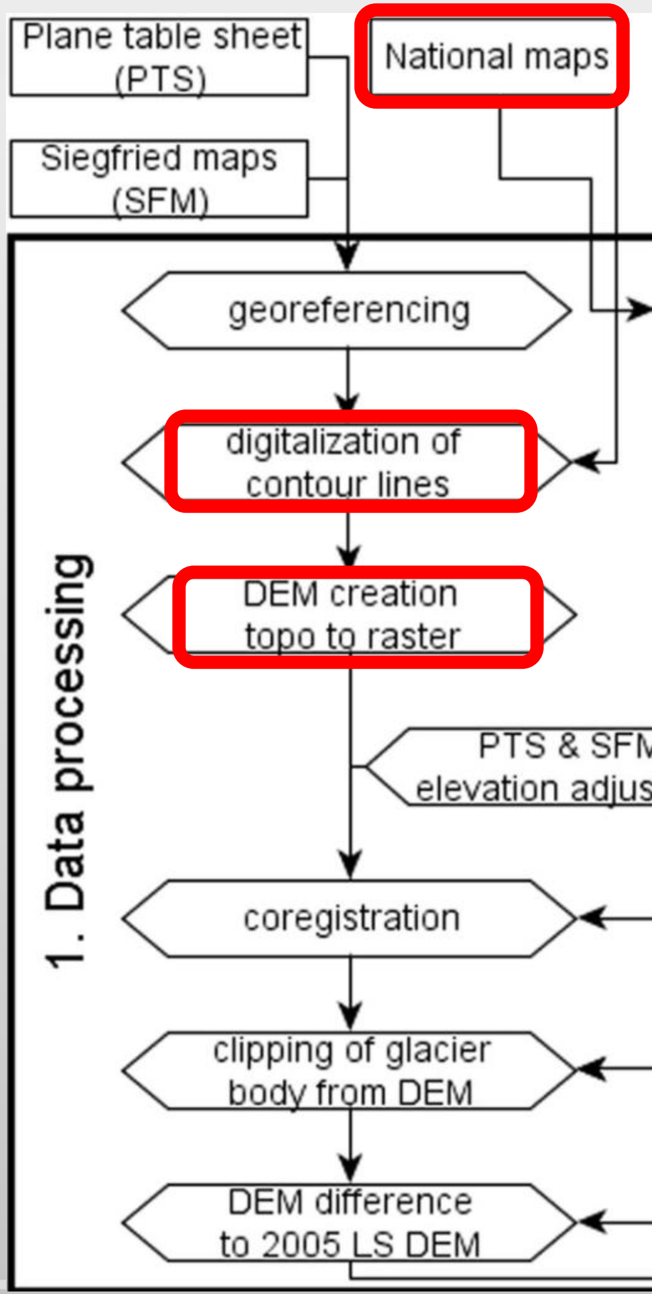
- What does it mean when the lines are all close together?
- What does it mean when the lines are spread far apart?
- Where on the map do you think streams would flow during the rainy season or in the spring when snow melts?
- What direction would you think the streams flow?
- Where are the flat areas?
- Where are the cliffs?

DEM generation: map digitization

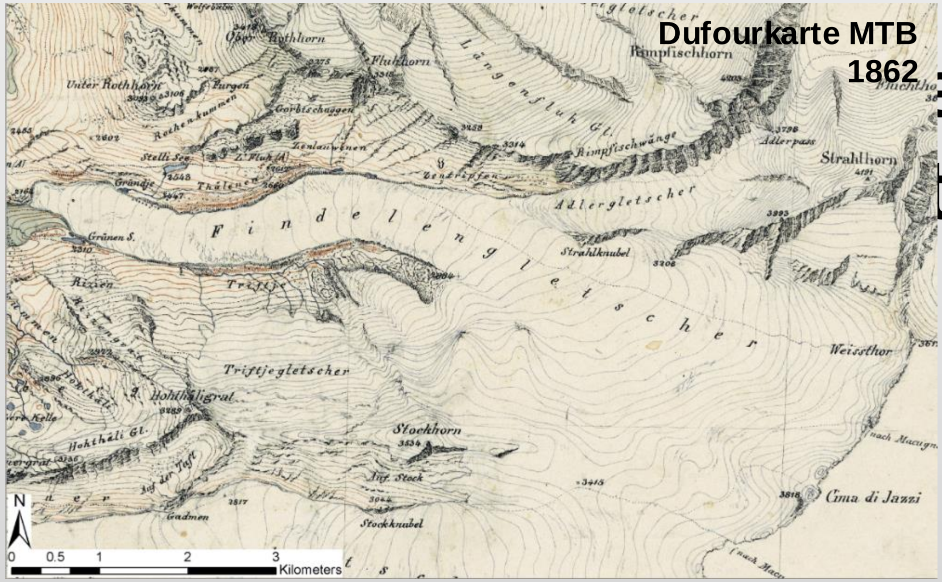
- Application: Long-term DEM generation based on historical topographic maps

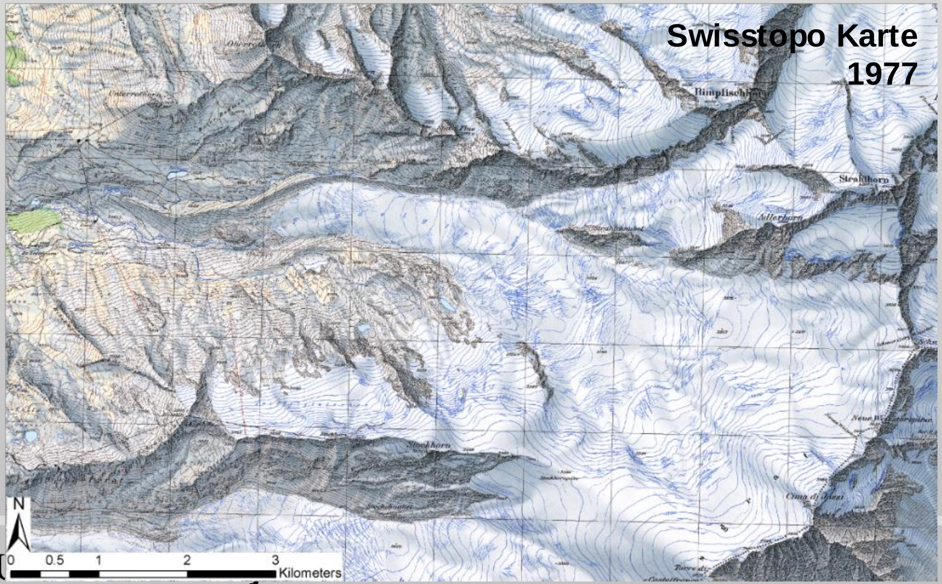


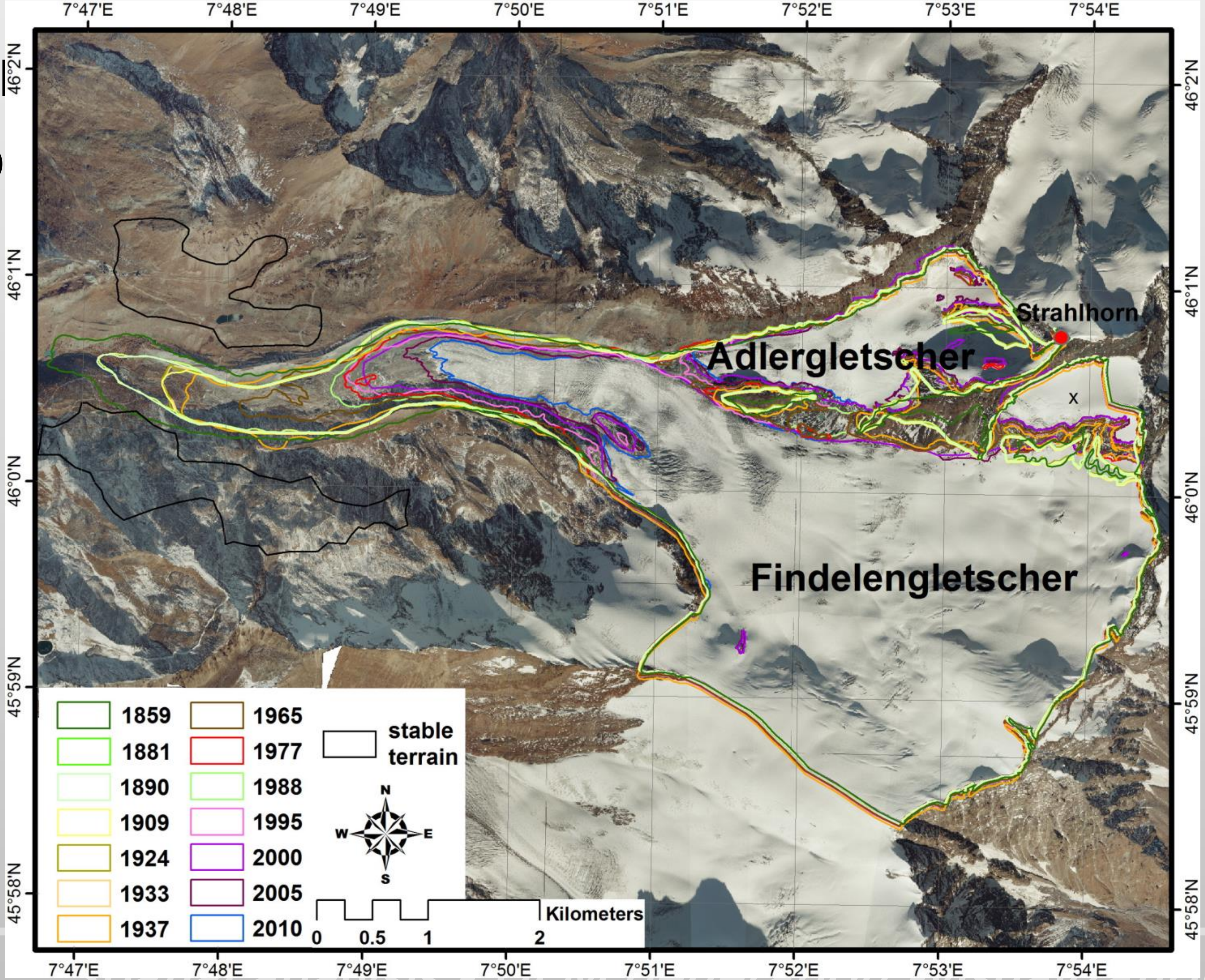
"Historical analysis and visualization of the retreat of Findelengletscher, Switzerland, 1859–2010." Rastner et al., 2016



DEM generation: map digitization







DEM generation

- **Elevation raster – matrix with elevation information**
  - Most common representation of the elevation
  - Easy analyses and modelling
  - Rigid data structure (i.e. resolution)
  - Limited adaption to topographic structures
  - The topographic surface height z is a function of planimetric coordinates

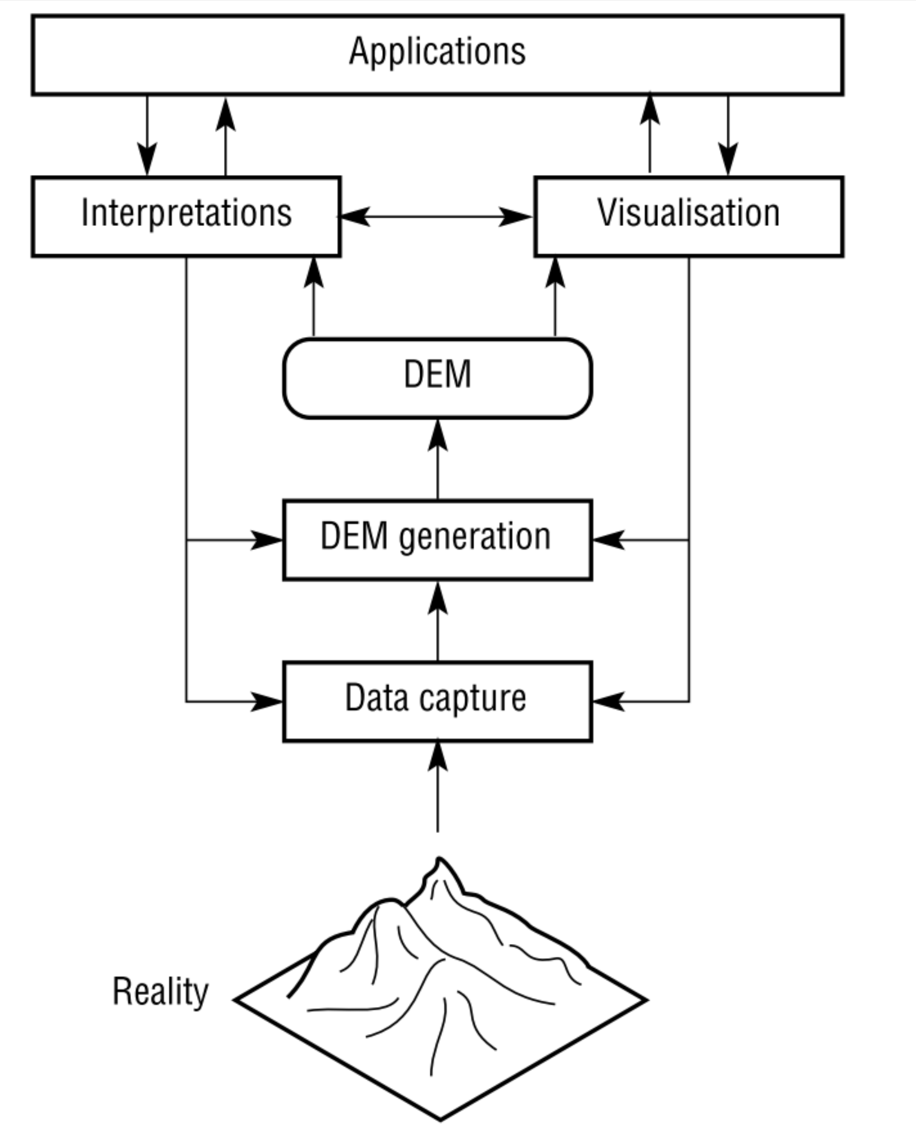
$$z = f(x, y)$$

Comparison between lines, raster and TIN

- **DTM describes continuous topography (ground level)**
- **Different data model:**
  - Raster (grid model) vs Vector (elevation curves or TIN)
- **Resolution?**
  - Grid (cell) size = fixed distance between point heights
  - Elevation curves: equidistance, vertical resolution
  - TIN: variable resolution ≈ average point distance
- **Accuracy?**
  - Depends on measurement method (quality), density (quantity), roughness and topography (e.g. slope)
  - High resolution does not necessarily mean good DTM, but a good DTM needs high resolution (and accurate data!) To describe small feature

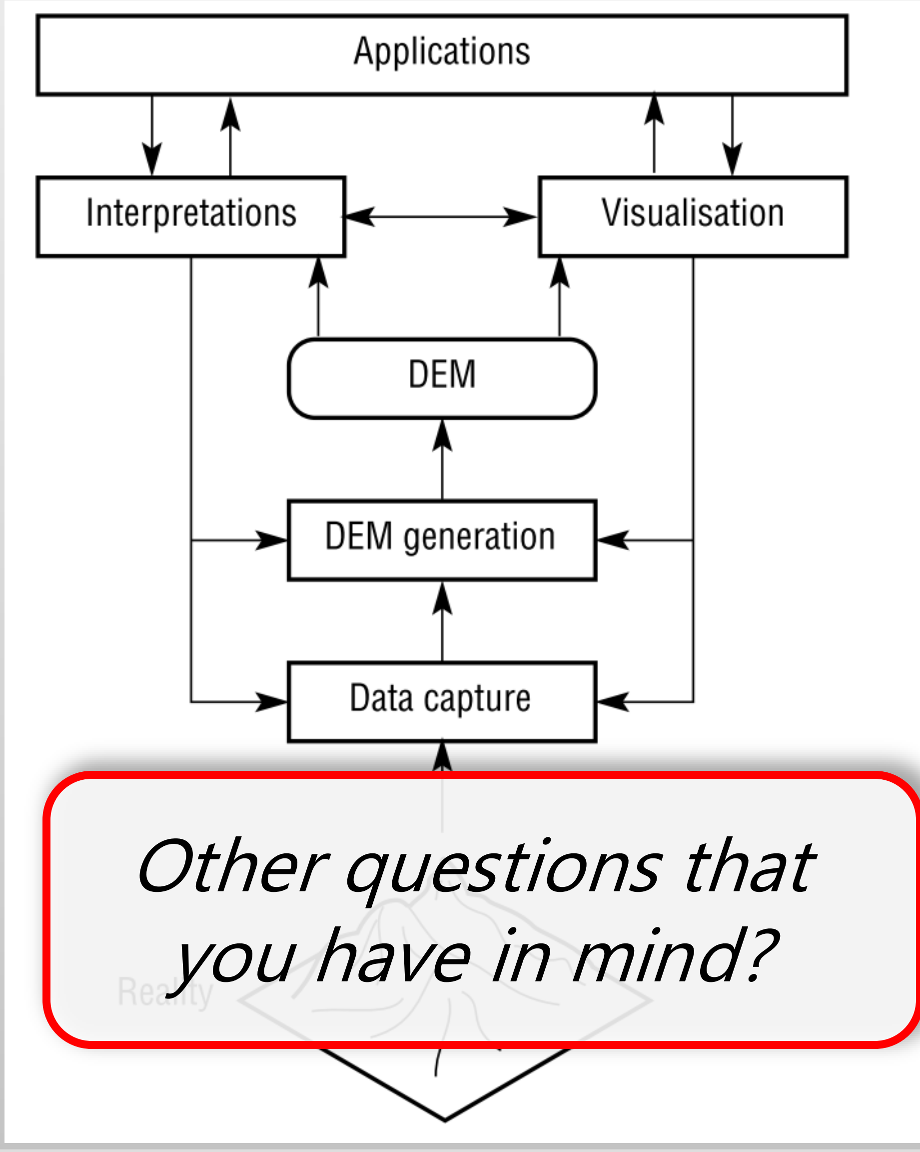
DEM

- **The main tasks associated with DEM**
  - The applications should guide data capture
  - The **resolution** of **data** source should guide the choice of **resolution** of generated **DEMs**
  - The **resolution** of **DEM** should be matched to the **natural scales** of terrain-dependent applications
  - Analysis of the errors associated with these data sources is an essential part of DEM generation.



DEM

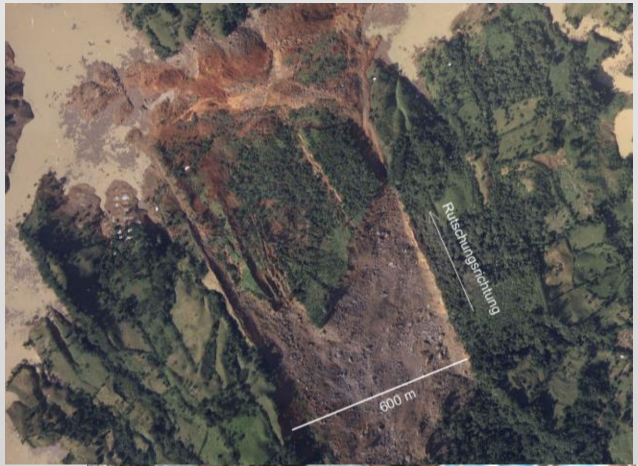
- **Some questions to answer when choosing the data and interpolation method:**
  - What is the area I have to reconstruct?
  - What is the topography of my area (e.g. elevation, roughness, slope, vegetation, land cover, etc.)?
  - What do I need to analyze (volume, river dynamics, glacier mass balance, soil erosion, etc…)
  - What's the resolution (point density) of the point cloud that you get from the data?
  - Do you need cm/mm/m accuracy in the vertical or the horizontal?

