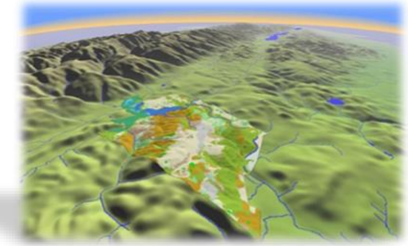
NICHOLAS SCHOOL OF THE ENVIRONMENT AND EARTH SCIENCES
DUKE UNIVERSITY



ENVIRON 761: Elevation, Terrain, & Ecology (II): Terrain Analyses

Instructor: John Fay

Elevation, terrain & ecology: Overview

I. Ecohydrology & conservation
- Surface terrain and the hydrologic cycle
- GIS techniques for modeling surface flow using a DEM

II. Vegetation patterns across ecological gradients
- Properties of a terrain that drive these gradients
- GIS techniques to derive surface properties from a DEM

Vegetation & topographic position

Vegetation in geographic space

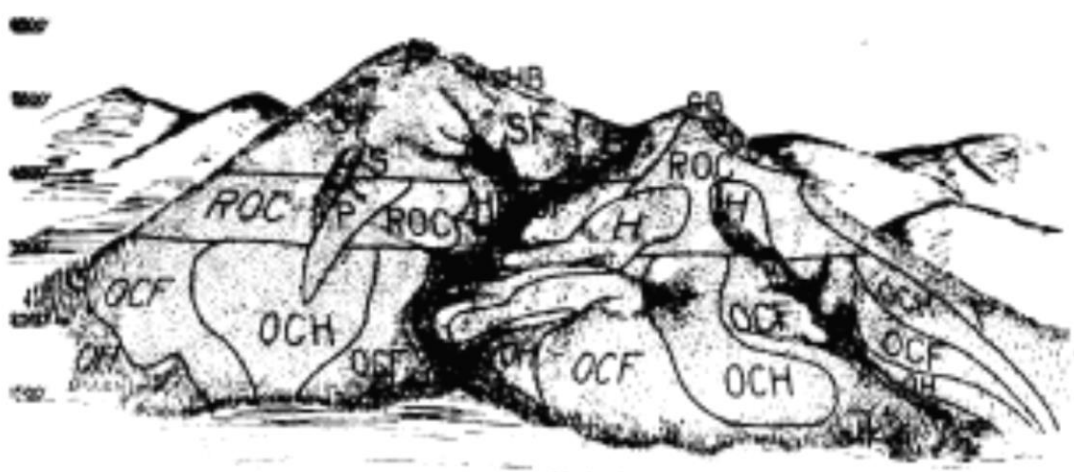


FIG. 21. Topographic disposition of vegetation types. View of idealized mountain and valley, looking east, with 6500-ft peak bearing subalpine forest on left, lower 5500-ft peak covered up to summit bald with deciduous forest on right. Vegetation types:

BG—Beech Gap
CF—Cove Forest
F—Fraser Fir Forest
GB—Grassy Bald
H—Hemlock Forest
HB—Heath Bald
OCF—Chestnut Oak-Chestnut Forest
OCH—Chestnut Oak-Chestnut Heath
OH—Oak-Hickory Forest
P—Pine Forest and Pine Heath
ROC—Red Oak-Chestnut Forest
S—Spruce Forest
SF—Spruce-Fir Forest
WOC—White Oak-Chestnut Forest

The Smokies
(Whittaker 1956)

Vegetation in parameter space

elevation

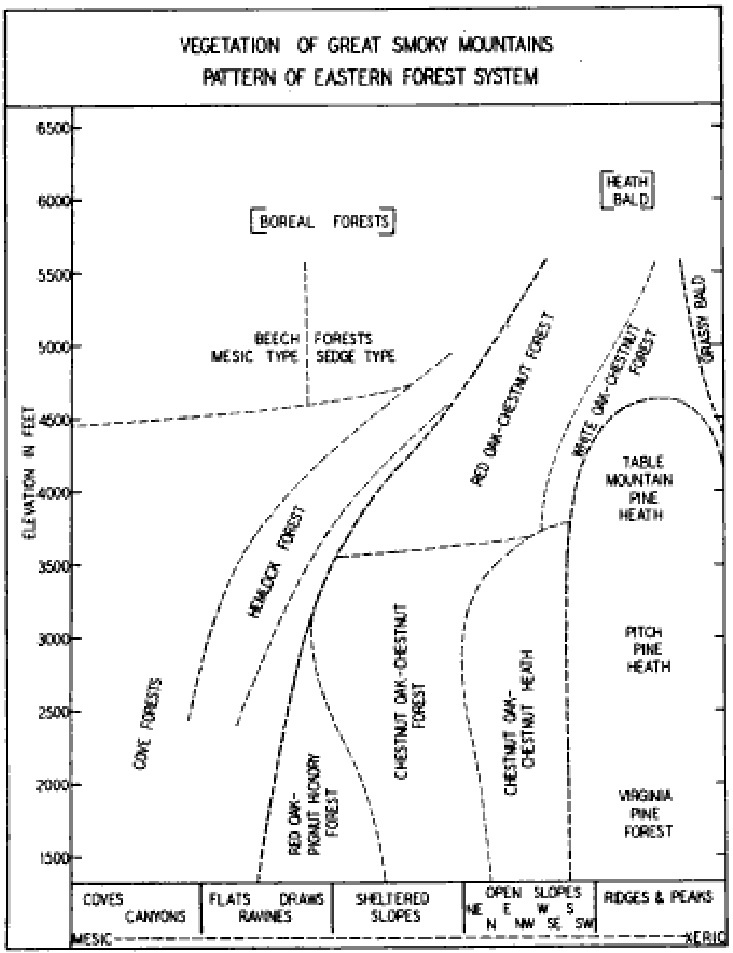


FIG. 19. (Vegetation of Great Smoky Mountains, pattern of Eastern Forest System.)

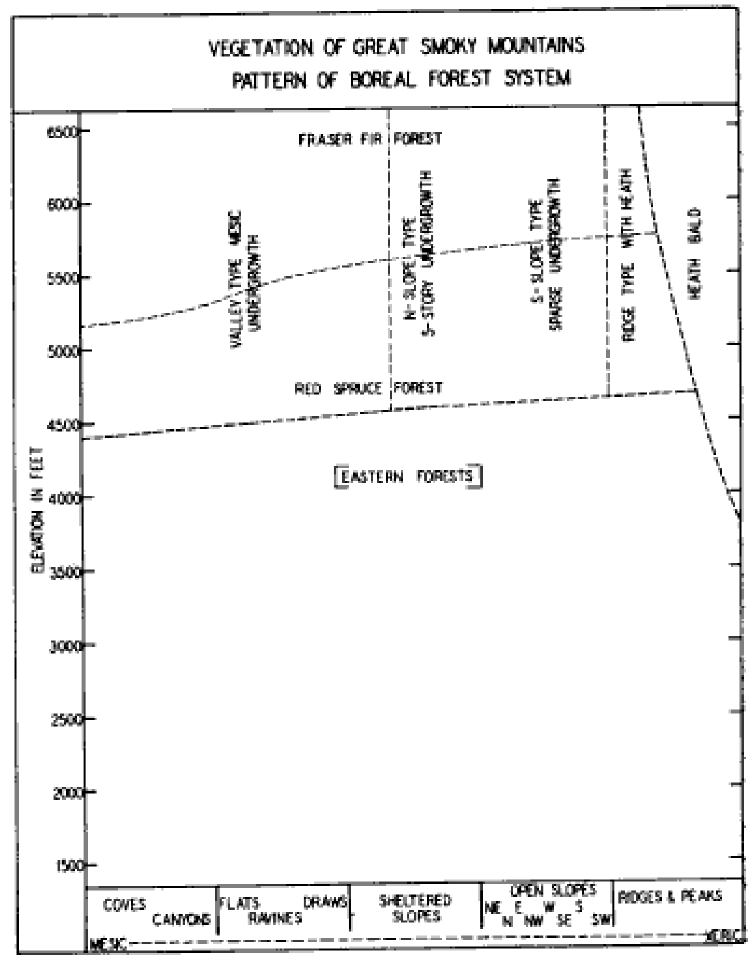
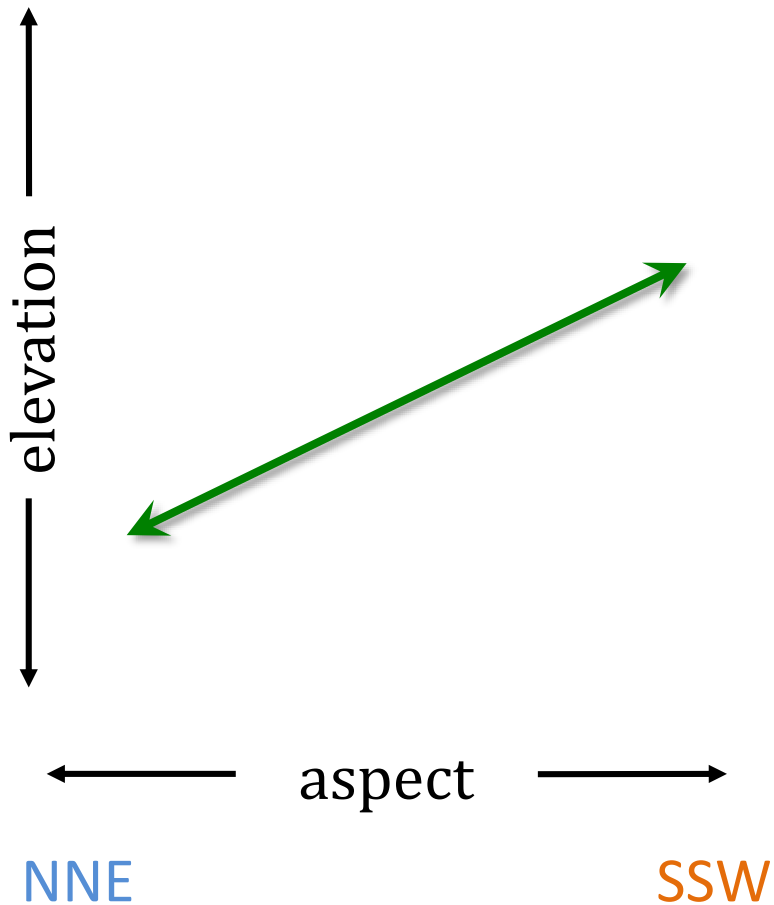


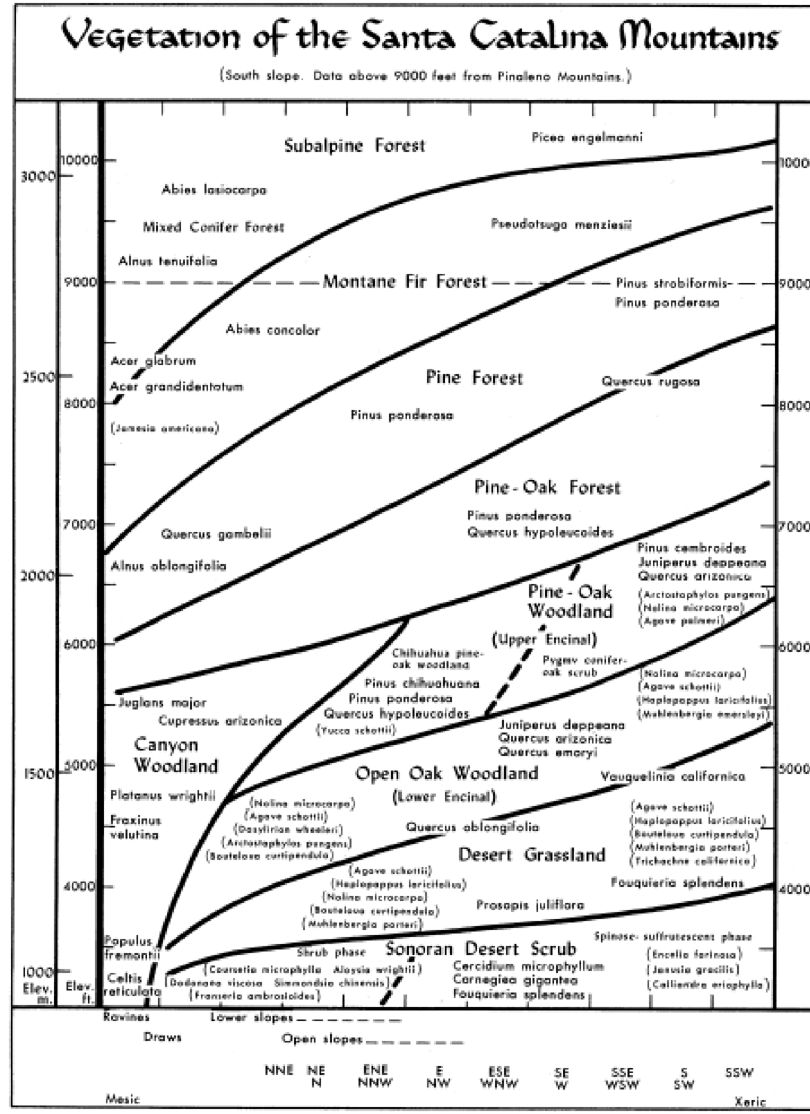
FIG. 20. (Vegetation of Great Smoky Mountains, pattern of Boreal Forest System.)

cove ⟷ ridge

(Whittaker 1956, p58)

