


The Multi-Angle Imager for Aerosols (MAIA) Investigation: Application of spaceborne spectropolarimetry to speciated airborne particulate matter exposure and human health



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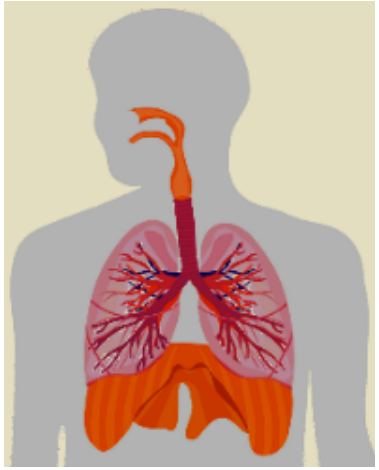
APOLO-19
Lille, France

Airborne particulate matter (PM): a major risk to human health

4.1 million premature deaths per year — the top environmental risk factor worldwide

MODIS and MISR used to determine PM exposure



Airborne PM has been associated with

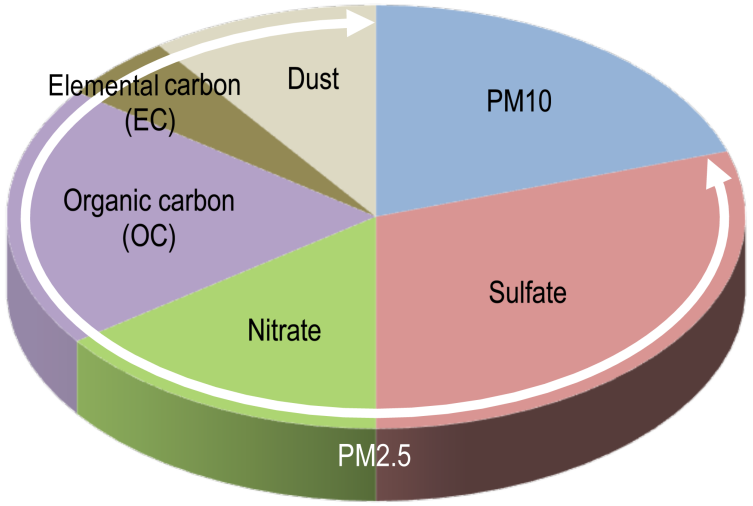
- cardiovascular disease and mortality
- respiratory disease
- pregnancy complications and low birth weight
- lung cancer
- many other adverse health outcomes

Motivation for MAIA



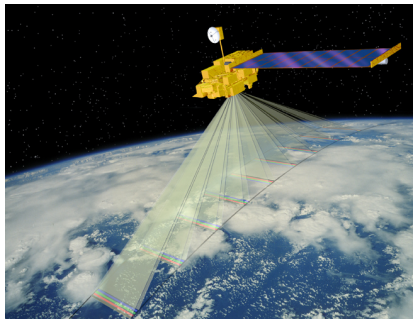



While PM is a known health risk, the relative toxicity of different PM types—mixtures of particles with different sizes, shapes, and compositions—is not well understood.



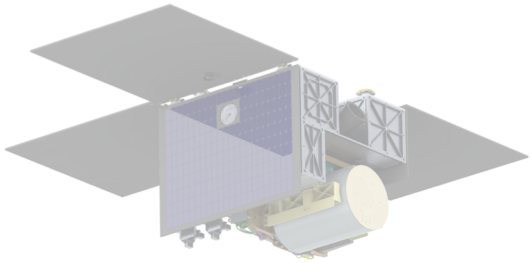
MAIA's primary objective is to link exposure to different types of PM with human health.

From MISR to MSPI to MAIA



Multi-angle Imaging SpectroRadiometer (MISR)

