National Aeronautics and Space Administration

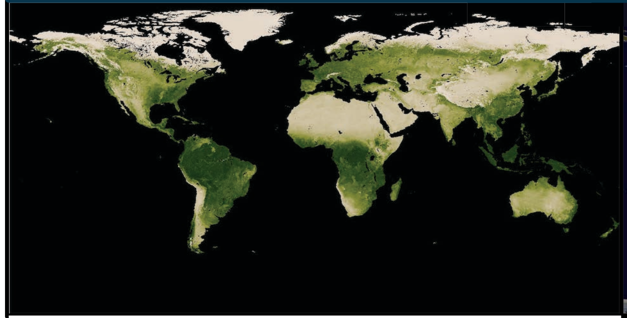
Part 5:
Post-Fire Impacts: Water Resources and Disasters

Amita Mehta, Sean McCartney, Erika Podest, & Elijah Orland

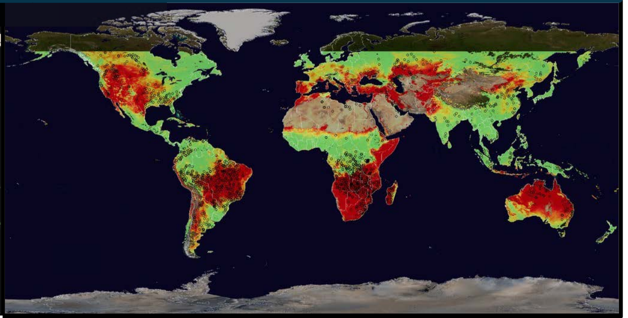
May 25, 2021

Webinar Agenda

Pre-Fire

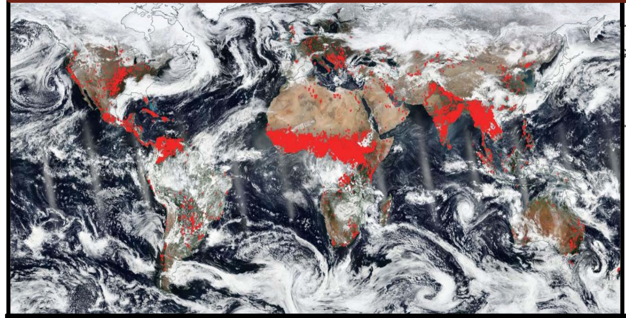


Session 1:
Climate and Hydrology

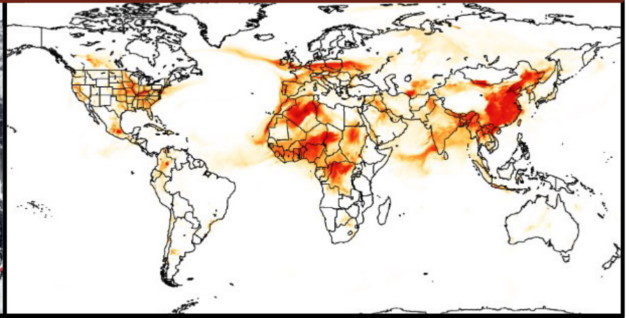


Session 2:
Vegetation

During-Fire

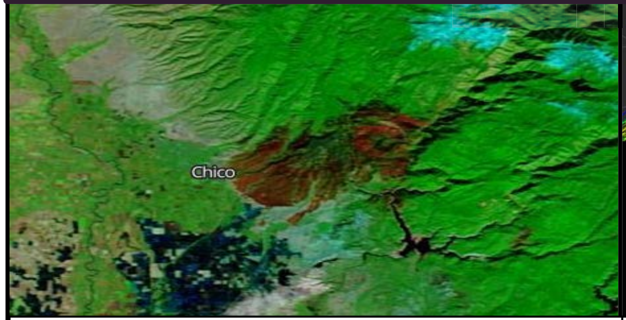


Session 3:
Active Fires and Smoke

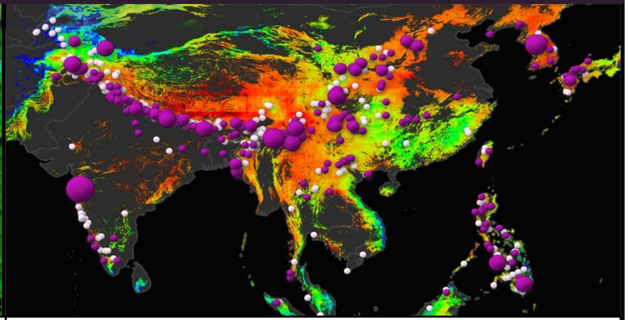


Session 4:
Smoke Forecasting

Post-Fire



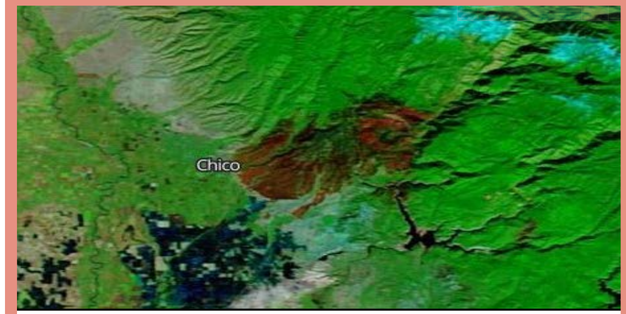
Session 5:
Climate & Hydrology



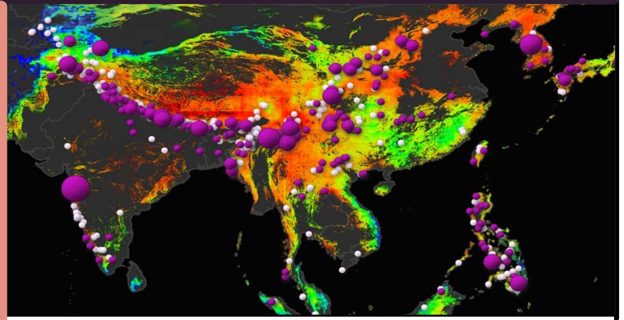
Session 6:
Vegetation

Webinar Agenda

Post-Fire



Session 5:
Climate & Hydrology



Session 6:
Vegetation

Amita Mehta

Sean McCartney

Erika Podest

Eli Orland

Part 5 Outline

- Post-Fire Impacts on Water Resources and Disasters
- Case Studies:
  - Post-Fire Water Quality Monitoring in California
  - Post-Fire Impacts in Portugal
  - Monitoring Post-fire Landslides

Ventura River post-fire sedimentation 2019
Image Credit: venturariver.org

Post-Fire Impacts

- Fires are a part of the natural forest, grassland, and tundra environment.
- Fires have long-lasting impacts to surrounding human lives and infrastructure.
- Some of the major post-fire impacts on environment are:
  - Release of carbon dioxide and soot particles in the atmosphere, thereby influencing climate
  - Change in soil chemistry and reduction in soil fertility
  - Destruction of vegetation leading to increased runoff and soil erosion
  - Influence on nutrient cycling and flow
  - Destruction of ecosystems and wildlife

http://www.geog.leeds.ac.uk/courses/level3/geog3320/studentwork/groupd/positiveandnegative.html

Post-Fire Impacts on Water Resources

- Wildfires have short- and long-term impacts on water resources.
- In the short term, post-fire erosion and runoff transport sediments, debris, and chemicals to streams, lakes, and water-supply reservoirs affecting drinking water quality.
- In the long term, fires can alter watershed characteristics and streamflow patterns.

https://www.usgs.gov/mission-areas/water-resources/science/water-quality-after-wildfire?qt-science_center_objects=0#qt-science_center_objects

Post-Fire Ash Spills

Image Credit: USDA Forest Service

Image Credit: Moisés Cruz Ballesta

Post-Fire Impacts on Water Resources

- In the U.S., approximately 80 percent of freshwater resources originate on forested land.
- More than 3,400 communities rely on public drinking water systems located in watersheds on forest lands.
- Wildfires have a substantial impact on the quantity and quality of runoff used for source water and to support fisheries and aquatic habitats.

Dead rainbow trout (*Oncorhynchus mykiss*) in the Big Tujunga Watershed during the 2009 Station Fire, California. Image Credit: USGS

https://www.usgs.gov/mission-areas/water-resources/science/water-quality-after-wildfire?qt-science_center_objects=0#qt-science_center_objects

Post-Fire Impacts on Water Resources

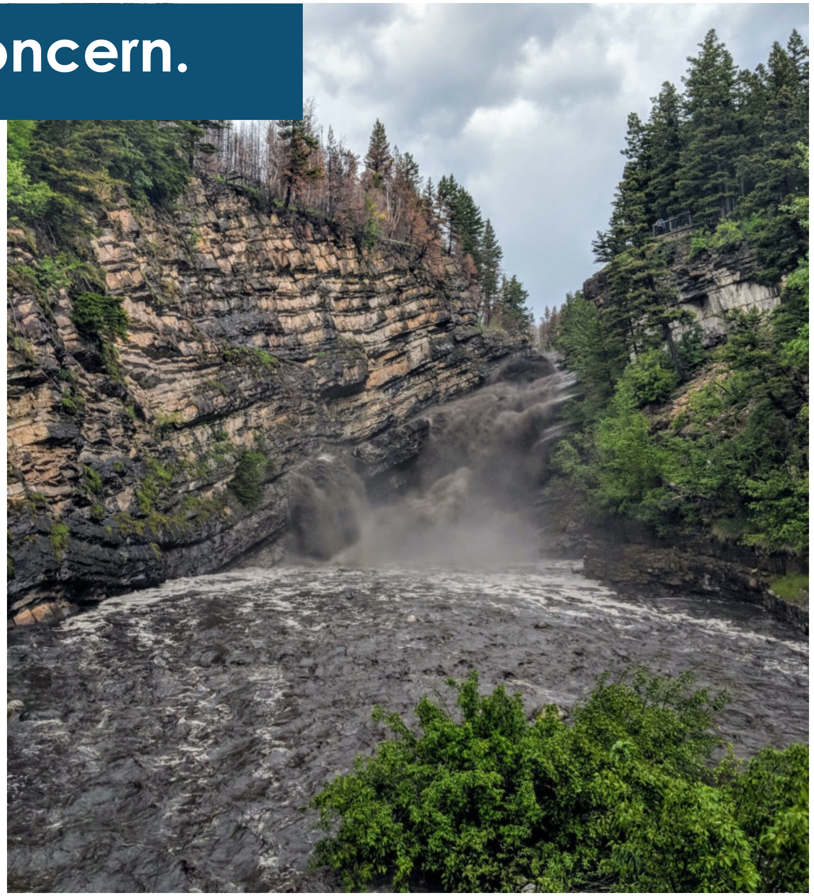
Post-fire impacts on water quality are a worldwide concern.

"All communities that draw water from forested watersheds will eventually have to deal with water that has been degraded by fire."

"After fires in Australia, the quality of the water was so poor that Canberra was forced to build a new water treatment plant."

"With fires burning bigger, hotter, and more frequently, the threats to water supplies and aquatic systems are bound to escalate."

https://e360.yale.edu/features/how-wildfires-are-polluting-rivers-and-threatening-water-supplies



Cameron Falls runs black with soot and charred debris one year after a fire burned through Waterton Lakes National Park in Alberta.
Image Credit: Parks Canada/Kaleigh Watson

Post-Fire Impacts on Water Resources

- Runoff from burned area brings ash, nitrates, sediments, and bacteria (e.g., *E. coli*) to rivers, lakes, and reservoirs, demanding increased pre-treatment of drinking water.
- During and immediately after a fire, operations of water treatment plants may be interrupted, often resulting in changing source-water supply to stored water or other secondary sources.
- In the long term, change in drinking water chemistry can force changes in water treatment.

Watershed-level primary risk factors to runoff and surface water, post-wildfire, depend on:

- Burn patterns and intensity
- Topography
- Vegetation
- Soil quality
- Hydrology

https://www.usgs.gov/mission-areas/water-resources/science/water-quality-after-wildfire?qt-science_center_objects=0#qt-science_center_objects

Post-Fire Impacts on Flooding

- Vegetation absorbs rainfall and reduces runoff.
- Wildfires destroy forest/vegetation, leaving the ground burned, barren, and unable to absorb water.
- As a result, post-fire moderate to heavy rainfall and increased runoff can trigger flash floods, debris flow, and even landslides.
- Flood risk remains higher until vegetation is restored and can take up to 5 years after a wildfire event.

Santa Barbara County responders launched into rescue mode in the early-morning hours of Jan. 9, 2018, after debris flows devastated Montecito. Image Credit: Ray Ford/Noozhawk Photo

https://www.ready.gov/sites/default/files/Flood_After_Fire_Fact_Sheet.pdf

Post-Fire Impacts on Flooding and Water Quality

- In 2014, the Silverado Fire burned approximately 2.5 $miles^2$ in Orange County, California.
- After the fire, the USGS installed an automated rain-triggered camera to monitor post-wildfire flooding and debris flow at the outlet of a small 0.4 $mile^2$ basin within the burn area.
- This video shows the initial surge and peak flow triggered by an intense rainstorm on July 19, 2015.

https://youtu.be/VwPnKCx2SNM
Video Credit: Steve Wessells, USGS

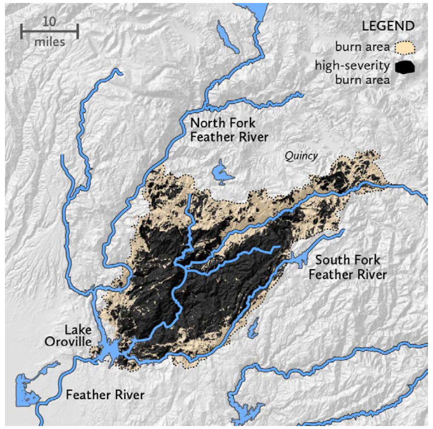
https://ca.water.usgs.gov/wildfires/wildfires-debris-flow.html

Post-Fire Water Quality Monitoring in California

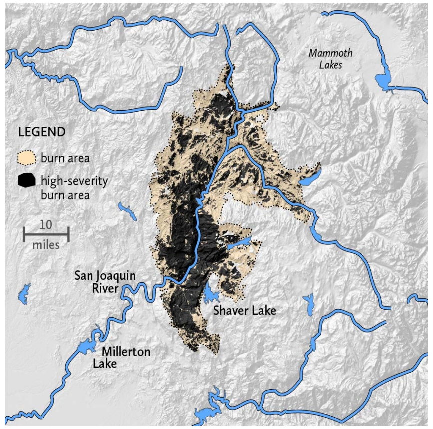
Post-Fire Burn Area Around Water Bodies in California (2020)

Fires: 2020

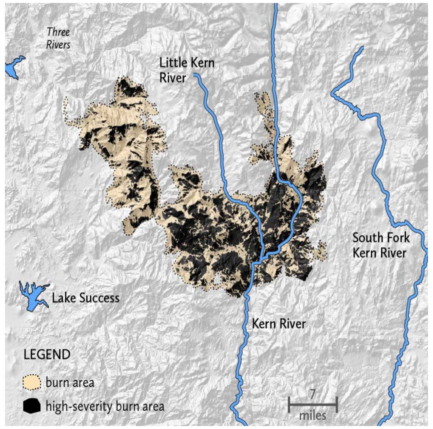
North Complex Fire and the Feather River



