INTRODUCTION TO EARTH OBSERVATION SATELLITE IMAGERY

TRAINING EVENT ORGANIZED BY AMEP – SESMIN

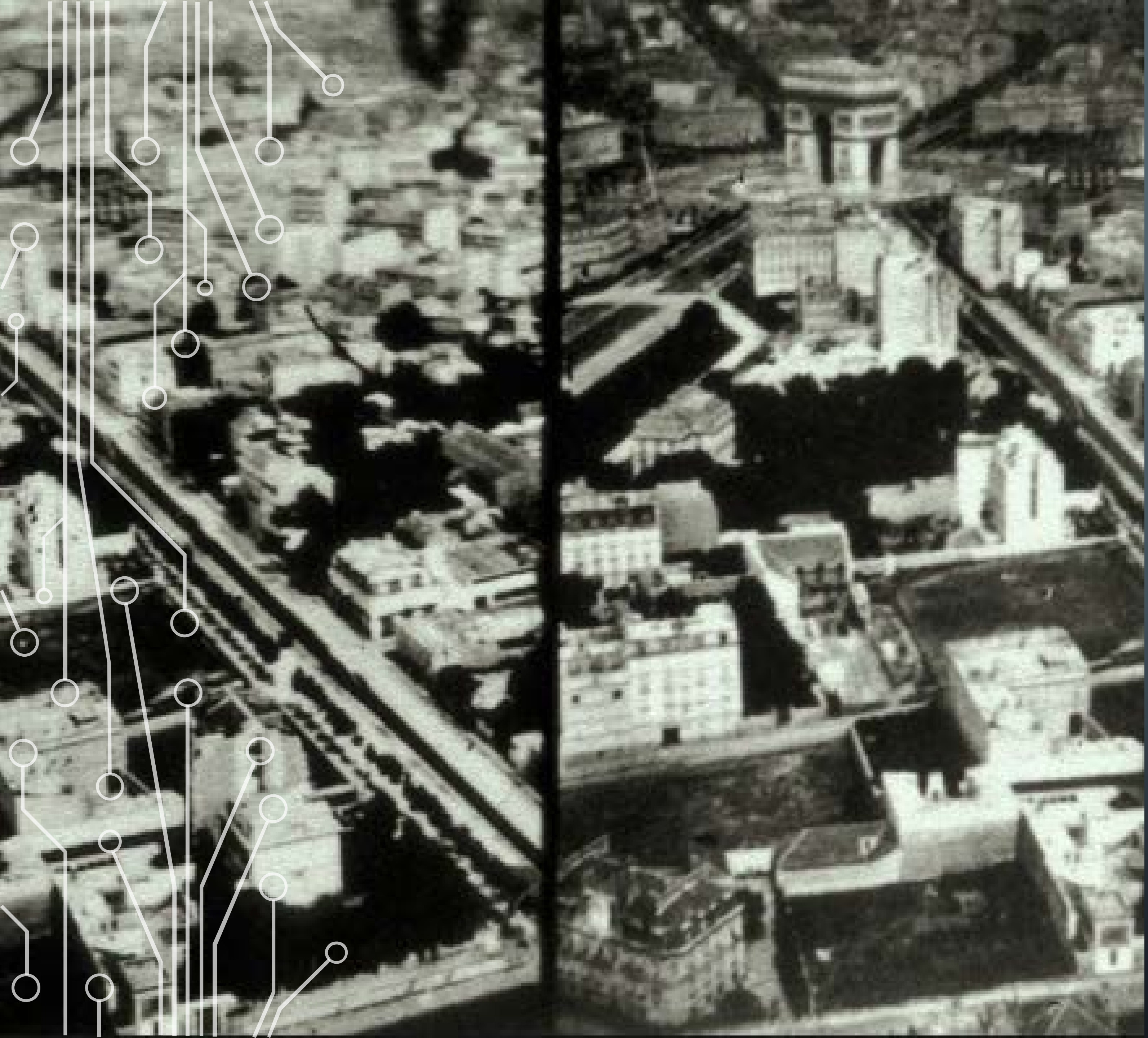
TERELJ, 2019.02.15

WHAT YOU CAN FIND IN THIS SESSION…

A LITTLE BIT OF HISTORY

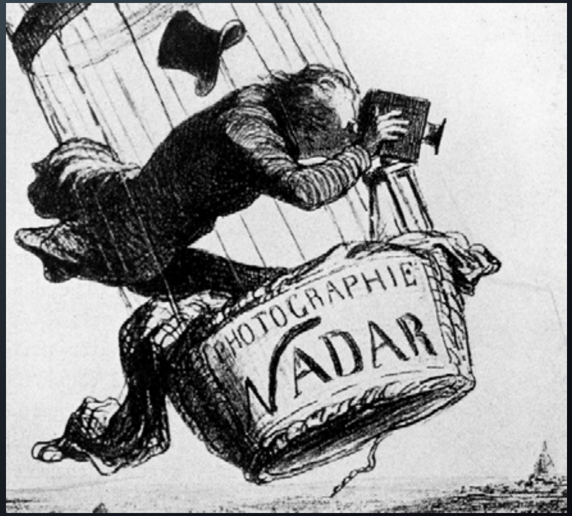
SOME THEORY

SOME PRACTICAL EXAMPLES



BRIEF HISTORY OF EARTH OBSERVATION: SELECTED MILESTONES

GASPARD-FÉLIX TOURNACHON (NADAR), 1858 (BATTLE FIELDS), HERE: PARIS 1867



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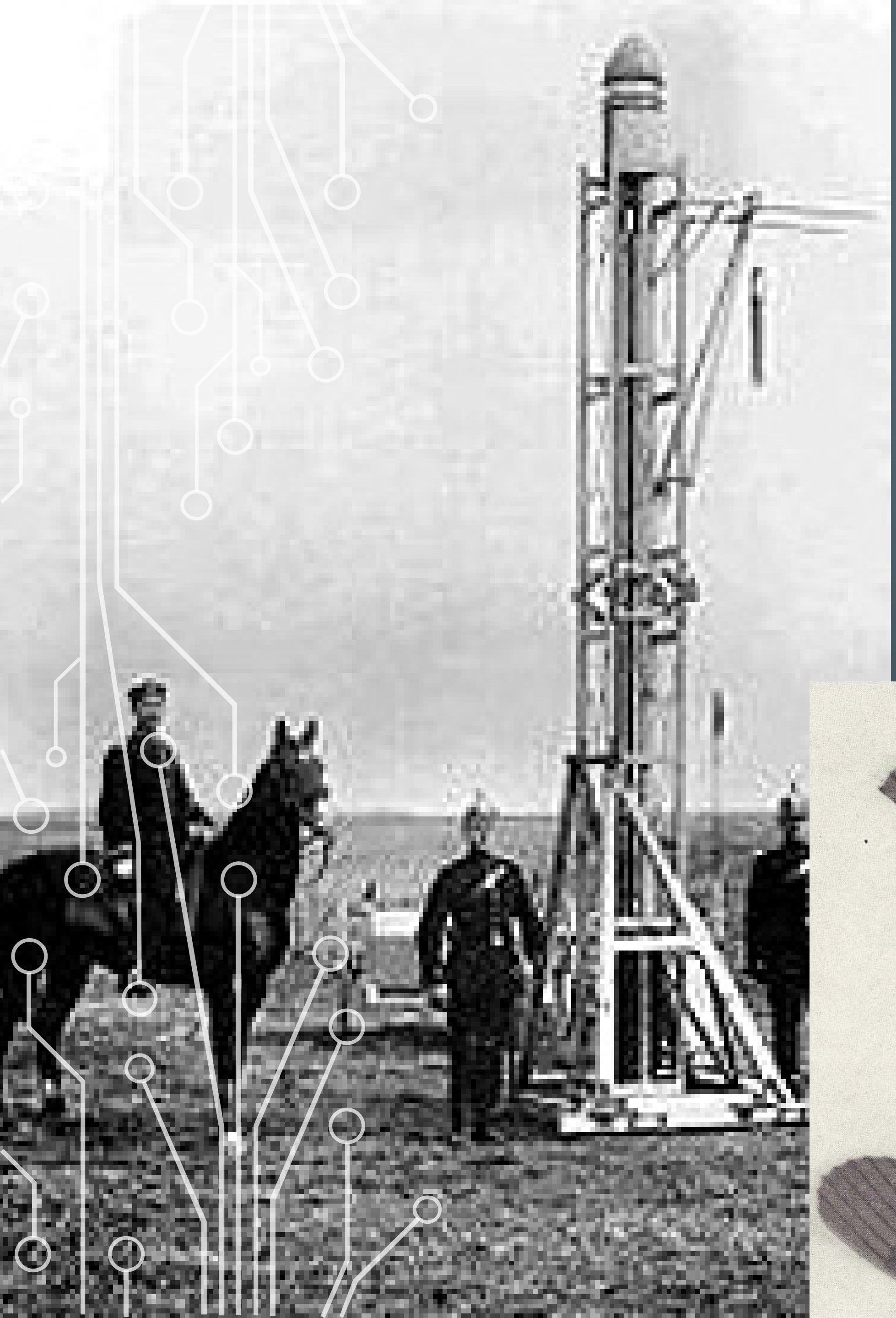
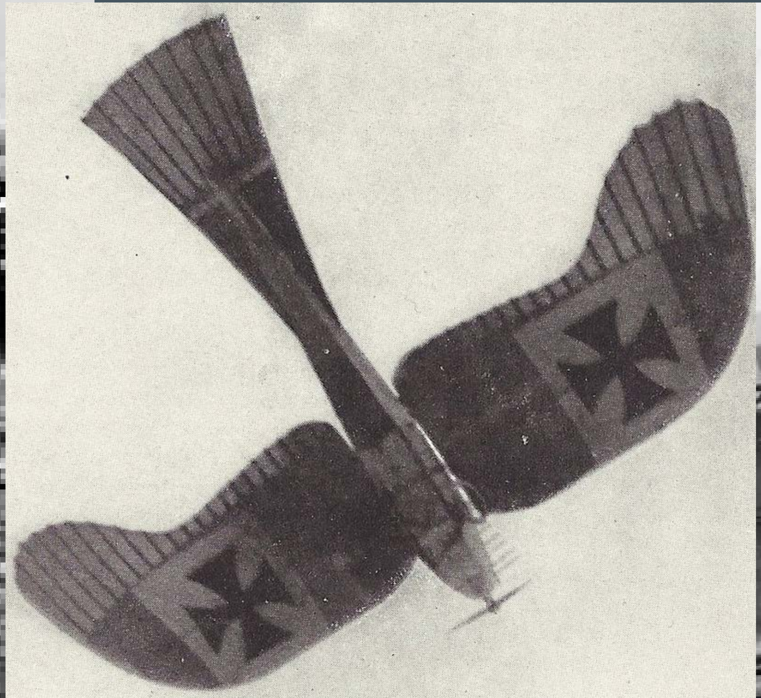


FIRST UNMANNED AERIAL PHOTOS: ALFRED MAUL'S "RAKETE" (DRESDEN, 1900)

FIRST SPECIALIZED AERIAL CAMERAS: DEVELOPED AND USED DURING FIRST WORLD WAR (UK, GERMANY, FRANCE)



