Jet Propulsion Laboratory
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The Multi-Angle Imager for Aerosols (MAIA): From Aerosol Optical Depth from Space to Near-Surface Particulate Matter

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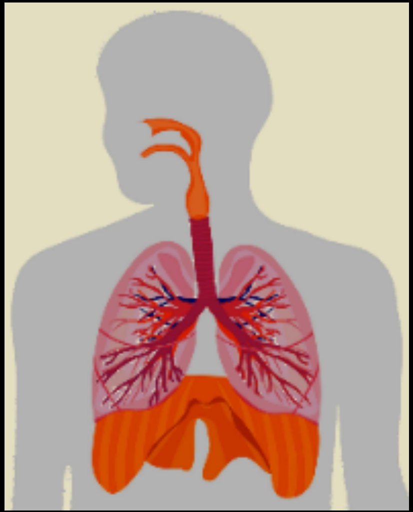
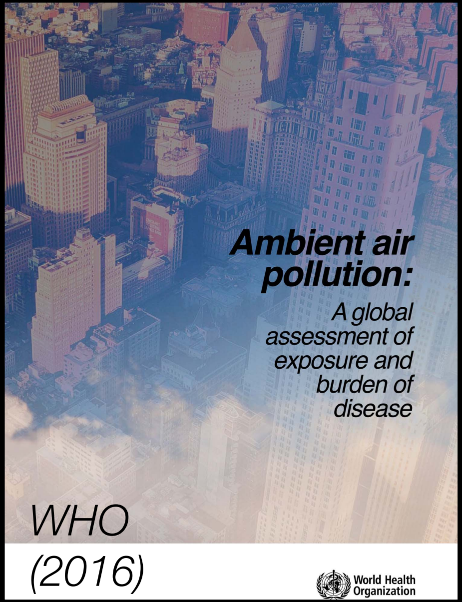
Aerosol impacts on human health



Global Burden of Disease: PM is the top environmental risk factor worldwide

Aerosol impacts on human health

Cause of premature death	Number worldwide fatalities in 1 year
Shark attacks	6
Malaria	429,000
Traffic accidents	1,250,000
Outdoor PM	>4,000,000



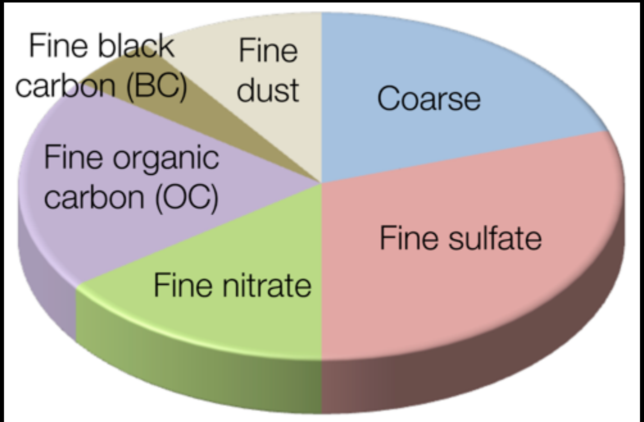
Annual healthcare costs:
$21B (2015), $176B (2060)

Annual lost workdays
1.2 billion (2015), 3.7 billion (2060)

Motivation for MAIA

- Although PM is known to cause many health problems, the relative toxicity of specific PM types is not well understood.

- PM type: fractional proportion of coarse particles (diameters between 2.5 and 10 μm), fine particles (diameters $\leq$ 2.5 μm), and physical and chemical components of $PM_{2.5}$ in the aerosols we breathe.



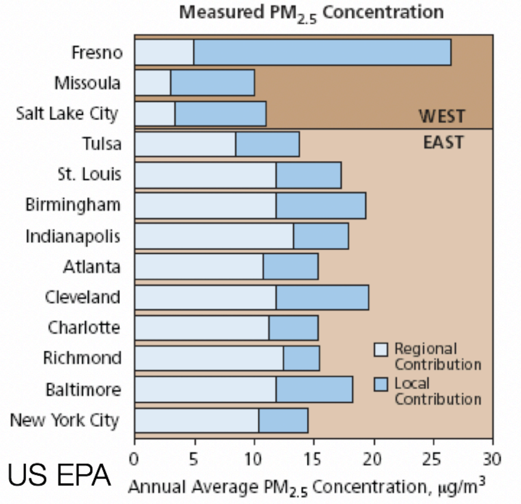
PM components of interest to MAIA



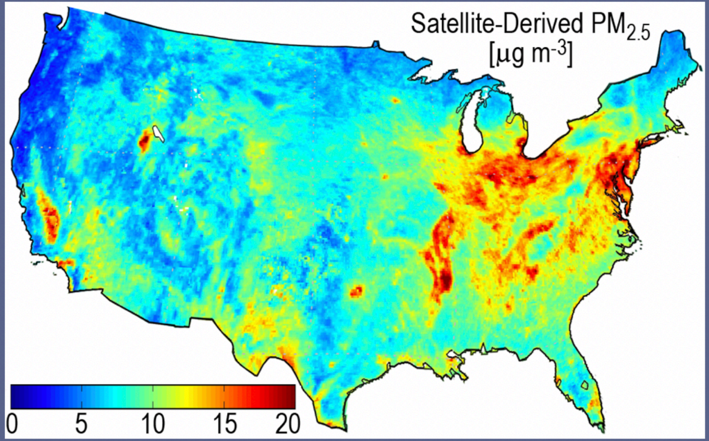



In situ monitoring and remote sensing

In situ	Remote sensing
• measure mass and composition • high accuracy at point locations • sparsely distributed	• retrieve mass or composition indirectly using microphysical and optical indicators of particle type • dense, uniform spatial sampling over large areas

