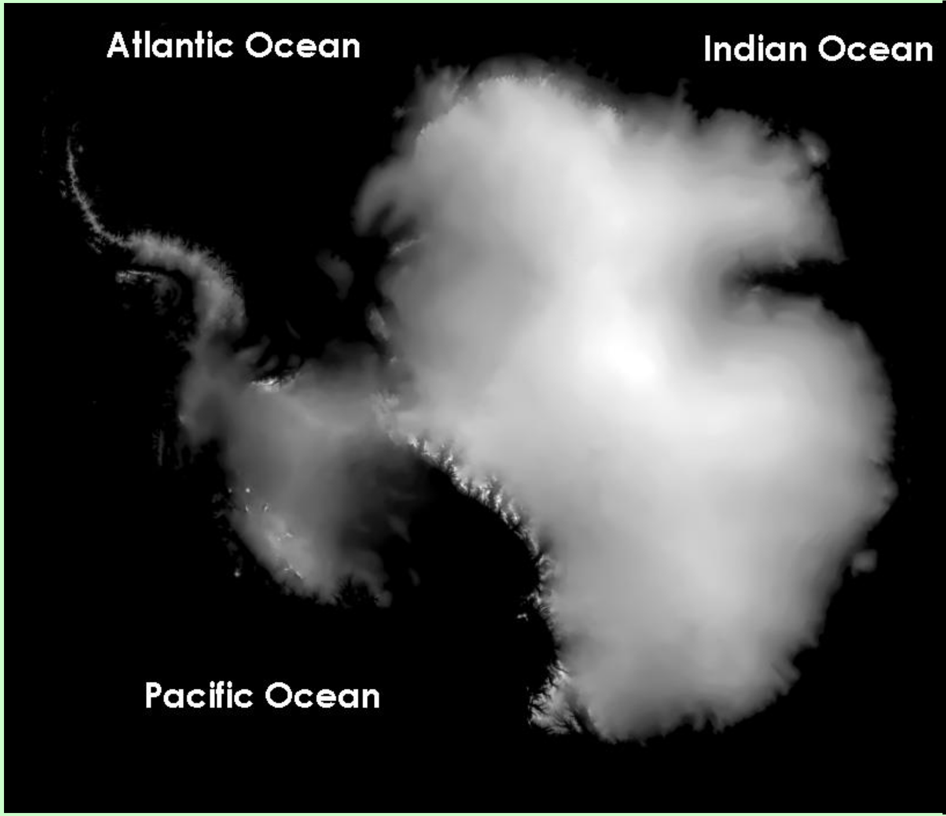
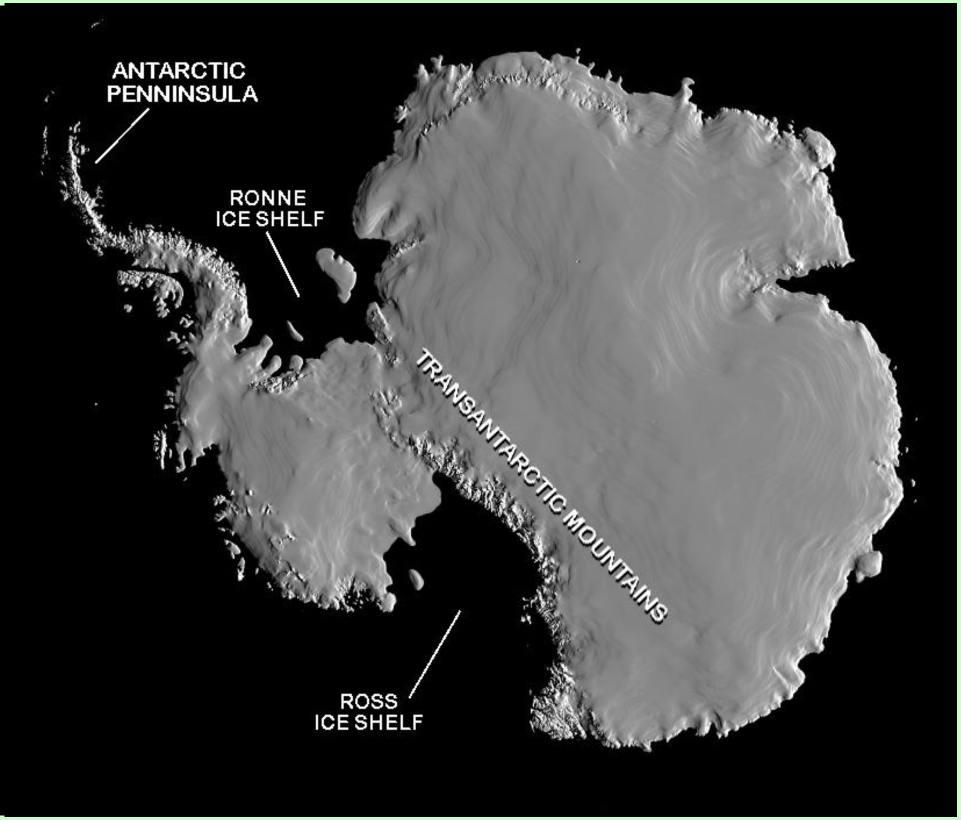
Spatial Analysis: Terrain Analysis