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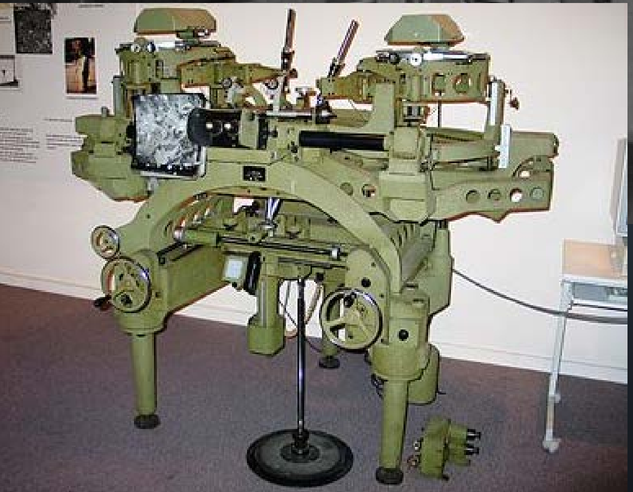


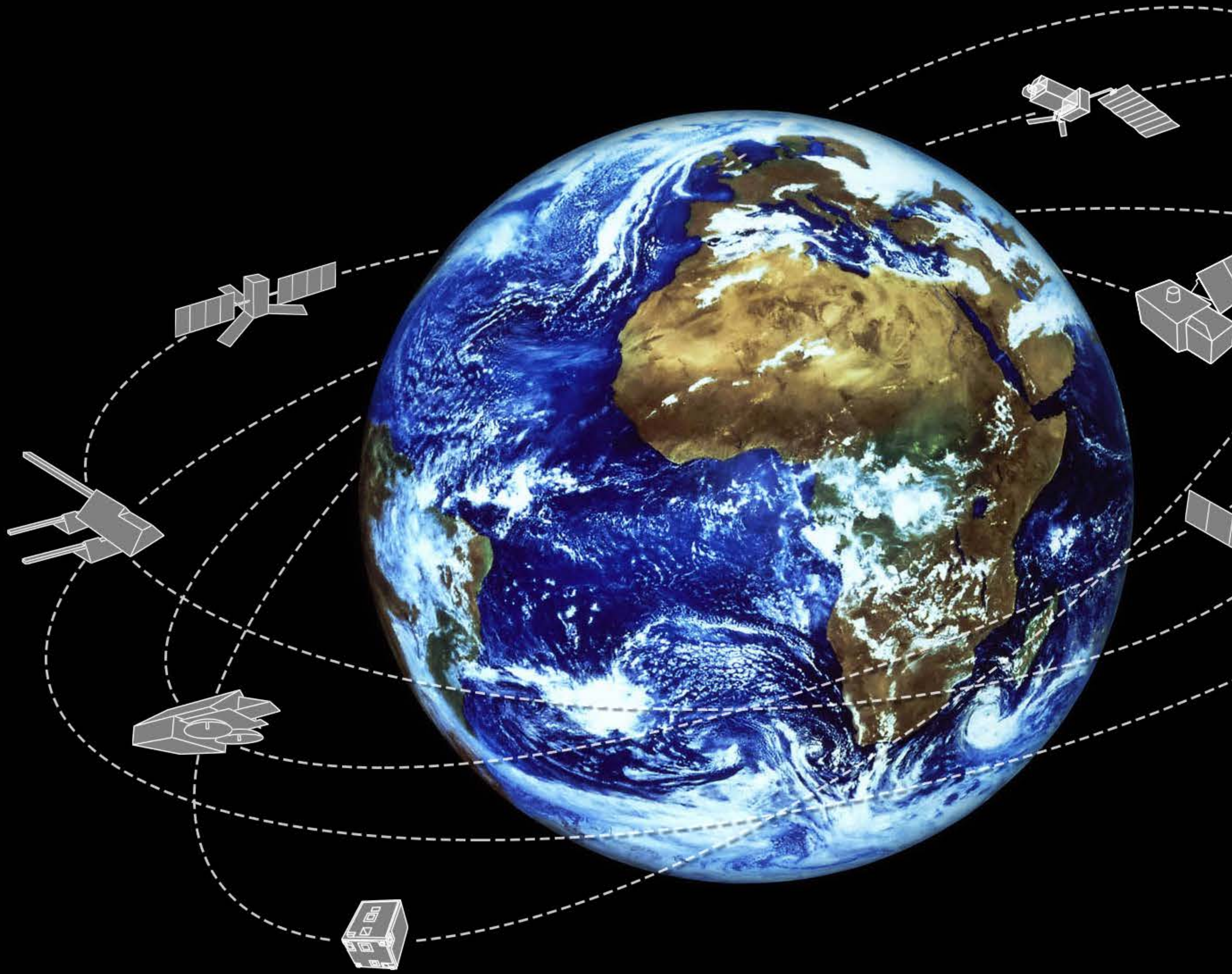
FIRST MACHINES DERIVING ELEVATIONS / CONTOURS FROM STEREO PAIRS: “OREL-ZEISS'SCHER STEREOAUTOGRAPH” (AUSTRIA/GERMANY, 1907); BETTER MACHINES BECAME A STANDARD AROUND 1950

FIRST SPECIALIZED AIRCRAFT / CAMERA COMBINATION: TALBERT ABRAMS’ “P-1 EXPLORER” (USA, 1937)

BRIEF HISTORY OF EARTH OBSERVATION: SELECTED MILESTONES

LANDMARK EARTH OBSERVATION SATELLITES:

- SPUTNIK 1 (SOVIET UNION, 1957): NOT VERY FUNCTIONAL
- TIROS-1 (USA, 1960): WEATHER OBSERVATION
- LANDSAT 1 (USA, 1972): THE FIRST "REAL ONE" FOR MAPPING



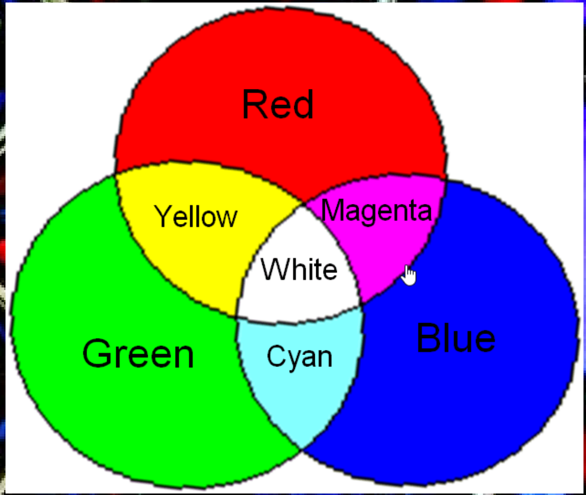
EARTH OBSERVATION SATELLITE SYSTEMS: TODAY'S STATUS

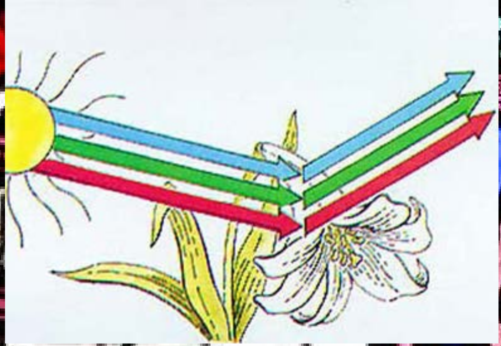
- > 400 active EOS
- Different purposes/applications:
  - Environment
  - Mapping at different scales
  - Defence
  - Weather / atmosphere
  - Wild fires / disasters
  - Change detection
  - Agriculture / precision farming
  - Many others
- Different specifications
- National prestige objects

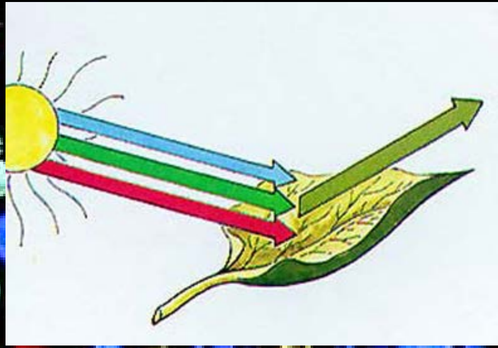
WHAT DOES AN EOS "SEE"?

- Passive systems register:
  - Sunlight reflected by the earth's surface (or by clouds…)
  - Light or thermal waves emitted by the earth's surface (cities, etc.)
- Active systems register the return of signals emitted by themselves and reflected by the earth's surface or atmosphere (radar, …)

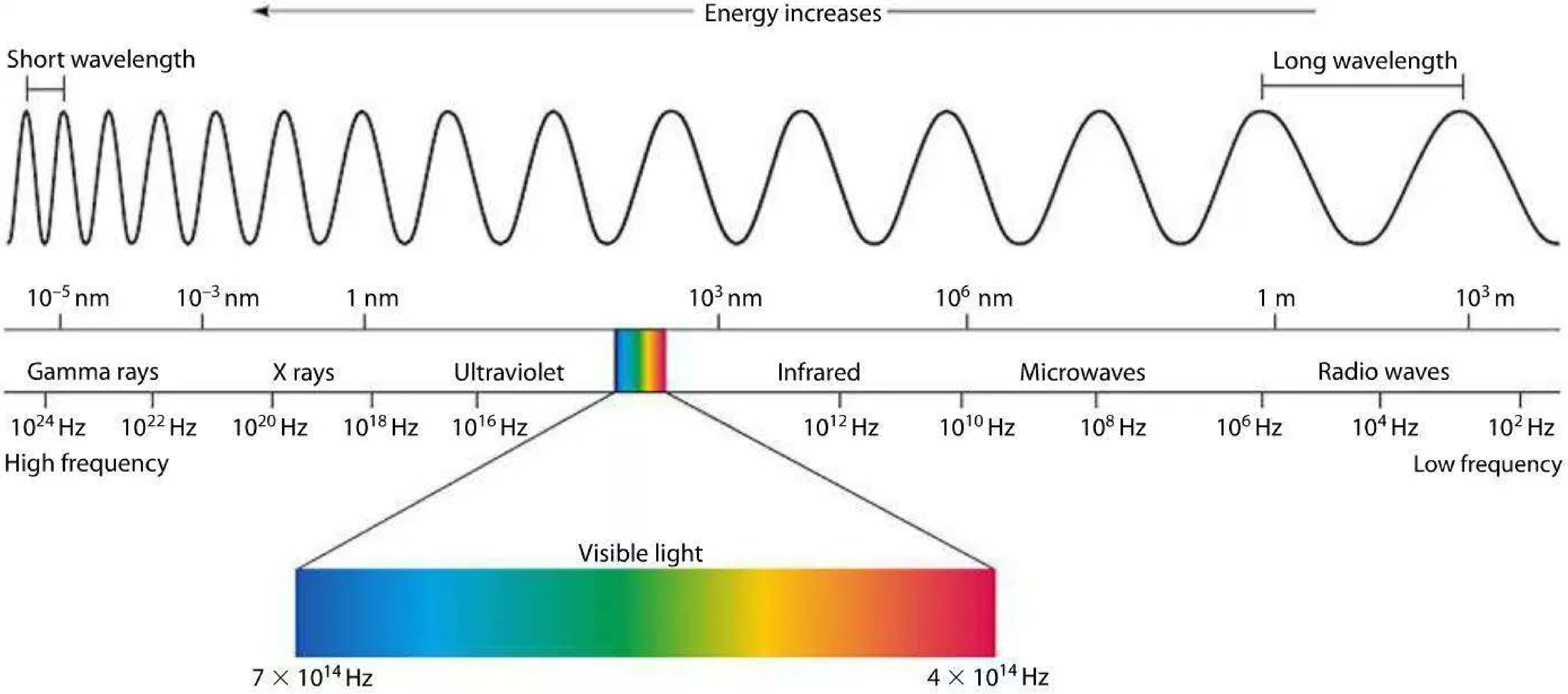
HOW DO WE SEE COLOUR?







