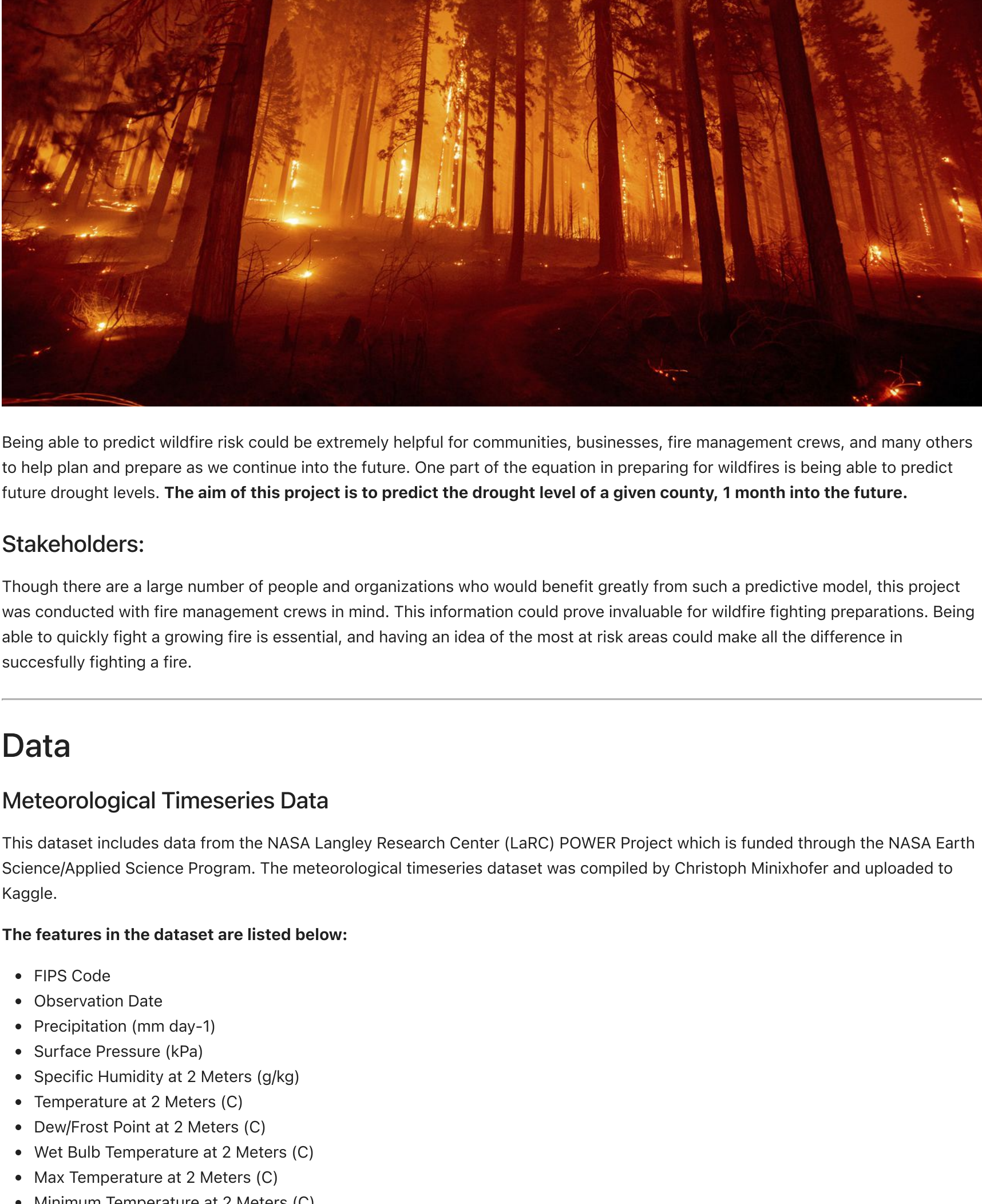


Drought Prediction Capstone Project

Introduction

Problem Statement:

All around the world wildfires are damaging the lives and property of many people. Due to a multitude of factors such as drought, bark-beetle infestation, bad fire management practices, increases in outdoor recreation, degrading energy infrastructure, and much more, the western United States is now host to catastrophic wildfires that haven't been witnessed in recorded history. Unfortunately, climate scientists warn that this is the 'new normal'.



