USFS-CSU Joint Venture Agreement (2022-2023): Developing a Gridded Model for Probabilistic Forecasting of Wildland-Fire Ignitions over Alaska

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Final Report

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1. Introduction

The National Predictive Services (NPS) asked the USFS Rocky Mountain Center for Fire-Weather Intelligence (RMC) as a part of the *Fire, Fuel, and Smoke Science Program* (FFS) at the USFS Rocky Mountain Research Station (RMRS) to assist with the development of a system of statistical models for predicting the ignition probability (chance of start) & growth potential of wildfires on a national grid using NWS meteorological forecast data as input. The development of this gridded system of predictive equations was envisioned to proceed in several stages.

This Report describes the datasets and computational procedures utilized to develop and test the system of predictive wildfire-ignition equations for the state of Alaska. Real-time operational wildfire-ignition forecasts are available at the RMC Website.

2. Data and Methods

2.1. Gridded Data Sets Used

Three 9-year long grided records of weather reanalysis fields, observed lightning strikes and wildfire occurrences over Alaska were combined to produce *daily* datasets (from 12:00 to 12:00 UTC) of 20-km horizontal resolution. Grid cells listed as water, lakes, or ocean were excluded from the model development.

a. The NOAA North American Regional Reanalysis (NARR) containing 3-D fields from 00:00, 03:00, 06:00, 09:00, 12:00, 15:00, 18:00, and 21:00 UTC for the period January 2012 – December 2021 were previously downloaded in GRIB2 format and archived on the RMC machines.

b. Lightning stroke data provided by the Alaska Lightning Detection Network (ALDN).

c. Global Forecast System (GFS) 3-h forecast data fields in GRIB2 format (0.25 x 0.25 degree through 10 days) were archived for the peak fire season (May – September) of 2018 to verify the ignition forecast equations. GFS forecast fields were used to produce real-time ignition forecasts for AK posted at the RMC Website. Additionally, GFS forecast data were also utilized to produce experimental wildfire ignition-probability forecasts beginning in May of 2024.

d. Wildfire Occurrence Data over AK from 2012 to 2020 provided by Karen Short.

e. Monthly Leaf Area Index (LAI) from WRF.

f. Canadian Forest Fire Weather Indices (CWFIS).

g. Digital maps of vegetation cover types and percent vegetation cover.

The combined contribution of vegetation layers to the prediction scheme turned out to be very small.

2.2. Statistical Approach and Computational Procedures for Ignition Probabilities

We employed a statistical method that is similar to the one used in the development of the wildfire-ignition forecast model for ConUS (see this 2022 Report). It involved the application of Principal Component Analysis (PCA) with orthogonal rotation used to reduce the initial set of 204 meteorological driving variables from the lower atmosphere of the NARR dataset to a smaller subset of statistically significant fire-ignition predictors. Figure 1 schematically illustrates this PCA procedure. The reduced set of predictors was then subjected to logistic regression analyses to yield equations for computing the probabilities of one or more wildfire ignitions.

The resulting predictive equations can be applied not just to NARR fields but to the output from any numerical weather prediction model as well such as GFS and WRF to forecast ignition probabilities. The "R" statistical package, an open-source software, was utilized to perform PCA and the logistic regressions required to derive the final set of equations. Resampling the original datasets to a common grid of 20-km horizontal resolution was done using the GEMPAK (GEneral Meteorology PAcKage) software jointly developed by NASA and Unidata.

