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Satellite-based Earth Observation/Remote Sensing and Data

09/09/2024

Booker Ogutu

Outline

- What is RS/what does it measure?
- EMR/Spectrum and regions used for environmental RS (Spectra)
- Types of Remote Sensing Systems - Passive/Active sensors
    - Optical, LIDAR, RADAR
- Key Characteristics of Remote Sensing Data
    - The four resolutions
- Key EO programmes(current and future missions) for environmental applications
    - Public
    - Commercial
- Key sources/portals for RS data

Remote Sensing

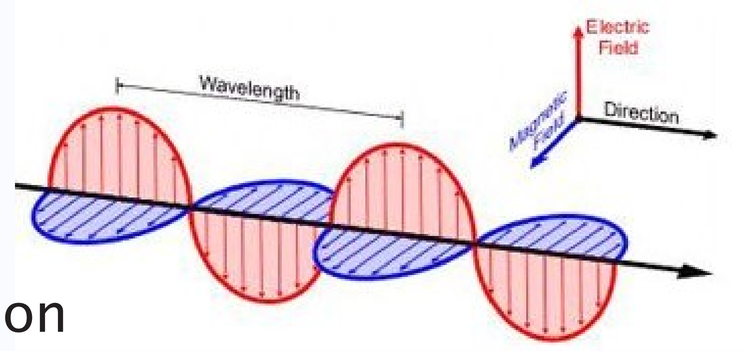
- Collection of information about an object without coming into physical contact with that object
- “Collection and interpretation of measurements of electromagnetic radiation reflected or emitted by a target(e.g., Earth surface, Atmosphere) in one or more regions of the electromagnetic spectrum” (*Mather and Koch, 2011*)
  - Relies on measurements of Electromagnetic Radiation (EMR) made at a distance.
  - Different targets *reflect, absorb, transmit* or *emit* EMR in different proportions across the EM spectrum which allows these targets to be ‘*uniquely*’ identified
- RS is powerful when those data are arranged into an image (2D) and combined with other spatial location (3D) or as a time series (4D).

What is collected in RS?

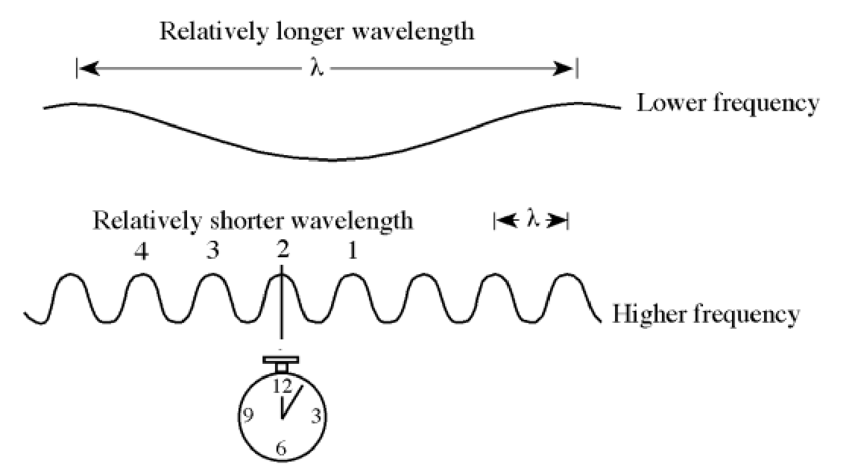
What is EMR ?

- EMR is a form of energy that propagates both as electrical and magnetic waves travelling in packets of energy called photons
- Behaves both as a *wave* and *stream* of particles at sub-atomic level

The wave model of EMR energy

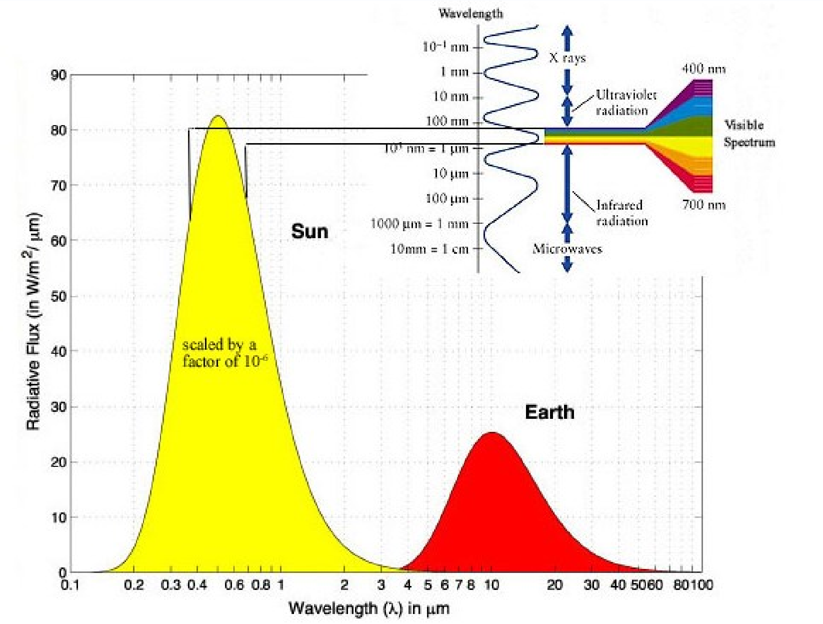


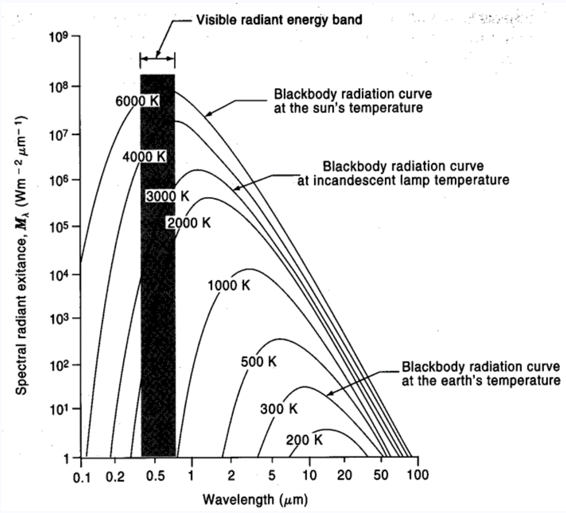
- EMR wave is an *electric field* (E), *perpendicular* to *magnetic field*(M) and to the direction of travel
- Wave model - useful for distinguishing different types of radiation
  - Wavelength (λ) = distance between crests/troughs (meters or fractions of meter e.g. μm, nm)
  - Frequency (*f*)= number of crests/troughs passing through a fixed point/per unit time
  - Wavelength(λ) = c/f , where c is speed of light
  - As (*f*) increases λ decreases

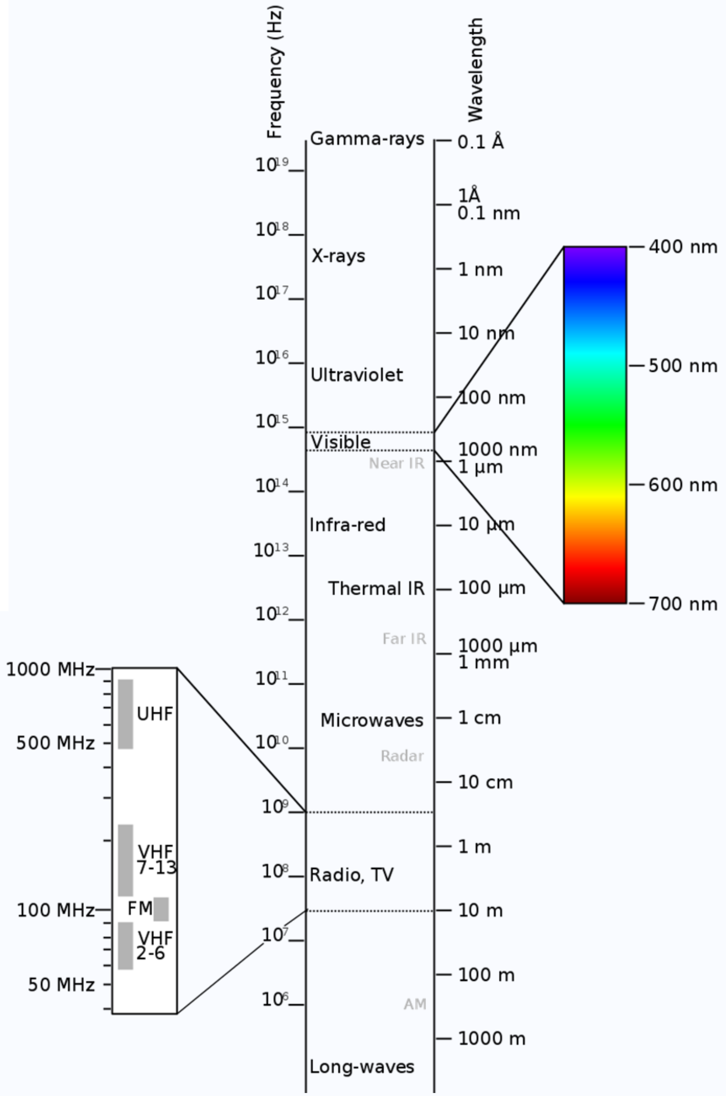


Sources of EMR and the Electromagnetic Spectrum

- All matter > O K (~ -273° C) emit radiation (due to vibration of atoms) at different magnitudes and compositions of λ (Electromagnetic Spectrum)







- Visible part - very small part
  - from visible blue (shorter λ)
  - to visible red (longer λ)
  - ~0.4 to ~0.7µm

Violet: 0.4 - 0.446 µm
Blue: 0.446 - 0.500 µm
Green: 0.500 - 0.578 µm
Yellow: 0.578 - 0.592 µm
Orange: 0.592 - 0.620 µm
Red: 0.620 - 0.7 µm

