RAP- and HRRR-Smoke Operational forecasting models User's guide

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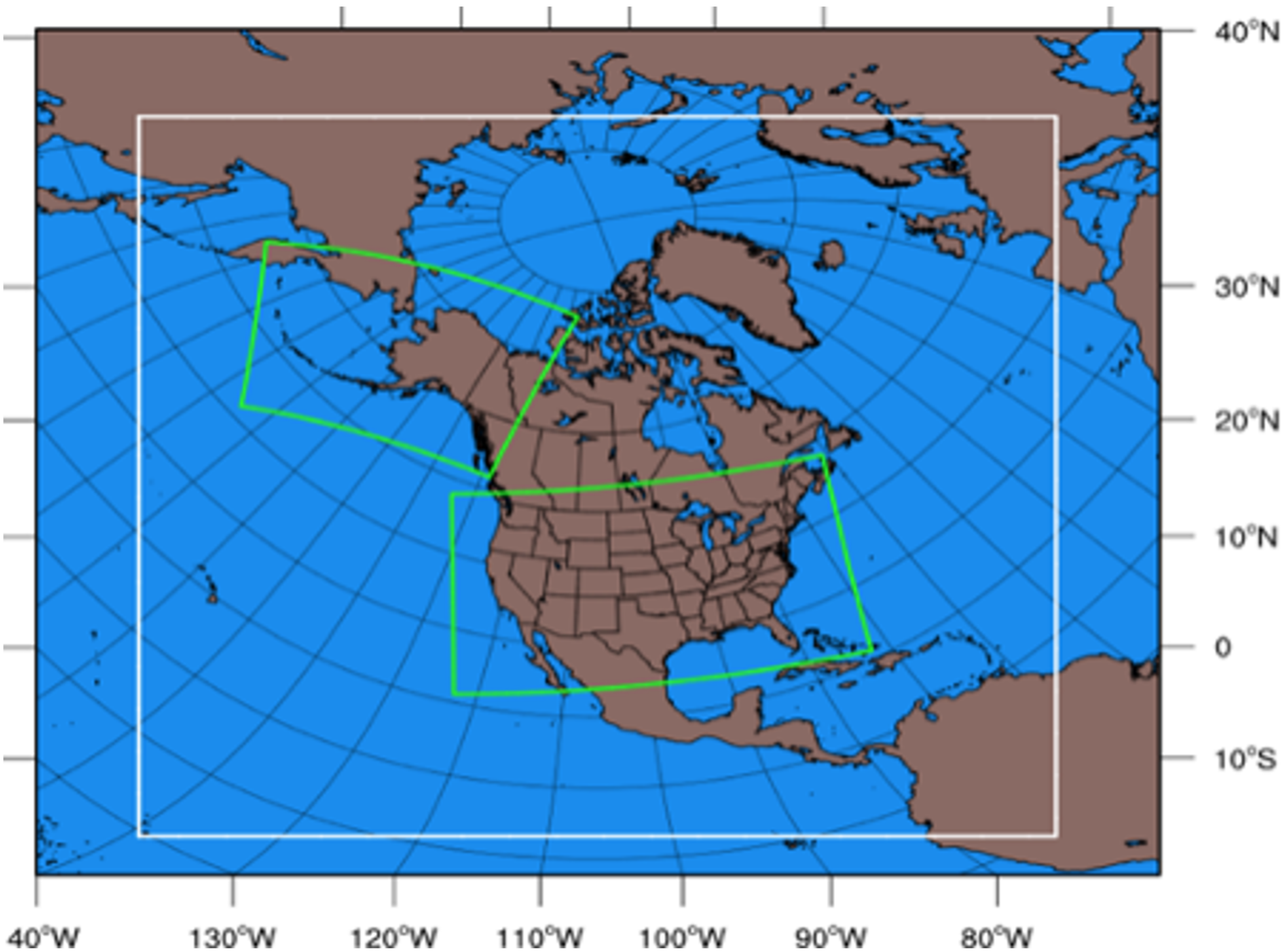

NOAA's operational weather-smoke forecast models:
RAP-Smoke (white), **13.5** km resolution
https://rapidrefresh.noaa.gov/RAPsmoke/

HRRR-Smoke model domains (green), **3 km** resolution:
https://rapidrefresh.noaa.gov/hrrr/HRRRsmoke/
https://rapidrefresh.noaa.gov/hrrr/HRRR-AKsmoke/

All the models use the same biomass burning emission and smoke modules. Both RAP-Smoke and HRRR-Smoke start a new forecast every hour. HRRR-Smoke-AK is initialized every 3 hours.

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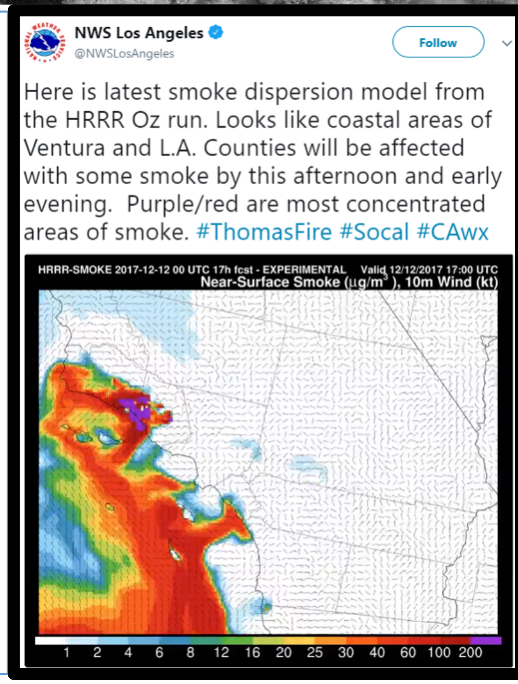
Why is the HRRR-Smoke Model Important?

