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 (°) 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

ZNB1	ZNB2	ZNB3
ZNB4	ZNB5	ZNB6
ZNB7	ZNB8	ZNB9

ZNB1	ZNB2	ZNB3	ZNB4	ZNB5
ZNB6	ZNB7	ZNB8	ZNB9	ZNB10
ZNB11	ZNB12	ZNB13	ZNB14	ZNB15
ZNB16	ZNB17	ZNB18	ZNB19	ZNB20
ZNB21	ZNB22	ZNB23	ZNB24	ZNB25

G is the first derivative in the x direction (dz/dx)
H is the first derivative in the *y direction (dz/dy)*
zNB5 is the (central) cell for which the final value of slope is desired

zNB1,2,3,4,6,7,8,9 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

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

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

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

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

elevations

2 1

4

3

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

df/dx

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?

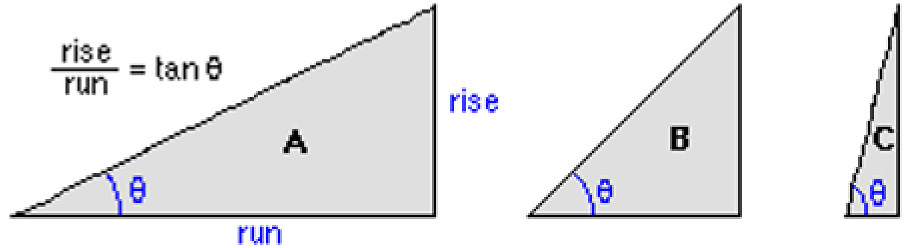
La PENDENZA esprime la massima variazione del valore di quota relativo ad un insieme di celle del sistema di rappresentazione del DEM.

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 = θ

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



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

a	b	c
d	e	f
g	h	i

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

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

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

$$\deg = \operatorname{atan}(S)$$

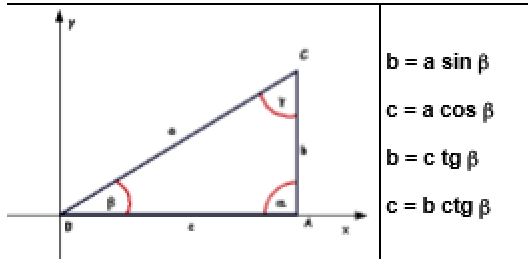
$$S = dz/dh$$

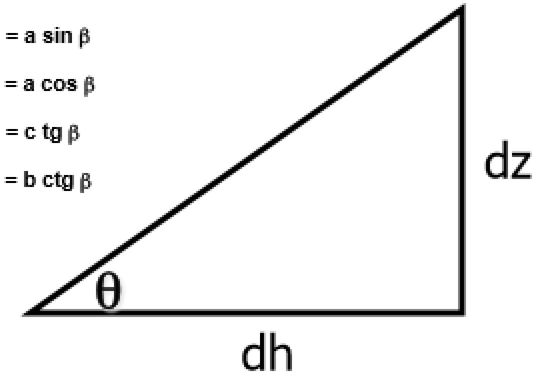
$$S = \tan(\theta)$$

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

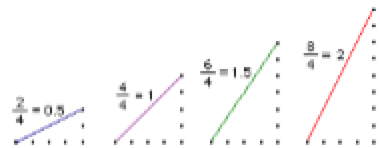
$$\text{Slope}(\text{deg}) = \tan^{-1}(S) * (360/2\pi)$$

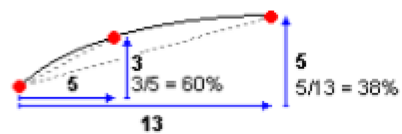
$$\text{Slope}(\text{rad}) = \tan^{-1}(S)$$





S = 1 = 100% = 45°





$$[dz/dx] = ((c + 2f + i) - (a + 2d + g) / (8 * x\_cell\_size)$$
$$= ((50+60+10)-(50+60+8))/(8*5)$$
$$= (120-118)/40$$
$$= 0.05$$

$$[dz/dy] = ((g + 2h + i) - (a + 2b + c) / (8 * x\_cell\_size)$$
$$= ((8+20+10)-(50+90+50))/(8*5)$$
$$= (38-190)/40$$
$$= -3.8$$

5m

50	45	50	5m
30	30	30	
8	10	10	

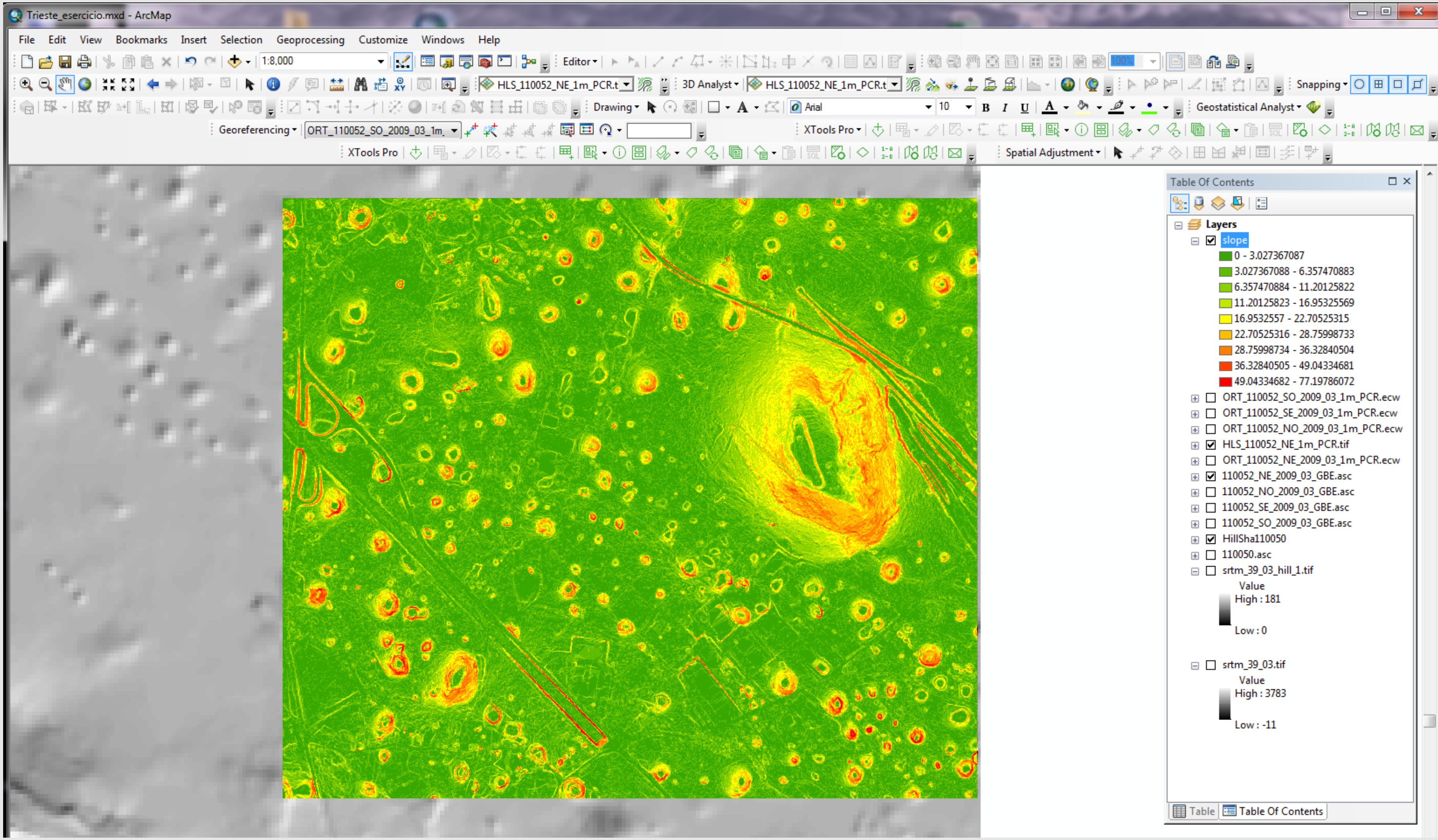
⇨

50	56	59
71	**75**	70
60	63	57

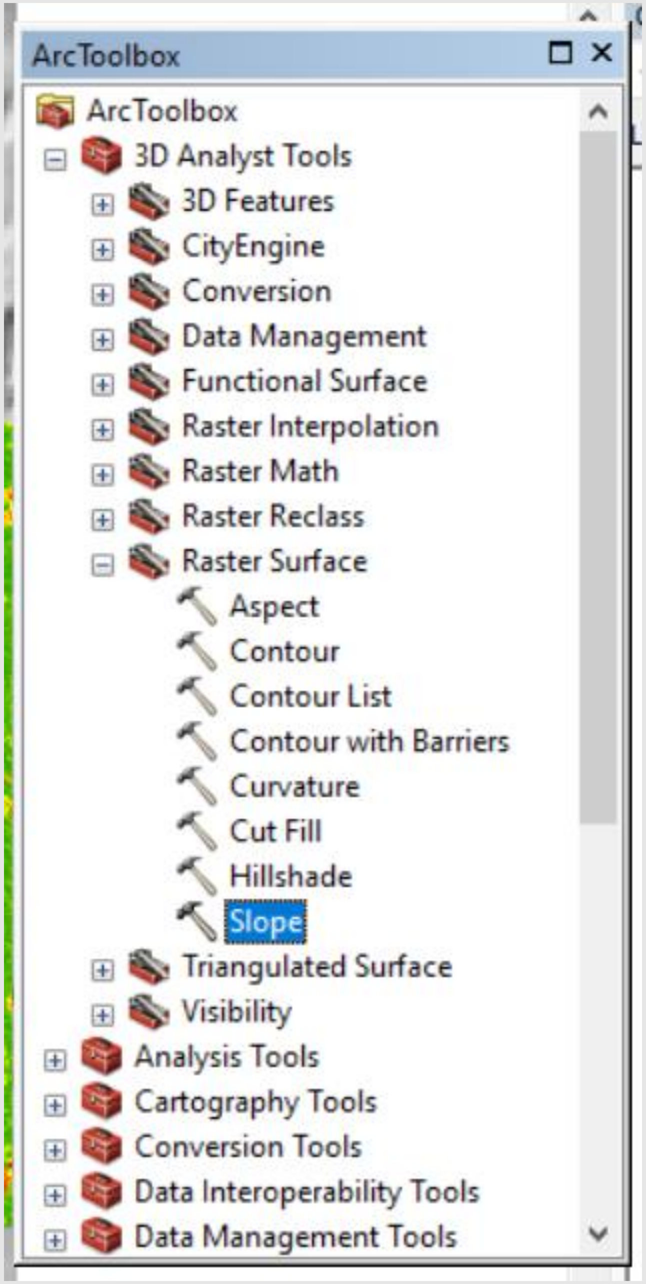
$$S = \sqrt{(dz/dx)^2 + (dz/dy)^2}$$
$$= \sqrt{(0.05)^2 + (-3.8)^2}$$
$$= \sqrt{0.0025 + 14.44}$$
$$= 3.80032$$

