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6 Forest ecosystems and remote sensing

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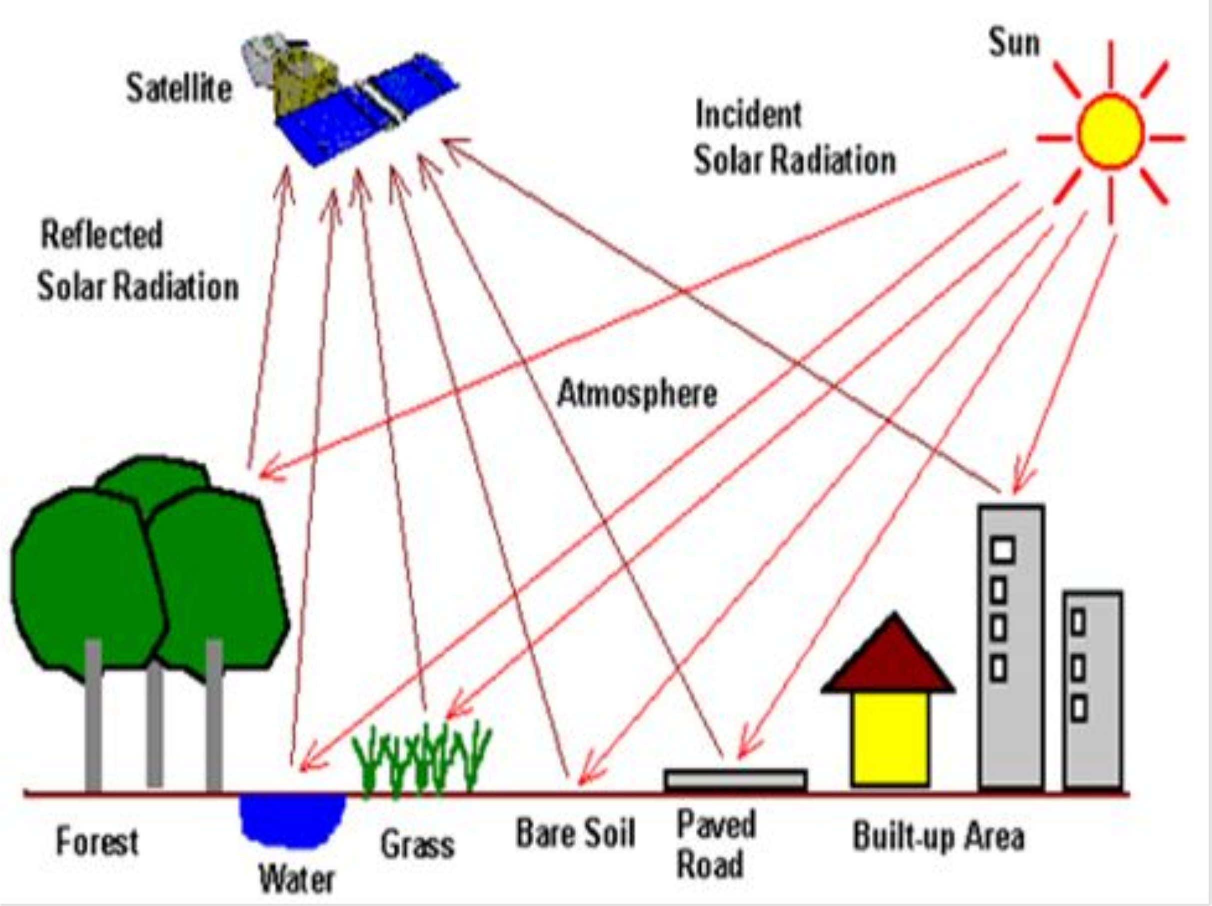
University of Botswana
INES Ruhengeri Institute of Applied Sciences

Recap

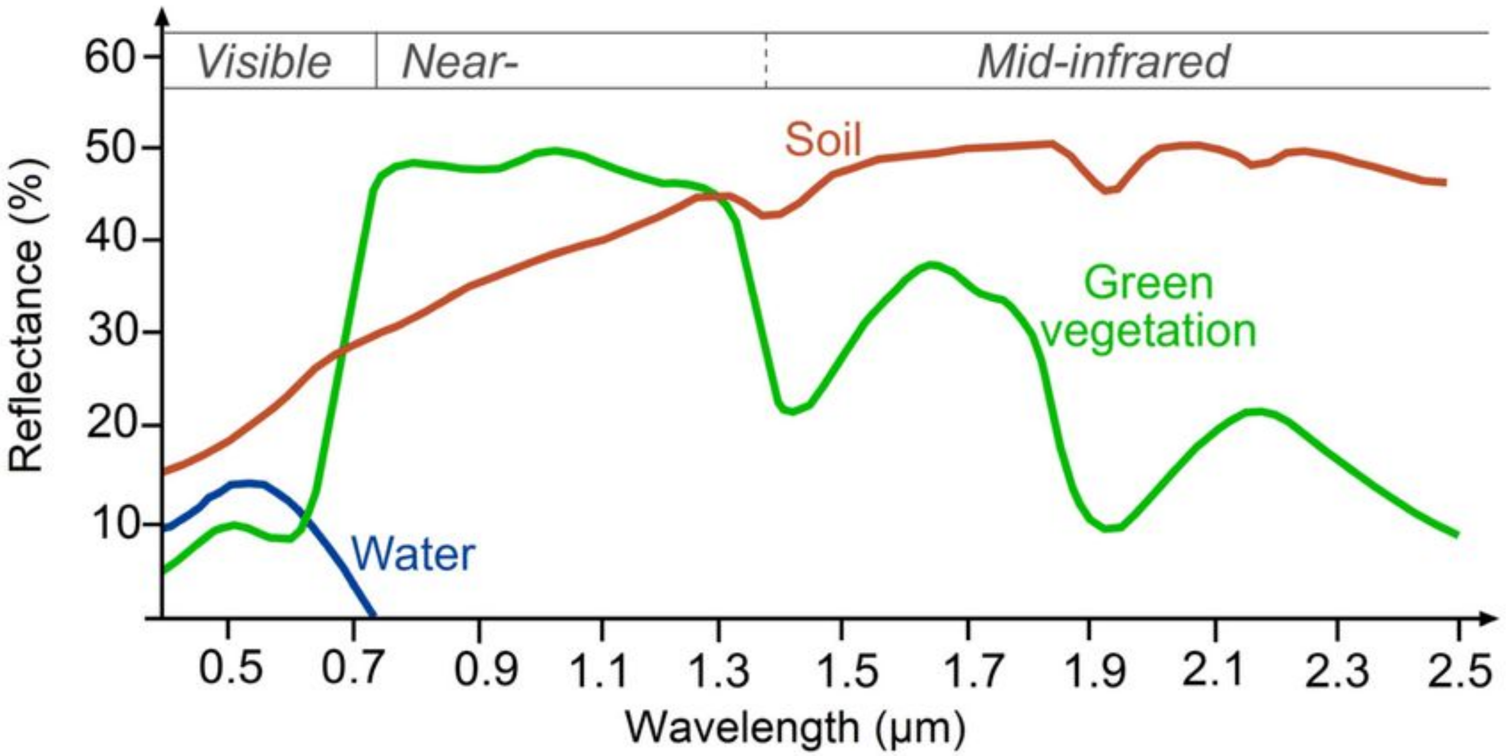
Characteristics of EM Radiation



- All objects with a temperature above zero **emit** electromagnetic radiation
- Objects **reflect** electromagnetic radiation emitted by other objects

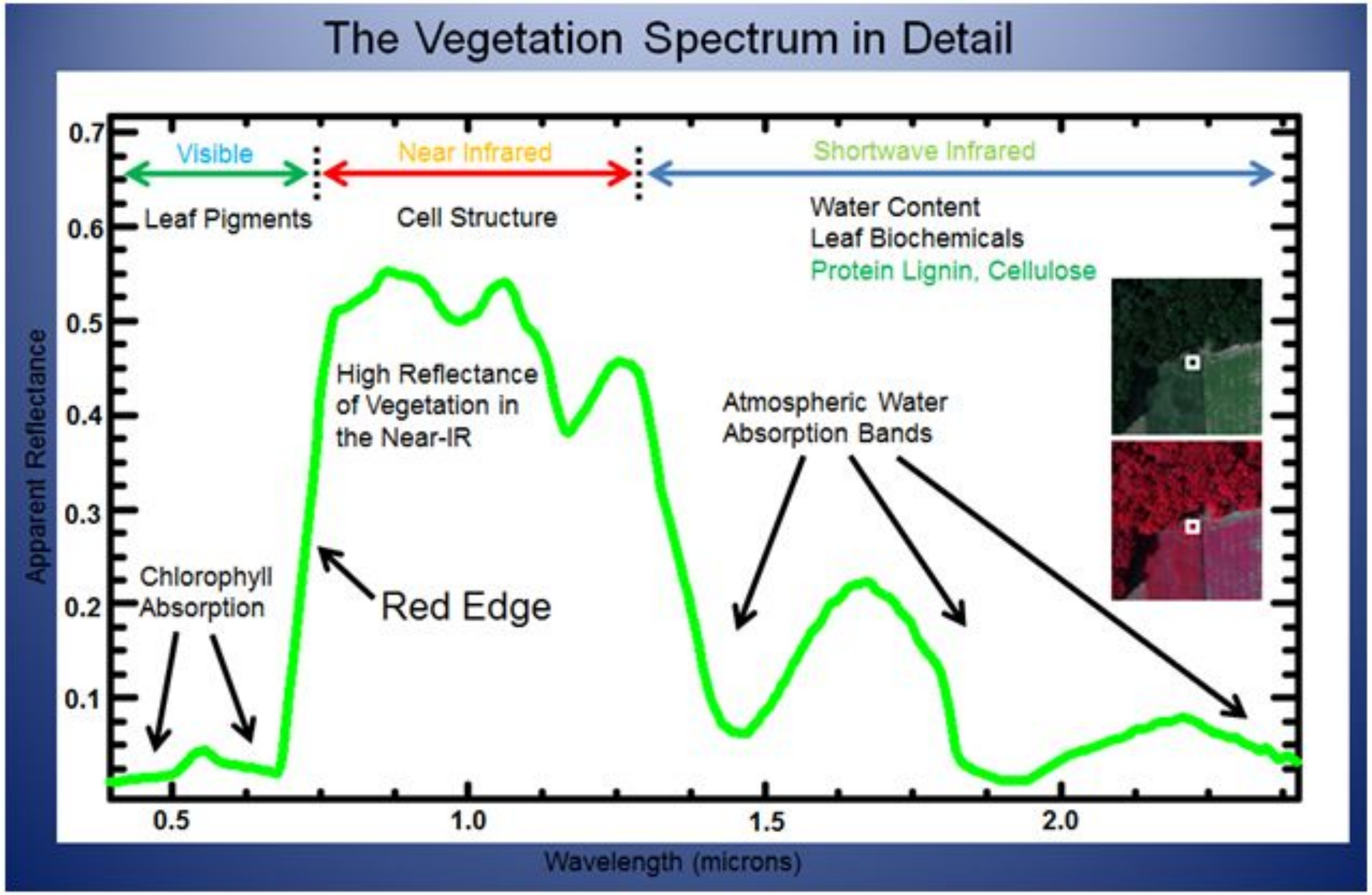
 Key basis of remote sensing because earth's surface materials reflect light in unique ways

Spectral Reflectance curves



- Different materials reflect and absorb different wavelengths of electromagnetic radiation.
- You can look at the reflected wavelengths detected by a sensor and determine the type of material it reflected from. This is known as a spectral signature.