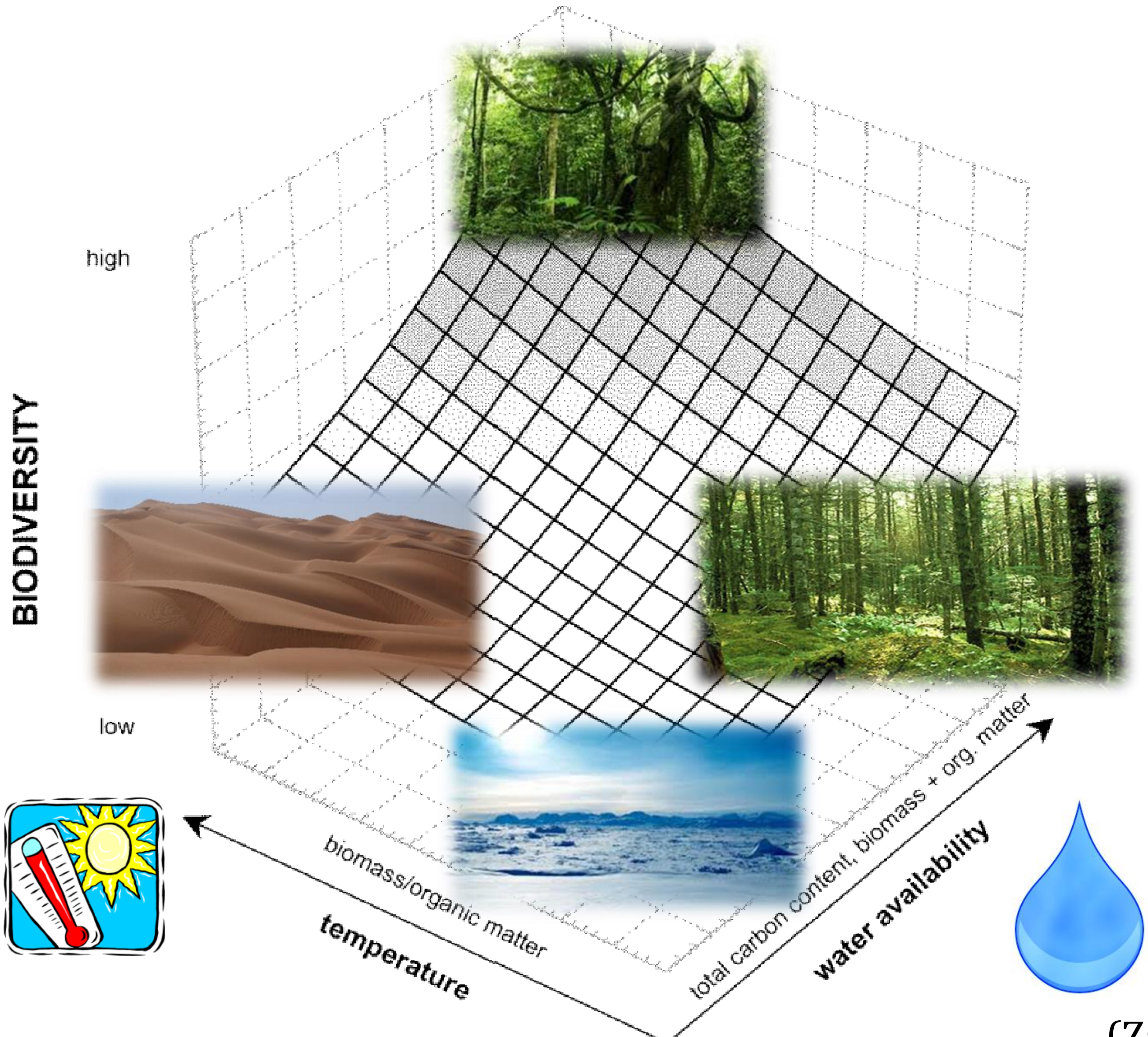
Vegetation in parameter space





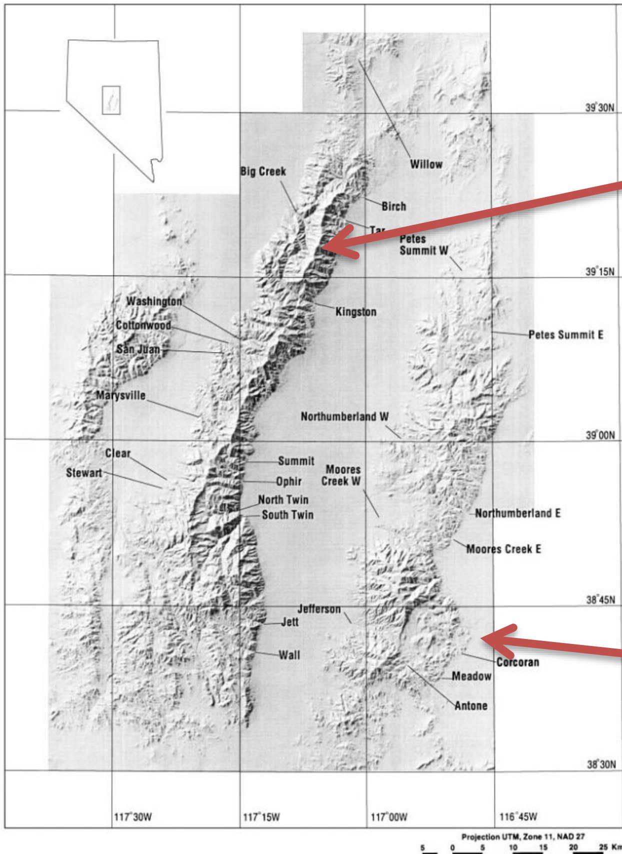
(Whittaker & Niering 1965)

Drivers of biodiversity



(Zalewski 2002)

Butterfly species richness & topography…



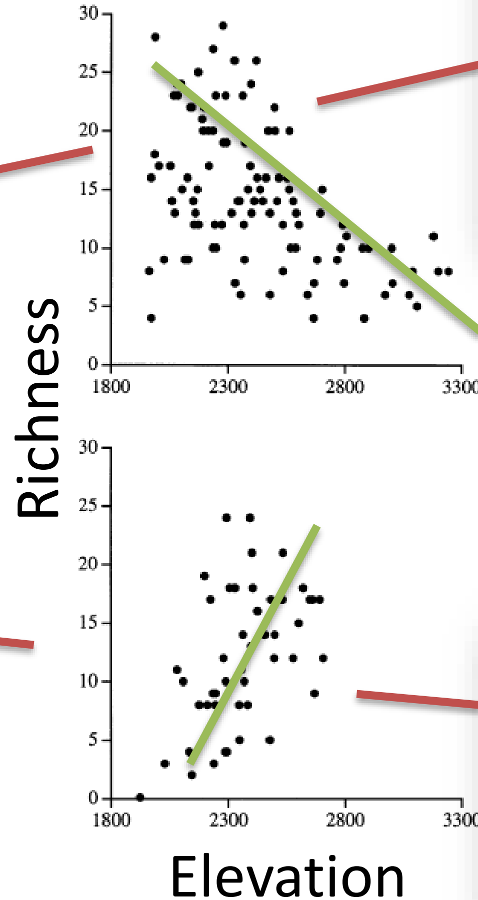


Table 3 Effect of elevation on other environmental variables in the Toiyabe Range.

Independent variable	r^2	$F_{1,101}$	P
Distance to water	0.14	16.4	< 0.001
Canyon depth	0.22	27.6	< 0.001
Canyon width	0.35	53.2	< 0.001

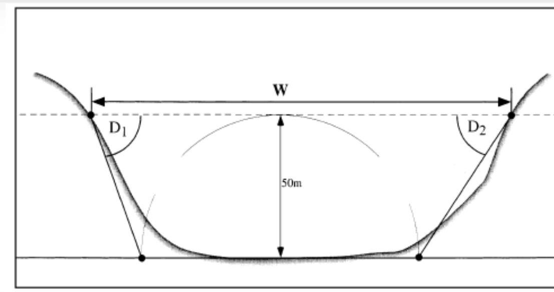


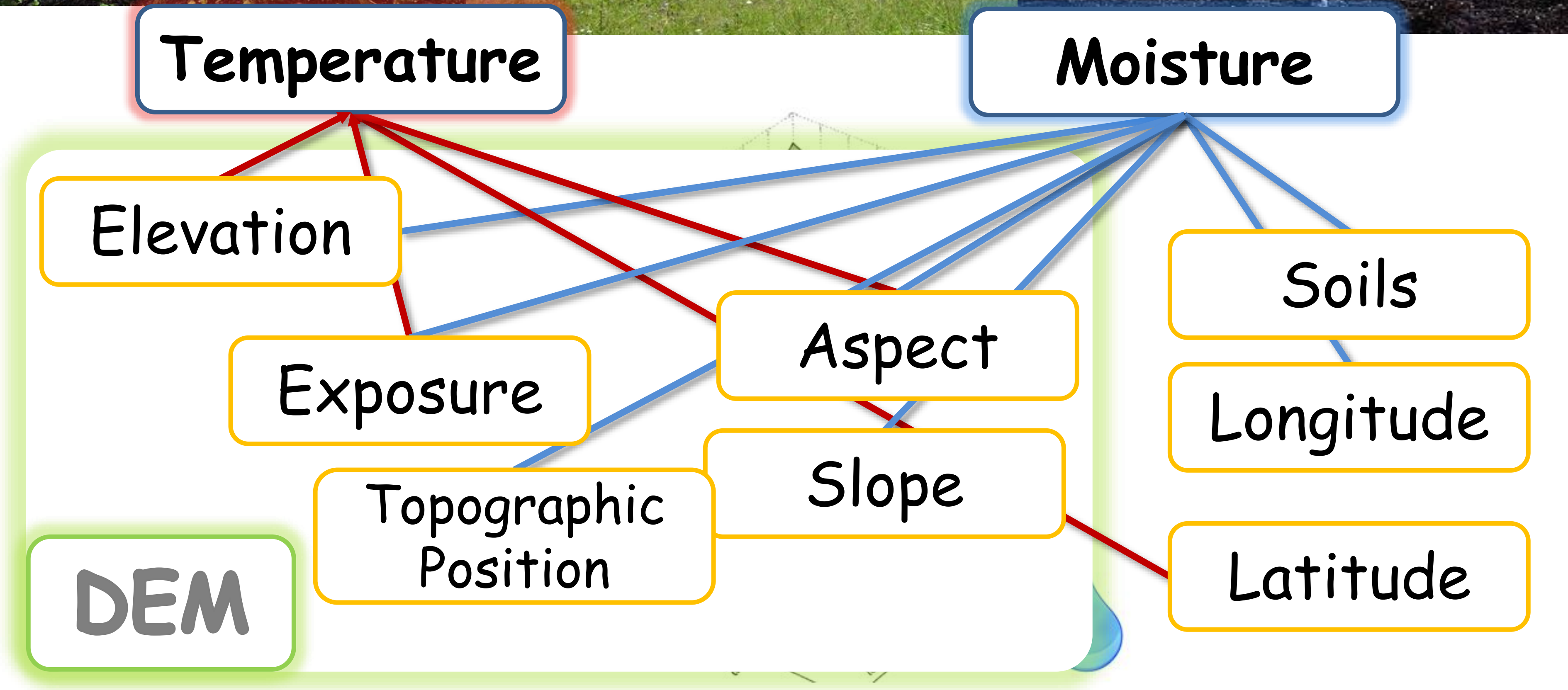
Table 5 Effect of elevation on other environmental variables in the Toquima Range.

Independent variable	r^2	$F_{1,48}$	P
Distance to water	0.03	1.7	0.20
Canyon depth	0.01	0.5	0.48
Canyon width	0.02	0.8	0.37

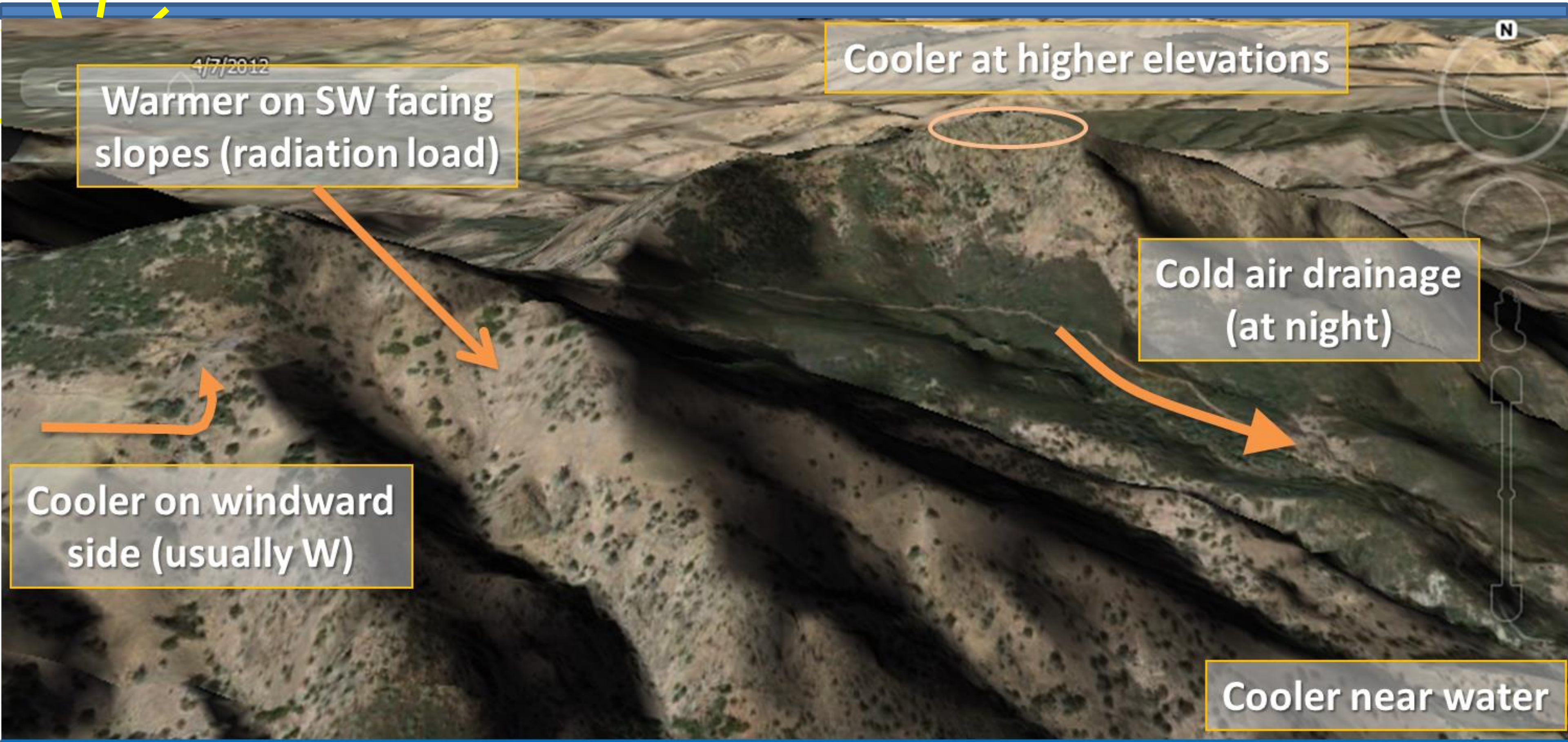
At finer scales, it's more complicated…

(Fleishman, et al. 2000)

