CEGE0096: Geospatial Programming

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Lecture 10:
Remote Sensing

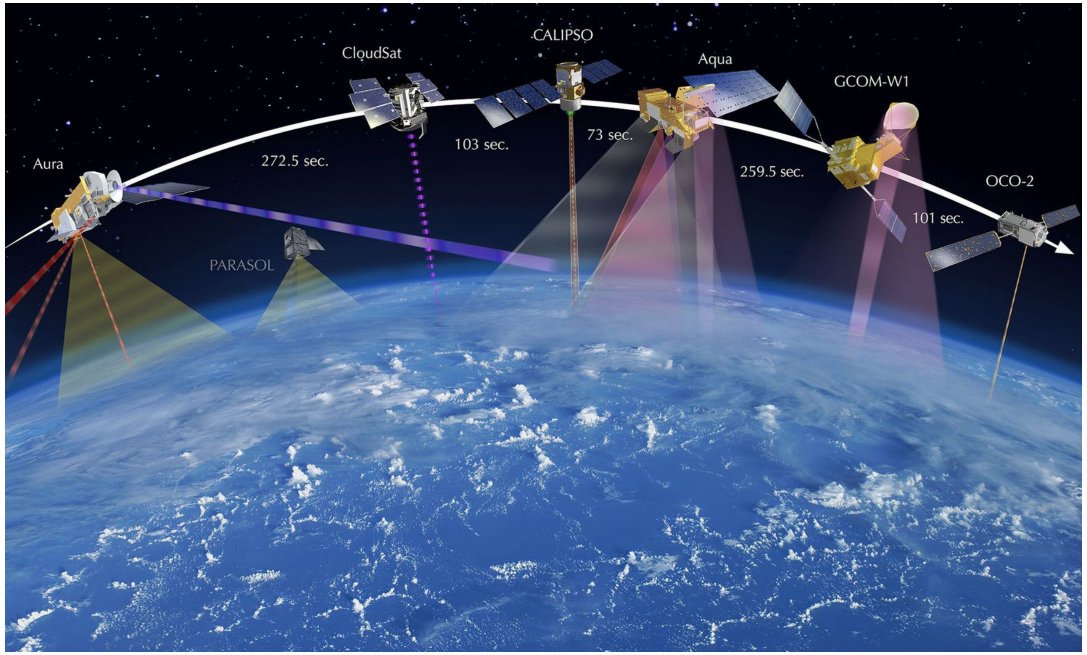
What is Remote Sensing?

The science of **obtaining information** about objects or areas **from a distance**, typically from aircraft or satellites

Brief history of remote sensing

Pre-Space Age (1800s-1957)

Post-Space Age (1957-)



Brief history of remote sensing (2)

Pre-Space Age (1800s-1957)

- Photography (1800s)
- First flight (early 1900s)
- **WWII (1939-1945)**
  - Aerial photography is key military asset
  - Radar invented
- Spy planes (U-2) during Cold War

Post-Space Age (1957-)

- Sputnik 1 - first satellite launched by USSR (1957), followed by US' Explorer 1 (1958)
  - 5 other countries launch their first satellite in the next decade
- US' Landsat programme (1972-) for continuous Earth monitoring
- Copernicus programme (EU; 2014-)

Copernicus Programme

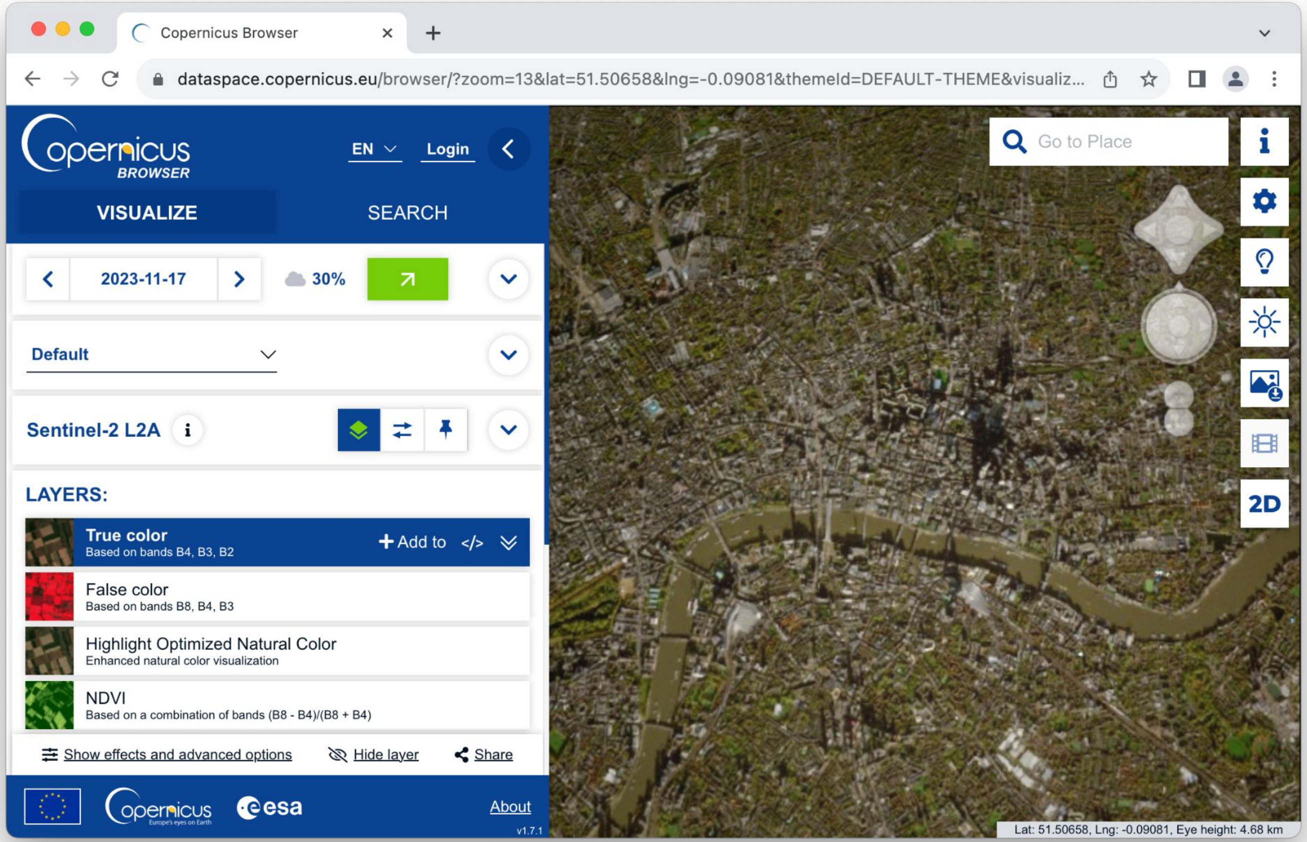
- Copernicus is the Earth observation component of the EU Space programme, launched in 2014

- Collects and distributes timely global data about the atmosphere, land and sea from **Sentinel** and other satellites

- The data is free and easily accessible

Copernicus Browser

- You can use *Copernicus Browser (DataSpace)* to explore and download Copernicus imagery for any part of the world
- New imagery available every 1-5 days depending on the programme
- https://dataspace.copernicus.eu/browser/



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Types of Remote Sensing Technologies

About electromagnetic radiation

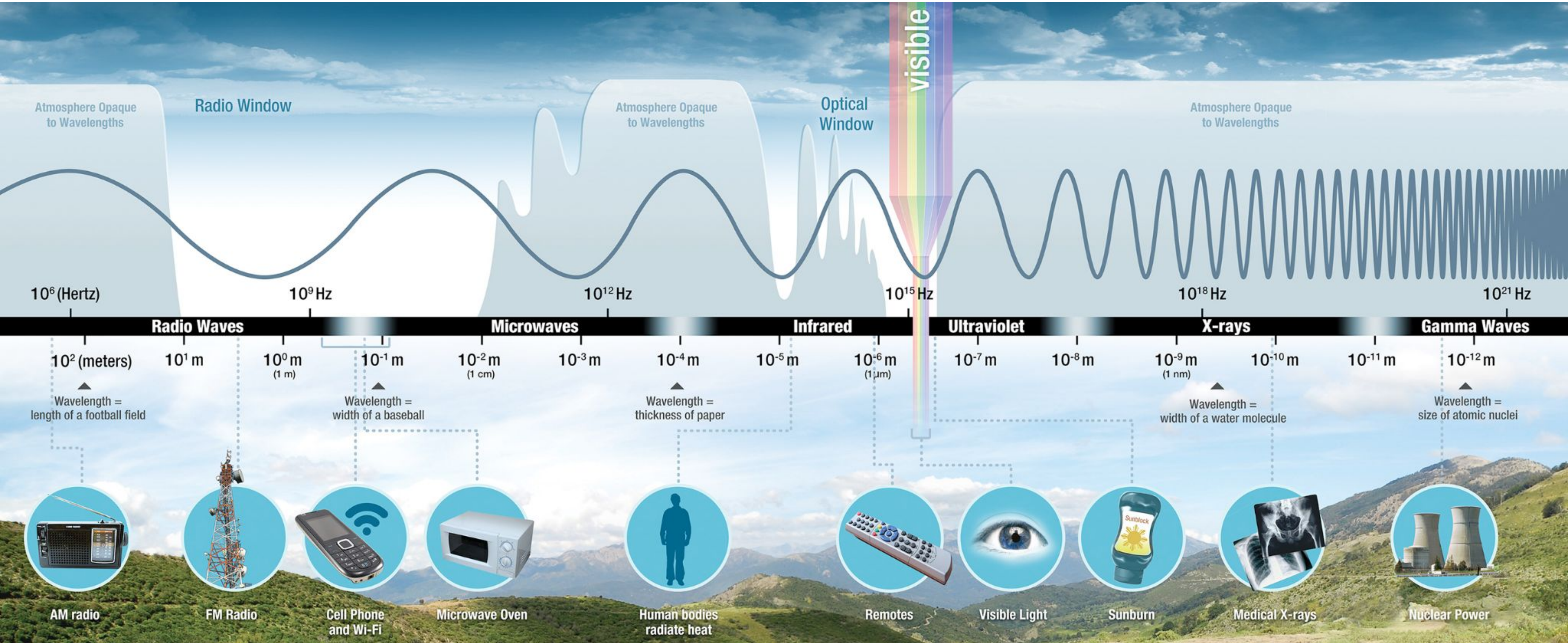
- The energy Earth receives from the sun is called **electromagnetic radiation (EM)**

- Radiation is reflected, absorbed, and emitted by the Earth's atmosphere and surface

- Radiation comes in different wave frequencies that form the **electromagnetic spectrum**
    - This includes visible light, as well as other waves not detected by human eye

