SATELLITE DATA IN AGRICULTURAL AND ENVIRONMENTAL ECONOMICS

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Winter semester 2026

Land Economics Group

MEO LAB

SATELLITE DATA
IN AGRICULTURAL AND ENVIRONMENTAL
ECONOMICS

UNIVERSITÄT BONN

FROM SATELLITES TO INFORMATION

GEOSPATIAL DATA

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PRESS → OR SPACE. →

Lecture Overview

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1 **Coordinates and Reference Systems**

2 **Remote Sensing**
Optical · Radar



3 **Geo-information Systems (GIS)**

4 **Earth System Models**

Coordinates

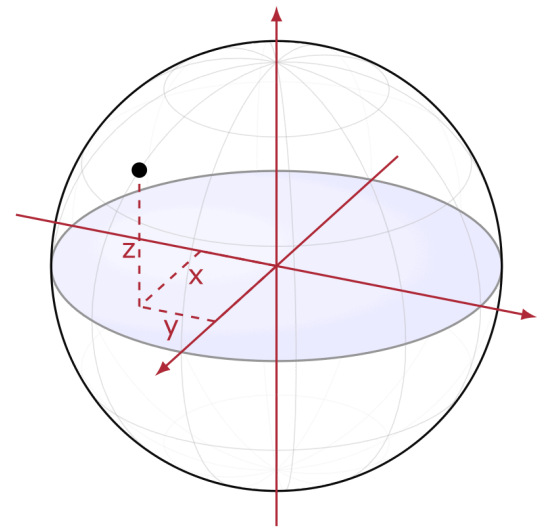
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U.S. Government — Extracted from the PDF version of the ***Vol 26-4 2004 DISAM Journal*** (direct PDF [1]), via **Wikipedia**.

Cartesian Coordinates x,y,z

A location can be represented by three orthogonal coordinates $\mathbf{p} = (x, y, z)$ in an Earth-Centered, Earth-Fixed (ECEF) coordinate system



Spherical Coordinates

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Expressing location on the surface of Earth is often more practical than working directly in 3D Cartesian coordinates $x, y, z \mapsto \lambda, \varphi, r$ of longitude λ, latitude φ, and constant radius r

Spherical to Cartesian

$$x = r \cos\varphi \cos\lambda$$

$$y = r \cos\varphi \sin\lambda$$

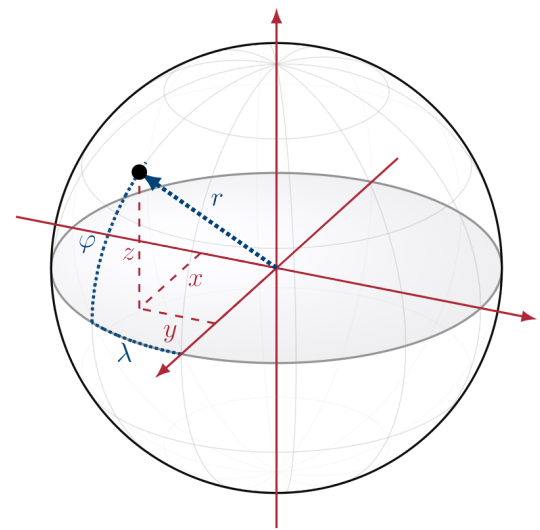
$$z = r \sin\varphi$$

Cartesian to spherical

$$r = \sqrt{x^2 + y^2 + z^2}$$

$$\lambda = \operatorname{atan2}(y, x)$$

$$\varphi = \arcsin\left(\frac{z}{r}\right)$$



Ellipsoidal Coordinates

But the Earth is not a sphere: It is an ellipsoid.

Geodetic to Cartesian

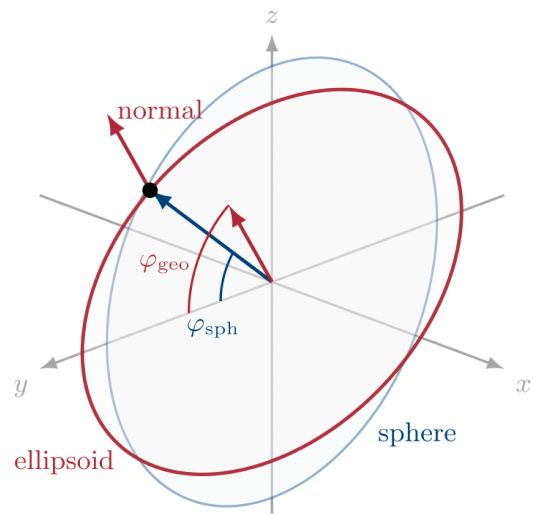
$$
\begin{aligned}
x &= (N(\varphi) + h)\cos\varphi\cos\lambda \\
y &= (N(\varphi) + h)\cos\varphi\sin\lambda \\
z &= \left((1-e^2)N(\varphi) + h\right)\sin\varphi
\end{aligned}
$$

$$
N(\varphi) = \frac{a}{\sqrt{1 - e^2\sin^2\varphi}}
$$

$$
e^2 = \frac{a^2 - b^2}{a^2}
$$

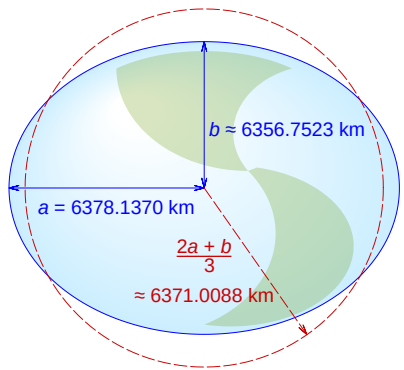
Cartesian to Geodetic

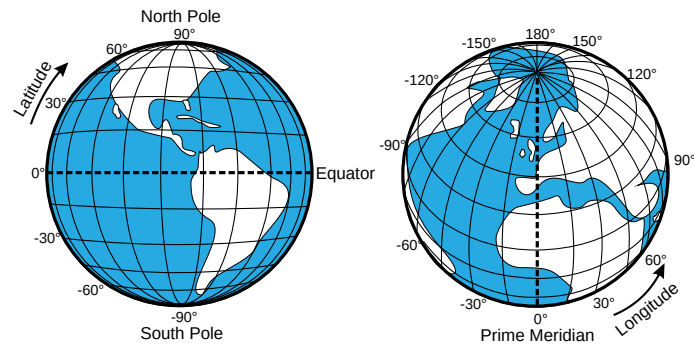
The inverse is usually computed iteratively.
See Wikipedia .



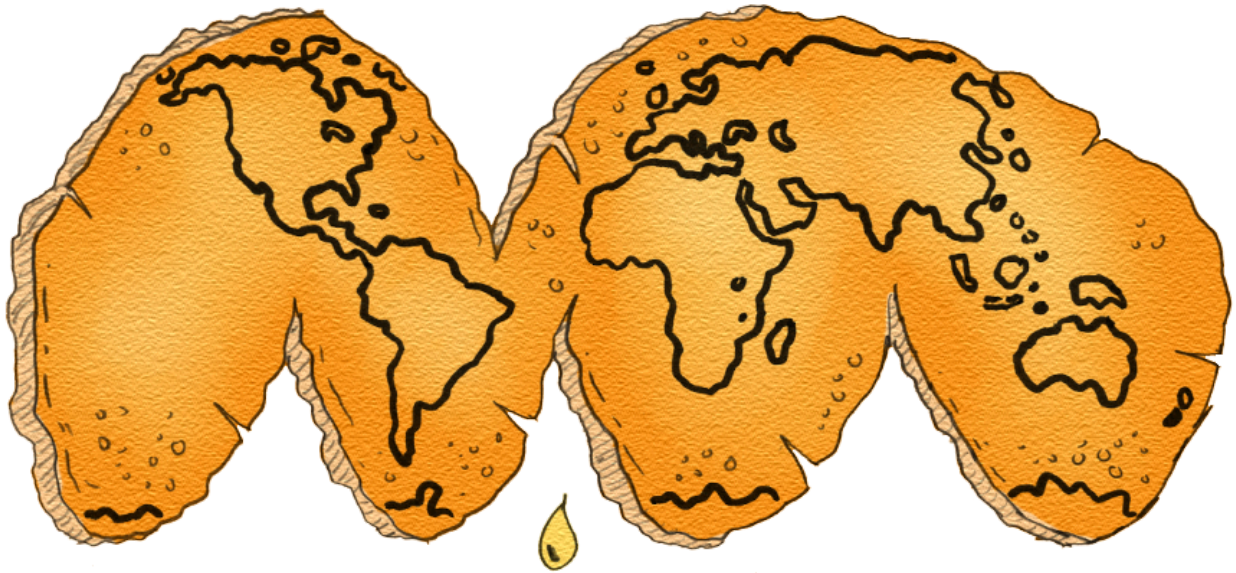
World Geodetic System 1984 (WGS 84)

WGS 84 is the global reference system used by GPS and most web mapping workflows.





Map Projections



Flattening a sphere onto a plane always stretches, tears, or squashes something.

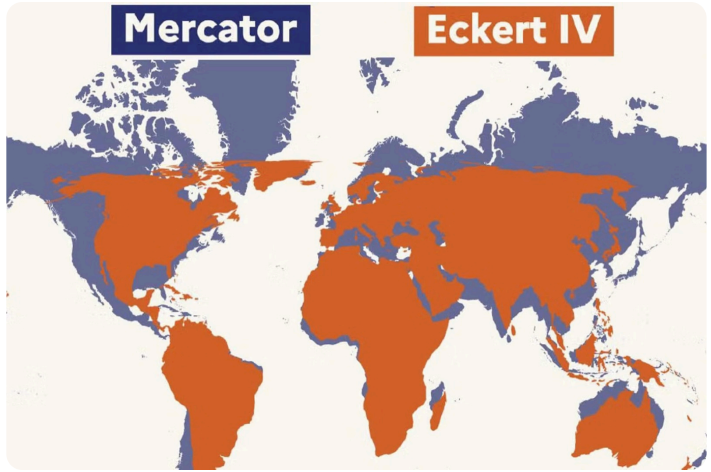
Illustration: Michael Kline, *How To Peel a Planet*, Dogfoose.com (2011).

Equal Angle vs Equal Area

No flat map can preserve all of these at once. Every projection is a **trade-off**:

- **Angles** (conformal), e.g. Mercator
- **Area** (equal-area), e.g. Equal Earth
- **Distance** (equidistant), along selected lines

On 4 September 2026, the UN General Assembly voted 164–1 to adopt the **"Correct the Map"** resolution. Sponsored by Togo and the African Union, the non-binding vote encourages replacing the 16th-century Mercator projection with the 2018 **Equal Earth** projection to represent Africa's true size.

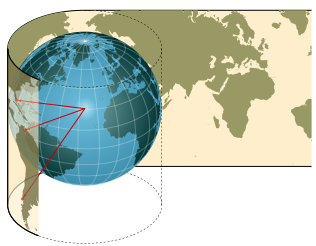


Mercator (blue) vs an equal-area projection, Eckert IV (orange). Image: The Guardian.

Cylindrical Map Projections and Web Mercator

Cylindrical projections - Mercator

A cylinder touches or cuts the globe along a line or lines. The classic case is a cylinder around the equator.



Cylindrical projections minimize distortion along their standard line(s).

Web Mercator

Web Mercator is the projection used by many web maps. It is a cylindrical, conformal projection: local shapes are preserved, but areas grow strongly toward the poles.



Figure: Strebe / Wikimedia Commons · CC BY-SA 3.0.

Web maps trade area accuracy for visually stable local shapes and simple tiled rendering.

Cylindrical Map Projections and UTM

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Cylindrical projections - UTM

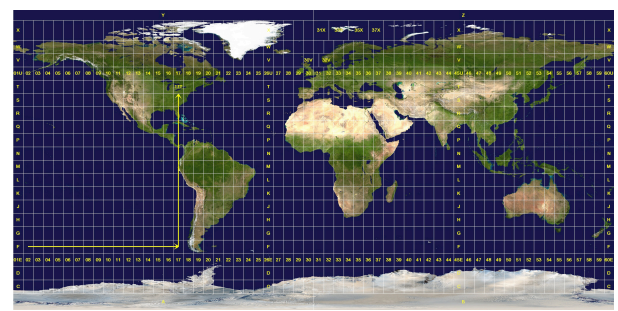
The Universal Transverse Mercator system rotates the cylinder: each zone uses a transverse cylinder around a local central meridian.



UTM turns longitude/latitude into local metric coordinates: easting and northing.

Universal Transverse Mercator (UTM)

Pre-defined UTM zones give geodata local coordinate systems with comparatively low distortion inside each zone.



UTM uses different cylinders to avoid local distortions.

Radius: Atmosphere and Ocean

Geospatial fields are not only horizontal.

They also vary vertically:

- wind fields change across atmospheric columns
- ocean currents differ at the surface and at depth
- temperature, humidity, pressure, and salinity depend on height or depth
- many Earth-system processes require a vertical coordinate

Location often means latitude, longitude, and height or depth.

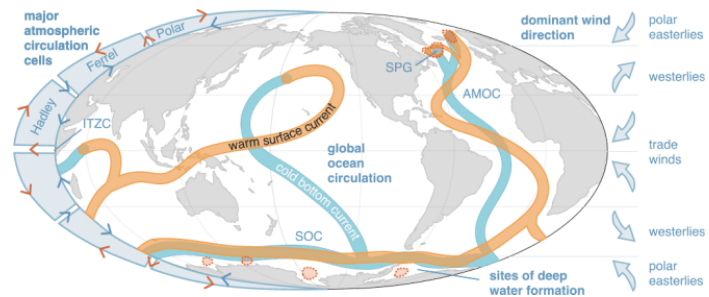


Figure: University of Exeter, ***Atmospheric circulation cells, dominant wind directions, key ocean basins, surface currents and deep water formation sites***. Licensed under CC-BY-SA: Creative Commons Attribution-Share Alike 4.0 International. The rest of this slide deck remains CC-BY-NC.

Time: The Earth is Dynamic

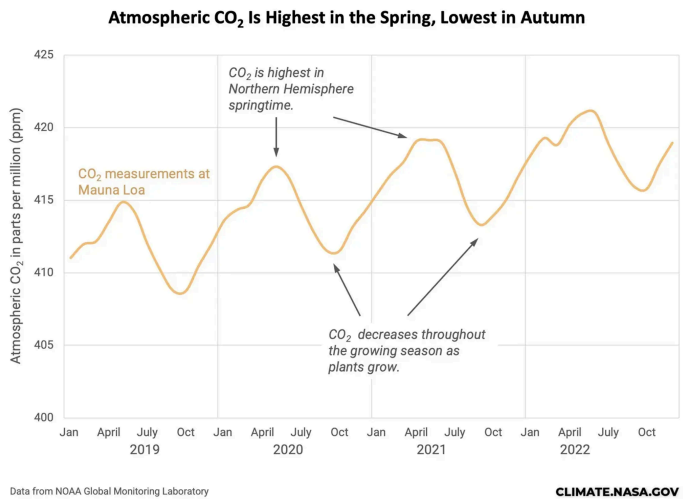


Figure: NASA Science, **Carbon Dioxide**.