Creek Fire and the San Joaquin River



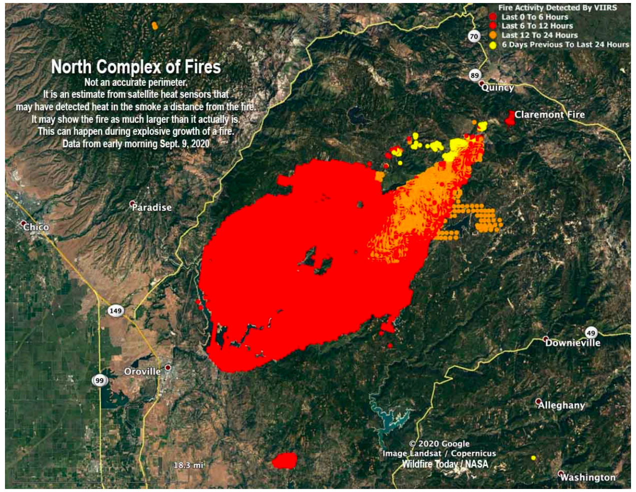
SQF Complex Fire and the Kern River



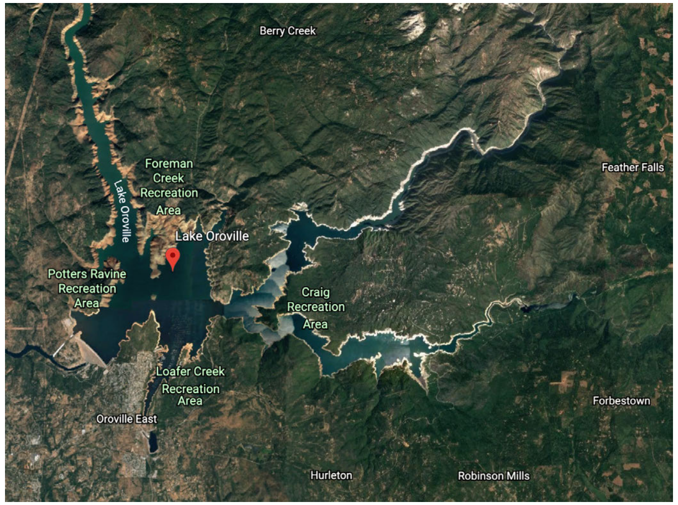
https://sierranevada.ca.gov/2020-megafires-create-risks-for-californias-water-supply/

California North Complex 2020: Bear Fire and Water Quality

- Started by lightning strikes on Aug. 17, resulting in a fire storm on Sept. 8.
- The onset of intense winds started with the fire storm.
- This merged with another lightning-sparked fire, making the North Complex Fire.
- The Western part of the North Complex burned over 70,000 acres by Sept. 11.
- The fire severely damaged communities around Lake Oroville and the Feather River watershed.



https://wildfiretoday.com/tag/bear-fire/



Bear Fire Impact on Lake Oroville Community

- The North Complex or Bear Fire destroyed vast swaths of forest, increasing the chances of ash and debris flow into Lake Oroville via the Feather River.
- The Feather River is a hatchery for Chinook salmon returning upriver to spawn.
- Lake Oroville supplies drinking water to 25 million people in southern California and the impacts could be wide-ranging.

https://water.ca.gov/News/Blog/2020/September/Oroville-Update-9-11-20

https://www.actionnewsnow.com/content/news/Heres-what-you-need-to-know-about-Lake-Orovilles-water-after-the-fires-572720451.html

A boat motors by as the Bidwell Bar Bridge is surrounded by fire in Lake Oroville during the Bear Fire in Northern California on September 9. Image Credit: Josh Edelson/AFP

Monitoring and Planning for Post-Fire Water Quality Impact Feather River Watershed

*Giovanni Map and Time Series Analyses are used for:

- MODIS NDVI
- IMERG Precipitation
- GLDAS Soil Moisture and Runoff

*APPeeARS is used to obtain SRTM terrain maps.

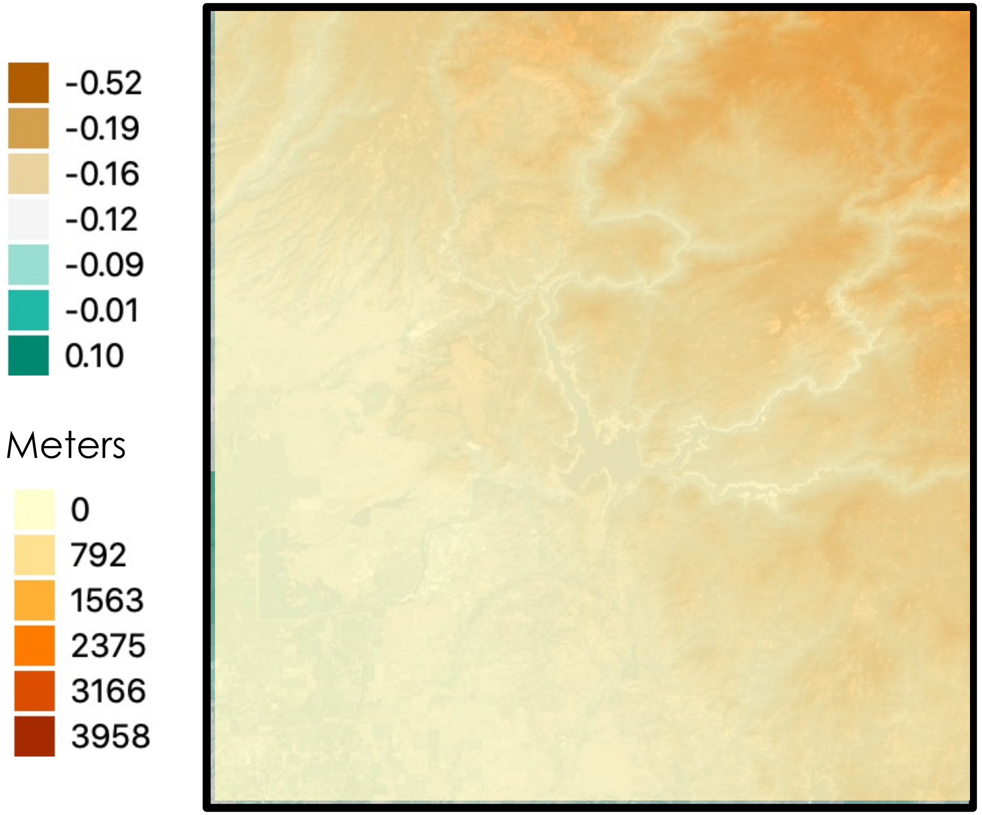
+Monitoring Water Quality:

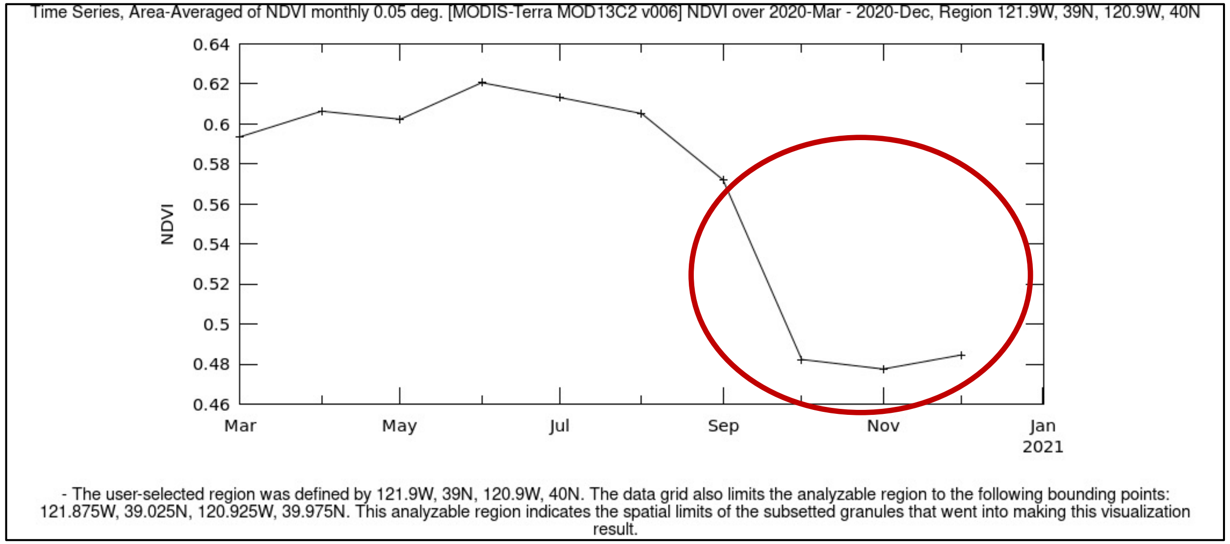
- Landsat imagery of the lake
- Image processing to derive suspended sediments/turbidity

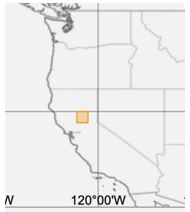
*Session-1 and Session-2 covered these datasets.
+Details can be found in ARSET webinars on Water Quality Monitoring.

Feather River Watershed Post-Fire MODIS NDVI

NDVI Anomalies (November - May 2020)





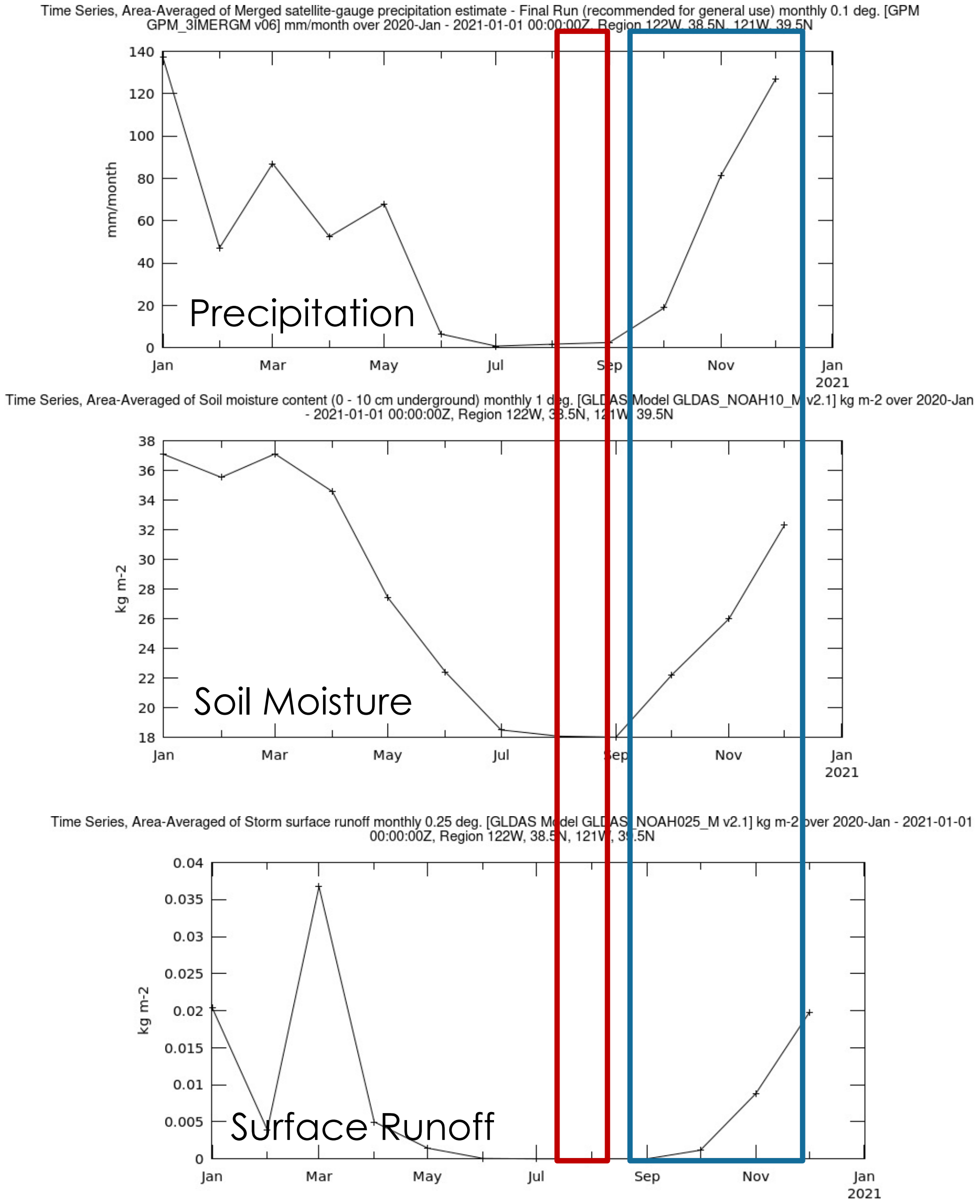


- A post-fire decrease in NDVI was observed.
- Negative anomalies in NDVI indicate the destruction of vegetation.
- Lake Oroville is downslope from the mountains to the east.

Monitoring Hydrology Components Around Lake Oroville

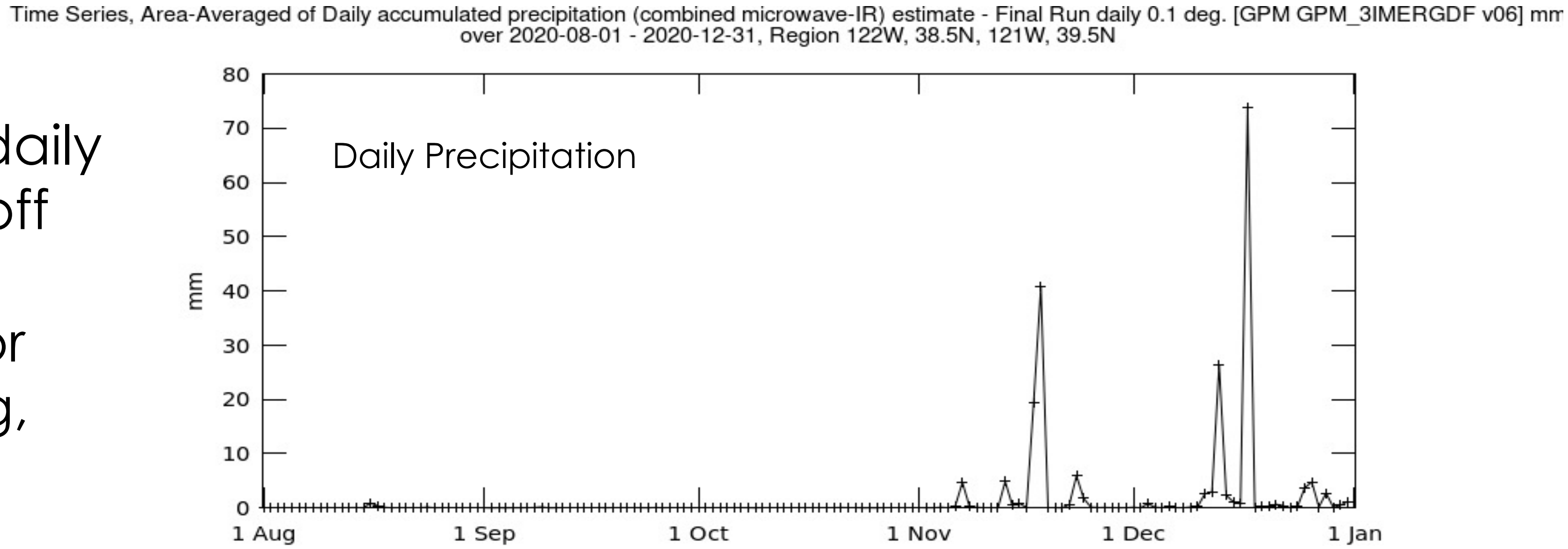
- Minimum precipitation, soil moisture, and runoff were observed during Bear Fire events.
- Post-fire precipitation increased in the fall season and resulted in increased soil moisture and runoff.