Landscape scale *gradient analysis*

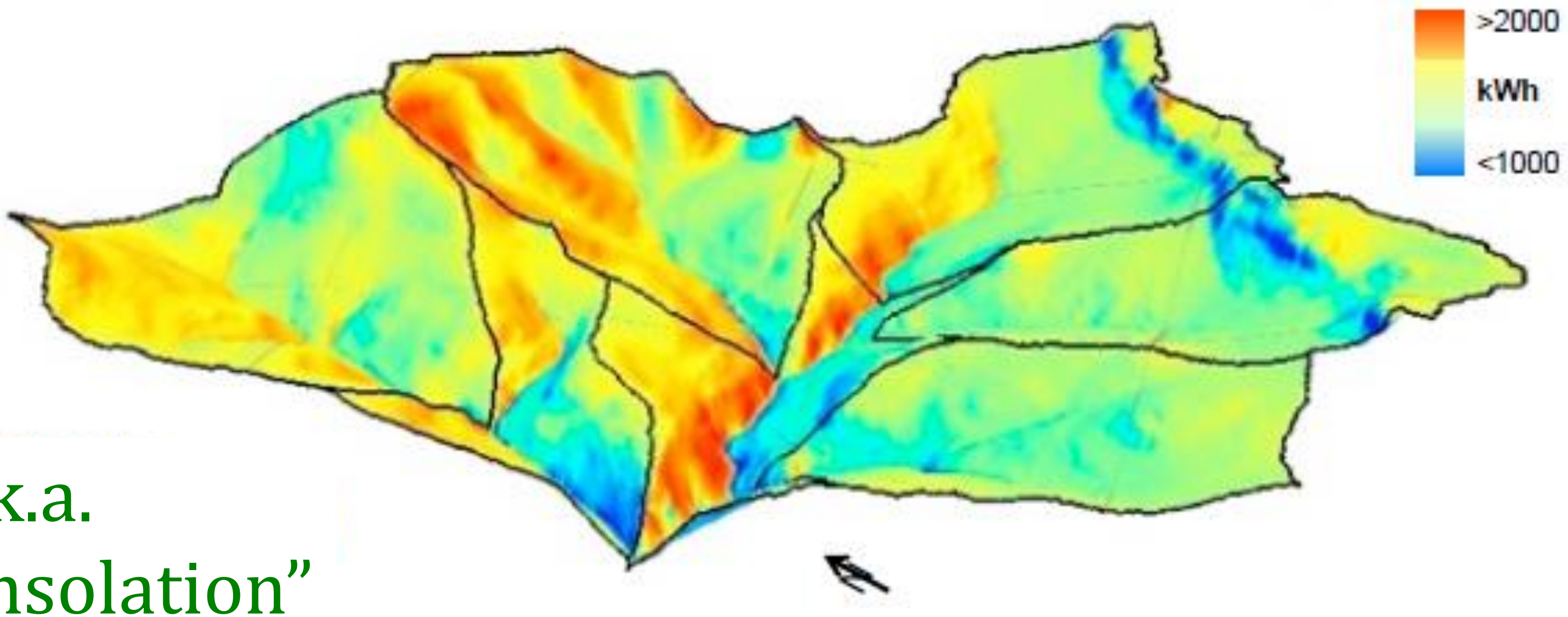


Landscape-scale: temperature



- latitude
- elevation (lapse rate)
- topographic exposure (via radiation or cold-air drainage)
- air moisture content (dist. to streams, lakes, oceans)

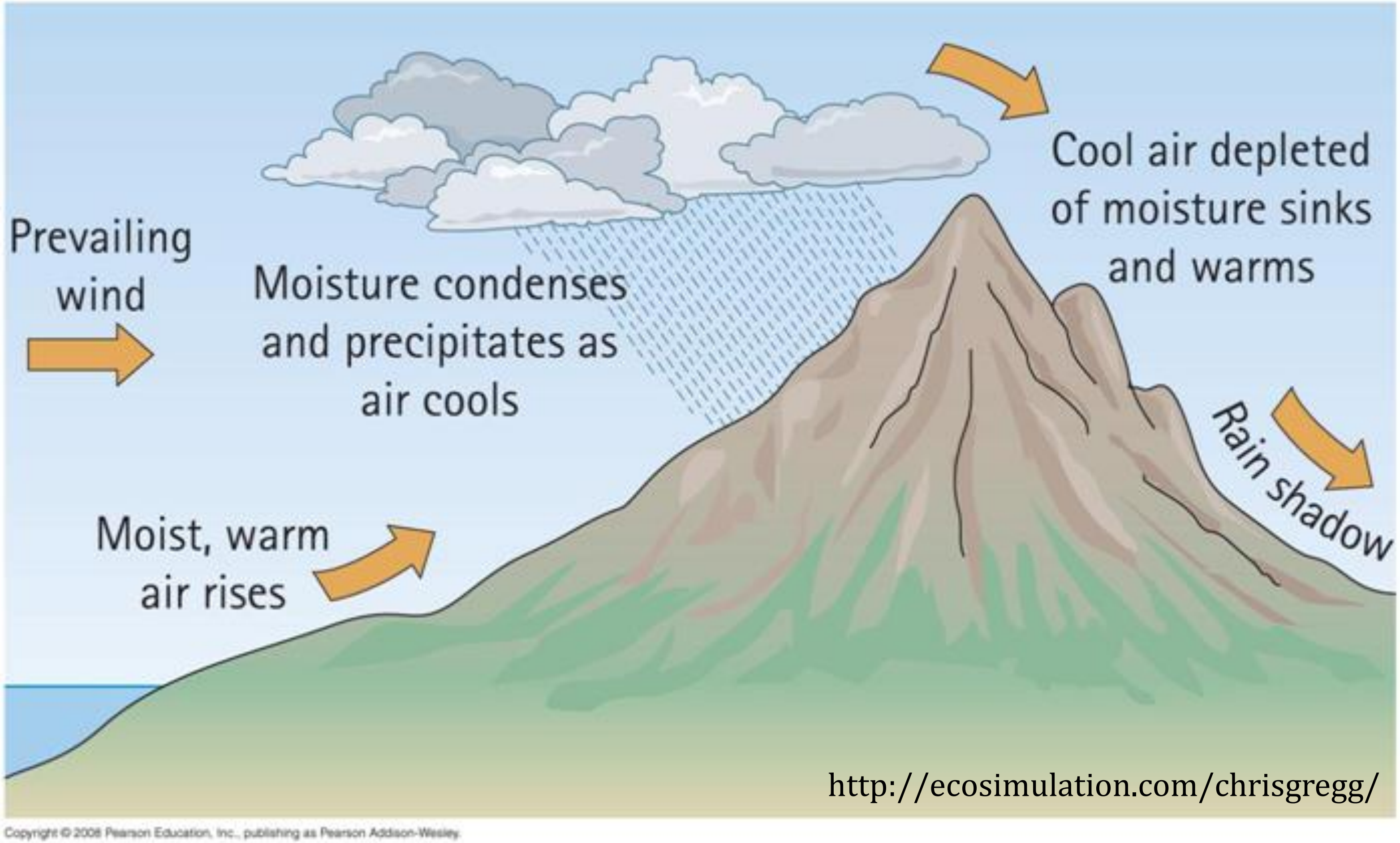
Landscape-scale: solar radiation



a.k.a.
"insolation"

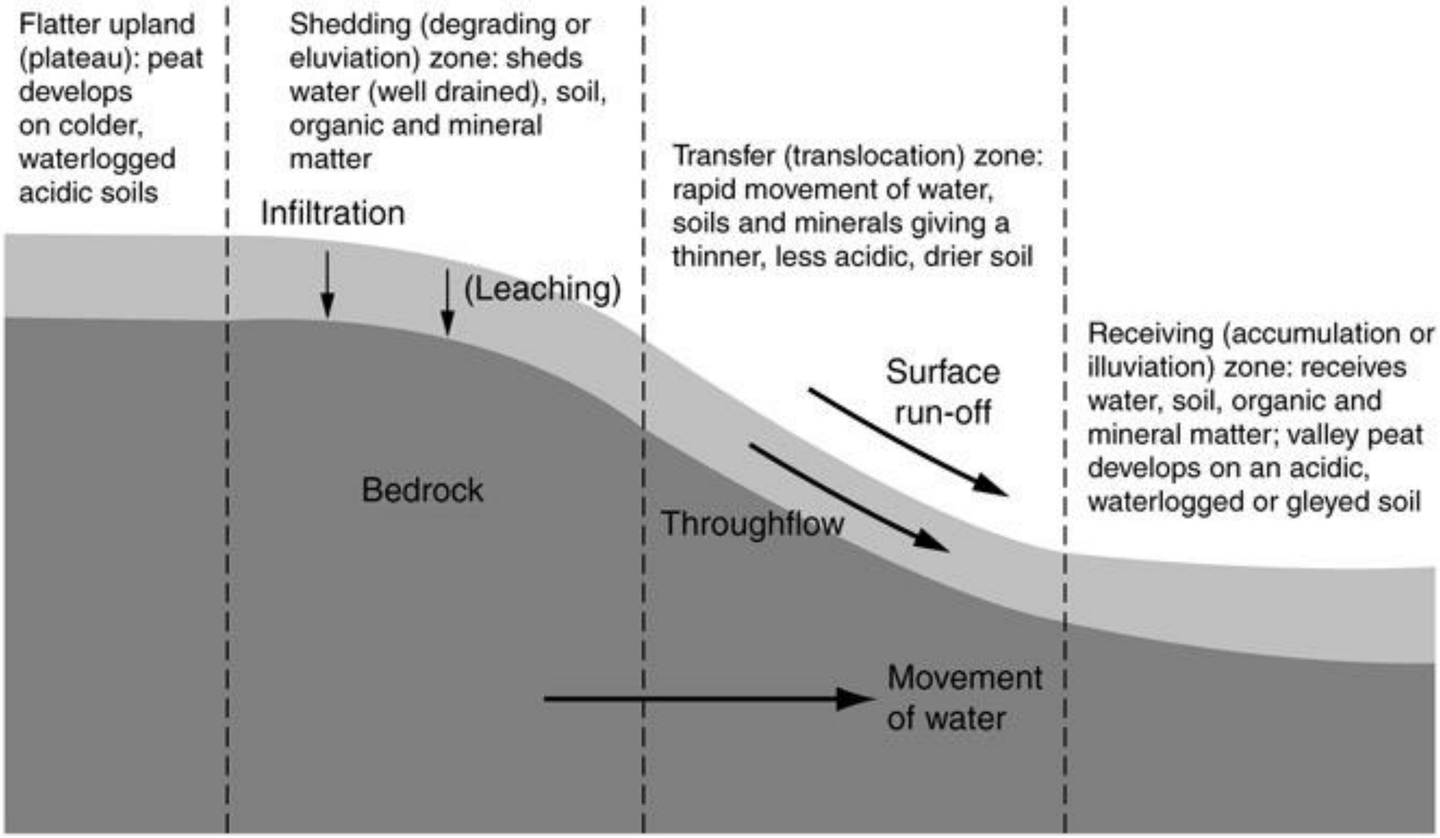
- latitude (declination)
- elevation (via clouds & atmospheric effects)
- topographic exposure

Landscape-scale: precipitation



- longitude (due to airmass dynamics and N-S mountain ranges)
- elevation (orographic lifting)
- storms (patchy)

Landform & edaphic factors



http://www.geocases2.co.uk/printable/soil.htm

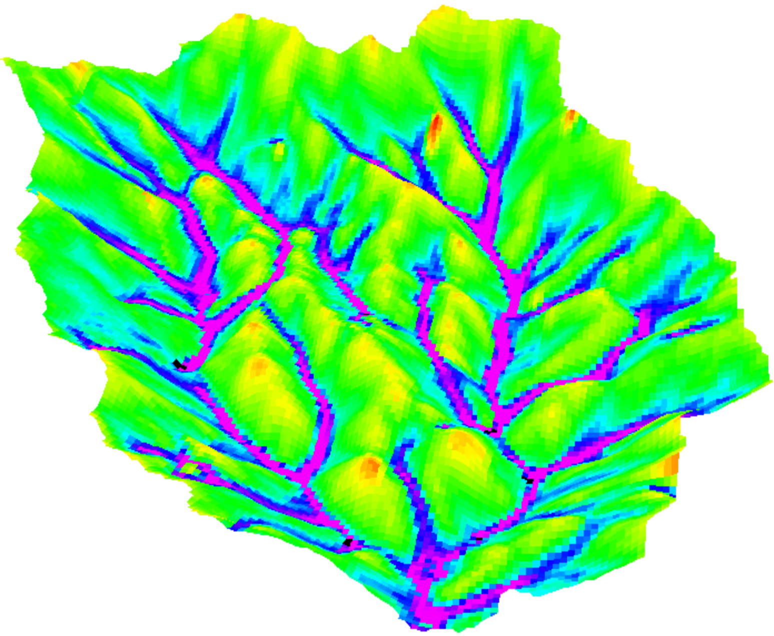
- soils/parent material
- slope
- topographic position

Landscape scale phenomena: proxies & GIS

Task:

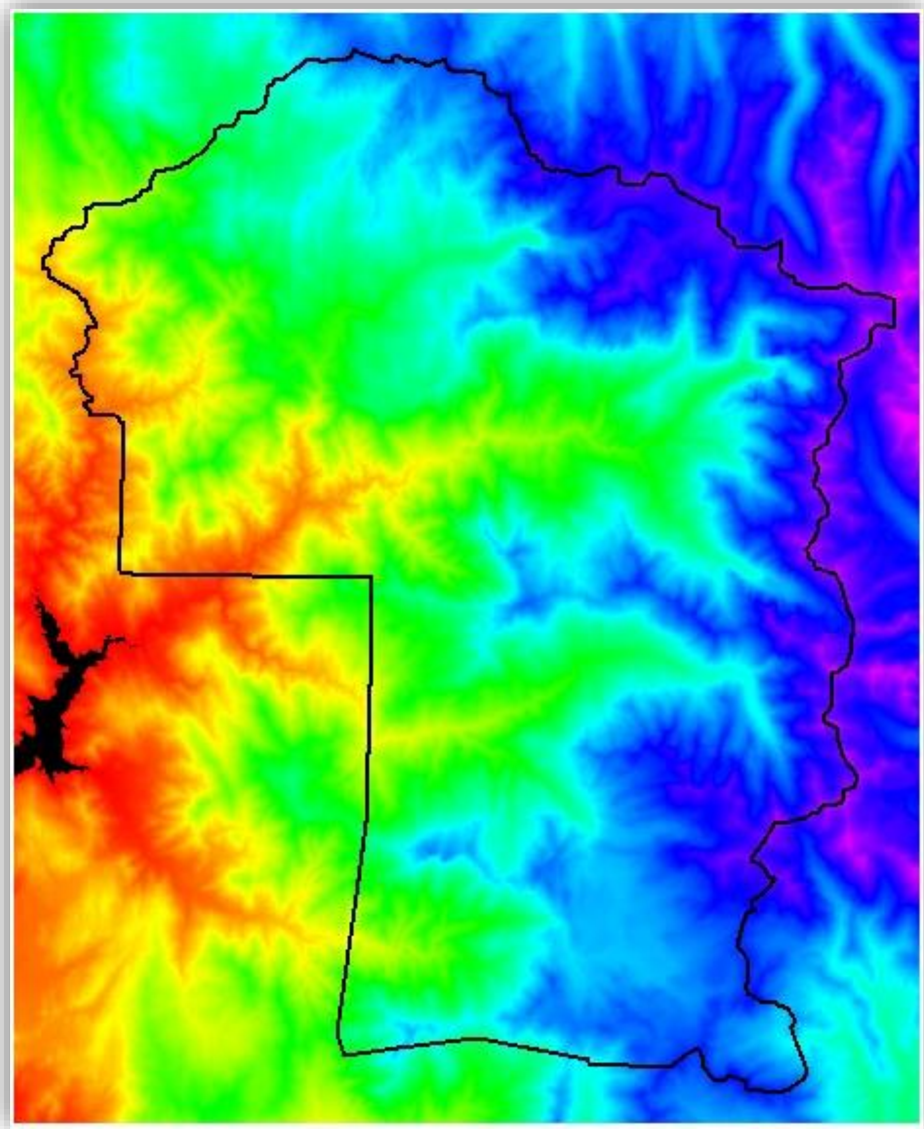
Find useful predictive proxies for broad-scale applications that are correlated with the actual processes