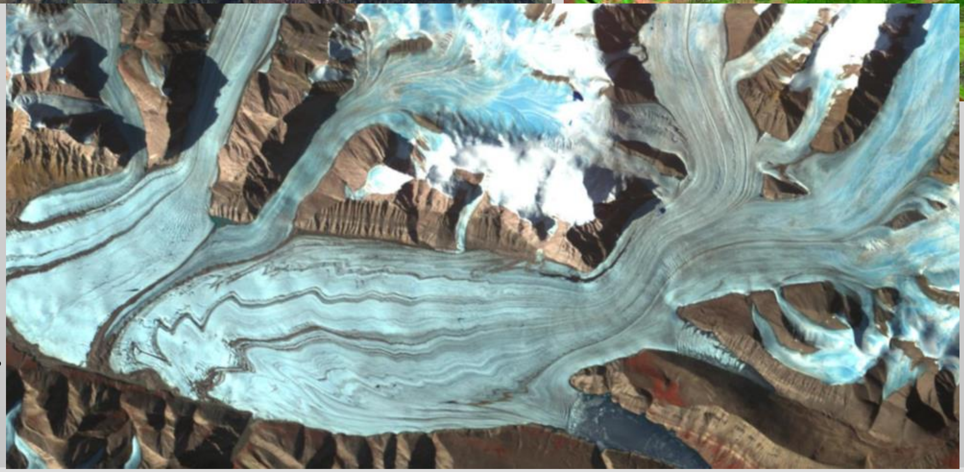


Other questions that you have in mind?

DEM applications

- Elevation data are some of the most important and widely-used data in the GIS world
  - Applications in…
    - Geomorphology
    - Glaciology
    - Geology
    - Forestry
    - Hydrology
    - Landscape ecology
    - Natural hazards
    - Archaeology
    - And many, many others…





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- Las file
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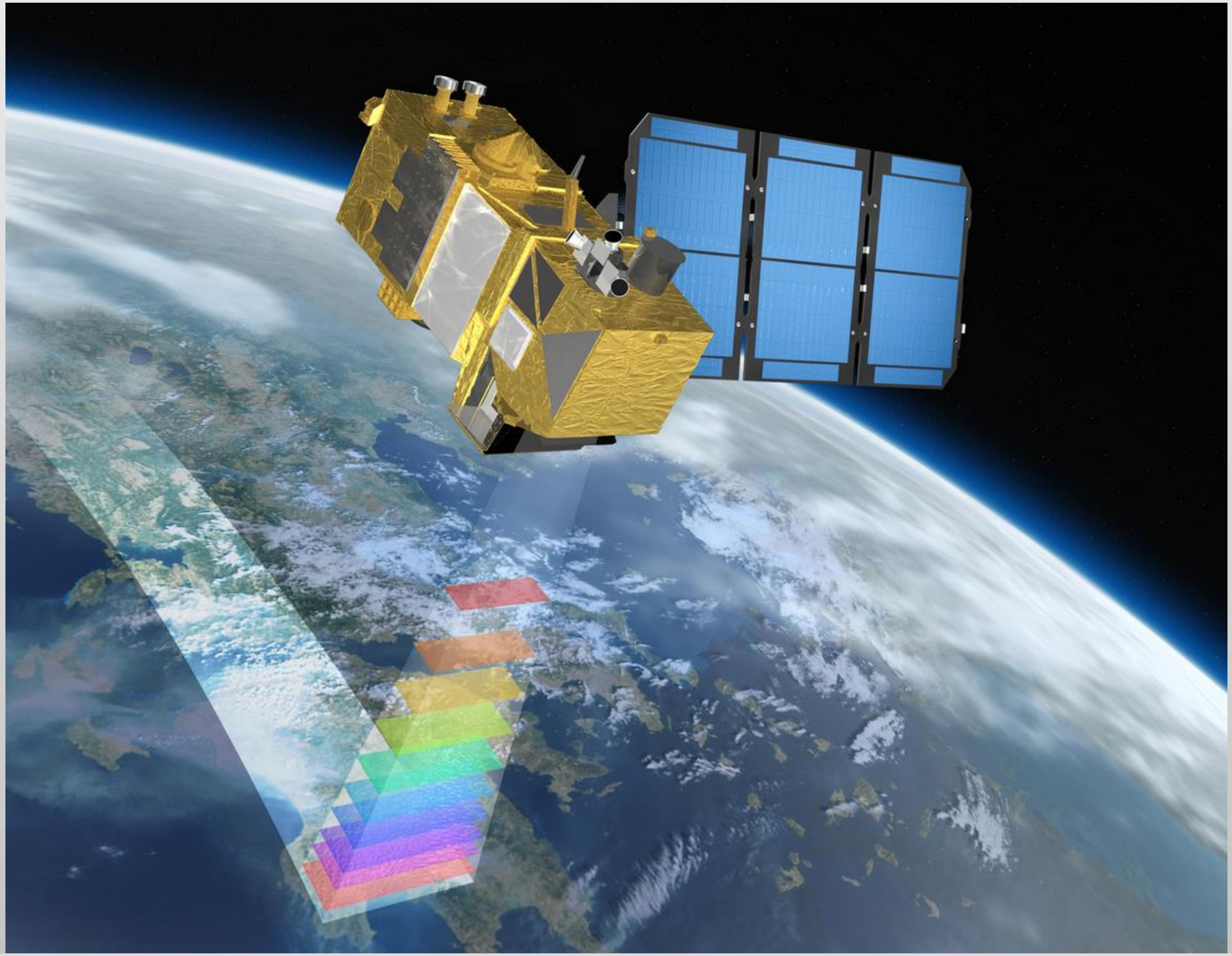
- Example

Today's topics

Elevation (DEM) data capture



Elevation data sources

- **Spaceborne remote sensing**
  - Stereoscopic satellite imagery
  - Radar-based satellite imagery (e.g. Synthetic aperture radar, SAR)
- **Airborne remote sensing:**
  - Lidar (e.g. Airborne laser scanning, ALS)
  - Photogrammetry (e.g. aerial images, UAV photogrammetry, existing cartographic maps)
- **Ground-based remote sensing and data survey:**
  - Real Time Kinematic Global Positioning System (RTK-GPS)
  - Total Station
  - Terrestrial laser scanning (TLS)
  - Terrestrial photogrammetry

Elevation data sources

- **GPS Points**
  - Irregularly spaced
  - May or may not represent surface-specific peaks and pits
  - Used for control,
    - quality assessment
    - benchmarking other data
    - Ground control points for photogrammetric and Lidar data collection
  - Potentially significant attribution per point
  - Typically small quantities

Elevation data sources: Remote sensing

- **Passive**
  - Camera
- **Active**
  - SAR
  - Laser scanner (Lidar)

Sensors - categories

- **Optical**
  - In general short wavelength
- **Thermal**
- **Microwave**
  - Wavelength from 1cm-1m

- **Spaceborne**
- **Airborne**
- **Close-range/ ground-based**

- **Polar orbiting**
- **Geostationary**
  - Over the equator

Elevation data sources: Remote sensing

- **Remote sensing methods can be compared considering**
  - Sensor parameters
    - Type of sensor: passive, active
    - Which part of the electromagnetic spectrum is covered?
  - Costs
  - Accuracy
  - Temporal resolution: data availability (start and end of the measurements)
  - Spatial resolution (sampling density)
  - Pre-processing requirements

  - (Accessibility to the area and flexibility)

Elevation data sources: LiDAR

☐ Direct measurements of the elevation

LiDAR (LIght Detection And Ranging) is an optical remote-sensing technique that uses laser light to densely sample the surface of the Earth producing highly accurate x,y,z measurements (point cloud).

General characteristics of Lidar:

- LiDAR point clouds stored in LAS format
- High point spacing density (approximately 1-100 points per square meter, Airborne and TLS)
- Often, but not always, filtered to bare earth points
- Every point contains attributes stored with the x,y,z data (e.g. intensity, time, echo)
- Large quantities of point data

Elevation data sources: Lidar

- Direct measurements of the elevation (ground, plane or satellite)

Airborne laser scanning (ALS)

Terrestrial laser scanning (TLS)

Data format:

- 3D Point cloud (x,y,z, *attributes*)
  - Elevation
  - Intensity information
- File format: .las, .laz

Elevation data

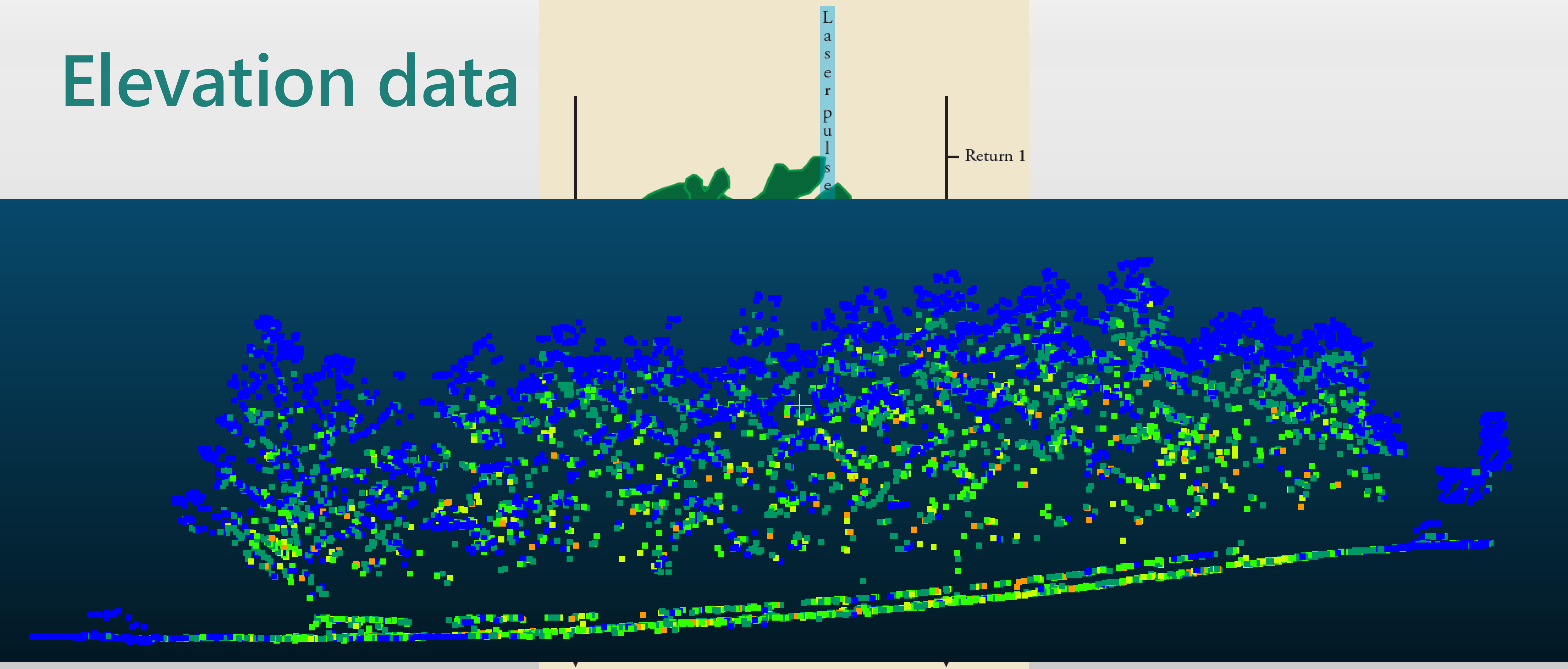
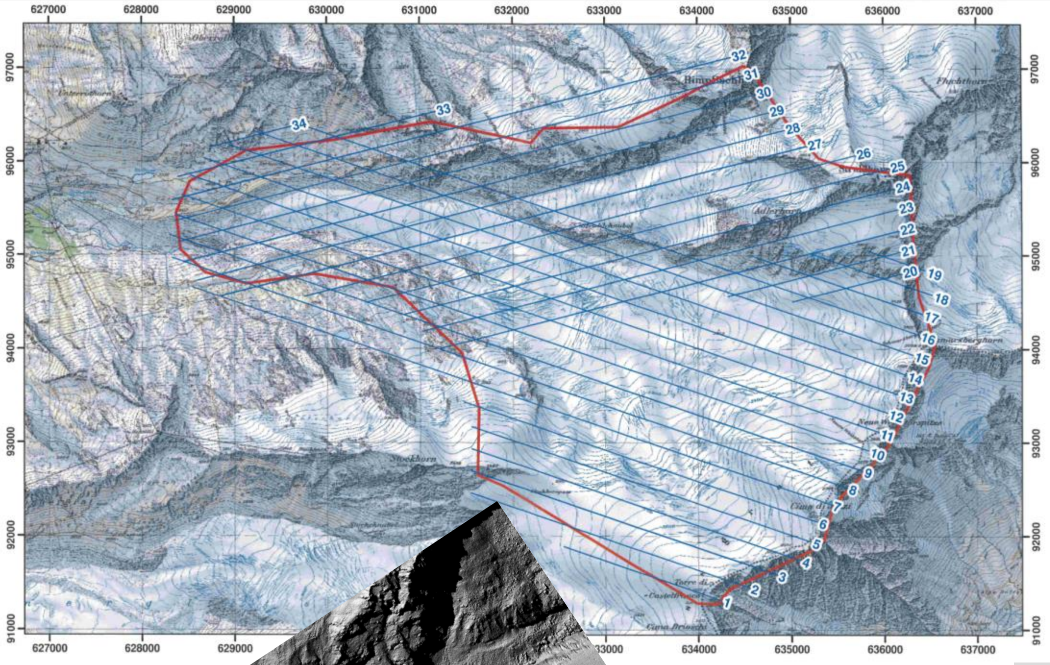


Fig. B3.
Example of a LiDAR mounted on an aeroplane. A signal is returned to the sensor on the aeroplane everytime the laser pulse encounters an obstacle, represented by Return 1-5. Modified from Andersen *et al.* (2006).

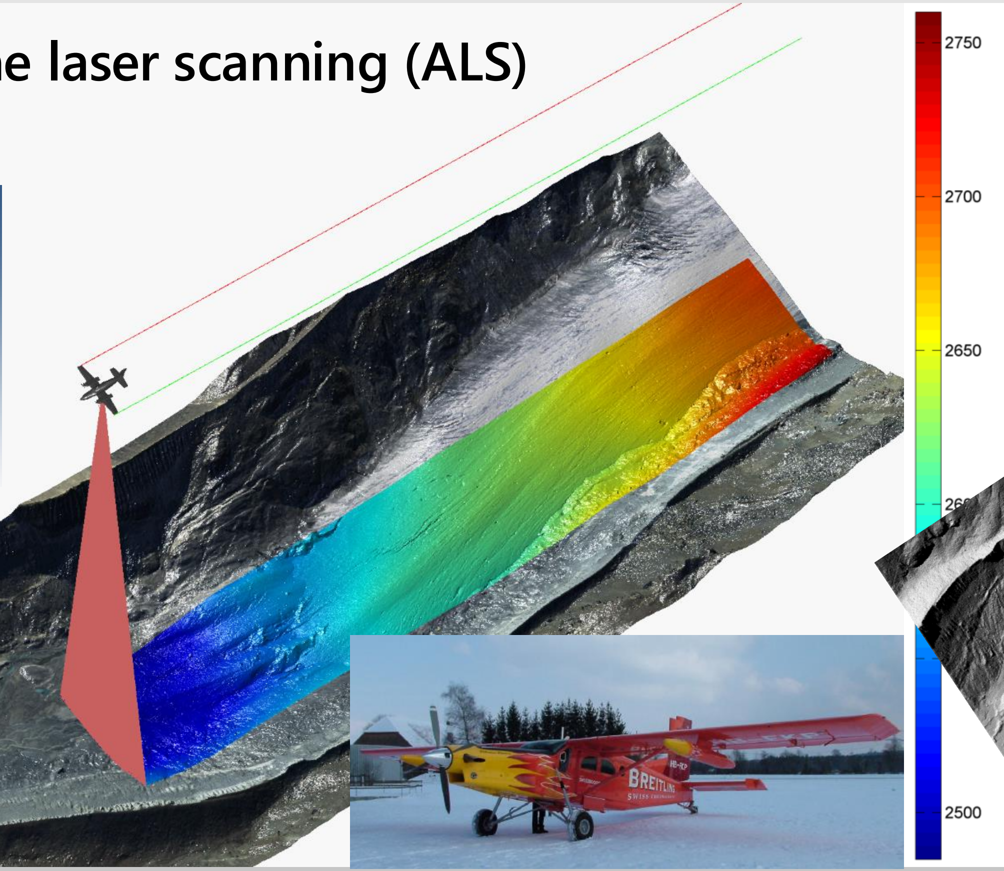
Bernhardson 2018

Elevation data sources: Lid

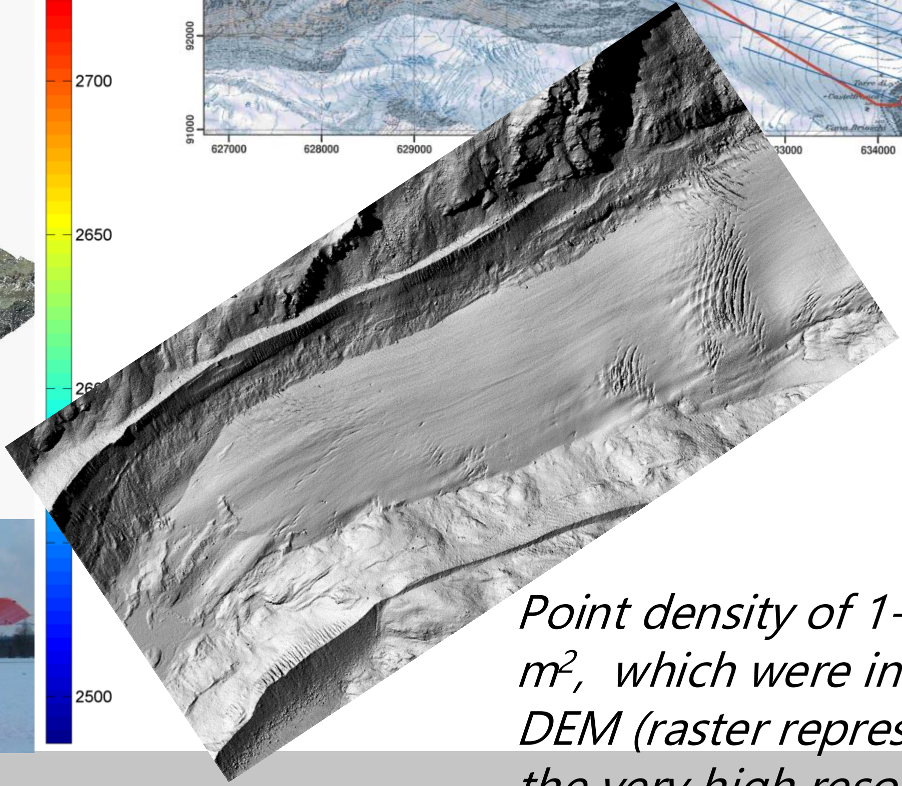
- Direct measurements of the elevatio



Airborne laser scanning (ALS)



Courtesy of BSF Swissphoto



Point density of 1-14 point per m^2, which were interpolated to a DEM (raster representation) with the very high resolution of 1m

Joerg et al. 2012. Uncertainty assessment of multi-temporal airborne laser scanning data: A case study on an Alpine glacier