BUT FOR AN EOS THERE IS SO MUCH MORE TO SEE…

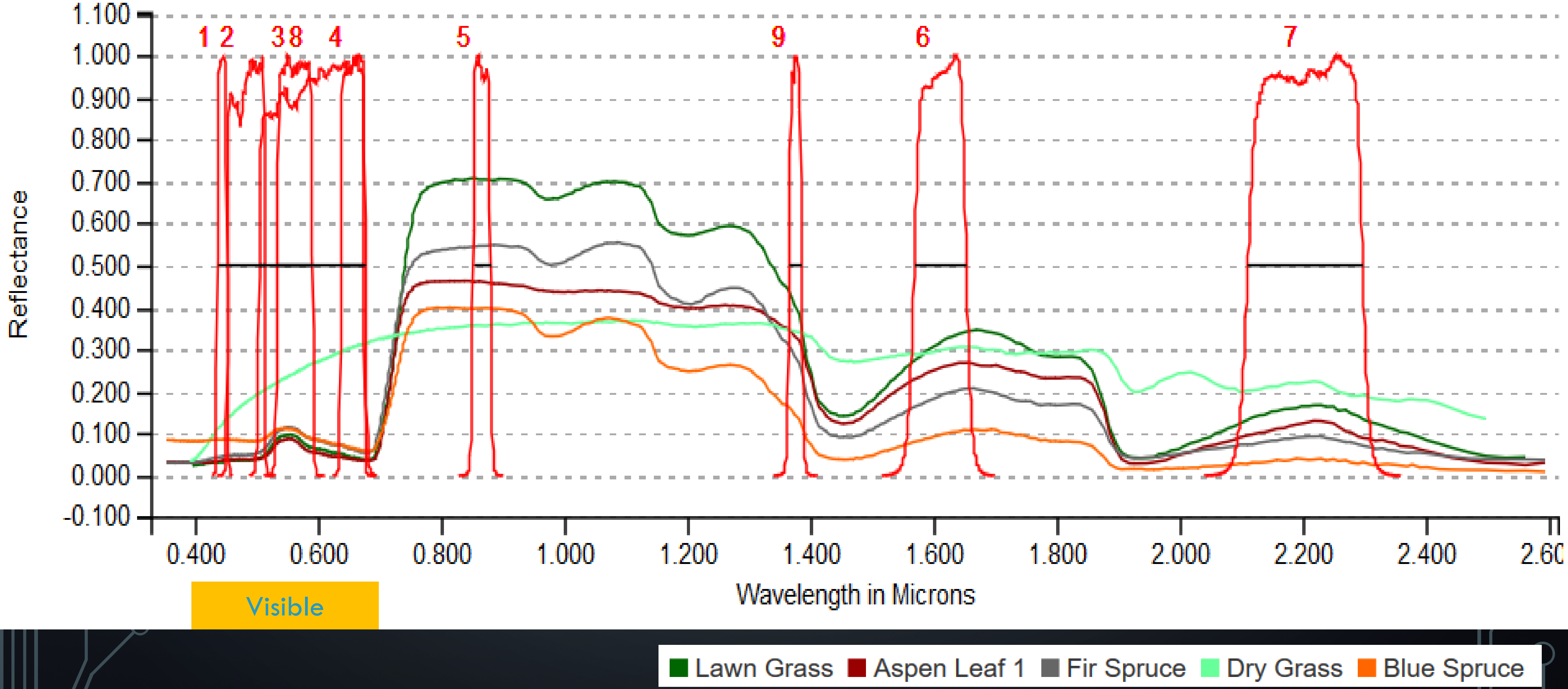


WHY IS COVERING MANY SPECTRAL BANDS IMPORTANT?

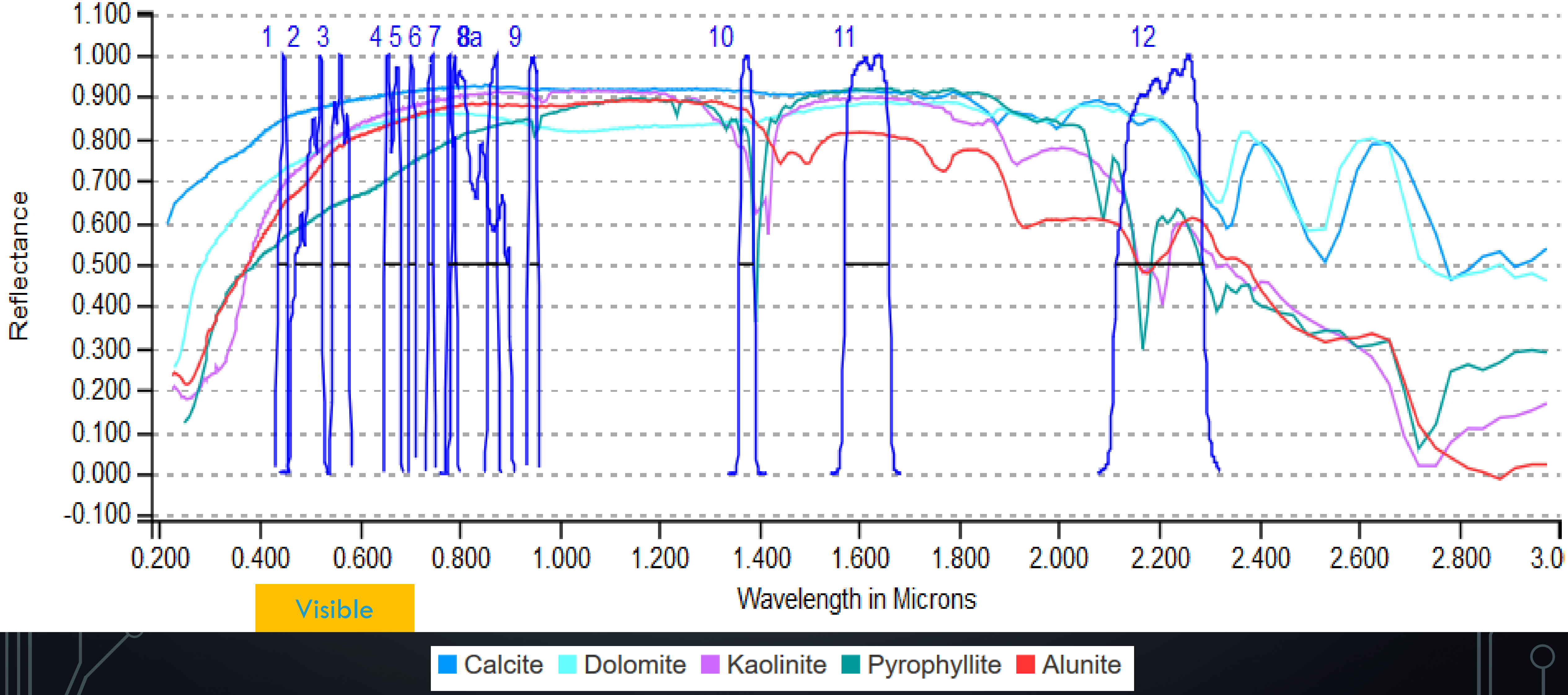
- All objects have a specific and typical way how they reflect or absorb sunlight (e.g. to produce energy) in different parts of the electromagnetic spectrum: their so-called spectral signature
- BTW, that is why:
  - We recognize active tree leaves as “green” (they absorb red and blue sun rays to produce energy / sugar, and reflect a little bit of the green spectrum)
  - It’s dark in a dense forest – even the “little bit of green” is eaten by the multitude of plants
  - Associate clear, deep waters with blue color – all other parts of the visible spectrum are absorbed to warm up the water
  - Hard coal looks black – it sucks all waves / energy
  - Snow is white and tends to melt very slowly – it reflects red, green and blue
- Spectral signatures of objects might be similar in the visual spectrum, but different in other parts of the electromagnetic spectrum; that’s why having many bands can be important!
- The following examples are taken from the USGS Spectroscopy Lab:

  https://landsat.usgs.gov/spectral-characteristics-viewer

SPECTRAL SIGNATURES AND LANDSAT 8 OLI BANDS



SPECTRAL SIGNATURES AND SENTINEL 2A BANDS



HOW CAN WE SEE WHAT AN EOS CAN SEE?

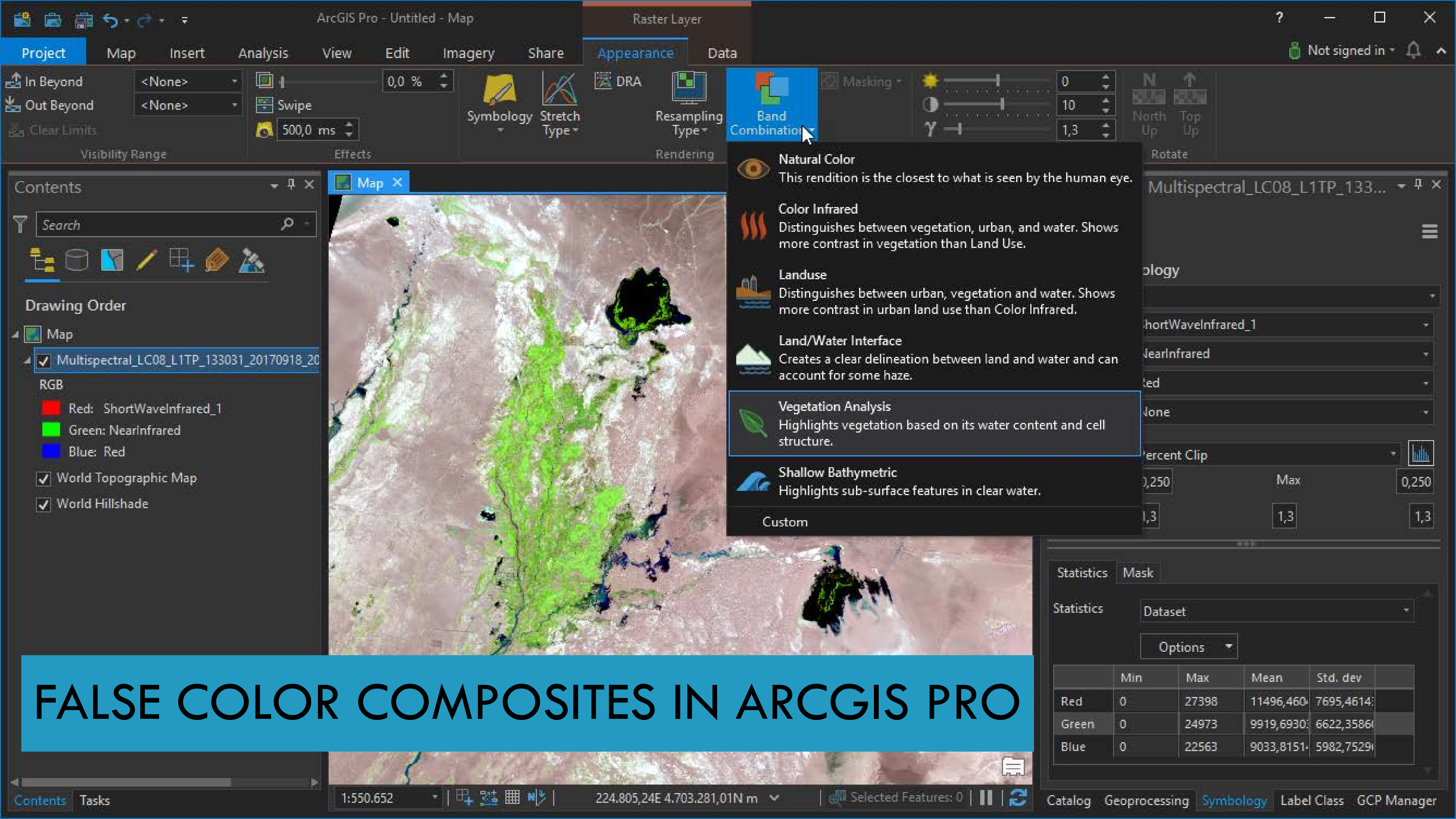
TRUE COLOR COMPOSITE (RGB)

