Forest Fire Impacts on Air Quality in Western Canada

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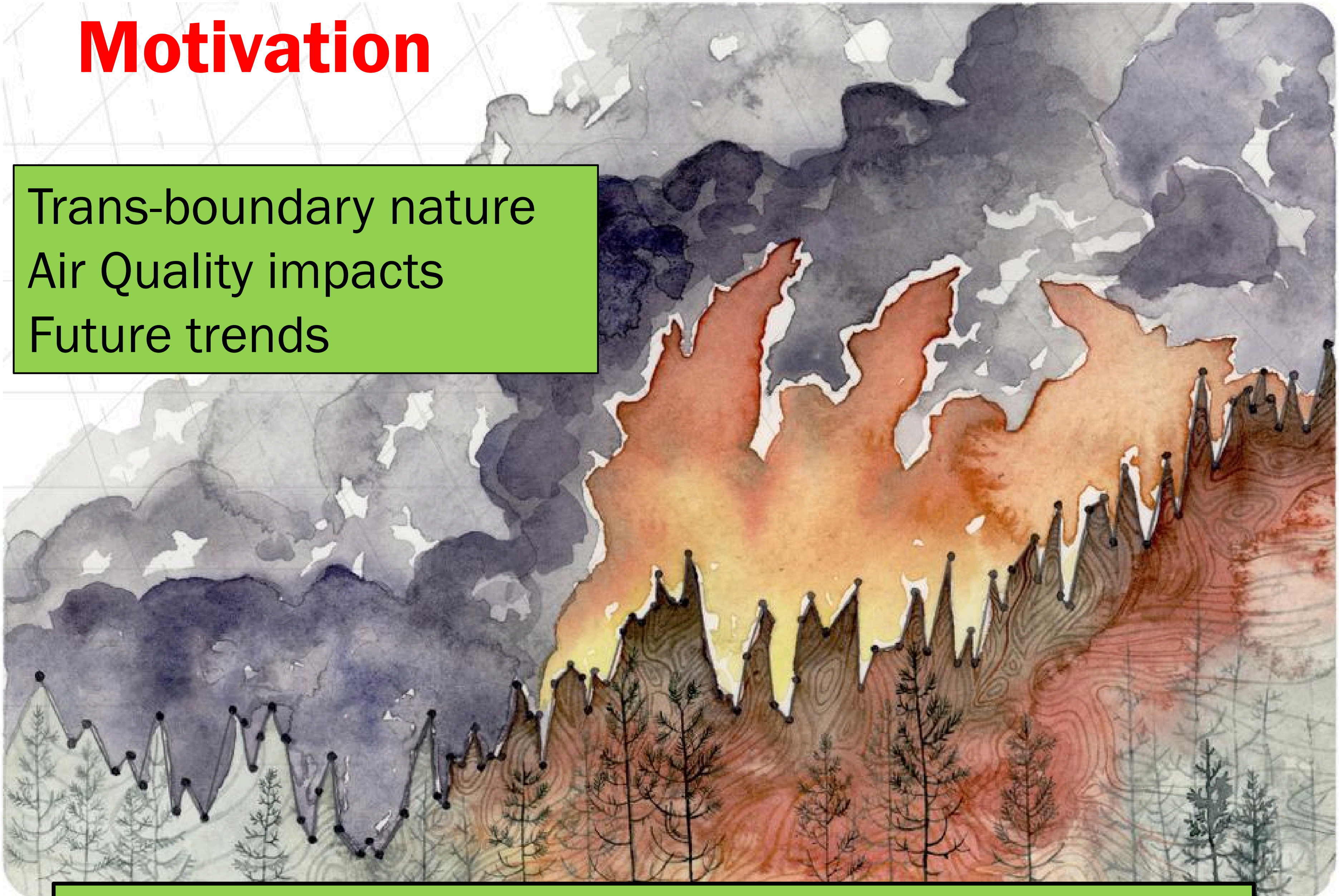
MODIS (Terra) satellite imagery of Northern Saskatchewan - July 9, 2015

Motivation

Trans-boundary nature
Air Quality impacts
Future trends



Increased Forest Fire Activity, watercolor. Data in image is based on @ClimateCentral temp data 1880-present. Jill Pelto. pic.twitter.com/9hIr9efVPm

Trans boundary nature

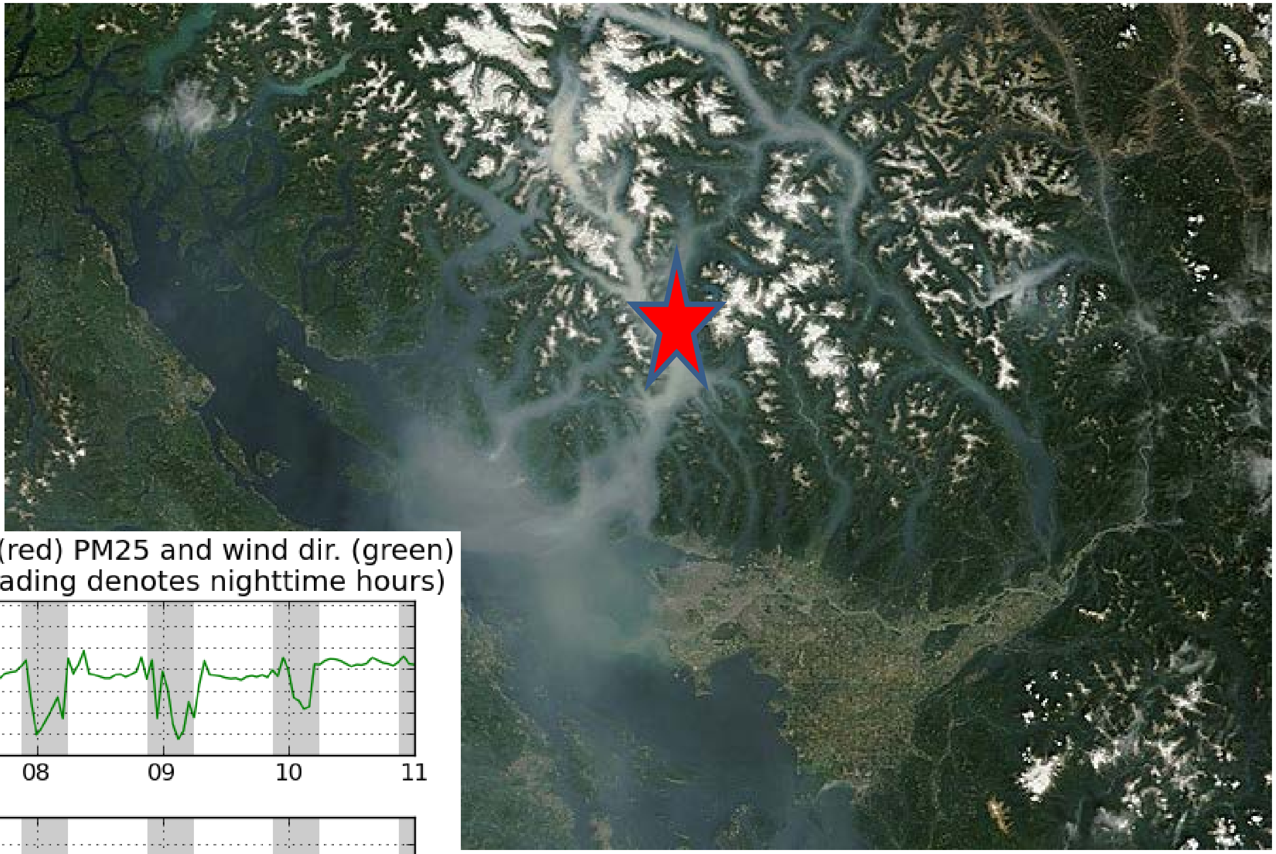
Forest fires often impact large areas downwind creating trans-boundary (both provincial and international) transport

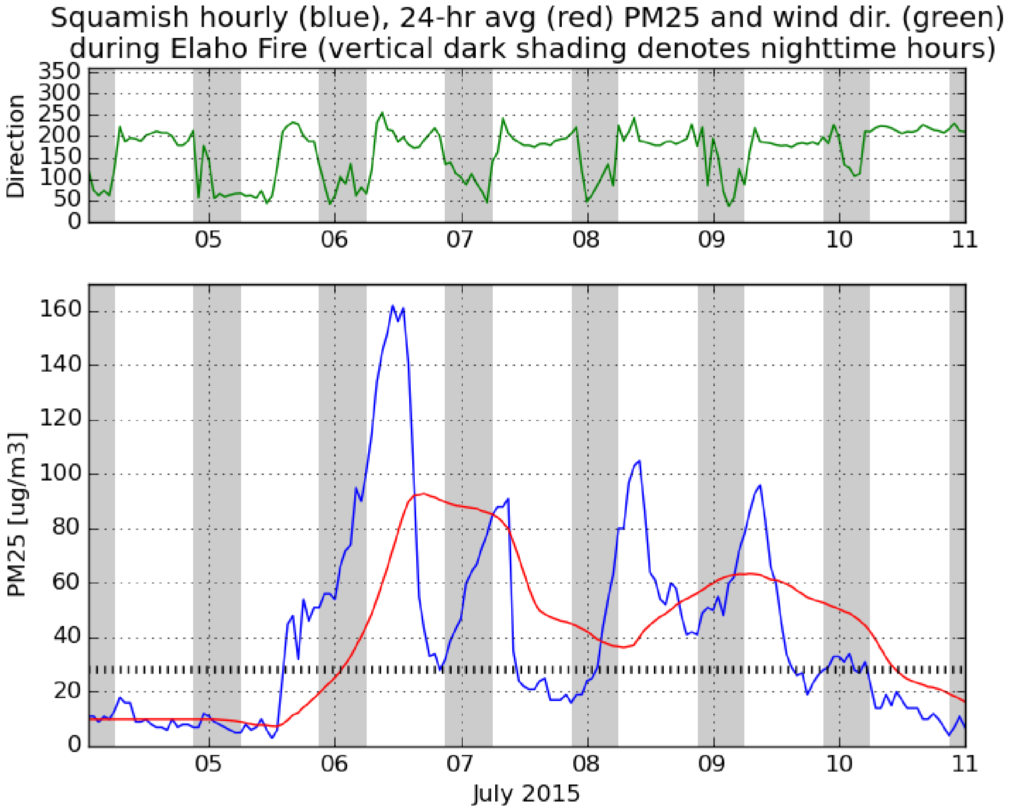
Smoke from forest fires in B.C. and the United States cloud Alberta's skyline. *TED RHODES / CALGARY HERALD*

The Calgary Fire Department has issued a fire ban as smoke from fires in the Pacific Northwest continues to blow into Alberta, leading to poor air quality that presents a "high" health risk.

NASA Worldview Aug 25, 2015

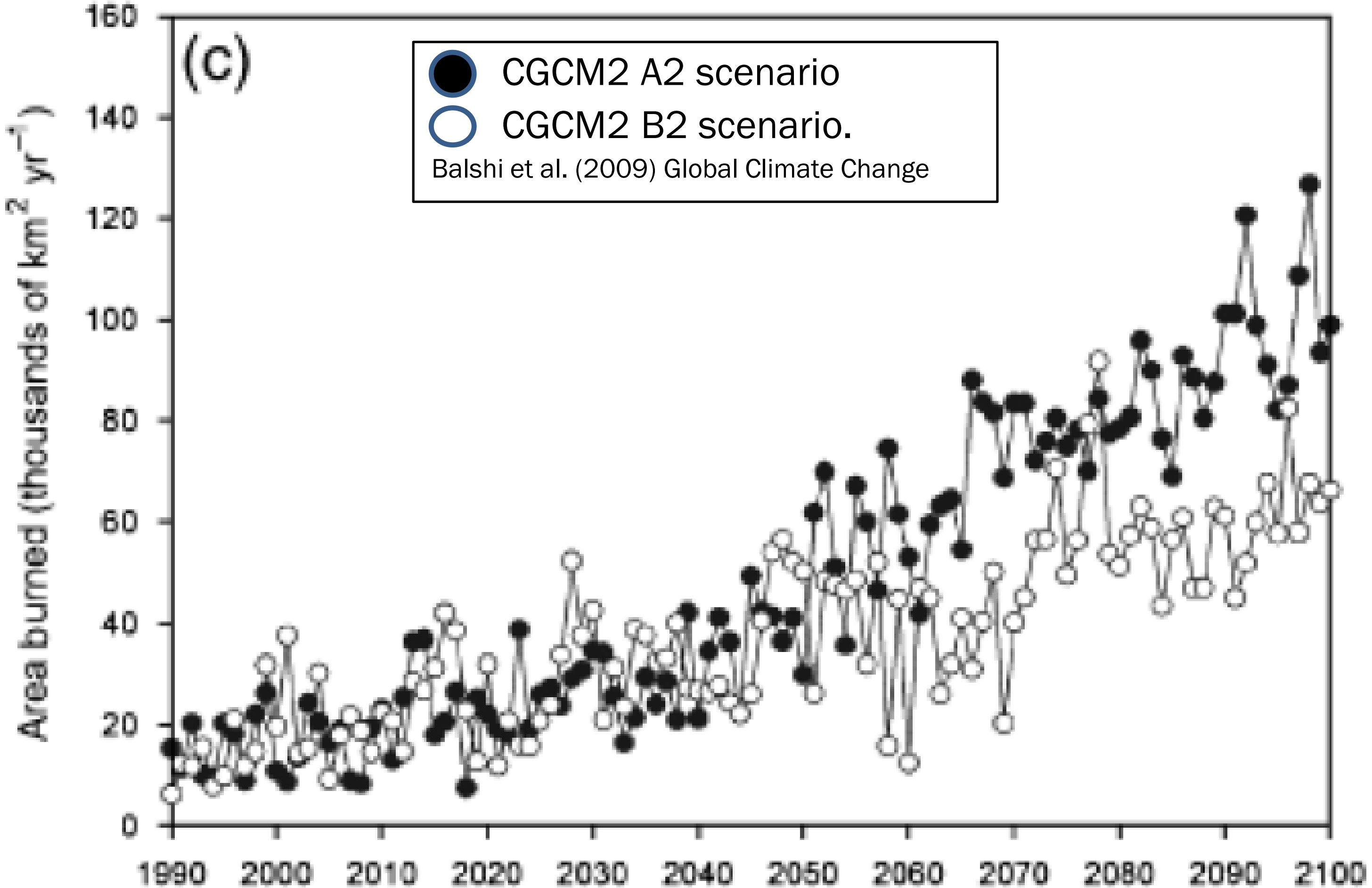
AQ Impacts





Forest fires impacts are sporadic but when they occur they can lead to AQ exceedances many times greater than CAAQS standards

Future Trends in Western Canada
Forest Fire behaviour



Potential for increased forest fire activity under climate change

Methodology

- Create statistical models for daily PM2.5 and ozone concentrations at all AQ stations in Western Canada
- Train models on ‘smoke free’ days
  - Use HMS shapefiles and associate ‘none’ categories with smoke-free
- Compare predictions versus observations on ‘smoke’ days
  - Use HMS shapefiles and associate ‘low’, ‘medium’ or ‘high’ categories with smoky days
- Some component of residual likely due to forest fires
- If possible, correlate residuals with spatial data in order to interpolate impacts across all of Western Canada

GAM for daily PM2.5

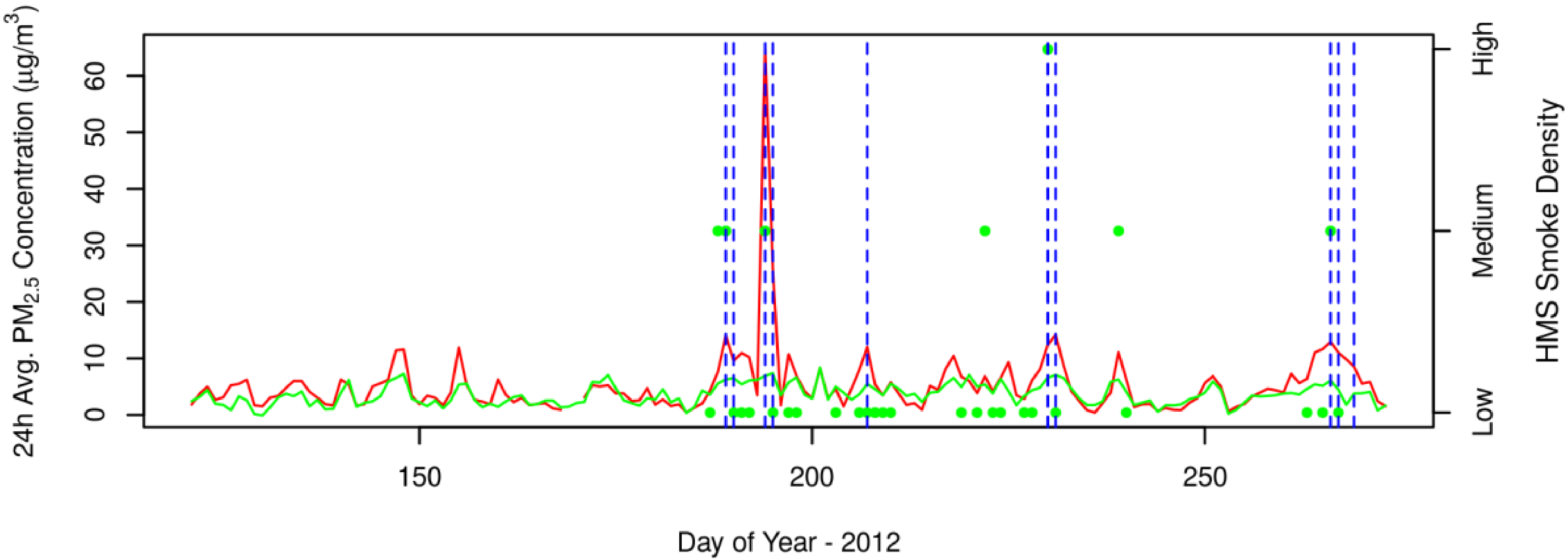
$$\mathrm{PM}_{2.5} \sim \beta_0 + \beta_1(\mathrm{Syn}_{\mathrm{sfc}}) + \beta_2(\mathrm{Syn}_{500}) + \beta_3(\mathrm{Syn}_{700}) + f(\mathrm{Temp}) + f(\mathrm{MLD}) + f(\mathrm{U}, \mathrm{V})$$

- Syn_{sfc}, Syn_{500} and Syn_{700} :daily categorical variables from a synoptic typing of summer (MJJAS) surface, 500 mb and 700 mb NCEP (1948-2015) pressure fields
- Temp, MLD, U, V: daily CFSR 2m temperature, mixed layer depth and 10m wind components

β_1, β_2, β_3: Linear regression terms for the synoptic typing variables

f() : smooth regression terms for temperature. MLD, etc

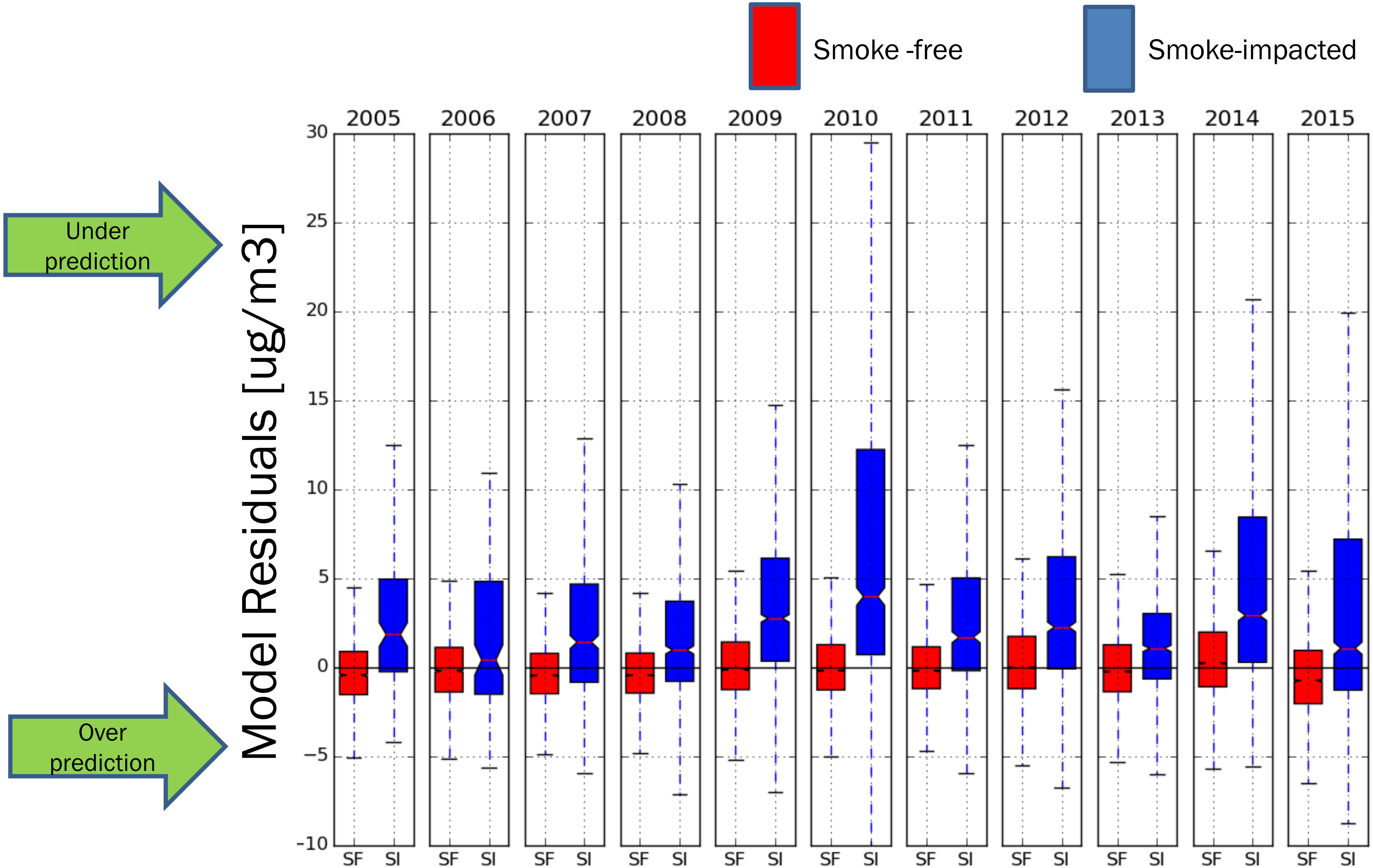
Model Results - Concentrations



- Comparison between modelled (green line) and observed (red line) PM values in Edson, AB
- HMS smoke density (green circles)
- Dates that have been manually flagged are identified by the dashed blue lines

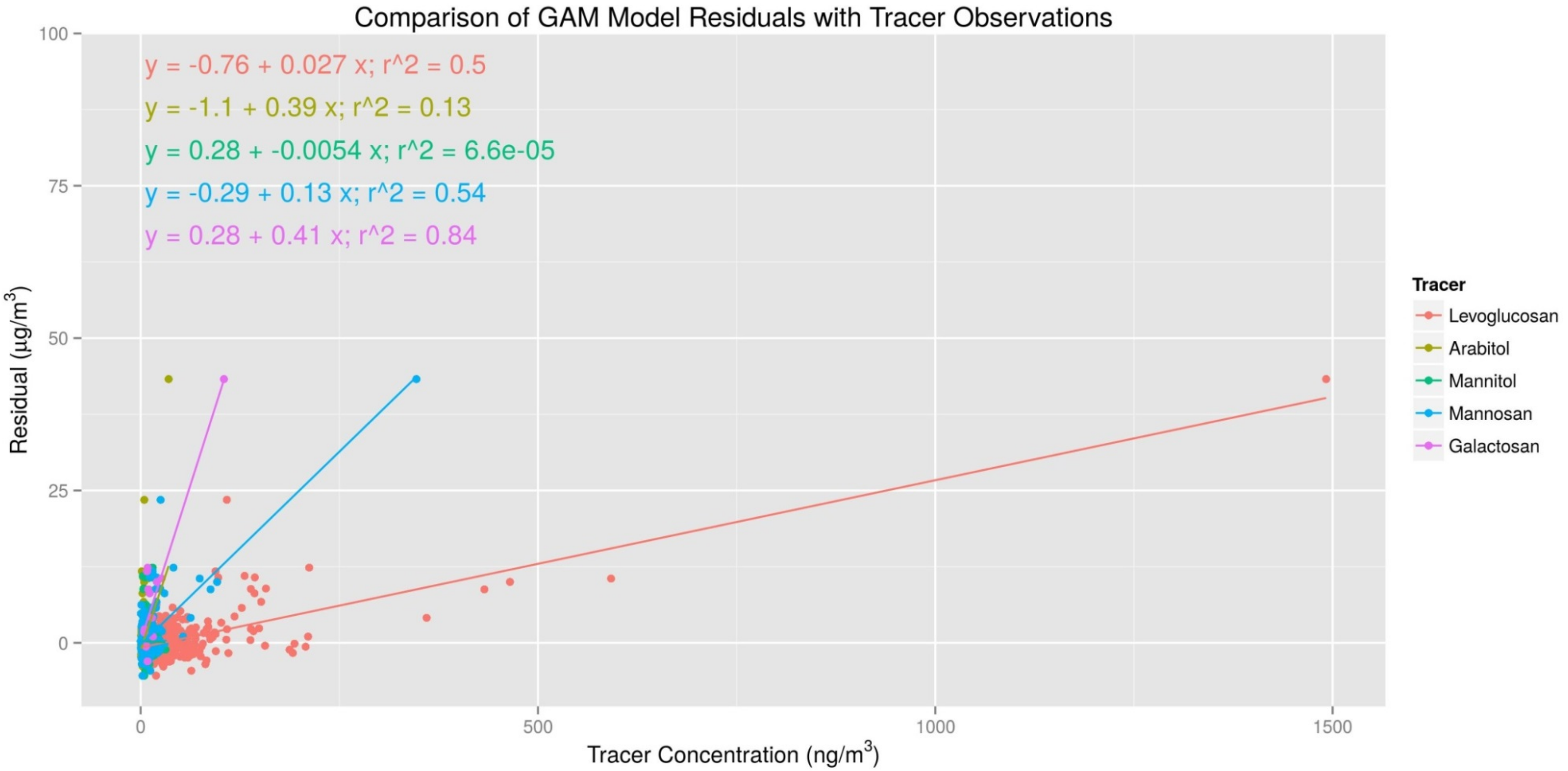
→ Not all smoke days are associated with high PM25

Model Results - Residuals



Clear relationship between HMS smoke density and model residuals for most years (in magnitude of residuals and variability of residuals)

Model Validation
PM2.5 residuals versus tracers



- Observations from 4 stations (3 in BC, 1 in AB)
- Levoglucosan (red), mannosan (blue), galactosan (purple) have all been previously shown to serve as tracers for biomass burning (*Sullivan* et al. 2014)

Spatial Interpolation

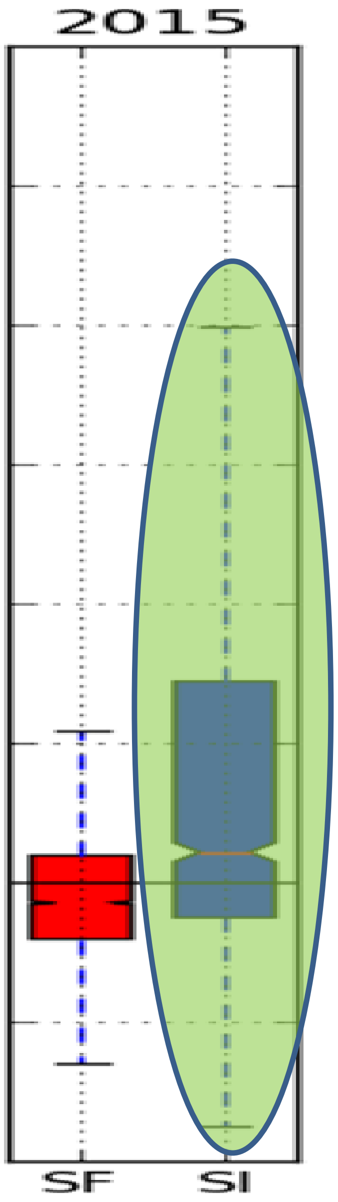
What causes variability in total forest fire PM contribution at each station?

- Create linear model for association between residuals and different spatial predictors:

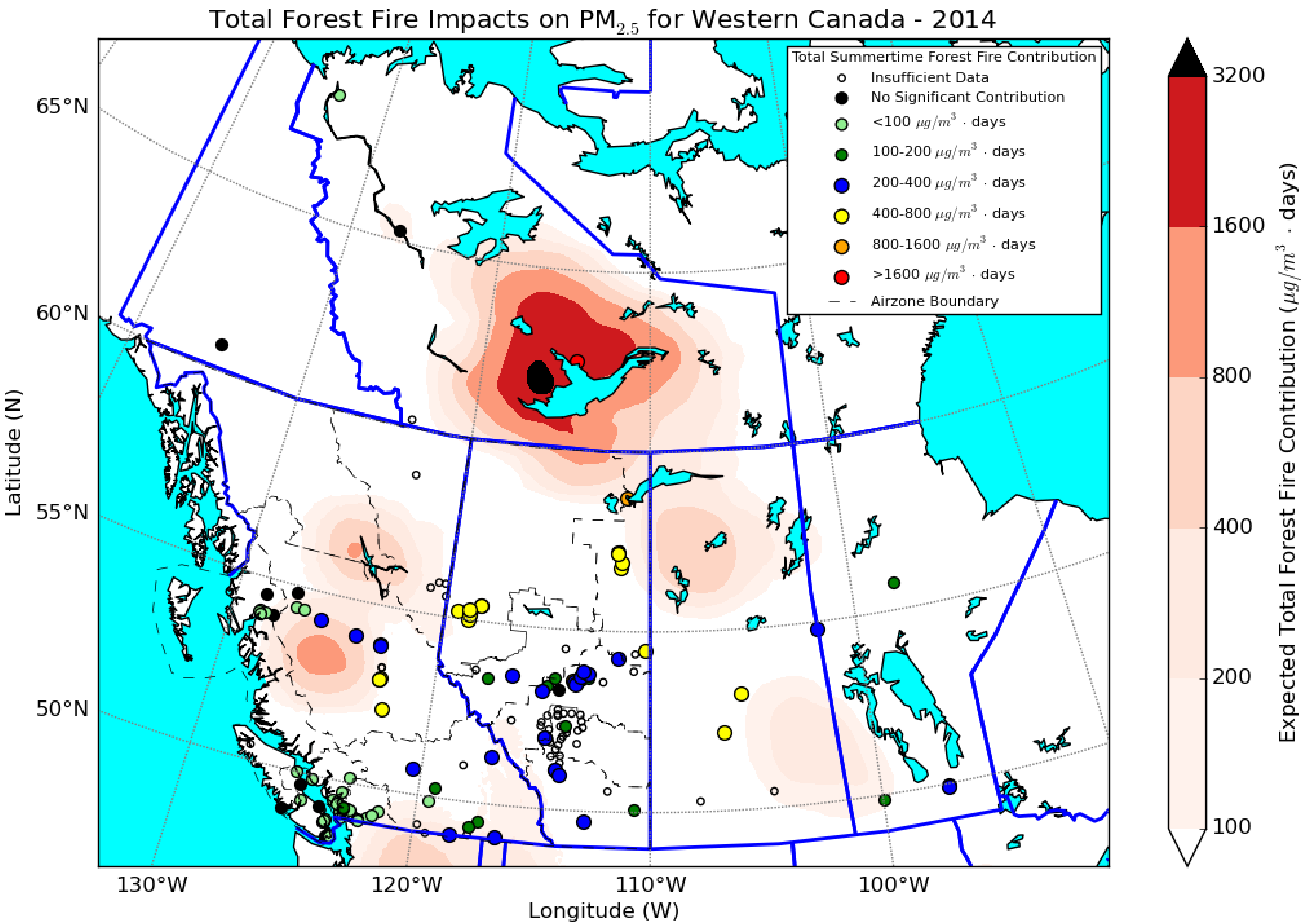
$$\text{Total PM}_{2.5} \sim \beta_0 + \beta_1\text{totaldays} + \beta_2\text{FSI} + \beta_3\text{Elev} + \beta_4\text{Steep}$$

  - Total number of smoke-affected days
  - Weighted avg of fire intensity (FRP) within surrounding 500 km x 500 km region
  - Local elevation
  - Steepness index (calculated from variability in elevation in surrounding 50 km x 50 km)

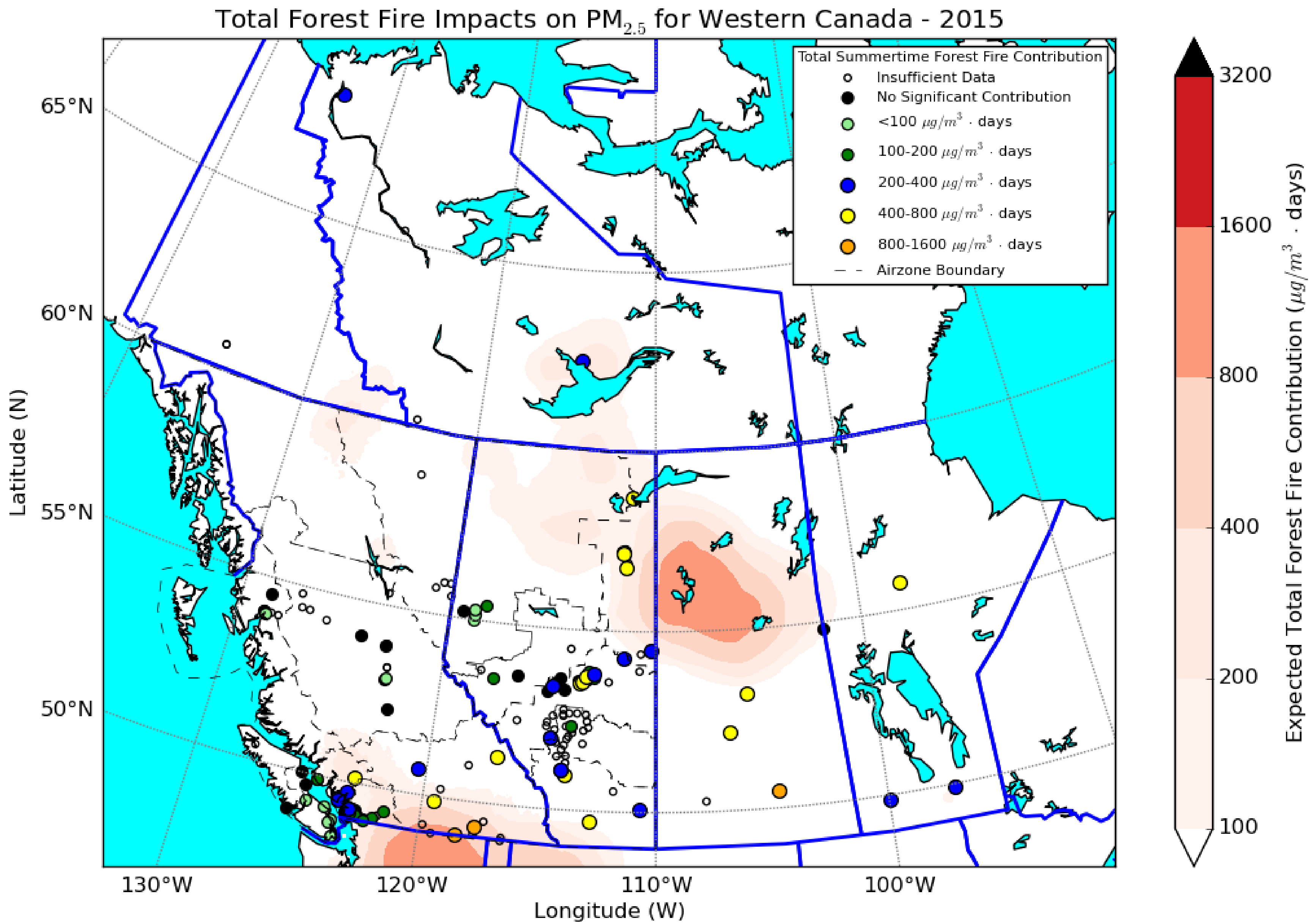
- Linear model explains most (R^2 = 0.67) of the residual variability at each station



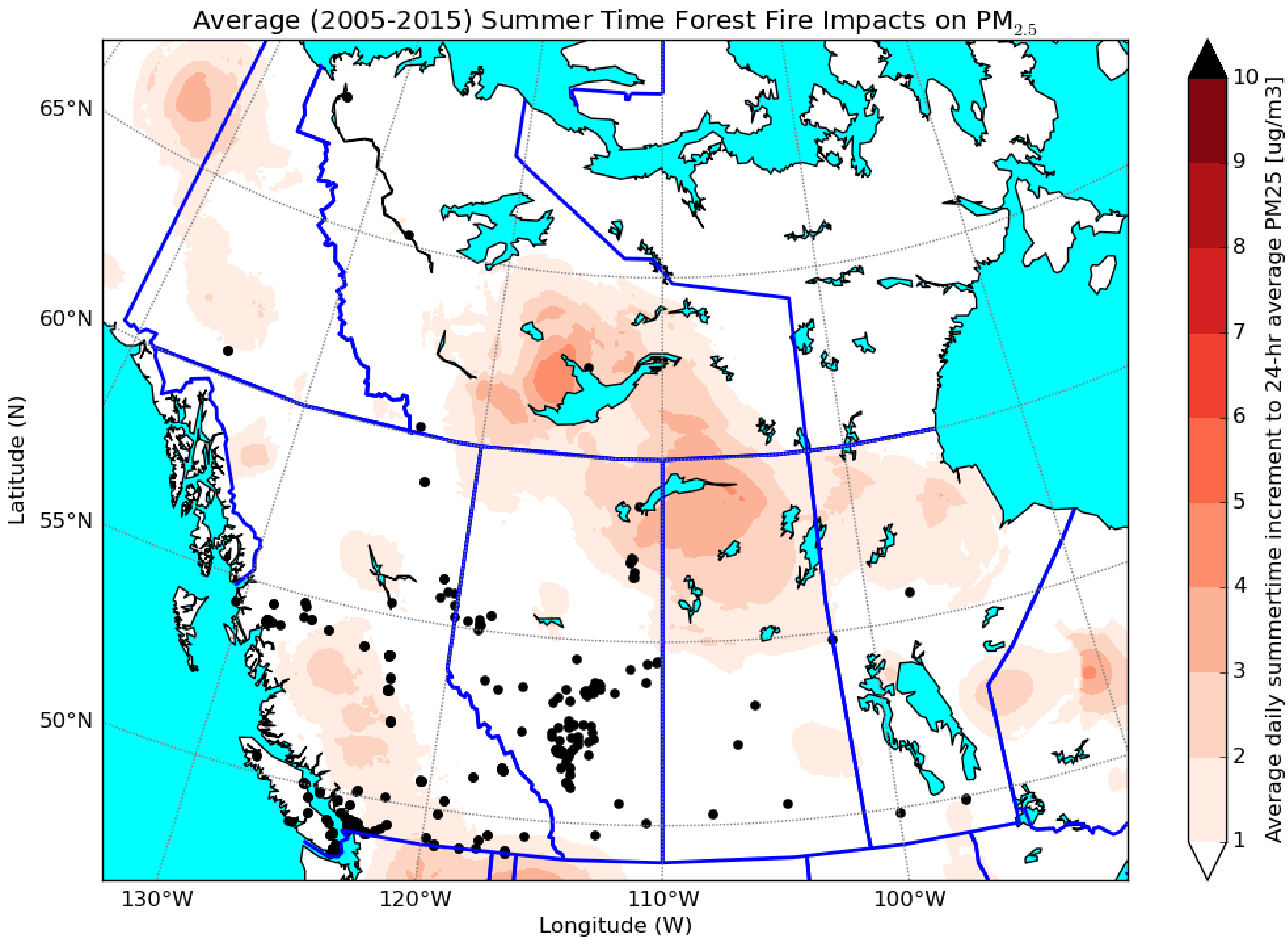
PM2.5 Results



PM2.5 Results



PM2.5 Results



GAM Ozone Model

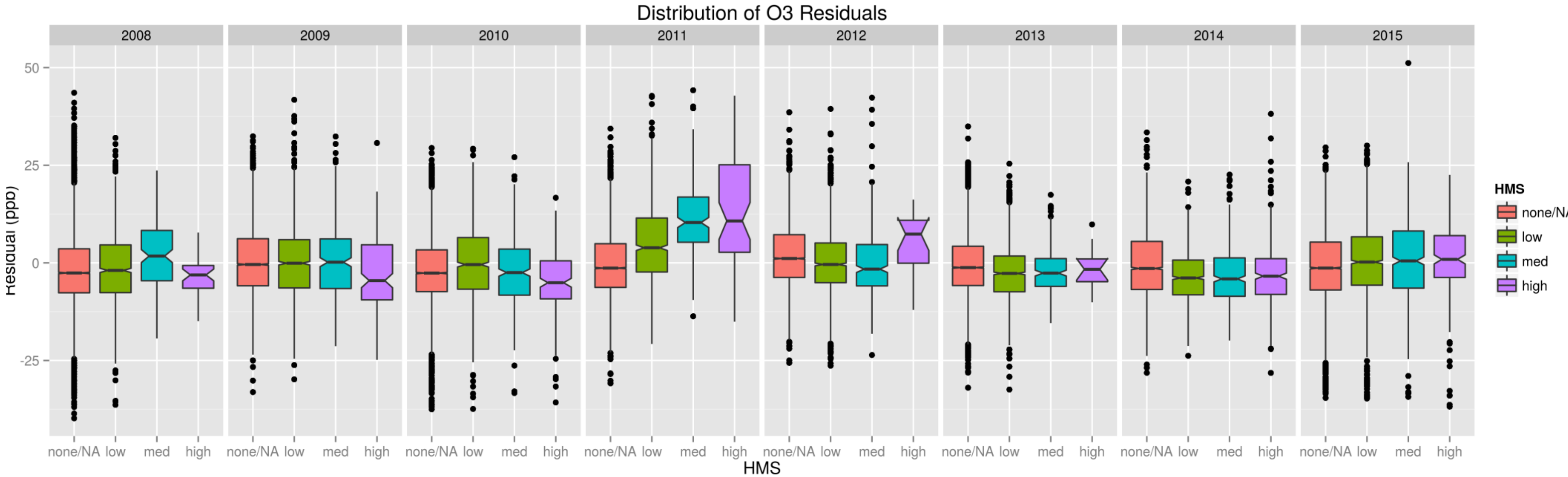
$$O_3 \sim \beta_0 + \beta_1(\mathrm{Syn_{sfc}}) + \beta_2(\mathrm{Syn_{500}}) + \beta_3(\mathrm{Syn_{700}}) + f(\mathrm{DoY}) + f(\mathrm{Temp}) + f(\mathrm{MLD}) + f(\mathrm{U,V})$$

- $\mathrm{Syn_{sfc}}$, $\mathrm{Syn_{500}}$ and $\mathrm{Syn_{700}}$:daily categorical variables from a synoptic typing of summer (MJJAS) surface, 500 mb and 700 mb NCEP (1948-2015) pressure fields
- Temp, MLD, U, V: daily CFSR 2m temperature, mixed layer depth and 10m wind components
- DoY: Day of year (1-365)

β_1, β_2, β_3: Linear regression terms for the synoptic typing variables

f() : smooth regression terms for temperature. MLD, etc

Model Residuals – versus HMS



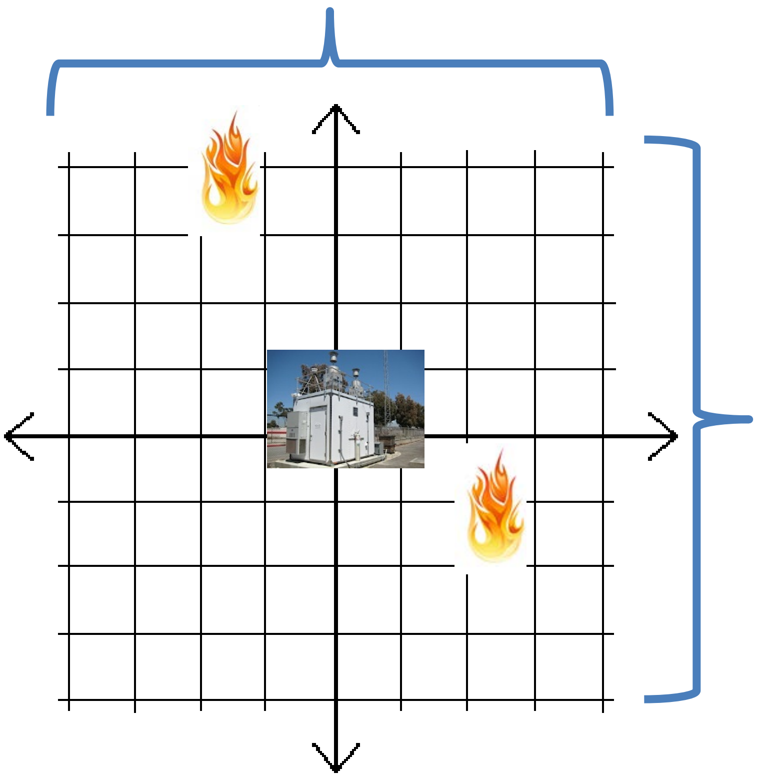
Problem:

- Relationship between model residuals and HMS smoke data is less clear
- Different screening technique necessary
  - *Brey & Fischer 2015* combine HMS data and PM observations

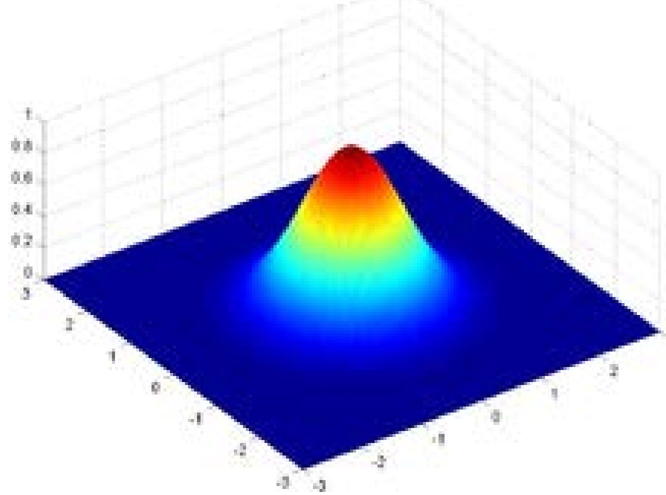
Fire Severity Index

$$\text{FSI} = \sum_{i=1 j=1} \left(\text{FRP}_{ij} \times w_{ij}\right), \text{ where } w_{ij} = \exp\left(\frac{-d_{ij}}{k}\right)$$

