AESB2440: Geostatistics & Remote Sensing

Lecture 9: Geometric Terrain Analysis

May 11, 2015

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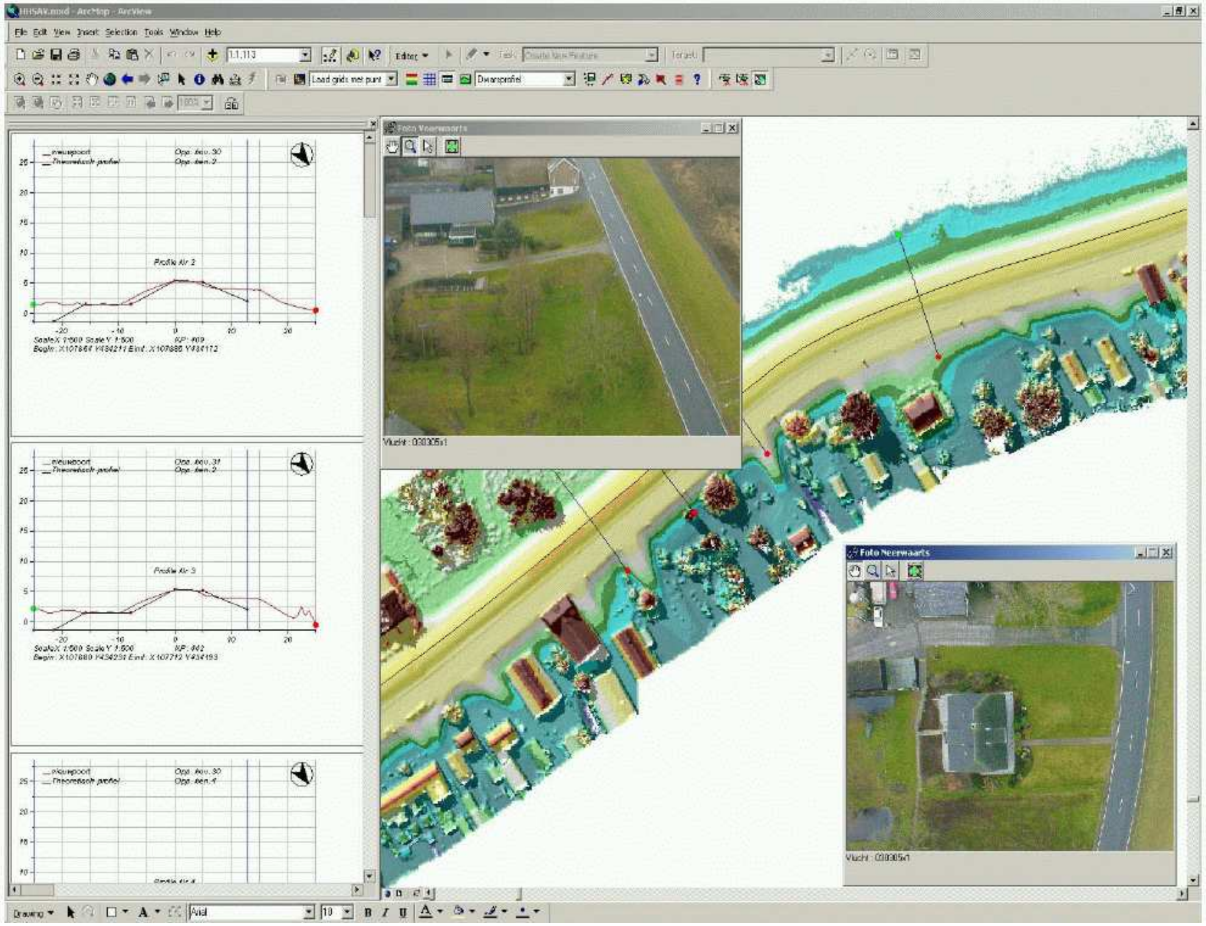
Why geometric terrain analysis?

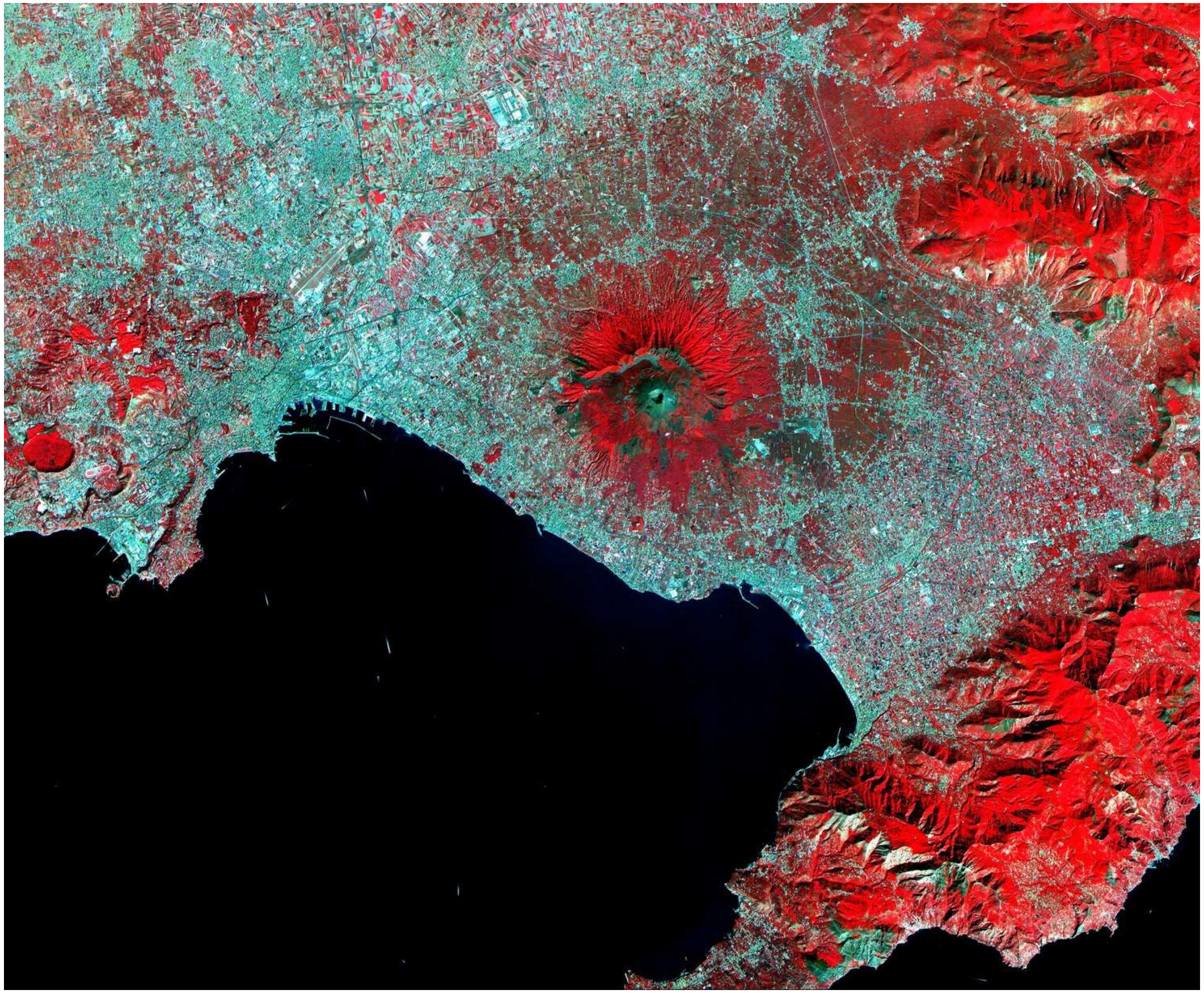
Dike Inspection



Worst possible flooding

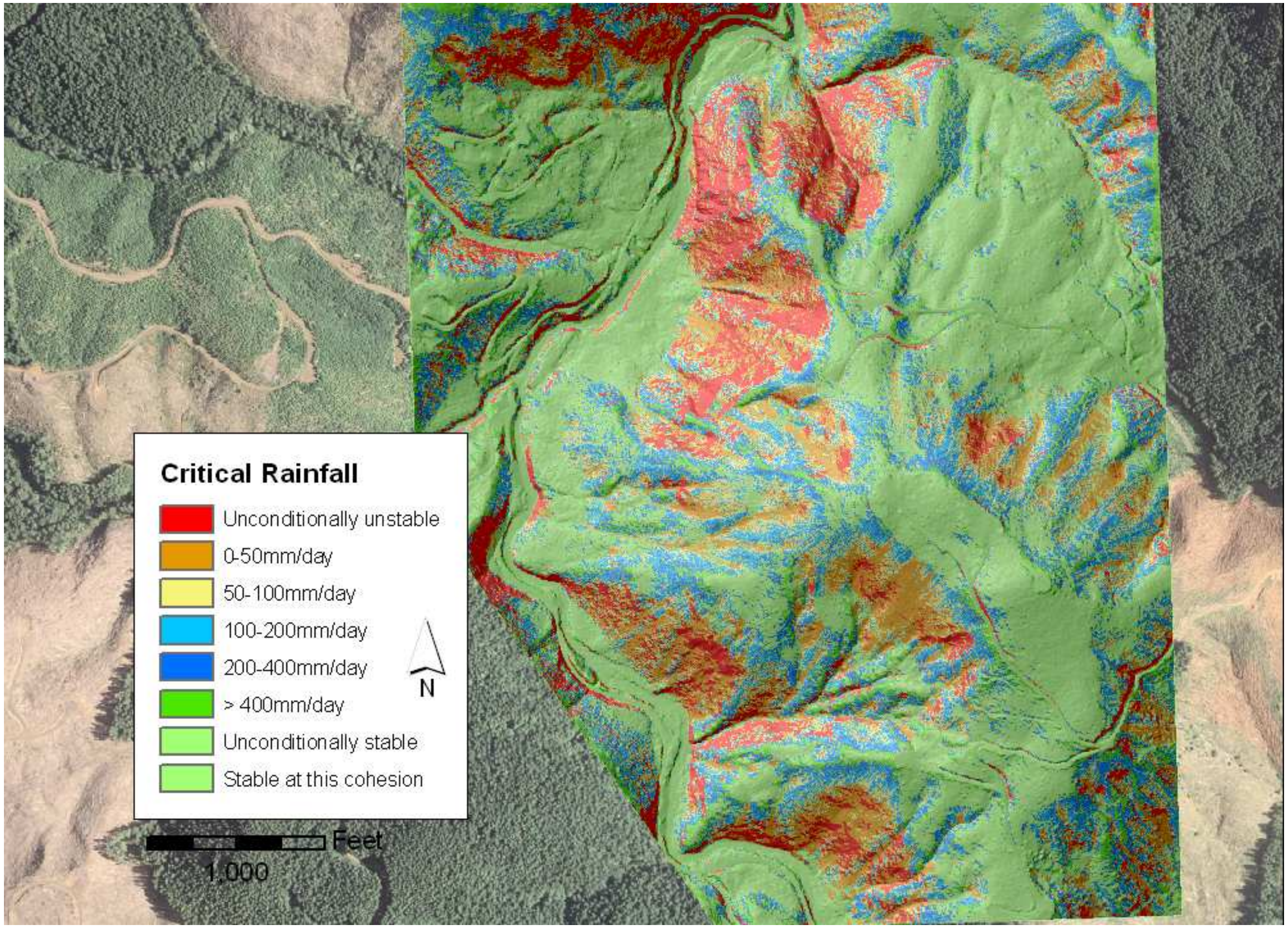
Source http://www.vpro.nl/metropolis/speel.WO_VPRO_032787.html

Lava flow



Source http://earthobservatory.nasa.gov/IOTD/view.php?id=1045&eocn=image&eoci=related_image

Slope stability



Source http://gis.ess.washington.edu/areas/littlemountain/

Contents

Terrain analysis

- Slope, aspect and orientation
- Relation with gradient
- Estimations from DEM data

Drainage Networks

- D8 method
- Flow accumulation

C. Slope, aspect and orientation

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Discrete Differential Geometry

