Building Capacity to Use Earth Observations in Addressing Environmental Challenges in Bhutan

Day 1 – Overview of Data Products from Earth Observations and Earth Science Models for Environmental Monitoring

Environmental Strengths in Bhutan

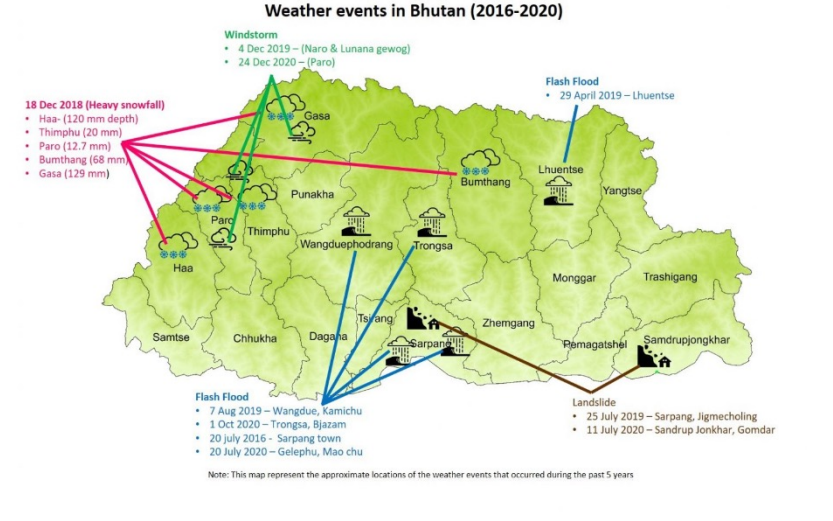
- Abundance of water resources through river discharge from:
  - Pre-monsoon and monsoon rainfall
  - Snow melt and glaciers
- World's first carbon negative country
- Close to 70.77% of the country covered by forest with 457 tons of carbon stalk in biomass
- Remarkable socio-economic advancement in last decades
- Planned climate change adaptation projects for disaster management (e.g., floods, landslides, forest fire)

Report to UNFCC
UNDP, UNDP Climate Adaptation

Environmental Challenges in Bhutan

- A small country with diverse climate zones:
  - Subtropical, Temperate, and Alpine
  - Numerous micro-climates due to varied topography
- A rise in the range of 0.8°C – 1.6°C is projected for annual mean temperature in Bhutan between 2021 and 2050.
- Bhutan is exposed to multiple hazards:
  - Storms, Floods, and Landslides
  - Glacial Lake Outflow Floods (GLOFs)
  - Forest Fires
- Economy is primarily dependent on climate-sensitive sectors:
  - Agriculture, Forestry, and Hydropower

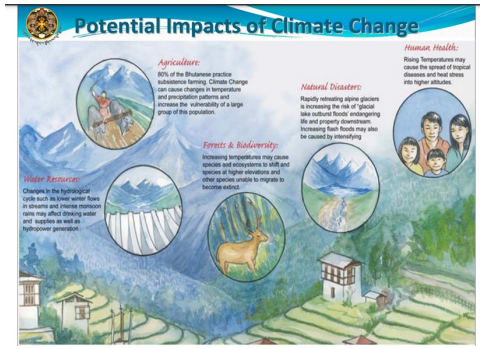
Fig 1. Glacier retreating at an alarming rate. Credit: CSD, NCHM



Report to UNFCC
Climate Knowledge Portal – World Bank
Natiional Center for Hydrology and Meteorology, Royal, Government of Bhutan

Objective:

- By the end of this presentation, you will have comprehensive information about Earth observations and Earth system models useful for monitoring:
  - Climate Change
  - Disasters Including Extreme Weather, Floods, Landslides, and Wildfires
  - Landcover Including Forestry, Agriculture, and Urban Growth



[Prevention Web]

[The Bhutanese]

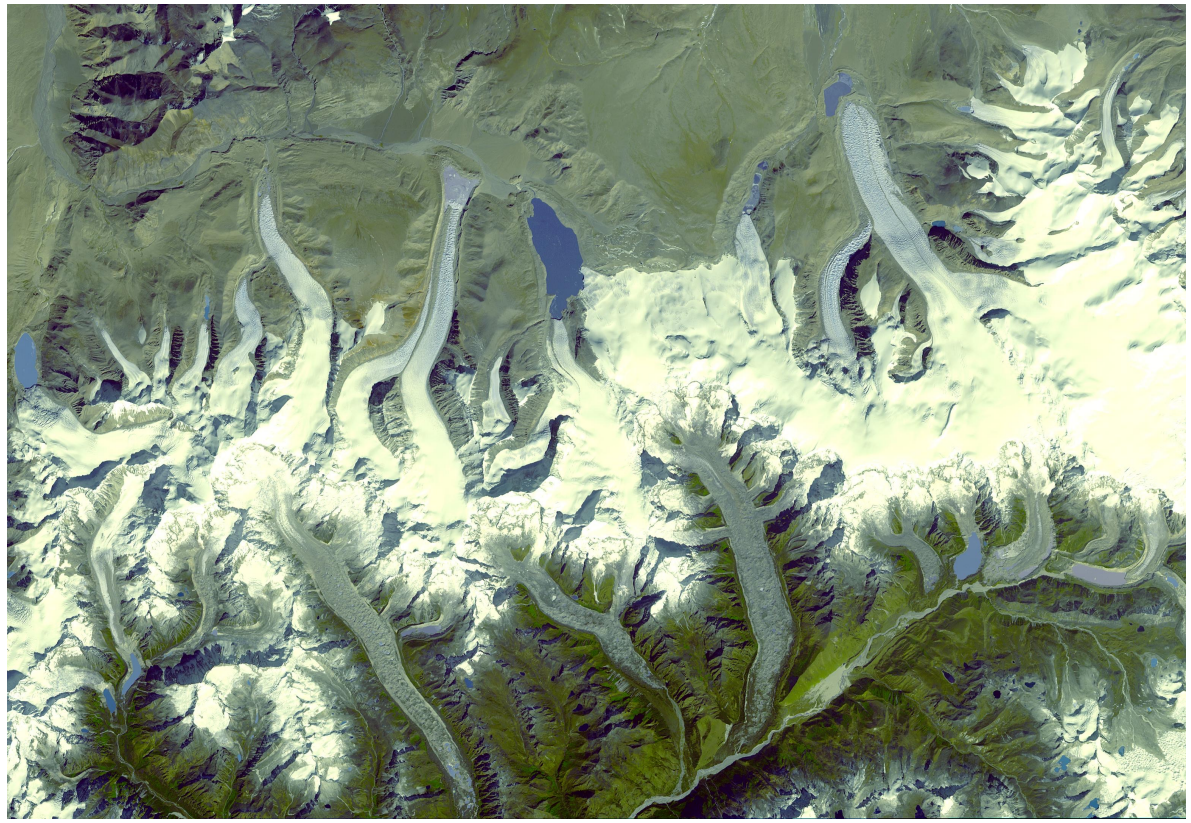
Rice terraces in Bhutan.

