Surface and Field Analysis

Part 1: Surface models and geometry

Sourav Bhadra, Ph. D.

GIS4120/5120 Geospatial Analytics
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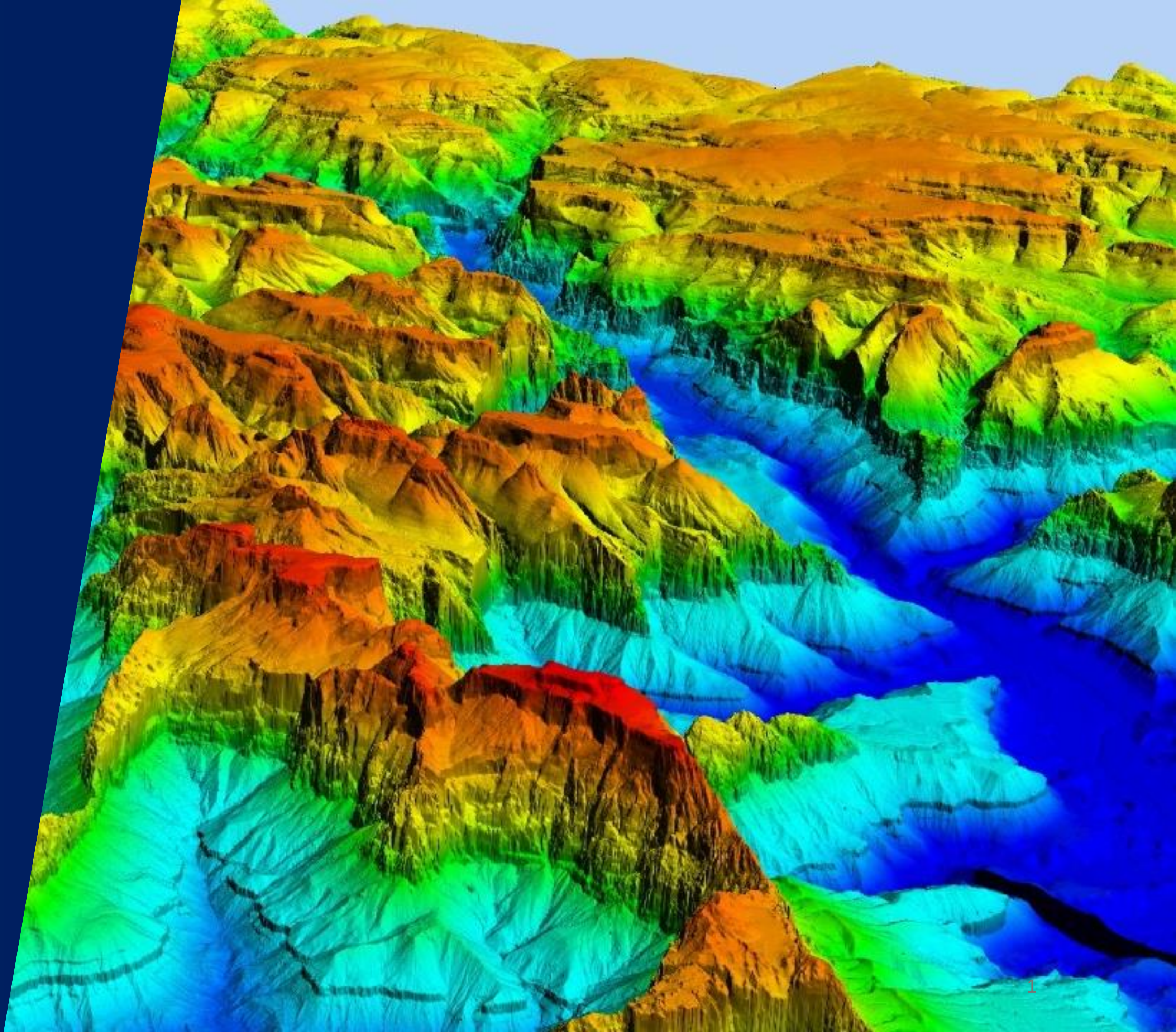
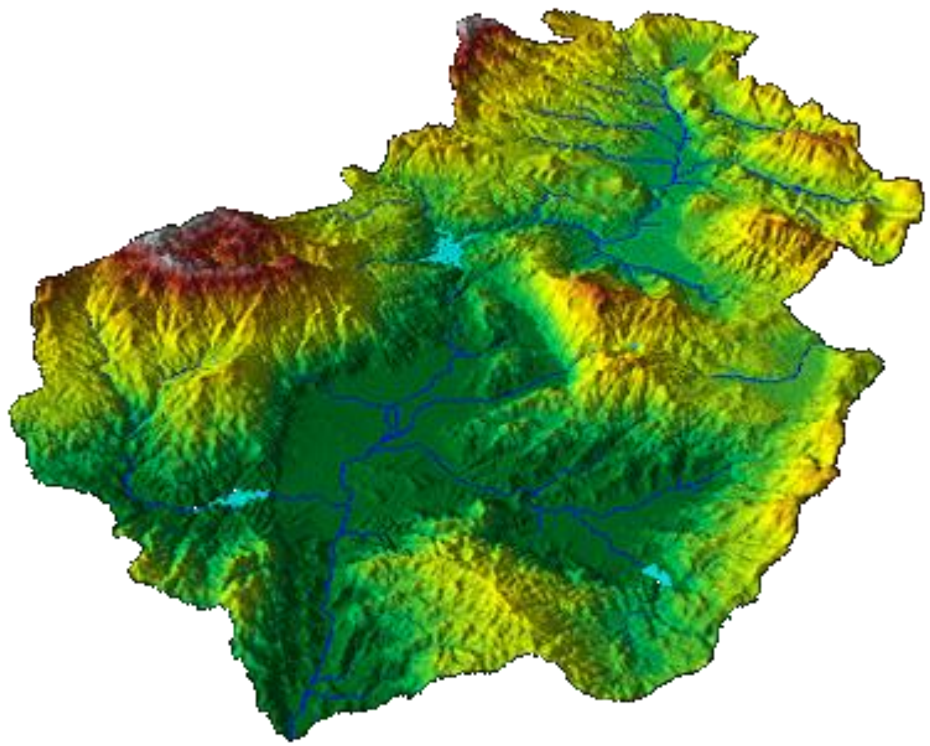


Modeling Surfaces

What is a surface?

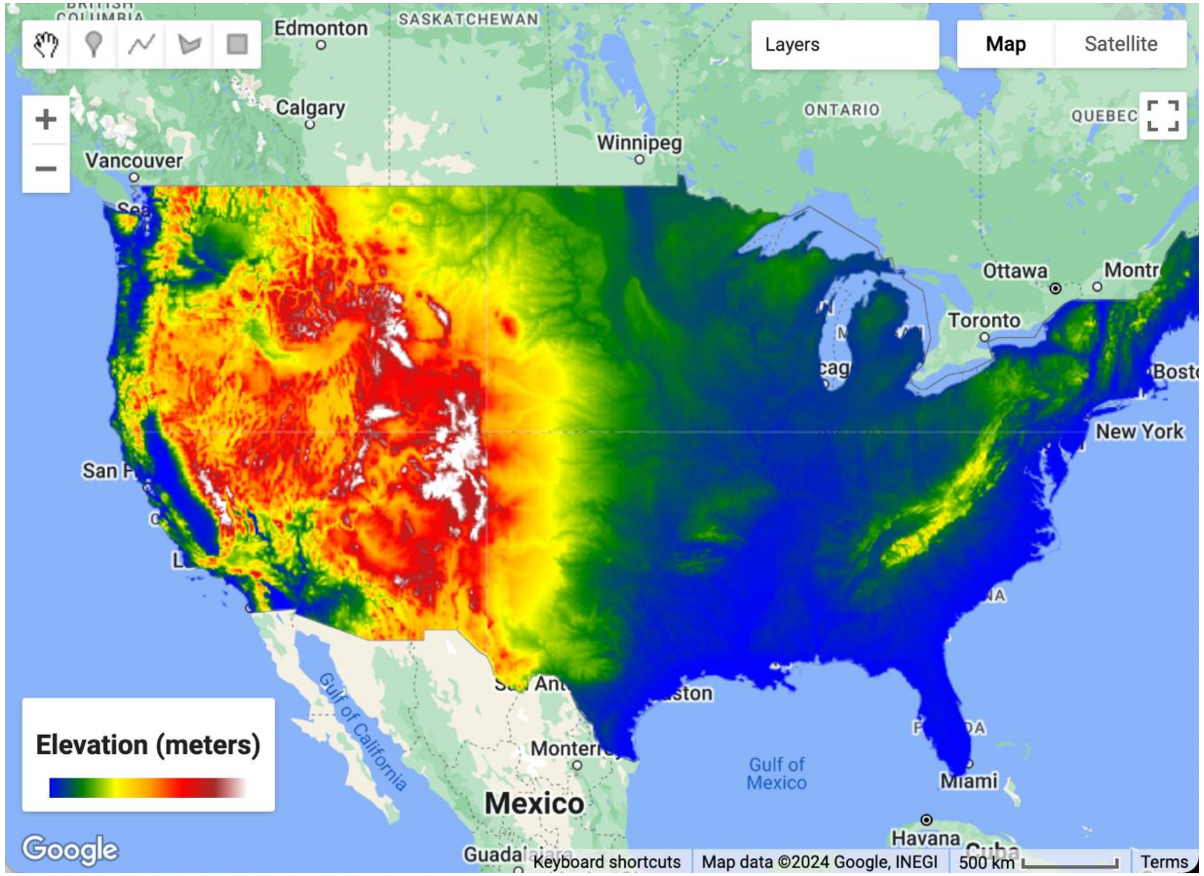
- A **surface** refers to a continuous field of values that represent a geographic phenomenon
- Surfaces typically describe spatial phenomena that vary continuously across space rather than being discrete points or polygons.