How to obtain and use discrete equivalents of the notions of

Gradient - ‘First derivative‘

Curvature - ‘Second derivative‘

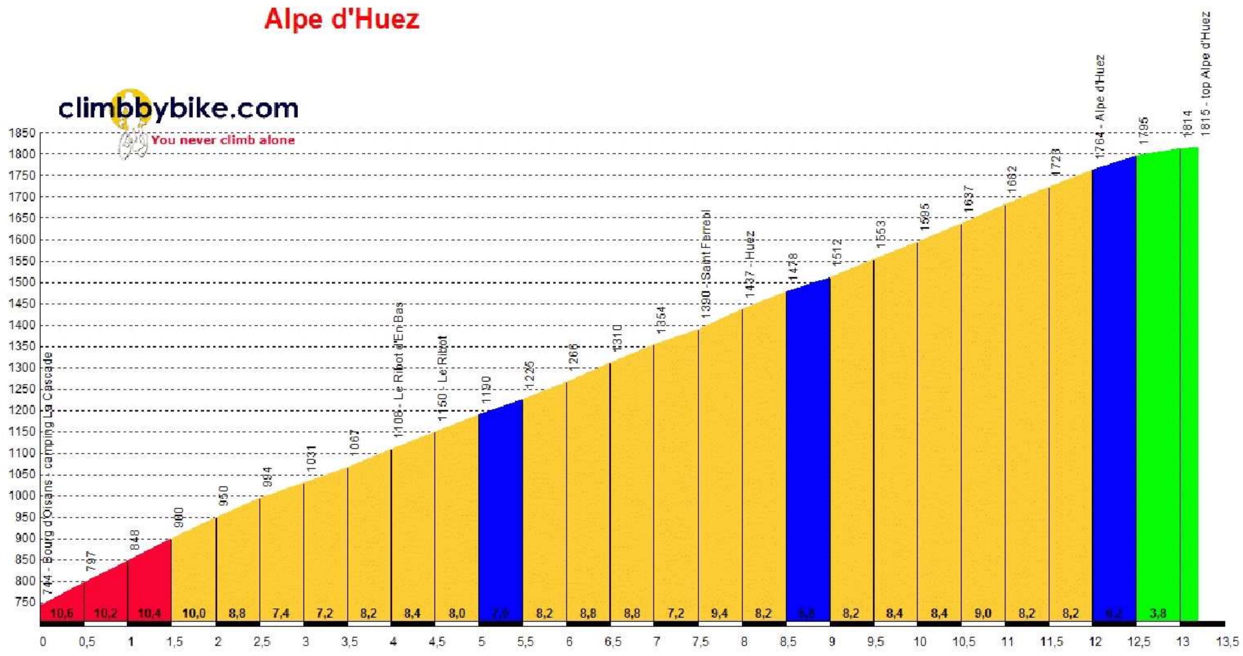
We consider three different representations of $2\frac{1}{2}$D surfaces:

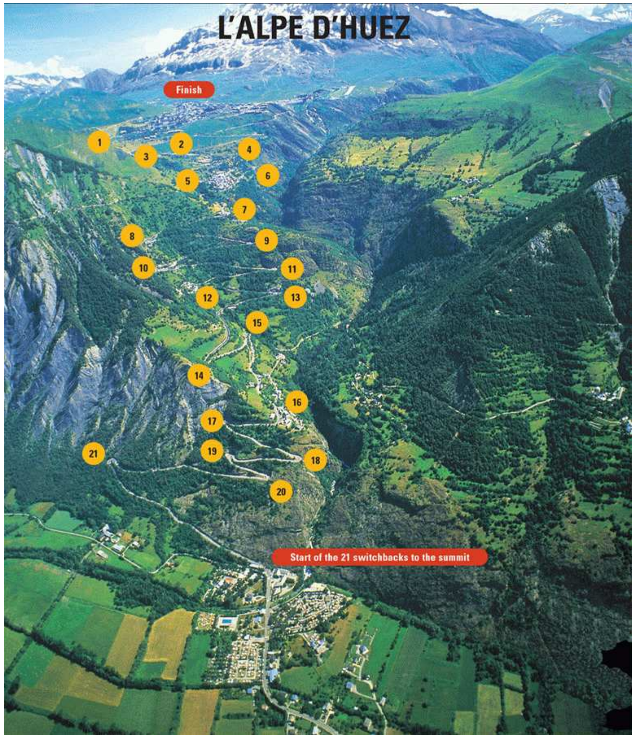
1. Analytical function
2. Regular grid/Raster approximation
3. TIN approximation

[Technical Reference:
On the angular defect of triangulations and the pointwise approximation of curvatures
V. Borrelli, F. Cazals and J.-M. Morvan *Computer Aided Geometric Design*, 20(6), 2003, pp 319-341]

Question: what does ‘discrete‘ means here?

Slope - in ‘real life‘



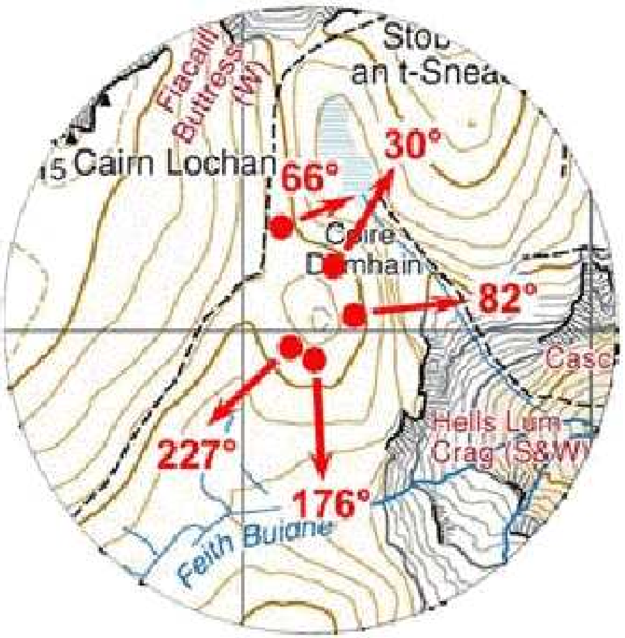


1D Slope - steepness of terrain at a point in a certain direction (e.g. in the direction of the road)

2D Slope - maximal steepness of terrain at a point

Aspect - in ‘real life‘

Aspect - direction of steepest slope



[Source: http://ben-nevis.com/navigation/slope-aspect.php]

Question. Relation with strike and dip?

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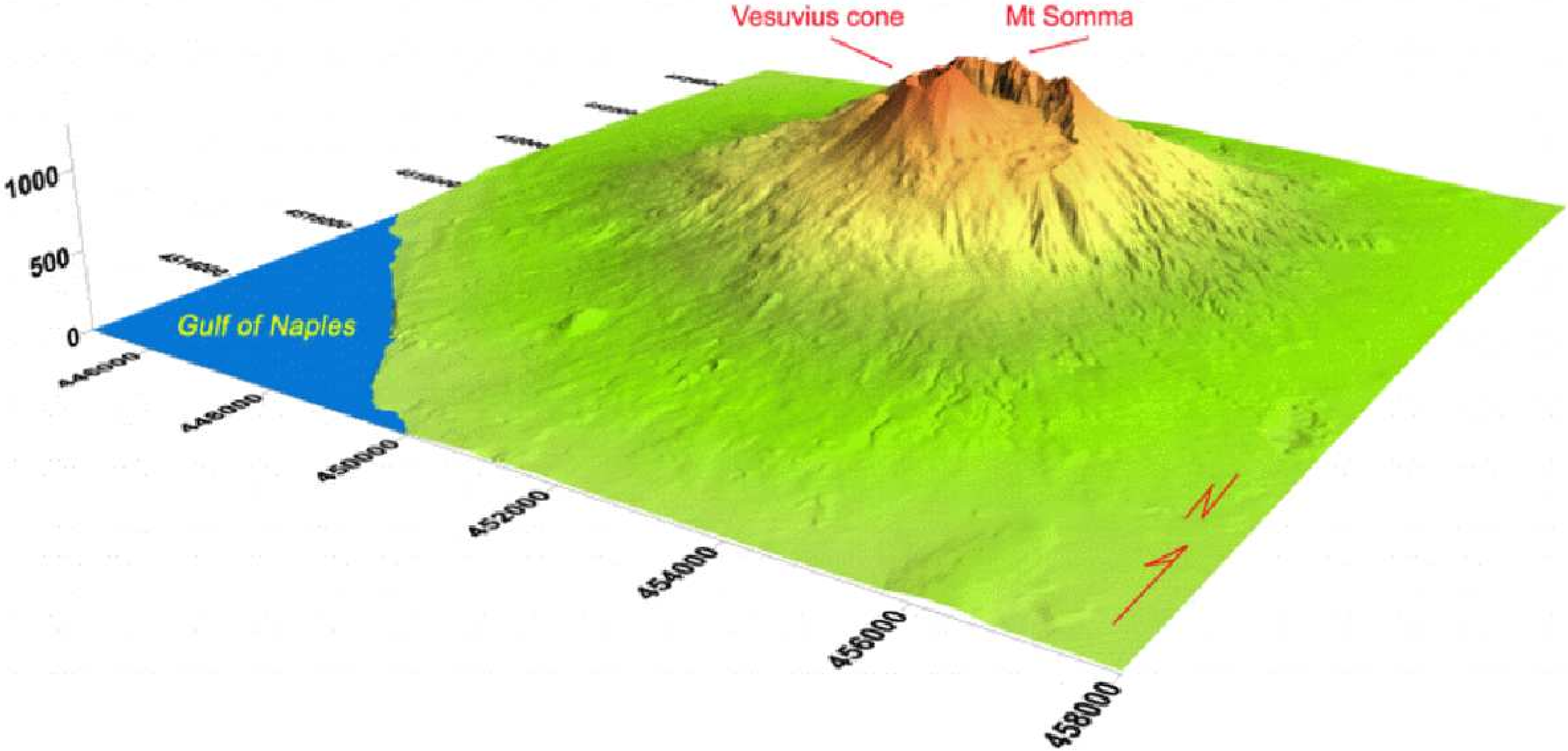
Vesuv in 3D



