USE OF FIRE PRODUCTS IN THE HRRR-SMOKE MODEL

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Introduction

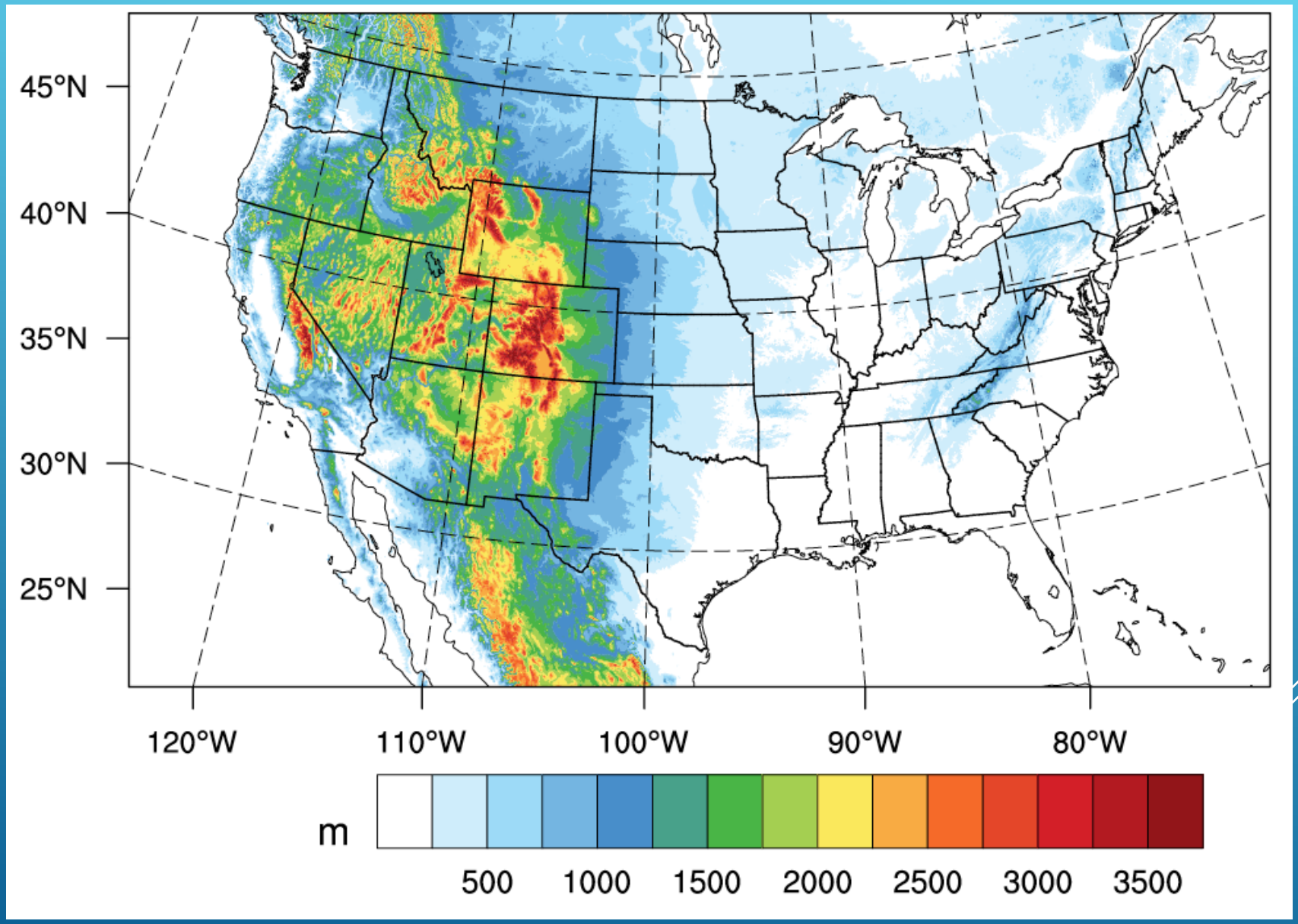
- High Resolution Rapid Refresh (HRRR) is a numerical weather prediction system running operationally at the National Center for Environmental Prediction (NCEP) and in real time at NOAA Earth System Research Laboratory/ Global Systems Division (NOAA/ESRL/GSD).
- The HRRR modeling system has been developed and tested at NOAA/ESRL/GSD. The HRRR modeling system is based on the Weather Research and Forecasting (WRF) model.
- Currently offline air quality models with relatively coarser resolution are mostly used for smoke forecast. A very few air quality models use the satellite Fire Radiative Power (FRP) data to predict fire emissions and plume rise.
- The goal of this project "**Towards the Inclusion of VIIRS Fire Products into the HRRR Real-Time Forecasts**" funded by the JPSS proving ground and risk reduction program is to include the **VIIRS products like active fire location and FRP data** into a coupled air quality model (**HRRR-Smoke**), in order to improve the numerical prediction of fire emissions and smoke dispersion in forecast models used at NOAA, also to study smoke impact on weather.
- The HRRR-Smoke model (modified version of the WRF-Chem online air quality model) configuration is based on the HRRR model with added smoke tracer emitted as fine particulate matter by biomass burning emissions (including simulation of plume rise by the model).

The Rapid Refresh and High-Resolution Rapid Refresh (http://ruc.noaa.gov)

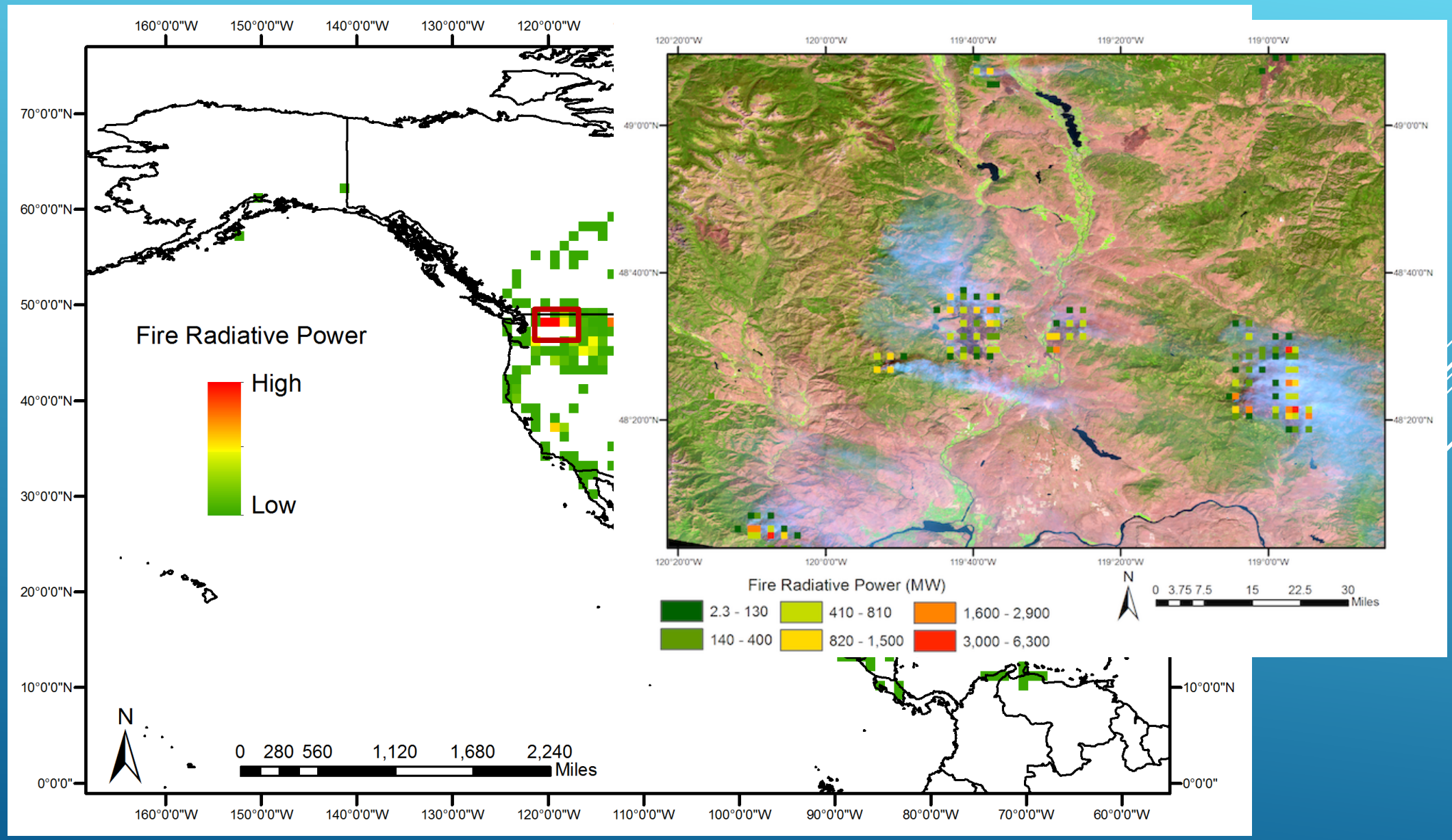
- The **Rapid Refresh (RAP)** is the continental-scale NOAA **hourly-updated** assimilation/modeling system operational at NCEP. RAP covers **North America** and is comprised primarily of a numerical forecast model and an analysis/assimilation system to initialize that model. RAP is complemented by the higher-resolution 3km **High-Resolution Rapid Refresh (HRRR)** model, which is also updated hourly and covering a smaller geographic domain.
- The **HRRR** is a NOAA real-time **3-km resolution, hourly updated, cloud-resolving, convection-allowing** atmospheric model, initialized by 3km grids with 3km radar assimilation. Radar data is assimilated in the HRRR every 15 min over a 1-h period adding further detail to that provided by the hourly data assimilation from the 13km radar-enhanced Rapid Refresh .
- The **experimental HRRR** is run by NOAA/ESRL/GSD as a real-time demonstration of advanced versions of the HRRR, ahead of the NCEP operational version. Experimental versions of the HRRR started to run in **2010** and from October 2014 onward, continuing to run more advanced versions than the NCEP operational version but with slightly lower reliability. Usually yearly upgrades are made at ESRL.
- HRRRv2 physics description in Benjamin et al. 2016, A North American Hourly Assimilation and Model Forecast Cycle: The Rapid Refresh. *Mon. Wea. Rev.***44**, 1669-1694.

