NASA DEVELOP National Program
2022 Fall Project Proposal

North Carolina – NCEI
Gatlinburg & Beatty Wildfires

Evaluating the Role of Soil Moisture in Determining Vegetation Health, Fuel Loads, and Wildfires in the Gatlinburg and Bootleg Fires

Project Overview

Project Synopsis: Partnering with the Western Regional Climate Center (WRCC), National Integrated Drought Information System (NIDIS), North Carolina State Climate Office, and Oklahoma State University, this project will evaluate how measures of remotely sensed standardized soil moisture compare to measures of vegetation health and fire fuel indices leading up to the 2016 Gatlinburg, TN and 2021 Bootleg, OR fires. The project team will produce fuel load maps using traditional fire fuel indices and vegetation indices derived from Landsat 8 OLI and analyze antecedent soil moisture conditions obtained from ESA CCI SM using various standardization approaches. The team will then assess the relationship between fuel load and soil moisture to investigate which metrics best align with fuel buildup 6 months prior to the fire events. Following the project, this analysis will enhance partners' understanding of soil moisture and fuel load behavior ahead of a fire event and help inform future fire and drought monitoring decisions.

Study Location: Gatlinburg Fire, TN and Bootleg Fire, OR
Study Period: May 2016 – November 2016; January 2021 – July 2021

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Partner Overview

Partner Organizations:

Organization	Contact (Name, Position/Title)	Partner Type	Sector
Desert Research Institute, Western Regional Climate Center	Dr. Timothy Brown, Director	End User	Non-profit
NOAA, National Integrated Drought Information System	Marina Skumanich, Program Specialist for the National Coordinated Soil Moisture Monitoring Network; Britt Parker, Regional Drought Information Coordinator Pacific Northwest Region	End User	Federal Government

North Carolina State Climate Office	Dr. Sheila Saia, Associate Director; Corey Davis, Assistant State Climatologist	End User	State Government
Oklahoma State University	Dr. Tyson Ochsner, Professor of Plant & Soil Sciences	Collaborator	Academic

End User Overview

End User's Current Decision-Making Process & Capacity to use Earth Observations: The NC State Climate Office synthesizes climate, hydrology, and ecology information for regional agencies and pursues research projects to address the needs of these stakeholder groups. These efforts include monitoring the states' atmospheric and soil parameters with a network of *in situ* stations and developing visualization tools such as the Fire Weather Intelligence Portal. The Gatlinburg fire began in the Great Smoky Mountains National Park, which straddles the border of North Carolina and Tennessee, the NC State Climate Office is interested in investigating conditions that led to the devastating wildfire on their border and shares similar climate conditions with North Carolina. Similarly, the WRCC leverages a variety of climate and hydrology indices to provide information related to drought and climate variability in the western United States and develop products for wildfire management. In collaboration with the WRCC, NIDIS launched a strategy to identify priorities and actions to improve products and communication in the drought and fire communities. Additionally, NIDIS is leading an effort to establish a National Coordinated Soil Moisture Monitoring Network to support improved early hazard warning systems and reduce risks from drought and wildfire by combining *in situ*, satellite, and modeled products. However, soil moisture observations are not traditionally used in fire-related indices, as such, partners are interested in exploring how soil moisture conditions can inform measures of fuel loads and vegetation in the lead-up to wildfires.

Earth Observations Overview

Earth Observations:

Platform & Sensor	Parameters	Use
Landsat 8 OLI	Surface reflectance, Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Soil Adjusted Vegetation Index (SAVI)	Spectral signatures and indices will be used to calculate measures of vegetation health at a 30 m resolution six months leading up to the fire events. These measures of vegetation health will be compared to standardized measures of soil moisture conditions.
SMAP	Soil Moisture	Soil moisture observations from SMAP are used as inputs to the ESA CCI SM dataset. Soil moisture observations from ESA CCI SM will be used to calculate antecedent soil moisture conditions in the lead up to the fire events using three standardization approaches.

