Using the satellite fire radiative data in mesoscale smoke and weather forecasting applications

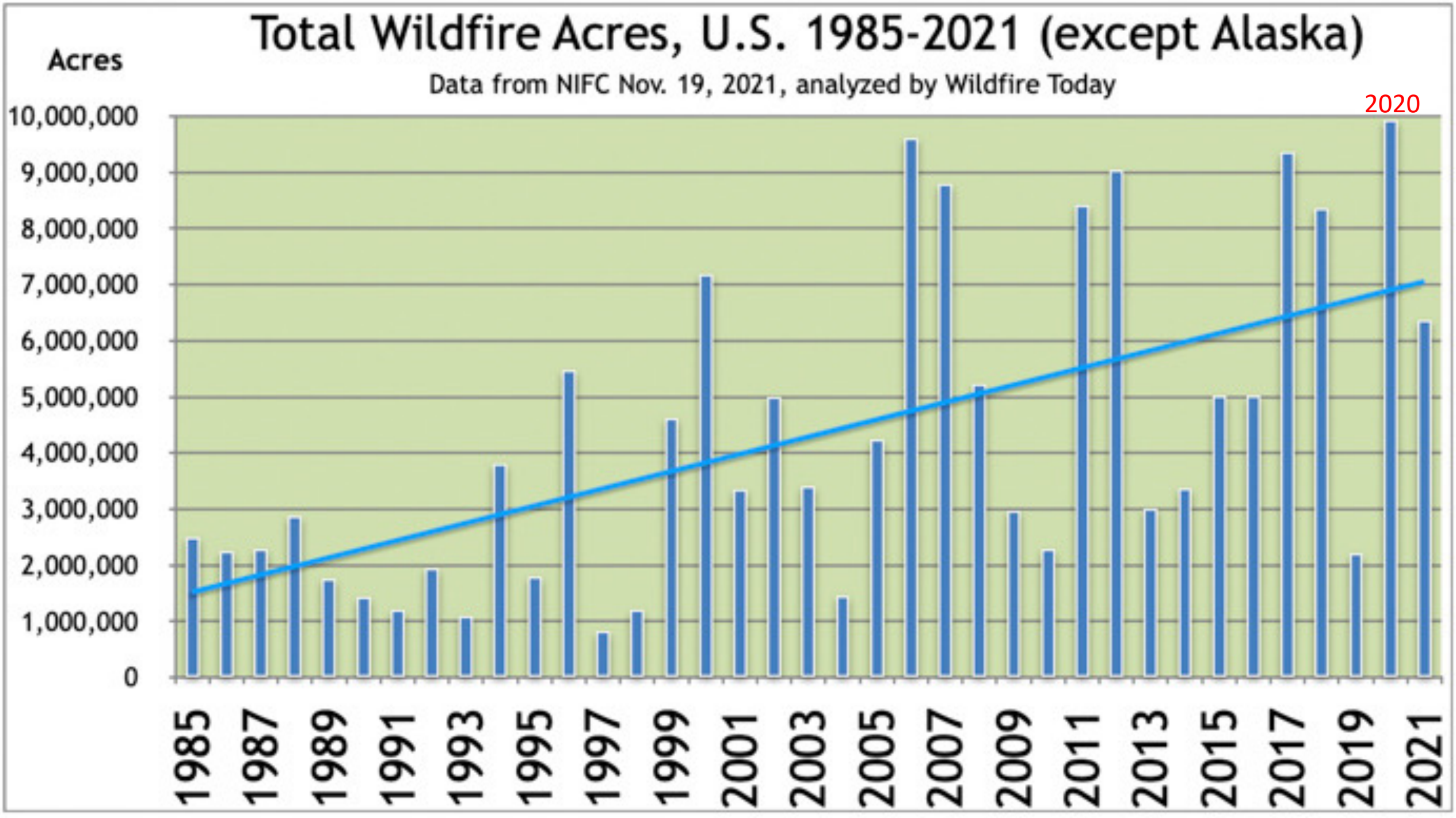
Ravan Ahmadov[1,2] (*ravan.ahmadov@noaa.gov*) on behalf of the wider development team, which spans CU Boulder CIRES, South Dakota State Univ., NOAA/ GSL, CSL, ARL, EMC, NESDIS, NASA and FIREX-AQ teams

1) CIRES, University of Colorado, Boulder, CO 80309, USA,

2) NOAA Global Systems Laboratory, Boulder, CO 80305, USA

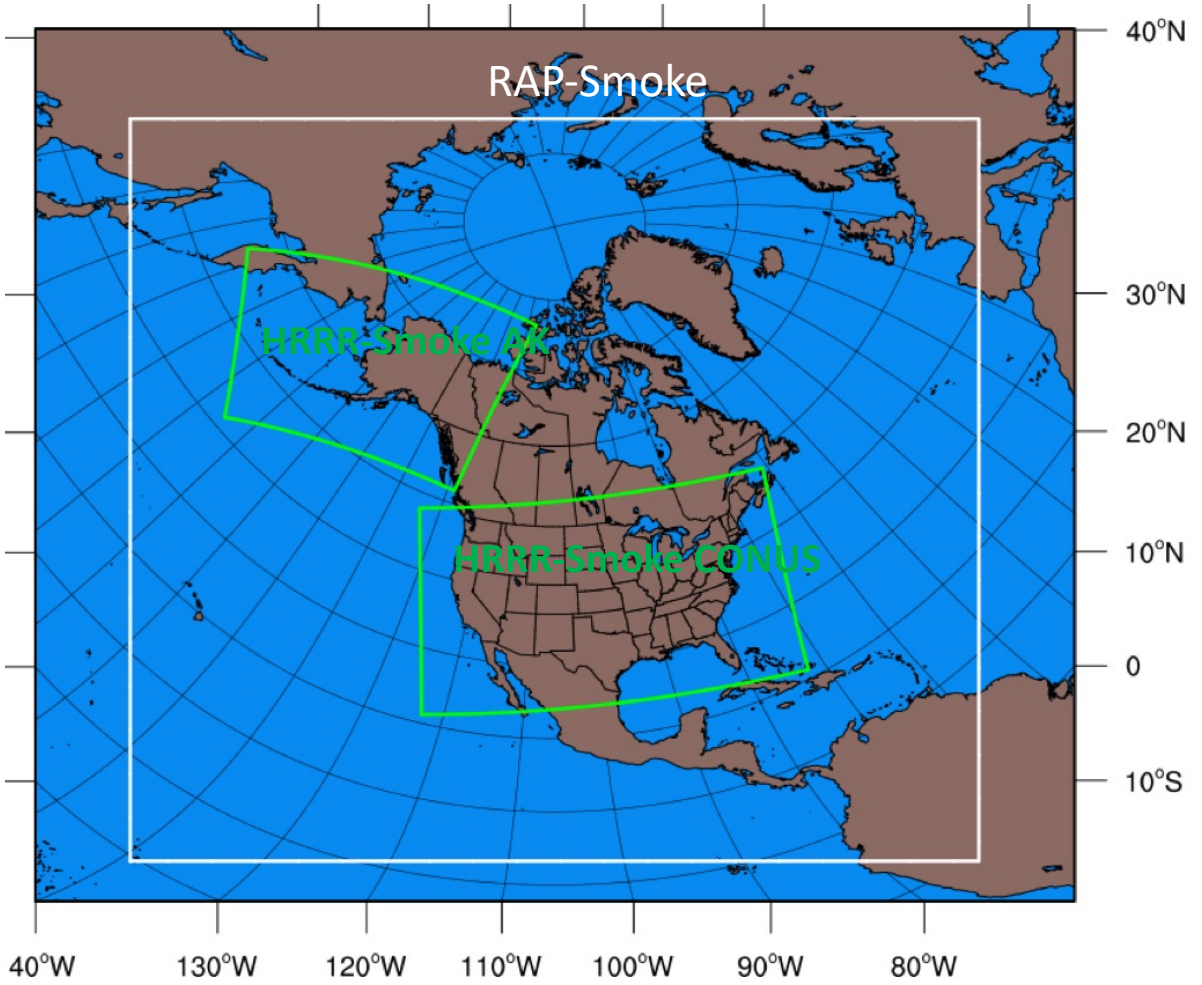
Acknowledgement: JPSS PGRR program

Lightning Complex fire in Vacaville, California
August 19, 2020 (AP Photo/Noah Berger)


Total Wildfire Acres, U.S. 1985-2021 (except Alaska)
Data from NIFC Nov. 19, 2021, analyzed by Wildfire Today
Acres
10,000,000
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
2020
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021

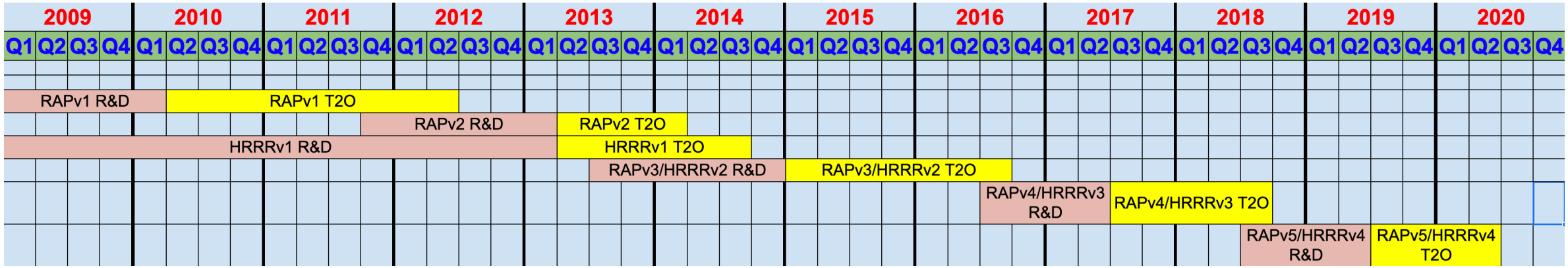
NOAA's current operational high-resolution weather-smoke forecasting models

- A **smoke tracer** is added to the RAP/HRRR weather forecast models
- The satellite fire radiative power (FRP) data are used to estimate the fire emissions and heat fluxes in real time
- RAP-Smoke enables simulating smoke transport over Central and North Americas, and provides lateral boundary conditions of smoke to HRRR-Smoke.
- The **HRRR-Smoke** (3km) model is able to capture the mesoscale flows and smoke transport in complex terrain
- Smoke feedbacks on radiation and visibility are included in these models
- The smoke forecasting capability was transitioned to NOAA's operational RAPv5/HRRRv4 systems in December, 2020



Rapid Refresh (RAP), 13.5km resolution
High-Resolution Rapid Refresh (HRRR), **3km** res.
(https://rapidrefresh.noaa.gov/)

RAP/HRRR Implementation History



NWS NCEP and WFOs – Feedback "O2R" and Implementations "R2O"

Aviation (FAA, NCAR, MIT/LL, AWC) – CoSPA Project – SIP/FIP/GTG/etc… – 15 min output

Severe (SPC, NSSL) – Vortex II/SE Projects – WoF – Hourly Maximum Fields

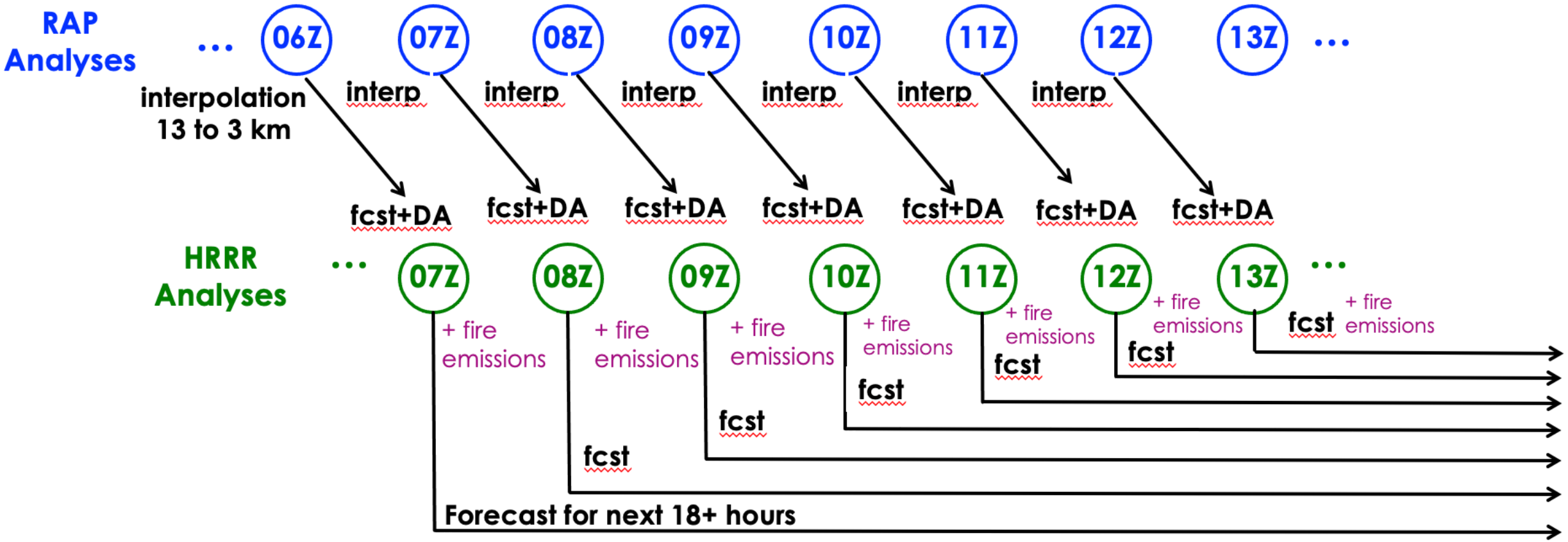
Energy (DOE) – WFIP 1/2, SFIP Projects – Averaged Direct/Diffuse Rad/Wind