Figure: Google Earth Engine, **MODIS NDVI time series animation**. Licensed under CC-BY.

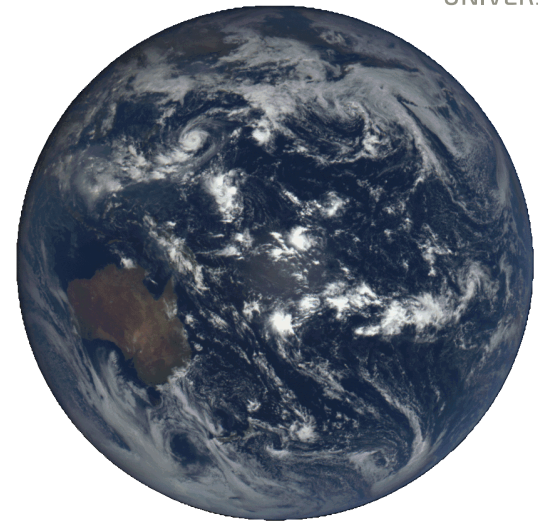
Time: Common Frequencies

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Earth observations contain processes at many characteristic temporal frequencies.

Time scale	Frequency	Examples
Seconds to minutes	High frequency	Wind gusts, turbulence, lightning, traffic, waves, sensor noise
Minutes to hours	Sub-daily	Cloud motion, precipitation cells, tides, urban mobility, river discharge
~12 hours	Semi-diurnal	Ocean tides, coastal water levels
24 hours	Daily / diurnal	Temperature cycle, solar radiation, human activity, vegetation
Several days	Weather	Storms, pressure systems, cloud regimes, heatwaves, cold fronts
Weekly	Anthropogenic	Commuting, energy use, shipping patterns, some air pollution signals
Monthly / ~29.5 days	Lunar	Spring-neap tide cycle, moon-related illumination effects
Seasonal / annual	Yearly	Phenology, crop cycles, snow cover, monsoon, sea ice, temperature
Interannual	2-7 years	ENSO / El Nino, drought cycles, vegetation anomalies
Decadal	10+ years	Climate variability, land-use change, glacier retreat, urban expansion
Multi-decadal to centennial	Long-term trend	Climate change, sea-level rise, ecosystem shifts

Remote Sensing



Campbell & Shin (2011), Figure 1.8.

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2 **Remote Sensing**

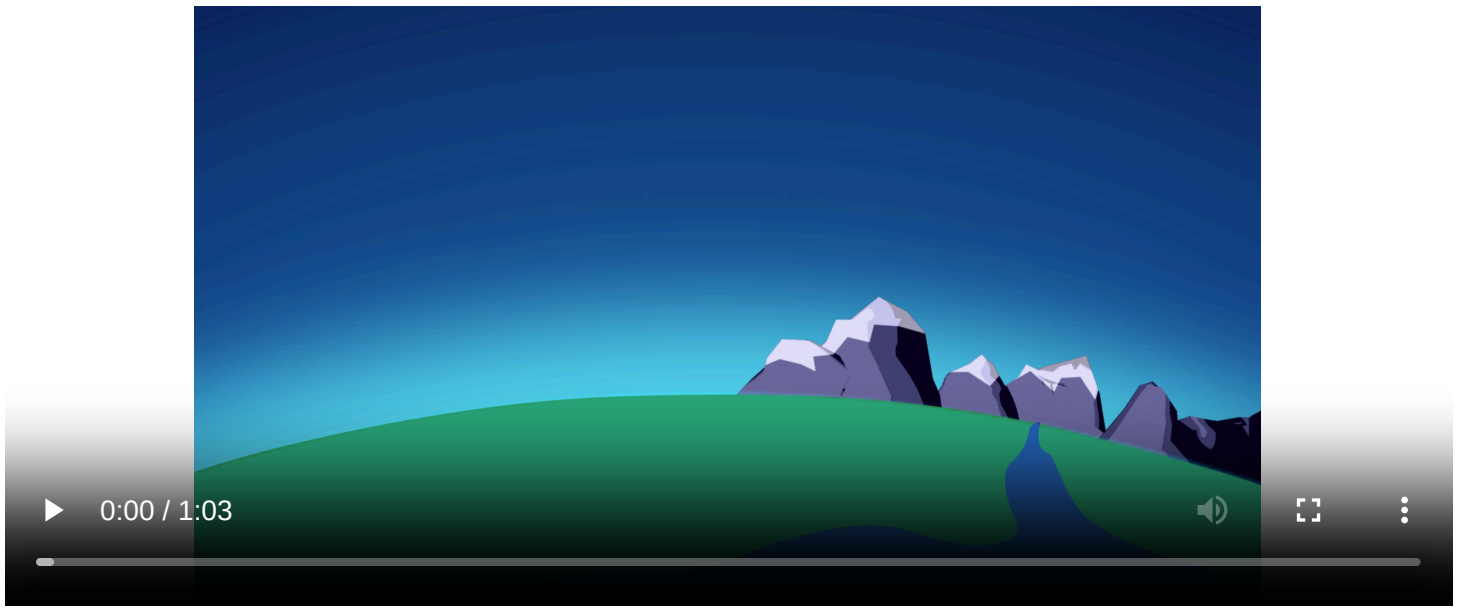
Optical · Radar



Remote Sensing

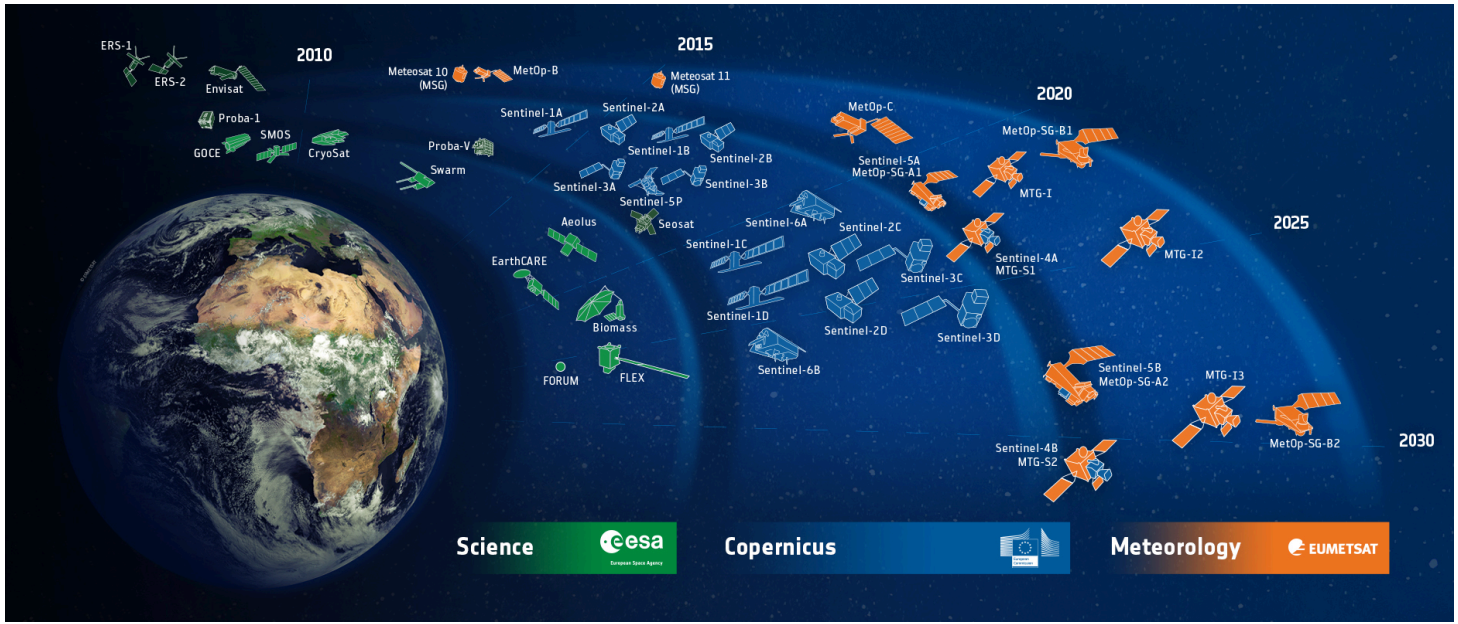
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Identifying, observing, and measuring an object without coming into direct contact with it.



Credit: NASA's Goddard Space Flight Center, Animator: Amy Moran (Global Science and Technology, Inc.), Scientist: Matthew Rodell (NASA/GSFC) · ORCID

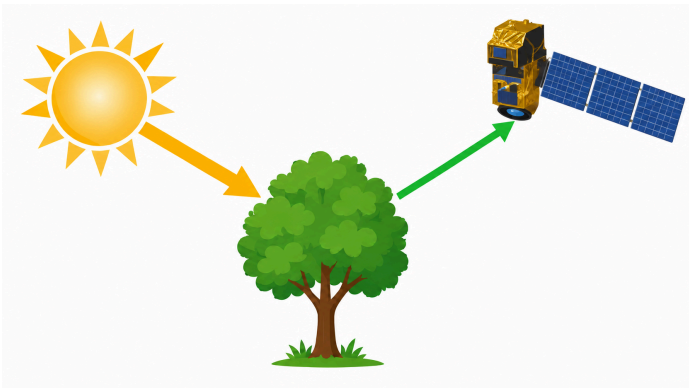
European Earth Observation Satellites



Active and Passive Remote Sensing

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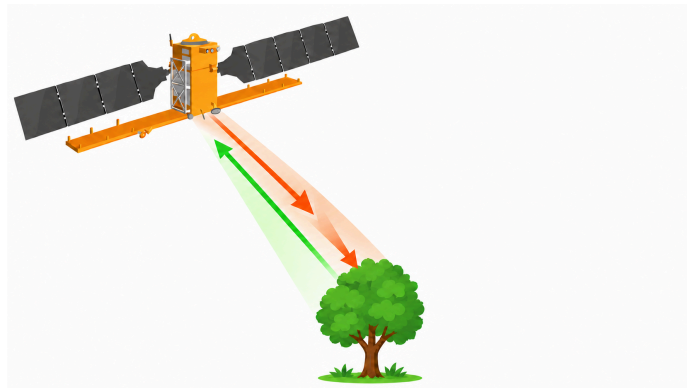
Passive Remote Sensing



Sunlight → reflected → sensed by the satellite

Example: optical satellites

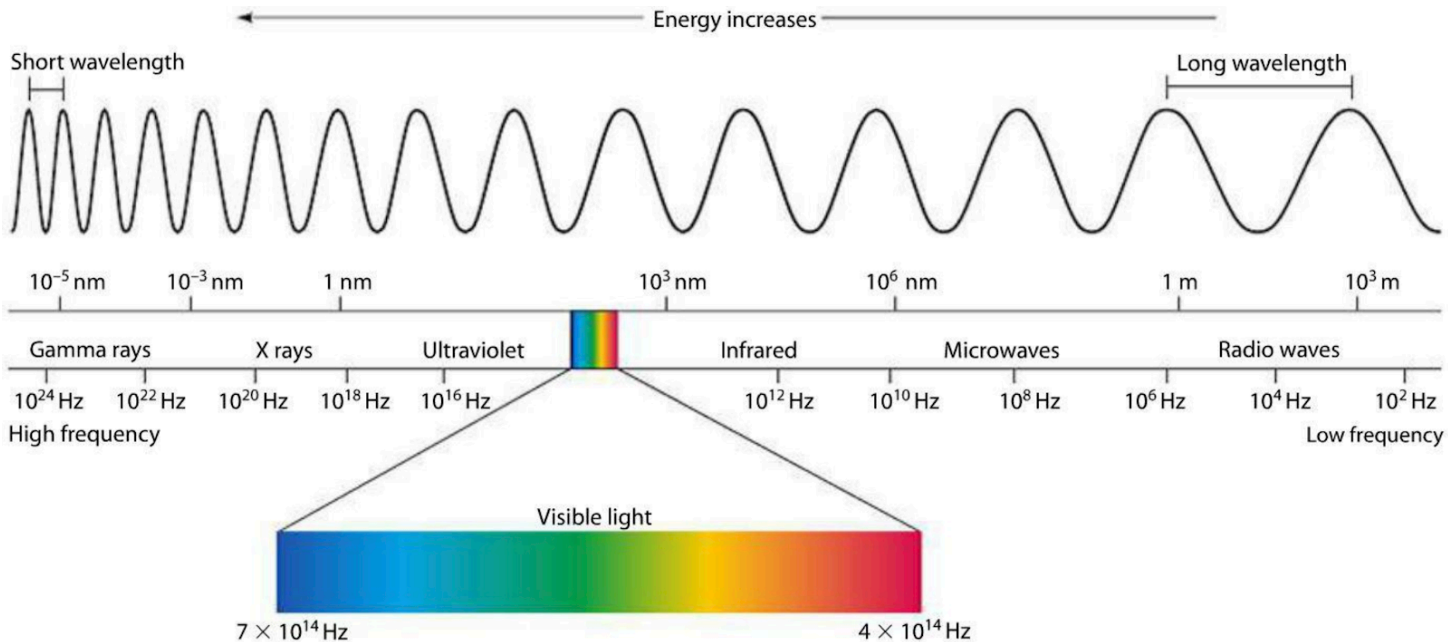
Active Remote Sensing



Satellite emits energy → reflected → sensed

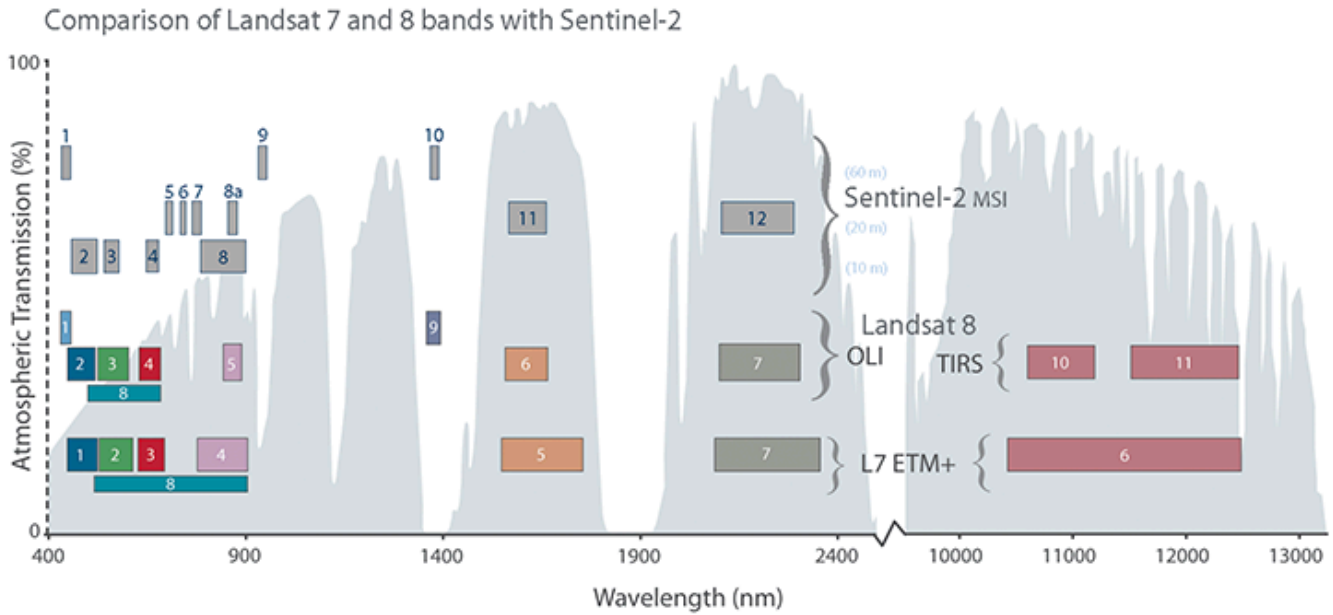
Examples: nadir lidar and side-looking radar

Electromagnetic Spectrum



Sources: EarthDaily · miniphysics.com

Different Satellites - Different Spectral Bands



Source: NASA Landsat (Public domain) · USGS copy.

