ANIMOVE 2024 - REMOTE SENSING

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Overview

What is Remote Sensing?

- Introduction to Remote Sensing & main concepts

Focus on Optical Remote Sensing

- Dive In Optical Remote Sensing concepts

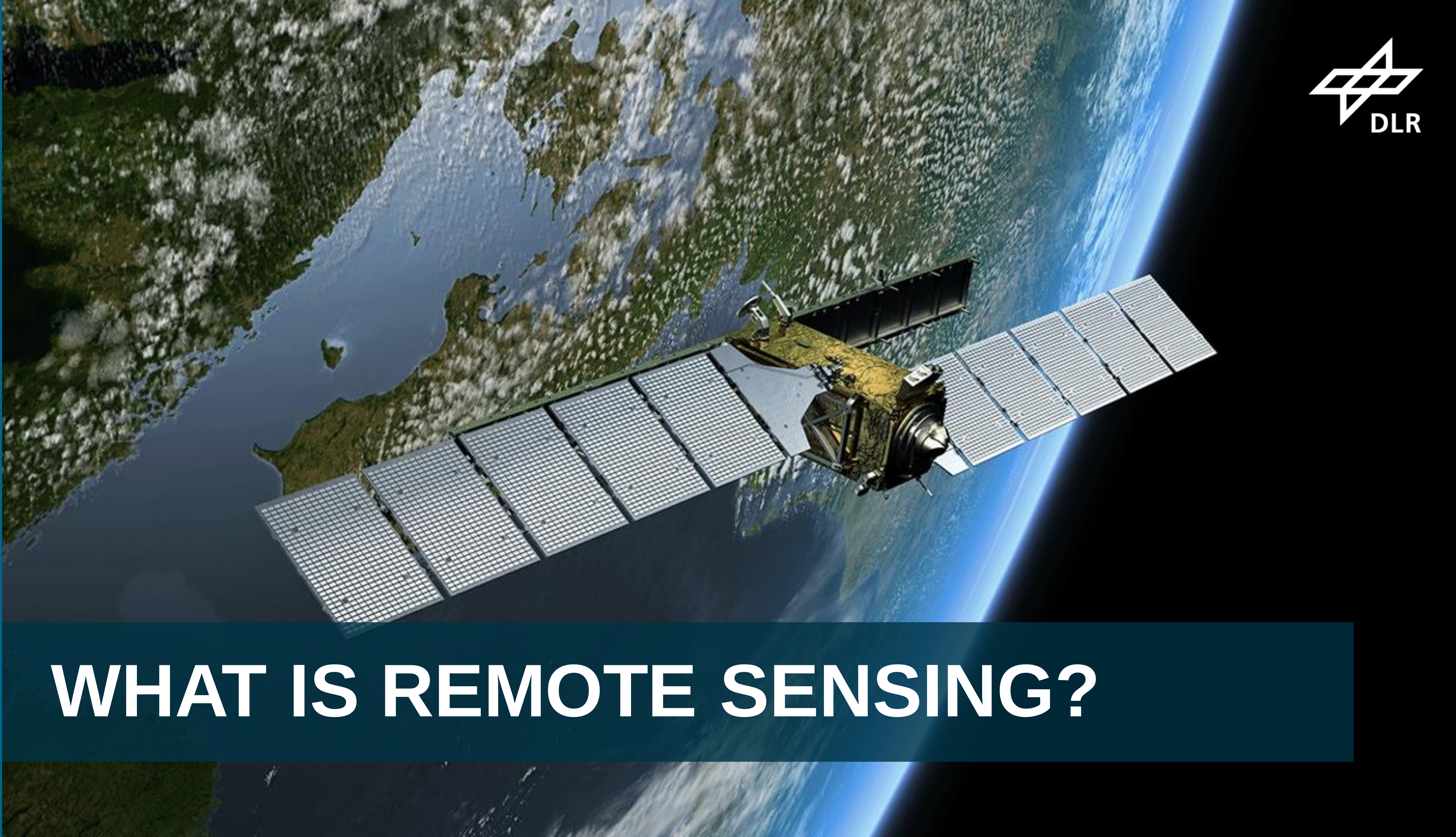
A bit of Pracical examples

- Illustration of the concepts & examples

Data Sources

- Data structure and some common data providers

Bildquelle hier angeben



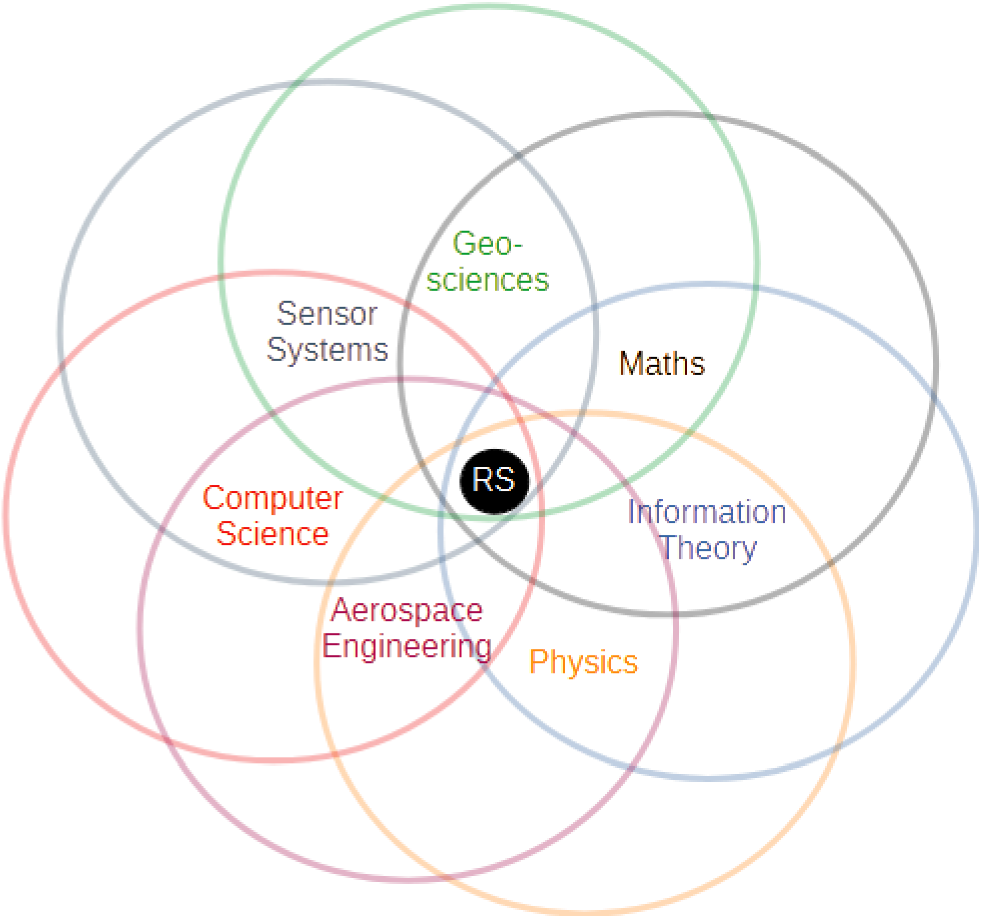
WHAT IS REMOTE SENSING?

Earth Observation & Remote Sensing

- *Earth Observation (EO)*
  It is the act the gathering of information about Earth. It encompasses numerous techniques and approaches, one of which is remote sensing.

- *Remote Sensing (RS)*
  - It is the science of obtaining information about objects **without being in direct physical contact** with the object.
  - It encompasses Earth observation from either space (satellites) or air (aircrafts/drones) but also covers other topics such as military intelligence.

- *In Situ Observation/Data*
  - Data or observations collected **directly in contact** with the objects of interest
  - Can typically be combined with remote sensing data to 'get the best of both worlds'



- *Note: RS is a multidisciplinary topic and there is no know-it-all expert*

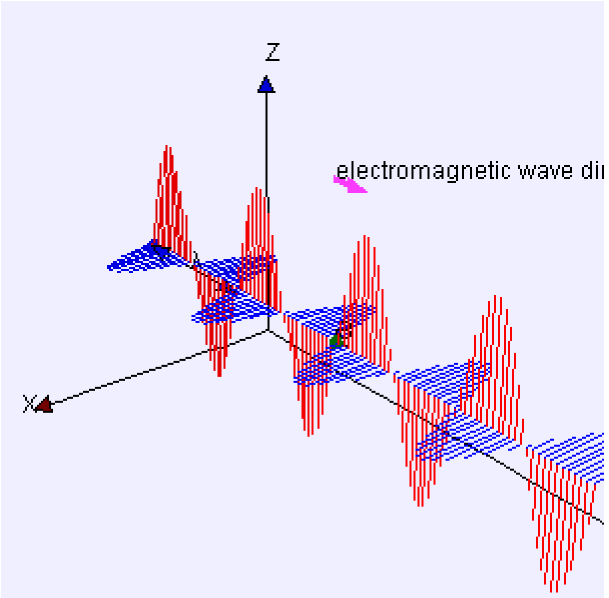
What is ‚sensed‘ by remote sensing?

- Remote Sensing is typically measuring Electro-magnetic radiations
  - Typical examples are light and radio-waves
  - This presentation is focusing on them, as they represent the majority of available sources of data

- There exist however many ‘niche’ or ‘exotic’ types of measurements. Some examples are
  - Gravimetry (measuring the gravitation field)
    - E.g. GOCE https://www.esa.int/Applications/Observing_the_Earth/FutureEO/GOCE
  - Magnetomers (measuring magnetic fields)
    - E.g. MagSat https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1979-094A
  - Particules (protons, alpha particules, heavy ions, …)
    - E.g. GOES Solar and Galatic Proton sensor: https://www.goes-r.gov/products/baseline-solar-galactic-protons.html
  - Sound
    - E.g. Sonar and Sodar
  - Etc.
    - Science is the limit ;)

What is Electro-Magnetic Radiation ?
Bits of (very simplified) theory

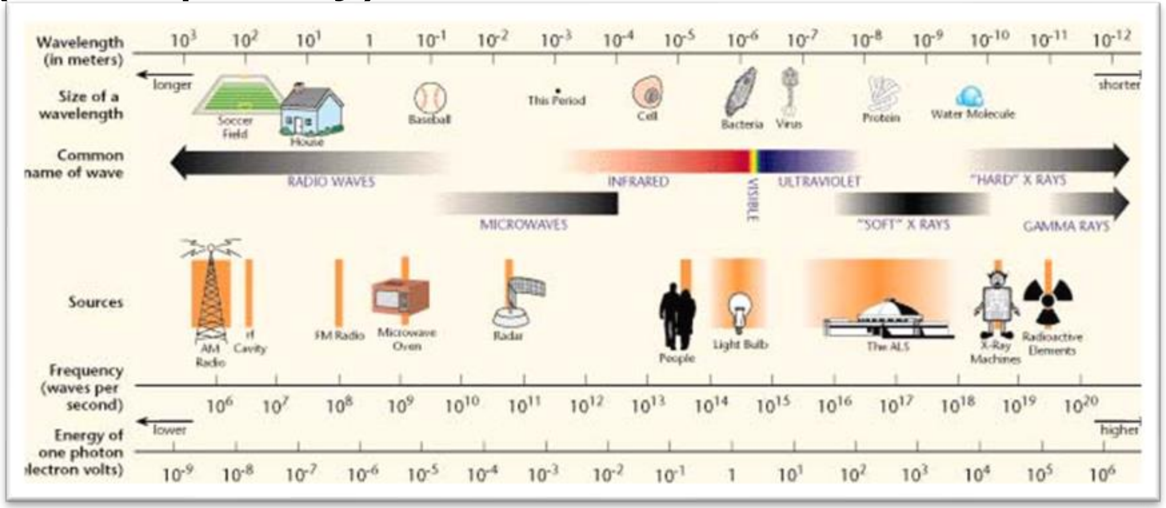
- Electro-magnetic radiation is a synchronised oscillation of electric and magnetic fields (yes, that doesn't really answer the question)
  - In practice it can be seen as particles (photons) behaving like a wave (i.e. having a wavelength - λ - and a frequency - v):
  - **Wavelength**: ‚distance‘ covered by a full oscillation
  - **Frequency**: kind of the ‚speed‘ for a full oscillation
    - Photons travel (in the vacuum) at the speed of light (about 300’000’000 m/s)
    - Their frequency is equal to the speed of light divided by their wavelength
  - In other words, both frequency and wavelength are directly related
  - Using one or the other is (almost) only a matter of taste



Source

What is Electro-Magnetic Radiation?
Why is this relevant for practice

- The wavelength (or frequency) is a core characteristic of the measurement



Source

  - *Visible' light (VIS):* wavelengths ranging from roughly 400 to 700nm
  - *Infra-Red (IR):* longer wavelengths from about 700nm up to a few hundred micro-meters
    - Near Infra-Red (NIR): 700-1,000nm is just the same as the visible light (but we don't see it)
    - Short Wave-Infra-Red (SWIR): 1,000 – 2,500nm is quite similar in behaviour
    - Mid-Wave Infra-Red (MWIR): 3,000 – 6,000nm and Long-Wave Infra-Red (LWIR): 7,500 - 14,000 nm corresponds to 'thermal' radiations

Why do we define these domains?

