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

- **Life (Biosphere)**
  - Health
  - Loss of Life
  - Loss of Property
  - Economic Impacts

- **Air (Atmosphere)**
  - Energy Budget
  - Air Quality
  - Greenhouse Gases
  - Cloud Physics

- **Land (Lithosphere)**
  - Soil Composition
  - Erosion
  - Landslides

- **Water (Hydrosphere)**
  - Drought
  - Water Quality
  - Flooding

- **Fire & Smoke**
# Types of Fire

<table>
<thead>
<tr>
<th></th>
<th>Wildfire or Wildland</th>
<th>Deforestation</th>
<th>Agricultural</th>
<th>Peat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>What does it burn?</strong></td>
<td>Forests, shrubs, grass</td>
<td>Forests</td>
<td>Crops, grasses, shrubs</td>
<td>Peat (soil-like material)</td>
</tr>
<tr>
<td><strong>When does it burn?</strong></td>
<td>Dry seasons, variable from year to year</td>
<td>Seasonal</td>
<td>Seasonal</td>
<td>Seasonal, variable from year to year</td>
</tr>
<tr>
<td><strong>Why did it burn?</strong></td>
<td>Humans (prescribed burns, accidental, arson), or natural (lightning)</td>
<td>Humans (forest clearing for livestock and crops)</td>
<td>Humans (burning prior to or after a growing season to clear fields for crops)</td>
<td>Humans (clearing land for crops and animal grazing), natural (permafrost thaw)</td>
</tr>
<tr>
<td><strong>How did it burn?</strong></td>
<td>Low to extreme, can burn millions of acres if not controlled</td>
<td>Medium to high intensity</td>
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<td></td>
</tr>
<tr>
<td>How did it burn?</td>
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### Wildfire or Wildland
- **What does it burn?**
  - Forests, shrub, grass
- **When does it burn?**
  - Year round, variable from year to year
- **Why did it burn?**
  - Humans (prescribed burns, accidental, arson), or natural (lightning)
- **How did it burn?**
  - Low to extreme, can burn millions of acres if not controlled

### Deforestation
- **What does it burn?**
  - Forests
- **When does it burn?**
  - Seasonal
- **Why did it burn?**
  - Humans (forest clearing for livestock and crops)
- **How did it burn?**
  - Medium to high intensity

### Locations
- **Australia**
  - Jan 01, 2020
- **Western US**
  - Sep 09, 2020
- **South America**
  - Sep 14, 2020
## Types of Fire

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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**

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

For more information, visit [appliedsciences.nasa.gov/arset](http://appliedsciences.nasa.gov/arset)
ARSET Team Members

Ana Prados
Program Lead

David Barbato
Spanish Translator

Zach Bengtsson
Instructor

Brock Blevins
Training Coordinator

Annelise Carleton-Hug
Program Evaluator

Melanie Follette-Cook
Instructor

Pawan Gupta
Lead Instructor

Selwyn Hudson-Odoi
Training Coordinator

Marines Martins
Project Support

Sean McCartney
Instructor

Amber McCullum
Lead Instructor

Amita Mehta
Lead Instructor

Jonathan O’Brien
Technical Writer/Editor

Erika Podest
Lead Instructor

Juan Torres-Pérez
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
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).
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 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Satellite</th>
<th>Sensors</th>
<th>Spatial/Temporal Resolutions and Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Combined TRMM &amp; GPM</td>
<td>Microwave Radiometer (TMI, GMI) and RADAR (PR, DPR)</td>
<td>0.1° x 0.1°&lt;sup&gt;°&lt;/sup&gt;, 30-minute, Daily, Monthly</td>
</tr>
<tr>
<td></td>
<td>With Multiple Satellite Constellation</td>
<td>Microwave Imagers and Sounders Calibrated with GPM Sensor Data</td>
<td>6/2000 to present</td>
</tr>
<tr>
<td>Soil Moisture</td>
<td>SMAP</td>
<td>L-Band Microwave Radiometer</td>
<td>9 km x 9 km &amp; 36 km x 36 km, Daily</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3/2015 to present</td>
</tr>
</tbody>
</table>