HRRR CONUS domain (terrain)

3km resolution
1800x1060 pixels
50 vertical levels

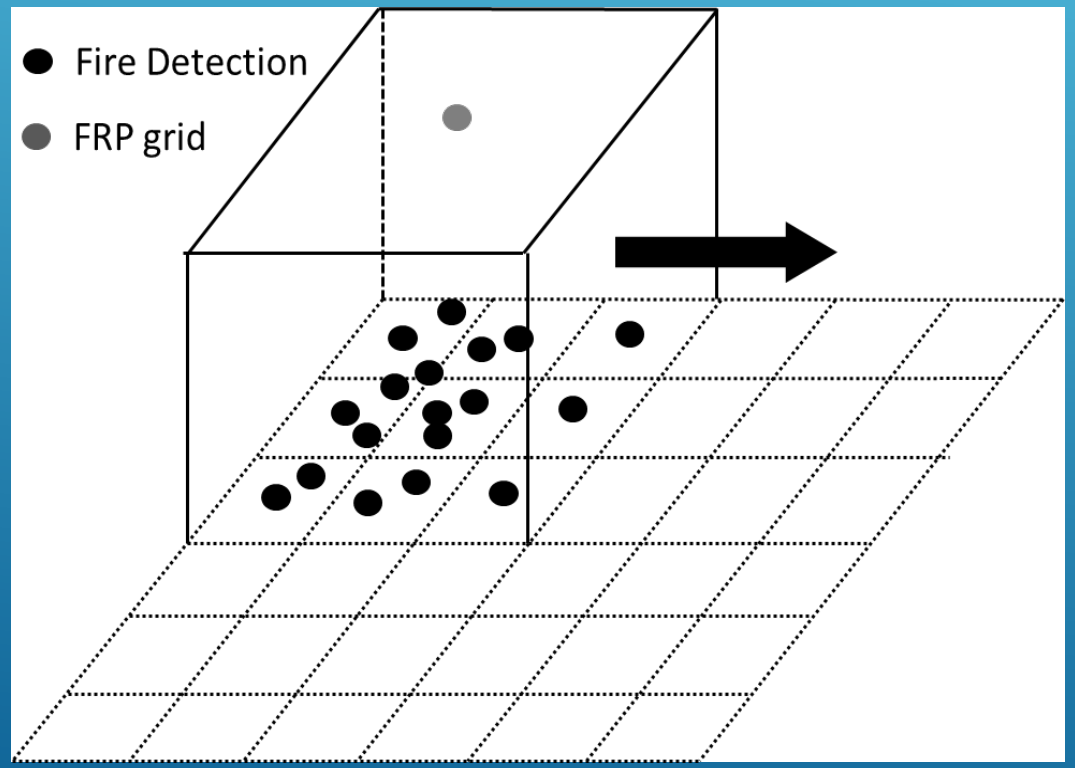


VISIBLE INFRARED IMAGING RADIOMETER SUITE (VIIRS) FRP DATA
AUGUST 15-31, 2015

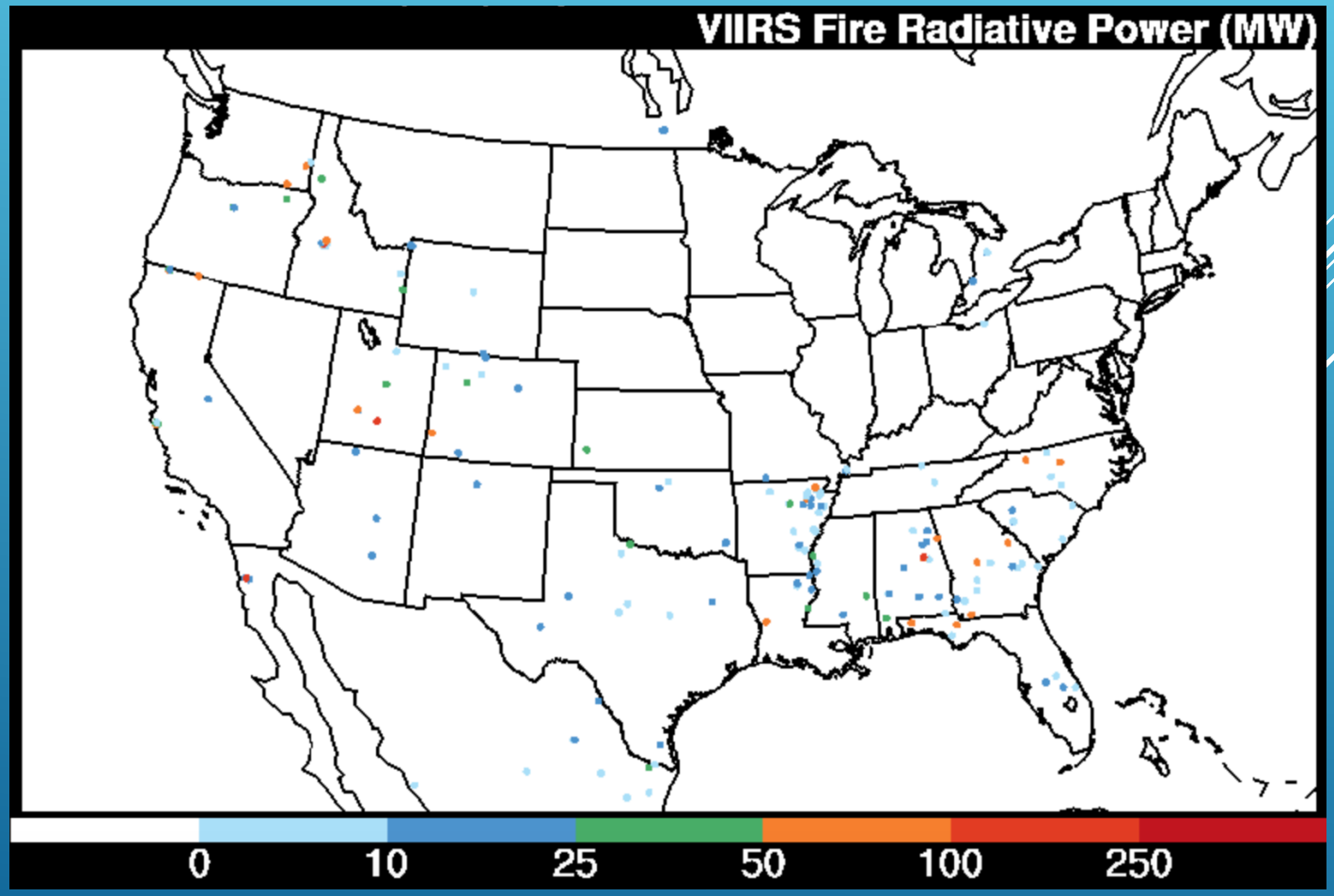


Mapping the VIIRS FRP data to the HRRR-Smoke CONUS grid

The clustering procedure performs a combination of all detected fires from VIIRS according to the model spatial resolution and grid configuration.

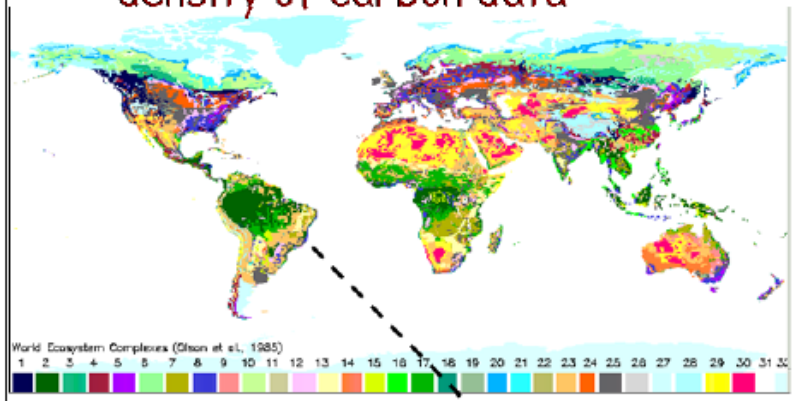


Averaged VIIRS FRP data mapped over 3x3km HRRR CONUS grid pixels for September 9, 2016

