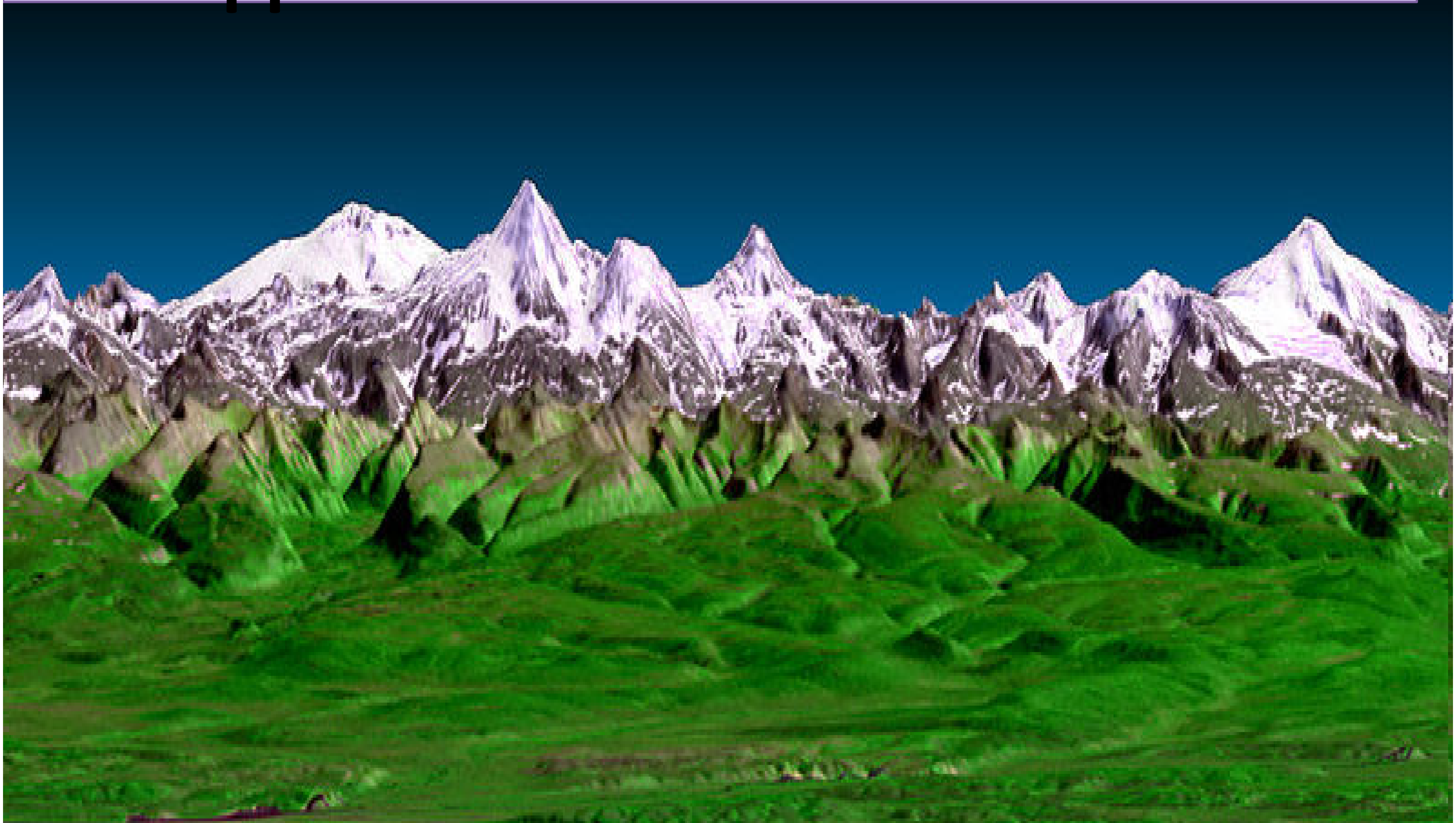
DEM Generation Concepts & Applications in Water Resources

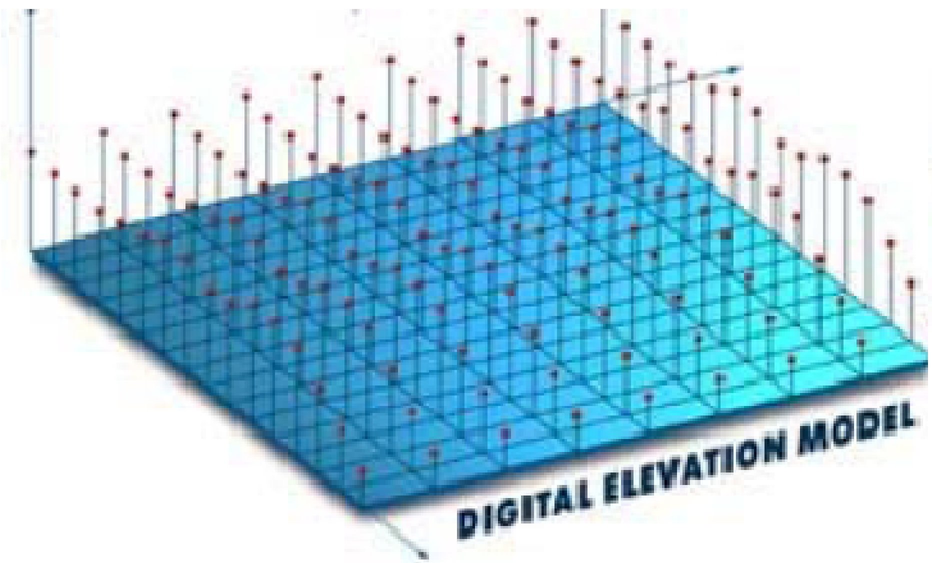


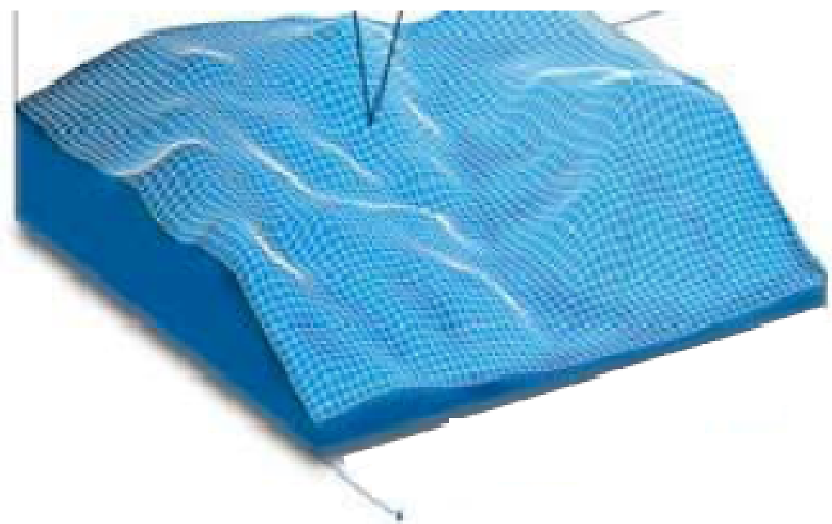
J.Nalini,AS&DMG

Digital Elevation Model (DEM) is

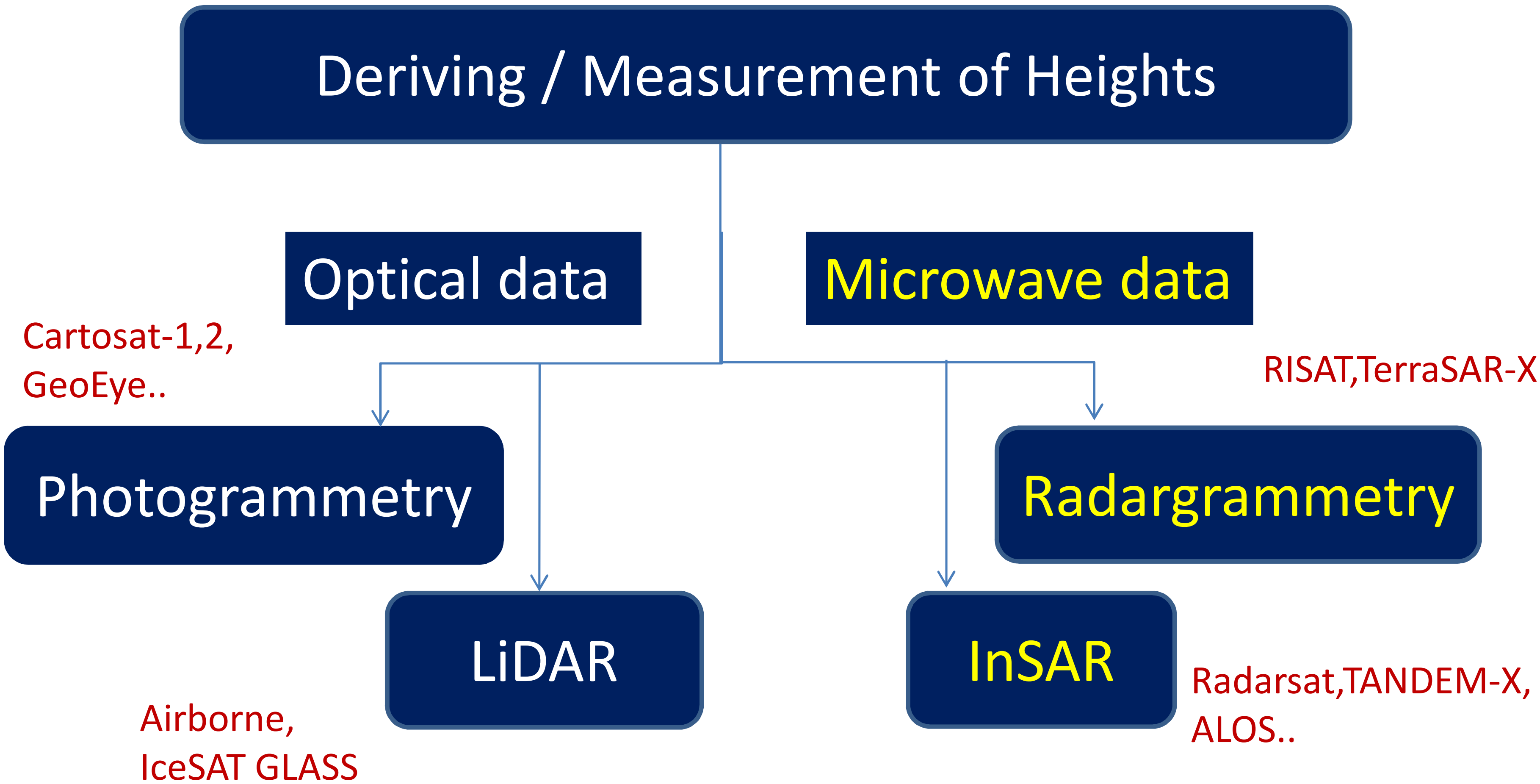
Digital representation of a elevation information along terrain

Digital Elevation Models (DEM)





Digital Elevation Model



Ground surveys Leveling

Digital Level

Staff

Ground surveys

TOTAL STATION

GPS SURVEY

Digital Elevation Model (DEM)

- **It is an array of regularly spaced elevation values referenced horizontally to a projection or to a geographic coordinate system**

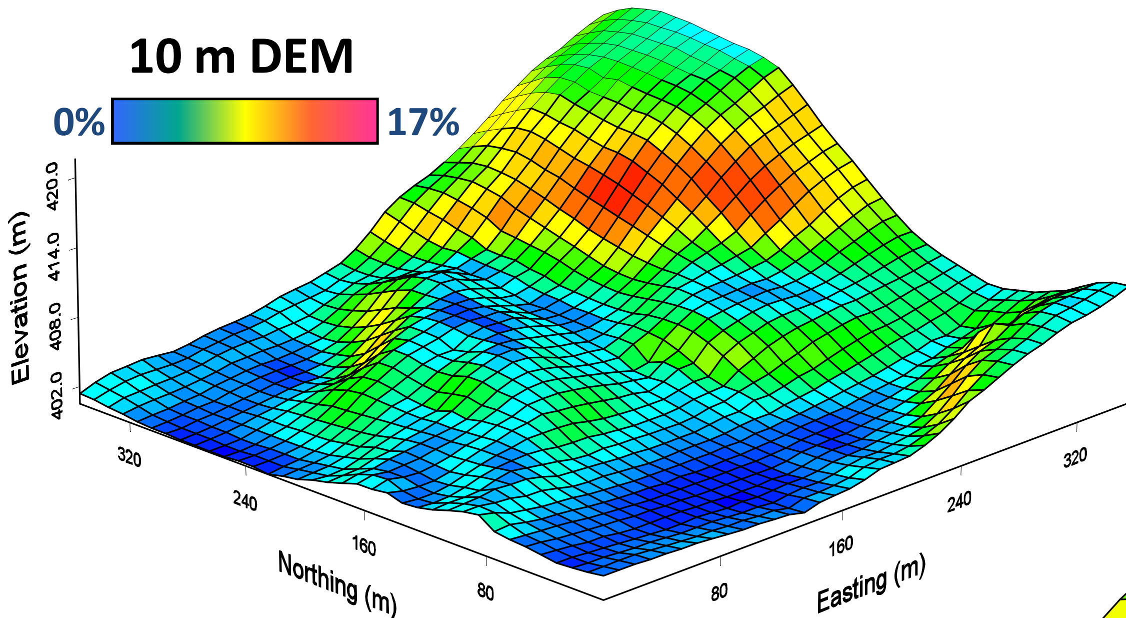
Digital Terrain Model (DTM)

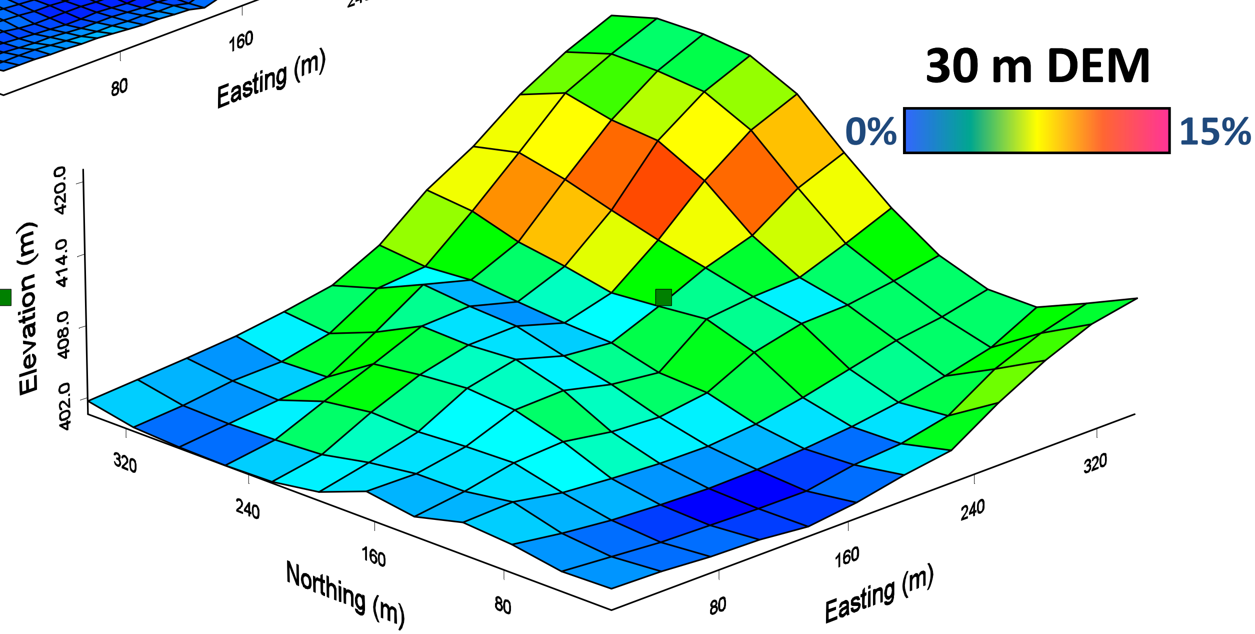
- **Implies a model of the surface of the Earth**
- **Includes terrain features such as rivers, break lines and ridges**
- **DTM/DEM are often used synonymously**

Digital Surface Model (DSM)

