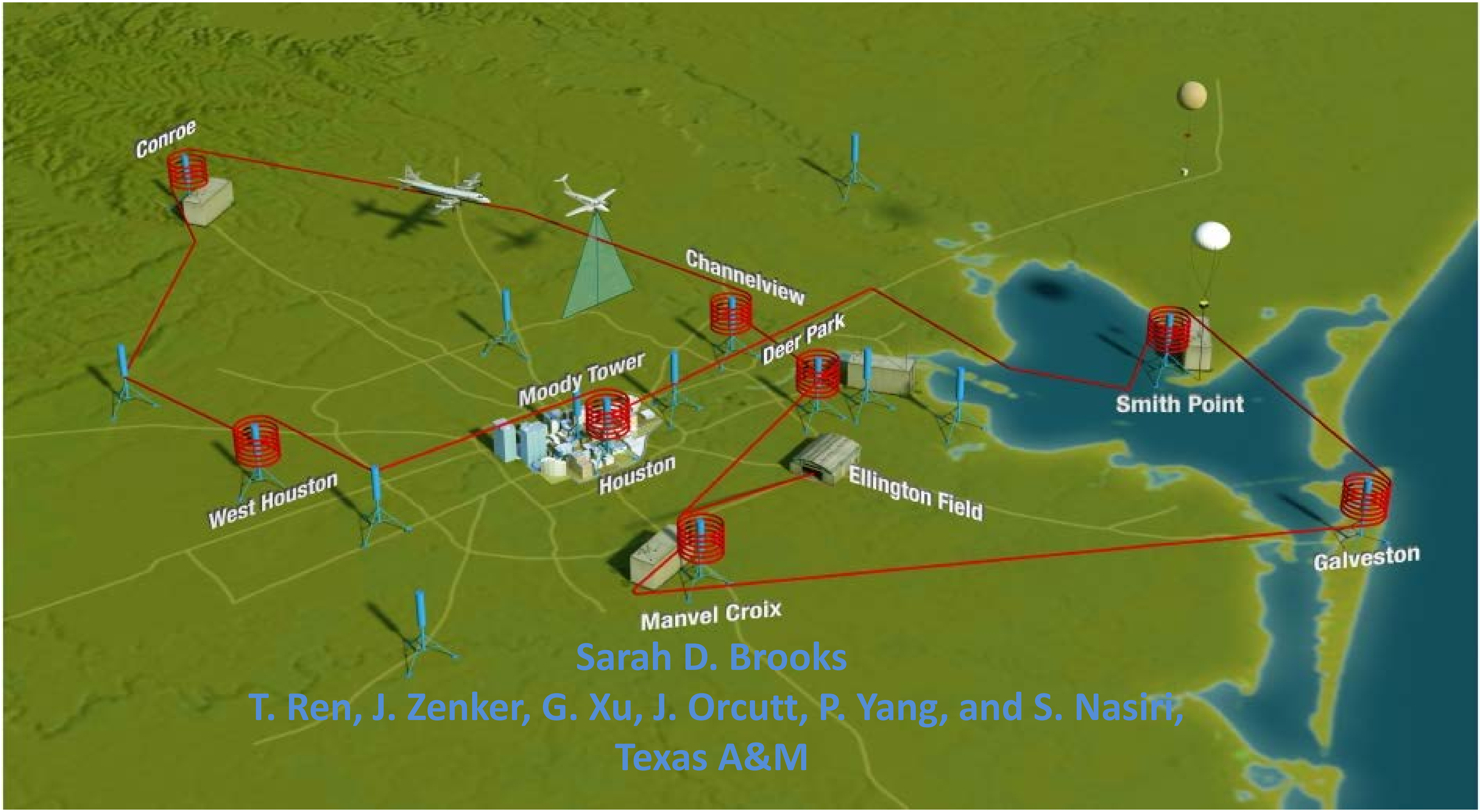
Sources and Properties of Atmospheric Aerosol in Texas: DISCOVER-AQ Measurements and Validation



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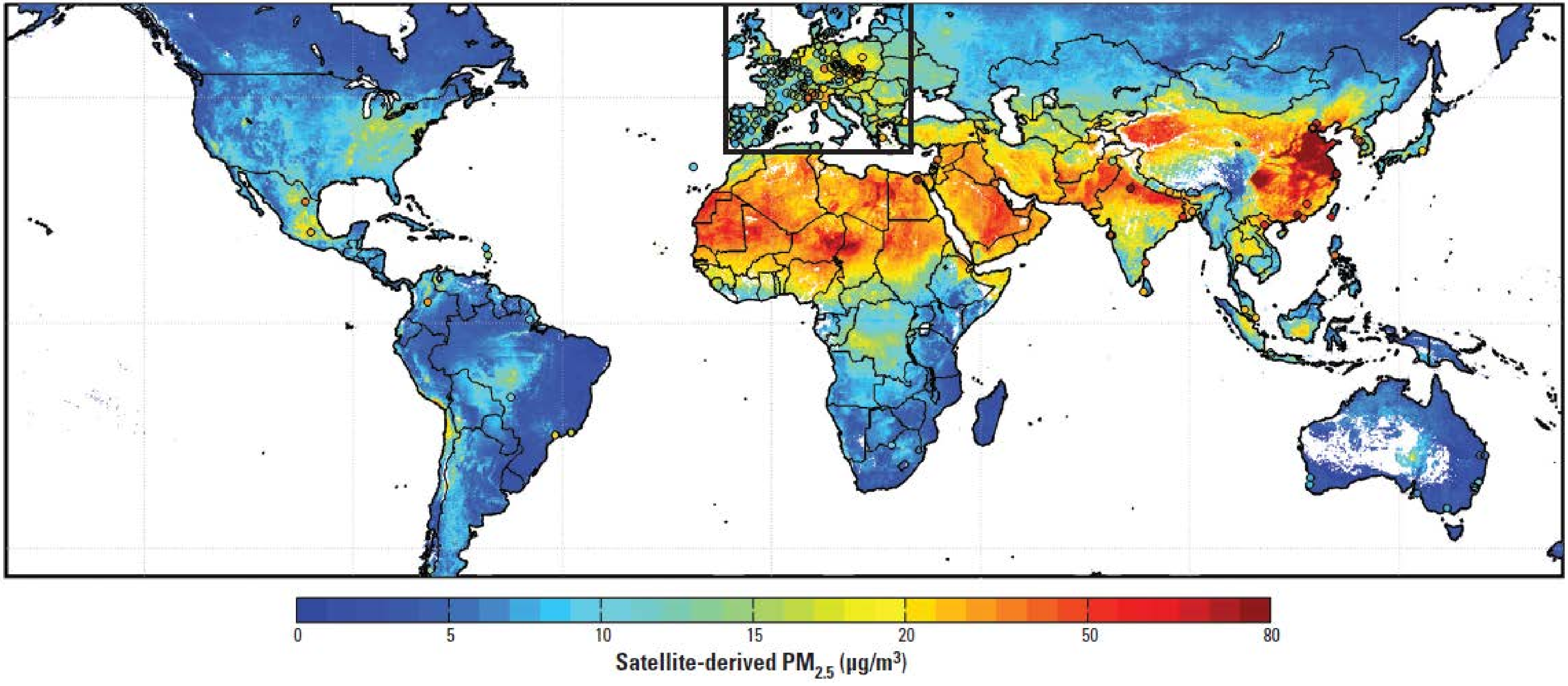
Texas A&M

Thanks to: Rebecca Sheesley and Sascha Usenko, Baylor
Barry Lefer, U. Houston, AQRP

Can particulate air quality be monitored reliably from space?



[van donkelaar et al. 2010]

Objectives

- NASA DISCOVER-AQ objective: Test satellite's ability to measure air pollution

- Field Test a prototype aerosol scattering instrument

  Cloud and Aerosol Spectrometer Probe with Polarization (CASPOL)

- Compare MODIS with CASPOL:

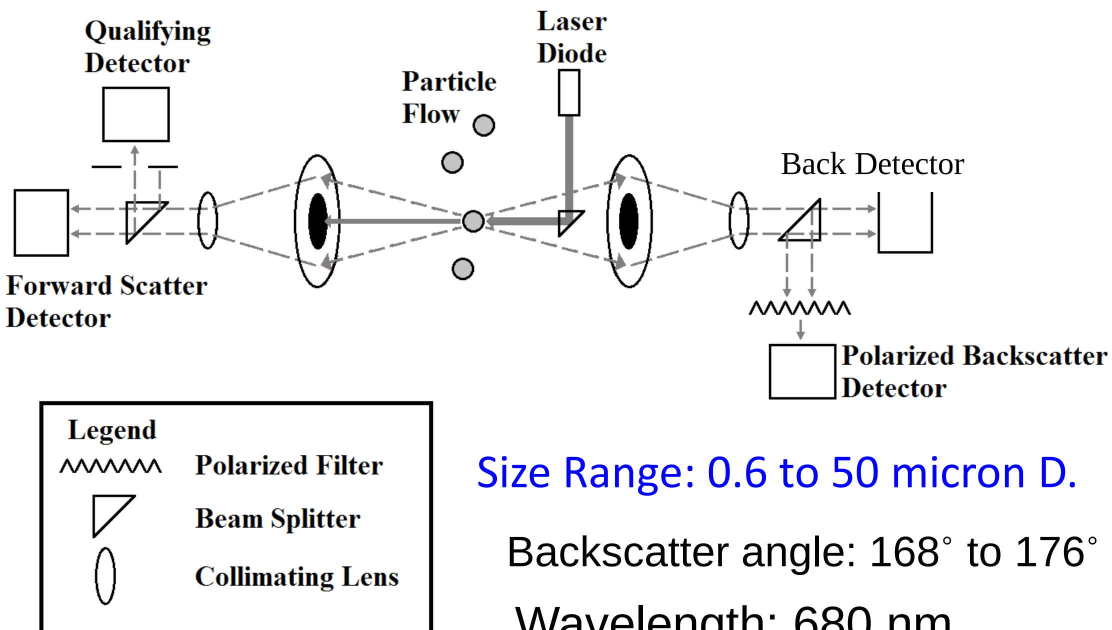
  Assess and potentially improve aerosol assumptions in the MODIS algorithm using CASPOL data

- Compare CALIOP with CASPOL

  Compare backscatter and depolarization

  Assess the optical criteria of the CALIOP aerosol typing

Cloud and Aerosol Spectrometer with Polarization(CASPOL)