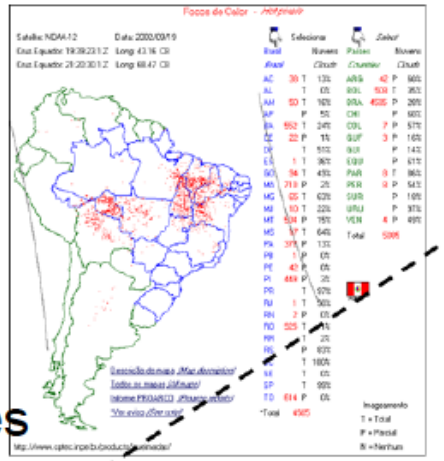


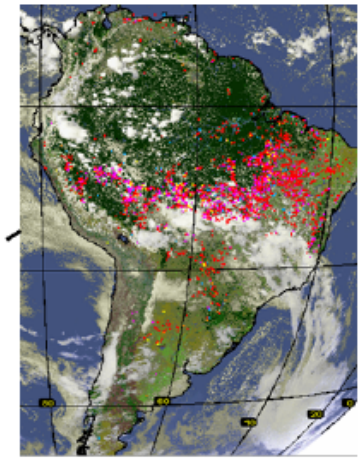
Brazilian Biomass Burning Emission parameterization used in HRRR-Smoke

density of carbon data



near real time fire product

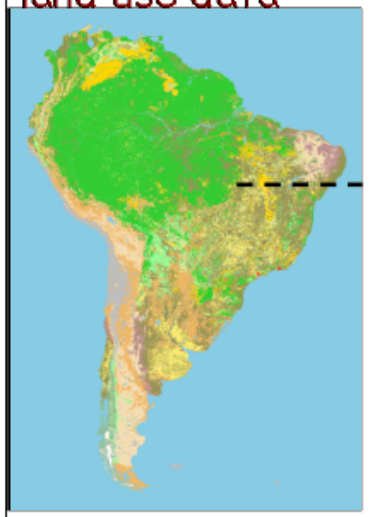


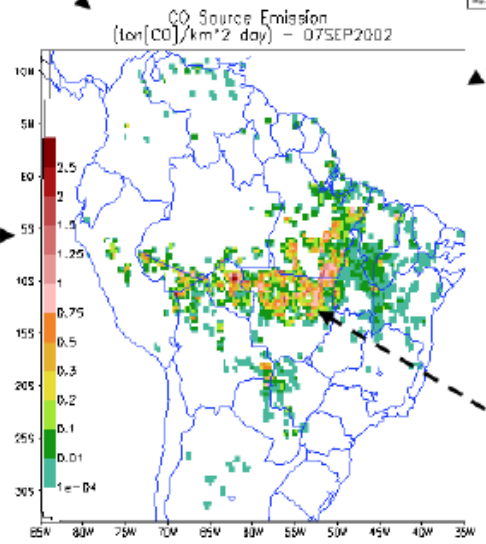


6 types of biomes

110 chemical species

land use data





Andreae and Merlet, 2001

emission & combustion factors

Biome category	Emission Factor for CO (g/kg)	Emission Factor for PM2.5 (g/kg)	Aboveground biomass density (α, kg/m^2)	Combustion factor (β, fraction)
Tropical forest[1]	110.	8.3	20.7	0.48
South America savanna[2]	63.	4.4	0.9	0.78
Pasture[3]	49.	2.1	0.7	1.00

[1] Average values for primary and second-growth tropical forests, [2] Average values for campo cerrado (C3) and cerrado sensu stricto (C4), [3] value for campo limpo (C1). All numbers are from Ward et al..

mas

$$M_{[\eta]} =$$

CO source emission (kg m^{-2}day^{-1})

M.Bela et al. (WRF-Chem tutorial)

Freitas et a

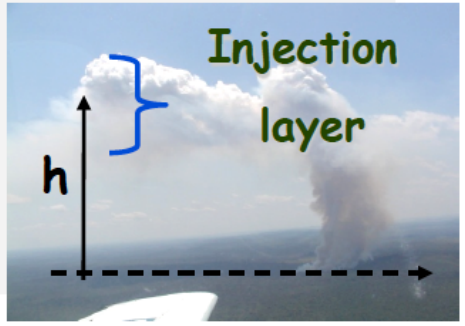
New parameterization:
BB emissions are based on the Fire Radiative Energy Calculated using Fire Radiative Power (FRP)

Smoldering and flaming emissions in HRRR-Smoke

To calculate plume rise we need to know heat flux.
The traditional approach in the model to calculate plume rise:
Use constant fire released heat flux numbers for a given land use class,
e.g. Tropical Forest: min and max heat flux = 30, 80 kW/m2

New approach:
Heat flux ~ FRP/ burnt_area
FRP measured by satellites, in this case VIIRS
Burnt_area is determined by using fire size

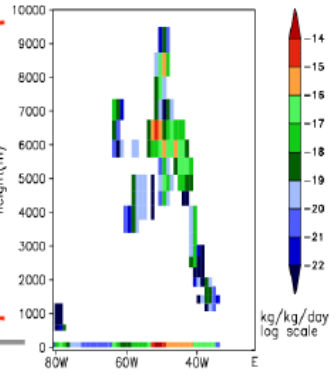
$$\text{flaming term}: E_\eta = \frac{(1-\lambda)F_\eta}{\rho_{air}\Delta z_{\text{injection layer}}}$$



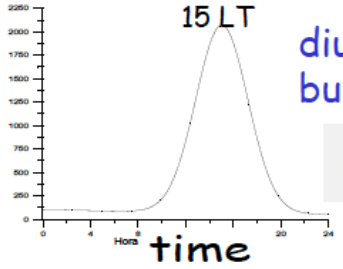
Example in the model:

flaming emission

smoldering emission



$r(t)$



diurnal cycle of the burning for S. America:

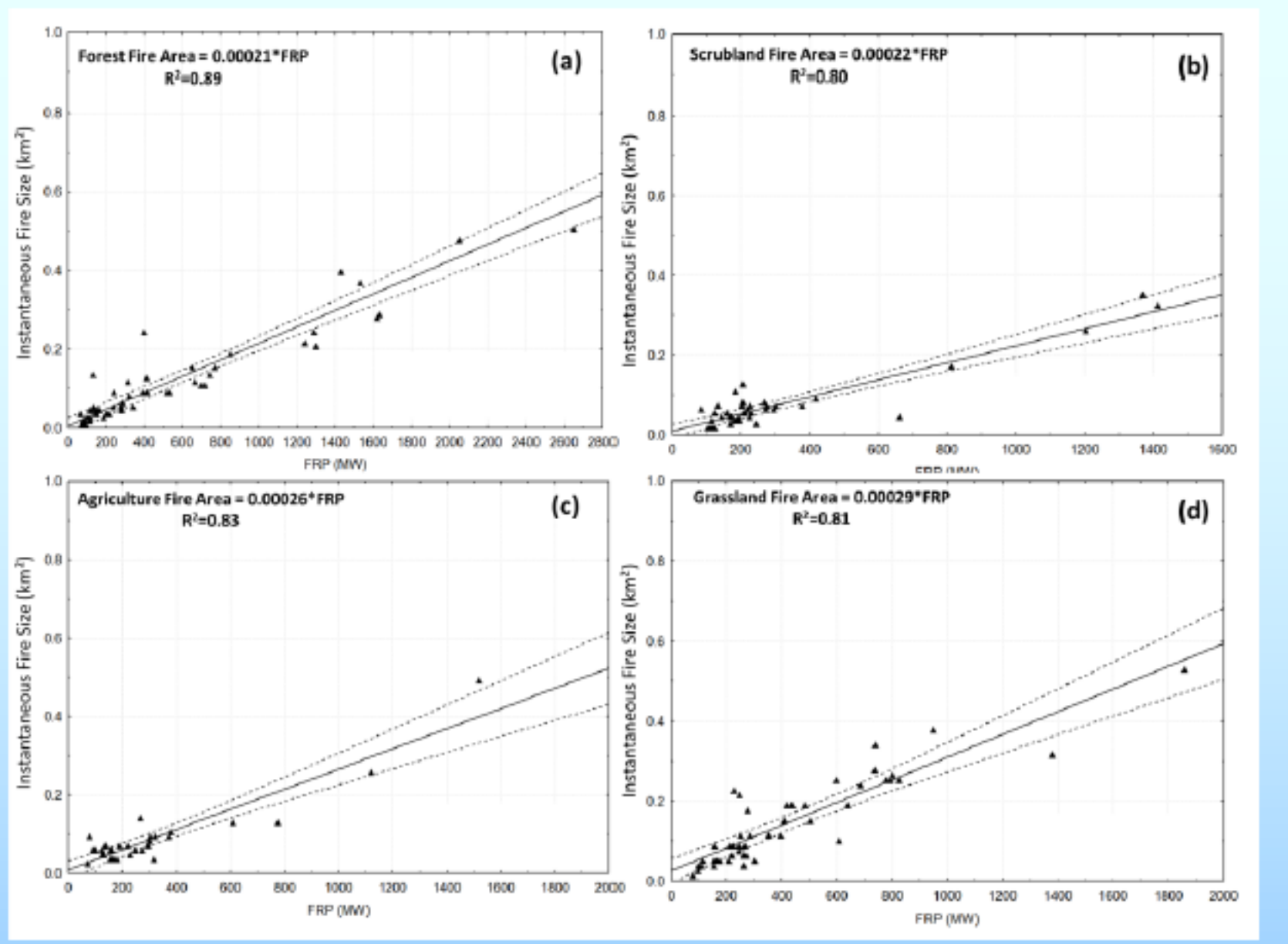
$$E_\eta(t) = r(t)E_\eta$$

Freitas et al. (2011)

