PEER2PEER

TRANSBOUNDARY WATER SECURITY

Google Earth Engine for Water Resources

Annika Hjelmstad

Debora Yumi de Oliveira

University of Dar es Salaam, Tanzania, 2025

NATIONAL ACADEMIES Sciences Engineering Medicine

About PEER2PEER

The goal of **PEER2PEER** is to create a **global network of regional water networks** to drive knowledge exchange and data sharing among US researchers and international partners to **advance transboundary water research** and prepare the next generation of water professionals.

Google Earth Engine

https://www.nationalacademies.org/our-work/accelnet-peer2peer-international-convergence-research-networks-in-transboundary-water-security

About this workshop

- The focus of today’s workshop is on using Google Earth Engine for hydrology and water resources, with a focus on developing the following skills:
- **Use remote sensing data for hydrology & water resource applications**
- **Work with large global datasets remotely using GEE servers**
- **Use the Python interface to Google Earth Engine in an extensible computational environment**

Image source: https://earthengine.google.com/

Agenda

09:00 - 09:40
Introduction to GEE lecture and Jupyter notebook setup

Objectives: Learn what data is available on GEE
Understand how to access GEE resources remotely
Set up computing environment

09:40 - 10:00
Tutorial 1: Exploring GEE catalog

Objectives: Be able to run code in a Jupyter notebook
Learn how to read data from GEE image collections
Learn how to make a map of an image with `geemap`

10:00 - 11:00
Tutorial 2: Surface water change over time

Objectives: Use remote sensing data to characterize surface water
Understand limitations of remote sensing data
Analyze change in surface water area over time

11:00 - 12:00
Tutorial 3: Water storage changes at the basin scale

Objectives: Analyze changes in total water storage at the basin scale

Training materials

All training materials
are available at:

uci-chrs.github.io/GEE-Training-2025

Can also type in:
tinyurl.com/2ukc8v2e

Google Earth Engine:
Remote Sensing Data

Google Earth Engine stores > 50 petabytes of earth observation data

Image source: https://commons.m.wikimedia.org/wiki/File:NASA_Earth_satellites_currently_operating_(9-2013)_(8703587212).jpg

Image source: https://datacenters.google/photo-gallery/

GEE servers store and provide computational access to satellite imagery and other GIS data

Remote Sensing

Pros	Cons
❑ Global coverage	❑ Atmospheric interference
❑ Temporal coverage	❑ High data volume
❑ Accessibility	❑ Resolution limitations
❑ Consistency	❑ Sensor and calibration errors
❑ Low cost for end users	❑ High operational costs

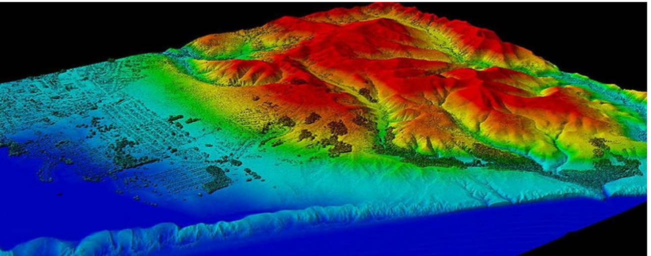
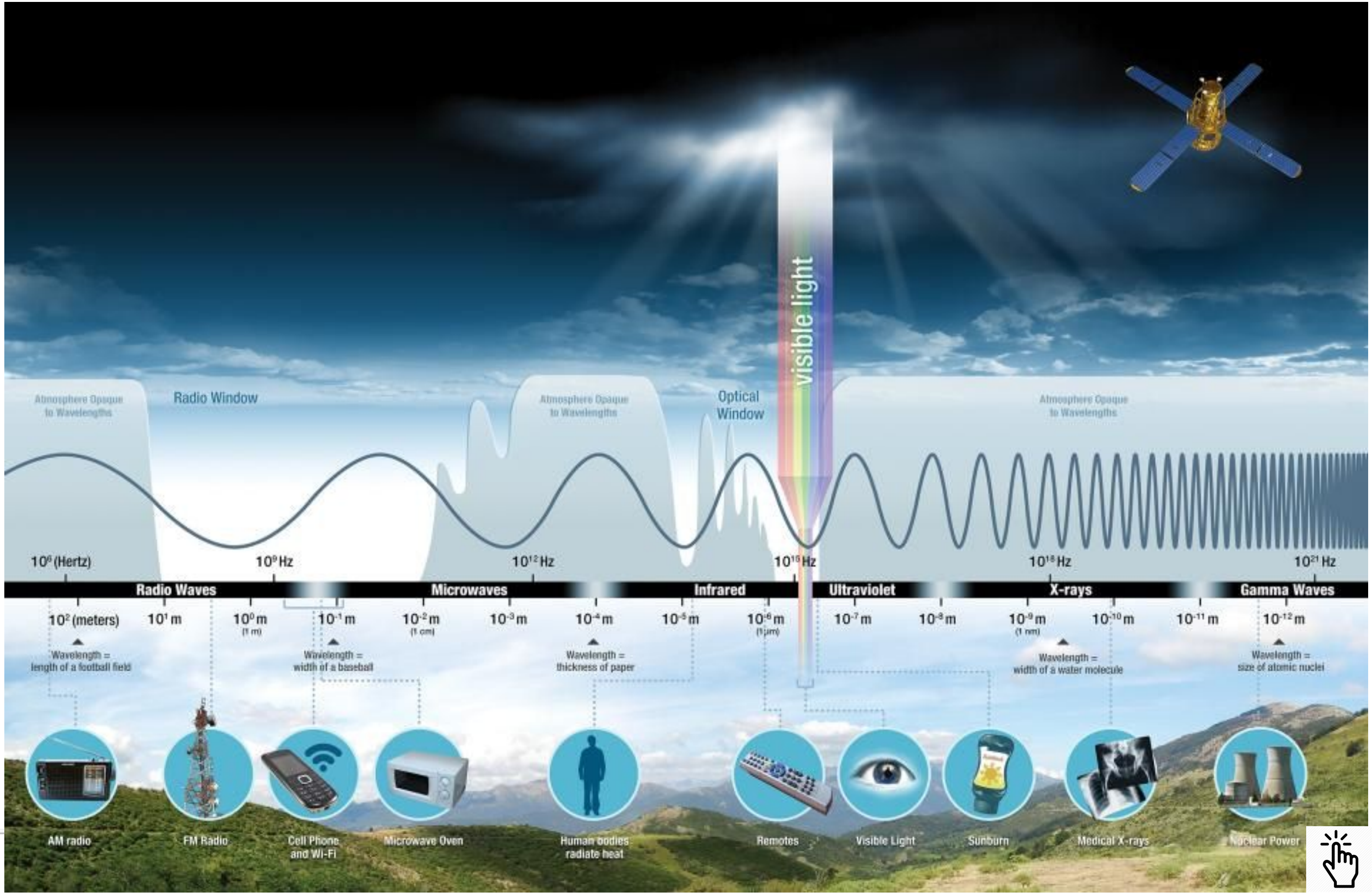


Image source: https://geodesy.noaa.gov/INFO/facts/remote-sensing.shtml

Image source: Geospatialworld.net

Satellite remote sensing data: a primer

Image source: https://www.earthdata.nasa.gov/learn/earth-observation-data-basics/remote-sensing

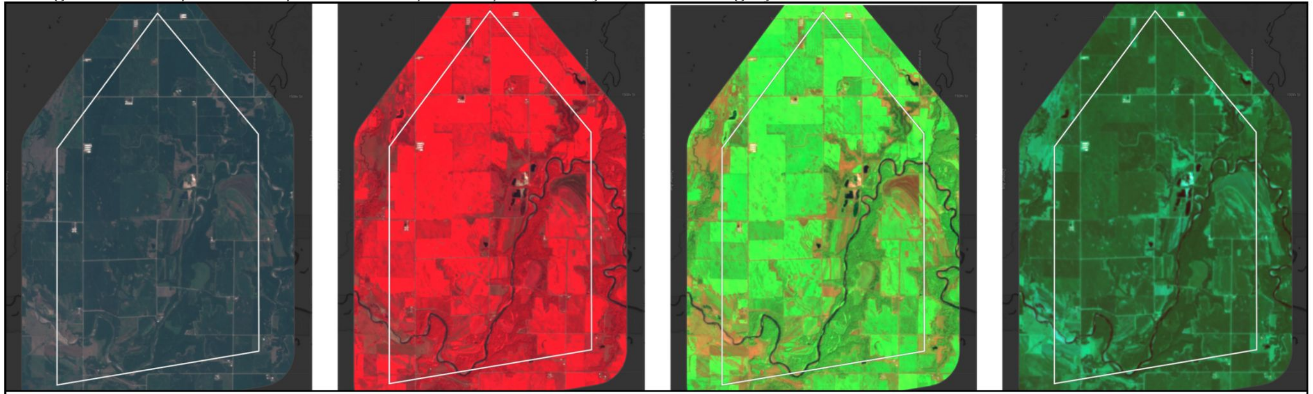


Satellites measure **light* reflected from the earth** at different wavelengths, which we can convert into useful information

**electromagnetic radiation*

Satellite remote sensing data: a primer

Image source: https://www.upstream.tech/posts/a-primer-on-false-color-imagery



Truecolor; NIR, Red, Green; SWIR, NIR, Green; Blue, SWIR. Copernicus Sentinel data 2022.

Image source: https://www.earthdata.nasa.gov/learn/earth-observation-data-basics/remote-sensing

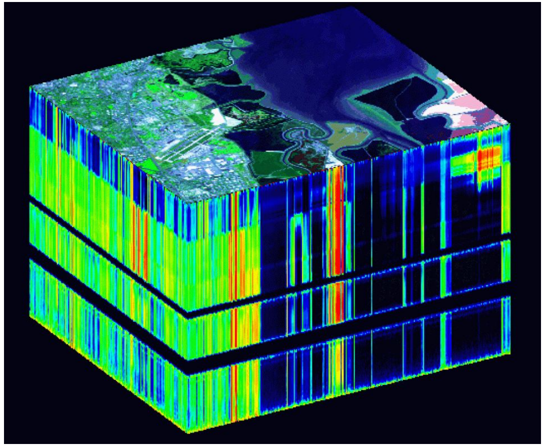
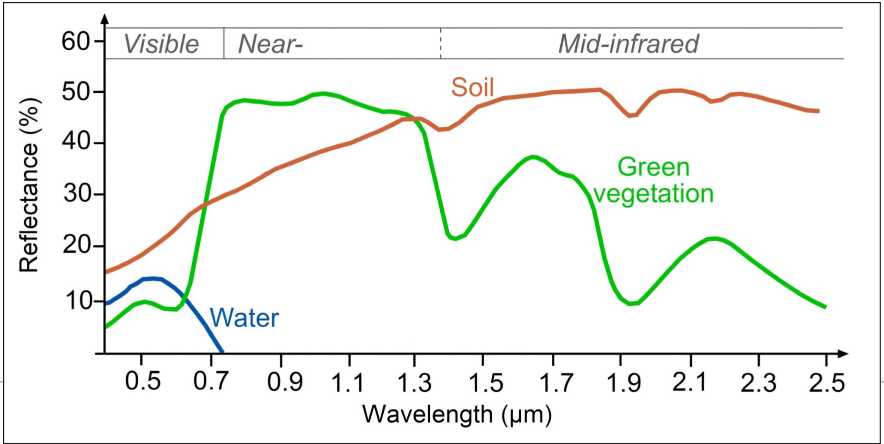