Hydrology (WPC, OWP) – AQPI, NWM Projs, PQPF/Ptype

Air Quality (WFOs) – Smoke, Feedbacks (*started in 2016*)

Coupling – FVCOM, Lakes

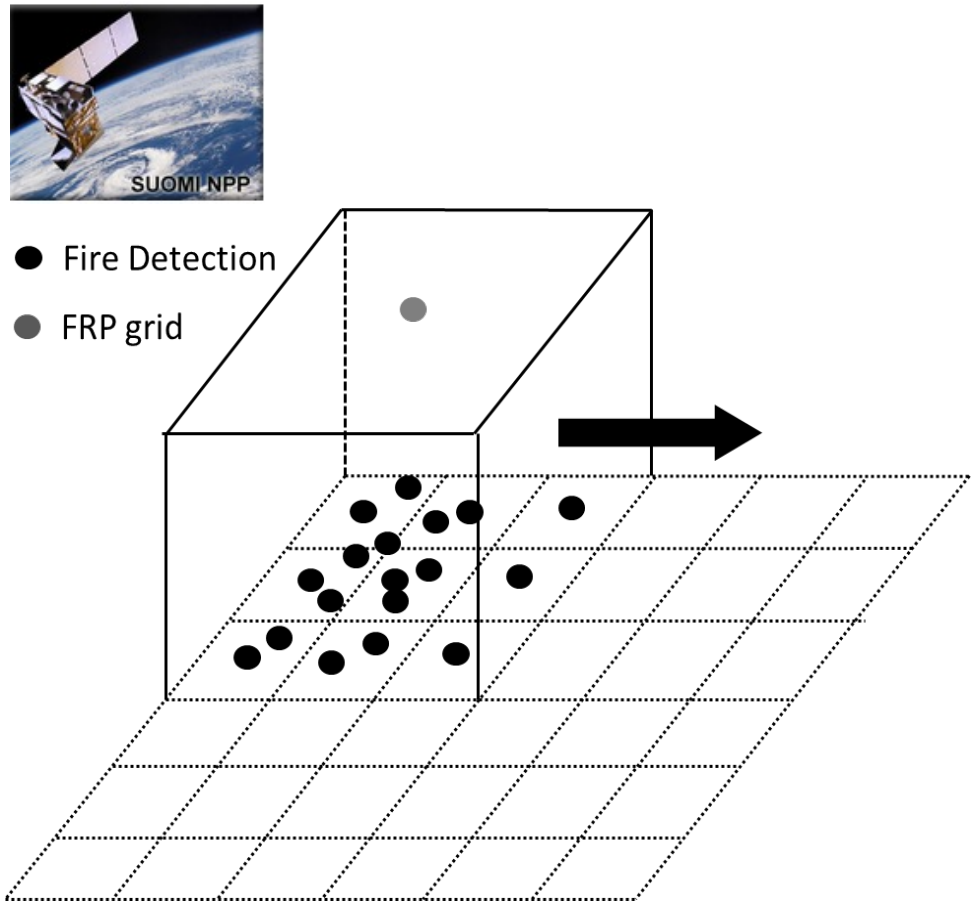
Hourly cycle of HRRR-Smoke: 1-h spin-up for each forecast
A new forecast is produced 24 times a day



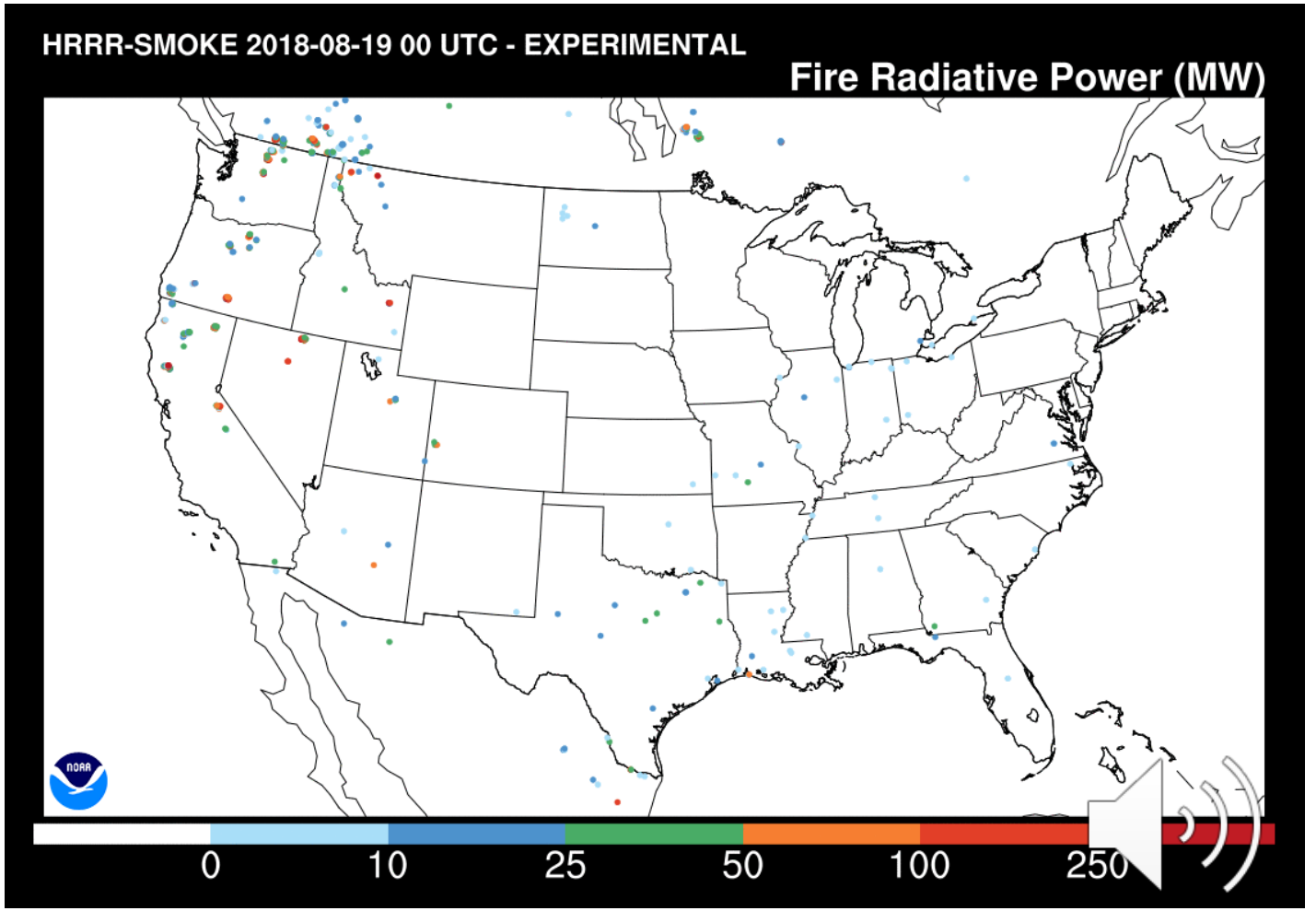
- Starting March 2018 smoke emissions are simulated every hour for input to RAP/HRRR-Smoke. Simulated 3D smoke fields are cycled between the consecutive RAP/HRRR-Smoke forecasts.

Mapping the satellite FRP data to the HRRR-Smoke CONUS grid

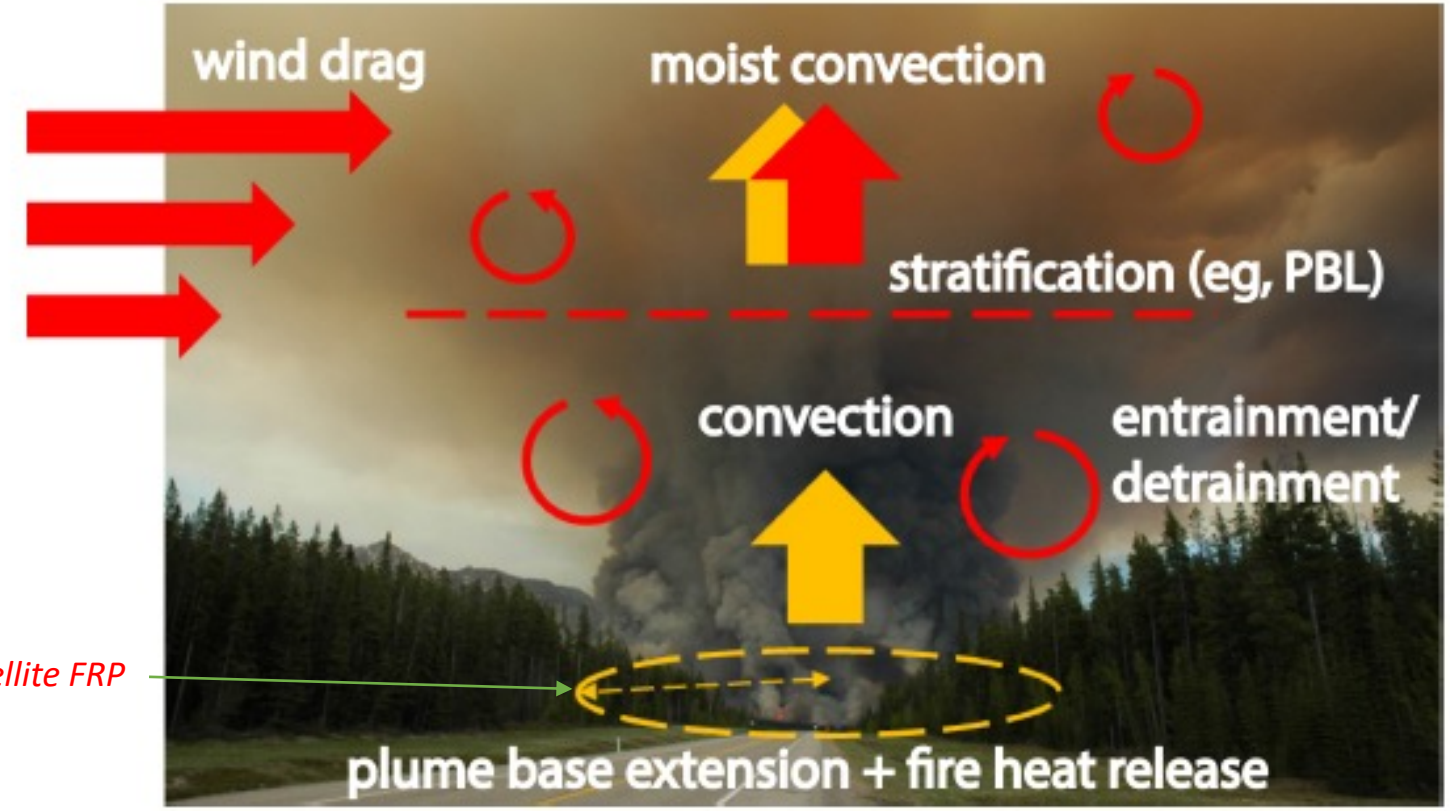
The clustering procedure performs a combination of all detected fires from VIIRS (S-NPP and NOAA-20) and MODIS (Terra and Aqua) according to the model spatial resolution and grid configuration



24hr average FRP data mapped over 3x3km HRRR CONUS grid pixels for August 19, 2018



Fire plume rise dynamics



Satellite FRP

Paugam et al., ACP, 2016

We use the satellite FRP data to estimate the fire heat fluxes in HRRR-Smoke

1D plume rise model (Freitas et al., 2007)

$$\frac{\partial w}{\partial t} + w\frac{\partial w}{\partial z} = \frac{1}{1+\gamma} gB - \frac{2\alpha}{R} w^2 + \frac{\partial}{\partial z}\left(K_m \frac{\partial w}{\partial z}\right) \quad (1)$$