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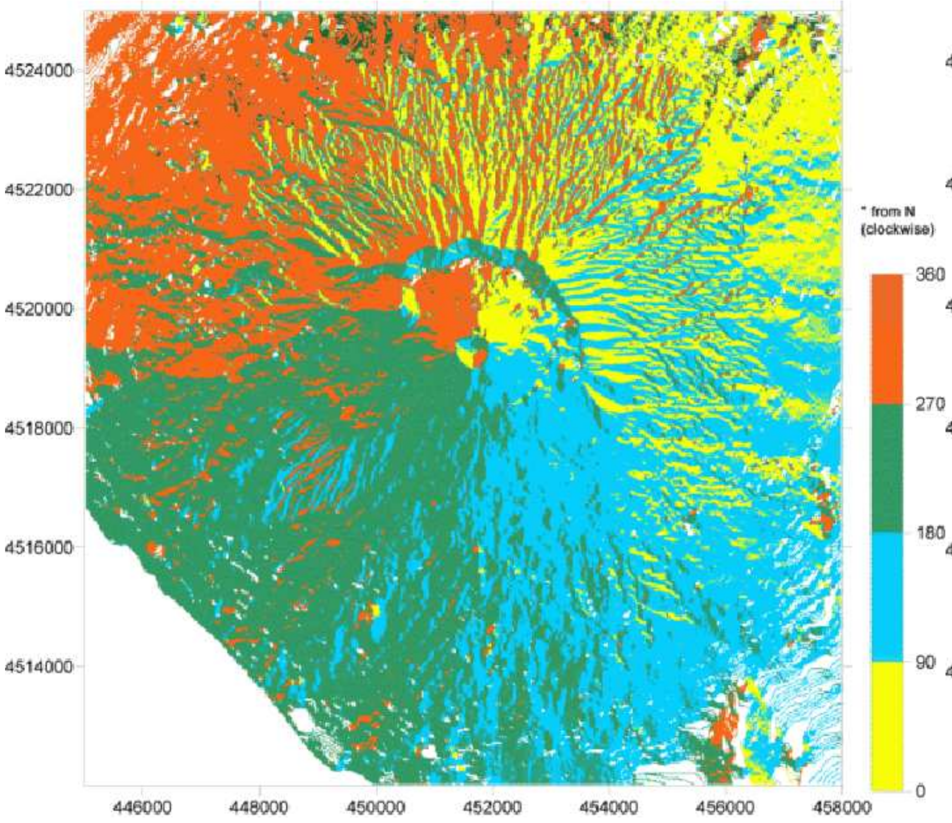
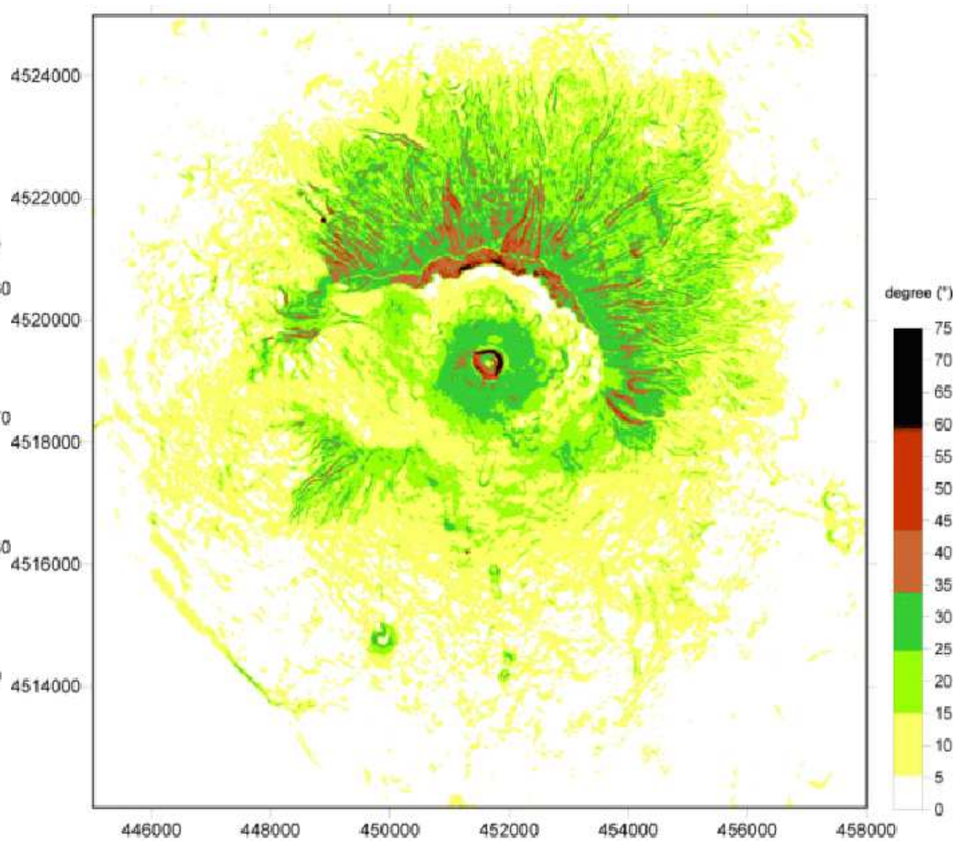
Vesuv, aspect slope





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Gradient and aspect

Let

$$\begin{aligned} f : \mathbb{R}^2 &\rightarrow \mathbb{R} \\ (x, y) &\mapsto f(x, y, z) \end{aligned}$$

the gradient of f at p is the vector

$$\nabla(f)(p) = (\frac{\partial f}{\partial x}(p), \frac{\partial f}{\partial y}(p))$$

The gradient (vector) points in the direction of maximal change.
This direction between 0° and 360° is the aspect

The slope is the magnitude of maximal change, which can be quantified as the length $\|\nabla f\|$ of the gradient vector.

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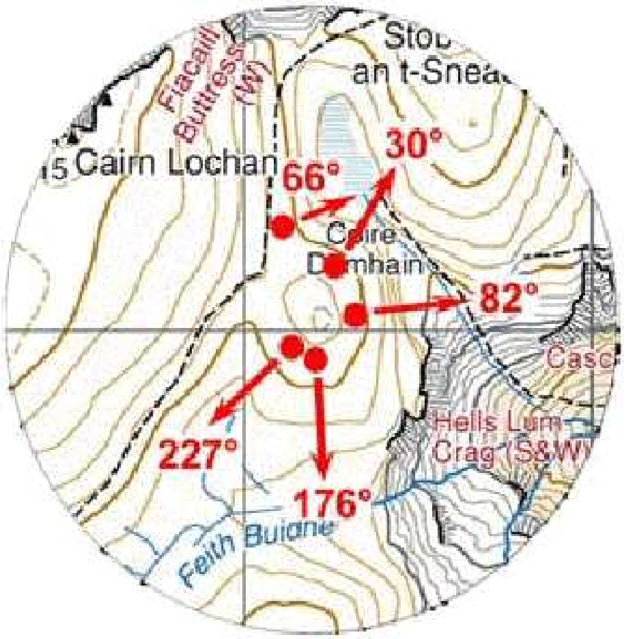
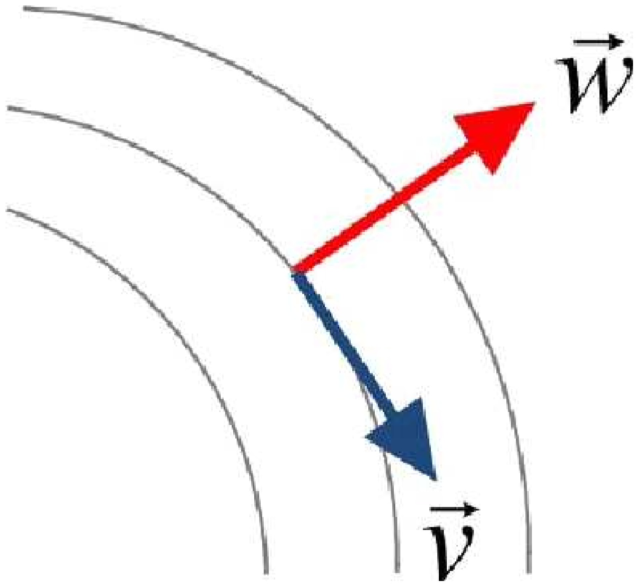
Contour lines

Isoline/Contourline: curves of constant elevation





Theorem The gradient vector is always perpendicular to the contour line

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Proof of Theorem

Let $\nabla f(x, y)$ be the gradient at a point of the isoline $f(x, y) = c$.

Assume the isoline curve f_c can be smoothly parameterized by arc length as

$$x = x(s), \quad y = y(s)$$

The unit tangent vector to f_c at s is

$$T(s) = \left(\frac{dx}{ds}\right)\mathbf{i} + \left(\frac{dy}{ds}\right)\mathbf{j}$$

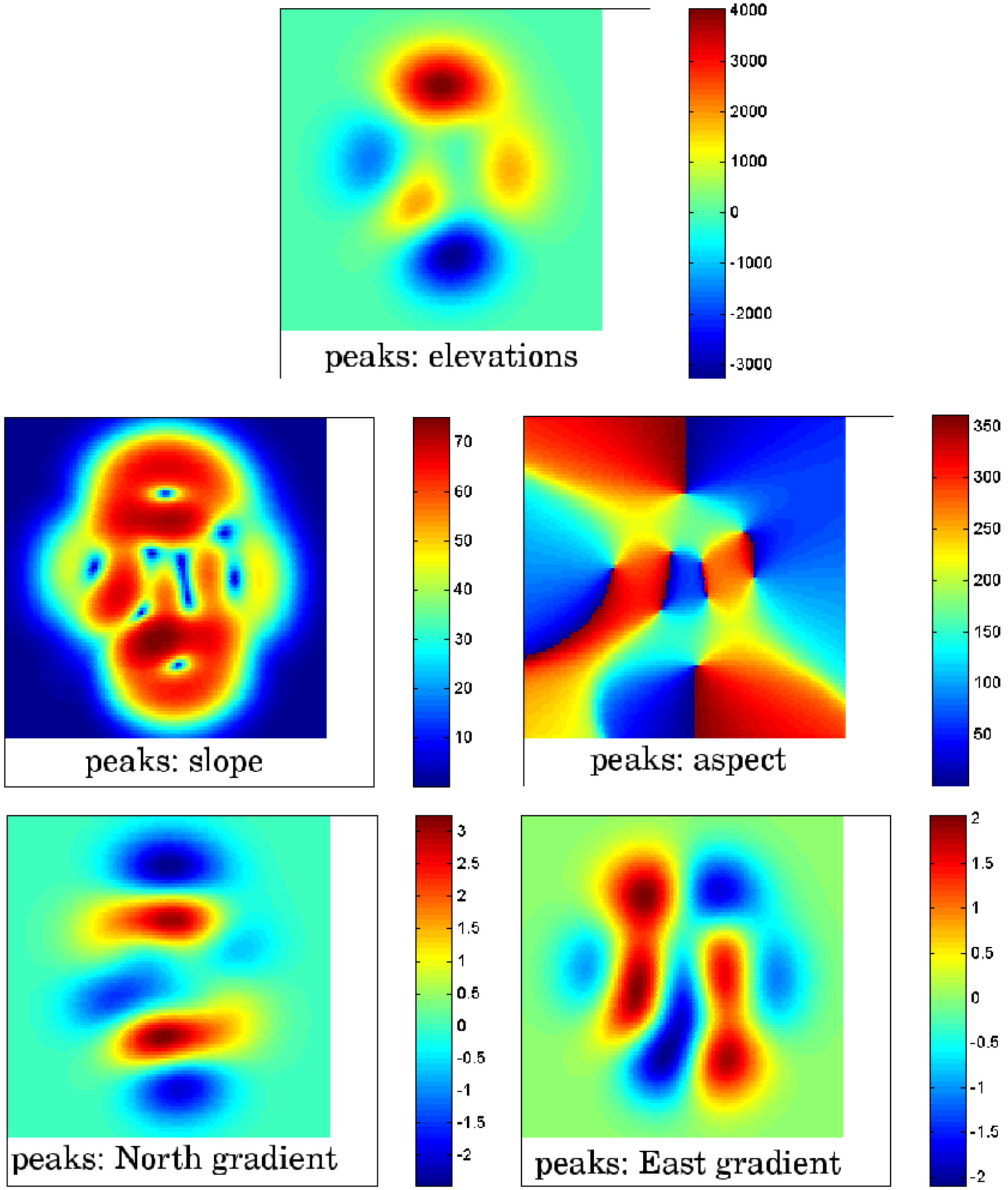
Differentiate the equation $f(x, y) = c$ w.r.t. s using the chain rule:

$$\frac{\partial f}{\partial x}\frac{dx}{ds} + \frac{\partial f}{\partial y}\frac{dy}{ds} = 0$$