Image source: https://boisestate.pressbooks.pub/chemistry/chapter/3-1-electromagnetic-energy/



Any 3 channels can substitute the visible red, green, and blue to produce a **false color** image, which can reveal details not available in the visible spectrum

Types of satellites

Type & path of orbit

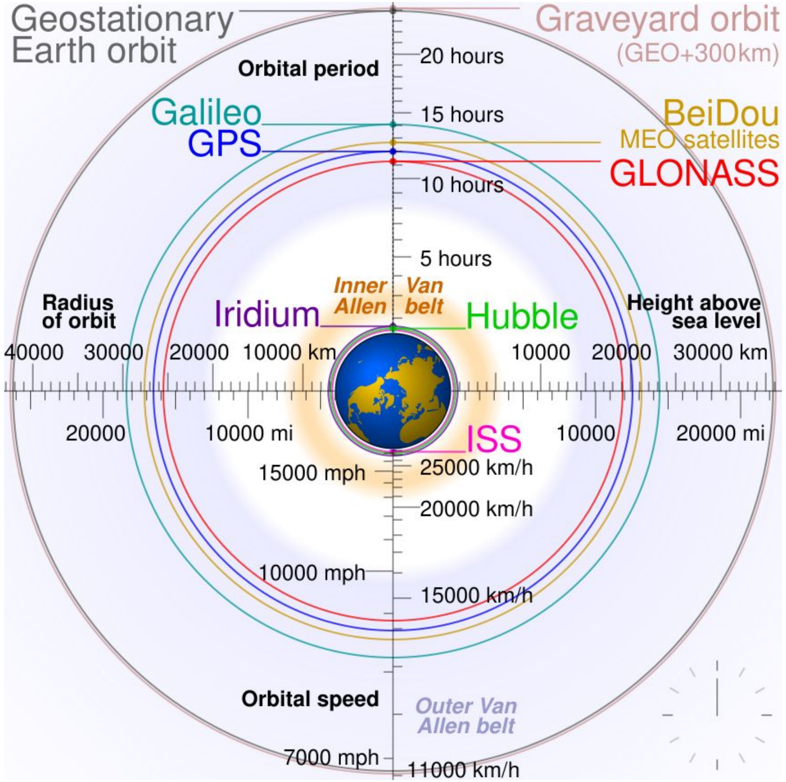


Image source: https://en.wikipedia.org/wiki/File:Comparison_satellite_navigation_orbits.svg

Sensing method

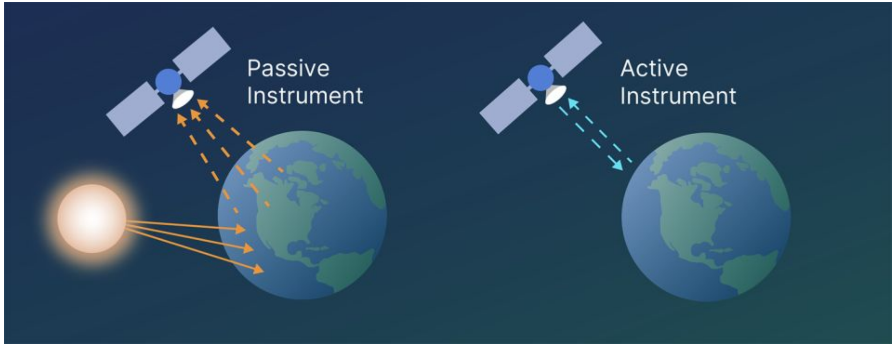


Image source: https://www.earthdata.nasa.gov/learn/earth-observation-data-basics/remote-sensing

Spectral bands

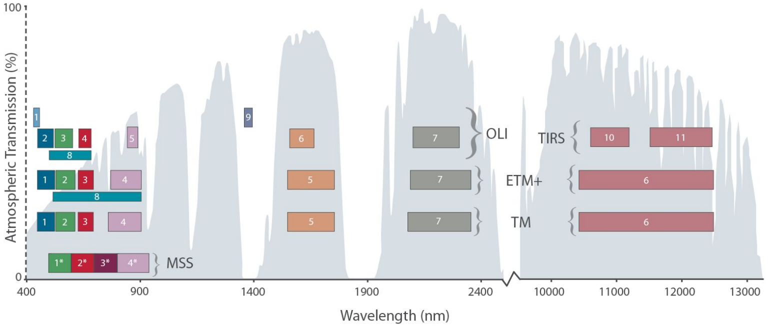
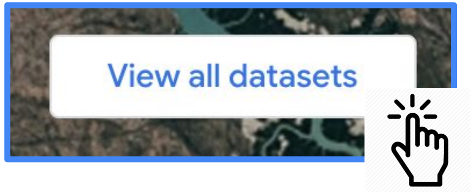


Image source: https://landsat.gsfc.nasa.gov/about/technical-details/

The Earth Engine Data Catalog



Landsat & Sentinel 1, 2
10-30m, weekly

MODIS
250m daily

Vector Data
WDPA, Tiger

Terrain & Land Cover

Weather & Climate
NOAA NCEP, OMI, ...

