Coupled retrieval of aerosol properties, water-vapor abundance and surface reflectance

using Airborne Multiangle SpectroPolarimeter Imager (AirMSPI)

Feng Xu

David J. Diner, Ming Luo, Felix Seidel, Dejian Fu

Jet Propulsion Laboratory

California Institute of Technology

and

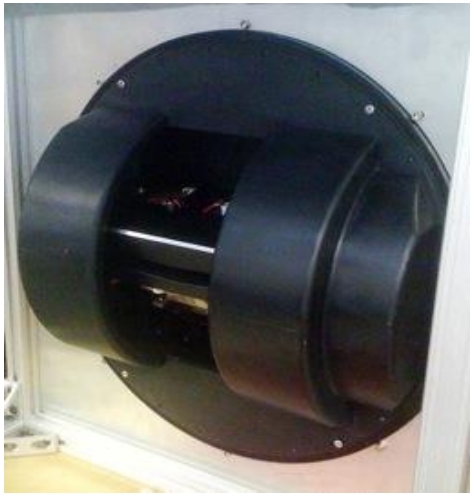
Oleg Dubovik

LOA, University of Lille, France

20 Mar 2017

© 2017 California Institute of Technology. Government sponsorship acknowledged.

AirMSPI



AirMSPI characteristics (Diner et al., 2013, AMT)	
Spectral bands	355, 380, 445, 470*, 555, 660*, 865*, 935 nm (*polarimetric)
Multiangle viewing	Two modes: step-and-stare (targeted) and continuous sweeps 9 angles with FOV of ±67° along track 10 m spatial resolution viewing 10 km x 11 km area (nadir)
Platform	Flies on NASA high-altitude (20 km) ER-2

AirMSPI retrieval – current status

Retrieval over ocean

Bio-optical model constraints on relating water-leaving radiance to Chlorophyll-a concentration. Retrieve aerosol loading, refractive index, size distribution, aerosol layer location, Chl-a concentration

➔ AOD, SSA, water-leaving radiance (*Xu et al. AMT, 2016*)

Retrieval over land

Physical constraints on surface reflection shape variation across spectral bands. Retrieve aerosol and surface BRDF and BPDF model parameters

➔ AOD, SSA, Surface albedo (*Xu et al. JGR, submitted*)

Retrieval over cloud

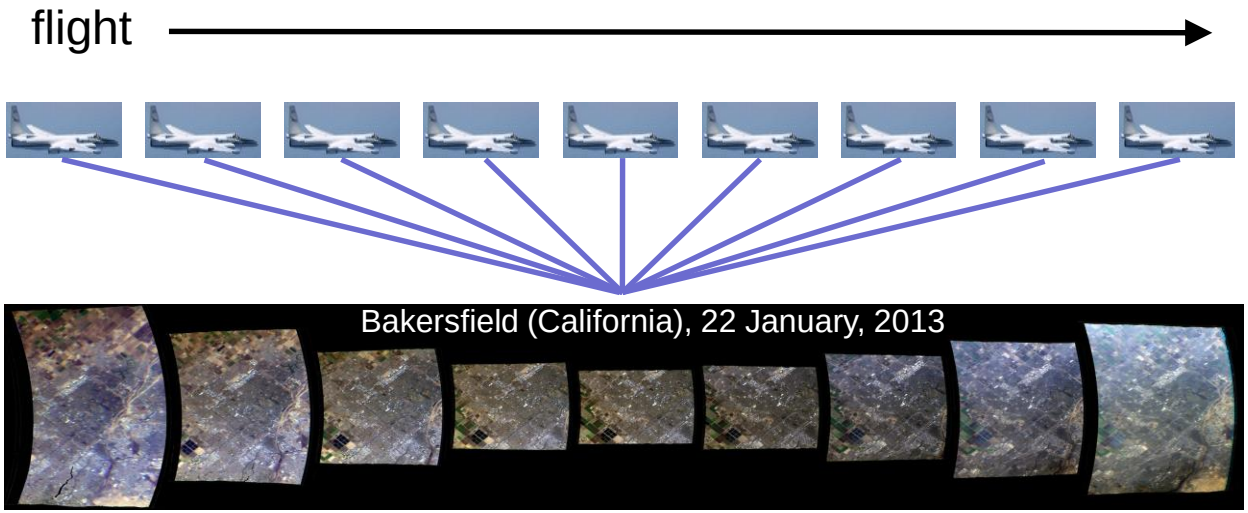
Use polarimetric observations to retrieve

➔ cloud-top droplet size distribution - operational product to release in 2017 (*Xu et al. ATBD, 2017*)

➔ above-cloud aerosol size and optical depth - research algorithm under development

AirMSPI coupled aerosol and surface retrieval

Observational constraints



Physical constraints

Smooth temporal variations of surface reflection property

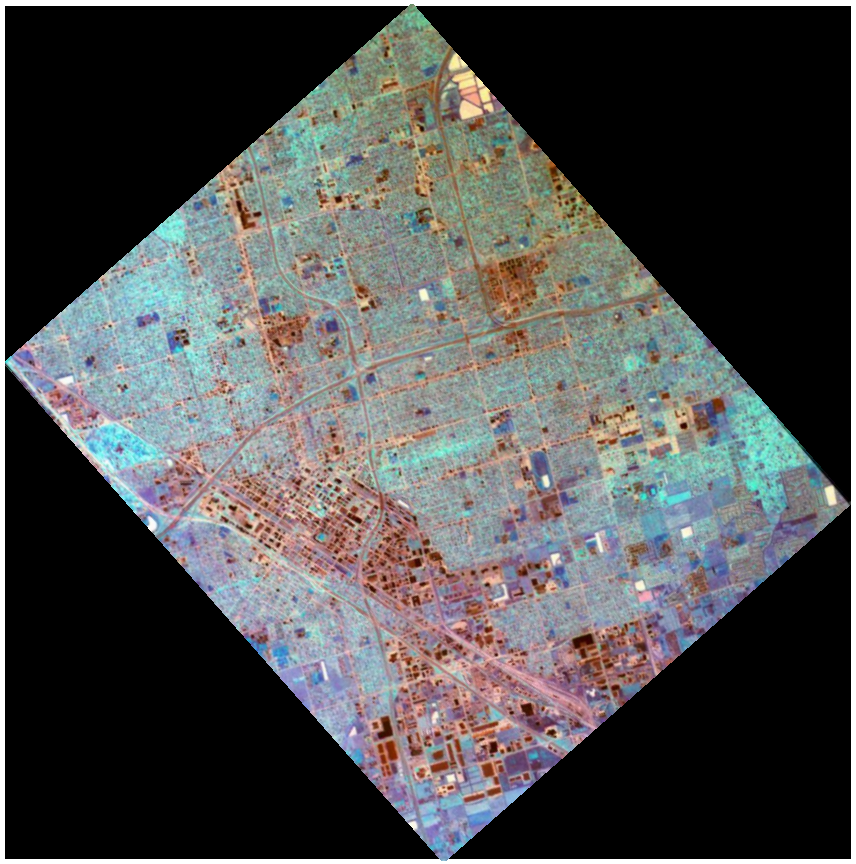
Smooth spatial variations of aerosol property

Surface BRDF shape & spectral shape of aerosol optical properties

Multi-pixel algorithm
(Dubovik et al., 2011, Xu et al., 2016)