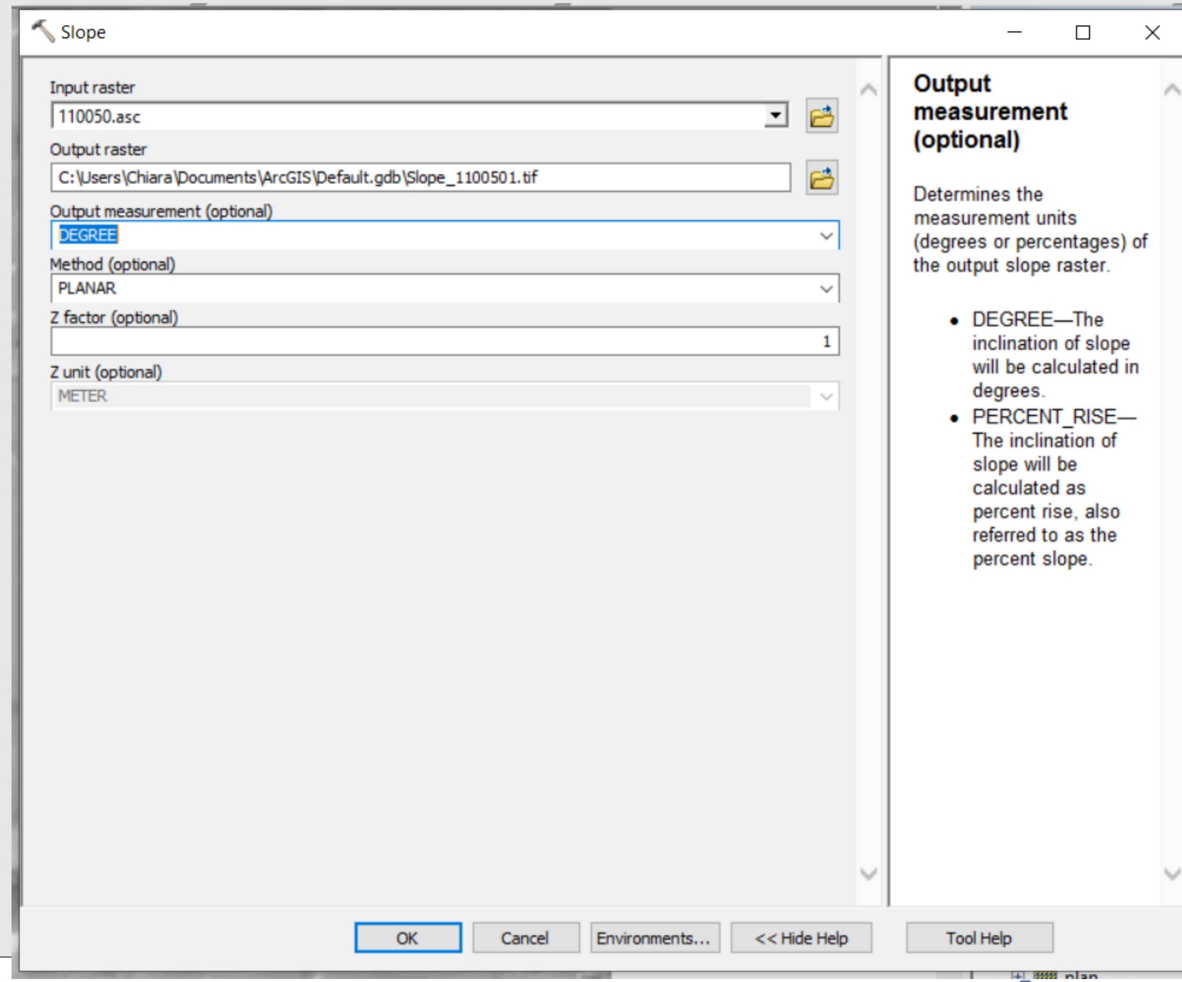
$$Slope(\text{rad}) = \arctan(S)$$
$$Slope(\text{deg}) = \arctan(S) * (360/2\pi)$$
$$= \arctan(3.80032) * 57.29578$$
$$= 1.31349 * 57.29578$$
$$= 75.25762$$

SLOPE in ArcGIS in °



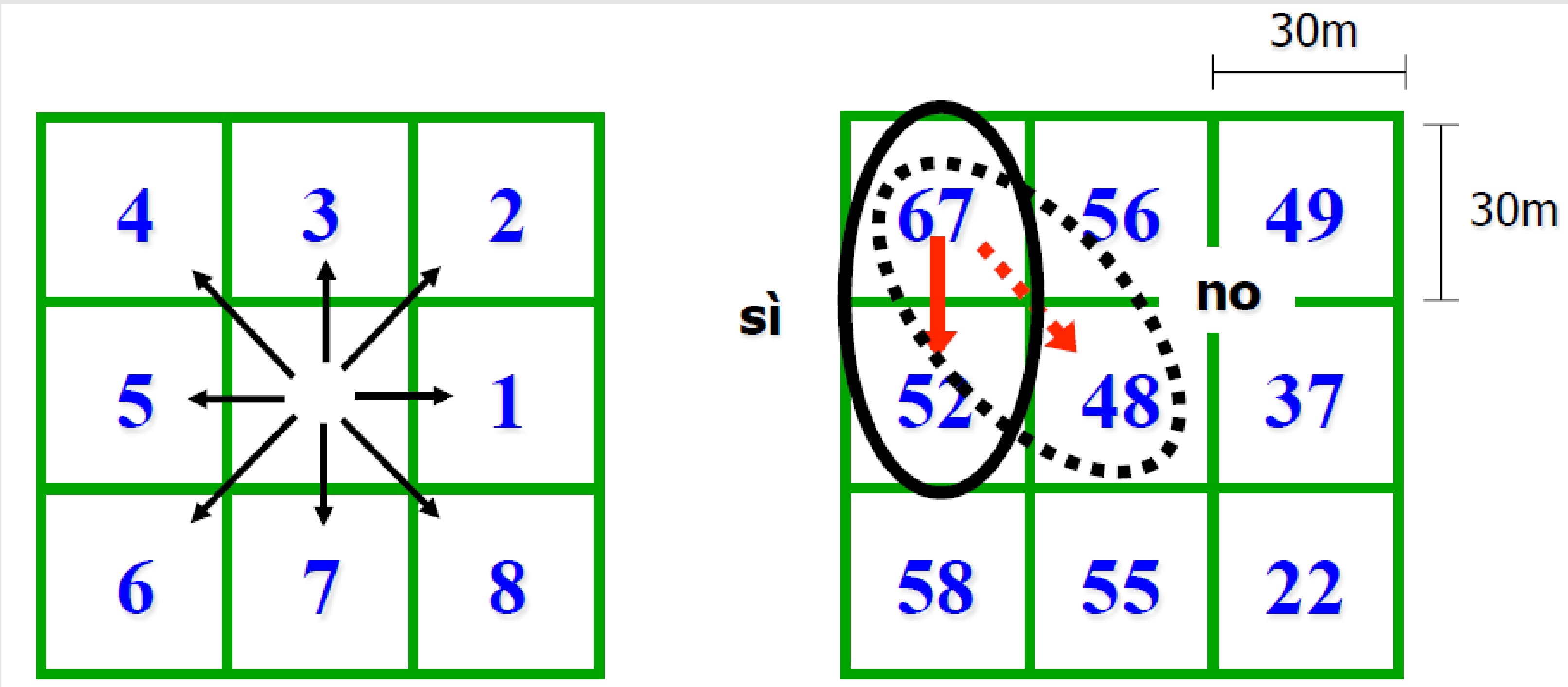
SLOPE in ArcGIS in °
come lo ottengo?





PENDENZA LOCALE

Permette di identificare le direzioni di drenaggio
Eight Direction Pour Point Model D8 (O’Challangan and Mark, 1984)



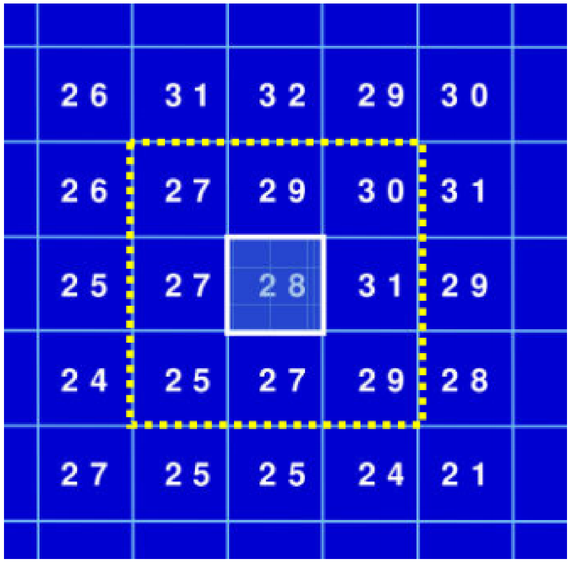
Definisce la direzione di massima pendenza da una cella ad una delle otto celle adiacenti