... and upload your own vectors and rasters

> 200 public datasets

> 5 million images

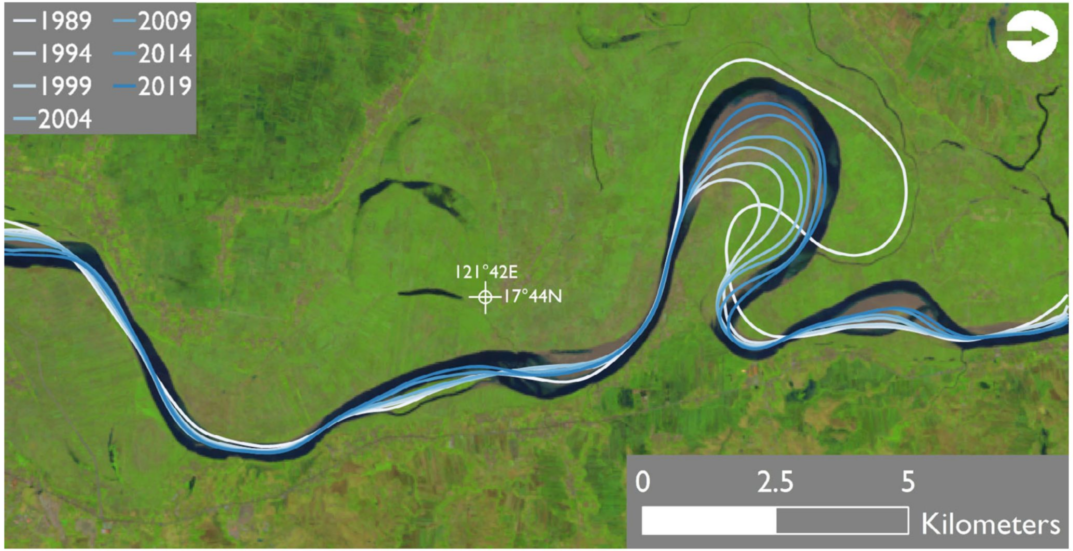
> 4000 new images every day

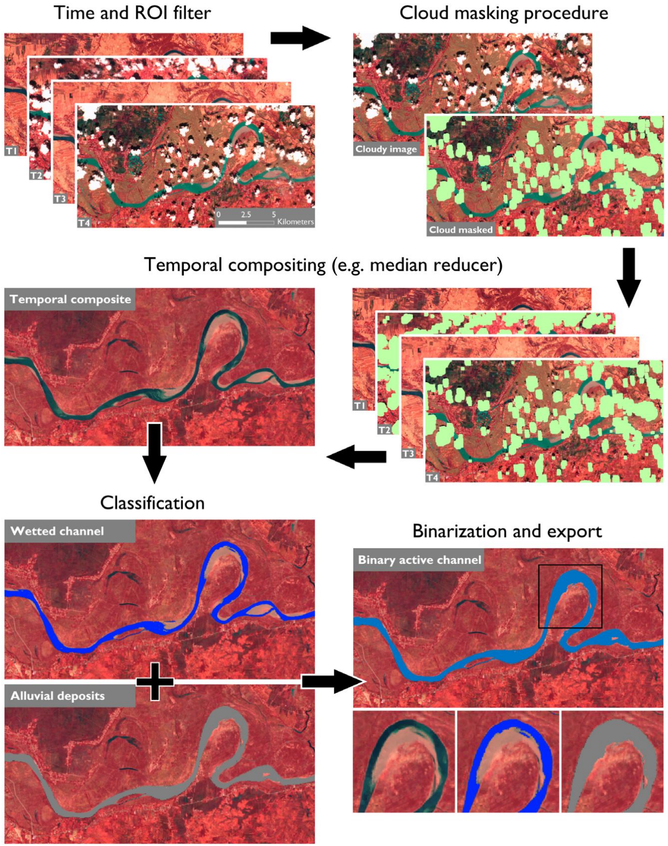
> 7 petabytes of data

Google Earth Engine:
Hydrology and Water Resources
Research Applications

Google Earth Engine

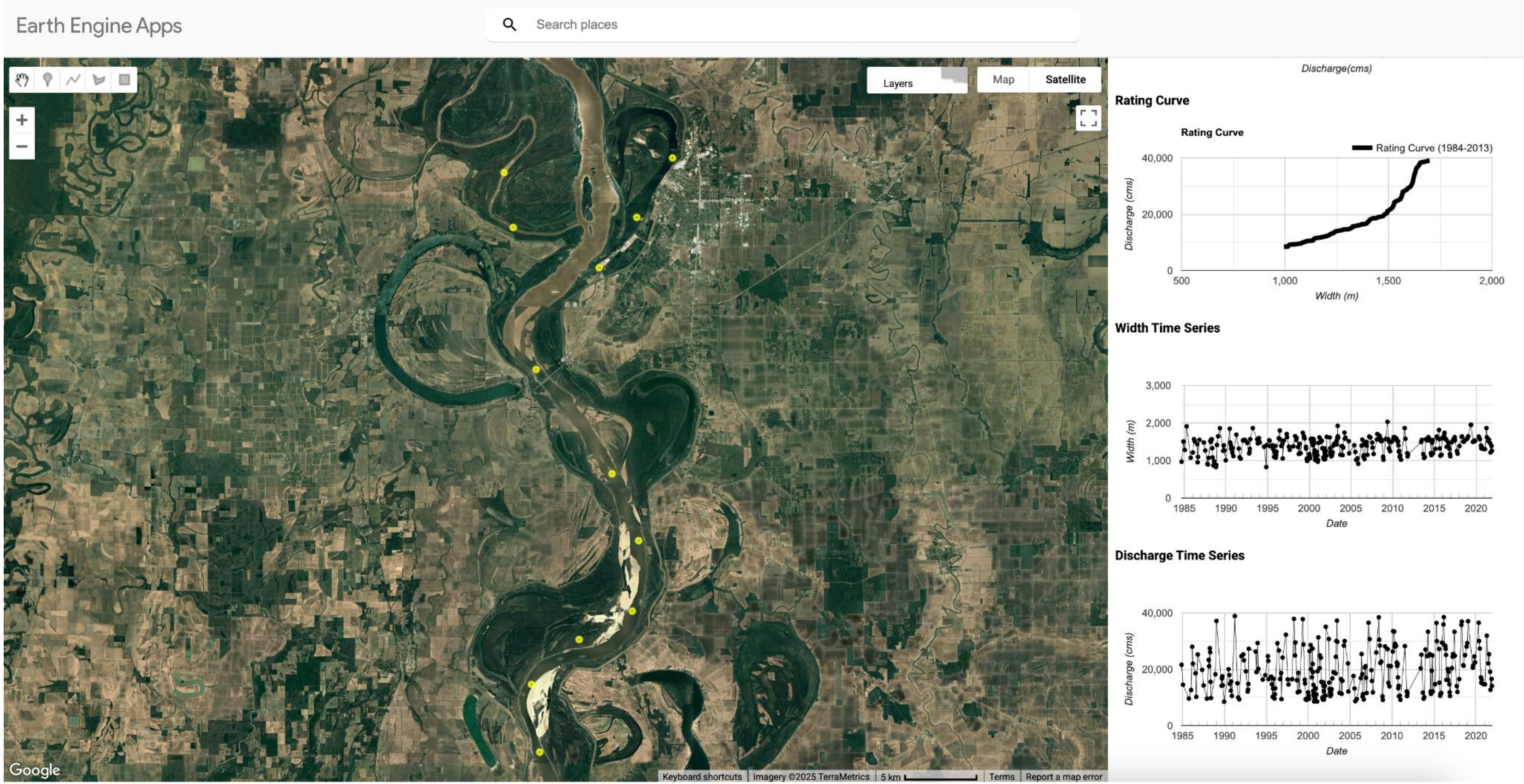
Detecting river channel change





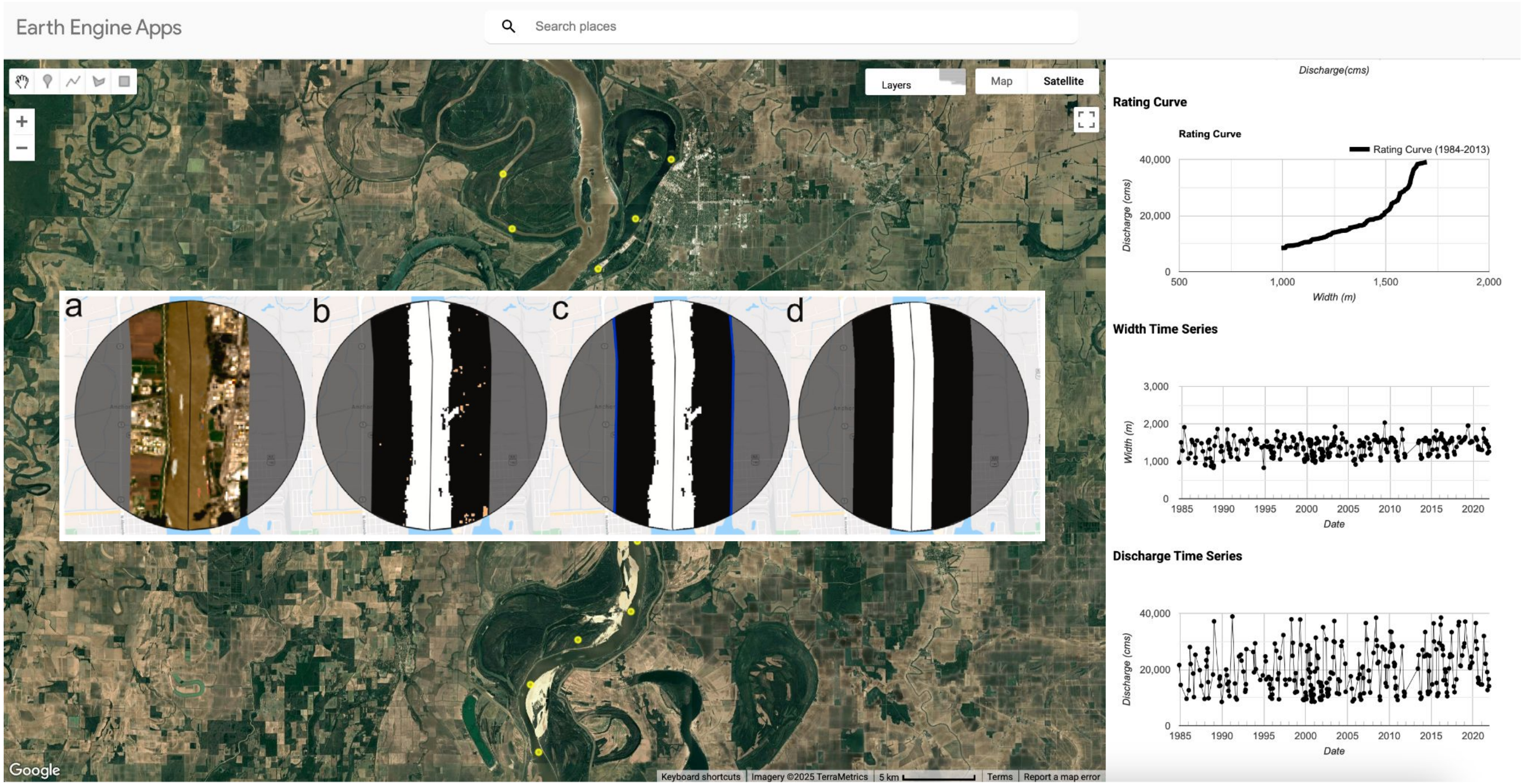
Boothroyd et al. (2021) *WIREs Water*

River discharge estimation



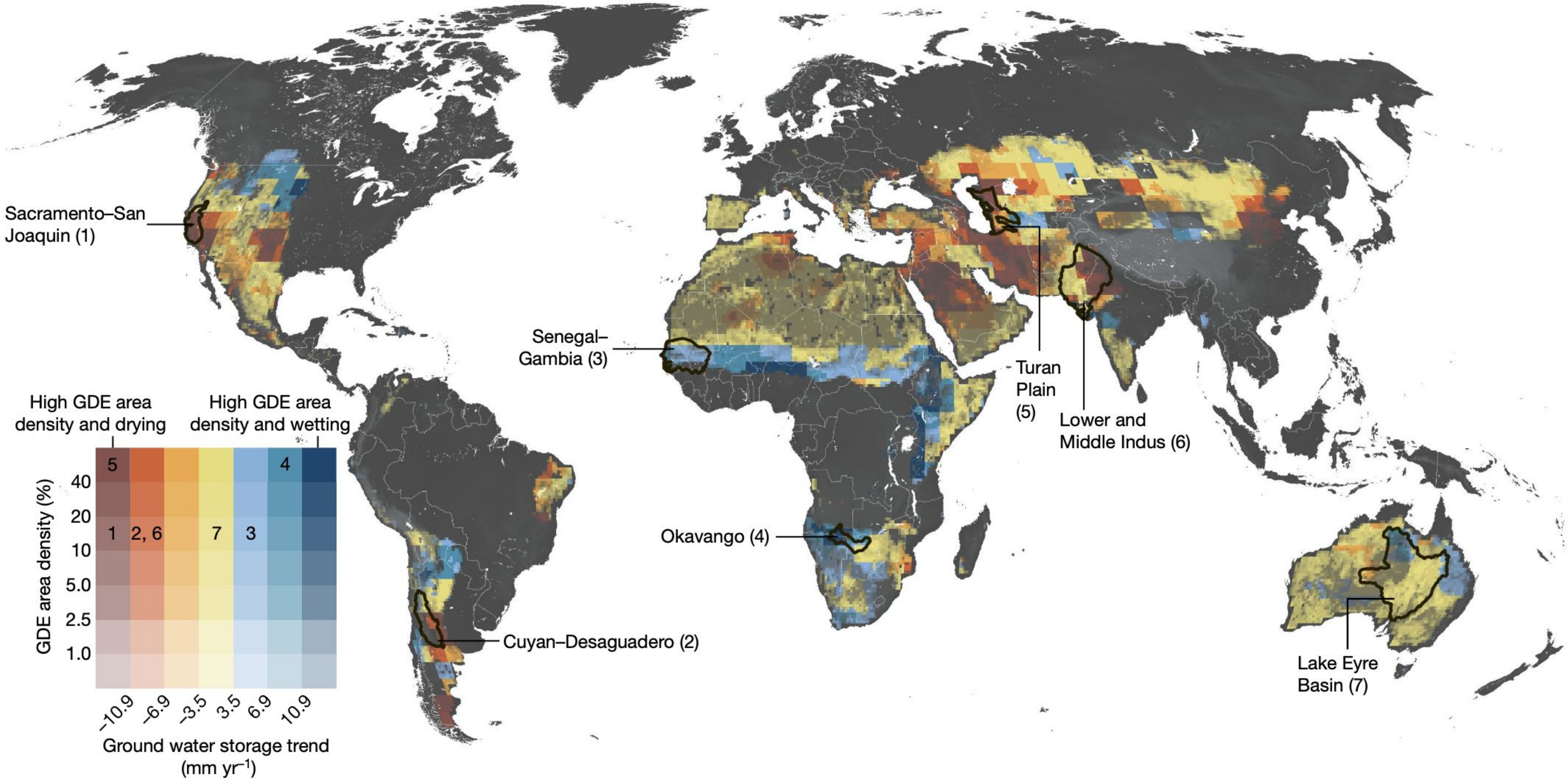
Riggs et al. (2022) *Environmental Modelling & Software*