- temperature
- precipitation
- radiation load
- drainage, soils

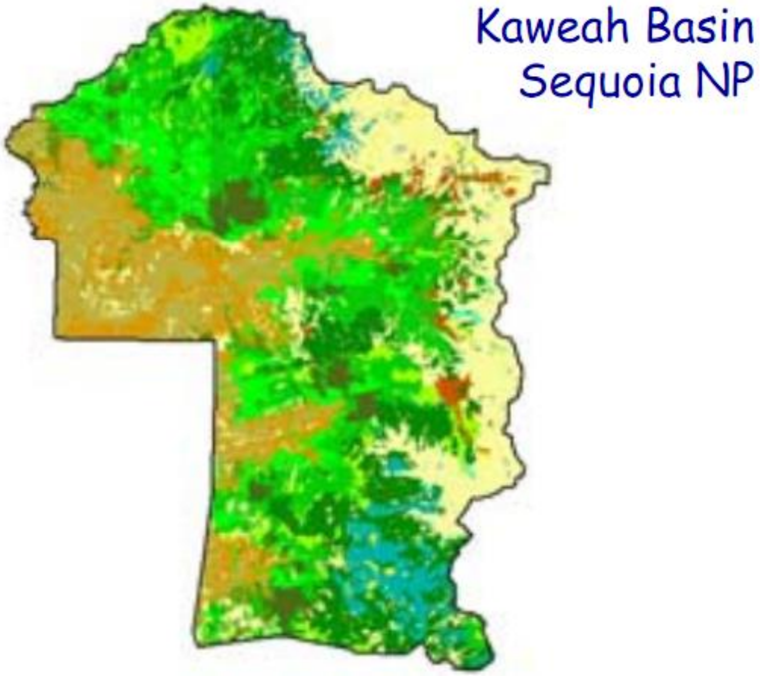


Learn to think like a computer…

Temperature & Precipitation → Elevation

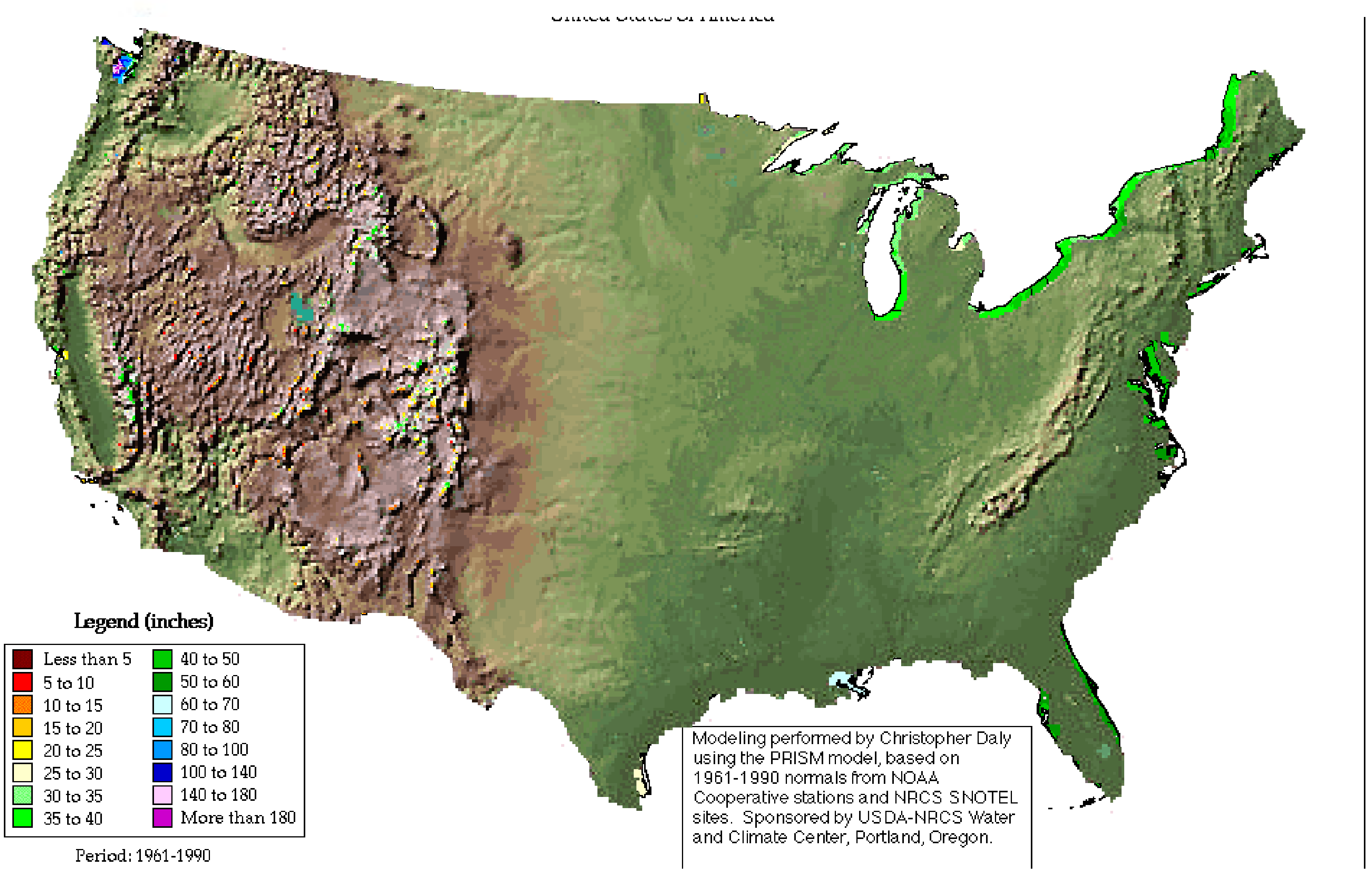


low (hot, dry)
middle
high (cold, wet)



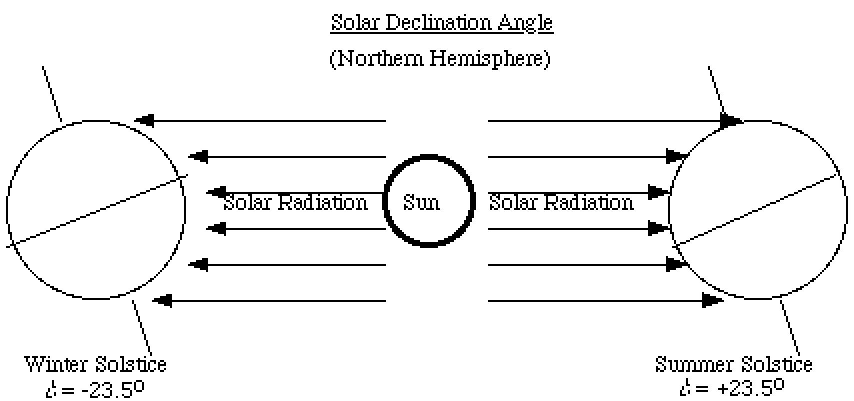
Urban (2000)