Being able to predict wildfire risk could be extremely helpful for communities, businesses, fire management crews, and many others to help plan and prepare as we continue into the future. One part of the equation in preparing for wildfires is being able to predict future drought levels. **The aim of this project is to predict the drought level of a given county, 1 month into the future.**

Stakeholders:

Though there are a large number of people and organizations who would benefit greatly from such a predictive model, this project was conducted with fire management crews in mind. This information could prove invaluable for wildfire fighting preparations. Being able to quickly fight a growing fire is essential, and having an idea of the most at risk areas could make all the difference in successfully fighting a fire.

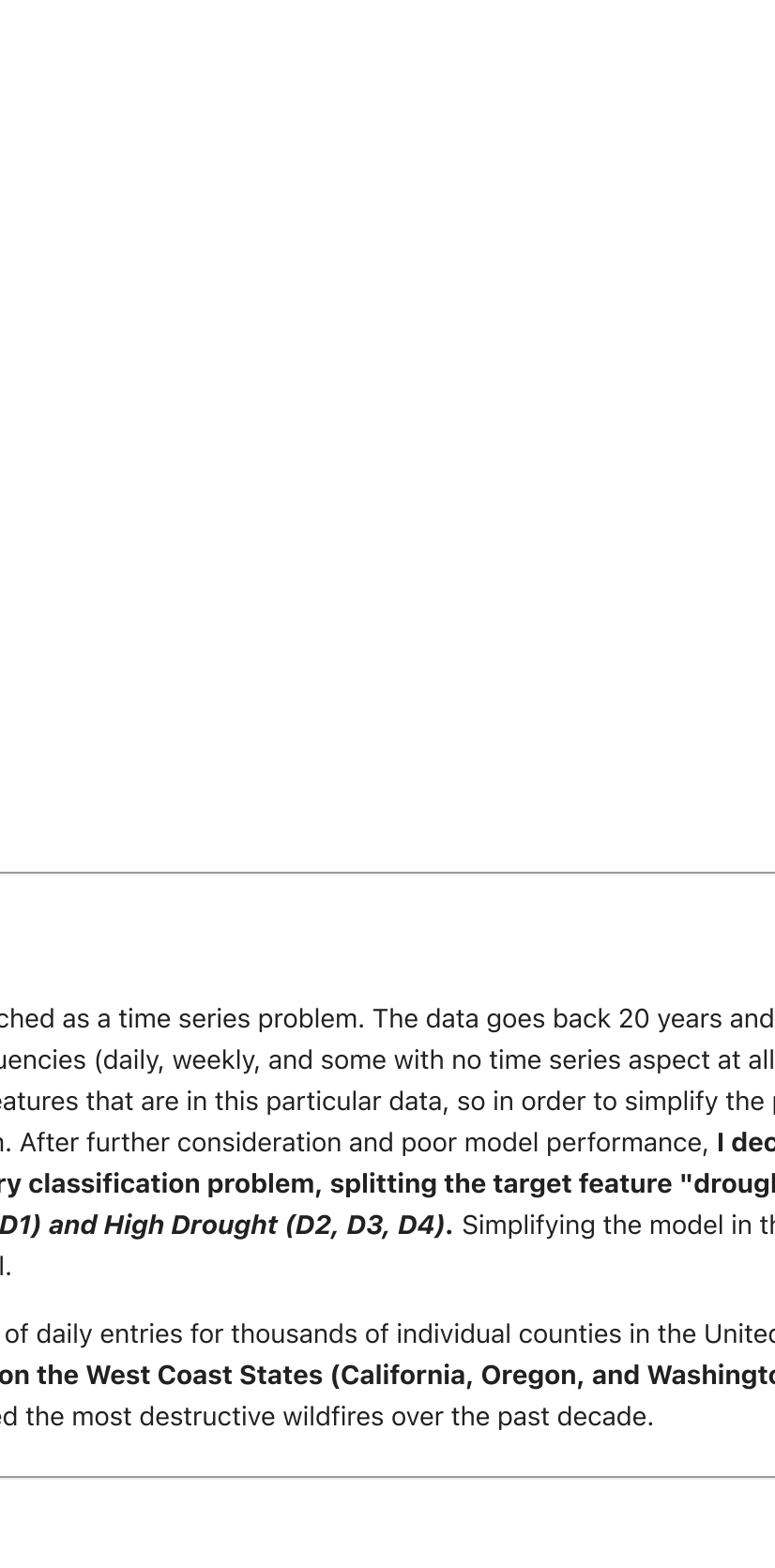
Data

Meteorological Timeseries Data

This dataset includes data from the NASA Langley Research Center (LaRC) POWER Project which is funded through the NASA Earth Science/Applied Science Program. The meteorological timeseries dataset was compiled by Christoph Minixhofer and uploaded to Kaggle.

The features in the dataset are listed below:

- FIPS Code
- Observation Date
- Precipitation (mm day⁻¹)
- Surface Pressure (kPa)
- Specific Humidity at 2 Meters (g/kg)
- Temperature at 2 Meters (C)
- Dew/Frost Point at 2 Meters (C)
- Wet Bulb Temperature at 2 Meters (C)
- Max Temperature at 2 Meters (C)
- Minimum Temperature at 2 Meters (C)
- Temperature Range at 2 Meters (C)
- Earth Skin Temperature (C)
- Wind Speed at 10 Meters (m/s)
- Minimum Wind Speed at 10 Meters (m/s)
- Maximum Wind Speed at 10 Meters (m/s)
- Wind Speed Range at 10 Meters (m/s)
- Wind Speed at 50 Meters (m/s)
- Maximum Wind Speed at 50 Meters (m/s)
- Minimum Wind Speed at 50 Meters (m/s)
- Wind Speed Range at 50 Meters (m/s)



US Drought Monitor Data (Target Feature)