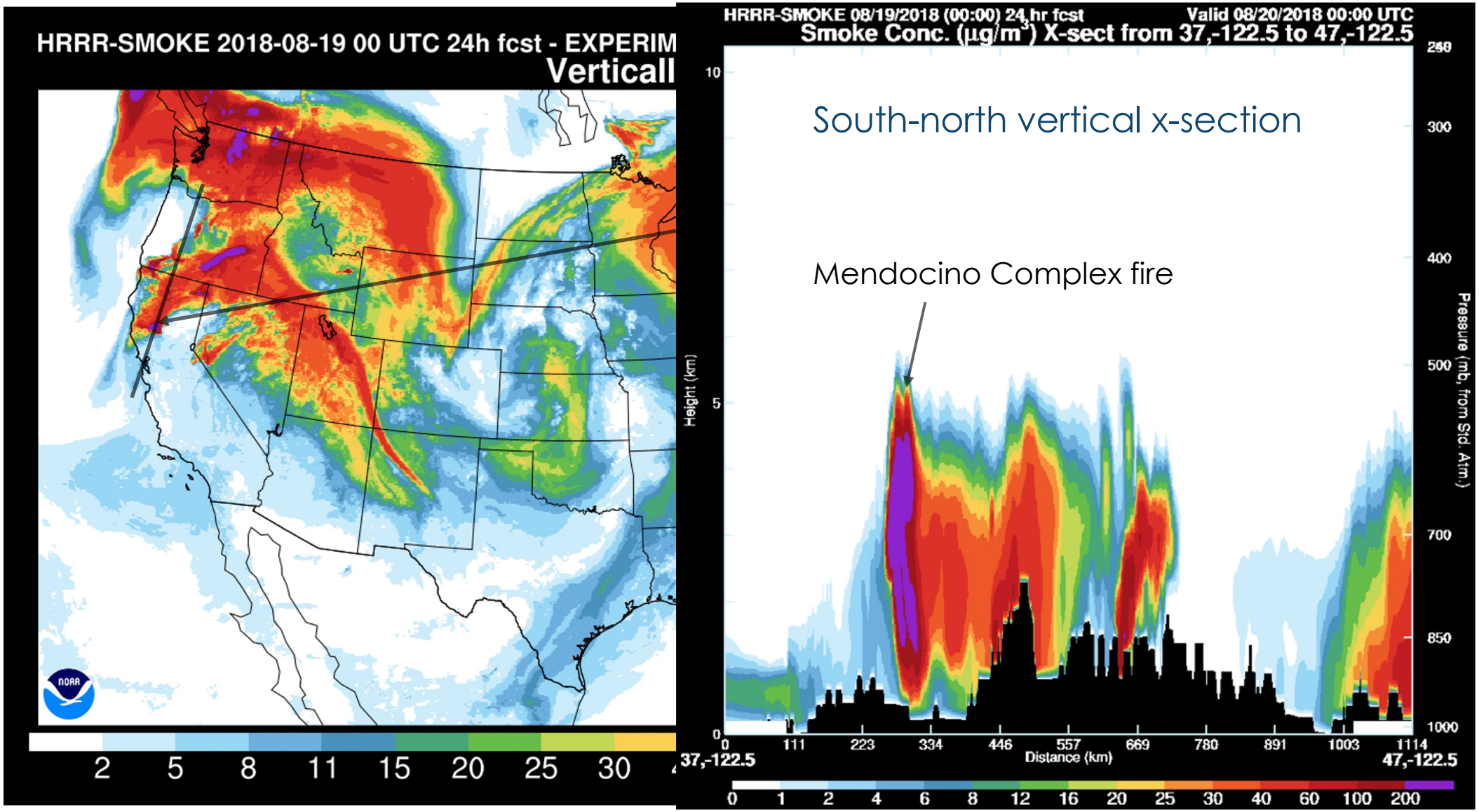
$$\frac{\partial T}{\partial t} + w\frac{\partial T}{\partial z} = -w\frac{g}{c_p} - \frac{2\alpha}{R}|w|(T - T_e) + \frac{\partial}{\partial z}\left(K_T \frac{\partial T}{\partial z}\right) + \left(\frac{\partial T}{\partial t}\right)_{\text{microphysics}} \quad (2)$$

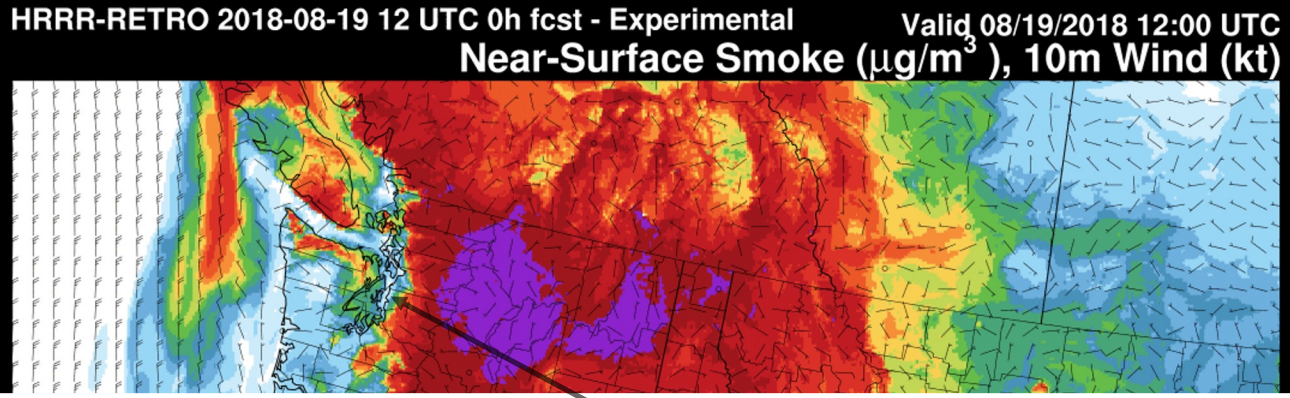
$$\frac{\partial r_v}{\partial t} + w\frac{\partial r_v}{\partial z} = -\frac{2\alpha}{R}|w|(r_v - r_{ve}) + \frac{\partial}{\partial z}\left(K_T \frac{\partial r_v}{\partial z}\right) + \left(\frac{\partial r_v}{\partial t}\right)_{\text{microphysics}} \quad (3)$$

$$\frac{\partial r_c}{\partial t} + w\frac{\partial r_c}{\partial z} = -\frac{2\alpha}{R}|w| r_c + \frac{\partial}{\partial z}\left(K_T \frac{\partial r_c}{\partial z}\right) + \left(\frac{\partial r_c}{\partial t}\right)_{\text{microphysics}} \quad (4)$$

$$\frac{\partial r_{\text{ice,rain}}}{\partial t} + w\frac{\partial r_{\text{ice,rain}}}{\partial z} = -\frac{2\alpha}{R}|w| r_{\text{ice,rain}} + \frac{\partial}{\partial z}\left(K_T \frac{\partial r_{\text{ice,rain}}}{\partial z}\right) + \left(\frac{\partial r_{\text{ice,rain}}}{\partial t}\right)_{\text{microphysics}} + \text{sedim}_{\text{ice,rain}} \quad (5)$$

Smoke forecast for August 19, 2018 (rapidrefresh.noaa.gov/hrrr/HRRRsmoke/)



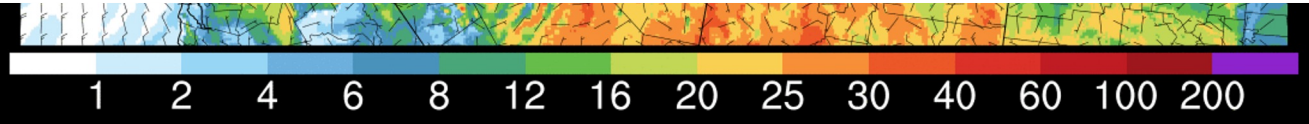


U.S.

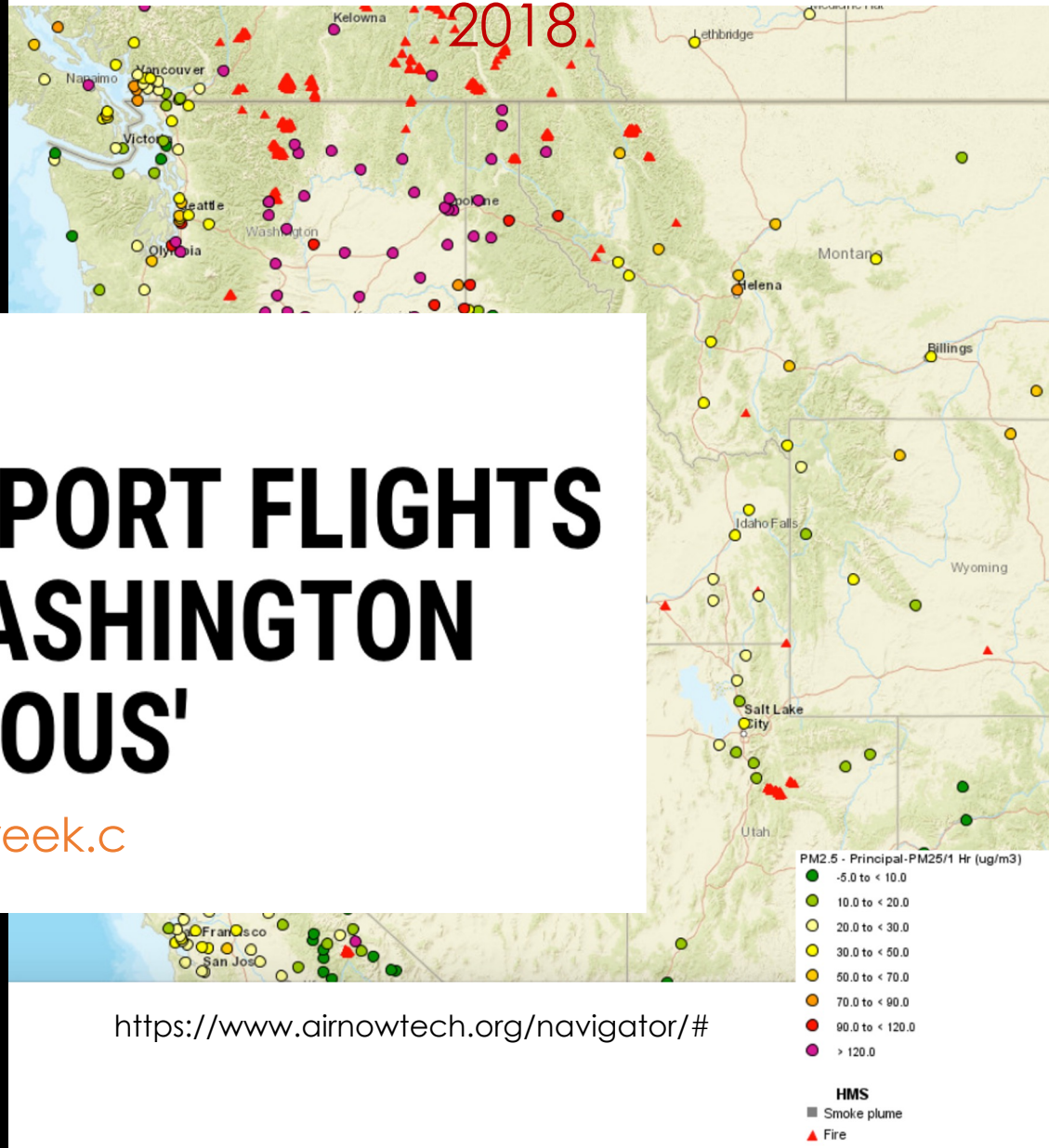
WILDFIRE SMOKE: SEA-TAC AIRPORT FLIGHTS DELAYED AS AIR QUALITY IN WASHINGTON STATE CITY BECOMES 'HAZARDOUS'