- The way radiations interact with the matter depends on their wavelengths
  - Different wavelengths domains typically require different types of sensors to be measured
    - E.g. Visible to SWIR sensors can be seen as 'just' a high-end digital camera
    - E.g. Micro-wave and above are measured with antenna

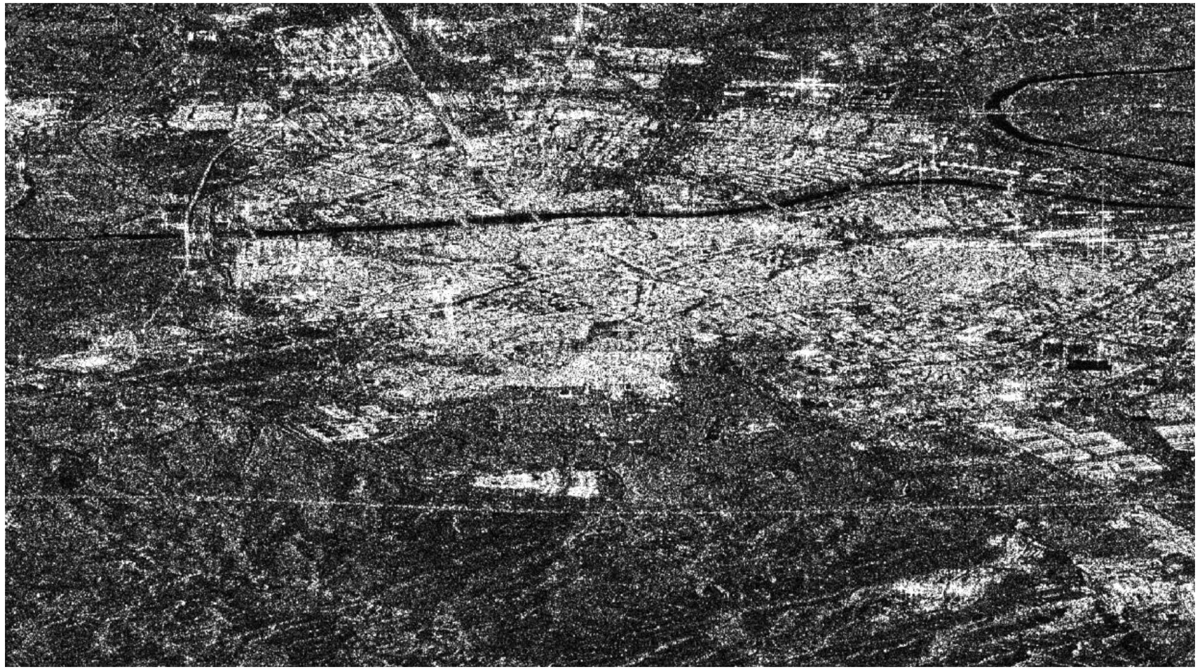
Copernicus

DLR

  - 'What' is exactly measured also depend on wavelength
    - In VIS, e.g. its mostly solar radiation
    - Different methods & expertise is are involved for different domains
  - The following focuses only on the Visible to LWIR domains (400 to 14,000 nm)
    - This corresponds to the 'most' intuitive domain as it is similar to how we perceive the world
  - This does however exclude a complete family of measurements: 'microwaves' (1mm to 30cm)
    - They are used in RADAR remote sensing

Radar Versus Optical

Toulouse, France



Sentinel 1

Sentinel 2

- Note: The Radar is actually even a bit more complex, as we are representing only one of its components

Interactions

- Electro-magnetic radiations interact with the medium they encounter
  - As a function of the wavelength
  - Typically, as combination of absorption, reflection/scattering and transmission
  - Example VIS domain:
    - A mirror is mostly reflecting
    - A window is mostly transmitting
    - A black solid is mostly absorbing
  - These interactions bring along advantages and disadvantages:
    - Advantage: You can derive information about the medium composition
      - E.g. some gazes absorb specific wavelengths making the atmosphere ‘opaque’ – characterising ‘how opaque’ they are, allows to infer the atmospheric composition
    - Disadvantage: You have to ‘correct’ for unwanted effects
      - E.g. before deriving information about the earth surface, you will have to correct for effects introduced by the atmosphere

Sneak View – some examples

[argosfp7project]

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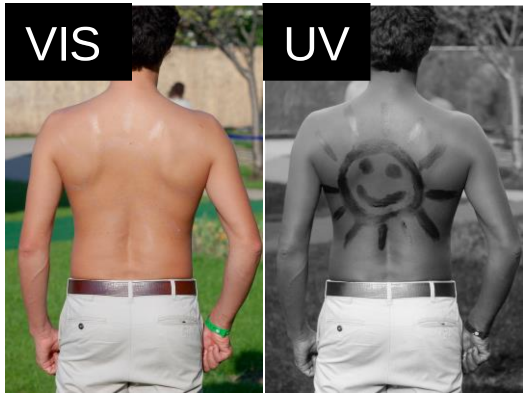

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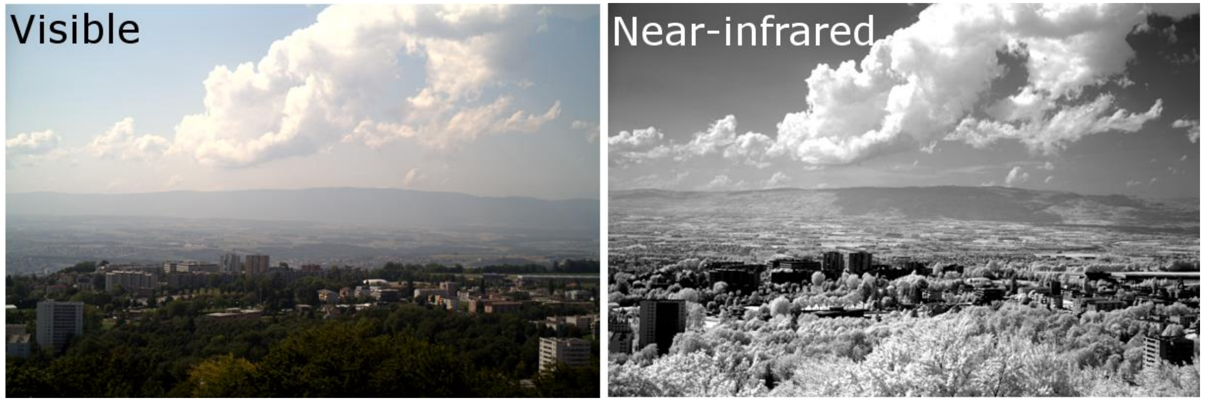
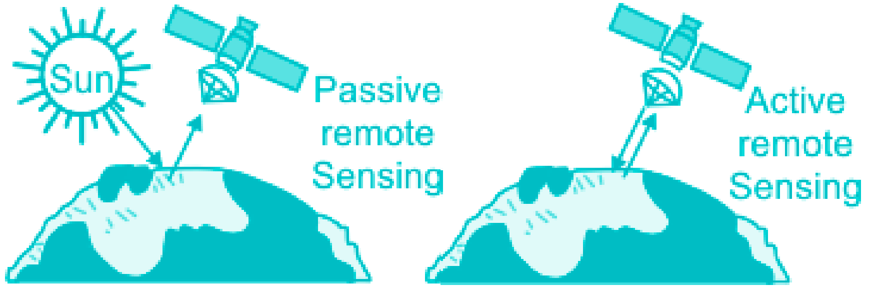


Where does the energy come from?



- There are two main ways measuring

	Passive	Active
Principles	'Just' measure whatever comes to you	Emit a radiation and measure what is coming back
Pros/Cons	Lower energy consumption (i.e. easier to measure 'continuously') Needs 'someone' else to produce the energy, can't measure when it is not present	High energy consumption (harder to measure continuously) Better control of the signal
Example	Digital Camera, optical sensor	LiDAR, Radar, Digital Camera with flash

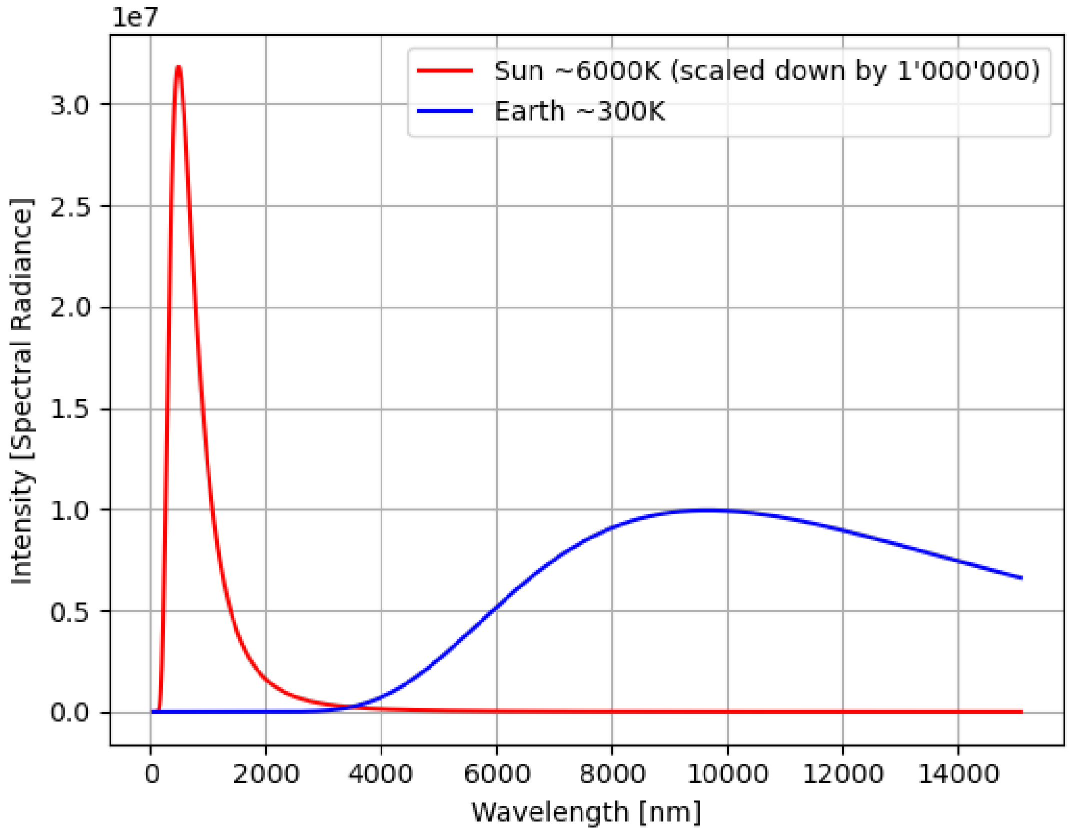
PASSIVE MEASUREMENT - VIS TO LWIR

Where is the radiation passive sensors measure coming from?

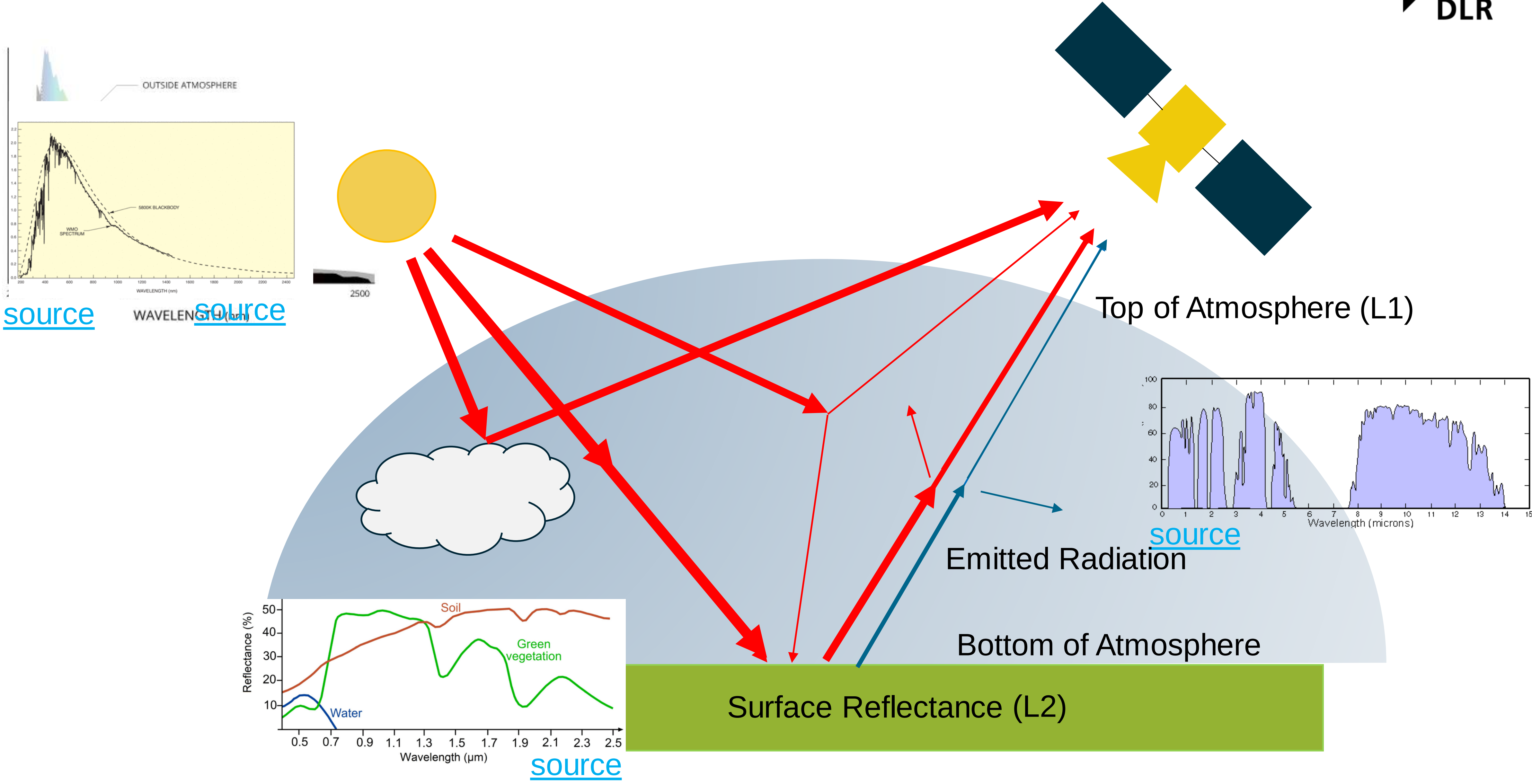
- Most surfaces emit radiation depending on their temperature
  - The intensity and wavelength depends on the temperature

