National Aeronautics and Space Administration

Satellite Observations and Tools for Fire Risk, Detection, and Analysis

NASA ARSET Team

May 11, 13, 18, 20, 25, & 27, 2021

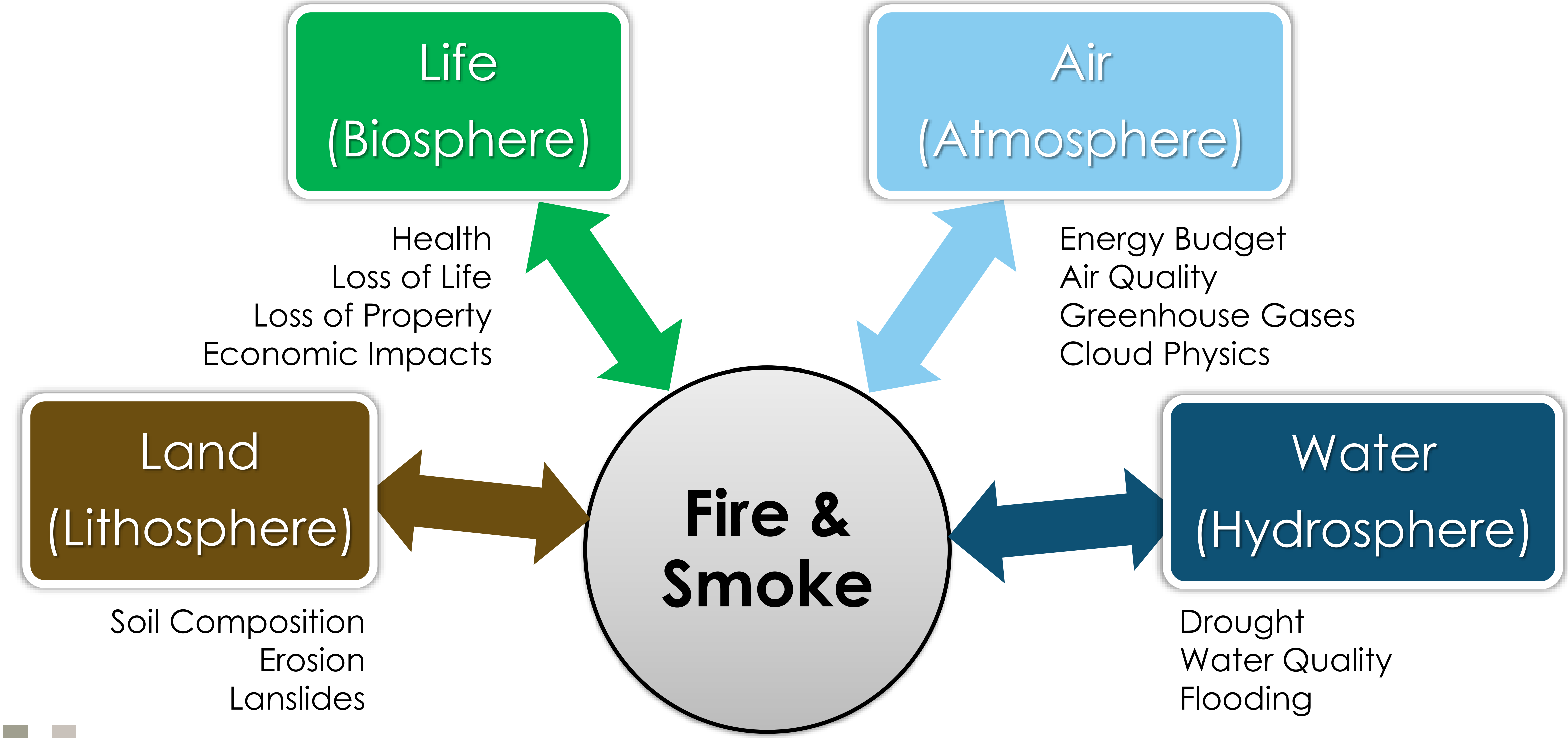
Fire is a global phenomenon. Many ecosystems benefit from fires, which clear out dead material, releasing trapped nutrients and promoting new growth. However, fire can also have negative consequences such as loss of life and property, hazardous air quality, soil erosion, and water contamination.

Fires can range in intensity from very large, like the Australian and California wildfires of 2019 and 2020 that transported smoke around the entire globe, to very small waste burning fires that are too small to be detected by satellites, yet can have significant impacts for the air people breathe.

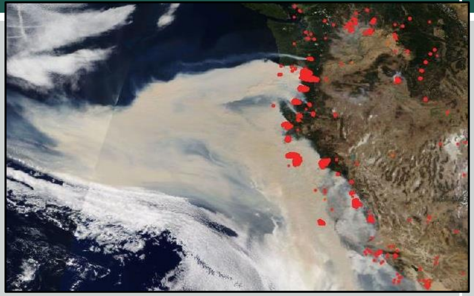
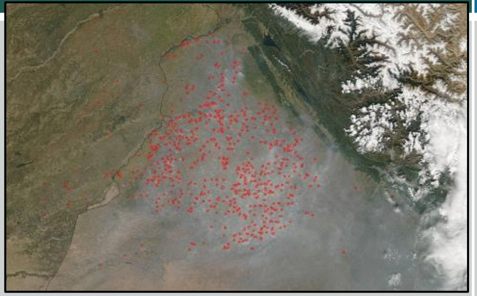
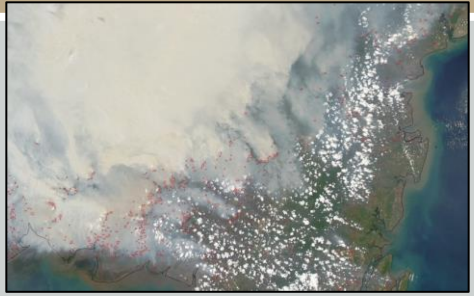
At NASA we observe all aspects of fire, from examining vegetation and weather patterns that might increase the chances of fire or its severity, to detecting fires when they burn and forecasting smoke, to analyzing the areas burned by fires and their impacts on ecosystems and water quality.

This training will introduce users to NASA tools and observations that can be used to analyze each stage of fire: pre-fire, during-fire, and post-fire.

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?	Humans (prescribed burns, accidental, arson), or natural (lightning)	Humans (forest clearing for livestock and crops)	Humans (burning prior to or after a growing season to clear fields for crops)	Humans (clearing land for crops and animal grazing), natural (permafrost thaw)
How did it burn?	Low to extreme, can burn millions of acres if not controlled	Medium to high intensity	Lower intensity	Very low intensity, burns underground, difficult to put out

Types of Fire

	Wildfire or Wildland	Deforestation
What does it burn?	Forests, shrub, grass	Forests
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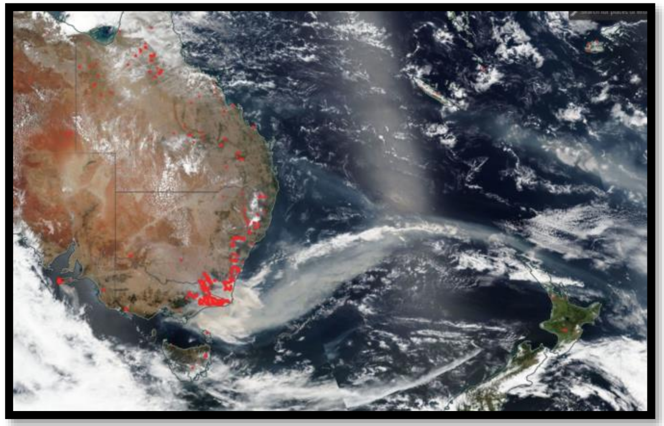
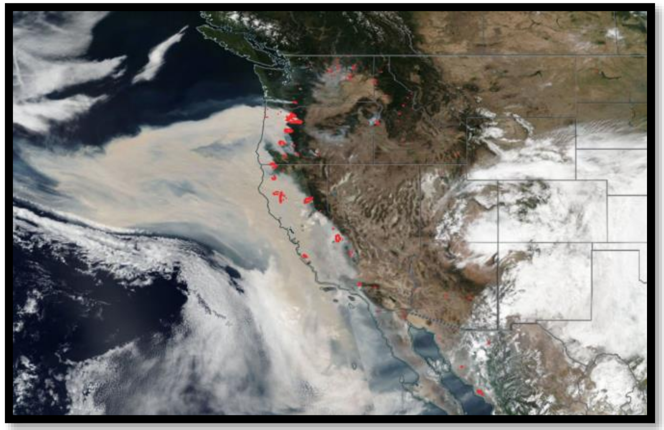
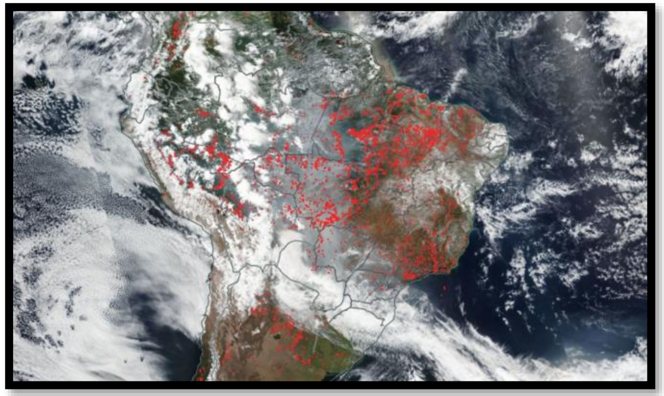


Australia
Jan 01, 2020



Western US
Sep 09, 2020



South America
Sep 14, 2020

Types of Fire

	Agricultural	Peat
What does it burn?	Crops, grasses, shrubs	Peat (soil-like material)
When does it burn?	Seasonal	Seasonal, variable from year to year
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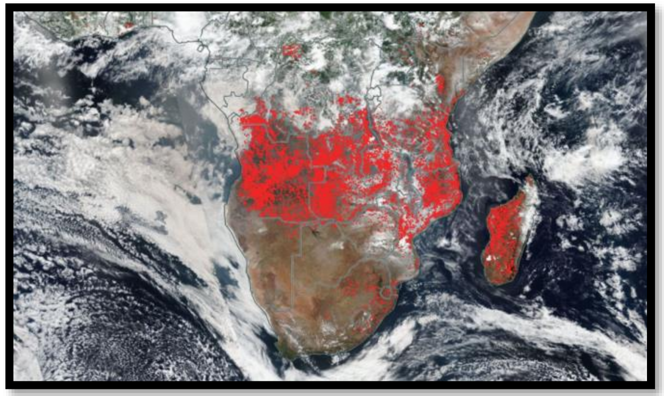
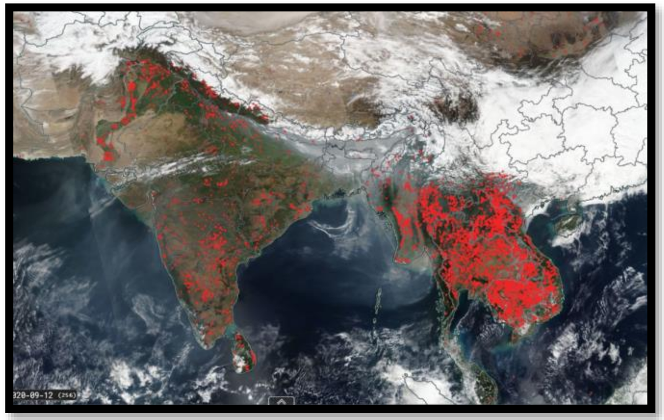
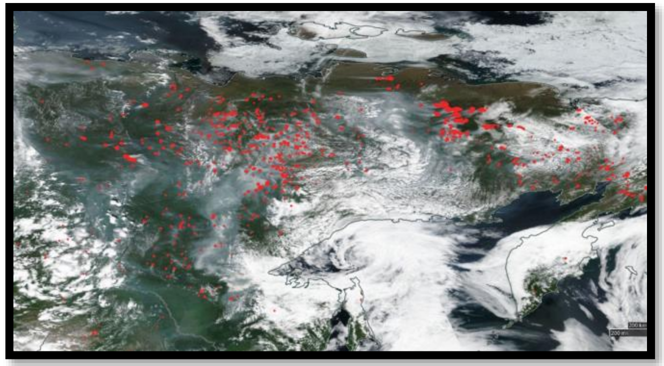


Africa
Sep 12, 2020



Southeast Asia
Feb 15, 2020



Siberia
Jul 01, 2020

About ARSET

- *ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.*

- Our trainings are:
  - Online and *in-person
  - Open to anyone
  - Live, instructor-led or self-guided
  - Tailored to those with a range of experience in remote sensing, from **introductory** to **advanced**

- ARSET offers trainings for:
  - Disasters
  - Health & Air Quality
  - Land Management
  - Water Resources

For more information, visit appliedsciences.nasa.gov/arset

*ARSET is not currently offering in-person trainings due to the COVID-19 pandemic.

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Lead Instructor


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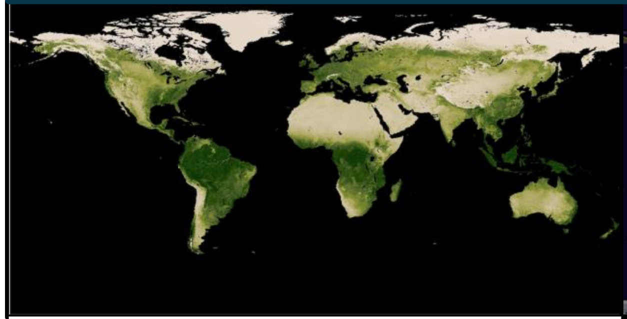
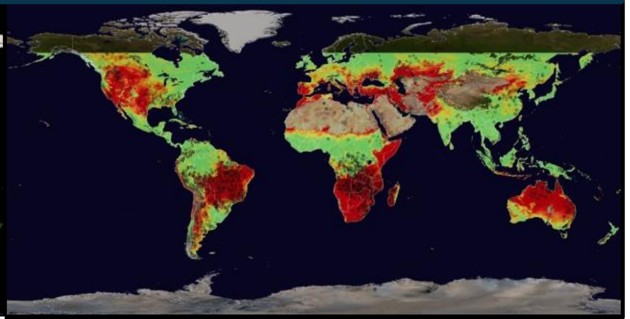
Instructor


Robert Field
Guest Speaker

Webinar Agenda

Pre-Fire

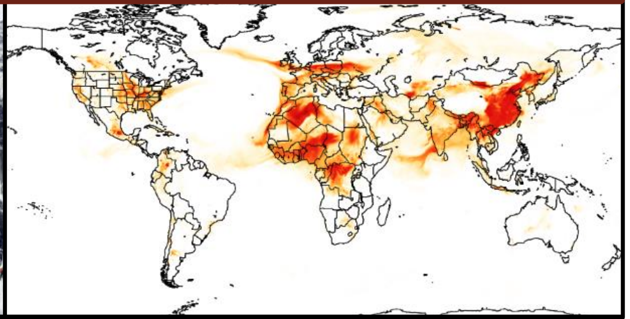




Session 1:
Climate and Hydrology

Session 2:
Vegetation

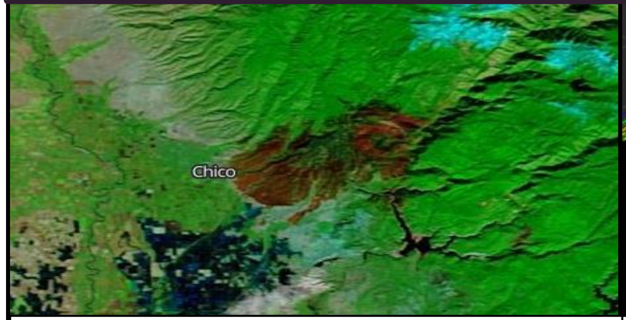
During-Fire

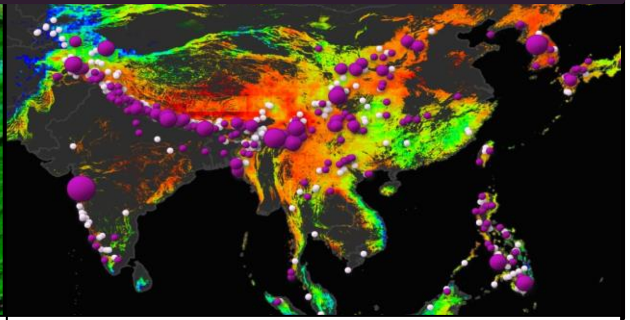


Session 3:
Active Fires and Smoke

Session 4:
Smoke Forecasting

Post-Fire



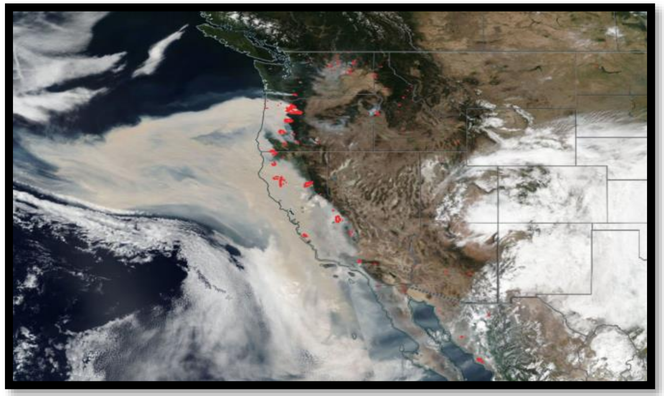


Session 5:
Climate & Hydrology

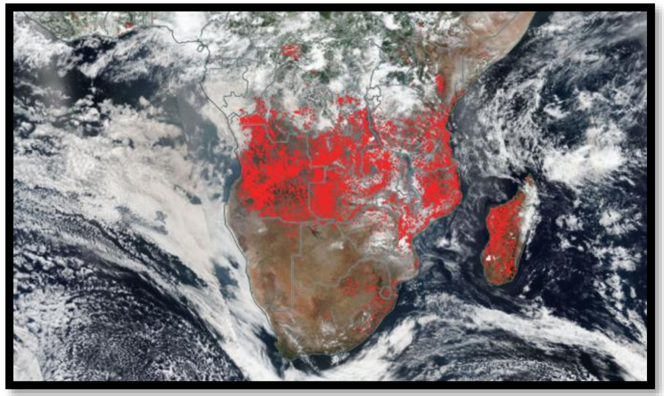
Session 6:
Vegetation

Webinar Case Studies

Western US Wildfires
Aug-Sep 2020



Agricultural Fires –
Sub-Saharan Africa
Aug-Sep 2020



Wildfires in Southern
Mexico
May 2019

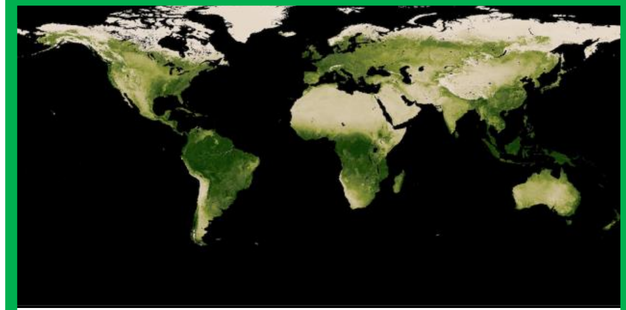
Training Objectives

By the end of this training attendees will understand:

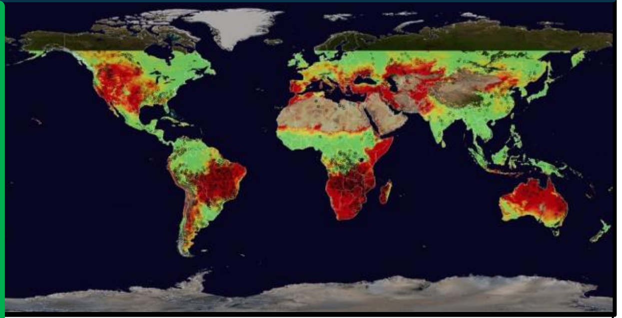
- Terminology regarding type and components of fire (pre, during, post)
- Climatic and biophysical conditions pre-, during-, and post-fire
- The satellites and instruments used in conducting fire science
- The applications of passive and active remote sensing for fires
- How to visualize fire emissions and particulate matter
- The use of tools for active fires, emissions, and burned areas
- How to acquire data for conducting analysis in a given study area

Webinar Agenda

Pre-Fire



Session 1:
Climate and Hydrology



Session 2:
Vegetation

Amita Mehta

Sean McCartney

Robert Field

National Aeronautics and Space Administration

Pre-Fire Risk Assessment: Climate, Weather, and Hydrology Conditions

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 a 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; Fasullo 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).

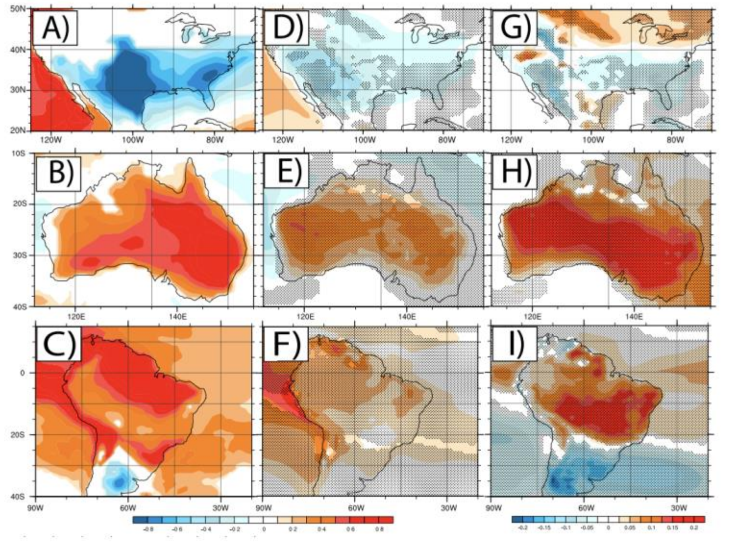


Figure 1. Twentieth century (1920–1980) regressed July-June surface temperature responses to Niño3.4 sea surface temperature in units of K K^{-1} in (left column) ERA20C and (middle column) Community Earth System Model (CESM) for (a and d) North America, (b and e) Australia, and (c and f) South America, 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).

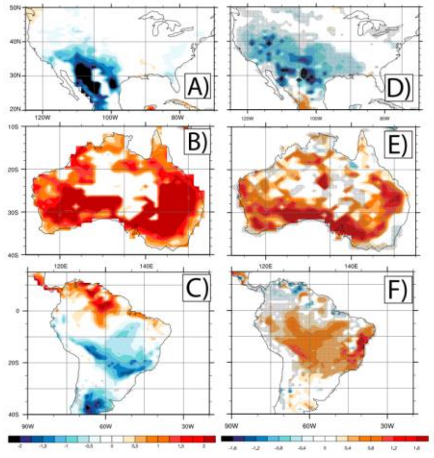


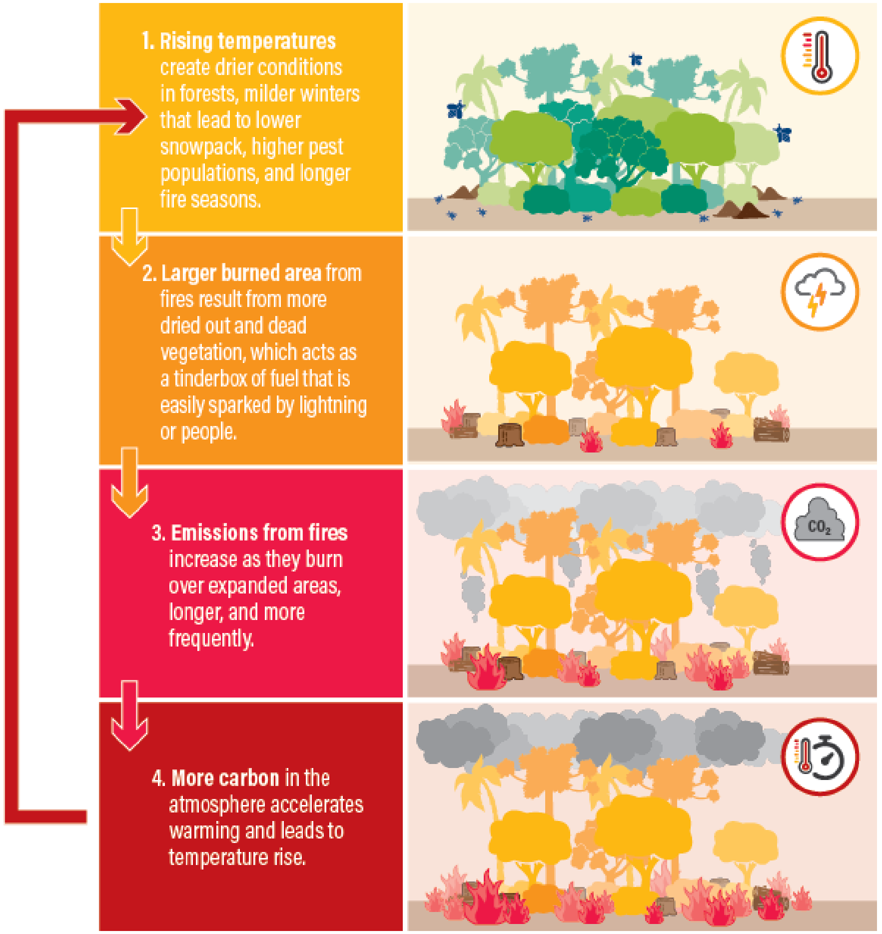
Figure 2. As for Figures 1d–1i, except for fire probability (F_P) in units of % K^{-1}.

Fasullo et al. 2018

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).

Fires and the Climate Feedback Loop

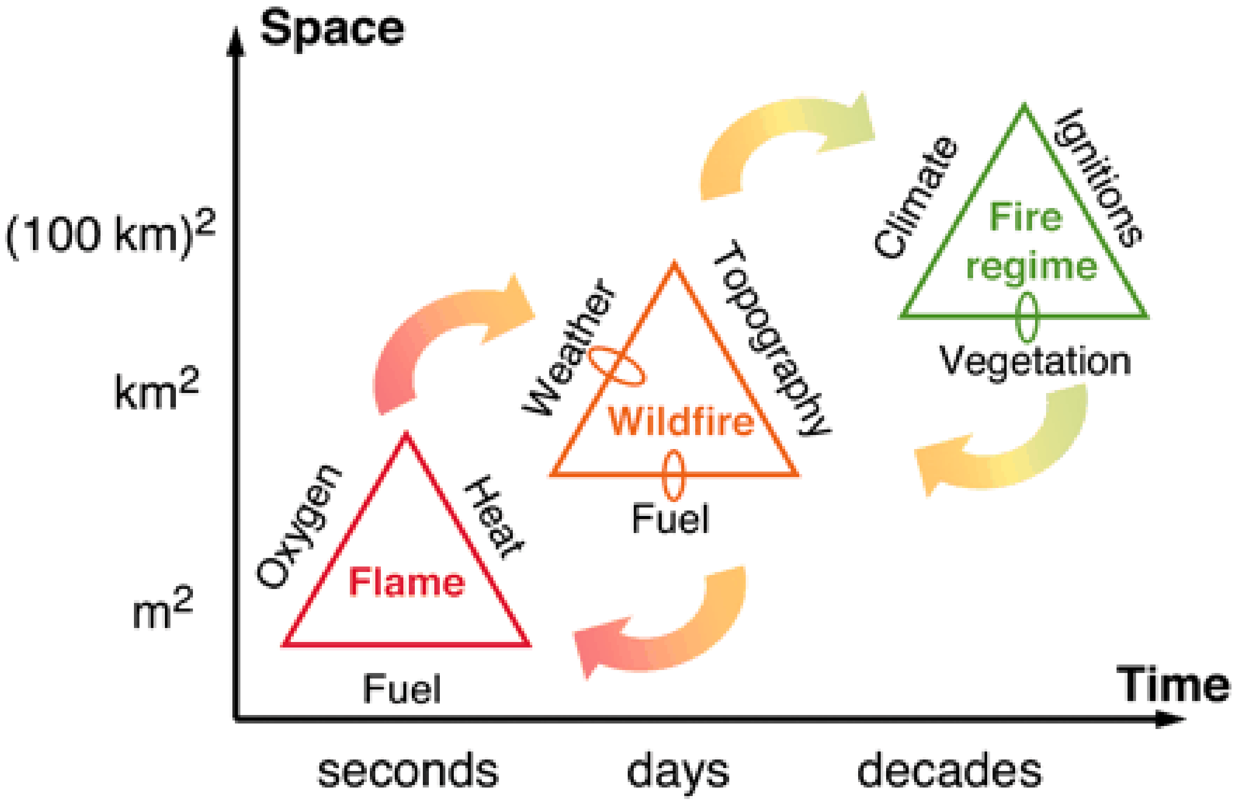


Source: Global Forest Watch.
20.09.15

GLOBAL FOREST WATCH WORLD RESOURCES INSTITUTE

Climate Variability & Change and Fire Weather

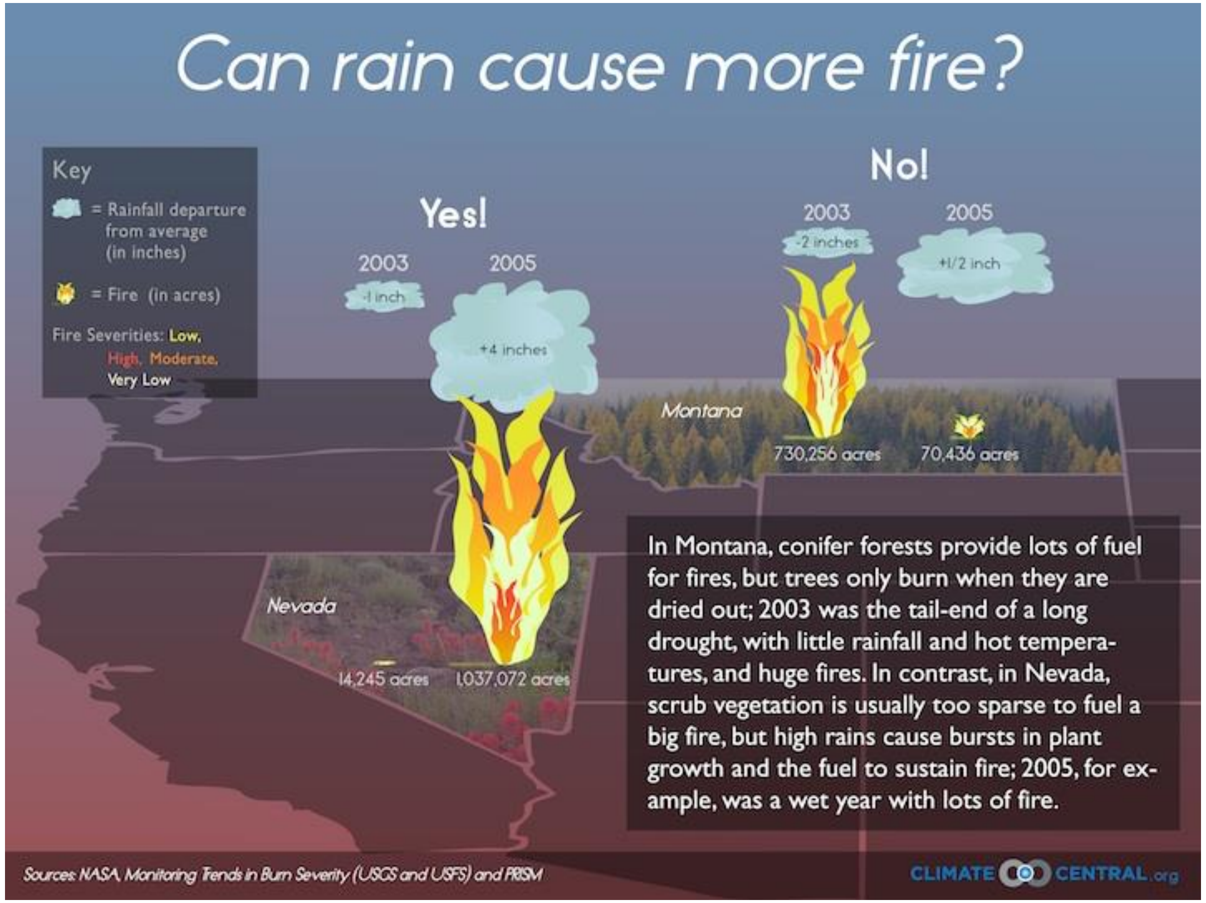
- Fire weather is a combination of temperature, precipitation, winds, and humidity conducive to high potential of fire activities.
- Climate conditions influence fire weather, soil moisture, and vegetation productivity, affecting fire activities.



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.

Precipitation and Wildfires

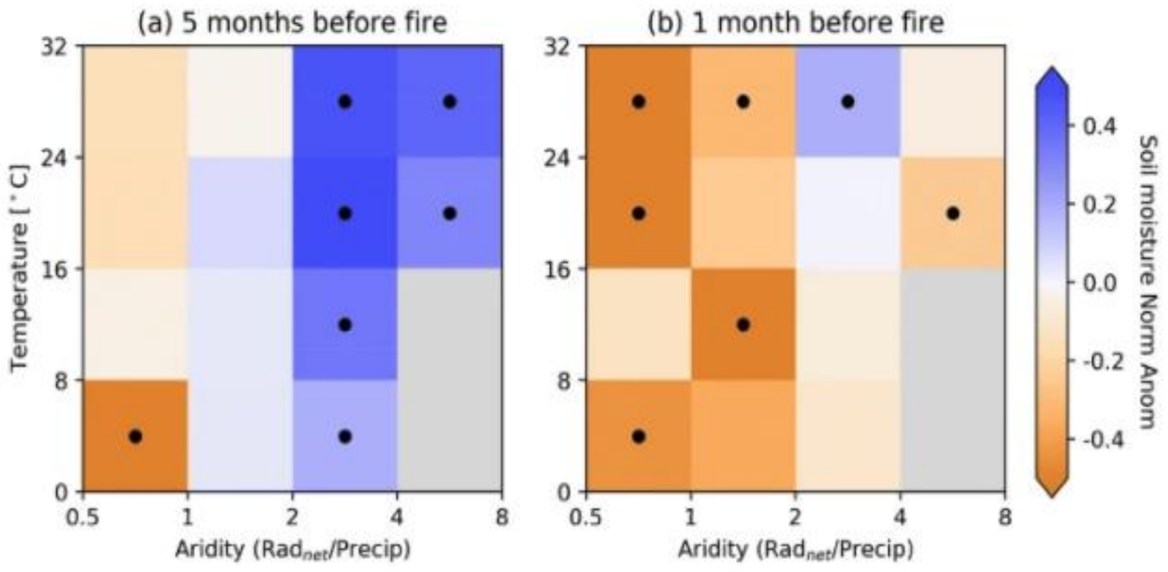
- Excessive precipitation during the growing season increases vegetation growth that becomes fuel for fire in the subsequent dry season.
- Pre-fire season rainfall and number of rainy days in fire seasons affect wildfire extent and severity (Holden et al., 2018, 2012).
- Precipitation patterns and amount affect surface temperature and soil moisture which also impact pre-fire risk.