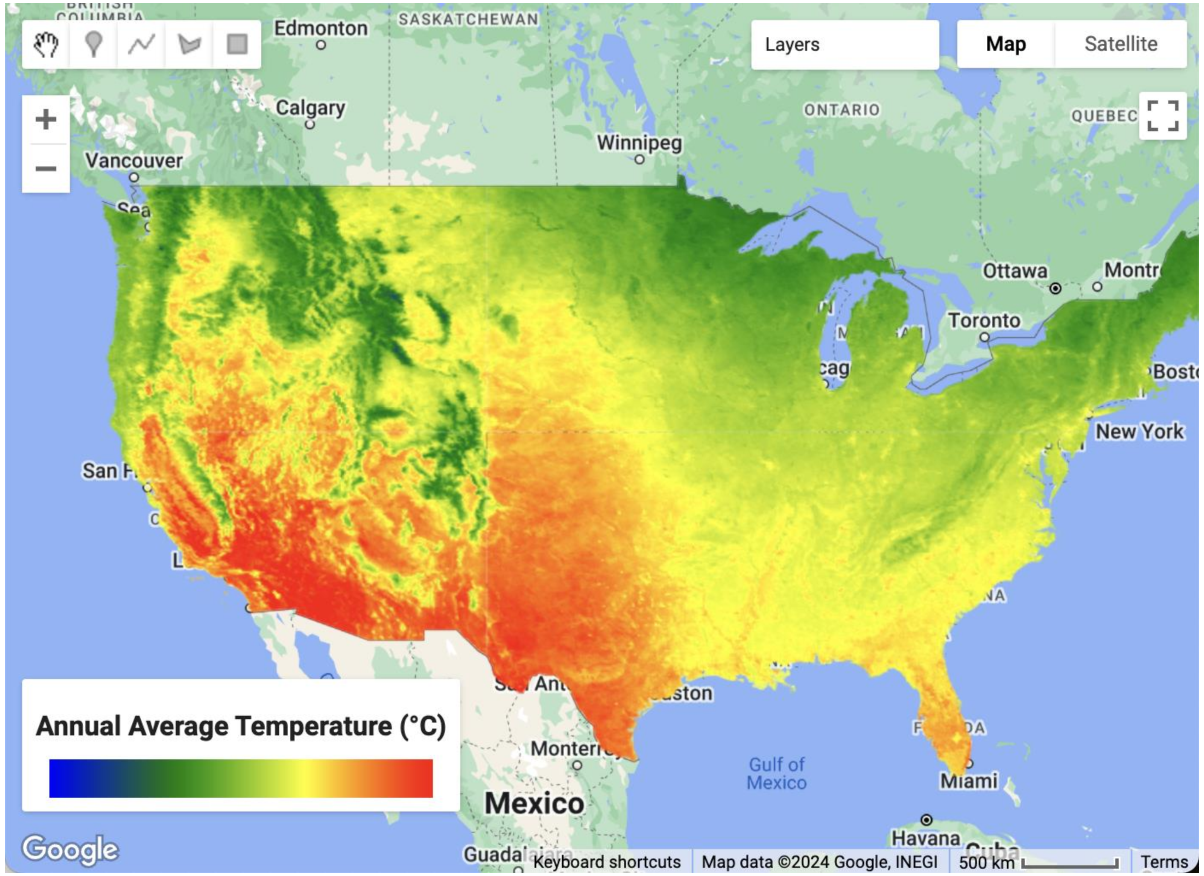
Source

Some examples of surfaces

Digital Elevation Model from SRTM

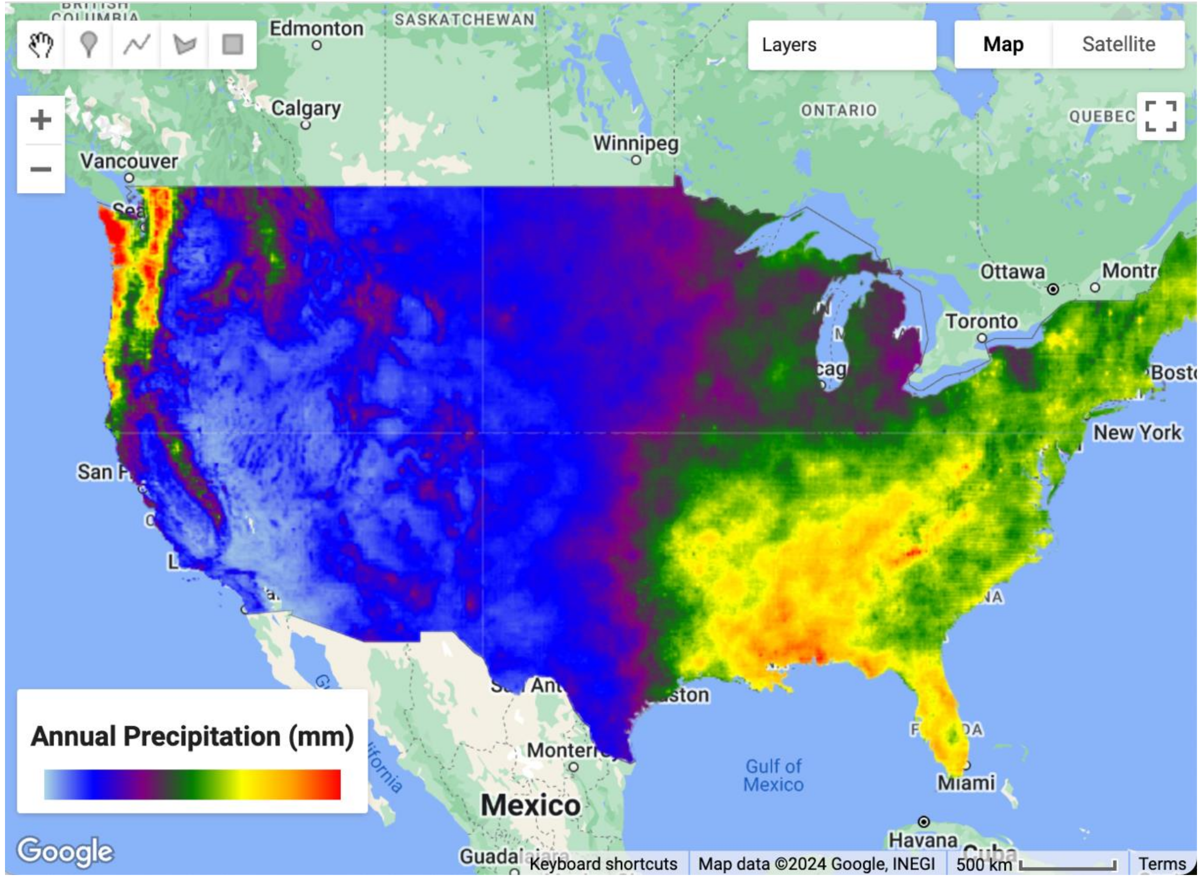


Annual Land Surface temperature from MODIS

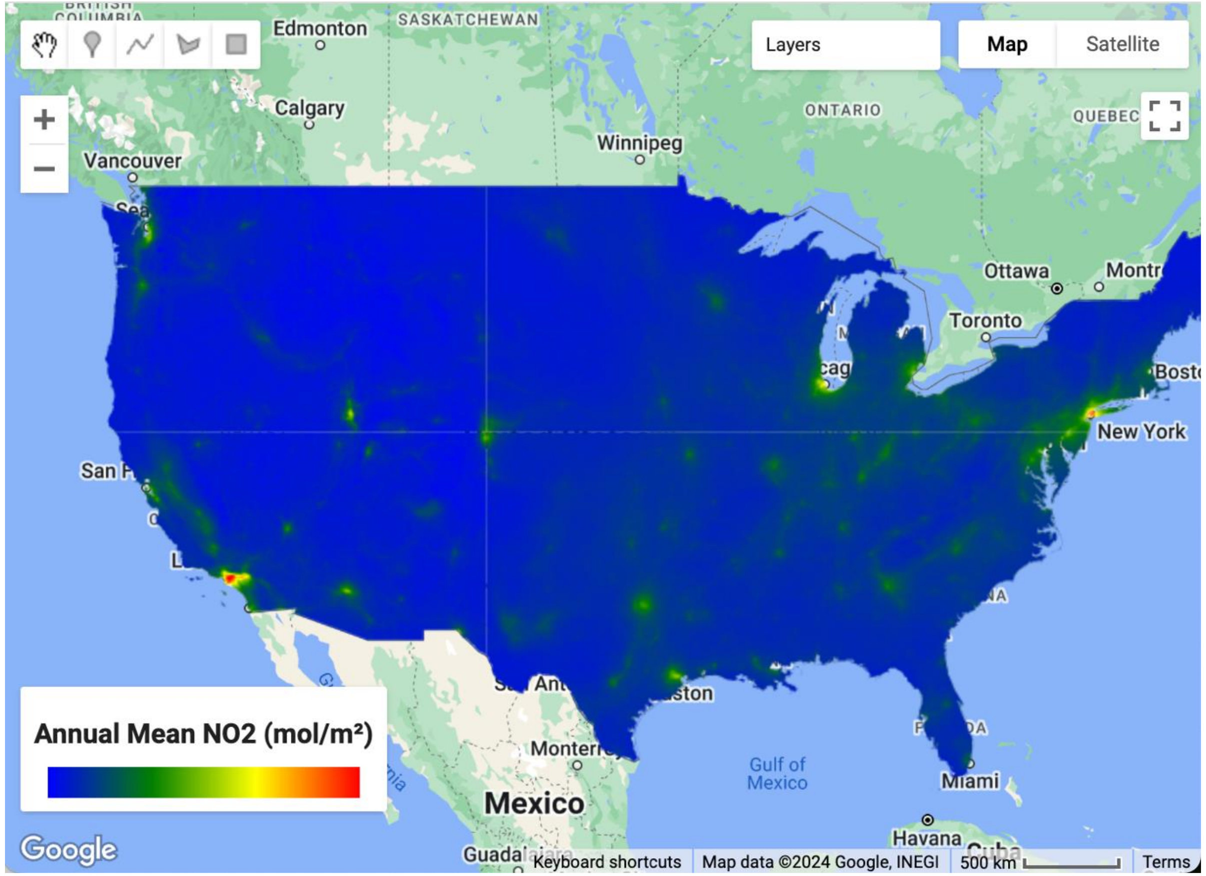


Some examples of surfaces

Annual Precipitation from CHIRPS in 2022

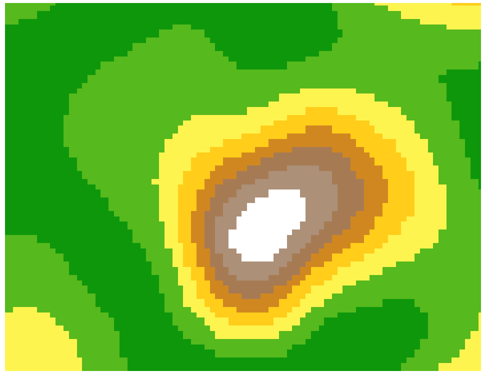


Annual Mean NO2 Pollution in 2022

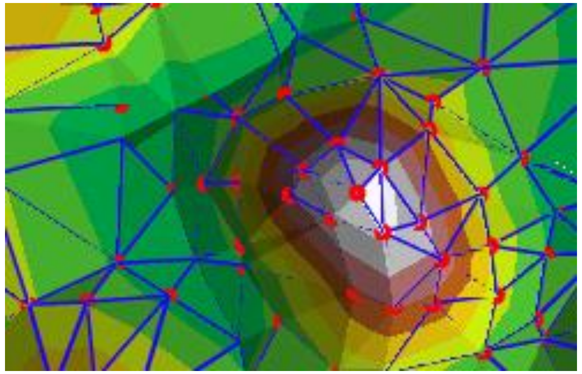


Four types of surface models

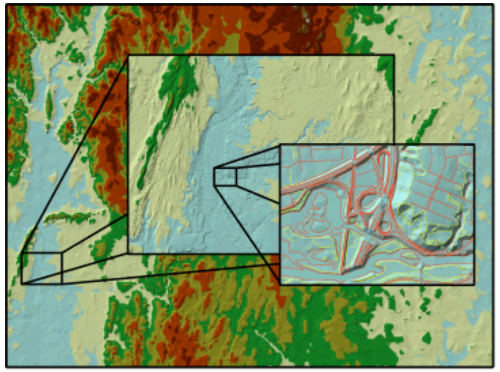
Raster



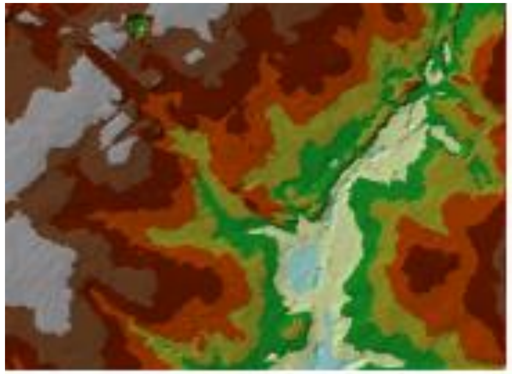
TIN



Terrain

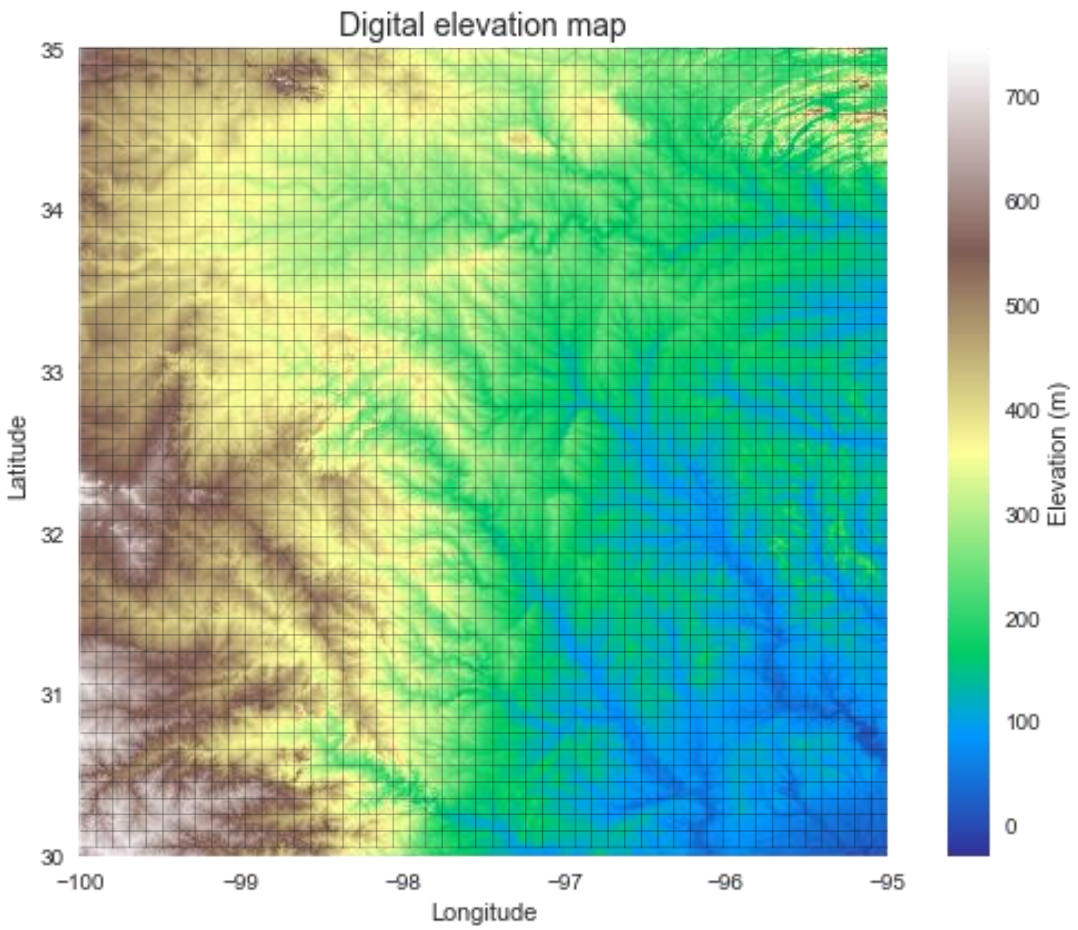


LAS



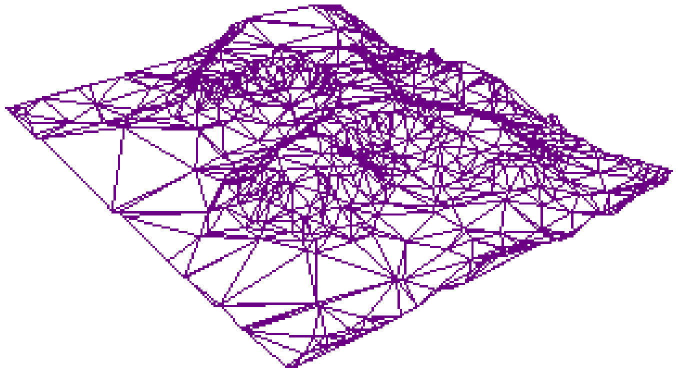
Raster Surface Model

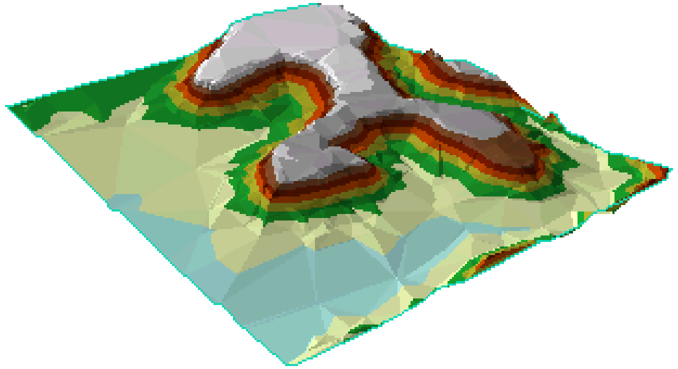
- Assumptions
  - Unform and isotropic grid structure
  - Single value per cell
  - Continuous or gradual variation
  - Spatial precision depends on resolution
  - No overlap between cells
  - Discrete sampling of continuous phenomenon
  - Inherent generalization of spatial autocorrelation



Triangulated Irregular Network (TIN)

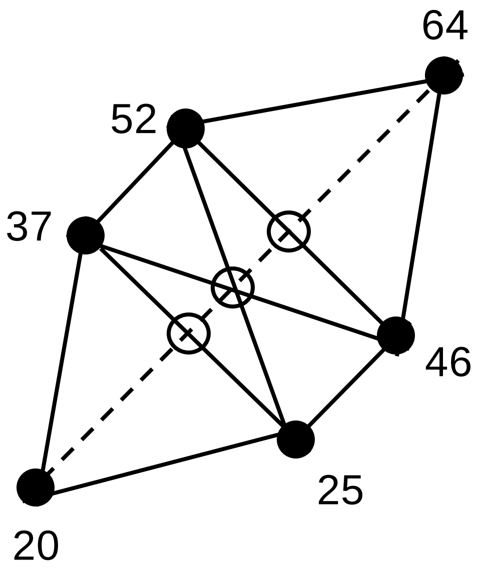
- A Triangulated Irregular Network (TIN) represents space using **a set of non-overlapping triangles** that border one another and vary in size and proportion.
- Assumptions
  - Surface is composed of triangular facets
  - Irregularly spaced data points
  - Surface is continuous, no gap
  - Resolution is adaptive, depends on the availability of points
  - Non-overlapping triangles
  - No abrupt changes between triangles
  - Triangles as flat planes