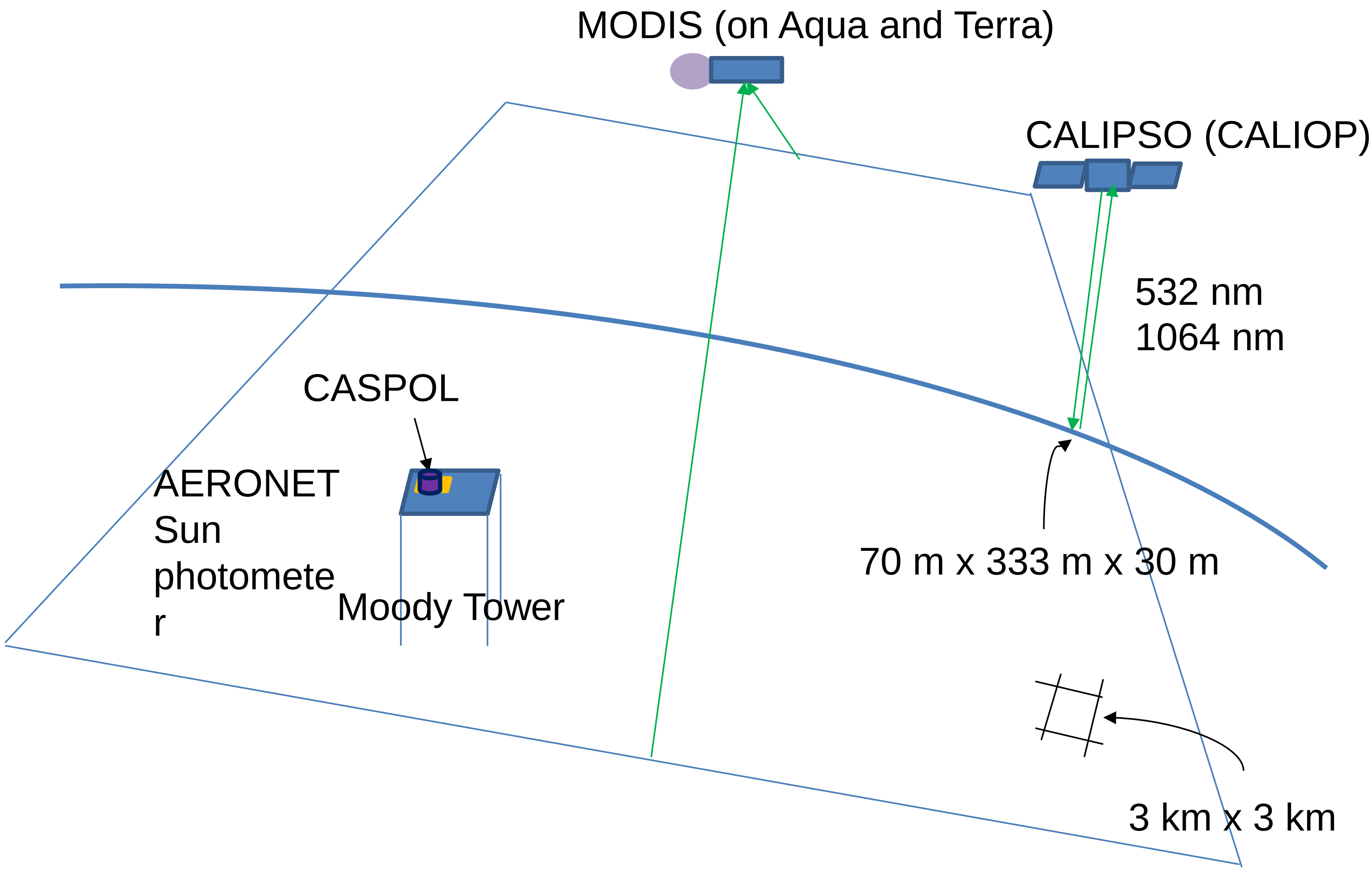
Size Range: 0.6 to 50 micron D.

Backscatter angle: 168° to 176°

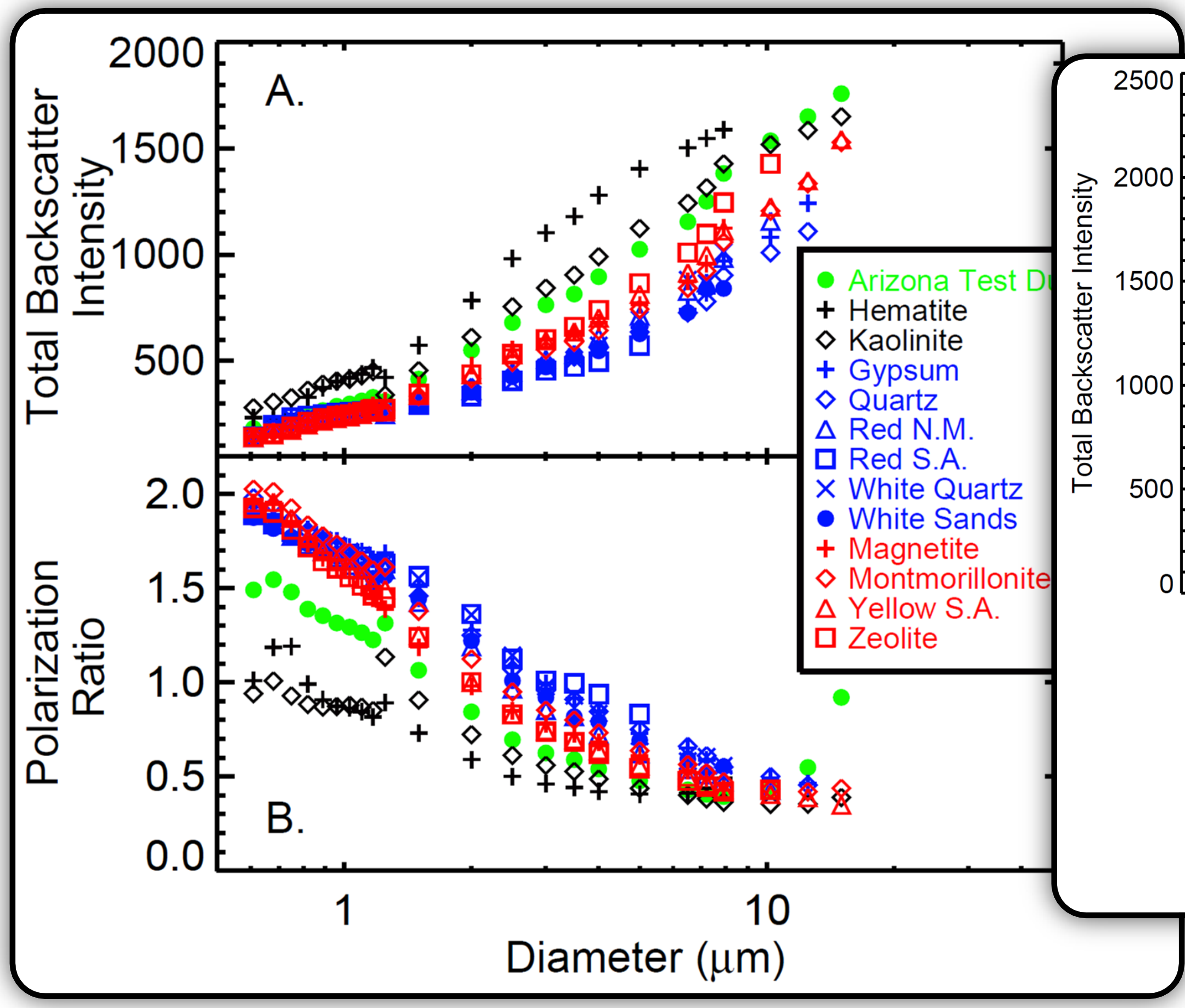
Wavelength: 680 nm

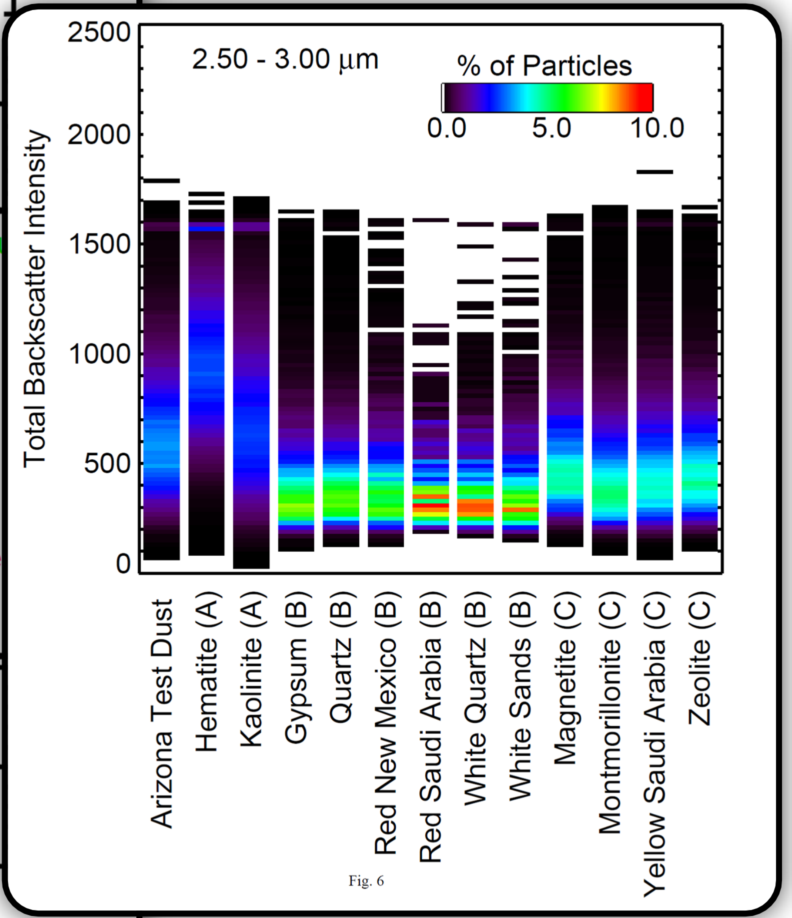
Glen and Brooks, Atm. Chem. Phys., 2013

Satellite and In-situ Instrument Intercomparison



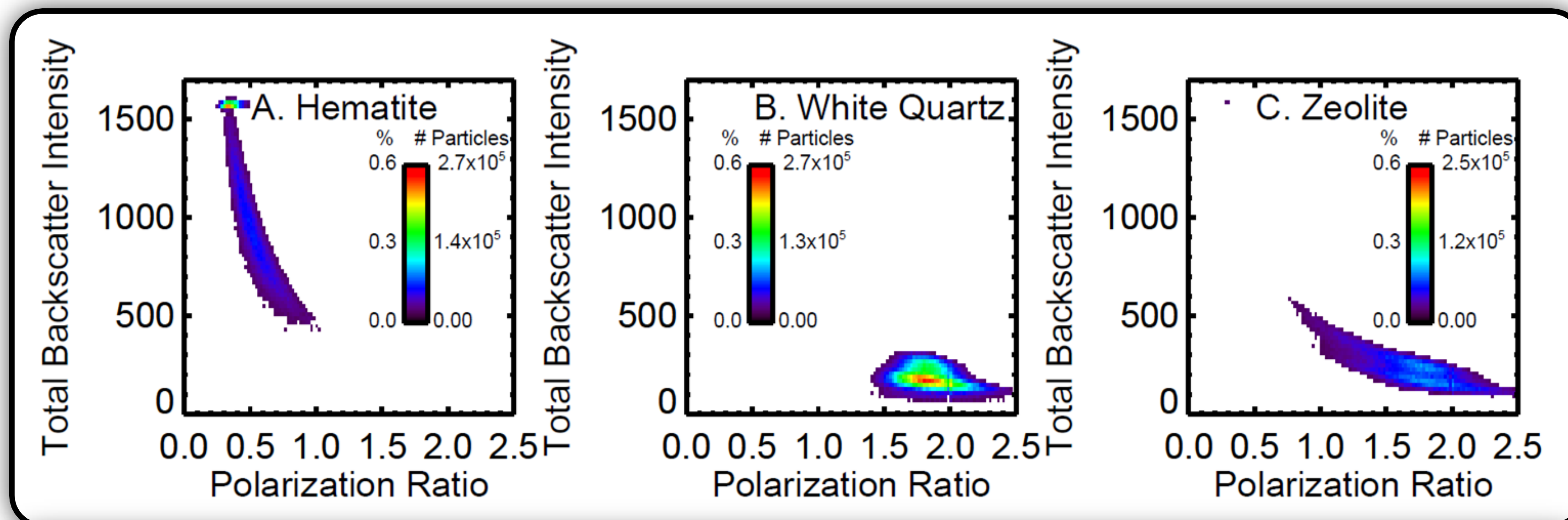
CASPOL Optical Properties of Atmospheric Dusts