TRMM: Tropical Rainfall Measurement Mission  
GPM: Global Precipitation Measurement  
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://www.youtube.com/watch?v=MISLC--HNxo)  
## Weather, Climate, and Hydrology Data

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

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

GOES-5 FP: Goddard Earth Observing System, Version 5 (GEOS-5) Forward Processing  
[https://gmao.gsfc.nasa.gov/weather_prediction/](https://gmao.gsfc.nasa.gov/weather_prediction/)

NLDAS: North American Land Data Assimilation System  
[https://ldas.gsfc.nasa.gov/nldas](https://ldas.gsfc.nasa.gov/nldas)

GLDAS: Global Land Data Assimilation System  
[https://ldas.gsfc.nasa.gov/gldas](https://ldas.gsfc.nasa.gov/gldas)

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NASA’s Applied Remote Sensing Training Program
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.

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
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

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

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

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

Data Access Tools
# Data Access

<table>
<thead>
<tr>
<th>Data</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMERG, MERRA-2, LDAS</td>
<td>Giovanni</td>
</tr>
<tr>
<td></td>
<td><a href="https://giovanni.gsfc.nasa.gov/giovanni/">https://giovanni.gsfc.nasa.gov/giovanni/</a></td>
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<tr>
<td></td>
<td>GES DISC</td>
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<tr>
<td>SMAP</td>
<td><strong>Application for Extracting and Exploring Analysis Ready Samples (AppEEARS)</strong></td>
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<td><a href="https://lpdaacsvc.cr.usgs.gov/appeears/">https://lpdaacsvc.cr.usgs.gov/appeears/</a></td>
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<td>GEOS-5</td>
<td>Weather Analysis and Forecast</td>
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<td><a href="https://portal.nccs.nasa.gov/datashare/gmao/geos-fp/forecast/">https://portal.nccs.nasa.gov/datashare/gmao/geos-fp/forecast/</a></td>
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IMERG, GLDAS, and NLDAS can also be analyzed on Google Earth Engine. [https://developers.google.com/earth-engine/datasets/tags/climate](https://developers.google.com/earth-engine/datasets/tags/climate)
GEOS DISC

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

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

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_Nx**

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`
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/

Maps
- Time Averaged Map
  - Animation
    - Limited to: 365 time steps
  - Map, Difference of Time Averaged
  - Map, Accumulated
  - Time Averaged Overlay Map
  - Monthly and Seasonal Averages

Comparisons
- Map, Correlation

Scatter, Area Averaged (Static)
- Scatter (Interactive)
  - Limited to: 30000 points
- Scatter (Static)
- Scatter, Time-Averaged (Interactive)
  - Limited to: 30000 points

Vertical
- Cross Section, Latitude-Pressure
- Cross Section, Longitude-Pressure
- Cross Section, Time-Pressure
- Vertical Profile

Time Series
- Hovmoller, Longitude-Averaged
- Hovmoller, Latitude-Averaged
- Time Series, Area-Averaged Differences
- Time Series, Area-Averaged
- Time Series, Seasonal

Miscellaneous
- Zonal Mean
- Histogram
### Giovanni: IMERG, MERRA-2, & GLDAS Data Access and Analysis

#### GLDAS-2.1 Monthly Soil Moisture

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Source</th>
<th>Temp.Res.</th>
<th>Spat.Res.</th>
<th>Begin Date</th>
<th>End Date</th>
</tr>
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<tbody>
<tr>
<td>Soil moisture content (10 - 40 cm underground)</td>
<td>kg m-2</td>
<td>GLDAS Model</td>
<td>Monthly</td>
<td>0.25 °</td>
<td>2000-01-01</td>
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<tr>
<td>Soil moisture content (0 - 10 cm underground)</td>
<td>kg m-2</td>
<td>GLDAS Model</td>
<td>Monthly</td>
<td>1 °</td>
<td>2000-01-01</td>
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For MERRA-2 File Names: [https://gmao.gsfc.nasa.gov/pubs/docs/Bosilovich785.pdf](https://gmao.gsfc.nasa.gov/pubs/docs/Bosilovich785.pdf)

NASA's Applied Remote Sensing Training Program
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/
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.