Source

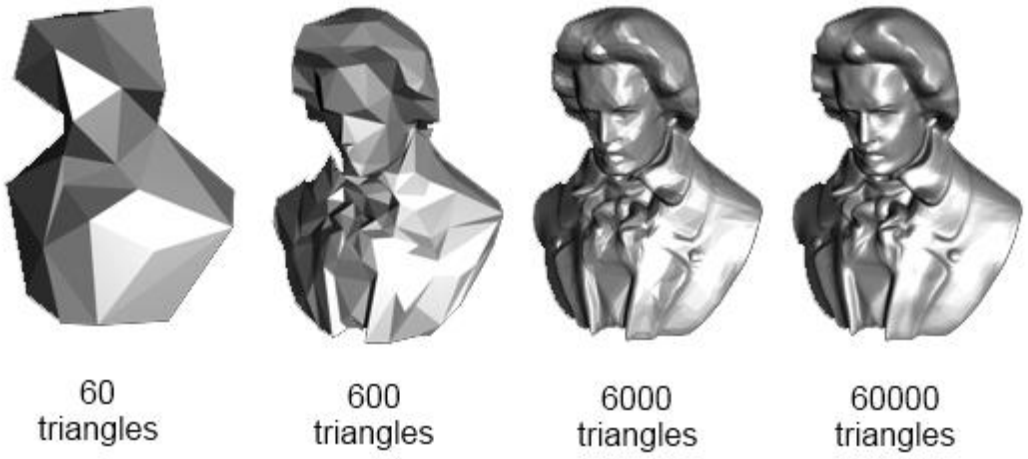
How TINs are formed?



- Nodes: Fundamental building blocks, points from (x, y, z) coordinates.
- Edges: Nodes are connected to there nearest neighbors by edges, according to a set of rules.
- Triangles: Triangles are constructed based on the input of mass points and breaklines, which provide information and constraints about the surface.
- Breaklines: A linear break in the surface can be defined, By connecting points on a valley floor or along the edge of a cliff

TINs can be also found in gaming and VFX industry

Triangles are also used as ”mesh” in the 3D gaming, animation and VFX technology as it is easier to work with rendering.



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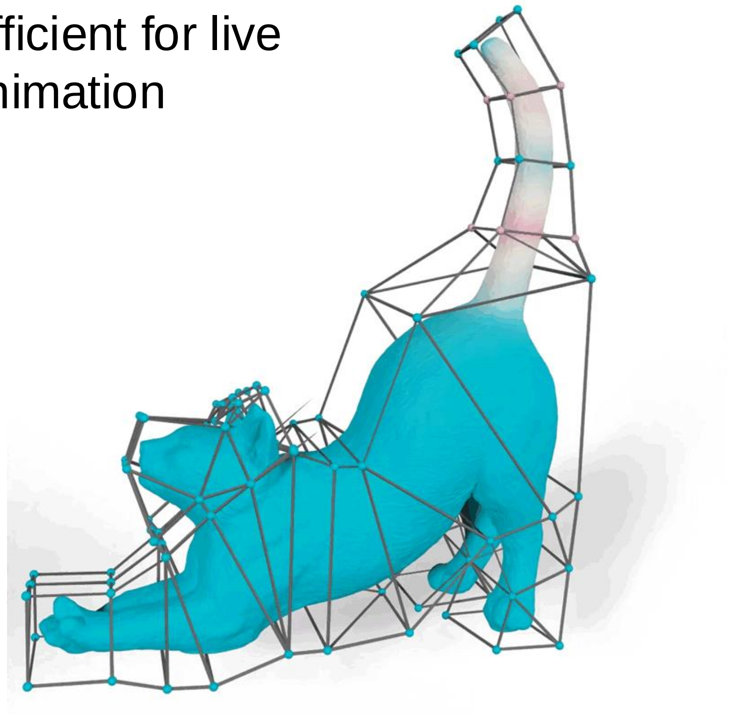
Efficient for live animation



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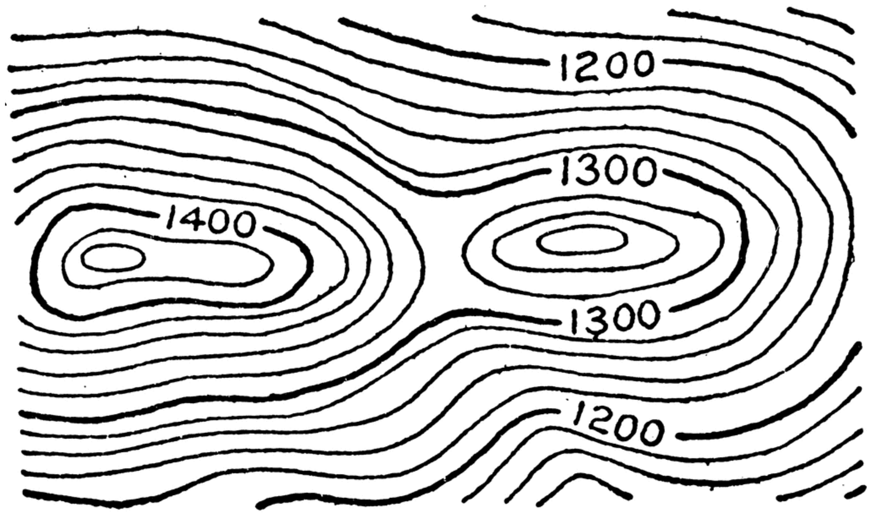
Contours, another visualization of surface

- Contours are lines on a map that represent points of equal elevation or altitude.
- A two-dimensional way of illustrating the three-dimensional characteristics of a terrain.
- Are typically drawn at regular intervals of elevation.
- When contour lines are close together, they represent a steep slope or rapid elevation change.



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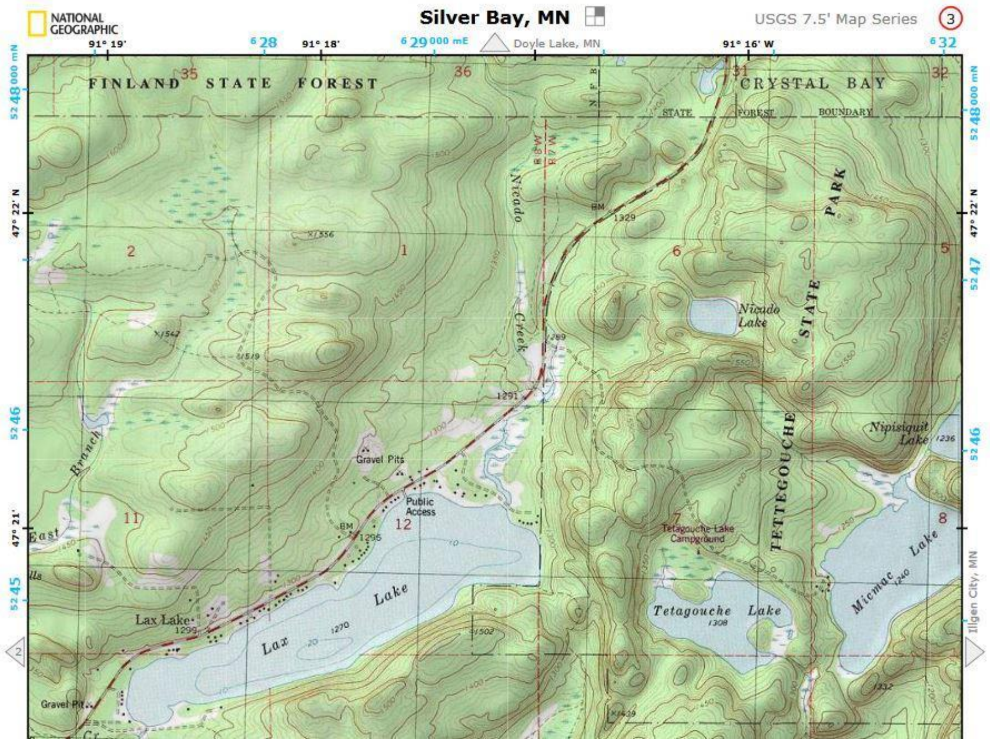
Contours are only limited to visualization purposes, specially when visualized with other features in a topographic map. Not a good data model to use in an analysis.