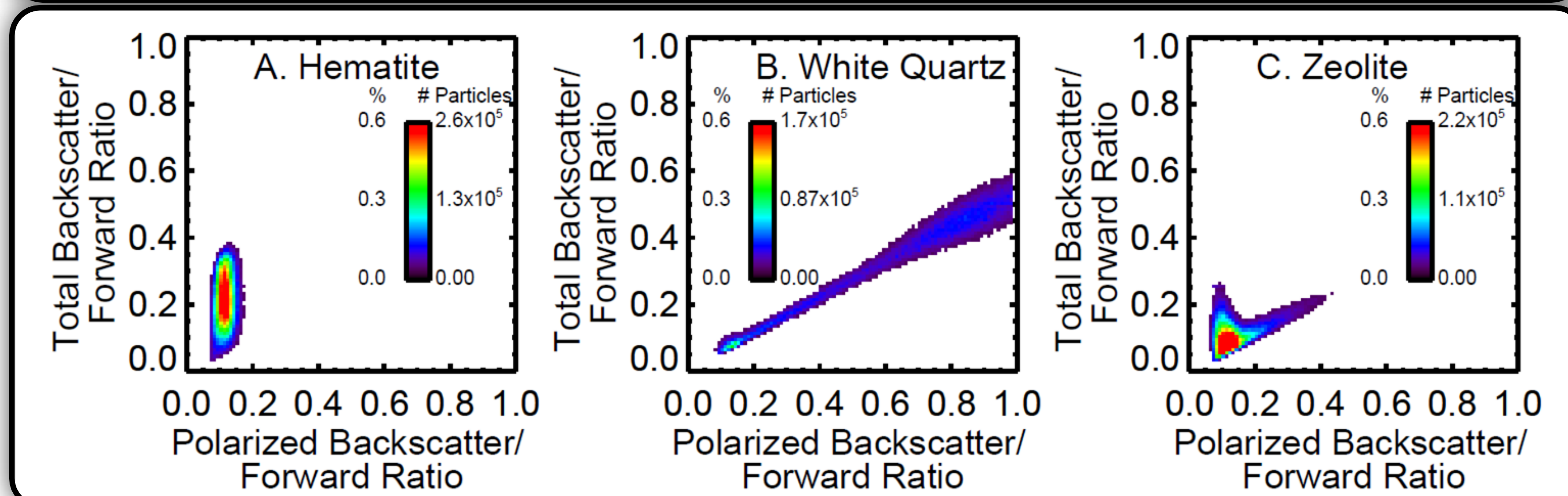




Glen and Brooks, Atm. Chem. Phys., 2013

Optical Scattering Signatures of Various Dusts

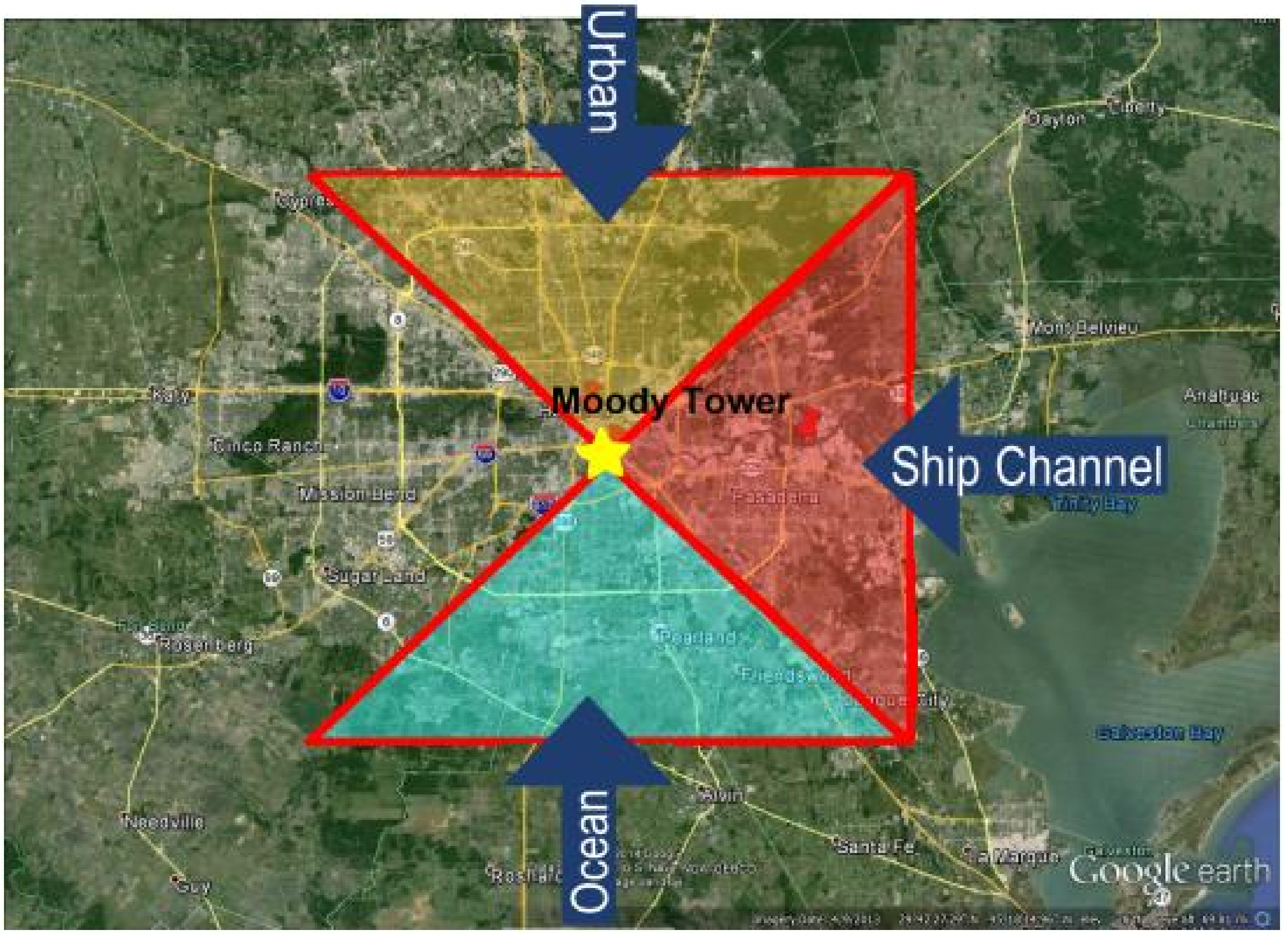




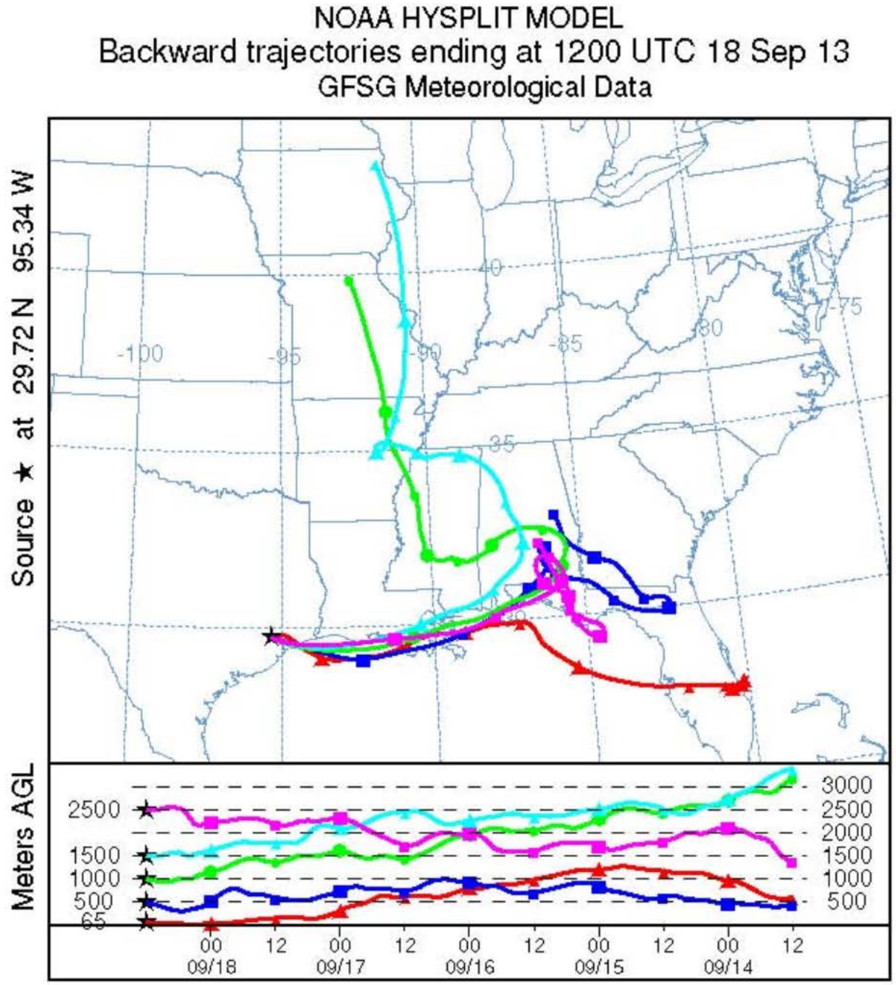
Dusts can be classified into 3 types based on signatures. Glen and Brooks, ACP, 2013

