# Overcoming Barriers in Applying Satellite-Derived $PM_{2.5}$ to Health

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ROLLINS SCHOOL OF PUBLIC HEALTH
EMORY

HAQAST4

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# Motivation

- $PM_{2.5}$ : airborne particles with an aerodynamic diameter of 2.5 µm or less
- $PM_{2.5}$ is one of most important public health concerns worldwide.
  - Associated with 4.2 million deaths in 2015 (GBD, 2016)
  - Associated with 2.7-3.4 million preterm births in 2010 (Malley et al., 2017)

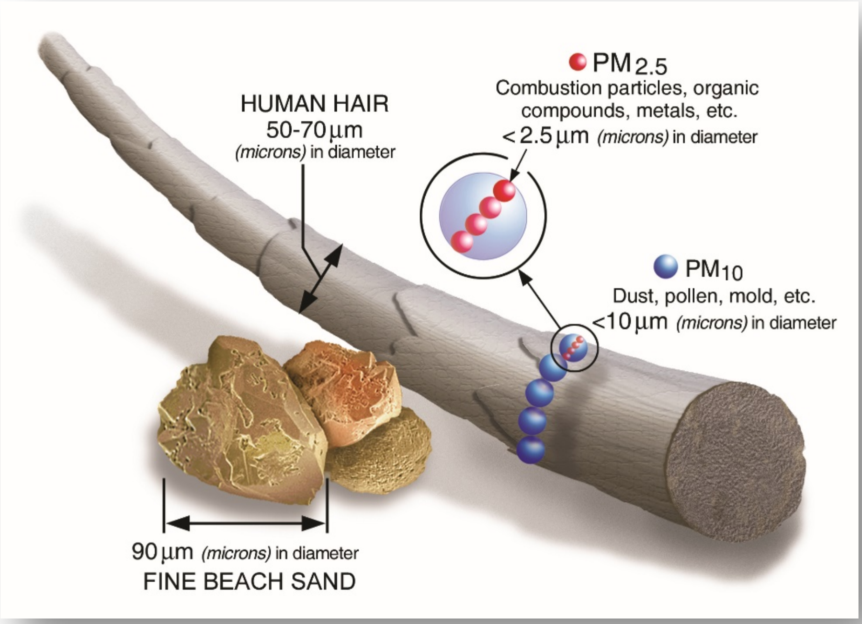
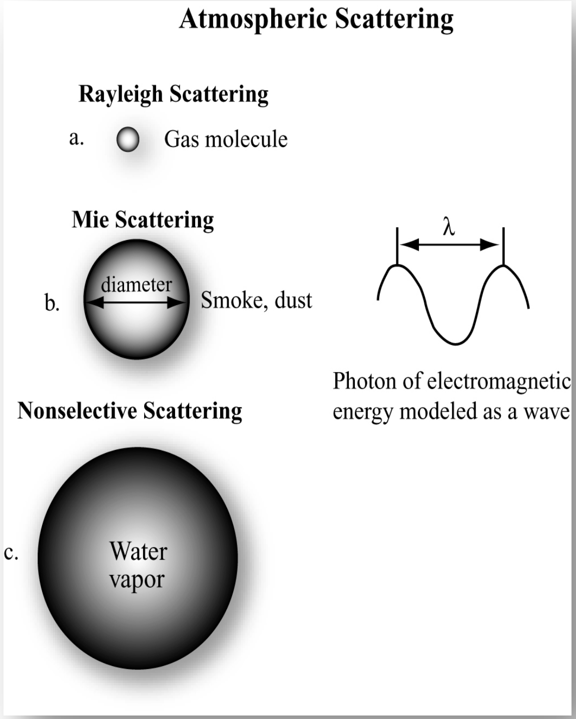



*Image courtesy of USEPA*

# PM2.5 and Satellite AOD

- Aerosol Optical Depth (AOD)
  - The integral of aerosol extinction coefficients along the atmospheric column
  - <u>Broad coverage, high spatial resolution, long data record</u>
  - Satellite AOD retrieved at visible wavelengths is most sensitive to PM 0.1-2 $\mu m$. AOD is dominated by near-surface emissions sources so it is a good indicator of PM2.5 most of the time.



# Satellite-based $PM_{2.5}$ models are being used to estimate exposure in health effects research

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Articles

Estimates and 25
attributable to ar
from the Global B

Aaron J Cohen*, Michael Brauer*, Richard
Lalit Dandona, Rakhi Dandona, Valery Fei
Lidia Morawska, C Arden Pope III, Hwashi
Theo Vos, Christopher J L Murray, Mohan

The NEW ENGLAND JOURNAL of MEDICINE

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Qian Di, M.S., Yan Wang, M.S
Christine Choirat, P

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Associations between birth outcomes and maternal $PM_{2.5}$ exposure in Shanghai: A comparison of three exposure assessment approaches