## California Fire Frequency

[https://www.fire.ca.gov/](https://www.fire.ca.gov/)

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

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

<table>
<thead>
<tr>
<th>Interval</th>
<th>Fires</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 1, 2020 through December 29, 2020</td>
<td>8,112</td>
<td>1,443,152</td>
</tr>
<tr>
<td>January 1, 2019 through December 29, 2019</td>
<td>5,687</td>
<td>137,126</td>
</tr>
<tr>
<td>5 year average (same interval)</td>
<td>5,856</td>
<td>446,360</td>
</tr>
<tr>
<td>2020 Combined YTD (CALFIRE &amp; Federal)</td>
<td>9,917</td>
<td>4,257,863</td>
</tr>
</tbody>
</table>

(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

- 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.
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:

DJF

<table>
<thead>
<tr>
<th>mm/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.8044</td>
</tr>
<tr>
<td>43.5587</td>
</tr>
<tr>
<td>58.3130</td>
</tr>
<tr>
<td>73.0673</td>
</tr>
<tr>
<td>87.8216</td>
</tr>
<tr>
<td>102.5758</td>
</tr>
<tr>
<td>117.3301</td>
</tr>
<tr>
<td>132.0844</td>
</tr>
<tr>
<td>146.8357</td>
</tr>
<tr>
<td>161.5930</td>
</tr>
<tr>
<td>176.3473</td>
</tr>
<tr>
<td>191.1016</td>
</tr>
<tr>
<td>205.8659</td>
</tr>
<tr>
<td>220.6102</td>
</tr>
<tr>
<td>235.3645</td>
</tr>
<tr>
<td>250.1188</td>
</tr>
<tr>
<td>264.8730</td>
</tr>
<tr>
<td>279.6273</td>
</tr>
<tr>
<td>294.3816</td>
</tr>
<tr>
<td>309.1359</td>
</tr>
</tbody>
</table>

MAM

<table>
<thead>
<tr>
<th>mm/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1571</td>
</tr>
<tr>
<td>12.0111</td>
</tr>
<tr>
<td>19.8651</td>
</tr>
<tr>
<td>27.7190</td>
</tr>
<tr>
<td>35.5730</td>
</tr>
<tr>
<td>43.4269</td>
</tr>
<tr>
<td>51.2809</td>
</tr>
<tr>
<td>59.1349</td>
</tr>
<tr>
<td>66.9888</td>
</tr>
<tr>
<td>74.8428</td>
</tr>
<tr>
<td>82.6967</td>
</tr>
<tr>
<td>90.5507</td>
</tr>
<tr>
<td>98.4047</td>
</tr>
<tr>
<td>106.2586</td>
</tr>
<tr>
<td>114.1126</td>
</tr>
<tr>
<td>121.9665</td>
</tr>
<tr>
<td>129.8205</td>
</tr>
<tr>
<td>137.6745</td>
</tr>
<tr>
<td>145.5284</td>
</tr>
<tr>
<td>153.3824</td>
</tr>
<tr>
<td>161.9343</td>
</tr>
</tbody>
</table>
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:

![Maps showing soil moisture distribution for DJF and MAM seasons.](image.png)
Pre-Fire Season Anomalies of Temperature, Precipitation, Soil Moisture for 2020 DJF (Top) and MAM (Bottom)

Temperature

<table>
<thead>
<tr>
<th>K</th>
<th>mm/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.0959</td>
<td>-108.3848</td>
</tr>
<tr>
<td>0.1685</td>
<td>-90.6080</td>
</tr>
<tr>
<td>0.4329</td>
<td>-72.8312</td>
</tr>
<tr>
<td>0.6973</td>
<td>-55.0543</td>
</tr>
<tr>
<td>0.9616</td>
<td>-37.2775</td>
</tr>
<tr>
<td>1.2260</td>
<td>-19.5006</td>
</tr>
<tr>
<td></td>
<td>-1.7238</td>
</tr>
<tr>
<td></td>
<td>16.0530</td>
</tr>
<tr>
<td></td>
<td>33.8299</td>
</tr>
<tr>
<td></td>
<td>51.6067</td>
</tr>
</tbody>
</table>

