

# ALGORITMI GEOMORFOMETRICI

Gran parte degli algoritmi geomorfometrici sono derivati dai DEM mediante quella che viene chiamata *neighborhood analysis* (analisi di vicinanza).

Si tratta di una procedura attraverso la quale matrici di piccole dimensioni (**moving windows**) si muovono partendo dalla prima cella in alto a sinistra fino ad arrivare all'ultima in basso a destra, ripercorrendo tutto il raster e ripetendo una formula matematica ad ogni posizionamento.

# Una delle applicazioni permette di determinare l'acclività (SLOPE)

In generale, la PENDENZA esprime la massima variazione del valore di quota relativo ad un insieme di celle del sistema di rappresentazione del DEM.

Può essere espressa in gradi ( $^{\circ}$ ) o in percentuale (%).

|        |       |       |
|--------|-------|-------|
| -1, 1  | 0, 1  | 1, 1  |
| -1, 0  | 0, 0  | 1, 0  |
| -1, -1 | 0, -1 | 1, -1 |

Matrice 3x3

|        |        |       |       |       |
|--------|--------|-------|-------|-------|
| -2, 2  | -1, 2  | 0, 2  | 1, 2  | 2, 2  |
| -2, 1  | -1, 1  | 0, 1  | 1, 1  | 2, 1  |
| -2, 0  | -1, 0  | 0, 0  | 1, 0  | 2, 0  |
| -2, -1 | -1, -1 | 0, -1 | 1, -1 | 2, -1 |
| -2, -2 | -1, -2 | 0, -2 | 1, -2 | 2, -2 |

Matrice 5x5

$G$  is the first derivative in the  $x$  direction ( $dz/dx$ )

$H$  is the first derivative in the  $y$  direction ( $dz/dy$ )

$z_{NB5}$  is the (central) cell for which the final value of slope is desired

$z_{NB1,2,3,4,6,7,8,9}$  are the eight neighbouring cells

$s$  is pixel size in metres

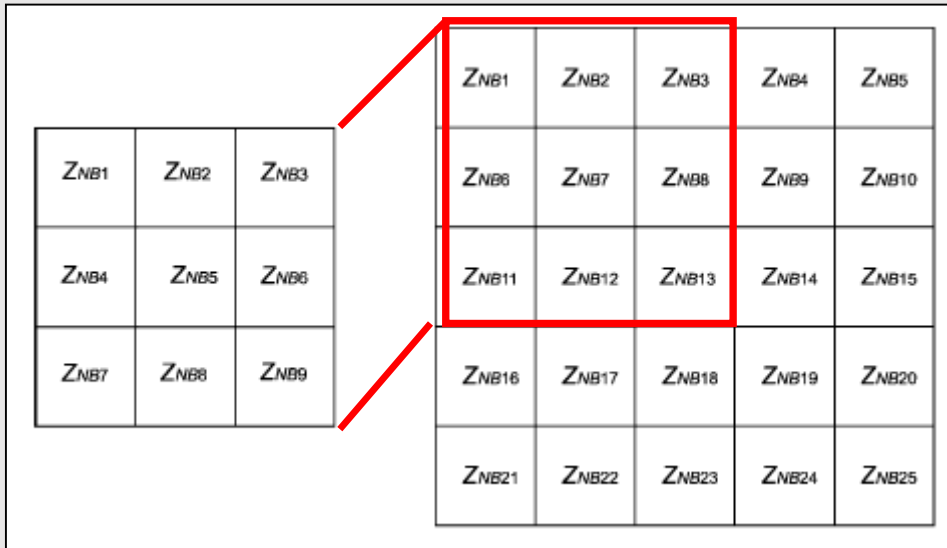
The slope gradient as a tangent is finally computed as:

## METODO DI EVANS-YOUNG

$$\text{SLOPE} = \sqrt{H^2 + G^2}$$

$$G = \frac{z_{NB3} + z_{NB6} + z_{NB9} - z_{NB1} - z_{NB4} - z_{NB7}}{6 \cdot \Delta s}$$

$$H = \frac{z_{NB1} + z_{NB2} + z_{NB3} - z_{NB7} - z_{NB8} - z_{NB9}}{6 \cdot \Delta s}$$



2 elevations 1

|    |    |    |    |    |    |
|----|----|----|----|----|----|
| 10 | 16 | 23 | 16 | 9  | 6  |
| 14 | 11 | 18 | 11 | 18 | 19 |
| 19 | 15 | 13 | 21 | 23 | 25 |
| 22 | 20 | 19 | 14 | 38 | 45 |
| 24 | 20 | 20 | 28 | 18 | 49 |
| 23 | 24 | 34 | 38 | 45 | 51 |

G  $\frac{23+18+13-10-14-19}{6 \times 10} = 0.1833$

|       |       |      |       |       |       |
|-------|-------|------|-------|-------|-------|
| 0.15  | 0.50  | 0.00 | -0.47 | -0.20 | -0.08 |
| -0.02 | 0.18  | 0.10 | -0.07 | 0.03  | 0.00  |
| -0.12 | -0.05 | 0.00 | 0.48  | 0.72  | 0.17  |
| -0.13 | -0.18 | 0.13 | 0.45  | 0.93  | 0.67  |
| -0.05 | 0.10  | 0.27 | 0.47  | 1.08  | 0.73  |
| -0.03 | 0.30  | 0.60 | 0.33  | 0.78  | 0.72  |

Su una matrice 6x6, uso una finestra 3x3 e il metodo di **Evans-Young** per il calcolo della pendenza in %

H

$\frac{19+15+13-10-16-23}{6 \times 10} = -0.0333$

df/dy

|       |       |       |       |       |       |
|-------|-------|-------|-------|-------|-------|
| -0.05 | 0.10  | 0.25  | 0.02  | -0.28 | -0.58 |
| -0.28 | -0.03 | 0.10  | -0.15 | -0.63 | -0.87 |
| -0.35 | -0.27 | -0.22 | -0.40 | -0.82 | -1.20 |
| -0.25 | -0.28 | -0.32 | -0.15 | -0.43 | -0.72 |
| -0.17 | -0.37 | -0.72 | -0.77 | -0.62 | -0.32 |
| -0.03 | -0.28 | -0.47 | -0.85 | -0.65 | -0.52 |

$\sqrt{(0.1833)^2 + (-0.0333)^2} = 19\%$

|    |    |    |    |     |     |
|----|----|----|----|-----|-----|
| 16 | 51 | 25 | 47 | 35  | 59  |
| 28 | 19 | 14 | 16 | 63  | 87  |
| 37 | 27 | 22 | 63 | 109 | 121 |
| 28 | 34 | 34 | 47 | 103 | 98  |
| 17 | 38 | 77 | 90 | 125 | 80  |
| 5  | 41 | 76 | 91 | 102 | 88  |

slope (%)

# Come calcolo lo SLOPE con ArcGIS?

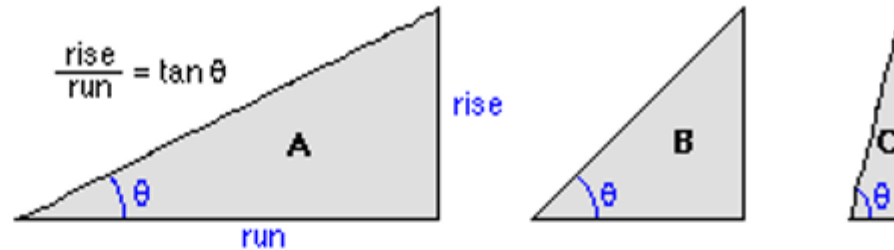
La PENDENZA esprime la massima variazione del valore di quota relativo ad un insieme di celle del sistema di rappresentazione del DEM.

## Metodo di HORN 1981

Calcola, per ogni cella del modello “raster-grid” ed in relazione alle celle immediatamente circostanti a quella considerata, il tasso massimo di variazione del valore di altitudine (coordinata Z) rispetto al piano di riferimento; la funzione opera progressivamente per un porzione di raster comprendente le otto celle immediatamente circostanti a quella soggetta al calcolo (in totale vengono considerate ad ogni calcolo 3 x 3 celle). Gli output della funzione possono essere espressi secondo due diverse unità di misura fondamentali ovvero: **pendenza espressa in gradi (°)** oppure **pendenza espressa in percentuale (%)**.

Degree of slope =  $\theta$

Percent of slope =  $\frac{\text{rise}}{\text{run}} * 100$



|                    |    |     |     |
|--------------------|----|-----|-----|
| Degree of slope =  | 30 | 45  | 76  |
| Percent of slope = | 58 | 100 | 373 |

|   |   |   |
|---|---|---|
| a | b | c |
| d | e | f |
| g | h | i |

$$\frac{dz}{dx} = \frac{(c + 2f + i) - (a + 2d + g)}{8 * x\_cell\_size}$$

$$\frac{dz}{dy} = \frac{(g + 2h + i) - (a + 2b + c)}{8 * y\_cell\_size}$$

$$S = \sqrt{\left(\frac{dz}{dx}\right)^2 + \left(\frac{dz}{dy}\right)^2} \quad \text{deg} = \text{atan}(S)$$

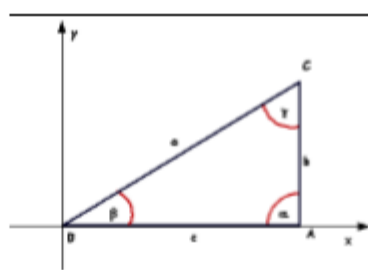
$$S = dz/dh$$

$$S = \tan(\theta)$$

$$\text{Slope (\%)} = (S) * 100$$

$$\text{Slope (deg)} = \tan^{-1}(S) * (360/2\pi)$$

$$\text{Slope (rad)} = \tan^{-1}(S)$$

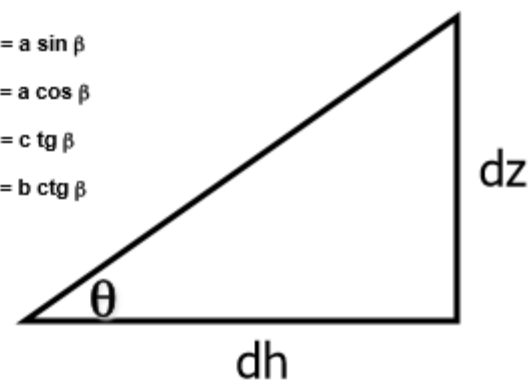


$$b = a \sin \beta$$

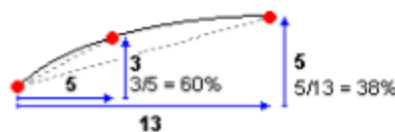
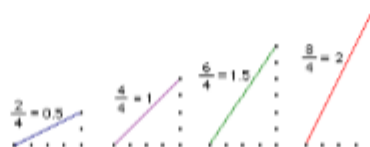
$$c = a \cos \beta$$

$$b = c \operatorname{tg} \beta$$

$$c = b \operatorname{ctg} \beta$$



$$S = 1 = 100\% = 45^\circ$$



$$\begin{aligned} [dz/dx] &= ((c + 2f + i) - (a + 2d + g)) / (8 * x_{cell\_size}) \\ &= ((50 + 60 + 10) - (50 + 60 + 8)) / (8 * 5) \\ &= (120 - 118) / 40 \\ &= 0.05 \end{aligned}$$

$$\begin{aligned} [dz/dy] &= ((g + 2h + i) - (a + 2b + c)) / (8 * x_{cell\_size}) \\ &= ((8 + 20 + 10) - (50 + 90 + 50)) / (8 * 5) \\ &= (38 - 190) / 40 \\ &= -3.8 \end{aligned}$$

|    |    |    |
|----|----|----|
| 5m |    |    |
| 50 | 45 | 50 |
| 30 | 30 | 30 |
| 8  | 10 | 10 |