Can the CASPOL differentiate between in-situ aerosol types? DISCOVER-AQ

Fall, 2013

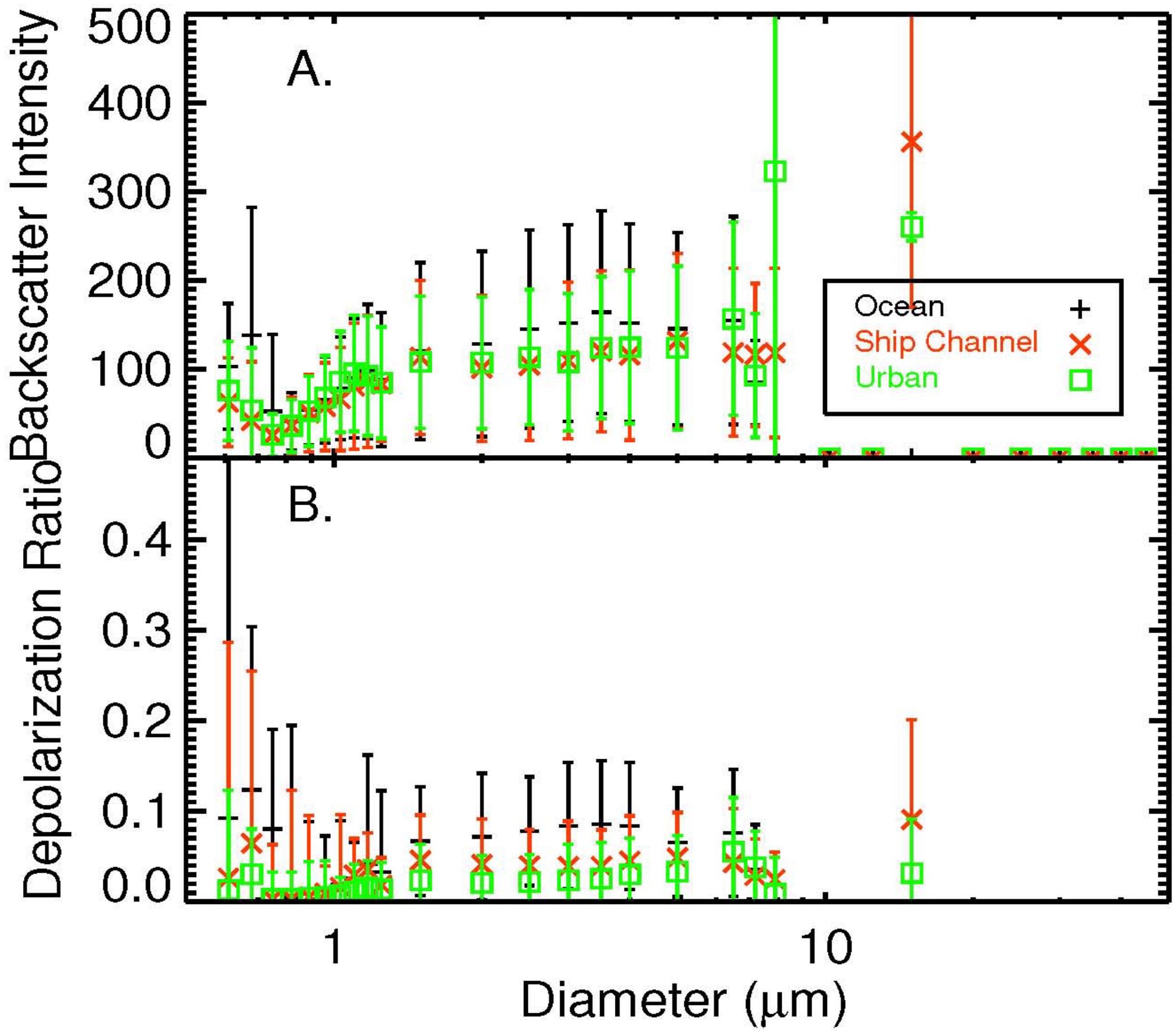


HYSPLIT Backtrajectories

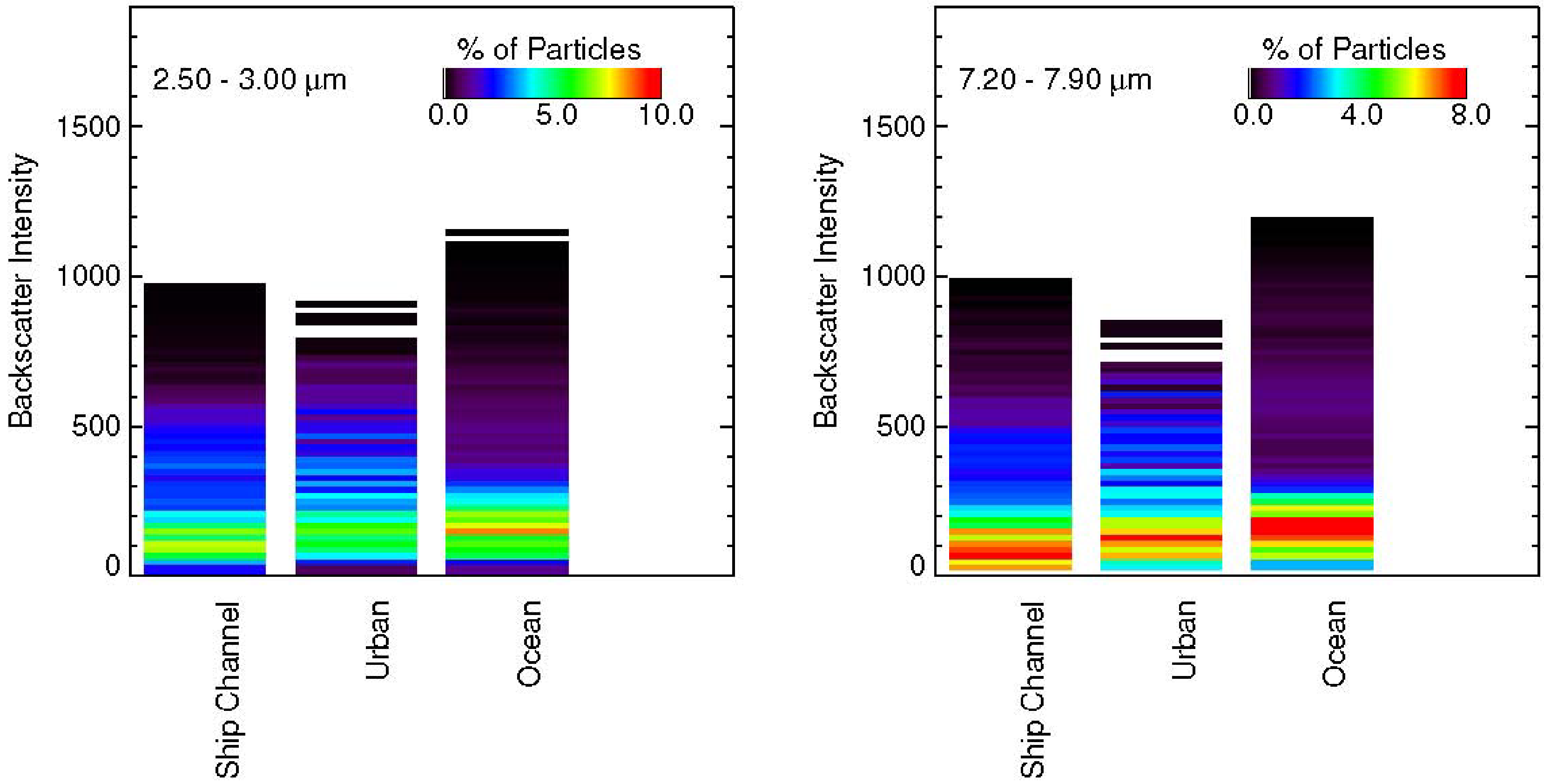


5 day trajectory, each hr of CASPOL data.

CASPOL data for aerosols from the 3 major source regions.

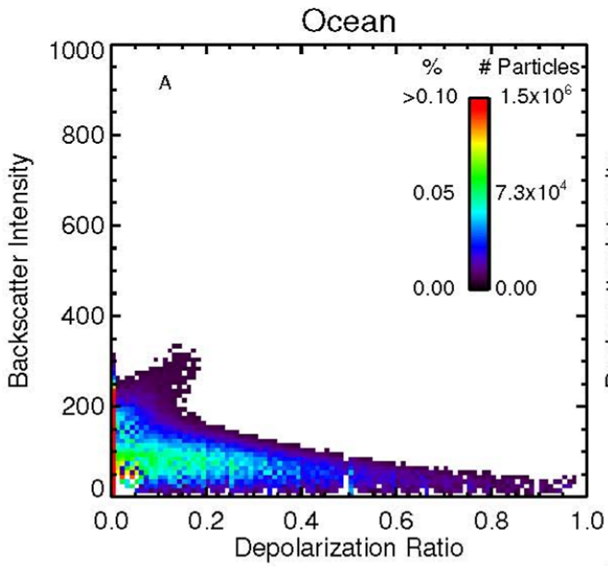


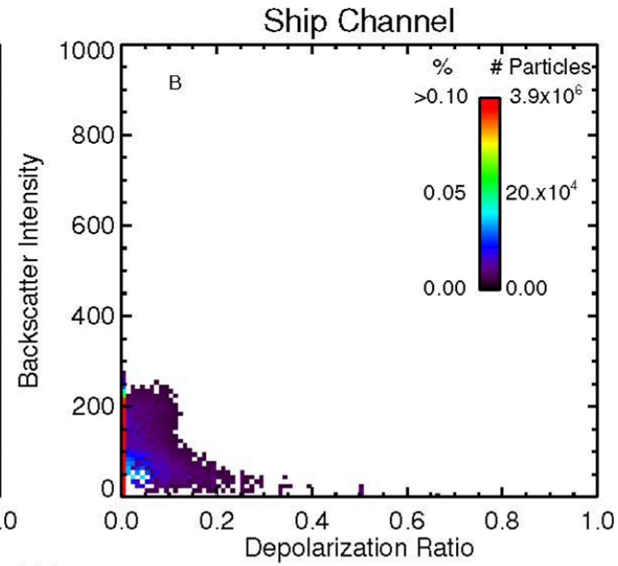
CASPOL data for aerosols from the 3 major source regions.



