Digital Terrain Modeling

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INPE - DPI

Topics

Definitions

Sources

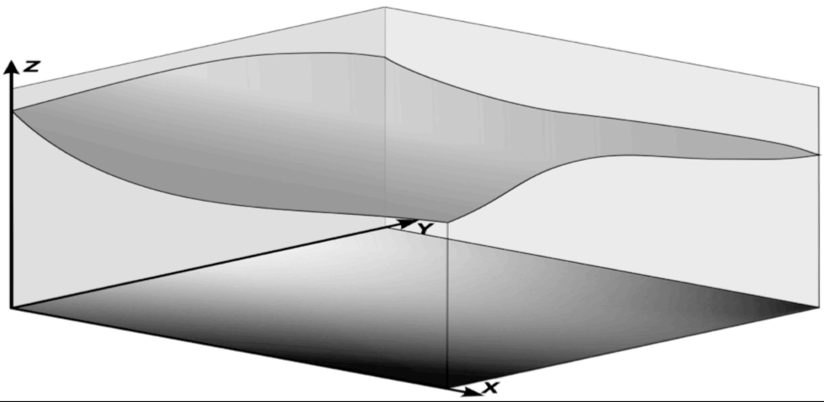
Models

Products

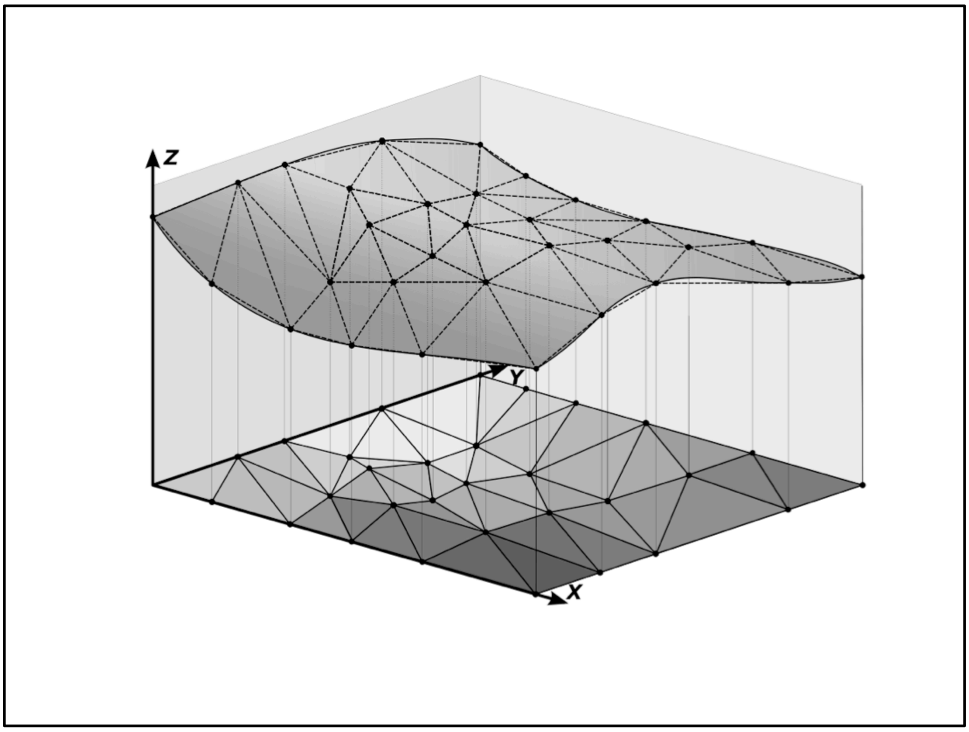
What are Elevation Models

Computational Representation of the distribution of a geographic phenomenon

Phenomenon: Terrain Elevation



Here we define our elevation models.


Z
Y
X

Naming

DTM, DSM, DEM
TIN

M: Model, Modeling

D: Digital

T: Terrain

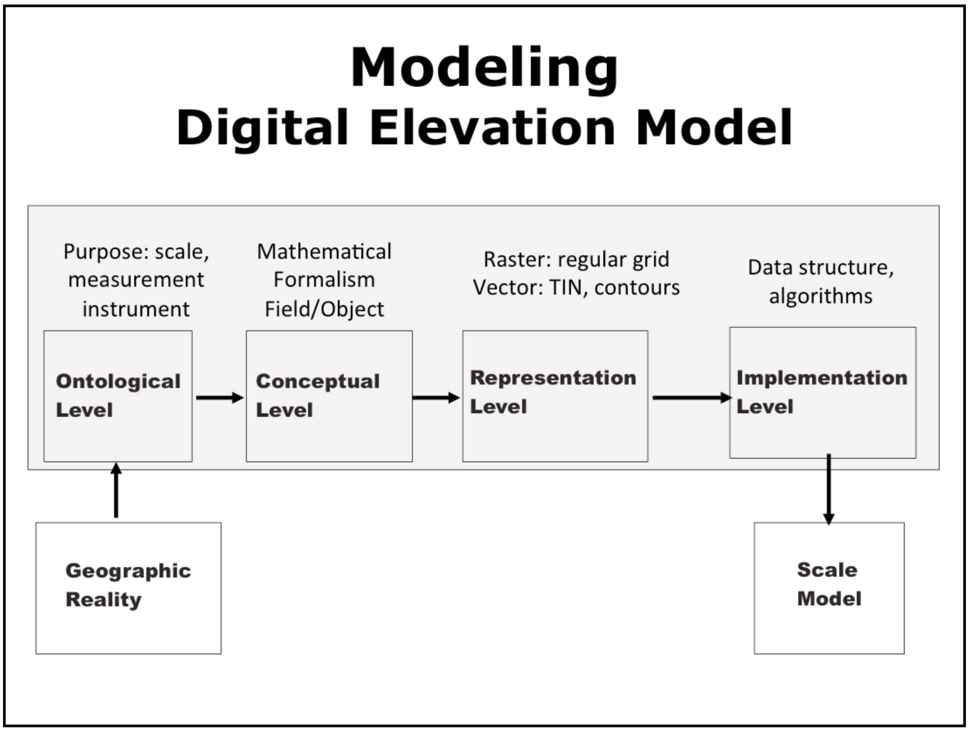
E: Elevation

S: Surface

Most correct - DEM

The Acronyms for elevation models are diverse. Usually what the letters stands for are listed here. The must be a difference between terrain, elevation and surface. Terrain does not indicate that the value associated with the model is elevation and could be the value of any other geographic phenomenon at that location. Surface indicates that the value is associated with the top of whatever is located at that location, so usually the term surface is used when we know that the elevation is added to the tree tops, for example. That is why elevation is the best term.

TIN is Triangulated Irregular Network, a different elevation model that uses triangles to represent the elevation.



In the modeling process we need to transport data from the real world to the representation inside the computer.

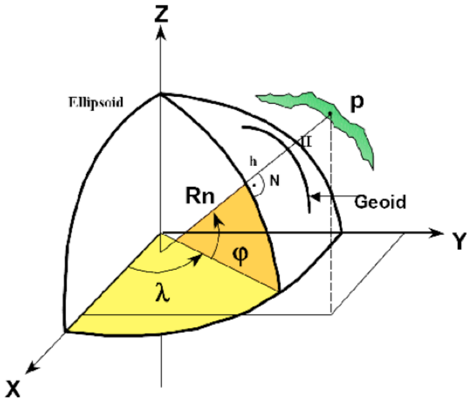
This levels approach helps this procedure.

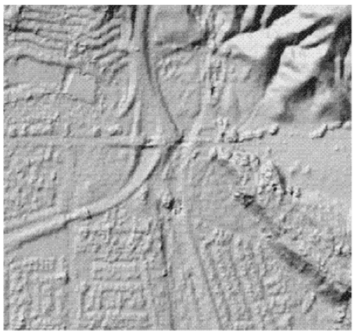
In the ontological level we define the geographic reality entities from applications point of view.

The conceptual takes the data to the field formalism.

Representation level has the regular grid, TINs, and contour lines maps that are implemented by data structures in the Implementation level. We also include the algorithms in the implementation level.

