The East 4th Ring Road, facing west towards Beijing on December 2, 2015

Polarimetric characterization of speciated particulate matter (PM)

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[2]University of Nebraska - Lincoln

Jet Propulsion Laboratory
California Institute of Technology

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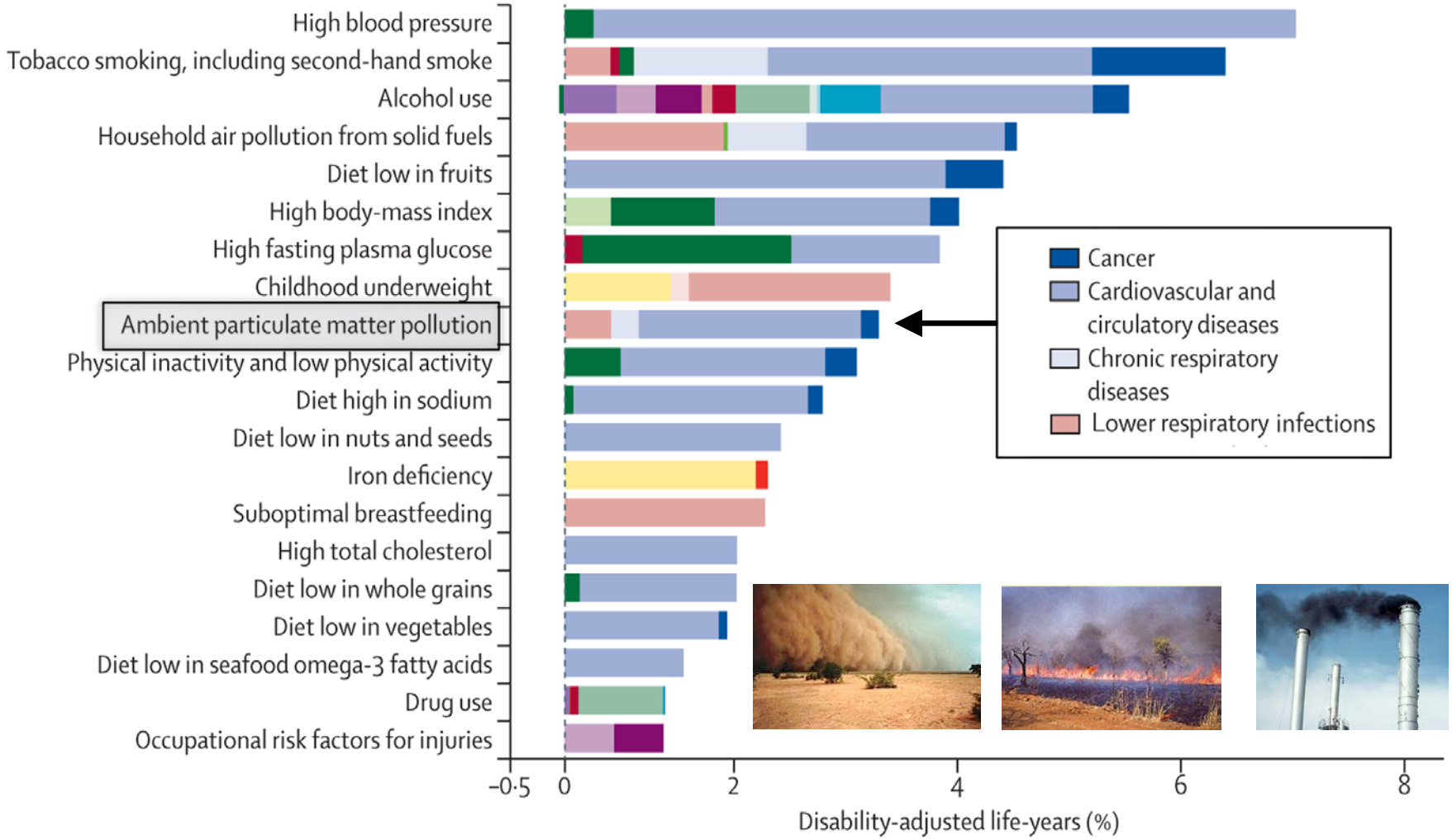
Government sponsorship acknowledged.

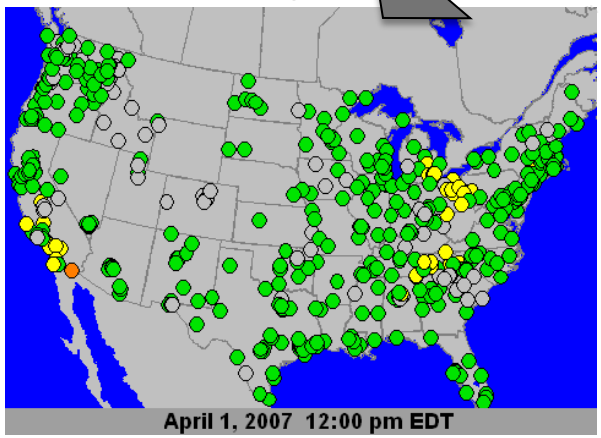
Global Burden of Disease Study 2010

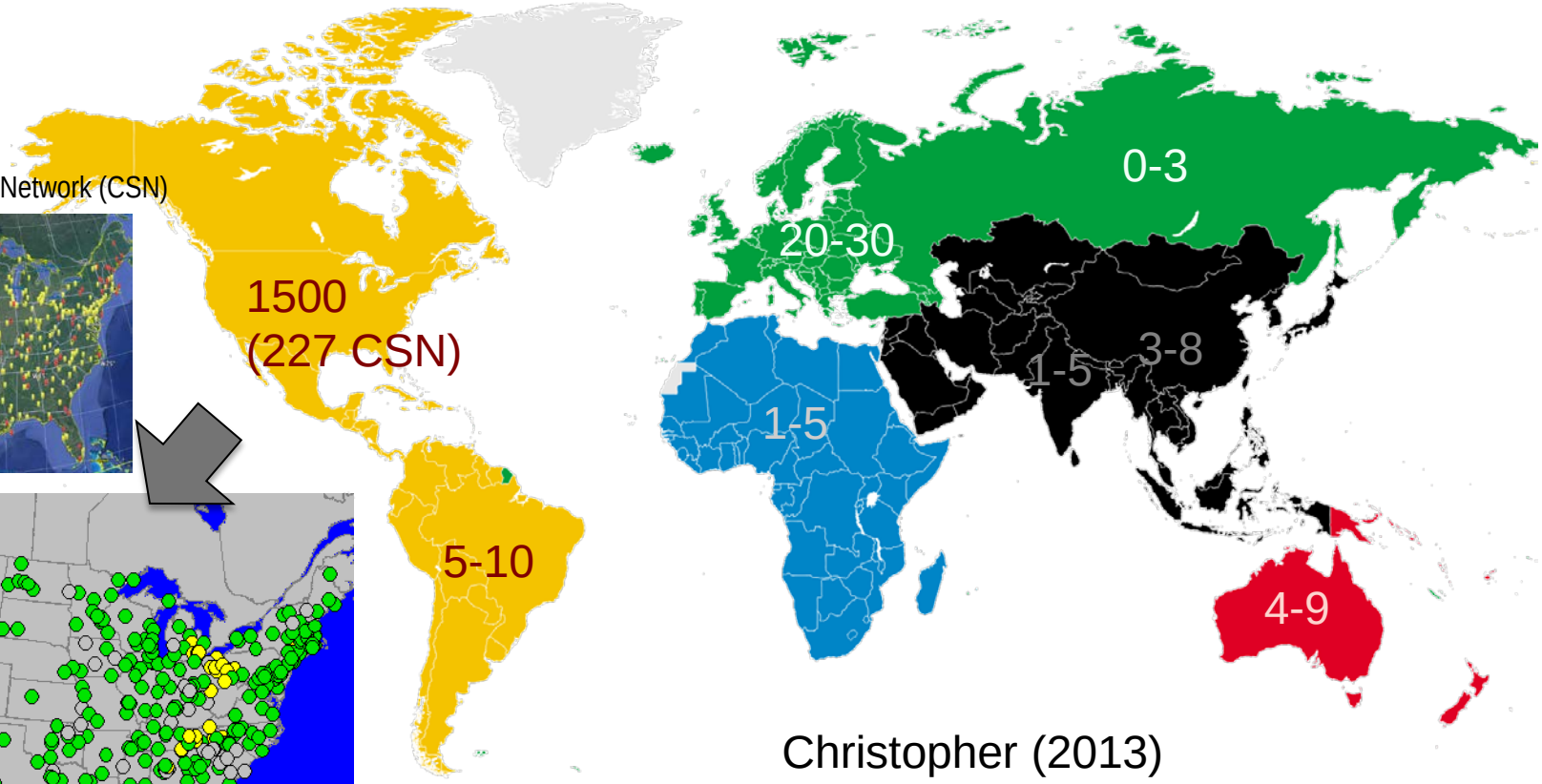


Lim et al. (2012)

Surface $PM_{2.5}$ mass monitors are sparse

Chemical Speciation Network (CSN)

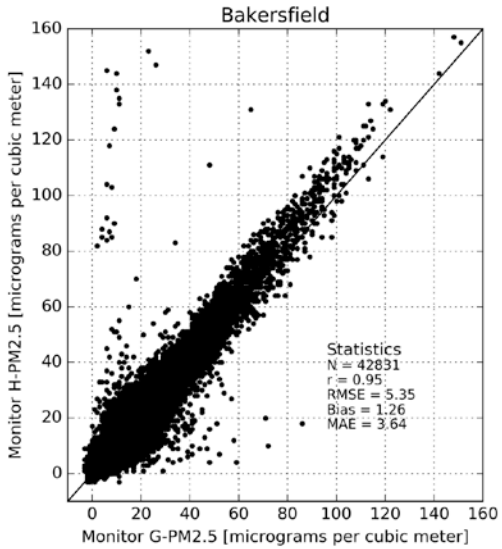


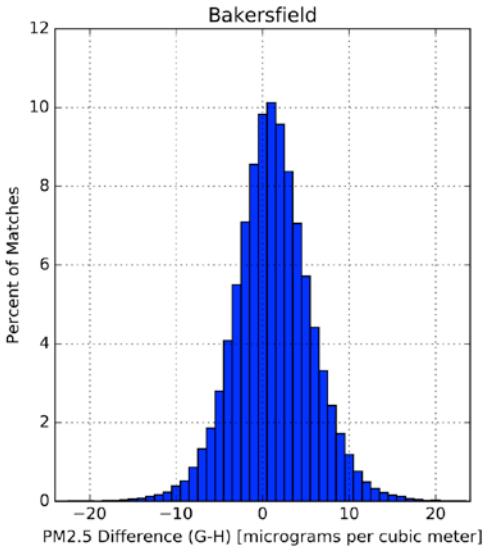


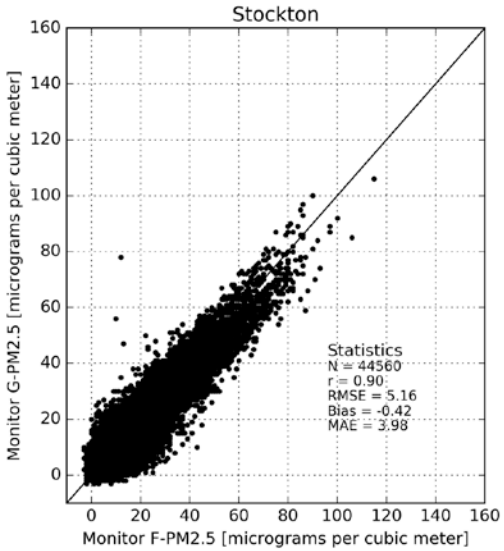
Christopher (2013)