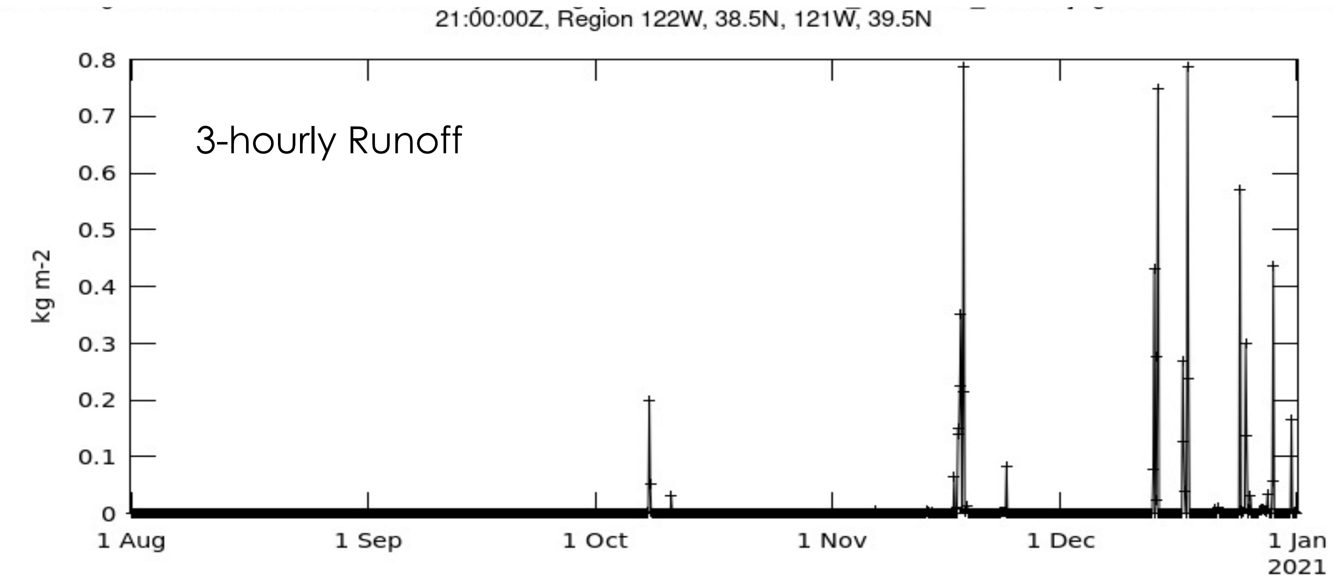
- Decreases in vegetation and increases in rainfall, soil moisture, and runoff potentially increase the post-fire risk of:
- Sediment and debris flow in the Feather river tributaries and Lake Oroville.
- Flooding and landslides in the region.



Monitoring Post-Fire Hydrology Components Around Lake Oroville

- Monitoring daily/sub-daily precipitation and runoff helps predict the subsequent risk of poor water quality, flooding, and landslides.





Monitoring Landsat Images for Sedimentation

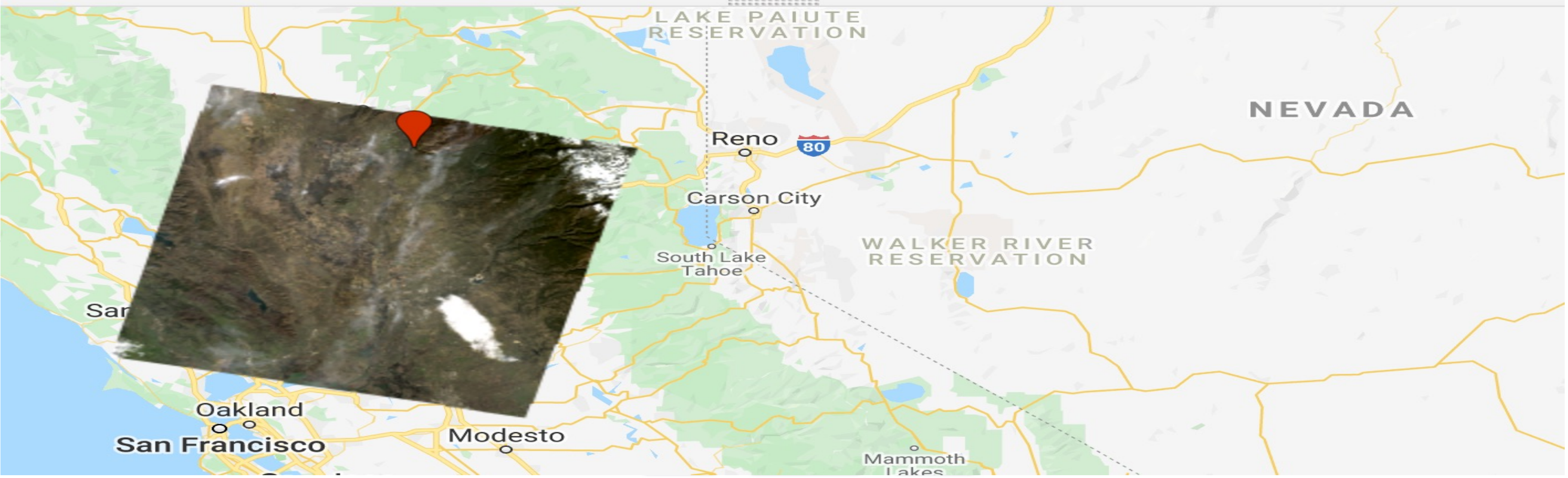
- Landsat-8 surface reflectance from Google Earth Engine https://earthengine.google.com/

LANDSAT_LC08_C01_T1_SR (copy) | Get Link | Save | Run | Reset | Apps

```
Imports (1 entry)
  var geometry: Point (-121.46, 39.56)

var image = ee.Image('LANDSAT/LC08/C01/T1_SR/LC08_044033_20210116');

var visParams = {
  bands: ['B4', 'B3', 'B2'],
  min: 0,
  max: 3000,
  gamma: 1.4,
};
Map.setCenter(-121.4616, 39.5599, 9);
Map.addLayer(image, visParams);
```



Monitoring Landsat Images for Sedimentation

- Landsat-8 surface reflectance for January 16, 2021 from Google Earth Engine

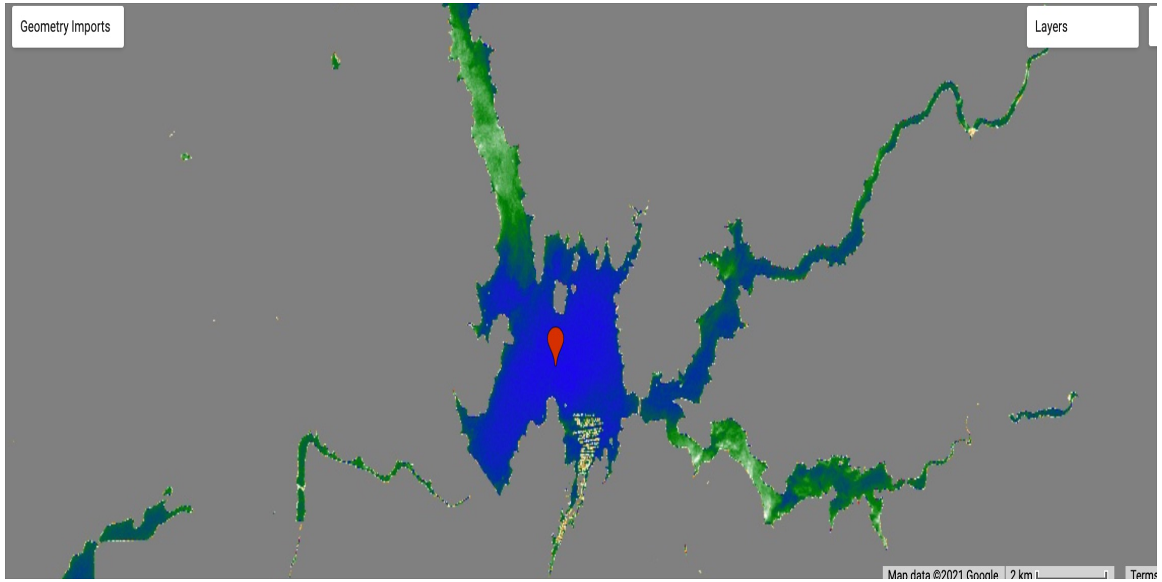
For quantitative image processing, see:

https://appliedsciences.nasa.gov/join-mission/training/english/arset-processing-satellite-imagery-monitoring-water-quality

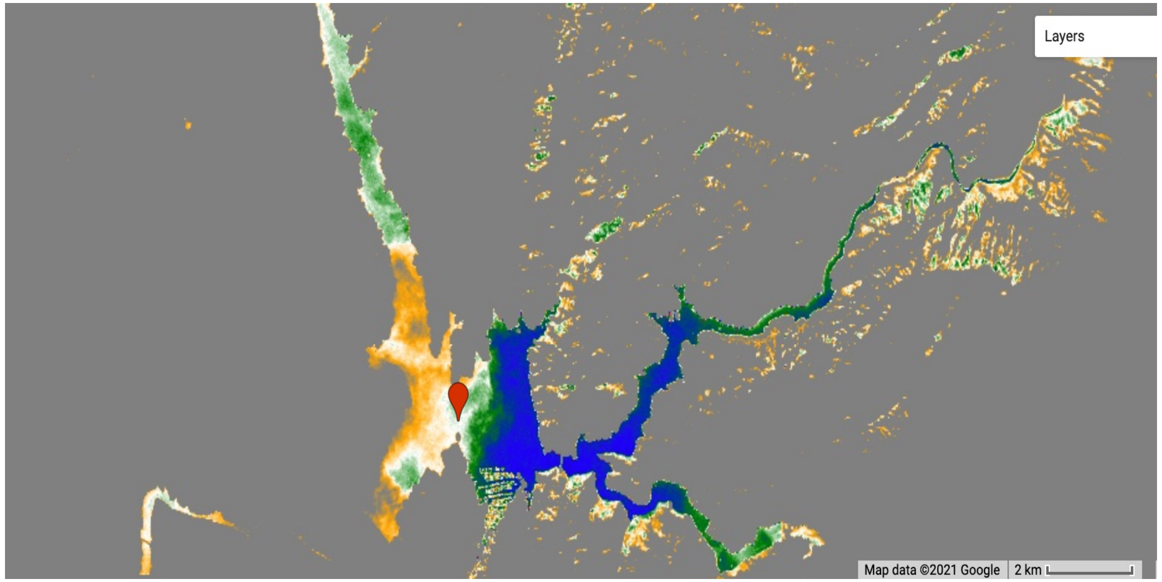
Monitoring Landsat Images for Sedimentation

Landsat-8 near Infrared (NIR) band surface reflectance from Google Earth Engine likely indicating presence of suspended sediments in western Lake Oroville

3 April 2020



16 January 2021



Landsat 8 NIR band has shown significant correlation with suspended sediments in streams (Santiago et al., 2018)

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Case Study II: Post-Fire Analysis for Portugal

Portugal's Geography

- Area on the Iberian Peninsula with archipelagos in the Atlantic Ocean
- Mainland Elevation: 0 - 2,000 meters
- Mountainous in Northern interior. South is characterized by rolling plains
- Mediterranean Climate: **Hot-summer** in the South and central interior; **warm summer** in the North
- Mediterranean ecosystems are prone to forest fires

Image Credit: Wikimedia Commons

Portugal's 2017 Fire Season

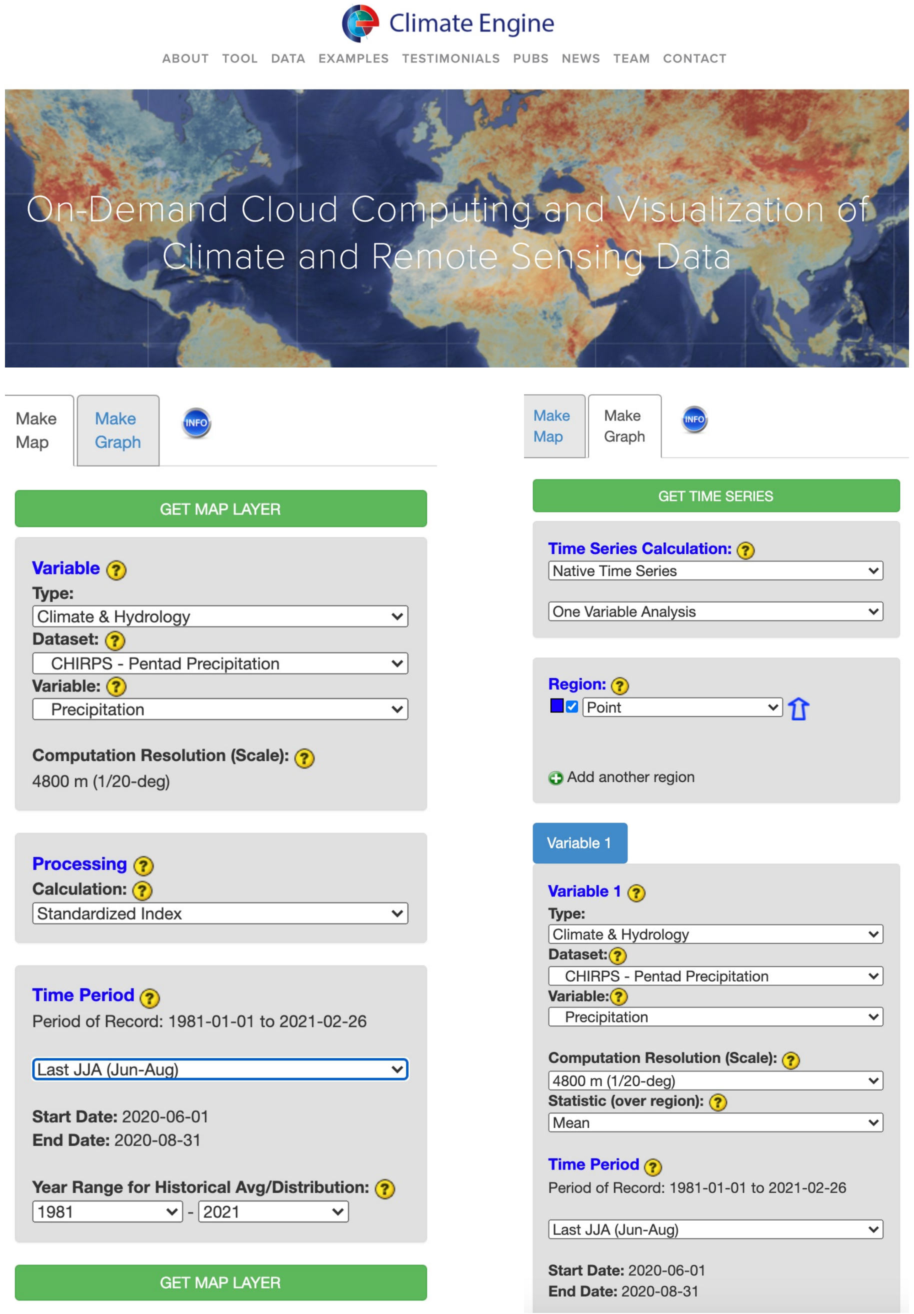
- A record 500,000 hectares burned during the extreme wildfire season.
- 120 human lives lost
- Two main fire events: June and October
- Events affected by the compound effect of summer (June-July-August) drought and high temperature conditions during the fire season
- Intense heat wave preceded the fires, with many areas of Portugal seeing temperatures in excess of 40 °C