BY **JASON MURDOCK** ON 8/20/18 AT 4:17 AM EDT

Newsweek.com

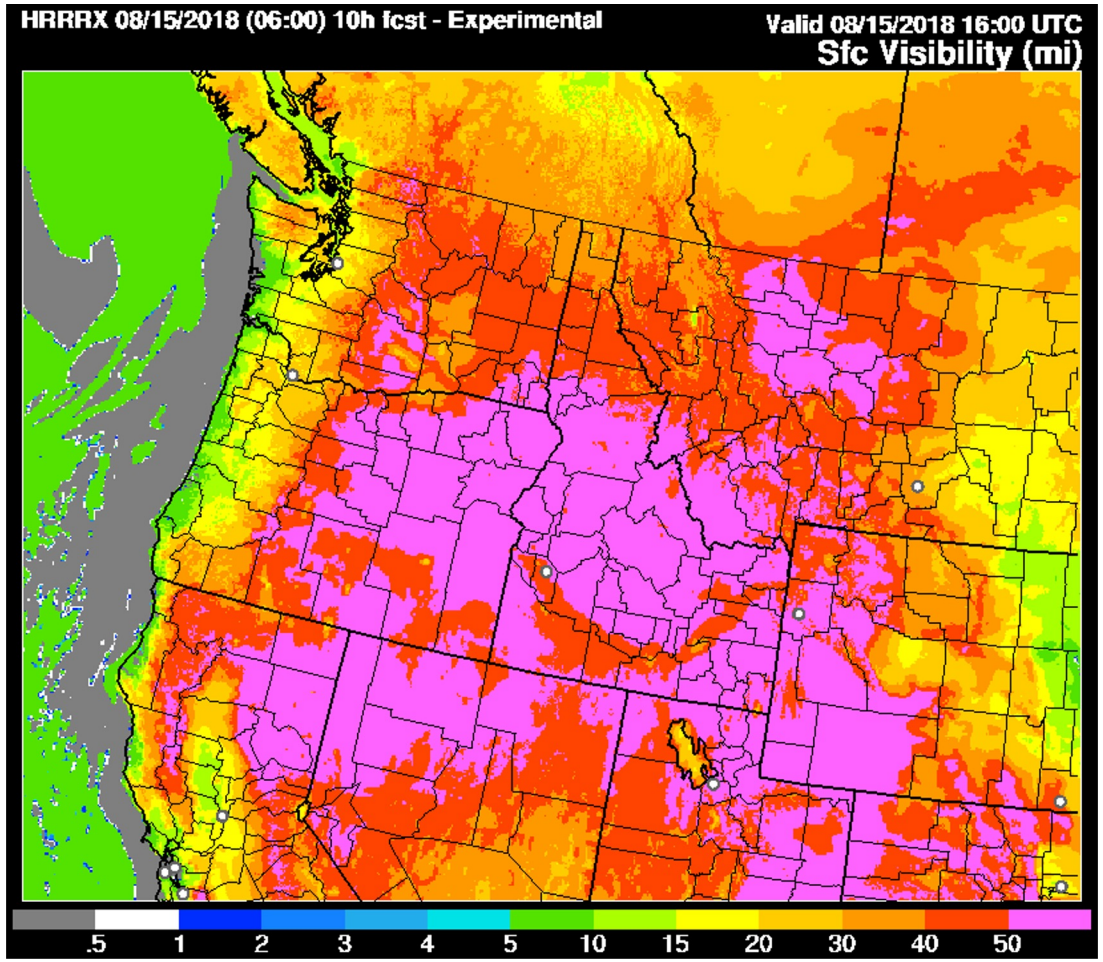


$PM_{2.5}$ concentrations (AirNow network) 8pm PDT, August 19, 2018.

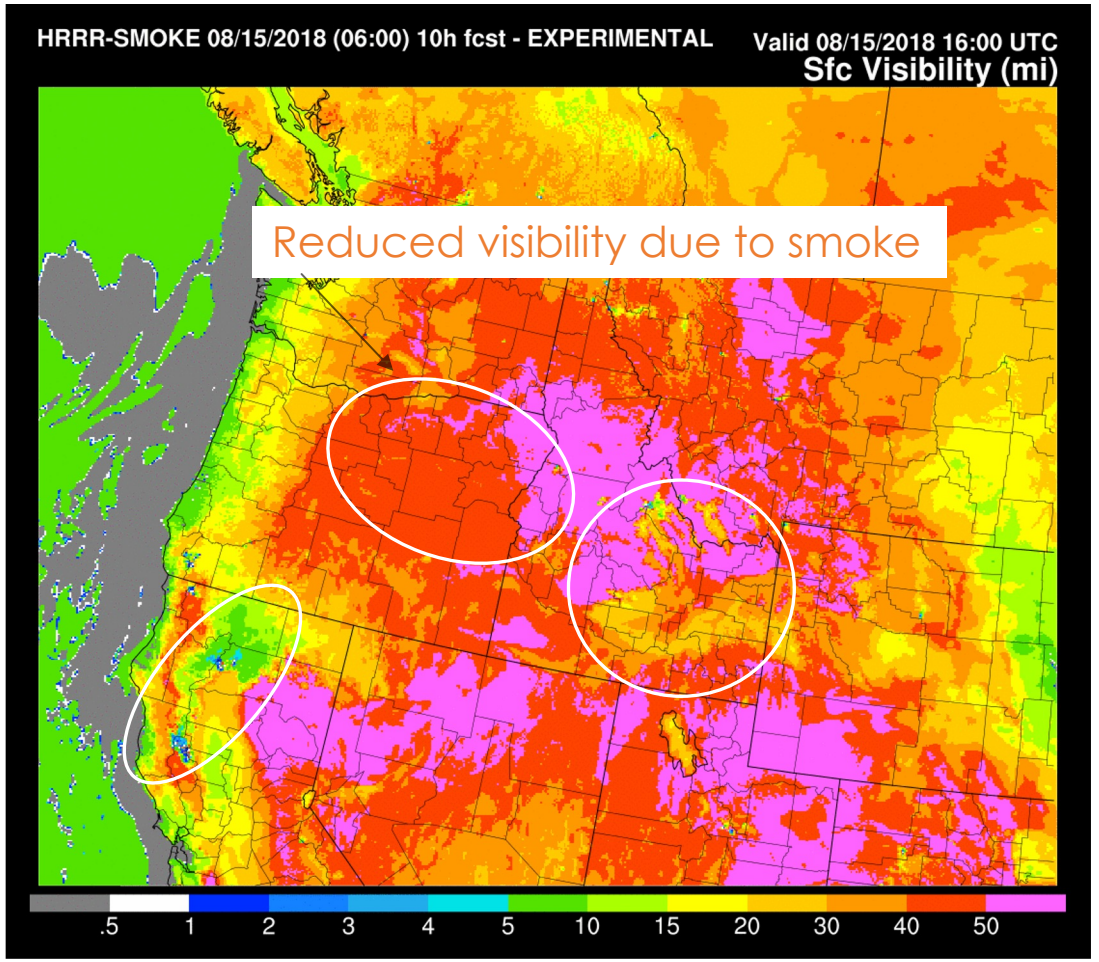


https://www.airnowtech.org/navigator/#

Surface visibility forecasts by HRRR-Smoke



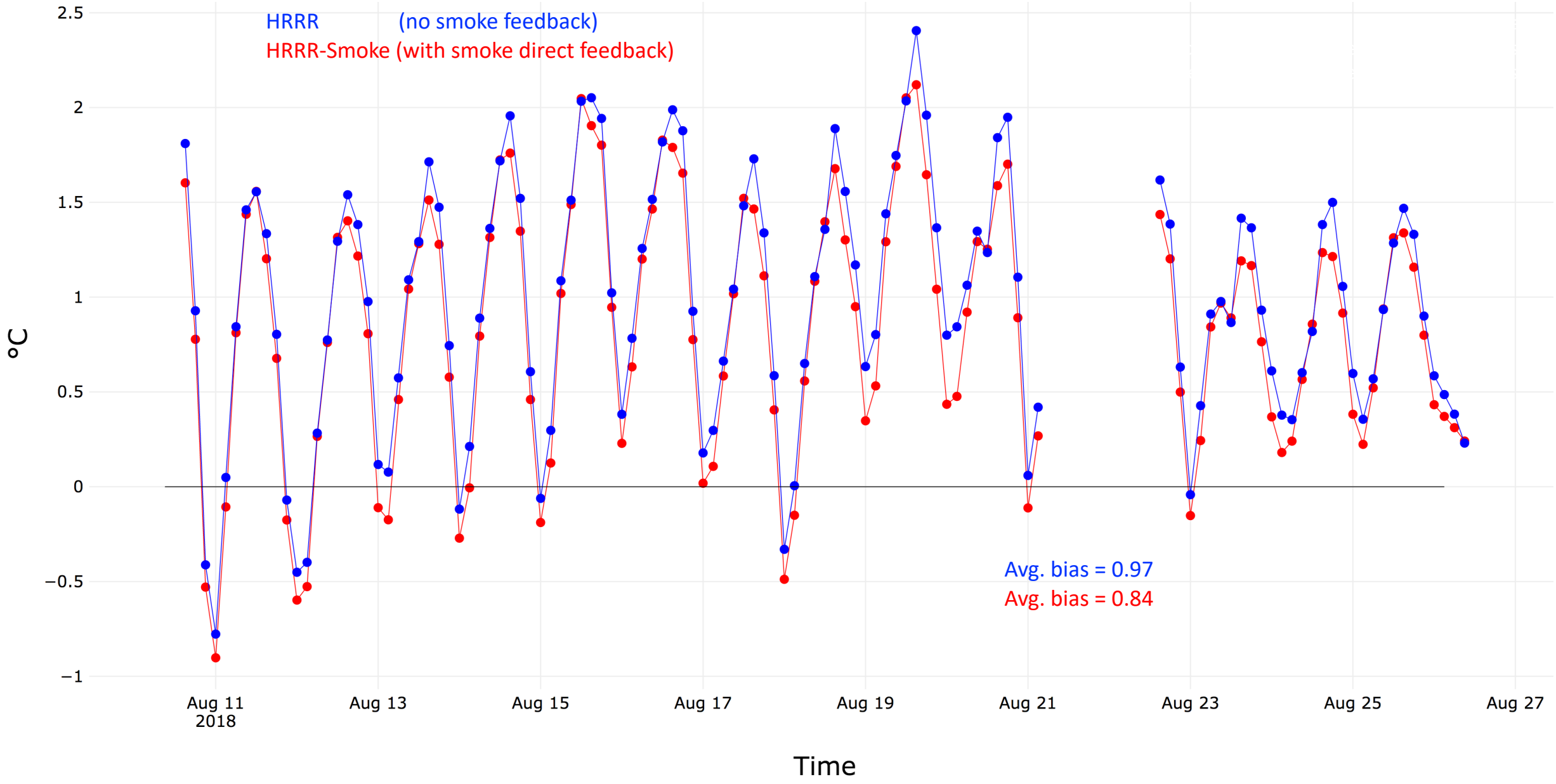
HRRR model w/o smoke



HRRR model with smoke

Visibility is an important forecast product (traffic, aviation…)

Verification of avg. 2m temp bias (model-obs.) of 12 hour HRRR-Smoke forecasts over western US



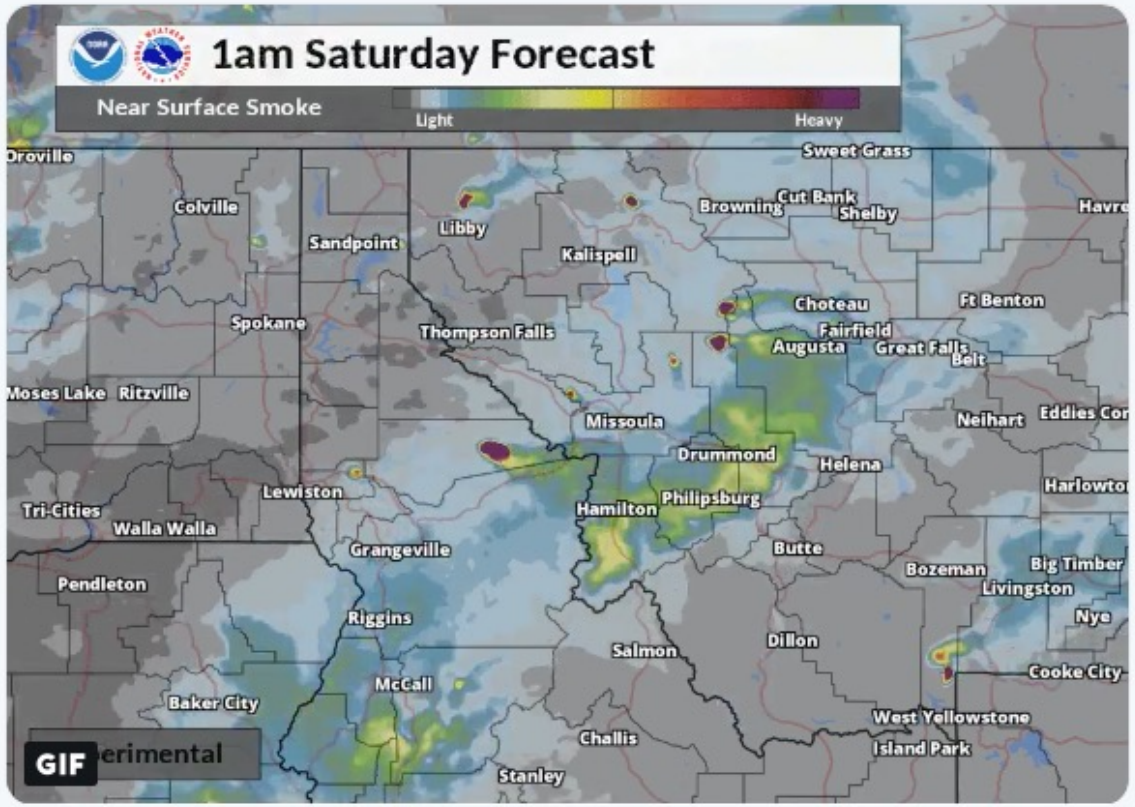
An unexpected smoke impact from a prescribed fire, Sep 7, 2018