CASPOL Optical Signatures

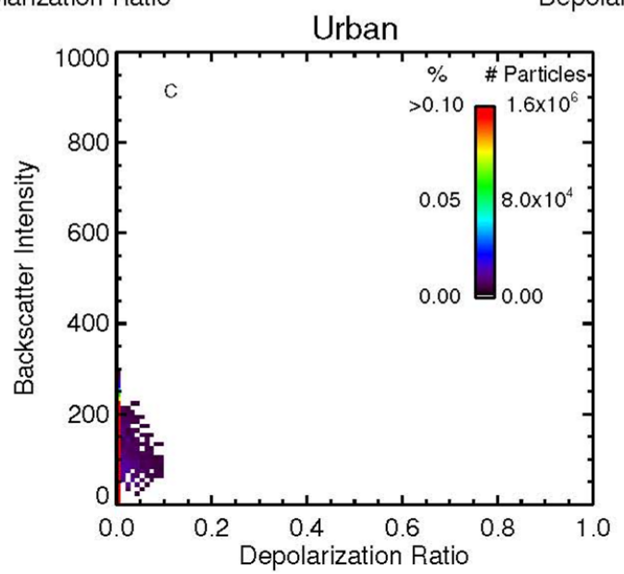
Ocean
/Transported





Ship Channel

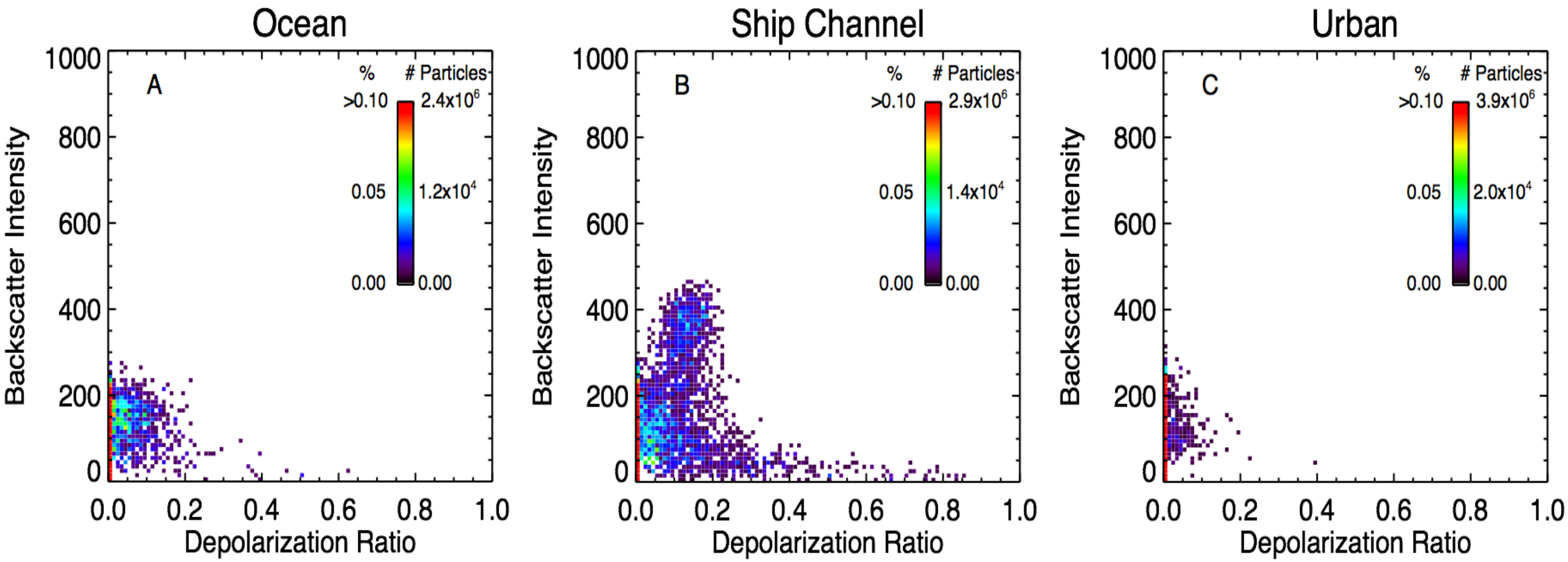
Urban



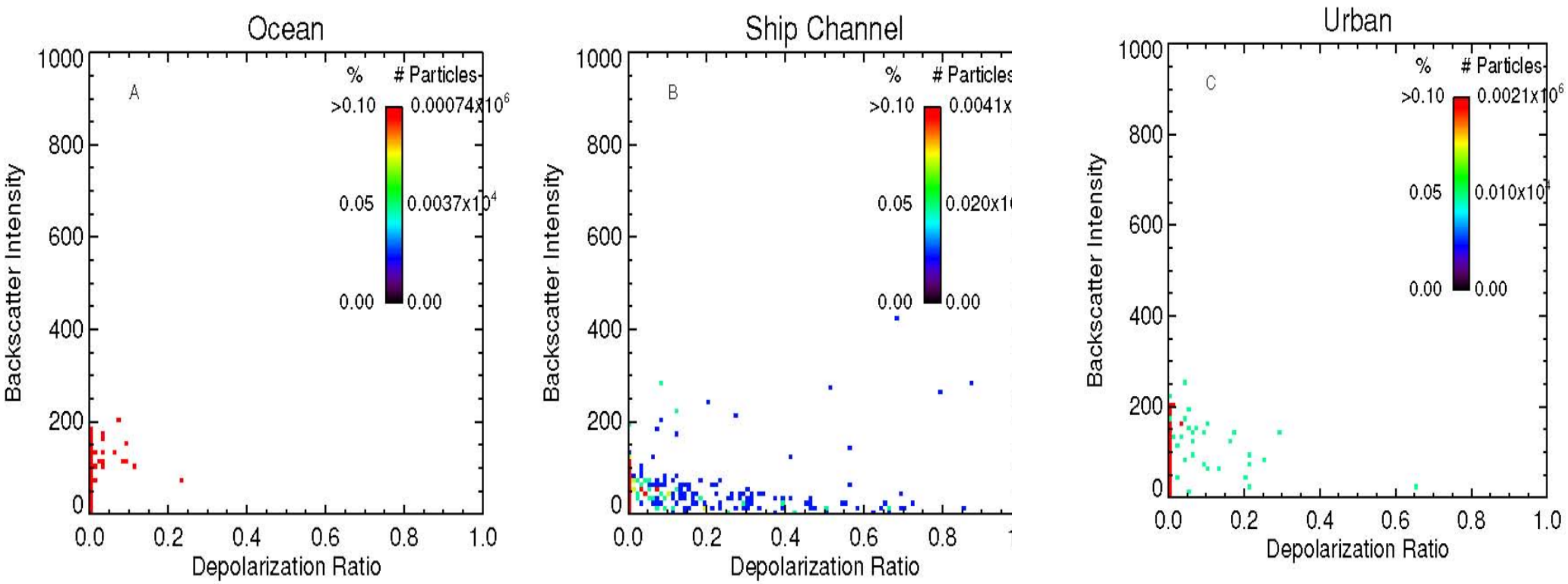
Rules for using the scattering signatures to differentiate the Ship Channel, Urban, and Ocean aerosol source locations.

	Ship Channel	Urban	Ocean
Shape	Shallow Curve	Semi-Circle	Steep Curve
Depolarization Ratio	<0.7	<0.1	>1.0
Backscatter Intensity (a.u.)	<250	<200	<400
Maximum % of Particles	0.05	0.01	0.10

Optical signatures for eight hours periods of data for the Ocean, Ship Channel, and Urban sources.

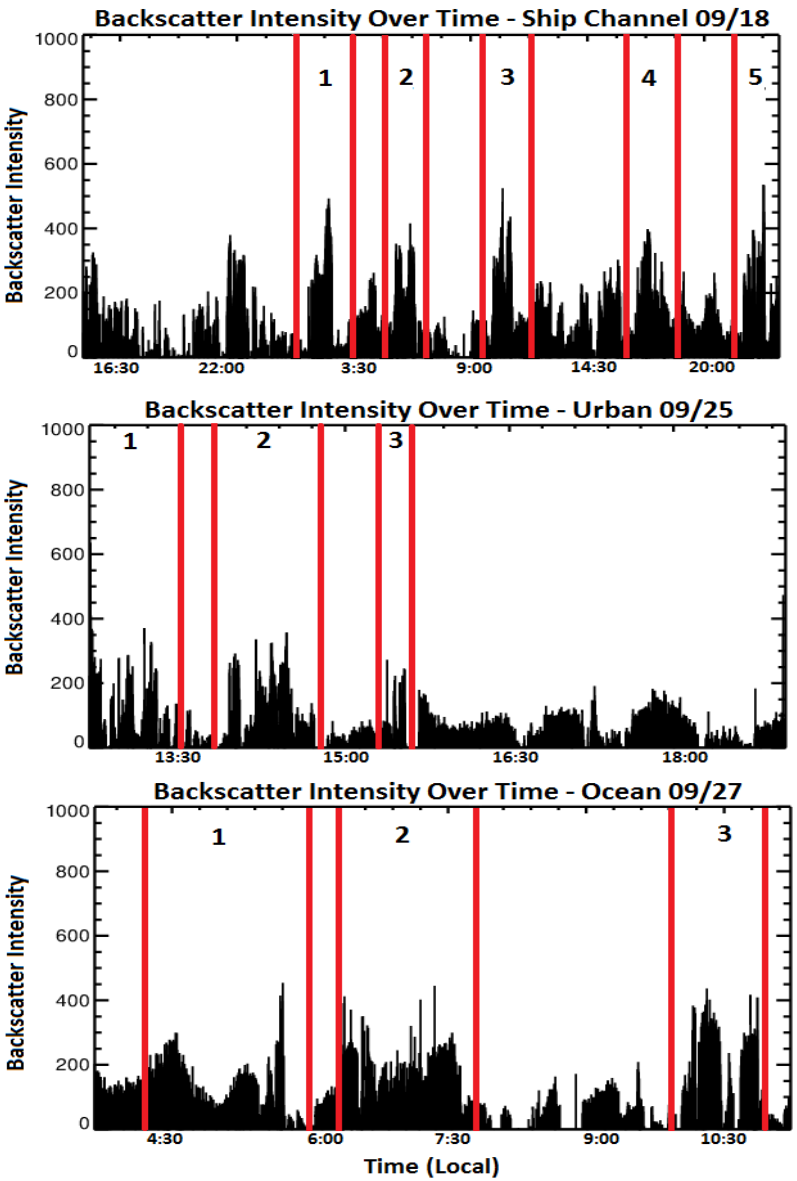


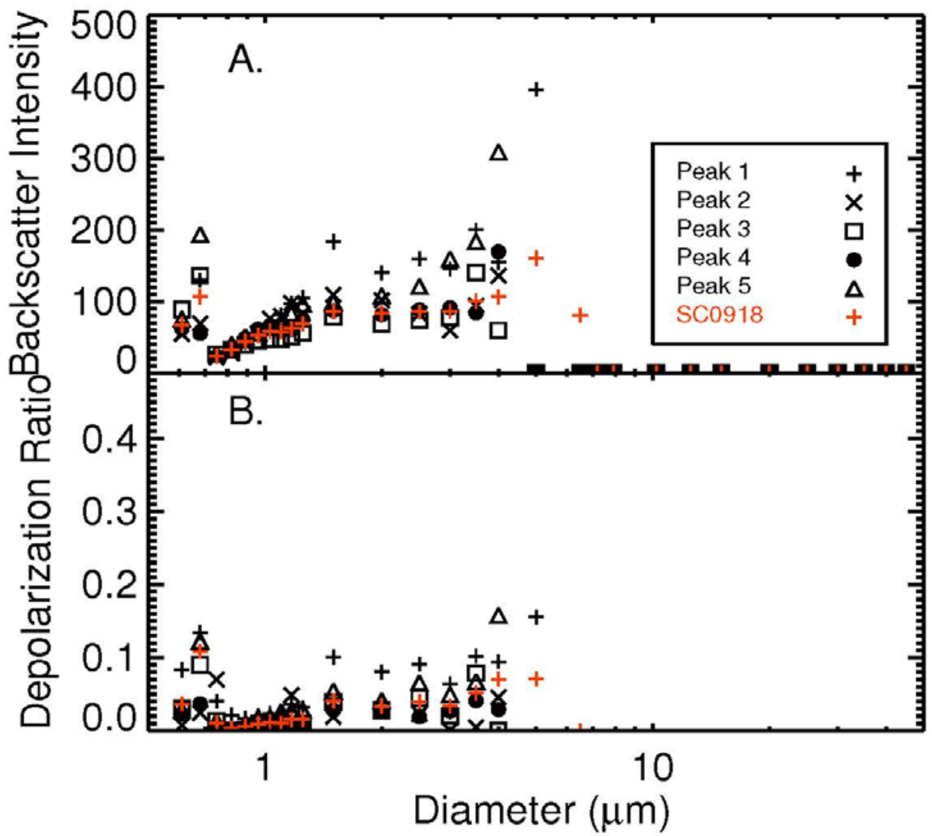
Optical signatures for one hour periods of data for the Ocean, Ship Channel, and Urban sources.



For one hour periods, cannot differentiate between Ship Channel and Urban Pollution.

The backscatter intensity per time.





If the number concentration is high enough, ~200 L^{-1}, the CASPOL scattering signature is representative of the aerosol source with only one hour of data.

CASPOL Summary

The CASPOL provides single particle measurements of aerosol concentration, size
(0.3 to 30 microns diameter), backscattering and depolarization.

Optical signatures can distinguish between Ship Channel, Urban, and Ocean/Transported Aerosol Types

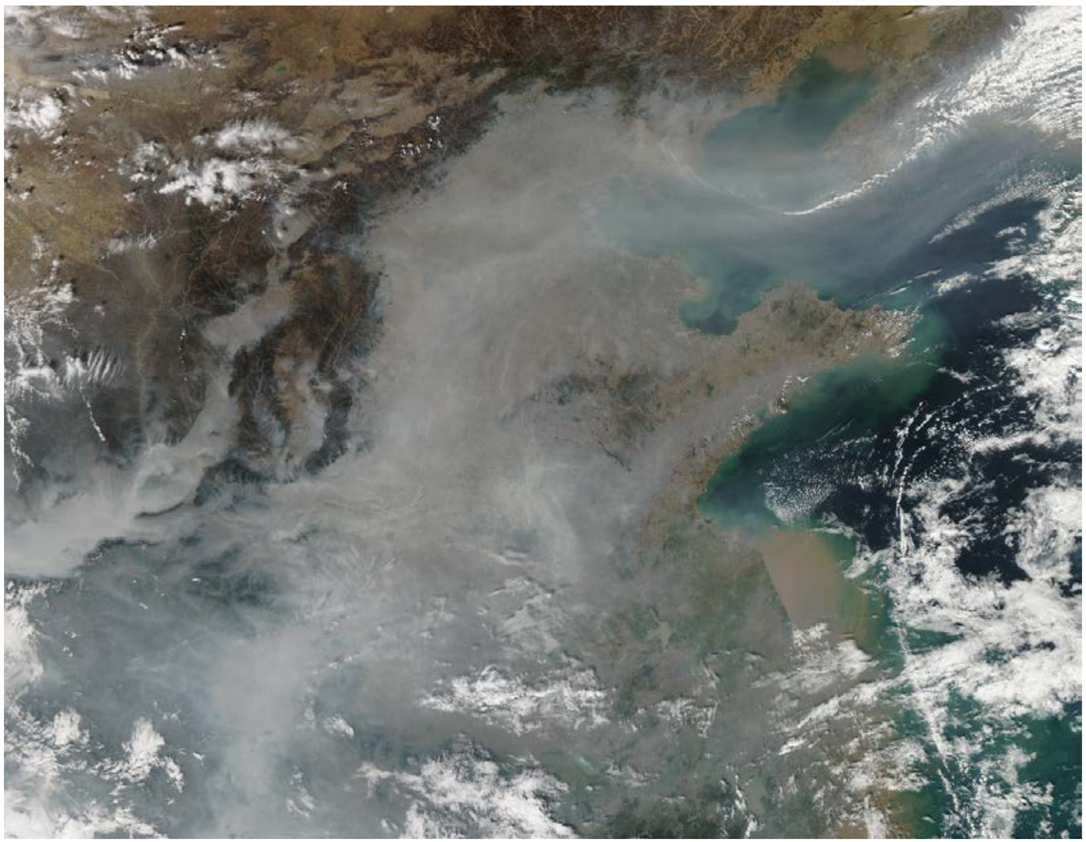
- 8+hr periods of data
- 200+ particles/l