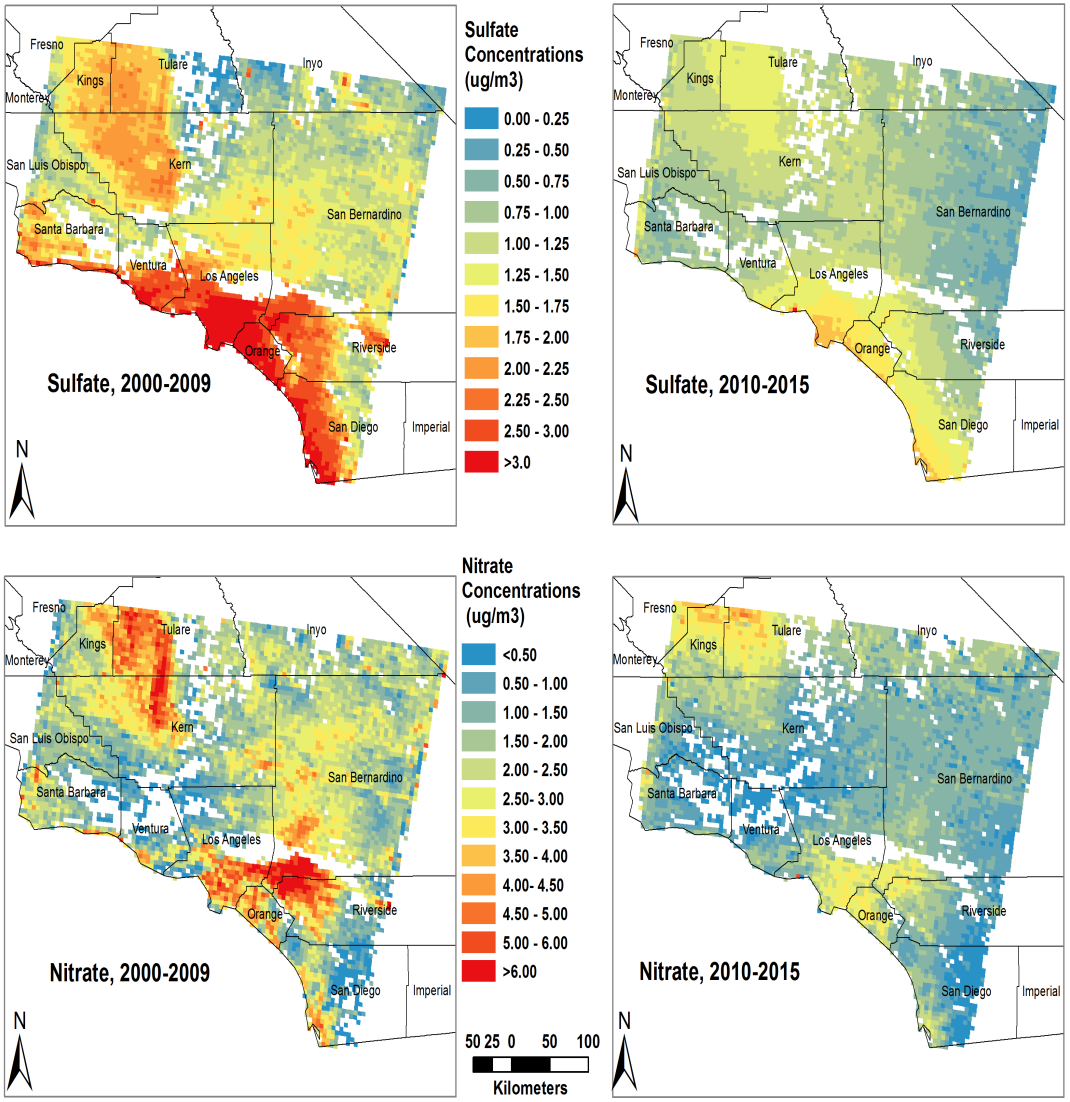
Airborne Multiangle SpectroPolarimetric Imagers (AirMSPI/AirMSPI-2)



Multi-Angle Imager for Aerosols (MAIA)

Mission start	1999 (still operating)	Since 2010	~2022 (3 year mission)
Platform	NASA/Terra	NASA/ER-2 aircraft	General Atomics/OTB-2
Coverage	Global	Targeted	Targeted
Revisit frequency	~once per week	N/A	~3.5 times per week
Multi-angle viewing method	9 fixed cameras	Pointable camera	Pointable camera
Number of spectral bands	4 (VNIR)	AirMSPI: 8 (UV/VNIR) AirMSPI-2: 12 (UV/VNIR/SWIR)	14 (UV/VNIR/SWIR)
Polarization	No	3 bands (AirMSPI) 5 bands (AirMSPI-2)	3 bands
Aerosol resolution	4.4 km	Sub-km	1 km

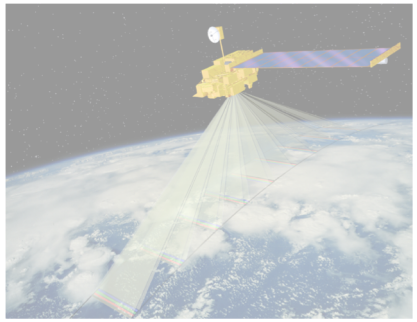
Speciated PM2.5 mapping with MISR



Multi-year means of predicted sulfate and nitrate $PM_{2.5}$ concentrations

Meng et al. (2018)

From MISR to MSPI to MAIA



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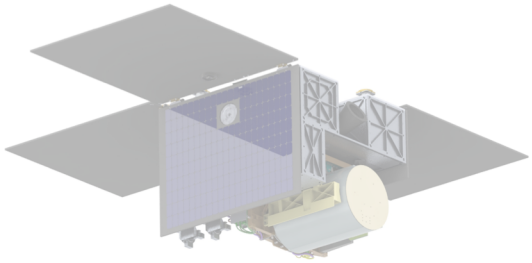