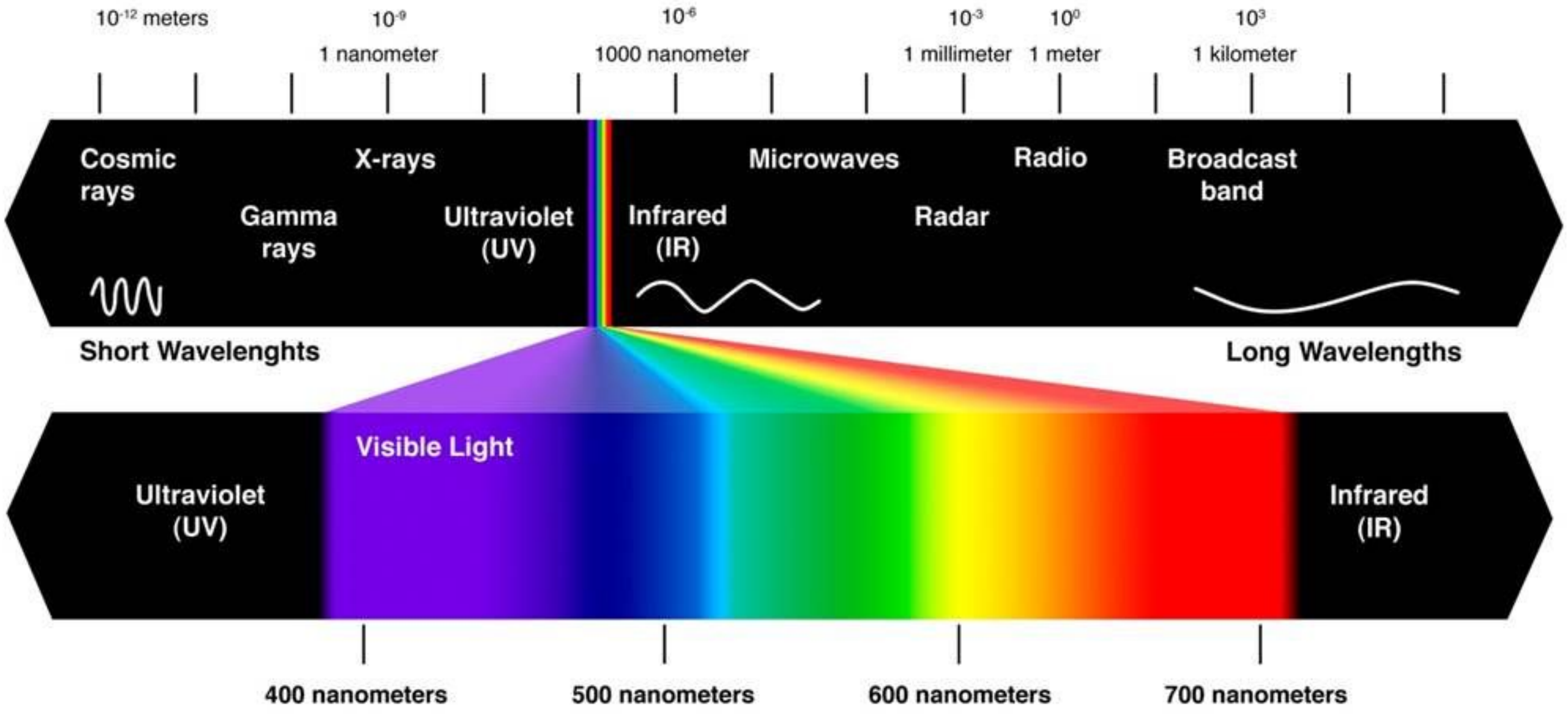
Electromagnetic spectrum

Illustration: NASA



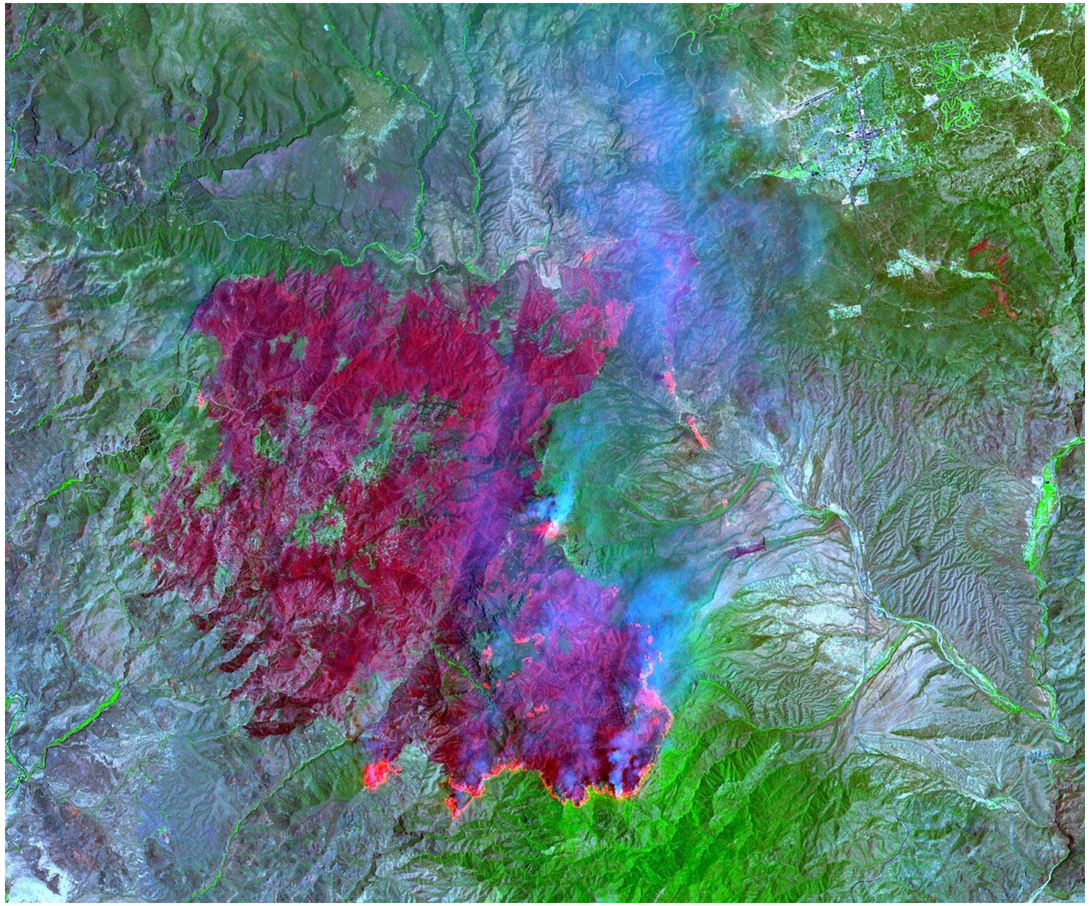
Visible light

Illustration: Wikimedia Commons



Infrared radiation

- Sits between microwaves and visible light at ~750 nanometers to 100 micrometers
- Invisible to human eye but can be detected by satellite sensors
- Emitted by warm objects, so widely used to detect land and sea surface temperatures, forest fires and other hot objects



Spectral Signatures

- Different materials reflect and absorb different wavelengths of EM radiation

- You can record and plot reflected wavelengths detected by a sensor to get a “spectral signature” to identify **the type of material it is reflected from**

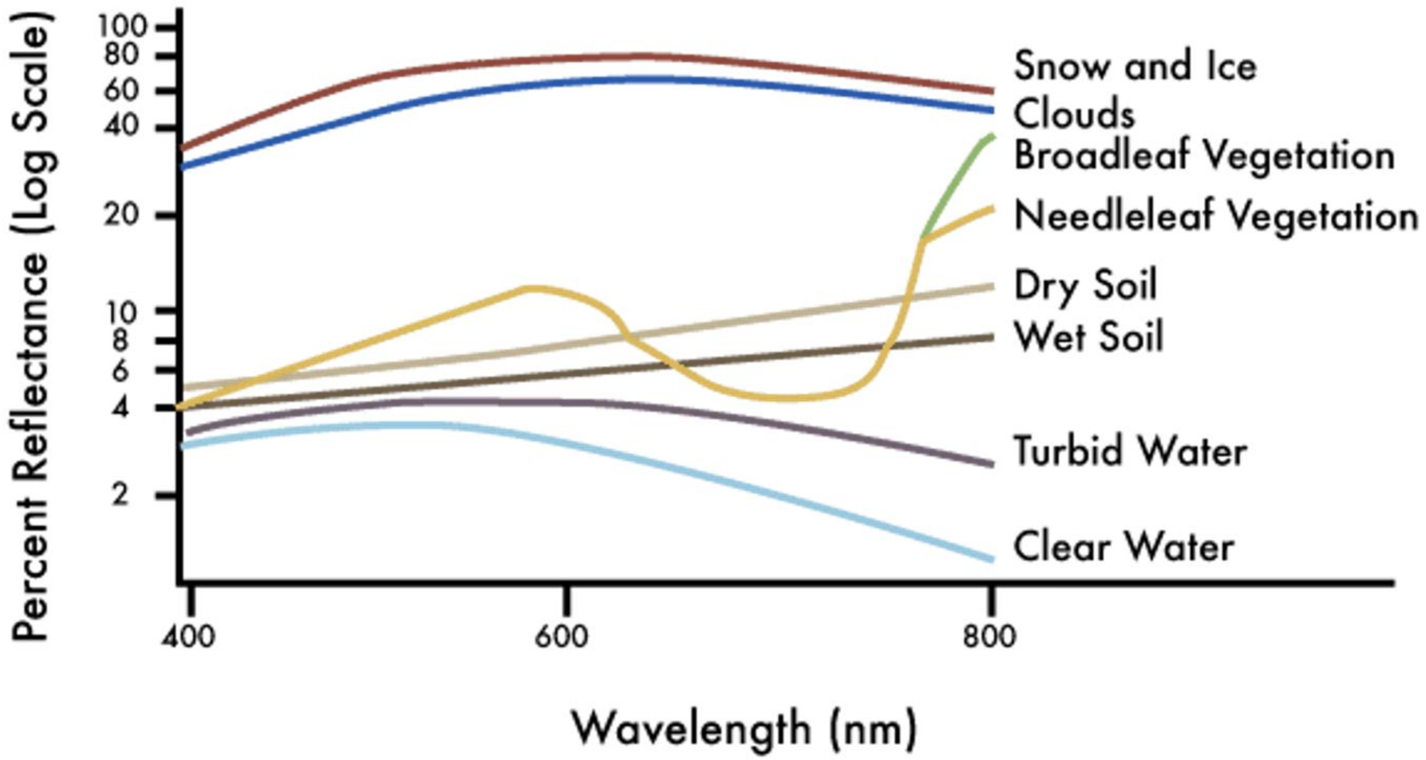


Illustration: NASA Applied Remote Sensing Training Program

Passive sensors

Passive remote sensors measure radiant energy that is reflected by the atmosphere:

- Normally operate in visible, infrared, thermal infrared, and microwave portions of the EM spectrum → usually cannot penetrate clouds

- Used to measure land and sea surface temperature, vegetation properties, cloud and aerosol properties, and other physical attributes

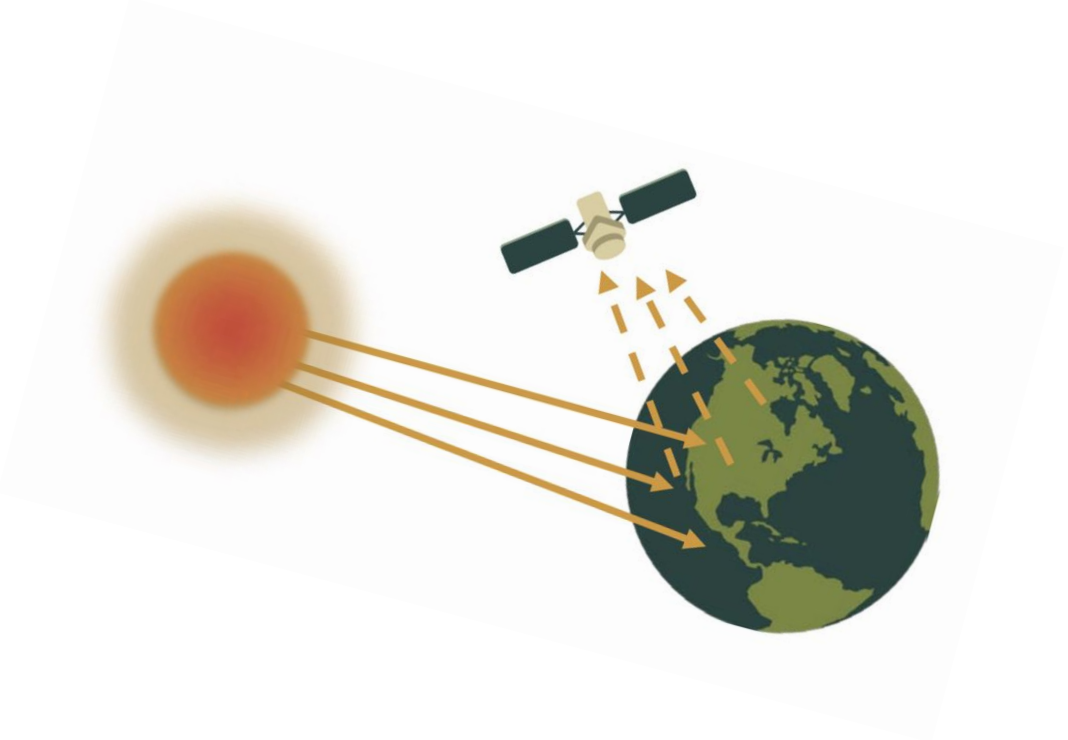


Illustration: NASA Applied Remote Sensing Training Program

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Active sensors

Active remote sensors provide their own energy source for illumination, typically in the microwave EM spectrum:

- Able to penetrate through clouds as well as ‘see’ through the night
- Useful to identify forest structure, precipitation and winds, sea surface topography, and ice
- Examples: LiDAR, RADAR, Laser Altimeter

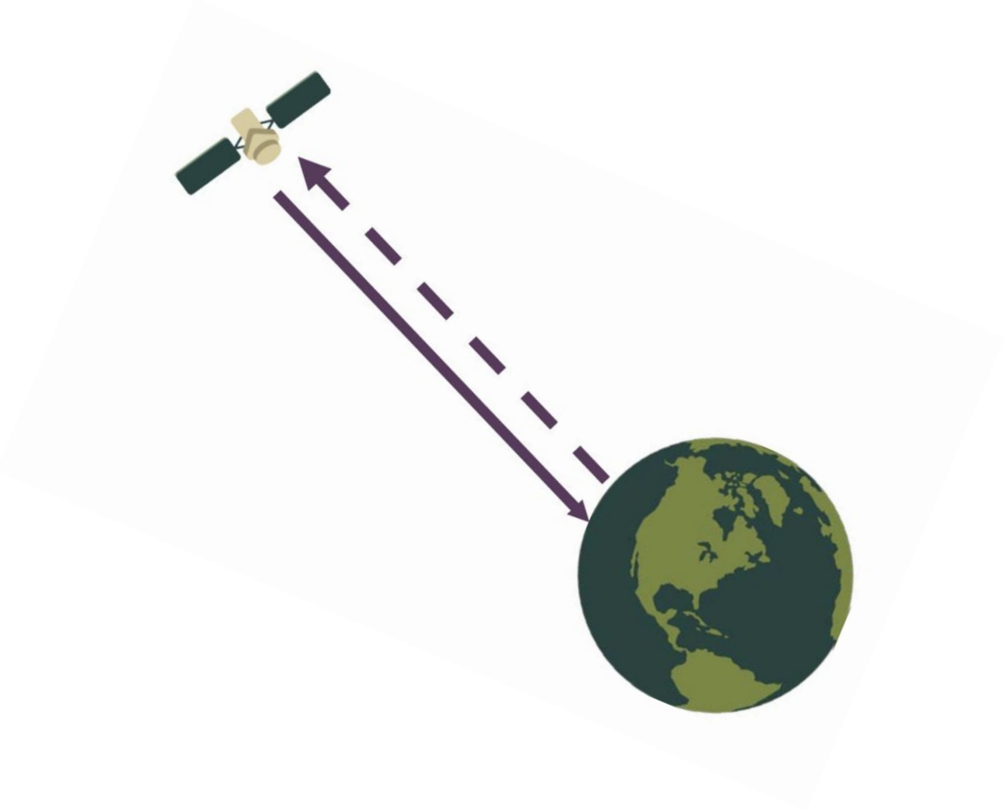

Illustration: NASA Applied Remote Sensing Training Program

Multispectral sensors

- Sensors monitor wavelengths in bands
- Typically, we call sensors **multispectral** if they can measure values in 3 to 10-15 bands
- **Hyperspectral** sensors are those that can observe 100s or 1000s of (narrower) bands. They have very high *spectral resolution*
- Sentinel-2 (pictured) MultiSpectral Instrument samples 13 spectral bands at different *spatial* resolutions (4 at 10m, 6 at 20m, 3 at 60m)