River discharge estimation



Riggs et al. (2022) *Environmental Modelling & Software*

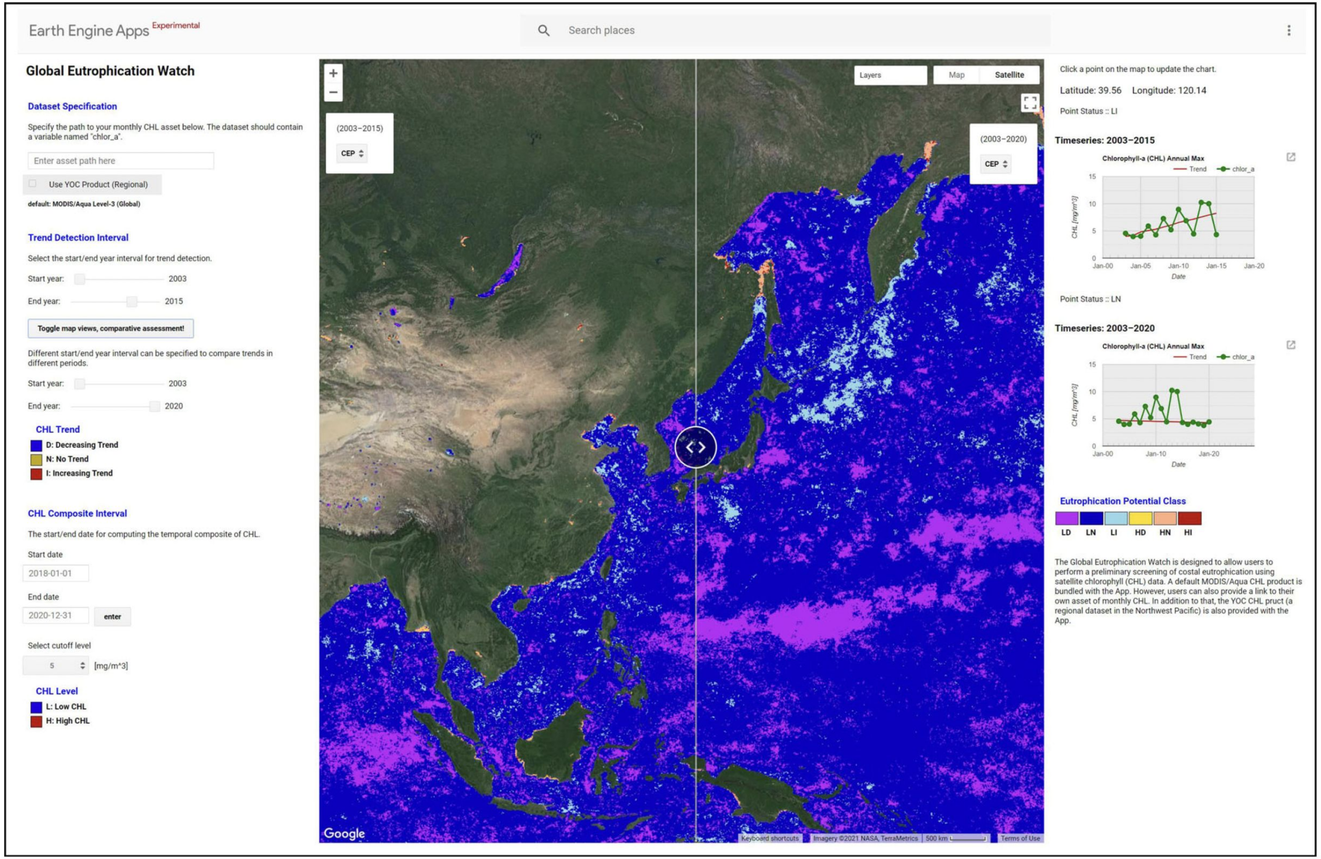
Groundwater storage trends



Google Earth Engine

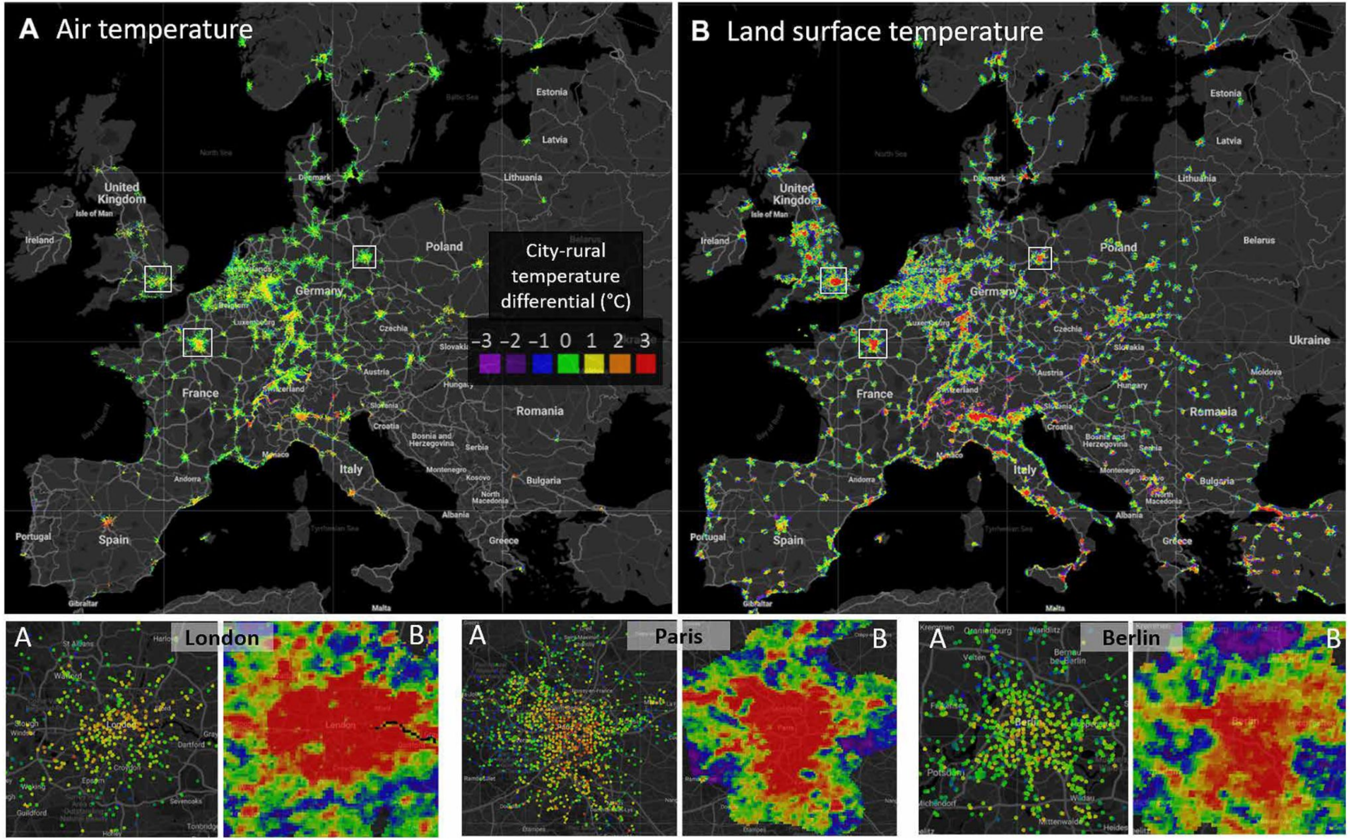
Rohde et al. (2024) *Nature*

Tracking water quality parameters



Maúre et al. (2021) *Nature Communications*

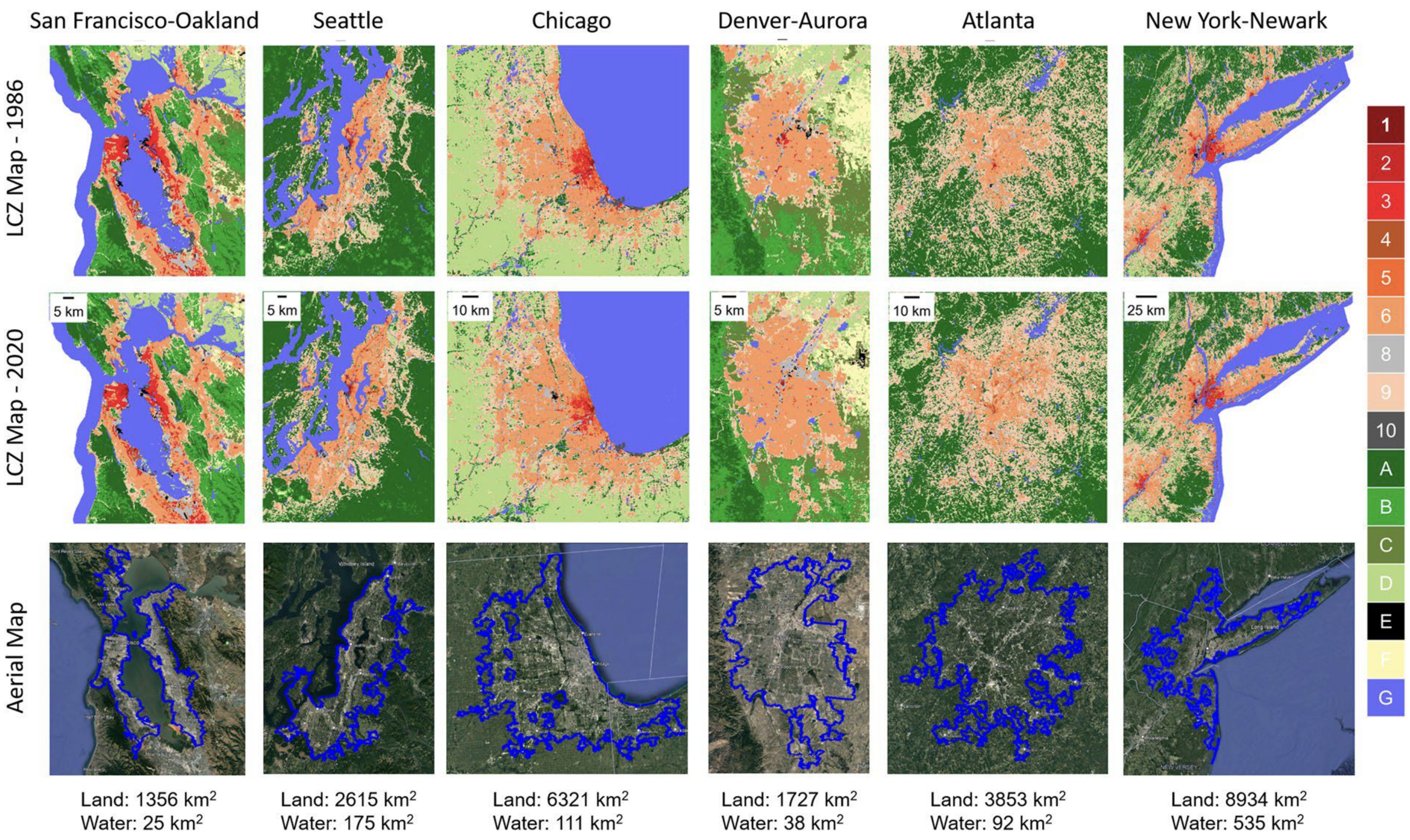
Mapping urban heat islands



Google Earth Engine

Venter et al. (2021) *Science Advances*

Mapping urban form into local climate zones



Qi et al. (2024) *Scientific Data*

Before we get started:
Google Colab setup

Google Colab Setup

Please open
the instructions at:

uci-chrs.github.io/GEE-Training-2025/setup

Google Colab Setup

1. **Create a Google Cloud project** at https://console.cloud.google.com/earth-engine
   a. Remember your **project ID**
2. **Enable the Google Earth Engine API for your cloud project** at https://console.cloud.google.com/home/dashboard
3. **Register your Google Cloud project as non-commercial** at https://console.cloud.google.com/earth-engine
4. **Open a Colab notebook and authenticate with your Google Cloud project ID** at https://colab.research.google.com/

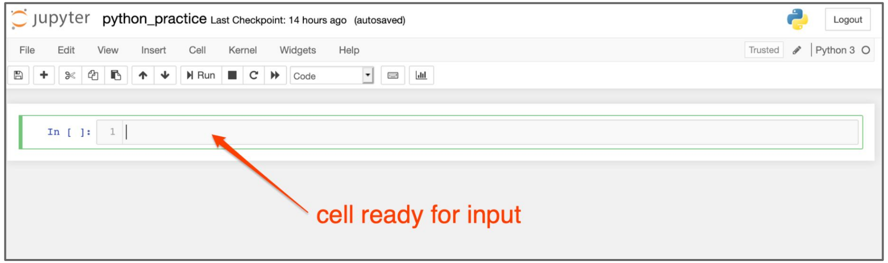
How does it work?

- Each code cell in the jupyter notebook executes Python code

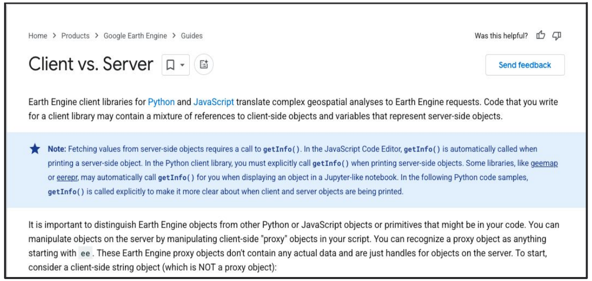
- Every operation using the **ee** prefix is a **proxy object** for data and operations on the **Google Earth Engine servers**, not on your computer. **ee** objects and code shouldn't be mixed with regular Python code!