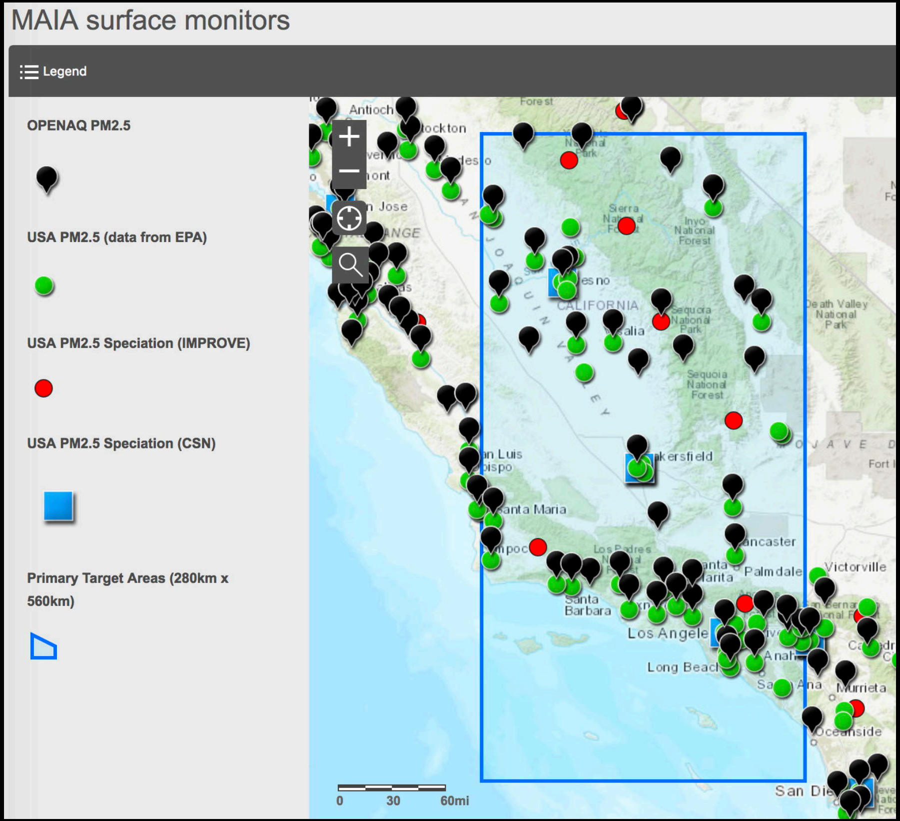


US EPA



MISR + MODIS (van Donkelaar et al., 2010)

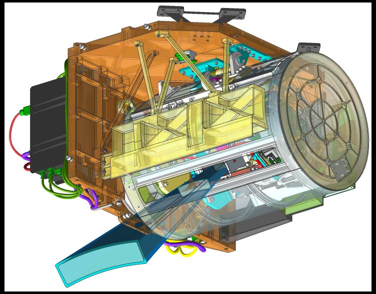
In situ monitoring is relatively sparse

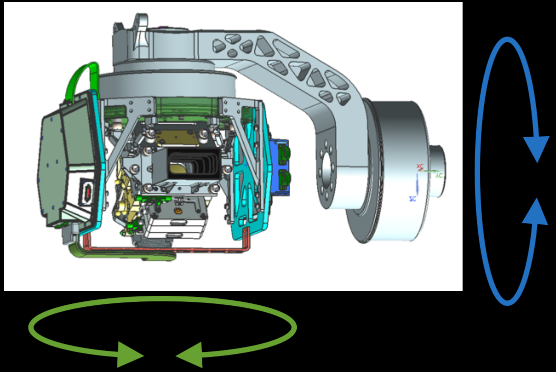


Monitor Type	Number
Total $PM_{2.5}$ (OpenAQ)	42
Total $PM_{2.5}$ (EPA)	41
Speciated $PM_{2.5}$ (IMPROVE)	6
Speciated $PM_{2.5}$ (CSN)	4

Greater LA Population = 18.8 million

MAIA satellite instrument





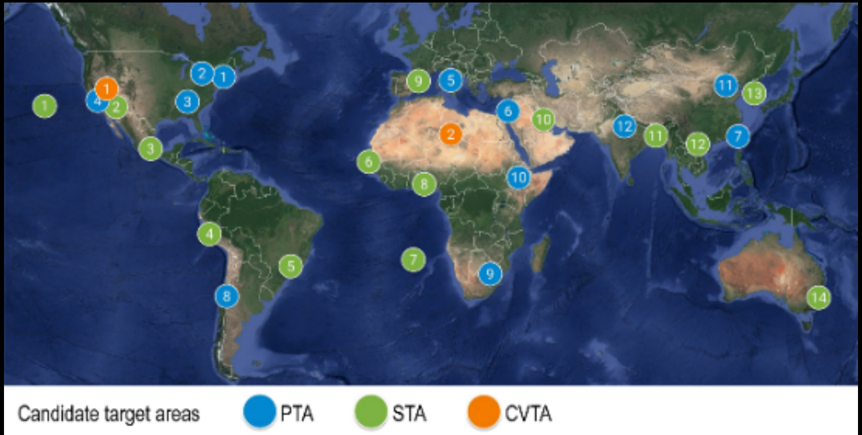
MAIA contains a UV-VNIR-SWIR spectropolarimetric camera mounted on a 2-axis gimbal to characterize aerosol physical components

- Along-track gimbal enables target observations at multiple view angles (typically 5-9)
- Cross-track gimbal enables target observations 3-5 times/week
- Baseline orbit: 10:30 a.m. equator-crossing time, ascending node, sun-synchronous
- Launch: 2022 (to be confirmed)

Band (nm)	365	391	415	444	550	646	750	763	866	943	1044	1610	1886	2126
Polarimetric				✓		✓					✓			

MAIA investigation is target based

- Primary Target Areas (PTAs): for epidemiological studies
- Secondary Target Areas (STAs): secondary studies (e.g., climate)
- Calibration/Validation Target Areas (CVTAs): instrument calibration, product validation