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

Soil Moisture and Wildfires

- Pre-fire season soil moisture anomalies (departure from long-term mean) help assess 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.

Monitoring Weather, Climate, and Hydrology Conditions

- Precipitation
- Soil Moisture
- Temperature
- Humidity
- Winds
- Vegetation*
- Topography*

*Parts 2, 5, 6 of the webinar series.

NASA remote sensing and Earth system models provide weather, climate, and hydrology data for pre-fire, during-fire, and post-fire conditions.

Remote Sensing and Modeling Data For Monitoring Weather, Climate, and Hydrology Conditions

Weather, Climate, and Hydrology 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 6/2000 to present
Soil Moisture	SMAP	L-Band Microwave Radiometer	9 km x 9 km & 36 km x 36 km Daily 3/2015 to present

TRMM: Tropical Rainfall Measurement Mission
GPM: Global Precipitation Measurement
Land Data Assimilation System
SMAP: Soil Moisture Active Passive
IMERG:The Integrated Multi-satellitE Retrievals for GPM

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

Weather, Climate, and Hydrology Data

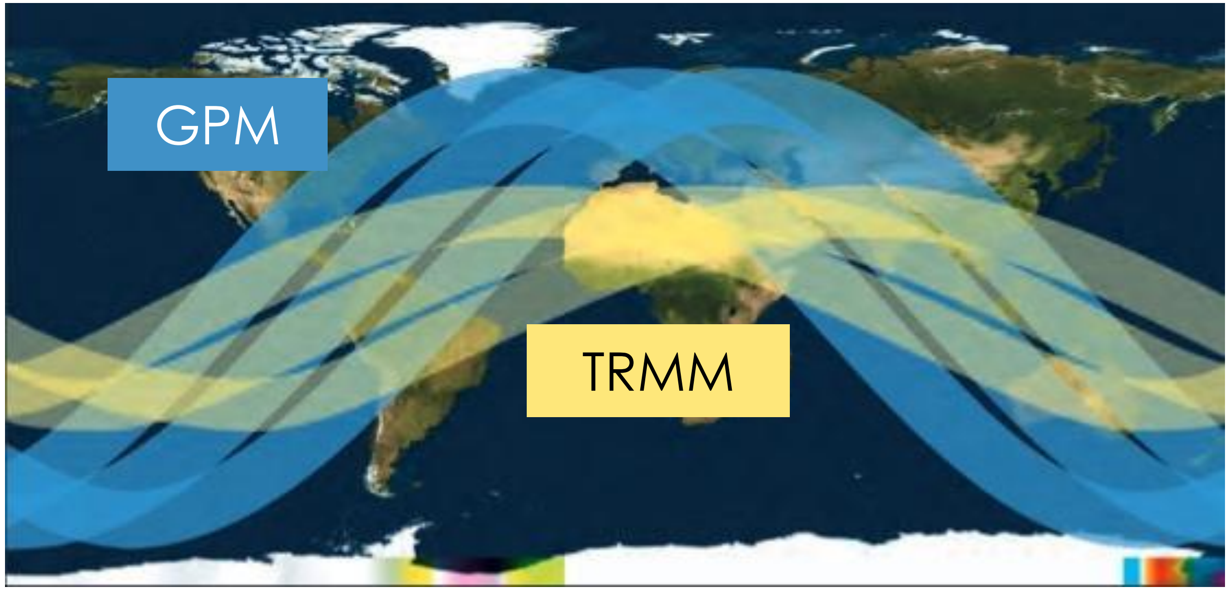
Parameter	Model	Spatial/Temporal Resolutions and Coverage
Precipitation, Temperature, Relative Humidity, Winds	MERRA-2	0.5° x 0.667°, Hourly, Monthly 1980 to Present
Precipitation, Temperature, Relative Humidity, Winds	GEOS-5 FP	0.3125°x0.25° Hourly, Near-real Time and 5-day Forecast
Soil Moisture	NLDAS	0.125° x 0.125°, Hourly, Monthly 1979 to Present
	GLDAS v2.1	0.25° x 0.25°, 1° x 1°, 3-hourly, Monthly 2000 to Present

MERRA-2:Modern-Era Retrospective analysis for Research and Applications, Version 2
https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/index.php
GOES-5 FP: Goddard Earth Observing System, Version 5 (GEOS-5) Forward Processing
https://gmao.gsfc.nasa.gov/weather_prediction/
NLDAS: North American Land Data Assimilation System https://ldas.gsfc.nasa.gov/nldas
GLDAS: Global Land Data Assimilation System https://ldas.gsfc.nasa.gov/gldas

Global Precipitation Measurement (GPM) Mission

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

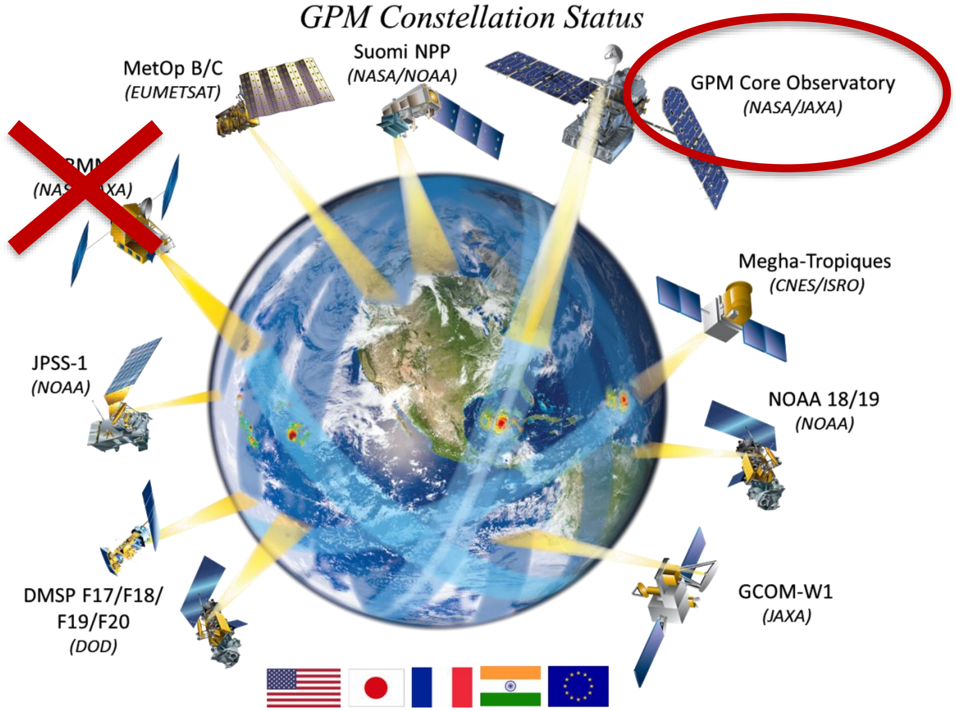
- Core satellite launched Feb 27, 2014
  - Non-polar, low-inclination orbit
    - Altitude: 407 km
- Spatial Coverage:
  - 16 orbits a day, covering global area between 65°S and 65°N
- Along with a constellation of satellites, GPM has a revisit time of 2-4 hrs. over land
- Sensors:
  - GMI (GPM Microwave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



Global Precipitation Measurement (GPM) Mission & Tropical Rainfall Measurement Mission (TRMM)

IMERG Version 06 Data

- IMERG is a single integrated code system for near-real and post-real time
- Multiple runs for different user requirements for latency and accuracy
  - "Early" – 4 hr. (flash flooding)
  - "Late" – 14 hr. (crop forecasting)
  - "Final" – 3 months (research)
- Morphing of precipitation based on numerical models poleward of 60° N/S latitude.
- Overall calibration is provided by TRMM and GPM Combined Radar-Radiometer Algorithm. TRMM June 2000-May 2014, GPM thereafter.
- IMERG is adjusted to GPCP monthly climatology zonally to achieve a bias profile that is considered reasonable.

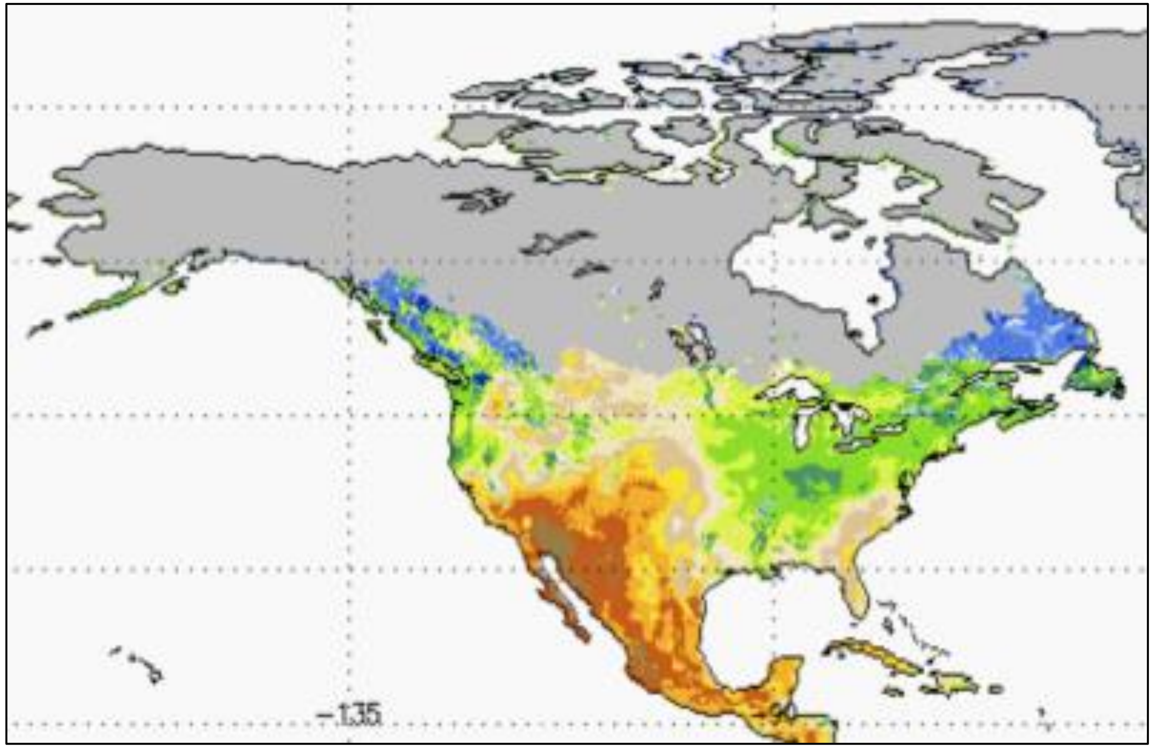


Soil Moisture Active Passive (SMAP)

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



NASA Earth System Model Forecast (GEOS-5)

https://gmao.gsfc.nasa.gov/GEOS_systems/

- Goddard Earth Observing System (GEOS)-5 provides near real-time data and forecast data
- Data available at 5/16 x 1/4-degree long-lat grid, 42 vertical level
- Surface data available every hour
- Atmospheric (A), Oceanic (O), and Coupled A-O General Circulation Model configuration options
- Chemistry-Climate and Chemistry-Transport models available

Weather Maps

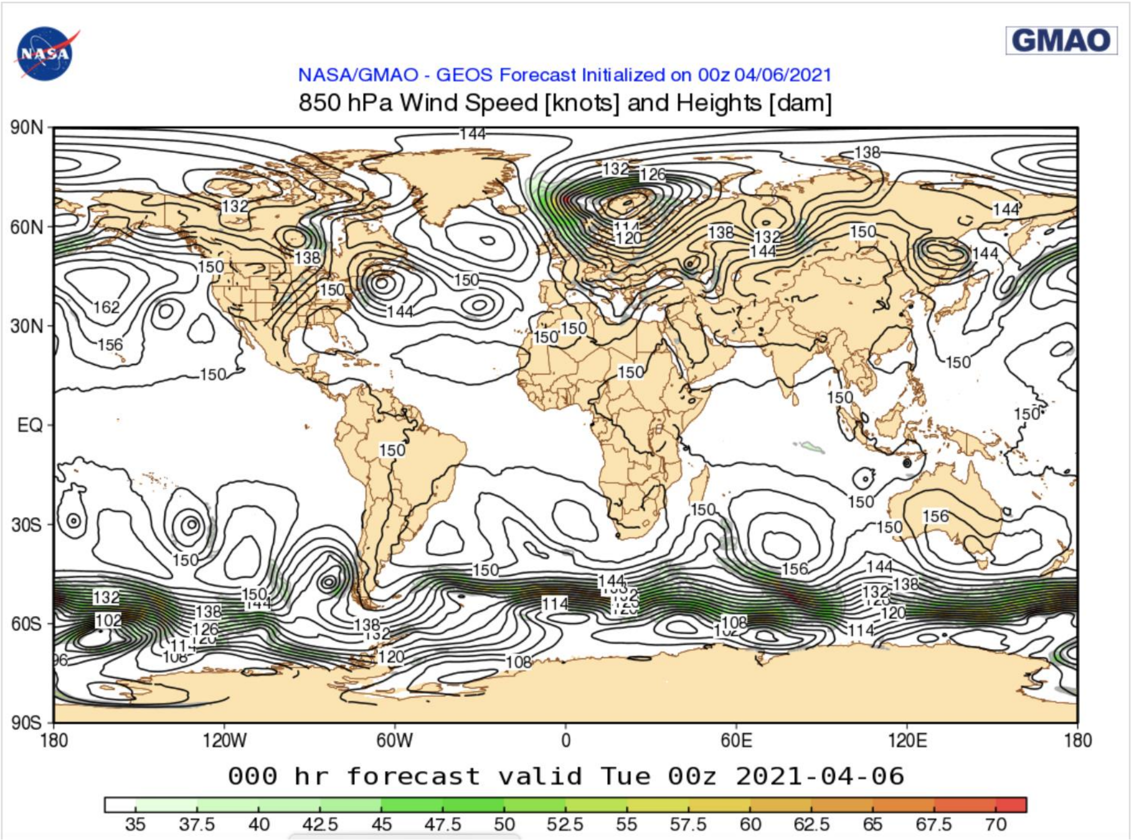
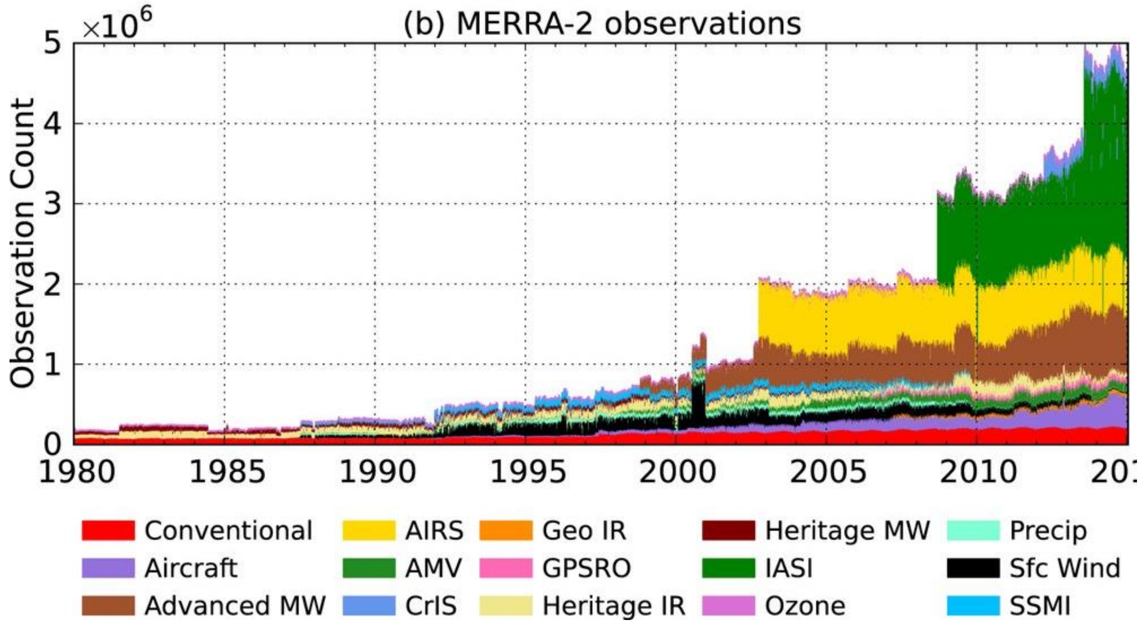


Image Credit: NASA GMAO

MERRA-2

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

- Blends the vast quantities of observational data with output data from the Goddard Earth Observing System (GEOS-5) 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

Global Land Data Assimilation System (GLDAS)

http://ldas.gsfc.nasa.gov/gldas/

A water and energy balance model with assimilation of remote sensing data.

Inputs:

- Rainfall: TRMM and Multi-Satellite-Based Data
- Meteorological Data: Global Reanalysis and Observations-Based Data from Princeton University
- Vegetation Mask, Land/Water Mask, Leaf Area Index (LAI): MODIS (GLDAS-2)
- Clouds and Snow (for surface radiation): NOAA and DMSP Satellites

Integrated Outputs Include:

- Soil Moisture
- Evapotranspiration
- Surface/Sub-Surface Runoff
- Snow Water Equivalent

Reference: Rodell, M., P. R. Houser, U. Jambor, J. Gottschalck, K. Mitchell, C.-J. Meng, K. Arsenault, B. Cosgrove, J. Radakovich, M. Bosilovich, J. K. Entin, J. P. Walker, D. Lohmann, and D. Toll, 2004. The Global Land Data Assimilation System. Bulletin of the American Meteorological Society, 85(3):381–394.

North American Land Data Assimilation System-2 (NLDAS-2)

http://ldas.gsfc.nasa.gov/nldas/

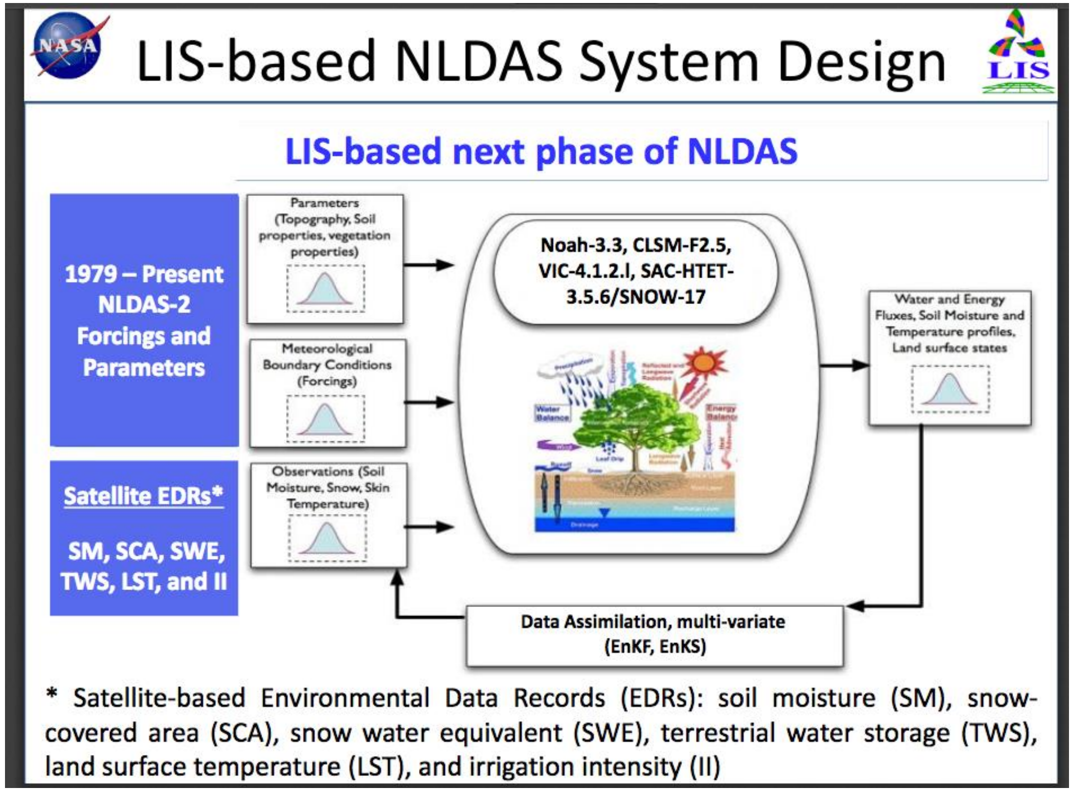
Four land surface model versions: Noah, CLM2, Mosaic, and VIC

Inputs:

- Precipitation: NOAA-CPC Rain Gauges
- Meteorological Data, Surface Radiation Data: North American Regional Analysis

Integrated Outputs Include:

- Soil Moisture
- Evapotranspiration
- Surface/Sub-Surface Runoff
- Snow Water Equivalent



Courtesy: David Mocko (NASA-GSFC), http://ldas.gsfc.nasa.gov/nldas/presentations/NLDAS-LIS-status-future_2015-03-11.pdf

Data Access Tools

Data Access

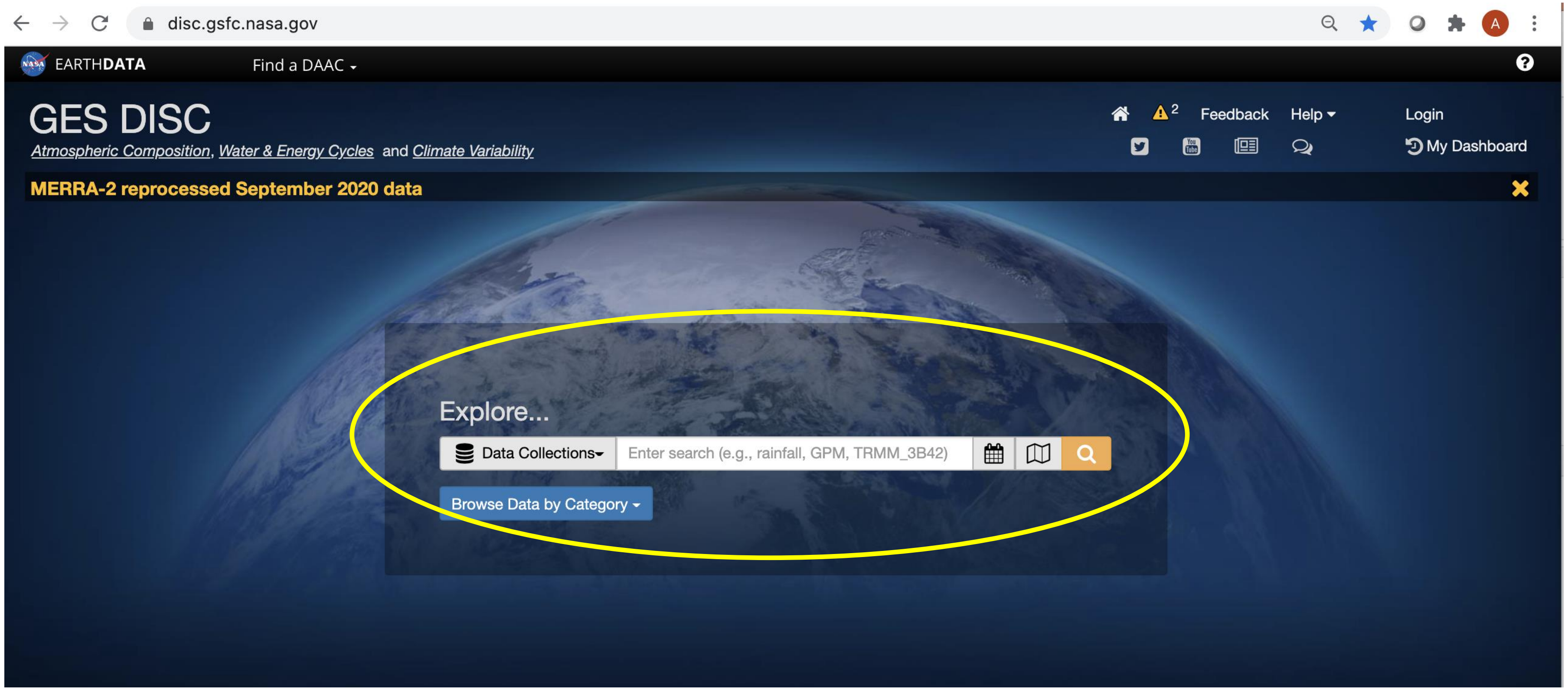
Data	Website
IMERG, MERRA-2, LDAS	Giovanni https://giovanni.gsfc.nasa.gov/giovanni/ GES DISC https://daac.gsfc.nasa.gov/
SMAP	**App**lication for **E**xtracting and **E**xploring **A**nalysis **R**eady **S**amples (***AppEEARS***) https://lpdaacsvc.cr.usgs.gov/appeears/
GEOS-5	Weather Analysis and Forecast https://portal.nccs.nasa.gov/datashare/gmao/geos-fp/forecast/

IMERG, GLDAS, and NLDAS can also be analyzed on Google Earth Engine.
https://developers.google.com/earth-engine/datasets/tags/climate

GES DISC

https://disc.gsfc.nasa.gov/

- Recommended for bulk download of data
- Allows spatial, temporal, and variable sub-setting



NASA Earthdata Login Required https://urs.earthdata.nasa.gov/profile

Data Search

GES DISC

https://disc.gsfc.nasa.gov/

Data File Links for MERRA-2 tavgM_2d_slv_Nx: 2d,Monthly mean,Time-Averaged,Single-Level,Assimilation,Single-Level Diagnostics V5.12.4

Results (found 4 links in range from 2020-08-01 to 2020-08-31):

Download links list (This list is valid for 2 days) | Instructions for downloading

FAQ - General data questions
FAQ - focus on science content
README Document
MERRA2_400.tavgM_2d_slv_N

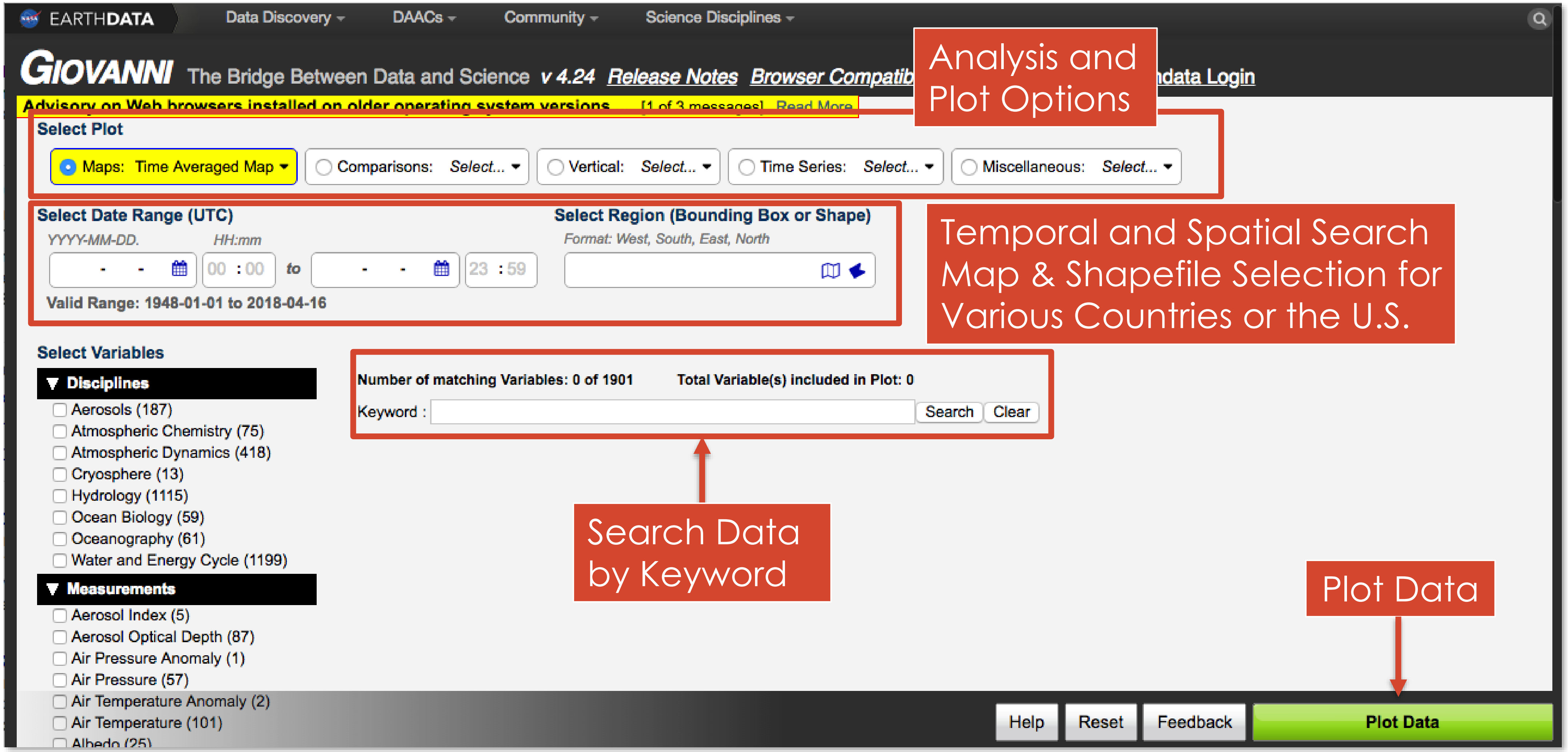
1. If you have not already done so, please register!
   - Create an Earthdata account
   - Link GES DISC with your account
   - Verify by downloading this example data file URL
2. Download the list of links
3. Follow the instructions for wget or curl

▸ Selected Parameters

Job ID: 6086e93f0ea8dea9c8762ebf

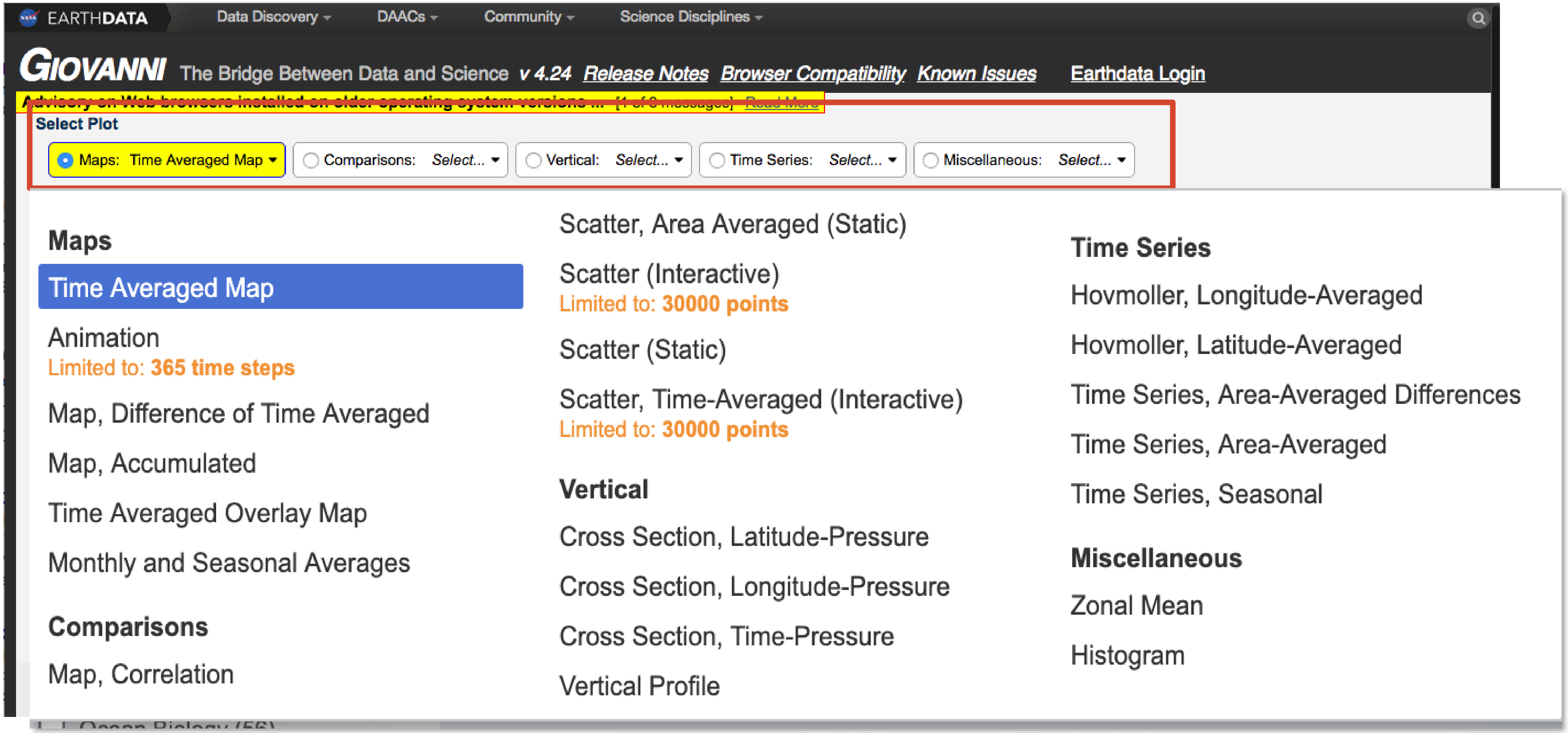
Giovanni: IMERG, MERRA-2, & GLDAS Data Access and Analysis

https://giovanni.gsfc.nasa.gov/giovanni/



Giovanni Data Analysis Options

https://giovanni.gsfc.nasa.gov/giovanni/



Giovanni: IMERG, MERRA-2, & GLDAS Data Access and Analysis

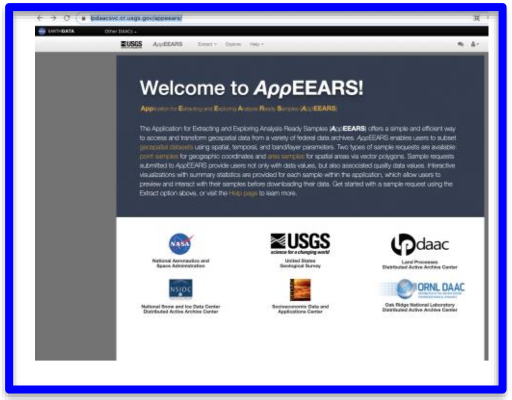
Keyword : GLDAS-2.1 Monthly Soil Moisture Search Clear