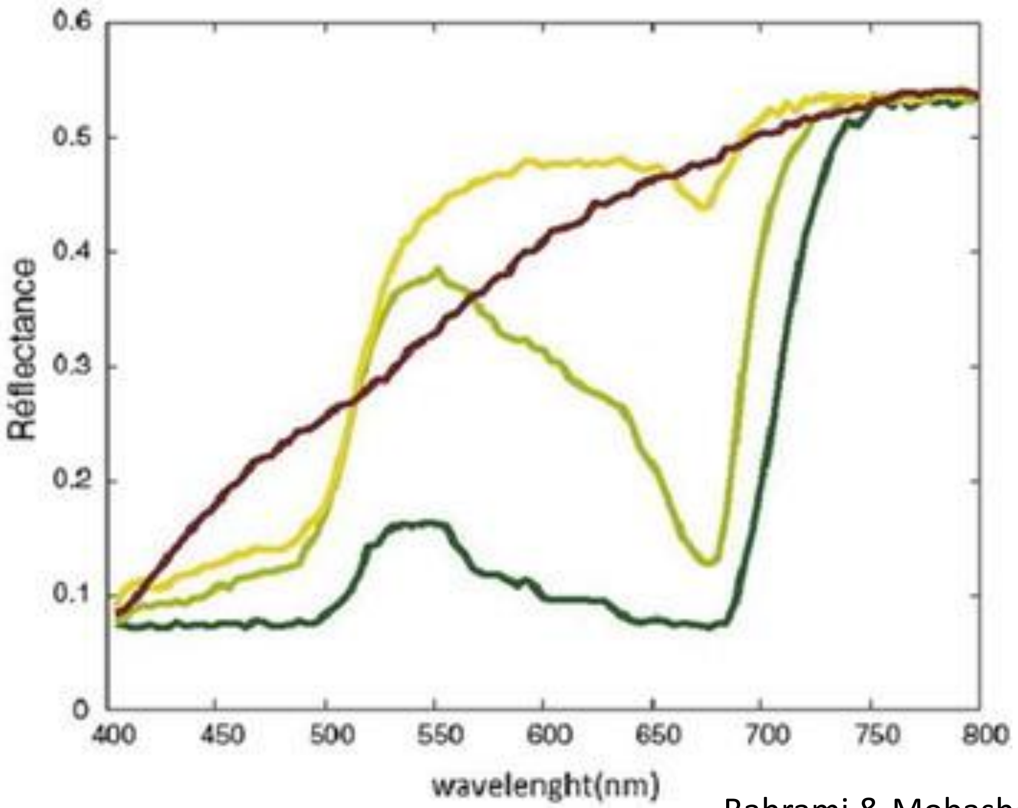
Spectral Reflectance curves - **Vegetation**



- Certain pigments in plant leaves strongly absorb wavelengths of visible (red) light.
- The leaves themselves strongly reflect wavelengths of near-infrared light, which is invisible to human eyes.
- As a plant canopy changes from early growth to late-season maturity and senescence, these reflectance properties also change.
- Since we can't see infrared radiation, we see healthy vegetation as green.

Spectral Reflectance curves - **Vegetation**

- As plants stops or reduces chlorophyll production, it absorbs less in the red bands (therefore reflects more red) and starts producing more yellow color of “dying” vegetation
- Red color of some leaves produced by carotenoids which are always present but are usually masked by chlorophyll.



Bahrami & Mobasheri, 2020

Forest ecosystems

Functions of forests

Economic Functions

- Timber, paper, and non-timber products
- Jobs and livelihoods in forestry & tourism
- Carbon trading and ecosystem services

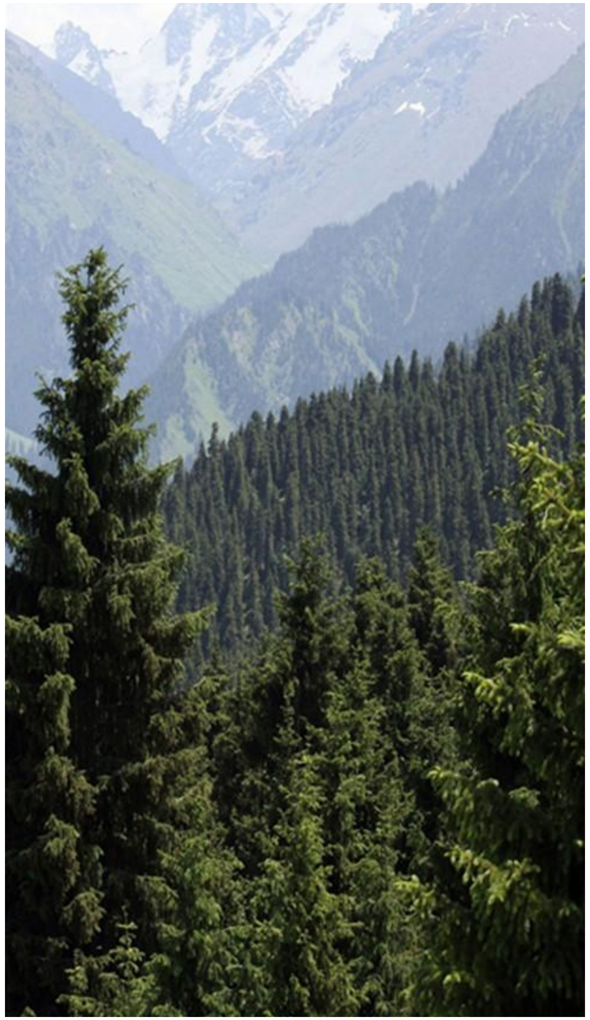
Ecological Functions

- Biodiversity hotspot: home to plants, animals & microorganisms
- Climate regulation: carbon storage & oxygen production
- Soil and water conservation, preventing erosion

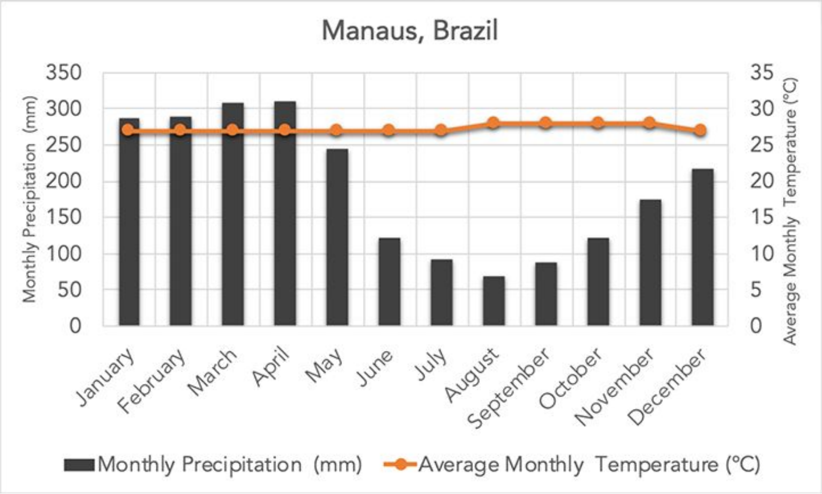
Cultural & Social Aspects

- Sacred sites & indigenous traditions
- Recreation, tourism, and well-being
- Education and scientific research

