# Images from Outer Space: The Impact of Satellite Data on the Prediction and Operations of the 2019 Kincade Fire

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## I. Abstract

Satellite data is quickly playing a prominent role in influencing both the forecasts and operational decisions that surround emergency wildfire situations. This investigation uses the 2019 Kincade fire as a case study into what forms of satellite imagery can most effectively be used in predicting the spread of wildfires and executing emergency evacuations and protocol; this analysis will provide a cornerstone for assessing the economic value of satellite data for firefighting support. This study details a great deal of potential satellite imagery resources that can be used for prediction and investigation including those from polar-orbiting and geostationary platforms alongside surface and upper observations, output from weather models that var in resolution, and video from new camera systems. Overall, the Kincade Fire allows for an analysis in the context of assessing what forms of information are most essential to fire incident operations and forecasting needs of emergency responders and meteorologists. In a cross-sectional assessment of the information each form of imagery provides, this study concludes that operations should rely heavily on geostationary imagery for immediate directions and polar orbiting imagery for confirmation of ongoing evacuation and emergency procedures. It also concludes that predictions should rely heavily on the HRRR smoke and wind models in order to forecast the spread of the fire and its relevant smoke plume(s). Finally, GLM imagery should be reviewed post-hoc when trying to determine the ignition source for the wildfire, should that ignition be suspected as dry lightning; it can also be used to help identify convection to properly locate potential new fires, especially in areas where weather radar coverage is very poor.

## II. Introduction

For many years, satellite data has played an important role in understanding the surface data of meteorological phenomena. In the world of fire weather, satellites have aided in directing both the forecasts and operational decisions surrounding major disasters throughout history. One particular fire event that relied heavily on the usage of satellite information was the 2019 Kincade Fire. Throughout this disaster, certain forms of satellite data proved more useful than others with regards to predictions and strategic operational decisions being made. As such, this paper will report on how to most effectively use available satellite imagery for the purpose of forecasting fire weather and crafting emergency response operations by using the 2019 Kincade Fire as a case study. In doing so, the following assessment will provide recommendations on when to implement certain satellite data and which forms of data provide the most insight into specific situations, allowing for improvements on the interaction of satellite data and operational forecasting to be made.

In order to create a case study of the 2019 Kincade Fire and its use of satellite imagery, it's important to first provide background information about the event itself. The Kincade Fire first began at 9:27 PM on October 23rd 2019 just northeast of Geyserville CA. Starting on around October 22nd, the National Weather Service predicted the potential for critical wildfire conditions across the northern Bay Area in California and issues a 'historic' fire weather event locally. This forecast was made due to predicted sustained winds of 20+ miles per hour with higher gusts. In addition, relative humidity levels were predicted to remain at 15-20% and would eventually fall into single digit percentiles. Alongside low relative humidity, elevated temperatures were prevalent in the area due to a stable high-pressure system that had come down from the Rockies and remained stationary over the northern Bay Area. Finally, a major offshore wind event was anticipated and building just off the coast of California. These factors combined with combustible dry fuels brough fire risk to critical conditions. In anticipation of the dangerous fire weather potential, the PG&E power company shut off power to the northern Bay Area by mid-day on October 23rd. Despite these efforts, the fire's ignition is generally attributed to stray sparks or an electrical malfunction over a rural area around 9:00 PM when remote sensing cameras picked up the first signs of flames and smoke.

Following the fire's ignition, emergency personnel from Cal Fire and The National Weather Service responded immediately, conducting mass evacuations of Geyserville, Healdsburg, and the Windsor communities. Following this call for evacuation, most if not all community members evacuated as instructed. The Red Cross teamed up locally with law enforcement and Cal fire to create evacuation centers where individuals (particularly those from financially impoverished communities) could reside temporarily during the fire. As the Kincade blaze continued to grow, it was only fueled more by an offshore wind event that came into the northern Bay Area on October 27th-28th. This wind clocked gusts as high as 70+ miles per hour and pushed the fire rapidly in a southward. From October 26th onward, a massive smoke plume visible from space spread out in a northwestern direction across the Pacific Ocean and coastal cities in California. The smoke eventually dissipated but did create air quality problems for southern California. The fire was not extinguished until November 6th which was nearly 15 days later. The blaze went on to destroy 77,758 acres of land.