Ancillary Datasets:

- European Space Agency Climate Change Initiative Soil Moisture Version v07.1 (ESA CCI SM) – Calculate antecedent soil moisture conditions six months prior to the fire events using three standardization approaches, interannual standardized soil moisture, period of record standardized soil moisture, fraction of available water based on soil property and compare these metrics to measures of vegetation health and fire fuel indices

- United States Forest Service (USFS) Wildland Fire Assessment System (WFAS) Keetch Byram Drought Index (KDBI) – Compare and correlate this drought index specifically used for fire potential assessments with antecedent moisture conditions six months prior to the fire events

Decision Support Tool & End Product Overview

End Products:

End Product	Partner Use	Datasets & Analyses	Software Release Category
Fuel Load Maps and Spatially Averaged Time Series	This product will be used to understand fuel load and vegetation health changes prior to the fire events. A comparison of various indices will help partners understand the differences and limitations of fuel load and vegetation health metrics for future monitoring.	Maps and time series detailing fire fuel load change six months prior to the two fire events will be created using spectral vegetation indices from Landsat 8 OLI such as NDVI, EVI, SAVI as well as the Keetch-Byram Drought Index (KBDI).	II
Antecedent Moisture Conditions Analyses	The antecedent moisture condition analyses will illustrate soil moisture behavior in the lead up to two fire events using various standardization approaches. This analysis will help partners understand how pre-fire soil moisture behavior varies across standardization approaches, which may inform the selection of a specific standardization method for future fire and moisture monitoring efforts.	The calculation of antecedent soil moisture conditions from the ESA CCI SM datasets six months prior to the two fire events using three standardization approaches, including interannual standardized soil moisture, period of record standardized soil moisture, and fraction of available water based on soil property.	II
Fuel Load and Antecedent Moisture Comparison	This product will illustrate which vegetation health and fuel buildup metrics best align with antecedent moisture conditions. This comparison will help inform partners' future fire and moisture monitoring decisions regarding fuel load and vegetation metric selection, and soil moisture standardization approaches used in their communication, monitoring, and product development efforts.	Correlations between fuel load spatially averaged time series from Landsat 8 OLI, KBDI, and antecedent soil moisture conditions from ESA CCI SM will be calculated and used to inform which metrics best align with fuel buildup ahead of a fire event.	II

Project Timeline & Previous Related Work

Project Timeline: 1 Term: 2022 Fall

Notes & References:

Notes: There was also partner and advisor interest in expanding this analysis to look at different types of wildfire fuel, such as grassland fires, soil fires, or timber fires. Given the short 10-week term, this does not seem within the scope of a single term project, however, depending on the outcome of the first term of this project, we could consider a second term to expand to different fuel load types.

References:

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

Objectives

This project has three main objectives, listed below.

- Analyze antecedent soil moisture conditions 6 months preceding two fire events using three standardization approaches
    - End Product: Antecedent Moisture Conditions Analyses
- Calculate fuel load and vegetation health changes using spectral vegetation indices and KBDI prior to the fire events
    - Fuel Load Maps and Spatially Averaged Time Series
- Assess the relationship between antecedent soil moisture conditions and fuel load and vegetation indices to investigate which metrics best align with fuel buildup 6 months prior to the fire events
    - Fuel Load and Antecedent Moisture Comparison

Background Information on Wildfires

We will need to conduct literature review on our two fire case studies, I have compiled some information about the fires to get you started below. Additionally, check out the literature folder where you will find reports on the Gatlinburg fire.