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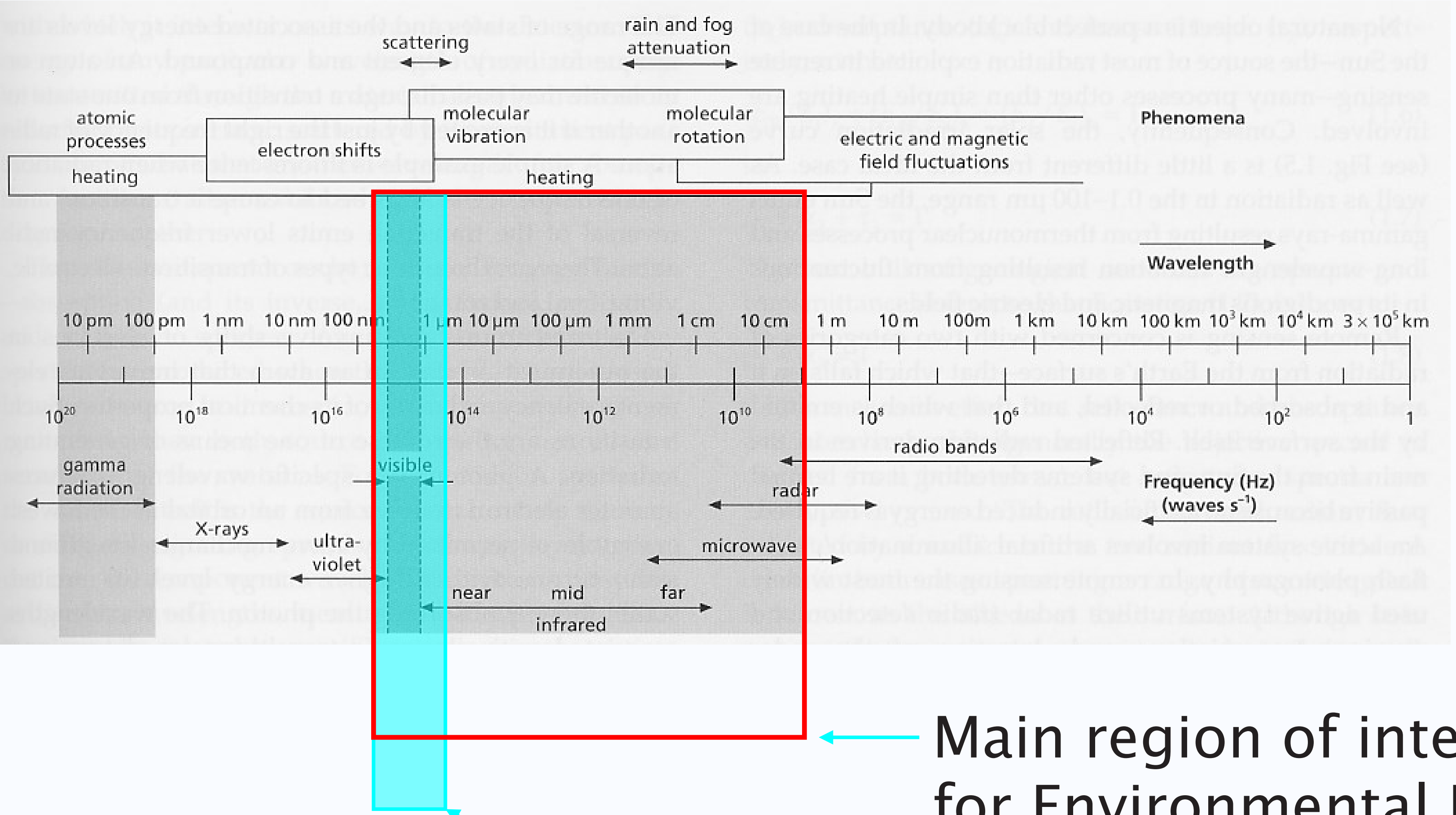
The Electromagnetic Spectrum

Environmental remote sensing



Main region of interest for Environmental RS

Optical region : 0.35 - 2.50μm

Remote Sensing Process- EMR Interference

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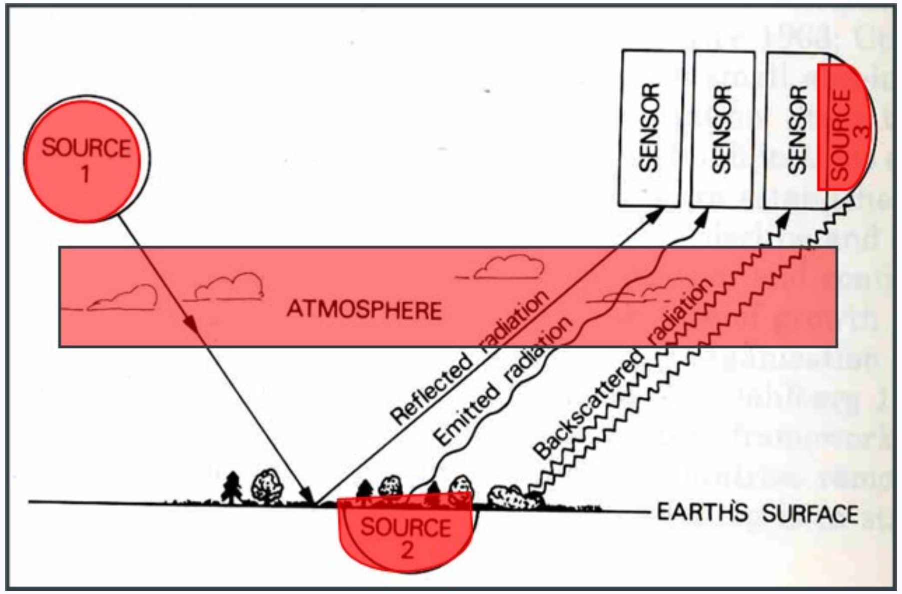
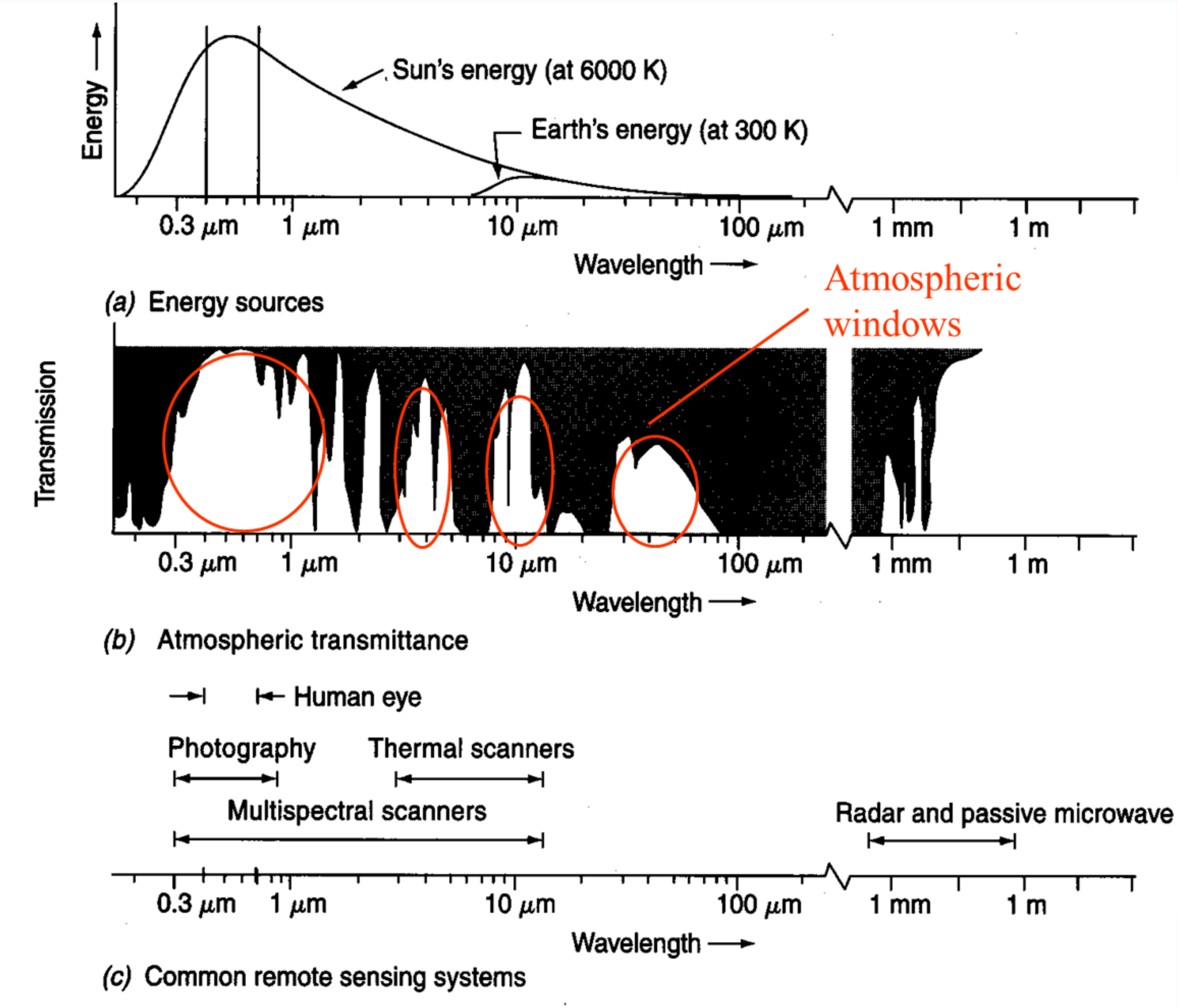
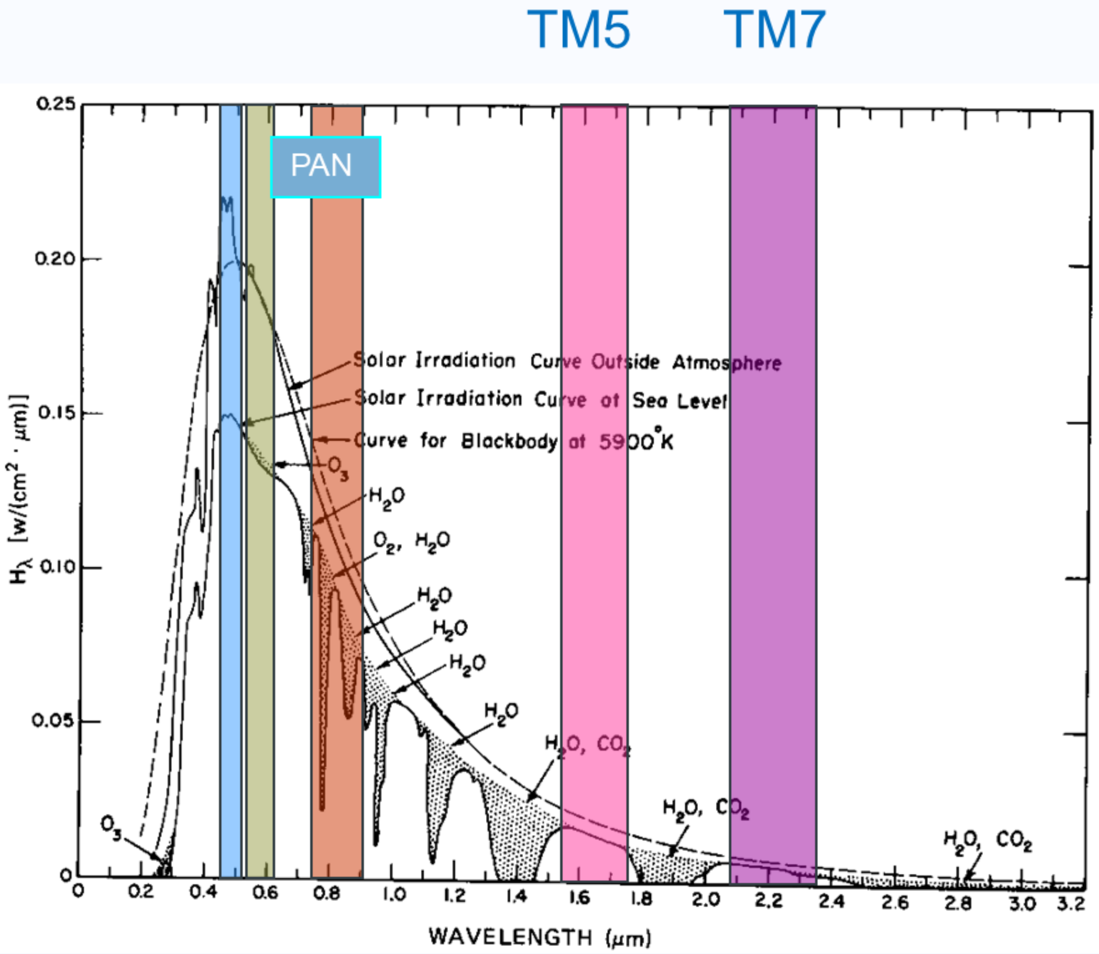
Radiation passing through a media-Atmosphere