June 2017 wildfire in Portugal
Image Credit: Miguel Riopa/Agence France-Presse

Climate Engine

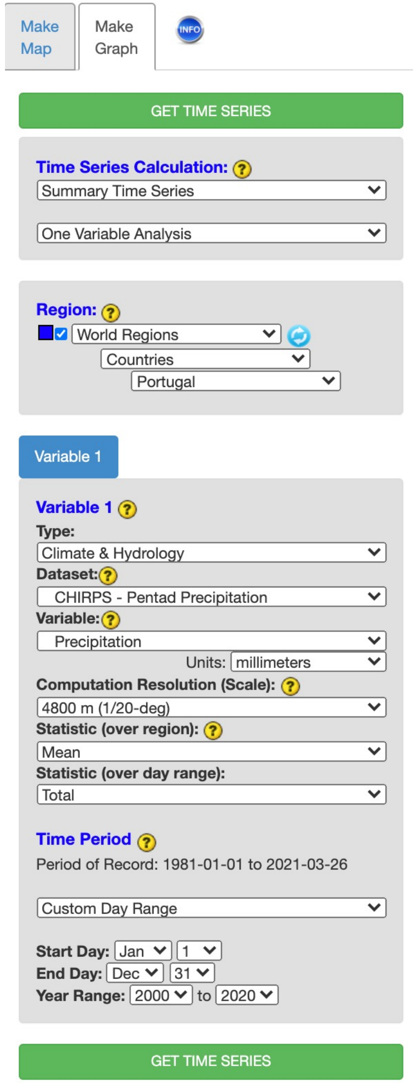
http://climateengine.org/

- Uses Google Earth Engine for on-demand processing of satellite and climate data via web browser
- Overcomes computational limitations of big data for use in real-time monitoring
- Comprehensive set of variables that provides indicators of climate impacts
- Can share map or time series results with web URL links

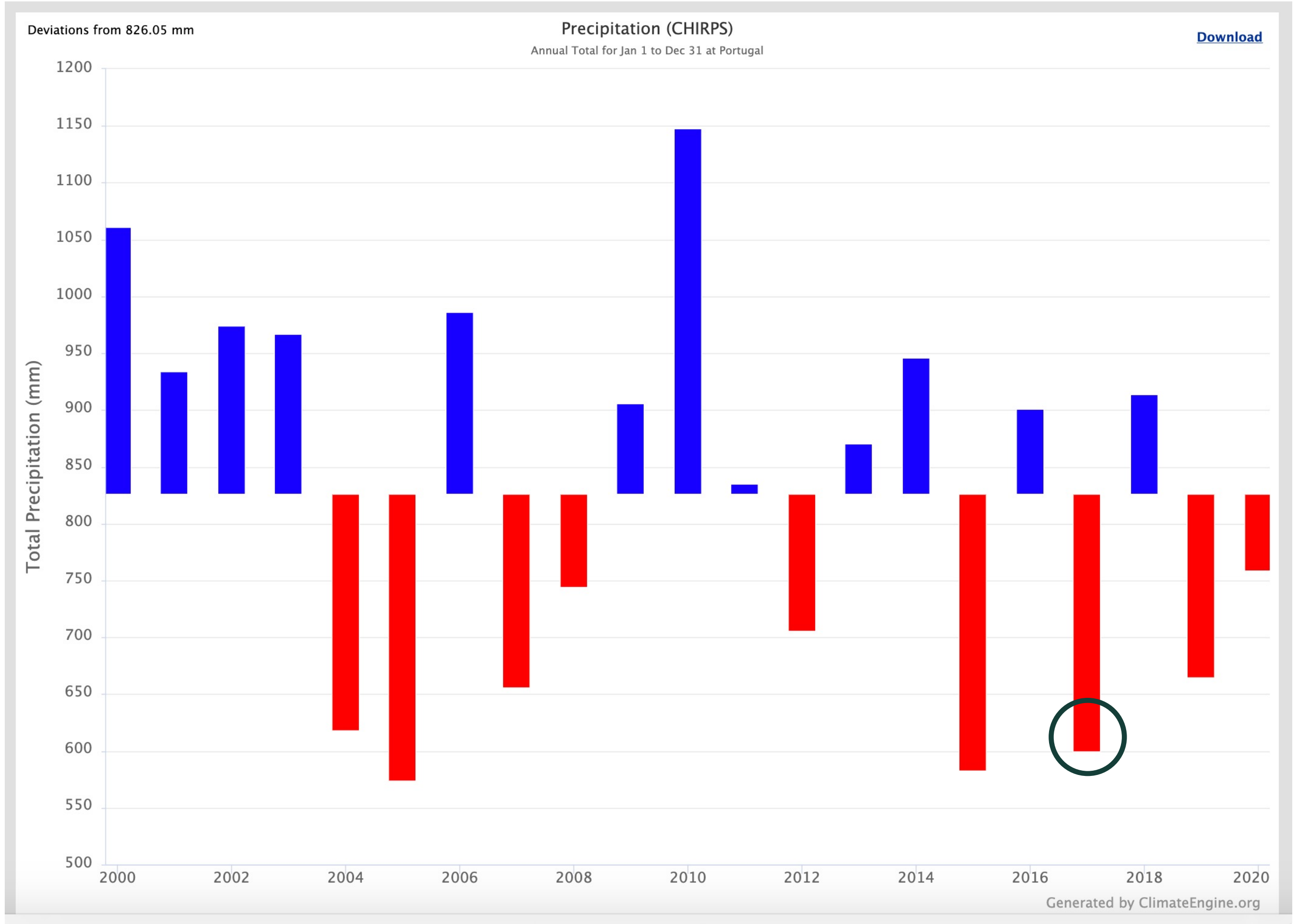


Precipitation Deviation from Mean

- Graph showing CHIRPS Pentad precipitation deviations from mean from 2000 to 2020
- 2017 circled to highlight precipitation deficit for the year



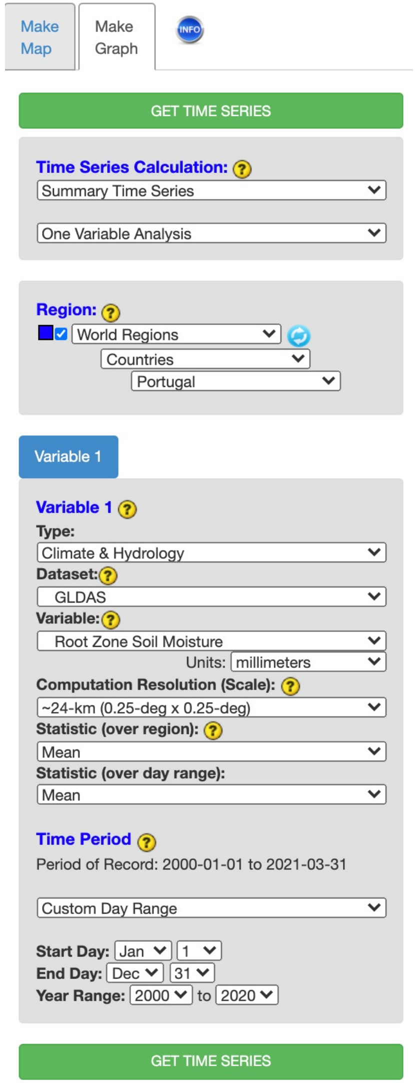
Jan – Dec: 2000 - 2020



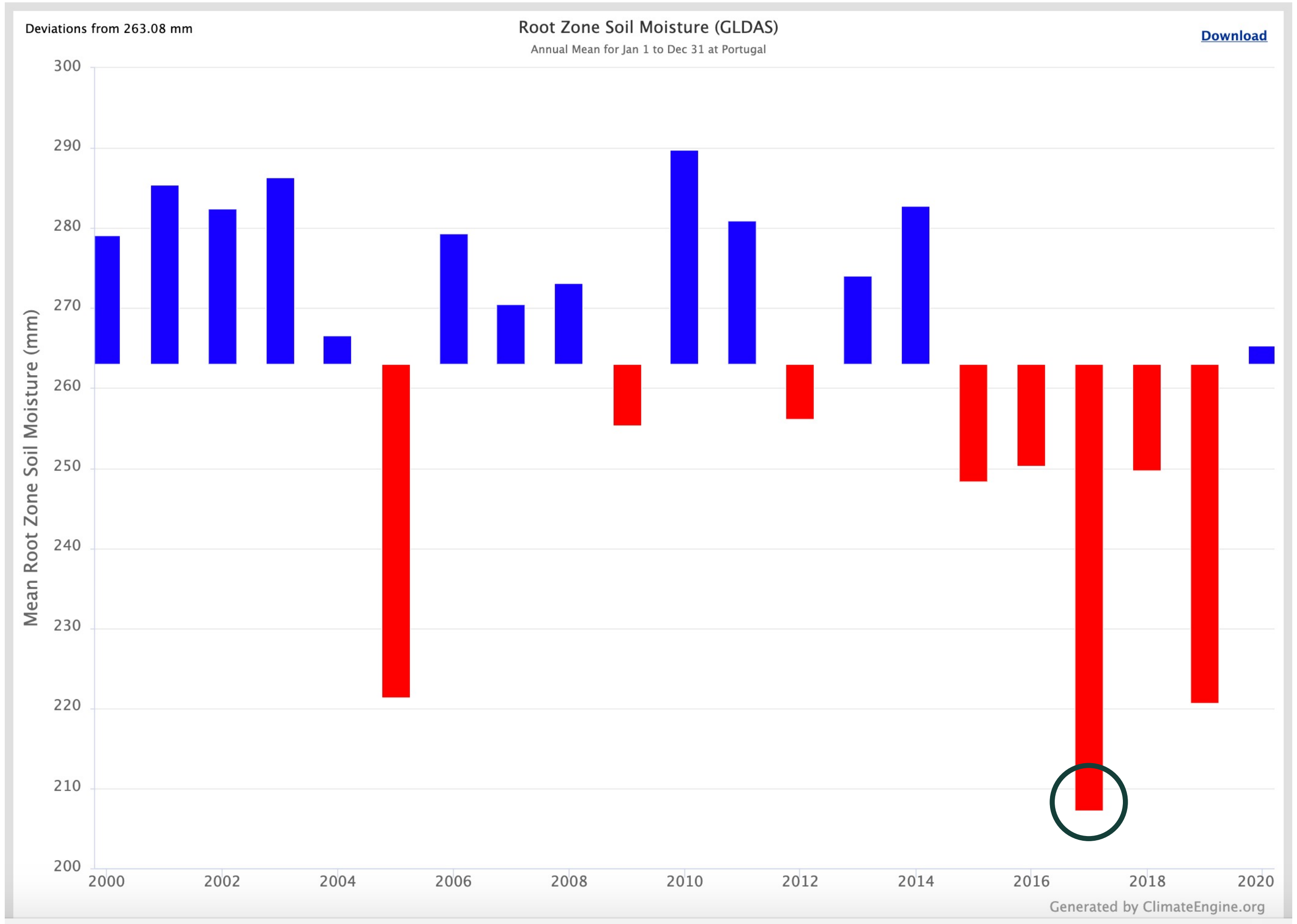
◯ = 2017

Root Zone Soil Moisture Deviation from Mean

- Graph showing GLDAS Root Zone Soil Moisture deviations from mean from 2000 to 2020
- 2017 circled to highlight root zone soil moisture deficit for the year



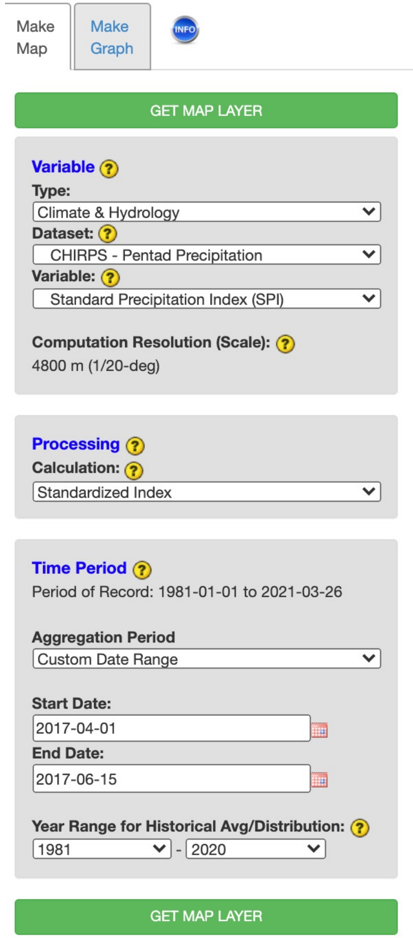
Jan – Dec: 2000 - 2020

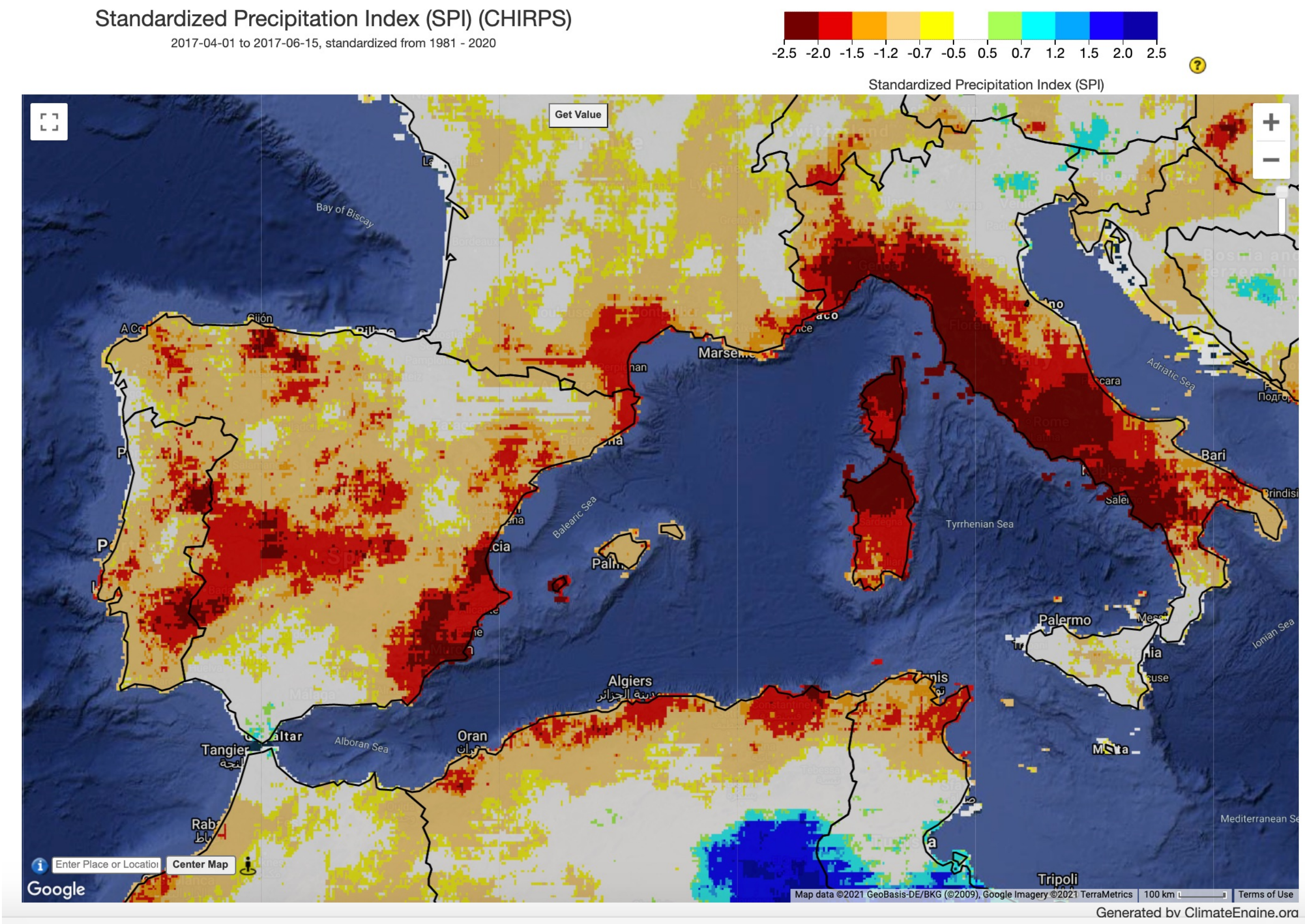


○ = 2017

Standardized Precipitation Index (SPI) for 2017

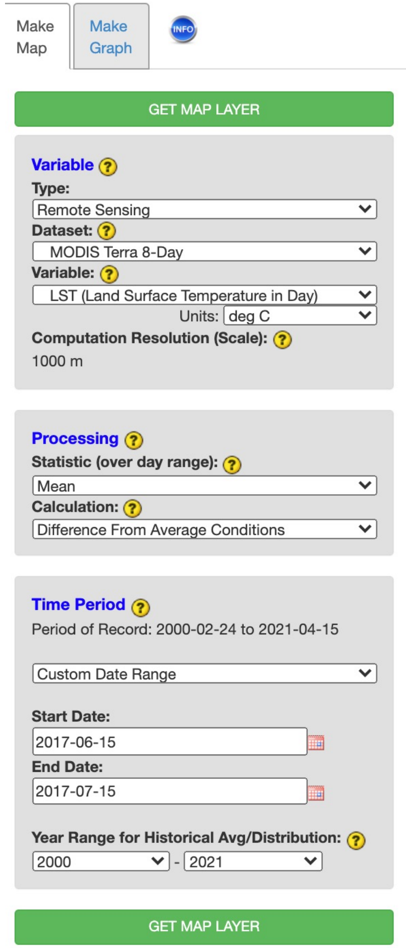
- CHIRPS Pentad 2.5-month SPI leading up to first major wildfire of season
- Precipitation deficits in much of Southern Europe for this time period

