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The Environmental Science Education for Sustainable Human Health

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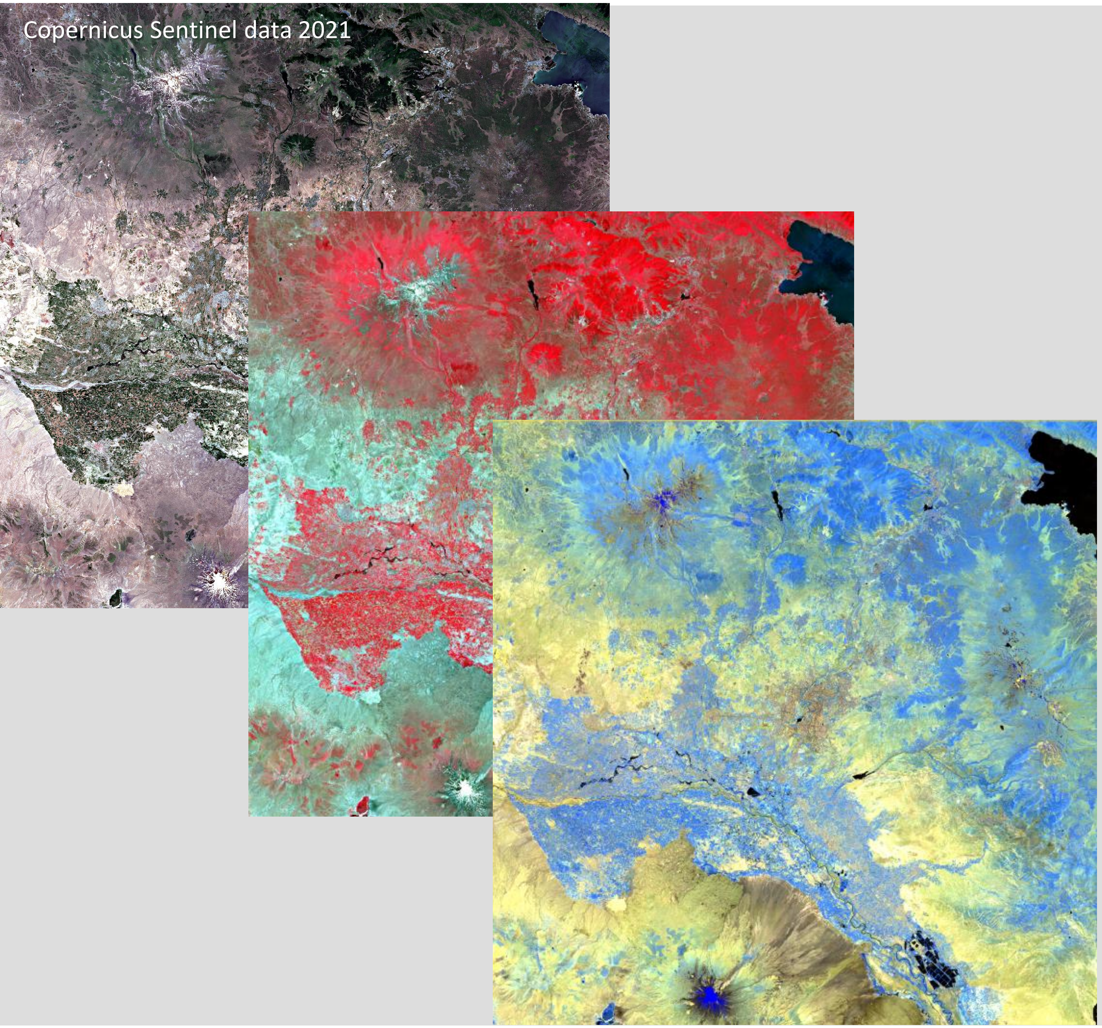


Remote Sensing for Land Cover Mapping and Analysis

Dr. Michael Denk

Institute of Geosciences and Geography
Martin Luther University Halle-Wittenberg

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. **Introduction to Land Cover/Land Use**

II. **General workflow for analyzing Earth Observation data**

- Data acquisition
- Data pre-processing
- Data visualisation & interpretation
- **Land cover analysis via indices & classification**
- Post classification / validation

Literature recommendations

Introduction to Land Cover / Land Use classification systems

Land Cover Classification Systems

Land Cover: Biophysical cover of the Earth´s surface, including natural as well as man-made materials

Land Use: Refers to the function and purpose of the land cover

Classification: Arrangement of data in groups or categories following specific data characteristics

Land Cover Classification Systems: “systematic framework with the name of the classes and the criteria used to distinguish them, and the relation between classes” (di Gregorio and Jansen 1997)

USGS Land Cover Classification Systems

A Land Use and Land Cover Classification System for Use with Remote Sensor Data

By JAMES R. ANDERSON, ERNEST E. HARDY, JOHN T. ROACH, *and* RICHARD E. WITMER

After Anderson et al. 1976:

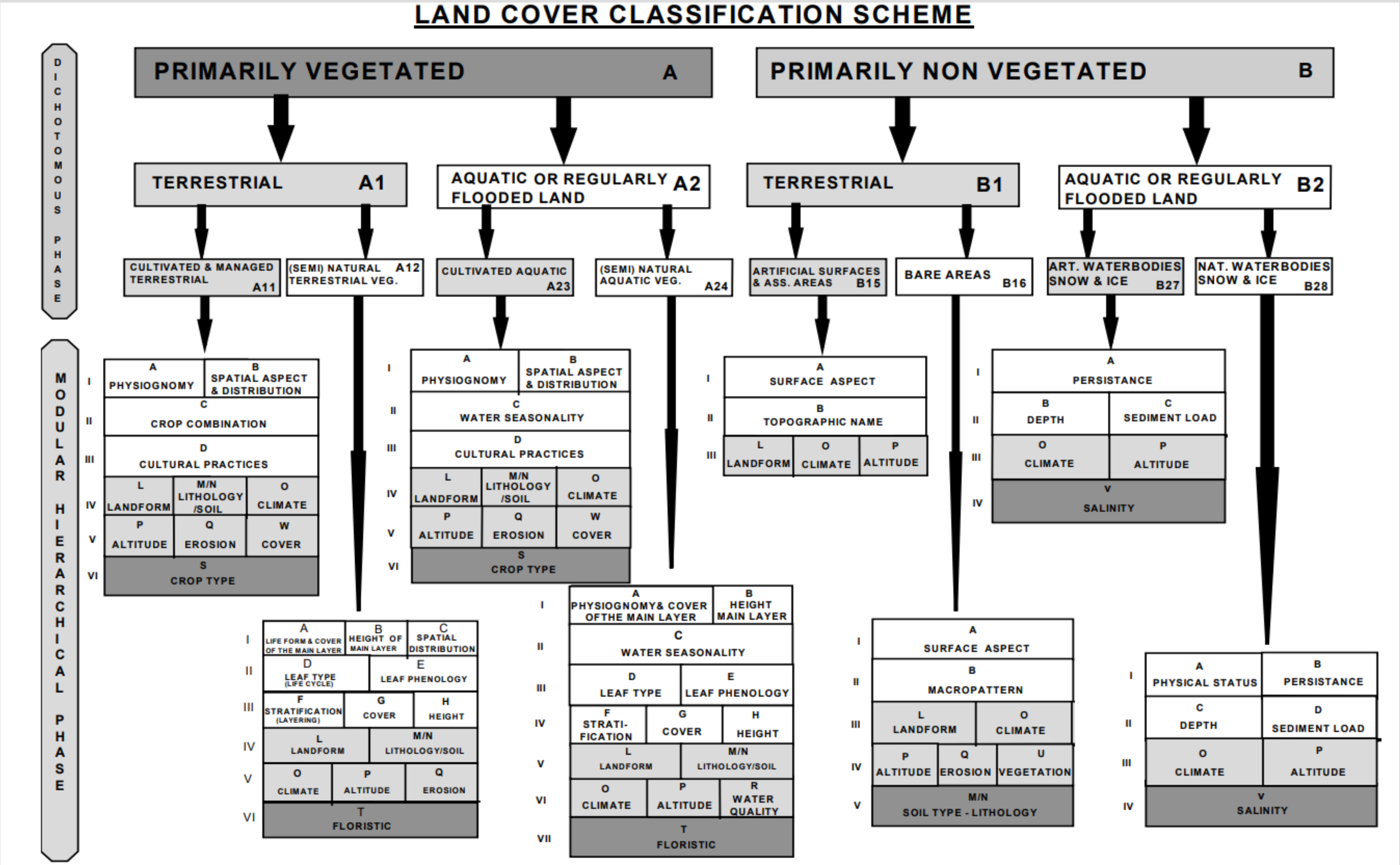
- Nine major land cover categories
- 37 sub-categories
- Scale: 1:250000 and 1:100000
- Successor: USGS's National Land Cover Data (NLCD)

1	Urban or Built-up Land	11	Residential.
		12	Commercial and Services.
		13	Industrial.
		14	Transportation, Communications, and Utilities.
		15	Industrial and Commercial Complexes.
		16	Mixed Urban or Built-up Land.
		17	Other Urban or Built-up Land.
2	Agricultural Land	21	Cropland and Pasture.
		22	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas.
		23	Confined Feeding Operations.
		24	Other Agricultural Land.
3	Rangeland	31	Herbaceous Rangeland.
		32	Shrub and Brush Rangeland.
		33	Mixed Rangeland.
4	Forest Land	41	Deciduous Forest Land.
		42	Evergreen Forest Land.
		43	Mixed Forest Land.
5	Water	51	Streams and Canals.
		52	Lakes.
		53	Reservoirs.
		54	Bays and Estuaries.
6	Wetland	61	Forested Wetland.
		62	Nonforested Wetland.
7	Barren Land	71	Dry Salt Flats.
		72	Beaches.
		73	Sandy Areas other than Beaches.
		74	Bare Exposed Rock.
		75	Strip Mines. Quarries, and Gravel Pits.
		76	Transitional Areas.
		77	Mixed Barren Land.
8	Tundra	81	Shrub and Brush Tundra.
		82	Herbaceous Tundra.
		83	Bare Ground Tundra.
		84	Wet Tundra.
		85	Mixed Tundra.
9	Perennial Snow or Ice	91	Perennial Snowfields.
		92	Glaciers.

FAO LCCS

- Developed by FAO and UNEP
- 2 main phases:
  I. Dichotomous phase → 8 major land cover types
  II. Modular-Hierarchical Phase in "which land cover classes are created by the combination of sets of pre-defined classifiers, which are different for each of the eight major land cover types. "
- Further information:
  - http://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1036361/
  - http://www.fao.org/3/x0596e/x0596e00.htm

FAO LCCS



Credit: Gregorio & Jansen 1998

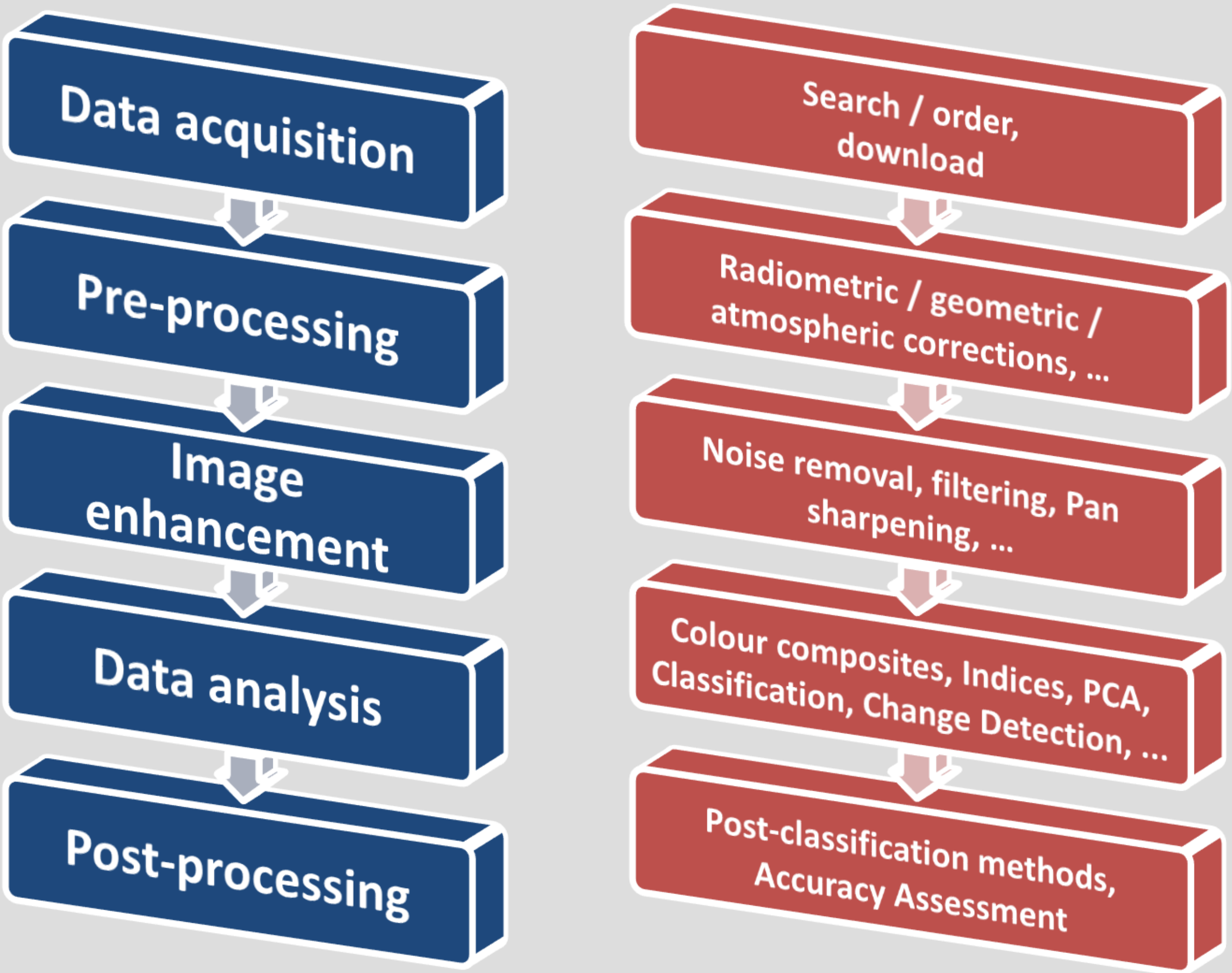
CORINE Land Cover Classification System

- CORINE = Coordination of Information on the Environment
- Programme initiated by the European Commission in 1985
- Commissioned by the European Environment Agency (EEA)
- 13 main and 44 sub LULC classes
- Use of satellite imagery data
- Reference years: 1990, 2000, 2006, 2012, 2018.
- Scale: 1:100,000, MMU: 25 ha
- Further info: https://land.copernicus.eu/pan-european/corine-land-cover

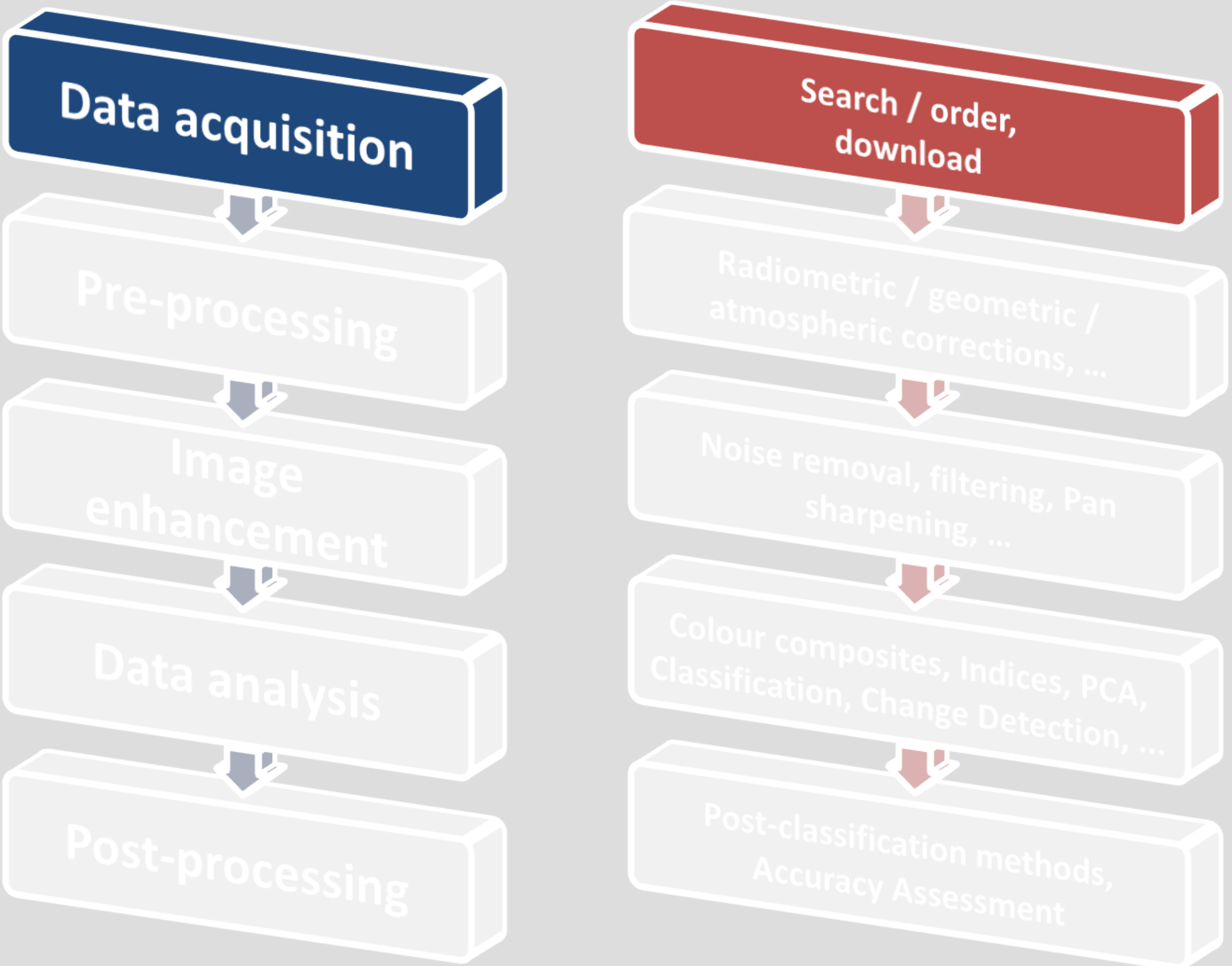
CORINE Land Cover 2006 for Germany
Credit: Umweltbundesamt

General workflow of analysing Earth Observation data - Let´s analyse the land cover in Armenia using Sentinel 2 data!

General workflow for satellite image analysis



General workflow for satellite image analysis



Data aqcuisition

Landsat, MODIS, ASTER data archives and others:

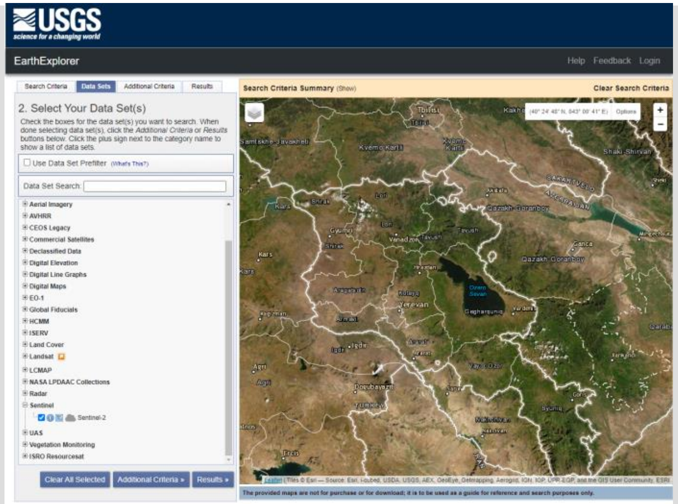
- NASA Earthdata Search
- USGS Earth Explorer, USGS Glovis
- LandsatLook Viewer
- Land Processes Distributed Active Archive Center (LP DAA)
- MODIS: https://modis.gsfc.nasa.gov/tools/
- LAAADS DAAC: https://ladsweb.modaps.eosdis.nasa.gov/

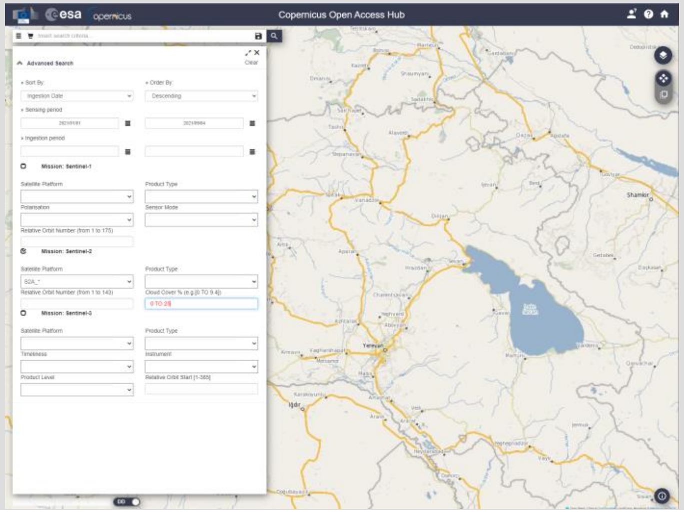
Sentinel data:

- Copernicus Open Access Hub
- Sentinel2Look Viewer
- USGS Earth Explorer, USGS Glovis

GeoEye, IKONOS, Planet, Quickbird, WorldView, …:

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



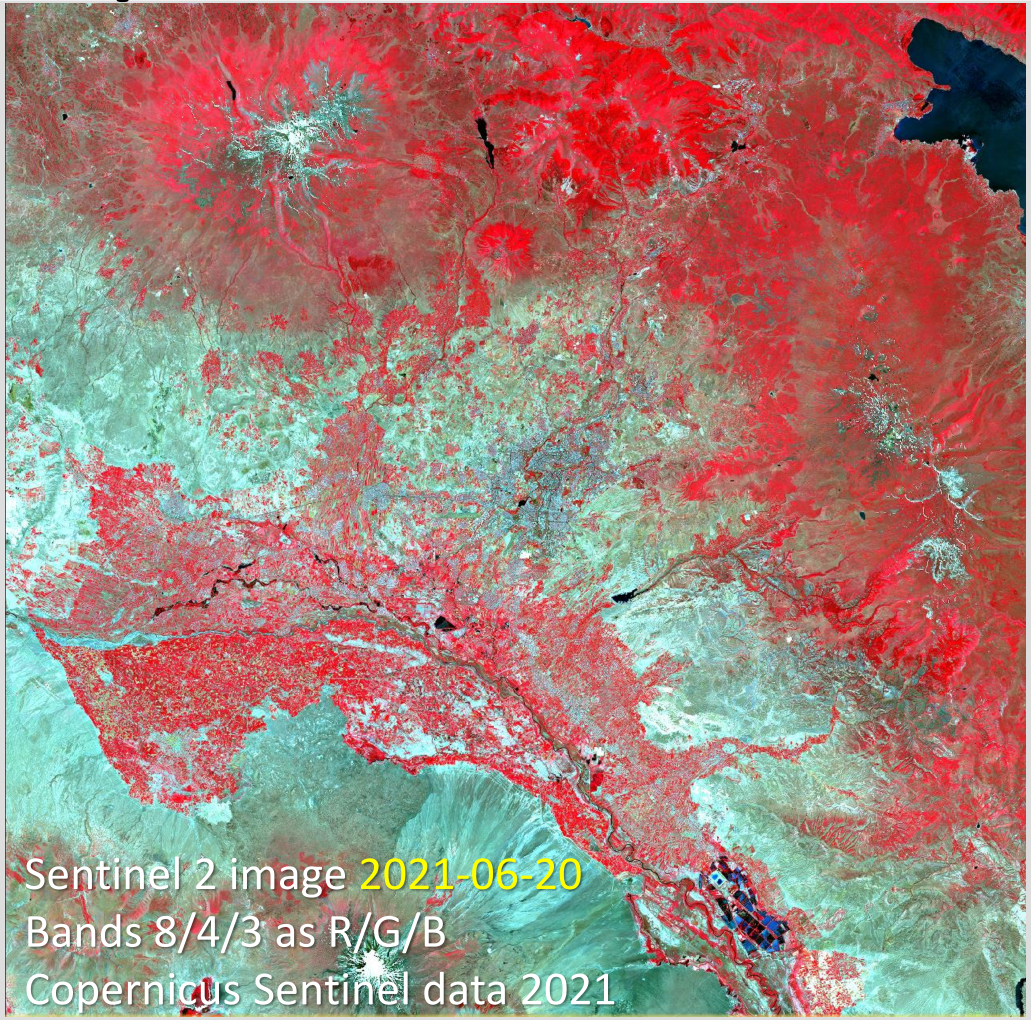


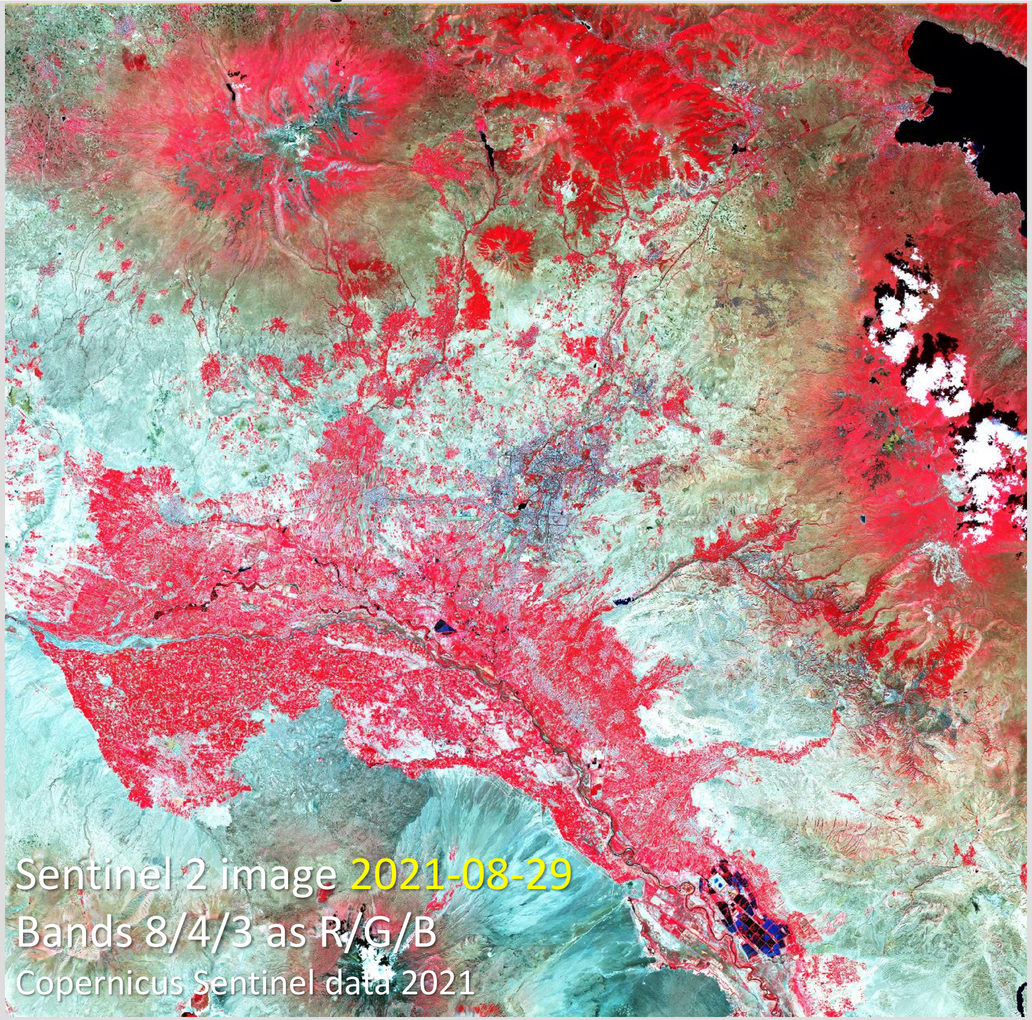
Aspects to consider during data acquisition

- Questions and requirements for sensor and data characteristics! (→ remember the resolutions!)
- Data availability (spatial, temporal)
- Atmospheric conditions, cloud cover
- Price (commercial & free data!)
- Seasonal aspects (rainy/dry season, vegetation period/plant cover, ...)
- Vegetation as disturbing or desirable factor? (possible indicator effects?)