Earth Observation Satellites

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Passive Remote Sensing - Examples from 07.02.2020



High Resolution

e.g., WorldView-3, PlanetScope, < 10 m



Medium Resolution 10m-30m

Sentinel-2, 13-band multispectral



Low Resolution

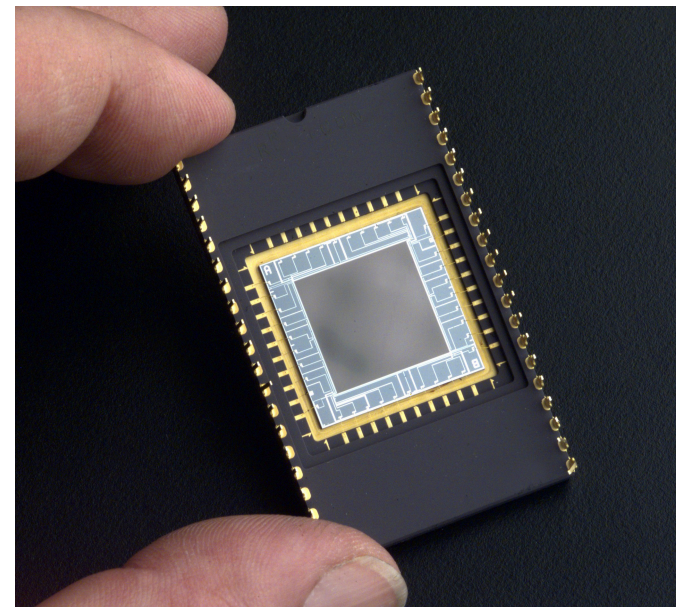
MODIS, 250m - 1km, 36-band multispectral

2D Frame Camera Arrays

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DSLR camera



CCD detector

DSLR: Bill Bertram / Wikimedia Commons · CC BY-SA 2.5. CCD: NASA/JPL / Wikimedia Commons · Public domain.

2D Frame Camera Arrays — PlanetScope

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High-resolution satellite constellations



PlanetScope image



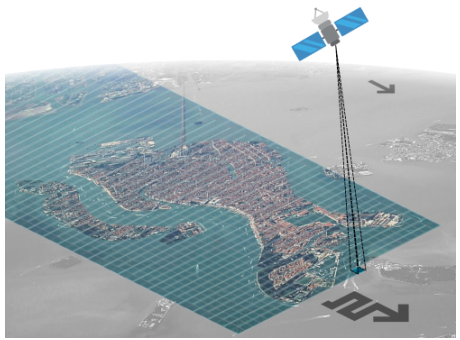
PlanetScope Dove

Satellite image: Planet. Dove: BELSPO Earth Observation.

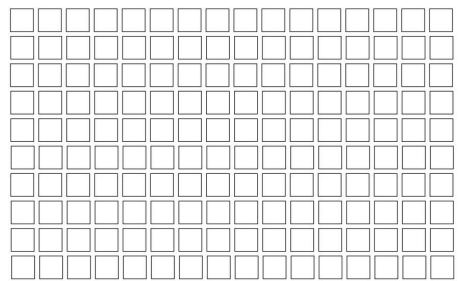
Whisk-broom Scanners

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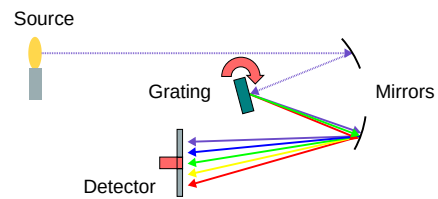
E.g., Landsat series up to 7



Whisk-broom scanning



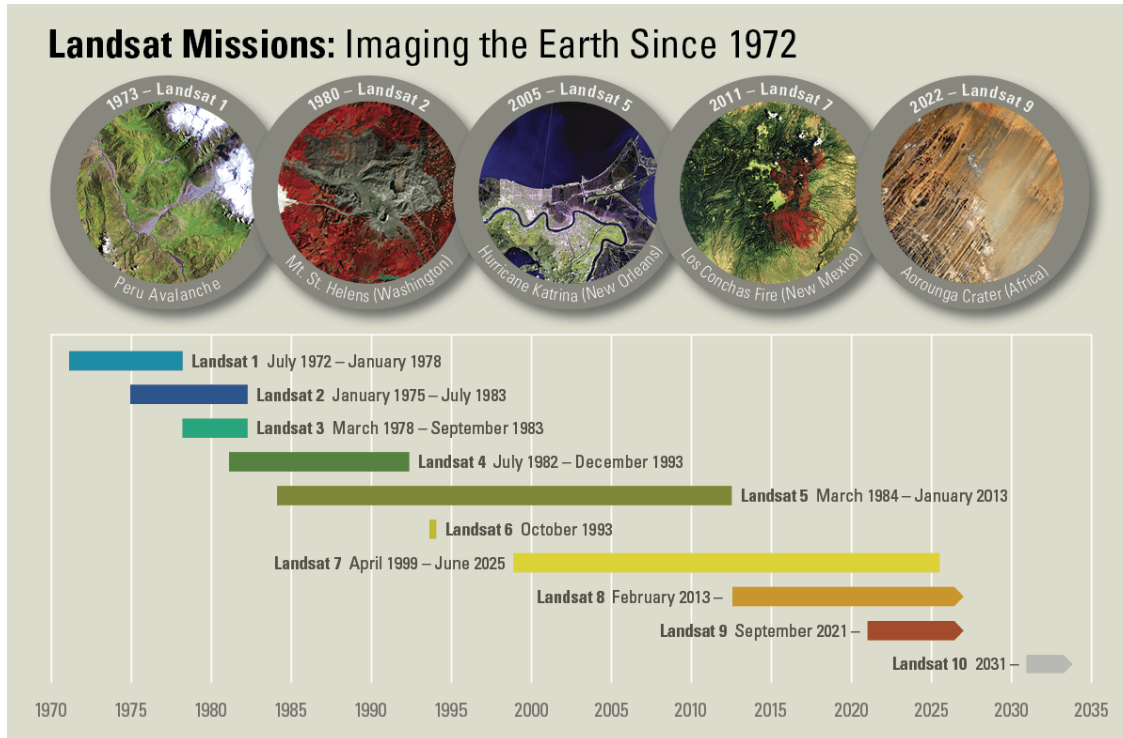
Building an image



Spectrometer

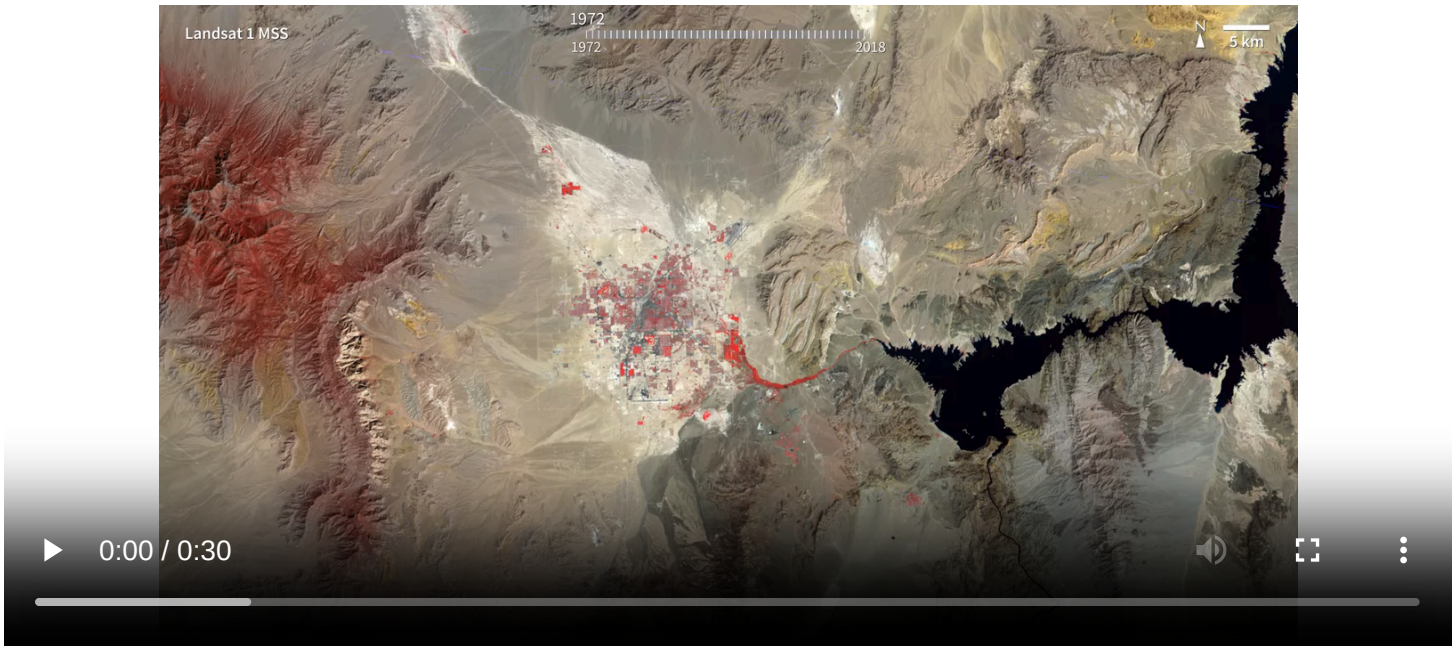
Sources: CMG Lee, Chris 73 & Emoji One contributors · Ccarmour · Jooja / Wikimedia Commons · CC BY-SA 4.0.

Landsat Series



Source: USGS — Landsat Missions.

Landsat Series — Las Vegas



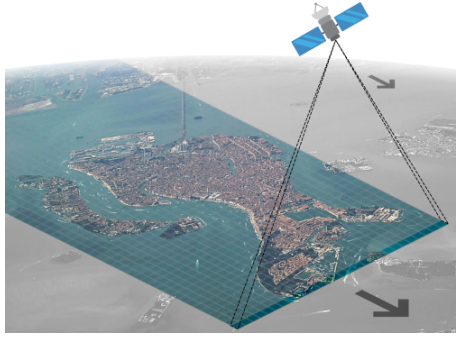
Source: NASA Scientific Visualization Studio — Las Vegas.

Push-broom Scanners

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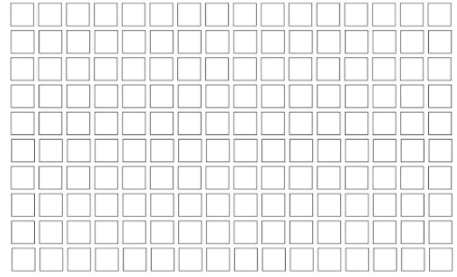
E.g., Sentinel-2

Push-broom



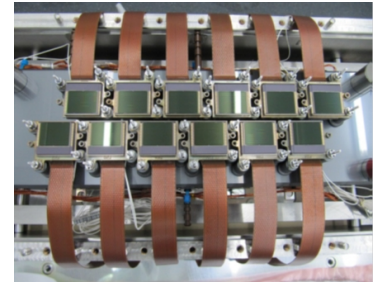
Detector row: captures a whole line at once.

Building an Image

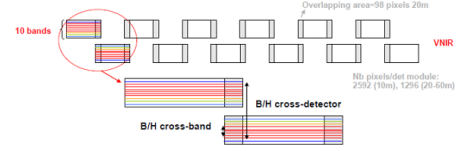


Satellite motion adds new lines → **raster image**.

Sentinel-2 MSI Detectors



Credit: Astrium SAS (France) and e2v Technologies (UK), via SentiWiki.

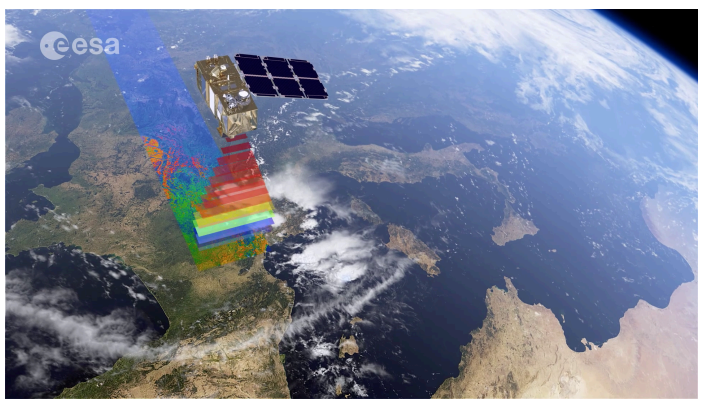


Parallax figure derived from MSI instrument documentation, via SentiWiki.