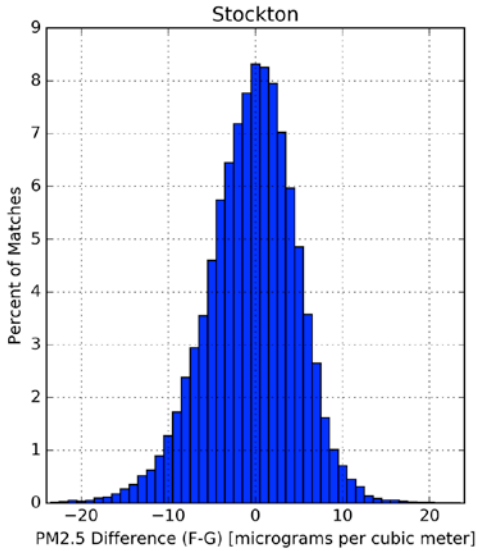
Although the EPA operates > 1000 $PM_{2.5}$ monitors in the US, vast rural and suburban areas are not covered; CSN sampling frequency is 1-3 to 1-6 days

‘Twin’ monitors comparisons









RMSE ~ 5 $\mu g/m^3$ in instantaneous observations of $PM_{2.5}$

How precise can we approach a limit of EPA data uncertainty in satellite observations?

MAIA Science Objective

PI: David Diner

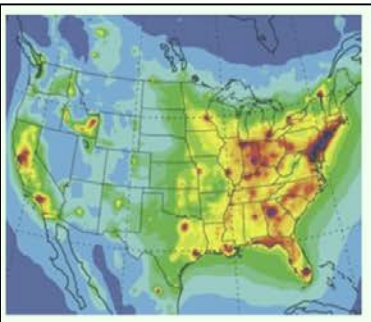
MAIA

- **MAIA's primary science objective is to associate *specific types* of airborne particulate matter (PM) with adverse health outcomes**
- Observations of major cities on five continents will provide large sample sizes to conduct statistically robust epidemiological studies
- Secondary targets will also be observed to enable other types of aerosol and cloud investigations

MAIA Science Implementation

How are we measuring and what will we do with the data?

MAIA's spaceborne observations of PM concentrations in major cities around the globe wield enormous statistical power for associating PM exposure and disease.



A state-of-the-art chemical transport model (CTM) provides initial estimates of the abundances of different aerosol types, along with their vertical distributions.

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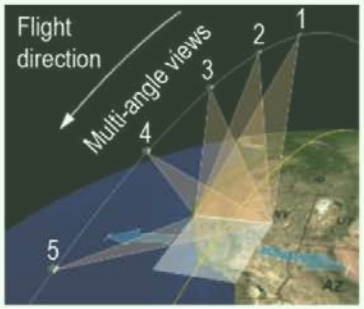

The MAIA instrument uses the proven power of multi-angle and multispectral radiometry and polarimetry to eliminate CTM biases and retrieve fractional aerosol optical depths of different particle types.

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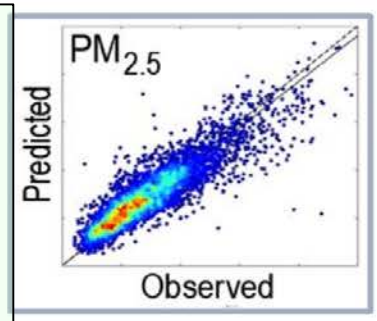

Geostatistical models (GSMs) derived from collocated surface and MAIA measurements relate these fractional aerosol optical depths to near-surface concentrations of major PM constituents.

+

Geocoded birth, death, and hospital records and established epidemiological methodologies are used to associate PM exposure with adverse health outcomes.

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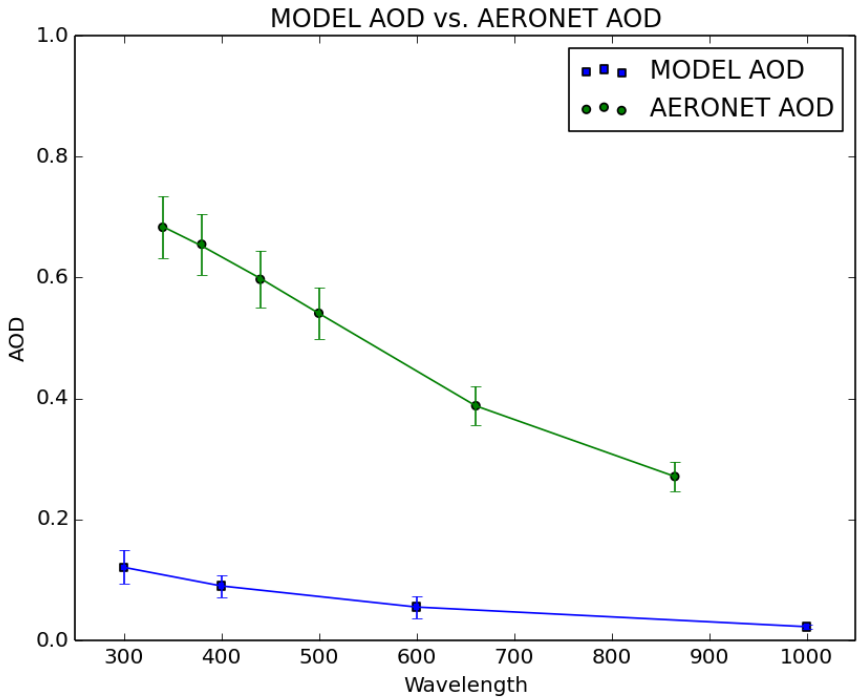
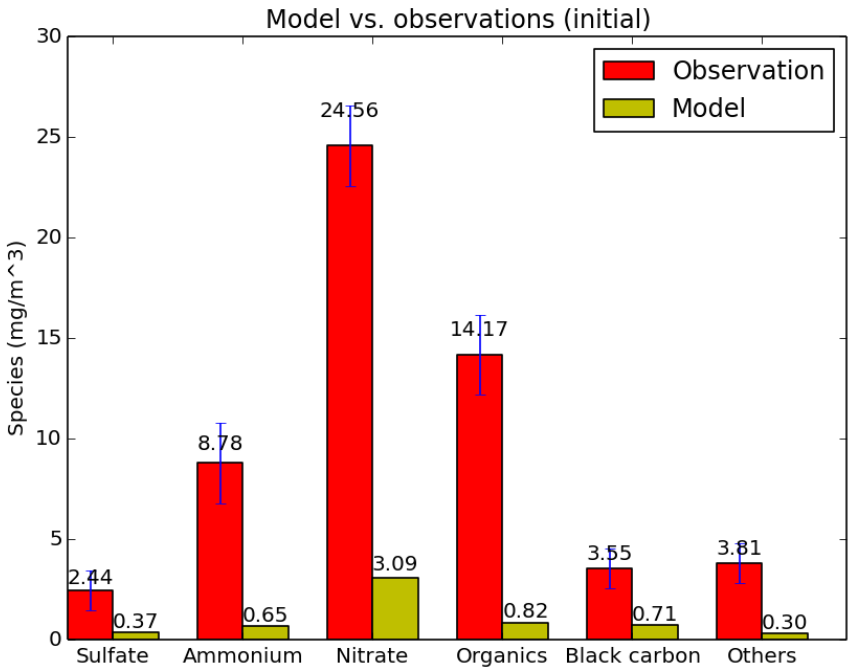
The MAIA investigation addresses NASA's EVI-3 goal of using observations from space and inter-disciplinary Earth science research to benefit society.