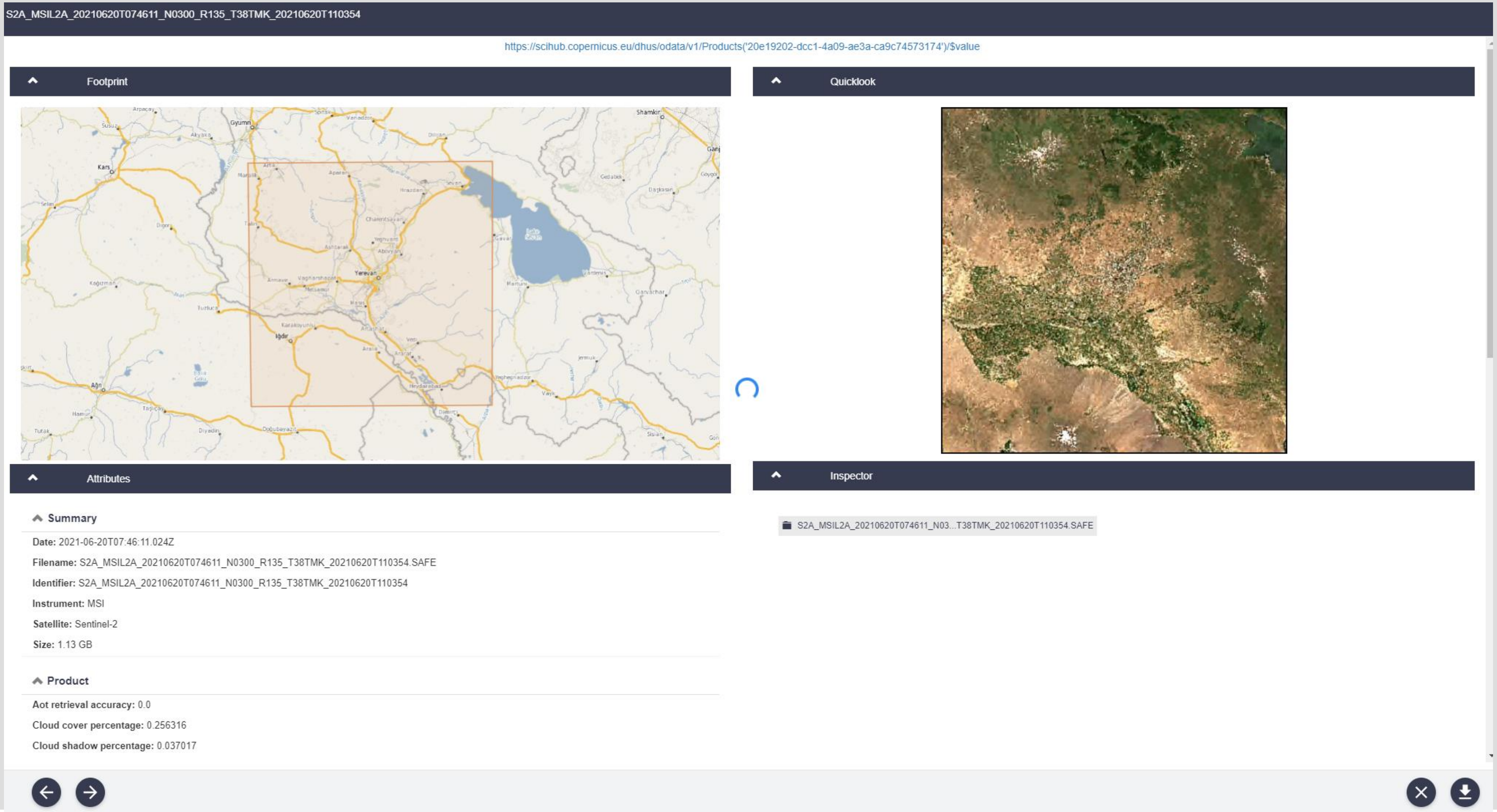
Photos: © Denk

Aspects to consider during data acquisition



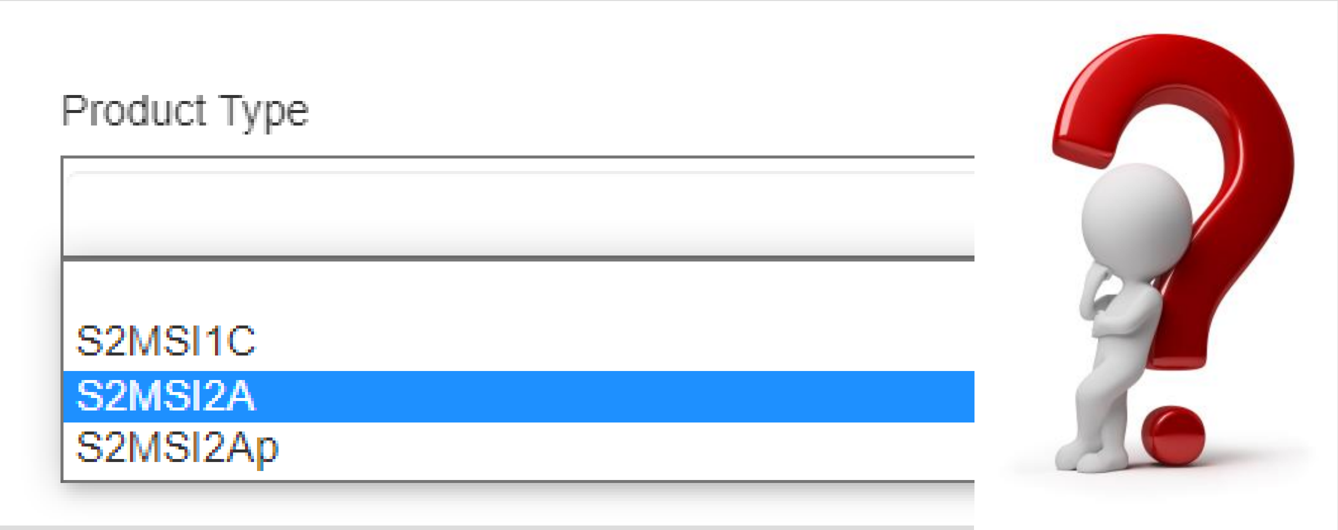


Select the right data sets

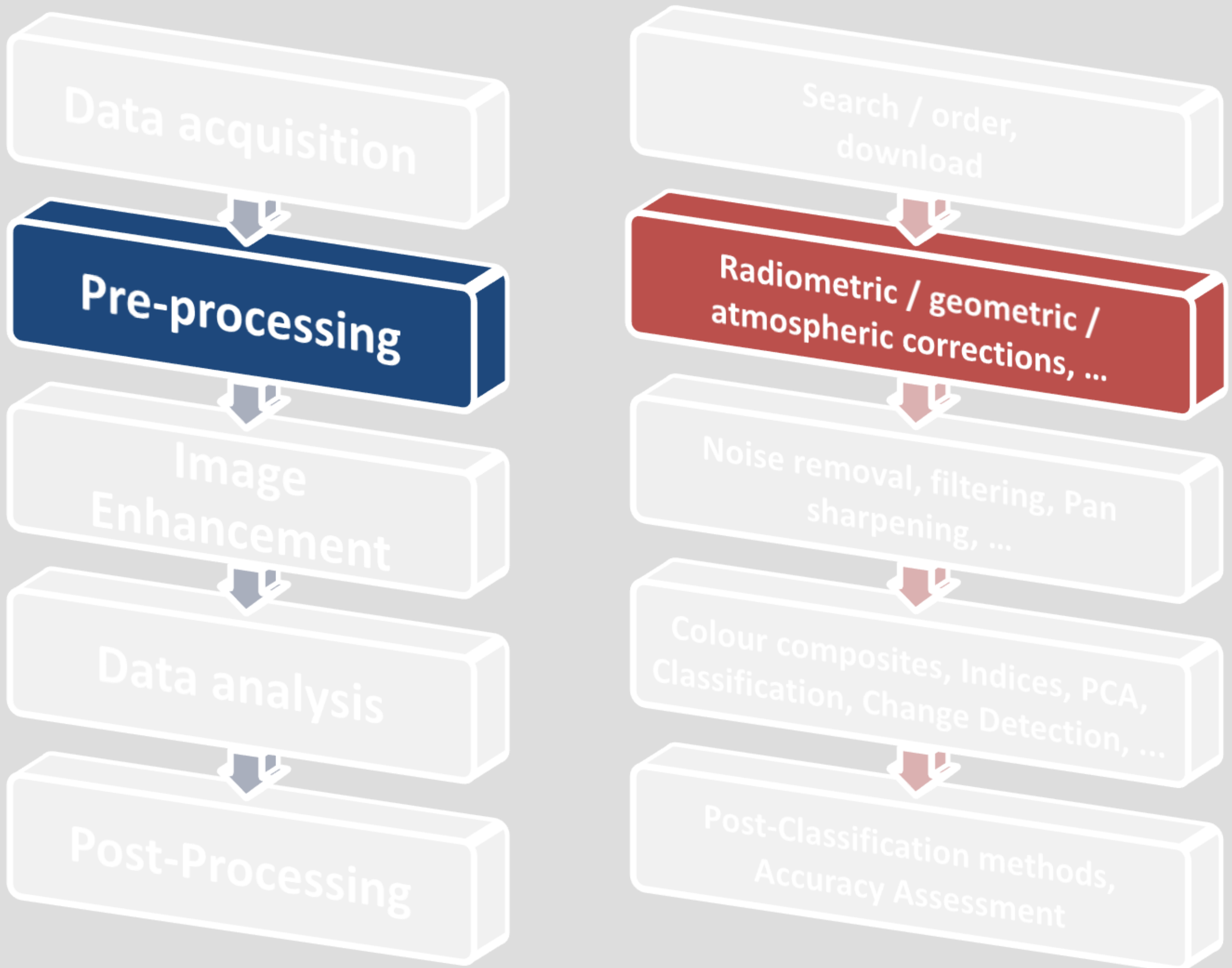


Download the data

Stop - wait a moment …



General workflow for satellite image analysis



Why do we need to correct the data?

Data correction is necessary to…

- Remove radiometric and geometric errors and unwanted atmospheric effects
- Transform data values into meaningful units for quali- and quantitative analysis
- Establish correct spatial reference for using data in relation to other thematic data in GIS and other applications and to allow correct measurements of distances, directions, areas

What should be corrected?

- Internal and external errors
- Systematic and non-systematic errors

Radiometric pre-processing

- Calibrating raw data values into radiometric values (radiance)
- Correcting radiometric errors (random, instrument-related):
  - Stripes ("striping")
  - Line start/stop problems, (partially) missing lines ("drop outs")
  - Bad pixel - no recording of spectral data in one pixel (in case of multiple pixels: "shot noise")
  - Terrain effects, Effects due to illumination and scan angles

Geometric corrections

Geometric correction of distortions due to…

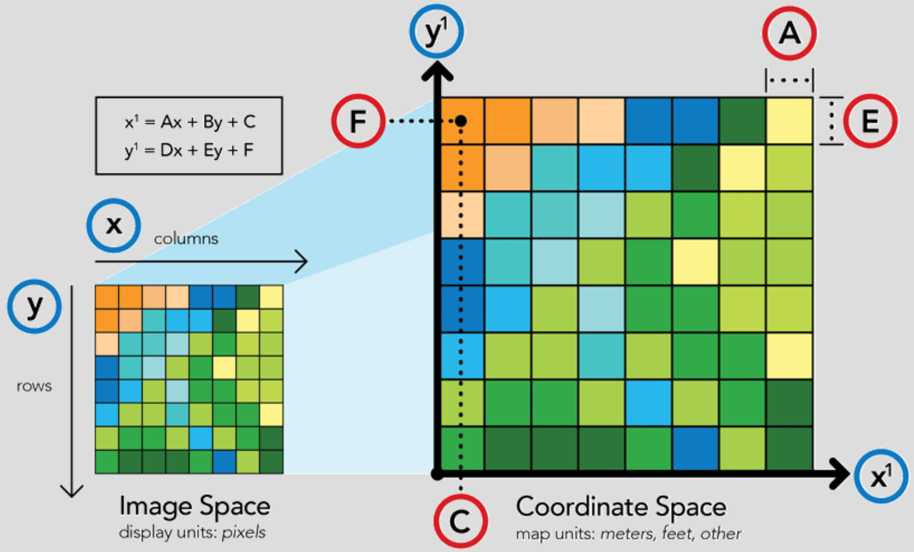
Internal errors (systematic):

- Earth rotation effects
- Terrain related distortions (different distance from different points of the ground surface to the sensor!)
- Distortions due to lenses/optics, sensor tilt

External (unsystematic):

- Movements of the platform (mainly aircraft)

Georeferencing of satellite imagery



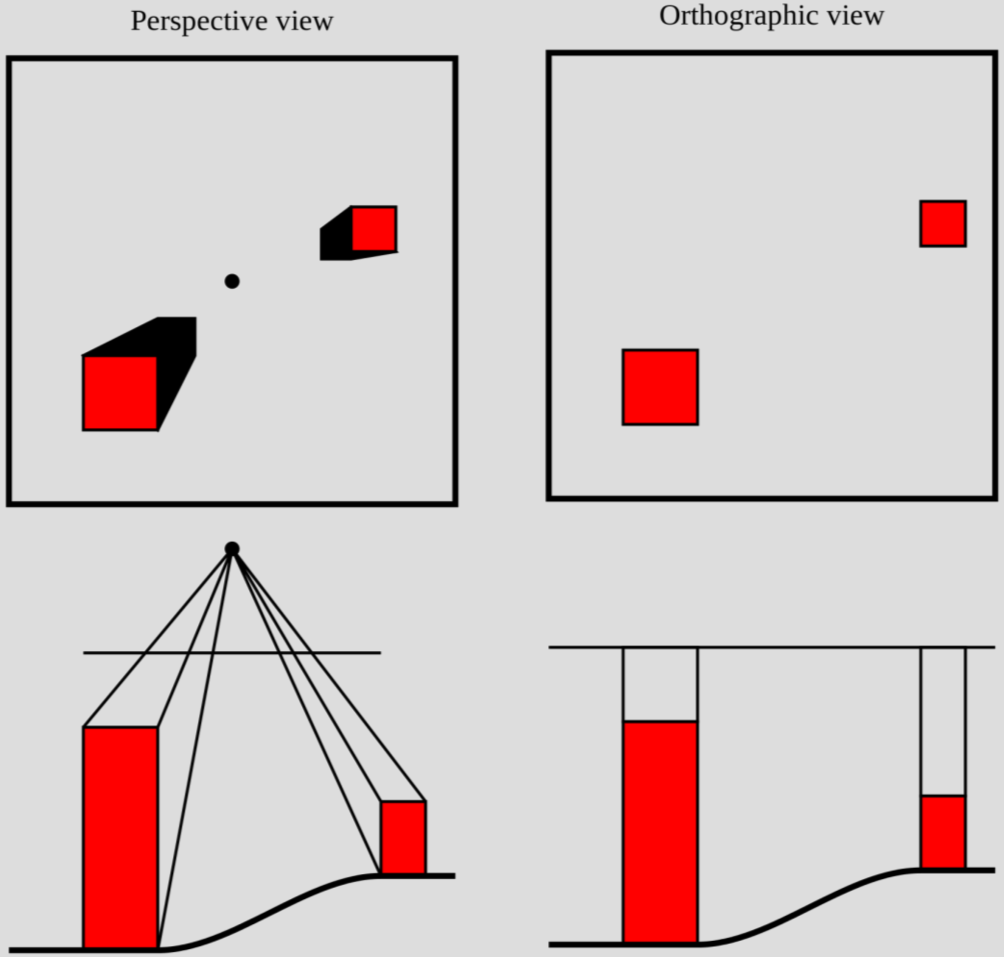
x is the column count in image space.
y is the row count in image space.
x¹ is the horizontal value in coordinate space.
y¹ is the vertical value in coordinate space.

A is the width of the cell in map units.
B is a rotation term.
C is the x¹ value of the center of the upper-left cell.
D is a rotation term.
E is the negative height of the cell in map units.
F is the y¹ value of the center of the upper-left cell.

Credit: https://www.esri.com/about/newsroom/arcuser/understanding-raster-georeferencing/

Georeferencing = Transformation of image coordinates into geographic or metric coordinate systems using reference data (other data set with spatial reference, GCPs)

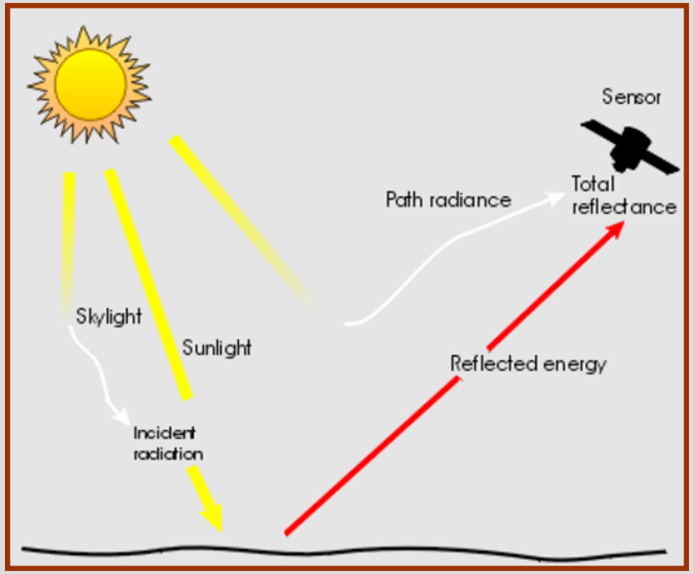
Orthorectification of satellite imagery

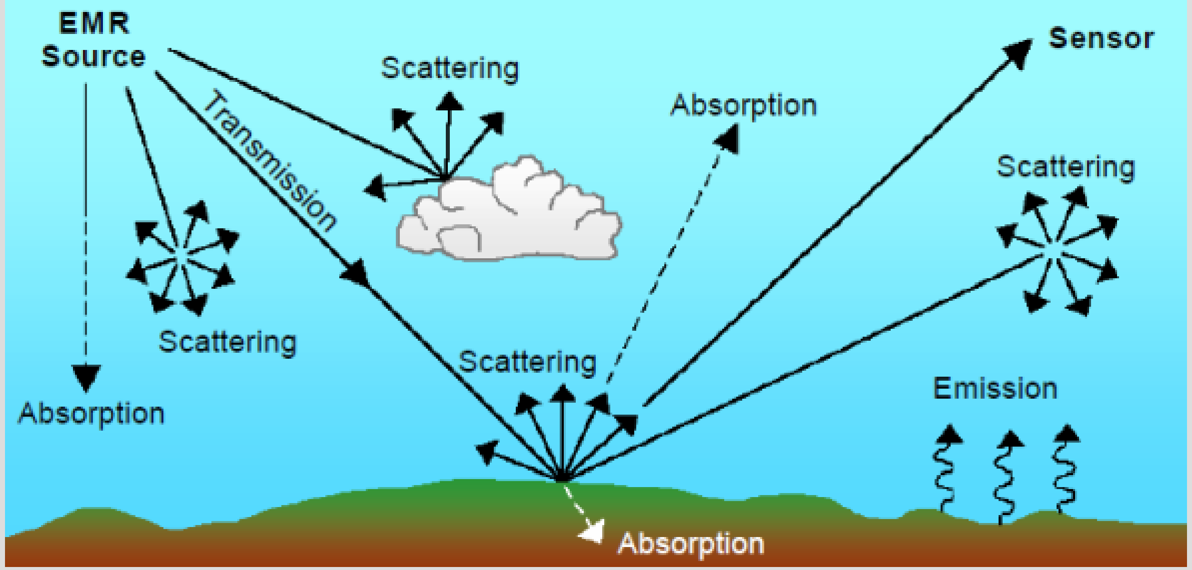


Crecit: By SVG by User:Pieter Kuiper - Original w:Image:OrthoPerspective.JPG by w:User:Kymstar, which probably was from "GIS fundamentals" by Paul Bolstad., Public Domain, https://commons.wikimedia.org/w/index.php?curid=5252153

- Required for an accurate representation of the Earth's surface (homogeneous scale within the image)
- Central to orthogonal projection
- Adjusted for topographic relief, lens distortion, and camera tilt
- Corrections require a DEM (and Rational polynomial coefficients (RPCs))
- Further reading: https://www.satimagingcorp.com/services/orthorectification/

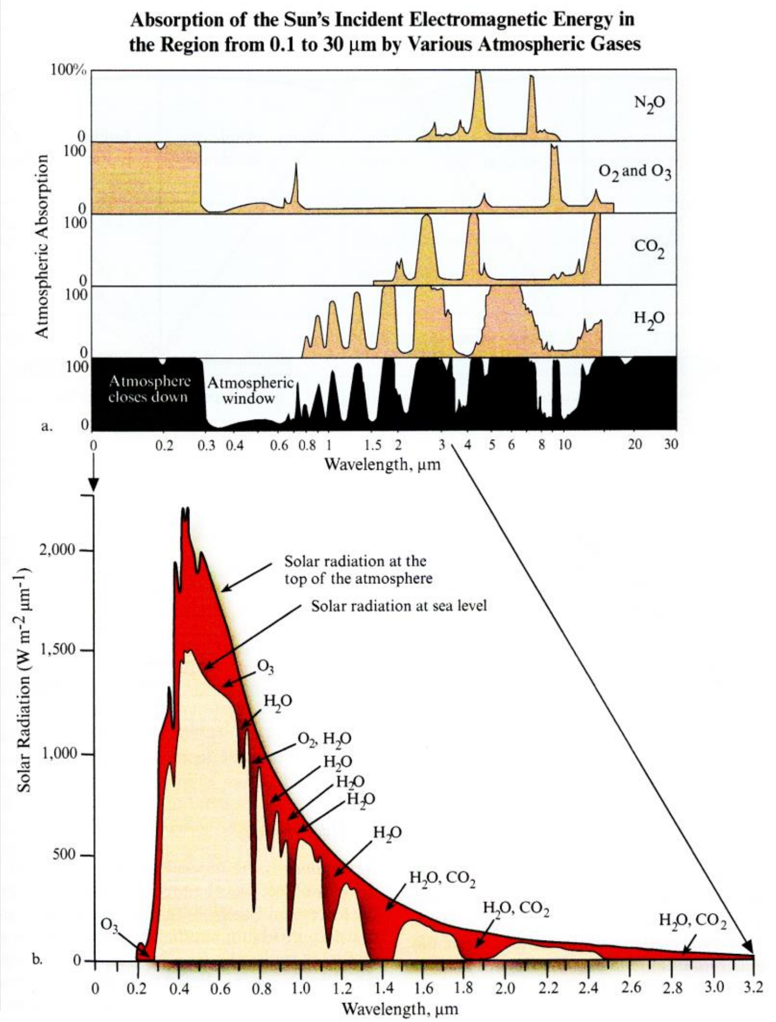
Atmospheric scattering and absorption processes

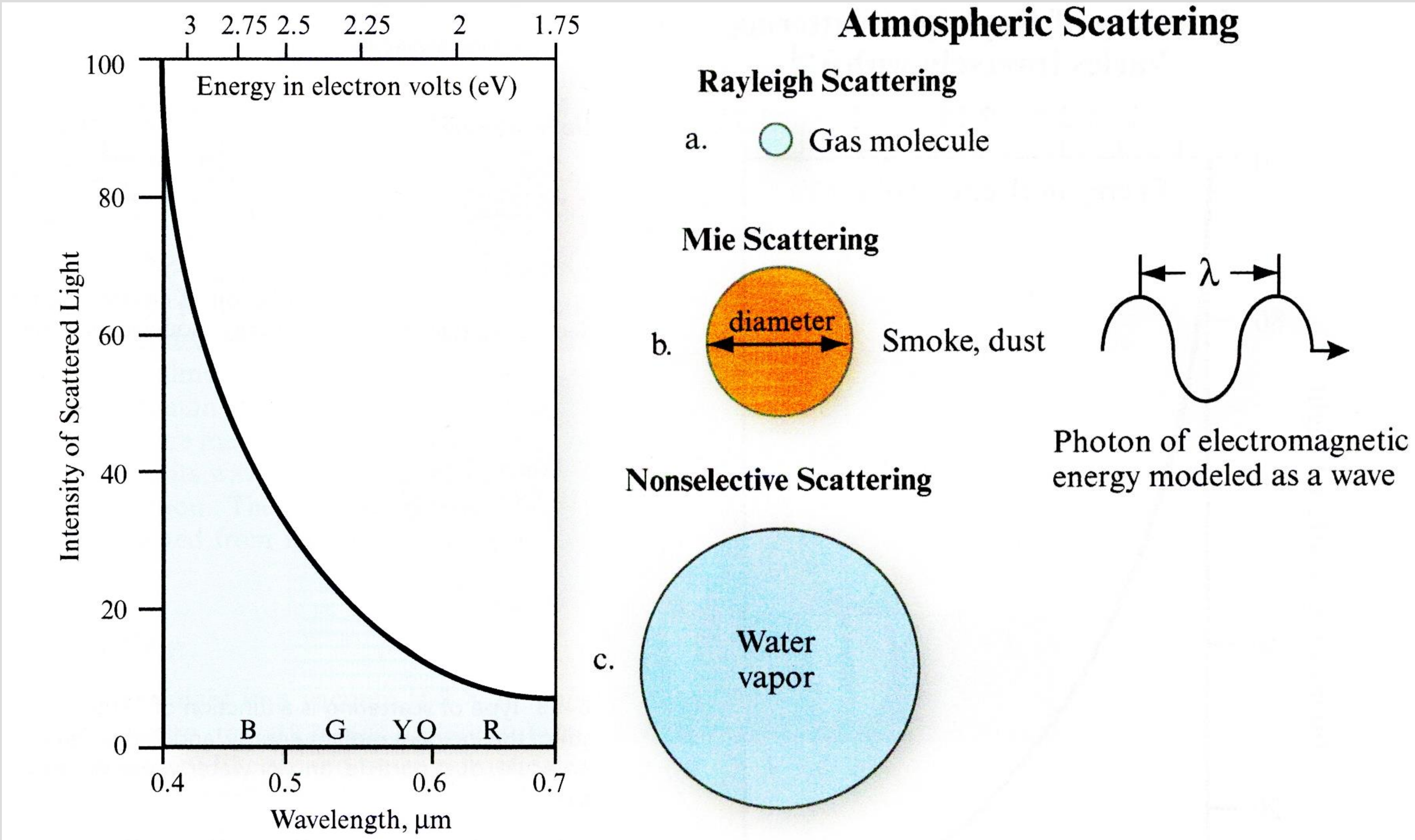




Credit: http://remote-sensing.net/concepts.html

Atmospheric scattering and absorption processes

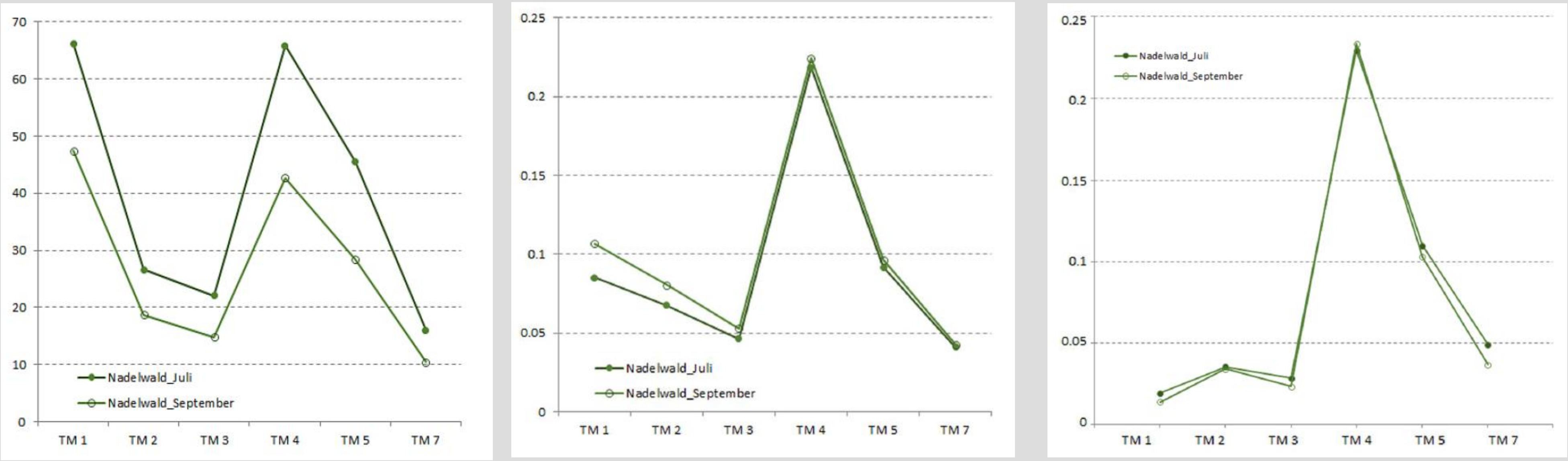




Credit: Jensen 2016

Transforming raw data values to reflectance values

Raw data from sensor (DN) → DN to radiance → Top of Atmosphere (TOA) Reflectane → Surface Reflectance

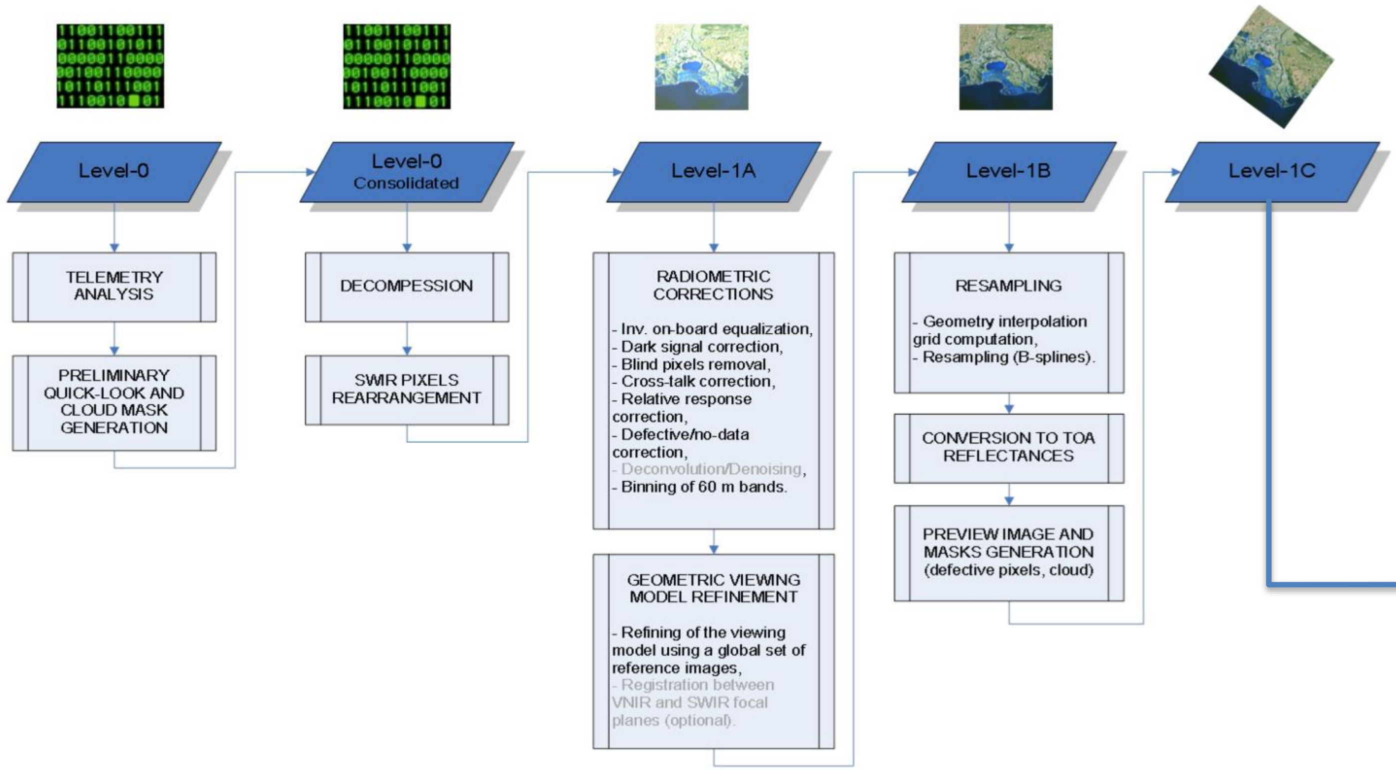


(DN)

TOA reflectane

Surface reflectance

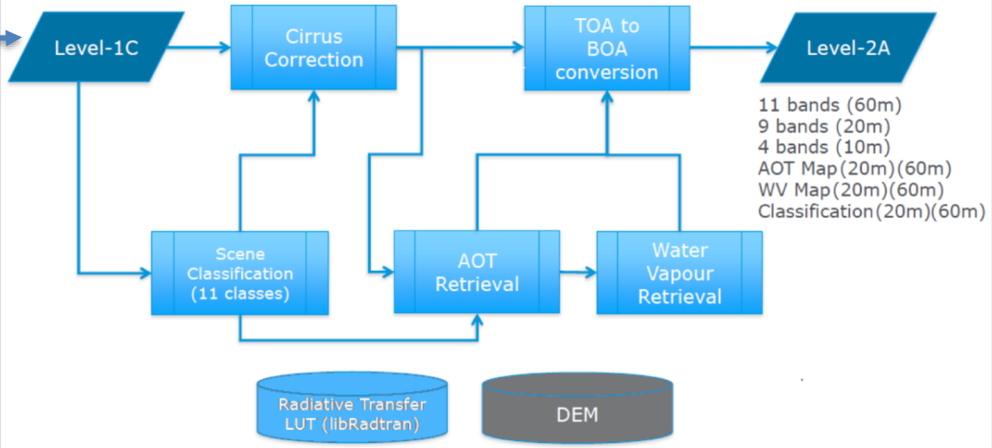
Processing levels of Sentinel 2 data



Open Access Article

Copernicus Sentinel-2A Calibration and Products Validation Status

by Ferran Gascon [1,*], Catherine Bouzinac [2,*], Olivier Thépaut [2], Mathieu Jung [3], Benjamin Francesconi [4], Jérôme Louis [5], Vincent Lonjou [6], Bruno Lafrance [2], Stéphane Massera [7], Angélique Gaudel-Vacaresse [6], Florie Languille [6], Bahjat Alhammoud [8], Françoise Viallefont [9], Bringfried Pflug [10], Jakub Bieniarz [10], Sébastien Clerc [8,*], Laëtitia Pessiot [2], Thierry Trémas [6], Enrico Cadau [1], Roberto De Bonis [1], Claudia Isola [1], Philippe Martimort [1] and Valérie Fernandez [1]



Credit and further reading: Gascon et al. 2017, Remote Sens. 2017, 9(6), 584; https://doi.org/10.3390/rs9060584

What software to use?