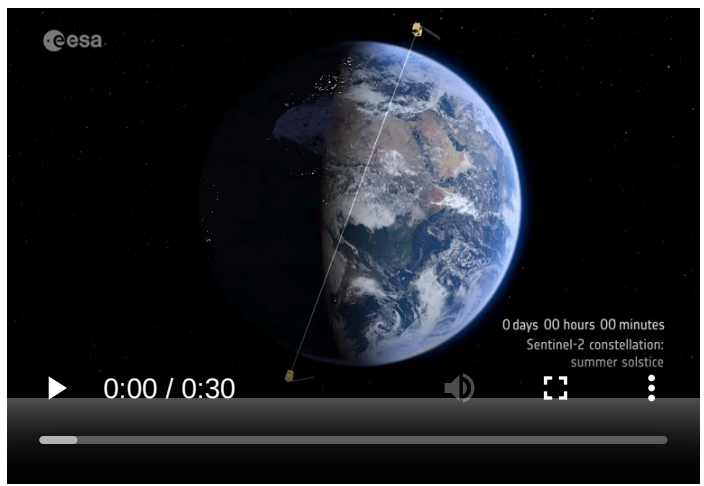
Example Sentinel-2 Constellation

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Three Satellites (2015, 2017, and 2024)

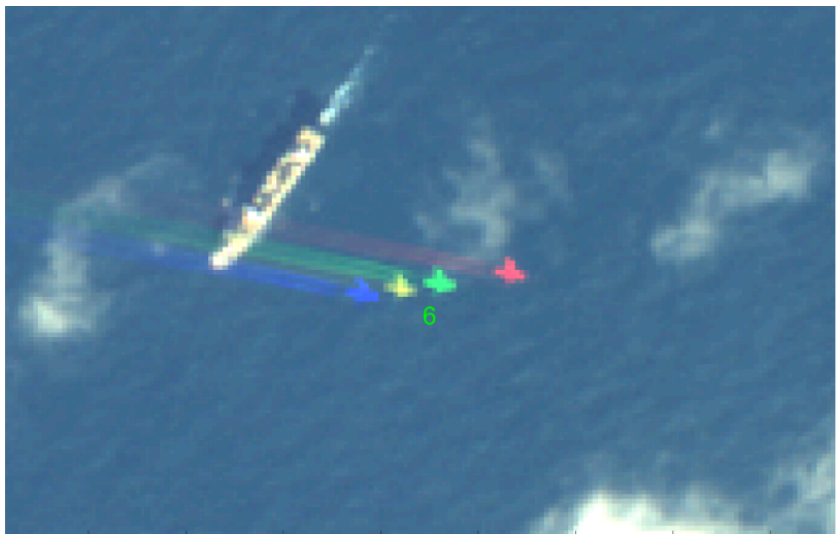


Source: ESA — Mapping in colour.



Source: ESA.

Task: Explain the Plane Rainbow



Sentinel-2 captured an aircraft flying over the sea.

Why does the plane appear **several times, in different colours**?

> **Hint: think back to the push-broom detector layout.**

Source: P. Heiselberg & H. Heiselberg (2021). *Aircraft Detection above Clouds by Sentinel-2 MSI Parallax*. Remote Sensing 13(15), 3016. CC BY 4.0.

Spatial-Temporal-Spectral Juggling

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Ultimately, it is about **photon energy hitting the pixels of a sensor**.

1. **Spatial resolution:** if a pixel covers only a small ground area, few photons are reflected into it.
2. **Spectral resolution:** if a pixel captures only a narrow range of wavelengths, it receives less energy, so the pixels need to be larger.
3. **Temporal resolution:** medium-resolution satellites capture wide swaths daily or weekly; high-resolution satellites only capture a small area per overpass.

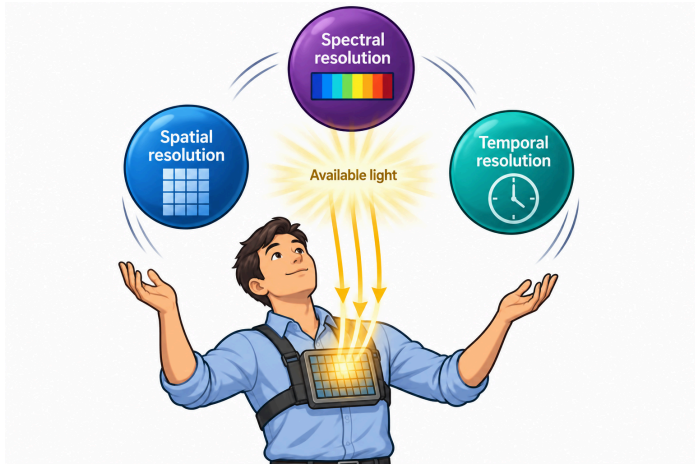


Image: ChatGPT-generated.

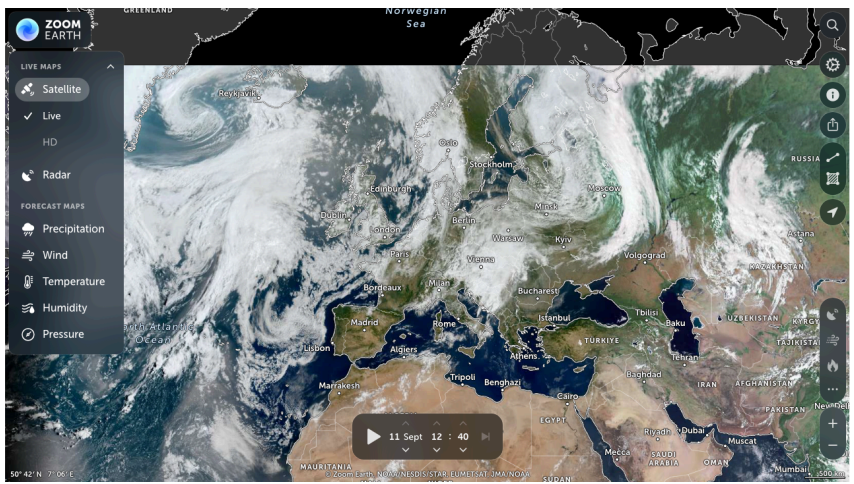
Weather and Meteorological Satellites

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Passive Remote Sensing

METEOSAT — Geostationary Orbit (~36 000 km)

📍 Fixed view over Europe & Africa 🔭 500 m – 2 km 🕐 Every 10 min

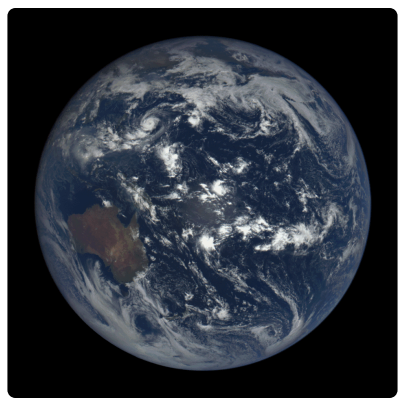


Click to open the live satellite view. Source: Zoom Earth.

DSCOVR EPIC — L1 Lagrange Point (~1.5M km)

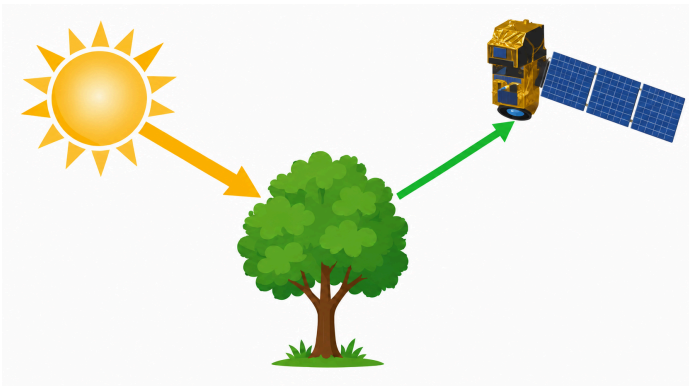
📍 Full sunlit Earth in every image

🔭 8 – 20 km · 🕐 Every ~2 h



DSCOVR EPIC — NASA / Wikimedia Commons. Public domain.

Takeaways — Passive Remote Sensing



Sunlight → reflected → sensed by the satellite

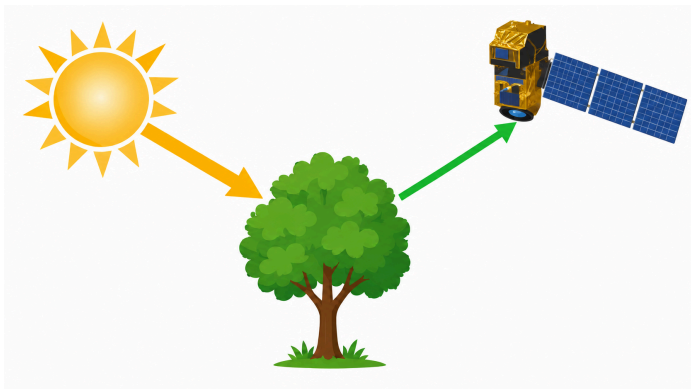
Example: optical satellites

- Measures **reflected sunlight** or **heat emitted by Earth**.
- Sunlight-based images need daylight; thermal images work **day and night**.
- **Clouds can block the view** of the surface.
- Different spectral bands help distinguish **water, vegetation, and built-up areas**.
- Choose data based on the **detail, coverage, and update frequency** you need.

Active Remote Sensing

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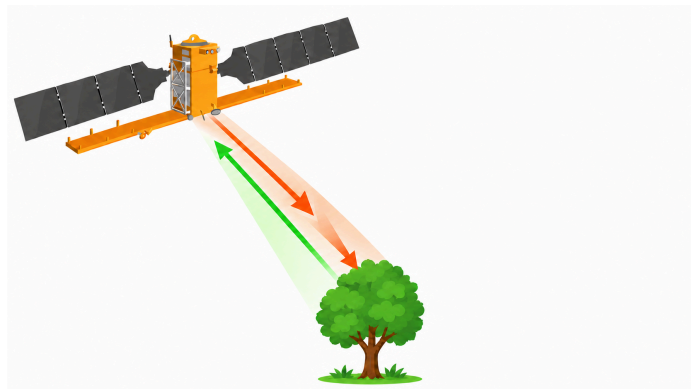
Passive Remote Sensing



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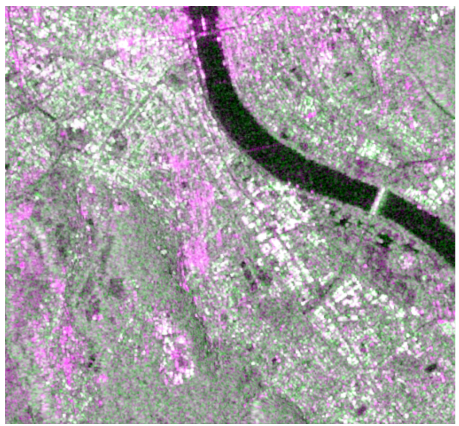
Active Remote Sensing



Satellite emits energy → reflected → sensed

Examples: nadir lidar and side-looking radar

Active Remote Sensing - RADAR and LIDAR



Sentinel-1 SAR Raster

Side-looking radar processed as a pixel grid



Radar Altimetry Tracks

Nadir measurements along point tracks

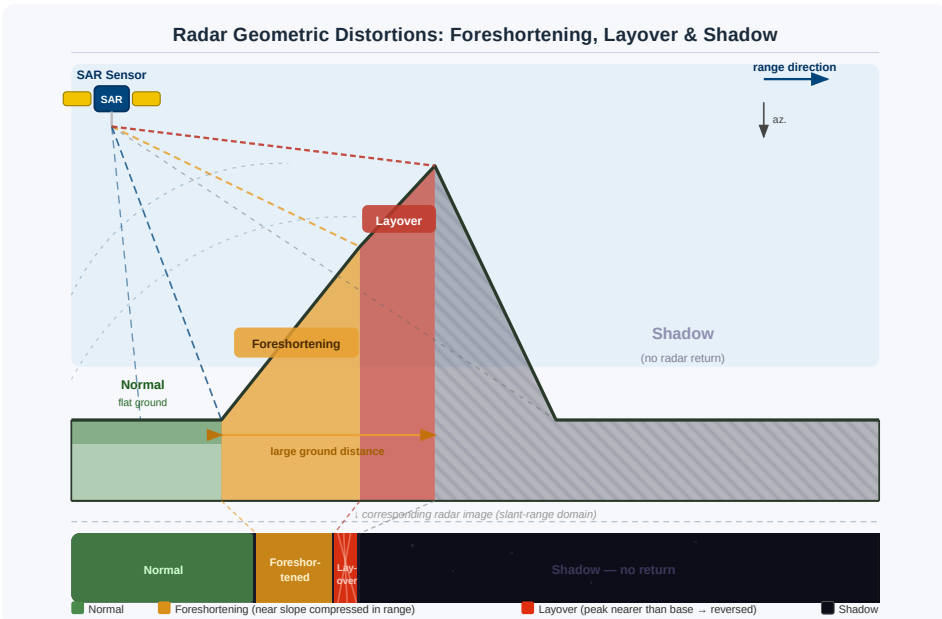


GEDI Lidar Footprints

Nadir samples along point tracks

Geometry of side-looking RADAR

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Example: TerraSAR-X

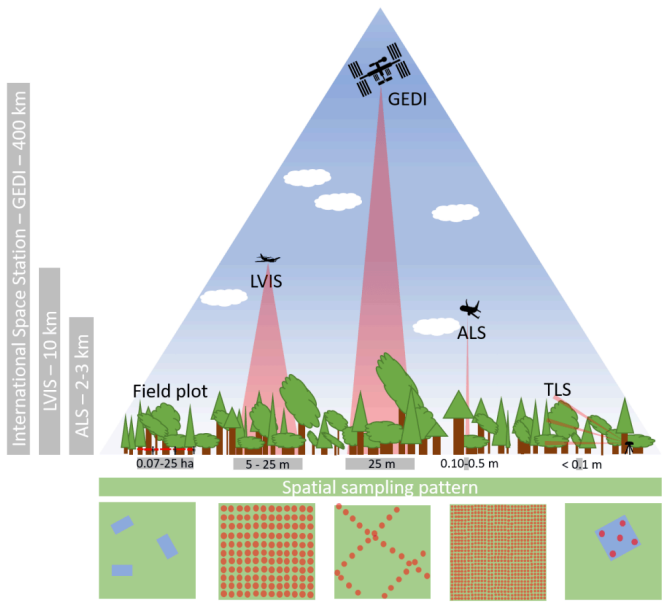


Figure uploaded by Richard Bamler.

