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

Day 2 – Monitoring Pre-, Active-, and Post-Fire Conditions

Objectives

By the end of this presentation, you will be able to:

- Recognize the influence of weather, climate, hydrology, and vegetation on wildfires
- Identify data products relevant for:
  - Assessing pre-fire environmental conditions
  - Monitoring active fires
- Recognize how to analyze environmental data to assess pre-fire risk conditions and monitor active fires using GEE

Outline

- Factors affecting pre-fire risks
- Data products relevant for assessing and monitoring fire conditions
  - Pre-Fire Risk
  - Active Fires: Intensity and Burn Rate
- Demonstrations:

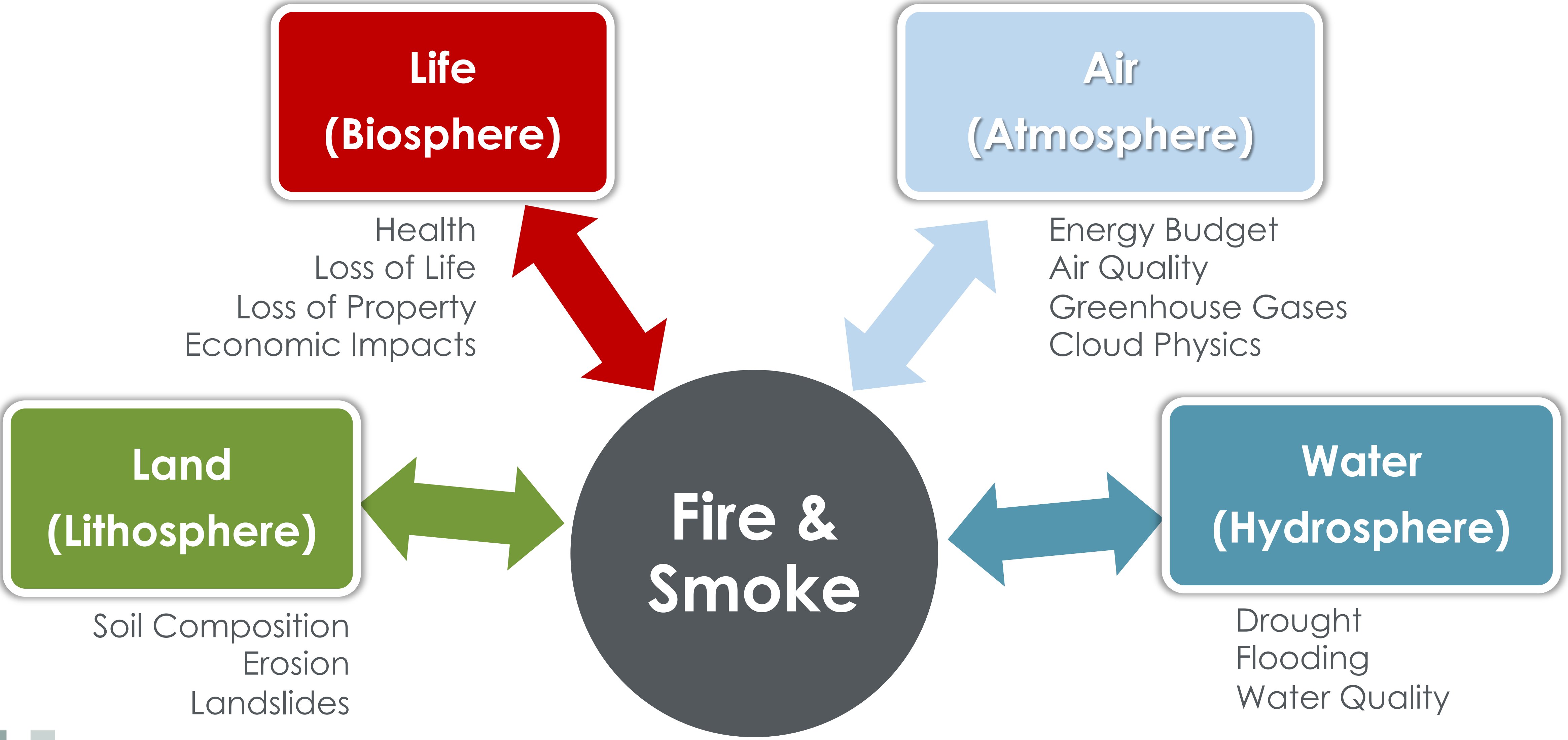
[Forest Fire Monitoring in Bhutan]

Case Study: April 8-16, 2023 Fires in Mongar District of Bhutan

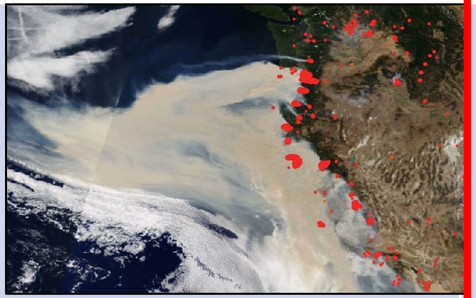
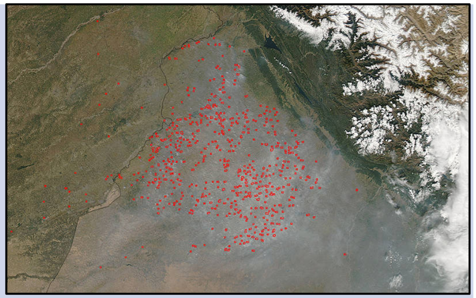
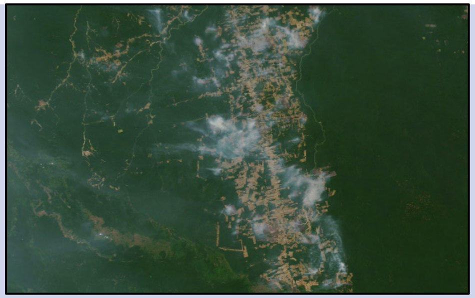
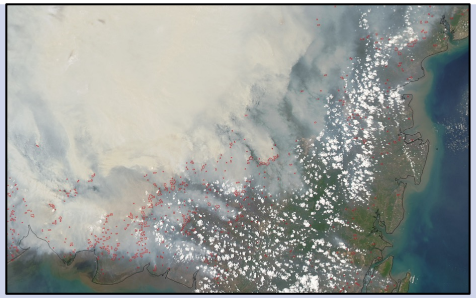
- Analysis of pre-fire weather and fire fuel conditions using GEE
- Monitoring active fire using Worldview and GEE

Factors Influencing Pre-Fire Risk

Fire in the Earth System



Types of Fire

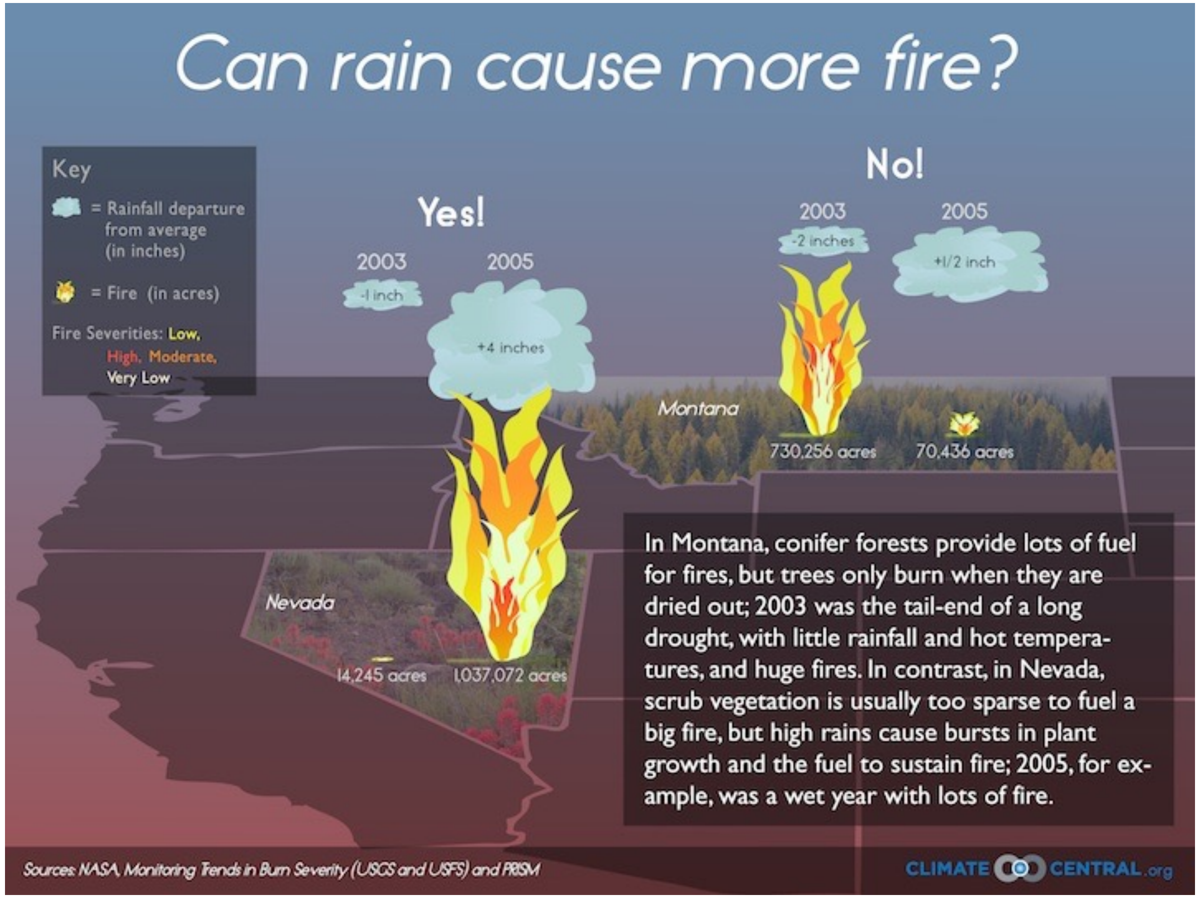
	Wildfire or Wildland	Deforestation	Agricultural	Peat
				
What does it burn?	Forests, Shrubs, Grass	Forests	Crops, Grasses, Shrubs	Peat (Soil-Like Material)
When does it burn?	Dry Seasons, Variable from Year to Year	Seasonal	Seasonal	Seasonal, Variable from Year to Year
Why did it burn?	Natural (Lightning), or Humans (Prescribed Burns, Accidental, Arson)	Humans (forest clearing for livestock and crops)	Humans (burn prior to or after a growing season to clear fields for crops)	Natural (permafrost thaw), Humans (clear land for crops and animal grazing)
How did it burn?	Higher Intensity, can burn millions of acres if not controlled	High Intensity	Lower Intensity	Very Low Intensity, burns underground, difficult to put out

Precipitation and Wildfires

- Precipitation excess during growing season increases growth of vegetation that becomes fuel for fire in subsequent dry season.

- Pre-fire season rainfall, rainfall, and number of rainy days in fire seasons affect wildfire extent and severity (Holden et al., 2018, 2012).

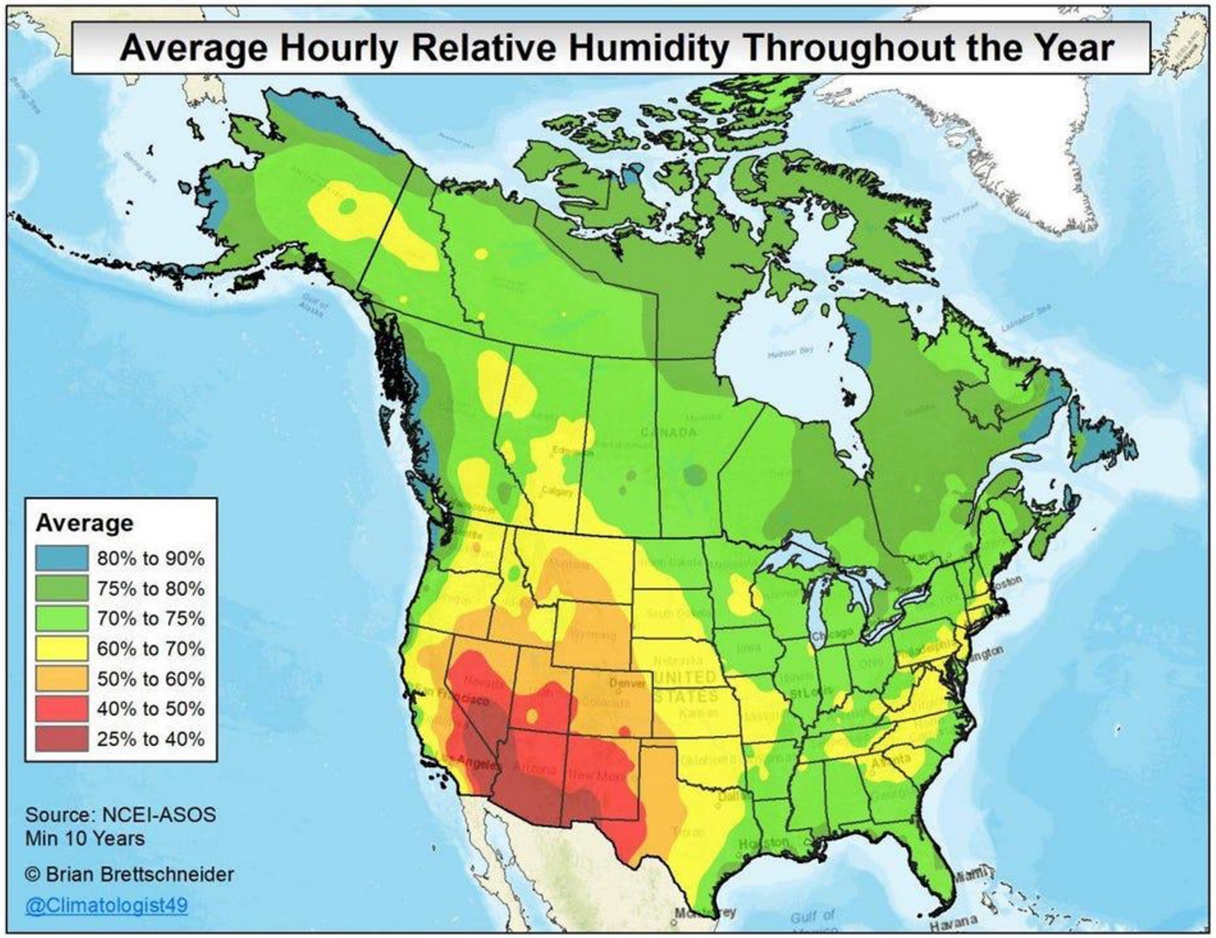
- Precipitation patterns and amount affect surface temperature and soil moisture which also impact pre-fire risk.



