# Digital Terrain Modeling

*Laércio Namikawa*

INPE - DPI

# Topics

Definitions

Sources

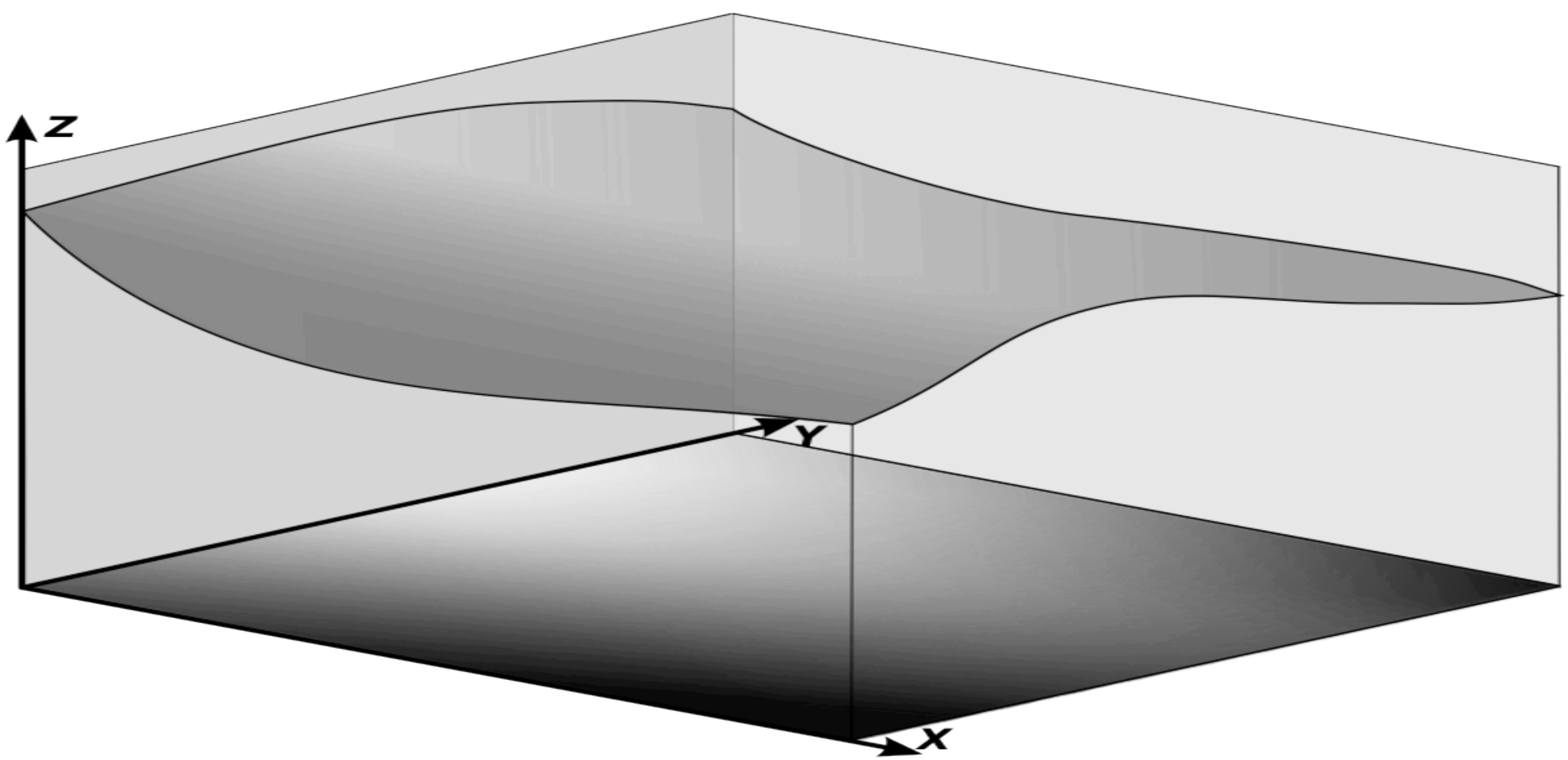
Models

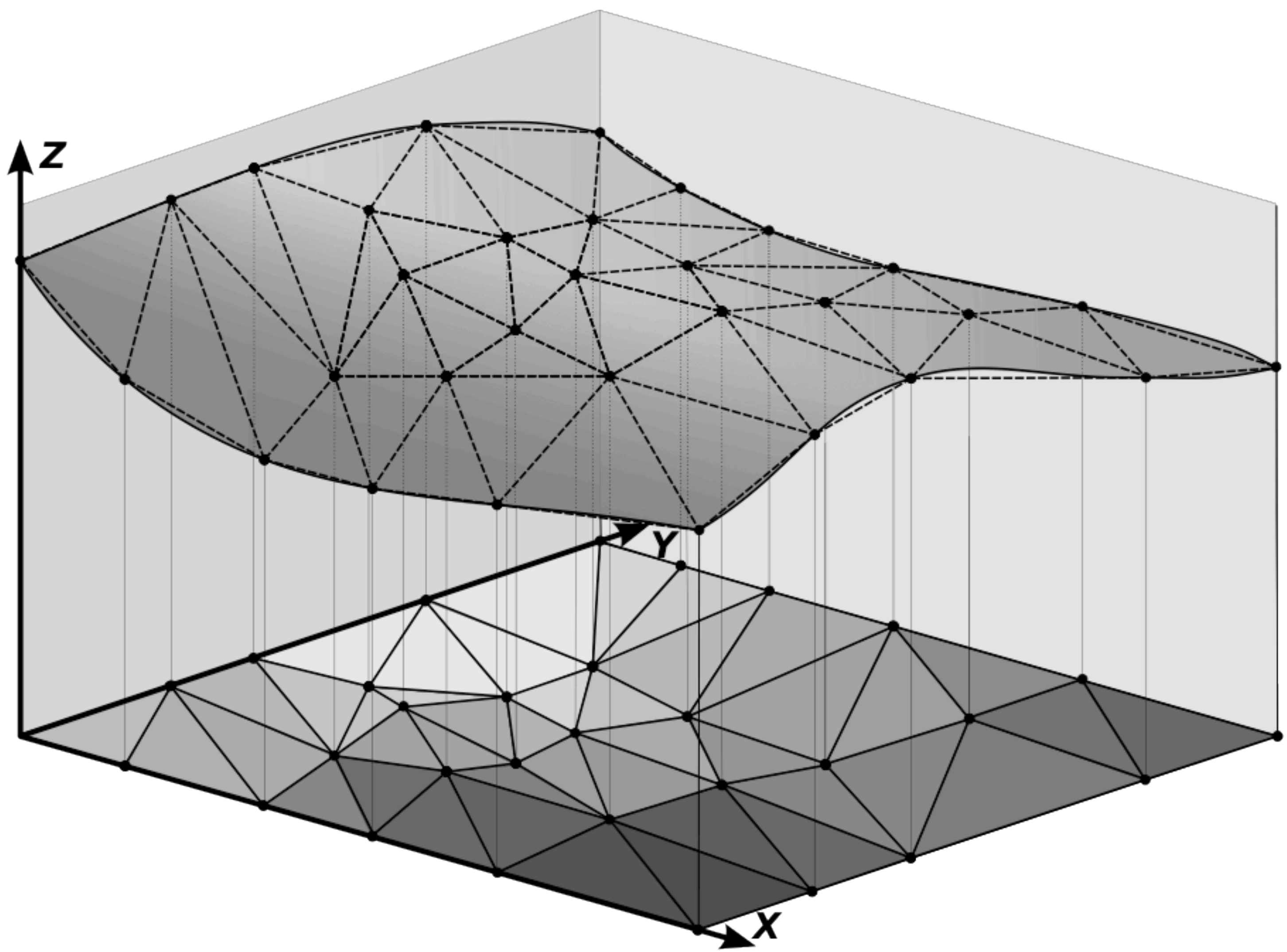
Products

# What are Elevation Models

Computational Representation of the distribution of a geographic phenomenon

Phenomenon: Terrain Elevation





z
Y
X

# Naming
## DTM, DSM, DEM
## TIN

M: Model, Modeling

D: Digital

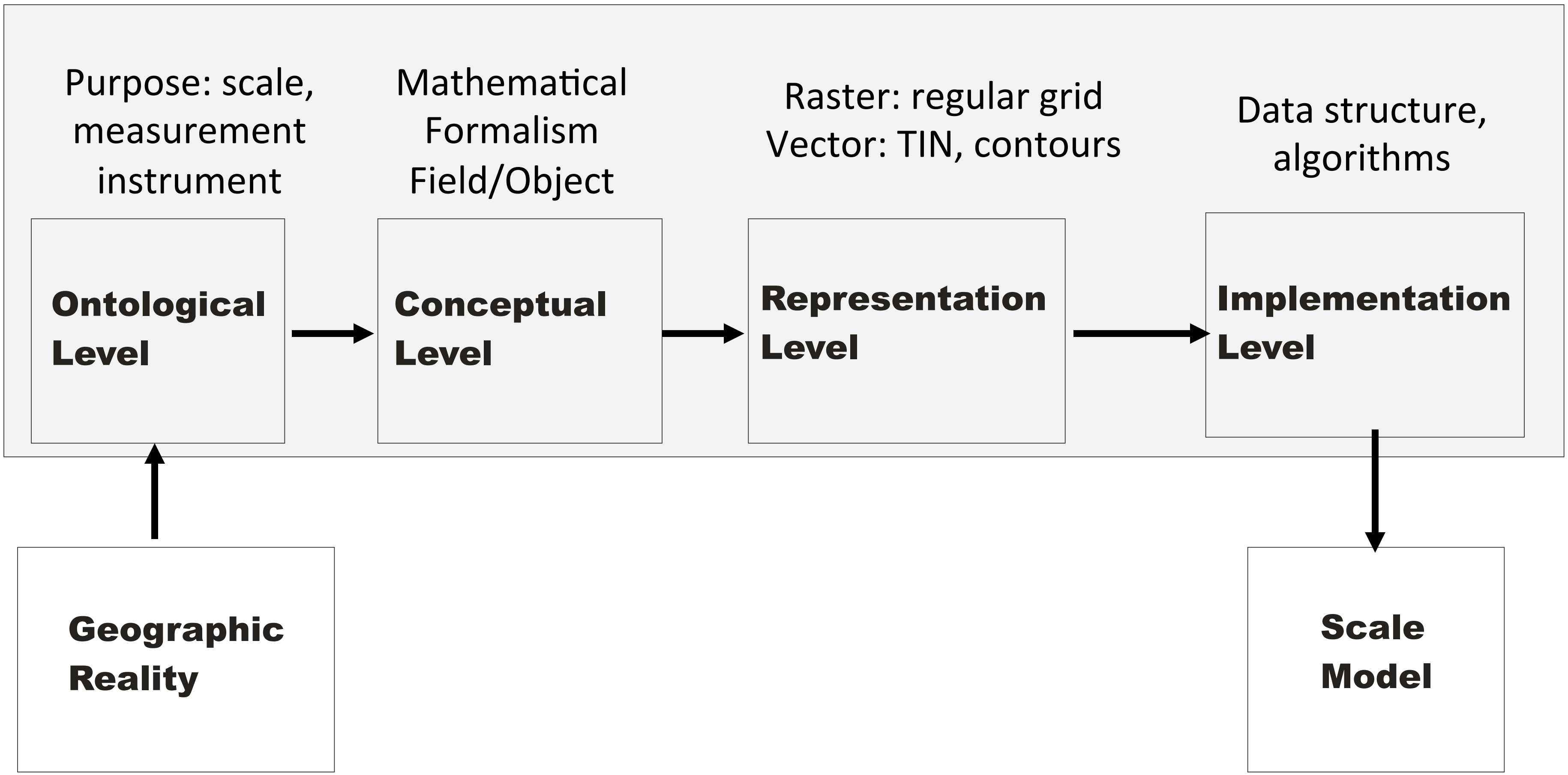
T: Terrain

E: Elevation

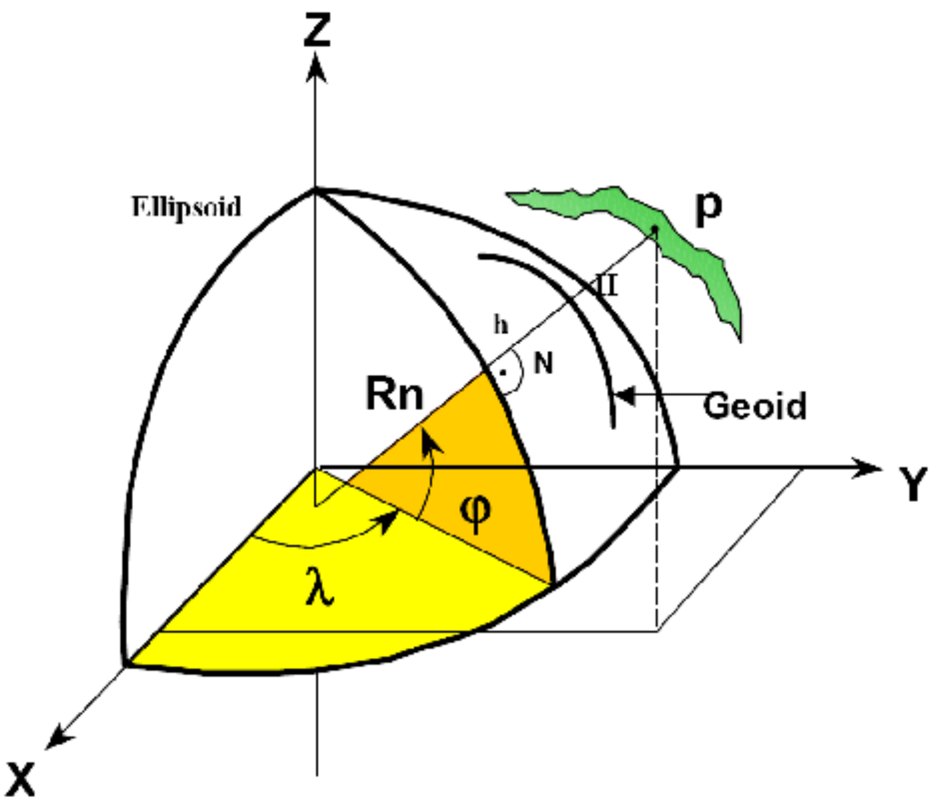
S: Surface

Most correct - DEM

# Modeling
# Digital Elevation Model



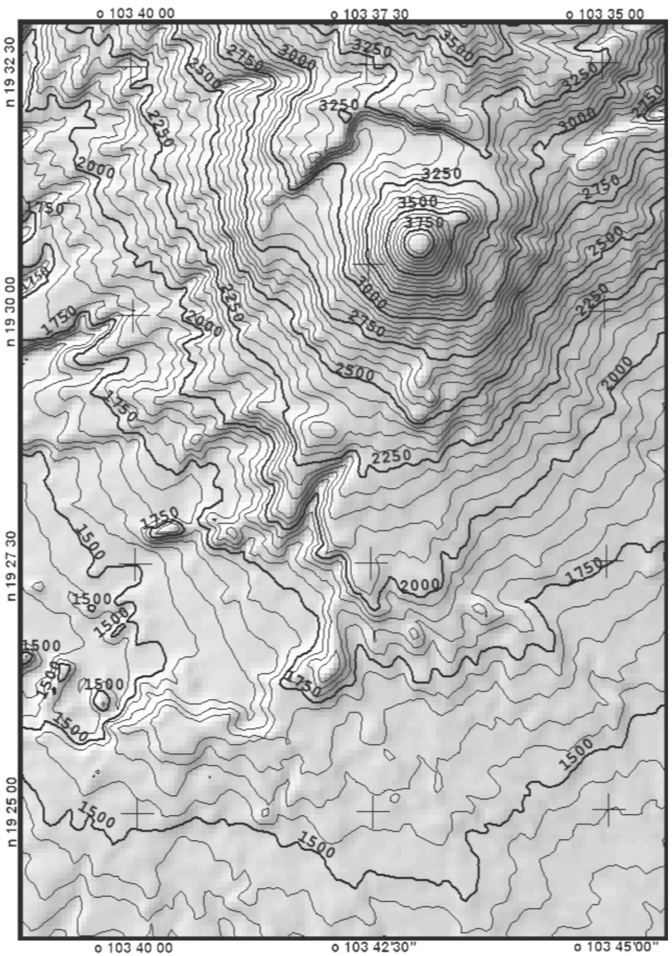
# Elevation in the Real World



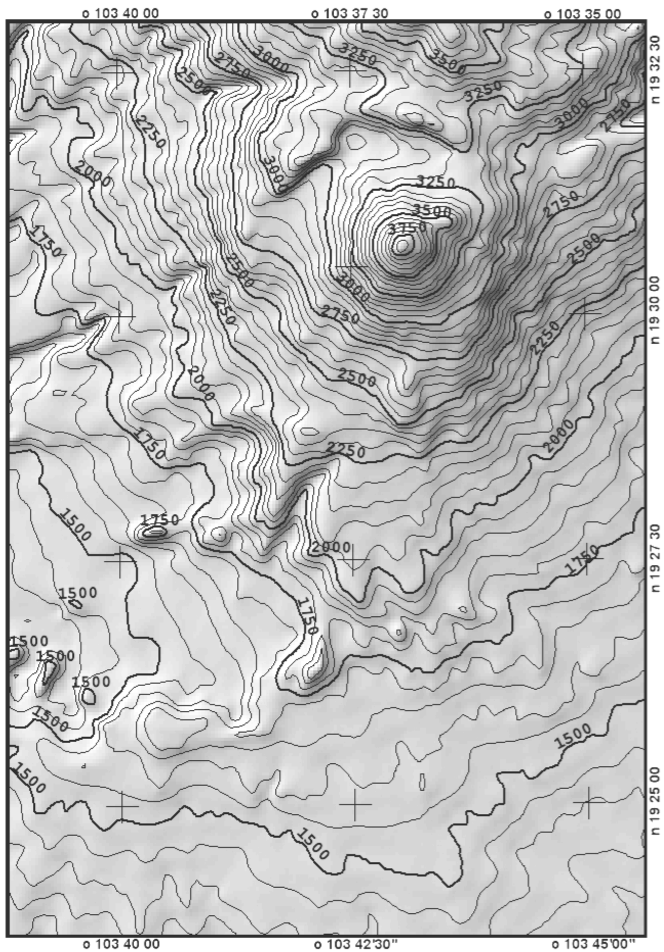

Ayers, H. B. (2000). Local Geoid Models for 3-D Helmert Transformations, Leica Geosystems Ltd