1 NE US
2 NE Canada
3 SE US
4 SW US
5 Italy
6 Israel
7 Taiwan
8 Chile
9 South Africa
10 Ethiopia
11 China
12 India

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

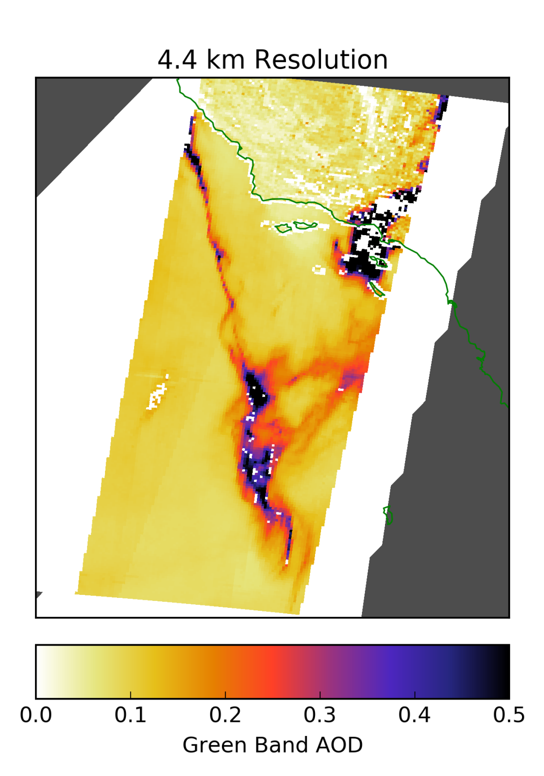
Candidate sites, subject to update

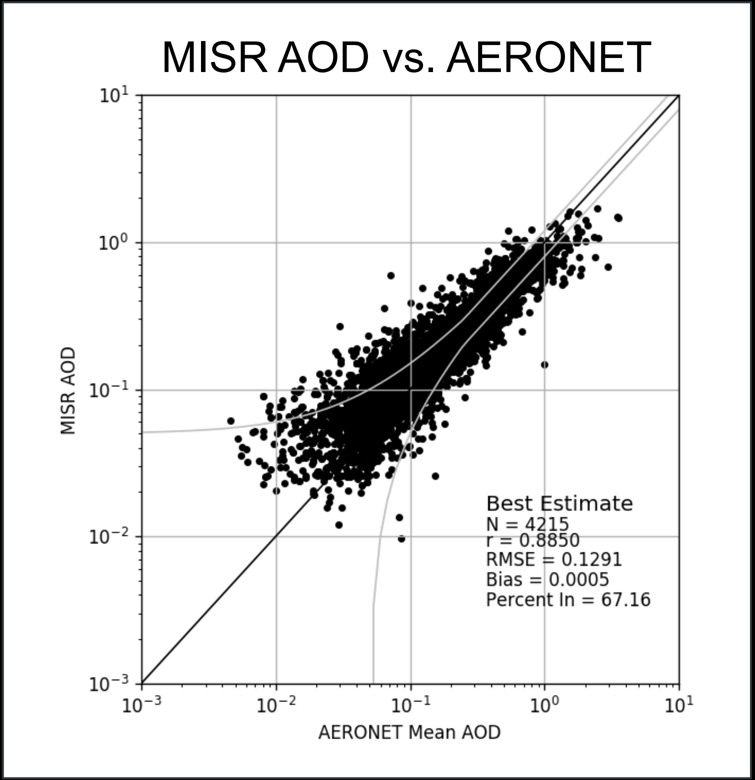
Target dimensions: ~ 300 km x 400 km

MAIA data products

Data level	Description
0	Downlinked instrument telemetry
1	Calibrated and georectified radiance and linear polarization imagery (250 – 500 m spatial resolution) View and solar geometry, latitude, longitude
2	Cloud-screened total and fractional aerosol particle properties at time of satellite overpass (1 km spatial resolution) 24-hr averaged concentrations of PM_{10}, $PM_{2.5}$, and speciated $PM_{2.5}$ on days and locations coincident instrument observations (1 km spatial resolution)
4	Spatially and temporally gap-filled 24-hr averaged concentrations of daily PM_{10}, $PM_{2.5}$, and speciated $PM_{2.5}$ (1 km spatial resolution)

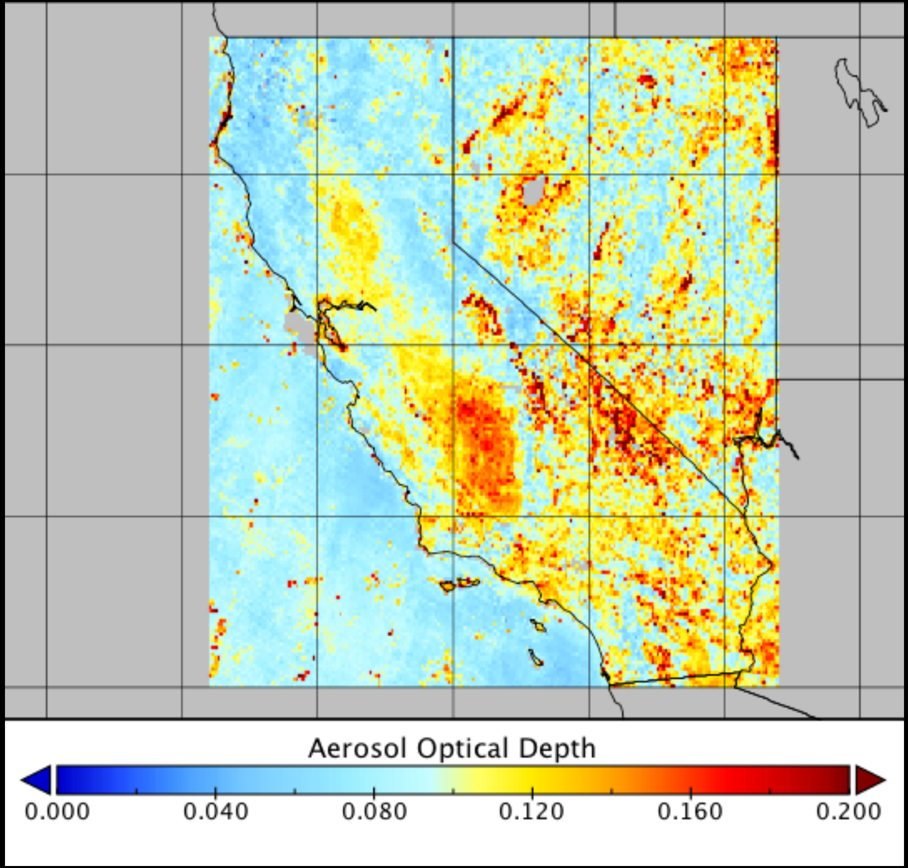
Satellite aerosol retrievals





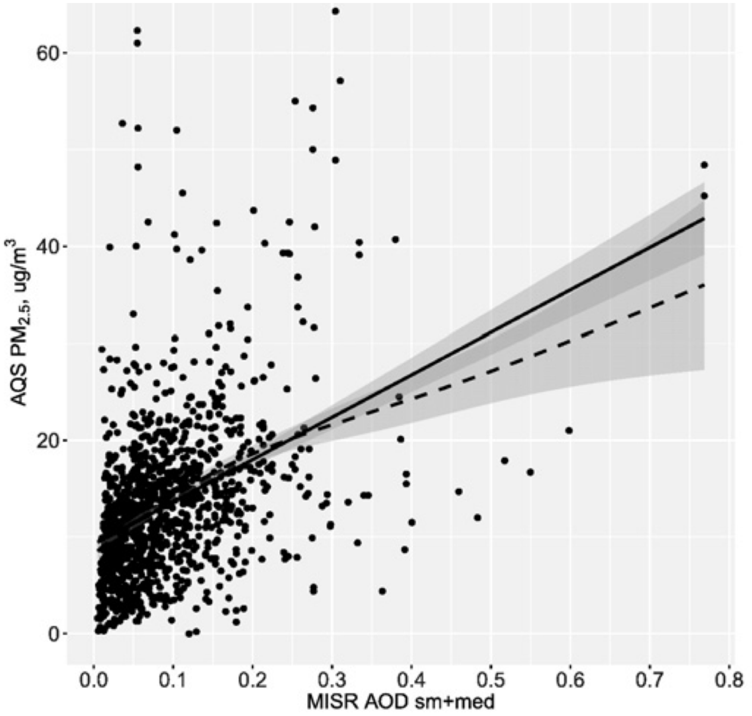
- Yield total column estimates of aerosol optical depth (AOD) and aerosol type in cloud free conditions
- Show good agreement with ground-based sun photometers (AERONET)
- Provide high spatial resolution (km-scale) representation not available from networks of ground-based monitors and global coverage