The US Drought Monitor collects drought scores for counties throughout the US on a scale from No Drought - D4. In the dataset these values are floating point values ranging from 0-5, 0 corresponding to No Drought and 5 corresponding to D4. These values are the county average and are collected weekly.

D0	Abnormally Dry	<ul style="list-style-type: none">Going into drought:<ul style="list-style-type: none">short-term dryness slowing planting, growth of crops or pasturesComing out of drought:<ul style="list-style-type: none">some lingering water deficitspastures or crops not fully recovered
D1	Moderate Drought	<ul style="list-style-type: none">Some damage to crops, pasturesStreams, reservoirs, or wells low, some water shortages developing or imminentVoluntary water-use restrictions requested
D2	Severe Drought	<ul style="list-style-type: none">Crop or pasture losses likelyWater shortages commonWater restrictions imposed
D3	Extreme Drought	<ul style="list-style-type: none">Major crop/pasture lossesWidespread water shortages or restrictions
D4	Exceptional Drought	<ul style="list-style-type: none">Exceptional and widespread crop/pasture lossesShortages of water in reservoirs, streams, and wells creating water emergencies

Soil Data

The features in the soil dataset are from the Harmonized World Soil Database, which contains data generated by the NASA Shuttle Radar Topographic Mission (SRTM). This includes digital elevation data (DEMs) for over 80% of the globe with 3 arc second (approximately 90 meter) resolution at the equator.

The terrain slopes of a given county (FIPS code) are included as a percentage of the entire area that each slope category represents. The slope categories add up to a value of 1 (100%). Similarly, slope percentage for a given county are included and add up to a value of 1 (100%). Other features represent land and soil characteristics.