Types of forest

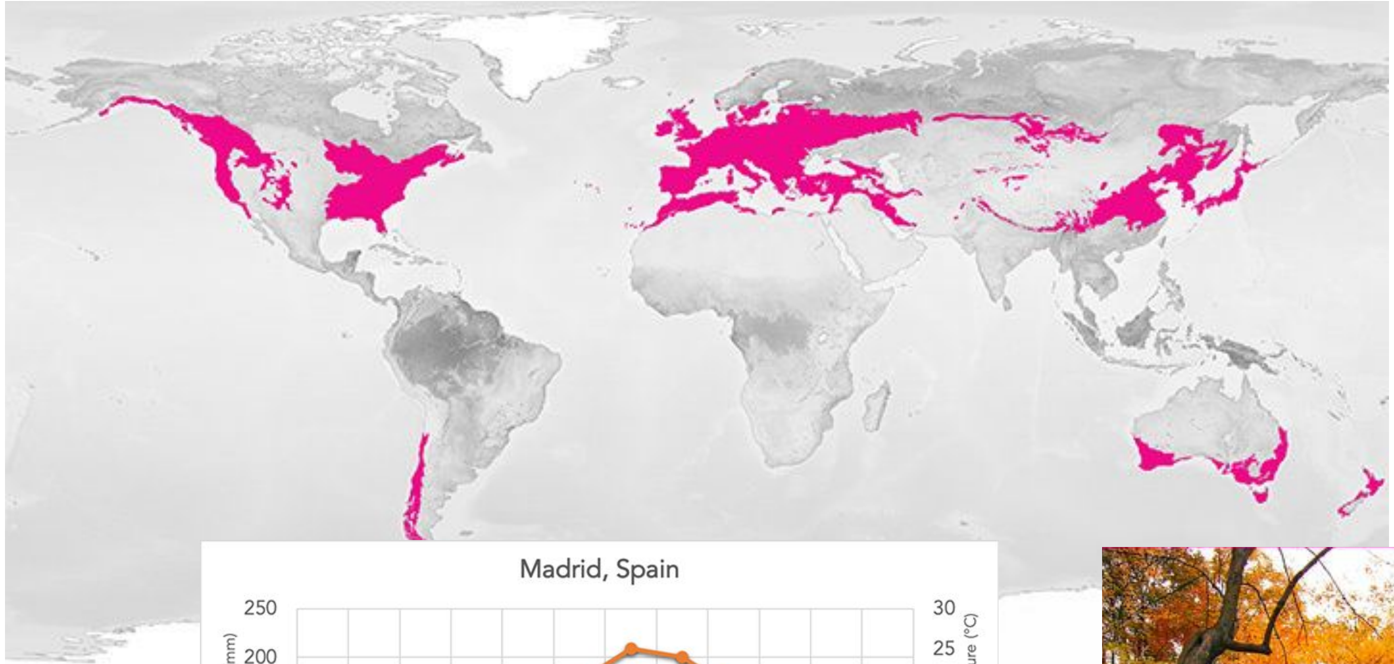


Types of forest- Tropical Rainforest

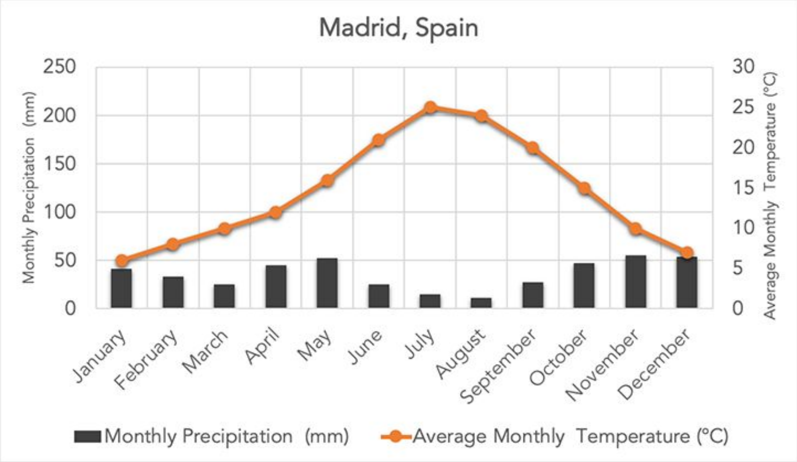


NASA (2025)

Types of forest- Temperate Deciduous Forests



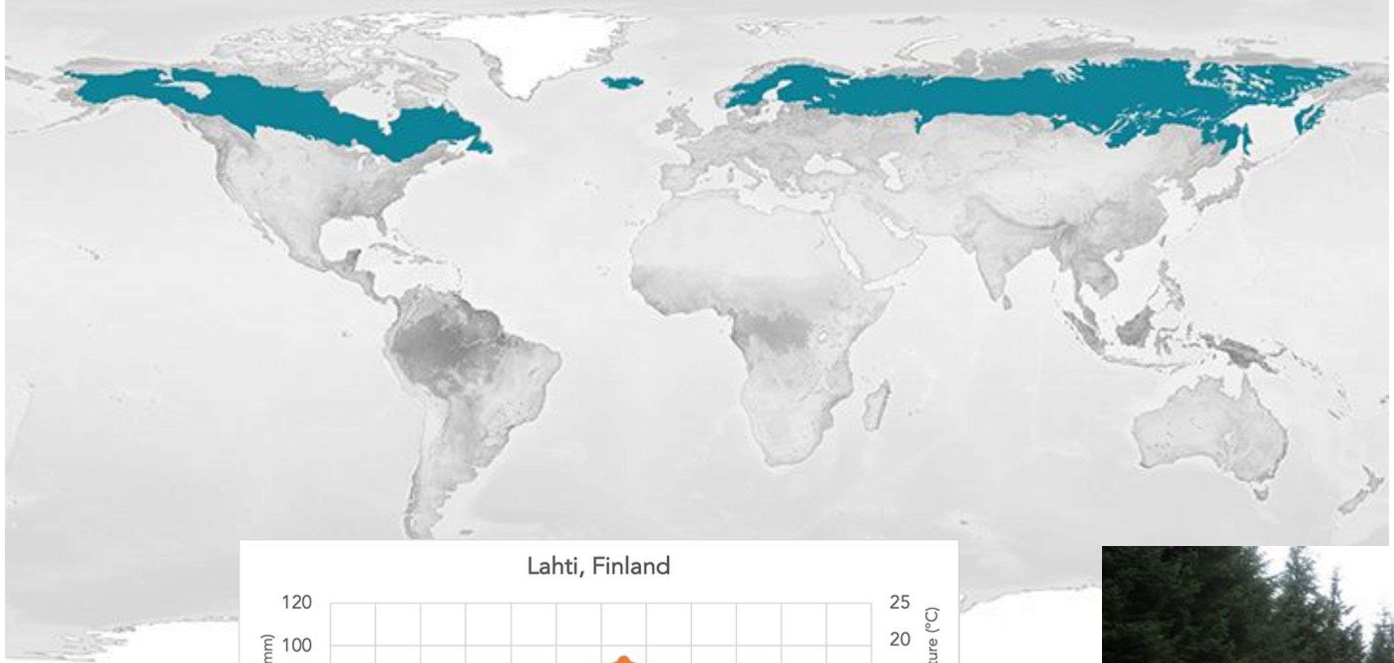
NASA 2025)

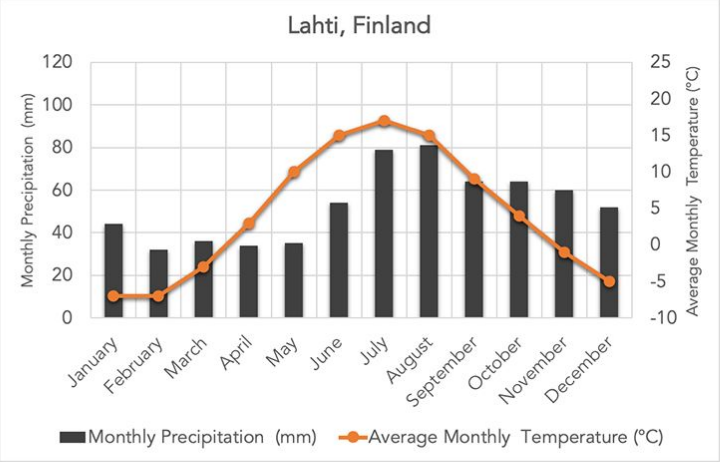


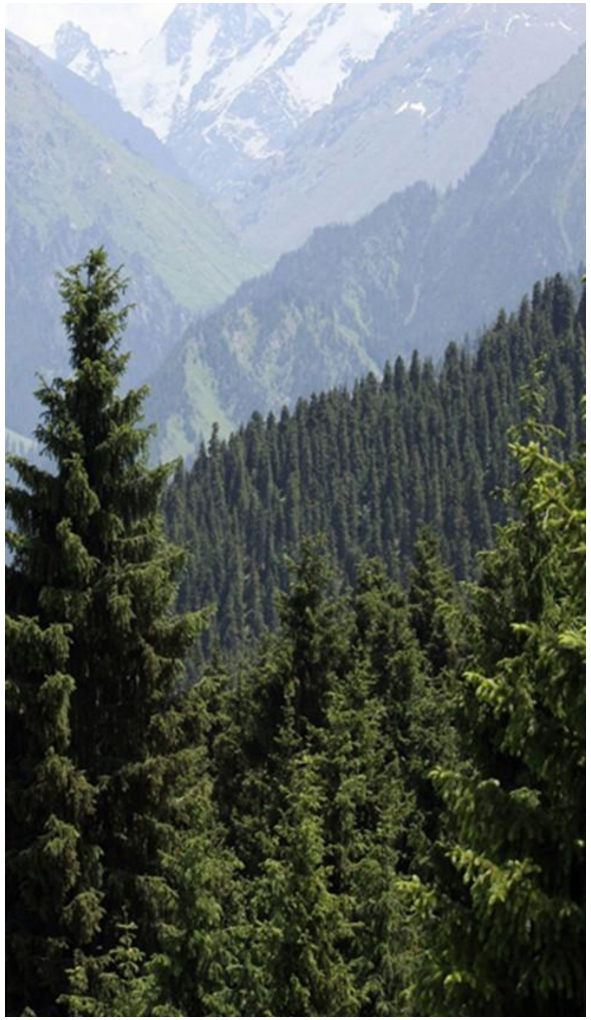
Types of forest- Coniferous Forest

Lubasi (2009)

NASA 2025)







Major threats

Deforestation
- Logging for timber, paper, and fuel.
- Agricultural expansion (soy, palm oil, cattle ranching).
- Urbanization and infrastructure development.

Climate Change
- Increased droughts weaken trees and ecosystems.
- Rising temperatures cause more frequent wildfires.
- Shifts in rainfall patterns affect forest growth and regeneration.

Biodiversity Loss
- Habitat destruction endangers species.
- Disrupts ecosystems and food chains.
- Reduces genetic diversity, making species more vulnerable.

Agenda 2030-SDGs

Biodiversity Protection

- Preserve ecosystems, combat deforestation, and protect endangered species to maintain biodiversity.

Sustainable Land Use

- Promote responsible agriculture, reforestation, and soil conservation to prevent desertification and land degradation.

Combat Climate Change

- Strengthen policies to reduce habitat loss, restore natural landscapes, and enhance carbon sequestration efforts.