Applications

- Real time monitoring of aerosols - limited
- Improvement of Satellite Monitoring of Aerosols

MODIS (Moderate Resolution Imaging Spectroradiometer)

Air pollution observed by MODIS

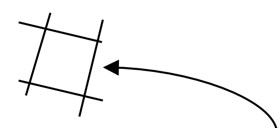


MODIS true color composite

MODIS Collection 6

The MODIS Aerosol Product monitors the ambient aerosol optical depth

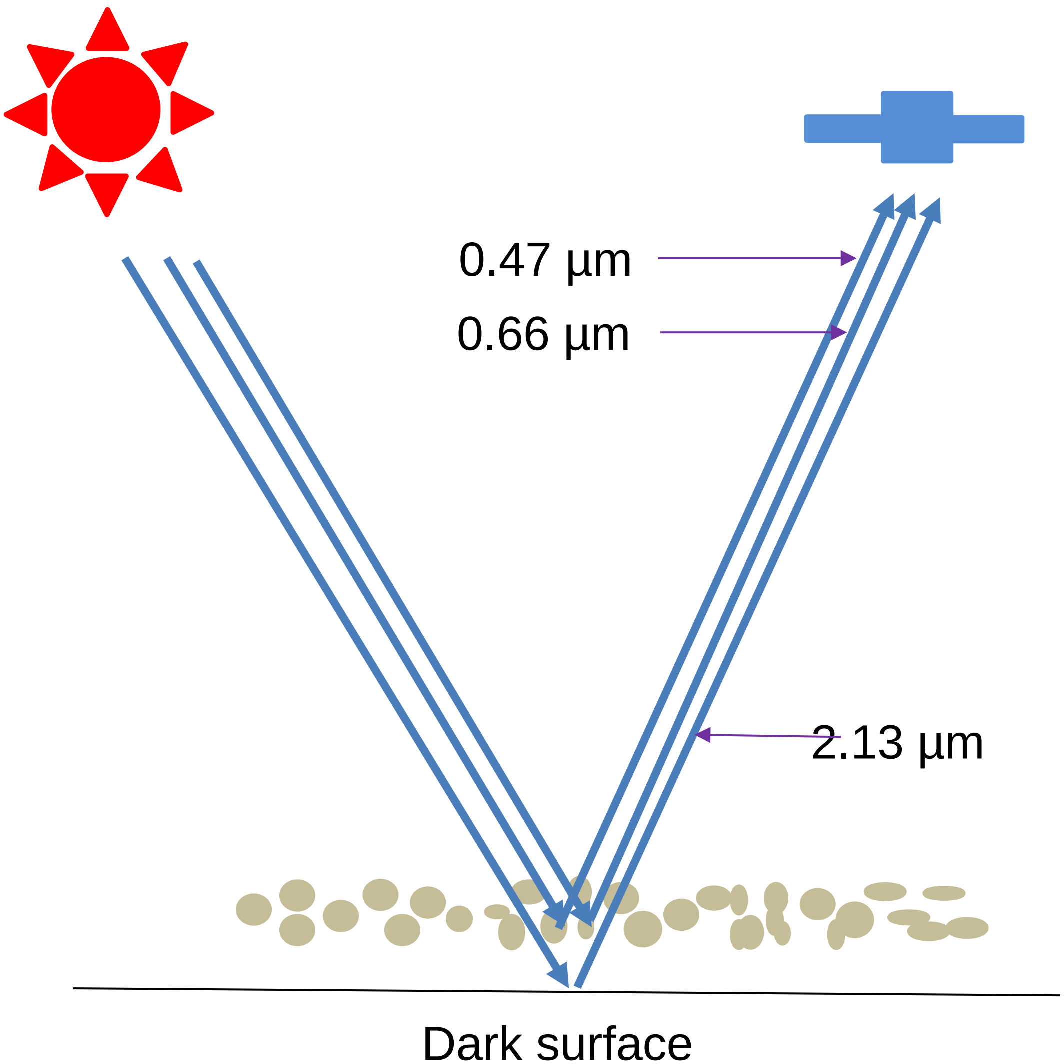
The aerosol type is derived over the continents.



3 km x 3 km

[earthobservatory.nasa.gov]

MODIS aerosol retrievals



[King et al., 1999, Kaufman et al., 1997]

Aerosol assumptions

Reflectance Function:

$$R_a \approx \frac{\omega_0 \tau_a p_a(\Theta)}{4\mu\mu_0}$$

ω= Single scatter albedo

T_a = aerosol optical thickness

$P_a(\Theta)$ = scattering phase function

u the absolute value of the cosine of the zenith angle q

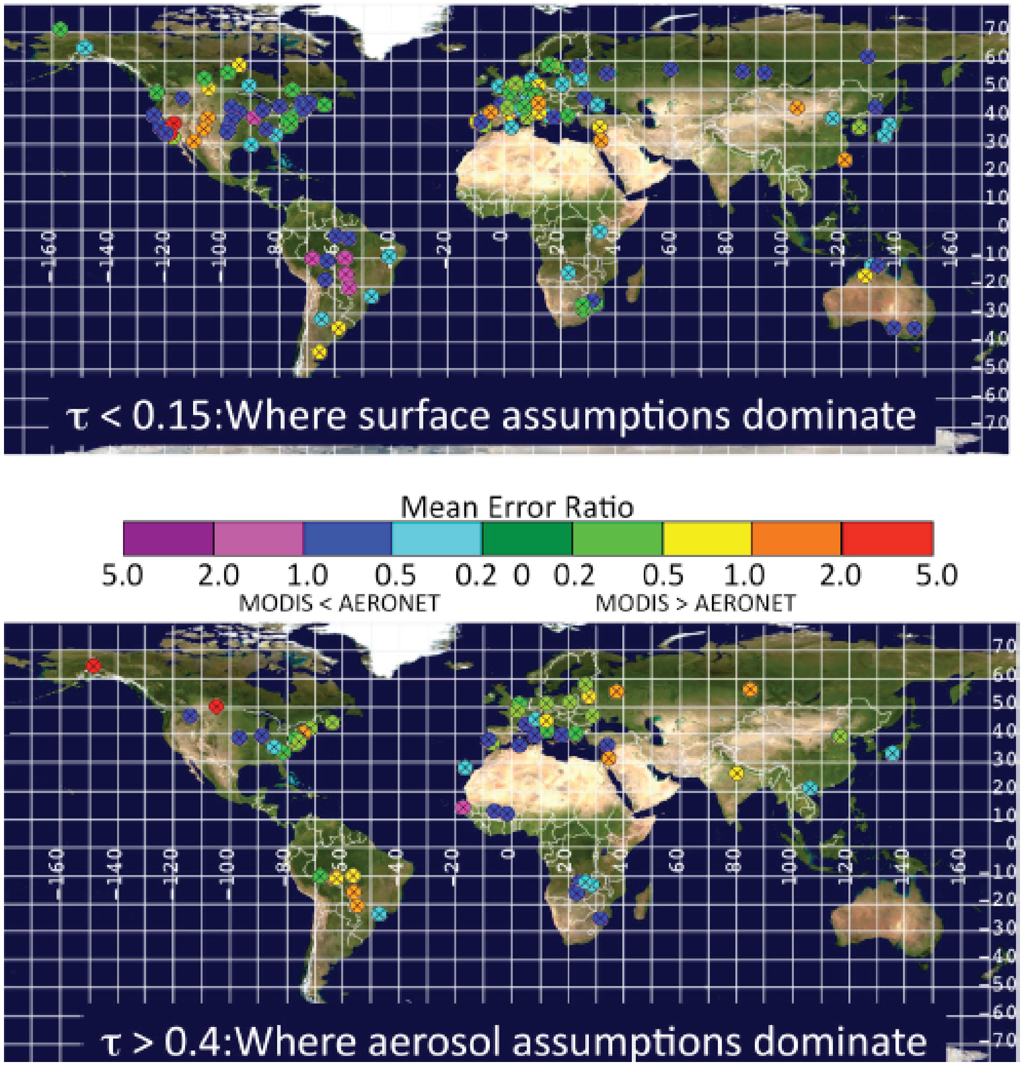
uo the cosine of the solar zenith angle **q**0.

Surface assumptions

$$R_{surf,\ 0.49\ \mu m} = R_{surf,\ 2.2\ \mu m} / 4$$

$$R_{surf,\ 0.66\ \mu m} = R_{surf,\ 2.2\ \mu m} / 2$$

Uncertainties of surface and aerosol assumptions



Surface assumptions dominate the uncertainty in urban or coastal areas and brighter elevated surfaces.

Aerosol assumptions dominate the uncertainty in the biomass burning region.

[Levy et al. 2010]

Optical thickness

MODIS aerosol assumption

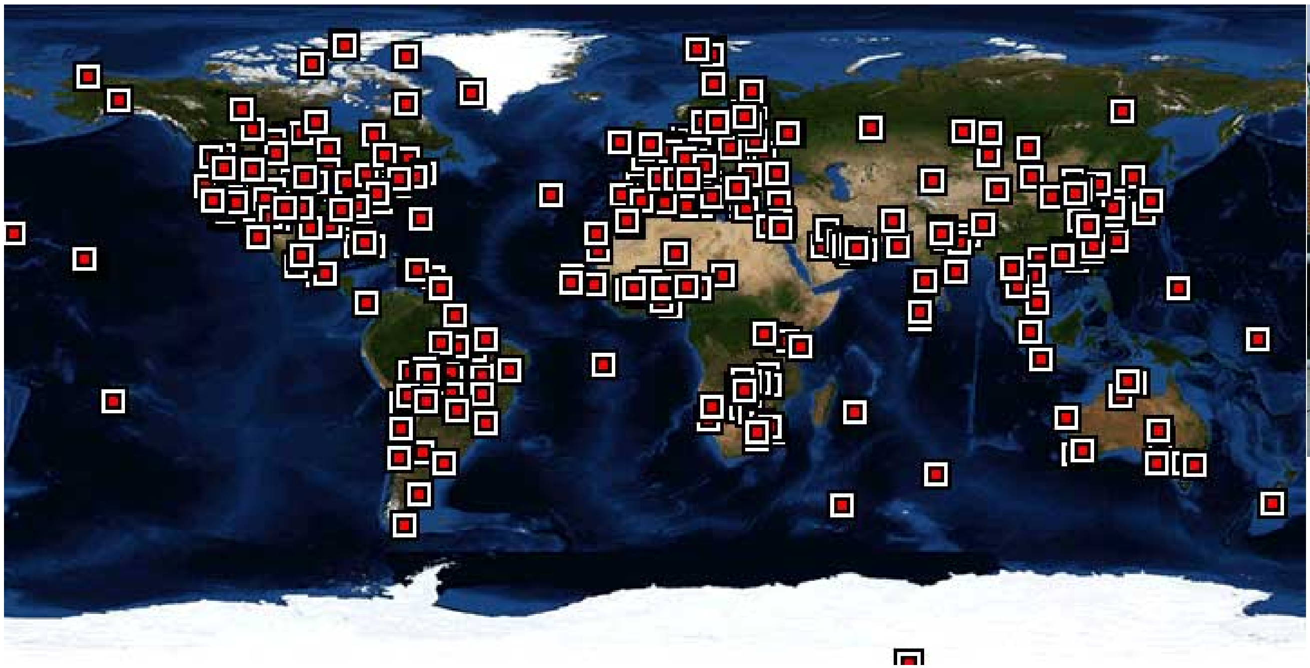
A mixture of a fine mode and a coarse mode over the dark surface