QGIS

R

ERDAS IMAGINE®

PCI GEOMATICS

Orfeo ToolBox
Orfeo ToolBox is not a black box

Semi-Automatic Classification Plugin

EnMAP-Box 3

Get the Information
You Need from Imagery.
ENVI
Version 5.5.3

SAGA
System for Automated Geoscientific Analyses

GRASS GIS
The world's leading Free GIS software

ILWIS

SNAP

Google Earth Engine

esri

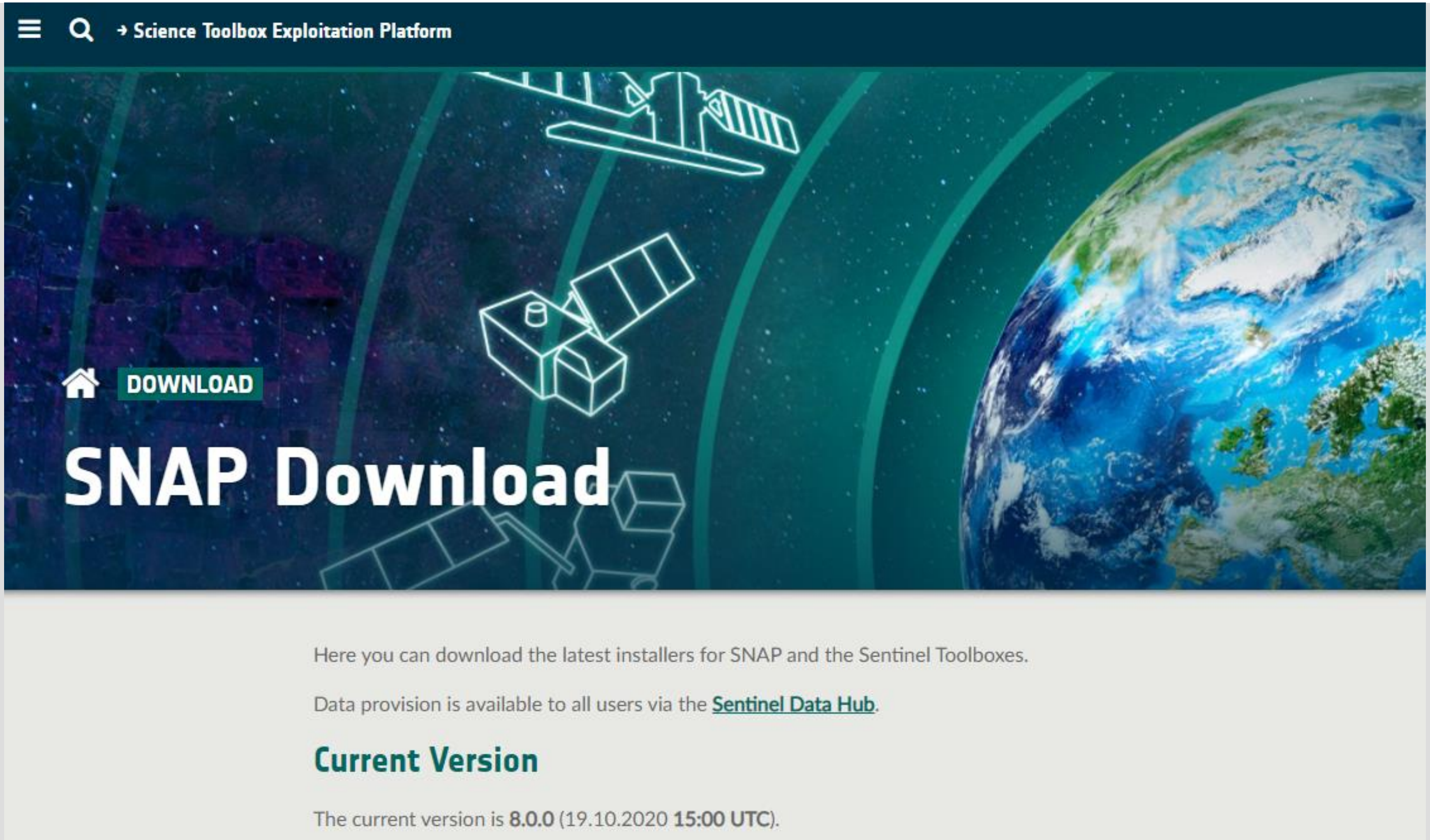
What software to use?

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

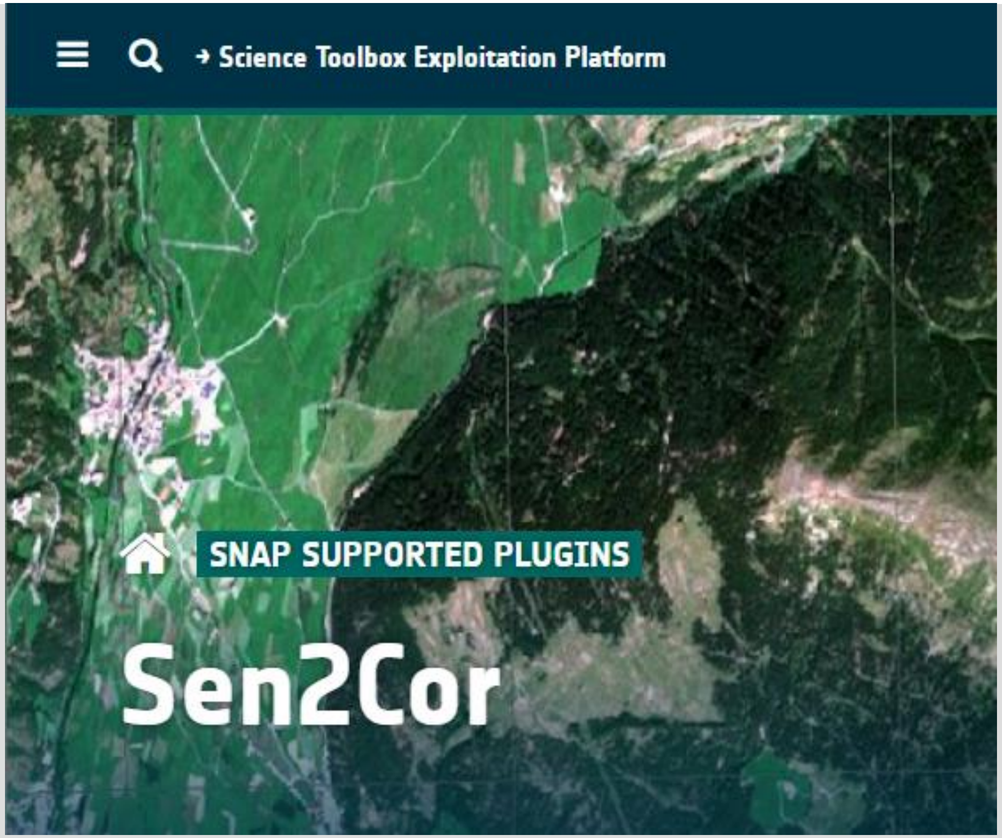
Orfeo ToolBox
Orfeo ToolBox is not a black box

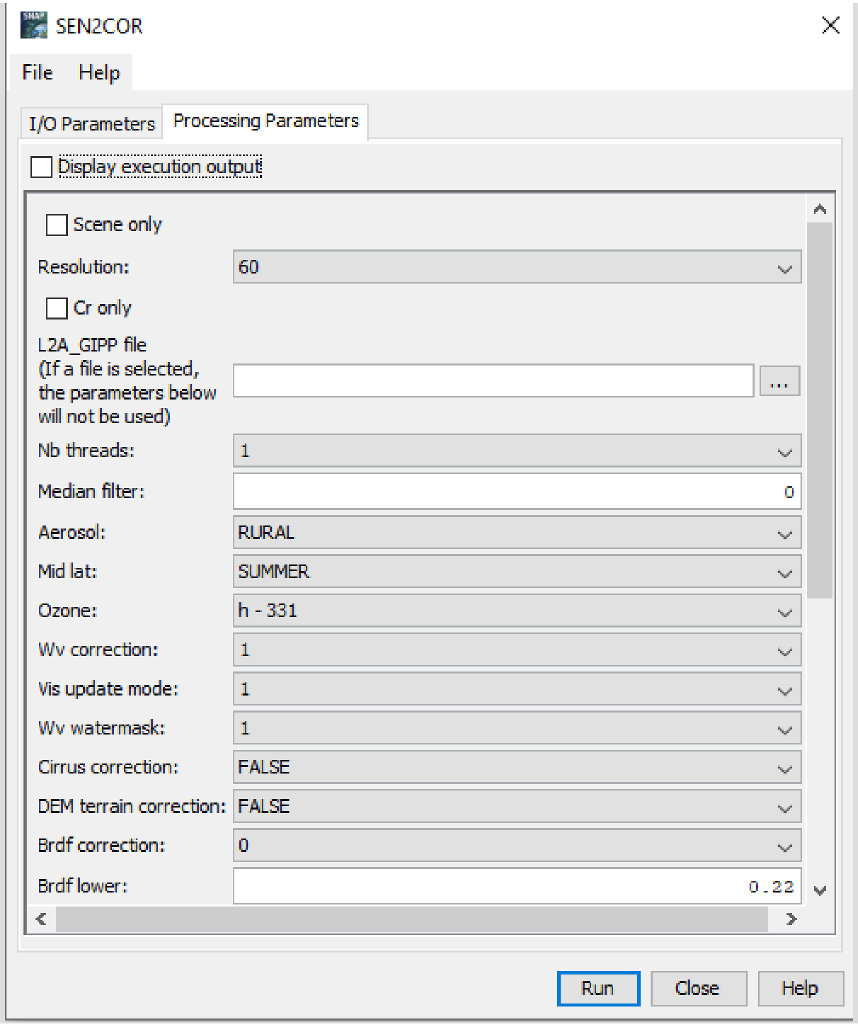
EnMAP-Box 3

What software to use?



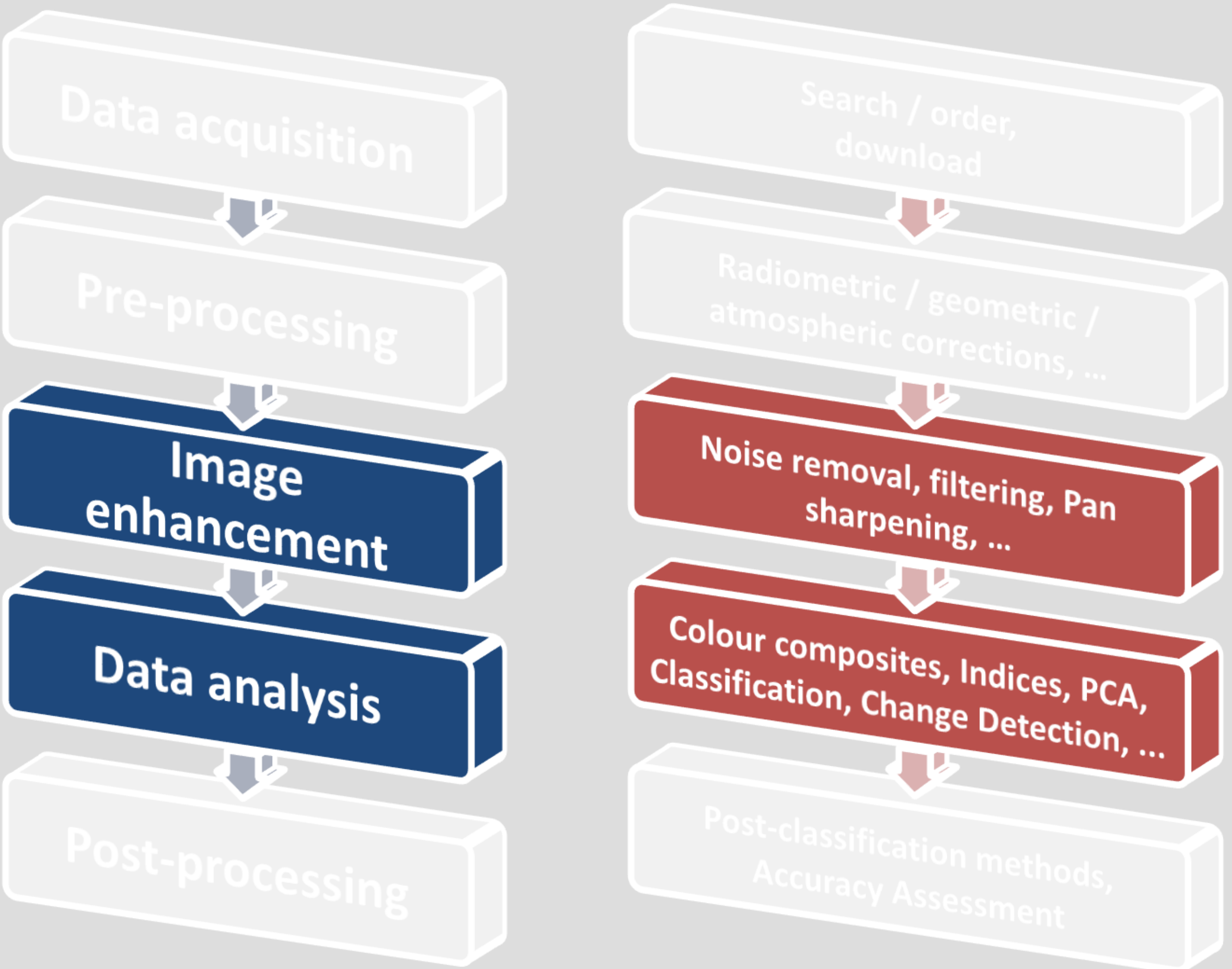
What software to use?





https://step.esa.int/main/snap-supported-plugins/sen2cor/

General workflow for satellite image analysis



File structure

Name	Änderungsdatum	Typ	Größe
AUX_DATA		Dateiordner	
DATASTRIP	09.09.2021 14:38	Dateiordner	
GRANULE	09.09.2021 14:37	Dateiordner	
HTML	09.09.2021 14:38	Dateiordner	
rep_info	09.09.2021 14:38	Dateiordner	
INSPIRE	20.06.2021 16:12	XML-Dokument	19 KB
manifest.safe	20.06.2021 16:12	SAFE-Datei	90 KB
MTD_MSIL2A	20.06.2021 16:12	XML-Dokument	53 KB

Meta data file that can be read by SNAP and other software

Name	Änderungsdatum	Typ	Größe
T38TMK_20210620T074611_AOT_20m	20.06.2021 16:12		2.994 KB
T38TMK_20210620T074611_B02_20m	20.06.2021 16:12		33.034 KB
T38TMK_20210620T074611_B03_20m	20.06.2021 16:12		32.950 KB
T38TMK_20210620T074611_B04_20m	20.06.2021 16:12		33.048 KB
T38TMK_20210620T074611_B05_20m	20.06.2021 16:12		32.932 KB
T38TMK_20210620T074611_B06_20m	20.06.2021 16:12		32.924 KB
T38TMK_20210620T074611_B07_20m	20.06.2021 16:12		33.013 KB
T38TMK_20210620T074611_B8A_20m	20.06.2021 16:12		33.102 KB
T38TMK_20210620T074611_B11_20m	20.06.2021 16:12		33.063 KB
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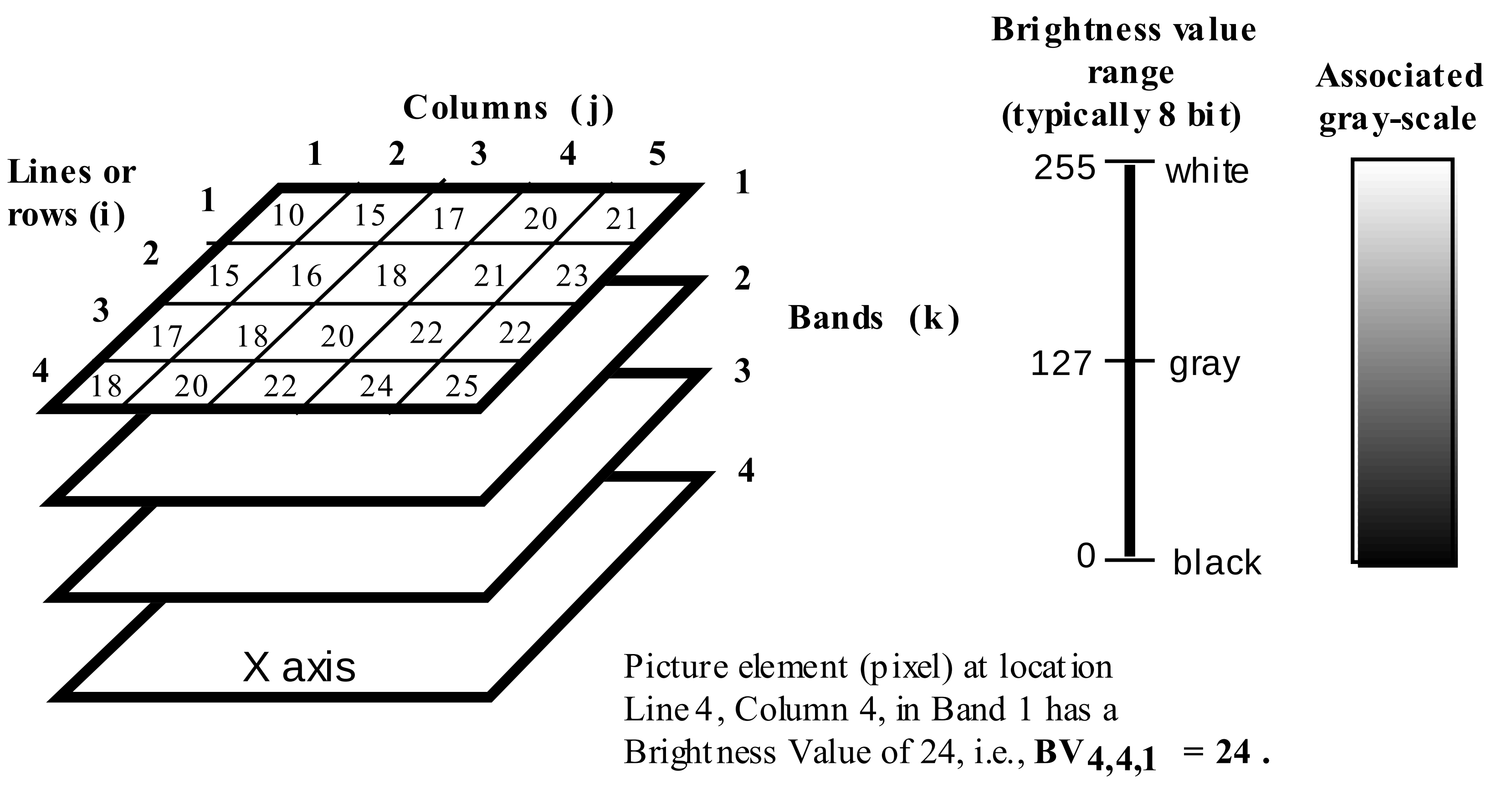
T38TMK_20210620T074611_SCL_20m	20.06.2021 16:12		2.758 KB
T38TMK_20210620T074611_TCI_20m	20.06.2021 16:12		33.005 KB
T38TMK_20210620T074611_WVP_20m	20.06.2021 16:12		28.840 KB

The actual image files

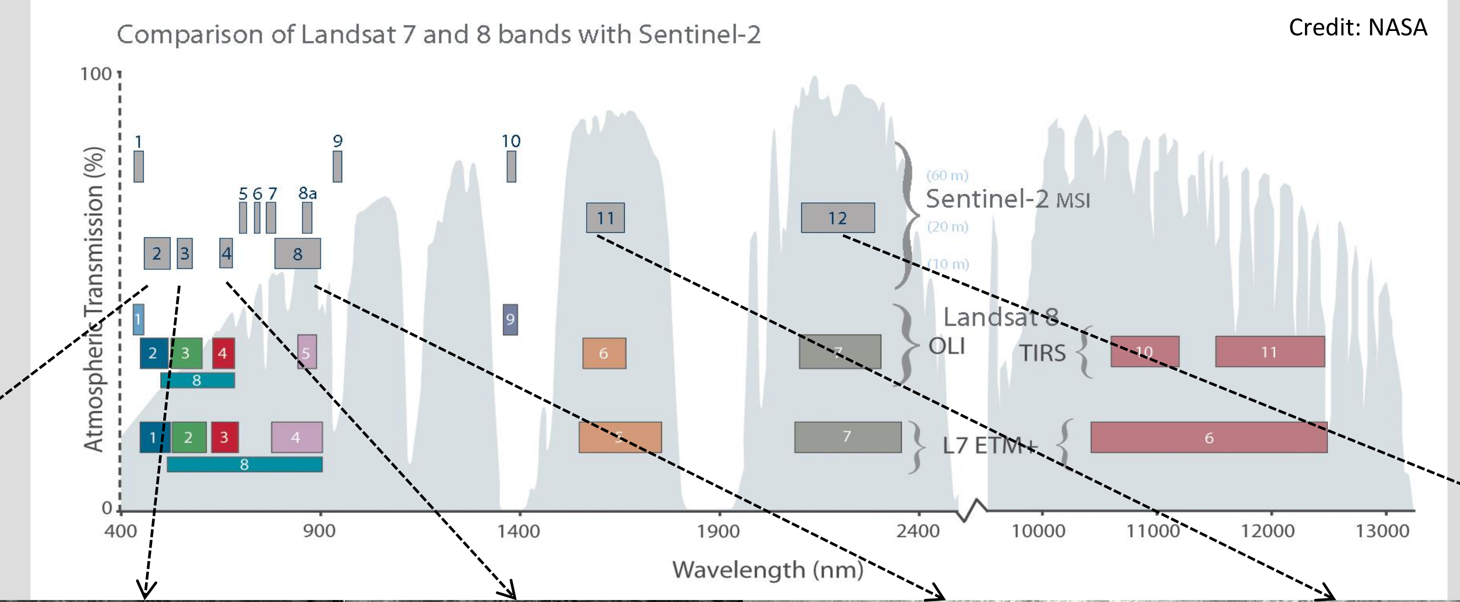
Several operations require that the used bands have the same spatial resolution
→ **resampling** to 10, 20 or 60 m

Structure of data

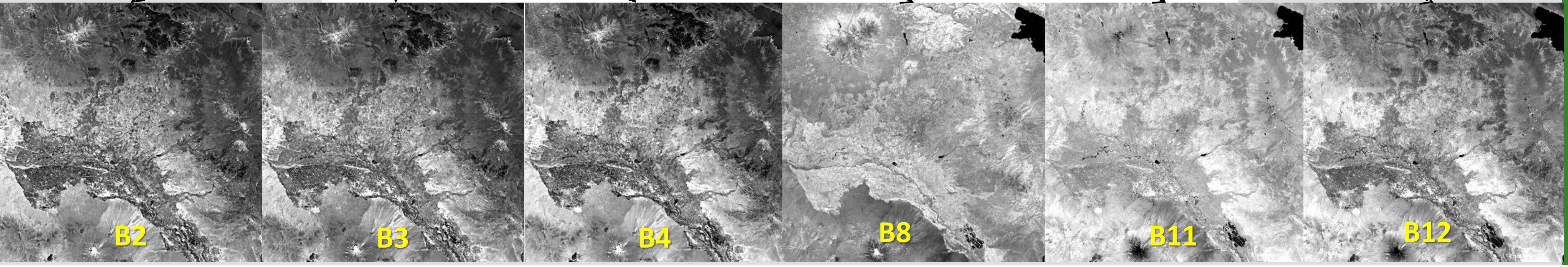


Credit: Jensen 2000

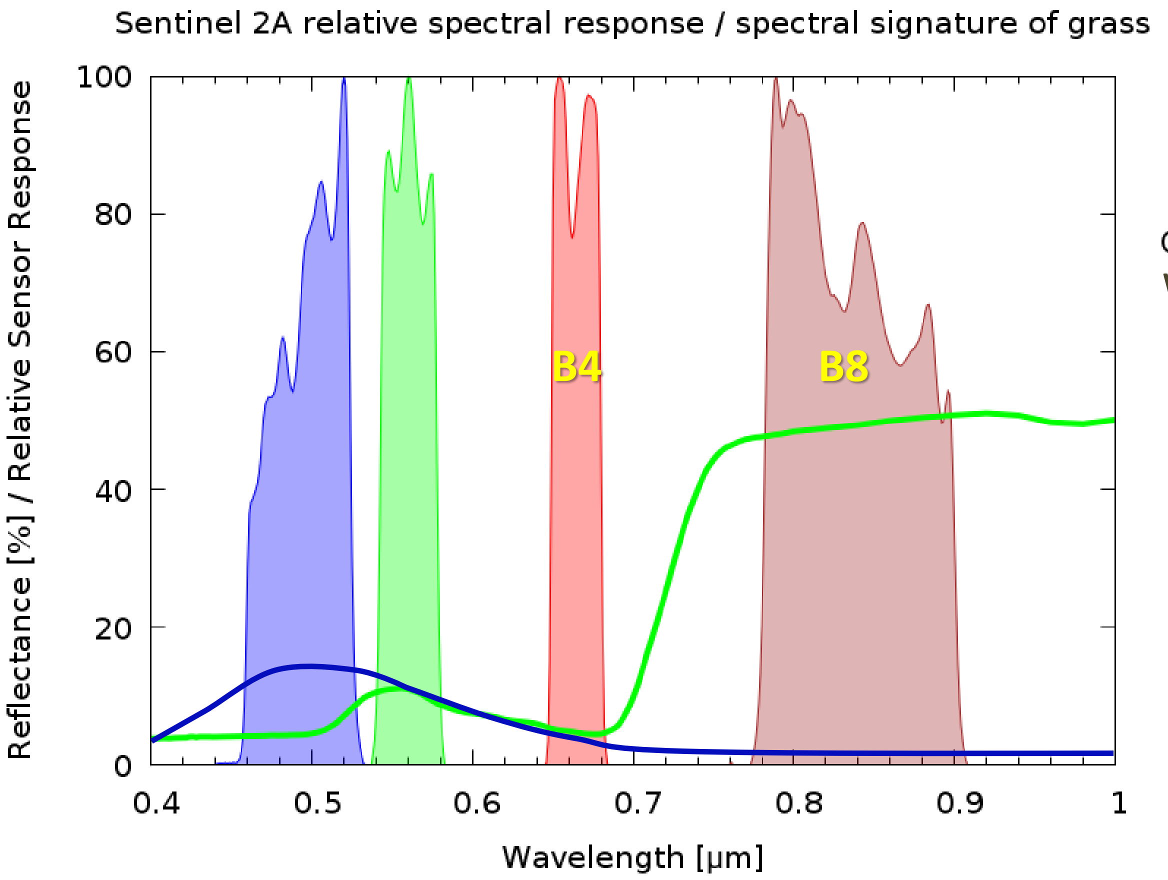
Understanding the data

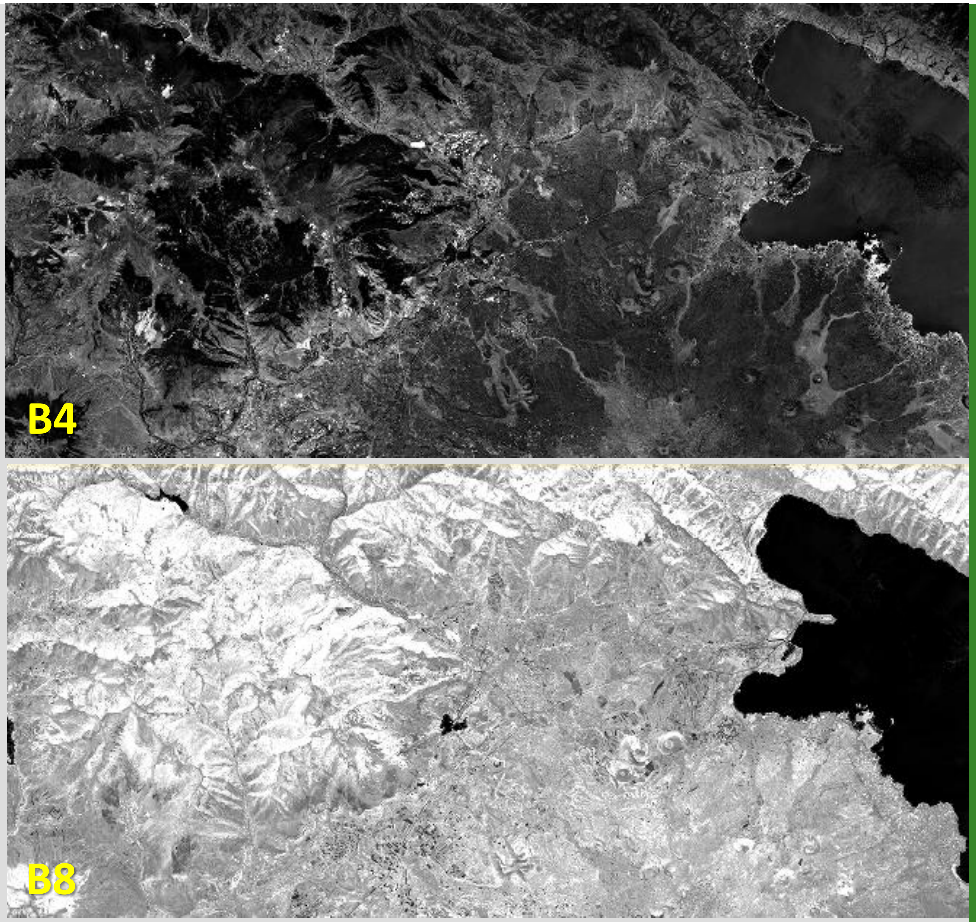


Copernicus Sentinel data 2021



Understanding the data

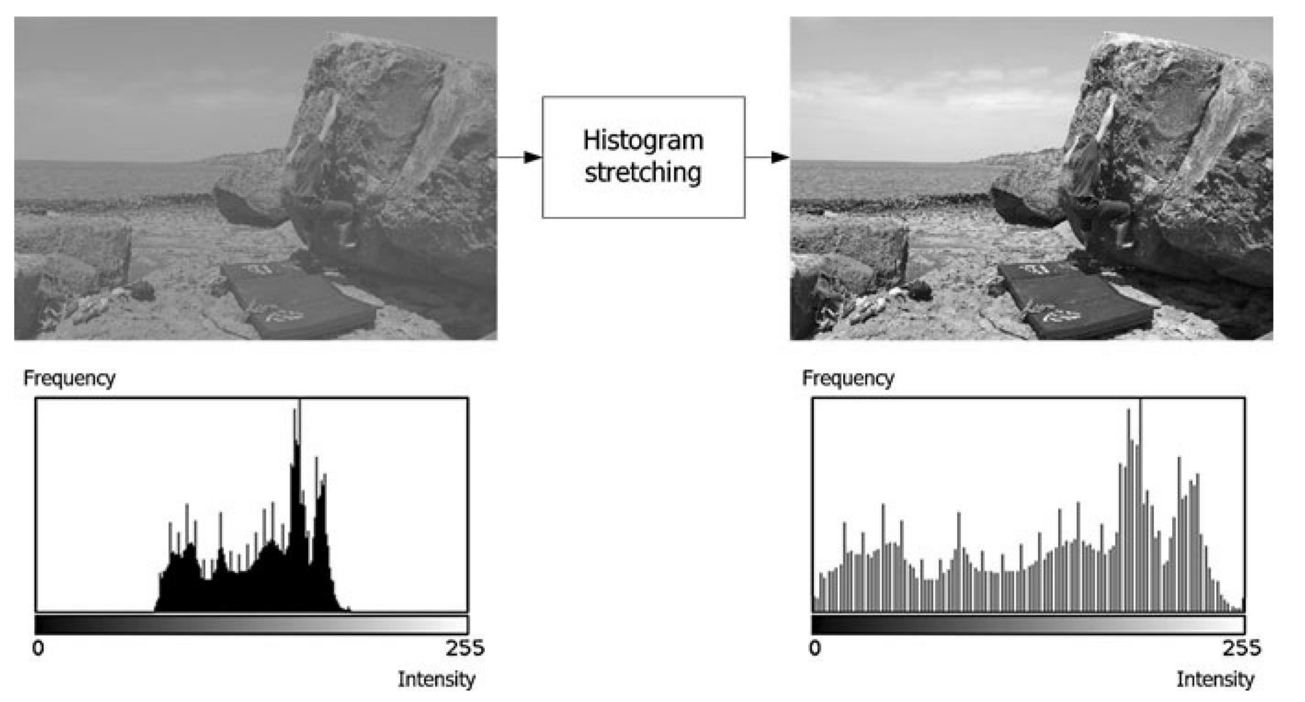




Credits: Modified after De Angelis 2017, https://scientiaplusconscientia.wordpress.com/2017/03/04/remote-sensing-comparison-landsat-sentinel-visible-infrared-spectrum/