https://www.climatecentral.org/gallery/graphics/can-rain-cause-more-fire

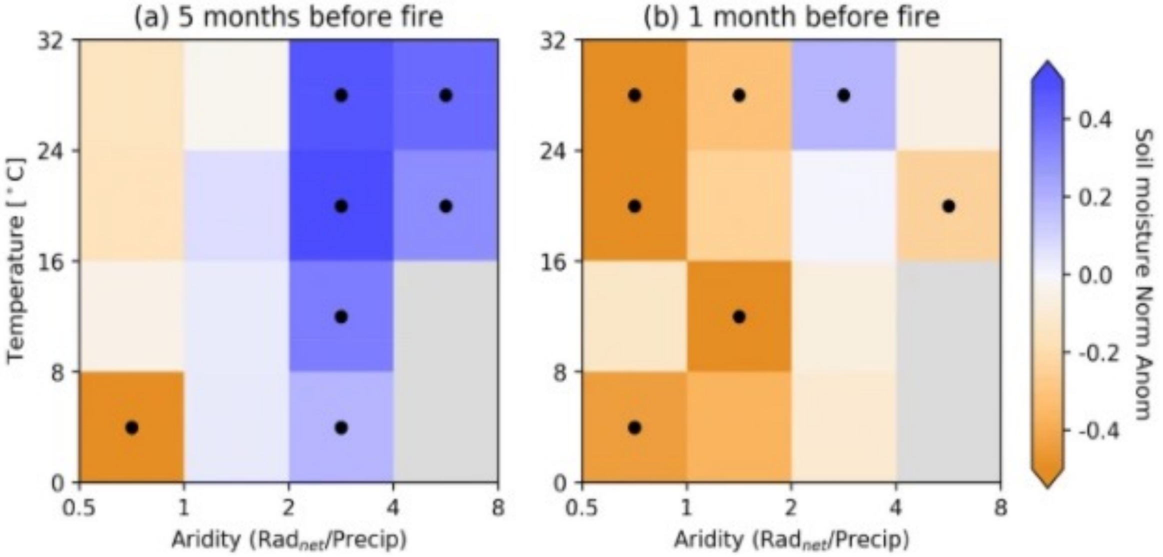
Humidity and Wildfires

- **Relative Humidity (RH):** The ratio of the amount of moisture in the air to the amount of moisture necessary to saturate the air at the same temperature and pressure.
- **Low Humidity:** Air takes moisture from the fuels, drying out vegetation.
- When RH decreases, fire behavior increases.



Soil Moisture and Wildfires

- Pre-fire soil moisture anomalies (departure from long-term mean) increases risk of wildfires.
- It has been noted that in arid regions, wetter soil moisture anomalies promote vegetation growth that can fuel fires. In humid regions dry soil moisture anomalies generally precede fires (e.g., Sungmin et al., 2020).



Consecutive wet and dry soil moisture conditions promote wildfires. Normalized soil moisture anomalies at (**a**) 5 months and (**b**) 1 month before the month with the largest burned area. Grid cells are grouped with respect to long-term temperature and aridity. Median values across grid cells in each box are shown. Boxes with less than 25 grid cells are discarded and shown in gray. Black dots within the boxes denote significant anomalies at the 90%-level.

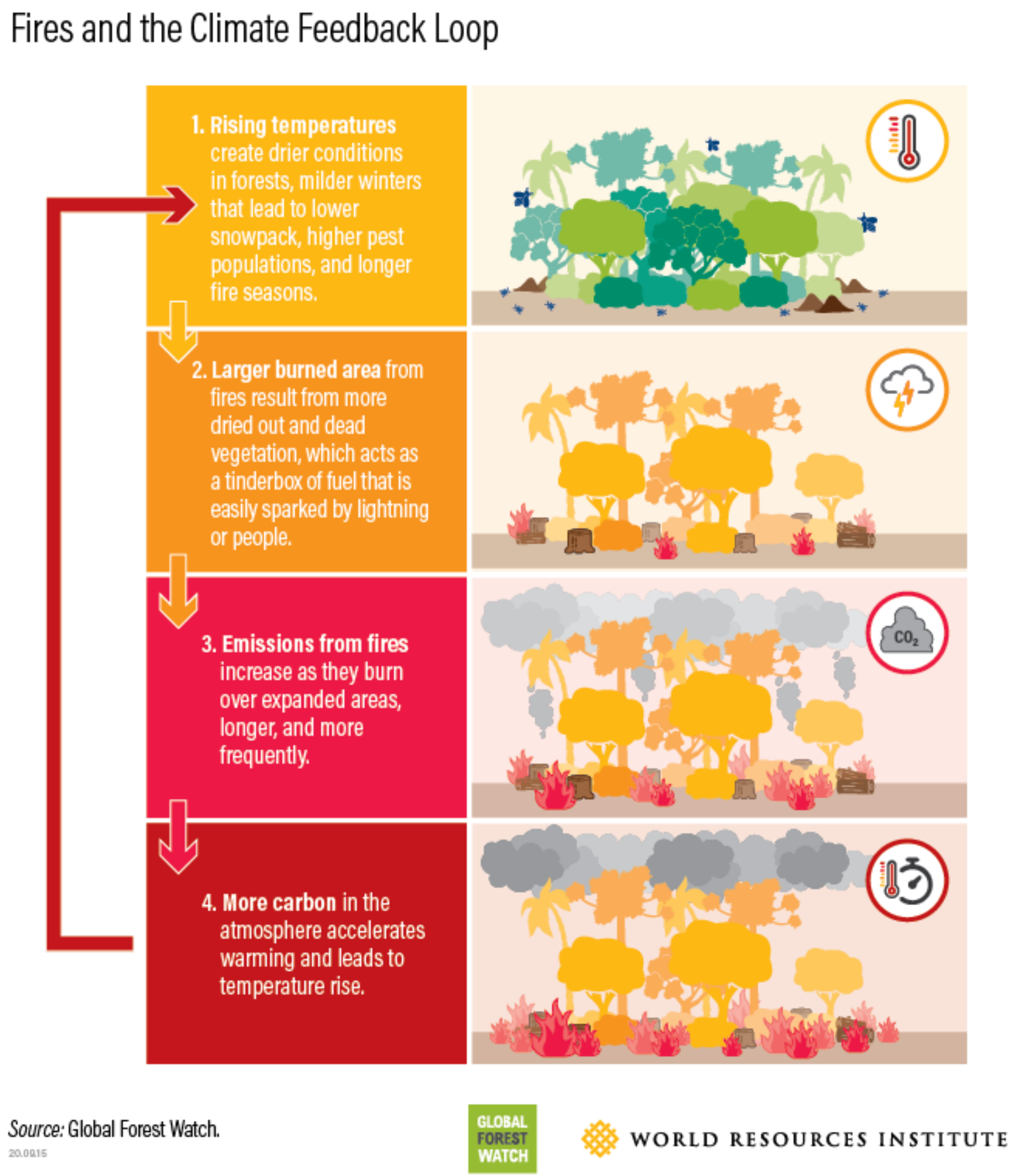
Winds and Wildfires

- Wind speeds affect wildfire spread.
- When wind speeds are high and fuels are critically dry, the time available to prepare a more exacting prediction is limited (Alexander and Cruz 2019).

Image Credit: Mike Lewelling, National Park Service

Climate and Wildfires

- Increasing temperature due to climate change and resulting dry and warm conditions influence fire activities (e.g., Brown et al., 2021; Van Oldenborgh et al., 2021; Madadgar et al., 2020; Gross et al., 2020).



Climate and Wildfires

- Fires reflect a complex connection between weather and climate conditions and ecosystem processes.
- Numerous studies have indicated that fire frequency, spatial extent, and duration show close association with climate variability on seasonal to interannual and decadal time scales (e.g., Cardil et al., 2021; Shen et al, 2019; Dowdy, 2018; Fassulo et al., 2018; Holz et al., 2012; Werf et al., 2008; Verdon et al., 2004).
- Climate change, along with the variability, is also considered responsible for increasing fire activities worldwide (e.g., Abatzoglou et al., 2019).

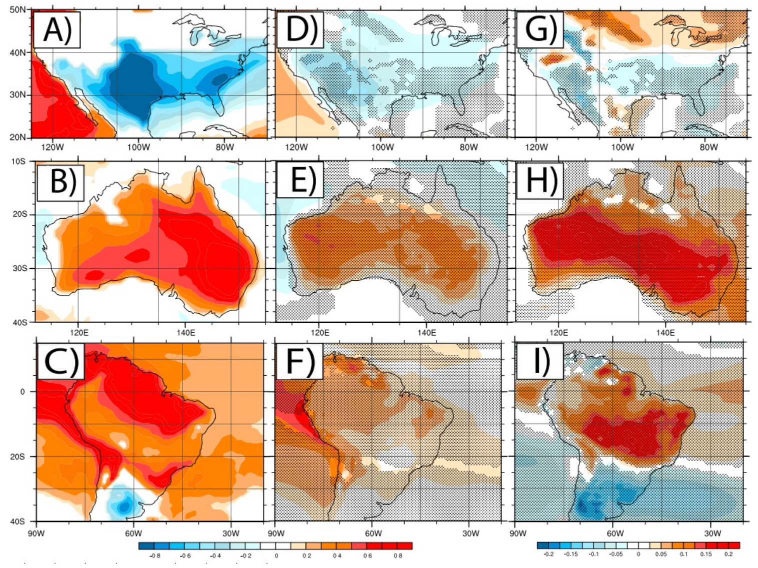


Figure 1. Twentieth century (1920–1980) regressed July-June surface temperature responses to Niño3.4 sea surface temperature in units of K K^{-1} in (left column) ERA20C and (middle column) Community Earth System Model (CESM) for (a and d) North America, (b and e) Australia, and (c and f) South America, along with (g–i) their corresponding CESM projected changes by the late 21st century (2040–2100). Stippled regions in CESM panels correspond to locations where the significance of the sign of the projected change exceeds 95% (i.e., ensemble mean change exceeds twice the ensemble standard error).

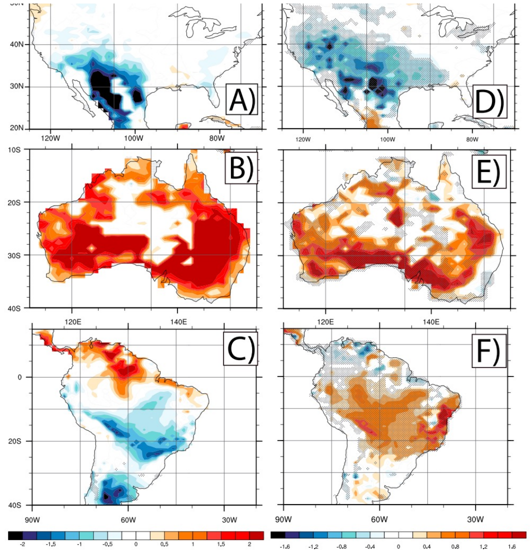
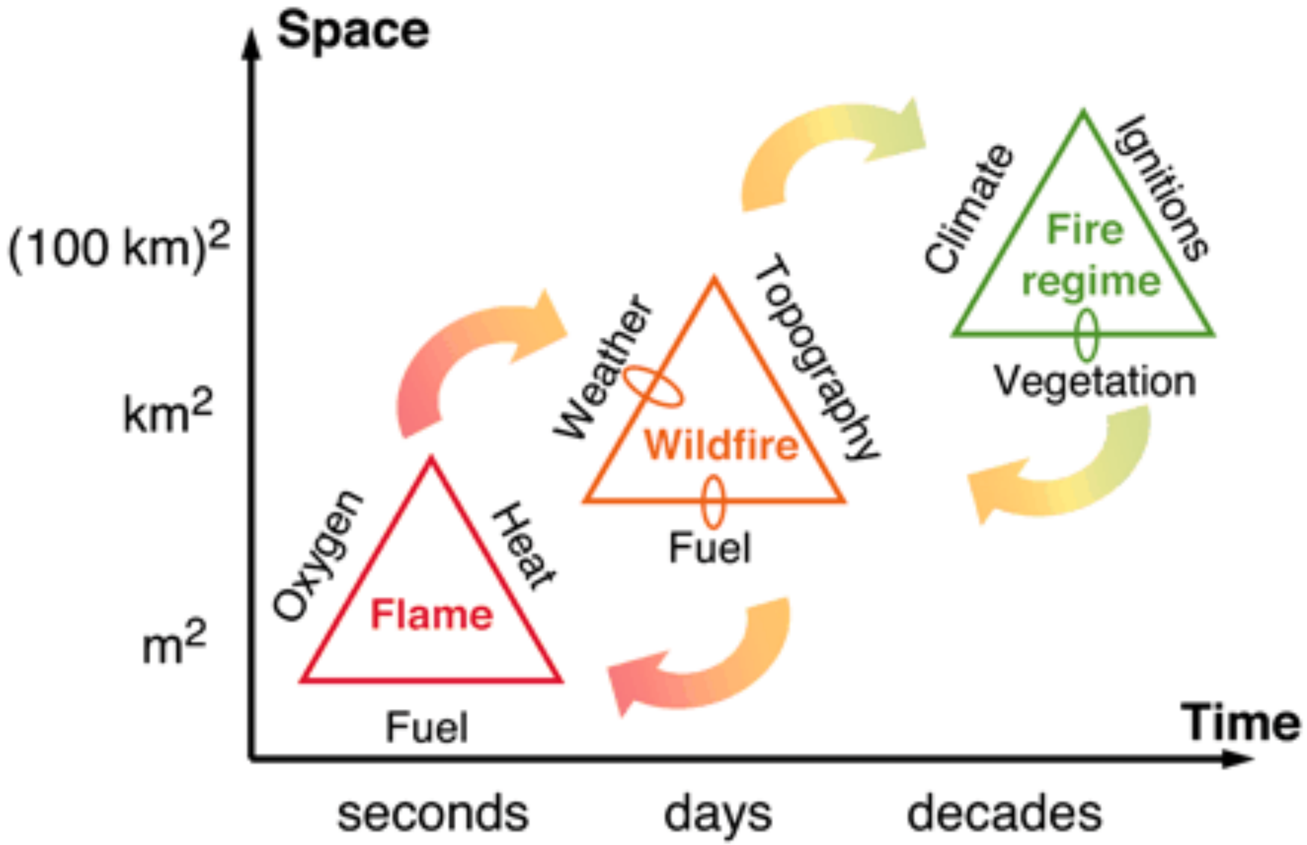


Figure 2. As for Figures 1d–1i, except for fire probability (F_P) in units of % K^{-1}.