- All radiation passes through the atmosphere which can result in:
    - Scattering, absorption, reflected, refracted
- This alter the radiation's
    - Speed, Frequency, Intensity, Direction
- Wavelength dependent
    - Mainly affects visible and infrared wavelengths (i.e. short wavelengths)
    - Minor effect on microwave wavelengths (>1mm in length)



Atmospheric windows (Important in Optical RS)

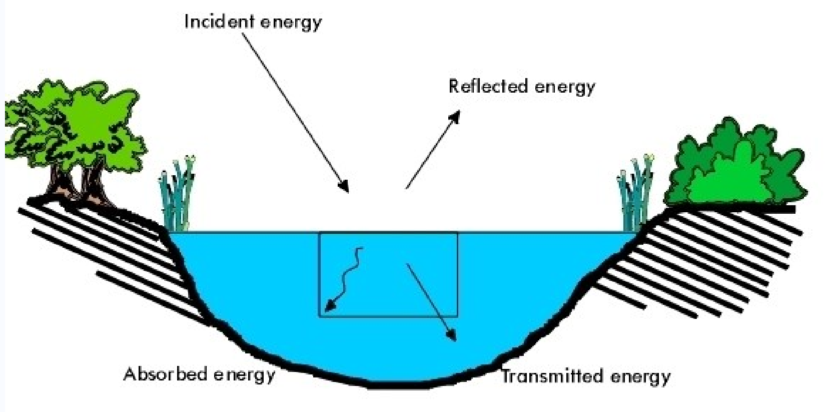




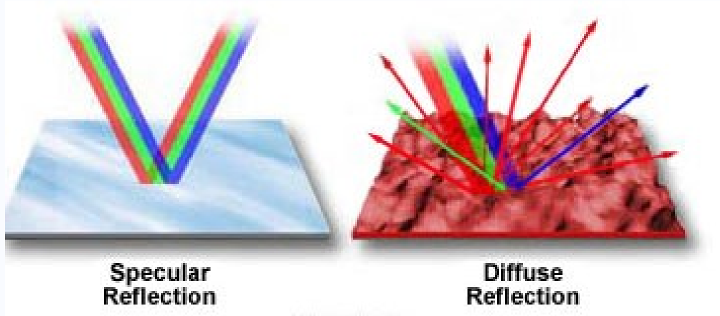
EMR Interaction with the Earth's Surface

Depends on:

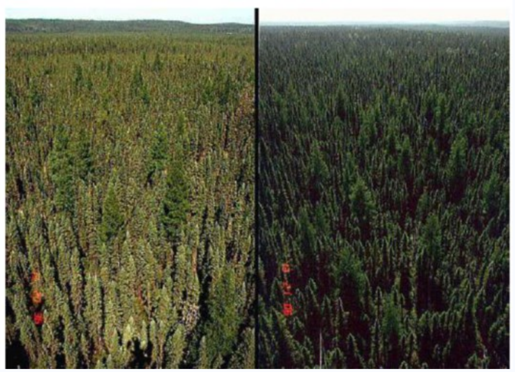
1. Material type (*e.g. vegetation, soil, water, metal*) and their characteristics



2. Nature of the surface
   - Specular — Smooth (minimal interaction)
   - Diffuse — Rough



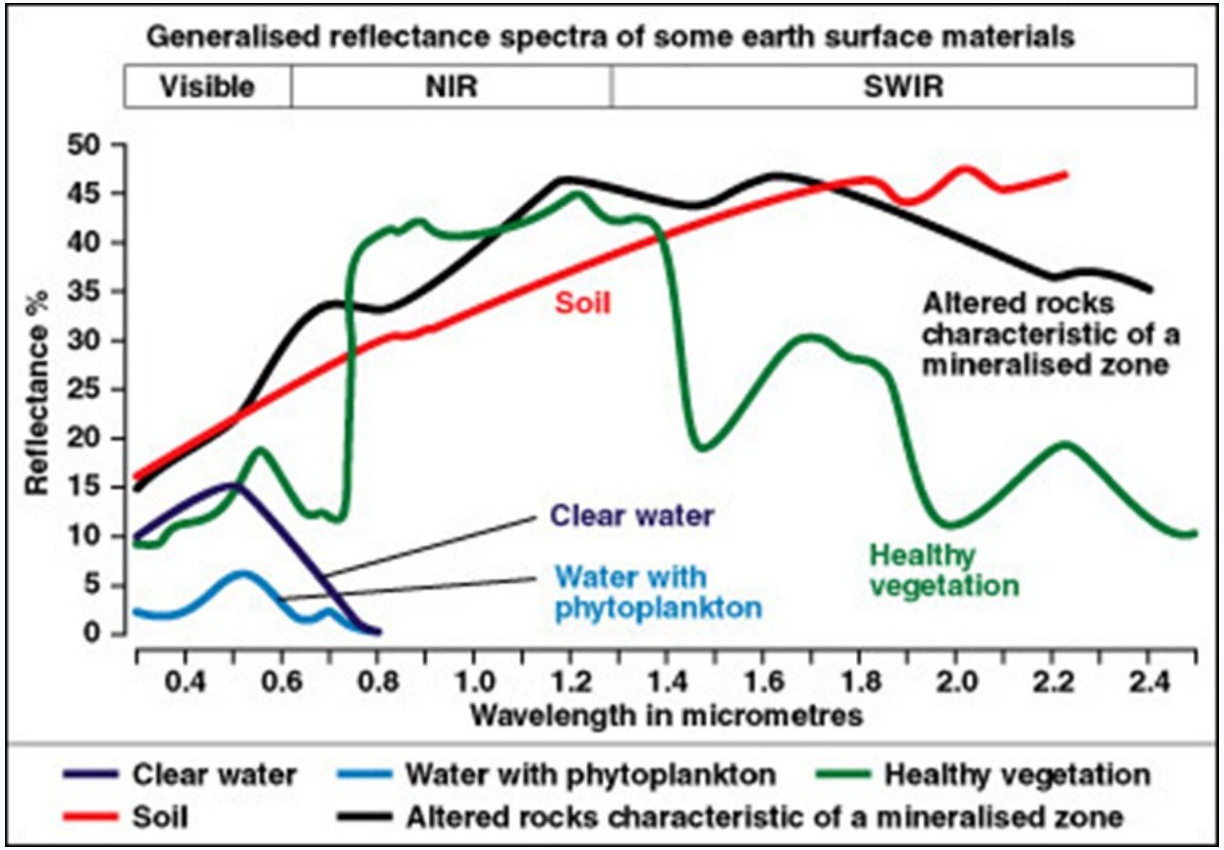
3. Spectral wavelength (Visible, NIR, SWIR, Microwave)



4. Other factors (e.g. time of the day, view/illumination angle, slope)

Reflectance properties of Earth surface features

- Three key features/material on the Earth's Surface in RS
  - Vegetation
  - Soil
  - Water

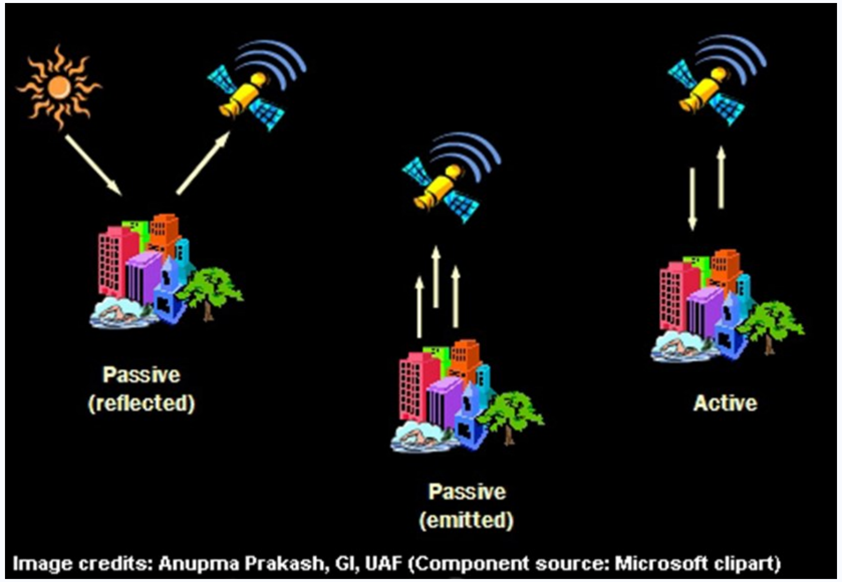


- Every material has a *'unique signature'* , providing insight into the material - Signature not 'constant'