Image: European Space Agency

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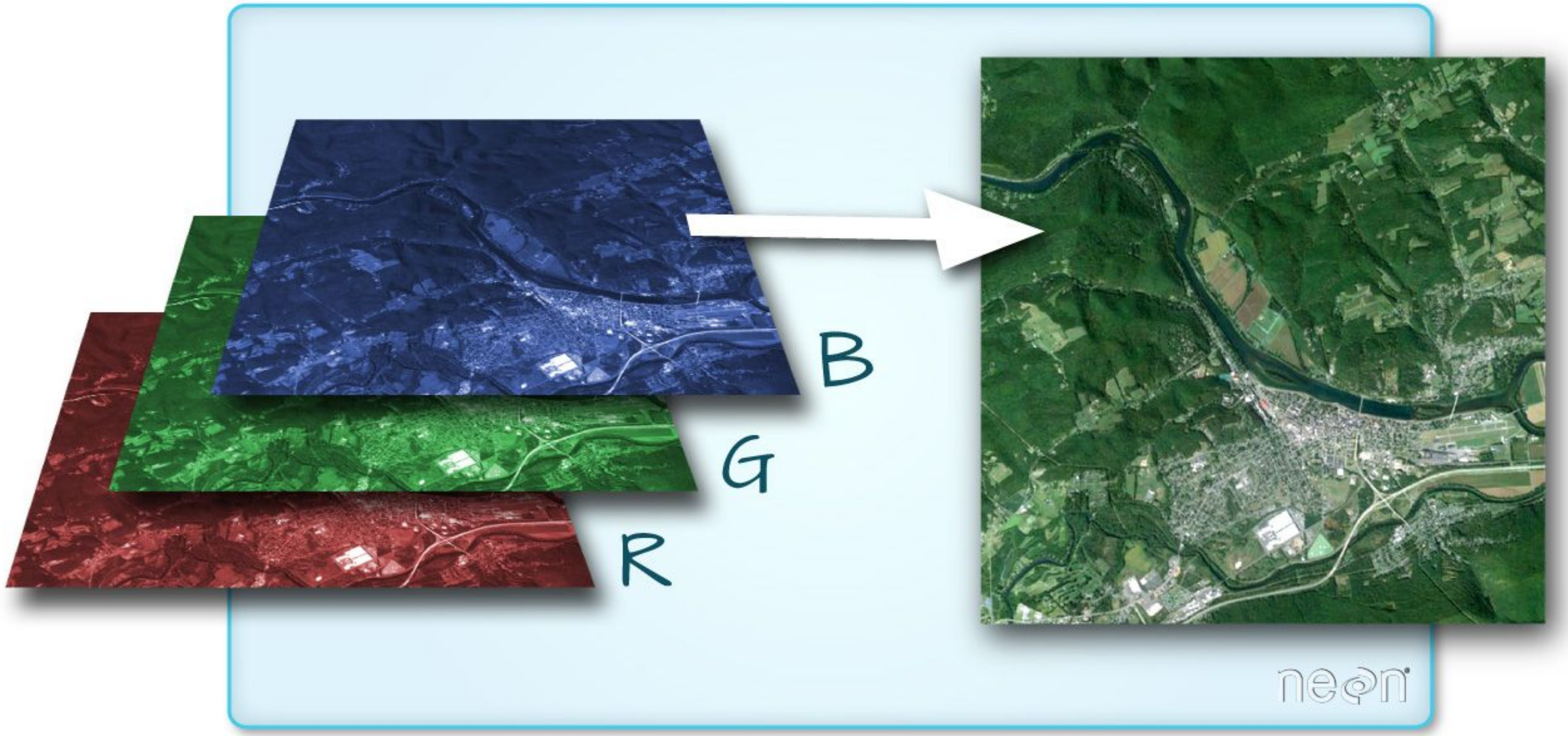
When added, Red, Green, and Blue wavelengths produce an image our eye is accustomed to

Illustration: Colin Williams, NEON



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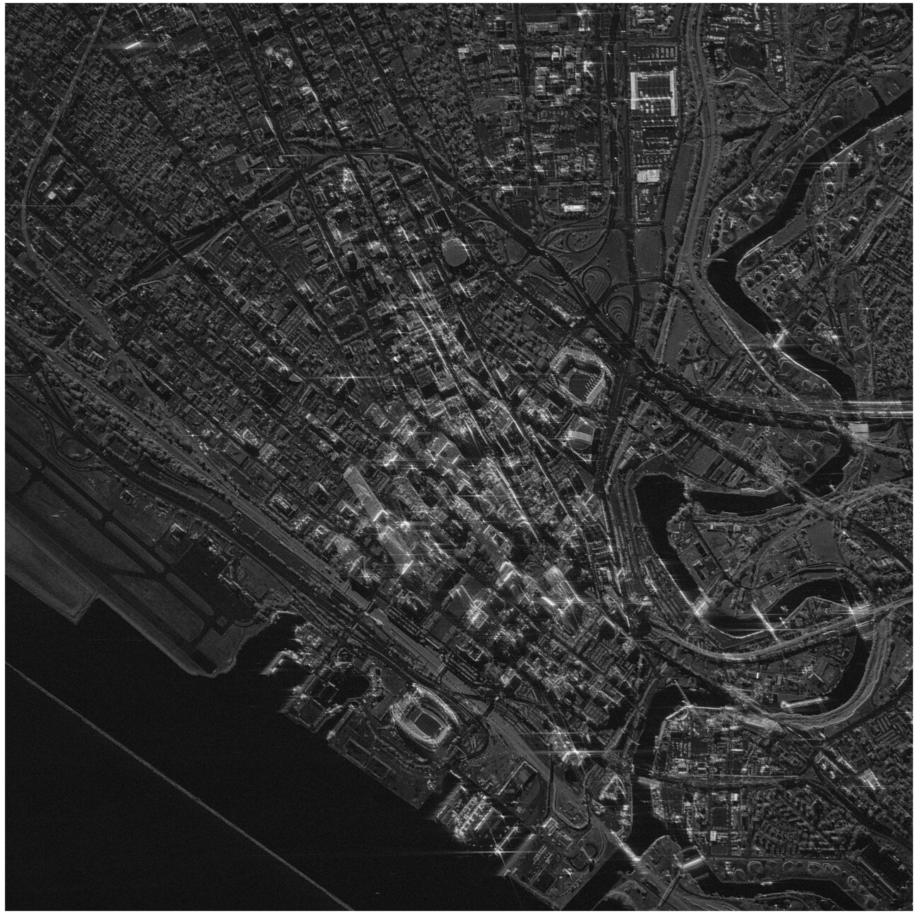
Radar and Synthetic Aperture Radar (SAR) sensors

- Radar sensors are ***active*** sensors that use longer wavelengths (centimeter to meter scale)

- Can “see” through the clouds unlike optical sensors. The longer the wavelengths, the better the object penetration

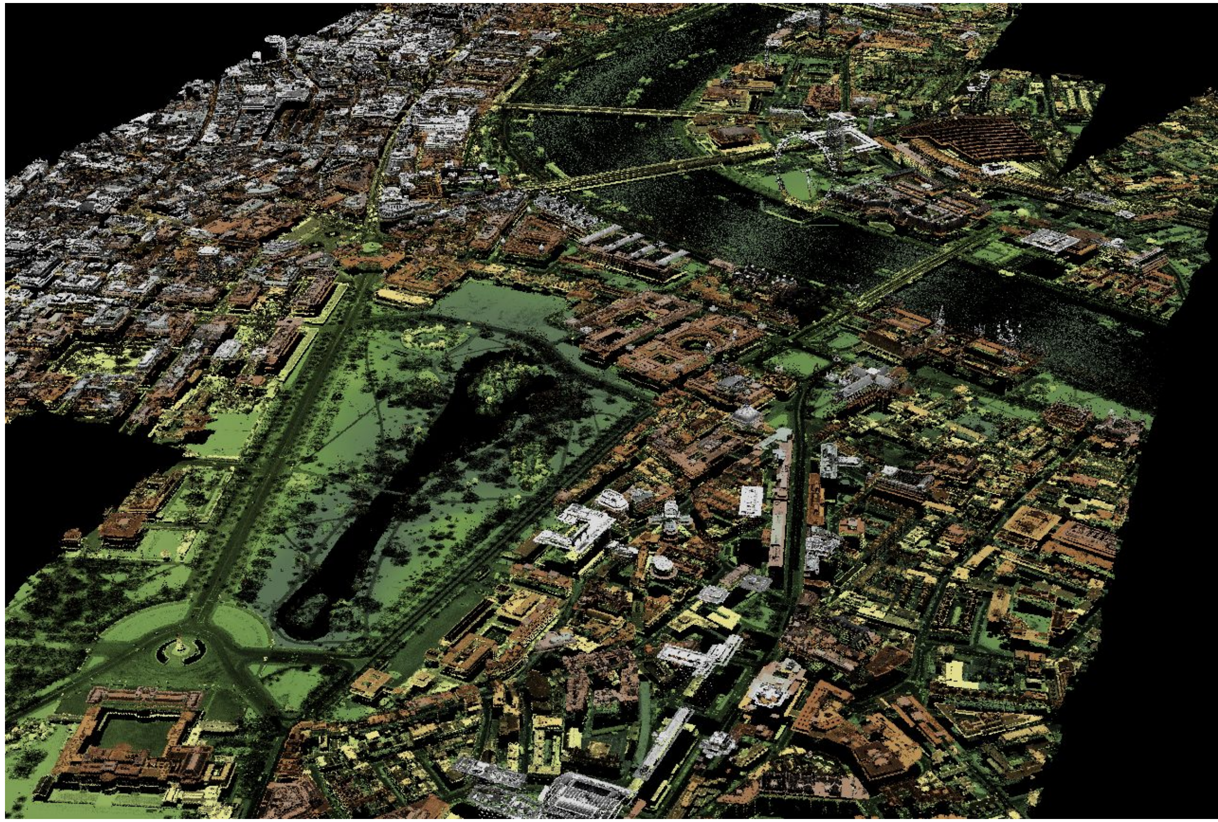
- Sentinel-1A is the first satellite to provide free SAR imagery in 2014



SAR imagery of Cleveland, Ohio by Umbra

LiDAR sensors

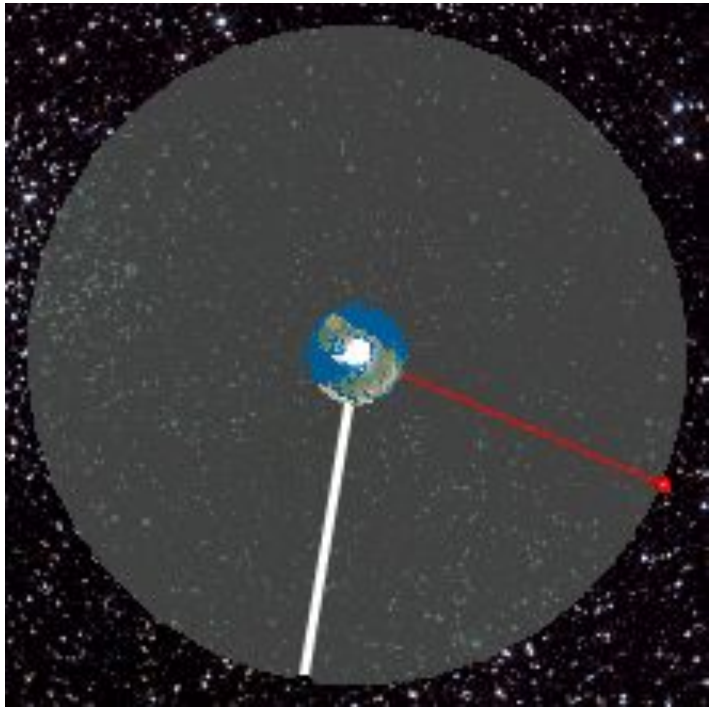
- "Light detection and ranging"
- Targets objects with a laser and records how long it takes for the light to return (***active*** sensors)
- Usually installed on drones or planes
- UK has produced 1m resolution LIDAR imagery for all of England - see https://digimap.edina.ac.uk/lidar



Data Acquisition and Platforms

Satellites - Geostationary Orbit

- Satellite flies above the equator at height of ~36,000km and follows the Earth's rotation
- Multiple daily observations
- Limited spatial coverage (always the same observation area)
- Typically communications and weather satellites