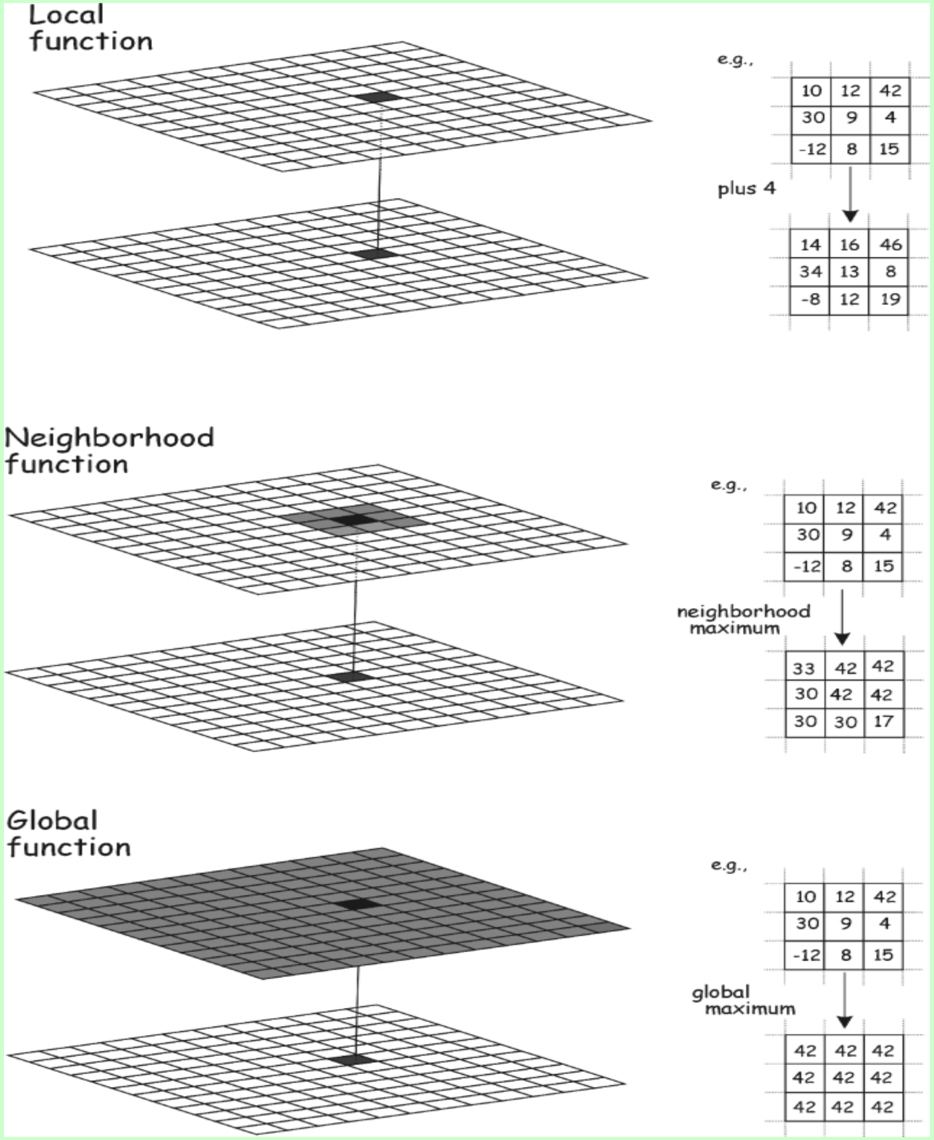
- Slope: maximum rate of change (% or degrees);
- Aspect: identifies steepest downslope direction (0 → true north, 90 → East);
- Hillshade: hypothetical illumination surface;
- Viewshed: identifies visibility of observation points or cell locations;
- Watershed: identifies watershed and creates drainage network.