Elevation data sources: Lidar

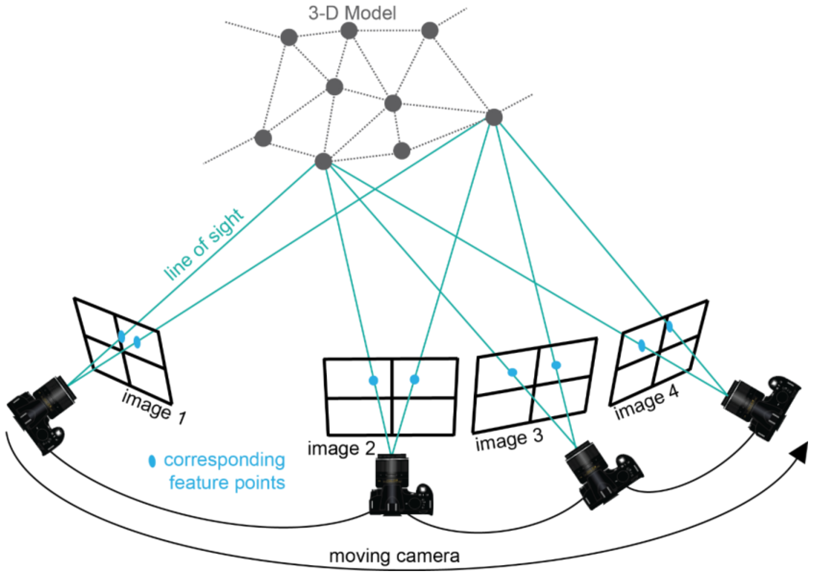
- Direct measuremen

Airborne laser scanning (ALS)

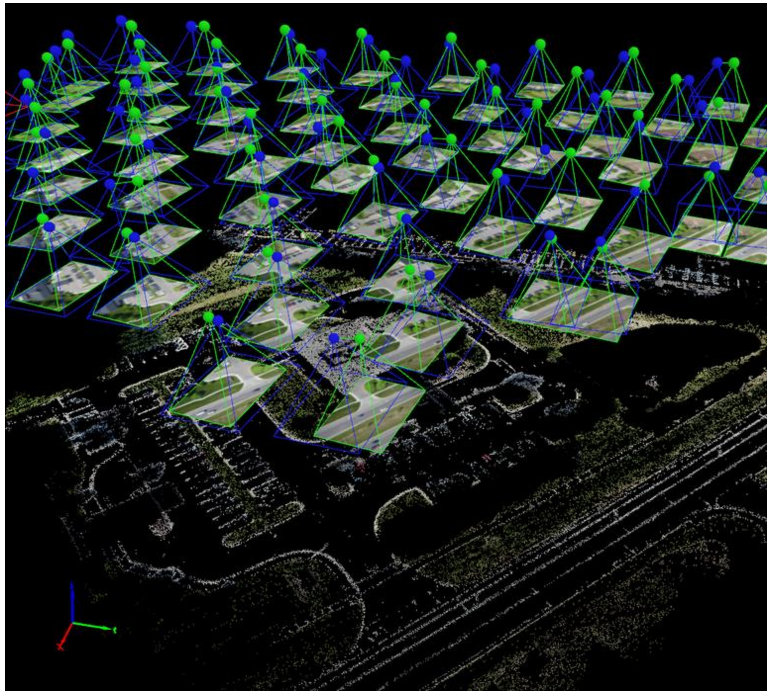
Elevation data sources: Photogrammetry

- Digital photogrammetry, terrestrial, aerial and satellite images

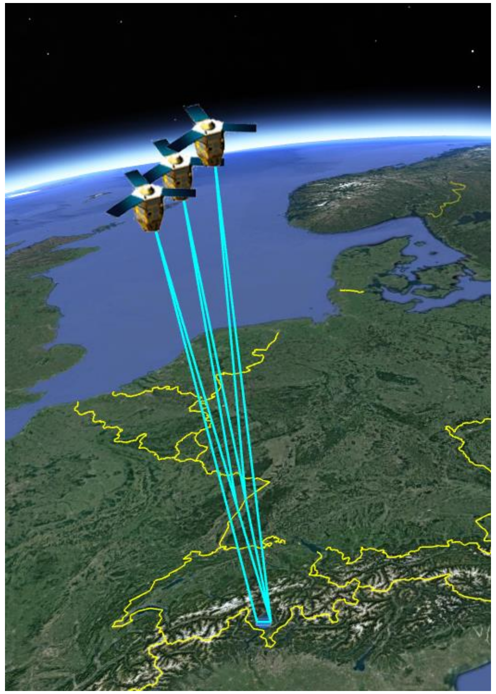
Terrestrial Structure from Motion
(ground based)



Aerial, UAV photogrammetry
Flight height ~2000 asl



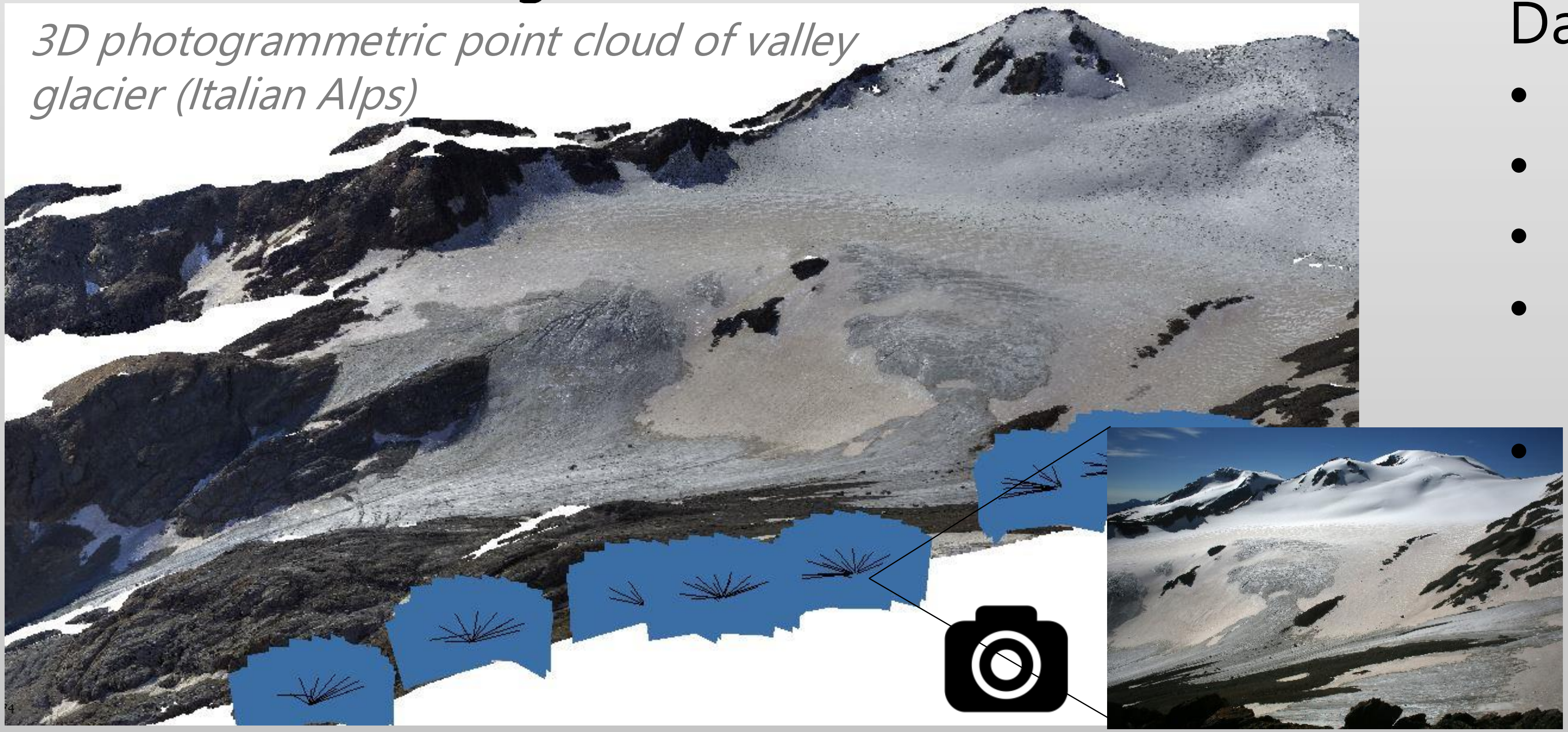
Stereo (tri-stereo) Satellite
(Pleiades, orbit height ~680 km)



Elevation data sources: Photogrammetry

- Digital photogrammetry, terrestrial aerial and satellite images

Terrestrial images (Structure from Motion)



3D photogrammetric point cloud of valley glacier (Italian Alps)

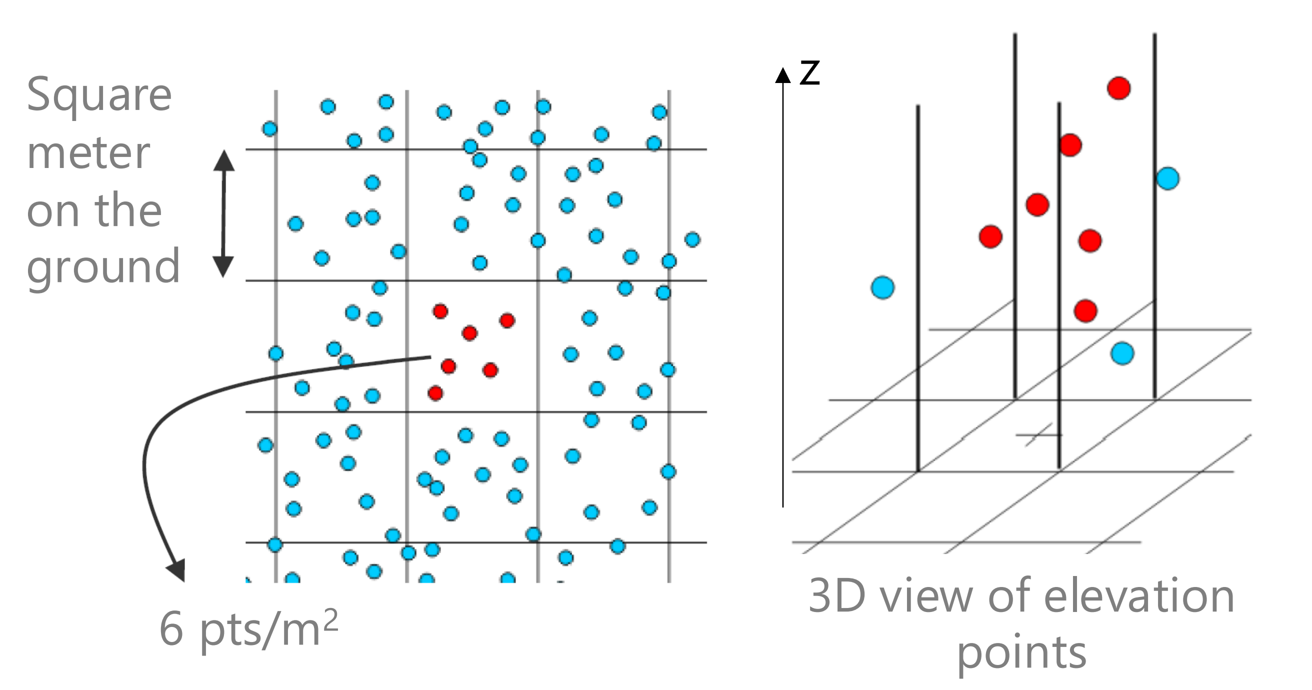
Data format:

- 3D Point cloud (x,y,z)
- .las, .laz
- RGB (digital camera)
- Black/white colour (frame camera)
- Multispectral band, e.g. NIR (depends on the sensors)

DEM from point cloud

- **Common information of 3D point cloud**
  – Point density or ground spacing: the distance between points at the ground (usually in point per square meter, pts/m^2), at which the 3D points are generated or collected.

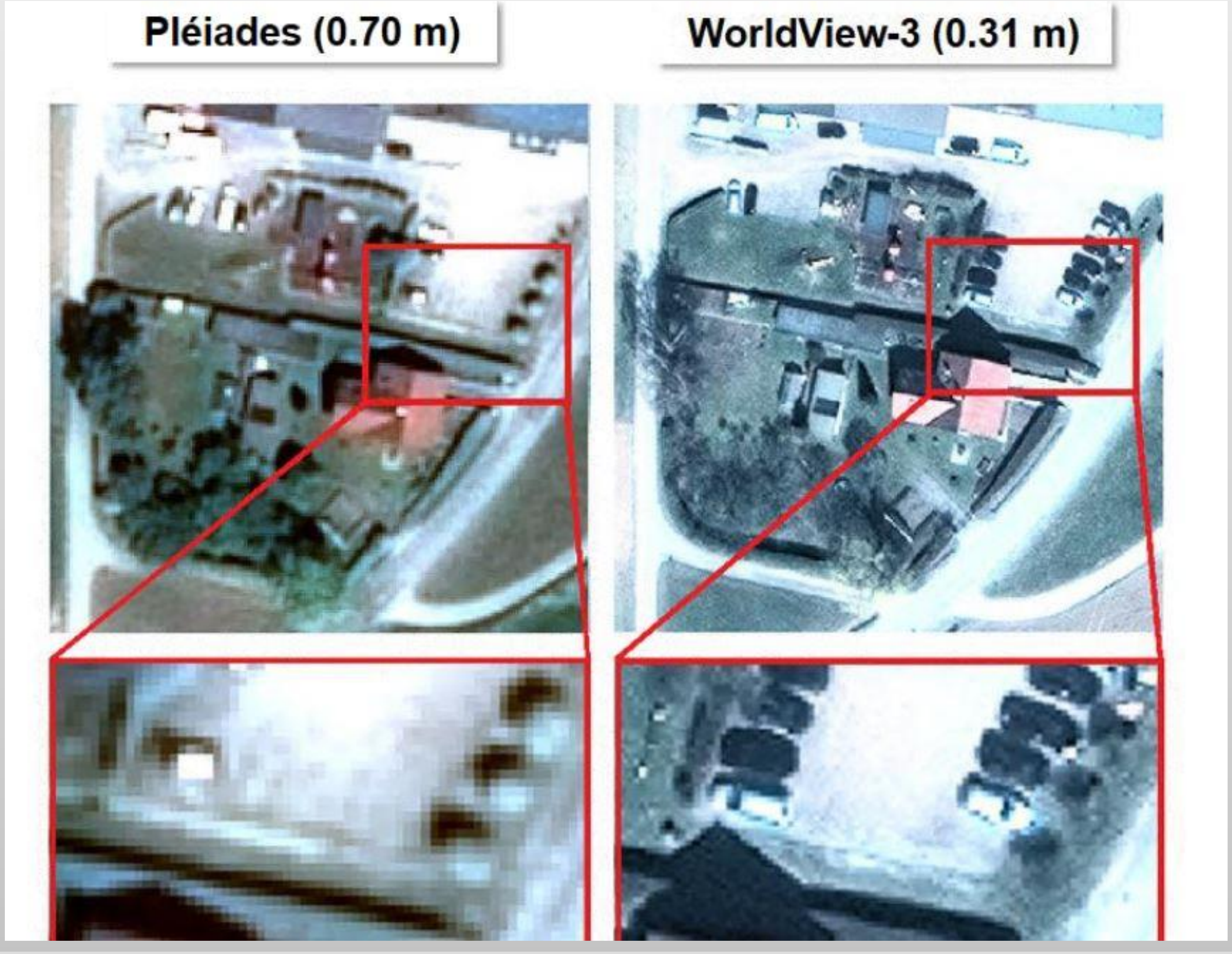
  – **The point density defines the details (resolution) of your DEM**



DEM from point cloud

<u>DEM from Image</u>:

- The point density is defined by the pixel size (pixel resolution)
- The resolution depends on the source image pixel size which depends on sensor and on the distance of the sensor to the object (e.g. flight height in aerial surveying)

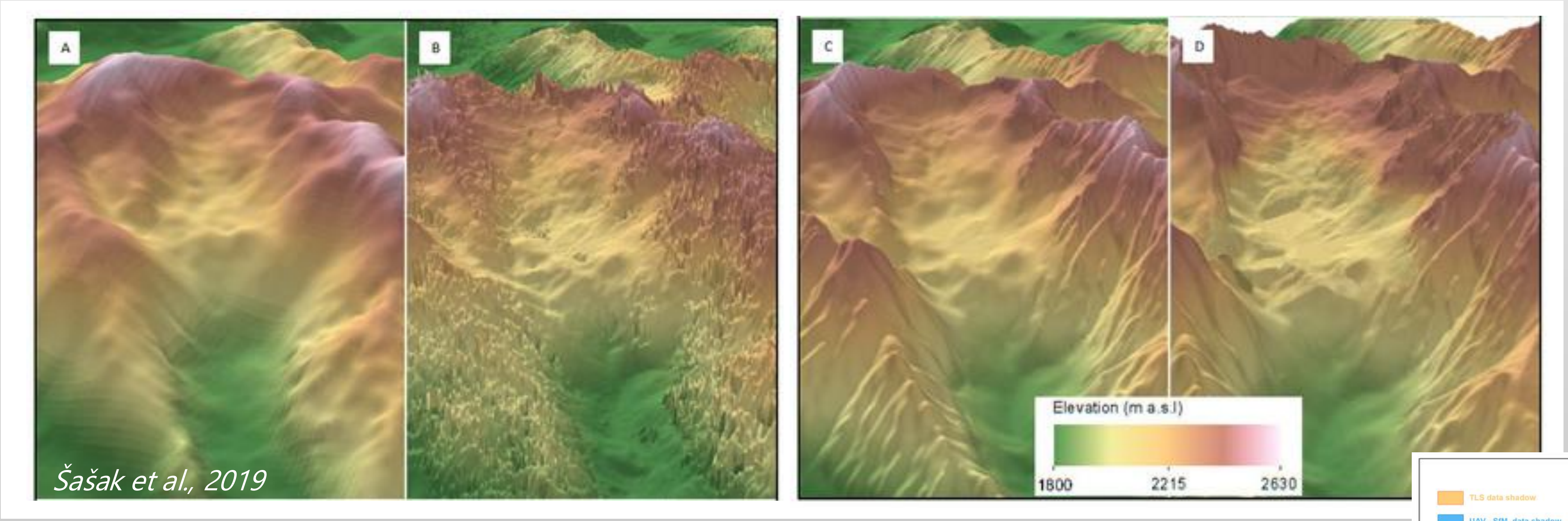


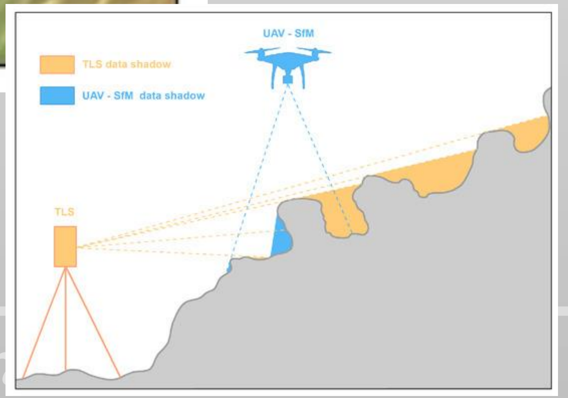
Level of detail of two satellite images: Pleiades vs WorldView

DEM from point cloud

<u>DEM from Lidar and SAR:</u>

- The resolution depends on the distance object-sensor and sensor characteristics



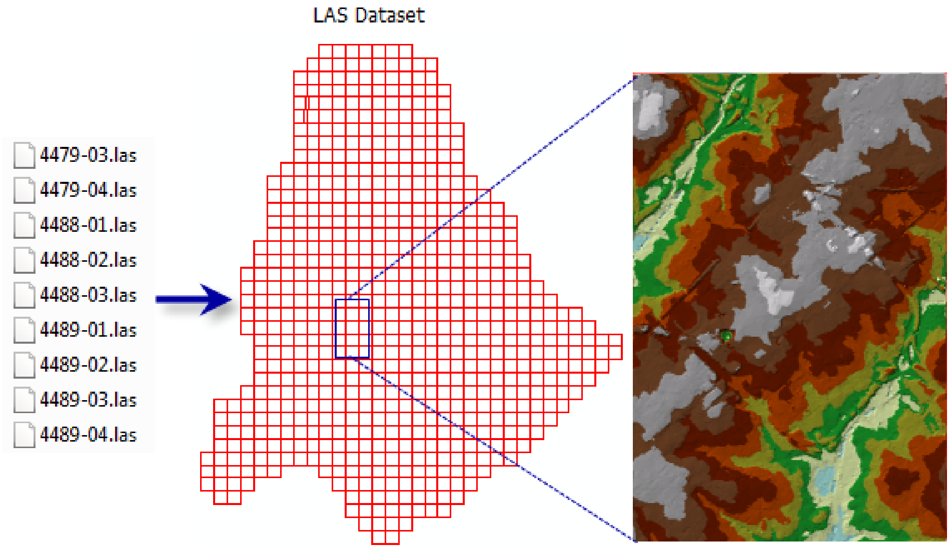


Level of detail of DEMs derived from (**A**) the **SRTM data**, (**B**) **TANDEM-X** data, (**C**) topographic contours (national DEM), and (**D**) fused **TLS and UAV-SfM** data. All DEMs were resampled to 10 m spatial resolution.