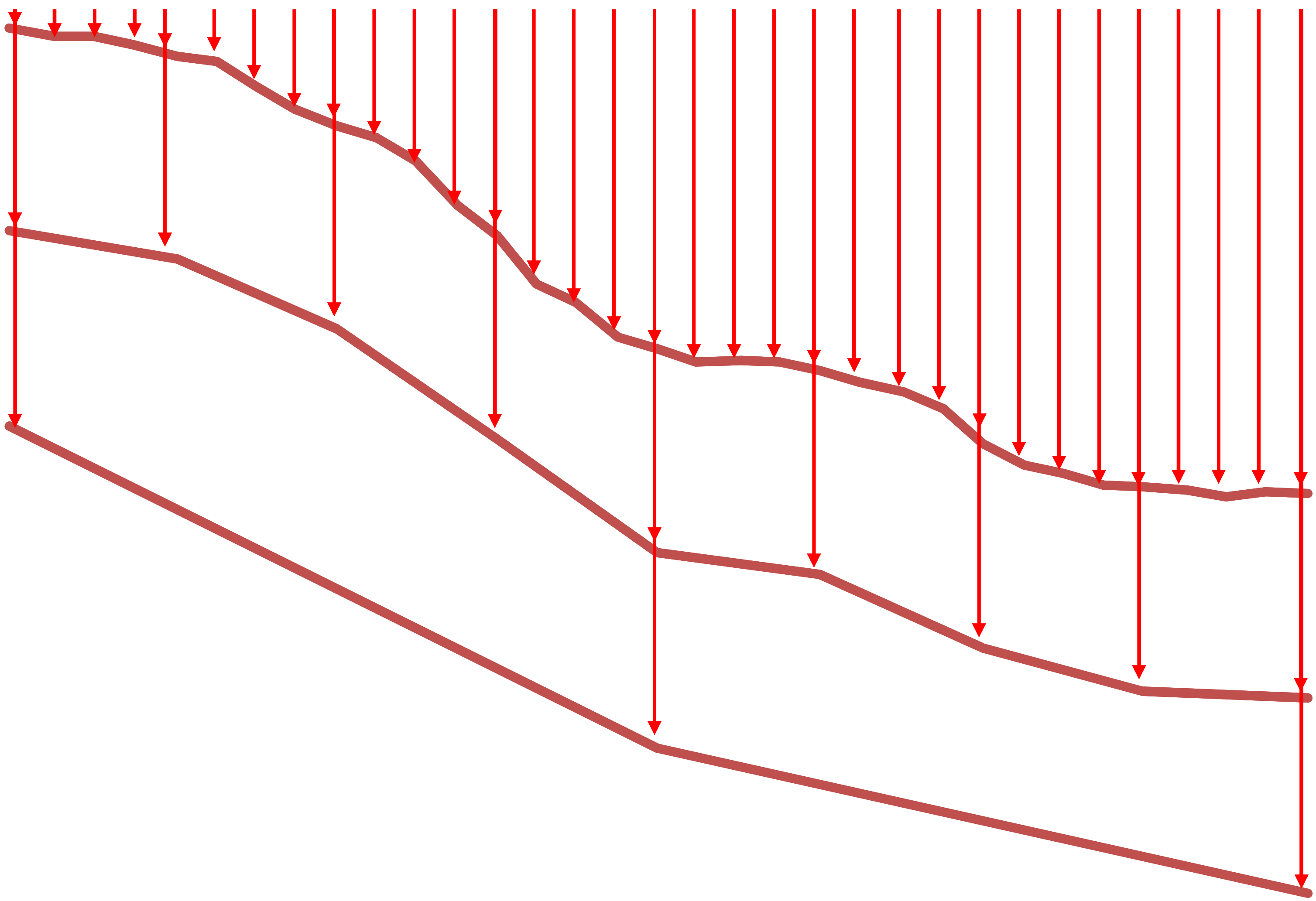
- **Digital Surface Model (DSM)**
- **Includes all features such as buildings, trees** etc;

DEM Resolution





DEM Horizontal Resolution

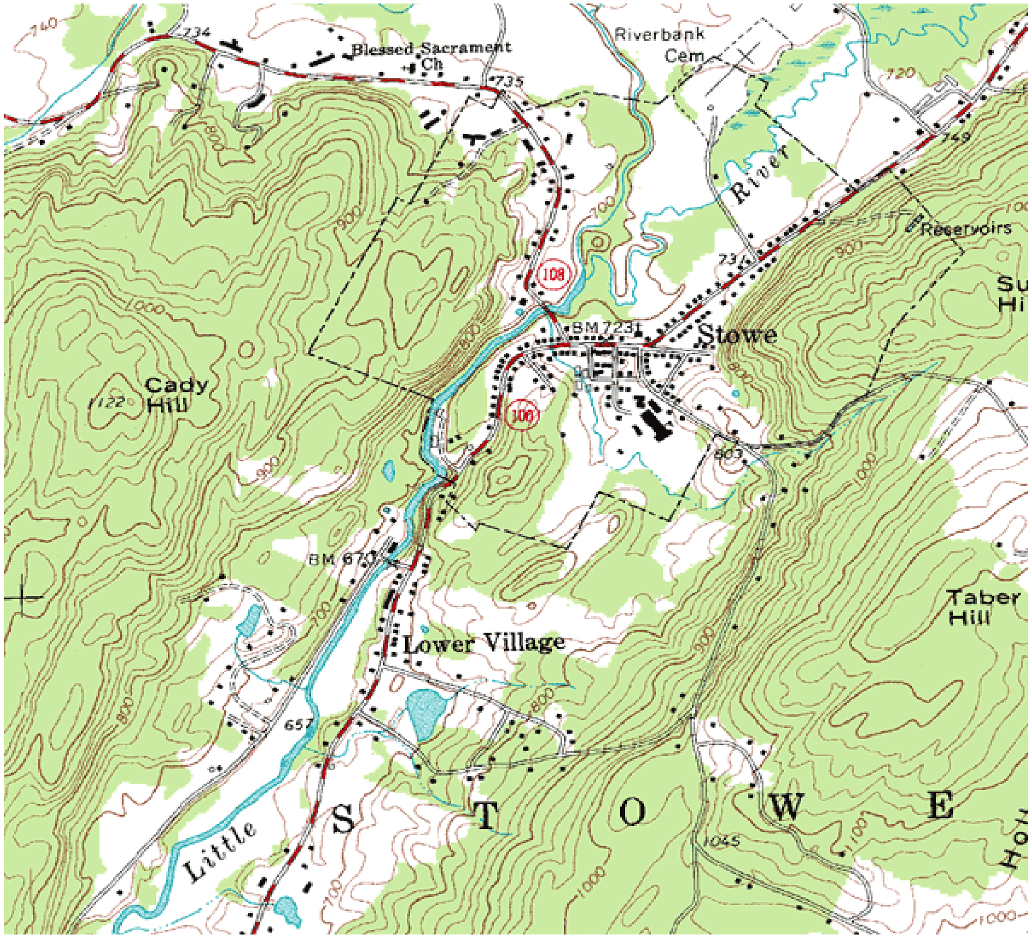


DEM ACQUISITION METHODS

Acquisition Methods	Accuracy of Data	Speed	Cost	Applications Domain
Traditional Surveying	High (cm-m)	Very Slow	Very high	Small areas
GPS survey	Relatively high (cm-m)	Slow	Relatively high	Small areas
Photogrammetry	Medium to high (cm-m	Fast	Relatively slow	Medium to large areas
Space Photogrammetry	Low to medium (m)	Very fast	Low	Large areas
InSAR	Low (m)	Very fast	Low	Large areas
Radargrmmetry	Very low (10m)	Very fast	Low	Large areas
LIDAR	High (cm)	Fast	High	Medium to large areas
Map digitization	Relatively low (m)	Slow	High	Any area size
Map scanning	Relatively low (m)	Fast	Low	Any area size

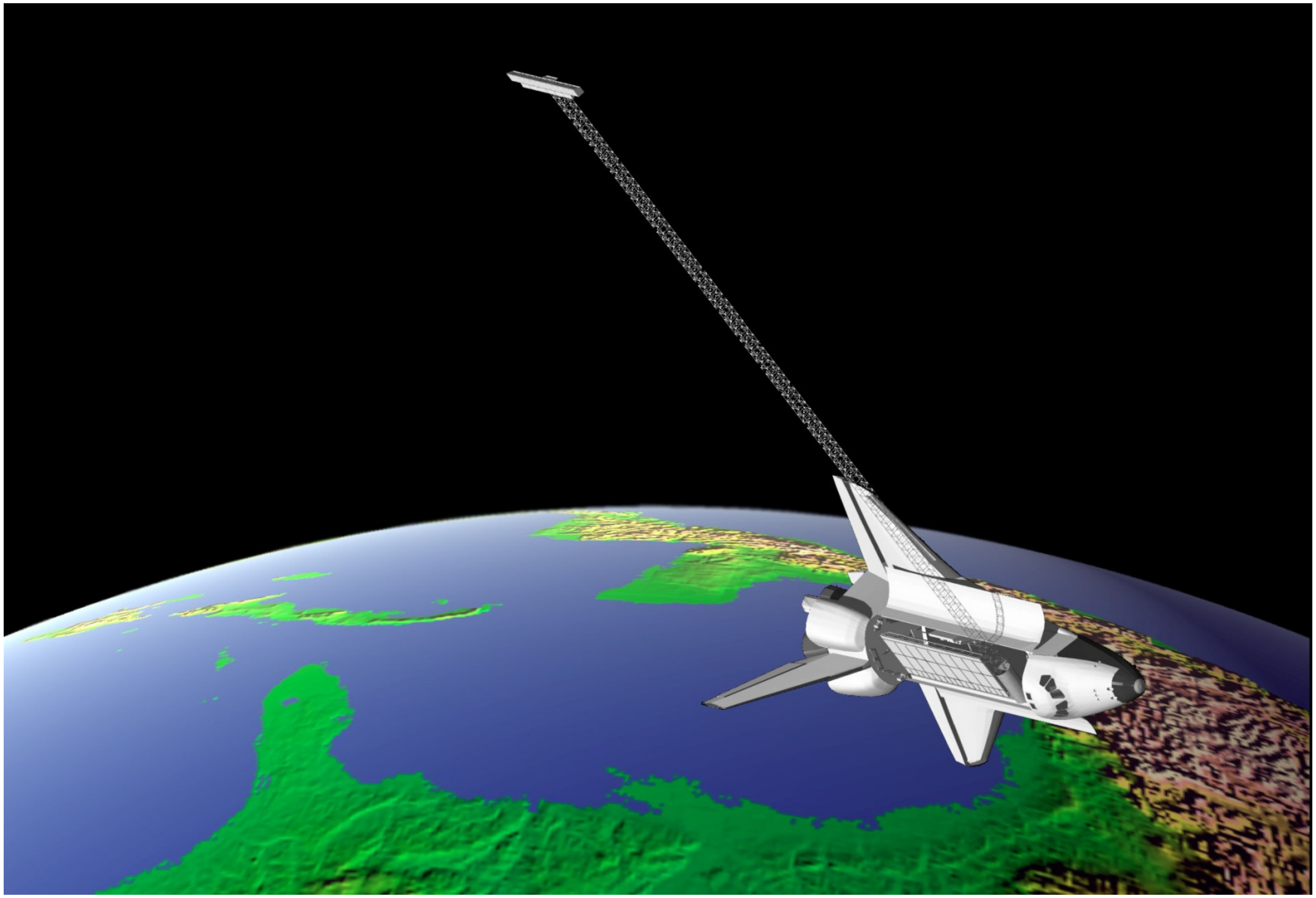
Source : Zhilin Li et. al. 2005

EXISTING MAPS



- ➢Digitisation
- ➢Scanning

SRTM

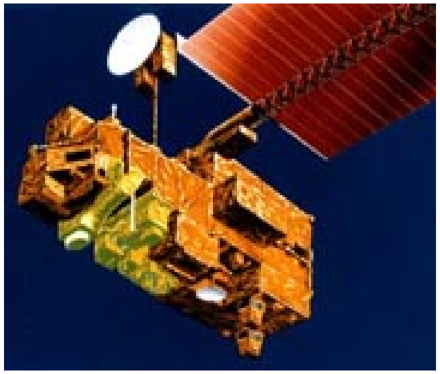


SRTM

- single-pass, across-track IFSAR to collect X-band and C-band
- To cover landmass of the Earth between 60 deg North and 56 deg south latitude
- unrestricted 3 arc-second data for entire globe (C-band)
- unrestricted 1 arc-second data for the U.S (C-band)
- X-band DEM is processed by DLR, Germany

ASTER

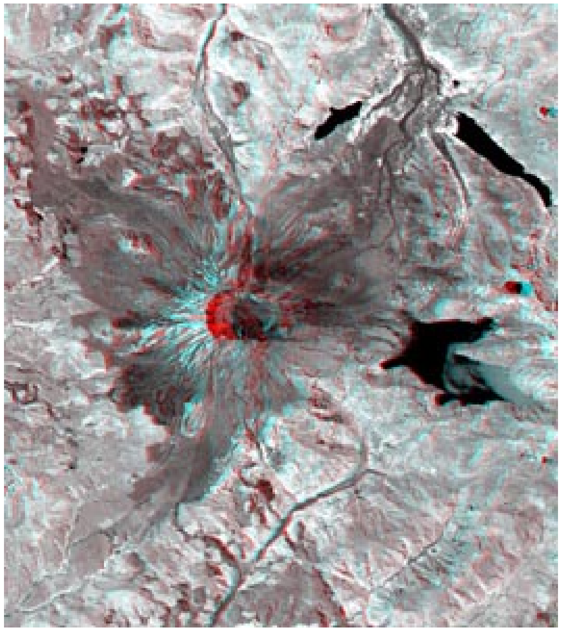
•**ASTER**=Advanced Spaceborne Thermal Emission and Reflection Radiometer
•collected from Terra spacecraft launched in 1999 as part of NASA's Earth Observing System (EOS)
•Obtains multispectral image (extract data on surface temperature, emissivity, reflectance and elevation)



varying spectral ranges (VNIR, SWIR,TIR)

•VNIR Band 3N and 3B (nadir- and backward-looking) creates stereo pair to find height

•VNIR instrument data recorded at 15m resolution



DEM Sources

Ground Surveys,

Contours from existing topographical maps

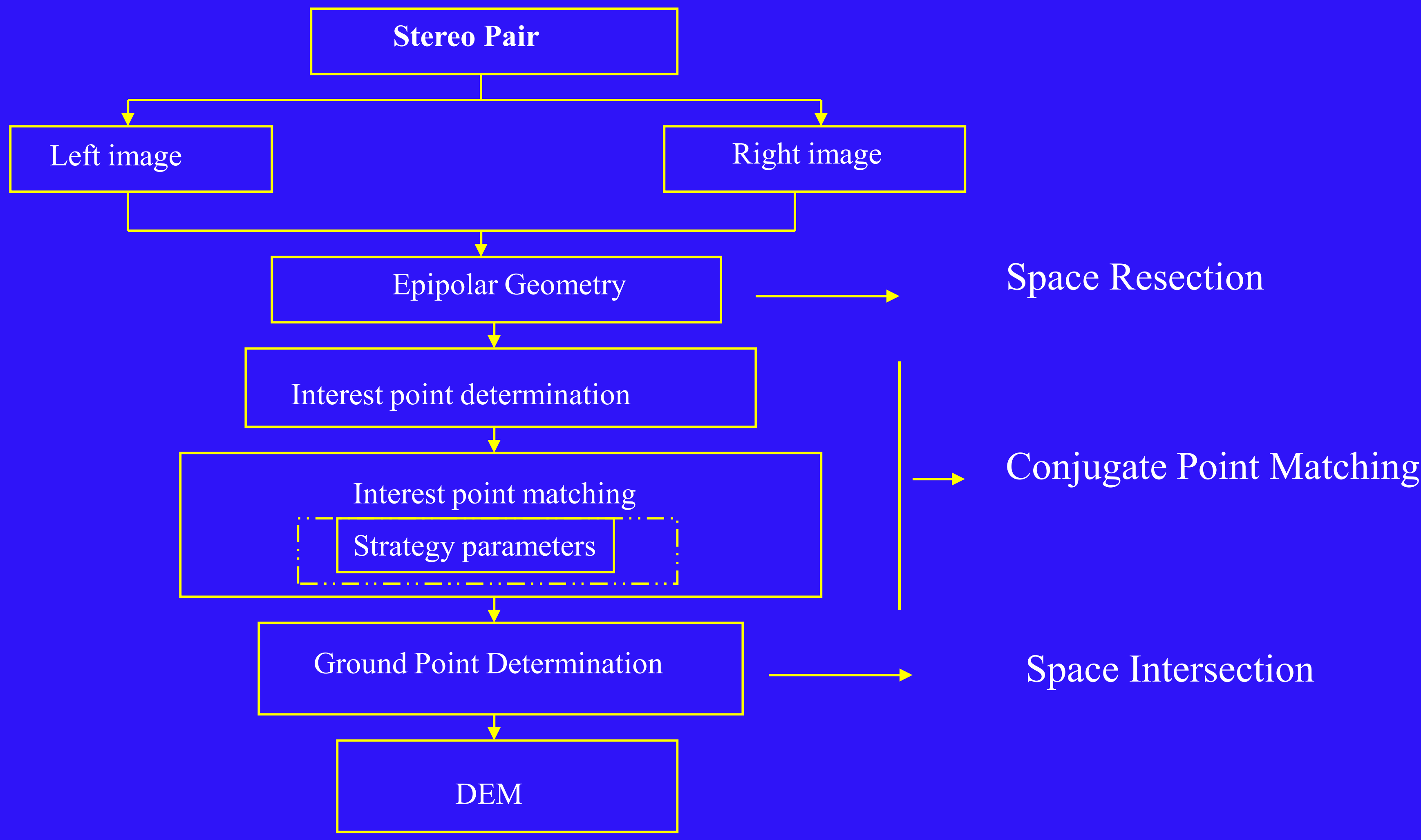
Aerial /Satellite Photogrammetriy

Lidar Technology,

Space borne Stereo data

Interferometer techniques

DEM Generation using Photogrammetric techniques



Space Resection (collinearity condition)

Defines the relationship between space, Image and object coordinate system

Collinearity condition states that camera position, image point,

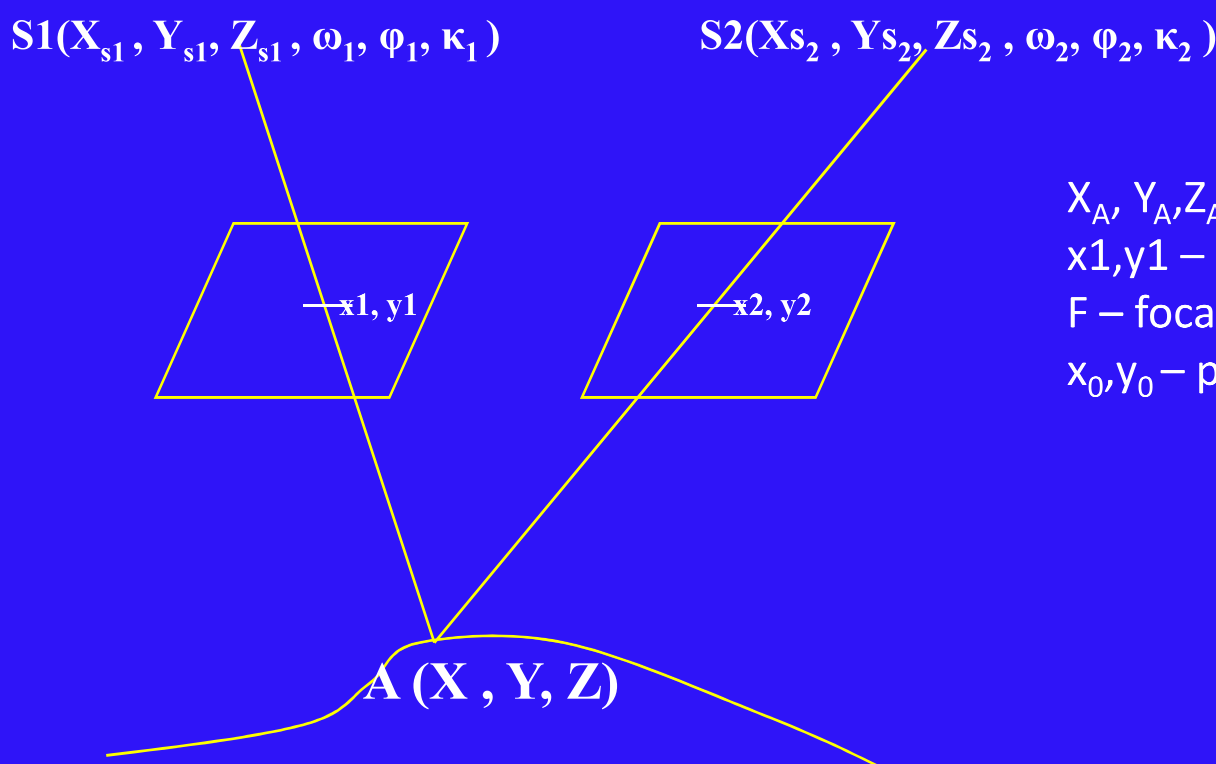
Object point lie in a straight line.