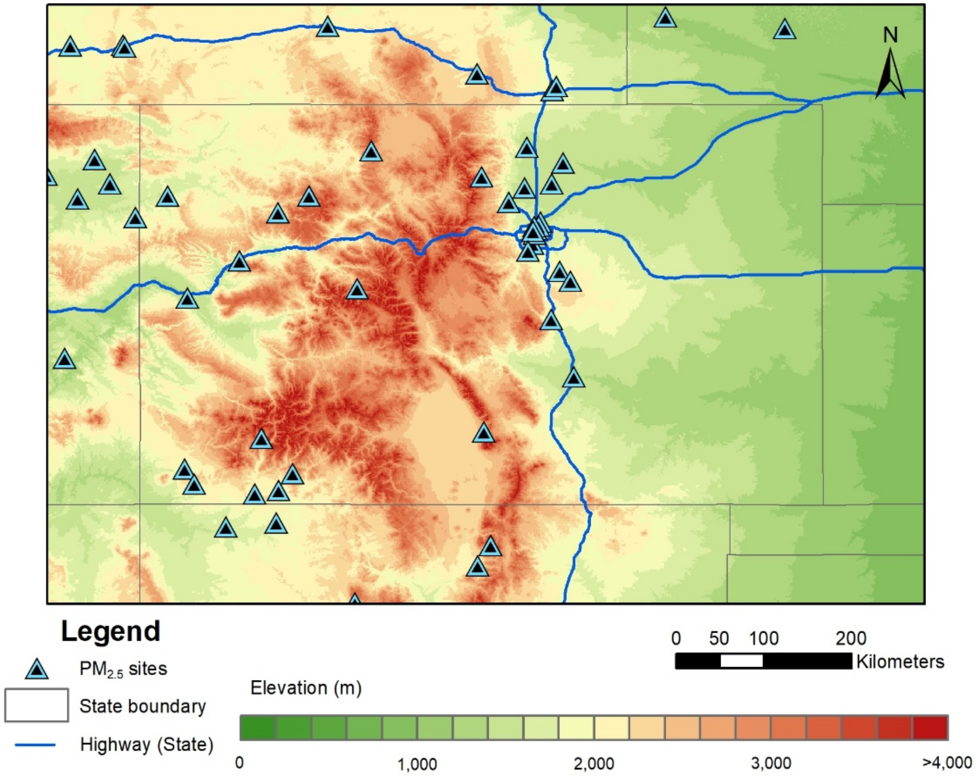
Qingyang Xiao[a,1], Hanyi Chen[b,c,1], Matthew J. Strickland[d], Haidong Kan[e], Howard H. Chang[f], Mitchel Klein[a], Chen Yang[g,c], Xia Meng[a], Yang Liu[a,*]

# Current Barriers

1. Almost every health study needs a custom PM2.5 exposure model to meet its study design, period, and resolution requirements
2. Epidemiologists and other health researchers need the support of exposure modelers and NASA satellite experts
3. Satellite data are difficult to handle and not made with health applications in mind

# Barrier 1 & 2 example: Associations of wildfire-specific $PM_{2.5}$ exposure on cardiorespiratory events in Colorado

Study Objective: estimate respiratory and cardiovascular health effects of wildfire $PM_{2.5}$ in Colorado during the fire seasons of 2011-2014 using wildfire $PM_{2.5}$ separated from background ambient $PM_{2.5}$ levels



# Study co-authors & collaborators

- Emory: G. Geng, X. Hu, X. Meng, E. Saikawa, N. Murray, H. Chang, Y. Liu
- NOAA Air Resources Lab: D. Tong, P. Lee
- University of Tennessee: J. Fu
- University of Nevada Reno: M. Strickland
- CDPHE: K. Bol

# Two-stage Bayesian $PM_{2.5}$ exposure Model

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Stage 1: Bayesian downscaler

**Monitoring measurements**

**MAIAC or CMAQ value at grid cell s and time t**

$$PM_{2.5}(s,t) = \alpha(s,t) + \beta(s,t)\, X(s,t) + \gamma Z_{st} + \varepsilon(s,t)$$

**Additive and multiplicative calibration**

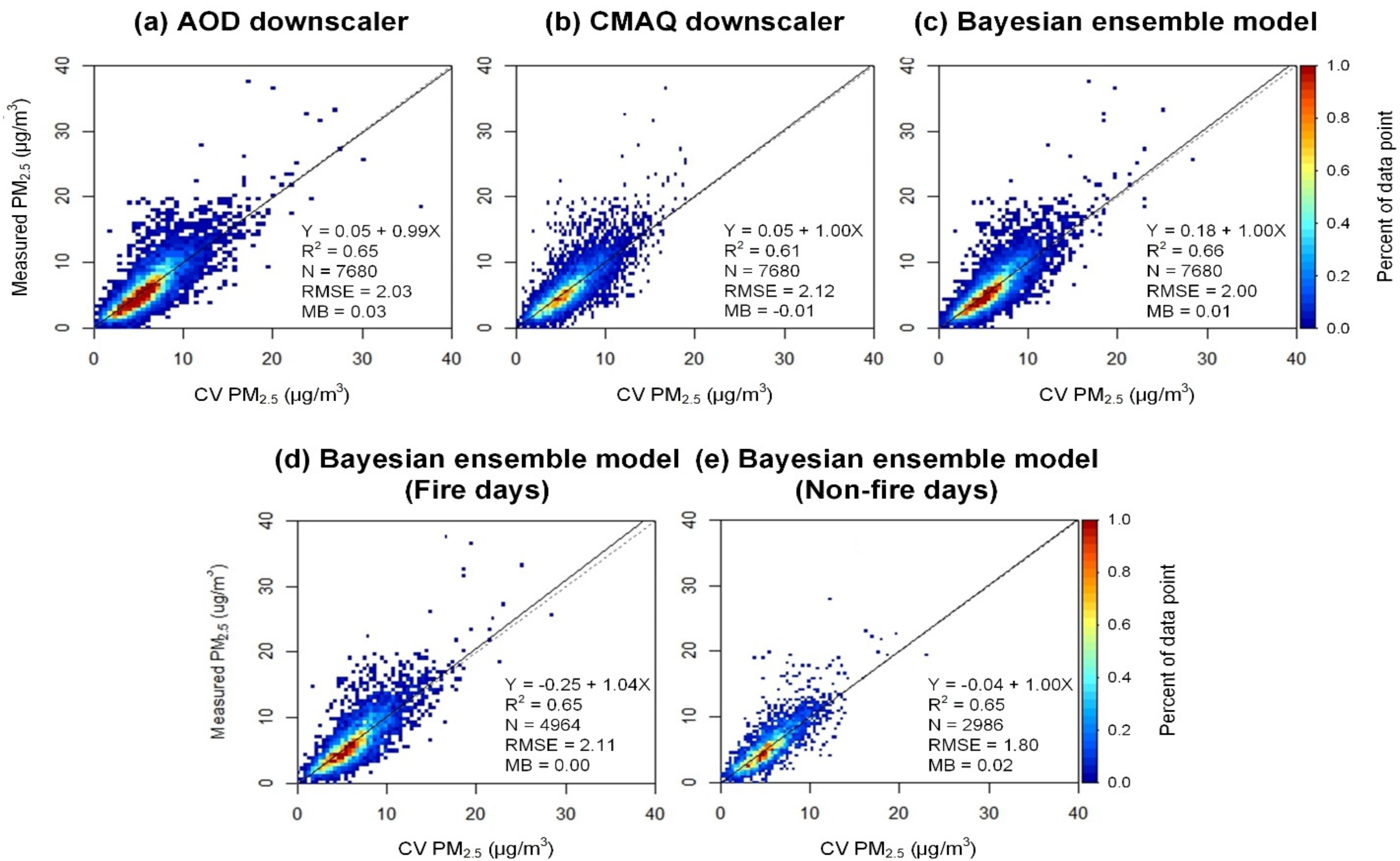
**Zst depends on met and land use parameters.**