Satellite aerosol retrievals



Simple AOD-PM regressions are insufficient

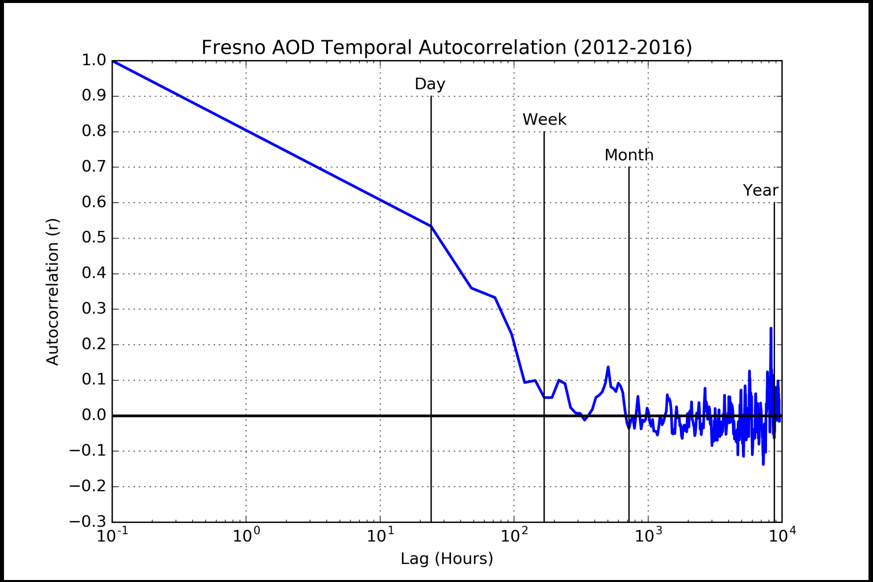
Scatterplot of MISR AOD vs. $PM_{2.5}$ from the EPA Air Quality System (AQS) in Greater Los Angeles

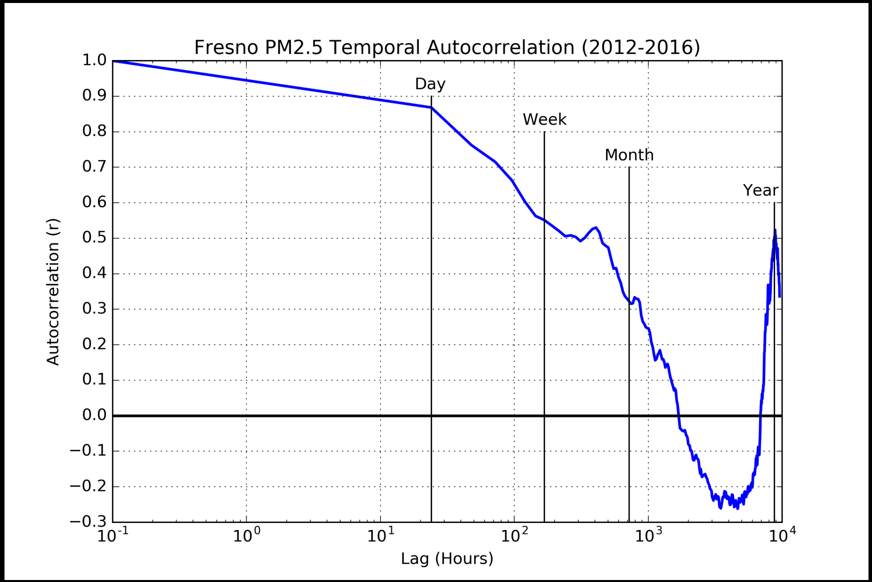


- A linear regression between MISR AOD (small + medium particles) and $PM_{2.5}$ for the Greater Los Angeles area (solid) has a coefficient of determination (R^2) of only 0.17
- A non-linear model (dashed) has an $R^2 = 0.20$

Simple AOD-PM regressions are insufficient

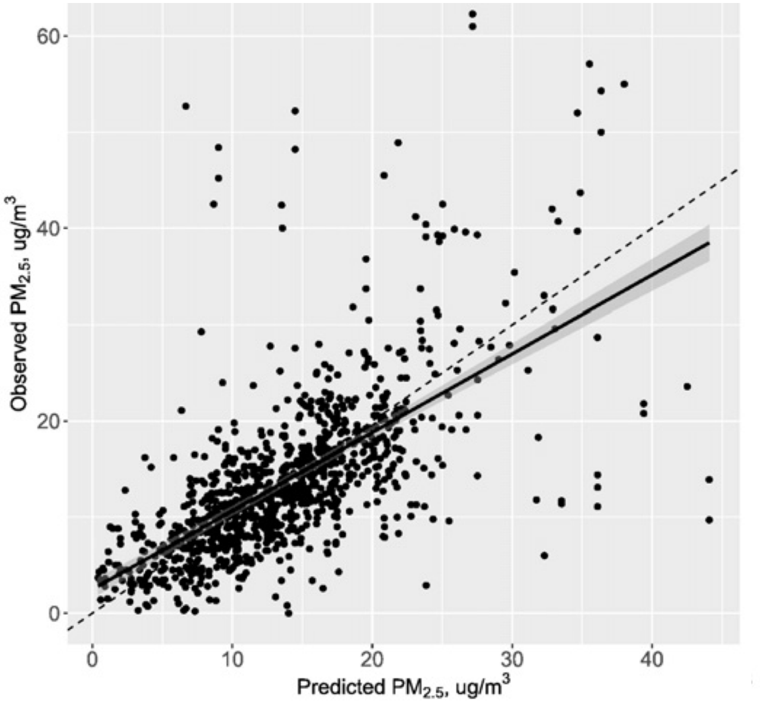
- Examination of the temporal statistics for 4 years of AERONET AOD data and surface $PM_{2.5}$ data for Fresno, CA shows very different temporal behavior between AOD and $PM_{2.5}$ with longer correlation times for $PM_{2.5}$ and stronger seasonality