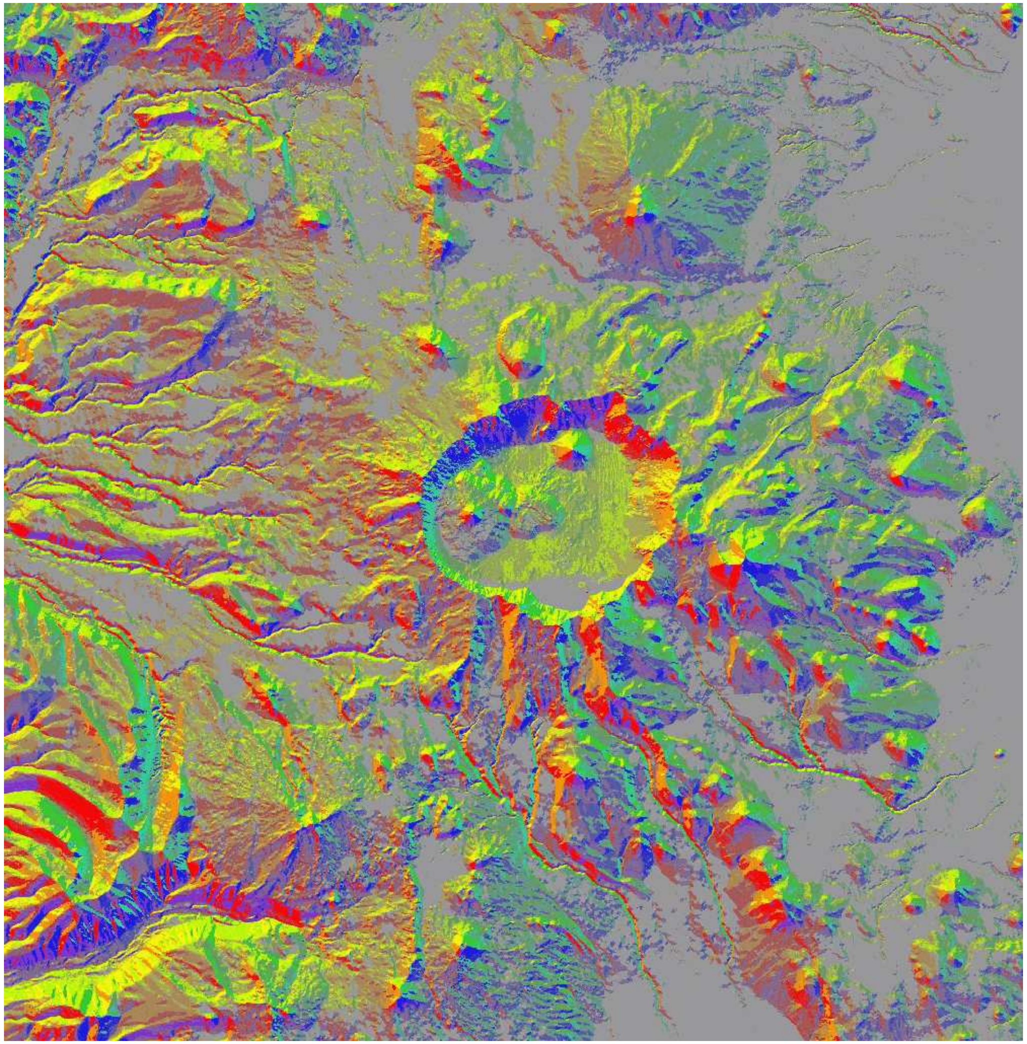
or

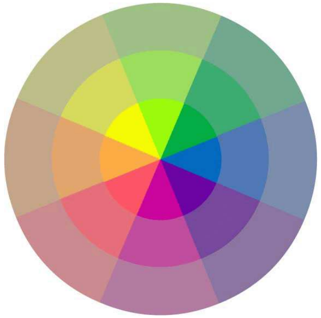
$$\left(\frac{\partial f}{\partial x}\mathbf{i} + \frac{\partial f}{\partial y}\mathbf{j}\right) \cdot \left(\frac{dx}{ds}\mathbf{i} + \frac{dy}{ds}\mathbf{j}\right) = \nabla f(x, y) \cdot T(s) = 0$$

[Proof from Calculus, H. Anton]


peaks: elevations
4000
3000
2000
1000
0
-1000
-2000
-3000
peaks: slope
70
60
50
40
30
20
10
peaks: aspect
350
300
250
200
150
100
50
peaks: North gradient
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
peaks: East gradient
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2

Aspect and Slope together





Source: http://blogs.esri.com/Support/blogs/mappingcenter/archive/2008/05/22/aspect-slope-map.aspx

Gradient image

From elevation raster to gradient raster

range image	$d(\text{column}, \text{row})$
gradient image	$g = \nabla d = (d_c, d_r)$

Example

1	2	3	3	1
1	3	3	2	1
0	3	4	3	2
0	3	5	4	3

Range image

1	1	0	-2
2	0	-1	-1
3	1	-1	-1
3	2	-1	-1

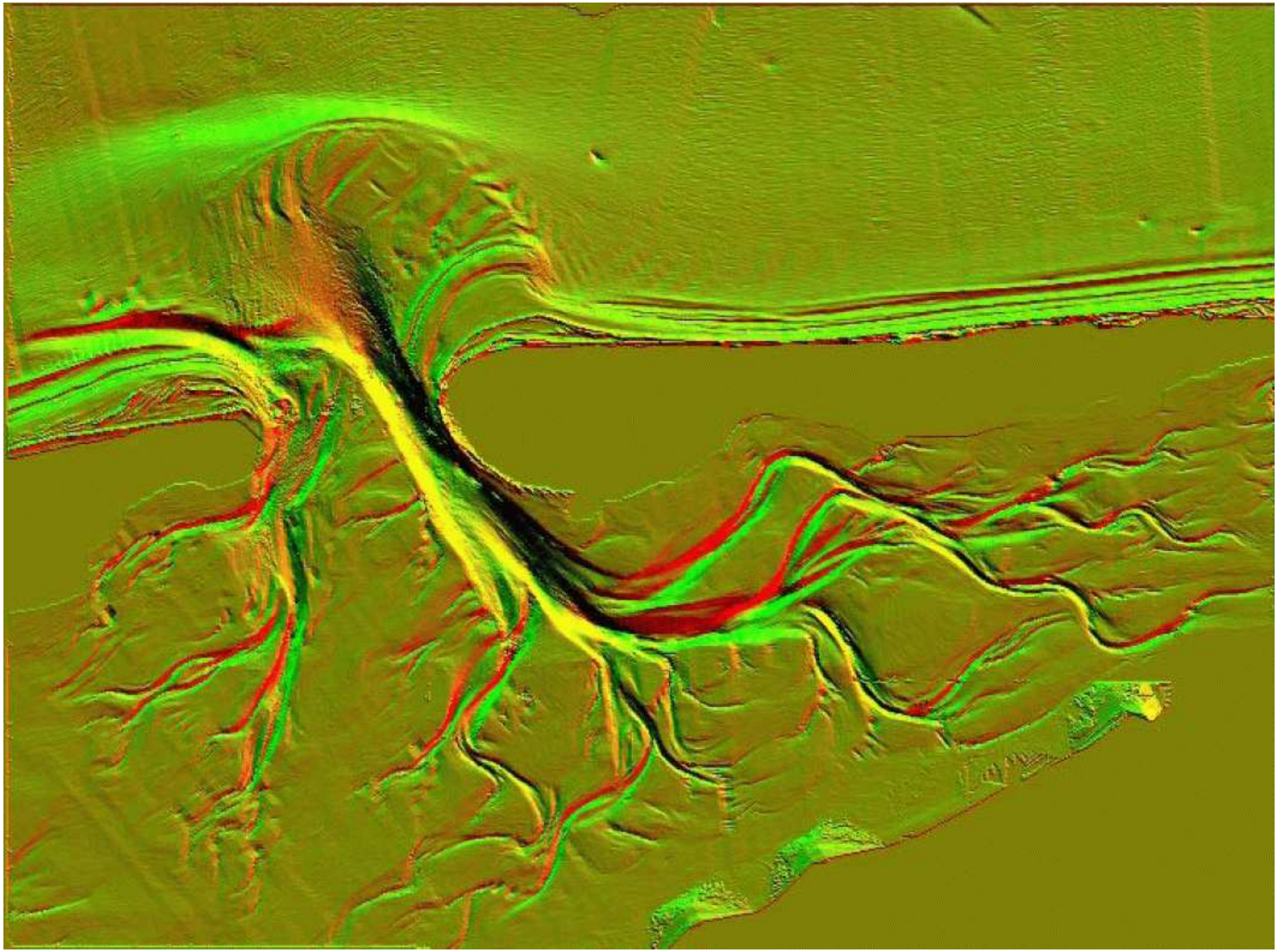
Row gradient image

0	-1	0	-1	0
-1	0	-1	1	1
0	0	-1	1	1

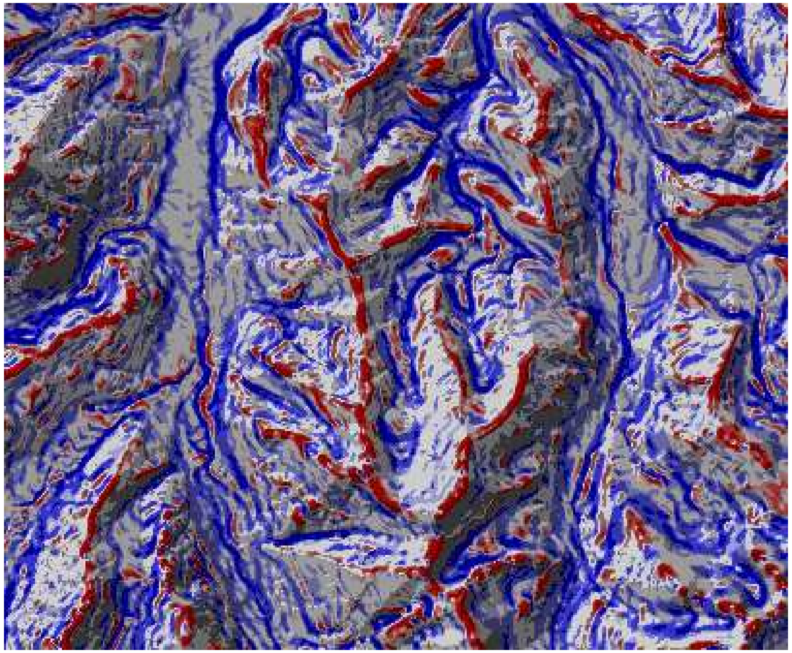
Column gradient image

Remark: Note that here raster and image are equivalent notions

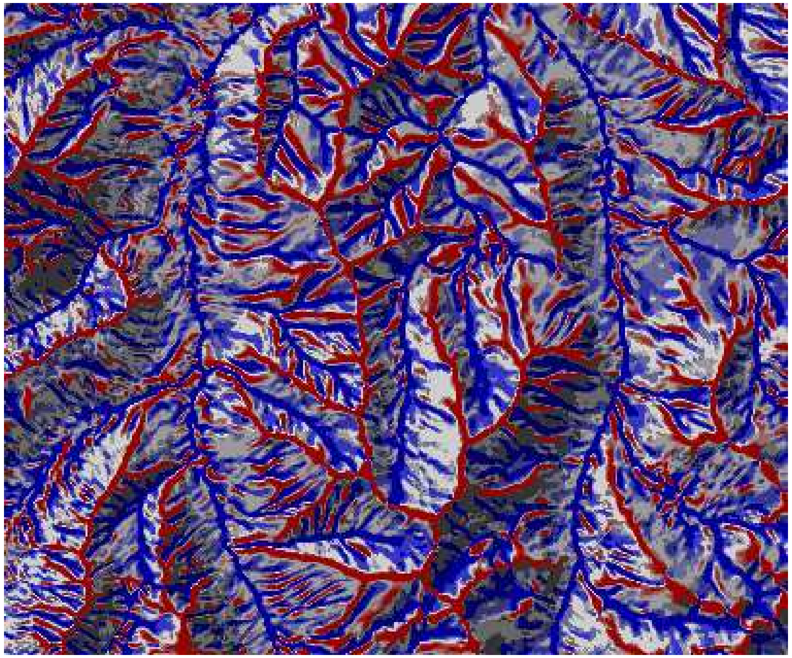
Waddenzee: colored by x- and y-slope



Curvature: $\approx$ 2nd derivative



'Profile Curvature'



'Planar Curvature'