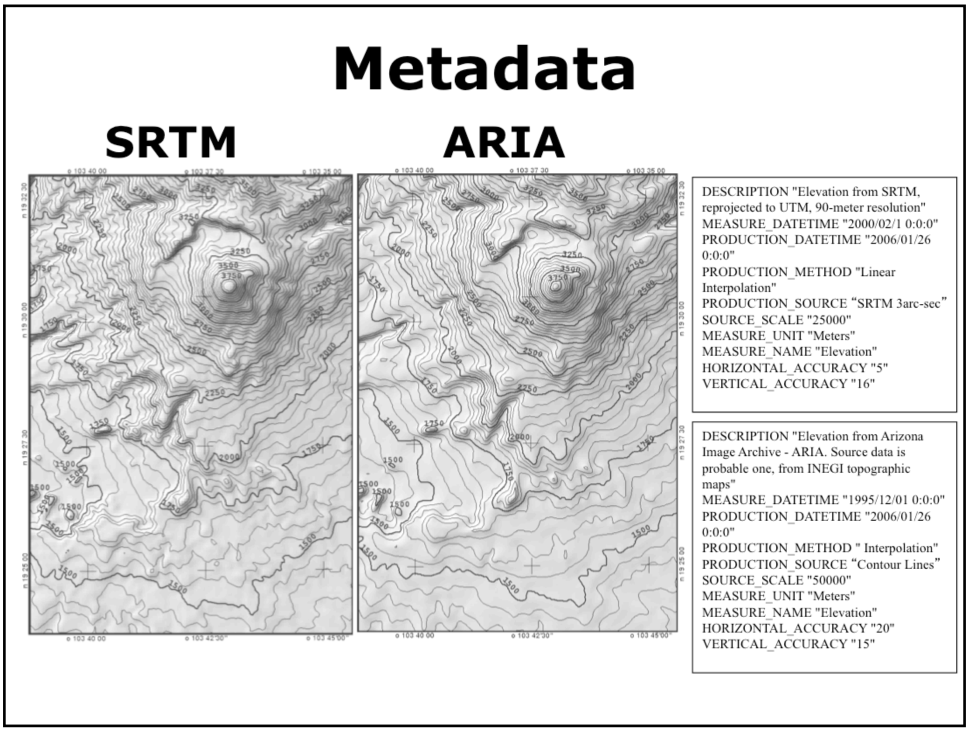
Elevation in the Real World





Ayers, H. B. (2000). Local Geoid Models for 3-D Helmert Transformations, Leica Geosystems Ltd

This slide shows how elevation is formally defined. It is taken using the correct cartographic ref



Another aspect that has to be considered is if the data to be used contains metadata describing the collection and processing of the raw data. These information are important to help define the applicability of the data. In this slide, two DTMs are shown, and one can notice some differences that are related to the acquisition and processing.

Data Sources

Field Surveys

Photogrammetry – Stereoscopic analysis of images

Cartographic sources – Contour lines and profiles

Radar Interferometry - Synthetic Aperture Radar Interferometry (InSAR) – Aerial, Satellite, Space Shuttle (SRTM)

LIDAR - Light detecting and ranging – Aerial, Satelite

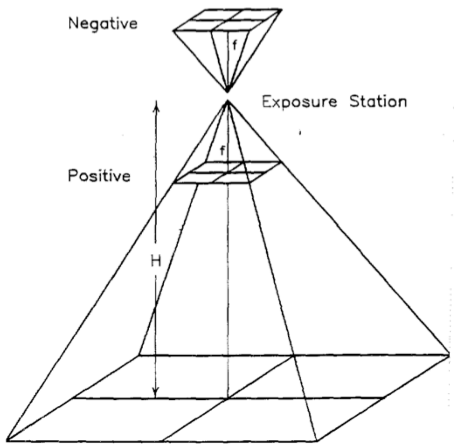
GPS - Global Positioning System

This slide lists some of the main sources of raw data for a DTM.

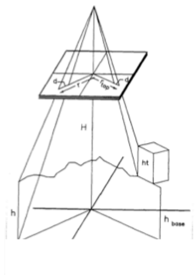
Photogrammetry

Photogrammetry is based on measuring the difference between the positions of the same target in two overlapping images. The difference in position is directly related to their difference in elevation.

Geometria de Aquisição

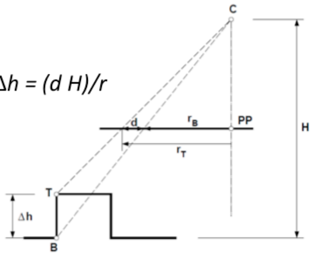


Deslocamento Devido ao Relevo



$\Delta h = (d\ H)/r$

d = image displacement
r = radial distance from the principal point to the image point
H = flying height above ground



Parallax Equations

$p_a = x_a - x'_a$

$h_A = H - B.f/p_a$

$X_A = B.x_a/p_a$

$Y_A = B.y_a/p_a$

where

p_a : parallax of point A

h_A : elevation of point A above vertical datum

H : flying height above vertical datum

B : distance between the exposure stations

f : focal length of the camera

X_A, Y_A : ground coordinates of point A in the XY coordinate system with origin at point P on vertical datum of the left photo. X axis is in same vertical plane as x and x' flight axes and Y axis passes through P and is perpendicular to the X axis

x_a, y_a : photo coordinates of point a measured with respect to the flight line axes on the left photo

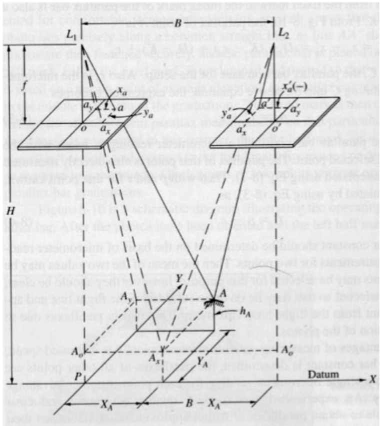
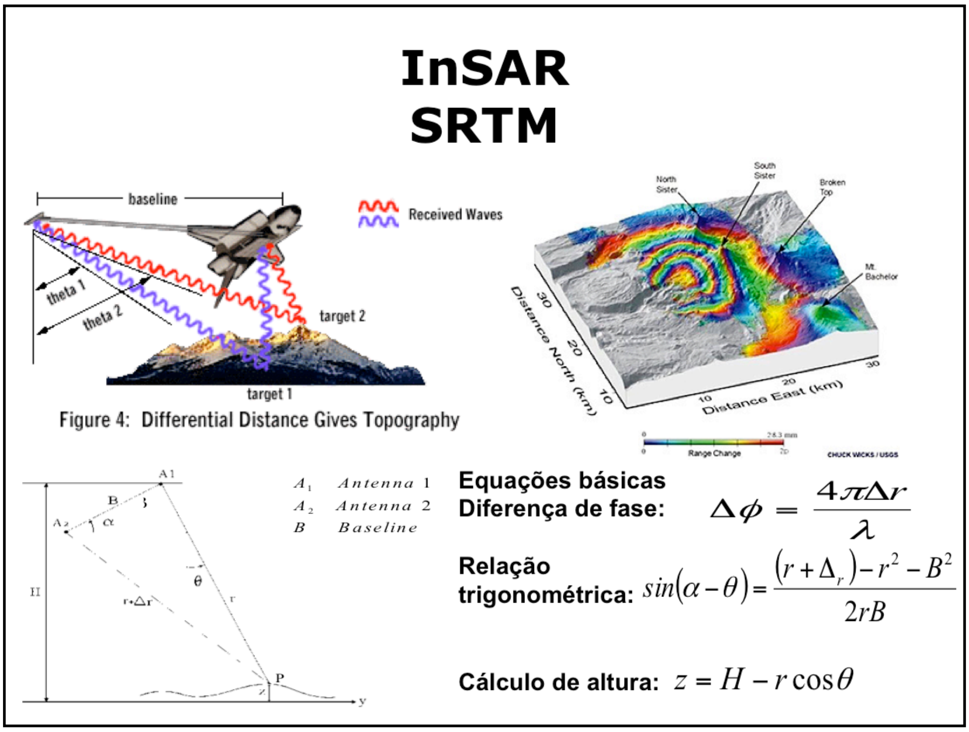


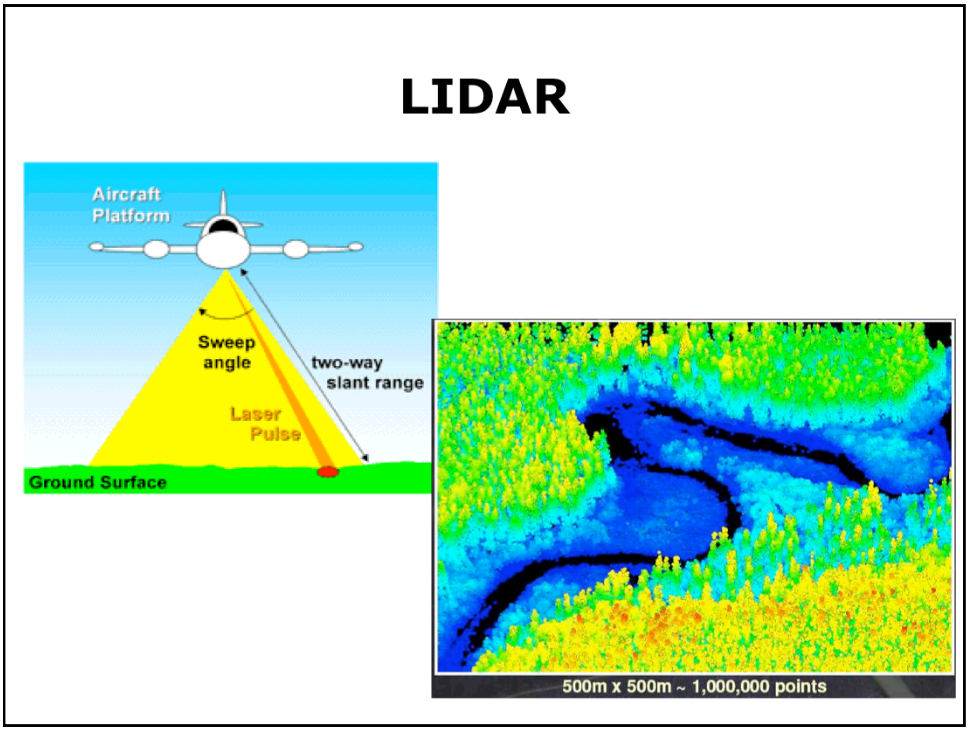
FIGURE 8-11
Geometry of an overlapping pair of vertical photographs.