Importance of the frequently updated high-resolution weather/smoke forecasting

HRRR-Smoke forecast tweeted by NWS Missoula

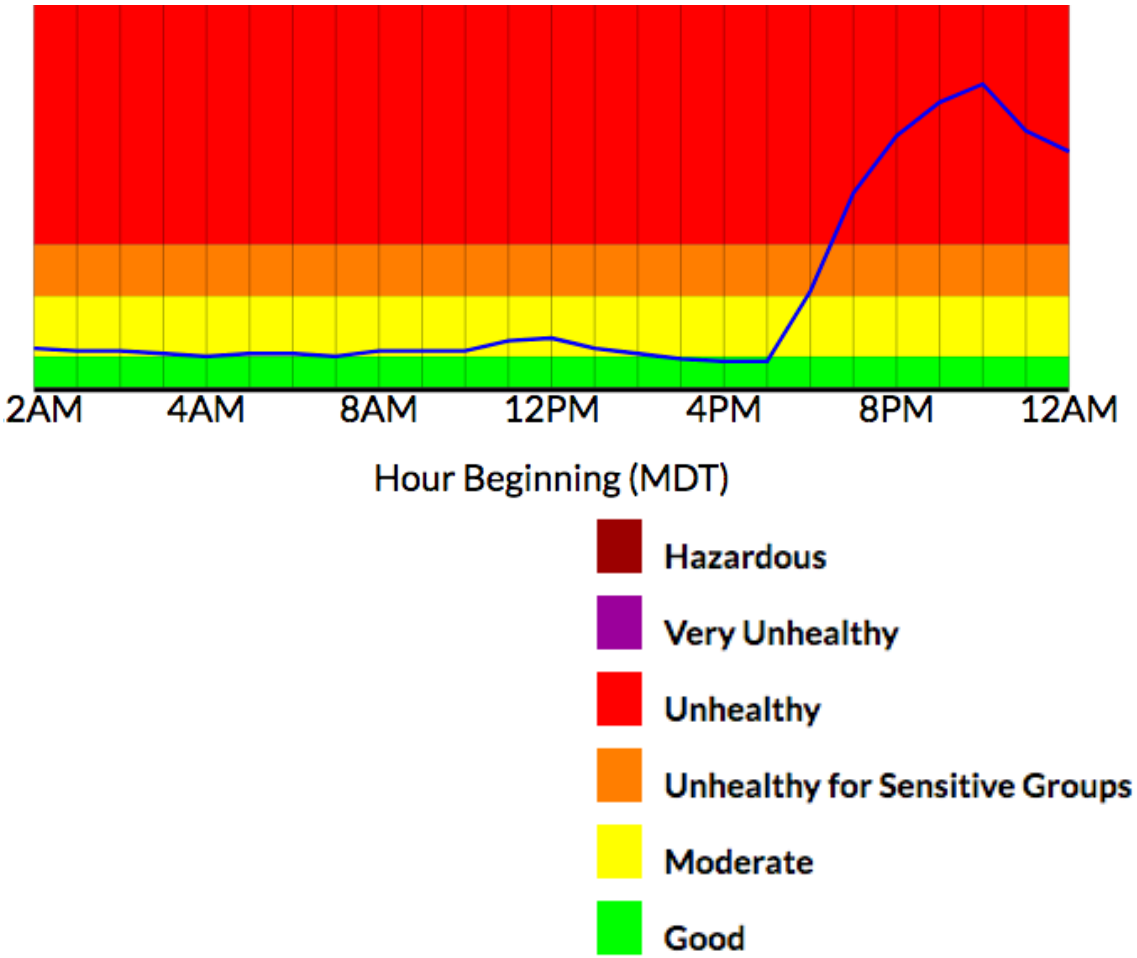
NWS Missoula @NWSMissoula · 7 Sep 2018

[655pm] UPDATE: **Smoke** in the #Missoula & #Bitterroot valleys, as seen in our fcst model's depiction of **smoke** movement, is coming from a sizable prescribed burn going on in Clearwater County, ID. If the winds stay on track, it should clear out in by midnight.

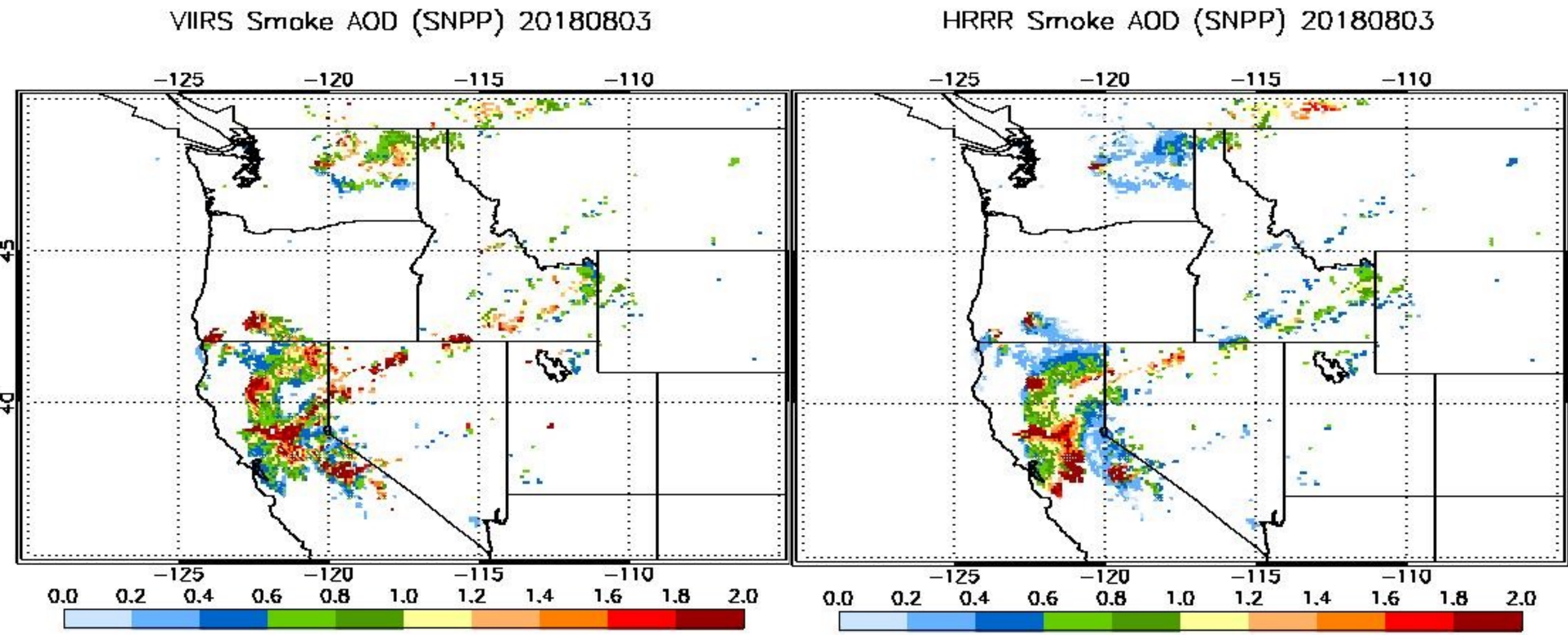


Hourly $PM_{2.5}$ concentrations detected in Missoula, MT

By 8pm the concentrations exceeded 100 ug/m^3 !



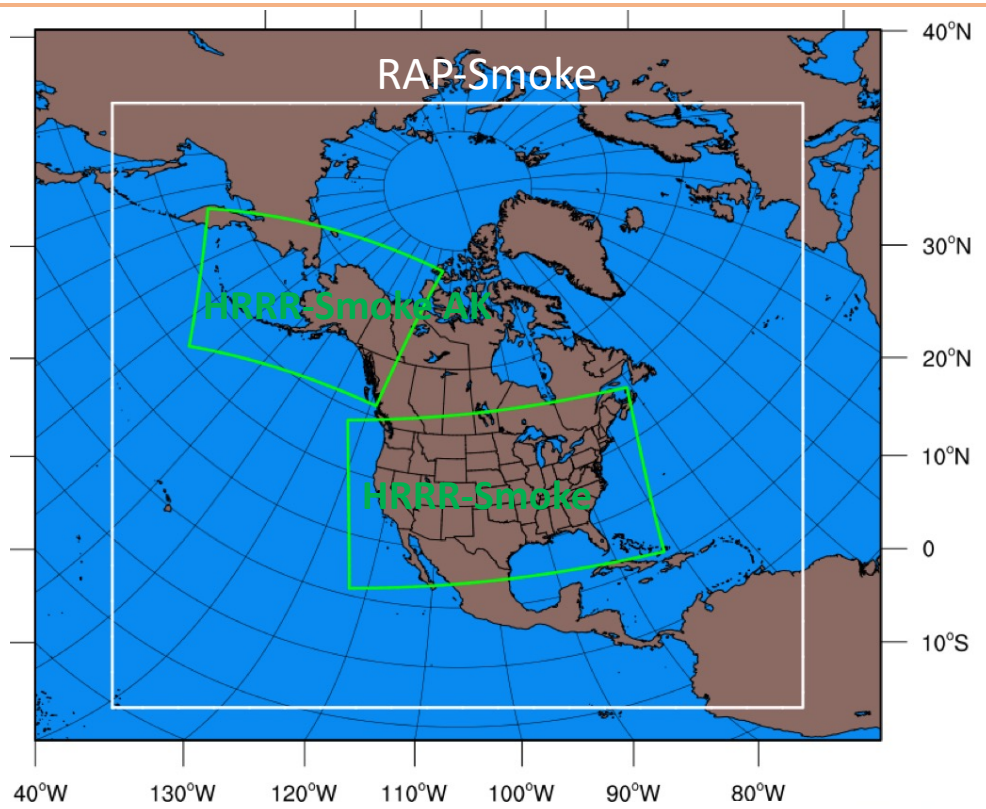
Verification of the vertically integrated smoke forecasts using the VIIRS AOD data



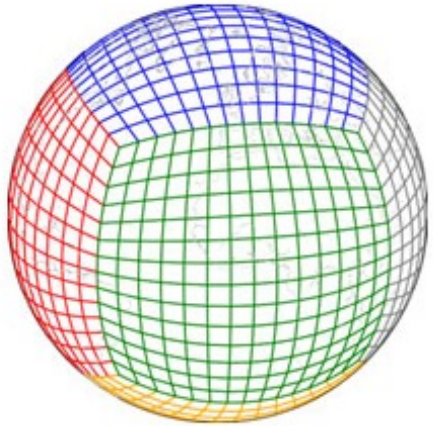
The model does NOT simulate the aerosol composition, aging (important for the aged smoke) and hygroscopicity