Model-constrained retrievals

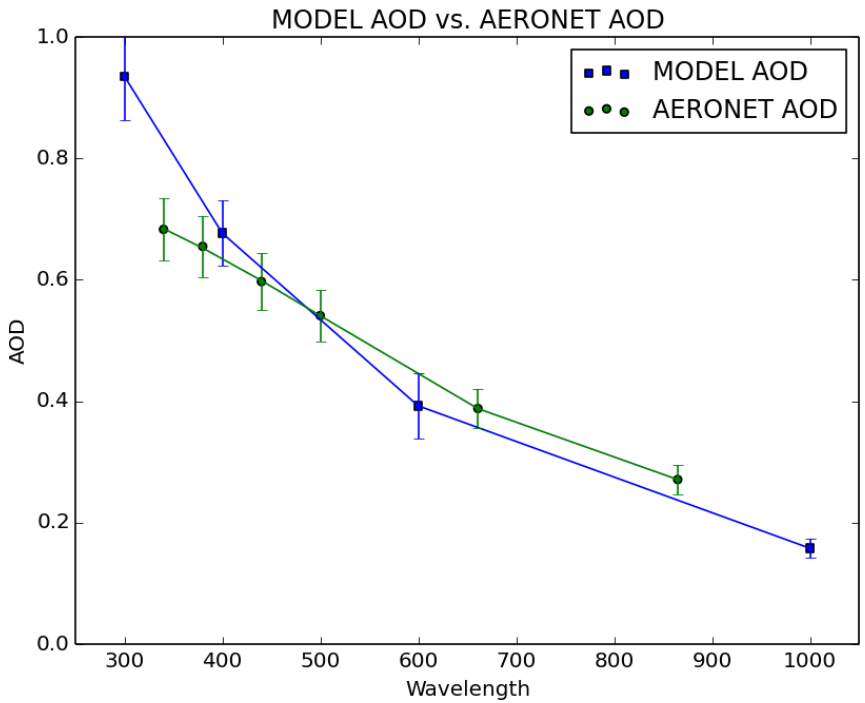
WRF-Chem AOD biases

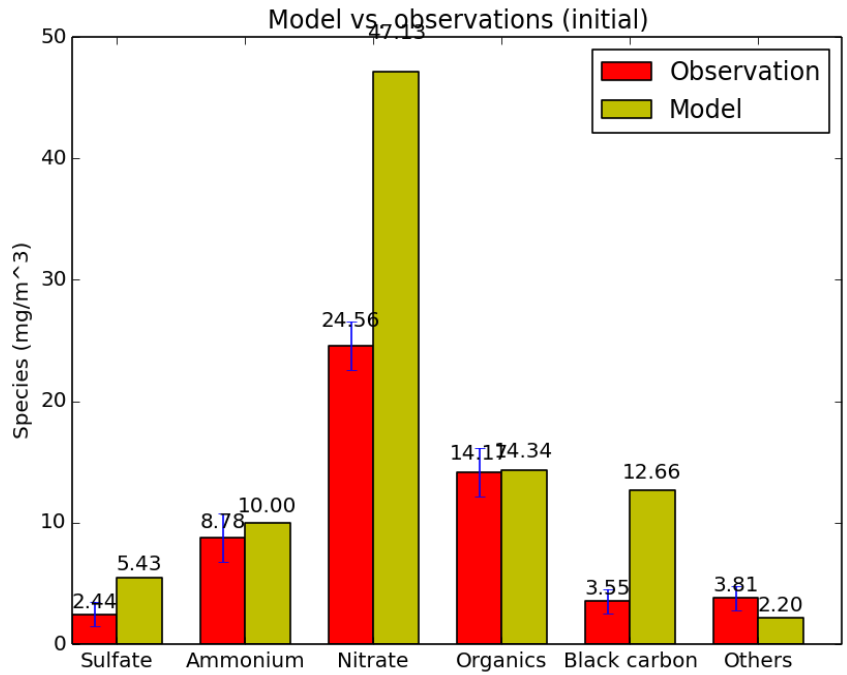




Large uncertainties currently exist in WRF-Chem (and other chemical transport model) estimates of the concentration the various aerosol species (e.g., black carbon, sulfate, dust, etc.).

AOD adjustment approach

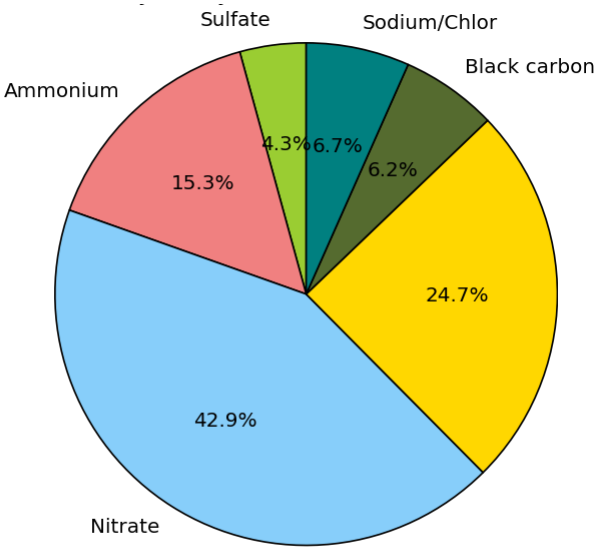




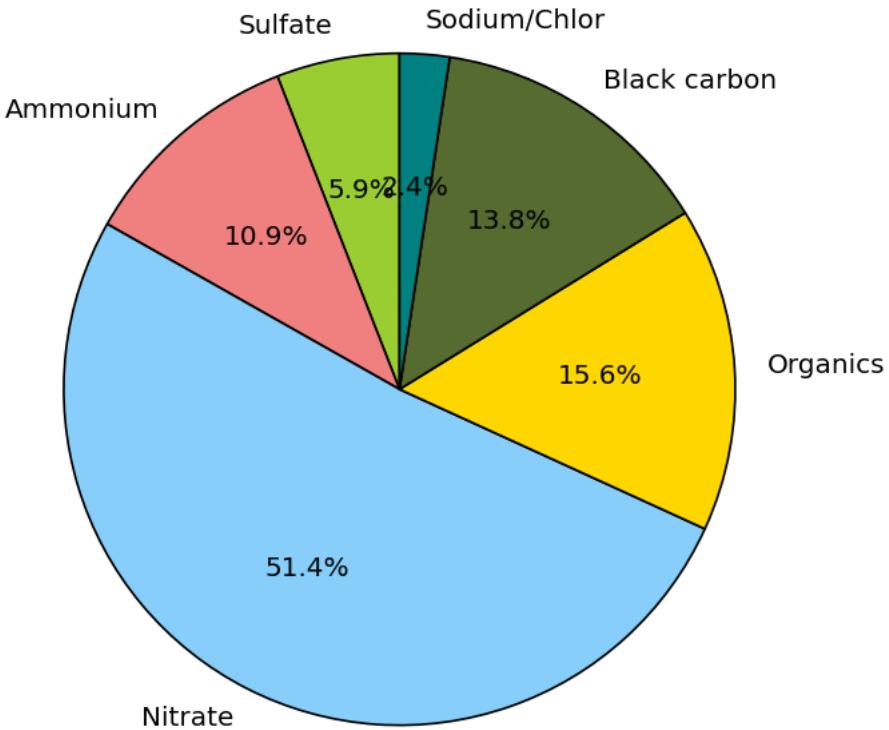
Simple AOD 500nm adjustment while improving $PM_{2.5}$ predictions still bias by ~50% for selected aerosol species