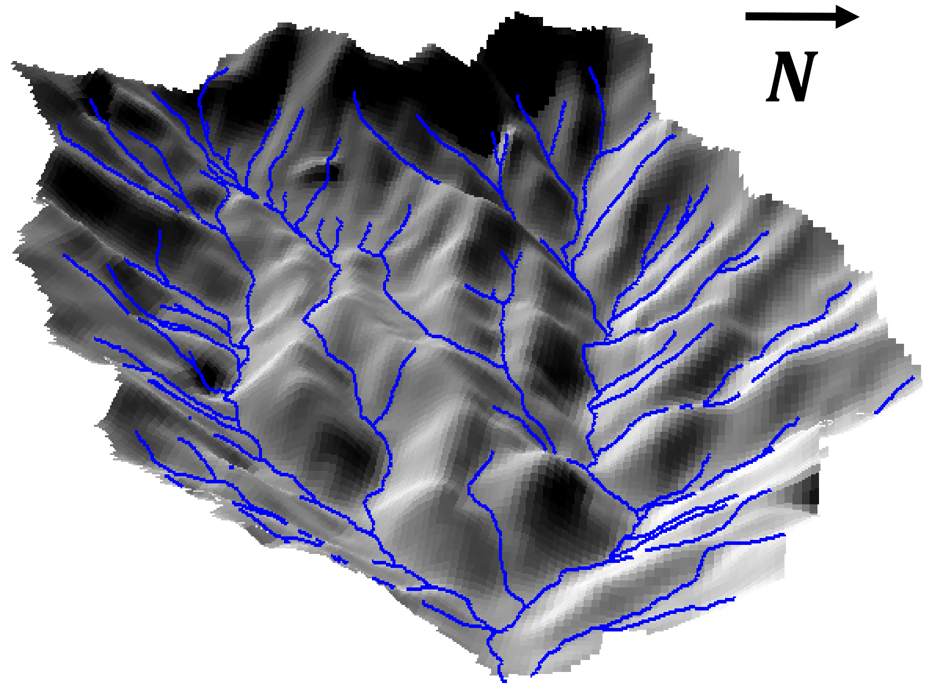
Temperature & Precipitation → Elevation

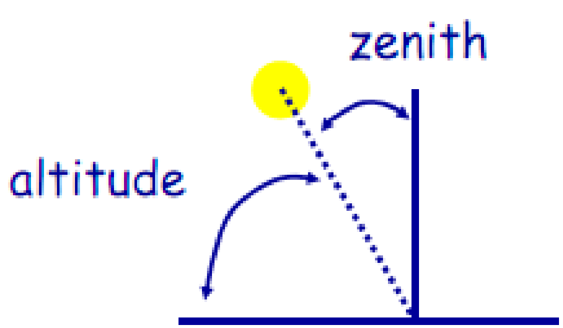


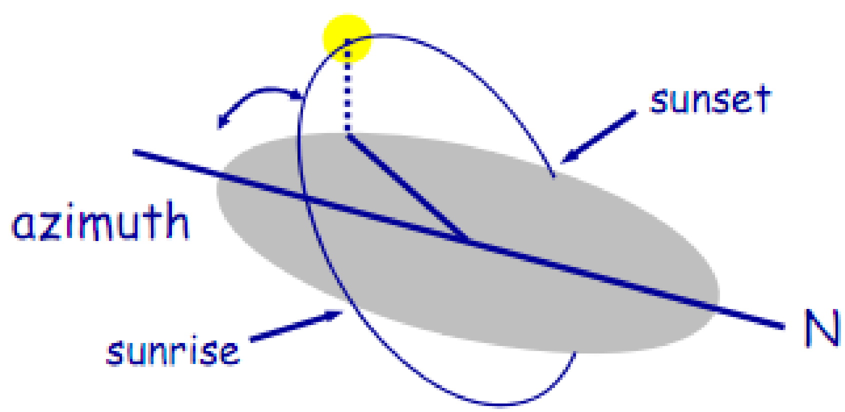
Radiation → Hillshading

analytic hillshading in ArcGIS

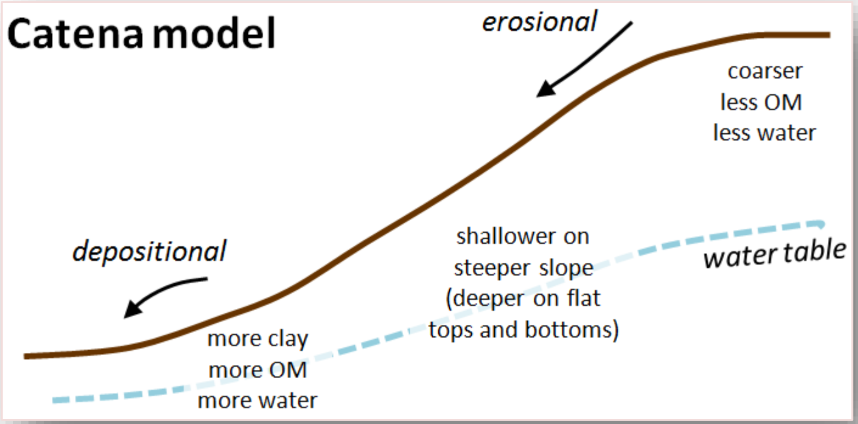


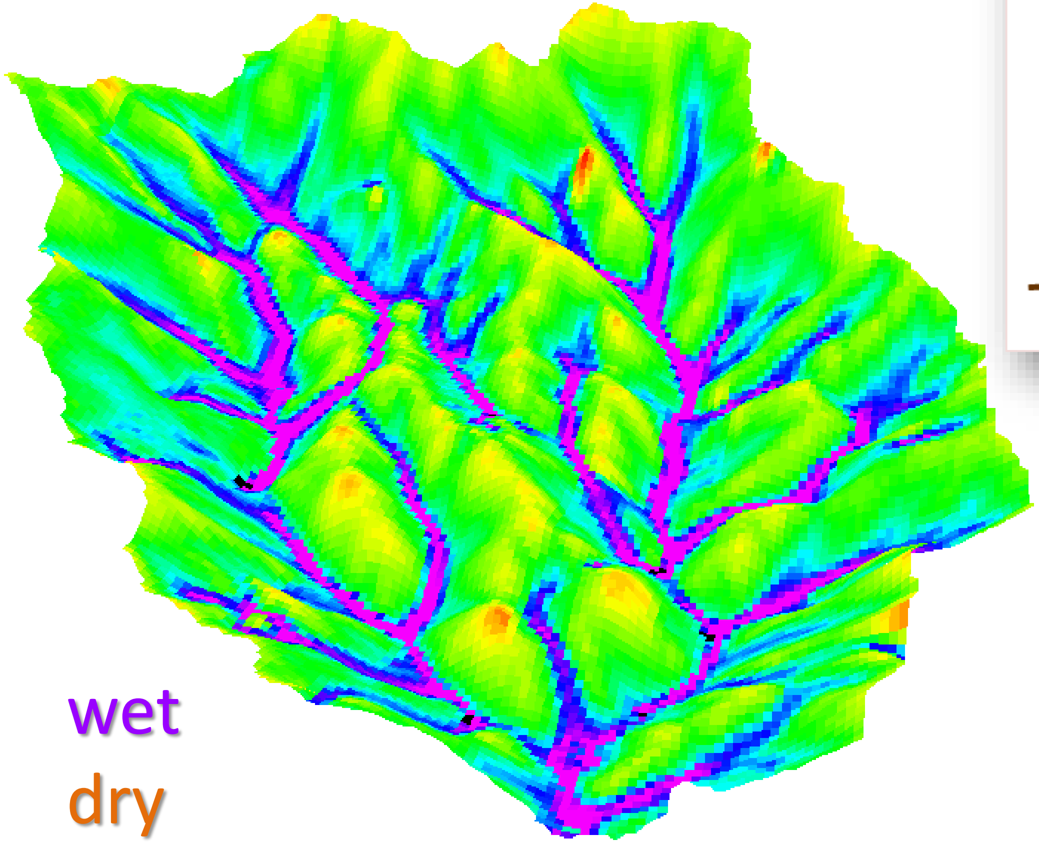






Moisture → Topographic convergence

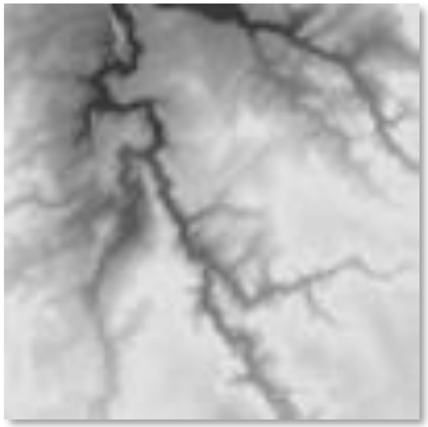




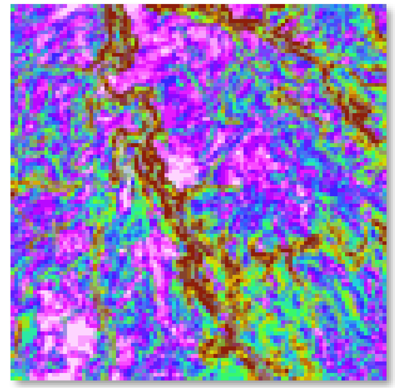
TCI = *ln*[upslope area/*tan*(slope)]

Landscape variables derived from DEM

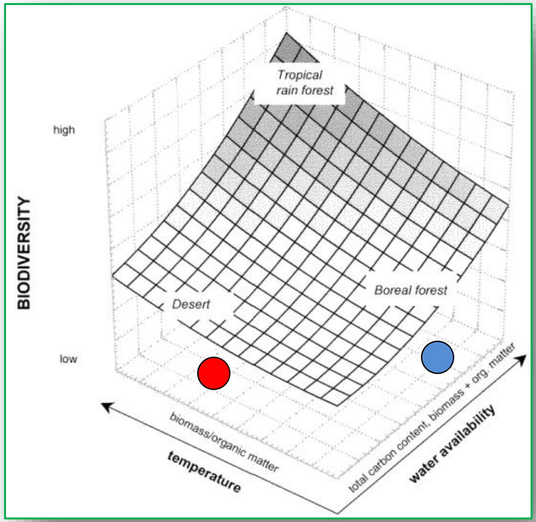
Energy (T°)
Moisture

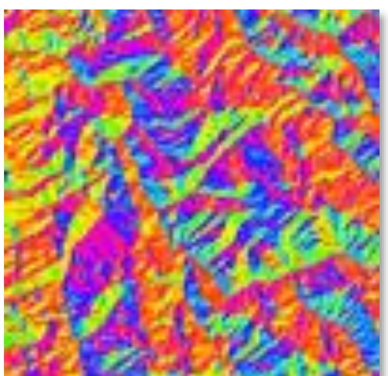


DEM

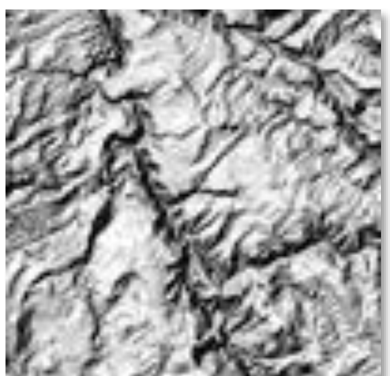


Slope

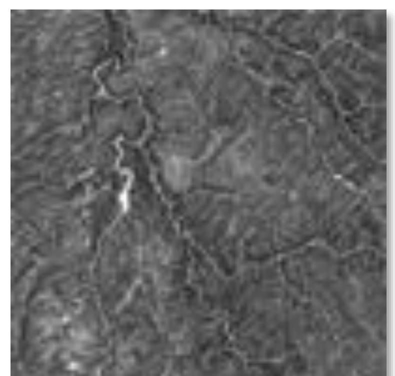




Aspect

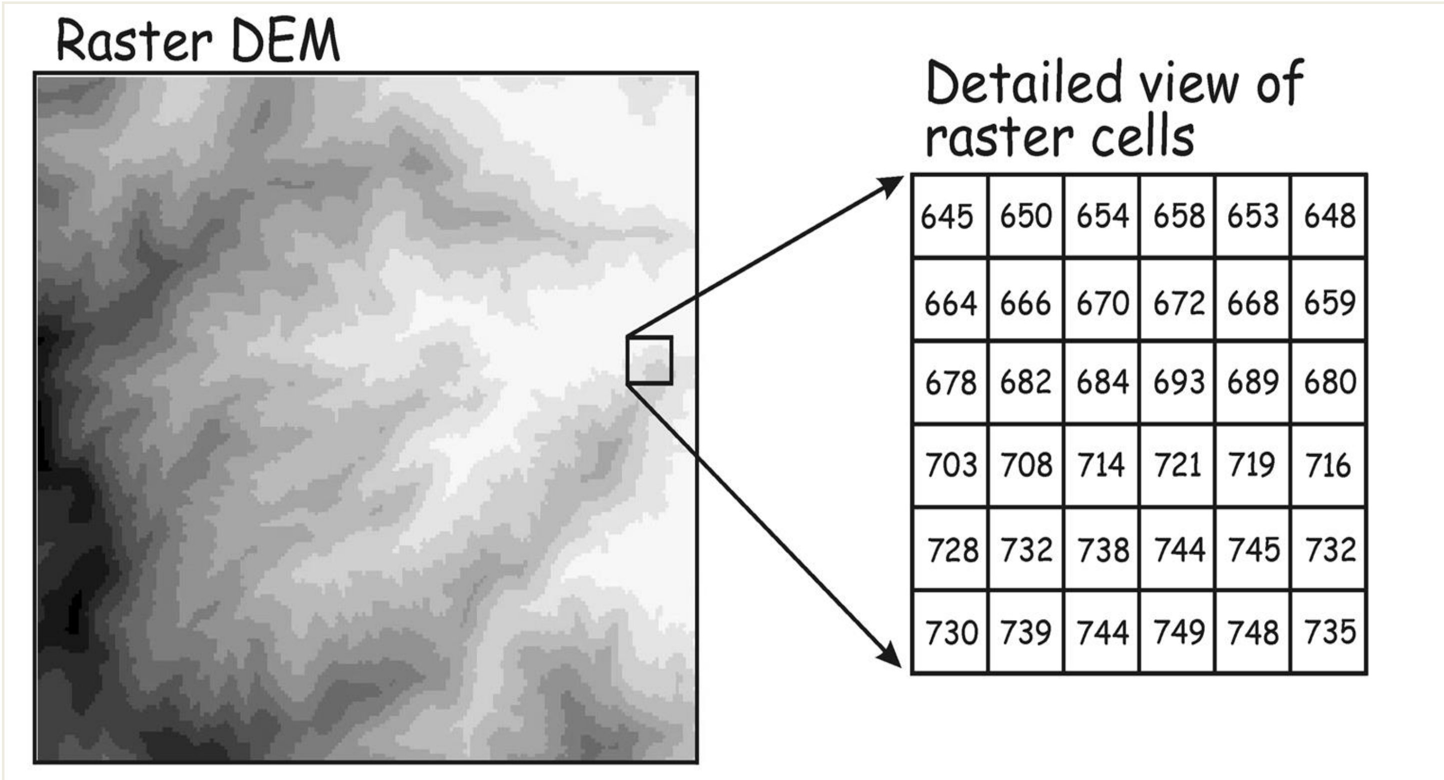


Shaded Relief



Topographic Convergence

Digital Elevation Models



645	650	654	658	653	648
664	666	670	672	668	659
678	682	684	693	689	680
703	708	714	721	719	716
728	732	738	744	745	732
730	739	744	749	748	735

Surface analyses from DEM data

Tool	Description
Aspect	Derives aspect from a raster surface. The aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors.
Contour	Creates a line feature class of contours (isolines) from a raster surface.
Contour List	Creates a feature class of selected contour values from a raster surface.
Contour with Barriers	Creates contours from a raster surface. The inclusion of barrier features will allow one to independently generate contours on either side of a barrier.
Curvature	Calculates the curvature of a raster surface, optionally including profile and plan curvature.
Cut Fill	Calculates the volume change between two surfaces. This is typically used for cut and fill operations.
Hillshade	Creates a shaded relief from a surface raster by considering the illumination source angle and shadows.
Observer Points	Identifies which observer points are visible from each raster surface location.
Slope	Identifies the slope (gradient, or rate of maximum change in z-value) from each cell of a raster surface.
Viewshed	Determines the raster surface locations visible to a set of observer features.

Topographic Slope

Max. rate of change [in elevation] between a cell and its 8 neighbors

Fits a plane to the z-values of a 3 x 3 cell neighborhood around the processing or center cell. The slope value of this plane is calculated using the average maximum technique

a	b	c
d	e	f
g	h	i

50	45	50
30	30	30
8	10	10

```
[dz/dx] = ((c + 2f + i) - (a + 2d + g) / (8 * x_cellsize)        = 0.05

[dz/dy] = ((g + 2h + i) - (a + 2b + c)) / (8 * y_cellsize)       = -3.8
```

59	56	59
71	75	70
60	63	57

$$
\begin{aligned}
rise\_run &= \sqrt{([dz/dx]^2 + [dz/dy]^2)} \\
&= \sqrt{((0.05)^2 + (-3.8)^2)} \\
&= \sqrt{(0.0025 + 14.44)} \\
&= 3.80032
\end{aligned}
$$

Expressed as rise/run (pct. rise) or degrees

Aspect

Downslope direction of the maximum rate of change in [elevation from] each cell to its neighbors

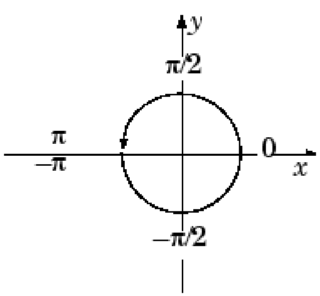
Uses same plane used to derive slope, calculates the downslope angle of this plane, and converts it to a compass direction

a	b	c
d	e	f
g	h	i

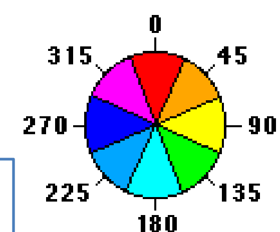
101	92	85
101	92	85
101	91	84

```
[dz/dx] = ((c + 2f + i) - (a + 2d + g)) / 8
        = ((85 + 170 + 84)) - (101 + 202 + 101)) / 8
        = -8.125

[dz/dy] = ((g + 2h + i) - (a + 2b + c)) / 8
        = ((101 + 182 + 84) - (101 + 184 + 85)) / 8
        = -0.375

aspect = 57.29578 * atan2 ([dz/dy], -[dz/dx])
       = 57.29578 * atan2 (-0.375, 8.125)
```

= -2.64




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



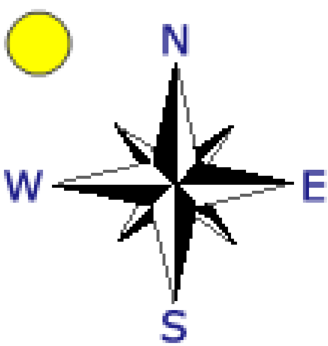
Aspect directions

= 92.64 (East)

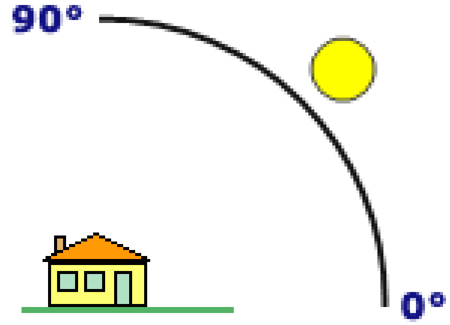
Hillshade

Obtains the hypothetical illumination of a surface by determining illumination values for each cell in a raster

Assigns values (0–255) based on how much light from the hypothetical light source is received (based on aspect and shadowing) of the cell amongst its neighbors.



