Geospatial analysis using GEE for Remote Sensing and Agriculture

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International Conference on Sustainable & Resilient Future
Bridging Science, Policy, and Practice

urban kisaan

Cropin™

Contents

With the End in mind!

Agriculture-Not Business as usual!

YALE Climate Connections

UN report: The world's farms stretched to 'a breaking point'

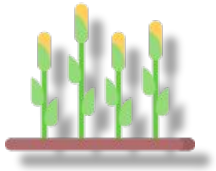
The world's climate-stressed and pollution-degraded farming and agricultural system must shift quickly to sustainable practices to feed an additional 2 billion mouths expected by 2050, a new United Nations report finds.

by **DANA NUCCITELLI**
JANUARY 19, 2022

Forbes

Agriculture is not in good shape overall. The sector contributes 20% of humanity's total greenhouse gas emissions. Fertilizer overuse triggers some 405 marine dead zones in coastal waters worldwide. Massive plantings of single kinds of crops, pesticide application and agriculture-related deforestation are major contributors to the extinction of wildlife species.

Biodiversity Loss and Climate Change threatens food security

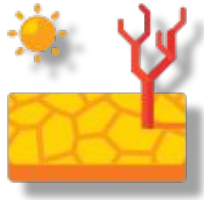


Monocultures and intensification has eroded genetic diversity, and increased vulnerability to diseases, pests, and climate shocks.

Just 12 plants provide 75% of the world's nutrition!

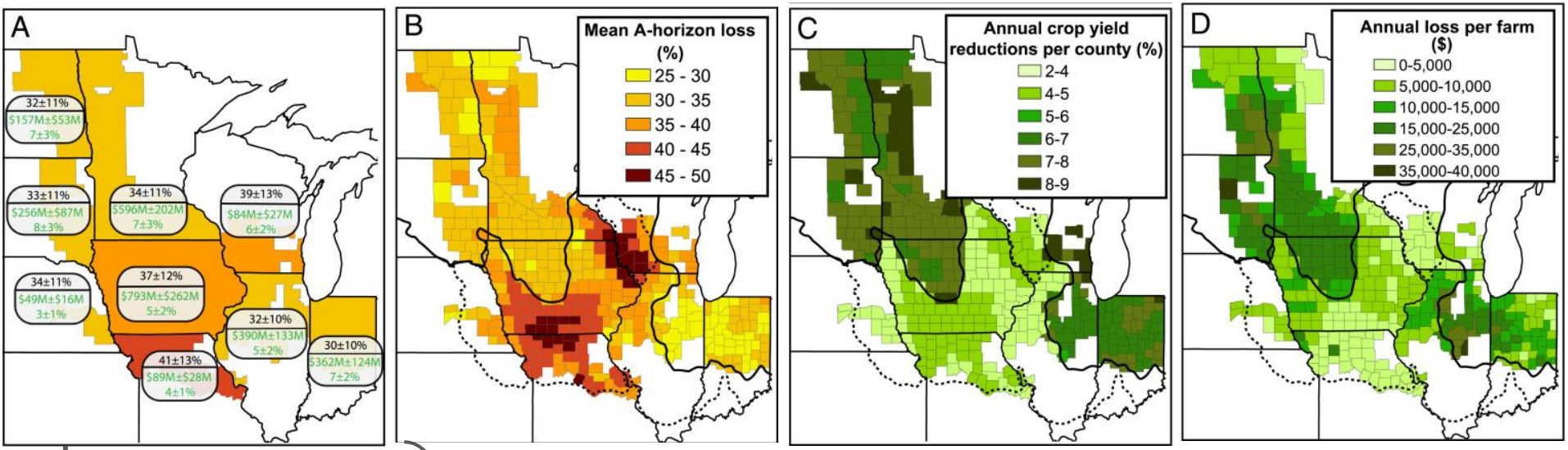
75% of global food crops depend on pollinators. Populations are declining due to climate, habitat loss and pesticides.

~One-third of the topsoil in the Corn Belt has been lost. Globally, ~ 33% soils are moderately to highly degraded. (Slide 5)



With climate change, many existing agriculture lands will become unsuitable to grow crops (Slide 6).

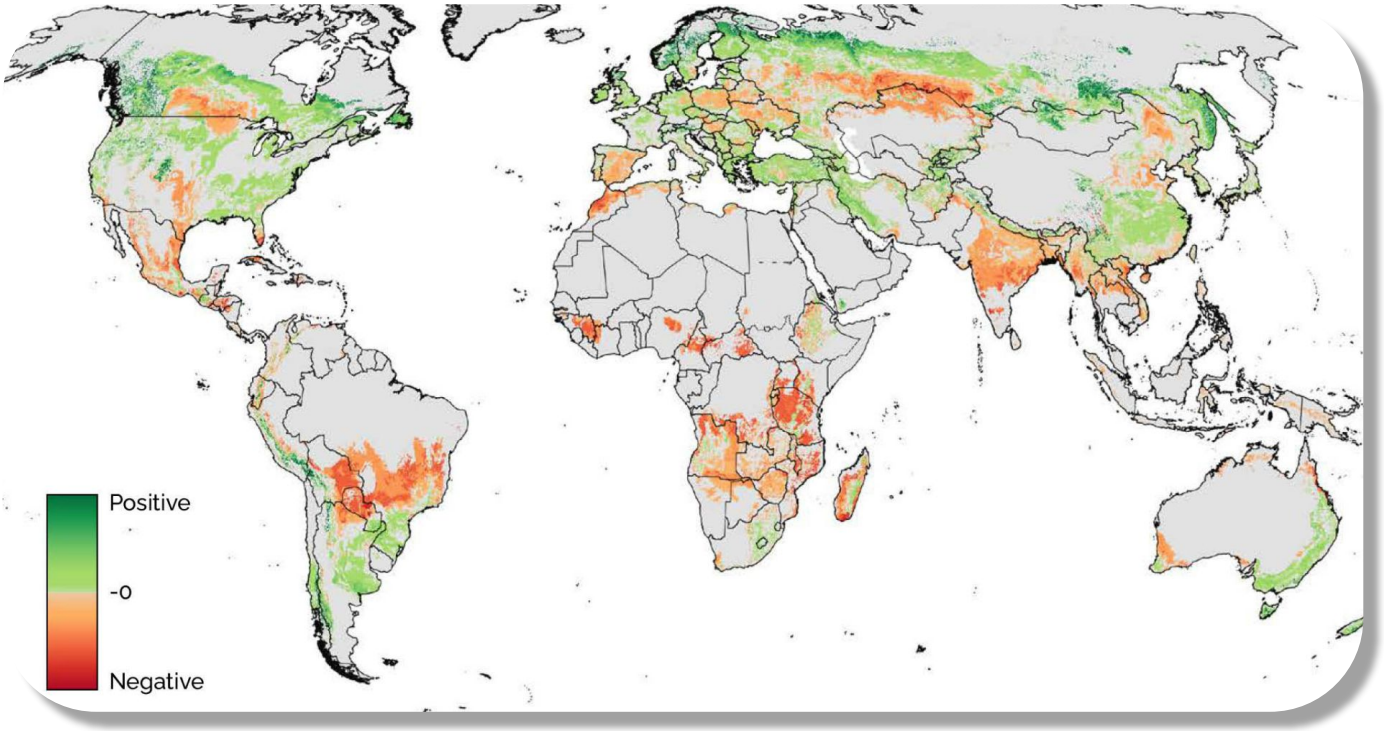
Extent of soil loss and impact across the US Corn Belt



(B) Loss of the topmost layer of soil containing the highest concentration of organic matter, nutrients, and biological activity, (C) loss in yield and (D) revenue loss per farm

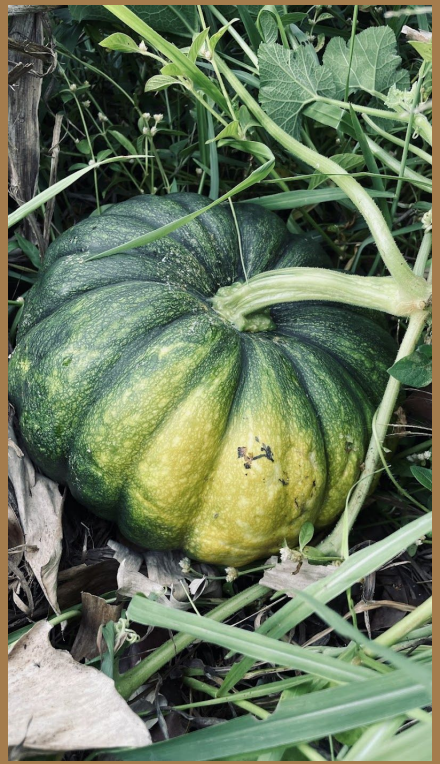
(A) Aggregated percent A-horizon loss (black text) and annual economic losses expressed in millions of dollars (M) and as a percentage relative to uneroded soils (green text) for each state within the region.

Change in Crop Growing Suitability



Shifts in land areas suitable for rainfed wheat for a high-emission/high-temperature scenario to the 2080s (RCP 8.5), leading to a 4.2 °C temperature increase


We cannot change the past but we can create a better future!