DEM: What is a LAS file?

- **LAS file is an industry-standard binary format for storing airborne LiDAR data (in general 3D point cloud)**
  - Quickly display and conduct a statistical analysis of point clouds (ArcMap: *LAS Point Statistics As Raster*)
  - Create surface DEM or TIN directly: (ArcMap: *LAS Dataset To Raster, LAS Dataset To TIN)*
  - Conduct initial quality check, assessing data coverage and point sample density
  - Standard classification of the LAS points
  - Incorporate additional surface features with xyz information: e.g. intensity
  - High compression: smaller file size

Commonly point cloud (.las) are divided in tiles and you have a LAS dataset



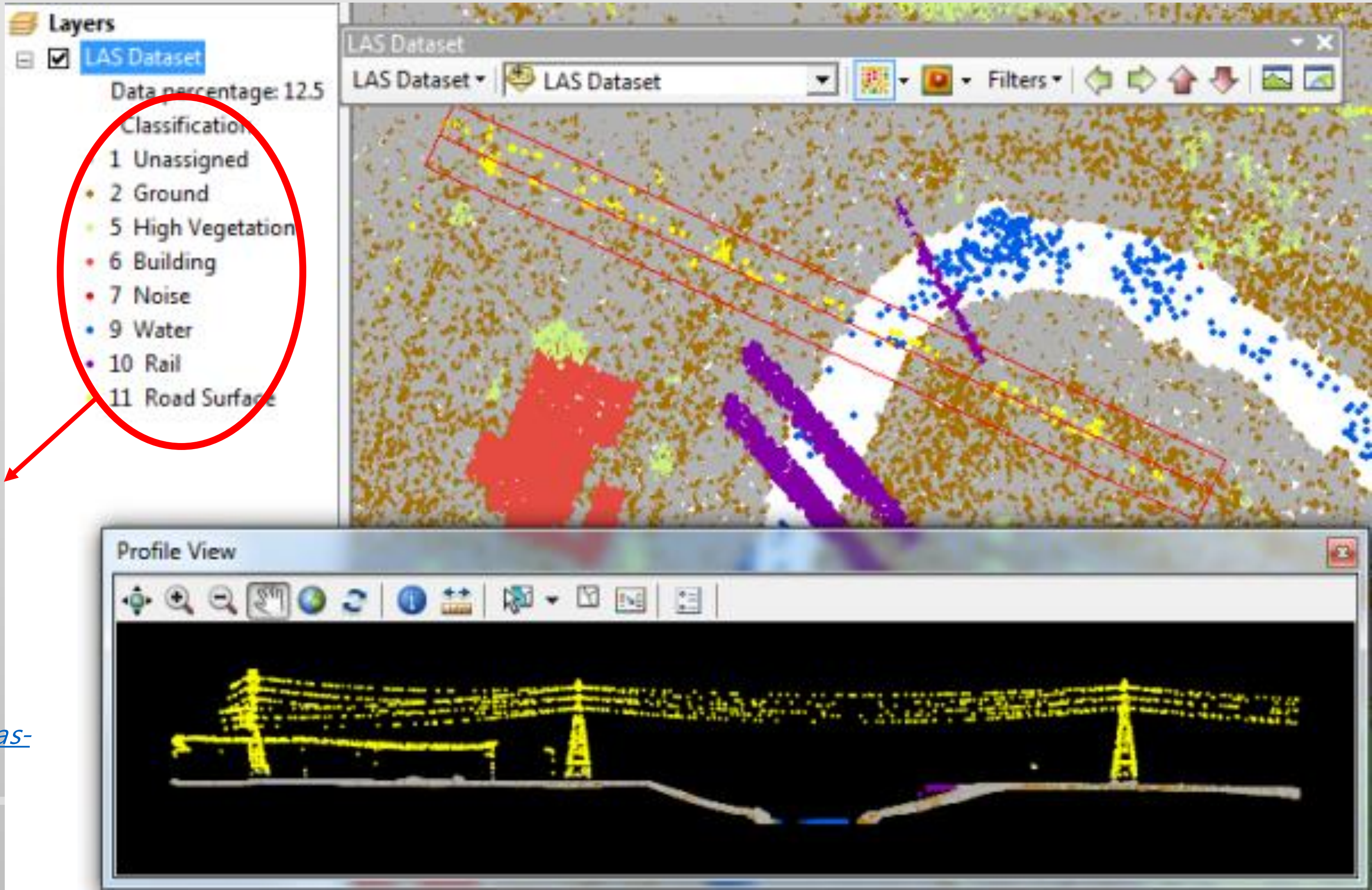
Example of the file size of a 1-square-km tile at 2 pts/m^2
- LAS File Size: 248,408 KB
- ASCII All Points Size: 292,766 KB

DEM: What is a LAS file?

☐ **Point cloud classification (mainly LiDAR points)**

- Each LIDAR point in a LAS file can have a classification code set for it.
- Classifying LIDAR data allows you to organize points into specific data classes

LAS Classification Code



https://desktop.arcgis.com/en/arcmap/latest/manage-data/las-dataset/working-with-las-classifications-in-arcgis.htm

DEM: What is a LAS file?

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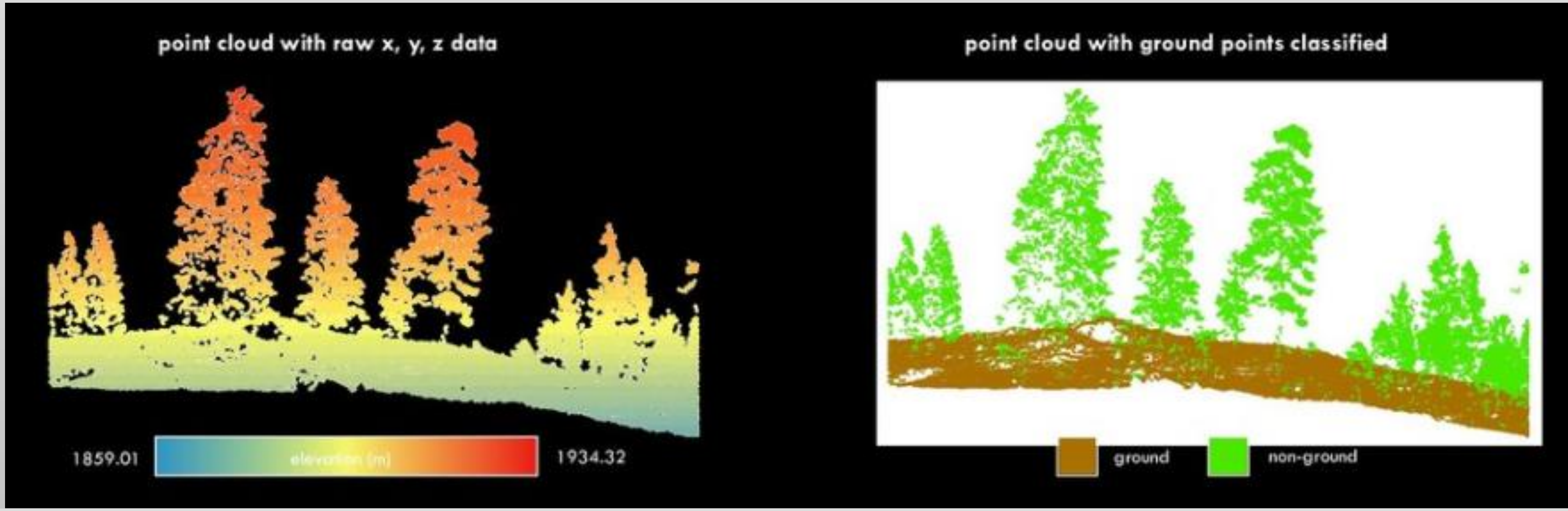
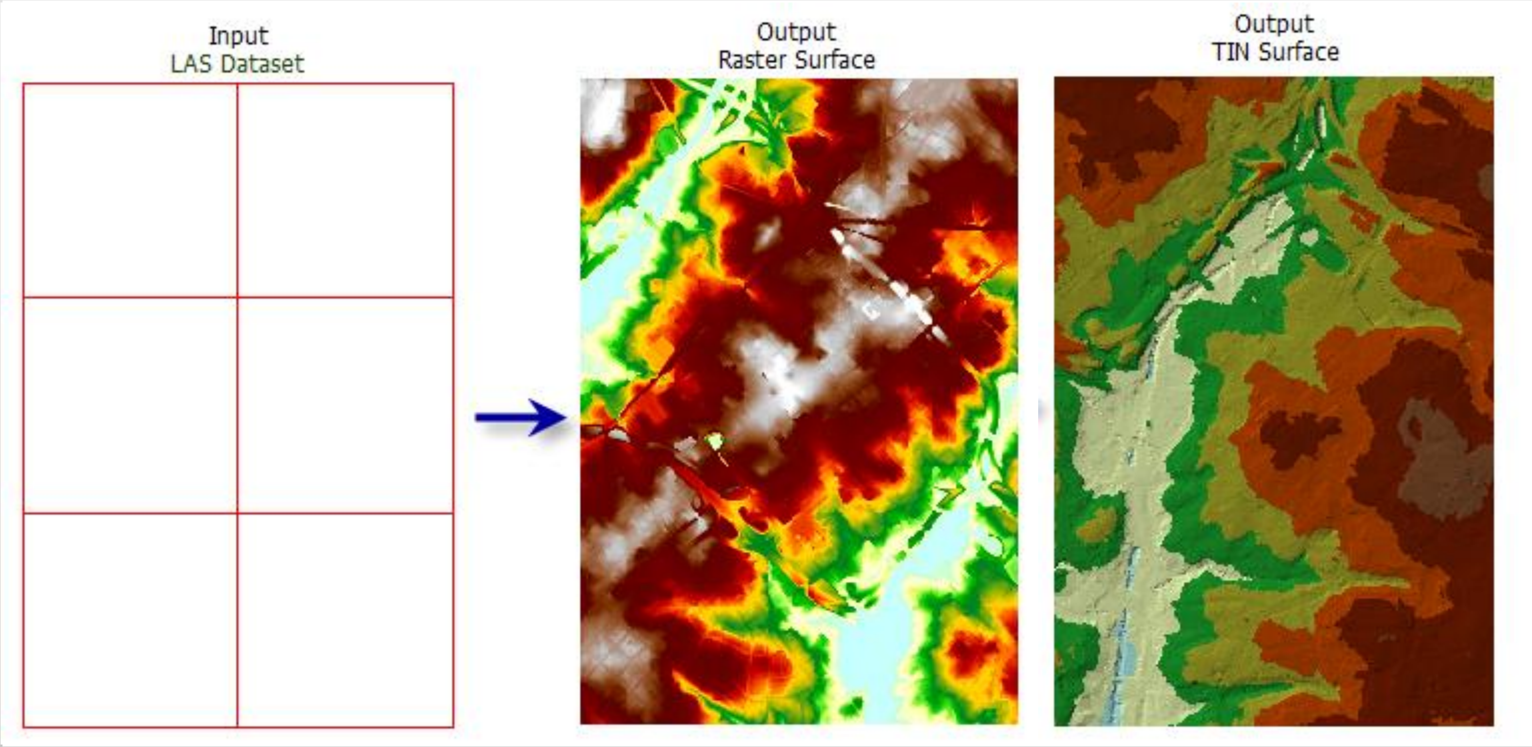
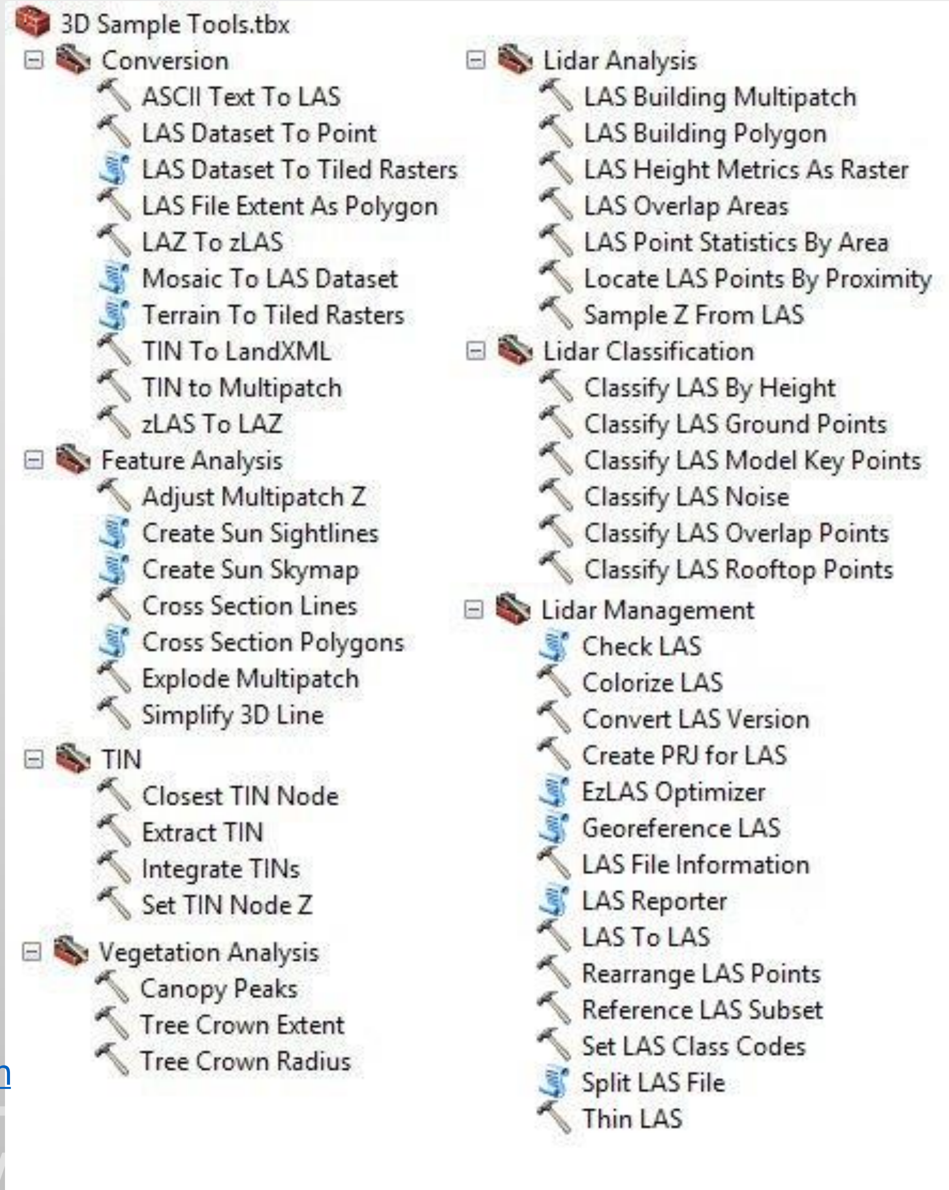


DEM: Work with LAS files

- ArcMap tool for LAS file

LAS Dataset To Raster LAS Dataset To TIN





https://desktop.arcgis.com/en/arcmap/latest/tools/3d-analyst-toolbox/las-dataset-to-tin.htm

DEM: Point cloud interpolation

- Interpolates a DTM or a DSM from a point cloud using one of the interpolation methods

NEXT STEP:
from the point cloud you create your grid by interpolating the points

DEM: Point cloud interpolation

- **Interpolates a DTM or a DSM from a point cloud using one of the interpolation methods**
  - TRIANGULATION — triangulated irregular network (TIN) linear interpolation designed for irregularly distributed sparse points
  - NATURAL_NEIGHBOR —This is similar to triangulation but generates a smoother surface and is more computationally intensive.
  - IDW —This is used for regularly distributed dense points, such as point cloud LAS files from Lidar. The IDW search radius is automatically computed based on average point density.
  - KRIGING

Lecture 3 & 4

(The form of the point cloud can be either LAS files or a solution point table)

DEM: Point cloud interpolation

- **Interpolates a DTM or a DSM from a point cloud using one of the interpolation methods**
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  - KRIGING

(The form of the point cloud can be either LAS files or a solution point table)

The choice depends:

- *Data source (Lidar, photogram.)*
- *Point density (resolution of your point cloud)*
- *Applications*

...

<u>There is no best option</u>, Combination and adjustment of these algorithms also exist

DEM: Point cloud interpolation

- **Void filling**

  Areas of NoData may exist where pixels do not have enough information from the input to generate any values

  - A fill DEM is a DEM raster where no Data area are filled
  - The Void fill method is an interpolation:
    - NONE—NoData is assigned to the cell.
    - SIMPLE—Averages the values from data cells immediately surrounding a NoData cell to eliminate small voids.
    - LINEAR—Triangulates across void areas and uses linear interpolation on the triangulated value to determine the cell value.
    - NATURAL_NEIGHBOR—Uses natural neighbor interpolation to determine the cell value.