WRF-Chem aerosol species fractions

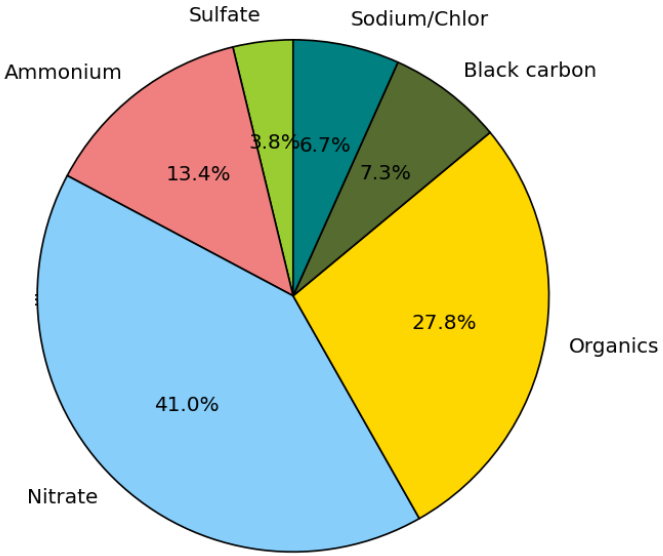
January 1 – surface Network data



January 6 – WRF-Chem speciation

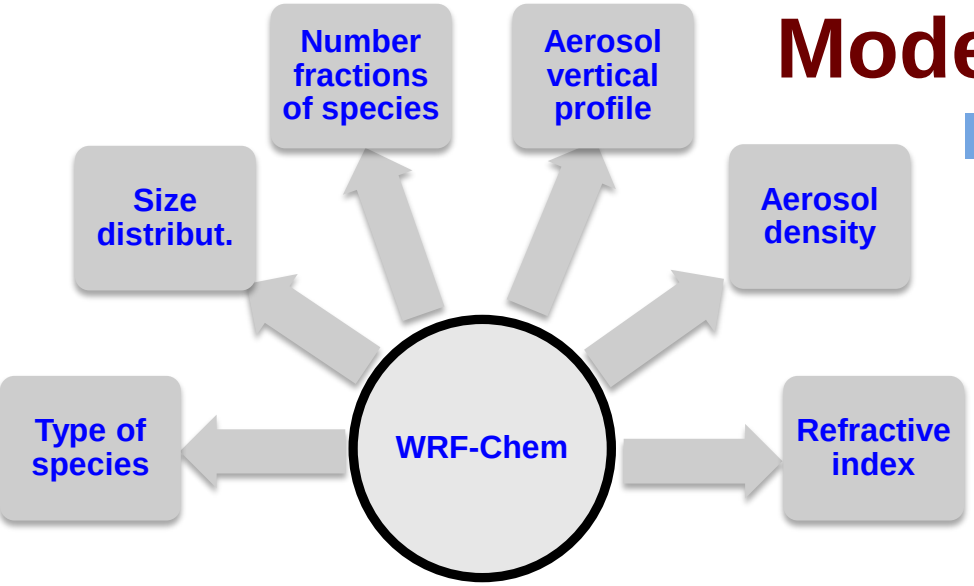


January 7 – surface Network data

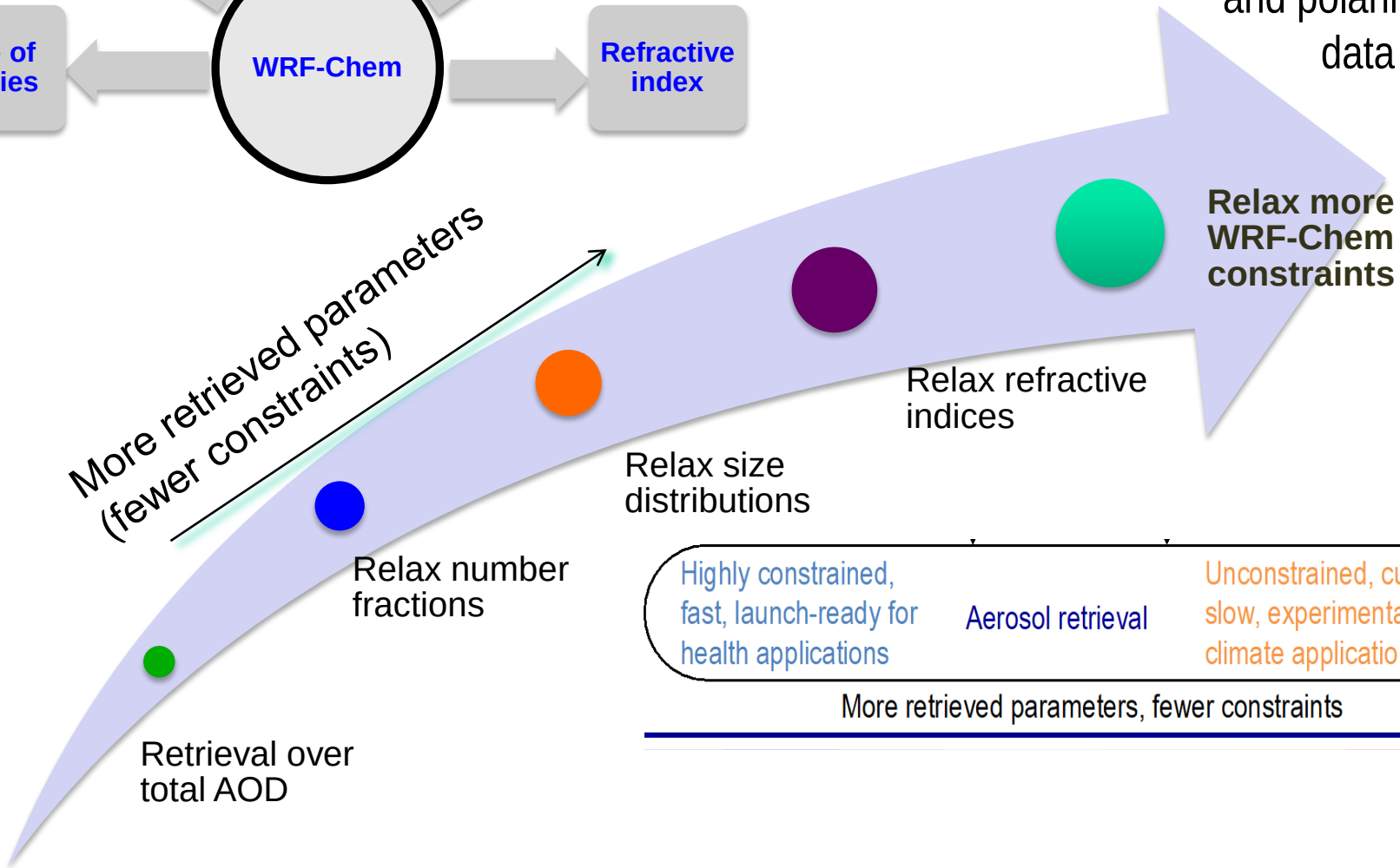


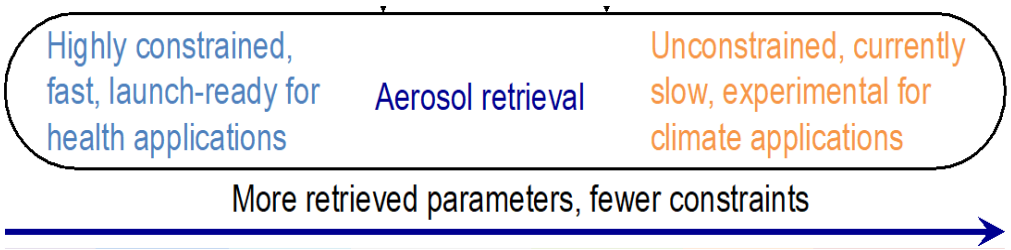
Chemical Transport models (CTM) do well in predicting the types of aerosols present at a given location and time

Model-constrained retrieval



Minimize error between model and polarimetric data

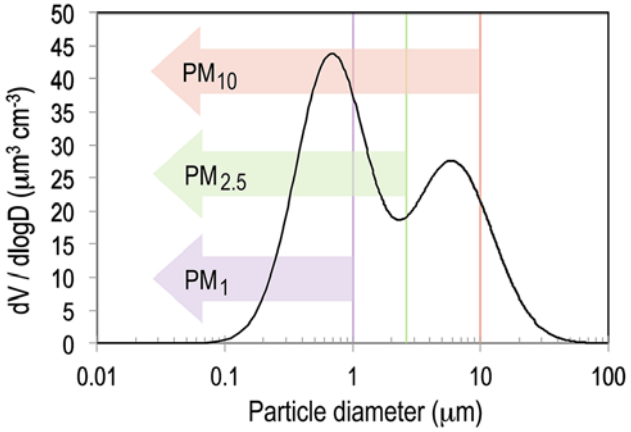




ImPACT-PM – California Central Valley

As a pathfinder to **MAIA**, the ImPACT-PM project was a joint JPL/Caltech effort to combine measurements from MISR and AirMSPI with in situ airborne measurements and a chemical transport model to validate remote sensing retrievals of different ***types*** of airborne particulate matter.

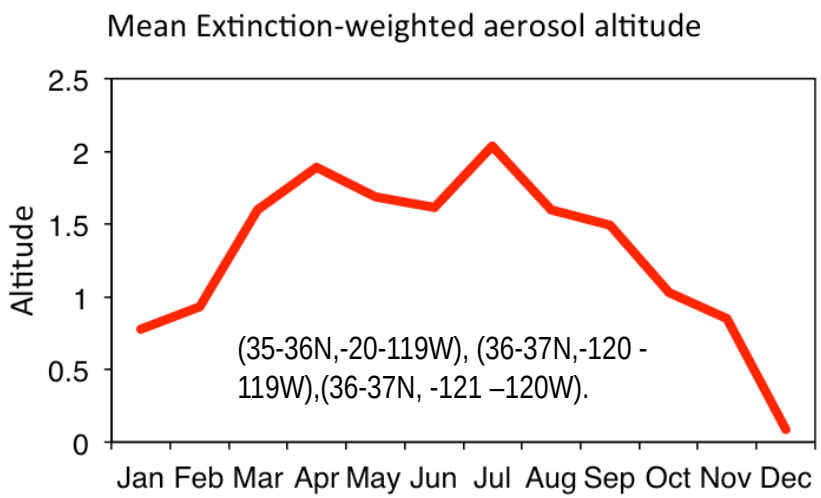
Goal: Demonstrate that multiangular polarimetric observations from the AirMSPI instrument combined with WRF-Chem high-resolution modeling are a promising tool for retrieving $PM_{2.5}$ by particle type

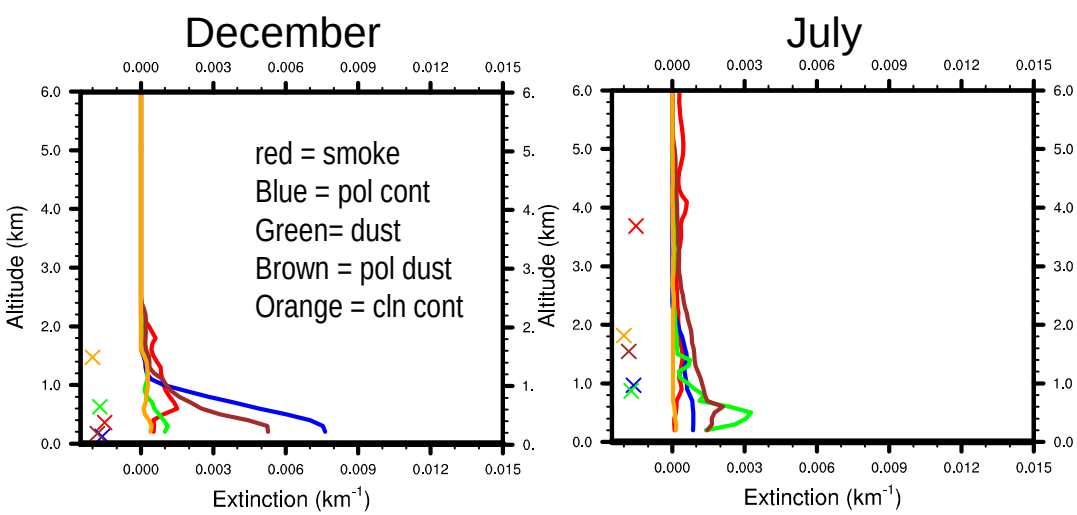


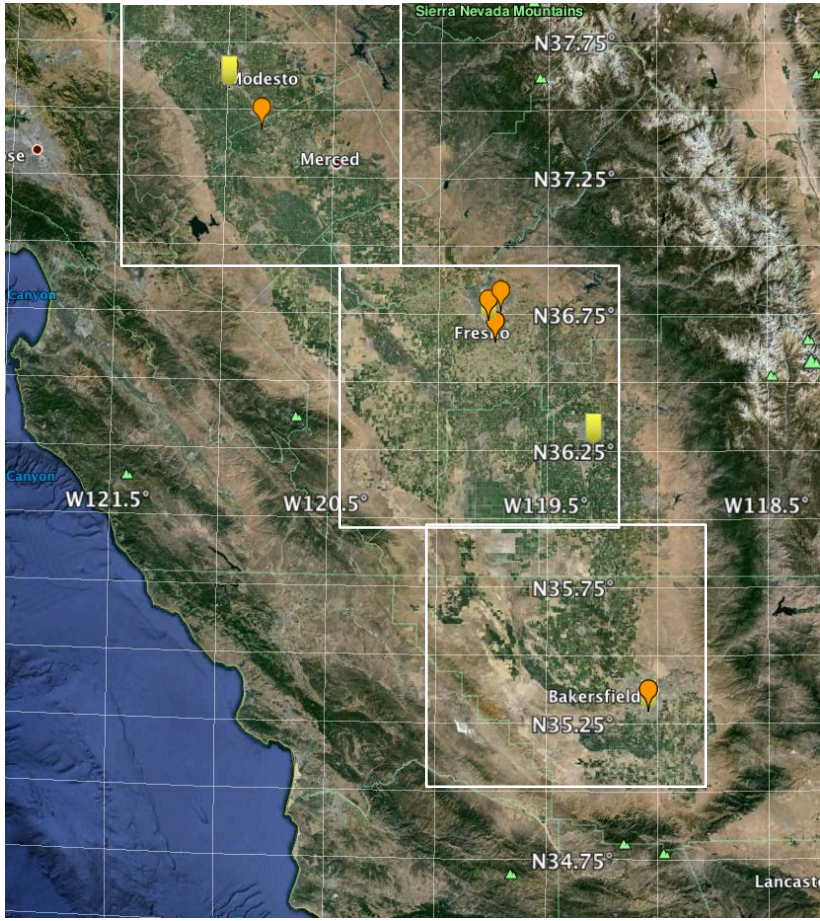
Infusion Path:

- Collect AirMSPI data over the California Central Valley EPA sites
- Evaluate WRF-Chem simulations over the Central Valley
- Integrate WRF-Chem initial guess into AirMSPI retrievals
- Validate model-constrained polarimetric retrievals of PM types