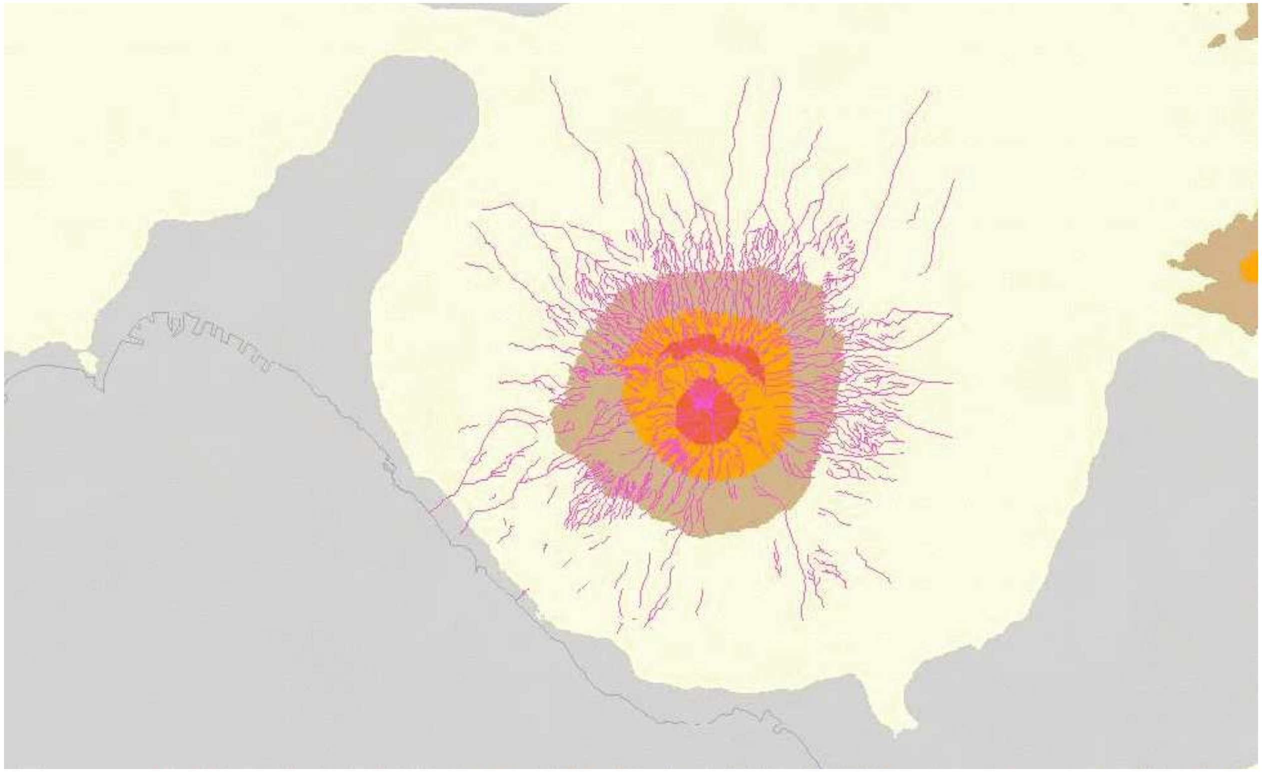
[Source: http://www-vv.slu.se/fs/tatry/fin_rapp/FR_22.htm]

Profile curvature $\sim$ 'Shape of the relief in the direction of the slope'

Planar curvature $\sim$ 'Shape of the relief perpendicular to the slope'

D. Drainage Networks

Vesuv again



Source http://ipf.ov.ingv.it:81/pmapper/map.phtml?config=siscam&dg=reg_sud,SR_Cam_45

Contents

A. Watersheds and Drainage Networks

- Definitions
- Examples

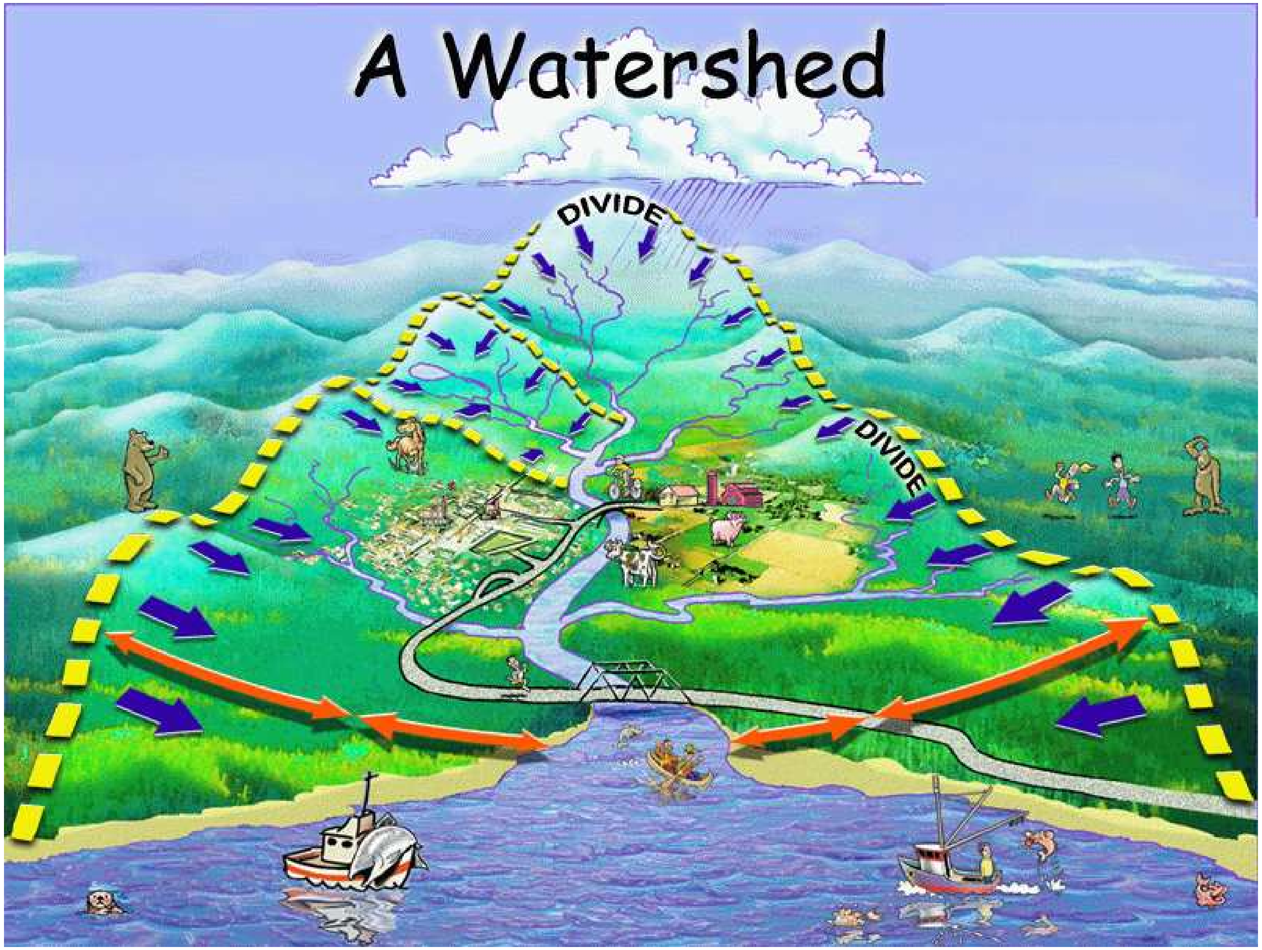
B. D8 algorithm

- Drain direction
- Flow accumulation
- Pour-points
- Dealing with flat areas

C. Hydrosheds

- Example of a drainage network product

Watersheds



Watershed: area of land that captures water in a common water body, like river or lake

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River catchments

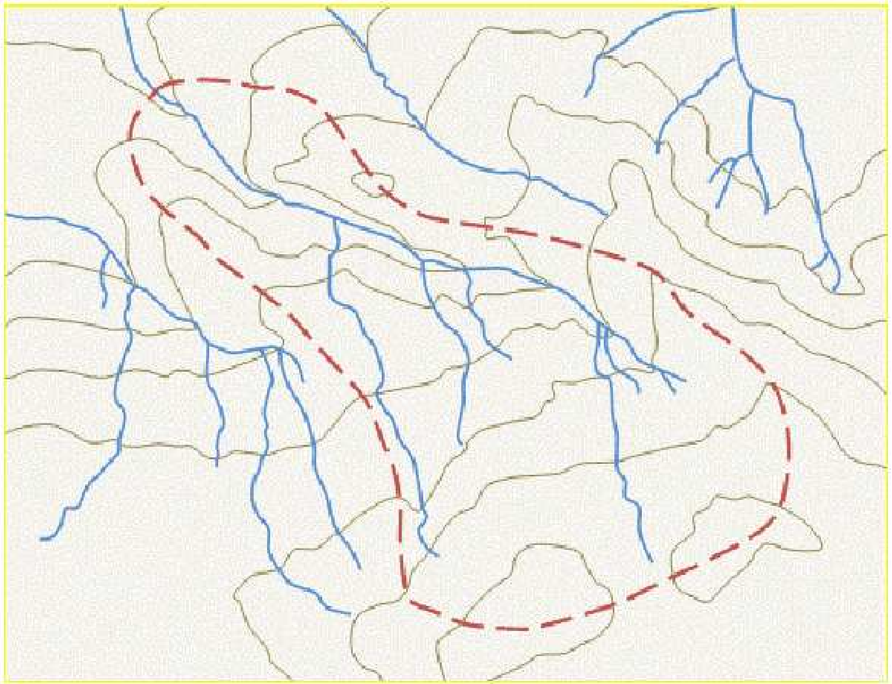
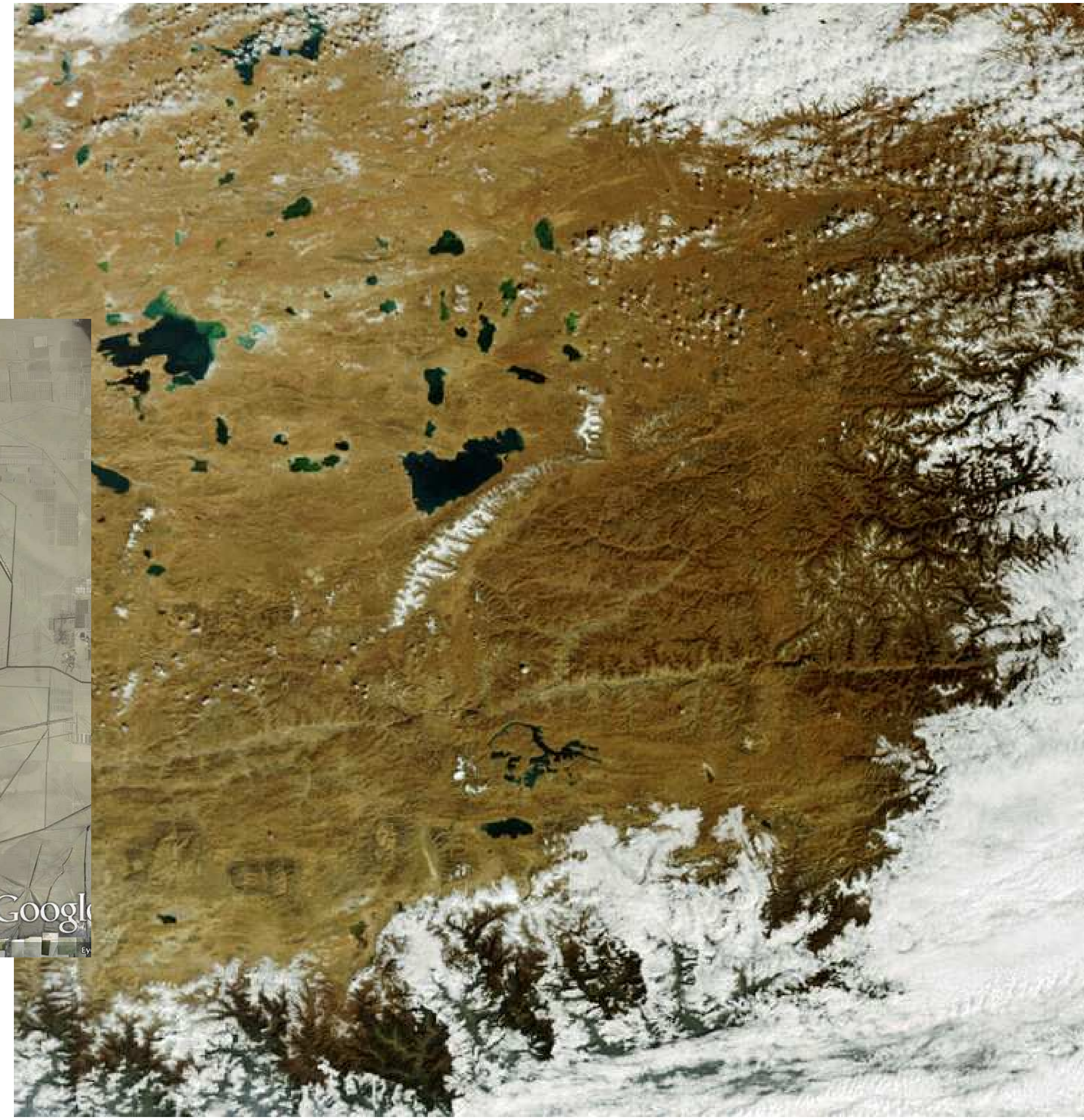