Copernicus Sentinel data 2021

Understanding the data



Credit: http://what-when-how.com/wp-content/uploads/2012/07/tmp26dc100.png

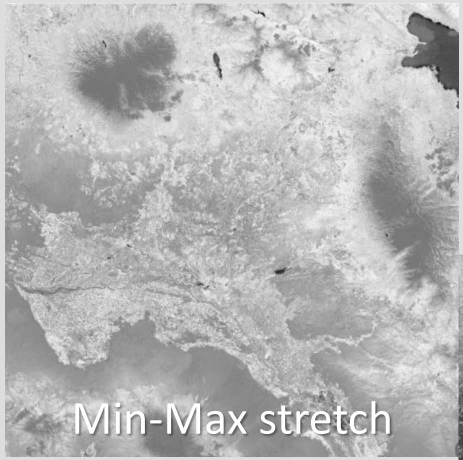
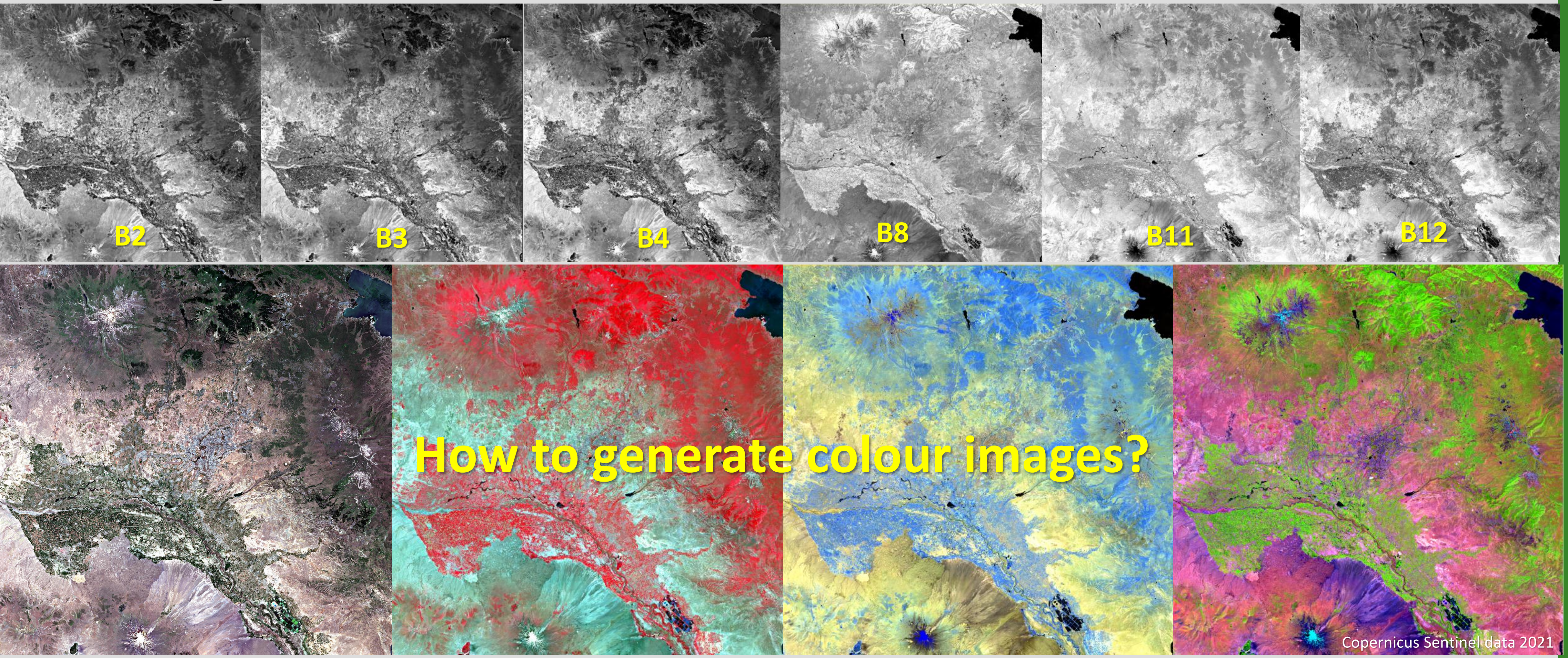
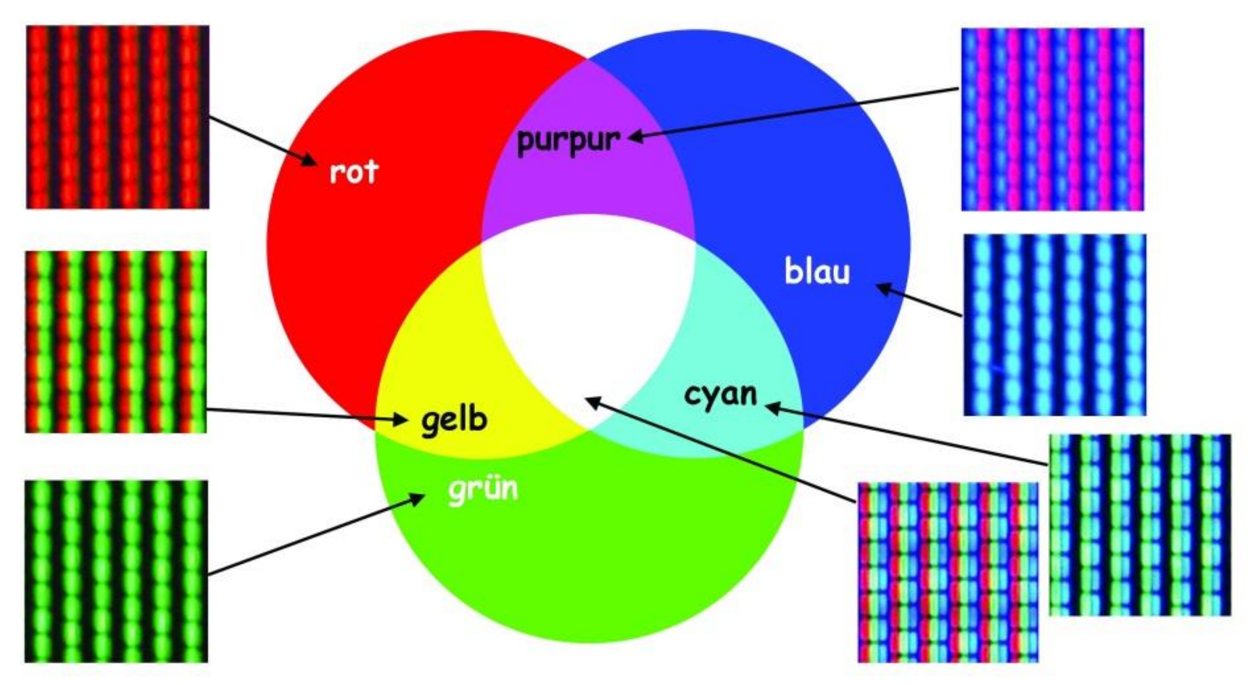


Image visualisation



Additive colour (mixing) syste,

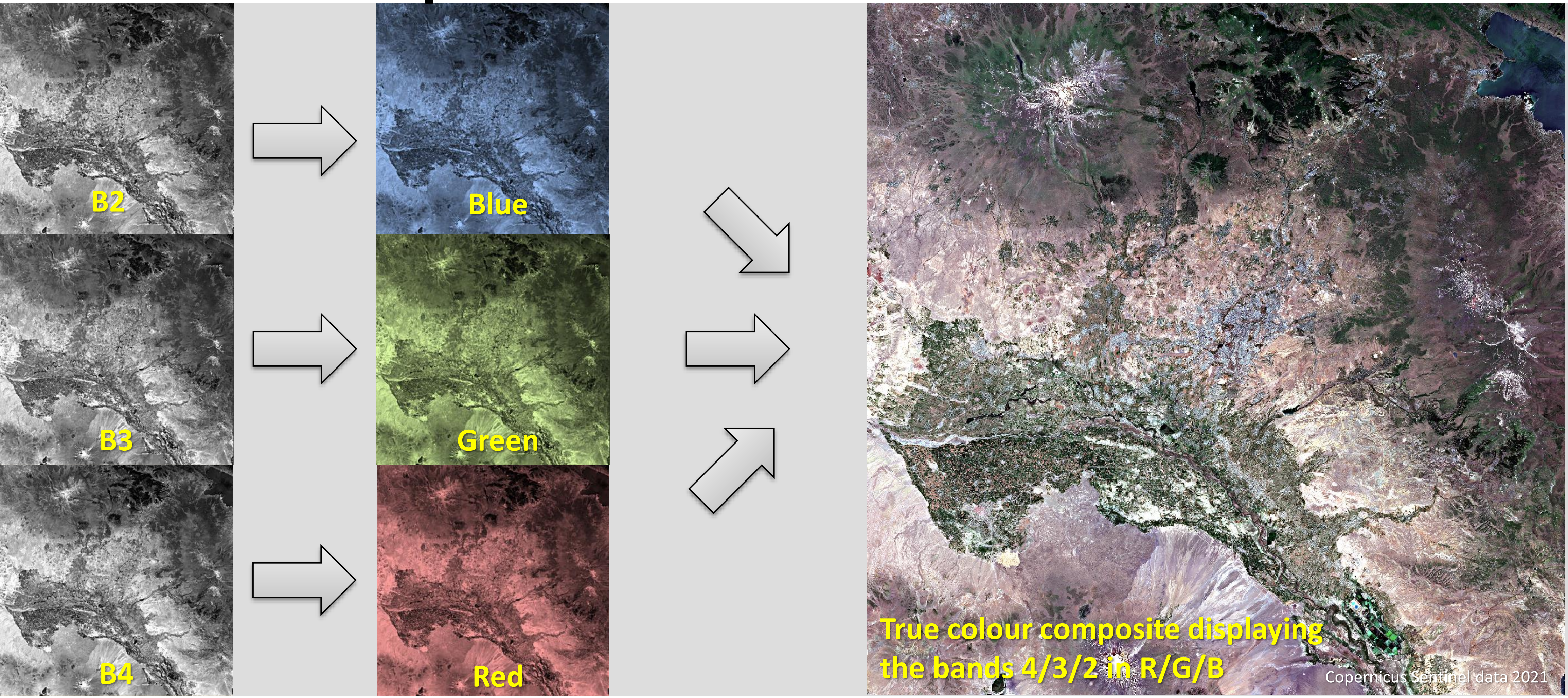


Credit: https://commons.wikimedia.org/wiki/File:Additive_Farbmischung.jpg; Martin Apolin

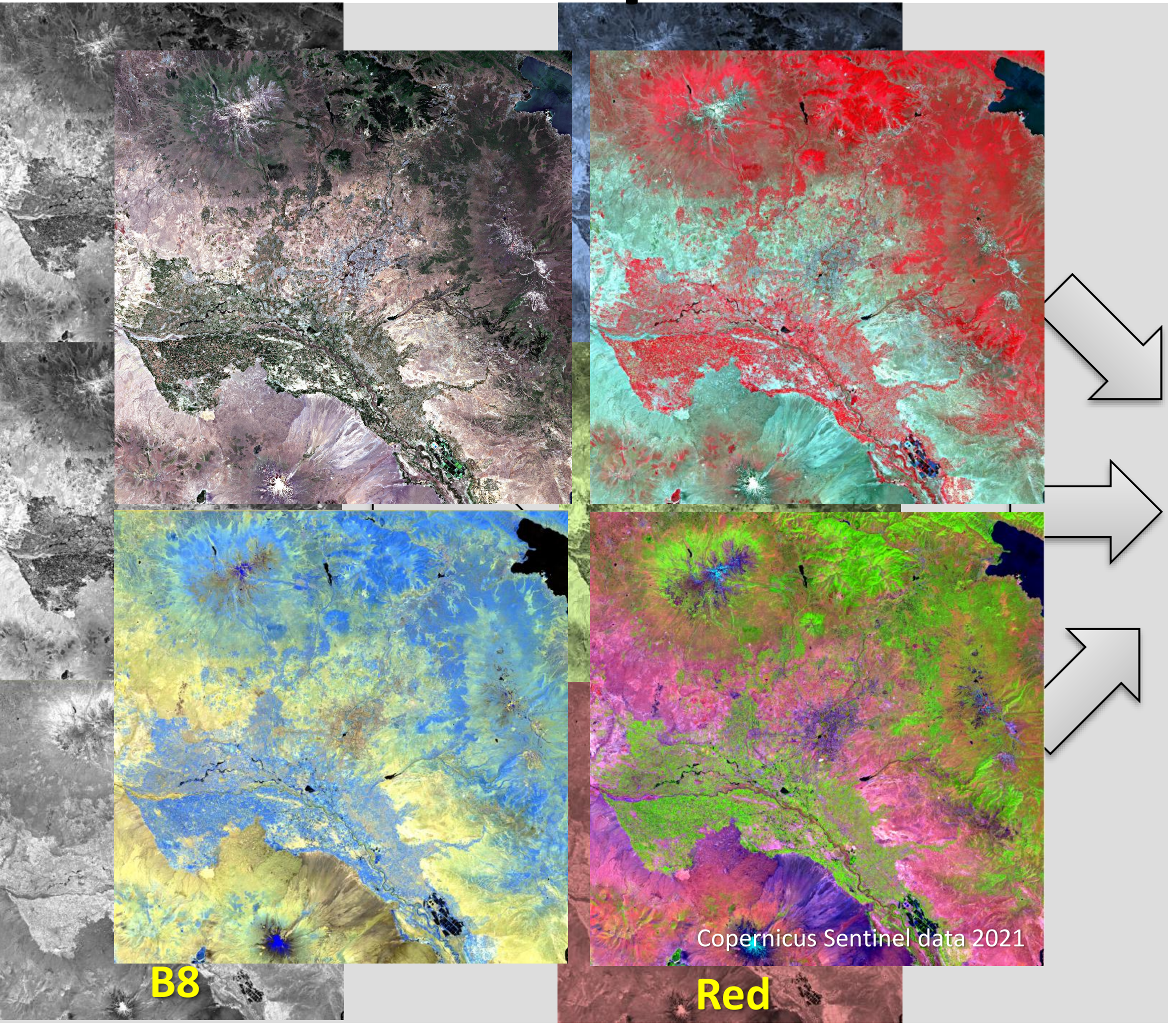
3 primary colours - red (R), green (G), blue (B) → **RGB**

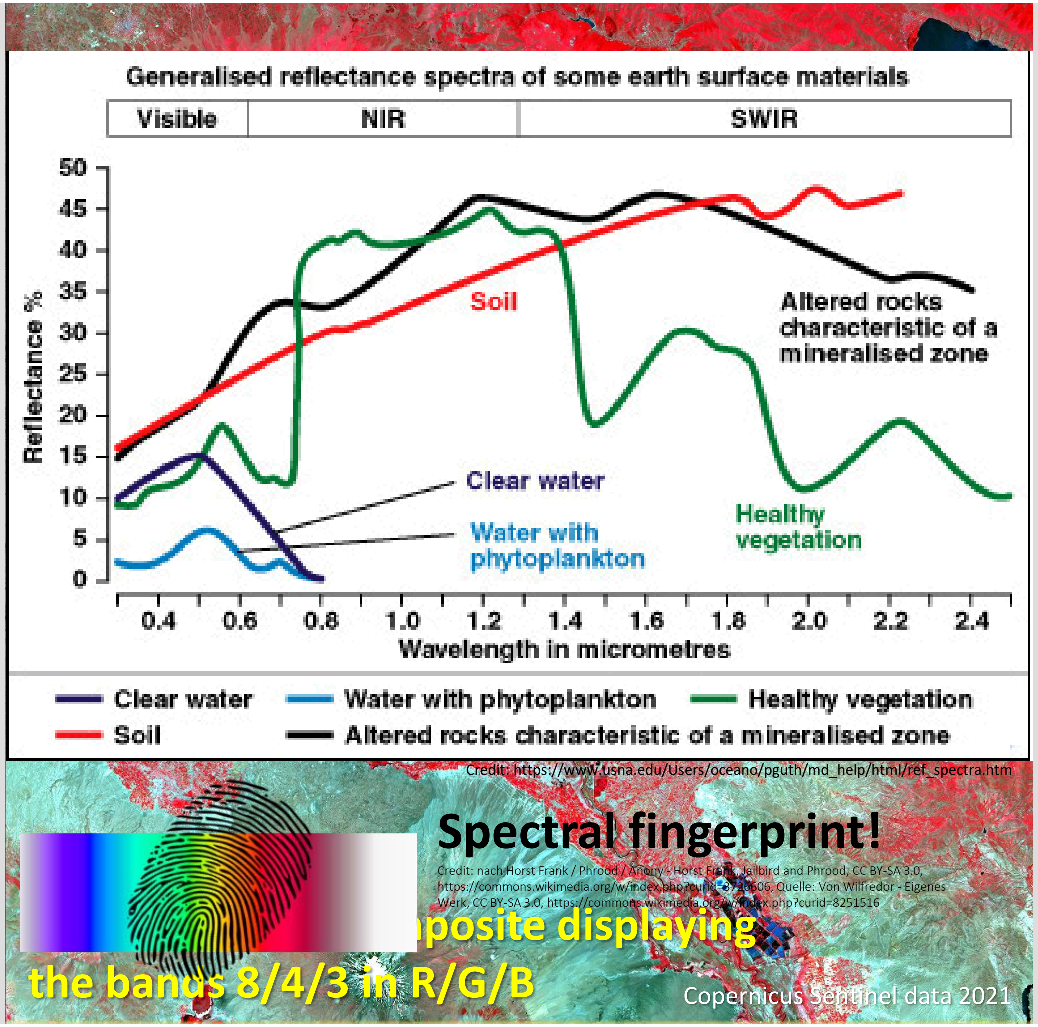
- Assigning each of the three primary colour channels to one image (spectral band)
- Basic colours are usually coded in 8 bit = 256 different values
- In combination: 16.8 million possible colours

Colour composites

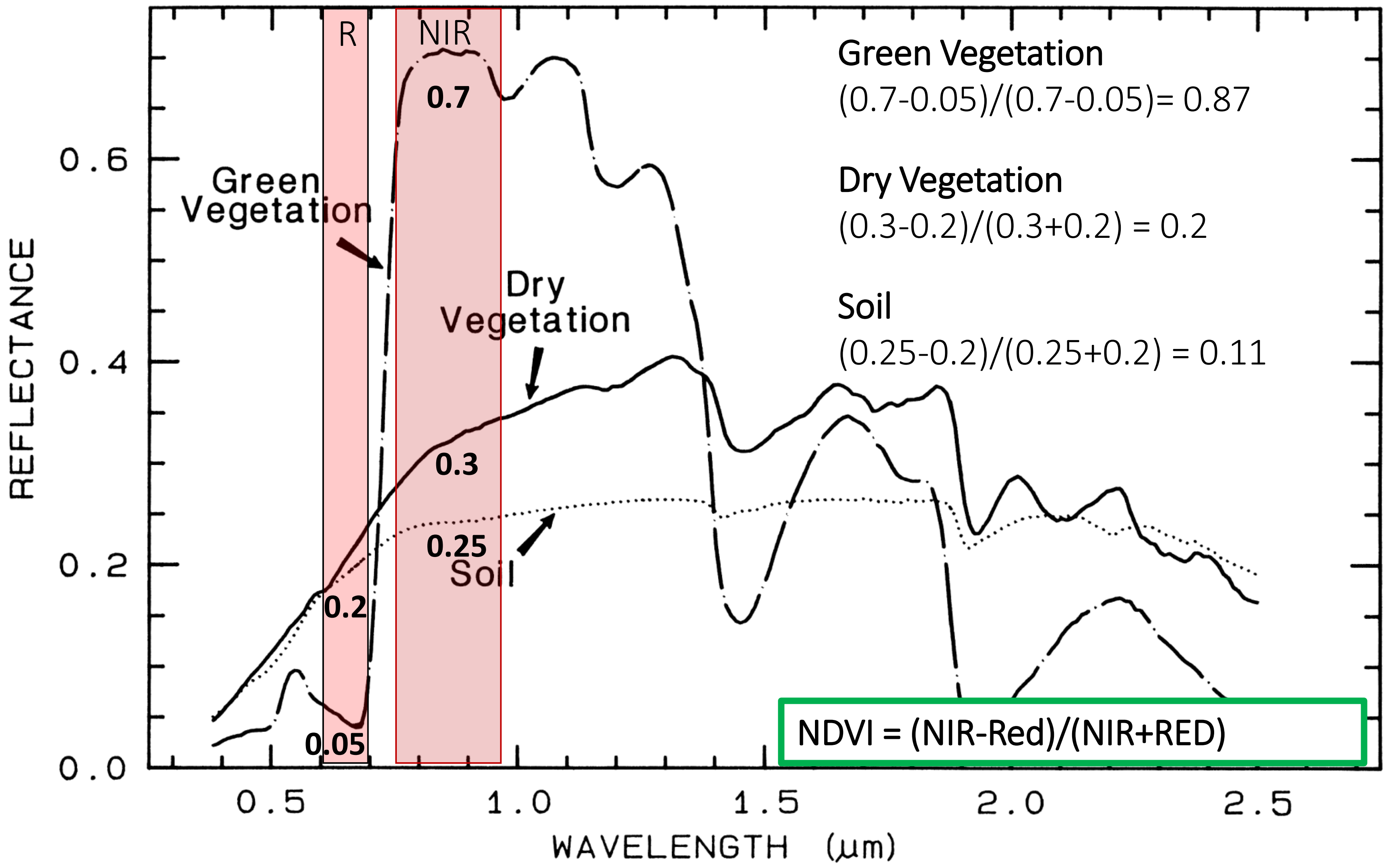


Colour composites





Extract LULC information via spectral indices



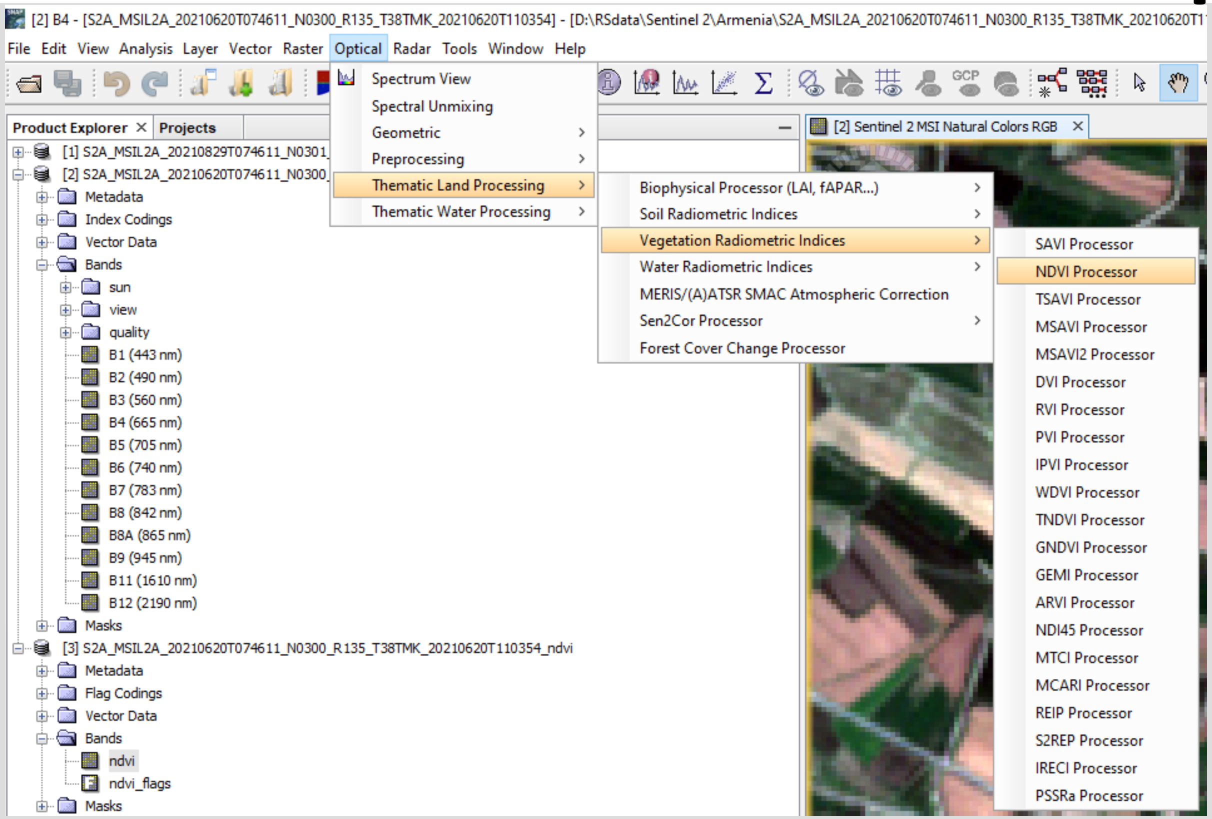
Extract LULC information via spectral indices

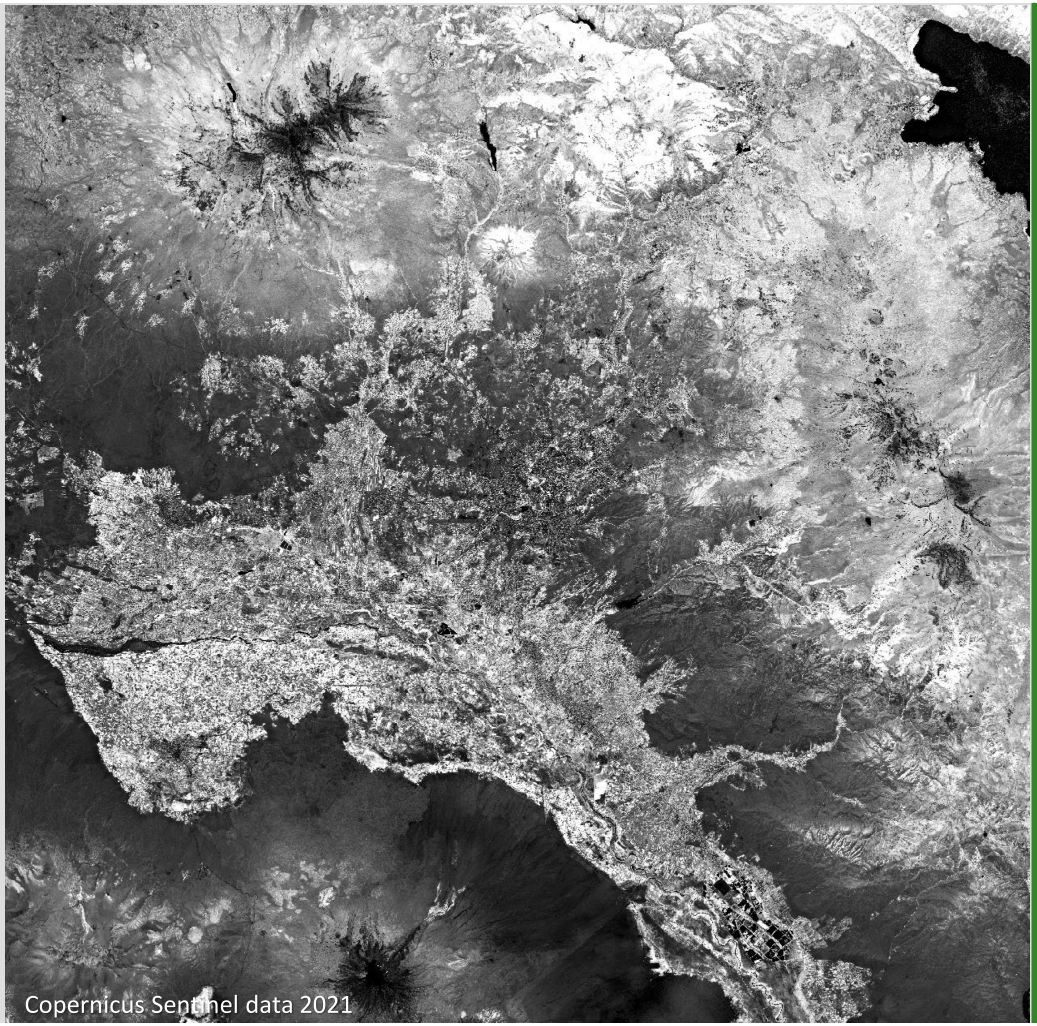
Index	Formulation	Reference
Simple Ratio	$SR = \frac{\rho_{NIR}}{\rho_{Red}}$	(Jordan, 1969)
Normalized Difference Vegetation Index	$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}$	(Rouse et al., 1974)
Enhanced Vegetation Index	$EVI = 2.5 \frac{\rho_{NIR} - \rho_{Red}}{1 + \rho_{NIR} + 6\rho_{Red} - 7.5\rho_{Blue}}$	(Huete et al., 1996; 1997)
Green Atmospherically Resistant Vegetation Index	$GARI = \frac{\rho_{NIR} - [\rho_{Green} - \gamma(\rho_{Blue} - \rho_{Red})]}{\rho_{NIR} + [\rho_{Green} - \gamma(\rho_{Blue} - \rho_{Red})]}$	(Gitelson et al., 1996)
Wide-Dynamic Range Vegetation Index	$WDRVI = \frac{\alpha \cdot \rho_{NIR} - \rho_{Red}}{\alpha \cdot \rho_{NIR} + \rho_{Red}}$	(Gitelson, 2004)
Green Chlorophyll Index	$CI_{Green} = \frac{\rho_{NIR}}{\rho_{Green}} - 1$	Gitelson et al., (2003a), (2003c), (2005)
Red-edge Chlorophyll Index	$CI_{Red-edge} = \frac{\rho_{NIR}}{\rho_{Red-edge}} - 1$	Gitelson et al., (2003a), (2003c), (2005)
MERIS Terrestrial Chlorophyll Index	$MTCI = \frac{\rho_{NIR} - \rho_{Red-edge}}{\rho_{Red\ edge} - \rho_{Red}}$	(Dash and Curran, 2004)