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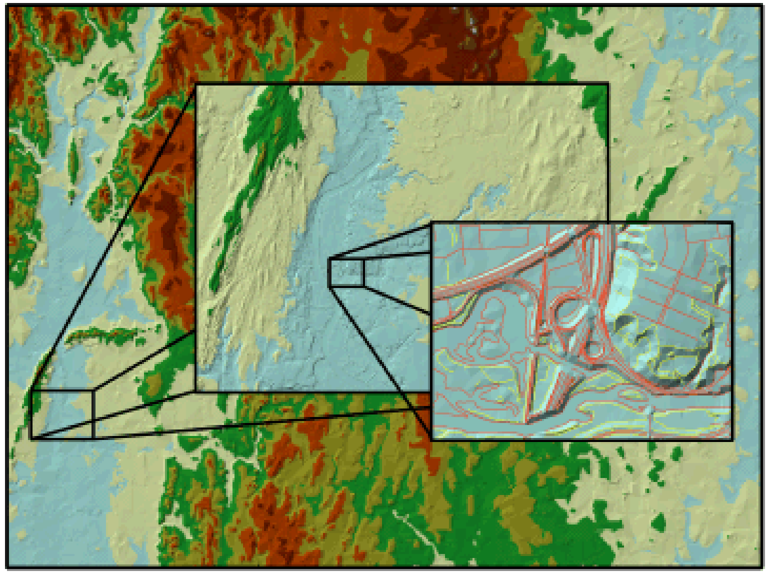
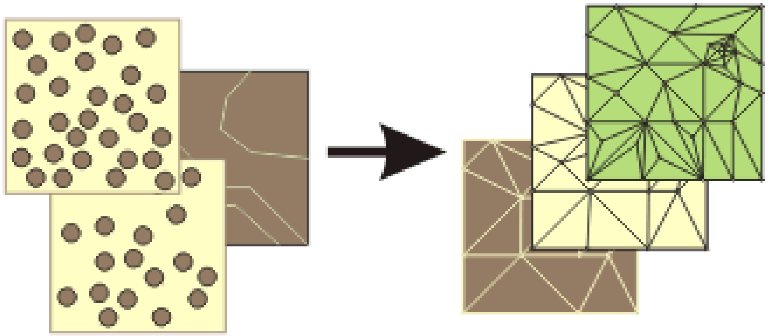
Terrain Dataset

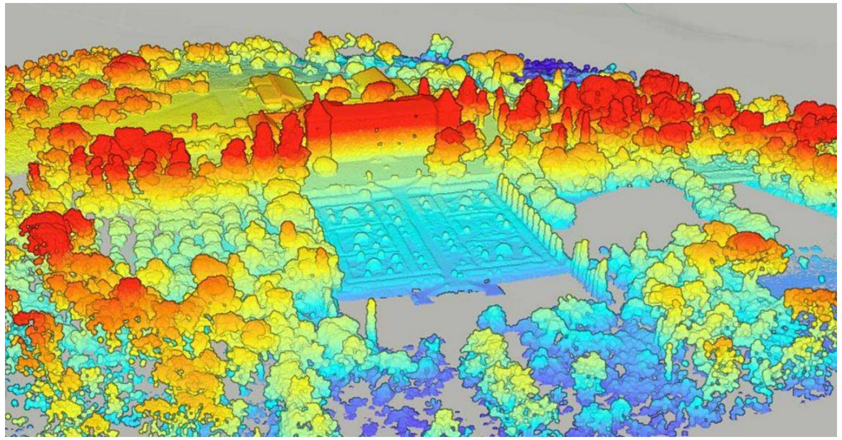




- Terrain datasets are designed to manage and model large-scale, point-based data.
- Proprietary ArcGIS Geodatabase feature.
- Terrain datasets use a series of rules and conditions to index source data into TIN pyramids, allowing surfaces to be generated at varying resolutions on the fly.
- As users zoom in, the terrain dynamically adjusts to display higher-resolution surfaces using more points, without sacrificing performance.
- Various feature classes, including lidar, sonar, and elevation points, can participate in the creation of terrain datasets.

LAS datasets are native to LiDAR point cloud

- LiDAR is an active remote sensing technology that results in very high-resolution point cloud with accurate x, y, and z information about the surface.
- The output of LiDAR is called LAS dataset



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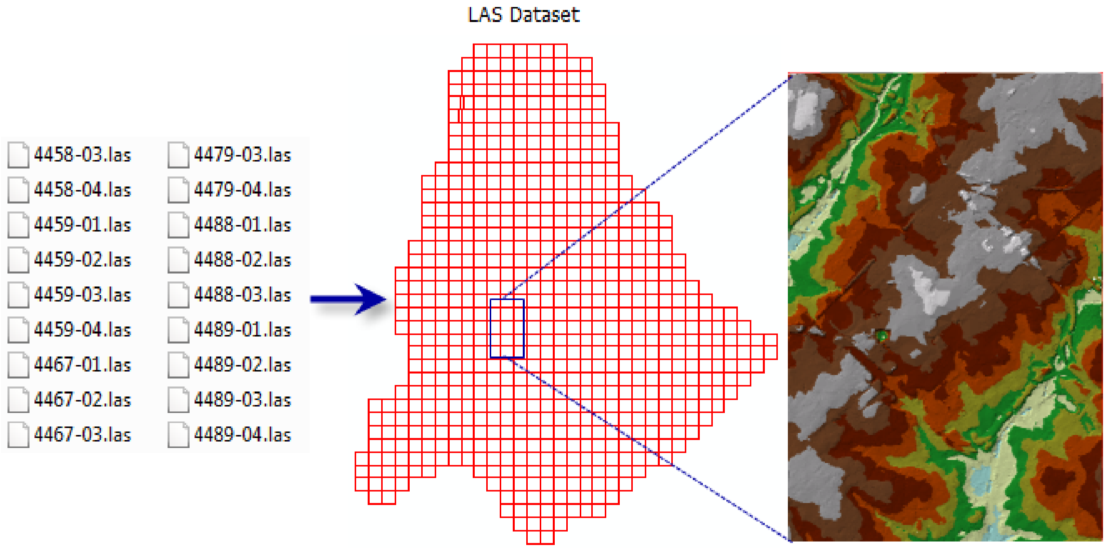
- LAS dataset stores references to one or more LAS files, which are binary formats for airborne lidar data.
- LAS datasets can also reference surface constraints such as breaklines, water polygons, or boundaries
- Provide detailed statistics and area coverage for lidar point cloud data

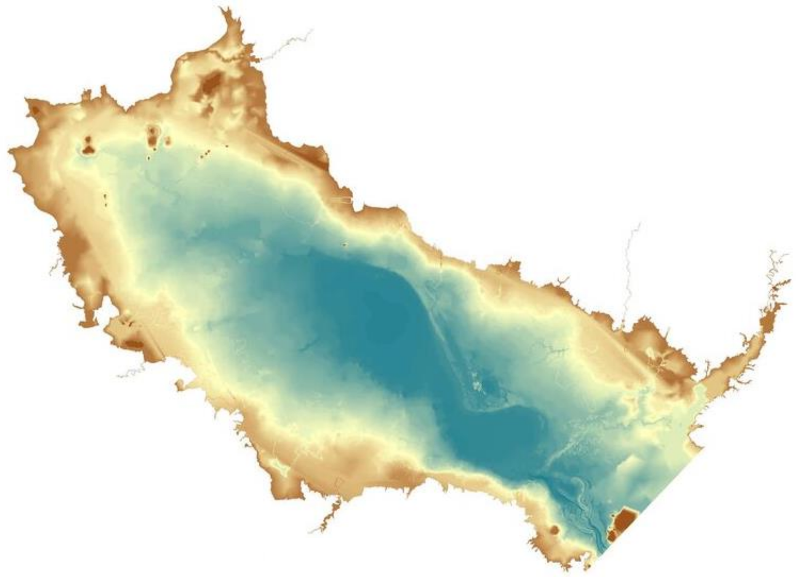


Source

Surface Geometry

Geospatial analytics often deals with grid or raster-based surface when calculating geometry attributes

- Surface geometries refer to the shape, structure, and characteristics of a physical surface in a geographic area.
- Grid-based data is useful for efficiently storing, processing, and analyzing continuous spatial phenomena.



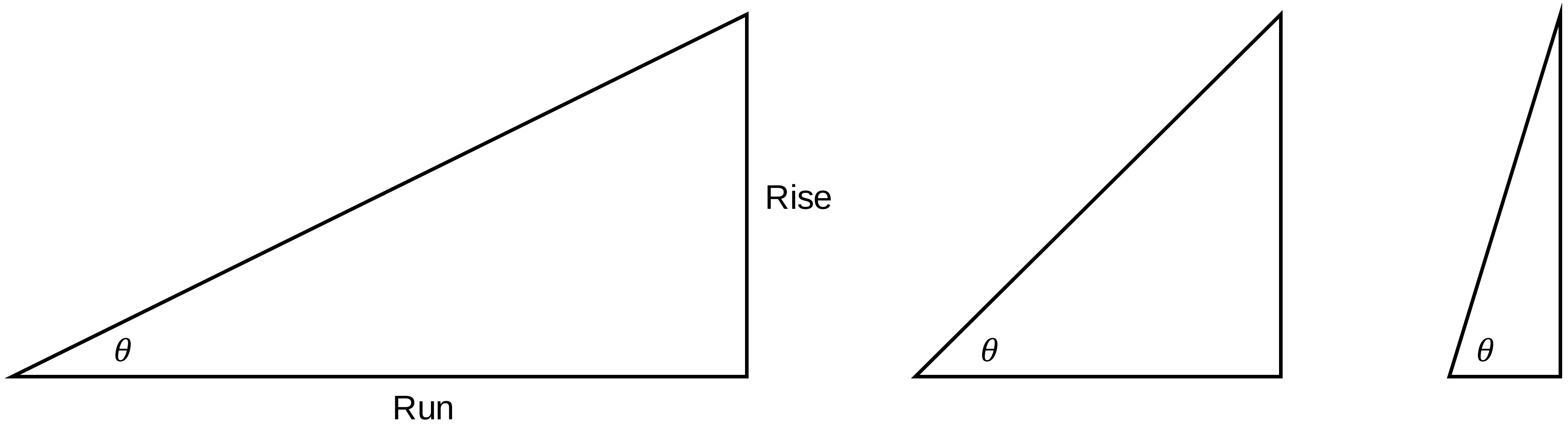
- Slope, Aspect and Curvature are the most common surface geometry attributes.
- Numerous applications use these surface geometry attributes aggregated within zones, such as
  - Understanding terrain
  - Hydrological modeling
  - Urban planning (assess buildable plans, cost)
  - Landslide risks
  - Agriculture

Source

Slope measures the terrain steepness

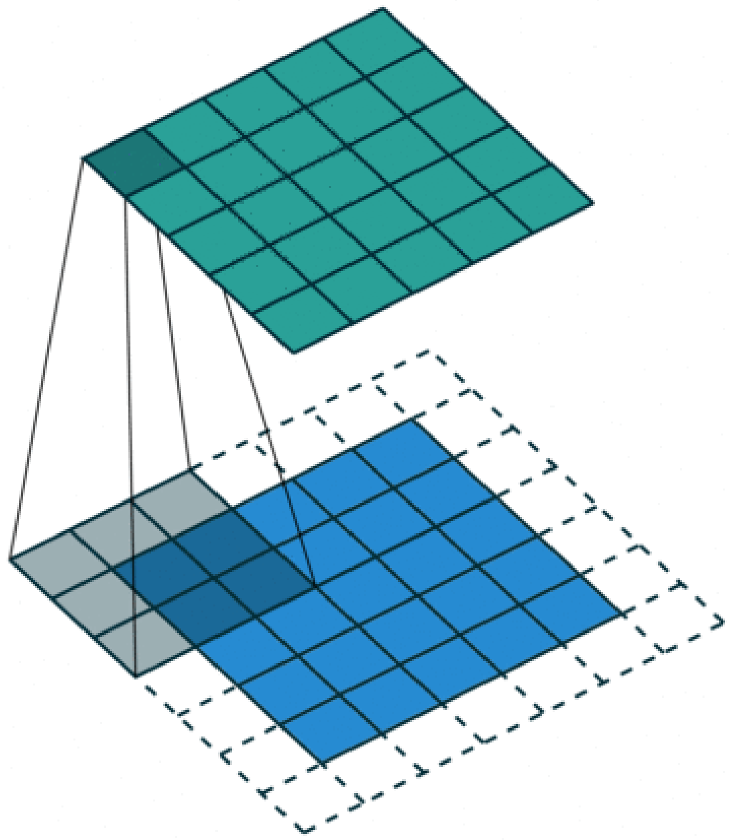
$$\theta = arctan(\frac{Rise}{Run})$$

$$Percent = \frac{Rise}{Run} * 100$$



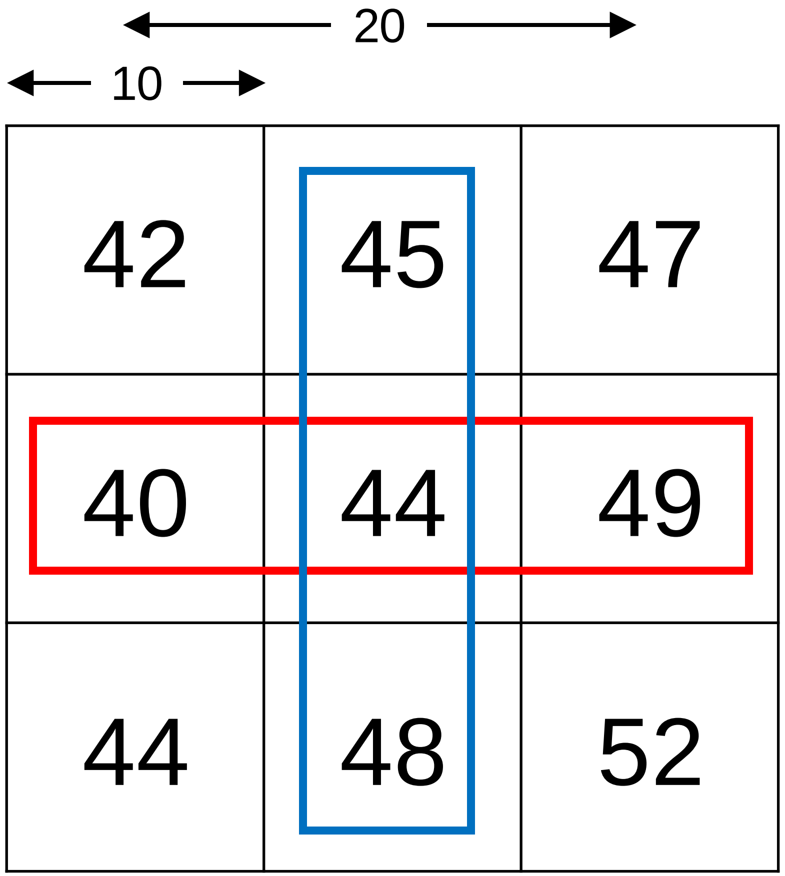
30°	45°	76°
58%	100%	373%

Calculating slope in terms of a raster surface



- The slope is calculated using a moving window, which can be 3*3 or even more.
- Two methods: Planar and Geodesic
- Two ways to calculate in Planar:
  - 4 nearest approach
  - 3rd order finite approach