- Elevation
- 0% ≤ slope ≤ 0.5%
- 0.5% ≤ slope ≤ 2%
- 2% ≤ slope ≤ 5%
- 5% ≤ slope ≤ 10%
- 10% ≤ slope ≤ 15%
- 15% ≤ slope ≤ 30%
- 30% ≤ slope ≤ 45%
- Slope > 45%
- North Aspect
- East Aspect
- South Aspect
- West Aspect
- Unknown Aspect
- Mapped Water Bodies
- Sparsely Vegetated Land
- Built-up Land
- Grass/Scrub/Woodland
- Forest Land
- Rain-fed Cultivated Land
- Irrigated Cultivated Land
- Total Cultivated Land
- Nutrient Availability
- Nutrient Retention Capacity
- Rooting Conditions
- Oxygen Availability to Roots
- Excess Salts
- Toxicity
- Workability

Methods

This problem was initially approached as a time series problem. The data goes back 20 years and contains numerous features, some of which have different time frequencies (daily, weekly, and some with no time series aspect at all). Time series problems can be quite tricky, especially with the features that are in this particular data, so in order to simplify the problem I decided to turn it into a multi-class classification problem. After further consideration and poor model performance, **I decided to simplify the problem even further by turning it into a binary classification problem, splitting the target feature "drought score" into two categories: Low Drought (No Drought, D0, D1) and High Drought (D2, D3, D4).** Simplifying the model in this way produced a more reliable model that was far more practical.

The full dataset included millions of daily entries for thousands of individual counties in the United States. **A smaller subset of this data was created that focussed on the West Coast States (California, Oregon, and Washington).** These particular states were selected as they have experienced the most destructive wildfires over the past decade.

Data Cleaning

The data cleaning and preparation was by far the most complex stage of this project, as it required a great deal of feature engineering and involved data with different collection frequencies. I needed to preserve the time series information by aggregating the sum and averages of certain meteorological features. I developed functions that would create new datasets with the desired features for each county (FIPS Code) and then combine them into one large dataset. *This methodology was applied to create a West Coast dataset (California, Oregon, and Washington) and a Full dataset (entire United States).*

The developed functions performed the following operations:

- Aggregated the sums and averages of the daily meteorological features
- Extracted the month from the date of each entry
- Dropped all NaN values, to make the time frequency of the data uniform (weekly)
- Rounded the drought scores to change from floating point numbers to integers*
- Created new features that showed the previous and following month's drought scores
- Combined county datasets into one large dataset

After these datasets were compiled I added the soil data for each county.

*Drought scores were originally floating point numbers due to the method of collection involving the averaging of scores within a single county

By the end of this process the final datasets had 56 features. The full training dataset had 3,014,760 entries and the west coast training dataset had 129,010 entries.

`python def sum_func(df, col):` Aggregates the rolling sum of a column and creates a new column for the aggregated data. Intended for precipitation calculations.

```
'''
df['{col}_7d_sum'] = df[col].rolling(window = 7).sum().round(2)

df['{col}_30d_sum'] = df[col].rolling(window = 30).sum().round(2)

df['{col}_90d_sum'] = df[col].rolling(window = 90).sum().round(2)
```

`def avg_func(df, col):`

```
'''
Aggregates the rolling average of a column and creates a new column for
the aggregated data. Intended for non-precipitation calculations.
'''

df['{col}_7d_avg'] = df[col].rolling(window = 7).mean().round(2)
df['{col}_30d_avg'] = df[col].rolling(window = 30).mean().round(2)
```