Credits: Viña et al. 2011

Also interesting: https://www.indexdatabase.de/

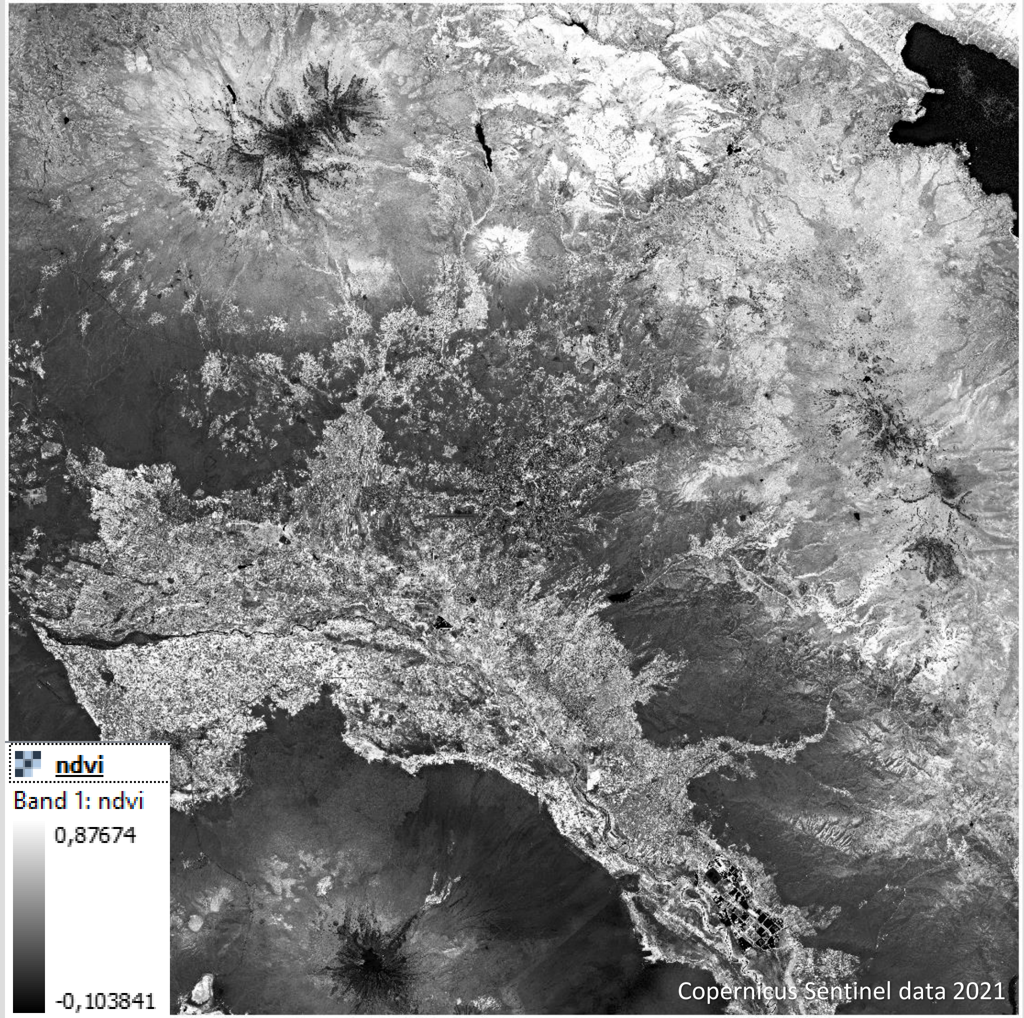
Extract LULC information via spectral indices

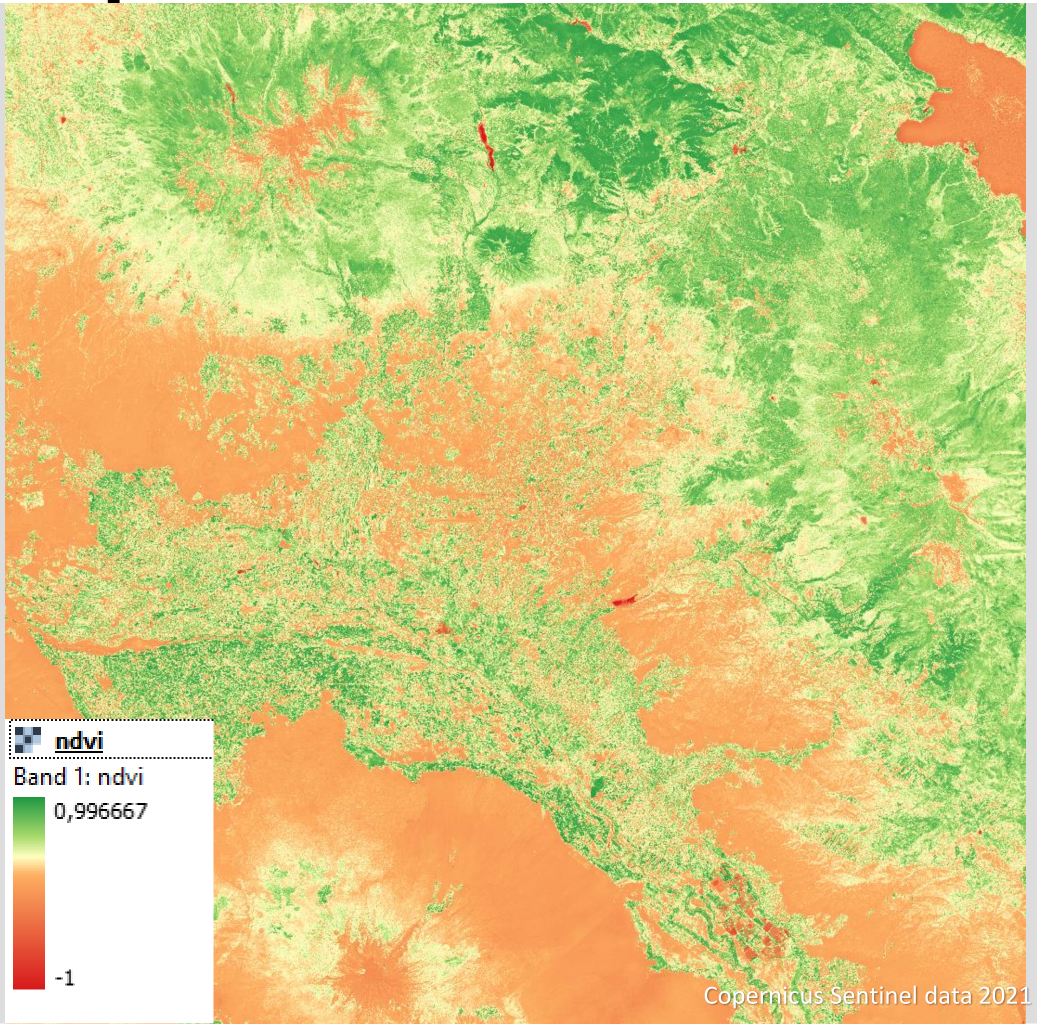




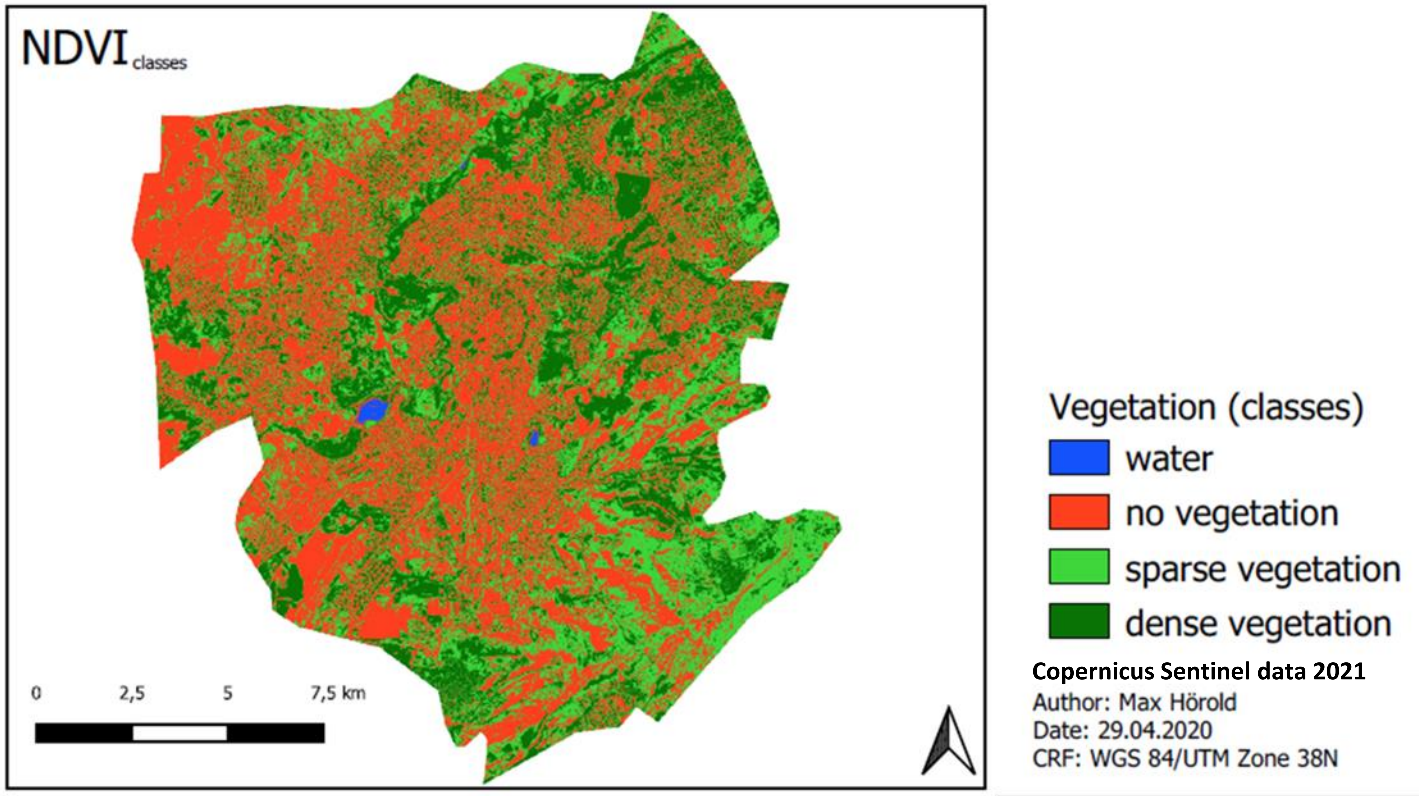
Copernicus Sentinel data 2021

Extract LULC information via spectral indices





Extract LULC information via spectral indices



Reclassification of NDVI values:

-1	< 0	Water (or shadow)
~ 0	to 0.2	No vegetation (soil, …)
~ 0.2 to 0.5		Sparse vegetation
> 0.2 to 1		Dense vegetation

NDVI sometimes not preferable for delineating water and non water areas

Extract LULC information via spectral indices

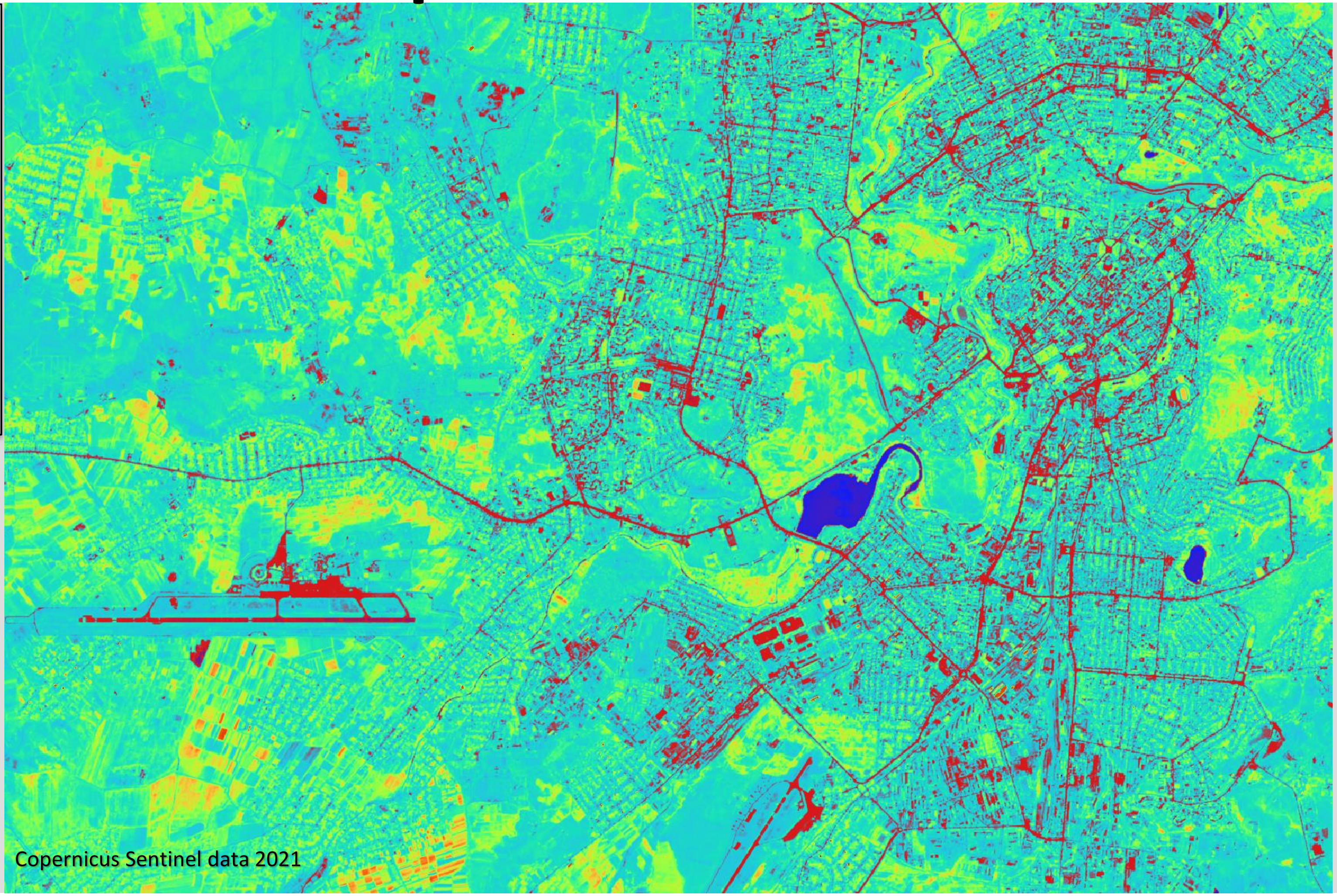
WaLMa

(Water Land Mask)

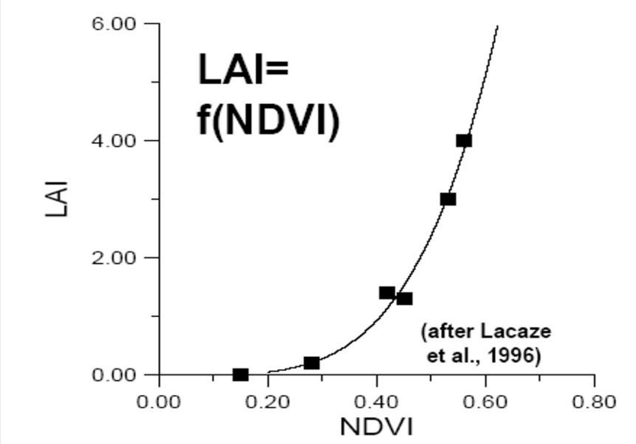
(Zober 2002, Groth 2016)

(NIR-(0.321*RED))*10

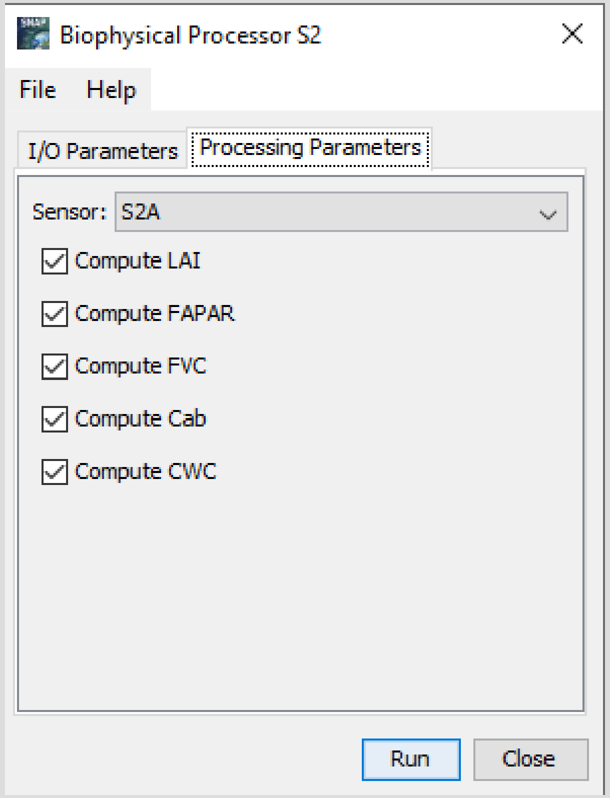
WaLMA performs greatly in delineating water from non water areas and is even useful for delineating urban fabric

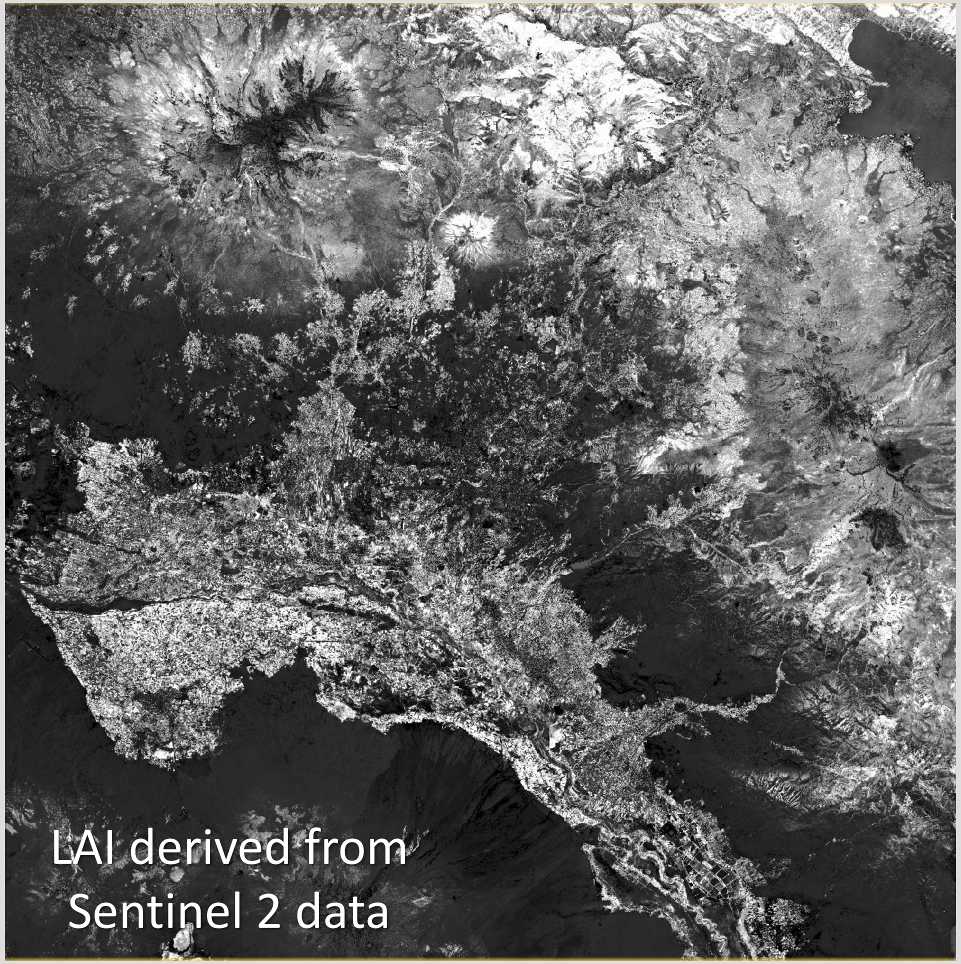


Vegetation indices and biophysical parameters



NDVI – LAI – Biomass!





Geological/mineralogical indices

ELSEVIER

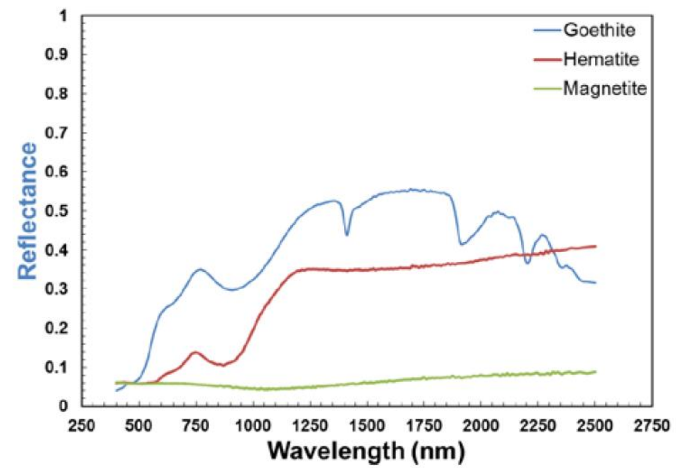
International Journal of Applied Earth Observation and Geoinformation

Volume 14, Issue 1, February 2012, Pages 112-128

Review

Multi- and hyperspectral geologic remote sensing: A review

Freek D. van der Meer, Harald M.A. van der Werff, Frank J.A. van Ruitenbeek, Chris A. Hecker, Wim H. Bakker, Marleen F. Noomen, Mark van der Meijde, E. John M. Carranza, J. Boudewijn de Smeth, Tsehaie Woldai



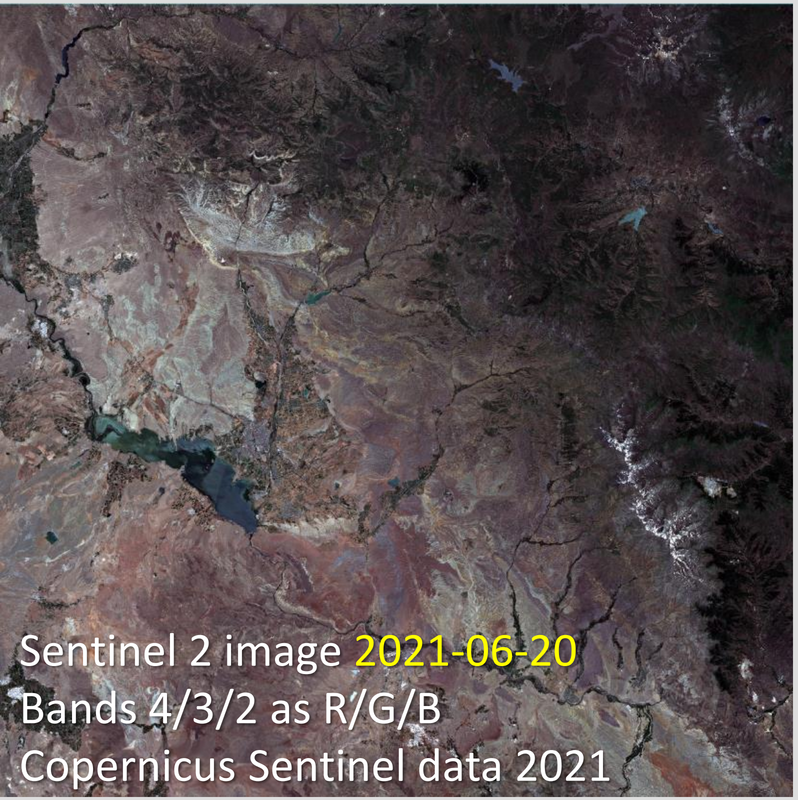
Spectral fingerprint!

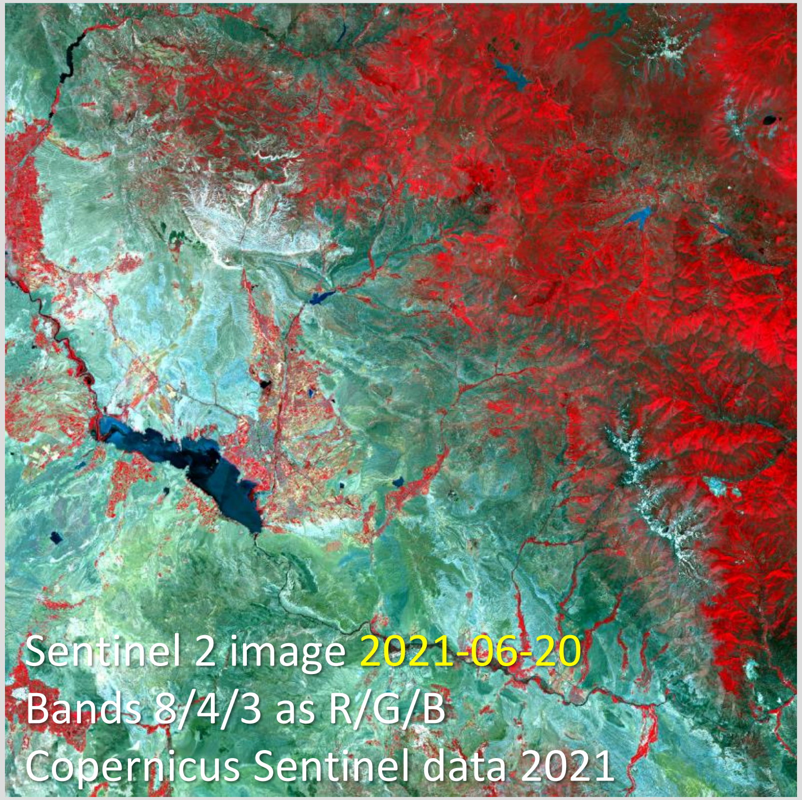
Feature	ASTER	Sentinel-2
Iron		
Ferric Iron, Fe3+	2/1	4/3
Ferrous Iron, Fe2+	5/3 + 1/2	12/8 + 3/4
Laterite	4/5	11/12†
Gossan	4/2	11/4
Ferrous silicates (Biotite, chloride, amphibole)	5/4	12/11†
Ferric oxides	4/3	11/8
Carbonates / Mafic minerals		
Carbonate / Chlorite / Epidote	(7+9)/8	–
Epidote / Chlorite/ Amphibole	(6+9)/(7+8)	–
Amphibole / MgOH	(6+9)/8	–
Amphibole	6/8	–
Dolomite	(6+8)/7	–
Silicates		
Sericite / Muscovite / Illite / Smectite	(5+7)/6	–
Alunite, Kaolinite, Pyrophyllite	(4+6)/5	–
Phengitic	5/6	–
Muscovite	7/6	–
Kaolinite	7/5	–
Clay	$(5\times7)/6^2$	–
Alteration	4/5	11/12†
Host rock	5/6	–
Other		
Vegetation	3/2	8/4
NDVI	(3-2)/(3+2)	(8-4)/(8+4)

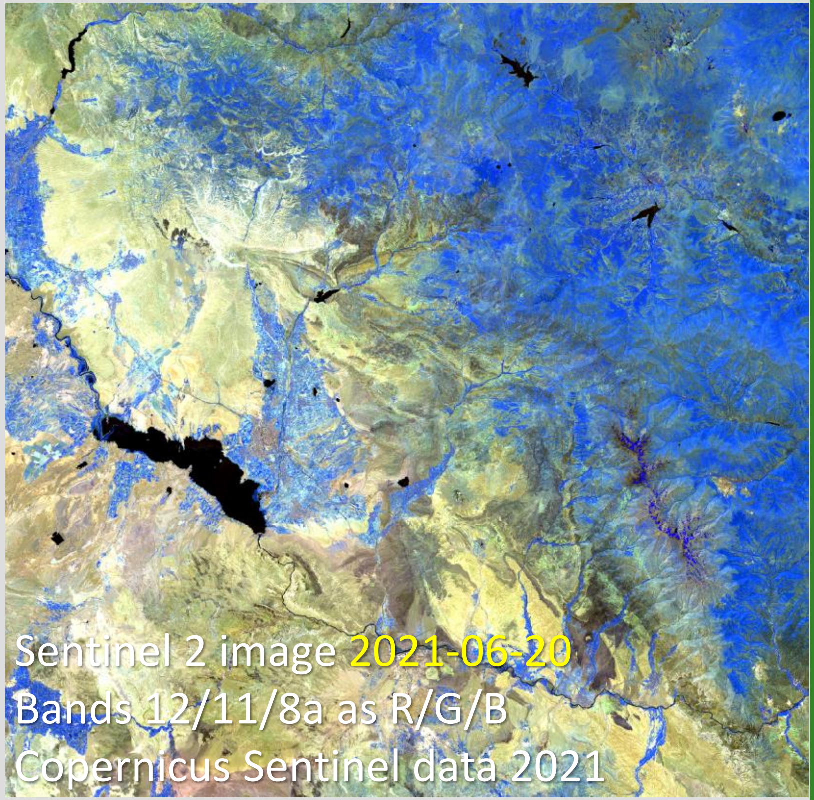
† ASTER bands 5–7 fall within band 12 of Sentinel-2.