**Independent Normal error**

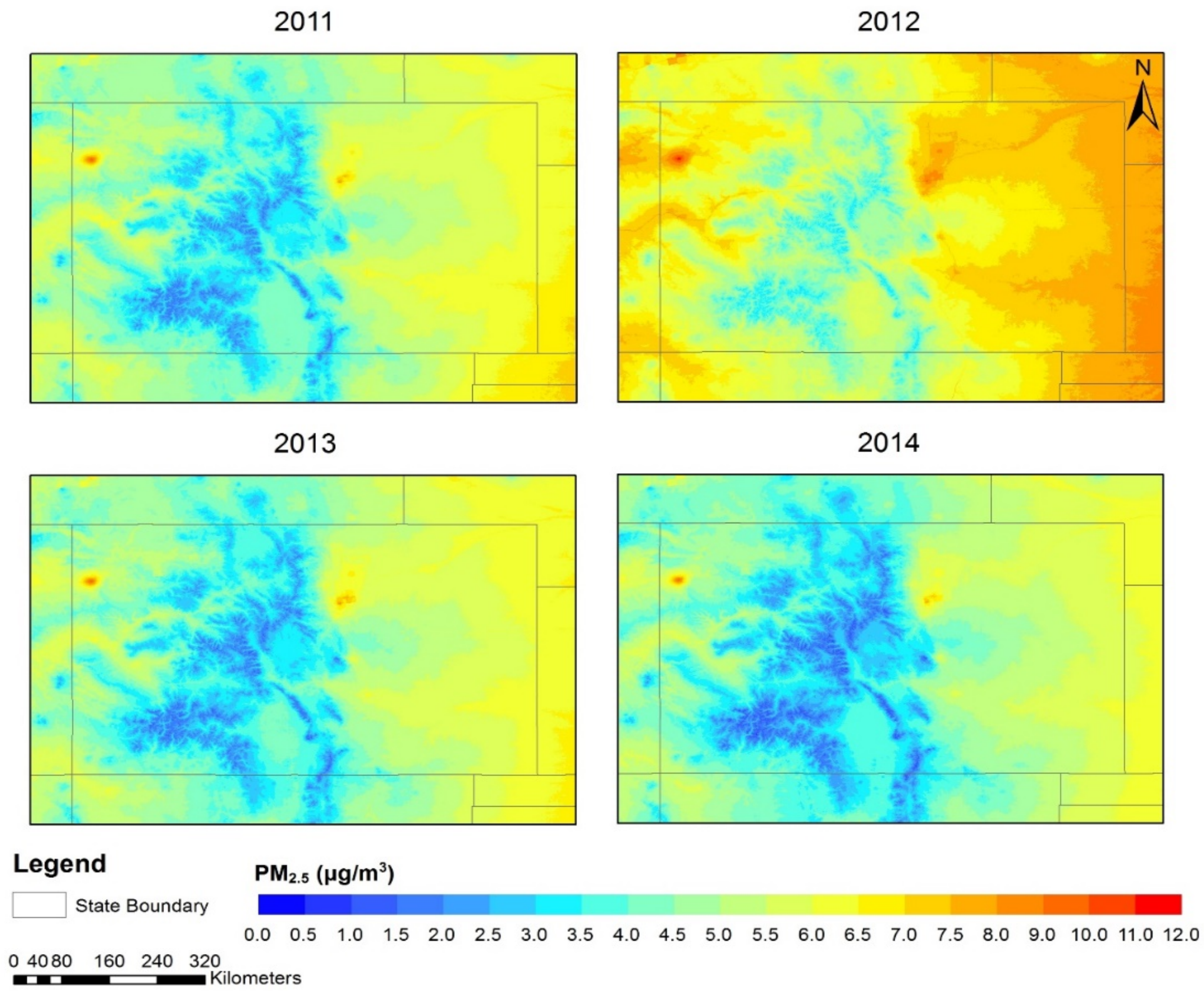
Stage 2: Bayesian ensemble weighting

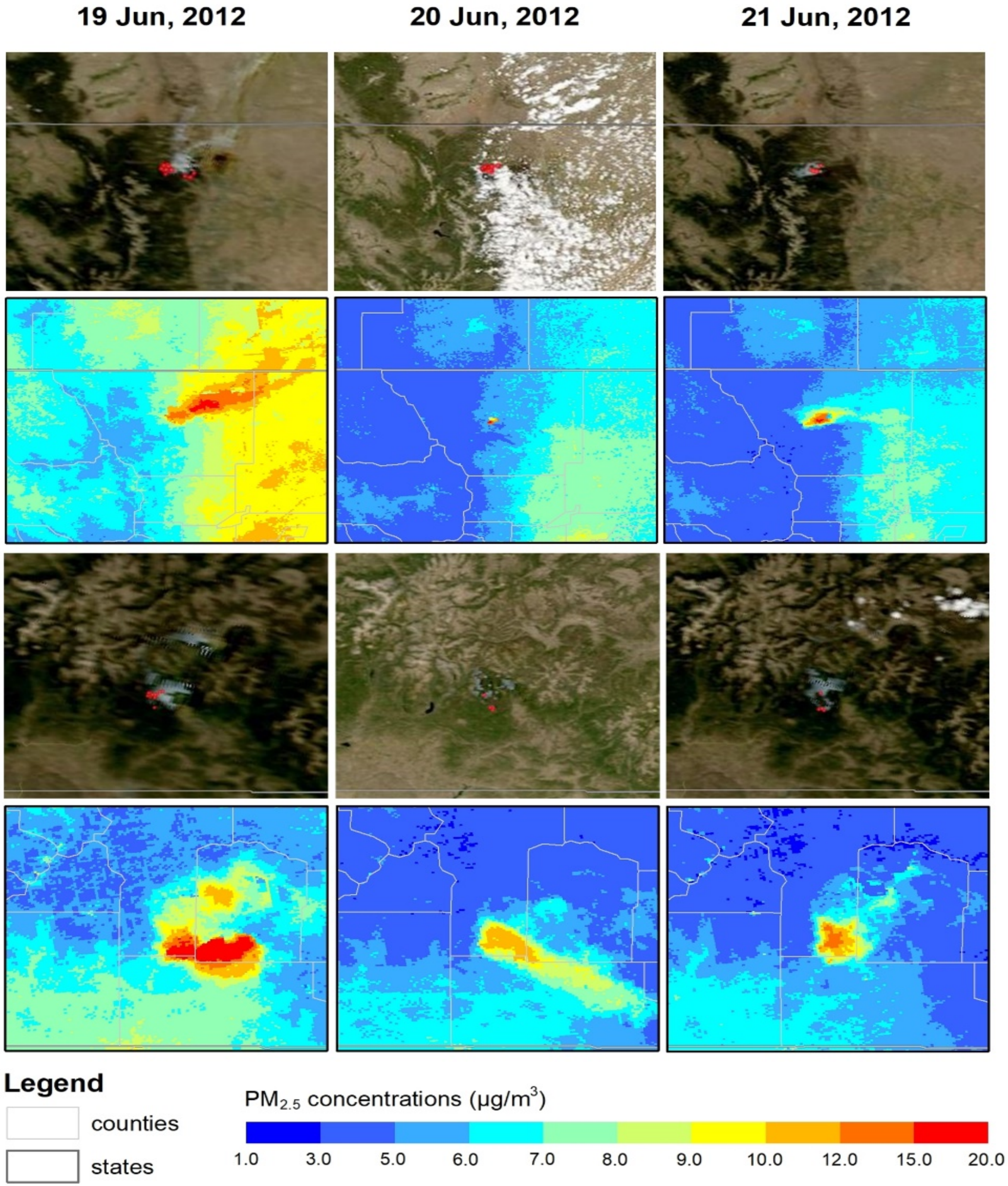
$$PM_{2.5}(s,t) = (1 - w_s)\, PM_{s,t}^{AOD} + w_s\, PM_{s,t}^{CMAQ}$$