The High-Resolution Rapid Refresh Smoke (HRRR-Smoke) is a three-dimensional coupled weather-smoke model that allows simulation of mesoscale flows and smoke dispersion over complex terrain, in the boundary layer and aloft at high spatial resolution over the CONUS domain. The smoke model comprises a suite of fire and environmental products for forecasters during the fire weather season. Products derived from the HRRR-Smoke model include 3D distribution of smoke, 24hr average FRP, the meteorological prognostic variables and diagnostic fields. The description of all the diagnostic fields can be found here: https://repository.library.noaa.gov/view/noaa/32904



Social media post from NWS–Los Angeles, CA using the Near-Surface Smoke product from HRRR-Smoke model, initialized at 00 UTC, 12 December 2017.

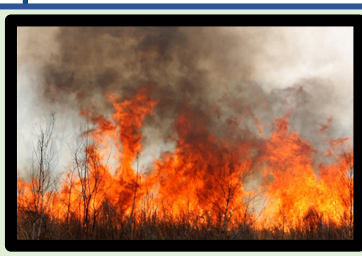
What are the HRRR-Smoke Model specifications and resolutions?

Data used	Spatial Resolution	Temporal Resolution
• Meteorological observations (including radar, 3D aircraft obs.) assimilated every hour • Boundary conditions (met + smoke) from North American scale RAP-Smoke model • Polar-orbiting (2 VIIRS and 2 MODIS) FRP data	• 3-km horizontal grid spacing • 50 vertical levels	• Updated every hour • Forecast lead time is 48 hours at 00, 06, 12, and 18 UTC • Forecast lead time is 18 hours at other times of day

Impact on Operations

Primary Application

Fire intensity and forecasted fire smoke: Identifies areas that exhibit intense fires and forecasts smoke dispersion over flat and complex terrain.

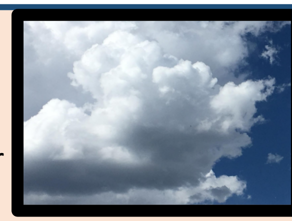


Meteorology: HRRR-Smoke utilizes meteorological input data prepared by the GSI data assimilation system for HRRR and boundary conditions from RAP-smoke forecast model (covering North America).

Parameterization: Model incorporates biomass burning emissions and inline plume rise parameterization based on satellite FRP data.

Limitations

Missed Detections: Fire detections in the model could be missing due to cloud coverage, or infrequent overpass times by polar orbiting satellites.



Model input: A simple diurnal cycle is applied for the biomass burning emissions. Fire behavior dependence on weather or fire suppression is not simulated by the model. HRRR-Smoke assumes persistence in forecasting the biomass burning emissions.

Accuracy: Uncertainties in the satellite FRP data and estimates of the biomass burning emissions impact the accuracy of the smoke concentration forecasts. Uncertainties in weather forecasting by HRRR will also affect smoke forecasts (wind speed/direction, mixing layer height, etc.).

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Model: HRRR-NCEP-smoke (Operational) **Domain:** Full **Date:** 31 Oct 2021 - 20Z

	All times	Loop	Sun 20	Sun 21	Sun 22	Sun 23	Mon 00	Mon 01	Mon 02	Mon 03	Mon 04	Mon 05	Mon 06	Mon 07	Mon 08	Mon 09	Mon 10	Mon 11	Mon 12	Mon 13	Mon 14
			00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
all fields			00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
fire radiative power	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
near-surface smoke	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
1000 ft AGL smoke	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
6000 ft AGL smoke	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
vertically integrated smoke	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
10m gust potential	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
PBL height	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
1h precip	✔	✔		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
2m temperature	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
surface visibility	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
Hourly Wildfire Potential	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
cross section BOU smoke																					
cross section MKX smoke																					
cross section SEA smoke																					
cross section 40N smoke																					
cross section 45N smoke																					
cross section NW Coast smoke																					
cross section CA smoke																					

NOAA/GSL's RAP- and HRRR-Smoke websites display various plots of smoke and meteorological forecast fields. Users can choose the plots for the **full** model domain (e.g. CONUS for HRRR-Smoke) or various sectors under the "**Domain**" menu bar of the website. Users can view the vertical cross-section plots by selecting the "**XSection**" option under the "**Domain**" menu bar. The website displays the forecast fields from the operational RAP/HRRR systems since December 2020. In order to view the experimental forecast plots prior to December 2020, users need to select the "**Experimental**" option under the "**Model**" menu bar.

The RAP/HRRR-Smoke pages display several meteorological fields. For all the other meteorological forecast plots users can visit the regular RAP and HRRR pages, e.g. https://rapidrefresh.noaa.gov/hrrr/HRRR/