Aerosol loading and microphysical properties, and surface reflectance

Features of multi-pixel retrieval algorithm



AirMSPI Fresno image
2013-01-06T20:23UTC

AirMSPI single-pixel retrieval:

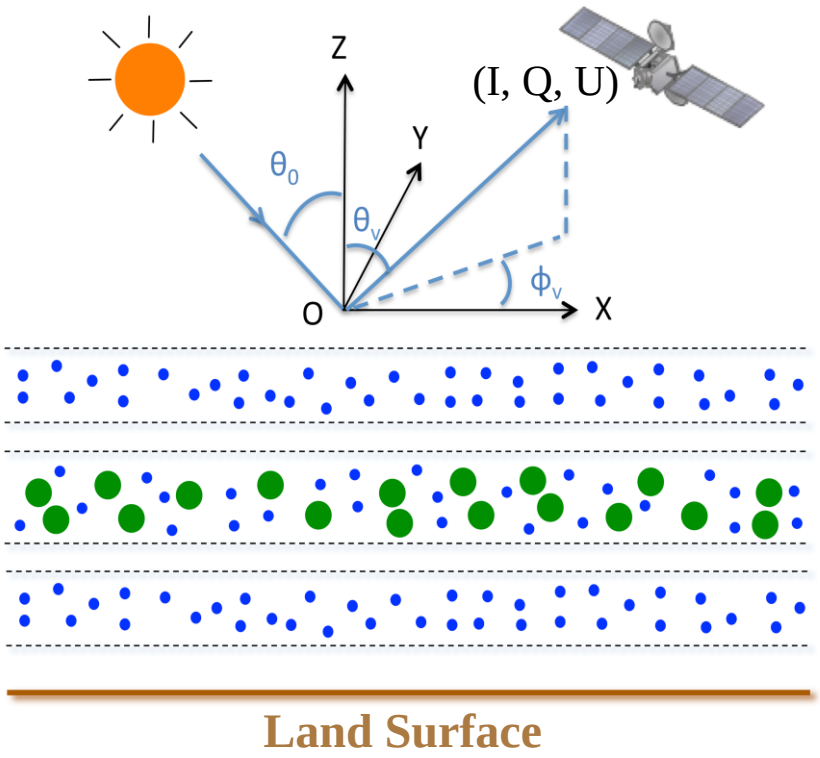
- Uses 9 angles/band

AirMSPI multi-pixel retrieval:

- uses 9 x N_{pixel} observations/band, with smoothness constraints imposed on aerosol spatial variations
- uses surface contrast to help decouple atmosphere from surface
- uses temporal revisits to enhance surface retrieval
- has flexibility of including new observational and modeling constraints into retrieval

Coupled aerosol-surface RT model

Coupled atmosphere – surface system



Aerosol parameters:

- Volume concentration
- Size distribution
- Aerosol layer central height & width
- Refractive index
- Nonspherical particle fraction

Surface parameters:

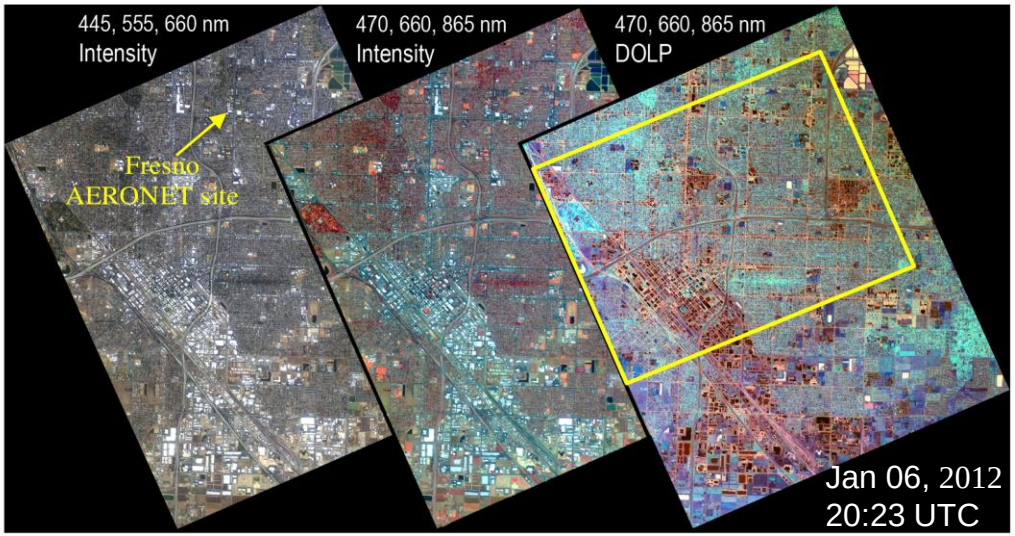
- BRDF parameters
- BPDF parameters

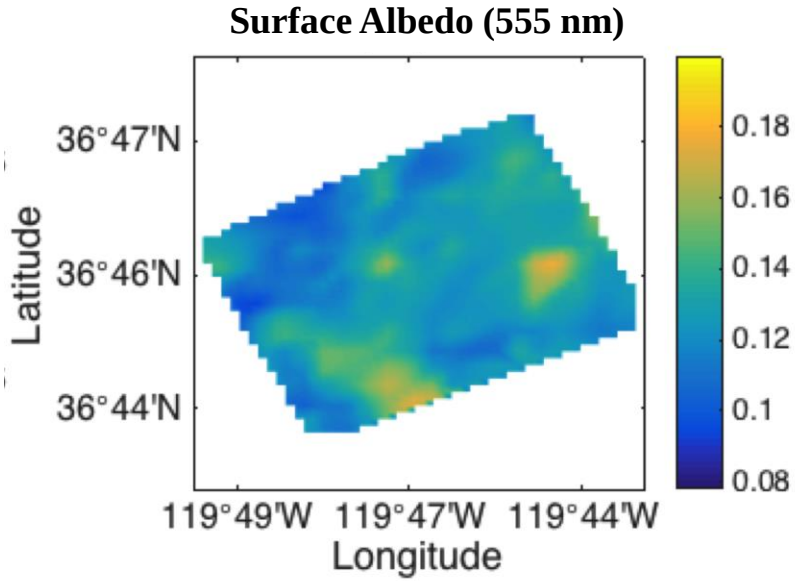
Radiative transfer:

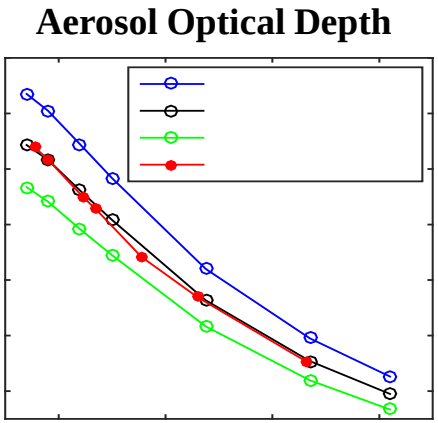
- Markov chain in mixed layer
- Doubling in Rayleigh layers