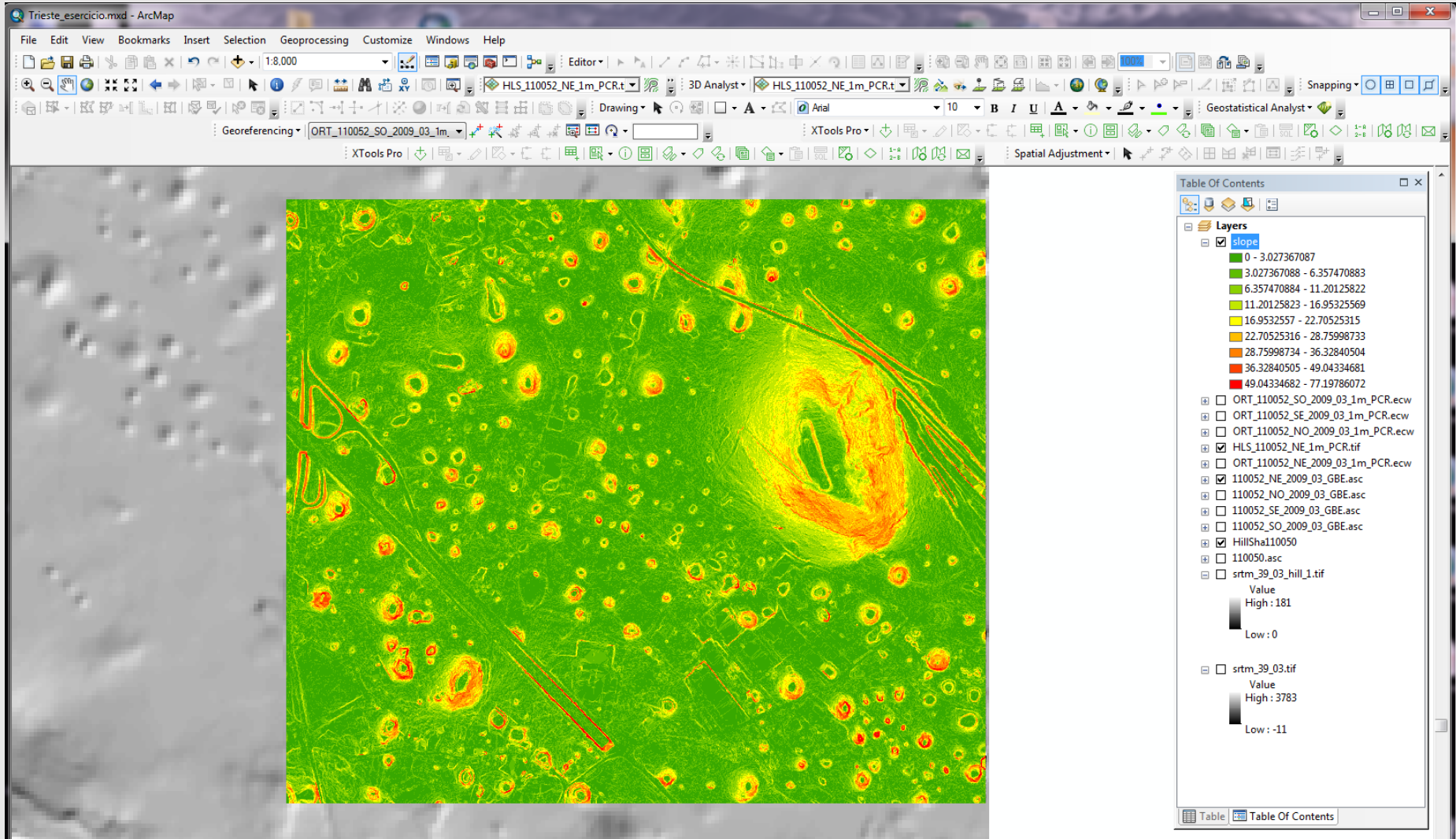
5m
⇒

|    |    |    |
|----|----|----|
| 50 | 56 | 59 |
| 71 | 75 | 70 |
| 60 | 63 | 57 |

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

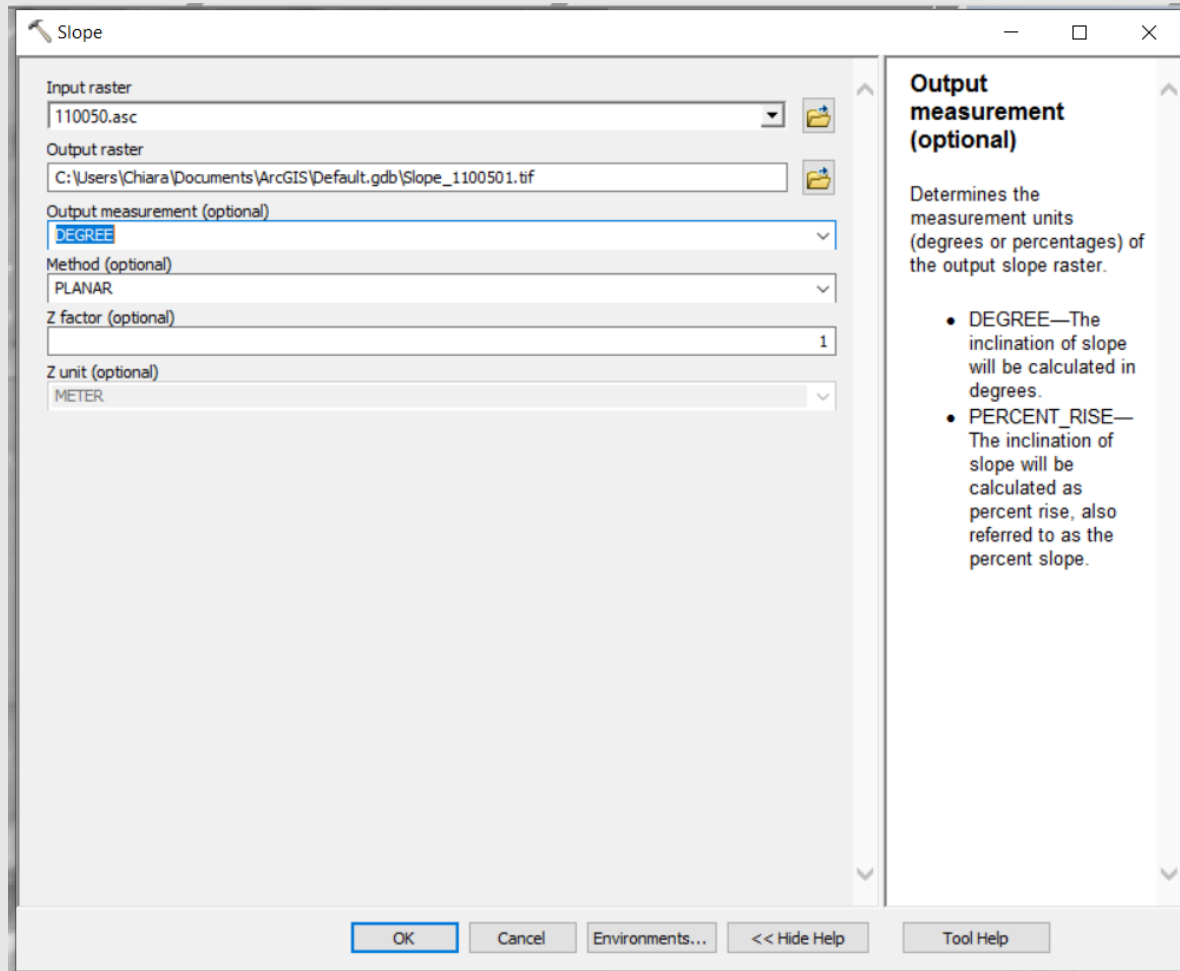
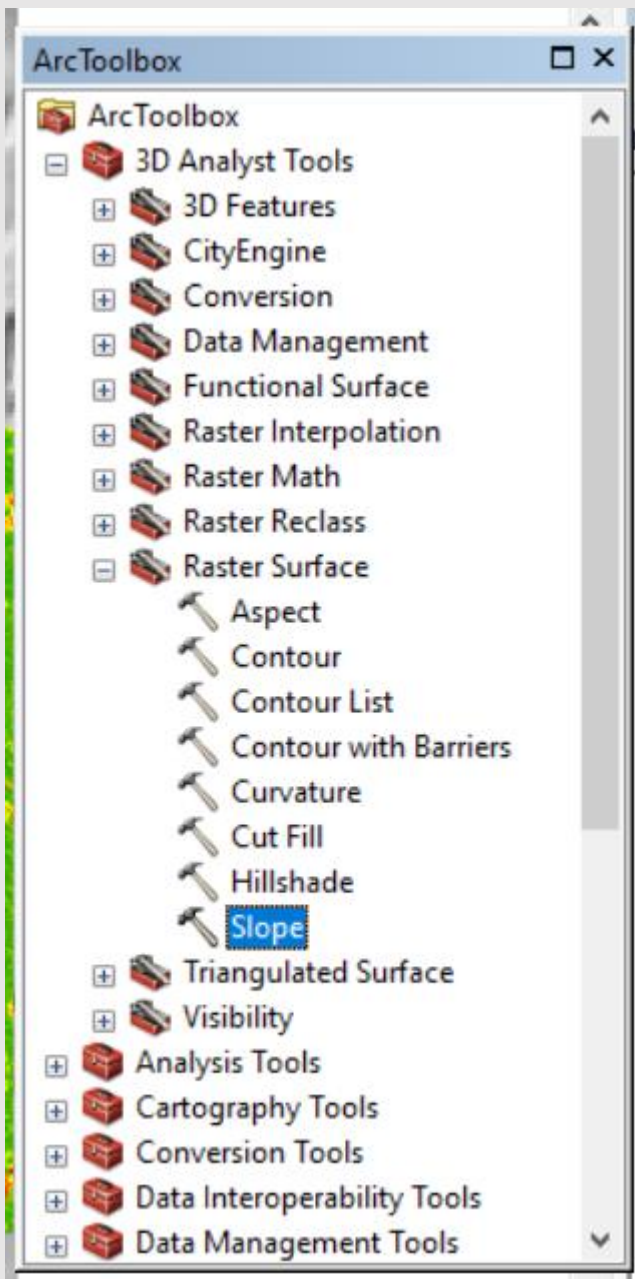
$$\begin{aligned} \text{Slope(rad)} &= \arctan(S) \\ \text{Slope(deg)} &= \arctan(S) * (360/2\pi) \\ &= \arctan(3.80032) * 57.29578 \\ &= 1.31349 * 57.29578 \\ &= 75.25762 \end{aligned}$$