# Metadata

## SRTM




## ARIA




DESCRIPTION "Elevation from SRTM, reprojected to UTM, 90-meter resolution"
MEASURE_DATETIME "2000/02/1 0:0:0"
PRODUCTION_DATETIME "2006/01/26 0:0:0"
PRODUCTION_METHOD "Linear Interpolation"
PRODUCTION_SOURCE “SRTM 3arc-sec”
SOURCE_SCALE "25000"
MEASURE_UNIT "Meters"
MEASURE_NAME "Elevation"
HORIZONTAL_ACCURACY "5"
VERTICAL_ACCURACY "16"

DESCRIPTION "Elevation from Arizona Image Archive - ARIA. Source data is probable one, from INEGI topographic maps"
MEASURE_DATETIME "1995/12/01 0:0:0"
PRODUCTION_DATETIME "2006/01/26 0:0:0"
PRODUCTION_METHOD " Interpolation"
PRODUCTION_SOURCE “Contour Lines”
SOURCE_SCALE "50000"
MEASURE_UNIT "Meters"
MEASURE_NAME "Elevation"
HORIZONTAL_ACCURACY "20"
VERTICAL_ACCURACY "15"

# Data Sources

Field Surveys

Photogrammetry – Stereoscopic analysis of images

Cartographic sources – Contour lines and profiles

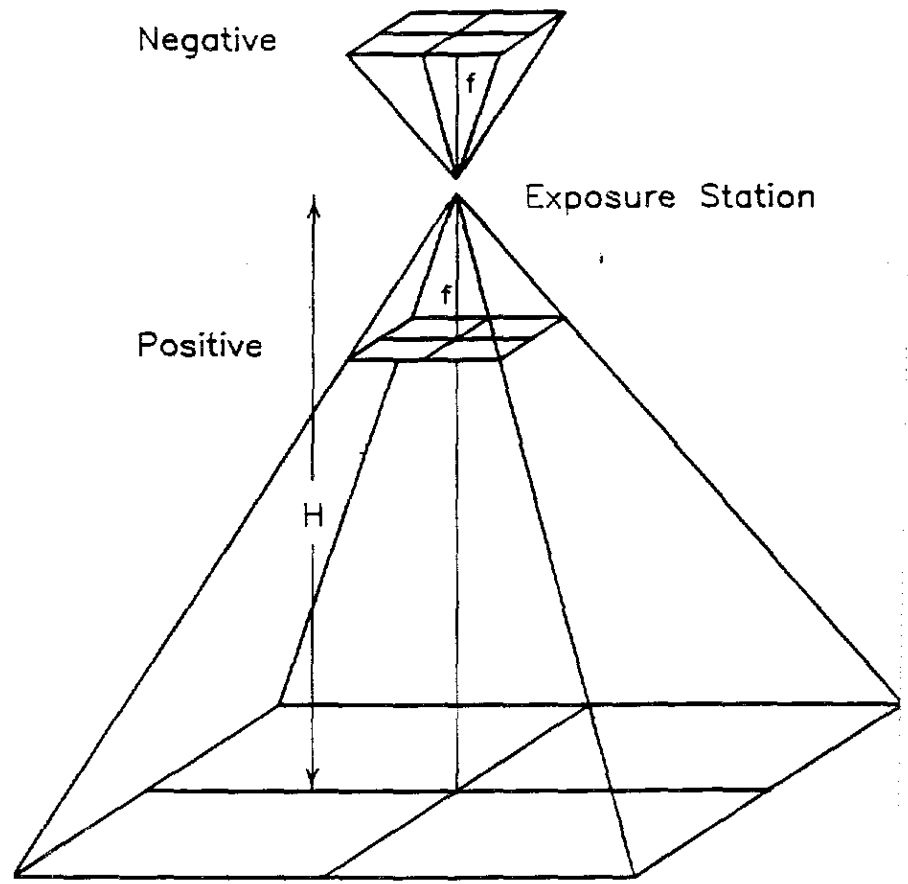
Radar Interferometry - Synthetic Aperture Radar Interferometry (InSAR) – Aerial, Satellite, Space Shuttle (SRTM)

LIDAR - Light detecting and ranging – Aerial, Satelite

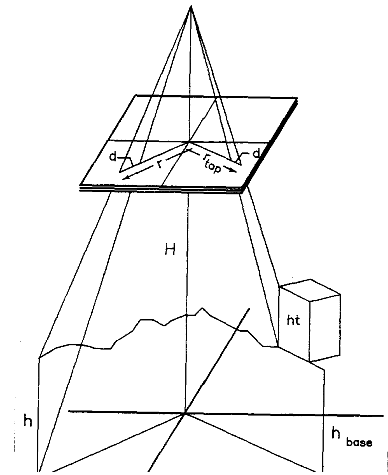
GPS - Global Positioning System

# Photogrammetry

# Geometria de Aquisição

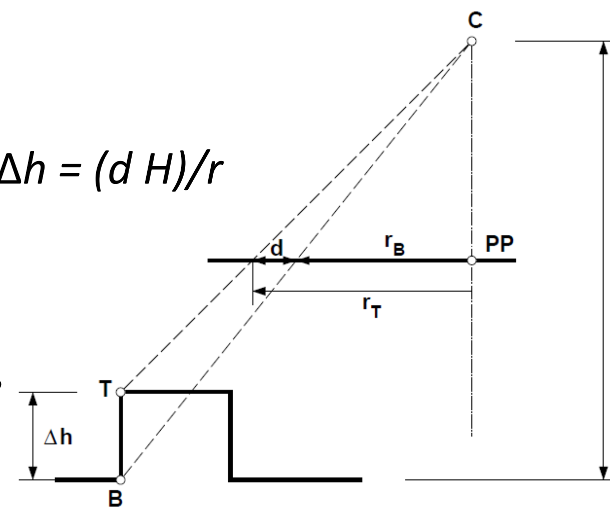


# Deslocamento Devido ao Relevo




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

*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

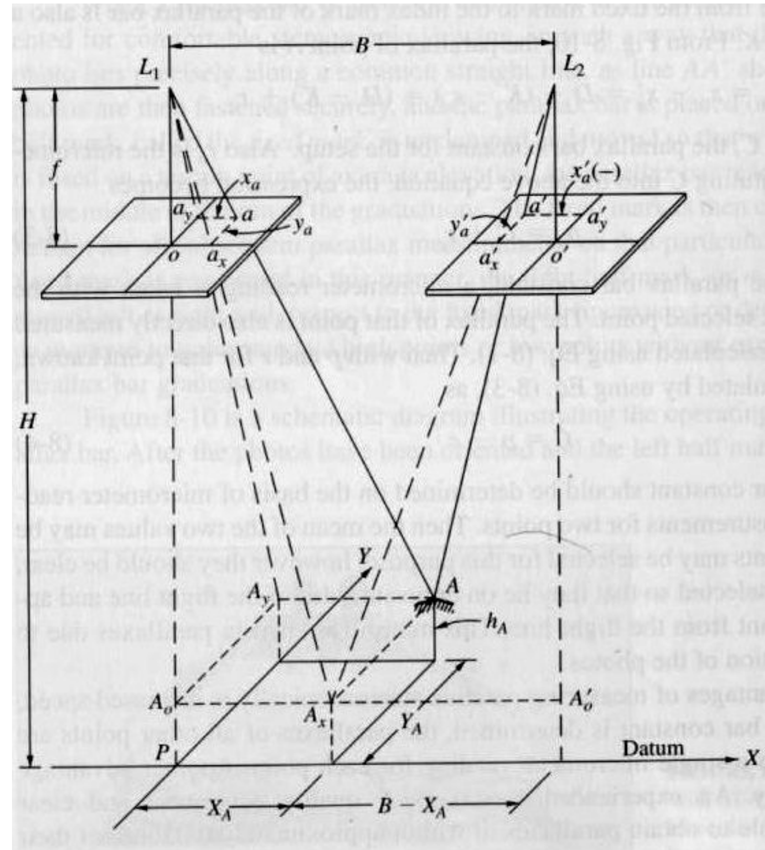



FIGURE 8-11
Geometry of an overlapping pair of vertical photographs.

# InSAR
# SRTM

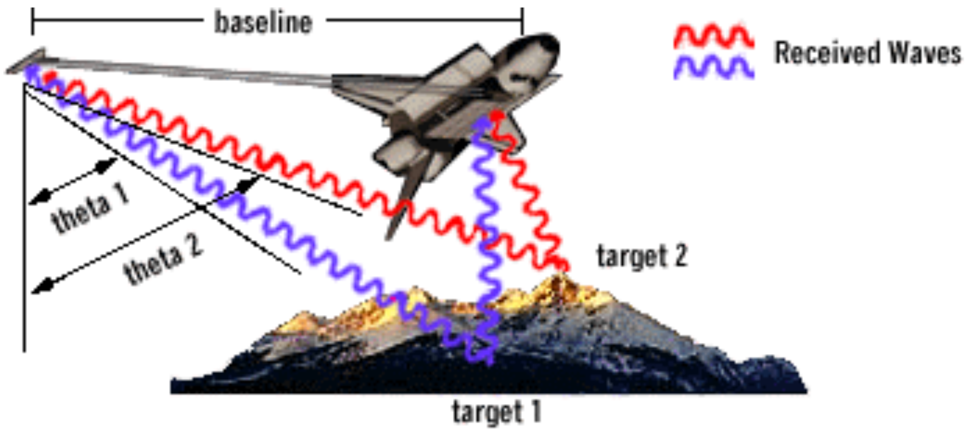
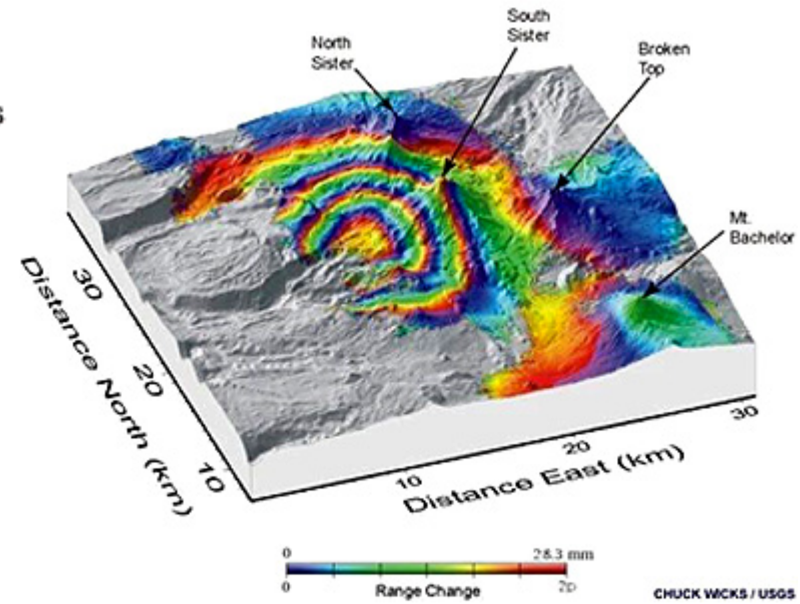
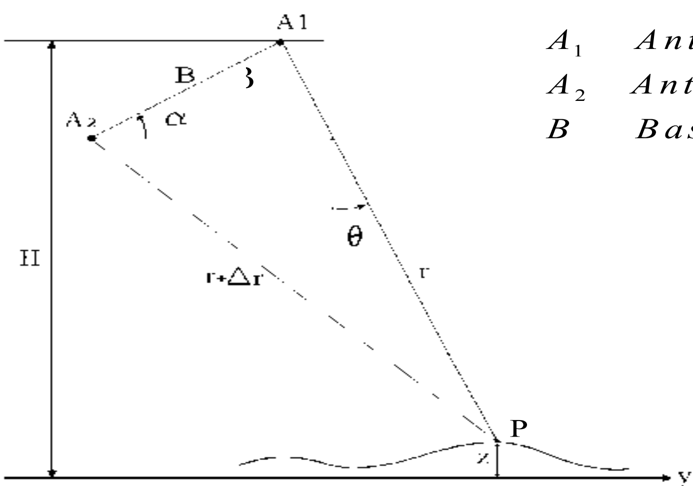