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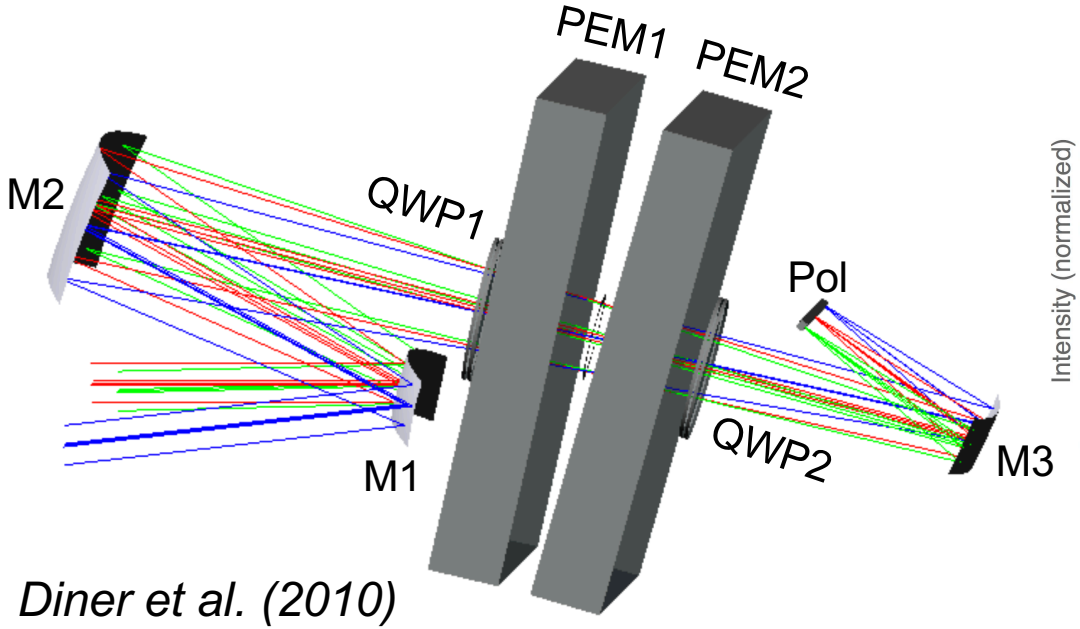
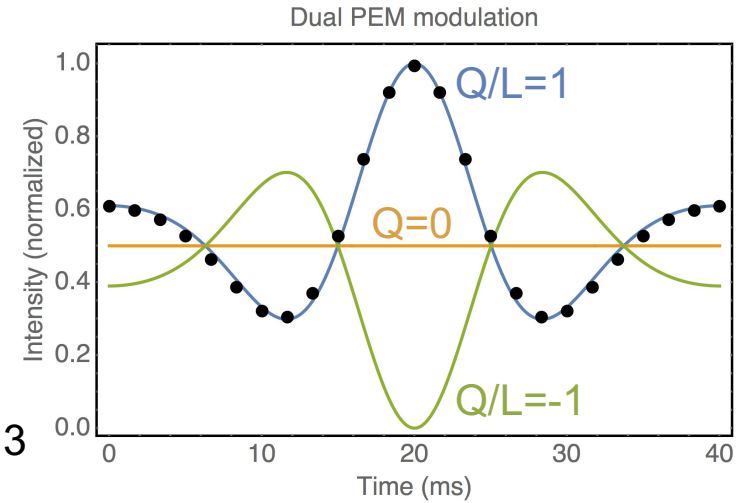
Polarization measurement technique

- Dual photoelastic modulators (PEMs)
- Achromatic quarter-wave plates (QWPs) to modulate linear polarization
- Fixed 0°, 45° wire grid polarizer strips on adjacent detector rows
- Total and polarized radiance (Q or U) from same pixel → ratio independent of optical transmittance or detector gain
- Linear signal equation

$$S(t) = L + Q\,F(t)$$

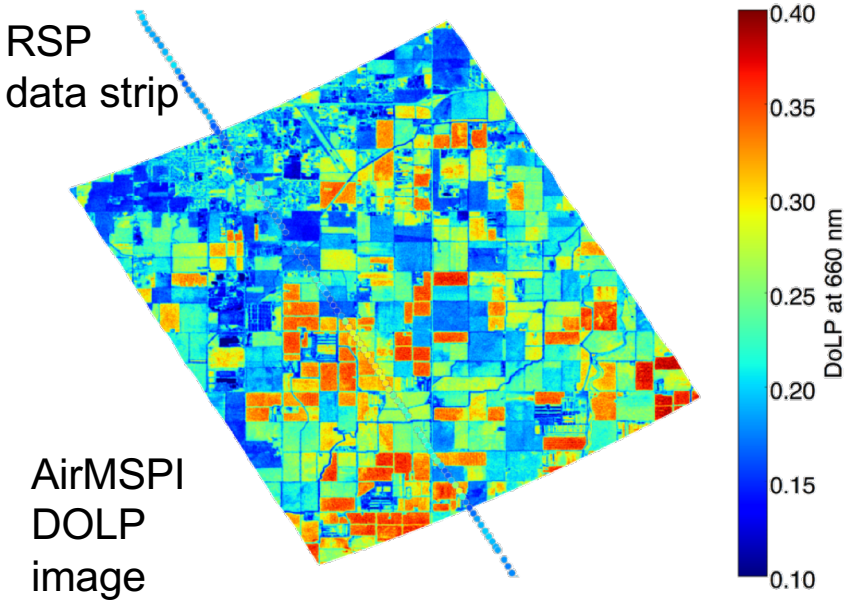


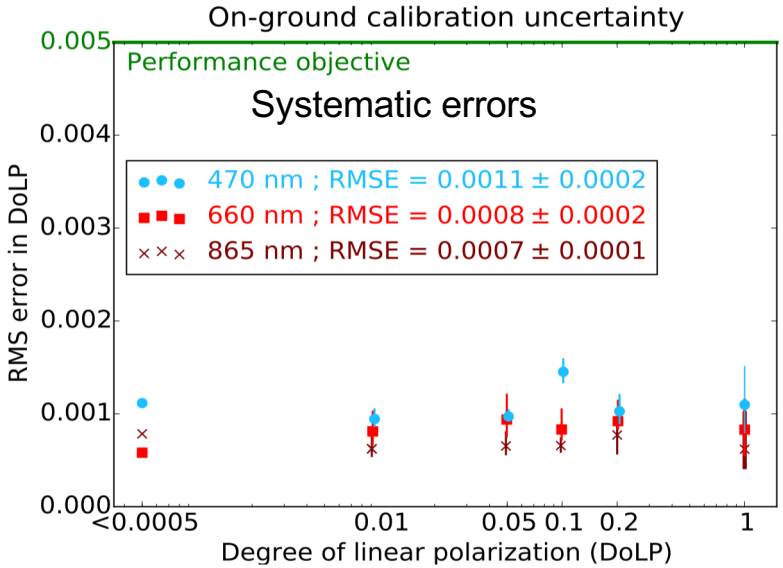
Diner et al. (2010)