www.ee.uta.edu/Online/Devarajan/EE6358/Spring_08/Presentations/Photogrammetry/520Mathematics-080116.ppt (06/08/13)



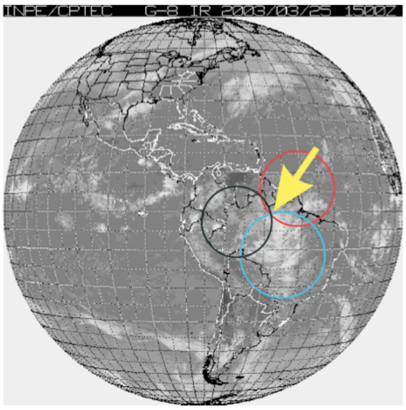
Synthetic Aperture Radar Interferometry measures elevation by the differences in phase between the signal reflected from the same target in two antennas located in different positions. The phase is related to the distance between the antennas and the target, which can be converted into elevation if there are control points on the ground or if the platform position is well defined.

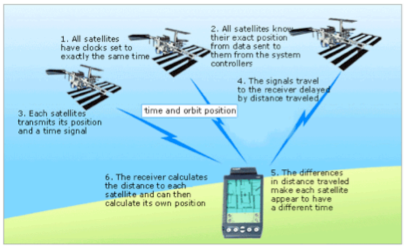
The slide shows the interferometry model used in the SRTM –Shuttle Radar Topographic Mission, which flew in February/ 2000 and collected elevation for most of the world.



LIDAR uses laser pulses and the distance between the platform and the target on the ground is measured by the time difference between the emission and the retrieval of the laser pulse. If the platform position is well known, then , elevation can be extracted directly from the time difference.

GPS





Global Positioning Systems uses triangulation between at least 3 satellites and the position of the sensor on the ground. Since the clocks on the satellites and on the sensor are synchronized,

The time difference will indicate the position of the sensor in 3 dimensions, therefore, with an associated Earth model, the elevation is defined.

Data Collection

Precision

- Measurement instrument

Accuracy

- Instrument calibration

Validity

- Correctly executed measurement

Reliability

- Measurement is repeatable

There are some factors that have to be considered when measuring elevation during data collection. Of course, the usual user does cannot interfere with these factors but it's important to know which roles they can play on the quality and fitness for use of the final DTM

Digital Model Constraints

Finite:
- specification of the expected bounds for the data.
- amount of data: storage capacity and processing power.

Discrete (integer):
- the smallest difference between values that can be discerned

Define
- minimum distance between different locations,
- minimum difference in value,
- maximum size of region under study,
- maximum amount of data

There are constraints associated with the digital world, which is finite and discrete. These constrains will define the minimum and maximum presented in this slide.

Data Quality

Quality is a generic term that depends on the context

- In geographic representation context, more difficult to define given that physical characteristics of geographical reality can not be directly assessed

Related to accuracy, precision, consistency, and completeness of the representation.

Elevation representation:

- accuracy is defined as the measure of its quality.

In the same way with any other data that is used, elevation quality is important when using DTMs for decision making.

Accuracy

- Measure of how different the representation is in relation to the real world entity
- Metrics
  - Root Mean Square Error (RMSE) and the vertical accuracy at 95% confidence
- DEM accuracy is difficult to be assessed since there is no independent model of the real world to test our digital model against
- "True value" of elevation is just a representation that is considered to have higher accuracy than the one having its accuracy defined.
- Accuracy of DEMs is dependent on the Earth's surface characteristics and the measurement techniques
  - Errors are not randomly distributed over the entire DEM

Measure of quality of DTM is given by accuracy.

Quality Factors

Measurement Instrument

Data Processing

Digital Representation

Algorithms

Quality of a DTM depends on many factors, starting from the data collection design, including the choice of the measurement instrument, the raw data processing, the constraints of the digital representation and the algorithms.

Error Sources

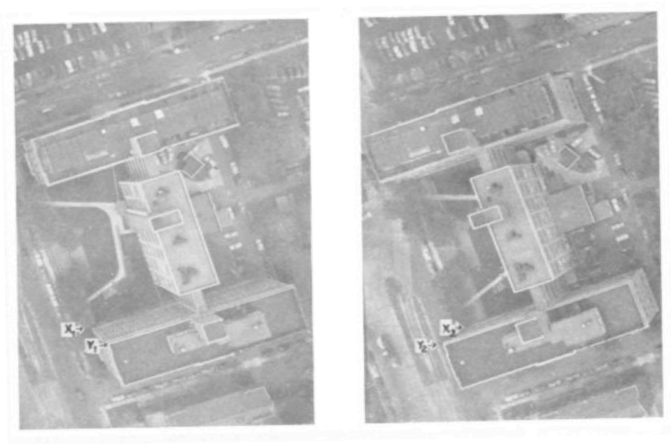
Ground Surveys – Depend on instruments and methods - highly accurate, surveyor is at the field.

Photogrammetric Data Capture – Paralax principle – Stereocorrelation. Accuracy dependent on photograph scale, image resolution, discernibility of image features. Correlation window (10x10 pixels)

Some of the error sources are described in this slide. For the photogrammetry procedures the characteristics of the image and the algorithms used to match features are the main factors.

Error Sources

Photogrammetric Data Capture



This slide shows two images taken from two different positions, where some of image characteristics can be seen. For example, can features be individually recognized in the image?

Error Sources

Cartographic Sources – Dependent on original data, usually photogrammetric, equipment/operator lag, analog recording precision, digitalization or scanning resolution, map resolution →0.4 mm of scale.

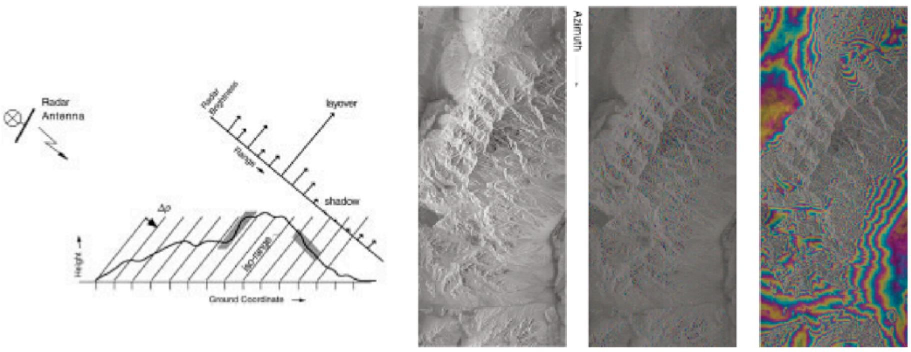
InSAR – Ground Range Resolution, layover/shadowing effects, speckle noise, vegetation depending on band.

For cartographic sources, we should know the quality of the original data and of the representation. We also have to remember the restrictions due to the human restrictions such as the smallest feature that can be drawn and identified in paper representation.