Credit: van der Meer F.D. et al. (2020) - Potential of ESA's Sentinel-2 for geological applications. Remote Sensing of Environment 148:124–133, DOI:10.1016/j.rse.2014.03.022

Geological/mineralogical indices

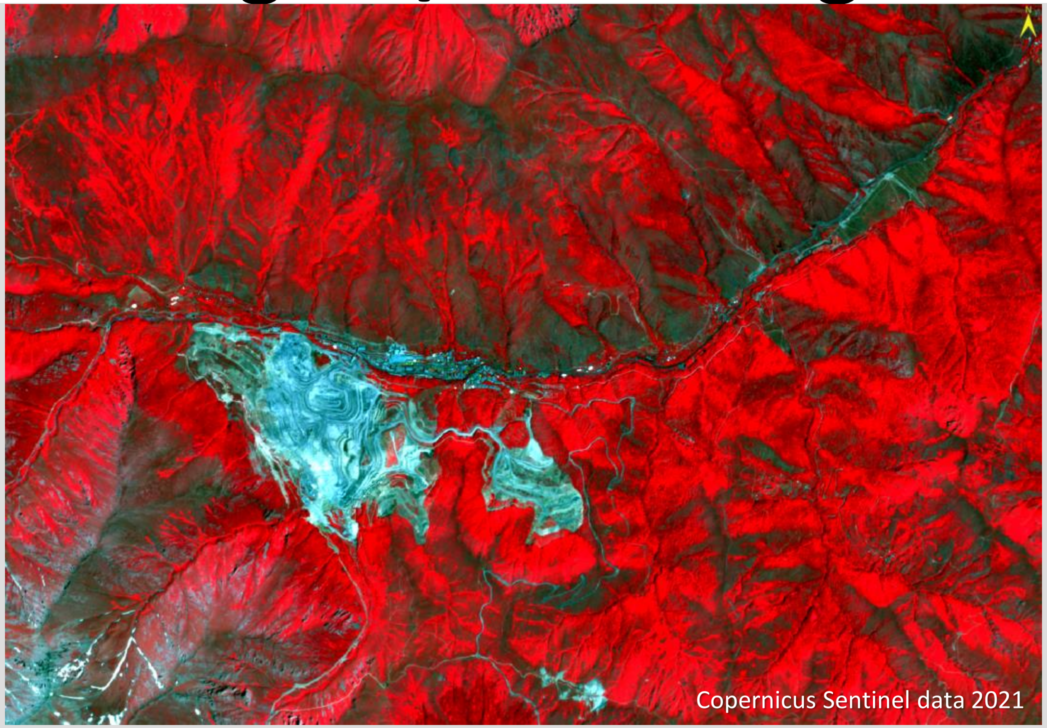




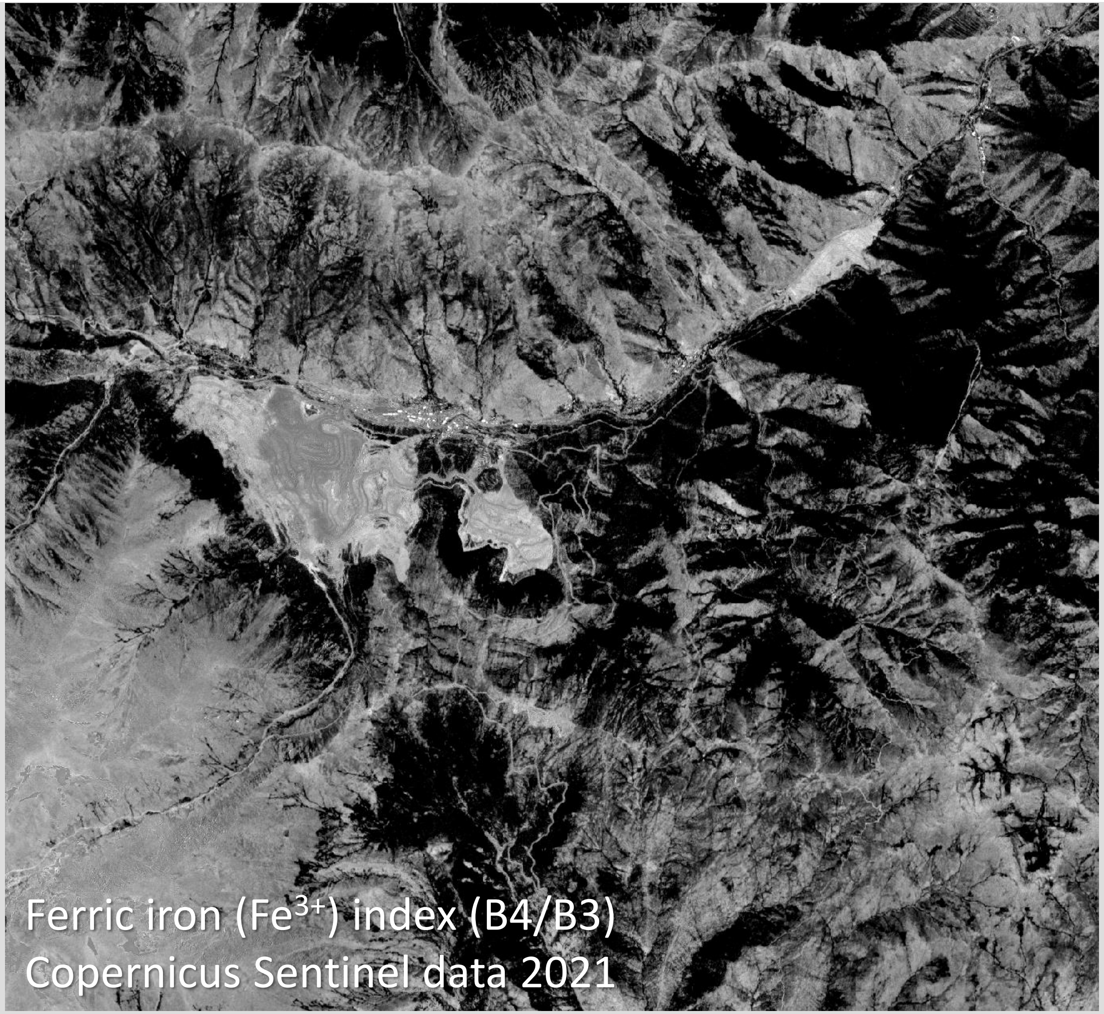


Copernicus Sentinel data 2021

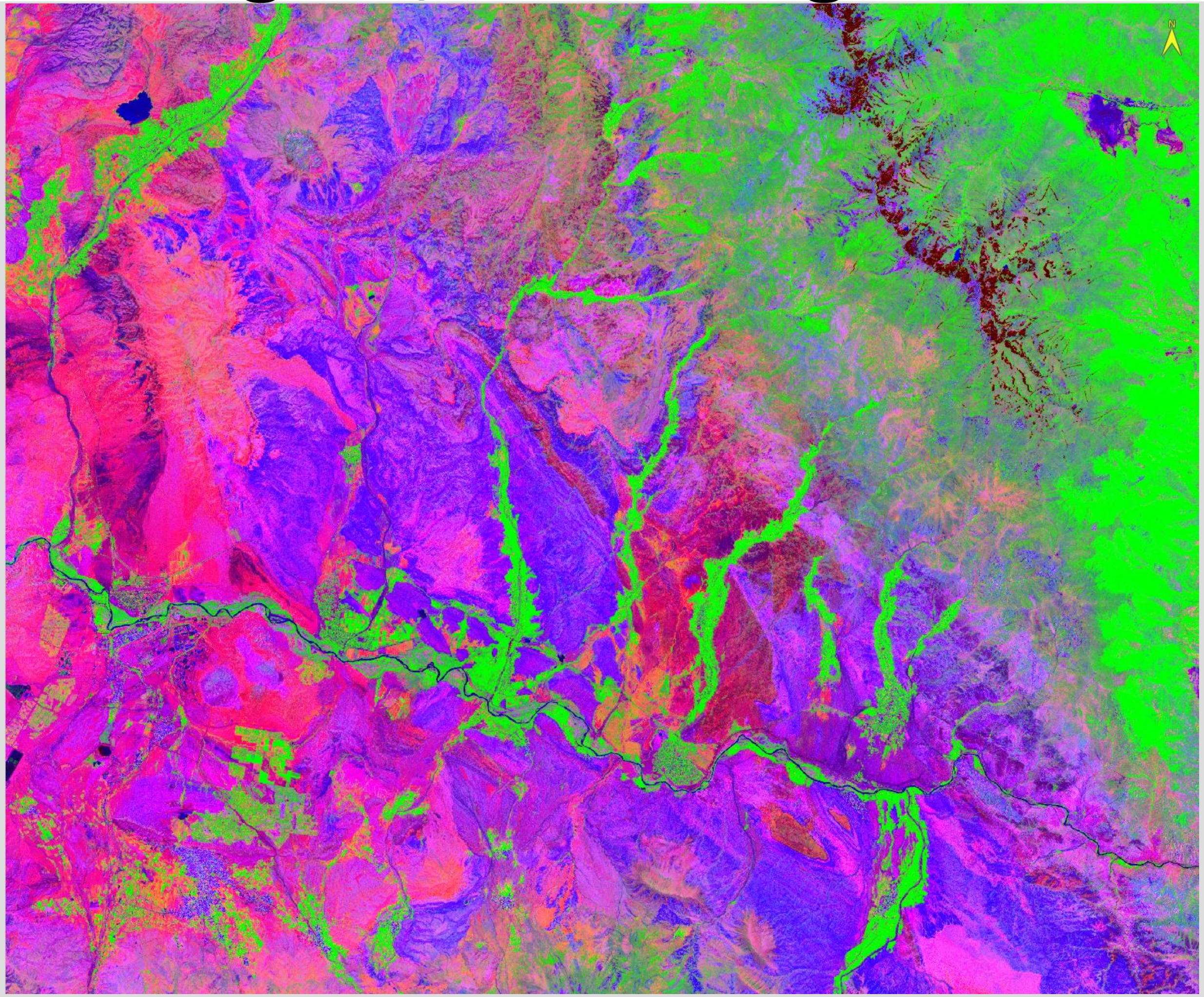
Geological/mineralogical indices

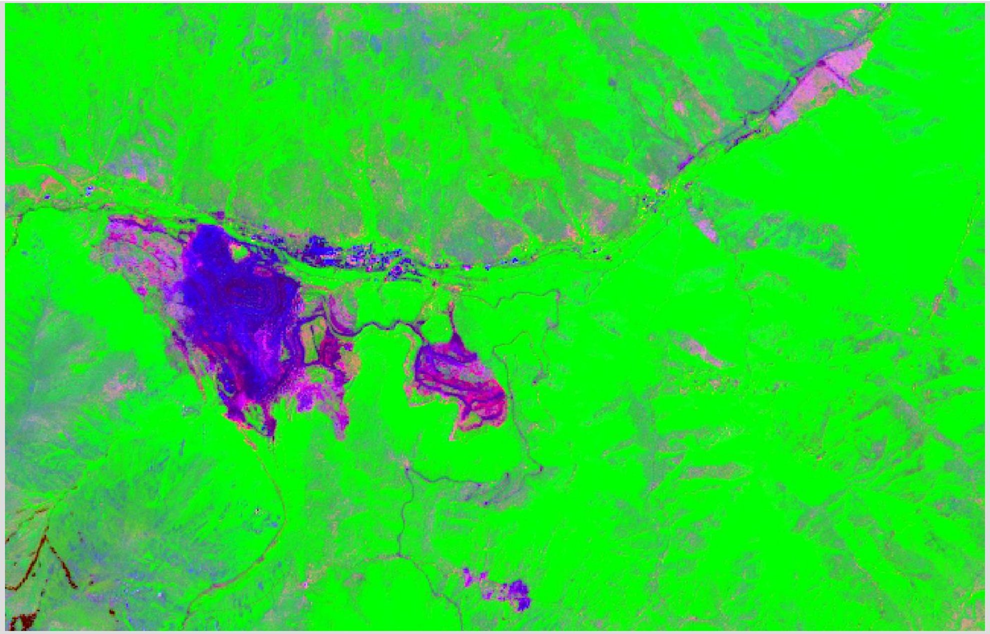


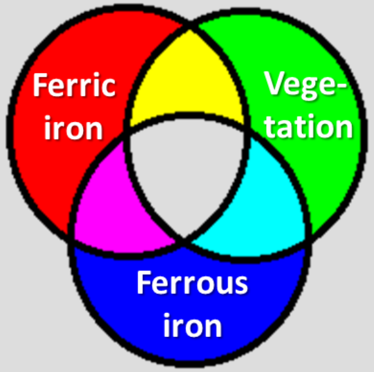
The Kajaran mining area



Geological/mineralogical indices





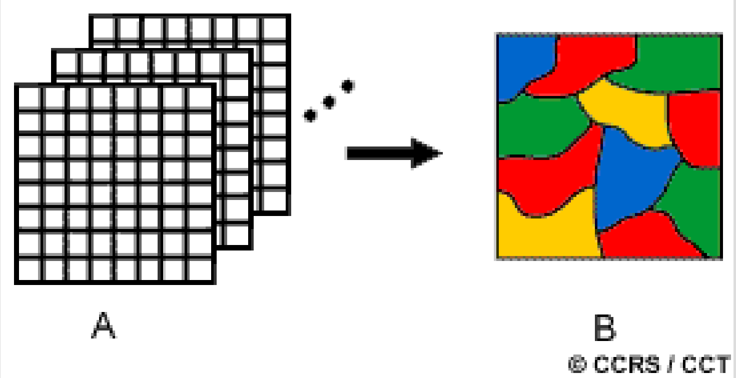


Copernicus Sentinel data 2021

Image classification

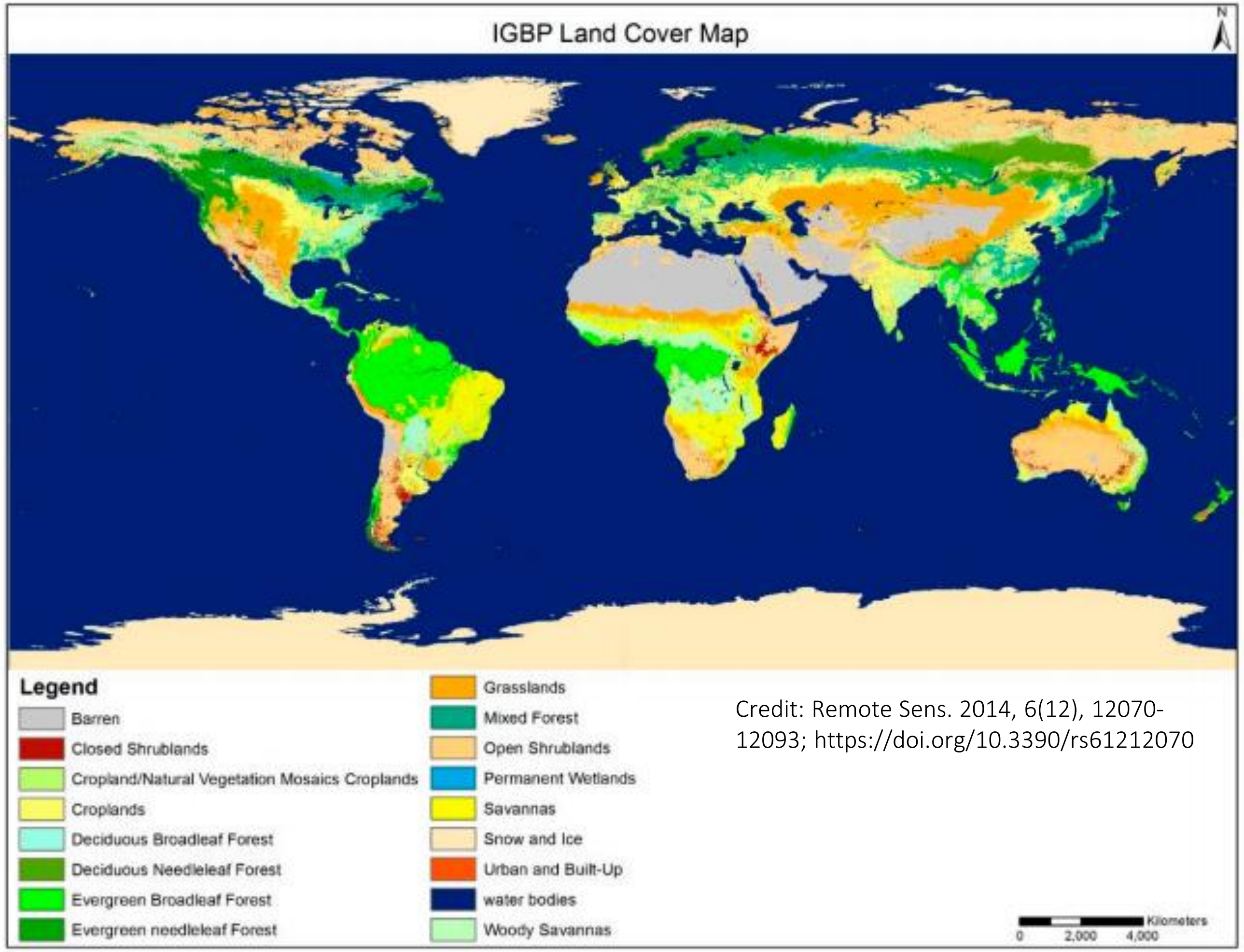
- Automatic categorization of all image pixels into land cover classes (Lillesand & Kiefer 2000)

- Assignment of pixels to groups which represent meaningful thematic classes according to specific characteristics



Credit: Canada Centre for Mapping and Earth Observation (or Canada Centre for remote Sensing), Natural Resources Canada

Image classification



Credit: Remote Sens. 2014, 6(12), 12070-12093; https://doi.org/10.3390/rs61212070

Open Access Review

Global Land Cover Mapping: A Review and Uncertainty Analysis

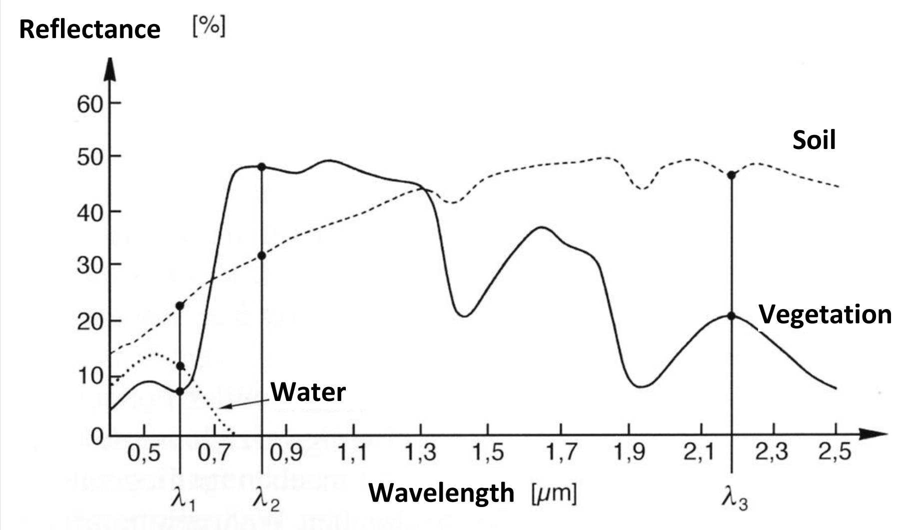
by Russell G. Congalton [1,*,†], Jianyu Gu [1,2,†], Kamini Yadav [1], Prasad Thenkabail [3] and Mutlu Ozdogan [4]

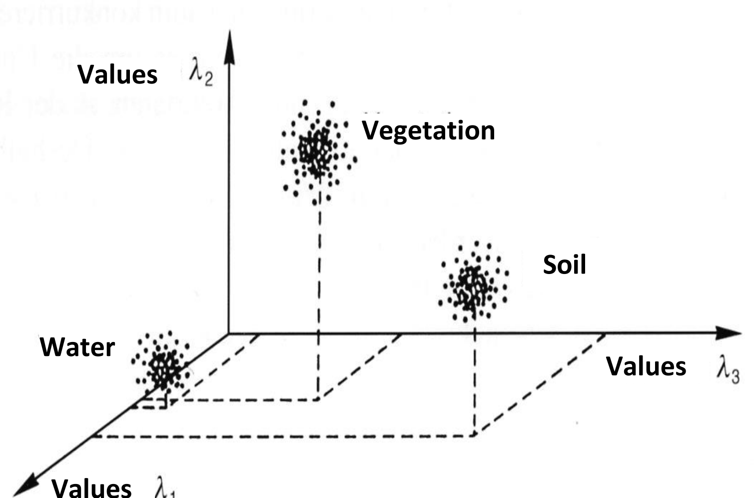
Open Access Editor's Choice Review

Sentinel-2 Data for Land Cover/Use Mapping: A Review

by Darius Phiri [1,*], Matamyo Simwanda [1], Serajis Salekin [2], Vincent R. Nyirenda [3], Yuji Murayama [4] and Manjula Ranagalage [4,5]

Image classification – Basic problem





Credits: Albertz 2001

- Spectral information can be represented in a **multidimensional feature space**
- **Dimensions** of the feature space = **number of spectral bands**
- Spectrally similar pixel values are close to each other in the feature space

Image classification – Basic problem

This is how the reality looks like…

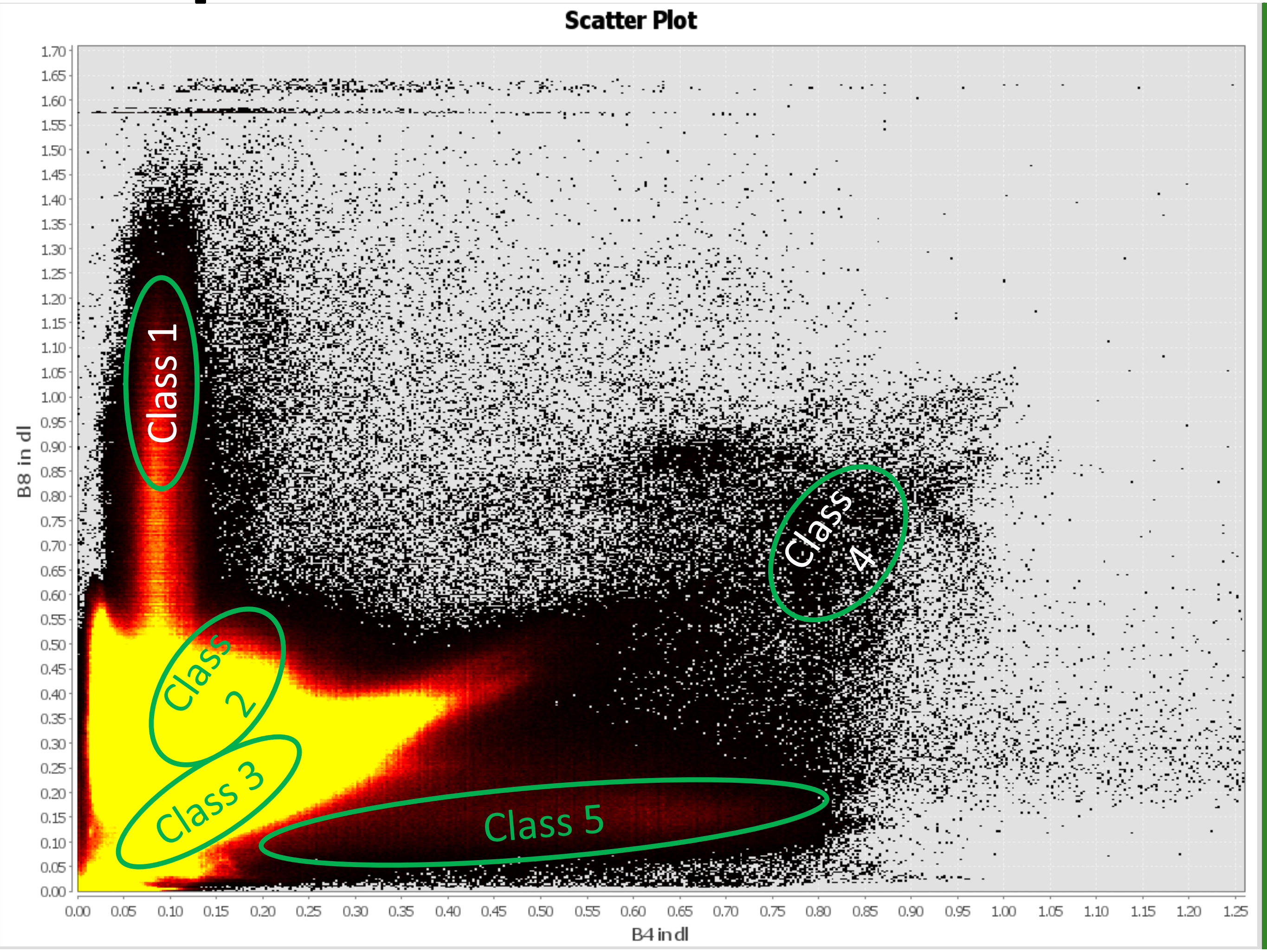
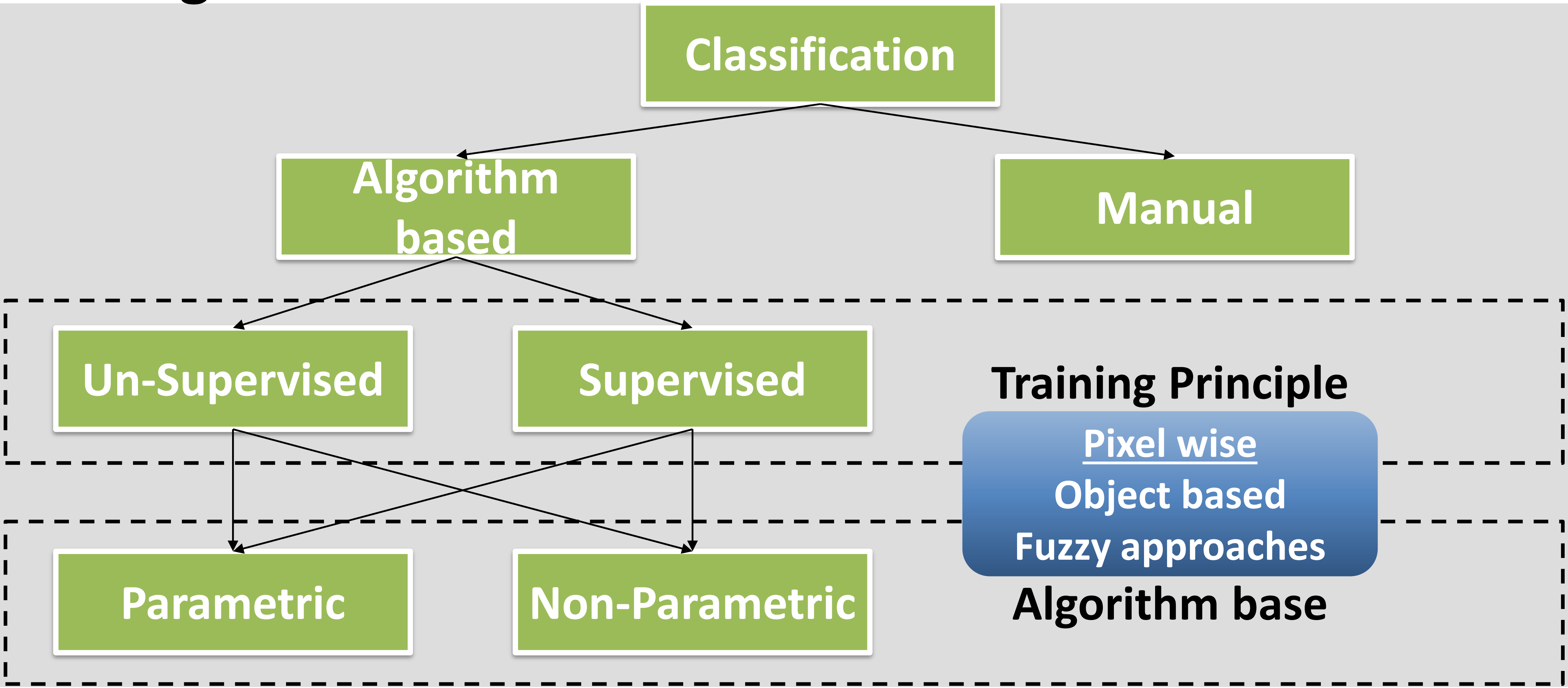
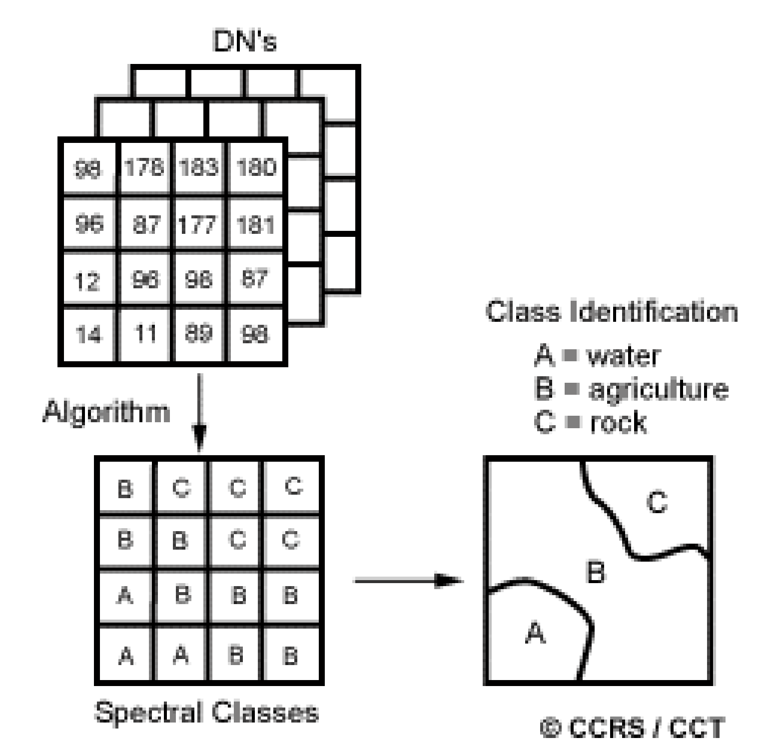


Image classification



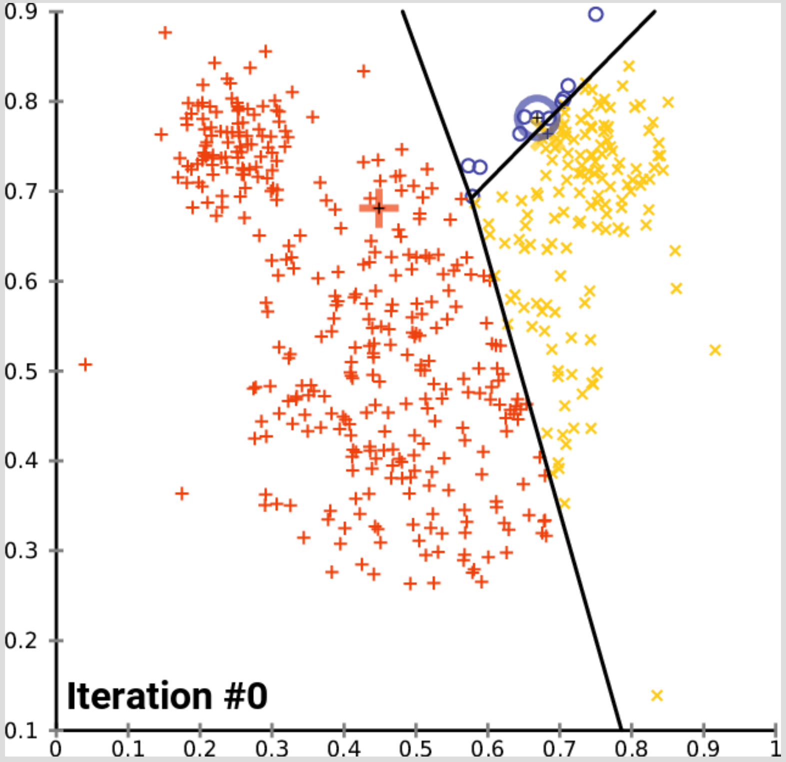
Unsupervised classification

- No training of the classifier
- Only the number of classes is defined, not the meaning of the classes
- Purely statistical approach
- Well known methods: ISODATA Clustering, K-Means Clustering