Raster Spatial Analysis

- Local: single cell (e.g., maximum, minimum values);
- Focal: cells within a neighborhood (e.g., mean, sum);
- Zonal: cells in each defined zone



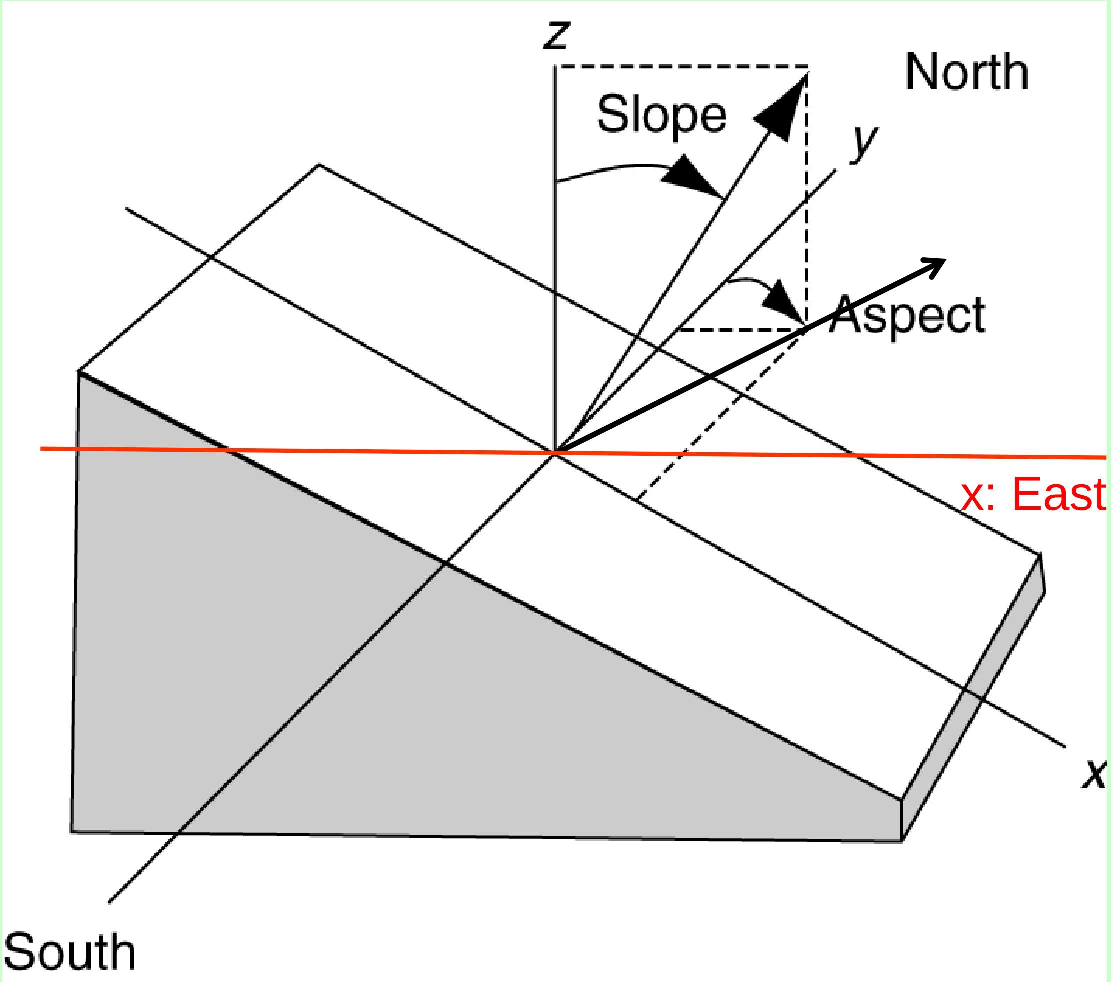
DEM Algorithms

- ☑ What are algorithms?
  - Procedures;
  - Behind buttons on the GUI.
- ☑ Computation for:
  - Slope;
  - Aspect;
  - Hillshade;
- ☑ Coverage:
  - What are they in geometry?
  - What are the calculation formula?
  - What are the differences among these algorithms?
  - Which algorithm is the best?