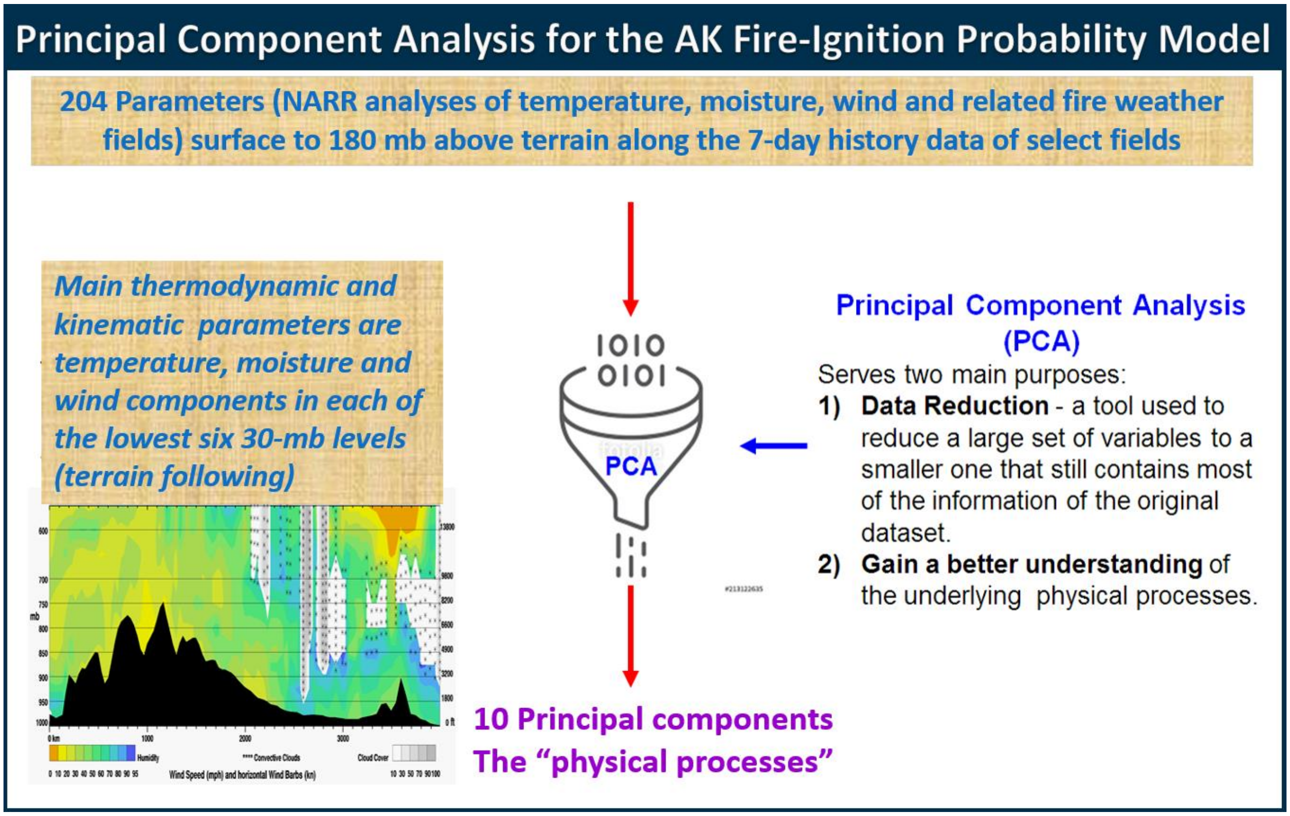

Figure 1. Schematic representation of the Principal Component Analysis (PCA) employed to identify significant predictors of wildfire ignitions. Meteorological data for the period 2012 – 2020 were obtained from the lowest terrain following 180 mb layer of the NARR data set.

The data processing went through the following procedure:

- Rescale original NARR fire-weather parameters (e.g., temperature, moisture, wind speed/direction etc.) to a uniform 20-km resolution grid covering the lower atmosphere (from the surface to 180 mb above the surface, terrain following) using GEMPAK.

- Aggregate the at 3-hour NARR fire-weather meteorological fields (such as maximum temperature, minimum humidity, max wind speed etc.) covering a period of 9 years (i.e., from 2012 through 2020) to 24-hour *daily totals* representing the time from 12:00 to 12:00 UTC.

- Generate a *daily* lightning climatology for the 2012 - 2020 period using NARR data and Bothwell's Cloud-to-Ground Lightning Model, and a fire-ignition climatology for the 2012 – 2020 period covering Alaska using Karen Short's updated Wildfire Occurrence dataset. The lightning forecast model used to generate Alaska's lightning climatology is described in this 2023 Report.

- Incorporate daily Canadian Forest Fire Weather Indices (CWFIS), monthly Leaf Area Index (LAI) and vegetation maps into the NARR-based predictor dataset. The CWFIS code was obtained and run with NARR fields to produce a historical dataset of daily fire-weather indices.

