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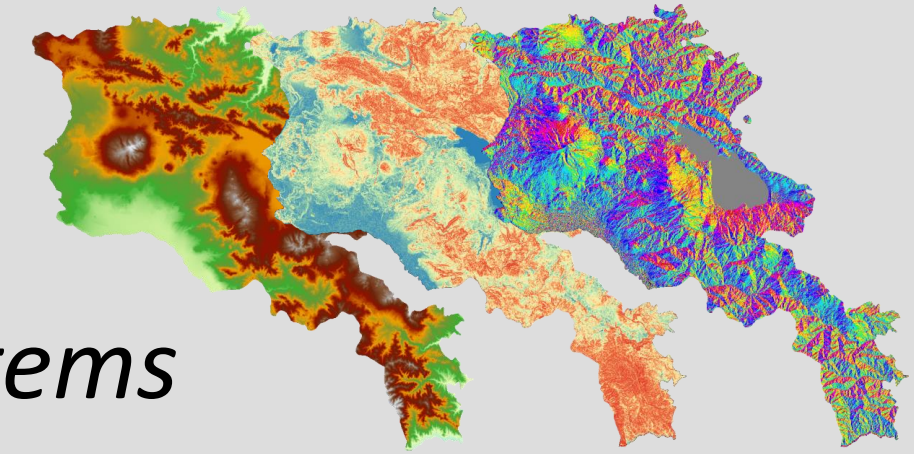
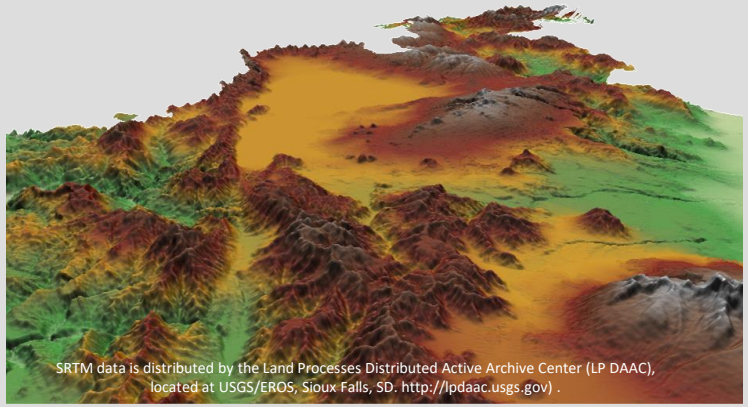
Analysis and Visualization of Digital Elevation Models using Geographical Information Systems



Dr. Michael Denk

Institute of Geosciences and Geography
Martin Luther University Halle-Wittenberg



SRTM data is distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/EROS, Sioux Falls, SD. http://lpdaac.usgs.gov) .

Introduction lecturer

Dr. Michael Denk

- Study of Geography at the MLU Halle-Wittenberg
- PhD in spectroscopy of industrial by-products

Research interests:

- Hyperspectral and multispectral remote sensing
- Visible light to the longwave infrared spectroscopy
- Exploration of anthropogenic deposits
- Spectroscopy of soils, rocks & man-made materials

Contents of this lecture

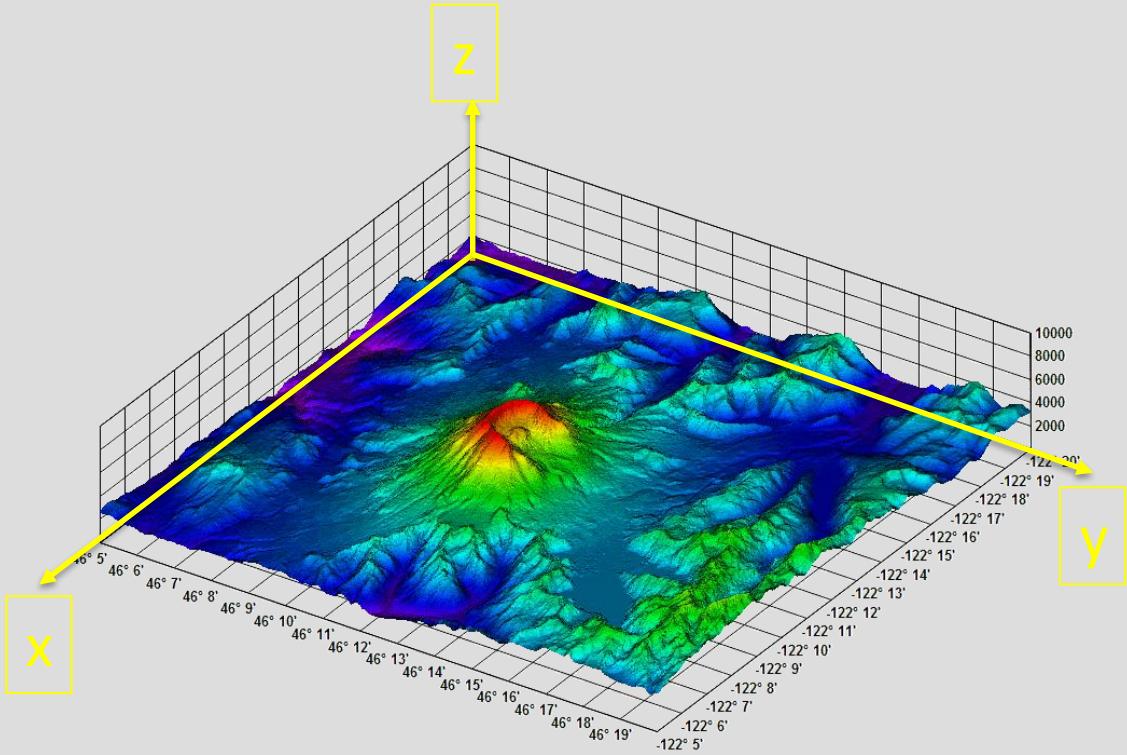
I. DEM in a nutshell: terminology, sources, global data sets

II. Practical example of DEM analysis and visualisation

Digital Elevation Models

What is Digital Elevation data?

- Digital, three dimensional representation of elevation data
- Contains x, y and z information
- Different formats (raster, vector)



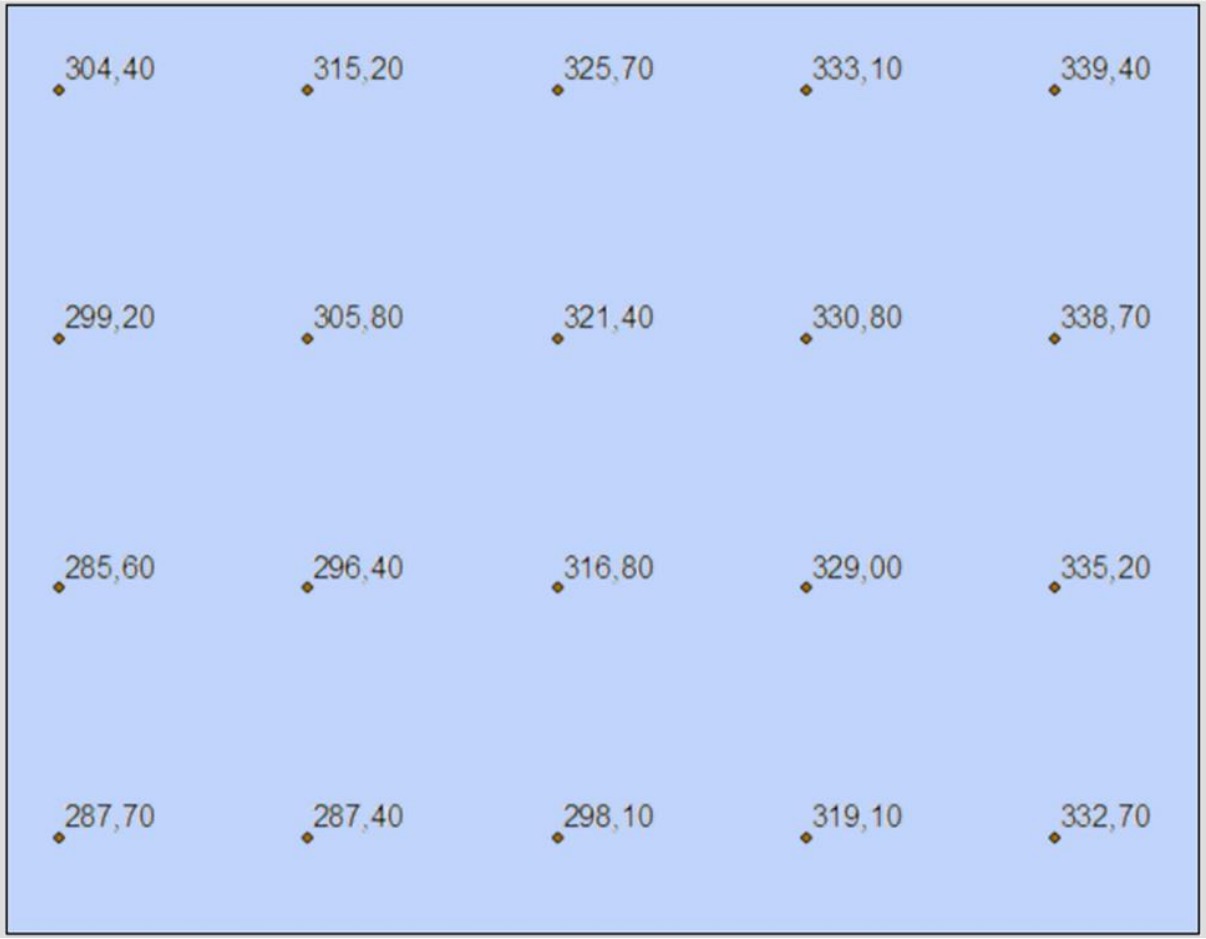
Source: modified after https://www.dplot.com/office_market.htm

Digital Elevation Models

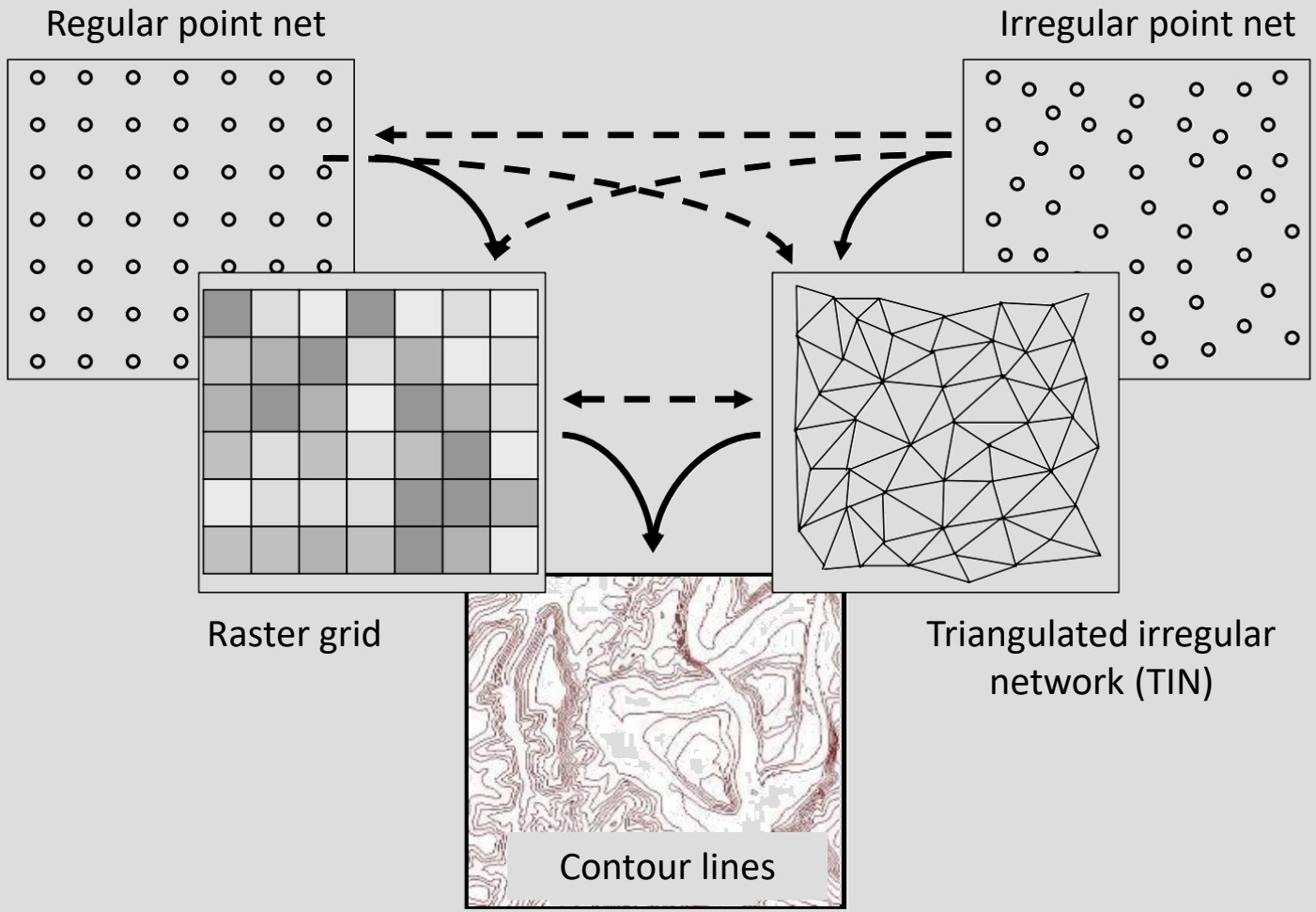
DEM as text

X	Y	Z
2553000,000	5498040,000	476,000
2553000,000	5498080,000	479,100
2553000,000	5498120,000	482,000
2553000,000	5498160,000	484,500
2553000,000	5498200,000	485,400
2553000,000	5498240,000	486,100
2553000,000	5498280,000	486,900
2553000,000	5498320,000	485,700
2553000,000	5498360,000	483,600
2553000,000	5498400,000	482,000
2553000,000	5498440,000	480,400
2553000,000	5498480,000	478,400
2553000,000	5498520,000	476,000
2553000,000	5498560,000	473,900
2553000,000	5498600,000	472,900
2553000,000	5498640,000	473,000
2553000,000	5498680,000	473,200
2553000,000	5498720,000	475,200
2553000,000	5498760,000	477,400
2553000,000	5498800,000	479,800
2553000,000	5498840,000	482,500
2553000,000	5498880,000	486,000
2553000,000	5498920,000	489,600
2553000,000	5498960,000	493,000
2553000,000	5499000,000	496,500

DEM as vector data

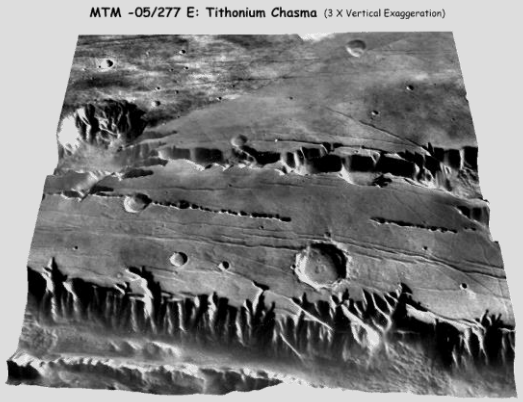


Digital Elevation Models



Terminology

Digital Elevation Models (DEM): DEM contains elevation information stored in digital a format
Digitale Surface Models (DSM)
Digitale Terrain Models (DTM)



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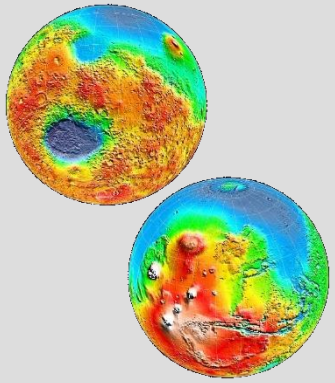
By User:W!B: - http://www.maps-for-free.com/, GFDL, https://commons.wikimedia.org/w/index.php?curid=5115489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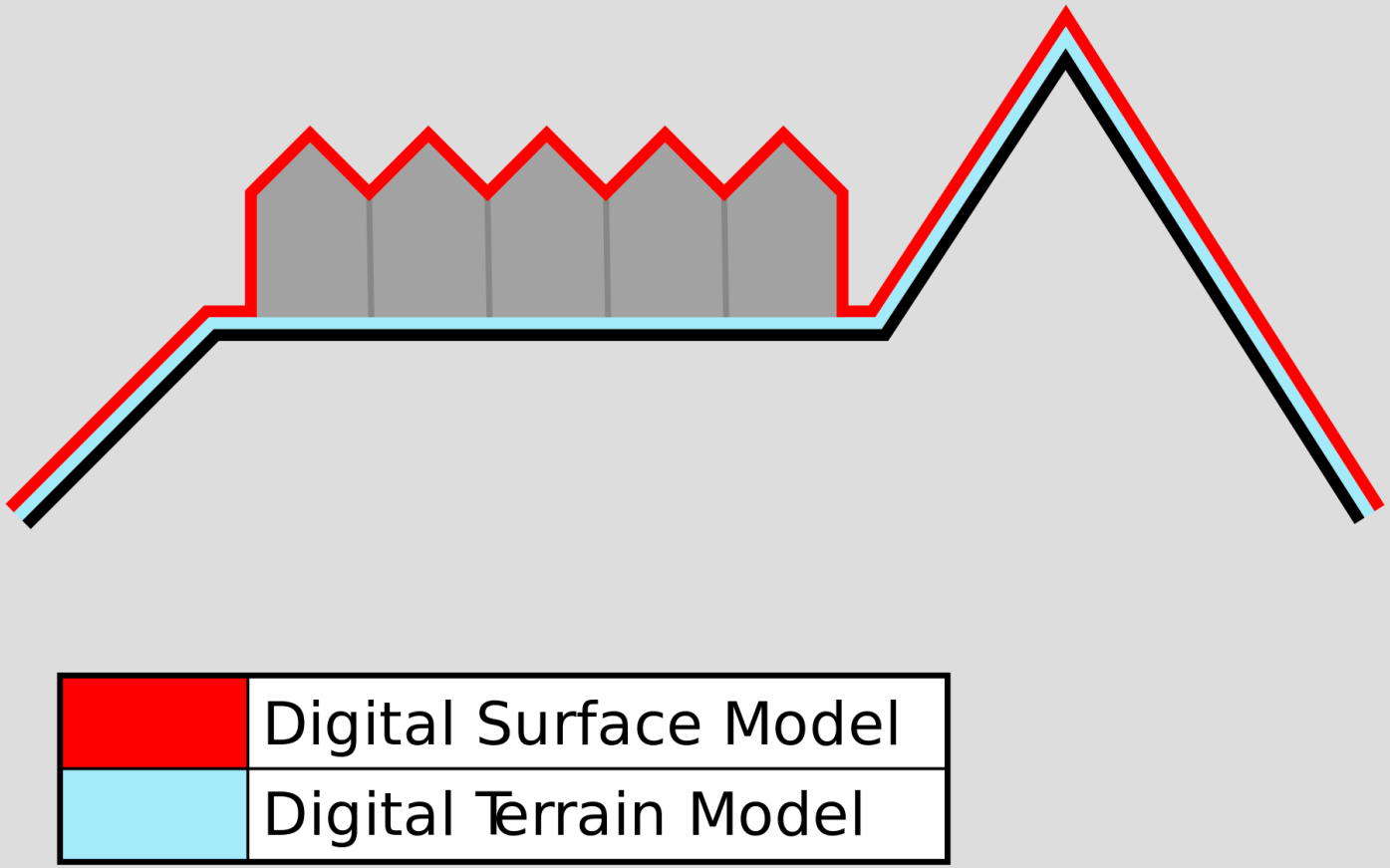
Terminology



“Services” provided by DEM

- Digital storage, analyses and visualisation of elevation information
- Intersection of elevation data and other data
- Digital terrain analysis (local, complex and combined morphometric parameters)
- Graphical representation of elevation information in 2D and 3D
- Various applications: water level simulations (flood events!), volume calculations, land slides, land subsidence, etc.