[World Atlas]

[Dialogue Earth]

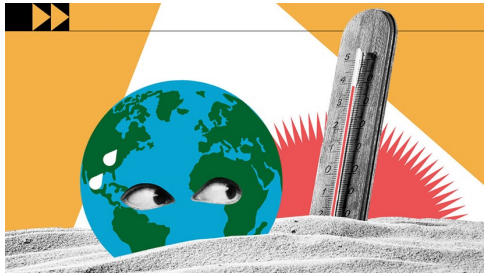
Outline

- Atmospheric and land parameters relevant for assessing climate change, disasters, and landcover
- Overview of relevant satellites, sensors, and Earth system models



Geophysical Parameters for Monitoring Climate, Weather, Disasters, Landcover, and Urban Growth

- Temperature (Surface, Air)
- Precipitation (Rain, Snow)
- Snow Melt
- Soil Moisture
- Runoff
- Humidity
- Winds
- Vegetation
- Topography
- Human Settlement and Built-Up Areas
- Population Density



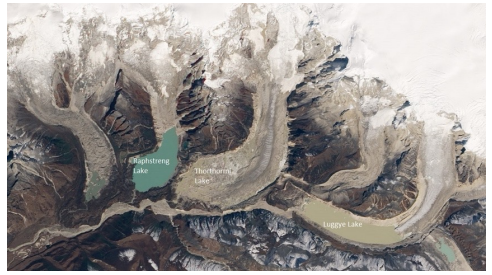
UN

The Bhutanese

WWF

SAM

BBS



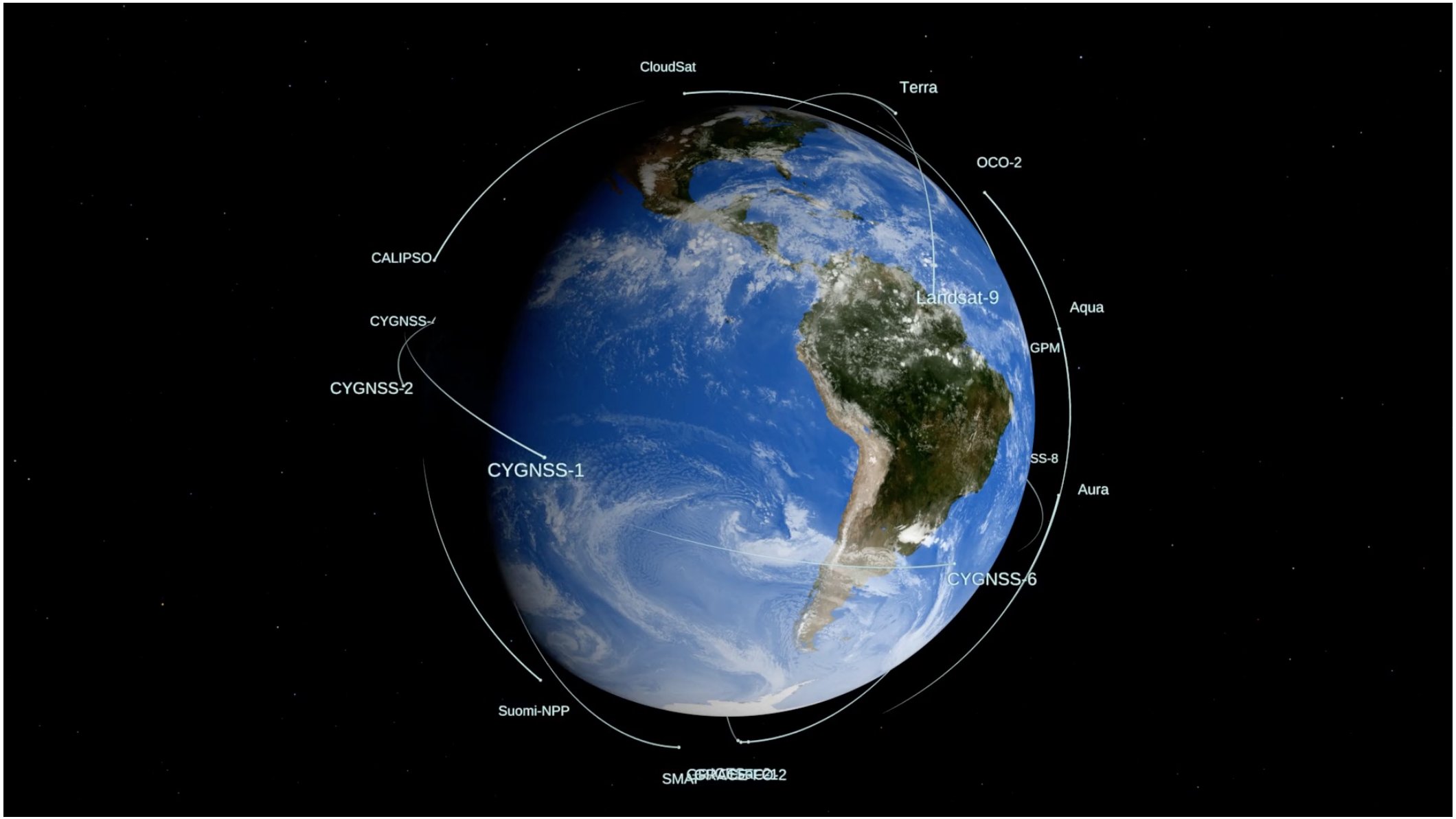
Dialog Earth

Geophysical Parameters for Monitoring Climate, Weather, Disasters, Landcover, and Urban Growth

- Temperature (Surface, Air)
- Precipitation (Rain, Snow)
- Snow Melt
- Soil Moisture
- Runoff
- Humidity
- Winds
- Vegetation
- Topography
- Human Settlement and Built-Up Areas
- Population Density

NASA remote sensing observations and Earth system models provide these parameters.

NASA Earth Observing Satellites



Overview of Relevant Satellites, Sensors, and Earth System Models

Satellites and Sensors for Climate, Weather, and Disasters Data

Parameter	Satellite	Sensors	Spatial/Temporal Resolutions and Coverage
Precipitation	Combined TRMM & GPM With Multiple Satellite Constellation **IMERG**	Microwave Radiometer (TMI, GMI) and RADAR (PR, DPR) Microwave Imagers and Sounders Calibrated with GPM Sensor Data	0.1° x 0.1° 30-Minute, Daily, Monthly 06/2000 to Present
Soil Moisture	SMAP	L Band Microwave Radiometer	9 km x 9 km & 36 km x 36 km 2-3 Day 3/2015 to present

TRMM: Tropical Rainfall Measurement Mission
GPM: Global Precipitation Measurements
SMAP: Soil Moisture Active Passive

MERRA-2: Modern-Era Retrospective analysis for Research and Applications, Version 2
NLDAS/GLDAS: North American/Global Land Data Assimilation System

For details see:
https://www.youtube.com/watch?v=MISLC--HNxo
https://appliedsciences.nasa.gov/join-mission/training/english/arset-applications-gpm-imerg-reanalysis-assessing-extreme-dry-and-wet

Satellites and Sensors for Landcover

Satellite	Sensor	Spatial/Temporal Resolutions and Coverage
*Landsat 4 Landsat 5 Landsat 7 Landsat 8 Landsat 9	Thematic Mapper (TM) Enhanced Thematic Mapper (ETM+) Operational Land Imager (OLI & OLI2) Thermal Infrared Sensor (TIRS & TIRS2)	30 m, 185 km Swath 16-Day 7/1982 – 12/1993 3/1984 – 01/2013 4/1999 – Present 02/2013 – Present 09/2021 – Present
Terra Aqua	Advanced Spaceborne Thermal Emission and Reflection Radiometer(ASTER) & MODIS MODerate-resolution Imaging Spectroradiometer (MODIS)	250m – 1 km, 2350 km Swath 12/1999 – Present Daily, 8-days, Monthly 04/2002 – Present
ESA - Sentinel 2A Sentinel 2B	[1]MultiSpectral Instrument (MSI)	10m and 20 m 290 m Swath 07/2015 – Present 03/2017 – Present
Suomi National Polar Partnership (NSPP) Joint Polar Satellite System-1 (NOAA 20)	Visible Infrared Imaging Radiometer Suite (VIIRS)	375 m and 750 m 3000 km Swath Daily, 10/2011 – Present 11/2018 – Present

*Landsat 1, 2, and 3 had Multi Spectral Scanner that did not have thermal IR bands

Satellites and Sensors for Landcover

Satellite	Sensor	Spatial/Temporal Resolutions and Coverage
Sentinel-1	C-band Synthetic Aperture Radar (SAR)	5x20 m, 80 km , 250m, and 400m Swaths 12-Day 2014 – Present
ALOS and ALOS-2	L-Band PALSAR	10 m and 30 m 40 km to 490 km swath 2006 – Present (No data from 2011 to 20014)

Earth System Models for Climate, Weather, and Disasters Data

Parameter	Model	Spatial/Temporal Resolutions and Coverage
Winds, Humidity	MERRA-2	0.5° x 0.667°, Hourly, Monthly 1980 to Present
Climate Change Projections of Downscaled Surface minimum and maximum Temperatures and Precipitation, Humidity, Surface Radiation	NEX-GDDP (CMIP 6)	0.25° x 0.25° Daily 1950 through 2100