Fassulo et al. 2018

Climate Variability & Change and Fire Weather

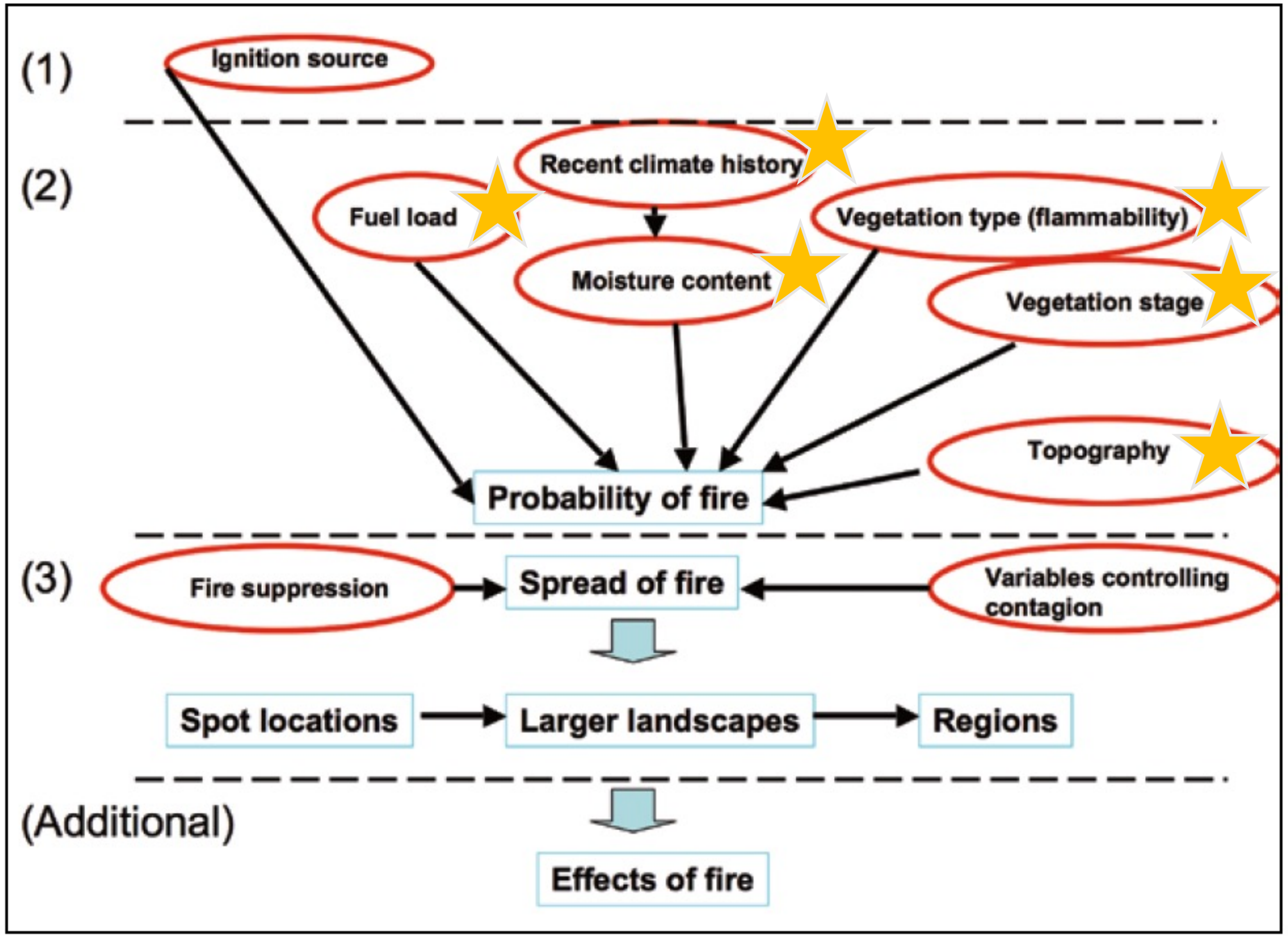
- Fire weather is a combination of temperature, precipitation, winds, and humidity conducive to a high potential of fire activities.
- Climate conditions influence fire weather, soil moisture, and vegetation productivity, affecting fire activities.



Moritz et al. (2005): Controls on fire at different scales. Dominant factors that influence fire at the scale of a flame, a single wildfire, and a fire regime.

Fire Risk Mapping Framework

Where remotely sensed data can be used independently or with ground-based observations



Calculation of fire risk: There are three aspects to predicting fire: (1) the probability of ignition; (2) the biophysical influences on fire, such as fuel load, moisture content, flammability of the vegetation, and topography; and (3) the spread of fire once it gets established.

Image Credit: Weinstein and Woodbury, USFS

Comprehensive fire risk maps are challenging to produce due to the many factors that impact the probability of fire.

Topography: Elevation

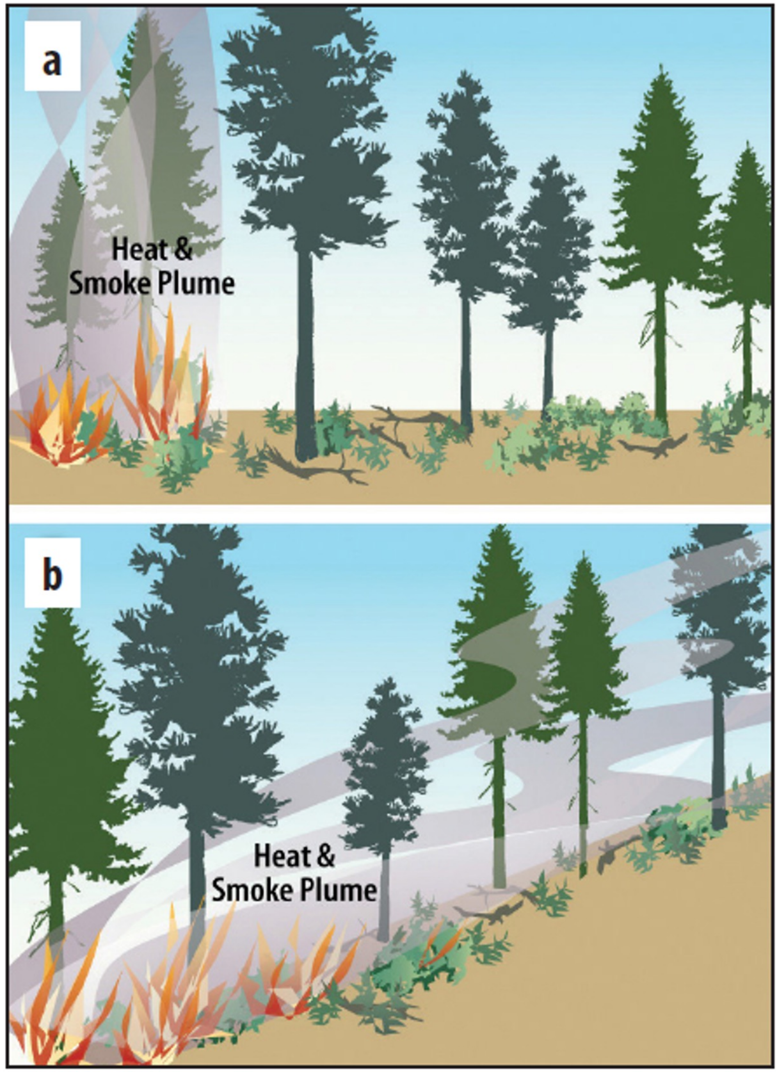
- **Elevation Impacts:**
  - Amount and timing of precipitation
  - Wind exposure
  - Seasonal drying of fuels
  - Lightning strikes

- **Examples:** Lower elevations tend to dry out faster, thus they experience increased fire spread.

This perspective view, combining a Landsat image with SRTM topography, shows topography. Image Credit: NASA

Topography: Slope

- **Increased Slope = Faster Fire Spread**
- **Slope Position: Where does the fire have room to move?**
  - Fires that start at the bottom of the slope have greater area to spread.
  - As heat rises in front of the fire, it more effectively preheats and dries upslope fuels, making for more rapid combustion.

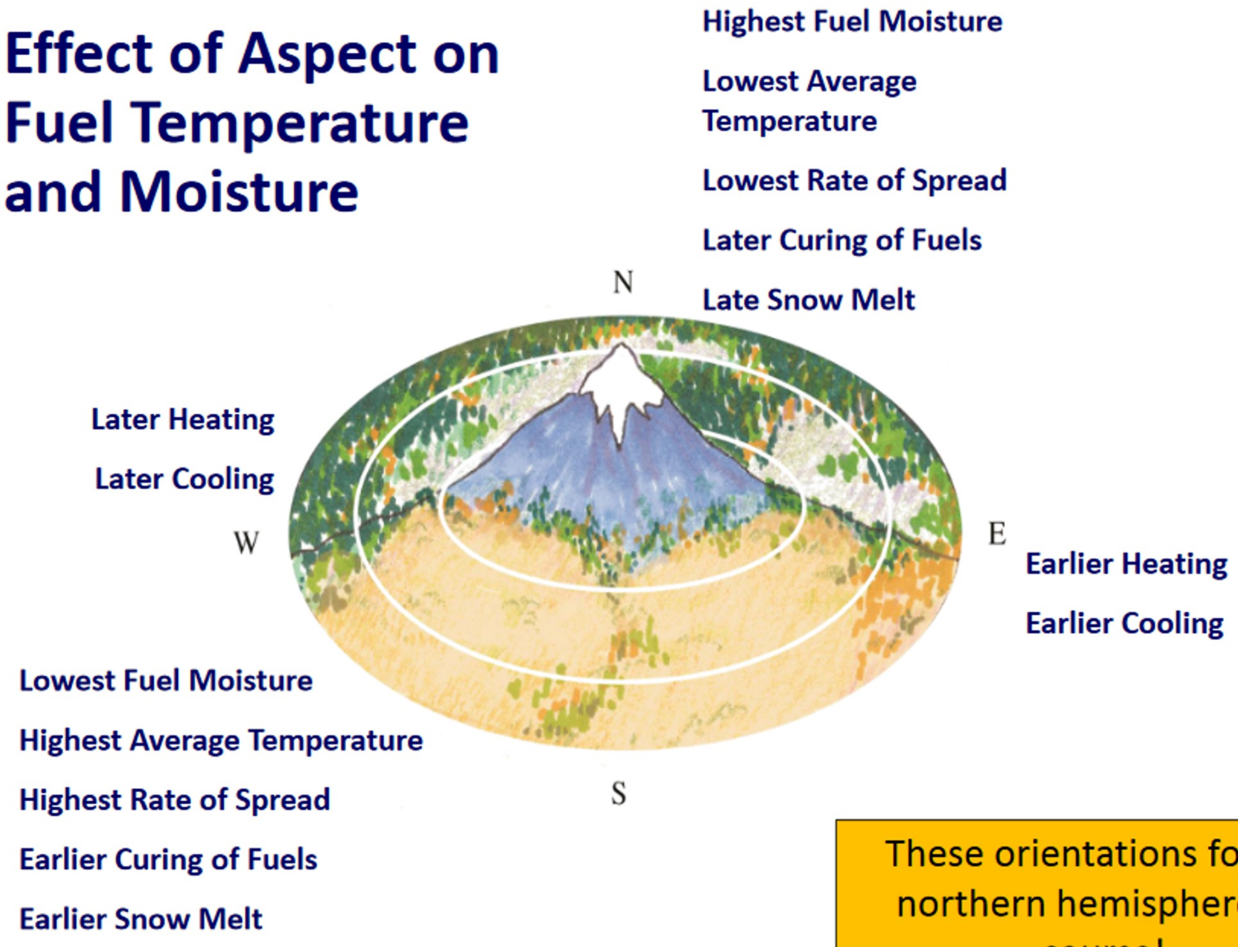


Fires spread more quickly uphill. Image Credit: Fitzgerald, Oregon State University

Uphill fire scars. Image Credit: [University of Arizona]

Topography: Aspect

- **Direction of the Slope**
  - Solar Radiation
    - Example: South-facing slopes have higher solar radiation and drier fuels.
  - Vegetation Type
    - Example: South and West facing slopes have less vegetation.

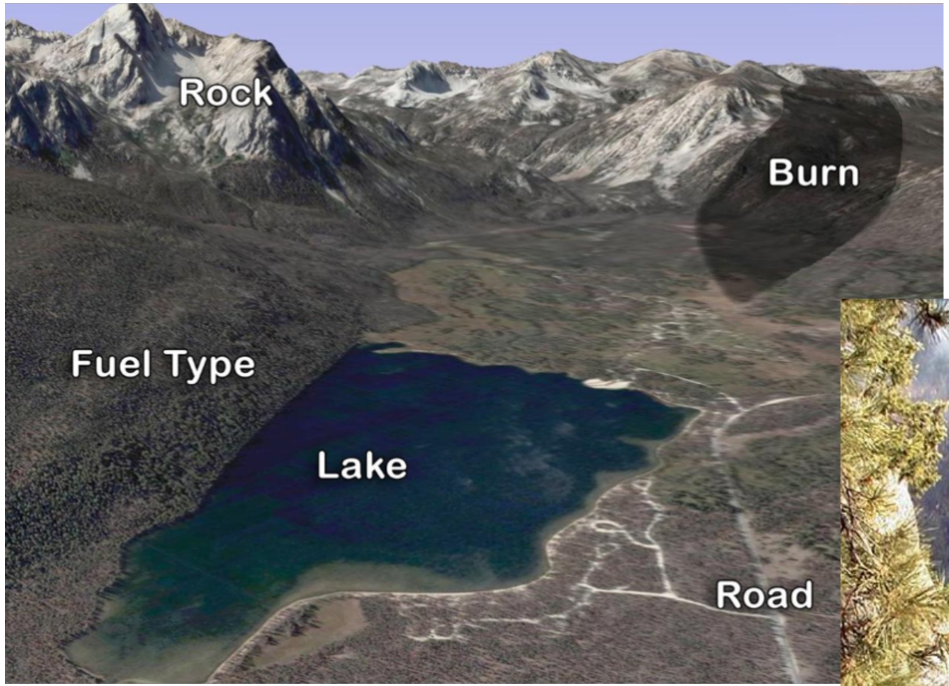


These orientations for the northern hemisphere, of course!