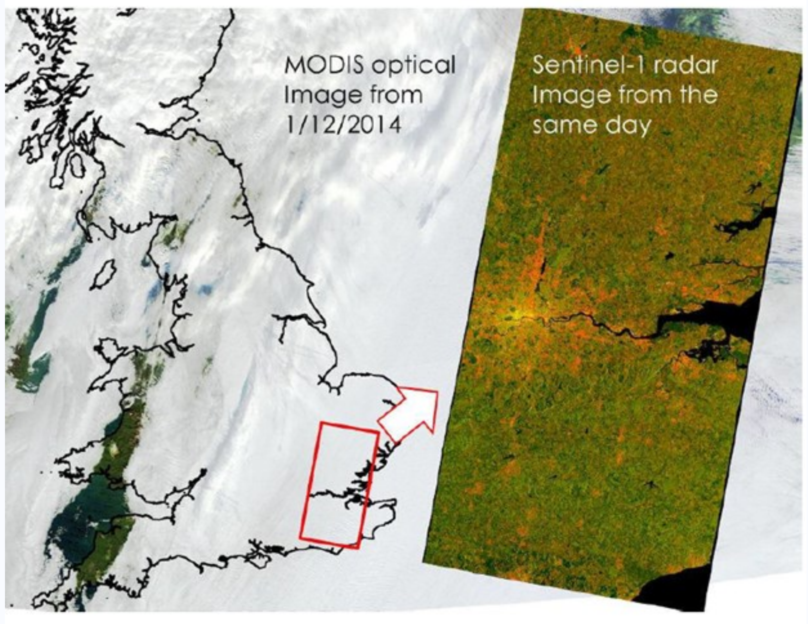
- Important in the choice of wavebands used for specific applications

Types of Remote Sensing Systems

1. Passive Systems
   a. Naturally occurring energy
   b. If sun ,can only collect data during the day
   c. Most Optical RS systems (Landsat series, Sentinel-2, 3)



2. Active Systems
   a. Own energy
   b. Measurement anytime
   c. LIDAR (Green,NIR) – (Two-way time of flight)
   d. RADAR – Microwave spectrum- (Records amplitude and phase of waves backscatter)- (minimal cloud interference) (e.g., Sentinel-1)



Remote Sensing Data Characteristics

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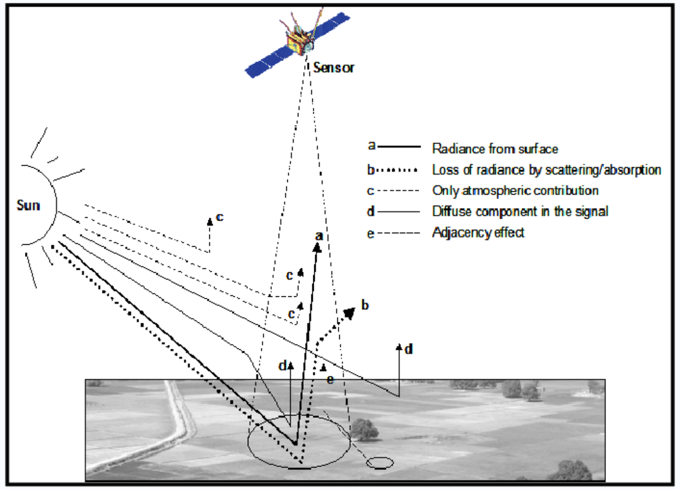
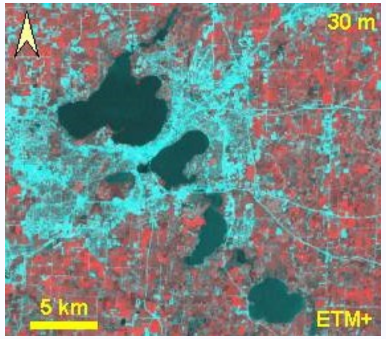
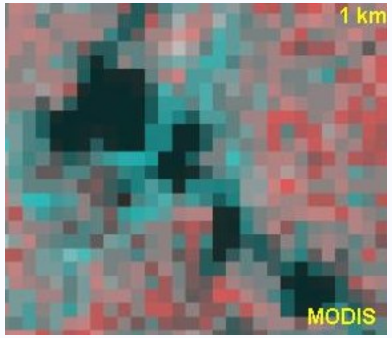
Spatial Characteristics

- Describes the instantaneous ground sampled by the sensor
- Mainly determined by the IFOV and altitude of the sensor
    - B = CA
        - B= diameter of ground sampling element (m)
        - C= flying height of the sensor (m)
        - A=IFOV(radians)
- High resolution(finer detail), Low resolution(less detail)

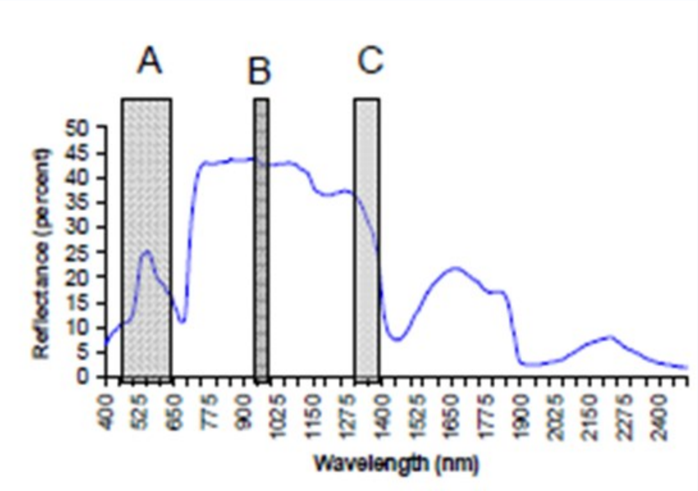






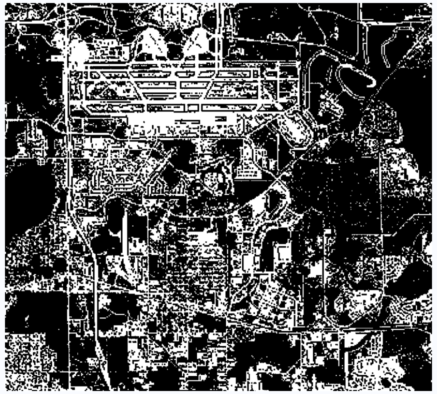
Spectral characteristics

- The number, dimension, and location of specific wavebands of the EMR that a sensor is capable of measuring
- Most sensors observe in many bands
    - **Panchromatic** (wide band e.g. entire visible parts)
    - **Multi-spectral** (several bands - Examples: Landsat, Sentinel 2, Sentinel 3)
    - **Hyperspectral** (100's of contiguous bands- Examples: EnMap, PRISMA, DESIS)

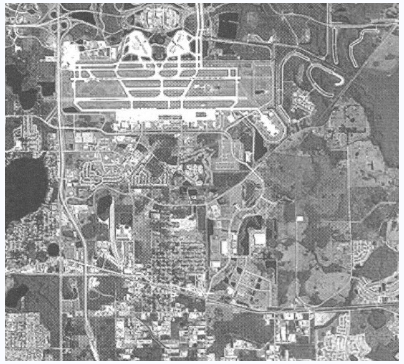


Radiometric characteristics

- The number of unique values that can be recorded by a sensor when measuring reflected or emitted EMR
- Quantified as integer (e.g., 256, 4096, etc.) and expressed in *bits*
- The higher the radiometric resolution, the better the quality of data-closer to the sample signal



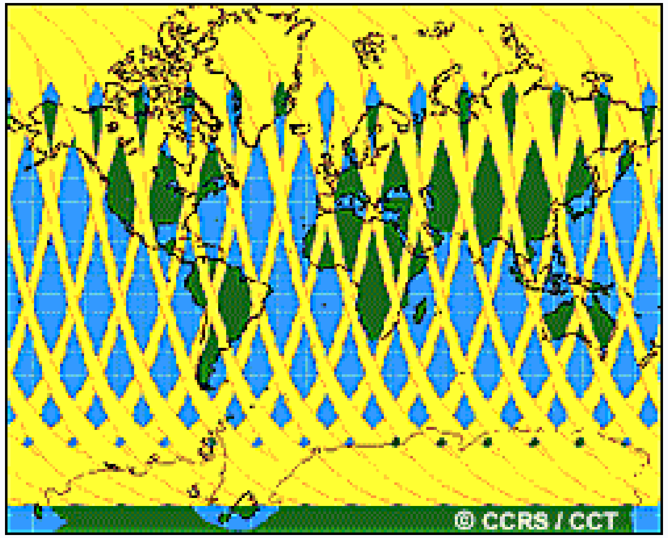
2 grey levels



256 grey levels

Temporal characteristics

- Time before the satellite passes back over the same spot on the Earth's surface.
- This is usually defined in days (e.g., Landsat 8/9 = 16 days)
- As spatial resolution ↑, temporal resolution ↓
- Can be increased by looking off-nadir and through use of constellations (e.g., Planet Labs, Sentinel missions)



Key EO programmes for environmental applications(Public)