VERSUS

FALSE COLOR COMPOSITES

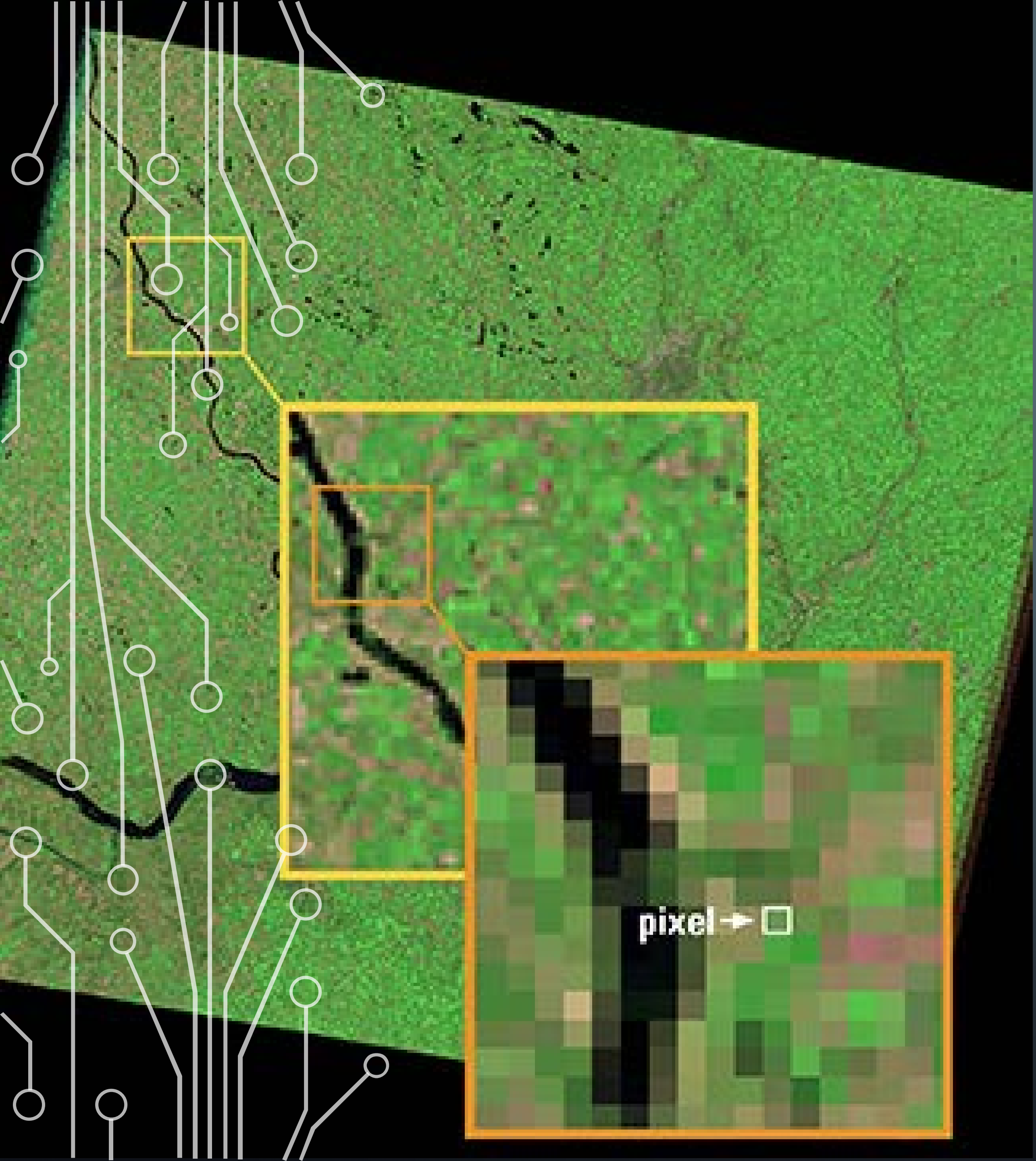
FALSE COLOR COMPOSITES HELP SEEING THINGS THAT OTHERWISE OUR EYES COULD NOT SEE

FALSE COLOR COMPOSITES IN ARCGIS PRO



So, which EOS is the best?

....well, it depends...



…THE ONE THAT SHOWS MOST DETAIL…

- *Spatial resolution* is the key term: higher resolution is able to show smaller objects on the earth
- Most satellite images are composed of a matrix of *picture elements* (= pixels, cells); they are square and represent a certain area on the earth's surface
- For an object on the earth's surface to be detected, its size generally has to be equal to or larger than one pixel
- If one pixel covers several objects, their spectral signatures (colors) get mixed and get unrecognizable

DIGITALGLOBE'S WORLDVIEW

- WordView 3, launched 2014, of DigitalGlobe (USA), operates the commercial EOS with the highest resolution:

  31 cm

- Followed by:
  - GeoEye 1 (DigitalGlobe): 46 cm / 41 cm
  - WorldView 2 (DigitalGlobe): 46 cm
  - WorldView 1 (DigitalGlobe): 46 cm
  - KompSat 3A (KARI): 55 cm
- Main applications:
  - Large and medium scale mapping
  - Defence
  - Civil engineering
  - Urban planning / mapping / 3D
  - Open pit mining
  - Disaster response

…AND THE MOST ACCURATE ONE: DIGITALGLOBE‘S WORLDVIEW

- How accurate is the location of objects shown in satellite images, compared to real-world coordinates?
- All imagery can be made “spatially accurate” with ground control points… but it takes time and money
- Imagery of DigitalGlobe’s WordView/GeoEye series has an unprecedented locational accuracy of:

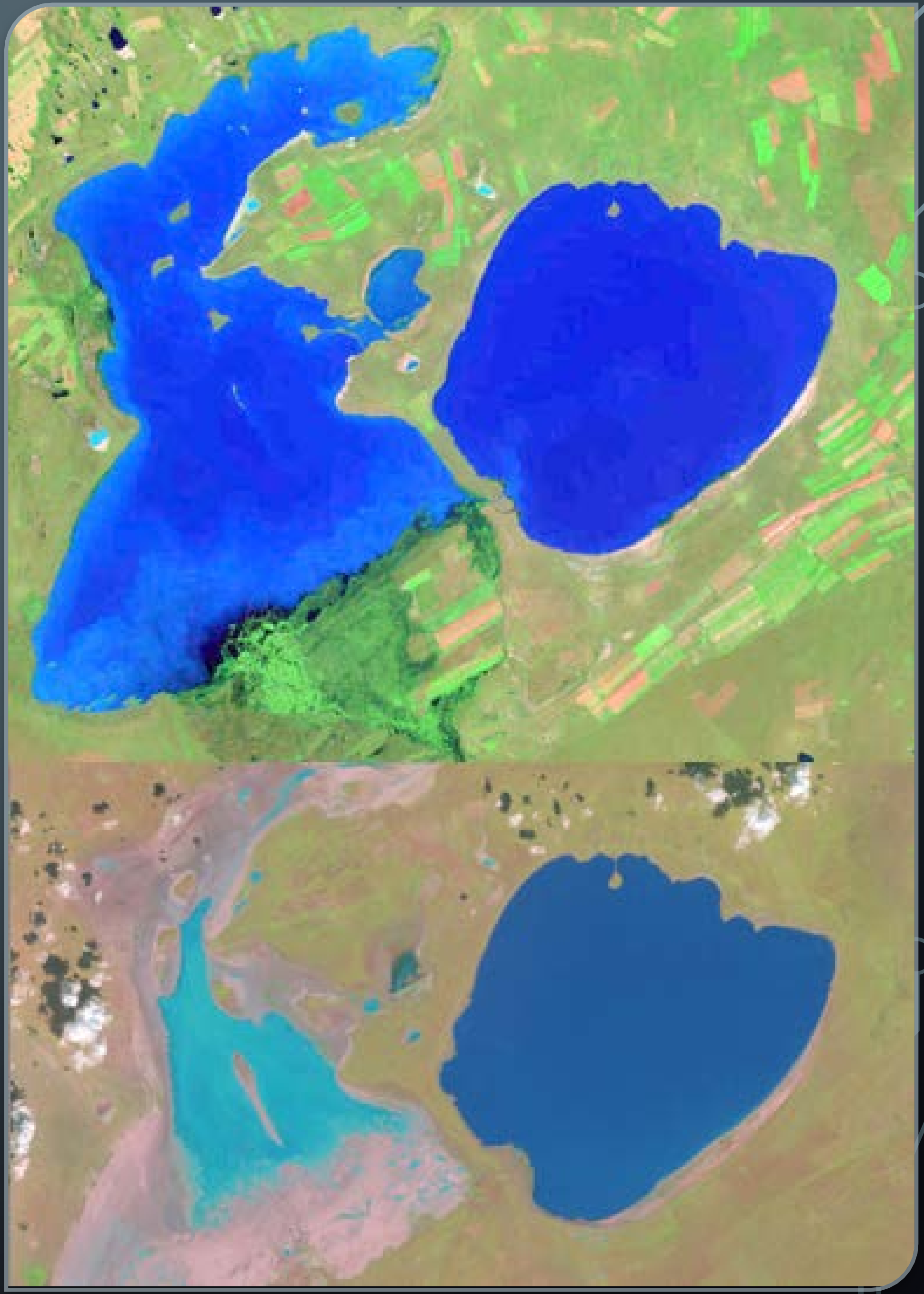
  2.5 m

- Considering the pixel size, Landsat and Sentinel are leading, with an accuracy at the level of 1-2 pixels

…THE ONE WITH THE LONGEST HISTORY…

- Detection of environmental change is one of the most important applications of satellite imagery:
  - Deforestation
  - Desertification
  - Water resources
  - Situation of farmlands / crop production
  - Haylands / grasslands sustainability
  - Erosion of soils
- These medium and long term monitoring activities require image time series of EOS with similar sensor characteristics