- From 400 to 2,500 nm the main contributor is primarily the Sun (6,000 K)

- For MWIR to LWIR contributions from objects on Earth start being also observable
  - These temperatures on Earth can reach a few 100°Celsius (e.g. Lava 1,200°C)
  - Thus the (improper) name ‘thermal’ remote sensing

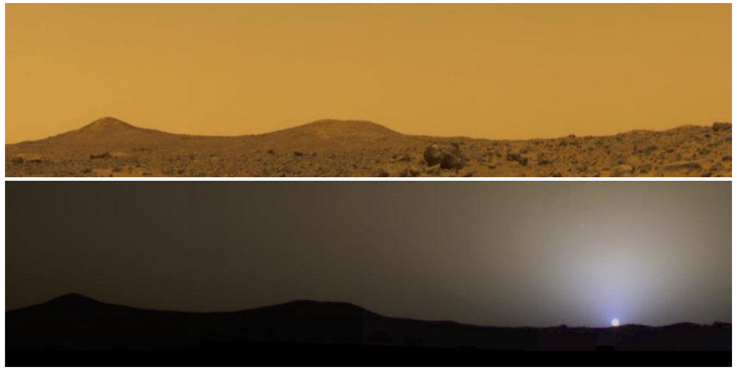


Path to Sensor – typical measurement



Path to Measurement – good to know

- In the VIS to SWIR the atmosphere is significantly interacting with Electro-magnetic radiations
  - One example is the presence of clouds
    - About 67% of Earth's surface is covered by clouds at a given time (King et al., 2013).
    - It is slightly better over land, and slightly worse over waters
  - Another example is the scattering of the 'shorter' wavelength
    - Molecules and aerosols sometime 'reemit'/ redirect radiations in a random direction
      - This typically affects 'smaller' radiation (in VIS - blue)
      - This is the reason why the sky appears 'blue'
      - Note: the scattering (and effects) depends on the atmospheric conditions
  - You can't afford to 'ignore' the interaction with the atmosphere!!!



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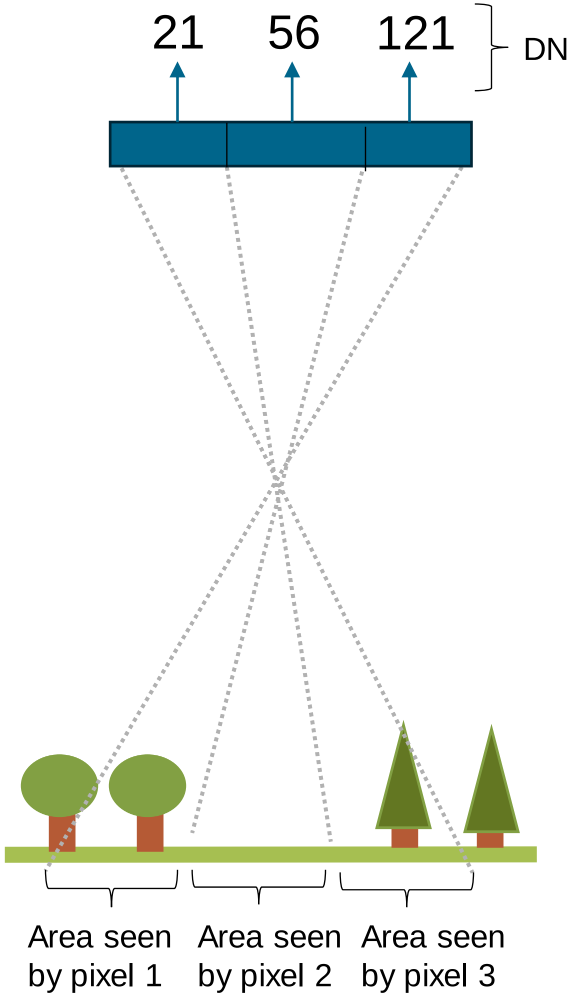
Extreme example – On Mars, the Sky has a different appearance than on Earth. One of the reasons is the different scattering due to different atmosphere

How are we measuring?

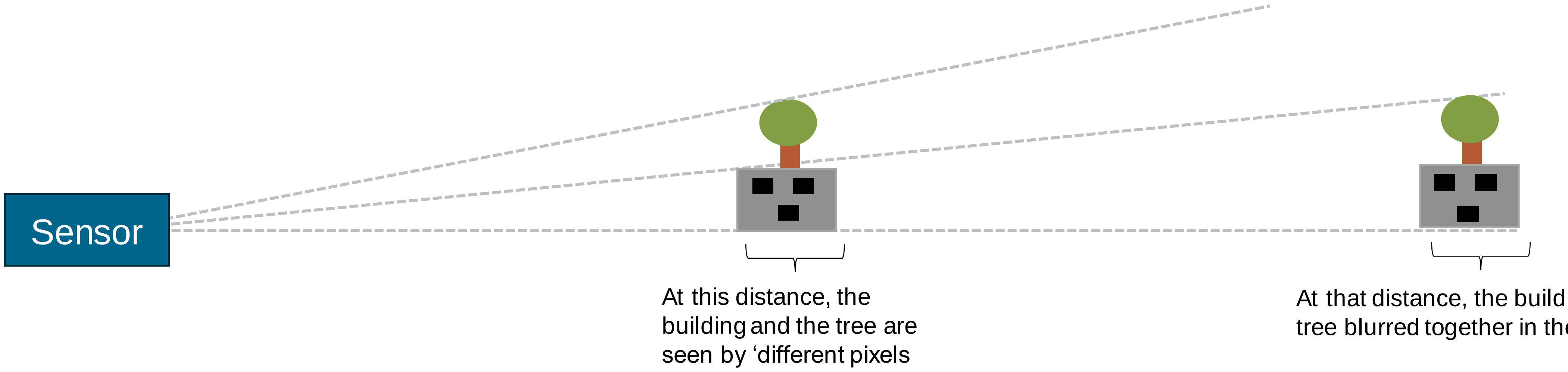
- In the VIS-SWIR domain sensors are ‘digital cameras’
  - The detector is made of several ‘pixels’ each looking in a given direction
- They count photons at a given wavelength coming from a given direction over a given time
  - Photons per second per solid angle per area per wavelength is ‘the radiance’
  - The number of photons collected converted to a numerical value (DN)
  - Using calibration information, you can relate the DN to an actual radiance: this is your measurement (Top of Atmosphere)



- The MWIR/LWIR sensors can be a bit different, but can usually be used ‘as if they were the same’

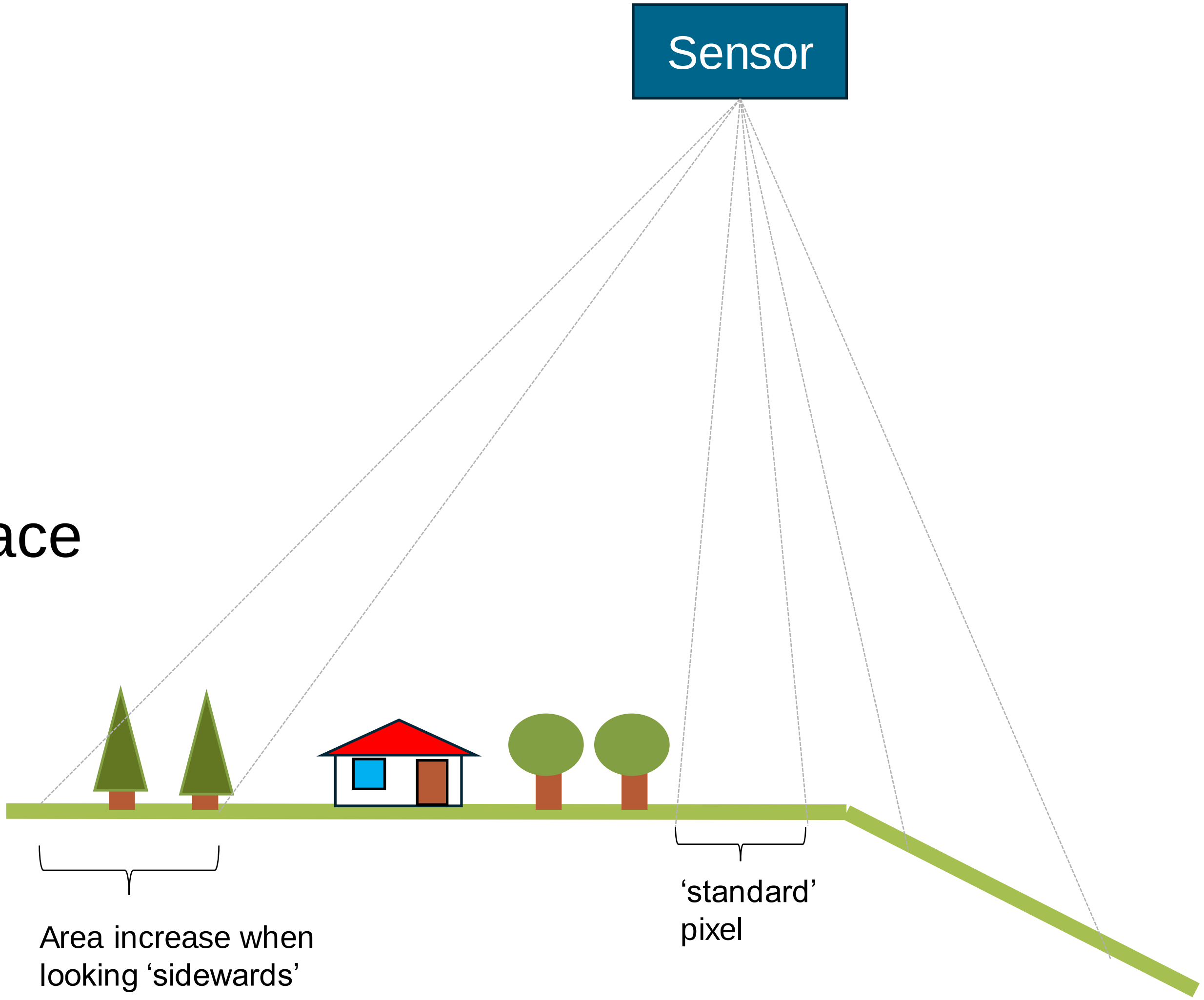
How are we measuring? Focus on geometry

- Each Pixel corresponds to an ‘angle’ - not directly a size
  - The ‘size’ of the angle depends on the sensor characteristics
  - *This is quite the ‘same’ as how our eyes work*
    - The ‘area’ seen by a pixel (or us) is dependent on
      - How far the object is
      - How is the object ‘tilted’ w.r.t. the sensor
  - If several objects are covered by the same pixel, they will be ‘mixed’ or ‘blurred’ together by that pixel



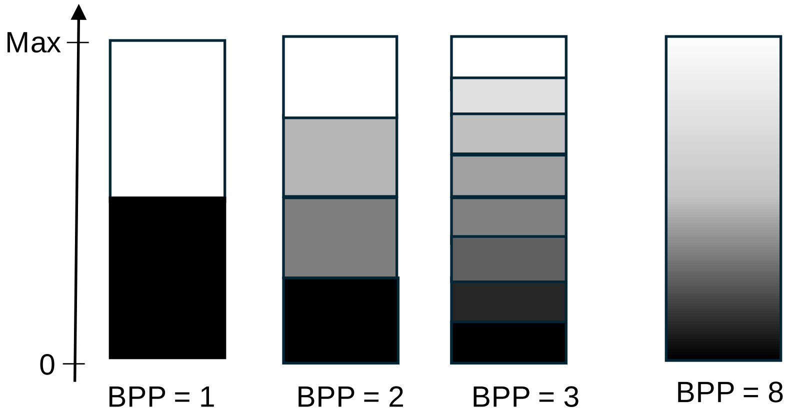
How are we measuring? Geometry & Spatial Resolution

- When looking 'down' on Earth the angle defines a 'size' of a pixel
  - This is the 'spatial resolution'
- The resolution depends on
  - The sensor itself
  - The sensor orientation
  - Where in the sensor the pixel is located
  - What is the shape of the terrain
- Associating each pixel to a given surface area is the 'georeferencing'
- Correcting the data so that all pixels cover an equal "quadratic" area is the ortho-rectification
  - 'common' understanding of spatial resolution from data perspective



How are we measuring? Focus Digital Number & Bit Per Pixels

- The Bit Per Pixel (BPP) defines ‘how many radiances’ can be represented by a sensor (radiometric resolution)
- A sensor with b BPP can represent 2^b different radiances
- The ‘maximum’ radiance depends on the sensor
  - If you look at too ‘bright’ target (e.g. clouds) you might saturate
- The ‘intensity’ is typically represented in grey-scale
  - Black being low radiance, white being the maximum radiance