Produce from the GAIA Earth community lab


Geospatial AI

Systemic Integration Agriculture

Farm

Environment

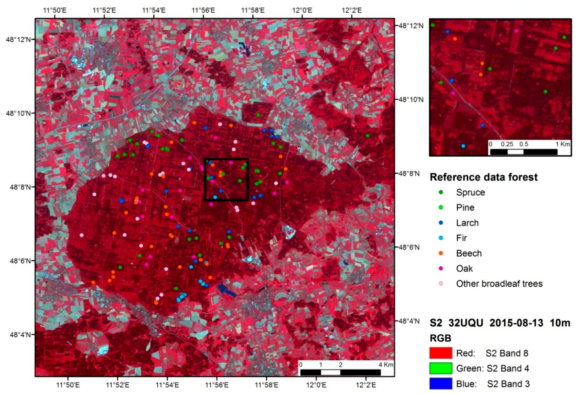
Forestry

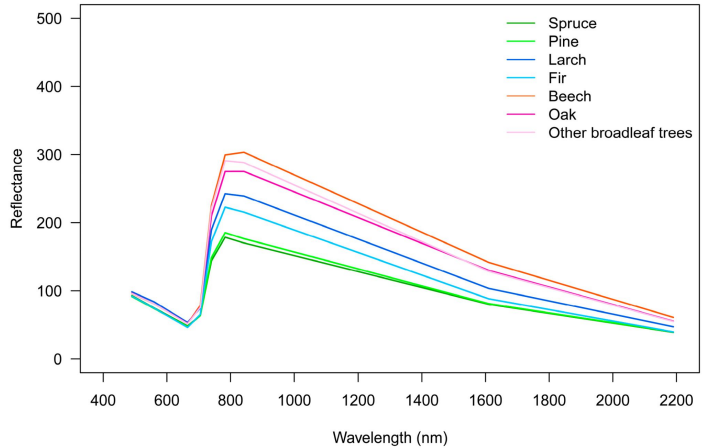
Geology

Not Obvious Applications

Biodiversity Mapping

Measurable Indicators and Metrics

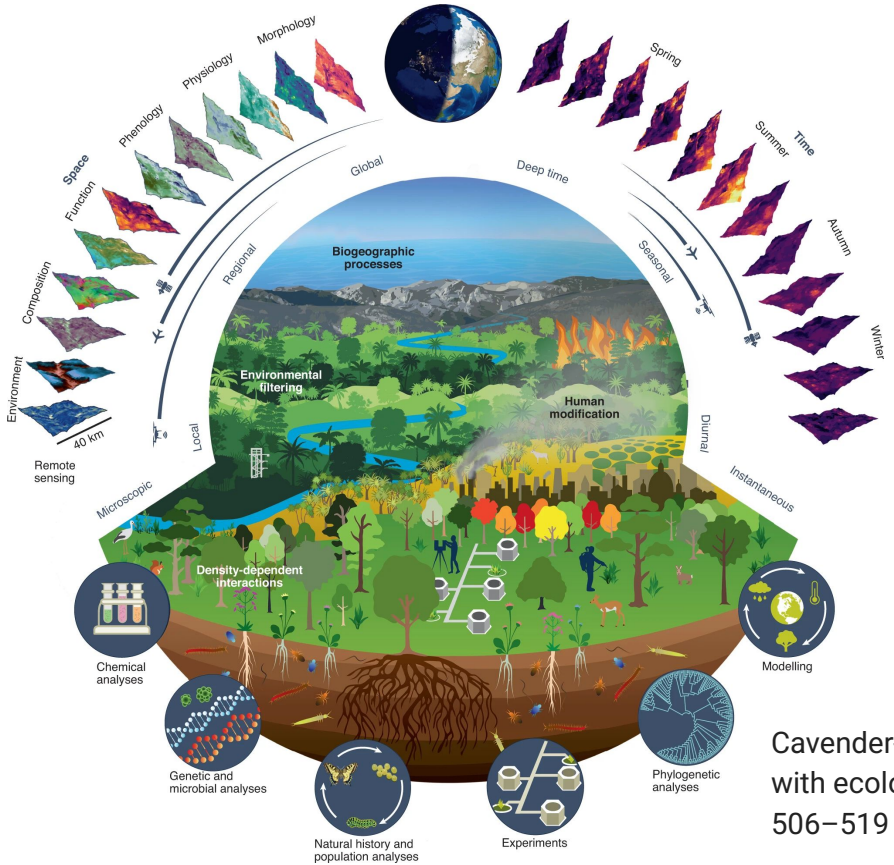




(above) Sentinel-2 scene of forest test site and (below) average spectral signatures of tree species (Spruce, Pine, Larch, Fir, Beech, Oak, broadleaf)

Immitzer, M., Vuolo, F., & Atzberger, C. (2016). First Experience with Sentinel-2 Data for Crop and Tree Species Classifications in Central Europe. *Remote Sensing*, *8*(3), 166. https://doi.org/10.3390/rs8030166

Forestry



- Habitat Mapping and Monitoring: Mapping of landcover transformations and identifying critical habitats for protection or restoration. Tracking changes in vegetation cover, deforestation rates, and land use over time.
- Wildlife Tracking and Conflict Mitigation: Monitor animal movements and manage human-wildlife conflicts by identifying corridors that minimize habitat disruptions.
- Illegal Activity Detection: Detect activities like deforestation in protected areas, enabling timely interventions.

Cavender-Bares, J., Schneider, F.D., Santos, M.J. *et al.* Integrating remote sensing with ecology and evolution to advance biodiversity conservation. *Nat Ecol Evol* 6, 506–519 (2022). https://doi.org/10.1038/s41559-022-01702-5

Remote Sensing

Remote Sensing

"Remote sensing is the process of collecting information about the Earth's surface without physical contact, typically using satellites, drones, or aircraft."

Working:

- Sensors detect reflected or emitted electromagnetic radiation from objects on Earth
- Data is captured as images or spectral measurements

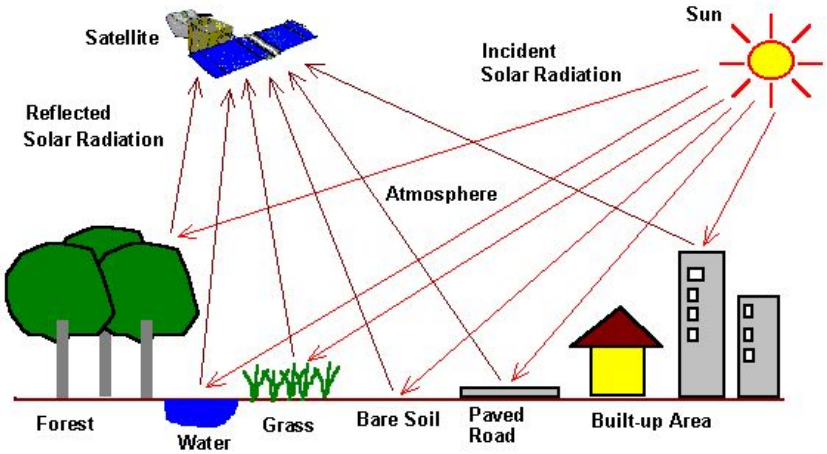
Types

- Passive → Uses natural energy (e.g., sunlight reflected from Earth)
- Active → Uses emitted energy (e.g., RADAR, LiDAR)