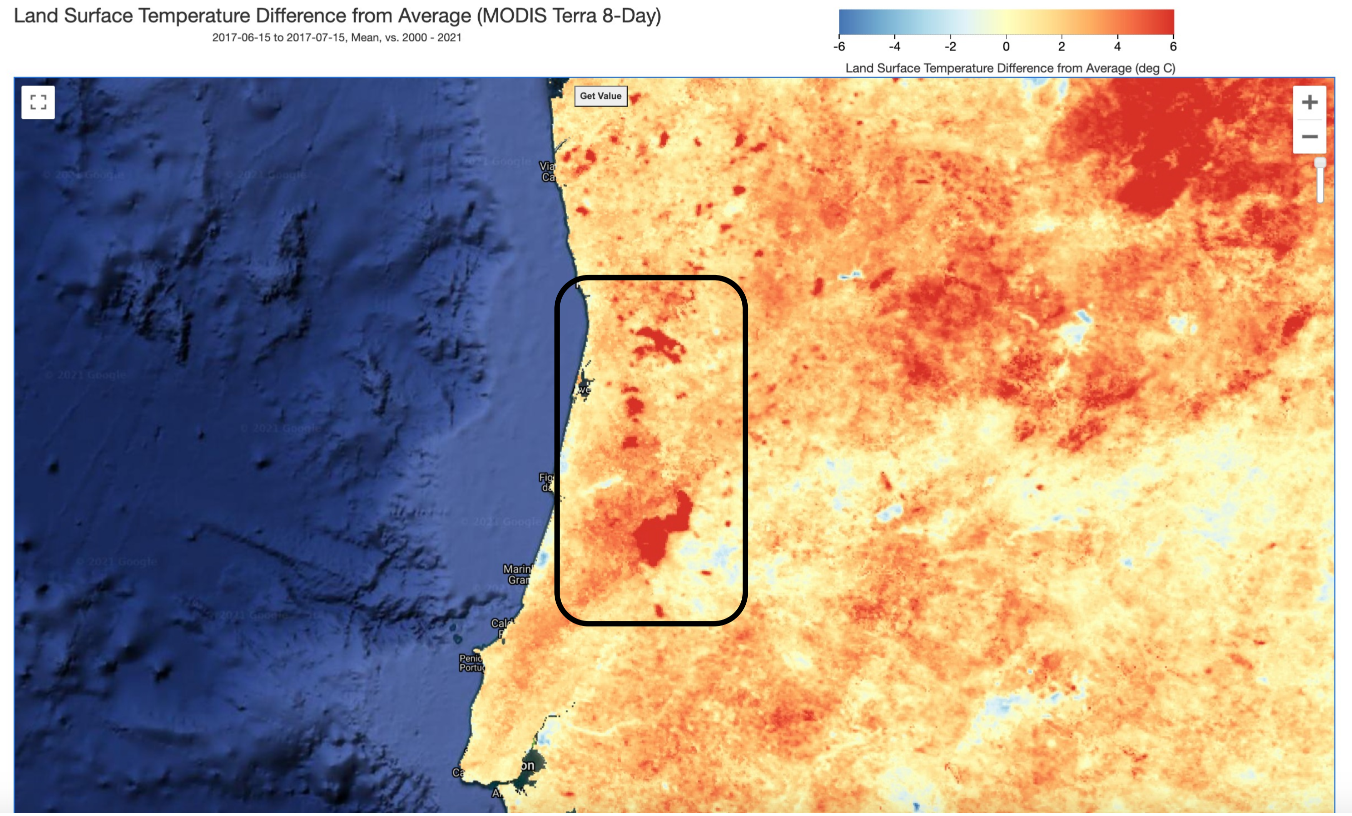




MODIS Land Surface Temperature

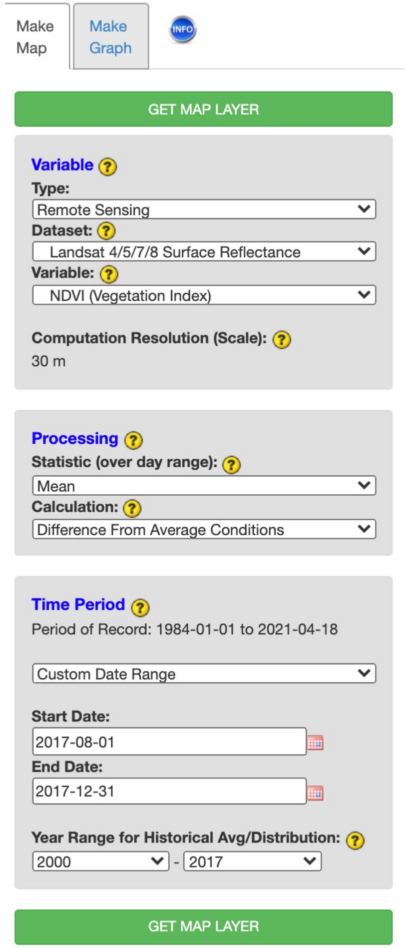
- MODIS Terra 8-day land surface temperature difference from average showing active burn areas, burn scars, and dry vegetation from June 15 - July 15, 2017

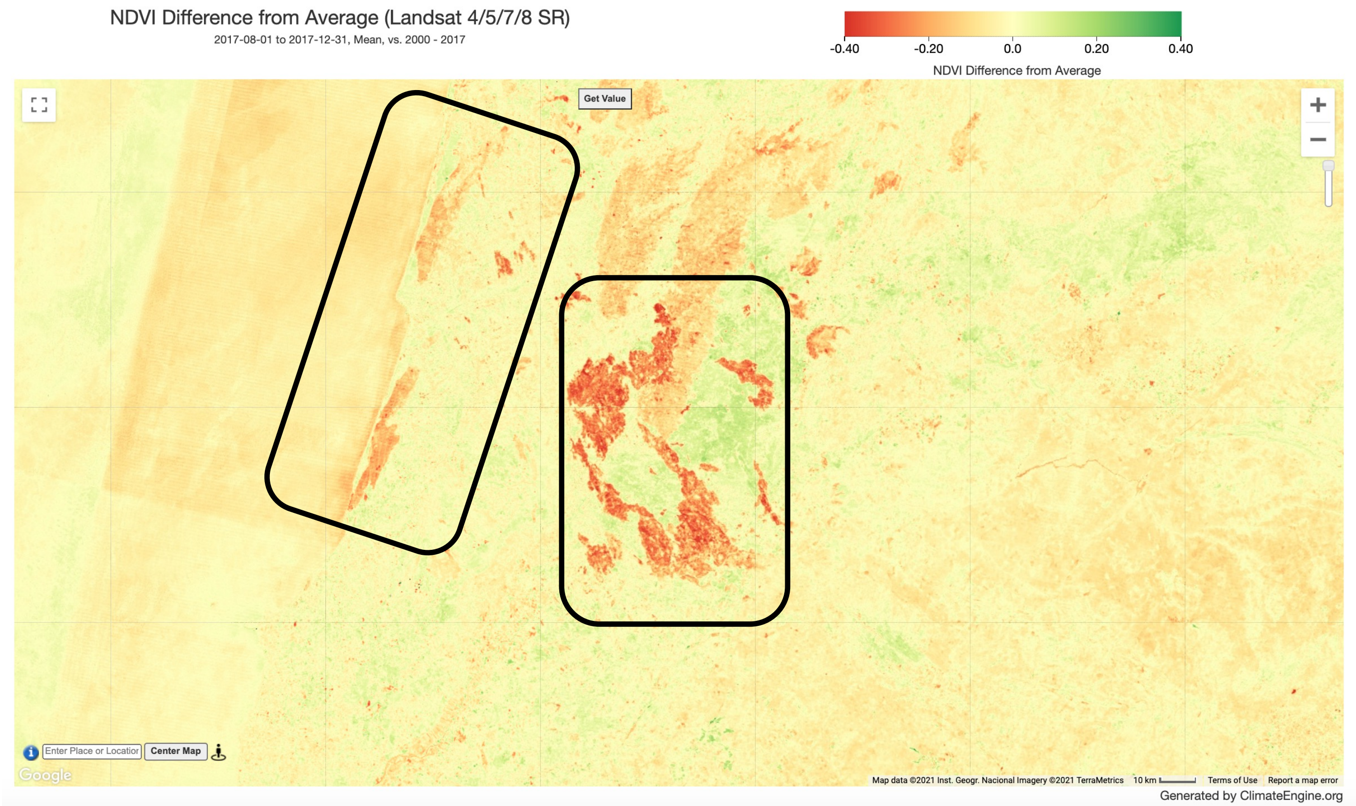




Landsat NDVI Difference from Average (2017)

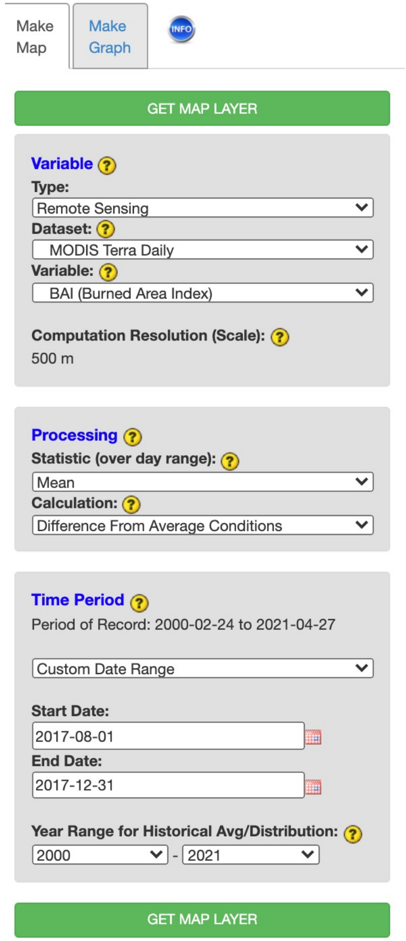
- Landsat 7/8 NDVI difference from average for Aug – Dec 2017 compared to historical average
- Post-fire burned areas in red

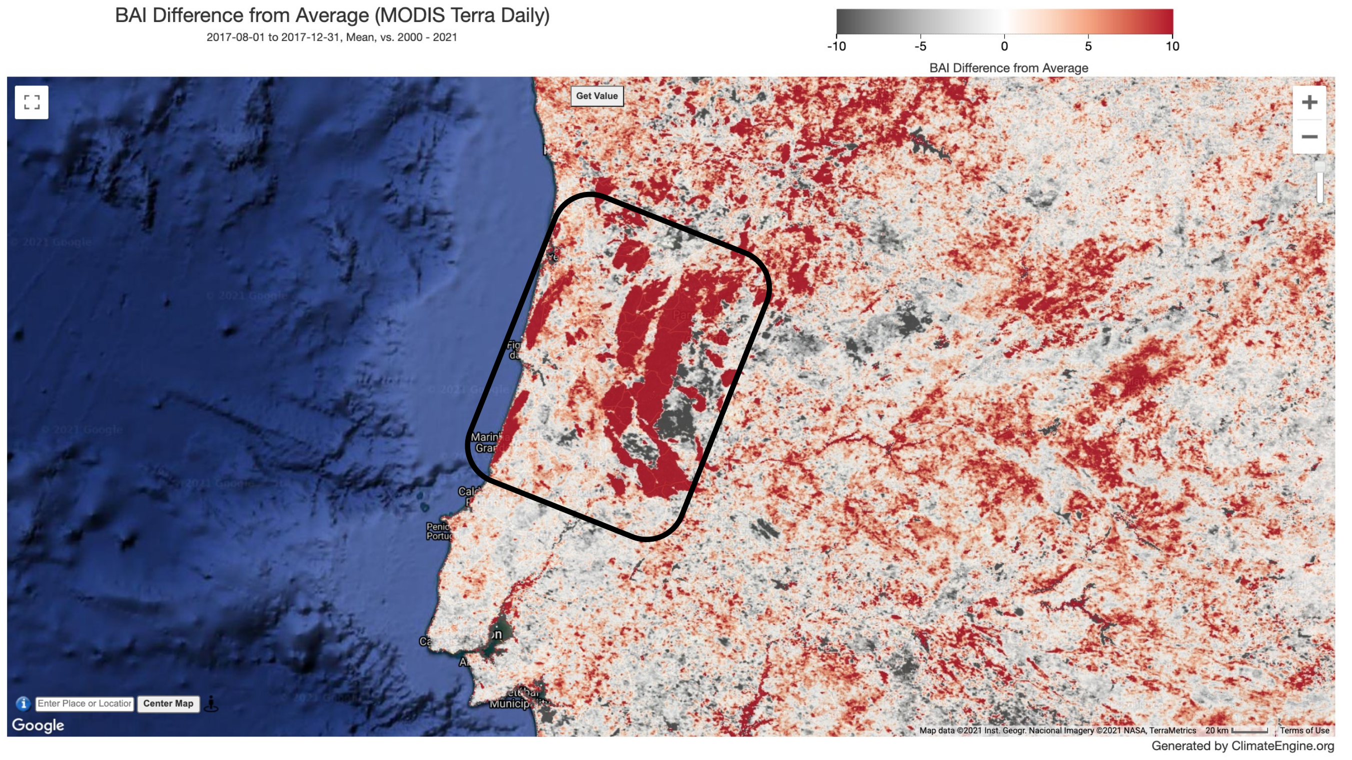




MODIS Burned Area Index (BAI) Difference from Average

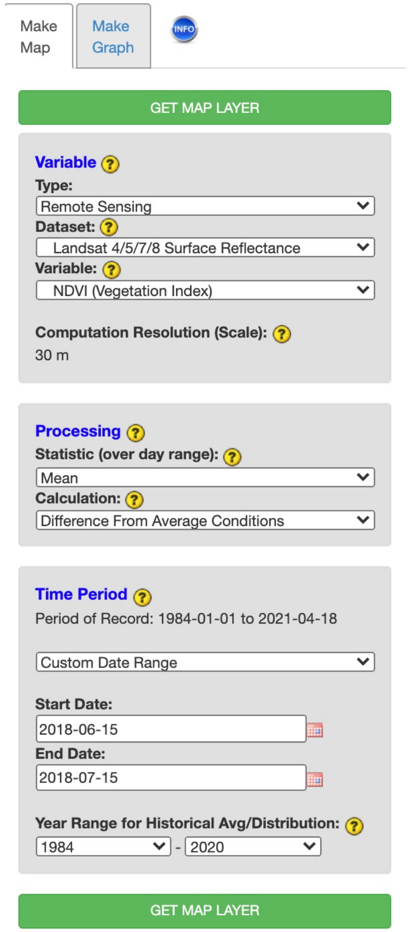
- MODIS Terra BAI difference from average for Aug – Dec 2017 compared to historical average
- Large swaths of central Portugal heavily impacted by 2017 wildfires