`def create_dataframe(df, fips_id):`

```
'''
Creates a dataframe for a single fips code (county) from the input dataframe.
Utilizes previously defined sum_func and avg_func and removes most non-aggregated
features. Removes NaN values that were introduced from the rolling sum and rolling
average functions. Rounds the drought score feature to make it a categorical
feature and then creates new 'month_ago', '11_months_ago', and 'month_ahead' features.
'''

#Creating the dataframe
fips_df = df[df['fips'].isin([fips_id])]

#Making the dataframe multi-index
fips_df.set_index(['fips', 'date'], inplace = True)

#Creating lists to iterate over
sum_cols = ['precip']
avg_cols = ['surface_pressure', 'specific_humidity', 'temp_2m_min', 'temp_2m_max',
            'dewpoint_2m', 'earthskin_temp', 'wind_10m', 'wind_50m']

#Aggregating new columns
for col in sum_cols:
    sum_func(fips_df, f'{col}')

for col in avg_cols:
    avg_func(fips_df, f'{col}')
```

```
#Resetting the index now that columns have been aggregated to select for relevant columns
fips_df.reset_index(inplace = True)

#Converting to datetime object
fips_df['date'] = fips_df['date'].astype('datetime64[ns]')
```

```
#Adding month column
fips_df['month'] = fips_df['date'].dt.month

#Selecting for desired features in dataframe
fips_df = fips_df[['fips', 'date', 'month', 'score', 'precip_7d_sum', 'precip_30d_sum',
'precip_90d_sum',
'surface_pressure_7d_avg', 'surface_pressure_30d_avg',
'specific_humidity_7d_avg',
'specific_humidity_30d_avg', 'temp_2m_min_7d_avg', 'temp_2m_min_30d_avg',
'temp_2m_max_7d_avg', 'temp_2m_max_30d_avg', 'dewpoint_2m_7d_avg',
'dewpoint_2m_30d_avg', 'earthskin_temp_7d_avg', 'earthskin_temp_30d_avg',
'wind_10m_7d_avg', 'wind_10m_30d_avg', 'wind_50m_7d_avg', 'wind_50m_30d_avg']]
```

```
#Removing rows that are before 2000-04-01 since first 90 days of data will have NaN values for
#precip_90d_sum
fips_df = fips_df[~(fips_df['date'] < '2000-04-01')]
```

#Dropping all NaN values to show only weekly data now that all other columns have been aggregated

```
fips_df = fips_df.dropna()

#Rounding score
fips_df['rounded_score'] = fips_df['score'].round()

#Selecting for previous and future month drought score
fips_df['month_ago_score'] = fips_df['rounded_score'].shift(periods = 4)
fips_df['month_ahead_score'] = fips_df['rounded_score'].shift(periods = -4)
```

```
#Selecting/ordering desired features in dataframe with new columns added
fips_df = fips_df[['fips', 'date', 'month', 'month_ahead_score', 'rounded_score',
'month_ago_score',
'precip_7d_sum', 'precip_30d_sum', 'precip_90d_sum',
'surface_pressure_7d_avg', 'surface_pressure_30d_avg',
'specific_humidity_7d_avg',
'temp_2m_min_7d_avg', 'temp_2m_min_30d_avg', 'temp_2m_max_7d_avg',
'temp_2m_max_30d_avg', 'dewpoint_2m_7d_avg', 'dewpoint_2m_30d_avg',
'earthskin_temp_7d_avg', 'earthskin_temp_30d_avg', 'wind_10m_7d_avg',
'wind_10m_30d_avg', 'wind_50m_7d_avg', 'wind_50m_30d_avg']]
```

```
#Dropping NaN values
fips_df.dropna(inplace = True)

return fips_df
```