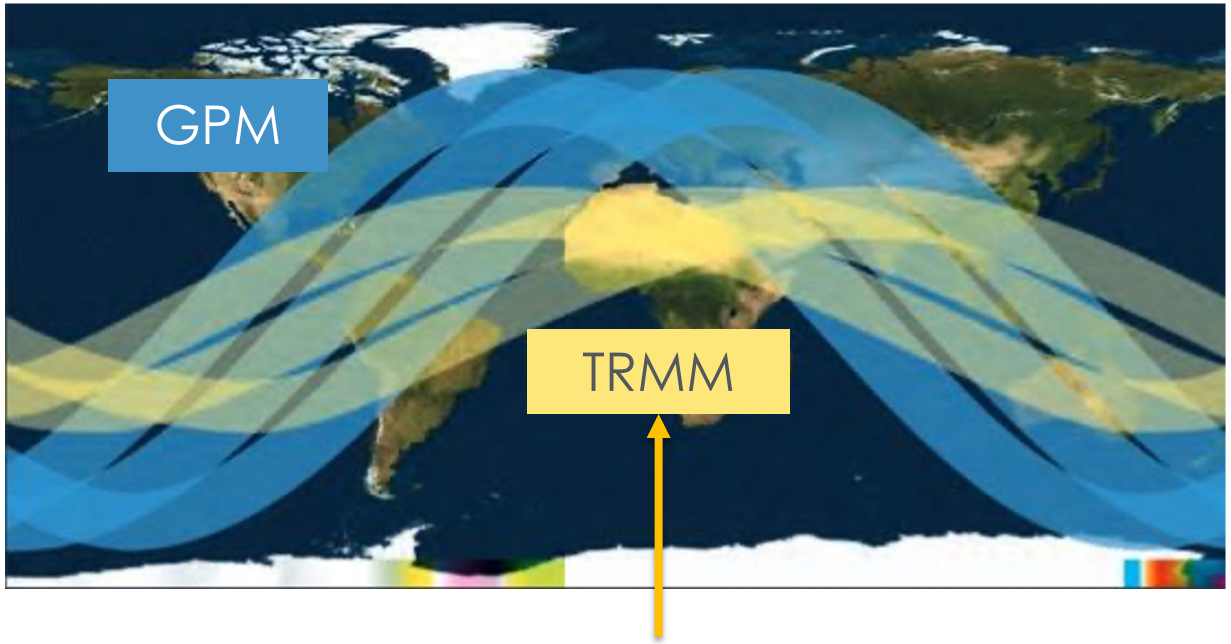
MERRA-2: Modern-Era Retrospective analysis for Research and Applications, Version 2

NEX-GDDP: The NASA Earth Exchange Global Daily Downscaled Projections for Coupled Model Intercomparison Project Phase 5 (CMIP 6)

Global Precipitation Measurement (GPM) Mission

http://pmm.nasa.gov/GPM/

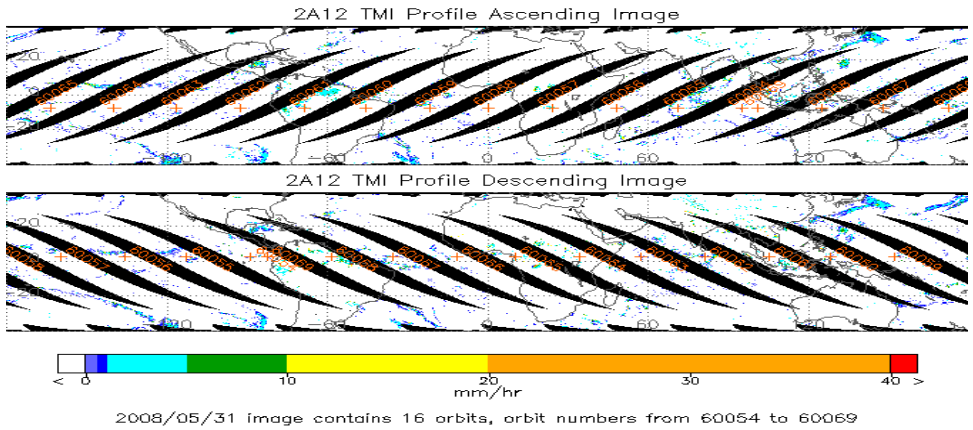
- Core satellite launched Feb 27, 2014
  - Non-polar, low-inclination orbit
    - Altitude: 407 km
- Spatial Coverage:
  - 16 orbits a day, covering global area between 65°S and 65°N
- Along with a constellation of satellites, GPM has a revisit time of 2-4 hours over land.
- Sensors:
  - GMI (GPM Microwave Imager)
  - DPR (Dual Precipitation Radar)



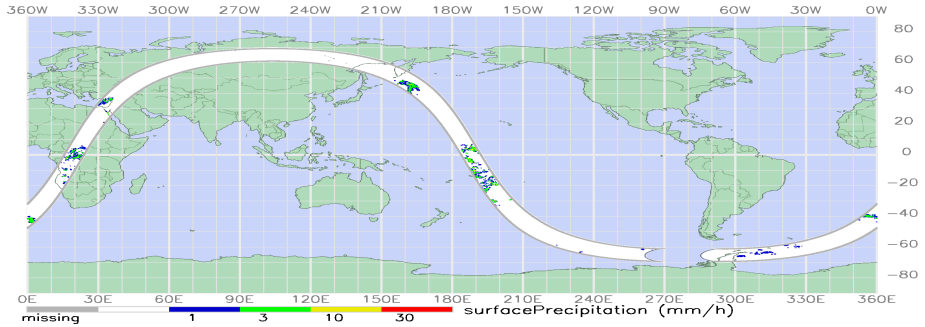
Tropical Rainfall Measurement Mission

TRMM and GPM Precipitation Sensor Summary

TMI Swath



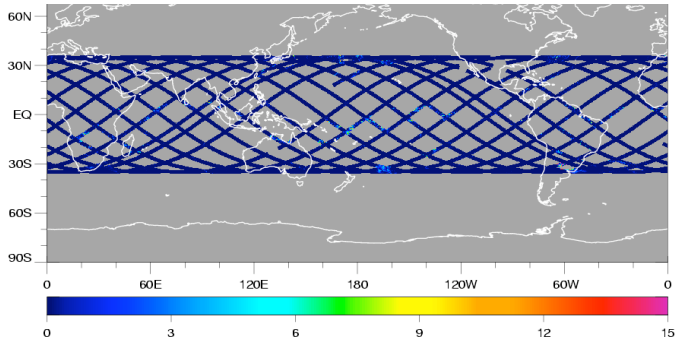
GMI Swath



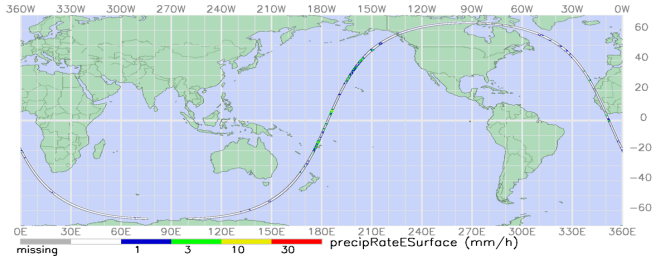
- **Channel Frequencies (GHz):**
  TMI: 10.7, 19.4, 21.3, 37, 85.5
  GMI: 10.6, 18.7, 23.8, 36.5, 89,166,183
- **Swaths:**
  TMI: 760 km (878 km after 8/2001)
  GMI: 885 km
- **Spatial Resolution:** Frequency-Dependent, Varies from 4.3 to 32 km
- About 16 orbits per day, non-continuous spatial coverage

TRMM and GPM Precipitation Sensor Summary

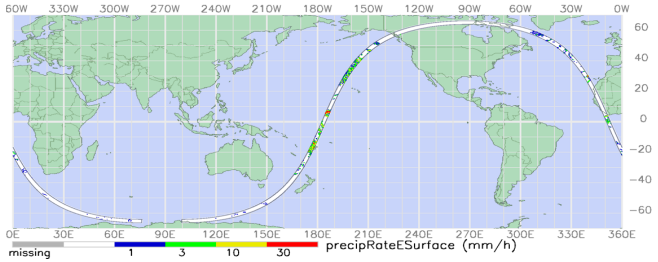
PR Swath
(Ku 13.6 GHz)