# SLOPE in ArcGIS in °





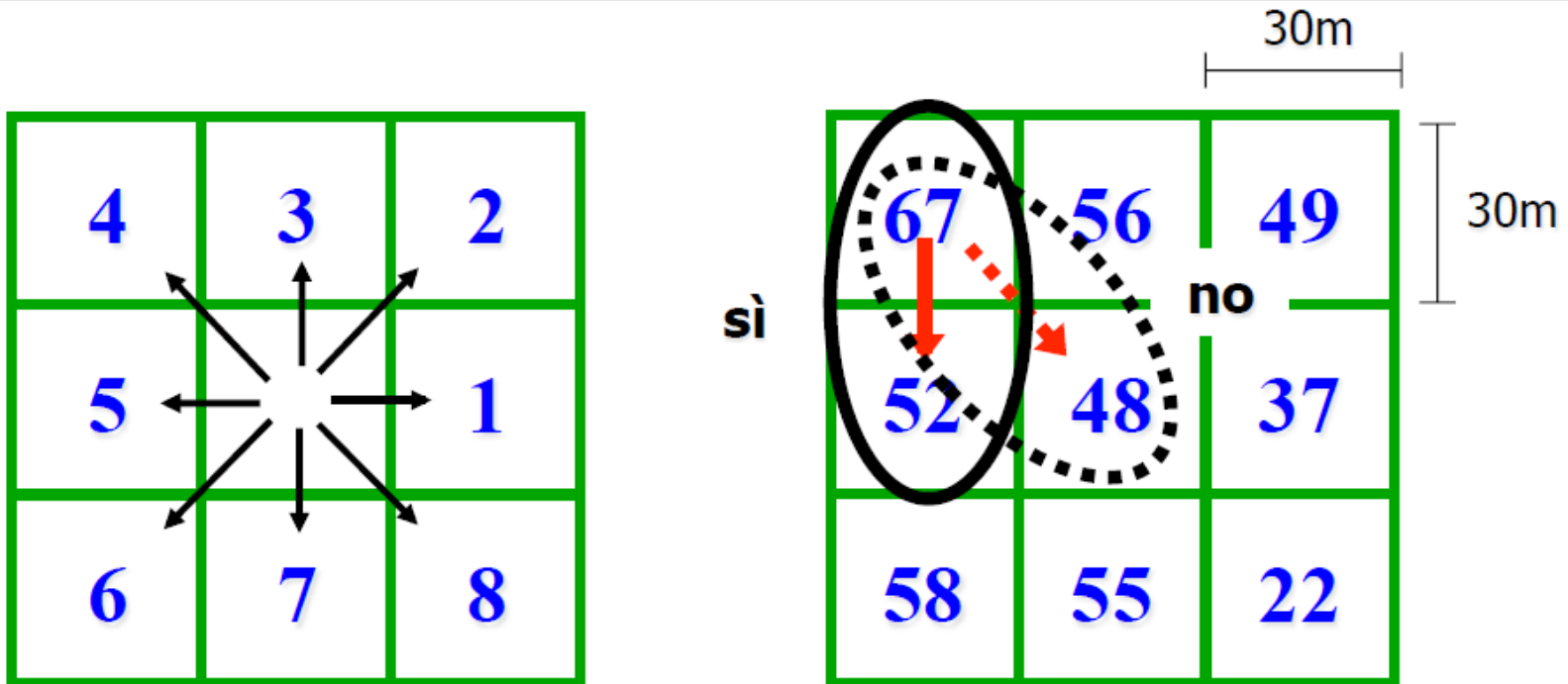
# SLOPE in ArcGIS in ° come lo ottengo?



# PENDENZA LOCALE

Permette di identificare le direzioni di drenaggio

Eight Direction Pour Point Model D8 (O'Challangan and Mark, 1984)



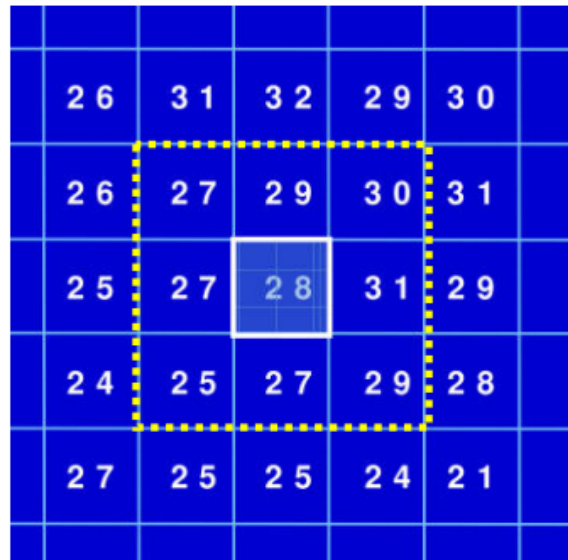
Definisce la direzione di massima pendenza da una cella ad una delle otto celle adiacenti

Slope (S) =  $dz/dh$   
Steepest down slope direction

$$\frac{67 - 52}{30} = 0.50$$

$$\frac{67 - 48}{30\sqrt{2}} = 0.45$$

# Esempio di calcolo



dimensione celle: 10 x 10 m



## Pendenze individuali

$$N = [(29 - 28) / 10] * 100 = 10\%$$

$$NE = [(30 - 28) / 14] * 100 = 14\%$$

$$E = [(31 - 28) / 10] * 100 = 30\%$$

$$SE = [(29 - 28) / 14] * 100 = 7\%$$

$$S = [(27 - 28) / 10] * 100 = -10\%$$

$$SW = [(25 - 28) / 14] * 100 = -21\%$$

$$W = [(27 - 28) / 10] * 100 = -10\%$$

$$NW = [(27 - 28) / 14] * 100 = -7\%$$

Massimo = 30 %    Mediana = 10%    Media = 13%



La distanza tra i centri di due celle adiacenti è diversa a seconda della direzione considerata !

# Esempio di calcolo

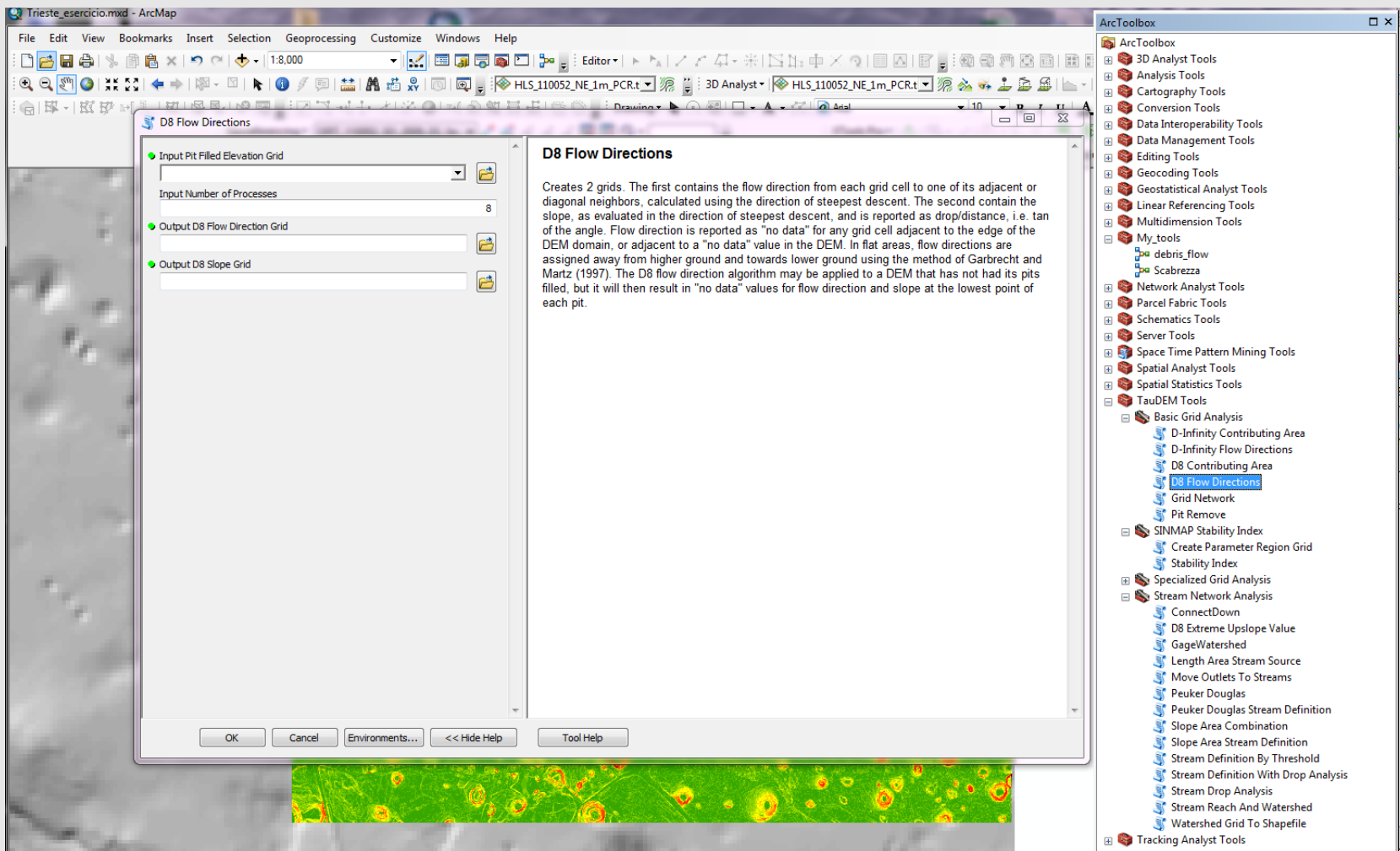


$$\text{Slope} = (\text{rise} / \text{run}) \cdot 100$$

Il segno della pendenza indica la **direzione del flusso superficiale**:

- positivo  $\Rightarrow$  flussi entranti nella cella
- negativo  $\Rightarrow$  flussi uscenti dalla cella

# Tau DEM Tool

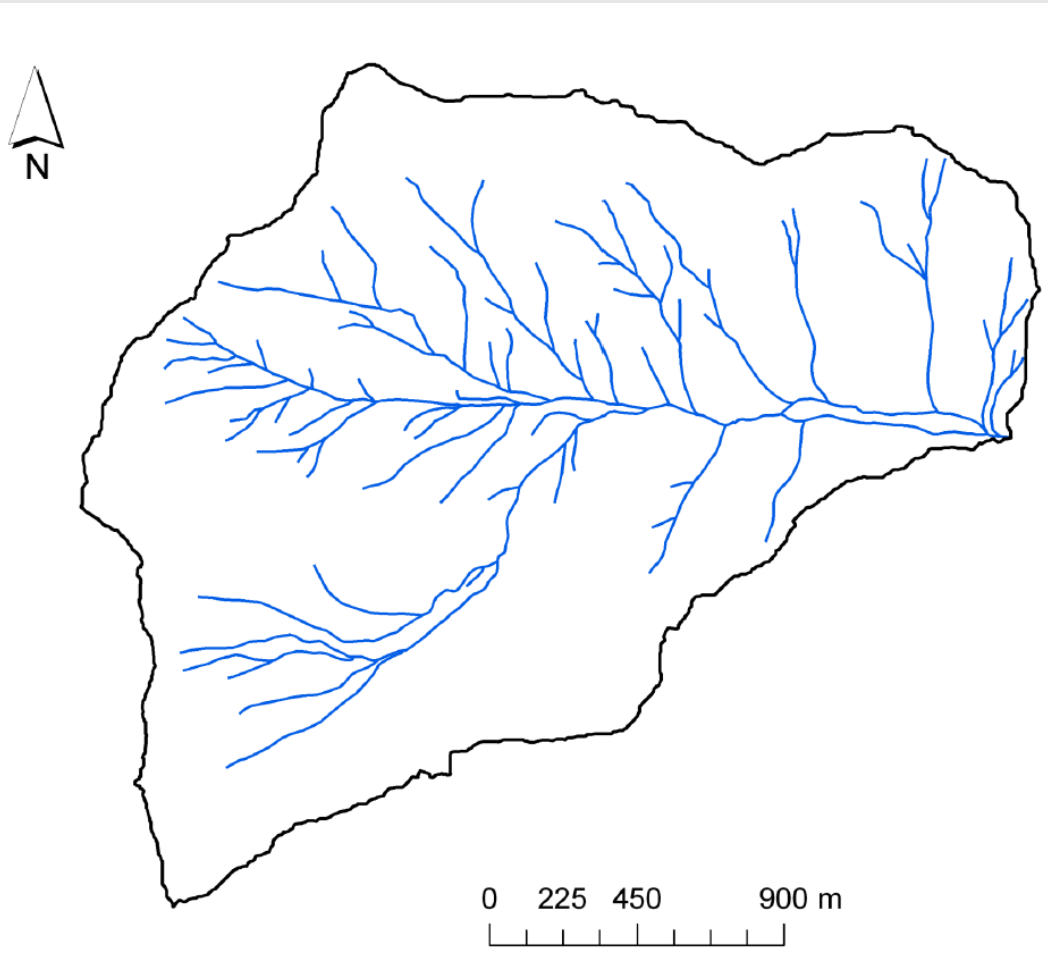


Algoritmo TauDEM scaricabile da:

<http://hydrology.usu.edu/taudem/taudem5/downloads2.html>

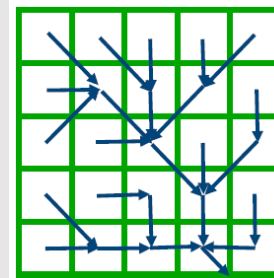
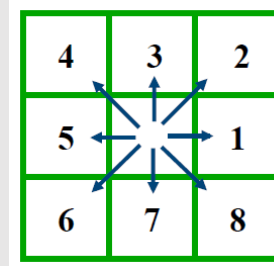
Chiara Calligaris, Ph.D. – D.M.G. Università degli Studi di Trieste

# A cosa serve tutto questo???



A ricavare da un DEM, un  
RETICOLO IDROGRAFICO  
DI SINTESI

Eight direction pour point model D8



A 5x5 grid of numbers representing drainage areas. The central cell (row 3, column 3) is highlighted with a red border. The values are: Row 1: 1, 1, 1, 1, 1; Row 2: 1, 4, 3, 3, 1; Row 3: 1, 1, 12, 1, 2; Row 4: 1, 1, 2, 16, 1; Row 5: 1, 3, 6, 25, 2.