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%

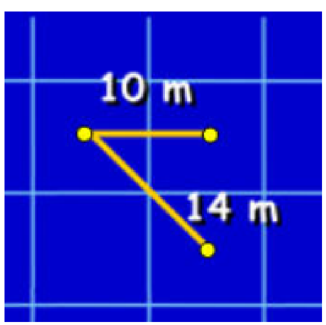
S = [(27 – 28) / 10] * 100 = -10%

SW = [(25 – 28) / 14] * 100 = -21%

W = [(27 – 28) / 10] * 100 = -10%

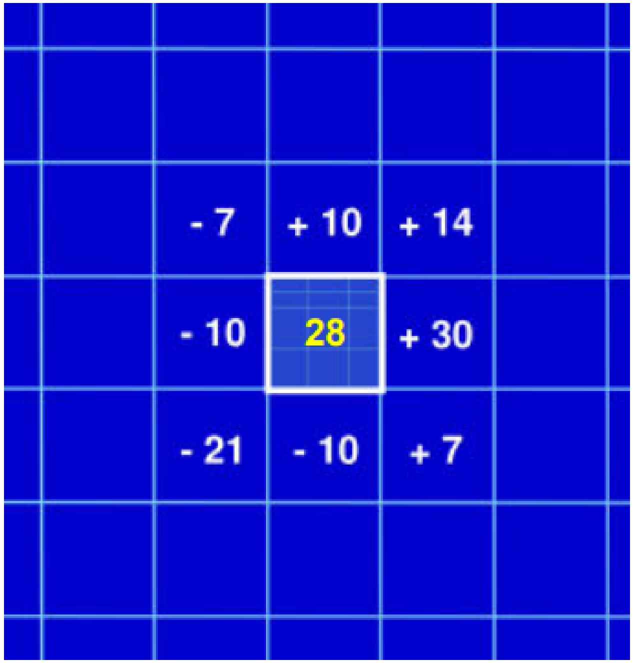
NW = [(27 – 28) / 14] * 100 = -7%

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

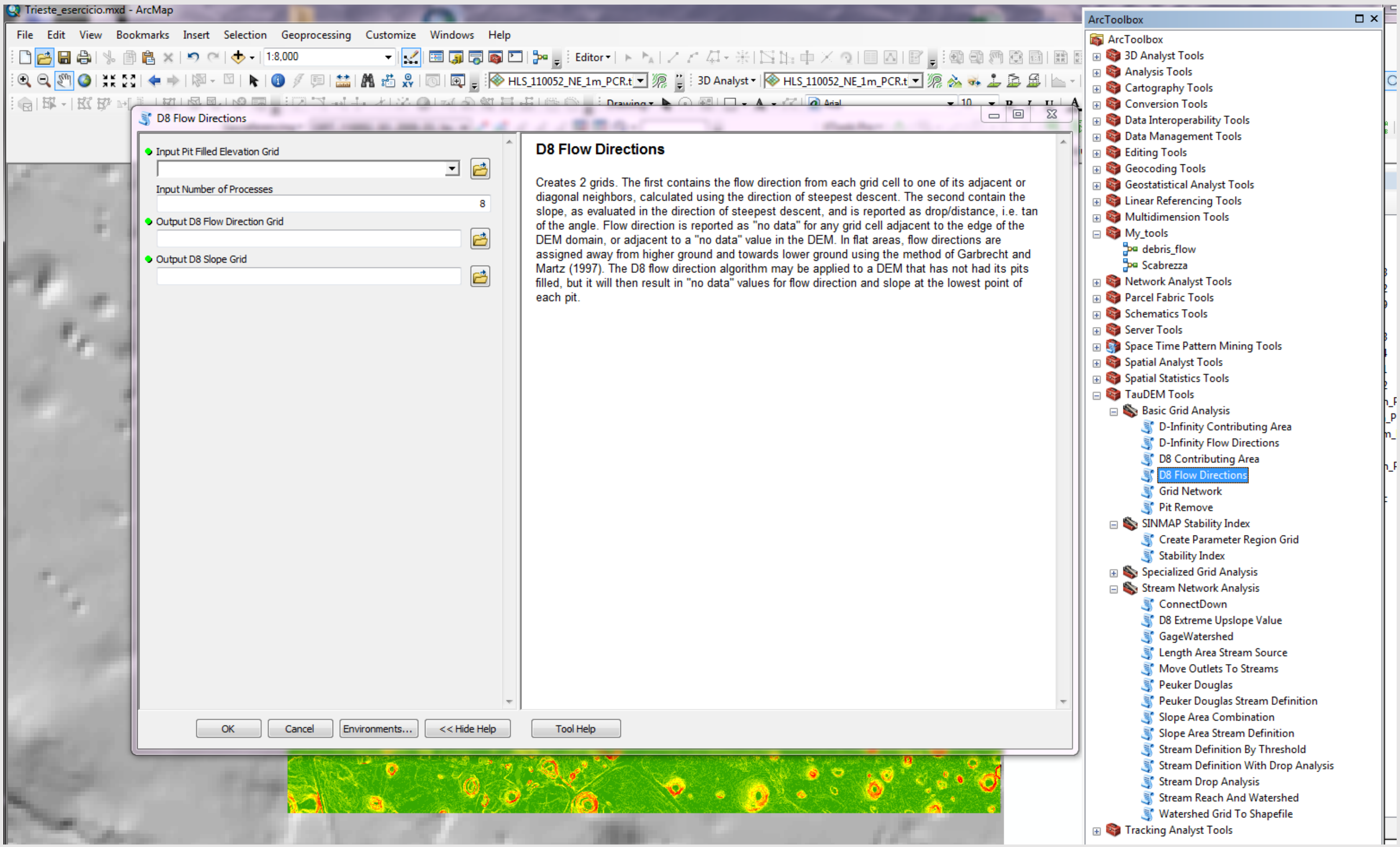


Slope = (rise/ run) · 100

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

- positivo ⇒ flussi entranti nella cella
- negativo ⇒ flussi uscenti dalla cella

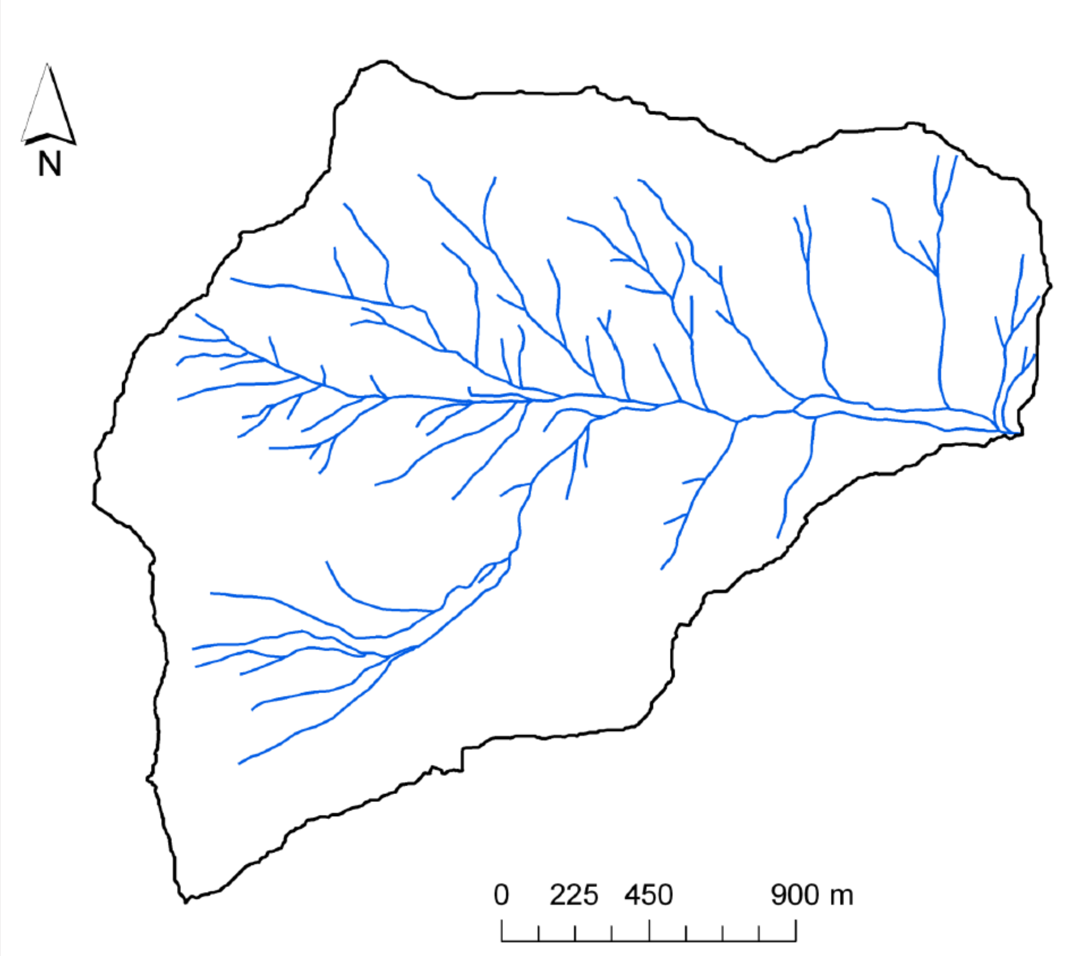
Tau DEM Tool



Algoritmo TauDEM scaricabile da:

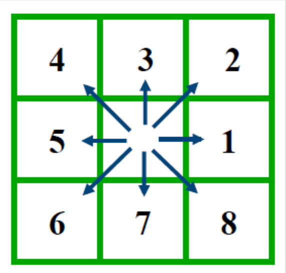
http://hydrology.usu.edu/taudem/taudem5/downloads2.html

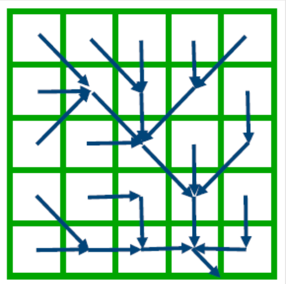
A cosa serve tutto questo???