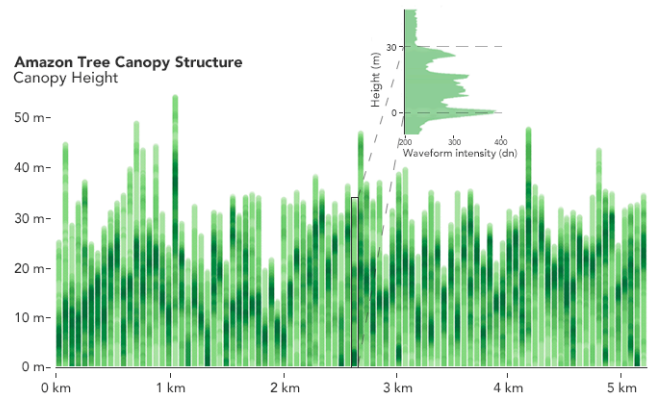
LIDAR Backscatter for Vegetation Canopy

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Sampling Geometry

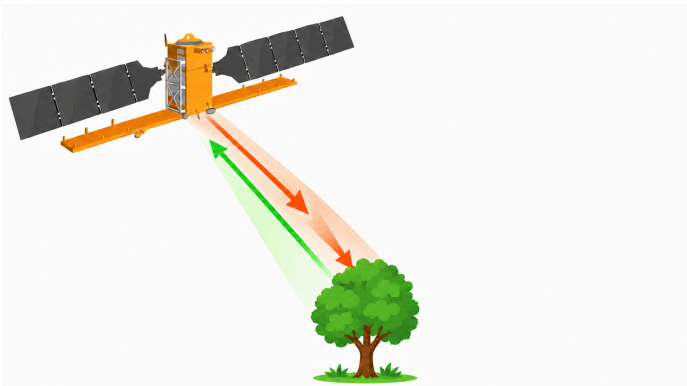


Canopy Structure



Figures in both panels: NASA and University of Maryland.

Takeaways — Active Remote Sensing



Sensor emits signal → return measured

Examples: SAR, LiDAR, radar altimetry

- Carries its own illumination — **independent of sunlight**, enabling imaging at night and in polar winter.
- **Penetrates clouds** and light rain (radar), overcoming a key limitation of optical sensors.
- Measures **physical surface properties** directly: backscatter, elevation, distance, or canopy structure.
- SAR captures **surface roughness, moisture, and deformation** through phase and amplitude.
- Radar altimetry delivers precise **surface height** along nadir tracks — not a full 2D image.
- LiDAR records **3D point clouds**: tree height, building geometry, terrain beneath vegetation.
- Shorter wavelengths (LiDAR) give finer detail; longer wavelengths (L-band radar) penetrate canopy and soil.

Gravity Measurements from Two Satellites

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Other Remote Sensing: Satellite Gravimetry

GRACE Follow-On

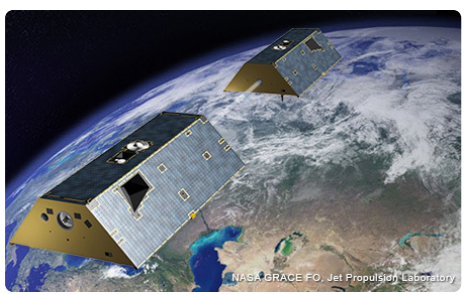
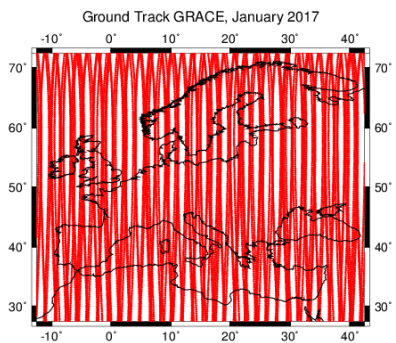


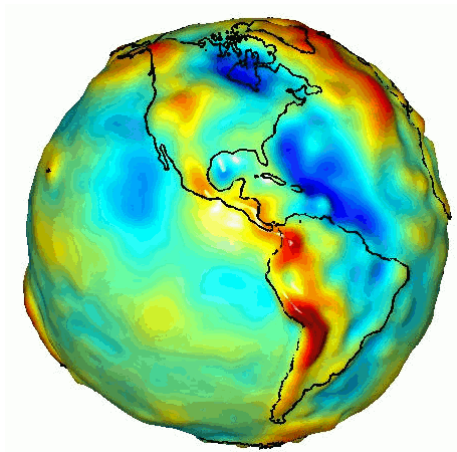
Figure: NASA/JPL.

Ground Track



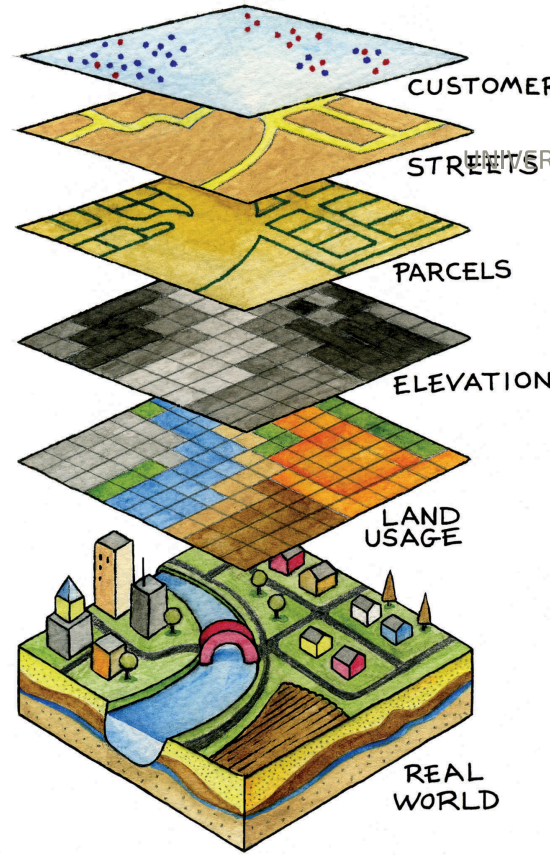
Ground Track GRACE, January 2017. Credit: Ch. Dahle, GFZ.

GRACE Geoid



Animation: Wikipedia; NASA/JPL/University of Texas Center for Space Research.

Geo-information Science



Campbell & Shin (2011), Figure 1.8.

Lecture Overview

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1 **Coordinates and Reference Systems**

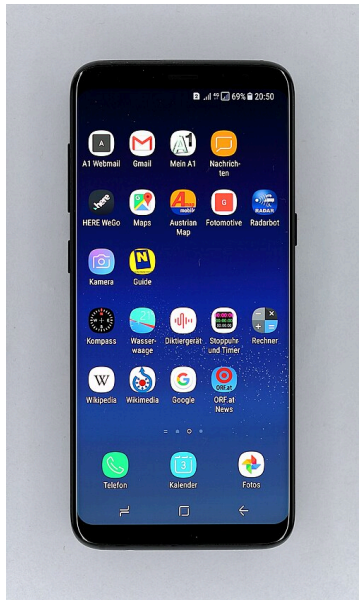
2 **Remote Sensing**
Optical · Radar



3 **Geo-information Systems (GIS)**

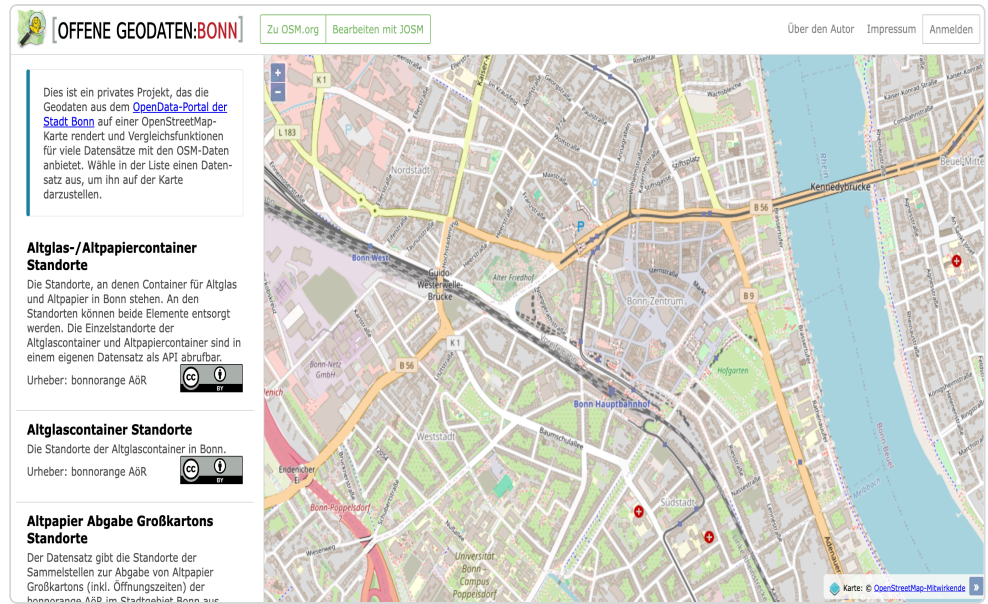
We also gather a lot of Spatial Information

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📍 **GPS location**

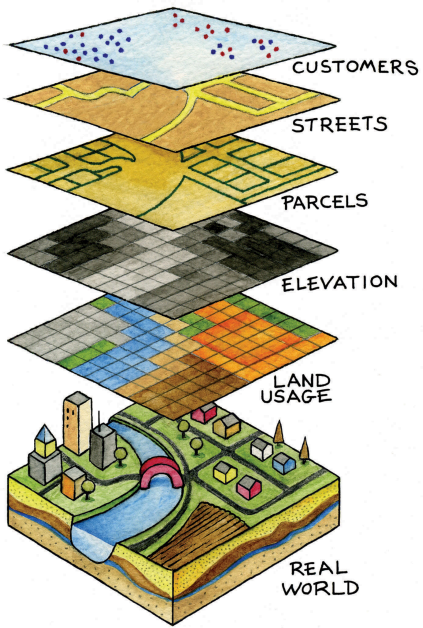
C.Stadler/Bwag / Wikimedia Commons · CC BY-SA 4.0



Open city geodata: Offene Geodaten Bonn

Screenshot: Offene Geodaten Bonn · Map data © OpenStreetMap contributors

Vector and Raster Data



Campbell & Shin (2011), Fig. 1.8

GIS organises geographic information as **stacked, queryable layers** — each layer aligns to the same coordinate reference system and carries thematic information about the world.

Vector data

Points, lines, polygons + attribute table

Raster data

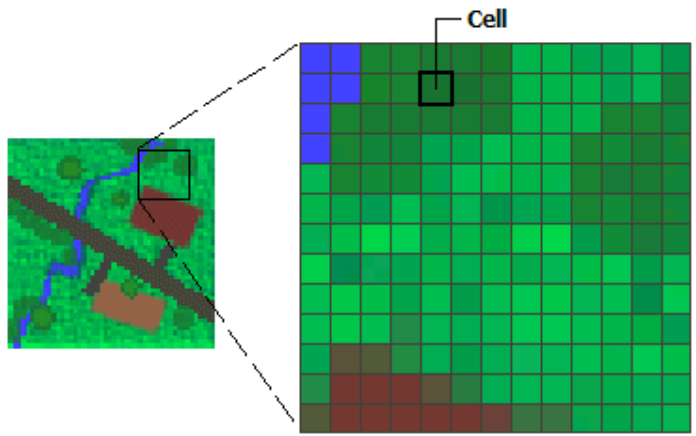
Grids of continuous values: elevation, imagery

Key data sources: OpenStreetMap, administrative databases, land use / land cover classifications, cadastral records, sensor networks.

Raster Data

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A Grid of Cells



A raster divides space into a regular grid of **cells (pixels)**, each holding one value.

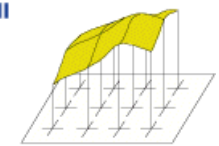
Area or Center?

Does the value refer to the whole cell area or just its center? **It depends on the data.**

Value applies to the center point of the cell

For certain types of data, the cell value represents a measured value at the center point of the cell. An example is a raster of elevation

315	319	321	323
317	323	328	326
313	318	325	323



Value applies to the whole area of the cell

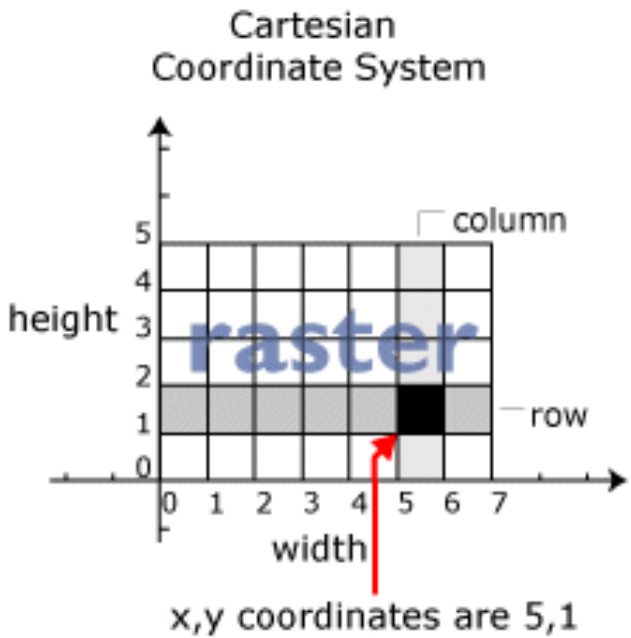
For most data, the cell value represents a sampling of a phenomenon, and the value is presumed to represent the whole cell square.