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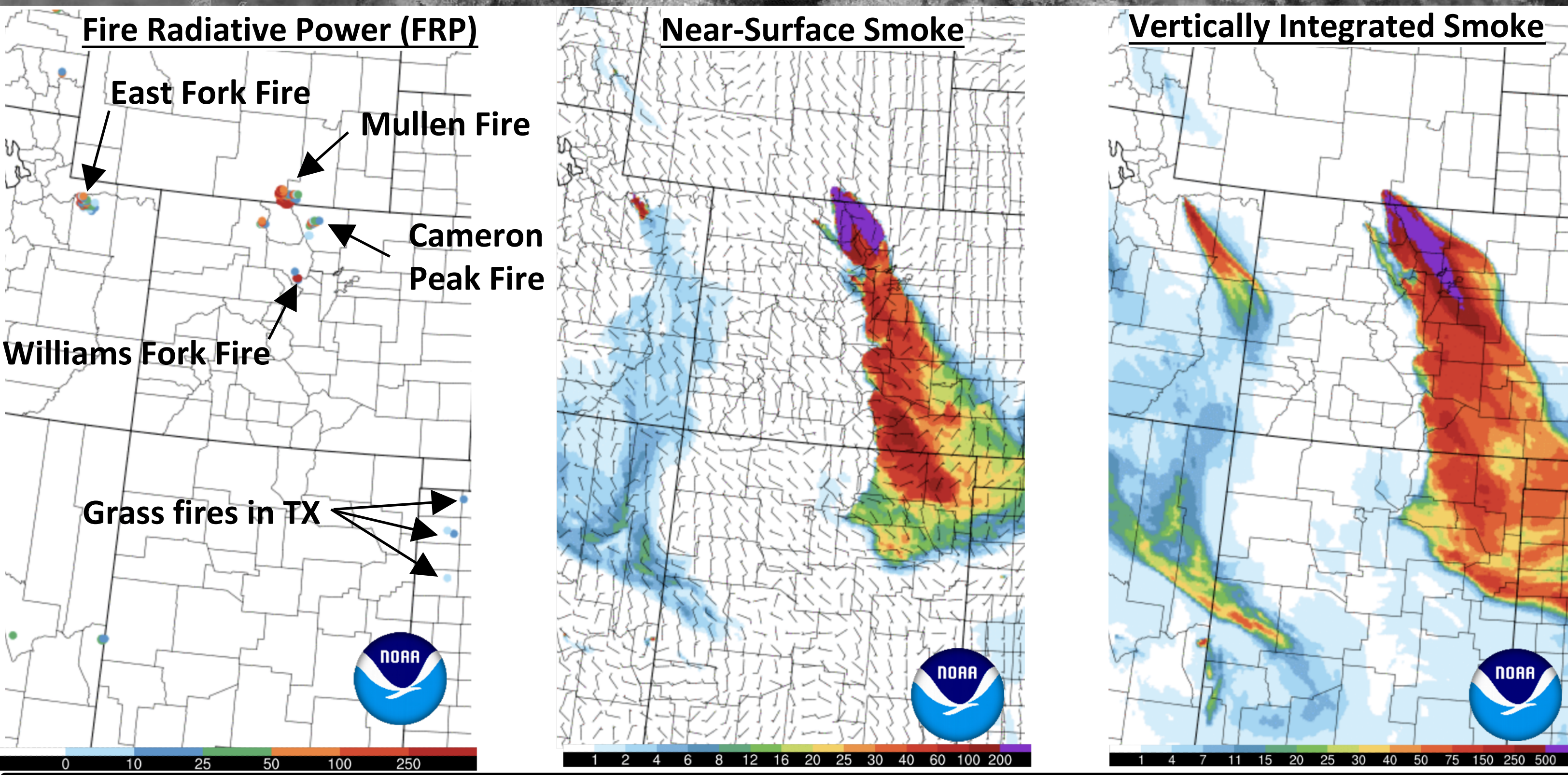
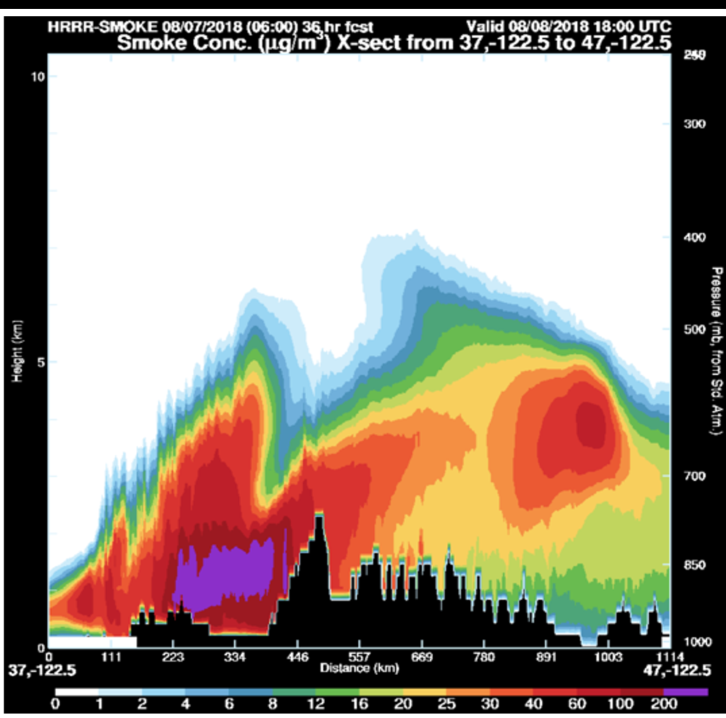


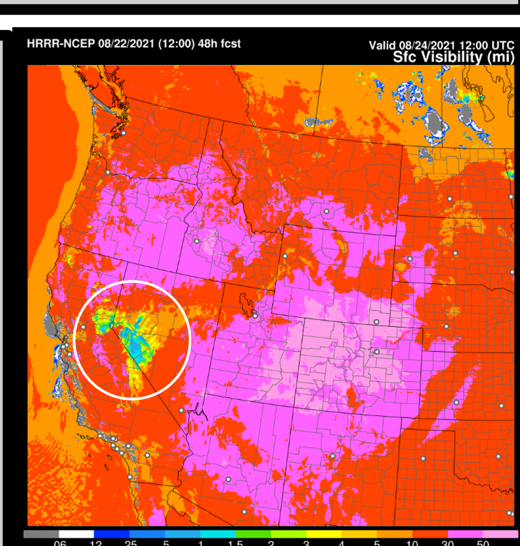
Fire Radiative Power (left, expressed in MW), Near-Surface Smoke (center, expressed in μg/m^3), and Vertically Integrated Smoke (right, expressed in mg/m^2) products, derived from the HRRR-Smoke model. The Near-Surface Smoke overlays 10-meter wind data, expressed in knots. The displayed products highlight numerous fires in the Rocky Mountain region. These are 48h forecasts initialized at 00 UTC 1 Oct 2020, valid at 00 UTC 3 Oct 2020.