	Variable	Units	Source	Temp.Res.	Spat.Res.	Begin Date	End Date
☐	Soil moisture content (10 - 40 cm underground) (GLDAS_NOAH025_M v2.1)	kg m-2	GLDAS Model	Monthly	0.25 °	2000-01-01	2020-11-30
☐	Soil moisture content (40 - 100 cm underground) (GLDAS_NOAH025_M v2.1)	kg m-2	GLDAS Model	Monthly	0.25 °	2000-01-01	2020-11-30
☑	**Soil moisture content (0 - 10 cm underground) (GLDAS_NOAH025_M v2.1)**	**kg m-2**	**GLDAS Model**	**Monthly**	**0.25 °**	**2000-01-01**	**2020-11-30**
☐	Soil moisture content (100 - 200 cm underground) (GLDAS_NOAH025_M v2.1)	kg m-2	GLDAS Model	Monthly	0.25 °	2000-01-01	2020-11-30
☐	Soil moisture content (0 - 10 cm underground) (GLDAS_NOAH10_M v2.1)	kg m-2	GLDAS Model	Monthly	1 °	2000-01-01	2020-11-30
☐	Soil moisture content (40 - 100 cm underground) (GLDAS_NOAH10_M v2.1)	kg m-2	GLDAS Model	Monthly	1 °	2000-01-01	2020-11-30
☐	Soil moisture content (100 - 200 cm underground) (GLDAS_NOAH10_M v2.1)	kg m-2	GLDAS Model	Monthly	1 °	2000-01-01	2020-11-30
☐	Soil moisture content (10 - 40 cm underground) (GLDAS_NOAH10_M v2.1)	kg m-2	GLDAS Model	Monthly	1 °	2000-01-01	2020-11-30
☐	Root zone soil moisture (GLDAS_NOAH025_M v2.1)	kg m-2	GLDAS Model	Monthly	0.25 °	2000-01-01	2020-11-30
☐	Root zone soil moisture (GLDAS_NOAH10_M v2.1)	kg m-2	GLDAS Model	Monthly	1 °	2000-01-01	2020-11-30

For MERRA-2 File Names: https://gmao.gsfc.nasa.gov/pubs/docs/Bosilovich785.pdf

SMAP Soil Moisture Data Access

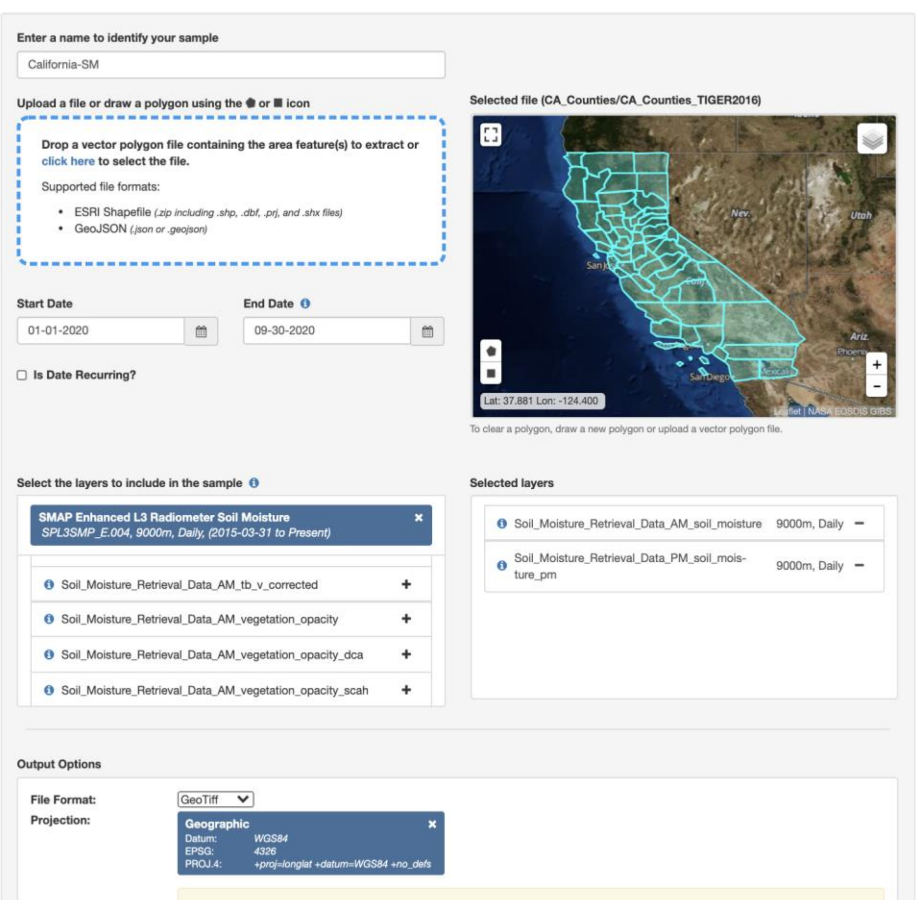
https://lpdaacsvc.cr.usgs.gov/appeears/

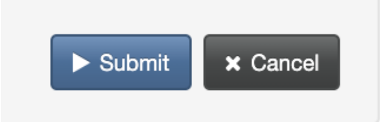


Spatial Selection for a Shapefile

Temporal Selection

Product Search and Selection





Spatial Selection

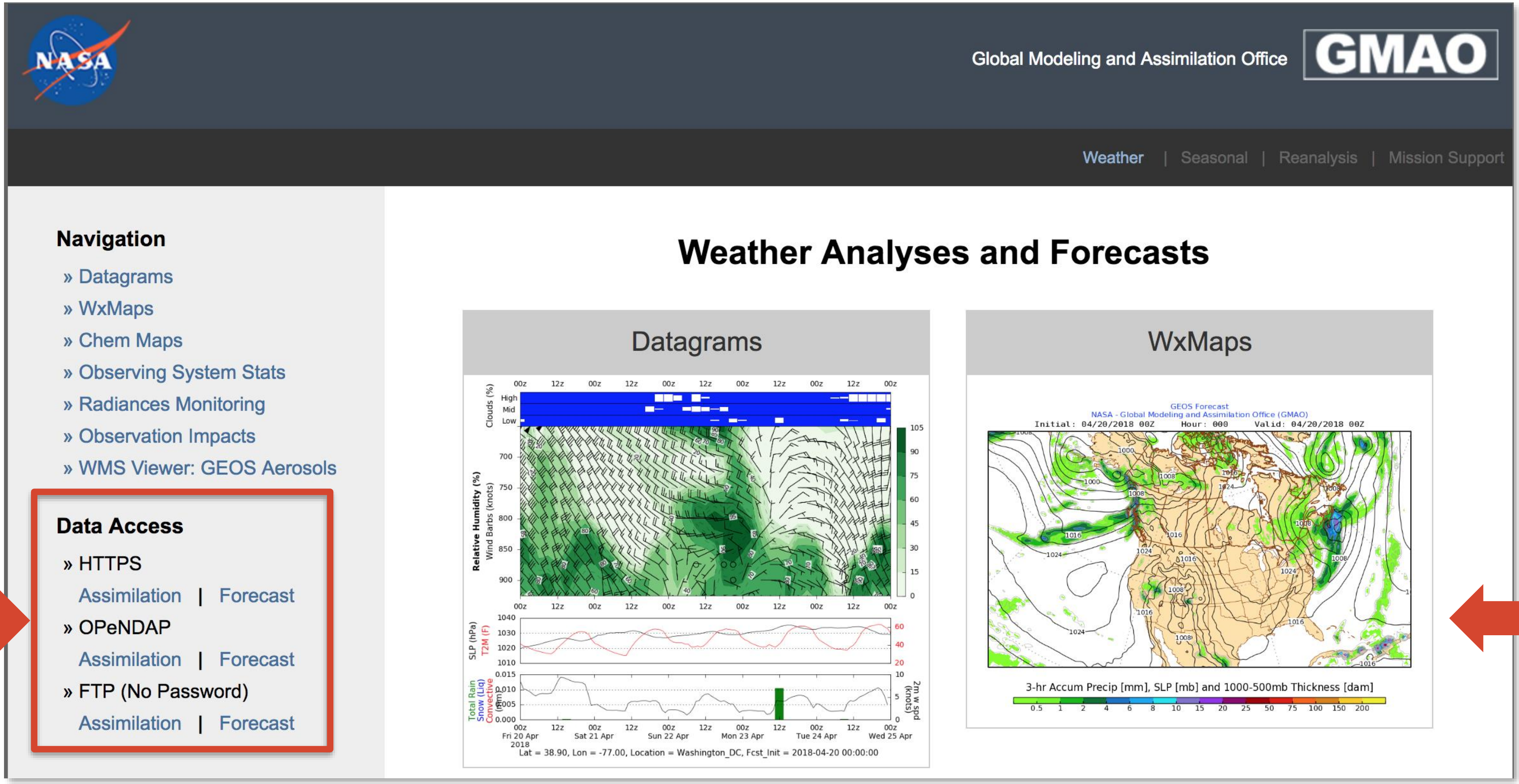
Data Format

Submit Data Order

GEOS-5

https://fluid.nccs.nasa.gov/weather/

Data

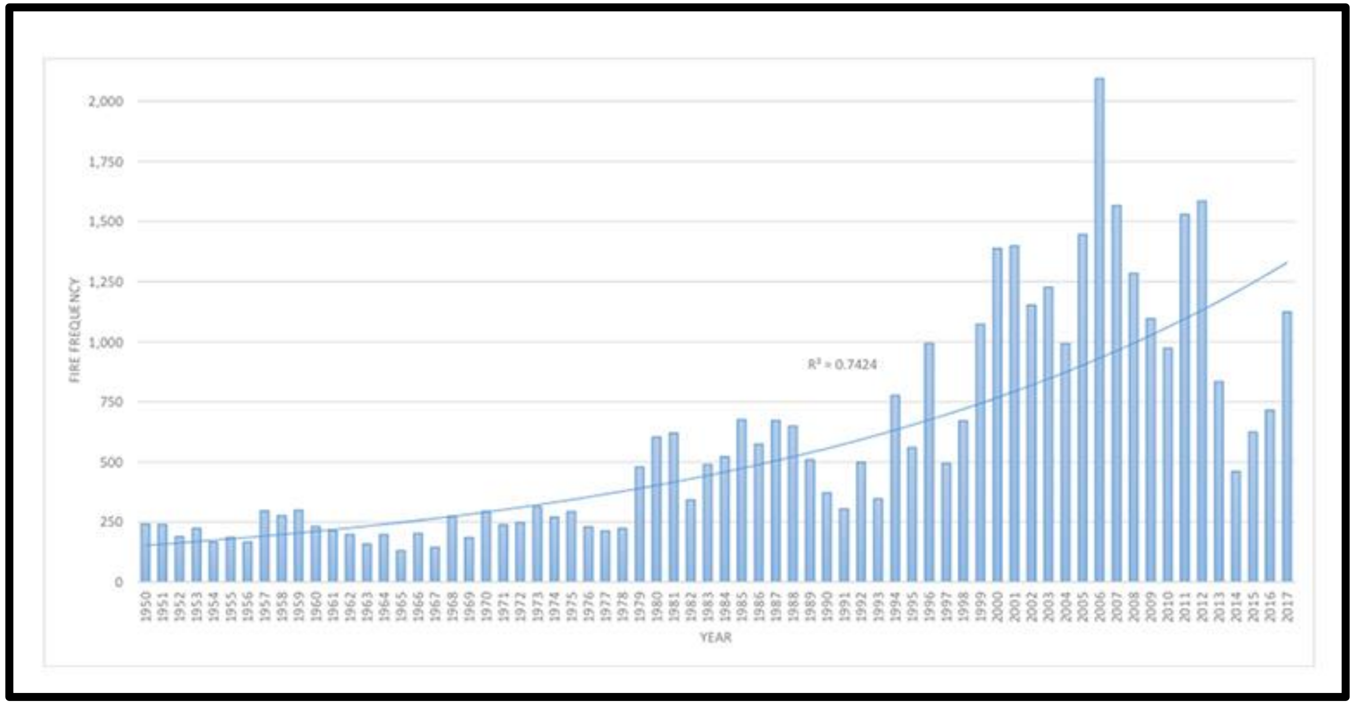


Maps

Case Study I: Pre-Fire Analysis for 2020 California Fires

Climate and Wildfires

A steady increase in the number of fires in the Western U.S.



https://climate.nasa.gov/blog/2830/six-trends-to-know-about-fire-season-in-the-western-us/

California Fire Frequency

https://www.fire.ca.gov/

Year	Fire Frequency	Fire Area
2020	8112	1443152
2019	7148	277285
2018	7,948	1,975,086
2017	9,270	1,548,429
2016	6,954	669,534
2015	8,283	880,899
2014	7,233	625,540
2013	7,413	449,178
2012	7,041	829,224
2011	7,732	228,599
2010	6,394	134,462
2009	7,010	451,969
2008	6,255	1,593,690

California Fires: 2020

https://www.fire.ca.gov/incidents/2020/

2020 Fire Statistics

The below statistics are tracked on a weekly basis and provide a snapshot of the number of fires and acres burned. These are preliminary numbers taken from our Computer Aided Dispatch (CAD) system, and will likely change as dispatched wildfires may end up being other types of fires or false alarms. These numbers are sub to change until the final fire season reports are completed and tabulated.

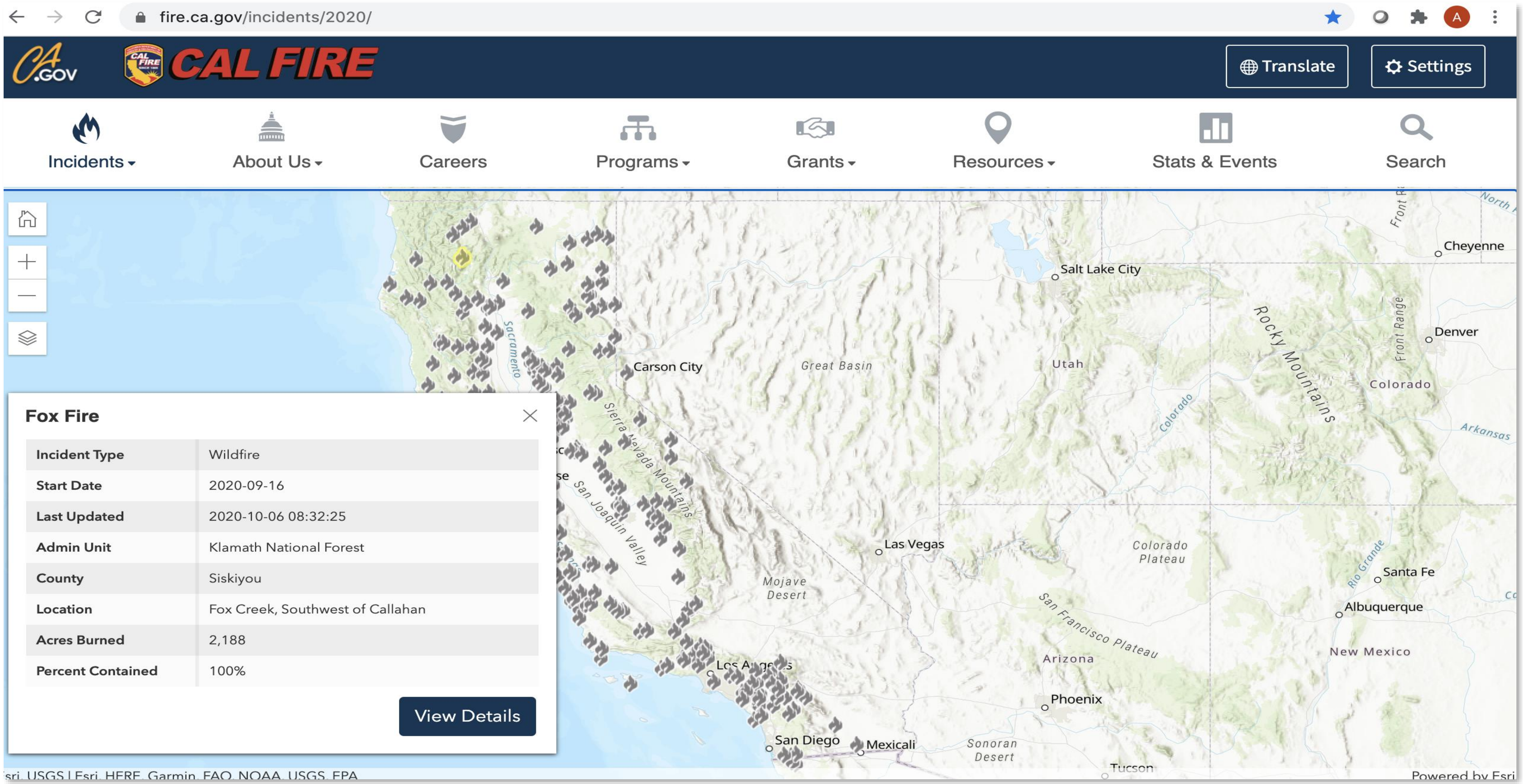
Number of Fires and Acres:

Interval	Fires	Acres
January 1, 2020 through December 29, 2020	8,112	1,443,152
January 1, 2019 through December 29, 2019	5,687	137,126
5 year average (same interval)	5,856	446,960
2020 Combined YTD (CALFIRE & Federal)	9,917	4,257,863

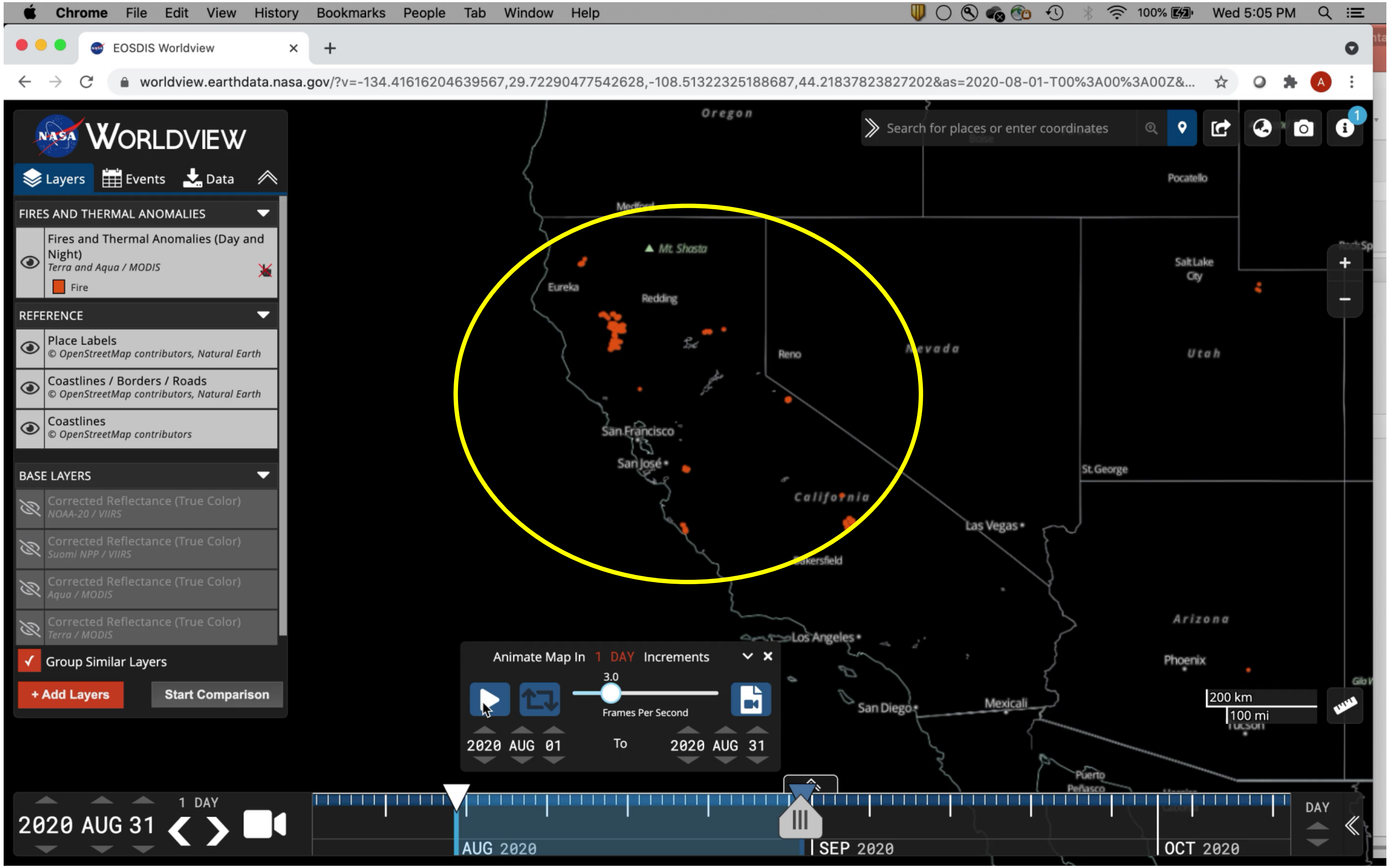
(Statistics include all wildfires responded to by CAL FIRE in both the State Responsibility Area, as well as the Local Responsibility Area under contract with the department. Statistics may not include wildfires in State Responsibility Area protected by CAL FIRE's contract counties. ****Final numbers will be provided in the annual Wildfire Activity Statistics Report (Redbook) once it's published.)****

California Fires: 2020

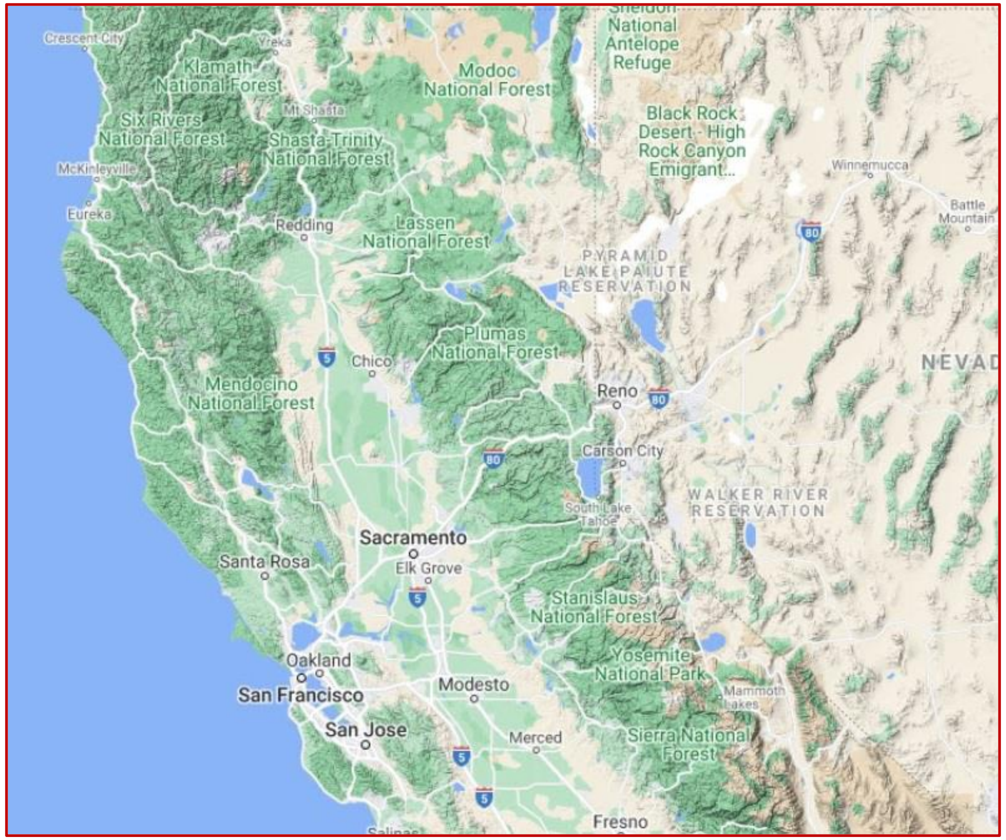
https://www.fire.ca.gov/incidents/2020/



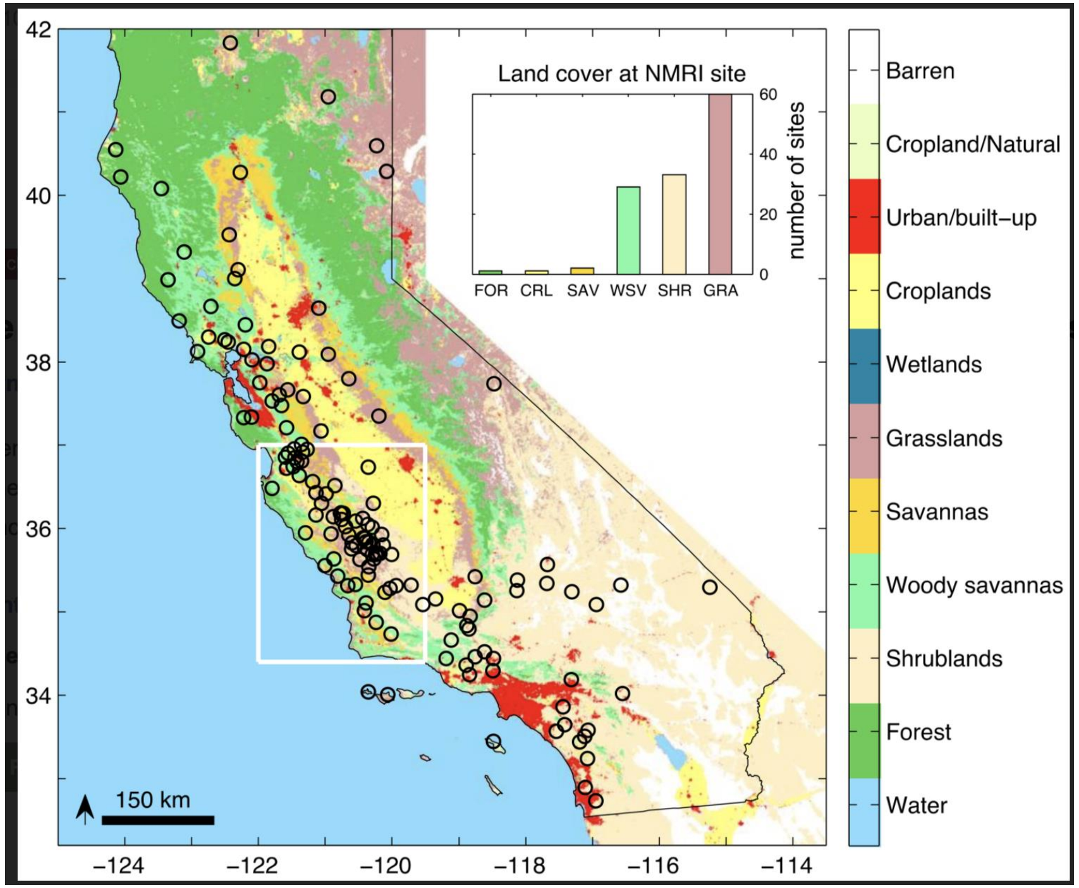
California Fires: August 2020



California Terrain and Landcover



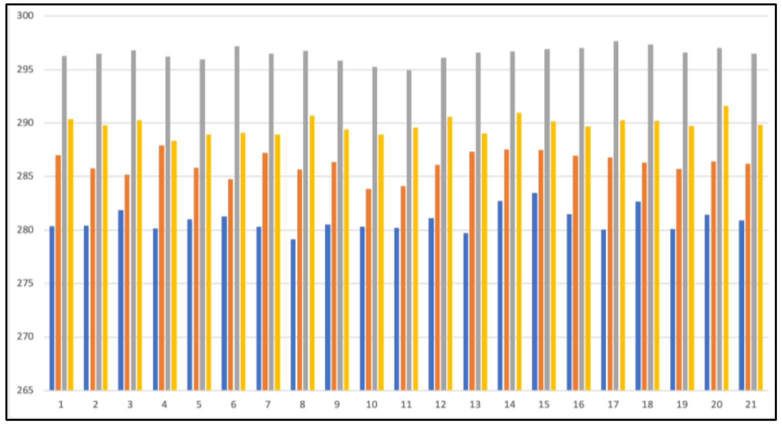
Google Terrain Map



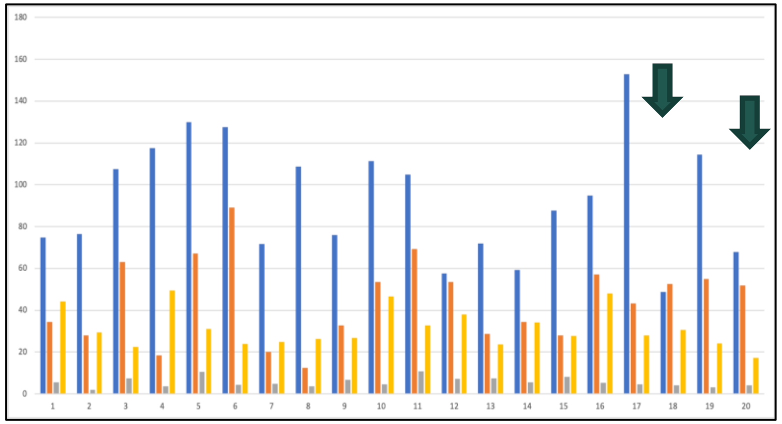
https://www.mdpi.com/2072-4292/10/4/630/htm#

California Area-Averaged Temperature, Precipitation, & Soil Moisture

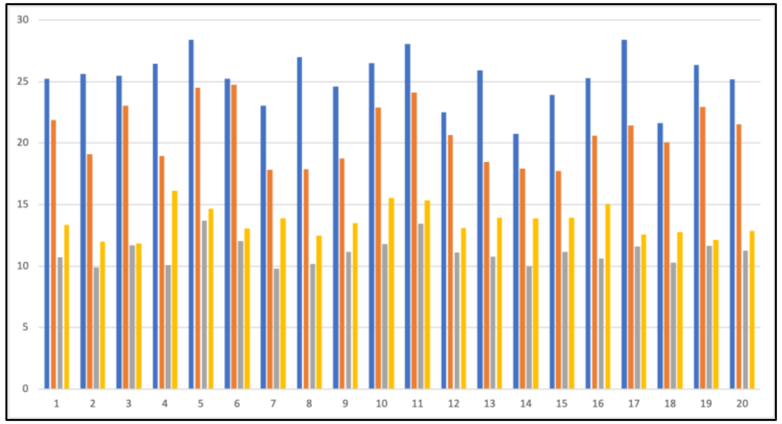
MERRA-2 10-m Temperature (K)



IMERG Precipitation (mm/month)



GLDAS Soil Moisture 0-10 cm (Kg/m^3)



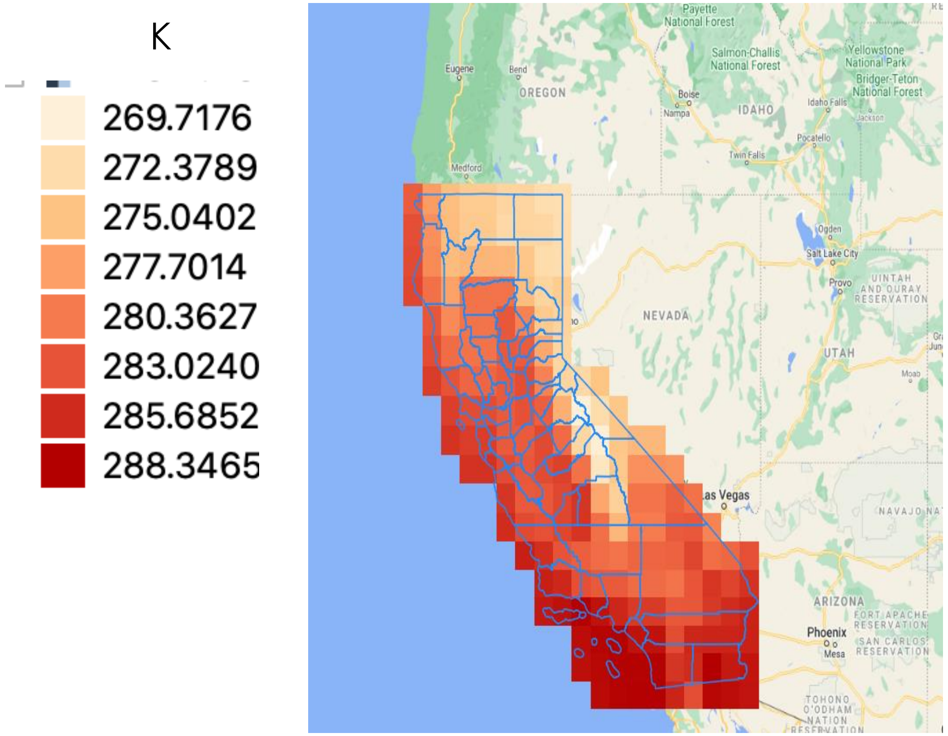
DJF MAM JJA SON

- Wet and cold winters
- Warm and dry summers
- Significant interannual variability of precipitation and soil moisture

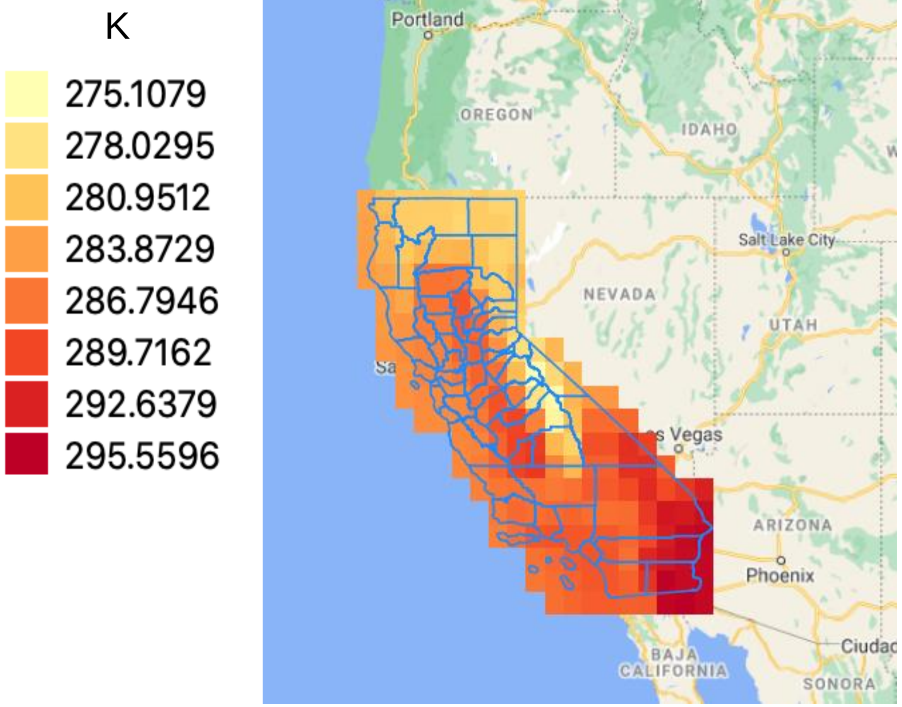
Pre-Fire Season Temperature Climatology: DJF and MAM

- Using Giovanni, seasonal mean maps (averaged over 2001 to 2020) for California are calculated for **December-January-February (DJF) and March-April-May (MAM)** from MERRA-2 10-m temperature