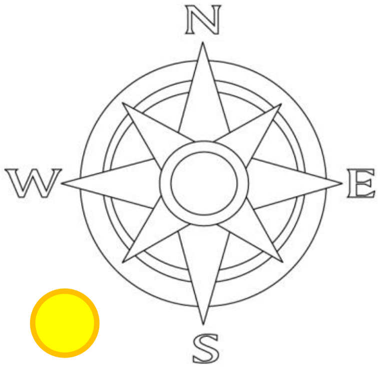
Aziumuth



Altitude

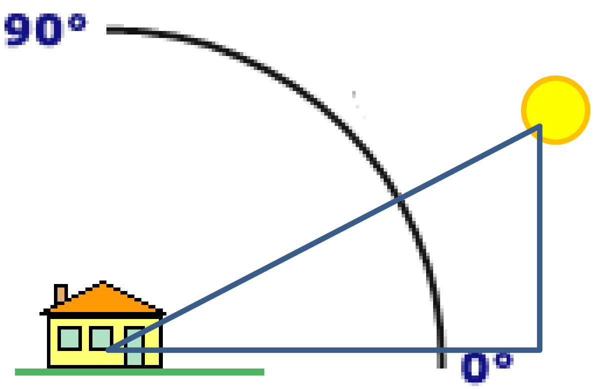
Analytical hillshading (for insolation)

Set sun position to *(for N. America)*:



- ...warming part of day (afternoon): Azimuth = 225° (SW)

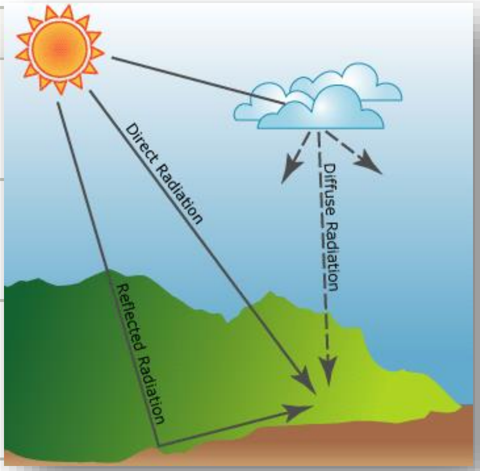
- ...average high point in sky (during growing season): Altitude = 30°



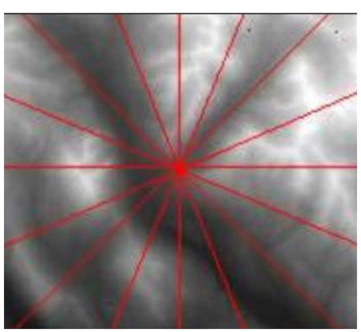
- *Alternatively, use solar calculators get precise solar angle: http://www.esrl.noaa.gov/gmd/grad/solcalc/*

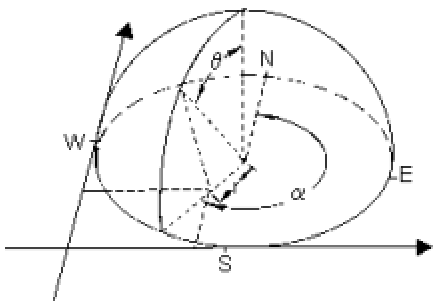
Other insolation tools

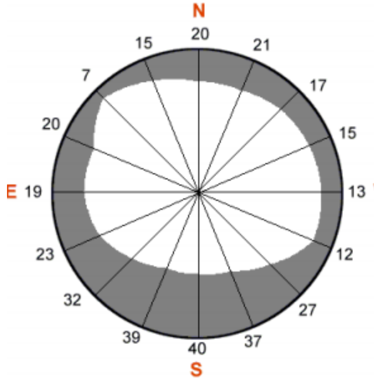
Tool	Description
Area Solar Radiation	Derives incoming solar radiation from a raster surface.
Points Solar Radiation	Derives incoming solar radiation for specific locations in a point feature class or location table.
Solar Radiation Graphics	Derives raster representations of a hemispherical viewshed, sunmap, and skymap, which are used in the calculation of direct, diffuse, and global solar radiation.

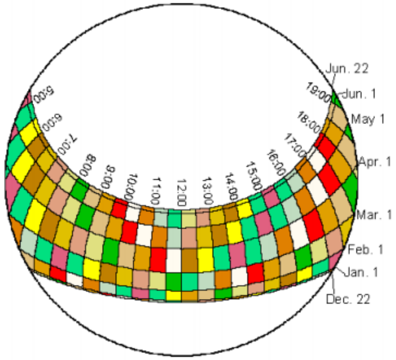


http://www.fs.fed.us/informs/solaranalyst/solar_analyst_users_guide.pdf









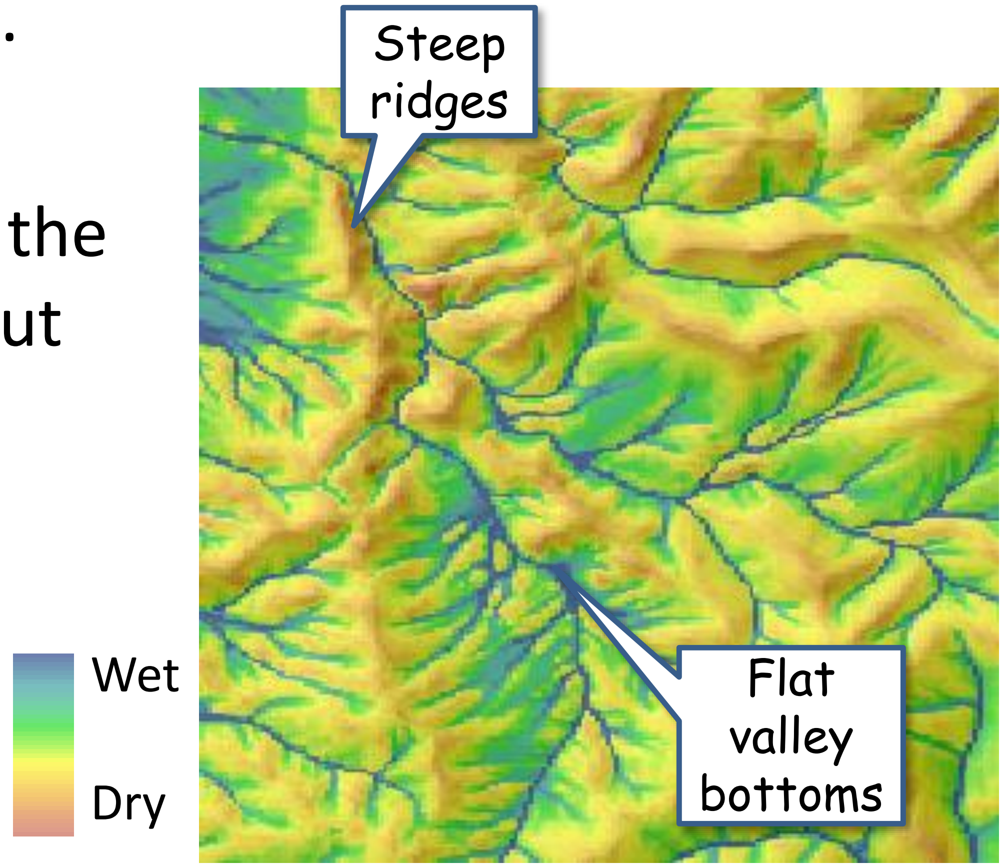
Topographic Convergence Index (TCI)

Estimates moisture from upstream area & slope

- The more area a location drains, the more surface runoff is likely to pass through it.

- The steeper the location, the less likely moisture stay put

$$\frac{\ln(Accumulation)}{\tan(Slope)}$$



Topographic Position

Calculates local convexity and concavity by comparing a cell's elevation relative to its neighbors.

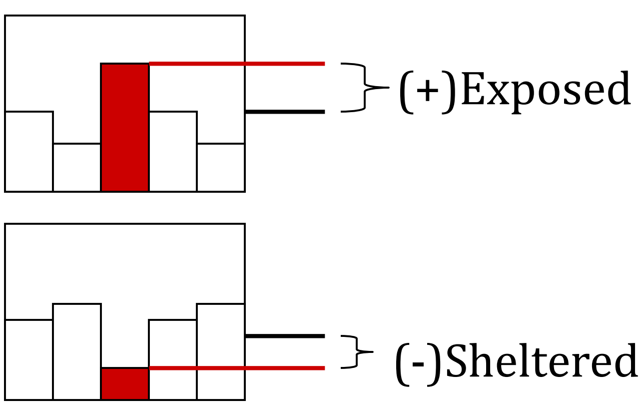
50	45	50
30	30	30
8	10	10

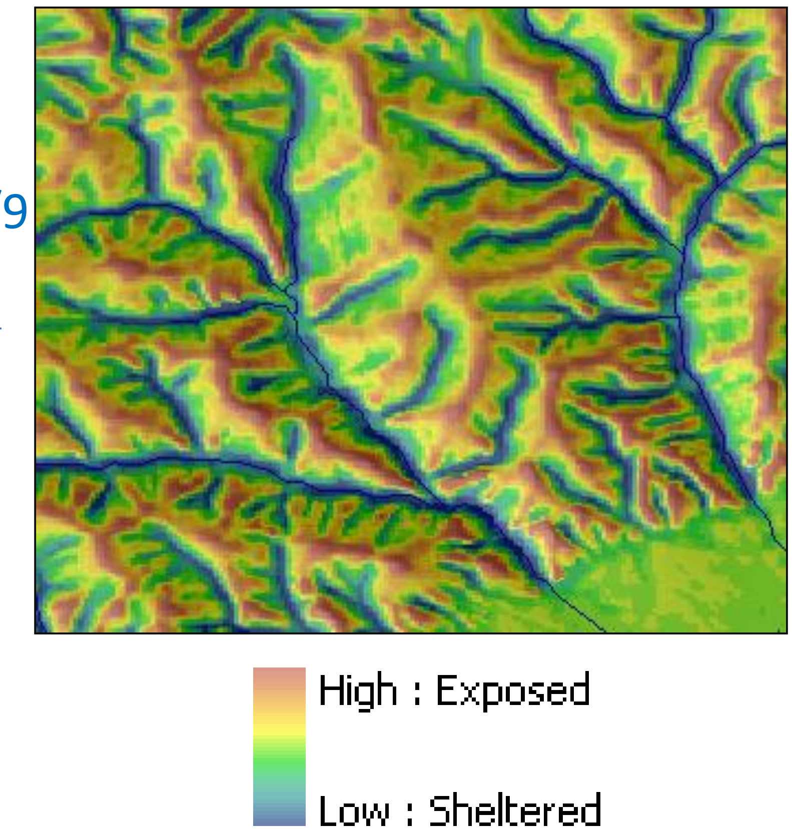
Mean elev (3x3):

= (50+45+50+30+30+30+8+10+10)/9

= 29.2

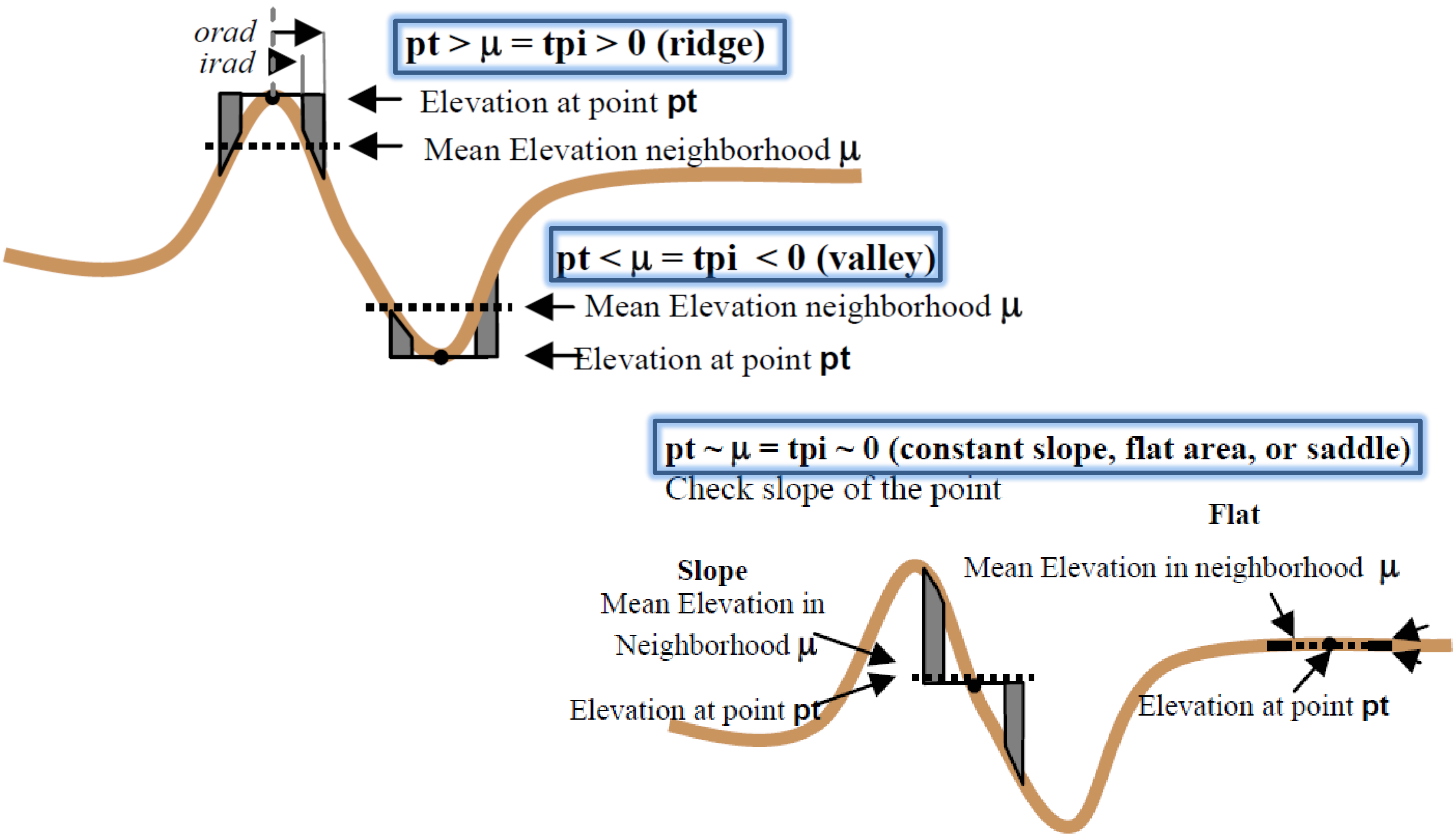
30 – 29.2 = 0.8 = *exposed (convex)*





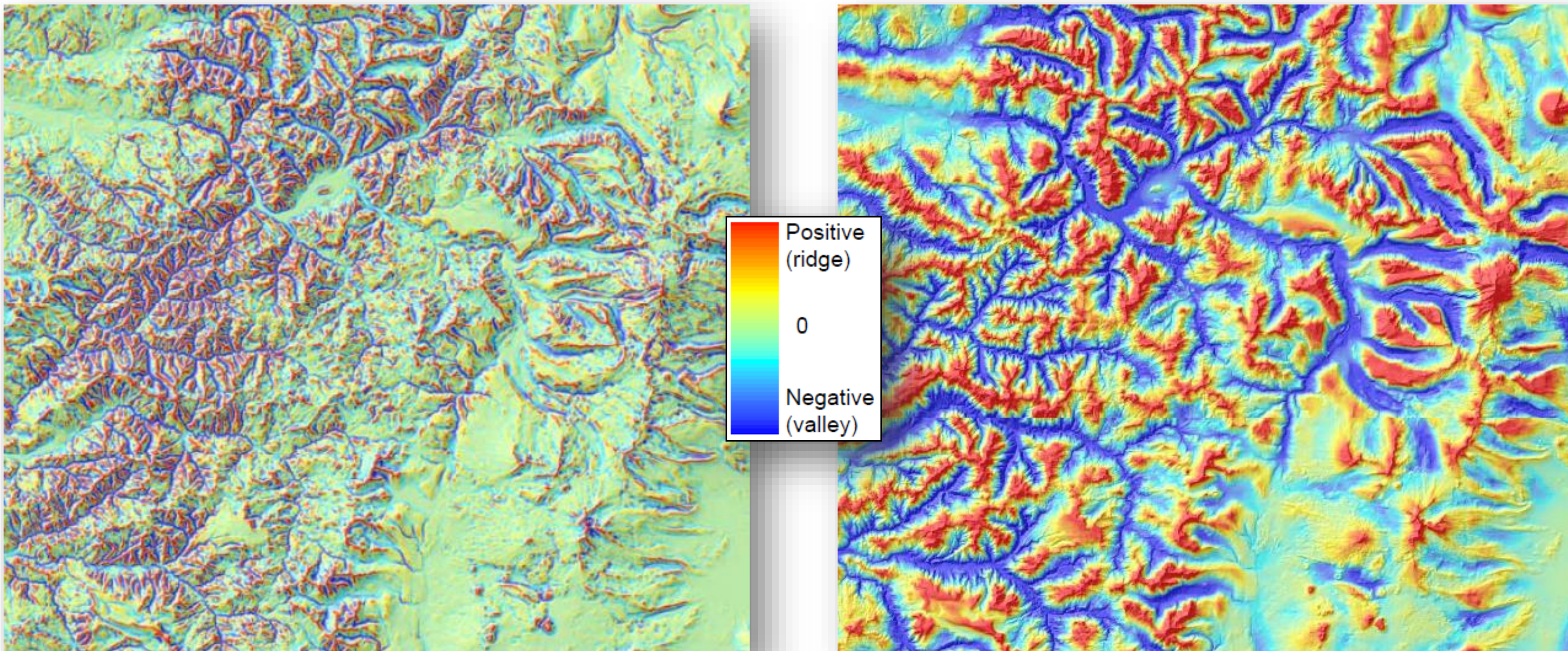
Topographic Position

http://www.jennessent.com/downloads/tpi-poster-tnc_18x22.pdf



Topographic position

- Adjusting the neighborhood reveals different features…



tpi300 = int((dem – focalmean(dem, annulus, 5, 10)) + 0.5)