Vegetation Indices

- Part of Multispectral Remote Sensing
- Simple and easy-to-understand approach for measuring vegetation
- Mainly based on the ratio of reflection in the red spectral range and near-infrared (NIR)
- A commonly used analysis technique in satellite remote sensing
- The most well-known index is the **Normalized Difference Vegetation Index (NDVI)**

Normalized Difference Vegetation Index (NDVI)

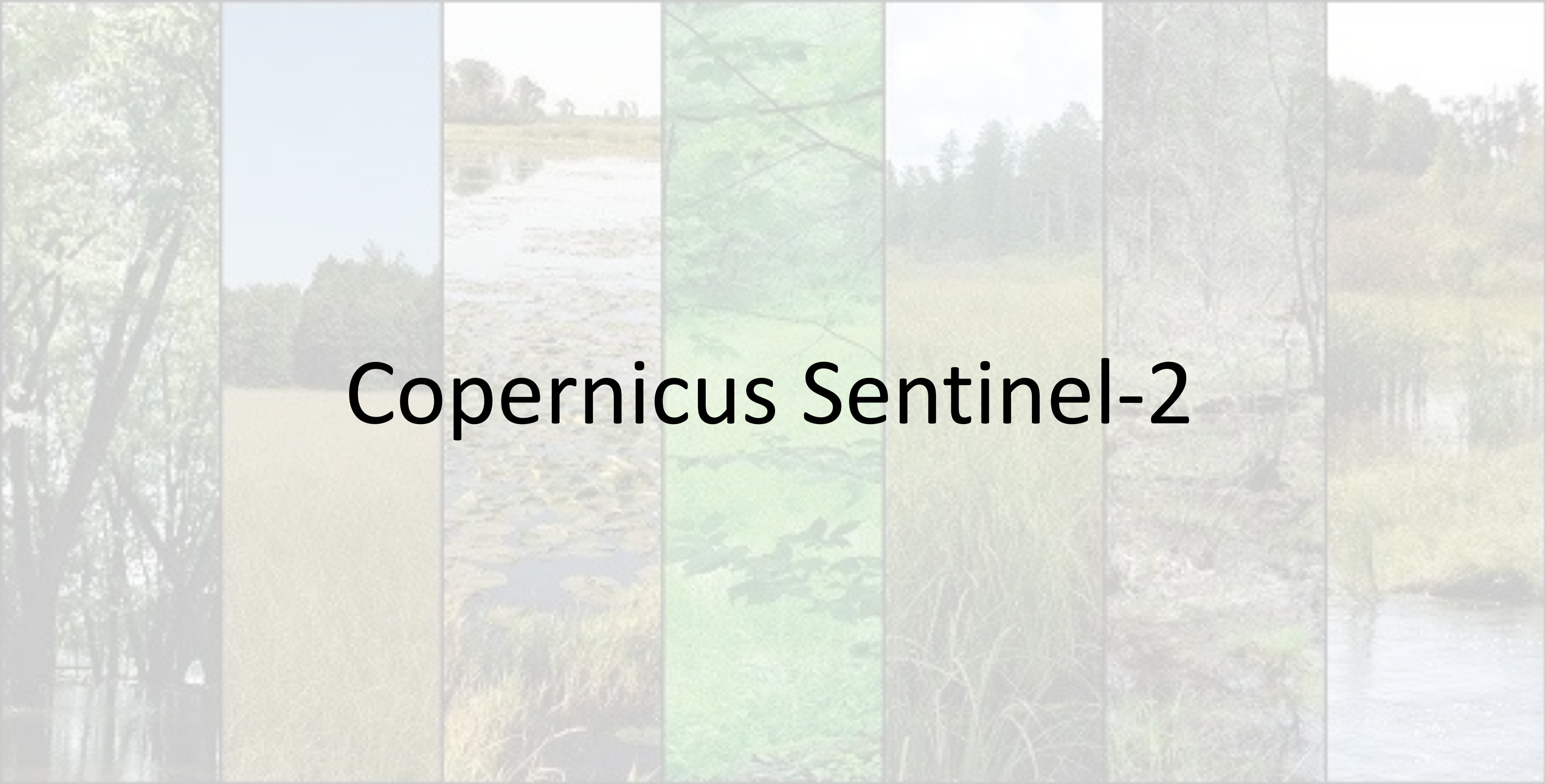
- Is formed by calculating the ratio of the difference between the reflectance in near-infrared (NIR) and visible red (VISr) and their sum.

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$

- Value range NDVI = [-1, +1]
- Typical values :
  - Dense vegetation: 0,7
  - Dry bare soil: 0,025
  - Clouds: 0,002
  - Snow and ice: -0,046
  - Water: -0,257

Other Vegetation Indices

	EVI (Enhanced Vegetation Index)	Leaf Area Index (LAI)	Normalized Difference Moisture Index (NDMI)
Formula			
Application			
Advantages			



Copernicus Sentinel-2

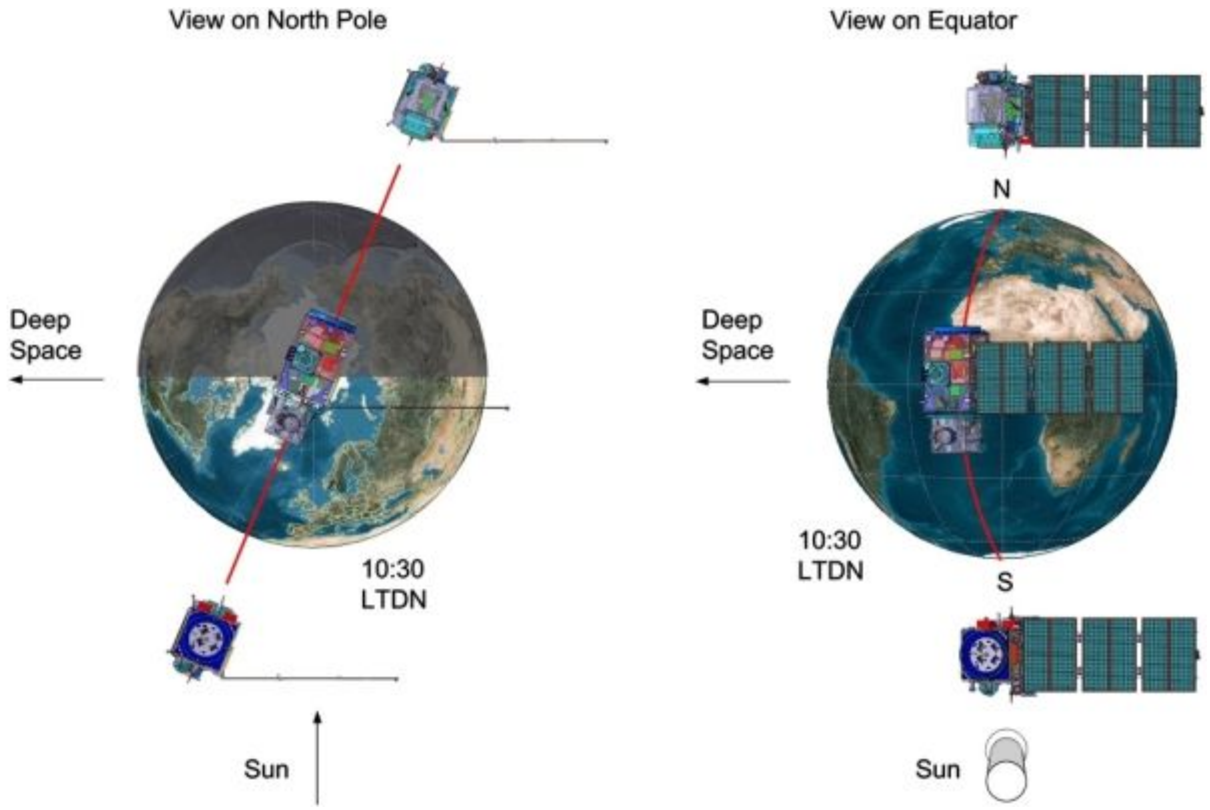
General information

- The Copernicus Sentinel-2 mission is based on a constellation of two identical satellites in the same orbit.
- Each satellite carries an innovative wide swath high-resolution multispectral imager with 13 spectral bands for a new perspective of our land and vegetation.
- Launch dates:
  - Sentinel-2A: 23 June 2015
  - Sentinel-2B: 7 March 2017
  - Sentinel-2C: 5 September 2024

ESA (2025)

General information

- Resolution: 10 m
- Spectral bands: 13
- Swath: 290 km
- Revisit-time: 5 days
- Orbit Period: 100.6 minutes

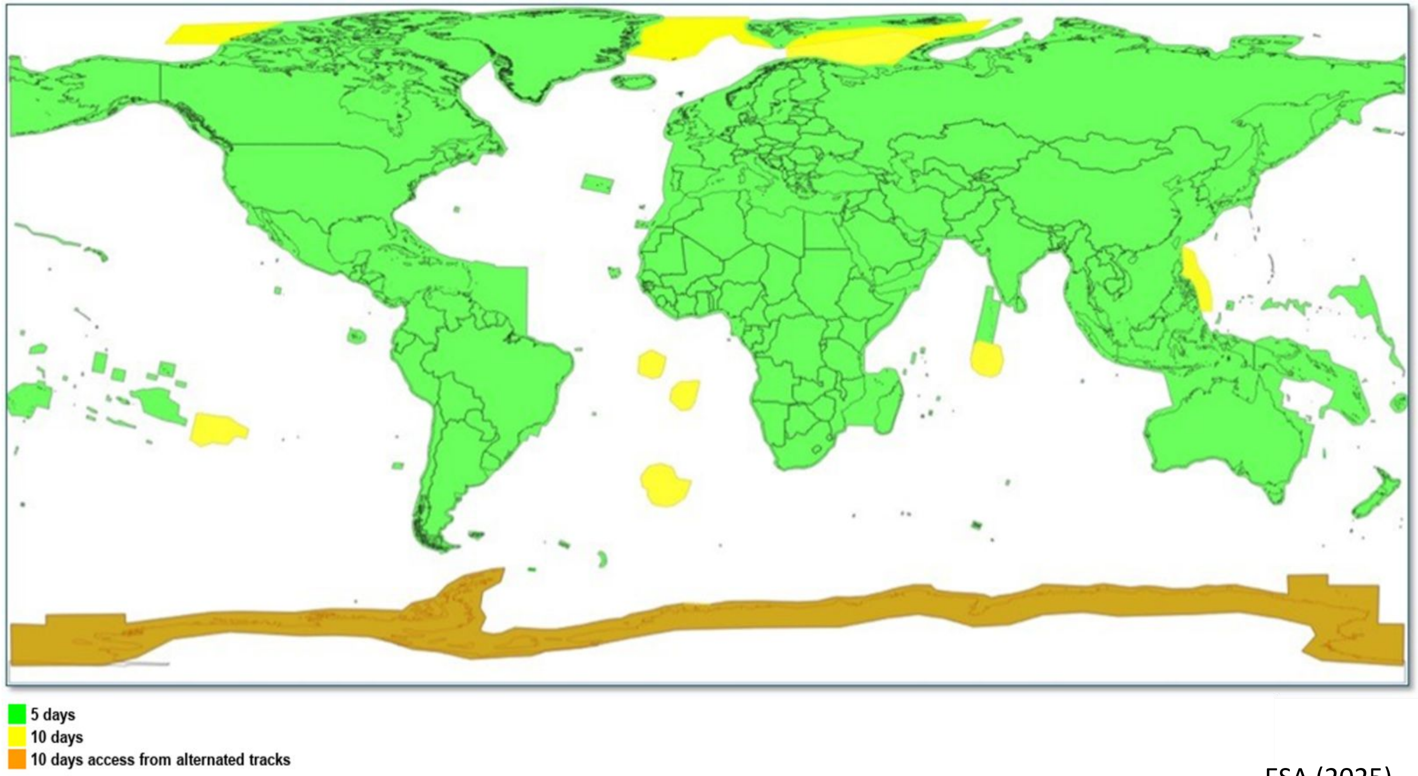


The Twin-Satellite Sentinel-2 Orbital Configuration

ESA (2025)