DJF

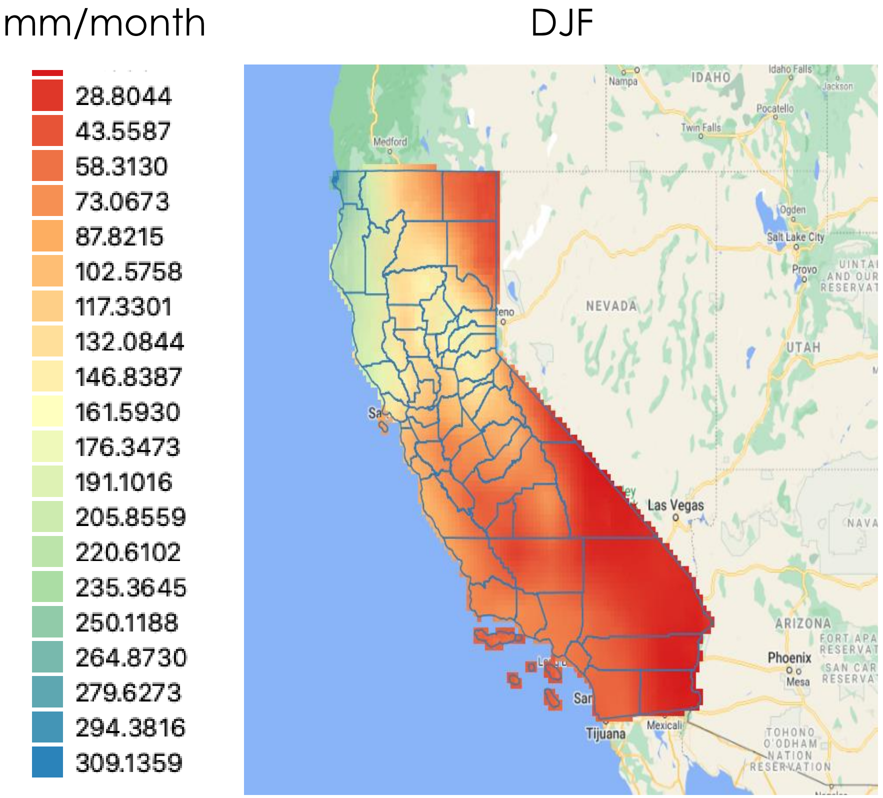


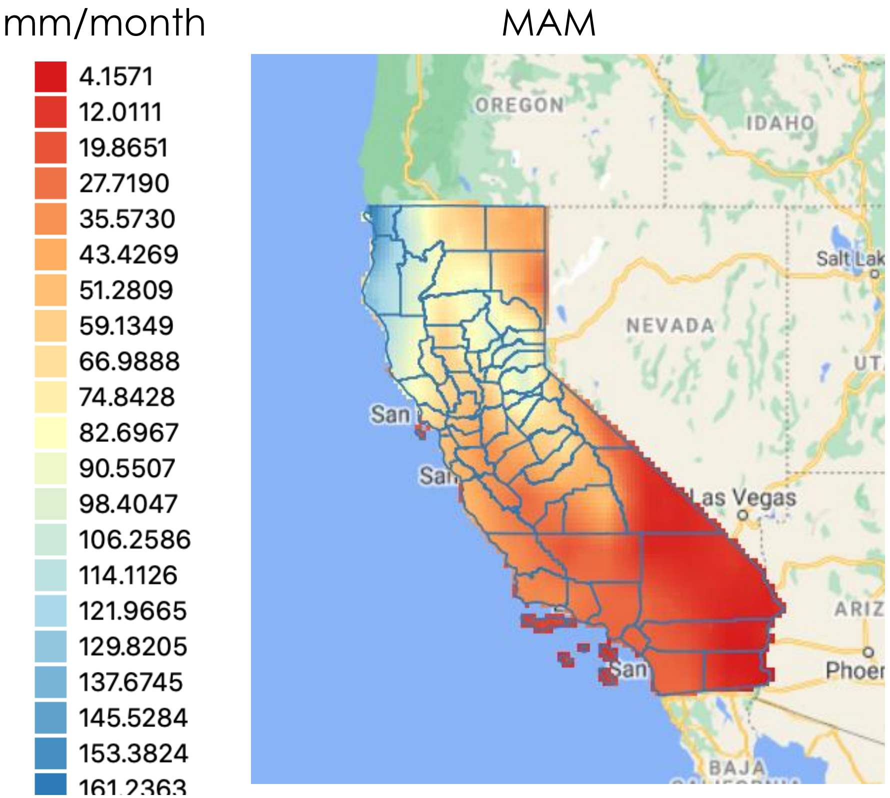
MAM



Pre-Fire Season Precipitation Climatology: DJF and MAM

- Using Giovanni, seasonal mean maps (averaged over 2001 to 2020) for California are calculated for **December-January-February (DJF)** and **March-April-May (MAM)** from IMERG Final precipitation:





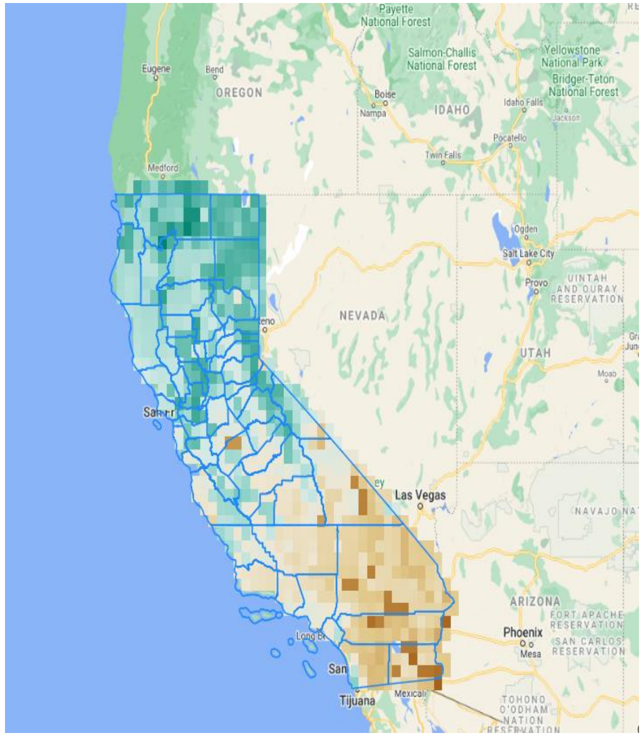
Pre-Fire Season Soil Moisture Climatology: DJF and MAM

- Using Giovanni, seasonal mean maps (averaged over 2001 to 2020) for California are calculated for **December-January-February (DJF)** and **March-April-May (MAM)** from GLDAS 0–10 cm sol moisture:

DJF

Kg/m^2

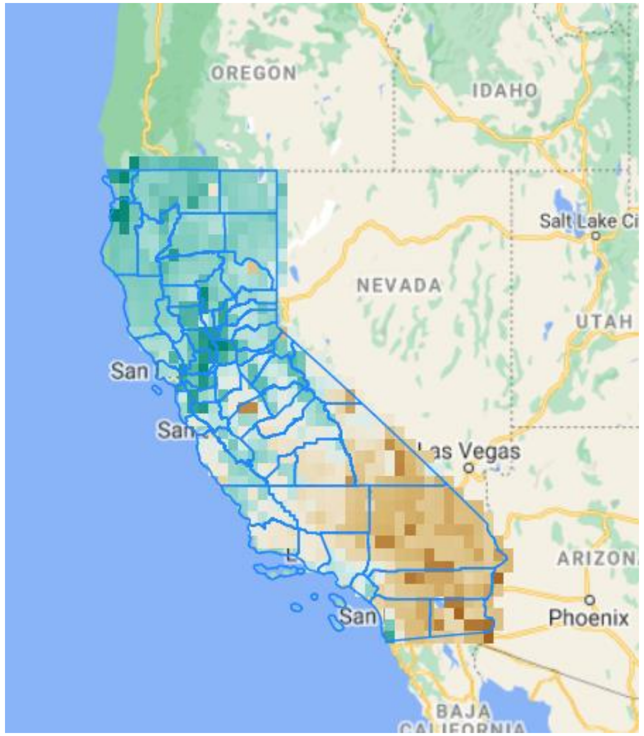
- 7.7674
- 12.4638
- 17.1601
- 21.8565
- 26.5529
- 31.2492
- 35.9456
- 40.6419



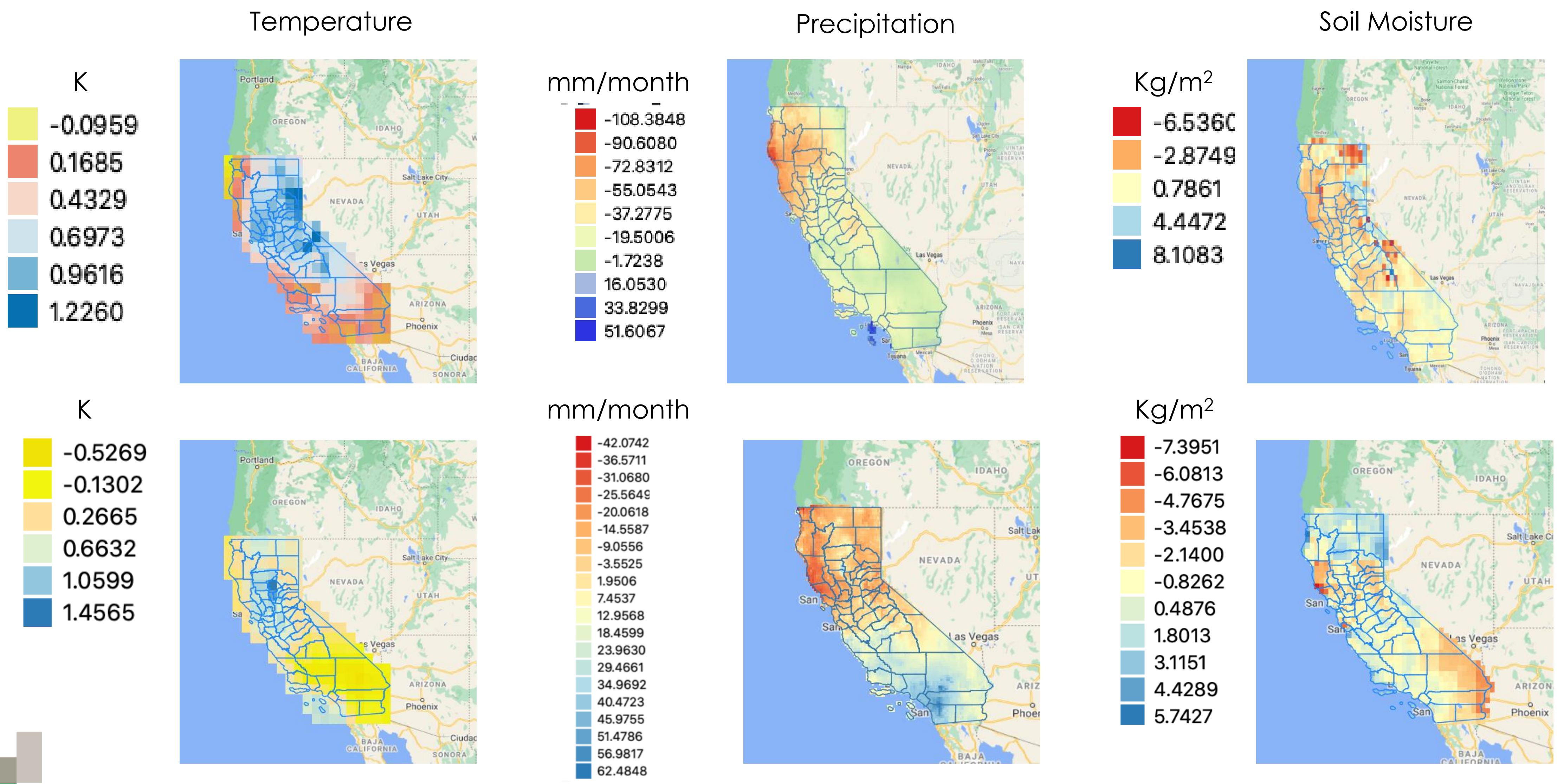
MAM

Kg/m^2

- 5.3041
- 8.5692
- 11.8343
- 15.0995
- 18.3646
- 21.6297
- 24.8948
- 28.1599
- 31.4250
- 34.6901

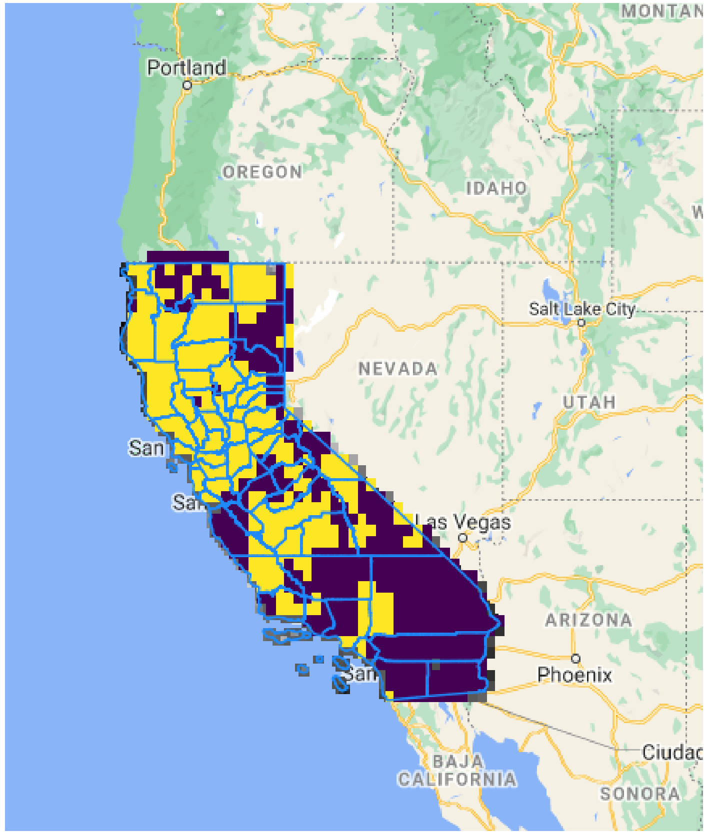


Pre-Fire Season Anomalies of Temperature, Precipitation, Soil Moisture for 2020 DJF (Top) and MAM (Bottom)

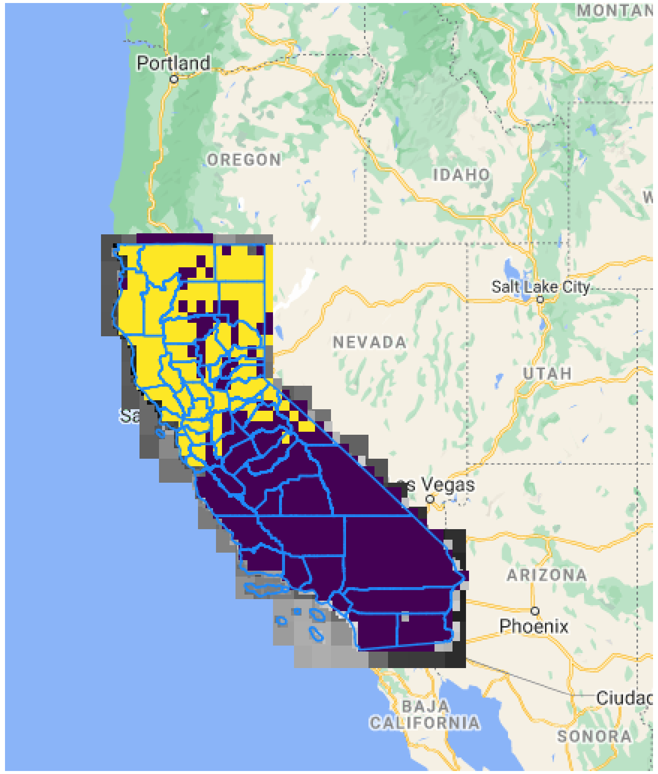


Seasonal Climate Indicator For Potential Fire Risk Areas

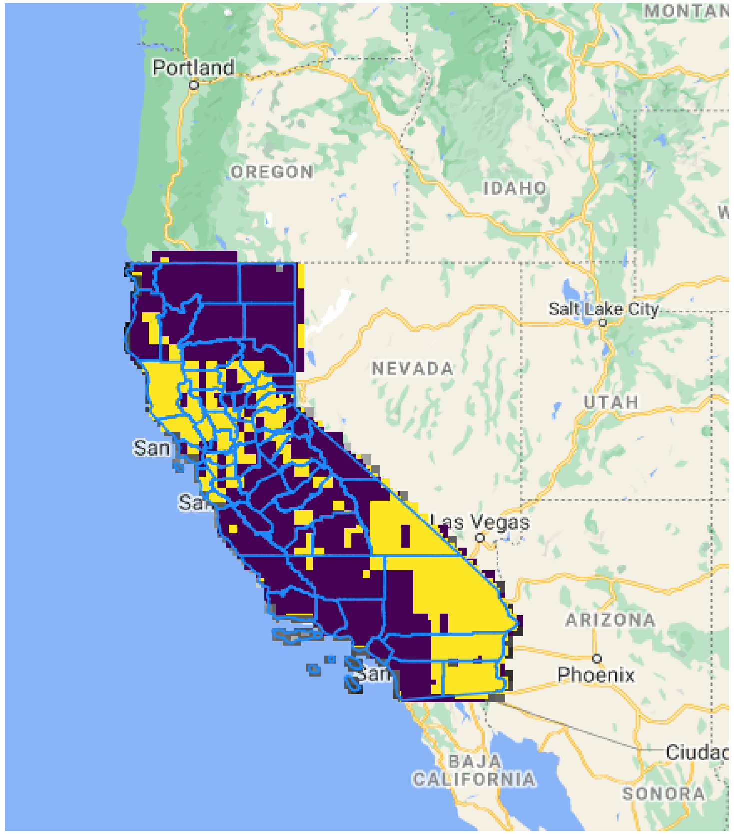
December-January-February 2020



March-April-May 2020

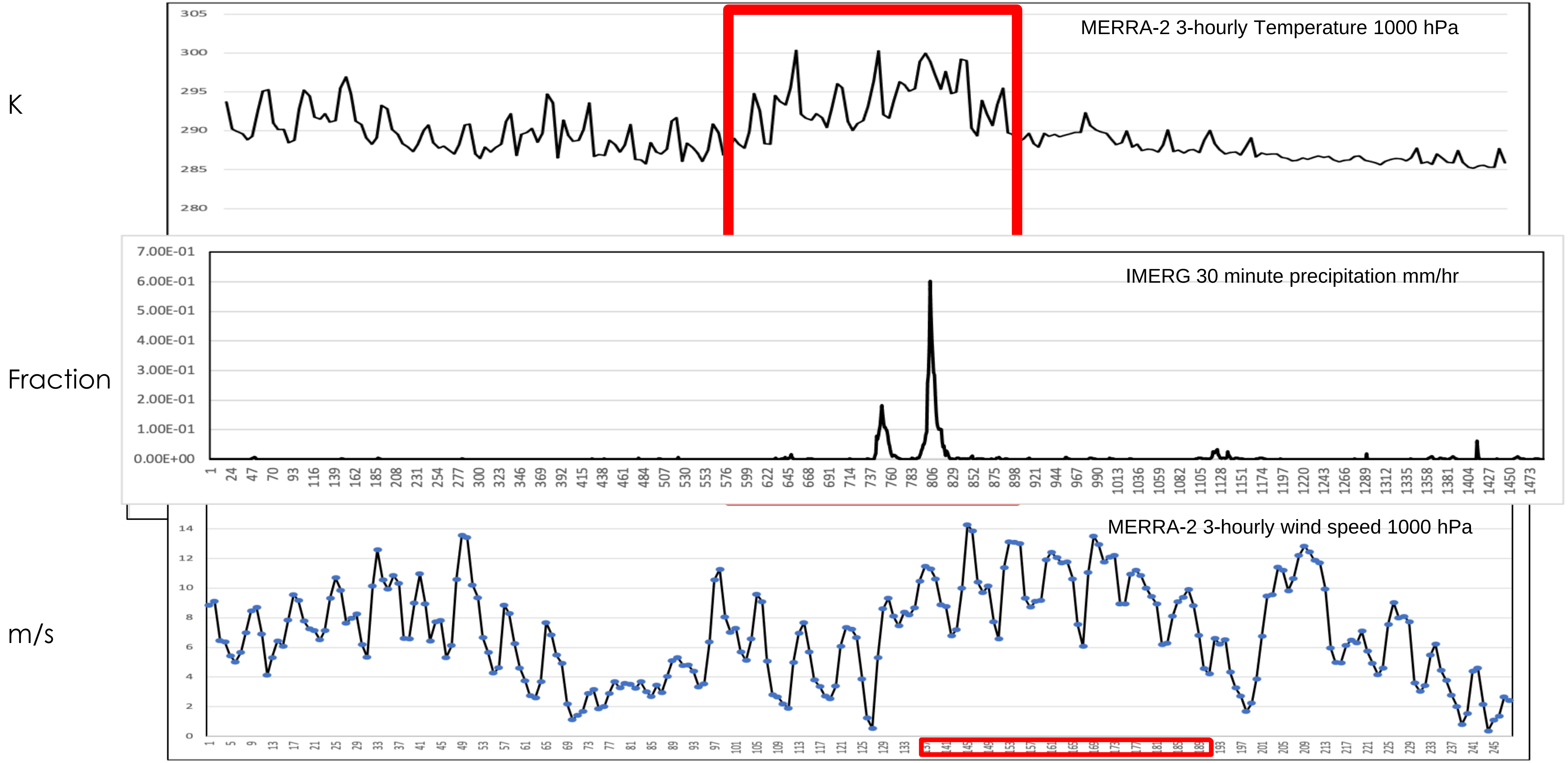


June-July-August 2020



Warmer than normal temperature and below normal precipitation and soil moisture

Weather Condition During Fire Activity (August 2020)



From 3-Hourly MERRA-2 Data

Case Study II: Pre-Fire Analysis for Zambia

Zambia Geography

- Landlocked country in Southern Africa
- Drained by two major river basins: Zambezi and Congo
- 1,000 m to 1,600 m above sea level
- Tropical wet and dry climate with three distinct seasons: 1) **Warm dry** season from April through early August, 2) **Hot dry** season from mid-August through October, and 3) **Hot wet** season from November through March

Image Credit: Wikimedia Commons

Zambia Fire Regime

- Dominated by vast tracks of fire-prone vegetation including woodland savannas and grasslands.
- Fire has been used by humans in this landscape for millennia (Eriksen, 2007).
- Fire is a tool for clearing vegetation for agriculture, improving pastures for grazing, hunting, and stimulating the growth of non-timber forest products.
- Bush fire is a frequent process on the landscape, estimated to annually burn ~25% of Zambia's land area (Sikaundi, 2013).

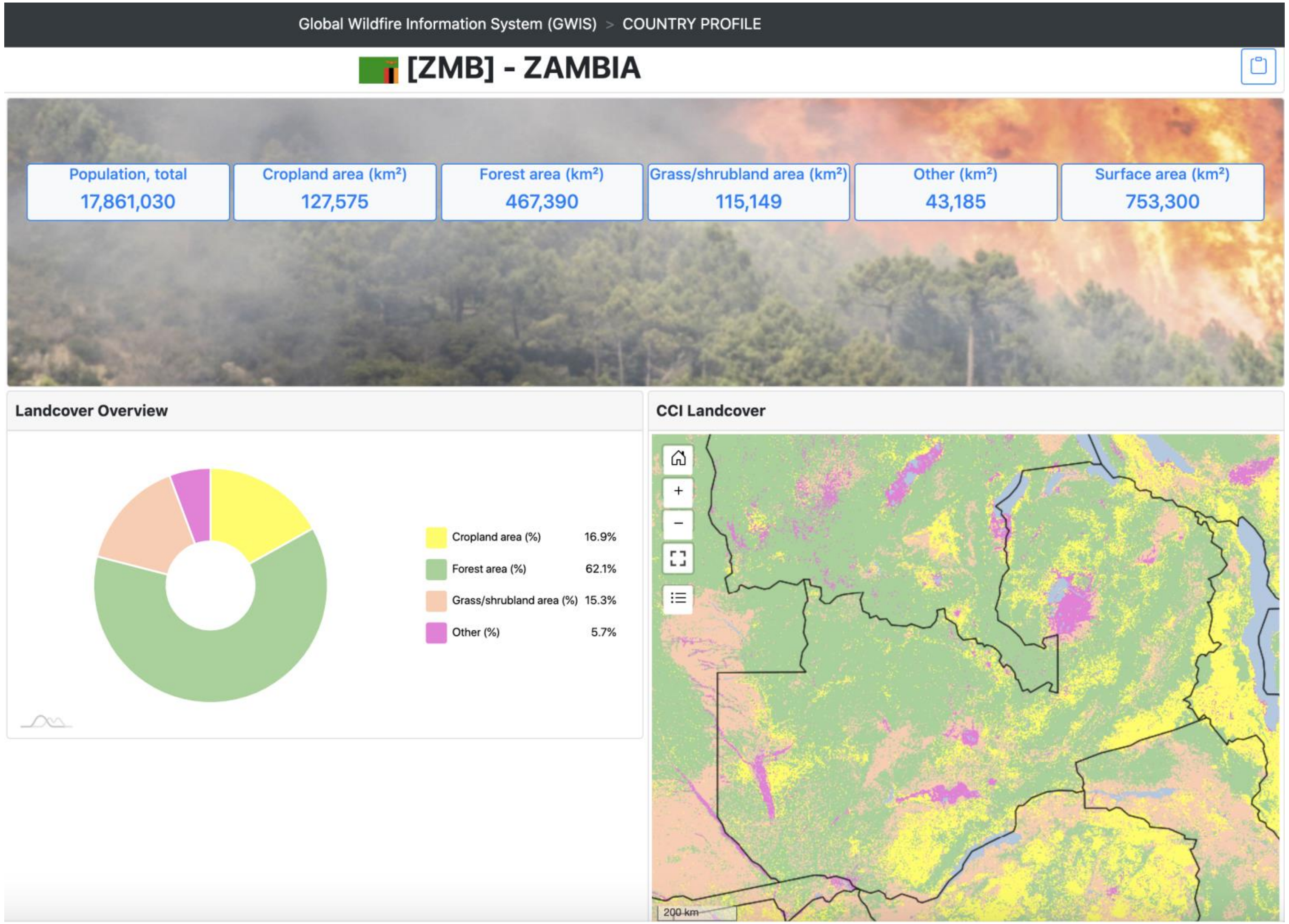
Miombo woodlands in Zambia
Image Credit: Geoff Gallice