The model does NOT include anthropogenic aerosols and dust

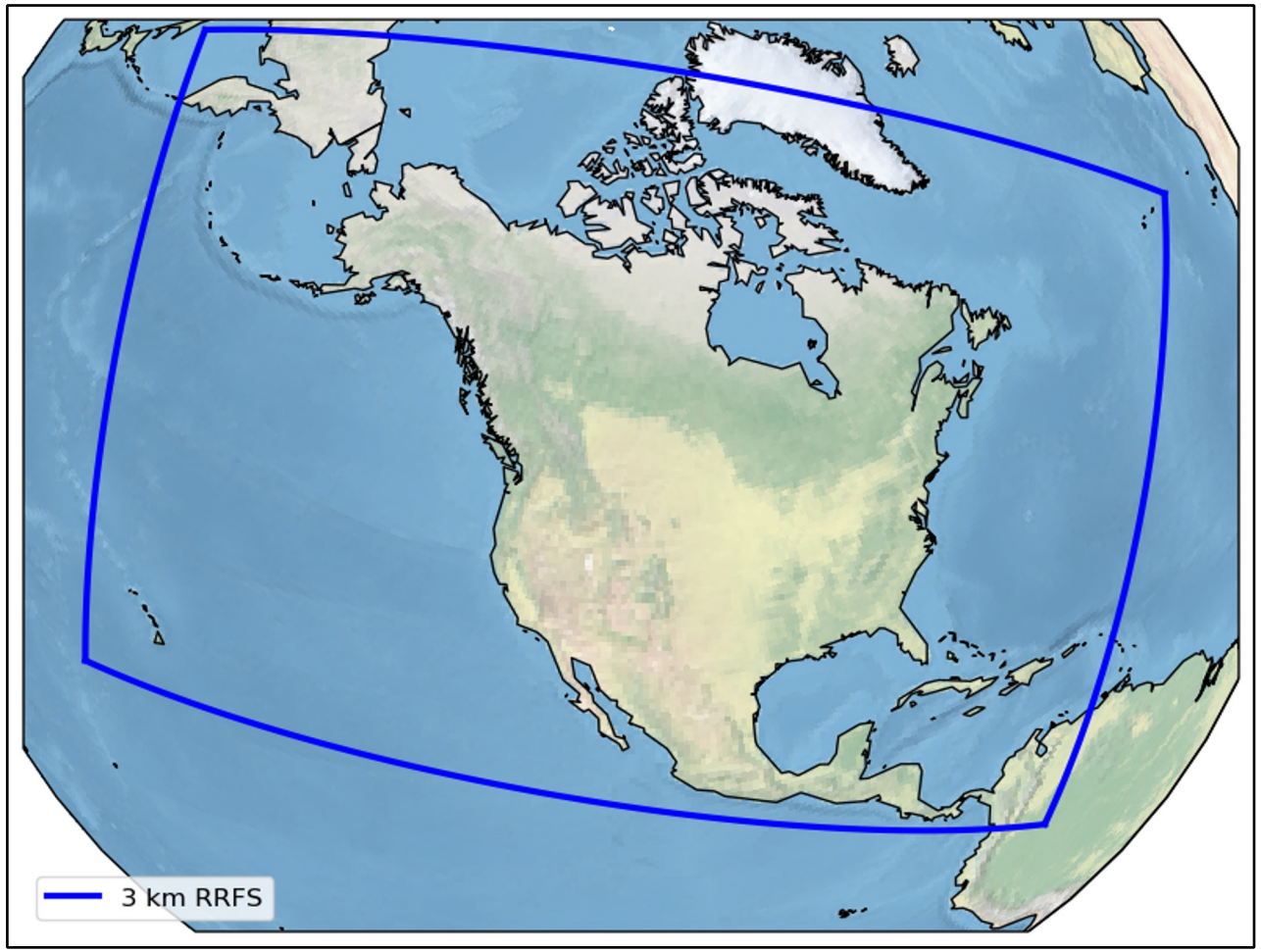
Transitioning of the RAP/HRRR-Smoke models to the FV3 dynamical core



Finite-Volume Cubed-Sphere Dynamical Core (FV3)

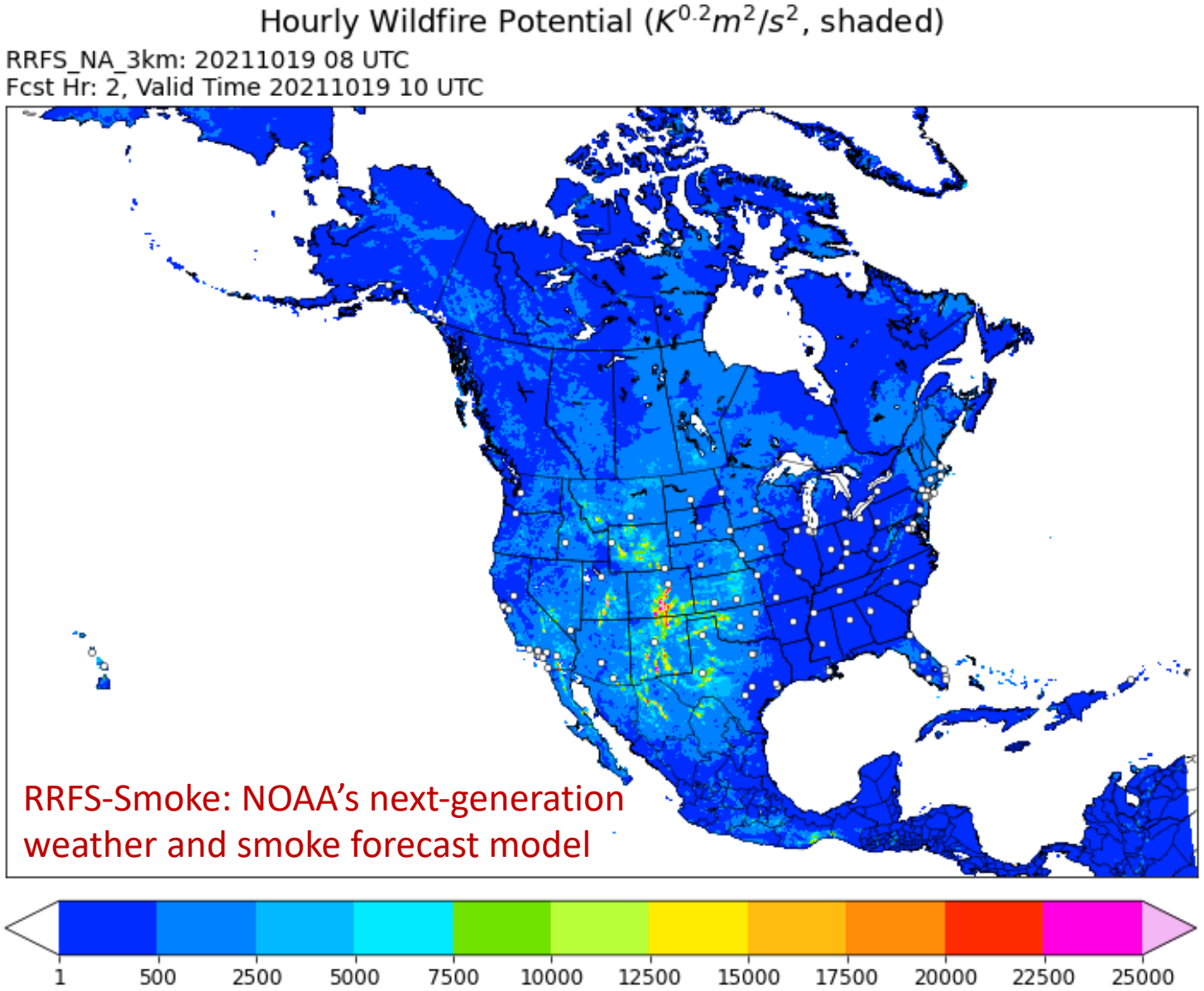


3 km resolution FV3 limited area model domain



Rapid Refresh Forecasting System (RRFS)
https://rapidrefresh.noaa.gov/RRFS/

Hourly Wildfire Potential (HWP) diagnostic product for use in the RRFS-Smoke model



The capability to simulate fire weather depends on capturing mesoscale phenomena. Convection-allowing models (like HRRR and RRFS) with 3km grid spacing are capable of representing deep convective storms and their outflows, as well as terrain-induced circulations.

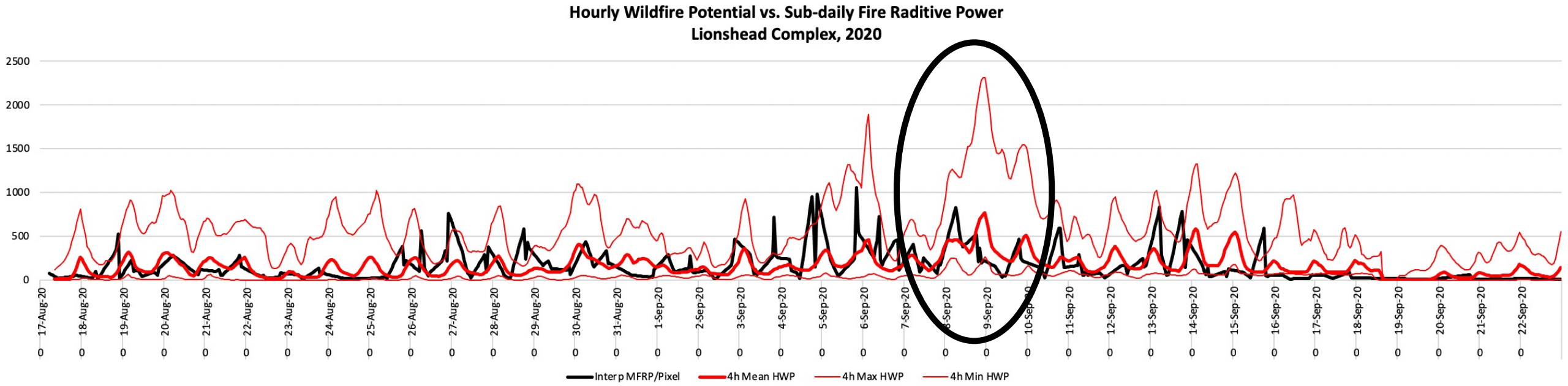
Hourly Wildfire Potential is a new diagnostic product based on hourly air temperature, humidity, wind gust potential and soil moisture model output.

HWP is provided in real time along with other NWP products from the experimental RRFS: https://rapidrefresh.noaa.gov/RRFS/

Example time series: Lionshead Complex (Oregon, 2020)

Here we show times series of the HWP over a 27 x 27 km box from the 3-km HRRR, averaged over the previous 4 hours. The max and min curves are the spatial max and min in the 27 x 27 km box. We plot 10 x HWP to better match the FRP values.

For this fire, the HWP indicated a period of elevated fire conditions due to strong offshore winds in the 8-9 Sep 2020 period.



Summary and Future Plans

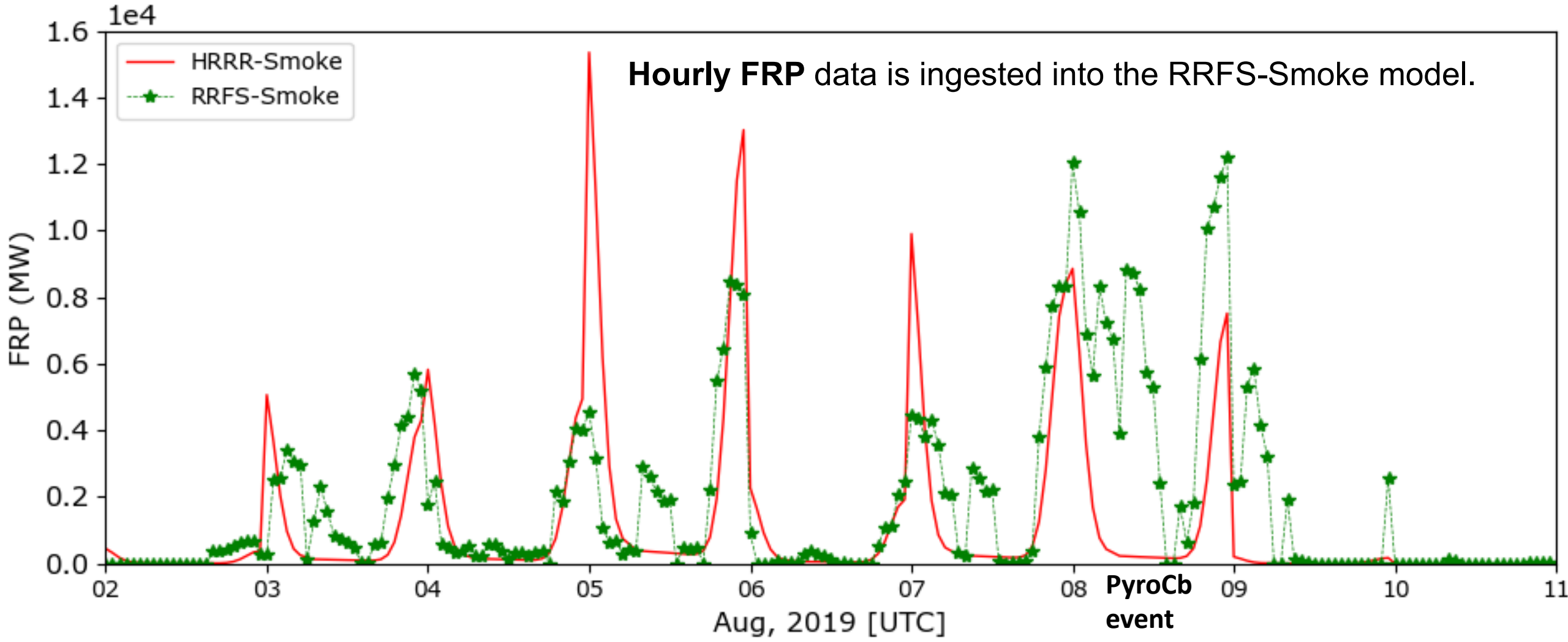
Following on the HRRR-Smoke model's successful transition to the operations a new high-resolution smoke forecast model based on the FV3 dynamical core limited area model capability is being developed at NOAA/GSL in collaboration with other research groups.

The new model covers the entire North and Central Americas at 3km resolution, which will allow to replace the 3 RAP/HRRR-Smoke domains with a single model grid.