The position of Image defined by (Xs , Ys , Zs)
Three rotations angles (row (ω), pitch (φ), and yaw (κ)) defines the angular orientation (Attitude parameters)

The exterior orientation parameters defined by (Xs , Ys , Zs, ω, φ, κ)

$$x1 - x_o = \frac{-f\,[\,m_{11}(X_A - X_{s1}] + m_{12}(Y_A - Y_{s1}) + m_{13}(Z_A - Z_{s1})]}{[\,m_{31}(X_A - X_{s1}] + m_{32}(Y_A - Y_{s1}) + m_{33}(Z_A - Z_{s1})]}$$

$$y1 - y_o = \frac{-f\,[\,m_{21}(X_A - X_{s1}] + m_{22}(Y_A - Ys1) + m_{23}(Z_A - Z_{s1})]}{[m_{31}(X_A - X_{s1}] + m_{32}(Y_A - Y_{s1}) + m_{33}(Z_A - Z_{s1})]}$$



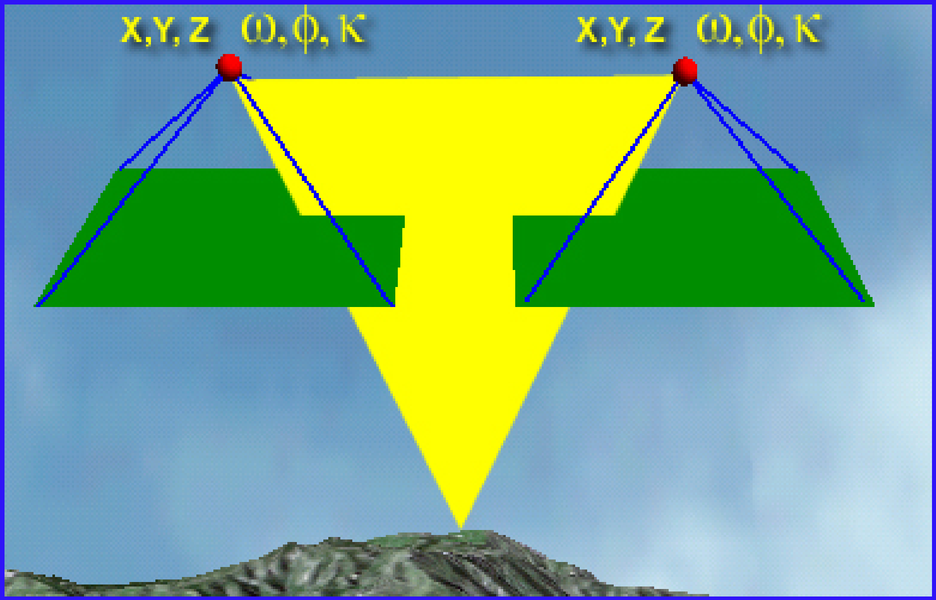
X_A, Y_A,Z_A – ground coordinates

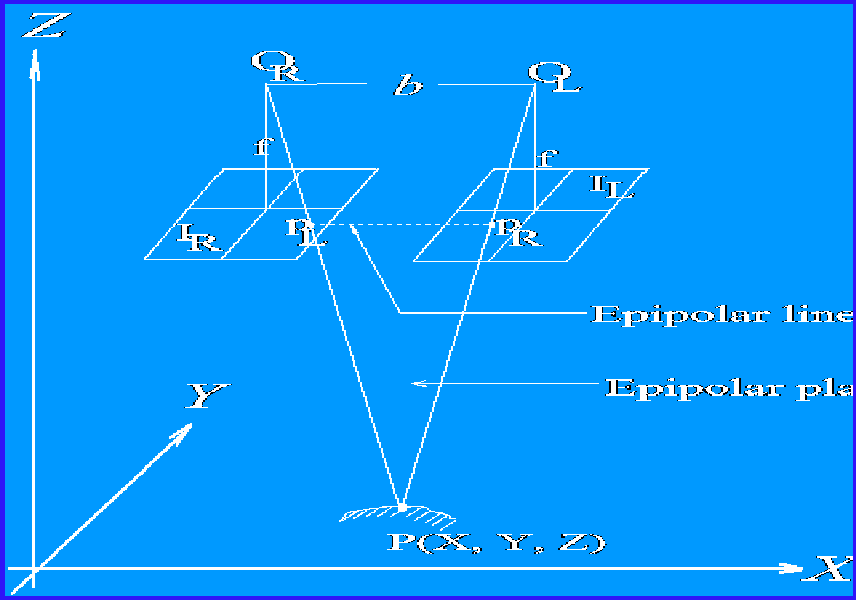
x1,y1 – image coordinates

F – focal length

x_0,y_0 – p.p coordinates

- The Epipolar plane concept constrains the search area
- The plane formed between two perspective centers and a ground feature





Measurement of Elevation

Conjugate Point Matching

Fundamental process in photogrammetry is to identify and measure

Conjugate points in two or more overlapping images

--interactive method

--Automatic method

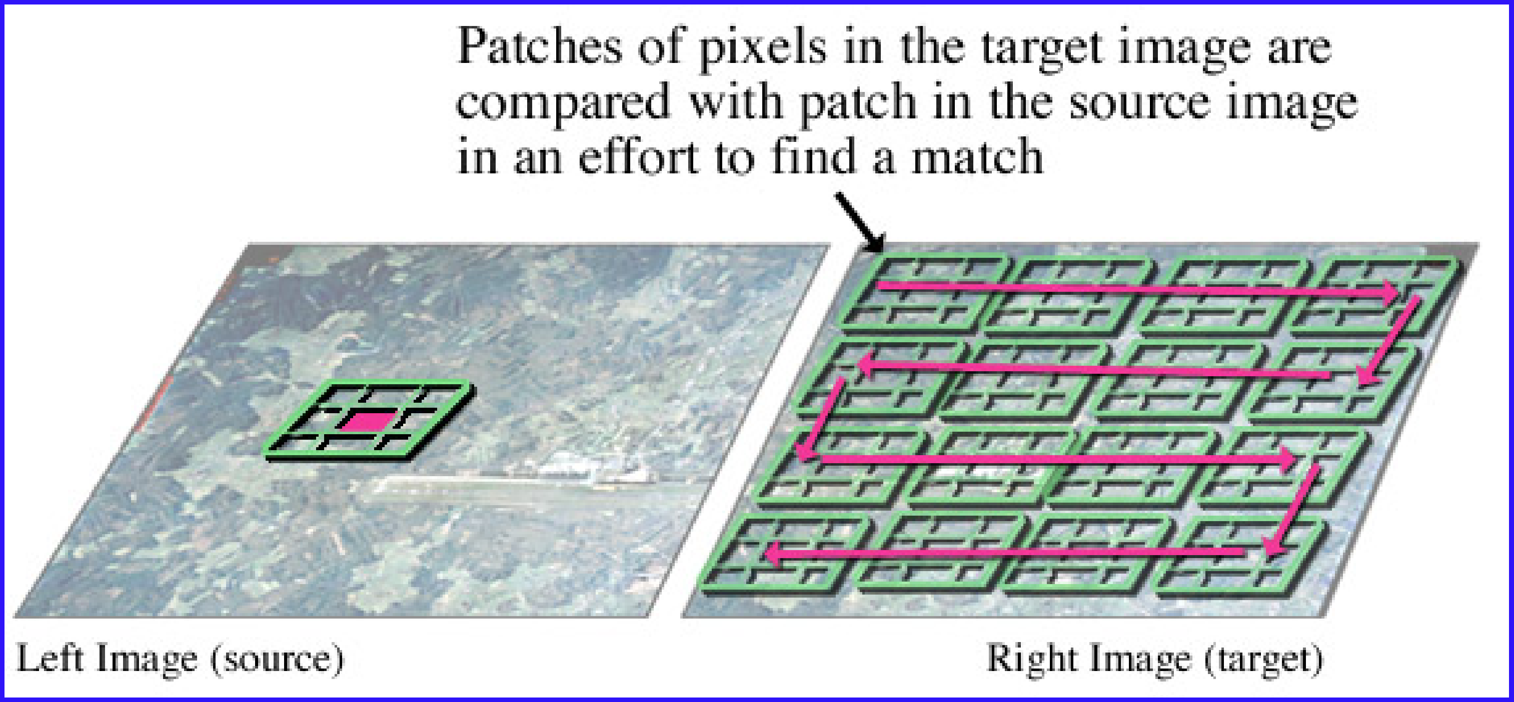


Image Matching Techniques

Area based matching techniques :

- Determines Correspondence between two image areas according to grey level Values

- Reference window is the source window on the first image, which remains at a Constant location. Search windows are candid windows on the second image that Are evaluated relative to the reference window.

Feature based matching techniques:

- The features used as matching entities .

- In digital photogrammetry, interest points are most often used

Space Intersection (Determination of 3D Ground coordinates)

Procedure of computing the ground coordinates from a pair of over lapping images

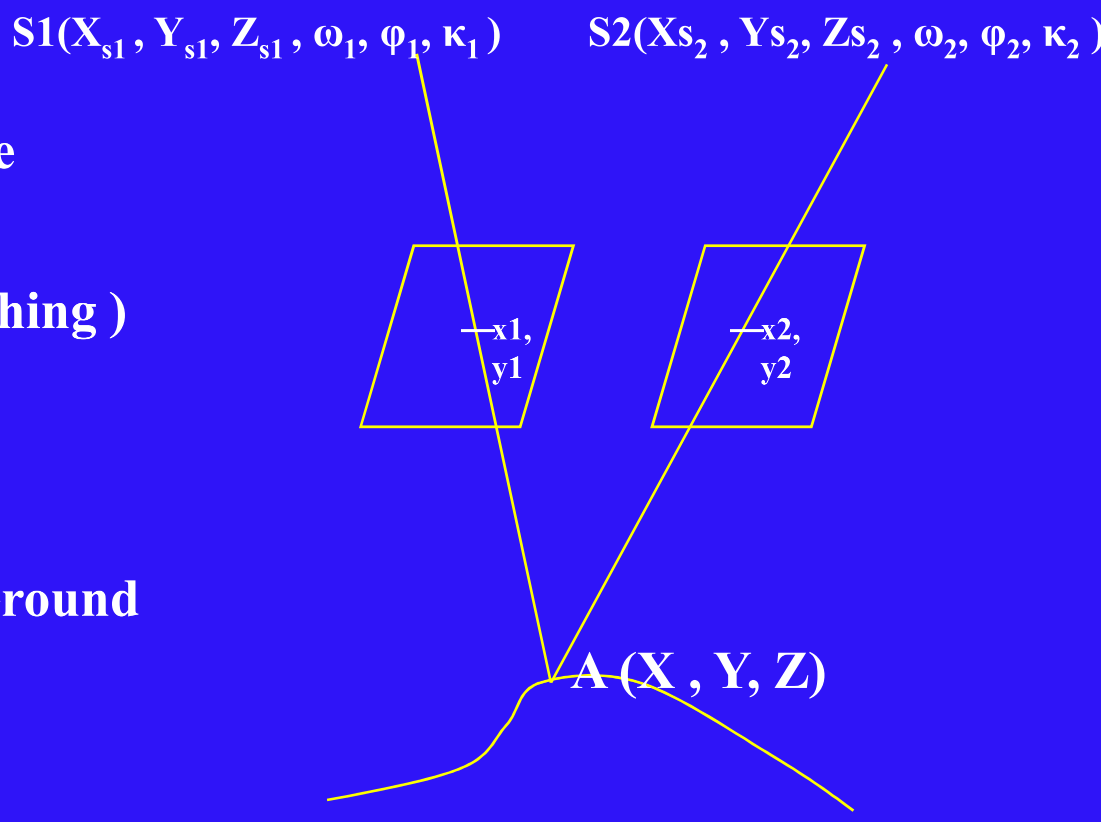
Inputs

Orientation Parameters (Space Resection)

Conjugate points (Image matching)

Outputs

Irregular distribution of 3-d Ground coordinates (X,Y,Z)



Regular DEM Generation:

Various Interpolation techniques can be applied to generate regular DEM from set of irregular points

Weighted Average Method:

With in a neighborhood of point with unknown z-value, closer to the point in question influence more compared to point farther apart.

weights are assigned to all neighborhood points as inverse function of the distance

$$Z = \sum_{j=1}^{n} w_j Z_j \qquad \sum w_j = 1$$

$$W_j = d(ij)^{-2} / \sum d(ij)^{-2}$$

d(ij)- distance between point in question i and neighborhood point j

$n = 6$ to 8

AERIAL SURVEY

- Aerial Services & Digital Mapping Area (ASDM) of NRSC-ISRO is an unique facility with end-to-end state-of-the-art infrastructure and capability in the domain of Aerial photography and Airbone LIDAR from data acquisition , data processing, product generation

- Two Super King Air B200 aircraft
- Flying altitude 35000ft
- Max.speed: 220kts
- Endurance: 4hr + diversion reserves

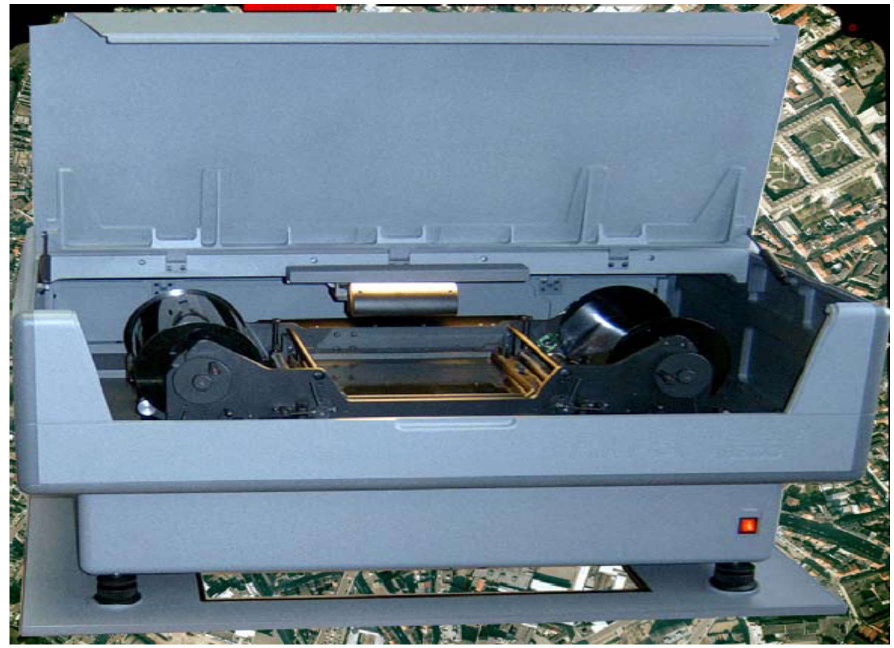
Sensors :

Aerial Film Camera
Aeriai Digital Camera – 2 No.s
Airborne Lidar Sensor- 2 No.s
Synthetic Aperture Radar- DMAR (C- band), developed by SAC-ISRO, Ahmedabad

ANALOG AERIAL CAMERA

Focal length - 305 mm
Field of View - 56^0

High Precision Photogrammetric Scanner



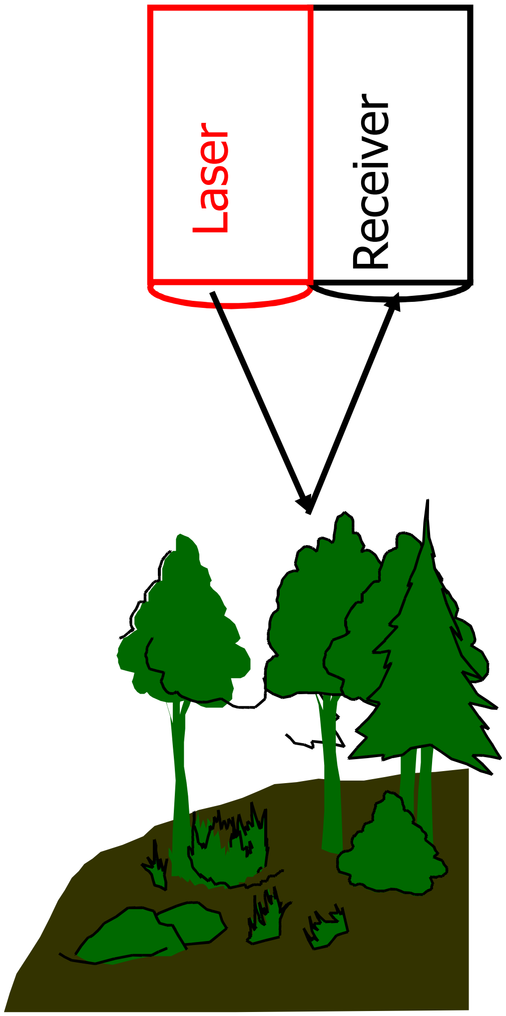
convert Film data acquired with Analog Film Camera to Digital Images