The plots in the low left panel shows the south-north vertical cross section of smoke concentrations (expressed in μg/m^3) along the west coast, with south to the left and north to the right, derived from the HRRR-Smoke model. Underlying terrain height is indicated in black shading along the lower boundary. This is a 36h forecast initialized at 06 UTC 7 Aug 2018, valid at 18 UTC 8 Aug 2018.

Surface visibility forecast (in miles) based on the visibility diagnostics, which includes the smoke extinction in addition to the effect of relative humidify and hydrometeors.

The very low visibility in parts of the western US (highlighted with a white circle) is caused by the dense smoke during the 2021 fire season.



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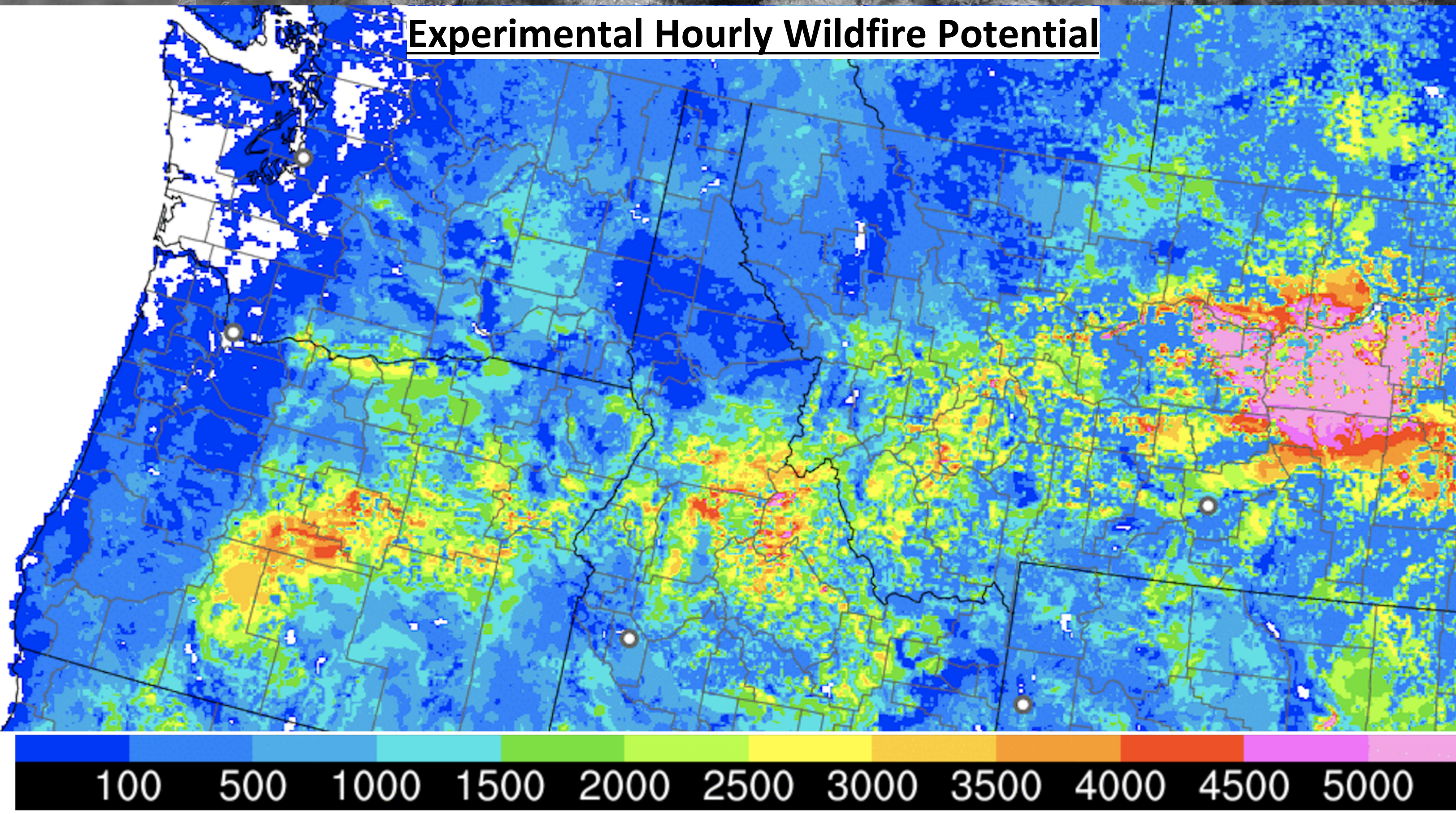
Experimental Hourly Wildfire Potential



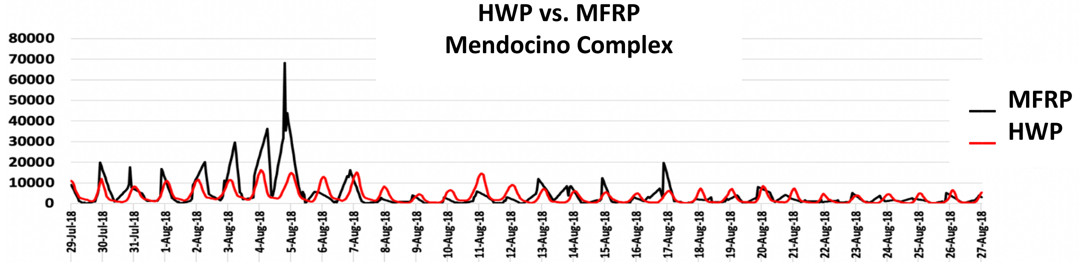
Experimental Hourly Wildfire Potential (HWP), derived from the operational HRRR predictions of meteorological conditions and soil moisture availability. The HWP is expressed in units of $K^{0.7}$ $m^{1.3}$ $s^{-1.3}$. This is a 12h forecast of HWP valid at 19 UTC 3 July 2021, showing a region of elevated fire potential from central Oregon to eastern Montana.