DEM: Point cloud interpolation

- Topo to grid solution (Topo to raster)

  Areas of NoData may exist where pixels do not have enough information from the input to generate any values

  - Gridding based on contour data, without first making a TIN
  - Based on a "minimum curvature interpolation"
  - Adaption of terrain features by allowing sharp breaks, filling up of sinks and enforcing correct drainage direction
  - Inclusion of river network data and break lines for interpolation
  - "Hydrological" and therefore also "geomorphologic correct" interpolator

https://pro.arcgis.com/en/pro-app/latest/tool-reference/3d-analyst/topo-to-raster.htm

Learning Objectives

1

Elevation data
- Definition
- DEM data structure
- Contour line, TIN, raster

2

Elevation data source:
- Remote sensing
- Photogrammetry
- Las file
- DEM generation

3

DEM visualization
- Hillshaded
- Example

Today's topics

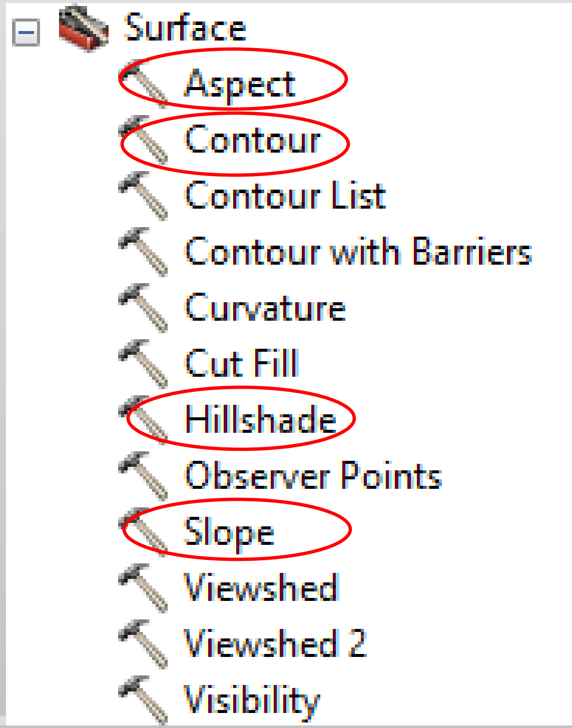
DEM visualization

- Introduction: Deriving additional descriptors of land shape (i.e., morphometry) from elevation/terrain data.

Terrain descriptor in ArcGIS

- Contour
- Hillshade
- Solar Radiation
- Slope
- Aspect
- Profile curvature
- Plan curvature
- Viewshed
- Cut Fill

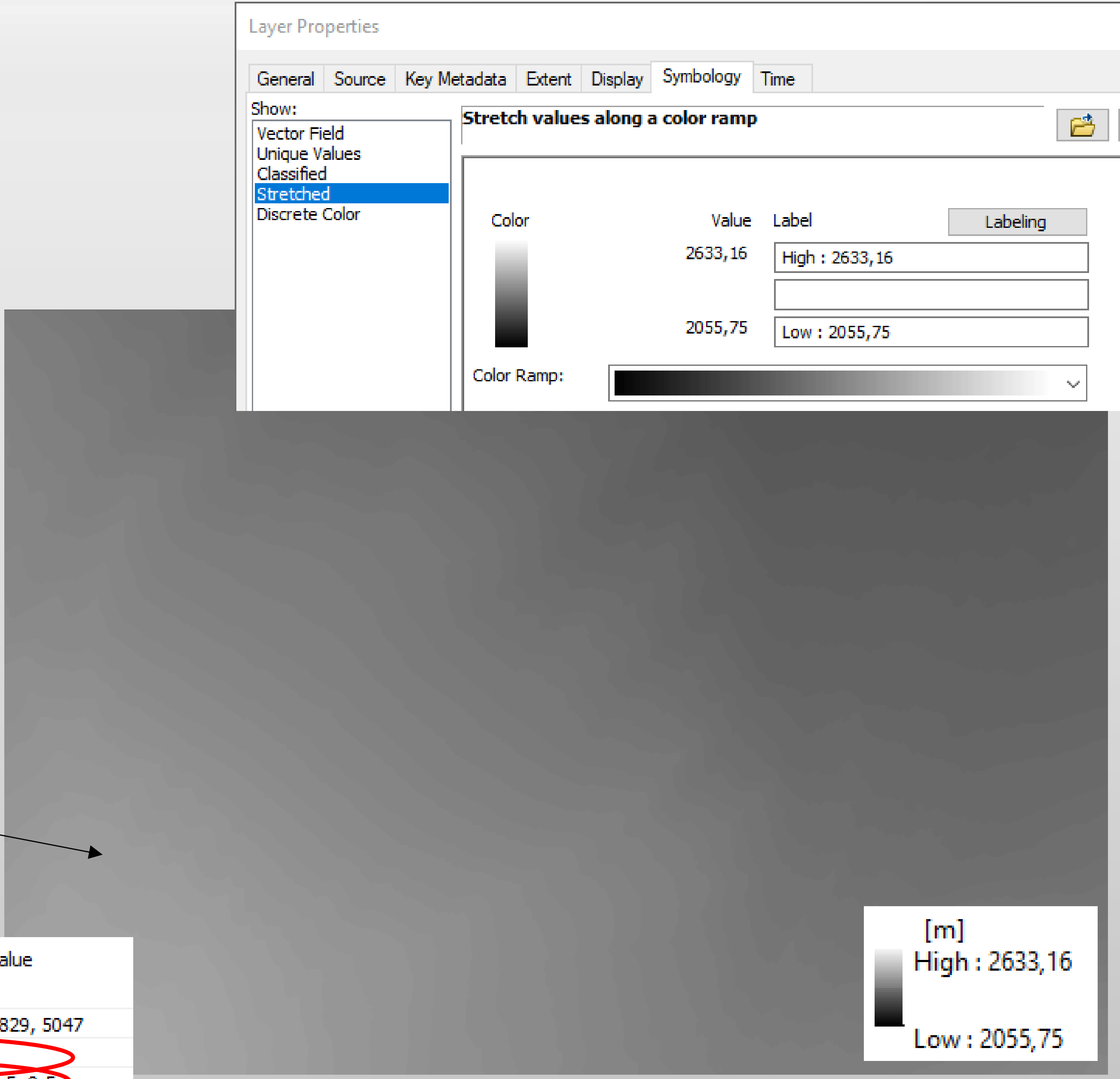
Terrain descriptor in ArcGIS



DEM visualization

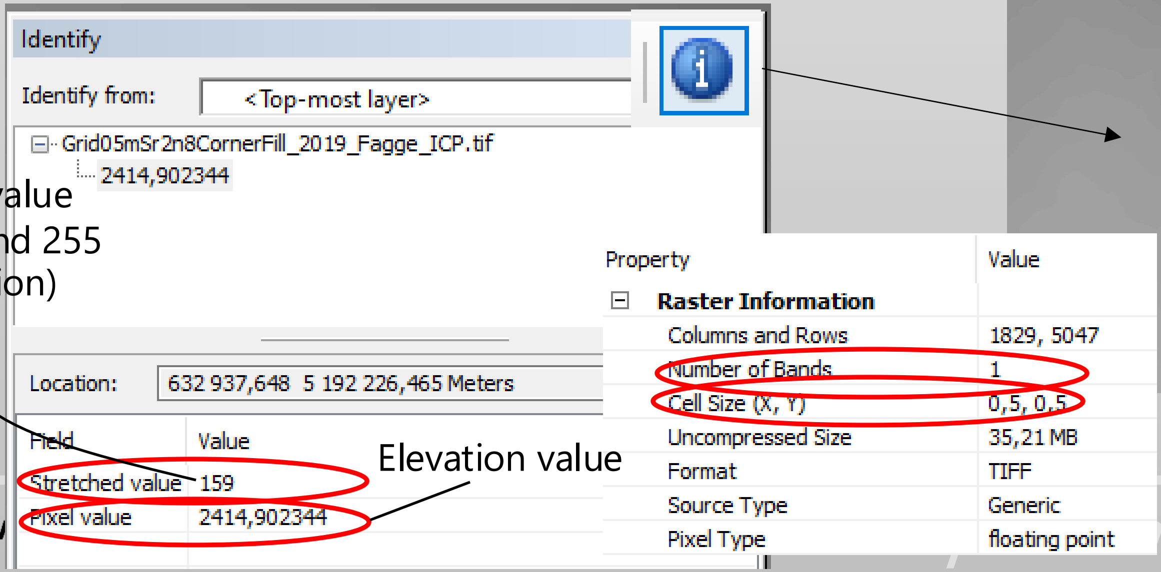
DEM raster visualization

By default, a DEM (i.e. grid) is displayed as a grayscale image. The grayscale value is stretched between the high and low elevation values.



Example: front moraine

Stretched value between 0 and 255 (visualization)

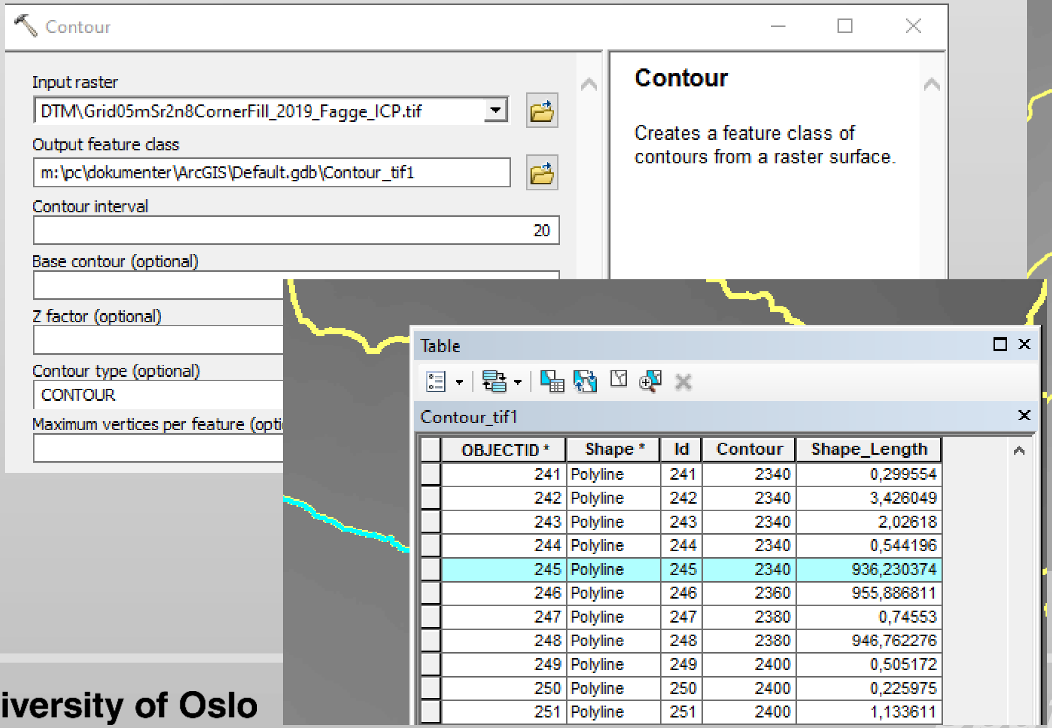


Elevation value

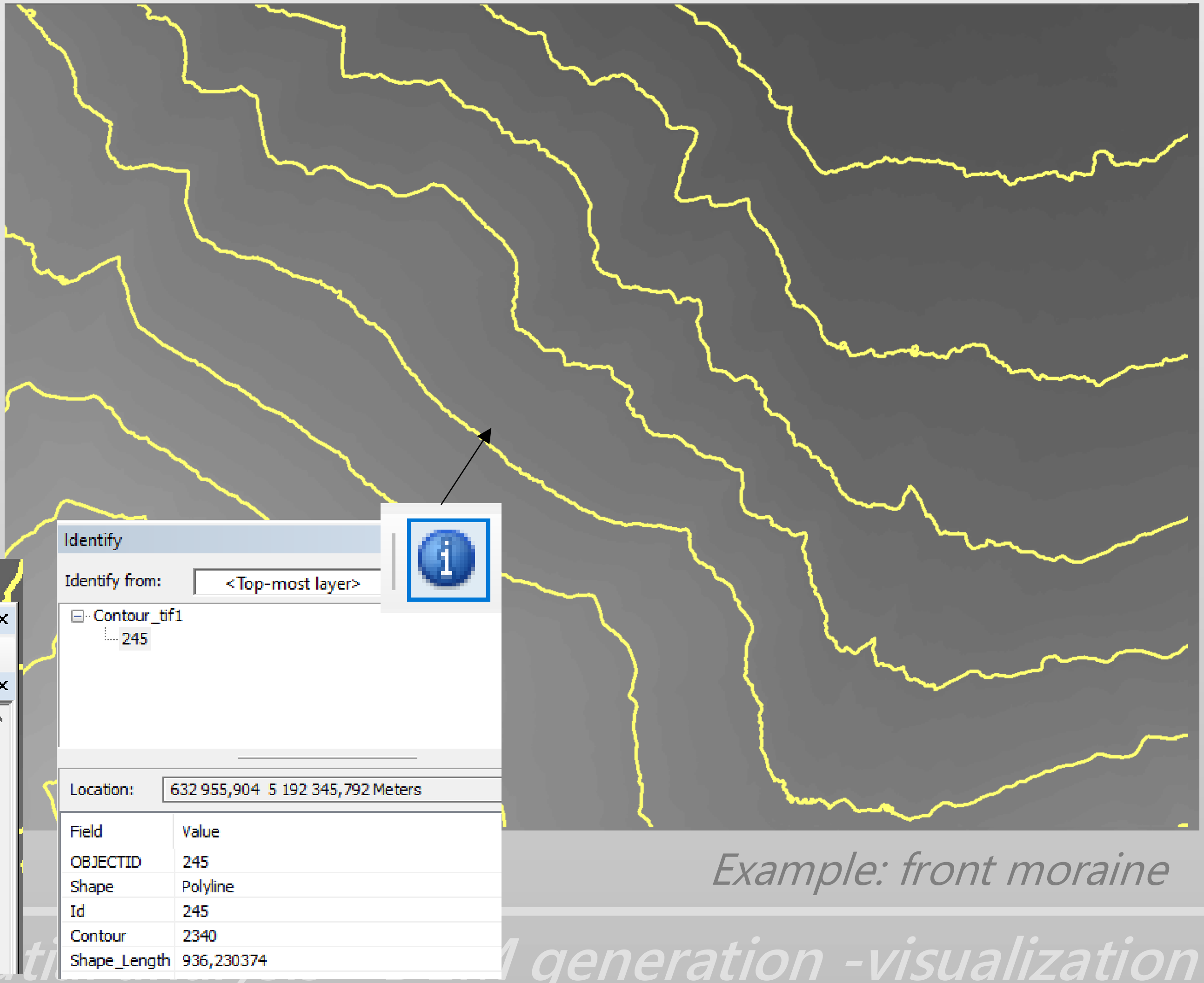
DEM visualization

- ☐ **Contour line visualization**

Contour is a tool for visualizing the spatial distribution of elevations in the DEM



OBJECTID *	Shape *	Id	Contour	Shape_Length
241	Polyline	241	2340	0,299554
242	Polyline	242	2340	3,426049
243	Polyline	243	2340	2,02618
244	Polyline	244	2340	0,544196
245	Polyline	245	2340	936,230374
246	Polyline	246	2360	955,886811
247	Polyline	247	2380	0,74553
248	Polyline	248	2380	946,762276
249	Polyline	249	2400	0,505172
250	Polyline	250	2400	0,225975
251	Polyline	251	2400	1,133611

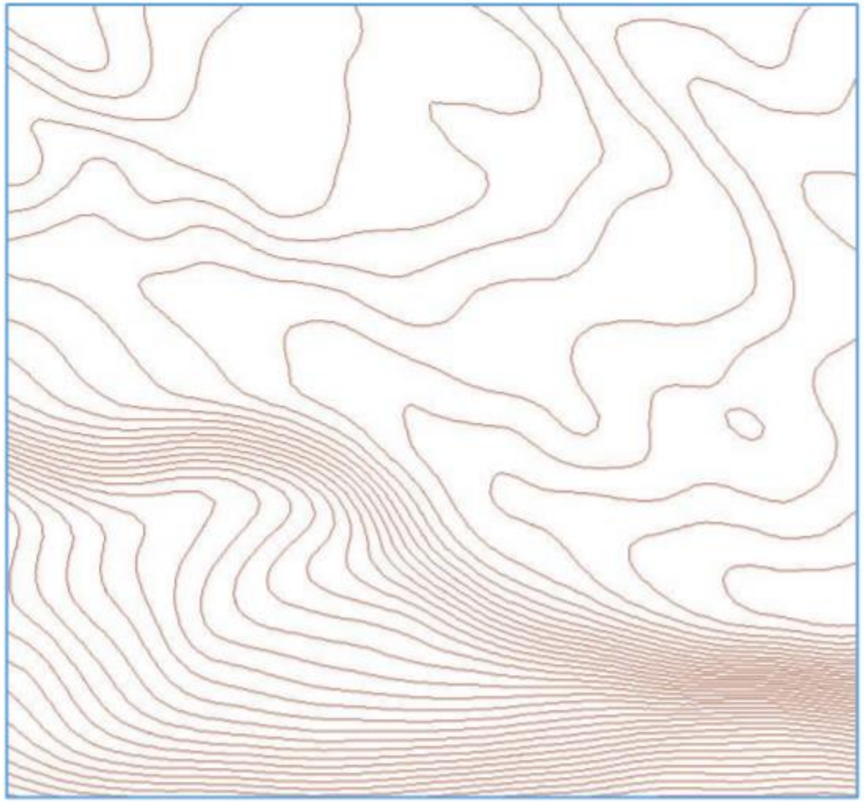


Example: front moraine

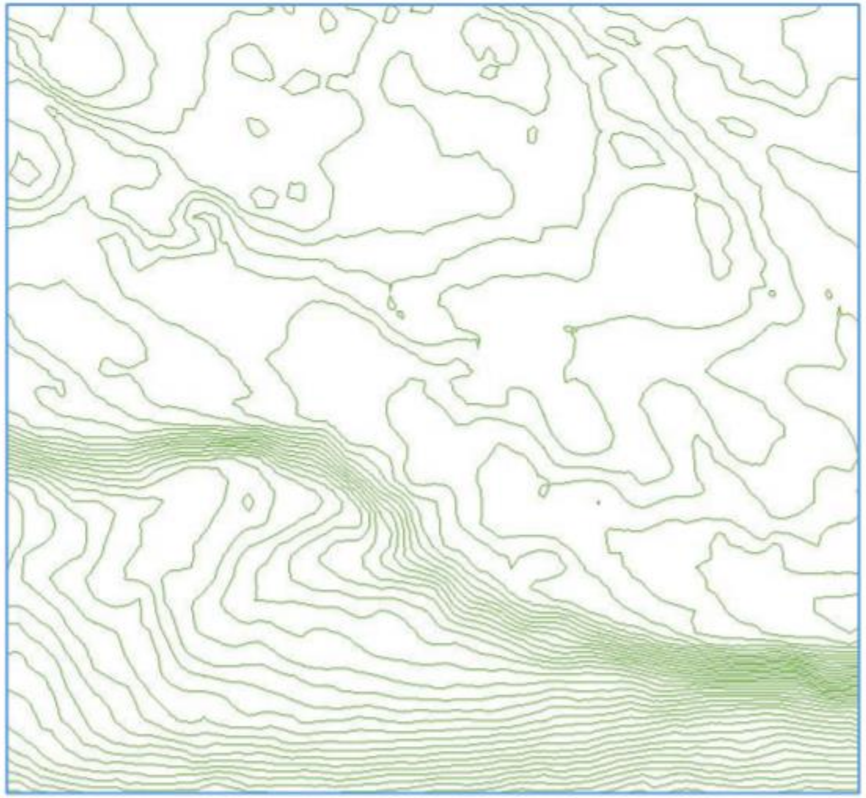
DEM visualization

- Contour line visualization

Smooth contour lines



Contour lines from a raw DEM

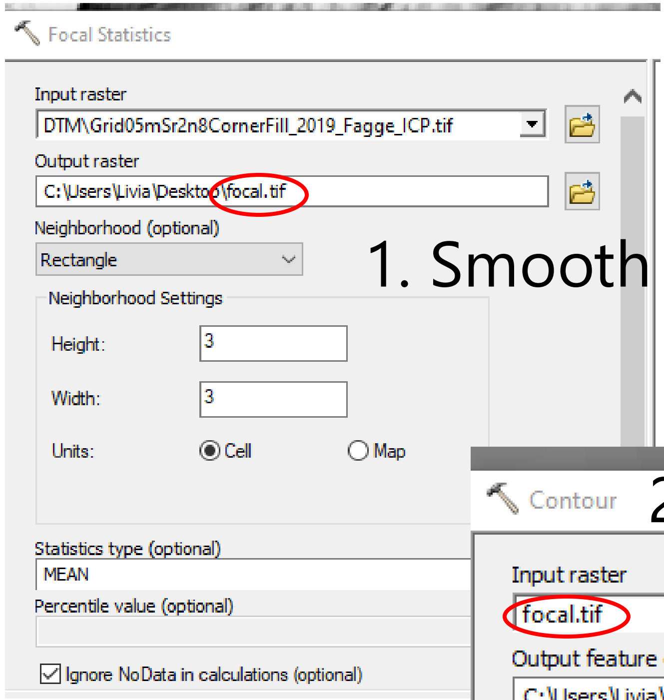


NOTE: In order to create smooth contour lines, you first need to smooth the DEM (in ArcGIS >Focal Statistics tool)