Drainage Area

Grid network

Tarolli, Cavalli, 2017 – Geomorphometry course

# CURVATURA

Il parametro curvatura **esprime la vera e propria curvatura (concavità e/o convessità) di una superficie rappresentata da un DEM**. Una curvatura caratterizzata da valore negativo identifica la presenza di una superficie convessa mentre, al contrario, una curvatura caratterizzata da valore positivo identifica la presenza di una superficie concava. Un valore uguale a zero indica infine la presenza di una superficie pianeggiante.

$$\nabla^2 z = \left( \frac{\partial^2 z}{\partial x^2} + \frac{\partial^2 z}{\partial y^2} \right)$$

z rappresenta la quota

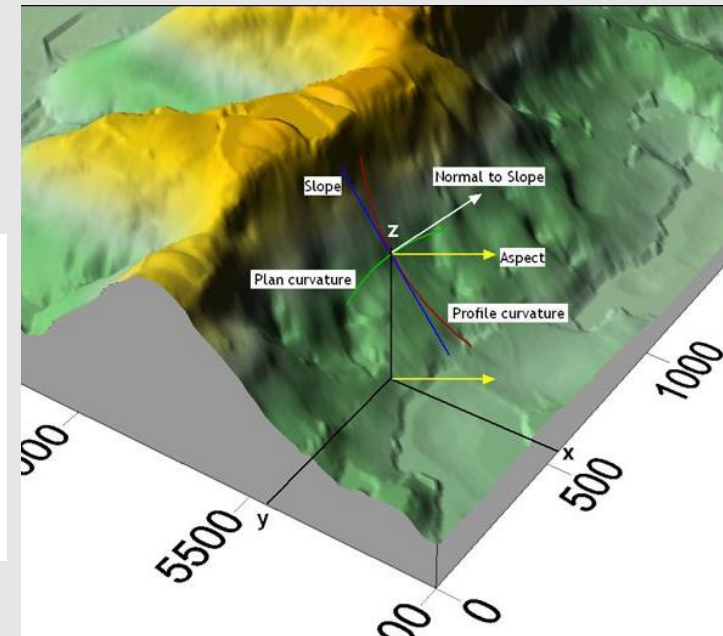
$\frac{\partial^2 z}{\partial x^2}$  rappresenta il grado di convergenza e/o divergenza perpendicolare alla linea di massima pendenza

$\frac{\partial^2 z}{\partial y^2}$  rappresenta la convessità e/o la concavità lungo la direzione della massima pendenza.

$\nabla^2 z < 0$  (superficie divergente/convessa): processi di versante non canalizzati;

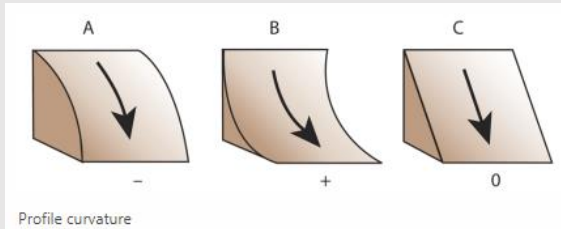
$\nabla^2 z > 0$  (superficie concava/convergente): processi canalizzati;

Derivata seconda della superficie polinomiale di quarto ordine calcolata su una finestra 3x3 (Zevenbergen and Thorne, 1987)

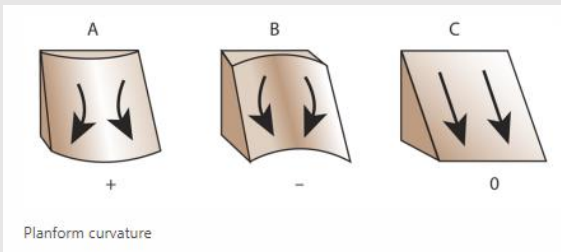


Tarolli, 2017 – Geomorphometry course

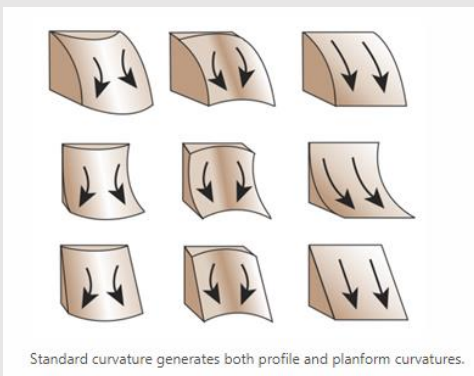
# TIPI DI CURVATURA



La **Profile curvature** indica la direzione di massima pendenza di un versante. Interessa l'accelerazione e la decelerazione del flusso attraverso la superficie. Un valore negativo **(A)** indica che la superficie è convessa verso l'alto in quella cella e il flusso sarà decelerato. Un profilo positivo **(B)** indica che la superficie è concava verso l'alto e favorirà l'accelerazione del flusso. Un valore di zero indica che la superficie è lineare **(C)**.



La **Planform curvature** (comunemente definita **plan curvature**) è perpendicolare alla direzione della massima pendenza. Fa riferimento alla convergenza o divergenza di flusso lungo una superficie. Un valore positivo **(A)** è indice di una superficie convessa lateralmente in corrispondenza di una determinata cella. Un valore negativo **(B)** indica che la superficie è naturalmente concava in corrispondenza della cella. Un valore di zero indica che la superficie non ha curvature, è lineare **(C)**.



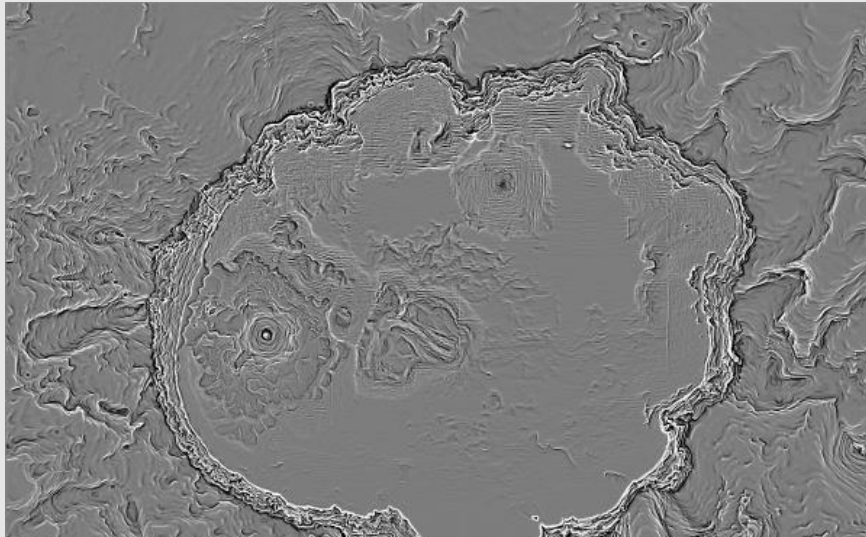
La **Standard curvature** combina entrambe le tipologie di curvature. La profile curvature condiziona l'accelerazione e/o la decelerazione di un flusso che scorre sulla superficie e pertanto, influenza i processi di erosione e di deposizione. La plan curvature influenza la convergenza o divergenza di un flusso. Considerando entrambe le tipologie, è possibile capire in maniera più accurata la modalità di scorrimento del flusso su una superficie.

Di fianco: Le colonne mostrano la plan curvature e le righe la profile curvature.

Le planform columns sono positive, negative, o andando da sinistra a destra. Le profile curves sono negative, positive, o -0, procedendo dall'alto verso il basso.

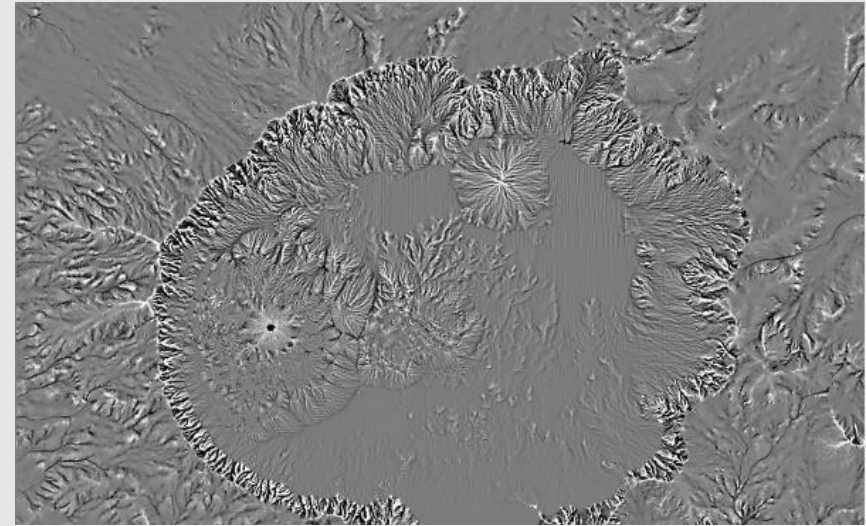


# Profile curvature



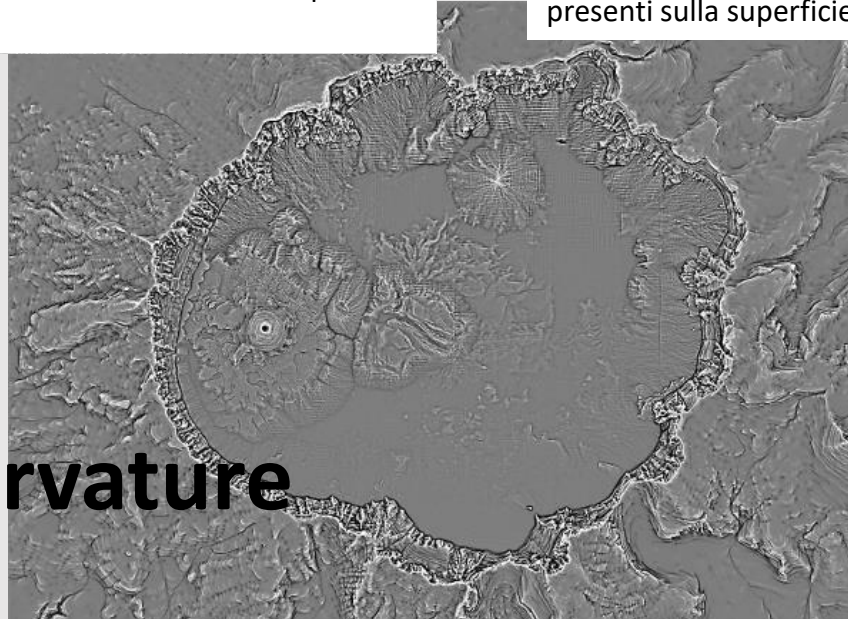
Su questo raster vengono enfatizzati i terrazzamenti presenti sulla superficie.

# Plan curvature



Su questo raster vengono enfatizzati le creste e le valli presenti sulla superficie.

# Standard curvature



Su questo raster vengono enfatizzate le creste, le valli, ma anche i terrazzamenti a scapito di tutte le morfologie.