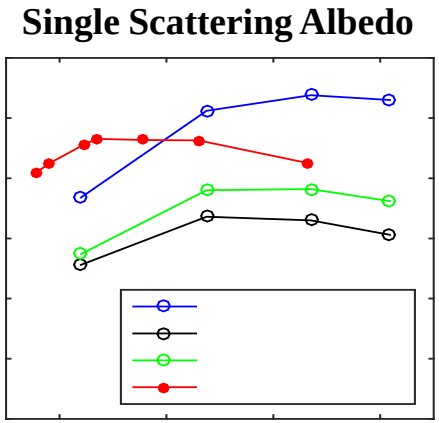
Retrieval: Multi-pixel algorithm

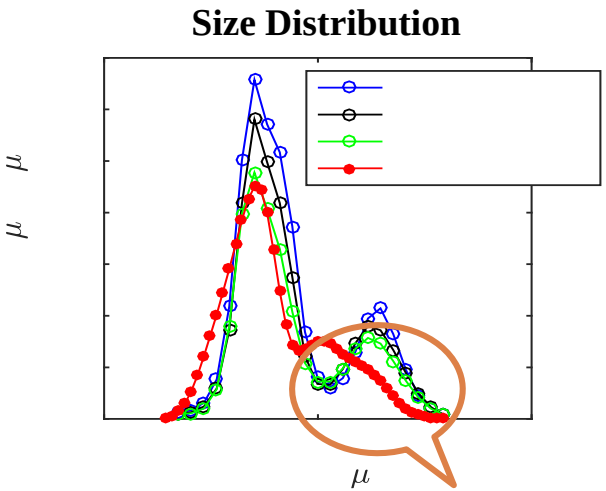
Example retrieval over AERONET Fresno site