Figure 4: Differential Distance Gives Topography




$A_1$ *Antenna 1*
$A_2$ *Antenna 2*
$B$ *Baseline*

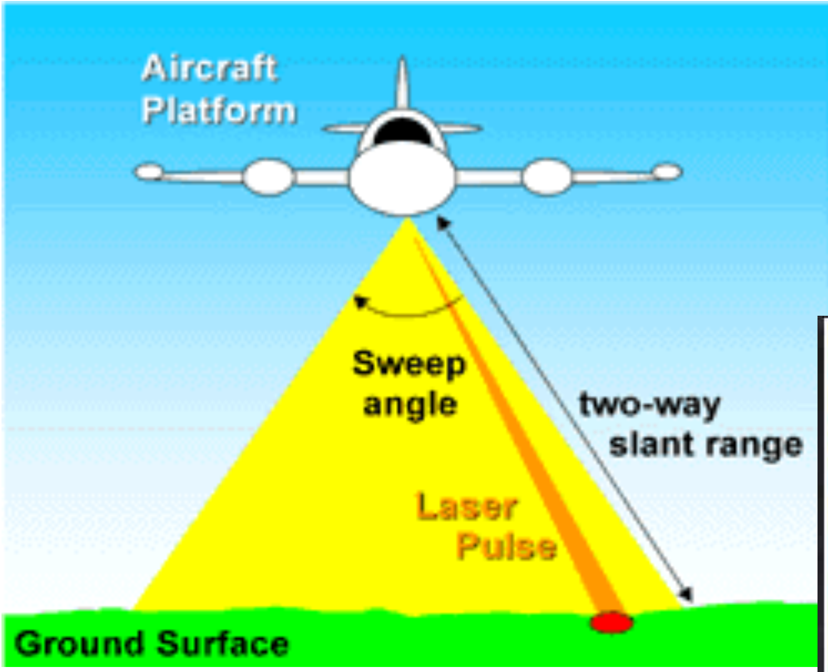
**Equações básicas**

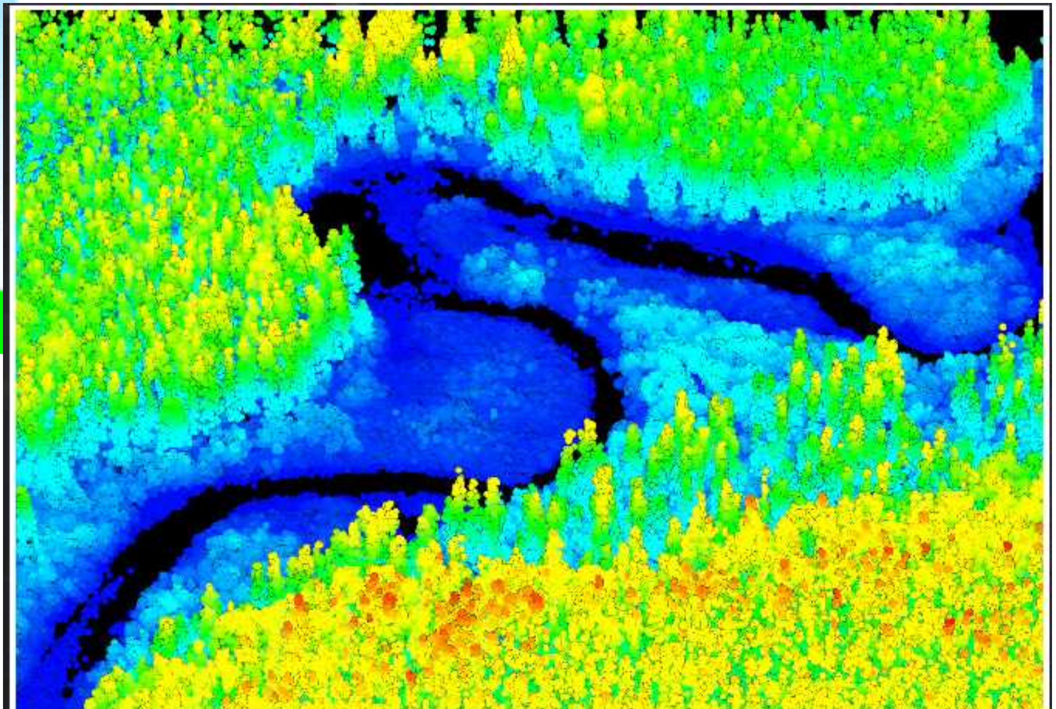
**Diferença de fase:** $$\Delta\phi = \frac{4\pi\Delta r}{\lambda}$$

**Relação trigonométrica:** $$sin(\alpha-\theta) = \frac{(r+\Delta_r) - r^2 - B^2}{2rB}$$

**Cálculo de altura:** $$z = H - r\cos\theta$$

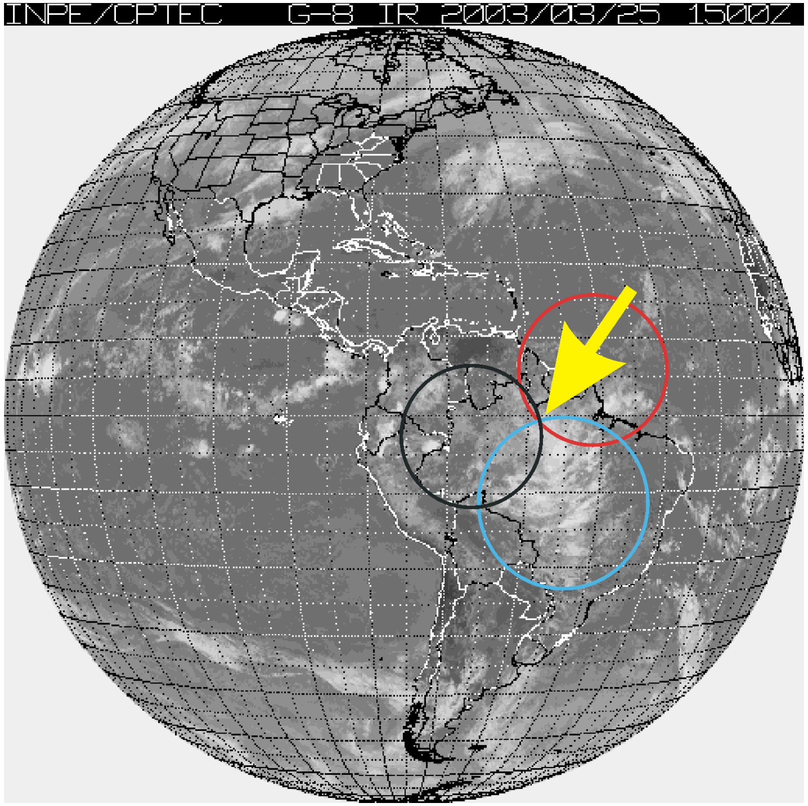
# LIDAR

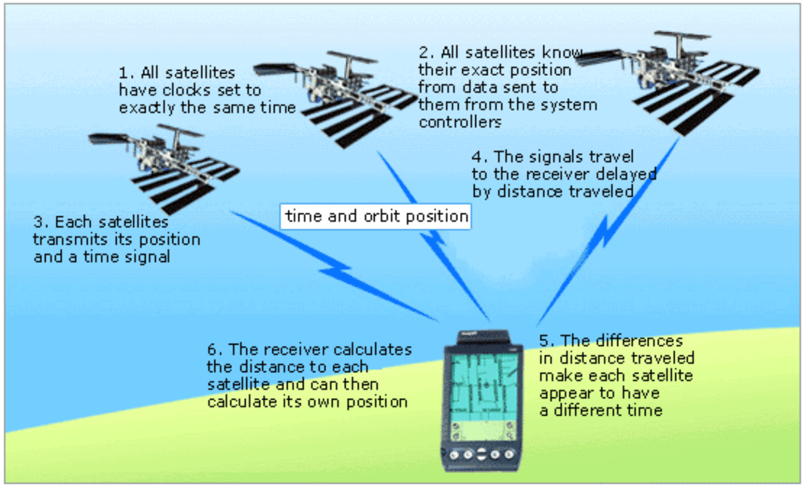


500m x 500m ~ 1,000,000 points

# GPS


INPE/CPTEC G-8 IR 2003/03/25 1500Z


1. All satellites have clocks set to exactly the same time
2. All satellites know their exact position from data sent to them from the system controllers
3. Each satellites transmits its position and a time signal
time and orbit position
4. The signals travel to the receiver delayed by distance traveled
5. The differences in distance traveled make each satellite appear to have a different time
6. The receiver calculates the distance to each satellite and can then calculate its own position

# Data Collection

- Precision
  - Measurement instrument
- Accuracy
  - Instrument calibration
- Validity
  - Correctly executed measurement
- Reliability
  - Measurement is repeatable

# 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

# 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.

# 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

# Quality Factors

Measurement Instrument

Data Processing

Digital Representation

Algorithms

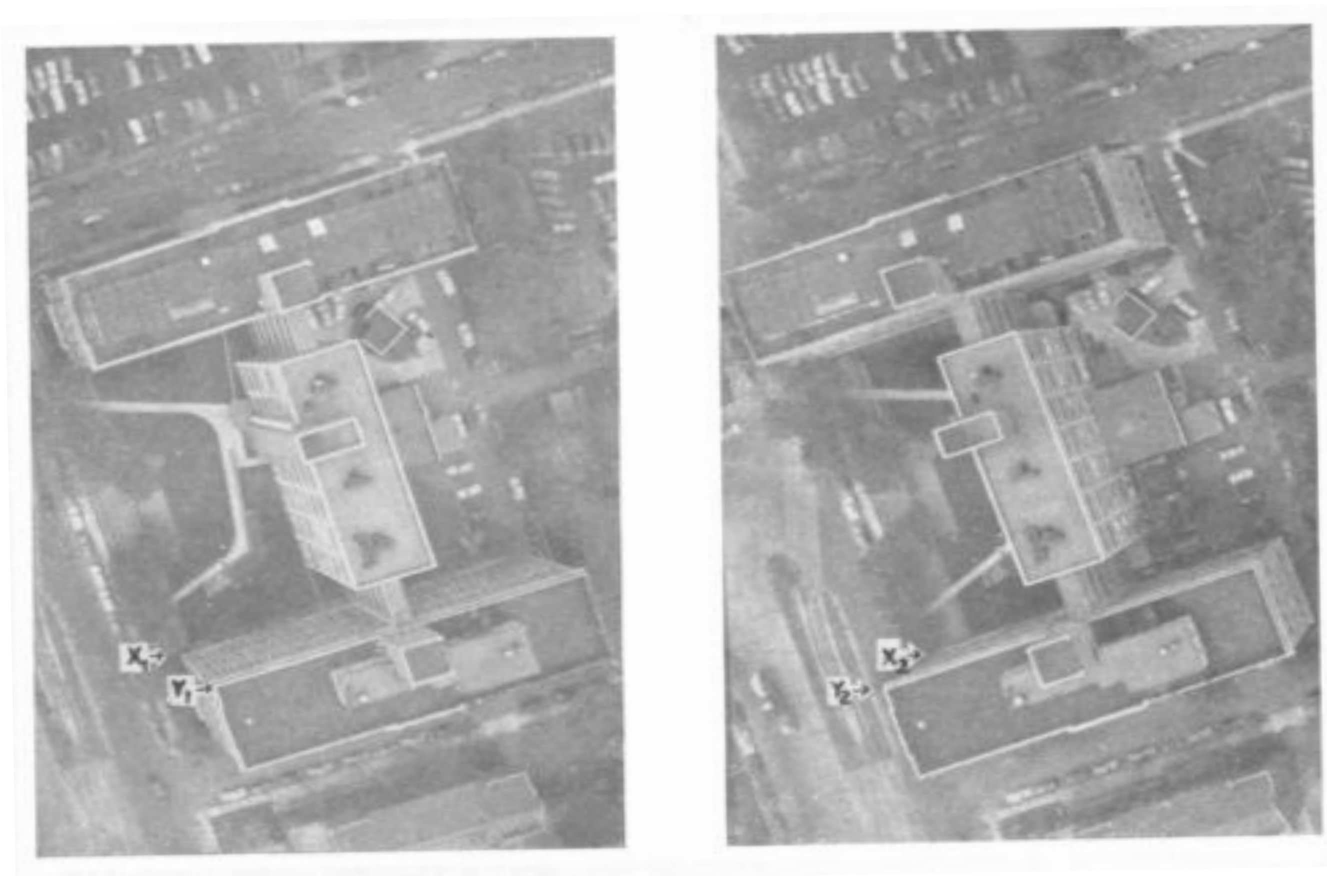
# Error Sources

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)

# Error Sources

## Photogrammetric Data Capture

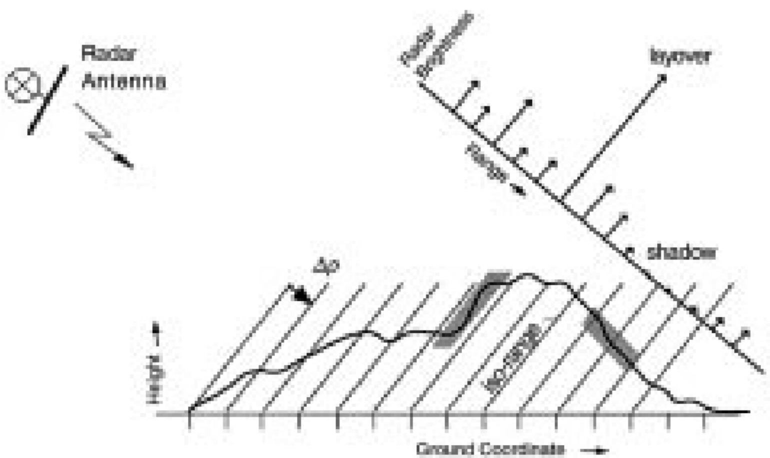


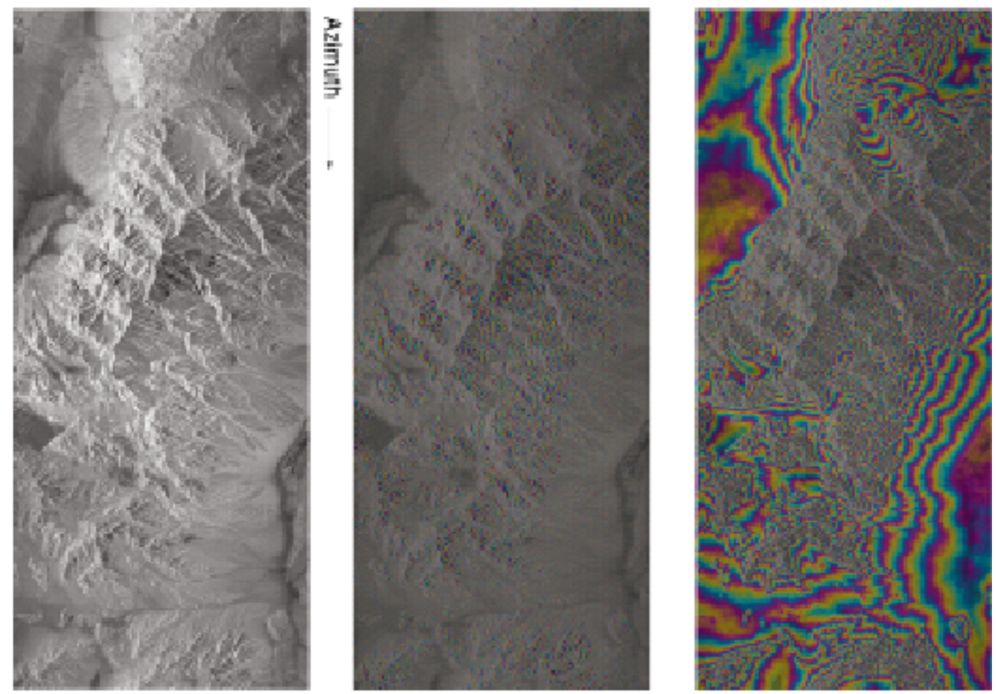
# Error Sources

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.