Tari Nuur, Dornod, August 1998 and August 2011

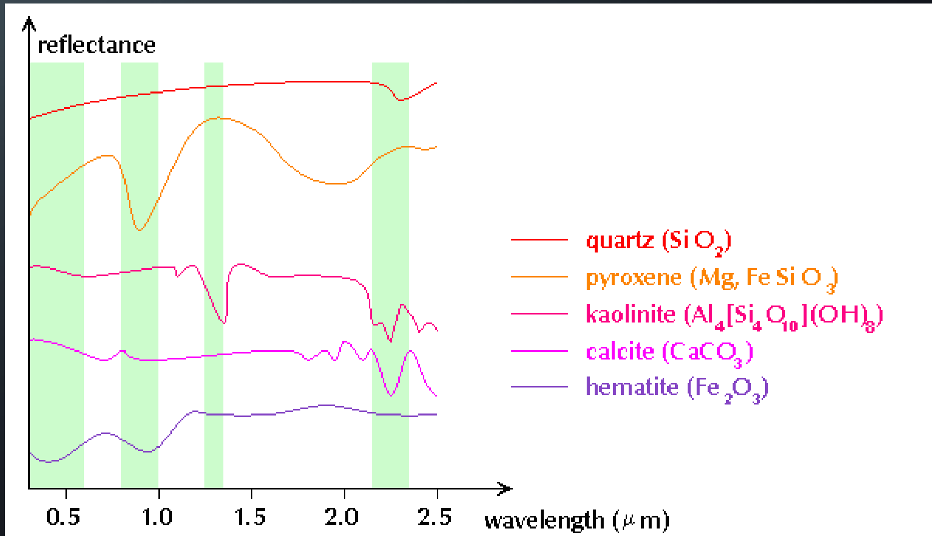


THE LANDSAT PROGRAM

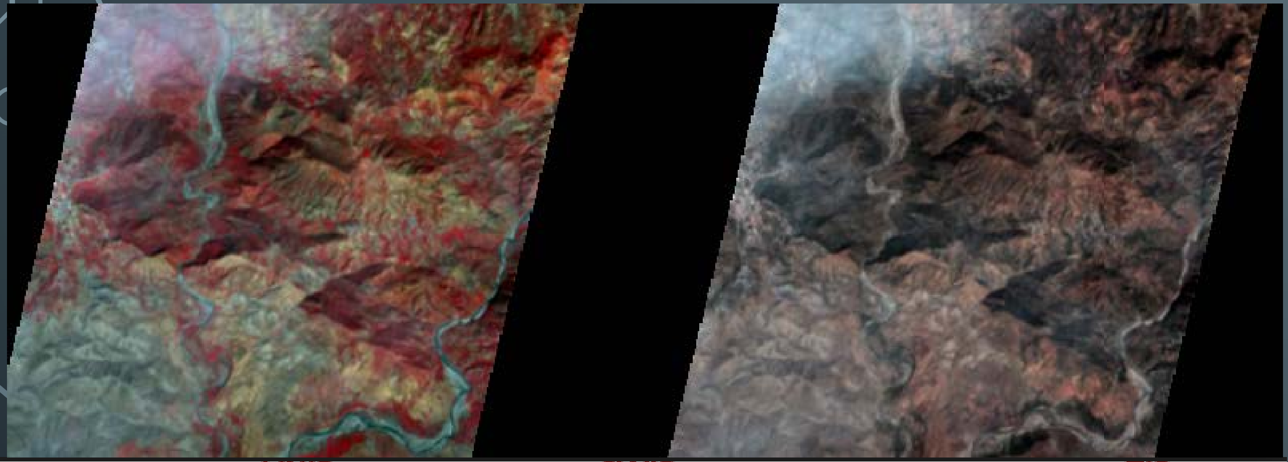
- The Landsat program (USA, NASA/USGS) is the longest-running enterprise for acquisition of satellite imagery of the earth
- It is monitoring the earth since 1972 with improving, but backwards compatible chararteristics:
  - Improved resolution: 60 m → 30 m → 15 m (panchromatic)
  - Additional spectral bands, but always containing the “classic” Green / Red / NIR coverage
- Since 2015/2017 further supplemented by Sentinel 2A/2B (EU) at up to 10 m resolution

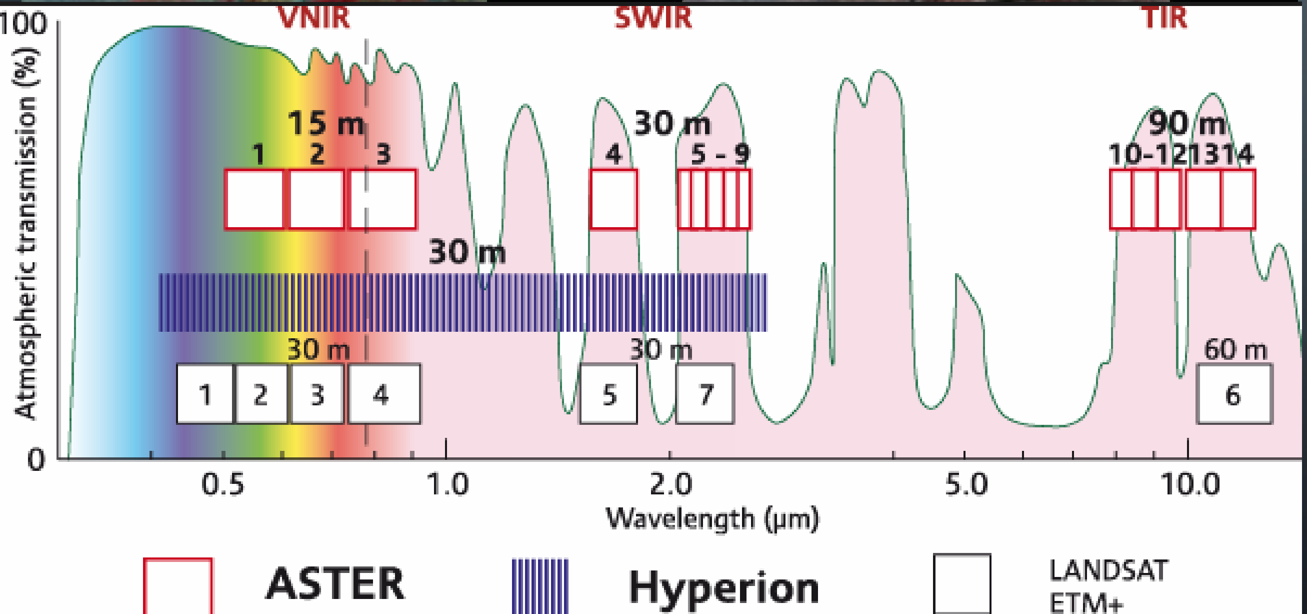
…THE ONE WITH MOST SPECTRAL BANDS…

- Many applications of satellite imagery rely on accurately detecting spectral signatures of the earth's surface:
  - Vegetation
  - Crops
  - Soils
  - Geology, mineralogy
- *Hyperspectral* imagery allows to identify more details of spectral signatures:
  - Huge amount of spectral bands
  - Each band must cover only a very slim part of the electromagnetic spectrum to avoid mixing up spectral characteristics



EARTH OBSERVER 1 HYPERION





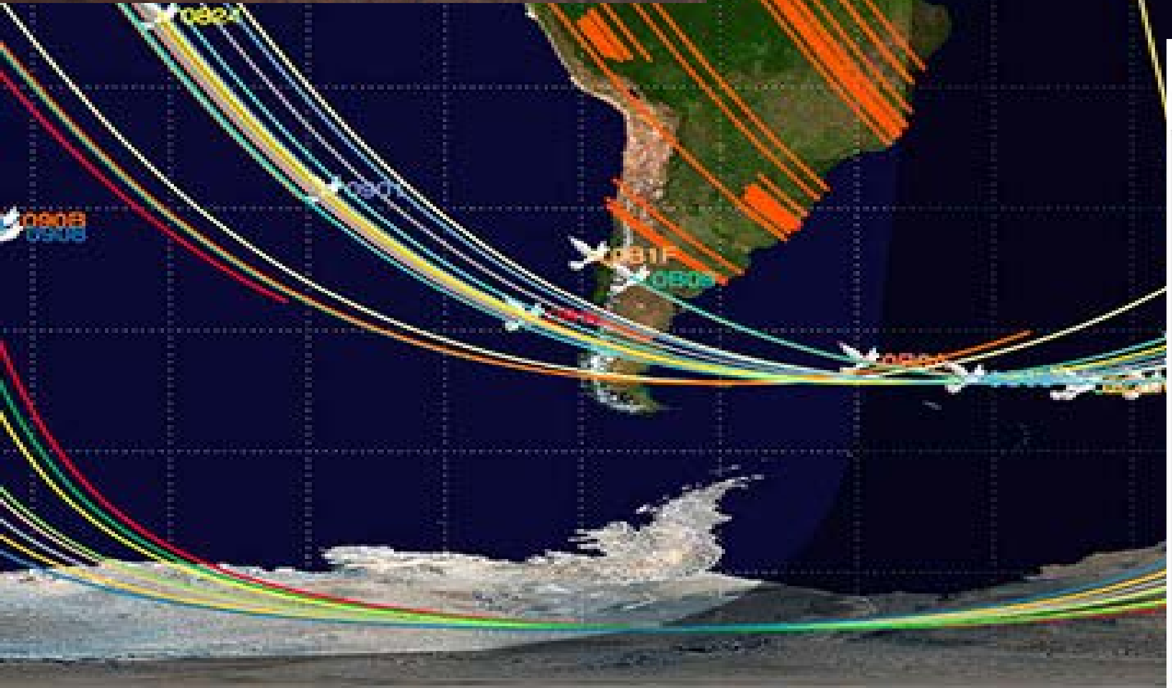
- EO-1 HYPERION (NASA) is the one and only champion in this field:
  - 220 slim bands
  - 30 m resolution
  - Launched 2000, decommissioned 2017
- Several other hyperspectral mission failed, or are not really hyperspectral
- Processing of the data is still an issue
- Another drawback: rocks are usually made up of a number of mineral types in varying mixtures, and are often covered by further layers of minerals deposited in erosion processes → many signatures are mixed, even more at a pixel coverage of 900 m^2