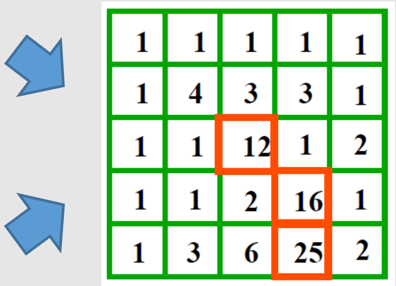
A ricavare da un DEM, un RETICOLO IDROGRAFICO DI SINTESI

Eight direction pour point model D8





Grid network



Drainage Area

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

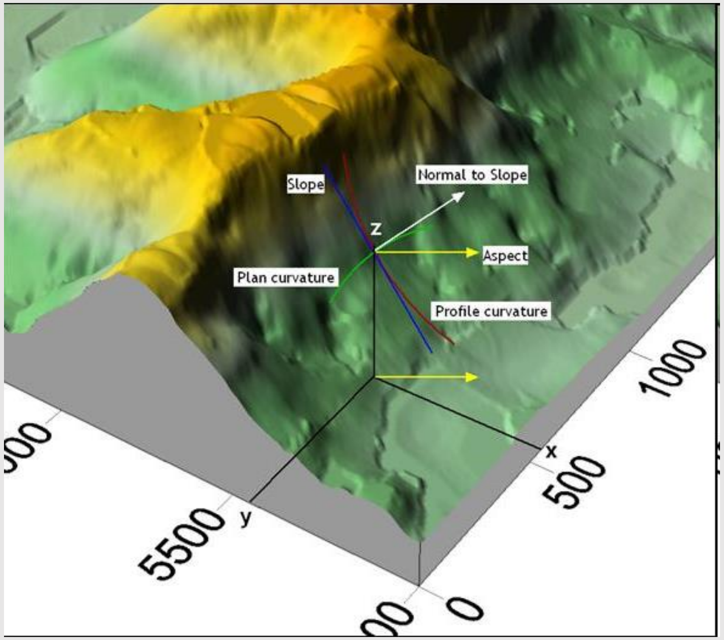
$\frac{\partial^2 z}{\partial x^2}$ rappresenta il grado di convergenza e/o divergenza perpendicolare alla linea di massima pendenza

$\frac{\partial^2 z}{\partial y^2}$ 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;

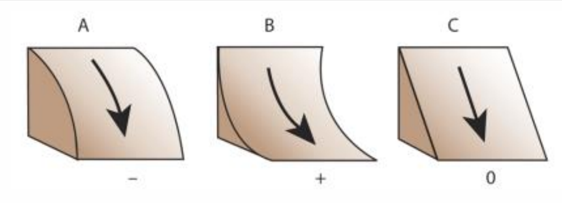
$\nabla^2 z > 0$ (superficie concava/convergente): processi canalizzati;

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



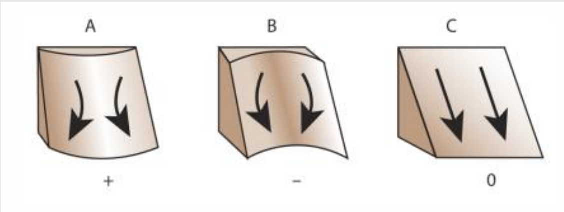
Tarolli, 2017 – Geomorphometry course

TIPI DI CURVATURA



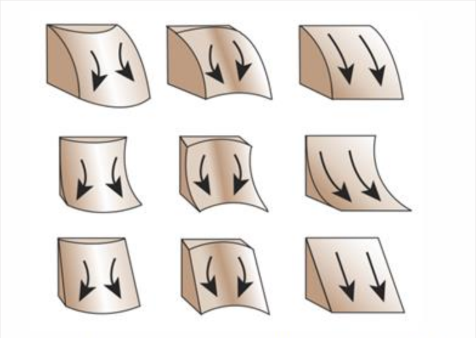
Profile curvature

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).**



Planform curvature

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).**

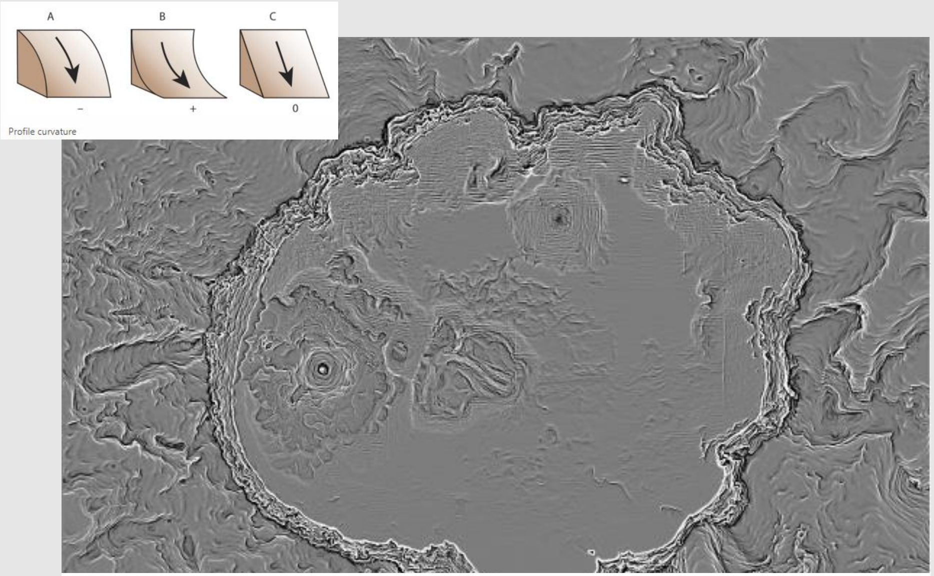

Standard curvature generates both profile and planform curvatures.

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.

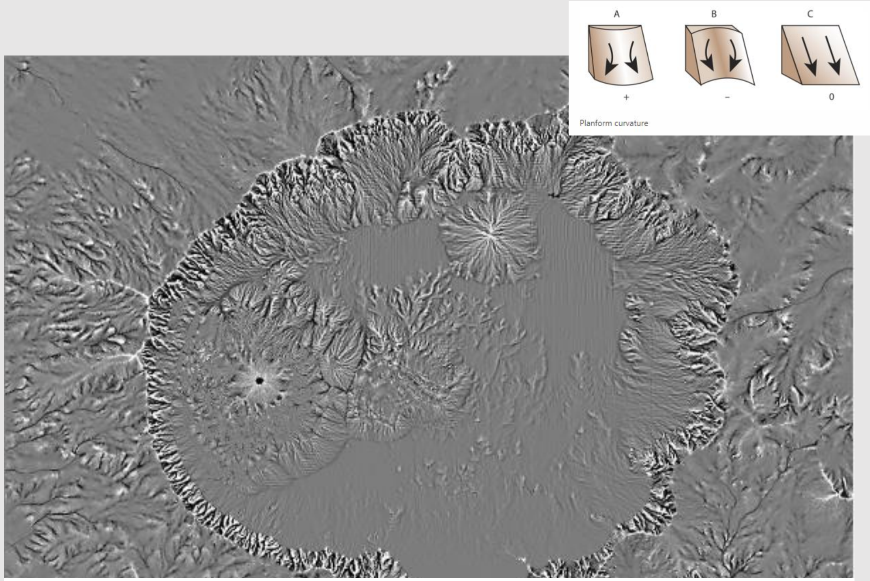
Le planform columns sono positive, negative, o andando da sinistra a destra. Le profiles curves sono negative, positive, o -0, procedendo dall'alto verso il basso.

Profile curvature



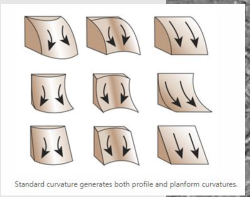
Su questo raster vengono enfatizzati i terrazzamenti presenti sulla superficie.