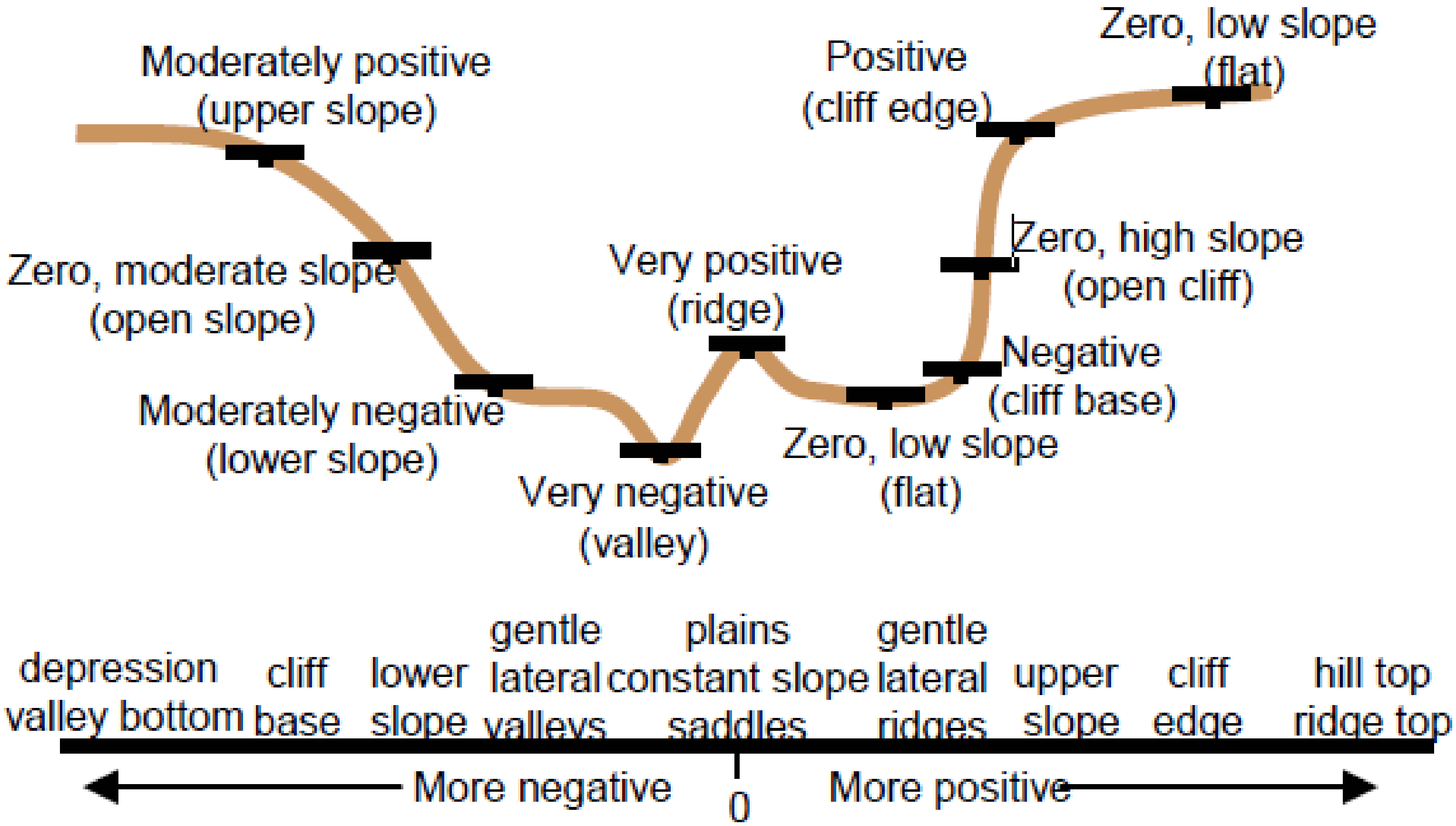
tpi2000 = int((dem – focalmean(dem, annulus, 62, 67)) + 0.5)

The Nature Conservancy
SAVING THE LAST GREAT PLACES ON EARTH

Topographic Position and Landforms Analysis
Andrew D. Weiss, The Nature Conservancy

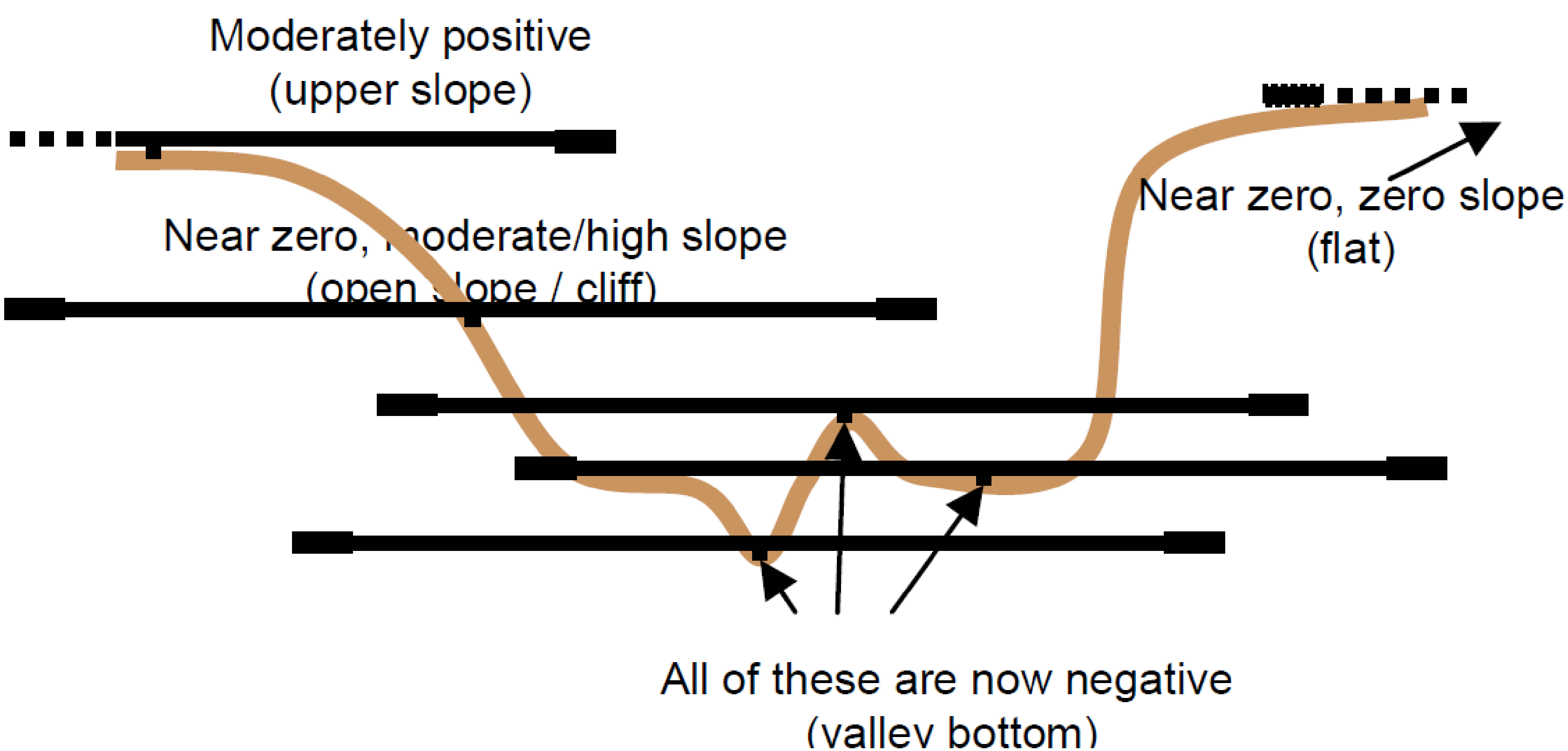
Slope position

By thresholding the continuous TPI values **at a given scale**, and checking the slope for values near zero, landscapes can be classified into discrete slope position classes.



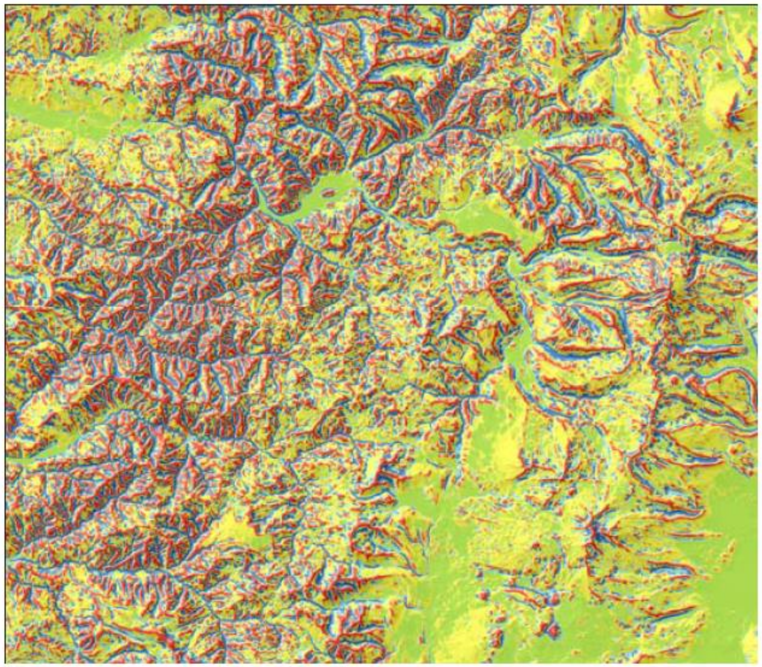
Slope position

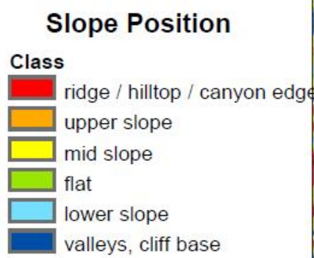
A larger scale TPI makes the entire large valley a valley



Slope position

Fig. 3b – tpi300 thresholded by standard deviation units into 6 slope position classes





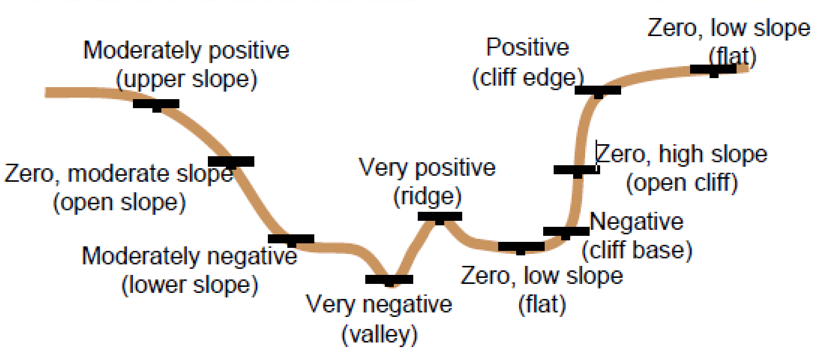
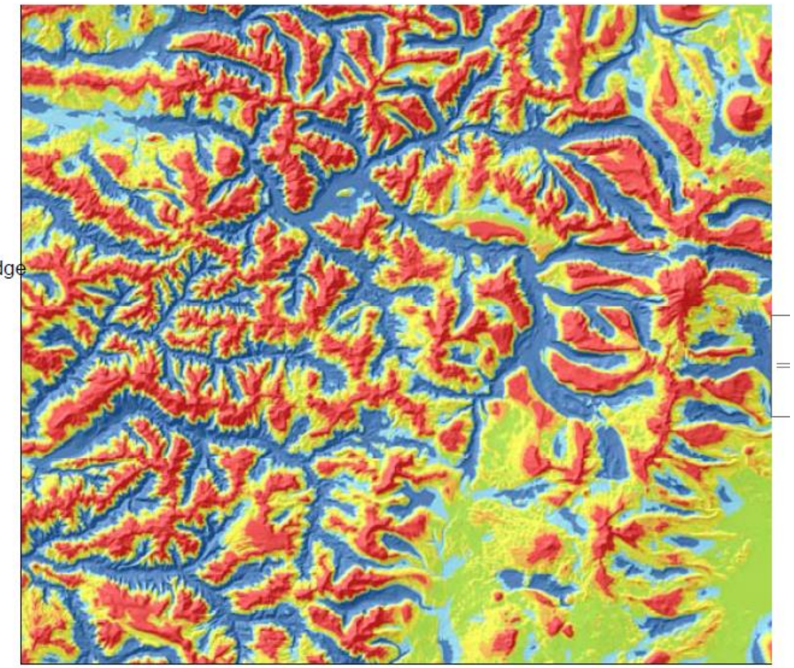
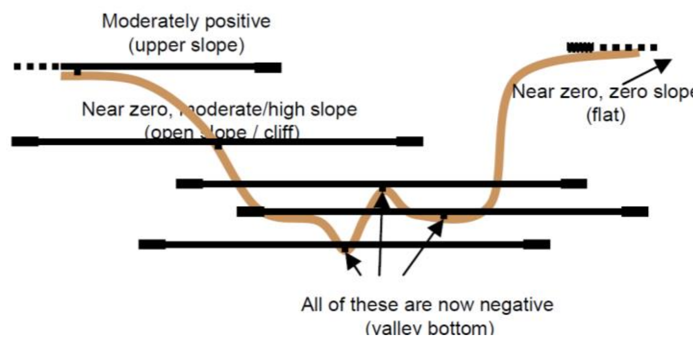