Why care about slope and Aspect?

- ☑ Identify potential sites for urban growth;
- ☑ Study water flow;
- ☑ Derive drainage patterns using DEMs;
- ☑ Understand solar radiation;
- ☑ Identify the habitats of plants;
- ☑ Apply environmental modeling.

Surface Geometry

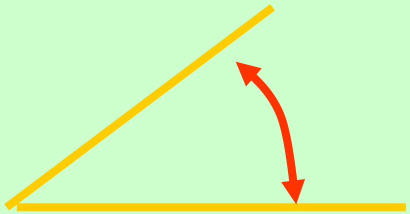


The normal vector to the cell is the directed line perpendicular to the cell. The quantity and direction of tilt of the normal vector determine the slope and aspect of the cell. (Redrawn from Hodgson, 1998, *CaGIS* 25, (3): pp. 173–185.)

Slope

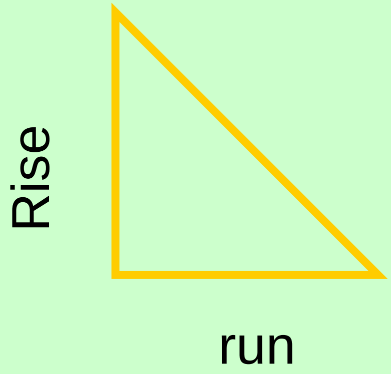
- ☑ Slope measures the steepness of the surface at any particular location.
- ☑ Two ways to express slopes:

As an angle from horizontal
- degrees



As a percent

100*(Rise/Run) = % gradient

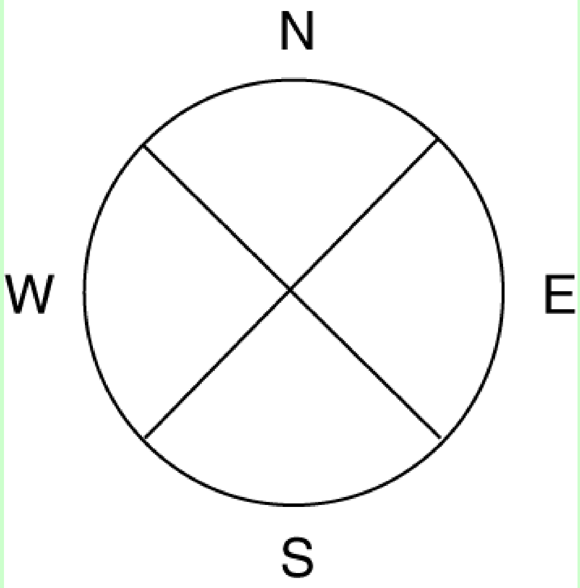


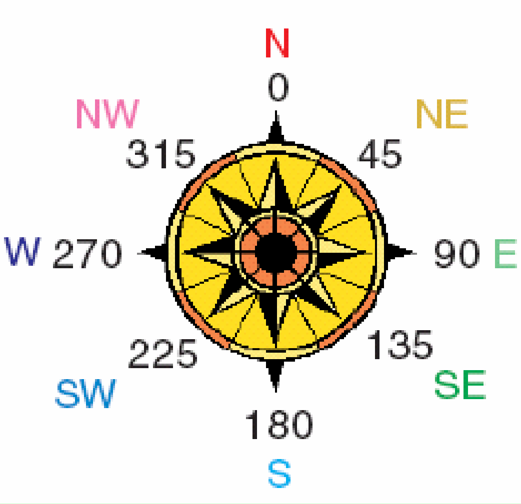
Angular slope = 45 deg

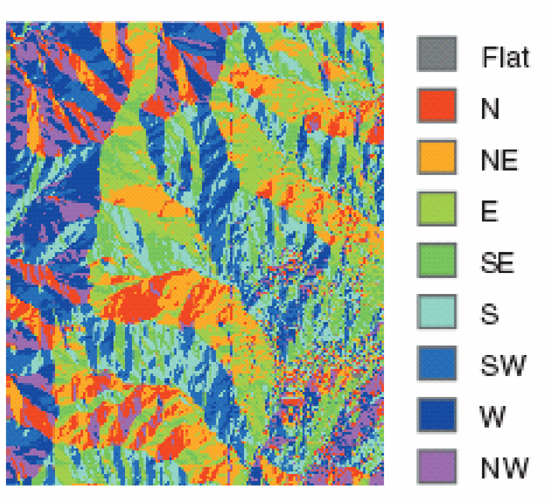
Percent slope = 100%

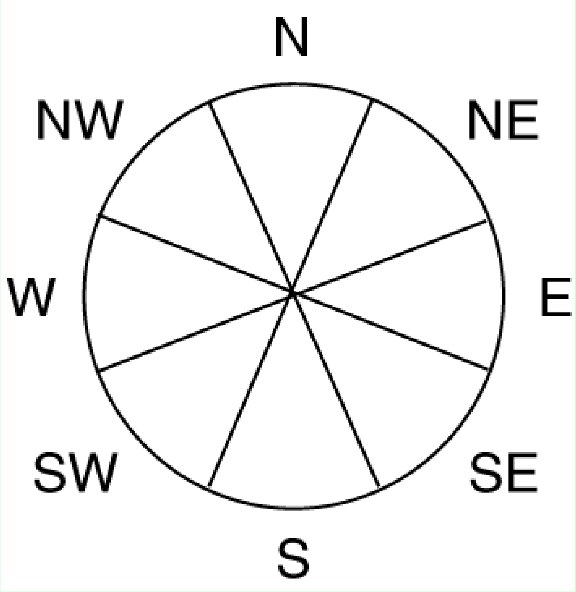
Aspect

- ☑ Aspect measures the direction of steepest slope for a location on the surface.
- ☑ It is usually measured in degrees, where 0 degrees is due north, 90 degrees is due east, 180 degrees is due south, and 270 degrees is due west.

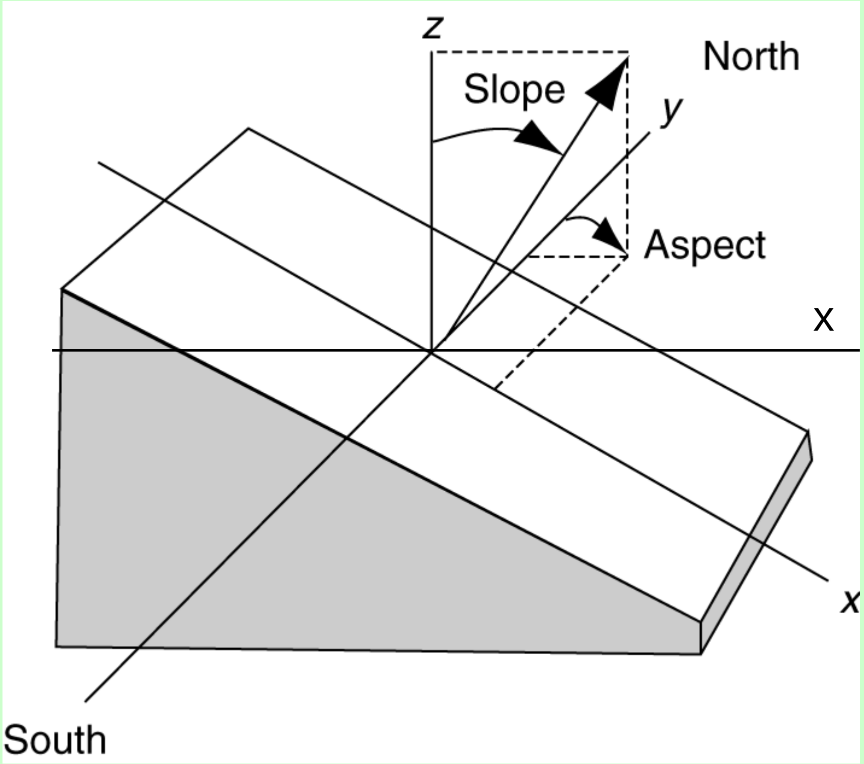








Slope & Aspect Derivation



$$Slope\ \% = \varsigma = \sqrt{\left(\left\{\frac{\Delta z}{\Delta x}\right\}^2 + \left\{\frac{\Delta z}{\Delta y}\right\}^2\right)}$$

and

$$Aspect\ \ angle = \theta = \arctan\left(\frac{-\dfrac{\Delta z}{\Delta y}}{\dfrac{\Delta z}{\Delta x}}\right)$$