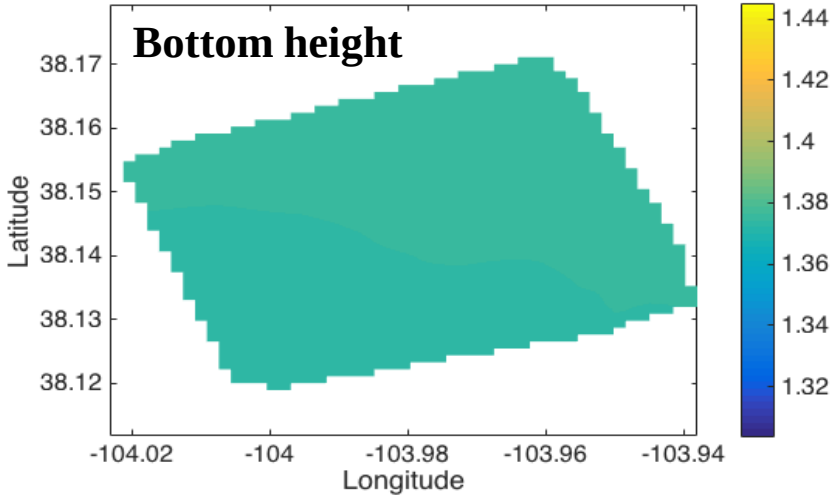


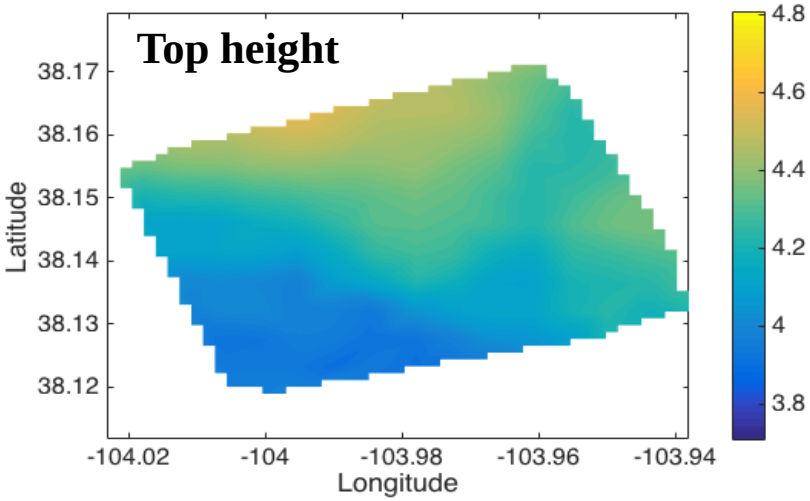




Reduced sensitivity to coarse mode with UV/VNIR observations only

Aerosol layer height retrieval

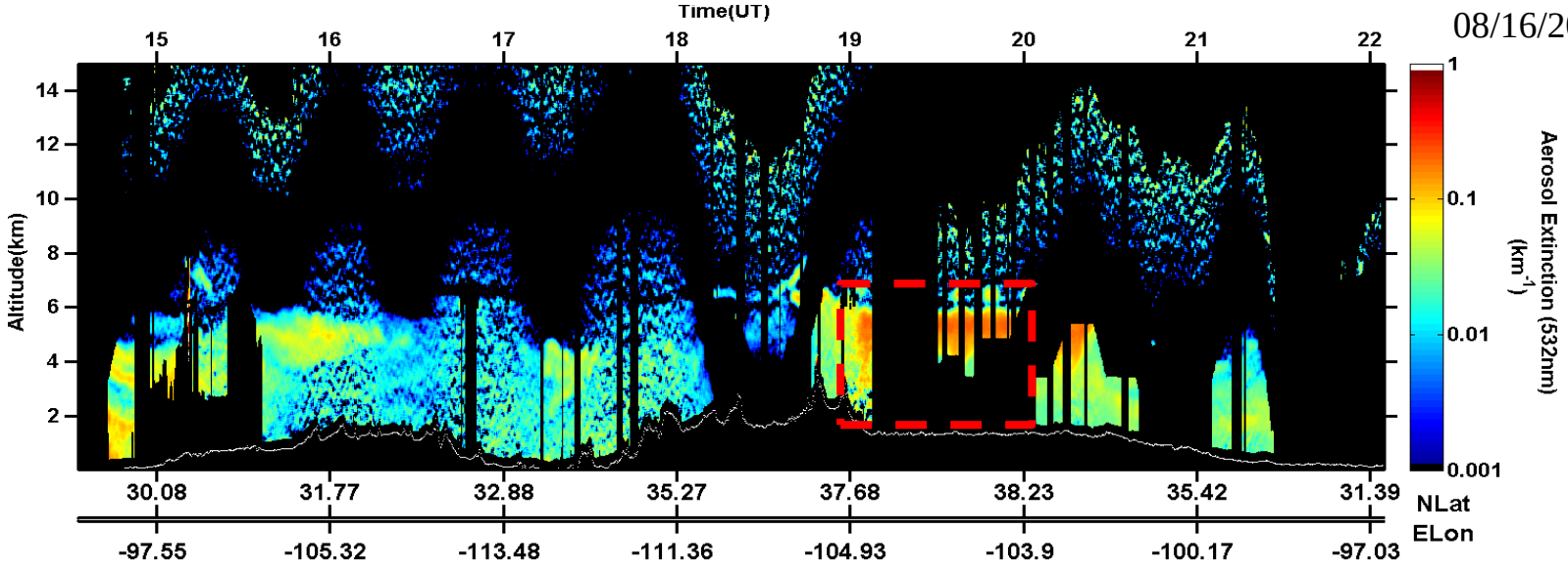




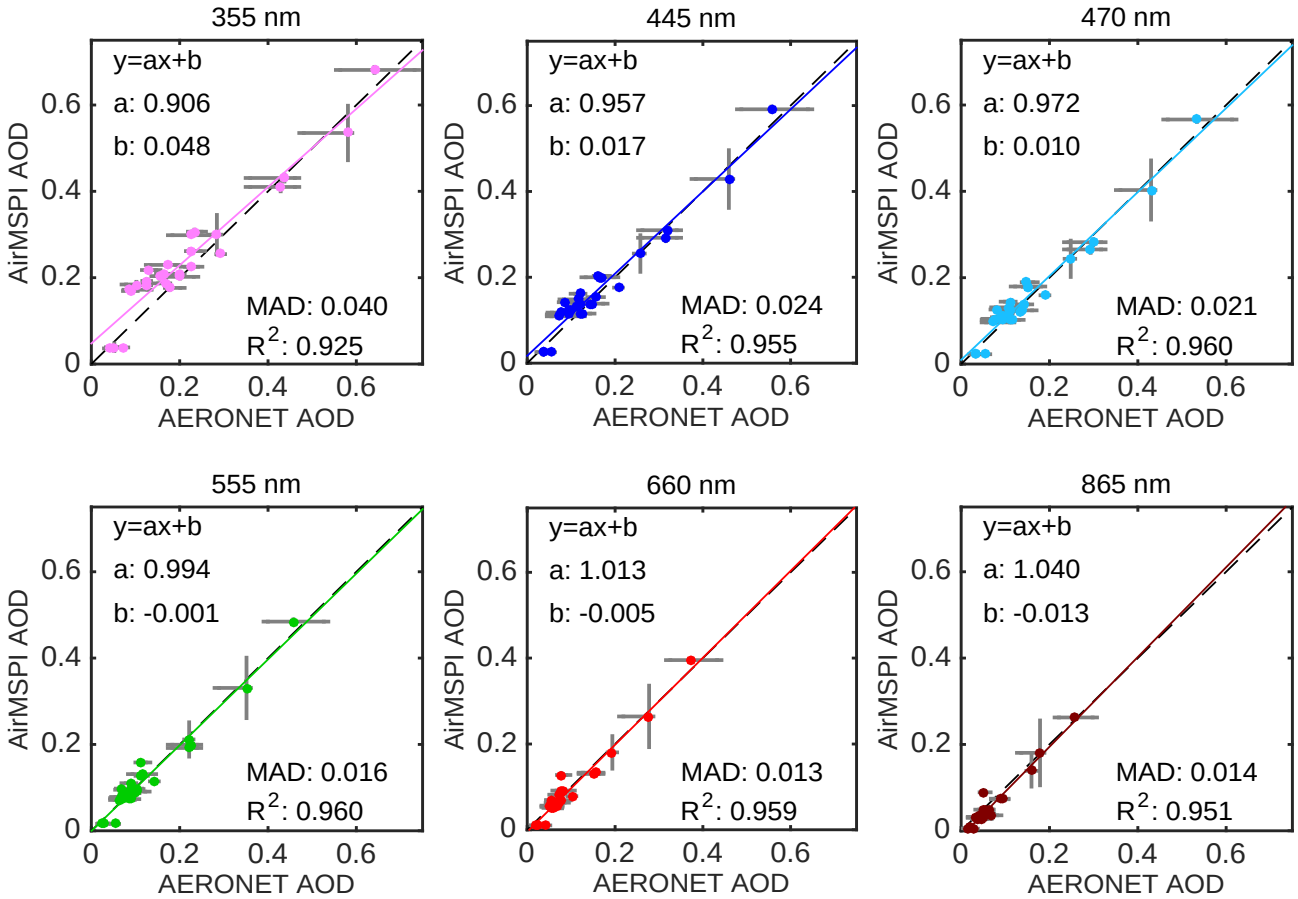
1.3-4.5 km from retrieval vs 1.5-6.0 km from Differential Absorption LIDAR meas.

Fowler, California

08/16/2013, SEAC^{4}RS



Retrieval over more AERONET sites



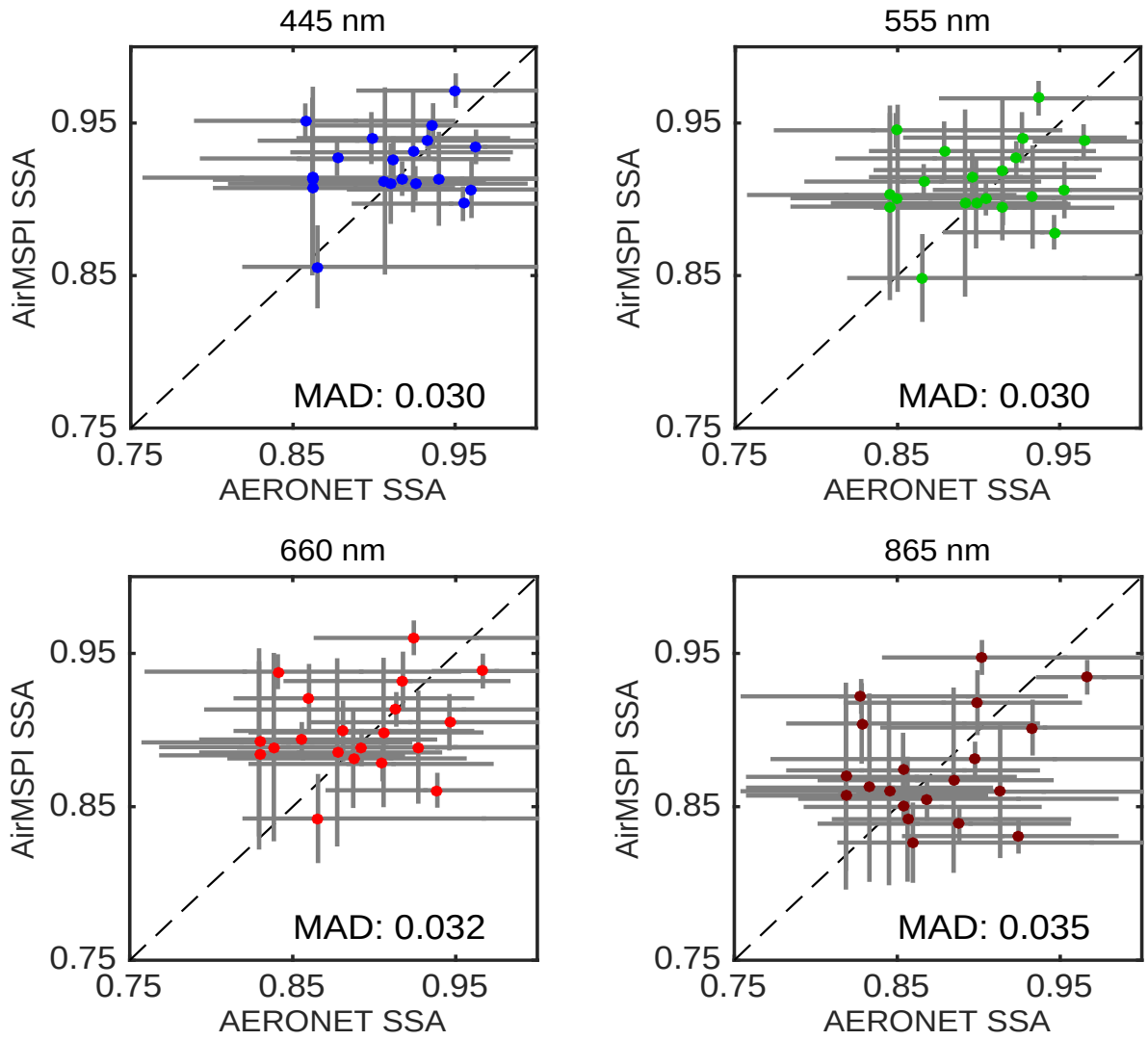
AERONET error bar: ±1 hr window statistics plus retrieval uncertainty estimate (Dubovik and King, 2000)