Airborne Digital Camera @ NRSC

Specification	UltraCam D	UltraCam Eagle
Format Size	PAN: 11,500 X 7,500 MS: 3,680 X 2,400	PAN: 20,010 X 13,080 MS: 6,670 X 4,360
Format Area (PAN)	86.25 Mega pixels	261.7 Mega pixels
Focal Length (PAN)	105mm	100mm
Memory Media	Hard Drive	SSD (Hot swappable)
IMU update rate	256Hz (Aerocontrol II)	400Hz (Aerocontrol III)
Swath @ 1000m (PAN)	985.71 m	1040.52 m
GSD @ 1000m (PAN)	8.6 cm	5.2cm
Swath @ 10cm GSD	1,150 m	2,001 m
Weight	250Kgs	130Kgs

Two no. of Digital Camera s are in operational@ NRSC

Airborne Lidar Sensor for Generation of high resolution DEM



- Works on the principle of ranging
- This is a non imaging sensor

$$R = c\frac{t}{2}$$

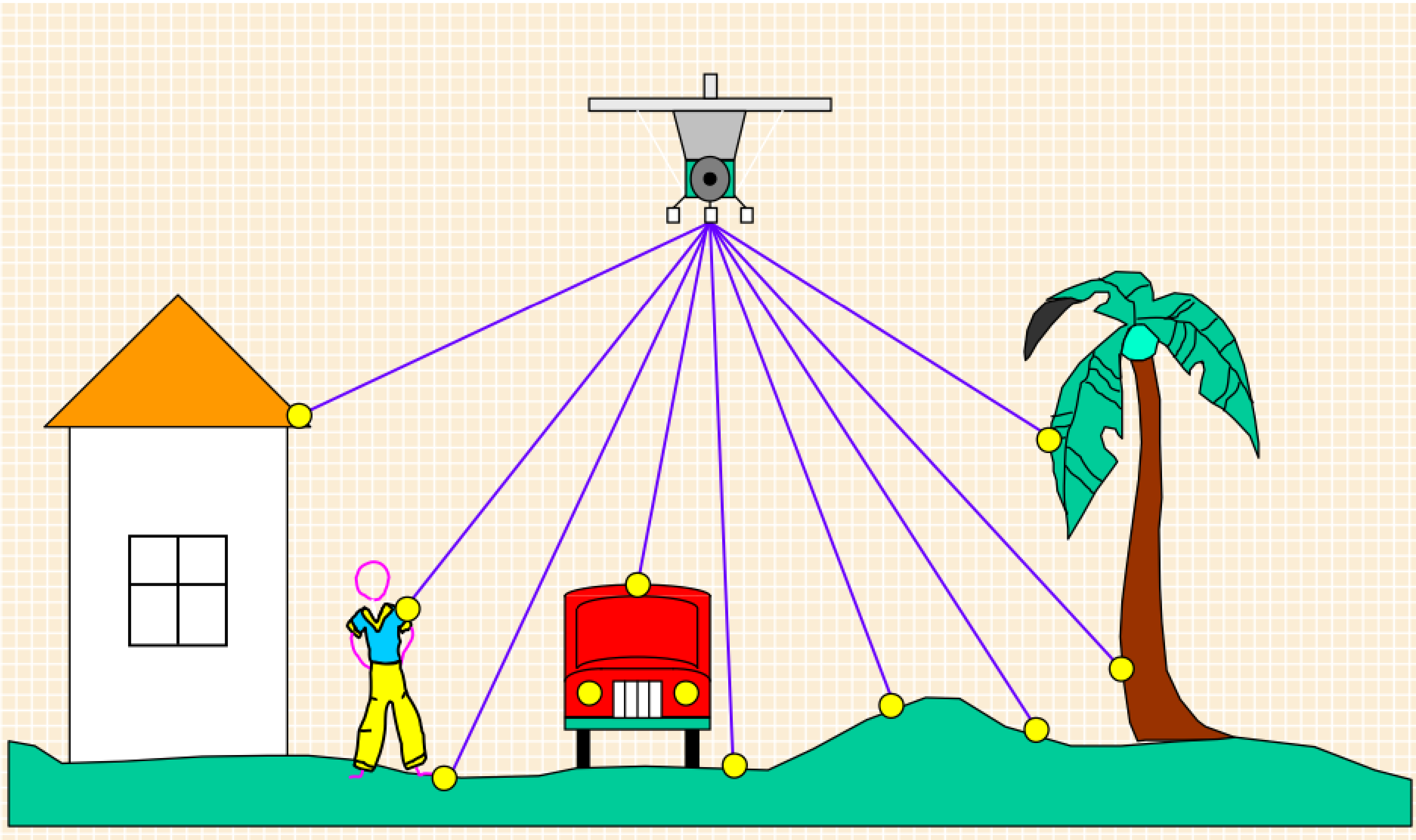
Where

R is the range in meters

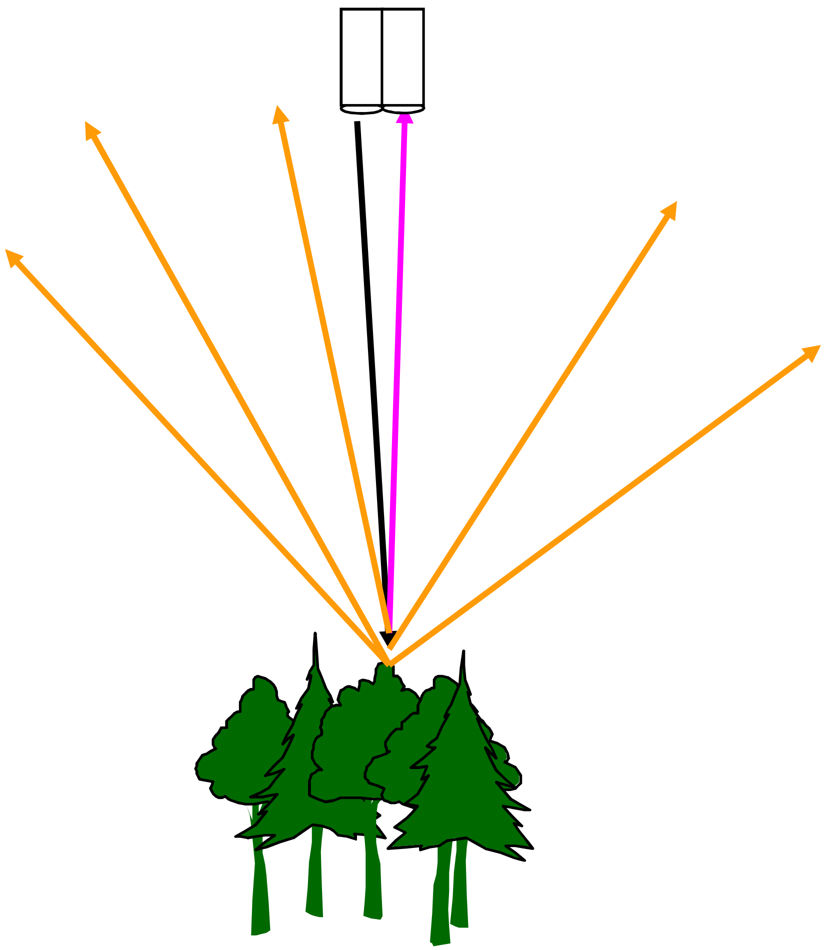
t is time in seconds

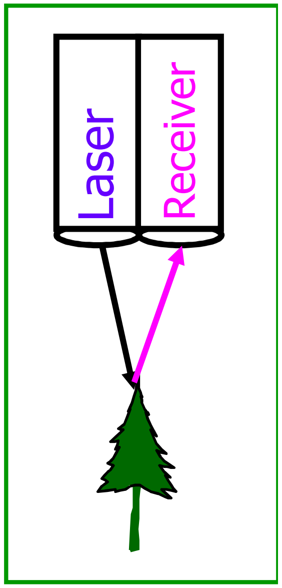
c is the speed of light in a vacuum 299,792,458 ms-1

LiDAR scanning – Line of sight



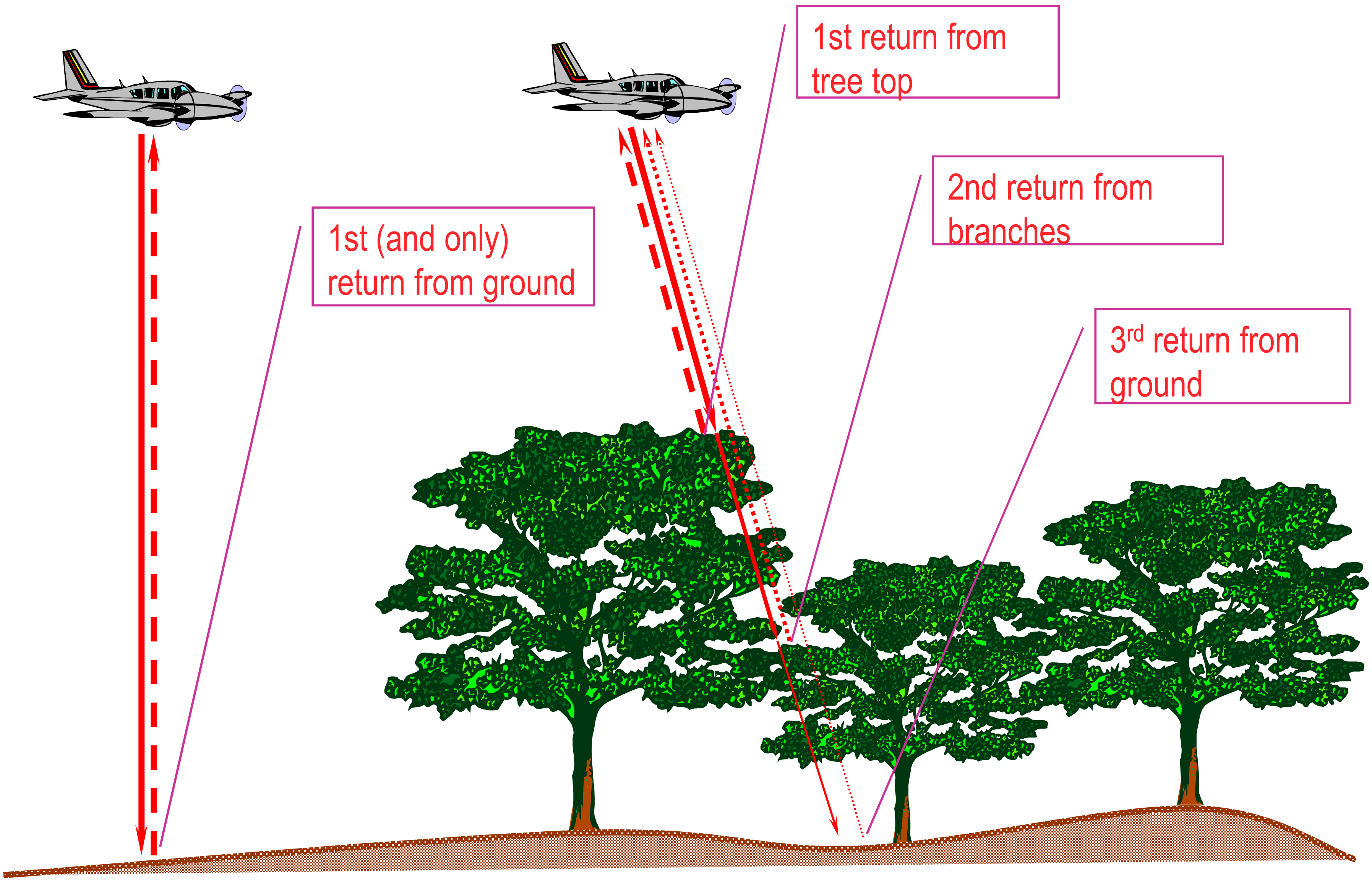
Return to the sensor





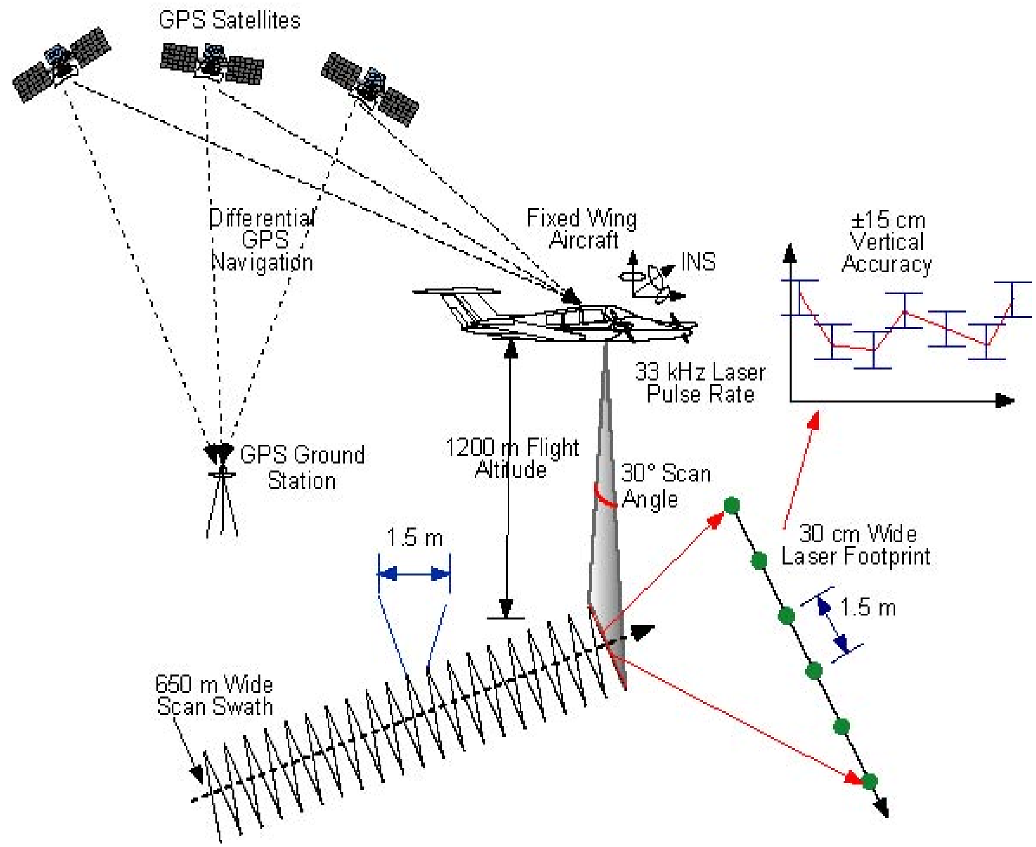
- A part of the transmitted energy only reflects back to the detector
- Other part of energy is either absorbed or scattered

Multiple-return technology



LIDAR technology

- Laser scanner mounted in aircraft emits laser beams with high frequency and receives the reflected beam.
- Time difference between emission of laser beam and reception of the reflected laser signal is recorded to get the distance (range).
- A rotating mirror facilitates scanning across the flight path
- GPS and IMU for position and orientation information

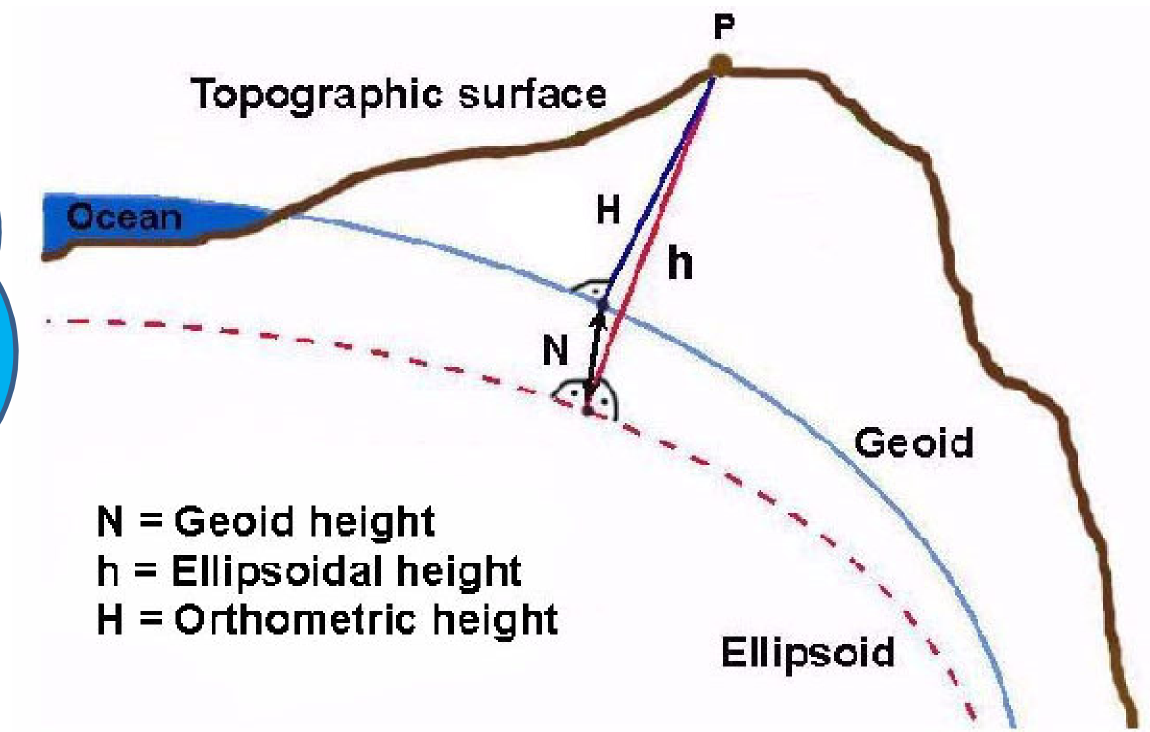


Vertical reference ?