Credit: Canada Centre for Mapping and Earth Observation (or Canada Centre for remote Sensing), Natural Resources Canada

Unsupervised classification - K-Means



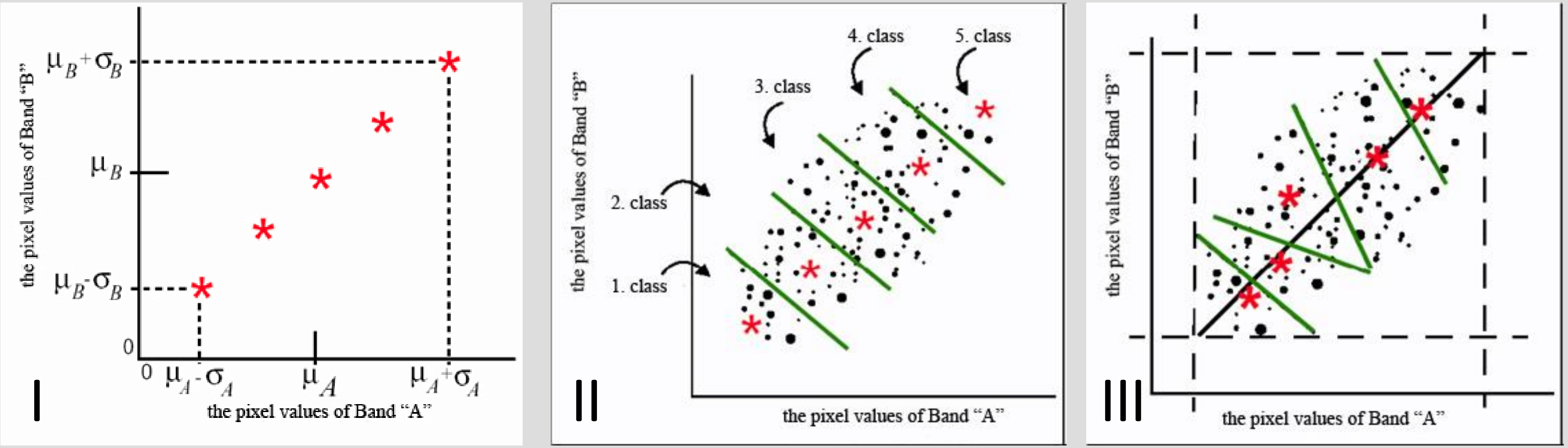
Credit: By Chire - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=59409335

- Common cluster method (Duda & Hart 1973)
- Parametric approach
- +: not interaction required; - empty classes possible

Steps:

1. Initial, arbitrary definition of starting centers of clusters (number of cluster centers = number of later clusters)
2. Assignment of all pixels to the respective next cluster center (cluster mean)
3. Recalculation of the cluster mean
4. Return to step 2 or end of clustering, if no more significant changes of cluster mean occur

Unsupervised classification - ISODATA

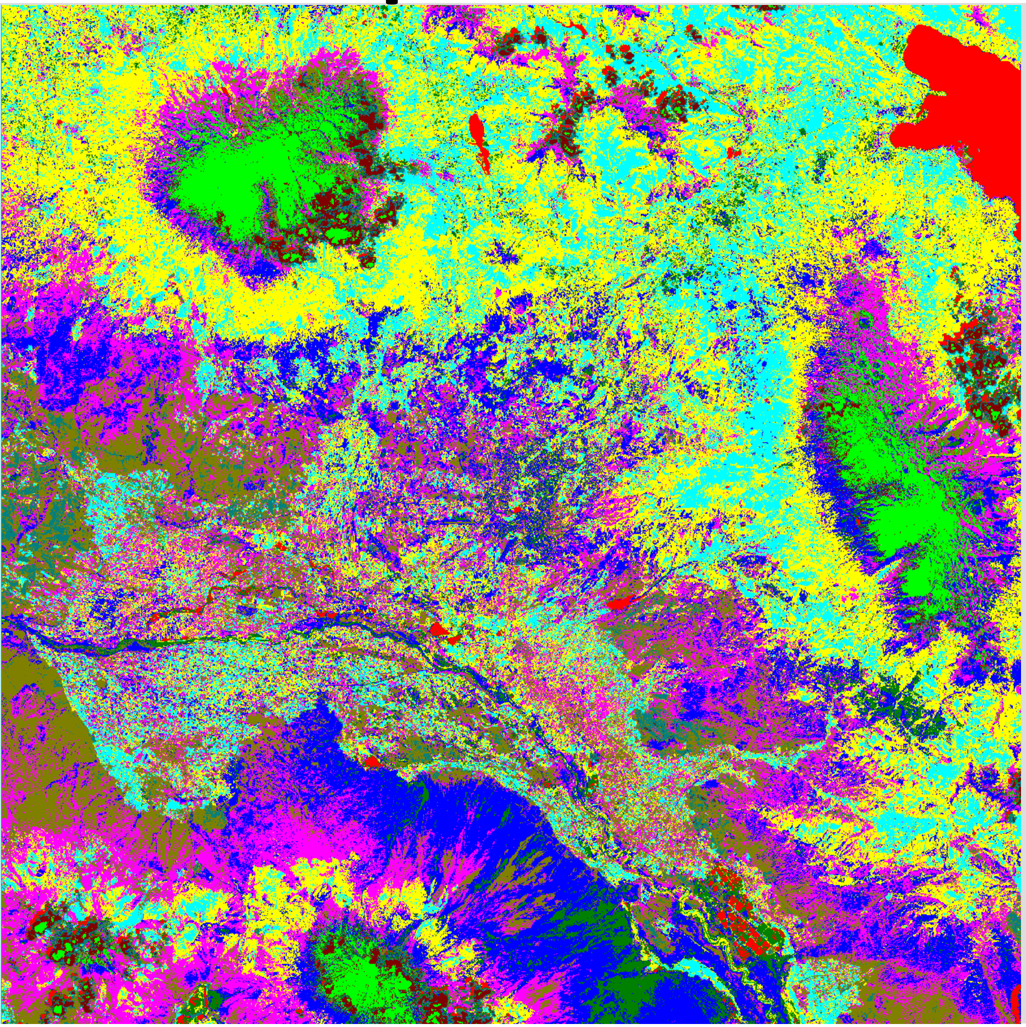


Credit:
Kristóf, D. and Belényesi, M., 2010

I. Definition of the number of classes
II. Assignment of pixels to the nearest cluster center (distance measures).
III. Iterative procedure: Recalculation of cluster centers and new pixel assignment (until no significant changes occur or max. number of iterations is reached)

In contrast to the K-Means method, the distance to the neighboring cluster is examined - clusters are then either deleted (insufficient number of pixels in the cluster), connected (minimum distance of the clusters not reached) or separated (if the stddev. or scatter is too large).

Example of an ISODATA classification

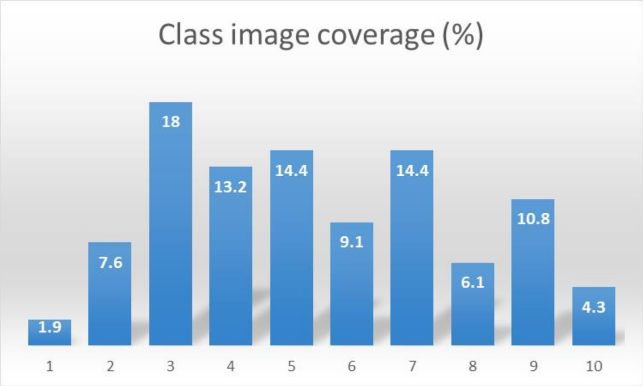


Results of a ISODATA classification

Number of classes = 10

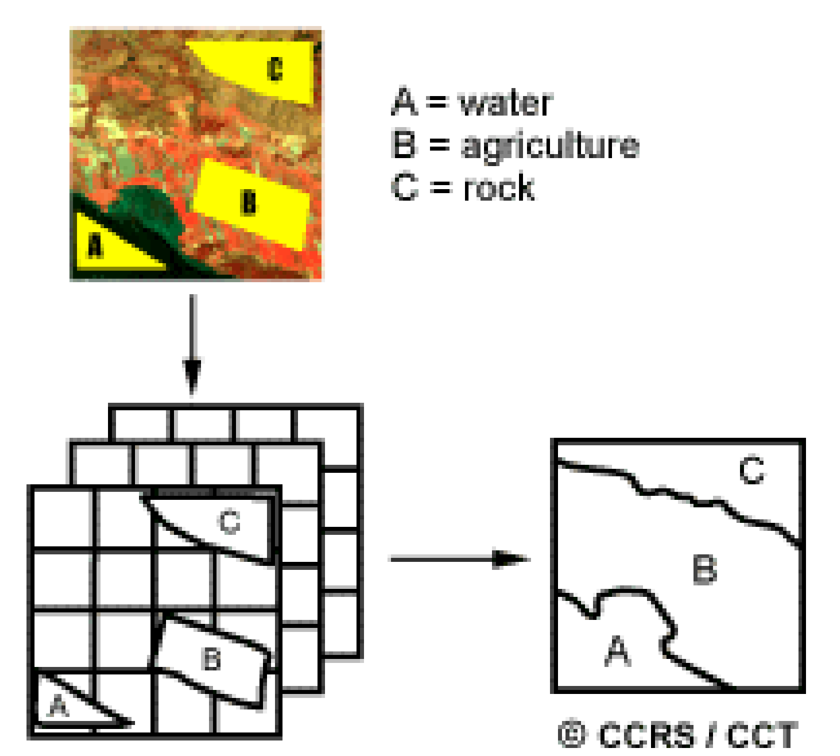
What do the colours represent?!

→ Requieres interpretation based on reference data or expert knowledge!



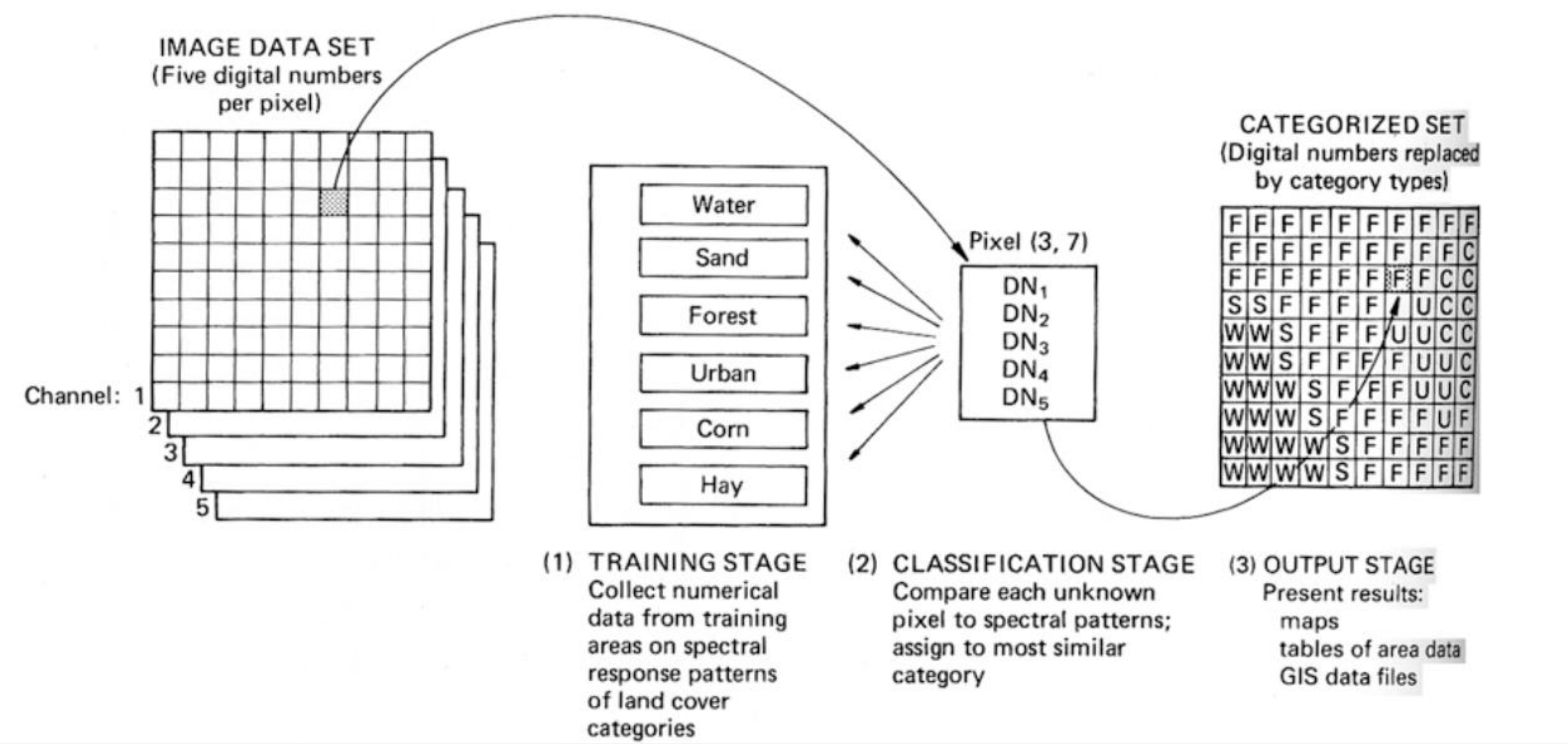
Supervised classification

- Classification after training the classifier with training regions/training data
- Number and importance of classes are defined a priori
- Knowledge of land use required
- Additional effort due to training
- Training via defined regions in the image ("on screen") or using training spectra (e.g. from reference libraries)



Credit: Canada Centre for Mapping and Earth Observation (or Canada Centre for remote Sensing), Natural Resources Canada

Supervised classification



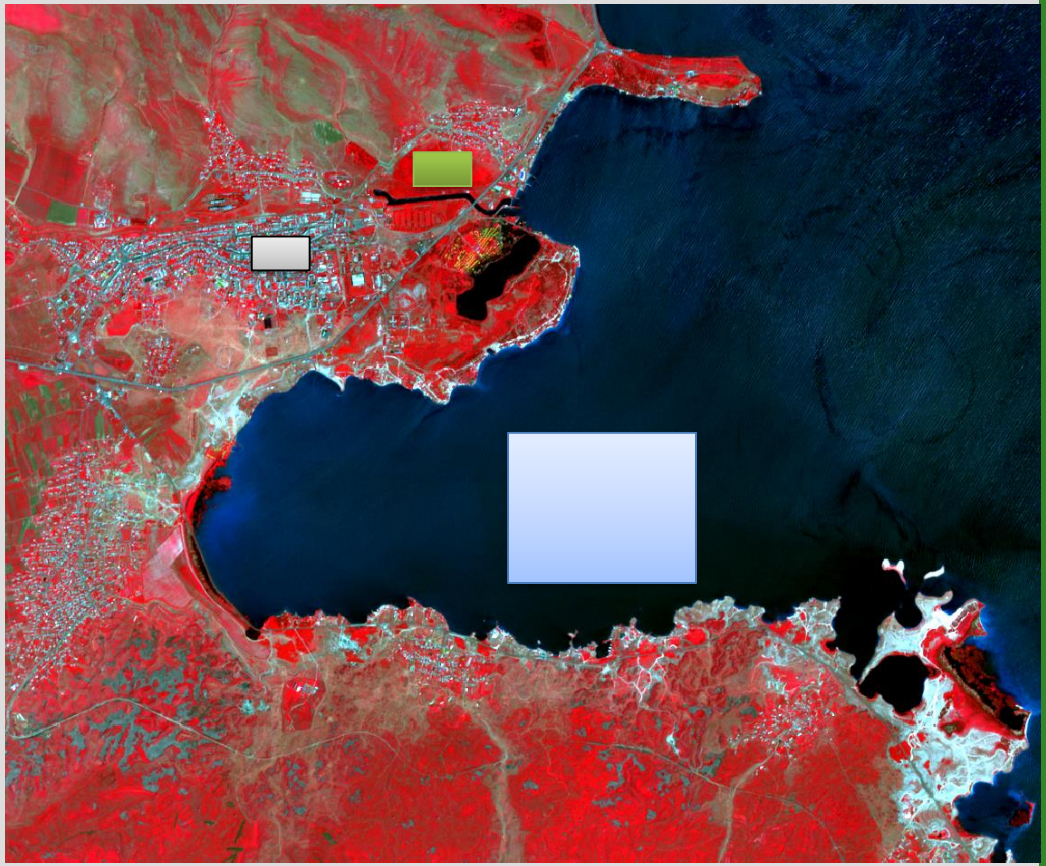
Basic steps of supervised image classification after Lillesand and Kiefer (2004)

Supervised classification – Training data

Criteria:

- Representative areas with class-typical signatures
- Homogeneous areas with pure signatures
- Consider intra-class variability
- Avoidance of mixed pixels

Instead of on-screen digitizing the training areas, the user might also use existing reference data/spectra

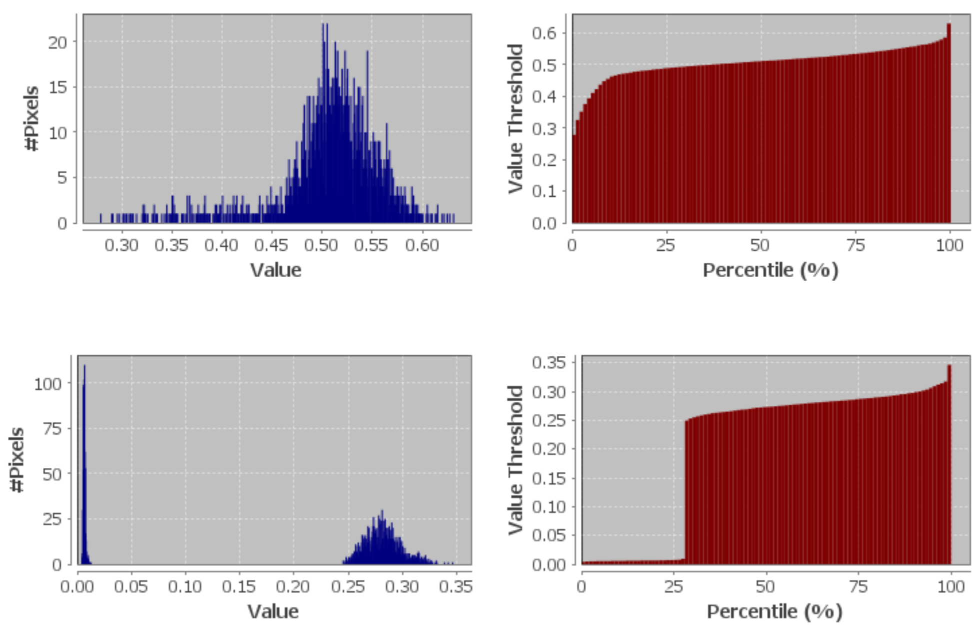


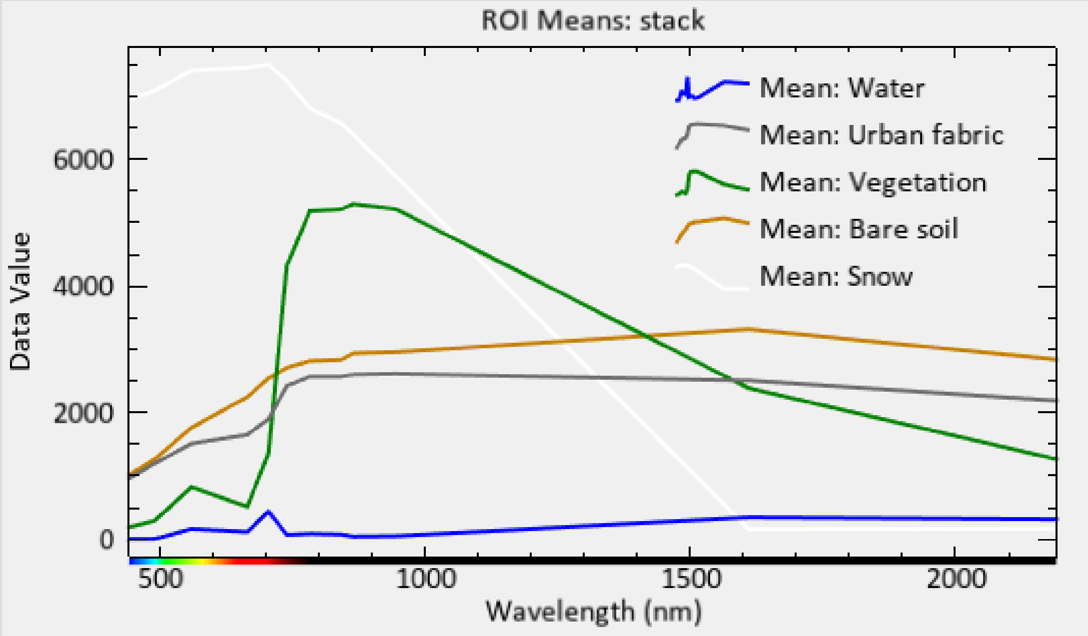
Supervised classification – Assessing training data

#Pixels total:	2447
Minimum:	0.2784
Maximum:	0.6308
Mean:	0.5075
Sigma:	0.0480
Median:	0.5125
Coef Variation:	0.1754
ENL:	32.4920
P75 threshold:	0.5353
P80 threshold:	0.5420
P85 threshold:	0.5497
P90 threshold:	0.5582
Max error:	3.524E-4

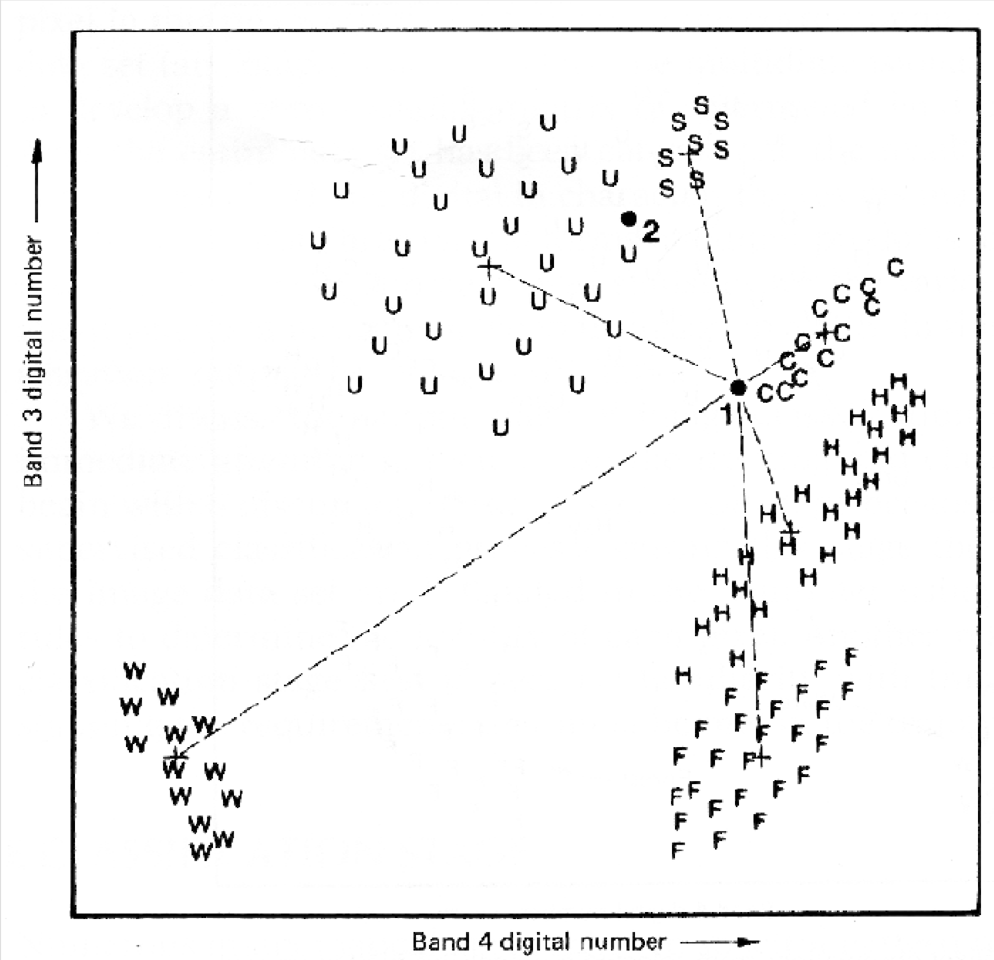
B8 with ROI-mask **Bare soil**

#Pixels total:	2470
Minimum:	0.0039
Maximum:	0.3460
Mean:	0.2064
Sigma:	0.1237
Median:	0.2731
Coef Variation:	0.6284
ENL:	2.5321
P75 threshold:	0.2872
P80 threshold:	0.2899
P85 threshold:	0.2937
P90 threshold:	0.2988
Max error:	3.421E-4





Minimum-Distance-(To-Mean) classification



Credit: Lillesand & Kiefer 2004

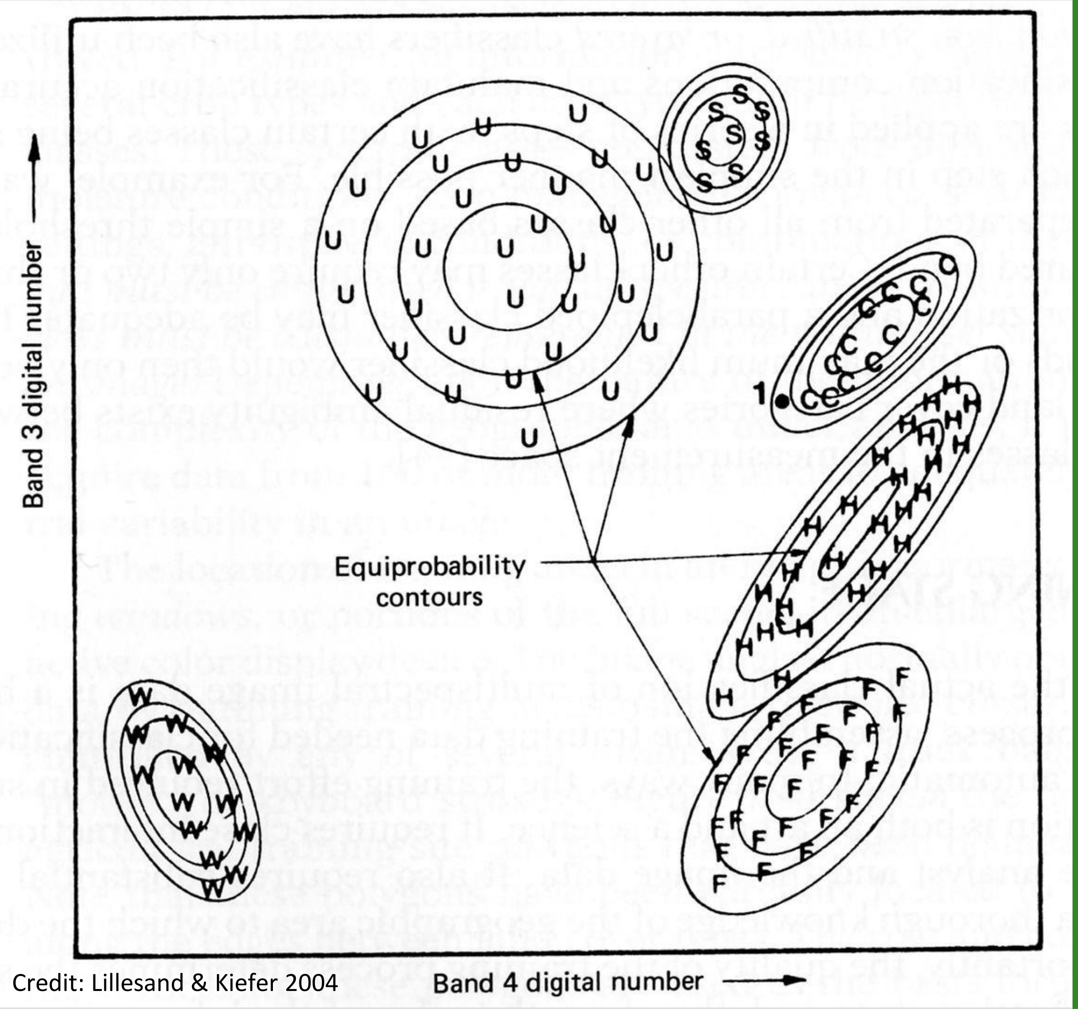
- Parametric approach
- Pro: simple, efficient
- Con: weak for high variable classes

Steps:

1. Determination of the mean values of the training area pixel values
2. Calculation of the Euclidean distance of the pixels to be classified from the mean value of the training data clusters
3. Assignment of the pixels to the class with the smallest distance to the mean value

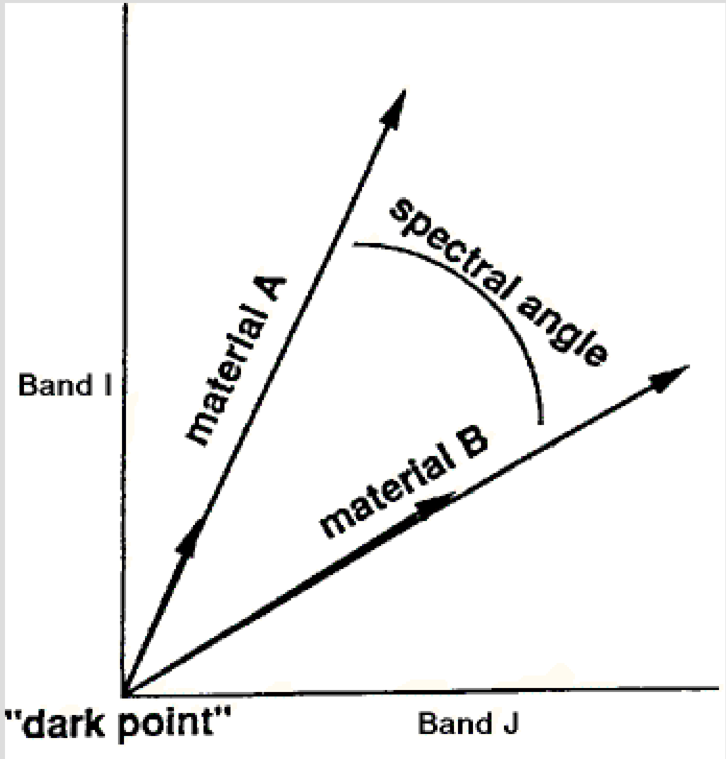
Maximum likelihood (ML) classifier

- Parametric approach - assumes Gaussian normal distribution
- Calculation of Probability Density Function
- Assignment of the pixel to the class with the highest probability of membership
- Pro: robust
- Con: processing intensive