# Landform Curvature

The DTM surface is approximated by a bivariate quadratic function ([Evans, 1979](#)), where  $x$ ,  $y$ , and  $Z$  are local coordinates, and  $a$  to  $f$  are quadratic coefficients. The coefficients can be solved within a window using simple combinations of neighboring cell. It performs well in the presence of elevation errors ([Albani et al. 2004](#); [Florinsky 1998](#))

$$Z = ax^2 + by^2 + cxy + dx + ey + f$$

According to [Evans \(1979\)](#) it is possible to derive two measures of minimum (concavity) and maximum (convexity) curvature with a multiple-scale parameterization by generalizing the calculation for different window sizes.

$$C_{\max} = n * g \left( -a - b + \sqrt{(a-b)^2 + c^2} \right)$$
$$C_{\min} = n * g \left( -a - b - \sqrt{(a-b)^2 + c^2} \right)$$

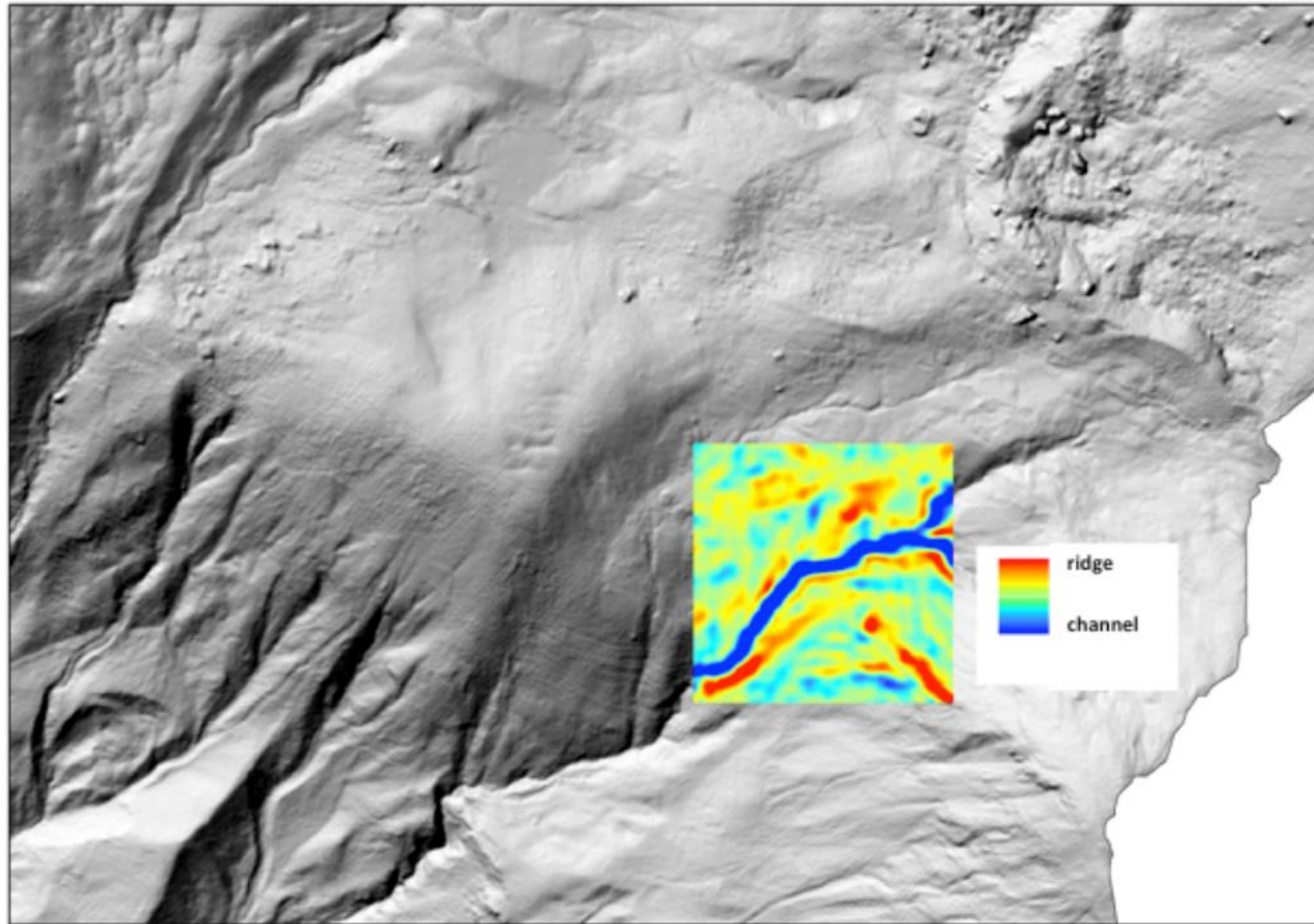
where  $g$  is the grid resolution of the DTM, and  $n$  is the size of the moving window

Nevertheless several method for curvature calculation are available. The work of [Shmidt et al. \(2003\)](#) gives a clear idea of this, it summarizes 17 different curvature measures clarifying the confusion caused by different terminologies

Tarolli, 2017

# Il risultato

## Landform curvature

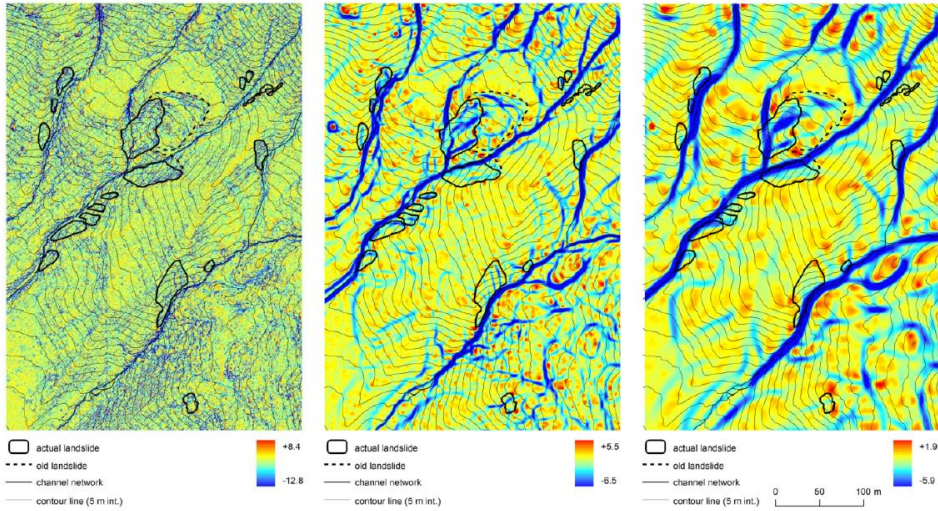


0 75 150 m

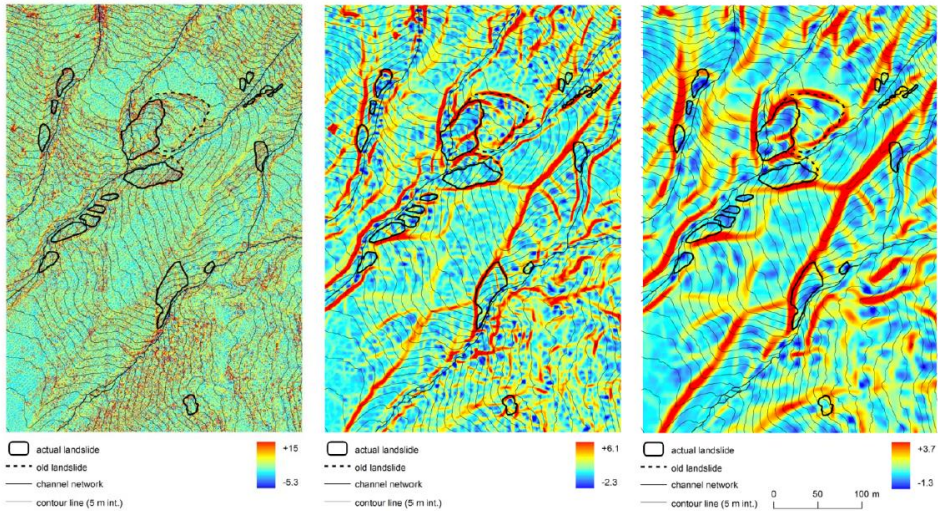
Tarolli, 2017

Chiara Calligaris, Ph.D. – D.M.G. Università degli Studi di Trieste

# Curvatura minima

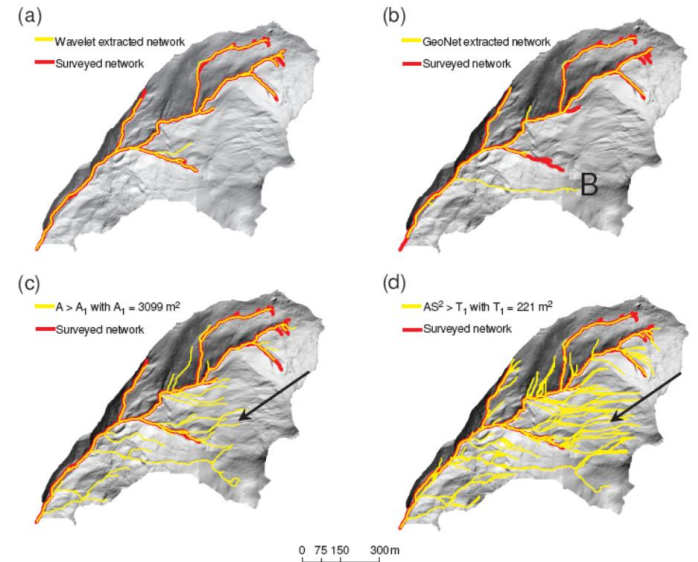


Pirotti and Tarolli, HP (2010)



Tarolli, Sofia, and Dalla Fontana, NH (2012)

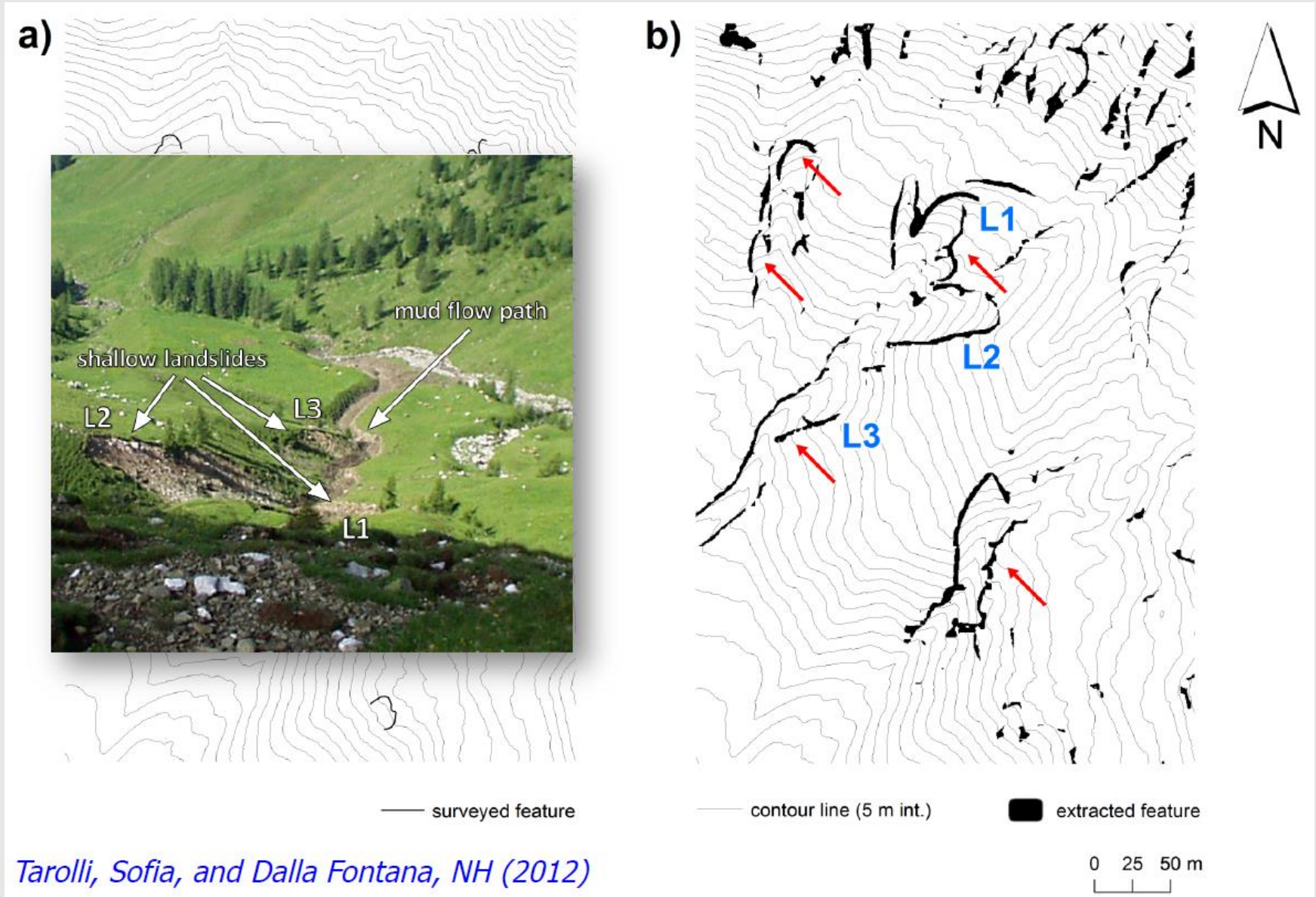
Passalacqua, P., Tarolli, P., Fofoula-Georgiou, E. (2010). Testing space-scale methodologies for automatic geomorphic feature extraction from LIDAR in a complex mountainous landscape, *Water Resources Research*, 46, W11535, ISSN: 0043-1397, doi:10.1029/2009WR008812