## III. Discussion

In order to better understand the interplay of satellite data with the forecasts and operational decisions of the 2019 Kincade Fire, this study conducted evaluations of many different forms of satellite data. The following section will detail these evaluations as they pertain to the Kincade Fire in greater depth, detailing their strengths and weaknesses with regards to fire weather scenarios.

### GOES-17

The GOES-17 geostationary satellite provides prominent minute-to-minute information regarding wildfires such as fire temperature, power, and even area in a geographical manner. These readings are conveyed through a series of different forms of imagery such as Fire Temp RGB (1-min), FDC Fire Temp (5-min), 3.9 SWIR (1-min), FDC Fire Power (5-min), FDC Fire Area (5-min), and FOG/LWIR-SWIR Diff (1-min). While these forms of imagery provide real-time data on the components of a fire, the images are however not as sharp as other forms of imagery, often consisting of wide and overexaggerated pixels. However, their minute-to-minute data remains an immensely important component of the satellite-fire prediction interaction.

In addition, the GOES-17 also produces the GLM FD and CONUS Lightning Viewer imagery as well. These images help one see precipitation across the United States as well as lightning strikes on a similarly minute-to-minute basis. This form of imagery is useful for determining if a wildfire's ignition is due to dry lightning. The GLM FD and CONUS Viewer (especially the FD viewer with regards to California wildfires) is also useful in helping forecast the spread of wildfires in places where radar is much harder to come by. Therefore, it helps supplement a lack of imagery when one exists.

## VIIRS Active Fires and Confidence Intervals

The VIIRS Active Fires and Confidence Intervals imagery provides users with current models of surface level fires. This imagery depicts both the geographic location of a fire as well as specific points of strength within the blaze. These points are much clearer than those produced by the GOES-17 and are more pinpricks of color that detail the intensity of said fire at a given location. One downside to this imagery however is that the VIIRS satellite is polar orbiting. As such, Active Fires and Confidence Interval imagery is only available a couple of times throughout a 24-hour period.

## HRRR

### Vertically Integrated Smoke

In general, the HRRR Vertically Integrated Smoke Model generates maps initiated by FRP signatures that show the spread, density, and dispersion of a smoke plume across a geographical area. This model is quite strong in showing a fire's geographical location as well as its general density. In addition, the HRRR Vertically Integrated Smoke Model produces its imagery on an hour by hour basis meaning that real-time data is prominently available to forecasters and operational decision makers whenever needed.

### Fire Radiative Power

The HRRR Fire Radiative Power Model creates maps of the United States as initiated by FRP signatures that show the intensity of a wildfire when it occurs. Much like the VIIRS imagery, this model depicts the intensity of a wildfire in a very clear manner, normally with a small dot colored based on its intensity. The strength of this model is that it allows one to understand geologically where the fire is located and how strong it is. However, the HRRR Fire Radiative Power Model only updates once (and occasionally twice) every 24-hour period. This mean that the data is not particularly real-time and will often either underestimate or overestimate the strength of the blaze based on the fire's growth during said 24-hour time period.

### Wind Speed and Direction

The HRRR Wind Speed and Direction Model depicts both the strength and intensity of winds across the United States as derived from FRP signatures. The imagery uses wind barbs to show the general direction in which the wind is occurring and colors to depict the speeds of wind. Much like the Vertically Integrated Smoke imagery, the Wind Speed and Direction Model is updated hourly and allows for near real time imagery of current wind speeds. This model is also quite useful as it allows for a more geographical understanding of wind speeds around the country.

**<u>Hawkeye RAWS</u>**

In terms of purpose, the NOAA Remote Automated Weather Stations (RAWS) serve as mechanized data collection sites that provide consistent real-time data about a weather event. These sites also catalogue data and aid in its archiving, allowing meteorologists to re-visit historical readings. The RAWS station data provides extensive graphs about everything from precipitation, mean wind speeds, mean wind direction, average air temperature, average fuel temperature, average relative humidity, battery voltage, direction of the maximum wind gusts, the maximum wind gust's speed, barometric pressure, and the solar radiation of a specific area. These in-depth and reliable measurements are consistent across time and easy to access through their provided online archive. Graphs can easily be curated and understood from data available at any given point in the site's collection time period. In this case, the Hawkeye RAWS station was most directly observed as it was the most central to the Kincade Fire's location.