# Model Performance



# Model predicted total $PM_{2.5}$ with full daily coverage at 1 km resolution



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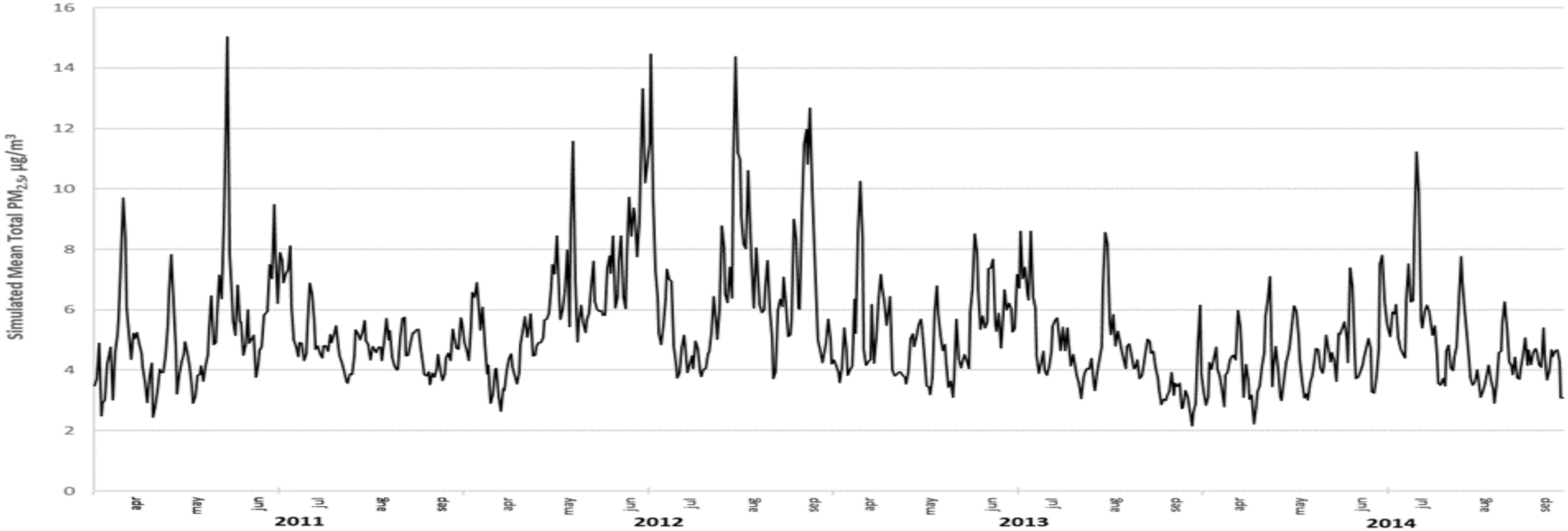
**High Park fire**