Gatlinburg Wildfire

- 2016 Gatlinburg, TN in late November-December
- Burned 17,000 acres
- In exceptional drought conditions according to the USDM (suffering extremely dry conditions for roughly 2 to 3 months)
- Mostly deciduous trees, ground fuel
- The National Park Service put together a fairly comprehensive review of the Chimney Tops 2 fire that affected Gatlinburg. It includes a timeline of the events, background on weather conditions, and a detailed appendix with fire danger and wind data from nearby weather stations
- While I admittedly didn't follow this particular fire too closely at the time since it was in Tennessee (not NC), my main memory is that it followed a mostly dry cold frontal passage that included extremely gusty winds, which ultimately helped the fire spread as rapidly as it did. Certainly the very dry landscape was a factor as well. I'm not sure if the indicators you're targeting will necessarily capture the wind component that made the Gatlinburg fire particularly bad. My guess is that they will show Gatlinburg as one of many dry areas with elevated fire risk at that time. That's at least partially confirmed by a check of the observed KBDIs in late November 2016, which showed widespread values of 600+ across east Tennessee. And ultimately, that's the purpose of fire danger indicators: not to tell exactly when and where a fire *will* ignite, but to show when and where that risk level is highest.

Bootleg Fire, OR

- July 6th- August 15th 2021

- Burned 413,717 acres
- In exceptional drought conditions according to USDM
- Mixed grass/shrub, timber understory, open to dense timber stands
- Here is a great StoryMap to review with information about the Bootleg fire- Link HERE

Soil Moisture Standardization Approaches

One of the main objectives of this project is investigating soil moisture via three different standardization approaches. I briefly described each of them below but this is a great topic to start conducting your literature review on! Additionally, discussing these three approaches with Ronnie in your first advising meeting would be a great first step as well.

- Interannual Standardized Anomaly
    - Computed climatology of volumetric soil moisture using a 15 day moving window to show soil moisture variability and highlight whether the time we are looking at is wetter or drier than normal
    - Ronnie has calculated this and will be providing this data to us
    - This paper of Ronnies can help provide a little more context about how this is calculated – Link HERE
- Period of Record Percentiles
    - Computed climatology of volumetric soil moisture without the 15 day moving window
    - The team will be calculating this themselves
- Fraction of Available Water
    - Available water in the soil in between the wilting point and field capacity
    - Ronnie will be providing this data or pointing us as to where to get it

Datasets Information and Links

Below, I have provided some additional information gathered from partners and online about the datasets we will be using. You can use this as a starting point for your data acquisition process and literature review.

European Space Agency Climate Change Initiative Soil Moisture Version v07.1 (ESA CCI SM)

- Link HERE
- Ronnie will be providing this dataset?

United States Forest Service (USFS) Wildland Fire Assessment System (WFAS) Keetch Byram Drought Index (KDBI)

- We will be getting KBDI from our partners, the North Carolina State Climate Office. They manage a portal called the Fire Weather Intelligence Portal where you can explore KBDI across the US from 2005-2022. However to download the data, you must use the THREDDS server provided in the link below.
- Daily Gridded KBDI from 2016 – Link Here
- Daily Gridded KBDI from 2021- Link Here
- Notes about KDBI:
    - KBDI is calculated once per day, typically at 1 pm local time alongside the suite of National Fire Danger Rating System parameters. Its inputs include the total precipitation and maximum temperature over the previous 24 hours.
    - As noted on this page, the inputs for KBDI are a location's latitude, its mean annual precipitation, the maximum air temperature in the previous 24 hours, and the total

precipitation in the previous 24 hours. Hot temperatures and dry weather cause the greatest daily increases in KBDI, especially in locations with relatively wet climates. As that page also notes, KBDI values only decrease when daily precipitation exceeds 0.20 inches, so during extended dry periods such as fall 2016 in the southern Appalachians, KBDIs just kept rising.
    - NC State Climate Office calculates the gridded KBDI product themselves, using normal precipitation from PRISM, daily precipitation totals from NWS AHPS, and daily maximum temperature as assessed using the RTMA (Real-Time Mesoscale Analysis) product.
    - NC State Climate Office has not formally documented this dataset vs. the station-based KBDI, but in their experience, the gridded product sometimes tends to slightly underestimate values. Coreys theory is that this may be due to the RTMA temperatures, which are only hourly and this may not capture the actual daily maxima that often occur between hours. Over time, those small differences (off by a degree or two almost every day) may then add up (or *not* add up, as it were) and be manifest as lower KBDIs. Interestingly, though, Corey noted while looking at the data around Gatlinburg in late November 2016 that the gridded KBDIs were at or slightly *higher* than the nearby stations, so it may not be a concern in that case. Just be aware that there can be a slight bias with the gridded product, typically by less than 100 points (e.g., if a station is reporting a KBDI of 500, the gridded total for that point is usually in the 400-500 range).
    - KDBI is less commonly used on the west coast.
- Guidance on navigating the THREDDS server:
    - To view the data without downloading it, you can click on the "Godiva2 (browser-based)" link, then open the left-side menu and select "KBDI", then choose the date of interest along the top.
    - If you want to view any other years, you should be able to change the "y2021" in the URL to "y[year]". We have data from 2005 to the present, and the 2022 file is updated every day.