Slope calculation using 4 nearest approach



$$dZ/dy = (45 - 48)/20 = -9.15$$

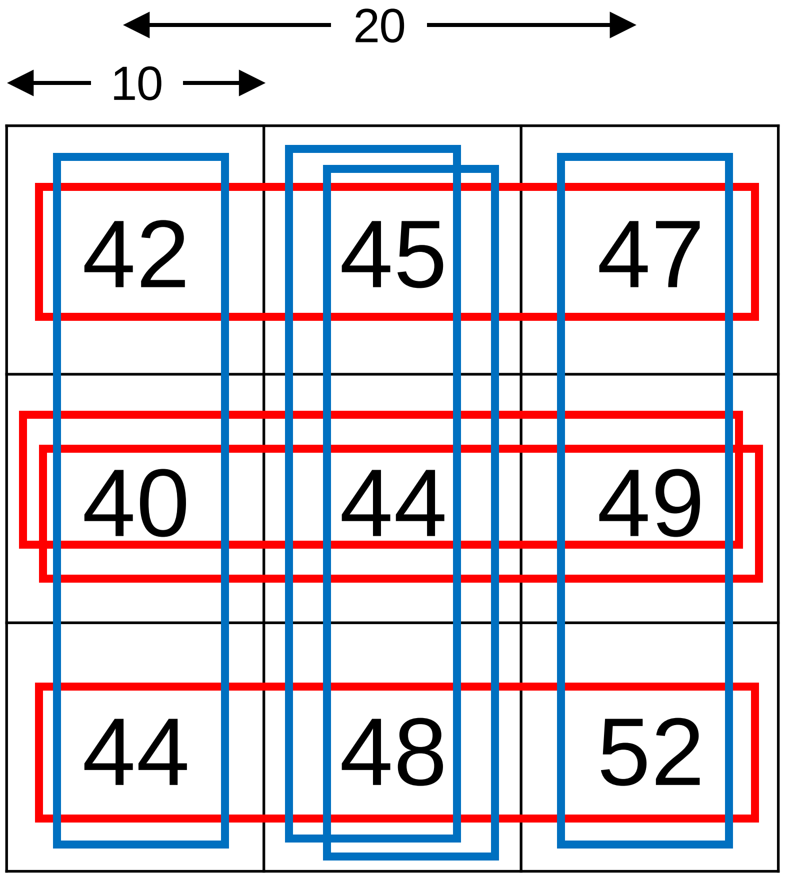
$$dZ/dx = (49 - 40)/20 = 0.45$$

$$Slope \ = \sqrt{\left(\frac{dZ}{dx}\right)^2 + \left(\frac{dZ}{dy}\right)^2}$$

$$= \sqrt{(0.45)^2 + (-0.15)^2}$$

$$= 0.474$$

Slope calculation using 3rd order finite approach



$$dZ/dx = \frac{(47-42) + 2*(49-40) + (52-44)}{4*20} = 0.39$$

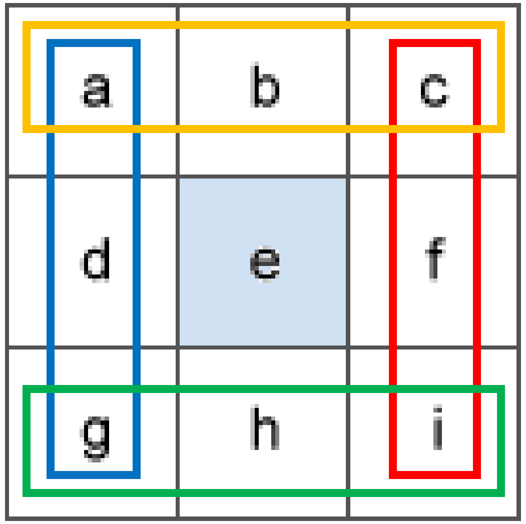
$$dZ/dy = \frac{(47-52) + 2*(45-48) + (42-44)}{4*20} = -0.16$$

$$Slope \; = \sqrt{\left(\frac{dZ}{dx}\right)^2 + \left(\frac{dZ}{dy}\right)^2}$$

$$= \sqrt{(0.39)^2 + (-0.16)^2}$$

$$= 0.422$$

Because of NoData, Slope is calculated slight differently in ArcGIS



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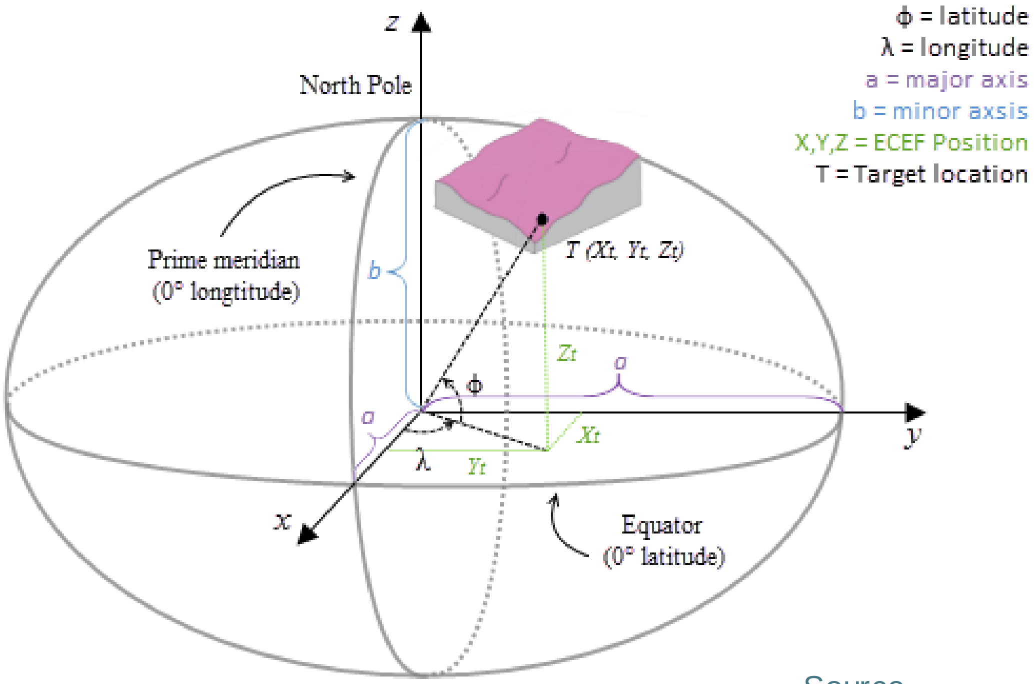
$$dZ/dx = \frac{\frac{c + 2f + i}{4 * w_1} - \frac{a + 2d + g}{4 * w_2}}{8 * x_{size}}$$

$$dZ/dy = \frac{\frac{g + 2h + i}{4 * w_3} - \frac{a + 2b + c}{4 * w_4}}{8 * y_{size}}$$

- *c*, *f*, and *i* all have valid values, $w_1 = (1 + 2 * 1 + 1) = 4$
- *i* is NoData, $w_1 = (1 + 2 * 1 + 0) = 3.$
- *f* is NoData, $w_1 = (1 + 2 * 0 + 1) = 2$

Slope calculation in geodesic plane

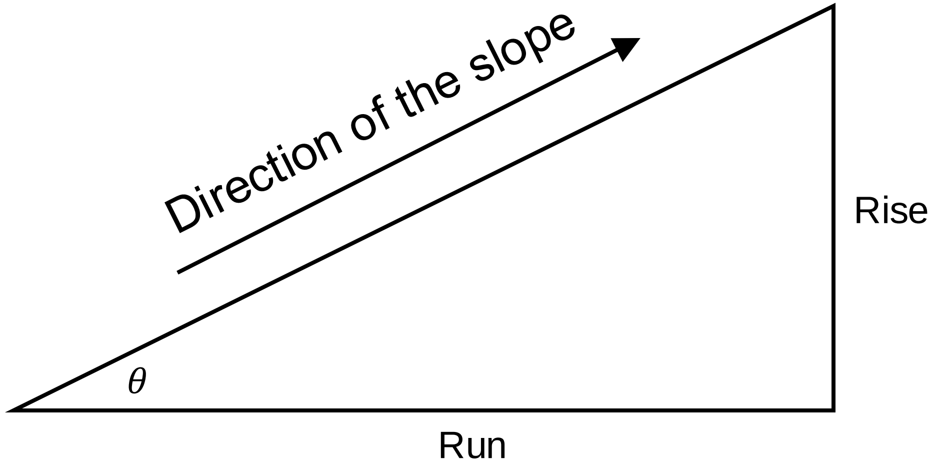
Earth centered, Earth faced (ECEF) coordinate system

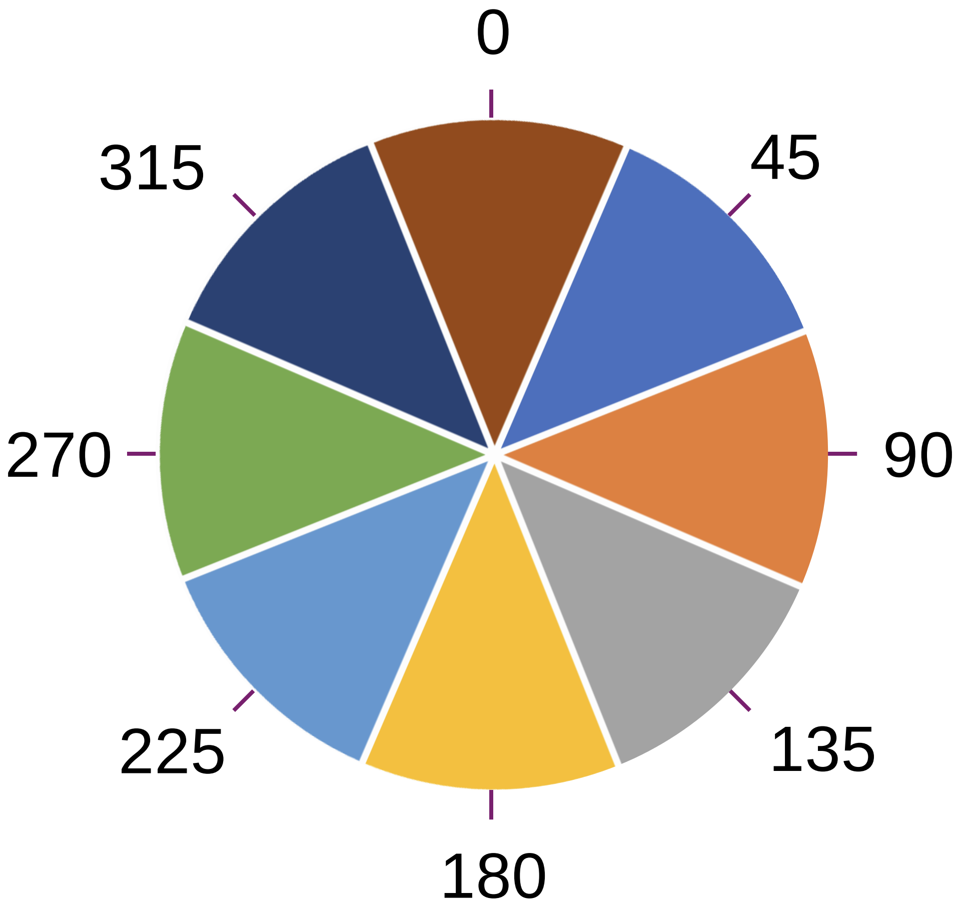


Source

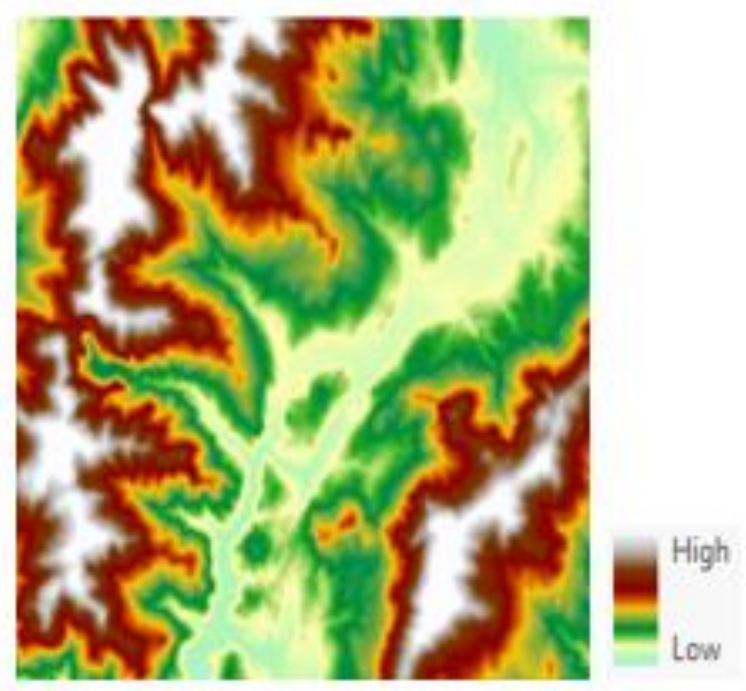
- **More accurate**: Accounts for the Earth's curvature, making it suitable for large-area studies or areas near the poles.
- **Correct for global scale**: Provides precise slope calculations across regions of varying latitudes, where planar projections would introduce errors.
- **Handles terrain more precisely**: Especially useful when calculating slopes over large terrains where slight elevation changes might otherwise be misrepresented.
- **More computationally expensive**: Requires more processing power and time compared to the simpler planar method, as it involves transformations to geodetic coordinates.