- As late as possible, we request the computed data from the GEE servers and bring it into our analysis as a Python data type instead of an ee proxy object by calling **.getInfo()** on an **ee** object

- Once we've called **.getInfo()**, we have a Python object and the rest of our analysis is done as a regular Python script.



For more information, see the **Client vs. Server page** of the GEE documentation



Home > Products > Google Earth Engine > Guides

Was this helpful?

Client vs. Server

Send feedback

Earth Engine client libraries for Python and JavaScript translate complex geospatial analyses to Earth Engine requests. Code that you write for a client library may contain a mixture of references to client-side objects and variables that represent server-side objects.

Note: Fetching values from server-side objects requires a call to `getInfo()`. In the JavaScript Code Editor, `getInfo()` is automatically called when printing a server-side object. In the Python client library, you must explicitly call `getInfo()` when printing server-side objects. Some libraries, like geemap or eerepr, may automatically call `getInfo()` for you when displaying an object in a Jupyter-like notebook. In the following Python code samples, `getInfo()` is called explicitly to make it more clear about when client and server objects are being printed.

It is important to distinguish Earth Engine objects from other Python or JavaScript objects or primitives that might be in your code. You can manipulate objects on the server by manipulating client-side "proxy" objects in your script. You can recognize a proxy object as anything starting with `ee`. These Earth Engine proxy objects don't contain any actual data and are just handles for objects on the server. To start, consider a client-side string object (which is NOT a proxy object):

How does it work?

- Each code cell in the jupyter notebook executes Python code
- Every operation using the **ee** prefix is a **proxy object** for data and operations on the **Google Earth Engine servers**, not on your computer. **ee** objects and code shouldn't be mixed with regular Python code!
- As late in the analysis as possible, we request the computed data from the GEE servers and bring it into our analysis as a Python data type instead of an ee proxy object calling **.getInfo()** on an **ee** object
- Once we've called .**getInfo()**, we have a regular Python object and the rest of our analysis

Remember

Anything with the **ee** prefix is a **proxy object** for something on the **GEE server**

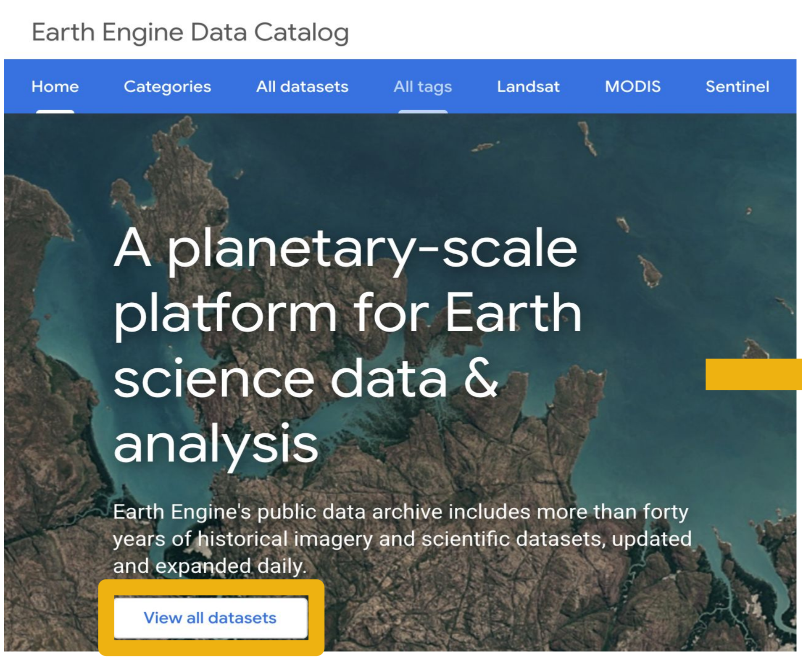
After the **.getInfo()** call, you are working with **regular Python code** in your computing environment.

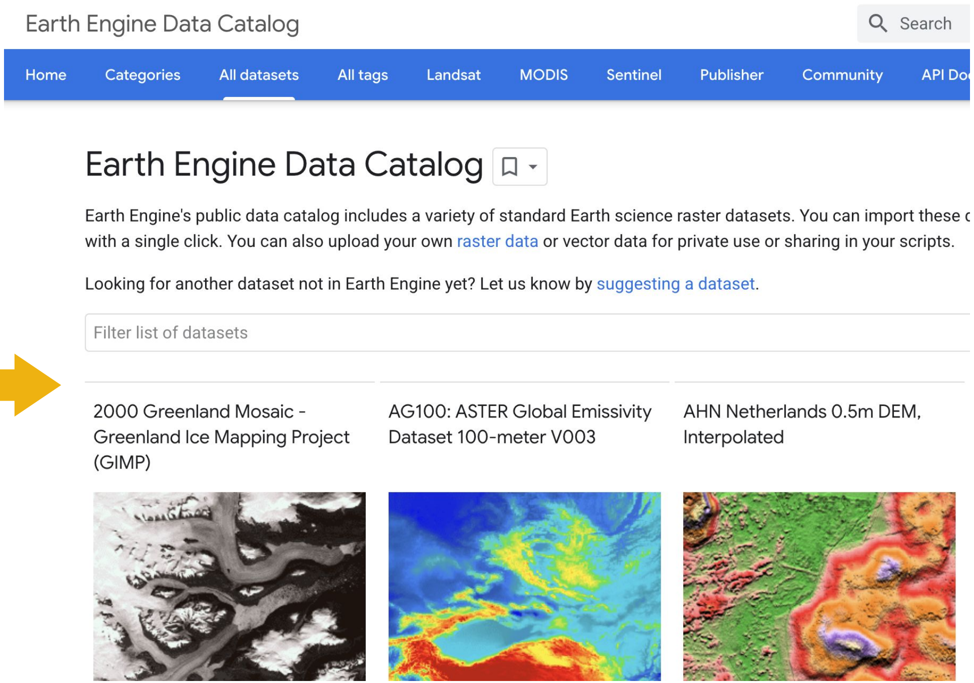
Tutorial 1

Exploring the Data Catalog

Data Catalog

Visit https://developers.google.com/earth-engine/datasets/ and **click** “View all datasets”. You can browse or search available datasets.





Jupyter Notebook for the Tutorial

Please open the Jupyter notebook

here

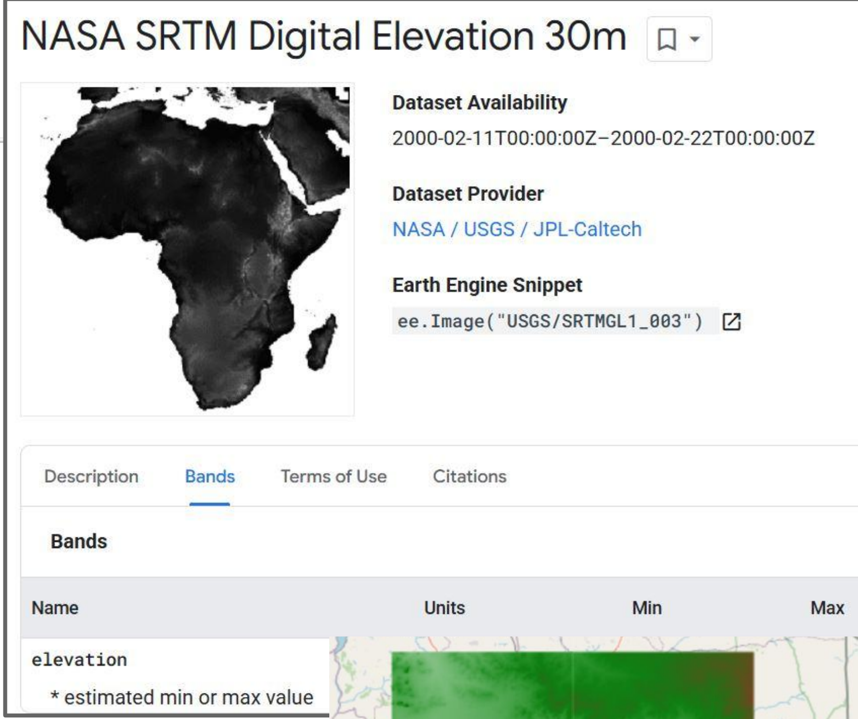
And click Open in Colab at the top

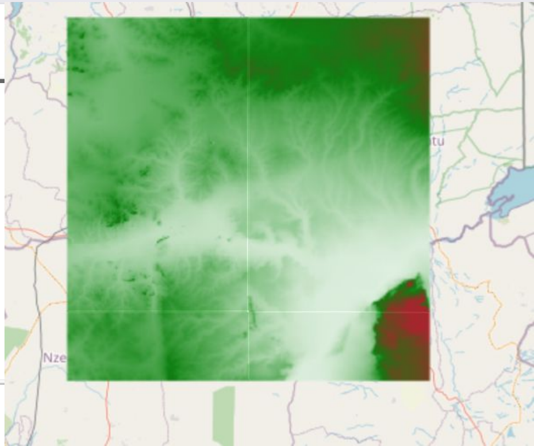
Then Copy to Drive

Elevation

The **Shuttle Radar Topography Mission** (SRTM) digital elevation data is an international research effort that obtained digital elevation models on a near-global scale and is provided by NASA JPL at a resolution of 30 meters.

Dataset: NASA SRTM Digital Elevation
Coverage: Global
Spatial Resolution: 30 meters
Earth Engine Snippet:
`ee.Image("USGS/SRTMGL1_003")`



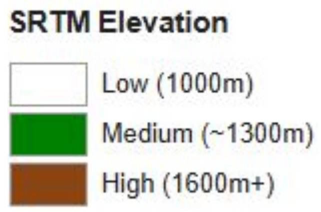


How to add Legends

1. Categorical

```
# Add legend to the map
legend_dict = {
    "Low (1000m)": "ffffff",
    "Medium (~1300m)": "008000",
    "High (1600m+)": "8b4513"}

# Generate and attach legend
Map1.add_legend(
    title="SRTM Elevation",
    legend_dict=legend_dict,
    draggable=False,
    output="srtm_legend.html",
)
```



2. Built-in Legend

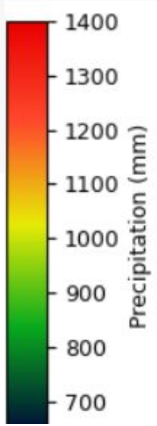
```
# Add the buil-in legend to the map
Map2.add_legend(
    title="ESA Land Cover Type",
    builtin_legend="ESA_WorldCover",
    draggable=False,
    position="bottomleft",
    style={"bottom": "5px"},
)

#Display the Map
Map2
```

3. Colorbar Legend

```
# Visualization parameters
precip_vis = {'min': 650,'max': 1400,
    'palette': ['001137', '0aab1e',
                'e7eb05', 'ff4a2d', 'e90000'],}

# Add a vertical colorbar Legend to the map
Map3.add_colorbar(
    precip_vis,
    label="Precipitation (mm)",
    layer_name="Yearly Rainfall",
    orientation="vertical",
    position="bottomleft",
    transparent_bg=True,
)
```



Land cover & land use

The **European Space Agency (ESA) WorldCover 10 m** 2021 product provides a global land cover map at a high spatial resolution of 10 meters, derived from Sentinel-1 and Sentinel-2 satellite data. This dataset includes 11 distinct land cover classes.