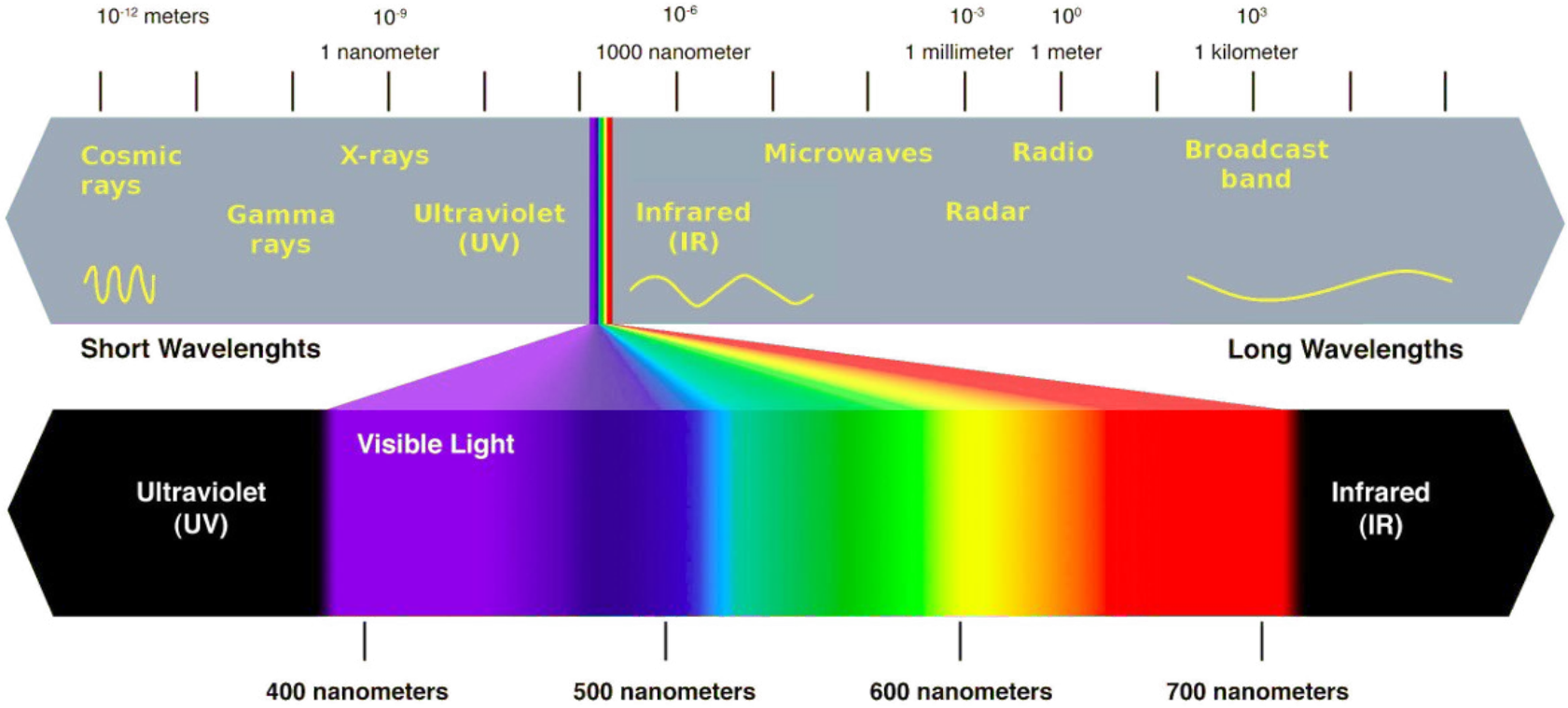
Data

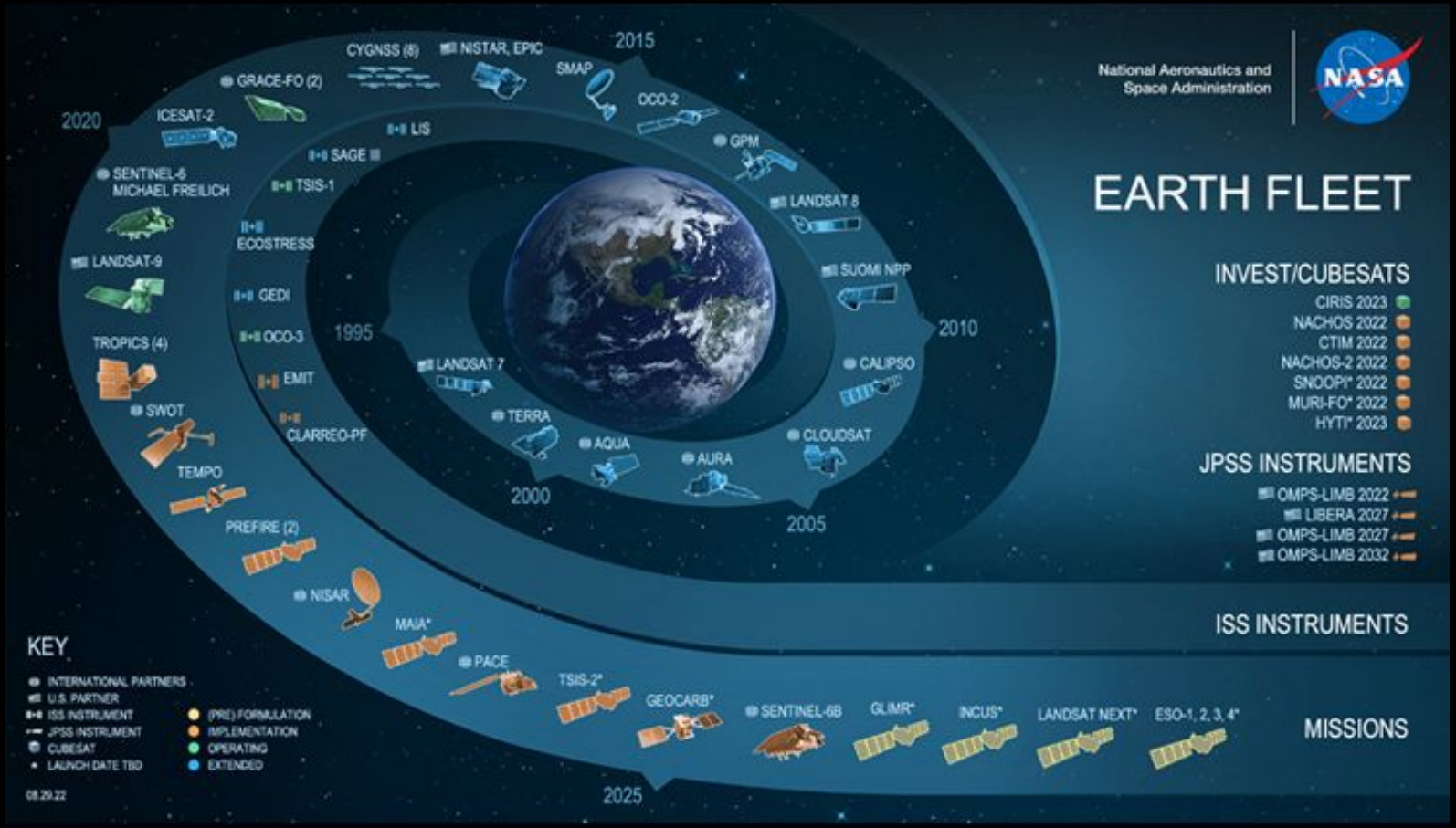
Raster data → Pixel-based imagery (satellite or aerial images)

Spectral bands → Visible, infrared, thermal, microwave



Satellite Imaging and Spectra




National Aeronautics and Space Administration
NASA
EARTH FLEET
1995
2000
2005
2010
2015
2020
2025
CYGNSS (8)
NISTAR, EPIC
SMAP
OCO-2
GPM
LANDSAT 8
SUOMI NPP
CALIPSO
CLOUDSAT
AURA
AQUA
TERRA
LANDSAT 7
GRACE-FO (2)
ICESAT-2
LIS
SAGE III
TSIS-1
ECOSTRESS
GEDI
OCO-3
EMIT
CLARREO-PF
SENTINEL-6 MICHAEL FREILICH
LANDSAT-9
TROPICS (4)
SWOT
TEMPO
PREFIRE (2)
NISAR
MAIA*
PACE
TSIS-2*
GEOCARB*
SENTINEL-6B
GLIMR*
INCUS*
LANDSAT NEXT*
ESO-1, 2, 3, 4*
INVEST/CUBESATS
CIRiS 2023
NACHOS 2022
CTIM 2022
NACHOS-2 2022
SNOOPI* 2022
MURI-FO* 2022
HYTI* 2023
JPSS INSTRUMENTS
OMPS-LIMB 2022
LIBERA 2027
OMPS-LIMB 2027
OMPS-LIMB 2032
ISS INSTRUMENTS
MISSIONS
KEY
INTERNATIONAL PARTNERS
U.S. PARTNER
ISS INSTRUMENT
JPSS INSTRUMENT
CUBESAT
LAUNCH DATE TBD
(PRE) FORMULATION
IMPLEMENTATION
OPERATING
EXTENDED
08.29.22

Global Satellite Fleet

Optical Data

1. Sentinel -2
2. Landsat 9, 8,7
3. Planetscope
4. MODIS
5. ASTER
6. WORLDVIEW
7. SPOT
8. JAXA
9. IRS LISS IV
10. Cartosat
11. PROBA-V,
12. AVHRR,
13. GPM/TRMM

Microwave Data

1. Sentinel 1
2. ALOS PALSAR
3. ICEYE
4. RISAT
5. TerraSAR - X
6. RADARSAT
7. KOMPSAT 6
8. TanDEM-x
9. NISAR
10. JERS

Hyperspectral

1. HySIS
2. Hyperion

LiDAR

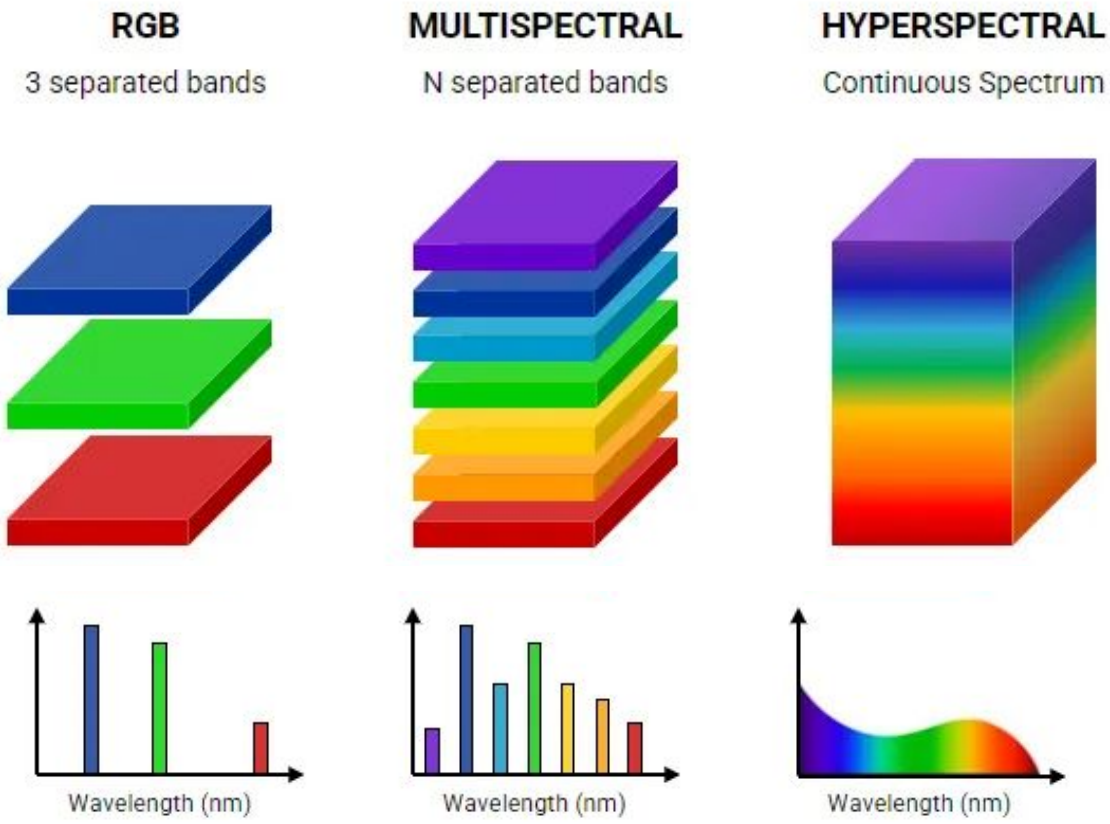
1. ICESat
2. ICESat-2

Others

1. SRTM DEM
2. ASTER DEM
3. VIIRS

Updated as of Aug 2025

Optical Imagery Types



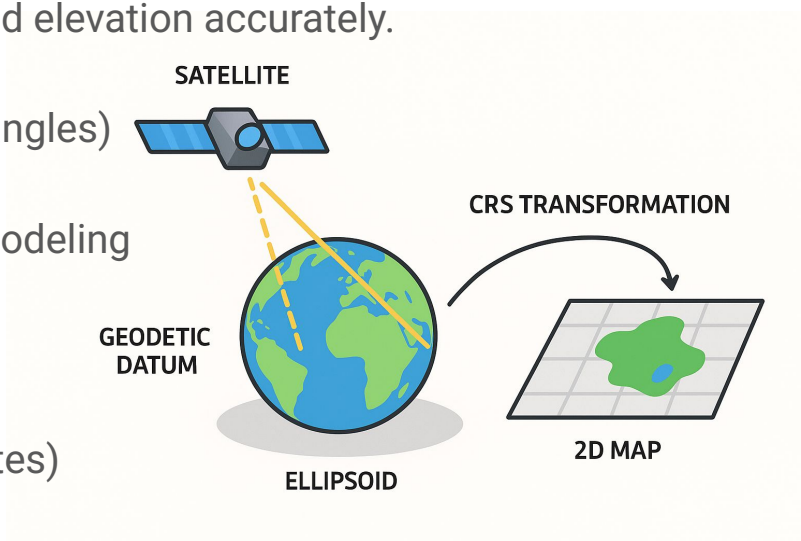
Source: Nireos

Optical Imagery Types

Feature	RGB	Multispectral	Hyperspectral
Number of Bands	3	4-15	100-200 +
Spectral Range	Visible only	Medium	High
Data Volume	Small	Moderate	Very Large
Typical Applications	Photography, basic monitoring	Crop/ vegetation health, LULC	Detailed crop stress, material identification, disease detection & many more
Cost	Low	Moderate	High
Processing Complexity	Low	Moderate	High

CRS or Coordinate Reference System

1. Coordinate Reference System (CRS)
   - Defines how geographic locations are represented on a flat map or globe.
   - It provides a framework to map latitude, longitude, and elevation accurately.
2. Why is it important?
   - Ensures accuracy in measurements (distance, area, angles)
   - Allows overlaying multiple datasets correctly
   - Essential for map projections, spatial analysis, and modeling
3. Types of CRS:
   - Geographic CRS (GCS):
     - Based on latitude & longitude
     - Example: WGS84 (used in GPS and most satellites)
   - Projected CRS (PCS):
     - Converts Earth's curved surface to 2D map
     - Examples: UTM (Universal Transverse Mercator), State Plane



Data, Compute and Learning!