Slope/Aspect Derivation

- Determining the slope plane:
  - Moving window
  - Determine the plane
    - $z = a + bx + cy$
- It can be proved that:
  - $c=\Delta z_y/\Delta y$
  - $b=\Delta z_x/\Delta x$
- Slope:
  - $S= \tan^{-1}(\mathrm{sqrt}(b^2 + c^2))$
- Aspect:
  - $A = \tan^{-1} (-c/b)$

Computing Algorithms for Slope and Aspect Using Grid-based DEM

- ☑ The slope and aspect for an area unit (i.e., a cell) are measured by DEM gradients.
- ☑ Different approximation (finite difference) methods have been proposed for calculating slope and aspect from an elevation raster. Usually based on a 3x3 moving window, these methods differ in the number of neighboring cells used in the estimation and the weight applying to each cell.

e_1	e_2	e_3
e_4	C_0	e_5
e_6	e_7	e_8

	e_2	
e_1	C_0	e_3
	e_4	

Differences in Slope/Aspect Calculation

- Window size: slopes are calculated locally in a neighborhood.
- Weight: according to distance: direct directions vs diagonal

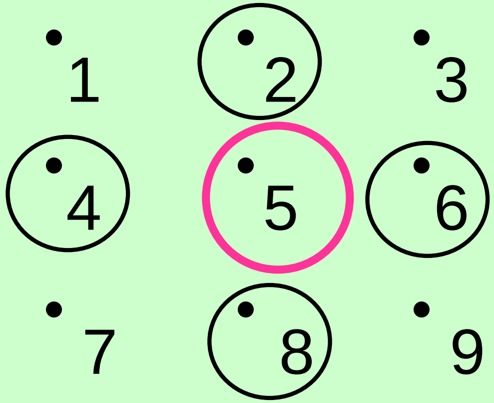
1.41…	1	1.41…
1	0	1
1.41…	1	1.41…

* cell size

Calculation in 4-neighborhood

- $b = (z_6 - z_4) / 2D$
- $c = (z_2 - z_8) / 2D$
  - b denotes slope in the x direction
  - c denotes slope in the y direction
  - D is the spacing of points (i.e., cell size, e.g., 30 m)

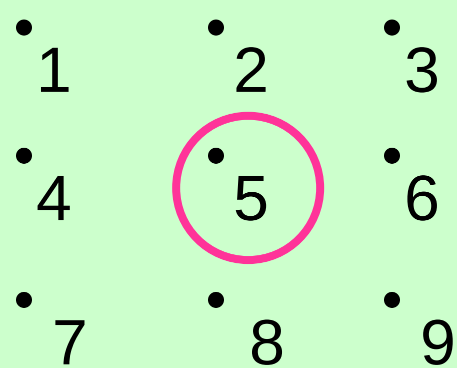
- Fleming and Hoffer (1979)



Calculation in 8-neighborhood

- $b = (z_3 + w*z_6 + z_9 - z_1 - w*z_4 - z_7) / (4+2*w)D$
- $c = (z_1 + w*z_2 + z_3 - z_7 - w*z_8 - z_9) / (4+2*w)D$
  - b denotes slope in the x direction
  - c denotes slope in the y direction
  - D is the spacing of points (e.g., 30 m)
- **weighting four closer neighbors higher**

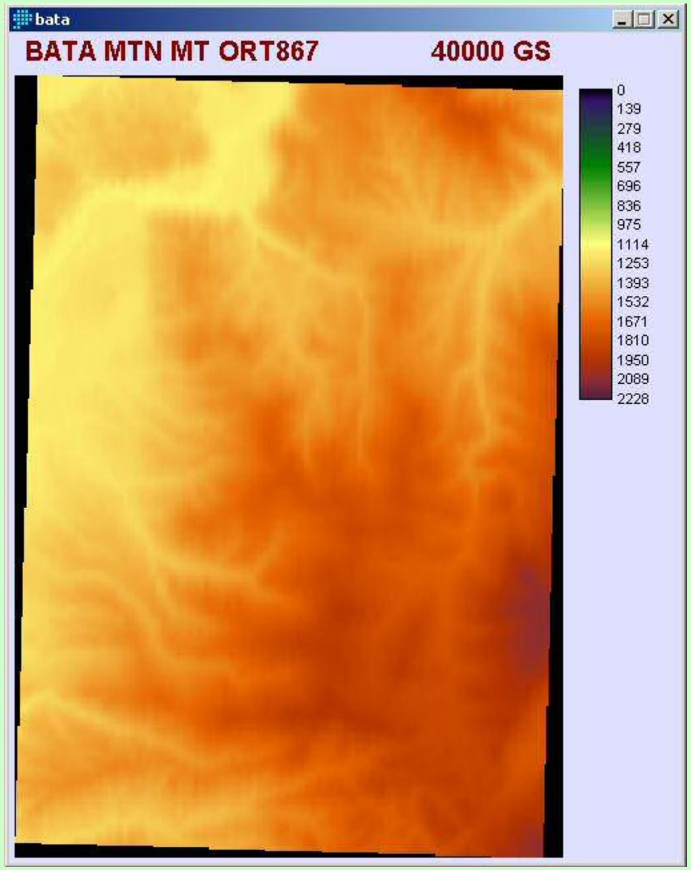
- **Sharpnack (1969): w=1**
- **Travis (1975): w=1.414**
- **Horn (1981): w=2**
- **Fleming (1979): w=?**