50	45	40	35
35	40	35	25
20	25	30	20



Figures: Esri — ArcMap documentation, *What is raster data?*

Raster Coordinates



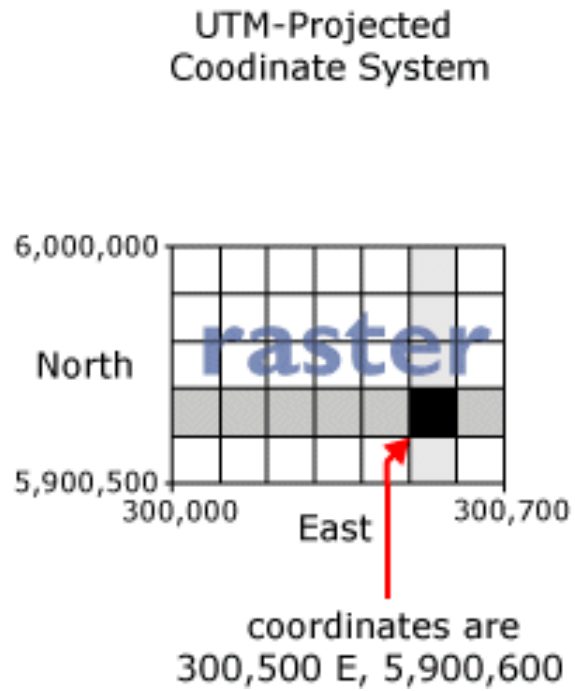
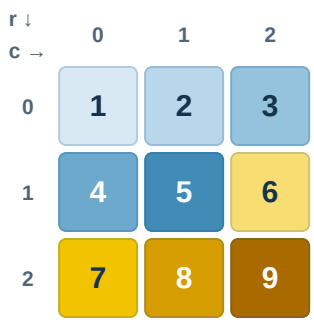


Figure: Esri — ArcMap documentation, *What is raster data?*

Raster Georeference

Raster images are georeferenced by an affine transformation A that defines the top left coordinate with pixel sizes.

$$[East, North, 1] = A\ [Col, Row, 1]$$

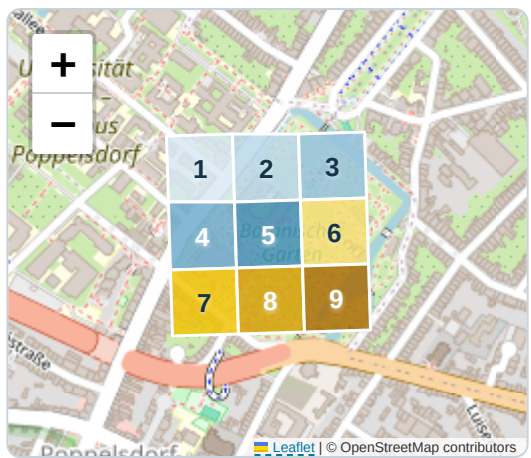


EPSG:32632 · WGS 84 / UTM zone 32N · metres

$$A = \begin{bmatrix} 100 & 0 & 365200 \\ 0 & -100 & 5621100 \\ 0 & 0 & 1 \end{bmatrix}$$

Apply transform

Initial transform applied



UTM coordinates are converted for the basemap display.

Task: Georeference this Image



EPSG:32632 · WGS 84 / UTM zone 32N · metres

$$A = \begin{bmatrix} & & \\ & & \\ 0 & 0 & 1 \end{bmatrix}$$

Transform

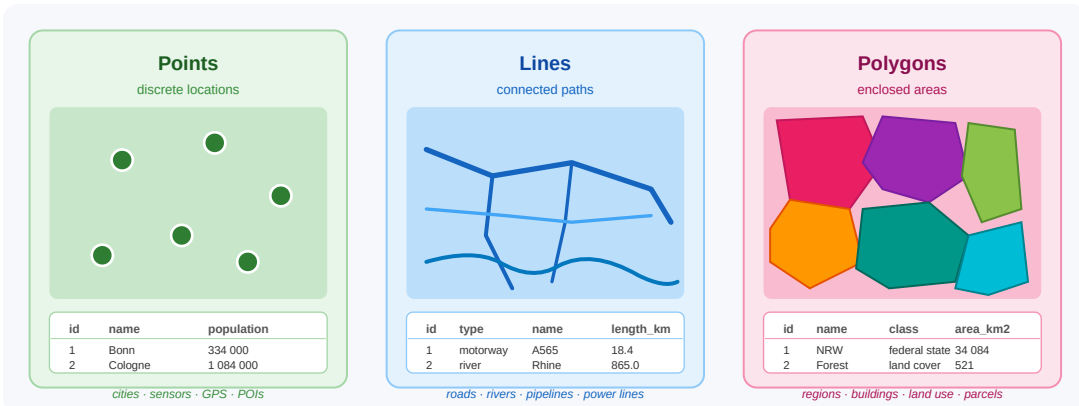
Fill all six entries, then transform



The **gdalinfo** output below provides metadata for this georeferenced image.

```
❯ gdalinfo Sentinel2_RGB_cloudfree_EPSG32632.tif
Driver: GTiff/GeoTIFF
Files: Sentinel2_RGB_cloudfree_EPSG32632.tif
Size is 47, 46
Coordinate System is:
PROJCRS["WGS 84 / UTM zone 32N",
    BASEGEOGCRS["WGS 84",
        DATUM["World Geodetic System 1984",
            ELLIPSOID["WGS 84",6378137,298.257223563,
                LENGTHUNIT["metre",1]]],
        PRIMEM["Greenwich",0,
            ANGLEUNIT["degree",0.0174532925199433]],
        ID["EPSG",4326]],
```

Vector Data — Geometry + Attributes



🟢 Points

Zero-dimensional locations: weather stations, cities, GPS waypoints, species occurrence records.

🔵 Lines

Ordered vertex sequences: roads, rivers, coastlines, pipelines, power lines, flight paths.

🔴 Polygons

Closed rings enclosing area: administrative units, building footprints, land-use patches, parcels.

Explore Vector Geometries

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GeoJSON

106 features


```
{
"type": "FeatureCollection",
"name": "combined_osm",
"xy_coordinate_resolution": 0.000000,
"features": [
{ "type": "Feature", "id": "map – points_678973937",
"properties": { "address": null, "barrier": null, "highway":
null, "is_in": null, "man_made": null, "name": "Zoologisches
Institut", "osm_id": "678973937", "other_tags":
"\"addr:city\"=>\"Bonn\",\"addr:country\"=>\"DE\",\"addr:house
number\"=>\"169\",\"addr:postcode\"=>\"53115\",\"addr:street\"
=>\"Meckenheimer Allee\",\"operator\"=>\"Universität
Bonn\",\"wheelchair\"=>\"limited\",\"wheelchair:description\"=
>\"Aufzug vorhanden, nur mit Schlüssel zugänglich\"", "place":
null, "ref": null, "source_layer": "map – points" },
"geometry": { "type": "Point", "coordinates": [ 7.092347,
50.7249324 ] } },
{ "type": "Feature", "id": "map – points_1564070251",
"properties": { "address": null, "barrier": "cycle_barrier",
"highway": null, "is_in": null, "man_made": null, "name":
null, "osm_id": "1564070251", "other_tags":
"\"cycle_barrier\"=>\"double\",\"cycle_barrier:installation\"=
>\"fixed\",\"width\"=>\"1.4\"", "place": null, "ref": null,
"source_layer": "map – points" }, "geometry": { "type":
"Point", "coordinates": [ 7.0910236, 50.7249277 ] } },
```


Leaflet map



Processing Geospatial Data - Locally

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GUI-based Programs

Mainly **ArcGIS** (commercial) and **QGIS** (open source).

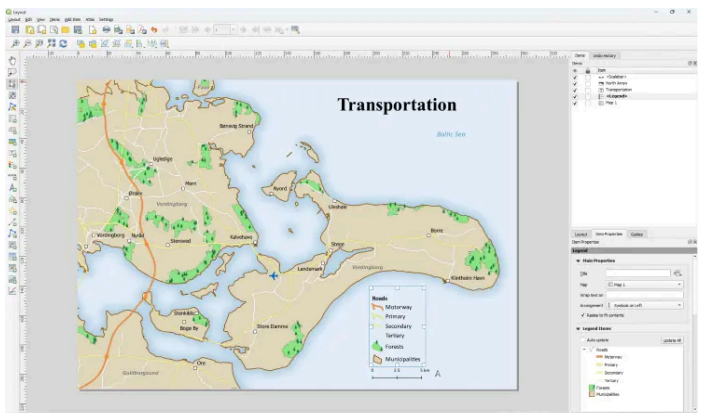
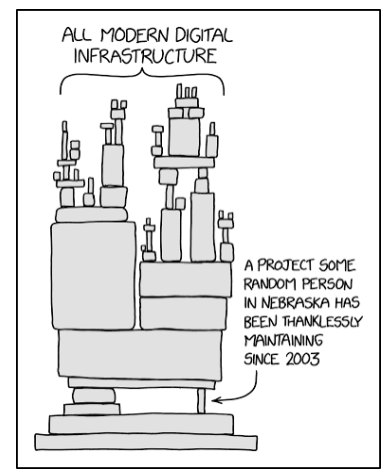


Image: QGIS

CLI-based

Geospatial **D**ata **A**bstraction **L**ibrary (GDAL)



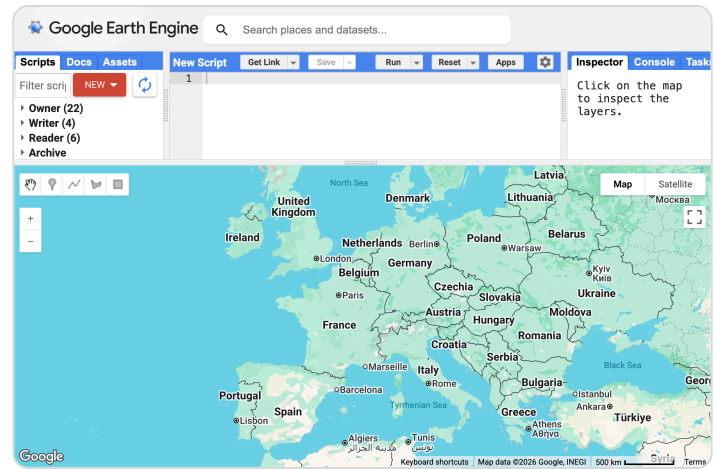
Comic: xkcd 2347 — Dependency · CC BY-NC 2.5. GDAL logo: Wikimedia Commons.

Processing Geospatial Data - On Server Infrastructure

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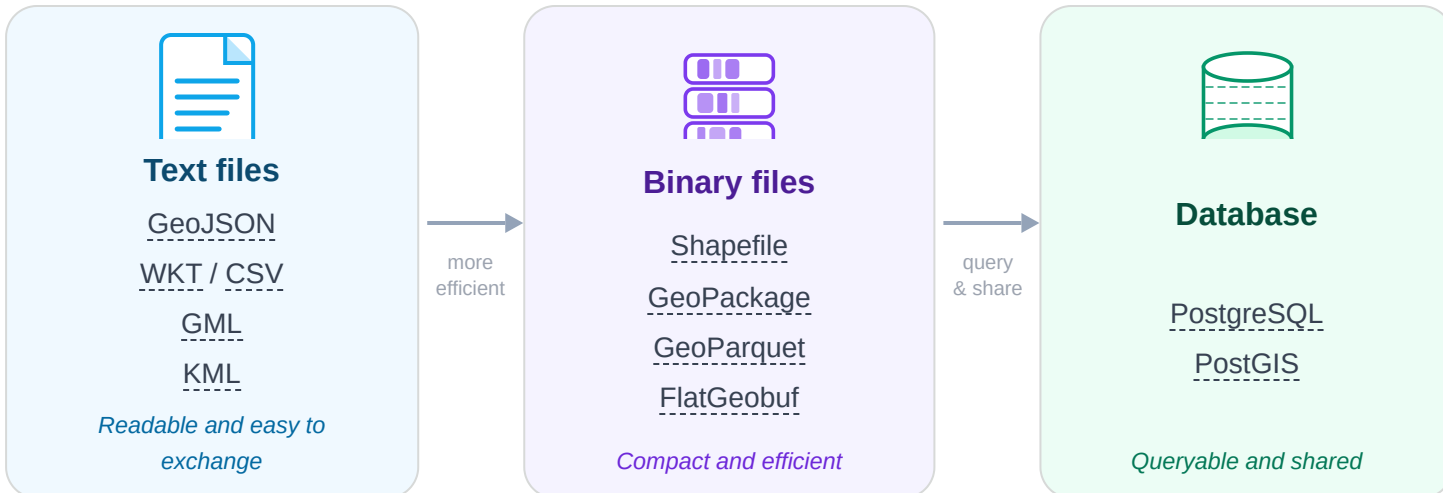
Google Earth Engine

- Petabyte-scale **catalog** of satellite imagery, climate, and model data.
- Processing runs on **Google's servers**: the code goes to the data, not the other way round.
- Scripted in **JavaScript** (Code Editor) or **Python**.
- Free for research and education; commercial use is paid.



Screenshot: Google Earth Engine Code Editor

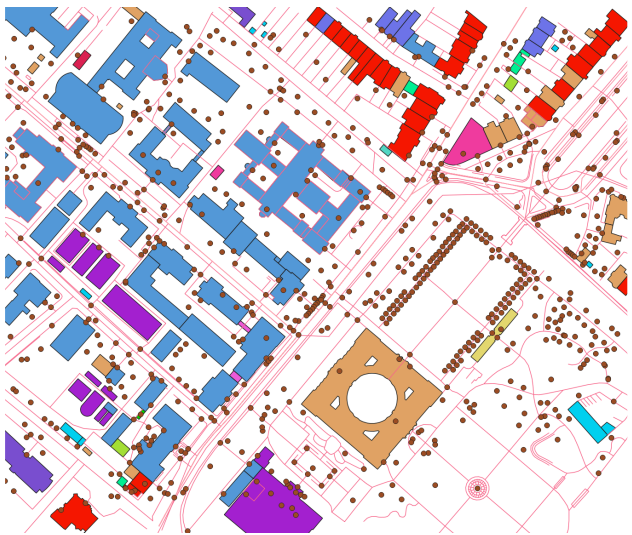
Geospatial Vector Data Formats & Storage



OpenStreetMap — the Wikipedia of geodata

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OSM Database



Points, lines, and polygons

Style and rasterize

→

OSM Background Map



Rendered raster tiles

Map data © OpenStreetMap contributors

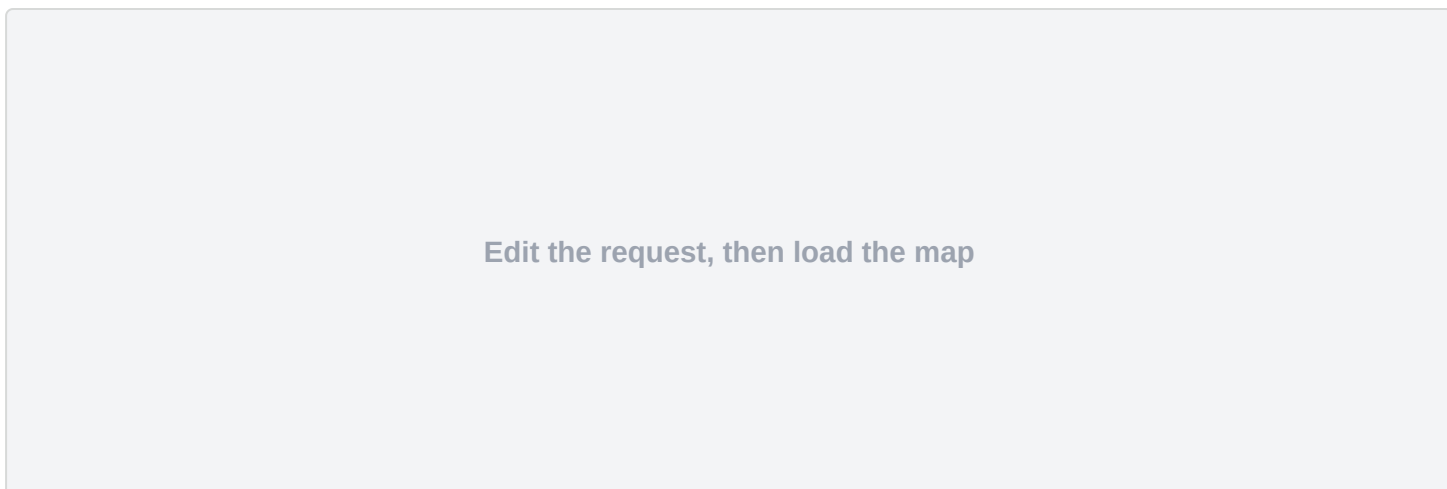
Web Map Service (WMS)