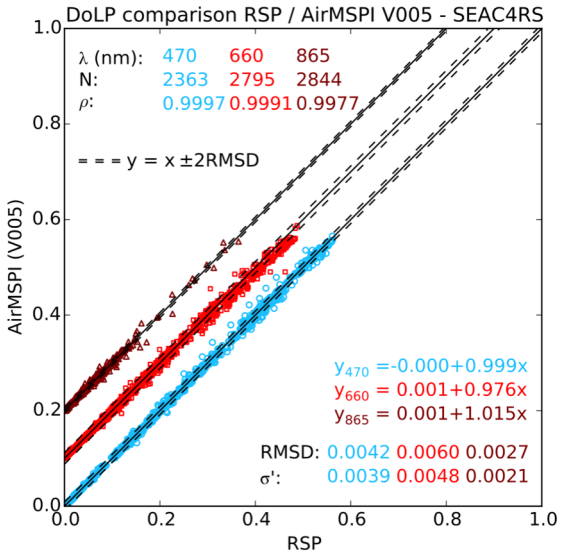


AirMSPI performance evaluations

Laboratory: comparison to polarization state generator



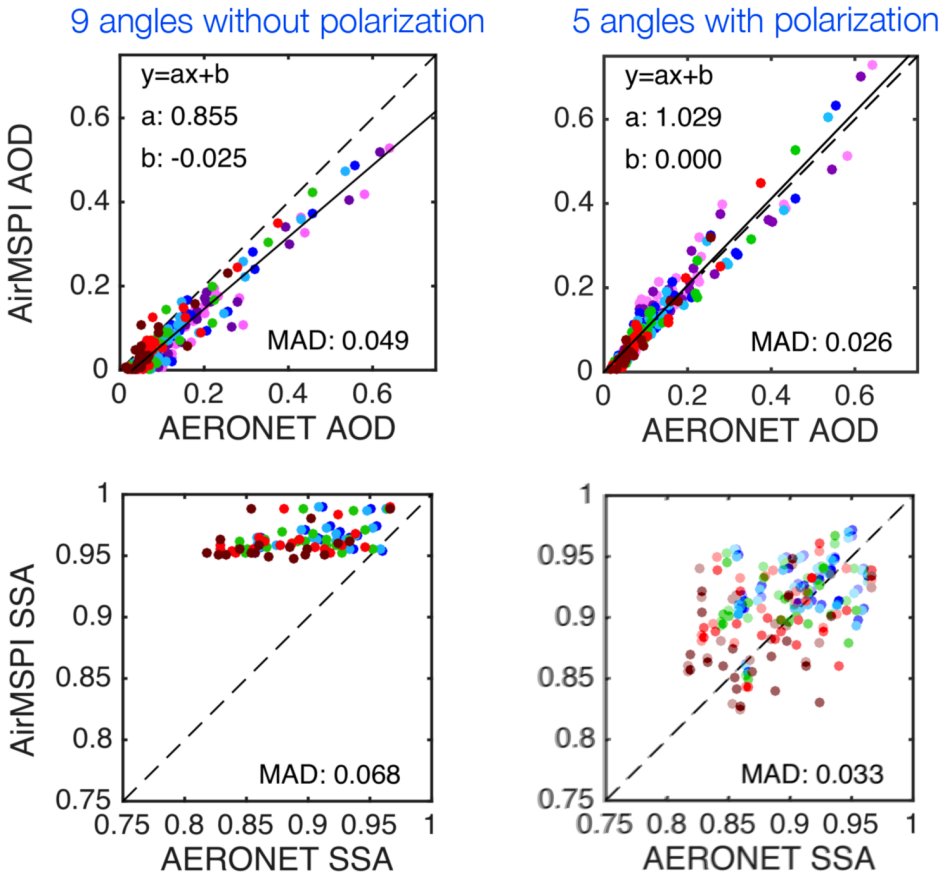




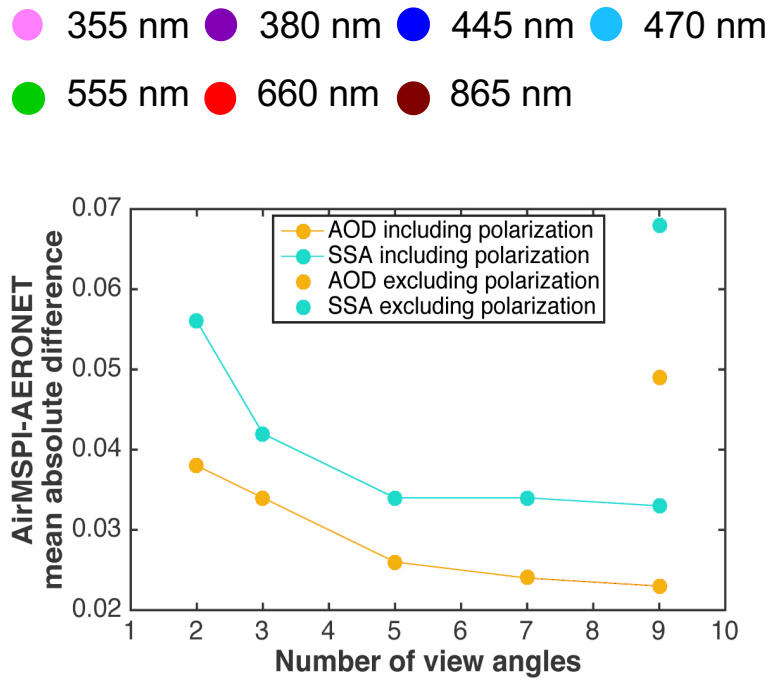
Flight: comparison to Research Scanning Polarimeter (RSP)

van Harten et al. (2018)