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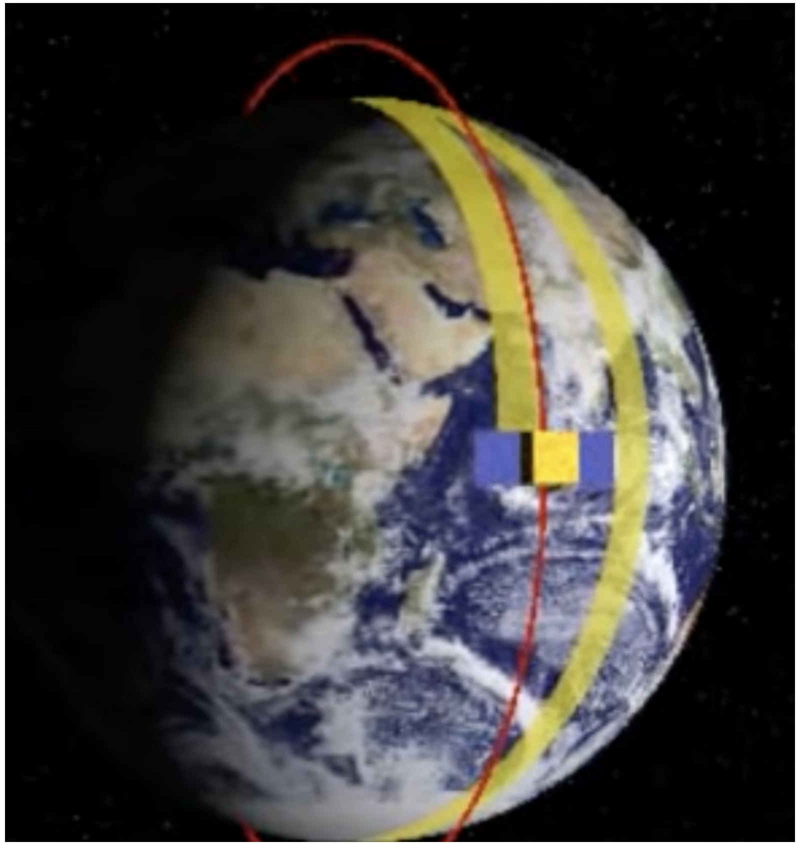
Satellites - Polar Orbit

- Satellites pass above or nearly above both poles
- Orbit is often **Sun-Synchronous (SSO)**, meaning satellites pass same spot at same time of day (e.g. London at 2pm)
- Typically fly at 700-800 km with orbital period of ~100 minutes producing global coverage in 1-30 days depending on how wide the observed path is
- Applications in Earth mapping, reconnaissance (“spying”), sometimes weather



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Aerial remote sensing

- During WWI, Germans were flying pigeons with attached mini cameras! (pictured)
- Today done using unmanned aerial vehicles (UAVs, or drones) and planes with attached sensors, such as cameras or LiDAR
- For example, Historic England uses aerial photography to monitor the condition of heritage assets (both natural and man-made)

Ground-based stations

- Cameras, ground vehicles, towers, cranes, buoys, boats… (Anything you can attach a sensor to)

- Useful for frequent but local observations

- Provide high resolution at small cost

Pictured is the weather radar OU-PRIME at the University of Oklahoma

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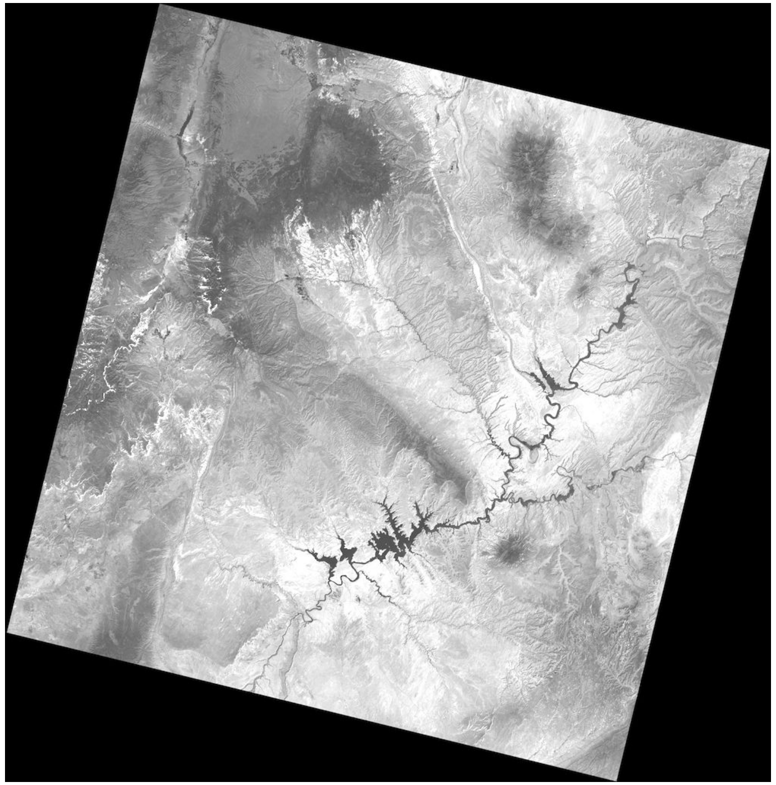
Remote Sensing in Data Science

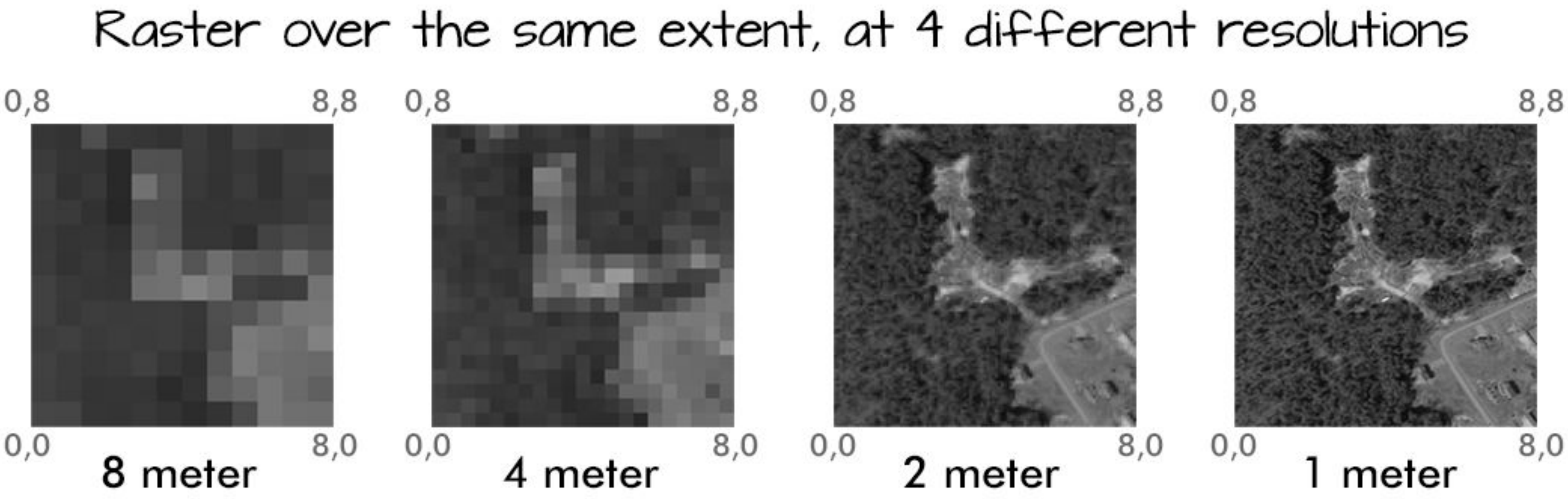
Raster files



- Typically, remote sensing data comes in raster files
- Raster files represent a (usually) square grid that is "mapped" to a real-world area at a particular resolution (for example, 1 cell = 30x30m). Most popular file format is GeoTIFF
- Each cell has 1 or more numeric values associated with it. Imagery from multispectral sensors may come in multiple files, one for each band
- The higher the spatial resolution, the larger the file

Spatial resolution example

Illustration: Colin Williams, NEON



Using `rasterio` to work with GeoTIFF files in Python

```
import rasterio

dataset = rasterio.open('example.tif')

dataset.width # returns width (in pixels)
dataset.height # returns height (in pixels)
dataset.count # returns number of bands

dataset.bounds # returns bounding box coords
dataset.crs # returns coordinate system
```

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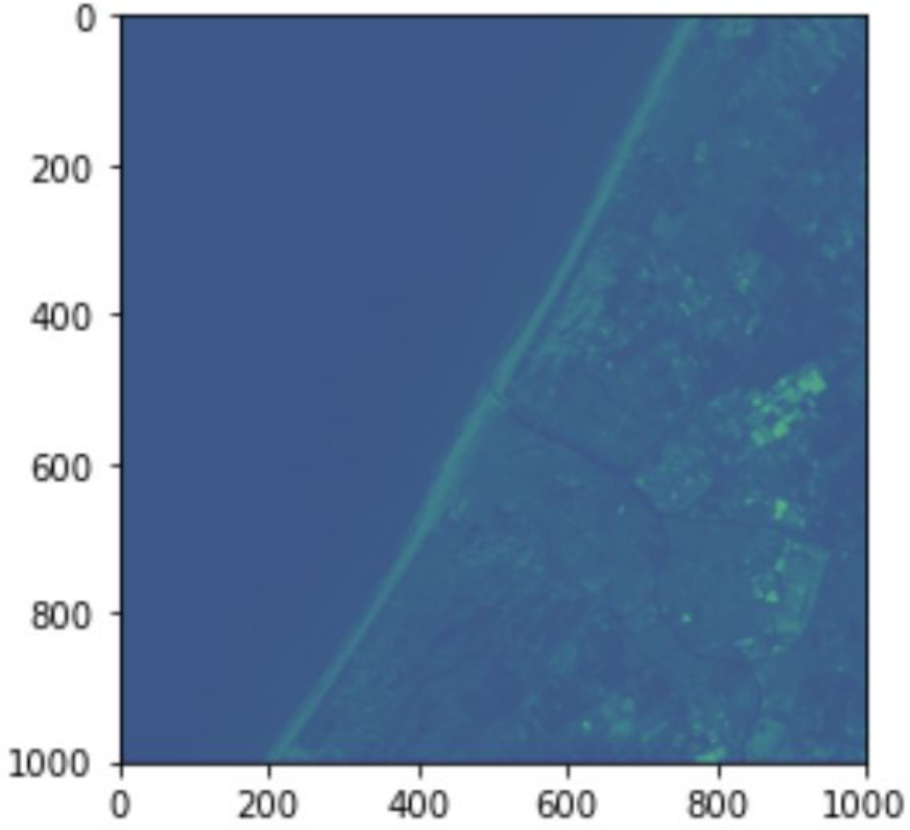
Using `rasterio` to work with GeoTIFF files in Python (2)

```
import matplotlib.pyplot as plt

print(dataset.count) # prints 3

# Read first band in 2D numpy array
band1 = dataset.read(1)

# Show rescaled values
plt.imshow( band1 ** (1/2) )
```



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Using `rasterio` to work with GeoTIFF files in Python (3)

```
print(band1)
```

```
[42]: band1

[42]: array([[   0,  799,  788, ..., 1061, 1433, 2430],
             [   0,  774,  792, ..., 1027, 1125, 1733],
             [   0,  797,  801, ..., 1046, 1040, 1100],
             ...,
             [   0,  826,  837, ..., 1562, 1489, 1740],
             [   0,  804,  825, ..., 1553, 1582, 1619],
             [   0,    0,    0, ...,    0,    0,    0]], dtype=uint16)
```

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What to do with remote sensing imagery

- Working with remote sensing images is largely working with 2D arrays (matrix algebra)

- For example, we can calculate various **Indices** based on different band values for the same pixel to identify pixel properties

- Or we could use pixel- and object-based algorithms to perform **feature extraction, land cover classification and segmentation**