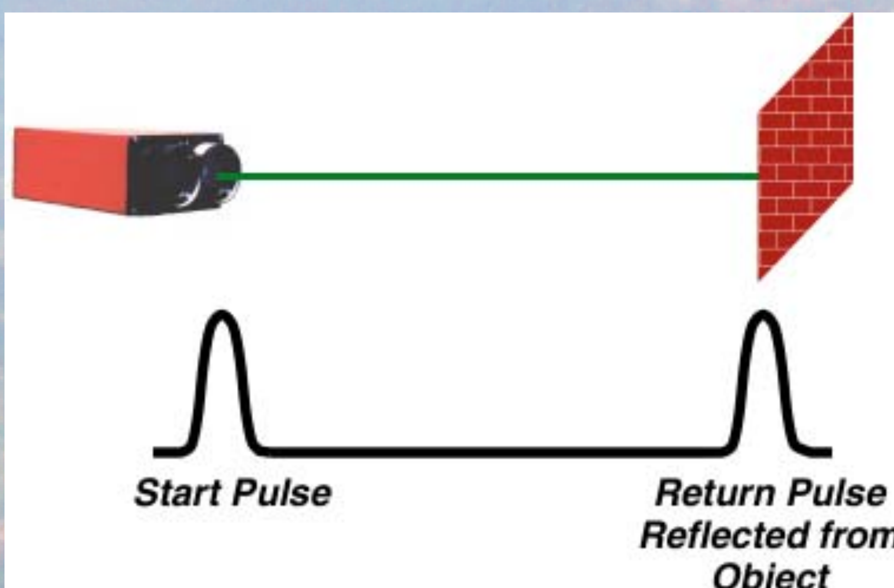
# Error Sources
## InSAR

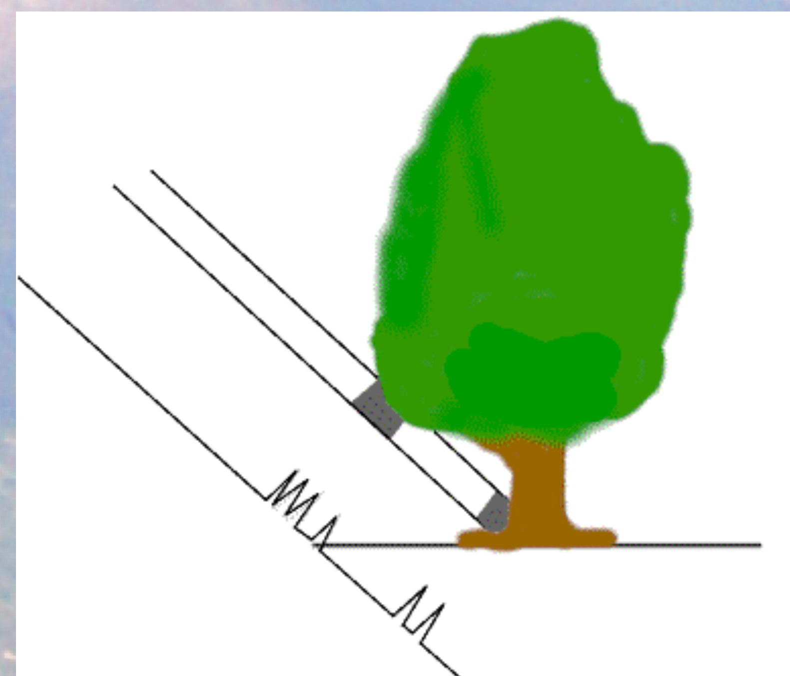


# Error Sources
## LIDAR

Pulse width, atmospheric effects, vegetation influence, footprint size (typical laser beam projects to 24–60 cm diameter at a distance of 1219 m)



# 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.

# 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

# Accuracy:

## SRTM C-Band DEM

Absolute

- 16 meters vertical 90% linear error (LE90)
- 20 meters horizontal 90% circular error (CE90)

Relative

- 10 meters vertical LE90
- 15 meters horizontal CE90

# 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

# DTM Representations

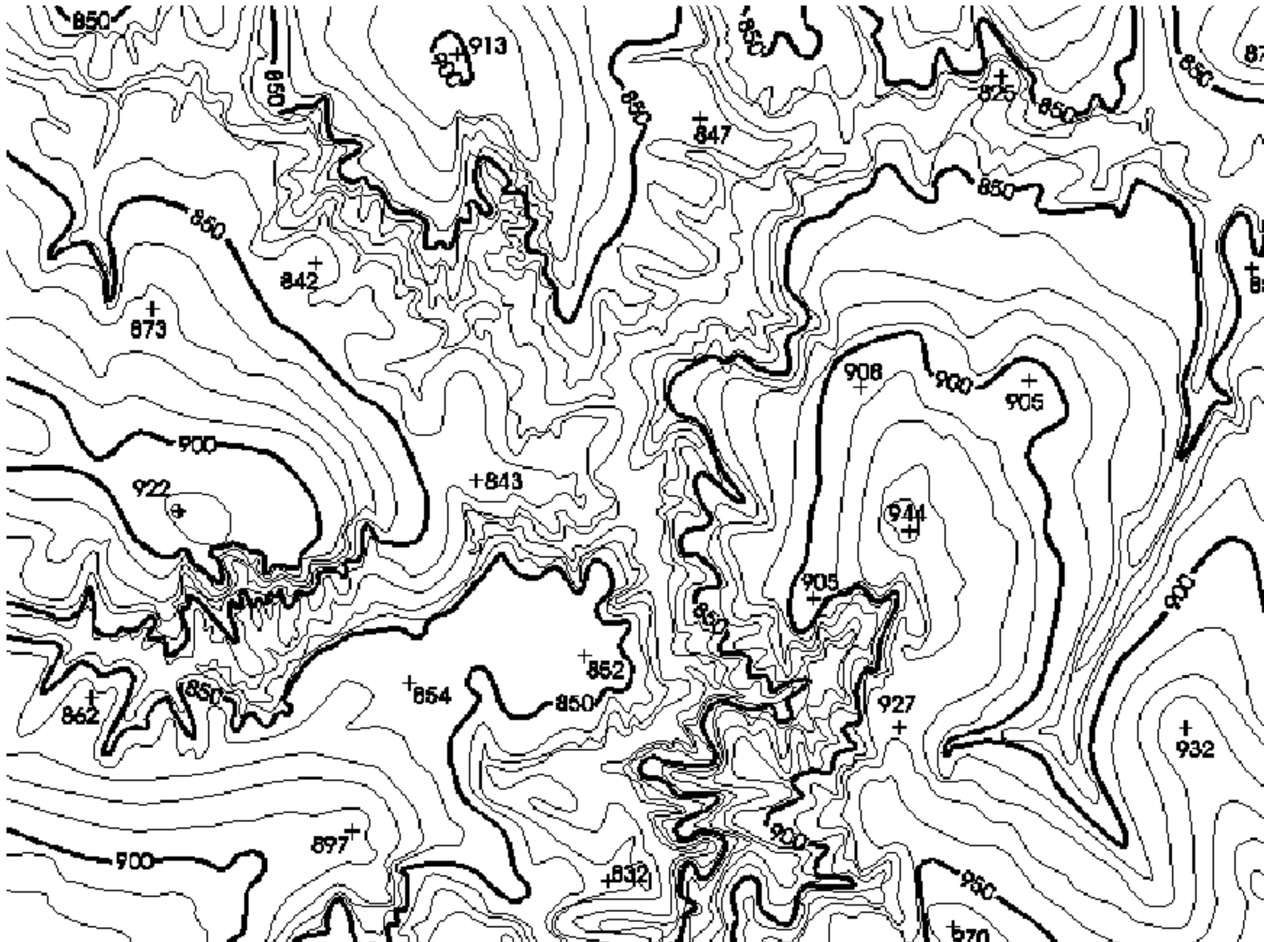
Contour Lines

Regular Grid

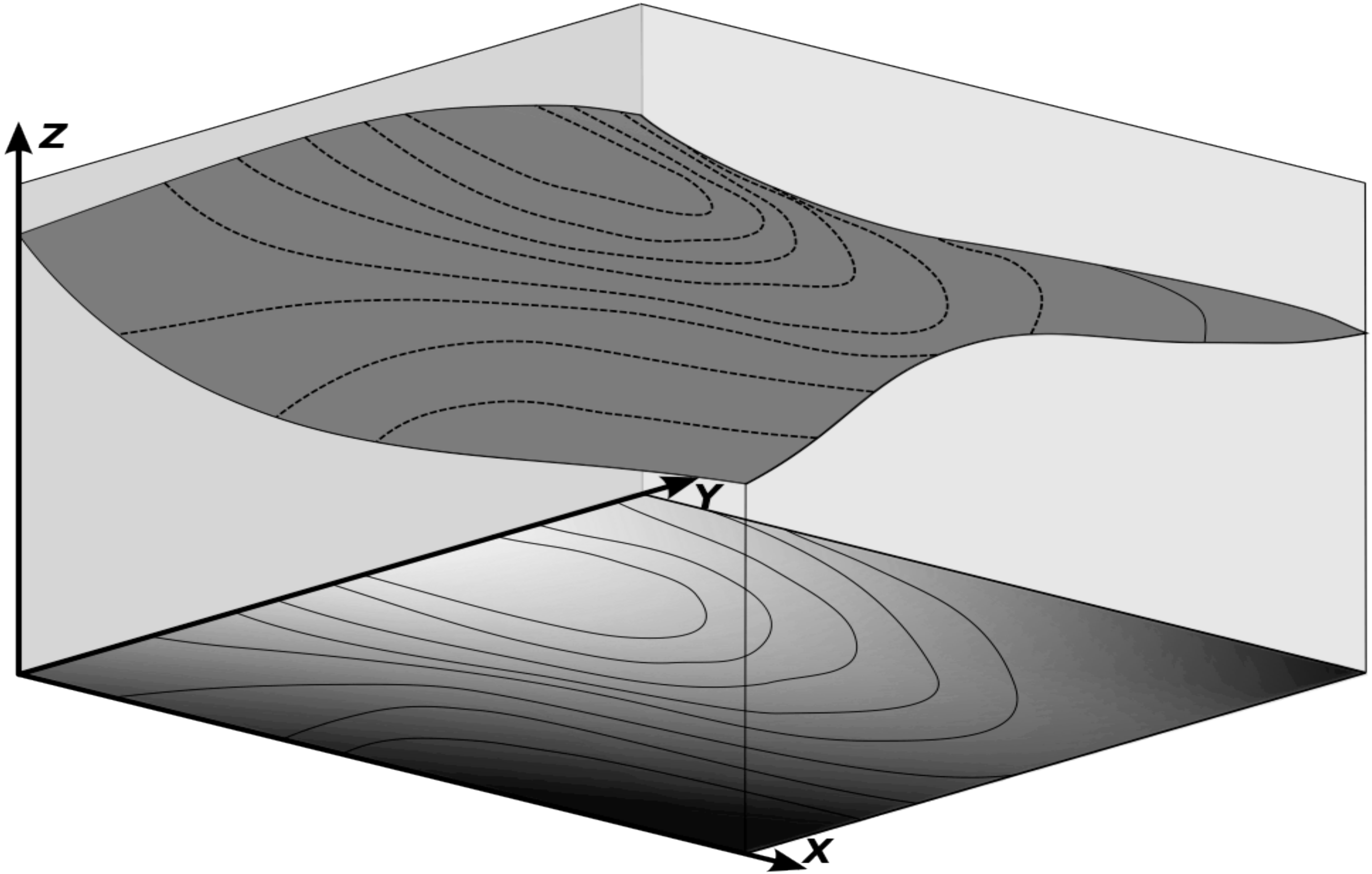
TIN – Triangulated Irregular Network

# Contour Lines

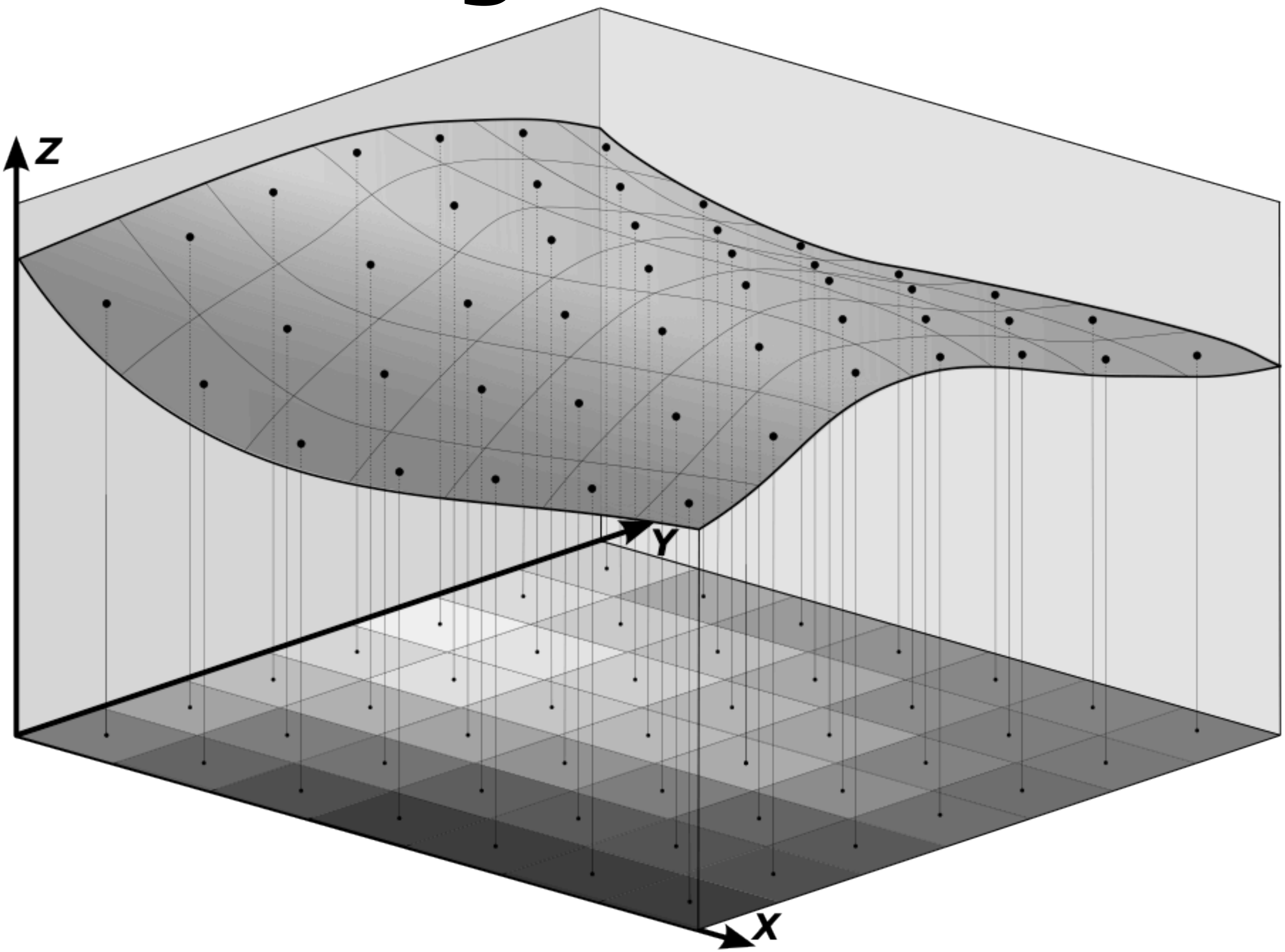
- Define the surface only along the lines
- Regions between two lines are inferred to be between the values of the lines