Global Wildfire Information System (GWIS) - Zambia

https://gwis.jrc.ec.europa.eu/apps/country.profile/overview/ZMB/ZMB

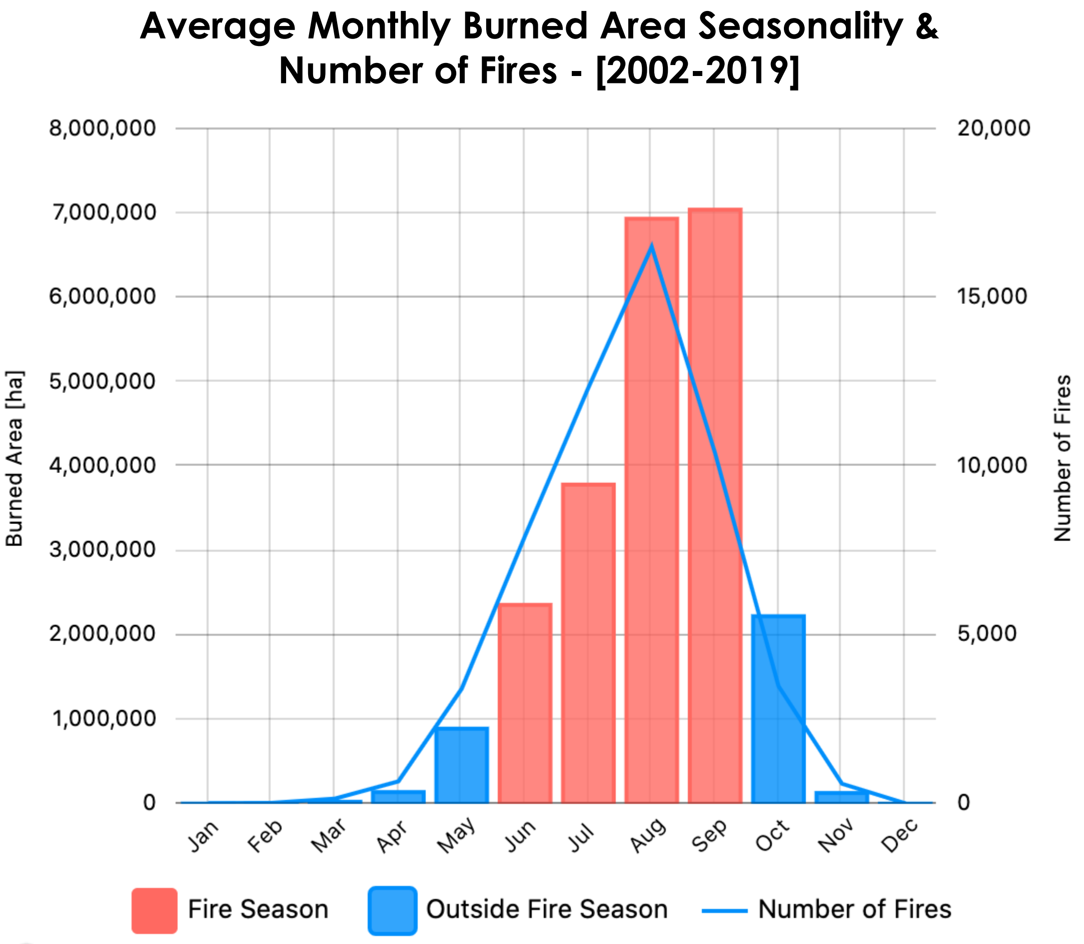
Country Profile

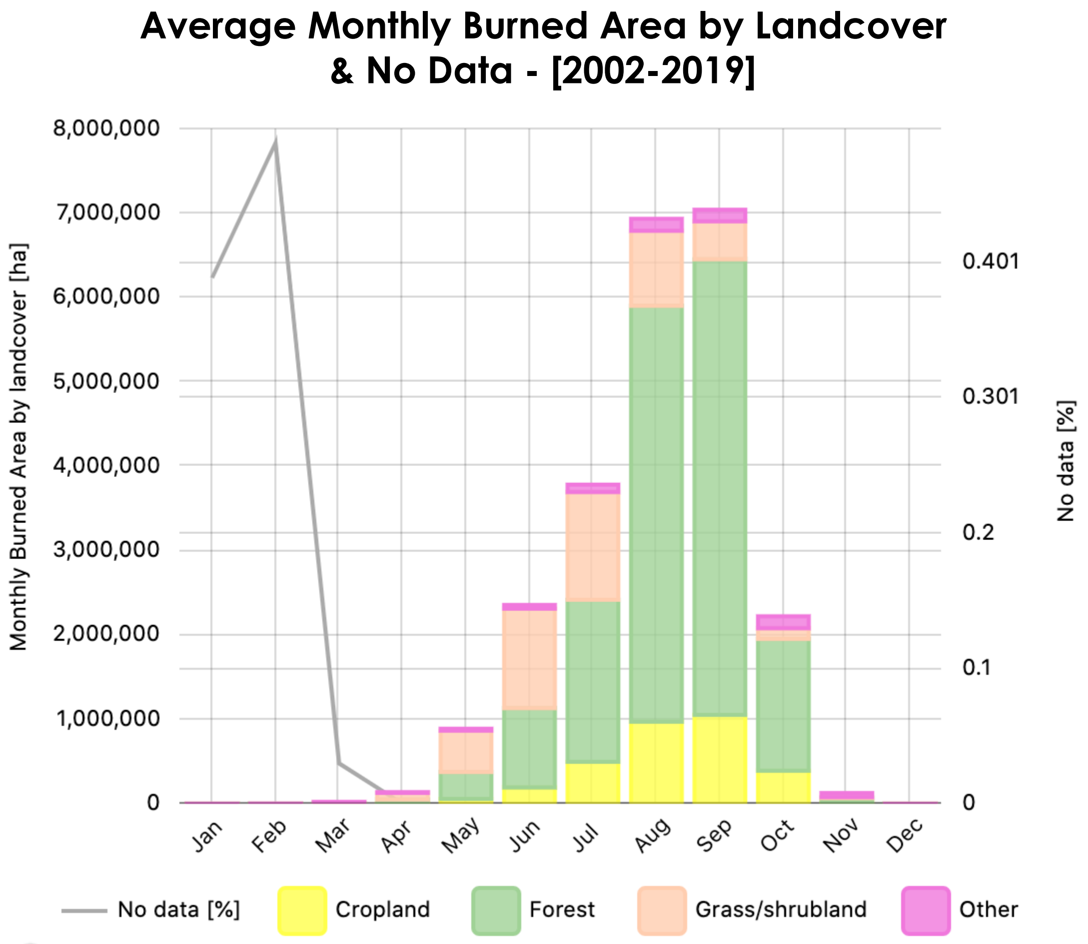
Landcover



Global Wildfire Information System (GWIS) - Zambia

https://gwis.jrc.ec.europa.eu/

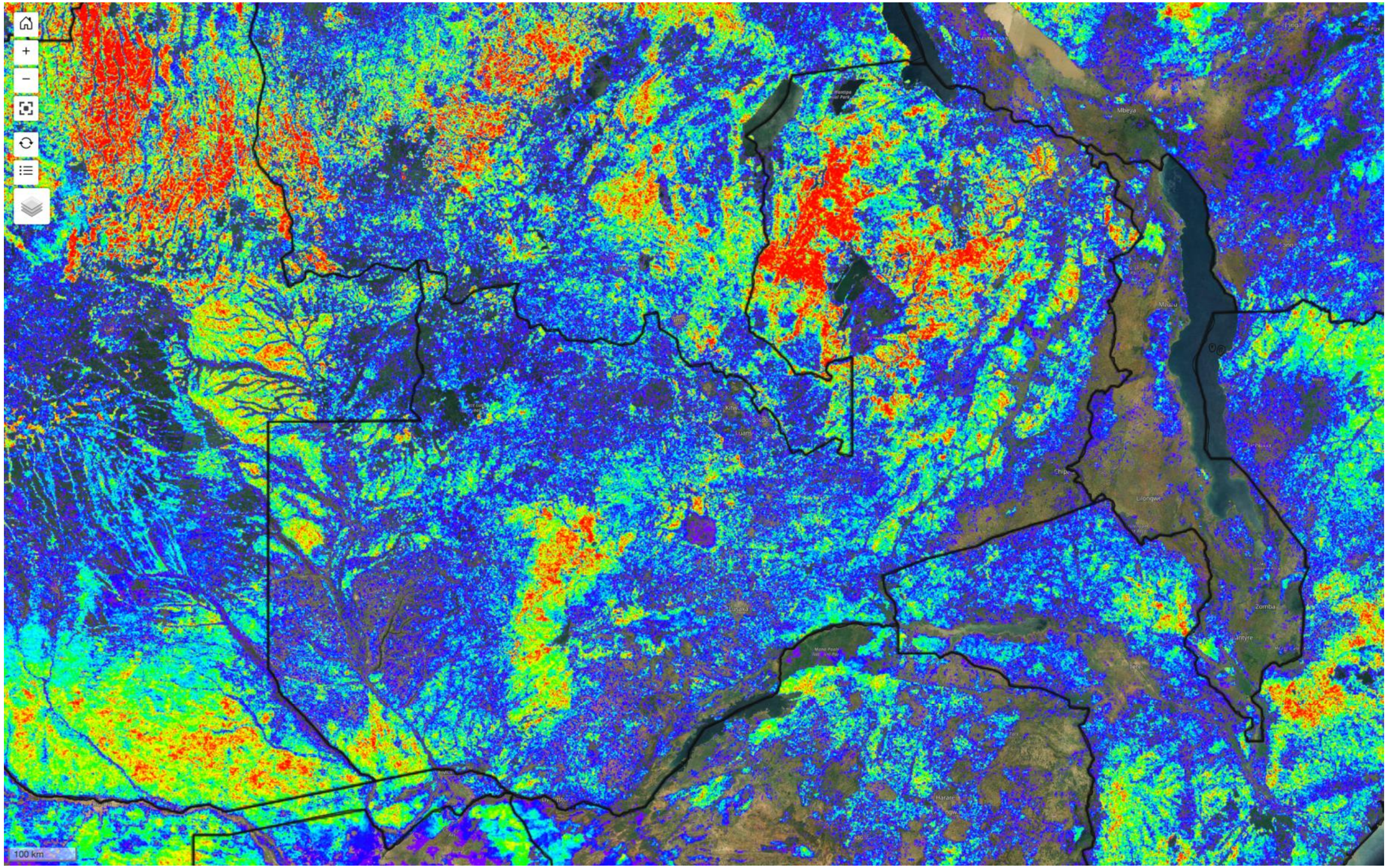




Global Wildfire Information System (GWIS) - Zambia

Fire Frequency:
2002 - 2019

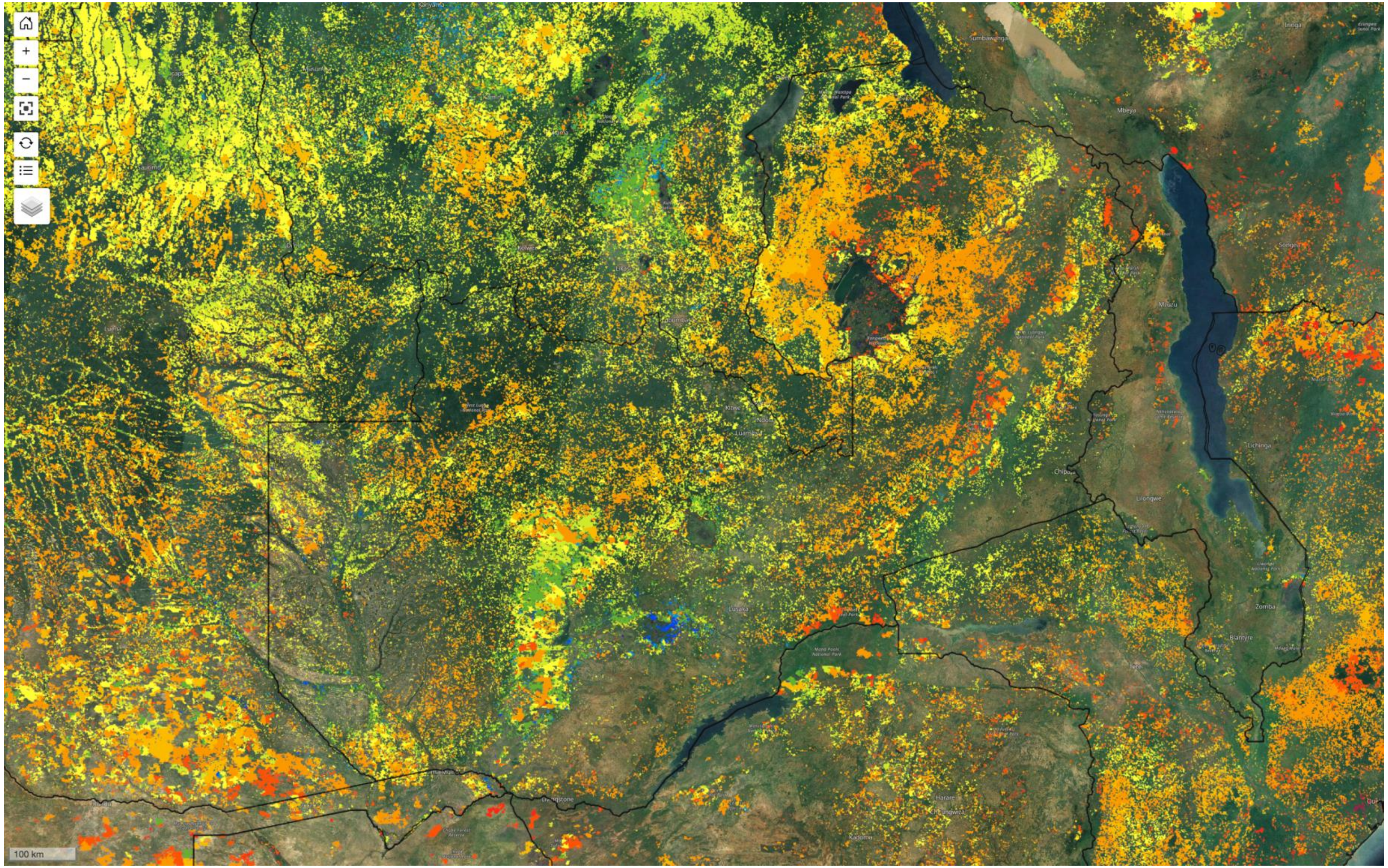
- 1 Occurrence
- 2 Occurrences
- 3 Occurrences
- 4 Occurrences
- 5 Occurrences
- 6 Occurrences
- 7 Occurrences
- 8 Occurrences
- 9 Occurrences
- 10 Occurrences
- 11 Occurrences
- 12 Occurrences
- 13 Occurrences
- 14 Occurrences
- 15 Occurrences
- 16 Occurrences
- 17 Occurrences
- 18 Occurrences



Global Wildfire Information System (GWIS) - Zambia

Cumulative Burned Area for 2019

- January
- February
- March
- April
- May
- June
- July
- August
- September
- October
- November
- December



Climate Engine

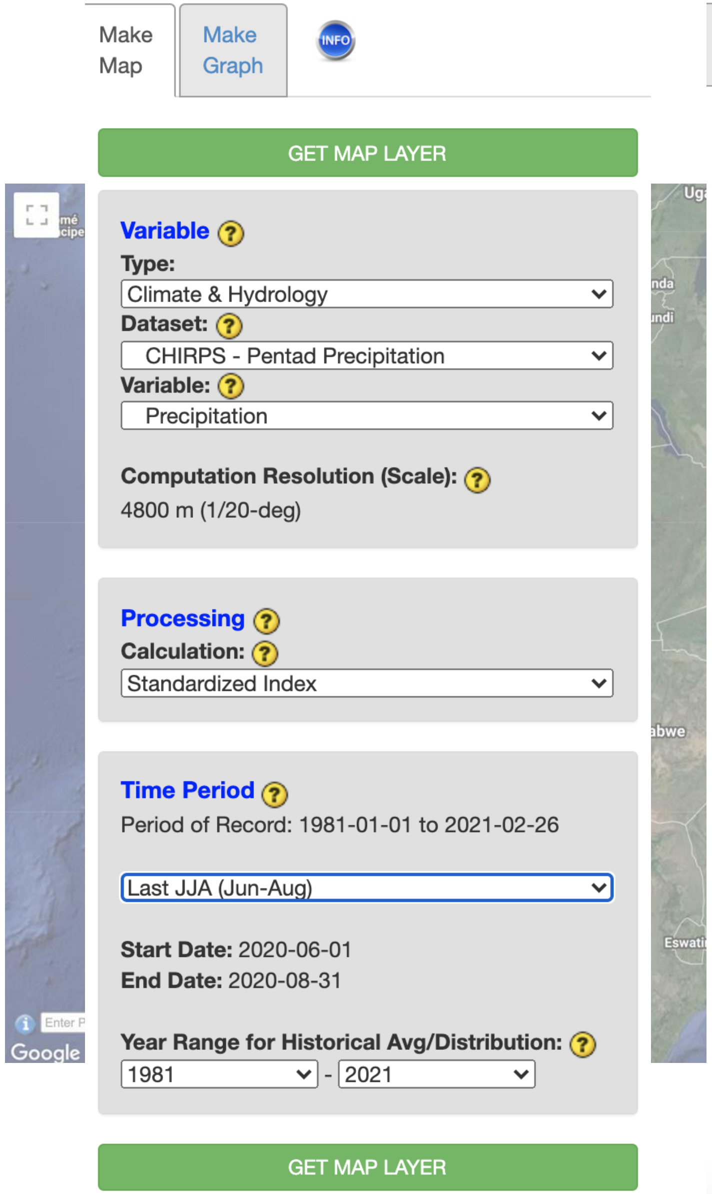
http://climateengine.org/

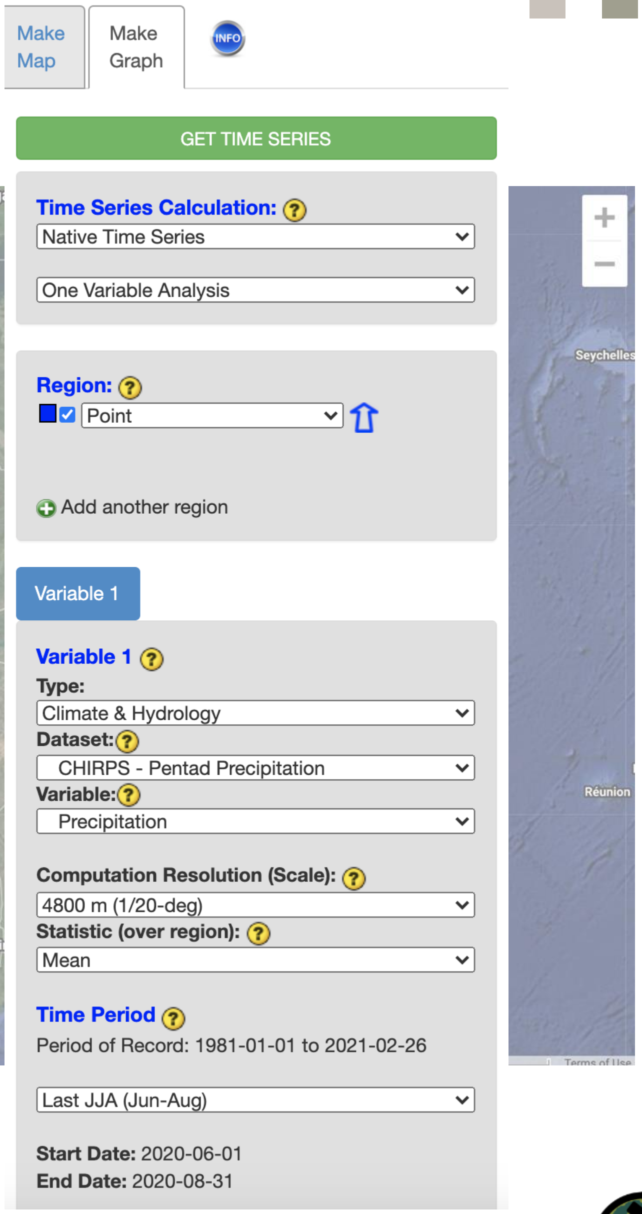
- Uses Google's Earth Engine for on-demand processing of satellite and climate data via web browser
- Time series and statistical summaries
- Downloadable results in GeoTIFF format and time series results as .csv or .xlsx format
- Share map or time series results with web URL links

Climate Engine

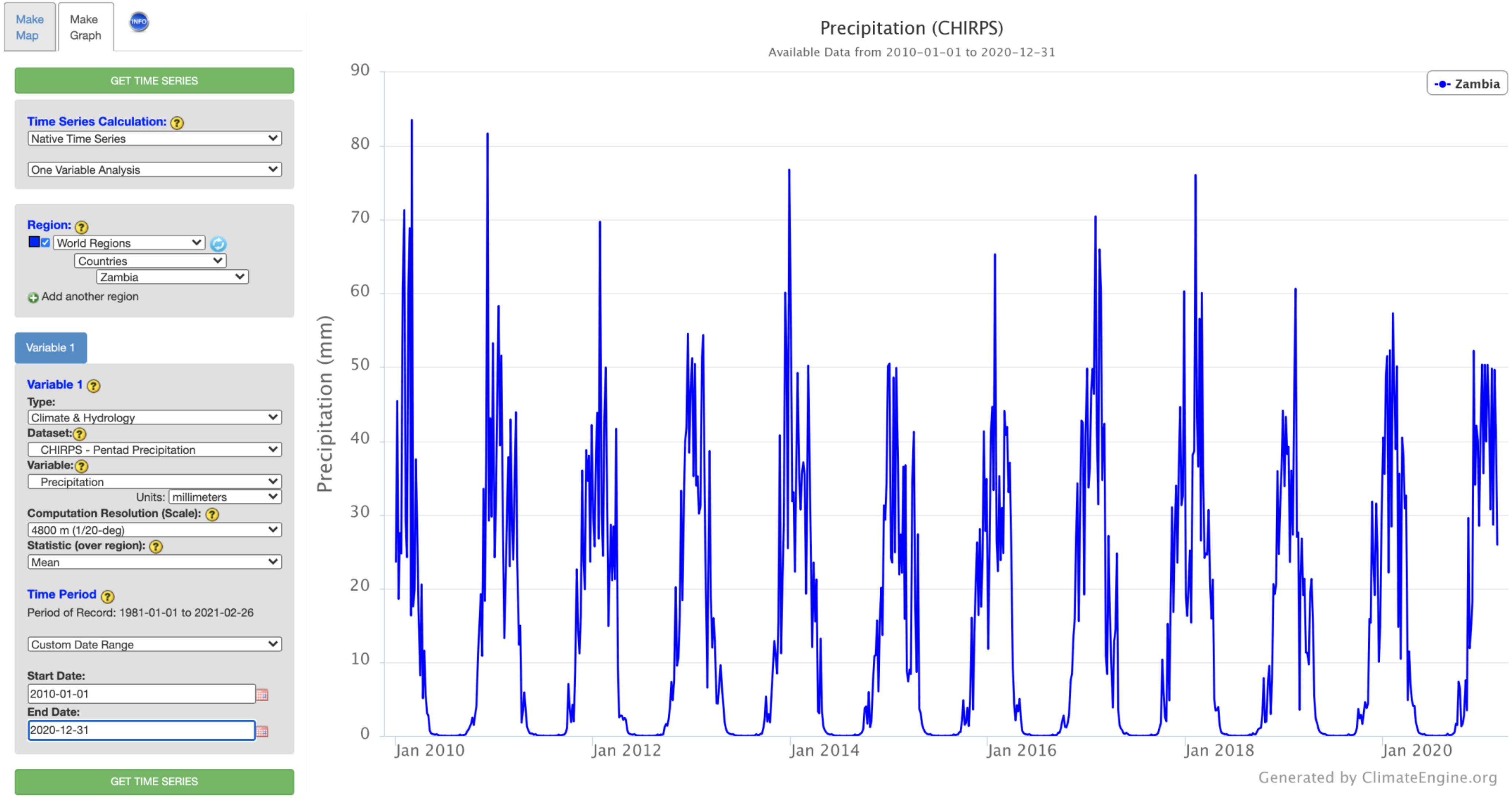
http://climateengine.org/

- Overcomes computational limitations of big data for use in real-time monitoring
- Fully customizable spatial and temporal analyses
- Comprehensive set of variables that provide early warning indicators of climate impacts such as drought, wildfire, and agricultural production

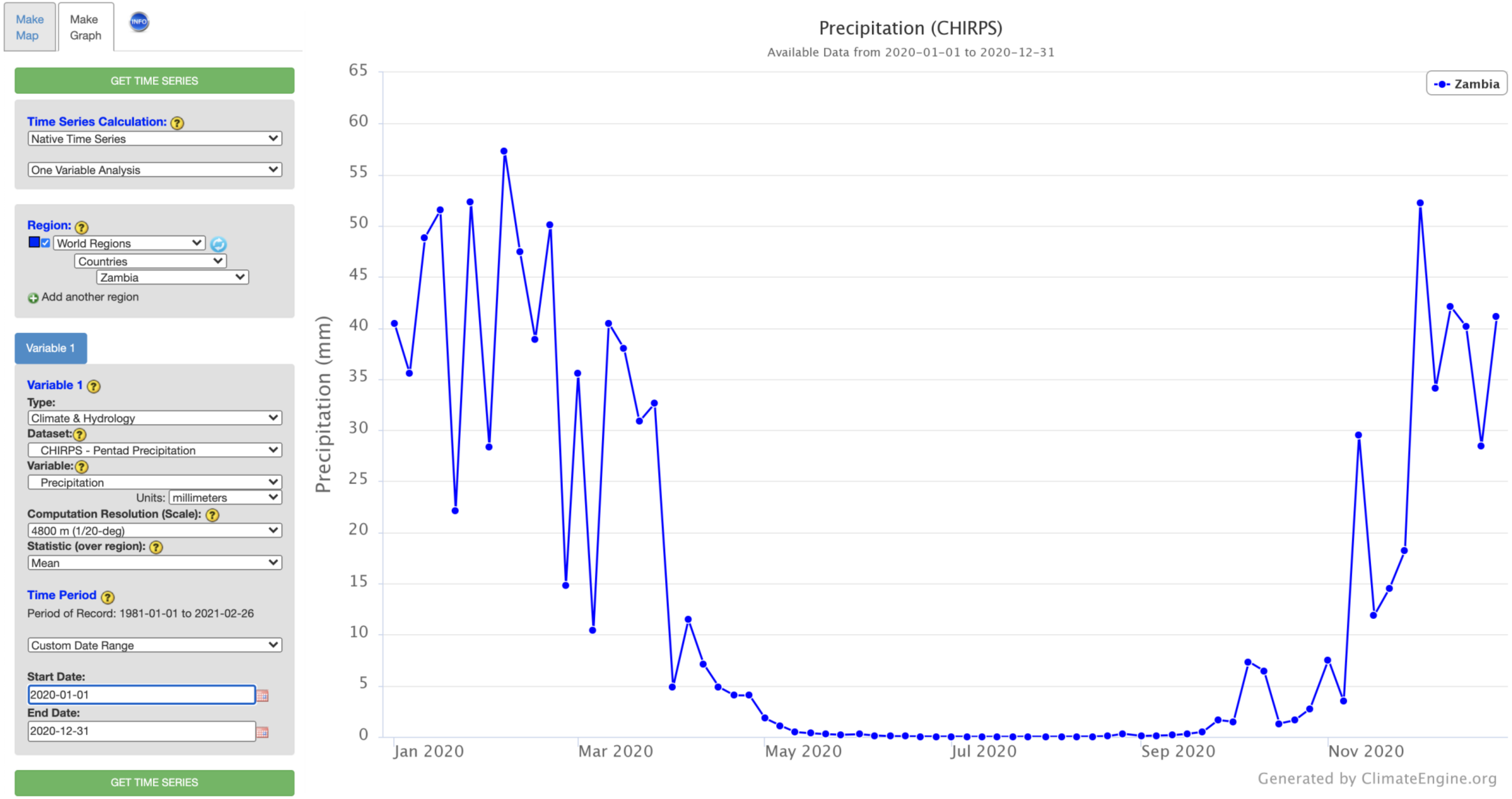




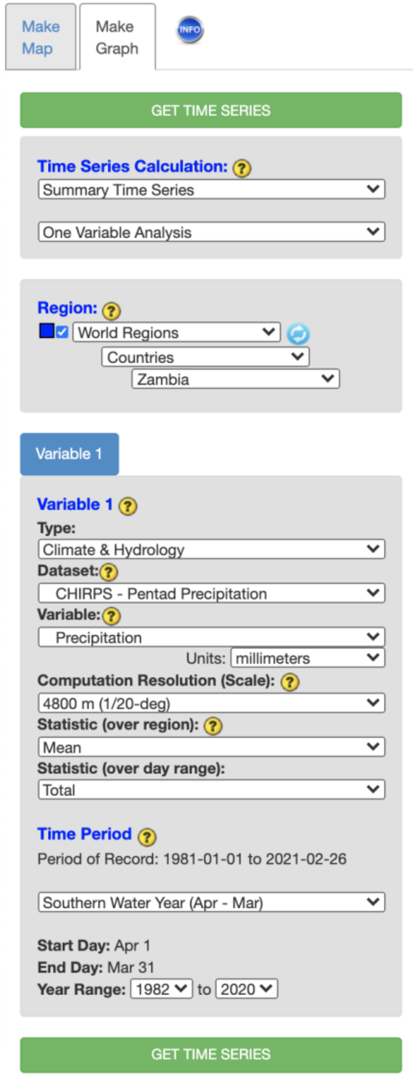
Precipitation Mean from 2010-2020 (Zambia)



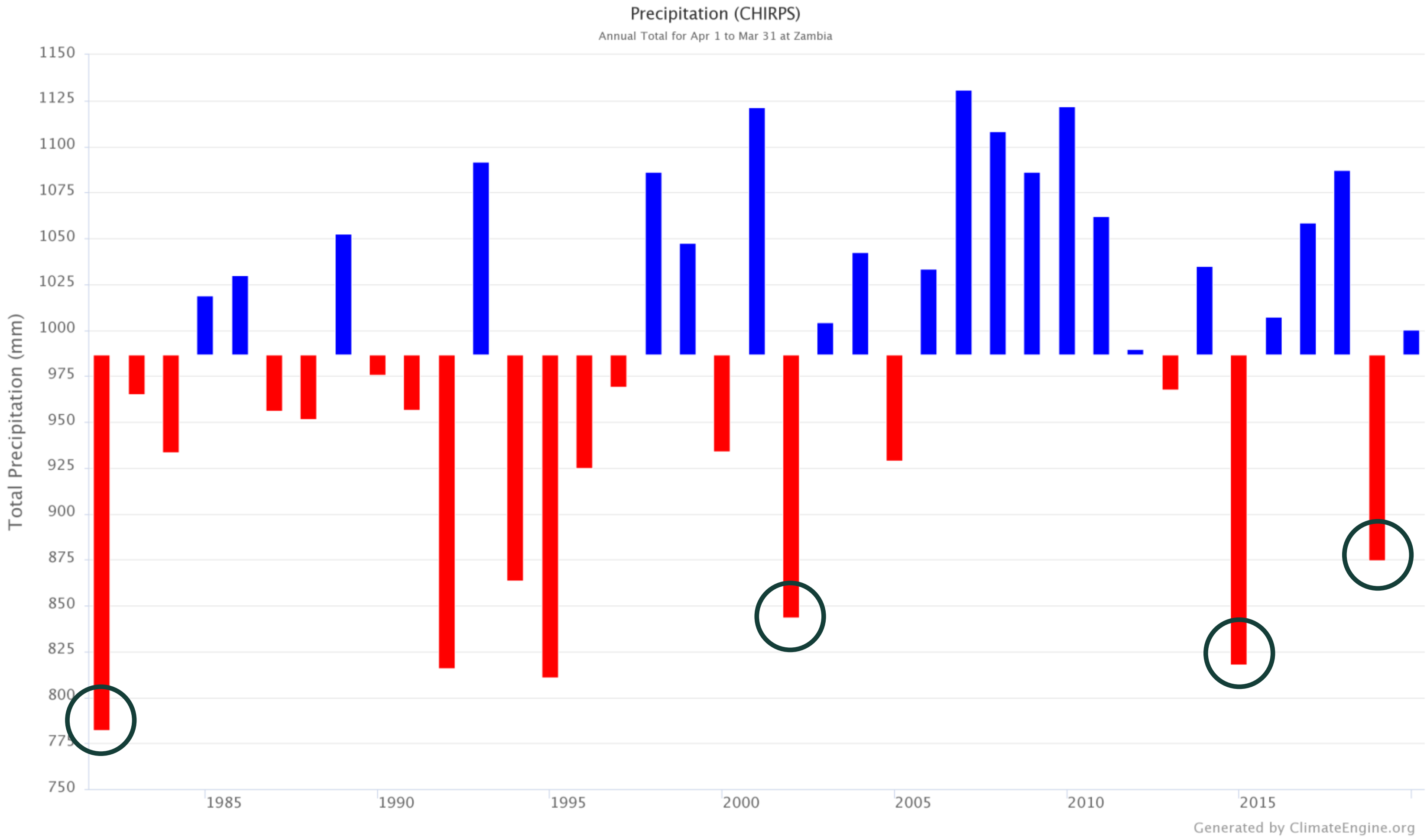
Precipitation Mean for 2020 (Zambia)



Precipitation Deviation from Mean (Zambia)



Southern Hemisphere Water Year (April-March) 1982 - 2020

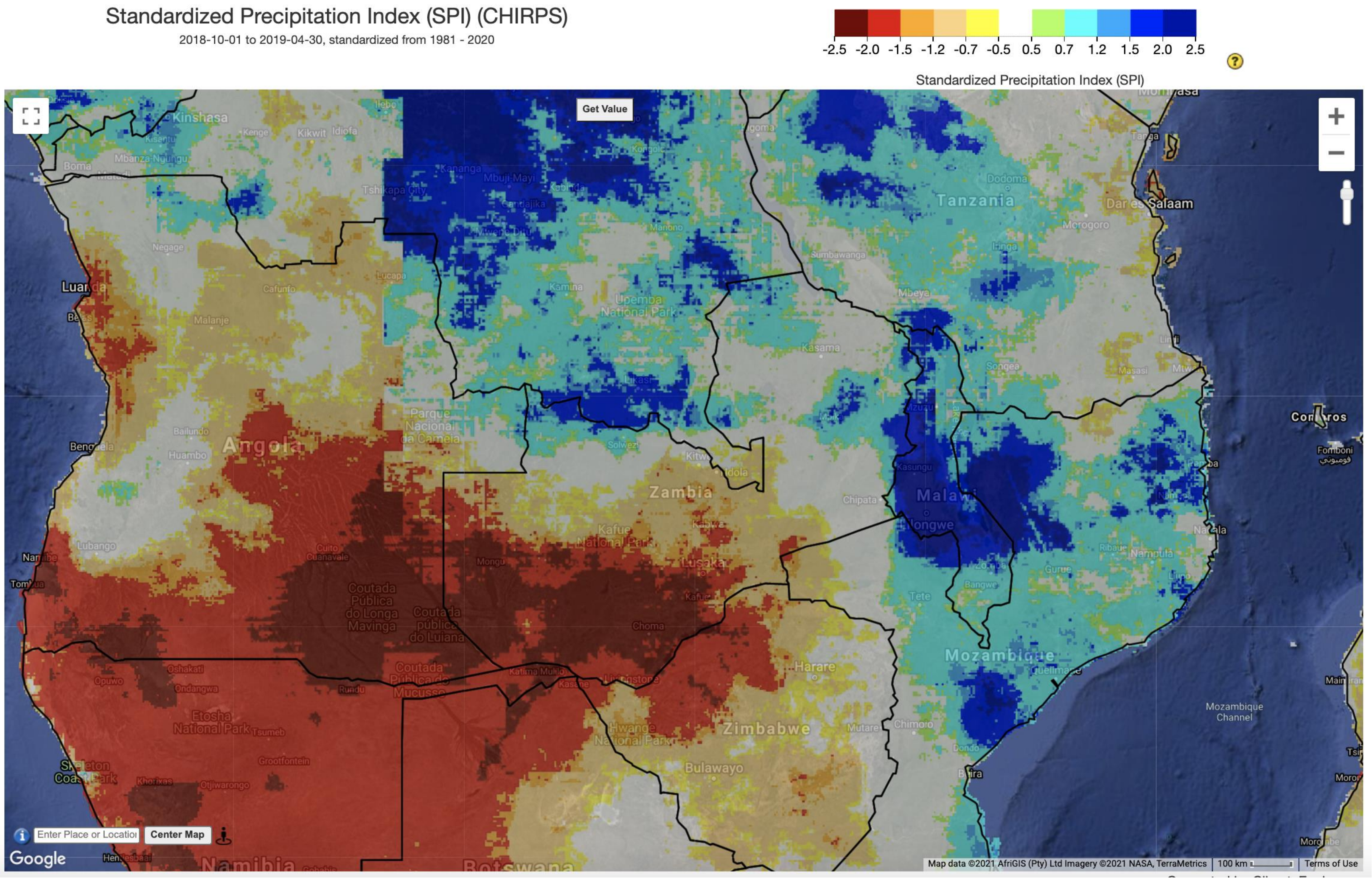


= El Nino Years

Standardized Precipitation Index for 2018/2019 Wet Season

October 1, 2018 to April 30, 2019

Much of Southern Zambia shows large deficits in precipitation compared to the other wet seasons from 1981-2020.

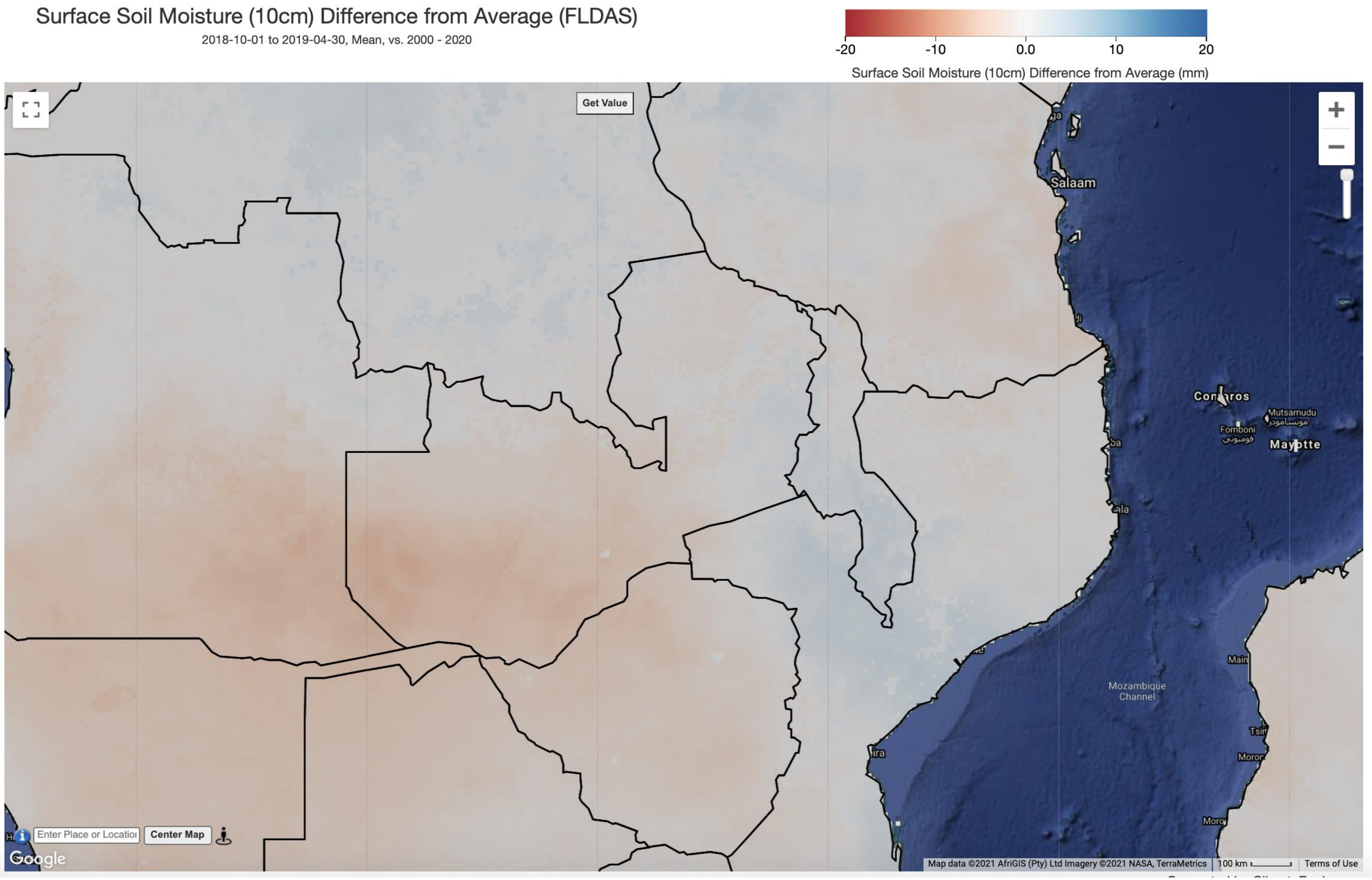


Surface Soil Moisture (10cm) Difference from Average for 2018/2019 Wet Season (FLDAS)

October 1, 2018 to April 30, 2019

Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS)

Much of Southern Zambia shows deficits in surface soil moisture compared to the other wet seasons from 1981-2020.