Aspect tells us which direction is the slope

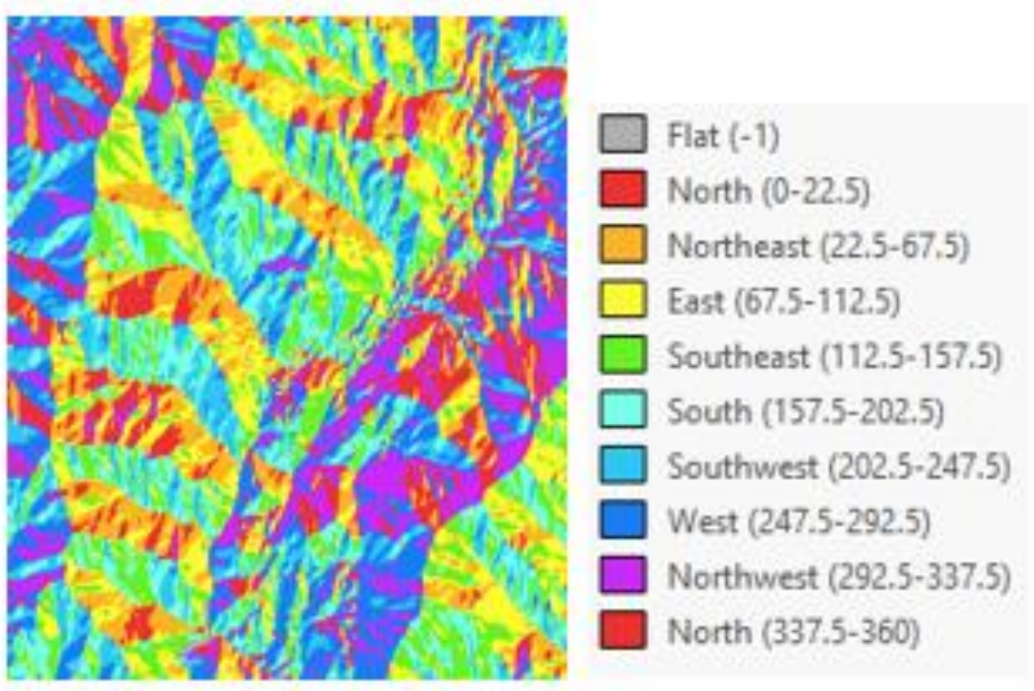




Aspect tells us which direction is the slope

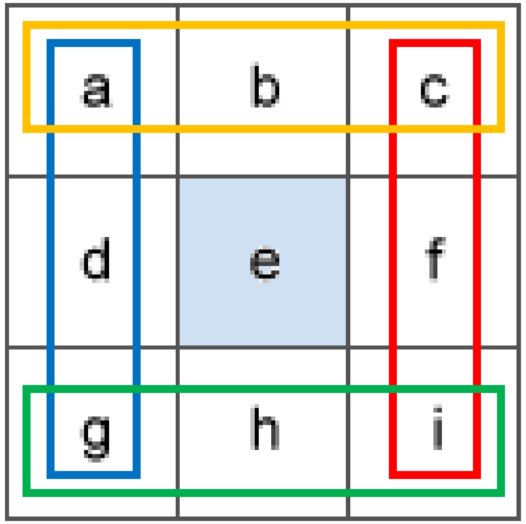


Input elevation raster



Output aspect raster

Aspect calculation is very similar to slope



Source

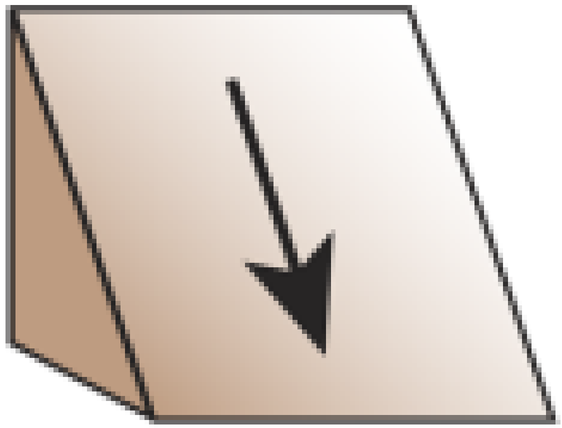
$$dZ/dx = \frac{\frac{c + 2f + i}{4 * w_1} - \frac{a + 2d + g}{4 * w_2}}{8 * x_{size}} \qquad dZ/dy = \frac{\frac{g + 2h + i}{4 * w_3} - \frac{a + 2b + c}{4 * w_4}}{8 * y_{size}}$$

$$Aspect = arctan2(dZ/dy, -dZ/dx)$$

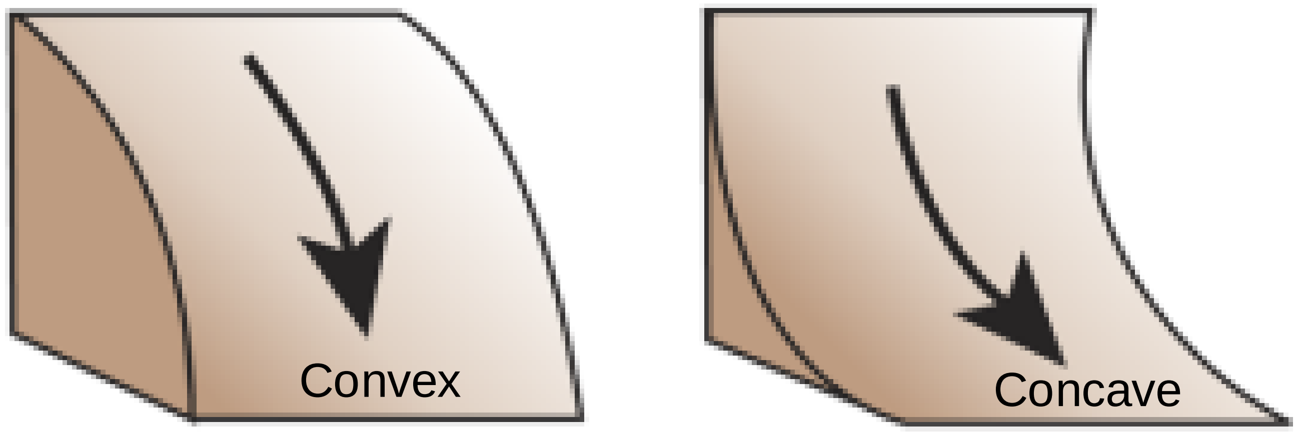
```
if aspect < 0:
    cell = 90.0 – aspect
else if aspect > 90.0:
    cell = 360.0 - aspect + 90.0
else:
    cell = 90.0 - aspect
```

What is curvature?

In this example, we know that there is a downward slope, and we can also calculate the magnitude of the slope.



The downward direction can sometimes follow a curved path instead of a straight line distance. The curve can be concave or convex or a combination of both. Curvature measures the curved directional change in pixel values.



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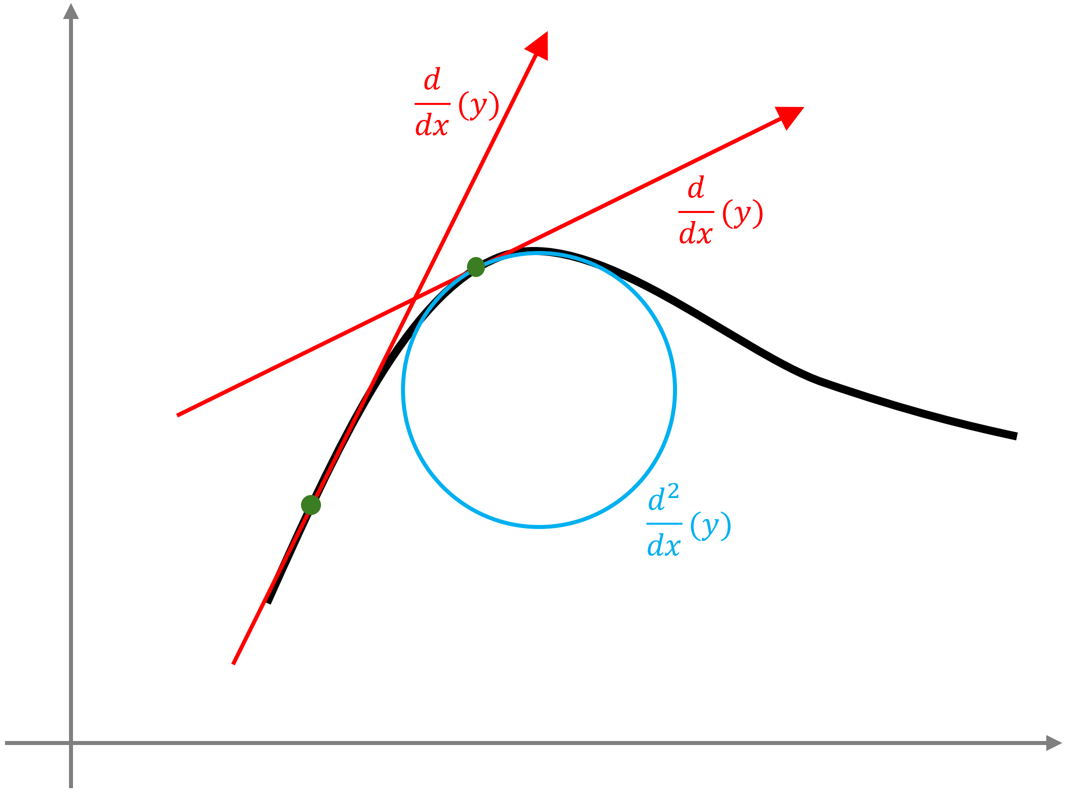
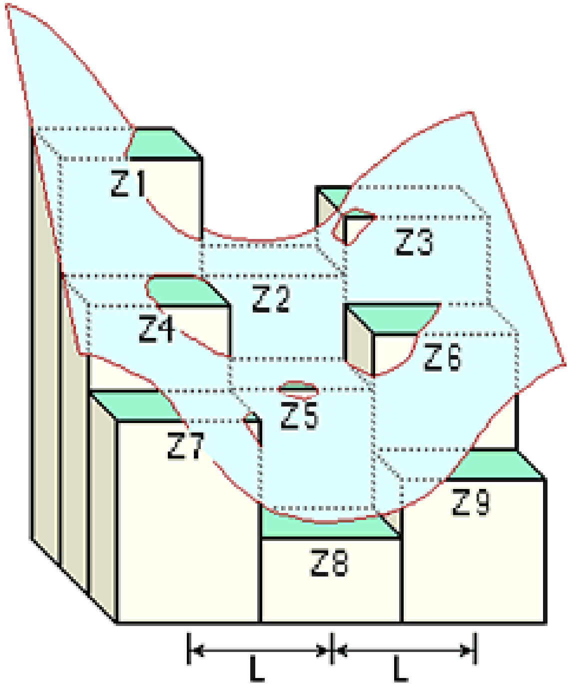
What is curvature?