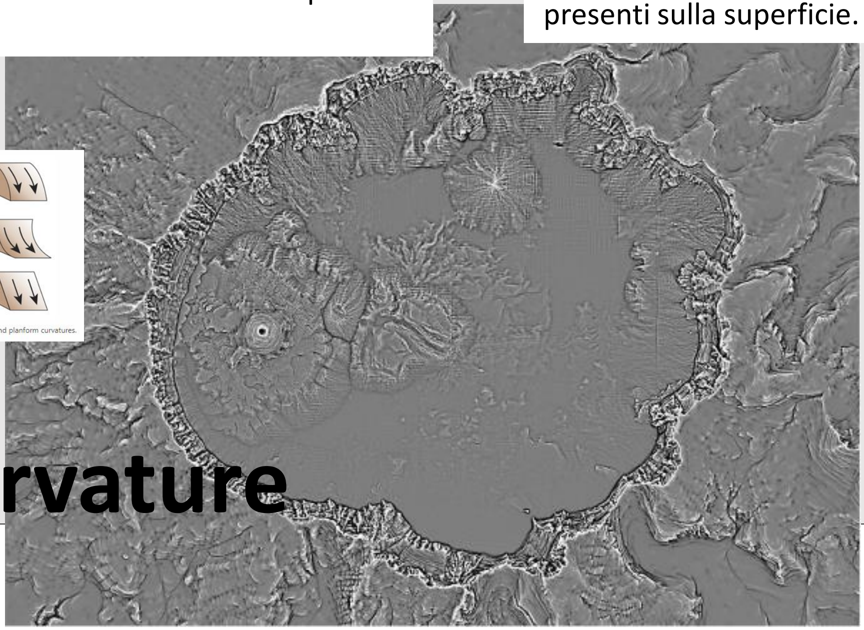
Plan curvature



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

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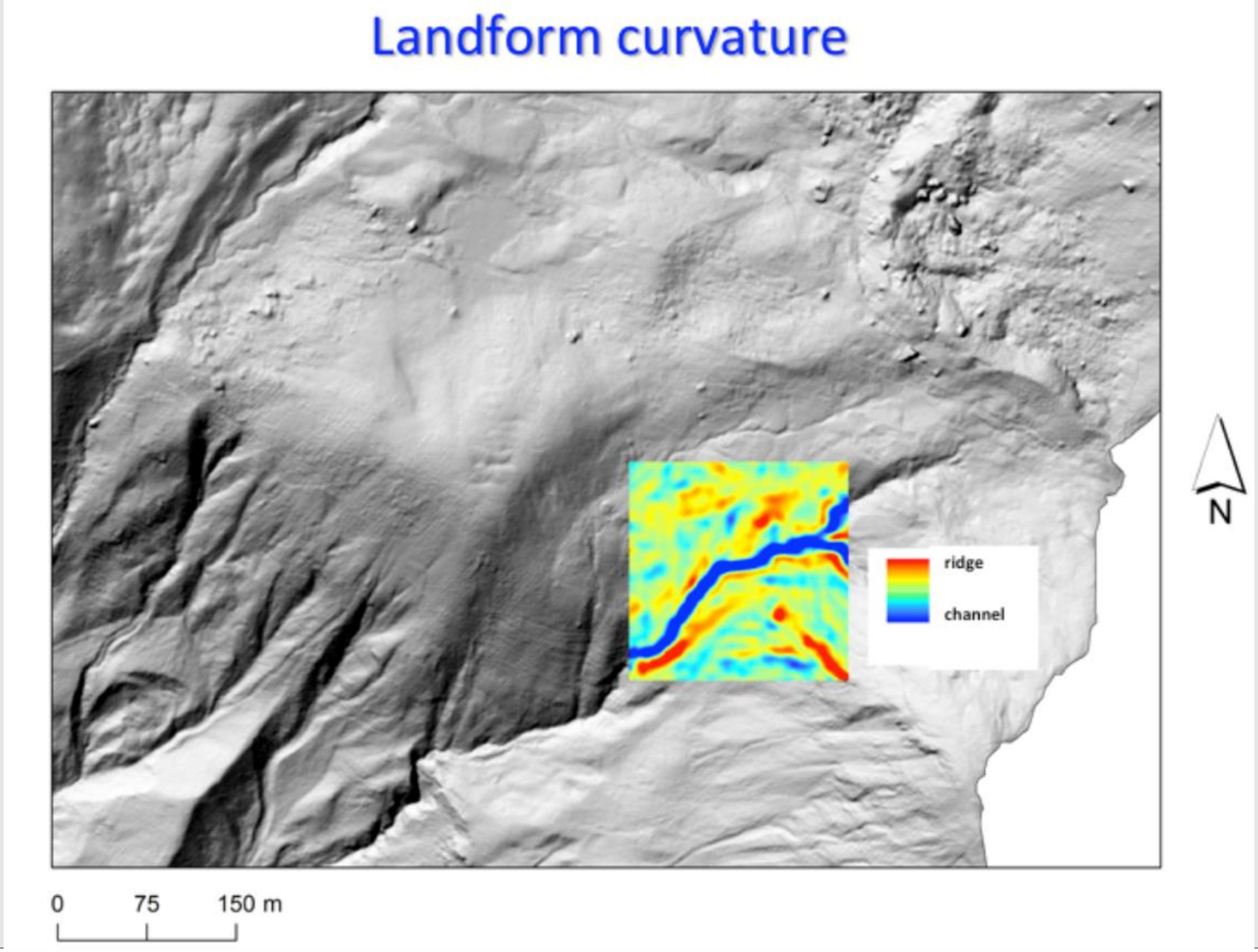
Il risultato



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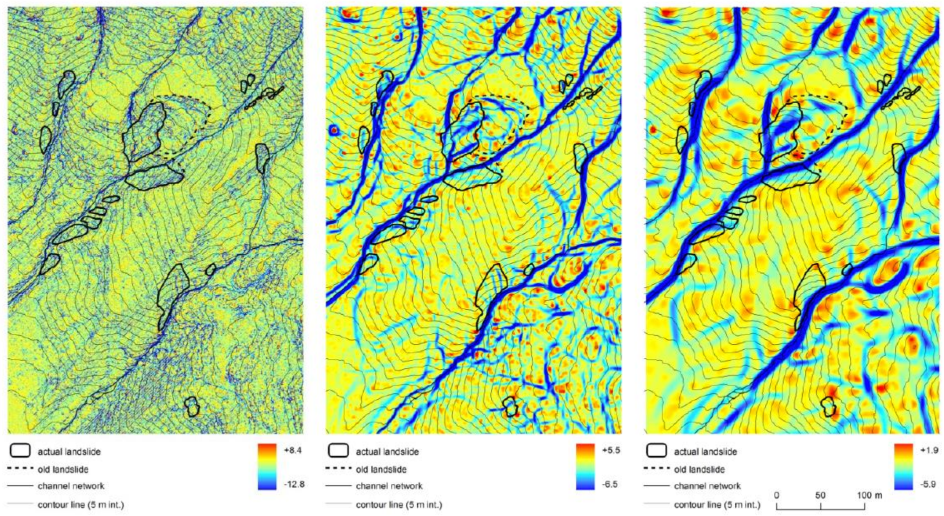
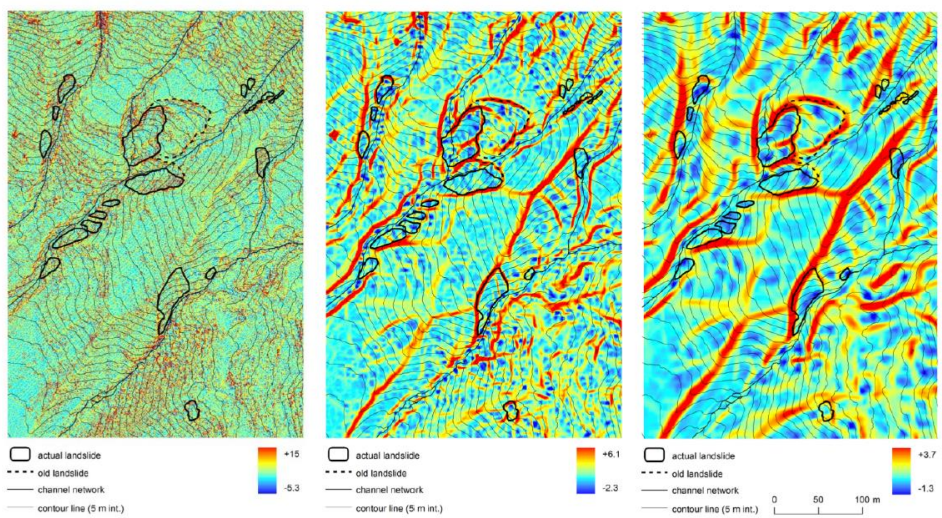
Curvatura minima



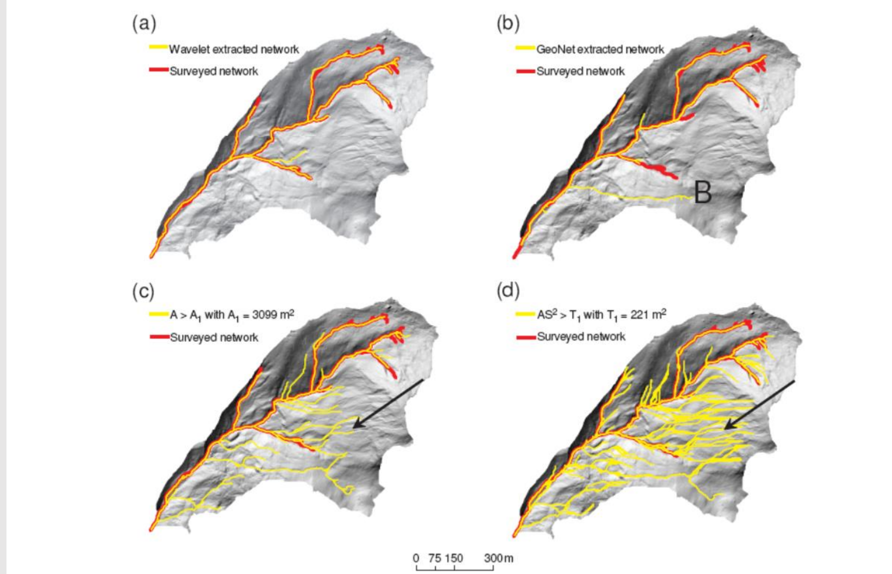
Pirotti and Tarolli, HP (2010)



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

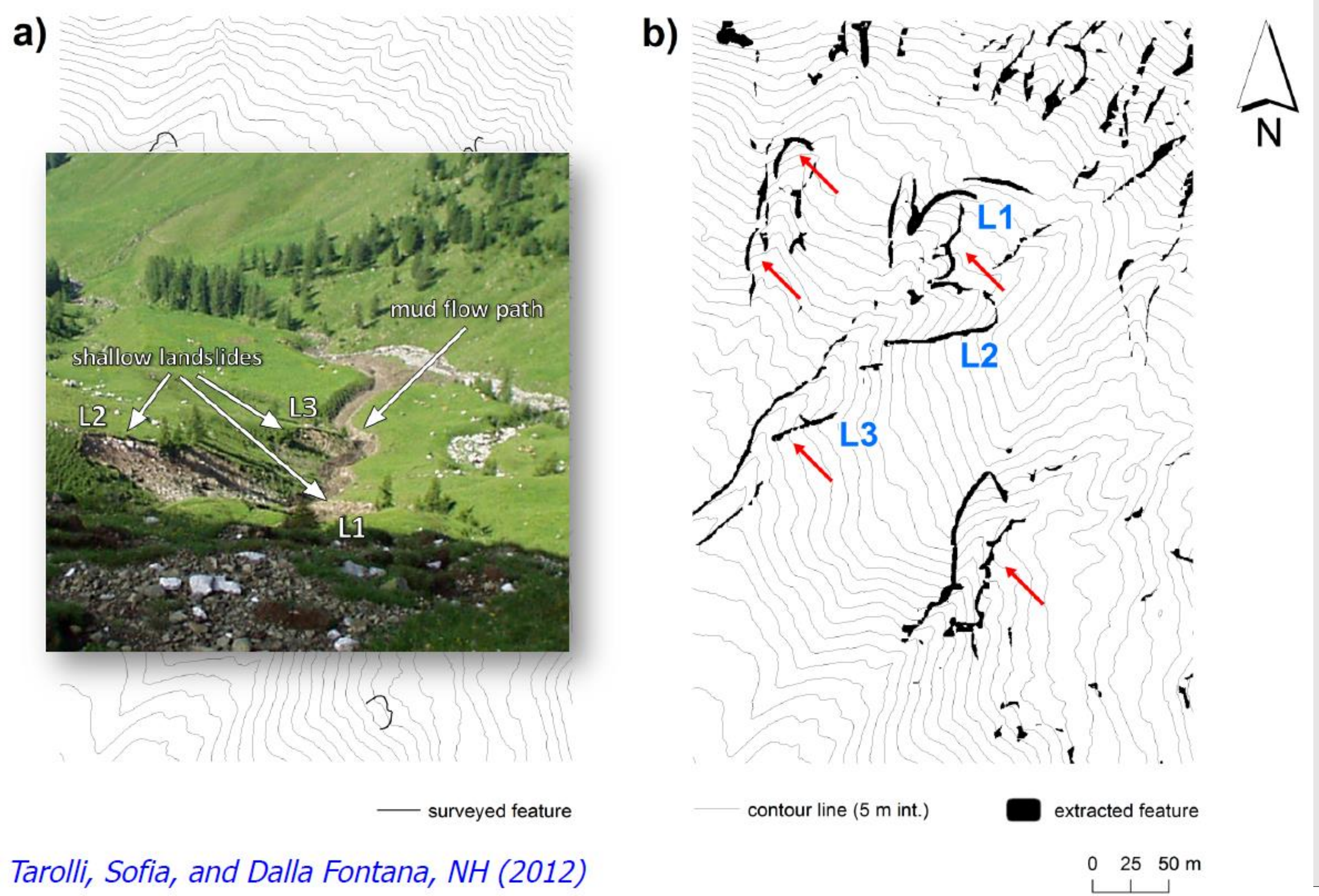
Curvatura massima

Passalacqua, P., Tarolli, P., Foufoula-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