Paolo Tarolli – Dip. TeSAF (Territorio e Sistemi Agro-Forestali) – Università di Padova

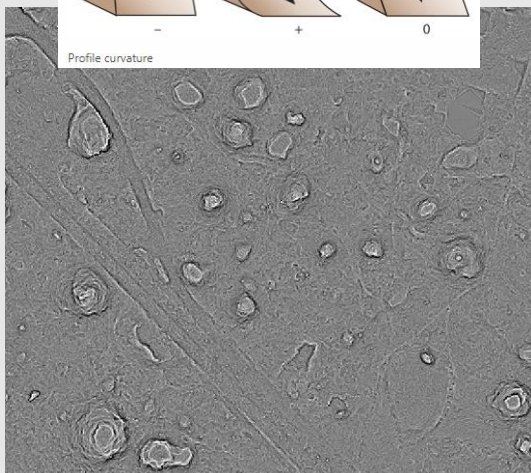
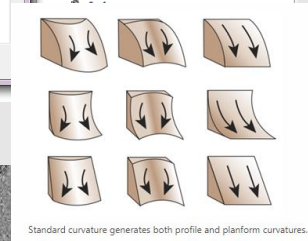
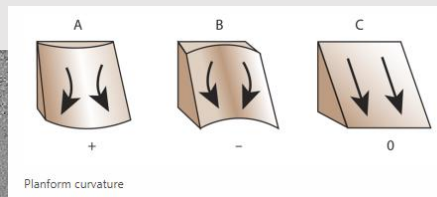
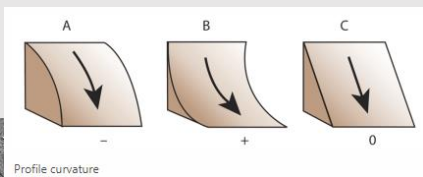
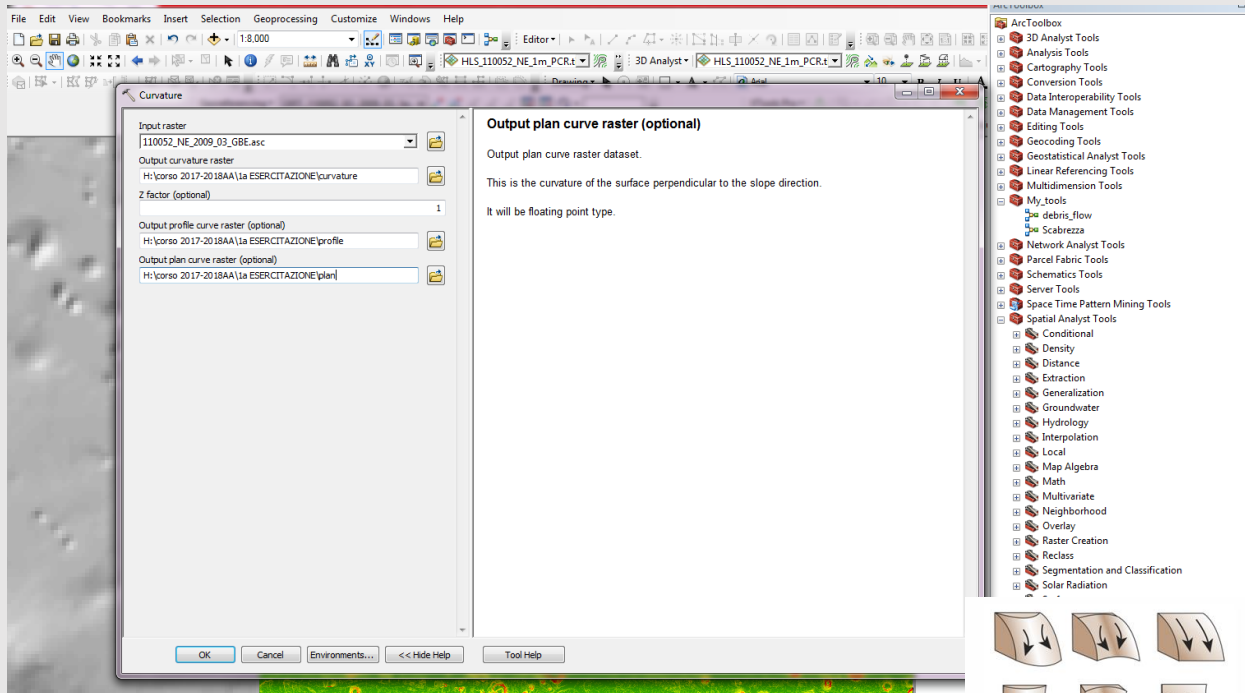
# Curvatura massima

# La curvatura della superficie come strumento per il riconoscimento e l'estrazione delle nicchie di frana

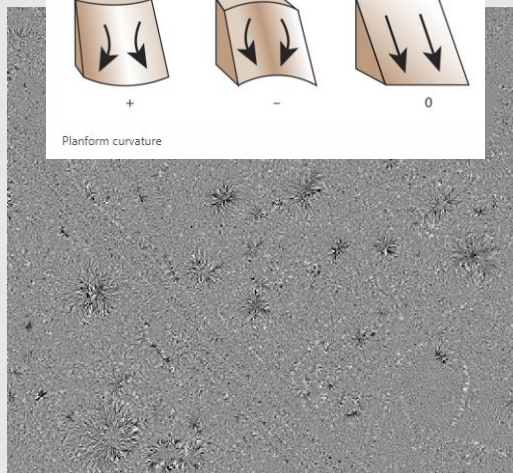


Tarolli, Sofia, and Dalla Fontana, NH (2012)

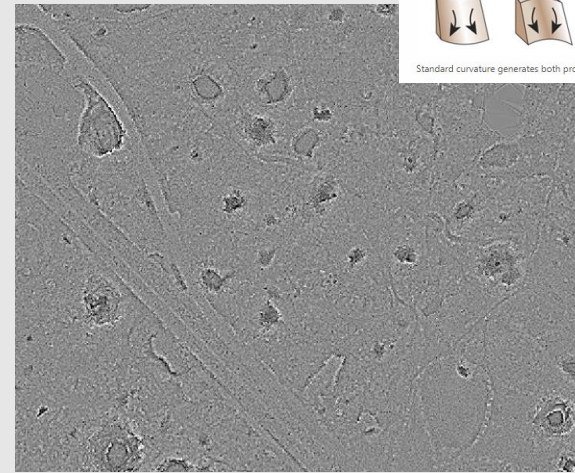
# Sulle doline del carso....



**Profile curvature**



**Plan curvature**



**Standard curvature**

# HILLSHADE

The **HILLSHADE** tool obtains the **hypothetical illumination of a surface by determining illumination values for each cell in a raster**. It does this by setting a position for a hypothetical light source and calculating the illumination values of each cell in relation to neighboring cells.

It can greatly enhance the visualization of a surface for analysis or graphical display, especially when using transparency.

By default, shadow and light are shades of gray associated with integers from 0 to 255 (increasing from black to white).

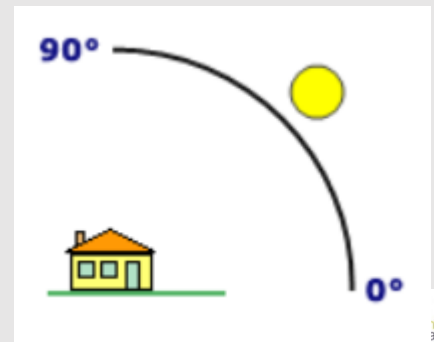
## Azimuth

The azimuth is the angular direction of the sun, measured from N in clockwise degrees from 0 to 360. An azimuth of 90 degrees is east. The default azimuth is 315 degrees (NW).