Fine modes classification:

Model	Refractive Index: k	Single scatter albedo (550 nm)
Non-absorb / Urban-Ind	1.42 - (-0.0015τ + 0.007)i	0.95
Moderately absorbing / Developing	1.43 - (-0.002τ + 0.008)i	0.92
Absorbing / Heavy Smoke	1.51 - 0.02i	0.87

DISCOVER-AQ

Aerosol Robotic Network (AERONET)



[www.nasa.gov]

Expected Error of MODIS AOD = ± (0.05 + 0.15τ)

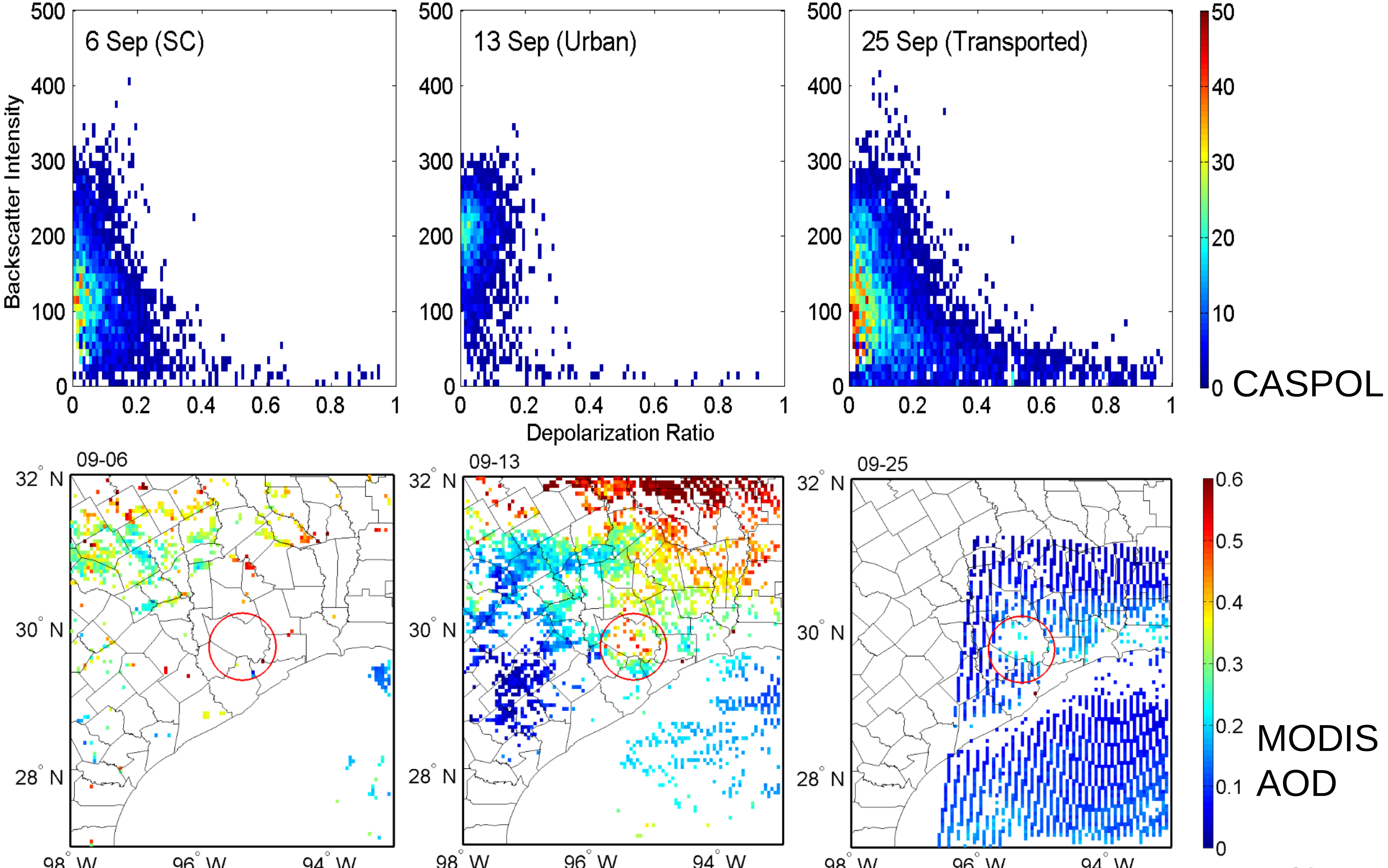
[Chu et al. 2002]

CASPOL - Satellite Intercomparison

Variables	Satellite data
AOD	MODIS 3 km Collection 6 (circle with a radius of 50 km)
Aerosol type	MODIS aerosol assumptions
Depolarization ratio	CALIOP level 2 aerosol layer products of the version 3.30 (25 km segment in the lower troposphere)
Backscatter intensity	CALIOP level 2 vertical mask products of the version 3.30 (necessary condition)

Variables	Ground-based instrument data
AOD	AERONET level 2.0 (±0.5 h)
Aerosol type	Inference from CASPOL optical signatures (±4 h)
Depolarization ratio	CASPOL backscatter (±1 h)
Backscatter intensity	CASPOL backscatter intensity (±1 h)

Optical signatures



MODIS – CASPOL comparisons

Date	Time (CDT)	CASPOL Aerosol Type	Terra AOD	AERONET AOD
6 Sep	12:30	Ship Channel	0.26	0.23
8 Sep	12:20	Transported	0.28	0.11
13 Sep	12:34	Urban	0.31	0.20
22 Sep	12:29	Transported	0.098	0.050
25 Sep	11:24	Transported	0.15	0.090
26 Sep	12:04	Transported	0.13	0.060

Date	Time (CDT)	CASPOL Aerosol Type	Aqua AOD	AERONET AOD
12 Sep	15:05	Ship Channel	0.10	0.10
18 Sep	14:30	Transported	0.15	0.10
25 Sep	14:35	Transported	0.13	0.12
26 Sep	15:20	Transported	0.14	0.086

No clear relationship between MODIS AOD and CASPOL aerosol type
The mean of MODIS AOD retrievals is greater than that of AERONET retrievals (at the 1% significance level).

CASPOL-MODIS conclusions

- MODIS AOD retrievals is greater than that of AERONET retrievals

→ Aerosols may be more absorbing than indicated by the MODIS retrievals

$$R_a \approx \frac{\omega_0 \tau_a p_a(\Theta)}{4\mu\mu_0}$$

- DISCOVER AQ: MODIS assumed weakly absorbing in all cases. Reassignment will not improve agreement with AERONET

- The aerosol mode assumption might not be the primary contributor to the AOD retrieval uncertainty.

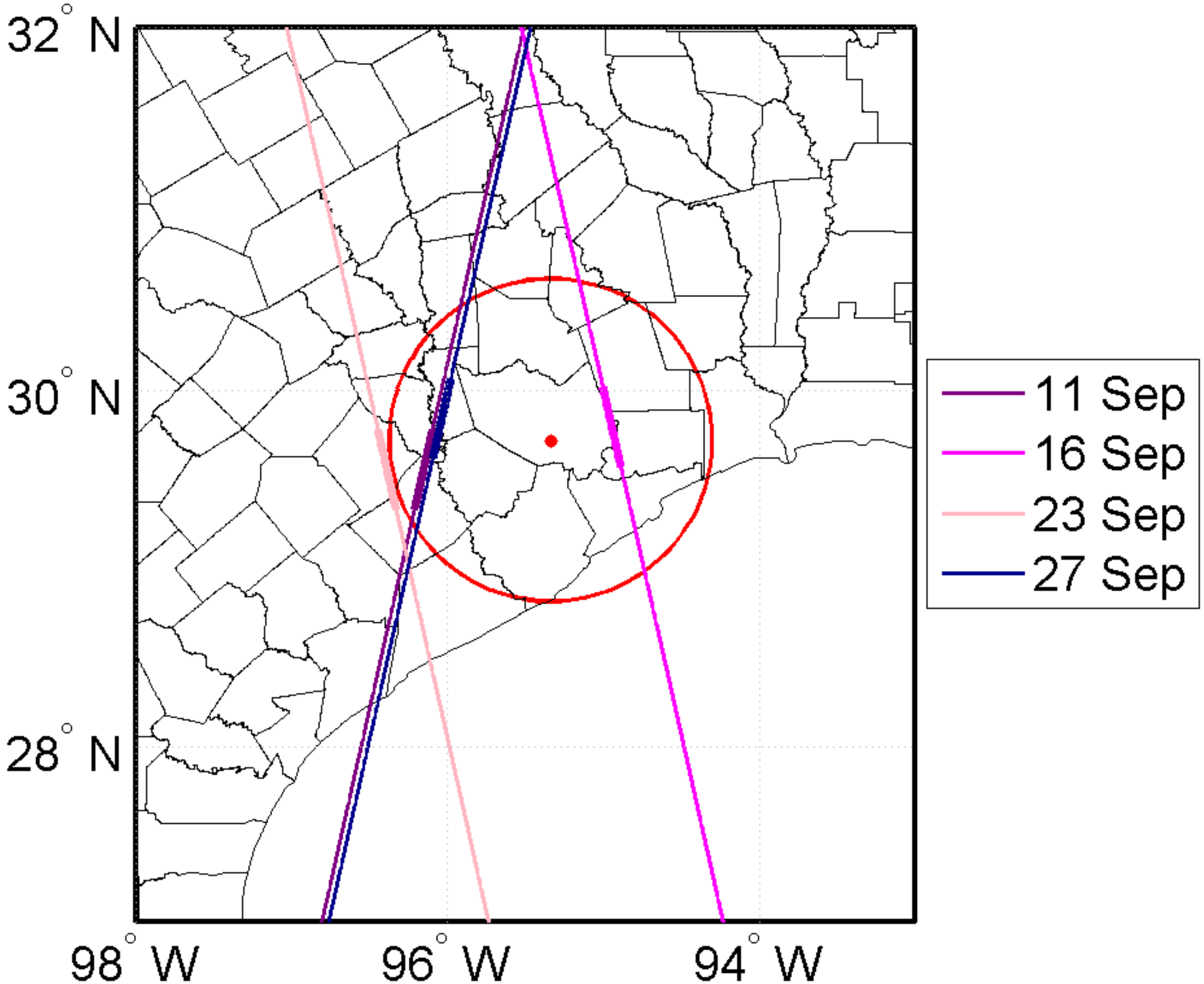
The Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on CALIPSO