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```
https://ows.terrestris.de/osm/service?
SERVICE=WMS&VERSION=1.1.1&REQUEST=GetMap&LAYERS=OSM-
WMS&STYLES=&SRS=EPSG:25832&BBOX=363400,5620400,367000,5621600&WIDTH=900
&HEIGHT=300&FORMAT=image/png
```

Load map

BBOX = WEST, SOUTH, EAST, NORTH



© OpenStreetMap contributors · WMS provided by terrestris

Web Feature Service (WFS)

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```
https://www.wfs.nrw.de/geobasis/wfs_nw_alkis_vereinfacht?
SERVICE=WFS&VERSION=2.0.0&REQUEST=GetFeature&TYPENAMES=ave:GebaeudeBauwerk&COUN
T=1000&SRSNAME=urn:ogc:def:crs:EPSG::4326&BBOX=50.719330278357,7.064421982400,5
0.730951027518,7.115835758151,urn:ogc:def:crs:EPSG::4326
```

Run WFS query

BBOX = WEST, SOUTH, EAST, NORTH

WMS: pixels · WFS: feature geometry

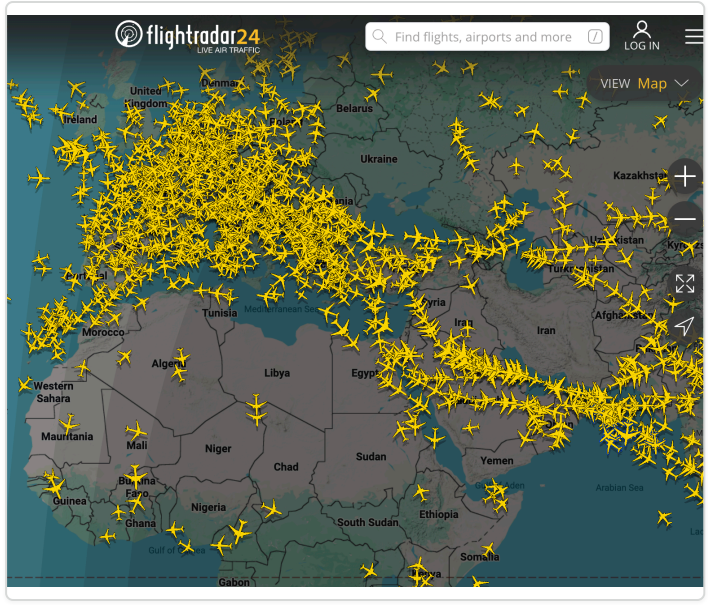
Edit the request, then run the WFS query

WFS data © Geobasis NRW

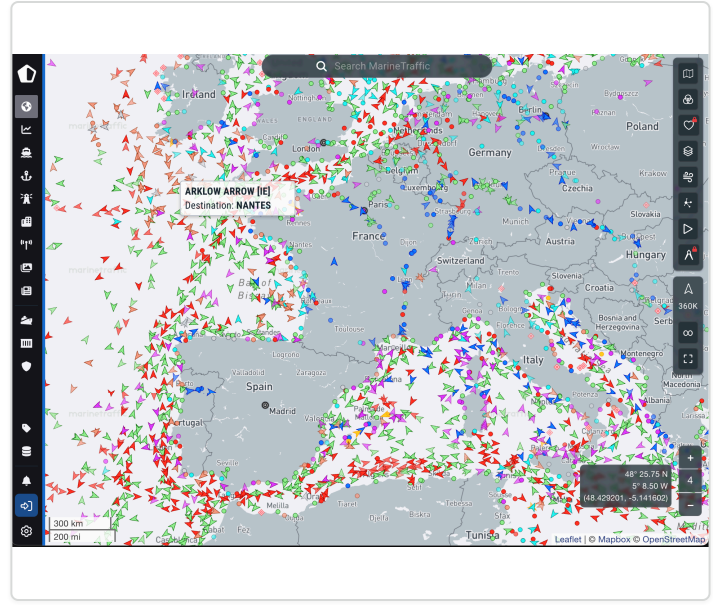
WFS/WMS in Practice

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Flightradar24



MarineTraffic



Administrative Boundaries

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GADM — Global Administrative Areas

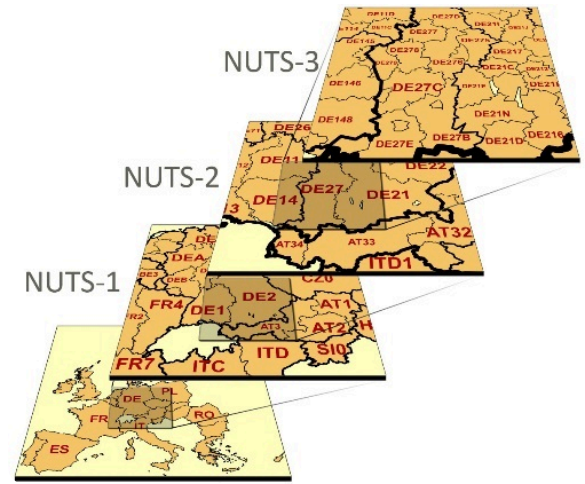


Germany · 6 nesting levels · global coverage

Freely available polygons for every country; widely used in ecological & socioeconomic modelling.

Gringer / Wikipedia · CC BY-SA

NUTS — EU Territorial Statistics Units



NUTS-1 → NUTS-2 → NUTS-3 · three nesting levels

EU standard: NUTS-1 (federal states), NUTS-2 (Regierungsbezirke), NUTS-3 (districts). Reference frame for Eurostat statistics.

© Eurostat · ec.europa.eu/eurostat

Land Use / Land Cover (LULC) Databases

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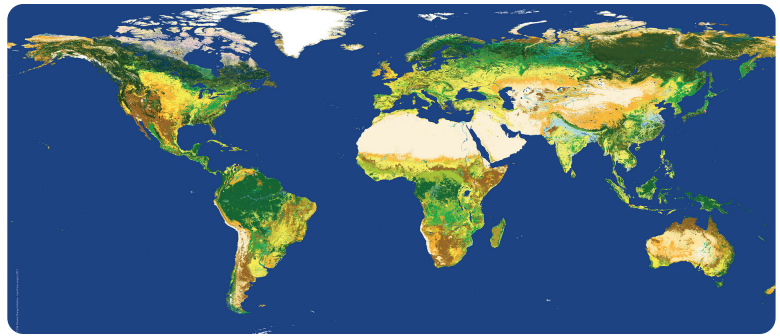
Land use describes human activity (agriculture, urban, forestry). **Land cover** describes the physical surface (vegetation, bare soil, water).

ESA WorldCover 2020–2021
10 m global · 11 classes · Sentinel-1 & -2

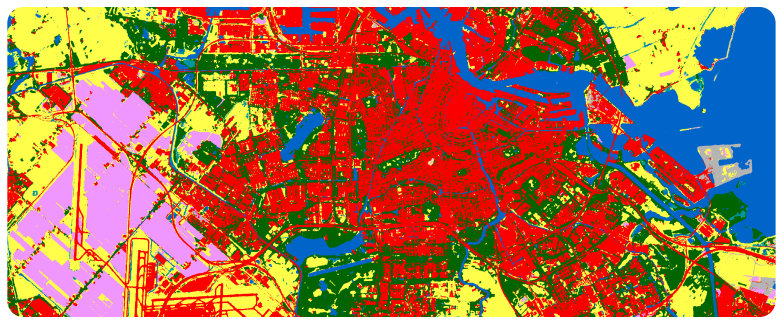
CORINE Land Cover (CLC) EU, since 1990
100 m · 44 classes · updated every 6 years

GlobeLand30 Global
30 m · 10 classes · 2000 / 2010 / 2020 epochs

Dynamic World (Google) Near-real-time
10 m · 9 classes · probabilistic per-scene output



Global land cover map 2015 · © ESA / ESA Climate Change Initiative

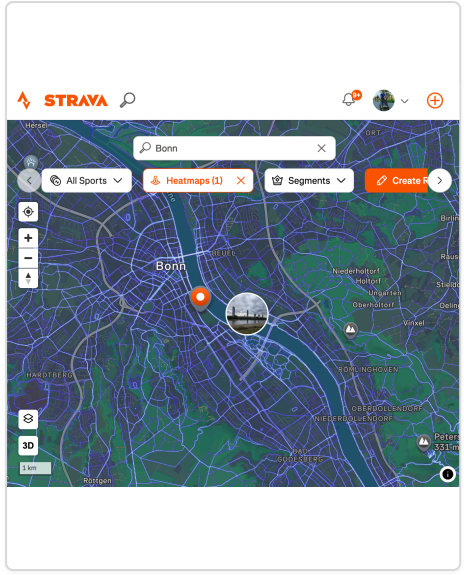


ESA WorldCover 10 m — Amsterdam · © Copernicus / ESA

Further GIS Examples

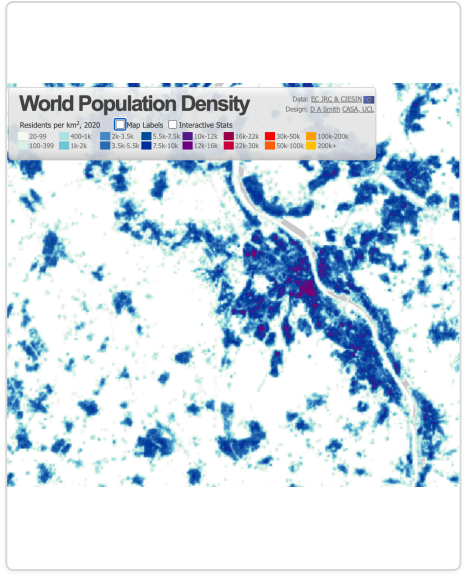
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Strava Heat Map



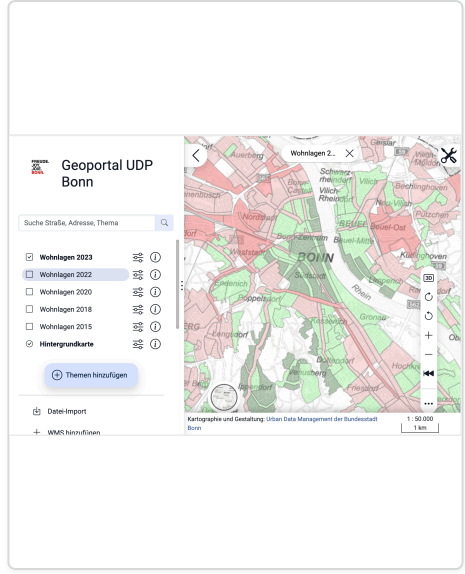
Screenshot: Strava

Population Density



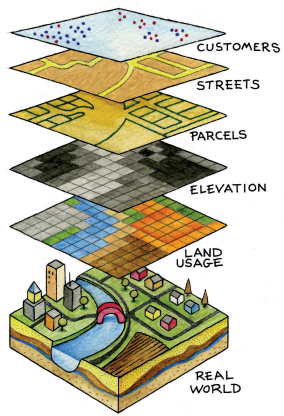
Screenshot: Luminocity3D

Quality of Living (Wohnlagen)



Screenshot: Gutachterausschuss Bonn

Takeaways - Geo-information Science

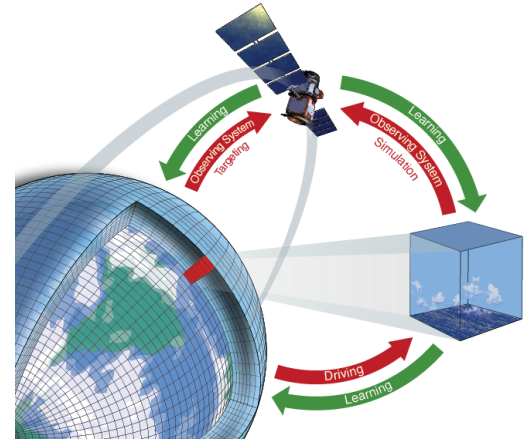


Real world → thematic layers → analysis

Examples: OSM, CORINE, GADM, cadastres

- GIS organises the world as **thematic layers** aligned to a shared coordinate reference system.
- Vector data combines **geometry** (points, lines, polygons) with an **attribute table** — enabling spatial and semantic queries.
- OpenStreetMap is the world's largest **open vector database**: roads, buildings, land use, and POIs contributed by millions.
- LULC databases (**ESA WorldCover, CORINE**) map land cover classes globally using satellite imagery — raster products with thematic labels.
- Administrative boundaries (**GADM, NUTS**) are the standard aggregation frame for statistics, policy, and spatial cross-validation.
- **Spatial joins** link vector layers: assign points to regions, aggregate raster values within polygons.

Earth System Models



Climate Modeling Alliance (CliMA), clima.caltech.edu.

Lecture Overview

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1 **Coordinates and Reference Systems**

2 **Remote Sensing**
Optical · Radar



3 **Geo-information Systems (GIS)**

4 **Earth System Models**

From Observations to Modelled Fields

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Data Observations

Satellites, stations, buoys, profiles

↓

Data Assimilation in Physical Models

Observations update the model state

↓

Simulation

Fields across space, time, and height or depth

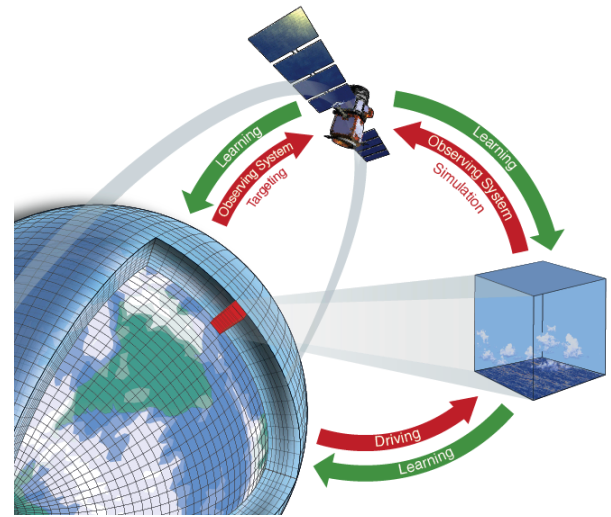
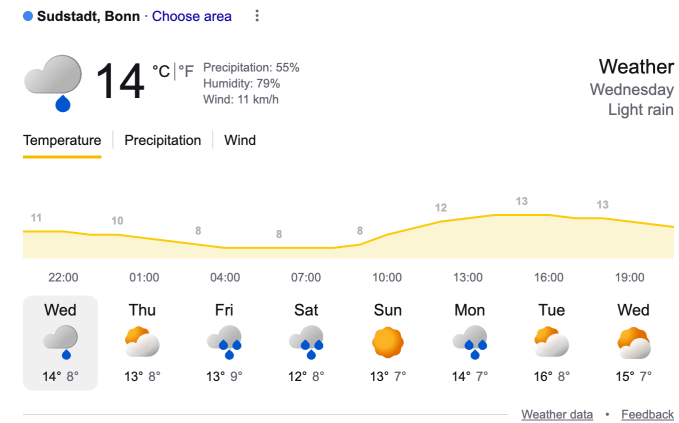


Figure: Climate Modeling Alliance (CliMA), clima.caltech.edu.