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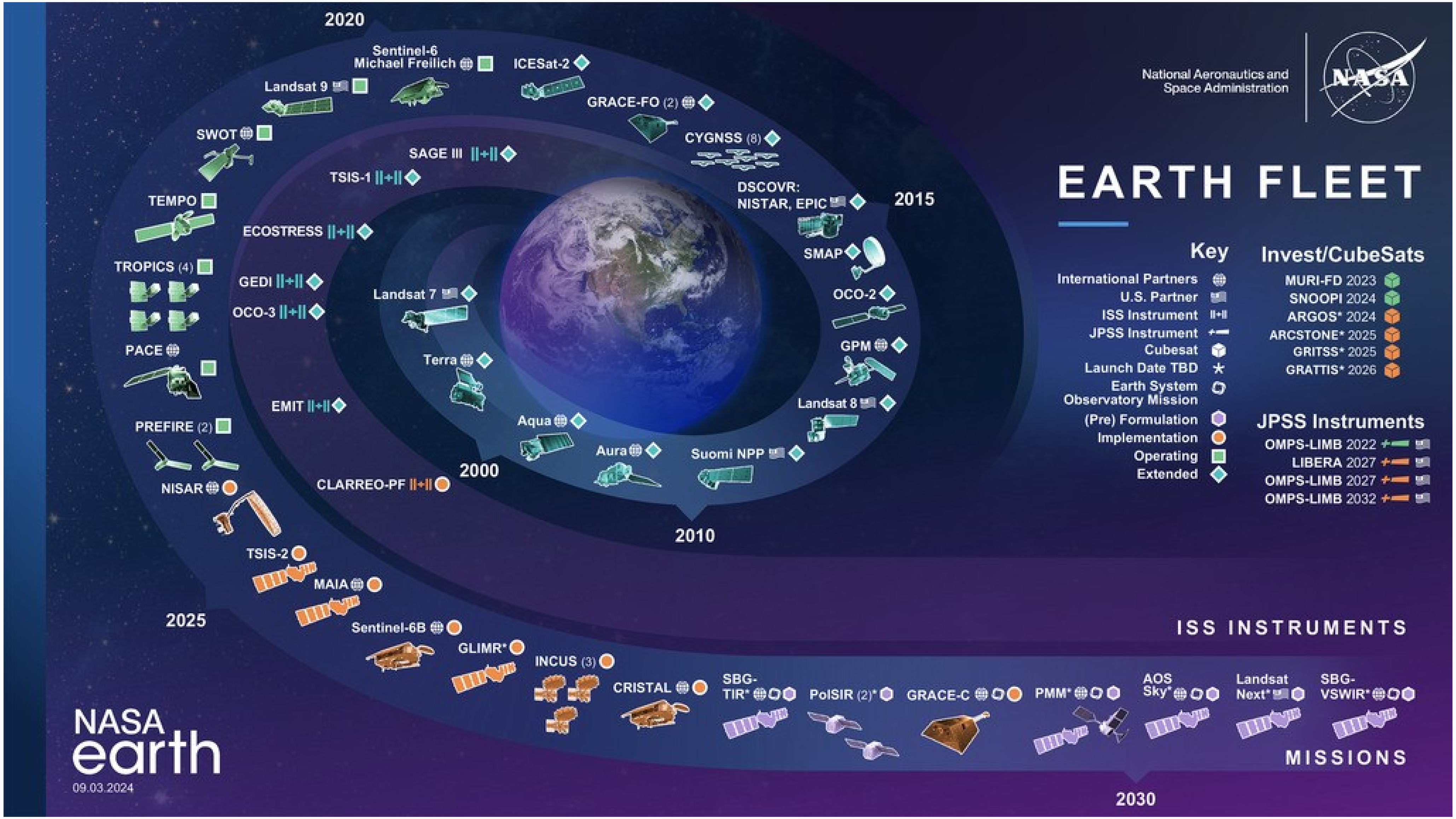
NASA Earth Science Missions

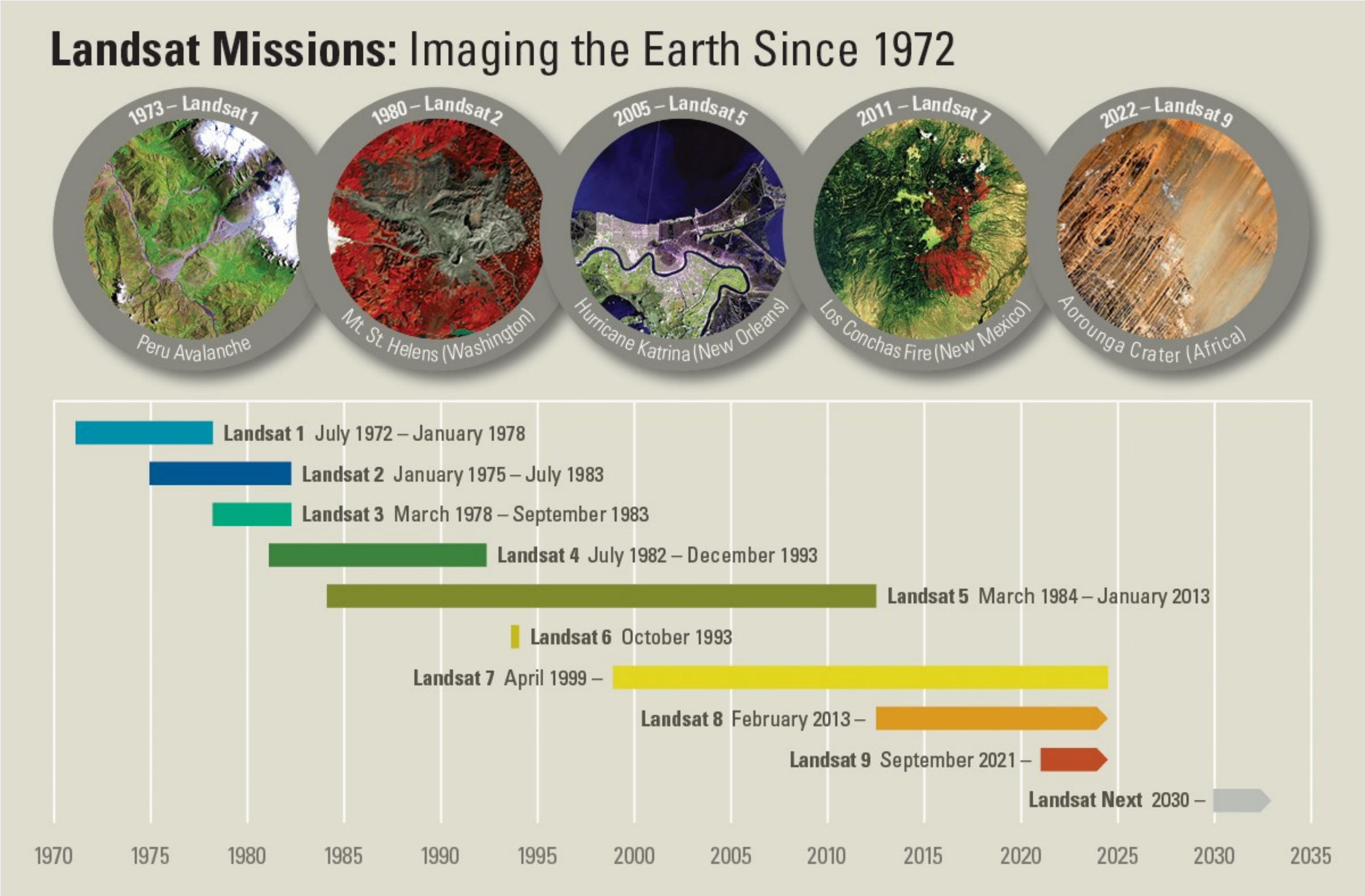


Source: https://svs.gsfc.nasa.gov/30065

Key EO programmes for environmental applications (Public)

The Landsat Program

- World's longest continuously acquired collection of space-based land remote sensing data. Managed by NASA and USGS

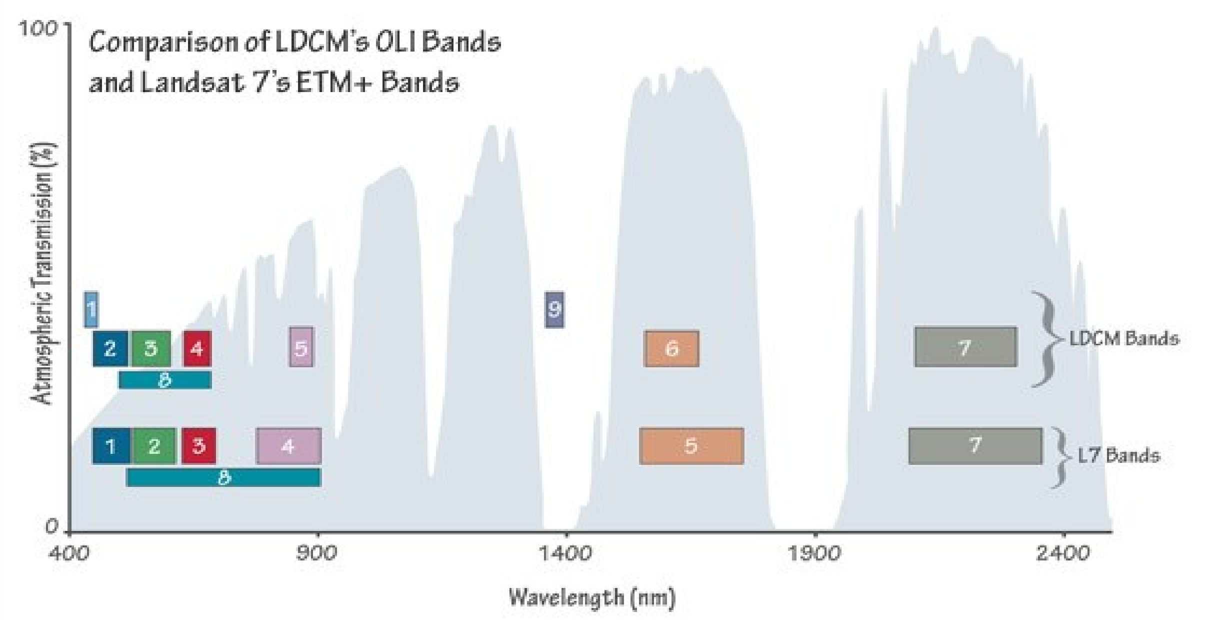


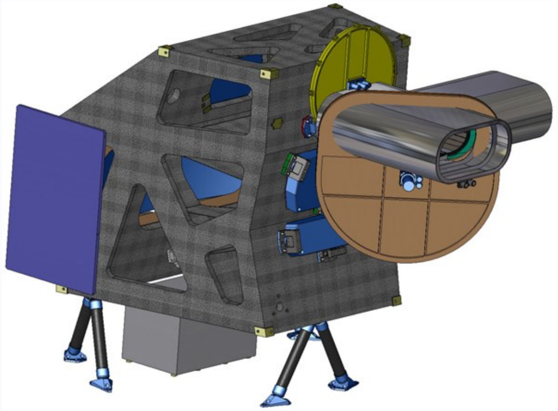
Source: https://www.usgs.gov/media/images/landsat-missions-timeline

Key EO programmes for environmental applications (Public)

The Landsat Data Continuity Mission-Landsat 8

- Launched on 11th Feb 2013
- Two instruments : Operational Land Imager (OLI) and the Thermal Infra-Red Sensor (TIRS).
- OLI-9 spectral bands and 30m spatial resolution (15m panchromatic), 2-TIR bands (100m and resampled to 30m)
- Pushbroom sensor, improved SNR, refined bandwidths, 12 bits (4096)