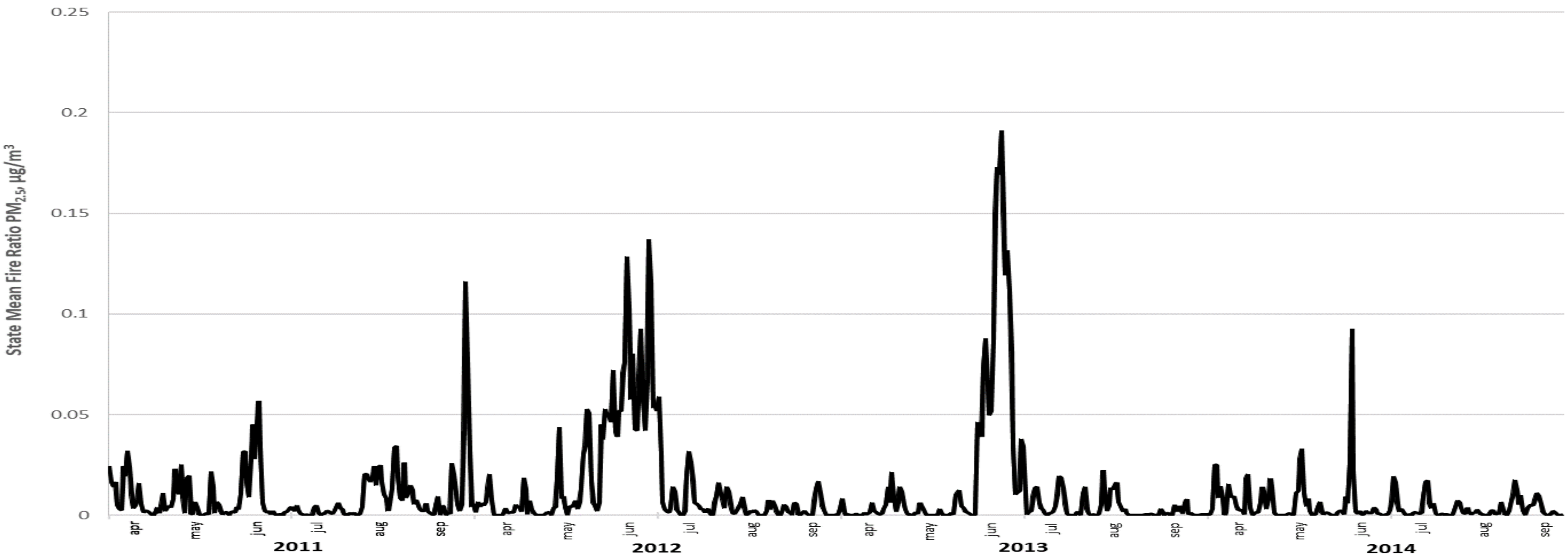
**Little Sand fire**

# Further processing for epidemiologic modeling

- Aggregated to a 4km grid to match the resolution of the health data
- MODIS active fire count data was obtained to specify fire days for each grid cell
- Fire-specific $PM_{2.5}$ concentrations were calculated by taking the difference between CMAQ models run with and without fire emissions