DPR Swaths
Ka 35.5 GHz



Ku 13.6 GHz



- **Radar Frequencies (GHz):**
  PR: 13.6 (Ku band)
  DPR: 13.6 and 35.5 (Ku and Ka bands)

- **Swaths (km):**
  PR: 215 (247 after 8/2001)
  DPR: 245 (Ku band) & 120 (Ka band)

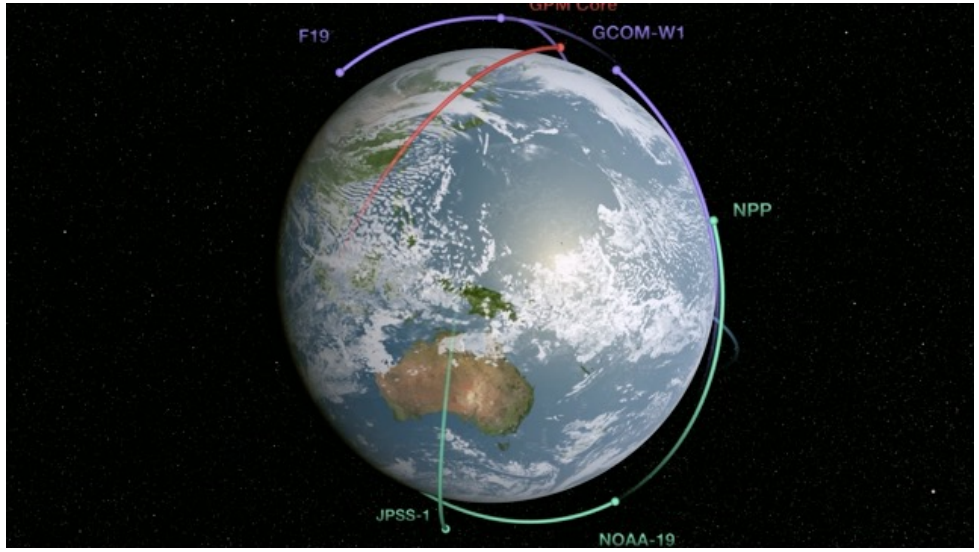
- **Spatial Resolution (km):**
  PR: 4.5 (5 after 8/2001)
  DPR: 5.3

- Narrower swaths compared to TMI & GMI

IMERG Version 06 Data

http://pmm.nasa.gov/sites/default/files/document_files/IMERG_ATBD_V4.5.pdf

- **Multiple runs accommodate different user requirements for latency and accuracy.**
  - "Early" – Now 5 hours (Flash Flooding) – Will be 4 hours
  - "Late" – Now 15 hours (Crop Forecasting) – Will be 12 hours
  - "Final" – 3 months (Research Data)



Note: Currently Version 7 is available, but we will use version 6 as it is easily accessible in Google Earth Engine.

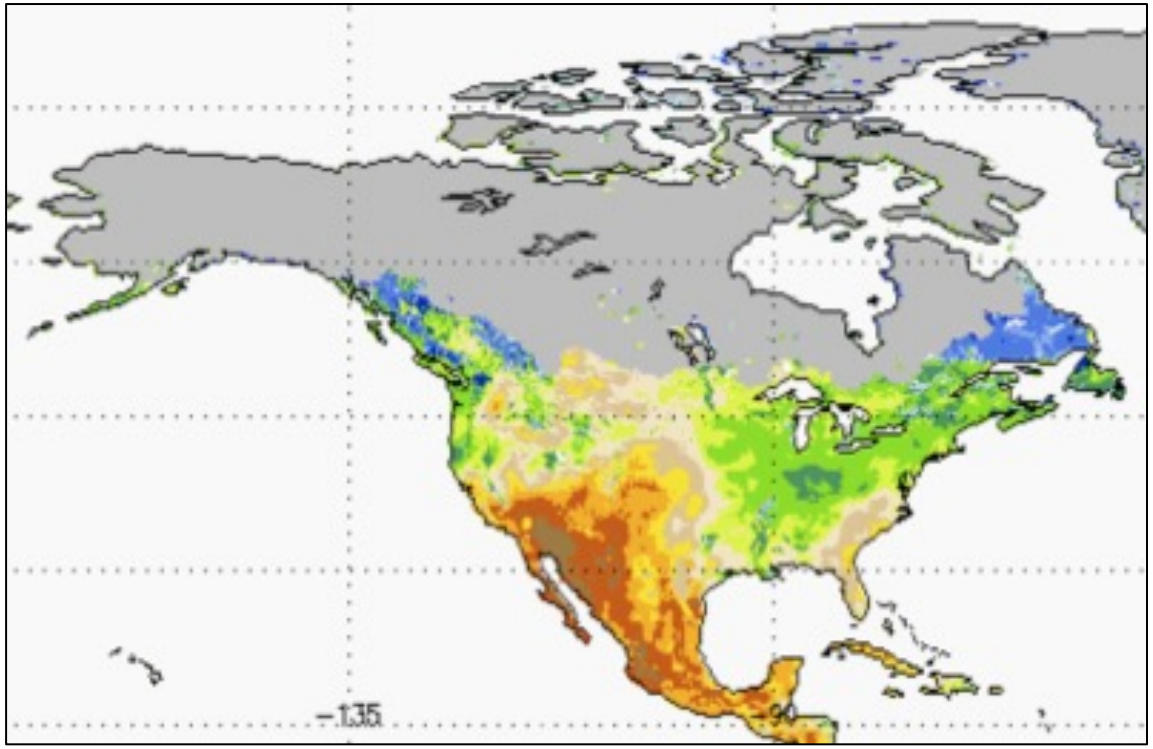
Based On: Huffman (https://www.youtube.com/watch?v=OyPUp7SuEy4&feature=youtu.be)

Soil Moisture Active Passive (SMAP)

http://smap.jpl.nasa.gov

- Polar Orbit
  - Altitude: 685 km
- Spatial Coverage:
  - Global
- Launched Jan 31, 2015
- Temporal Coverage:
  - Daily, March 2015 – Present
- Sensors:
  - Microwave Radiometer 1.41. GHz
  - Microwave Radar (Not Available)

Measures Moisture in the Top 5 cm of the Soil



Landsat and Sentinel-2

- **Landsat**
  - First Landsat launched in 1972
  - Landsat 9 launched in 2021
  - Multispectral, 30-meter pixels, 15-meter panchromatic band, 16-day revisit
- **Sentinel-2**
  - Launched in June 2015
  - Multispectral, 10-, 20-, and 60-meter pixel bands, 2-5-day revisit

- Optical spectral bands in both
- Landsat 8 and 9 have thermal IR bands
- Both used for mapping land cover
- Landsat TIRS data used for getting surface temperatures.