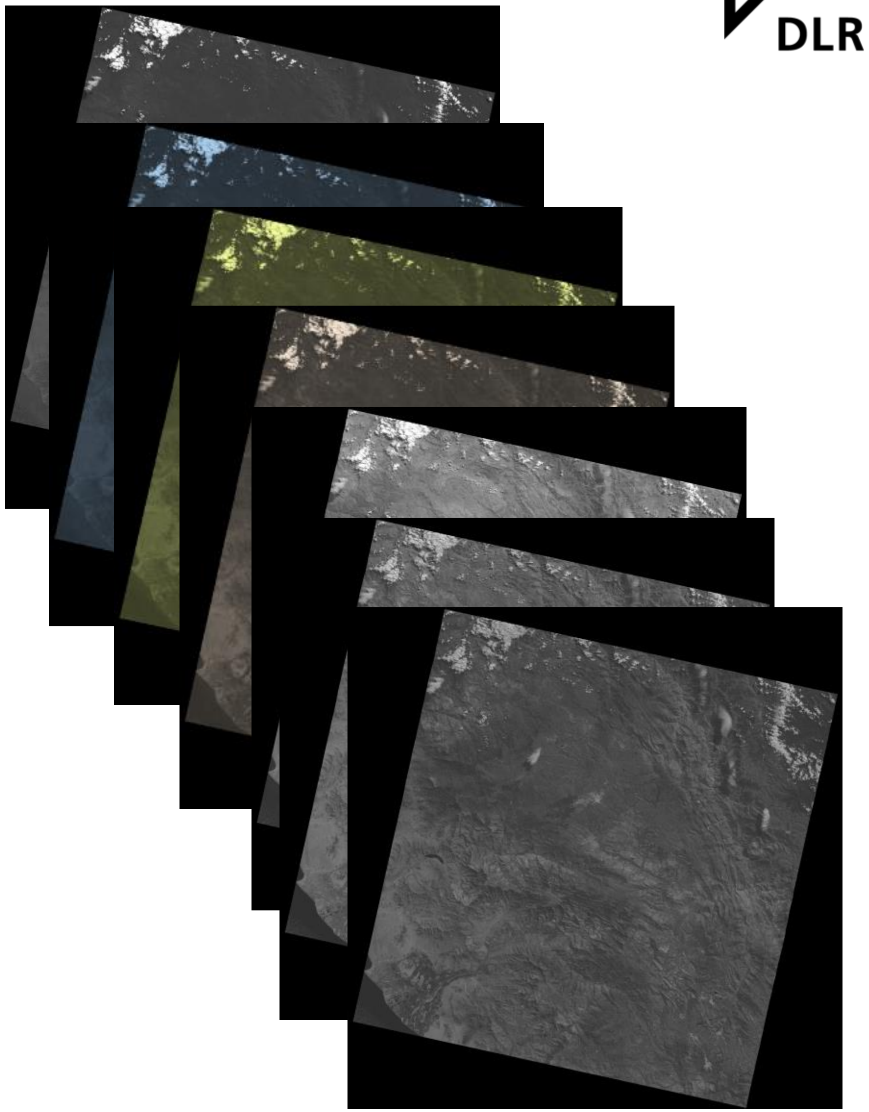


How are we measuring? The spectral resolution

- Sensors are typically collecting photons over a given wavelength intervals

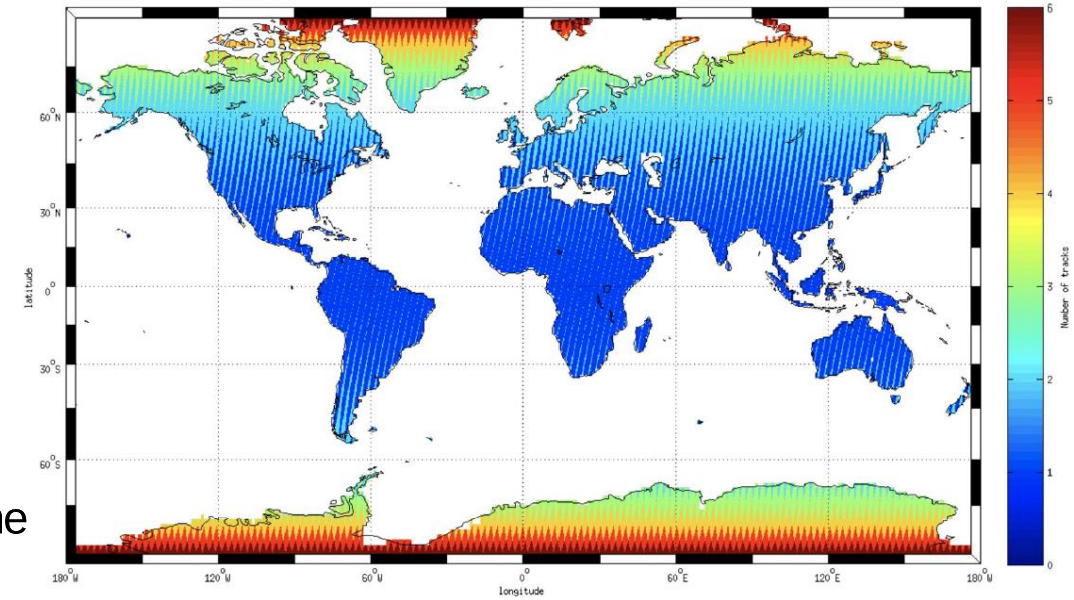
- Imagery is therefore made of several bands:
  - Each band is a measurement over a certain wavelength interval

- Spectral resolution: ability of a sensor to distinguish different wavelength intervals

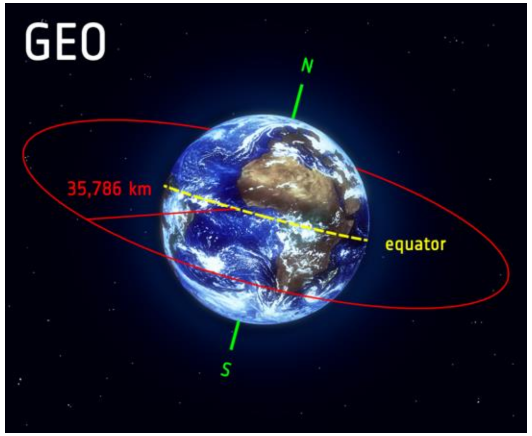


So much for the sensor – what's holding it and how does it record data?

- We focus here on satellite remote sensing
  - RS satellites typically operate on so-called Polar orbits:
    - Fly roughly 'North/South' following the Earth rotation
    - At Each orbit, the footprint is off-setted in longitude
    - Over time – the complete Earth is acquired
    - Allows to observe every spot of the Earth at the same time
  - There are however a few other orbits



Sentinel-2 Constellation Coverage (Source: ESA)



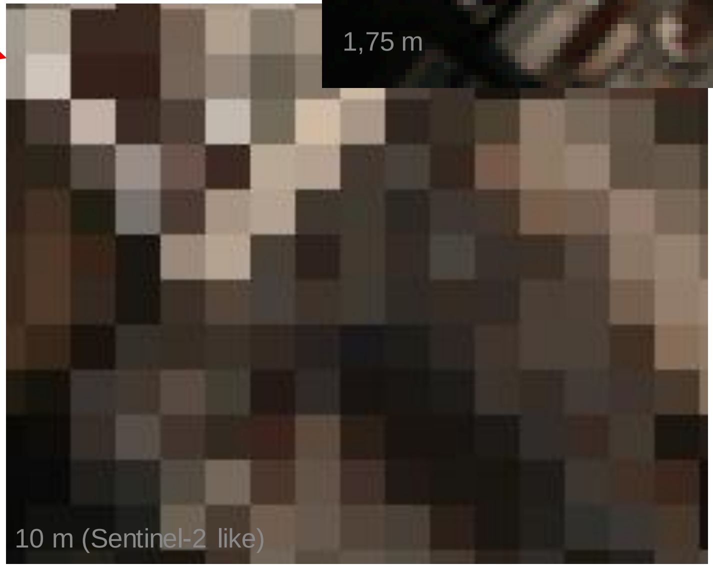
ESA: Geostationary_orbit

ESA: Sentinel-2_global_coverage

WHAT ABOUT PRACTICE?

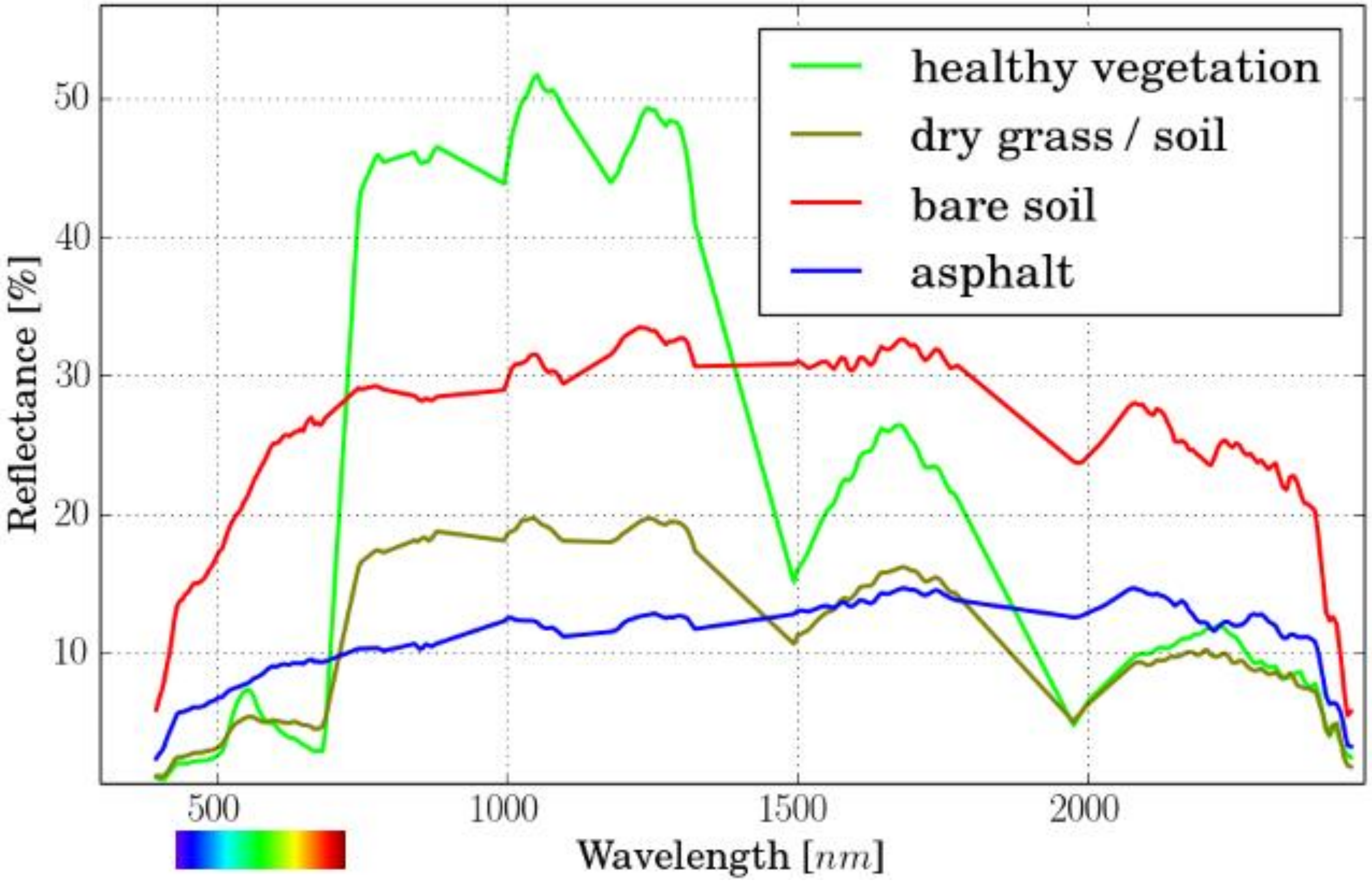
Spatial Resolution

40 cm

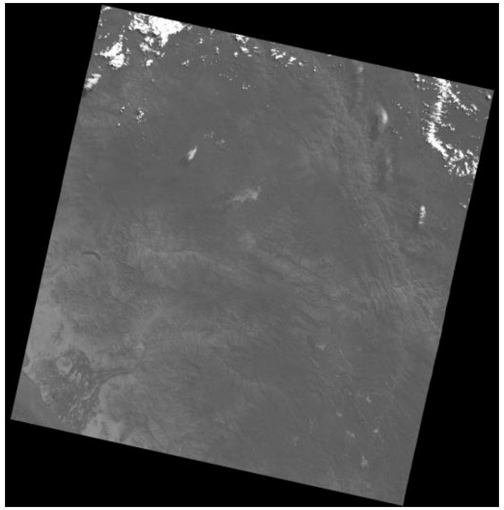


[Original Image: Maxar]

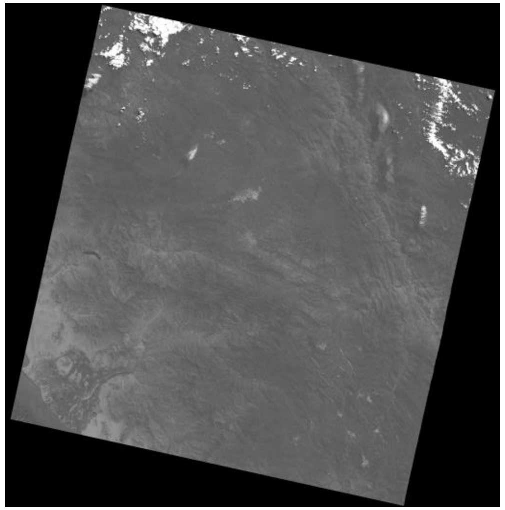
Wavelength & Spectral Information - Examples