- Vertical resolution
- Lidar backscattering measurement

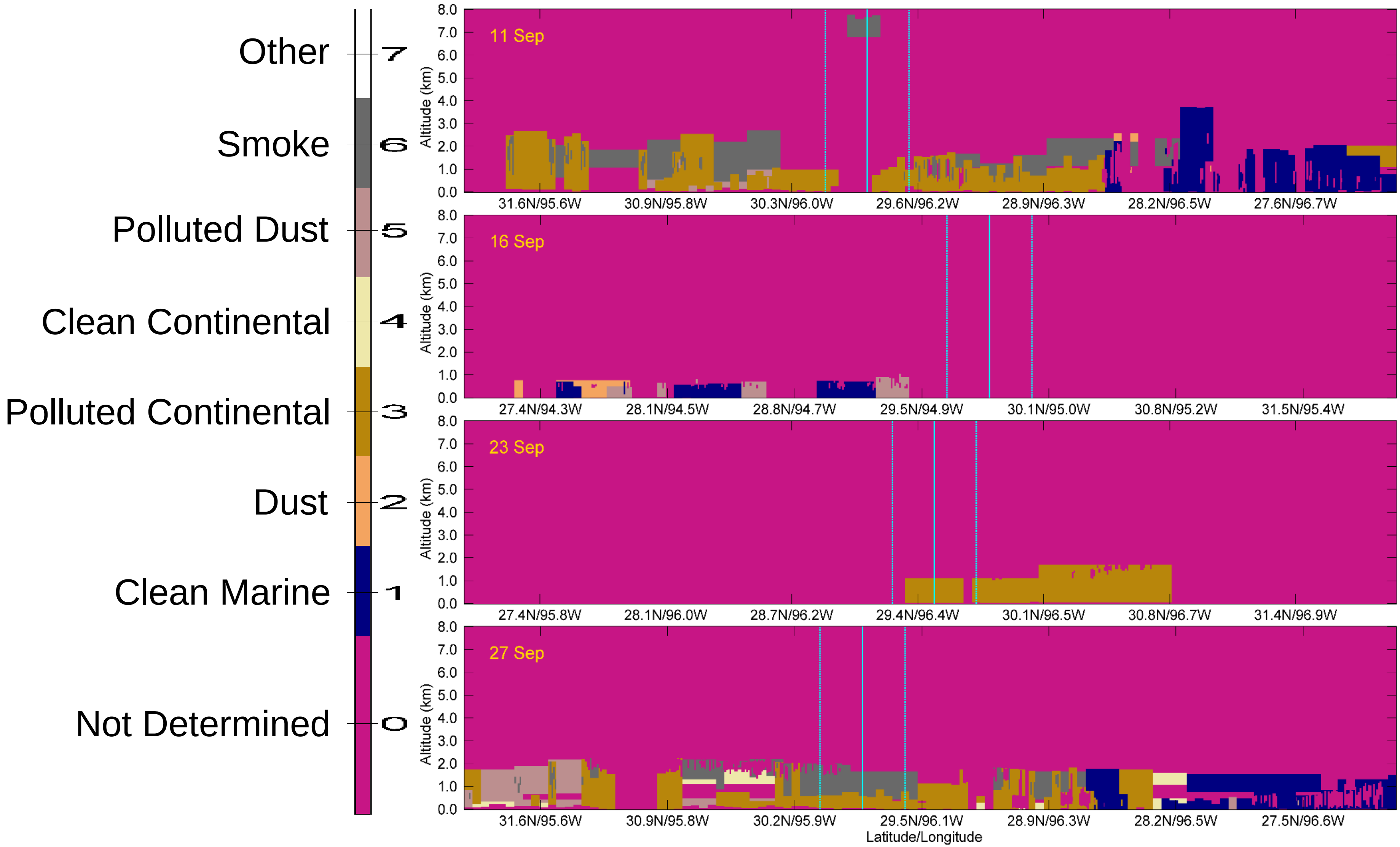
  at 532 nm

  (and 1064 nm)

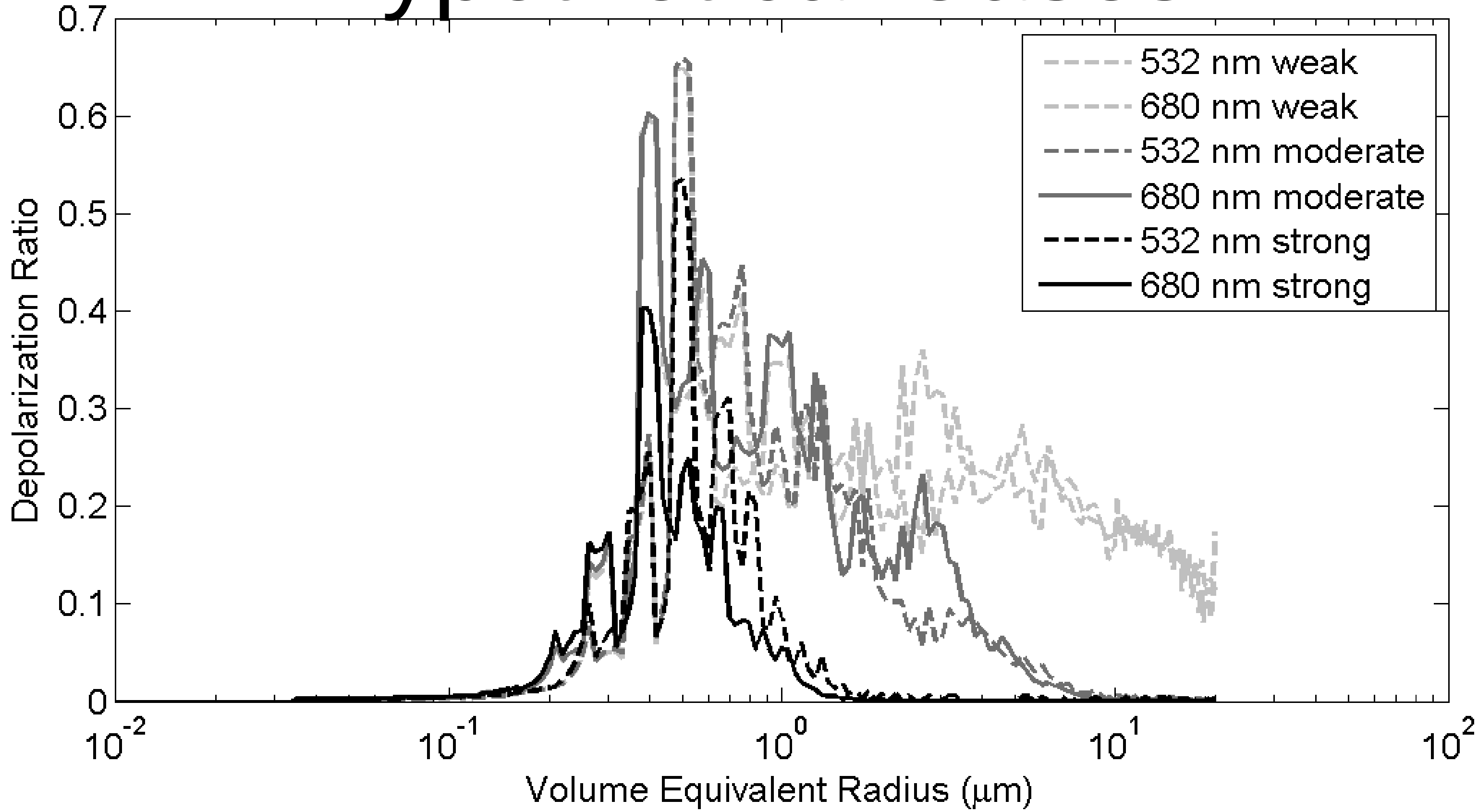
Tracks of CALIOP cases



CALIOP aerosol typing



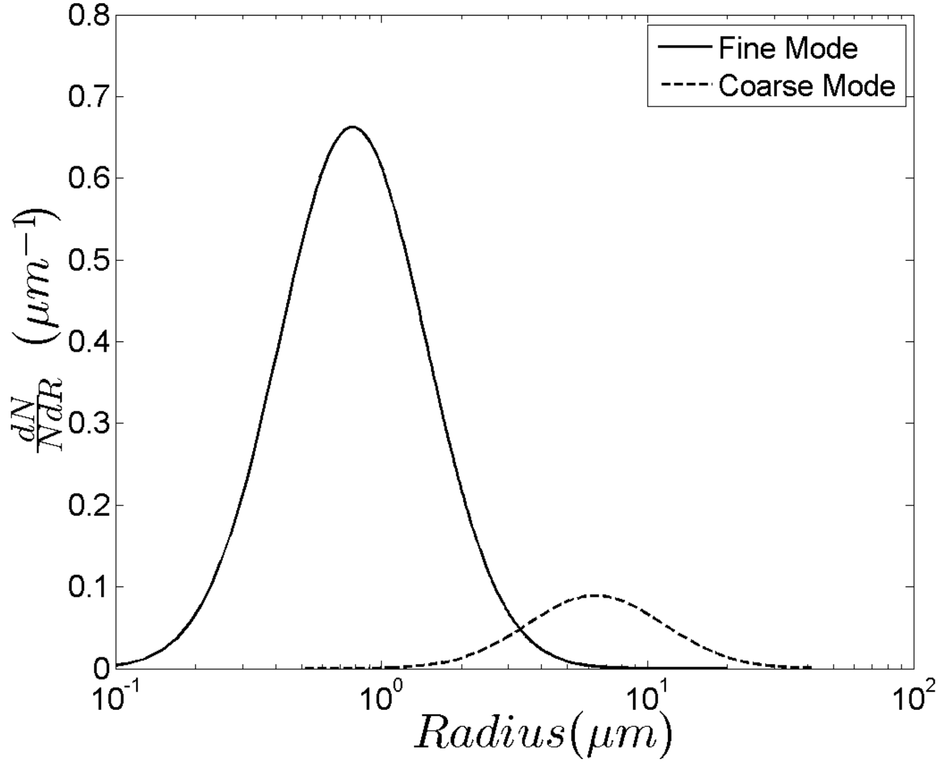
Predicted Depolarization Hypothetical Cases



	Weak	Moderate	Strong
Refractive Index	1.53 + 0.002i	1.53 + 0.02i	1.53 + 0.2i

[Courtesy of Guanglang Xu]

CASPOL vs. CALIOP Depolarization ratio difference



Depolarization Ratio Differenced

	Weak Absorption	Moderate Absorption	Strong Absorption
Fine Mode	-0.0377	-0.0285	0.0274
Coarse Mode	0.0417	0.0177	0.0146

DISCCOVER AQ
CALIOP – CASPOL Comparisons

Date	Latitude	Longitude	Distance (km)	CALIOP DPR	CASPOL DPR	CASPOL Backscatter Intensity
11 Sep	29.85	-96.08	73.07	0.014	0.016	64.8
16 Sep	29.81	-94.95	39.33	NA	0.026	40.2
23 Sep	29.51	-96.38	102.89	0.013	0.005	60.1
27 Sep	29.85	-96.04	68.98	0.014	0.007	60.9

The Observed CASPOL and CALIOP DPRs are similar.

However, little variation was observed from case to case.

More intercomparison cases are needed.

CASPOL – CALIOP Conclusions

- The theoretical study show that using CASPOL measurements to compare to CALIOP is an appropriate method

- Our conclusions are only valid for these four cases.
- More caes needed to test whether these are statistically representative.

CALIOP Conclusions

- The theoretical study shows that it is appropriated to compare CASPOL with CALIOP
- The CASPOL depolarization ratio and backscatter intensity measurements support the CALIOP decision tree.
- Our conclusions are only valid for these four cases and may not be statistically representative.

Ongoing work

Shorten intercomparison time periods to gain more cases (MODIS and CALIOP)

CASPOL	**MODIS**	**AERONET**
Aerosol Type - Optical Signatures	AOD	AOD
Size Distribution	Aerosol assumptions	Derived size distribution
Calculate Fine Mode Fraction	Fine mode fraction	