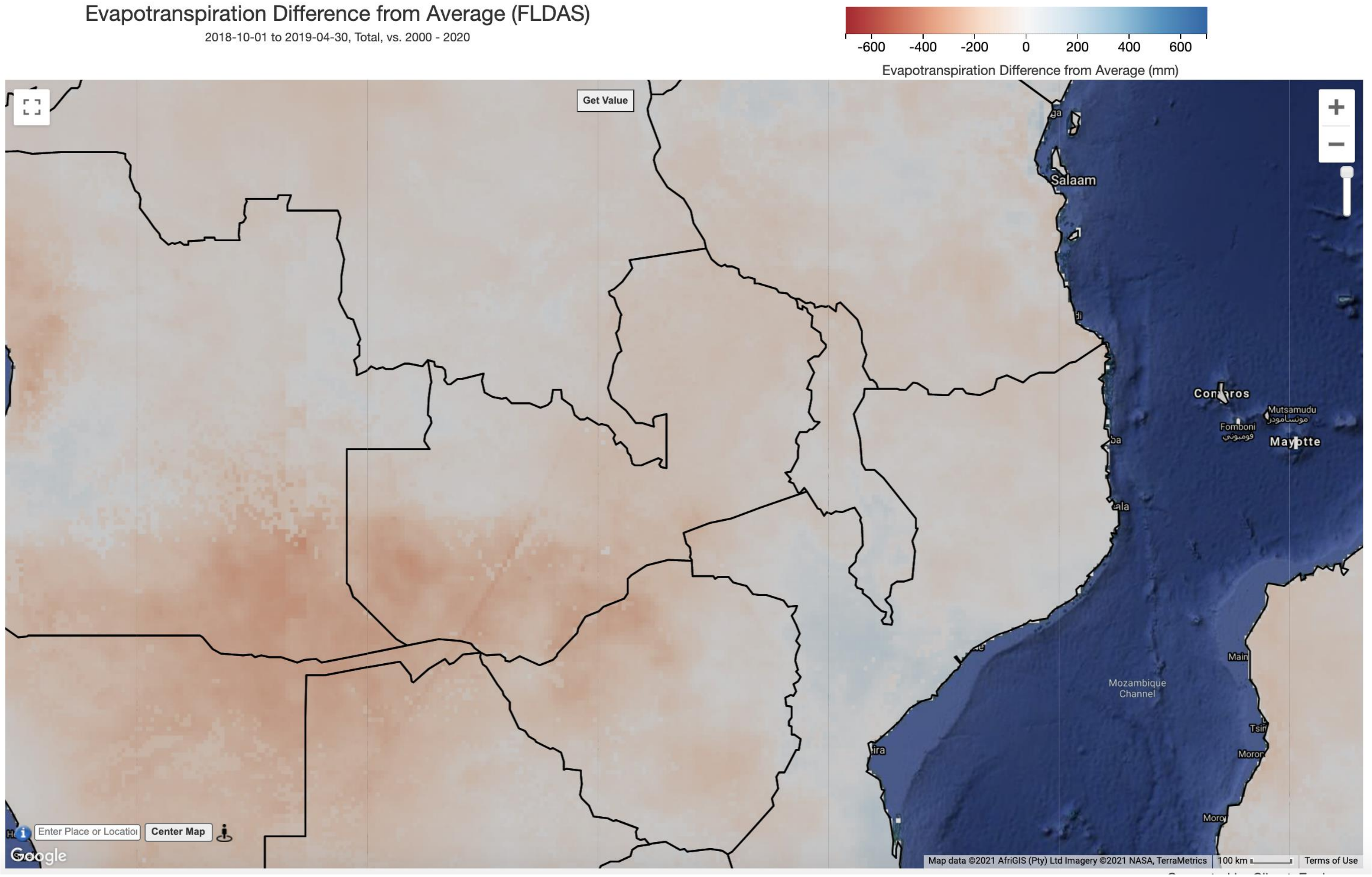


Evapotranspiration Difference from Average for 2018/2019 Wet Season (FLDAS)

October 1, 2018 to April 30, 2019

Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS)

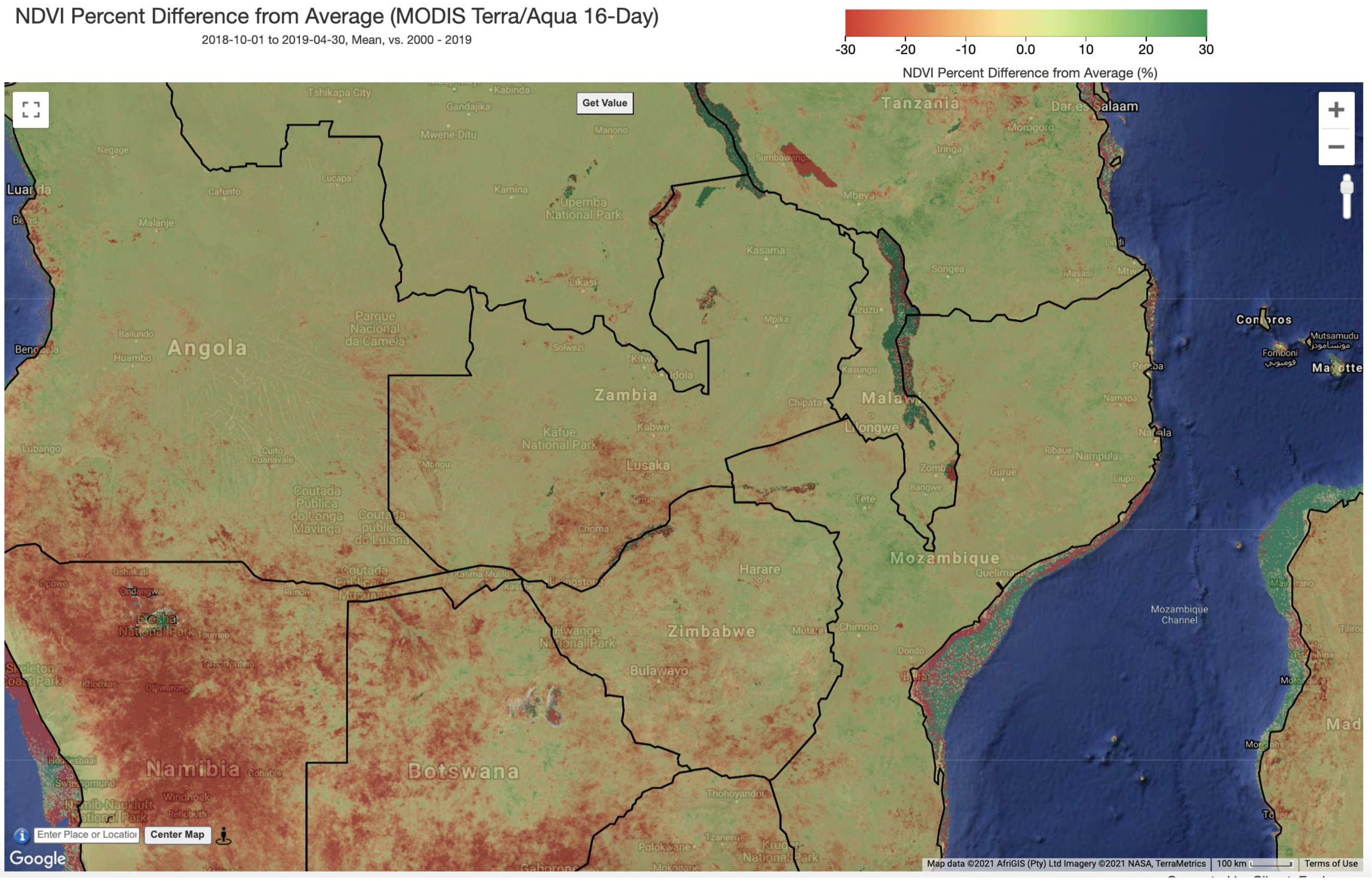
Much of Southern Zambia shows low evapotranspiration compared to the other wet seasons from 1981-2020.



NDVI Percent Difference from Average

October 1, 2018 to April 30, 2019

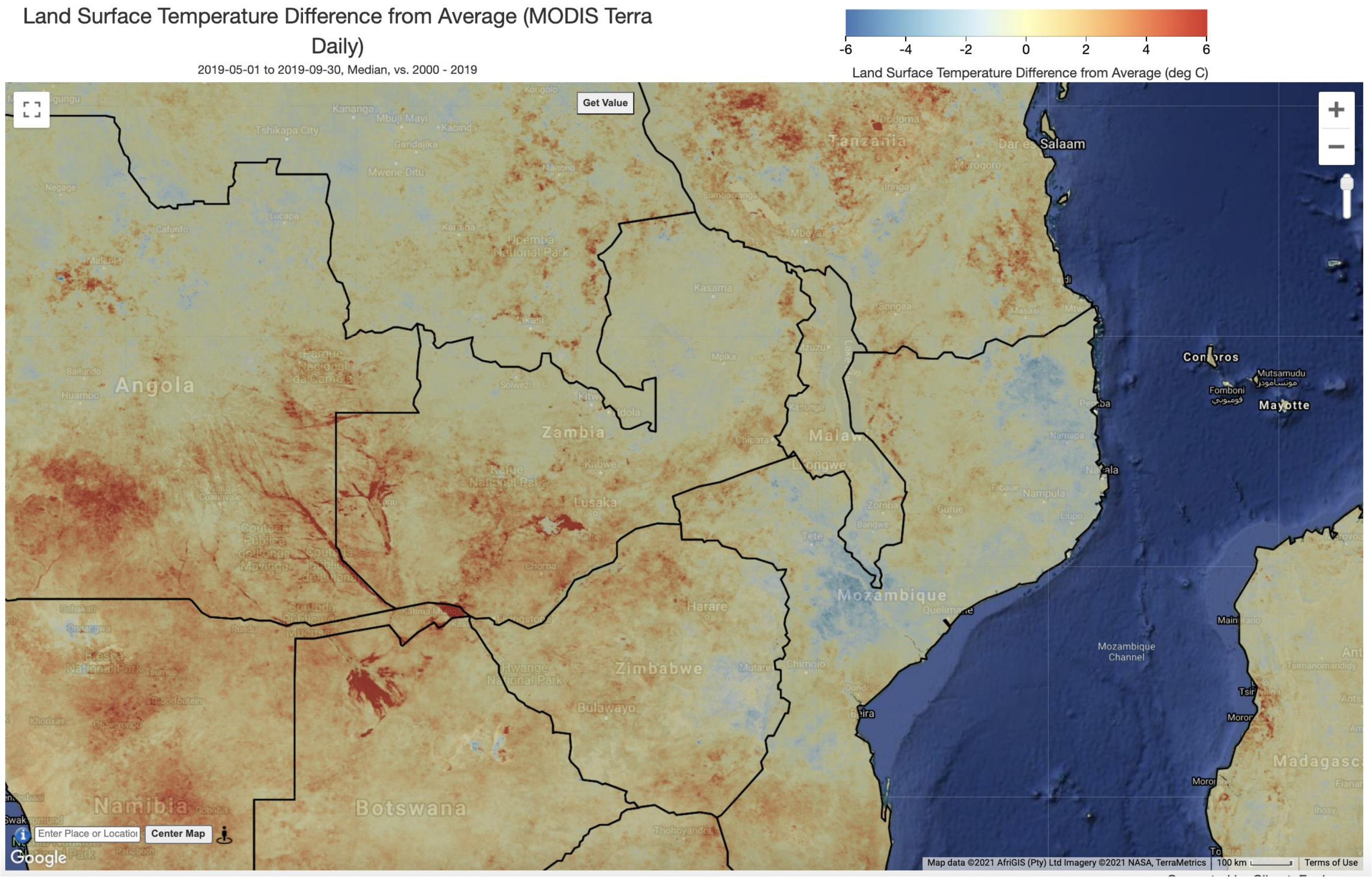
MODIS NDVI percent difference from average conditions compared to other wet seasons from 2000-2019



Land Surface Temperature for 2019 Dry Season

May 1, 2019 to September 30, 2019

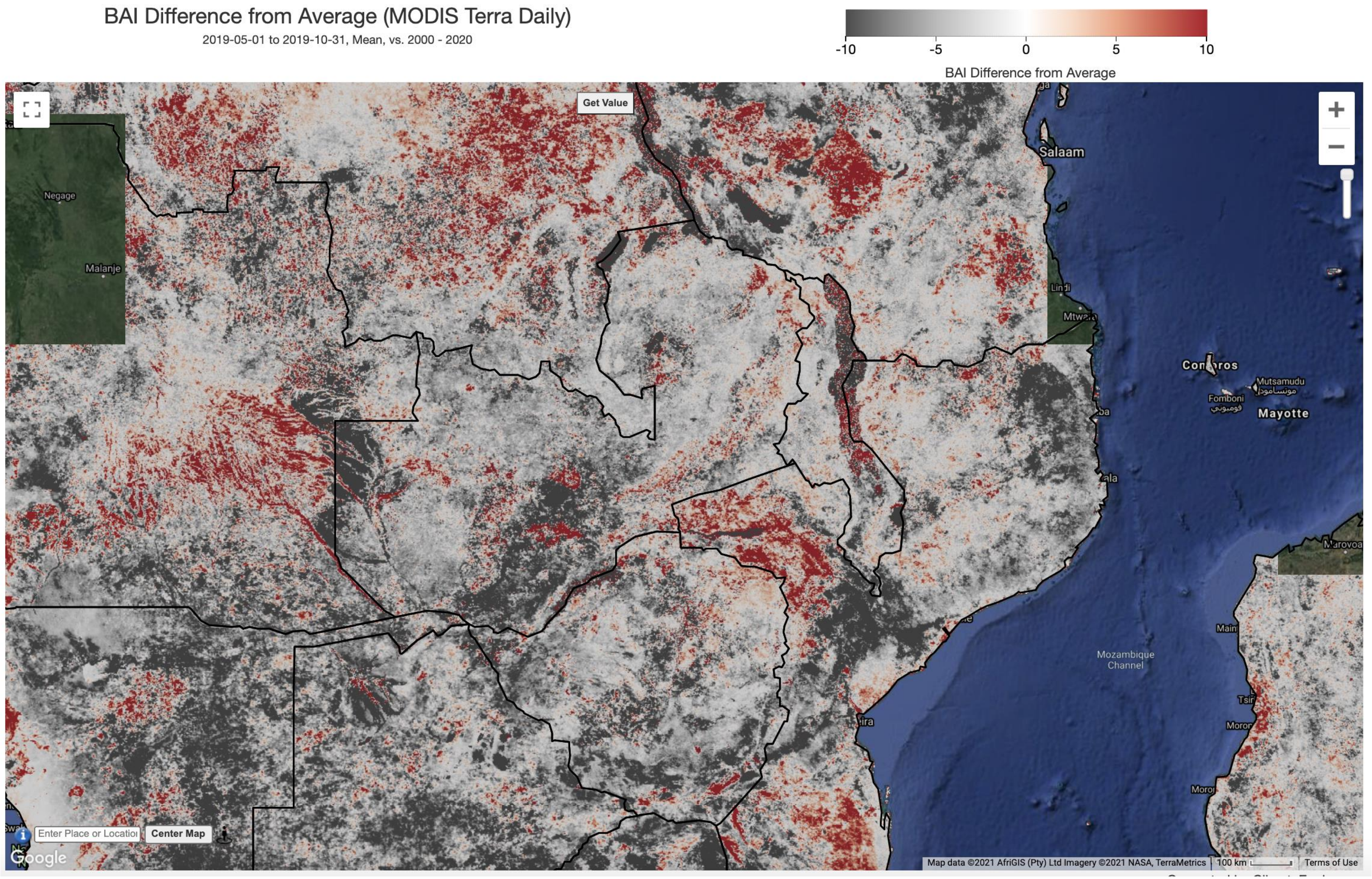
MODIS Land Surface Temperature difference from average conditions compared to other dry seasons from 2000-2019



Burned Area Index Difference from Average

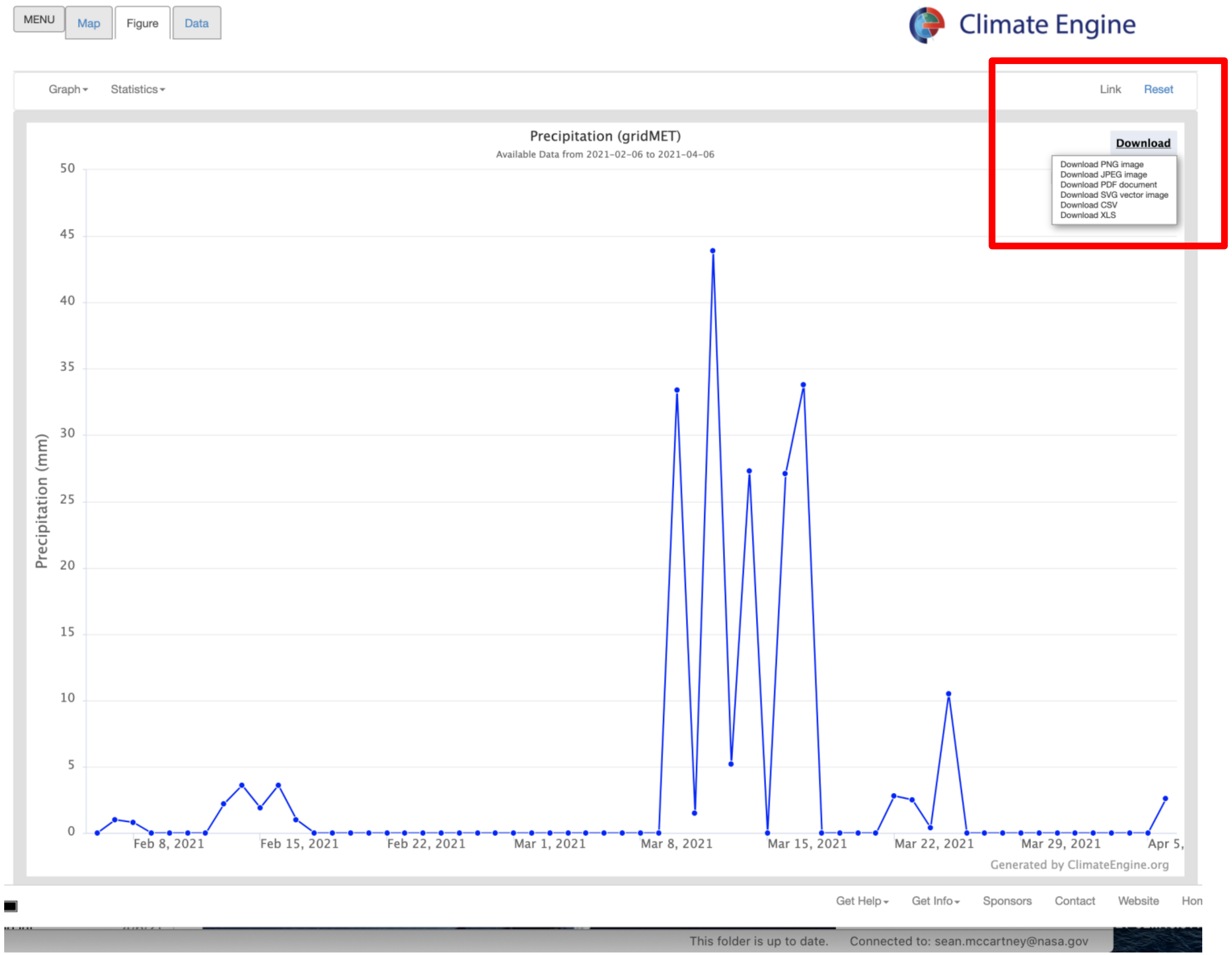
May 1, 2019 to October 31, 2019

MODIS BAI difference from average compared to other dry seasons from 2000-2019



Download and Share

- Download raster data in GeoTIFF format
- Download Graphs as PNG, JPEG, PDF, SVG, CSV, or XLS files
- Share a link to the last successful Map result from Climate Engine



Fire Danger

Robert Field

May 11, 2021

2010 FAO Wildland Fire Management Terminology

Fire Danger: "A general term used to express an assessment of both fixed and variable factors of the fire environment that determine the ease of ignition, rate of spread, difficulty of control, and fire impact."

Fire Danger Rating: "A component of a fire management system that integrates the effects of selected fire danger factors into one or more qualitative indices of current protection needs."

Credit: Dr. Veerachai Tanpipat
ASEAN Wildland Fire Special Research Unit

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.

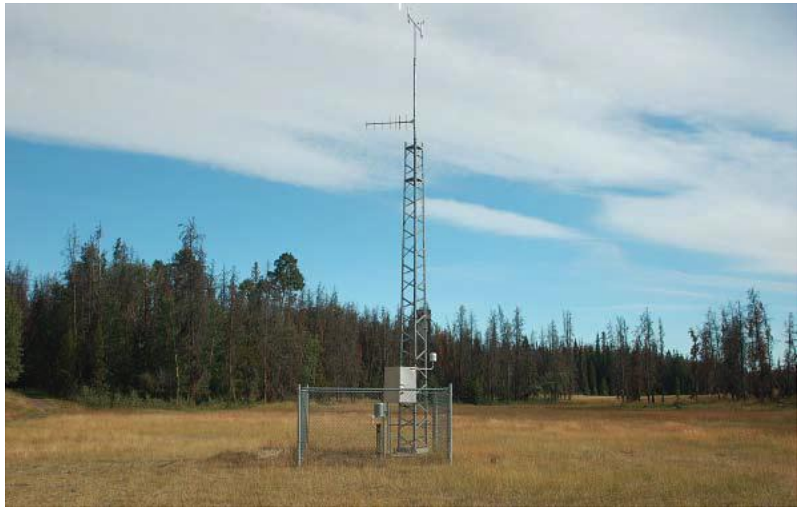
- Fire danger is distinct from **fire threat** (which includes negative impacts) or **fire occurrence prediction** (which includes sources of ignition).

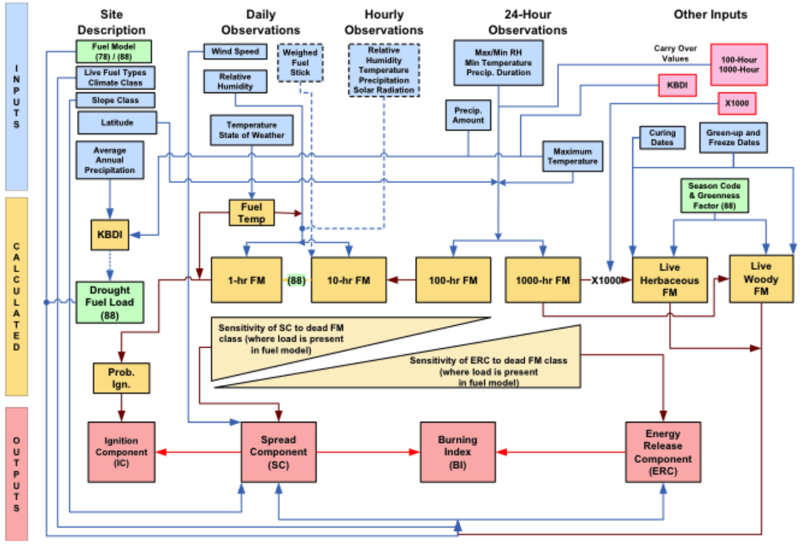
August 2007 experimental savannah fire on flat terrain in Kruger National Park, South Africa (Wooster et al., 2011, *ACP*)

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

Fire Danger Rating Systems can be Simple or Complicated

- For example:
  - **Crossover Rule of Thumb:** Extreme fire behavior is possible when 2m air temperature (in °C) is greater than relative humidity.
  - **Nesterov Index:** Today's index depends on the temperature, dew point, and number of days since rain.
  - **US National Fire Danger Rating System:** Energy Release Component depends on temperature, humidity, precipitation, wind speed, solar radiation, topography, state-of-weather, and the choice from 40 fuel types.
- All are useful and can be combined with other data.

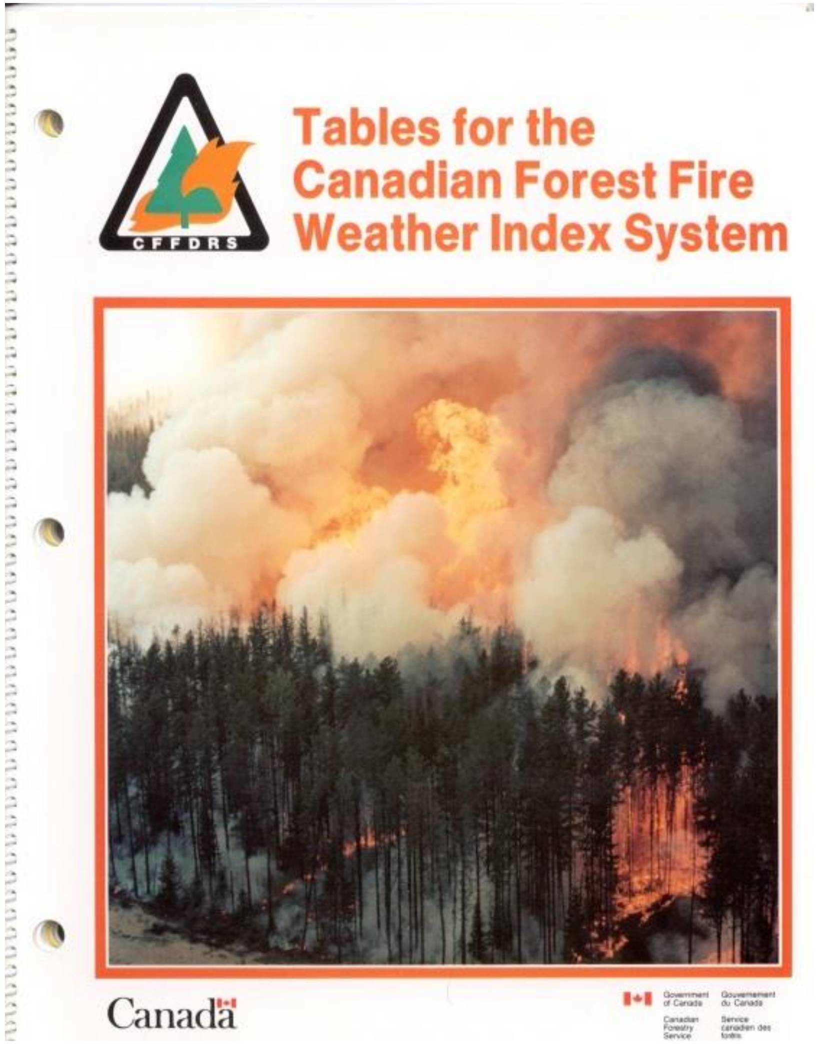




[Structure of the US National Fire Danger Rating System](#)

The Canadian Fire Weather Index (FWI) System

- It is an accounting system that tracks the moisture content of different fuel sizes and the potential fire behavior in a generic fuel type.
- Today's fire danger depends on past and present temperature, humidity, wind speed, and precipitation.
- It is designed to produce a maximum amount of information with a minimum amount of data.
- It is the most widely used fire danger rating system in the world.



FWI System Moisture Codes

- Fine Fuel Moisture Code (**FFMC**): A numerical rating of the moisture content of litter and other cured fine fuels. This code indicates the relative ease of ignition and flammability of fine fuel.

- Duff Moisture Code (**DMC**): A numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. This code indicates fuel consumption in moderate duff layers and medium-sized woody material.

- Drought Code (**DC**): A numerical rating of the average moisture content of deep, compact, organic layers. This code indicates seasonal drought effects on forest fuels and the amount of smoldering in deep duff layers and large logs.

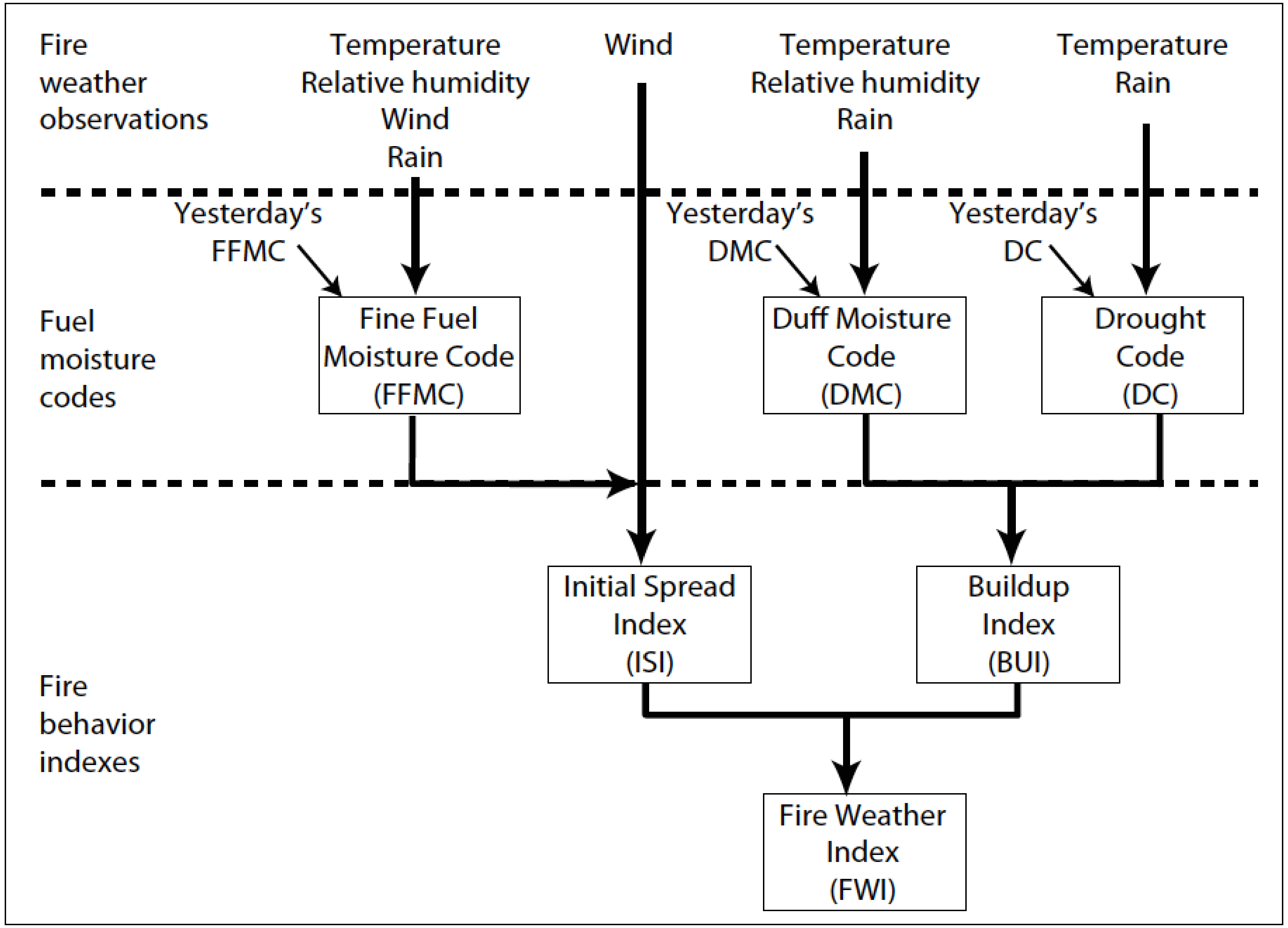
FWI System Fire Behavior Indices

- Initial Spread Index (**ISI**): A numerical rating of the expected rate of fire spread. It combines the effects of wind and FFMC on rate of spread but excludes the influence of variable quantities of fuel.

- Buildup Index (**BUI**): A numerical rating of the total amount of fuel available for combustion that combines DMC and DC.

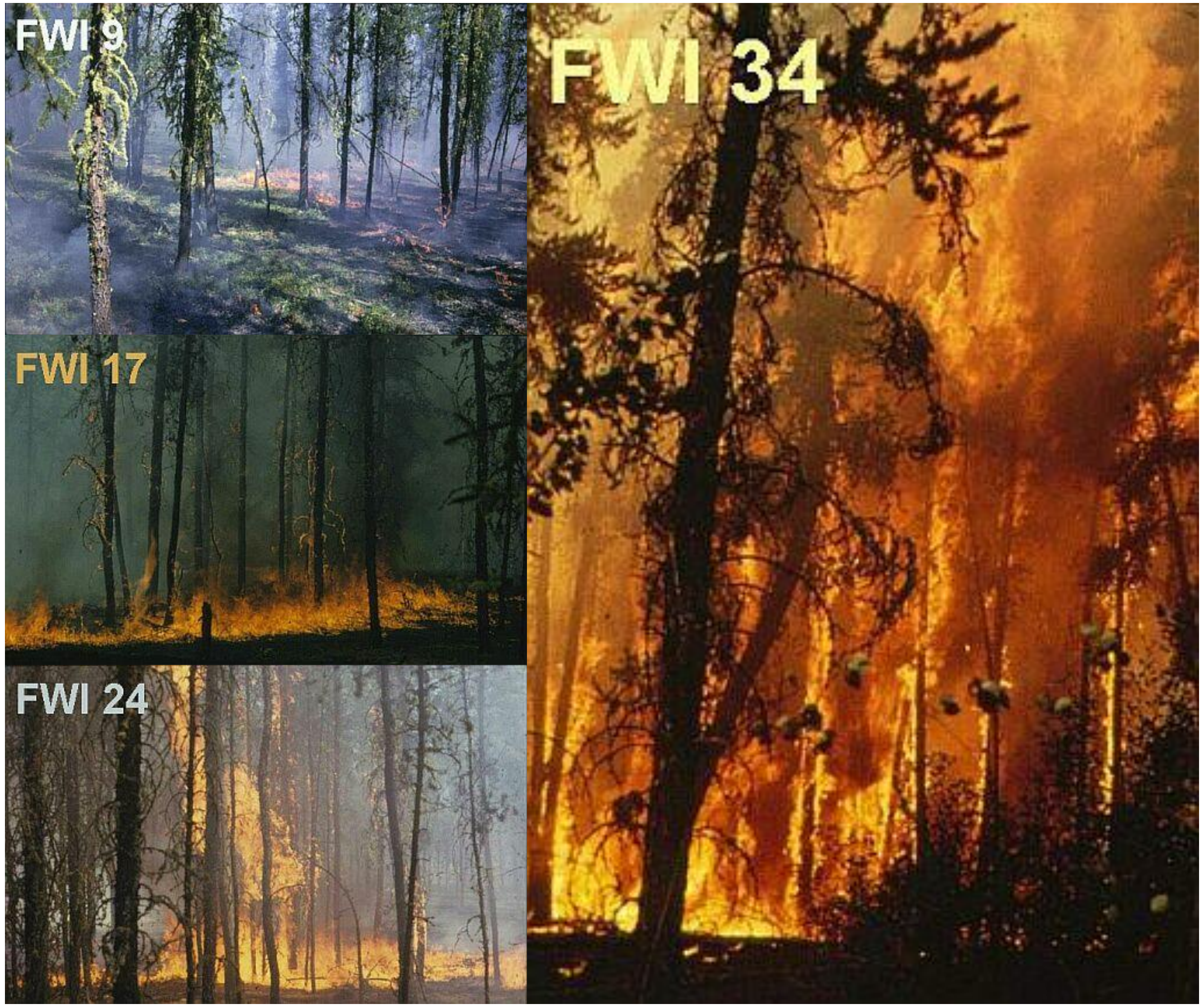
- Fire Weather Index (**FWI**): A numerical rating of fire intensity that combines ISI and BUI. It is suitable as an overall index of fire danger. The FWI component tracks closely with the 'Burning Index' of the US National Fire Danger Rating System.

FWI System Structure



[Lawson, B. D. and Armitage, O. B.: Weather guide for the Canadian Forest Fire Danger Rating System, Northern Forestry Centre, Edmonton, Canada, 73, 2008.]