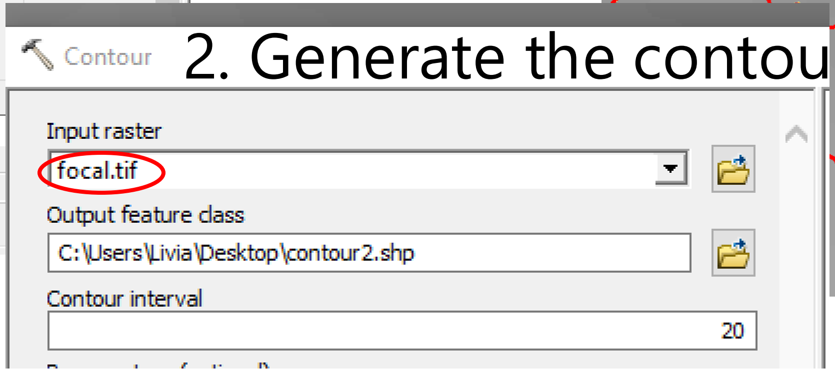
DEM visualization

Contour line visualization

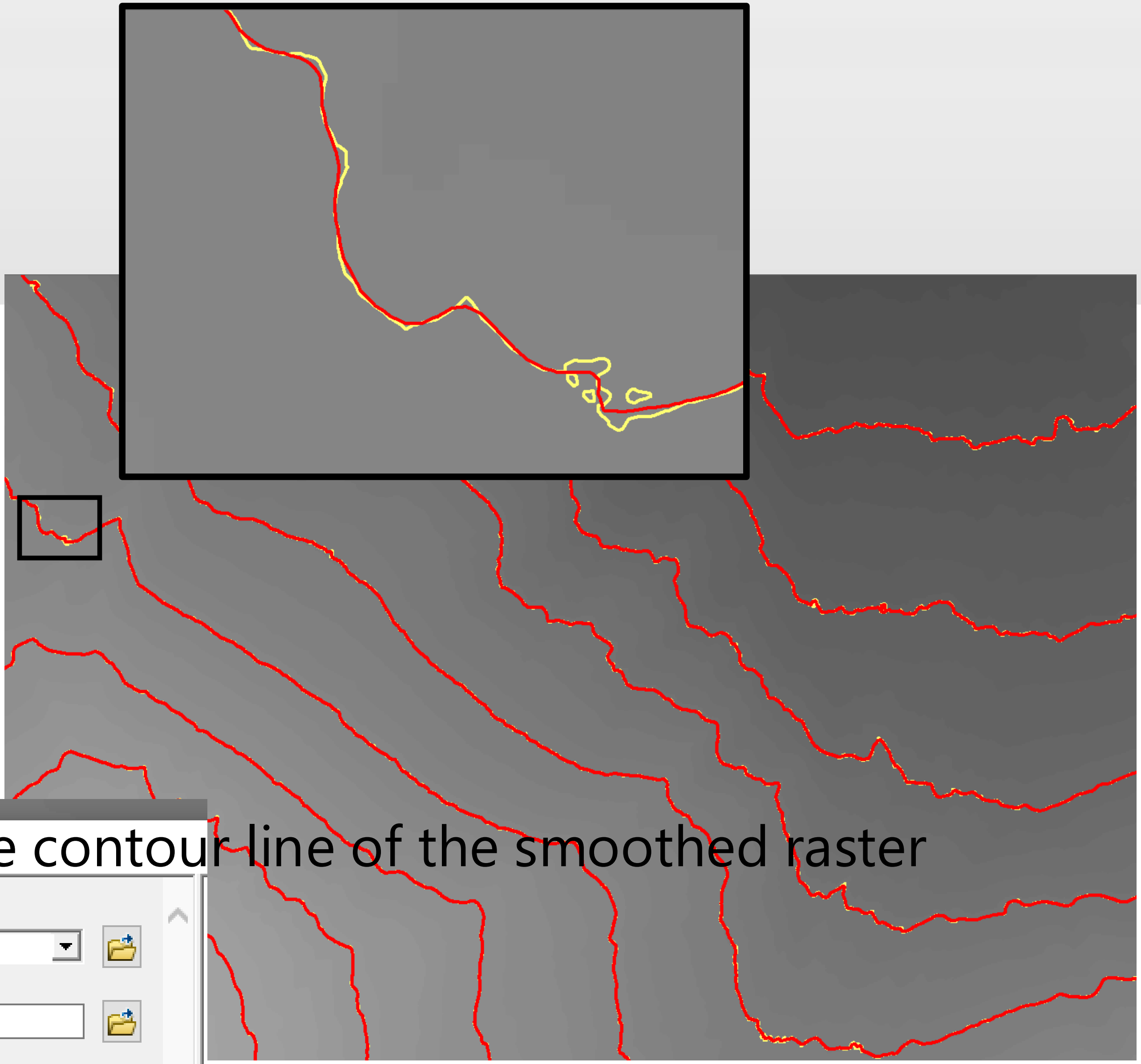
Smooth contour lines



1. Smooth the raster



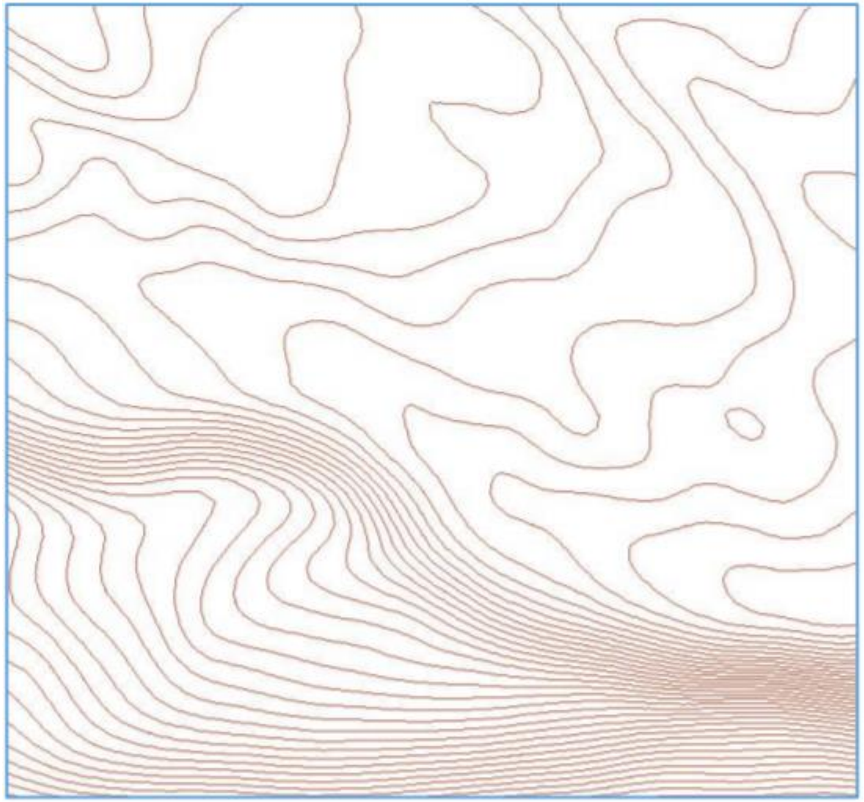
2. Generate the contour line of the smoothed raster



DEM visualization

- **Lines: contour lines (or contour) and contour map**

Smooth contour lines



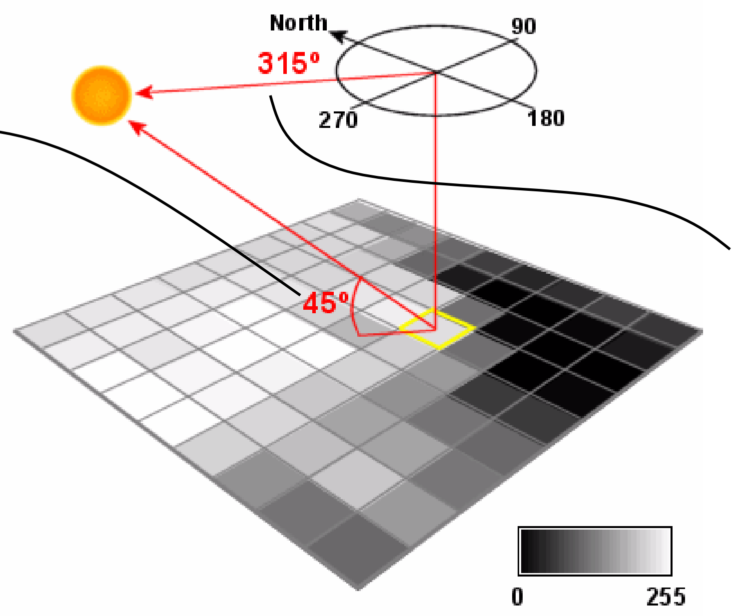
NOTE: A rule of the scale at which contour lines are generated: the spacing between the contour lines should be at least twice the pixel size of the DEM (Hengl et al.,2003).

DEM visualization

Shaded relief or hillshade

A hillshade is a grayscale 3D representation of the surface, with the sun's relative position taken into account for shading the image. This function uses the altitude and azimuth (sun direction 0-360 deg) properties to specify the sun's position.

- The inputs for this function are the DEM, and sun altitude and azimuth.
  - Sun altitude ~ time of year, 0°-90°
  - Solar azimuth ~ time of day (0°-360°)
- Hillshading computes surface illumination as values from 0 to 255
- Cells facing the sun are most illuminated (value close to 255) while cells facing away from the sun are in shadow



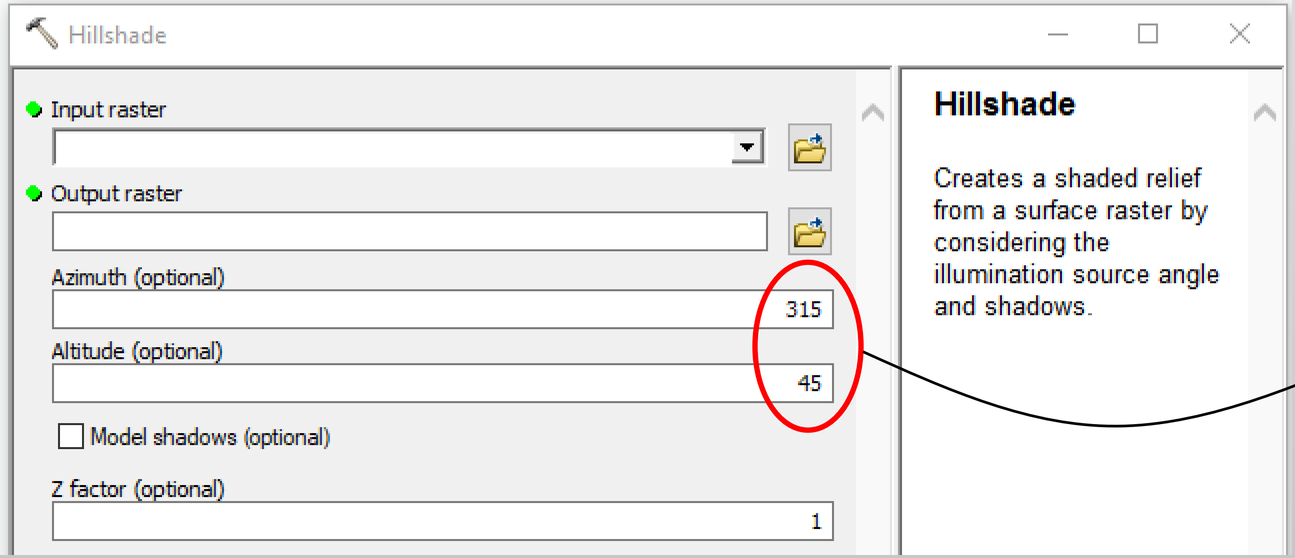
Azimuth is the sun's relative position along the horizon (in degrees). This position is indicated by the angle of the sun measured clockwise from the north. An azimuth of 0 degrees indicates north, east is 90 degrees, south is 180 degrees, and west is 270 degrees

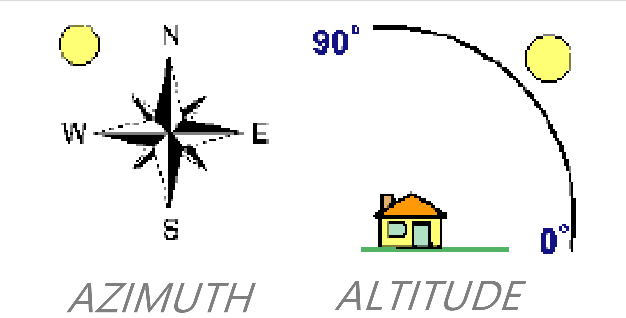
DEM visualization

☐ Shaded relief or hillshade

A hillshade is a grayscale 3D representation of the surface, with the sun's relative position taken into account for shading the image.

It can be generated using the *Hillshade* tool in ArcGIS

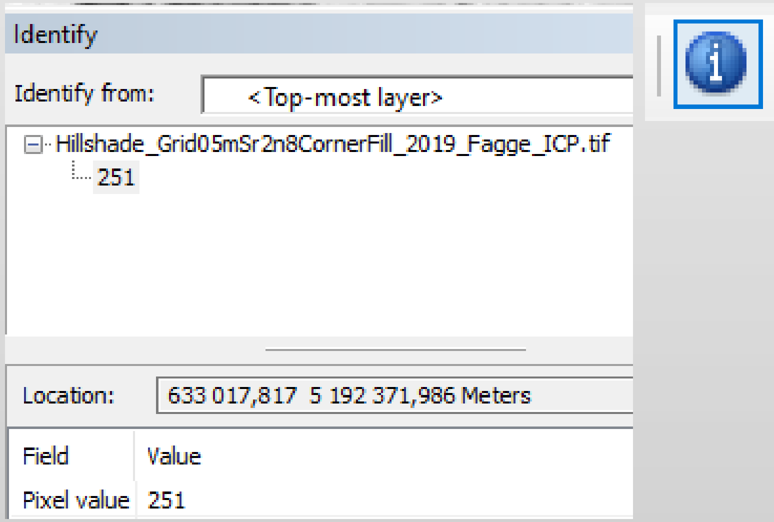




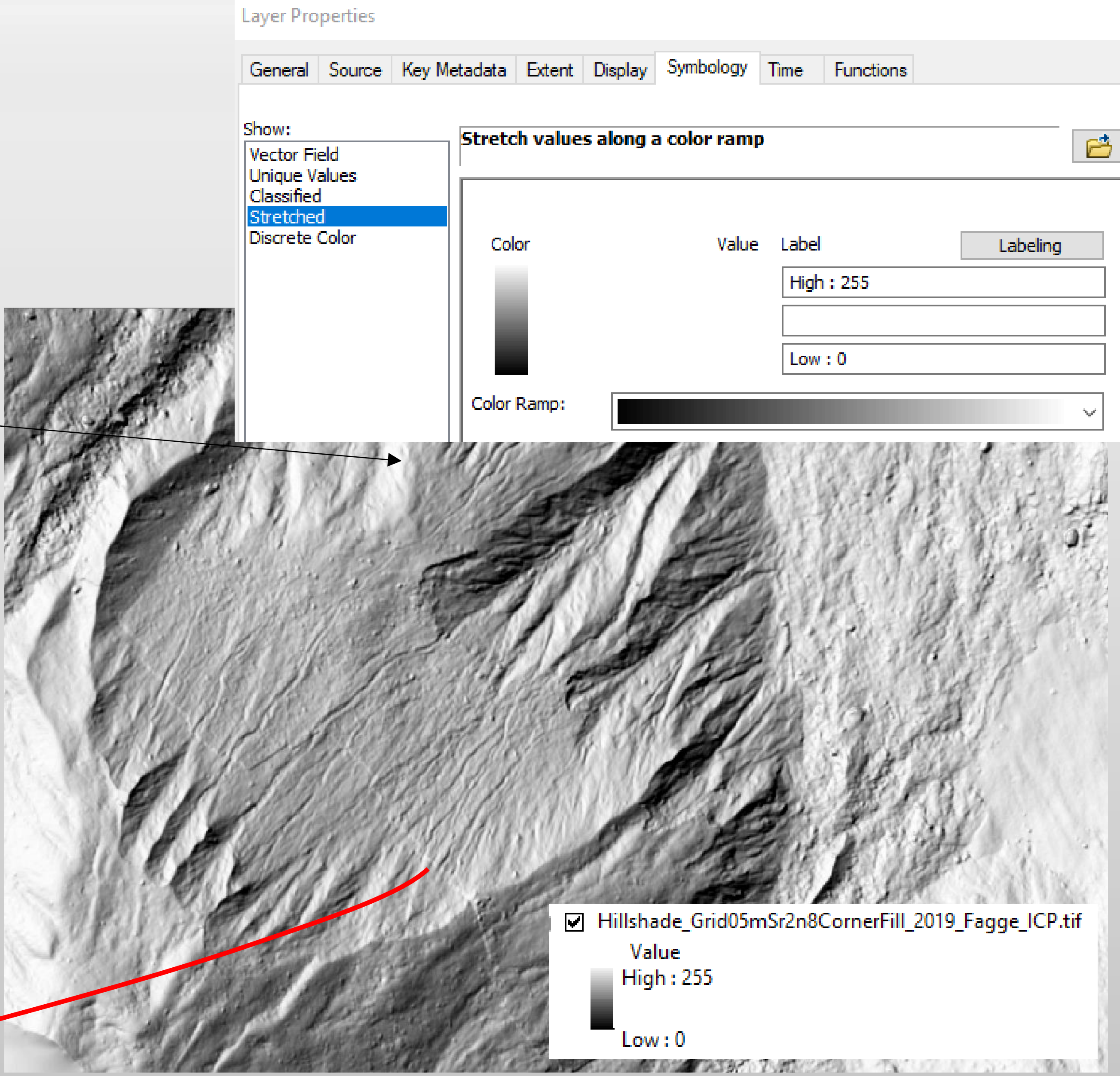
The ESRI default hillshade has an azimuth of 315 and an altitude of 45 degrees.

DEM visualization

- Hillshade visualization



What is this line here?