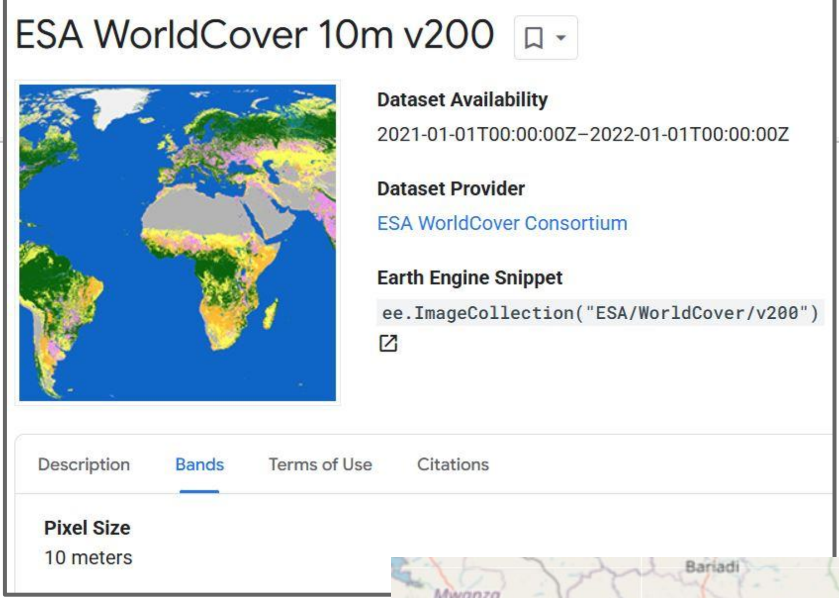
Dataset: ESA WorldCover 10m v200

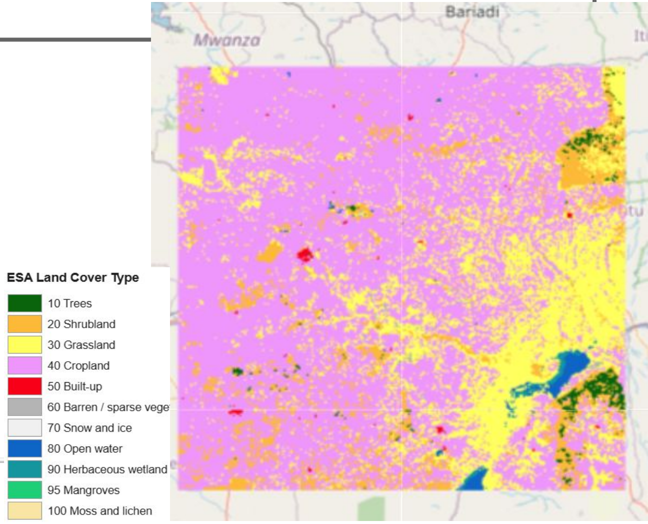
Coverage: Global

Spatial Resolution: 10 meters

Earth Engine Snippet:

```
ee.ImageCollection("ESA/WorldCover/v200")
```





Precipitation

PERSIANN-CDR is a daily quasi-global precipitation product that spans the period from 1983-01-01 to present. The data is produced quarterly, with a typical lag of three months.

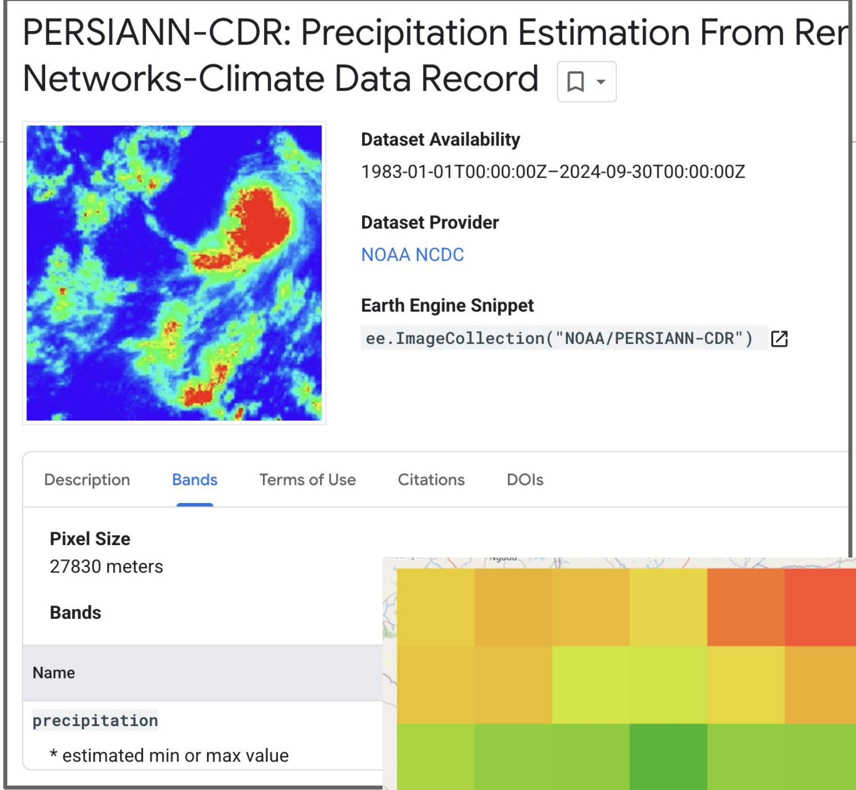
Dataset: PERSIANN-CDR

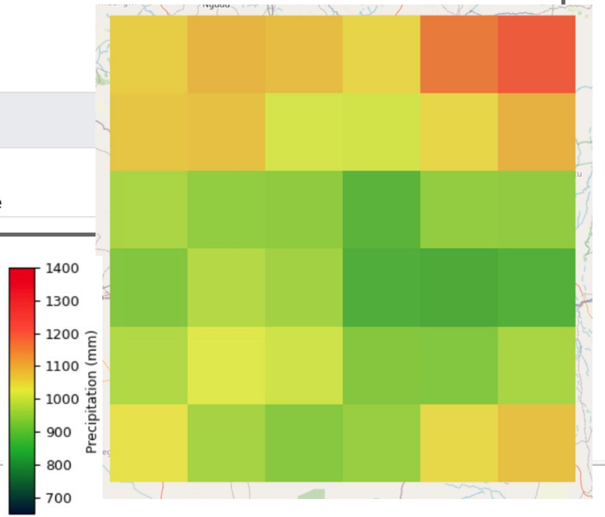
Coverage: Global 60°S to 60°N, 1983-

Spatial Resolution: 25 kilometers

Earth Engine Snippet:

`ee.ImageCollection("NOAA/PERSIANN-CDR")`





Precipitation

The **Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)** is a long-term, high-resolution rainfall dataset developed to support drought early warning and climate monitoring efforts.

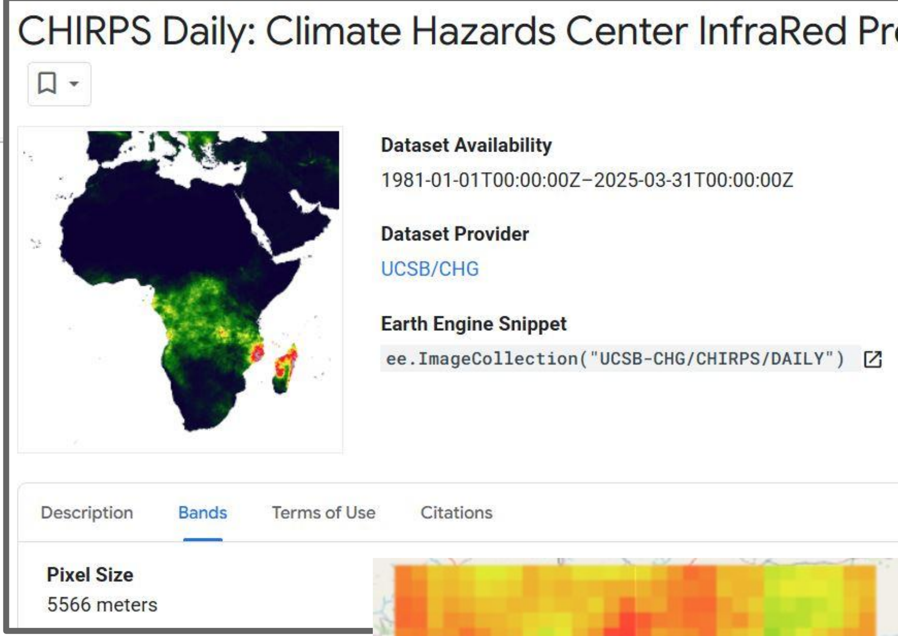
Dataset: CHIRPS Daily

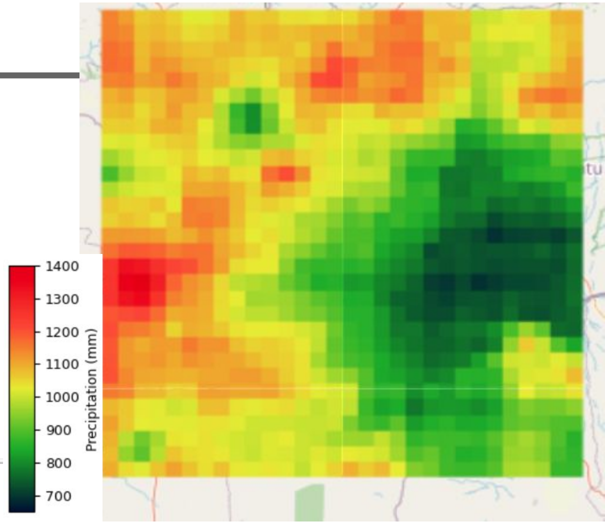
Coverage: Global 50°S to 50°N, 1981-

Spatial Resolution: 5.5 kilometers

Earth Engine Snippet:

```
ee.ImageCollection("UCSB-CHG/CHIRPS/DAILY")
```





Land Surface Temperature

The MODIS satellite's **MOD11A1 V6.1** product provides daily land surface temperature (LST) and emissivity data. The product includes both daytime and nighttime LST bands and their associated quality assurance layers, as well as MODIS thermal bands 31 and 32.