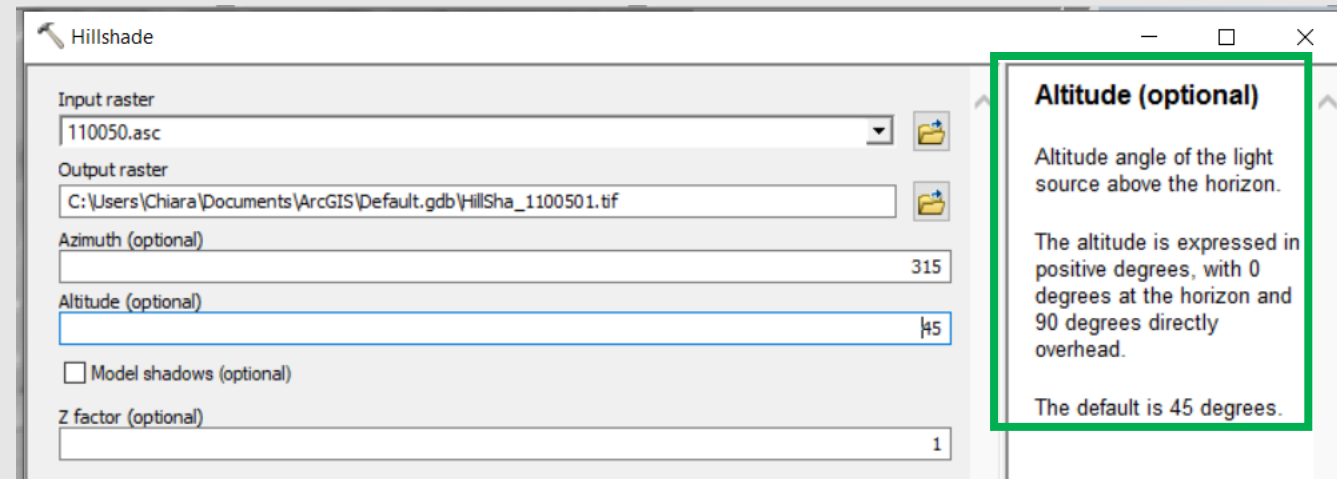
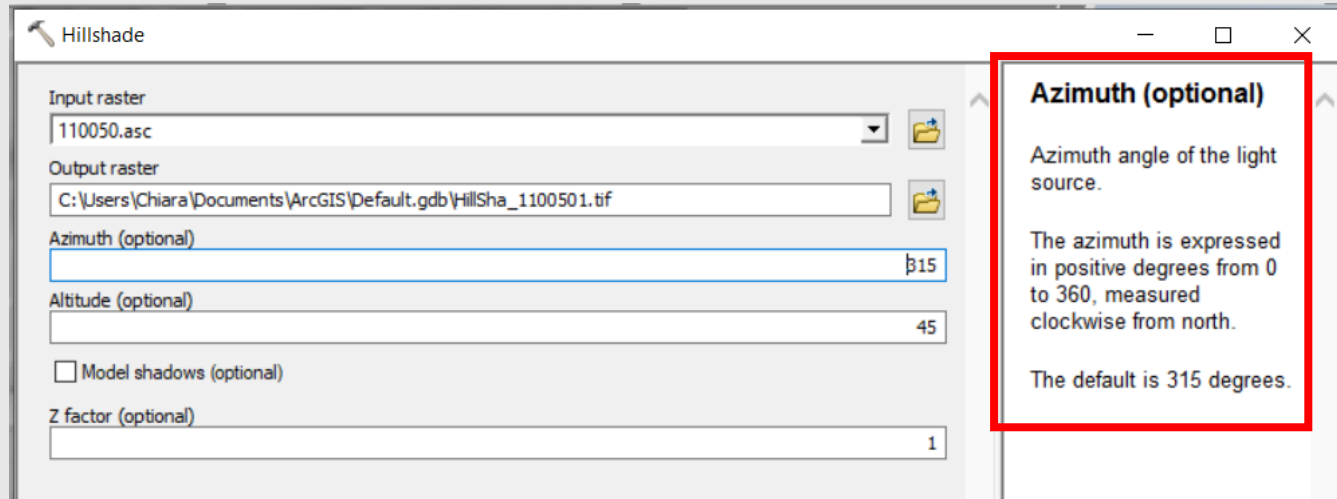
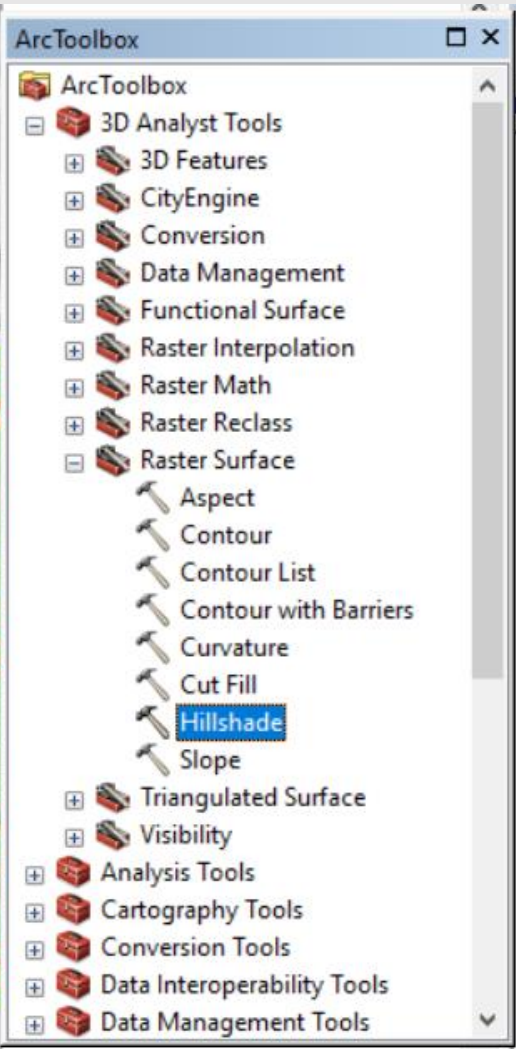


## Altitude

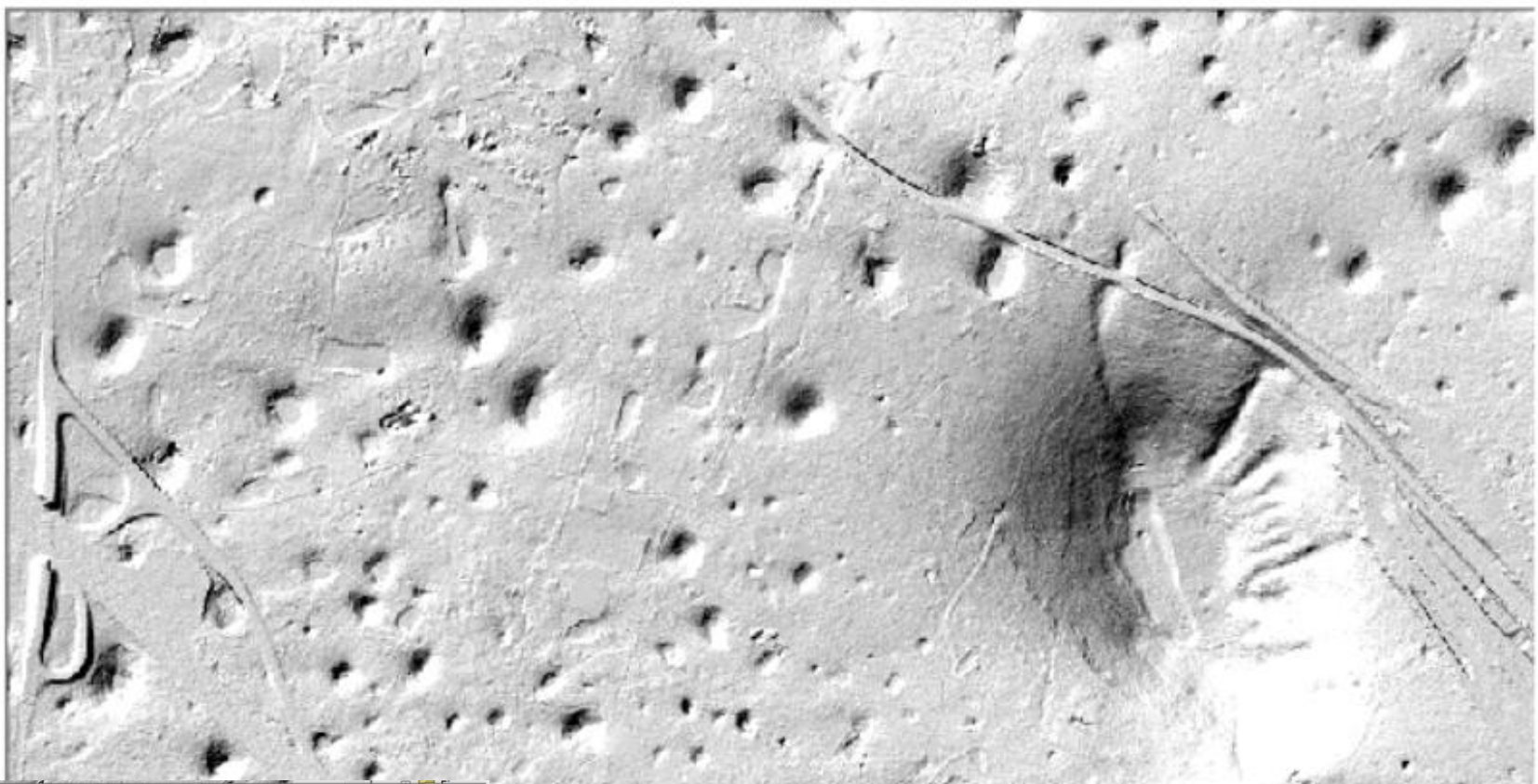
The altitude is the slope or angle of the illumination source above the horizon. The units are in degrees, from 0 (on the horizon) to 90 (overhead). The default is 45 degrees.



# HILLSHADE







Layer Properties

General Source Key Metadata Extent Display Symbology Time

Show:  
Vector Field  
Unique Values  
Classified  
Stretched  
Discrete Color

**Stretch values along a color ramp**

| Color | Value | Label      | Labeling                 |
|-------|-------|------------|--------------------------|
|       | 254   | high : 254 | <input type="checkbox"/> |
|       | 0     | Low : 0    | <input type="checkbox"/> |

Color Ramp:

Display Background Value: 0 as

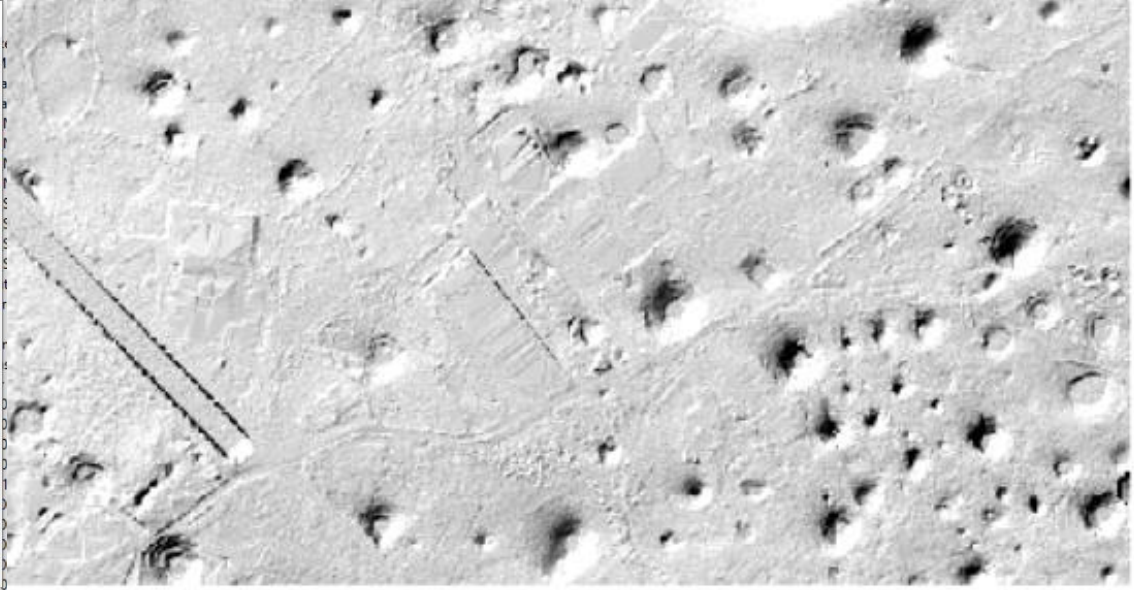
Use hillshade effect Z: 1 Display NoData as

Stretch  
Type: Percent Clip Histograms

min: 0,5 max: 0,5  Invert

Apply Gamma Stretch: 1

OK Annulla Applica



# HILLSHADE

## How hillshade is calculated

To calculate the shade value, first the altitude and azimuth of the illumination source are needed. These values will be processed with calculations for slope and aspect to determine the final hillshade value for each cell in the output raster.

## Hillshade algorithm

The algorithm for calculating the hillshade value is as follows:

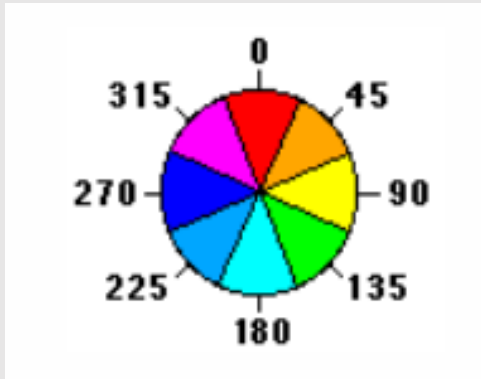
$$(1) \text{ Hillshade} = 255.0 * ((\cos(\text{Zenith\_rad}) * \cos(\text{Slope\_rad})) + (\sin(\text{Zenith\_rad}) * \sin(\text{Slope\_rad}) * \cos(\text{Azimuth\_rad} - \text{Aspect\_rad})))$$

<https://pro.arcgis.com/en/pro-app/tool-reference/3d-analyst/how-hillshade-works.htm>

# ESPOSIZIONE/ASPECT

Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. It can be thought of as the slope direction. The values of each cell in the output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas having no downslope direction are given a value of -1.

The value of each cell in an aspect dataset indicates the direction the cell's slope faces.