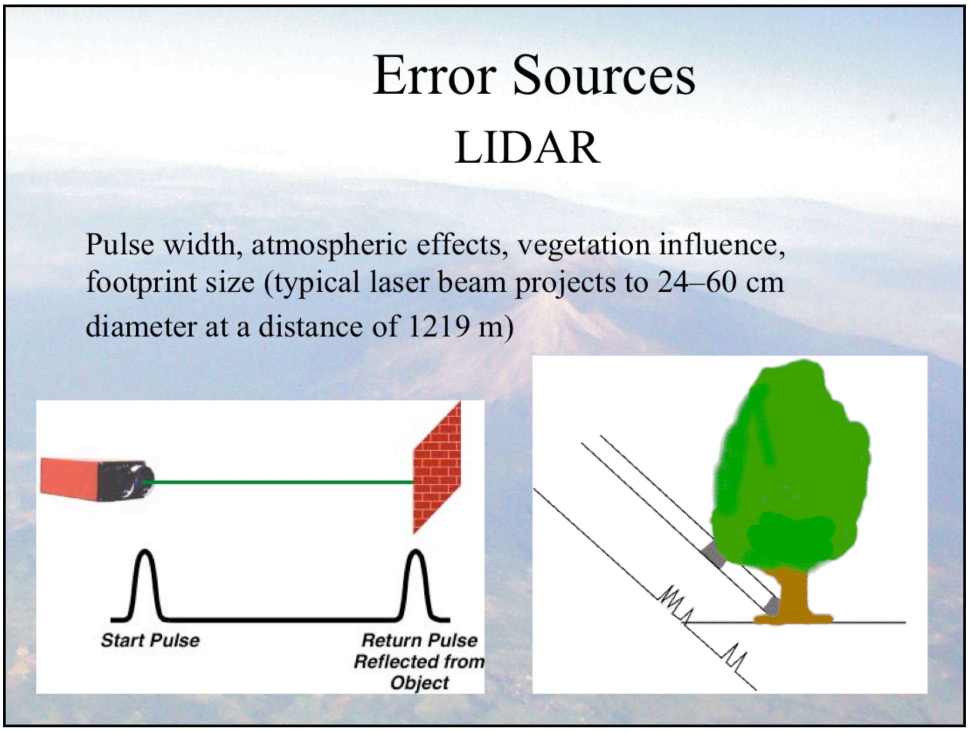
For Radar data, there are restrictions based on the physics of the electromagnetic waves reflection, electronic processing, noise, geometry – layover when farther objects return signal before nearer objects and shadowing when farther objects are hidden by nearer objects.

Error Sources

InSAR



This slide shows the layover and the shadowing effects. The images in the left show the pair of radar images and the interferogram with the phases coded in color.



LIDAR data reflects in this example from different heights in the tree. The data processing must select which signal return is the best representation of the elevation. One additional consideration is the effect of the laser footprint.

Accuracy:
USGS DEM

Level-1 DEM reserved for ones created by scanning National High Altitude Photography (NHAP)/NAPP photography.

- Vertical RMSE of 7 meters is the desired standard. A RMSE of 15 meters is the maximum permitted.

Level-2 DEM data sets have been processed or smoothed for consistency and edited to remove identifiable systematic errors and were derived from hyposographic and hydrographic data digitizing.

- RMSE of one-half contour interval is the maximum permitted.

Level-3 DEMs are derived from DLG data by incorporating selected elements from both hypsography (contours, spot elevations) and hydrography (lakes, shorelines, drainage).

- RMSE of one-third of the contour interval is the maximum permitted.

RMSE error is calculated on 27 sample points

- any 27 points distributed on the area.

This slide describes the accuracy requirement of the data from the US Geological Survey. The main point here is that the error is calculated using only 27 sample points. In addition, there is the consideration that the errors are randomly distributed, which cannot be a good assumption.

Accuracy:
ASTER DEM

Advanced Spaceborne Thermal Emission and Reflection Radiometer

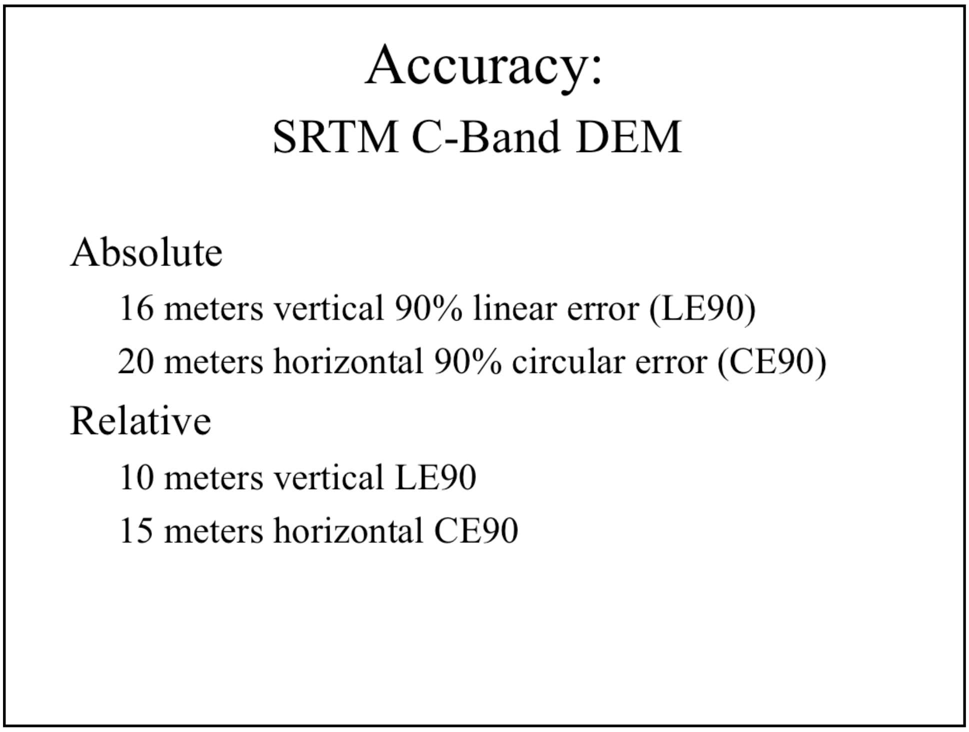
Generated from along-track stereo

Grid 30 meter

Estimated accuracy:

- Relative vertical accuracy between ±12 and 25 meters

As an example of DTM created from photogrammetric processing, the ASTER satellite imagery based DTM has this accuracy. One aspect to be considered here is that each pair of images have different accuracies based on the accuracy of the ground control points.



The SRTM DTM has these stated accuracies.

Accuracy:
LIDAR

ICESat
- 15 cm
- footprint: 60 m diameter

Saab TopEye system for of bare soil and low grass
- Between 10 and 16 cm RMSE

For some LIDAR sources, these are the accuracies. ICESat is a satellite designed to measure the height of glaciers and the TopEye is a sensor for aircraft platforms.

DTM Representations

Contour Lines

Regular Grid

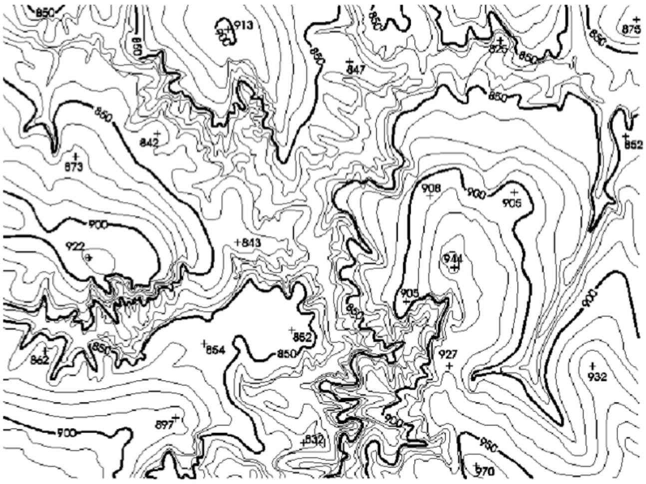
TIN – Triangulated Irregular Network

The DTM representations are necessary because they allow algorithms to be developed in order to generate products from the elevation samples in a easier way. Contour lines are not of easy processing, but is added to this list because some algorithm can use them.