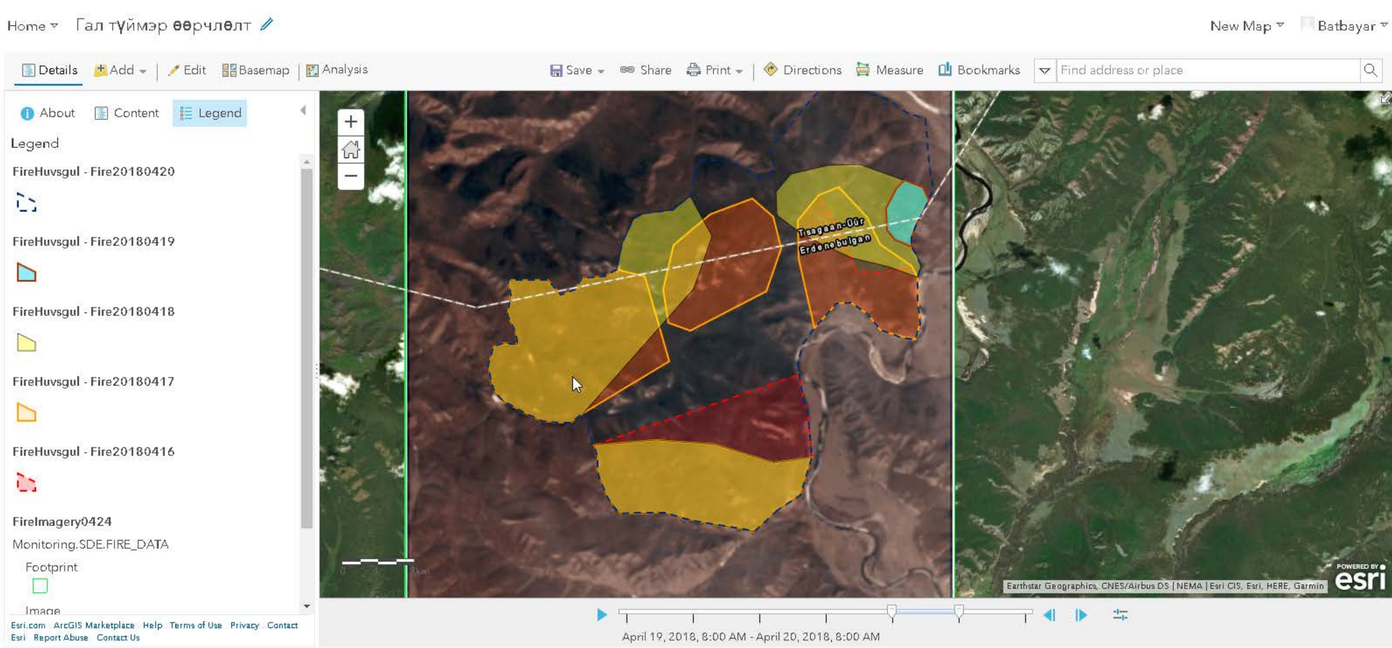
…THE FASTEST ONE…

- Some applications require imagery nearly in real-time:
  - Wild fires
  - Floodings
  - Earthquakes
  - Defence
  - National security
  - Precision agriculture
  - Illegal timber logging
  - Illegal mining, overspills, contamination of waters
- *Temporal resolu*tion is defined by the amount of time (e.g. days) that passes between imagery collection periods for a given surface location

THE PLANET CONSTELLATION

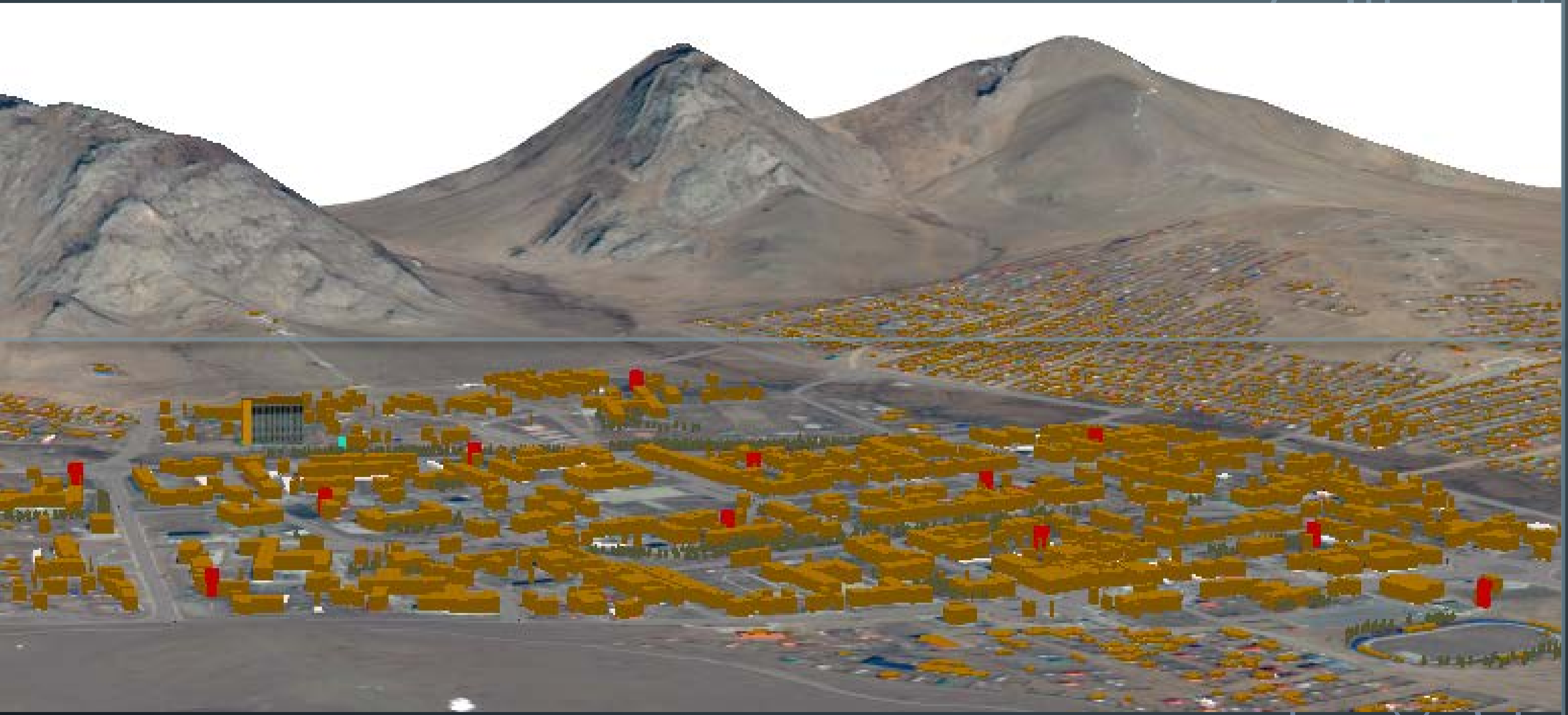
- Planet's constellation of over 200 Dove satellites guarantee that there is at least one image per day for each place e.g. in Mongolia
- Images are taken automatically (no "tasking") and transferred to the clients through Internet within one or two hours





WHAT ABOUT 3D?

- Some applications require elevations (XYZ) data:
  - Topographic mapping (contour lines)
  - Urban planning (3D city models, slopes)
  - Defence
  - Civil engineering (infrastructure planning)
  - Mining: volumes of pits and dumps
- Stereo images, or radar, are required for 3D; some EOS have stereo capabilities:
  - All DigitalGlobe WorldView and GeoEye systems
  - Pléiades (EADS, French-Italian)
  - SPOT (CNES, France; Azerbaijan)
  - KompSat (KARI, South Korea)
  - ASTER (NASA, USA; JAXA, Japan)
  - ALOS (JAXA, JAPAN)
  - IRS (ISRO, India)
  - Several Chinese systems (ZY3, other non-commercial ones)



TWO 3D EXAMPLES

- Tsetserleg urban planning 3D application based on WorldView 3 2018.04.18
- Open pit mining site based on WorldView 2 of 2012.09.13 and WorldView 3 of 2016.10.14

IMAGERY FOR GEOLOGICAL MAPPING AT MRPAM

- Probably best choices:
  - Landsat 8
  - Sentinel 2A / 2B
- Free
- Suitable for mapping up to ~1:75,000 scale, also supporting 1:50,000 scale
- Good spectral coverage
- Get online from: https://earthexplorer.usgs.gov/ (register for free):
  - All Landsat and Sentinel
  - Plus selected ASTER, EO-1 HYPERION, some ORBVIEW 3

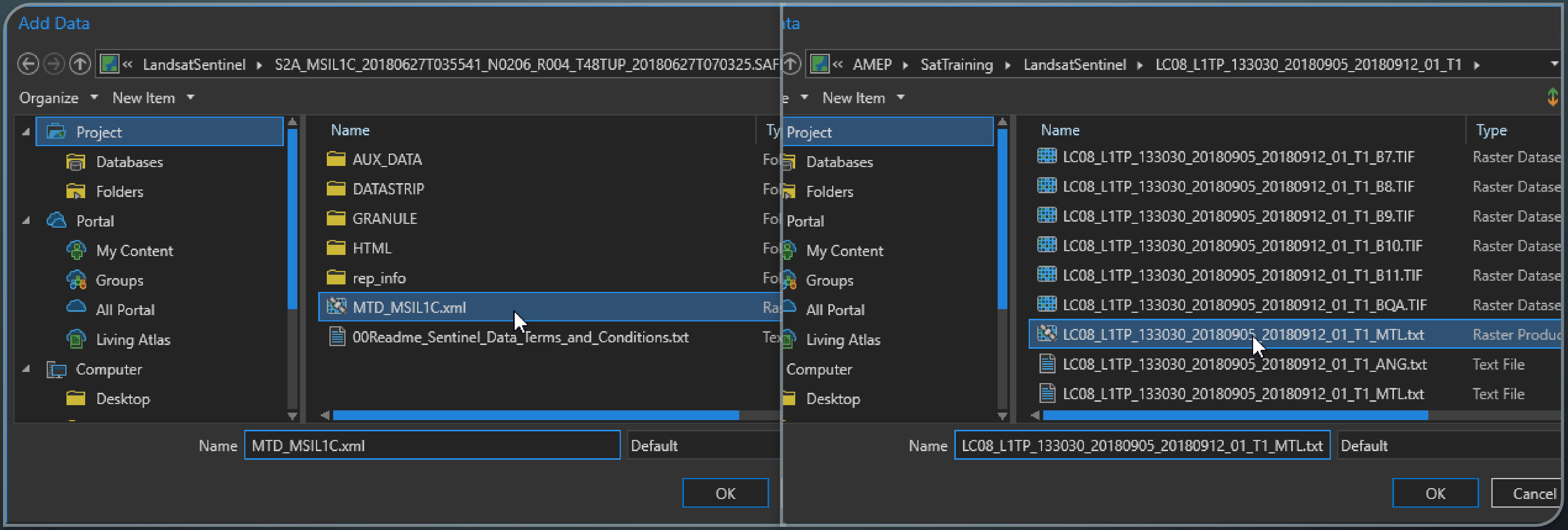
CHARACTERISTICS OF LANDSAT 8 AND SENTINEL 2

L8 Band		CW (µm)	Wavelength (lower-upper)	Bandwidth	Res. (m)		S2 Band		CW (µm)	Wavelength (min-max)	Bandwidth	Res. (m)
1	C/A	0.443	0.435 - 0.451	0.016	30	C/A	1	C/A	0.443	0.421 - 0.457	0.036	60
2	Blue	0.482	0.452 - 0.512	0.060	30	Blue	2	Blue	0.494	0.439 - 0.535	0.096	10
3	Green	0.561	0.533 - 0.590	0.057	30	Green	3	Green	0.560	0.537 - 0.582	0.045	10
4	Red	0.655	0.636 - 0.673	0.037	30	Red	4	Red	0.665	0.646 - 0.685	0.039	10
							5	VRE	0.704	0.694 - 0.714	0.020	20
							6	VRE	0.740	0.731 - 0.749	0.018	20
							7	VRE	0.781	0.768 - 0.796	0.028	20
							8	NIR	0.834	0.767 - 0.908	0.141	10
5	NIR	0.865	0.851 - 0.879	0.028	30	NIR	8a	NIR	0.864	0.848 - 0.881	0.033	20
							9	WV	0.944	0.931 - 0.958	0.027	60
9	Cirrus	1.373	1.363 - 1.384	0.020	30	Cirrus	10	Cirrus	1.375	1.338 - 1.414	0.076	60
6	SWIR	1.609	1.567 - 1.651	0.085	30	SWIR	11	SWIR	1.612	1.539 - 1.681	0.142	20
7	SWIR	2.201	2.107 - 2.294	0.187	30	SWIR	12	SWIR	2.194	2.072 - 2.312	0.240	20
8	Pan	0.590	0.503 - 0.676	0.172	15							
10	TIRS	10.895	10.60 - 11.19	0.590	100 *							
11	TIRS	12.005	11.50 - 12.51	1.010	100 *							