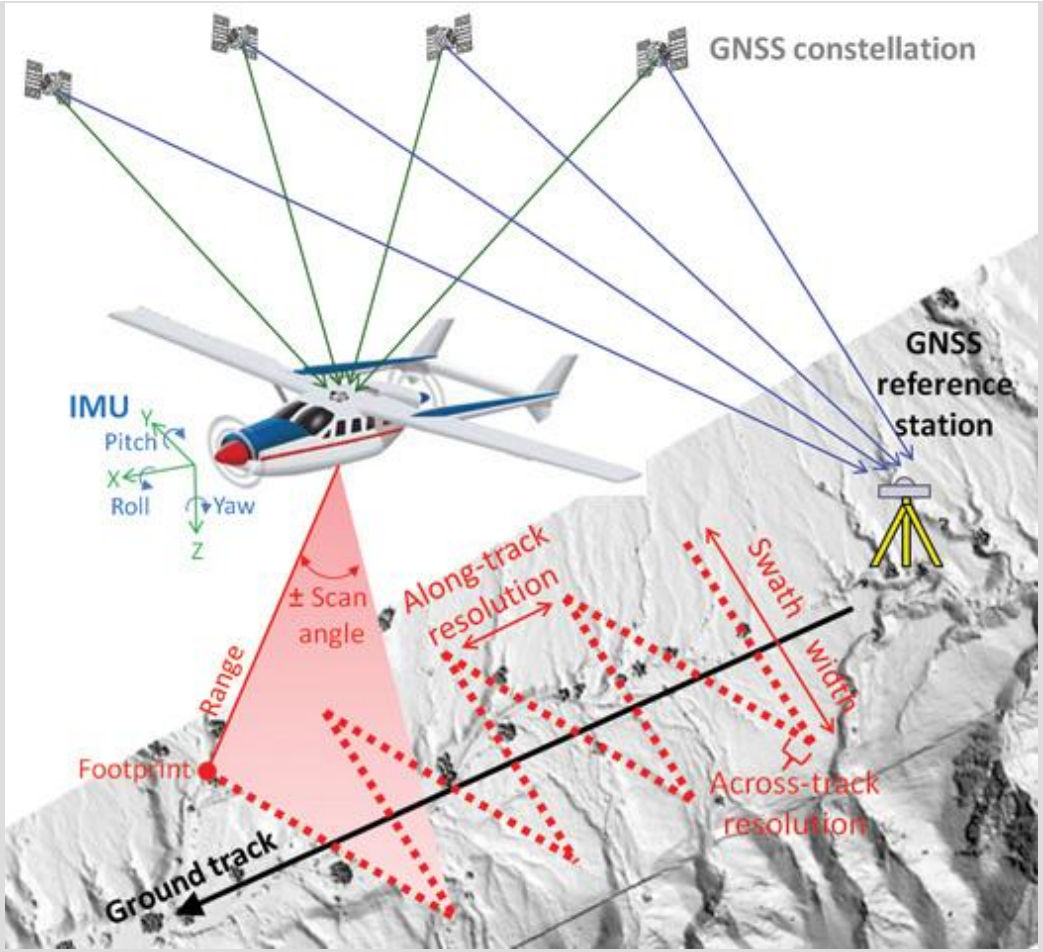
Sources of Digital Elevation Data

DEMs can be **generated from a variety of data** collected from **different platforms** (terrestrial, airborne, spaceborne):

- **Laser scanner** (**LiDAR**) data (e.g. DEM of national surveys)
- **RADAR** data (e.g. SRTM, WorldDEM)
- **Stereoscopic** imagery (e.g. ASTER-GDEM, ALOS World 3D)
- *GPS measurements*
- *Theodolite measurements*
- *Topographic maps*
- *…*

Laser scanning (LiDAR)

Laser scanning - Light Detection and Ranging (LiDAR)



Source: Fernandez-Diaz, J. C. (2011). Lifting the Canopy Veil - Airborne LiDAR for Archeology of Forested Areas. Imaging Notes, 26(2).

- Active remote sensing method
- Emission of laser pulses

→ Scattering from objects

→ reception of backscattered signals (travel time & intensity)

\+ known position of the platform (GPS)

→ calculation of distances

- Generation of DSM and DTM

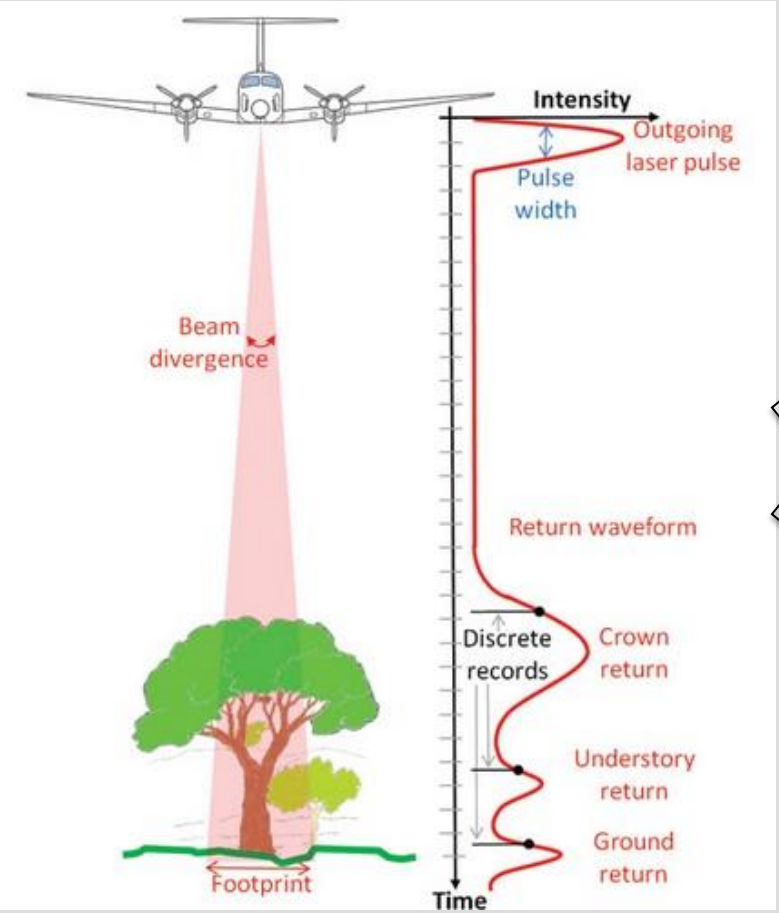
Laser scanning - Light Detection and Ranging (LiDAR)

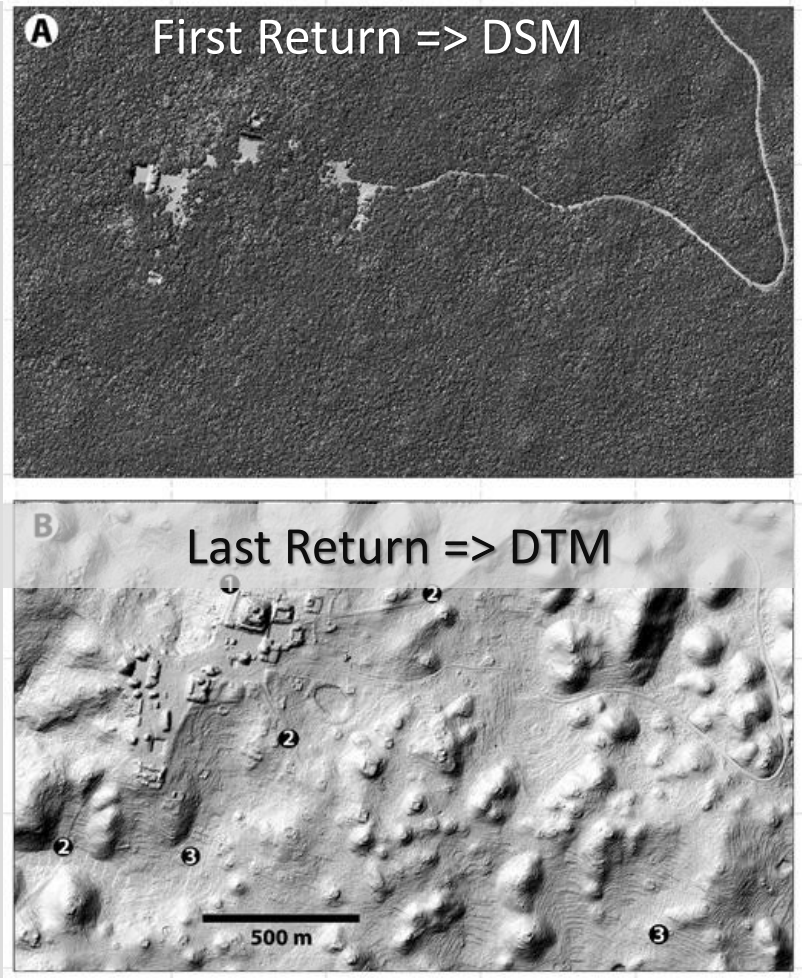
- Laser - Light Amplification by Stimulated Emission of Radiation
- Monochromatic radiation (VIS, NIR, but also SWIR)
- Modern laser scanners partly work in several spectral bands (multispectral lasers)
- Terrestrial & airborne use

Source: Von Dr. Schorsch - Modified image from de:image:FARO Laserscanner LS.JPG, removed commercial, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=1436648

Credit: Von Peter Haas, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=29077252

Laser scanning - Light Detection and Ranging (LiDAR)



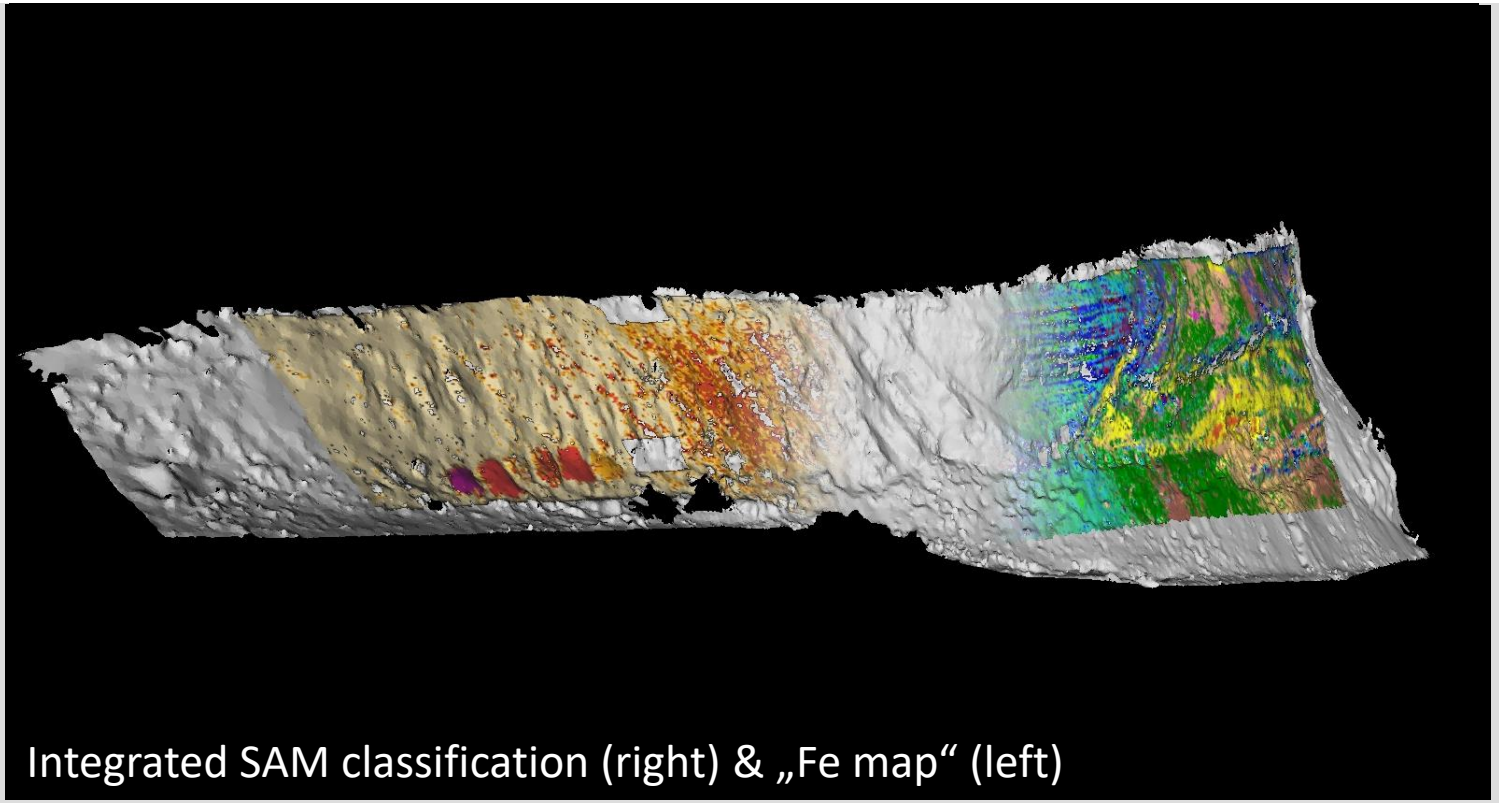


Sources: Fernandez-Diaz, J. C. (2011). Lifting the Canopy Veil - Airborne LiDAR for Archeology of Forested Areas. Imaging Notes, 26(2).

Laser scanning - Light Detection and Ranging (LiDAR)

Lasers canner

Riegl LMS Z420i
Nikon D100
Thales/Magellan/ Ashtech® ProMark2



Integrated SAM classification (right) & „Fe map“ (left)

Hyperspectral scan: T.H. Kurz, LiDAR-Scan: S.J. Buckley (VOG, Uni CIPR, Bergen)
Image analysis: M. Denk (MLU)

- Integration of photos, hyperspectral data and classifications into the LIDAR model
- Geometrically accurate localization of data and results

Radar remote sensing

Radar remote sensing in a nutshell

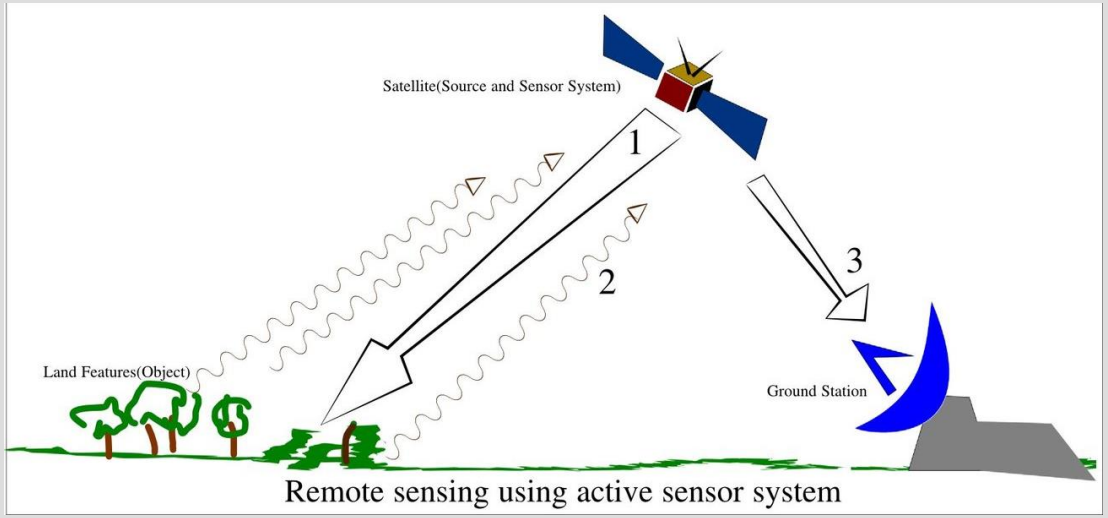
RADAR = RAdio Detection And Ranging

- **Active** observation system
- Uses **microwave radiation**

→ Relatively **unaffected by atmosphere**

→ **Penetrates clouds, soil, vegetation**, ice

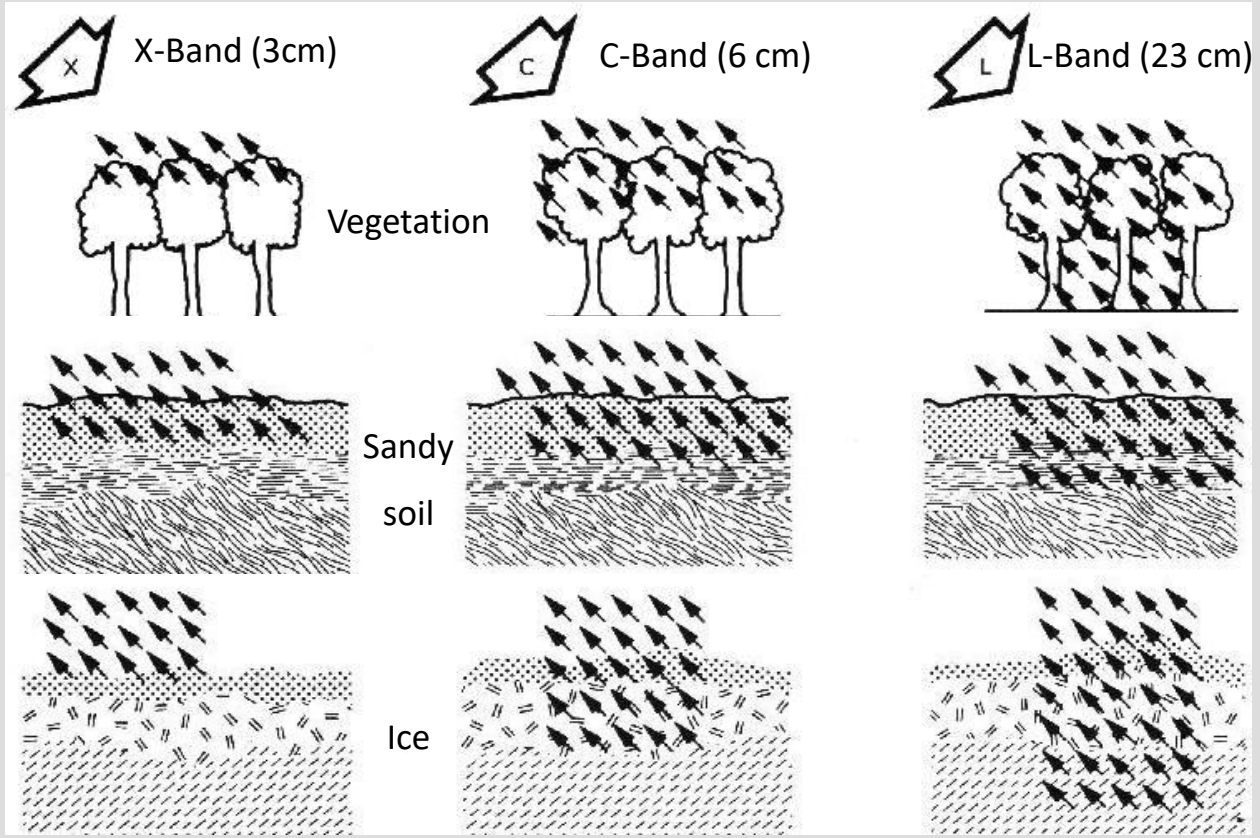
- **RAR (Real Aperture RADAR)** and **SAR (Synthetic Aperture RADAR)** systems
- Amplitude (amount of backscattered energy), Frequency, Polarization, Phase (propagation time) of emiited radiation is known
- Measures the „strength“ of the returned signal and distance to objects via signal runtime