Contour Lines

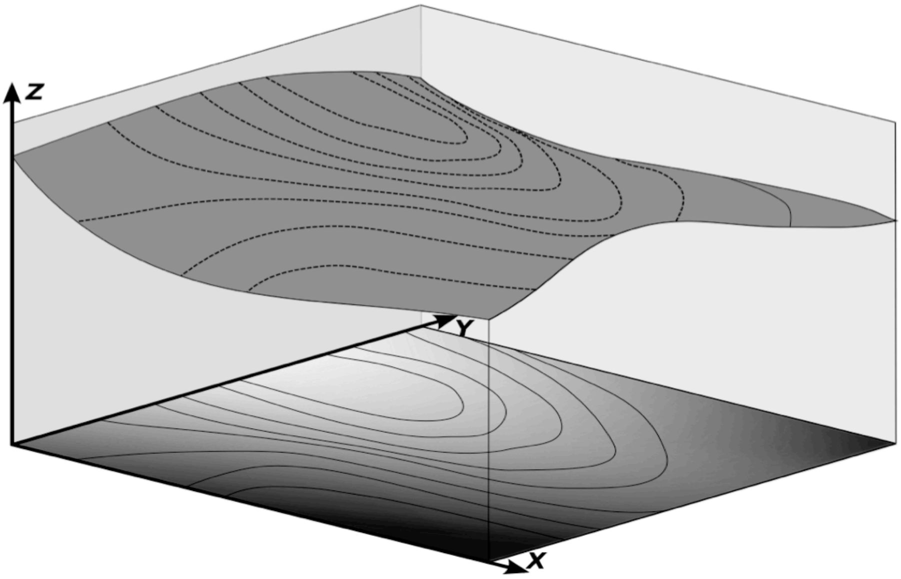
Define the surface only along the lines

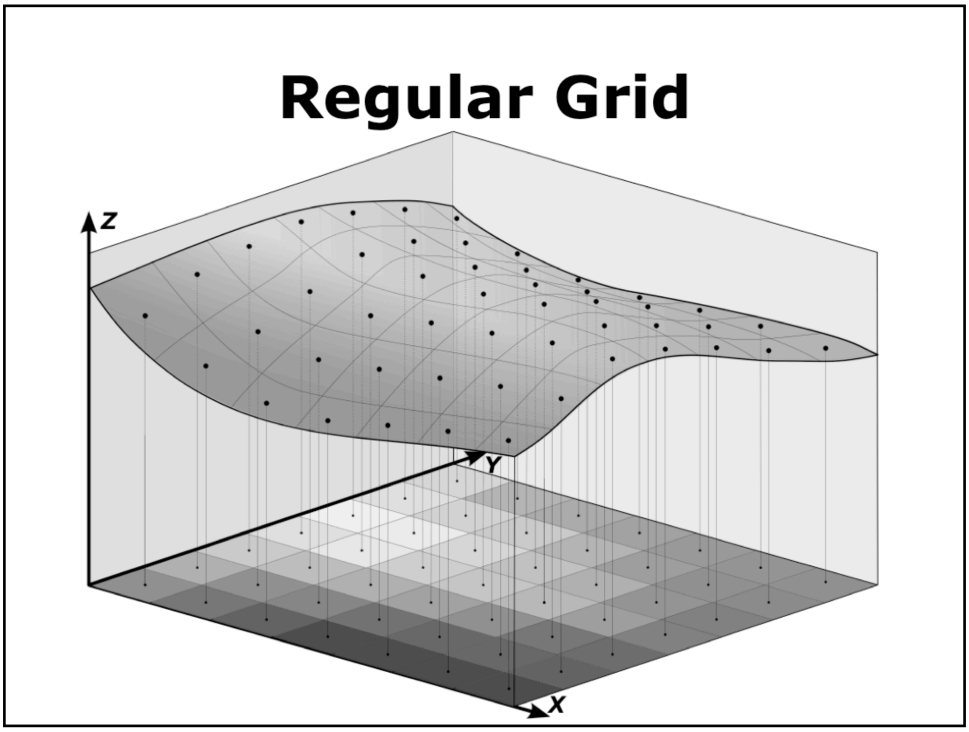
Regions between two lines are inferred to be between the values of the lines



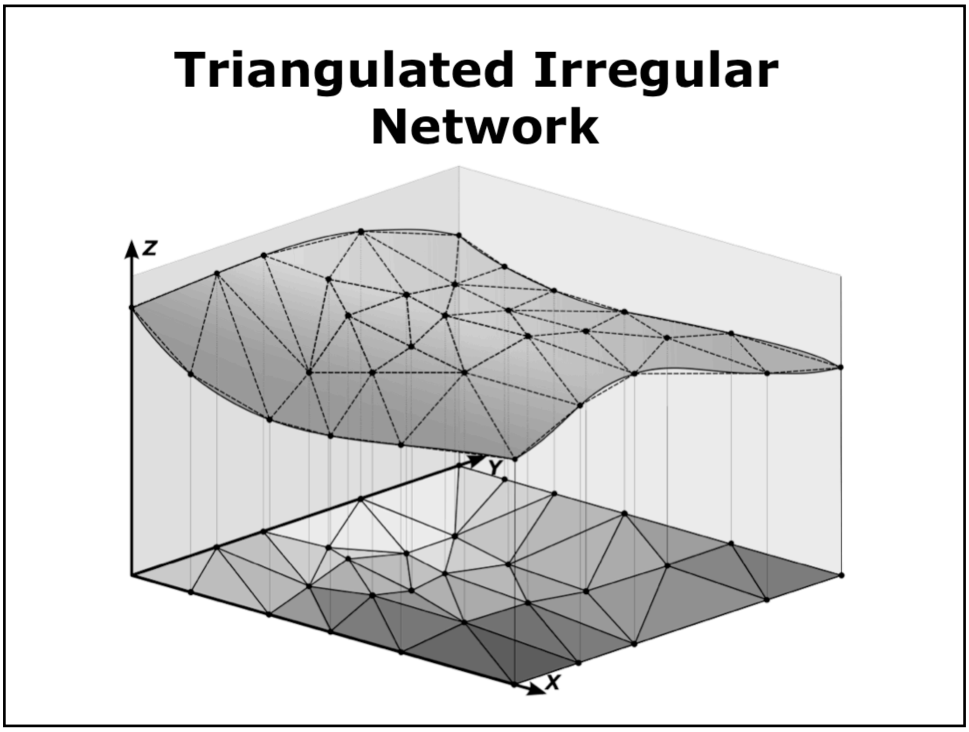
This slide shows an example of contour lines.

Contour Lines





Regular grid representation uses matrix cells to store the elevation value. Usually the values are considered to be the elevation at the center of the cell.

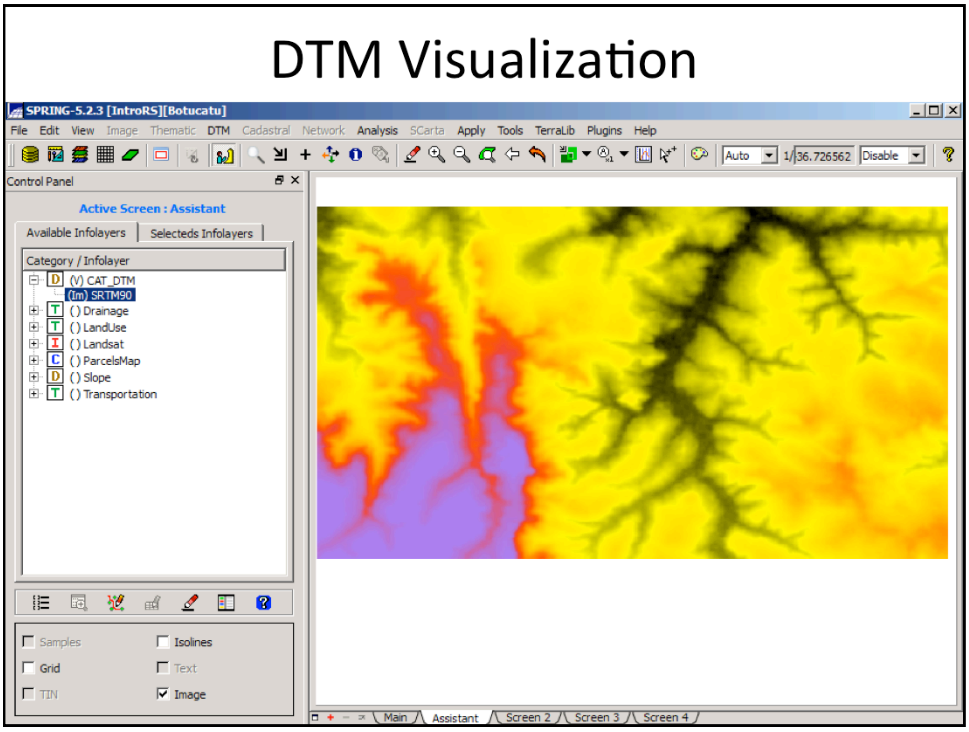


TIN uses irregular triangles to represent the elevation. The vertices of the triangles are elevation sample points. The triangles are created connecting these sample points. The surface is defined by an interpolating function, which can be a plane.

DTM Products

Generated from the models
Derivatives
Contour Lines
Profile
3D Visualization
Drainage Analysis

Now let's have a look on some products extracted from the DTM. Any of these products can be combined with other GIS data to contribute in managing the environment.



The DTM can be better visualized using a color scheme, such as the one presented in this slide, where the black colors indicate lower elevation and the purple indicates higher elevation.

Slope Angle and Aspect

$S = \text{arctg}\,\{[(\delta Z/\delta X)^2+(\delta Z/\delta Y)^2]^{1/2}\}$

$A = \text{arctg}\,[-(\delta Z/\delta Y)/(\delta Z/\delta X)]\quad(-\Pi < A < \Pi)$

$\delta Z/\delta X$ and $\delta Z/\delta Y$ are the partial derivatives in X and Y directions

Slope angle and aspect are calculated from the partial derivatives of the DTM in X and Y directions. The equations are shown in this slide.