Aerosol retrieval sensitivity to number of view angles, polarization

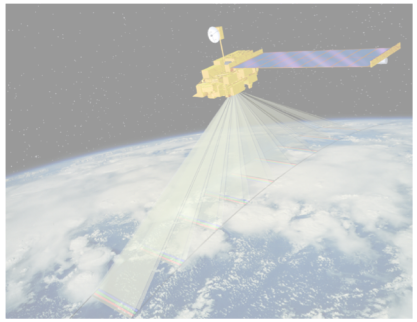


Xu et al. (2017)



Substantial improvement from 2-5 angles, smaller gain for >5 angles (cf. *Hasekamp & Landgraf, 2007; Wu et al. 2015*)

From MISR to MSPI to MAIA



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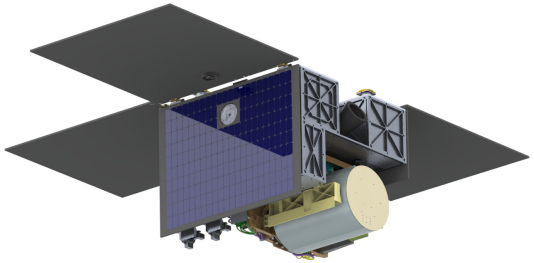

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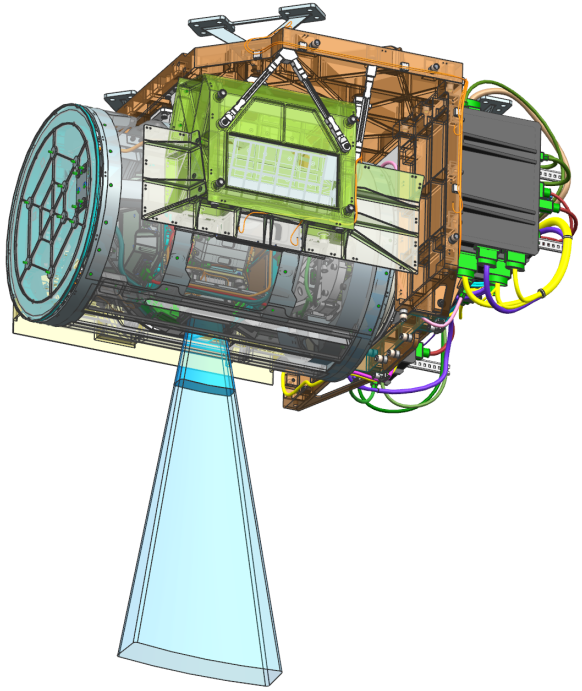
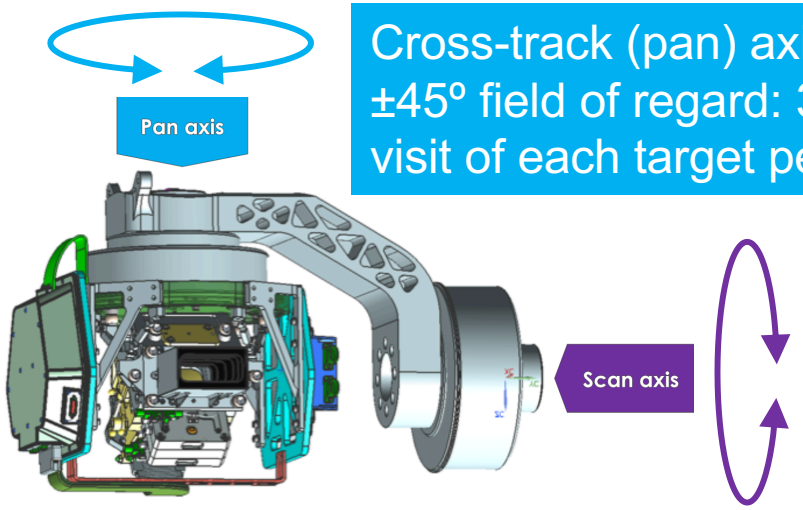
MAIA instrument provides multiangular, multispectral, polarimetric imagery





Cross-track (pan) axis provides ±45° field of regard: 3-4 repeat visit of each target per week

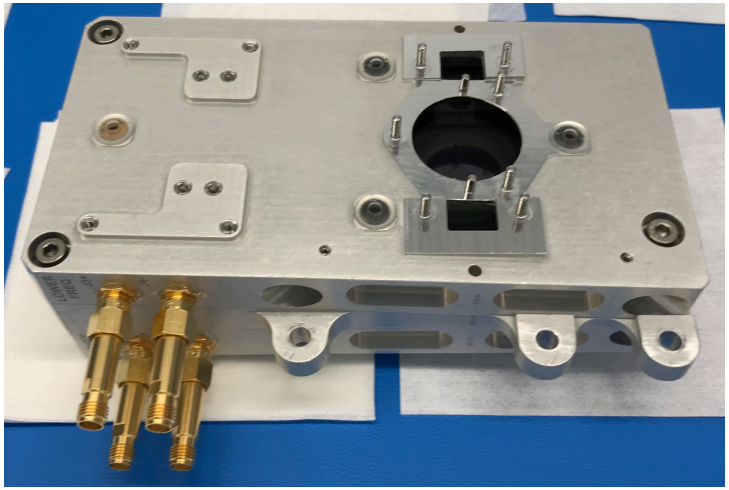
Scan axis provides along-track multiangle imagery (±60° at instrument)