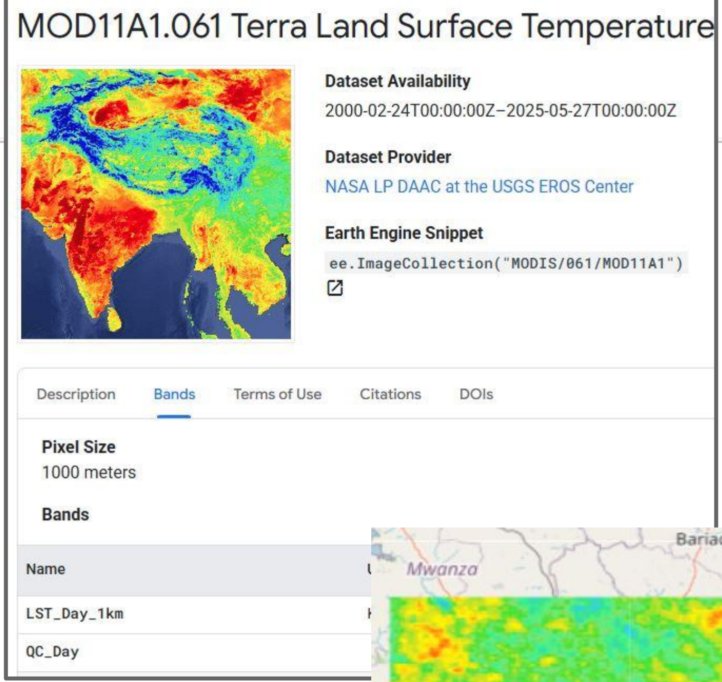
Dataset: MOD11A1 V6.1

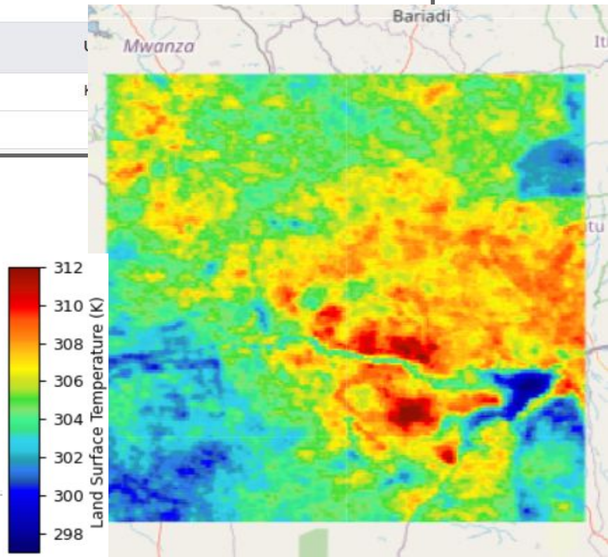
Coverage: Global, 2000-

Spatial Resolution: 1 kilometer

Earth Engine Snippet:

```
ee.ImageCollection("MODIS/061/MOD11A1")
```





Soil moisture

The **Soil Moisture Active Passive (SMAP)** mission is a NASA satellite observatory designed to measure the amount of water in the top 5 cm of soil across the globe, enabling detection of soil moisture changes driven by weather events, seasonal variation, and climatic shifts.

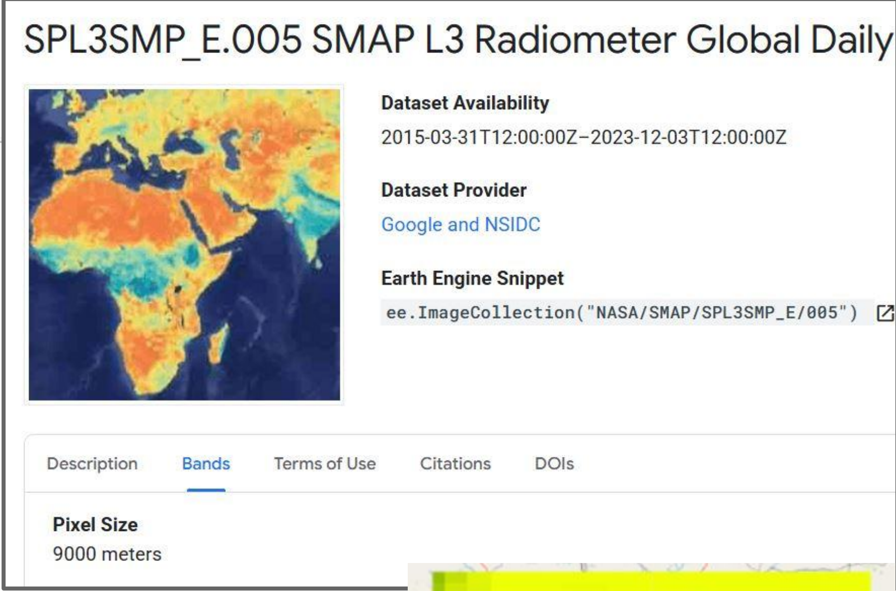
Dataset: SMAP L3 Radiometer

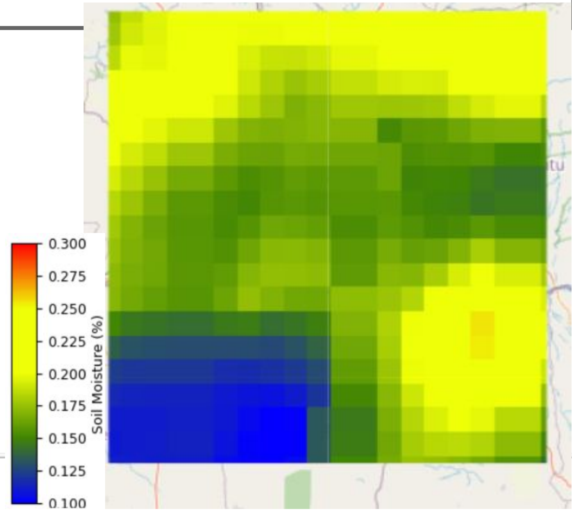
Coverage: Global, 2015-2023

Spatial Resolution: 9 kilometers

Earth Engine Snippet:

`ee.ImageCollection("NASA/SMAP/SPL3SMP_E/005")`





Google Earth Engine

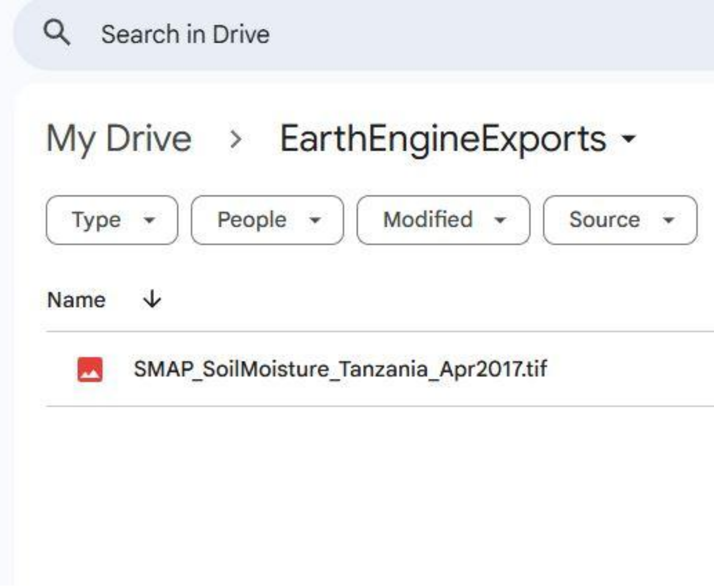
Downloading Datasets to Google Drive

After processing remote sensing datasets in Google Earth Engine (GEE), you can export the results to Google Drive using the **Export.image.toDrive()** function in Python. Follow the steps given below to access the download the data for your study region.

Export the image to your Google Drive

```
task = ee.batch.Export.image.toDrive(
    image=soil_moisture_am,
    description='SMAP_SoilMoisture_Apr2017',
    folder='EarthEngineExports',  # Your Drive folder name
    fileNamePrefix='SMAP_SoilMoisture_Tanzania_Apr2017',
    region=aoi,
    scale=10000,  # SMAP native resolution ~10 km
    crs='EPSG:4326',
    maxPixels=1e13
)

# Start the export task
task.start()
```



Tutorial 2

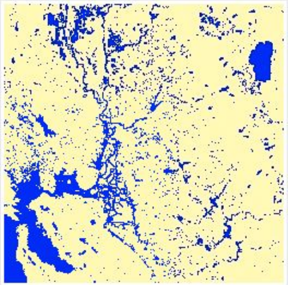
Surface Water Change Over Time

Google Earth Engine

Surface water dataset

- Derived from over 4 million images from the **Landsat** 5, 7, and 8 missions
- **Temporal coverage**: Monthly, 1984-2021
- **Spatial coverage**: 30m, Global (except for the poles)
- For more details, see the [corresponding paper in the journal Nature]()

JRC Monthly Water History, v1.4



Dataset Availability
1984-03-16T00:00:00Z–2022-01-01T00:00:00Z

Dataset Provider
EC JRC / Google

Earth Engine Snippet
`ee.ImageCollection("JRC/GSW1_4/MonthlyHistory")`

Description | Bands | Image Properties | Terms of Use | Citations

Pixel Size
30 meters

Bands

Name	Description
`water`	Water detection for the month.

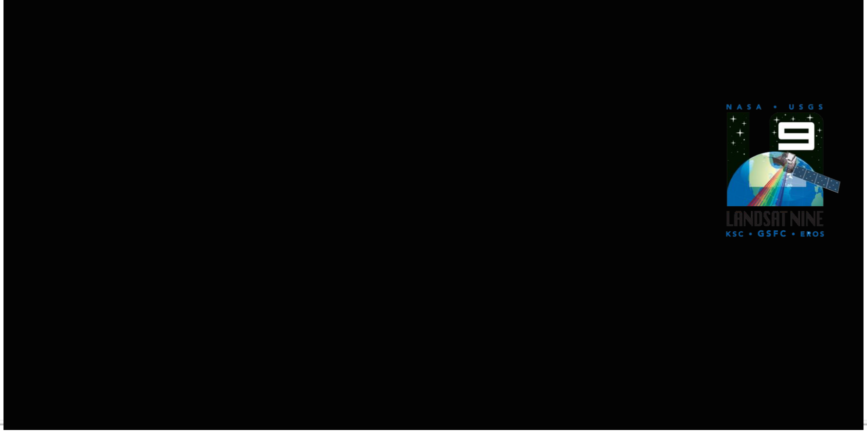
Bitmask for water

- Bits 0-1: Water detection
  - 0: No data
  - 1: Not water
  - 2: Water

Landsat

- The Landsat program (led by NASA and the USGS) is a set of low-earth orbit, passive **satellite Earth imaging missions** that date back to 1972.
- Landsat provides top-of-atmosphere reflectance & brightness temperature images

Image source: https://landsat.gsfc.nasa.gov/satellites/landsat-9/



USGS
science for a changing world

NASA Landsat Science

visible earth
Landsat Gallery

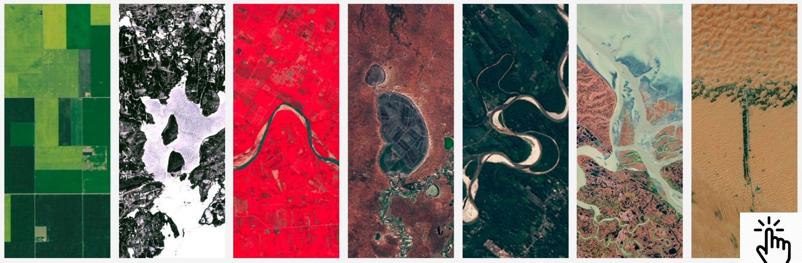


Image source: https://landsat.gsfc.nasa.gov/apps/YourNameInLandsat-main/index.html

Jupyter Notebook for the Tutorial

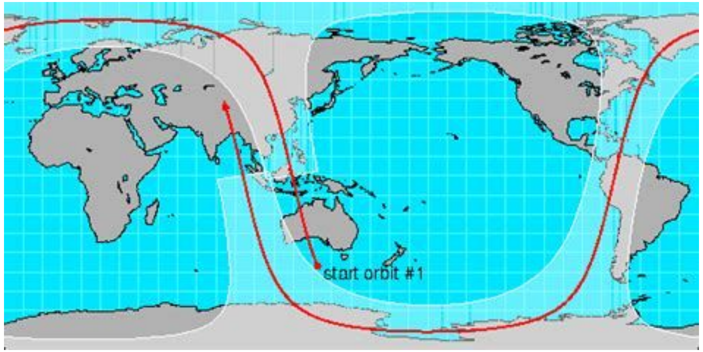
Please open the
Jupyter notebook
here

And click Open in Colab at the top

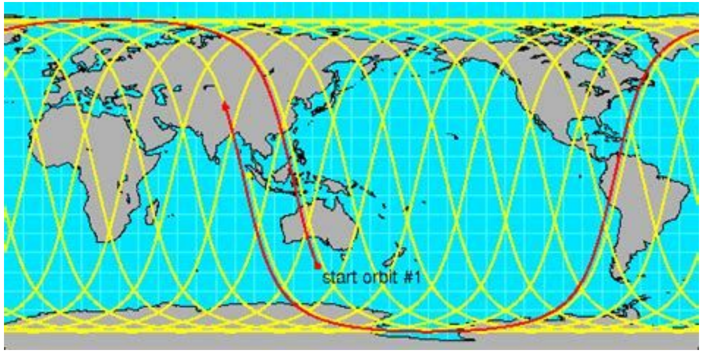
Then Copy to Drive

What makes satellites prone to errors and missing data?