Source: By Arkarjun - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=29727605

Radar remote sensing in a nutshell

- Microwaves: λ = ca. 1 mm – 1 m
- P-, L-, S-, C-, X-Band
- *Backscattering coefficient* is mainly effected by **surface roughness**, **surface geometry** and **dielectric properties** (which are affected by surface **moisture**)

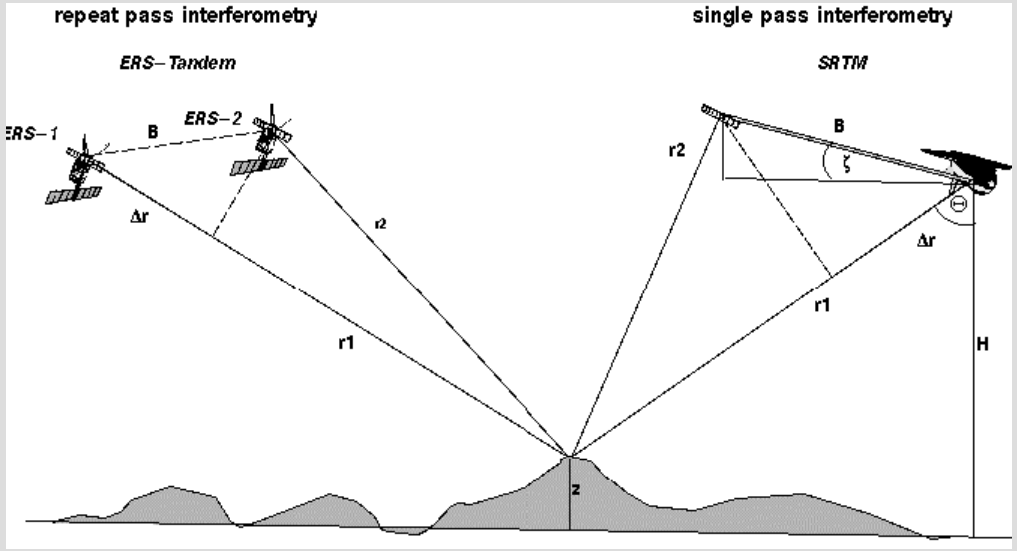


Source: FAO Remote Sensing Center (1993)

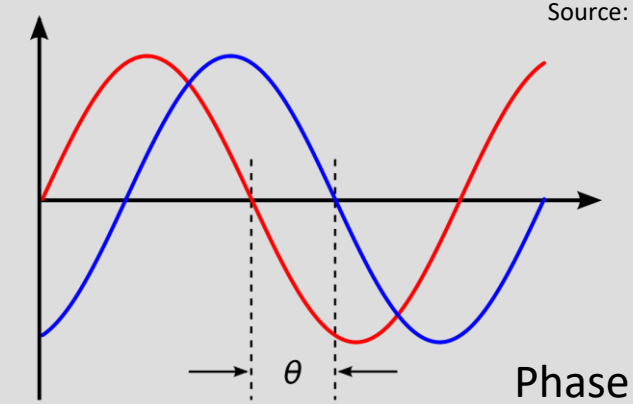
Interferometric synthetic aperture radar (InSAR)

DEM generation based on InSAR data:

- Two radar images are required
  a) recorded at the same time with two antennas of one platform or 2 platforms in “tandem mode” (single pass interferometry)
  b) Recorded by one or several platforms with time lag (dual/repeat pass interferometry)
- InSAR is utilising differences in the phase of the recorded signals, which depends on the distance to the ground
- Phase differences are converted to altitude

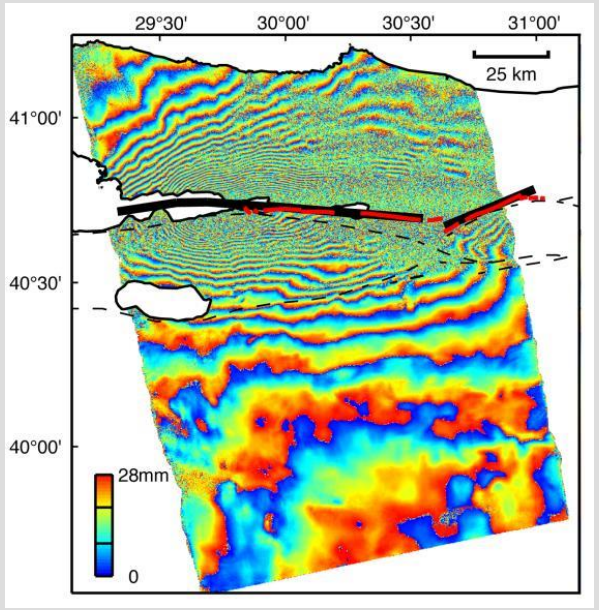


Source: Knöpfle et al. 1998

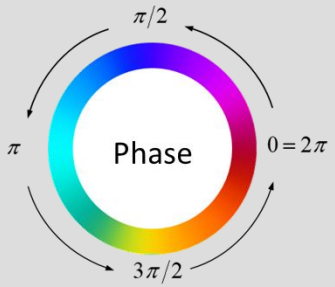


Source: By Peppergrower - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=6007495

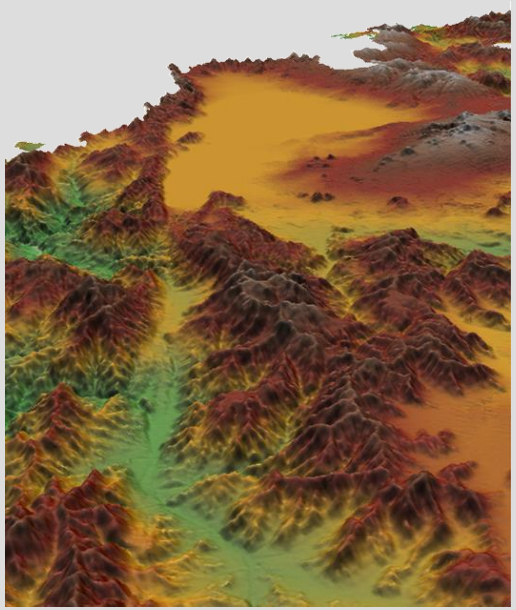
Interferometry and DEM generation



Interferogram*



Phase Unwrapping



DEM**

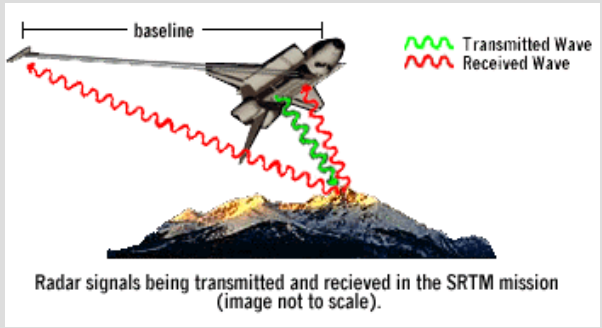
- Phase differences between two recordings are measured in radians
- Cyclic nature of phases → visualisation in coloured fringes
- Derivation of DEM or information on surface displacements

*Source: By NASA/JPL-Caltech - http://photojournal.jpl.nasa.gov/catalog/PIA00557, Public Domain, https://commons.wikimedia.org/w/index.php?curid=1861442
**SRTM are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/EROS, Sioux Falls, SD. http://lpdaac.usgs.gov) .

SRTM DEM

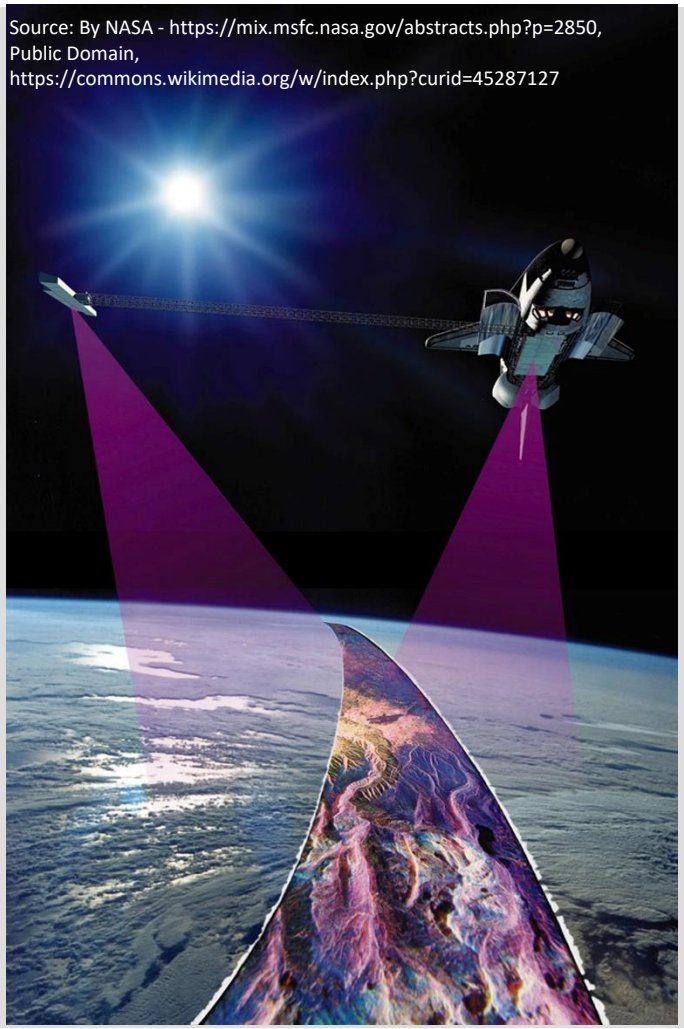
Shuttle Radar Topography Mission (SRTM)

- Data recorded in February 2000 within only 11 days
- Acquisition of data by means of 2 instruments: C-band (USA/NASA-JPL) - 5.6 cm; X-band (Ger/DLR, I/ASI), 3.1 cm
- Single Pass Interferometry
- Global coverage between 58° south and 60° north
- Data freely available in 1 and 3 arc seconds (~30 m and 90 m,)
- More info: https://dds.cr.usgs.gov/srtm/version2_1/Documentation/SRTM_Topo.pdf



Radar signals being transmitted and recieved in the SRTM mission (image not to scale).

Source: https://www2.jpl.nasa.gov/srtm/instrumentinterferometry.html


Source: By NASA - https://mix.msfc.nasa.gov/abstracts.php?p=2850, Public Domain, https://commons.wikimedia.org/w/index.php?curid=45287127

TerraSAR-X & TanDEM-X, WorldDEM

- TerraSAR-X since 2007, 2009 „twin“ TanDEM-X
- „X“ refers to X-Band (8,2–12,4 Ghz, 2.5-4 cm)
- Partnership of DLR and EADS Astrium (-> Airbus)
- Orbit in ~500 km
- Simultaneous acquisition of signals from different viewing angles by the 2 twin satellites
- WorldDEM: 12 m spatial res, vertical acc. > 2 m

Source: Von DLR - http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10422/, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=19369759

Source: Von DLR - http://www.dlr.de/media/en/desktopdefault.aspx/tabid-4986/8423_read-17283/8423_page-2, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=33027781

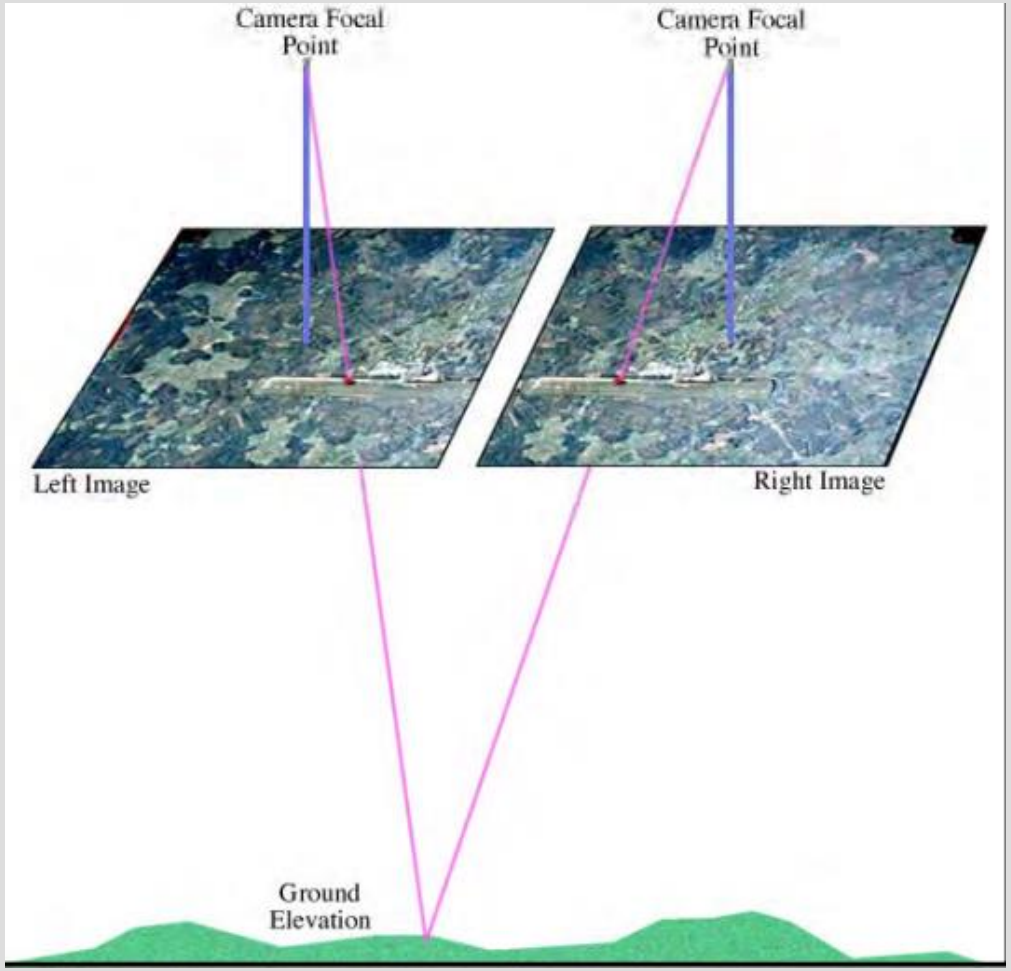
Sentinel 1

Source: Von Rama, CC BY-SA 2.0 fr, https://commons.wikimedia.org/w/index.php?curid=18948403

- Sentinel 1A, 1B, 1C, 1D
- Earth Observation Radar stallites of the Copernicus programme of the ESA
- Orbit 700 km
- C-band SAR (wavelength ~ 6cm)
- Active antenna consists of 560 coupled single antennas
- 4 different observation modes
- Data available via the Copernicus Open Access Hub https://scihub.copernicus.eu/

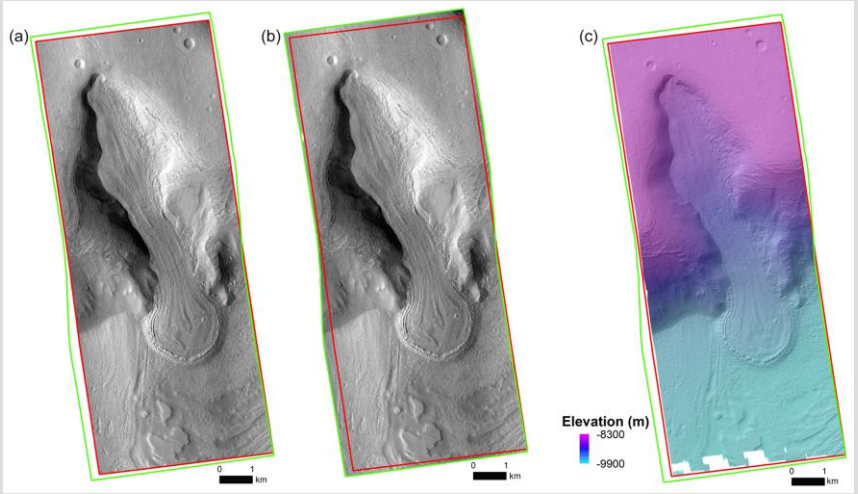
DEM based on stereo imagery

Principle of stereoscopic elevation measurements



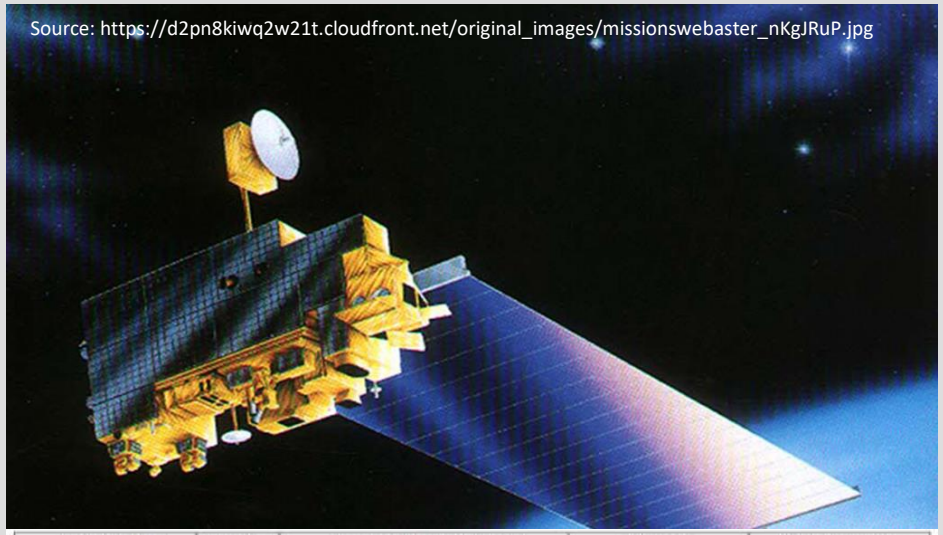
Hans-Gerd Maas Photogrammetrie Teil 1: Stereophotogrammetrie Technische Universität Dresden

- 2 (3), overlapping images, showing the same from different viewing angles
- Algorithms measure height difference from parallax difference (camera orientation, time between the two images is known)



Source: Hepburn et al. 2019, https://doi.org/10.5194/gi-8-293-2019

ASTER Global Digital Elevation Map (GDEM)


Source: https://d2pn8kiwq2w21t.cloudfront.net/original_images/missionswebaster_nKgJRuP.jpg

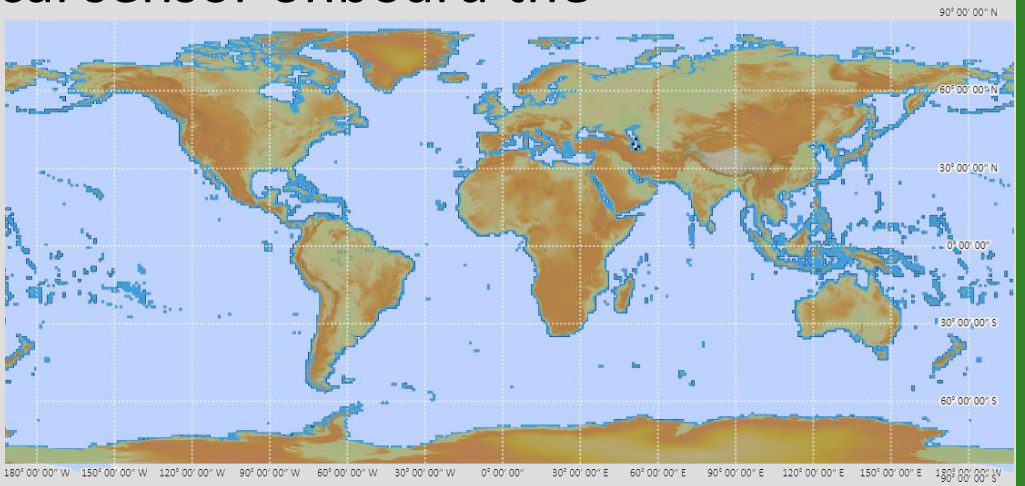
Subsystem	Band No.	Spectral Range (μm)	Spatial Resolution, m	Quantization Levels
VNIR	1	0.52-0.60	15	8 bits
	2	0.63-0.69		
	3N	0.78-0.86		
	3B	0.78-0.86		
SWIR	4	1.60-1.70	30	8 bits
	5	2.145-2.185		
	6	2.185-2.225		
	7	2.235-2.285		
	8	2.295-2.365		
	9	2.360-2.430		
TIR	10	8.125-8.475	90	12 bits
	11	8.475-8.825		
	12	8.925-9.275		
	13	10.25-10.95		
	14	10.95-11.65		

- ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer
- DEM based on stereo-pair images collected via ASTER bands 3N and 3B
- 30 m spatial resolution
- Coverage: 83°N to 83° S
- Current version: GDEM v3 (based on 2.3 million Aster images, comprises the ASTER Water Body data set (ASWBD))
- Availability: NASA Earthdata, Japan Space Systems
- Further info: https://earthdata.nasa.gov/learn/articles/new-aster-gdem

ALOS Global Digital Surface Model

ALOS World 3D - 30m (AW3D30)

- Global DSM, coverage 82°N to 82°S
- Based on stereo-pair images of the *Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM)* (optical sensor onboard the Advanced Land Observing Satellite "ALOS“)
- Spatial resolution: 1 arc second (~30 m)
- Further information:
- https://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm

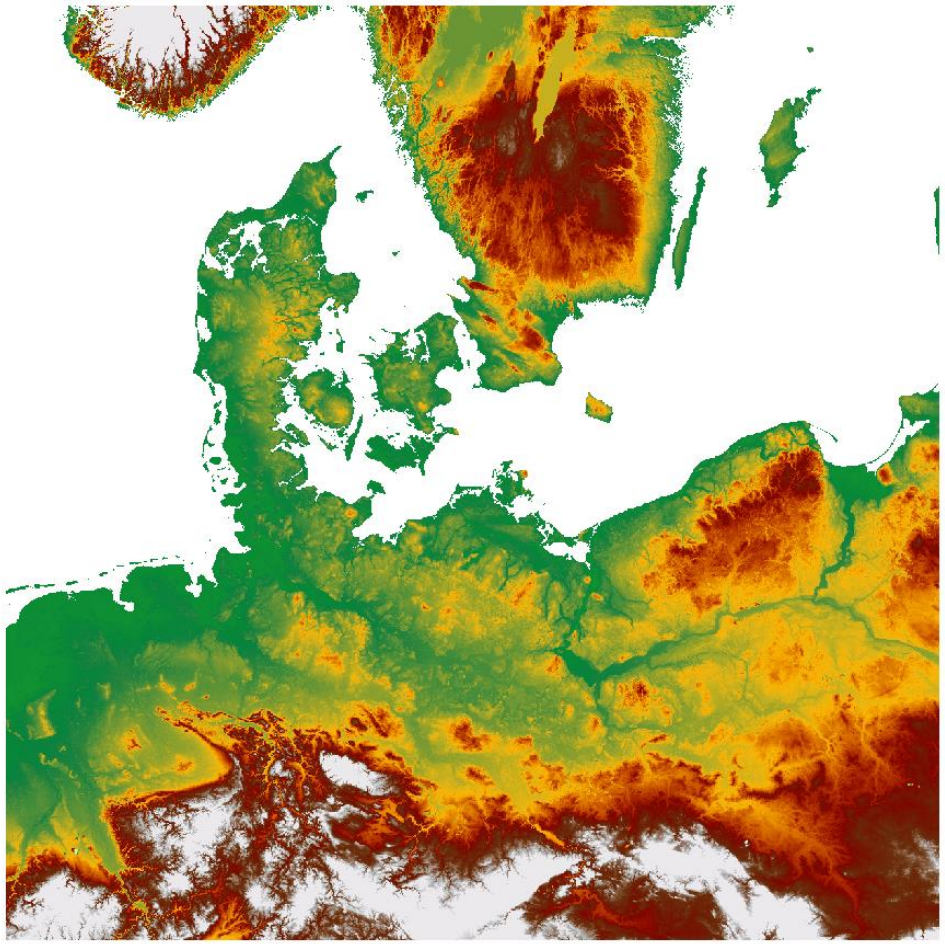


Source: https://www.eorc.jaxa.jp/ALOS/aw3d30/l_map_v2012.htm

EU-DEM

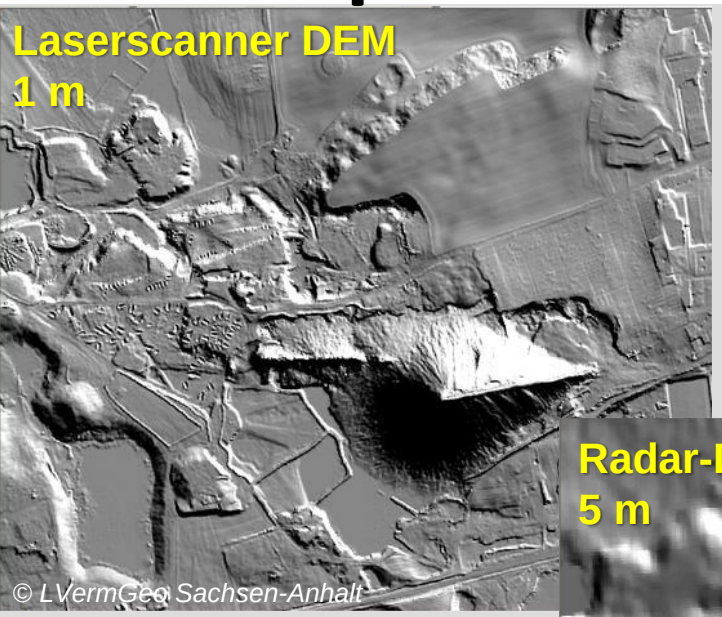
EU-DEM (v1.1):

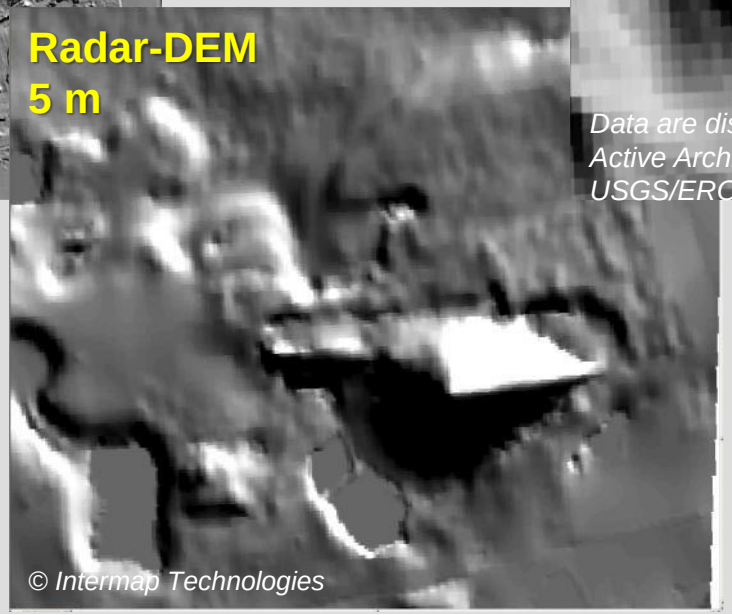
- 25 m spatial resolution
- +/- 7 m vertical accuracy
- GeoTiff 32 bit
- 1000 x 1000 km Tiles
- Hybrid of **SRTM and ASTER GDEM data**
- Further information: https://land.copernicus.eu/imagery-in-situ/eu-dem

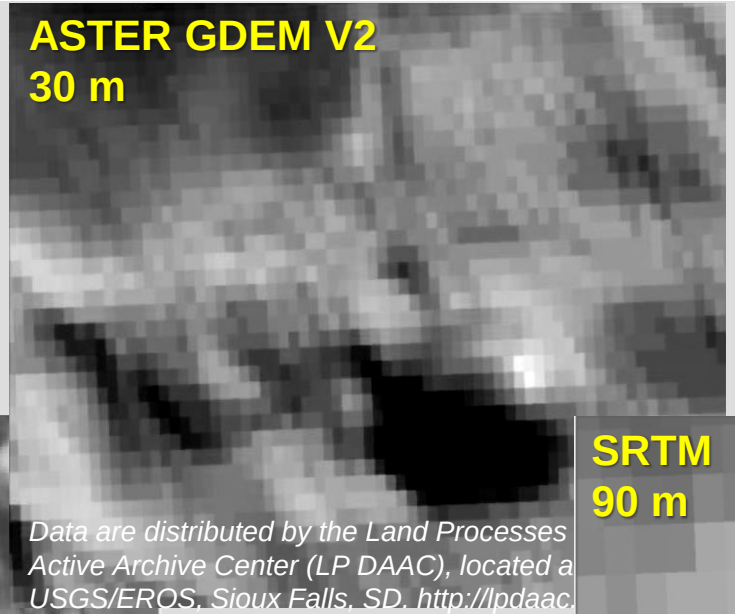


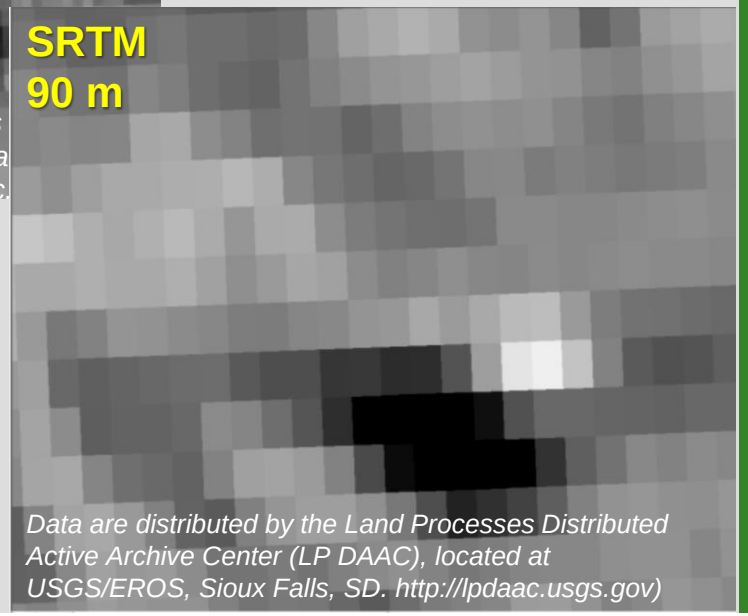
Source: Data generated with funding from the European Union; European Environment Agency (EEA) under the Copernicus program.

Comparison of DEM









Comparison of Global DEM

	ASTER GDEM	SRTM3*	GTOPO30**
Data source	ASTER	Space shuttle radar	From organizations around the world that have DEM data
Generation and distribution	METI/NASA	NASA/USGS	USGS
Release year	2009 ~	2003 ~	1996 ~
Data acquisition period	2000 ~ ongoing	11 days (in 2000)	
Posting interval	30m	90m	1000m
DEM accuracy (stdev.)	7~14m	10m	30m
DEM coverage	83° north ~ 83° south	60° north ~ 56° south	Global
Area of missing data	Areas with no ASTER data due to constant cloud cover (supplied by other DEM)	Topographically steep area (due to radar characteristics)	None

Source and many more information: https://ssl.jspacesystems.or.jp/ersdac/GDEM/E/2.html

Overview of Global DEM

Copernicus In Situ

EEA/IDM/15/026/LOT2
Overview of Global DEM

Doc. ID: EG-RPT-EEA-SC1-0023
Issue: 0.3
Date: 23/05/2017

Framework Service Contract EEA/IDM/15/026/LOT 2
for Services supporting the European Environment Agency's (EEA)
implementation of cross-cutting activities for coordination of the in situ component of the Copernicus Programme Services

Call for tenders No EEA/IDM/15/026

Lot 2 Spatial data themes

Overview of Global DEM
Assessment of the current global DEMs and requirements for an updated global DEM

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e-geos AN ASI/TELESPAZIO COMPANY · ISPRA · evenflow · planetek italia · Telespazio · EOXPLORE · arpae emilia-romagna · GAFAG

Comparison of commercial and freely-available global DEM:

https://insitu.copernicus.eu/library/reports/OverviewofGlobalDEM_i0r7.pdf

Practical Example:
Analysing DEM data of Armenia

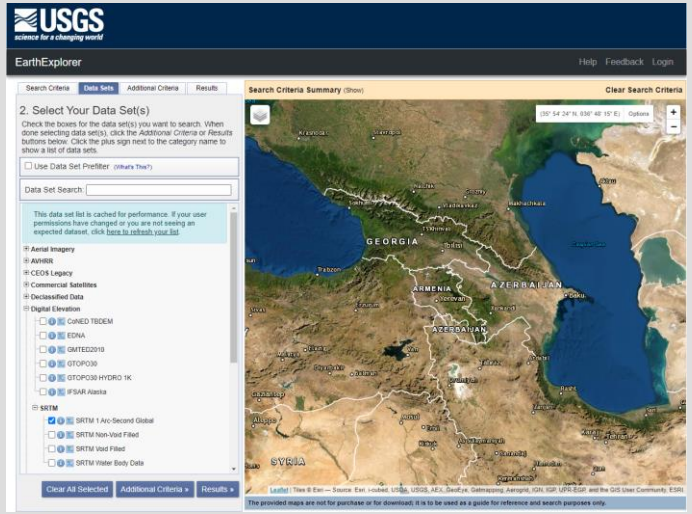
Where to get the data?

Landsat, MODIS, ASTER data archives and others:

- NASA Earthdata Search
- USGS Earth Explorer, USGS Glovis
- LandsatLook Viewer
- Land Processes Distributed Active Archive Center (LP DAA)
- MODIS: https://modis.gsfc.nasa.gov/tools/
- LAAADS DAAC: https://ladsweb.modaps.eosdis.nasa.gov/

Sentinel data:

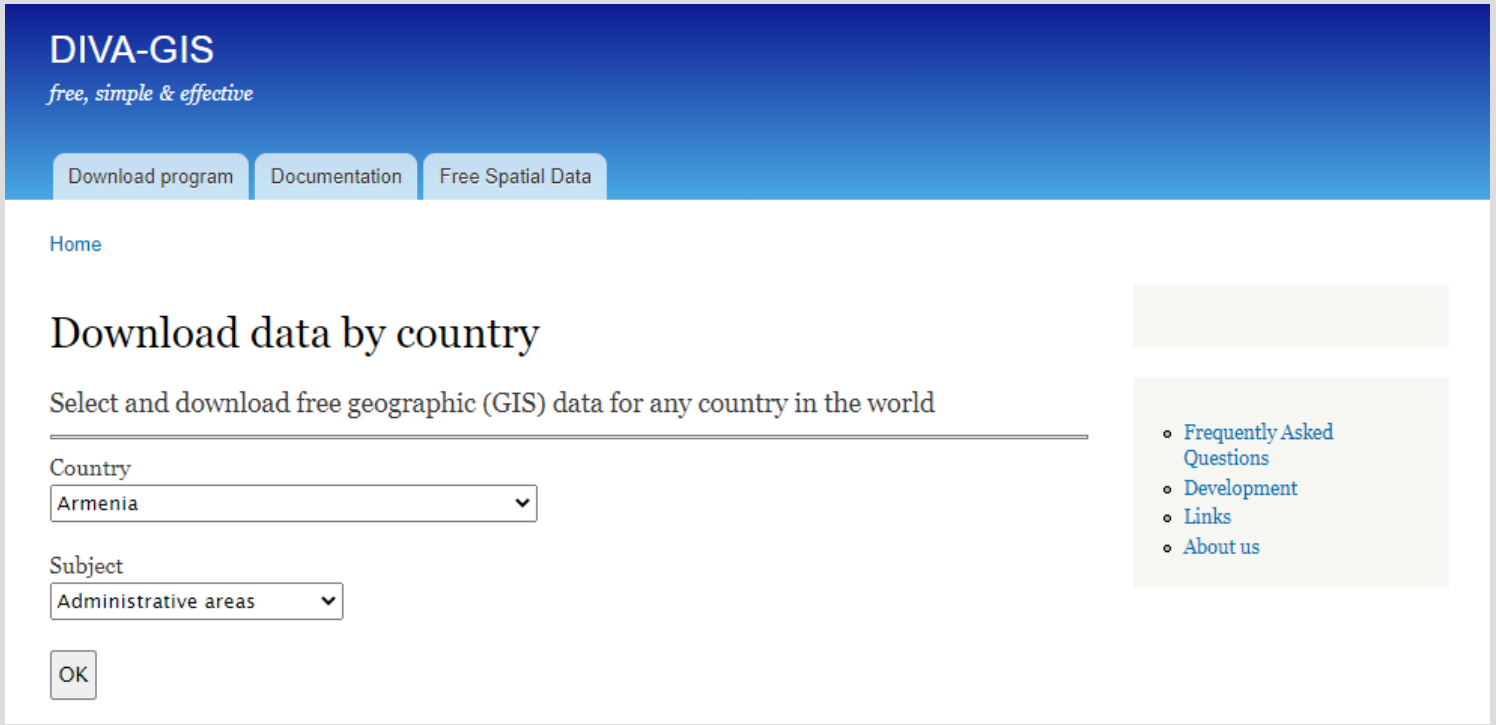
- Sentinel2Look Viewer
- Copernicus Open Access Hub



GeoEye, IKONOS, Planet, Quickbird, WorldView 1-4, …:

- Maxar - Search & Discovery
- Apollo Mapping - Image Hunter

Where to get the data?



Sources

Subject	Description	Source	Format	Resolution
Administrative areas (boundaries)	Country outlines and administrative subdivisions for all countries. The level of subdivision varies between countries	GADM, version 1.0	Vector (area)	-
Inland water	Rivers, canals, and lakes. Seperate files for line and area features	Digital Chart of the World	Vector (line and area)	-
Roads	Roads	Digital Chart of the World	Vector (line)	-
Railroads	Railroads	Digital Chart of the World	Vector (line)	-
Elevation	SRTM30 dataset. CGIAR-SRTM data aggregated to 30 seconds	CGIAR SRTM (3 seconds resolution)	Grid	30 seconds
Land cover	Land cover, original data resampled onto a 30 seconds grid	GLC2000	Grid	30 seconds
Population	Population density (old)	CIESIN, 2000. Global gridded population database	Grid	30 seconds
Climate	Monthly climate data	WorldClim	Grid	30 seconds
Gazetteer	A gazetteer is a list of place names and their coordinates. The files you can download here are for use in DIVA for automatic georeferencing (to assign coordinates to places). The files should be placed in the \gazet directory. (old, use Biogeomancer). They can also be used to map localities, however you can download more recent files from NIMA	U.S. National Imagery and Mapping Agency's (NIMA) database of foreign geographic feature names	DBF	-

You will find various free geospatial data sets on countries for example at the DIVA-GIS webpage (https://www.diva-gis.org/Data)

What software to use?