Derivatives Estimation

The partial derivatives are estimated using:

$$[\delta Z/\delta X]_{i,j} = [(Z_{i+1,j+1} + 2*Z_{i+1,j} + Z_{i+1,j-1}) – (Z_{i-1,j+1} + 2*Z_{i-1,j} + Z_{i-1,j-1})]/8*\delta X$$

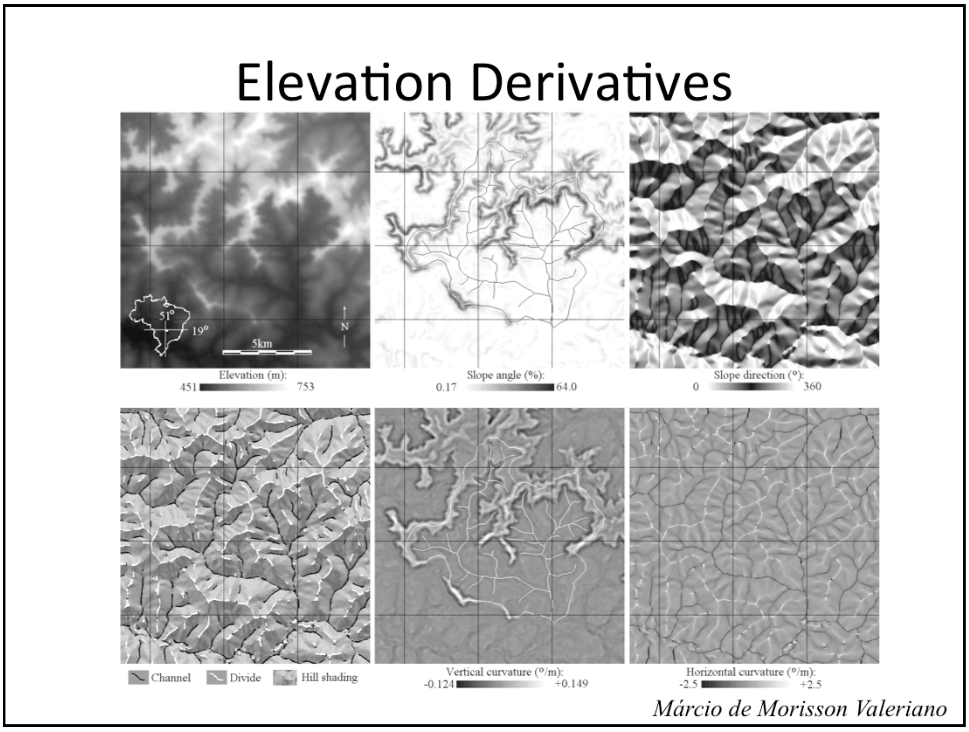
$$[\delta Z/\delta Y]_{i,j} = [(Z_{i+1,j+1} + 2*Z_{i,j+1} + Z_{i-1,j+1}) – (Z_{i+1,j+1} + 2*Z_{i,j-1} + Z_{i-1,j-1})]/8*\delta Y$$

where z elements are on the grid, indicated by:

$Z_{i-1,j+1}$	$Z_{i,j+1}$	$Z_{i+1,j+1}$
$Z_{i-1,j}$	$Z_{i,j}$	$Z_{i+1,j}$
$Z_{i-1,j-1}$	$Z_{i,j-1}$	$Z_{i+1,j-1}$

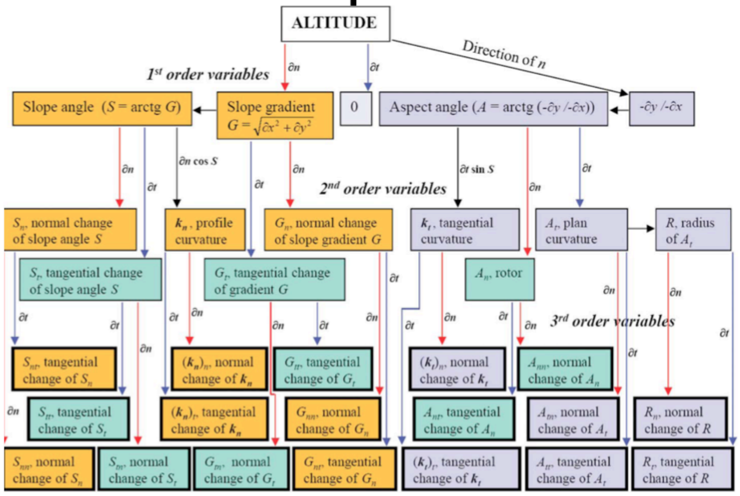
The estimation method that is most used in DTM analysis is this one. For the central cell i,j, the neighbors differences are used for the estimative. The difference in the same row – for x direction derivatives has twice as much influence when compared to the row above and below. The same applies for the difference in the i,j cell column.

Second order derivatives can be calculated using the same method, but using the first partial derivatives instead of the elevation values.



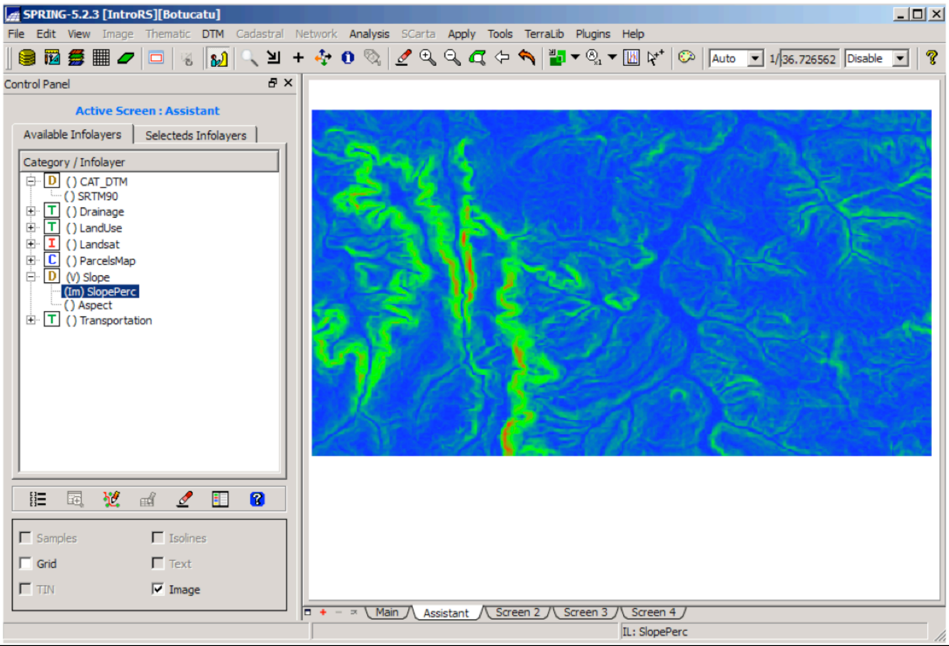
This slide shows some derivatives extracted from the elevation from SRTM. In order from top left clockwise, we can see the elevation grid, the slope angle – magnitude of the first derivative, slope direction – arc-tangent of the first derivatives, horizontal curvature – magnitude of the second derivatives in the highest slope direction, vertical curvature – magnitude of the second derivatives in the direction perpendicular to the highest slope direction, and a combined view of hill shading with horizontal curvature to indicate the channels and the basin divides.

Third-Order Geomorphometric Derivatives



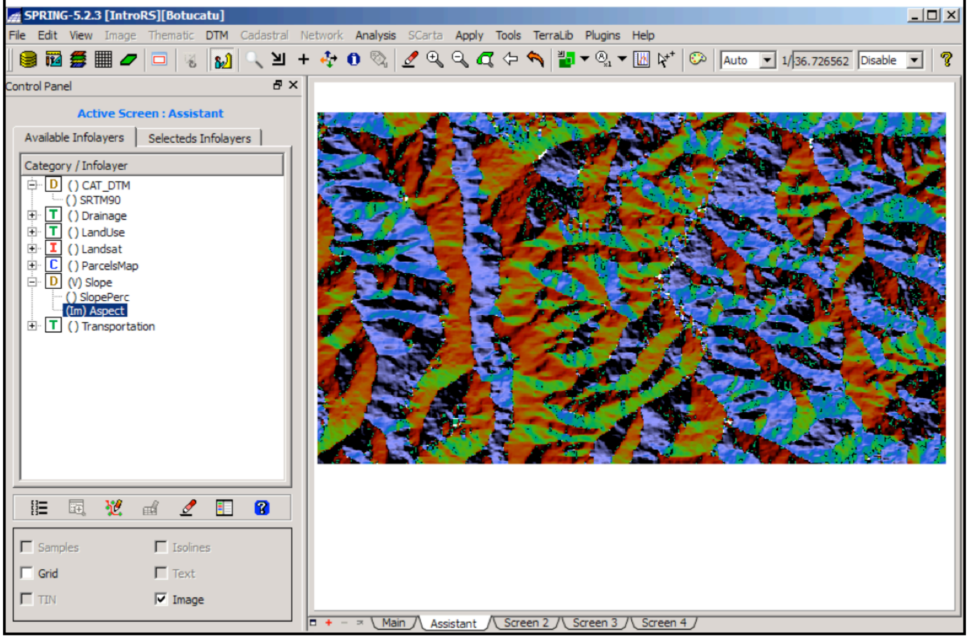
Jozef Minár , Marián Jenčo , Ian S. Evans , Jozef Minár Jr. , Martin Kadlec ,
Jozef Krcho , Jan Pacina , Libor Burian & Alexandra Benová (2013): Third-order geomorphometric variables (derivatives): definition, computation and utilization of changes of curvatures, International Journal of Geographical Information Science, DOI:10.1080/13658816.2013.792113