Central Valley aerosol profiles



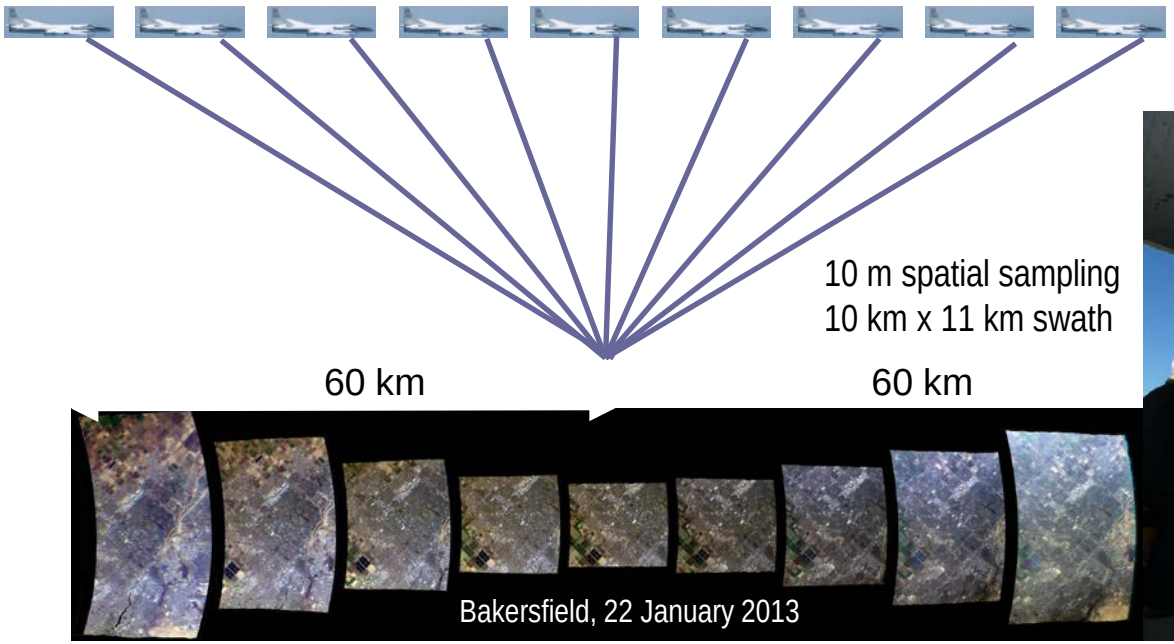




Courtesy of J. Campbell, NRL, and M. Tosca, JPL

Quantify the uncertainty of combined AirMSPI/WRF-Chem retrievals of speciated PM in $\mu g/m^3$ under elevated aerosol conditions; evaluate WRF-Chem vertical profiles

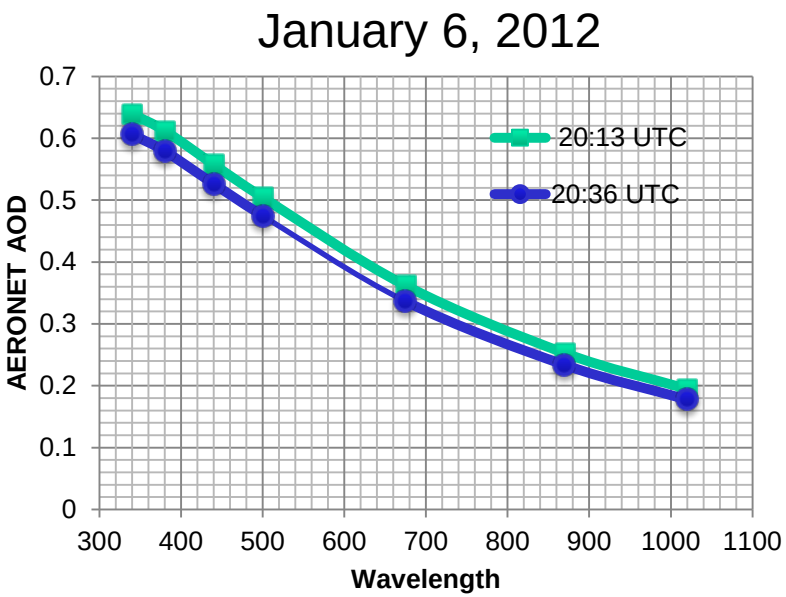
Impact-PM Implementation

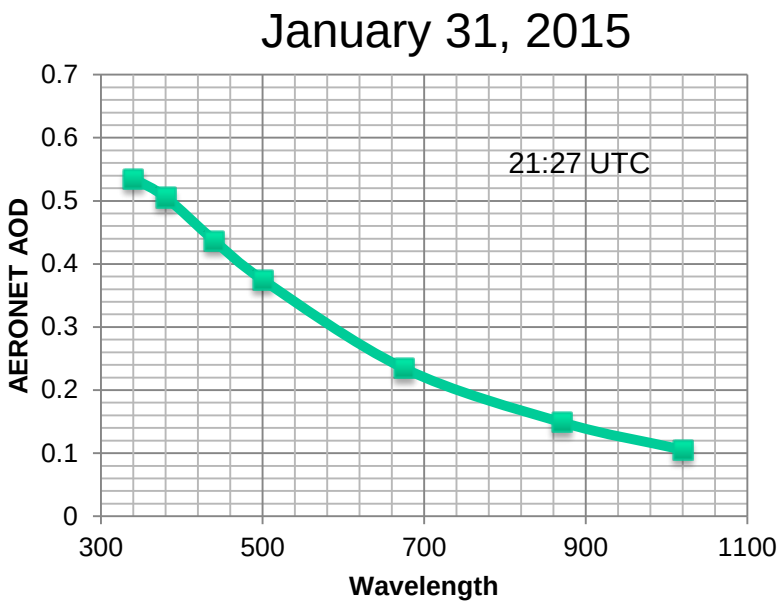


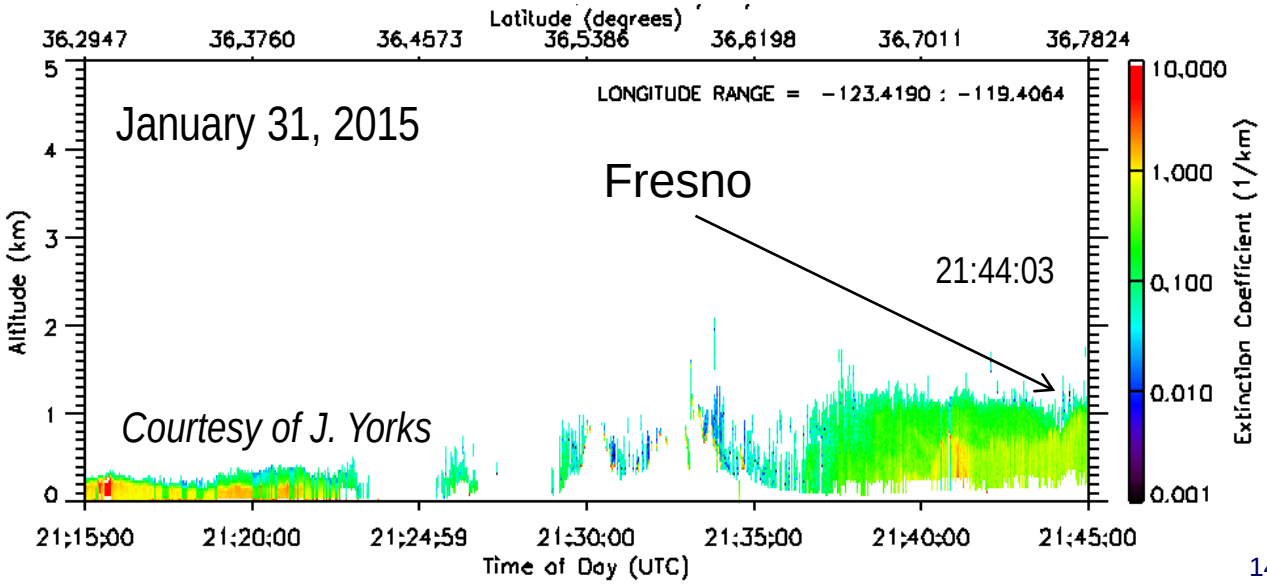
AirMSPI Aerosol Retrieval: from column to species properties

- The suitable data is identified: AirMSPI collected data over Fresno on January 6, 2012 and January 31, 2015 during aerosol pollution events
- The project-specific science flight targeting Fresno and Bakersfield EPA stations was accomplished on February 5, 2015. Collocated MISR data is available, and demonstrate gradient of pollution in the area.
- The field campaign is completed on July 5-8, 2016. Collocated MISR data is available on July 5 and 7th.