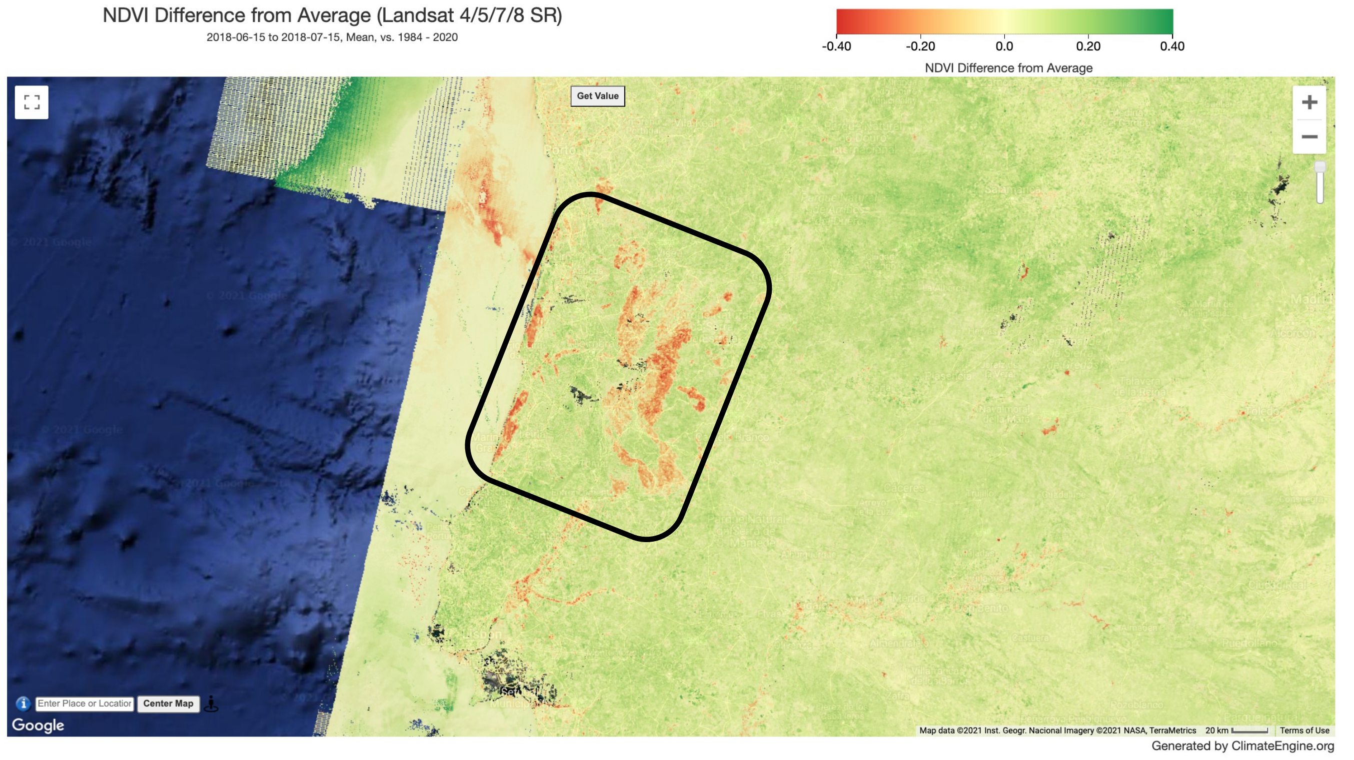




Landsat NDVI Difference from Average (2018)

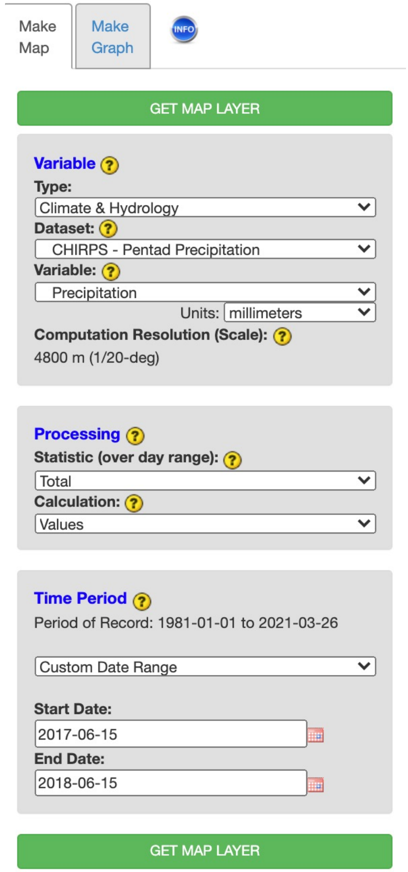
- Landsat 7/8 NDVI difference from average for June – July 2018 showing burned area one year after the devastating 2017 fires in Portugal

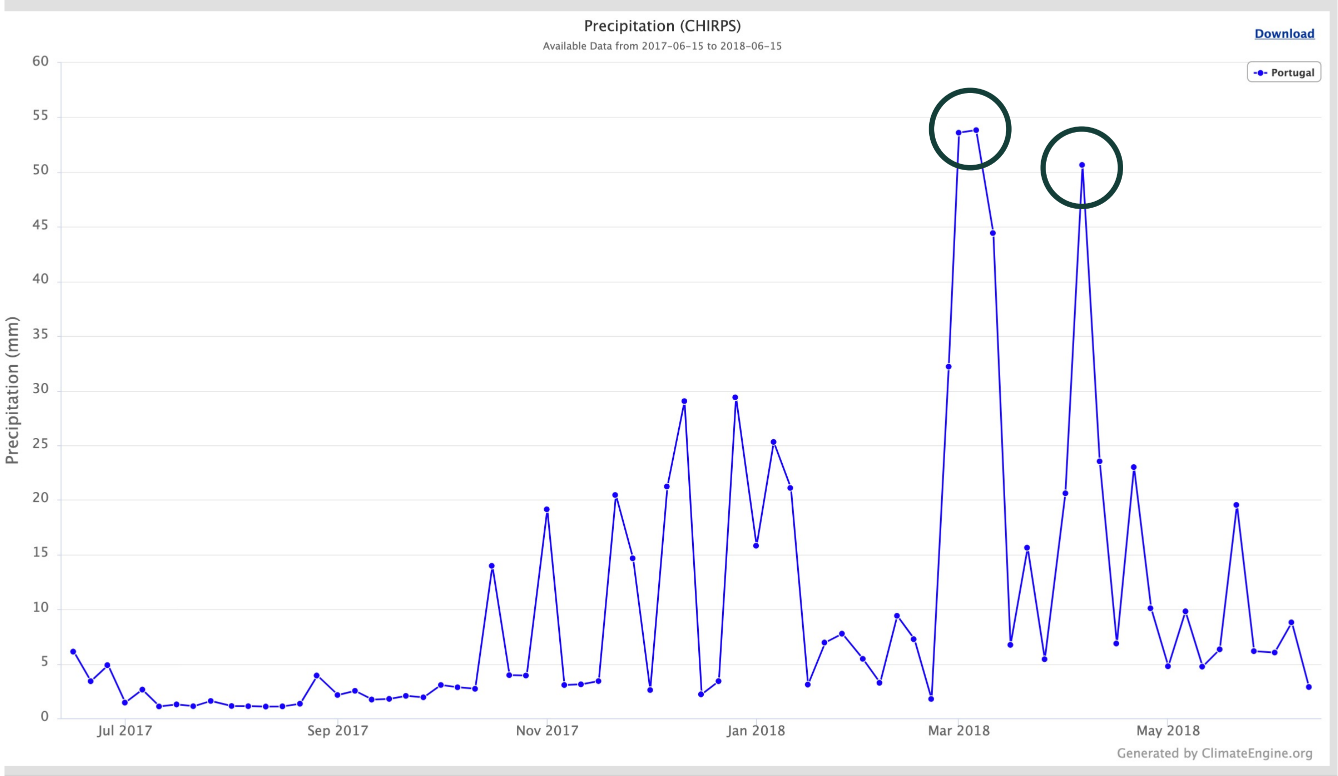




CHIRPS Pentad Precipitation 2017-2018

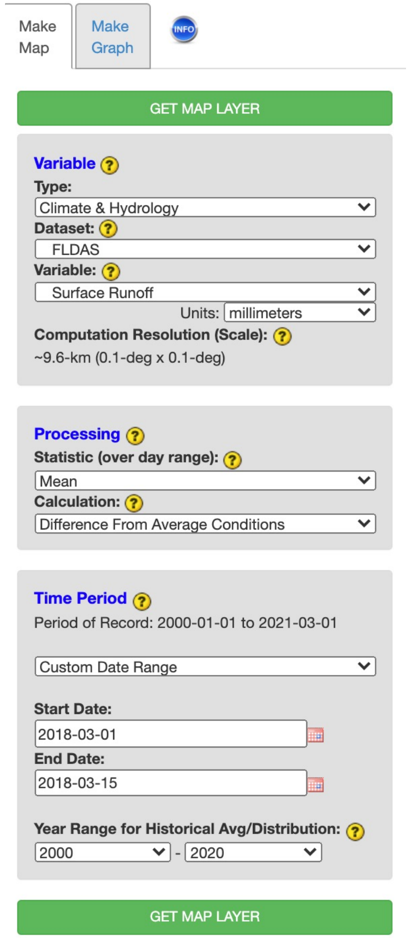
- Graph of CHIRPS Pentad precipitation showing rainfall events following the 2017 wildfire season
- Graph shows rainfall events in early March and April 2018 that could trigger debris flows or landslides

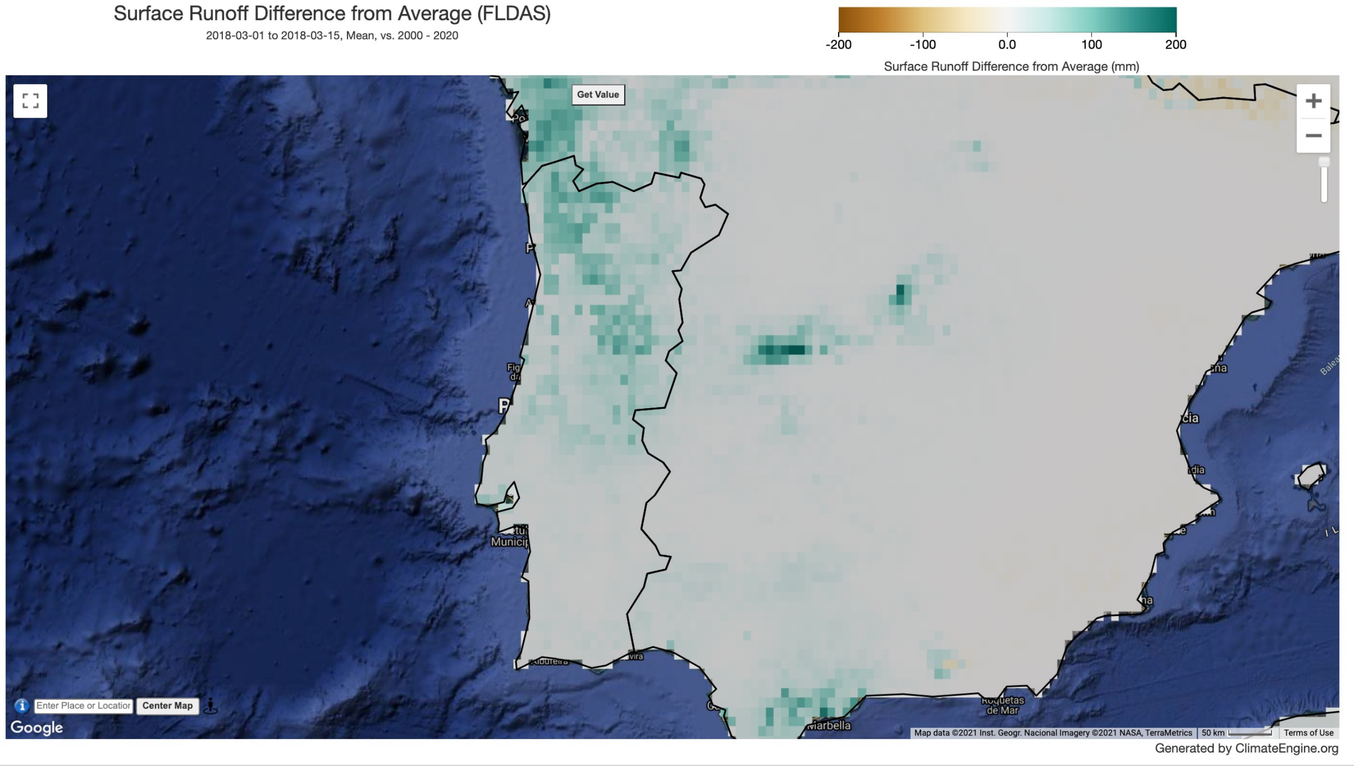




FLDAS Surface Runoff Difference from Average

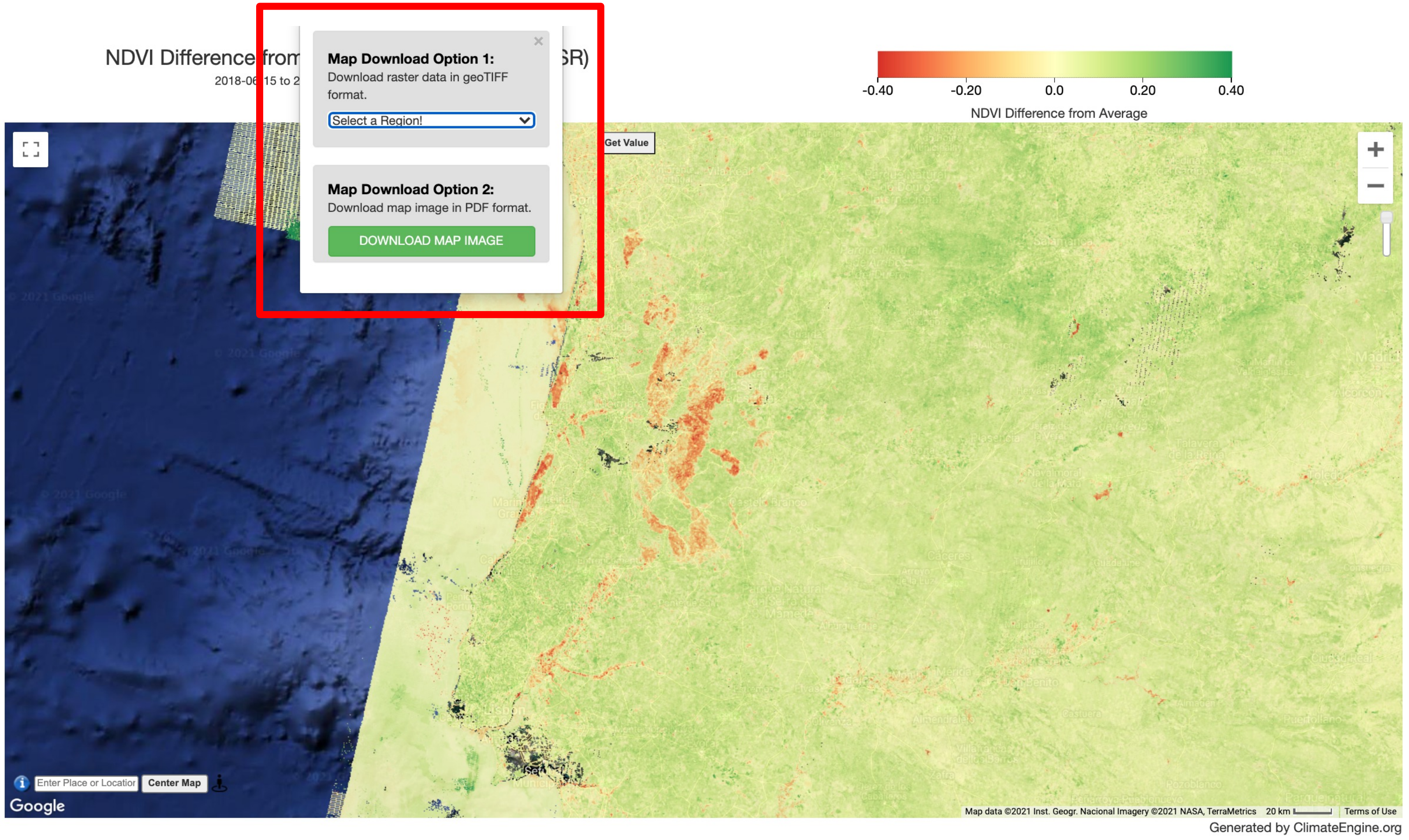
- FLDAS surface runoff anomalies can be used to characterize storm events, which could trigger debris flows or landslides.
- March 2018 precipitation event post-fire