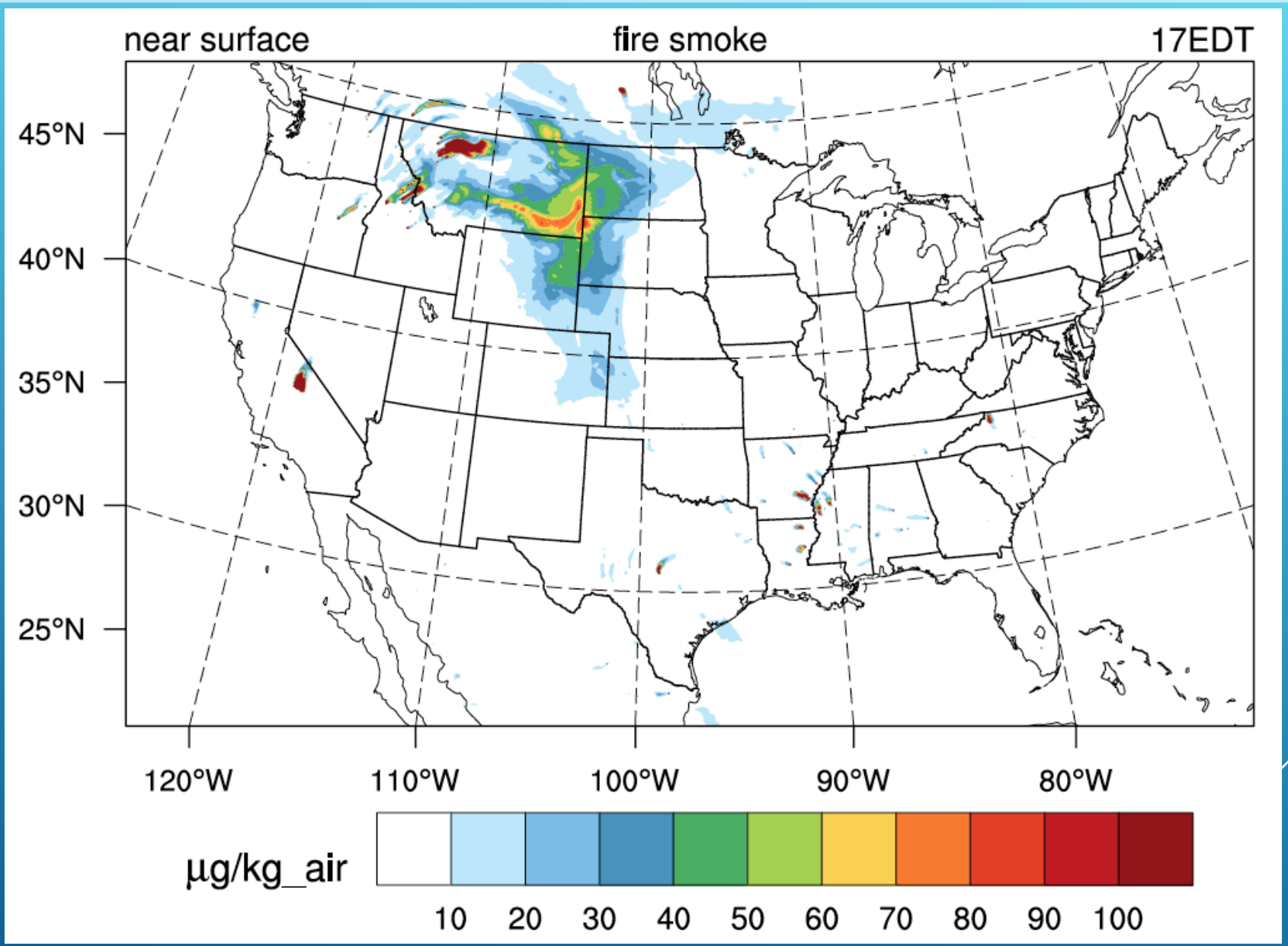
Adapted from M.Bela et al. (WRF-Chem tutorial)

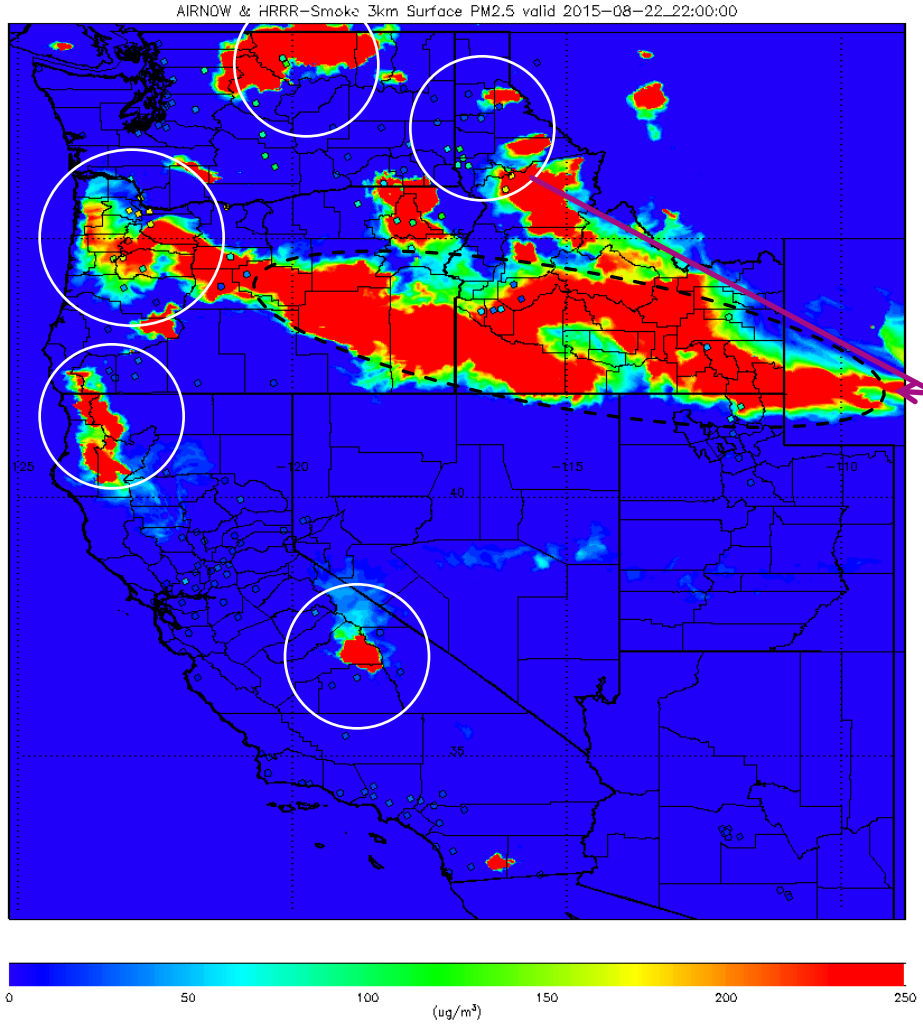
Fire size calculations using the satellite FRP data

Based on field studies in South America



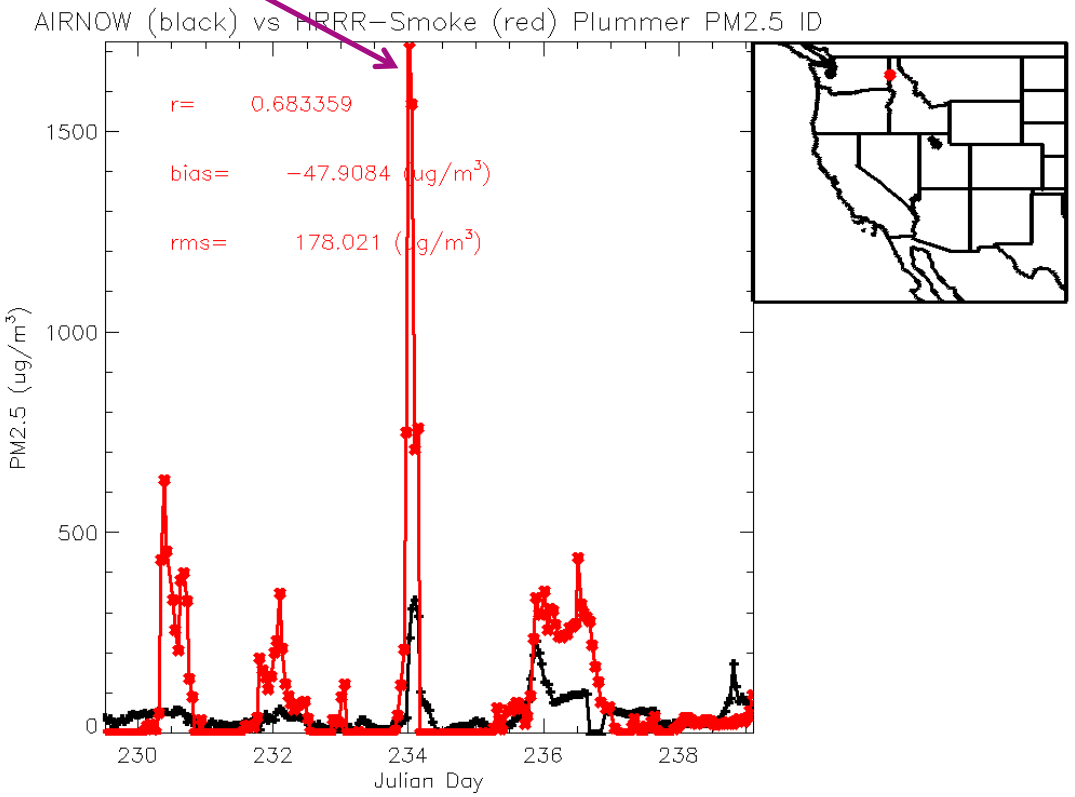
A CASE STUDY USING HRRR-SMOKE WITH VIIRS FRP DATA, AUGUST 28, 2015





HRRR-Smoke evaluations:
Old HRRR-Smoke simulation based on the traditional approach (using MODIS satellite fire detection)
22UTC August 22, 2015