- ‘Height’ can be depicted w.r.t two references

  - WGS84 – Ellipsoid (Mathematical surface)
  - MSL – Geiod (gravity dependent)

Difference
-100 to 70m



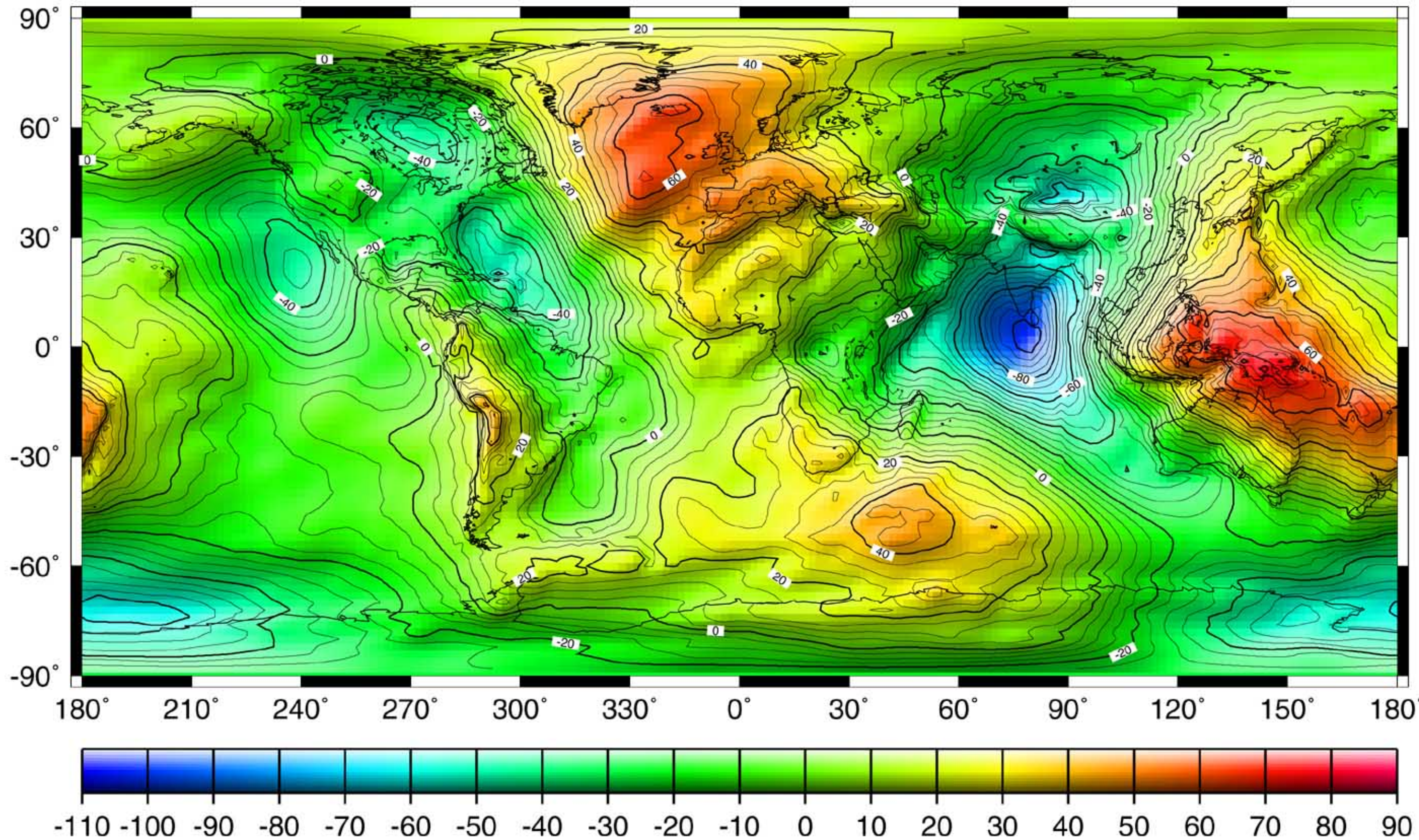
- Elevation: location of object from reference surface

- Level: relative location of objects from reference surface(difference of elevation)

- Topographic elevation: elevation of objects on earth

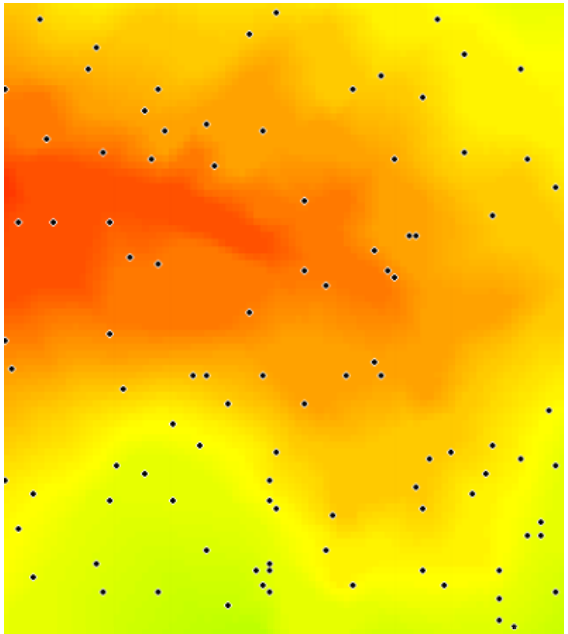
EGM-96 Geoid

to degree & order 180

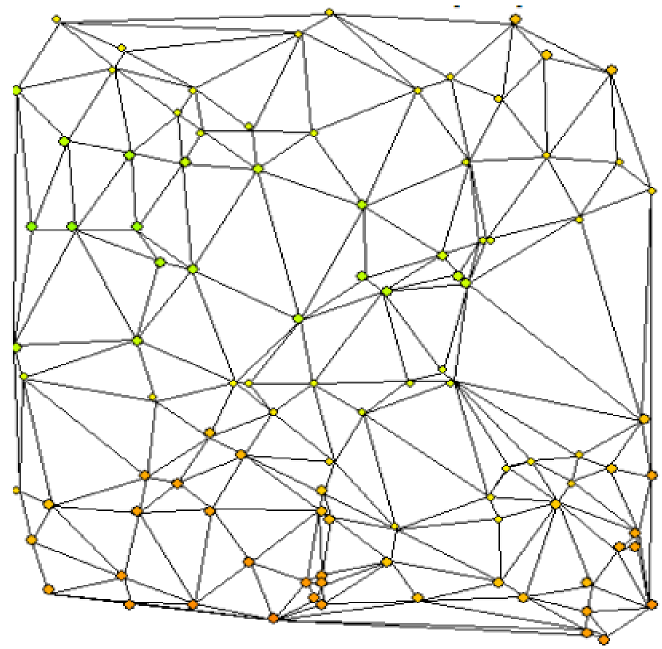


DEM Data Structures

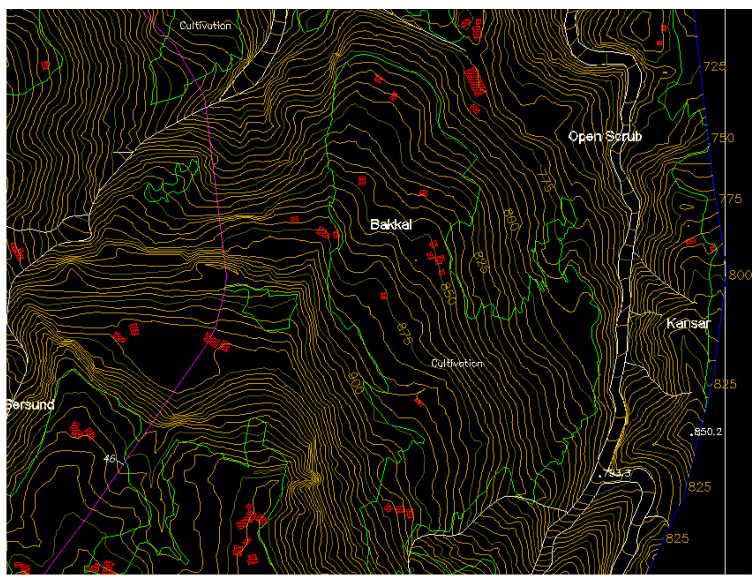
- Grid (regular)
- TIN
- Contours



Grid

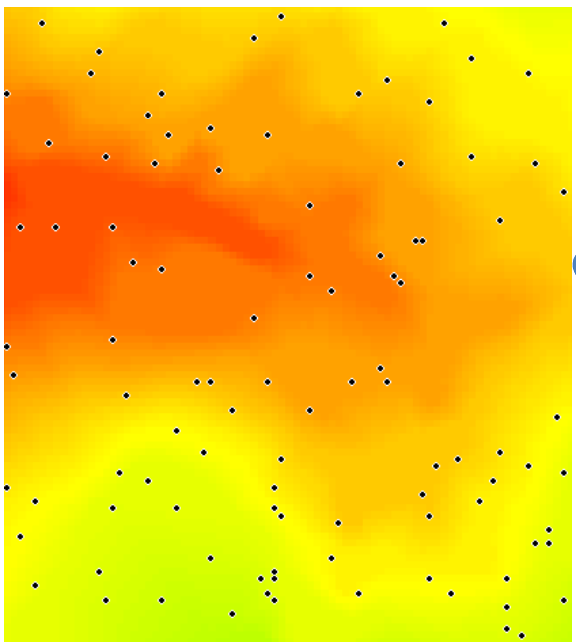


TIN

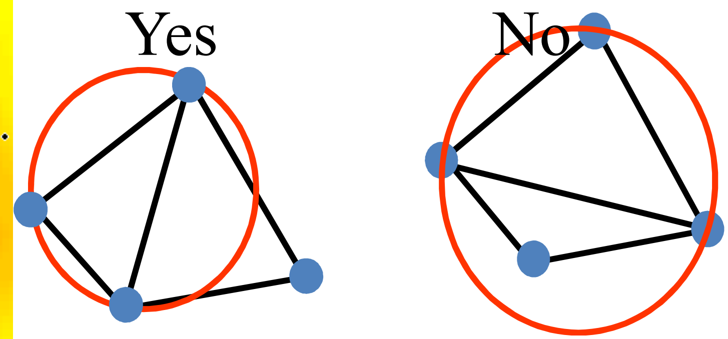


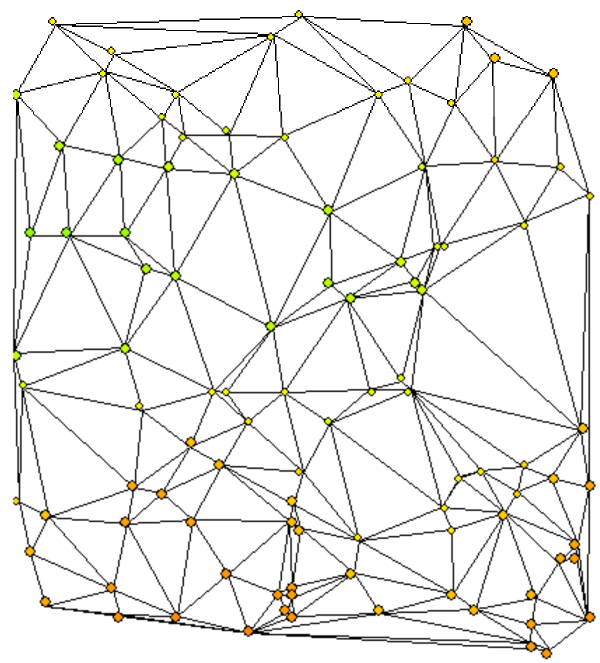
Contours

Triangulated Irregular Network



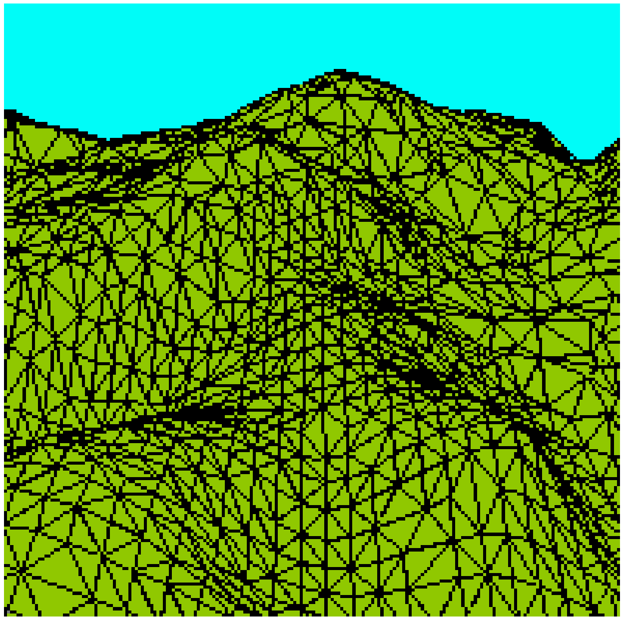
DEM with sample points

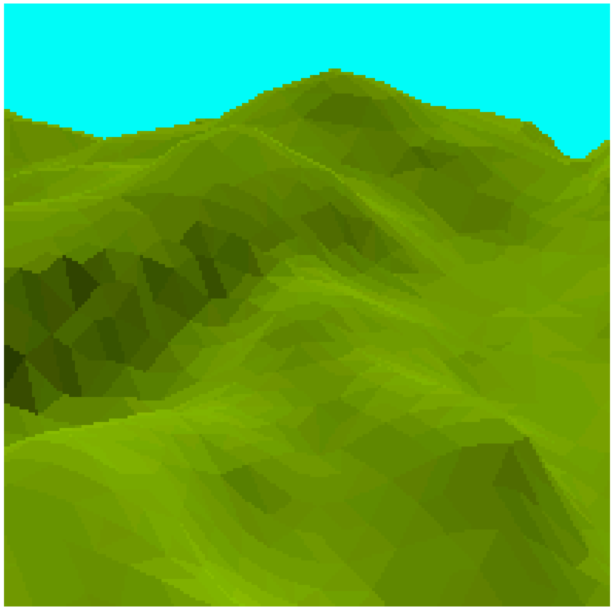




TIN based on same sample points

TINs





Example of a TIN based on irregularly distributed data

DEM Vs TIN

Digital Elevation Model (DEM)

Advantages

- Simple Conceptual Model
- Easy to relate to Other Raster data
- Irregularly spaced set of points can be converted to
- regular spacing by interpolation

Disadvantages

- Does not conform to variability Of Terrain
- Linear features are not well represented

TIN Model

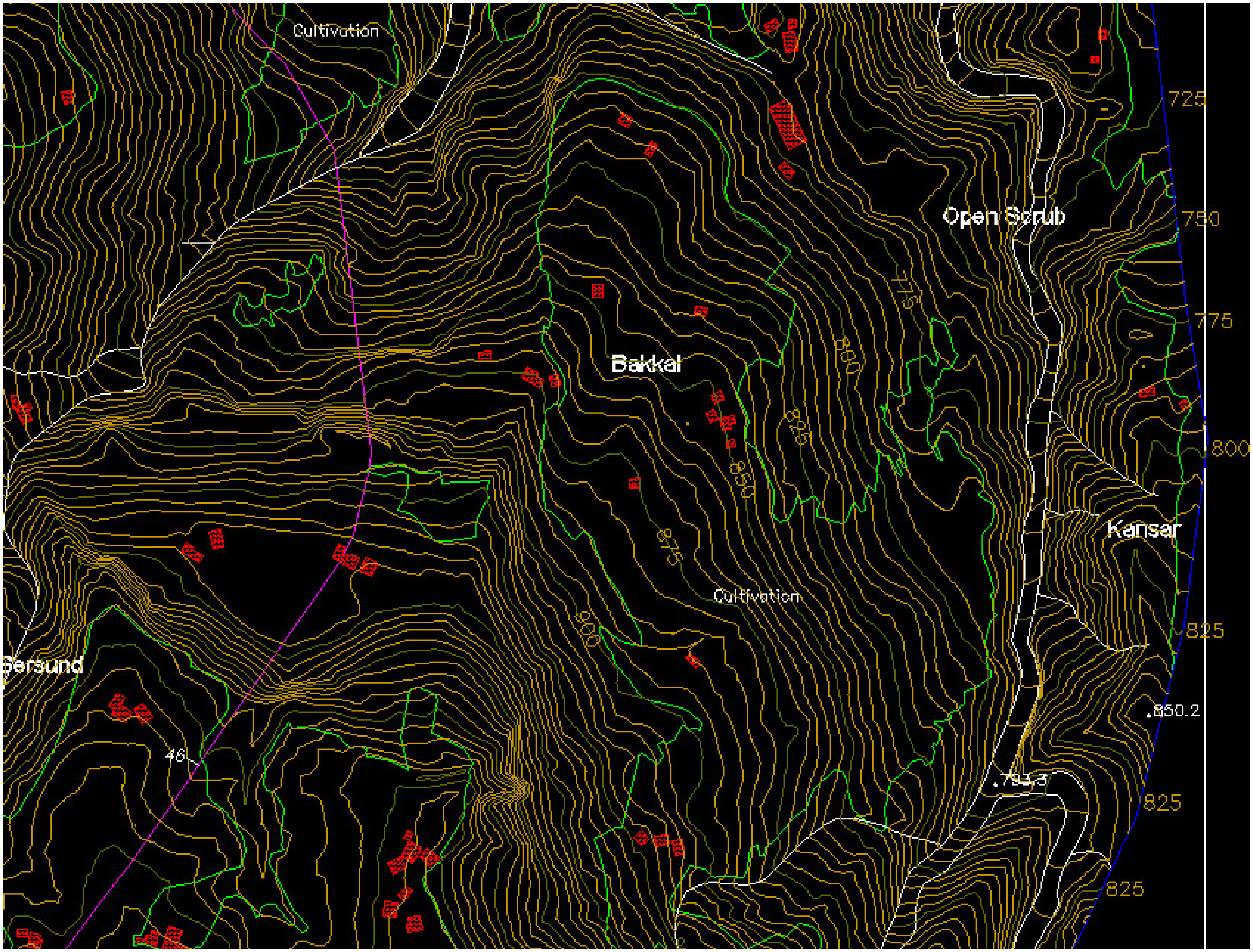
Advantages

- Can capture significant slope features (ridges, etc)
- Efficient, since require few triangles in flat area

Disadvantages

- Analysis involving
- comparison with other layers difficult

Contours


Cultivation
725
Open Scrub
750
775
Bakkal
800
825
850
Kansar
875
Cultivation
900
825
Gersund
.850.2
46
.793.3
825
825

Accuracy of a DEM

Depends on

- Source data
- Acquisition method
- Point spacing

Validation of DEM

Validation of DEM is carried by measuring the elevations of Independent Checkpoints (ICP) on DEM and ground.