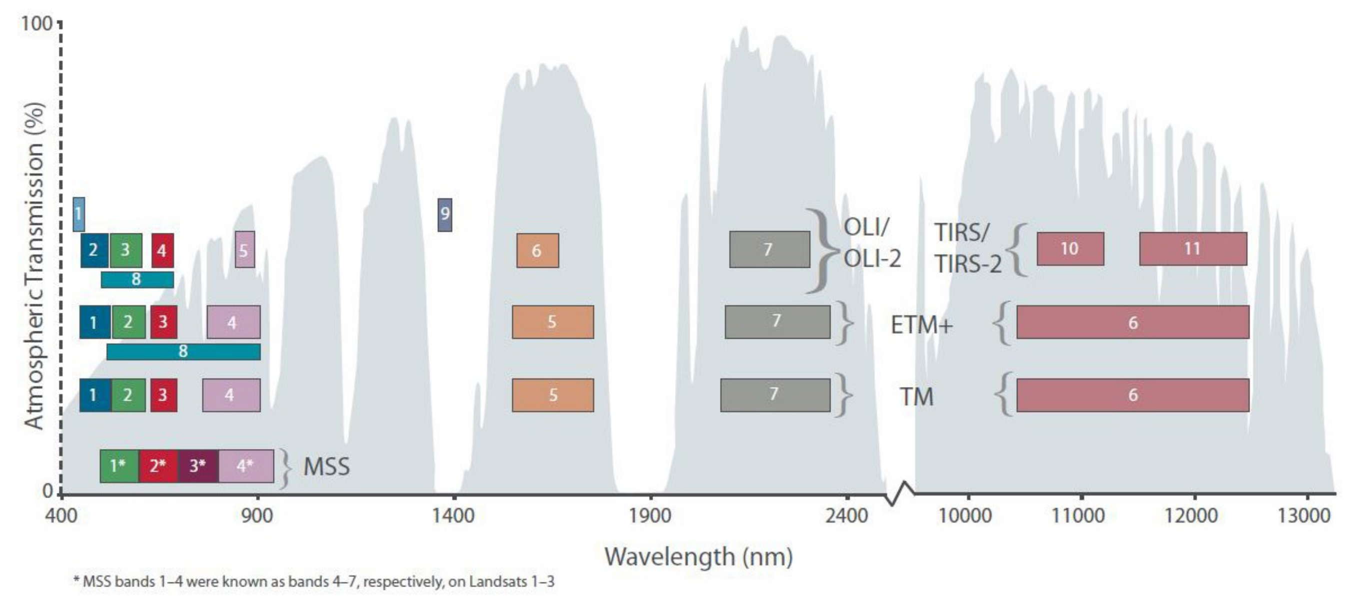




Key EO programmes for environmental applications(Public)

The Landsat 9 Mission

- Launched on 27th Sept 2021
- Operational Land Imager 2 (OLI-2) and the Thermal Infra-Red Sensor 2 (TIRS-2).
- Higher radiometric quantization for OLI-2 14 bit (16,384) compared to 12 bit (4096) for Landsat 8
- 9-OLI spectral bands and 30m spatial resolution(panchromatic band-15 m), 2-TIR bands

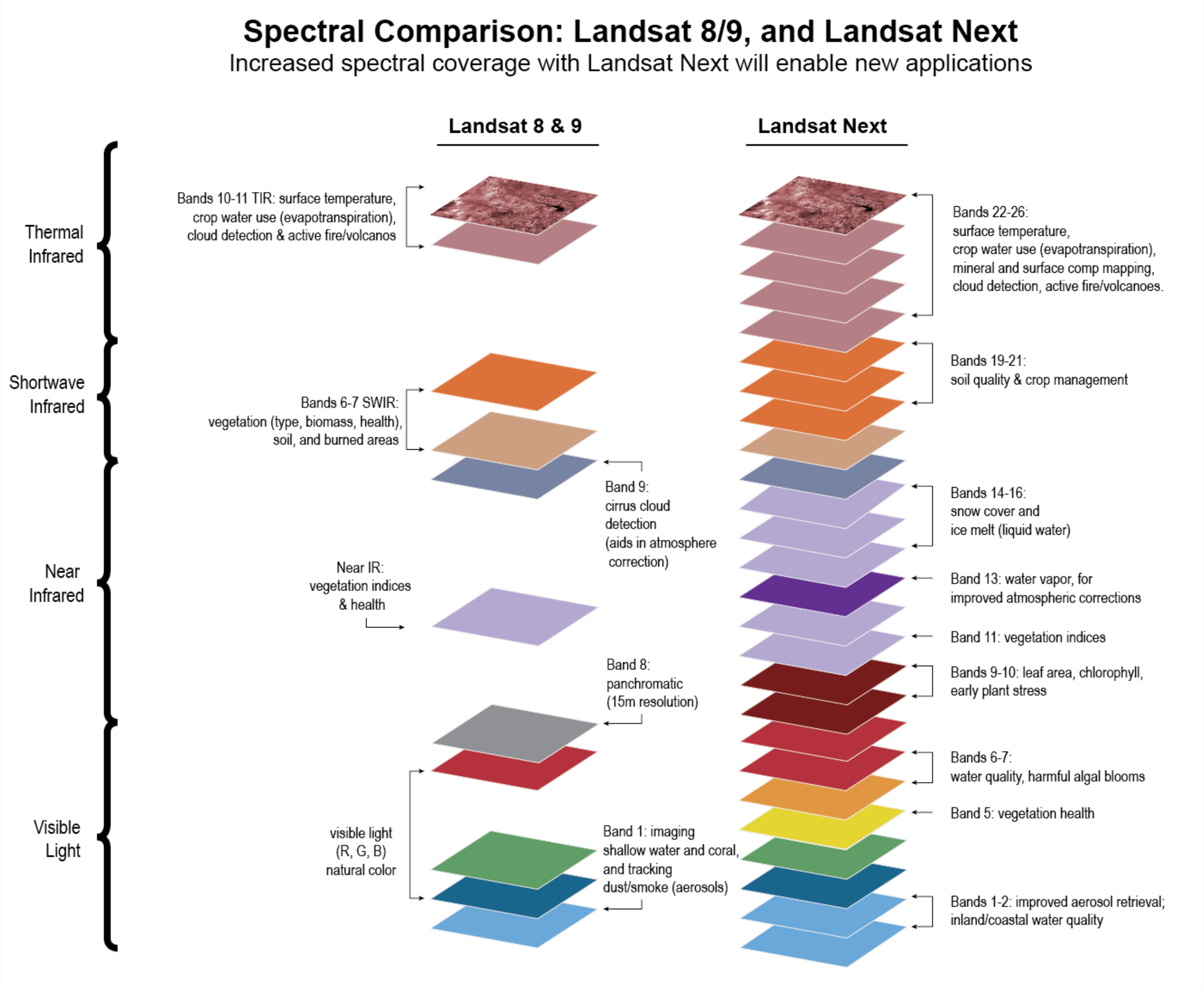


https://www.usgs.gov/landsat-missions/landsat-9#multimedia

Key EO programmes for environmental applications(Public)

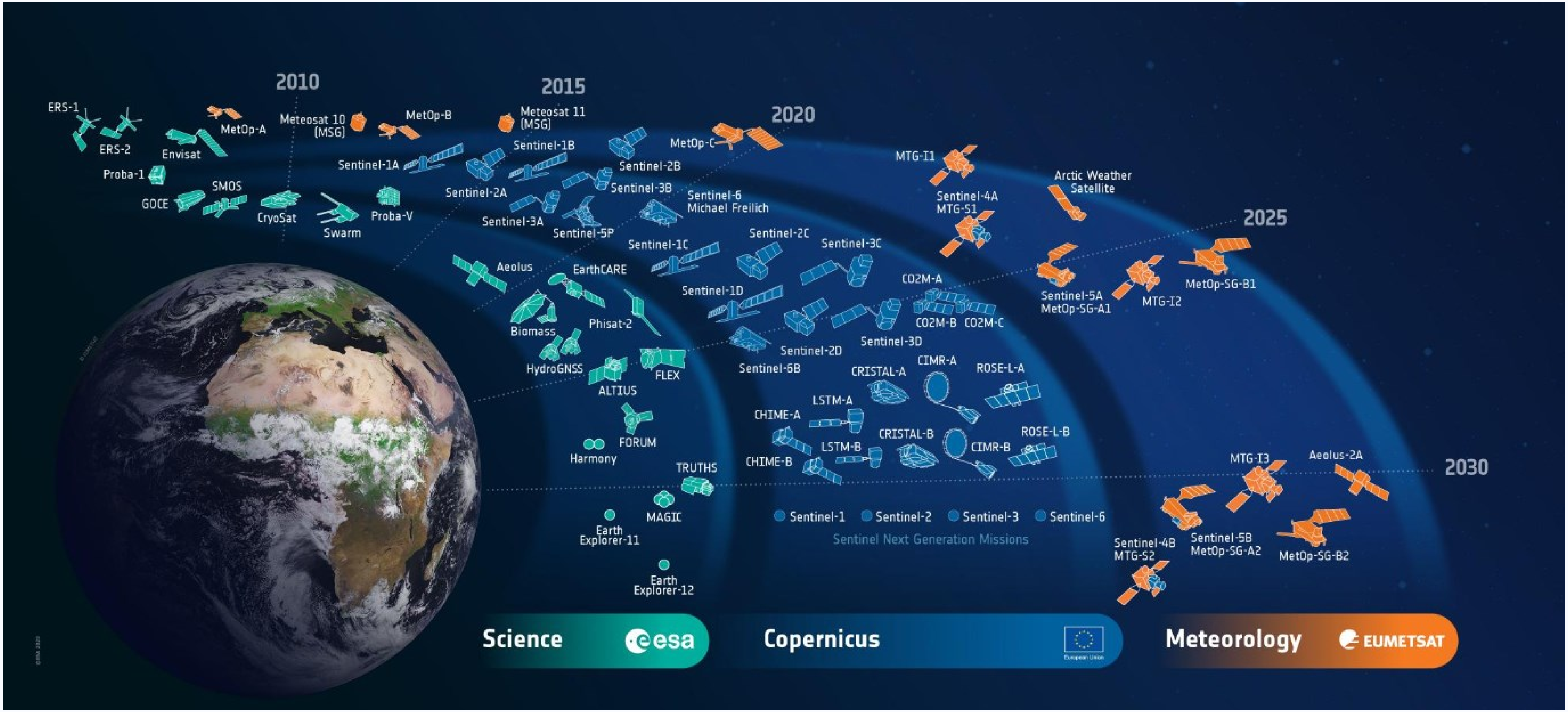
Future - The Landsat Next

- Constellation of three observatories
- 26-band "superspectral"
- Similarity in spectral/spatial resolution to Sentinel-2 mission
- Launch - 2030's



https://landsat.gsfc.nasa.gov/satellites/landsat-next/

European Space Agency (ESA)/EC Earth Missions



https://www.esa.int/ESA_Multimedia/Images/2019/05/ESA-developed_Earth_observation_missions

ESA/EC Copernicus Programme-Sentinel Missions

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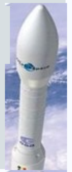
Sentinel 1 – C-Band SAR imaging
All weather, day/night applications, interferometry

2014 (A), 2015+ (B)

Sentinel 2 – Multispectral Imaging
Land applications: urban, forest, agriculture,..
Continuity of Landsat, SPOT