AirMSPI error bar: statistics over the image plus retrieval uncertainties (Xu et al., 2017)

28 AirMSPI scenarios acquired during NASA's PODEX, SEAC4RS, CalWater and ImPACT-PM field campaigns and collocated with AERONET reference aerosol data are selected for retrieval validation

AirMSPI data available at: https://eosweb.larc.nasa.gov/project/airmspi/

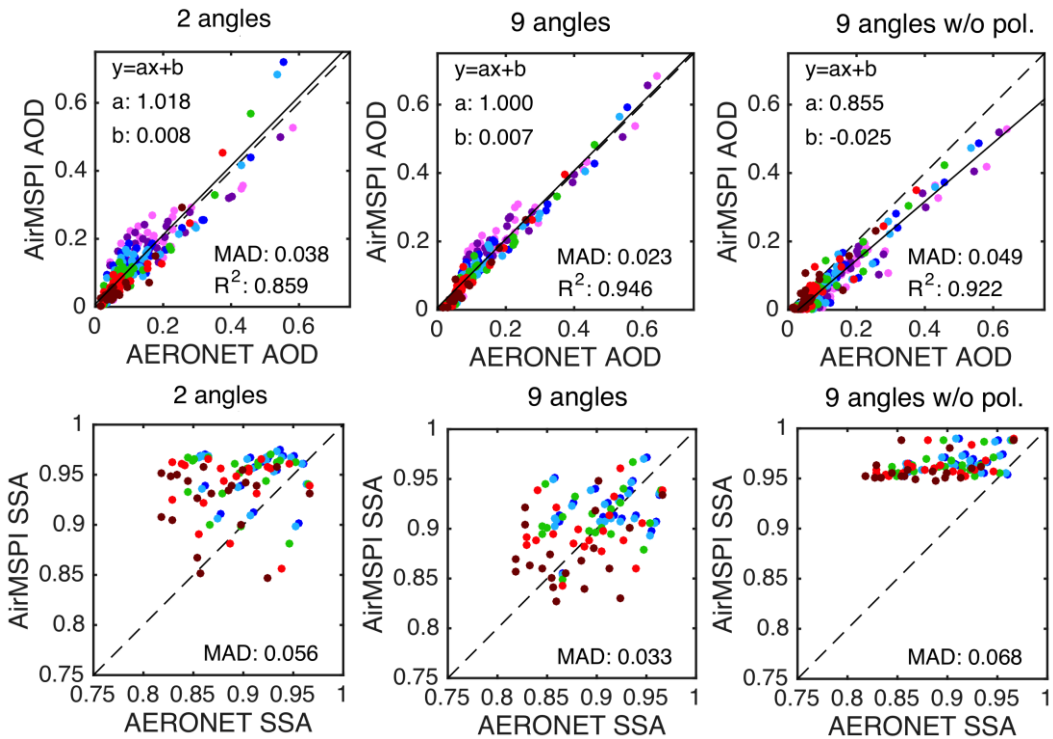
Retrieval over more AERONET sites

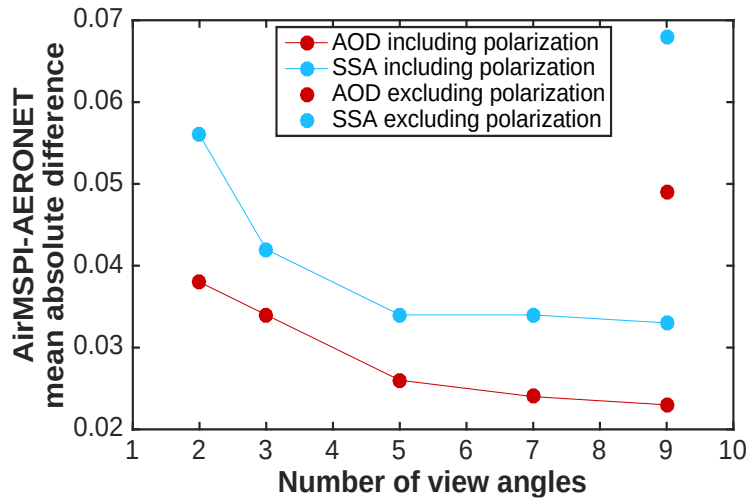


AERONET error bar: ±1 hr window statistics plus retrieval uncertainty estimate (Dubovik and King, 2000)

AirMSPI error bar: statistics over the image plus retrieval uncertainties (Xu et al., 2017)

Benefits of multiangle and polarimetric obs.

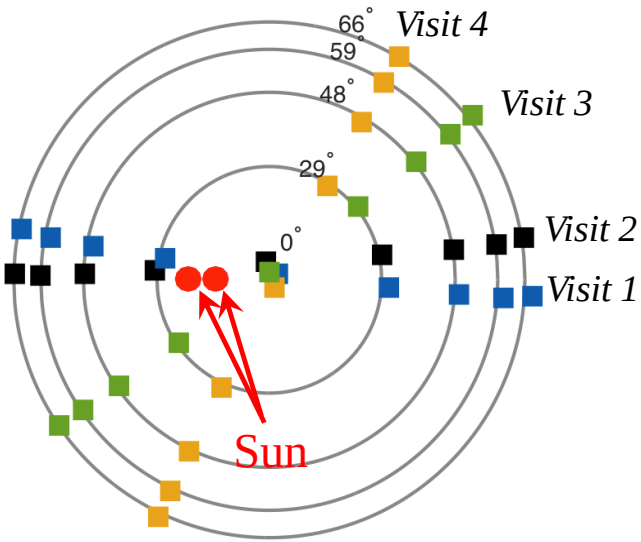




Data from multiple airborne campaigns *(Xu et al., 2017)*

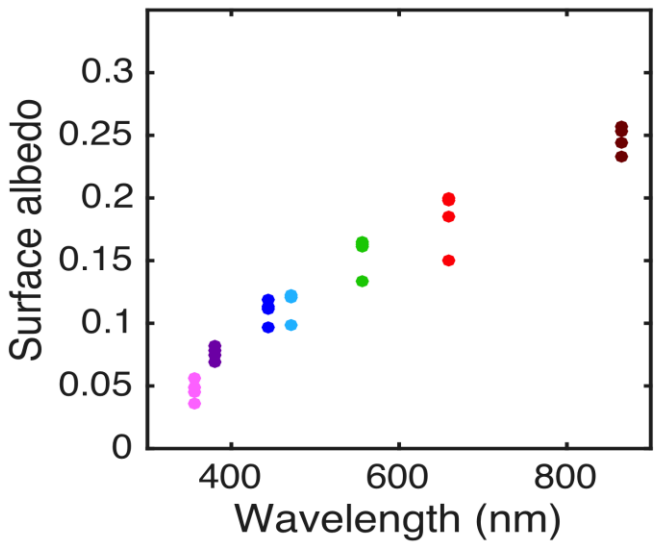
- ✓ Aerosol optical depth (AOD) and single scattering albedo (SSA) regression residuals and slopes improve with increasing number of view angles
  - Substantial gain from 2-5 angles, smaller gain for >5 view angles
- ✓ Polarimetry demonstrates significant benefits in improving AOD and SSA retrieval accuracies