Example: front moraine

DEM visualization

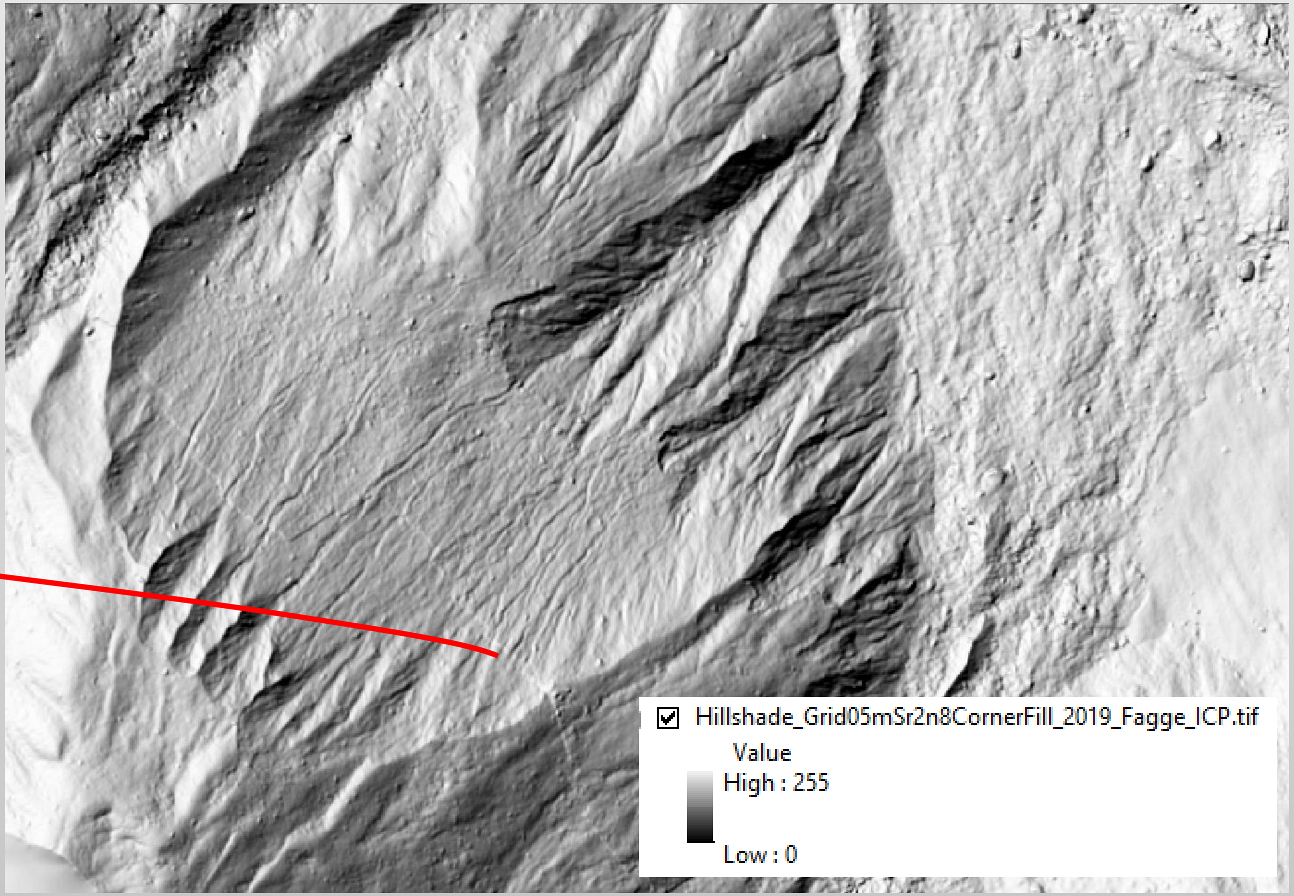
Because this drone was never meant for surveying and creates poor data.

UAV, Phantom ProDJI

☐ Hillshade visualization

Hillshade is a very useful tool to detect error, noise and artefact in your elevation row data (point cloud) and therefore in the DEM

The elevation data was collected with an UAV in two different days. This line is an offset in the point cloud generated from the UAV



Example: front moraine

DEM visualiza

- Hillshade visuali

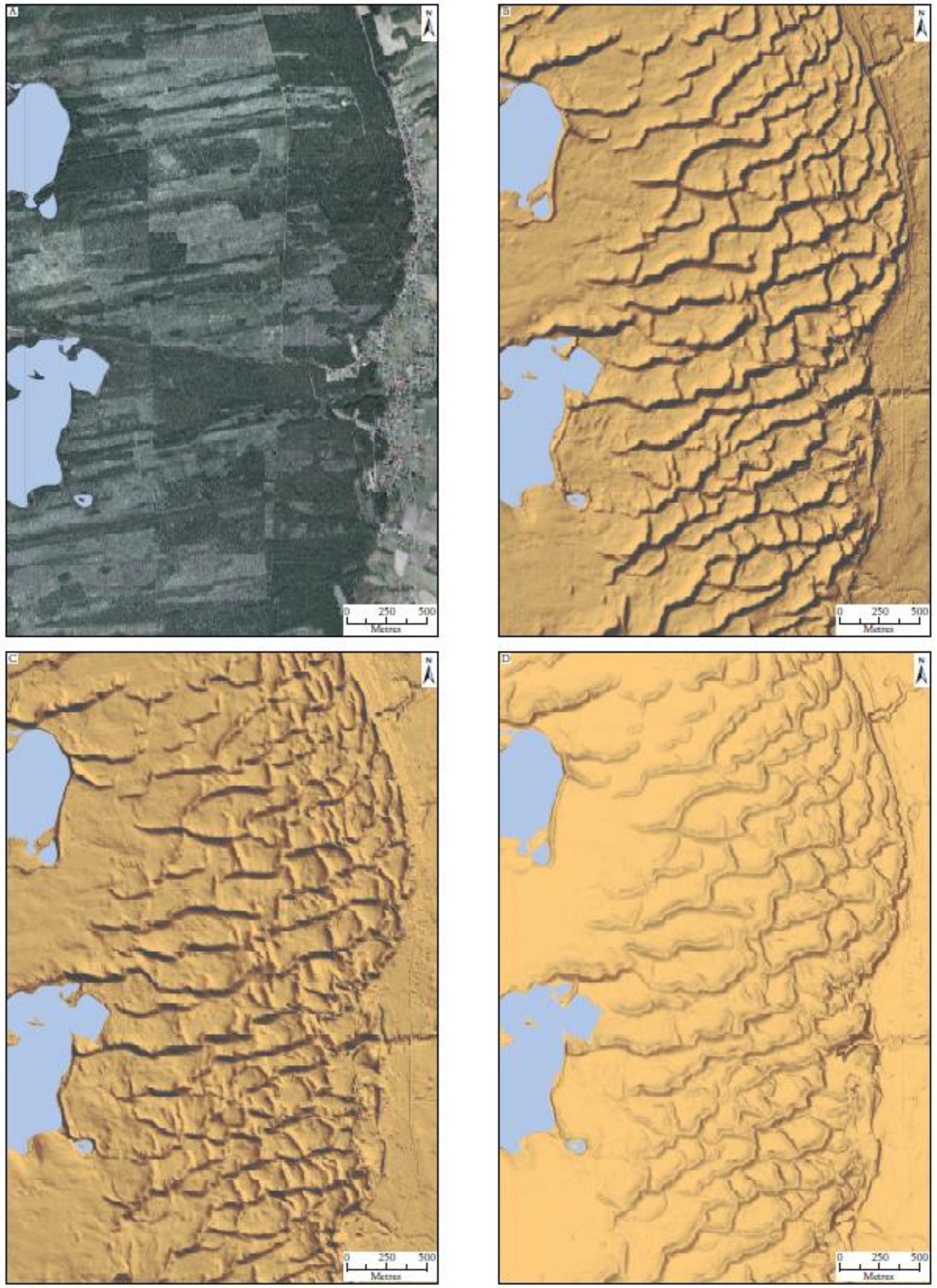


Fig. 7.
An orthophoto (A) and three hillshade models (B-D) over the same part of the Bonäsheden dune field. The figure emphasise two things: 1. The hillshade models display the topography of the dunes in a superior way compared to the orthophoto. 2. Depending on what azimuth and solar elevation are used in a hillshade model the impression of the terrain can differ substantially. Azimuth and solar elevation: B; 315°, 45°. C; 45°, 45°. D: 0°, 90° (© Lantmäteriet).

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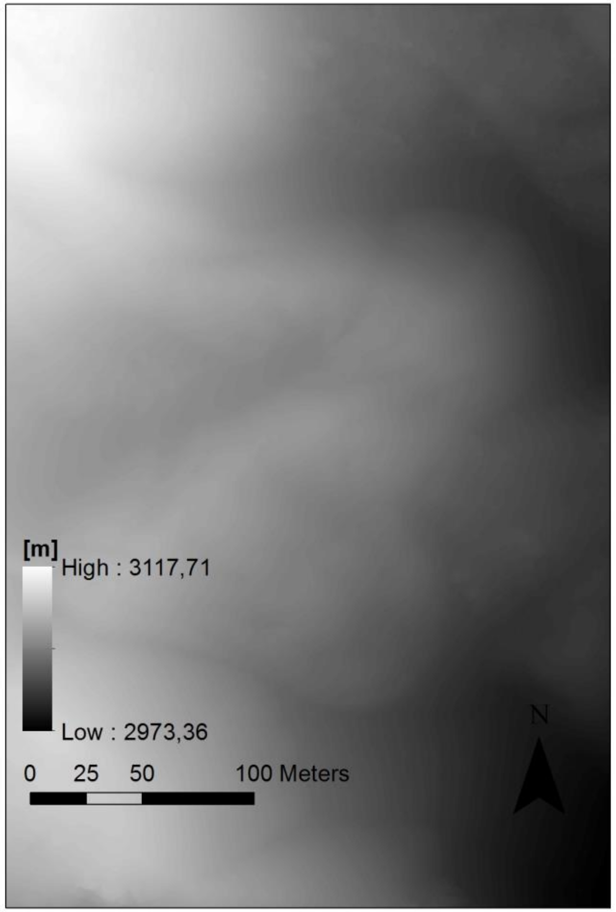
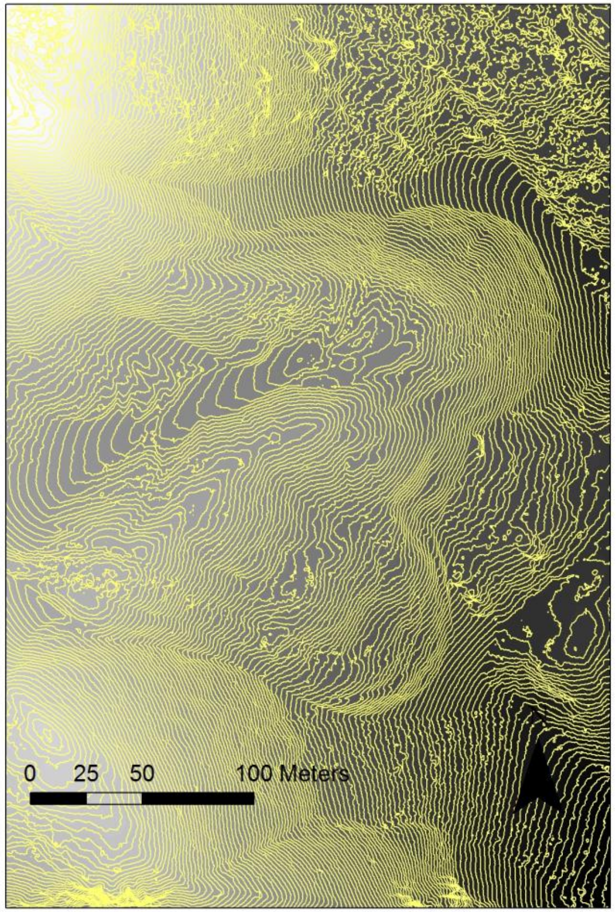
DEM visualization

- ☐ **Example: bilobate active rock glacier**

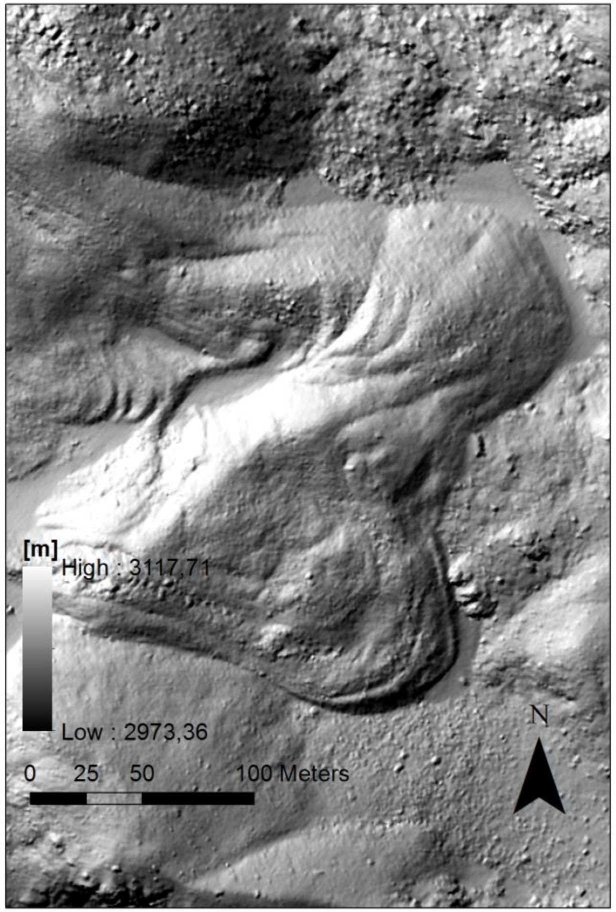
DEM (grid) for analysis



Contour lines for visualizing the spatial distribution of elevations in the DEM



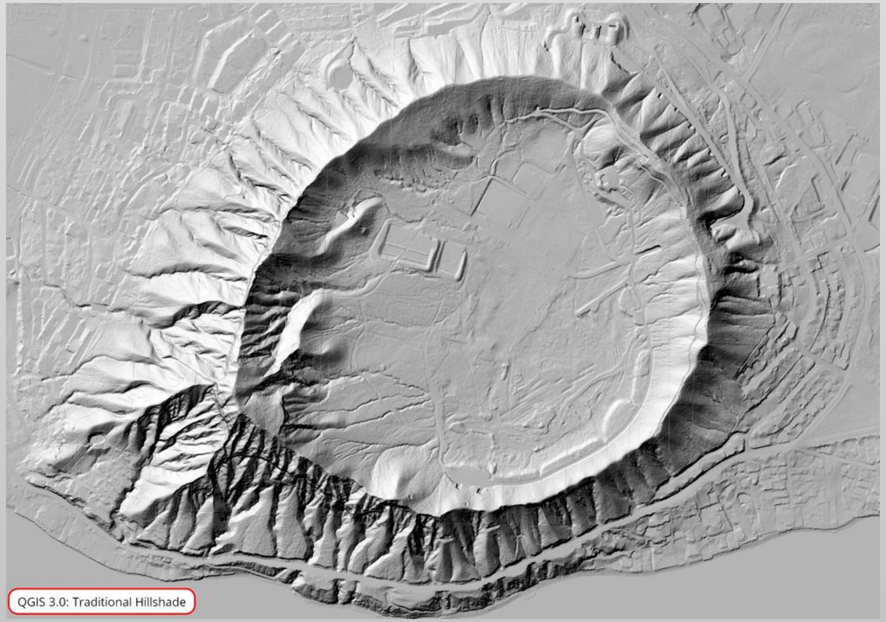
Hillshade DEM for visualizing the topography



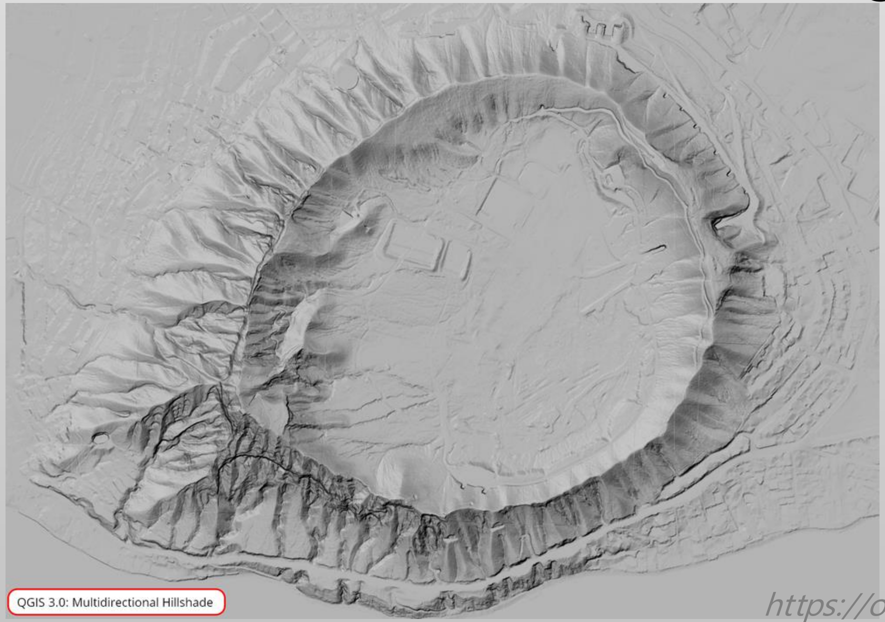
DEM visualization

- Shaded relief or hillshade

Traditional hillshade:
hillshade illuminated from 315 deg azimuth - so only single source of light



Multidirectional Hillshade:
a combination of hillshades illuminated from 225, 270, 315, and 360 deg azimuth - 4 different sources of light

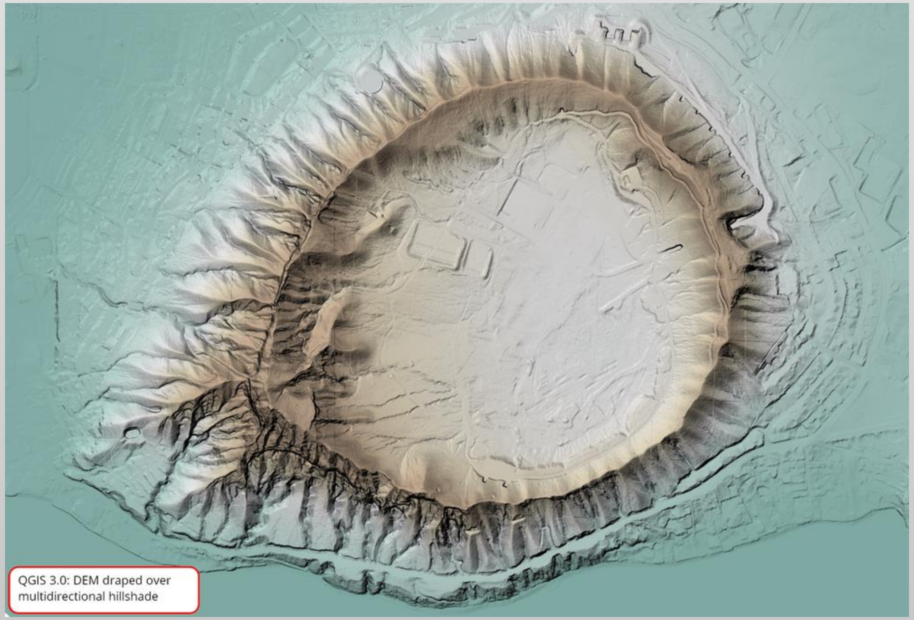


https://opengislab.com/

DEM visualization

- **Shaded relief or hillshade**

  Multidirectional hillshade draped over the coloured DEM



https://opengislab.com/

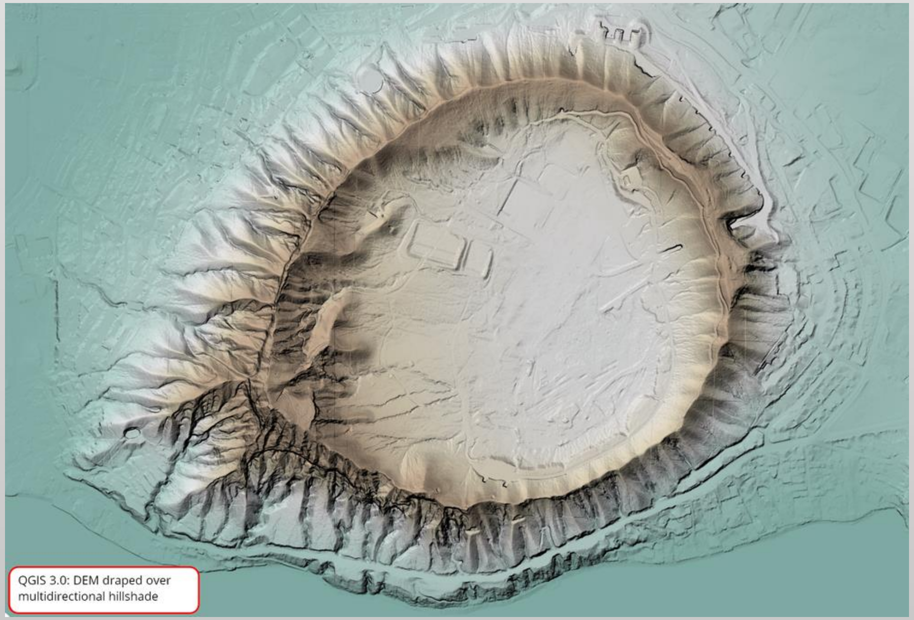
- Hillshade is not very useful from an analytical point, but a great **visualization tool**

- Often you display the hillshade in semi-transparent overlaid to a DEM. The colour is given by the DEM (stretched values of the elevation from the min to the max) and the hillshade highlight the topography.