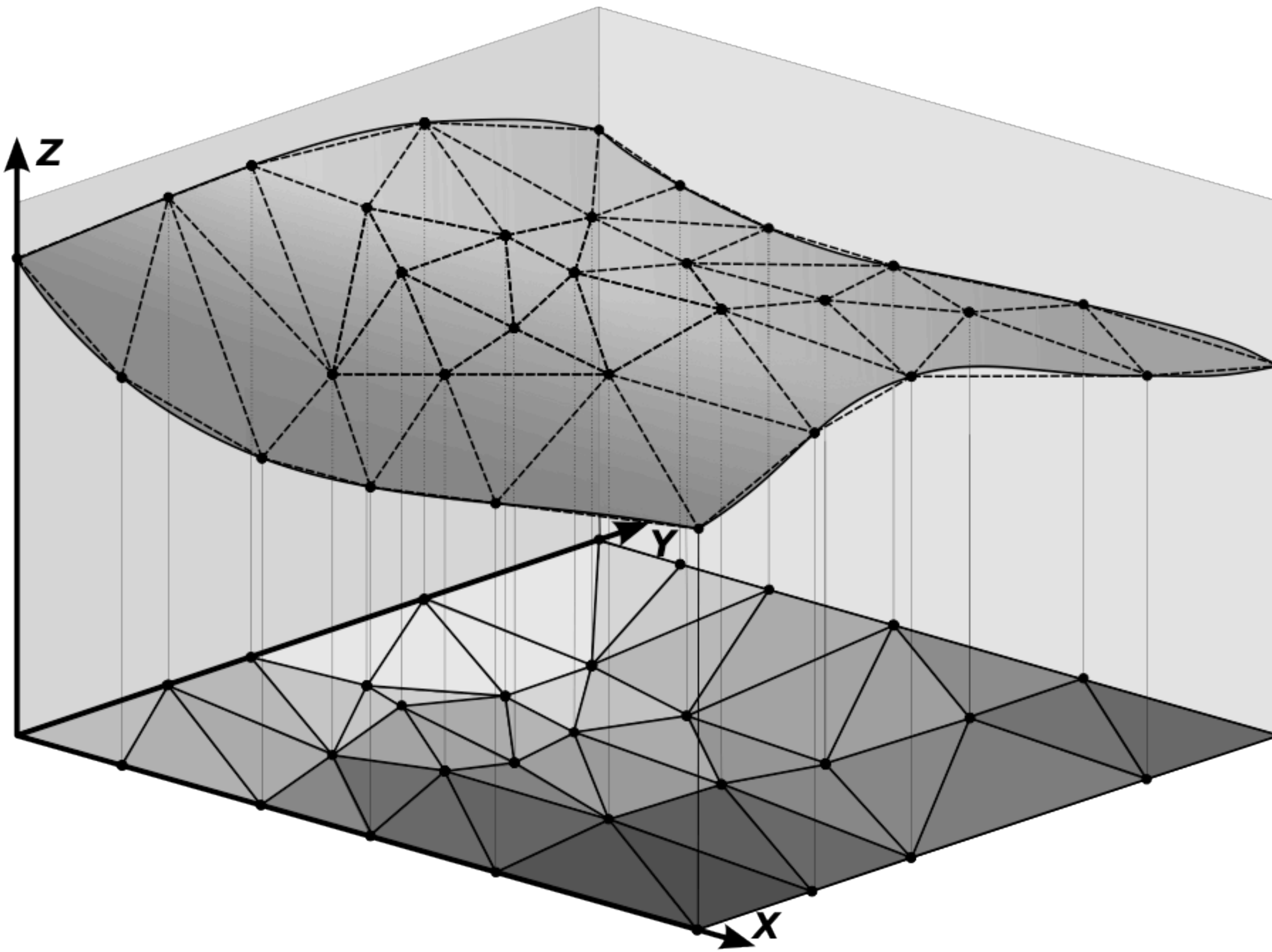
# Contour Lines



# Regular Grid



# Triangulated Irregular Network



# DTM Products

Generated from the models

Derivatives

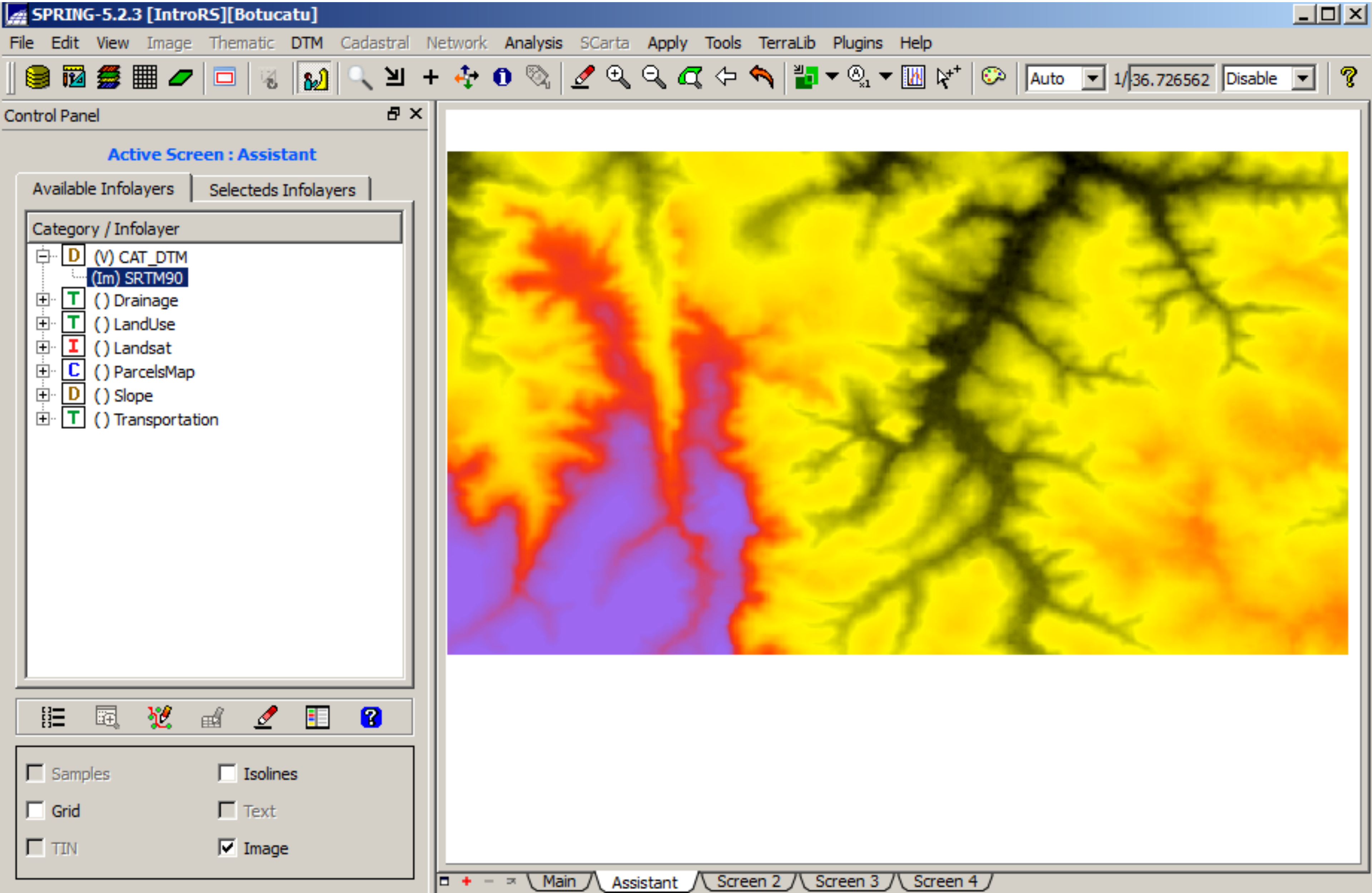
Contour Lines

Profile

3D Visualization

Drainage Analysis

# DTM Visualization



# Slope Angle and Aspect

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

**$A = \mathrm{arctg}\ [-(\delta Z/\delta Y)/(\delta Z/\delta X)]\ (-\Pi < A < \Pi)$**

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

# Derivatives Estimation

**The partial derivatives are estimated using:**

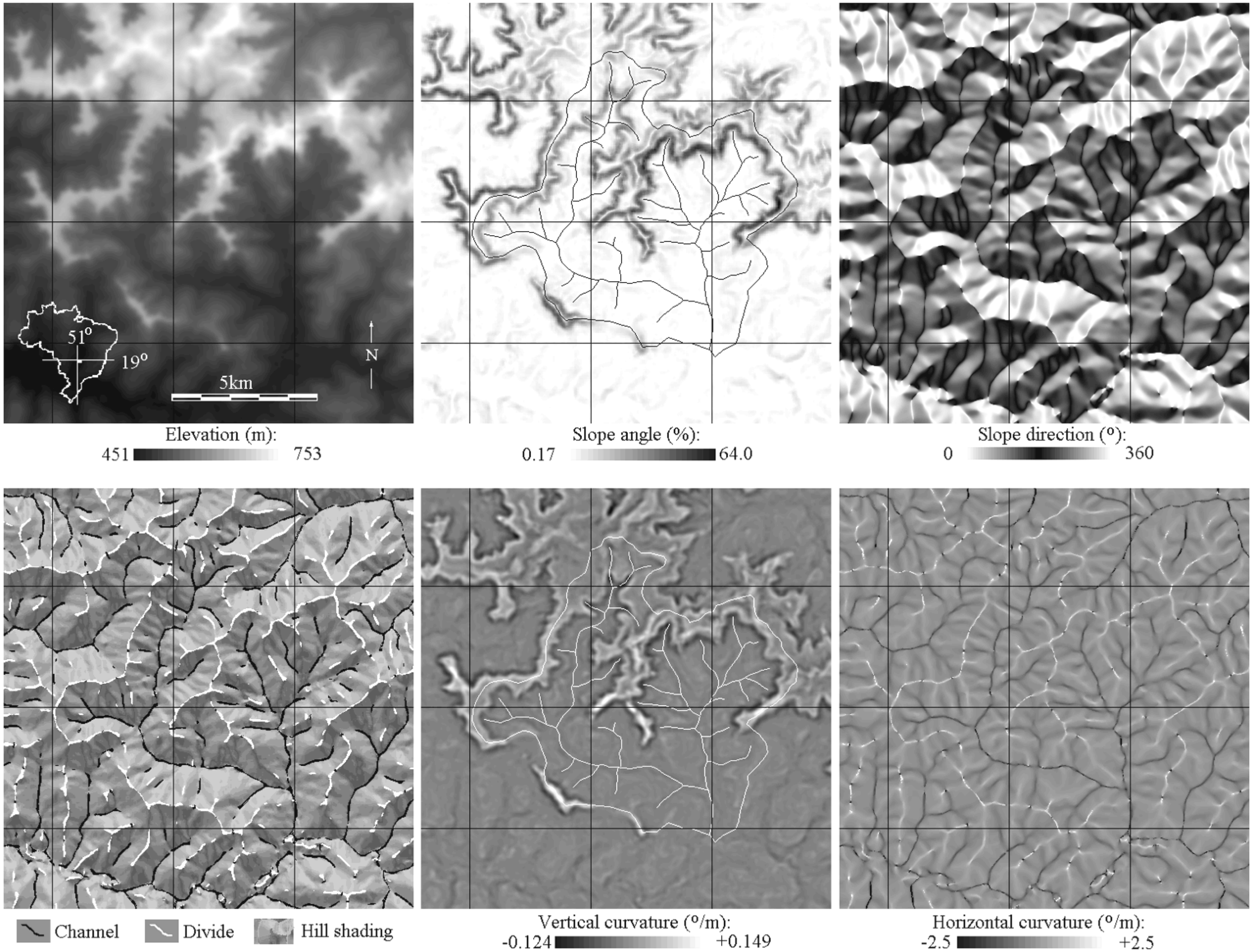
$[\delta Z/\delta X]_{i,j} = [( Z_{i+1,j+1} + 2*Z_{i+1,j} + Z_{i+1,j-1} ) – ( Z_{i-1,j+1} + 2*Z_{i-1,j} + Z_{i-1,j-1} )]/8*\delta X$

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

**where z elements are on the grid, indicated by:**

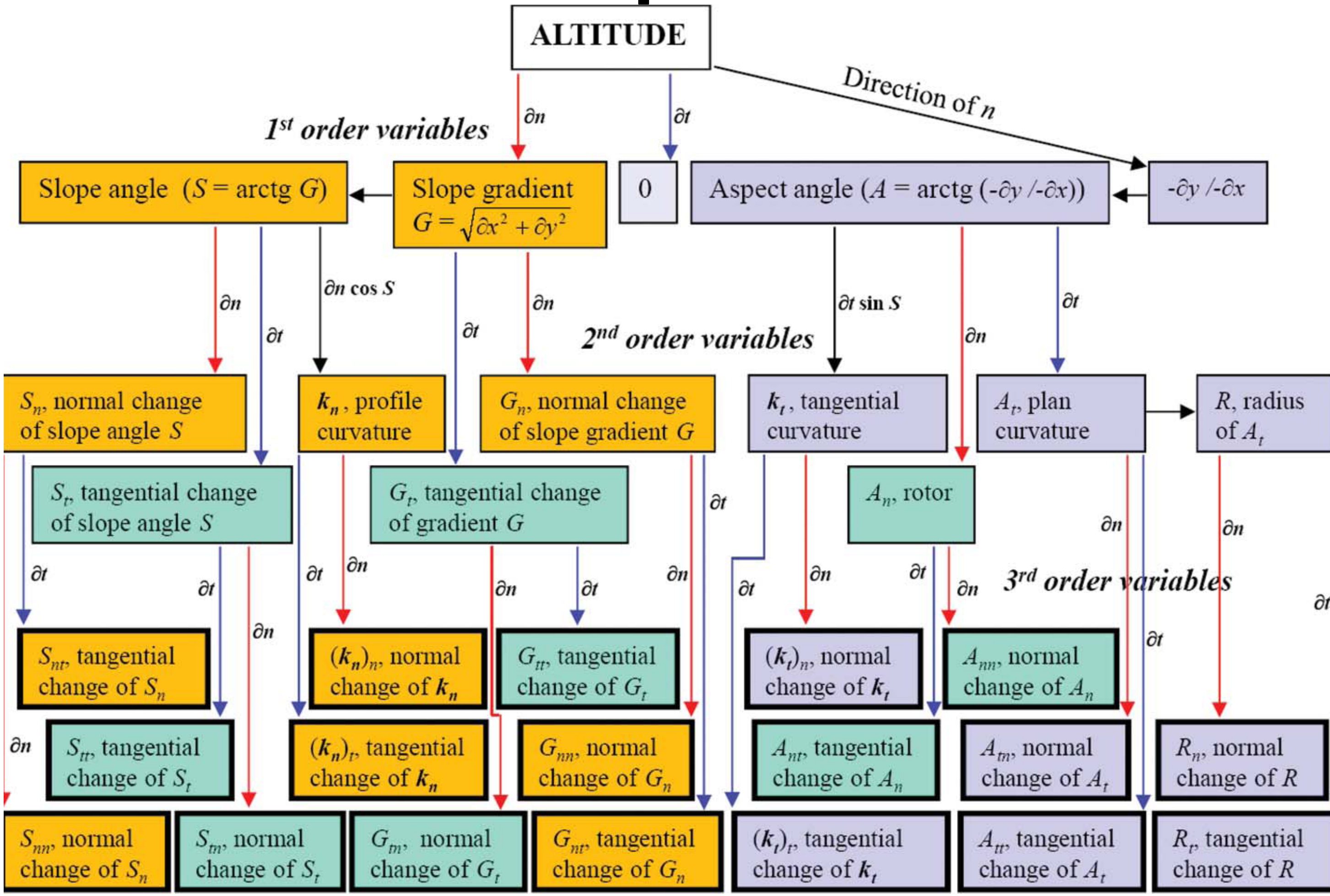
| | | |
|---|---|---|
| $Z_{i-1,j+1}$ | $Z_{i,j+1}$ | $Z_{i+1,j+1}$ |
| $Z_{i-1,j}$ | $Z_{i,j}$ | $Z_{i+1,j}$ |
| $Z_{i-1,j-1}$ | $Z_{i,j-1}$ | $Z_{i+1,j-1}$ |