FWI-Based Decision Aids

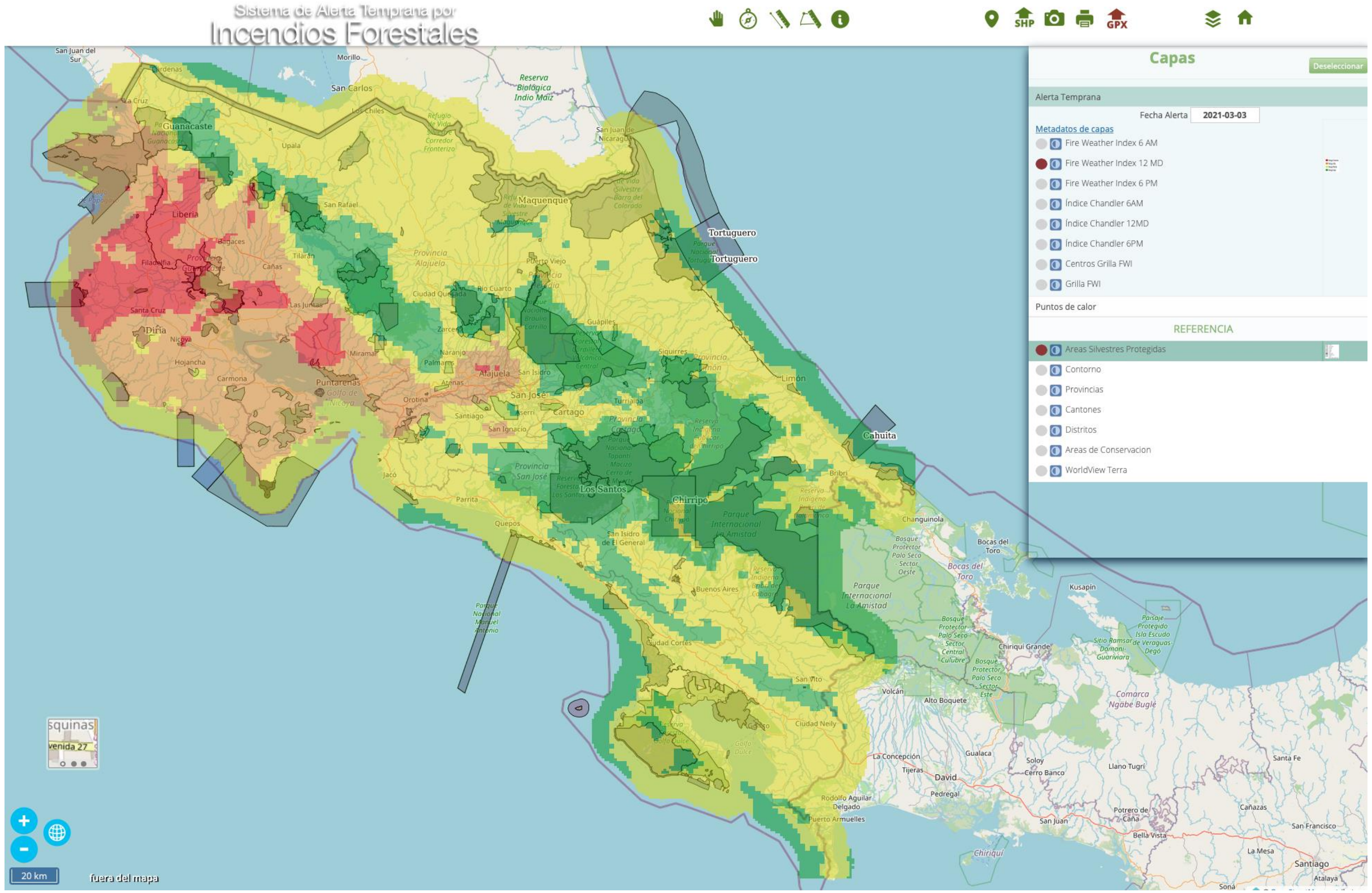


Fire behavior characteristics and fire suppression interpretations associated with the Fire Intensity Classes in Graph 2

Fire Intensity Class	Frontal fire intensity (kW/m)	Surface head fire[1] Flame length (m)	Surface head fire[1] Flame height (m)	Type of fire and fire suppression difficulty	Fire Weather Index[2] (FWI)
1	<10	<0.2	<0.1	Firebrands that cause an ignition to occur are self-extinguishing (i.e., fire fails to spread). Going fires remain of the smouldering ground or subsurface variety, provided there is a forest floor layer of significant depth and a general level of dryness[3]. Extensive mop-up is generally required.	0-3
2	10-500	0.2-1.4	0.1-1.0	Creeping or gentle surface fire. Direct manual attack at fire's head or flanks by firefighters with hand tools and water is possible. Constructed fireguard should hold.	4-13
3	500-2000	1.4-2.6	1.0-1.9	Low vigor to moderately or highly vigorous surface fire. Hand-constructed fireguards likely to be challenged. Heavy equipment (bulldozers, pumpers, retardant aircraft, skimmers, helicopter with bucket) generally successful in controlling fire.	14-23
4	2000-4000	2.6-3.5	1.9-2.5	Very vigorous or extremely intense surface fire (torching common). Control efforts at fire's head may fail.	24-28
5	>4000	>3.5	>2.5	Intermittent crown fire[4] to active crown fire development (at >10 000 kW/m)[5]. Very difficult to control. Suppression action must be restricted to fire's flanks. Indirect attack with aerial ignition (i.e., helitorch and/or A.I.D. dispenser) may be effective.	≥29

Alexander, M.E.; De Groot, W.J. 1988. Fire behavior in jack pine stands as related to the Canadian Forest Fire Weather Index System. Canadian Forest Service, Northern Forestry Centre, Edmonton, AB. Poster with text.

Local FWI Adaptation: Focus on Protected Areas in Costa Rica

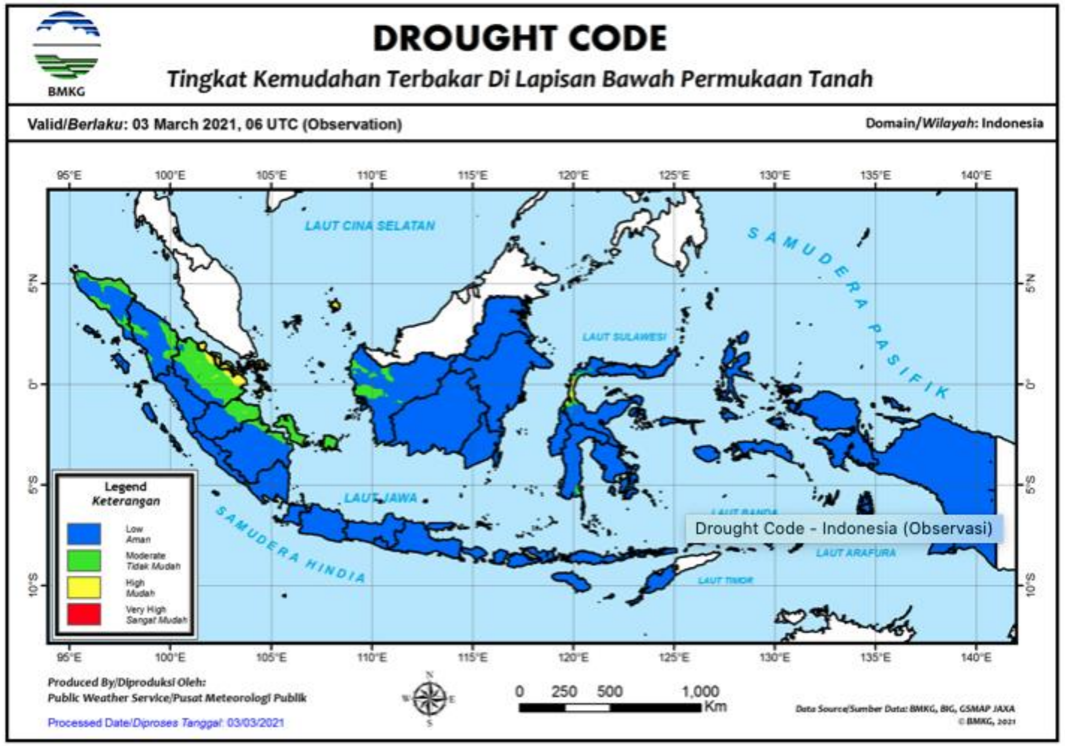


SINAC (Sistema Nacional de Áreas de Conservación / National System of Conservation Areas): https://gestion.incendiosforestales.cr/mapa/mapa

Local FWI Adaptation: Focus on Smoke-Haze in Indonesia

Drought Code

Indonesia (Observasi)



Drought Code (DC)

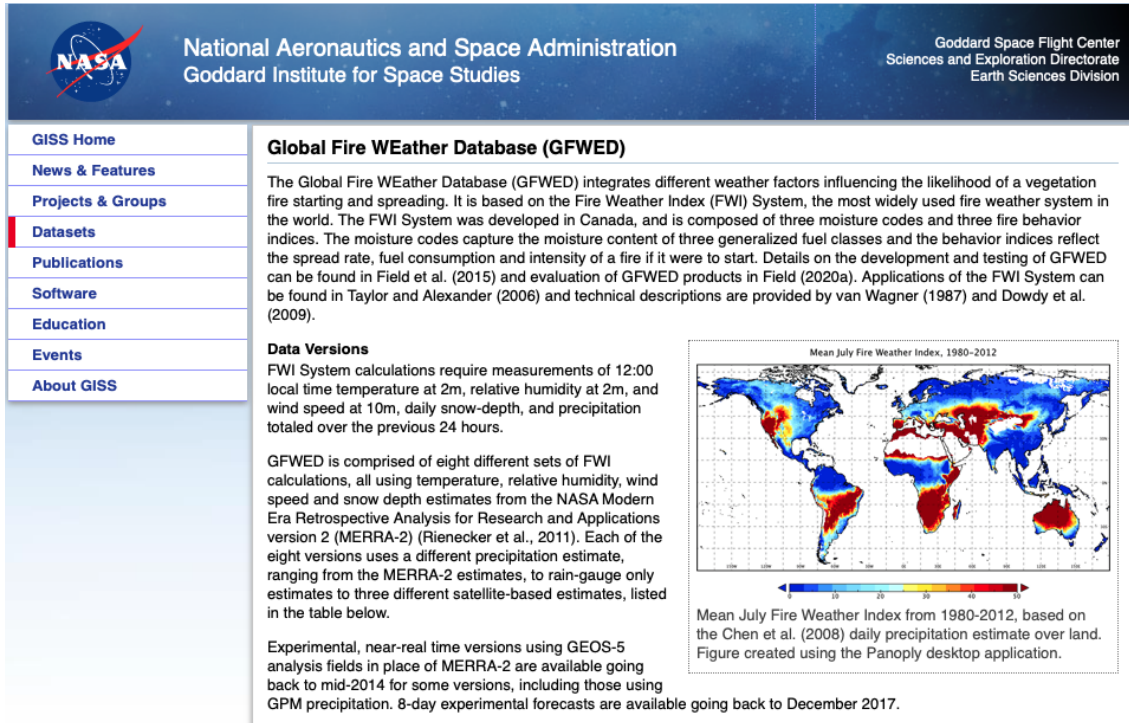
- DC menunjukkan tingkat potensi kemudahan terjadinya kebakaran ditinjau dari parameter cuaca pada bahan organik padat di lapisan bawah permukaan tanah dan bahan-bahan kayu berat (seperti gelondongan kayu) di permukaan tanah.
- Mewakili tingkat kekeringan lapisan tanah organik padat yang biasanya berada pada kedalaman >10 cm dan juga mewakili tingkat kekeringan bahan-bahan kayu berat (seperti gelondongan kayu) di permukaan tanah.

Warna	Rentang	Deskripsi
Biru	0 - 140	Kondisi lapisan permukaan tanah bagian bawah dalam kondisi **basah**. Perlu waktu lebih dari 4 pekan tanpa hujan untuk mencapai kondisi sangat kering.
Hijau	141 - 260	Kondisi lapisan permukaan tanah bagian bawah dalam kondisi **lembab**. Perlu waktu setidaknya 2 pekan tanpa hujan untuk mencapai kondisi sangat kering.
Kuning	261 - 350	Kondisi lapisan permukaan tanah bagian bawah dalam kondisi **kering**. Kekeringan mulai terjadi, pengawasan kegiatan pembakaran lahan perlu diperketat. Jika dalam kurun waktu 5 - 7 hari ke depan tidak terjadi hujan, dapat meningkat menjadi kategori sangat kering
Merah	>350	Kondisi lapisan permukaan tanah bagian bawah dalam kondisi **sangat kering**. Kekeringan mulai mencapai kondisi ekstrim, pelarangan kegiatan pembakaran lahan perlu digalakkan. *) Berdasarkan catatan historis, kondisi kabut asap sangat parah di Indonesia terjadi dalam rentang nilai ini.

BMKG (Badan Meteorologi, Klimatologi dan Geofisika/Indonesian Agency for Meteorology, Climatology and Geophysics)
https://www.bmkg.go.id/cuaca/kebakaran-hutan.bmkg

Global Fire Weather Database (GFWED)

- GFWED is a small ensemble of FWI calculations, meeting the global fire research and management communities' needs for consistent and complete fire danger data.
- Weather inputs come from weather reanalysis, weather forecasts, rain gauges, and satellites.
- The highest resolution is at 0.1° × 0.1° using NASA IMERG precipitation data.
- There are daily and monthly files in NetCDF format.


National Aeronautics and Space Administration
Goddard Institute for Space Studies

Goddard Space Flight Center
Sciences and Exploration Directorate
Earth Sciences Division

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Global Fire WEather Database (GFWED)

The Global Fire WEather Database (GFWED) integrates different weather factors influencing the likelihood of a vegetation fire starting and spreading. It is based on the Fire Weather Index (FWI) System, the most widely used fire weather system in the world. The FWI System was developed in Canada, and is composed of three moisture codes and three fire behavior indices. The moisture codes capture the moisture content of three generalized fuel classes and the behavior indices reflect the spread rate, fuel consumption and intensity of a fire if it were to start. Details on the development and testing of GFWED can be found in Field et al. (2015) and evaluation of GFWED products in Field (2020a). Applications of the FWI System can be found in Taylor and Alexander (2006) and technical descriptions are provided by van Wagner (1987) and Dowdy et al. (2009).

Data Versions

FWI System calculations require measurements of 12:00 local time temperature at 2m, relative humidity at 2m, and wind speed at 10m, daily snow-depth, and precipitation totaled over the previous 24 hours.

GFWED is comprised of eight different sets of FWI calculations, all using temperature, relative humidity, wind speed and snow depth estimates from the NASA Modern Era Retrospective Analysis for Research and Applications version 2 (MERRA-2) (Rienecker et al., 2011). Each of the eight versions uses a different precipitation estimate, ranging from the MERRA-2 estimates, to rain-gauge only estimates to three different satellite-based estimates, listed in the table below.

Mean July Fire Weather Index from 1980-2012, based on the Chen et al. (2008) daily precipitation estimate over land. Figure created using the Panoply desktop application.

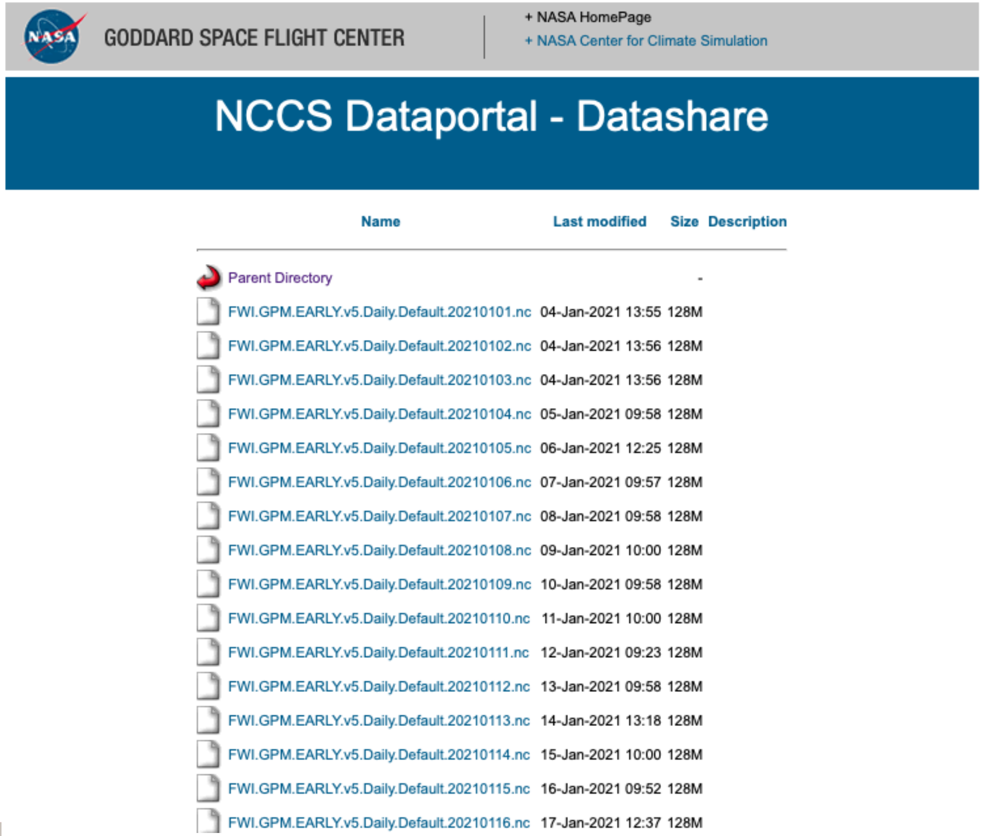
Experimental, near-real time versions using GEOS-5 analysis fields in place of MERRA-2 are available going back to mid-2014 for some versions, including those using GPM precipitation. 8-day experimental forecasts are available going back to December 2017.

https://data.giss.nasa.gov/impacts/gfwed/

GFWED Public Availability

NASA Center for Climate Simulation Dataportal
https://portal.nccs.nasa.gov/datashare/GlobalFWI/

NASA Panoply software can be used to make maps:
https://www.giss.nasa.gov/tools/panoply/



Name	Last modified	Size	Description
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FWI.GPM.EARLY.v5.Daily.Default.20210101.nc	04-Jan-2021 13:55	128M	
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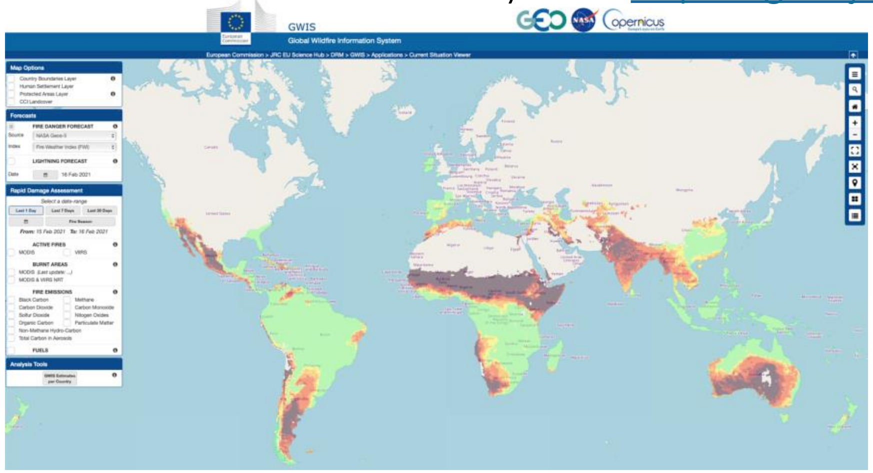
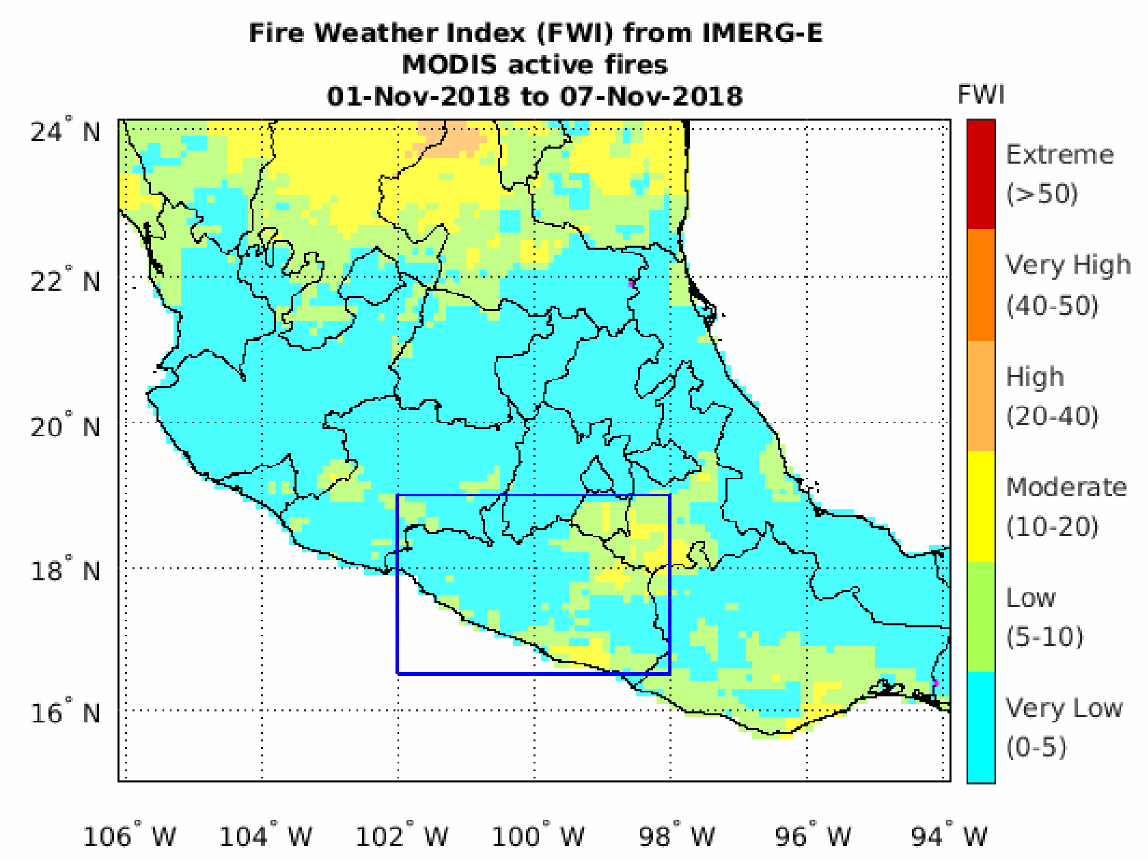
Global Wildfire Information System: https://gwis.jrc.ec.europa.eu

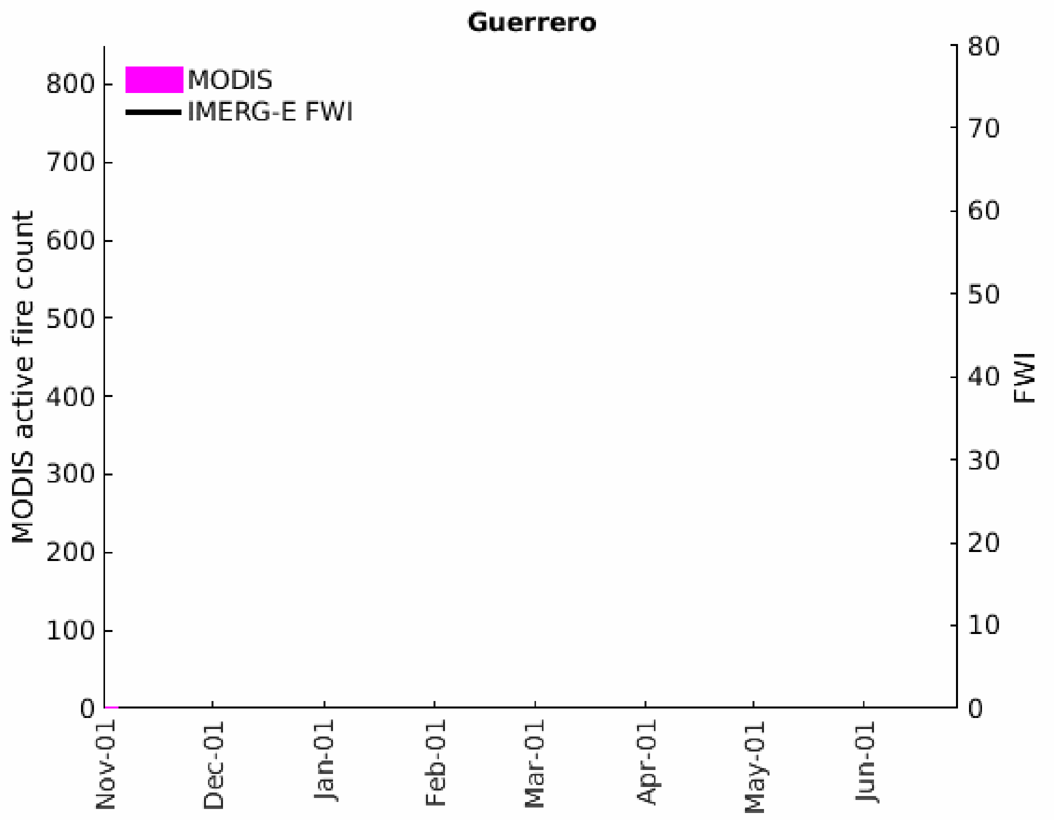


WRI Resource Watch: https://resourcewatch.org

Example: 2019 Fire Season in Southwest Mexico

How does weekly MODIS fire activity track with FWI?

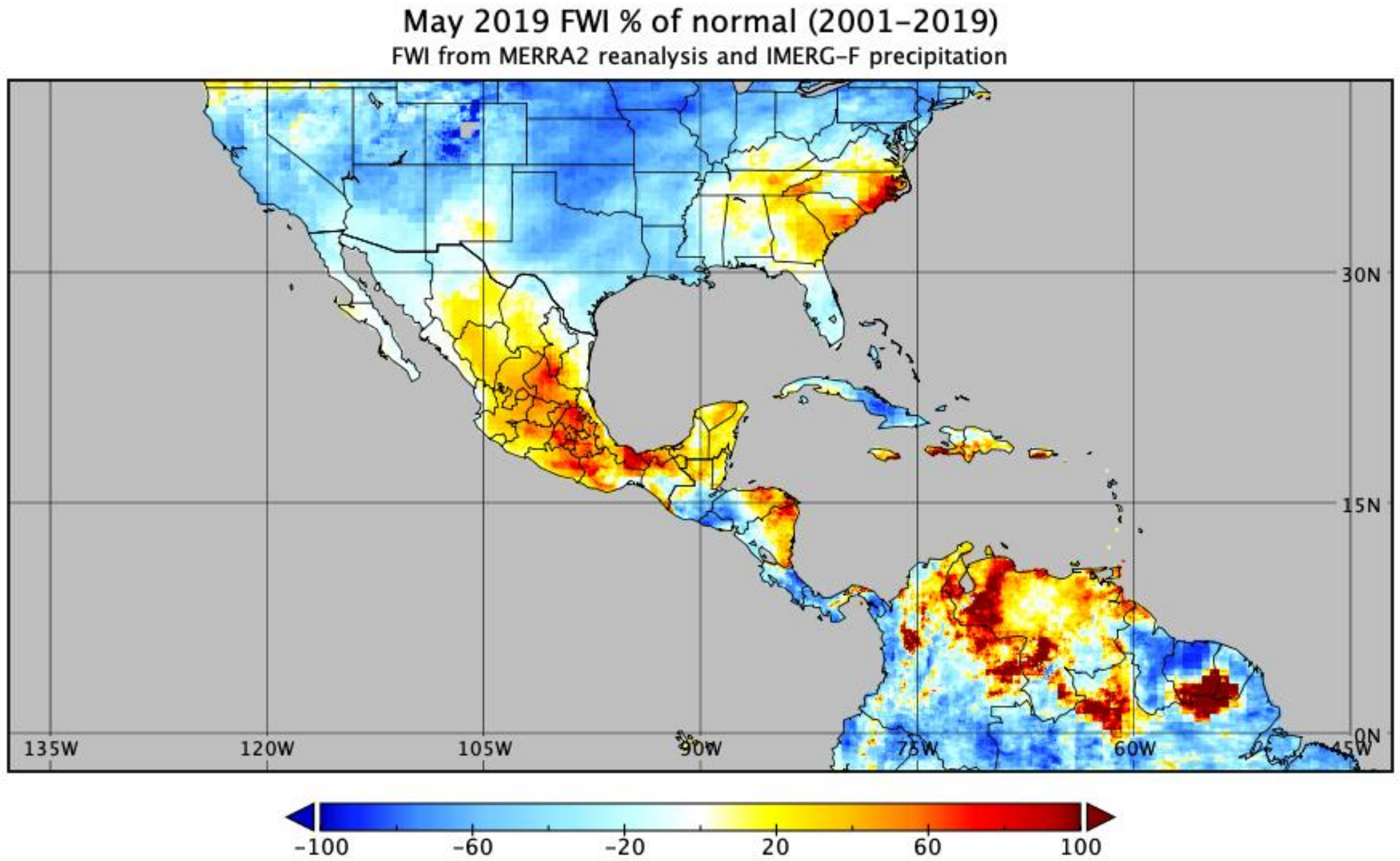




FWI categories from Global Wildland Information System
https://gwis.jrc.ec.europa.eu/about-gwis/technical-background/fire-danger-forecast

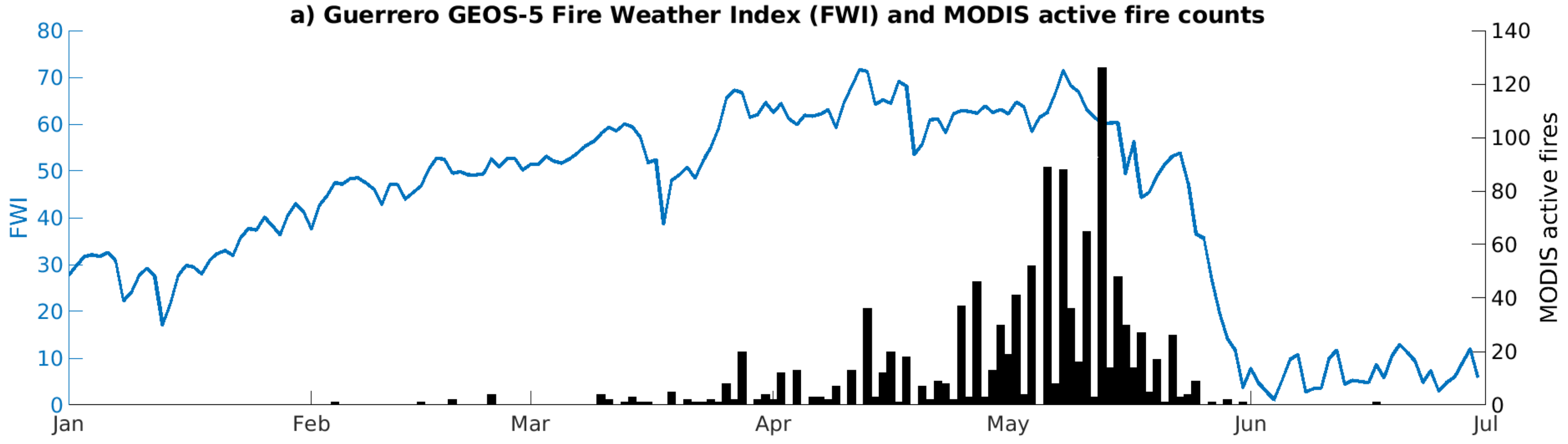
May 2019 FWI Anomaly in Context

Monthly and long-term mean files can be used to make simple anomaly maps.

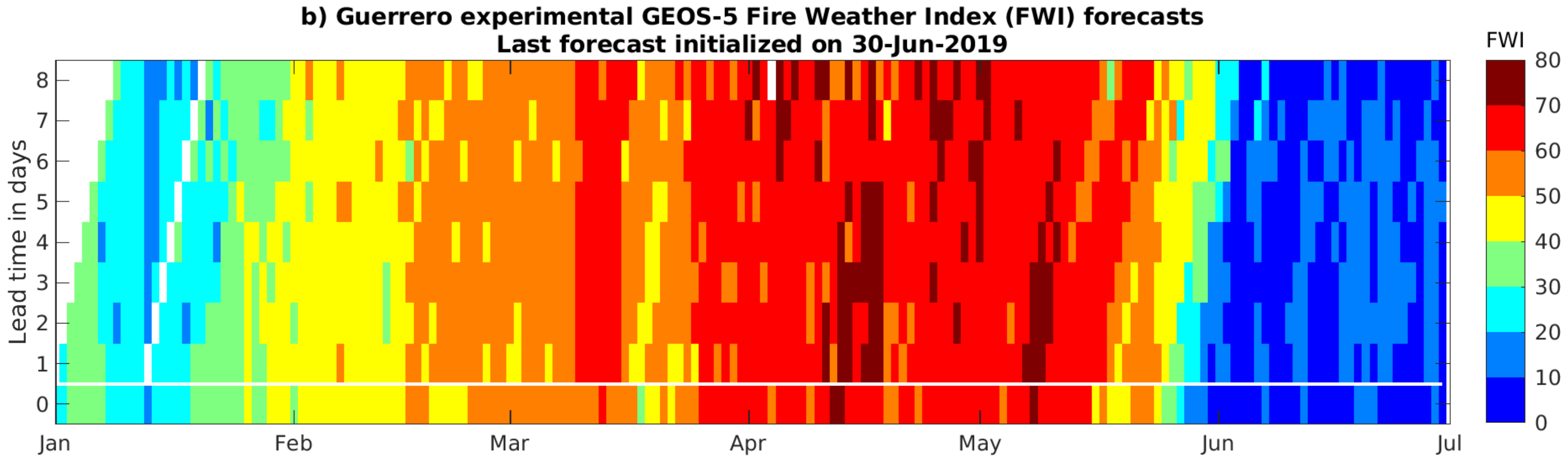


Made using NASA GISS Panoply: https://www.giss.nasa.gov/tools/panoply/

8-Day 2019 FWI Forecasts for Guerrero



Widespread fire activity starts when FWI is consistently > 50.



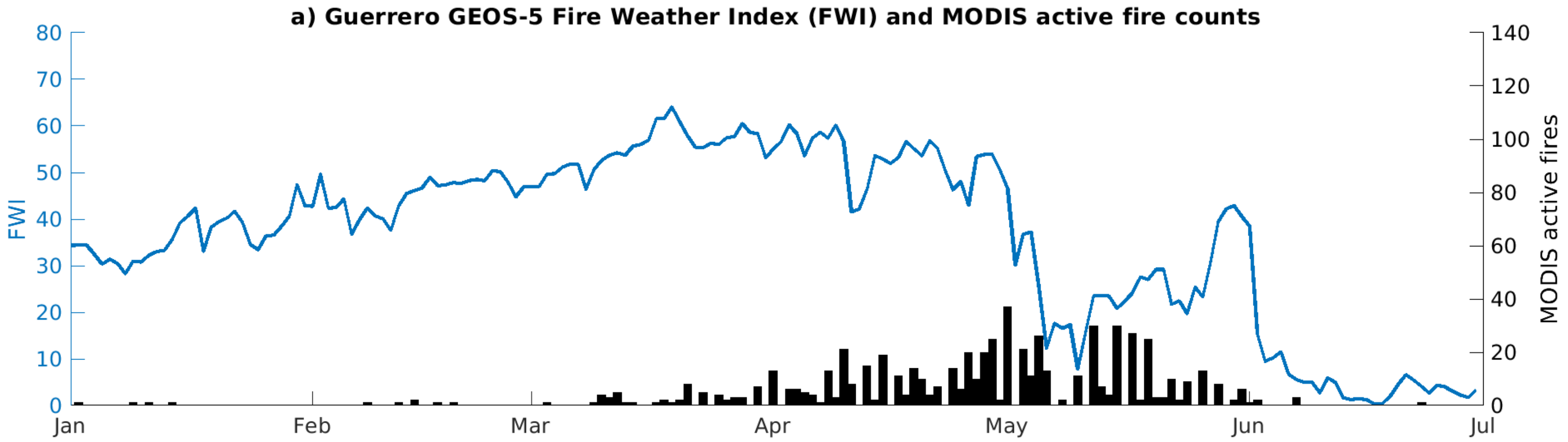
The bottom row is the same as the FWI in the panel above, but on a color scale.