# Predicted daily $PM_{2.5}$ and smoke contribution



# Ratios of fire $PM_{2.5}$ to total $PM_{2.5}$ ranged from 0 to 99.56%, with a mean ratio of 0.006%.

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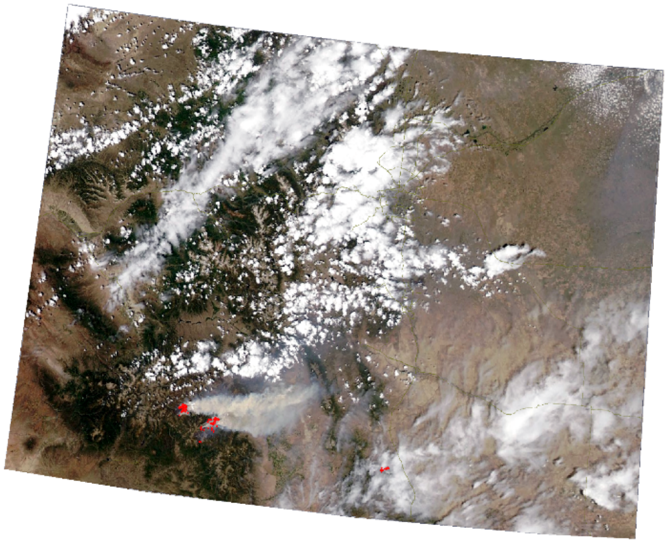
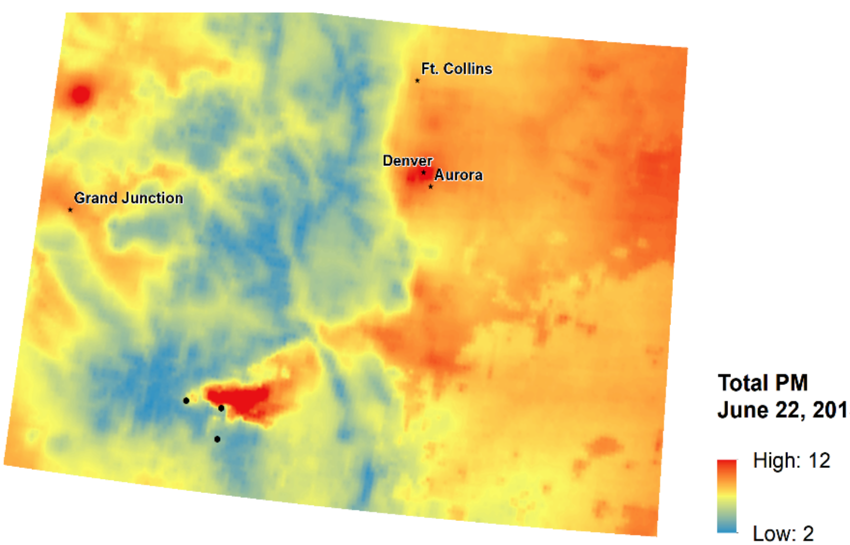
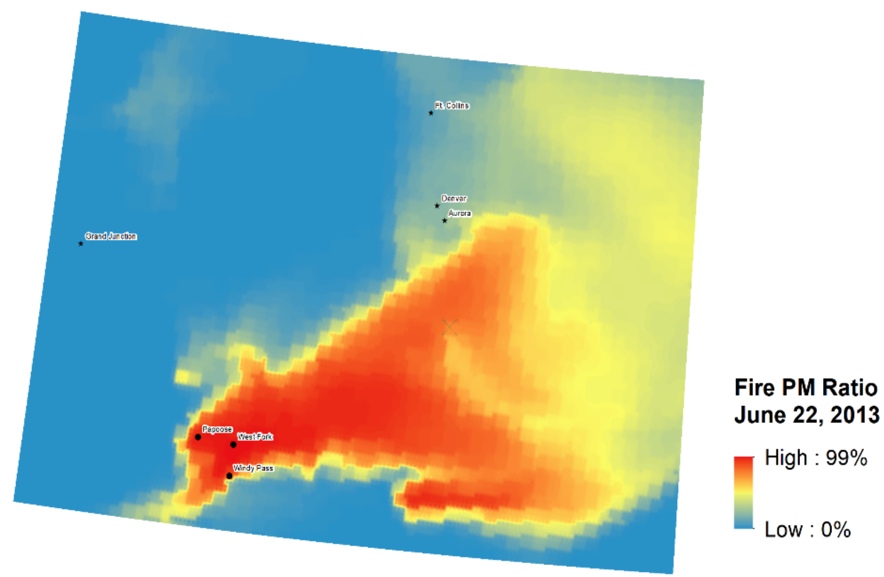


Satellite Smoke Plume, Modeled Total $PM_{2.5}$ and Fire $PM_{2.5}$ for West Fork Fire Complex, June 22, 2013



# Epidemiologic Models

Reference model with total PM2.5 as exposure controlling for temperature and time trend

$$logit\ P(\mathbf{X}) = \boldsymbol{\beta}(total_{3day}\ PM2.5) + \boldsymbol{\beta}(temp_{3day}\ PM2.5) + ns(doy)$$

Fire smoke PM2.5 model controlling for temperature, time trend, and non-fire $PM_{2.5}$

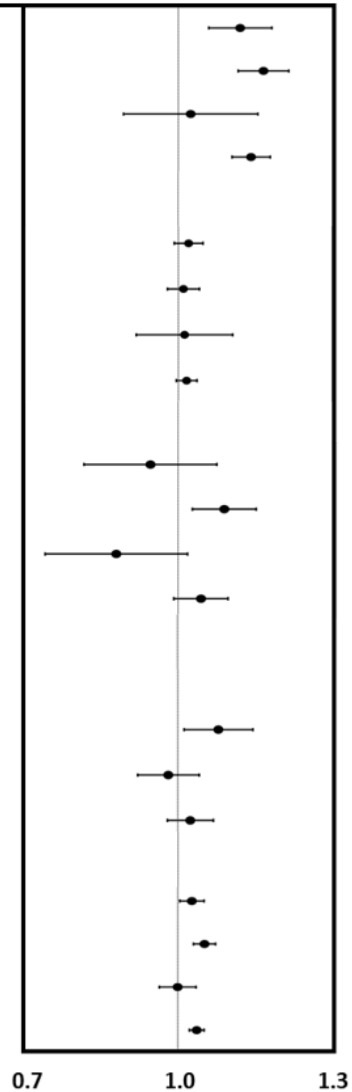
$$logit\ P(\mathbf{X}) = \boldsymbol{\beta}(fire_{3day}\ PM2.5) + \boldsymbol{\beta}(non-fire_{3day}\ PM2.5) + \boldsymbol{\beta}(temp_{3day}\ PM2.5) + ns(doy)$$

# Preliminary results, don't quote

- 446,106 geocoded ED visit and hospitalization events
- Using 3-day average total $PM_{2.5}$ as the exposure variable, ORs for respiratory outcomes were null
- Significant associations between 1μg/$m^3$ increase in 3-day moving average fire $PM_{2.5}$ exposures and asthma (OR 1.141, 95% CI (1.104, 1.179)) and combined respiratory disease (OR 1.036, 95% CI (1.022, 1.050))