Image Credit: University of Arizona

Topographic Features

- **Alter Fire Behavior**
  - Increase Spread
    - Narrow and wide canyons increase wind and fire spread.
  - Decrease Spread
    - Rock outcroppings, rivers, lakes, etc. can act as barriers to spread.



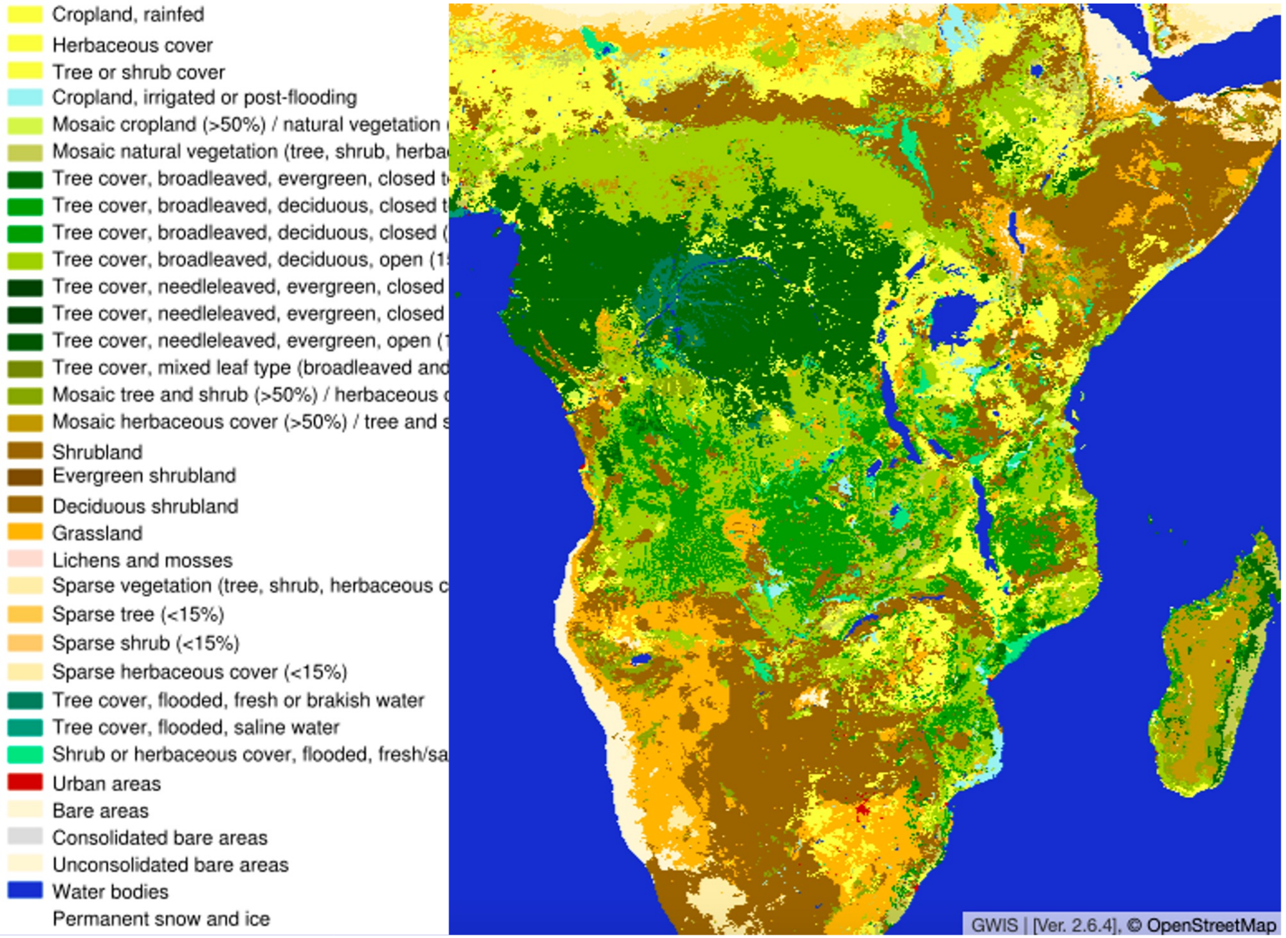
Barriers to fire spread (top) and an example of a deep canyon fire (right). Image Credit: University of Arizona

Vegetation Type and Extent

- **Land Cover Classification:** Grouping of spectrally similar pixels in remote sensing imagery based on land cover class (forest, shrubland, agriculture, etc.).

- **Fuel behavior varies with vegetation type.**
  - Example: Forests contain more biomass to sustain burning, but shrubland vegetations often ignites easier.

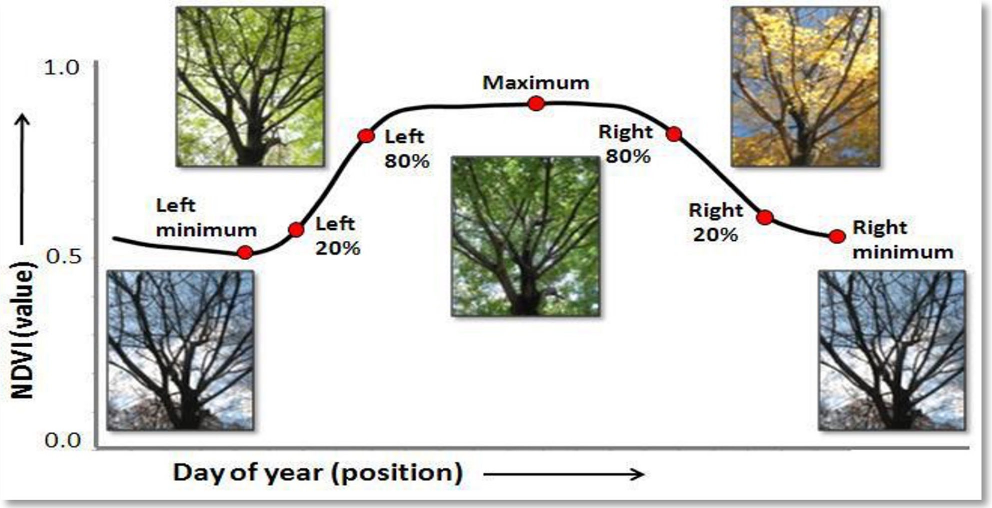
- **ARSET Trainings:**
  - Land Cover Classification
  - Forest Mapping and Monitoring with SAR Data



Global Wildfire Information System (GWIS) land cover classification layer for Sub-Saharan Africa. Image Credit: GWIS

Vegetation Stage and Health

- **Unhealthy vegetation** has a higher percentage of dead branches and leaves, providing easier-to-burn fuel for fires. The stage of vegetation also dictates the amount and type of fuel available for fires.
- **Vegetation Stage – Land Surface Phenology (LSP):**
  – Use of satellites and sensors to track seasonal patterns of variation in vegetated land surfaces
  – [ARSET Phenology Training]
- **Monitoring Stage and Health – Indices:**
  - **NDVI** – Normalized Difference Vegetation Index
  - **EVI** – Enhanced Vegetation Index
  - **SAVI** – Soil-Adjusted Vegetation Index
  - Vegetation Index Anomalies

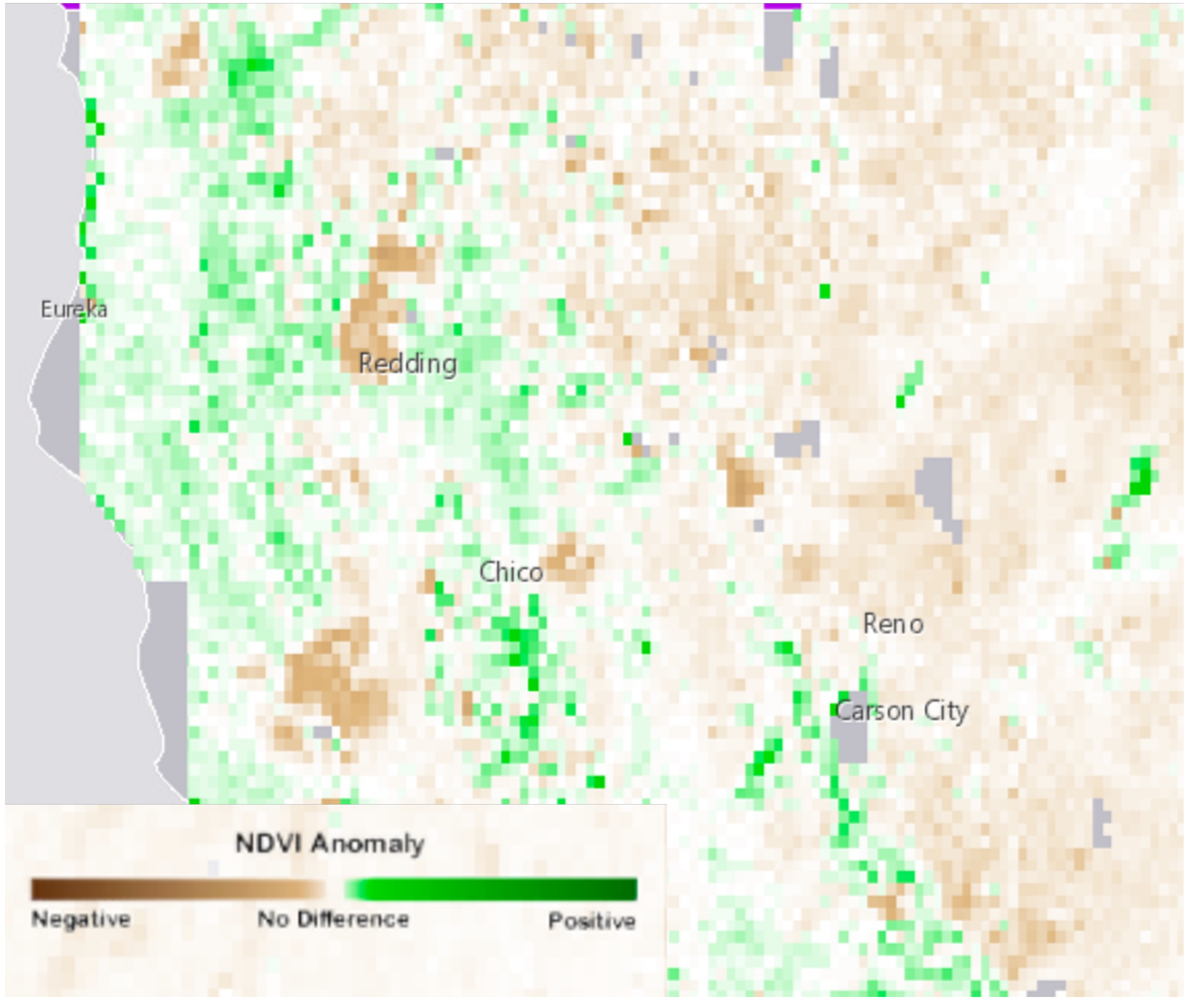


North America NDVI Images in Winter and Summer.

Image Credits: Montana Space Grant Consortium

Vegetation Index Anomalies

- **Anomalies** are a departure of a vegetation index from the long-term average and are generated by subtracting the long-term mean from the current value for that month of the year for each grid cell.
- These departures can indicate changes in vegetation health (due to drought, high temperatures, etc.).



VIIRS NDVI anomaly product for July 3, 2020 shows negative anomalies in northern California prior to August fires, indicating potential impacts to vegetation from dryness and high temperature. Image Credit: Crop Monitor

Vegetation Moisture

- **Low moisture vegetation (drier fuel)** is more likely to ignite and contribute to the spread of fire.
- **75%** of year-to-year variations in burned area can be explained by fuel aridity (Abatzoglou and Williams, 2016).
- **Vegetation Indices:**
  - Normalized Difference Water Index (NDWI), Normalized Dry Matter Index (NDMI), Evaporative Stress Index (ESI)
- **Radar** remote sensing of vegetation moisture.