Fitting a plane instead of a straight line



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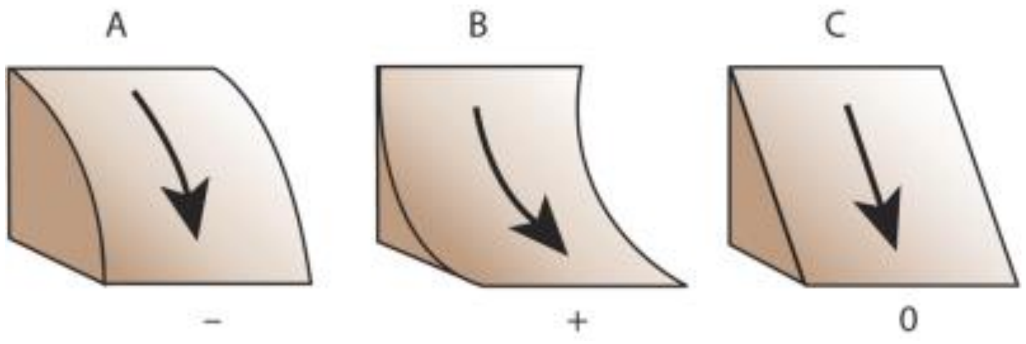
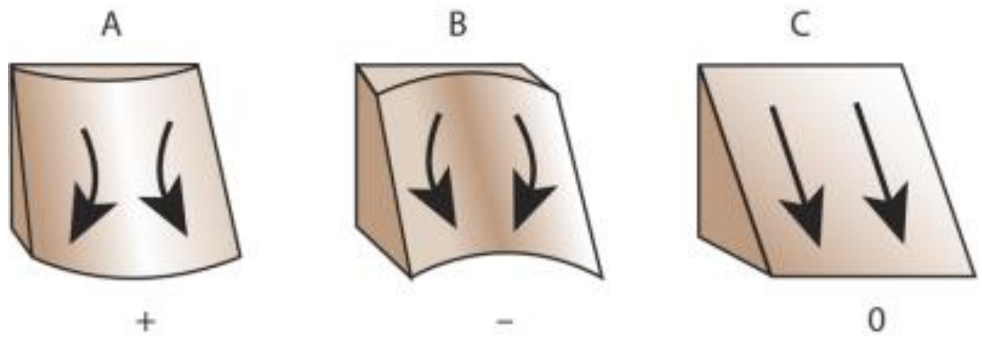
Interpreting the outputs of curvature

Profile Curvature



- Profile curvature is parallel to the direction of the maximum slope.
- (-)ve means upwardly convex.
- (+)ve means upwardly concave.
- 0 means linear.

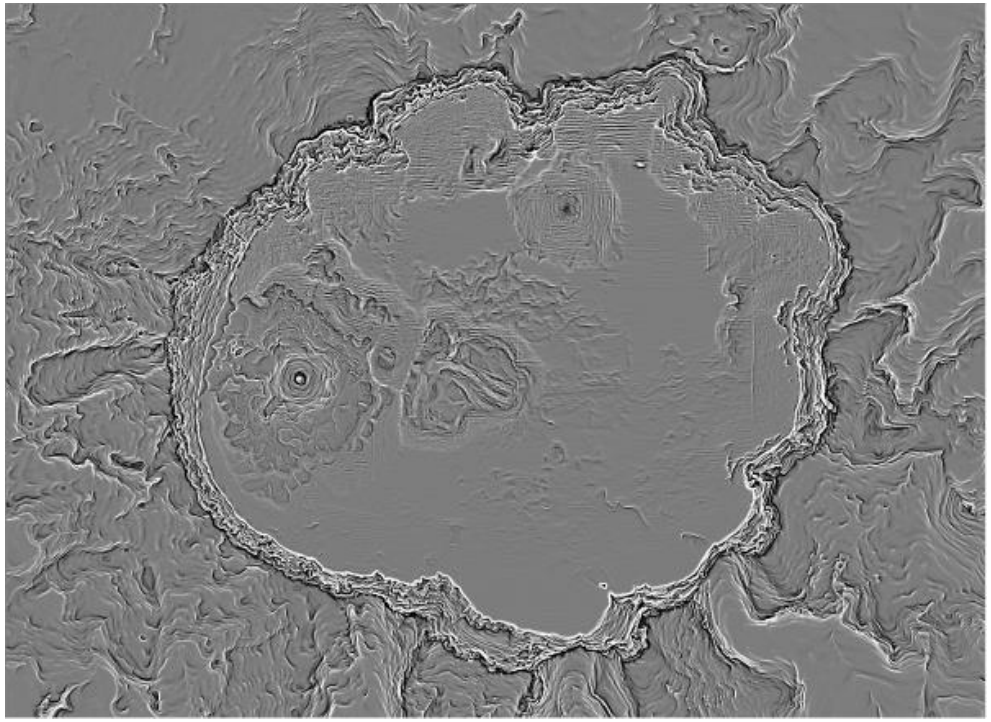
Plan Curvature



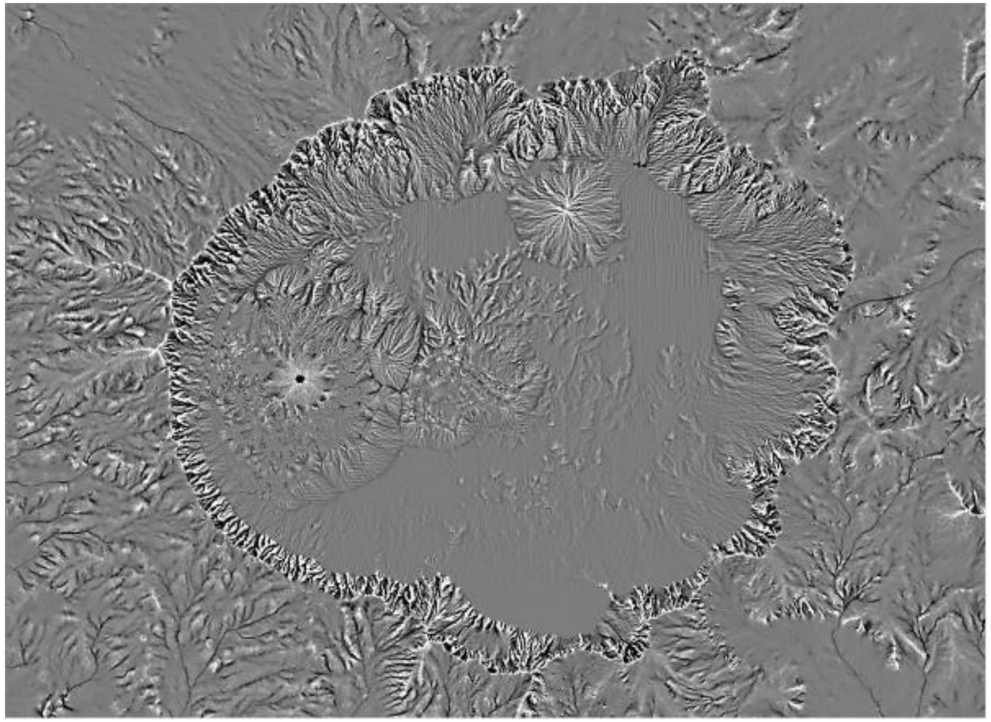
- Profile curvature is perpendicular to the direction of the maximum slope.
- (-)ve means sidewardly concave.
- (+)ve means sidewardly convex.
- 0 means linear.