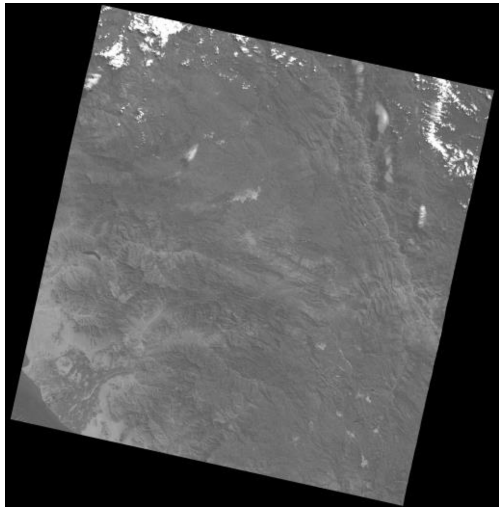
Spectral bands – Example Lansat 9



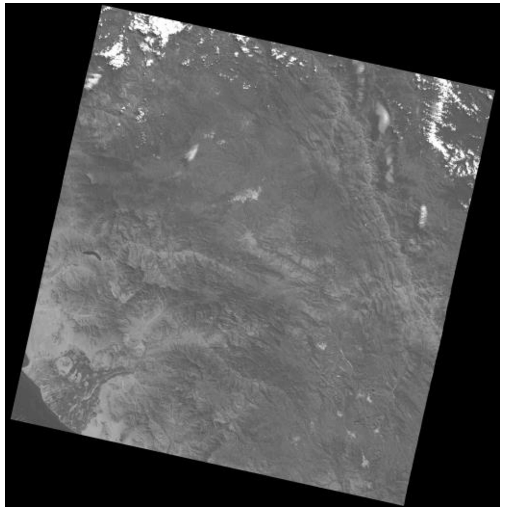
B1 ‘coastal aerosol’ 430-450 nm



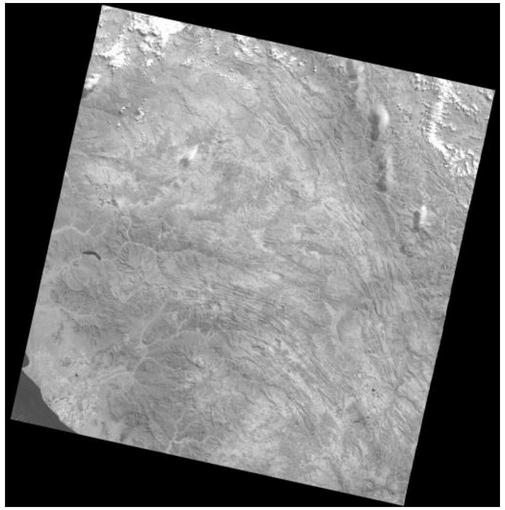
B2 ‘Blue’ 450-510



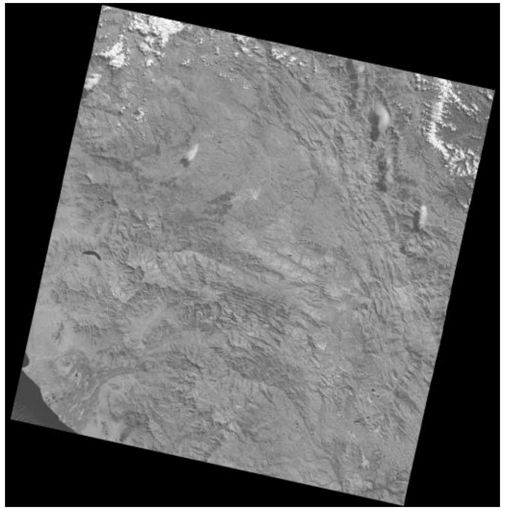
B3 ‘Green’ 530-590



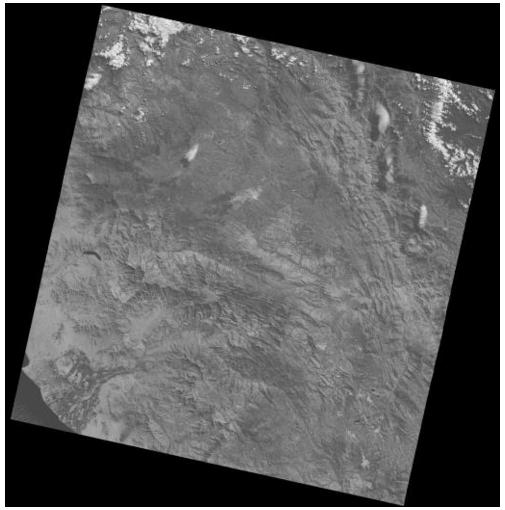
B4 ‘Red’ 640-670nm



B5 ‘nir’ 850-880 nm



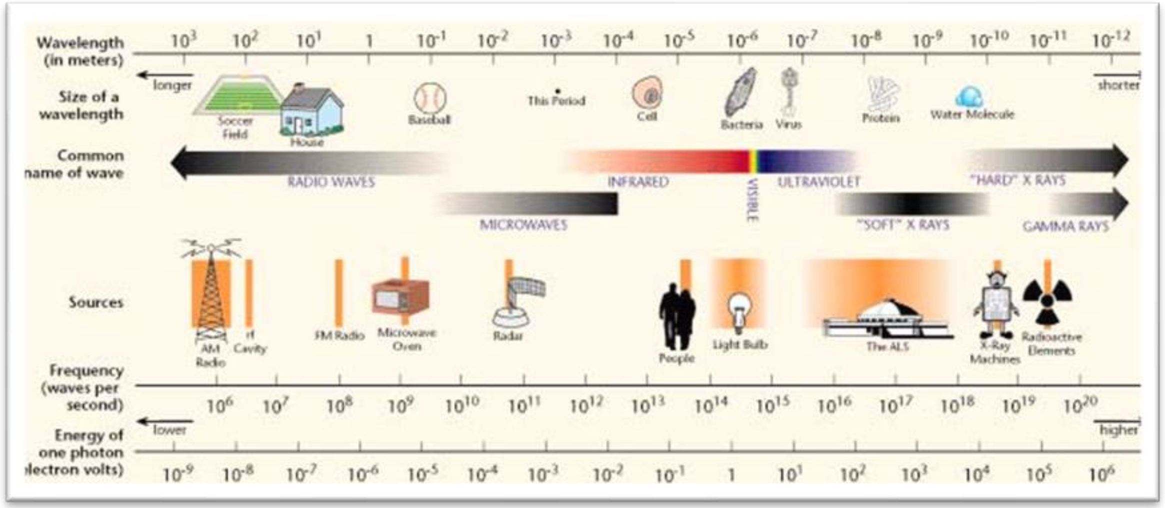
B6 ‘swir’1570-1650 nm



B7 ‘swir’ 2110-2290 nm

Trade-Offs to be considered

- A sensor is typically a trade-off
  - The smaller the pixels are, the ‘more’ geometry we can see…
    - But the sensor collects less photons (‘worse signal’)
    - But you’d need more pixels to cover a given area
  - The smaller the bands wavelength domain is, the more spectral details can be seen...
    - But the sensor collects less photons (‘worse signal’) are the bands are smaller



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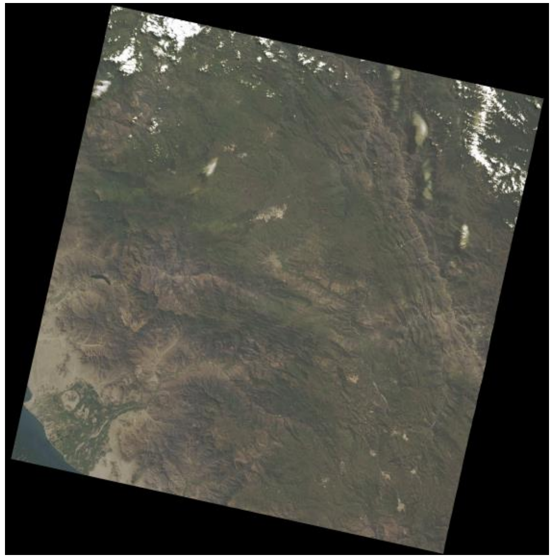
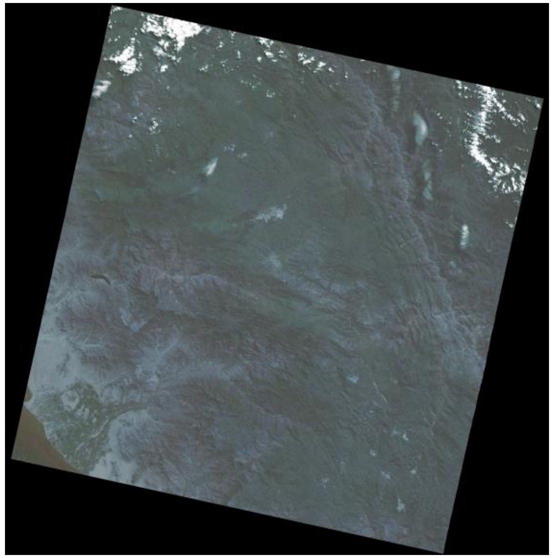
- There are also several technical trade-off to be considered when building the sensor, several being related to these aspects

Combining spectral bands - Theory

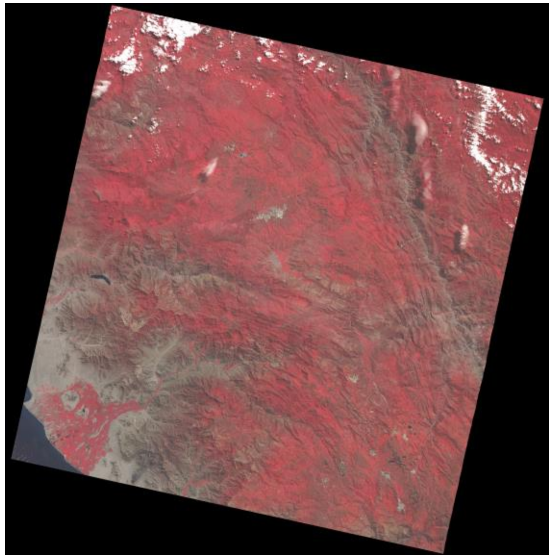
- Human vision / computer displays represent colours as a combination of ‘Red, Green and Blue (RGB)
  - To visualise further combinations on can rely on ‘false colour’ by displaying other bands instead of the classical red, blue and green ones
  - This allows to highlight visually ‘invisible’ spectral features



B2, B3, B4
blue, green, red



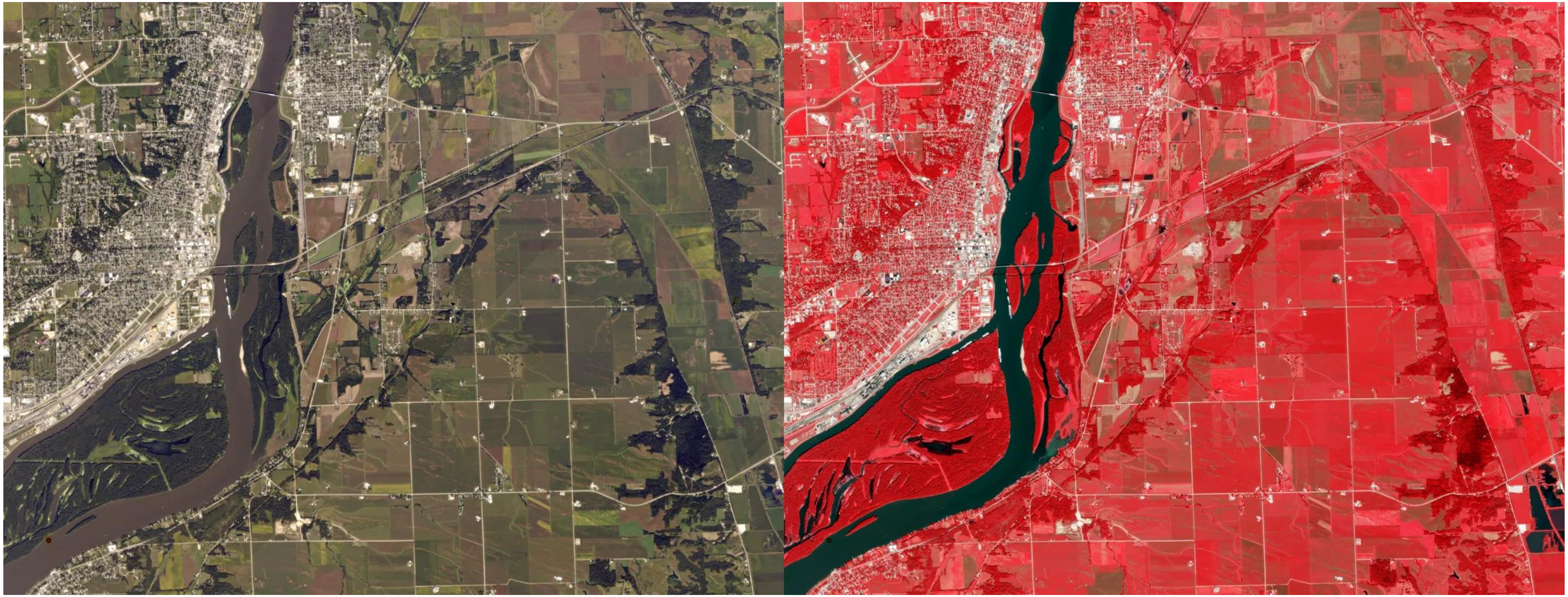
B4, B3, B2
red, green, blue



B3, B4, B5
green, red, nir

B7, B5, B2
swir, nir, blue

Combining Bands - Vegetation



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DATA & SENSOR SYSTEMS

Data Levels

- Remote sensing data is usually organised per processing levels (L):
  - L0: ‚Raw' data, as retrieved after been downloading from the satellite:
    - Cannot be used without expert knowledge on the satellite and ground segment.
  - L1A: ‚raw' data, but sorted out and linked to calibration data.
    - Cannot be used without expert knowledge on the satellite and ground segment
  - L1B: ‚radiometrically' calibrated data (top of atmosphere radiance') without geometric correction.
    - Can be used by advanced users in specific cases
  - L1C: Orthorectified L1B data (i.e. tiles of top of atmosphere radiance):
    - Can be used by advanced users, in specific cases
  - L2 / L2A: Atmospherically corrected data (i.e. surface reflectance):
    - Typically that's the data you'd like to use if you have to rely on RS data
  - L3/L4: inofficial names for either time series agregation and/or model outputs
    - Usage depends on what you'd like to do

no

maybe

yes

- Note:. Levels definition details vary from mission to mission and/or from agency to agency:
  - Always check the documentation!