Figure 1.2 Example catchment boundary (rivers, catchment boundary, contour lines)

Watersheds, catchments and basements are similar notions

Endorheic lakes



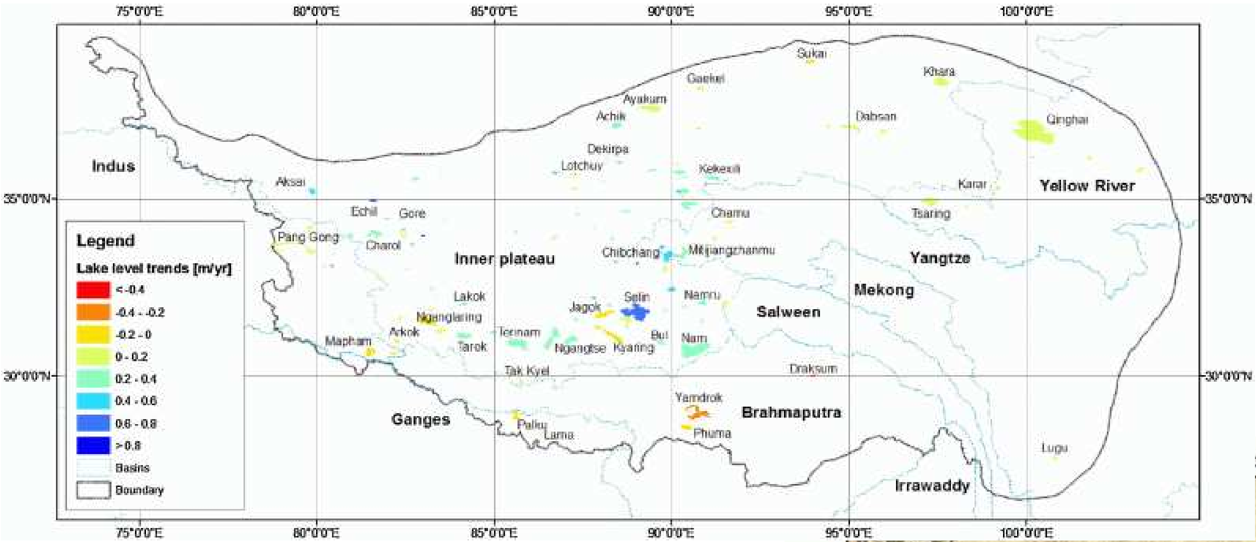
Question: Why are endorheic lakes salty?

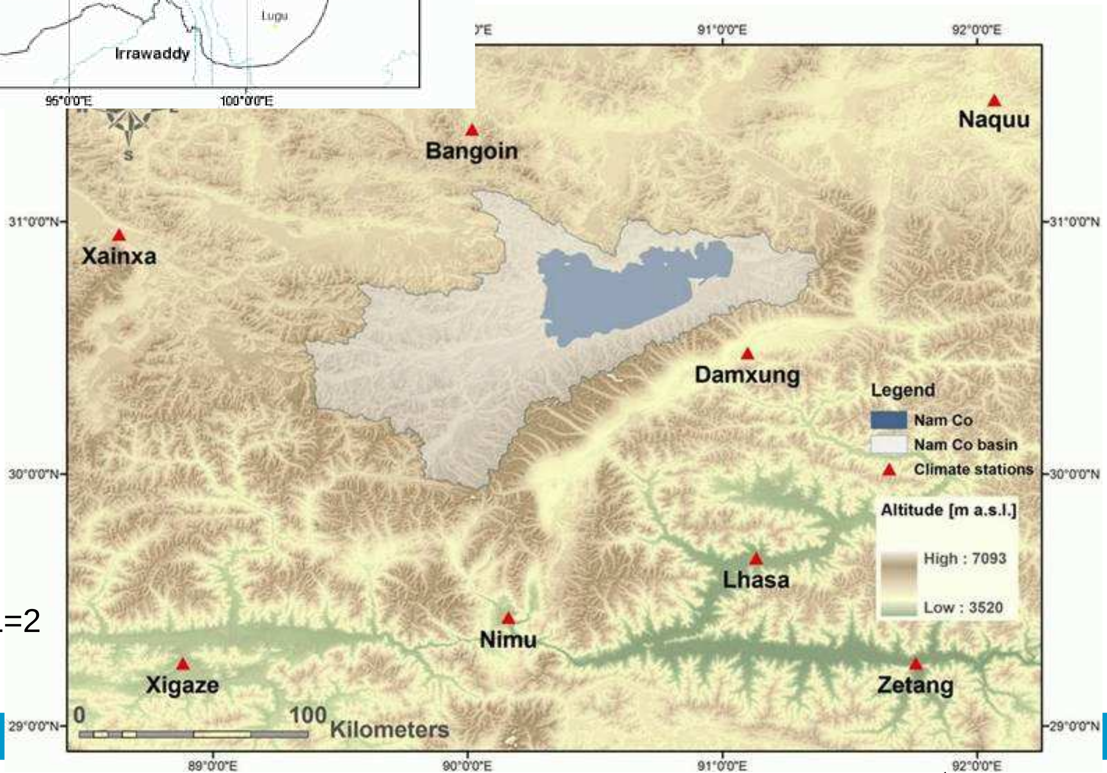
Source http://www.eosnap.com/lakes/lake-namtso-north-of-the-nyainqentanglha-mountains-tibet/

Source http://meltdownintibet.com/e$_$salt.htm

Tibet example

Source: ICESat derived elevation changes of Tibetan lakes between 2003 and 2009, V. Phan Hien et al.
Int. Jrnl. of Applied Earth Observation and Geoinformation, 17, pp. 12-22, 2012

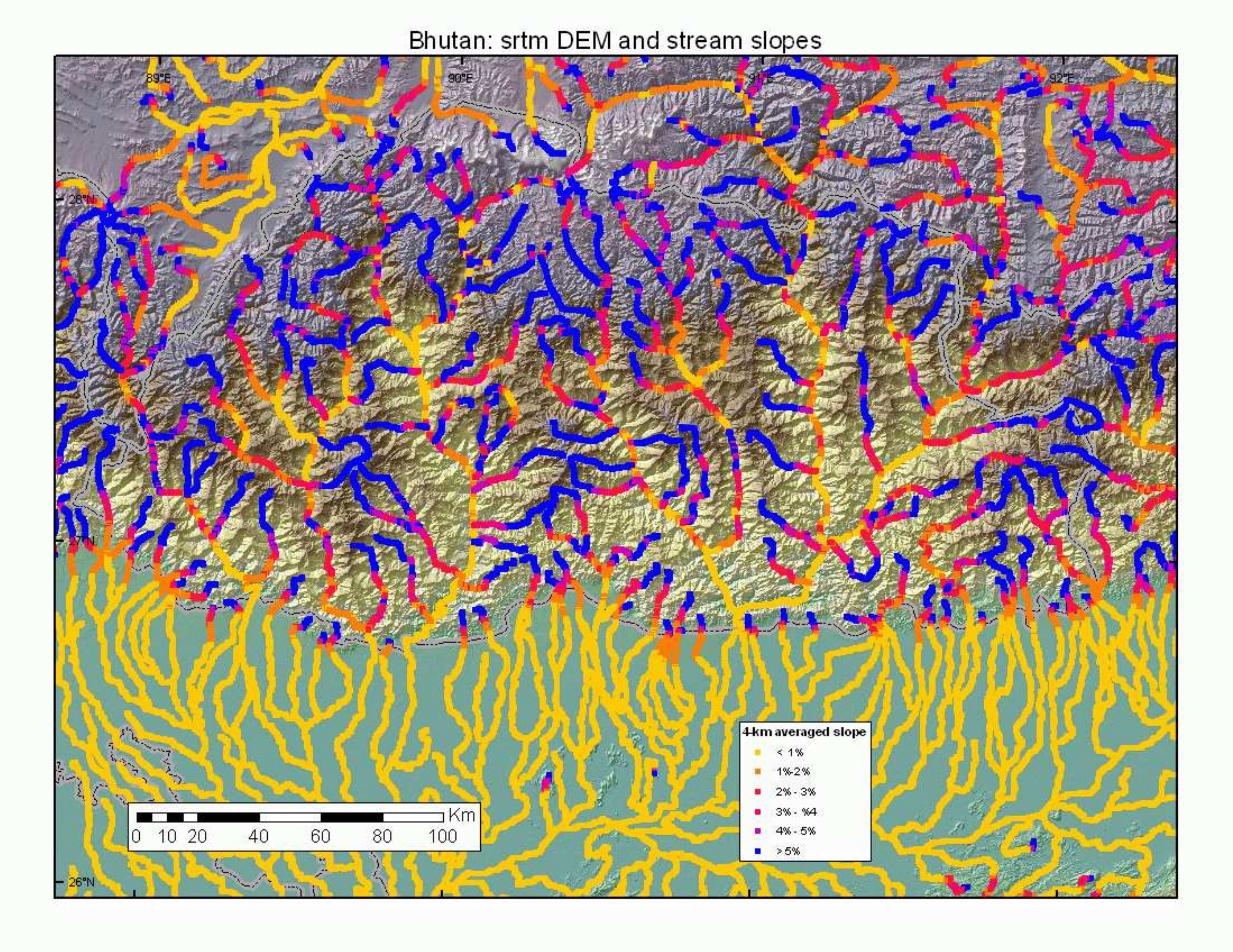




Source: http://www.geoinf.uni-jena.de/7353.0.html?&L=2

Bhutan Stream Slopes

Source: http://gis.ess.washington.edu/areas/Bhutan/streamslopes/index.html



Geometrical wishes and applications

Wishes:

1. Get catchment boundaries
2. Get stream locations

Applications:

- Assessing flooding risks
- Irrigation
- Geological interests
- Assessing polution risks
- Transport
- Water balance

D8 algorithm - Idea

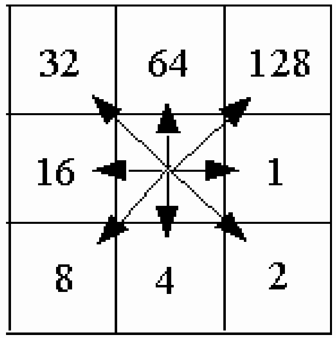
Grid Elevations:

(a)

78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

Direction Encoding:

(b)



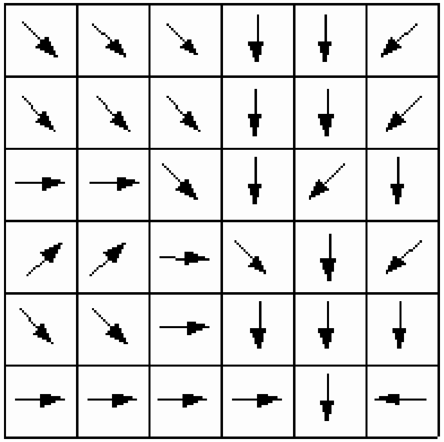
Encoded Grid Directions:

(c)

2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

Visualized Grid Directions:

(d)



(Source: http://www.nws.noaa.gov/oh/hrl/gis/data.html)

D8 algorithm - details

Input: DTM stored as regular grid

Assumption:
Water in each cell flows towards unique 8-neighboring cell, the cell in the direction of steepest descent

Question: are all cells on equal distance?