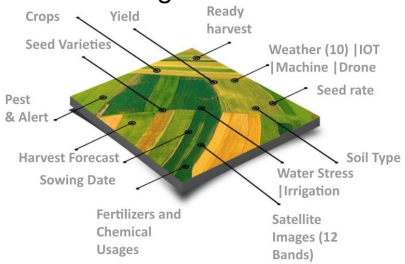
Data

Annotations/
Ground Truth/
SME

S3

Analysis
Ready
Data
(ARD)
Or
Cloud
Optimize
d
Data

Data
Source
&
Ingestion



Computing

Cloud

On-premise

Workflow
Orchestration

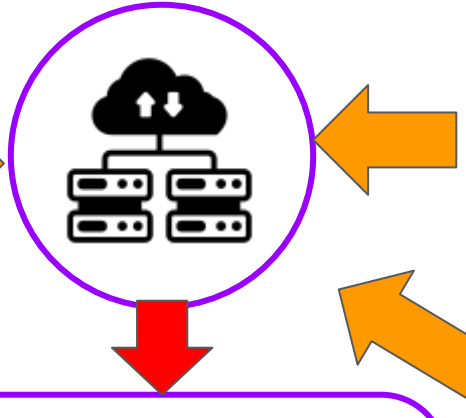
mlflow

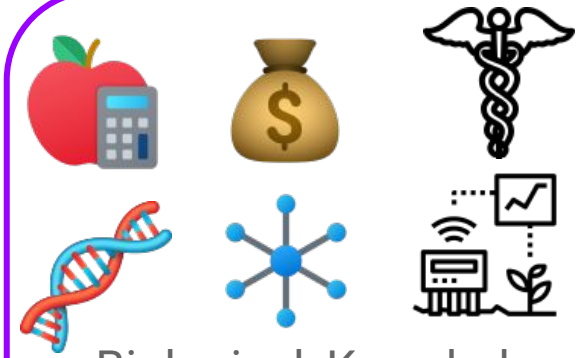
Learning

Model
Life Cycle,
Tracking
&
Orchestratio
n

Ecosystem for Agriculture and Food Security

Soil, Weather, Watershed, Irrigation, Land use (SoilGrids, AquaStat, CHIRPS, ECMWF)





Biological, Knowledge and Field Data (Health, Socio-Economic)

Science Models (DSSAT, DNDC, OpTis, CropSuite) &AI

Geospatial Data (Raster, Vector)

Useful Tools

- ArcGIS
  - Advanced commercial GIS platform for mapping, spatial analysis, and geostatistics

- QGIS
  - Free, open-source GIS tool for editing, analyzing, and visualizing spatial data
  - Supports a wide range of plugins and data formats, making it flexible for research & teaching

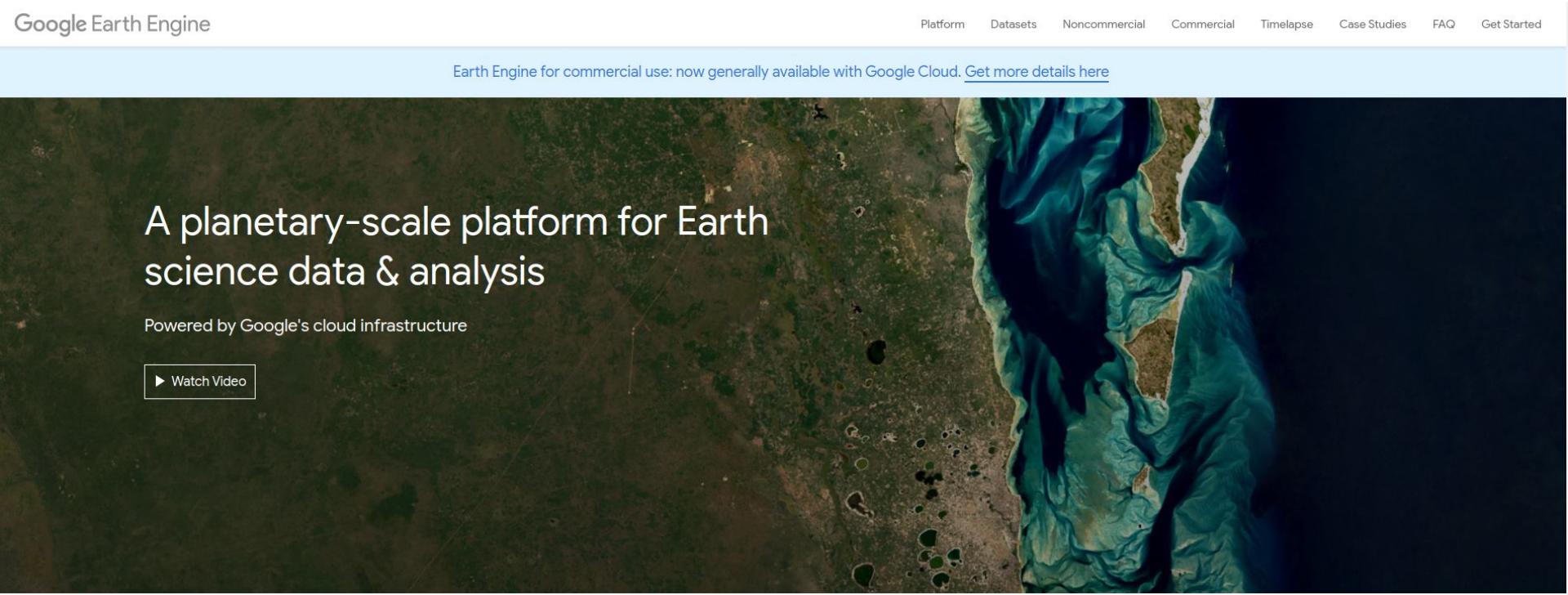
- Google Earth Engine (GEE) (focus of today's workshop)
  - Cloud-based platform with petabytes of satellite imagery & geospatial datasets
  - Enables large-scale, real-time analysis of environmental, agricultural, and climate data

Google Earth Engine

Earth Engine

https://earthengine.google.com/

- A planetary-scale platform for Earth science data & analysis



GEE

Definition

- Cloud-based platform for planetary-scale geospatial analysis
- Enables users to visualize, analyze, and process vast amounts of satellite imagery and geospatial data
- Supports remote sensing research, environmental monitoring, and global decision-making

Features

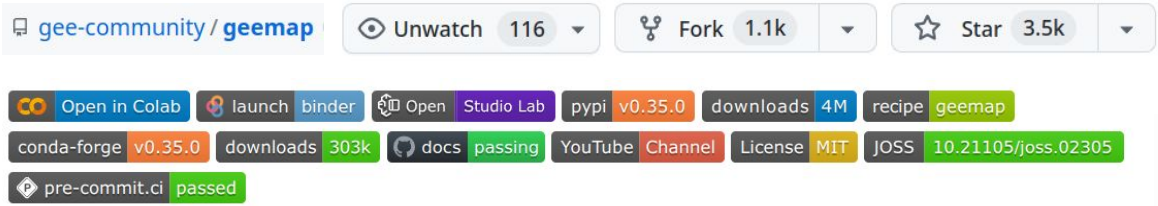
- Access to massive geospatial archives → Satellites, precipitation, LULC maps, climate, and weather data
- Process large datasets → Perform complex analyses at planetary scale using cloud infrastructure
- Visualize results → Interactive maps, charts, and export options
- Develop algorithms → Web-based code editor with JavaScript & Python APIs

Applications

- Environmental Monitoring: Deforestation, water resources, vegetation health, land cover changes
- Disaster Response: Flood mapping, wildfire monitoring, earthquake damage assessment
- Resource Management: Agriculture, forestry, climate impact studies
- Climate Science: Study temperature/precipitation trends, model climate change effects
- Urban Planning: Monitor urban growth and land use changes
- Health & Business: Disease outbreak prediction, supply chain risk assessment

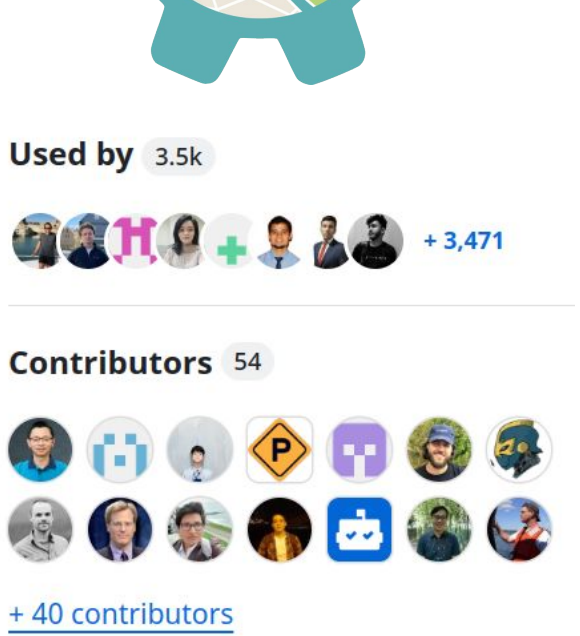
Geemap

- GitHub: https://github.com/gee-community/geemap
- Website: https://geemap.org



A Python package for interactive geospatial analysis and visualization with Google Earth Engine

- GitHub repo: https://github.com/gee-community/geemap
- Documentation: https://geemap.org
- PyPI: https://pypi.org/project/geemap
- Conda-forge: https://anaconda.org/conda-forge/geemap
- 360+ GEE notebook examples: https://github.com/giswqs/earthengine-py-notebooks
- GEE Tutorials on YouTube: https://youtube.com/@giswqs
- Free software: MIT license



Earth Engine Data Catalog

https://developers.google.com/earth-engine/datasets/

Landsat & Sentinel
10-30m, weekly

MODIS
250m daily

Vector Data
WDPA, TIGER, WHC

Terrain & Land Cover

Weather & Climate
NOAA NCEP, OMI, ...

