

Updates on AIRPACT-Fire: A Weather Driven Wildfire Emission Forecasting System & HRRR Based Smoke Nowcasting System

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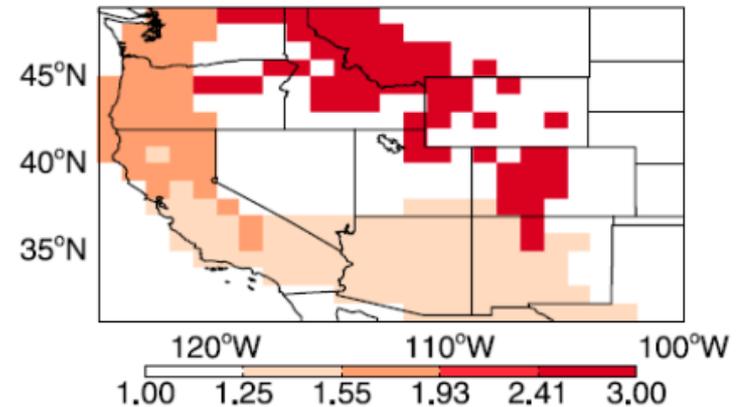
NW AIRQUEST Annual Meeting, Richland WA

15 June, 2017

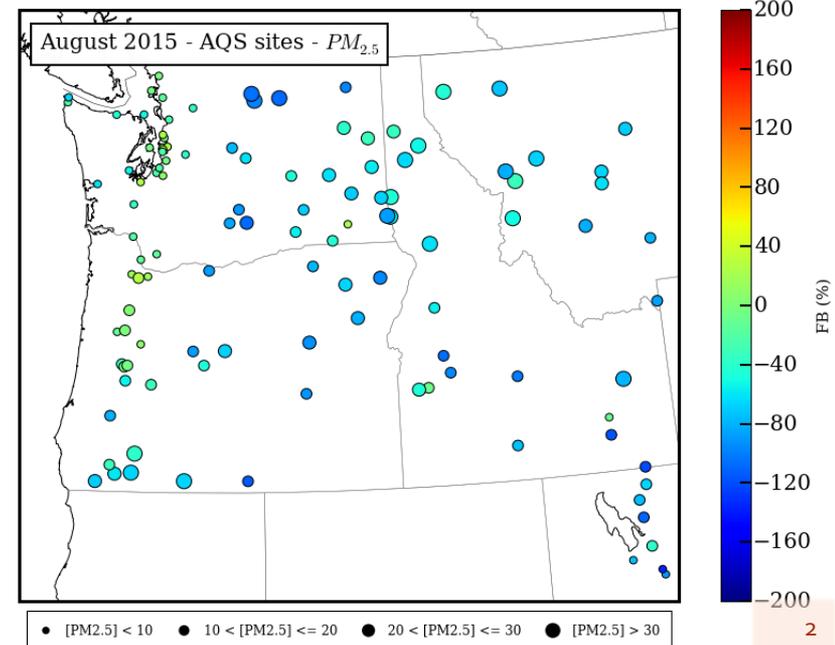
Motivation

- Wildfire activity is predicted to increase in the future – longer fire season and more emissions
- Smoke from wildfire can significantly degrade air quality, often pushing the Air Quality Index (AQI) to poor categories indicating its impact on human health
- Biomass burning can be a major cause of premature mortality in several regions of the world – 5% in US to 27% in Indonesia (Lelieveld et al., 2015)
- These highlight a greater need to accurately forecast air quality impacts, but current forecasting systems significantly under-predict $PM_{2.5}$ in wildfire seasons

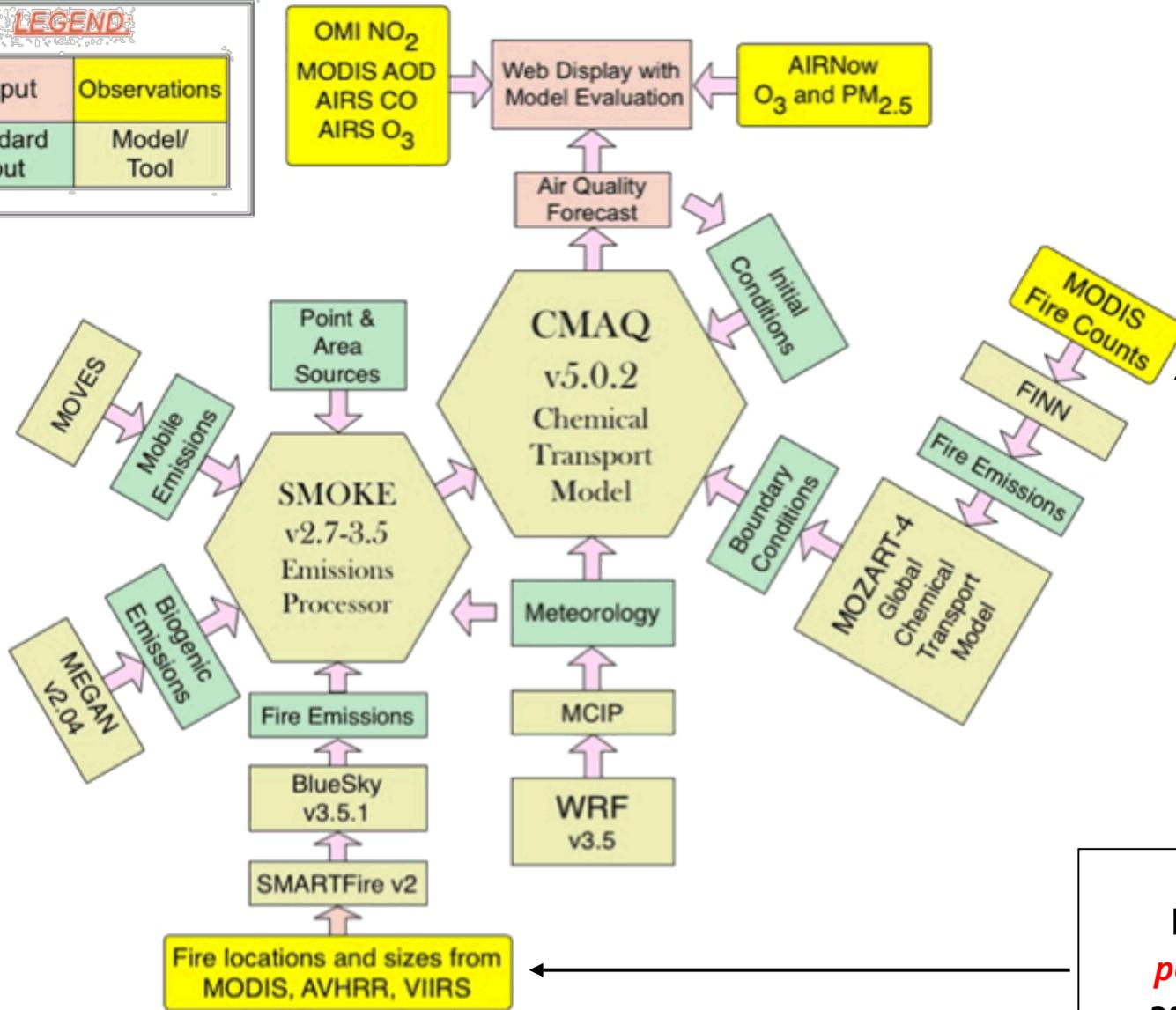
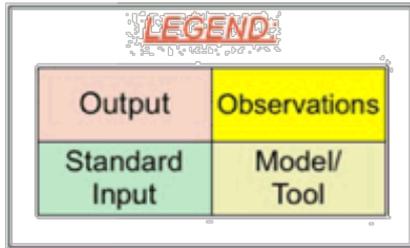
Ratio of predicted area in 2046-50 compared to 1996:2005



(Spracklen et al., 2009)



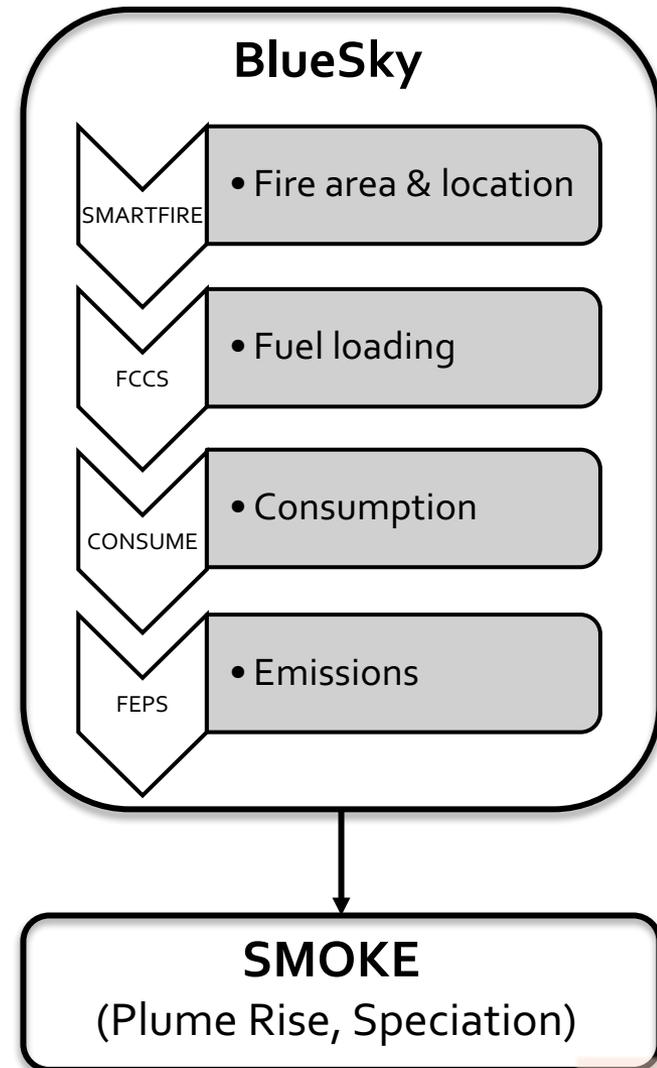
AIRPACT-5 Air Quality Forecasting System



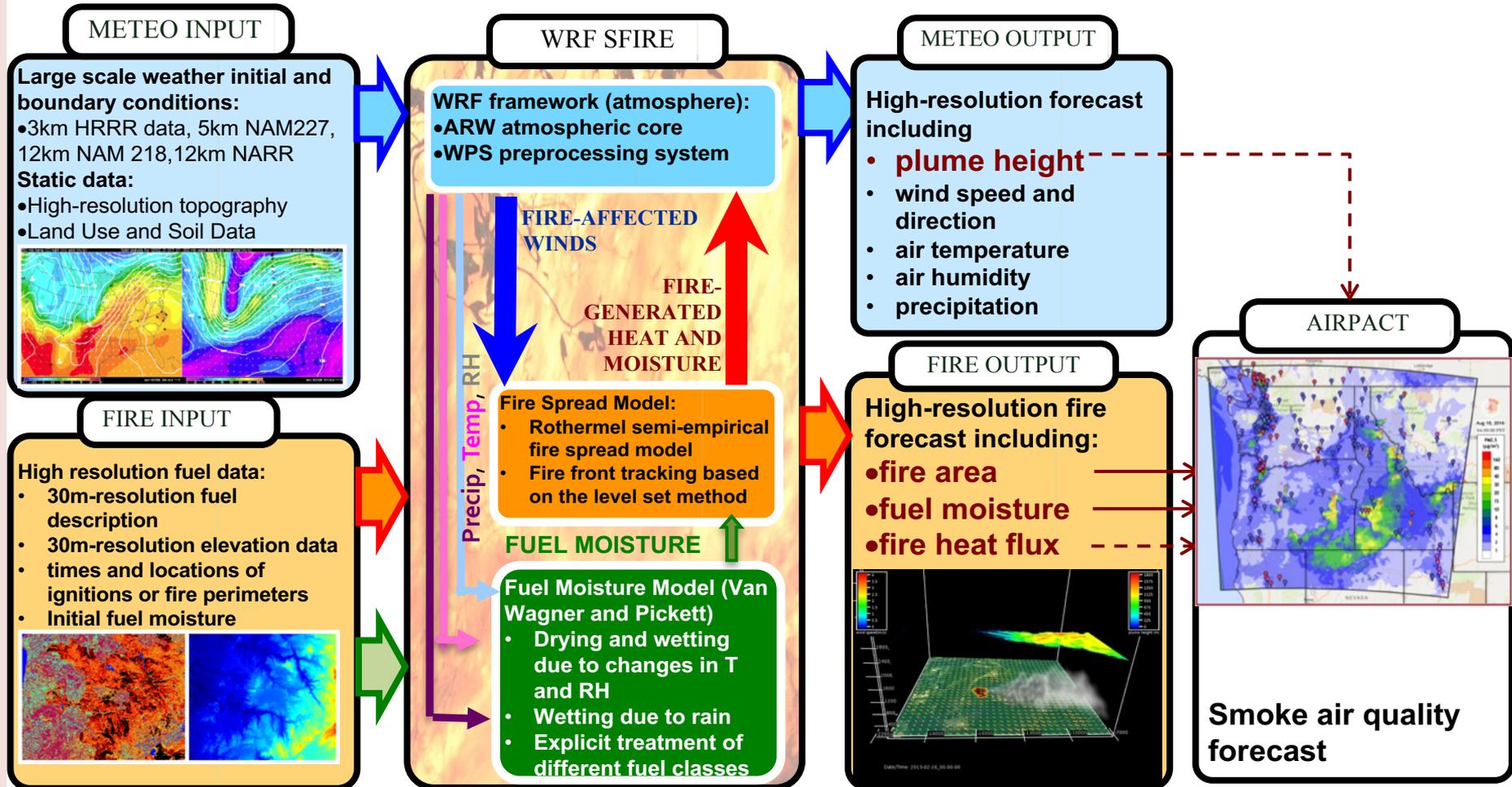
Fire area based on *persistence* assumption

Current Treatment of Fire Emissions

- Emissions of different pollutants depend on the fire area.
- However, there is no fire progression data on hourly basis, therefore a *persistence* assumption is used - meaning the fire area to burn tomorrow is assumed to be equal to today's satellite derived burn.
- This can introduce huge errors in emission calculation, since fires may progress significantly (1000s of acres in a single day).
- Additionally, no influence of fire on weather is accounted for in such a '*persistence*' assumption.

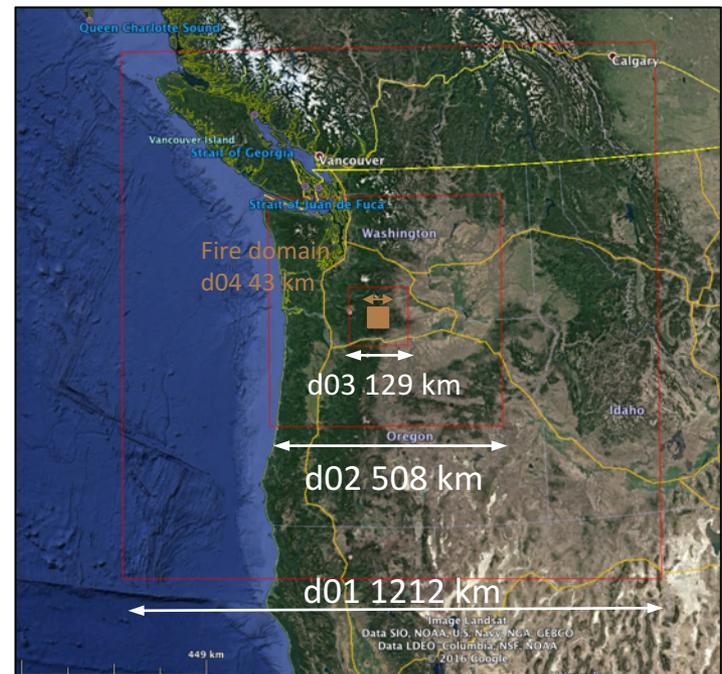


Coupled fire-atmosphere model (WRF-SFire) feeding an AQ model (AIRPACT)



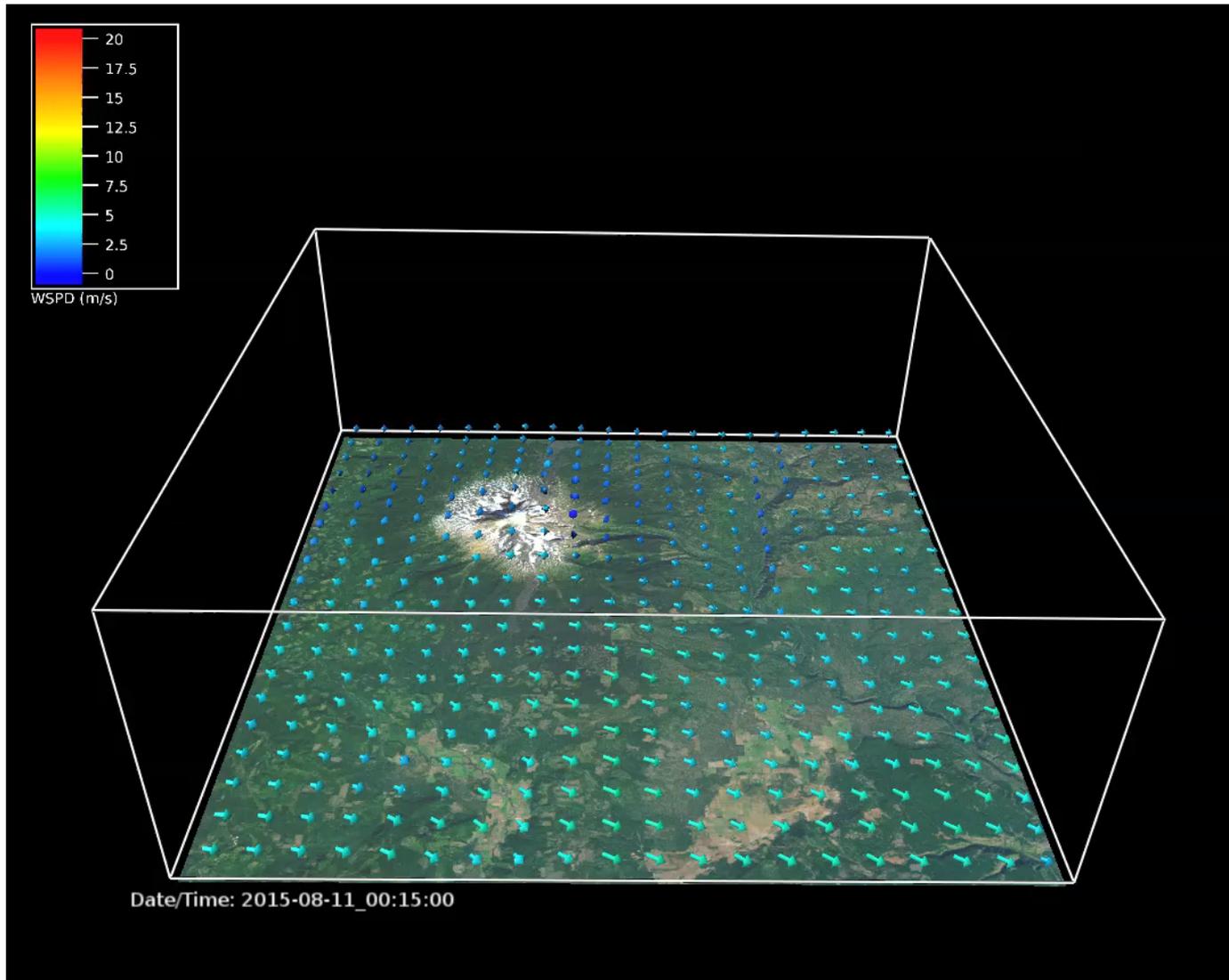
Test Case – Cougar Creek Fire WA 2015

- Relatively isolated fire event starting Aug 11 2015 (limited smoke contribution from other fires), MISR plume height detection (later into the fire progression), well documented fire growth, fire area 53,534 Acres
- WRF-SFIRE domain setup: 4 nested domains of 12km, 4km, 1.33km, 444m horizontal resolutions, 41 vertical levels
- Fire mesh 22m, fuel and elevation data resolution 30 m (LANDFIRE)
- Single point ignition
- Initial and boundary conditions for the atmospheric model from NARR
- Coupled fire-atmosphere simulation with two way coupling between fire and the atmosphere and between domains
- Simulation start 08.11.2015 00Z, fire ignition on 01Z
- Simulation length 132h



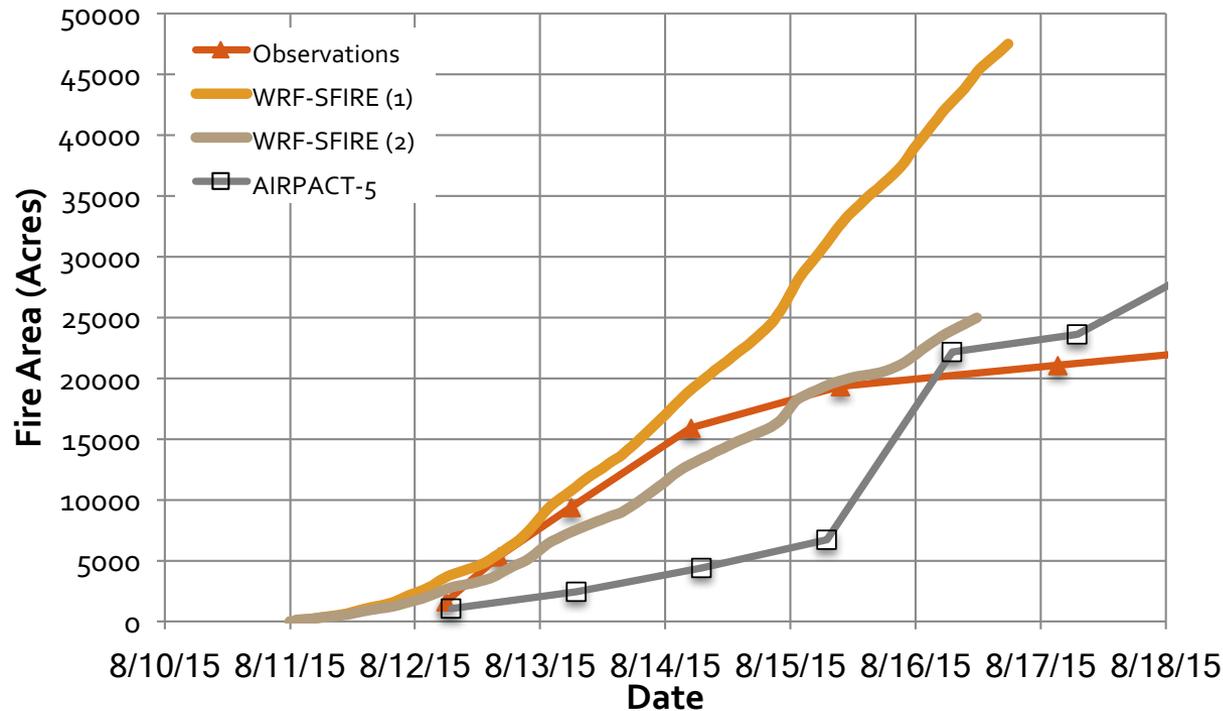
WRF-SFIRE Coupled Fire-Weather Simulation

- Simulated fire progression (fire area shown), 10m winds and smoke as a tracer



Simulated Fire Growth

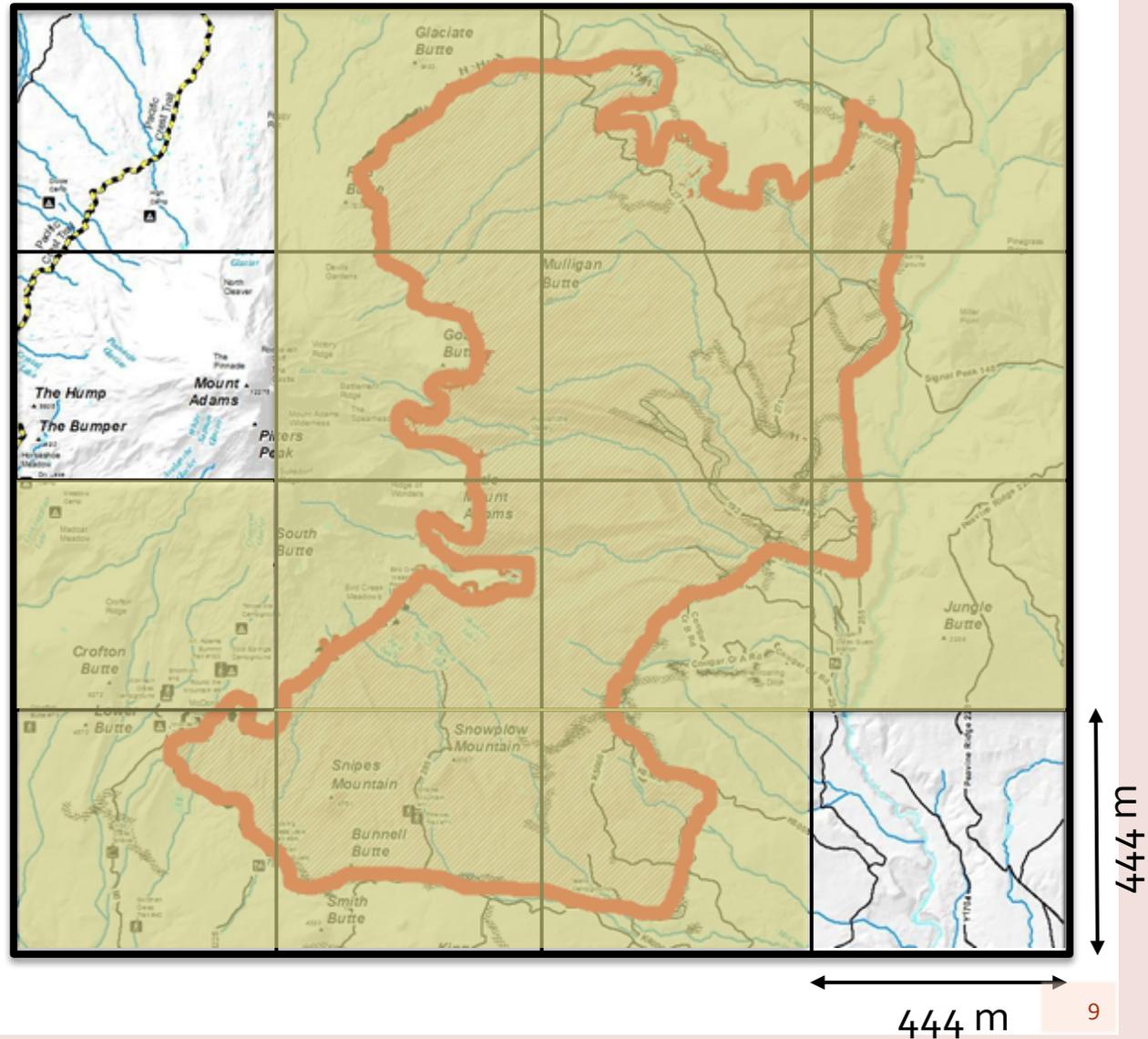
- Fire area observed, simulated by WRF-SFIRE, and projected (AIRPACT-5)



- In general, simulated fire area is closer to observations than the AIRPACT based on the assumption of fire persistence.
- Without any fire data assimilation in place, fire progression forecasts for more than 3 days will likely be associated with large errors.
- Simulated fire progression is sensitive to the fuel moisture used as an input into the model, therefore proper spatial 2D initialization of fuel moisture is very important.

Fire allocation based on WRF-SFire simulated fire area

- Orange area is hourly fire progression area
- Total fire area calculated for each grid cell
- Each grid cell acts as a single fire and has its own (hourly) area and location
- Thus, we use thousands of such grid cells as fire source

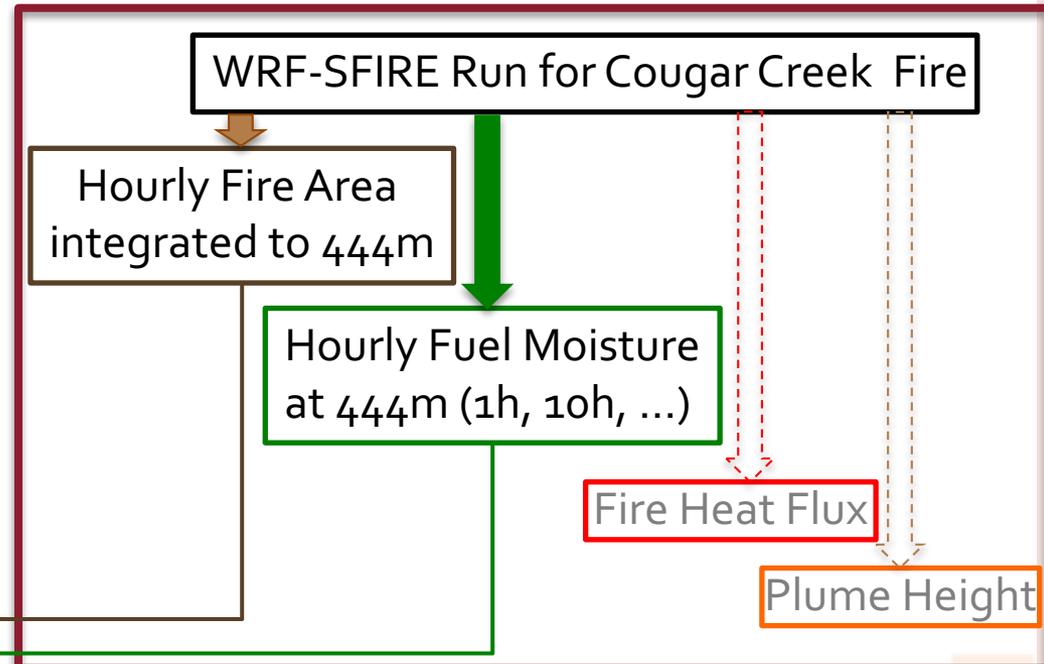
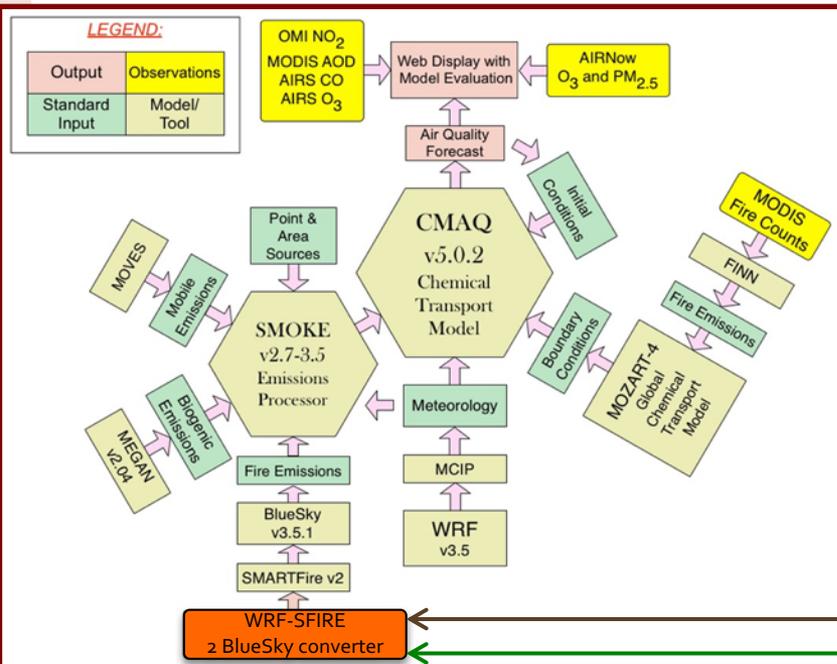


Different fire emission experiments

- **Base AIRPACT-5 case**
 - Fire emissions based on '*persistence*' assumption
- **APFire-1 experiment**
 - Hourly fire area integrated over an atmospheric grid cell size of 444 meters
 - Information of each fire grid cell is fed into BlueSky, representing a single fire (each with its own location, fire size and heat flux)
 - Thus, a single base case fire is now represented by multiple smaller fires
- **APFire-2 experiment**
 - Hourly fire area integrated over an atmospheric grid cell size of 444 meter
 - Information of each grid cell is fed into BlueSky, representing a single fire (each with its own location, fire size)
 - However, heat flux used in this case is the sum over all the pixels which will increase the plume rise estimate

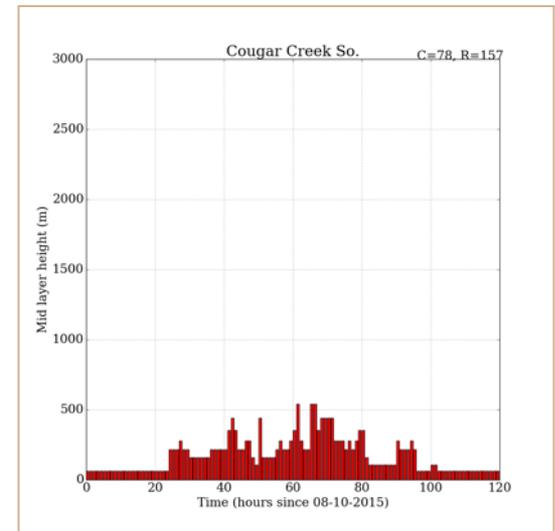
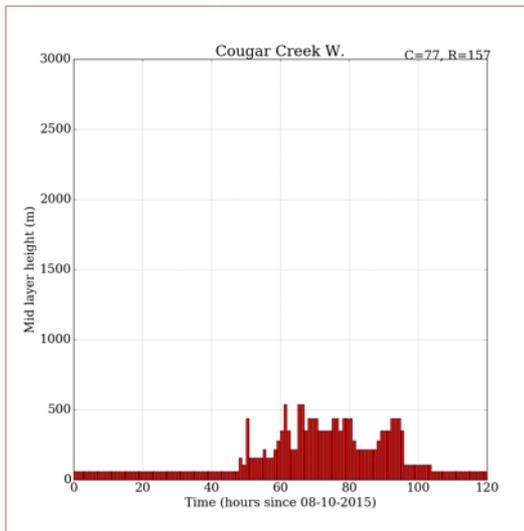
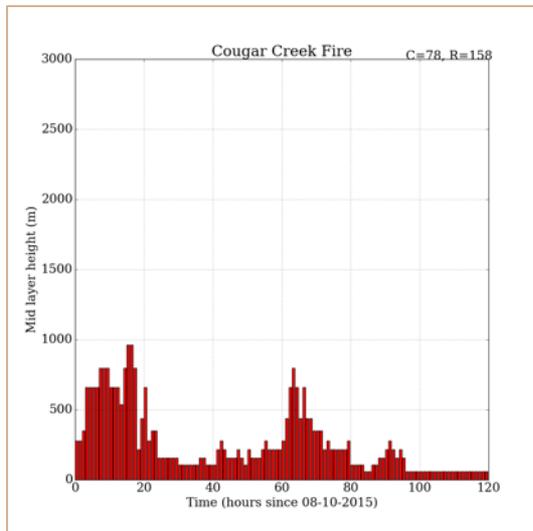
Integrating WRF-SFIRE with AIRPACT

- WRF-SFIRE resolves fire progression on 22-m resolution grid. The simulated fire area is then integrated over the 444-m atmospheric grid. Each grid cell containing an active fire is fed hourly into BlueSky as a separate fire with its own fire area and location
- For this test case over the whole simulation we fed BlueSky over 33,000 hourly fire records containing fire area and fuel moisture.

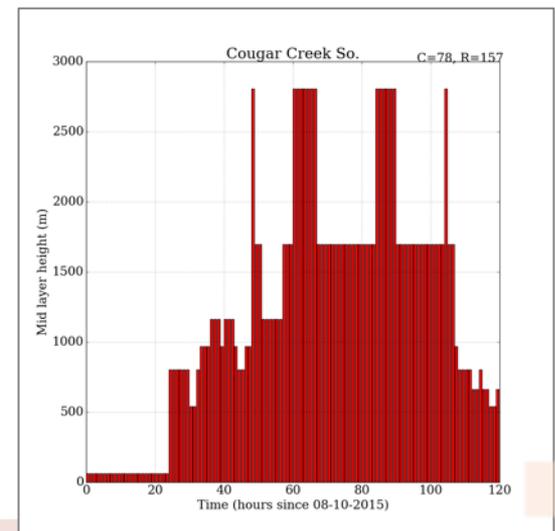
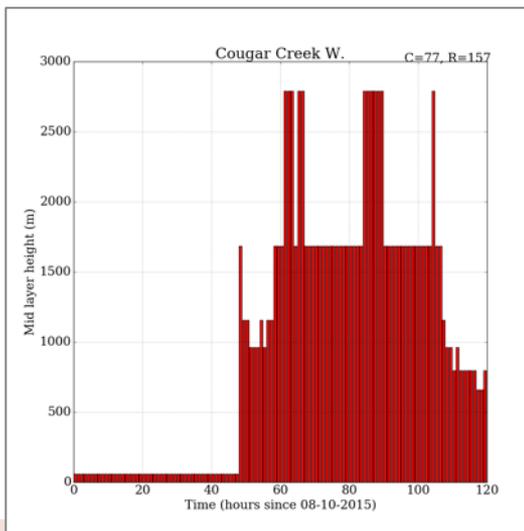
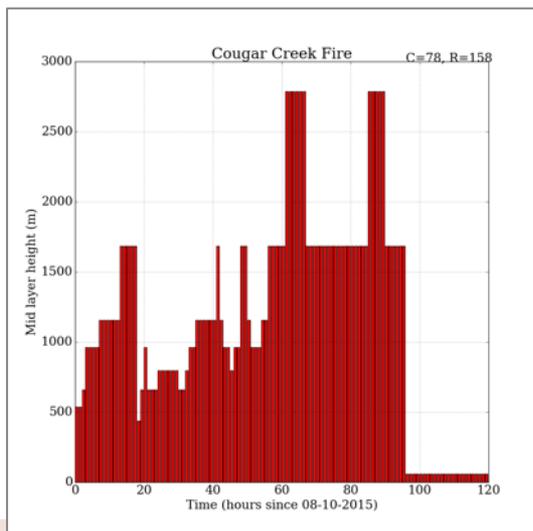


Plume height comparison – APFire-1 vs. APFire-2

APFire-1 plume heights up to 1.2km!

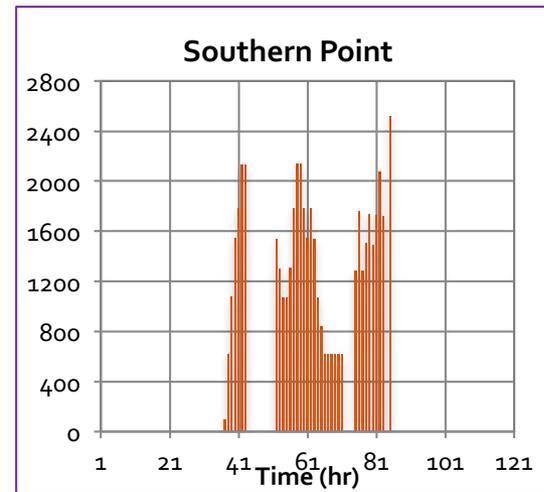
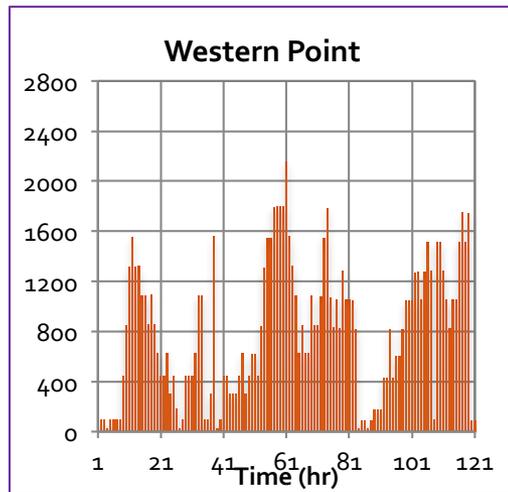
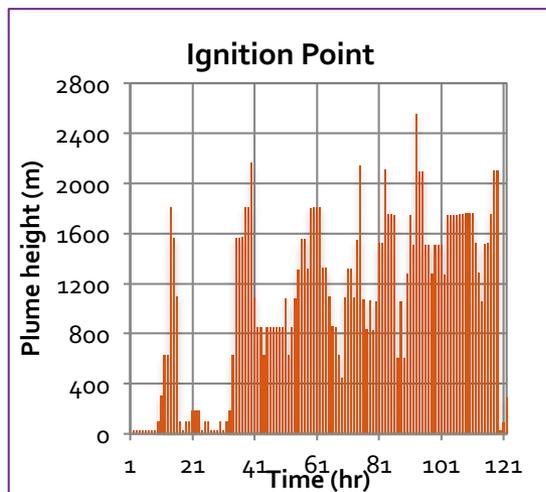


APFire2 – plume heights up to 2.8 km

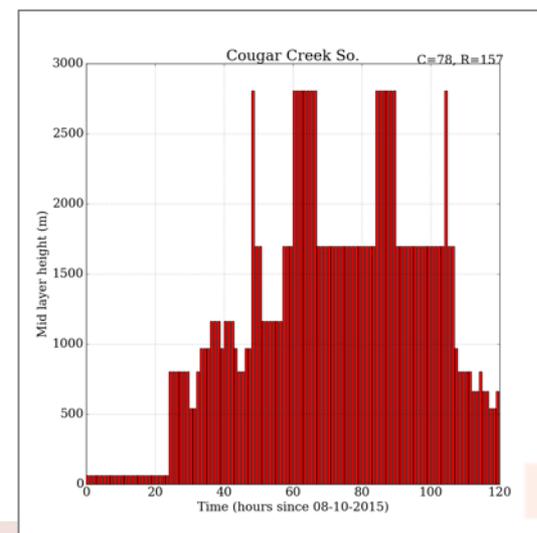
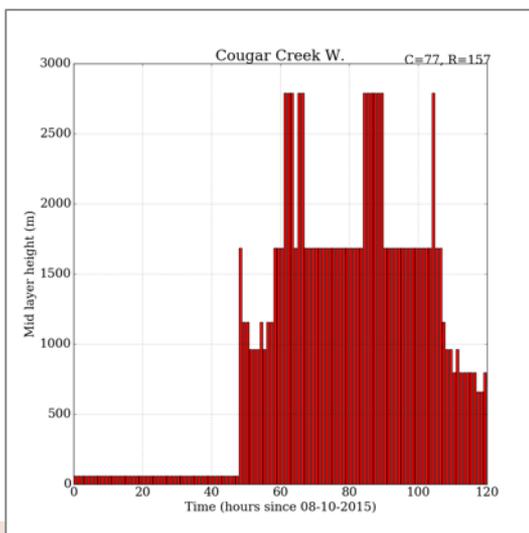
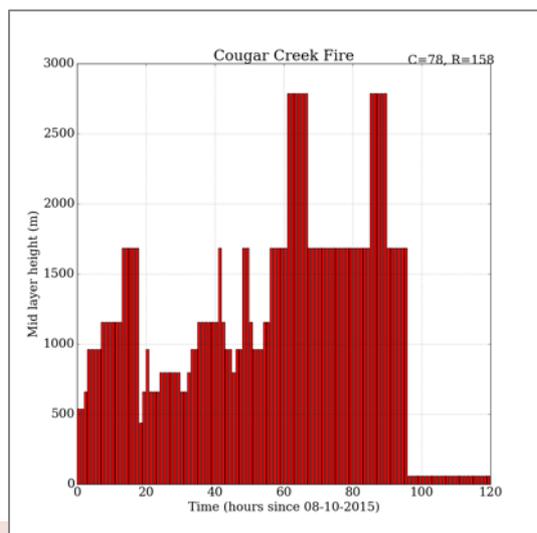


Plume height comparison – WRF-SFire vs. SFire-2

WRF-SFire – plume heights up to 2.5 km



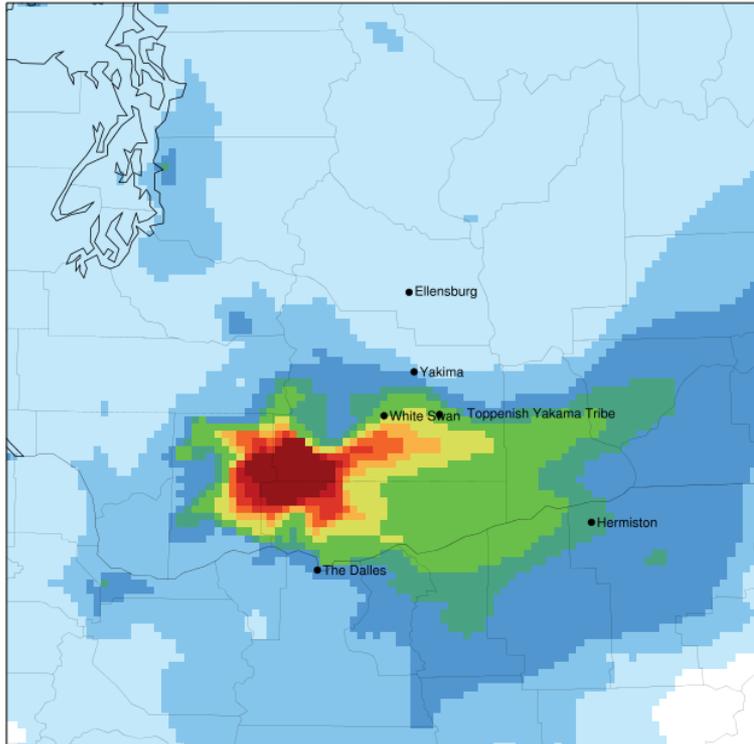
APFire2 – plume heights up to 2.8 km



Average PM_{2.5} between APFire-1 and APFire-2

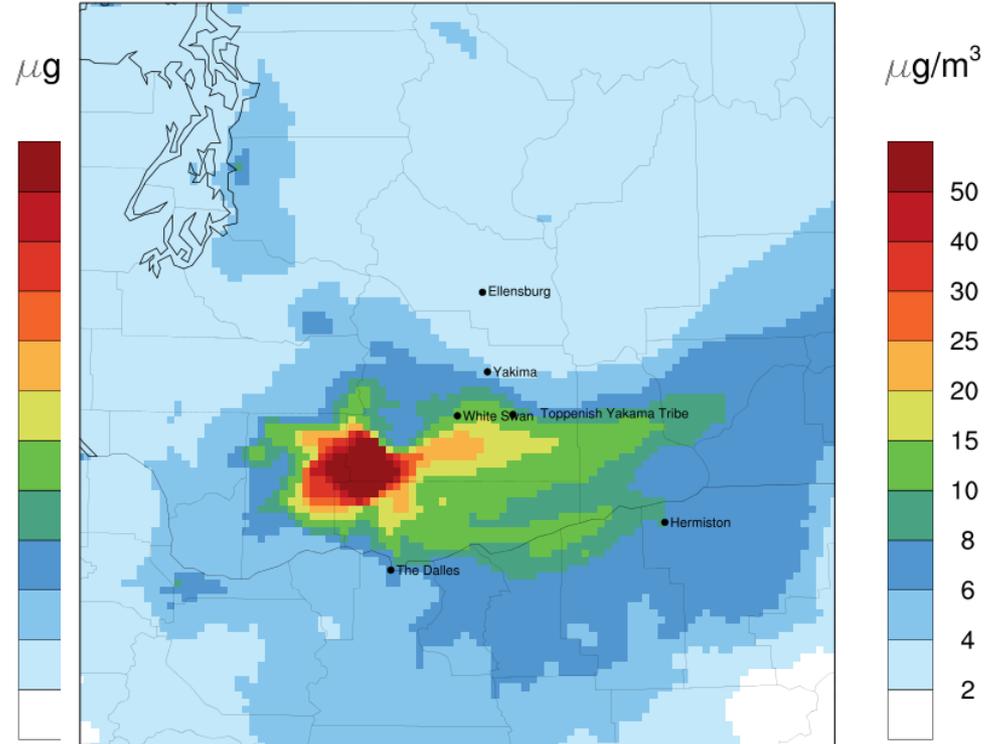
PM_{2.5}: APFire-1

Cougar Creek Fire Average: Aug 10-15, 2015

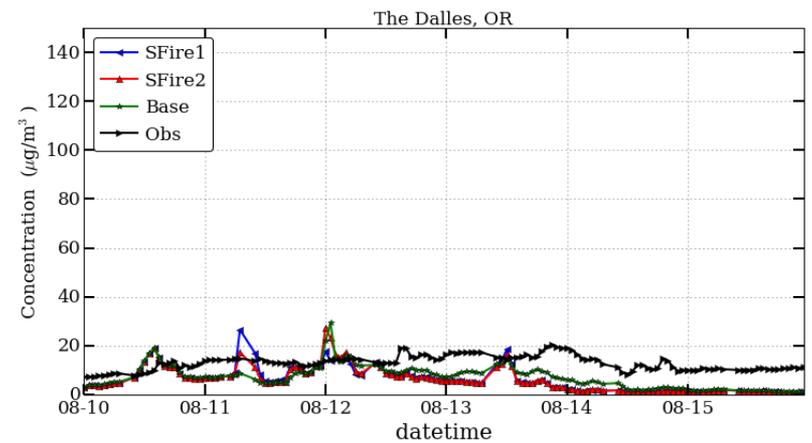
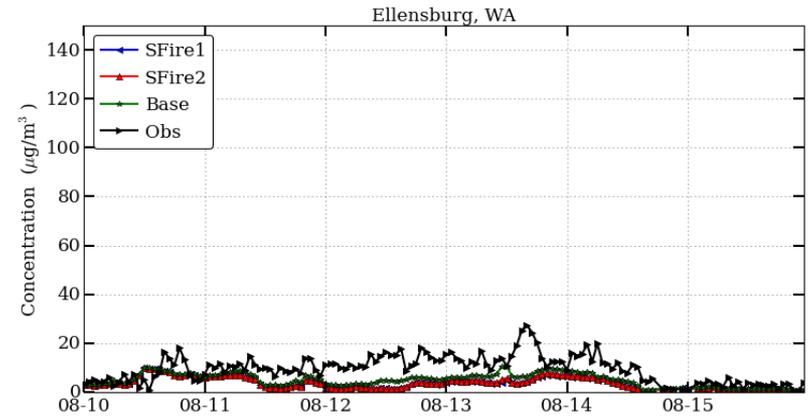
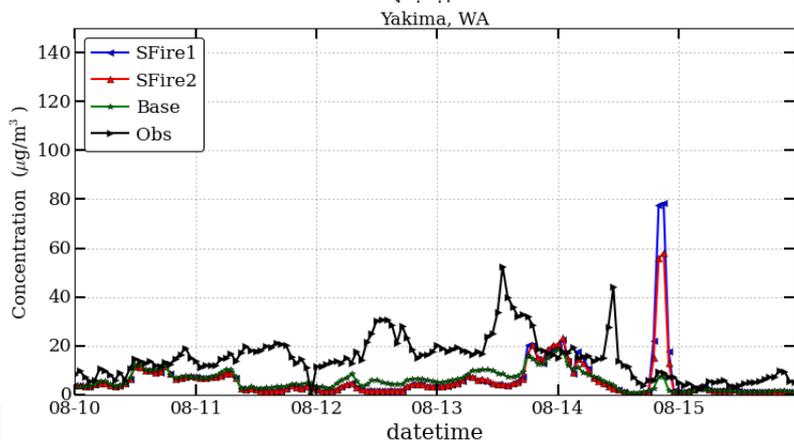
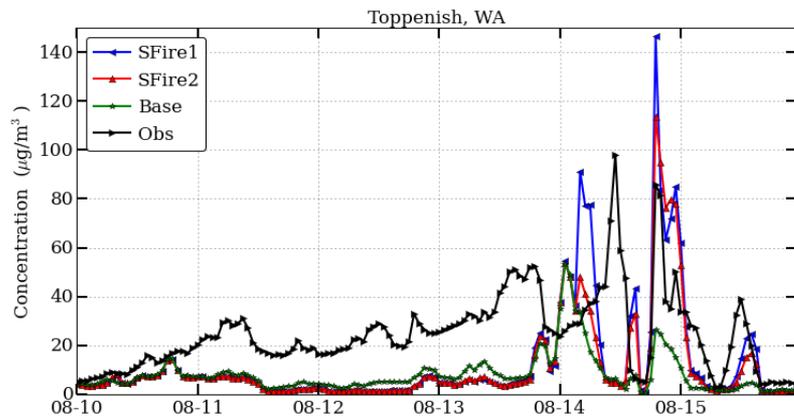
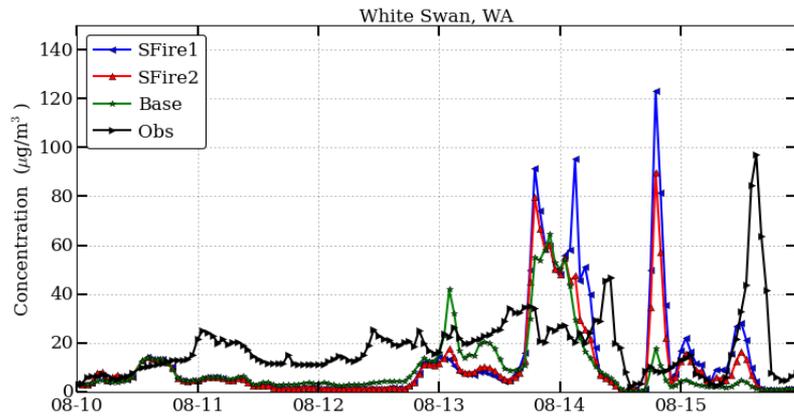


PM_{2.5}: APFire-2

Cougar Creek Fire Average: Aug 10-15, 2015



Simulated vs observed PM_{2.5} concentrations



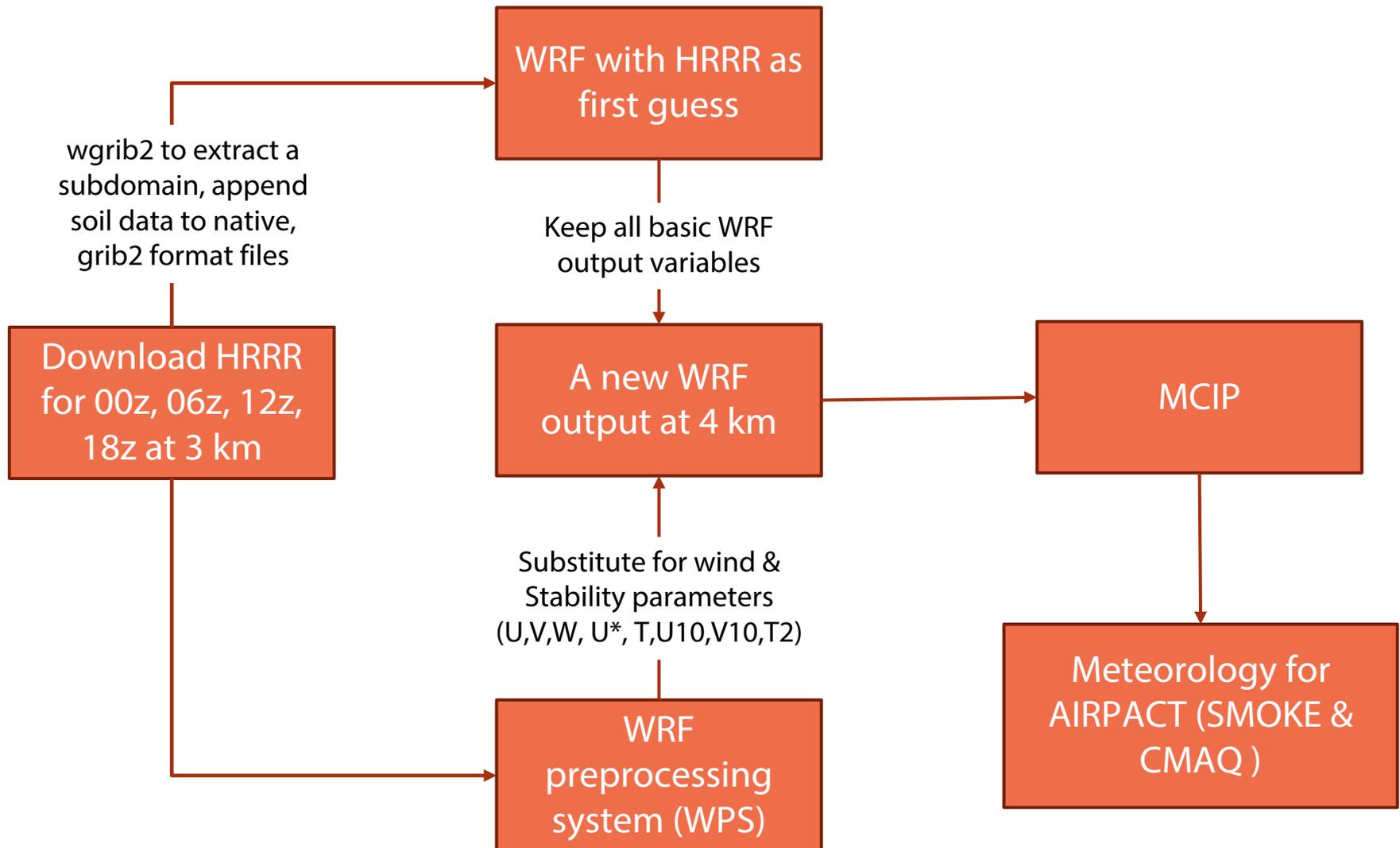
Use of High Resolution Rapid Refresh (HRRR) for Nowcasting

- What is HRRR? From HRRR website (<https://rapidrefresh.noaa.gov/hrrr/>)