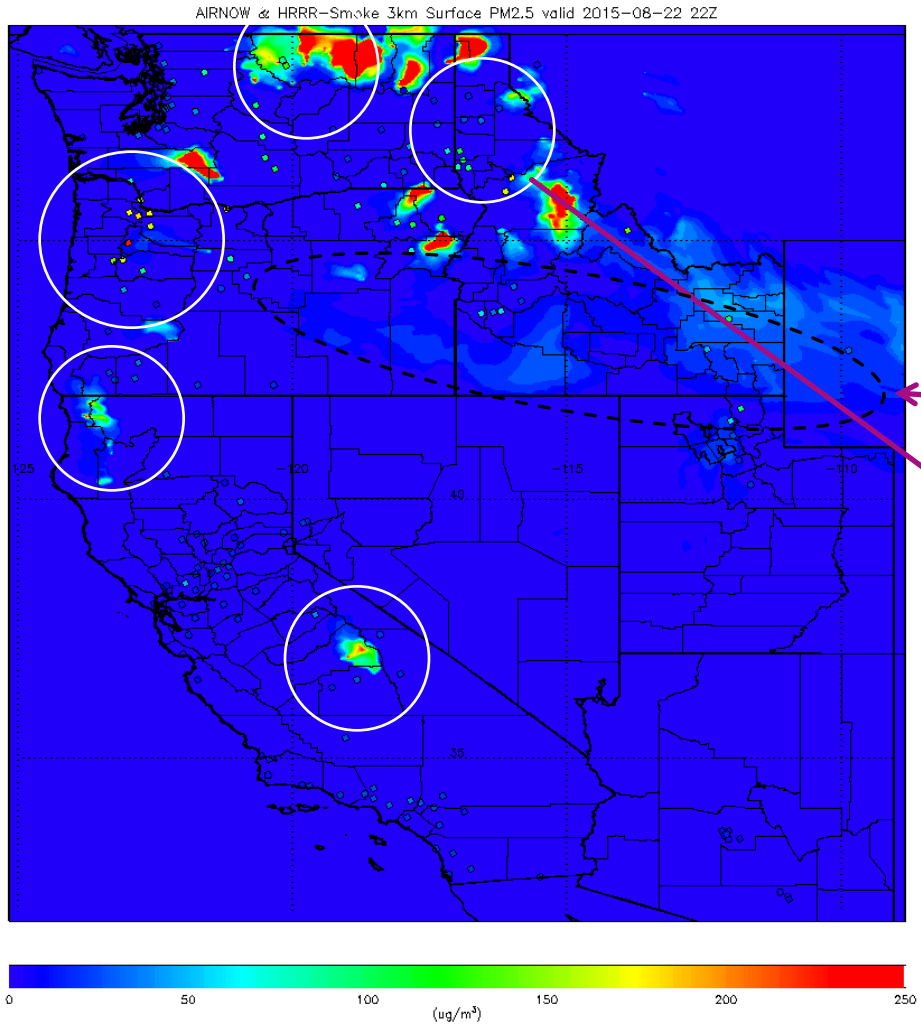
Downwind smoke plume overestimated



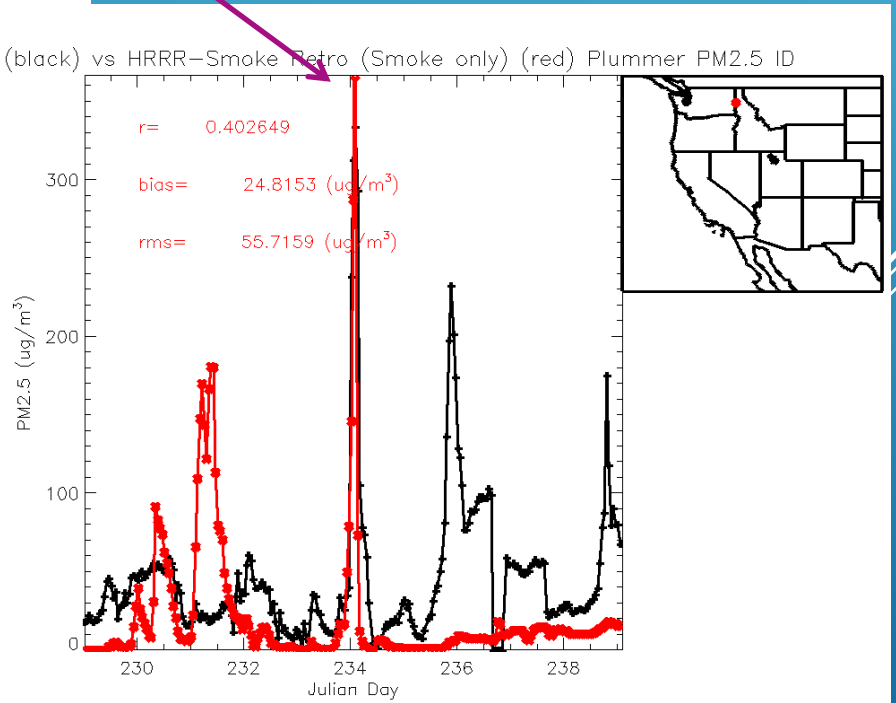
Old (CO tracer) Run
Model PM2.5 is derived from simulated CO mixing ratios
Anthropogenic emissions are not included!

HRRR-Smoke evaluations:

New HRRR-Smoke simulation using VIIRS FRP, 22UTC August 22, 2015



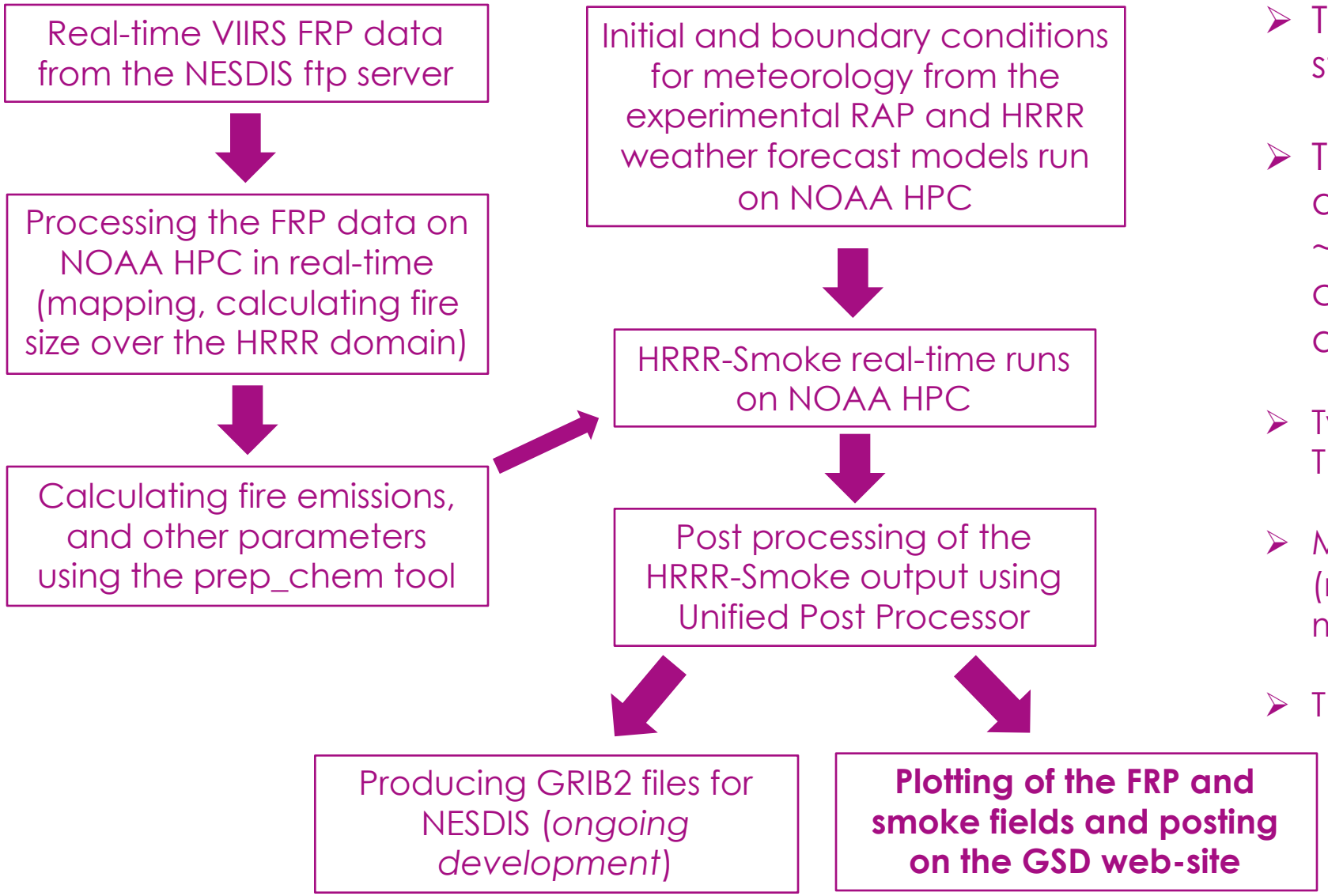
Downwind smoke plume significantly reduced!



New (smoke and primary tracer) Run

Bias=AIRNow - Model

Workflow of the real-time HRRR-Smoke modeling system



- The **experimental HRRR-Smoke** started in June, 2016.
- The system is run 4 times a day at 00, 06, 12 and 18 UTC. It takes ~4 hours to complete entire cycle. Forecast plots are posted as simulations progress.
- Two NOAA HPC systems (Jet and Theia) are used.
- Multiple real-time datasets (meteorological observations, GFS model output, satellite…) are used.
- The forecast lead time is **36 hours**.