Deriving the Hourly Wildfire Potential (HWP)

What is goal of the HWP? The HWP is designed to predict the potential for explosive fire growth and extreme fire behavior, based on high-resolution forecasts of meteorology and soil moisture.

How was the HWP derived? The HWP is a work in progress. The current HWP was derived based on comparison of HRRR meteorology / soil state with satellite-detected FRP for several major fires during 2018 - 2020. Prior research on defining other fire weather indices was also taken into consideration.

How does the HWP perform for a historical fire? Below is a time series of HWP vs. FRP for the Mendocino Complex fire, the largest wildfire in California during 2018. Shown is the period 28 July - 26 August 2018.



What are the uncertainties in HWP? Real wildfires encounter highly variable terrain and fuel, which is not captured by the HRRR HWP. In particular, subgrid (finer than 3-km) fuel variability is not currently represented by HRRR. Also, wildfires in the lower 48 United States are often aggressively suppressed near populated areas, leading the HWP to sometimes overestimate the potential for fire spread.

The HWP is based on:

W: 10-m Wind Gust Potential: This diagnostic product accounts for intermittent gusts due to boundary layer mixing.

DD: 2-m Dewpoint Depression: This is a measure of the dryness of the near-surface atmosphere.

M: Soil Moisture Availability: This is the ratio of soil moisture in the top level to the maximum soil moisture for the soil type.

S: Snow Water Equivalent factor: This factor varies linearly from 0 if there is 25 mm or greater snow water equivalent to 1 if no snow.

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Fire and smoke product definitions

Fire Radiative Power (FRP) – FRP data is processed during the HRRR-Smoke initialization, by processing FRP for the model domain detected during previous 24-hours by VIIRS (S-NPP and NOAA-20 satellites) and MODIS (Terra and Aqua satellites). The model simulates fire emissions and plume rise using the FRP fields with prescribed diurnal cycles for the duration of the smoke forecast (up to 18-48 hours for HRRR-Smoke).

Near-Surface Smoke – Fire emitted fine particulate matter ($PM_{2.5}$ or smoke) concentrations at ~8 meters above the ground or the 1st model level.

Vertically Integrated Smoke –Simulated total smoke mass within vertical columns over each model grid cell. Columns extend to ~25 kilometers above the ground. This product displays the total smoke load that includes smoke in the boundary layer as well as aloft, illustrating the integral amount of smoke throughout the atmosphere.

These products along with the meteorological fields are included in the GRIB2 files generated by the model forecasts.

GRIB2 file Information

What is GRIB2 format? GRIB2 is a format for distributing meteorological data. It utilizes compression to reduce the file size, allowing large datasets to be transferred relatively easily.

What tools are available to handle GRIB2 format? Many software packages commonly used in meteorology can handle GRIB2 format. For example, python has an open-source module *pygrib* for accessing GRIB2 files. The *wgrib2* tool is also useful for slicing and dicing GRIB2 files.

Where can I access the GRIB2 files? Files are publicly available via the NOAA/NCEP's NOMADS server:
https://www.nco.ncep.noaa.gov/pmb/products/hrrr/

Which GRIB2 files contain which variables? There are 3 GRIB2 file types:

hrrr.tHHz.wrfprsfFF.grib2 – variables on 37 isobaric levels

hrrr.tHHz.wrfnatfFF.grib2 – variables on 50 native model levels

hrrr.tHHz.wrfsfcfFF.grib2 – 2D variables

All file types contain near-surface smoke, fire radiative power, column-integrated smoke, and aerosol optical depth for smoke. Only the **wrfnat** files contain the 3D smoke variable.

Which variables are the smoke-related ones?

MASSDEN – smoke concentration ($\mu g/m^3$) valid near surface (~8m AGL) or on native model levels

COLMD – vertically integrated smoke (mg/m^2)

CFNSF – fire radiative power (MW)

AOTK – aerosol optical depth for smoke at 550 nm

The visibility and solar irradiance are also affected by smoke!

HH = 2-digit initial hour (UTC)

FF = 2-digit forecast length (h)

For more info about GRIB2 variables: https://www.nco.ncep.noaa.gov/pmb/docs/grib2/grib2_doc/

Frequently asked questions about accessing the HRRR-Smoke forecast products

How far back in time does HRRR-smoke forecast data exist?

The smoke capability was implemented as part of HRRRv4 on 2 Dec 2020. Prior to this date, smoke products were available from the Experimental HRRR (starting in Nov 2018), and from the Experimental HRRR-Smoke (run four times per day, starting in Apr 2016).

Where can I get the archived HRRR-Smoke output?

The operational forecast products are available at https://noaa-hrrr-bdp-pds.s3.amazonaws.com/index.html as well as at https://console.cloud.google.com/storage/browser/high-resolution-rapid-refresh

Hourly 2D analysis data (including smoke) from the experimental forecast products (beginning in Mar 2019) can be found at https://home.chpc.utah.edu/~u0553130/Brian_Blaylock/cgi-bin/hrrr_download.cgi

For earlier dates, 3D forecasts and analyses are archived on NOAA's High Performance Storage System.