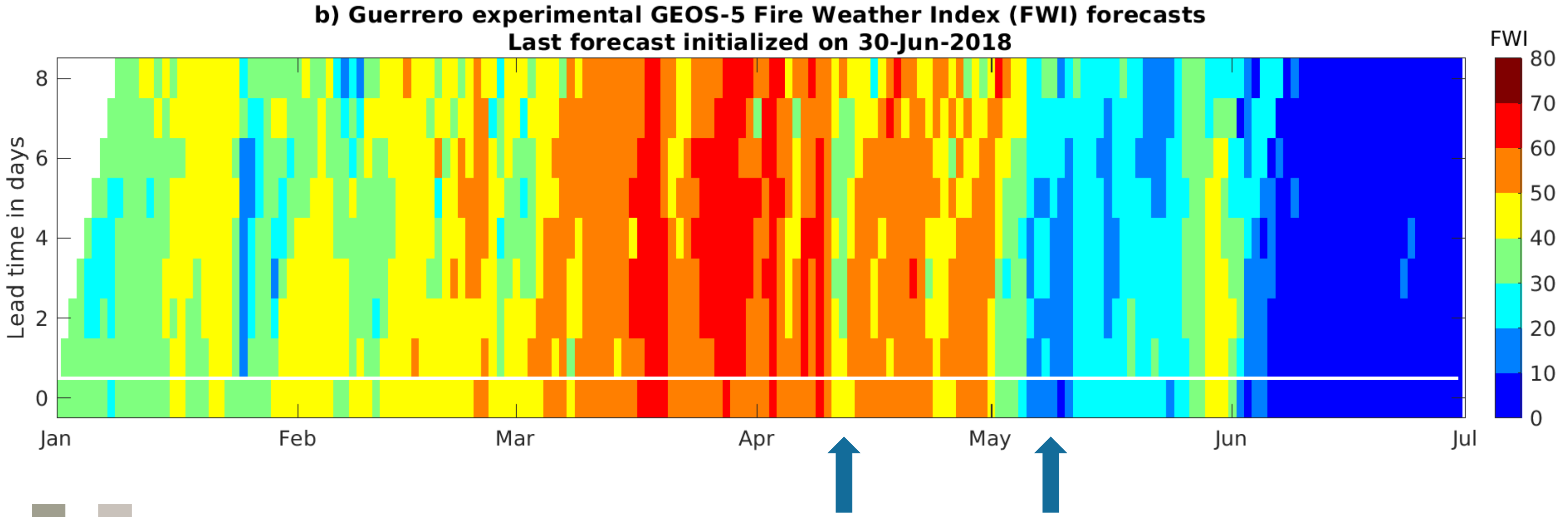
The rows above show the forecasts at different lead times.

A perfect forecast would appear as a vertical line with the same color.

Over Guerrero, there is a slight high bias, but the forecasts anticipate changes in FWI.

8-Day 2018 FWI Forecasts for Guerrero



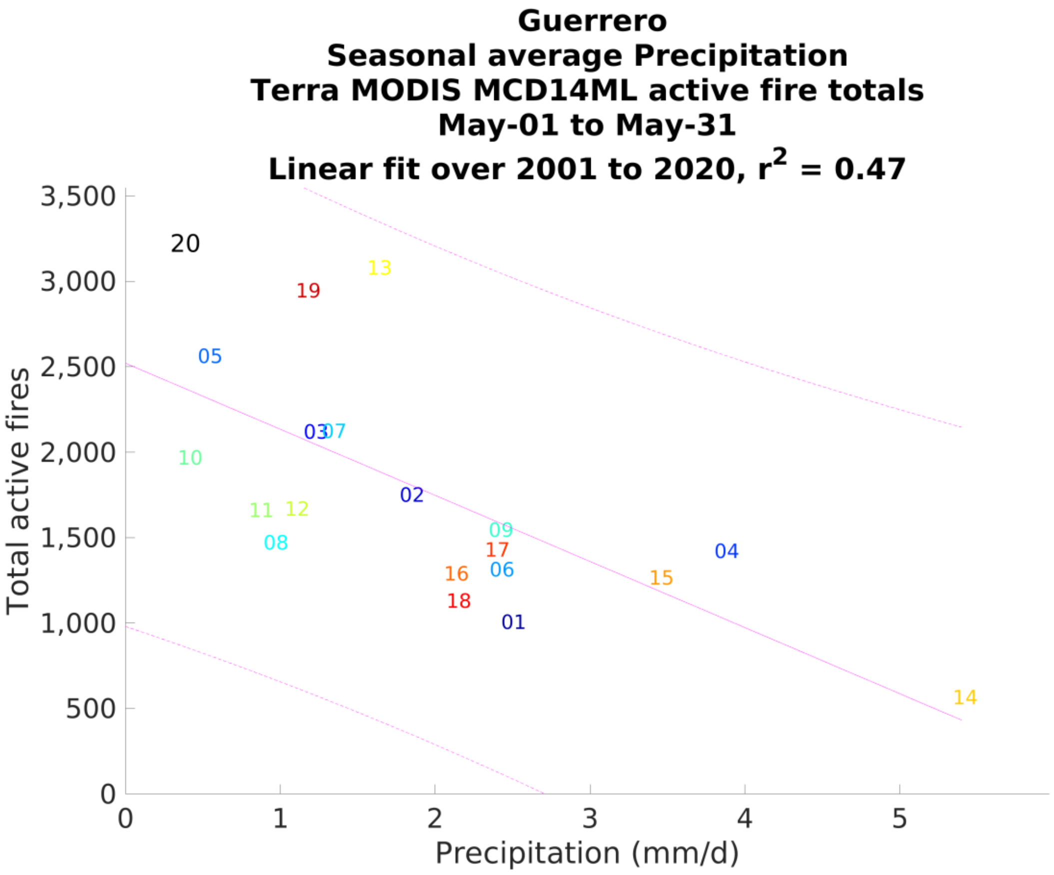


In 2018, there was lower FWI and less fire activity.

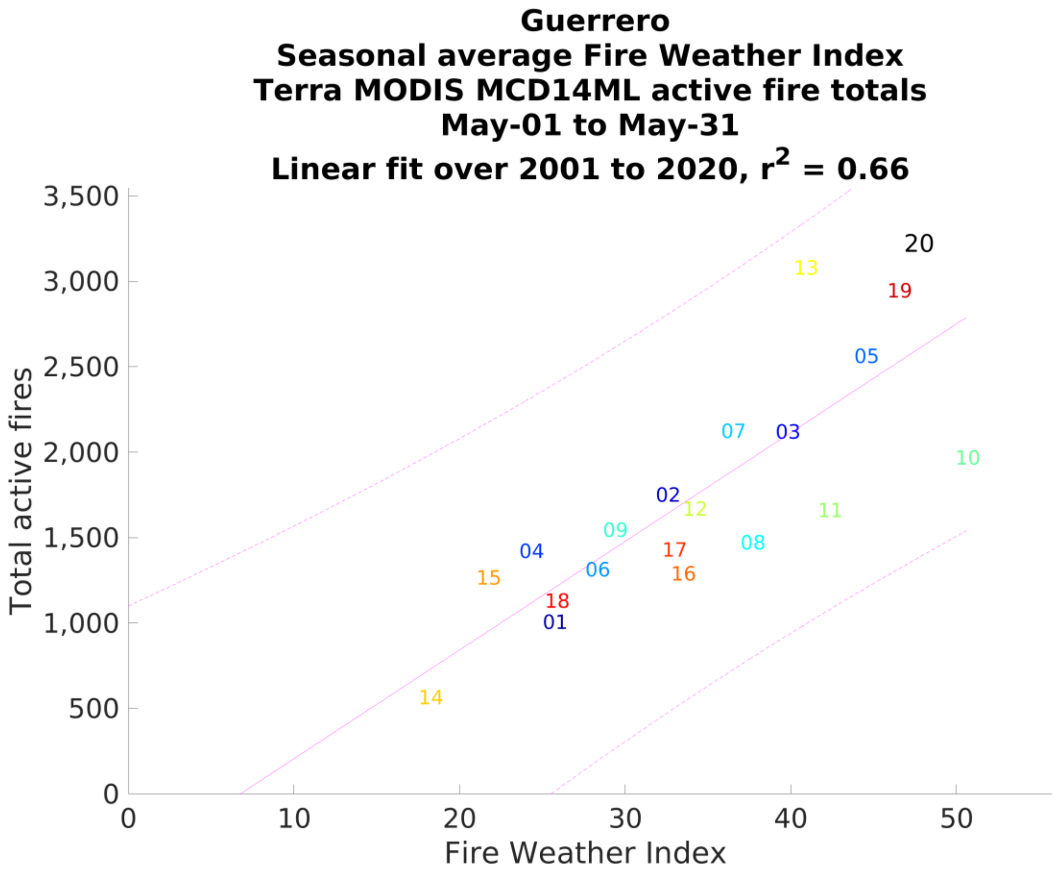
The quieter year is captured by the FWI forecasts, including precipitation in early April, and in mid-May, which ended the fire season.

2001-2020 Analysis of May MODIS Active Fires and FWI in Guerrero

May precipitation explains 47% of May fire activity in Guerrero.



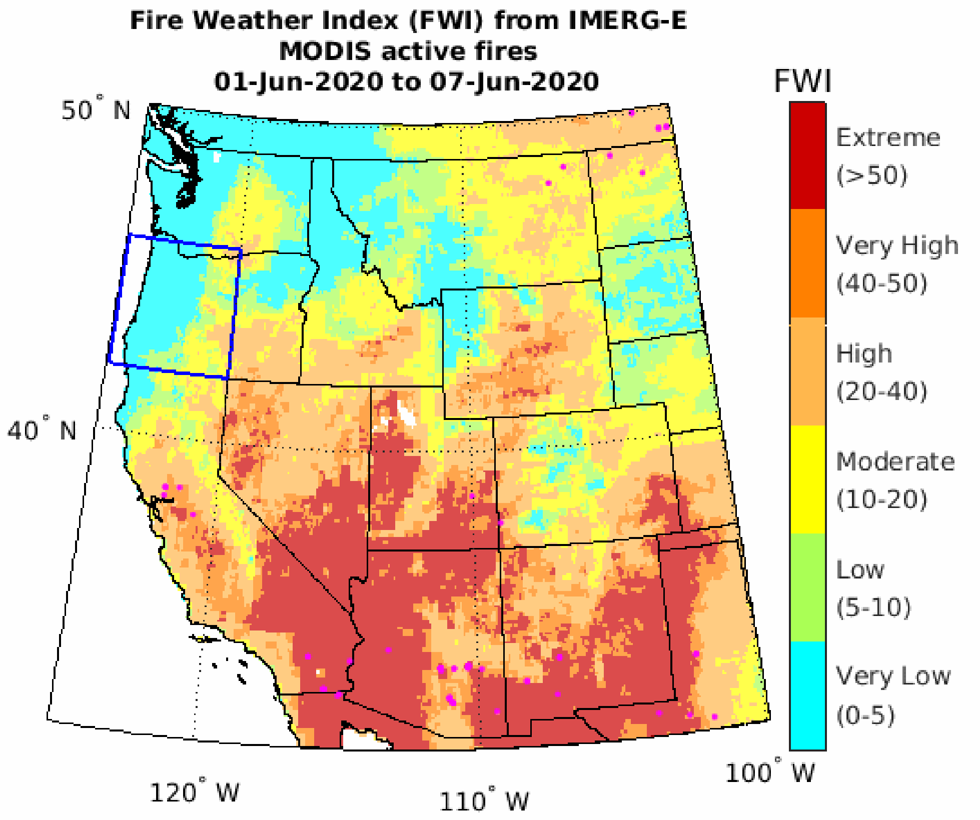
May FWI explains 66% of May fire activity in Guerrero.

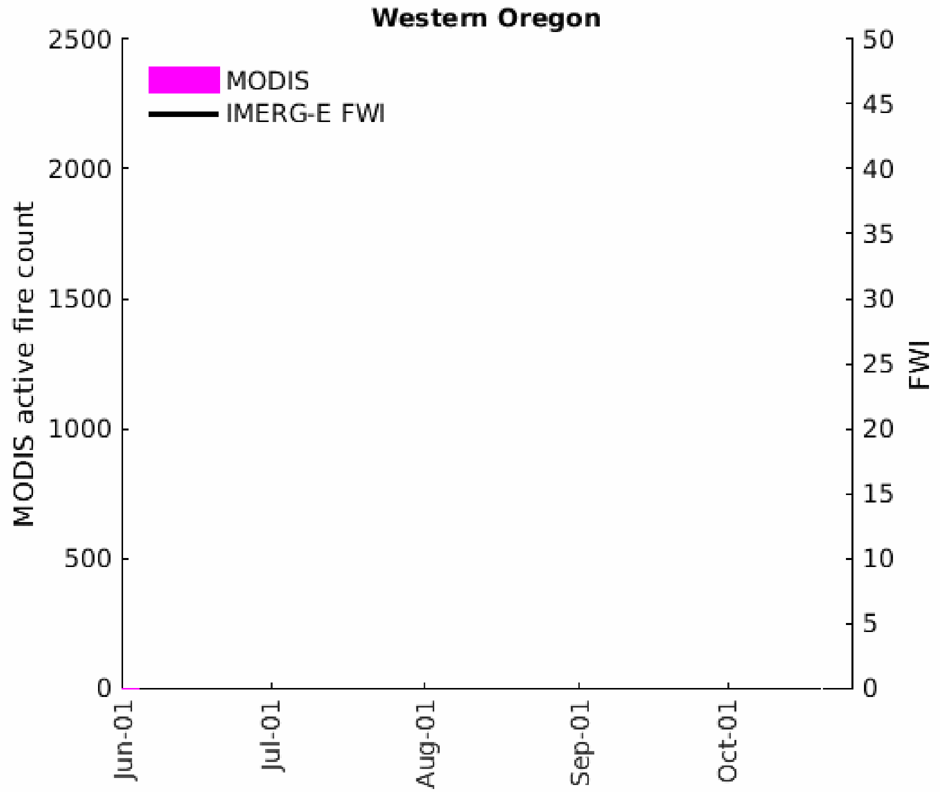


See how this compares to other regions in Abatzaglou et al. (2018, *Global Change Biology*)

Example: 2020 Western US Fire Season

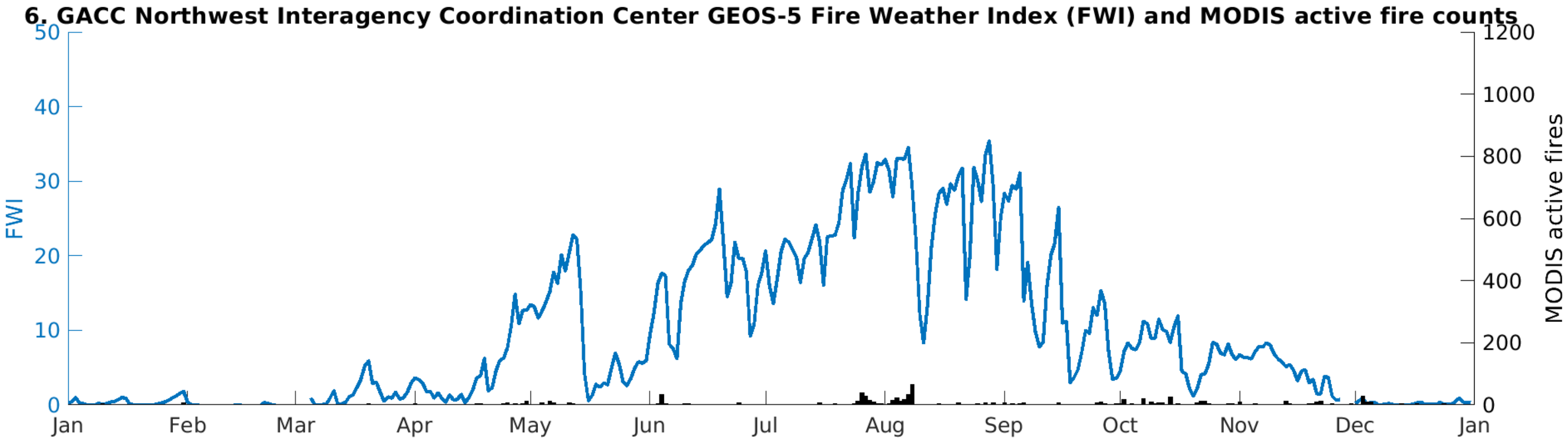
- How does weekly MODIS fire activity track with FWI?



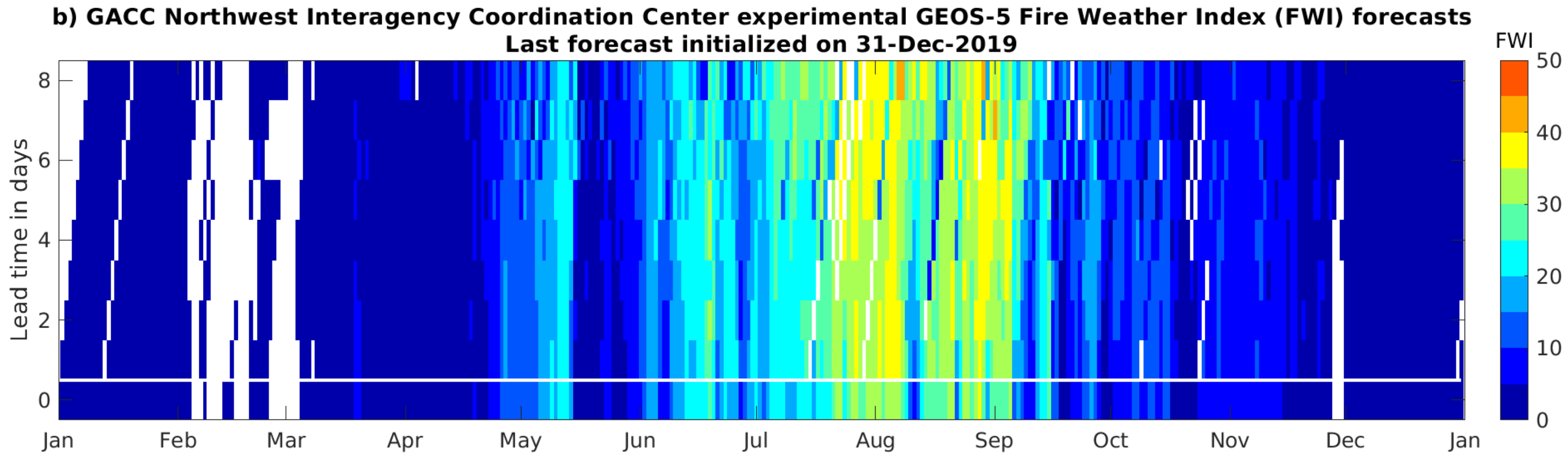


Note: The FWI tracks closely with the US National Fire Danger Rating System 'Burning Index'.

8-Day 2019 FWI Forecasts for National Interagency Fire Center Northwest Region

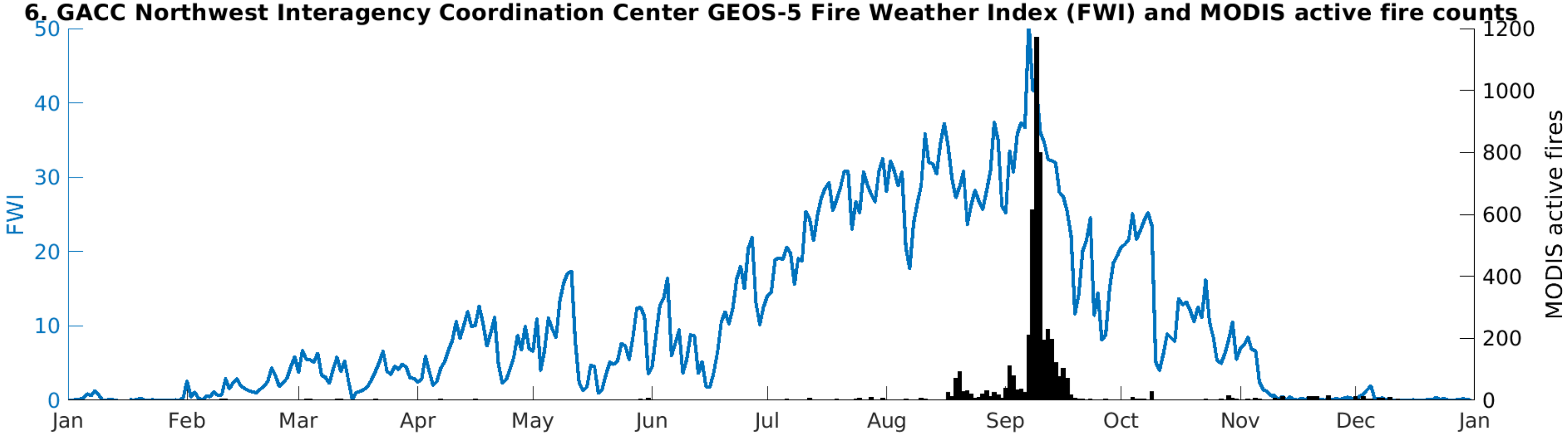


2019 was a quiet fire year over the NIFC Northwest Interagency Coordination region (Washington and Oregon). Rain in early May and mid-August prevented the FWI from climbing much higher than 30 during the summer.

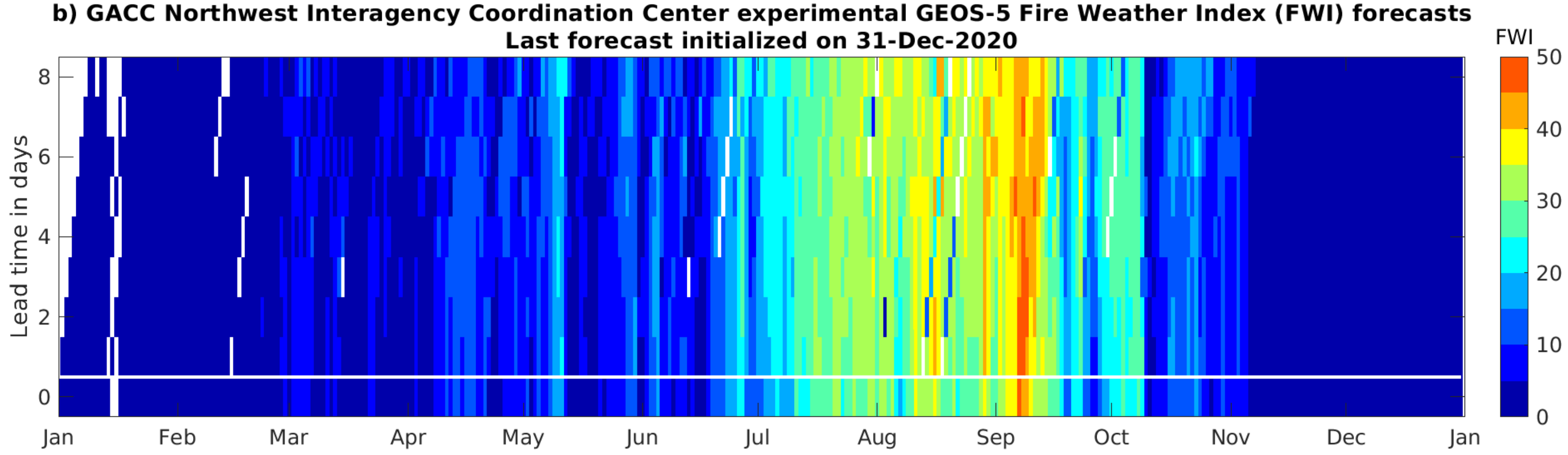


The May precipitation was well-forecast a week before. The August precipitation was well forecast 5 days before.

8-Day 2020 FWI Forecasts for National Interagency Fire Center Northwest Region



2020 was a very active fire year. May and June were wetter than 2019, but a dry July allowed the FWI to climb through the month. There was brief rain in early August, but not enough to lower the FWI.



The early September peak in FWI was well forecast a week before. This peak was due to strong winds and a drier than normal August.

Resources

- FAO Wildland Fire Management Terminology: http://www.fao.org/faoterm/en/?defaultCollId=13
- Introduction to the Canadian Fire Weather Index System: https://www.youtube.com/watch?v=mdeM-cBCQJA
- Global Fire Weather Database, including MATLAB code: https://data.giss.nasa.gov/impacts/gfwed/
- Canadian Forest Service FWI code in FORTRAN 95, C, C++, Python, Java and SAS/IML https://cfs.nrcan.gc.ca/publications?id=36461
- NOAA NCEI Integrated Surface Database of global, hourly weather data: https://www.ncdc.noaa.gov/isd
- Climate Toolbox for Wildfire, including NRT FWI and NFDRS products for US: https://climatetoolbox.org/wildfire

References

Cardil, A. M. Rodrigues, J. Ramirez, S. de-Miguel, C.A. Silva, M. Mariani, 2021: Coupled effects of climate teleconnections on drought, Santa Ana winds and wildfires in southern California, SCIENCE OF THE TOTAL ENVIRONMENT, 765, 10.1016/j.scitotenv.2020.142788.

Eriksen, C. 2007: Why do they burn the 'bush'? Fire, rural livelihoods, and conservation in Zambia. Geographical Journal 173: 242-256.

Fasullo, J. T., B. L. Otto-Bliesner, S. Stevenson, 2018: ENSO's Changing Influence on Temperature, Precipitation, and Wildfire in a Warming Climate, GEOPHYSICAL RESEARCH LETTERS,

Holden, Zachary A., Alan Swanson, Charles H. Luce, W. Matt Jolly, Marco Maneta, Jared W. Oyler, Dyer A. Warren, Russell Parsons, and David Affleck. “Decreasing Fire Season Precipitation Increased Recent Western US Forest Wildfire Activity.” Proceedings of the National Academy of Sciences 115, no. 36 (September 4, 2018): E8349. https://doi.org/10.1073/pnas.1802316115.

Shen, H. Z., S. Tao, Y. L. Chen, M. T. Odman, Y. F. Zou, Y. Huang, YH. Chen, Q. R. Zhong, Y.Y Zhang, Y.C. Chen, S. Su, N. Lin, S. J. Zhuo, B.G. Li, X.L. Wang, W.X. Liu, J.F. Liu, G.K. Pavur, A. G. Russell, 2019: Forecasts Using Both Large-Scale Climate Indices and Local Meteorological Parameters, GLOBAL BIOGEOCHEMICAL CYCLES, 33, 1129-1145, DOI: 10.1029/2019GB00618 .

Sikaundi, G., 2013: Use of remotely sensed data to monitor and manage wildfires in Zambia. Presentation at Inception Meeting on Miombo Forest Regeneration Project.

Van der Werf, G., J. T. Randesron, G. Louis, N. Gobron, A.J. Solman, 2008: Climate controls on the variability of fires in the tropics and subtropics, Global biogeochemical cycles, 22, https://doi.org/10.1029/2007GB003122.

Verdon, D. C; A. S. Kiem, S. W. Franks, 2004: Multi-decadal variability of forest fire risk - eastern Australia, INTERNATIONAL JOURNAL OF WILDLAND FIRE, 13, 165-171, DOI: 10.1071/WF03034.

Brown, H., Liu, X., Pokhrel, R. *et al.* Biomass burning aerosols in most climate models are too absorbing. *Nat Commun* 12, 277 (2021). https://doi.org/10.1038/s41467-020-20482-9.

van Oldenborgh, G. J., Krikken, F., Lewis, S., Leach, N. J., Lehner, F., Saunders, K. R., van Weele, M., Haustein, K., Li, S., Wallom, D., Sparrow, S., Arrighi, J., Singh, R. K., van Aalst, M. K., Philip, S. Y., Vautard, R., and Otto, F. E. L.: Attribution of the Australian bushfire risk to anthropogenic climate change, Nat. Hazards Earth Syst. Sci., 21, 941–960, https://doi.org/10.5194/nhess-21-941-2021, 2021.

Madadgar, Shahrbanou & AghaKouchak, Amir & Farahmand, Alireza & Davis, Steven. (2017). Probabilistic estimates of drought impacts on agricultural production: Drought Impacts on Agriculture. Geophysical Research Letters. 44. 10.1002/2017GL073606.

O, S., Hou, X. & Orth, R. Observational evidence of wildfire-promoting soil moisture anomalies. Sci Rep 10, 11008 (2020). https://doi.org/10.1038/s41598-020-67530-4

Holden et al., “Decreasing Fire Season Precipitation Increased Recent Western US Forest Wildfire Activity.” Proceedings of the National Academy of Sciences Sep 2018, 115 (36) E8349-E8357; DOI: 10.1073/pnas.1802316115

References

Review of different fire danger rating systems around the world
de Groot, W. J., Wotton, B. M., and Flannigan, M. D.: Wildland Fire Danger Rating and Early Warning Systems, in: Wildfire Hazards, Risks and Disasters, edited by: Shroder, J. F., and Paton, D., Elsevier, Oxford, 207-228, https://doi.org/10.1016/B978-0-12-410434-1.00011-7, 2015.

Latest Global Fire Weather Database reference
Field, R. D.: Evaluation of Global Fire Weather Database reanalysis and short-term forecast products, Natural Hazards and Earth System Sciences, 20, 1123-1147, 10.5194/nhess-20-1123-2020, 2020.

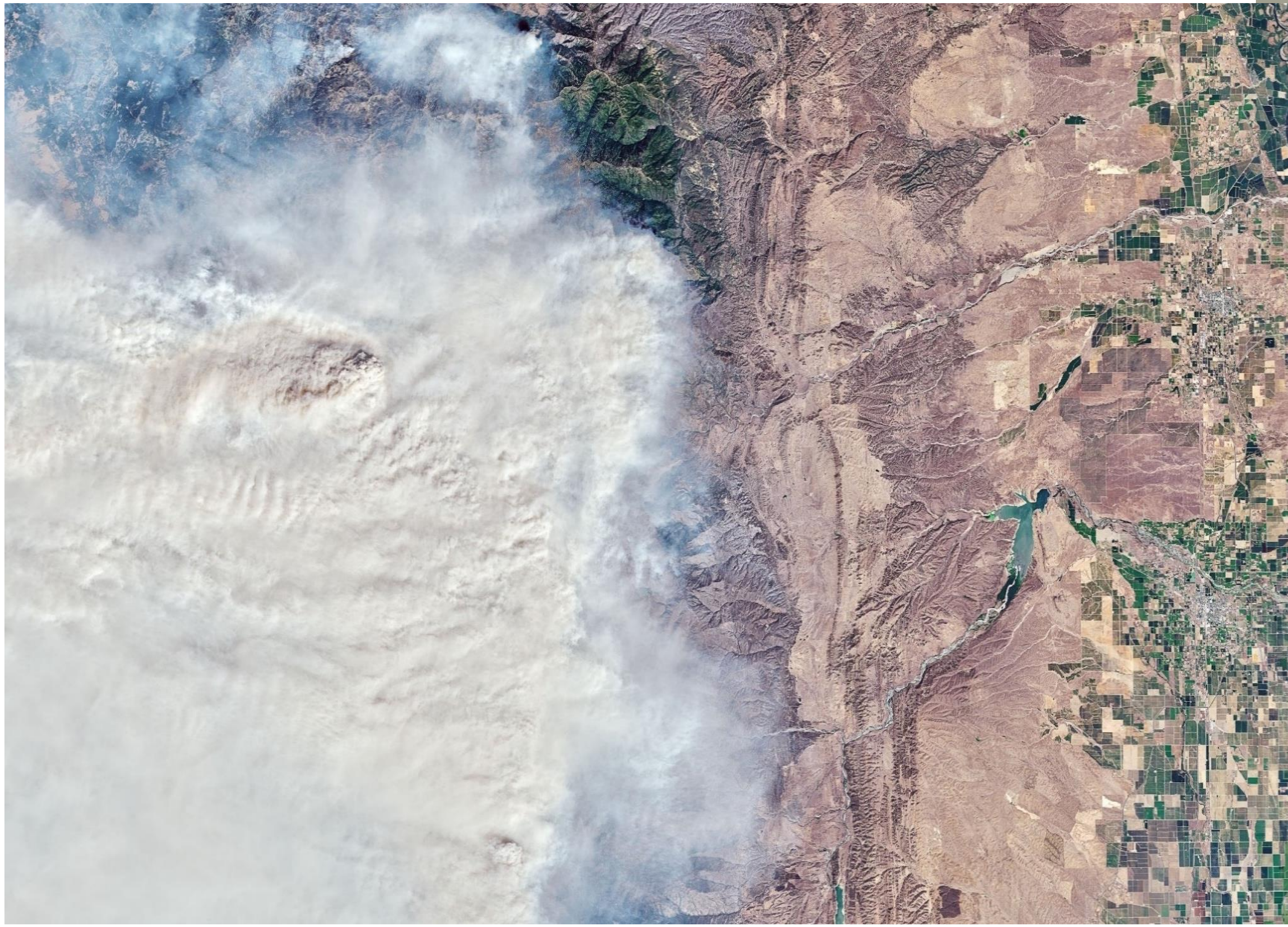
Fire danger rating research in the context of global fire management
Moore, P. F.: Global Wildland Fire Management Research Needs, Current Forestry Reports, 5, 210-225, 10.1007/s40725-019-00099-y, 2019.

Different approaches to fire danger rating with satellites
Pettinari, M. L. and Chuvieco, E.: Fire Danger Observed from Space, Surveys in Geophysics, 41, 1437-1459, 10.1007/s10712-020-09610-8, 2020.

Analysis showing how FWI and MODIS burned area are related globally
Abatzoglou, J. T., Williams, A. P., Boschetti, L., Zubkova, M., and Kolden, C. A.: Global patterns of interannual climate-fire relationships, Global Change Biology, 24, 5164-5175, 10.1111/gcb.14405, 2018.

Questions

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.



Homework and Certificate

- Three homework assignments:
  - Answers must be submitted via Google Form, accessed from the ARSET website.
  - Due date for all homework: June 8, 2021
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Contacts

- Trainers:
  - Melanie Follette Cook: melanie.cook@nasa.gov
  - Amita Mehta: amita.v.mehta@nasa.gov
  - Sean McCartney: sean.mccartney@nasa.gov
  - Robert Field: robert.field@columbia.edu
- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-satellite-observations-and-tools-fire-risk-detection-and
- ARSET Website:
  - https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

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Thank You!