... and upload your own vectors and rasters

1000+ public datasets

100+ petabytes (PB) of data = 100K+ TB

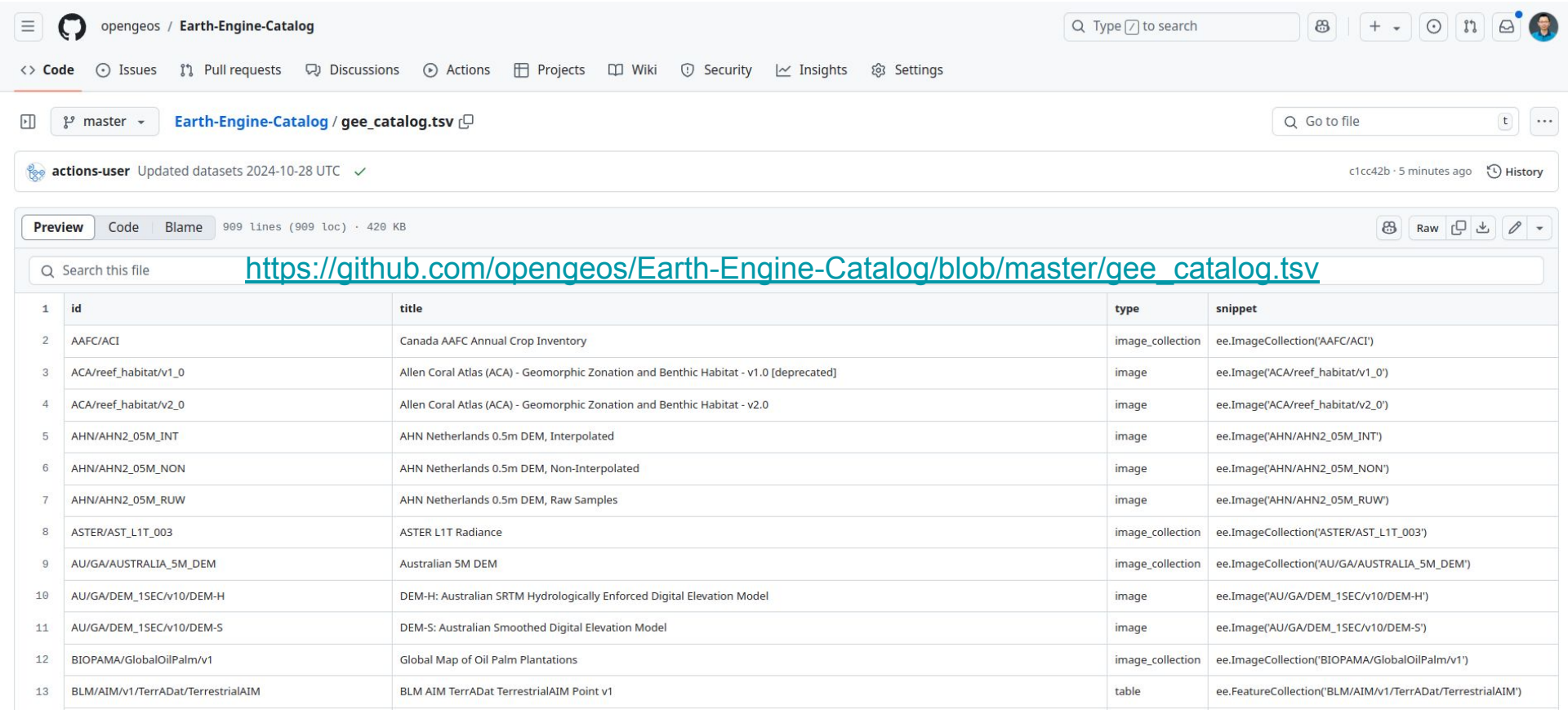
100+ datasets added yearly

1+ PB of new data every month

Credits to Earth Engine Team

https://earthengine-stac.storage.googleapis.com/catalog/catalog.json

Earth Engine SpatioTemporal Asset Catalog (STAC)



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4	ACA/reef_habitat/v2_0	Allen Coral Atlas (ACA) - Geomorphic Zonation and Benthic Habitat - v2.0	image	ee.Image('ACA/reef_habitat/v2_0')
5	AHN/AHN2_05M_INT	AHN Netherlands 0.5m DEM, Interpolated	image	ee.Image('AHN/AHN2_05M_INT')
6	AHN/AHN2_05M_NON	AHN Netherlands 0.5m DEM, Non-Interpolated	image	ee.Image('AHN/AHN2_05M_NON')
7	AHN/AHN2_05M_RUW	AHN Netherlands 0.5m DEM, Raw Samples	image	ee.Image('AHN/AHN2_05M_RUW')
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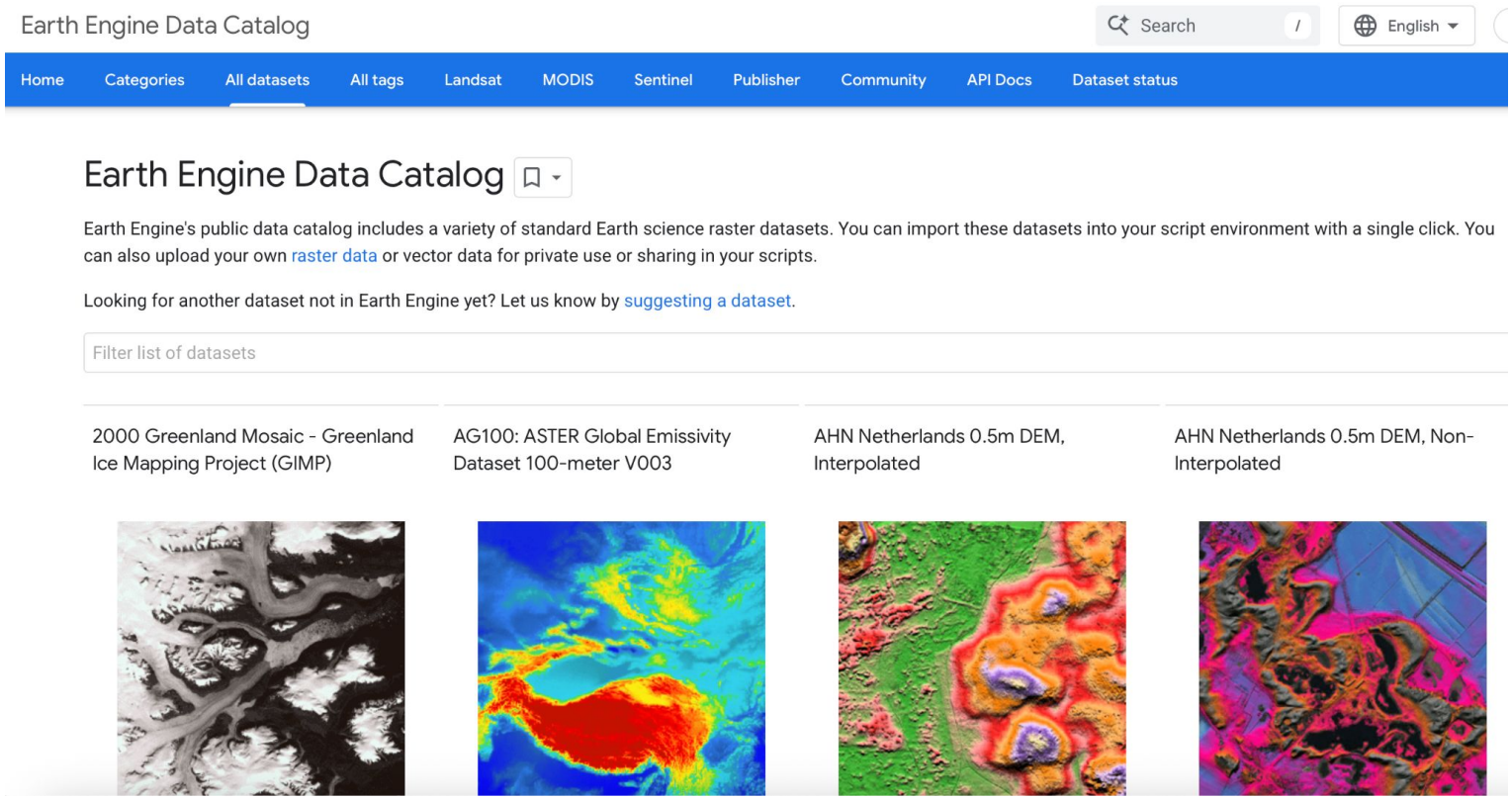
9	AU/GA/AUSTRALIA_5M_DEM	Australian 5M DEM	image_collection	ee.ImageCollection('AU/GA/AUSTRALIA_5M_DEM')
10	AU/GA/DEM_1SEC/v10/DEM-H	DEM-H: Australian SRTM Hydrologically Enforced Digital Elevation Model	image	ee.Image('AU/GA/DEM_1SEC/v10/DEM-H')
11	AU/GA/DEM_1SEC/v10/DEM-S	DEM-S: Australian Smoothed Digital Elevation Model	image	ee.Image('AU/GA/DEM_1SEC/v10/DEM-S')
12	BIOPAMA/GlobalOilPalm/v1	Global Map of Oil Palm Plantations	image_collection	ee.ImageCollection('BIOPAMA/GlobalOilPalm/v1')
13	BLM/AIM/v1/TerrADat/TerrestrialAIM	BLM AIM TerrADat TerrestrialAIM Point v1	table	ee.FeatureCollection('BLM/AIM/v1/TerrADat/TerrestrialAIM')

Catalog of Image Collections

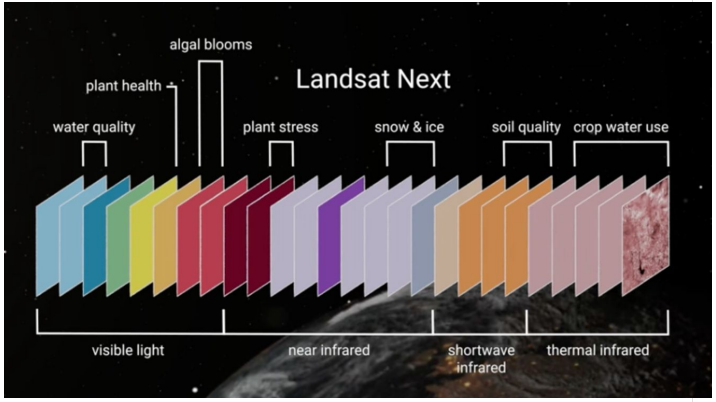
- **Satellite Imagery -** Optical and radar imagery for land, vegetation, water, and urban monitoring. Examples: Landsat, Sentinel
- **Elevation & Topography** - Digital representations of terrain to analyze slope, aspect, and elevation. Examples: SRTM (Shuttle Radar Topography Mission) , ASTER GDEM
- **Climate & Weather Data -** Observed or modeled climate and meteorological variables for environmental studies. Examples: ERA5 Reanalysis, CHIRPS
- **Land Cover & Land Use -** Classification of Earth's surface into forests, croplands, urban areas, Examples: ESA WorldCover, GlobCover
- **Hydrology & Water Resources -** Datasets capturing water bodies, rivers, lakes, wetlands, and water-related indices. Examples: JRC Global Surface Water, GRWL
- **Socioeconomic & Population Data -** Spatial datasets related to humans, settlements, and socioeconomic. Examples: VIIRS Night-Time Lights, WorldPop
- **Custom & Derived Collections -** User-generated or processed datasets for specific analyses. Examples: NDVI / EVI time-series, Cloud-free mosaics