2015 (A), 2016+ (B)

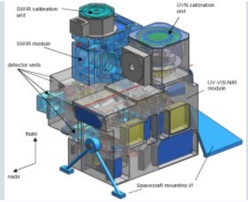


Sentinel 3 – Ocean and Global Land Monitoring
Wide-swath ocean colour, vegetation, sea/land surface temperature, altimetry

2016(A), 2017 (B)

Sentinel 4 – Geostationary atmospheric
Atmospheric composition monitoring, trans-boundary pollution

2018



Sentinel 5 and Precursor – Low-orbit atmospheric
Atmospheric composition monitoring

2016 (5P), 2019

Sentinel 6 – Radar Altimeter
Ocean topography

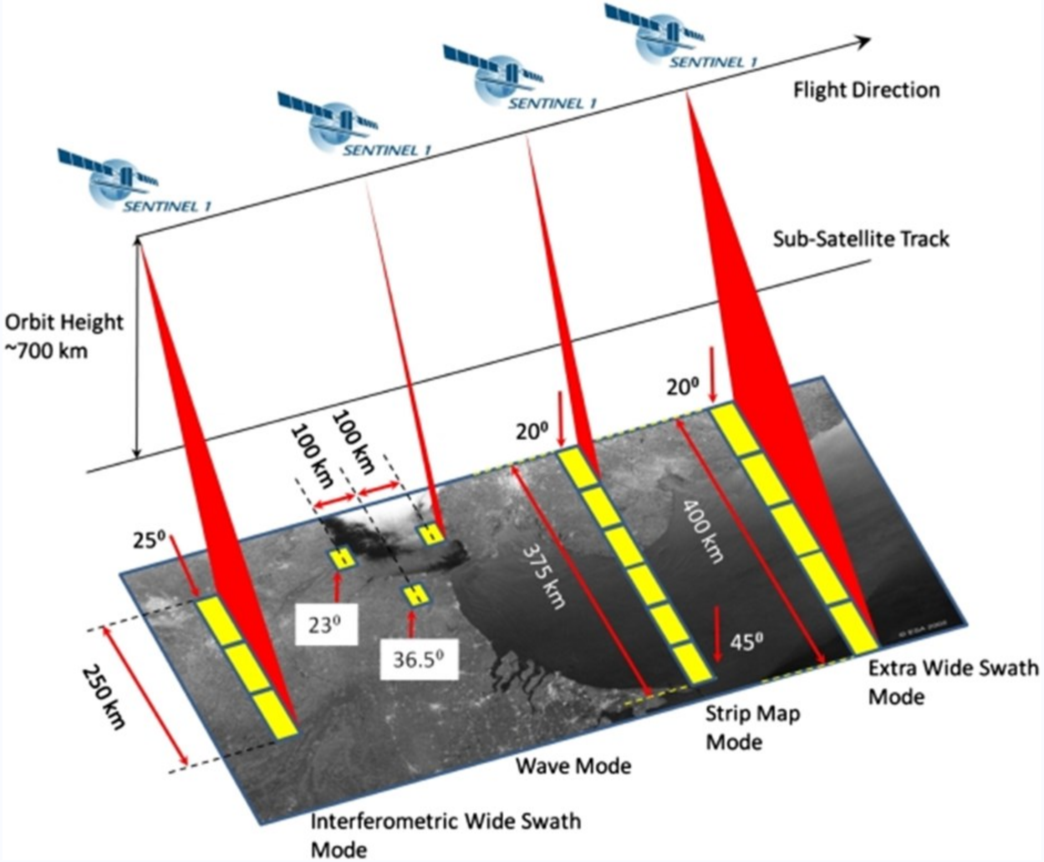
2020

http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4

ESA Copernicus Programme-Sentinel Missions

Sentinel 1A and 1B- RADAR

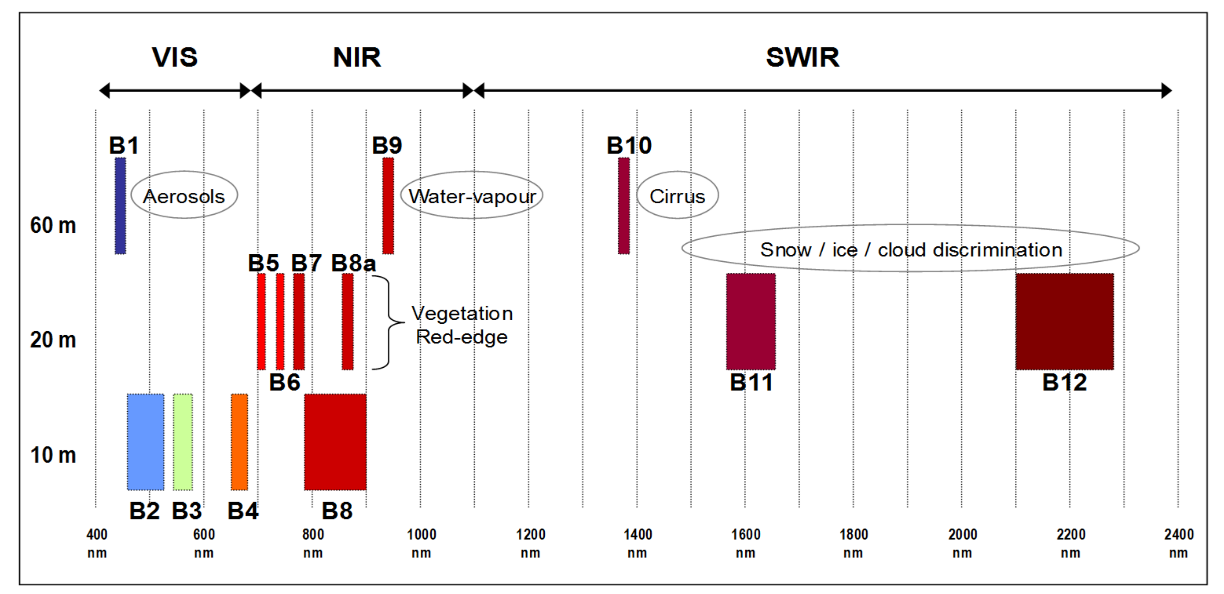
- S-1A launched April 2014 and S-1B launched in April 2016 (Failed in 2021)
- C-SAR (C-band Synthetic Aperture Radar)
- Resolution and Swath Width (Four modes):
  - Strip Map Mode: 80 km Swath, 5 x 5 m spatial resolution
  - Interferometric Wide Swath: 250 km Swath, 5x20 m spatial resolution
  - Extra-Wide Swath Mode: 400 km Swath, 25 x 100 m spatial resolution
  - Wave-Mode: 20 km x 20 km, 5 x 20m spatial resolution



ESA Copernicus Programme-Sentinel Missions

Sentinel 2 : Multispectral Optical Mission

- Multispectral Instrument: Pushbroom with 13 bands in the visible, near infra-red (VNIR) and short wave infra-red (SWIR) part of the spectrum
  - High spatial resolution: 10m, 20m and 60m;
  - Wide field of view: 290 km
  - Revisit: **5 days** at equator (with 2 satellites) under same viewing conditions
- Sentinel 2-C –launched 5th September 2024



Sierra Leone River Estuary:
Credit: ESA

ESA Copernicus Sentinel Expansion Missions

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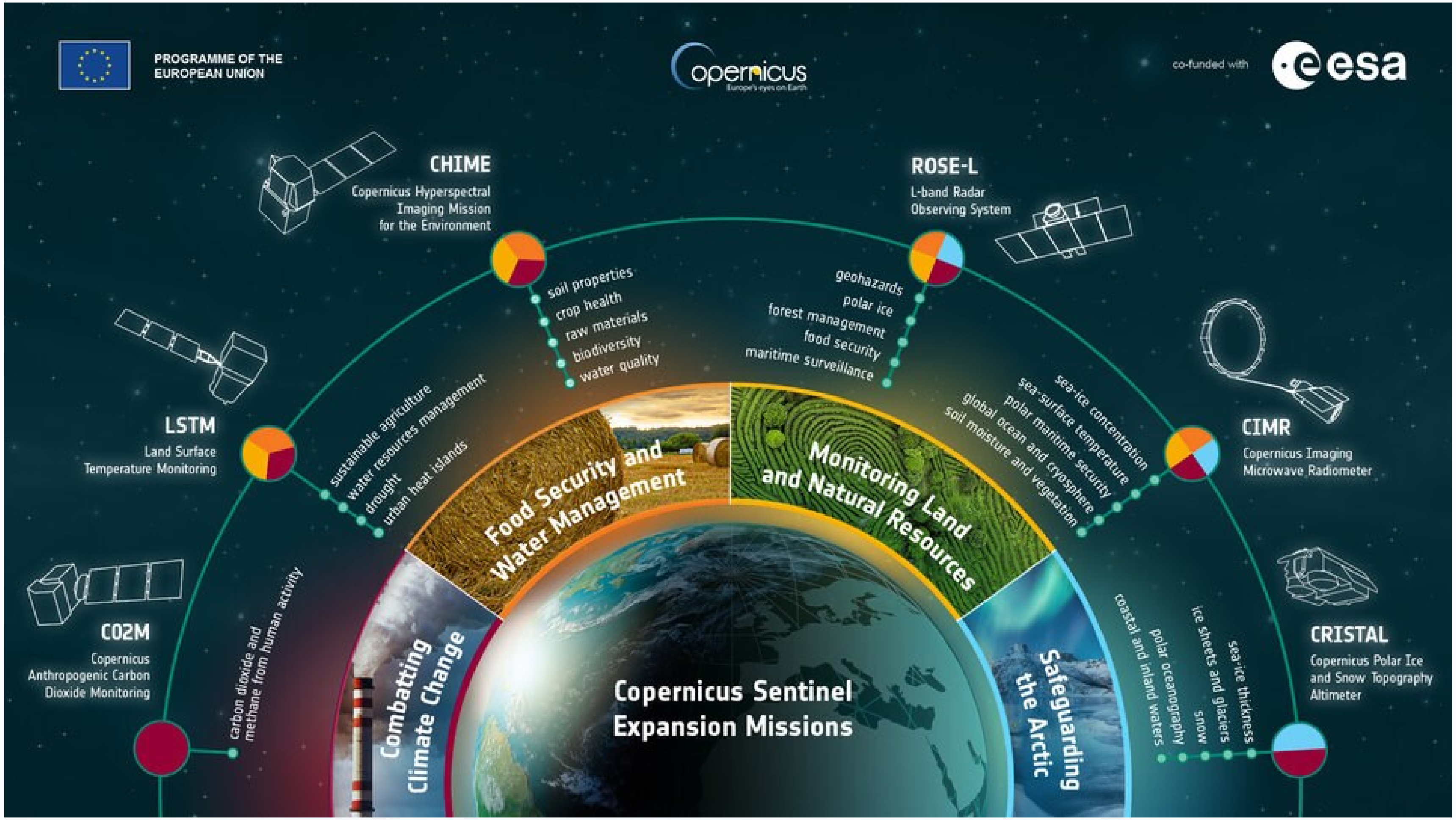
- ❑ Intended to expand the current capabilities of the Copernicus Space Component.