Benefits of target revisits

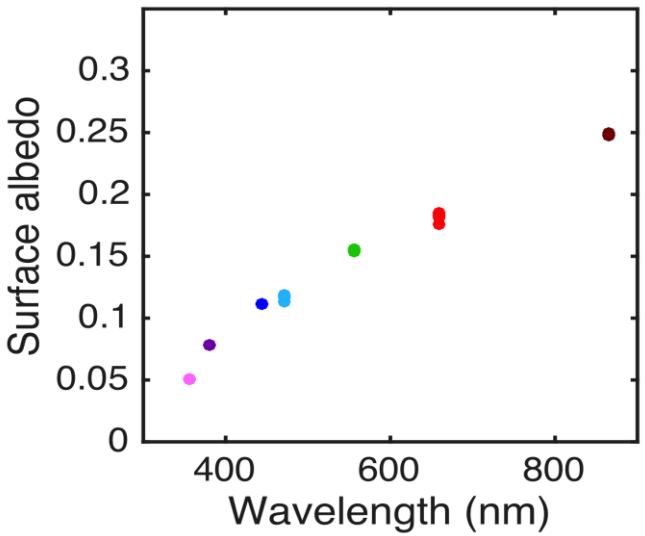


Viewing geometries of a Bakersfield surface pixel from four revisits during Jul 06-08, 2016

Temporally constrained surface



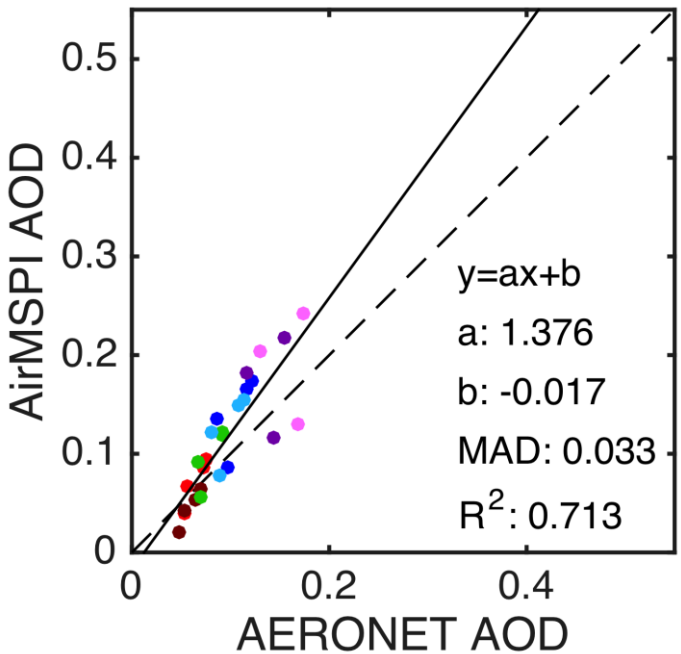
Temporally unconstrained surface



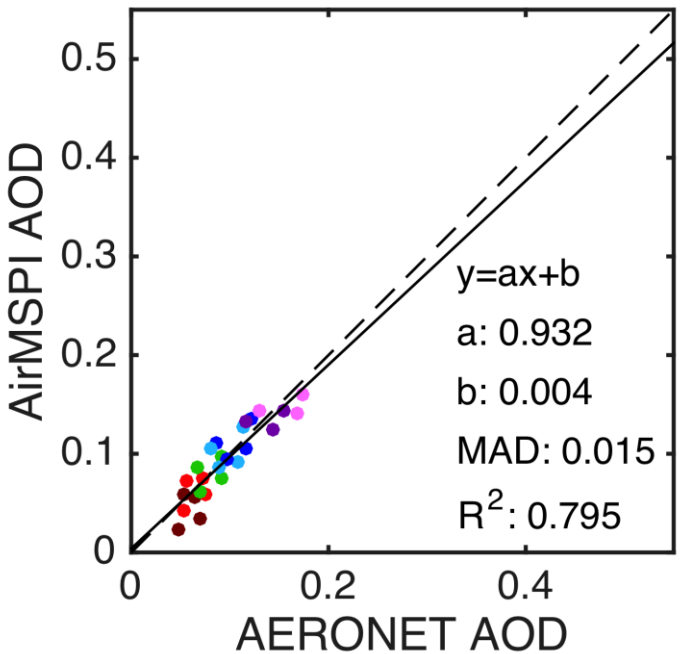
Using target revisits leads to better constraining of the surface BRDF due to the difference in viewing-illumination geometry.