QGIS

R

ERDAS IMAGINE®

PCI GEOMATICS

Orfeo ToolBox
Orfeo ToolBox is not a black box

Semi-Automatic Classification Plugin

SAGA
System for Automated Geoscientific Analyses

GRASS GIS
The world's leading Free GIS software

ILWIS

SNAP

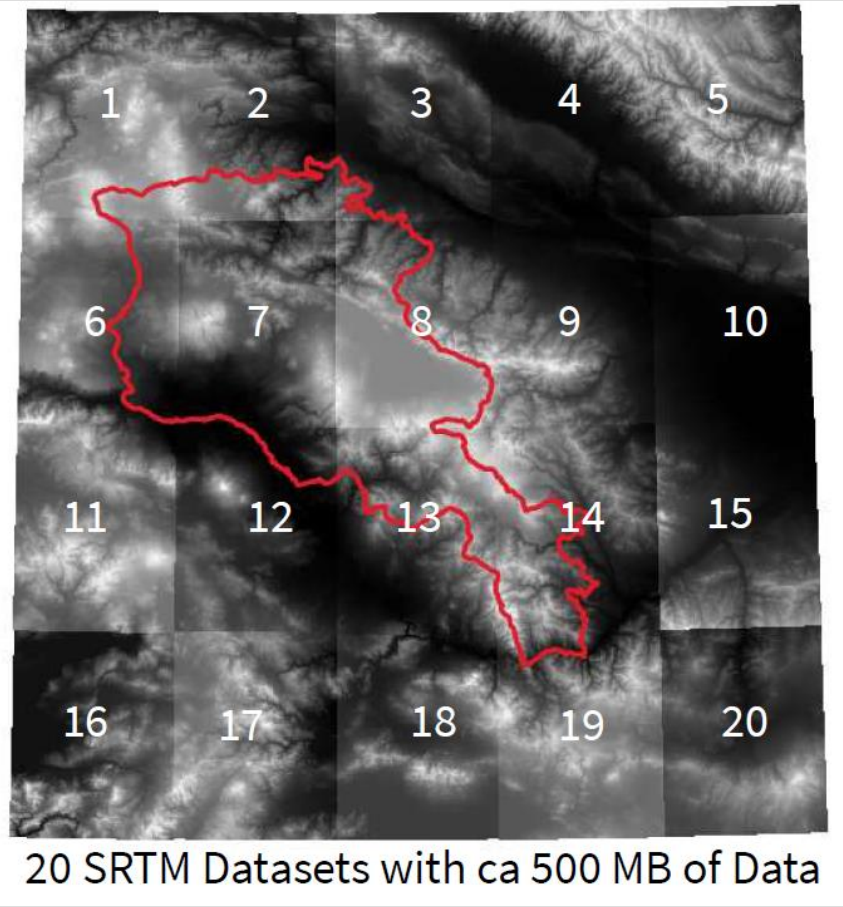
Google Earth Engine

esri

What software to use?

https://www.qgis.org/en/site/

Data mosaicking and resampling



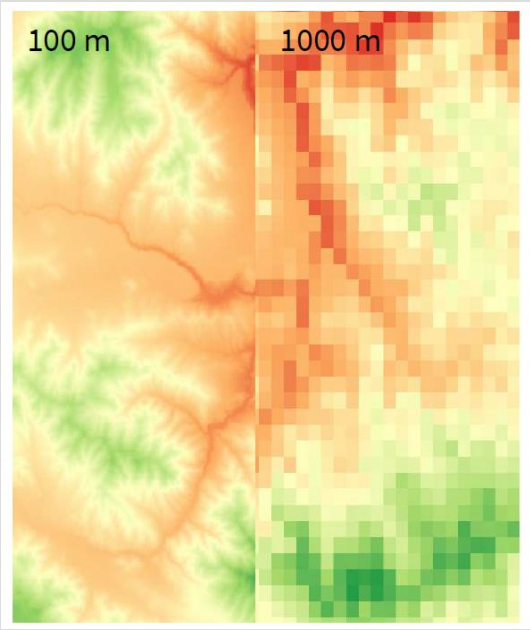
SRTM data is distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/EROS, Sioux Falls, SD. http://lpdaac.usgs.gov) .
Boundary from DIVA-GIS. These data were extracted from the GADM database (www.gadm.org), version 2.5, July 2015.

- ✓ SRTM data
- ✓ Vector data (boundaries, rivers, …)

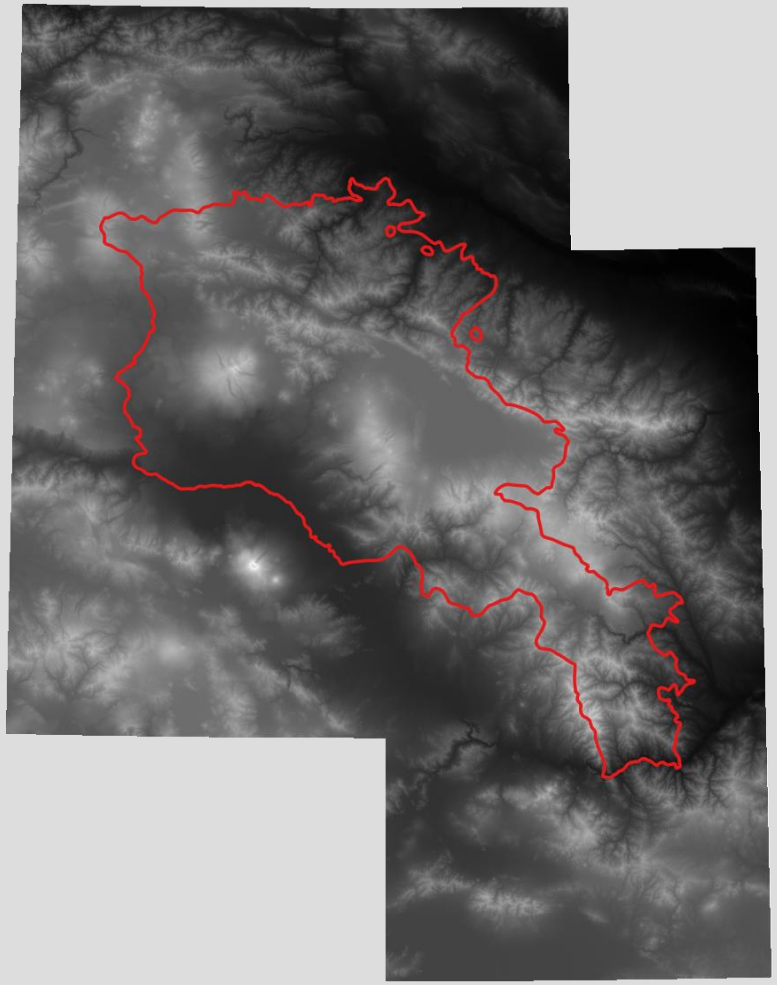
Original data: 20 SRTM tiles with 30 m resolution (~500 MB) required?

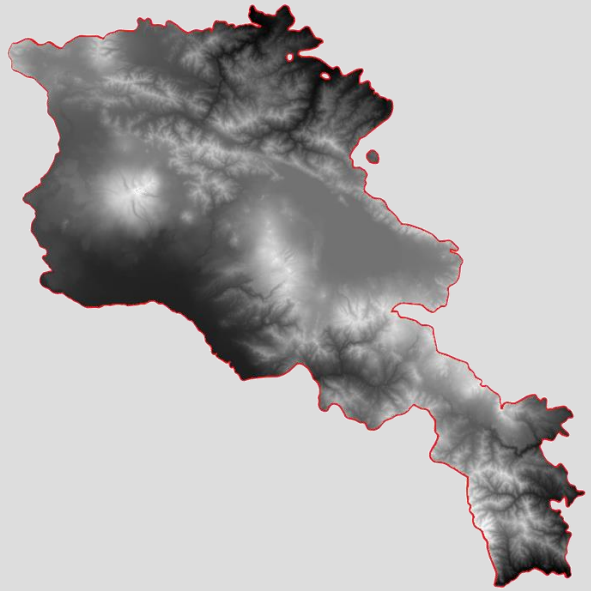
→ Resampling to 100 m

→ Mosaicking the tiles



Clipping the data





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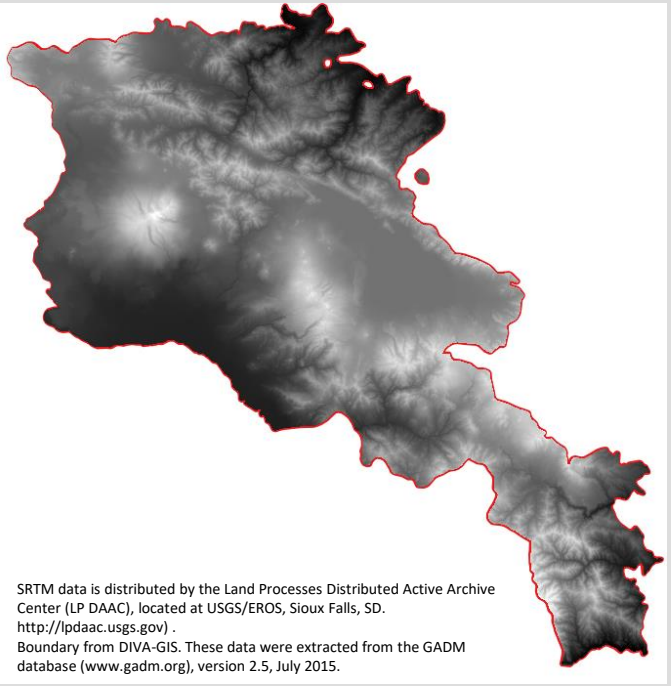
Understanding the data



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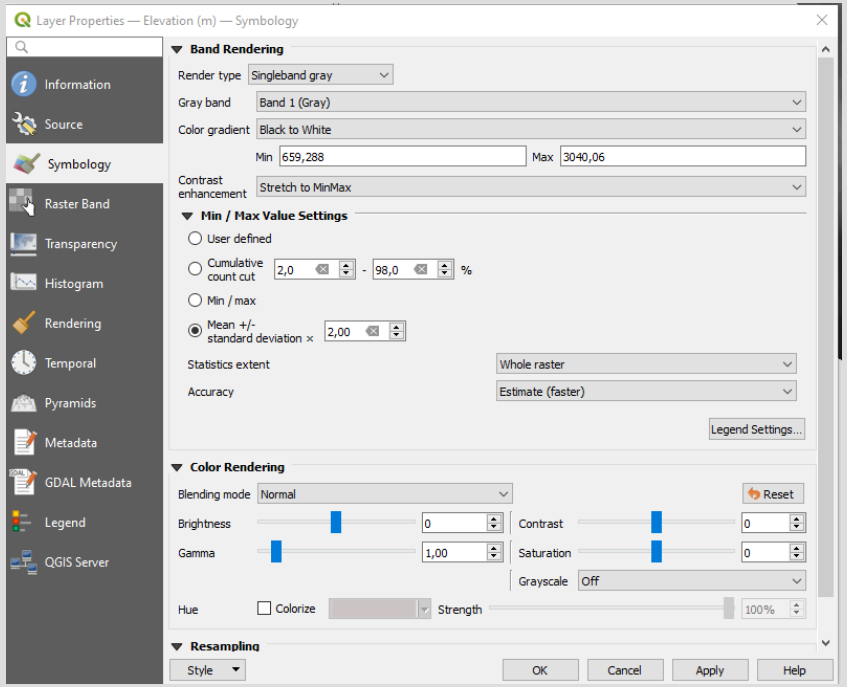
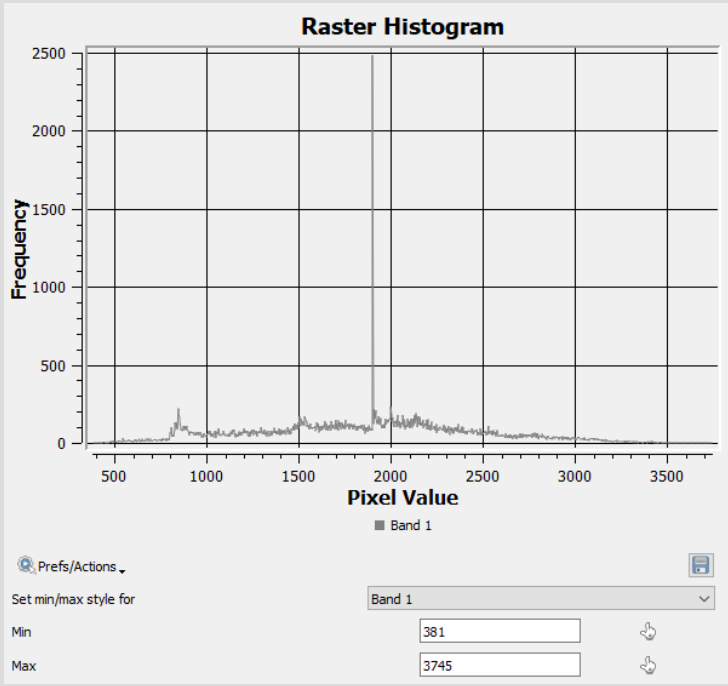
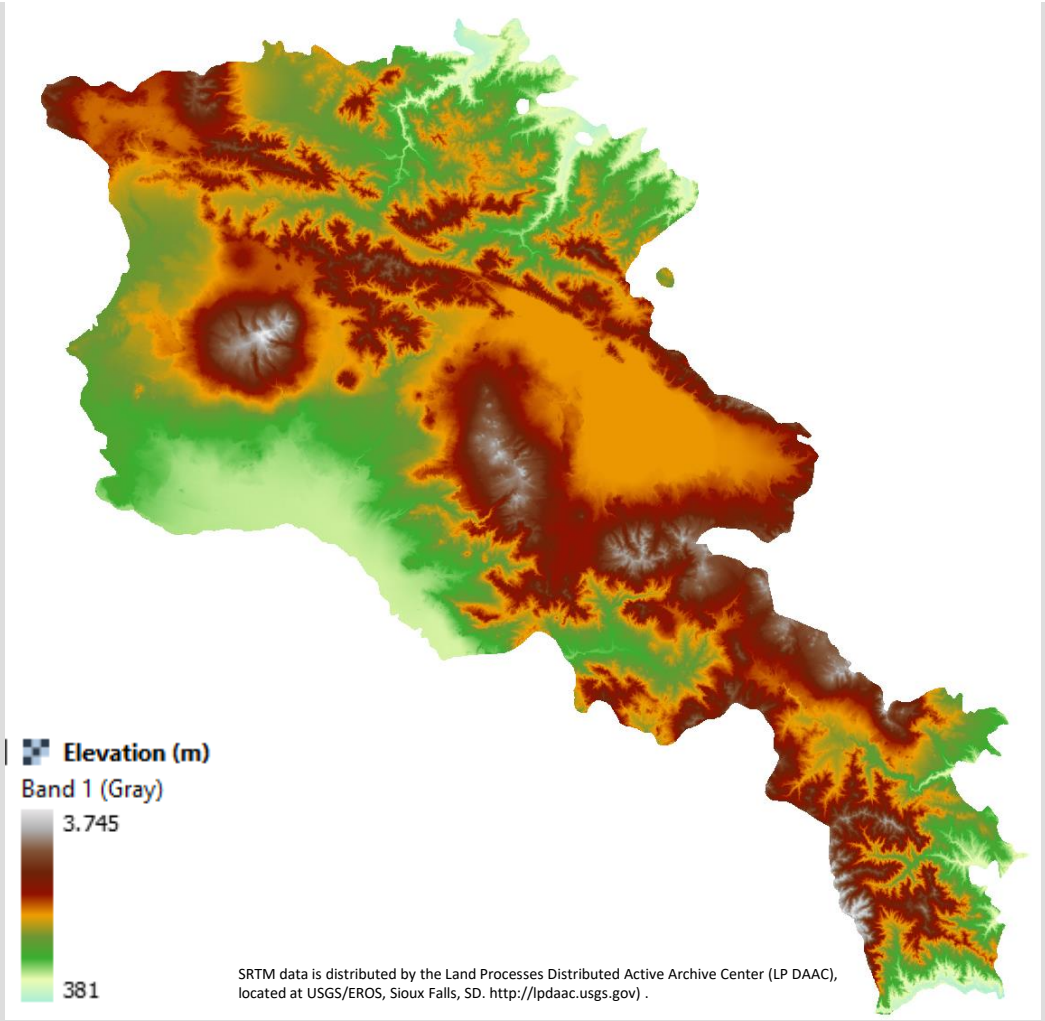
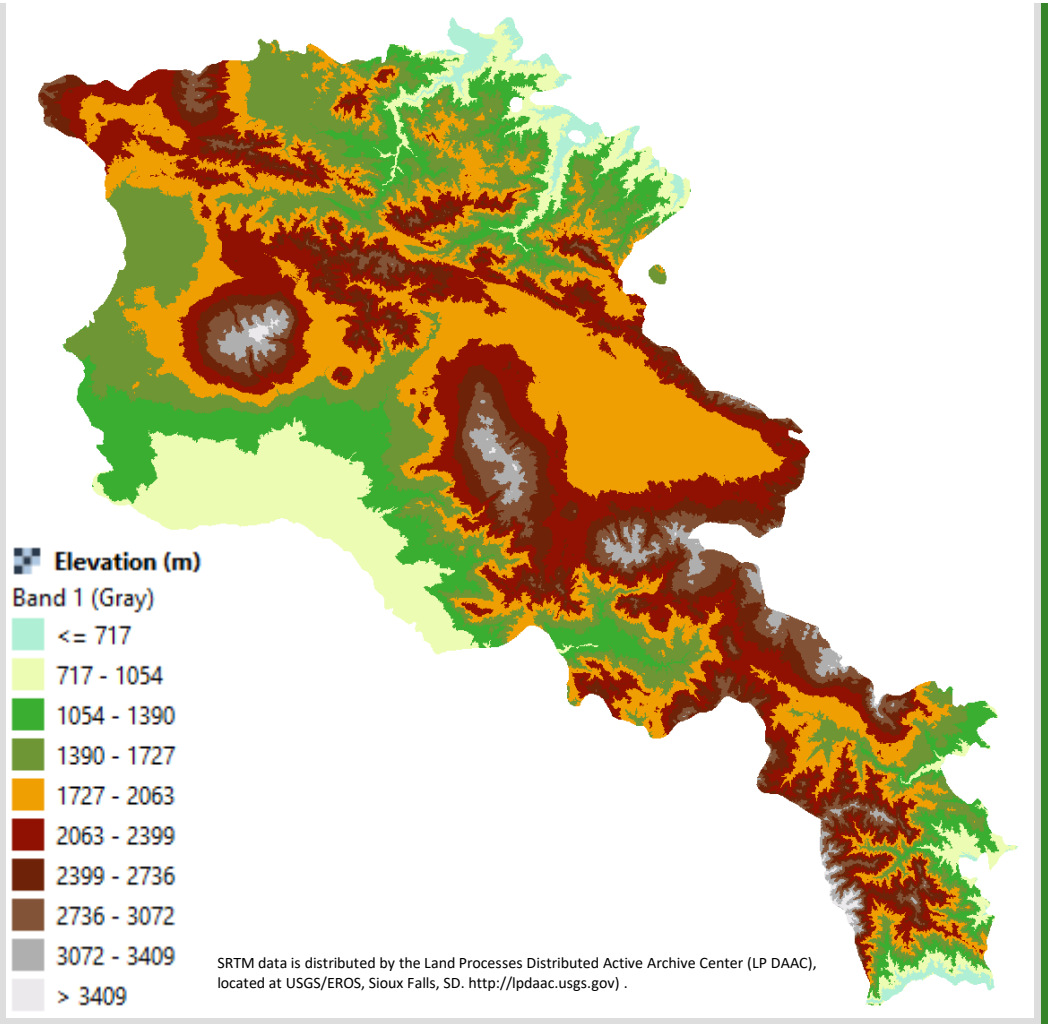