**<u>WFO Monterey 1km WRF Model</u>**

With regards to its purpose, the WFO Monterey 1km WRF Model provides valuable information about variables essential to forecasting such as wind speed, relative humidity, wind gusts, and temperature through use of terrain-based imagery. The strongest benefits of this form of satellite imagery is its ability to show variation in these variables based on geographical location. It shows these readings in a fairly real-time manner and catalogues historical data as well too. However, the WFO Monterey 1km WRF Model did have some prominent downfalls under this study's evaluation. For example, much of the imagery wasn't consistent and didn't always cover all areas of the map as desired. In addition, data regarding wind speeds was often times obscured by the terrain mapping, and sometimes the imagery wouldn't appear at all due to clunky programming. All in all, the WFO Monterey 1km WRF Model does have the benefit of including imagery alongside geographical locations, but it can be difficult and hard to use in most occasions.

## IV. Conclusions

In order to better understand the impact satellite data has on the forecasts and operational decisions of fire weather, this study has drawn separate conclusions about the usage of the many forms of satellite data assessed.

With regards to data from the GOES-17 satellite, one of the most important factors is the imagery's reliable real-time updates. During a fire weather crisis, having predictable updates is essential to both the forecasting and operational decision-making process. As such, the varying imagery from the GOES-17 satellite is quite useful in its regularity. With this in mind, one can conclude that imagery from the GOES-17 satellite should be used prominently for forecasting and operational decisions. While the imagery produced isn't as clear as say that produced by the VIIRS satellite, it is still consistent and reliable- two factors that are essential to forecasts and decisions being made in emergency situations. With this in mind, the GOES-17 East CONUS and FD Lightning Viewers were not much help to the Kincade fire. However, using this imagery post-hoc in a fire emergency scenario can help one determine the source of ignition if said source is estimated as being dry lightning. This imagery can also be essential to protecting firefighters by using it in areas where radar is underdeveloped. As such, this study recommends using the GOES-17 East FD and CONUS views (ideally the FD view if working with a California fire due to its greater visibility of the California coast) in detecting if a fire's start was due to dry lightning and/or to forecast the developments of fires where radar is not as available.

As mentioned earlier, the VIIRS satellite has the strong benefit of providing very clear imagery reports of a fire's geographical location and strength. However, due to VIIRS nature as a polar orbiting satellite, this imagery only updates once or twice every 24-hour period. As such, the imagery produced is not consistent enough to provide constant real-time data. Therefore, this study recommends that VIIRS satellite data be used simply to verify ongoing forecasting and operational decisions as it becomes available.

The HRRR Model provides imagery such as the vertically integrated smoke, fire radiative power, and wind speed and direction maps. Primarily, both the vertically integrated smoke and wind speed and direction maps produce real-time 3km data from FRP signatures on an hourly basis. This allows for detailed imagery about wind speed/direction and smoke dispersion to be available in real-time. However, the fire radiative power imagery only updates once or twice every 24-hour period, making it often outdated and irrelevant. As such, this study recommends that the vertically integrated smoke and the wind speed and direction maps be used for emergency forecasting and operational decisions. However, the fire radiative power models should not be used for these purposes if at all. GOES-17 imagery provides much more frequently updated imagery with regards to fire geographical location and strength that can replace the need for Fire Radiative Power.

The Hawkeye RAWS station provided detailed minute-to-minute data about the Kincade fire that was archived and easily accessible. A such, its extensive detail and real-time nature makes it quite useful for immediate forecasts and operation decisions. As such, this study recommends that it be used for real-time decisions during a fire weather emergency. While the WFO Monterey 1km WRF model provided similar information during the Kincade Fire, its program was much clunkier and often errored out due to technical difficulties. As such, this would make using its data much more difficult in a crisis scenario. As such, this study recommends not using the WFO 1km WRF model for fire emergencies and relying on more consistent minute to minute data like GOES-17, RAWS, and HRRR vertically integrated smoke and wind speed and direction models.

As such, these combinations of effective models used in their ideal situations are the most effective manner of implementing satellite data into the fire weather forecasting and operational decision-making process.

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## VI. References Overview

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*For more extensive evaluations and reports, please see the "2020 NOAA/NWS Study of Satellite Data's Impact on the 2019 Kincade Fire Resources Archive" PDF Document*