General information- geographical coverage

- All continental land surfaces (including inland waters) between 56°S and 82.8°N
- Coastal waters up to 20 km from the shore
- Islands >100 km²
- All EU islands
- The Mediterranean Sea
- All enclosed seas (e.g., Caspian Sea)
- Additional coverage based on Copernicus Services or member state requests (e.g., Antarctica, Baffin Bay)



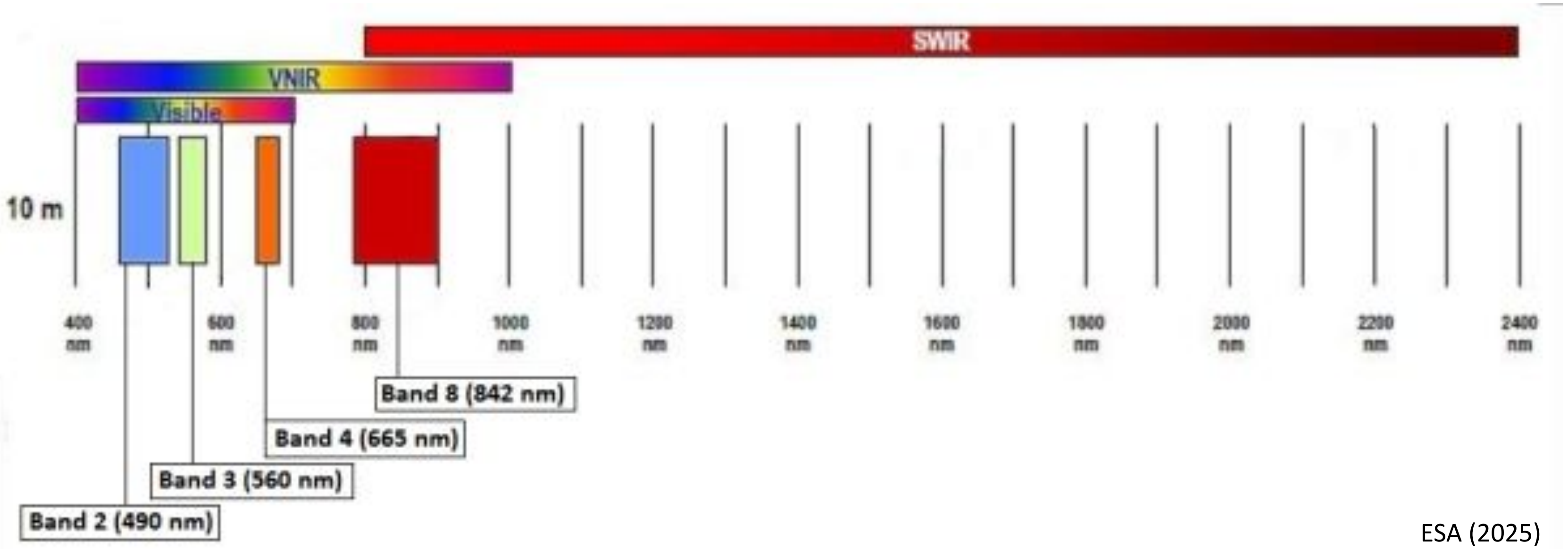
ESA (2025)

Coverage and revisit time for Sentinel-2 MSI acquisitions

General information- spatial resolution

Spectral bands: 13

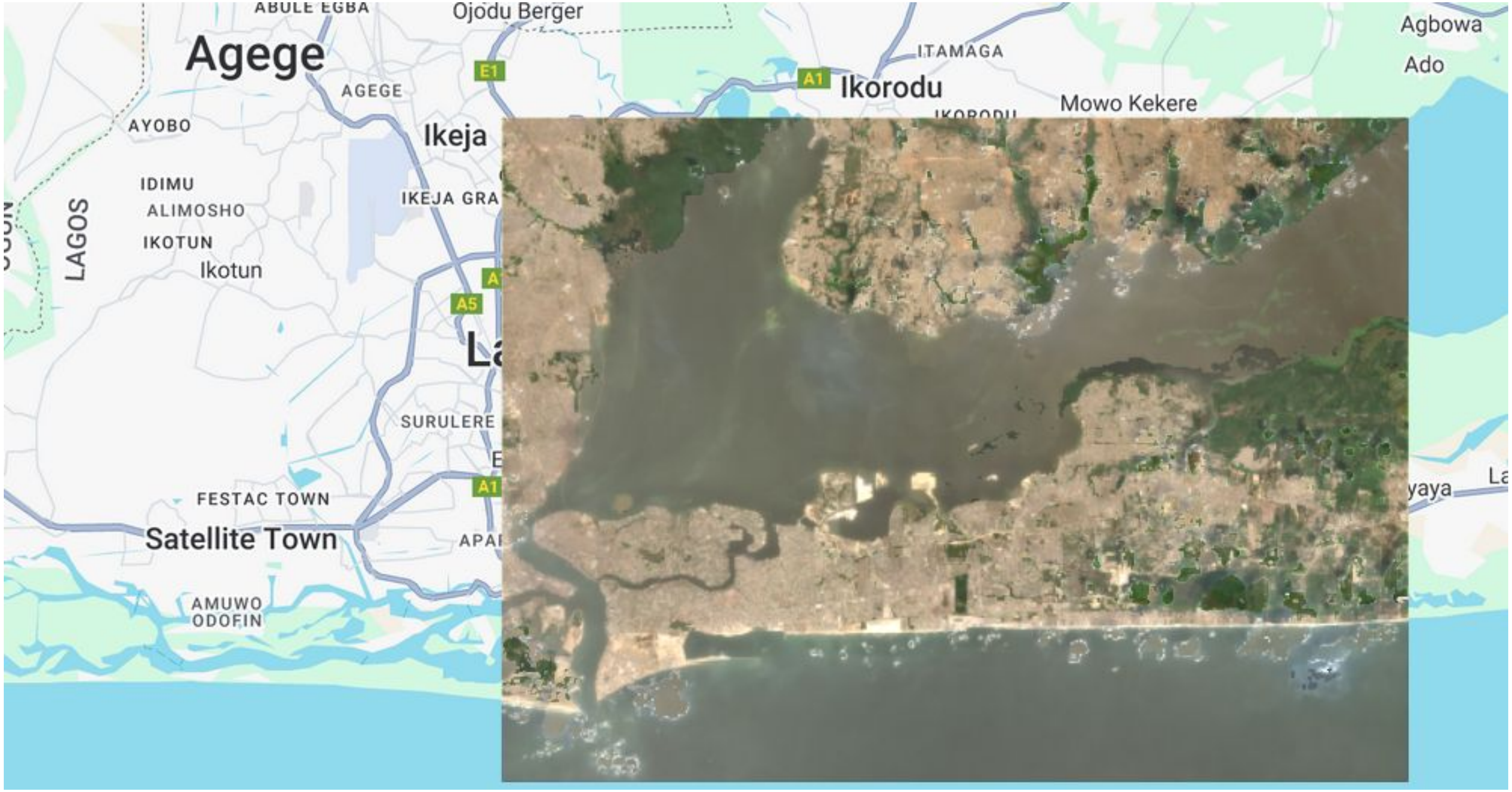
- 10 metre spatial resolution:
  - Band 2: 490 nm: Blue
  - Band 3: 560 nm: Green
  - Band 4: 665 nm: Red
  - Band 8: 842 nm: Near Infra-Red (NIR)



ESA (2025)