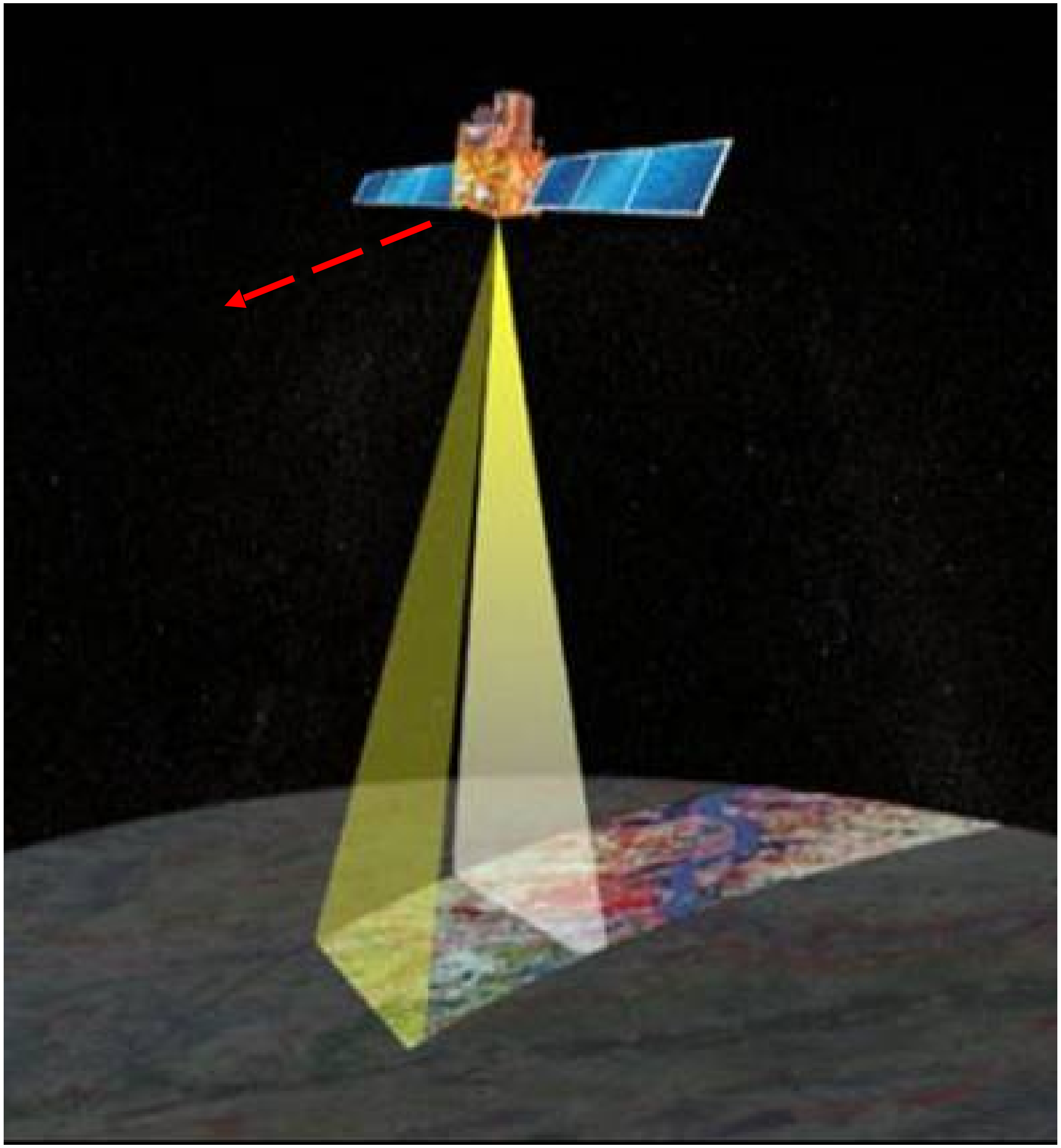
Root Mean Square Error (RMSE)

$$\text{RMSE} = \sqrt{\frac{\sum e_i^2}{n}}$$

$$e_i = Z\ \text{measured} - Z\ \text{ground}$$

Quality of DEM data depends upon:-–Terrain roughness –Data Capturing Source (Ex.- Satellite)–Sampling density (elevation data collection method) –Grid resolution or pixel size –Interpolation algorithm

Cartosat-1 Satellite (In track Stereo)



- < 2.5 m resolution
- Two Pan cameras - fore with 26 deg. and aft with -5 deg. Tilt(500 nm-850 nm)
- Swath 27.5 km for stereo and 55 km for monoscopic mode.
- 8 km overlap between adjacent paths
- 10 bits
- Facility for across track tilt to give better revisit

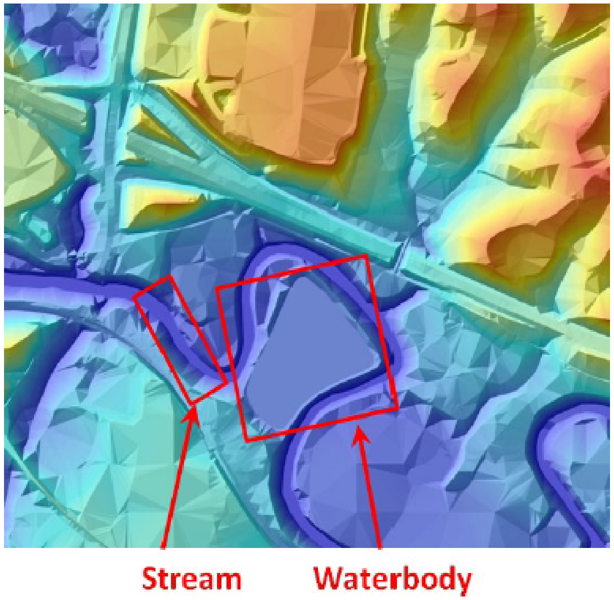


Figure 2: Traditional photogrammetric DTM.

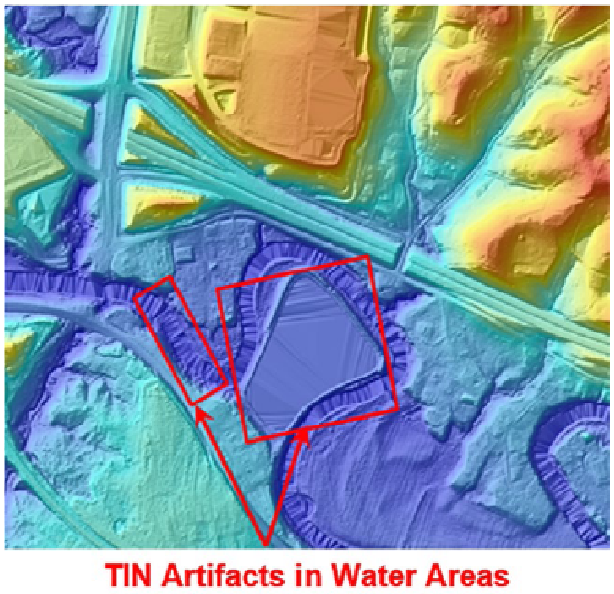


Figure 3: Pure lidar DTM without breaklines.

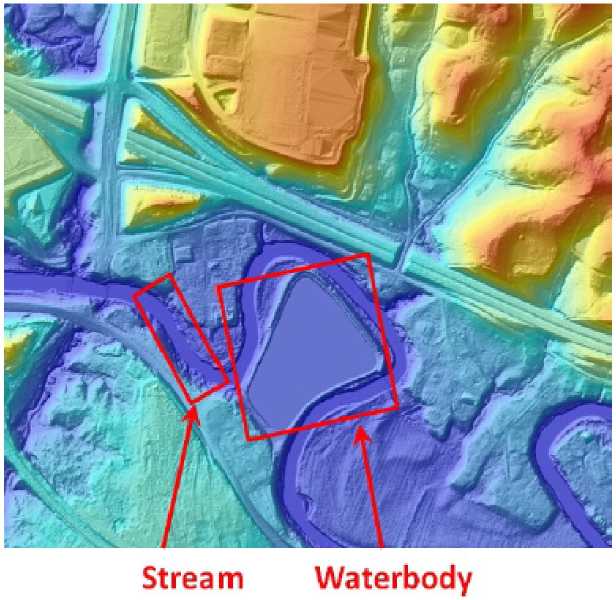


Figure 4: Hydro-flattened lidar DTM.

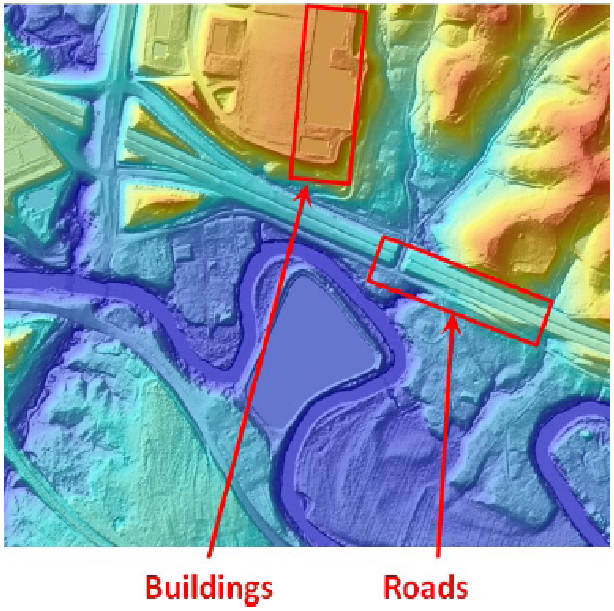


Figure 5: Lidar DTM with more breaklines.

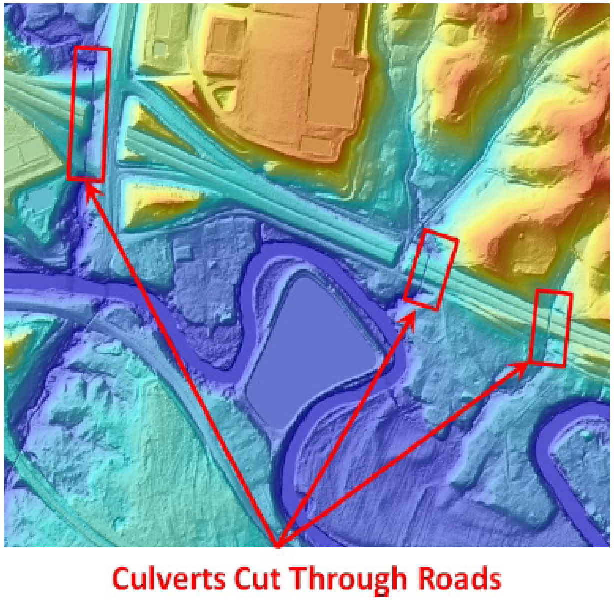


Figure 6: Hydro-enforced hydrologic surface.

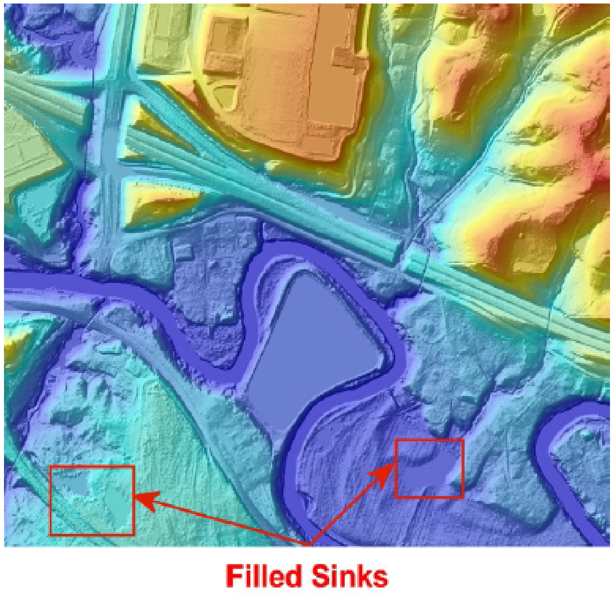


Figure 7: Hydro-conditioned hydrologic surface.

DEM APPLICATIONS

The importance and need of Digital Terrain Models

Digital Terrain Models are used in number of applications in the earth, environment and Engineering sciences

- **Civil Engineering : Cut and fill problems with road design, site planning**
- **Earth sciences : Modelling, analysis and interpretation of terrain morphology**
- **HYDROLOGICAL ENGINEERING**
- **Planning and resource management**
- **Surveying and Photogrammetry**
- **Military applications : Intervisibility analysis and Military applications**

Morphological attributes

- Elevation
- Slope
- Aspect
- curvature

Slope and aspect

- **Slope determines steepness & critical for resource managers (erosion & landslides assessment,) and land use planners (residential, roads, mountain sports, etc)**

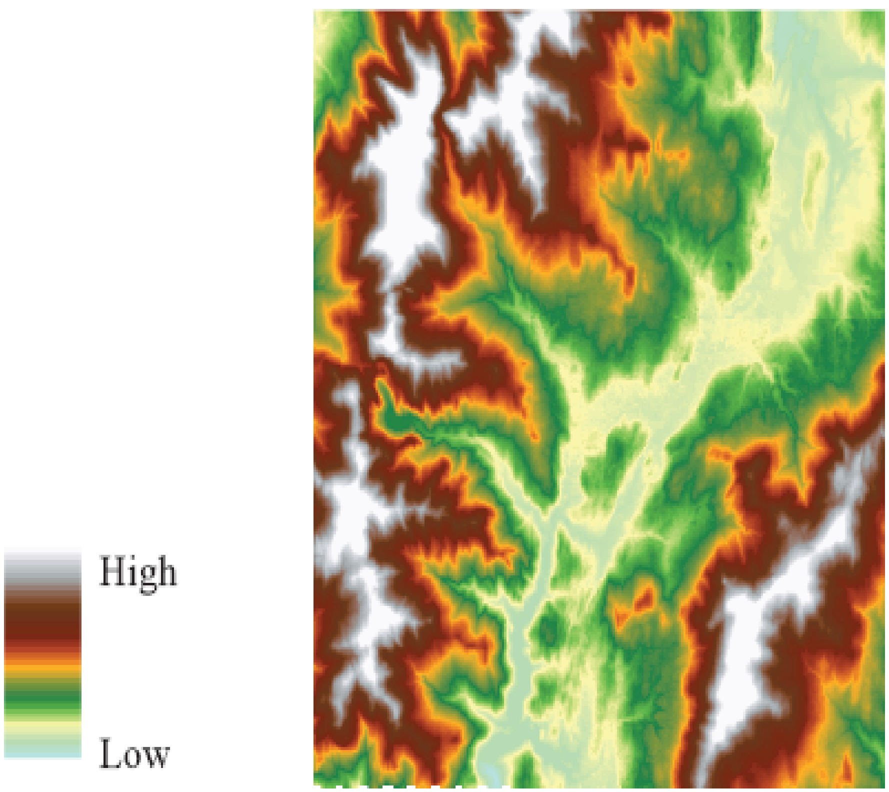
- **Aspect is the direction to which the slope faces (N,E,S,W)**

- **Both can help in predicting direction of downhill flows (hazards)**

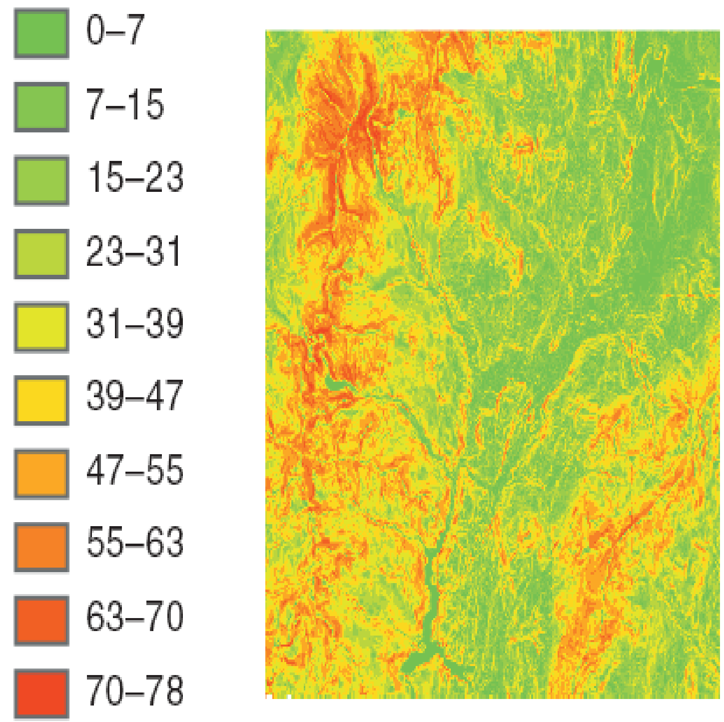
- **These analyses can only be conducted in GIS with the availability of elevation data (contours, DEM, TIN)**

- **Slope values range between 0 and 90 degrees, where 0 indicates no slope. Aspect is also measured in degrees. North is 0 degrees, east is 90 degrees, south is 180 degrees, and west is 270 degrees.**