Geostatistical multivariate models are effective

Scatterplot of Predicted $PM_{2.5}$ vs. $PM_{2.5}$ from the EPA Air Quality System (AQS) in Greater LA



- Including relative humidity and wind speed produces a prediction model for MISR AOD (small + medium particles) with $R^2 = 0.67$ [Franklin et al., 2017]
- A different study [Meng et al., 2018] demonstrated that MISR 4.4 km-resolution AOD retrievals could be used with other variables to predict $PM_{2.5}$ types in Southern California

Geostatistical regression models

- AOD is a column-integrated quantity (dimensionless)
- PM is a near-surface measure of mass concentration ($\mu g\ m^{-3}$)

$PM_{2.5,\ 10,\ \text{or speciated}\ 2.5}$ = α (space, time)

\+ β (space, time) x satellite AOD

\+ γ x geospatial terms (elevation, roadway density, land use, population)

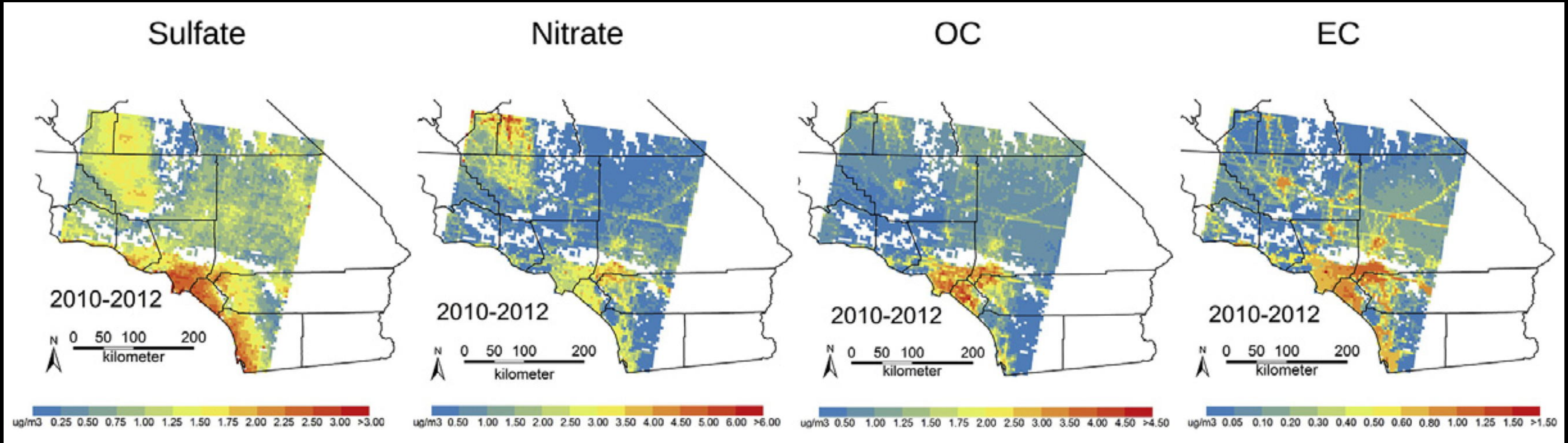
\+ δ x spatiotemporal terms (RH, PBLH, temperature, winds, other satellite aerosol parameters, altitude scaling from CTM)

\+ Uncertainties

The GRMs are trained using surface monitor data and then applied to the rest of the satellite observations.

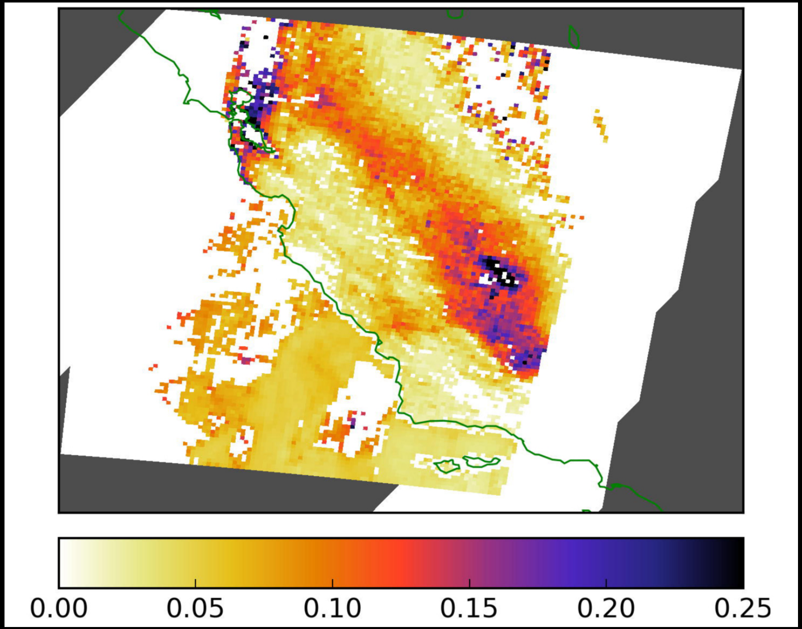
A similar GRM is used to bias-correct the CTM PM predictions, which are used for gap filling.

Geostatistical regression model results



- Sulfate (R^2 = 0.66), nitrate (R^2 = 0.62), organic carbon (R^2 = 0.55), elemental carbon (R^2 = 0.58) [Meng et al., 2018]

How the PM mapping process works



MISR aerosol optical depth (AOD) map of California
5 February 2016
4.4 km spatial resolution

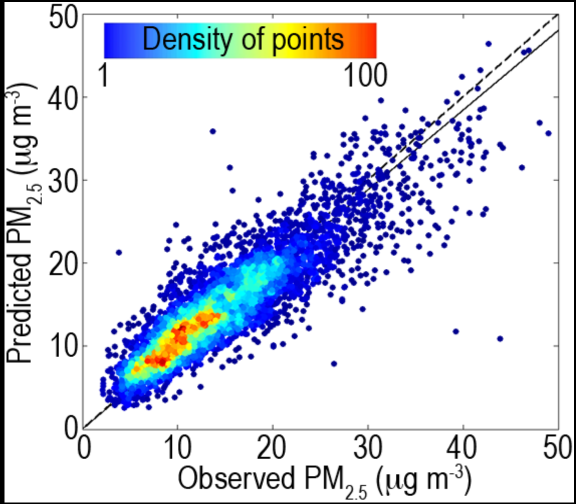
①

Satellite data are used to map column-integrated aerosol properties

How the PM mapping process works

② Collocated satellite and surface monitor data are used to generate empirical regression models relating AOD to PM