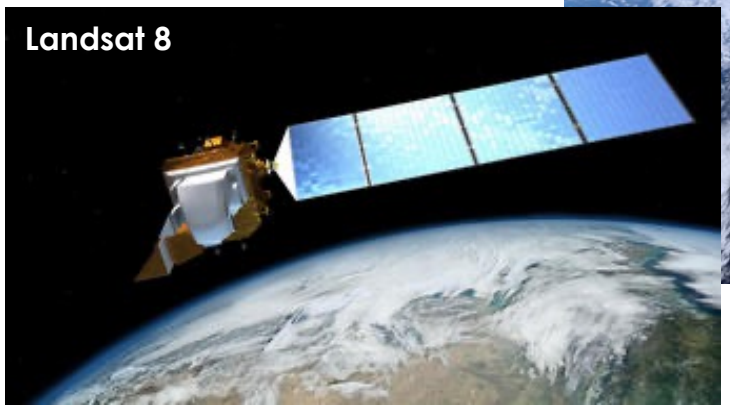
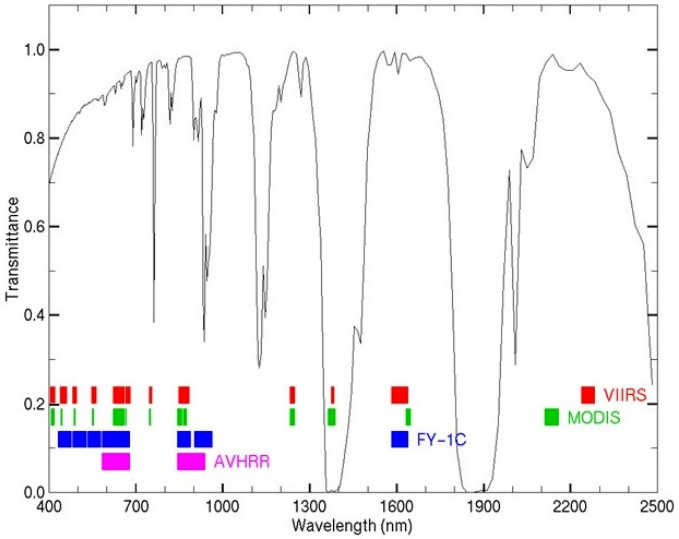


Image Credits: USGS, ESA

MODIS

- **Land Cover**
- **Land Surface Temperature**
- **Fire Detection**
- **Vegetation Indices:**
  - Vegetation extent and type
  - Vegetation stage and health (NDVI & EVI)
- Spatial Resolution:
  - 250 m, 500 m, 1 km
- Temporal Resolution:
  - Daily, 8-day, 16-day, monthly, quarterly, yearly
  - 2000 – Present
- Spectral Coverage:
  - 36 bands
    (red, blue, IR, NIR, Middle-IR)

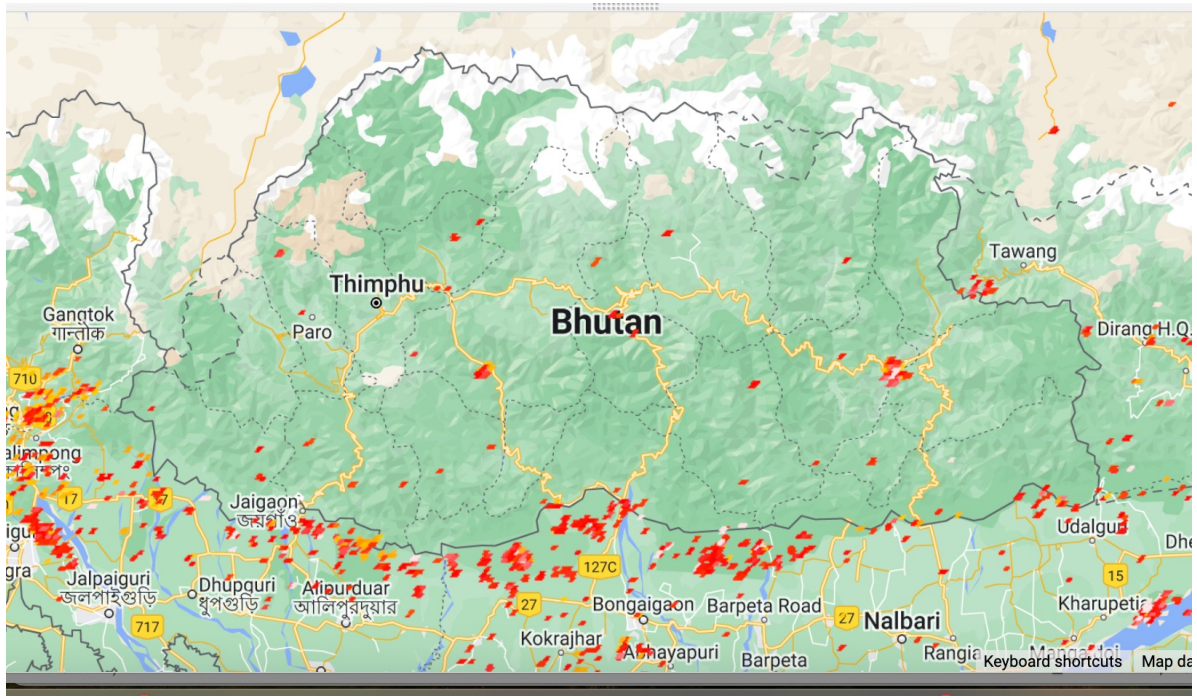
MODIS NDVI (from Google Earth Engine)



NDVI: Normalized Difference Vegetation Index
EVI: Enhanced Vegetation Index

Visible Infrared Imaging Radiometer Suite (VIIRS)

- **Fire Detection**
- **Vegetation Indices**
  - VIIRS vegetation indices include NDVI and EVI
- Launched in 2012: Collects Visible and Infrared Imagery
- Daily Temporal Resolution and Global Coverage
- Spectral Resolution: 22 bands (Visible, IR, NIR, Mid-IR, day/night)
- Spatial Resolution:
  - 5 High-Resolution Bands: 375 m
  - 16 Moderate-Resolution Bands: 750 m



VIIRS: Fires Detected During 1–31 March 2024 (GEE)

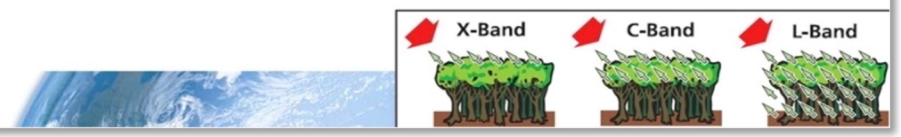
Sentinel-1: Synthetic Aperture Radar (SAR) Imagery

https://arset.gsfc.nasa.gov/disasters/webinars/intro-SAR

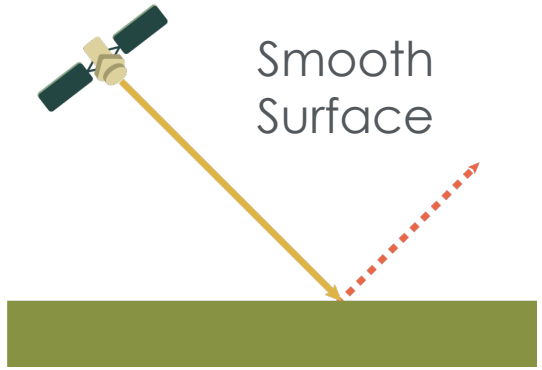
- SAR is an active sensor operating in microwave frequencies – it collects backscattered signal.
- The backscatter signal is primarily sensitive to surface structure.
- The scale of the objects on the surface relative to the wavelength determine how rough or smooth they appear to the radar signal and how bright or dark they will appear in the image.

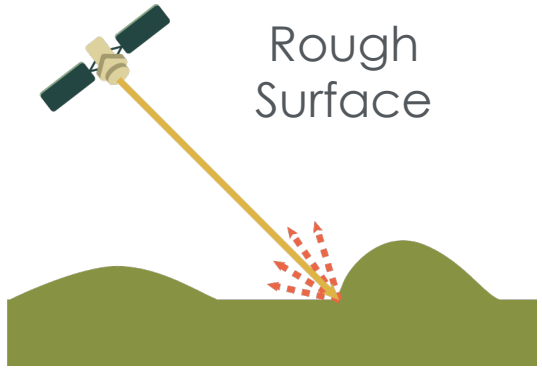
Commonly Used Frequency Bands

Frequency band	*Frequency range*	*Application Example*
• VHF	300 KHz - 300 MHz	Foliage/Ground penetration, biomass
• P-Band	300 MHz - 1 GHz	biomass, soil moisture, penetration
• L-Band	1 GHz - 2 GHz	agriculture, forestry, soil moisture
• C-Band	4 GHz - 8 GHz	ocean, agriculture
• X-Band	8 GHz - 12 GHz	agriculture, ocean, high resolution radar
• Ku-Band	14 GHz - 18 GHz	glaciology (snow cover mapping)
• Ka-Band	27 GHz - 47 GHz	high resolution radars



Backscattering Mechanisms





Sentinel-1 SAR

- **Land Cover**
- **Vegetation Type and Extent**
- **Inundated Surface**
- European Radar Observatory for the Copernicus joint initiative of the European Commission and the European Space Agency, launched in April 2014
- C-band SAR data
- 12-day revisit
- Resolution: 5 x 20 meters