Precipitation

<table>
<thead>
<tr>
<th>Kg/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>-6.5360</td>
</tr>
<tr>
<td>-2.8749</td>
</tr>
<tr>
<td>0.7861</td>
</tr>
<tr>
<td>4.4472</td>
</tr>
<tr>
<td>8.1083</td>
</tr>
</tbody>
</table>

Soil Moisture

<table>
<thead>
<tr>
<th>Kg/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>-7.3951</td>
</tr>
<tr>
<td>-6.0813</td>
</tr>
<tr>
<td>-4.7675</td>
</tr>
<tr>
<td>-3.4538</td>
</tr>
<tr>
<td>-2.1400</td>
</tr>
<tr>
<td>-0.8262</td>
</tr>
<tr>
<td>0.4876</td>
</tr>
<tr>
<td>1.8013</td>
</tr>
<tr>
<td>3.1151</td>
</tr>
<tr>
<td>4.4289</td>
</tr>
<tr>
<td>5.7427</td>
</tr>
</tbody>
</table>

NASA's Applied Remote Sensing Training Program
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

NASA’s Applied Remote Sensing Training Program
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).
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/

Average Monthly Burned Area Seasonality & Number of Fires - [2002-2019]

Average Monthly Burned Area by Landcover & No Data - [2002-2019]
Global Wildfire Information System (GWIS) - Zambia

Fire Frequency: 2002 - 2019
Global Wildfire Information System (GWIS) - Zambia

Cumulative Burned Area for 2019
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
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).
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.

• All are useful and can be combined with other data.
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.
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)

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

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.

<table>
<thead>
<tr>
<th>Warna</th>
<th>Rentang</th>
<th>Deskripsi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biru</td>
<td>0 - 140</td>
<td>Kondisi lapisan permukaan tanah bagian bawah dalam kondisi <strong>basah</strong>. Perlu waktu lebih dari 4 pekan tanpa hujan untuk mencapai kondisi sangat kering.</td>
</tr>
<tr>
<td>Hijau</td>
<td>141 - 260</td>
<td>Kondisi lapisan permukaan tanah bagian bawah dalam kondisi <strong>lembab</strong>. Perlu waktu setidaknya 2 pekan tanpa hujan untuk mencapai kondisi sangat kering.</td>
</tr>
<tr>
<td>Kuning</td>
<td>261 - 350</td>
<td>Kondisi lapisan permukaan tanah bagian bawah dalam kondisi <strong>keriting</strong>. Kekepingan 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</td>
</tr>
<tr>
<td>Merah</td>
<td>&gt;350</td>
<td>Kondisi lapisan permukaan tanah bagian bawah dalam kondisi <strong>sangat keriting</strong>. Kekepingan mulai mencapai kondisi ekstrim, pelarangan kegiatan pembakaran lahan perlu digalakkan.</td>
</tr>
</tbody>
</table>

*) Berdasarkan catatan historis, kondisi kabut asap sangat parah di Indonesia terjadi dalam rentang nilai ini.
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 $0.1^\circ \times 0.1^\circ$ using NASA IMERG precipitation data.
- There are daily and monthly files in NetCDF format.

[https://data.giss.nasa.gov/impacts/gfwed/](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/

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

NASA’s Applied Remote Sensing Training Program
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/
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.
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.
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 Abatzoglou 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’.
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.
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


- Introduction to the Canadian Fire Weather Index System: [https://www.youtube.com/watch?v=mdeM-cBCQJA](https://www.youtube.com/watch?v=mdeM-cBCQJA)

- Global Fire Weather Database, including MATLAB code: [https://data.giss.nasa.gov/impacts/gfwed/](https://data.giss.nasa.gov/impacts/gfwed/)


- NOAA NCEI Integrated Surface Database of global, hourly weather data: [https://www.ncdc.noaa.gov/isd](https://www.ncdc.noaa.gov/isd)

- Climate Toolbox for Wildfire, including NRT FWI and NFDRS products for US: [https://climatetoolbox.org/wildfire](https://climatetoolbox.org/wildfire)
References


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


References

Review of different fire danger rating systems around the world

Latest Global Fire Weather Database reference

Fire danger rating research in the context of global fire management

Different approaches to fire danger rating with satellites

Analysis showing how FWI and MODIS burned area are related globally
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:

• ARSET Website:
  – https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset
Thank You!