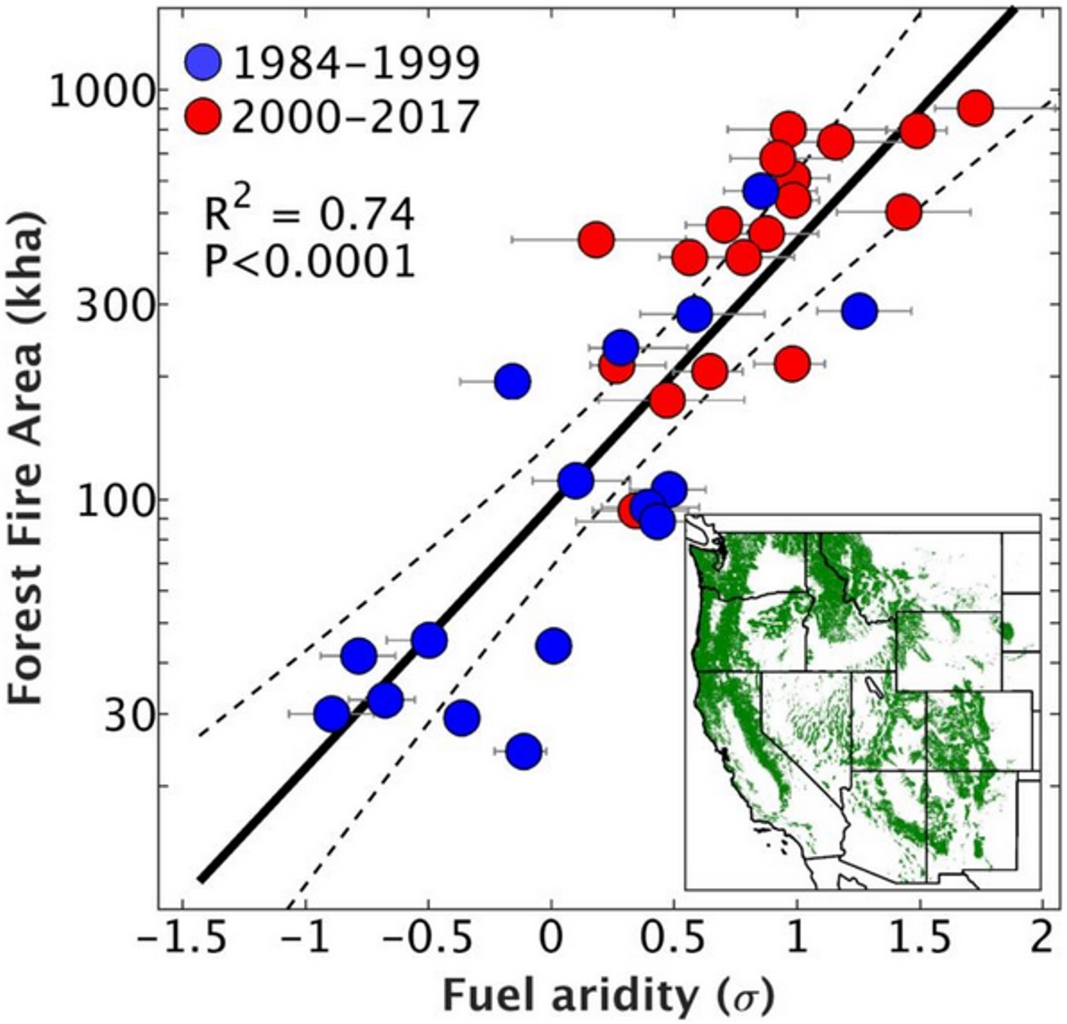
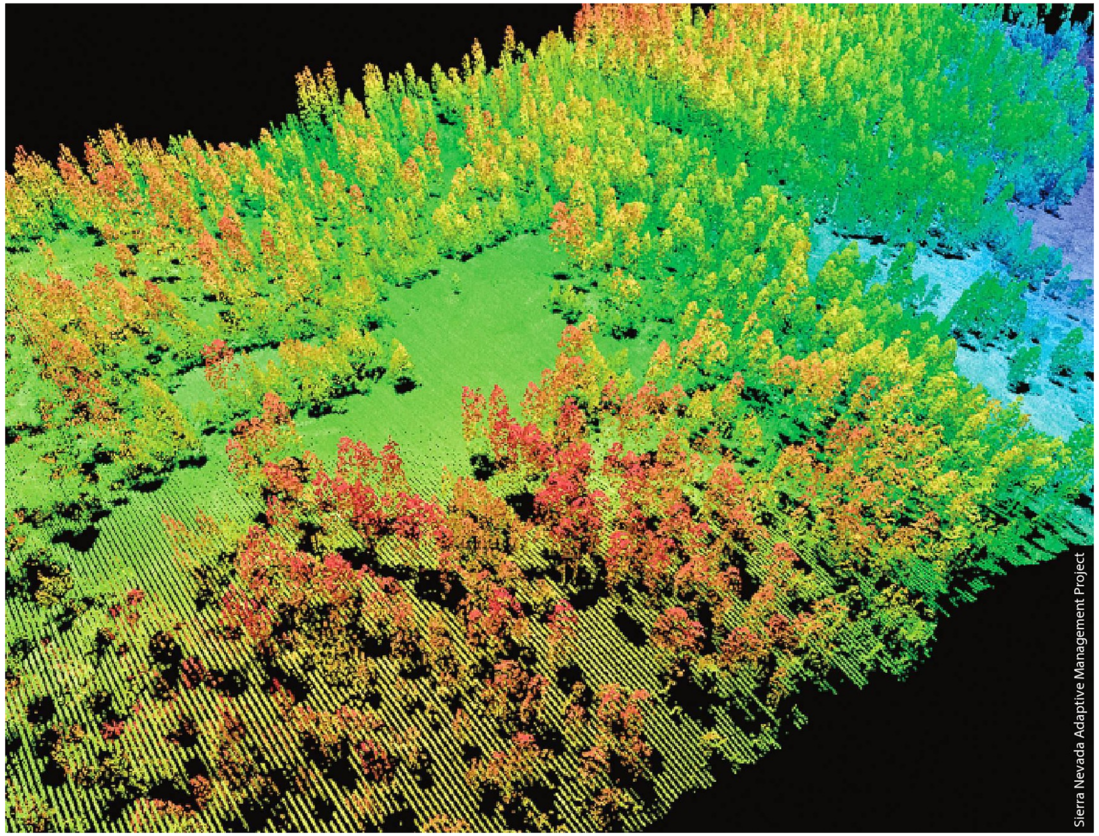


Image Credit: Abatzoglou and Williams 2016

Vegetation Structure

- **Canopy Height and Density**
  - The vertical and horizontal distribution of plant material in a forested ecosystem is a driver of fire spread.
- **Canopy structure** influences fire dynamics directly as fuel and indirectly through its influence on other variables in the fire environment, like fuel moisture below the canopy.
- Synthetic Aperture Radar (**SAR**) and Airborne Light Detection and Ranging (**LiDAR**) data can assess canopy structure over large areas.



Lidar points show trees in the Sierra National Forest, where much of the research on remote sensing has occurred. Image Credit: Keley and Tommaso, 2015

Canopy Height

- **Forest Stand Height (FSH): Average height of trees in a forest stand**
  - Indicator of age of forest and structure, especially the amount of Above Ground Biomass (ABG)
  - Can be used pre-fire to assess initial fuel availability

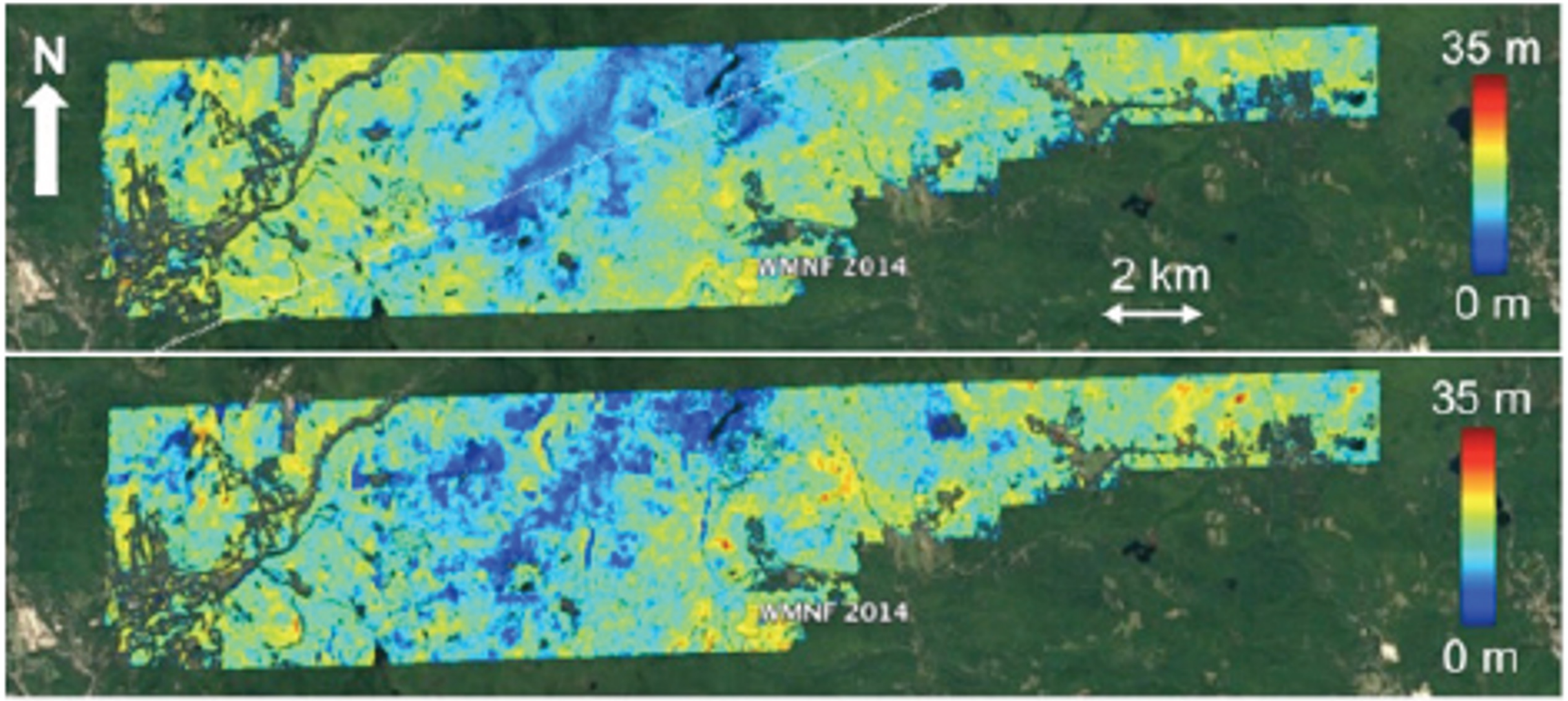
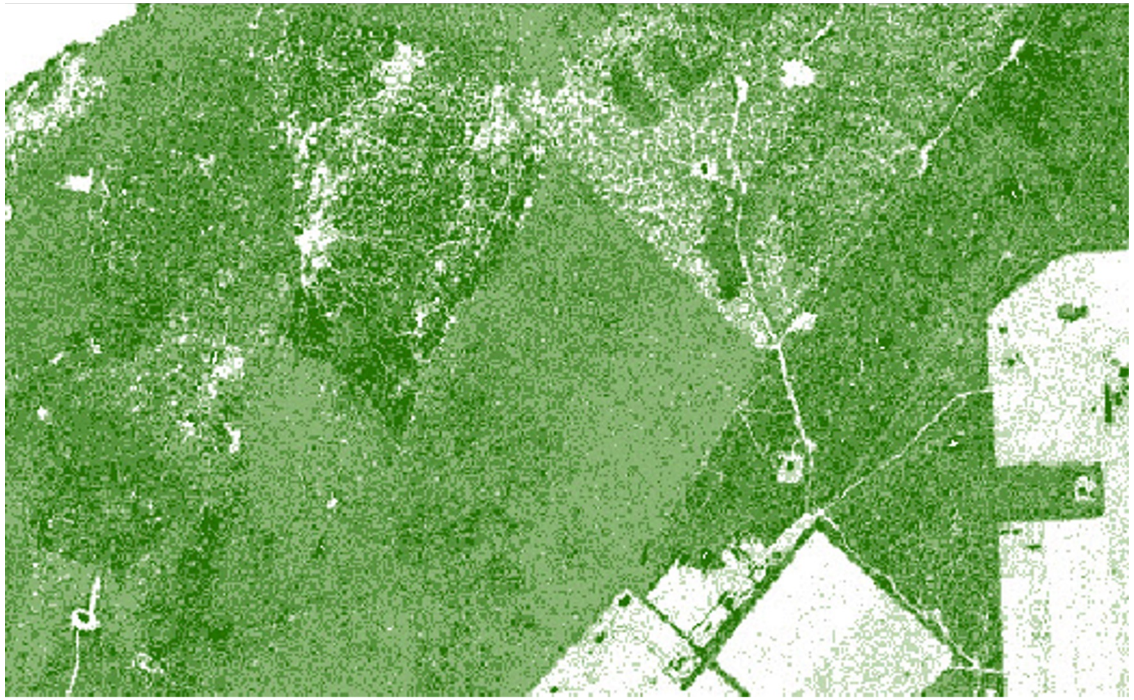


Image Credit: Li et al 2019

Canopy Density

- **Characteristic structure elements that can influence fire behavior:**
  - Openings
  - Single Trees
  - Clumps of Trees with Adjacent or Interlocking Crowns
- Once areas with dense vegetation catch fire, the fire is more likely to spread given access to high fuel load.
- Airborne Light Detection and Ranging (LiDAR) data can assess canopy structure over a large area.



Canopy density, where darker green indicates increasing density.
Image Credit: ArcGIS

Fire Danger

- **In practice, fire danger is about:**
  - **Topography**: Fires spread faster uphill. Fuels are drier on sun-facing slopes.
  - **Fuels**: Fire ignitions and behavior depend on the amount, structure, and condition of vegetation.
  - **Weather**: Weather controls fuel moisture and fire spread.

- **Fire danger** is distinct from **fire threat** (which includes negative impacts) or **fire occurrence prediction** (which includes sources of ignition).

August 2007 experimental savannah fire on flat terrain in Kruger National Park, South Africa (Wooster et al., 2011, *ACP*)

October 2014 experimental coniferous fire on complex terrain in Banff National Park, Canada (Coogan et al., 2020, *CJFR*)

Data Products Relevant for Assessing Pre-Fire Risk and Monitoring Active Fires

Geophysical Parameters for Pre-Fire Risk Assessment

Pre-Fire Risk Assessment

- Precipitation (GPM-IMERG, CHIRPS)
- Temperature (MODIS, Landsat)
- Humidity (MERRA-2)
- Winds (MERRA-2)
- Soil Moisture (SMAP)
- Vegetation (MODIS, VIIRS – NDVI)
- Topography (SRTM)

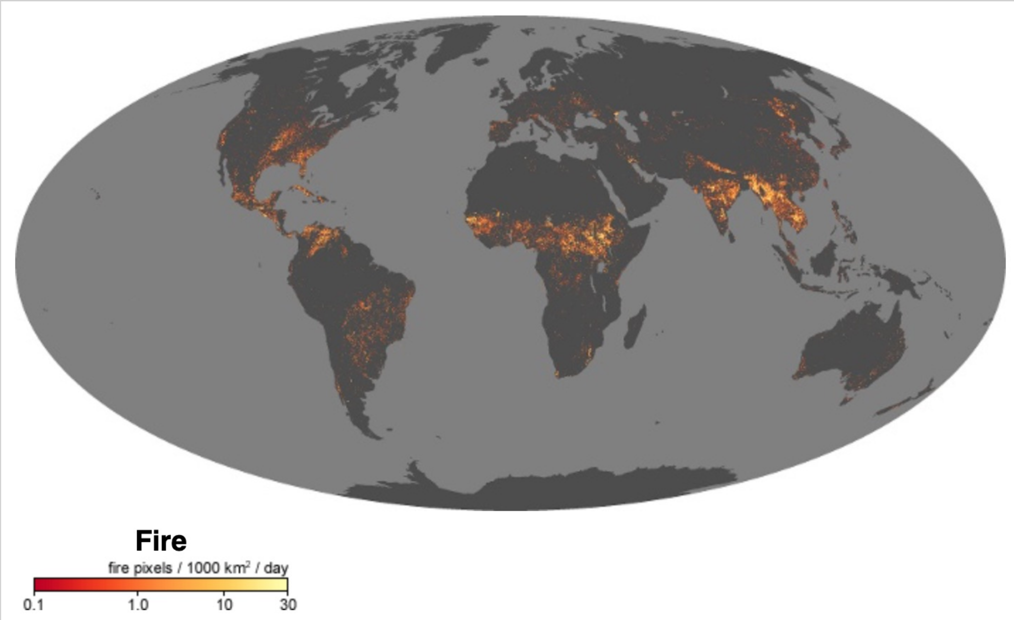
Used to assess fire weather, and fuel availability to identify conditions conducive for fires.