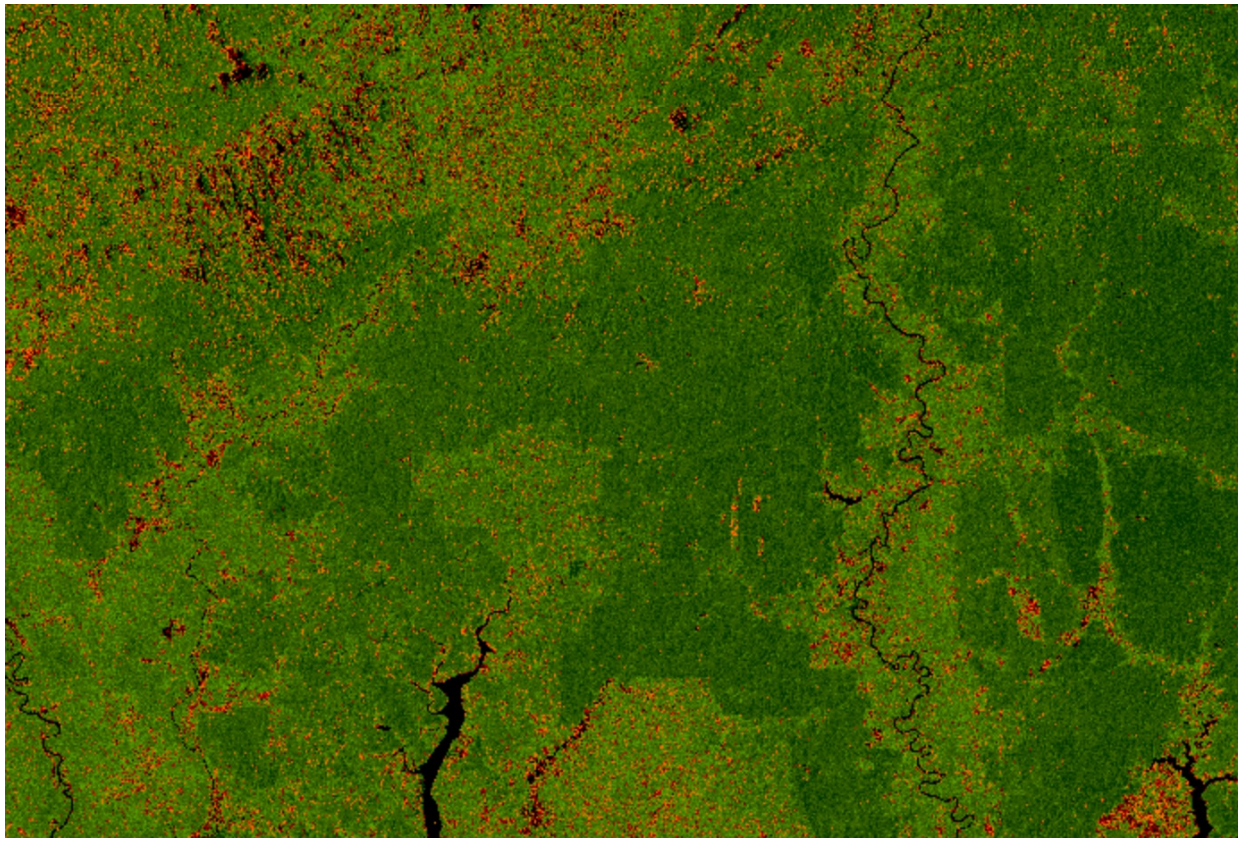
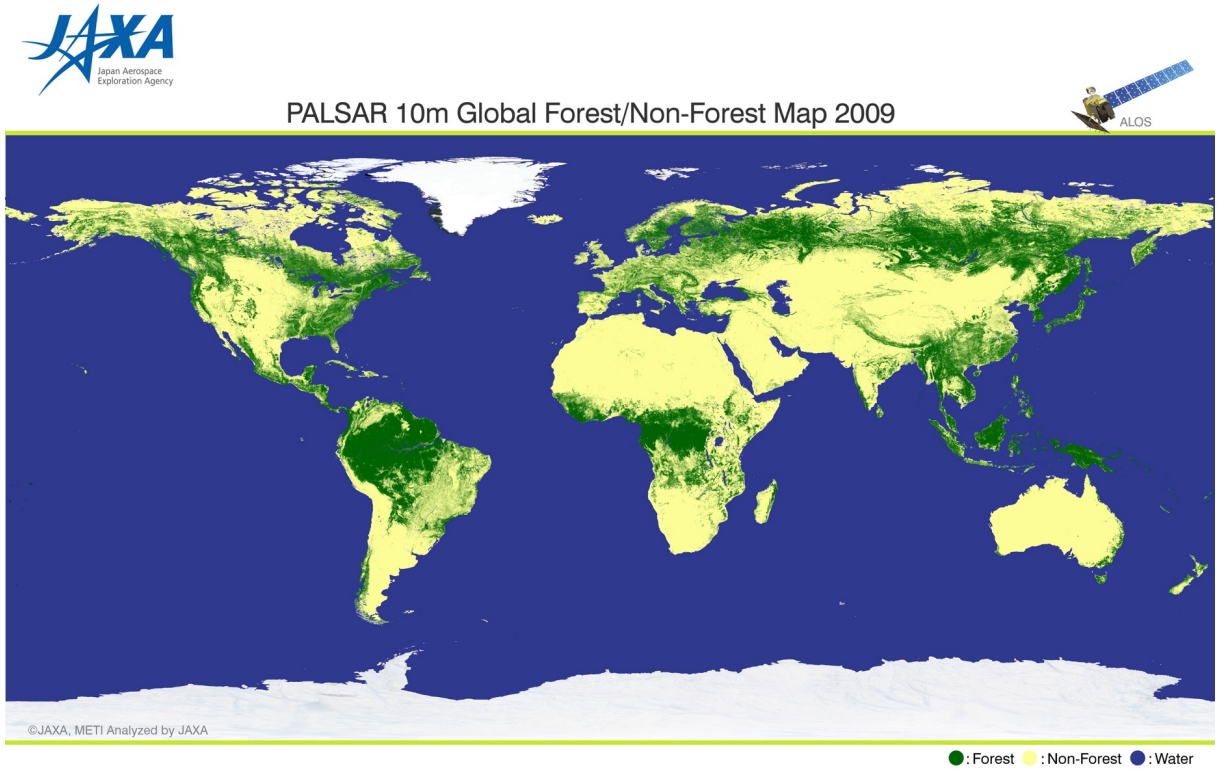


Image Credit: Sentinel Hub: SAR for Deforestation Detection

Advanced Land Observing Satellite (ALOS) and (ALOS2)

- **Vegetation and Terrain**
  - Vegetation Structure: Radar measurements of canopy height and density
  - Topography: DEM including elevation, aspect, slope, and features
- Japanese Space Agency, Phased Array L-band Synthetic Aperture Radar (PALSAR)
- Dates: 2006–2011