# Elevation Derivatives



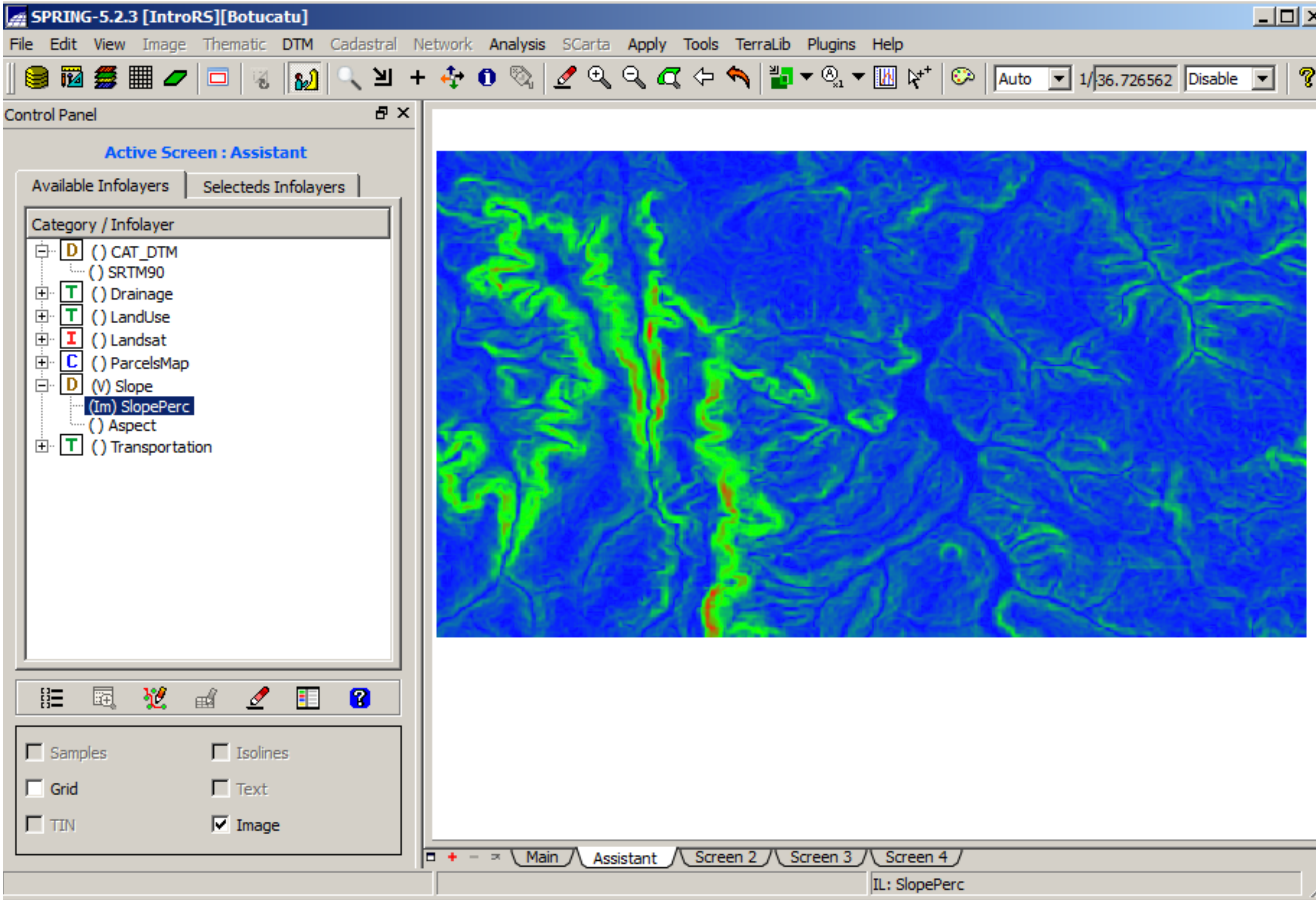

*Márcio de Morisson Valeriano*

# 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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C () ParcelsMap
D (V) Slope
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Screen 4
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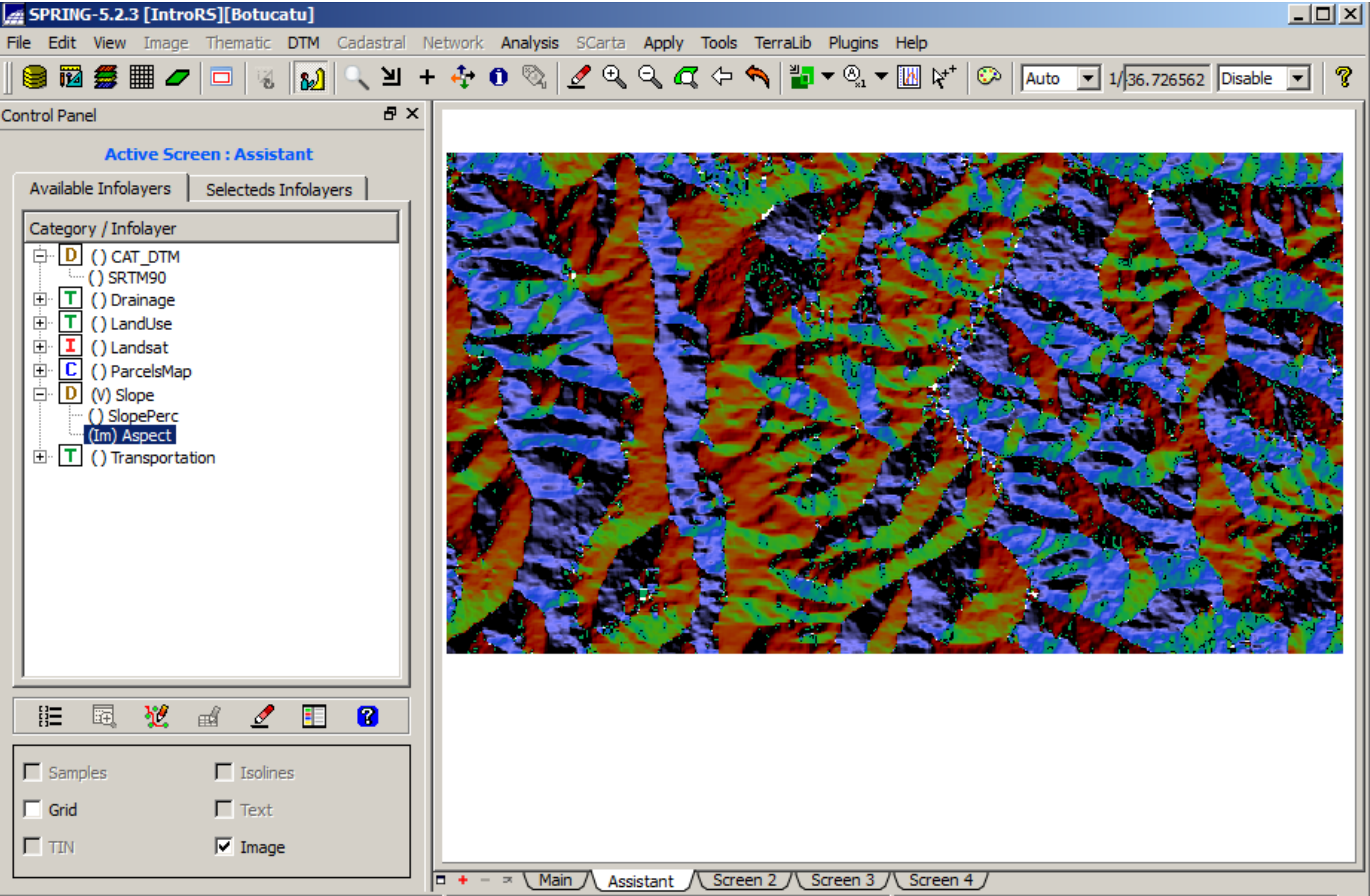
# Aspect



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() SlopePerc
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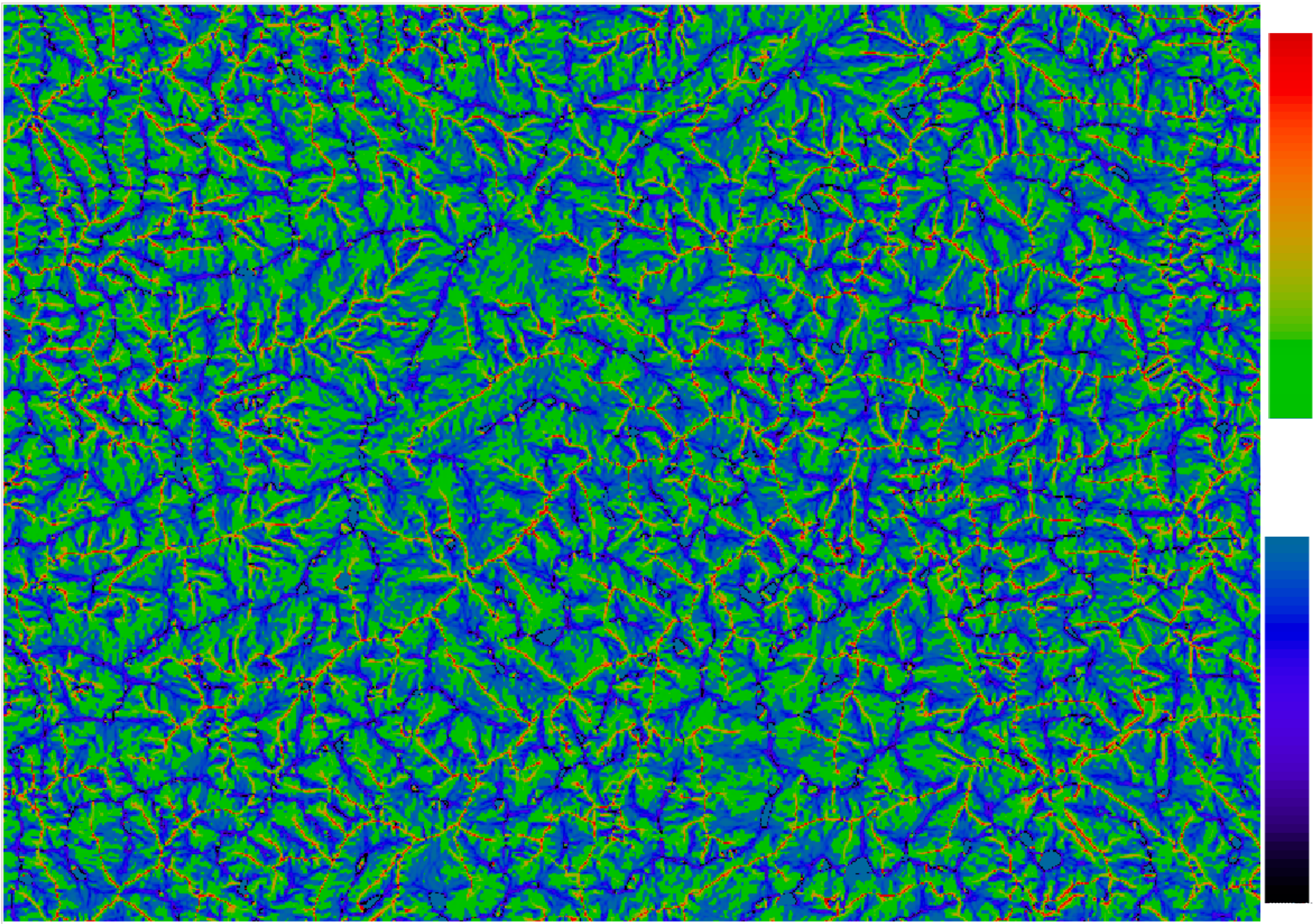
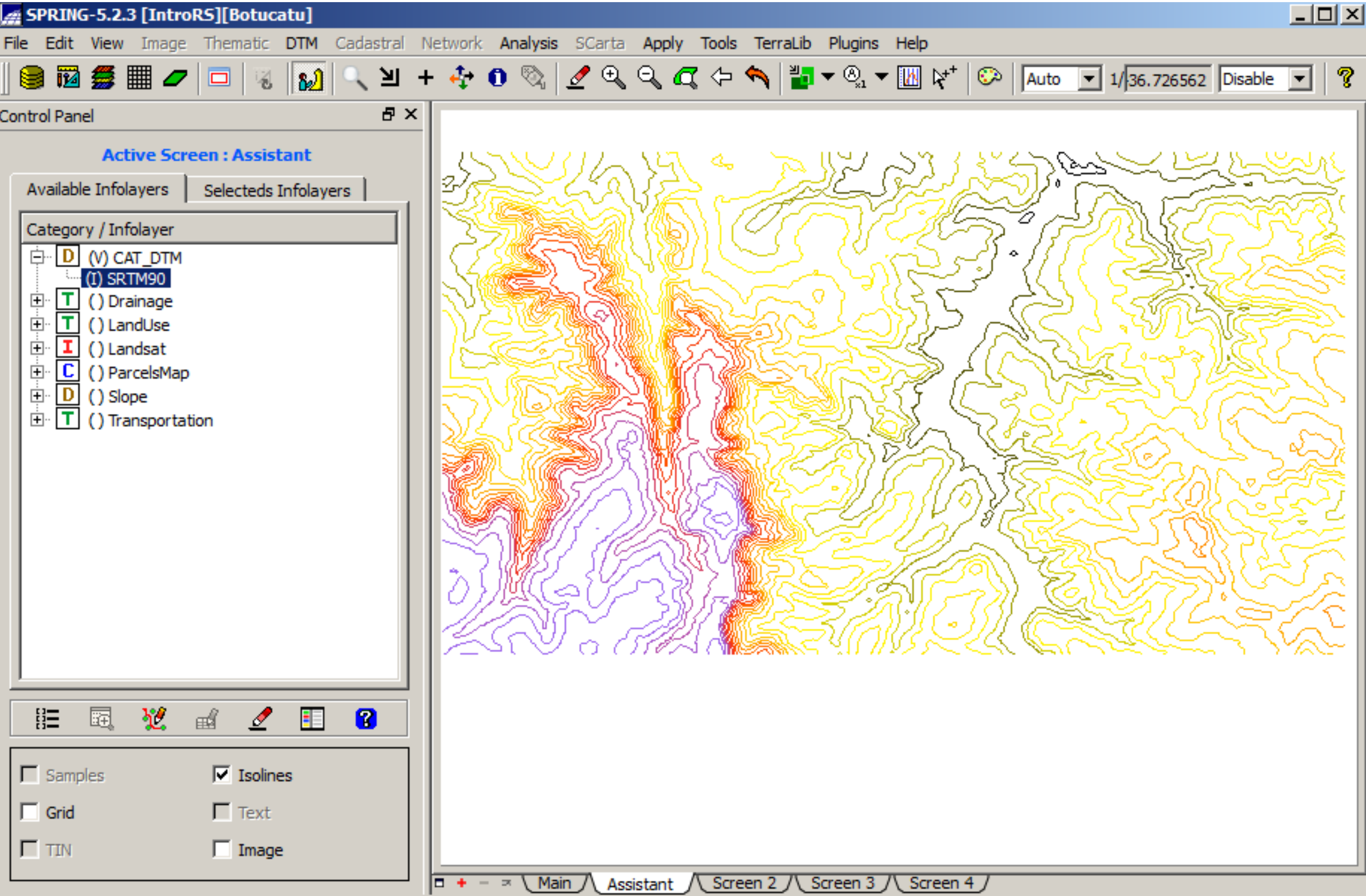
Image
Main
Assistant
Screen 2
Screen 3
Screen 4