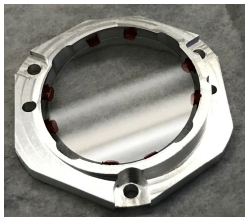
Detector	Silicon										HgCdTe			
Band (nm)	365	387	415	442	550	645	749	762.5	866	945	1040	1610	1885	2125
Polarimetric				pol		pol					pol			

O_2 H_2O

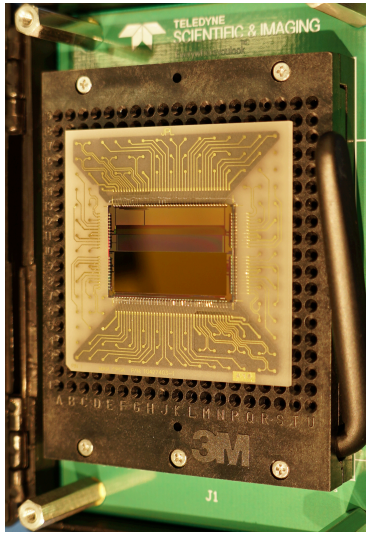
aerosol absorption — fine particles — cloud screening — coarse particles — cirrus

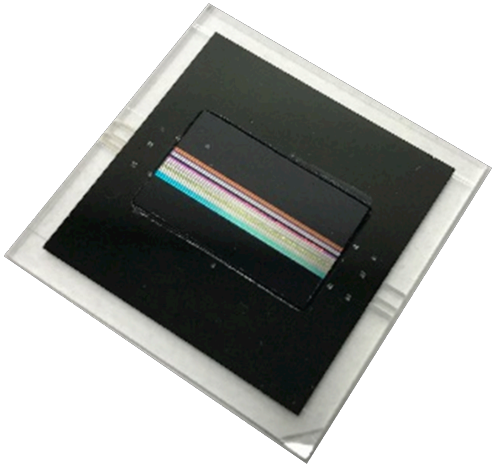
MAIA polarization imaging hardware





Dual photoelastic modulator assembly and quarter-wave plate test unit





Integrated UV/VNIR/SWIR focal plane array and stripe filter/polarizer assembly

MAIA will observe discrete, globally distributed target areas

- Primary Target Areas (PTAs): epidemiological studies
- Secondary Target Areas (STAs): air quality/climate studies or other applications
- Calibration/ Validation Target Areas (CVTAs): instrument calibration and product validation

Primary Target Areas

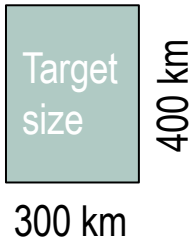
- USA-LosAngeles
- USA-Atlanta
- USA-Boston
- ESP-Barcelona
- ITA-Rome
- ZAF-Johannesburg
- ISR-TelAviv
- ETH-AddisAbaba
- IND-Delhi
- CHN-Beijing
- TWN-Taipei

Secondary Target Areas

- USA-Hilo
- PAC-OceanStCu
- USA-SanFrancisco
- USA-Phoenix
- USA-Denver
- MEX-MexicoCity
- CAN-Toronto
- PER-Lima
- CHL-Santiago
- BRA-SãoPaulo
- SEN-Dakar
- ATL-OceanStCu
- NGA-Lagos
- ZAF-CapeTown
- SRB-Belgrade
- KWT-KuwaitCity
- IND-Chennai
- BGD-Dhaka
- VNM-Hanoi
- MNG-Ulaanbaatar
- KOR-Seoul
- AUS-Sydney