Exploring the available Datasets



- 30 meters vs. 10 meters
- 11 bands vs. 26 bands
- 1 GB vs. 20 GB

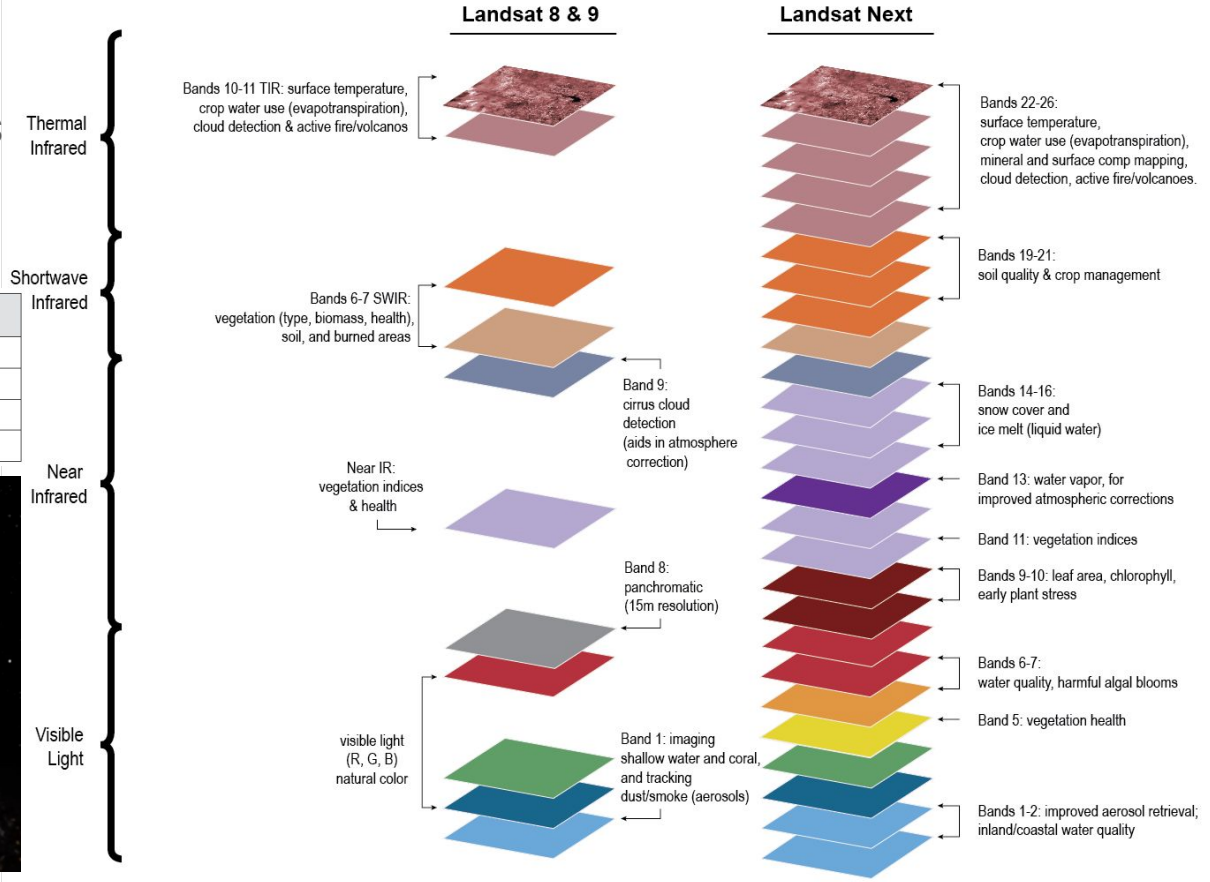
Sensor	Compressed file	Uncompressed file
Landsat 8 OLI/TIRS	919 MB	1.61 GB
Landsat 7 ETM+	235 MB	785 MB
Landsat 4–5 TM	150 MB	500 MB
Landsat 1–5 MSS	20 MB	75 MB



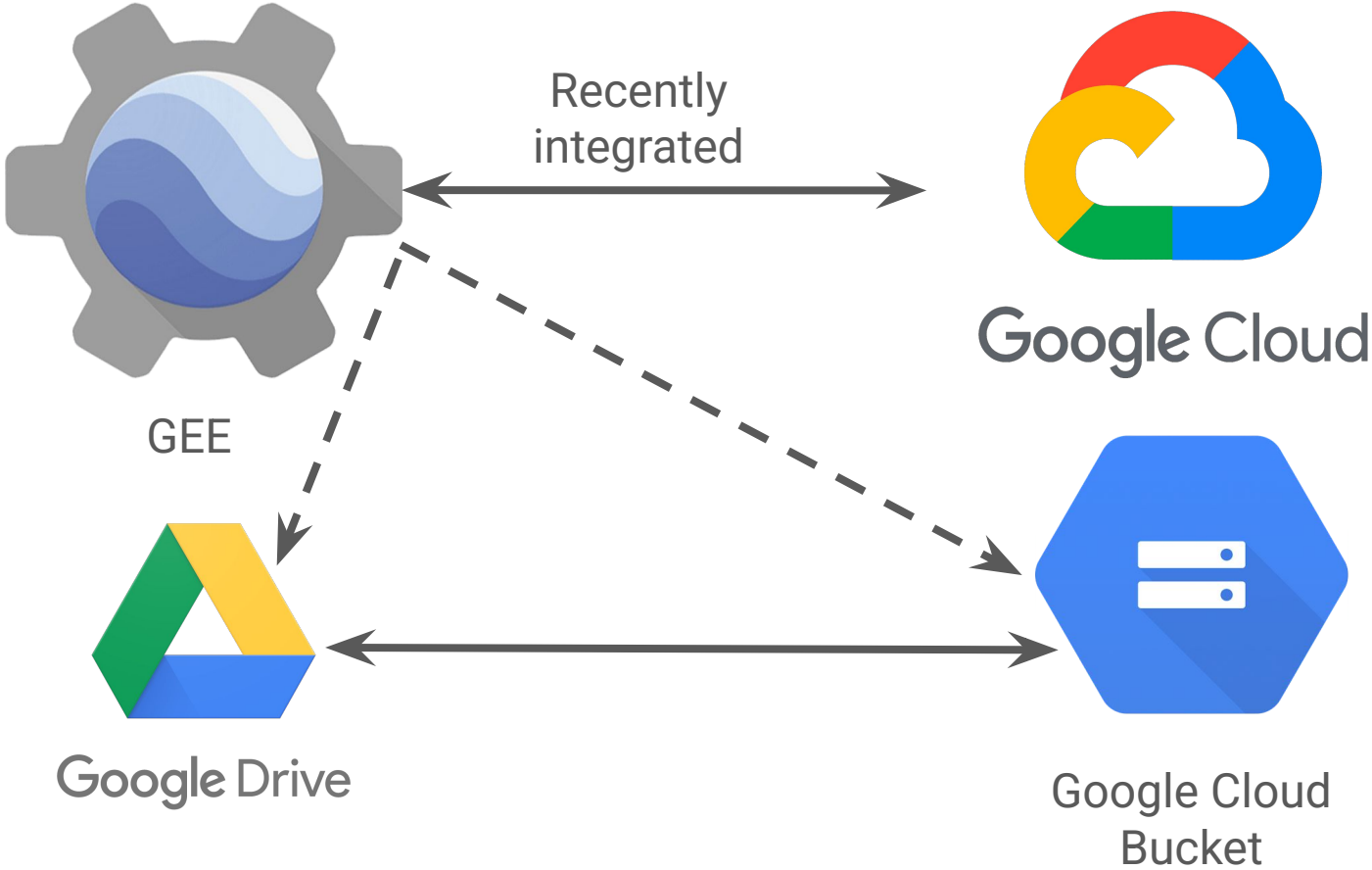
https://www.usgs.gov/landsat-missions/landsat-next

Spectral Comparison: Landsat 8/9, and Landsat Next

Increased spectral coverage with Landsat Next will enable new applications scheduled to launch in late 2030 or early 2031