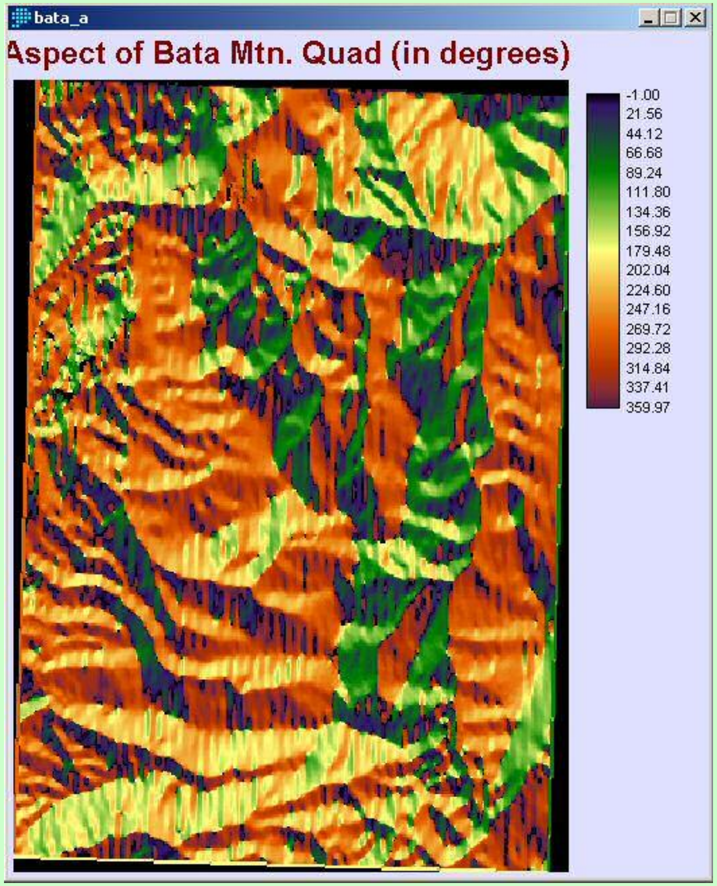


Which is best?

- Hodgson (1998): 4-neighbor!
  - Most precise;
  - Computationally economic.
- Nearly all GIS packages use 8-neighbor!
  - What algorithm does ArcGIS currently use?
- Why is that?
  - Think about DEM error.