Download and Share

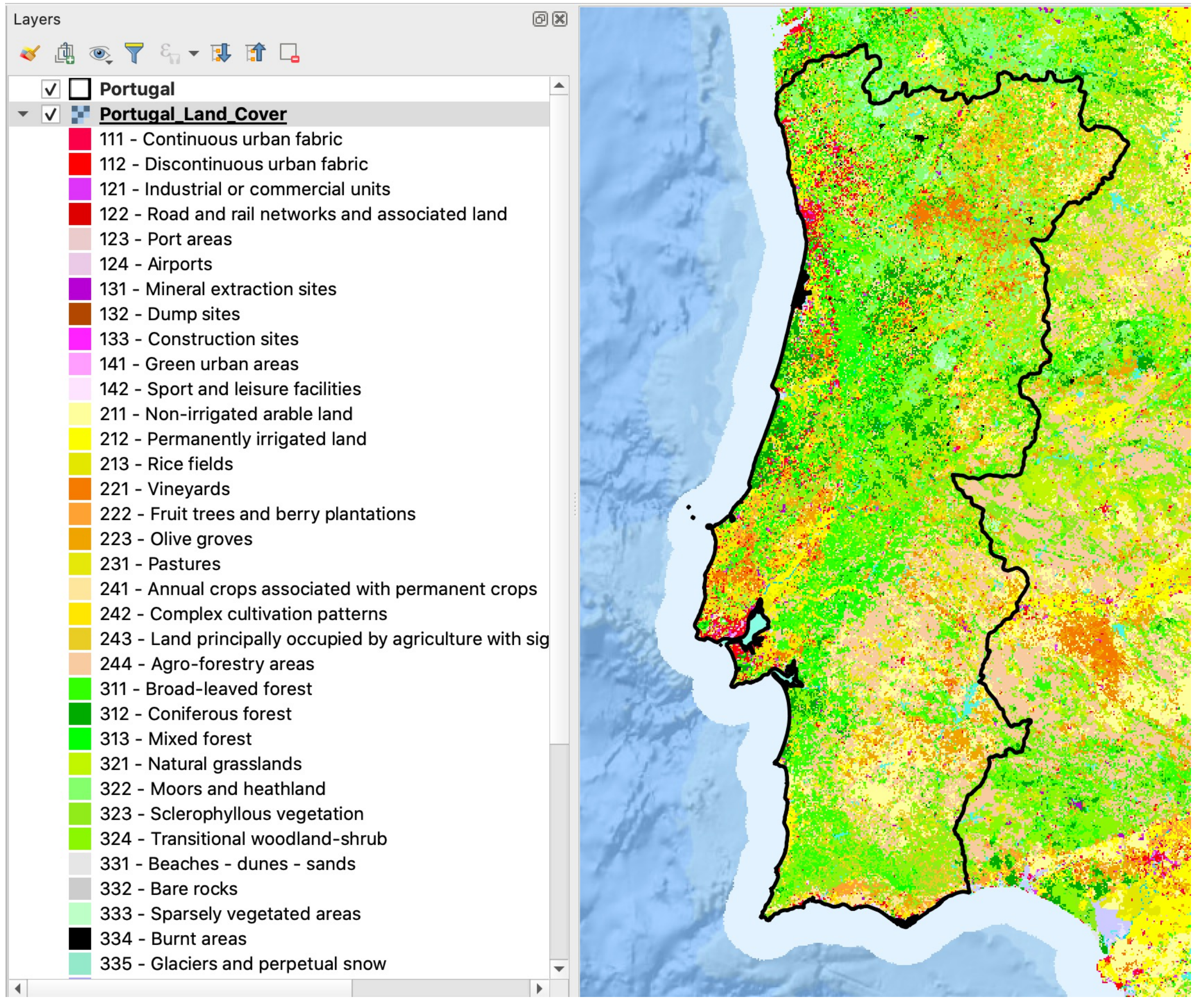
- Download raster data in GeoTIFF format
- Download Graphs as PNG, JPEG, PDF, SVG, CSV, or XLS files
- Share a link to the last successful Map result from Climate Engine



Copernicus Land Cover Map

https://land.copernicus.eu/pan-european

- Enables users to compare fire extent to validated land cover maps for Europe
- CORINE Land Cover (CLC) inventory: 1990, 2000, 2006, 2012, 2018
- Inventory of land cover in 44 classes
- Spatial Resolution = 100 m
- Time-series includes a land change layer
- Available for download as raster and vector files upon registering an account



Post-Fire Debris Flow Assessment via Remote Sensing

Elijah Orland – Goddard Space Flight Center

May 25, 2021

Overview

- In steep, unburned landscapes, vegetation and well-developed soils help regulate the shape and hydrological regime of hillslopes.

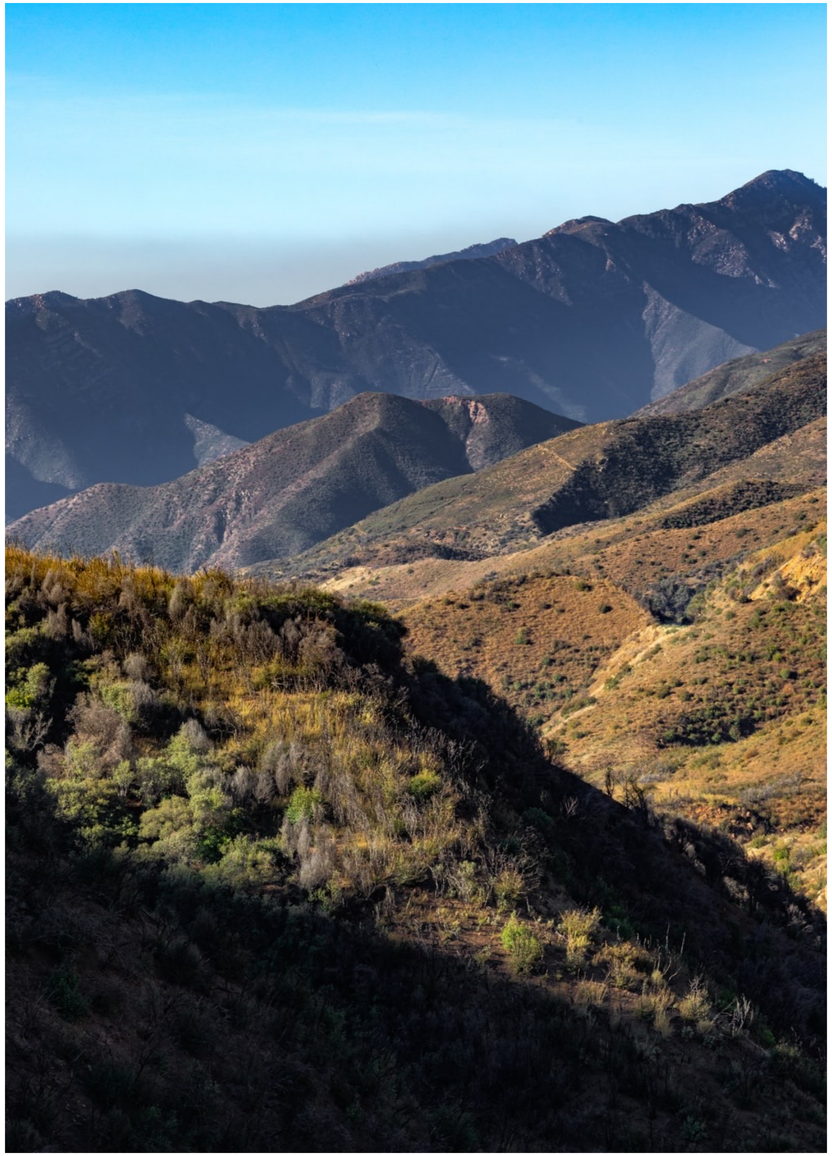


Image Credit: Dave Hoefler

The Effect of Fire

Wildfire affects this in two main ways:

1) It helps release trapped debris by destroying vegetation.
2) Burned soils are chemically altered by high heat to form a hydrophobic layer. This leads to increased runoff and erosion.

Image Credit: Joanne Francis

Post-Fire Debris Flows (PFDFs or DFs)

- With more loose debris and higher runoff/erosion, steep slopes are at an elevated risk for debris flows following wildfires.
- Recent literature demonstrates that even rainfall with 1–2-year recurrence intervals can initiate debris flow activity (Staley et al., 2020).

Debris Flow after the Station Fire
Image Credit: Susan Cannon, USGS

How can we model PFDF hazards with remote sensing?

- Previous models link topography, rainfall, and burn severity (intensity) with the occurrence of PFDFs – all of which are available globally via satellites.
- Recent example: Staley et al., 2017

Image Credit: NASA

Case Study: 2009 Station Fire, California (CA)

- Largest fire in CA for 2009 fire season (650 km^2)
- Two deaths
- >$100 million in damages

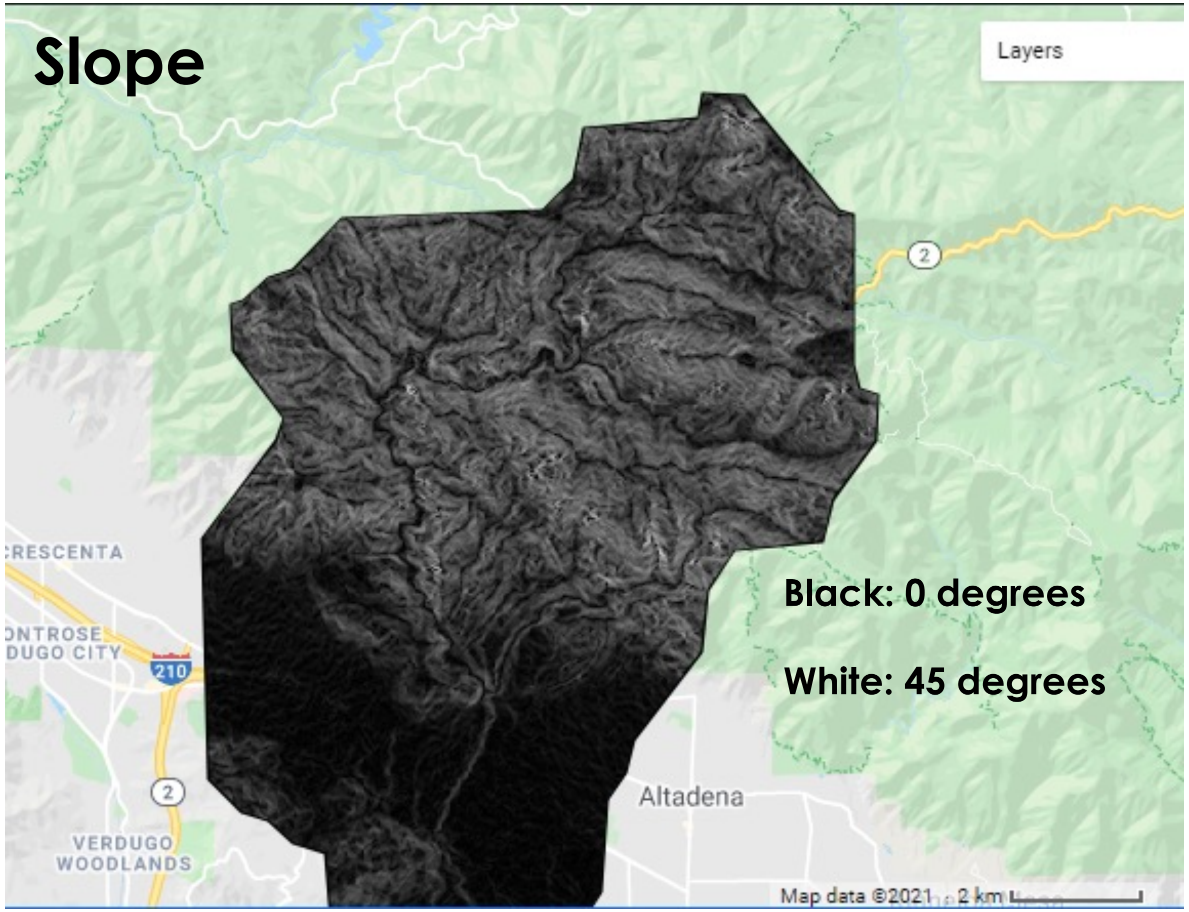
Station Fire over La Cañada Flintridge
Image Credit: mbtrama