- Perform PCA with varimax/orthogonal rotation on NARR data using 204 potential meteorological drivers with added fire and lightning climatological records to identify a subset of the best wildfire-ignition predictors. This resulted in 10 Principal Components (PCs) listed in Table 1 used as final predictors in each 24-hour period. In order to better capture the fire environment, the predictors for ignition probabilities were extracted from the NARR's lowest layer of the model atmosphere (i.e. from surface pressure to 180 mb above the surface, terrain-following). The 10 PCs (predictors) explained nearly 76% of the total variance of wildfire occurrences in every 24-hour period. The low-level atmospheric moisture fields emerged as the strongest predictor among the 10 PCs explaining 24% of the observed variance.

- Run "*R*" logistic regression scripts using the 10 Principal Components (PCs) to derive separate predictive equations for calculating probabilities of one or more *lightning-caused* ignition, *human-caused* ignition and *any-cause* ignitions that are representative of a 24-hour period (12:00 to 12:00 UTC each day) in every month during the active fire season (May through September). We found that monthly predictive equations of ignition probabilities better captured changing environmental conditions during the course of a fire season than a set of seasonal equations. Due to scarcity of wildfire ignitions in the early spring, winter and fall, the derivation of monthly logistic equations was limited to the active fire season only.

- Since only the months of June and July typically have a significant number of fire ignition events in Alaska, these two months were combined for all years to develop the equations. Thus, three equations were developed, one for each wildfire ignition cause: *lightning*, *human*, and *any cause*. Each equation was derived using data covering the entire state of Alaska.

- When run operationally using the Perfect Prognosis method, the ignition-forecast equations are combined with 3-D meteorological fields from GFS as well as lightning and fire-ignition climatologies to produce *daily* ignition probability forecasts (12:00 to 12:00 UTC) at 20-km resolution out to 7 days over Alaska.

Table 1. Top 10 Principal Components (drivers) of daily wildfire-ignition probabilities yielded by PCA. A 24-h day refers to a period from 12:00 to 12:00 UTC.

Parameter	Explained Variance (%)
Lower atmospheric moisture and temperature	21
Humidity at all levels and Haines indices	12
Soil moisture	6
U wind component	7
V wind component	7
Climatology of human-caused fires and all wildfires	3
Fosberg Index, Hot-Dry-Windy Index, Canadian Fire Indices, Soil temperatures	8
Lightning climatology and 7-day lightning probability	6
Leaf Area Index and percent vegetation cover	2
Climatology of Lightning Fires	3

3. **Results**

The above wildfire-ignition probability model was set up to produce operational forecasts for Alaska twice per day using NCEP GFS-forecast weather fields as drivers. The results in terms of various types of ignition-forecast probability maps are posted at the RMC Website.

3.1. ***Verification of Wildfire-Ignition Forecasts for June 2018 Using GFS Data***

We conducted a preliminary verification of the wildfire-ignition forecasts over AK using fire occurrence data from 2018 and independent GFS weather fields to drive our model.

A total of 47 new fires were reported around the state of AK on June 4 and 5 of 2018 according to the Alaska Interagency Coordination Center in Fairbanks. The majority of the new fires were caused by lightning in remote parts of northwest and southwest parts of the state. Nineteen new fires were reported around the state on June 4 and 28 new fires were reported on June 5. Figure 2 shows an overlay of lightning-caused ignition-forecast probabilities and actual observed fire starts on June 4th and 5th of 2018. Figure 3 depicts the same as Fig. 2 but for wildfire starts due to any cause. Figures 4 and 5 depict ROC curves of forecast wildfire-ignition probabilities over AK for forecast days 1 through 7 in June and July 2018. The Area Under the Curve (AUC) is greater than 0.8 on all forecast days, which indicates a good to excellent model skill. The quality of the ignition forecasts naturally deteriorates after day 5 due to a diminishing skill of the GFS weather forecast model. Figure 6 portrays a histogram of wildfire-occurrence frequency as a function of ignition chance. Most area of the state shows less than 6% chance for new fire start during June-July of 2018.