Identifying vegetation

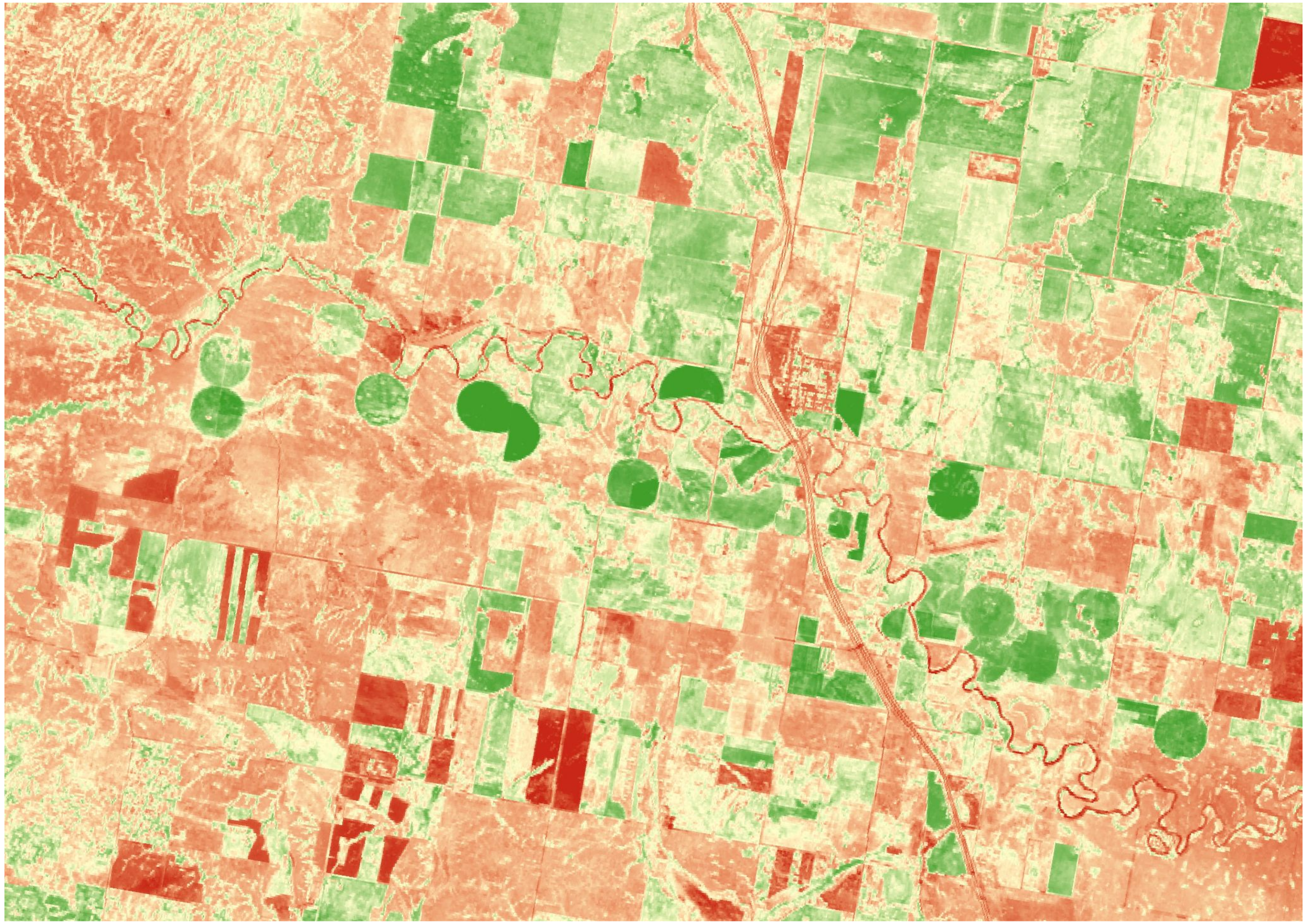
If we have near-infrared (NIR) and Red band values, we can calculate **Normalised Difference Vegetation Index (NDVI)** to detect presence of vegetation in the study area

Note that thresholds are flexible and should be chosen based on task

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})}$$

- Deserts, soil without vegetation would have low positive values (0.1-0.2)
- Vegetation would have NDVI values of 0.3+ (denser canopy will have values of up to ~0.8)
- Clouds and bodies of water may have negative values

Identifying vegetation (2)



NDVI of the area along the Milk River in Alberta, Canada, 2016

Green is high NDVI values (vegetation), red is low NDVI values representing dry patches and bodies of water

Source: US Geological Survey

Identifying water

If we have near-infrared (NIR) and either short-wave infrared (SWIR) or green band values, we can calculate **Normalised Difference Water Index (NDWI)** to detect presence of water in the study area

Note that thresholds are flexible and should be chosen based on task

$$\mathrm{NDWI} = \frac{(Xgreen - Xnir)}{(Xgreen + Xnir)}$$

positive values represent “wet” features (0.5+ are bodies of water)

Alternatively,

$$\mathrm{NDWI} = \frac{(Xnir - Xswir)}{(Xnir + Xswir)}$$

values of 0.3+ represent water

Classification in Remote Sensing

Unsupervised (Clustering)

- Common clustering algorithms are K-Means and ISODATA
- Labelling of clusters happens after classification, typically by a human expert
- Clustering is traditionally done at pixel-level

Supervised (Classification)

- We first create a training set of *representative* pixels with their relevant labels
- We then pick an ML algorithm to perform classification, such as K-Nearest Neighbours, Logistic Regression, Random Forest, PCA, SVM…

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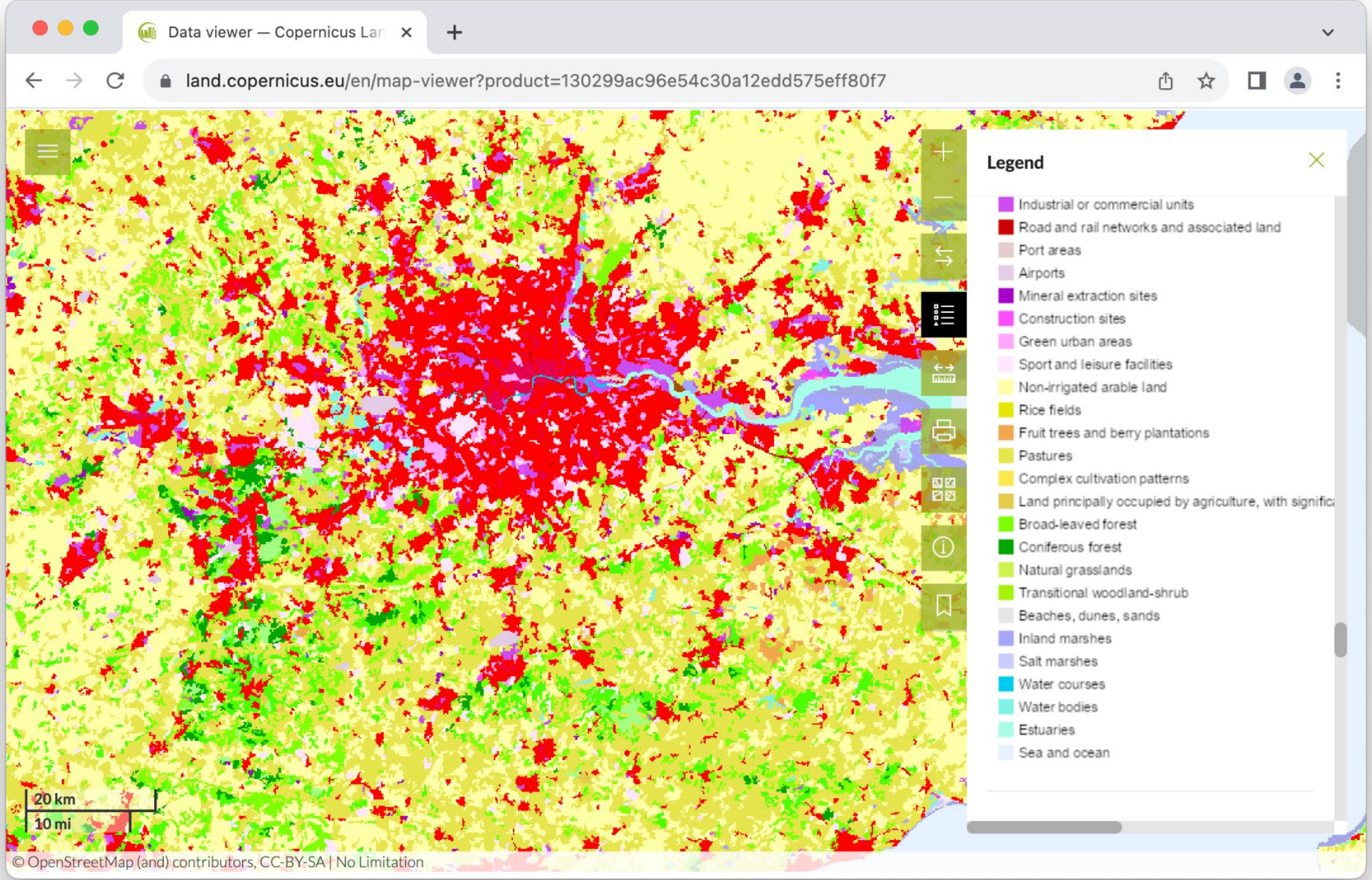
CORINE Land Cover



"CORINE Land Cover (CLC) product offers a pan-European land cover and land use inventory with 44 thematic classes, ranging from broad forested areas to individual vineyards"

Accessible via:

https://land.copernicus.eu/en/map-viewer

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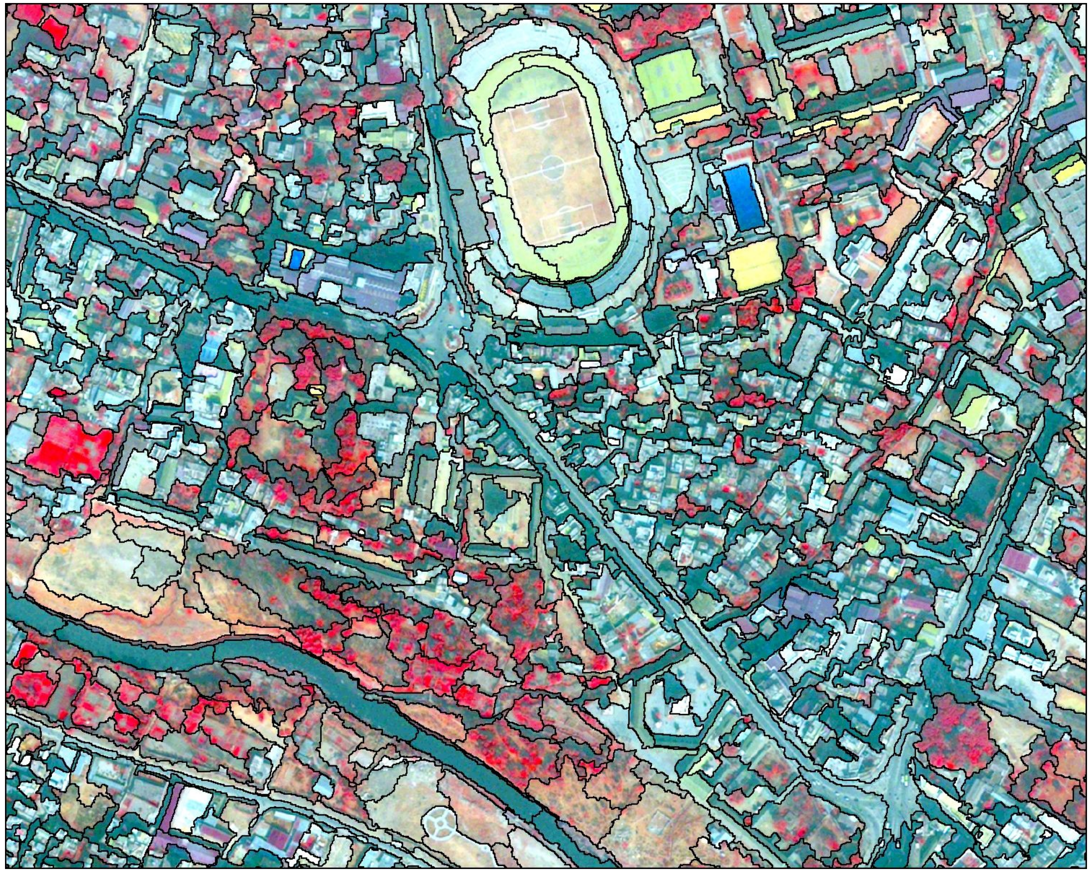
Object-Based Image Analysis (OBIA)

- Supervised and unsupervised algorithm from the previous slide are both pixel-based

- OBIA groups similar pixels into vector shapes using **multi-resolution segmentation**
  - You can choose to perform segmentation focusing on shape, texture, spectral signature
  - And classification is then performed on objects, not individual pixels



Object Detection Using ML/AI

- To perform automatic object detection, algorithms based on **Convolutional Neural Network** architecture are often used

- These include Region-based CNNs (R-CNNs), Faster R-CNNs, Mask R-CNN

- **You Only Look Once** (YOLO)

- **Transfer learning** (fine-tuning pre-trained image models on a small subset of new imagery) is also popular

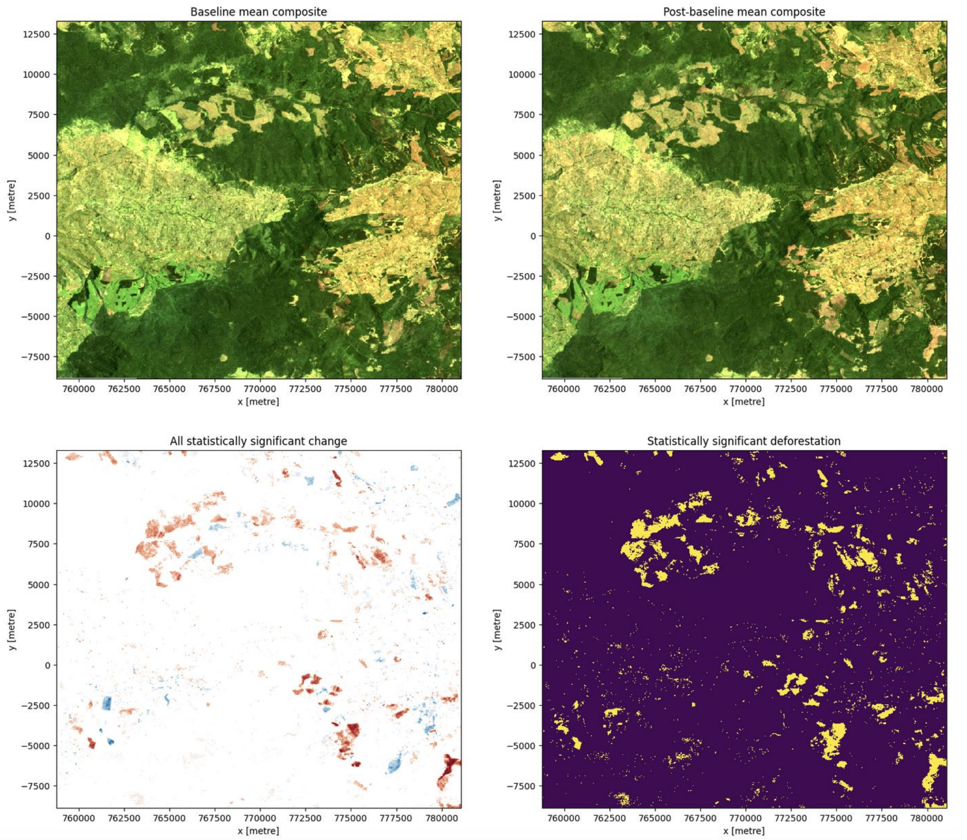
Image: https://link.springer.com/article/10.1007/s11042-021-10833-z/figures/9