`def create_compiled_dataframes(df, fips_list):`

```
'''
Creates and combines the dataframes of multiple counties into one dataframe, utilizing
the previously defined 'create_dataframe function' and a list of fips codes (counties)
to be concatenated.
'''

#Instantiating empty dictionary
test_dict = {}

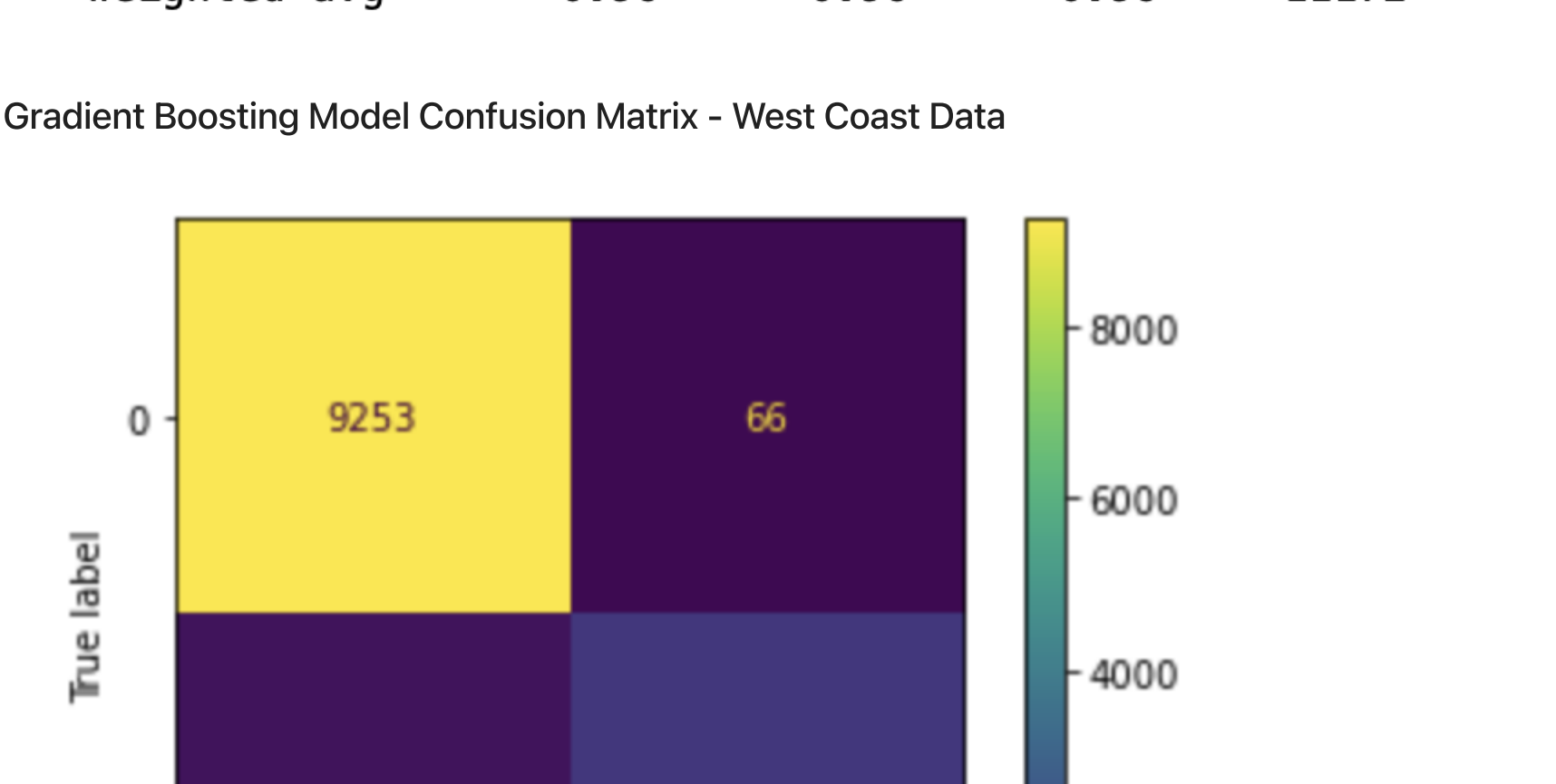
#Looping through fips code list and creating dataframe
for county in fips_list:
    test_dict[county] = create_dataframe(df, int(county))

#Combining dataframes
return pd.concat(test_dict.values(), ignore_index = True)
```

Exploratory Data Analysis

Recursive Feature Elimination

Recursive Feature Elimination was used to determine the most important features for predicting the target feature, 'month_ahead_score' and remove all unnecessary features.



From this visualization of feature importances in the RFE model, we can see that the current drought score, the score 1 month ago, and the precipitation sums are the most important features in predicting 'month_ahead_score'. I decided to include all of these features in the final dataset, greatly reducing the number of features from 56 to 10.