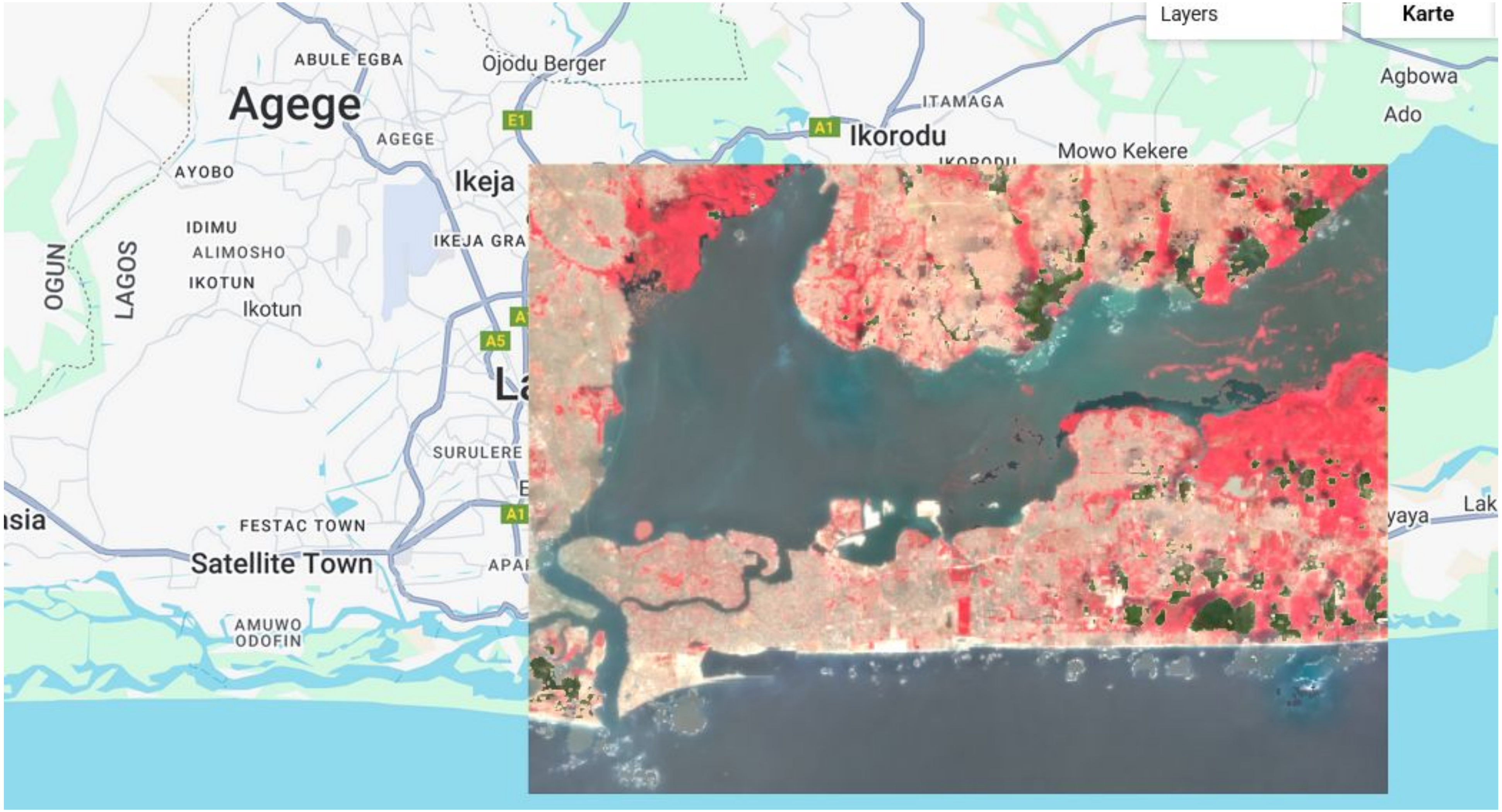
Sentinel-2 10 m spatial resolution bands

Example: R-G-B



Band combination: B4-B3-B2, Google Earth Engine: Lagos

Example: NDVI: NIR-R-G

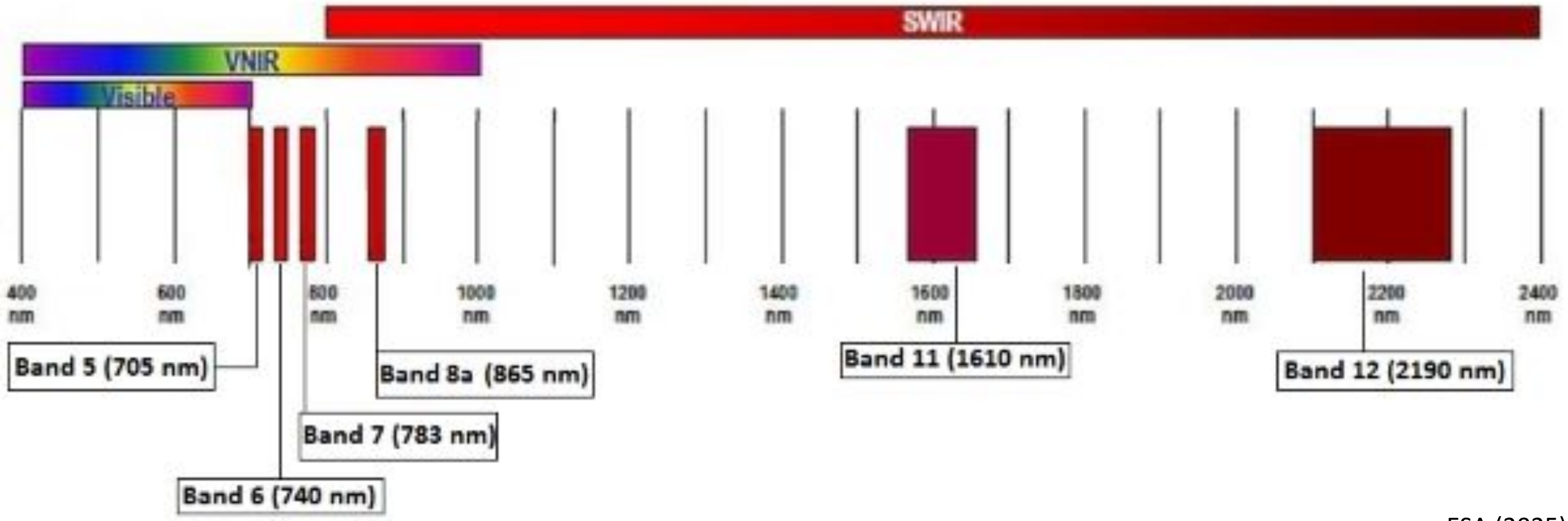


Band combination: B5-B4-B3, Google Earth Engine: Lagos

General information- spatial resolution

Spectral bands: 13

- 20 metre spatial resolution:
  - Band 5: 705 nm
  - Band 6: 740 nm
  - Band 7: 783 nm
  - Band 8a: 865 nm
  - Band 11: 1610 nm
  - Band 12: 2190 nm



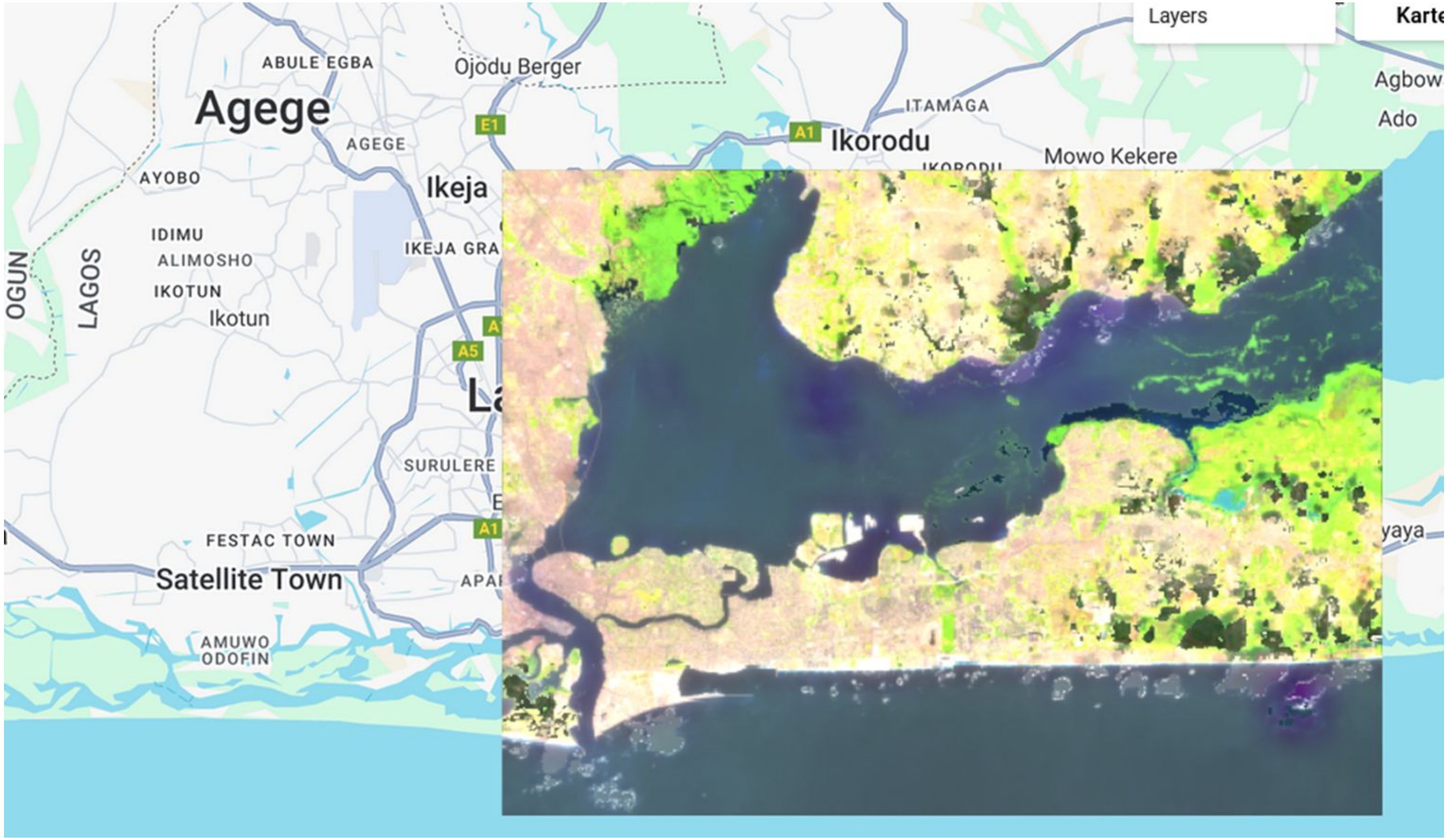
ESA (2025)