Change Detection Using ML/AI

- Change detection can be as simple as finding the difference in band values between the two images, and reclassifying difference values as “change” (higher difference values) or “no change” (lower difference values)

- Most algorithms for supervised pixel-based classification can be repurposed to detect pixel-based changes between images
  - Label pairs of pixels as ‘change’ or ‘no change’ between timestamps and let the ML decide

- In addition to pixel-based, we can analyse changes at object-level (by first using object detection in imagery)



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Time-Series Analysis of Remote Sensing Imagery

- As we accumulate more remote sensing imagery, we can perform temporal analysis to detect various changes on the planet, from crops growing over the summer to coastal erosion and urbanisation processes

- Much easier to compare imagery from the same observation programmes as sensors and resolution will be the same

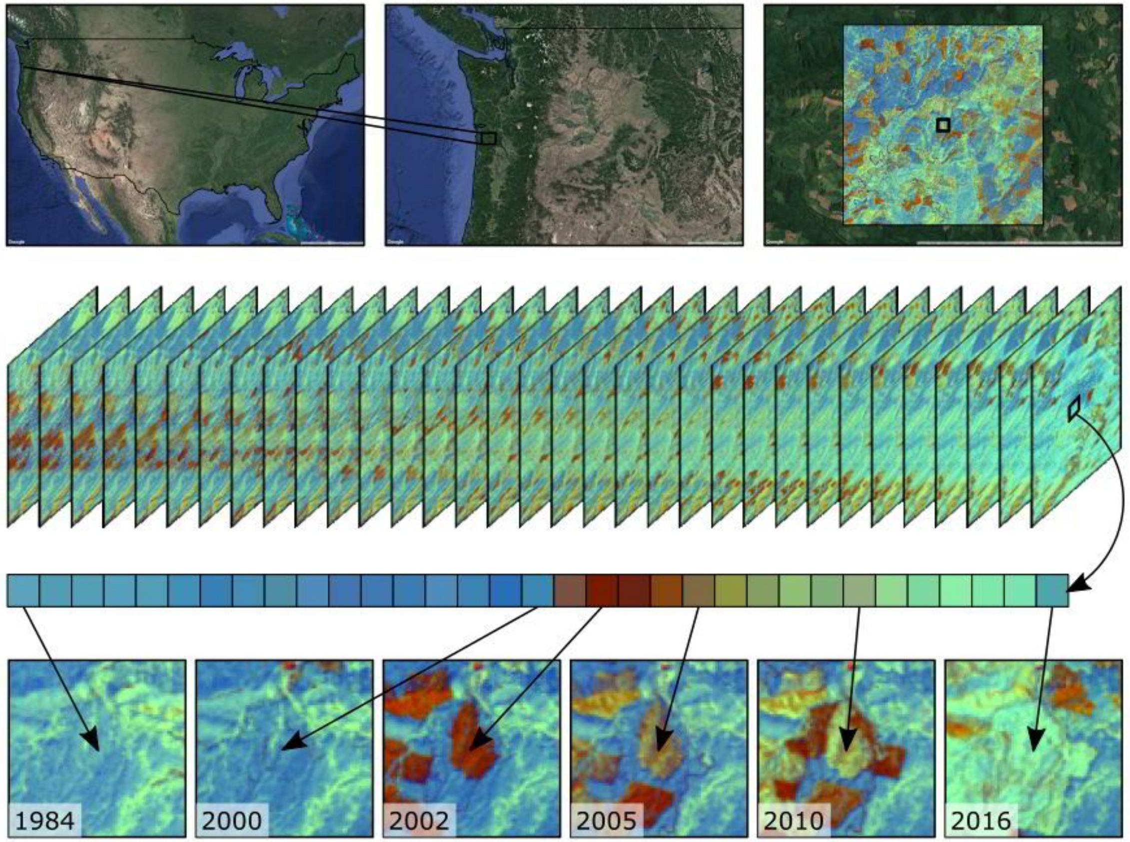


Image: https://emapr.github.io/LT-GEE/landtrendr.html

Time-Series Analysis of Remote Sensing Imagery (2)

1. Extract values for each relevant band, for each relevant pixel from different time periods

2. Standardise pixel values between time periods
   - Ensure spectral fidelity between sensors (use calibrated surface reflectance values if possible)
   - Fill in gaps (good luck with the clouds!)
   - Resolve outliers
   - Smooth and “detrend” data if needed

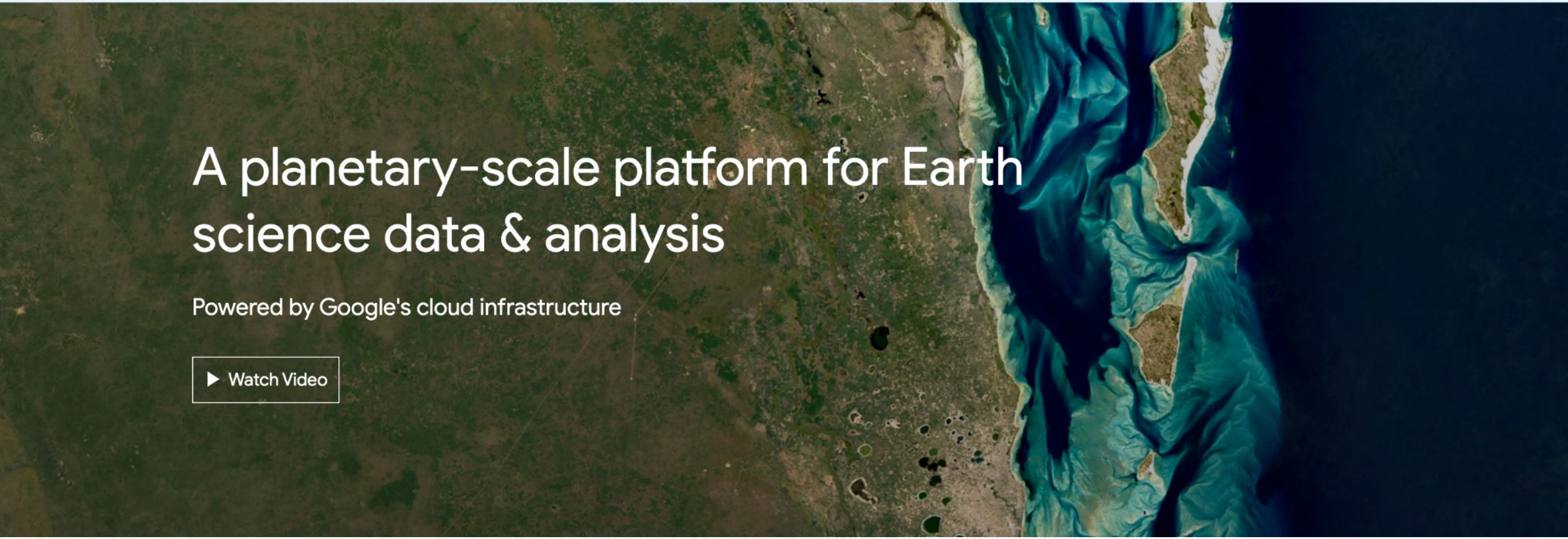
3. Apply a relevant algorithm, for example
   - LandTrendr
   - Continuous Change Detection and Classification (CCDC)

Intro to Google Earth Engine (GEE)

Google Earth Engine

Platform | Datasets | Noncommercial | Commercial | Timelapse | Case Studies | FAQ | Get Started

Earth Engine for commercial use: now generally available with Google Cloud. Get more details here



What is Google Earth Engine (GEE)?

- Traditionally, working with GIS has been desktop-based. You find, download and analyse data locally on your machine

- But it doesn't work well when dealing with large files and computationally expensive ML algorithms, as you are likely to run out of RAM, or storage space, or patience

- **Google Earth Engine** is one of the leading tools to work with remote sensing imagery at scale, fully in the cloud. It provides data + computational power

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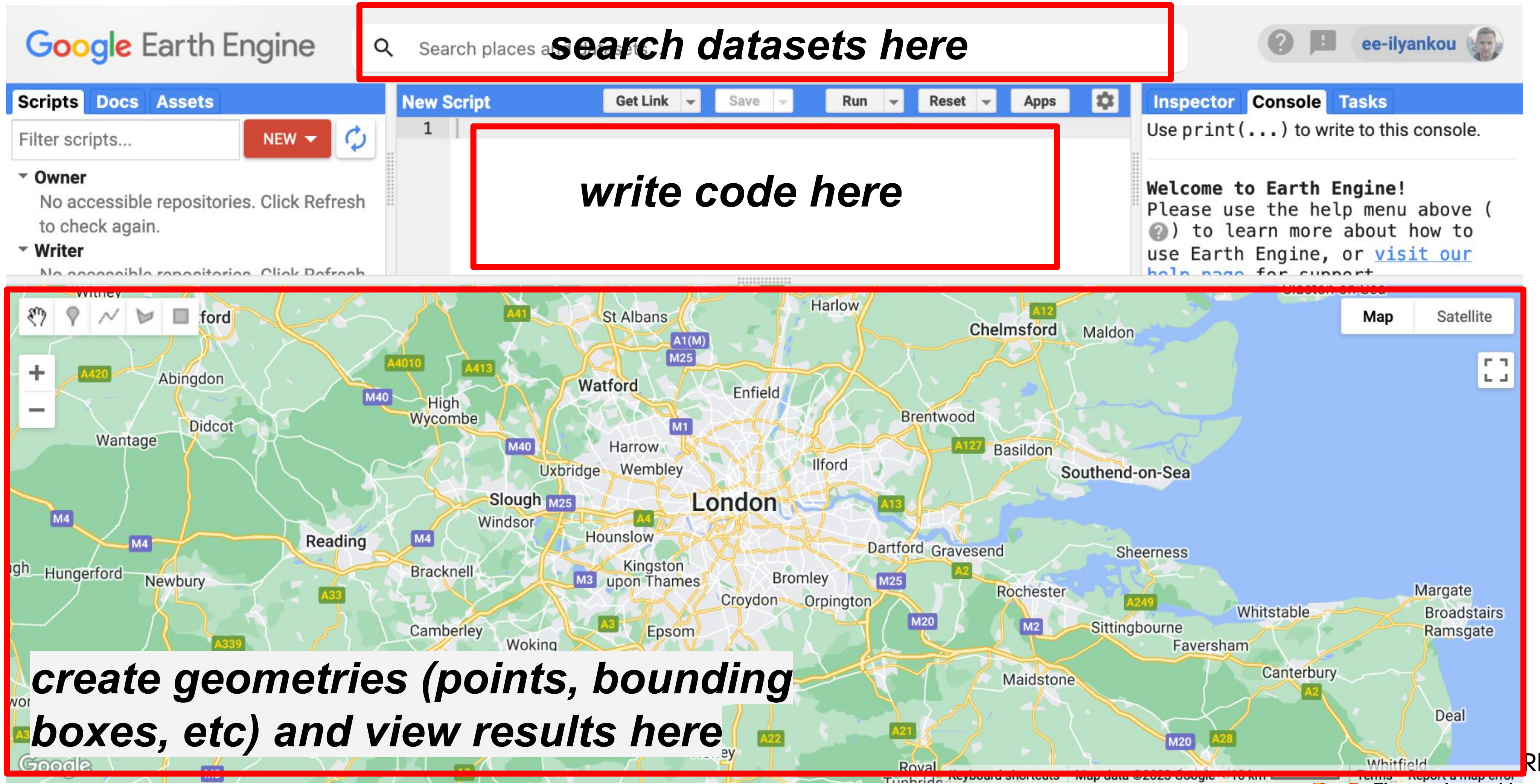
What makes GEE great?