  2014–Present
- 10 m & 30 m, 14-day revisit
- L-band SAR

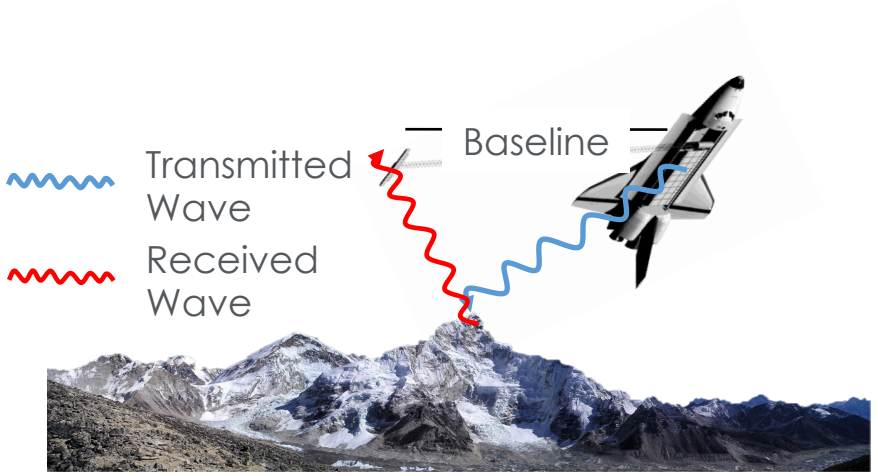


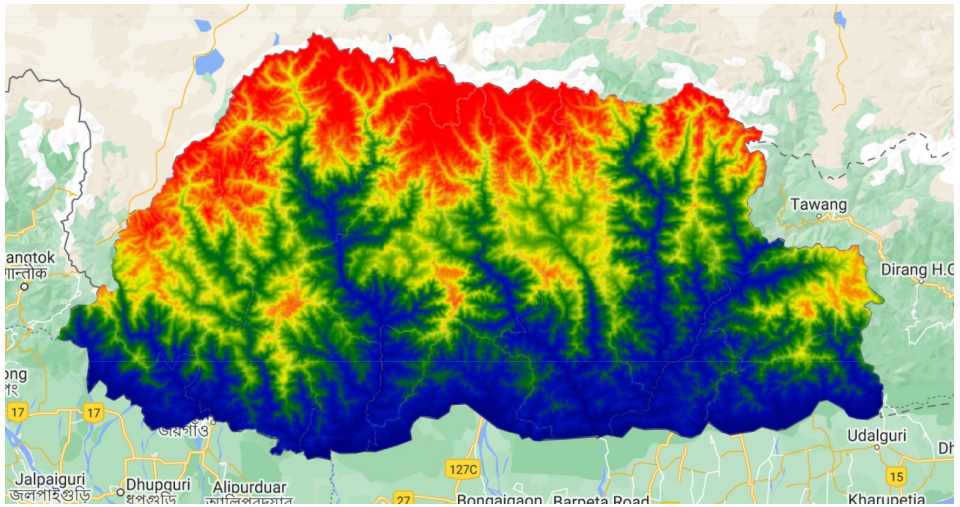
Global Forest-Nin-forest Map

Terrain Data From Shuttle Radar Topography Mission (SRTM)

https://www2.jpl.nasa.gov/srtm/mission.htm

- A C-band (5.6 cm) radar mission
- On NASA Space Shuttle Endeavour
- Completed February 2000
- 176 orbits around Earth in 11 days
- Acquired digital terrain elevation data of all land between 60°N – 56°S latitude
- ~80% of Earth's total land mass
- SRTM used interferometry to gather topographic (elevation) data
- Spatial Resolution: 30 m & 90 m



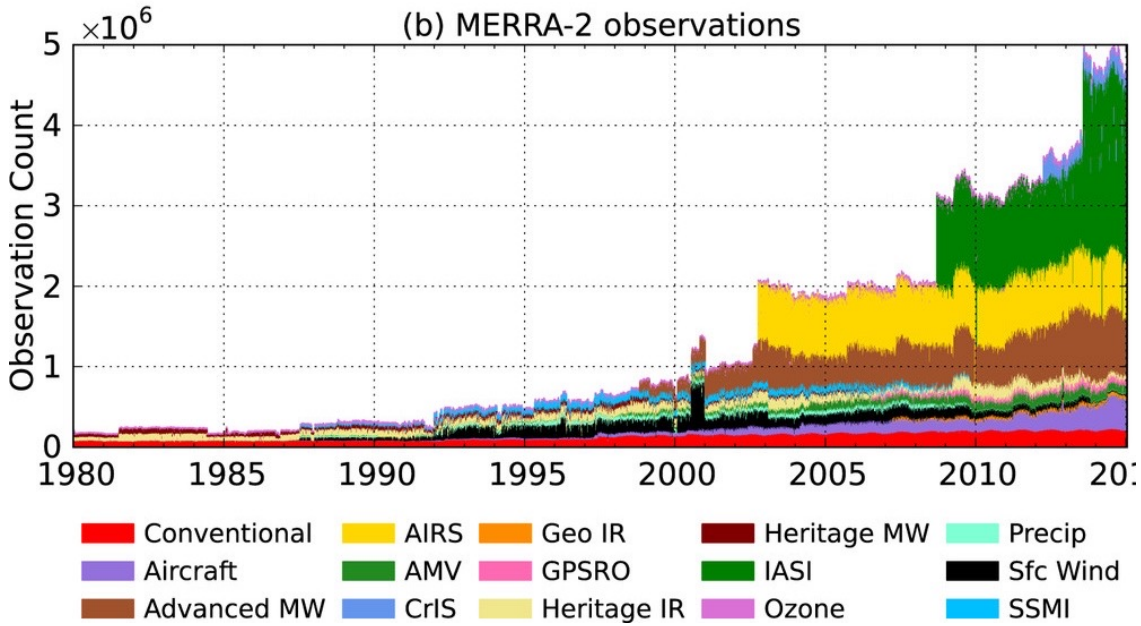


Bhutan Elevation (from Google Earth Engine)

MERRA-2

https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/

- Blends the vast quantities of observational data with output data of the Goddard Earth Observing System (GEOS) model (1980 – Present)
- Provides state-of-the-art global analyses on weather to climate time scales
- Focuses on improvement in the hydrological cycle



- **MERRA-2 Overview:** The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2)
- Ronald Gelaro et al., 2017, J. Clim. ,doi: 10.1175/JCLI-D-16-0758.1

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6)

https://www.nccs.nasa.gov/services/data-collections/land-based-products/nex-gddp-cmip6

- Model runs for four "Tier 1" greenhouse gas emissions scenarios – Shared Socioeconomic Pathways (SSPs)
- Provides a set of global, high-resolution, bias-corrected climate change projections at 0.25°, daily
- Data covers 1950 to 2100 – total of 18 TB of data
- Multiple Global Circulation Models included in CMIP6 are used in the downscaling.]
- Useful for evaluating climate change impacts

Note: Detailed of the model scenarios will be presented in Session 2.

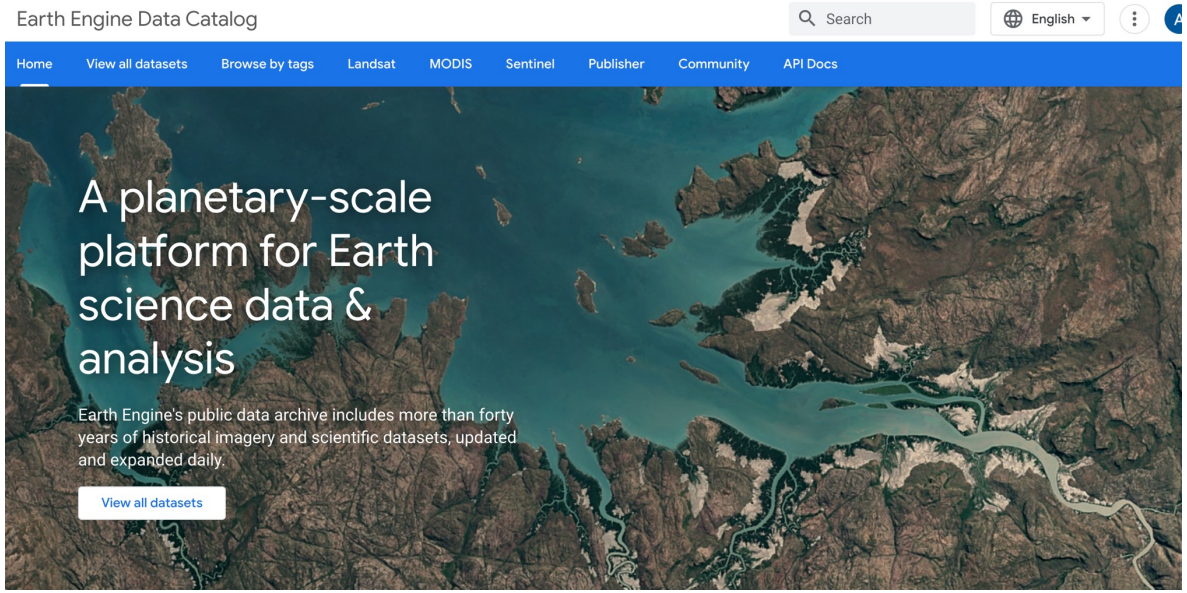
Reference: Thrasher, B., Wang, W., Michaelis, A. *et al.* NASA Global Daily Downscaled Projections, CMIP6. *Sci Data* **9**, 262 (2022). https://doi.org/10.1038/s41597-022-01393-4