NIR: Near infrared; SWIR: Shortwave infrared; C/A: Coastal/aerosol; VRE: Vegetation red edge
WV: Water vapour; Cirrus: high cloud detector; TIRS: Thermal infrared sensor

PRACTICE WITH ARCGIS PRO

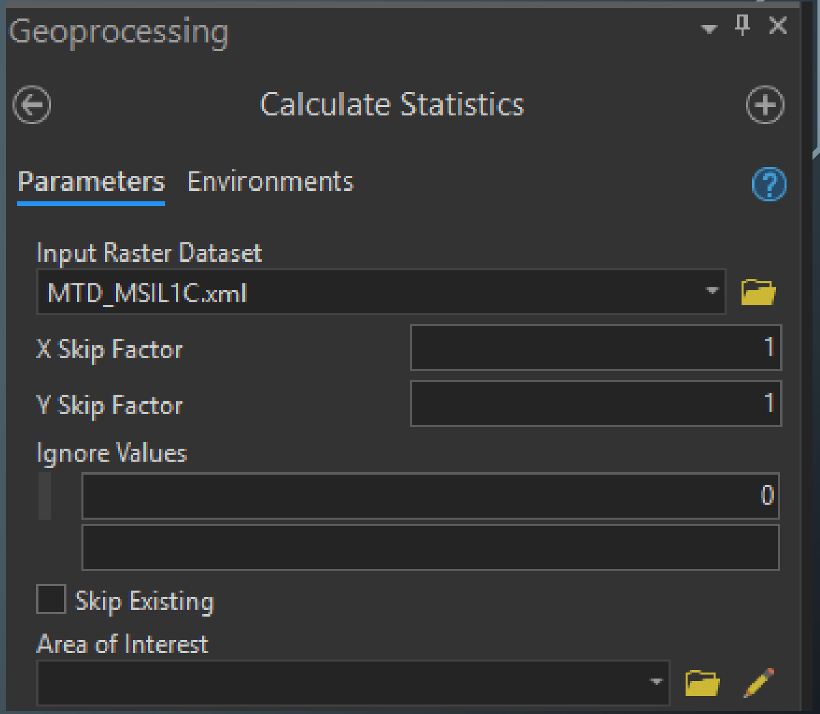
- First steps to do when working with a recently acquired satellite image:
  - Calculate statistics for enhanced display
  - Build pyramid layers for better performance
- Open the image:
  - As raw dataset (quick and easy)
  - As part of a mosaic dataset (providing additional functionality e.g. mosaicking)
- Compare suitability of different band combinations for your purpose and select the best one
- Pansharpen (Landsat, only visible spectrum bands) if using visible spectrum
- Enhance the image display characteristics
- Calculate indices

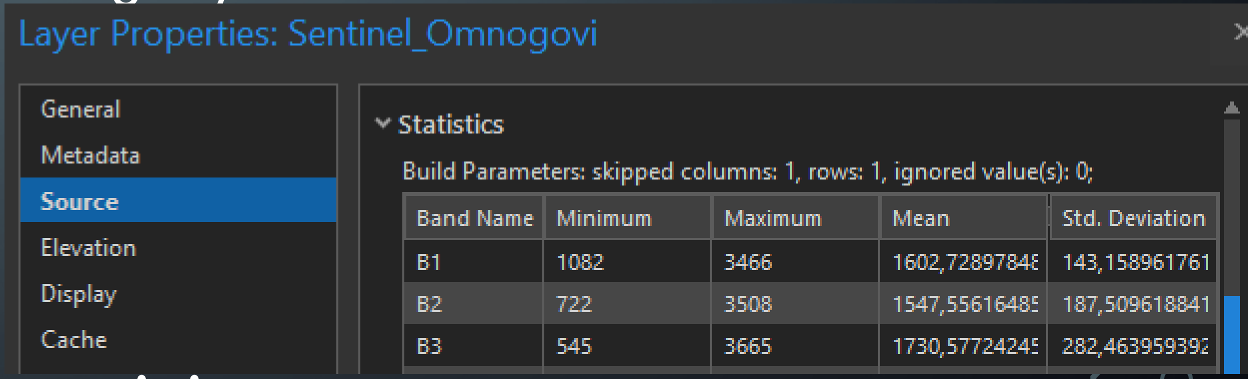


OPEN IMAGERY WITH ARCGIS PRO DIRECTLY BY OPENING THE IMAGE PACKAGE DESCRIPTION (XML OR TXT)

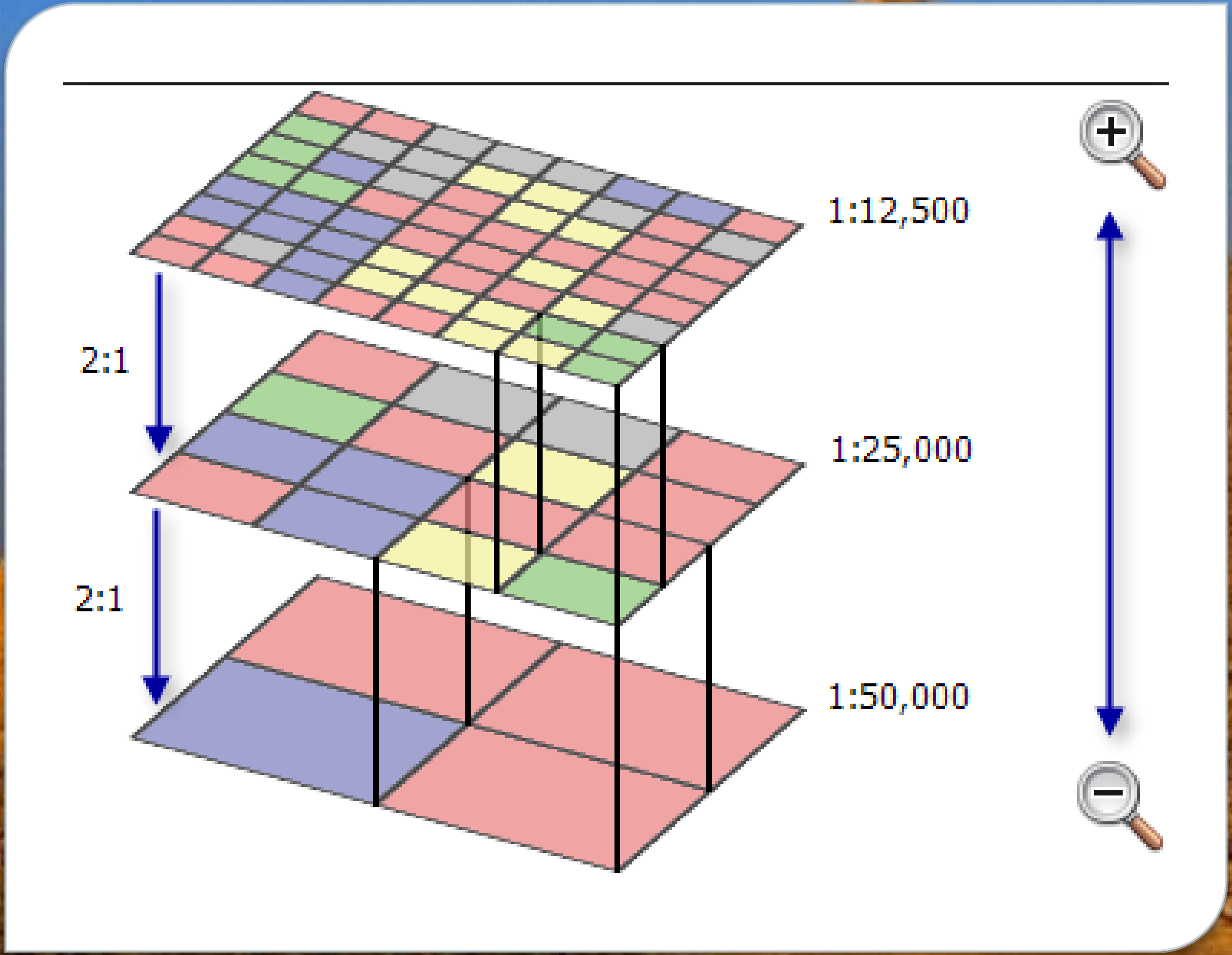
CALCULATE STATISTICS

- A satellite image consists of millions of cells, each one having a value between 0 and 65535 (12 bit stretched to 16 bit)
- For optimizing the display quality, the software needs to know about the distribution of these values in each band (is it rather dark, or bright?):
  - Statistics
  - Histograms (distribution of values)
- This is done by calculating statistics
- If you see a dark image → probably no statistics
- “0” = NoData (cells outside the actual image)