Which GRIB2 files from HRRR-Smoke shall I download?

If you are mostly interested in the near-surface smoke field (e.g. for health impact studies), then we recommend using the wrfsfc* GRIB2 files, which contain 2D variables.

Which forecast cycles GRIB2 files from HRRR-Smoke shall I use in real time?

Due to the rapidly updating cycle, the model generates large volumes of forecast data. We always recommend using the latest forecast cycle, which can represent better the latest wildfire activity based on the satellite detections. Moreover, the latest forecast assimilates the latest radar and other weather observations, and thus can be more accurate, for instance in rapidly evolving convective environment. Such weather phenomena can affect the smoke distribution significantly.

Visualization of the HRRR-Smoke products on other platforms

Web-based tool (smoke and surface visibility over zoomable map):
https://hwp-viz.gsd.esrl.noaa.gov/smoke/index.html

RealEarth (https://realearth.ssec.wisc.edu/); One can overlay locations and reports for large wildfires over the HRRR-Smoke forecast fields.

Weather Archive and Visualization Environment (WAVE) - interactive zooming capability, available to all NOAA staff; NOAA/GSL's version of WAVE: https://hwp-viz.gsd.esrl.noaa.gov/wave/

Advanced Weather Interactive Processing System (AWIIPS) – used by the NWS forecasters.

GeoCollaborate: https://fs.geocollaborate.com/dashboard/

References:

Ahmadov, R., G. Grell, E. James, et al., 2017: Using VIIRS fire radiative power data to simulate biomass burning emissions, plume rise and smoke transport in a real-time air quality modeling system. *Proceedings of the 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS),* 2806-2808. https://doi.org/10.1109/IGARSS.2017.8127581.

https://www.jpss.noaa.gov/assets/pdfs/science_publications/2020_science_seminar_digest.pdf

https://rapidrefresh.noaa.gov/pdf/Alexander_AMS_NWP_2020.pdf

Ye X., Arab P., Ahmadov R., James E. et al.: Evaluation and intercomparison of wildfire smoke forecasts from multiple modeling systems for the 2019 Williams Flats fire. *Atmos. Chem. Phys*., 21, 14427–14469, 2021. https://acp.copernicus.org/articles/21/14427/2021/

Benjamin S., Weygandt S., Brown J. et al. A North American Hourly Assimilation and Model Forecast Cycle: The Rapid Refresh. *Mon Weather Rev.* 2016;144(4):1669-94.

Benjamin S. et al. Diagnostic fields developed for hourly updated NOAA weather models. *NOAA Technical Memorandum OAR GSL-66*

https://rapidrefresh.noaa.gov/Diag-vars-NOAA-TechMemo.pdf

VIIRS Active Fire
Quick Guide

What is the VIIRS Active Fire Product?

The VIIRS Active Fire (VIIRS-AF) product provides detections of thermal anomalies across the globe on a daily basis. For those anomalies that can be linked to fires, whether manmade or tied to natural causes. The VIIRS-AF product can provide information about fire location and intensity which can be used to help in operational response decisions. The product consists of 6-minute granules in an unprojected segment of the VIIRS orbital swath. Distributed from the NOAA CLASS data archive in NetCDF format, the data consists of numerous fields that characterize the fire detections including latitude and longitude, brightness temperature, and fire radiative power (FRP), expressed in megawatts.

What is the VIIRS-AF Algorithm? Which spectral bands make up the algorithm?

The standard VIIRS-AF product is based on the same algorithm that Moderate Resolution Imaging Spectroradiometer (MODIS) uses. The current algorithm is referred to as “Collection 6” . This algorithm is a hybrid thresholding and contextual algorithm using radiometric signals from 4 and 11 micron bands (M13 and M15, respectively). Additional bands and a suite of tests are used to generate an internal cloud mask and reject false alarms.

Available in AWIPS-II for National Weather Service Forecasters

VIIRS-AF product data will be able to be retrieved from the Satellite Broadcast Network (SBN) over the experimental feed into AWIPS-II, version 16.4.1, in Summer 2017. VIIRS-AF will transition to a baseline product at a future date.

Data Access for Non-AWIPS-II users

For non-AWIPS-II users, refer to the ‘VIIRS Data Tutorial’ Link on the following website, (http://viirsfire.geog.umd.edu/docs/VIIRS_data_tutorial_2017a.pdf). The tutorial will highlight four different options to obtain VIIRS-AF data, and involves diagrams to assist users in deciding their preferred method of access via step-by-step process. Tutorial will also cover data latency and data consistency in relation to each option. The four options are depicted in the Figure 1 and are listed below:

1. Direct Broadcast
2. Near Real Time (NRT)
3. Non-NRT
4. Science

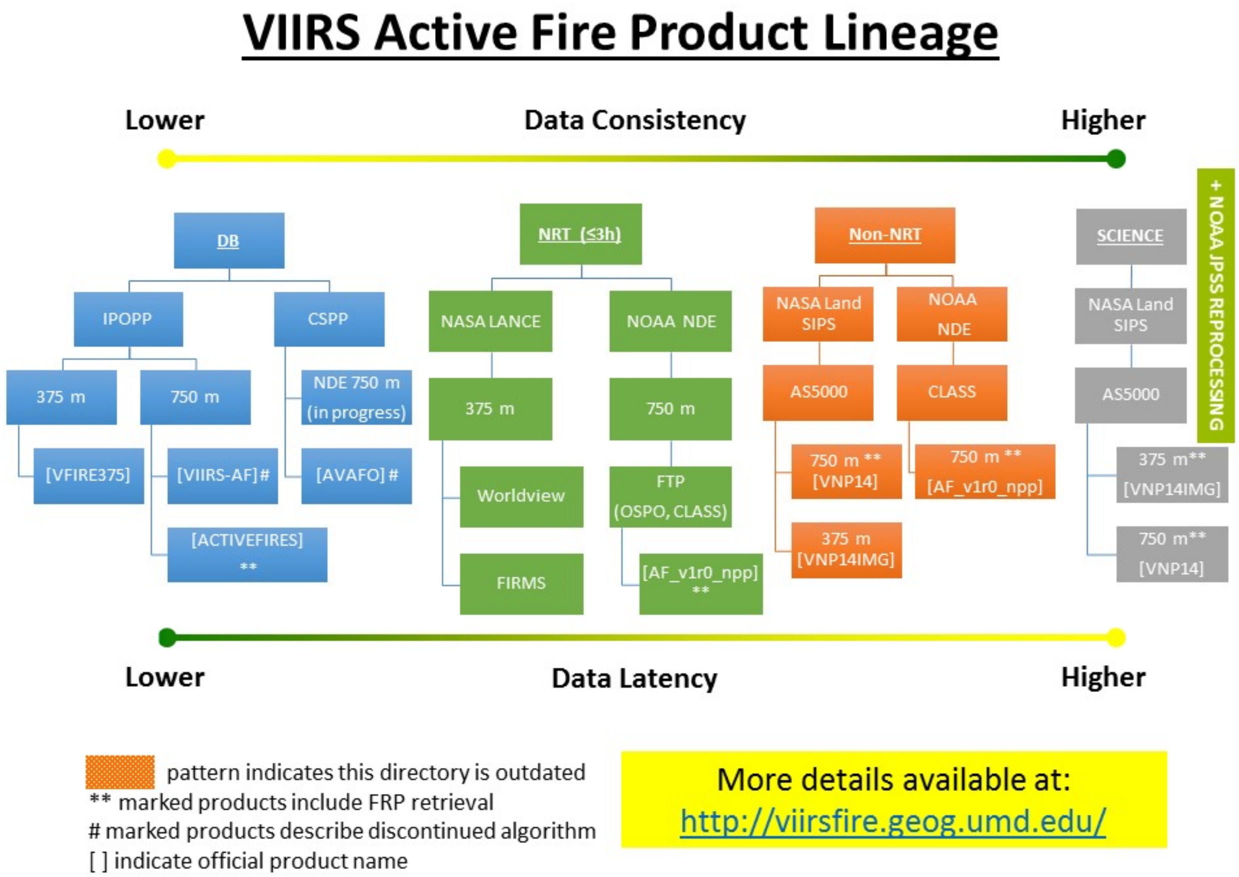

Figure 1. Describes the four options of acquiring VIIRS-AF data via Direct Broadcast (DB), Near Real Time (NRT), Non-NRT, and Science. The data consistency and data latency are also provided to help users decide their preferred method of access.

