# Modeling Of Large Wildfire Emissions In The Pacific Northwest

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## Background

### Purpose
➢ To get an idea of how different configurations in BlueSky numerically compare to one another in terms of their emission and plume rise output
➢ To evaluate the degree of correlation between BlueSky plume top predictions and data from MISR satellite retrieval estimates
➢ To compare modeled particulate emission output with emissions calculated from correlations with MODIS fire radiative power data
These goals aim to help validate the modeling framework's use for smoke forecasting and decision making with satellite retrieval measurements, and to better understand how possible module choices affect the output obtained from running BlueSky.

### Key Terms
**BlueSky**: A modeling framework linking a chain of modules which predict emissions, given information about fire locations and sizes.
**Plume top**: The maximum height which a smoke plume rises above the terrain, a parameter which is used as the plume injection height for emission transport modeling.
**MISR** (Multi-angle Imaging SpectroRadiometer): an instrument on NASA's Terra satellite which senses in four optical and near-infrared bands.[4]
**MODIS** (Moderate-resolution Imaging Spectroradiometer): A pair of instruments aboard NASA's Terra and Aqua satellites which can be used to detect atmospheric aerosols.[2]
**AIRPACT** (Air Indicator Report for Public Awareness and Community Tracking): Computer system which models air quality in the Pacific Northwest region.[1]

## BlueSky Modeling Pathway



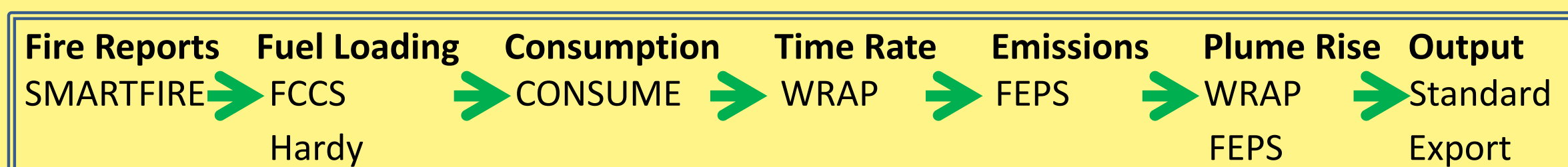| Fire Reports | Fuel Loading | Consumption | Time Rate | Emissions | Plume Rise | Output |
|---|---|---|---|---|---|---|
| SMARTFIRE | FCCS | CONSUME | WRAP | FEPS | WRAP | Standard |
| | Hardy | | | | FEPS | Export |

Figure 1. BlueSky Module Configurations Tested

**Fire Information**: Information about the location and area of each fire
❑ SMARTFIRE (Satellite Mapping Automated Reanalysis Tool for Fire Incident Reconciliation): A system which reconciles satellite fire detection with incident reports from firefighters. The algorithm is described by Raffuse et al.[6]

**Fuel Loading**: The amount of fuel which is available to burn in a fire
❑ FCCS (Fuel Characteristic Classification System): A 1 km resolution map of the U.S. characterizing fuel beds into one of 291 types.[7]
❑ Hardy: A modified version of the National Fire Danger Rating System which has higher fuel loading in the Western states.

**Consumption**: The amount of the fuel bed which gets consumed in a fire
❑ CONSUME: A module which uses one of four equation sets, consisting of empirical linear regression models applied over six strata. See Overview and Appendix C of the User's Guide for more information.[5]

**Time Rate**: The temporal pattern of consumption of fuel during a fire
❑ WRAP-WF (Western Regional Air Partnership): A fixed time profile designed for wildfires, where the fire persists through the day.

**Emissions**: Calculates the primary pollutants which get emitted during a fire
❑ FEPS (Fire Emission Production Simulator): Models emissions based on emission factors and combustion efficiency data. These are described in Appendix C of the FEPS user guide.[3]

**Plume Rise**: How high a smoke plume rises above the terrain
❑ WRAP: Classifies fires based on acreage and fuel loading into one of five classes, and then uses a corresponding buoyant efficiency profile to calculate plume rise.
❑ FEPS: A model which is based on Briggs equation for buoyant plumes.[3]

**Output**
❑ Standard: Outputs the emissions from each individual fire without considering dispersion.
❑ Export: For further processing such as in AIRPACT, to model the effects of atmospheric chemistry and transport.

## Methods

### Fires
• Seven fire cores were identified, coming from five large wildfire events
• Located In Idaho or Oregon
• During July or August of 2007

### MISR Plumes
• Matched with the fires according to their date and geographic location
• Largest nearby fire core from SMARTFIRE was used for comparison
• The overpass time corresponds approximately to 12:00 local time in BlueSky
• MISR plume top heights were corrected for median terrain heights
• Used to compare with the plume top output from BlueSky



Figure 2. Fire Locations

Table 1. Fire Date and Size

| # | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Date | 7/10 | 7/15 | 8/7 | 8/9 | 8/18 | 8/18 | 8/18 |
| Acreage* | 6075 | 435 | 952 | 832 | 1522 | 970 | 1757 |

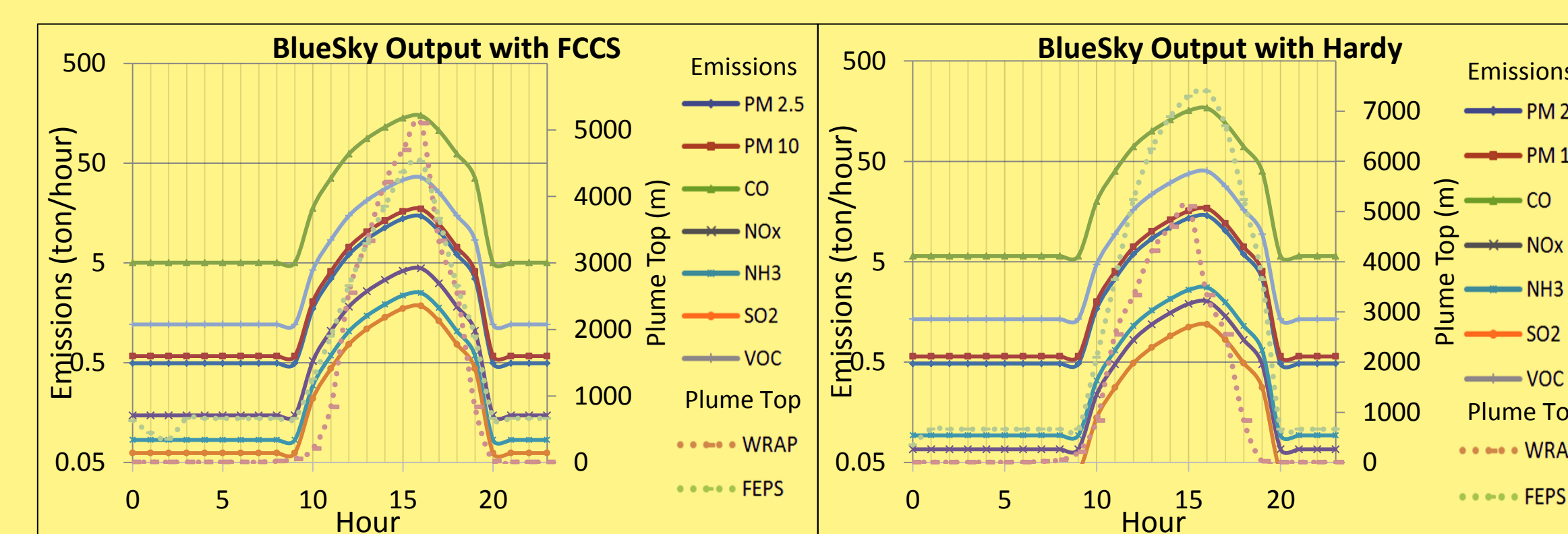\* Value from fire_locations.csv on match days

## Results



Figure 3. Emissions and Plume Top Comparison Using Two Fuel Loading Options
In this fire (Match #1), the emissions are very similar, however Hardy is generally higher, see Figure 5 and Table 2 for data using all seven fires
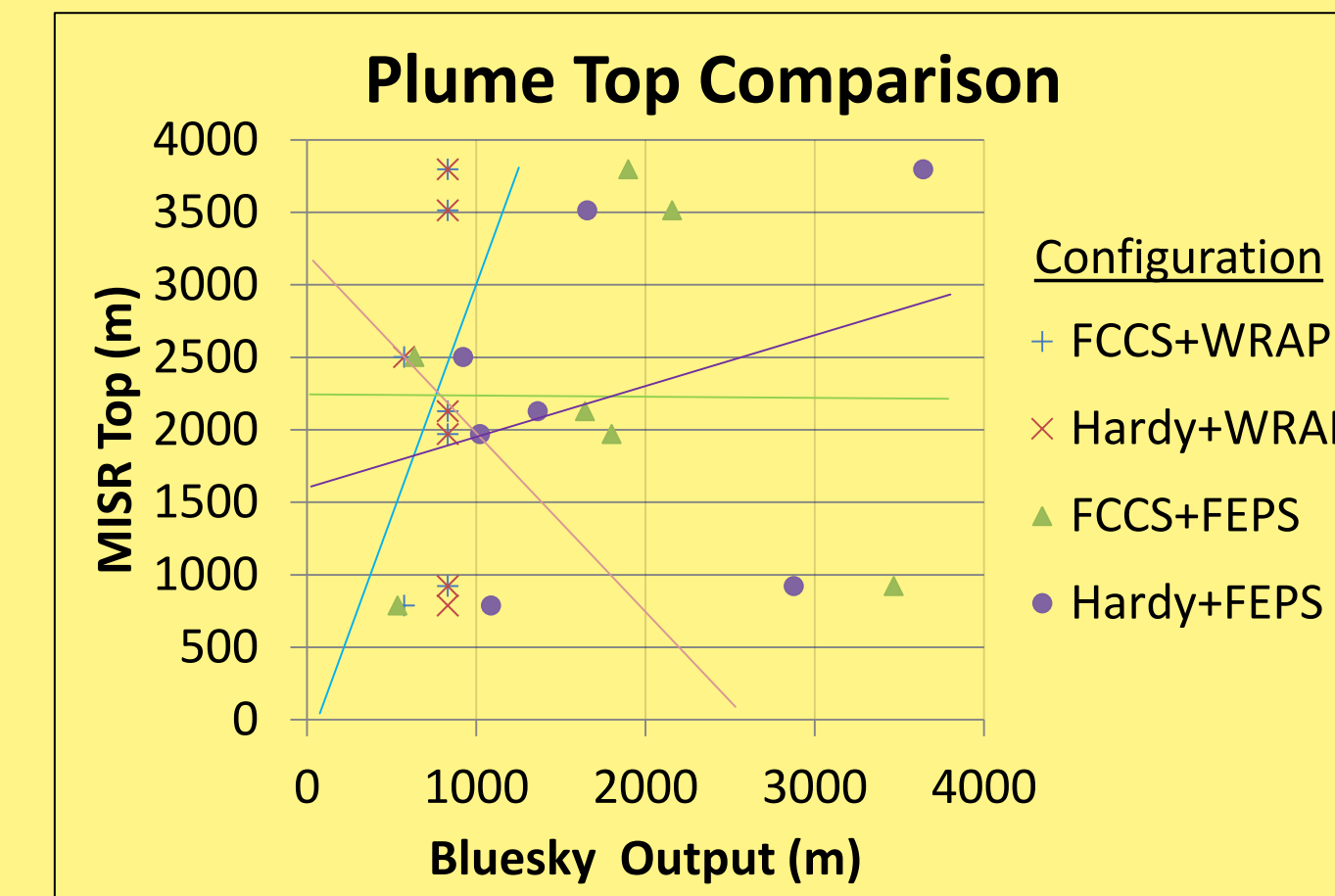


Table 2. Plume Top Statistics

| Configuration | Mean (m) | Mean bias (m)* | R² |
|---|---|---|---|
| FCCS+WRAP | 759.1 | -1471 | **0.12** |
| Hardy+WRAP | 795.7 | -1434 | 0.01 |
| FCCS+FEPS | 1735 | -495.1 | 0 |
| Hardy+FEPS | 1796 | **-433.8** | 0.1 |

(values with best agreement are bolded)
\* Mean bias = BlueSky - MISR
At the 1:00 time step the mean bias becomes positive, but the R² value remains similar

Figure 4. BlueSky vs. MISR Plume Top Correlations



Table 2. Total Day PM2.5 Emission Comparison

| PM2.5 | FCCS | Hardy |
|---|---|---|
| Mean (tons) | 605.9 | 280.9 |
| Std dev. (tons) | 636.6 | 182.7 |

Both methods use a fixed PM10/PM2.5 ratio
For Bluesky: 1.18
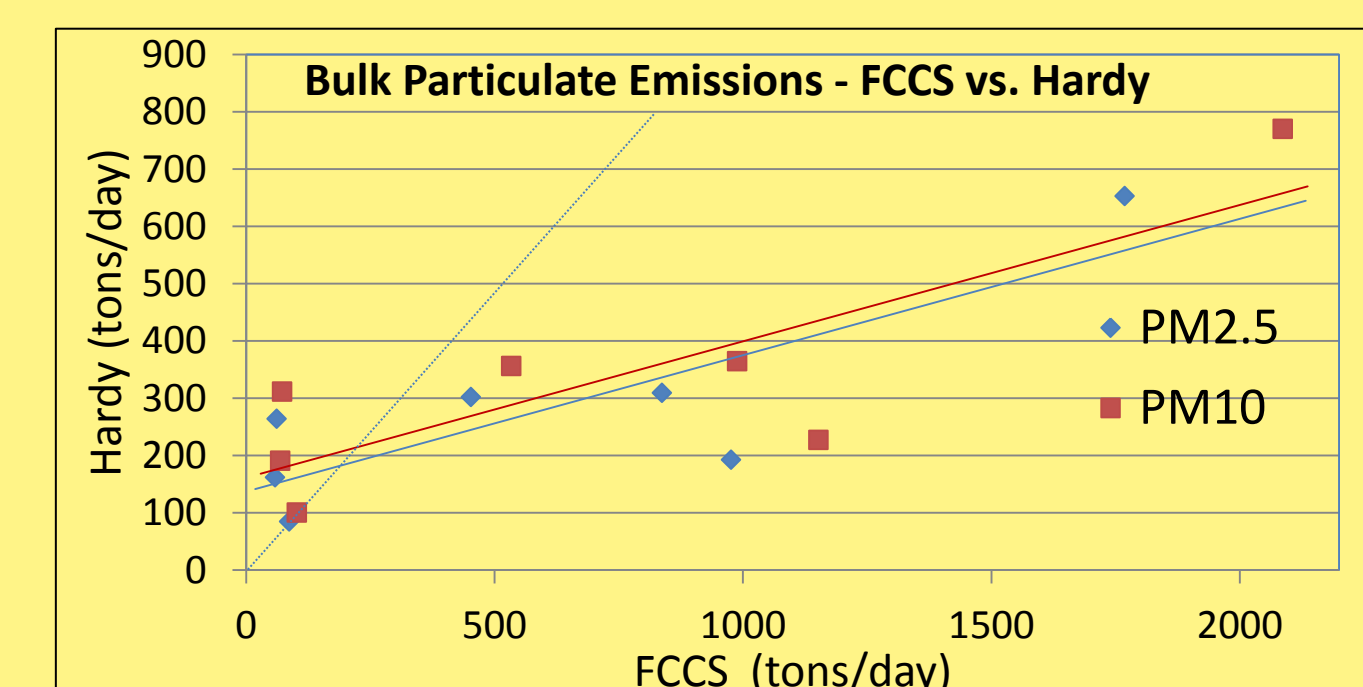For MODIS calculations: 1.11

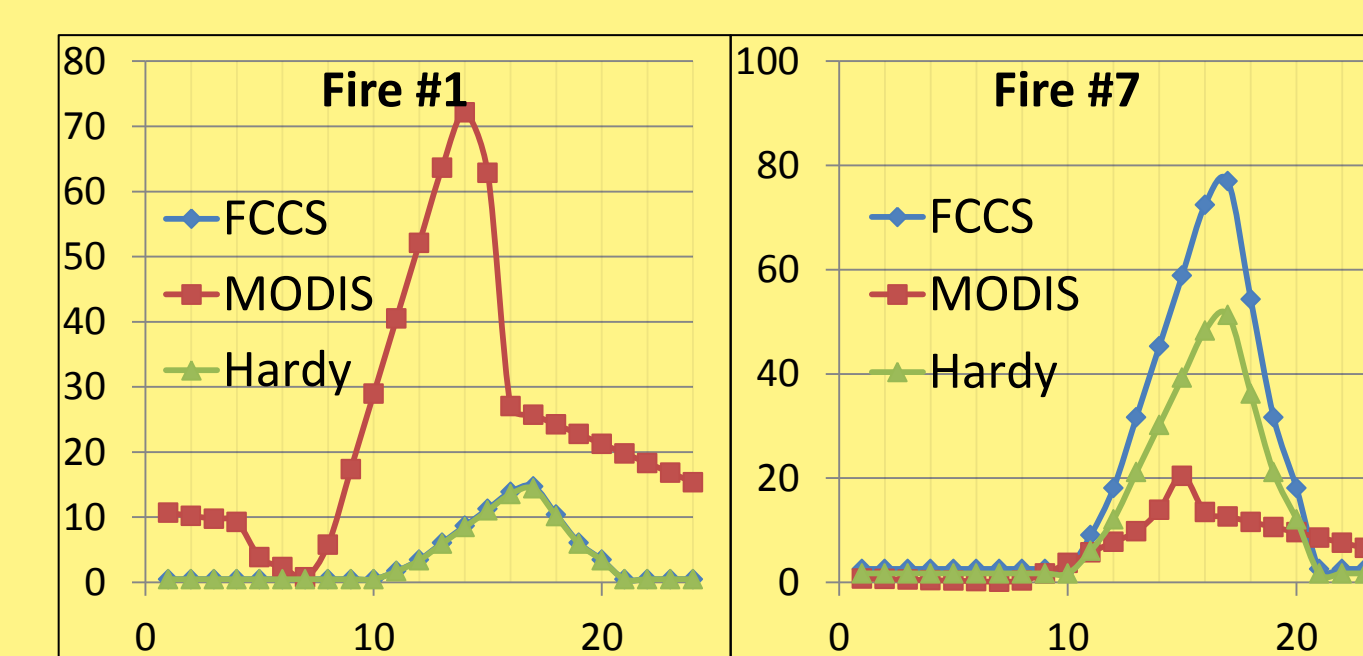Figure 5. Effect of Fuel Loading on PM Output



Figure 6. Two PM2.5 Hourly Profiles
The first case is typical in that MODIS greatly exceeds either BlueSky run. The second is typical in that FCCS exceeds Hardy in its emissions estimate.

Table 3. Bluesky vs. MODIS PM2.5 Correlations

| PM2.5 | Noon* | Daily |
|---|---|---|
| MODIS mean | 55.0 | 1183 |
| Bias, FCCS | **-30.8** | **-577.5** |
| Bias, Hardy | -43.8 | -902.5 |
| R², FCCS | **0.069** | **0.036** |
| R², Hardy | 0.025 | 0.004 |

\* Emissions from 12:00 to 1:00 local time

## Results

AIRPACT Output (July 10, 2007)       MODIS Aqua Image
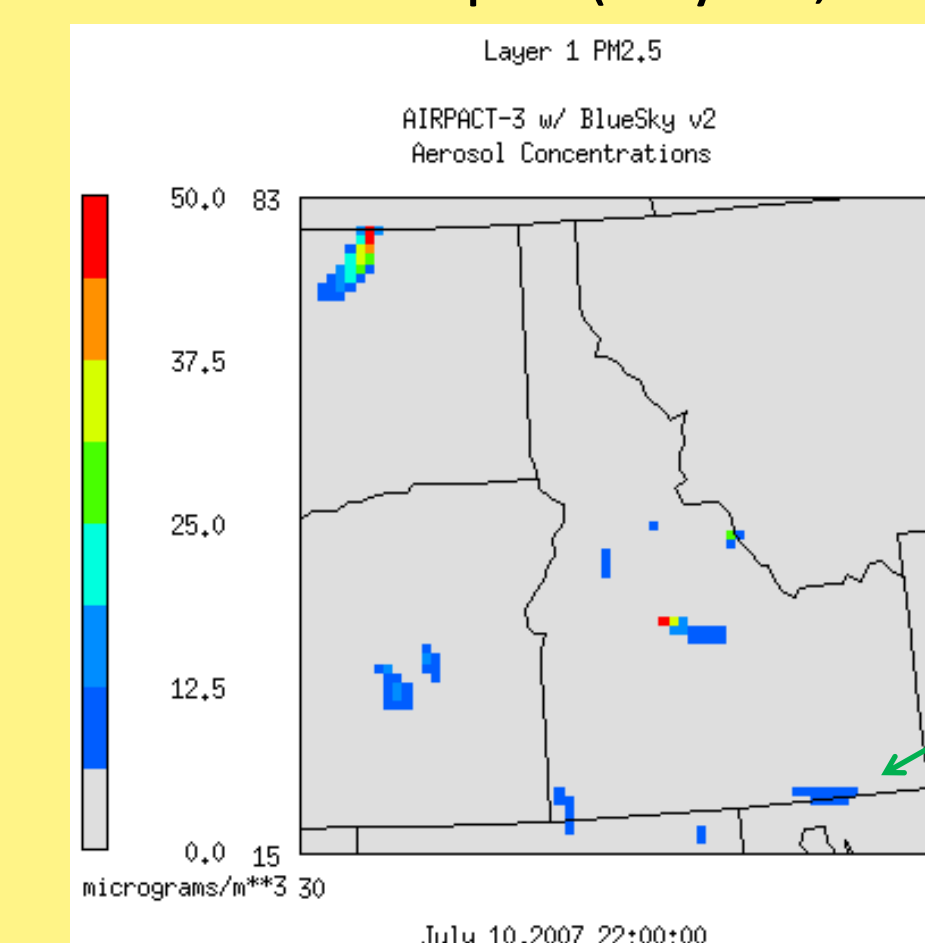


Figure 7. Modeled Aerosol Concentrations       Figure 8. Satellite Image of the Same Domain
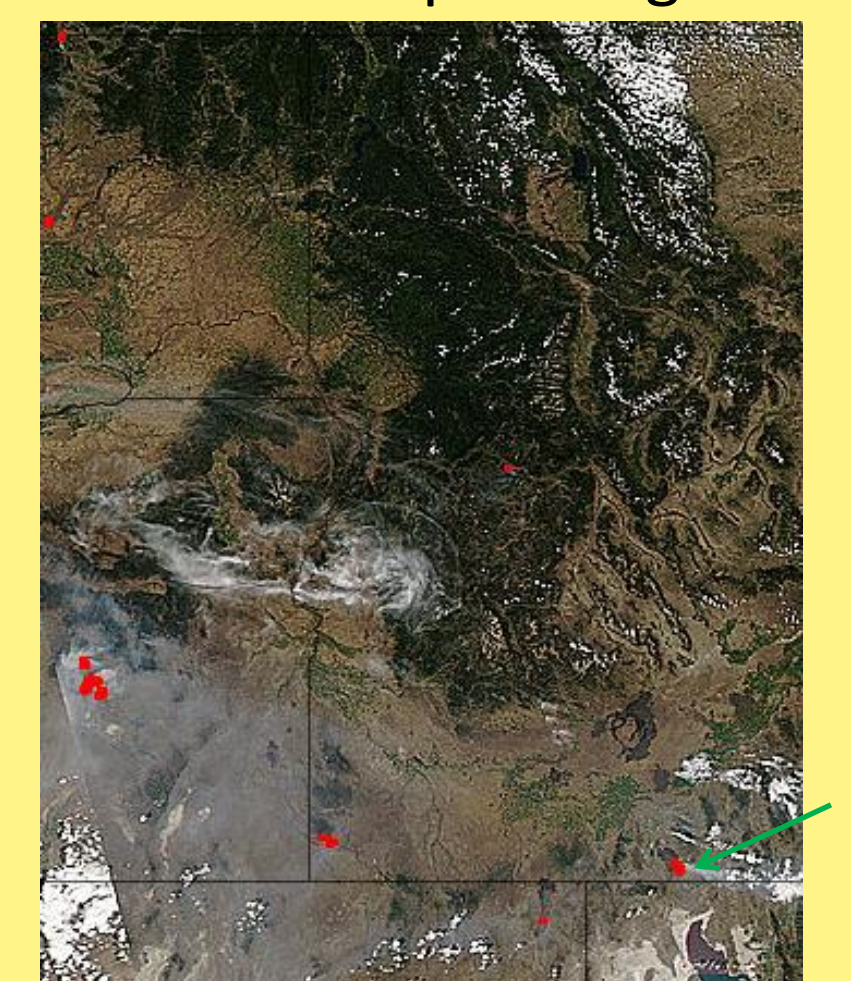
## Issues

• The way that BlueSky handles time zones and also how the time rate modules work create variability in how the data could be interpreted. Emission and plume values increase significantly during the early afternoon hours, so the comparison is sensitive to which time is chosen. The mean bias changes by thousands of meters, but the coefficient of determination (R²) is less affected.
• Conversion from aerosol to TPM (total particulate matter) or PM2.5 requires assumptions about how the particulate matter is speciated. Standard values are used from the literature.

## Conclusions

• The correlation between plume top and emissions is consistently low (≤ ~0.1)
• The use of Hardy for fuel loading and FEPS for plume rise gives the second best correlation and also the second best lowest absolute mean bias, so it could be considered the best configuration for realistic plume top output.
• FCCS better matches the particulate emission estimates derived from MODIS than does Hardy.
• The choice of modules used has a significant effect on emission estimates.

## Future Questions

• Are wildfires with many dispersed cores modeled more poorly than fires with a dominant fire core?
• How do model results compare at other times of the day to surface measurements?
• How would newer models like Daysmoke (for plume rise) and FOFEM (for consumption and emissions) affect the results?
• How would the output from other fires compare, such as for smaller wildfires or prescribed burns?

## References

1. Lamb, B.; et al. (2007). *Real-time numerical forecasting of wildfire emissions and perturbations to regional air quality*.
2. Justice, C.; et al. (1998). *The Moderate Resolution Imaging Spectroradiometer (MODIS): Land Remote Sensing for Global Change Research*.
3. Anderson, G.; et al. (2004). *Fire Emission Production Simulator (FEPS) User's Guide*.
4. Diner, D., et al. (1998). *Multi-angle Imaging SpectroRadiometer (MISR) Instrument Description and Experiment Overview*.
5. Prichard, S.; Ottmar, R.; Anderson, G. (2005). *Consume 3.0 User's Guide*.
6. Raffuse, S.; Pryden, D.; Sullivan, D. (2009). *SMARTFIRE Algorithm Description*.
7. Prichard, S.; et al. (2011). *FCCS User's Guide*.