Flow accumulation, per cell:
Sum of weights of all cells flowing to that cell.

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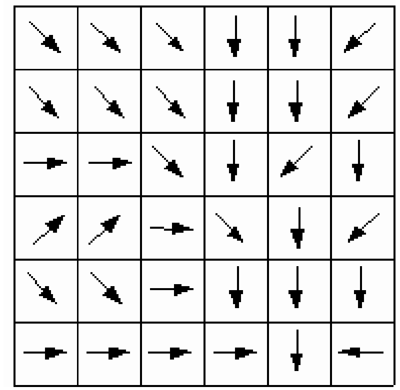
Flow accumulation - example

Elevations

78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12



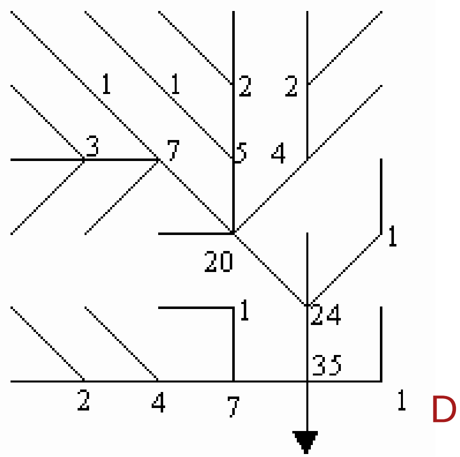
Directions

(a)

0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	1

Accumulation

(b)



Drainage network

Example: $35 = 7 + 24 + 1 + 3 \cdot 1$ (using equal weight for all cells)

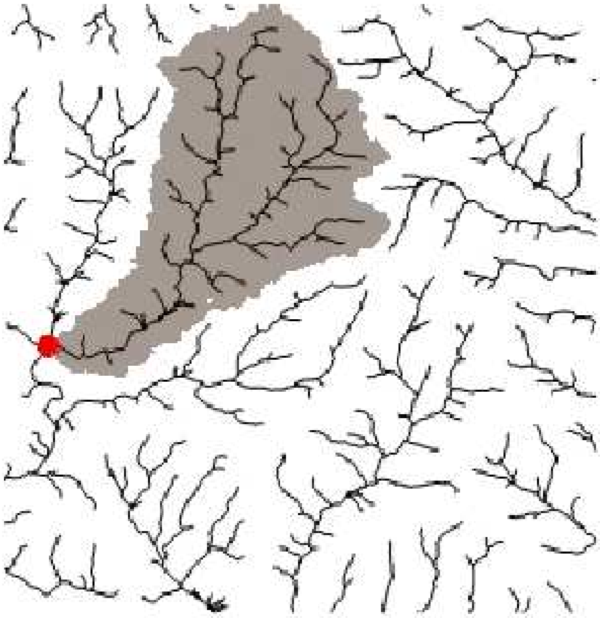
Towards D8 watersheds

Channel cells: cells that drain a minimum threshold area

Delineation of watersheds Input

1. Flow direction grid
2. Pour-points

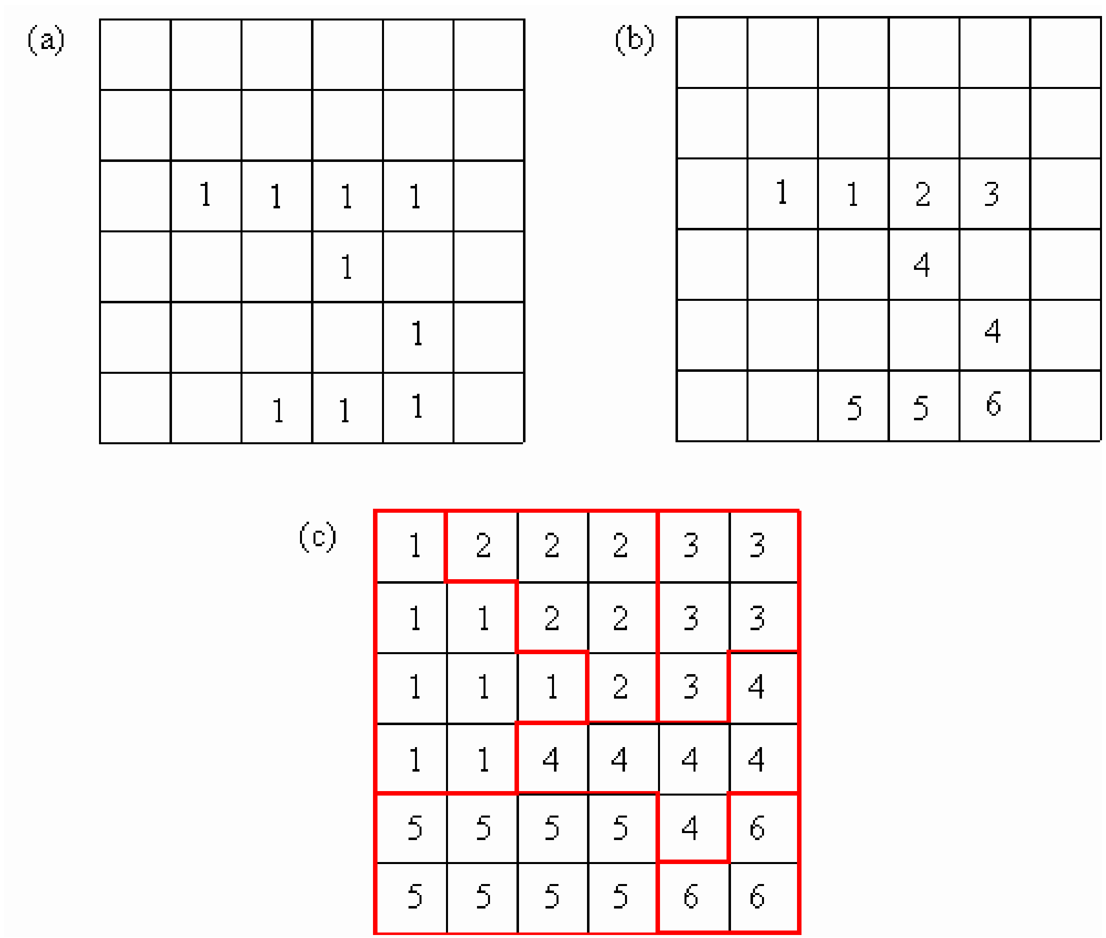
Automatic pour-point selection:
Downstream end of each link in the drainage network



D8 Watersheds

Accumulation $\geq$ 3

Labeling of stream links by integers



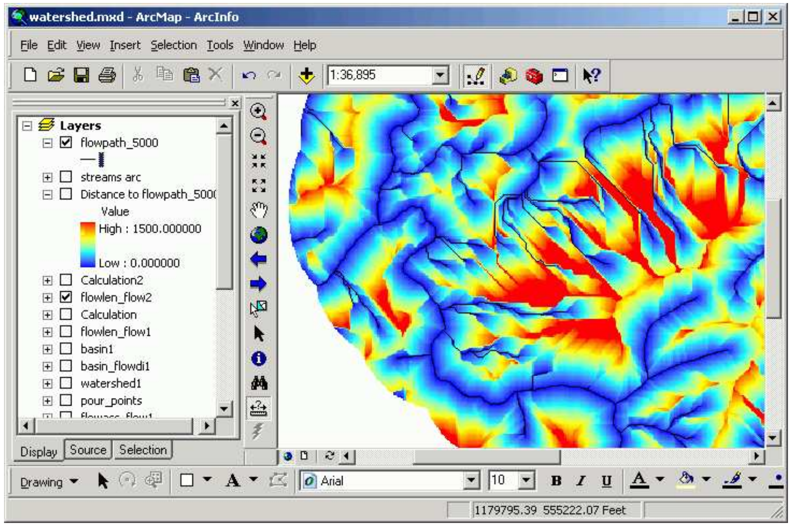
Division into subwatersheds

Flow Lengths

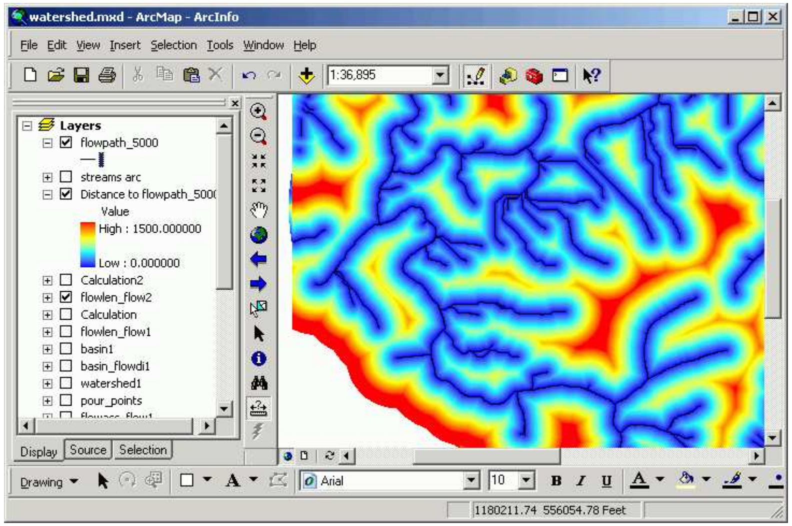
Flow Length:
length of path from cell to outlet

6.66	6.24	5.83	5.41	5.83	6.24
6.24	5.24	4.83	4.41	4.83	5.24
5.83	4.83	3.83	3.41	3.83	3.41
6.24	5.24	3.41	2.41	2.00	2.41
4.41	3.41	3.00	2.00	1.00	2.00
4.00	3.00	2.00	1.00	0.00	1.00

Running example



Distance to stream following flow



Euclidean distance to stream

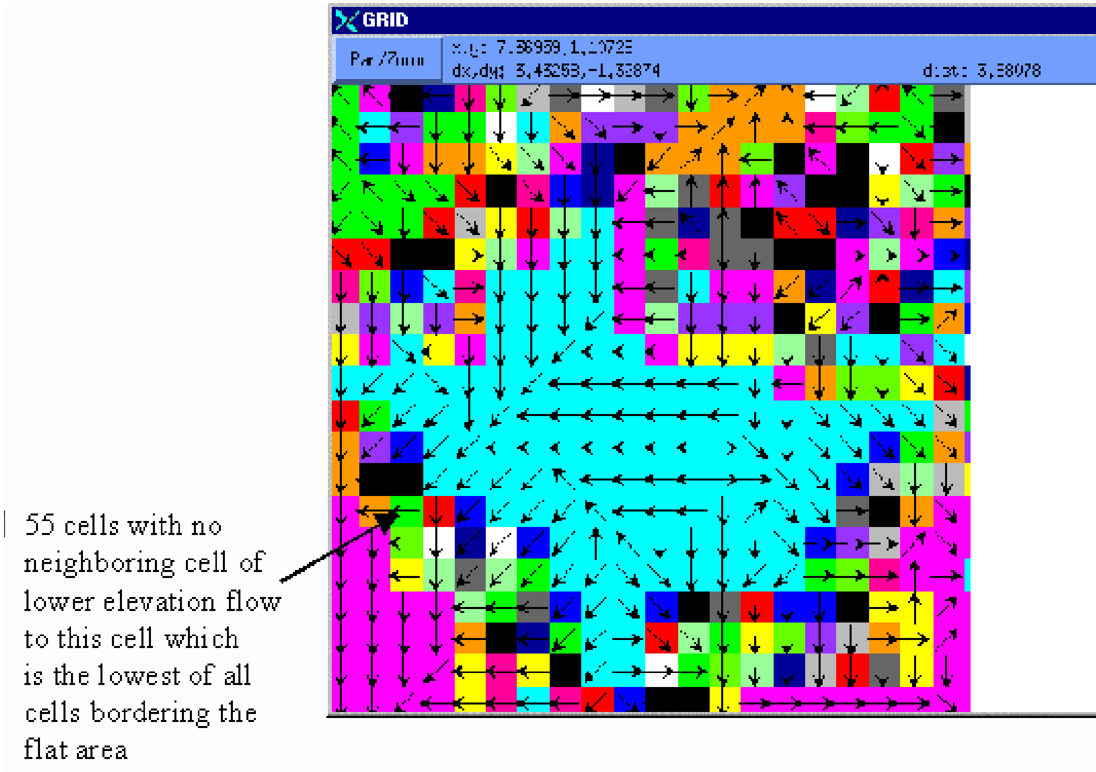
Problem areas

Possible flow direction modifications:

1) Route lakes to their outlets defined by

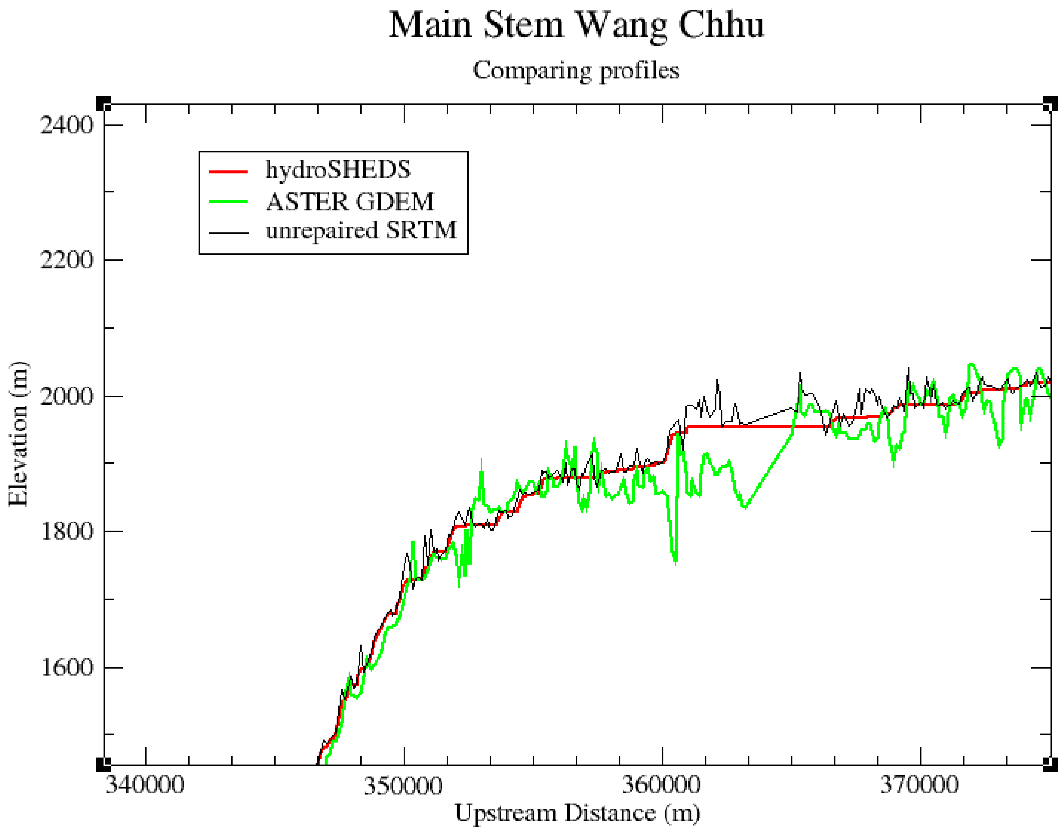
- rivers and streams, or by,
- lowest water edge elevation flowing away from the lake

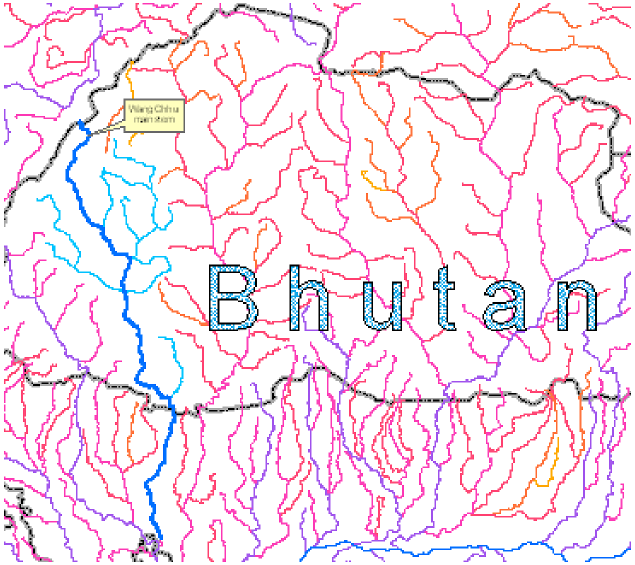
2) Route rivers from their headwate to their tail waters. Route cells immediately adjacent to rivers into the rivers



3)Route flat areas to intersecting streams or the nearest routed cell

Sinks & non-monotonocy





Source: http://gis.ess.washington.edu/areas/Bhutan/streamslopes/index.html

Sink identification

Sinks: interrupt continuous flow across the DEM surface

Some procedures implemented by Hydrosheds to improve river topology extraction:

Deepen river and lakes: Force flow to stay inside

Stream burning: Enforce known location of rivers; Lower elevation values (e.g. by 12 m) along a river with a buffer of e.g. 500m from the river center to the surroundings.

Sink filling: Raise elevations in the sink until outflow is possible

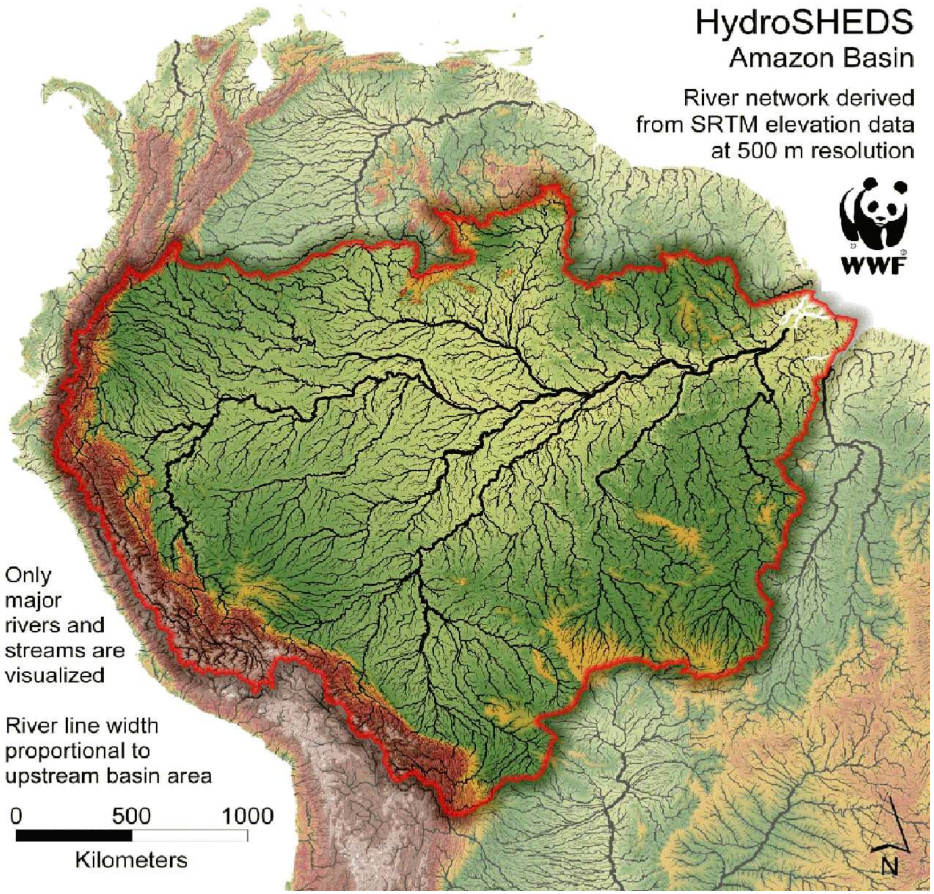
Carving: Remove rises in the river courses

Hydrosheds

http://hydrosheds.cr.usgs.gov/

Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales

- river networks
- watershed boundaries
- drainage directions
- flow accumulations



Hydrosheds example, Mekong river

Source: MSc thesis, Marjolein Koudijs

Project aim: monitoring Mekong water level changes using ICESat elevations

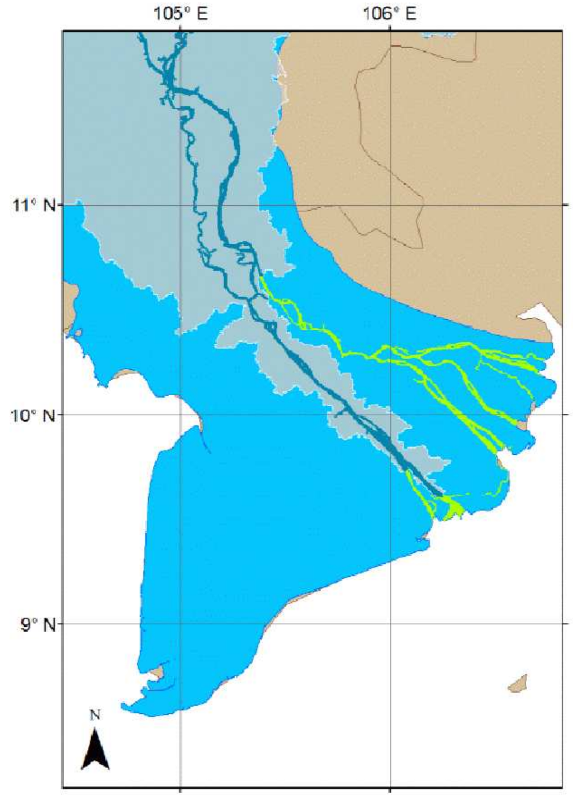


Figure 3.5: USGS drainage basin compared with IWMI drainage basin, distributaries in the Mekong River Delta (green lines) are excluded by USGS.

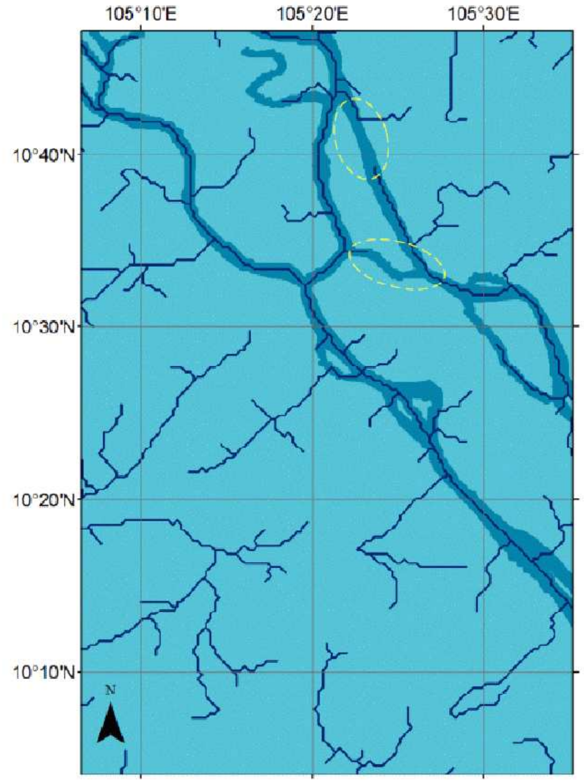


Figure 3.16: Errors in USGS HydroSHEDS River Network (RIV) causes absence of the complete left branch in the Mekong River Delta.

Conclusions

Local terrain analysis

- Surface normal and roughness are obtained by local least squares fitting
- Slope and aspect are derived from gradients
- Ridge and valley points: second derivative

Global terrain analysis

- Link local results (like gradients)
- Example: Path way of water is an important application of elevation data.
- Resolution issues and errors can spoil physical consistency

Exercises