Fig. 3c – tpi2000 thresholded by standard deviation units into 6 slope position classes



A larger scale TPI makes the entire large valley a valley



Slope position

- Choosing thresholds in calculating Slope Position

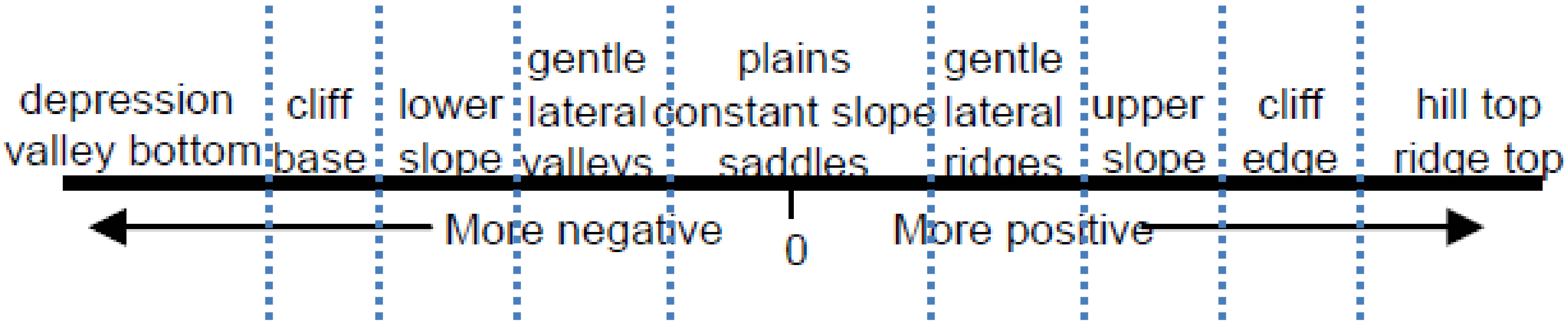


Table 1
Classification of the landscape into slope position classes.

Morphologic class	Weiss (2001)	Northwestern Belgium
Ridge	$z_0 > SD$	$z_0 > SD$
Upper slope	$SD \geq z_0 > 0.5SD$	$SD \geq z_0 > 0.5SD$
Middle slope	$0.5SD \geq z_0 \geq -0.5SD$, slope $> 5°$	Pos. values: $0.5SD \geq z_0 \geq 0$
Flat area	$0.5SD \geq z_0 \geq -0.5SD$, slope $\leq 5°$	Neg. values: $0 > z_0 \geq -0.5SD$
Lower slope	$-0.5SD > z_0 \geq -SD$	$-0.5SD > z_0 \geq -SD$
Valley	$z_0 < -SD$	$z_0 < -SD$

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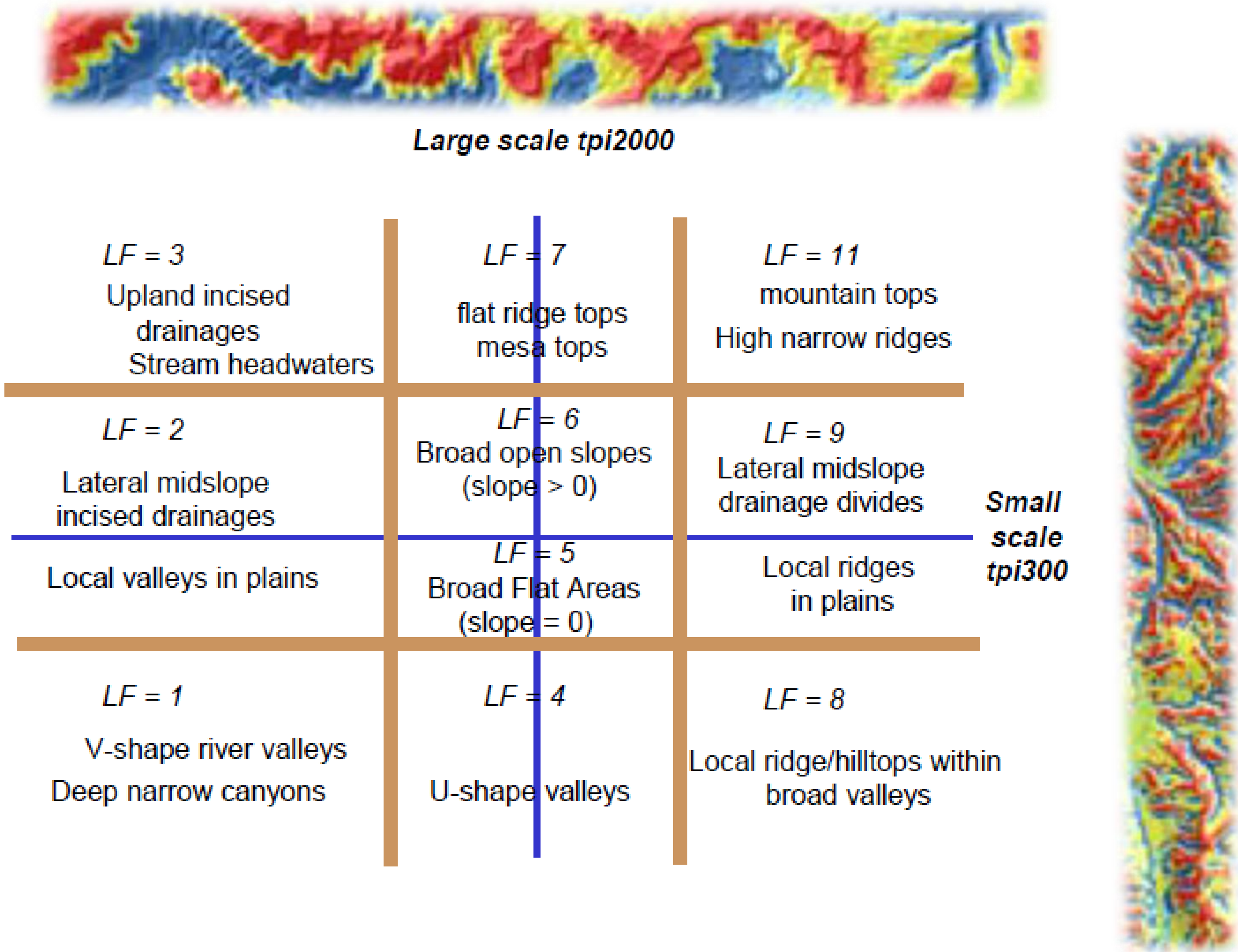
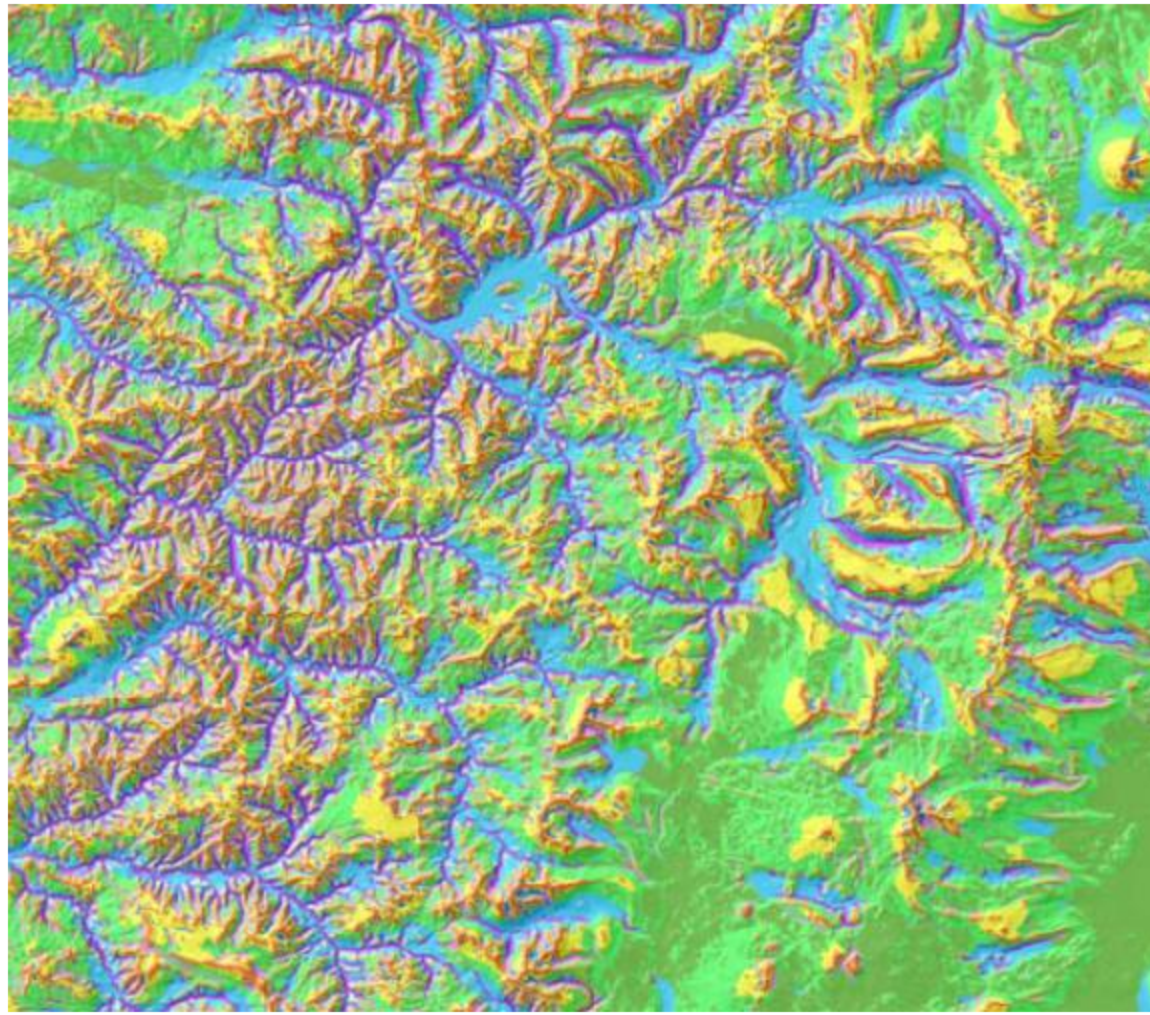
Land form



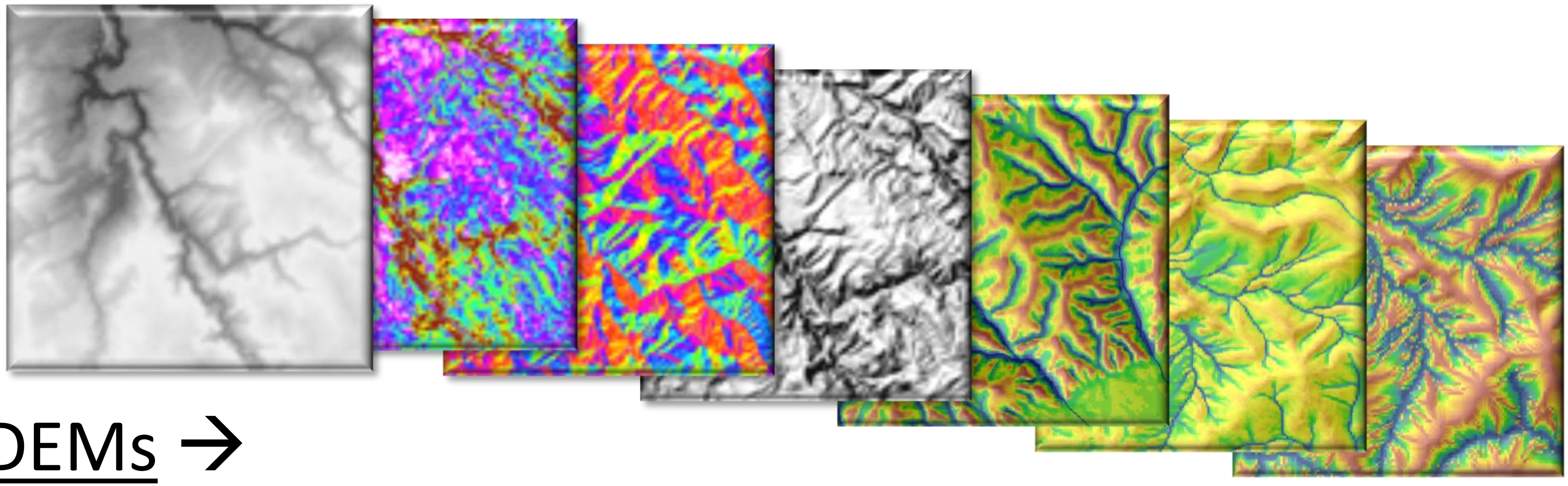
Large scale tpi2000
LF = 3
Upland incised drainages
Stream headwaters
LF = 7
flat ridge tops
mesa tops
LF = 11
mountain tops
High narrow ridges
LF = 2
Lateral midslope incised drainages
LF = 6
Broad open slopes
(slope > 0)
LF = 9
Lateral midslope drainage divides
Local valleys in plains
LF = 5
Broad Flat Areas
(slope = 0)
Local ridges in plains
LF = 1
V-shape river valleys
Deep narrow canyons
LF = 4
U-shape valleys
LF = 8
Local ridge/hilltops within broad valleys
Small scale tpi300

Land form

- Canyons, deeply incised streams
- Midslope drainages, shallow valleys
- Upland drainages, headwaters
- U-shaped valleys
- Plains
- Open slopes
- Upper slopes, mesas
- Local ridges/hills in valleys
- Midslope ridges, small hills in plains
- Mt tops, high ridges



Surface analyses: summary



DEMs →

- Slope
- Aspect
- Insolation
- Topo. position
- Topo. convergence
- Slope position
- Land form

Gradients

- Temperature
- Moisture

Biodiversity Proxies

Landscape Vegetation Patterns

Habitat Suitability

What's next

- In lab: create models to calculate these terrain surface parameters
- In lecture: move forward with hydrology tools to examine riparian zone dynamics