The real-time HRRR-Smoke web-site (rapidrefresh.noaa.gov/HRRRsmoke)

HRRR Model Fields - Experimental

Model: HRRR-smoke (Experimental) Area: NW Date: 14 Sep 2016 - 06Z

*** Experimental, Not for Official Guidance *** - see description. Alaska Version

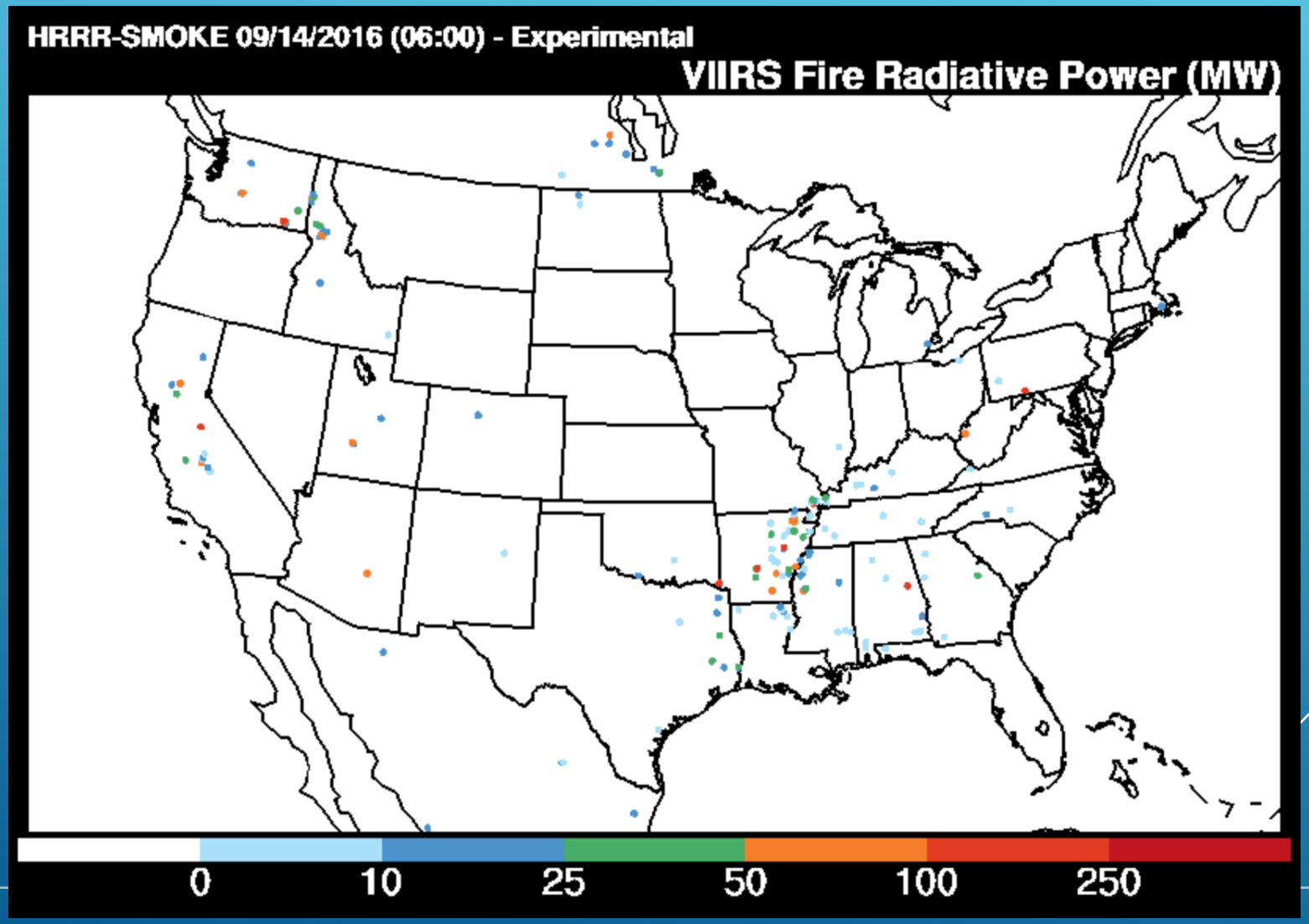
Model: HRRR-smoke (Experimental) **Domain:** NW **Date:** 14 Sep 2016 - 06Z

CONUS
NW
NC
NE
SW
SC
SE
Great Lakes
NE CO
SEA
SFO
MKX
OKX
IAD
MIA
ATL

	All times	Loop	Wed 06	Wed 07	We 08	ed 11	Wed 12	Wed 13	Wed 14	Wed 15	Wed 16	Wed 17	Wed 18
			00	01	02	05	06	07	08	09	10	11	12
all fields			00	01	02	05	06	07	08	09	10	11	12
fire radiative power	✔	✔	00	01	02	05	06	07	08	09	10	11	12
near-surface smoke	✔	✔	00	01	02	05	06	07	08	09	10	11	12
vertically integrated smoke	✔	✔	00	01	02	05	06	07	08	09	10	11	12

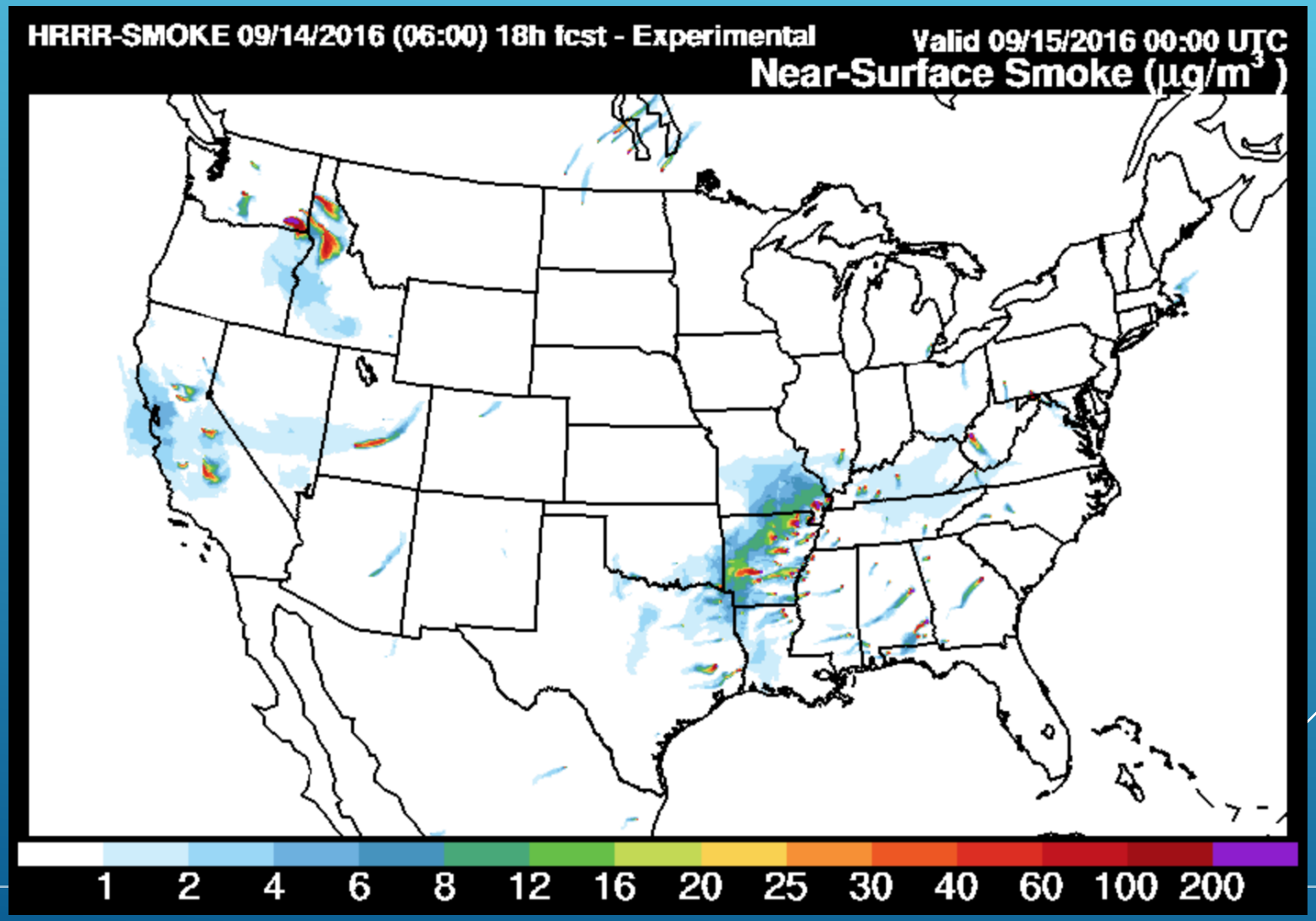
The “Fire Radiative Power” plots (rapidrefresh.noaa.gov/HRRRsmoke)

The FRP data are processed during HRRR-Smoke initialization by processing FRP for the model domain detected during previous 24 hours by VIIRS. Then the model simulates fire emissions and plume rise using the static FRP fields for 36 hours of smoke forecast. The following plot shows processed FRP values from VIIRS for the model grid cells (each size of 3x3 km) containing fires for 6Z September 14th, 2016 experimental smoke forecast.