# Age stratified results

| Health Outcome | Age | OR & 95% CI |
|---|---|---|
| Asthma | Child | 1.120 (1.059,1.185) |
| | Adult | 1.165 (1.116, 1.216) |
| | Elderly | 1.024 (0.894, 1.173) |
| | All | 1.141 (1.104,1.179) |
| Upper Respiratory Infection | Child | 1.020 (0.992,1.049) |
| | Adult | 1.010 (0.979,1.036) |
| | Elderly | 1.012 (0.918,1.115) |
| | All | 1.016 (0.996,1.037) |
| Bronchitis | Child | 0.948 (0.823,1.091) |
| | Adult | 1.087 (1.027,1.151) |
| | Elderly | 0.884 (0.750,1.041) |
| | All | 1.043 (0.992,1.096) |
| Chronic Obstructive Pulmonary Disease | Child | -- |
| | Adult | 1.078 (1.012,1.149) |
| | Elderly | 0.982 (0.923,1.045) |
| | All | 1.024 (0.980,1.070) |
| Respiratory Disease | Child | 1.027 (1.004,1.051) |
| | Adult | 1.051 (1.030,1.072) |
| | Elderly | 1.000 (0.965,1.037) |
| | All | 1.036 (1.022,1.050) |






M A I A

Associating airborne particle types with adverse health outcomes



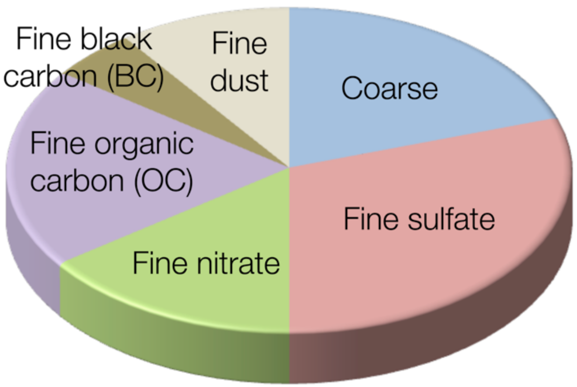
# Advances against Barrier 3: Multi-Angle Imager for Aerosols (MAIA)

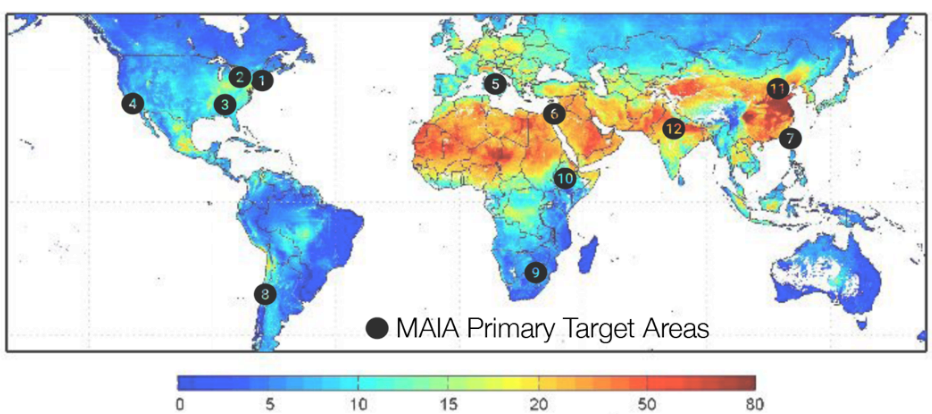
Modified from slides of David J. Diner, MAIA PI

# Health is part of the mission

MAIA's primary objective is to link exposure to different types of PM—mixtures of particles of various sizes, shapes, and compositions—with human health.

PM type and concentration




$PM_{2.5}$ derived from MISR and MODIS

| Exposure timescale<br>Health outcomes |
|---|
| Acute (days to weeks)<br>Emergency room visits, premature deaths |
| Subchronic (months)<br>Adverse birth outcomes, pregnancy complications |
| Chronic (years)<br>Cardiovascular and respiratory diseases |

MAIA Multi-Angle Imager for Aerosols

# Health is in the science team

JPL

| Principal Investigator | |
|---|---|
| David Diner | JPL |

| Co-Investigators: Instrument Characterization | |
|---|---|
| Carol Bruegge | JPL |
| Russell Chipman | Univ. of Arizona |
| Veljko Jovanovic | JPL |

| Co-Investigators:<br>Aerosol Remote Sensing, CTM Modeling, Validation | |
|---|---|
| Larry Di Girolamo | University of Illinois |
| Michael Garay | JPL |
| Edward Hyer | Naval Research Lab. |
| Olga Kalashnikova | JPL |
| Alexei Lyapustin | GSFC |
| Randall Martin | Dalhousie University |
| Jun Wang | University of Iowa |
| Feng Xu | JPL |

| Co-Investigators: PM Exposure, Epidemiology | |
|---|---|
| Michael Brauer | Univ. of British Columbia |
| Michael Jerrett | UCLA |
| Yang Liu | Emory University |
| Bart Ostro | UC Davis |
| Beate Ritz | UCLA |
| Joel Schwartz | Harvard University |

| Collaborators: Air Quality and Public Health | |
|---|---|
| Bert Brunekreef | Utrecht University |
| Sagnik Dey | IIT Delhi |
| Sina Hasheminassab | SCAQMD |
| Kembra Howdeshell | NIH |
| John Langstaff | EPA |
| Pius Lee | NOAA |
| Fuyuen Yip | CDC |

# Health is in the PTA selection

- Primary Target Areas (PTAs) are chosen by the MAIA Science Team for conducting epidemiological studies.
  - Candidate list currently includes 12 sites based on:
    - Science value to the MAIA investigation
    - Identification of sources of surface monitor data, complexity of interfaces, requirements for supplementary monitor deployments, and associated costs
    - Establishment of health study objectives, health data sources, and local collaborators
    - Cloud cover
    - Observability from orbit