Benefits of target revisits

With temporally constrained surface



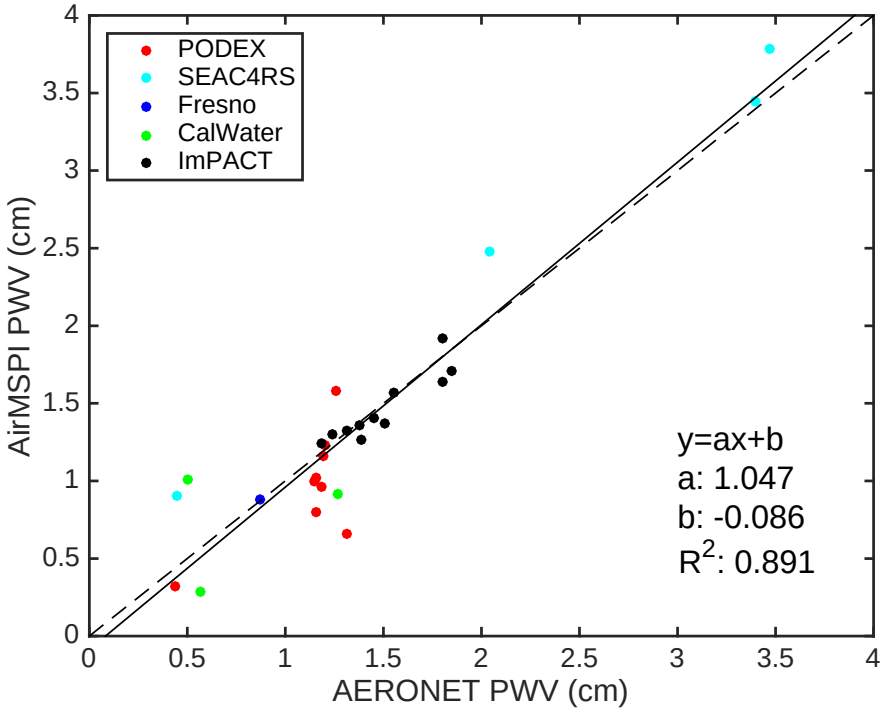
Without temporally constrained surface



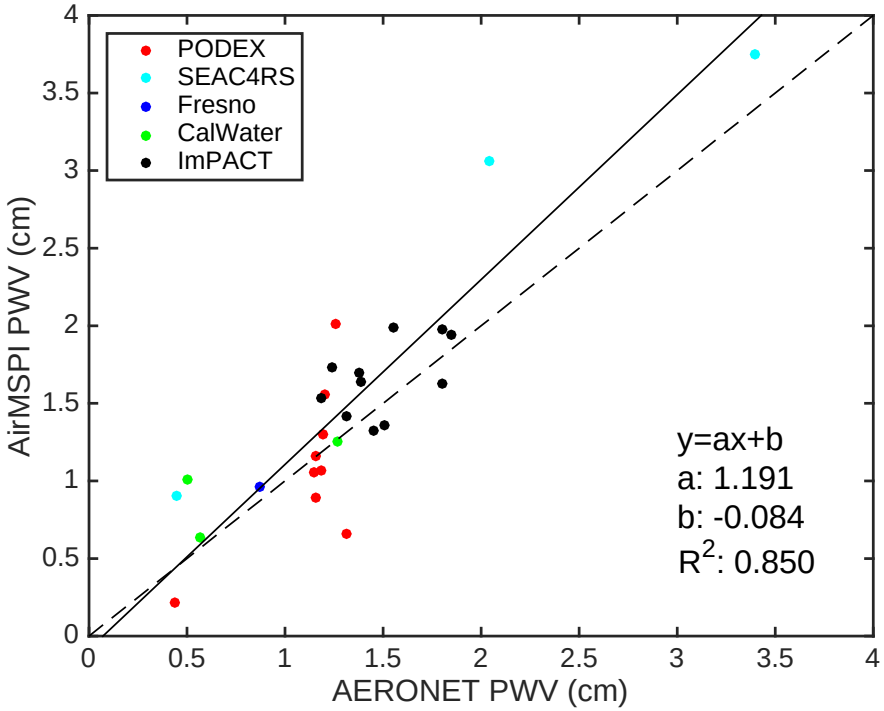
Better surface BRDF characterization using target revisits also improves aerosol retrieval.

Precipitable water vapor (PWV) retrieval

9-view angle retrieval



1-view angle retrieval



a) AirMSPI UV-NIR (355-865 nm) bands relied on for aerosol microphysical properties and surface reflection

b) 935 nm band relied on for PWV

c) Multiangle observations provide extra information to constrain PWV retrieval

Summary

- A multi-pixel approach has been developed for retrieving aerosol properties, water vapor abundance and surface reflection using AirMSPI;
- Validation of retrieval against AERONET reference data shows good agreement;
- A strong dependence of retrieval accuracy on the number of viewing angles is observed. The optimal number of viewing angle is ~7 for AOD retrieval. Increasing to 9 viewing angles further helps reduce SSA retrieval error;
- Multiangle observation effectively reduces PWV retrieval errors;
- Biases in AOD and SSA retrieval by mean values of ~0.02 and 0.05, respectively, are found when polarization measurements are omitted;
- Target revisits significantly help constrain both surface and aerosol retrieval.

A paper on part of this work “Coupled retrieval of aerosol properties and land surface reflection using AirMSPI” has been submitted to JGR, 2017