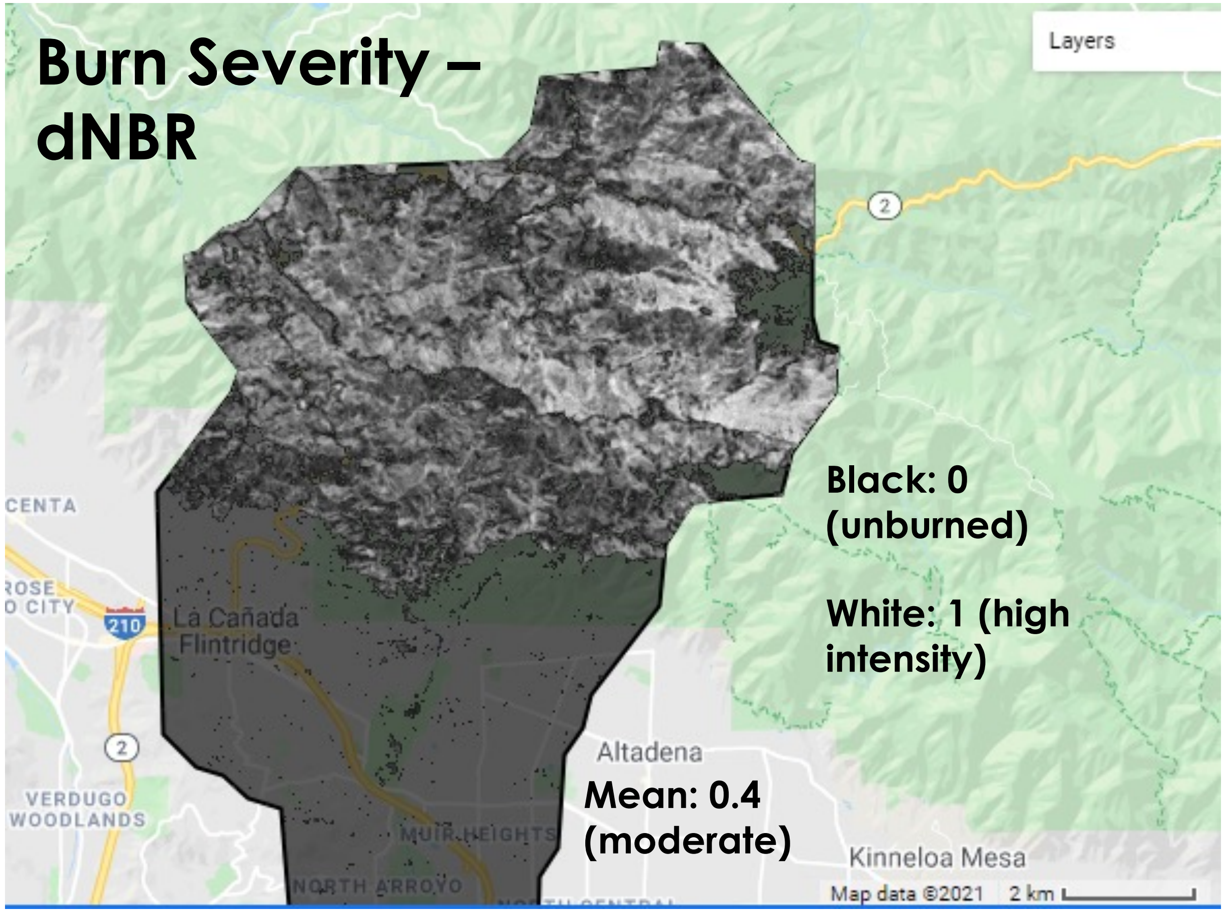
Conceptual Model

- Collect topographic, rainfall, and burn severity data for a basin via Google Earth Engine
  - Topography via NASADEM or SRTM (30 m)
  - Rainfall via *Integrated Multi-satellitE Retrievals for Global Precipitation Measurement* (IMERG) (~11 km)
  - Burn Severity via Landsat (30 m)
  - Global Basin Delineations via HydroSHEDS (tens of km^2)
- Assess relationship between input data and DF activity
  - Extensive database provided by the USGS to link timing and occurrence of DFs

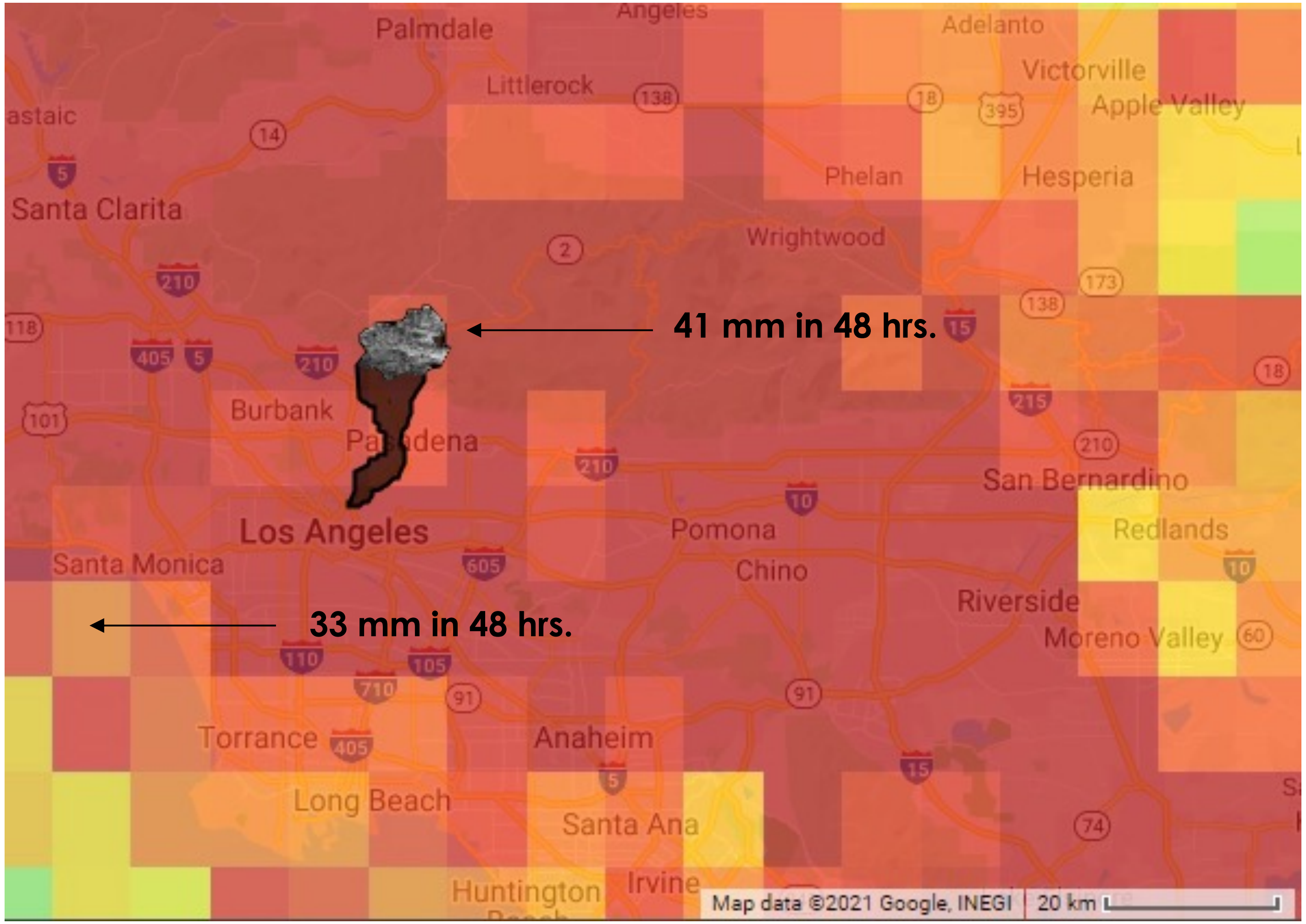
Example Basin in Station Fire Perimeter

Data Inputs – Slope and Burn Severity





Data Inputs - Rainfall



- In January 2010, California experienced several heavy storms. Included here is one between Jan 17-18.
- The pixels near burned area showed the highest IMERG-recorded rainfall in at least the last two years!
- *Based on the severity and topography of the burned area, would a model correctly predict any debris flows in this basin?*

Model Breakdown

Machine Learning algorithm that draws empirically-derived links between input variables and DF occurrence via USGS database

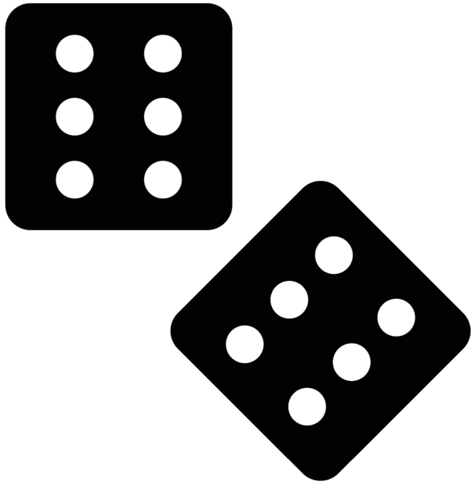
Slope + Burn Severity + Rainfall

↓

% Probability of DF Occurrence within Basin

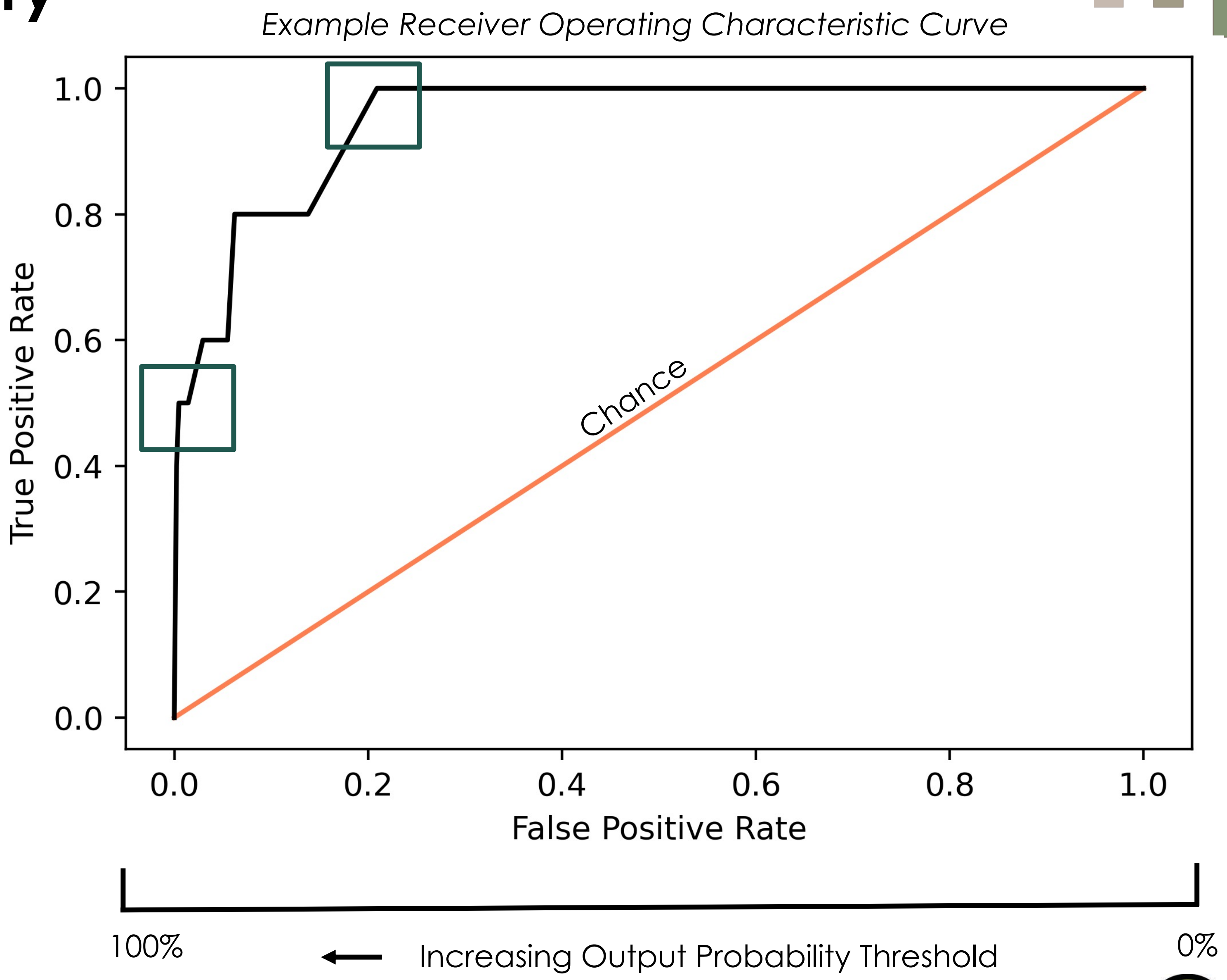
Understanding Model Probability

- Sample model output is 82% probability of DF, and in fact several DFs occurred. **So, what does this probability mean?**
- Predicting DFs requires drawing a decision boundary that maximizes DF occurrence but minimizes false alarms.



Setting a Decision Boundary

Find the optimal true positive rate (TPR) and false positive rate (FPR) pair for your needs.

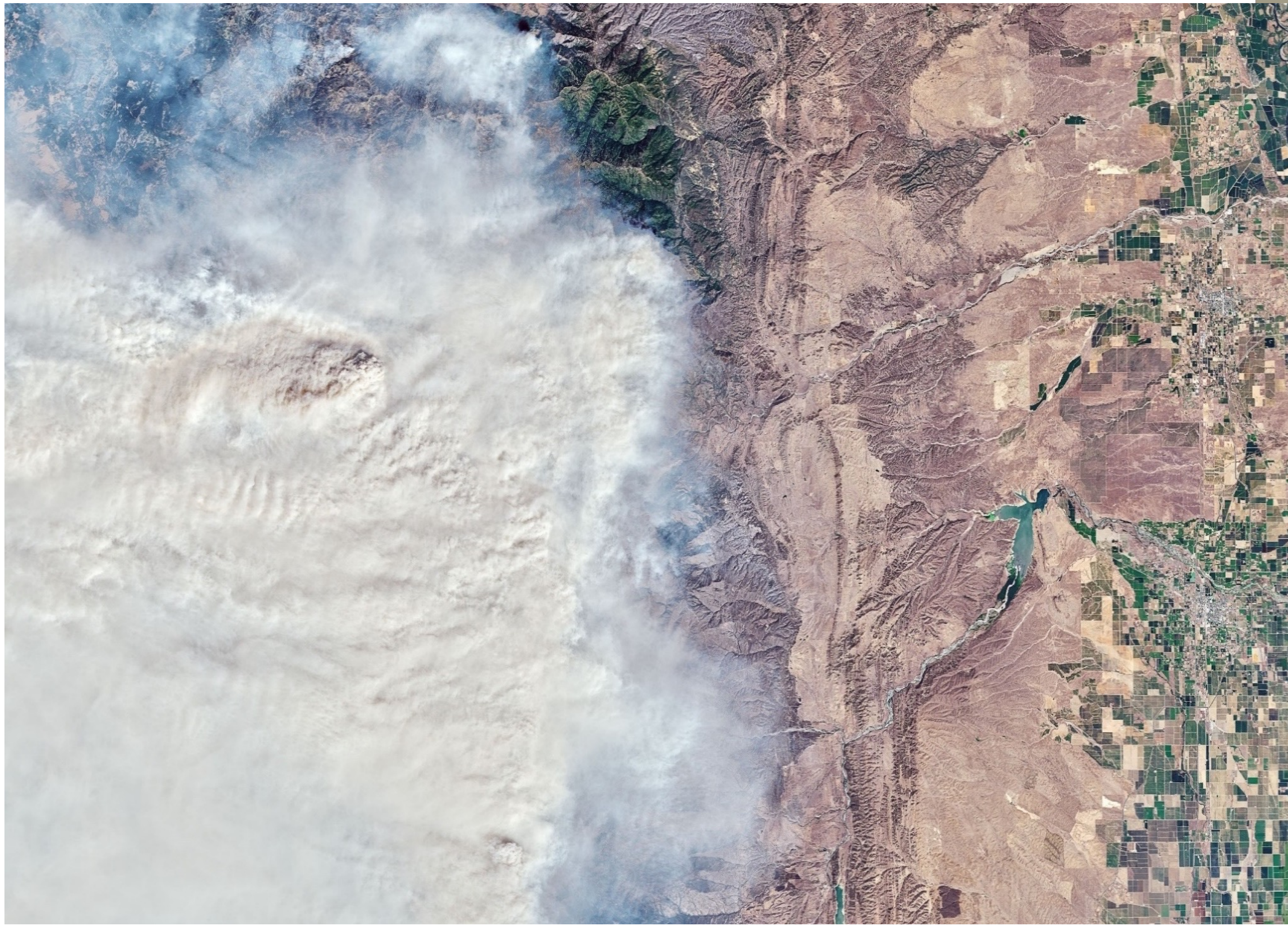


Recap

- A PFDF model can be developed by training on empirically-derived information relating topography, burn severity, and rainfall (all remotely sensed variables) to debris flow activity.
- Model output is a probability of occurrence, which is best used to guide placing a decision boundary that finds the optimal ratio of True/False positive occurrence.
- When trained on an adequate representation of data, it means we can use remote sensing to assess PFDF probability anywhere of interest!

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

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  - 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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References

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Thank You!