DEM visualization

- ☐ **Shaded relief or hillshade**

  Multidirectional hillshade draped over the coloured DEM



https://opengislab.com/

Why the hillshade is not super useful?

- Hillshade is not very useful from an analytical point, but a great **visualization tool**

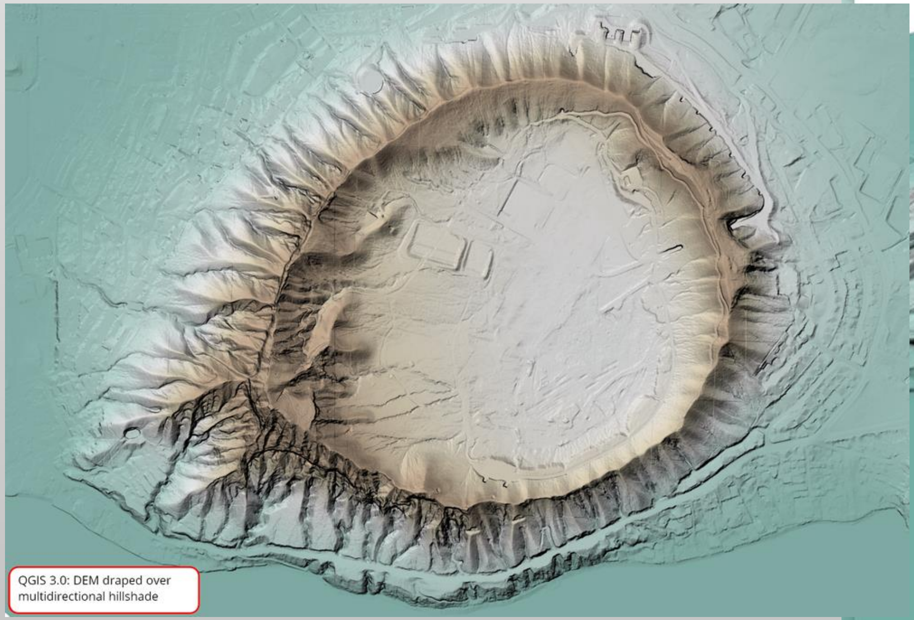
- Because it doesn't provide any true measure of solar radiation
- Just an 8-bit value (0-255) representing relative illumination

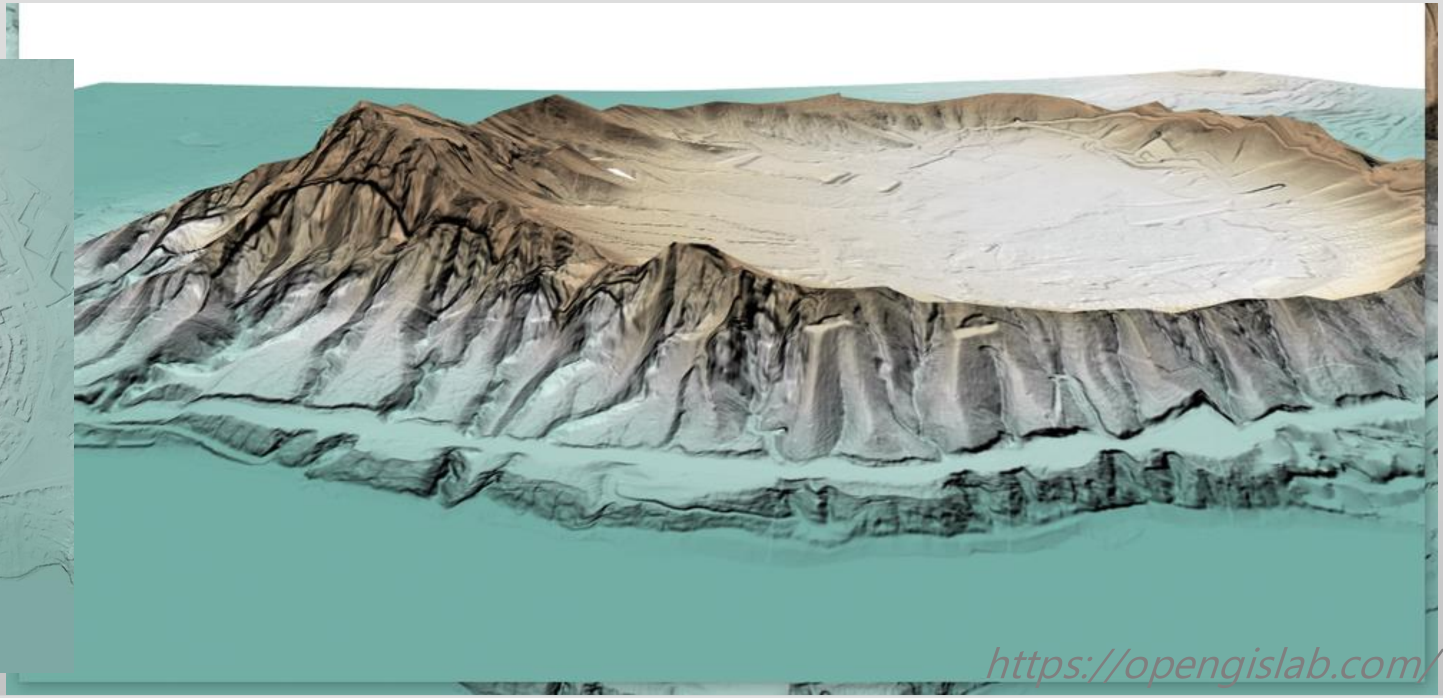
DEM visualization

- ☐ **Shaded relief or hillshade**

<u>Multidirectional hillshade draped over the coloured DEM</u>

<u>3D Map View to view/simulate 3D landscape (DEM)</u>





DEM visualization

- ☐ **Draping of an aerial map on DEM**

3D visualization of an aerial (ESRI Aerial base map) draped into the multidirectional hillshade.

https://opengislab.com/

DEM visualiz

- Shaded relief

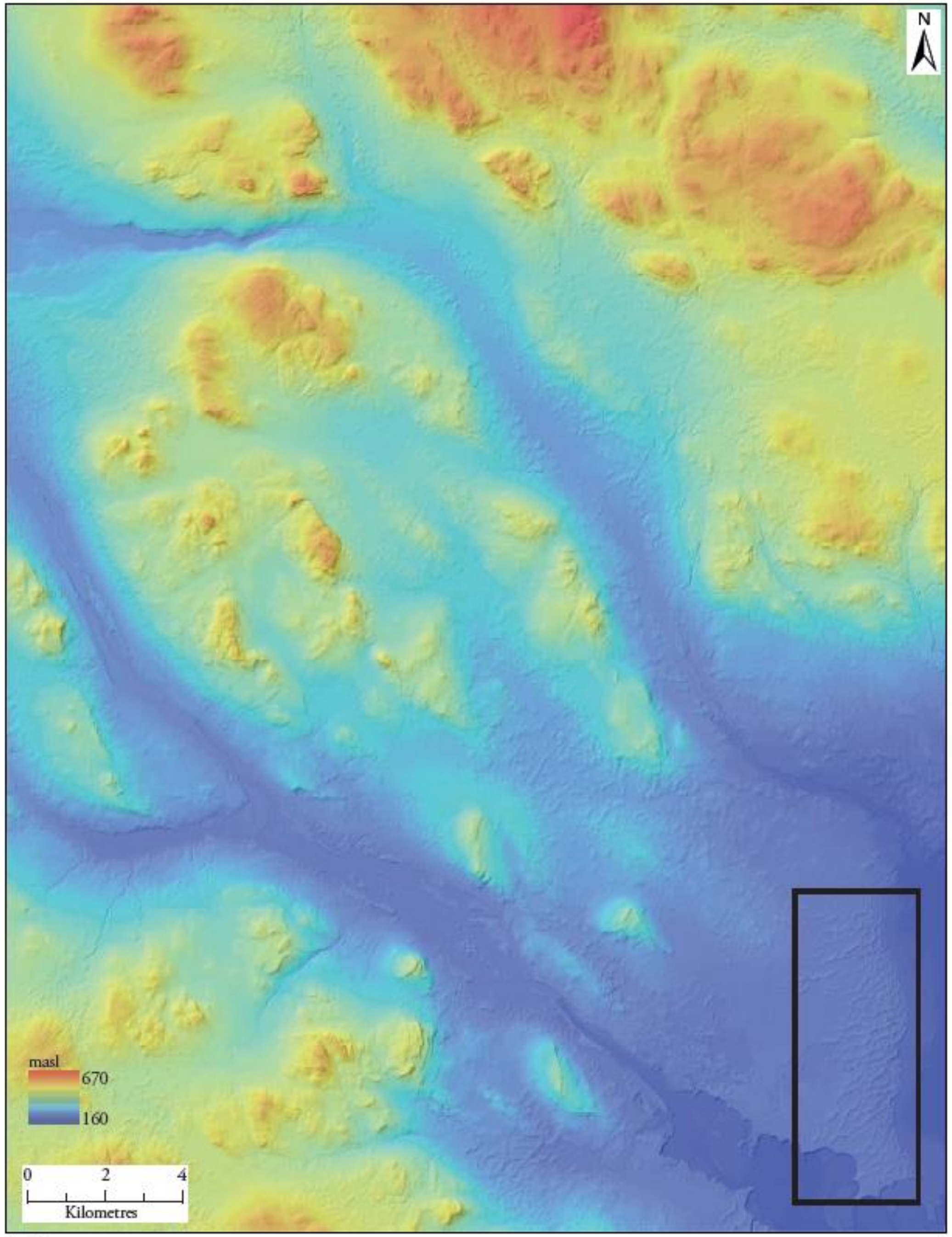


Fig. 6.
Relief shade model with the dune field of Bonäsheden, Dalarna County, marked by the black rectangle (© Lantmäteriet). Modified from Bernhardson and Alexanderson (2017).

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DEM visualiza

- Slope raster

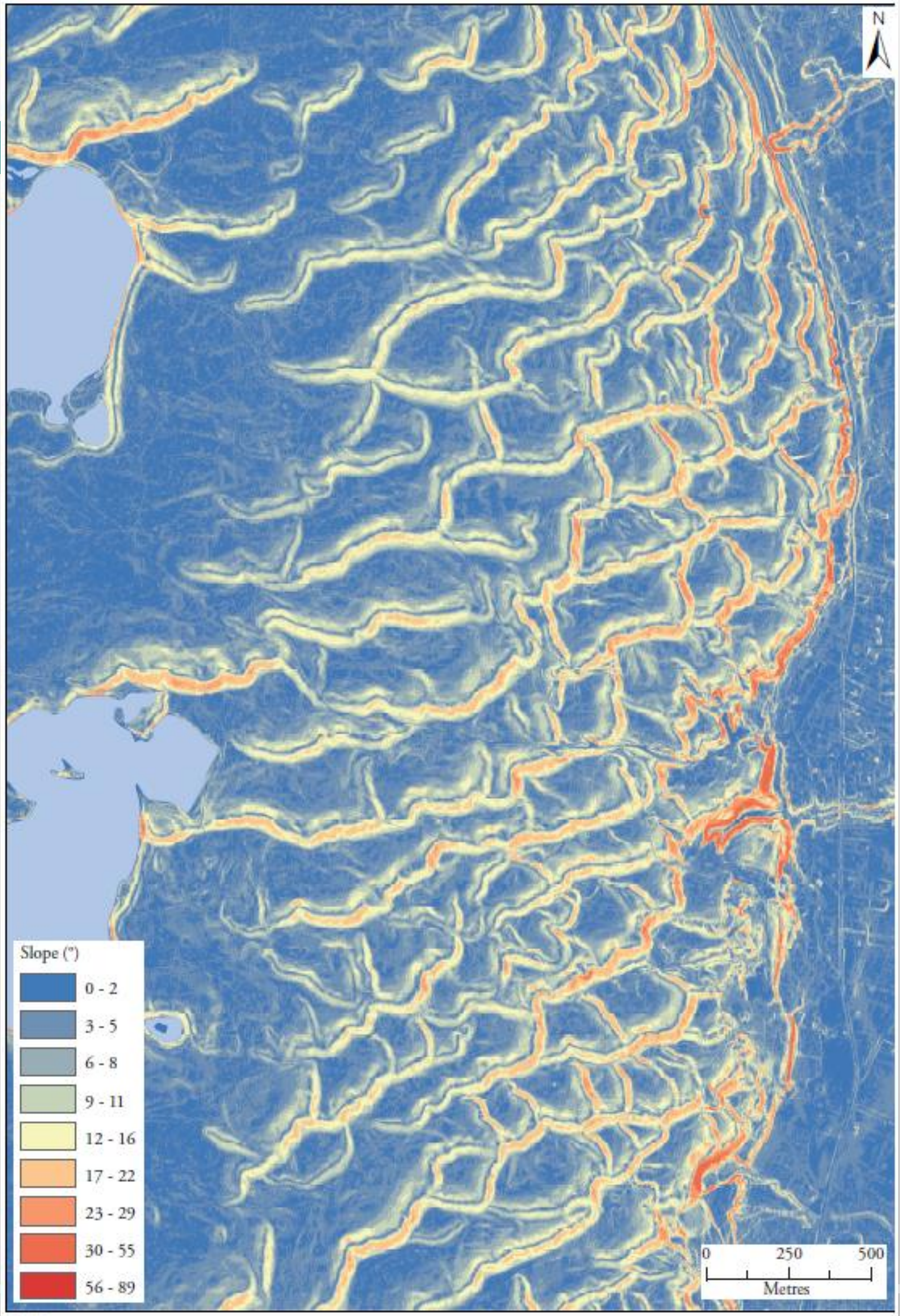

Fig. 8.
Slope raster image over a part of the Bonäsheden dune field. The steepness of the terrain is colour coded, see legend. Notice the difference in slope steepness between windward, blue and yellow, and lee sides, orange and red (© Lantmäteriet).

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DEM visualiza

- Aspect

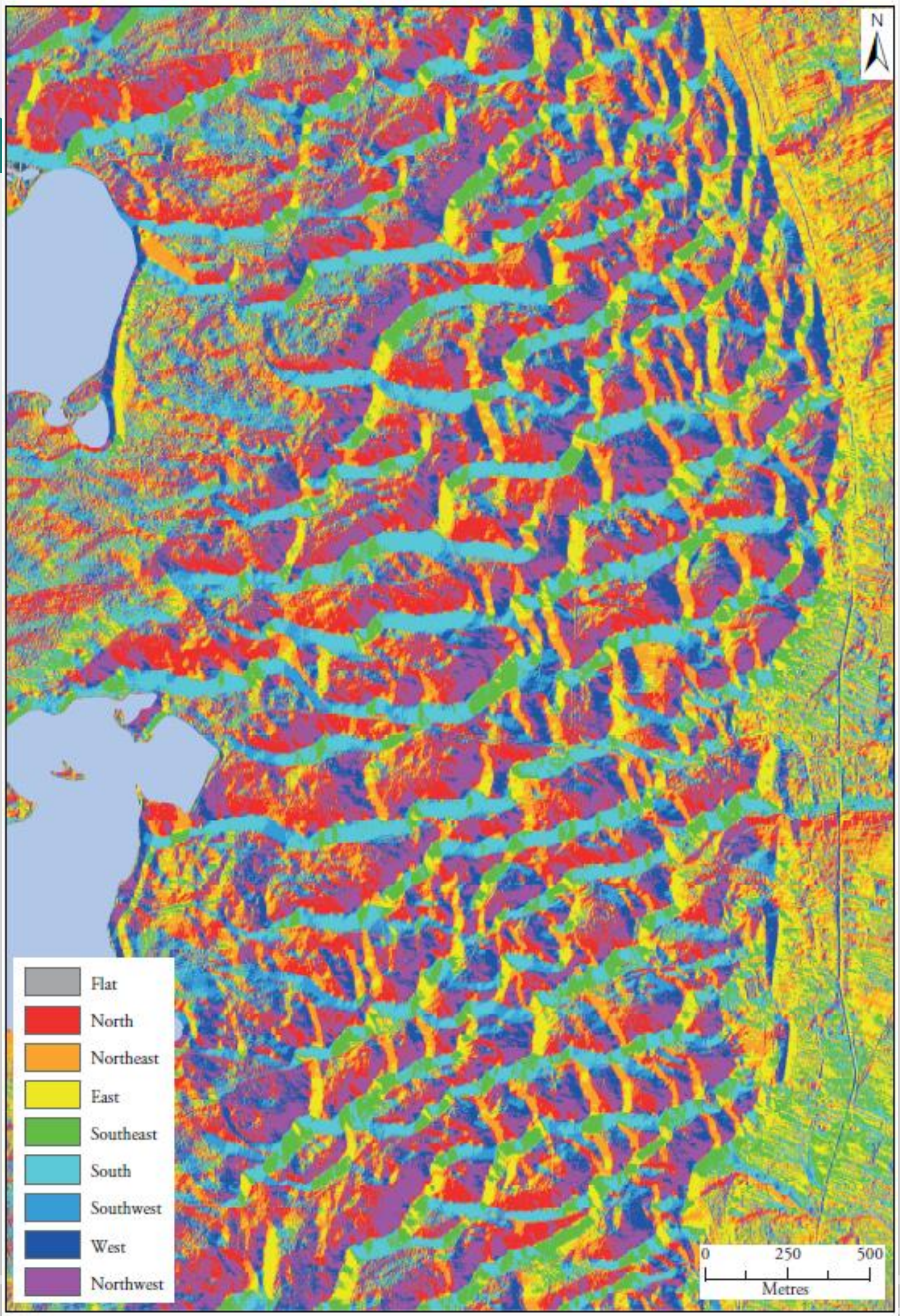

Fig. 9.
Aspect image over a part of the Bonäsheden dune field. The aspect of each cell is colour coded, see legend (© Lantmäteriet).

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Thanks!

Feedback questions