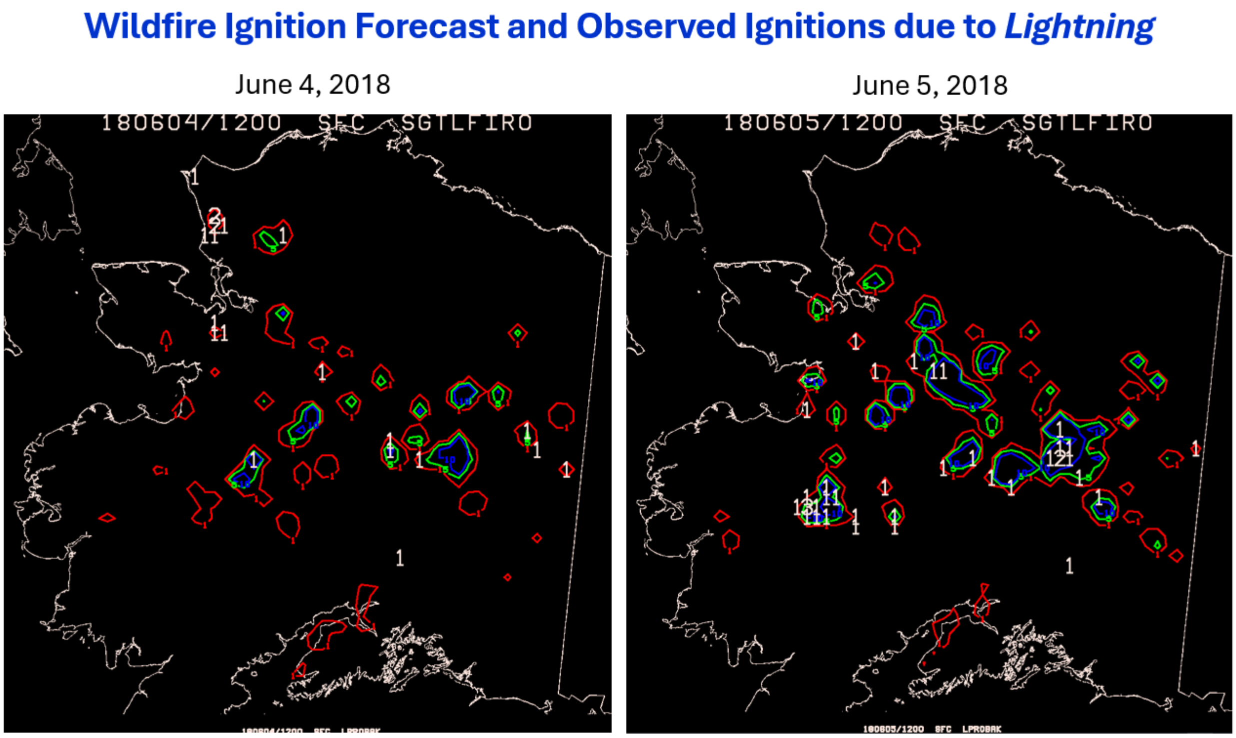

Figure 2. Wildfire ignition-forecast probabilities (colored contours) due to lightning overlaid on actual wildfire occurrences (numbers in white) for June 4th and 5th, 2018.