Slope Angle



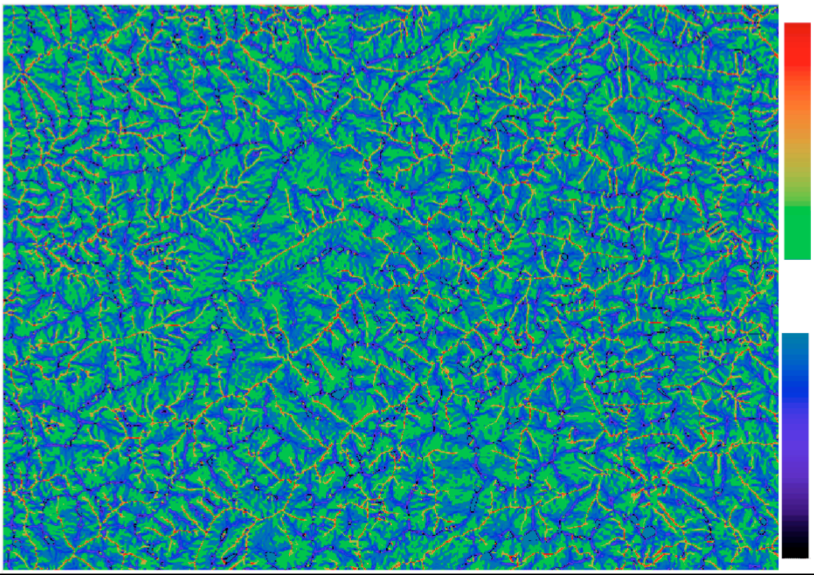
This slide shows the result of the slope angle calculation in SPRING. A color code was applied, with blue ones indicating small angles and reds indicating the large angles.

Aspect

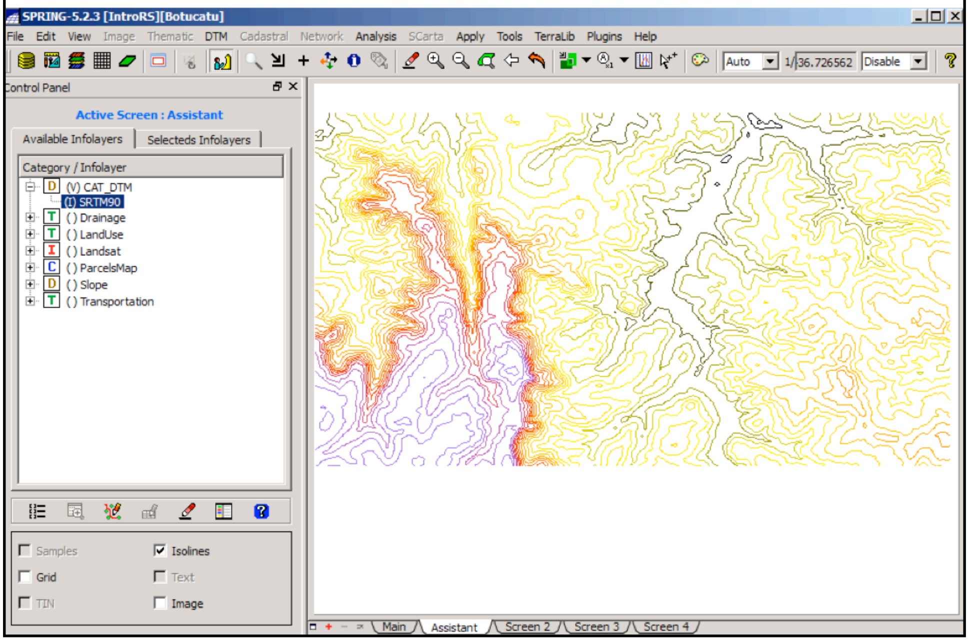


This map shows the aspect map extracted in SPRING. Since aspect is from 0 to 360 degrees, with 0 and 360 degrees indicating north, the colors associated to this maps is circular, with red indicating north wise directions.

Horizontal Curvature

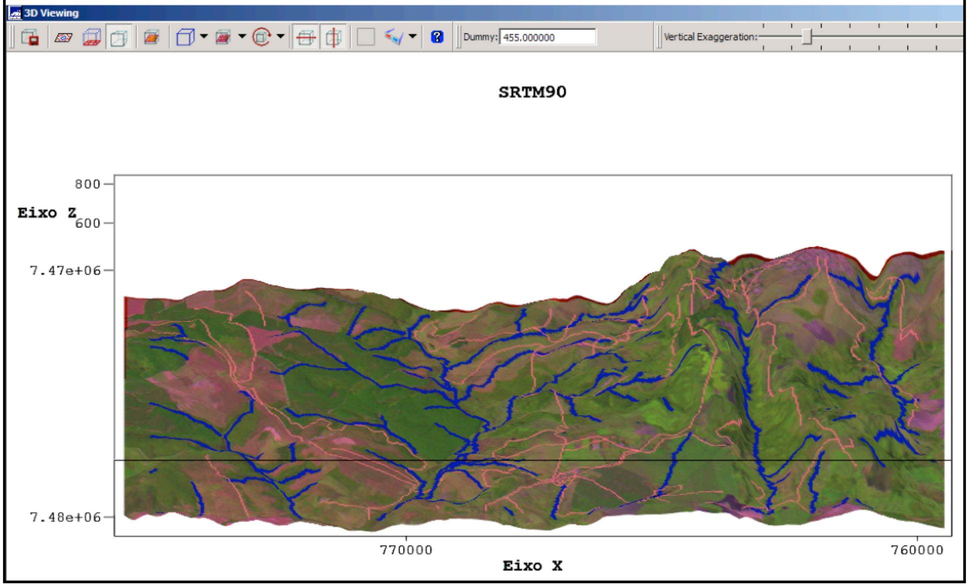


Contour Lines



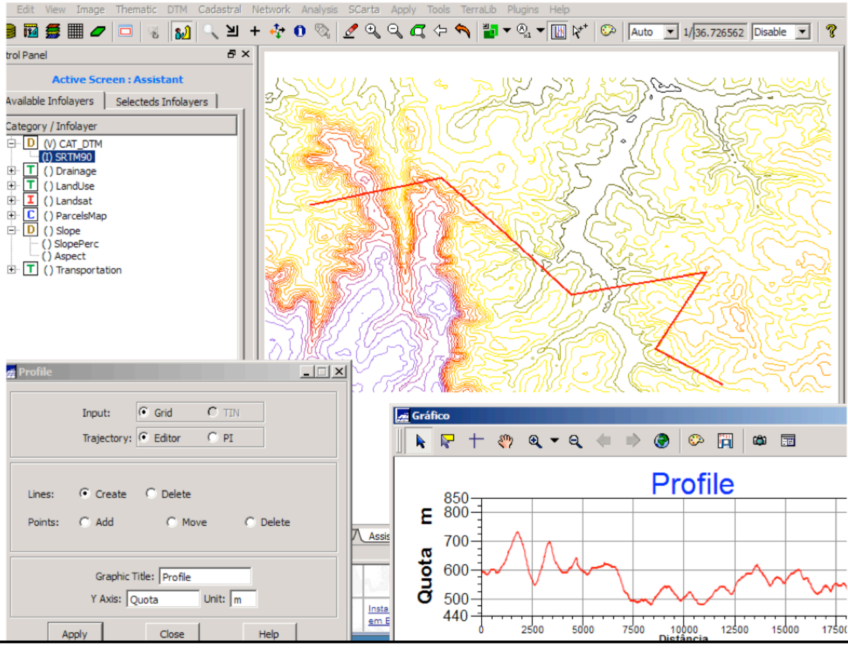
Contour Lines can be extracted from the DTM by finding the intersections between the contour line value and the each grid cell. The result will be a set of lines that can be presented in color, such as these shown in this slide.

3D Visualization



The 3D visualization may be helpful to understand the association of the elevation values with other parameters. In the example of this slide, the 3D view tool of SPRING was used to better understand the variation of the land cover in the region, including the drainage and the transportation lines.

Profile

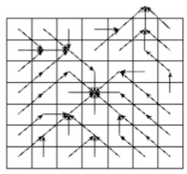


The profile tool provides a way to analyze how the elevation values vary along a line, such as the projected track of a highway. The analysis of the profile graphic may help define better tracks.