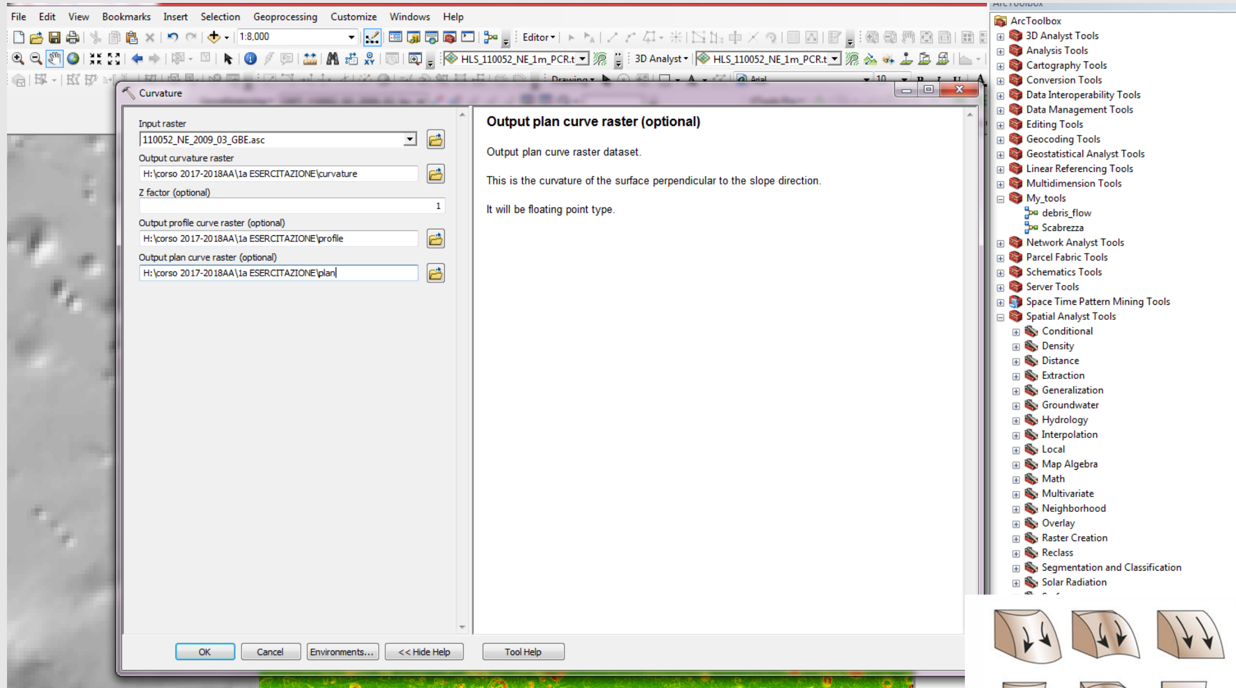
Paolo Tarolli – Dip. TeSAF (Territorio e Sistemi Agro-Forestali) – Università di Padova

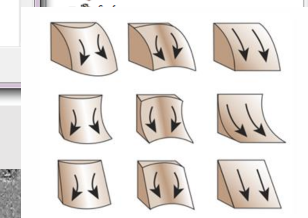
La curvatura della superficie come strumento per il riconoscimento e l'estrazione delle nicchie di frana



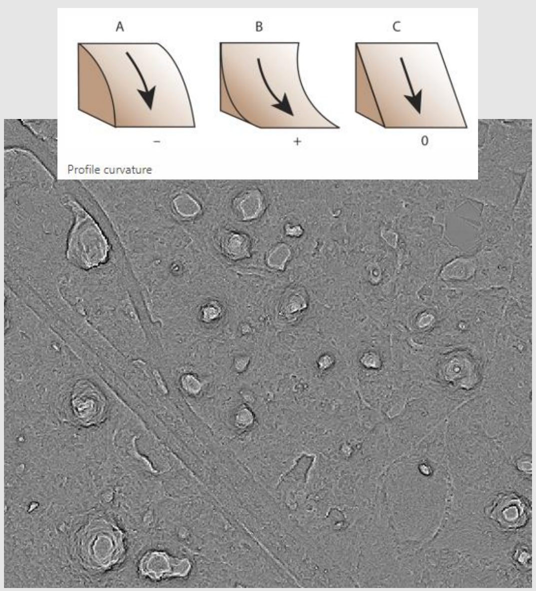
Tarolli, Sofia, and Dalla Fontana, NH (2012)

Sulle doline del carso….

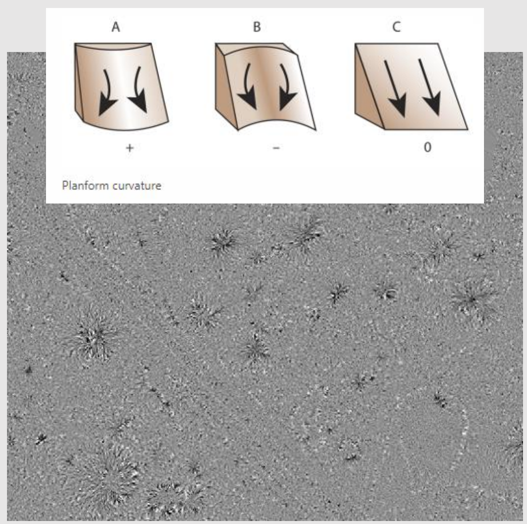




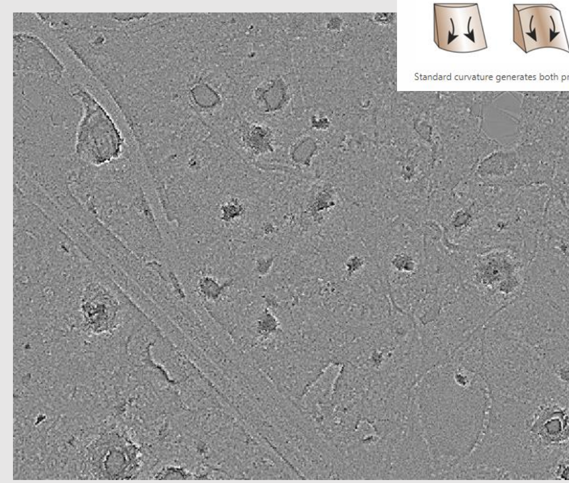
Standard curvature generates both profile and planform curvatures.



Profile curvature



Plan curvature



Standard curvature

HILLSHADE

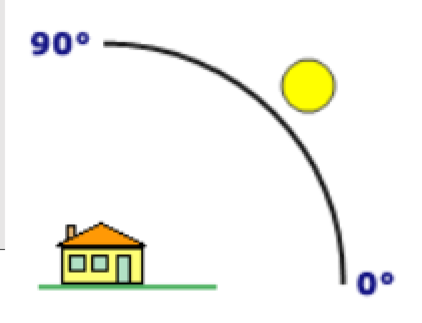
The **HILLSHADE** tool obtains **the hypothetical illumination of a surface by determining illumination values for each cell in a raster**. It does this by setting a position for a hypothetical light source and calculating the illumination values of each cell in relation to neighboring cells.
It can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

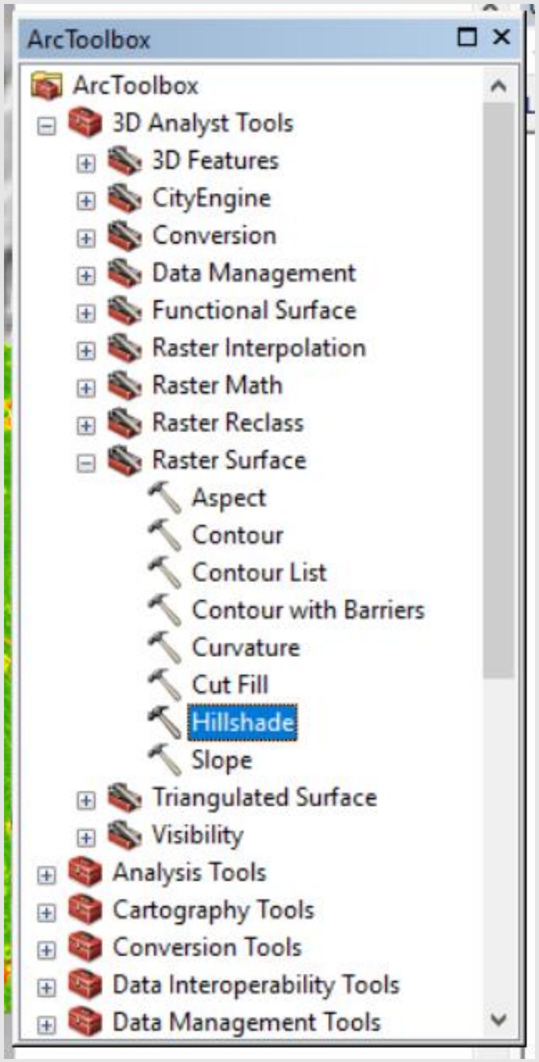
The azimuth is the angular direction of the sun, measured from N in clockwise degrees from 0 to 360. An azimuth of 90 degrees is east. The default azimuth is 315 degrees (NW).