- Free for academic and non-profit use
- A **multi-petabyte** catalogue of data (updated daily) that can be easily imported and analysed. This includes Landsat and Sentinel imagery, land use, historic weather data…
- Built-in algorithms, from simple band arithmetics to ML tools
- Expects code written in JavaScript, but provides a Python API

GEE Interface



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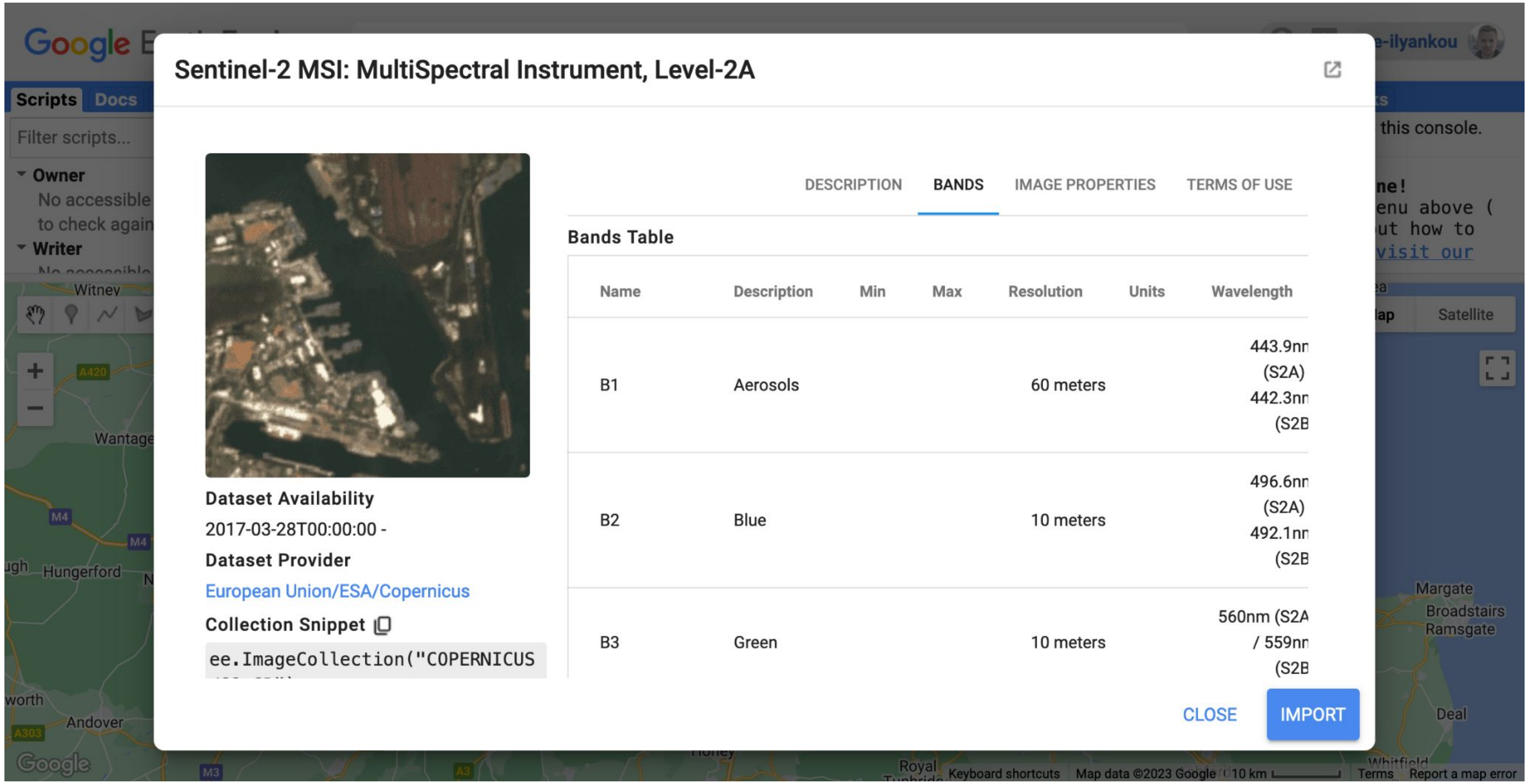
See dataset metadata in GEE



Create NDVI in GEE

```
// 1 - Import the relevant image collection (e.g. Sentinel 2, call it " landsat8")
// 2 - Use "Add a marker" to create the anchor point (" centralLondon")

var image = ee.Image(
  landsat8.filterBounds(centralLondon)
     .filterDate('2023-01-01', '2023-12-31')
     .sort('CLOUD_COVER')
     .first() // get least cloudy image in 2023
);

// Compute the Normalized Difference Vegetation Index (NDVI)
var nir = image.select('B5');
var red = image.select('B4');
var ndvi = nir.subtract(red).divide(nir.add(red)).rename('NDVI');

// Display the result.
Map.centerObject(image, 9);
var ndviParams = {min: -2, max: 2, palette: ['blue', 'white', 'green']};
Map.addLayer(ndvi, ndviParams, 'NDVI image');
```

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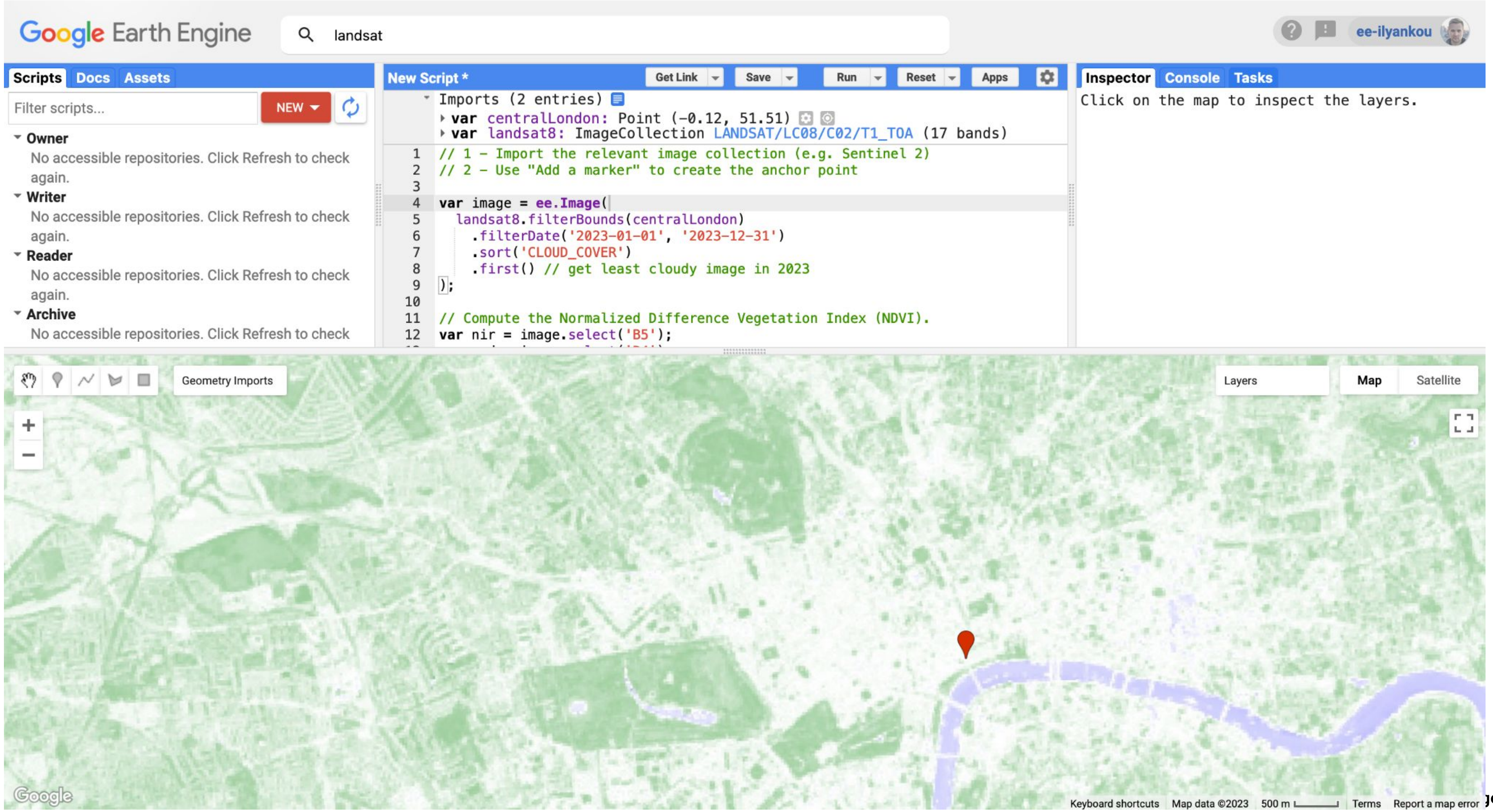
Create NDVI in GEE (2)

```
// 1 - Import the relevant image collection (e.g. Sentinel 2, call it " landsat8")
// 2 - Use "Add a marker" to create the anchor point (" centralLondon")

var image = ee.Image(
  landsat8.filterBounds(centralLondon)
    .filterDate('2023-01-01', '2023-12-31')
    .sort('CLOUD_COVER')
    .first() // get least cloudy image in 2023
);


var ndvi = image.normalizedDifference(['B5', 'B4']).rename('NDVI');



// Display the result.
Map.centerObject(image, 9);
var ndviParams = {min: -2, max: 2, palette: ['blue', 'white', 'green']};
Map.addLayer(ndvi, ndviParams, 'NDVI image');
```

Create NDVI in GEE (3)



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Export as GeoTIFF from GEE

1. Using GUI, create a new bounding polygon called **centralLondonPoly**

2. Run the following to generate an image to GDrive:

```
Export.image.toDrive({
  image: ndvi,
  description: 'NDVI_London',
  scale: 30, // metres per pixel
  region: centralLondonPoly
});
```

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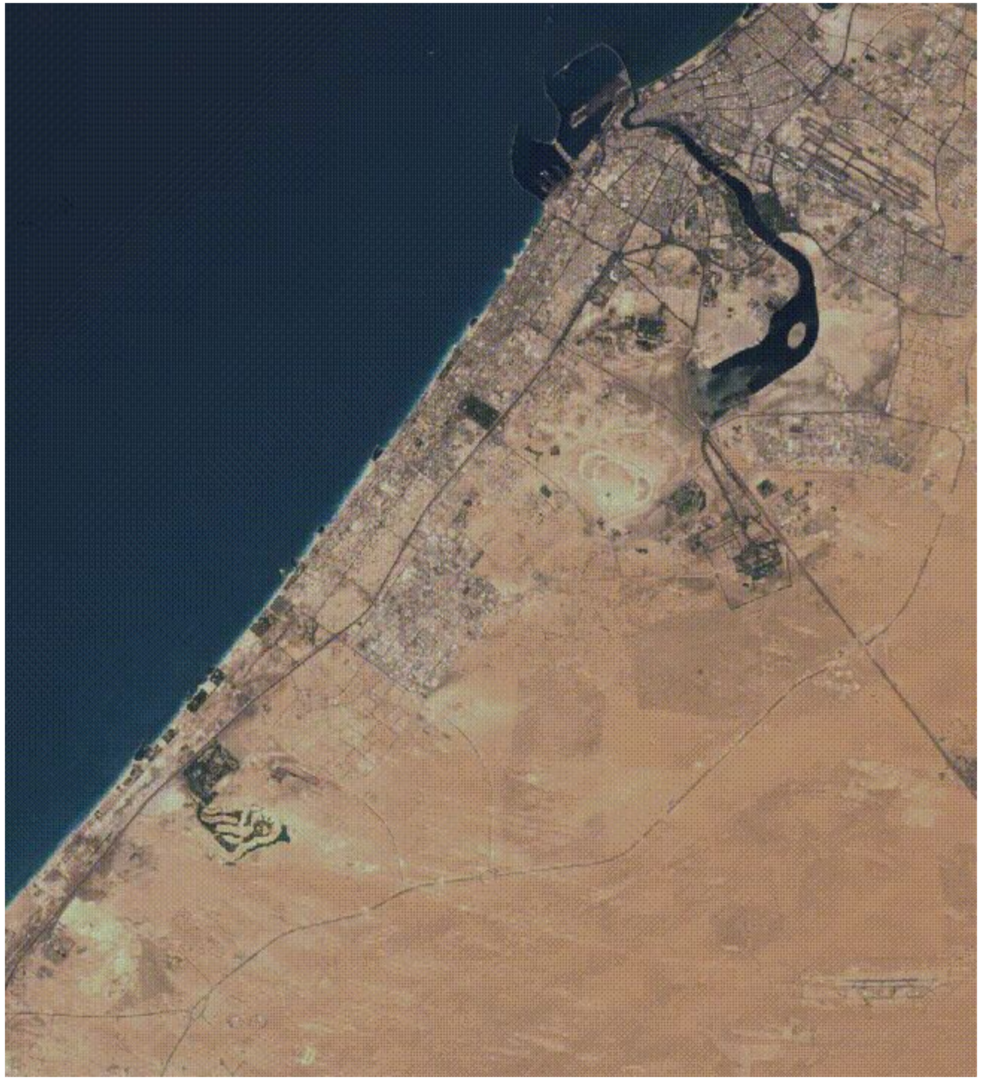
Create a timelapse in GEE



```
var allImages =
ee.ImageCollection('LANDSAT/LE07/C02/T1_RT_TOA')
 .filter(ee.Filter.eq('WRS_PATH', 160))
 .filter(ee.Filter.eq('WRS_ROW', 43))
 .filter(ee.Filter.lt('CLOUD_COVER', 30))
 .filterDate('2000-01-01', '2023-12-30')
 .select(['B3', 'B2', 'B1'])
 .map(function(image) {
  return image.multiply(512).uint8();
 });
Export.video.toDrive({
 collection: allImages,
 description: 'dubaiTimelapse',
 dimensions: 720,
 framesPerSecond: 8,
 region: ee.Geometry.Rectangle([55.1, 25.0,
55.4, 25.3])
});
```

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Applications of Remote Sensing

Agriculture 🌾

Crop health monitoring

- Vegetation indices (NDVI, NVI) help track health of crops and identify areas of disease or vegetation stress
- Can help predict yield

Precision agriculture

- Crop type mapping
- Optimised irrigation (water only where and when needed)
- Nutrient management

Environmental monitoring 🌳

Deforestation

- Using change detection in vegetation indices to track areas of declining vegetation