Examples of the VIIRS-AF Product

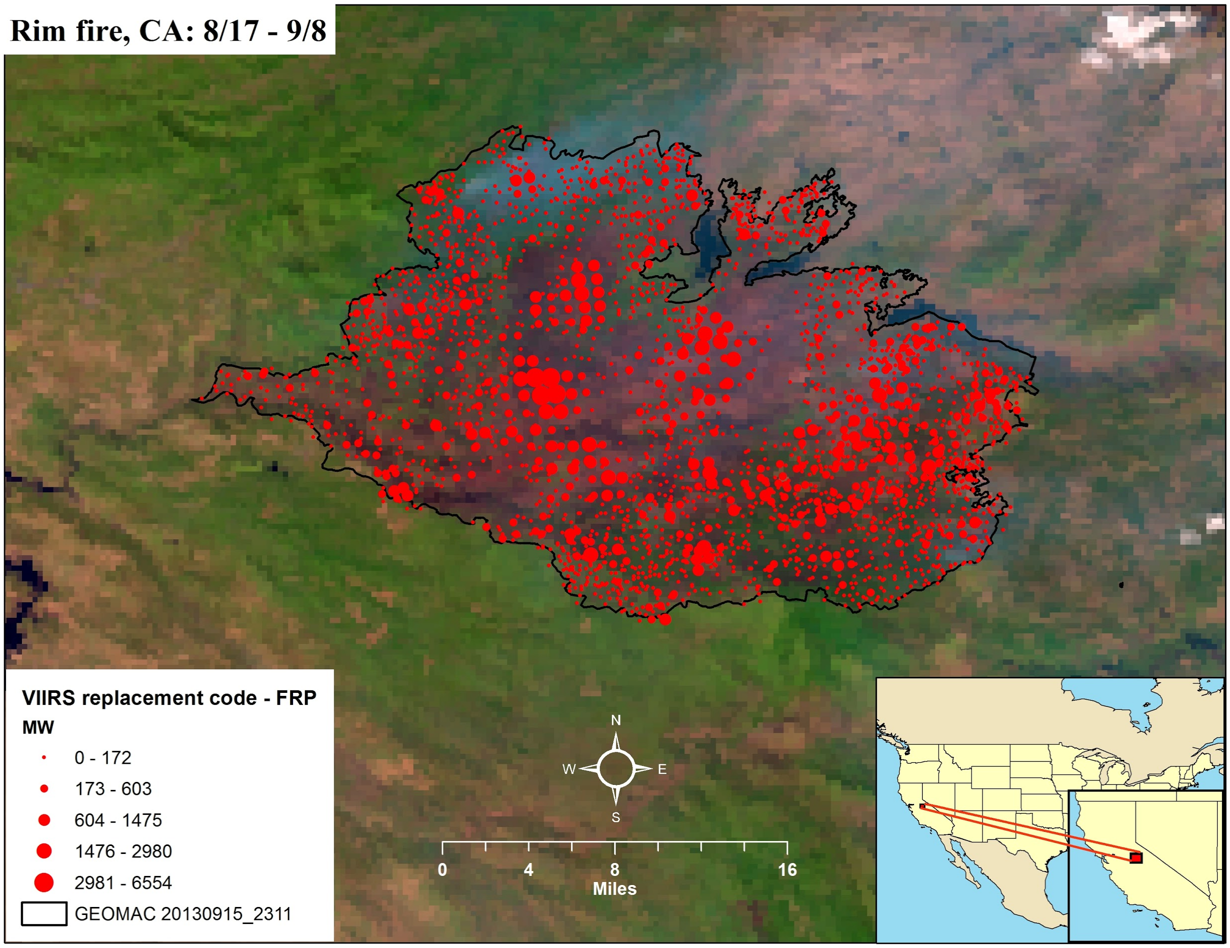

Figure 2. Rim Fire, 2013 California. The above image shows the fire progression between August 17th and September 9th. The size of the red circles indicates the level of the detections intensity in megawatts, referred to as fire radiative power (FRP).

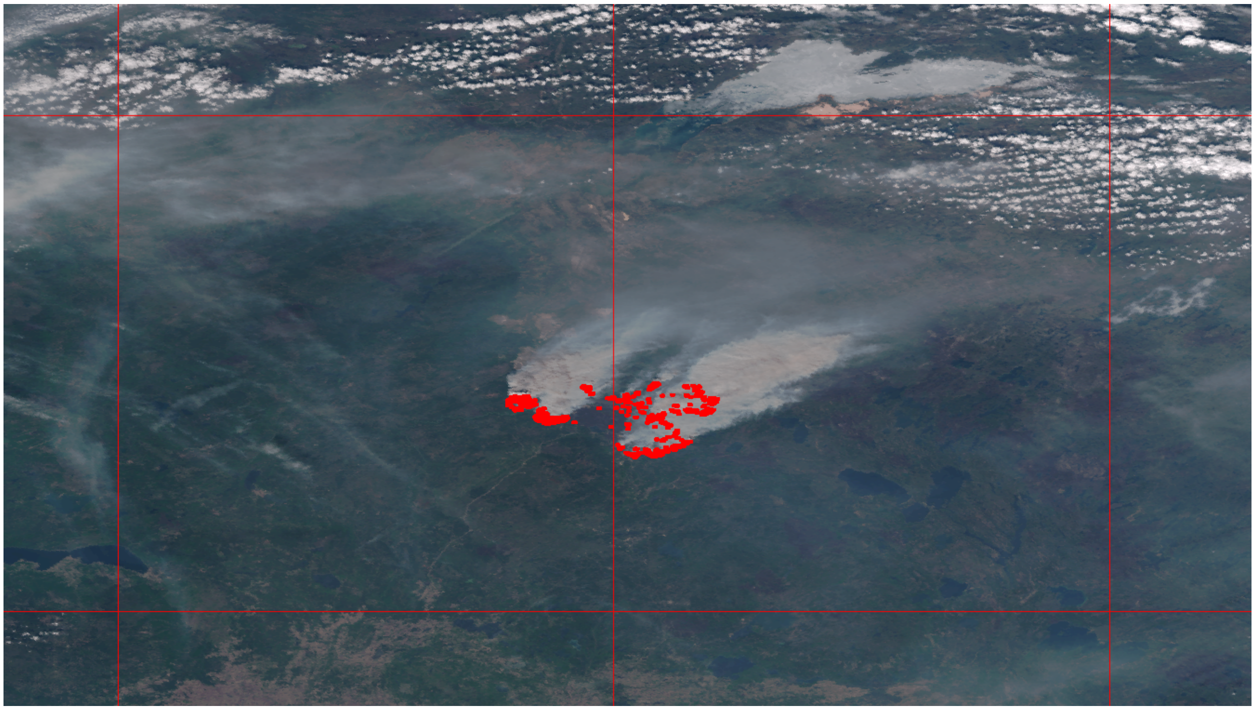

Figure 3. VIIRS-AF fire detections from the moderate resolution (750m) M-band product from the Ft. McMurray, Alberta, Canada, on May 16th, 2016.

Continued Evolution of the VIIRS-AF product

Currently, the VIIRS-AF product is a part of the Suomi-National Polar-orbiting Partnership (Suomi-NPP) satellite, a prototype for the forthcoming JPSS satellite series 1-4. Similar to MODIS, the VIIRS-AF product will be reprocessed periodically to make adjustments and improvements. These upgrades will ensure this product continues to be a valuable capability for use in support of the fire mission.

Supplemental Information and Links

1. VIIRS-AF Website: http://viirsfire.geog.umd.edu/
2. VIIRS-AF Maps (CONUS & GLOBAL): http://viirsfire.geog.umd.edu/pages/mapsData.php
3. Fire Blog: http://viirsfire.geog.umd.edu/pages/worklog.php
4. NOAA CLASS data archive link: https://www.class.ncdc.noaa.gov/

Contact information

Any questions about VIIRS-AF product, please contact with JPSS Program Office and CIRA/CSU:
JPSS Program Office, Bill Sjoberg: bill.sjoberg@noaa.gov
CIRA/CSU, Jorel Torres: Jorel.Torres@noaa.gov
Questions about algorithms, please contact with NOAA/NESDIS and University of Maryland:
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University of Maryland, Evan Ellicott: ellicott@umd.edu