**California & Oregon Ecological Forecasting**

Detecting and Forecasting Fog Occurrence, Frequency, and Change to Support Coast Redwood (*Sequoia sempervirens*) Habitat Assessments

**Project Team**

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**Project Overview**

***Project Synopsis:***

This project mapped past and present fog presence and longevity over the landscape of coastal California and Oregon using the Terra Moderate Resolution Imaging Spectroradiometer (MODIS) and the Geospatial Operational Environmental Satellite 17 (GOES-17) Advanced Baseline Imager (ABI). To shed light on the future of fog dynamics, the team modeled monthly fog presence for 2080 based on ClimateNA Representative Concentration Pathway (RCP) 4.5 ensemble projections. These maps and models will allow Save the Redwoods League (STRL) to determine how coast redwood habitat suitability may shift or expand under projected changes in climate and will aid the organization in evaluating the potential for northern range expansion and broader scale conservation planning.

***Abstract:***

Fog and low clouds play an important role in providing moisture to coastal ecosystems. Coast redwood (*Sequoia sempervirens*) forests are currently distributed along a narrow strip of coastline in California and Oregon and rely on the presence of marine fog for moisture availability during the dry season (June-October). Recent time series analyses presented an uncertain future of fog frequency; however, a decline in fog presence may have adverse effects on the coast redwood habitat. To support Save the Redwoods League, a non-profit organization dedicated to coast redwood forest management, the team analyzed hourly fog data from the Geospatial Operational Environmental Satellite 17 (GOES-17) Advanced Baseline Imager (ABI) and daily cloud cover data from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra satellite. To explore present day fog longevity, GOES-17 was utilized to map the number of fog hours per day for the 2019 and 2020 dry seasons. The MODIS cloud flag was used to map the presence or absence of daily fog, which was summarized to create a monthly fog frequency dataset and identify trends in fog presence between 2000-2020. Both datasets were used as inputs into the random forest machine learning algorithm to identify climatic drivers of fog presence and longevity over the landscape. The present-day models suggested that daily temperature difference is a driving force behind fog presence and longevity. Trends in fog presence from 2000-2020 indicated great interannual variability. Finally, fog presence was modeled under a 2080 climate projection to shed light on the future of fog presence under a projected warmer climate. Model results projected an overall decline in fog presence during the dry season in the 2080s. Decreased fog presence as a result of increased temperature difference under a warmer climate remains to be a topic of investigation as to the impact on future redwood habitat suitability.

***Key Terms:***

remote sensing, MODIS, GOES, fog, climate change, coast redwood, California, Oregon

***National Application Area Addressed:***Ecological Forecasting

***Study Location:*** California and Southwest Oregon coast

***Study Period:*** 2000 to 2020 (June to October); Forecasting to 2080

***Community Concerns:***

* Coast redwoods play a key role in maintaining a resilient surface climate as they are highly effective at capturing and transforming carbon dioxide.
* Recent time series analyses suggest a decline in coastal fog frequency over the landscape. Current and future distributions of fog as predictors of environmental suitability are not available or included in these analyses and projections. Because coast redwoods rely on fog for moisture during the dry season, it is critical to examine the potential implications of fog reduction in the coastal redwood ecoregion.
* A decline in fog frequency may lead to limited water availability and increased fire risk, which could result in a shift of suitable habitat for coast redwoods.

***Project Objectives:***

* Map fog presence and average hours per day for dry season months (June to October) between 2019 and 2020 utilizing GOES-17
* Develop a historical monthly fog frequency dataset for the redwood region and analyze changes and trends in fog presence over the past 20 years utilizing MODIS data from 2000-2020

Model the relationship between climate variables, fog longevity, and fog presence

* Apply models to predict fog presence under future climate conditions

**Partner Overview**

***Partner Organization:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **Save the Redwoods League** | Dr. Kristen Shive, Director of Science | End User | Yes |

***Decision-Making Practices & Policies:***

Save the Redwoods League is the primary non-profit conservation organization tasked with the protection, conservation, and restoration of the coast redwood forests of California and southwestern Oregon. The organization accomplishes this mission by “purchasing redwood forests, regenerating logged forests so they become spectacular havens for future generations, studying how to best protect and restore these global treasures, and introducing people to these magical places.” The organization utilizes intensively collected field data and LiDAR to support its decision-making processes; however, remotely sensed data currently play a very limited or non-existent role in these processes.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameter** | **Use** |
| **GOES-17 ABI** | Shortwave and longwave infrared bands (CH 13 & 7) | GOES-17 ABI imagery was used to create a “fog hours per day” dataset for the dry seasons of 2019 and 2020 for coastal California and Oregon.  |
| **Terra MODIS** | Cloud cover flag | The Terra MODIS 10:30AM cloud-flag was used to create monthly composites of daily fog presence from 2000 to 2020 in order to identify the conditions of current fog presence as well as forecast fog occurrence under future climate conditions. |

***Ancillary Datasets:***

* ClimateNA – Monthly climate normals and 2080 climate projections for current and future fog presence modeling
* Oregon State Parameter-elevation Regressions on Independent Slopes Model (PRISM) – Daily and monthly environmental indices for current and future fog presence modeling
* GRIDMET DROUGHT: CONUS drought indices – Monthly PDSI values indicating drought intensity and water stress for use in current fog presence modeling
* USGS NED Topographic Diversity – Elevation, slope, and aspect were derived from this dataset for use in current fog presence and longevity modeling

***Modeling:***

* Random forest (POC: Anthony Vorster, Colorado State University) – Establishing a statistical relationship between climatic and topographic variables and current fog presence and longevity to understand drivers of current fog presence and model future fog presence under projected climate scenarios

***Software & Scripting:***

* Google Earth Engine – Data collection, image processing, raster generation
* R Studio v1.2.1335 – Modeling execution, statistical analyses
* Esri ArcGIS v10.8.1 – End product and map generation

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used**  | **Partner Benefit & Use** | **Software Release Category** |
| **Maps of Fog Presence and Longevity (2000-2020**) | GOES-17 ABI, Terra MODIS | MODIS-derived maps of the rate of change of daily fog presence over the past 20 years were created for each month of the dry season to inform partners of areas where fog presence may be shifting. In addition, GOES-17-derived maps of ‘fog hours per day’ were created to present the partners with an estimate of the areas that experience least/most frequent fog on a daily basis. | N/A |
| **Maps of Current (2000-2020) and Future (2080) Fog Presence and Longevity** | GOES-17 ABI, Terra MODIS | We modeled relationships between both fog presence and fog longevity with several climatic and topographic variables using the random forest algorithm. The models were trained on data from both the GOES- and MODIS-derived fog products. The data and maps of these model results provide the project partners with novel information to evaluate redwood suitability given altered fog presence and longevity in a projected warmer climate. | N/A |

***Product Benefit to End User:***

This project will increase the scientific understanding of the potential for a northern range expansion of coast redwood (*Sequoia sempervirens*) under changing climate conditions. Project partners have requested new datasets to support projected habitat suitability to prioritize their conservation work, which includes property acquisition, restoration work, and research to protect and restore redwood forests. The resulting models of this project can inform where conservation and restoration activities and resources should be targeted, considering the many uncertainties about how climate change will impact Pacific Northwest forest communities. Following the term, managers can use these end products to create coast redwood habitat suitability models that can be employed to monitor areas thought to be most suitable for seedling establishment, supporting conservation decisions related to coast redwood’s continued natural recovery and potential for northern migration.

**References**

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