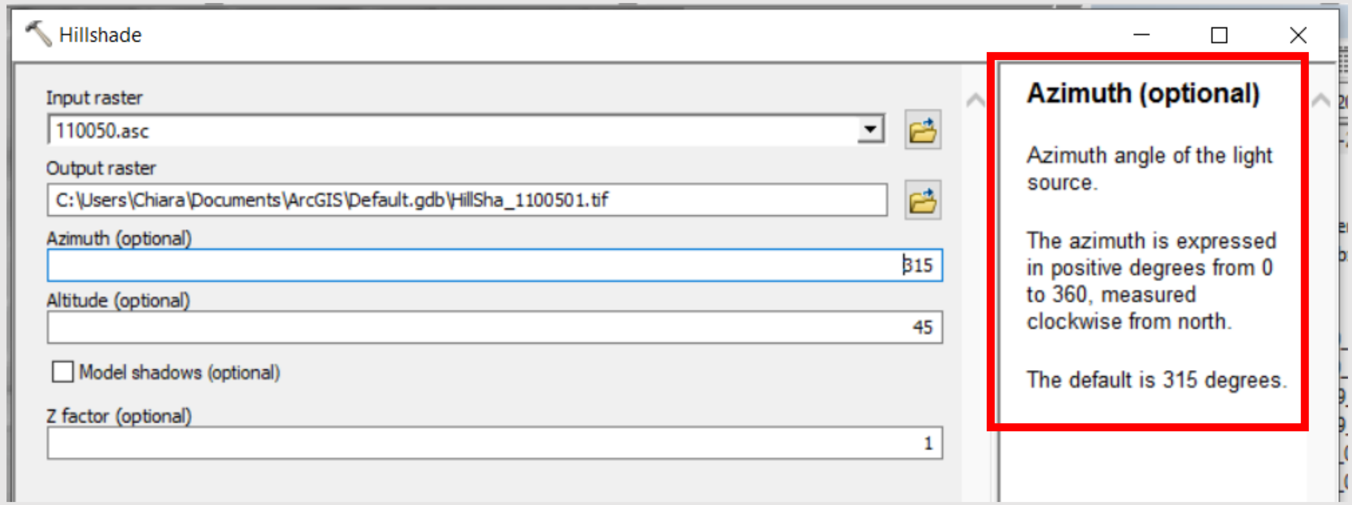
Altitude

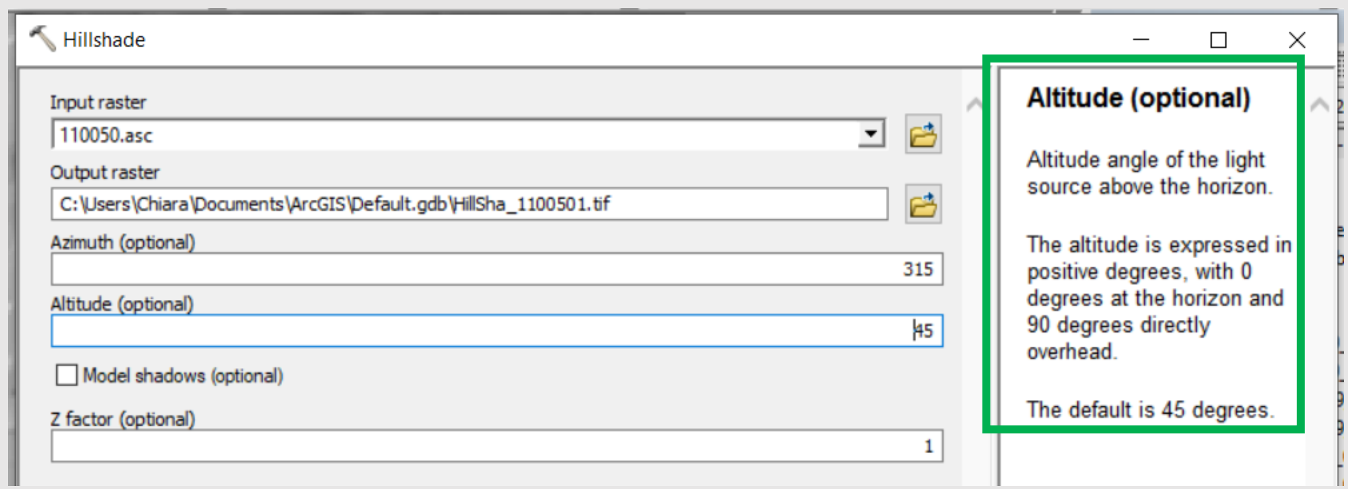
The altitude is the slope or angle of the illumination source above the horizon. The units are in degrees, from 0 (on the horizon) to 90 (overhead). The default is 45 degrees.

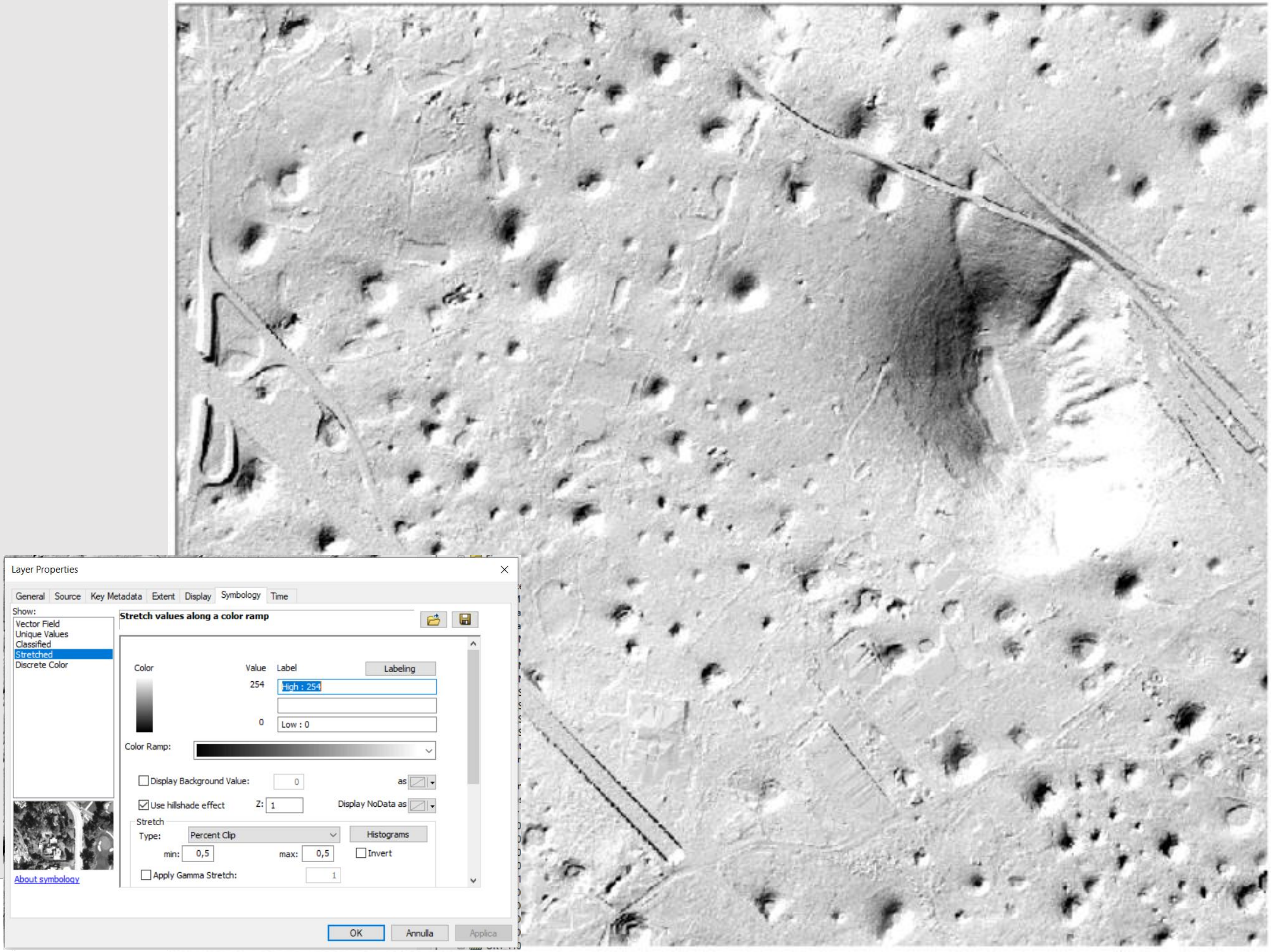


HILLSHADE


ArcToolbox
ArcToolbox
3D Analyst Tools
3D Features
CityEngine
Conversion
Data Management
Functional Surface
Raster Interpolation
Raster Math
Raster Reclass
Raster Surface
Aspect
Contour
Contour List
Contour with Barriers
Curvature
Cut Fill
Hillshade
Slope
Triangulated Surface
Visibility
Analysis Tools
Cartography Tools
Conversion Tools
Data Interoperability Tools
Data Management Tools


Hillshade
Input raster
110050.asc
Output raster
C:\Users\Chiara\Documents\ArcGIS\Default.gdb\HillSha_1100501.tif
Azimuth (optional)
315
Altitude (optional)
45
Model shadows (optional)
Z factor (optional)
1
Azimuth (optional)
Azimuth angle of the light source.
The azimuth is expressed in positive degrees from 0 to 360, measured clockwise from north.
The default is 315 degrees.


Hillshade
Input raster
110050.asc
Output raster
C:\Users\Chiara\Documents\ArcGIS\Default.gdb\HillSha_1100501.tif
Azimuth (optional)
315
Altitude (optional)
45
Model shadows (optional)
Z factor (optional)
1
Altitude (optional)
Altitude angle of the light source above the horizon.
The altitude is expressed in positive degrees, with 0 degrees at the horizon and 90 degrees directly overhead.
The default is 45 degrees.