## Why use the Aspect tool?

With the Aspect tool, you can do the following:

- Find all north-facing slopes on a mountain as part of a search for the best slopes for ski runs.
- Calculate the solar illumination for each location in a region as part of a study to determine the diversity of life at each site.
- Find all southerly slopes in a mountainous region to identify locations where the snow is likely to melt first as part of a study to identify those residential locations likely to be hit by runoff first.
- Identify areas of flat land to find an area for a plane to land in an emergency.

# ESPOSIZIONE/ASPECT

A **moving 3 x 3 window** visits each cell in the input raster, and for each cell in the center of the window, an aspect value is calculated **using an algorithm that incorporates the values of the cell's eight neighbors**. The cells are identified as letters a to i, with e representing the cell for which the aspect is being calculated.

The rate of change in the x direction for cell e is calculated with the following algorithm:

$$[dz/dx] = ((c + 2f + i) - (a + 2d + g)) / 8$$

The rate of change in the y direction for cell e is calculated with the following algorithm:

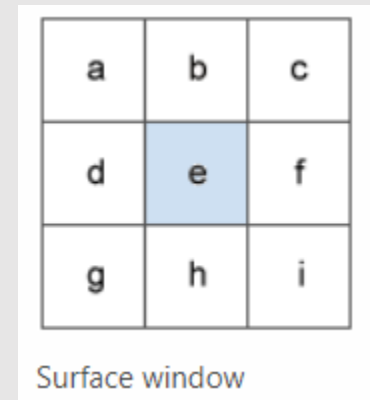
$$[dz/dy] = ((g + 2h + i) - (a + 2b + c)) / 8$$

Taking the rate of change in both the x and y direction for cell e, aspect is calculated using:

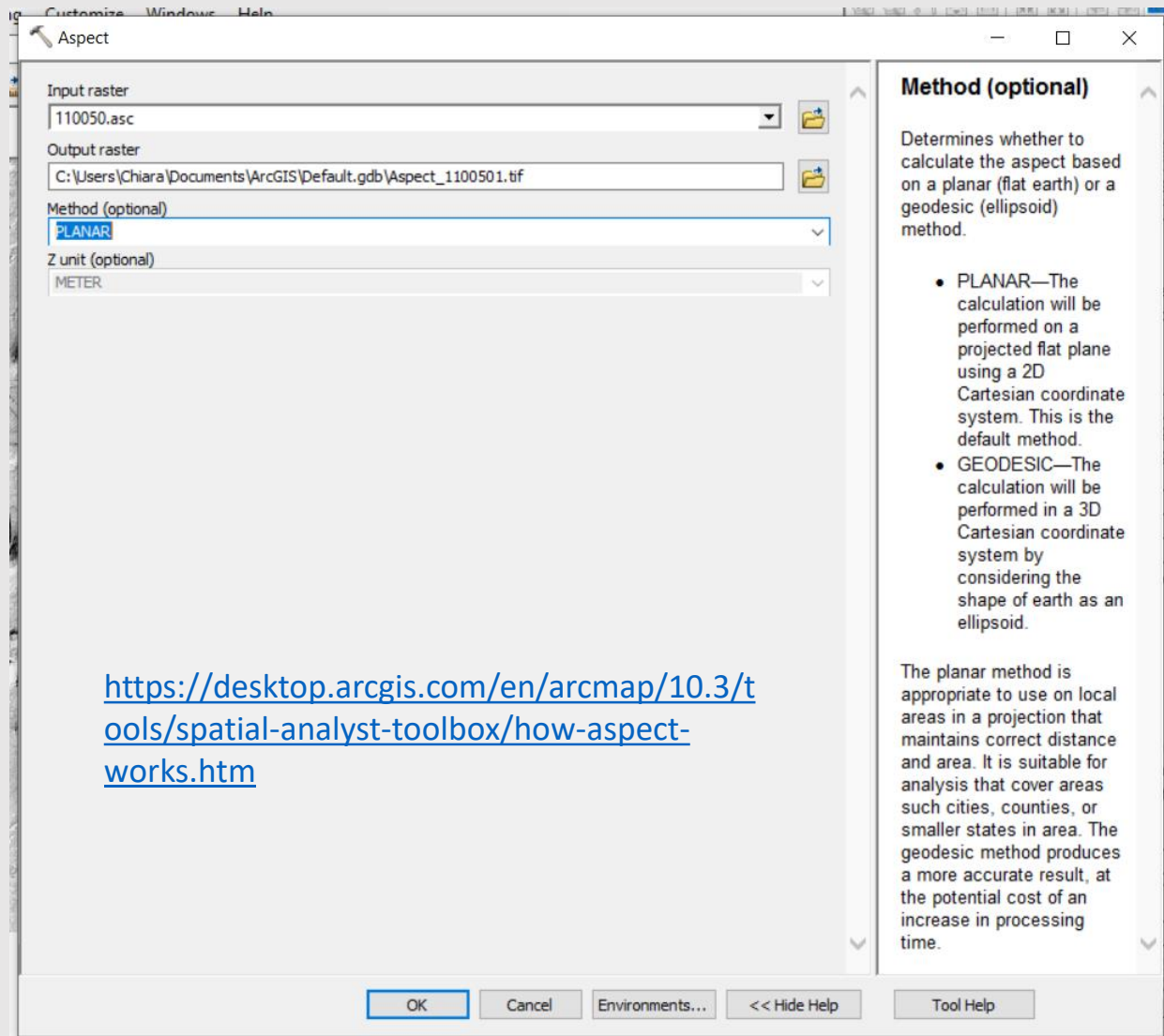
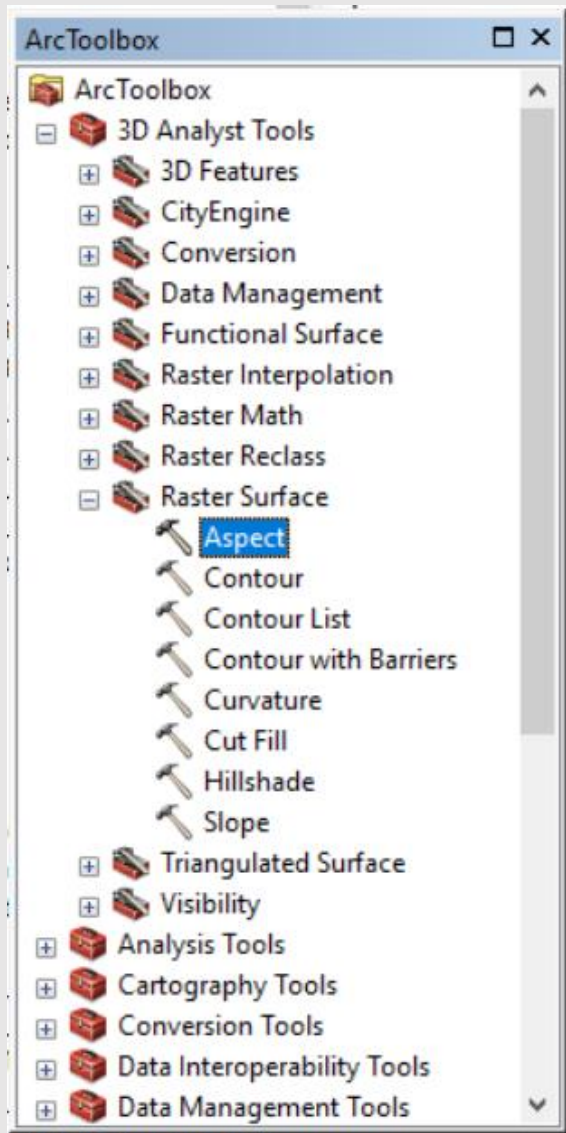
$$aspect = 57.29578 * \text{atan2} ([dz/dy], -[dz/dx])$$

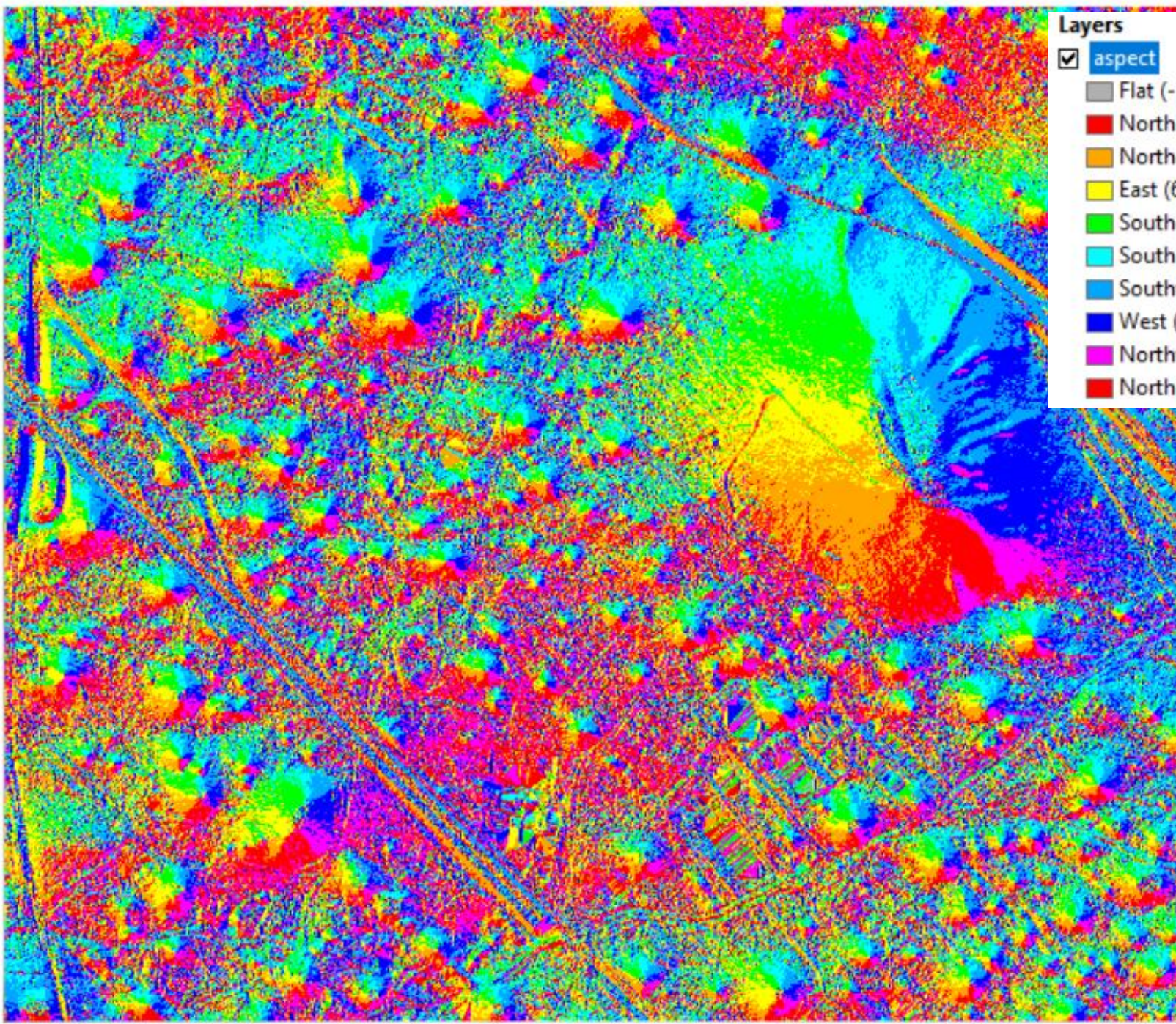
The aspect value is then converted to compass direction values (0-360 degrees), according to the following rule:

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



# ESPOSIZIONE/ASPECT





**Layers**

aspect

- Flat (-1)
- North (0-22.5)
- Northeast (22.5-67.5)
- East (67.5-112.5)
- Southeast (112.5-157.5)
- South (157.5-202.5)
- Southwest (202.5-247.5)
- West (247.5-292.5)
- Northwest (292.5-337.5)
- North (337.5-360)