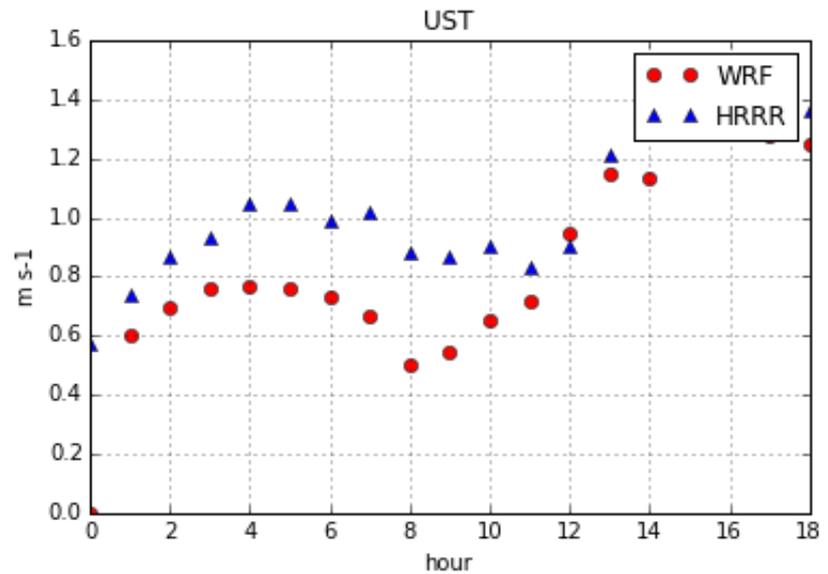
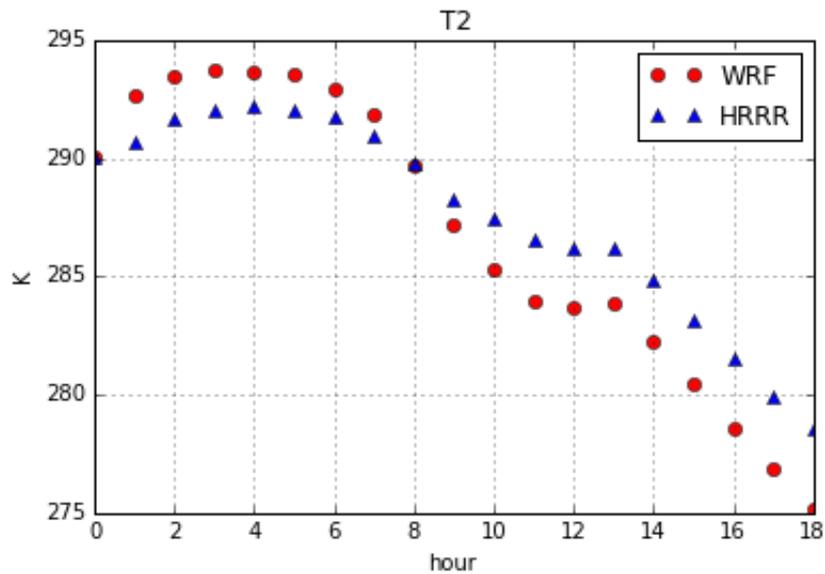
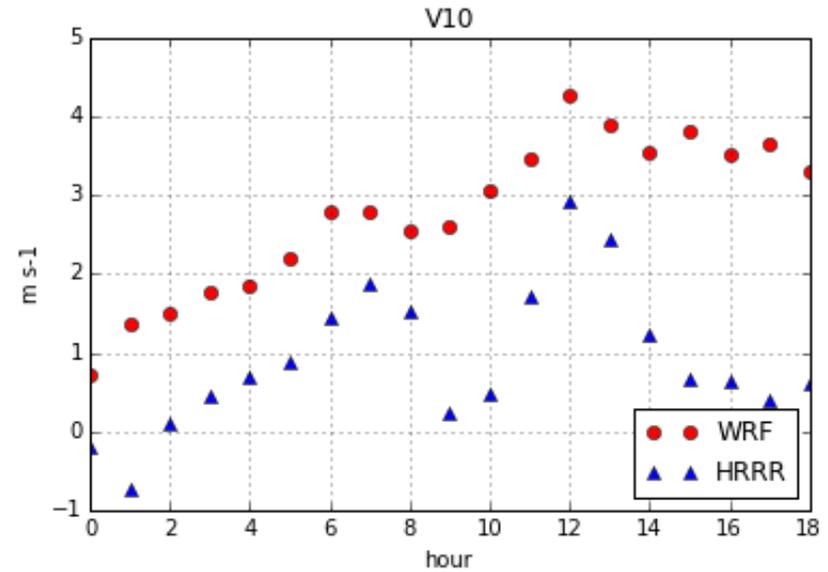
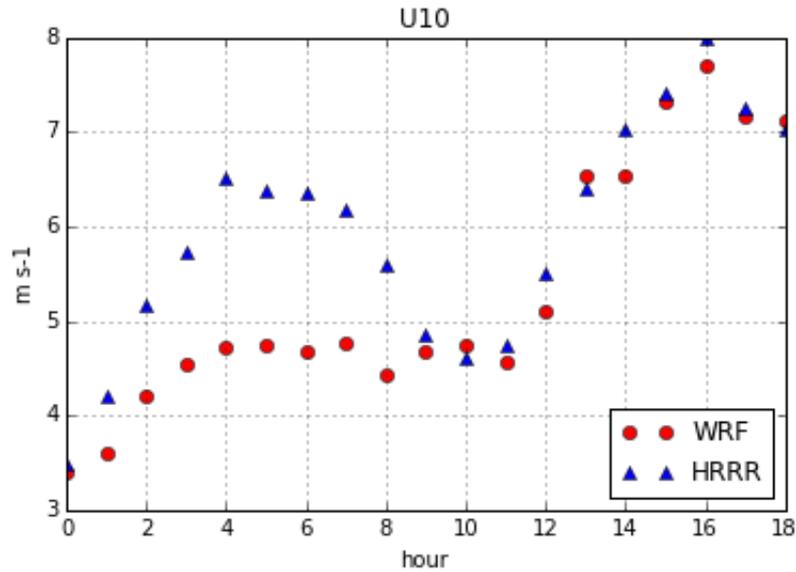
“The HRRR is a NOAA real-time 3 km resolution, hourly updated, cloud-resolving, convection-allowing atmospheric model, initialized by 3 km grids with 3 km radar assimilation. Radar data is assimilated in the HRRR every 15 min over a 1-h period adding further detail to that provided by the hourly data assimilation from the 13 km radar-enhanced Rapid Refresh”

- While HRRR uses WRF-ARW, public domain data is in grib2 format, and lacks several variables for driving CMAQ

HRRR initialized WRF to get Meteorology for CMAQ



Preliminary comparison of base WRF and HRRR



Development of Healthcare Demand App

- Healthcare demand app is under development as a part of EECS senior design project
 - 2 semester project – will resume in fall
- Matt Kadlec (WA Ecology) has compiled a list of concentration response function (C-R functions) after extensive review of literature specifically focusing on wildfire impacts on health endpoints
 - C-R function is smoke $PM_{2.5}$ concentration - health response factor
 - These C-R functions together with AIRPACT-Fire forecasts and population / demographic data will be used for developing the app

Smoke Concentration - Health Response functions

- Literature search for wildfire smoke health effects epidemiology studies
 - Found >300 articles
- Select studies with daily average PM_{2.5} concentrations and measured daily changes in health care service/symptom rates (Relative Risks, etc.)
 - 16 articles report a range of cardiovascular and respiratory effects
- Calculate C-R Functions → $\beta = \frac{\ln(RR)}{\Delta PM}$
- Pool any C-R functions assessed in multiple studies, *Examples:*
 - Asthma emergency dept. visits (2 studies)
 - Ischemic heart diseases emergency dept. visits (2 studies)
- Compile pooled and single-study C-R functions in a risk calculation worksheet →
- Transform AIRPACT-Fire PM_{2.5} forecasts to health risk forecasts using the C-R functions

All-age emergency dept. visits for any non-trauma cause					
ICD-10: A00-R99 Johnston et al 2014.pdf					
	0	1	2	3	Lag Days
	0.001012	0.000678	0.000678	0.000341	CRF β
	0.00017	0.000171	0.000171	0.000173	var
PM25 daily mean, min-max $\mu\text{g}/\text{m}^3$: Smoke day 39.1, 14.6-100.2; Nonfire day 9.9, 2.1-46.7					

	ug/m3	0	1	2	3	←	Lag Days
Friday, August 21, 2015	3.5	0	1	2	3		
Saturday, August 22, 2015	5.7	↓	↓	↓	↓		
Sunday, August 23, 2015	1.8						sum of daily extra risk
Monday, August 24, 2015	4.5					↓	
Tuesday, August 25, 2015	3.0	na	na	na	na	0	
Wednesday, August 26, 2015	366.5	0.449	na	na	na	0.449	
Thursday, August 27, 2015	251.1	0.289	0.282	na	na	0.572	
Friday, August 28, 2015	120.3	0.129	0.186	0.282	na	0.597	
Saturday, August 29, 2015	75.8	0.080	0.085	0.186	0.133	0.483	
Sunday, August 30, 2015	51.8	0.054	0.053	0.085	0.089	0.281	
Monday, August 31, 2015	88.5	0.094	0.036	0.053	0.042	0.224	
Tuesday, September 01, 2015	49.9	na	0.062	0.036	0.026	0.124	
Wednesday, September 02, 2015	10.1	na	na	0.062	0.018	0.080	
Thursday, September 03, 2015	1.7	na	na	na	0.031	0.031	
Friday, September 04, 2015	1.2	na	na	na	na	0	

Summary and Next Steps

■ Summary

- Successfully coupled WRF-SFIRE with AIRPACT air quality forecasting system.
- Between APFire-1 and APFire-2, we see an improvement in plume rise – APFire-2 plume rise is more realistic compared to APFire-1.
- APFire-2 has better prediction for some peak hours, but using this approach also gives some false alarms.
- Framework for using HRRR with CMAQ is in place, but more validation is needed.
- Health app development is in progress.

■ Next Steps

- A wind field comparison between WRF-SFire and AIRPACT meteorology
- More investigation of plume height – such as using WRF-SFIRE plume injection heights instead of Brigg's approach in SMOKE.
- Further coupling with AIRPACT – feeding heat flux directly from WRF-SFIRE.
- Testing & comparing HRRR based nowcasting system with AIRPACT-5 forecast.

We acknowledge the funding agency:
Joint Fire Science Program (JFSP)

Thank you !!

Questions / Comments?