Data Download

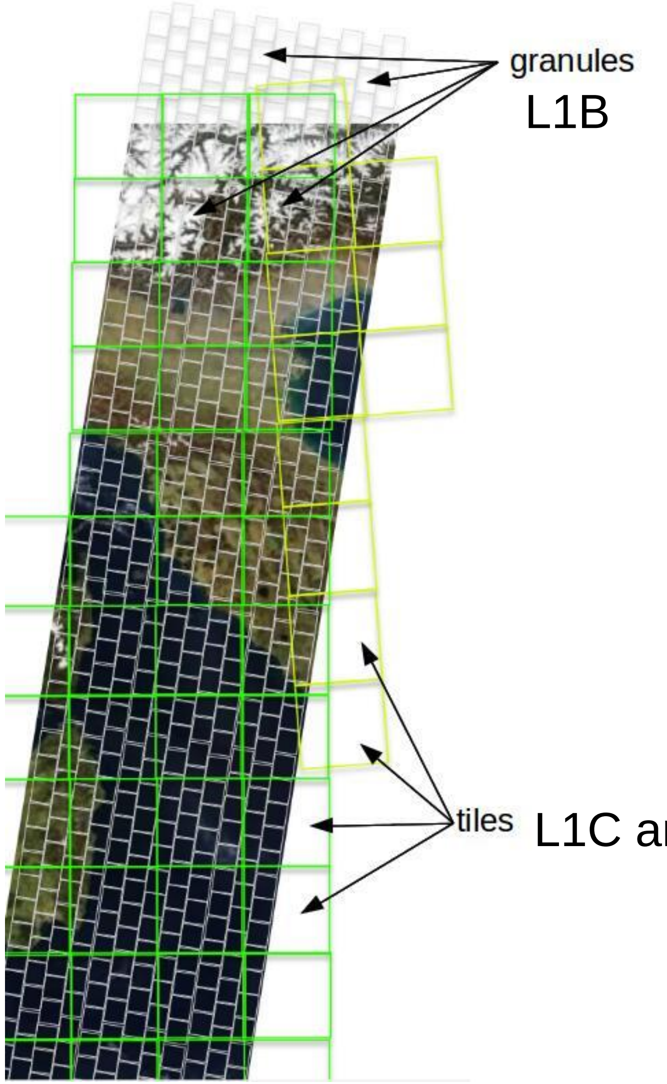

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Table 4: Level-2A Product name Nomenclature

Field	Signification	Length (max)	Example Value
MMM	Mission ID, e.g. S2A, S2B	3	S2A
n/a	Separator	1	_
DDDDDD	Semantic Descriptor, fixed string to identify Level-2A products	6	MSIL2A
n/a	Separator	1	
Datatake Sensing Time	UTC Date/Time with second's resolution. Format: YYYYMMDDThhmmss	15	20160814T102032
n/a	Separator	1	
Nxxyy	Production baseline	5	N0201
n/a	Separator	1	
ROOO	Orbit Number (Relative orbit number) R000-R143	4	R047
n/a	Separator	1	
Product Discriminator	Fixed string to distinguish different end user products associated to the same datatake. Format: YYYYMMDDThhmmss	15	20160803T124046
	Total length for main product directory name without extension.	**53**	

Example name Sentinel-2 file:
S2B_MSIL2A_20230613T102609_N0509_R108_T32TMT_20230613T151004

Sentinel-2-MSI-L2A-Product-Format-Specifications

Note: Again, all of the above is mission specific

Institutional Imagery Provider

- Traditionally Satellite Remote Sensing has been operated by state agencies
  - Most of the remote sensing data originates from such agencies
  - When searching for specific sensors or missions, they are typically the first stop
  - Some of the ‘usual’ suspects are (non exhaustive list)

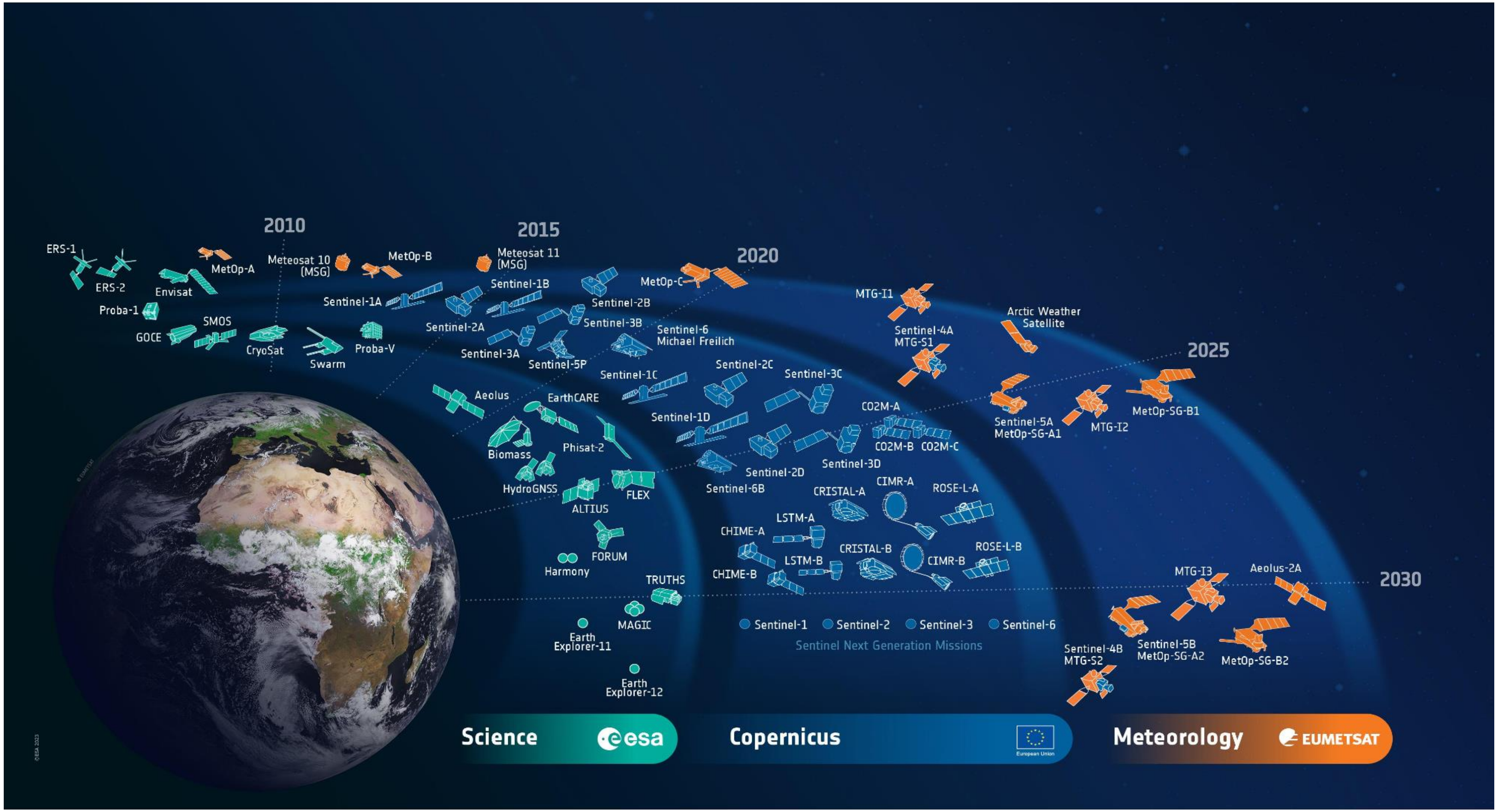
    ESA (Europe) :
    - https://earth.esa.int/eogateway/search?category=missions
    - See in particular the Earth Explorer https://earth.esa.int/eogateway/missions/earth-explorers
    - ESA also heads the EU program Copernicus: https://browser.dataspace.copernicus.eu
    - See also European Meteorological Agency (Eumetsat): https://data.eumetsat.int/

    USA:
    - NASA : https://www.earthdata.nasa.gov/
    - NOAA : https://data.noaa.gov/onestop/
    - USGS : https://earthexplorer.usgs.gov/

- Do not forget to check your ‘own’ space agencies
  - There are still many ‘national’ mission:
    - Centre national d’études spatiales (CNES) / France
    - German Aerospace Center (DLR) / Germany
    - Agenzia Spaziale Italiana (ASI) / Italy
    - Indian Space Research Organisation (ISRO) / India

    etc.

That’s a lot of data… even ‘just’ for ESA



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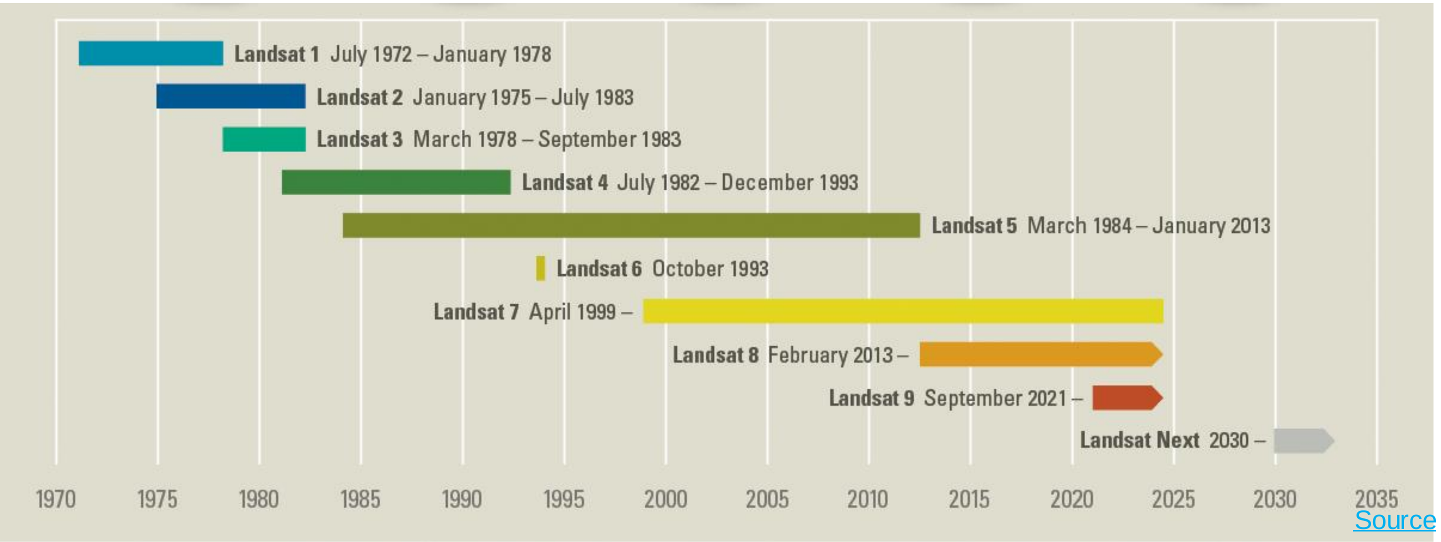
Focus – Landsat, the grandfather

Source

- Landsat is the oldest continuously serving constellation
  - Although sensors evolved over time, attention was paid to keep as much ‘backward’ compatibility as possible
- Main sensor characteristics (Landsat 8)
  - Spatial Resolution: 30 m (100 m – M/LWIR)
  - Spectral Range: 0.43 – 12.5 µm
  - Temporal Resolution: 16(8) days
  - Swath Size: 185 km



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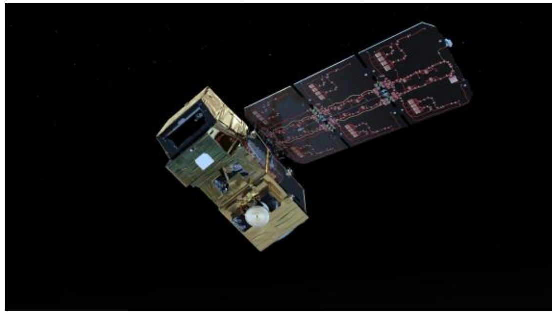
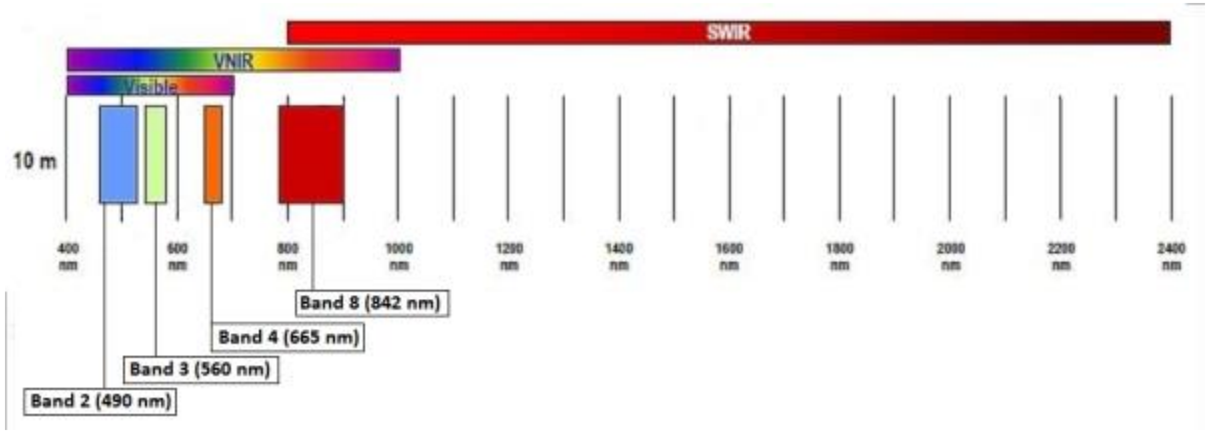
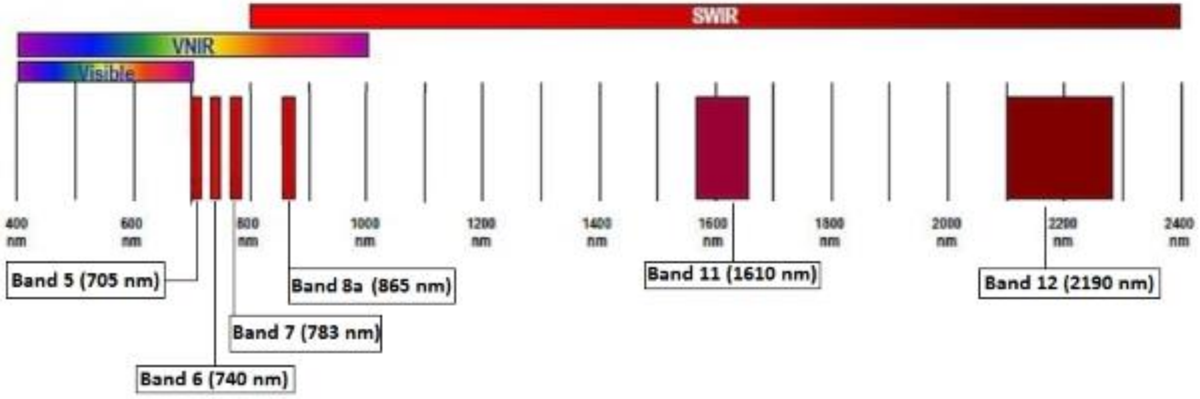
Focus - Sentinel 2, the work horse