Compute-GEE and Google Cloud

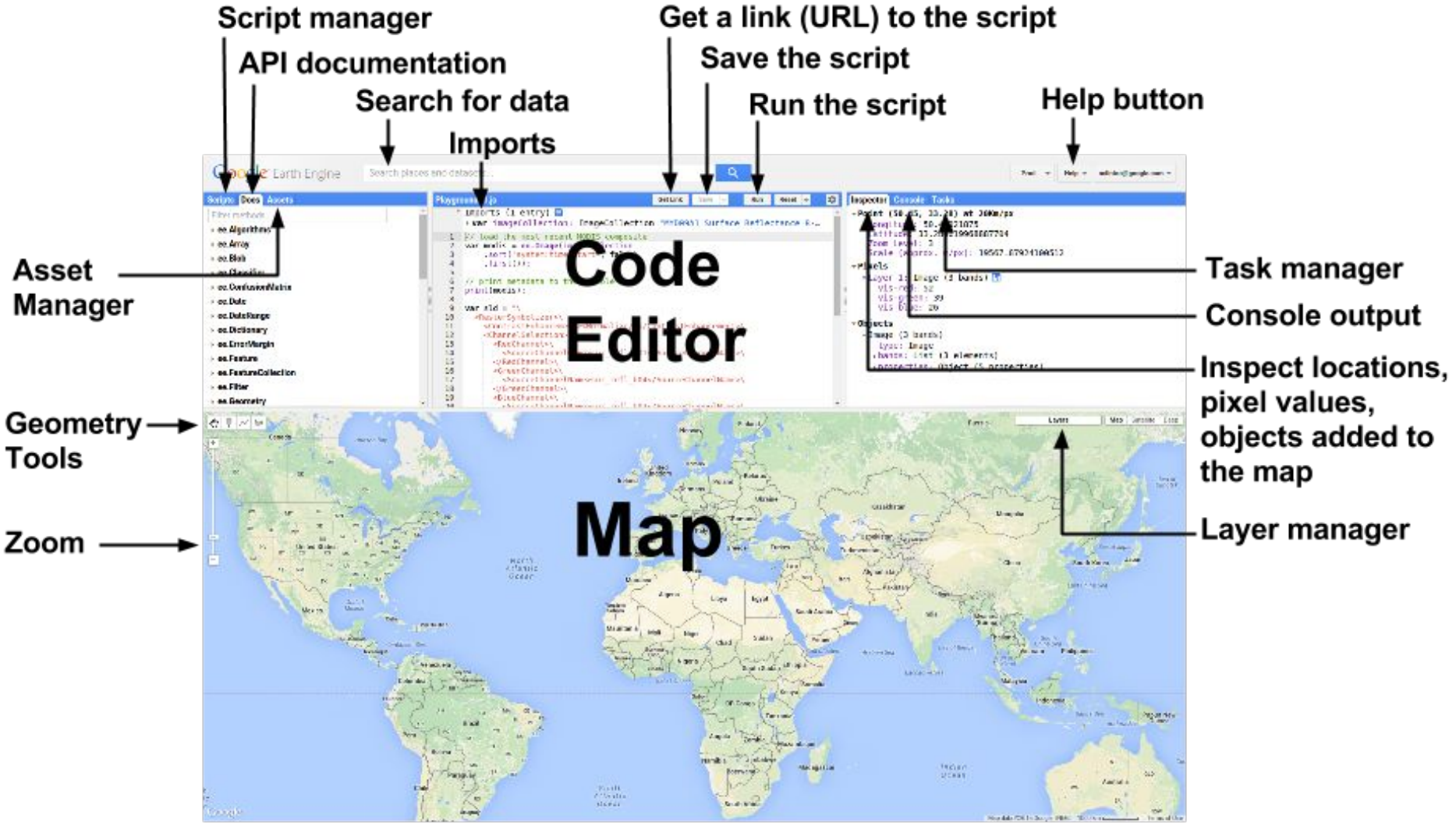


Demo and Check-in

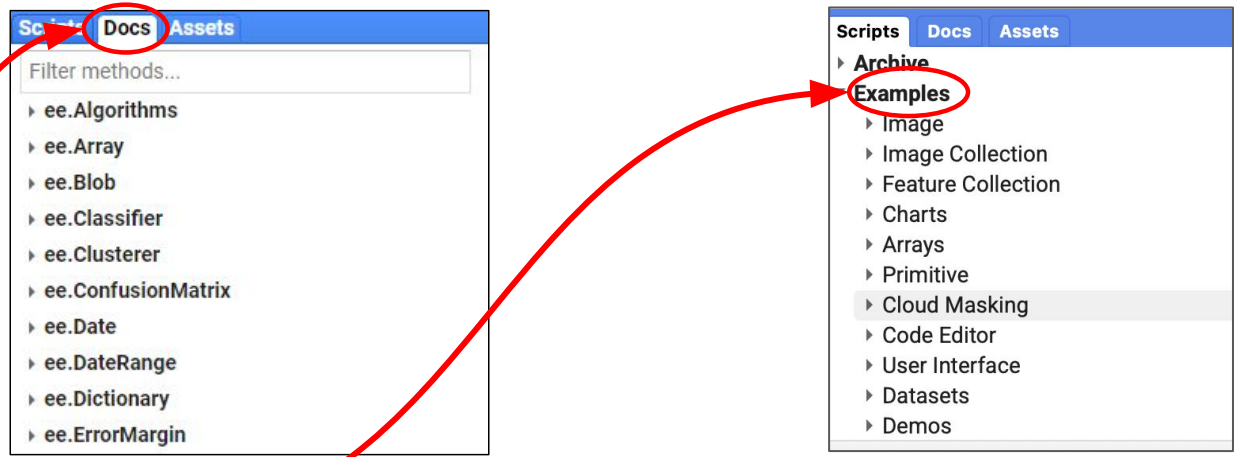
- Google Earth Engine Account Set up
- Project Initialization
- Go to https://code.earthengine.google.com/
- Create and choose appropriate plan
- Open Colab: http://colab.research.google.com/

Google Earth Engine

Google colab


Script manager
API documentation
Search for data
Imports
Get a link (URL) to the script
Save the script
Run the script
Help button
Asset Manager
Code Editor
Task manager
Console output
Inspect locations, pixel values, objects added to the map
Geometry Tools
Zoom
Map
Layer manager

Resources For Help



- Docs Tab
- Example Scripts
- Developer's Guide
- Google Earth Engine Developers Group

Vector Data

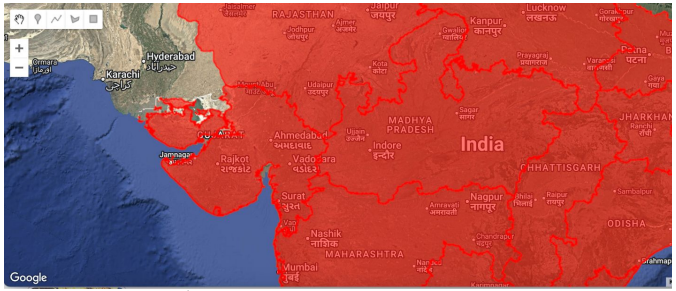
- Collection of geographic features represented as points, lines, or polygons, each with associated attributes is known as vector data.
- Describes discrete data such as countries, rivers or provinces.
- Accessible as Feature Collections in GEE
- Important Vector Data in GEE
    - GAUL (FAO Global Administrative Unit Layers) - Geographic boundaries
    - HydroSHEDS (Hydrological Data and Maps) - rivers
    - GHSL (Global Human Settlement Layer) - built-up/urban polygons and many more.

Vector data in GEE

```
var dataset = ee.FeatureCollection("DATASET_ID");
var filtered = dataset.filter(ee.Filter.eq('PROPERTY_NAME',
'VALUE'));
Map.addLayer(filtered, {color:'COLOR'}, 'Layer Name');
```

Sample:

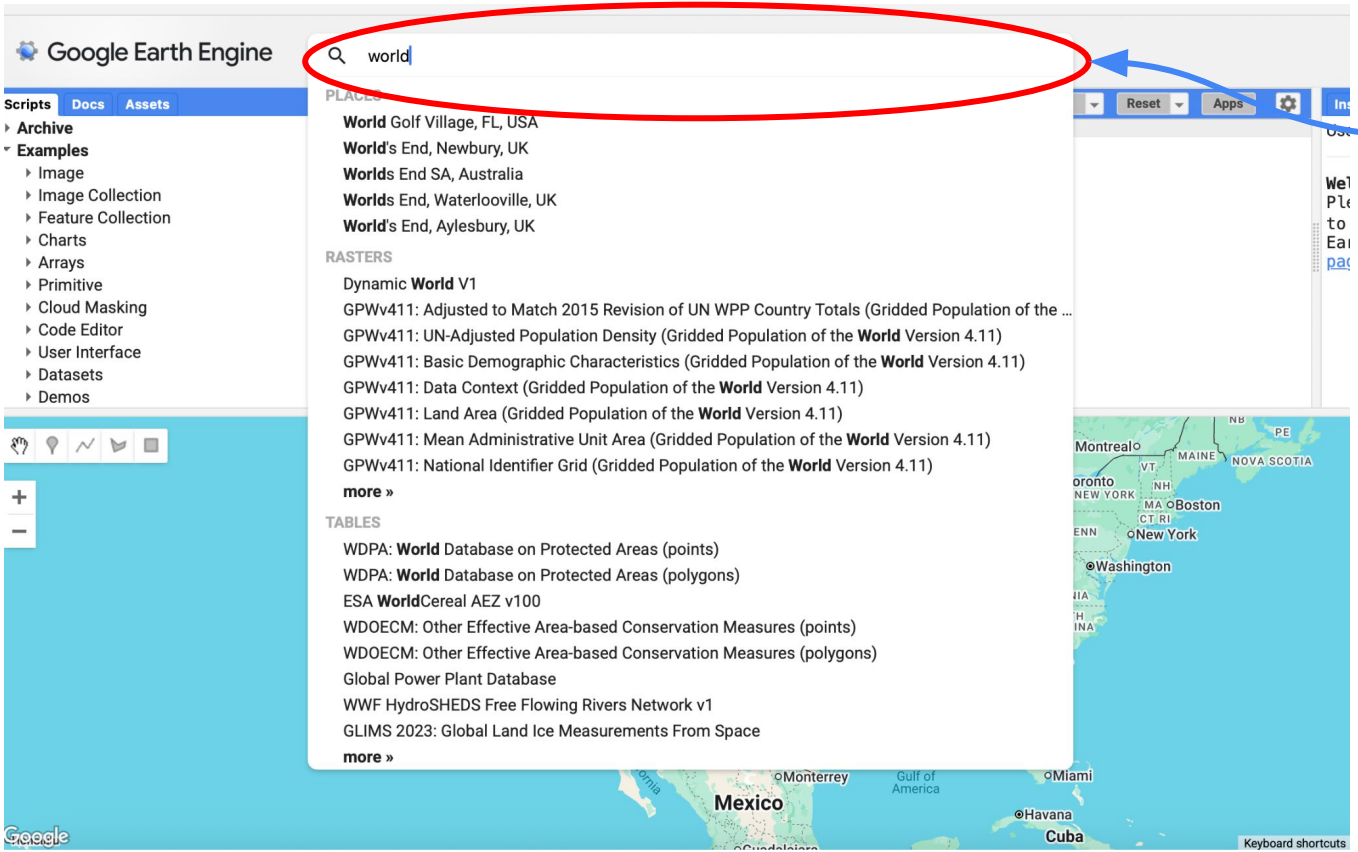
```
var dataset = ee.FeatureCollection("FAO/GAUL/2015/level1");
var filtered = dataset.filter(ee.Filter.eq('ADM0_NAME', 'India'));
Map.setCenter(79.68, 22.88, 6)
Map.addLayer(filtered, {color:'red'}, 'India States');
```




```
var dataset = ee.FeatureCollection("FAO/GAUL/2015/level1");
var filtered = dataset.filter(ee.Filter.eq('ADM0_NAME', 'India'));
Map.setCenter(79.68, 22.88, 6)
Map.addLayer(filtered, {color:'red'}, 'India States');
```

Simple Example

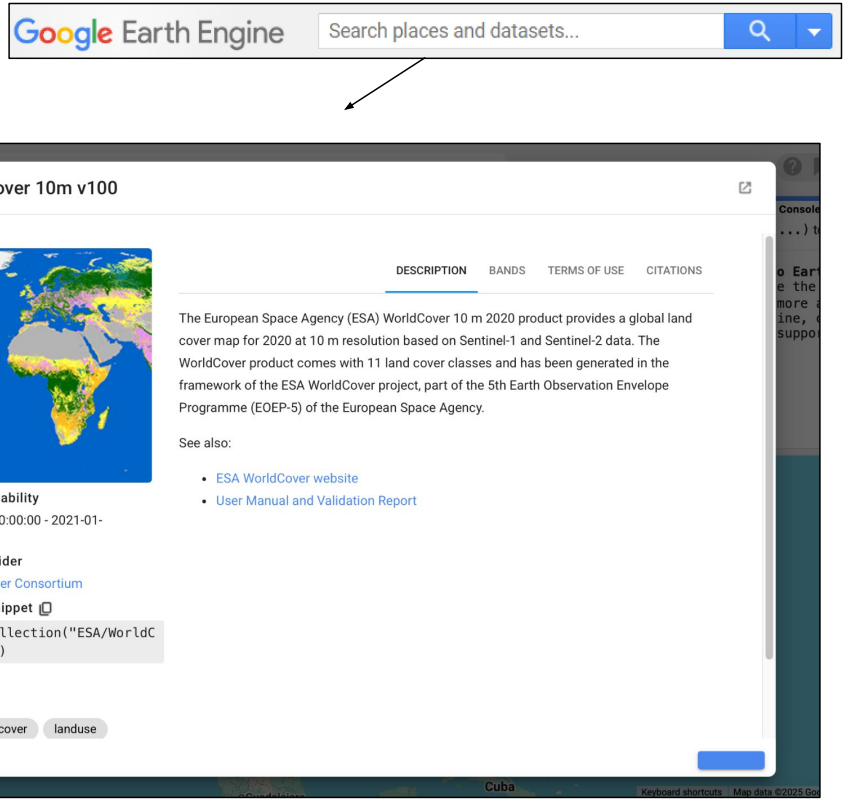
Importing GEE Datasets



Search Data

Importing GEE Datasets

1. Go to https://code.earthengine.google.com/
2. At the top of the page, use the search bar to search for datasets of interest (eg. “ESA WorldCover 10m v100”)
3. Select the appropriate dataset and click “Import”
4. The asset will appear as a new table under “Imports” in the central panel. Rename the dataset.




```
var visualization = {
  bands: ['Map'],
};
Map.addLayer(imageCollection, visualization,
'ESA WorldCover 10m v100')
```