Acknowledgments

Discussions with

Otto Hasekamp

Michael J. Garay

Olga V. Kalashnikova

Marcin Witek

AirMSPI field operations

Brian Rheingans

Mick Tosca

AirMSPI data processing

Michael Bull

Carol J. Bruegge

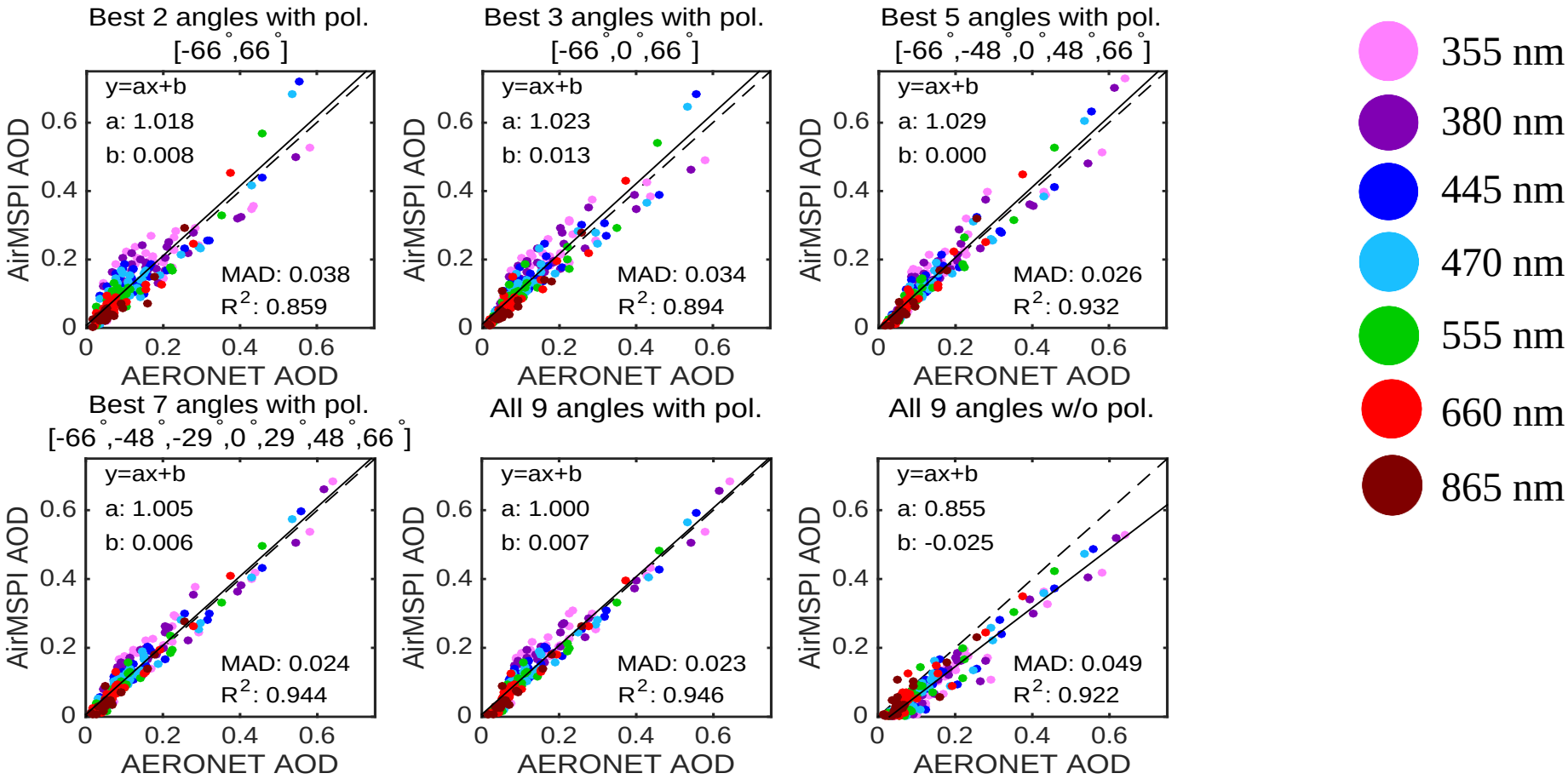
Gerard van Harten

Veljko Jovanovic

Irina N. Tkatcheva

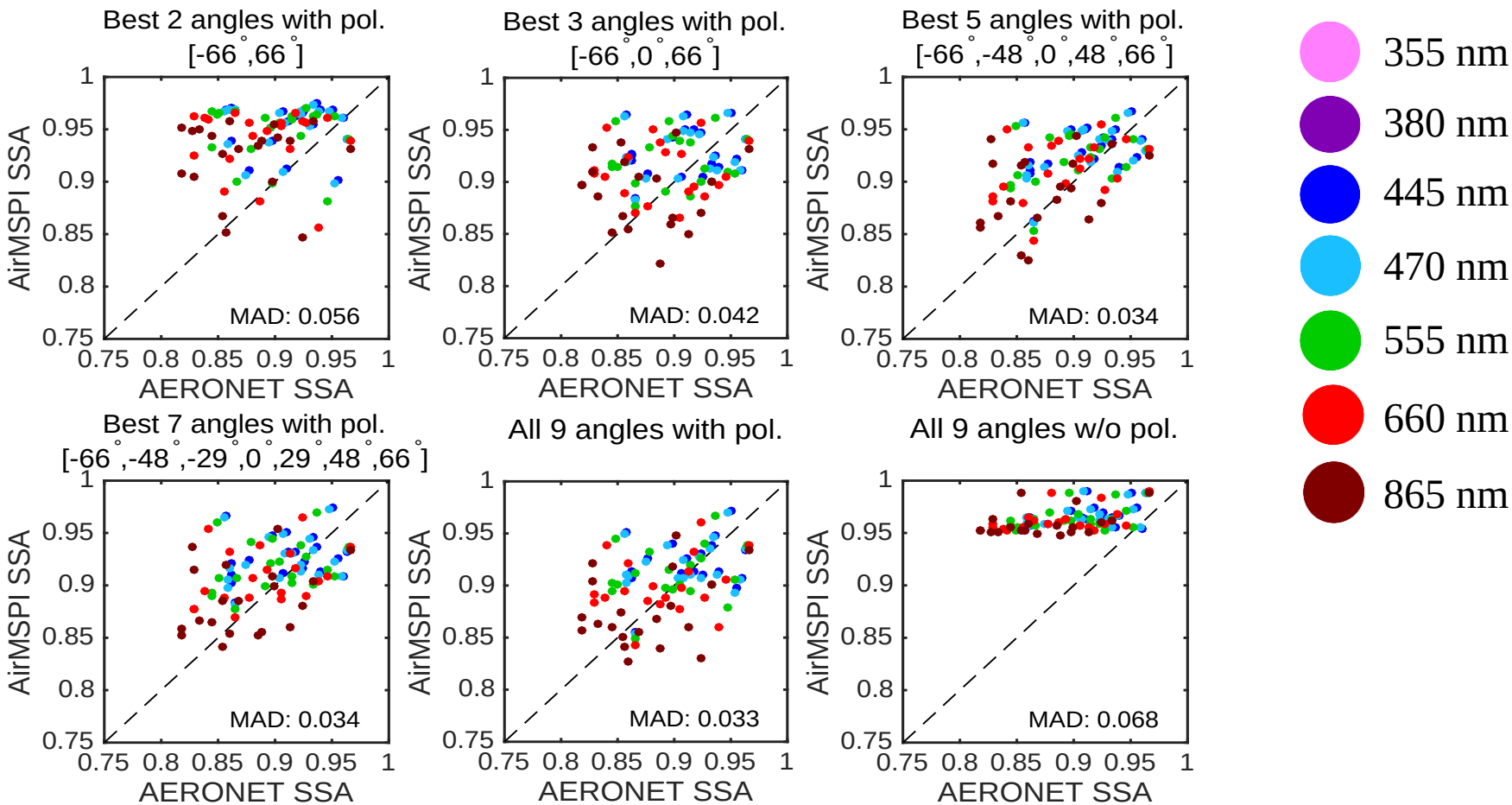
Benefits of multiangle and polarization-AOD

A1



Benefits of multiangle and polarization-SSA

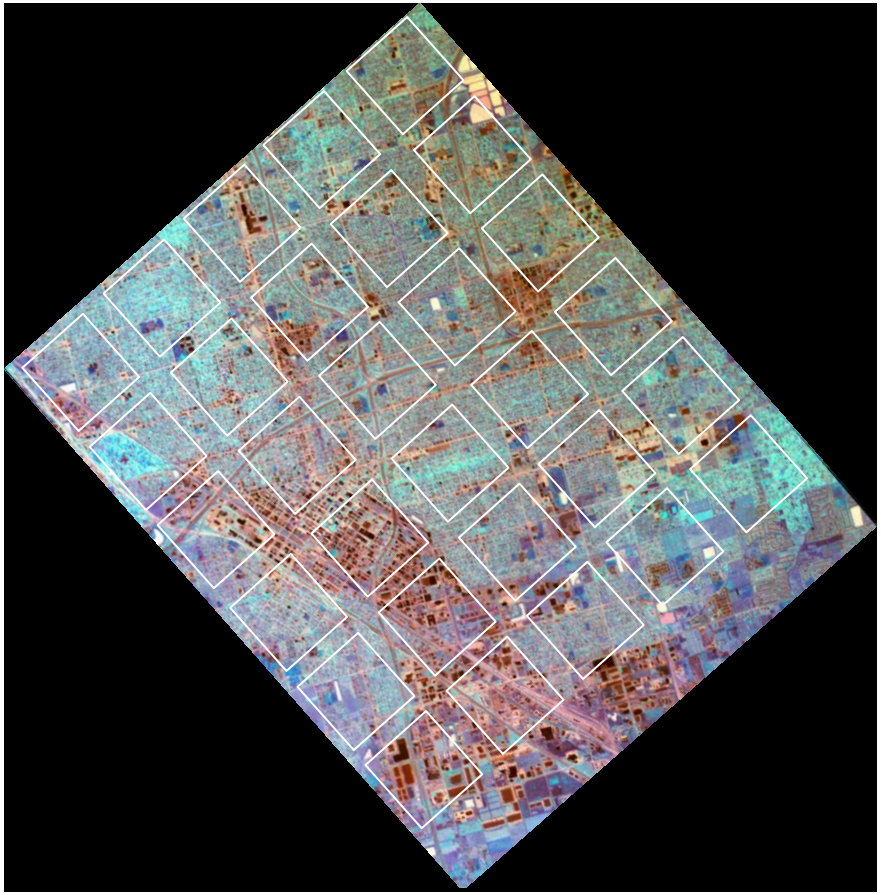
A2



Increasing viewing angle to be 9 still help SSA retrieval;
Dropping off polarization biases the SSA retrieval by 0.05.

Aerosol above land retrieval – algorithm feature

A3



AirMSPI Fresno image
2013-01-06T20:23UTC

Single-pixel retrieval:

- Uses 9 angles/band

Multi-pixel retrieval:

- uses 9 x N_{patch} observations/band, with smoothness constraints imposed on aerosol spatial variations
- Utilizes surface contrast to help decouple atmosphere and surface contributions
- Utilizes temporal revisits to constrain surface retrieval