Recall: Details of these data sets and their sources were provided in Parts 1 & 2.
All the parameters are available in GEE.

Data for Monitoring Active Fires from MODIS

MOD14/MYD14 Fire Product

- Thermal Anomalies/Fire products are derived from Terra and Aqua MODIS 4- and 11-micrometer radiances.
- A threshold from surface background radiance is used to detect fires.
- The data product includes fire occurrence (day/night), fire location, the logical criteria used for the fire selection, detection confidence, and Fire Radiative Powers.
- The data are available at daily, 1-km resolution.



MODIS Fire Map February 2024

Data for Monitoring Active Fires from VIIRS

VIIRS Fire Product

- Based on the MOD14/MYD14 algorithms
- There are two products at 750 m and 375 m resolutions, available at an approximately 12-hour interval.
- Fire detection and fire radiative power are available.

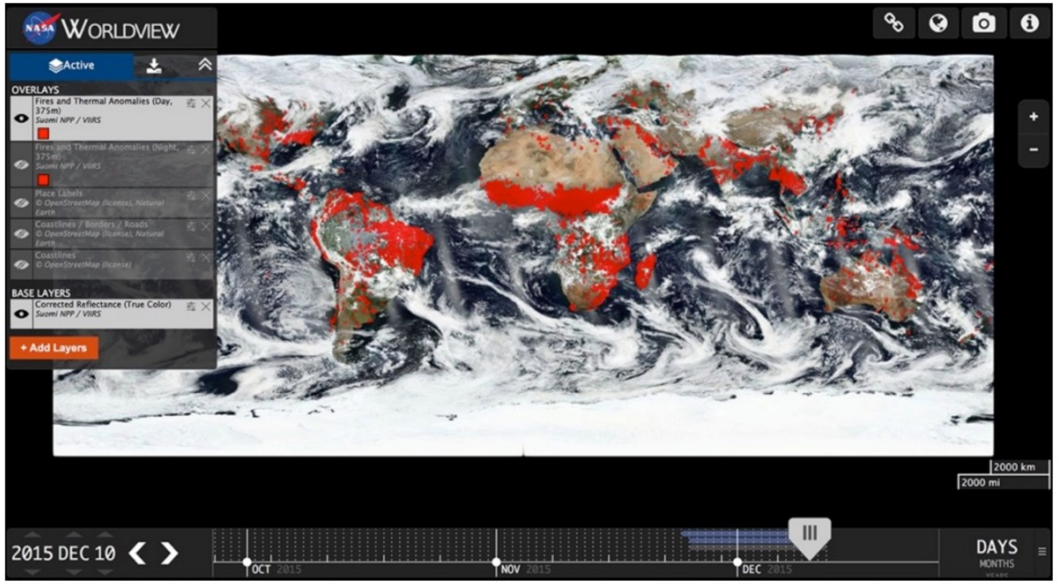
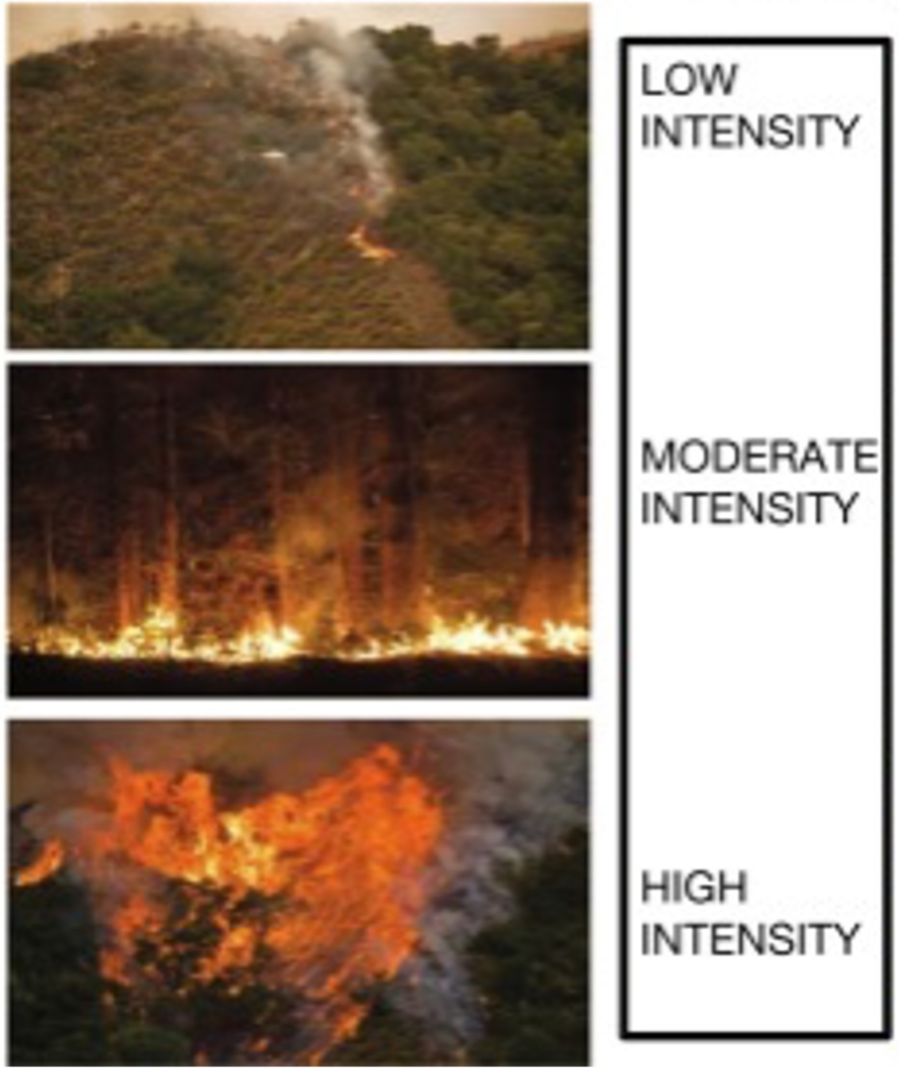


Figure 4: NASA's Worldview data display system showcasing VIIRS 375 m daytime global active fire detections for 10 December 2015.

VIIRS Fire Product User's Guide

Fire Radiative Power (FRP)

- **Fire Radiative Power (FRP):** The rate at which a burning landscape emits thermal radiative energy, measured in watts.
- Fire intensity depends on FPR and highly influences burn severity.
- *Varying relationships between fire size and fire radiative power are found; depends on the type of vegetation.

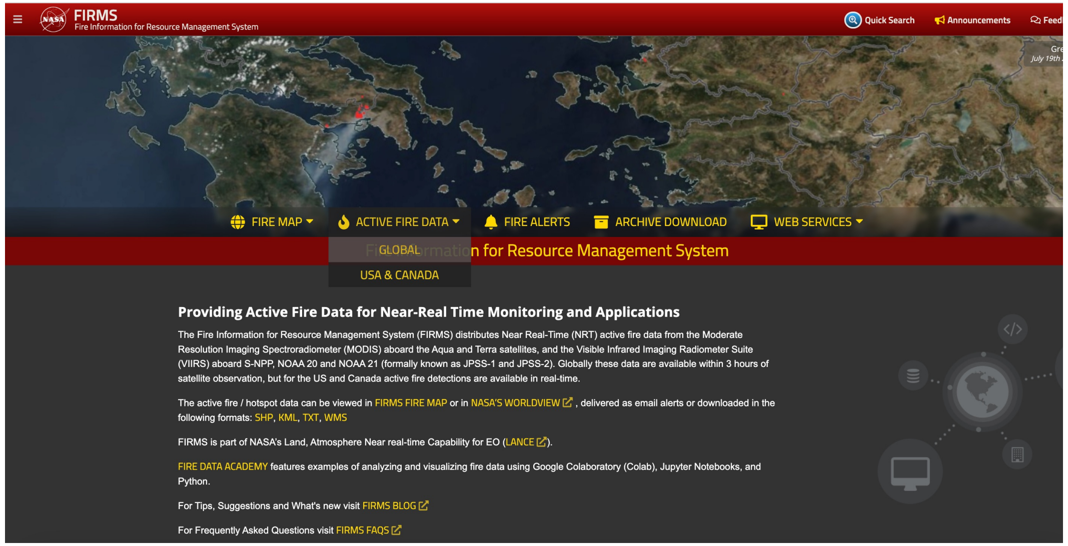


Example scale of fire intensity. Image Credit: NPS.gov, NIFC.gov, K. Crocker, D. A. DellaSala

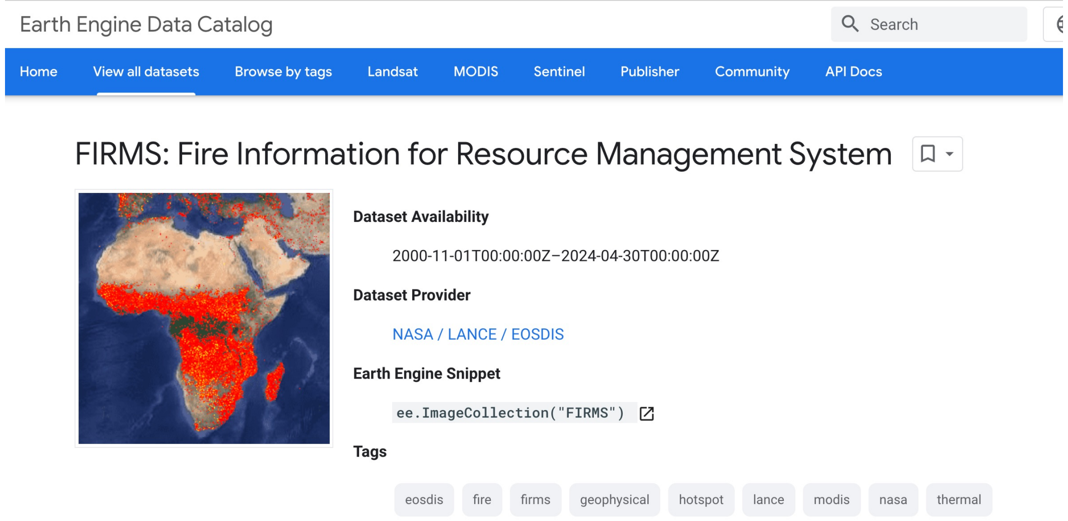
*Laurent, Pet al.,2019: Varying relationships between fire radiative power and fire size at a global scale, Biogeosciences, 16, 275–288, https://doi.org/10.5194/bg-16-275-2019.

FIRMS: Fire Information for Resource Management System

- Provides global, interactive, near-real time fire maps based on MODIS and VIIRS thermal anomalies.
- Uses Landsat OLI thermal anomalies over North America for fire detection.
- Available in NASA Worldview and GEE.

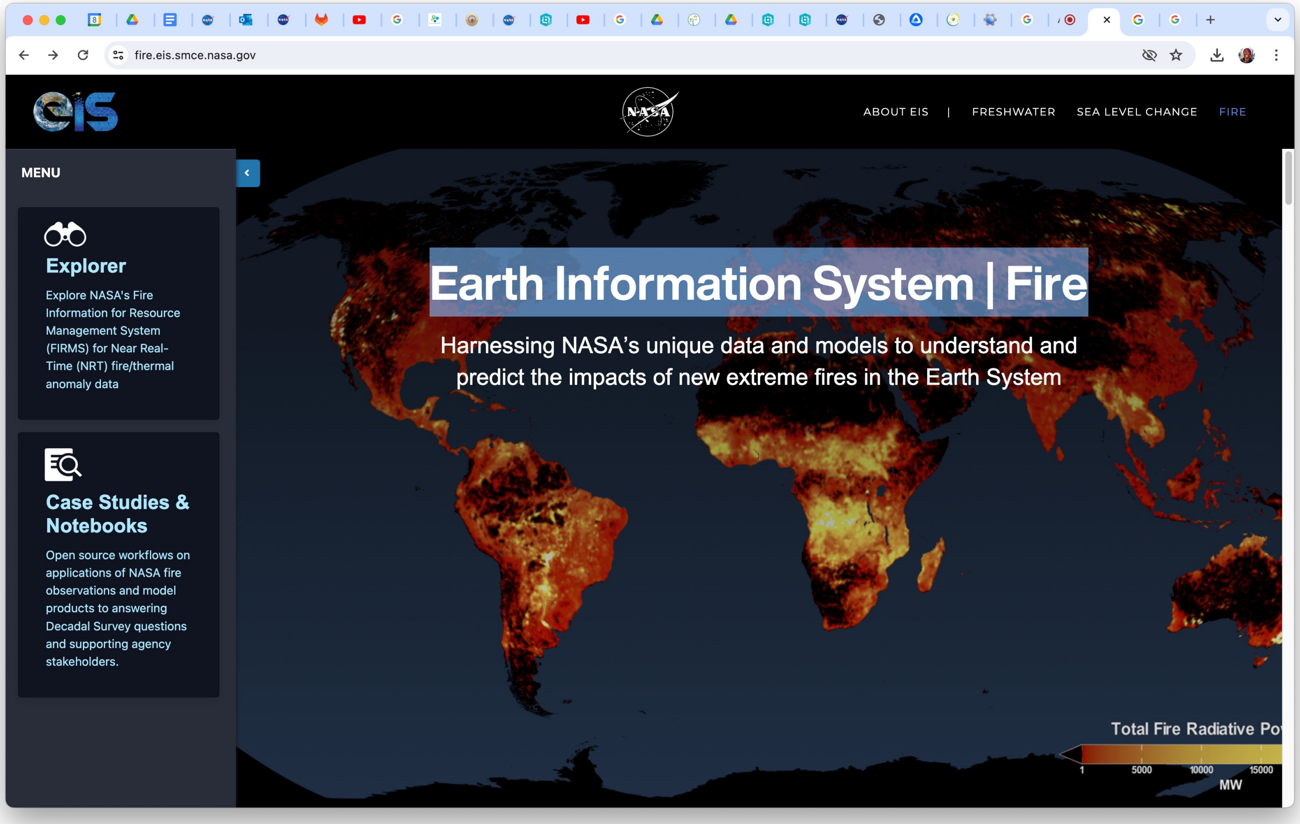


https://firms.modaps.eosdis.nasa.gov/



Earth Information System (EIS) – Fire

- The EIS is a platform for understanding and answering critical questions about Earth's complex System of Systems.
- Standardizing location, format, and distribution of fire data products facilitates development of applications that meet a wide range of user needs.
- https://fire.eis.smce.nasa.gov/