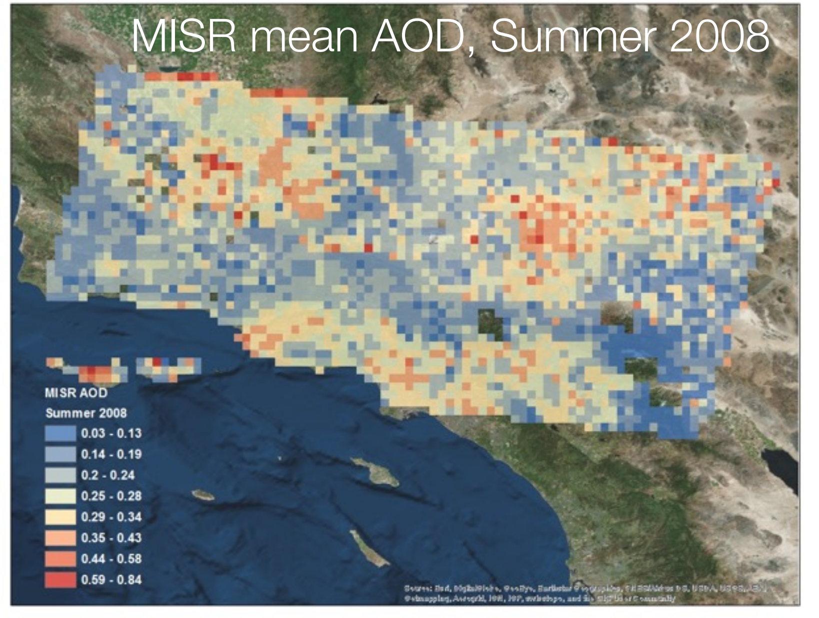
Surface PM monitors
Image credit: L. Tsutsui, KVPR

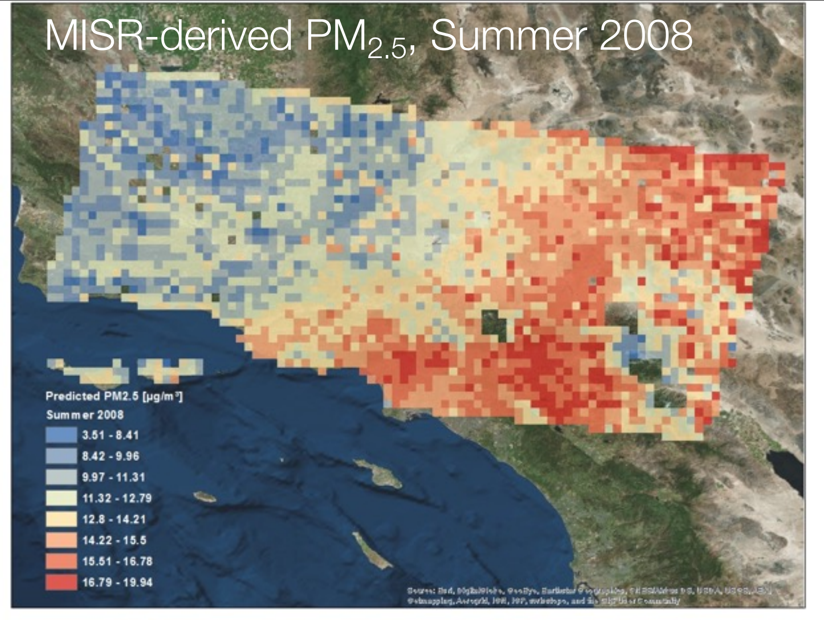


Regression parameters:
- AOD
- air temperature
- wind speed
- surface elevation
- length of major roads
- forest cover

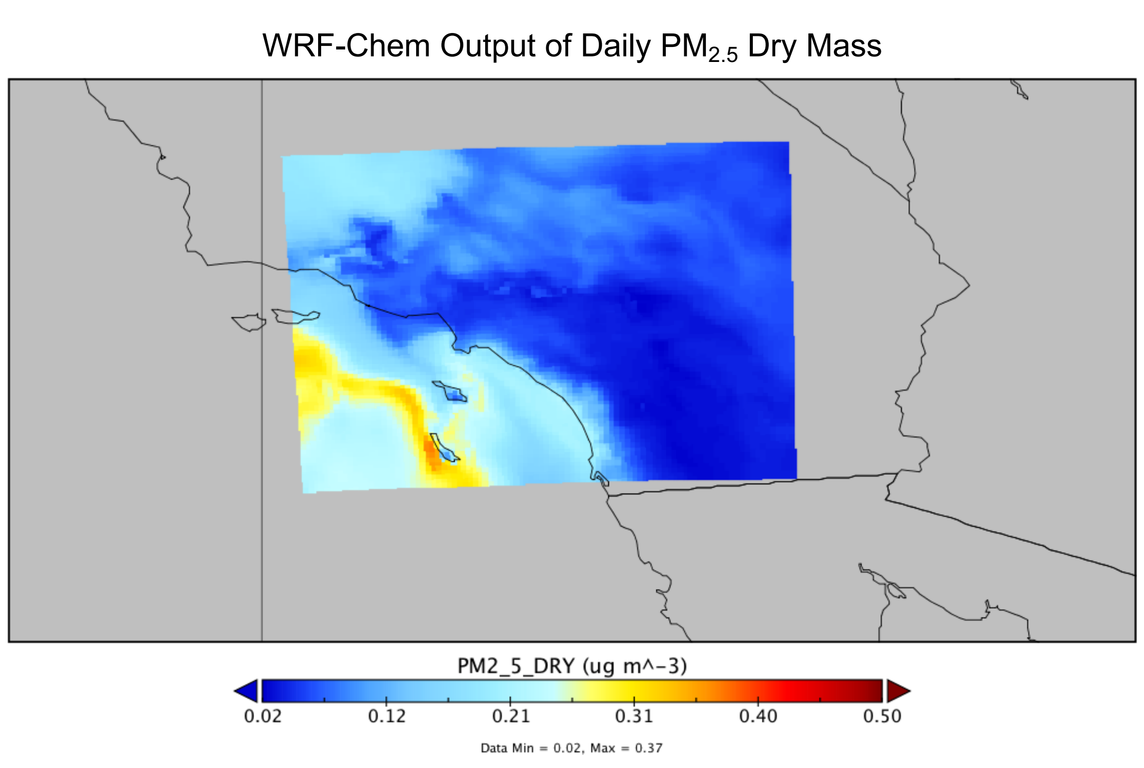
How the PM mapping process works

③ Once the regression models are "trained", they are applied to the satellite AOD data to create PM maps





What about chemical transport models?