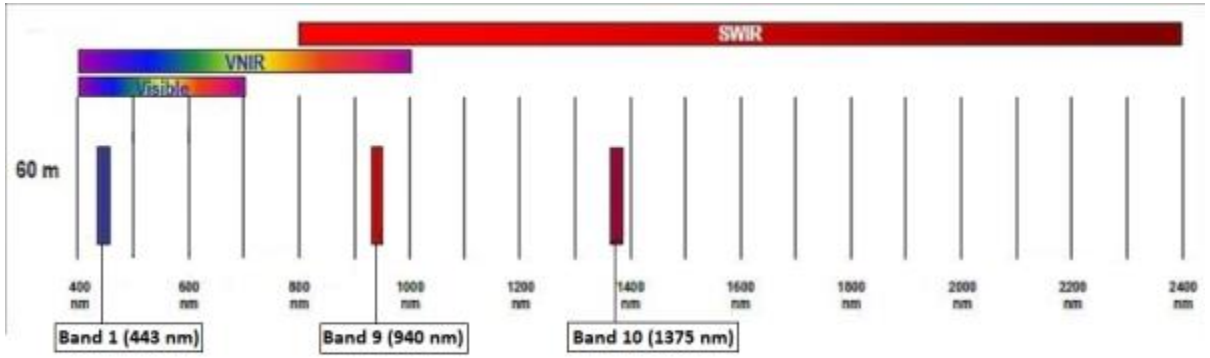


Source

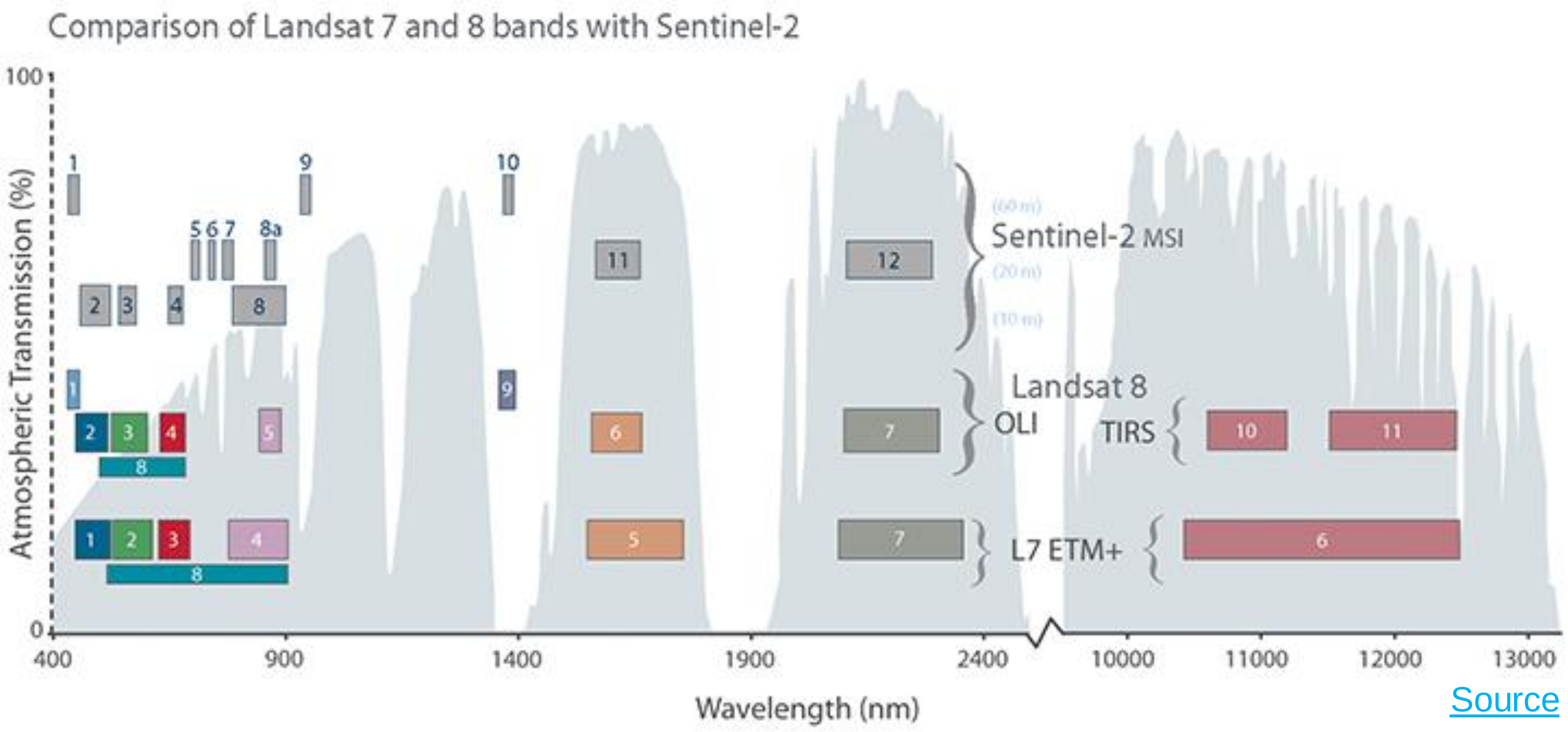
- Sentinel 2 is equivalent of Landsat within the Copernicus program
  - Currently (2024) constellation of 2 satellites (Sentinel 2A and Sentinel 2B)
  - Operational Since 2015(2017)
- Main sensor characteristics
  - Spatial Resolution: 10, 20 & 60 m
  - Spectral Range: 0.43 – 2,28 µm
  - Temporal Resolution: 10(5 days)
  - Swath Size: 290 km







Landsat & Sentinel



Source

LET‘S SWITCH TO PRACTICE

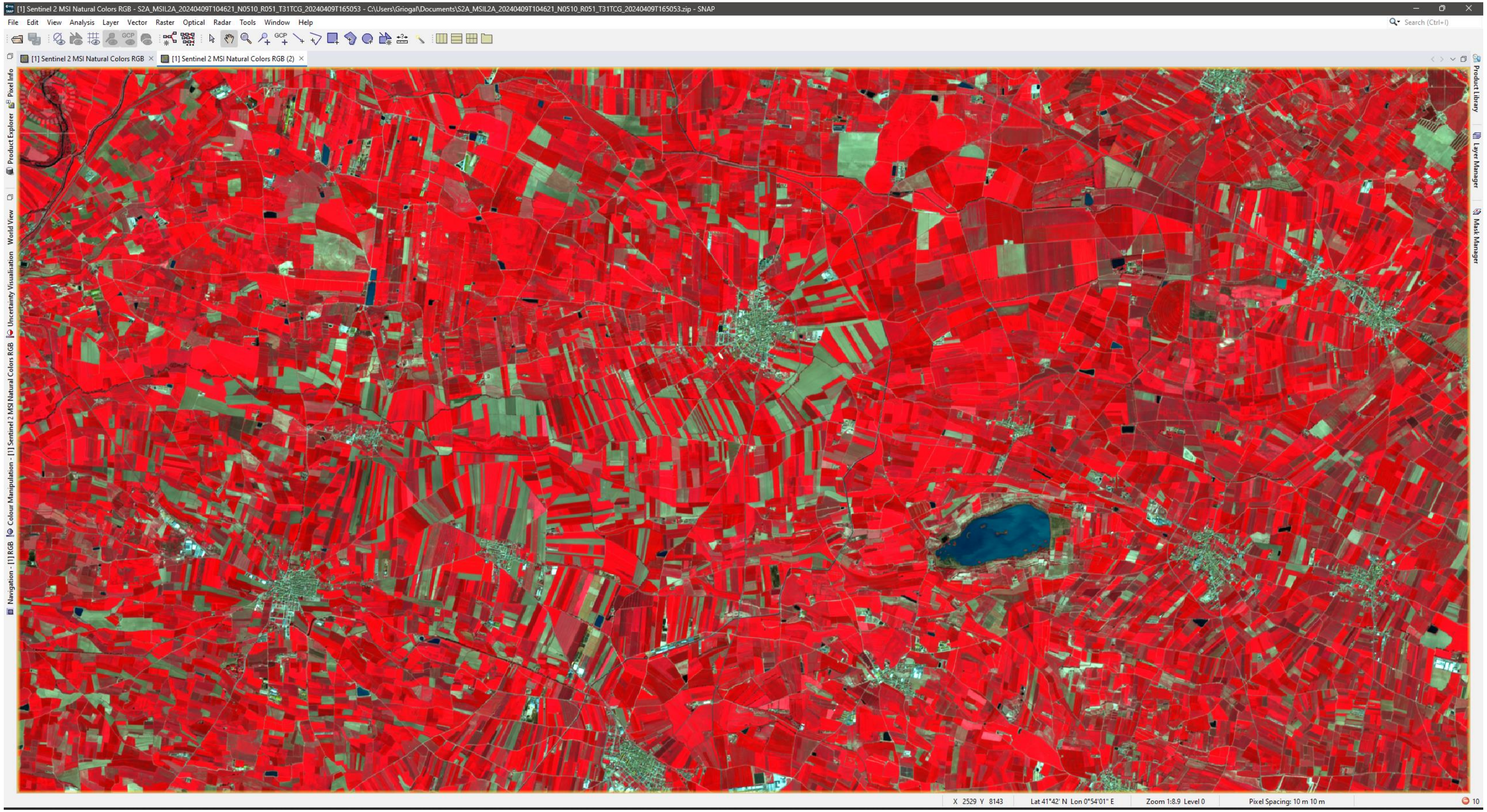
APPENDIX

DOWNLOAD/PROCESS DATA

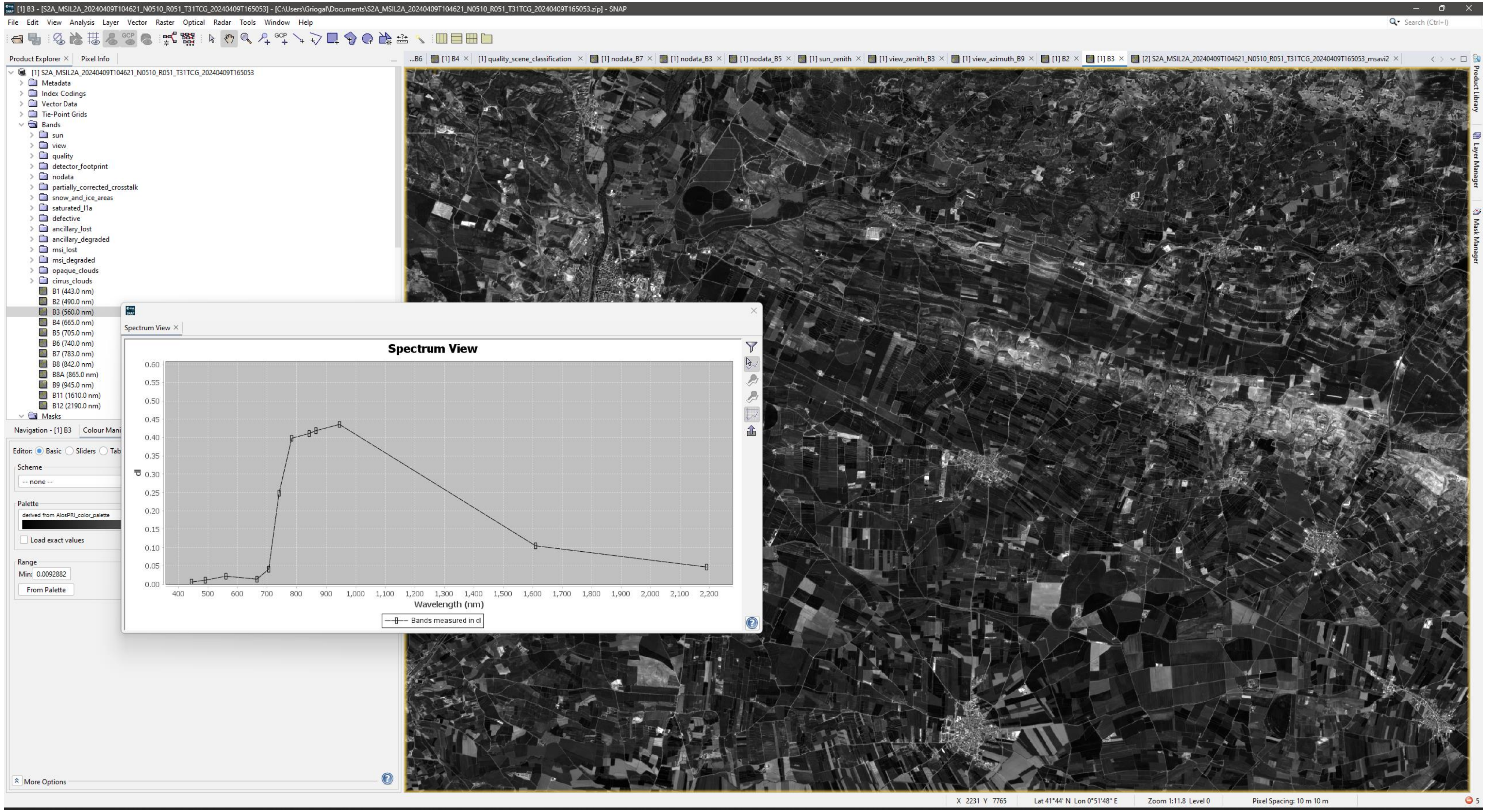
SeNtinel Applications Platform (SNAP)