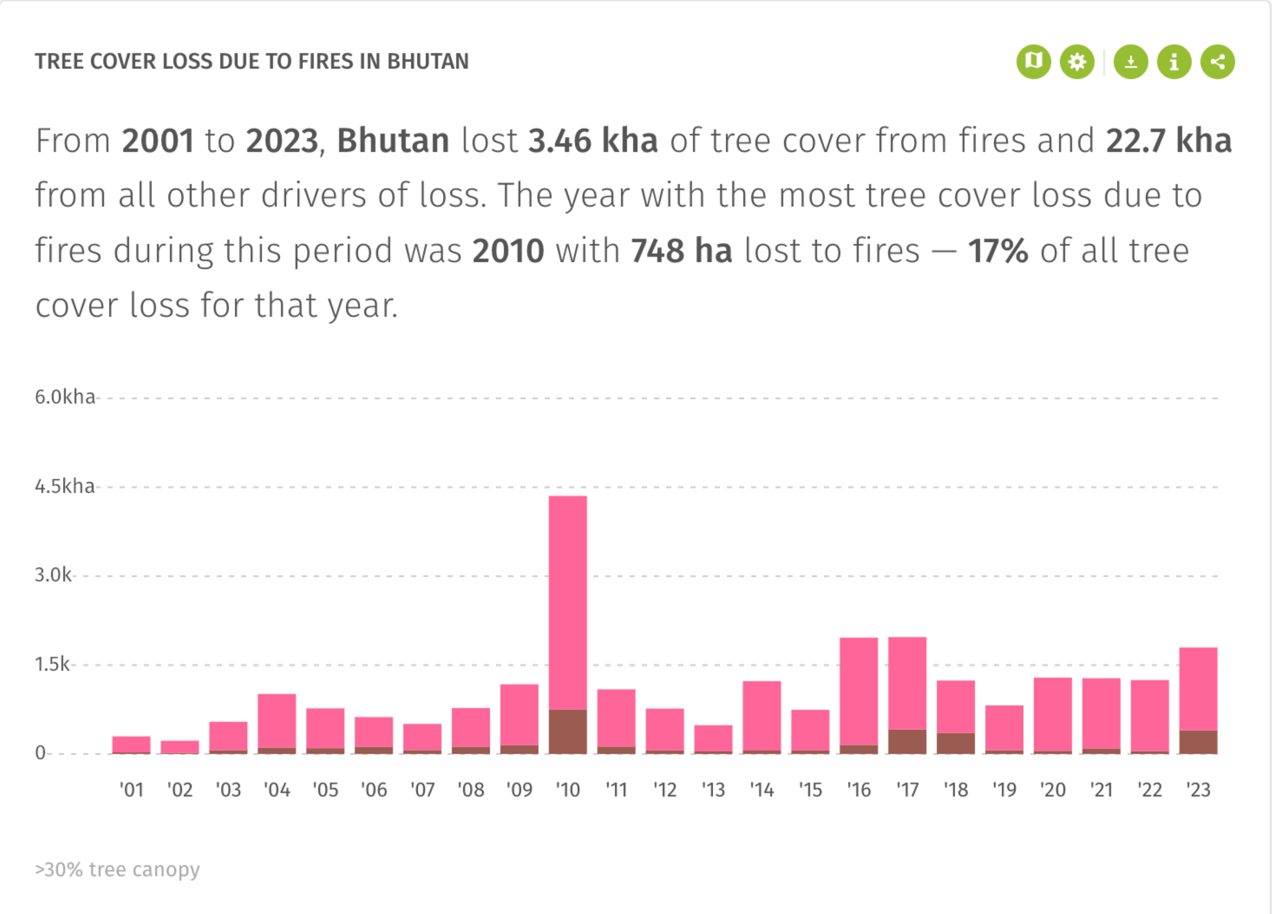


Demonstrations

Forest Fire Monitoring in Bhutan

Wildfires in Bhutan

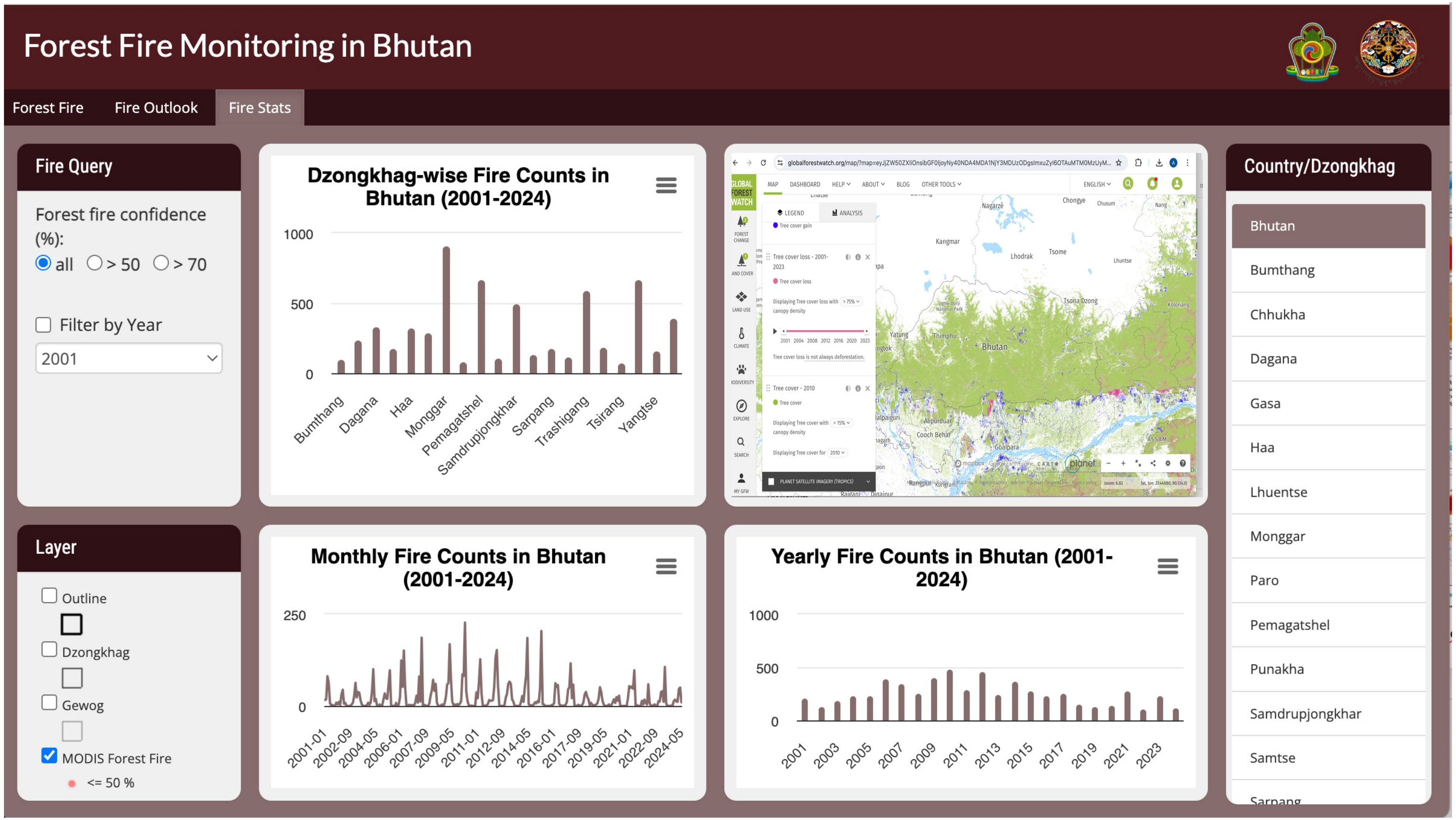
- The peak fire season in Bhutan is generally from mid to late February to April/early May.
- A major cause of loss of forest cover.
- Forest Fire Monitoring in Bhutan based on MODIS fire products provides historical and near-real time fire information.



Global Forest Watch

Wildfires in Bhutan

https://geoapps.icimod.org/BhutanForestFire/FireStats/

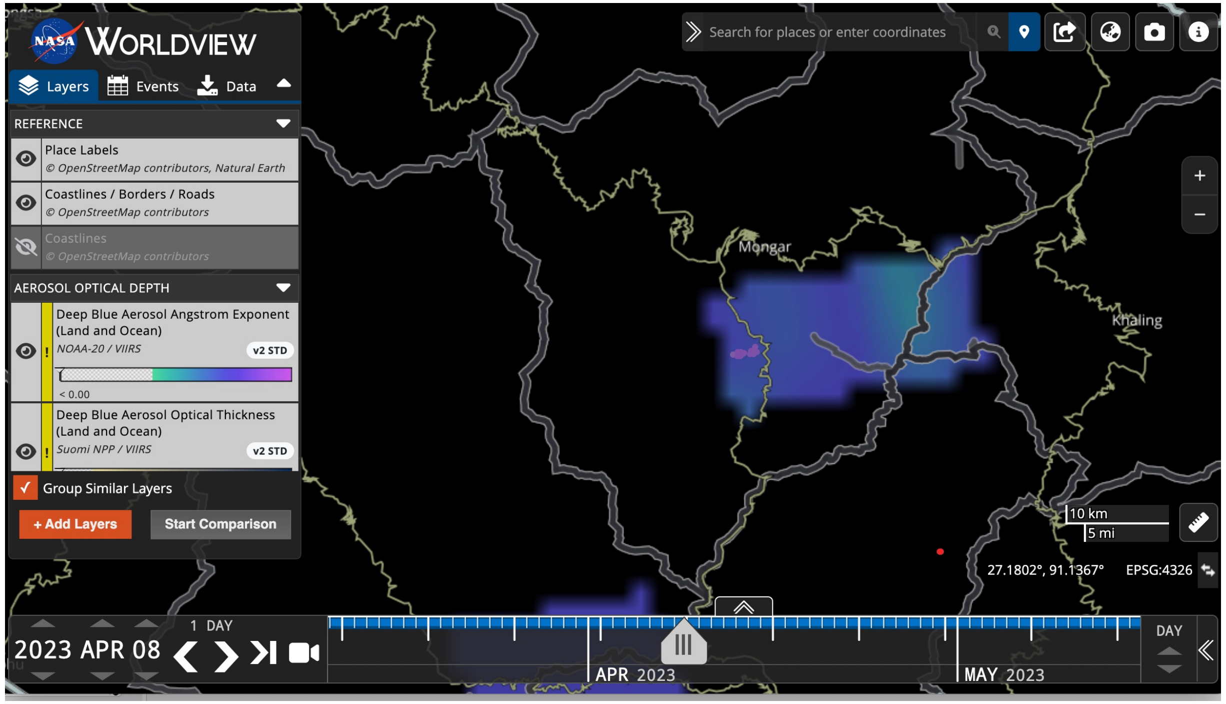


Case Study:

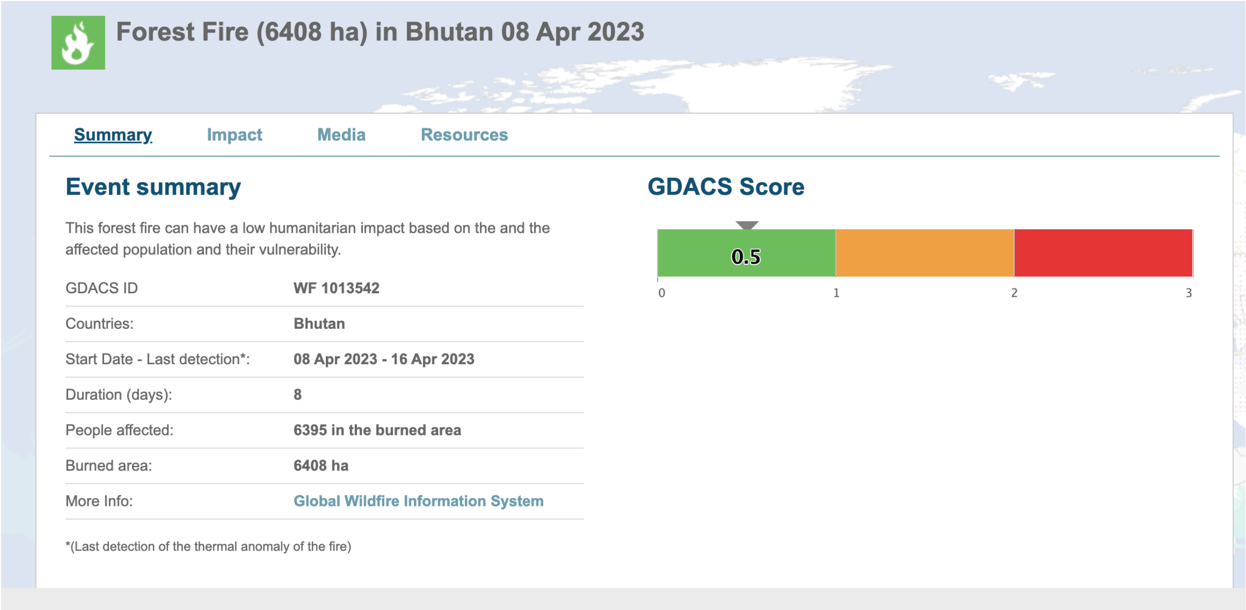
Pre-Fire Conditions and Active-Fire Monitoring in Mongar District (April 8-16, 2023) using GEE

Fire Case Study: April 8-16, 2023

- Fire started on 8th April in Mongar district.