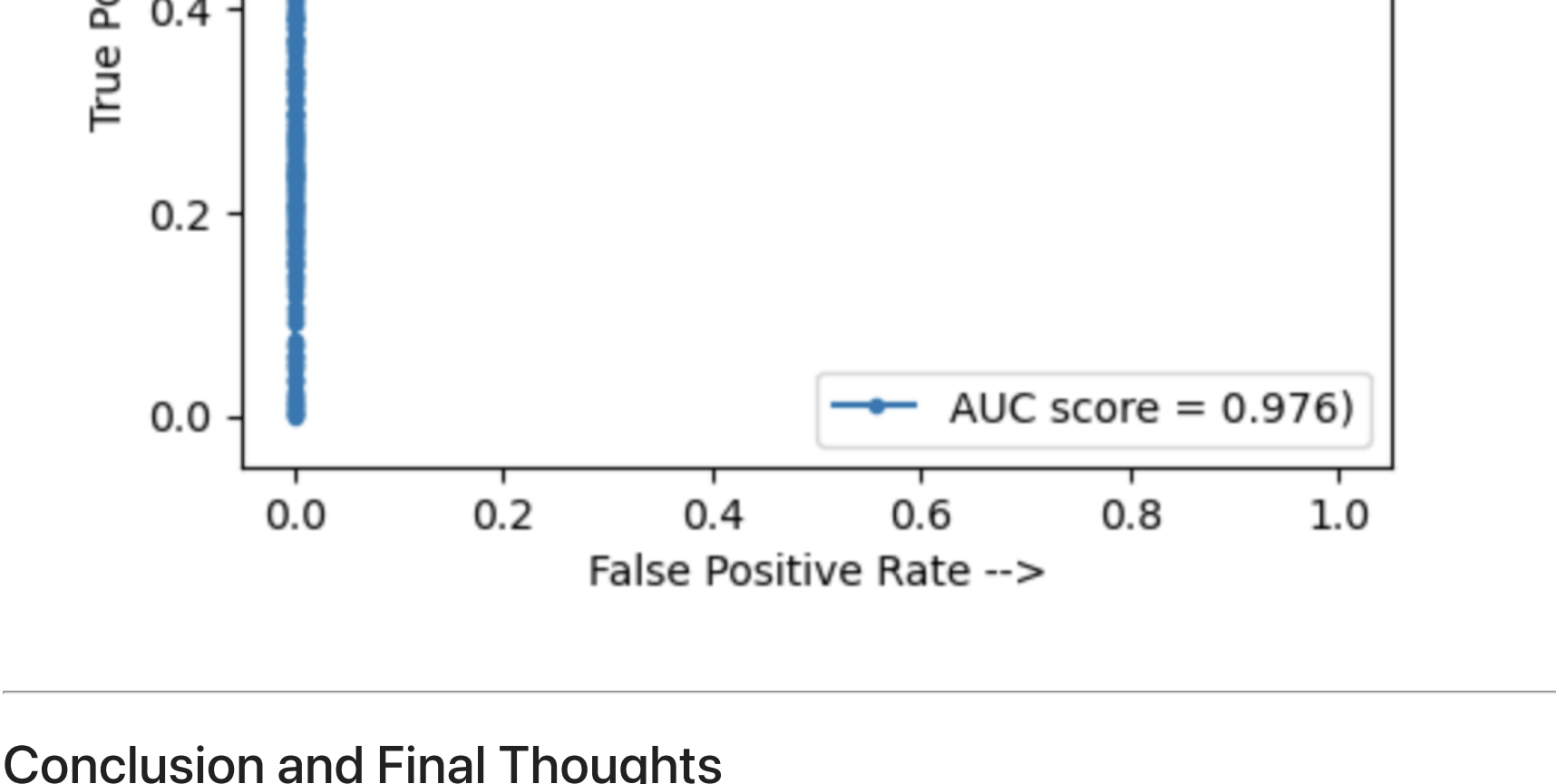
Visualizations

For this section I will display the histograms of the three most important features according to the RFE model:

- Drought Score
- Previous Month's Drought Score
- 90 Day Precipitation Sum

Drought Score

This visualization shows the distribution of drought scores in the West Coast training dataset.



Previous Month Drought Scores

This visualization shows the previous month's drought scores in the West Coast training dataset.



90 Day Precipitation Sum

This visualization shows the sum of the previous 90 days of precipitation in the West Coast training dataset.