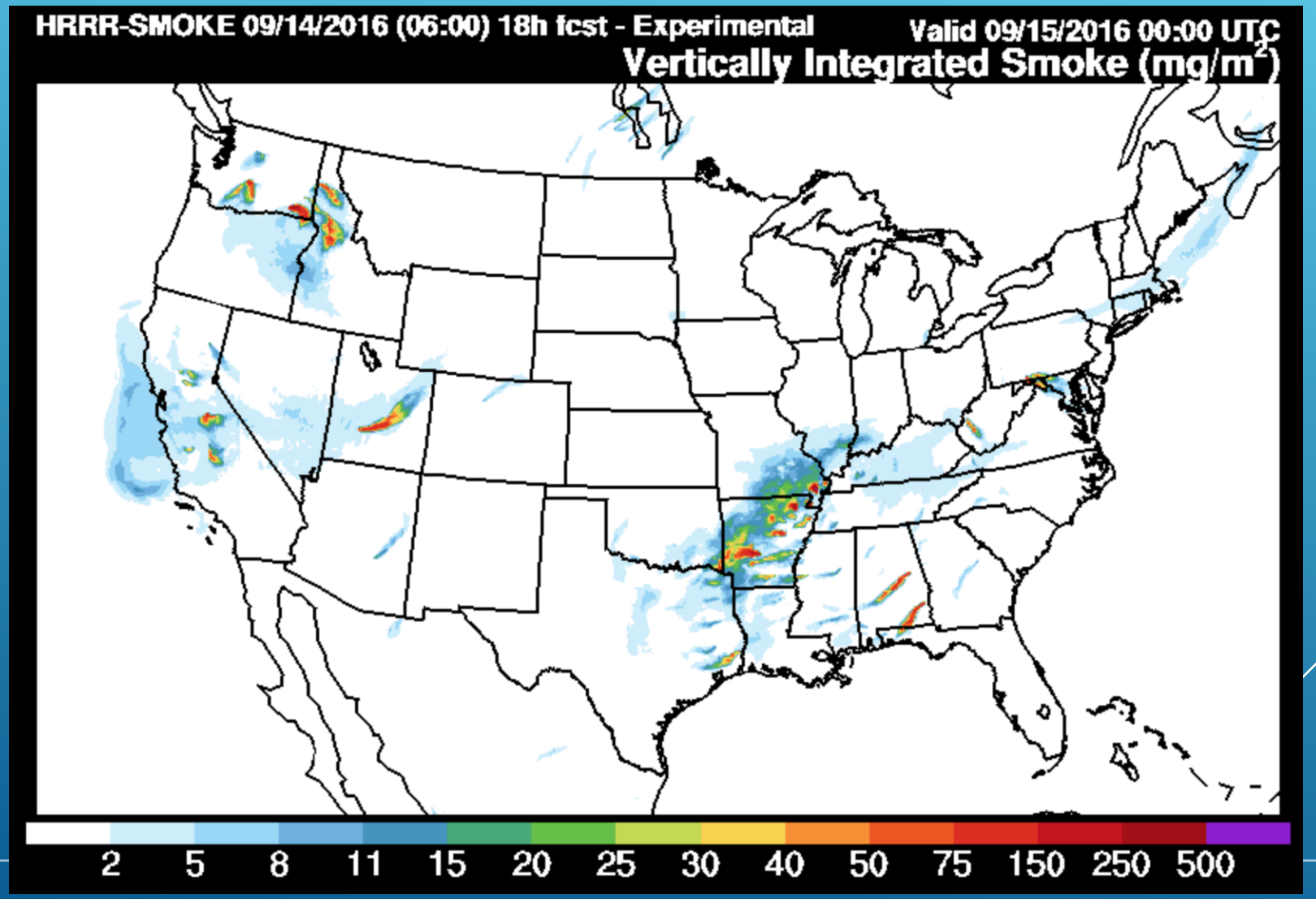
The “near surface fire smoke” plots (rapidrefresh.noaa.gov/HRRRsmoke)

This plot shows simulated fire emitted fine particulate matter (PM2.5 or fire smoke) concentrations at the first model level (~8m above ground). The following plot shows forecast of near-surface fire smoke for Sep 14th, 8pm EDT over the CONUS domain. This forecast is based on the model simulation of 18 hours from the model initialization time, which is 2am EDT, Sep. 14th.

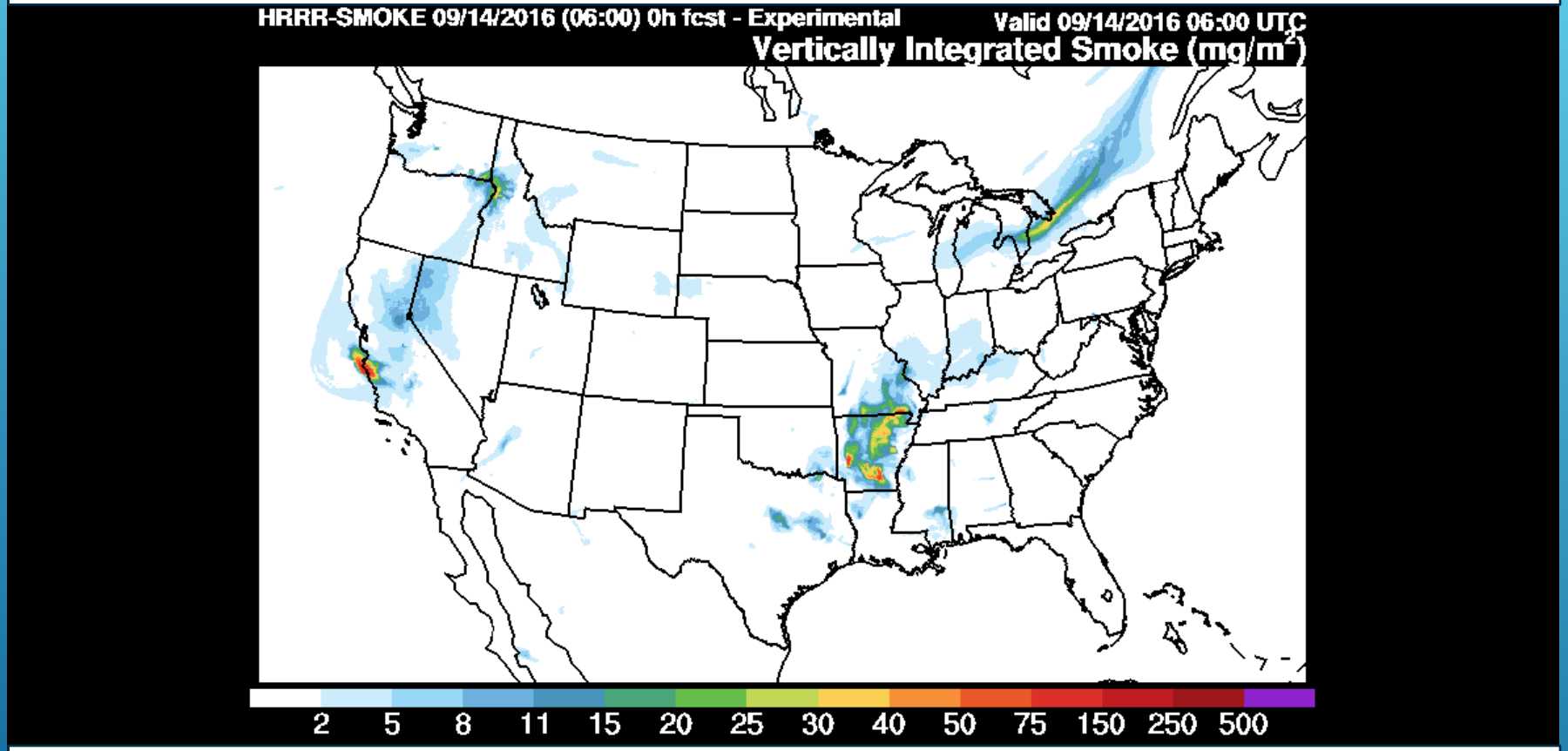


The “vertically integrated fire smoke” plots (rapidrefresh.noaa.gov/HRRRsmoke)

This plot shows simulated total PM2.5 mass within vertical columns over each model grid cell (or fire smoke). These columns reach as high as ~25 km above ground. The purpose of showing such plots is to display the effect of fire smoke load which includes smoke in boundary layer as well as aloft, illustrating the integral effect of fire smoke throughout the atmosphere. The following plot shows a forecast of vertically integrated fire smoke for Sep 14th 8pm EDT.



The HRRR-Smoke web-site (rapidrefresh.noaa.gov/HRRRsmoke)
Animating smoke plots using the "loop" feature