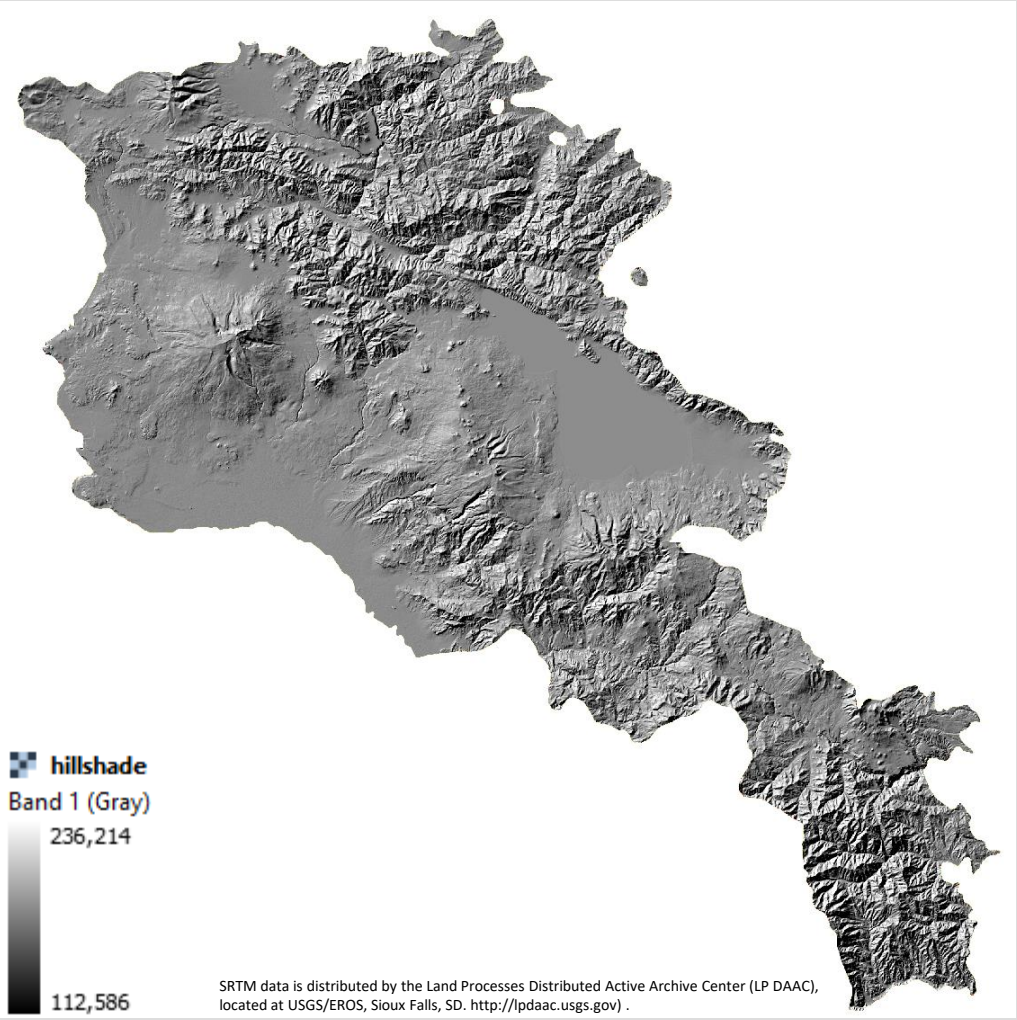
- Understand what the pixel values tell you
- Take a look at the data distribution using a histogram
- Stretch the histogram (if necessary)

Visualise elevation data





Hillshade



- A hillshade is a simulated illumination according to defined azimuth and zenith angles of an „articifial light source“
- Use sun position calculators to simulate different illumination conditions at specific days and daytimes → shadow detection in remote sensing imagey

Derivation of terrain parameters

- **Local morphometric parameters**

  (e.g. slope, aspect, curvature)

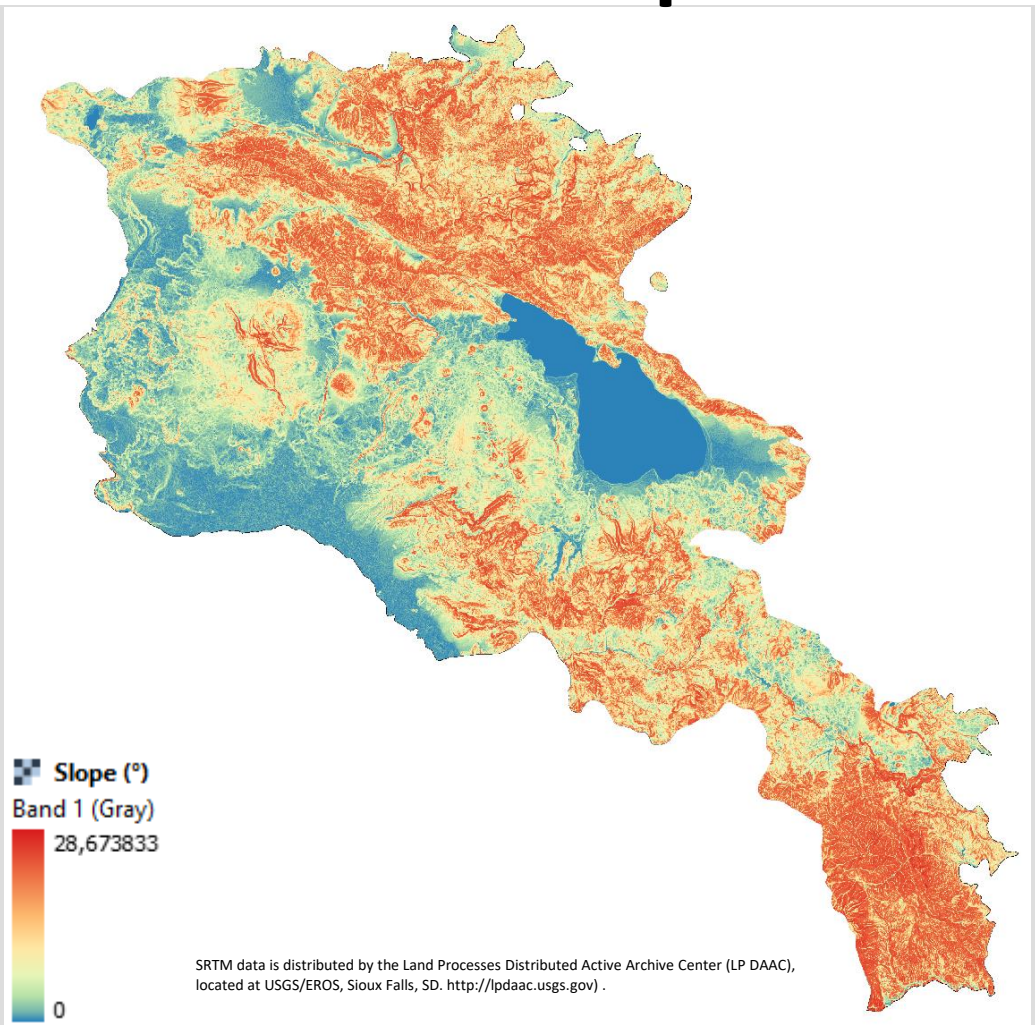
- **Complex morphometric parameters**

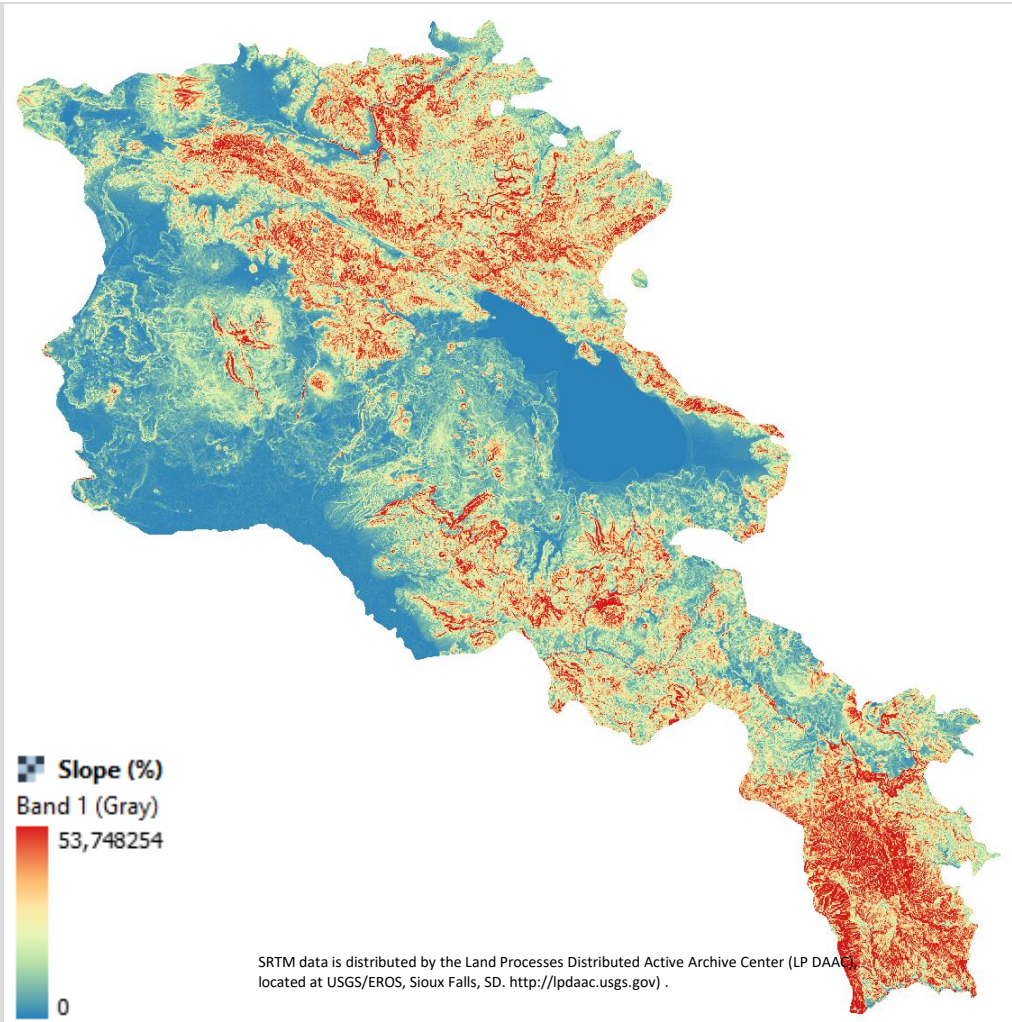
  (e.g. soil moisture index, catchment areas)

- **Combined morphometric parameters**

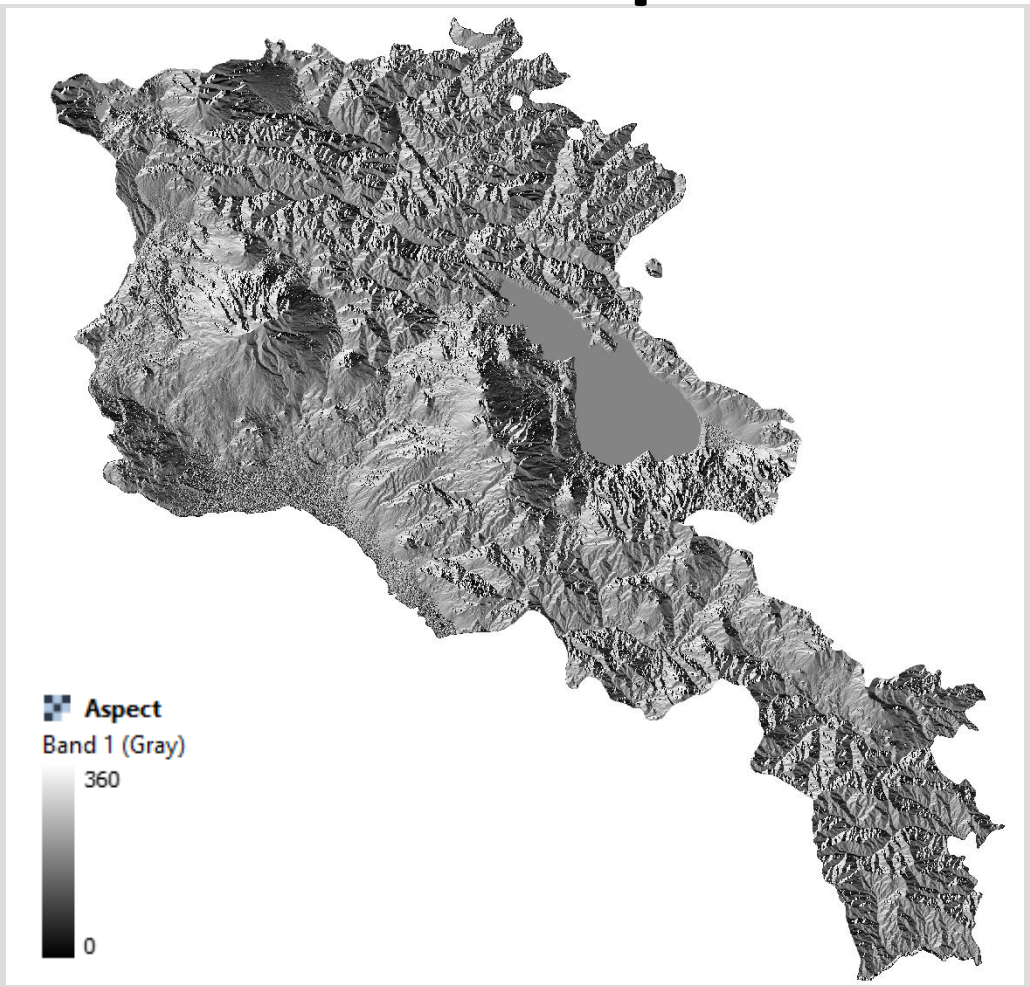
  (e.g. Terrain Classification Index for Lowlands)

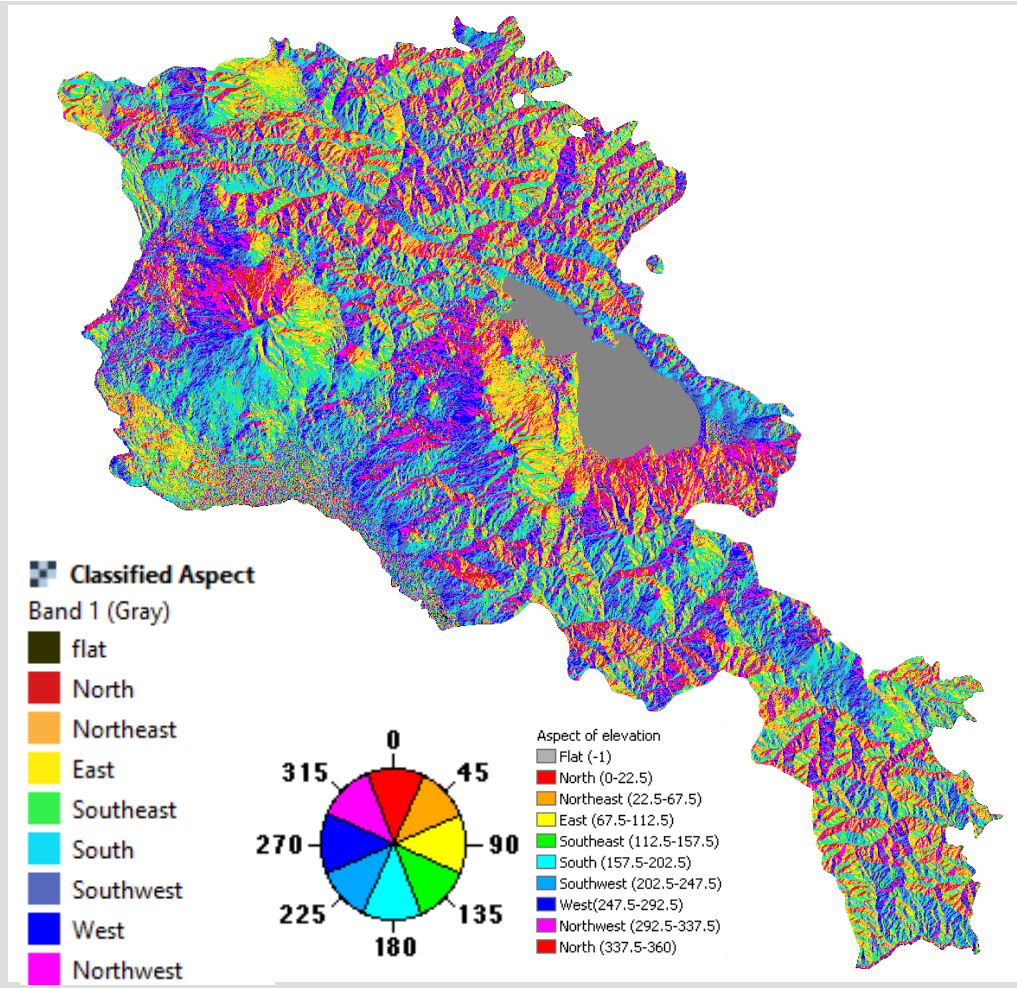
Calculate the slope





Calculate the aspect





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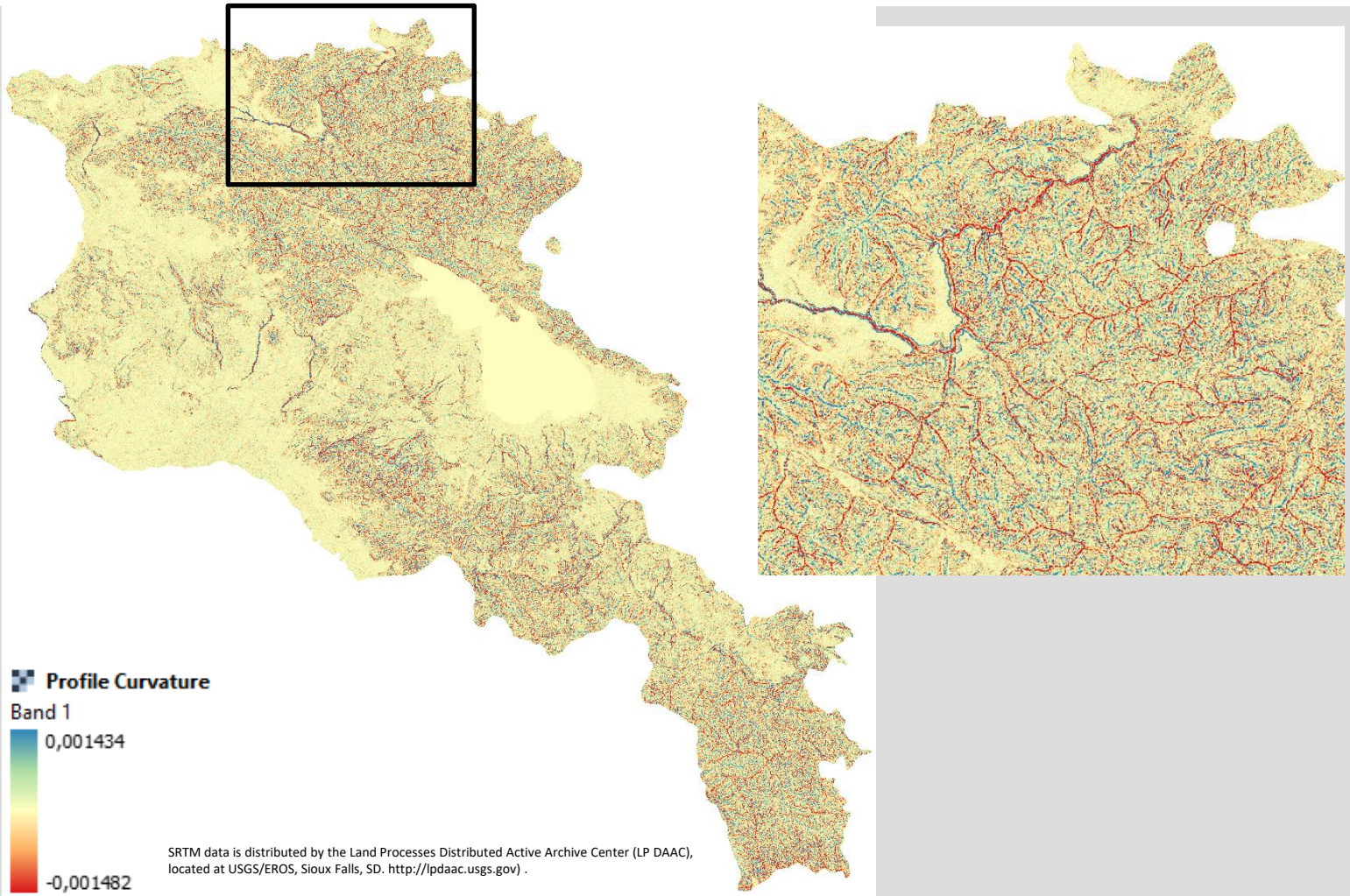
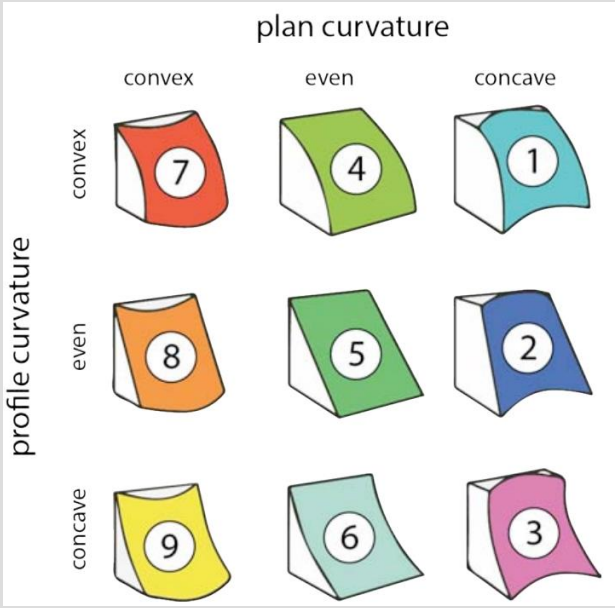
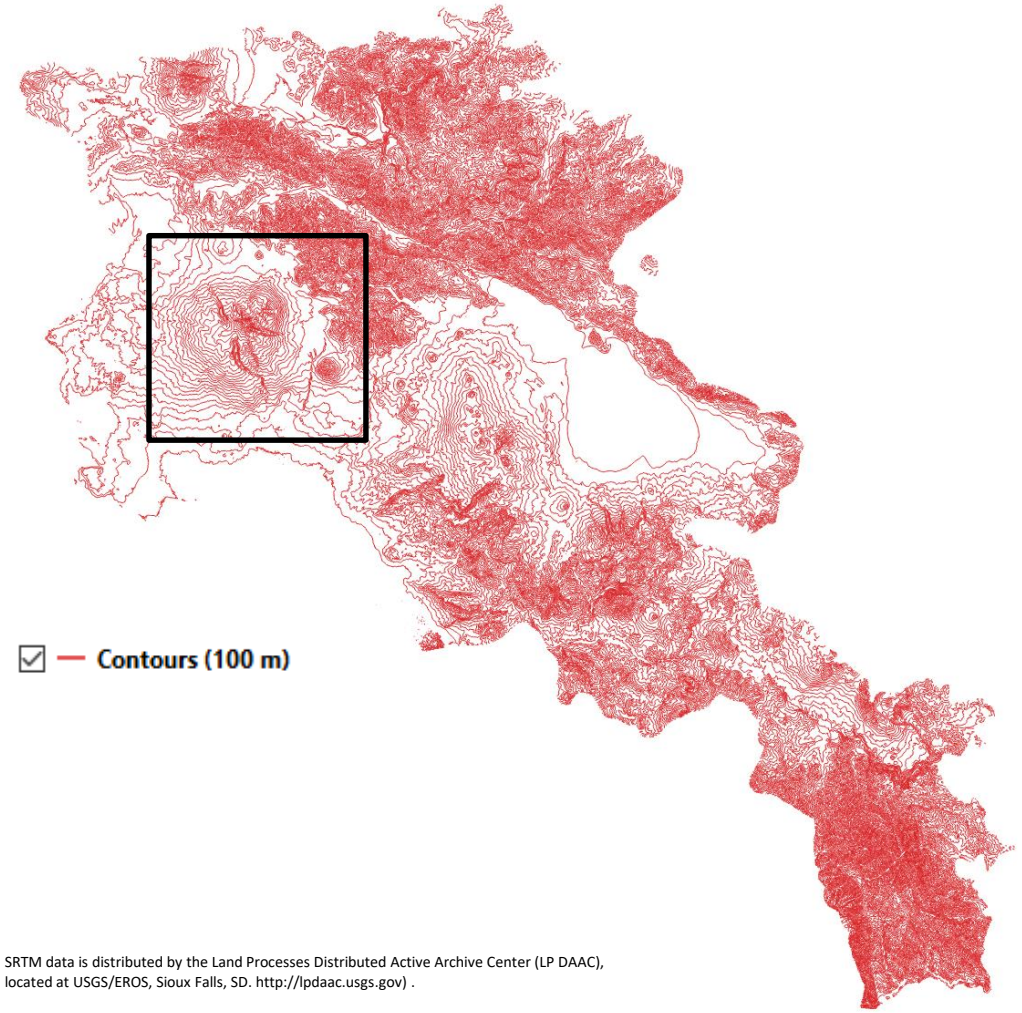
Calculate the curvature





Source: Vontobel et al. 2013: https://arc.lib.montana.edu/snow-science/objects/ISSW13_paper_O5-05.pdf

Derivation of contour lines



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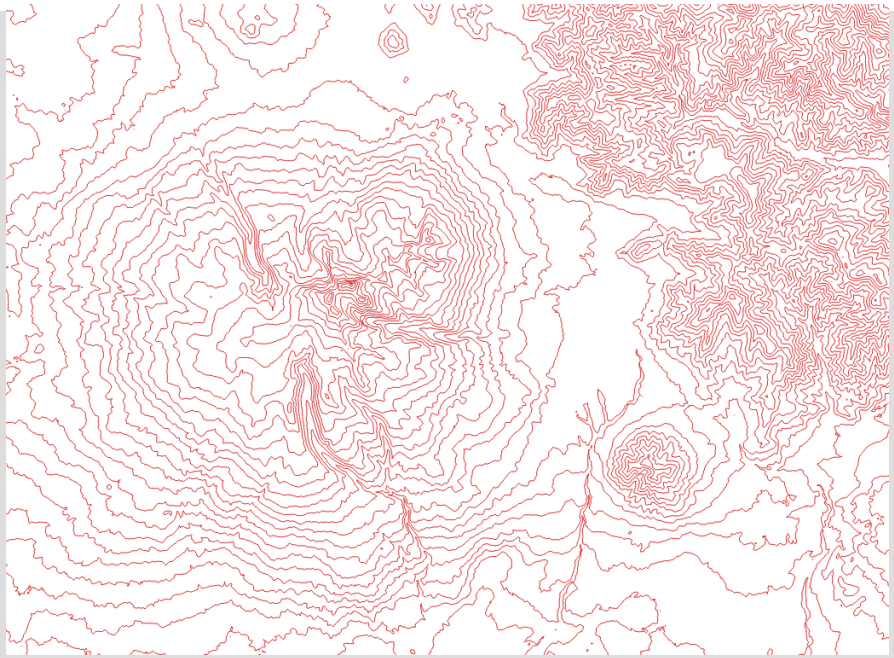
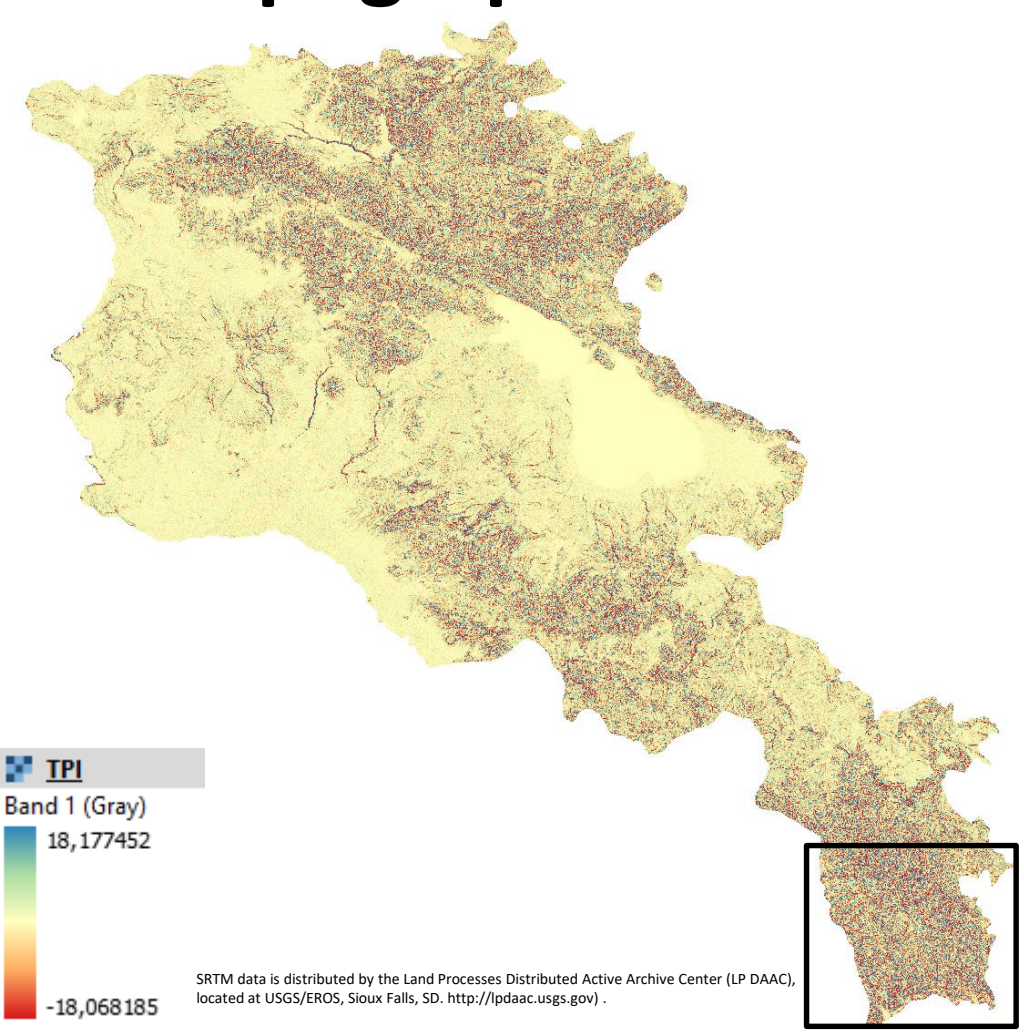


Topographic Position Index (TPI)



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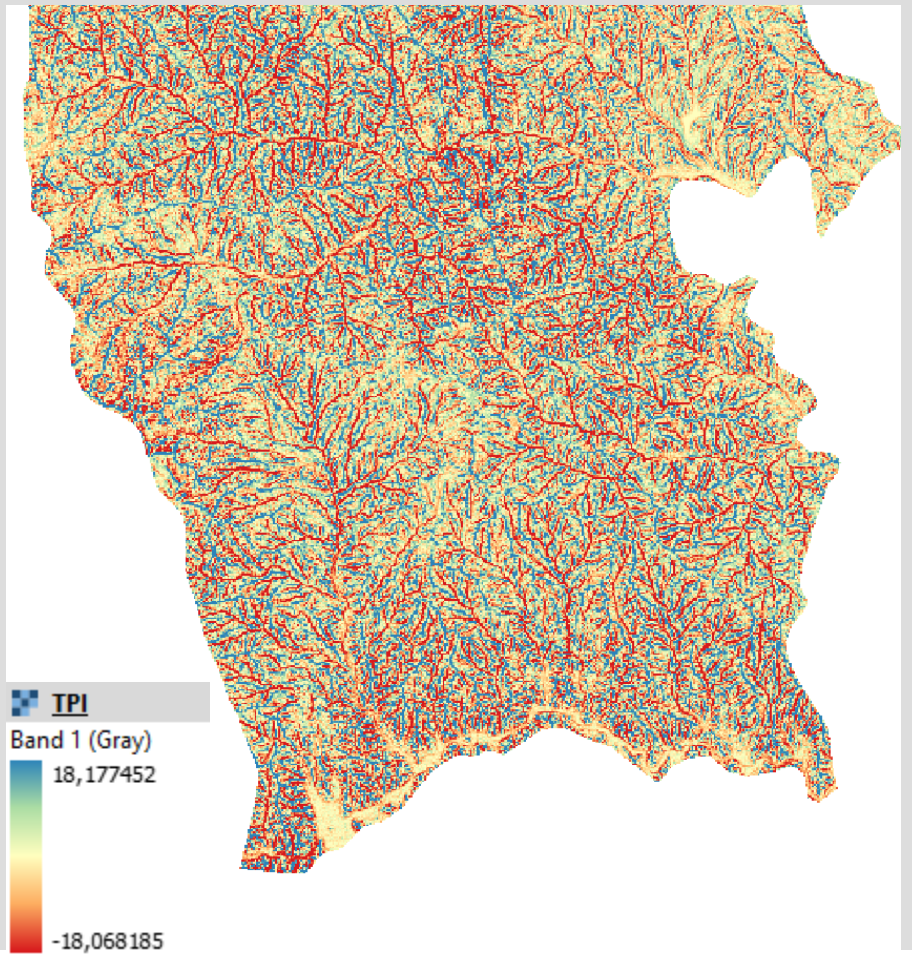
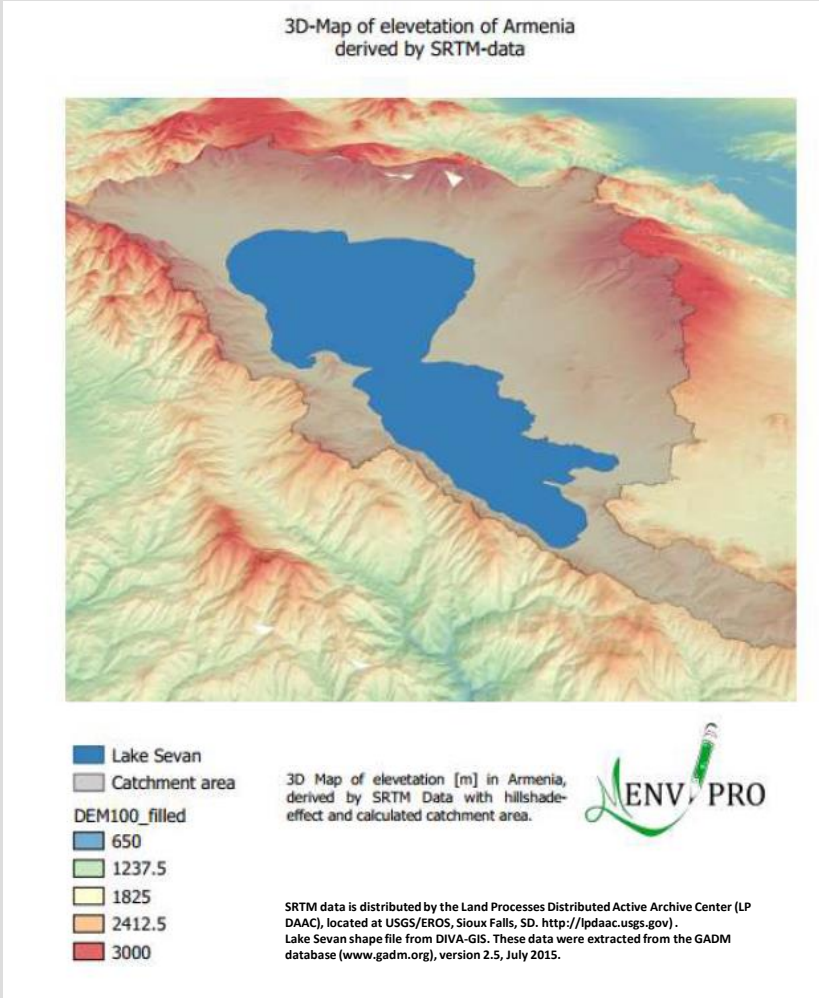


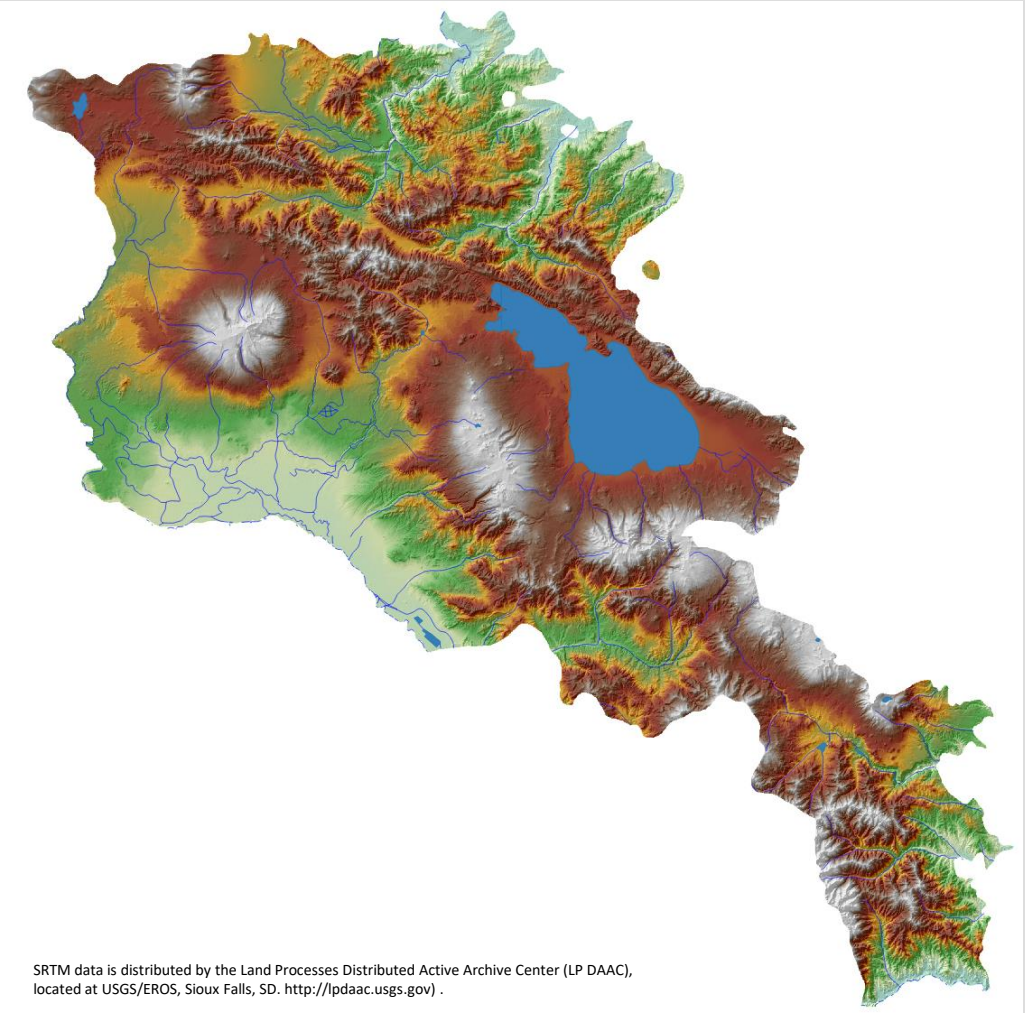
Hydrological analysis

Analysis of catchment areas, watersheds, flow direction, flow accumulation, etc.