Slope

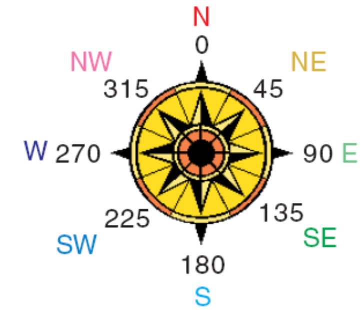


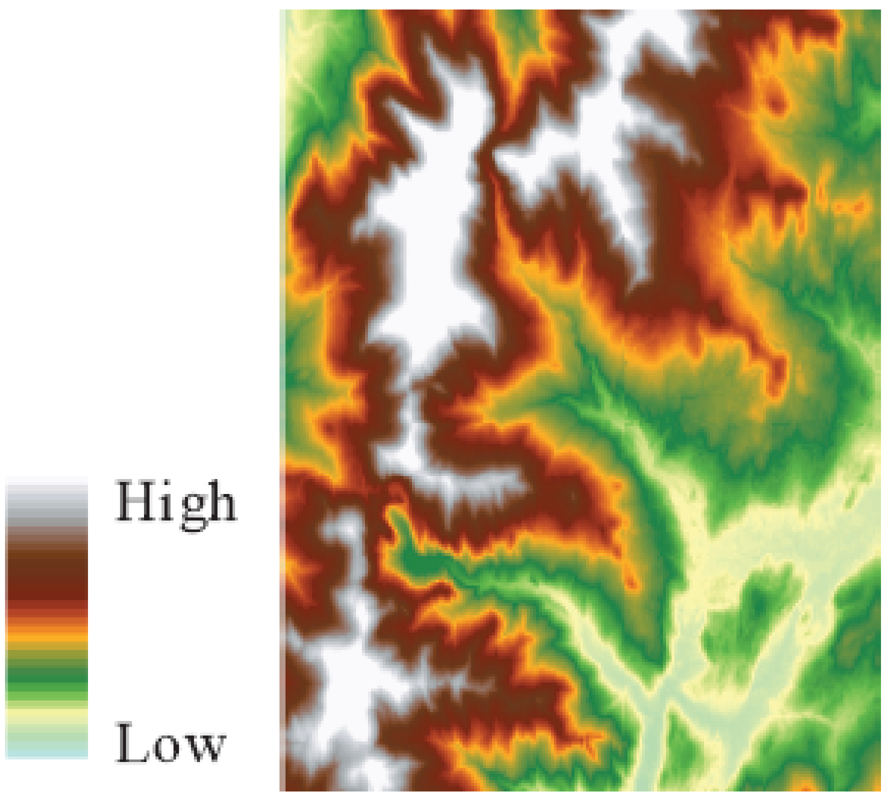
Elevation dataset

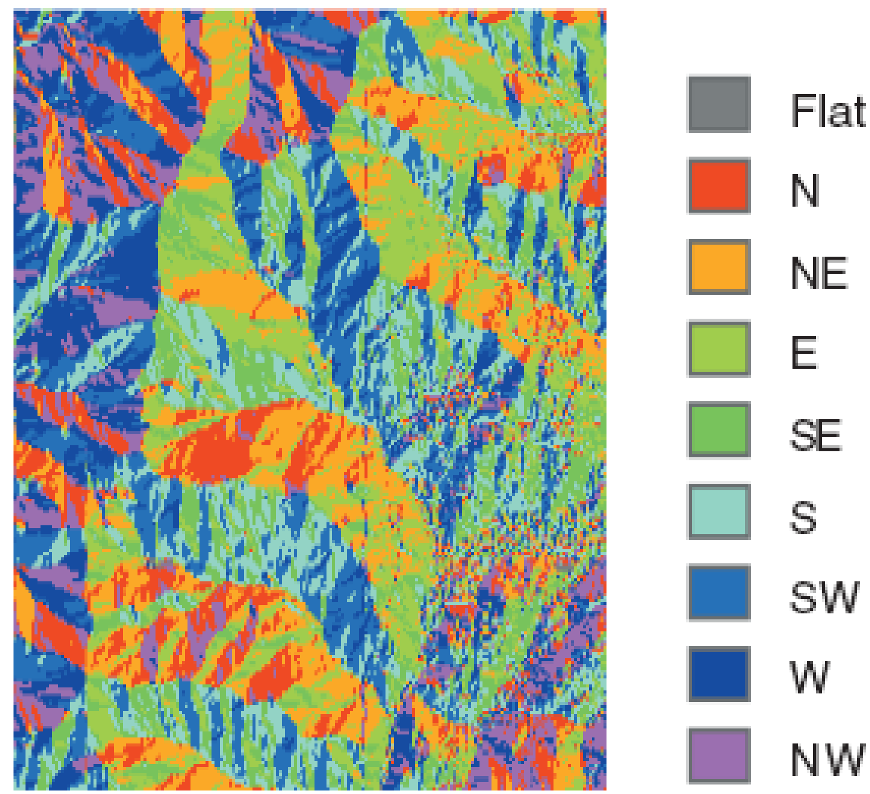


Output slope dataset
(in degrees)

Aspect

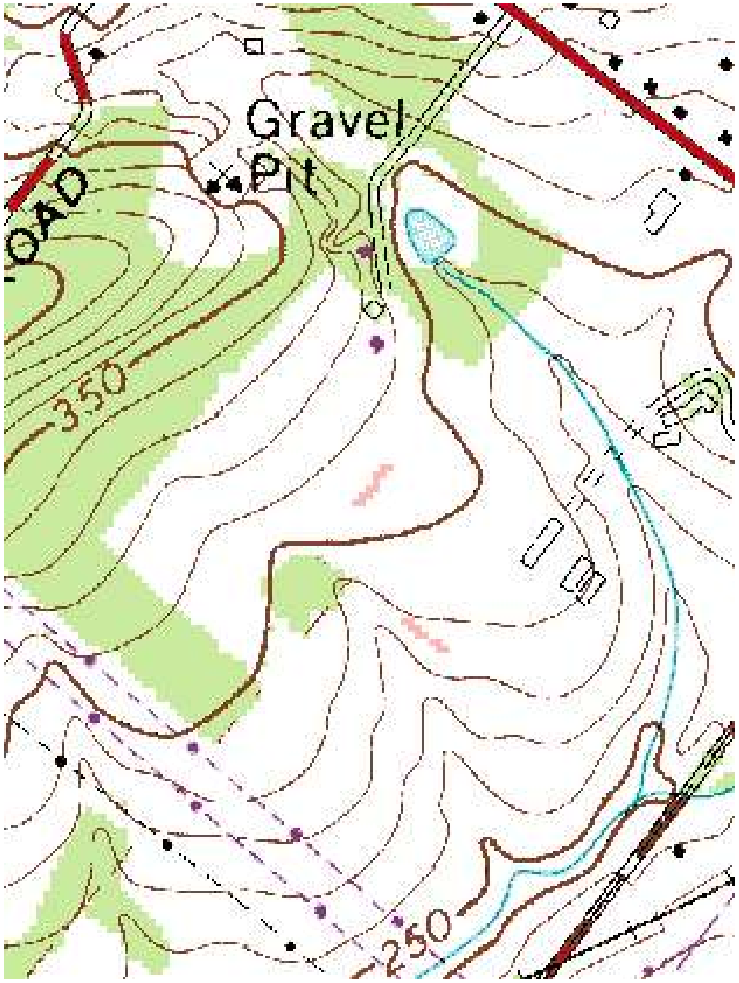

N
0
NE
45
90 E
135
SE
180
S
225
SW
W 270
315
NW


High
Low


Flat
N
NE
E
SE
S
SW
W
NW

Reading a topographic map- Streams

- The direction a streams is flowing is shown on a topographic map by the way a contour line crosses the stream.
- Streams are shown as a blue line on maps.
- When contour lines cross a stream it looks like an upside down V.



Flow direction

340	335	330
337	332	330
330	328	320

(elevations)

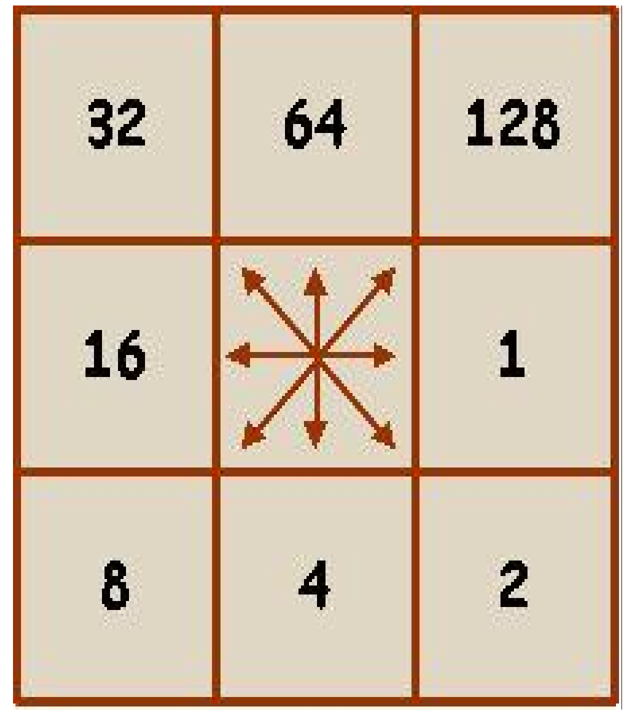
8/42.47	3/30	2/42.47
5/30	0	-2/30
-2/42.47	-2/30	-12/42.47

(difference/distance)

Flow Direction

The eight-direction pour point algorithm (D-8) assigns a flow direction code to each cell, based on the steepest downhill slope as defined by the DEM.

The flow direction code indicates the cell towards which the water flows.

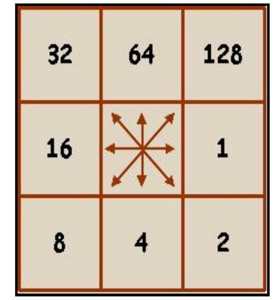


Flow direction

340	335	330	340	345
337	332	330	335	340
338	338	320	330	335
339	326	310	320	328
320	318	305	312	315

↘	↘	↓	↓	↙
→	↘	↓	↙	↓
↗	→	↘	↓	↙
↘	→	↓	↓	↓
→	→	→	↘	←

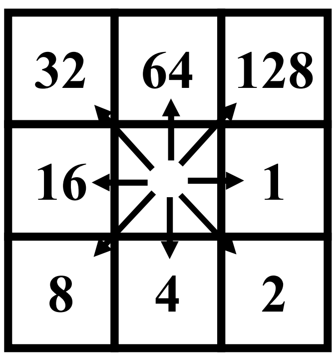
Flow Direction Grid

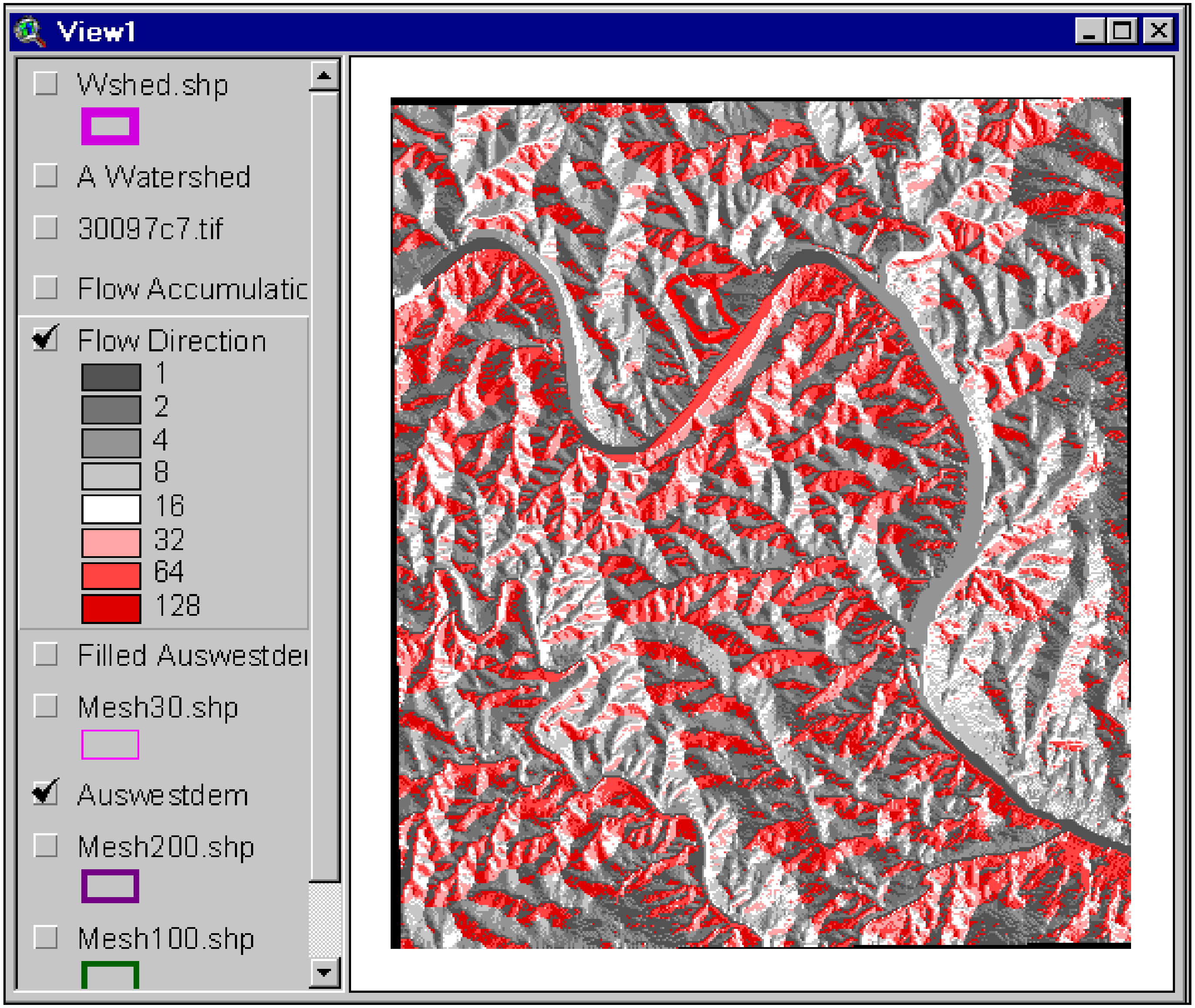


↘	↘	↓	↓	↙
→	↘	↓	↙	↓
↗	→	↘	↓	↙
↘	→	↓	↓	↓
→	→	→	↘	←

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

Flow Direction Grid

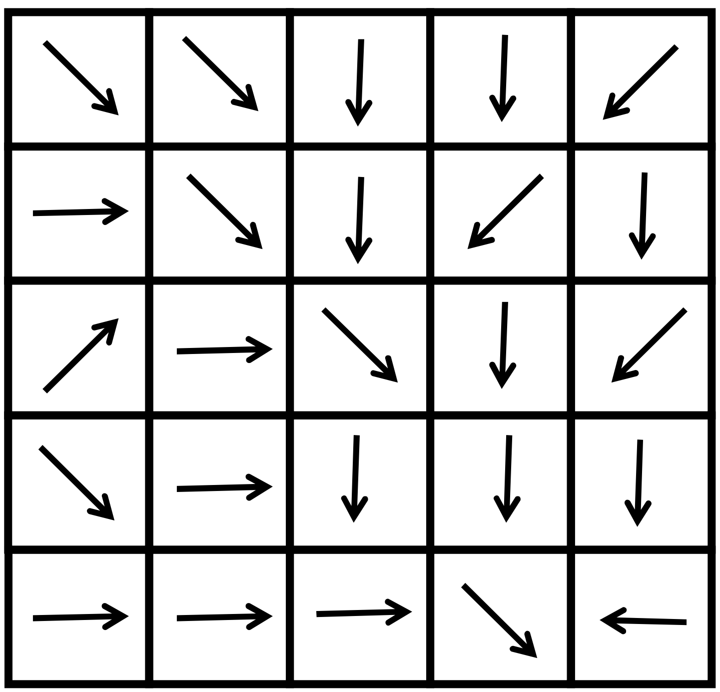


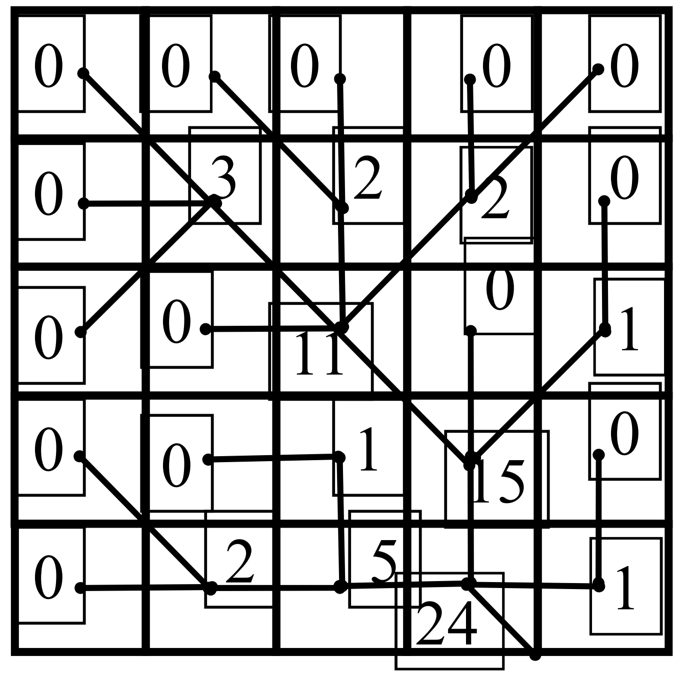


Flow Accumulation

Flow accumulation is a measure of the drainage area in units of grid cells.

The flow accumulation value of a cell is the sum of the flow accumulation values of the neighboring cells which flow into it.