Initial analysis: AirMSPI data over Fresno

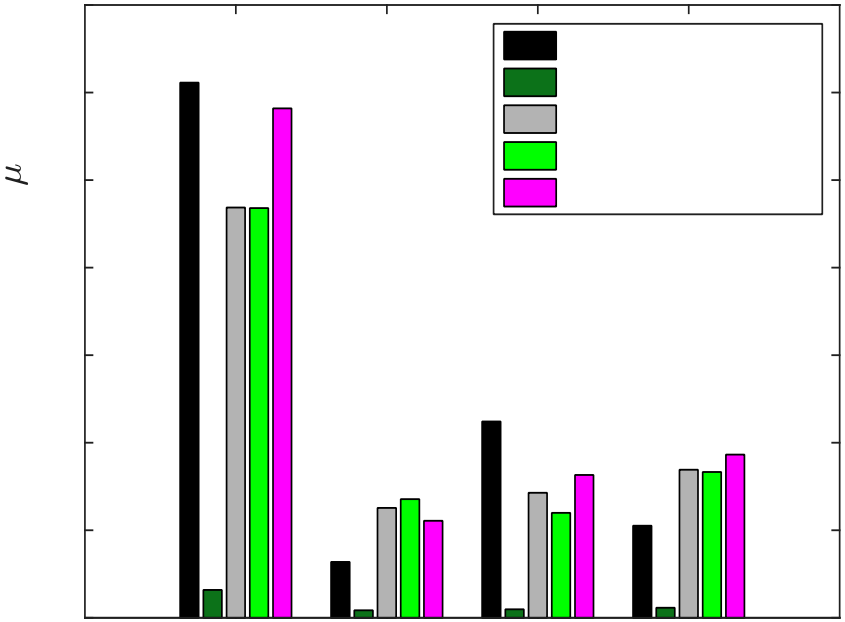




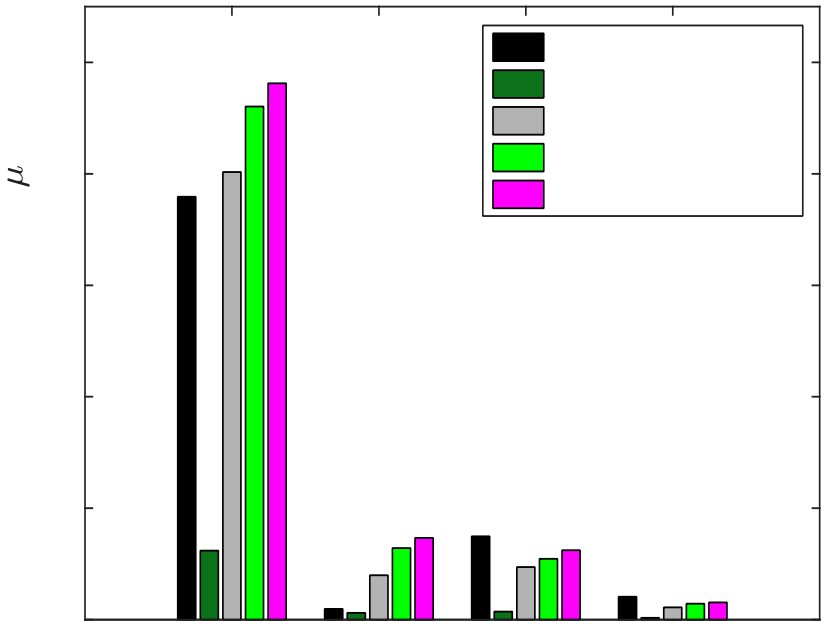


AirMSPI data collocated with EPA sites

Jan 06, 2012 engineering test flight

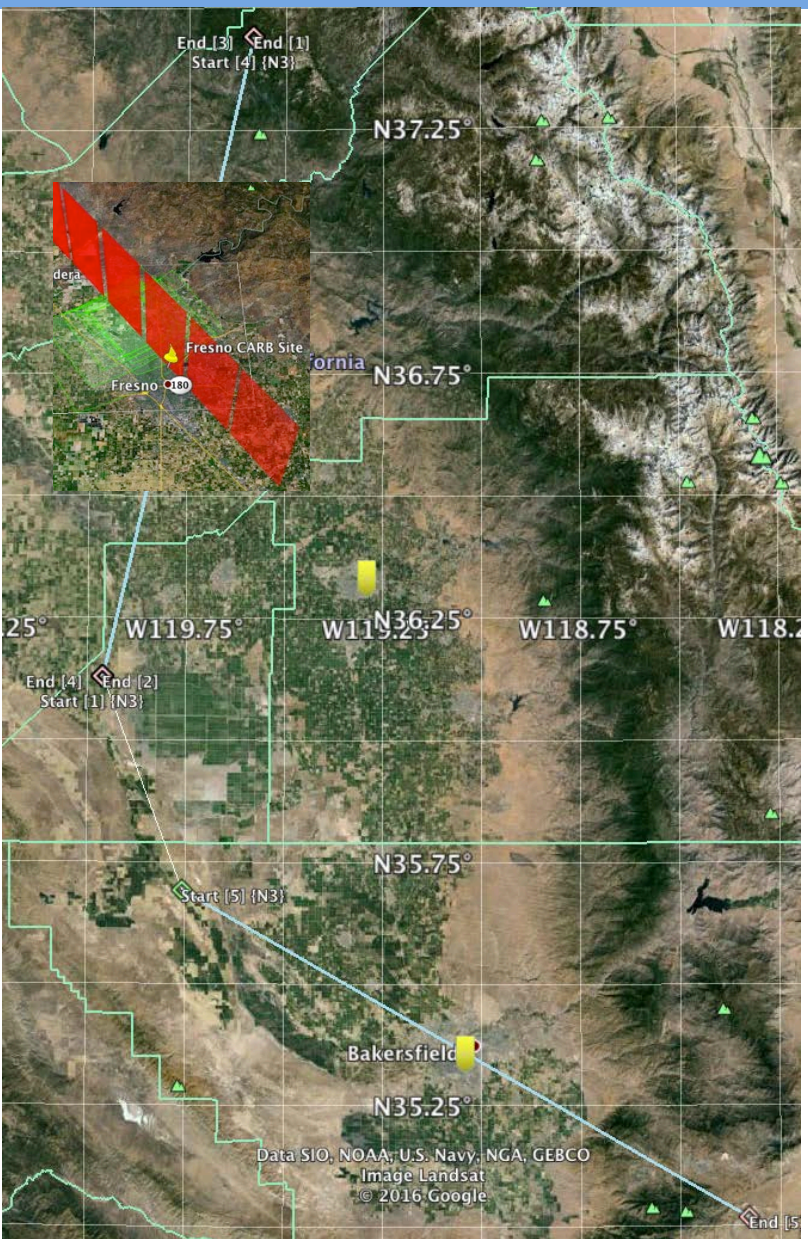


Jan 31, 2015 CalWater field campaign



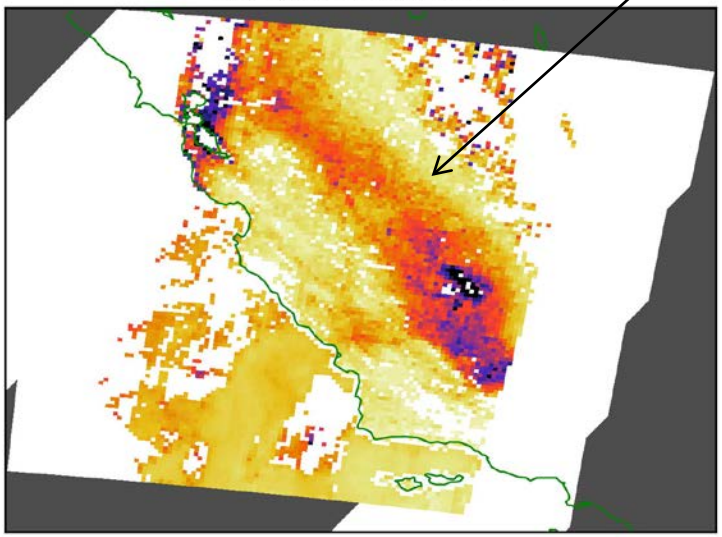
Multiangular polarimetric observations constrained by WRF-Chem model are promising tool for retrieval $PM_{2.5}$ by particle species (sulfate, nitrate, organic carbon, black carbon, dust)

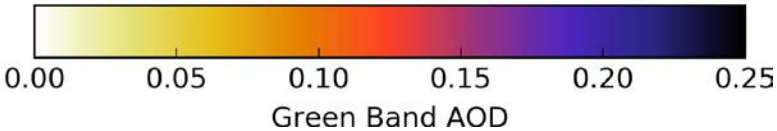
February 5, 2016 (MISR under-flight, Fresno)



Fresno

4.4 km Resolution



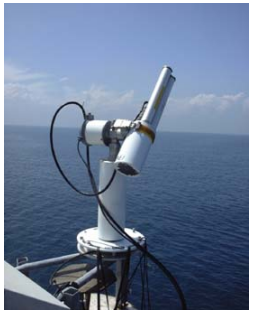


AERONET
AOD =0.09
at 500nm

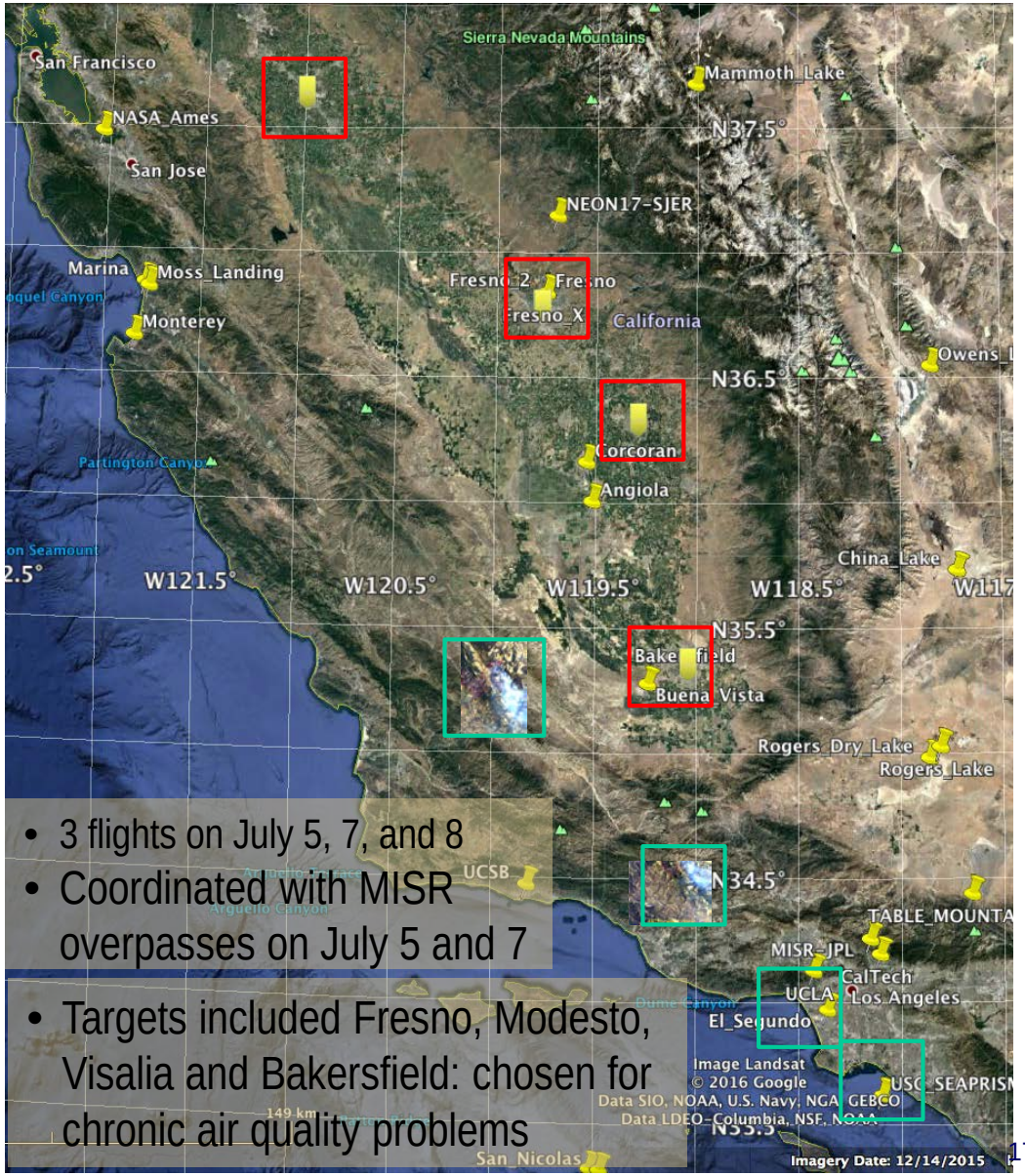
ImPACT-PM: July flights

Imaging Polarimetric Assessment and Characterization of Tropospheric Particulate Matter (ImPACT-PM)