Image Collection in GEE

- A sample template for loading the collection:

```
var collection = ee.ImageCollection("DATASET_NAME")
                .filterDate(START_DATE, END_DATE) // filter by date
                .filterBounds(ROI) // filter by ROI
                .filter(ee.Filter.lt(METADATA_FIELD, THRESHOLD_VALUE));
```

- Example:

```
var roi = ee.Geometry.Point([76.4910, 9.0886]) // Example: Amritapuri
          .buffer(5000); // 5 KM buffer
var collection = ee.ImageCollection("COPERNICUS/S2_SR")
                .filterDate(startDate, endDate)
                .filterBounds(roi)
                .filter(ee.Filter.lt('CLOUDY_PIXEL_PERCENTAGE', 20));
```

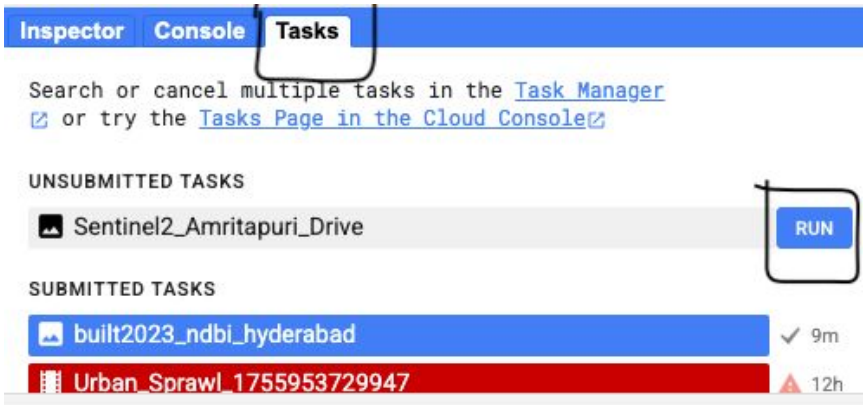
Exporting Options

Template to export an image to google drive

```
Export.image.toDrive({
  image: IMAGE_OBJECT,                  // The ee.Image you want to export
  description: "EXPORT_NAME",       // Task name shown in Tasks tab
  folder: "FOLDER_NAME",               // (Optional) Google Drive folder
  fileNamePrefix: "FILE_NAME",      // (Optional) file name prefix
  region: ROI,                                 // ee.Geometry (area to export)
  scale: SCALE_IN_METERS,         // e.g., 10 for Sentinel-2, 30 for Landsat
  crs: "PROJECTION",     // (Optional) coordinate system, e.g. "EPSG:4326"
  fileFormat: "FORMAT",               // Output format
  maxPixels: 1e13                       // Increase if large export
});
```

- Example:

```
Export.image.toDrive({
  image: composite,
  description: "Sentinel2_Export",
  folder: "GEE_Exports",
  fileNamePrefix: "Amritapuri_S2",
  region: roi,
  scale: 10,
  fileFormat: "GeoTIFF"
});
```



- Supported fileFormat options for export to drive: GeoTIFF, TFRecord.
- If you're exporting tables (`Export.table.toDrive()`), then you can also use `"CSV"`, `"SHP"`, `"GeoJSON"`, `"KML"`.

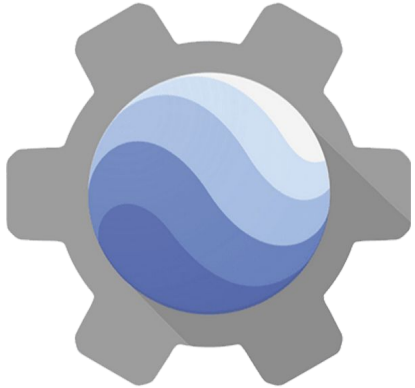
Google Cloud Storage

- Export to **Google Cloud Storage**

```
Export.image.toCloudStorage({
  image: composite,
  description: 'Sentinel2_CloudExport',
  bucket: 'your-bucket-name',
  scale: 10,
  region: roi
});
```

- Export to **Earth Engine Asset**

```
Export.image.toAsset({
  image: composite,
  description: 'Sentinel2_Asset',
  assetId: 'users/your_username/sentinel2_amritapuri',
  scale: 10,
  region: roi
});
```



Reduction on Data

Reduction in GEE means summarizing many values into fewer values using a statistical function (like mean, max, sum, etc.).

Various ways of reducing in GEE

- ImageCollection reduction → Combine multiple images over time into one
- Image reduction → Summarize pixel values in a region
- FeatureCollection reduction → Summarize attributes across features

```
var reducedImage = image.reduceRegion({
  reducer: ee.Reducer.mean(),  // can be mean, max, min, median etc.
  geometry: roi,
  scale: 30
});

var reducedCollection = collection.reduce(ee.Reducer.mean());
```

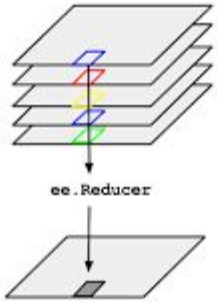


Image Collection reduction to composite

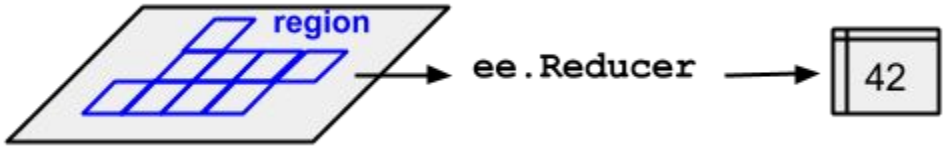


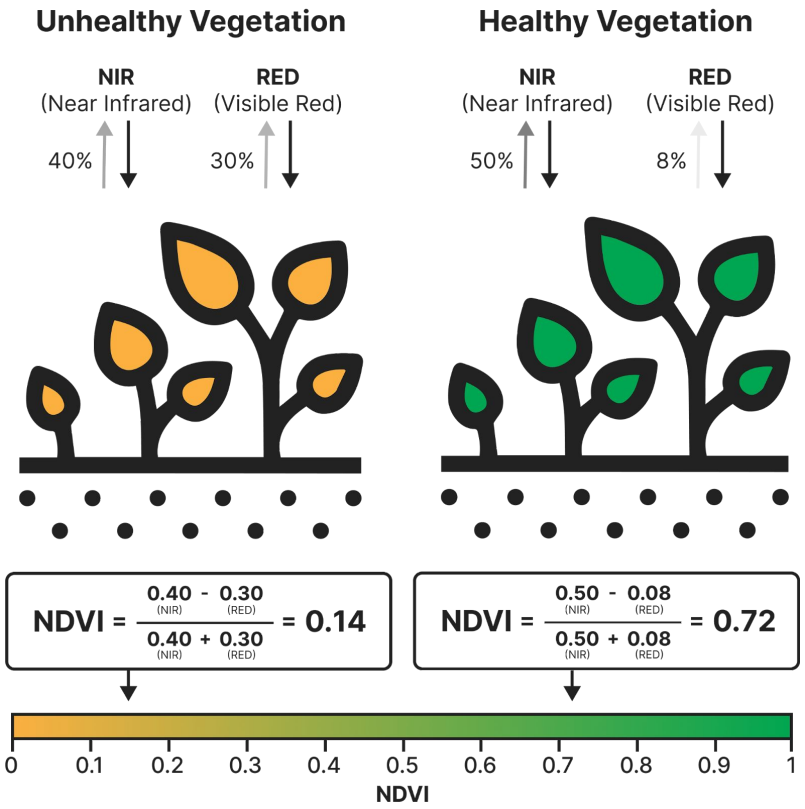
Image reduction to scalar

Case Studies

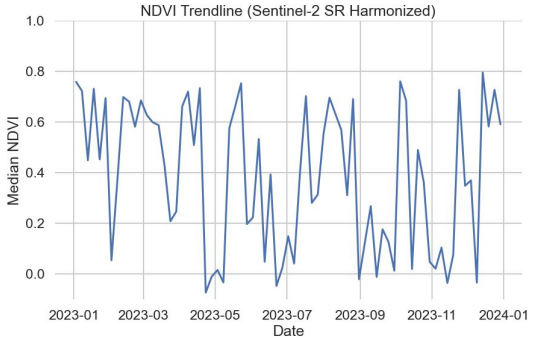
https://github.com/praveenpankaj/icsrf-geoai-tutorial/

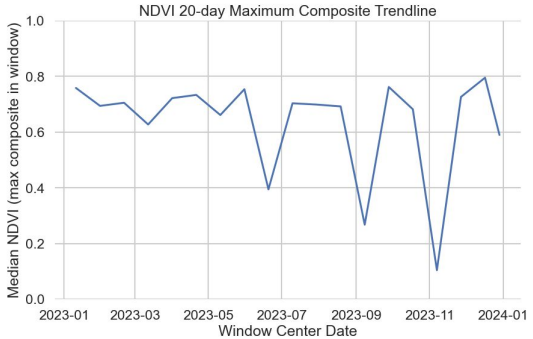
NDVI Estimation

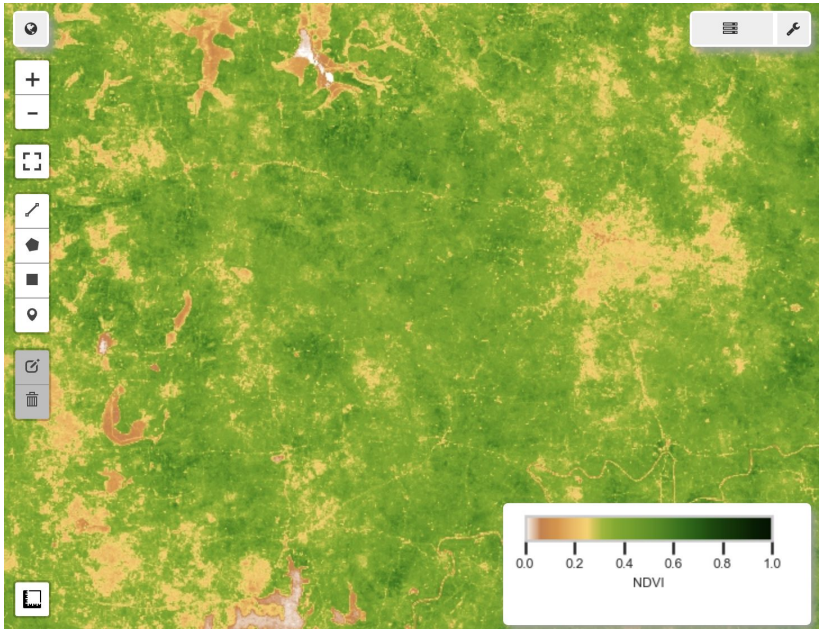
Normalized Difference Vegetation Index



NDVI Estimation







Github Repo Code

Thanks

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