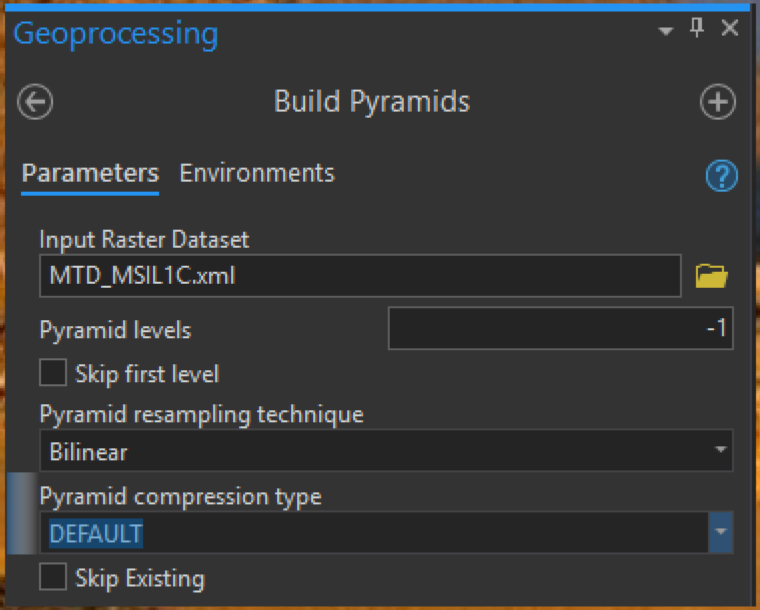




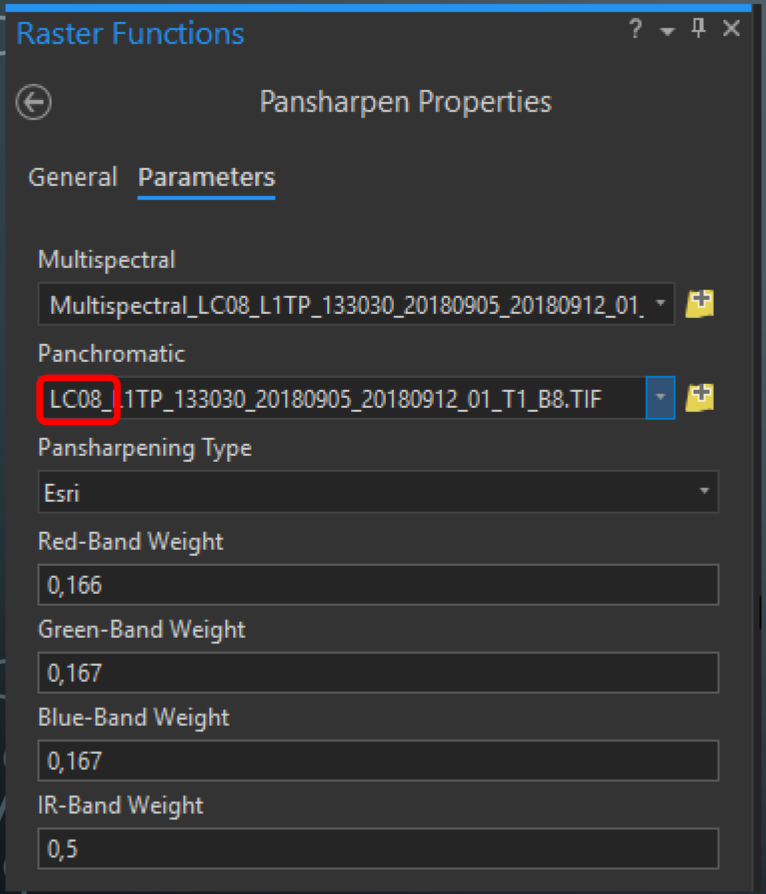
BUILD PYRAMIDS



- Pyramids (in our case) are reduced resolution versions of an image
- The help to speed up display at different map scales: for the selected map scale, the appropriate pyramid layer is shown, not the full resolution image



PANSHARPEN

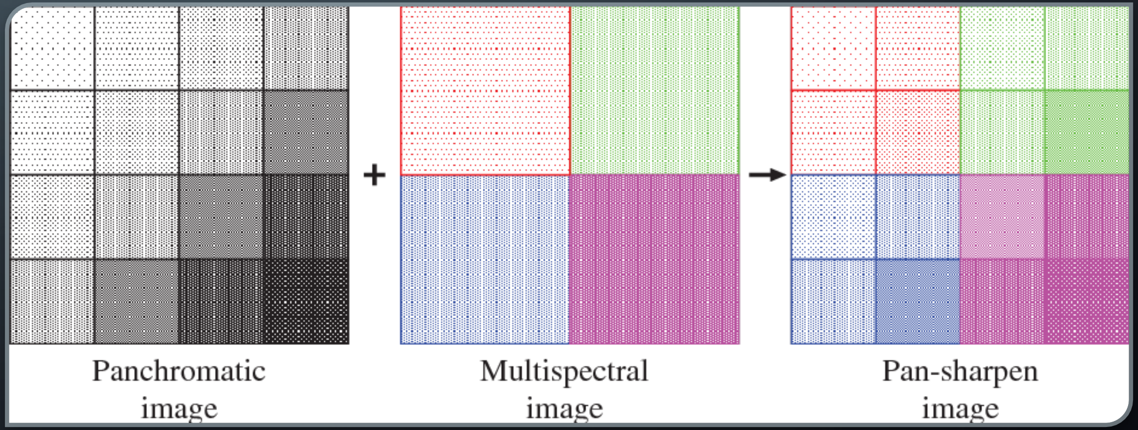


Pansharpening increases the spatial resolution of an image by merging a panchromatic image (high resolution) with a multispectral image (several bands, lower resolution)

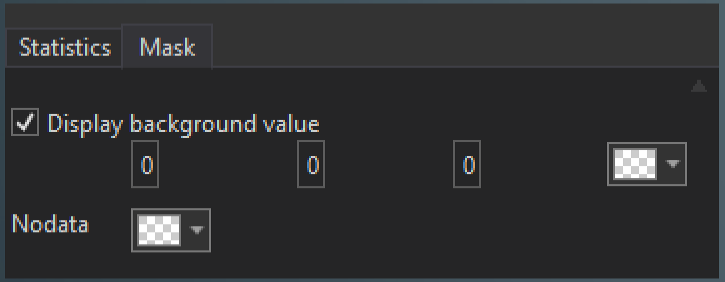
Preconditions:

- Imagery roughly taken at the same time
- Images match: same area, same georeference
- Images cover a similar range of the spectrum

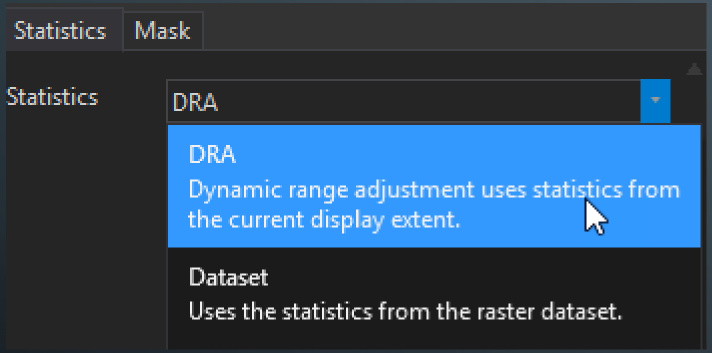
Different techniques are available, try them out!



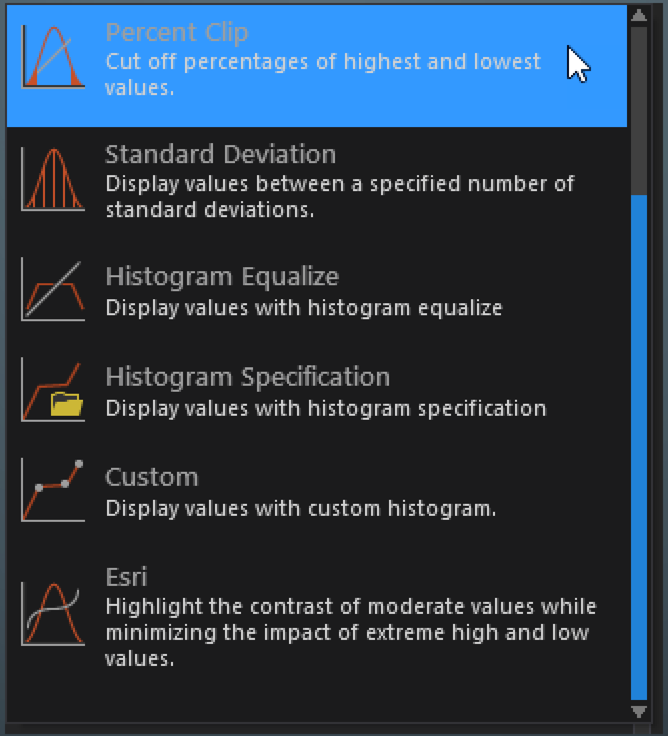
ENHANCE DISPLAY CHARACTERISTICS



Remove black edges (NoData)



Use Dynamic Range Adjustment if you want to automatically enhance the display when zooming

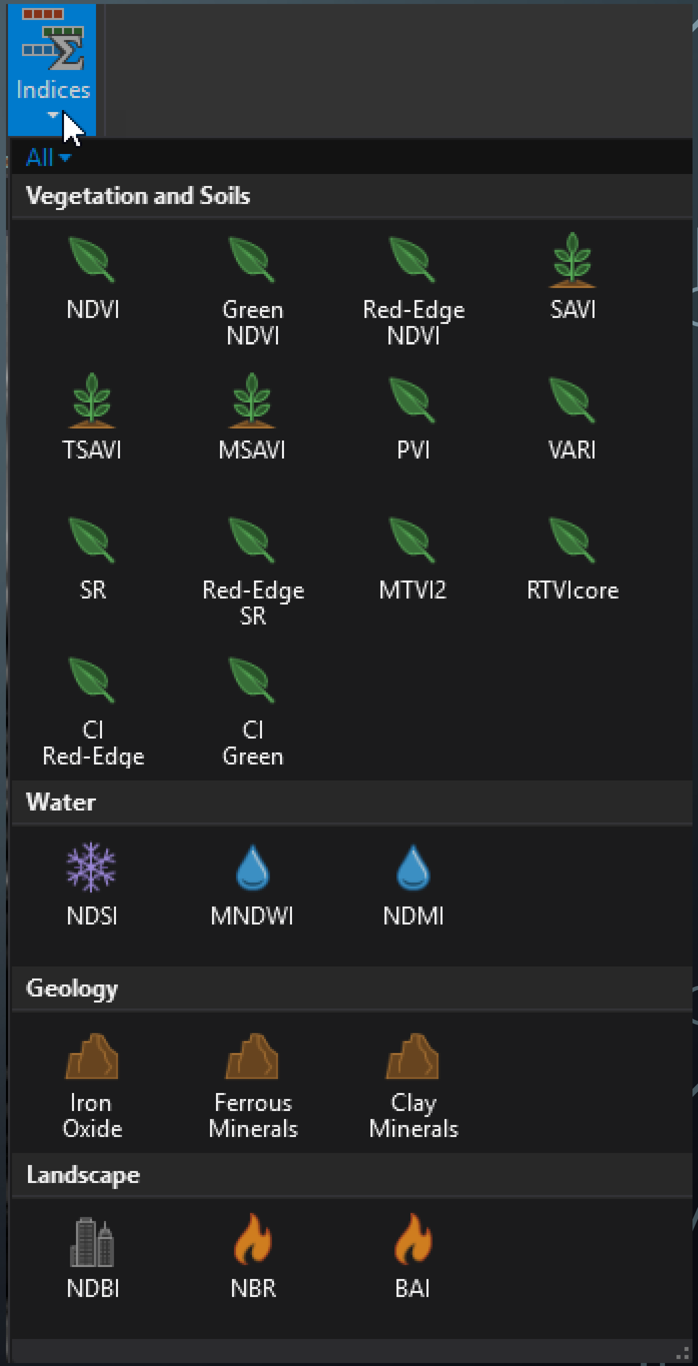


Change stretch type (to increase visibility of objects in certain contrast ranges)

Adjust stretch manually to histogram

CALCULATE INDICES

- Indices apply a mathematical formula to the values of two or more bands to create one new output band
- They focus on a specific topic and bring out certain information inherent in the imagery that is otherwise difficult to see
- Index functionality is accessible from the Imagery pane
- Actual contents depends on the image currently selected in the table of contents



GEOLOGY INDICES

CLAY MINERALS

The clay ratio is a ratio of the SWIR1 and SWIR2 bands. This ratio leverages the fact that hydrous minerals such as the clays, alunite absorb radiation in the 2.0–2.3 micron portion of the spectrum. This index mitigates illumination changes due to terrain since it is a ratio.

IRON OXIDE

The iron oxide ratio is a ratio of the red and blue wavelengths. The presence of limonitic-bearing phyllosilicates and limonitic iron oxide alteration cause absorption in blue band and reflectance in red band. This causes areas with strong iron alteration to be bright. The nature of the ratio allows this index to mitigate illumination differences caused by terrain shadowing.

FERROUS MINERALS

The ferrous minerals ratio highlights iron-bearing materials. It uses ratio between the SWIR band and the NIR band.

Many more indices are described here:
https://www.indexdatabase.de/
…and can be implemented with: