Population Exposure Assessment for Wildfire Smoke

Bonne Ford
Department of Atmospheric Science
Colorado State University
Fort Collins, CO

Goal of Exposure Assessments

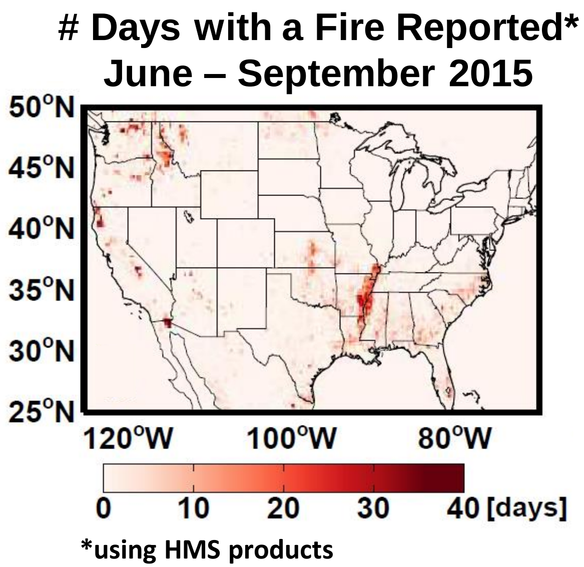
- **Retrospective:** Who was exposed?

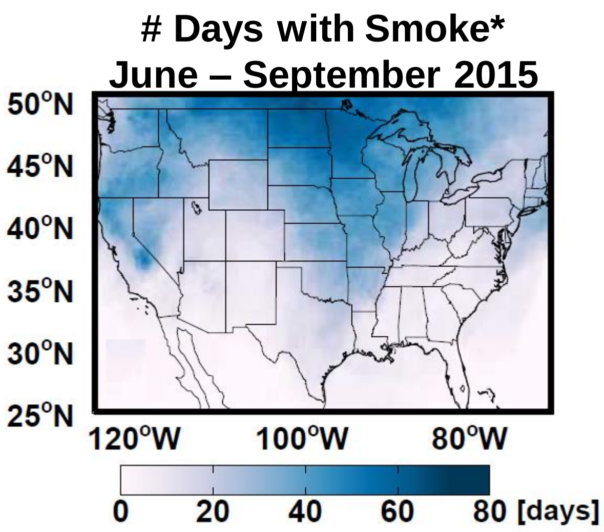
  (For how long? How much?)

  - Link exposure to other specific outcomes (health effects)
- **Prospective:** Who is at risk for exposure?
  - Reduce exposure
  - Provide/prepare resources

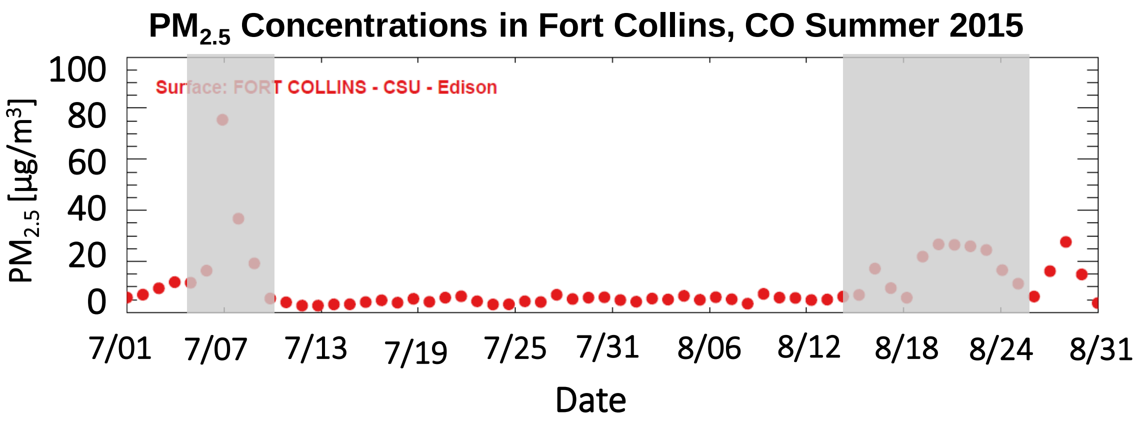
Assessing population exposure to wildfire smoke is challenging

- Smoke can travel long distances; exposure can occur far from the source





- Smoke concentrations are highly variable, in both space and time



Thus, a good exposure assessment requires tools with high resolution (spatial and temporal) and broad spatial coverage

Outline

- The ideal dataset for exposure assessment
- Conventional methods
    - And blended datasets
    - Forecast models
- Unconventional methods (crowd-sourcing/social media)
- New technologies: new satellites, low-cost sensors

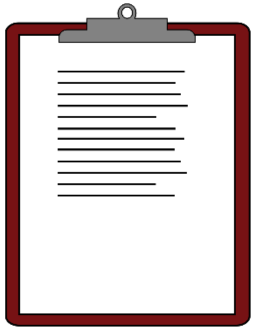
The ideal dataset for exposure assessment

Large group of people

Wearing personal monitors

Credit A. Birch

Charting personal history, symptoms, activities, and behaviors

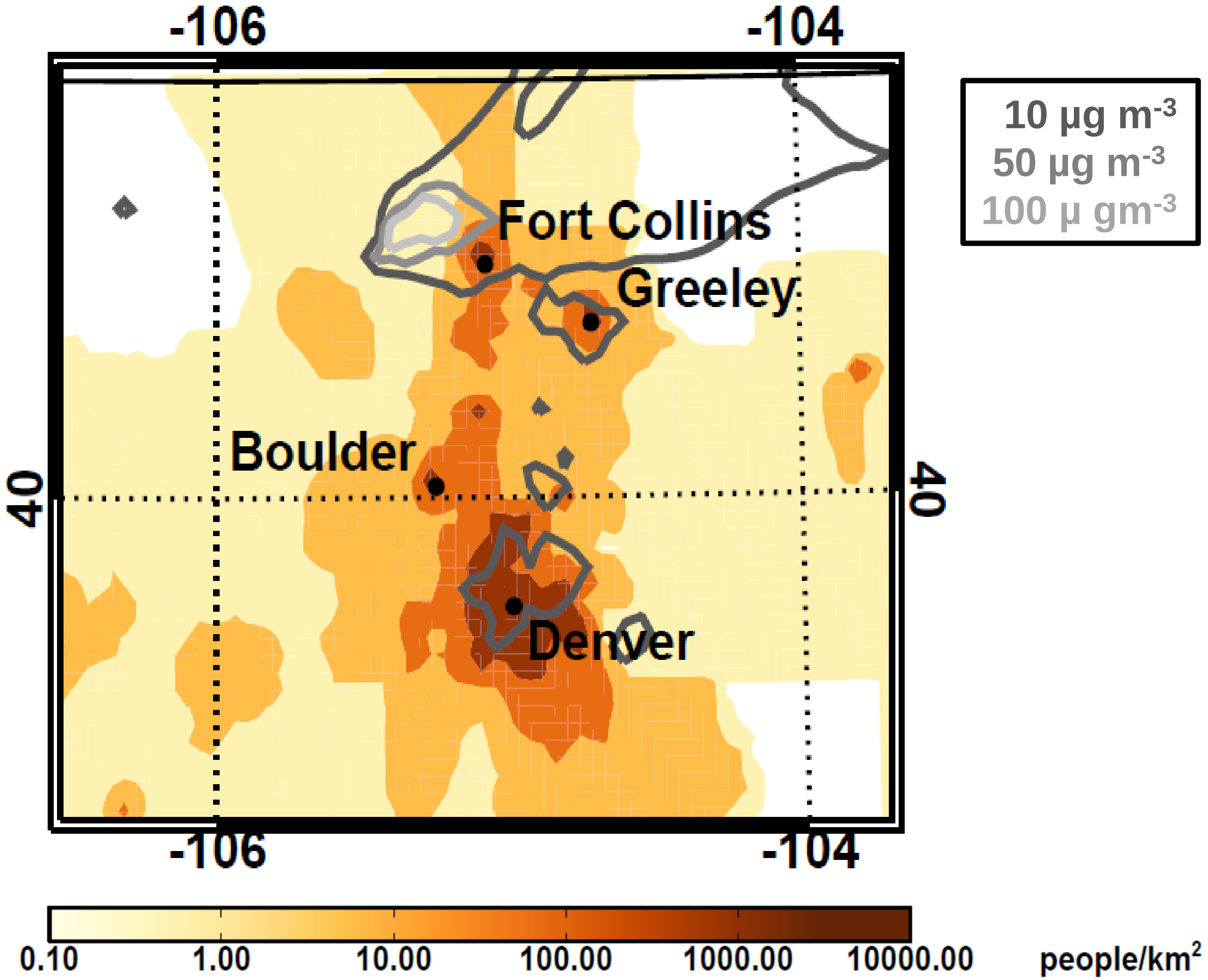


And giving us access to all their health records

- **Individual exposures within a population**
- **Little to no assumptions, more clearly determine cause and effect**

Instead, we generally try to determine population-level exposure

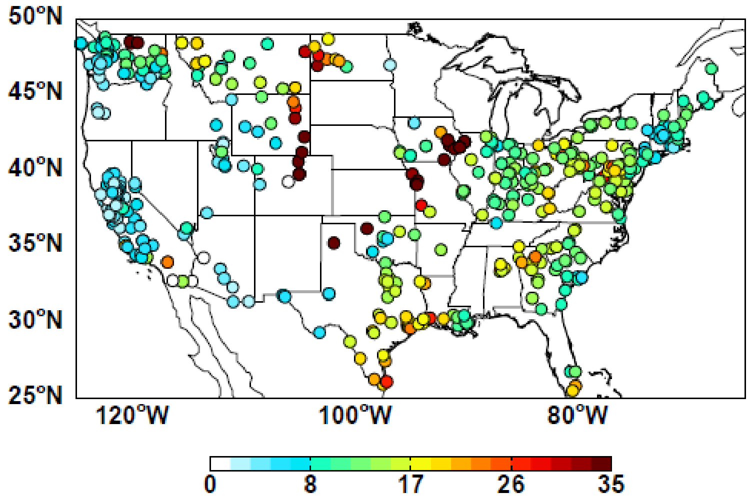
(exposure where people live or access healthcare)



Conventional Methods: 3 main tools

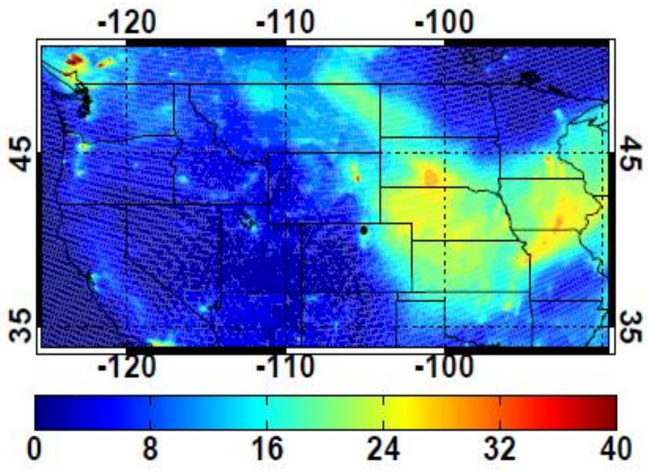
Ground Monitors

EPA AQS $PM_{2.5}$ 7 July 2015

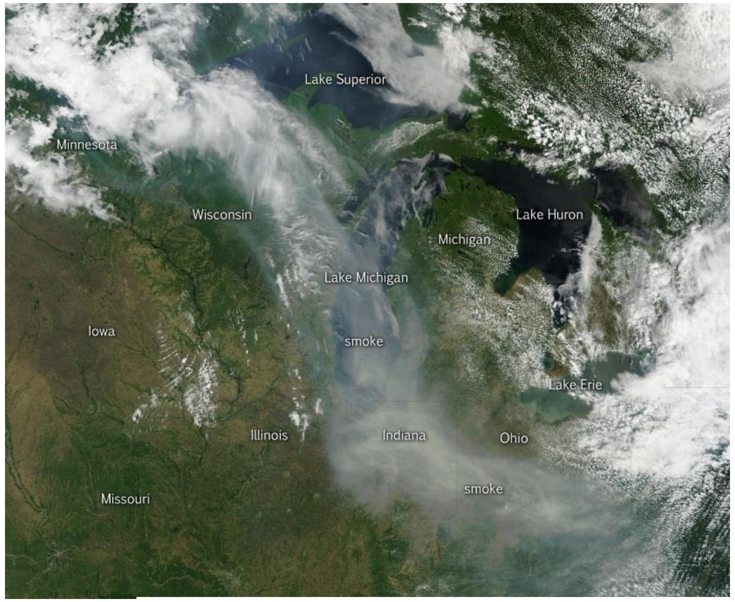


Atmospheric Models

WRF-Chem $PM_{2.5}$ 7 July 2015



Satellite Observations



MODIS True Color 30 June 2015

Each tool has its strengths and its limitations

(1) Ground/Surface Monitors

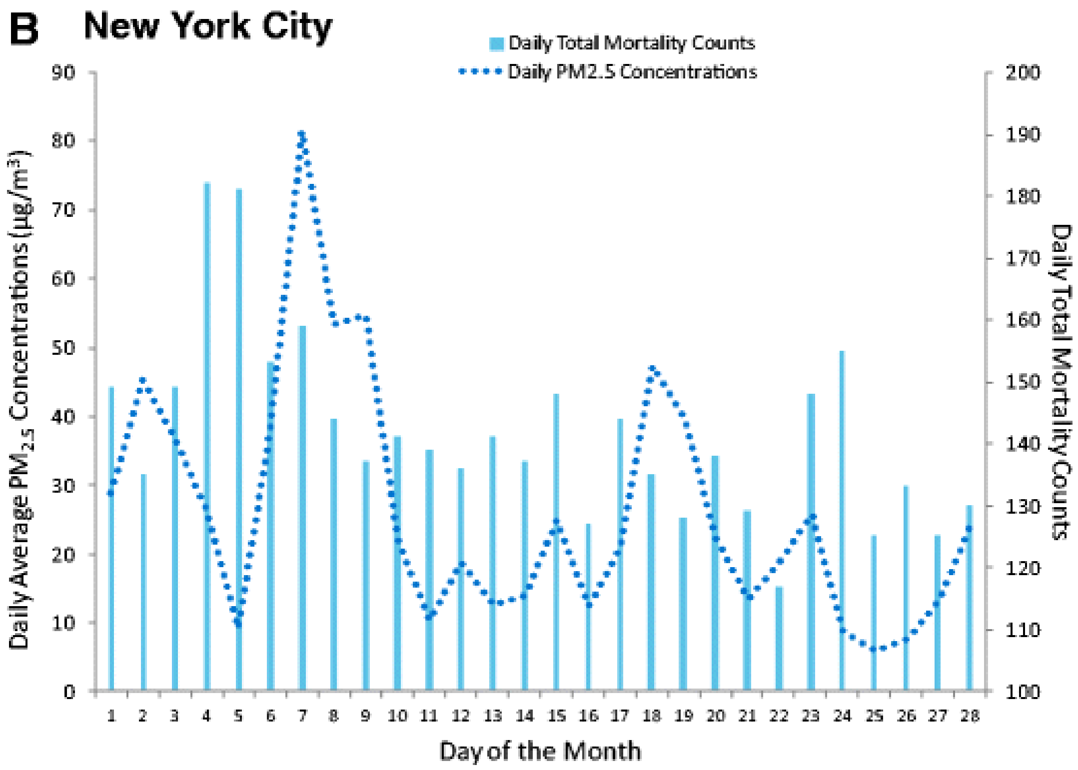
- Measuring Particle Mass ($PM_{2.5}$ or PM_{10})
  - Also, visual range (VR), extinction or AOD

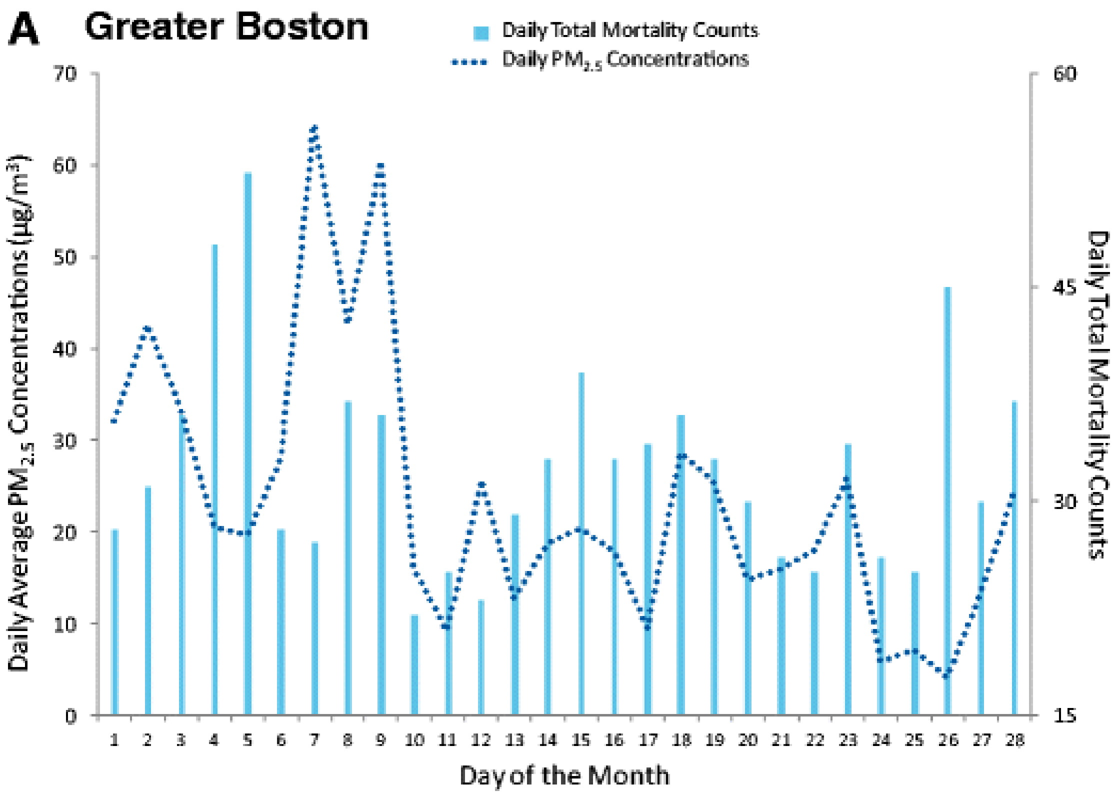
- Pros: Provide actual (or inferred) concentration at surface, where people breathe
- Cons: Limited in spatial extent, may be limited in temporal resolution (depending on measurement method/instrument)

- Challenges: distinguishing impact of smoke on total concentration (vs. from other sources)
- Methods: nearest monitor, interpolation, average over some geographical area

Example of using surface measurements

- Example of surface measurements used to estimate exposure in NYC and Boston for the 2002 Quebec fires





Zhu et al. 2016

Visual Range/Visibility

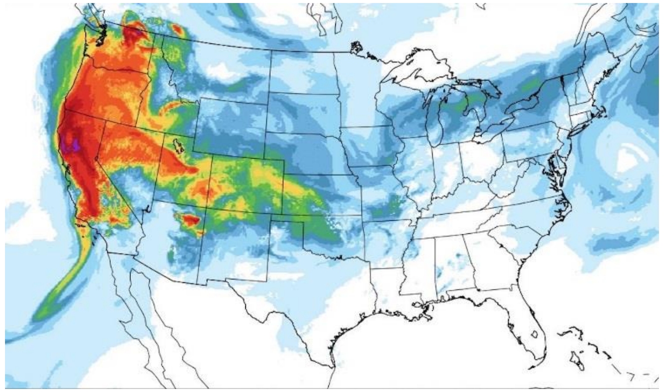
- Automated Surface Observing System (ASOS) at airports[1]
- Can relate to an extinction coefficient or a surface concentration (empirical relationship, IMPROVE network)
  - Impacted by relative humidity

- Human-sighted
  - In regions with no surface monitors, can train citizens to determine their own visual range to assess severity of smoke[2]
  - Does not correlate well with $PM_{2.5}$ concentrations[3]

Horsetooth Reservoir, CO

[1]Delfino et al., 2009/Wu et al., 2006
[2]O'Neill et al., 2013
[3]Schichtel and Husar, 1999

(2) Models

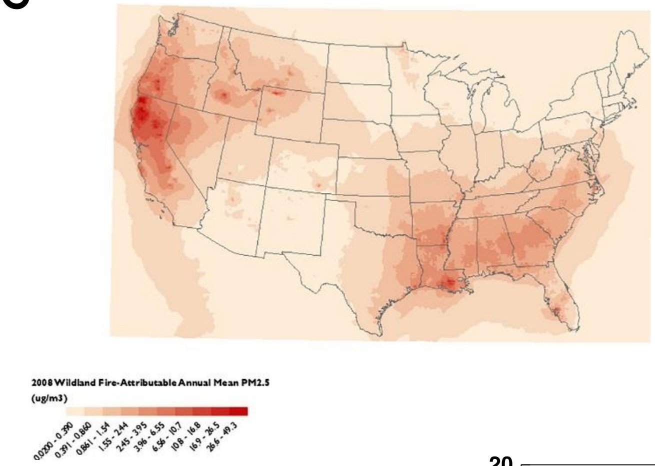


- Multiple kinds: Process-based (dispersion models, chemical transport models) or empirical models
- Process-based: combines fire information (location and emissions) with meteorological information to simulate smoke transport

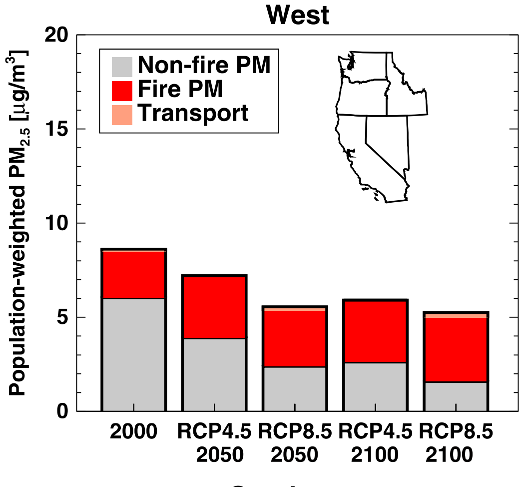
- Pro: Can provide excellent temporal and spatial coverage
- Pro: Can separate impact of smoke on concentrations
- Con: concentrations might not be right (very dependent on input meteorology and emissions- specifically, injection height!)

Examples using models to estimate smoke exposure

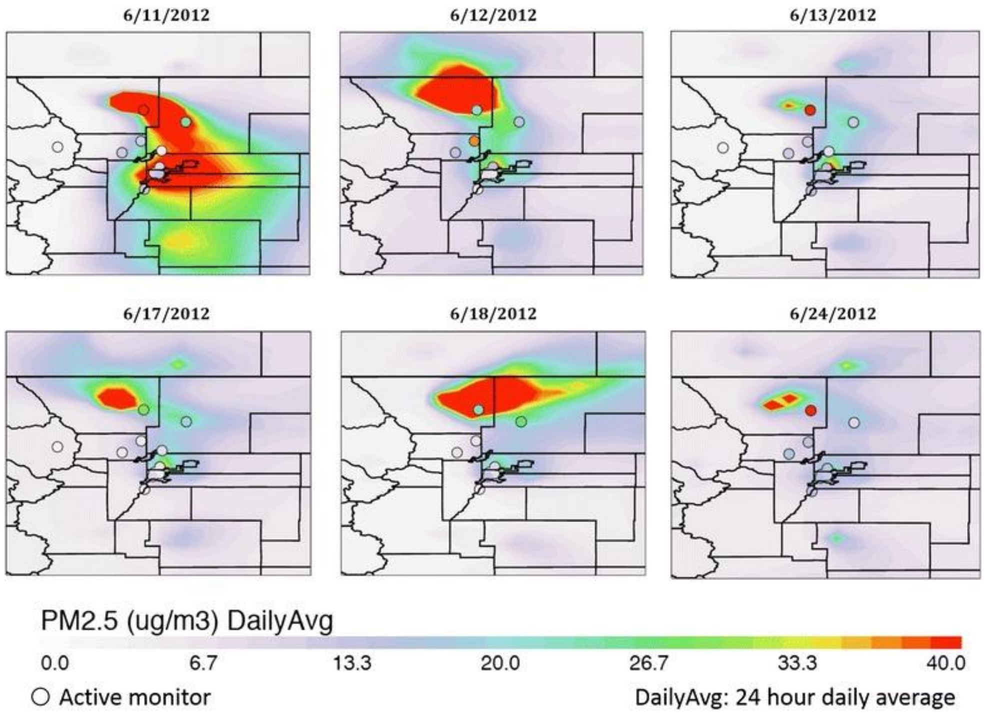
- National estimates (CMAQ) for smoke in the US[1]



- Land and atmosphere model (CESM) to predict future smoke exposure in the US[2]



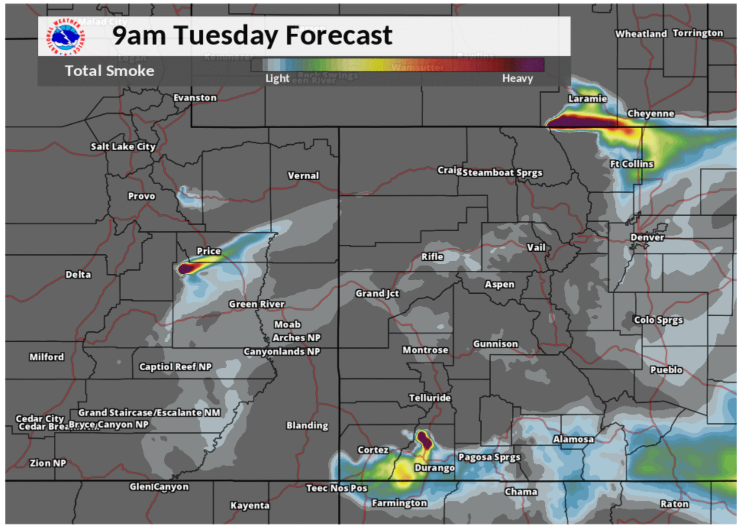
- WRF-Chem simulations of wildfires in Colorado 2012[3]



[1]Fann et al., 2018
[2]Ford et al., 2018
[3]Alman et al., 2016

Smoke Forecast Models are used for both retrospective and prospective exposure assessments

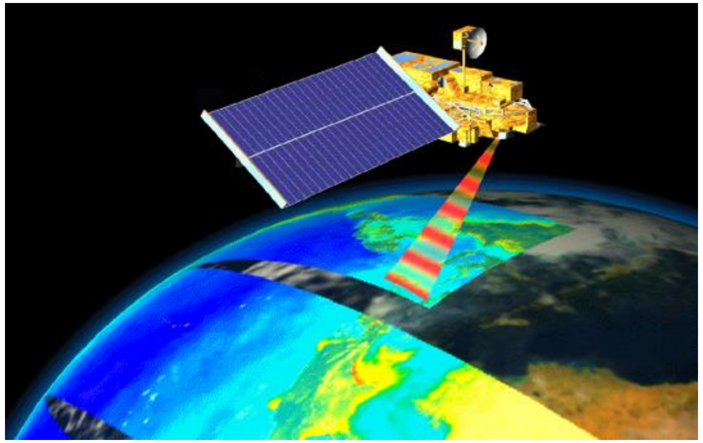
- Blue Sky[1]
- NOAA Smoke[2]
- NAAPS[3]
- FireWork[4]
- HRRR-Smoke



- Dispersion models tend to overpredict near sources and underpredict downwind
- Better on short timescales, because forecasting fire behavior (and response) is challenging
- Data fusion and data assimilation can improve smoke forecasts substantially

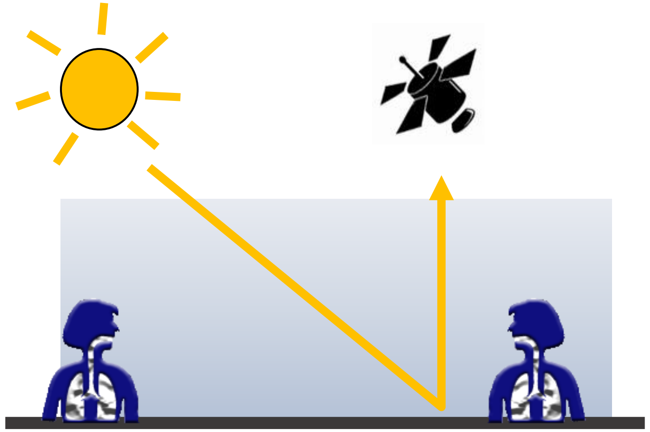
[1]Yuchi et al., 2016; [2]Rappold et al., 2012; [3]Faustini et al., 2015; [4]Yuchi et al., 2016

(3) Satellites

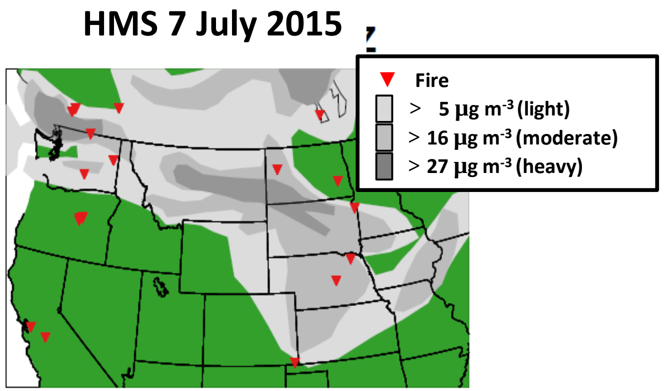


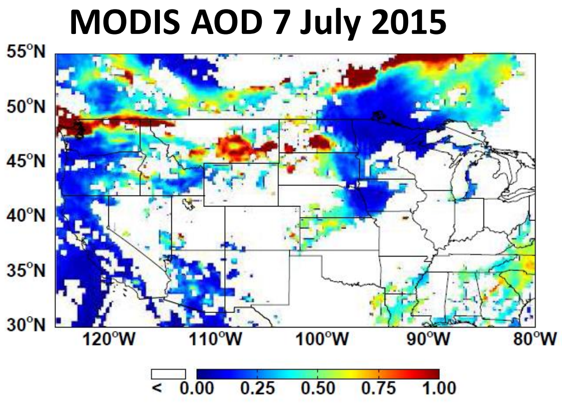
- Polar-orbiting vs. geostationary satellites
- Active vs. passive instruments
- Can provide good spatial coverage
  - May be limited spatial resolution
- May be limited in temporal coverage
  - Passive instruments are limited to daytime observations
- Difficult to distinguish smoke from clouds

- Give spatial extent, but not surface concentration
  (smoke can be elevated above the surface)



Satellite Instruments and Products

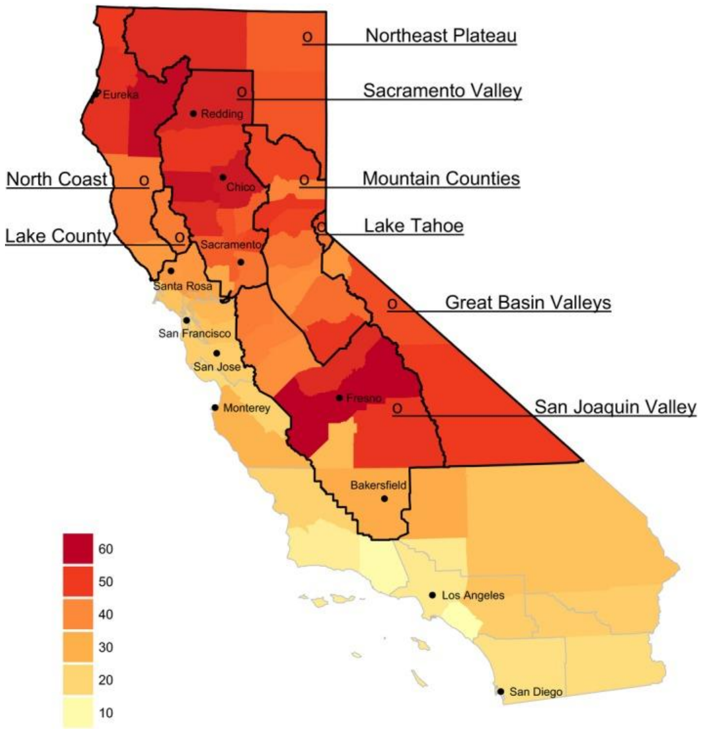




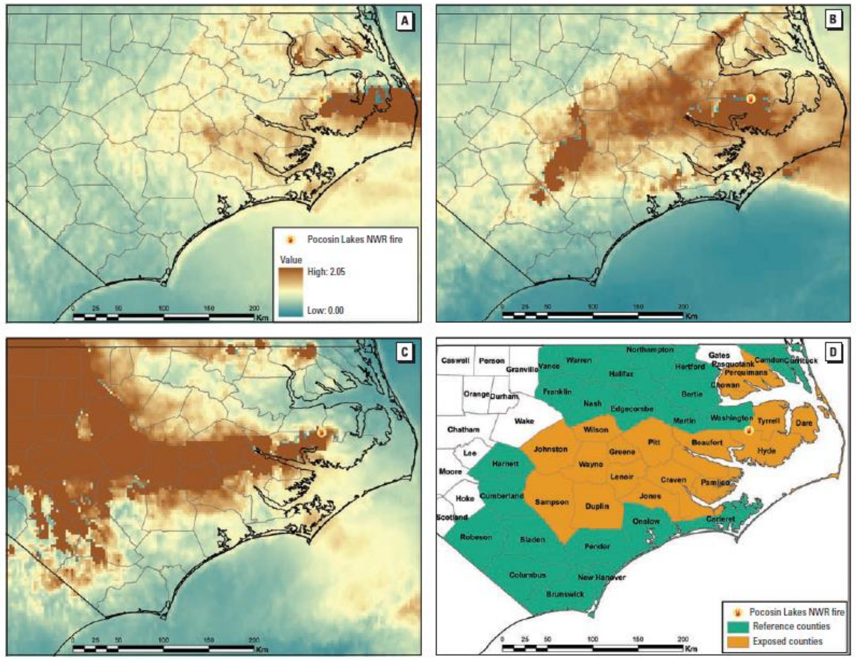
- Smoke Plumes from NOAA's Hazard Mapping System
- Aerosol Optical Depth (AOD)
  - MODIS Aqua and Terra, MISR, GASP
- Extinction Profiles
  - CALIPSO
- Plume Heights
  - MISR

Examples using satellite observations

- HMS smoke plumes for California fires in 2015[1]



- AOD for North Carolina peat bog fires in 2008[2]

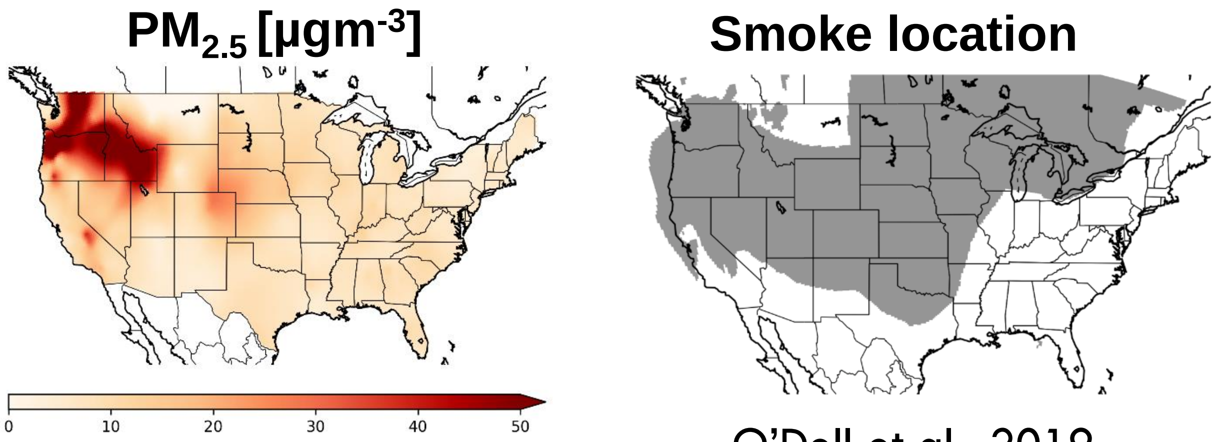


[1]Wettstein et al., 2018; [2]Rappold et al., 2011

Blended Methods

- Researchers seek to overcome limitations of individual tools by combining them
- Can combine other data as well (fire activity, weather)

- Statistical combination or simply a corroboration of a different exposure methods

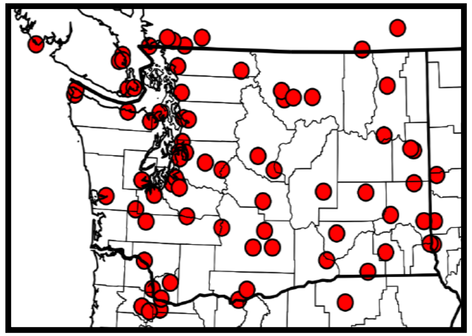


O’Dell et al., 2019

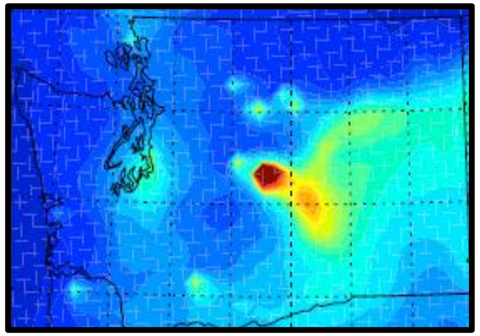
Examples of Blended Methods

- Empirical relationships between surface PM, MODIS AOD, HMS, MODIS Fire Radiative Power (FRP), etc.[1]
- Machine-learning[2]

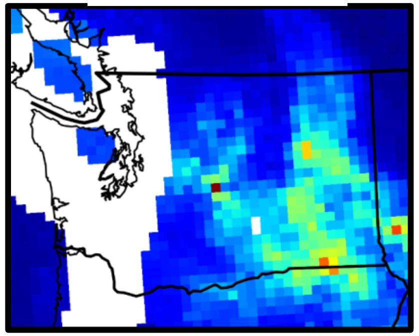
Surface $PM_{2.5}$ Measurements



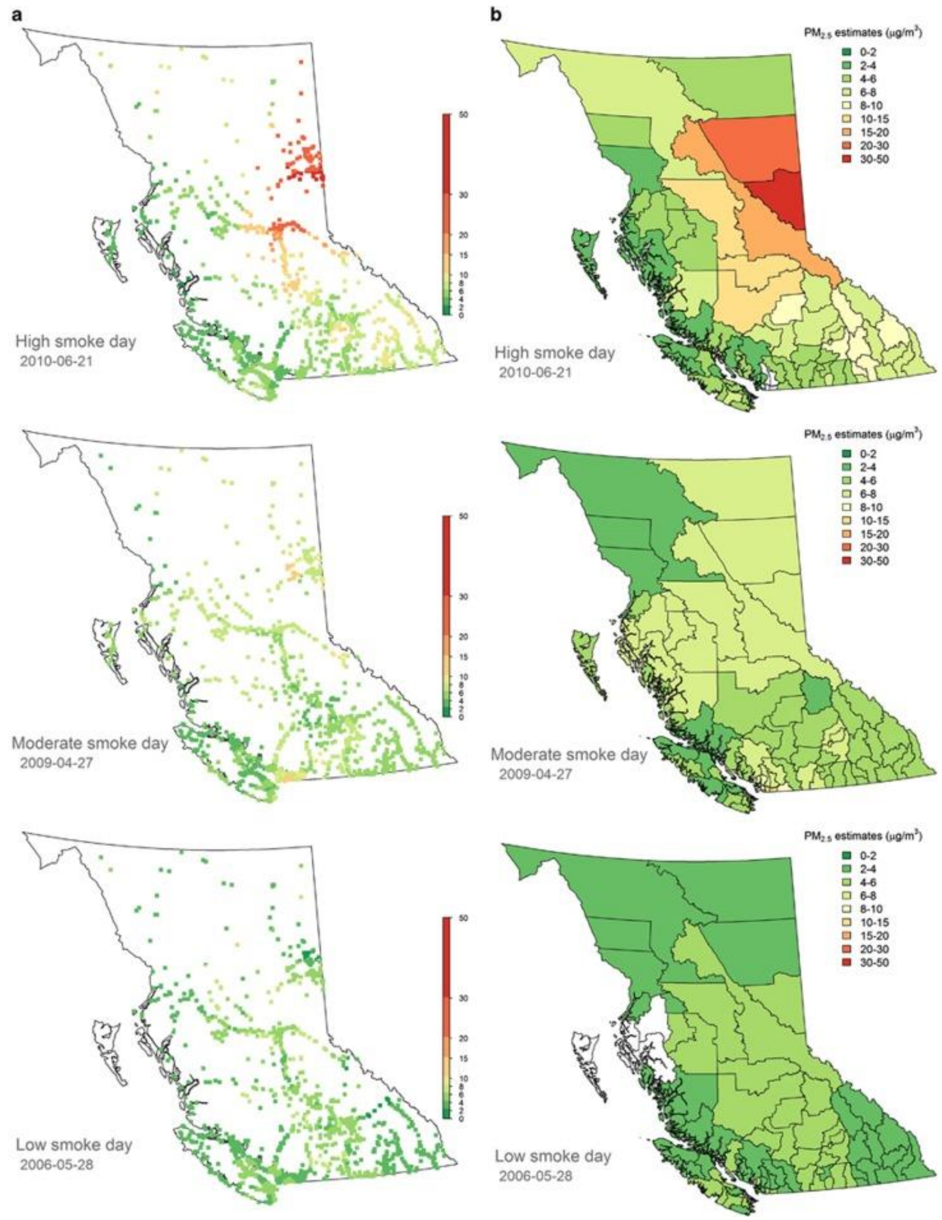
WRF-Chem Simulated $PM_{2.5}$



MODIS AOD



Lassman et al., 2017

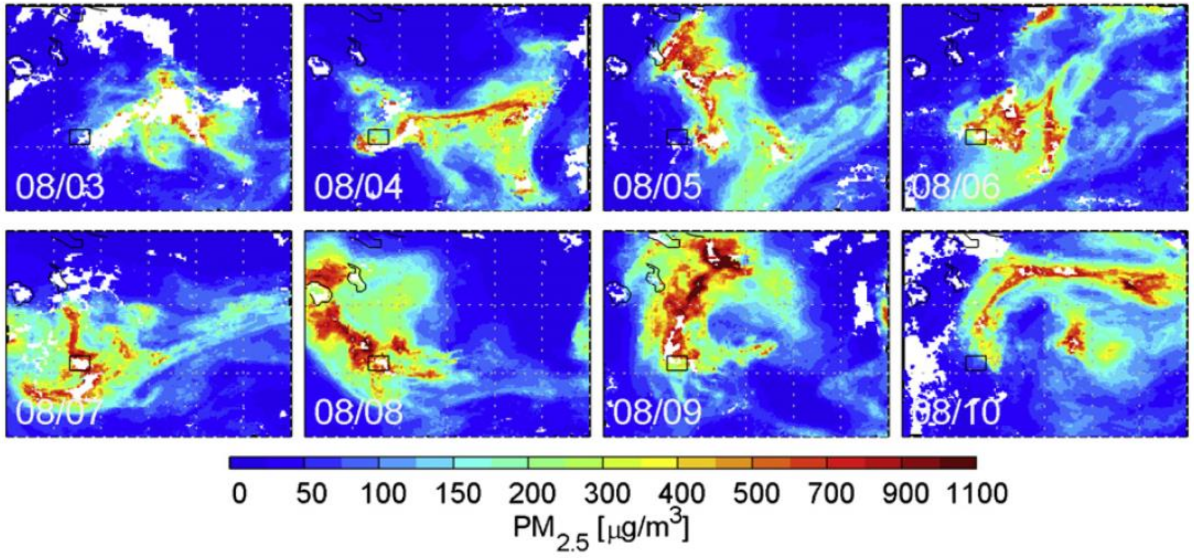


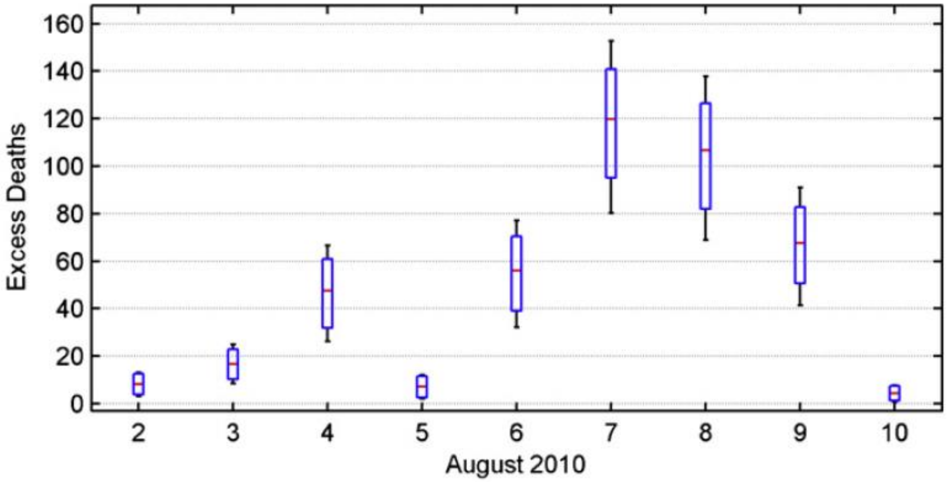
[1]Yao and Henderson, 2014 and Yao et al., 2016
[2] Reid et al., 2015

“Satellite-derived” $PM_{2.5}$

- Combines satellite AOD with a modeled relationship between PM and AOD (done for total $PM_{2.5}$ or sources/aerosol species)

- Example: Moscow wildfires of 2010[1]





[1]van Donkelaar et al., 2011

*Similar method used to estimate the global mortality burden of landscape fires in Johnston et al., 2012

Unconventional Methods: Crowd-sourcing/social media

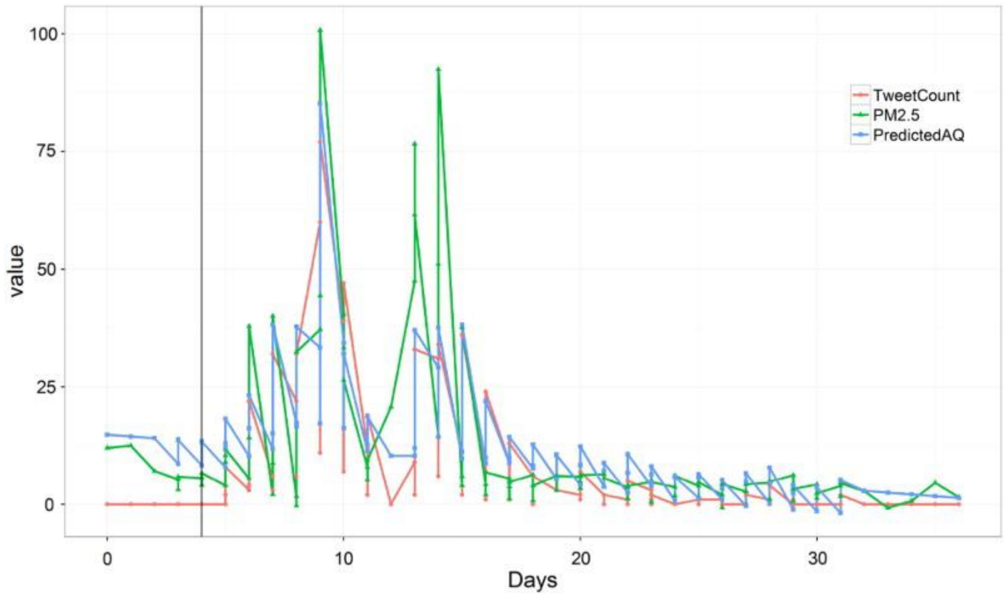
Our Reasoning:

- Can't people just tell us when they were exposed?!

- Can provide geographic information and potentially sentiments and health response

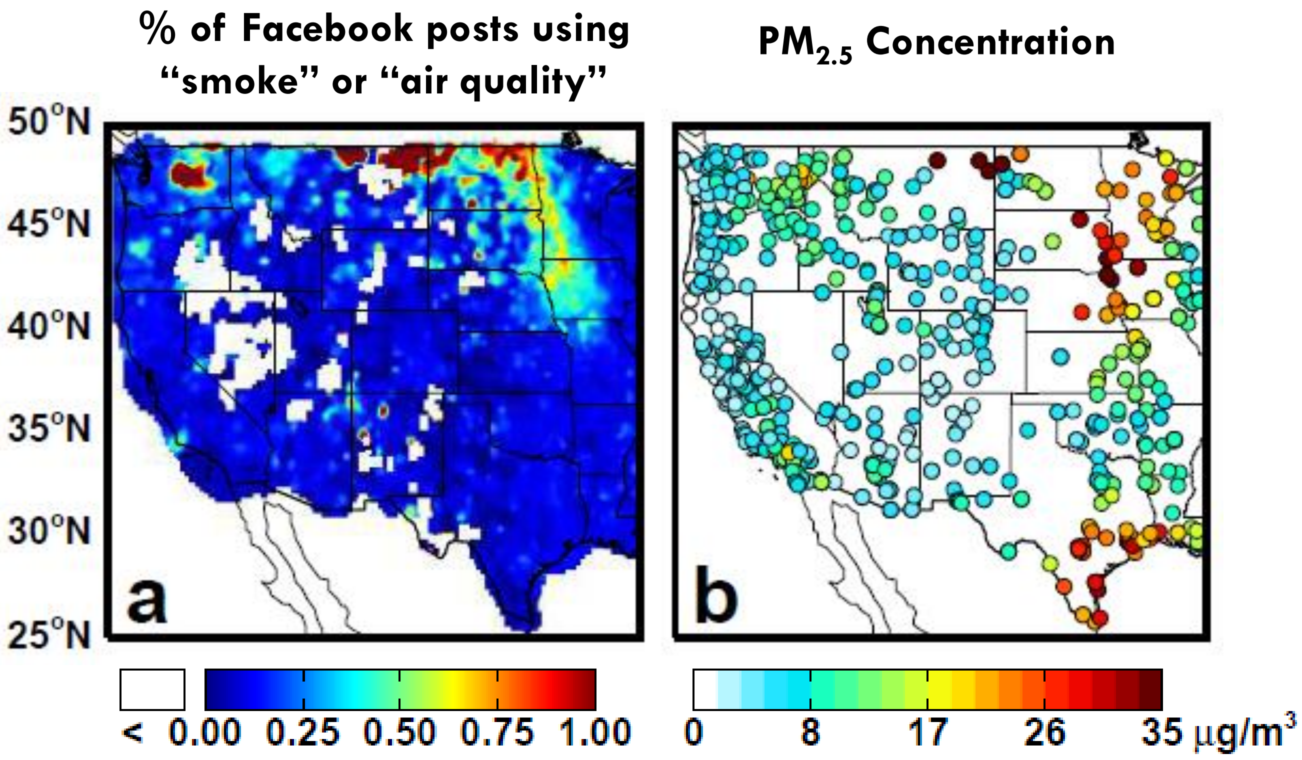
Social Media Examples

- Twitter activity from the California King Fire



(Sachdeva et al., 2016)

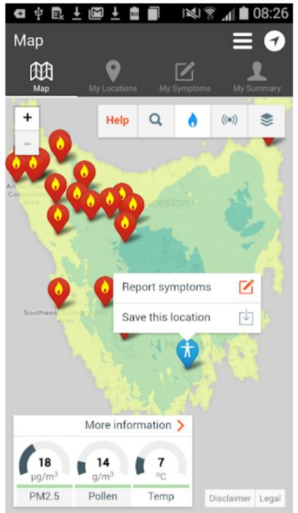
- Facebook posts for the 2015 wildfires in the western US



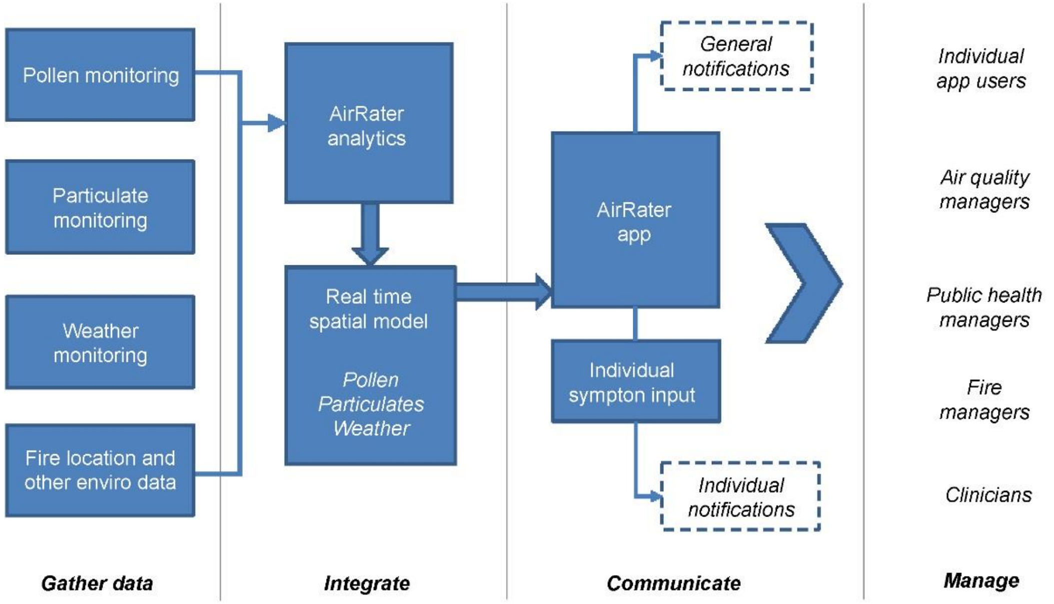
(Ford et al., 2017)

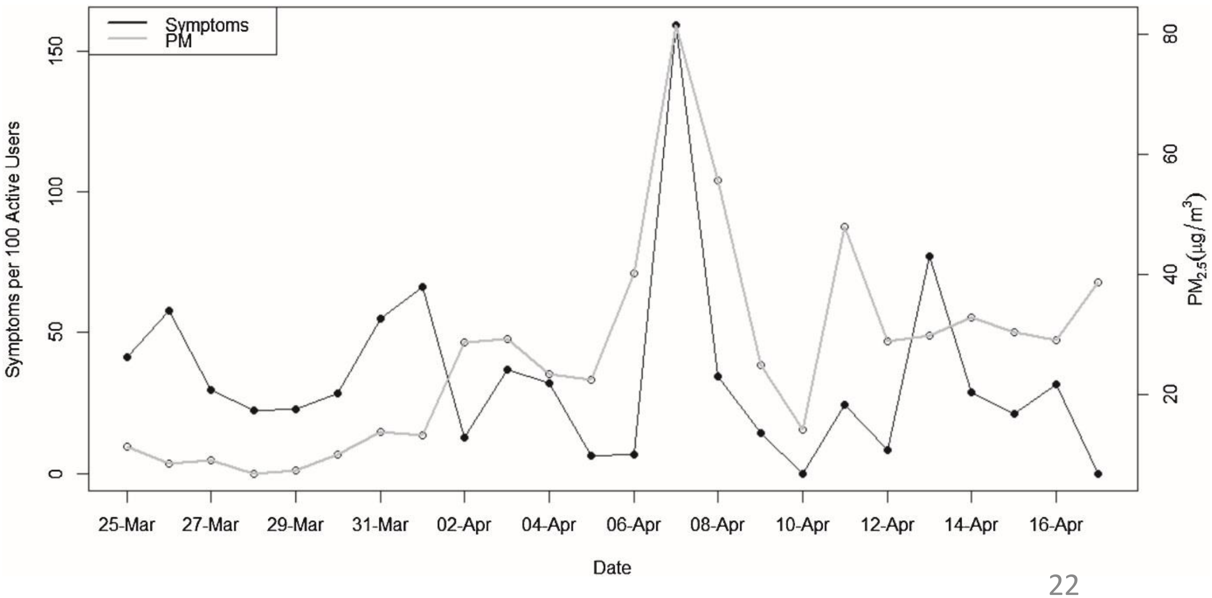
AirRater mobile application in Tasmania

- Integrated online platform that combines symptom surveillance, environmental monitoring, and notifications of changing environmental conditions



Uses a network of air monitoring stations and satellite data



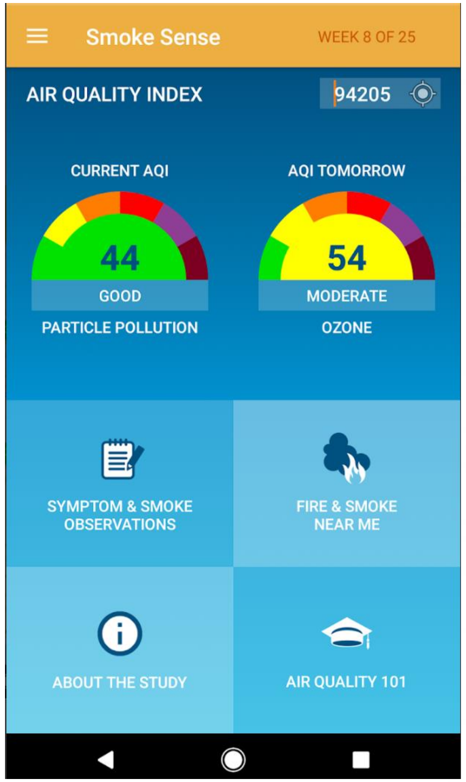


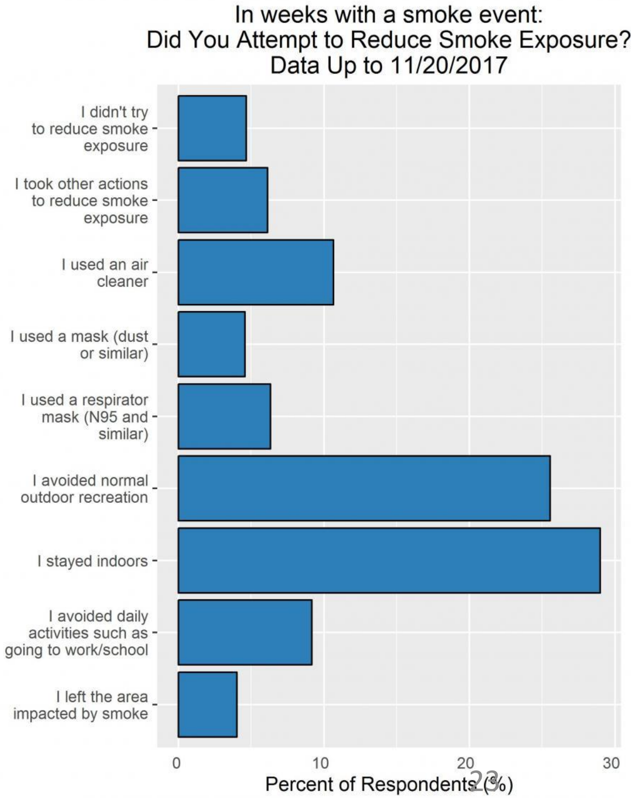
Johnston et al. 2018

EPA's Smoke Sense

- Mobile application citizen science project
- Goals:
  - Understand the subclinical health impacts of wildland fire smoke
  - Discover how people protect their health during smoke exposure
  - Develop effective strategies to communicate health risks from smoke exposure

Smoke Sense





New technologies

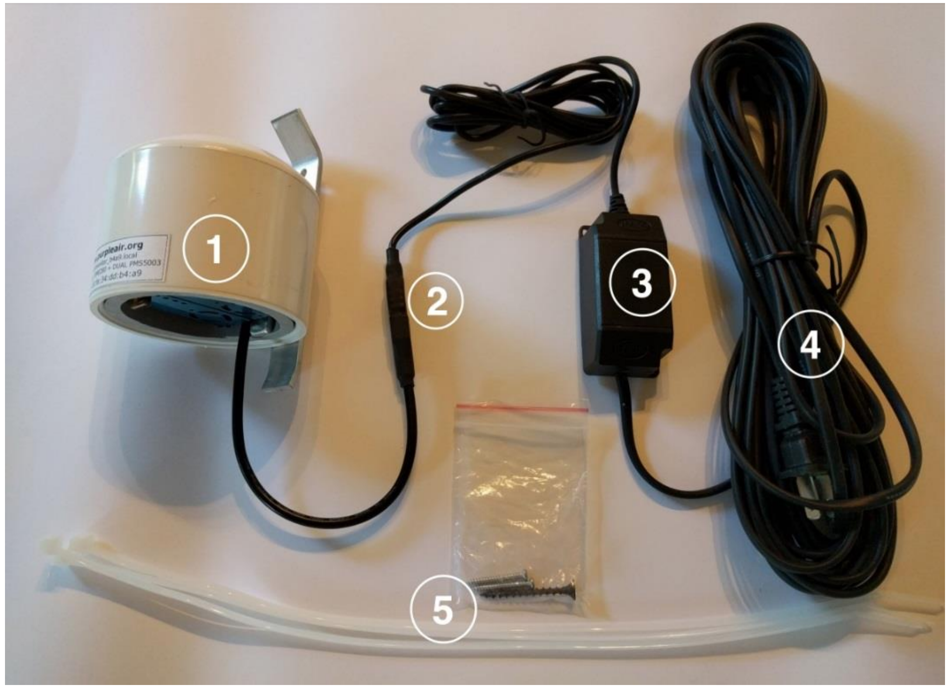
- Designed specifically to address many of the limitations of these conventional methods for measuring air quality
- Human health and exposure assessment commonly used in justification
  - Often mention wildfire smoke specifically
- Very expensive: satellites vs. very inexpensive: low-cost sensors
  - Both create a massive amount of data to store and analyze

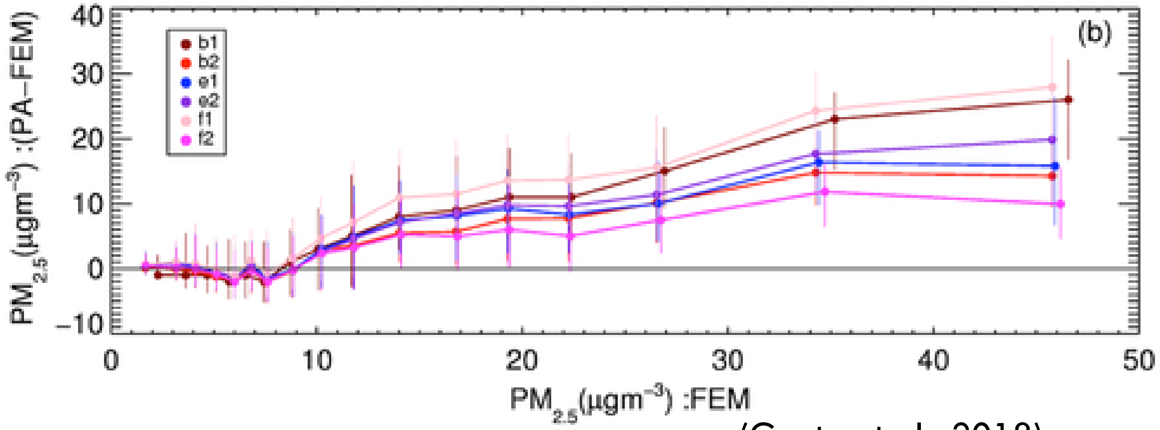
Low-cost sensors

- Goal is to provide high density of PM monitors
- Easy mobile application integration

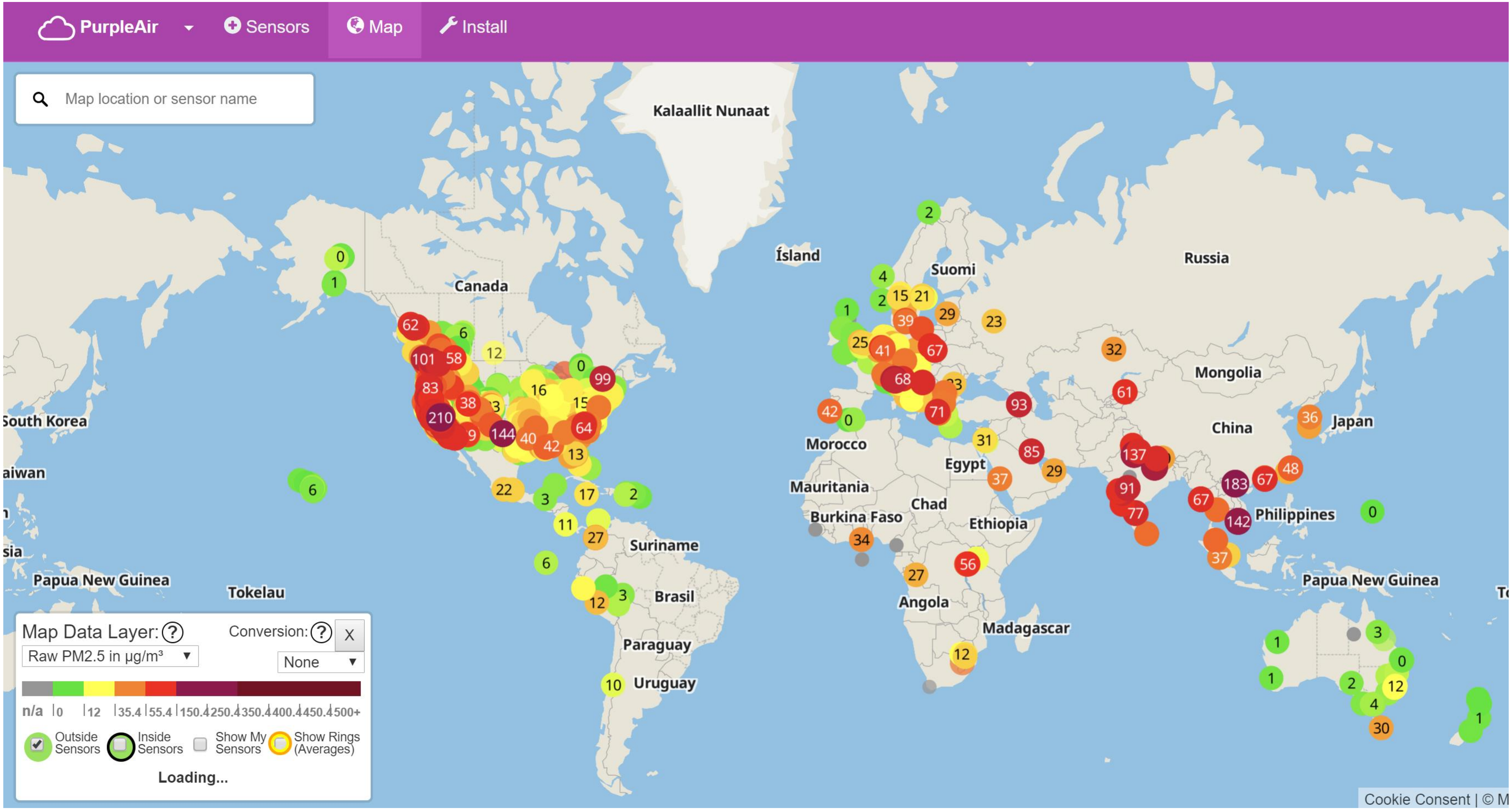
- Cons: Often have high uncertainty and lack a vigorous validation process
  - AQ-SPEC (http://www.aqmd.gov/aq-spec/evaluations)

- Potential to create correction factors or algorithms to correct bias
- Could provide exposure estimates for areas without standard surface monitors





(Gupta et al., 2018)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Sensors
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Chad
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Suriname
Brasil
Angola
Madagascar
Paraguay
Uruguay
Papua New Guinea
Tokelau
Map Data Layer:
Conversion:
Raw PM2.5 in µg/m³
None
n/a 0 12 35.4 55.4 150.4 250.4 350.4 400.4 450.4 500+
Outside Sensors
Inside Sensors
Show My Sensors
Show Rings (Averages)
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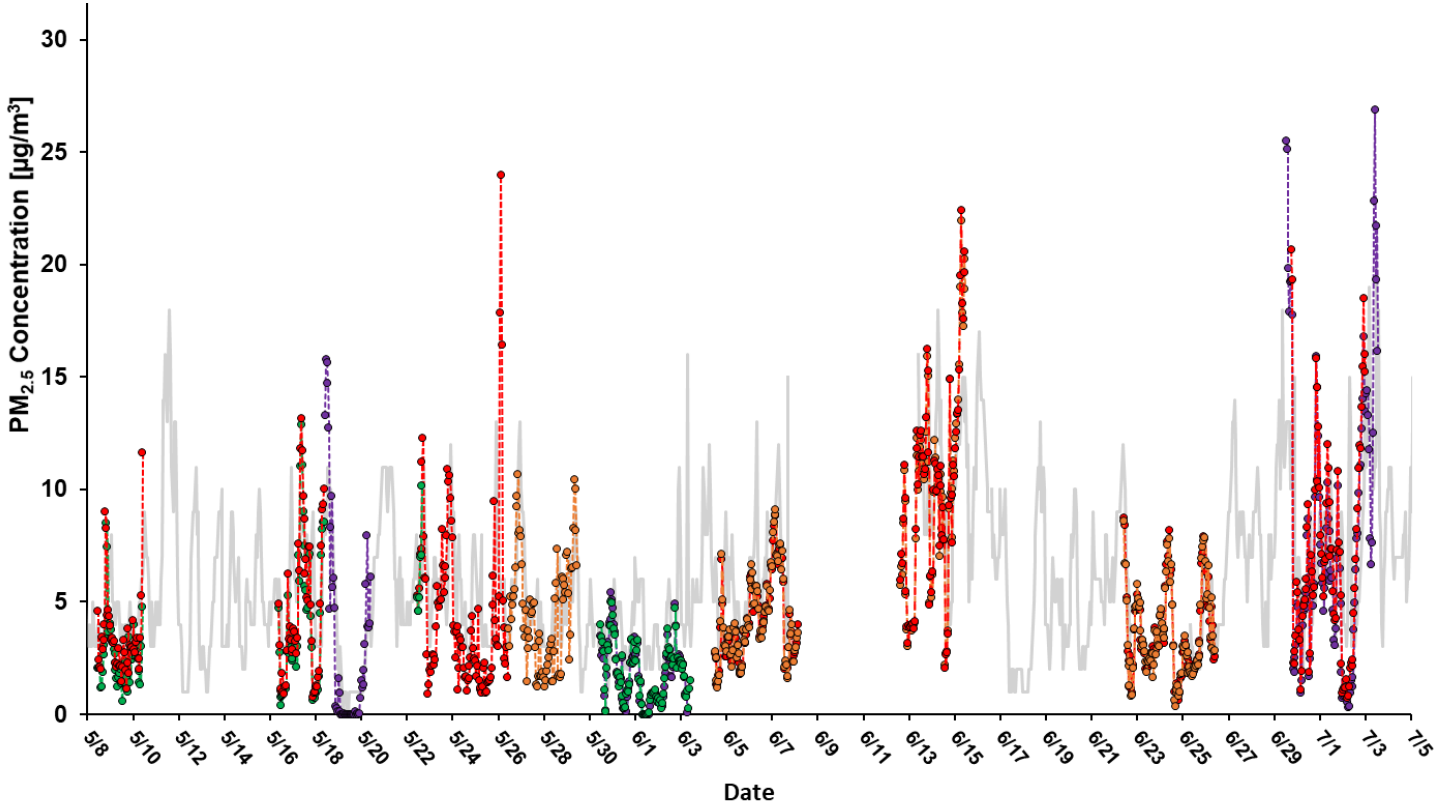
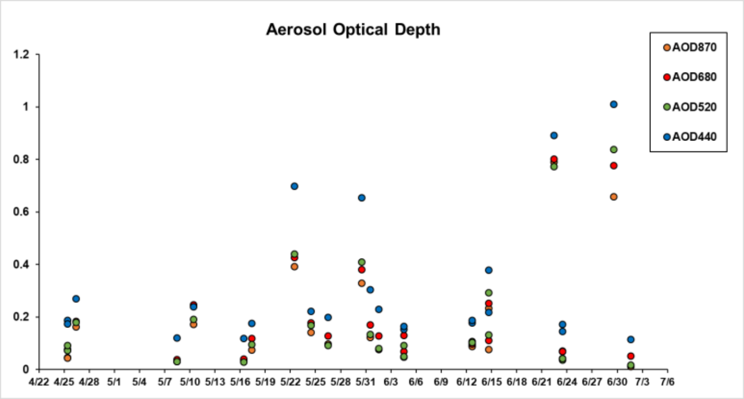
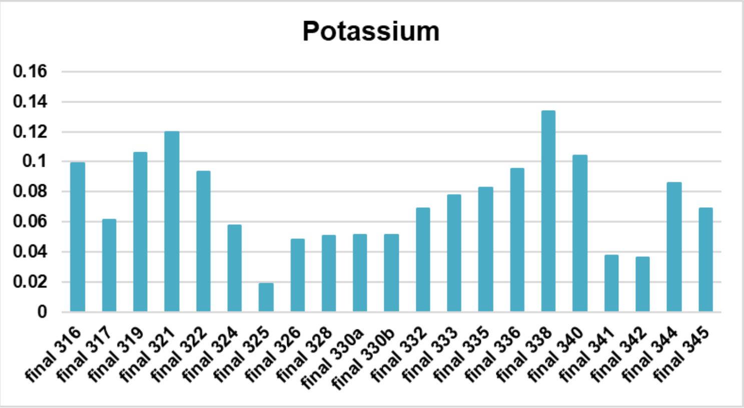
Aerosol Mass and Optical Depth (AMOD) Sampler (developed at CSU)

- Real-time $PM_{2.5}$ Sensor, Filter Measurement, and AOD at 4 wavelengths







New Satellites for Air Quality

- New generation of GOES satellites
    -

Concluding Thoughts

- There are many methods and tools that are used for exposure assessments; no consensus on the best method or tool
- But blended methods seem to produce the best estimates
- Studies that have tested multiple exposure estimates show they lead to different health effect estimates (Gan et al., 2017; Yuchi et al., 2016)

- New technologies are promising, specifically for real-time monitoring (will also improve forecasts)
- Need more work on integrating these datasets into mobile and web applications to provide information to the public in an easy to use format