[NASA Worldview:](https://worldview.earthdata.nasa.gov) Fire and Smoke Indicator – April 8, 2023



Global Disasters Alert and Coordination System (GDACS)

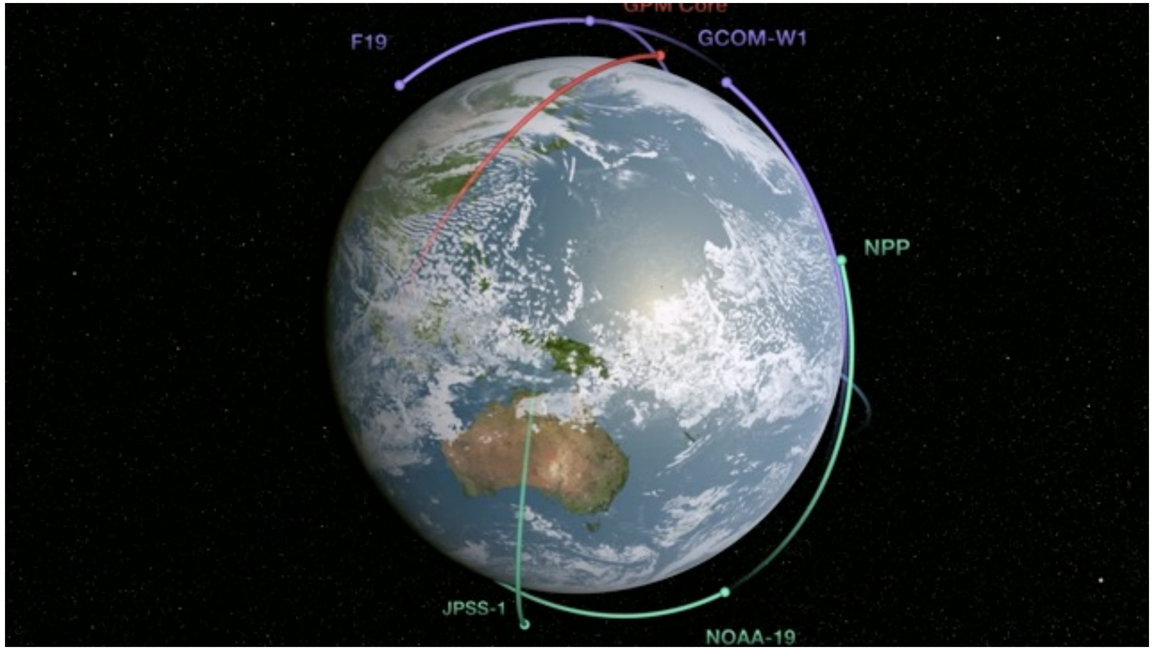
Demonstrations:
Monitoring Pre- and Active-Fire Conditions

Extra Slides

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.

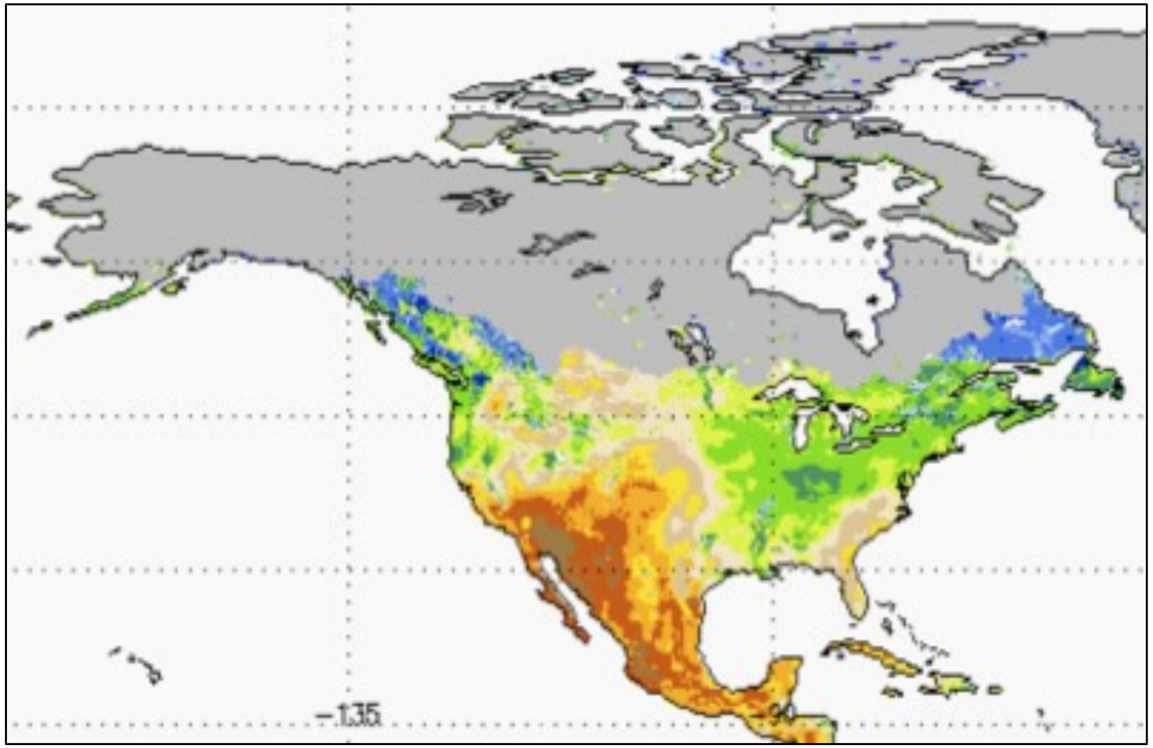
Based On: Huffman (https://www.youtube.com/watch?v=OyPUp7SuEy4&feature=youtu.be)

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



MODIS

NDVI: Normalized Difference Vegetation Index
EVI: Enhanced Vegetation Index

Land Cover

Land Surface Temperature

Fire Detection

Vegetation-Indices:

- Vegetation Extent and Type: Land cover classification
- Vegetation Stage and Health: NDVI, EVI, High Temporal Resolution Phenology

Spatial Resolution:

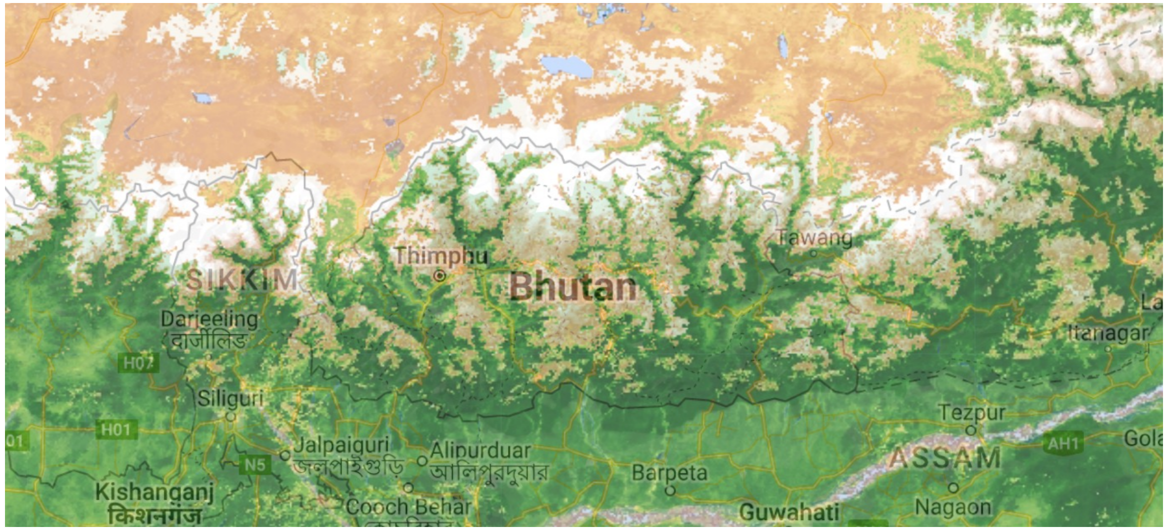
- 250 m, 500 m, 1 km

Temporal Resolution:

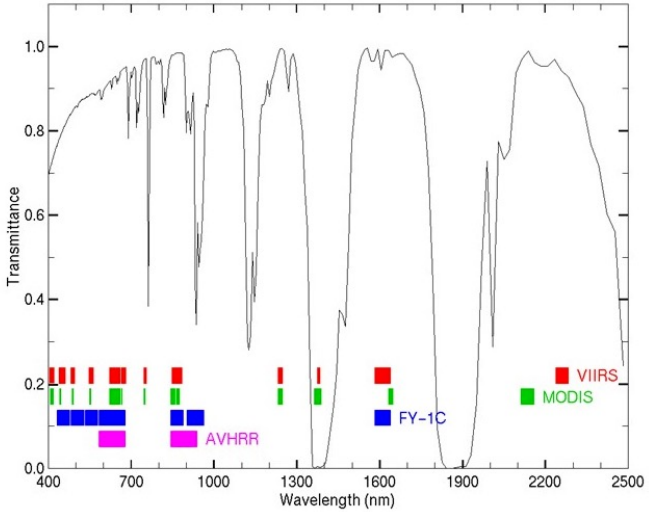
- Daily, 8-day, 16-day, monthly, quarterly, yearly
- 2000–Present

Spectral Coverage:

- 36 bands
  (red, blue, IR, NIR, Middle-IR)

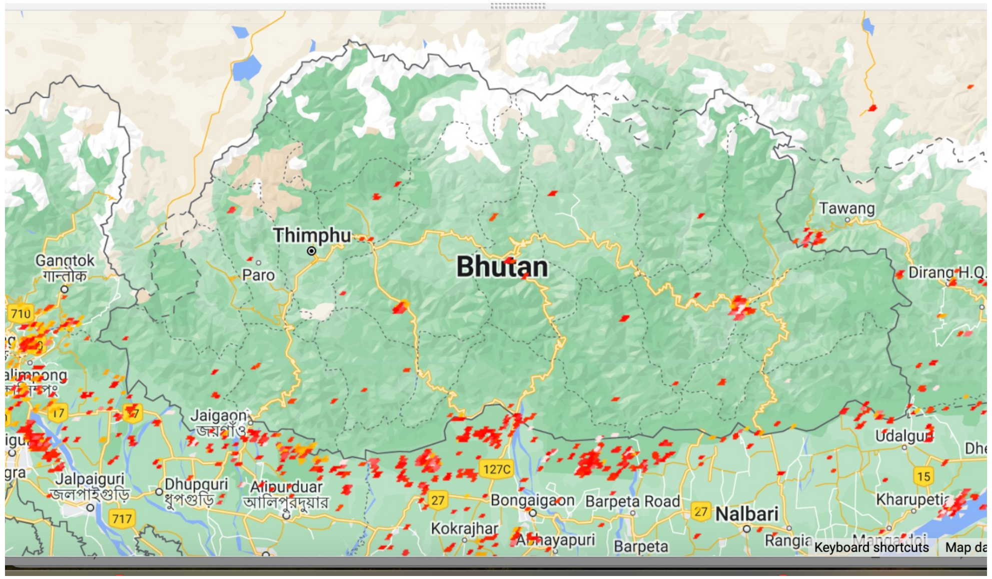


MODIS NDVI (from Google Earth Engine)



Visible Infrared Imaging Radiometer Suite (VIIRS)

- **Fire Detection**
- **Vegetation Indices**
  - VIIRS Vegetation Index include NDVI and EVI
  - Vegetation Health Index
- **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

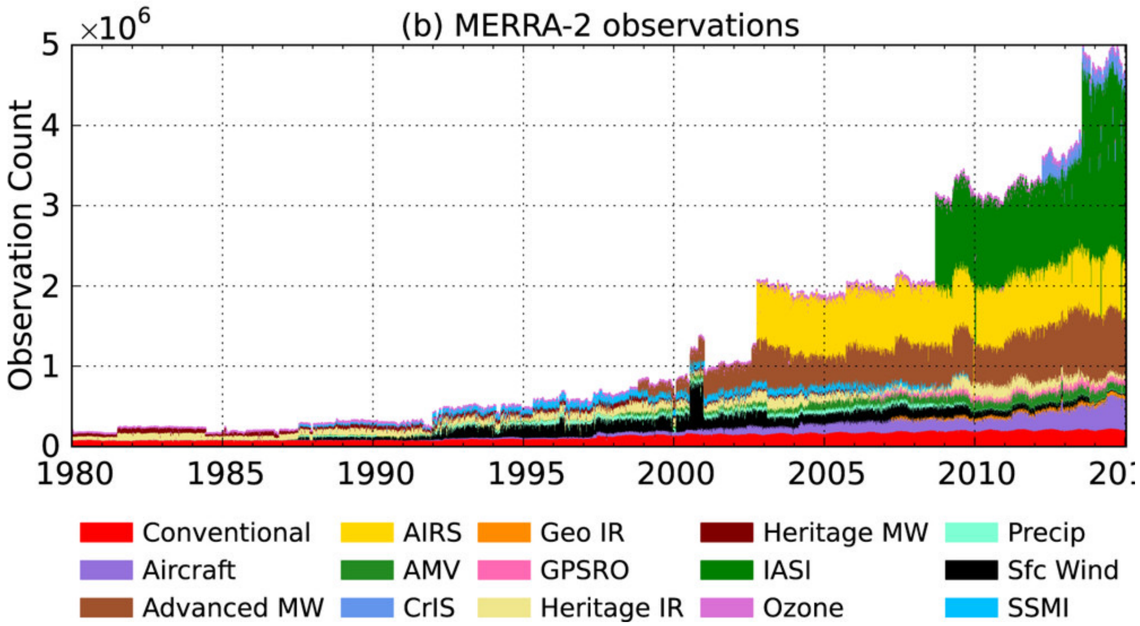


VIIRS: Fires Detected during 1 to 31 March 2024 (from Google Earth Engine)

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


CHINA
Gasa
Lhuntse
Trashi-
yangtse
Punakha
Bumthang
Paro
Thimphu
Wangdue
Phodrang
Trongsa
Haa
Trashigang
Mongar
Tsirang
Dagana
Zhemgang
Sarpang
Samtse
Chukha
Pema-
gatshel
Samdrup Jongkhar
INDIA