Sentinel-2 20 m spatial resolution bands

VNIR vegetation red edge spectral domain

Applications: snow/ice/cloud detection, or vegetation moisture stress assessment

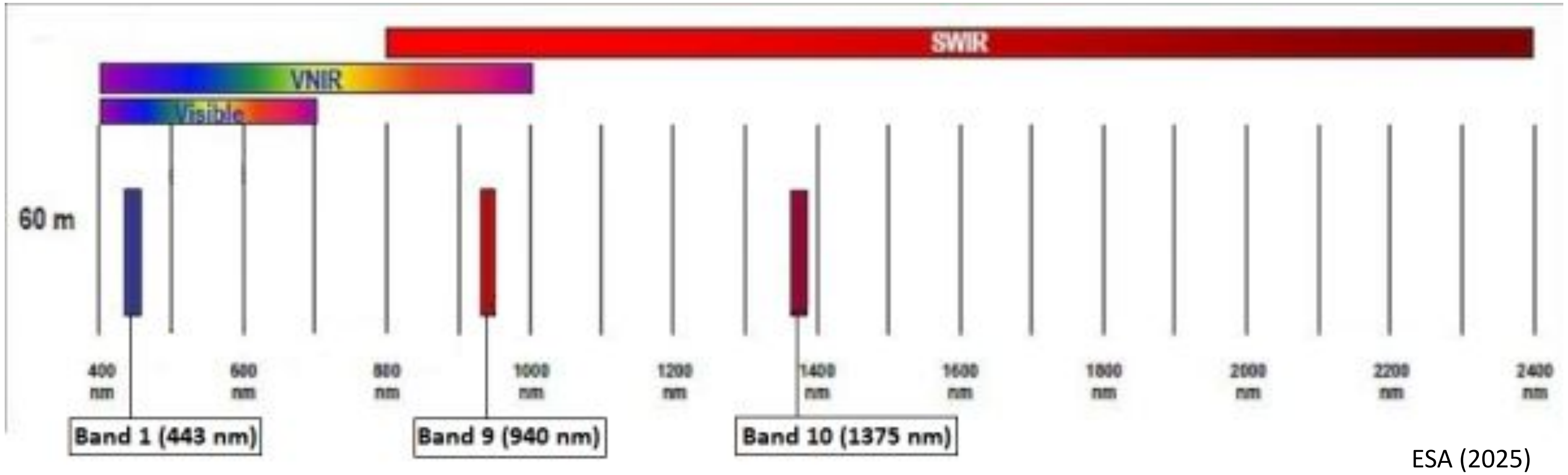
Example: Vegetation Analysis: SWIR 1-NIR-R



Band combination: B11- B5-B4, Earth Engine: Lagos

General information- spatial resolution

Spectral bands: 13	Application
• 60 metre spatial resolution:	mainly focused on cloud screening and atmospheric correction
• Band 1: 443 nm	Aerosols
• Band 9: 940 nm	water vapour
• Band 10: 1375 nm	cirrus detection



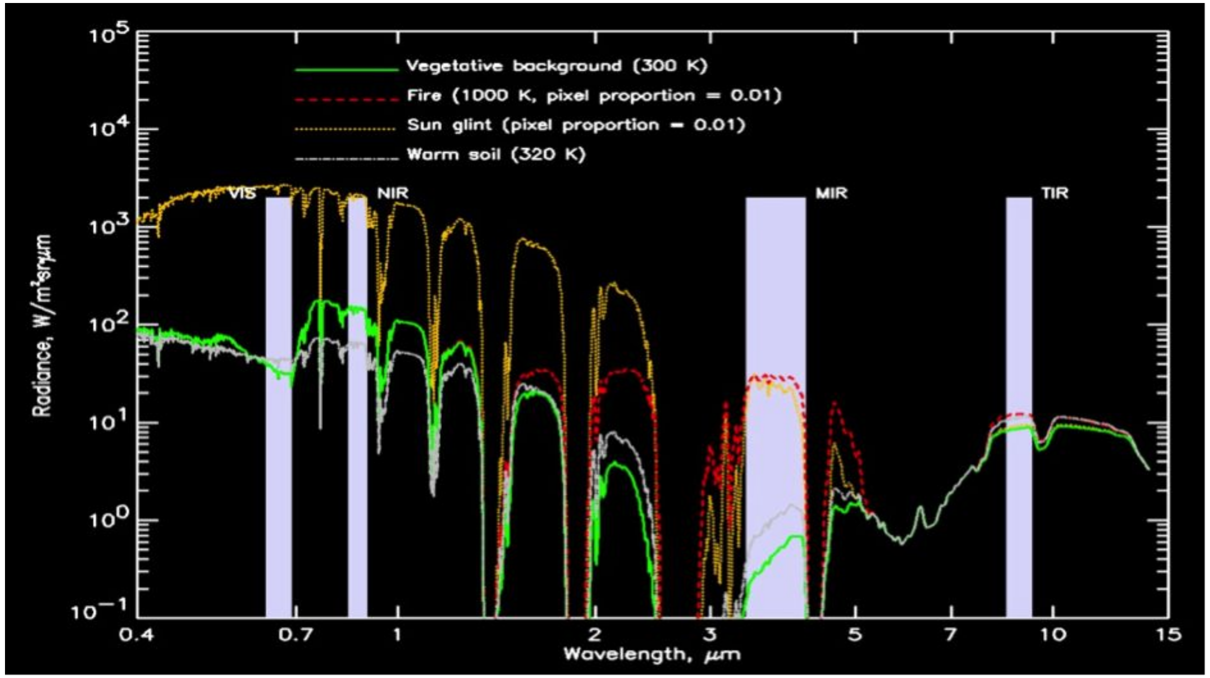
Sentinel-2 60 m spatial resolution bands

ESA (2025)

Application

Wildfire Monitoring Sentinel-2

- Wildfires contribute 25–35% of annual global greenhouse gas emissions.
- Monitoring large-scale fires is crucial to understand their impact on climate change.
- Remote sensing enables accurate documentation of fire extent and frequency.



Wildfire Monitoring Sentinel-2

Wildfire Extent Underestimated

- Sentinel-2 satellite data reveals 80% more burned land in Sub-Saharan Africa than previously estimated.
- 4.9 million km² burned in 2016—larger than India and Mongolia combined.

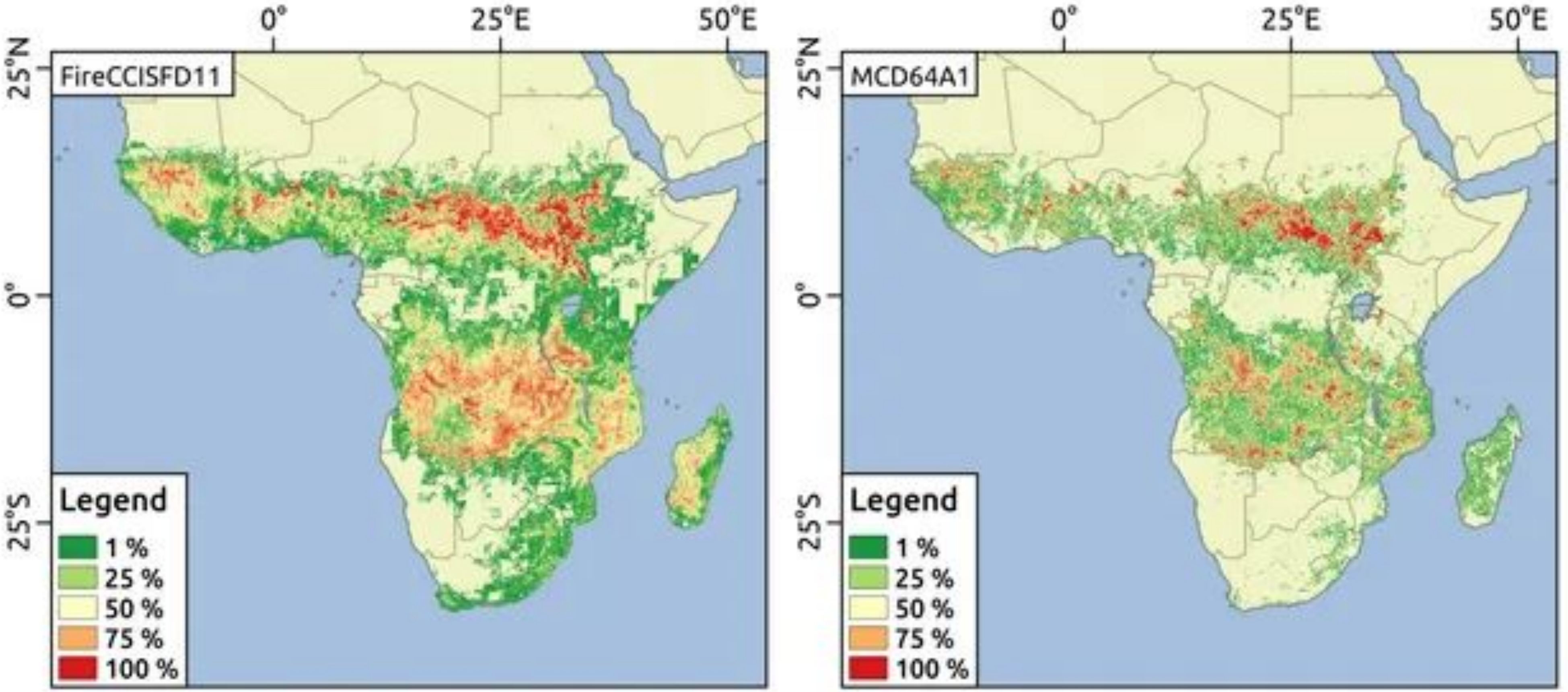
Remote Sensing Breakthrough

- High-resolution imagery allows detailed mapping of fire scars.
- Many detected fires are smaller than 100 hectares, often linked to agriculture and grazing.

- Impact on Climate & Land Use
- Fire contribute 25–35% of annual global greenhouse gas emissions.
- Small-scale fires influence deforestation, ecosystem changes, and carbon cycles.