Role	Name
JPL PI	**Olga Kalashnikova**
Caltech Co-I	**John Seinfeld**



July 5-8, 2016

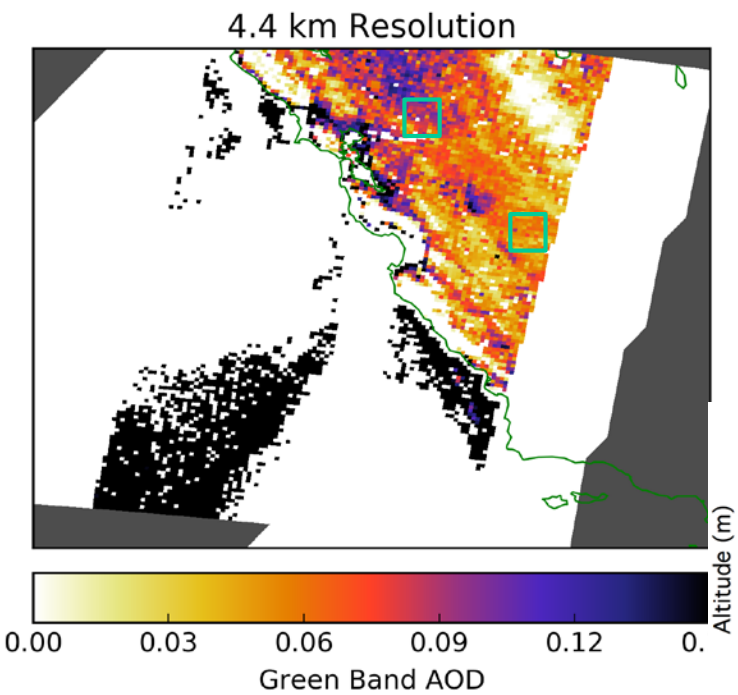


- 3 flights on July 5, 7, and 8
- Coordinated with MISR overpasses on July 5 and 7
- Targets included Fresno, Modesto, Visalia and Bakersfield: chosen for chronic air quality problems

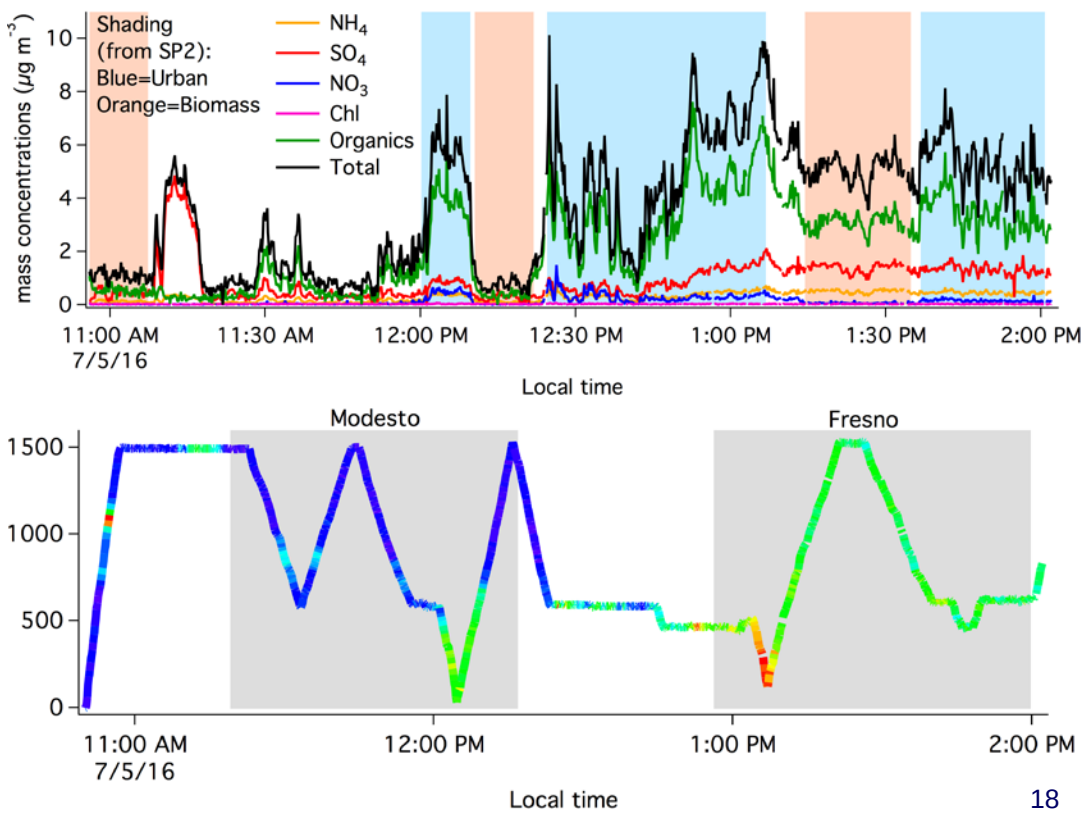
July flight primary objective

Quantify the uncertainty of combined AirMSPI/WRF-Chem retrievals of speciated PM in μg/m^3 through comparisons with both Caltech *in situ* and EPA ground-based measurements, develop spatial error estimates, and compare these results with EPA PM monitoring requirements.

MISR, July 5, 2016

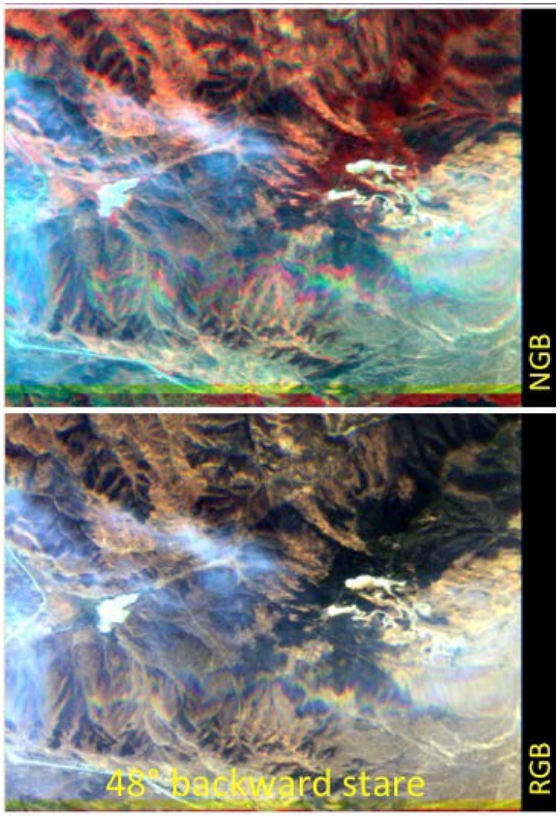


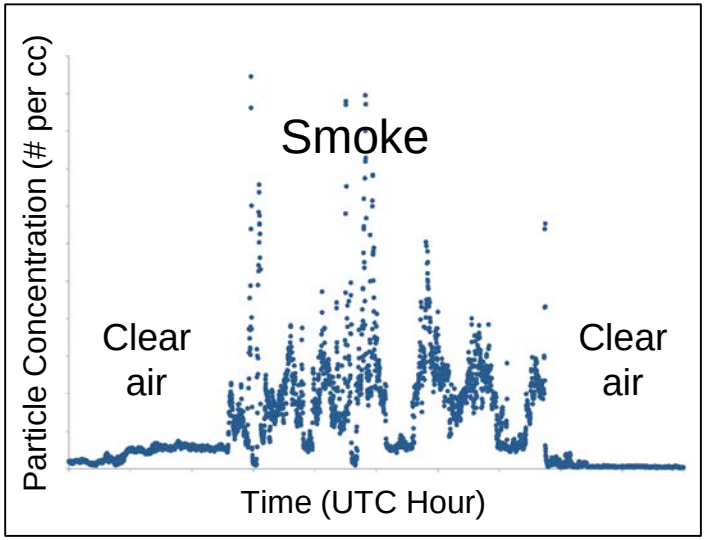
AMS data



July flights over local fires

Data collected over the Fort Fire on July 8, 2016





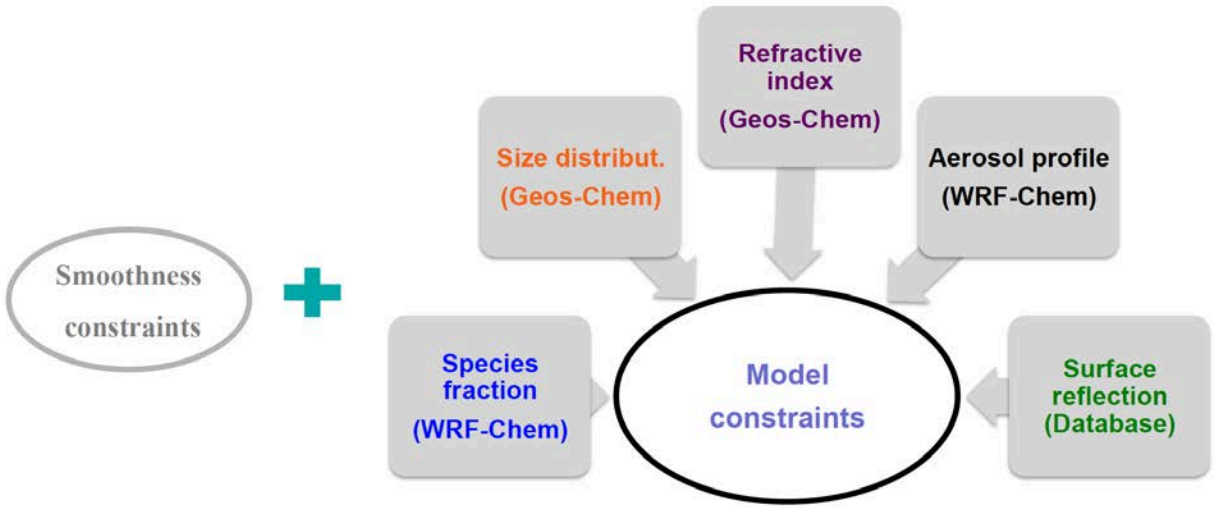
Particle concentration from Caltech's PCASP instrument on the CIRPAS Twin Otter aircraft