Familiar Example: Weather Forecast



Image: BBC, via The Guardian, 16 October 2010.



Screenshot: Google Weather.

IFS — Integrated Forecasting System

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Weather forecast model by the European Centre for Medium-Range Weather Forecasts (ECMWF)

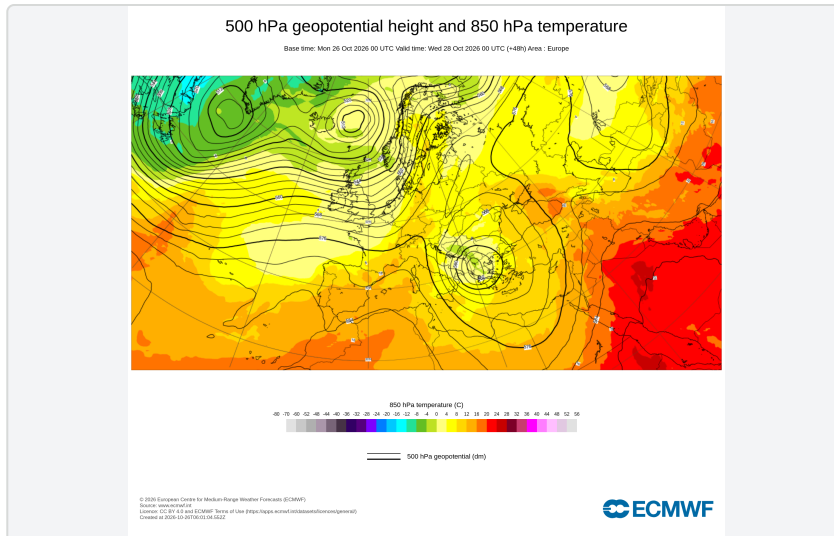
Model run (base time)
Mon 26 Oct, 00:00 UTC

Lead time: +48 h

0 h +10 days

Valid time
Wed 28 Oct, 00:00 UTC

Lines: 500 hPa height · Colours: 850 hPa temperature



ECMWF Open Charts · © ECMWF · CC BY 4.0

ERA5 — ECMWF Re-Analysis (5th generation)

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Atmospheric reanalysis of the global climate and weather since 1940

Data description	
Projection	Regular latitude-longitude grid
Horizontal coverage	Global
Horizontal resolution	Reanalysis: 0.25° × 0.25° (atmosphere), 0.5° × 0.5° (ocean waves) Mean, spread and members: 0.5° × 0.5° (atmosphere), 1° × 1° (ocean waves)
Temporal coverage	1940 to present
Temporal resolution	Hourly
Update frequency	Daily

Source: Copernicus Climate Data Store

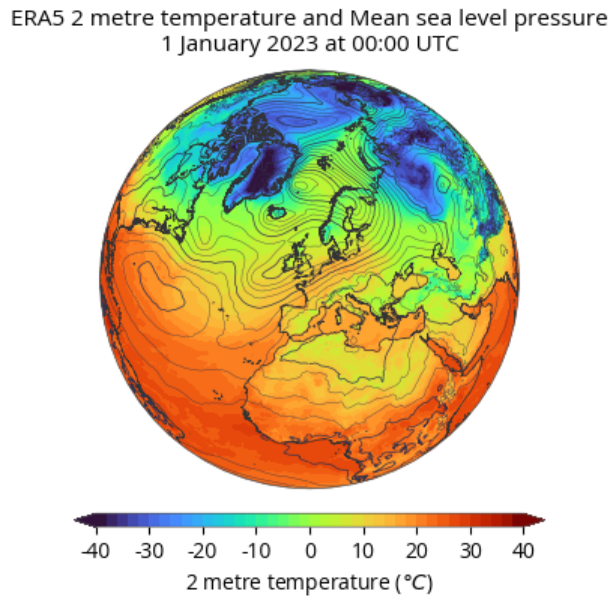


Image: Copernicus Climate Data Store

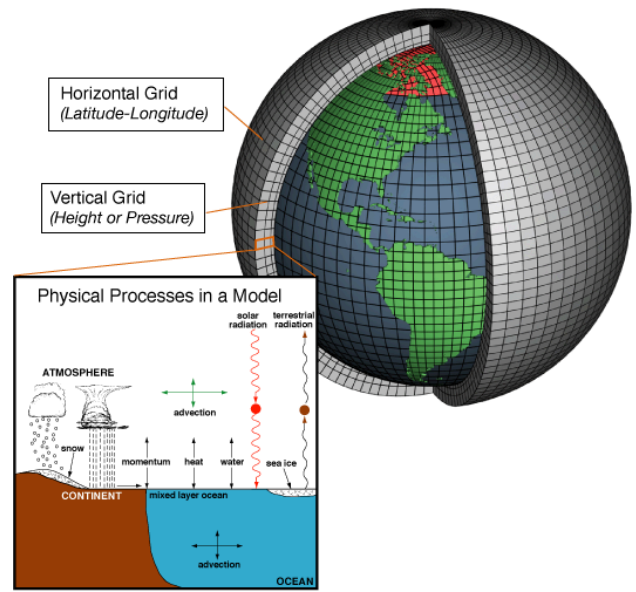
HYCOM — HYbrid Coordinate Ocean Model

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Ocean model by the U.S. National Ocean Partnership Program (NOPP)

- Ocean dynamics represented across horizontal locations and vertical layers.
- Temperature, salinity, sea level, and current velocity.
- HYCOM-based products include analyses, forecasts, and historical simulations.

Example: At a location, depth, and time, retrieve temperature and current velocity.



Source: HYCOM

Image: NOAA, via Wikimedia Commons · Public domain

eCLM — Community Land Model 5.0 (CLM5)

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Land surface model of the Community Earth System Model (CESM)

eCLM is based on the **Community Land Model 5.0 (CLM5)**, the land component of the Community Earth System Model (CESM).

- Models the land as the interface through which humanity **affects, adapts to, and mitigates** global environmental change.
- Covers biogeophysics, hydrology, plant physiology, biogeochemistry, land use, and ecosystem dynamics.
- Terrestrial ecosystems cycle **energy, water, chemical elements, and trace gases**, so they help determine climate.

Source: eCLM documentation

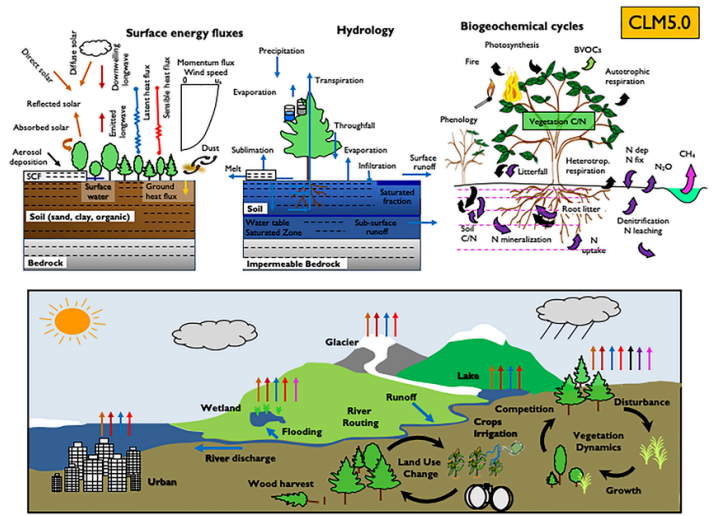


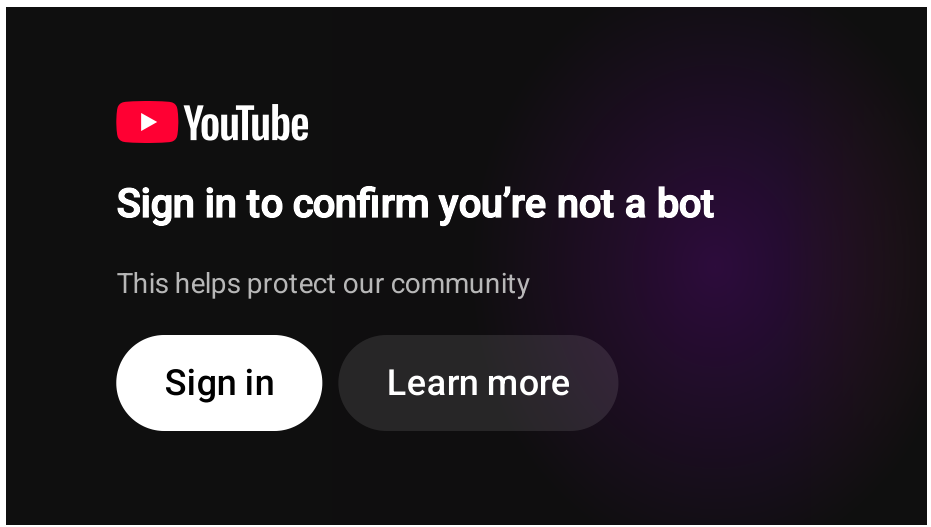
Fig. 1: Overview of land biogeophysical, biogeochemical and landscape processes simulated by eCLM, which is the same as CLM5. Lawrence et al. (2019).

CMIP6 — Coupled Model Intercomparison Project Phase 6

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Climate model ensemble by the World Climate Research Programme (WCRP)

Data description	
Resolution	0.25° (≈ 28 km), daily
Coverage	Global, 1950–2100
Historical	1950–2014
Projections	2015–2100
Models	34 climate models
Scenarios	SSP2-4.5, SSP5-8.5



Video: DKRZ / DLR, via YouTube · CC BY 4.0

Analysis, Forecast, Hindcast, Reanalysis, Projection

Product	Purpose
Analysis	Estimate the state at a given time using a model and available observations.
Forecast	Predict subsequent conditions from an initialized state.
Hindcast	Run a model for a past period; assimilation depends on the experiment.
Reanalysis	Reconstruct the past by assimilating archived observations with a consistent modelling system.
Climate projection	Simulate possible future climate under specified forcing scenarios.

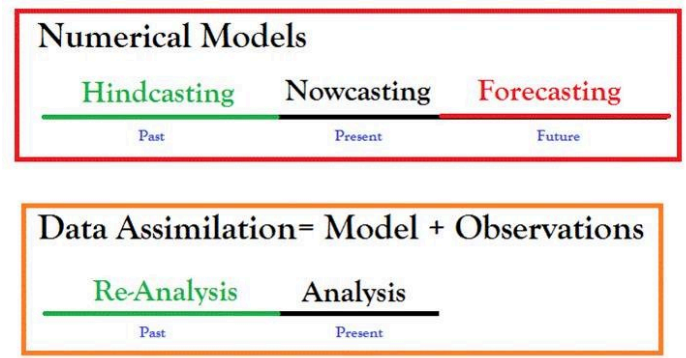


Figure: Schematic definitions of Forecast, Nowcast, Hindcast, Re-analysis and Analysis, S. Reddy et al., via ResearchGate.

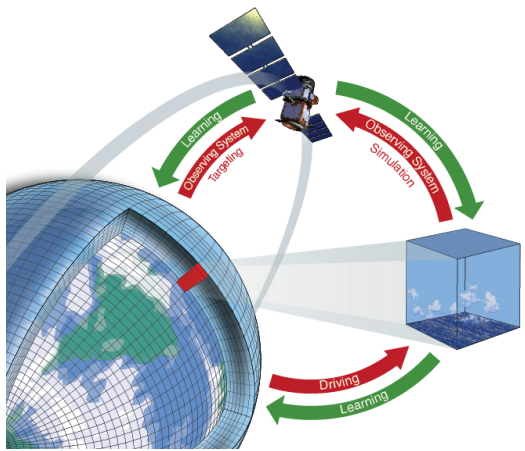
Earth System Model Outputs on Google Earth Engine

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Product in Earth Engine	Model or system	Product type	
NEX-GDDP, CMIP5	21 climate models, including CanESM2, CESM1-BGC and MPI-ESM-LR	Historical simulations and climate projections	Catalog
ERA5	ECMWF modelling and assimilation system	Atmospheric, land and ocean-wave reanalysis	Catalog
ERA5-Land	Land component of the ECMWF system, driven by ERA5	Historical land-surface reconstruction	Catalog
MERRA-2	NASA GEOS system	Atmospheric reanalysis, including aerosol products	Catalog
GLDAS-2.1	Noah land-surface model	Land-surface simulations: soil moisture, snow, water and energy fluxes	Catalog
CFSv2	NCEP coupled atmosphere–ocean–land–sea-ice model	Selected six-hour forecast fields	Catalog

Source: Earth Engine Data Catalog

Takeaways — Earth System Models



Observations → models + assimilation → gridded fields

Figure: Climate Modeling Alliance (CliMA)

- For **every coordinate**, these models provide **land use, land cover, precipitation, temperature, vegetation, wind, and water currents**.
- Model products are **estimates** of environmental conditions across space and time.
- Analysis, forecast, hindcast, reanalysis, and projection answer **different questions**.
- Check the product, time definition, resolution, units, and uncertainty before using a value.

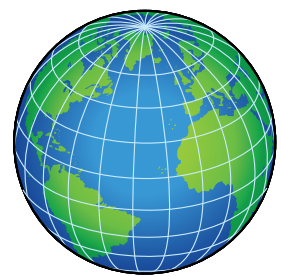
A complete grid does not imply perfect knowledge.

Lecture Recap

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1 **Coordinates and Reference Systems**

2 **Remote Sensing**
Optical · Radar



3 **Geo-information Systems (GIS)**

4 **Earth System Models**