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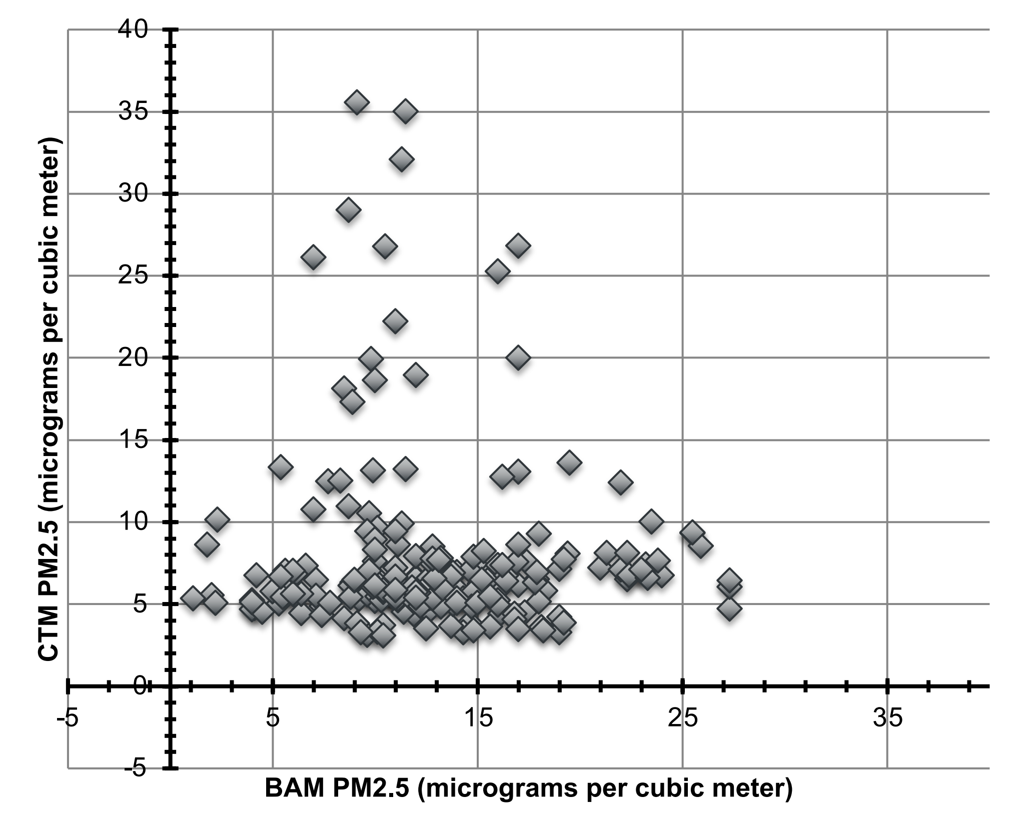
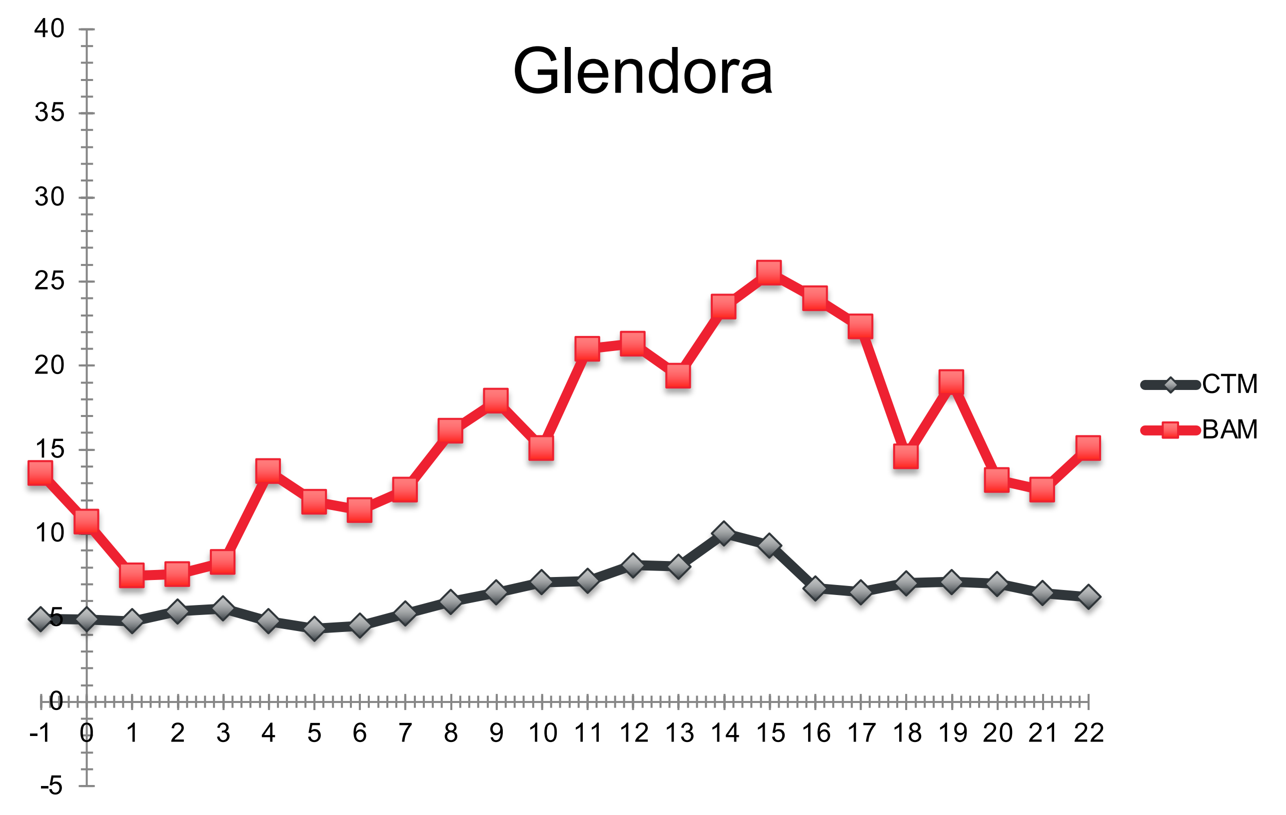


What about chemical transport models?

Site	24-Hour R^2	18 Hour R^2
LA-North	**0.140**	0.078
Glendora	**0.615**	0.559
Long Beach	0.001	0.001
Reseda	**0.007**	0.001
Santa Clarita	0.016	**0.035**
South Long Beach	0.002	**0.028**
Anaheim	0.000	**0.106**
Rubidoux	0.005	**0.067**
Ontario	0.029	**0.090**
Upland	**0.098**	0.014

What about chemical transport models?