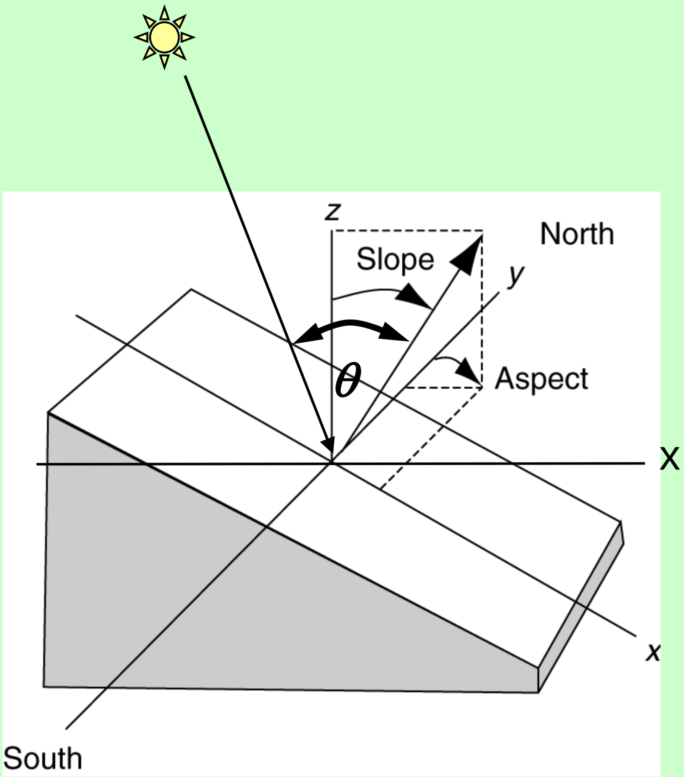
DEM Quality Issues





Hillshade from DEMs

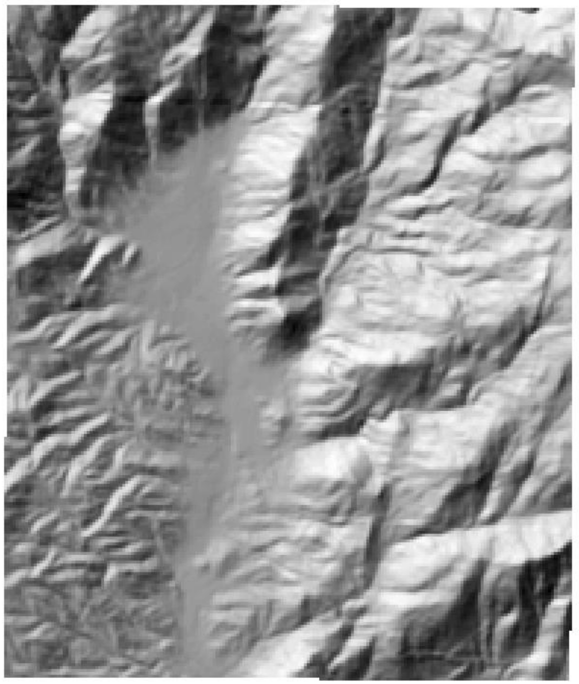
- ☑ Why Hillshade?
  - Visualization;
  - Radiation;
  - Plant habitat.
- ☑ How to compute hillshade?

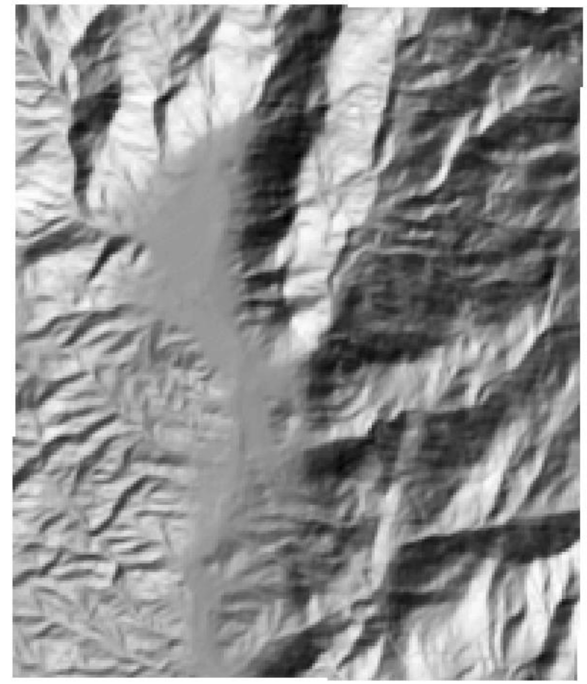


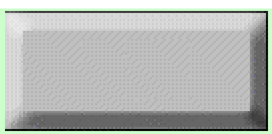
$$\cos\theta = \sin el \cdot \cos S + \cos el \cdot \sin S \cdot \cos(az - A)$$

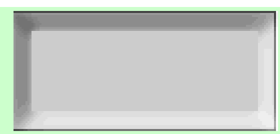
$$Hillshade = 255 \cdot \cos\theta$$

Positive and Negative Hillshade









- ☑ az=315 deg by default to ensure positive shade.
- ☑ A realistic az for solar radiation study.

Solar Irradiance

- Solar irradiance striking perpendicular surface
  - S = 1000 W/m2 as a constant.
- Solar irradiance on slope:

$$I = S \cdot \cos\theta$$

$$I = S \cdot Hillshade / 255$$