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
0
Low : 0
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
About symbology
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

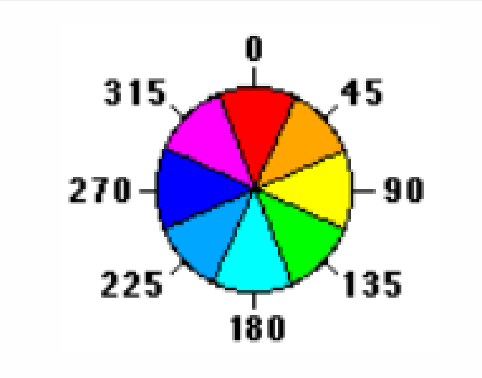
The algorithm for calculating the hillshade value is as follows:

```
(1)  Hillshade = 255.0 * ((cos(Zenith_rad) * cos(Slope_rad)) +
                 (sin(Zenith_rad) * sin(Slope_rad) * cos(Azimuth_rad - 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 * atan2 ([dz/dy], -[dz/dx])
```

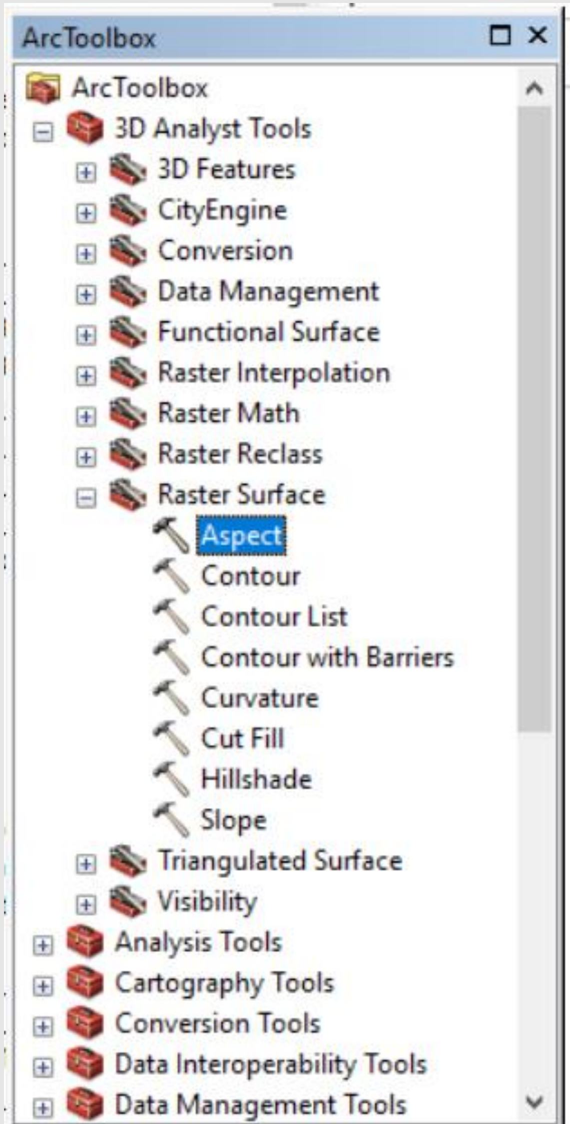
The aspect value is then converted to compass direction values (0-360 degrees), according to the following rule:

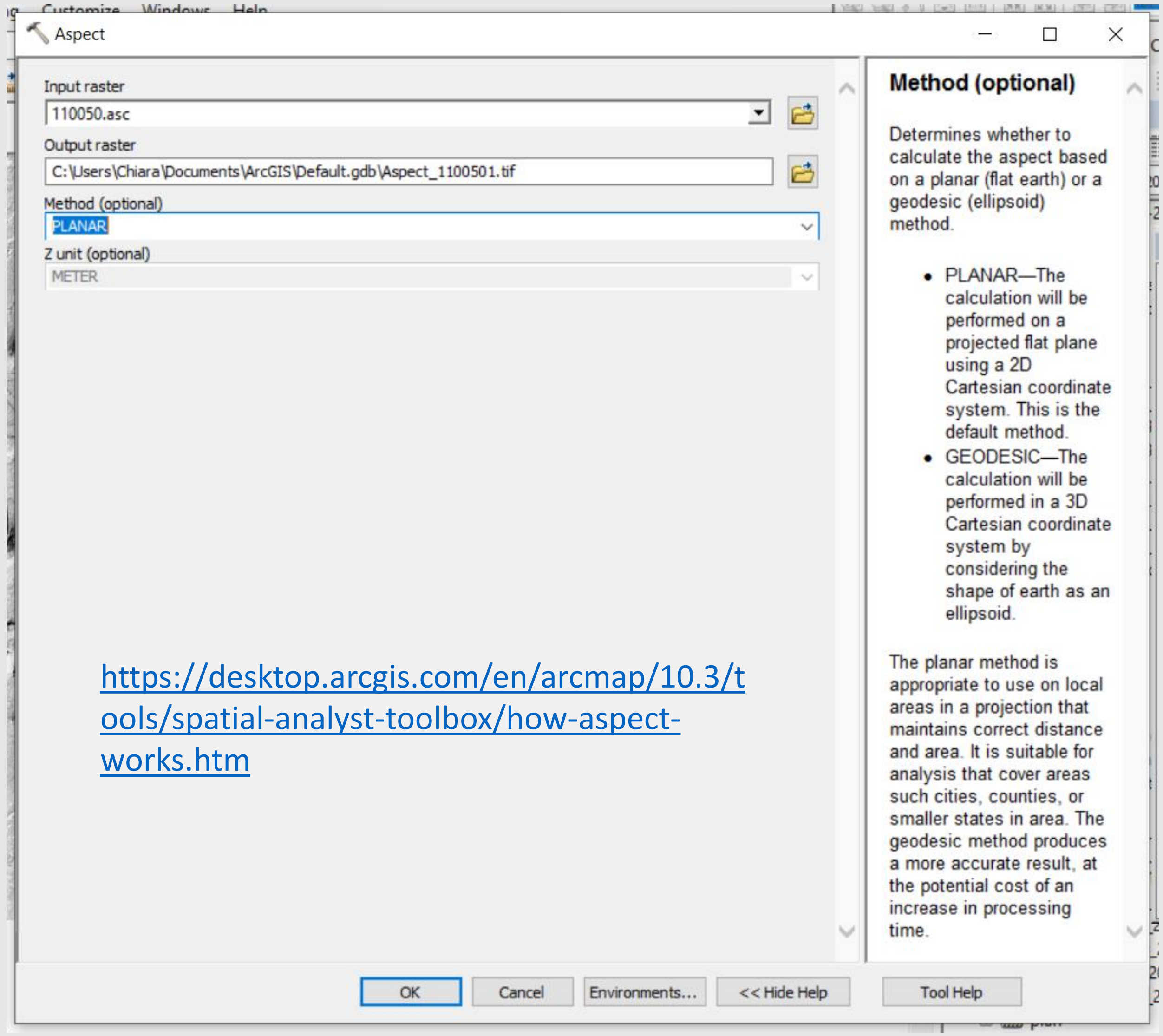
```
if aspect < 0
  cell = 90.0 - aspect  else if aspect > 90.0
  cell = 360.0 - aspect + 90.0
else
  cell = 90.0 - aspect
```

a	b	c
d	e	f
g	h	i

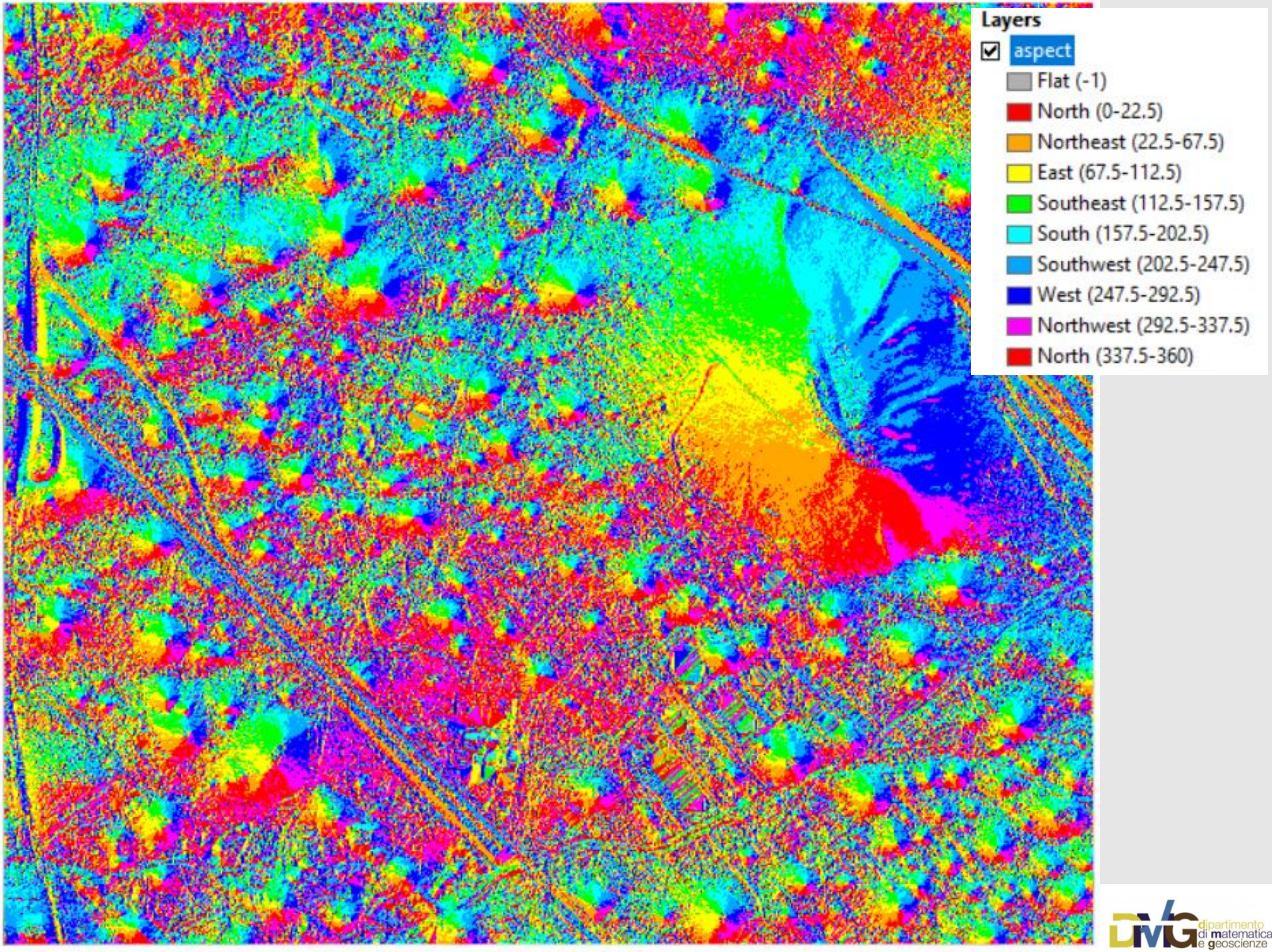
Surface window

ESPOSIZIONE/ASPECT





https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-aspect-works.htm


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)