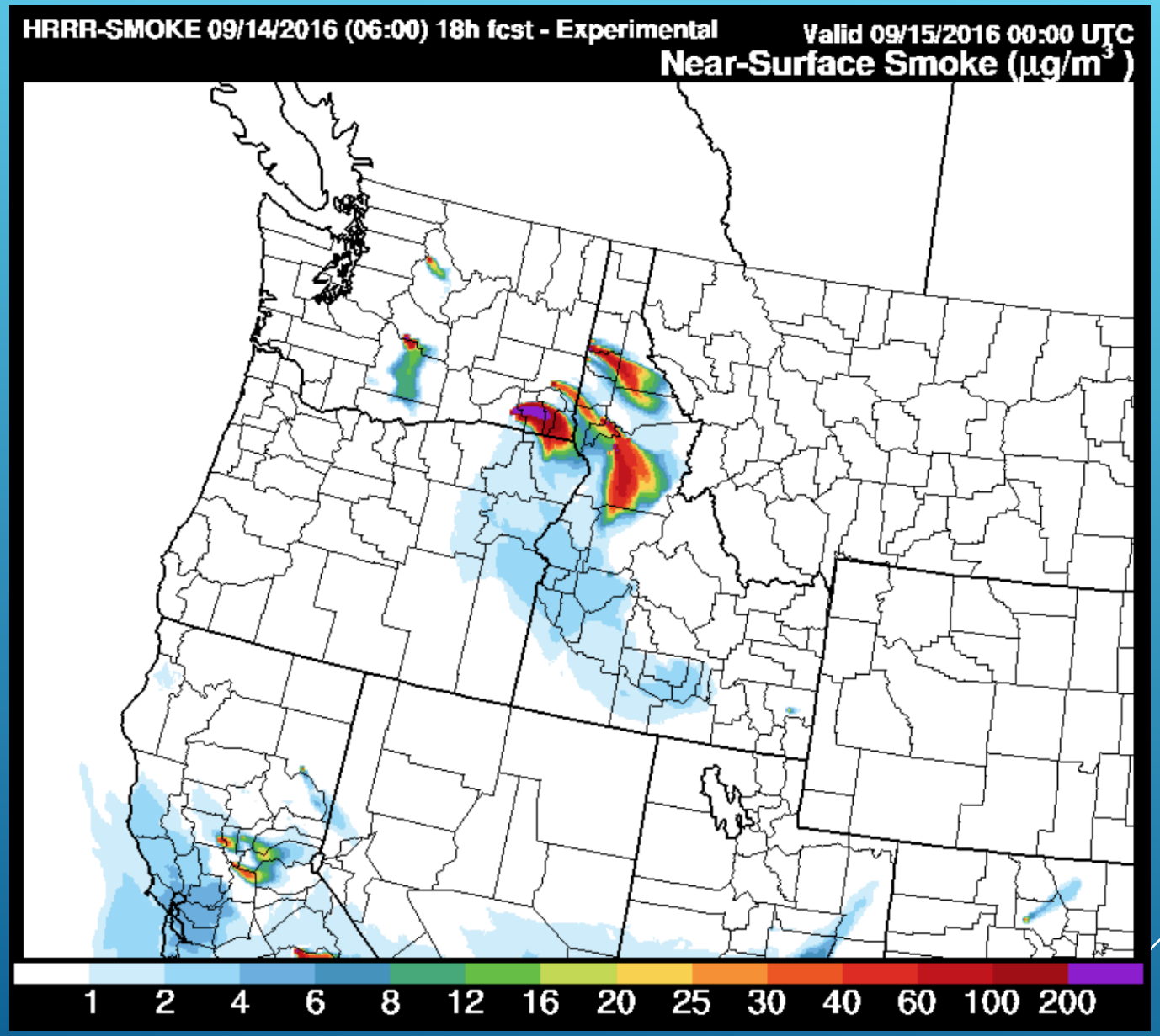


Sub-domains shown on the HRRR-Smoke web-site (rapidrefresh.noaa.gov/HRRRsmoke)

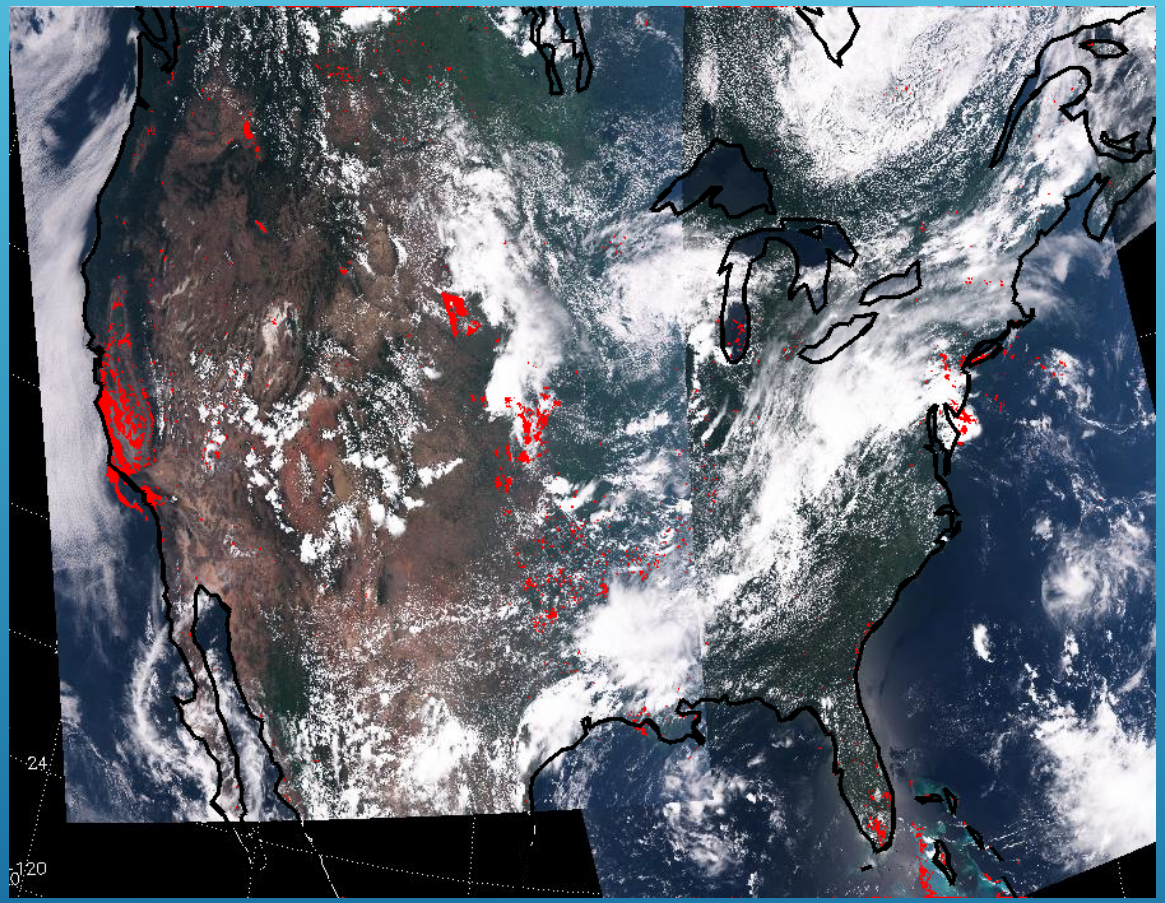
Zooming on different parts of the CONUS domain:

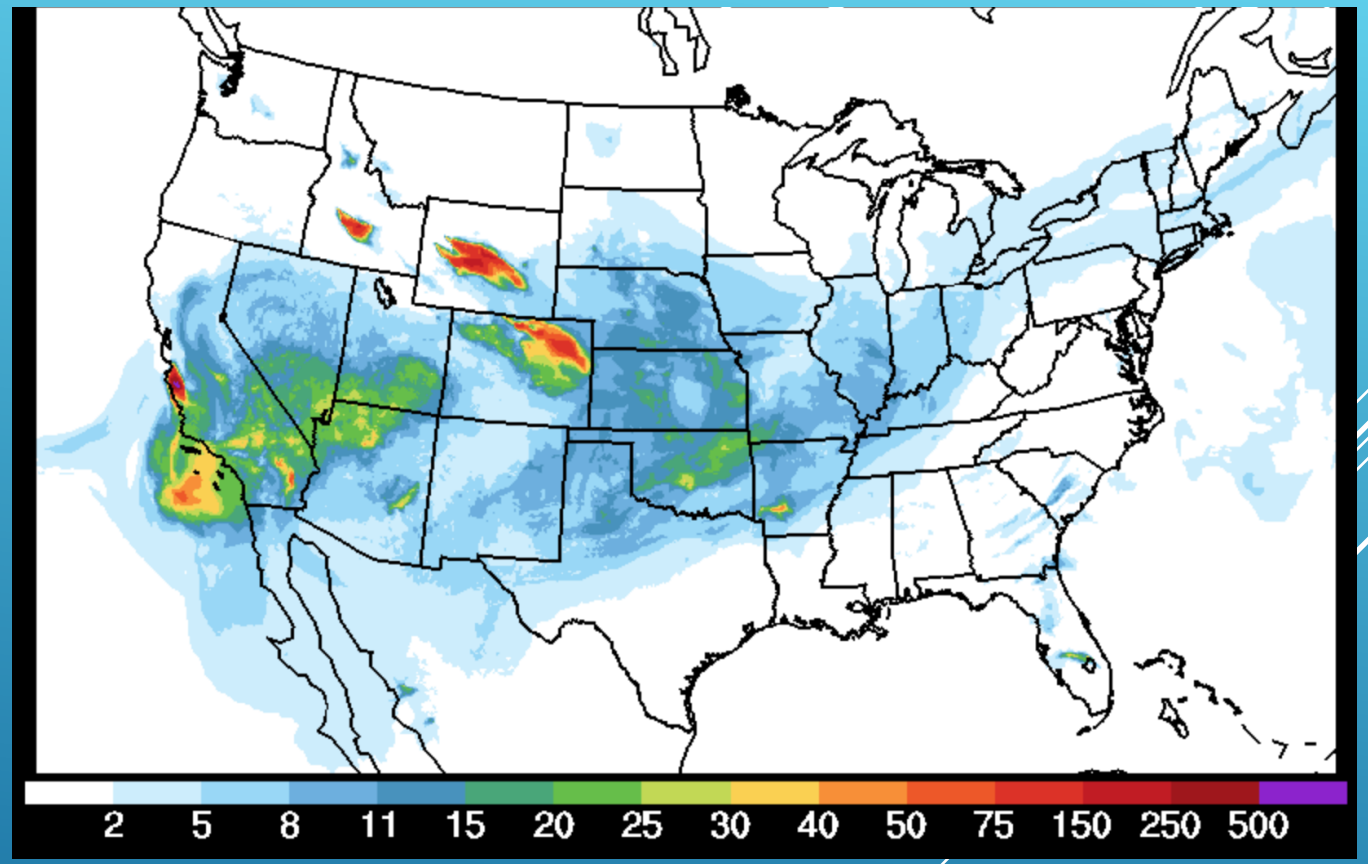
NW sub-domain

Forecast for today 6pm MDT



VIIRS smoke mask and HRRR-Smoke forecast for vertically integrated smoke, July 28 2016





Summary and future plans

- The HRRR-Smoke modeling system has been running in real-time at NOAA/ESRL/GSD providing users with 36 hourly smoke predictions in high spatial resolution.
- We have been getting valuable feedback from various users – IMETs, regional National Weather Services on the real-time HRRR-Smoke products.

- We plan working on better characterization of the diurnal cycle of fire emissions.
- Add another fire satellite detection data (MODIS)
- Study smoke impact on numerical weather prediction
- Synergy with other smoke forecast models: NAM-CMAQ, Blue Sky…
- Explore feasibility of HRRR-Smoke becoming an operational forecasting system at NCEP