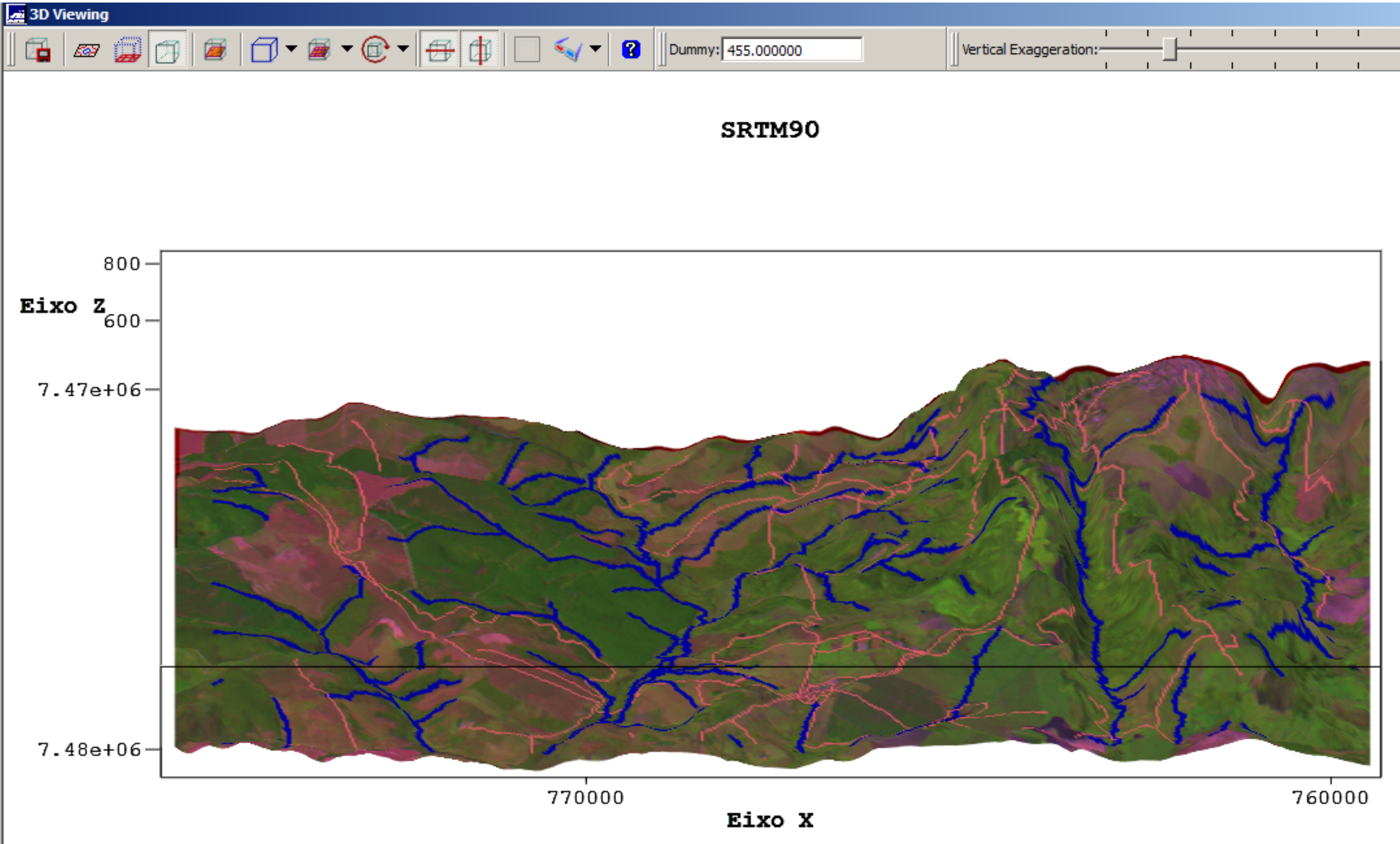
# Horizontal Curvature



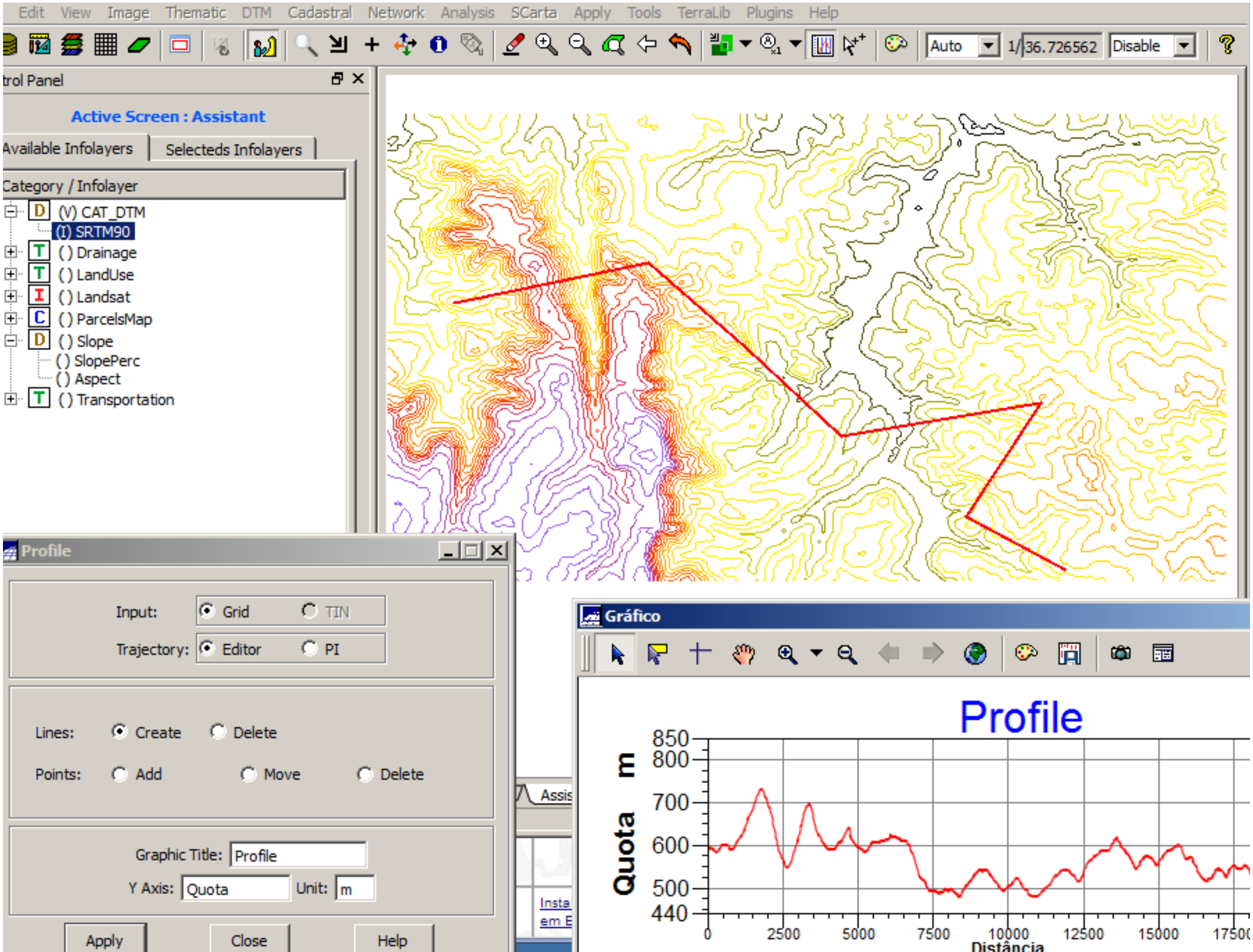
# Contour Lines



# 3D Visualization



# Profile



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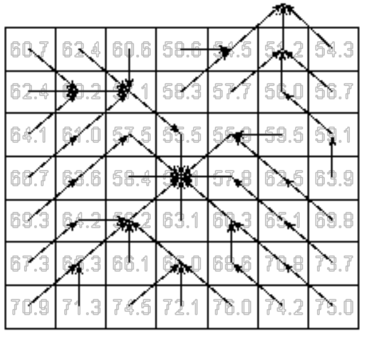
() Aspect
() Transportation
Profile
Input:
Grid
TIN
Trajectory:
Editor
PI
Lines:
Create
Delete
Points:
Add
Move
Delete
Graphic Title:
Profile
Y Axis:
Quota
Unit:
m
Apply
Close
Help
Gráfico
Profile
Quota m
850
800
700
600
500
440
0
2500
5000
7500
10000
12500
15000
Distância

# Drainage Analysis

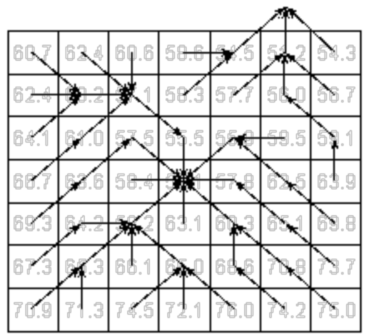
**Based on D8 Method**

| | | |
|---|---|---|
| 120 | 150 | 170 |
| 80 | 100 | 150 |
| 150 | 160 | 90 |

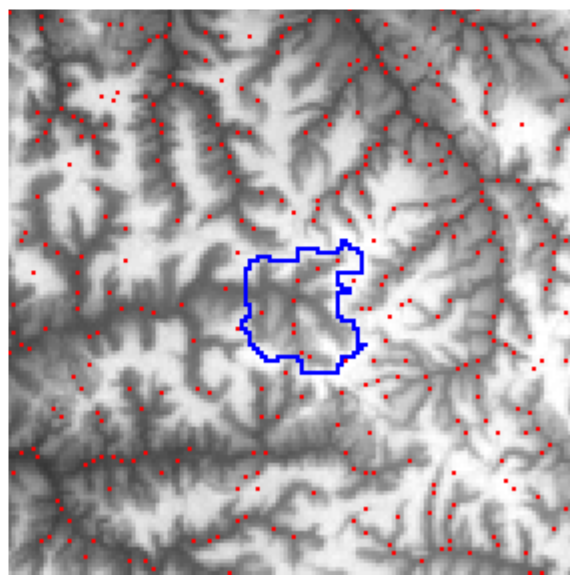


# DTM Hydrologically Corrected

| | | | | | | |
|---|---|---|---|---|---|---|
| 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 |

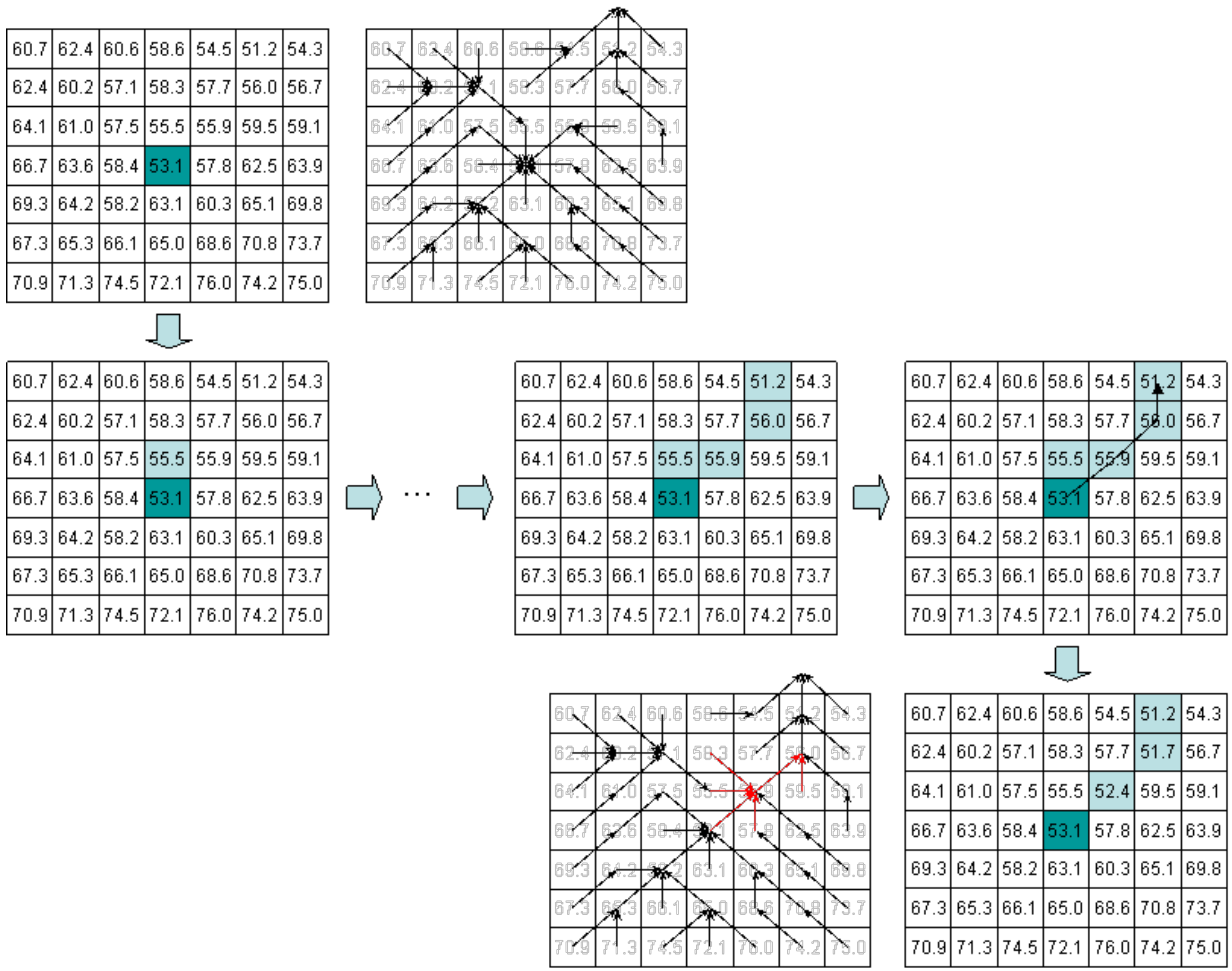


"sink"



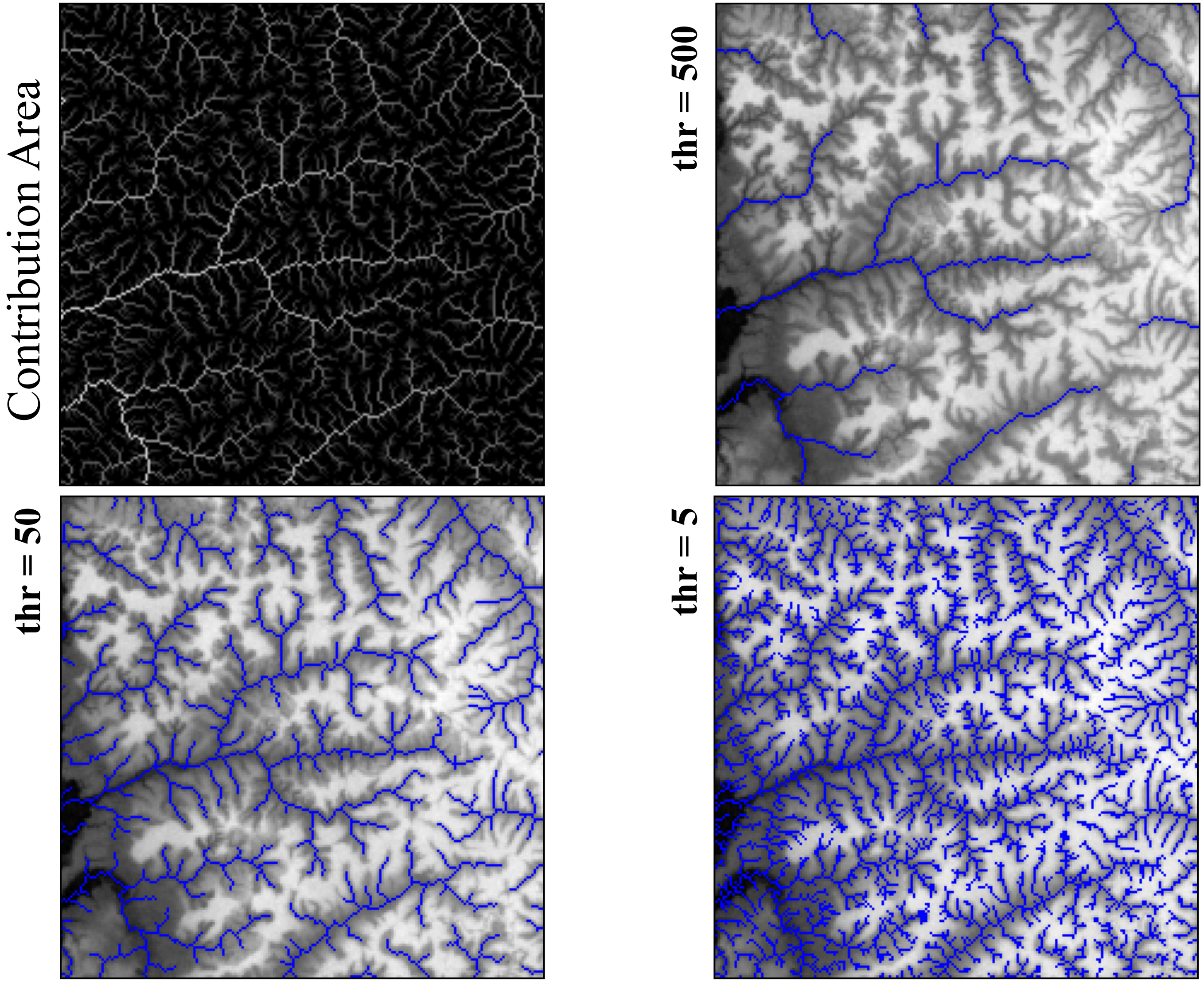
SRTM
"sinks"