Other advantages of the new weather-smoke forecasting model will be:

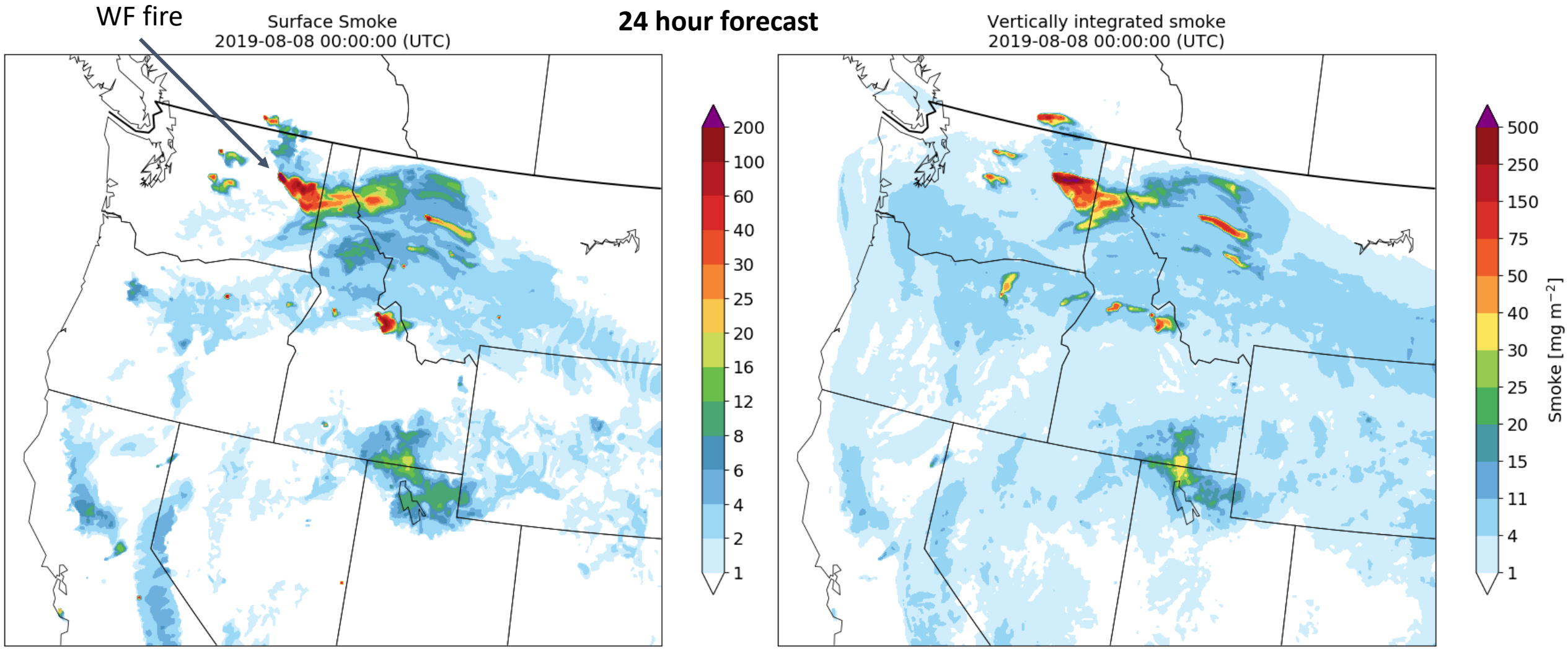
- Refined vertical grid, 65 vertical levels (*50 in HRRR*)
- Ingesting hourly GOES-16/17 ABI in addition to the VIIRS FRP data to estimate fire emissions
- Hourly Wildfire Potential diagnostic output and other fire weather capabilities
- Assimilation of the VIIRS Satellite AOD data
- Improved physics and dynamics capabilities

Time series of the hourly FRP for the Williams Flats fire

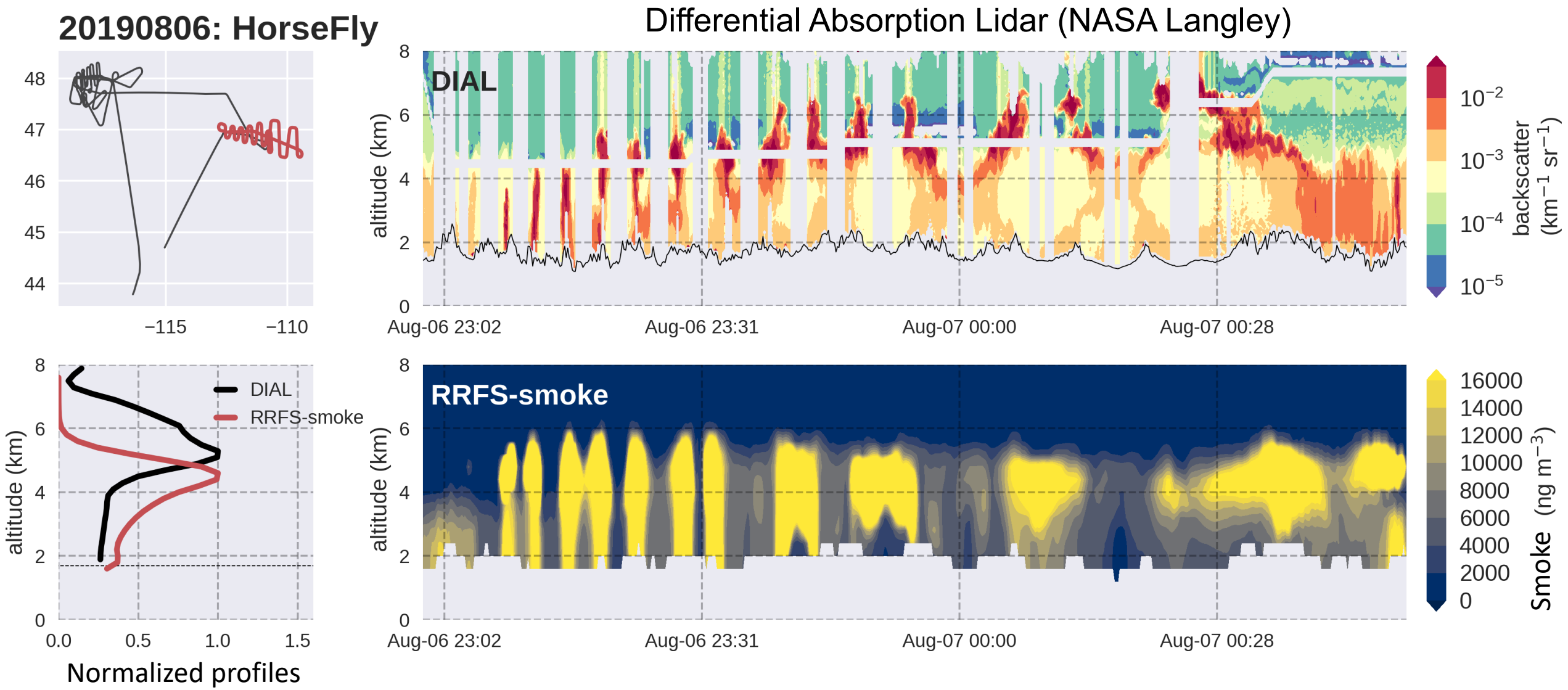


The HRRR-Smoke FRP time series is based on the VIIRS and MODIS data, and a climatological diurnal cycle.
The RRFS-Smoke FRP time series is based on the GOES-16/17 ABI and VIIRS data.

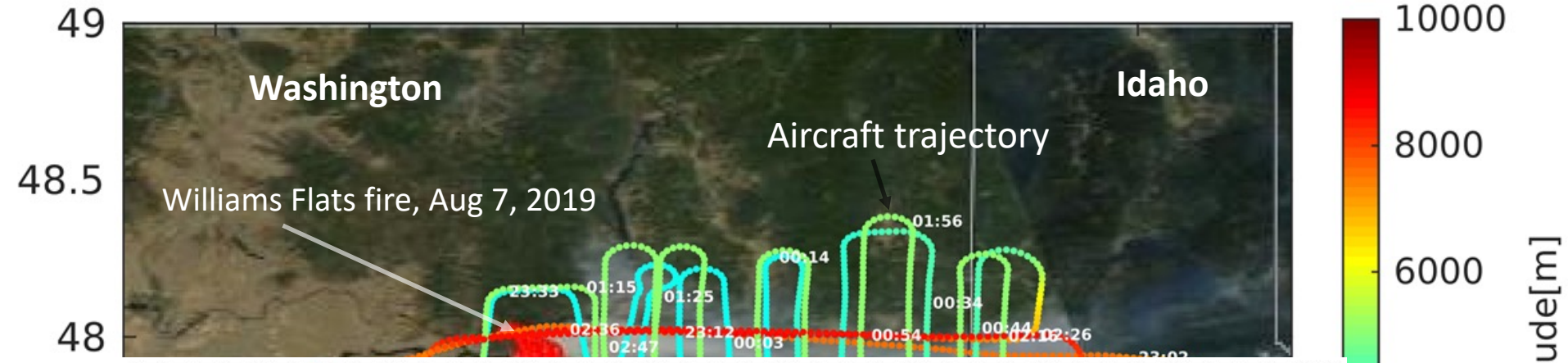
RRFS-Smoke simulations at **3km** resolution for FIREX-AQ

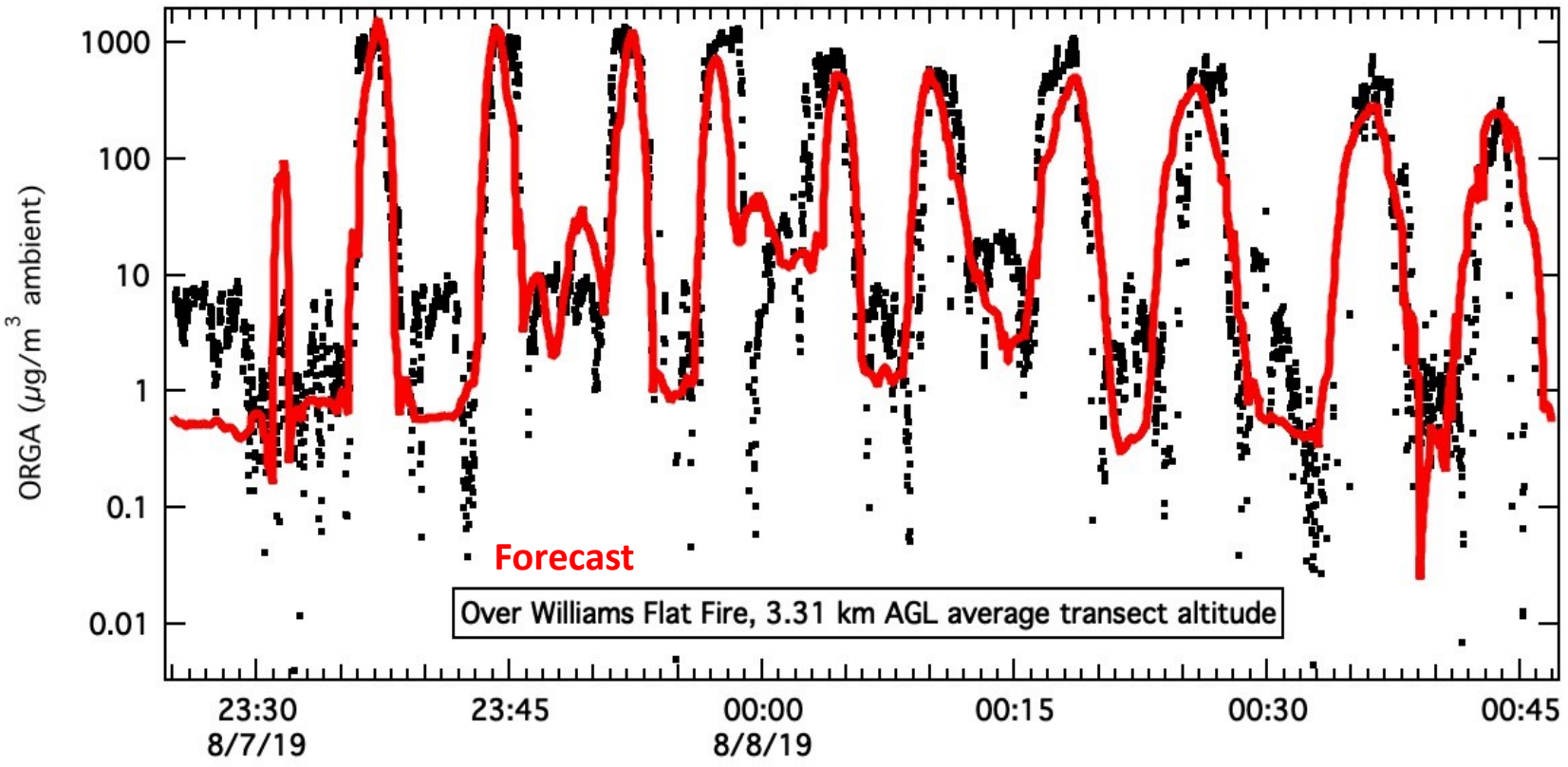


Verification of the RRFS-Smoke simulations by using the lidar measurements from FIREX-AQ (*preliminary results)*