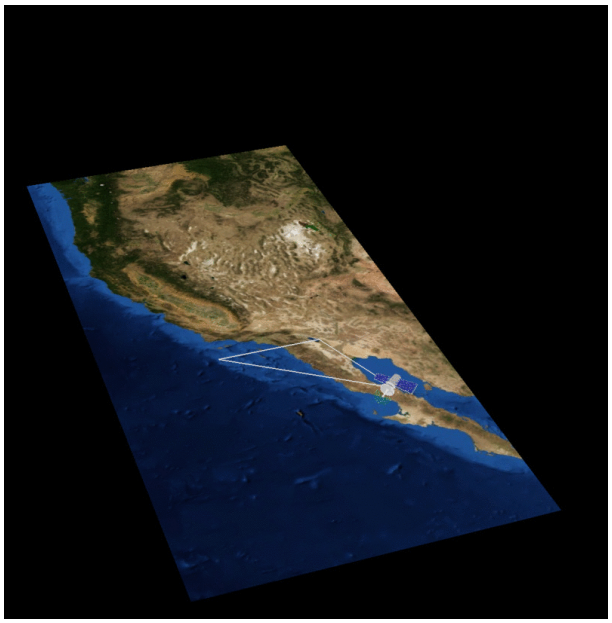
Calibration/Validation Target Areas

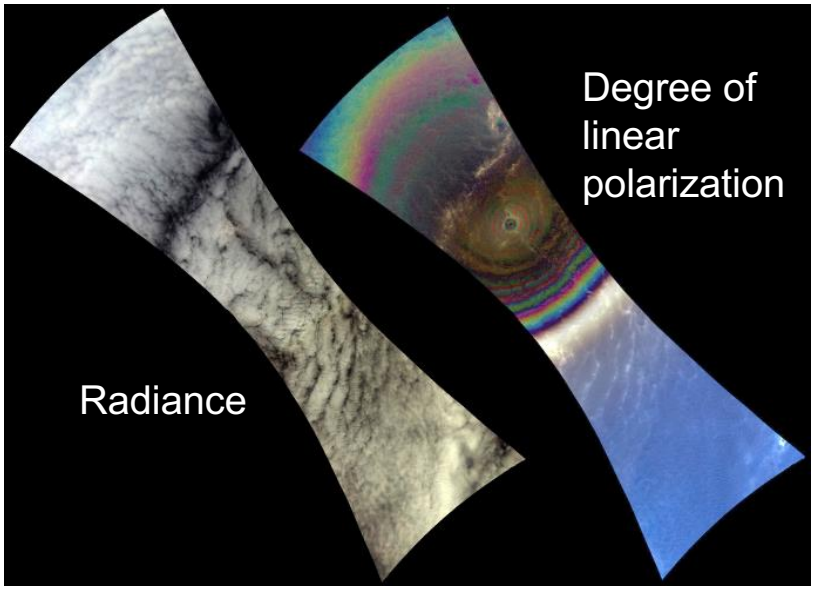
- USA-RailroadValley
- LBY-Libya4
- NAM-Gobabeb



Earth observation modes

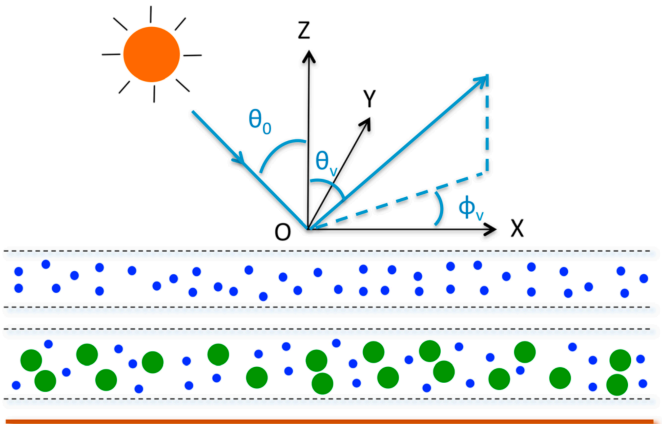
- Most Earth targets will be observed in “step and stare” mode





Sweep mode is used for study of cloud microphysics

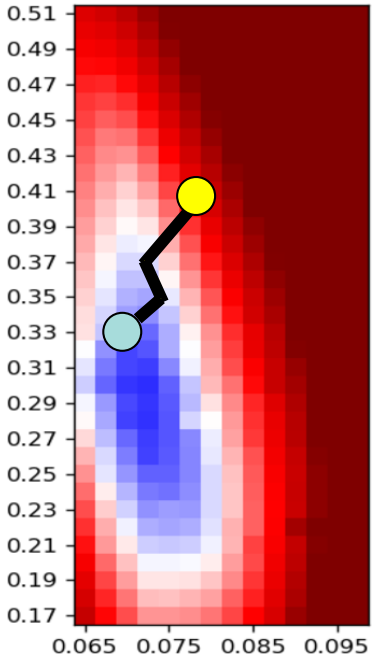
Radiative-transfer based aerosol retrievals



Light scattering models
Surface reflectance database
Smoothness constraints

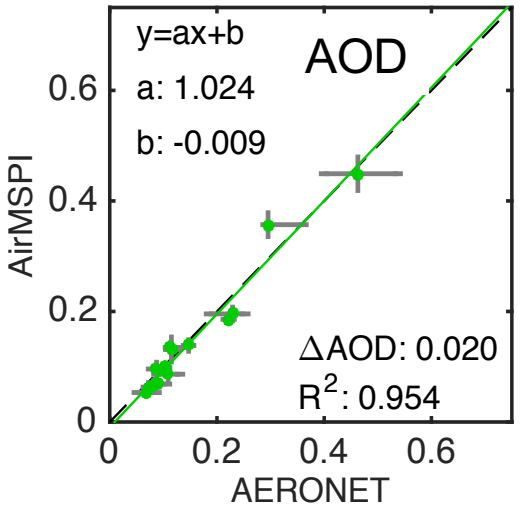
Xu et al. (2017)

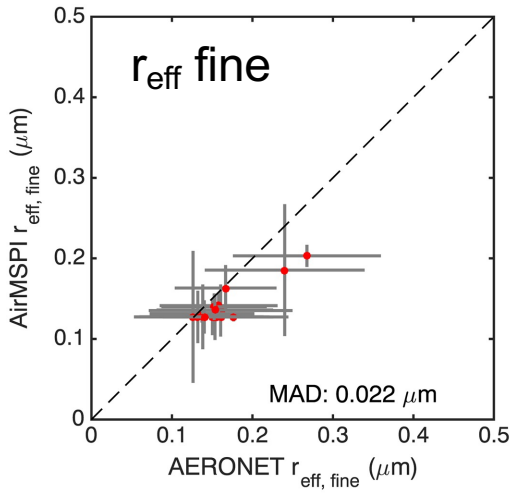
Multivariate cost function minimization using Jacobians