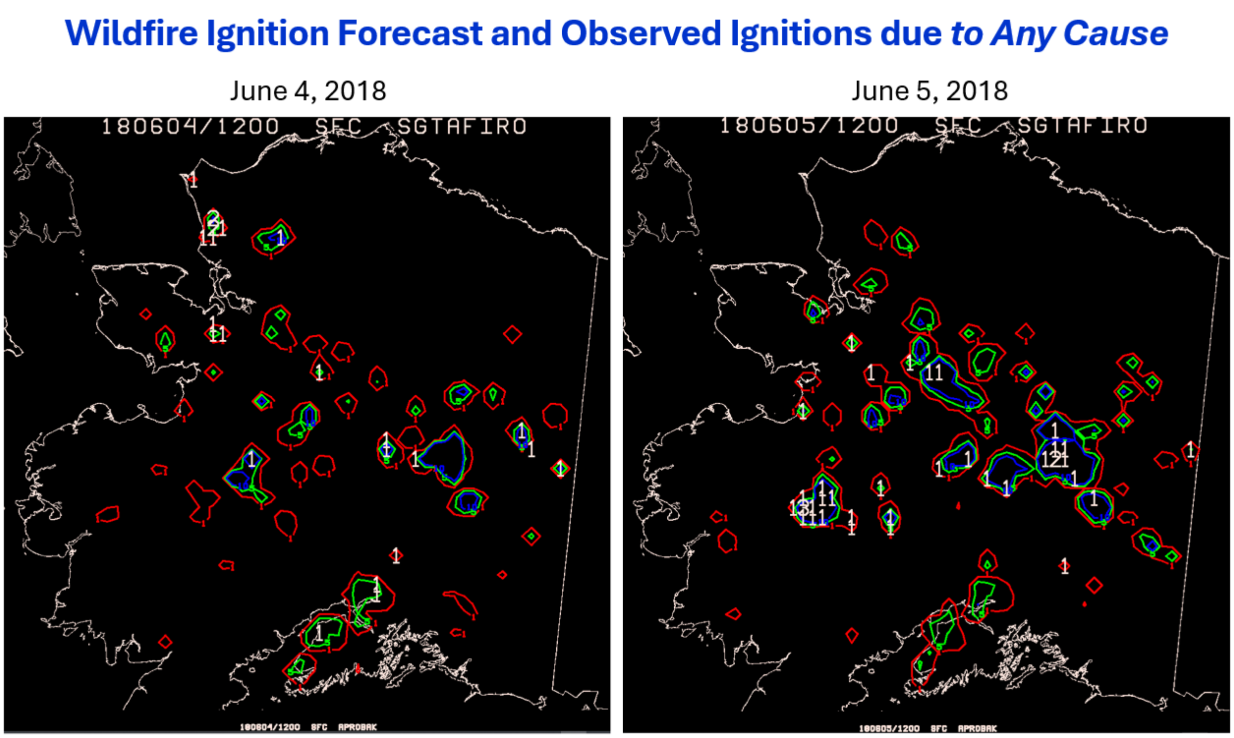

Figure 3. Wildfire ignition-forecast probabilities (colored contours) due to any cause overlaid on actual wildfire occurrences (numbers in white) for June 4th and 5th, 2018.