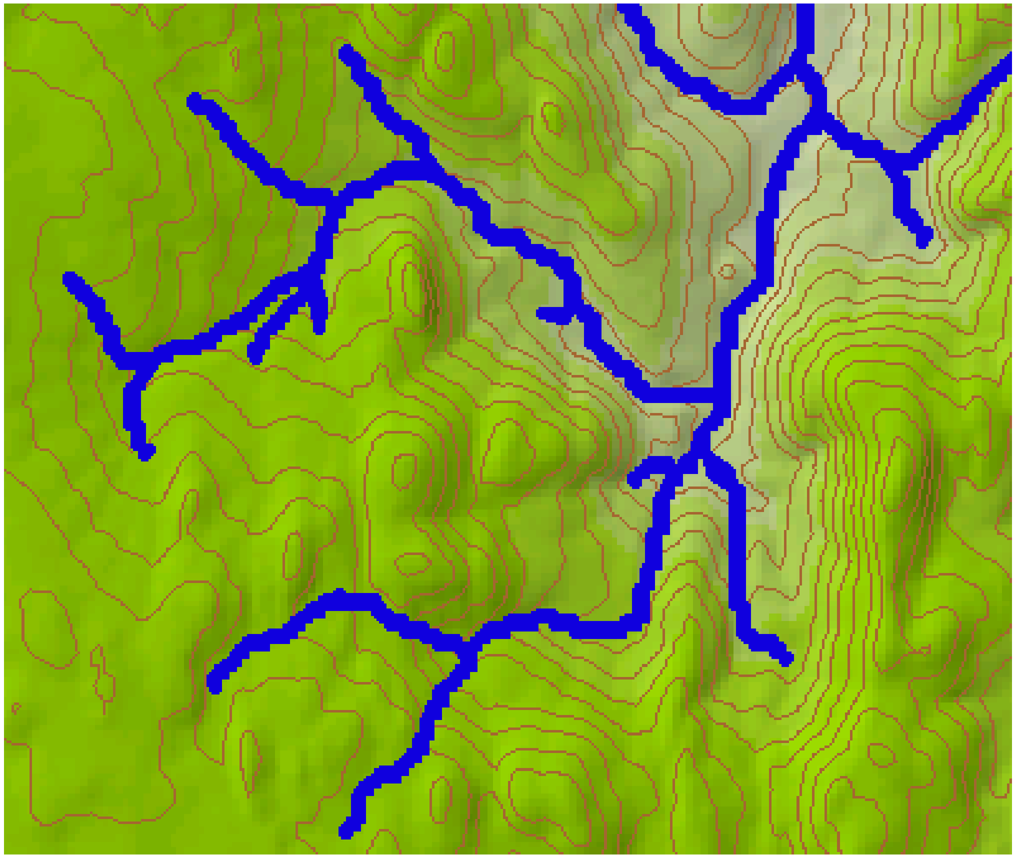




Flow Accumulation > 5 Cell Threshold

0	0	0	0	0
0	3	2	2	0
0	0	11	0	1
0	0	1	15	0
0	2	5	24	1

Flow accumulation as drainage network



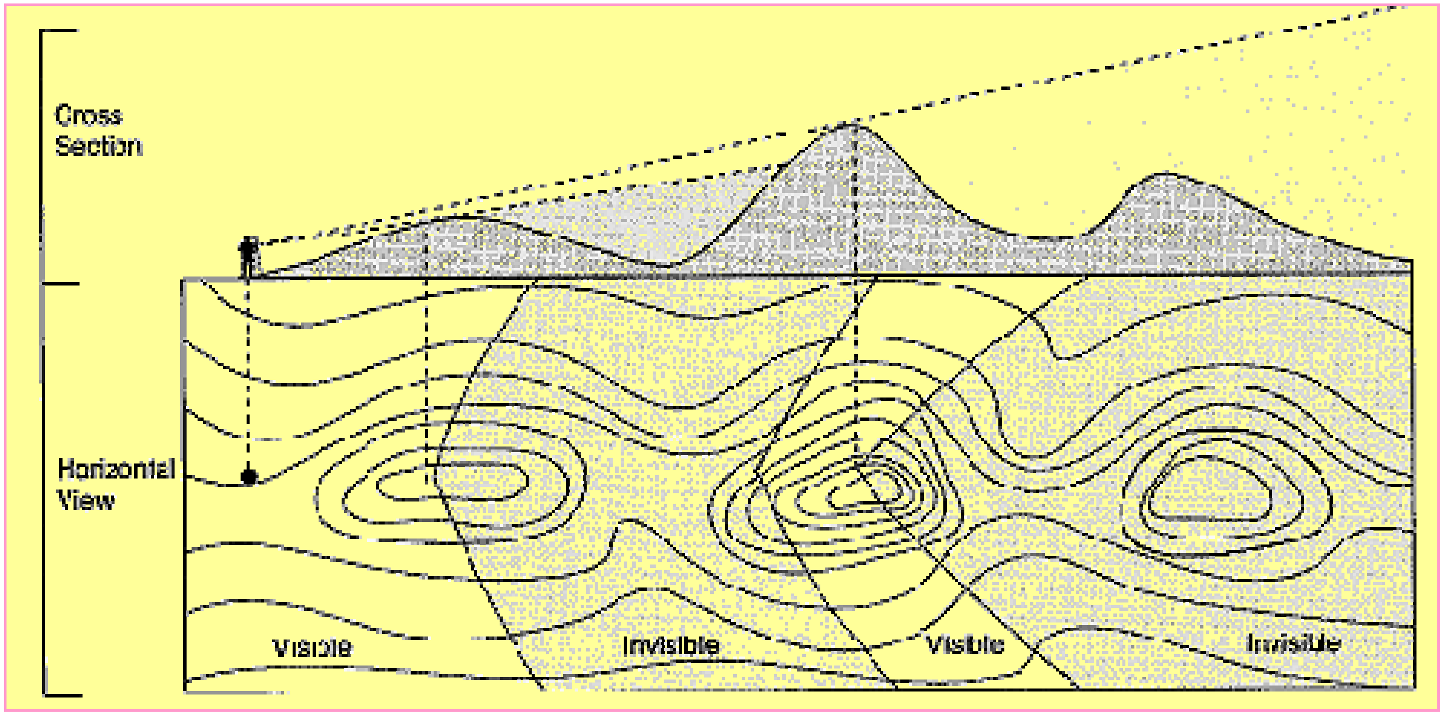
Drainage network as defined by cells above threshold value for region.

Visualization parameter

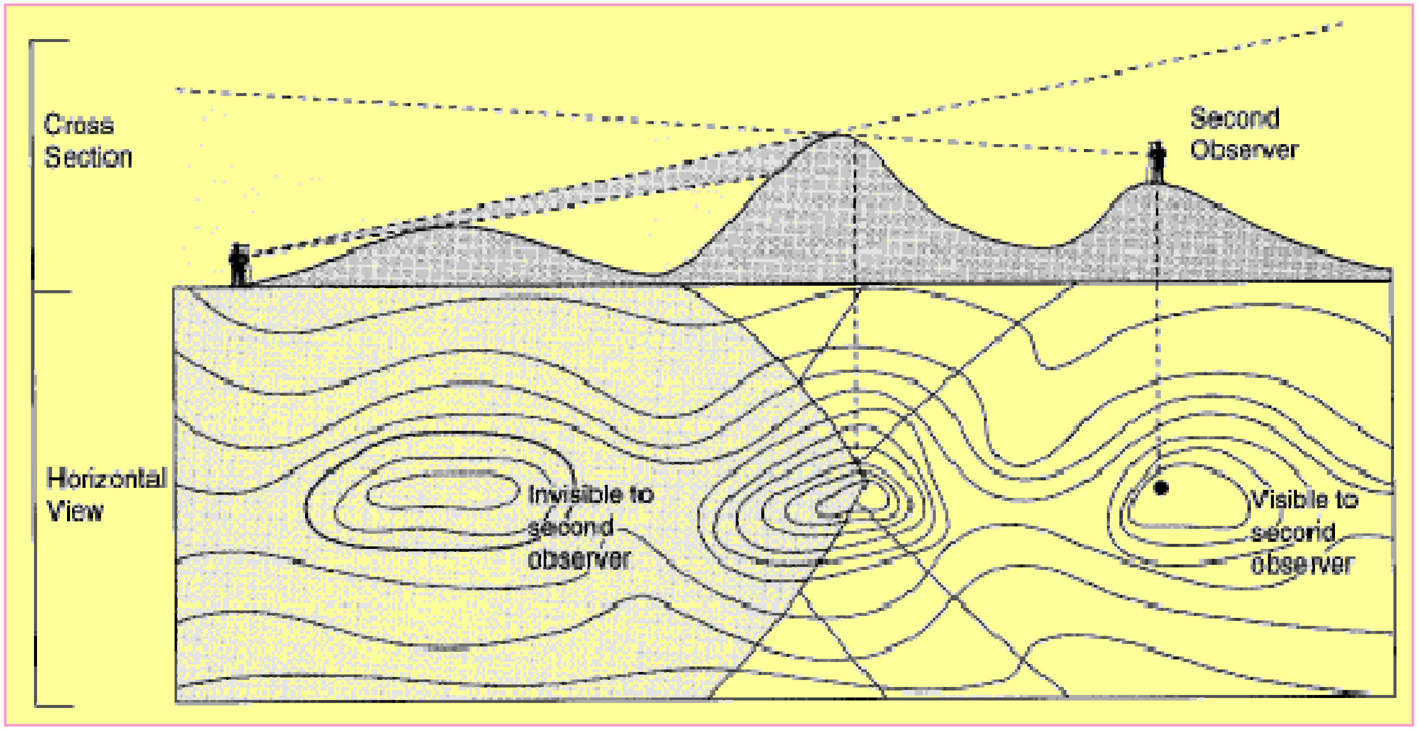
Line of sight

View shed

Visibility


Cross
Section
Horizontal
View
Visible
Invisible
Visible
Invisible

Two Observers



Orthophoto Generation

An unrectified aerial photograph will not show features in their correct locations due to displacements caused by the tilt of the sensor and by the relief in terrain.

What is Orthorectification?

The process of removing geometric error

- Camera orientation

- Relief displacement

Input data for Orthophoto

An image and a DTM covering the same area of the image

The exterior orientation parameters of the image

- The position vector – 3 parameters
- Orientation – 3 parameters

Orthophoto: Distortions due tilt and relief of the terrain are removed

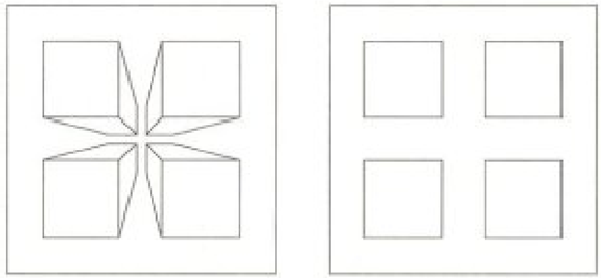
~~DIGITAL ELEVATON MODEL~~

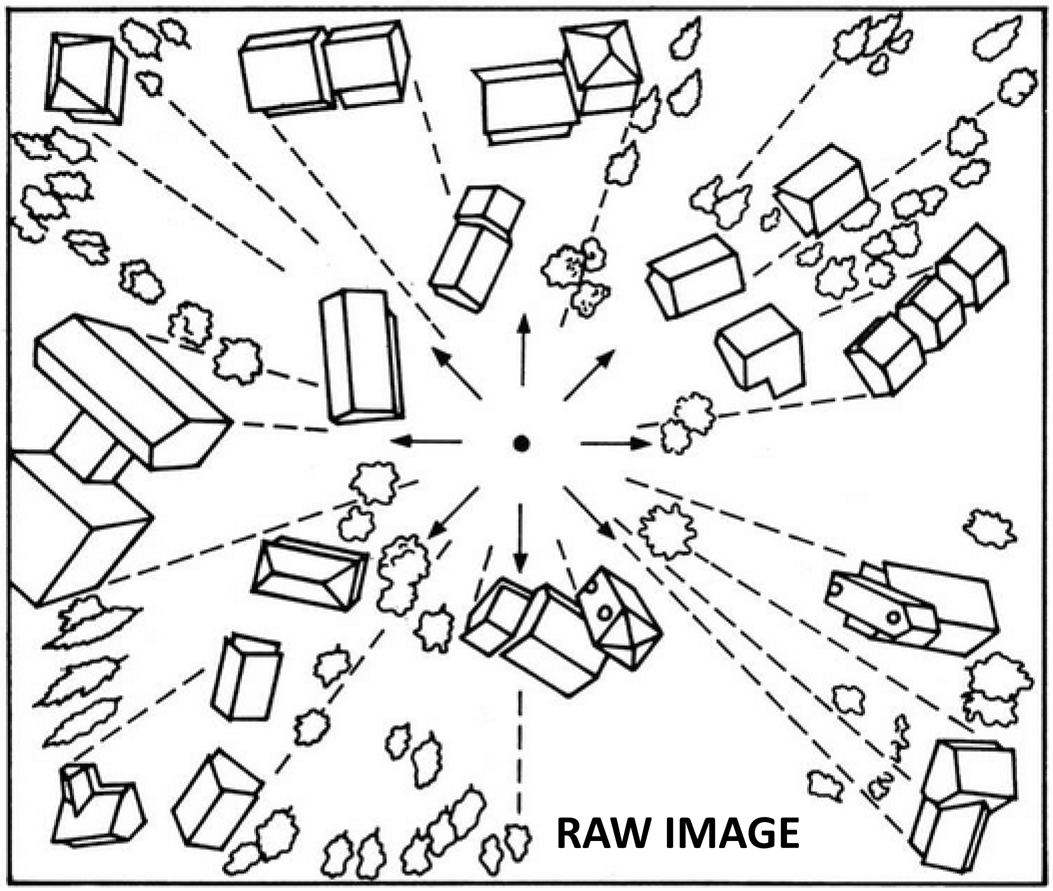
↓

ORTHOPHOTOS

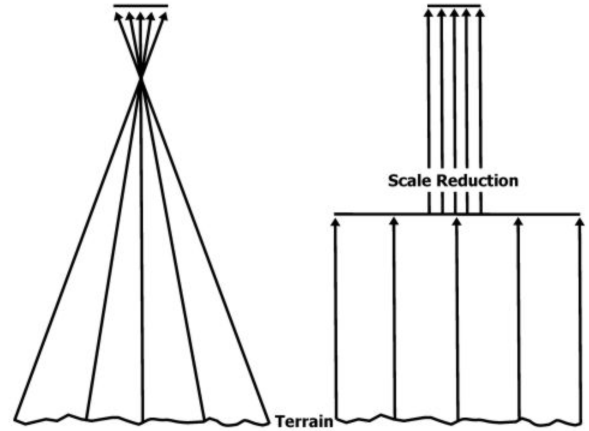
↓

ORTHOMOSAICS



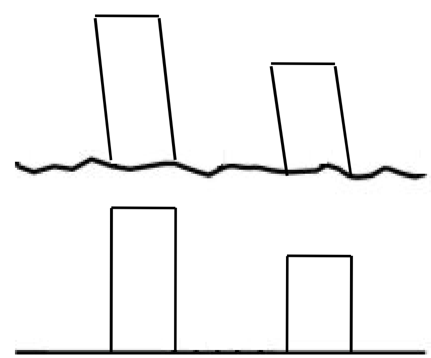


Perspective → Orthographic



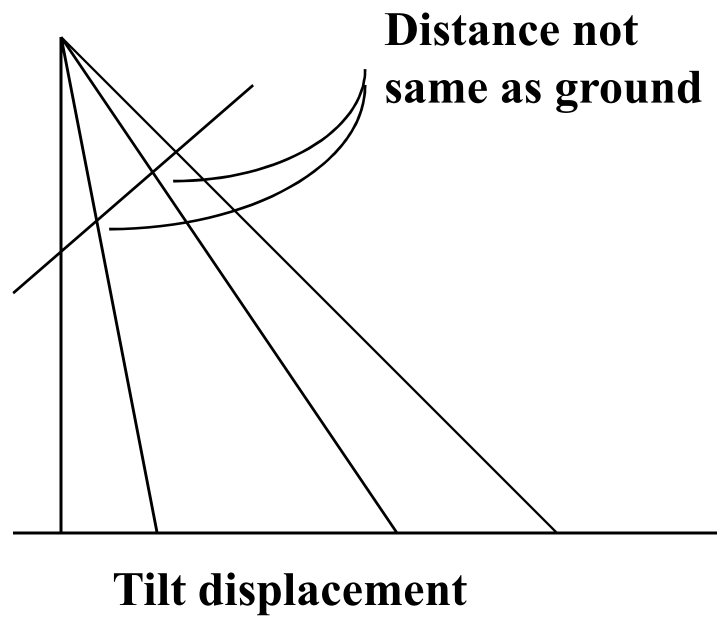
Relief/Terrain Correction (DEM)

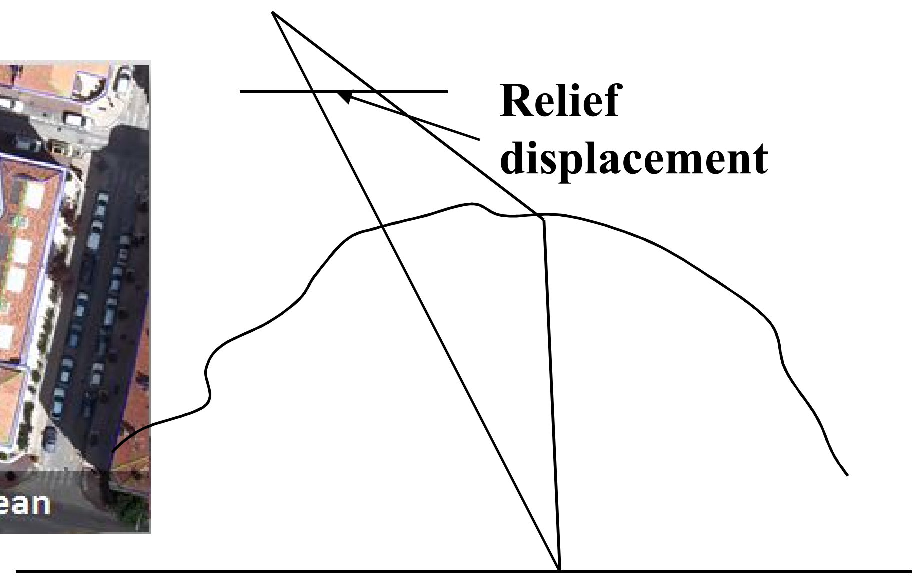
Surface Correction



Ortho Photo

True Ortho





Conclusions

DEM accuracy depends on source of data i.e. aerial/Satelite/lidar

Aerial photogrammetry/Lidar technology gives DEM accuracy up to sub meter Accuracy

Cartosat-1 stereo data gives DEM accuracy up to 4m

DEM is used many applications like viz. flood simulation, ortho photo generation, Volumetric analysis etc.