Drainage Analysis

Based on D8 Method

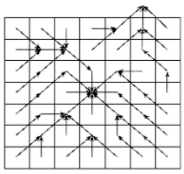
120	150	170
80 ⇐	100	150
150	160	90



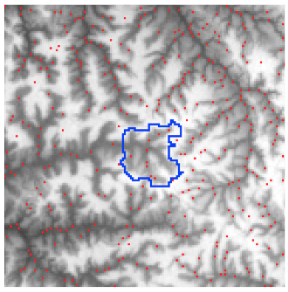
Drainage analysis include the definition of hydrography parameters from the DTM. The basis of the analysis is the use of the D8 method. This method is very simple, yet very used and few other improvements have shown to be better, although only for some special cases. The main idea is to look at the value of the center cell, 100 in this example, and direct the flow to the neighbor cell with the lowest value – 80 in this case. The whole grid is processed and the result is a grid with the flow directions.

DTM Hydrologically Corrected

60.7	62.4	60.6	58.6	54.5	51.2	54.3
62.4	60.2	57.1	58.3	57.7	56.0	56.7
64.1	61.0	57.5	55.5	55.9	59.5	59.1
66.7	63.6	58.4	53.1	57.8	62.5	63.9
69.3	64.2	58.2	63.1	60.3	65.1	69.8
67.3	65.3	66.1	65.0	68.6	70.8	73.7
70.9	71.3	74.5	72.1	76.0	74.2	75.0



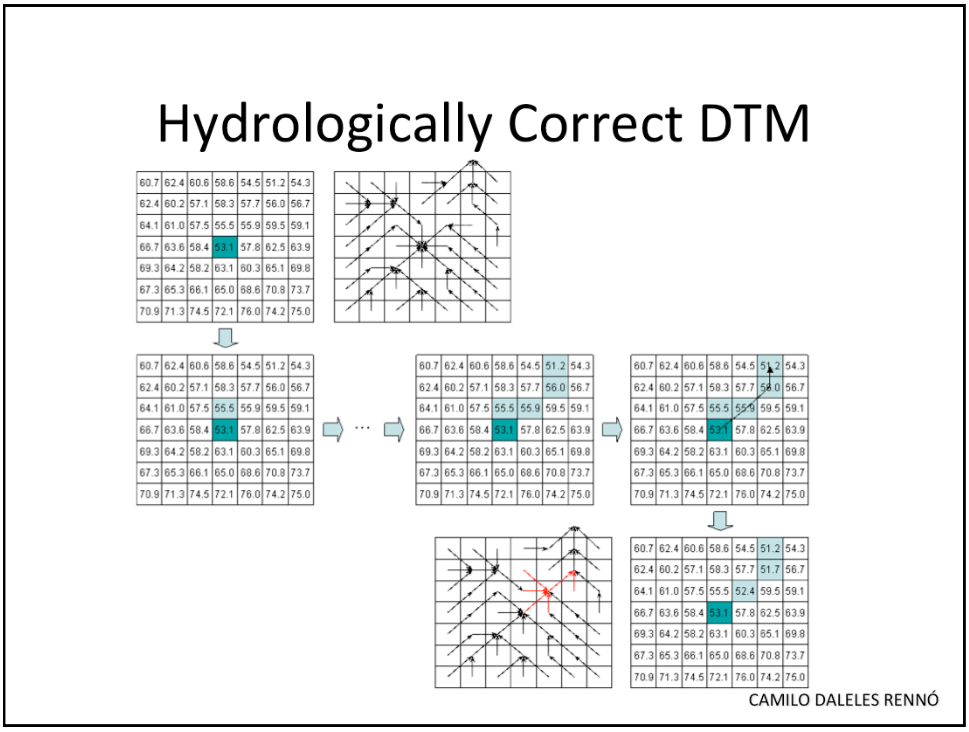
"sink"



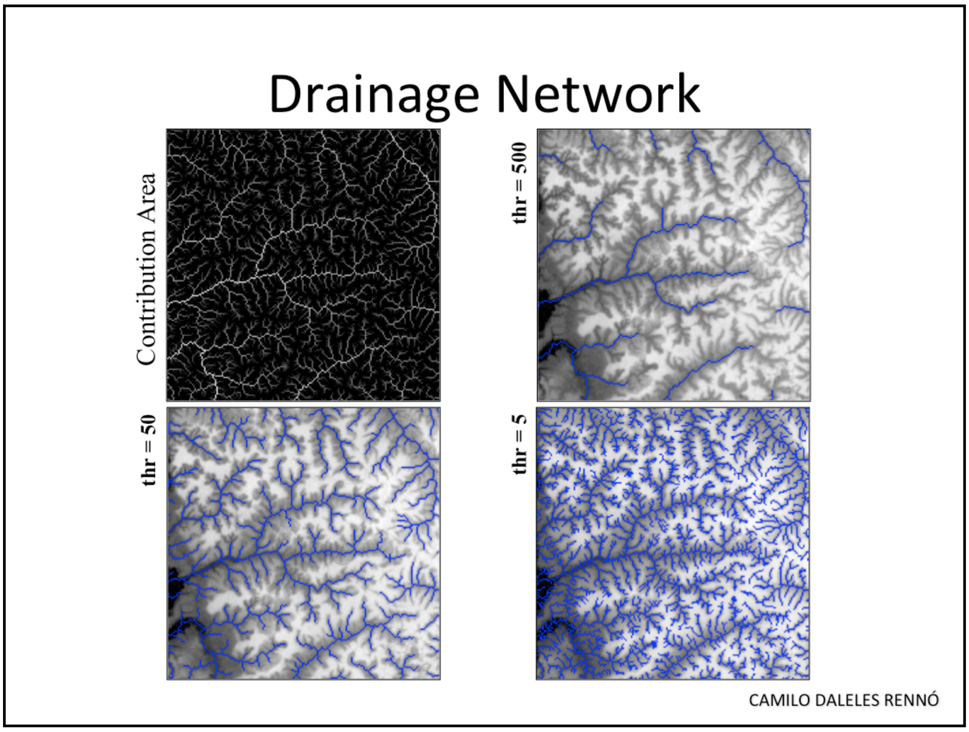
SRTM "sinks"

CAMILO DALELES RENNÓ

The improvement has to be on the DTM representation, using the D8 method. The main problem with the method is that if there is a grid cell that is lower than all its neighbors, then the flow will stop at that cell while in the real world the flow would go to some neighbor cell – unless it's a Karst environment. These are the sinks that should be eliminated by some DTM modification method.

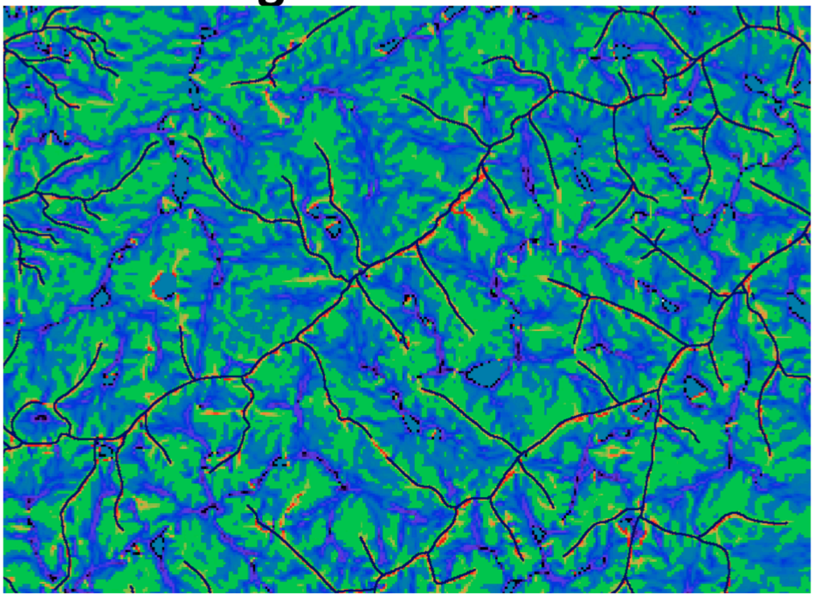


This slide shows one method of correcting the DTM to eliminate sinks. The idea is to look for lower values than the center cell at a distance greater than the nearest 3x3 neighborhood. When a neighbor in this greater neighborhood is lower than the center cell, then the values of the cells in the path and the elevation value of the center cell are changed by linear interpolation. This ensures that the sink will be eliminated because a flow path is carved to the lower value cell.



After the D8 method is applied, the flow network has been defined, However, it is important to obtain also the contribution area of each DTM grid cell. This contribution area grid contains the number of cells that contribute with water to the cell. The top left image shows the contribution area grid. To define the drainage network, a threshold is defined in order to simulate the contribution area that would be necessary for the water that is in the area to be over an amount which would make the water flow over the land and not be sub superficial flow. Of course there are many other factors that would define the location where a spring would appear. The most simple one is to just say that if the contribution area is more than the threshold, then a spring will start a drainage line. In this slide, there are three examples, one with threshold 500 cells, the other with 50 cells and the last with 5 cells.

Drainage From Curvature



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