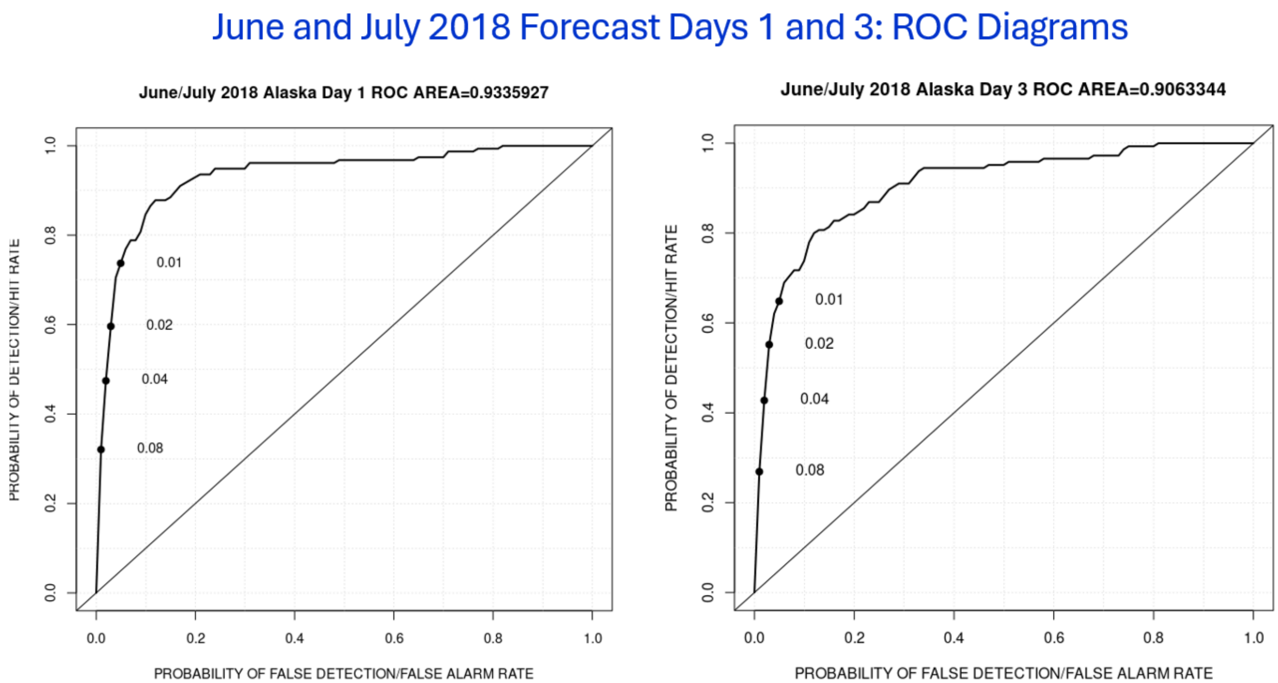

Figure 4. ROC curves of wildfire ignition-forecast probabilities for forecast days 1 and 3 over AK using model runs driven by GFS weather fields.

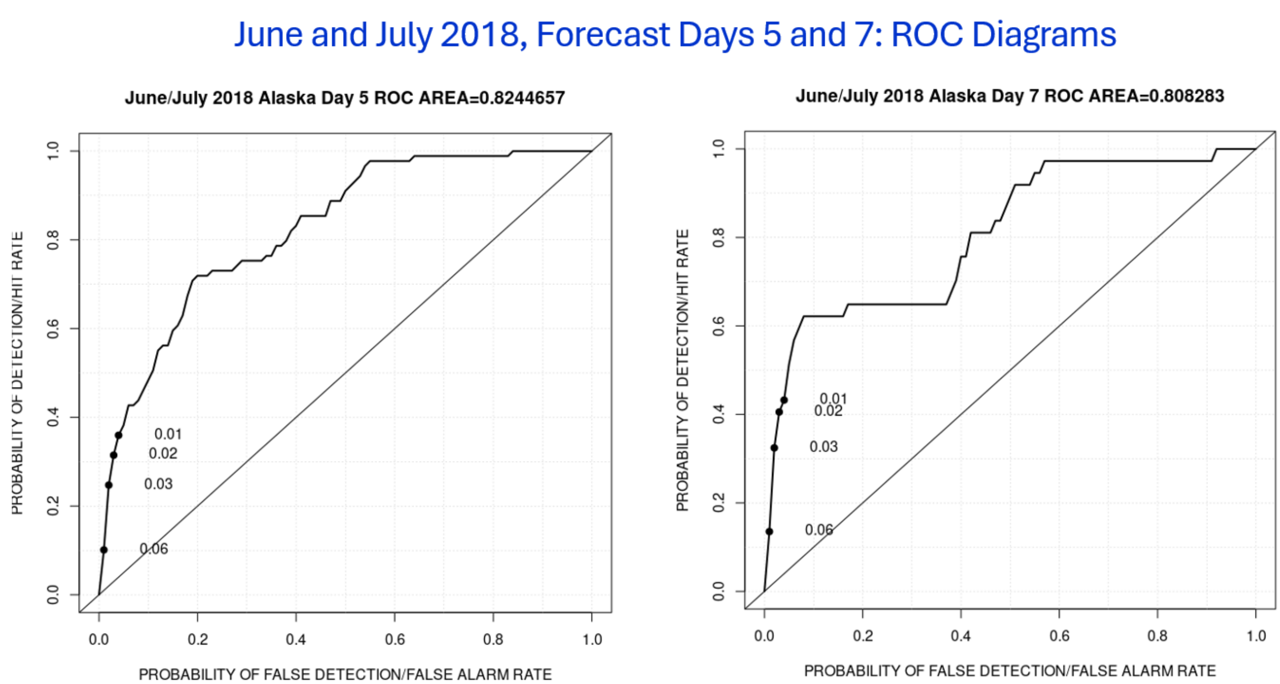

Figure 5. ROC curves of wildfire ignition-forecast probabilities for forecast days 5 and 7 over AK using model runs driven by GFS weather fields.