- Identify forest fires and areas of illegal logging

Urbanisation

- Classify land use, track changes in urban sprawls

- Estimate population and predict future growth in places with unreliable census

Glacier retreat

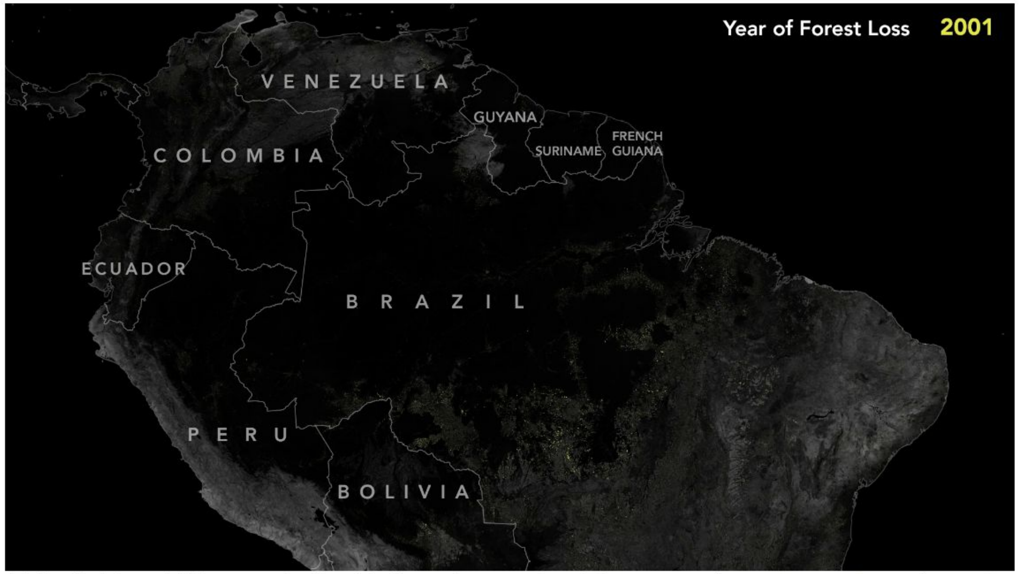
- Using time-series analysis of satellite imagery to map ice cover to help make sense of global warming

Maps Articles Blogs

NASA earth observatory

EO Exp

Tracking Amazon Deforestation from Above



Editor's Note: This story is the third part in a series. Please read part 1, part 2, and part 4 for a more complete picture of Amazon deforestation.

Scientists have used satellites to track the deforestation of the Amazon rainforest for several decades — enough time to see some remarkable shifts in the pace and location of clearing.

View this area in EO Explorer

Satellites have played a key role in monitoring and reducing the rate of deforestation in the rainforest.

Image of the Day for December 20, 2019

Instruments:
Landsat 5
Landsat 5 — TM
Landsat 7
Landsat 8
Landsat 8 — OLI

Appears in this Collection:
Amazon Deforestation

Deforestation of the Amazon rainforest is a well-researched subject that makes extensive use of remote sensing imagery

Source: NASA Earth Observatory

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Disaster management: Flood, wildfire, and hurricane tracking and prediction

- Most types of *early warning systems* rely on remote sensing data to monitor phenomena (weather, river levels…) **to predict** destructive outcomes

- Remote sensing can help **assess damage**, and facilitate planning of emergency response

- Map floodplains using digital elevation models

- Monitor sea surface temperature, wind and atmospheric conditions to predict development of hurricanes

- Track and predict the movement of hurricanes to minimise casualties

- Use vegetation index to identify drier areas that are more prone to wildfires

- Identify existing fires and smoke using thermal infrared sensors to alert local emergency services

In 2022, the US Department of Defence ran the **xView 3 Challenge** (https://iuu.xview.us/), a $150,000 competition to detect dark vessels using computer vision and global SAR satellite imagery. The winners (individuals and organisations) were announced on 31 January 2022.

“After the [SAR] images are collected, machine learning algorithms paint a detailed picture: where vessels are, how large they are, what they are doing and, based on that information, what are the odds that they are engaging in illegal activity”.

Source: https://www.akbizmag.com/industry/fisheries/illegal-fishing-ai/

Urban planning and infrastructure development 🏙️

- Use satellite imagery to perform land use segmentation and track urban expansion using change detection

- Identify suitable sites for large infrastructure projects by looking at terrain, population, and land cover

- Monitor infrastructure health using satellite imagery, LiDAR data, and "digital twins"

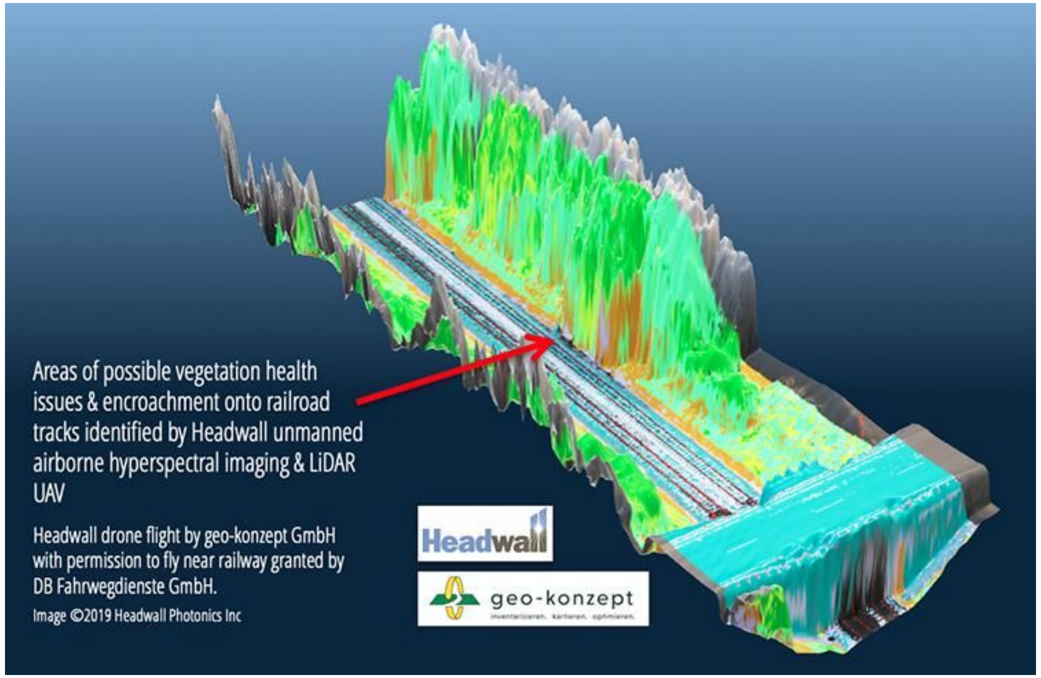

Image: Identifying vegetation and positions of potentially at-risk trees adjacent to the railway, Headwall BVBA + geo-konzept

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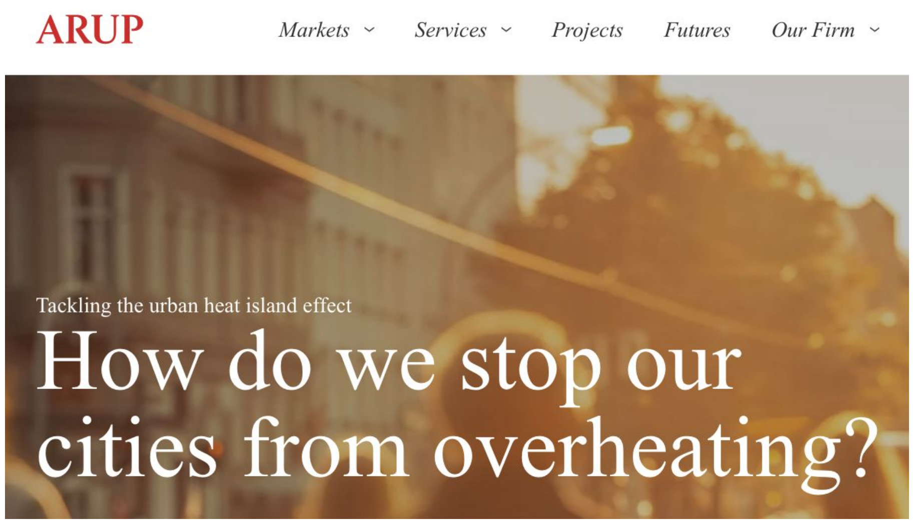
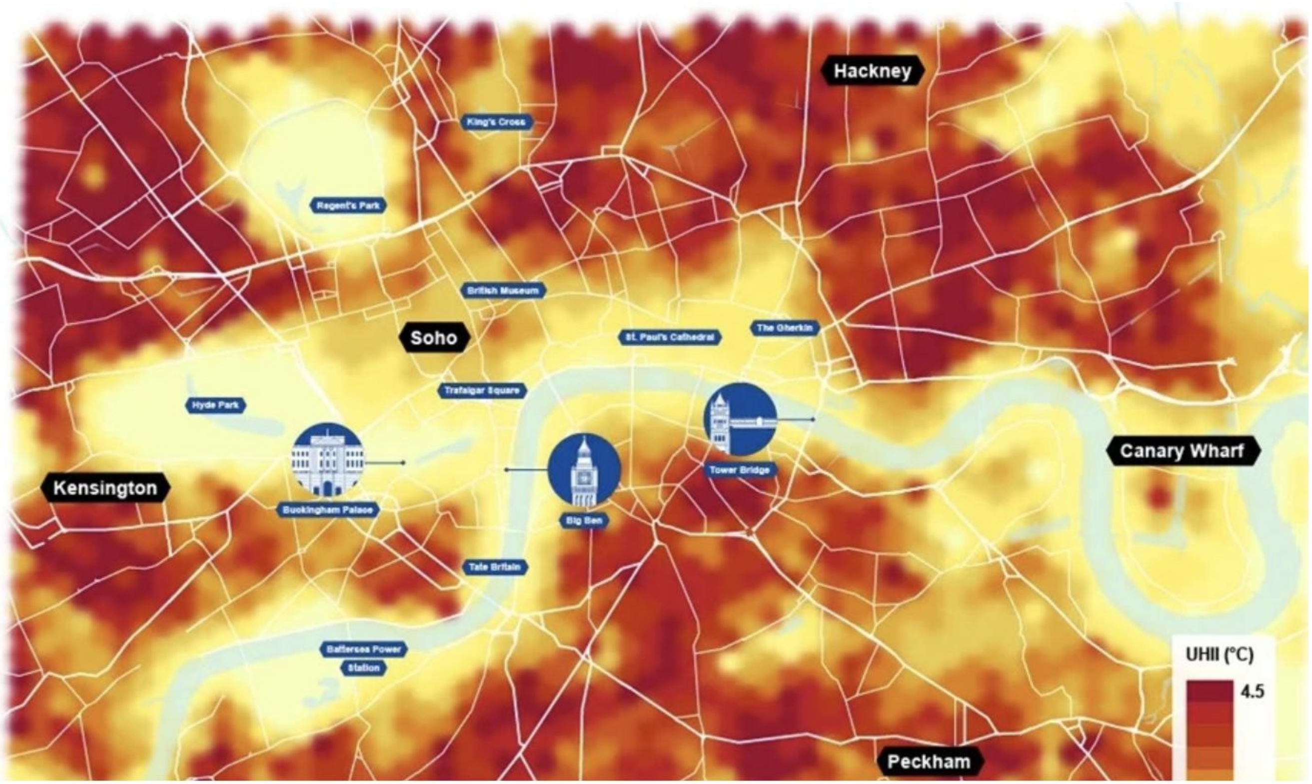
Arup's **Urban Heat Snapshot** report, which used AI + satellite images to perform heat modelling (UHeat)





French tax officials use AI to spot 20,000 undeclared pools

Scheme to be extended across the country after trial in nine departments led to extra €10m in tax receipts

France is believed to have about 3.2m private swimming pools. Photograph: François Lo Presti/AFP/Getty

French tax authorities using AI software have found thousands of undeclared private swimming pools, landing the owners with bills totalling about €10m.

The system, developed by Google and Capgemini, can identify pools on aerial images and cross-checks them with land registry databases. Launched as an experiment a year ago in nine French departments, it has uncovered 20,356 pools, the tax office said on Monday, and will be extended across the country.

French tax authorities used aerial imagery to identify swimming pools (=simple object detection), then cross-check those with the land registry database, and identify those built without permit

Source: Guardian, 29 August 2022

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Challenges and Considerations in Remote Sensing

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Data volume and storage

- We employ more sensors, constantly improving their spatial and temporal resolution → a lot more data that is being captured
- The move from desktop GIS to cloud-first GIS should eliminate this issue, but it comes at a cost, as well as privacy concerns
- In addition to storage, there are issues with data transfers and bandwidth (how to quickly move data from a distant sensor), data redundancy and security concerns
- Can we design “smart” sensors that do most of the processing and output the relevant data only (“edge computing”)?

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Cloud cover and atmospheric interference

- A lot of places are difficult to monitor well due to cloud cover, which is physically impossible to penetrate for shorter waves (think: visible light, red/green/blue)
  - “Missing” values need to be modelled or inferred

- Atmosphere absorbs some EM radiation (for example, ultraviolet radiation is almost entirely blocked by ozone), but does so unevenly depending on atmospheric composition → needs sophisticated algorithms to ‘clean’ values
  - This is usually done by data providers but may be done inconsistently

Ethical considerations: Privacy, surveillance, and geopolitical concerns

- As spatial and temporal resolution of the satellites increases, to what extent should satellites of one country be allowed to collect data on private property and activities of residents of another country?

- Where should remote sensing imagery be stored, and how should it be protected?

- Should we keep or destroy old and/or “unnecessary” data?

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