Evaluation of the HRRR-Smoke forecasts using the FIREX-AQ aircraft measurements

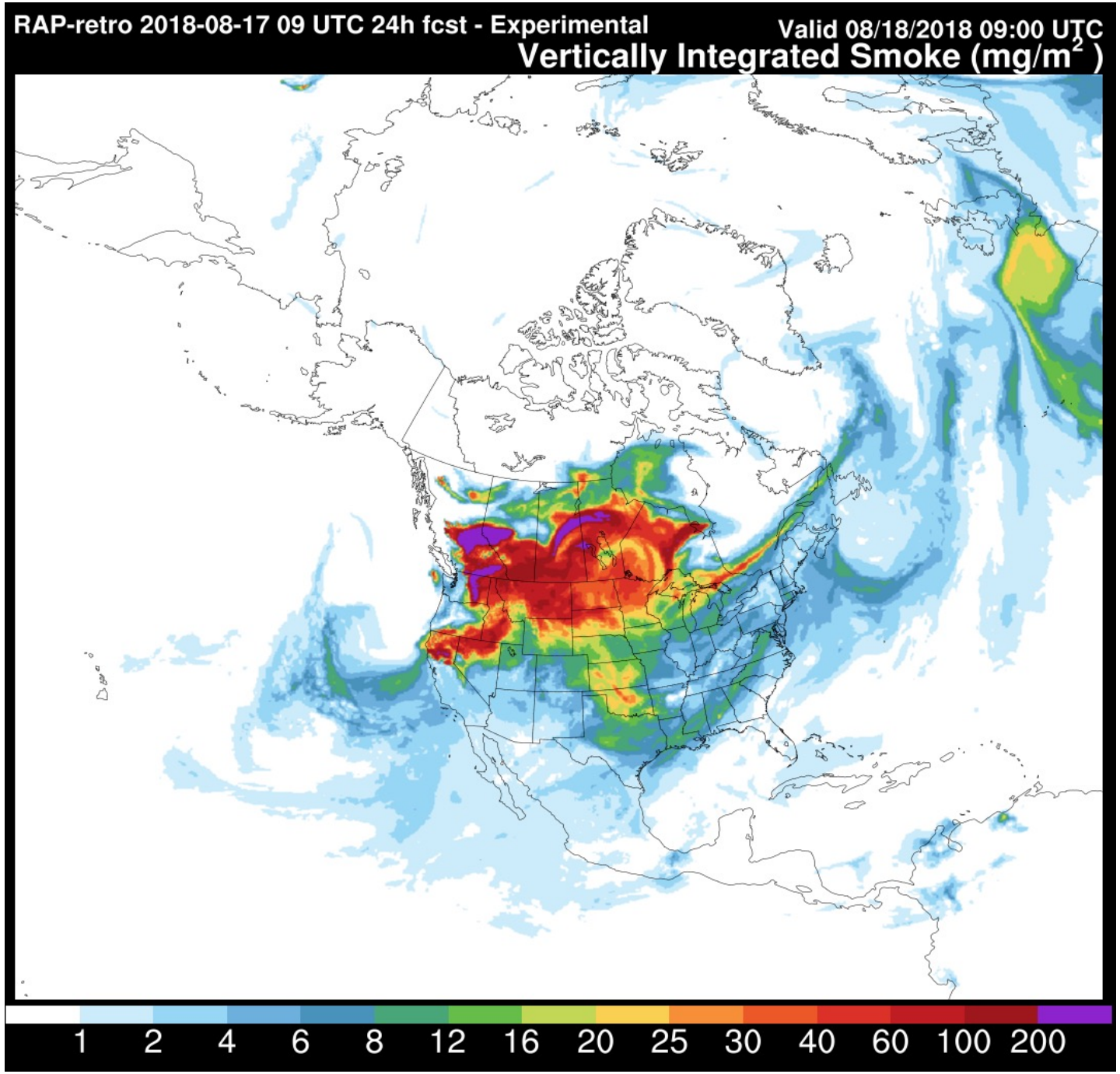




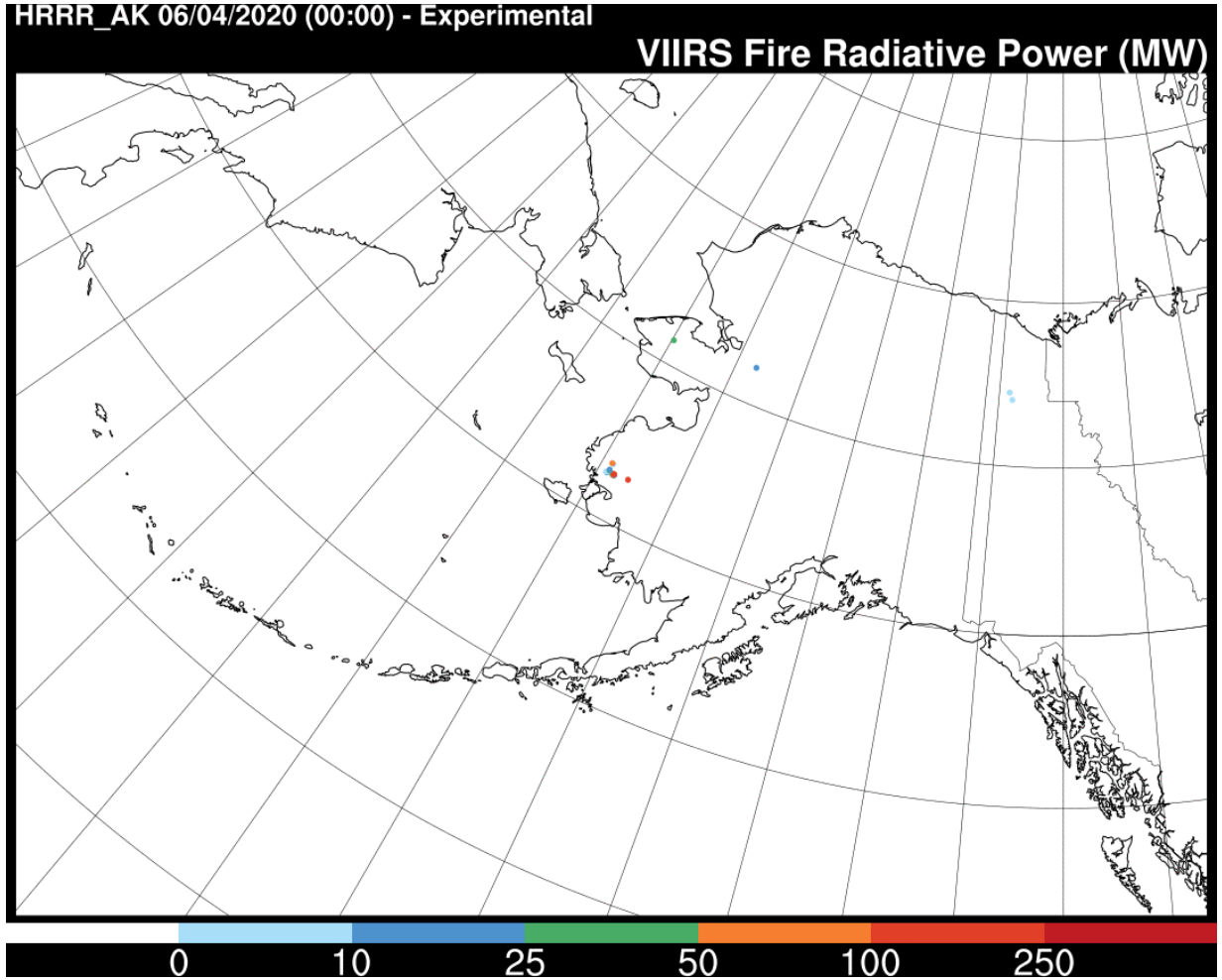
More detailed verification of HRRR-Smoke and other AQ forecast models for the Williams Flats fire can be found in *Ye et al., ACP 2021*

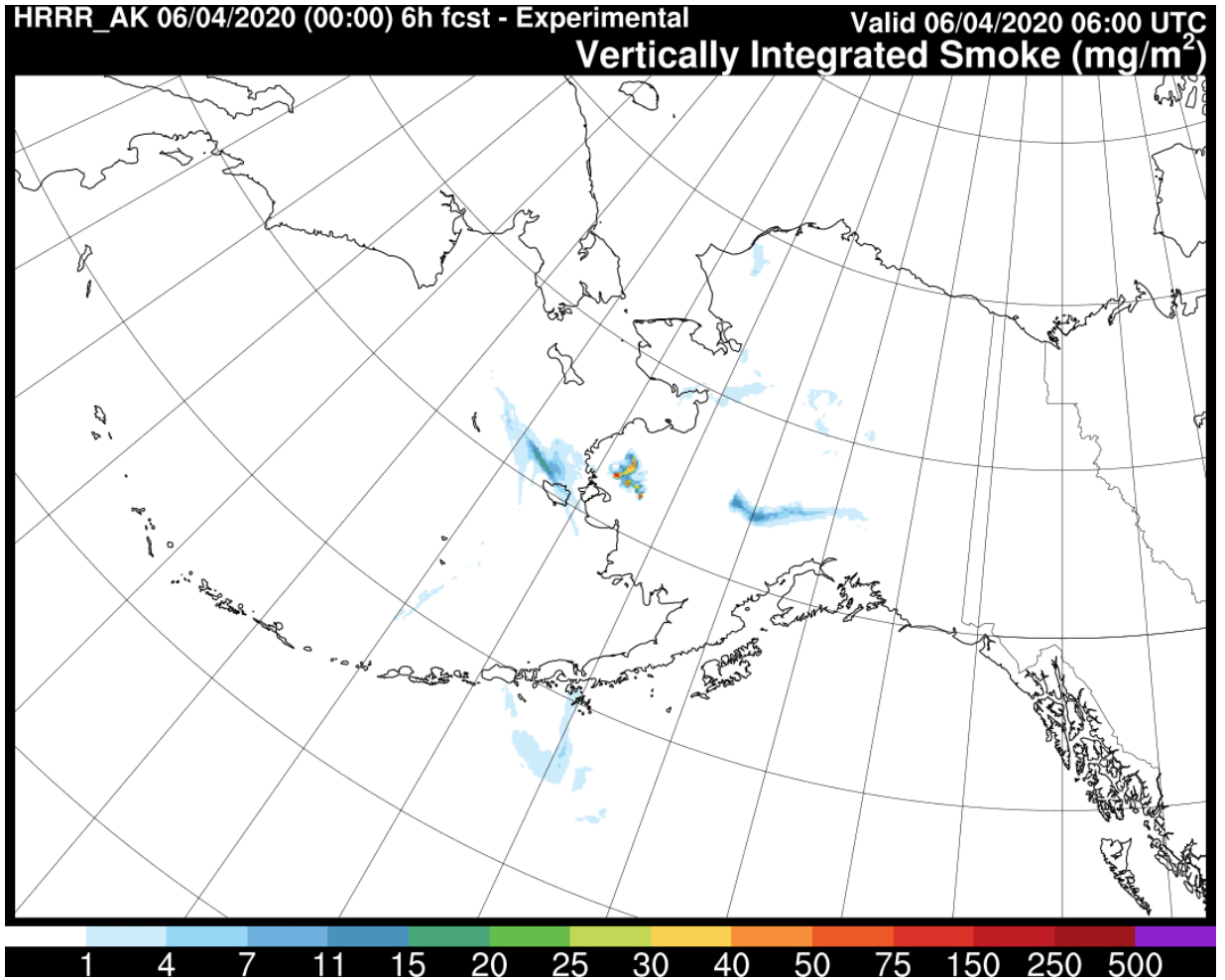
RAP-Smoke (13.5 km model resolution)
(*running since summer 2018*)

- Covers the entire North America. The products can be used for Canada, Alaska and other regions.
- The same meteorology as RAP;
- Taking advantage of the global satellite data coverage by VIIRS and MODIS;
- Feeds boundary conditions for smoke to the HRRR-Smoke over the CONUS domain;
- Enables capturing smoke transport from Canada and Mexico to CONUS;
- Forecast lead time is up to 51 hours. A new forecast starts every hour.
- The experimental smoke forecast products are displayed at: https://rapidrefresh.noaa.gov/RAPsmoke/



HRRR-AK-Smoke





https://rapidrefresh.noaa.gov/hrrr/HRRR-AKsmoke/