Interpreting the outputs of curvature

Profile Curvature

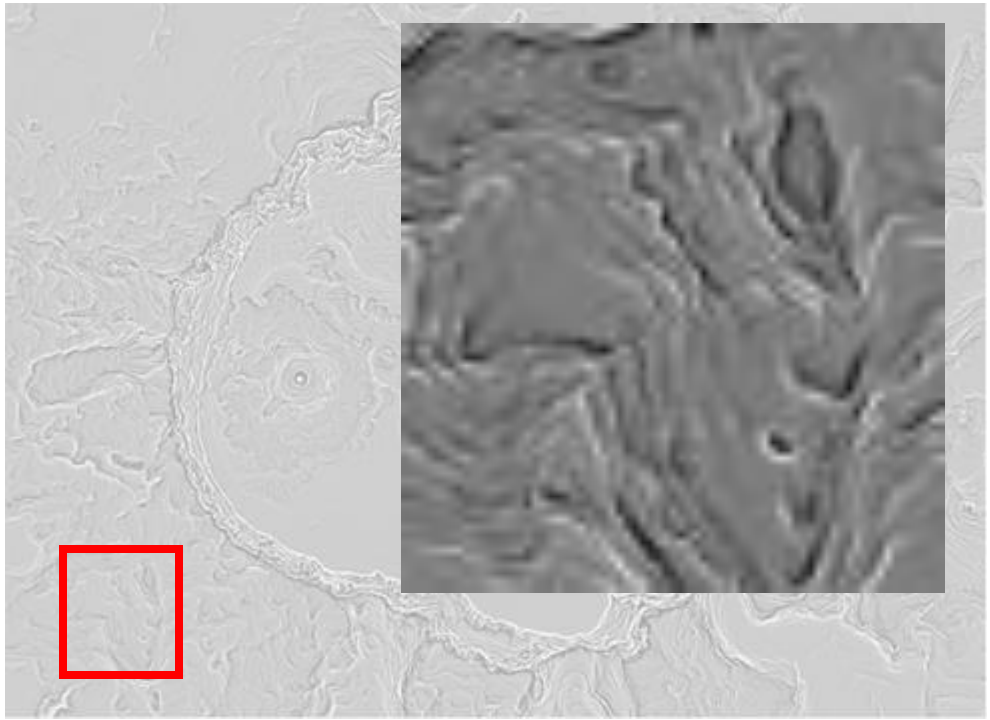


Plan Curvature



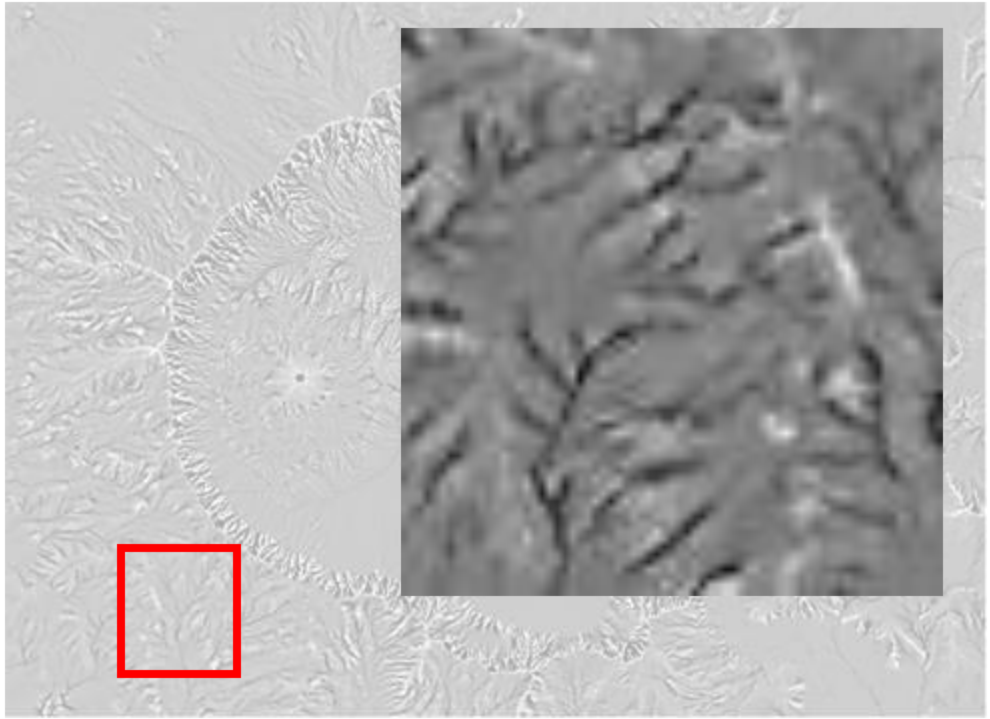
Interpreting the outputs of curvature

Profile Curvature



Emphasizes any terracing in the surface

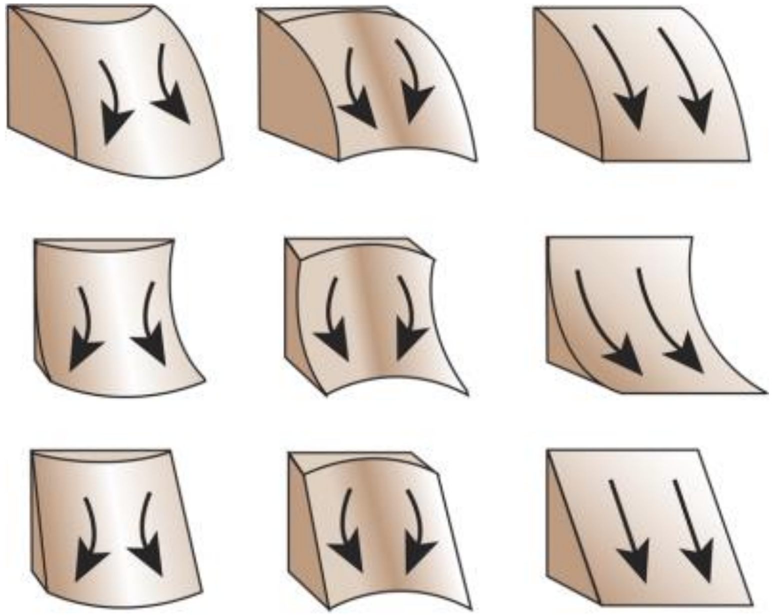
Plan Curvature



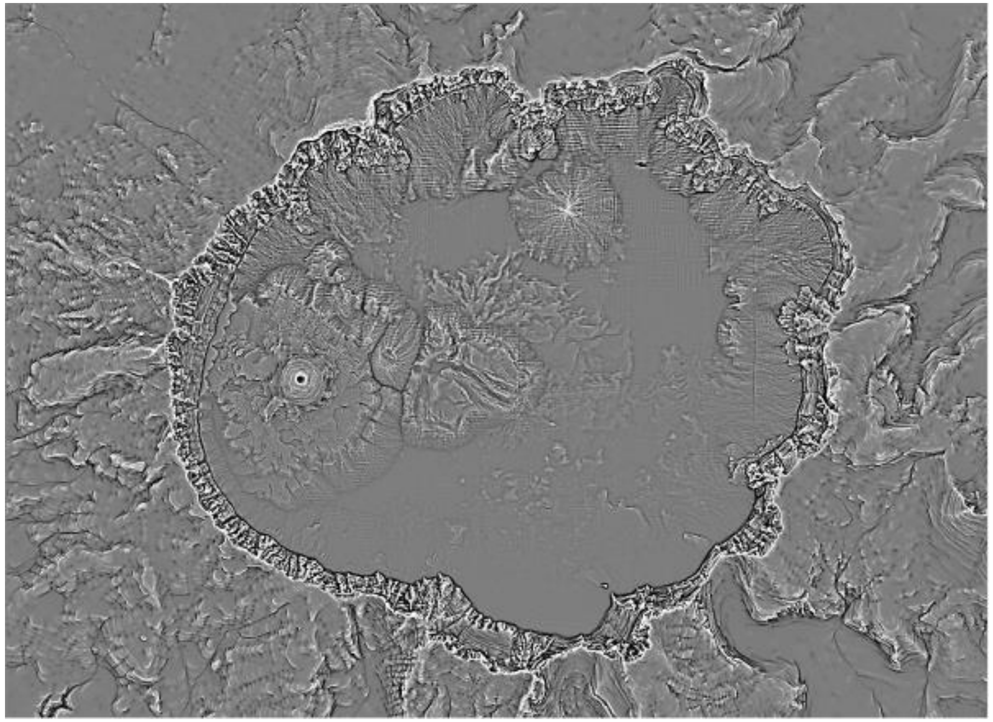
Emphasizes ridges and valleys in the surface

Interpreting the outputs of curvature

Combining both profile and plan curvature



Both the ridges and valleys and the terraces in the surface is visible



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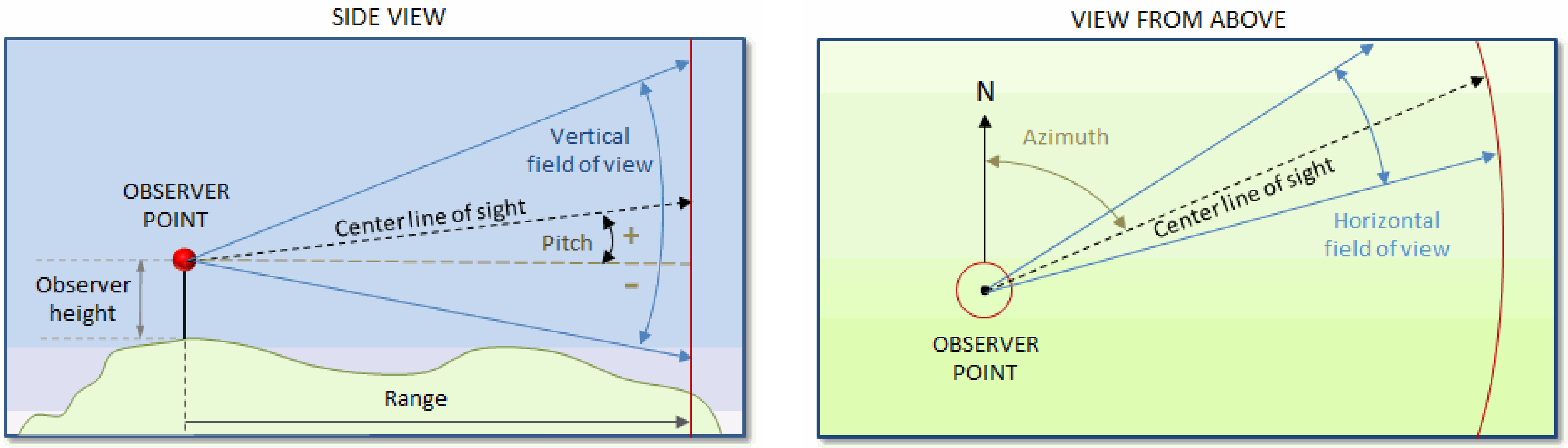
Interpreting the outputs of curvature

- The slope affects the overall rate of movement downslope. Aspect defines the direction of flow.
- The profile curvature affects the acceleration and deceleration of flow and, therefore, influences erosion and deposition.
- The plan curvature influences convergence and divergence of flow.
- Considering both plan and profile curvature together allows us to understand more accurately the flow across a surface.

Viewshed or Visibility analysis

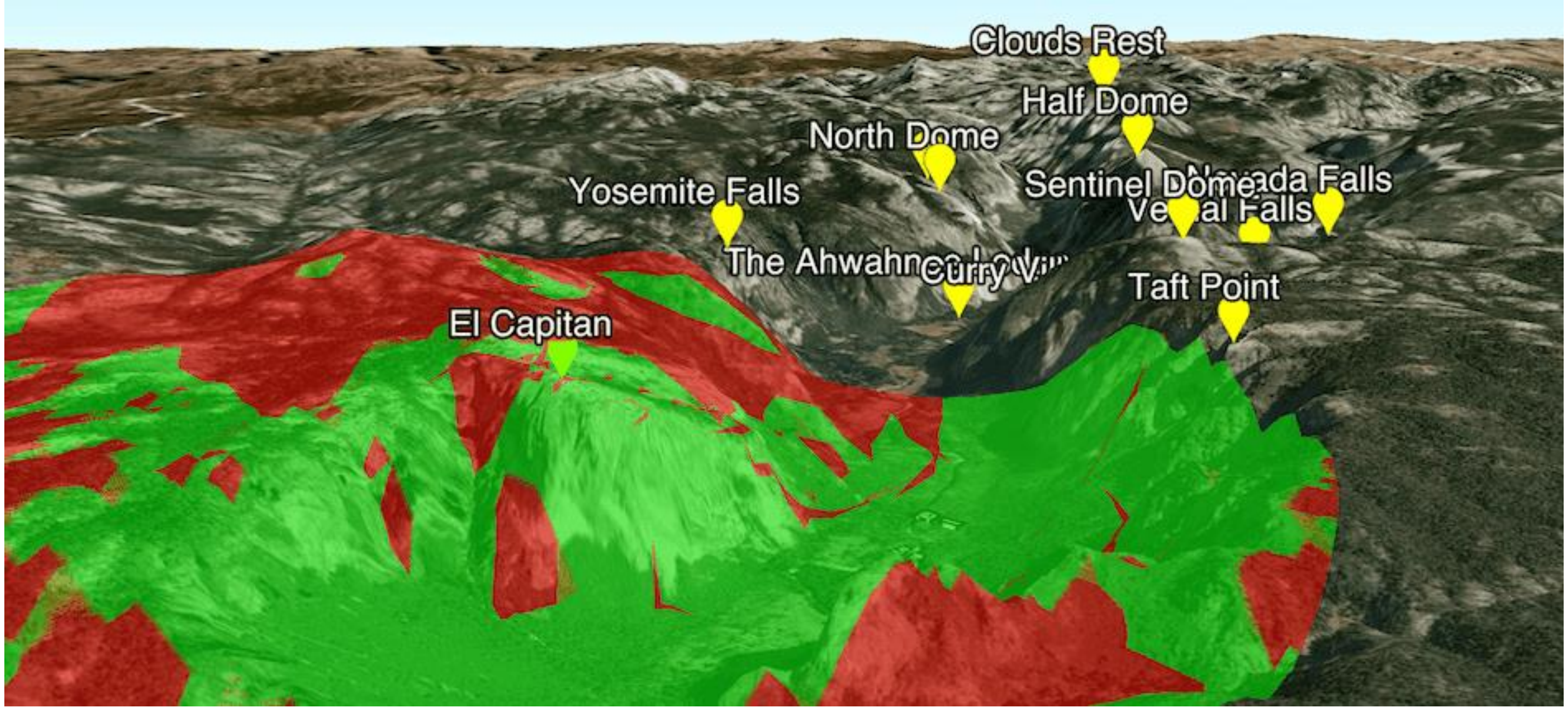
Viewshed analysis is the process of identifying locations that are visible from one or more observer points.



Source

Viewshed or Visibility analysis

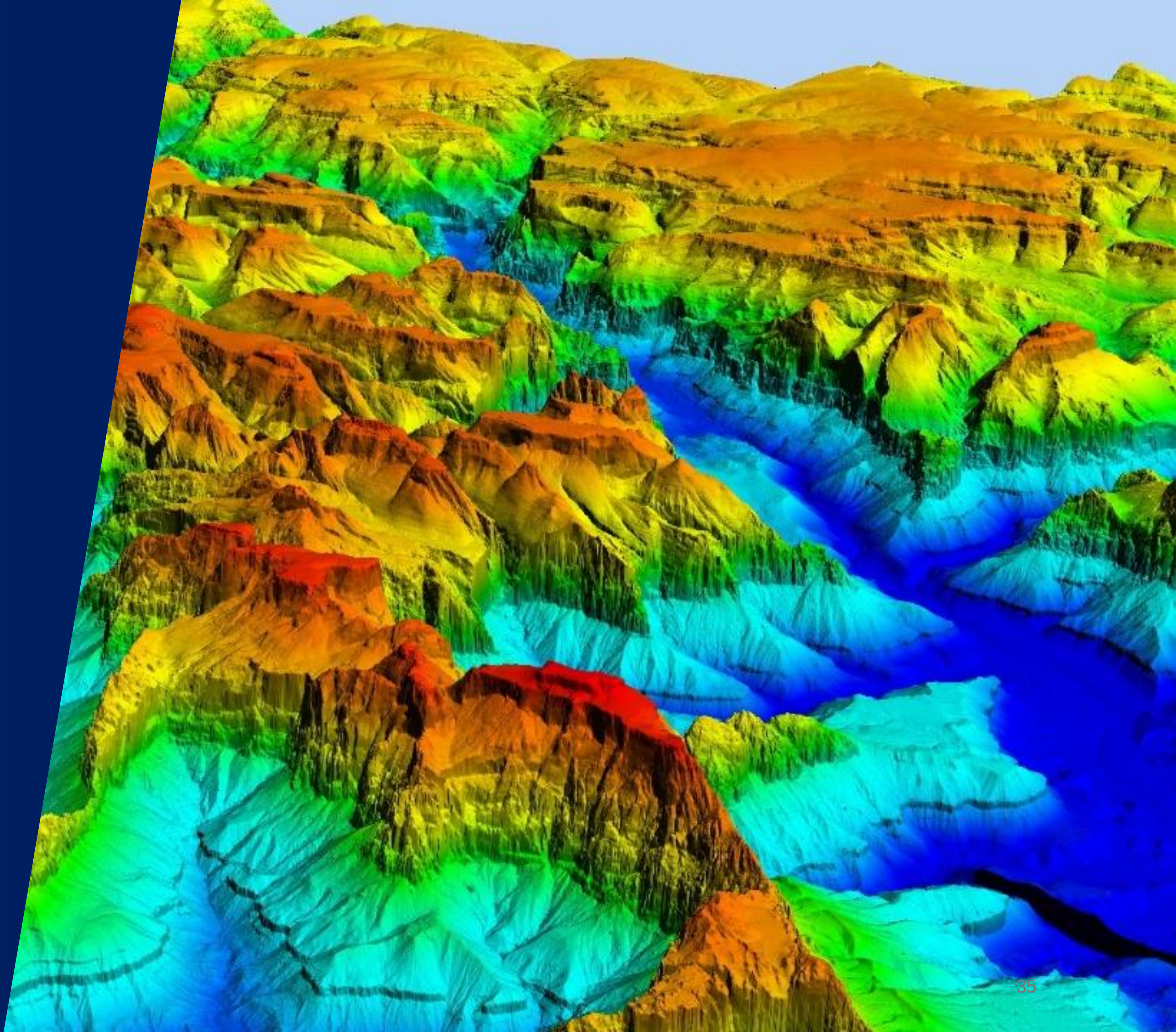
The visibility of parts of Yosemite Valley from the summit of El Capitan



Source

In summary

- There are four major types of surface data models, i.e., raster, vector (TINs, Countours), Terrain, and LAS
- Raster is the most useful data model for geospatial analytics
- Surface geometries are important attributes for many different applications
- Slope is the rate of change; aspect is the direction of change; and curvature is the slope of slope.



Thank You