# Hydrologically Correct DTM



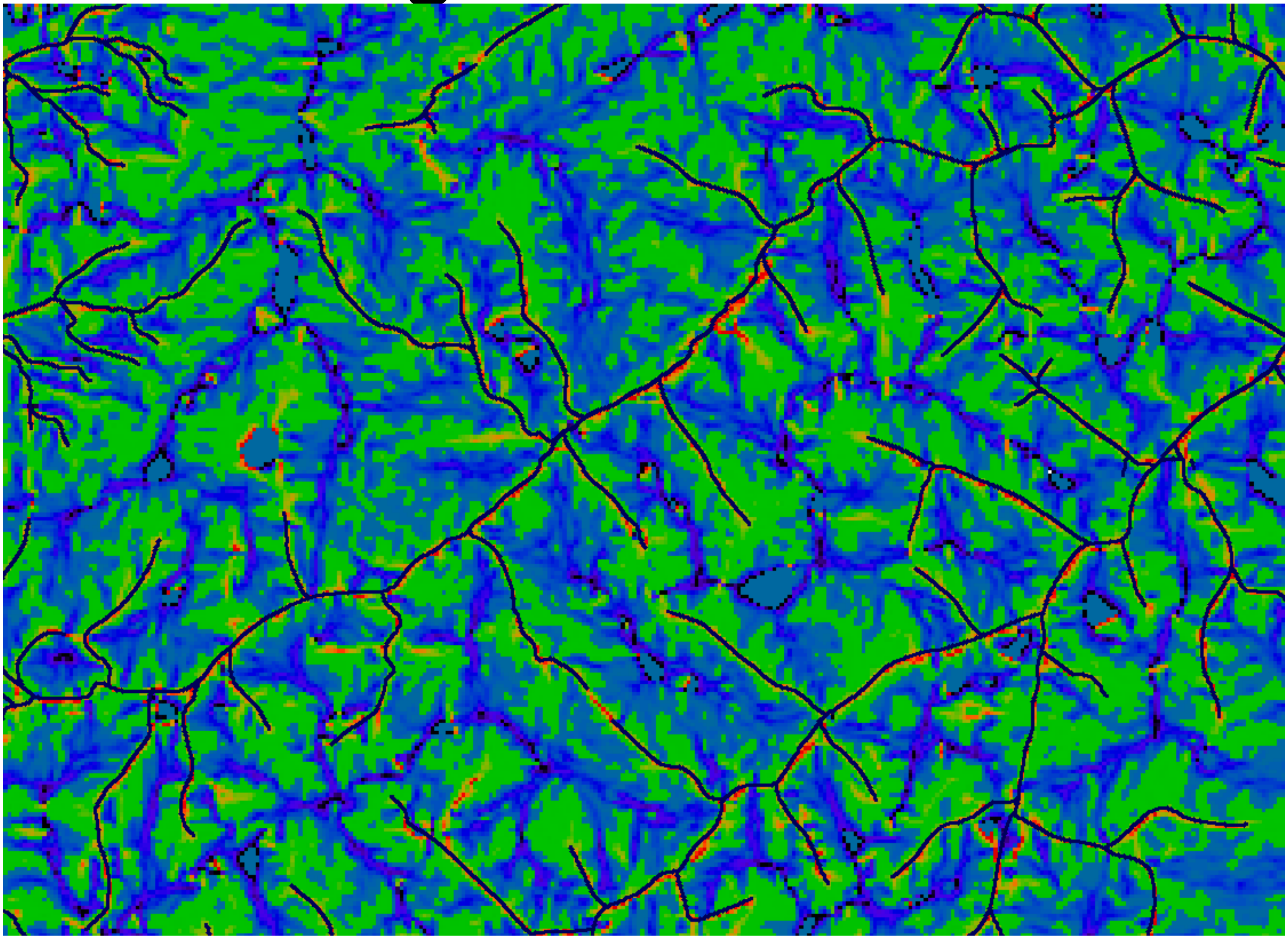

CAMILO DALELES RENNÓ

# Drainage Network




CAMILO DALELES RENNÓ

# Drainage From Curvature



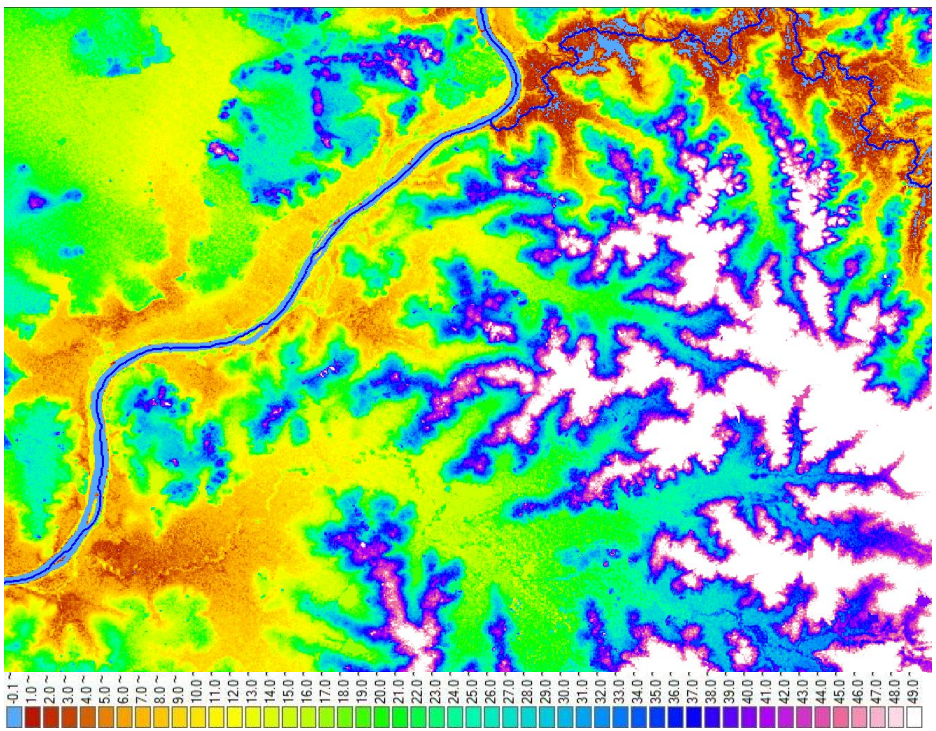
# Comparison: SRTM HAND and Flood Extents from Landsat 8 Imagery

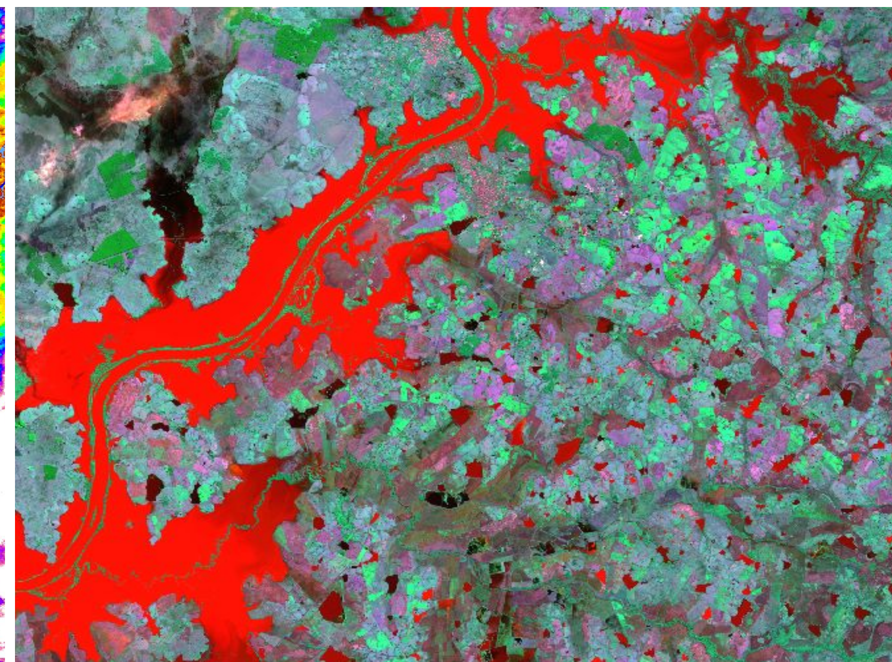
**HAND using 500K accumulated Cells to define drainage network**

**Landsat8: Acquired 2014/July/05**

**Flood Level 13 meters**

**Maximum level: 15 m on July 2nd**





(R) LC82240802014186LGN00_B4
(G) LC82240802014186LGN00_B5
(B) LC82240802014186LGN00_B6

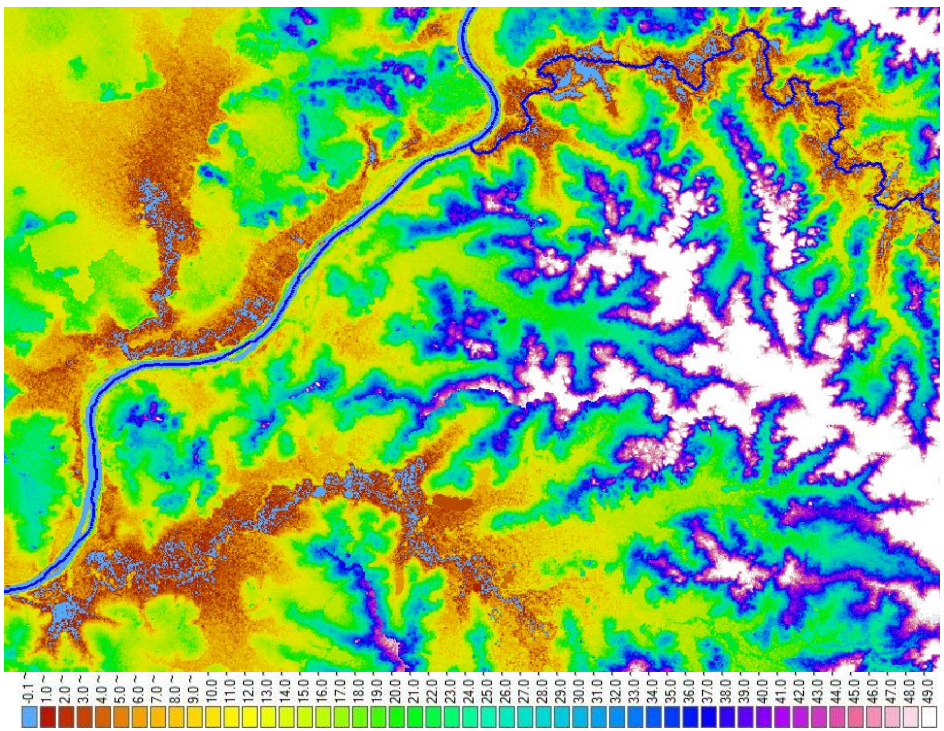
# Comparison: SRTM HAND and Flood Extents from Landsat 8 Imagery

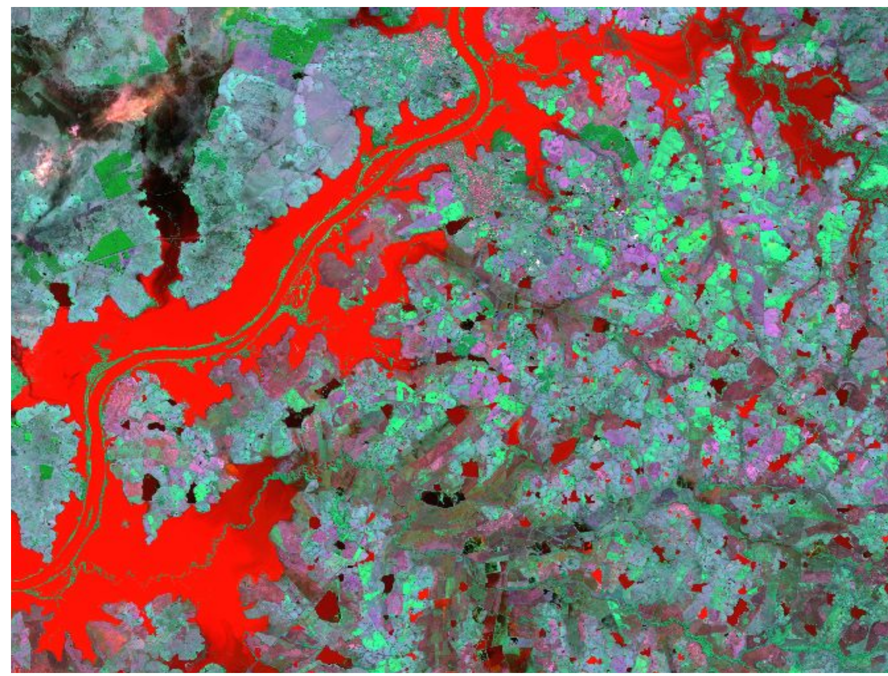
**HAND using 100K accumulated Cells to define drainage network**

**Landsat8: Acquired 2014/July/05**

**Flood Level 13 meters**

**Maximum level: 15 m on July 2nd**

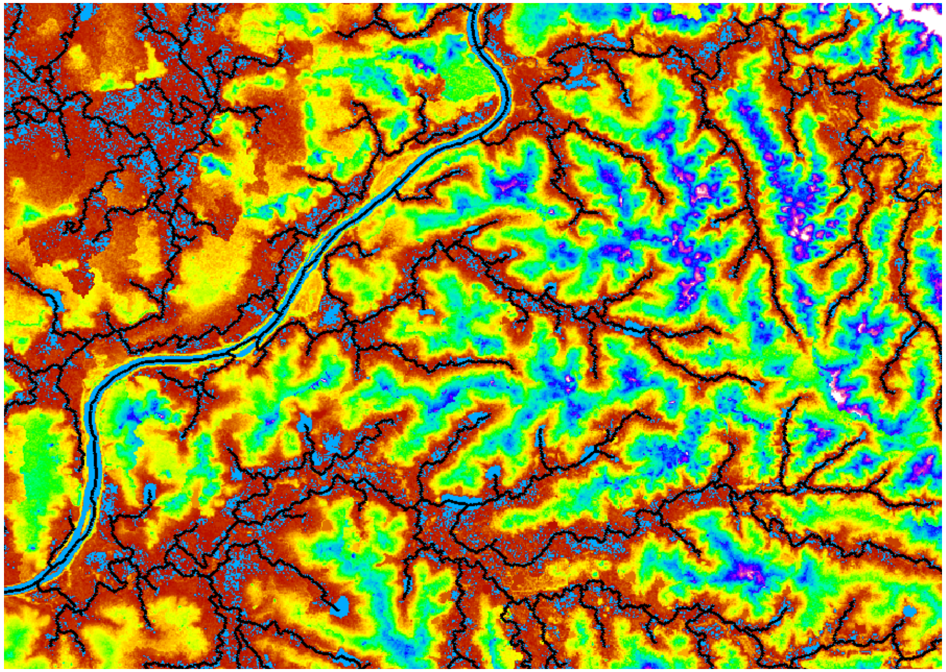


(R) LC82240802014186LGN00_B4
(G) LC82240802014186LGN00_B5
(B) LC82240802014186LGN00_B6

# Comparison: SRTM HAND and Flood Extents from Landsat 8 Imagery

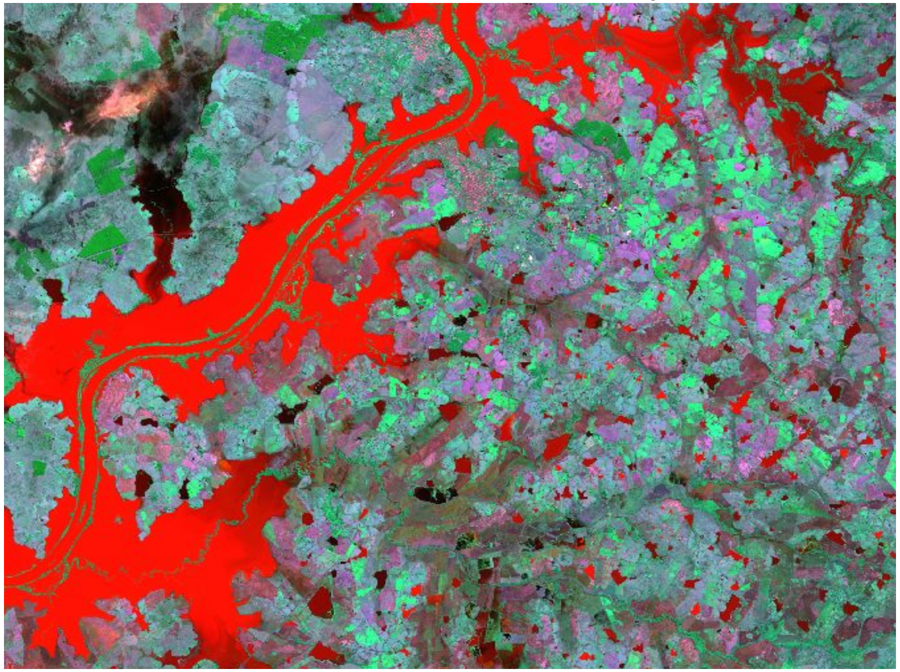
HAND using 1000 accumulated Cells to define drainage network



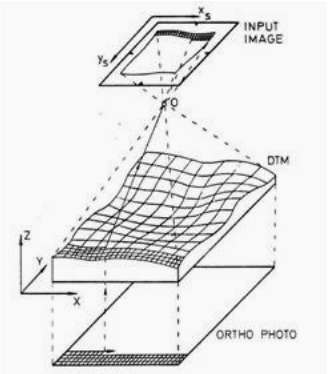
Landsat8: Acquired 2014/July/05

Flood Level 13 meters

Maximum level: 15 m on July 2nd



# Ortorretificação



# Referências

## Livros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