Ignition Probability Forecast Histogram: June-July 2018

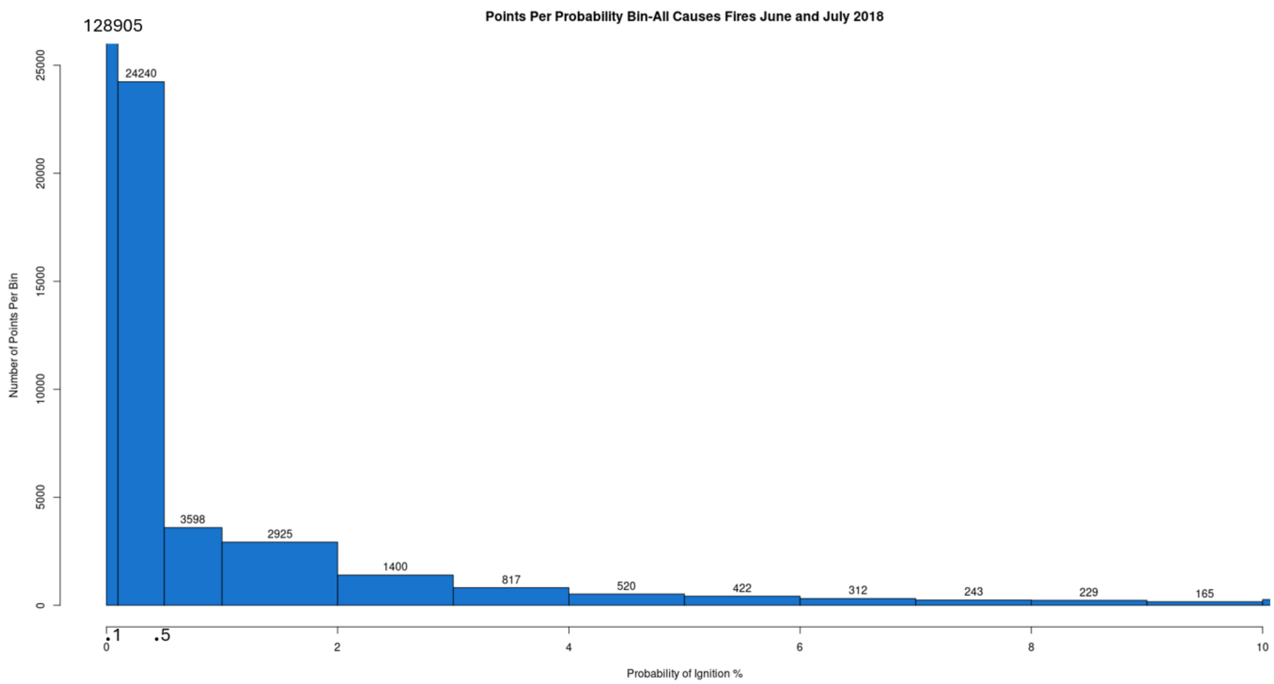

Figure 6. Histogram of ignition-probability forecast from model runs for June-July 2018. Note that most of the state area of AK had less than 6% chance of wildfire start.

4. Conclusion

The new wildfire-ignition forecast model for Alaska demonstrated acceptable to very good skill as an operational tool based on meteorological and fire-occurrence data from 2018. The model performance will continue to be evaluated over the next few years as more ignition data become available. The model currently runs twice per day using GFS forecast meteorological fields as input and 7-day predictions are posted in a form of animated (looping) maps on the RMC Website.

This is the first and only wildfire-start prediction model for AK developed by the USDA that provides *probabilistic forecasts of wildfire ignitions* on a uniform grid across the state. As such, the model meets the legal requirements set forth in SEC. 1114 (i) of the 2019 Conservation, Management, and Recreation Act (a.k.a. the Dingell Act) to develop a system for "*Predicting Where Wildfires Will Start*".

5. Acknowledgements

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