Demonstration:
Data Access in Google Earth Engine (GEE)

Google Earth Engine Data Access

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

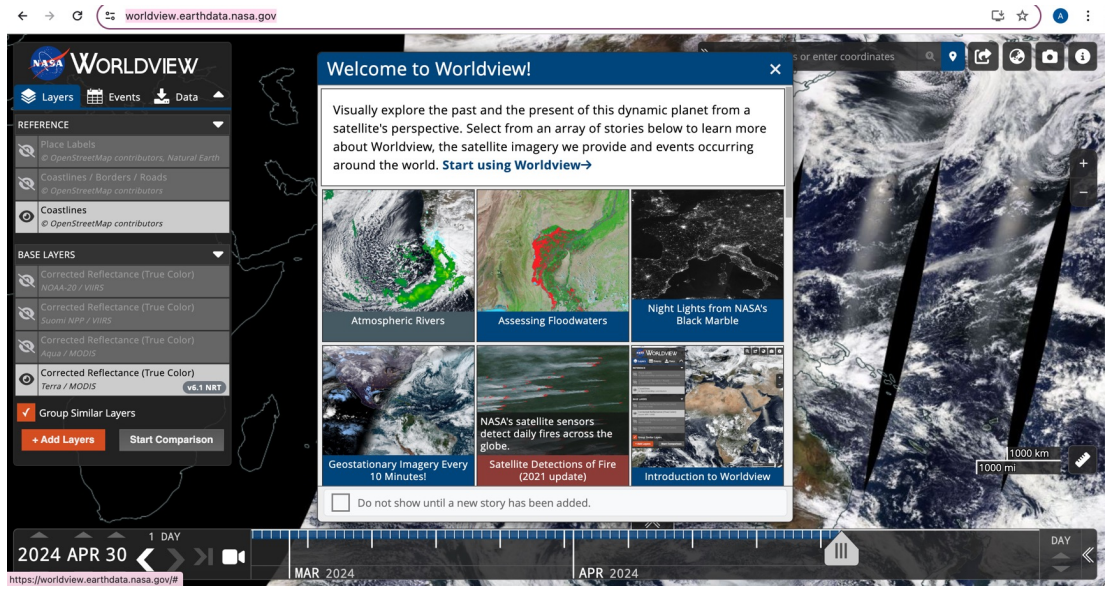
- In this training we will use Google Earth Engine for data search, analysis, and visualization.
- We will use derived geophysical parameters such as precipitation, soil moisture, and vegetation indices for analyzing weather, climate, fires, floods, and landslides.
- For land cover and land surface temperature, we will use optical reflectance from Landsat 8 & 9 and Sentinel-2. We will also utilize SAR backscatter data from Sentinel-1 and ALOS.



NASA Portals for Data Search, Download, and Visualization

NASA Data Portals

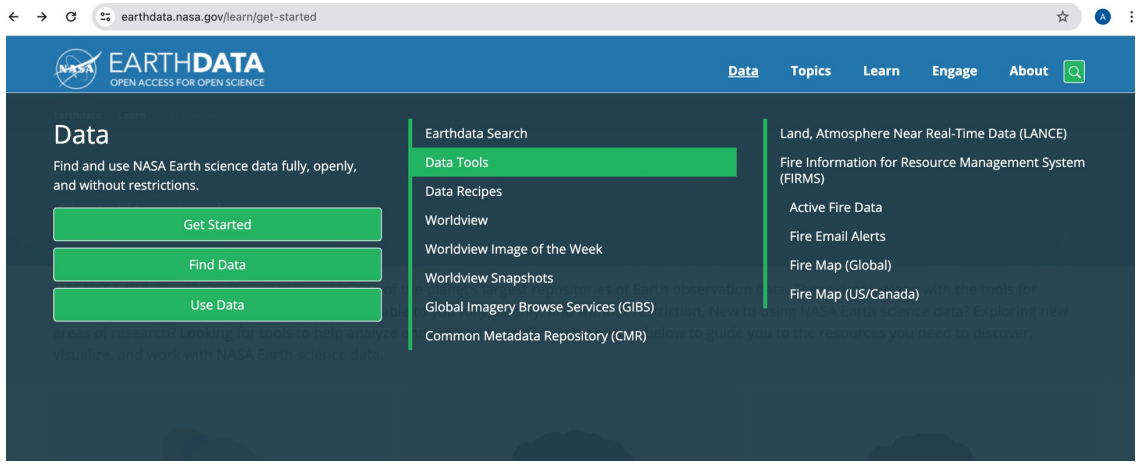
- In this training we will use Google Earth Engine for data search, analysis, and visualization.
- For bulk data download, however, several NASA portals are useful.
  - NASA Earthdata
  - NASA Worldview



NASA Earthdata

https://www.earthdata.nasa.gov/

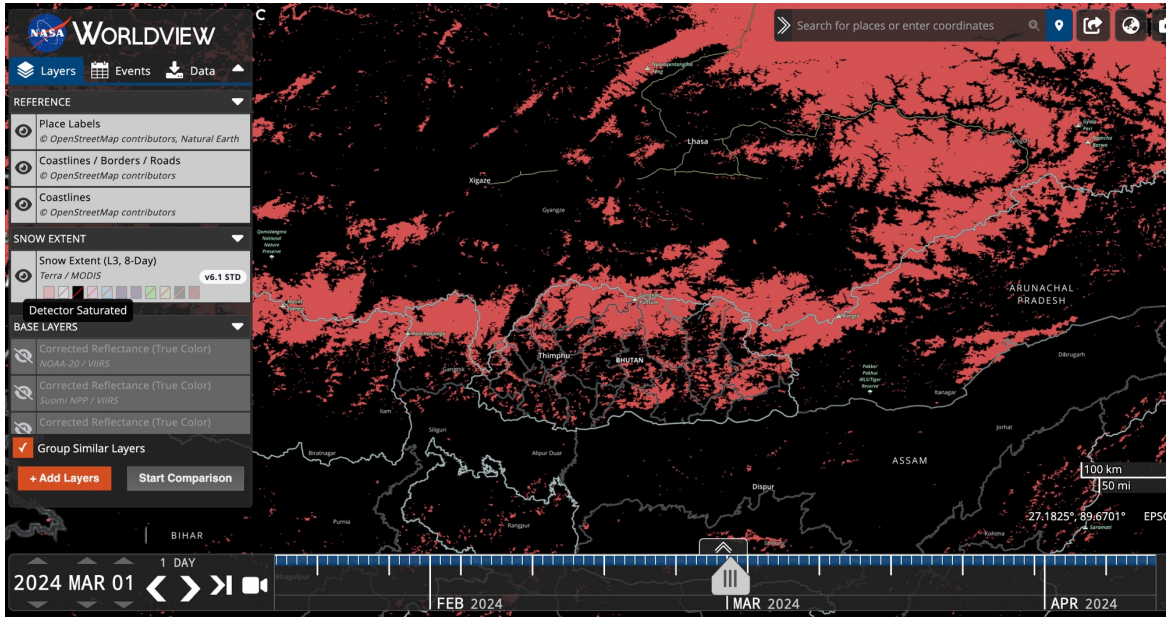
- NASA Earth Observations and model data are available from several Distributed Active Archive Centers (DAACs).
- NASA Earthdata portal allows data search, spatial and temporal subsets, and bulk download.
- Data download requires registration to Earthdata.
- All the data are open source and free.



NASA Worldview

https://www.earthdata.nasa.gov/worldview

- Provides the capability to interactively browse over 1,000 global satellite imagery layers.
- Several of the data layers are updated daily and are available in near-real time with a few hours of latency.
- Allows browsing multiple data layers with customized visualization.
- Includes data download capability.



MODIS Snow Extent on March 1, 2024

Demonstration:
Earthdata and Worldview