- Evaluate representation of BC in WRF-Chem
- Evaluate BC retrievals using Caltech campus instruments
- Perform joint analysis of Ground-MSPI and AirMSPI data
- Provide datasets for polarimeter inter-comparison
- Evaluate AirMSPI and SPEX capability for atmospheric correction

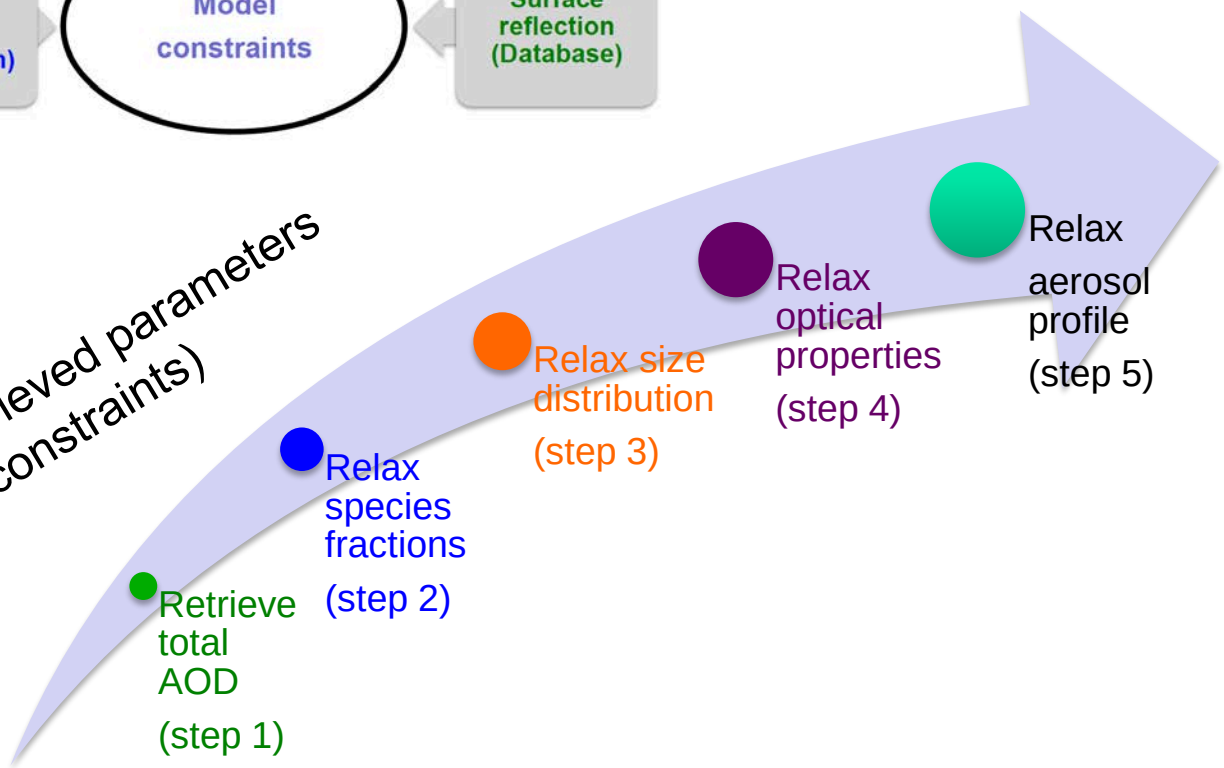
Concluding remarks

- Quantitative determination of PM distributions, trends, sources, and types is necessary for measuring and predicting exposure and toxicity
- Advanced polarimetric remote sensing technologies improve aerosol retrieval sensitivity to particle type
- MAIA major advance will be to partition $PM_{2.5}$ by particle species (sulfate, nitrate, organic carbon, black carbon, dust) over selected target areas
- We demonstrated that reliable conversion of column AOD and fractional AOD to $PM_{2.5}$ species is achievable trough combined WRF-Chem/AirMSPI retrievals
- ImPACT-PM July field campaign provided additional data to quantify the uncertainty of combined AirMSPI/WRF-Chem retrievals

From column to species retrievals

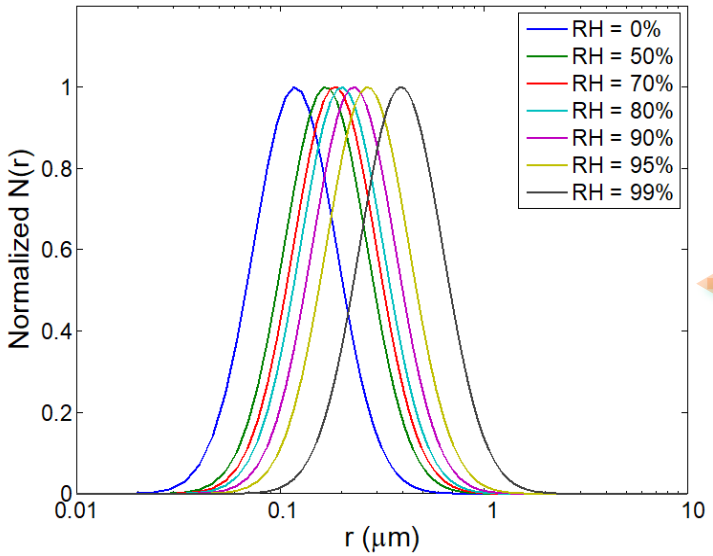


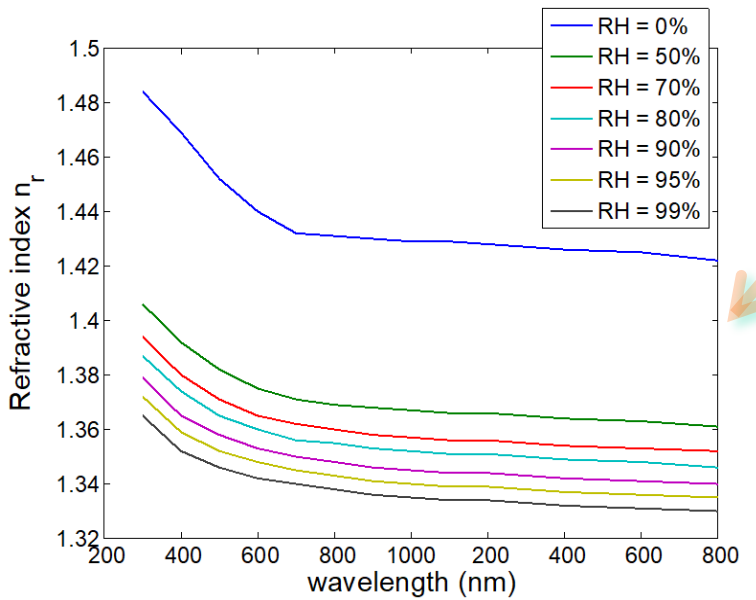
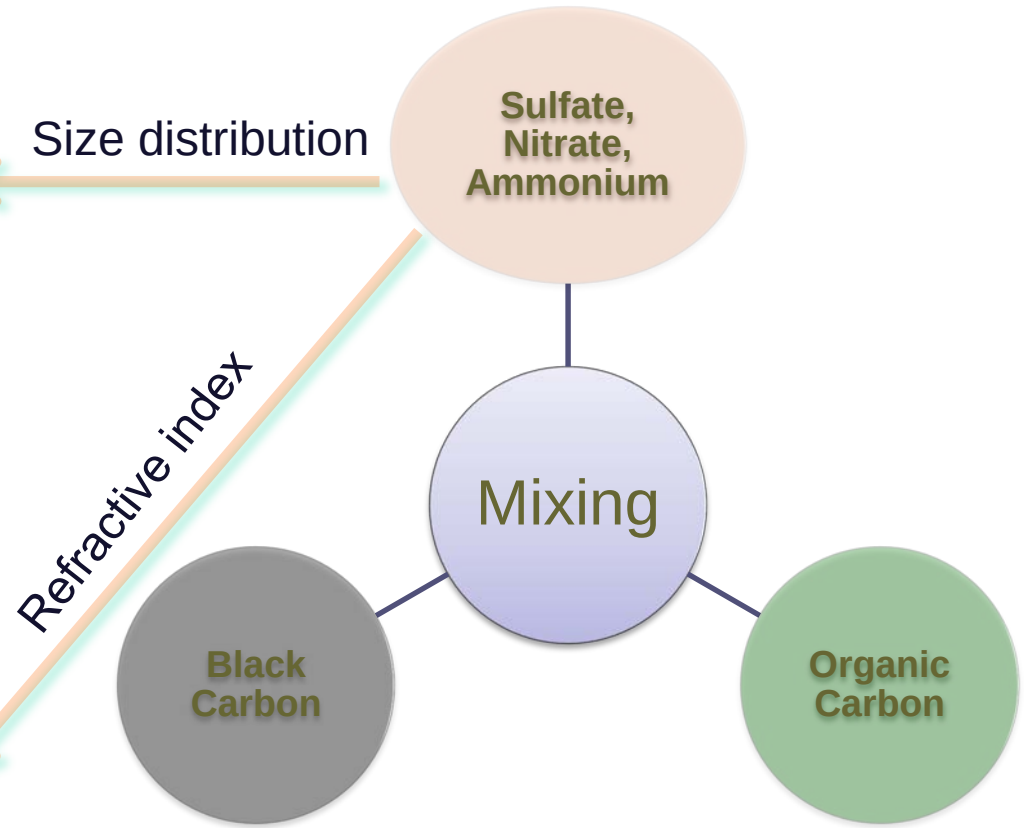
Both aerosol & surface are retrieved for initial test cases – but surface reflection dataset will be generated for MAIA retrieval



Minimize error between model and data

MAIA approach: Optical properties





Aerosol species