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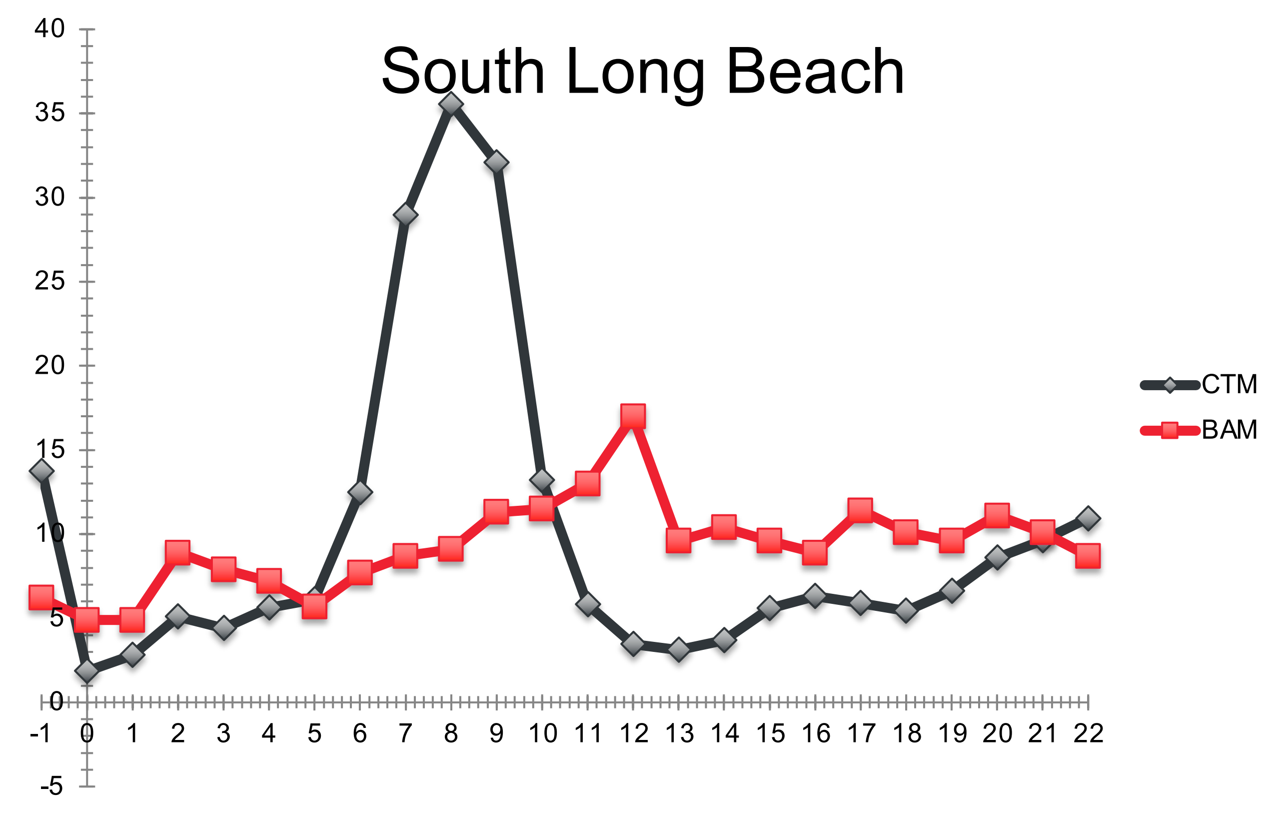
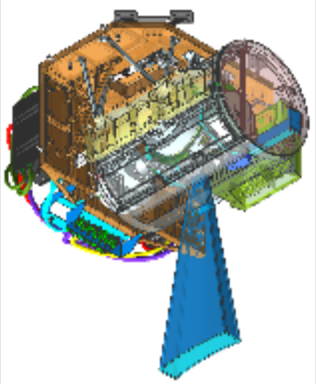
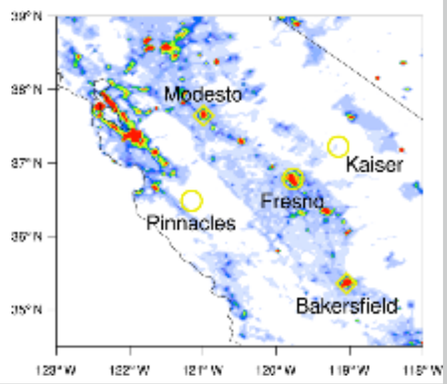


MAIA data sources





L. Tsutsui, KVPR

MAIA instrument

- Calibrated, georectified image data for retrieval of column-integrated aerosol properties.
- Parameters include aerosol optical depth (AOD), fractional AOD, particle size.

Chemical transport model (CTM) – WRF-Chem

- Informs column aerosol-to-surface PM regressions.
- Assists spatial/temporal gap-filling.
- Constrains aerosol vertical distributions.

Surface PM monitors

- Used to calibrate the PM predictor relationships.
- MAIA will use existing PM networks and deploy additional speciation monitors in collaboration with local investigators, environmental agencies, and US Embassies.

Health records

- Obtained from Vital Statistics, hospitals, HMOs, administrative records, cohorts.
- Used to associate PM exposure with health effects.

Surface monitoring

- Surface monitors are necessary to generate the geostatistical regression models coefficients
- For total $PM_{2.5}$, PM_{10}
  - We will use existing monitors where available, and aim to use data from at least 10 monitors of each type in each PTA (Ethiopia focus is $PM_{2.5}$, but requirement on number of monitors is not currently met)
  - Considering deployment of low-cost sensors as fallback
- For speciated $PM_{2.5}$
  - US/Canada: CSN, IMPROVE
  - Overseas:
    - Primarily will make use of the Surface PARTiculate mAtter Network (SPARTAN)
    - This will be supplemented with other existing monitors and stations to be deployed by the MAIA Project (e.g., a SPARTAN filter station at the US Embassy in Addis Ababa)
    - Seeking partnerships where possible to share resources
    - Also investigating deployment of aethalometers for black carbon

Summary

- The MAIA investigation strategy integrates MAIA instrument observations, PM surface monitor data, and WRF-Chem outputs to map size and compositional components of ambient PM.
- The MAIA instrument is currently in the detailed design and fabrication phase at JPL.
  - The instrument will be hosted on the General Atomics Orbital Test Bed (OTB)-2 satellite
  - Baseline orbit is 740 km altitude, sun-synchronous, 10:30 am equator-crossing time
  - Launch is currently planned for 2022 (to be confirmed) for 3-year baseline mission
- Epidemiologists on the MAIA team will conduct health impact investigations in the Primary Target Areas.
- MAIA data products will be publicly available, free of charge, for other researchers to use.

References

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