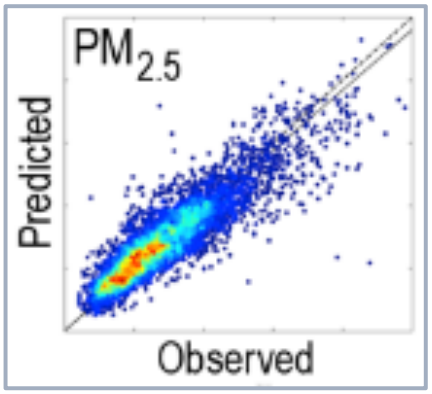
Starting point

Solution





Importance of surface monitors



Regression of retrieved aerosol properties against surface monitor (total and speciated PM) data is used to calibrate the aerosol-to-PM transformation

Geostatistical Regression Model (GRM)

$PM_{2.5}$, PM_{10} monitor data = α (Spatiotemporal offsets)

+ β x Aerosol optical depth

+ γ x Geospatial predictors (elevation, roads, green space)

+ δ x Spatiotemporal predictors (RH, PBLH, temperature, winds, additional aerosol parameters)

Collocated PM and predictor data are used to derive coefficients of the GRMs.

A Bayesian multivariate framework is used.

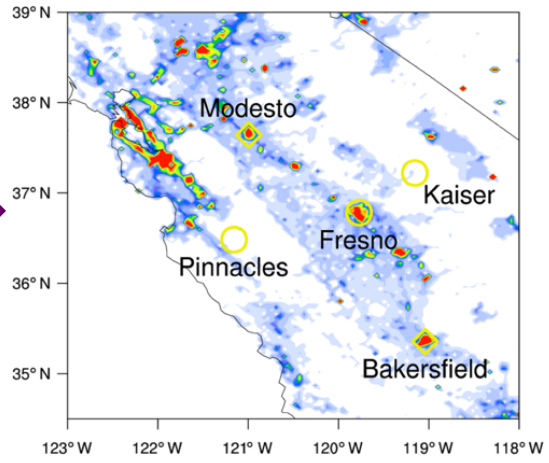
The calibrated GRMs are used to map PM at locations between monitors.

Bias-corrected chemical transport model (CTM) PM is used for spatial and temporal gap-filling

Satellite-based smoke emissions data (FLAMBE)

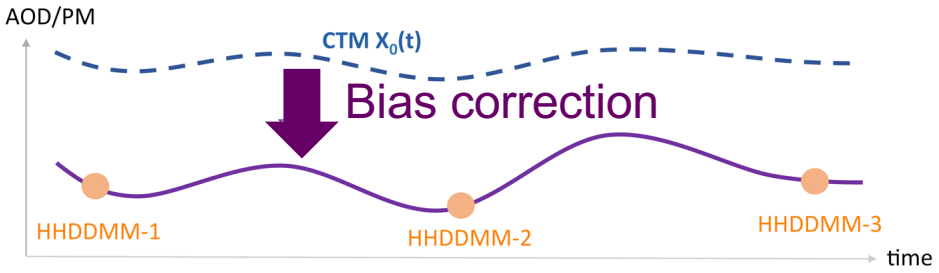
Quasi-static emissions inventories

GEOS-FP/ MERRA-2 boundary meteorology + chemistry



WRF-Chem

- Aerosol profiles
- 3-D meteorology
- PM speciation



A separate GRM is used to correct CTM biases and the results are merged with the satellite-based PM

Planned health investigations

PTA	Acute effects	Subchronic effects	Chronic effects
Southern Calif.		Birth outcomes	Cause-specific mortality
Georgia	Respiratory morbidity		
New England	Mortality, heart attack, stroke, pneumonia	Birth outcomes	Mortality, heart attack, stroke, pneumonia
Spain			Mortality, primary care outcomes physical/mental health outcomes
Italy	Cause-specific mortality, disease-specific hospital admissions		Cause-specific mortality, disease-specific hospital admissions
South Africa	Cause-specific mortality		
Israel	Mortality, heart attack, stroke, pneumonia	Birth outcomes	Mortality, heart attack, stroke, pneumonia
Taiwan		Pregnancy complications, birth outcomes	COPD, heart disease
Ethiopia		Preeclampsia, birth outcomes, childhood mortality/morbidity	Respiratory disease, cognition
China	Cardiovascular disease		
India	Mortality, cardiovascular/ respir. disease		Cardiovascular biomarkers

MAIA Science Team

Principal Investigator	
David Diner	JPL

Co-Investigators: Instrument Characterization	
Carol Bruegge	JPL
Russell Chipman	University of Arizona
Veljko Jovanovic	JPL

Co-Investigators: Aerosol Remote Sensing, Modeling, Validation	
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Michael Garay	JPL
Edward Hyer	Naval Research Lab.
Olga Kalashnikova	JPL
Alexei Lyapustin	GSFC
Randall Martin	Washington University
Jun Wang	University of Iowa
Feng Xu	University of Oklahoma

Co-Investigators: PM Exposure, Epidemiology	
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Michael Jerrett	UCLA
Yang Liu	Emory University
Bart Ostro	UC Davis
Beate Ritz	UCLA
Joel Schwartz	Harvard University

Collaborators: Air Quality and Public Health	
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Sina Hashimenassab	SCAQMD
Kembra Howdeshell	NIH
John Langstaff	EPA
Pius Lee	NOAA
Fuyuen Yip	CDC

Summary

- The MAIA instrument uses multiangle spectropolarimetry to constrain column-integrated aerosol particle properties.
- Instrument fabrication and surface monitor deployments are underway in preparation for mid-2022 launch.
- Retrieved aerosol parameters will be used in conjunction with surface monitor, land use, and CTM data to calibrate the GRMs used to map total and speciated PM.
- Epidemiologists on the MAIA team will conduct health impact investigations in the Primary Target Areas.