MAIA
Multi Angle Imager for Aerosols

# Products are made for health

JPL

| Data level | Description |
| --- | --- |
| 0 | Downlinked instrument telemetry |
| 1 | Calibrated and georectified radiance and linear polarization imagery<br>View and solar geometry, latitude, longitude |
| 2 | Cloud-screened total and fractional aerosol particle properties at time of satellite overpass<br>24-hr averaged concentrations of coarse PM, fine PM, and fine PM components on days and locations coincident instrument observations |
| 4 | Spatially and temporally gap-filled 24-hr averaged concentrations of daily coarse PM, fine PM, and fine PM components |

# Year 2 Progress Update, PI Liu

**Using Earth Observations to Support Regional and National Environmental Health Surveillance**

- Age-specific associations between ambient air pollution and respiratory emergency department visits
  - Baseline paper using EPA data in preparation. Will work with CDC on replacing exposure with satellite-based data.
  - Completed national Bayesian fusion modeling.
- Effect of Wildfire Smoke on ED Visits in Colorado
  - Satellite data fusion model completed. Epidemiologic study near completion.
  - Completed epidemiologic study on the effect of wildfire-specific PM2.5 exposure on acute health outcomes in Colorado.

**Tiger Team Participation**

- Pat Kinney: High Resolution Satellite-Based Assessments of Community Health
  - Completed 100 m satellite PM2.5 modeling in New York City. <u>Delivered data to Anenberg for multi-city HIA</u>.
  - Completed 1 km PM2.5 modeling in Imperial Valley.
  - Complete preliminary 1 km PM2.5 modeling in Southern California.
- Bryan Duncan: Demonstration of the Efficacy of Environmental Regulations in the Eastern U.S..
  - Completed the New York State long-term PM2.5 modeling. <u>Data delivered to Fiore for cross-comparison with other methods.</u>

- 2 conference talks, 3 stakeholder talks
- 2 paper published, 2 submitted, 4 in preparation

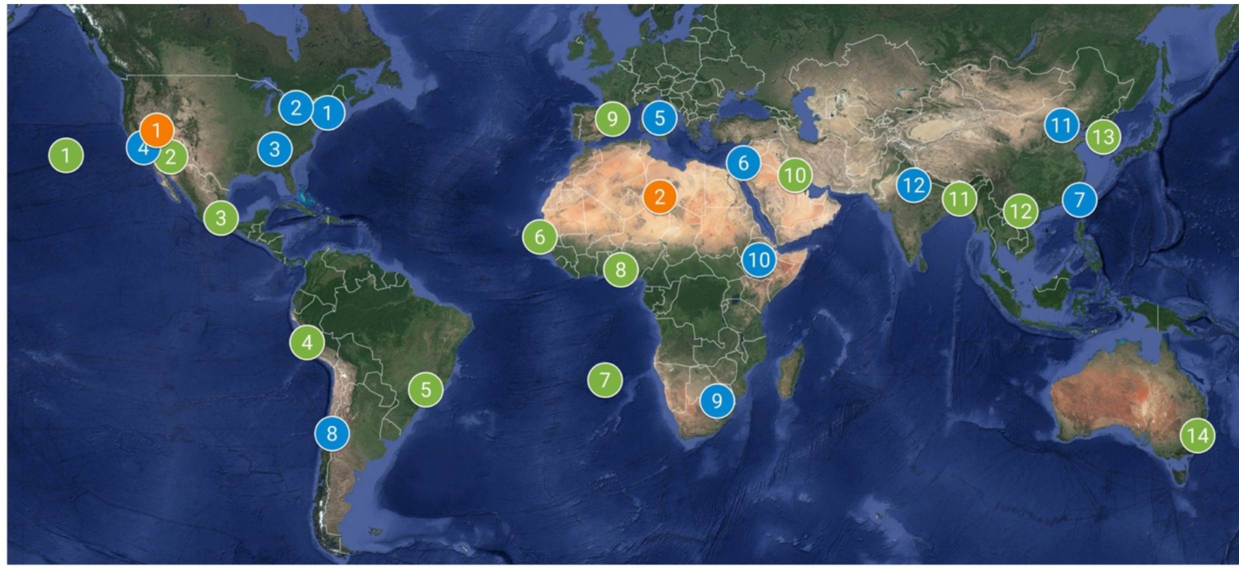
MAIA
Multi-Angle Imager for Aerosols

# Current Candidate Target Areas

JPL



1. NE US (Boston, Providence, Hartford, New York)
2. NE Canada (Toronto, Hamilton)
3. SE US (Atlanta Metro)
4. SW US (Fresno, Bakersfield, LA, Riverside, San Bernardino)
5. Italy (Rome, Bologna)
6. Israel (Haifa, Tel Aviv, Jerusalem, Beer Sheba)
7. Taiwan (Taipei, New Taipei, Taichung, Tainan, Kaohsiung)
8. Chile (Santiago, Concepción)
9. South Africa (Johannesburg, Pretoria)
10. Ethiopia (Addis Ababa, Adama)
11. China (Beijing)
12. India (Delhi)



Candidate target areas PTA STA CVTA

1. Cloud field
2. Arizona (Phoenix)
3. Mexico (Mexico City)
4. Peru (Lima)
5. Brazil (São Paulo)
6. Senegal (Dakar)
7. Cloud field
8. Nigeria (Lagos)
9. Spain (Barcelona)
10. Kuwait (Kuwait City)
11. Bangladesh (Dhaka)
12. Vietnam (Hanoi)
13. South Korea (Seoul)
14. Australia (Sydney)

1. Nevada (Railroad Valley)
2. Libya-4 desert site