- ESA made available several tools for working with Sentinel Data
  - Also covers a few other ESA missions
  - https://sentiwiki.copernicus.eu/web/sentinels-toolboxes
  - https://step.esa.int/main/download/snap-download/
- The Toolboxes can be used to
  - Download / Browse data
  - Visualise data and results
  - Apply standard corrections and processing to the data
  - Harmonise data with similar missions (e.g. Landsat to Sentinel-2)
- Several Tutorials as well as a forum can be found online
  - https://step.esa.int/main/doc/tutorials/

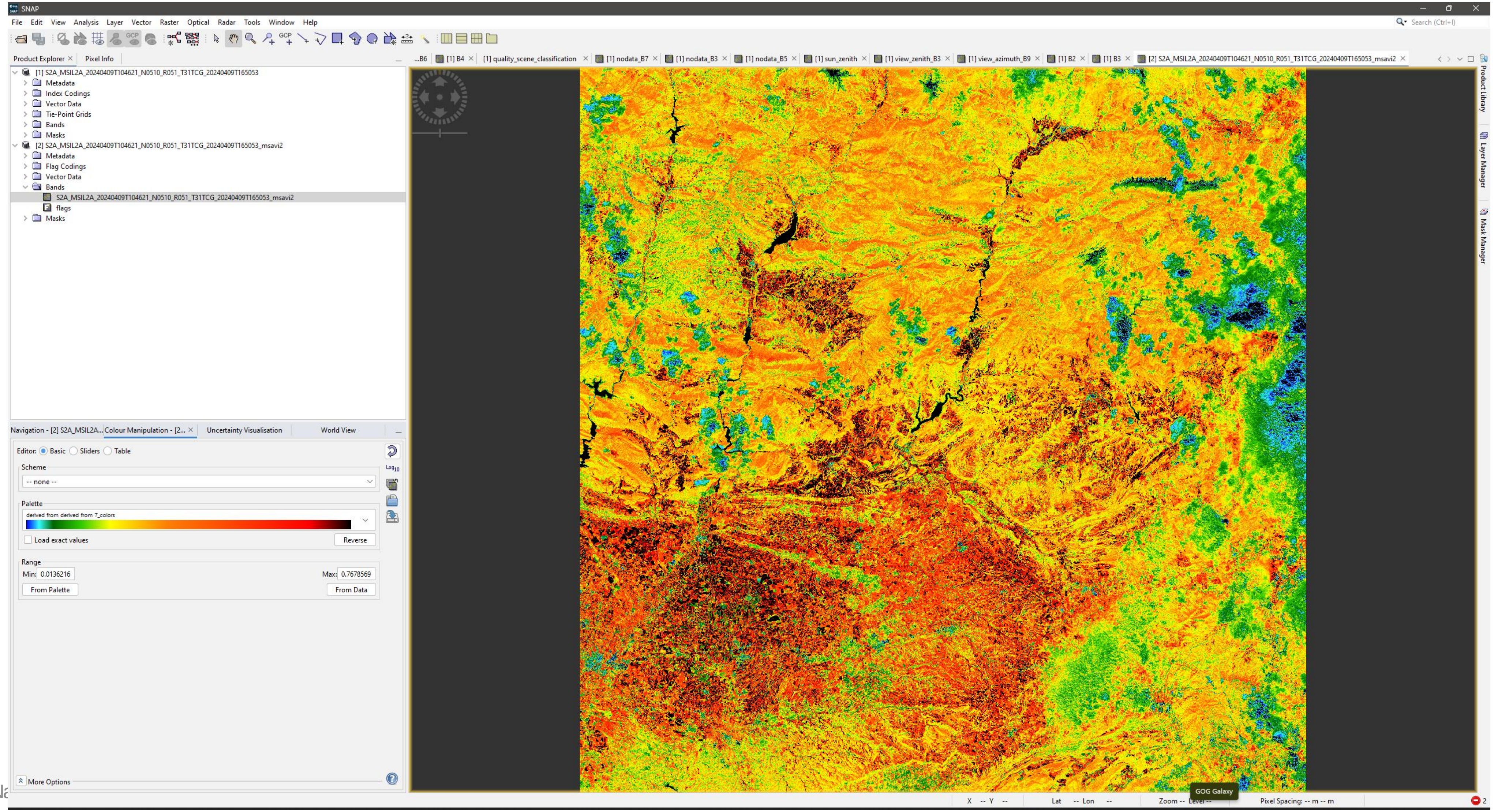
Snap / Sentinel 2 : example False Colour Visualisation



Snap / Sentinel 2 : example Spectrum Visualisation



Snap / Sentinel 2 : example MSAVI-2



Microsoft Planetary Computer

Microsoft planetary computer is similar to the functionalities of Google Earth Engine (GEE):
https://planetarycomputer.microsoft.com/docs/overview/about/

The Planetary Computer provides the following:

- Data catalogue with loads of EO/RS data
- APIs that allow users to search and process data

Getting started with Microsoft Planetary Computer R API:
https://planetarycomputer.microsoft.com/docs/quickstarts/reading-stac-r/

LIST OF RS DATA SOURCES

Commercial – SPOT & Pléiades

- Airbus (former SPOT Image) operates a constellation of high resolution satellites:
  - SPOT family (1986 – present)
    - High Resolution Imagery (a few meters), relatively large swath
    - https://earth.esa.int/eogateway/missions/spot
  - Pléiades (2011 – now)
    - Very High Resolution (<1m)
    - https://earth.esa.int/eogateway/missions/pleiades
- Although a commercial mission, numerous partnerships with science exist
  - Through ESA: https://earth.esa.int/eogateway/missions/pleiades-neo
  - Through Airbus: https://intelligence.airbus.com/about-us/academic
- Note: Airbus has its own portal API for managing its data
  - One Atlas: https://intelligence.airbus.com/imagery/how-to-order-imagery-and-data/

Commercial - Maxar

- Operates a large fleet of very high resolution satellites (15 cm to a few meters)
  - Best known is the Worldview series: https://www.maxar.com/maxar-intelligence/constellation
  - Offer very short revisit times
- Also proposes its ‘own’ platform
  - MGP https://www.maxar.com/maxar-intelligence/products/mgp-pro
- Note: as for Spot/Pléiades, some of the Maxar imagery is available through ESA
  - E.g. https://earth.esa.int/eogateway/missions/worldview

Commercial – See Also

- Many new (or not so old) companies are emerging:
  - Just to name a few…
    - https://www.constellr.com/ - land surface temperature
    - https://www.ghgsat.com/en/ - green-house gases
    - https://www.planet.com/ - imagery
    - https://satellogic.com/ - imagery
    - Etc.
  - When looking for data and/or partnership, a quick search beyond the 'usual suspects' might be worth it

Further Resources

- USGS Spectral Library
  - Collection of typical (in situ) reflectance spectra for surface materials
  - https://www.usgs.gov/labs/spectroscopy-lab/science/spectral-library

- MERRA 2 / ERA5
  - Collection of atmospheric data
  - https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/
  - https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=form

- All the above is non exhaustive
  - A quick search is always worth it ;)

Commercial Imagery Providers - generic

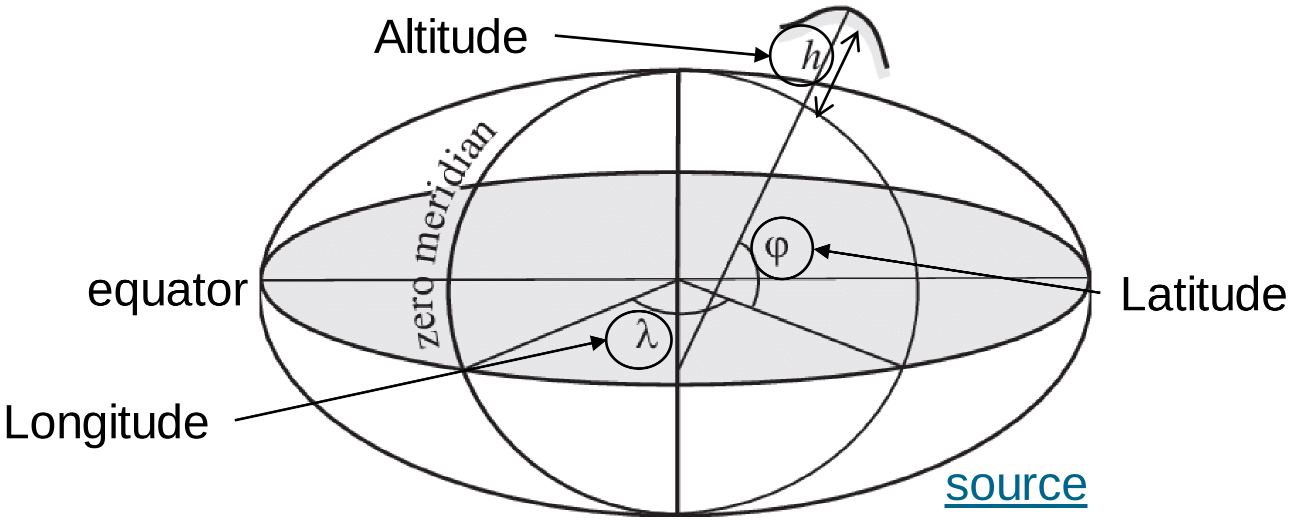
- Academic science typically relies on ‘free’ imaging
  - These are typically made available by governmental/state agencies
  - They are usually trade-off aiming at satisfying ‘most’ users
    - Aim at a wide & regular coverage, which come at the cost of spatial resolution

- There are however many commercial data provider
  - They typically sell the data to corporations and/or government
  - Use-cases are dominated by intelligence (especially commercial intelligence)
  - Data tend to be focusing on high spatial resolutions (few metres/sub-metres) with relatively good spectral resolution
    - This is done at the cost of coverage: you only acquire data when you have a user
  - Commercial doesn’t mean unavailable to academics/non-profit organizations
    - Some collaboration with space agencies do exit

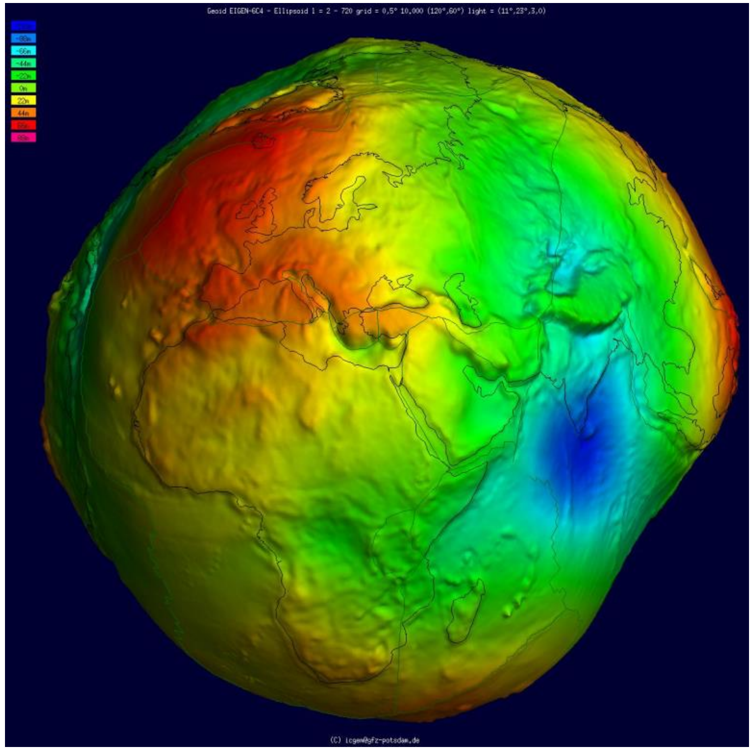
FEW THINGS ON PROJECTIONS

If only the Earth was flat...

- The Earth is not a sphere…
  - It can be modelled as the so-called ‘Geoid’
  - Is actually not ‘rigid’ (Earth-tides, plate tectonics, …)
- In practise, it is often ‘good’ enough to model the Earth as an ellipsoid
  - The best known is the World Geographic System 1984 or WGS-84



source



The Geoid – altitudes exaggerated by 10 000
source

- Issue: it is mathematically impossible to perfectly project any of these shapes to a 2D map

Projections

- As it is not possible to perfectly project the Earth Surface to a 2D map:
  - Compromise must be made – projection can for example be:
    - Conformal: preserves local angles, but not necessarily lengths
      - e.g. Mercator Projection
    - Equal-Area: preserves local areas, but not shapes-
      - e.g. Lambert projection
    - Equidistance: maintain scale along one or more line
      - e.g. equirectangular projection
    - Or a compromise amongst the above

  - Different data provider might use different projections
    - You might need to convert between different projections