→ Tutorial for modelling the catchment area of lake Sevan using free geodata and QGIS by Max Hörold



Combine different layers



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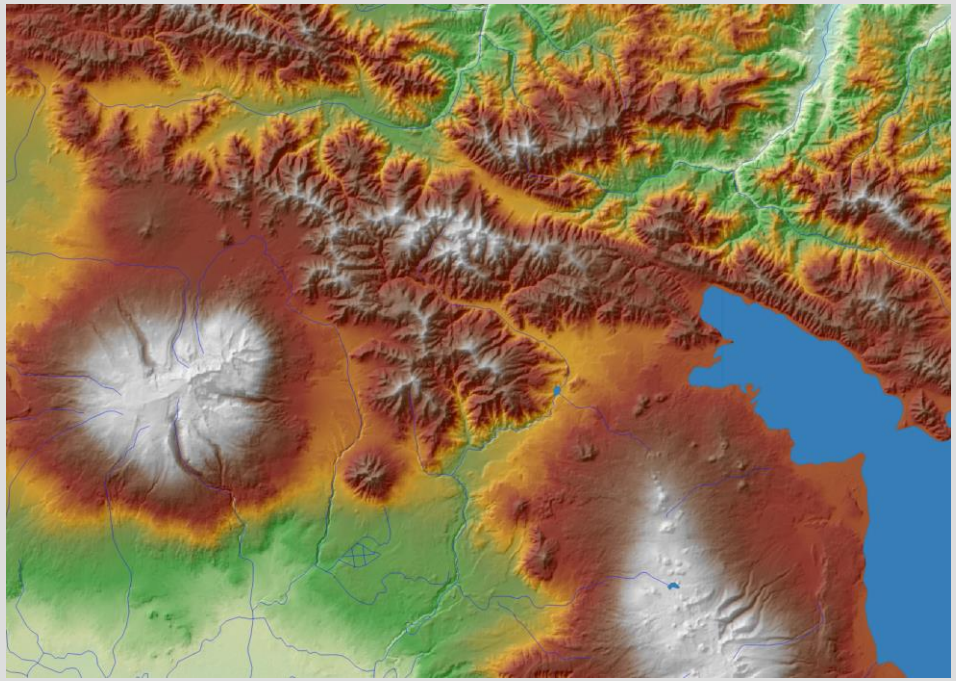
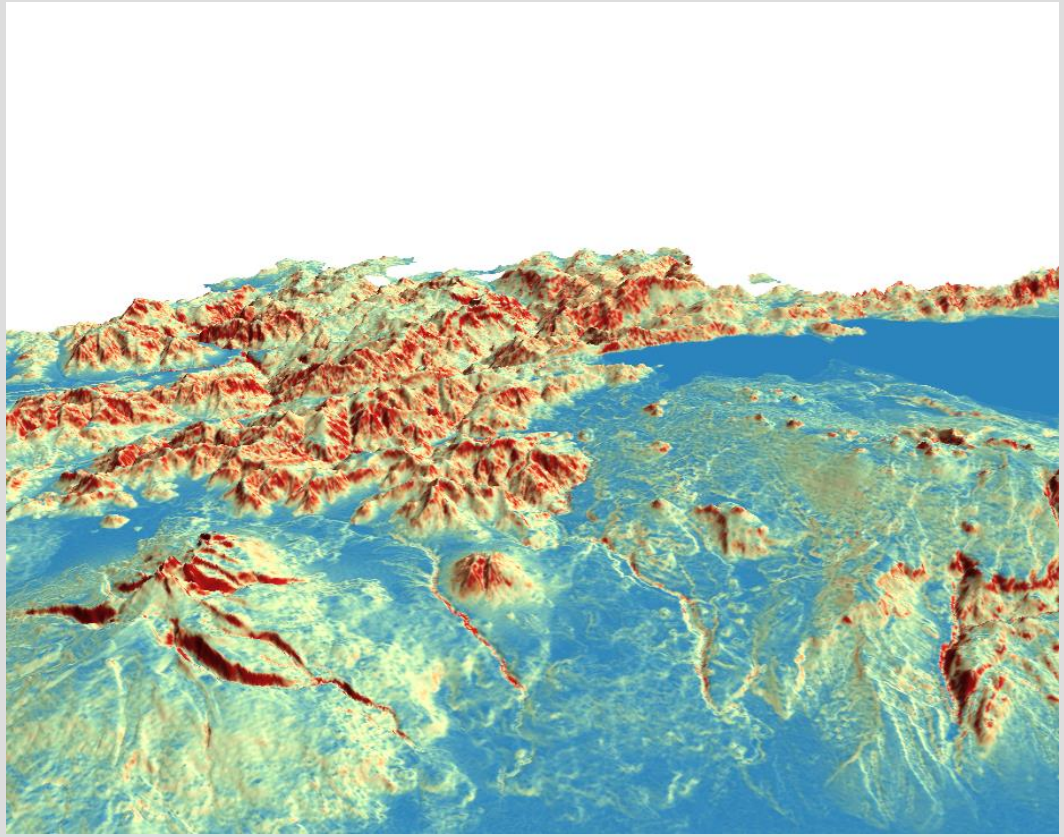
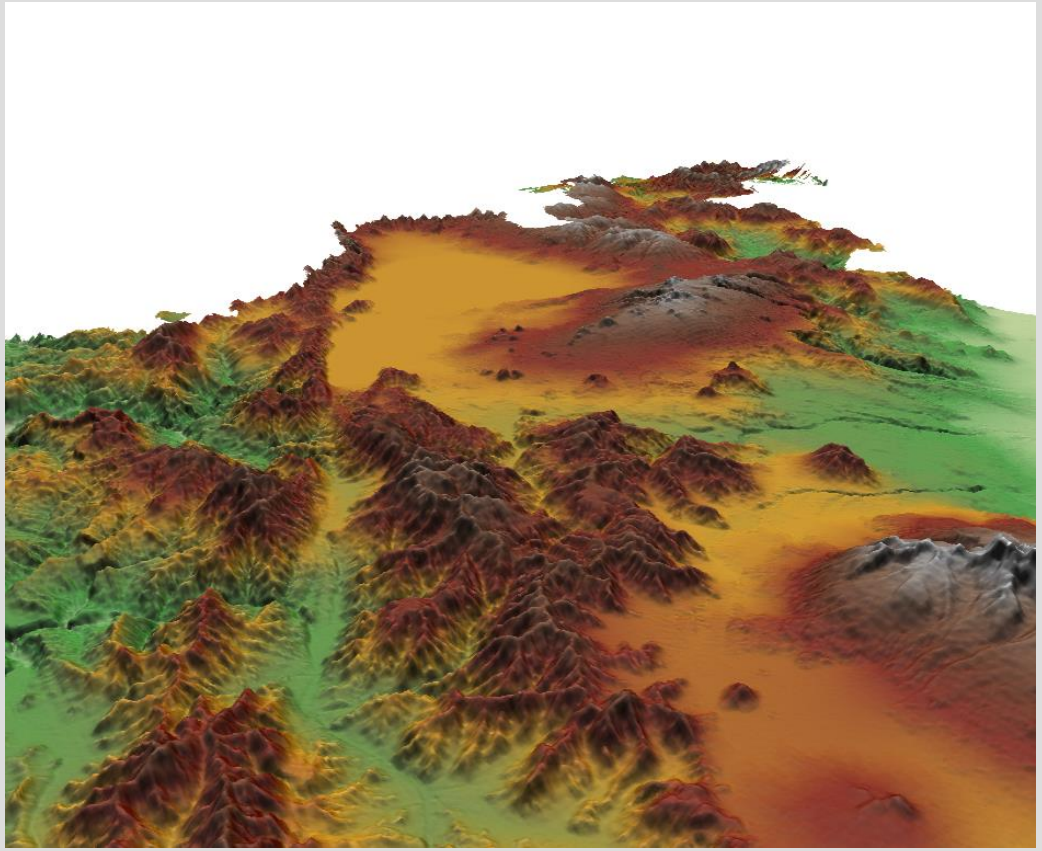


Visualision in 3D





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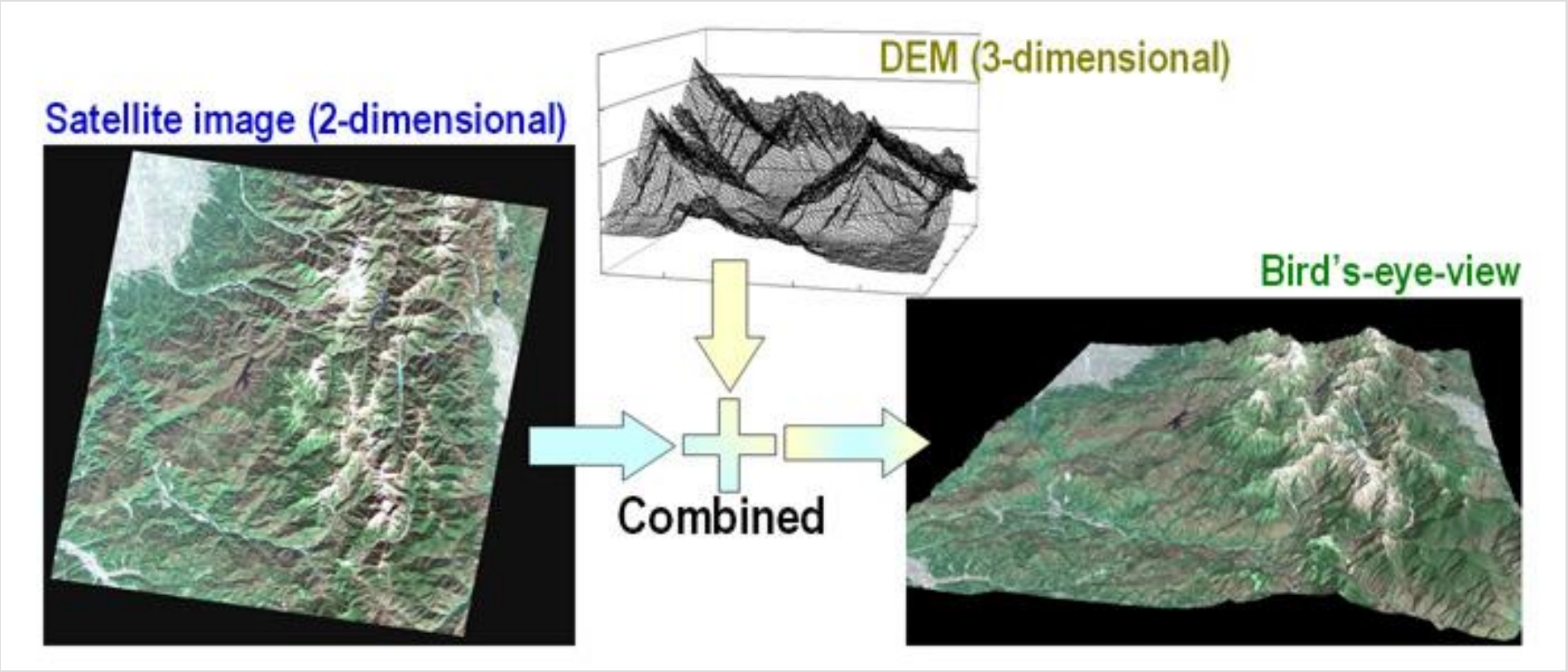
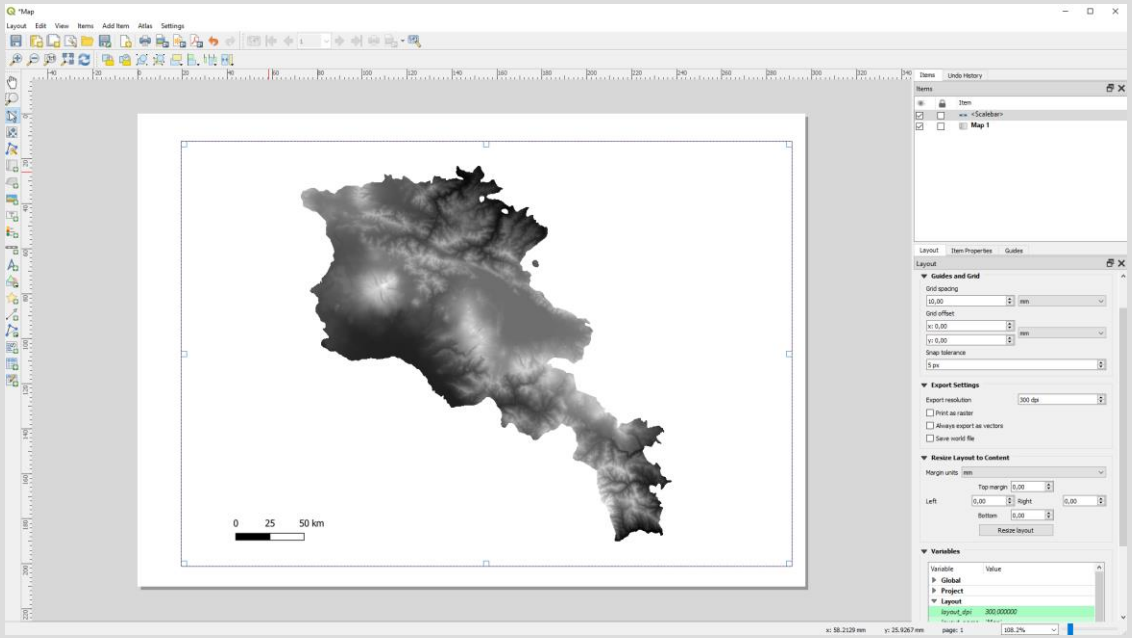
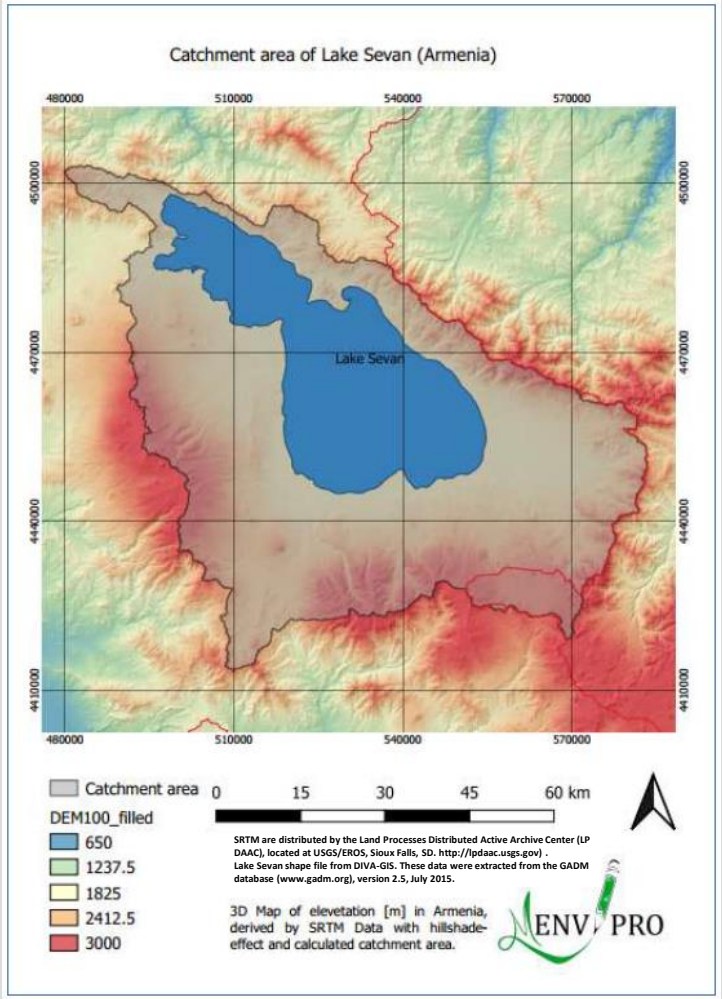


Source: https://ssl.jspacesystems.or.jp/ersdac/GDEM/E/2.html

Produce a map





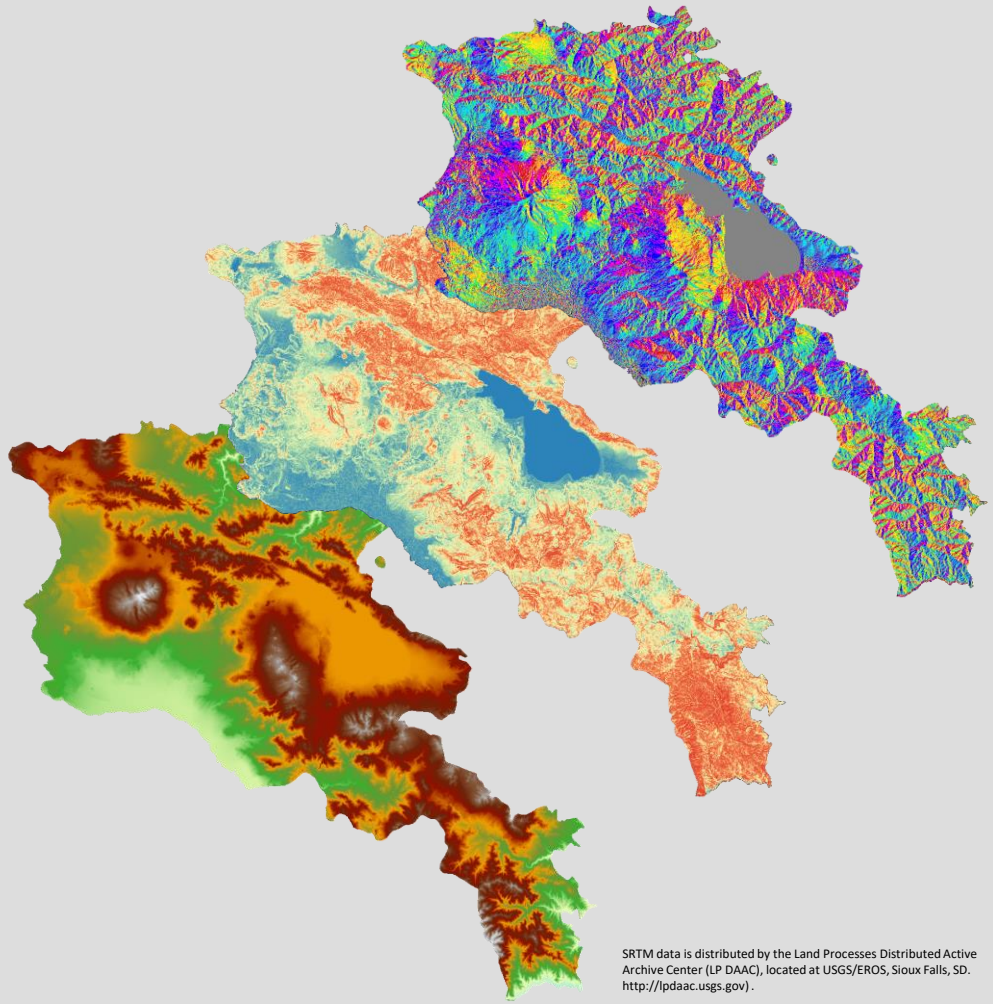
Important map elements:

- Title, legend, north arrow, scale bar
- Info on the coordinate system
- **Data sources, copyright info**
- Info on author and institution

Co-funded by the
Erasmus+ Programme
of the European Union

Thank you for your kind attention!

Dr. Michael Denk
michael.denk@geo.uni-halle.de



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