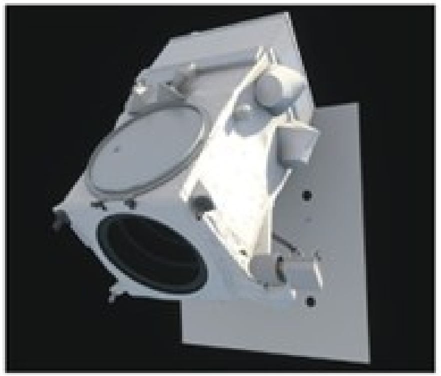
https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_Sentinel_Expansion_missions

- ❑ Science mission: Φsat-2 – Designed to demonstrate how different Artificial Intelligence technologies can advance observing Earth from space

https://www.esa.int/Applications/Observing_the_Earth/Phsat-2

EO programmes for environmental applications(Commercial)

1. **Planet** (https://www.planet.com/)- Constellation of CubeSats
   - ❑ Monitoring, Tasking, Analytic feeds, Hyperspectral data, Basemaps
2. **MAXAR:** https://www.maxar.com/
   - ❑ WorldView-1, 2,3, World-View Legion, GEOEYE-1,
3. **Airbus** (https://www.airbus.com/en/space/earth-observation/satellite-imagery) (Pléiades Neo, Pléiades, SPOT, DMC Constellation and Vision-1 optical satellites as well as the Radar Constellation (consisting of TerraSAR-X, TanDEM-X and PAZ).
4. **BLACKSKY** (https://www.blacksky.com/)
5. **Capella Space** https://www.blacksky.com/ (SAR data)
6. **ICEYE:** https://www.iceye.com/sar-data (SAR data)
7. **GHGSAT** (https://www.ghgsat.com/en/) CO_2/ Methane monitoring
8. Many more and expanding……



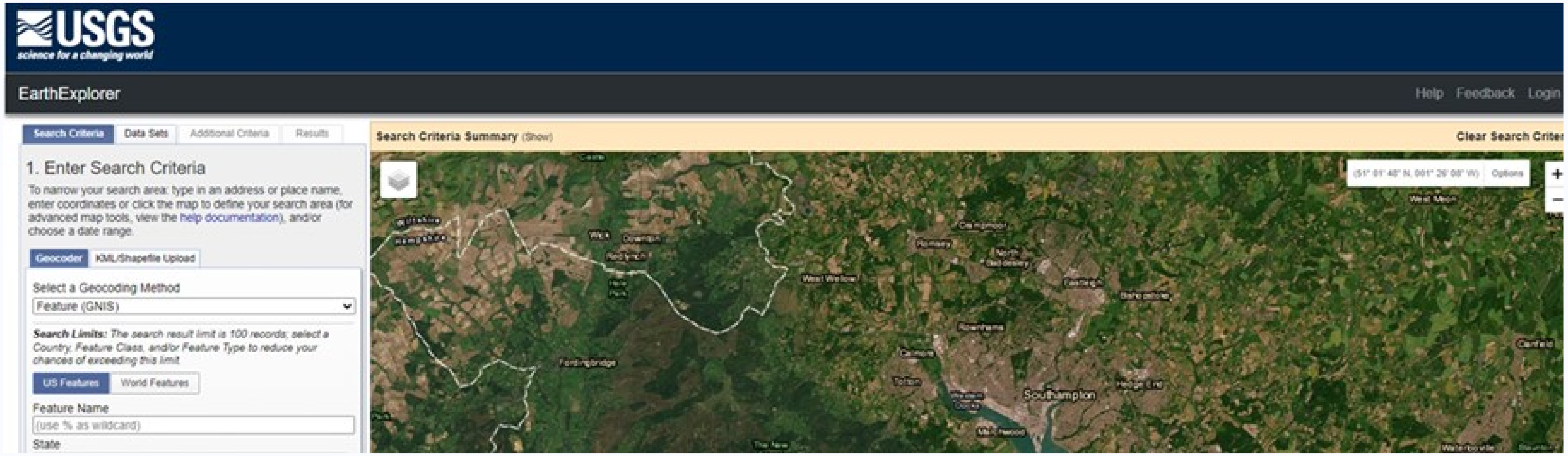
Artist's rendering of a WorldView Legion satellite

RS Data Portals

LP DAAC: https://lpdaac.usgs.gov/data/

- ❑ Land Processes Distributed Active Archive Center (LP DAAC)
- ❑ USGS and NASA partnership

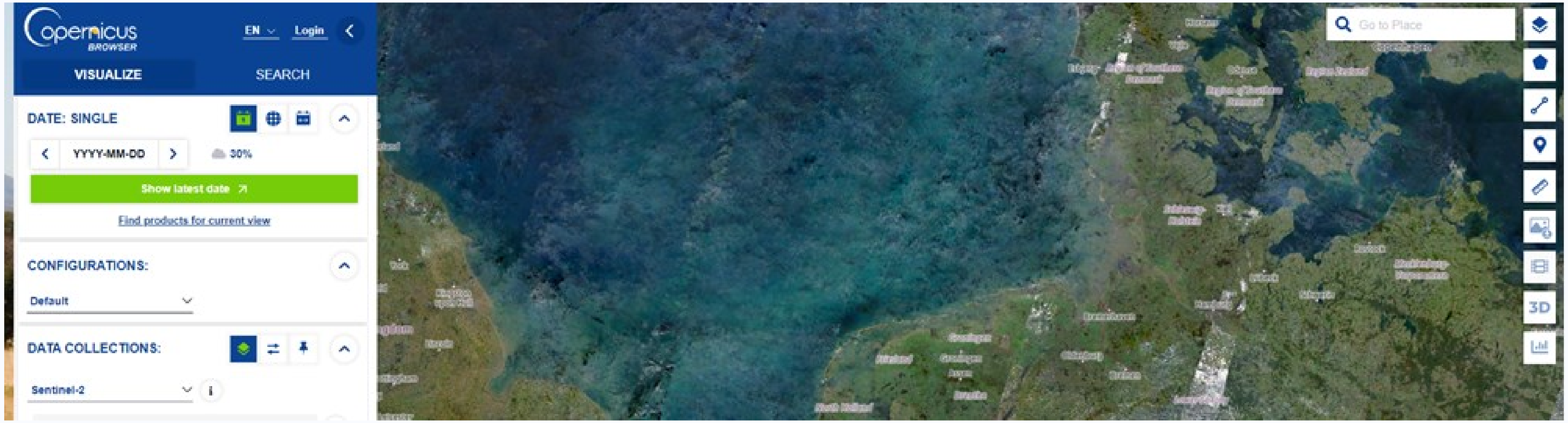
Earth Explorer: *https://earthexplorer.usgs.gov/*



RS Data Portals

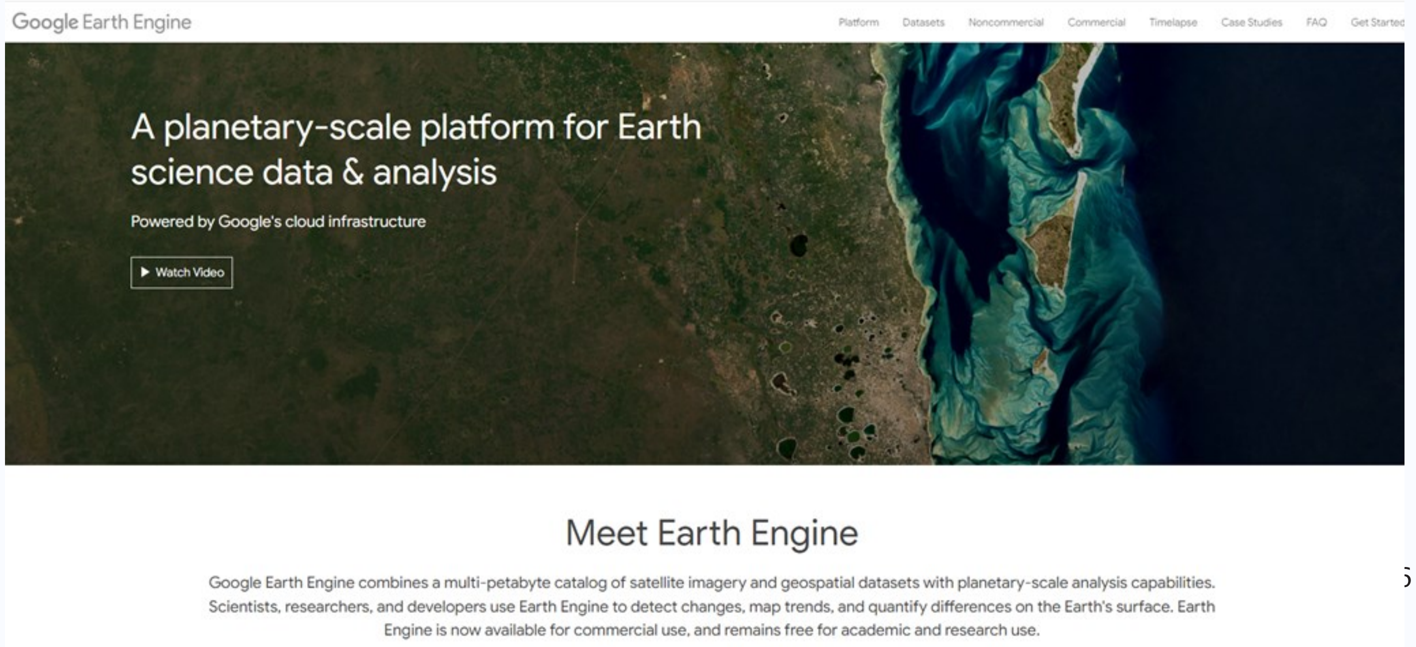
ESA Copernicus Data Space Ecosystem:

https://dataspace.copernicus.eu/



Google Earth Engine:

https://earthengine.google.com/



- Good review paper of EO data for environmental applications (2021):
  - *https://ecologicalprocesses.springeropen.com/articles/10.1186/s13717-020-00255-4*

Questions?