Landsat 8 OLI Calculated Indices

- Normalized Difference Vegetation Index (NDVI)- Link HERE
    - Estimates density of green on an area of land using difference between visible and near-infrared reflectance

- Soil Adjusted Vegetation Index (SAVI)- Link HERE
    - Used to correct NDVI for influence of soil brightness in areas where vegetative cover is low

- Enhanced Vegetation Index (EVI)- Link HERE
    - Similar to NDVI and used to quantify vegetation greenness. Corrects for some atmospheric conditions and canopy background noise and is more sensitive in areas with dense vegetation

Software & Scripting

Add info/tutorials here for R?
Raster package is Terra

- https://rspatial.org/terra/

Relevant ARSET trainings

1. 1. Using Earth Observations for Pre- and Post-Fire Monitoring: https://appliedsciences.nasa.gov/join-mission/training/english/arset-using-earth-observations-pre-and-post-fire-monitoring

2. Satellite Observations and Tools for Fire Risk, Detection, and Analysis: https://appliedsciences.nasa.gov/join-mission/training/english/arset-satellite-observations-and-tools-fire-risk-detection-and

3. Applications of GPM IMERG Reanalysis for Assessing Extreme Dry and Wet Periods: https://appliedsciences.nasa.gov/join-mission/training/english/arset-applications-gpm-imerg-reanalysis-assessing-extreme-dry-and-wet

4. Applications of Remote Sensing to Soil Moisture and Evapotranspiration: https://appliedsciences.nasa.gov/join-mission/training/english/arset-applications-remote-sensing-soil-moisture-and

R resources from Ronnie

- For R-training there is a very basic site to get in the ins and outs of the software. https://www.w3schools.com/r/default.asp

  Here is some examples on the terra package (I think Kathryn found this one while I was there): https://rspatial.org/terra/spatial/index.html

- I also like the terra.pdf that describes every function in the terra package. Don't read the whole thing but take a look at overlaying a series of rasters using function 'c' and app. App will apply a function of your choosing (i.e., mean, max, ecdf) to the cells of a combined raster set. https://cran.r-project.org/web/packages/terra/terra.pdf

Wish list items

With 10 weeks to conduct our project, it is important to prioritize and there are a lot of additional analyses we could consider. The partners expressed interest in the two I listed below. First focus on the objectives outlined in this proposal and if there is additional time, this could be something to consider. Additionally, it is good practice to keep a running list of "future work" ideas, these will be great to mention in your presentation and technical report at the end of the term!

- National Assessment of Major Wildfire Occurrences
  - There was interest from partners to conduct a national assessment of major wildfire occurrences and acreage burned by state using the USGS Earth Resources Observation and Science (EROS) and USDA Forest Service Geospatial Technology and Applications Center (GTAC) Monitoring Trends in Burn Severity (MTBS) dataset.
  - The team would calculate wildfire occurrence metrics across 51 US states, including Puerto Rico, such as frequency of wildfire occurrence by state, median acreage burned by state, and annual and seasonal variations by state to provide partners with additional context on wildfire behavior based on fuel type, including timer, grassland, or organic soil, that vary by state
- Additional indices of interest
  - Evaporative Stress Index/ VegDRI/ Vegetation Health Index – Link HERE & Link HERE