Modeling

Converting Target Feature to Binary

Before beginning the modeling process I changed from a multi-class classification problem to a binary classification problem (after initially poor model performance on the testing data). From the visualization of the West Coast training data below we can see that it is quite unbalanced. **"0" corresponds to Low Drought (No Drought, D0, D1) and "1" corresponds to High Drought (D2, D3, D4).**

Initial Model Assessment

Before diving deep into the modeling process, I also did a quick comparison of model performances to decide which three models to focus on. This comparison led me to focus on: **Random Forest Classifier, Bagging Classifier, Gradient Boosting Classifier**

	model	f1	precision	accuracy
1	RandomForestClassifier()	0.924706	0.945864	0.975254
4	BaggingClassifier()	0.919507	0.945403	0.973103
2	GradientBoostingClassifier()	0.899787	0.926956	0.967125
0	LogisticRegression()	0.892375	0.911200	0.964383
3	KNeighborsClassifier()	0.679851	0.844794	0.909523

Model Comparisons

Random Forest:

West Coast Dataset: \ Random Forest Model ROC AUC Score: 0.977\ Random Forest Model Class 1 Recall: 0.79\ Random Forest Model Class 1 F1-Score: 0.86

Random Forest Tuned Model ROC AUC Score: 0.978\ Random Forest Tuned Model Class 1 Recall: 0.79\ Random Forest Tuned Model Class 1 F1-Score: 0.86

Full Dataset: Random Forest Model ROC AUC Score: 0.964\ Random Forest Model Class 1 Recall Score: 0.63\ Random Forest Model Class 1 F1-Score: 0.70

Bagging:

West Coast Dataset: \ Bagging Model ROC AUC Score: 0.951\ Bagging Model Class 1 Recall: 0.77\ Bagging Model Class 1 F1-Score: 0.84

Bagging Tuned Model ROC AUC Score: 0.976\ Bagging Tuned Model Class 1 Recall: 0.79\ Bagging Tuned Model Class 1 F1-Score: 0.85

Full Dataset: Bagging Model ROC AUC Score: 0.923\ Bagging Model Class 1 Recall Score: 0.61\ Bagging Model Class 1 F1-Score: 0.68

Gradient Boosting:

West Coast Dataset: \ Gradient Boosting Model ROC AUC Score: 0.976\ Gradient Boosting Model Class 1 Recall: 0.80\ Gradient Boosting Model Class 1 F1-Score: 0.87

Gradient Boosting Tuned Model ROC AUC Score: 0.977\ Gradient Boosting Tuned Class 1 Recall: 0.80\ Gradient Boosting Tuned Class 1 F1-Score: 0.87

Full Dataset: Gradient Boosting Model ROC AUC Score: 0.977\ Gradient Boosting Model Class 1 Recall Score: 0.65\ Gradient Boosting Model Class 1 F1-Score: 0.71

Final Model Selection

Although all of the models performed relatively well, it seems like the **Gradient Boosting Model** is the best performing model for both the West Coast dataset and the Full dataset. Because the ROC AUC scores were fairly similar, I considered Recall and F1 scores in my decision. There was no significant improvement in the hyperparameter tuned model, so the final model will be generic. Because the West Coast model did perform better than the Full model, I will go forward with that one for the final model and limit any predictions to that region of the United States.

The final model has an ROC AUC Score of ~0.98 and a Recall Score of 80%. This indicates that **the model was able to correctly predict 80% of the actual high drought counties in the testing dataset.**

Gradient Boosting Model Classification Report - West Coast Data

Testing Data Classification		Report:		
	precision	recall	f1-score	support
0	0.96	0.99	0.98	9319
1	0.96	0.80	0.87	1853
accuracy			0.96	11172
macro avg	0.96	0.90	0.93	11172
weighted avg	0.96	0.96	0.96	11172

Gradient Boosting Model Confusion Matrix - West Coast Data

Gradient Boosting Model ROC Curve - West Coast Data

Conclusion and Final Thoughts

Overall this project was very fun and I learned a great deal. Feature engineering was the most fun part, and I enjoyed trying to create more functions in this project to limit copy/pasting and repetitive actions.

Future Improvements

There are a few things that could be done to potentially improve model performance in the future:

- Because droughts have gotten worse over time, the model might be limited in its predictive power by the way the training and testing data is split up (chronologically). Since I have removed the time-series component, it could be beneficial to combine the training and testing datasets (which are currently completely seperate) and do a train_test_split on the full dataset so that some of the later observations are included in the training data.
- I could consider more sophisticated approaches to dealing with the unbalanced dataset