500 km



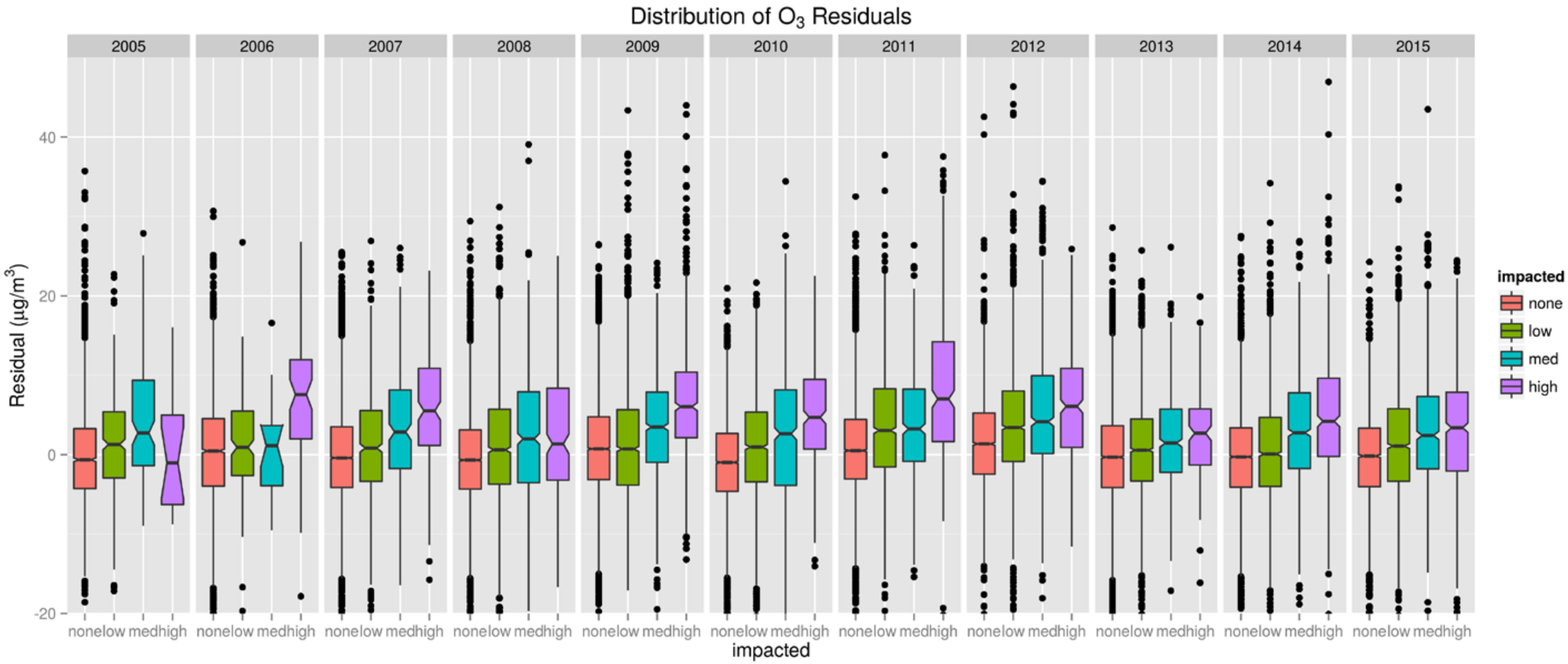
500 km



k = 100 km
e-folding distance

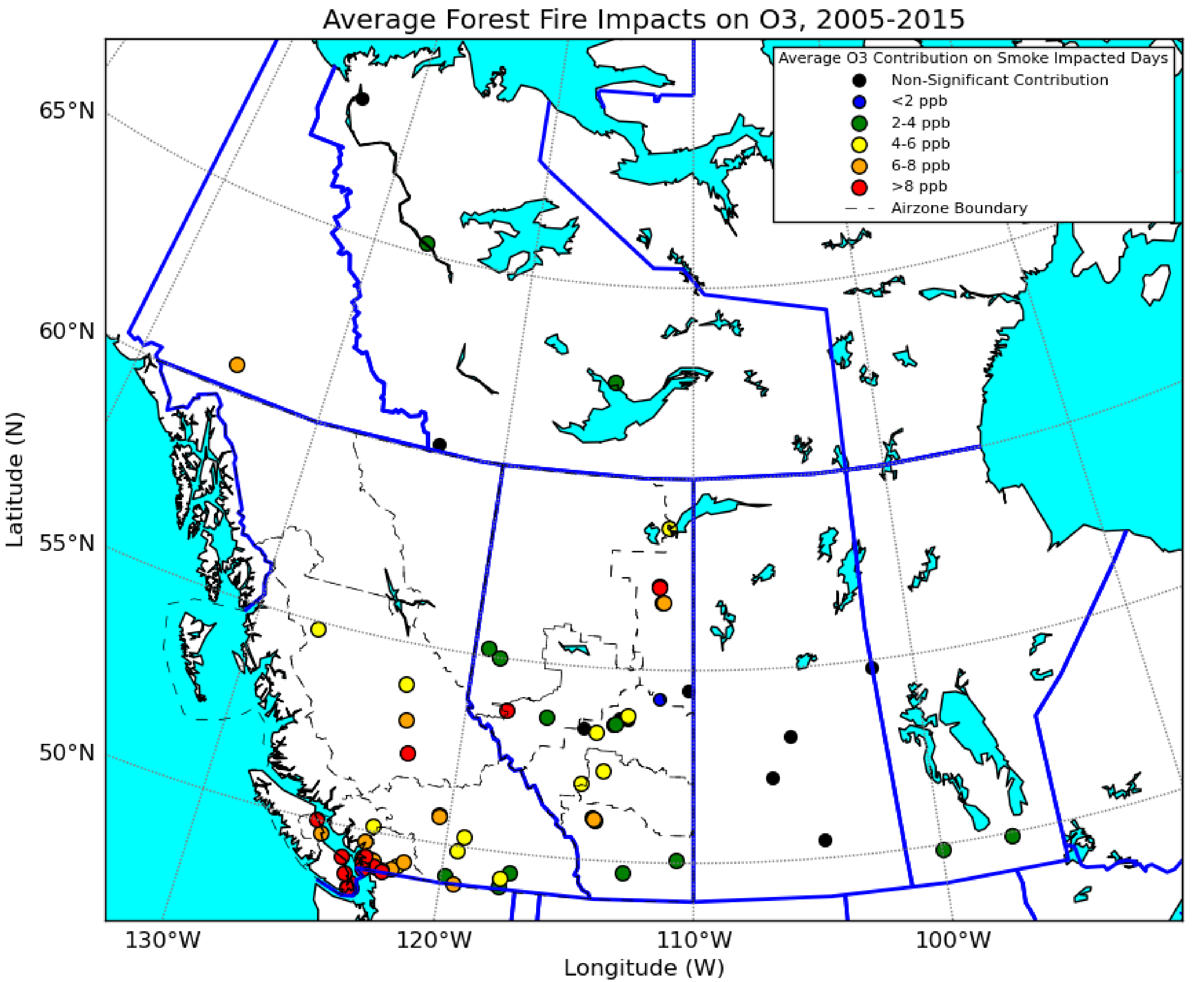
 = MODIS FRP

Model Residuals – versus FSI

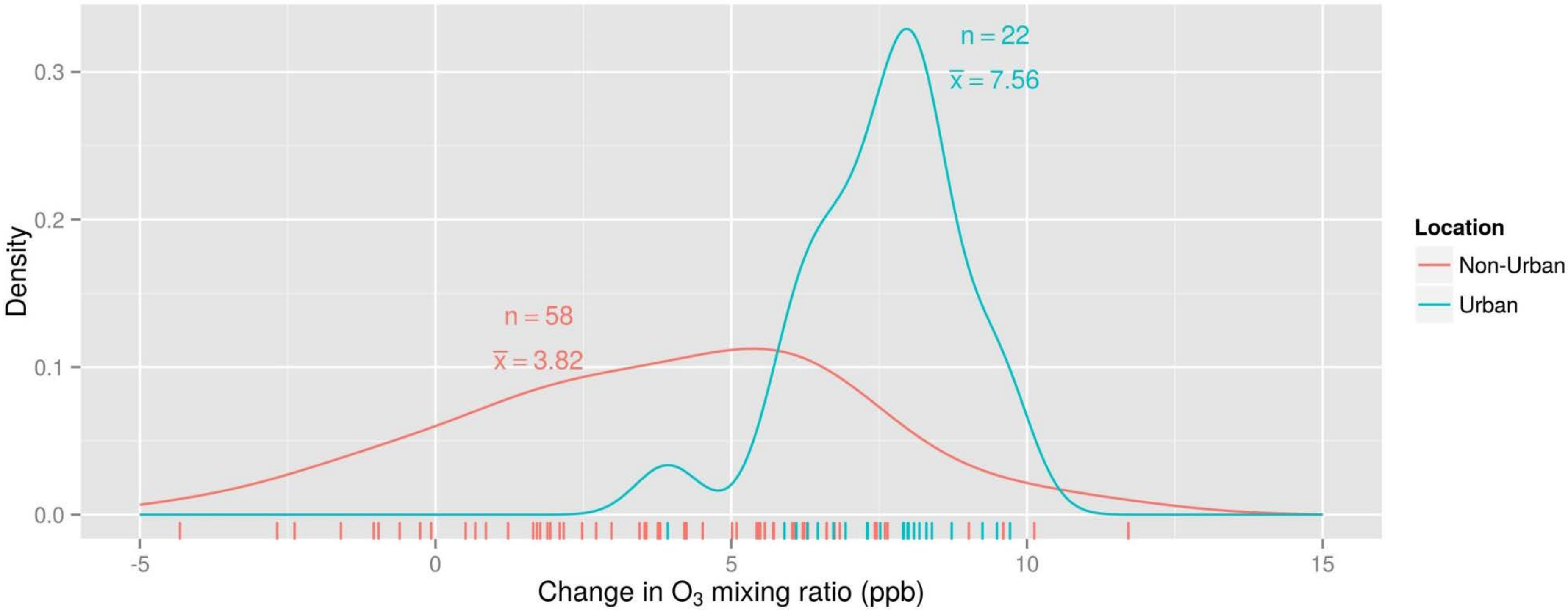


- FSI categorized based on percentiles:
  'low' (<80), 'med' ([80,95]) and 'high' (>95)
- Much better segregation between residuals and fire intensity
- FSI with buffer starts to get at dependence of FF impacts on ozone due to plume age (e.g. source distance)

O_3 Results – Average Per Smoke Day



O_3 Results – Urban vs Non-urban



- Significantly larger O3 enhancement in urban areas compared to non-urban areas
  - Based on thresholds for population density and NO_x emissions determined by natural breaks in the data from probability density function
- Similar relationship observed in *Brey & Fisher 2015*
- *Singh et al 2012* show some evidence that "forest fire plumes produced significant ozone when mixed with urban pollution by both providing precursors and reducing the titration effect

Summary of Results –PM2.5

- Presence of smoke from HMS is associated with high PM concentrations
- Total forest fire related PM is related to frequency of smoke, amount of emissions, and topographic factors
- Most strongly affected regions: N Sask., NWT
- First Nations areas are expected to have higher total impacts than urban areas

Summary of Results - Ozone

- Presence of smoke from HMS, in conjunction with elevated PM concentrations are associated with high O_3 concentrations
- Hard to interpolate, no meaningful associations found with O_3 impact and other predictors
- O_3 enhancement due to fires is larger on average for high-NO_x, high-population density regions
- Lower Mainland sees higher enhancements per fire event potentially due to urban O_3 chemistry

Future Work

- How will future climate change influence wildfires and their impact on PM2.5 concentrations?
- Use GCM output to calculate expected future burn areas using temperature, RH and other predictors
- Use these variables to extend the present analysis under different emission pathways

Average summertime wildfire impacts on 24-hr averaged PM2.5 versus area burned in Western Canada

Model Predicted (red) Linear Fit (blue) Estimated Future Impacts* (green)