- Future Research & Monitoring
- Plan to create a global 20m resolution fire map.
- Sentinel-2 data will help improve climate models and land management strategies.[ESA]

Wildfire Monitoring Sentinel-2



ESA

Assessment of Sentinel-2 Satellite Images and Random Forest Classifier for Rainforest Mapping in Gabon

- Adam Waśniewski, Agata Hościło, Bogdan Zagajewski, Dieudonné Moukétou-Tarazewicz

- Objectives:
  - Mapping forest cover and types in northwest Gabon
  - The goal was to analyze how different Sentinel-2 spectral bands, the **Normalized Difference Vegetation Index (NDVI)**, and a **Digital Elevation Model (DEM)** impact classification accuracy.

forests MDPI

Article

Assessment of Sentinel-2 Satellite Images and Random Forest Classifier for Rainforest Mapping in Gabon

Adam Waśniewski [1,2,*], Agata Hościło [2], Bogdan Zagajewski [1] and Dieudonné Moukétou-Tarazewicz [1,3]

1 Chair of Geomatics and Information Systems, Department of Geoinformatics, Cartography and Remote Sensing, University of Warsaw, Faculty of Geography and Regional Studies, Krakowskie Przedmieście 30, 00-927 Warsaw, Poland; bogdan@uw.edu.pl (B.Z.); diket22@hotmail.com (D.M.-T.)
2 Centre of Applied Geomatics, Institute of Geodesy and Cartography, Modzelewskiego 27, 02-679 Warsaw, Poland; agata.hoscilo@igik.edu.pl
3 Department of Geographical, Environmental and Marine Sciences, Faculty of Letters and Human Sciences, University Omar Bongo of Libreville, Libreville PO Box 17.043, Gabon
* Correspondence: adam.wasniewski@igik.edu.pl

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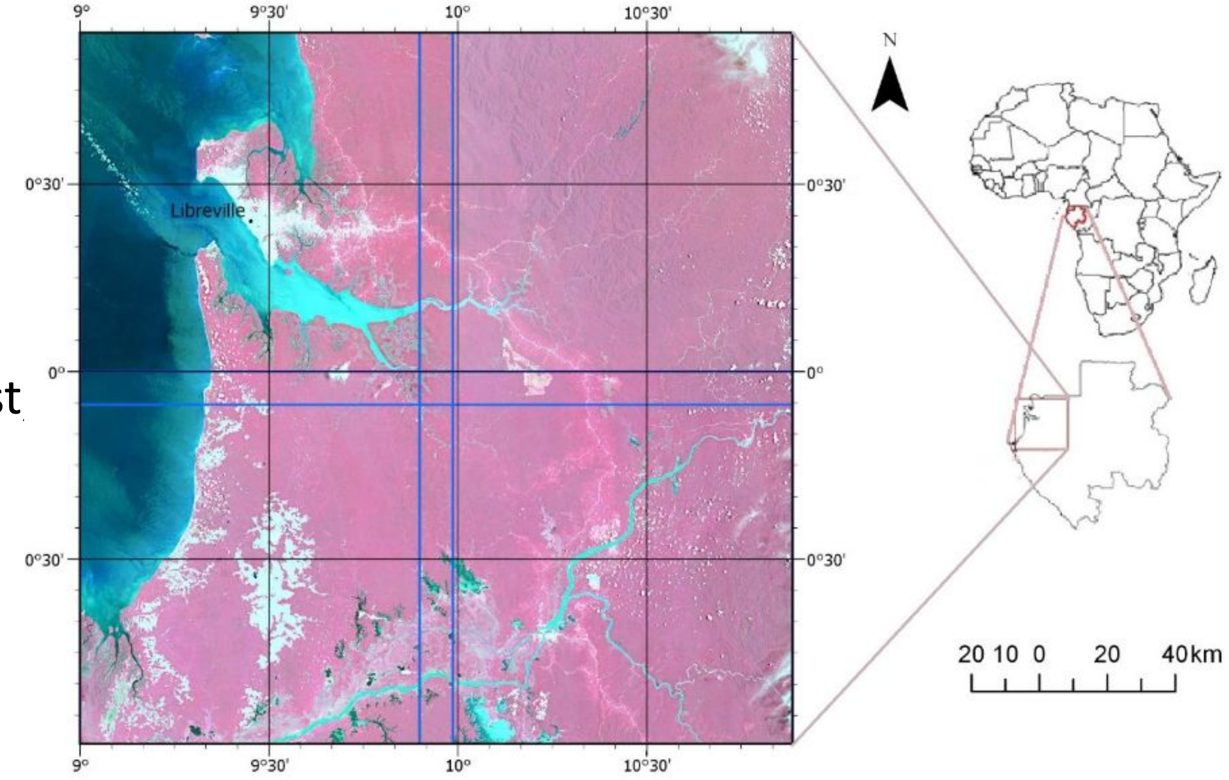
Abstract: This study is focused on the assessment of the potential of Sentinel-2 satellite images and the Random Forest classifier for mapping forest cover and forest types in northwest Gabon. The main goal was to investigate the impact of various spectral bands collected by the Sentinel-2 satellite, normalized difference vegetation index (NDVI) and digital elevation model (DEM), and their combination on the accuracy of the classification of forest cover and forest type. Within the study area, five classes of forest type were delineated: semi-evergreen moist forest, lowland forest, freshwater swamp forest, mangroves, and disturbed natural forest. The classification was performed using the Random Forest (RF) classifier. The overall accuracy for the forest cover ranged between 92.6% and 98.5%, whereas for forest type, the accuracy was 83.4 to 97.4%. The highest accuracy for forest cover and forest type classifications were obtained using a combination of spectral bands at spatial resolutions of 10 m and 20 m and DEM. In both cases, the use of the NDVI did not increase the classification accuracy. The DEM was shown to be the most important variable in distinguishing the forest type. Among the Sentinel-2 spectral bands, the red-edge followed by the SWIR contributed the most to the accuracy of the forest type classification. Additionally, the Random Forest model for forest cover classification was successfully transferred from one master image to other images. In contrast, the transferability of the forest type model was more complex, because of the heterogeneity of the forest type and environmental conditions across the study area.

Keywords: Sentinel-2; random forest; Gabon; forest type; tropical forest; forest cover

Assessment of Sentinel-2 Satellite Images and Random Forest Classifier for Rainforest Mapping in Gabon

Study area:

- around 40,000 km²
- overing by four Sentinel-2 scenes
- different forest types: mangroves,
- freshwater swamp forest, lowland forest, moist forest disturbed natural forest



Waśniewski et al. (2020)

Assessment of Sentinel-2 Satellite Images and Random Forest Classifier for Rainforest Mapping in Gabon

Data source:

Acquisition Date:
2 April 2017 (near cloud-free imagery)

Bands Used:
- 10 m resolution: B2 (Blue), B3 (Green), B4 (Red), B8 (NIR)
- 20 m resolution: B5, B6, B7 (Red-edge), B8a (NIR), B11, B12 (SWIR)
- 60 m resolution bands (B1, B9, B10) were not used

Trainings data:
- **Global Forest Watch** (2015, 30 m resolution)
- **GlobCover 2009**
- Local knowledge

Assessment of Sentinel-2 Satellite Images and Random Forest Classifier for Rainforest Mapping in Gabon

Methods:

- Random Forest (RF) classifier was used for both forest cover and forest type classification.
- 100 decision trees were trained.
- The RF classifier was implemented using imageRF in EnMAP-Box 2.0.2.

Classification Workflow

1. Forest Cover Classification:

- Training on the northwest Sentinel-2 image → applied to all other images.
- The classified forest mask was then used for forest type classification.

2. Forest Type Classification:

- Two separate models were trained:
    - Western Gabon: Northwest image → applied to Southwest image.
    - Eastern Gabon: Northeast image → applied to Southeast image.

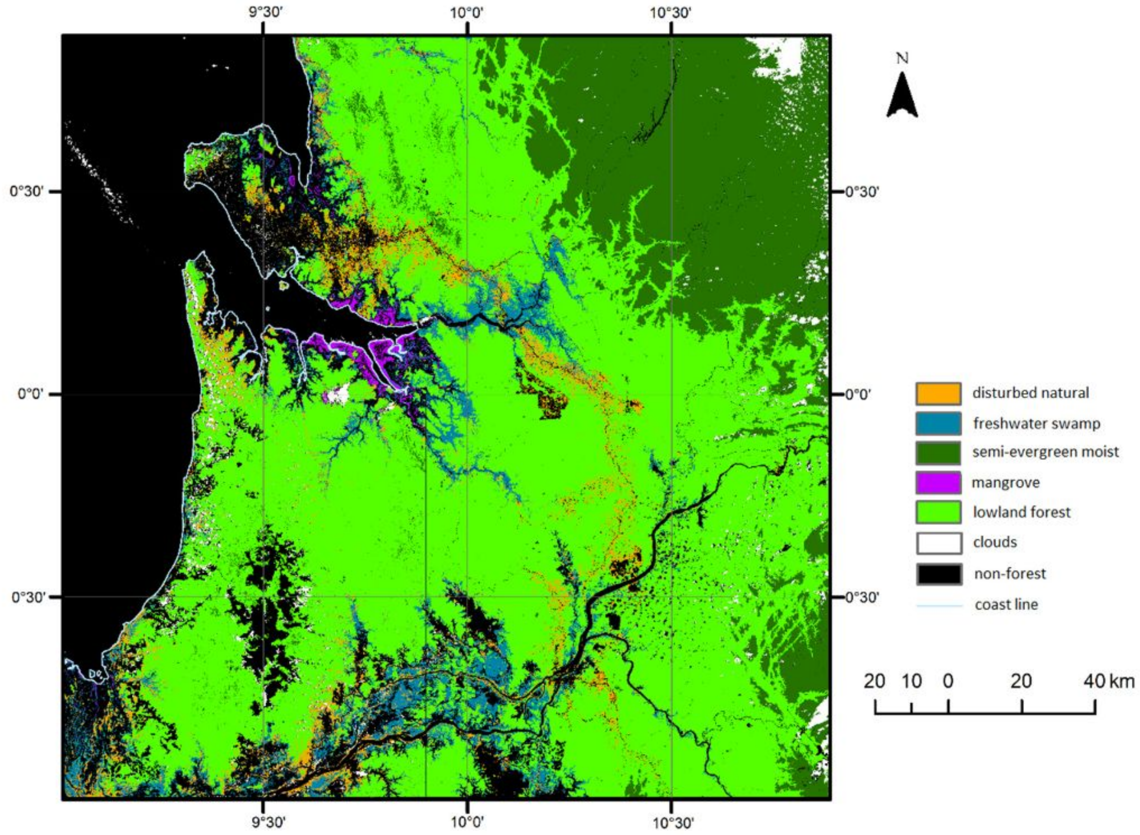
Key Parameters:

- Number of selected features = √(total features)
- Impurity criterion = Gini Index
- Minimum samples per node = 1

Assessment of Sentinel-2 Satellite Images and Random Forest Classifier for Rainforest Mapping in Gabon

Results:

- **Best classification results** were achieved using **Sentinel-2 spectral bands (10 m & 20 m resolution) combined with DEM**.
- **NDVI did not improve classification accuracy** significantly.
- **DEM was the most important factor** in distinguishing forest types.
- **Red-edge and SWIR bands** contributed most to forest type classification.
- **Classification Accuracy:**
  - Forest cover accuracy ranged from **92.6% to 98.5%**
  - Forest type classification accuracy ranged from **83.4% to 97.4%**



Waśniewski et al. (2020)

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Thank you for your attention!

Dr. Insa Otte (on behalf of the EOCap4Africa Team) and colleagues

insa.otte@uni-wuerzburg.de

Julius-Maximilians-UNIVERSITÄT WÜRZBURG

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