- Equipment failure
- Less coverage & resolution in early satellite missions
- Limited scan coverage depending on the type and orbital path of a satellite
- Satellites only directly measure **electromagnetic radiation** (EMR)
  - We use a variety of algorithms to process EMR data from different bands into estimates of different kinds of earth observations. These models are imperfect.



Polar orbiting satellite path



Images source: https://apollo.nvu.vsc.edu/classes/remote/lecture_notes/satellite/platforms/

Tutorial 3

Storage changes at the basin scale

Jupyter Notebook for the Tutorial

Please open the Jupyter notebook

here

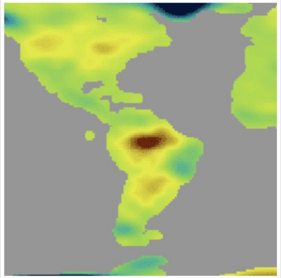
And click **Open in Colab** at the top

Then **Copy to Drive**

TWSA dataset

- Sum of all above and below surface water storages
  - Canopy water
  - Rivers and lakes
  - Soil moisture
  - Groundwater
- Derived from GRACE & GRACE-FO
- **Temporal coverage**: Monthly, 2002-2017
- **Spatial coverage**: 100 km, Global

GRACE Monthly Mass Grids Release 06 Version 04 - Land



Dataset Availability

2002-04-01T00:00:00Z–2017-01-07T00:00:00Z

Dataset Provider

NASA Jet Propulsion Laboratory

Earth Engine Snippet

```
ee.ImageCollection("NASA/GRACE/MASS_GRIDS_V04/LAND")
```

Tags

crs gfz grace gravity jpl land mass nasa surface-ground-water tellus water

Description | Bands | Image Properties | Terms of Use | Citations | DOIs

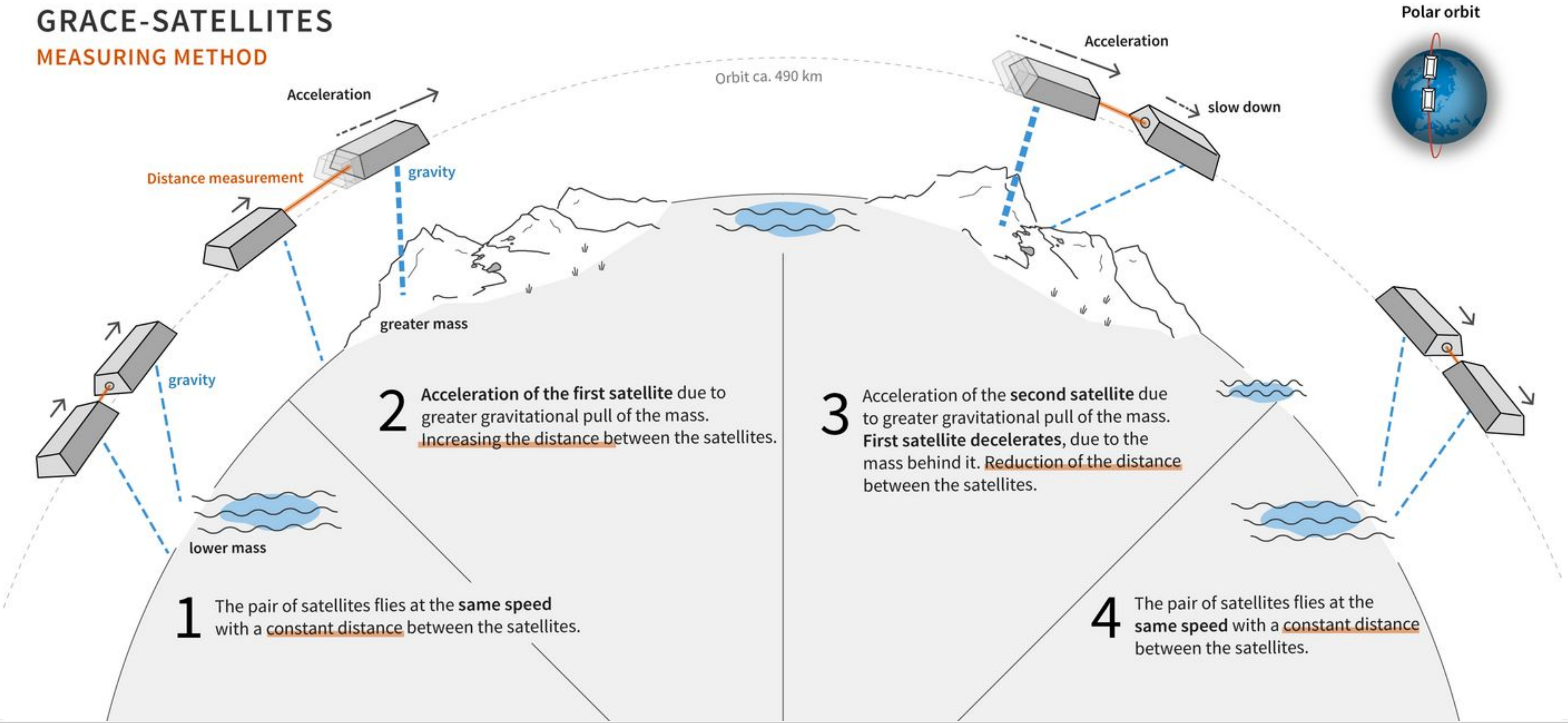
Pixel Size

111320 meters

Bands

Name	Units	Description
lwe_thickness_csr	cm	Equivalent liquid water thickness in centimeters calculated by CSR.
lwe_thickness_gfz	cm	Equivalent liquid water thickness in centimeters calculated by GFZ.
lwe_thickness_jpl	cm	Equivalent liquid water thickness in centimeters calculated by JPL.

GRACE



Google Earth Engine

Image source: https://www.globalwaterstorage.info/en/satellite-missions/measuring-principle

Basin boundaries

- Watersheds range from level 1 (coarse) to level 12 (detailed), using Pfastetter codes
- HydroBASINS is a component of HydroSHEDS

WWF HydroATLAS Basins Level 03

Dataset Availability

2000-02-22T00:00:00Z–2000-02-22T00:00:00Z

Dataset Provider

WWF

Earth Engine Snippet

```
ee.FeatureCollection("WWF/HydroATLAS/v1/Basins/level03")
```

WWF HydroATLAS Basins Level 04

Dataset Availability

2000-02-22T00:00:00Z–2000-02-22T00:00:00Z

Dataset Provider

WWF

Earth Engine Snippet

```
ee.FeatureCollection("WWF/HydroATLAS/v1/Basins/level04")
```

Thank you!

- For additional resources on learning GEE and Python, please see uci-chrs.github.io/GEE-Training-2025/additional-resources

- For further questions, feel free to contact Annika Hjelmstad at

ahjelmst@uci.edu

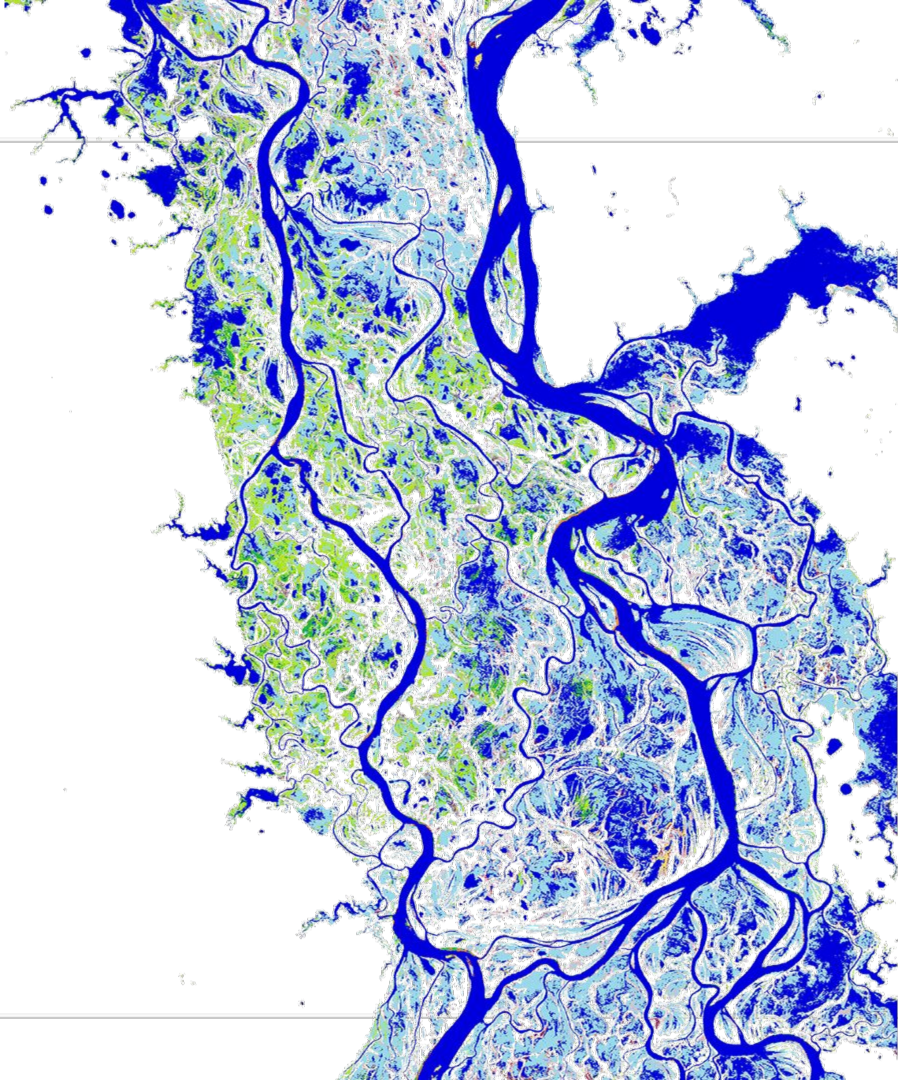


Image source: https://global-surface-water.appspot.com/