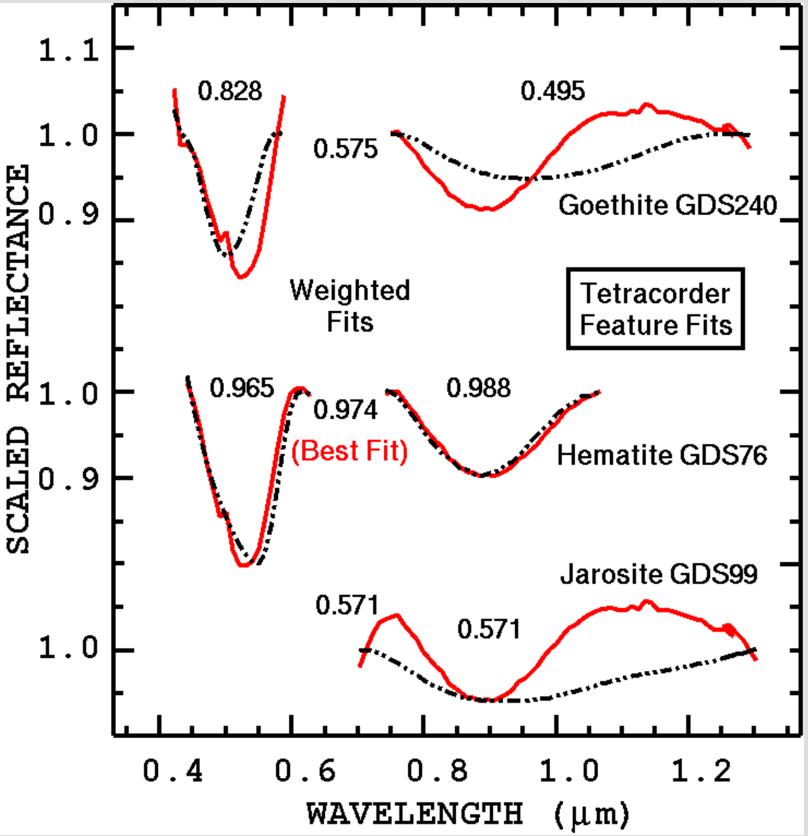


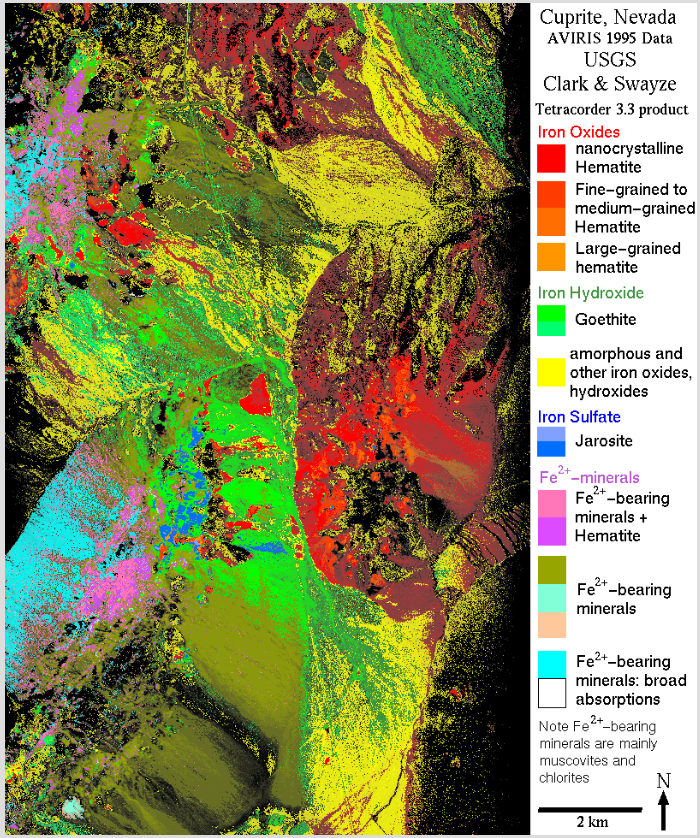
Credit: Lillesand & Kiefer 2004

Spectral Angle Mapper (SAM), Spectral Feature Fitting (SFF)



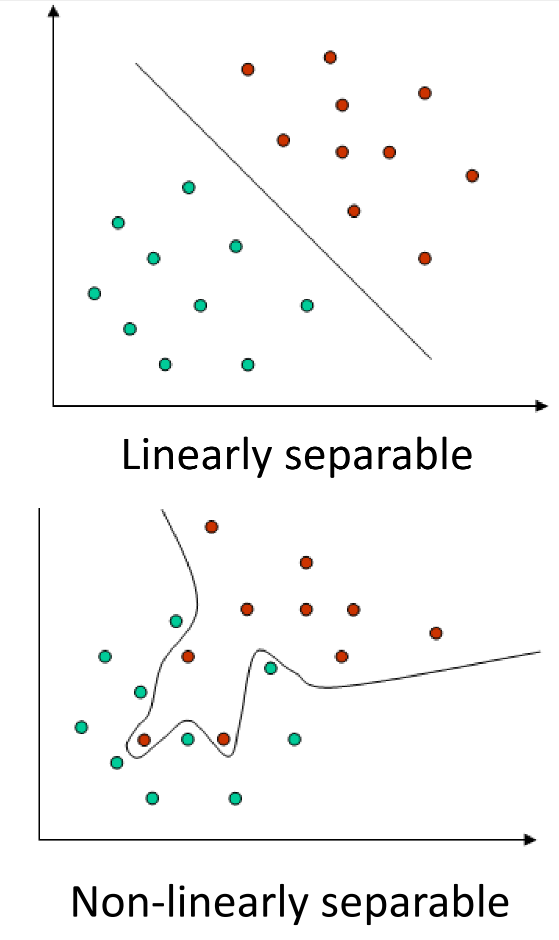
Credit: Kruse, F. A., A. B. Lefkoff, J. B. Boardman, K. B. Heidebrecht, A. T. Shapiro, P. J. Barloon, and A. F. H. Goetz. "The Spectral Image Processing System (SIPS) - Interactive Visualization and Analysis of Imaging spectrometer Data." *Remote Sensing of Environment* 44 (1993): 145-163.



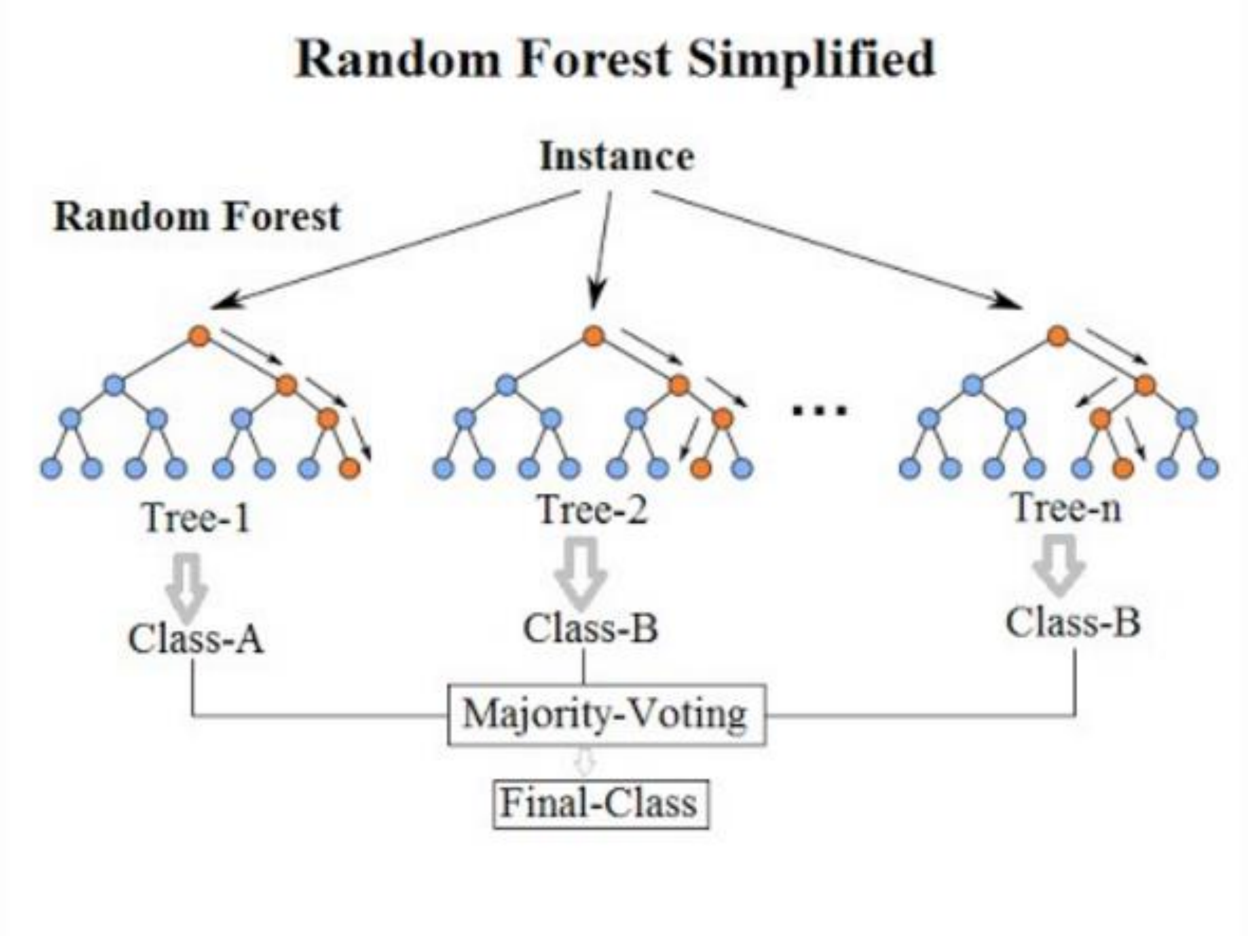


Credit: Clark, R. N., G. A. Swayze, K. E. Livo, R. F. Kokaly, S. J. Sutley, J. B. Dalton, R. R. McDougal, and C. A. Gent, Imaging spectroscopy: Earth and planetary remote sensing with the USGS Tetracorder and expert systems, J. Geophys. Res., 108(E12), 5131, doi:10.1029/2002JE001847, pages 5-1 to 5-44, December, 2003. http://speclab.cr.usgs.gov/PAPERS/tetracorder

Support Vector Machine (SVM), Random Forest (RF)



Credit: Von unbekannt - unbekannt, PD-Schöpfungshöhe, https://de.wikipedia.org/w/index.php?curid=1616694



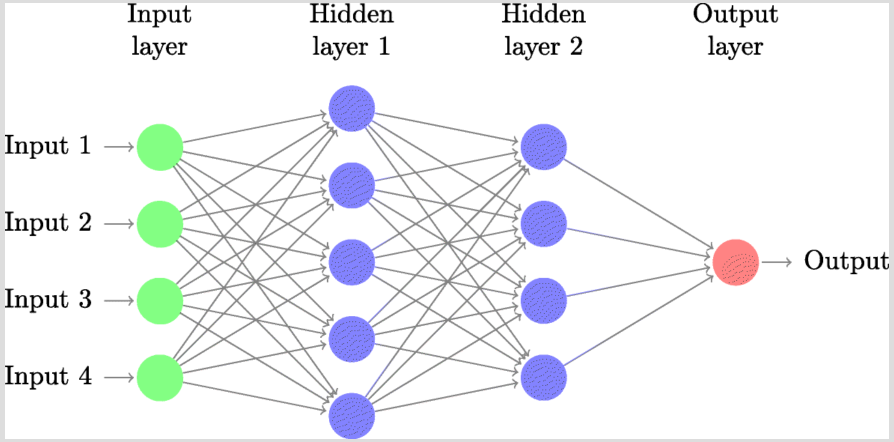
Credit: By Venkata Jagannath - https://community.tibco.com/wiki/random-forest-template-tibco-spotfirer-wiki-page, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=68995764

Neural Networks

Artificial Neural Networks (ANN)

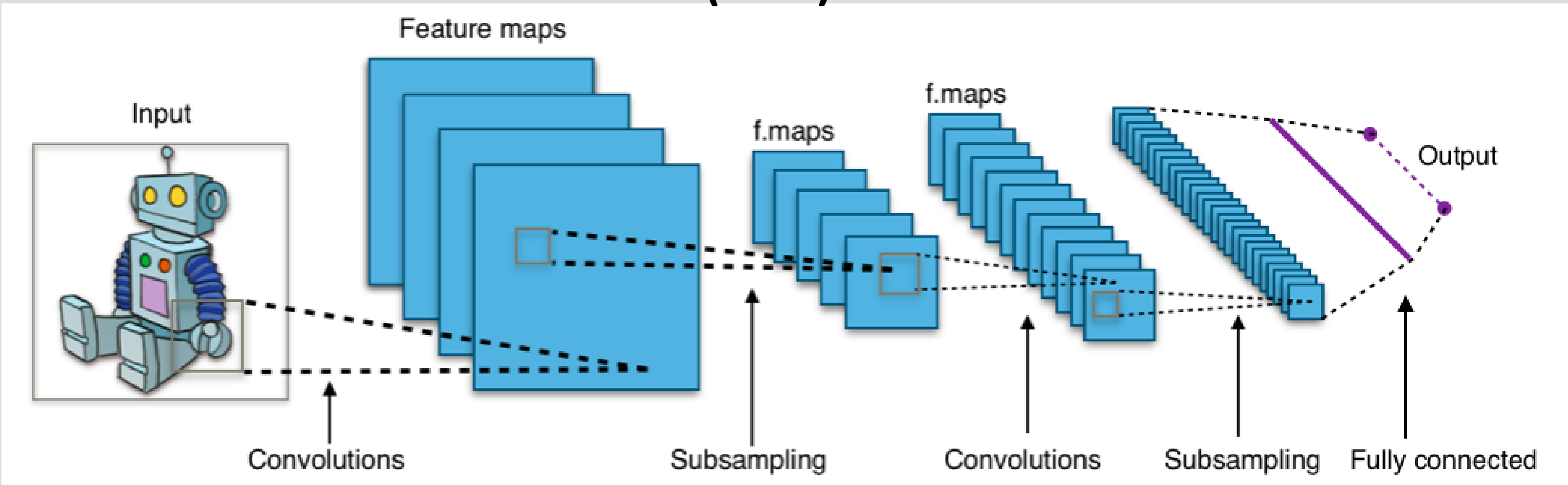
"A neural network consists of a number of interconnected nodes. Each node is a simple processing element that responds to the weighted inputs it receives from other nodes. The arrangement of the nodes is referred to as the network architecture." (Atkinson et al. 1997)

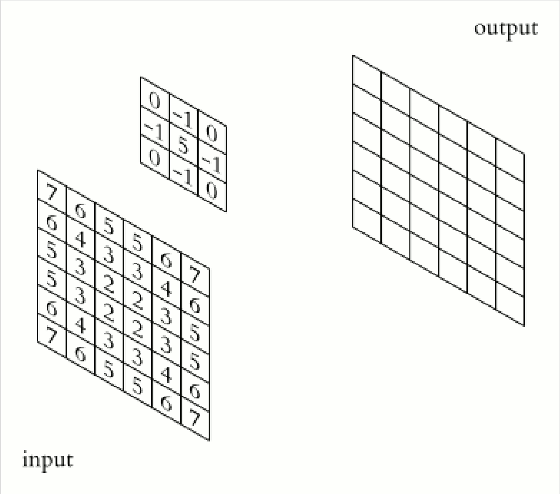
ATKINSON, P. M. & A. R. L. TATNALL (1997): Introduction Neural networks in remote sensing, International Journal of Remote Sensing, 18:4, 699-709.



Credit: Holmgren, G., Andersson, P., Jakobsson, A. *et al.* Artificial neural networks improve and simplify intensive care mortality prognostication: a national cohort study of 217,289 first-time intensive care unit admissions. *j intensive care* **7**, 44 (2019). https://doi.org/10.1186/s40560-019-0393-1

Convolutional Neural Networks (CNN)





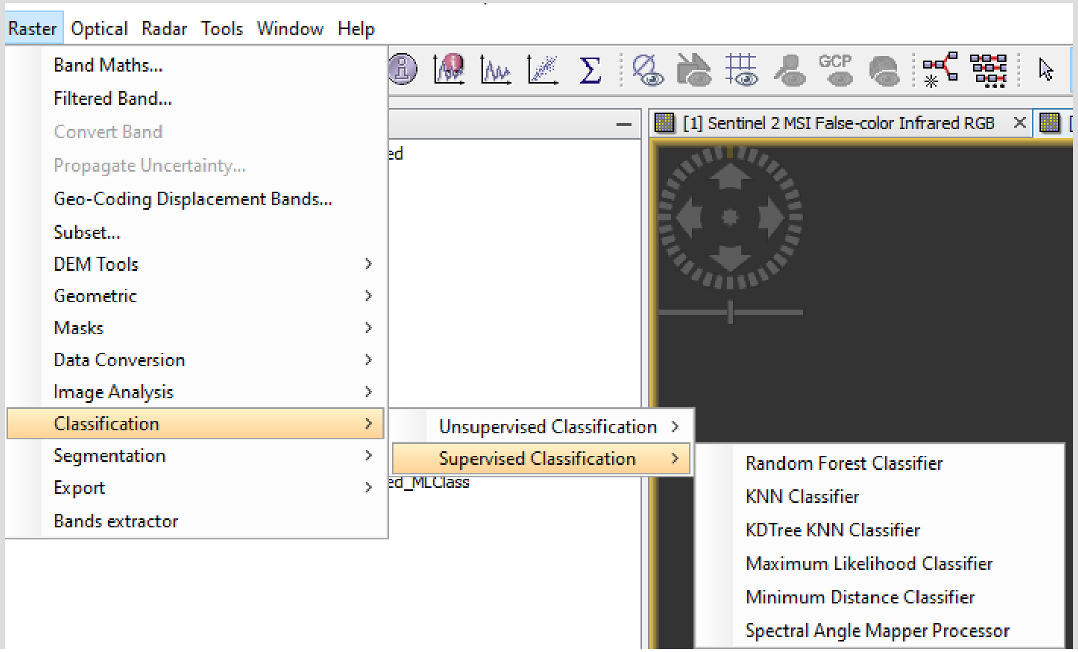
Credits: Von Aphex34 - Eigenes Werk, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=45679374, Von Michael Plotke - Eigenes Werk, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=24288958

Supervised classification – algorithm selection & processing

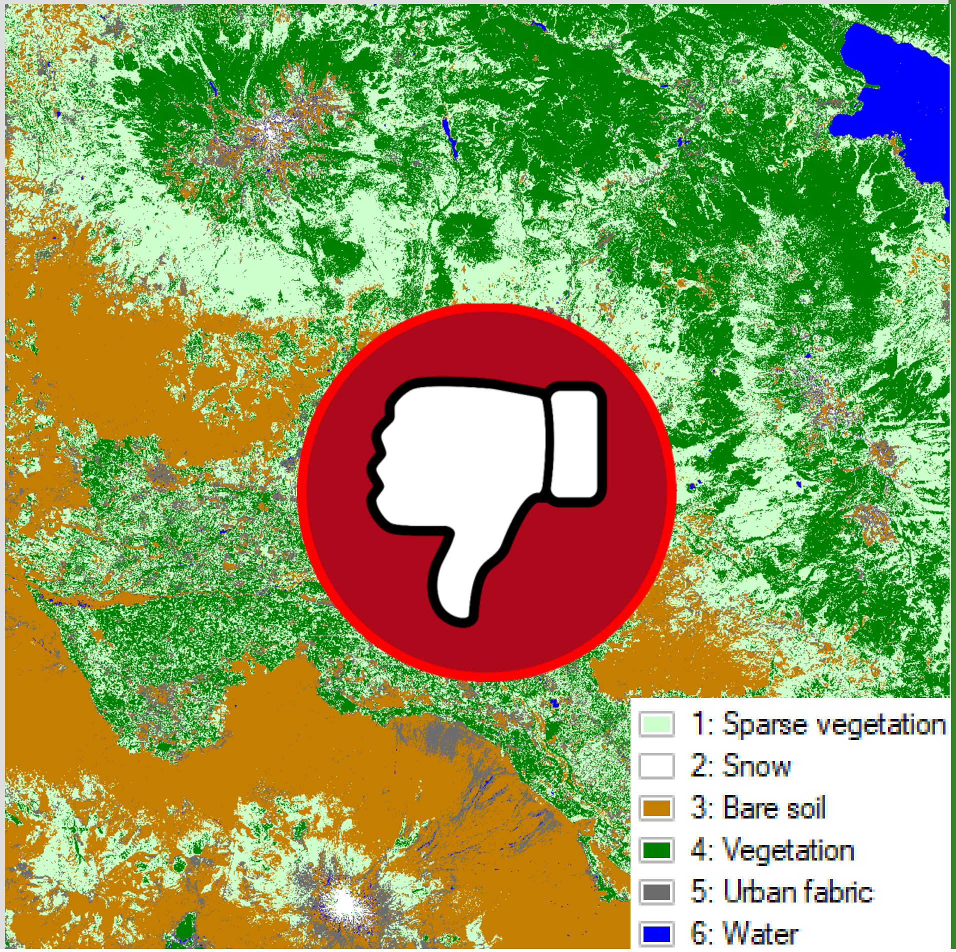
1. Training stage

Definition of 6 classes

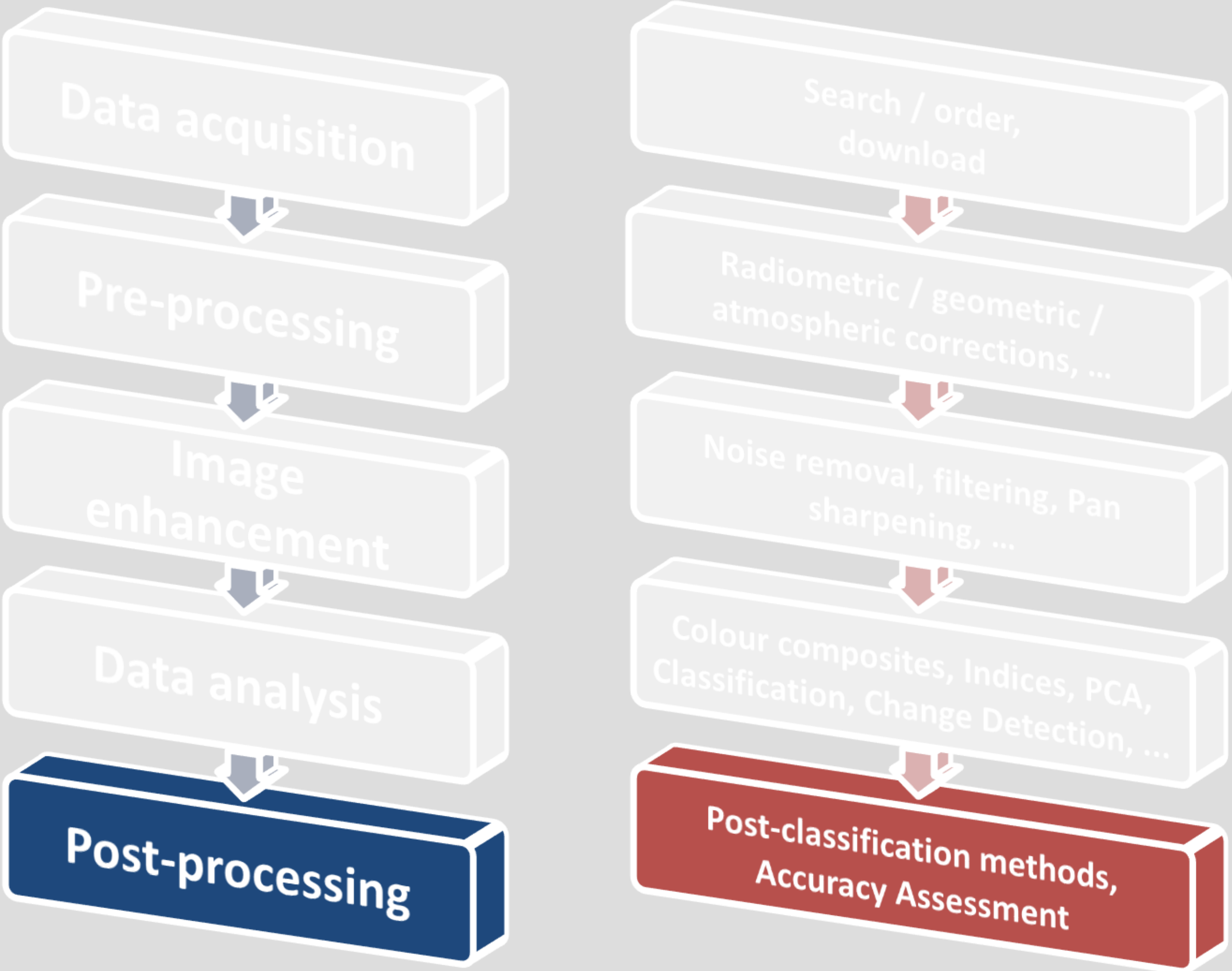
2. Classification stage



3. Output: Results of the ML classification



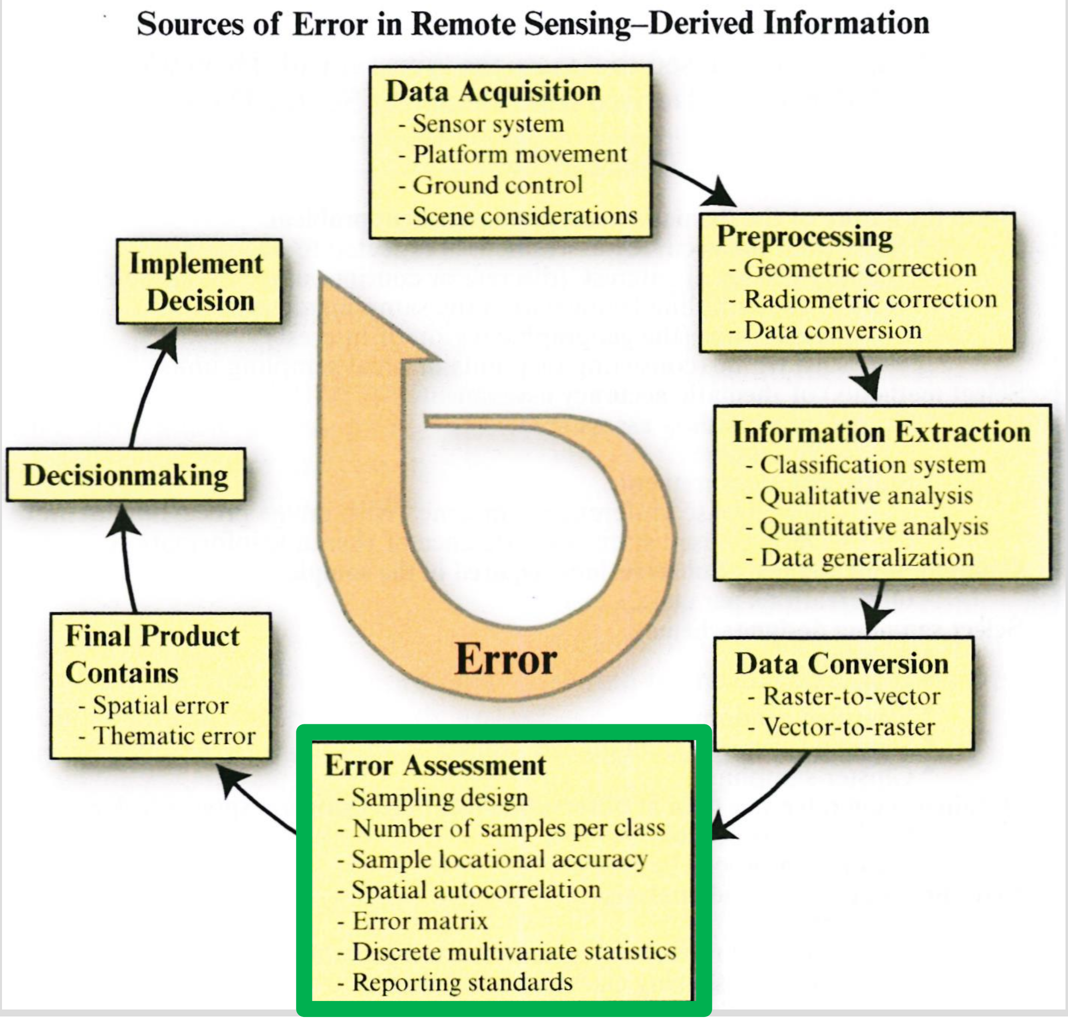
General workflow for satellite image analysis



Common post-processing steps

- Sieve
- Aggregate
- Eliminate
- Majority filters
- Raster to vector
- …

Error/Accuracy Assessment / Validation



Classification is not the end of the story!
It is important to asses the quality of the classification!

How well does the classification represent reality?
How accurately are the different LULC classes mapped?
How can the classification accuracy or error be quantified and communicated to users?

Credits: Jensen 2016

Validation methods

Validation

Visual check

Visual comparison of the classification results with the original images and other information sources

pros	Simple, fast for a first impression
cons	Highly subjective subjektiv
	Highly depending on the users knowledge
	Not quantitative

Digital assessment

Verification of the classification using reference data that were not used for the creation of the classification

pros	Quantitative method
	Transparent method
cons	Result highly depends from the number and quality of the reference data

Reference data

- Existing, validated results from other classifications
- Aerial photos, other satellite images, maps, ...
- Results from field surveys (GPS measurements, samples, ...)
- ...

Important: Evaluation of validation/reference data

- Can the needed information be derived from the reference data?
- Do the scales of the classification and the reference allow a meaningful validation of results?
- How is the positional accuracy of the data?
- Is the number of validation plots/points appropriate/statistically sound?
- According to which system were the reference points/areas recorded?

Confusion matrix

Class		Reference					
		Grass	Water	Sand	Forest	Total	User accuracy
Classification	Grass	4223	0	48	1785	6056	69.73%
	Water	0	1115	0	167	1282	86.97%
	Sand	22	9	652	154	837	77.90%
	Forest	545	237	63	7595	8440	89.99%
	Total	4790	1361	763	9701	16615	
Producer accuracy		88.16%	81.93%	85.45%	78.29%		

Overall accuracy	81.76%
Kappa coefficient	0.57
F1 Score	0.82

- Error of comission (false positives), error of omission (false negatives)
- Kappa coefficient
- F1 score

$$\hat{K} = \frac{\text{observed accuracy - chance agreement}}{\text{1 - chance agreement}}$$

$$F1 = 2 * \frac{(User\ Accuracy * Producer\ Accuracy)}{(User\ Accuracy + Producer\ Accuracy)}$$

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Thank you for your kind attention!

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