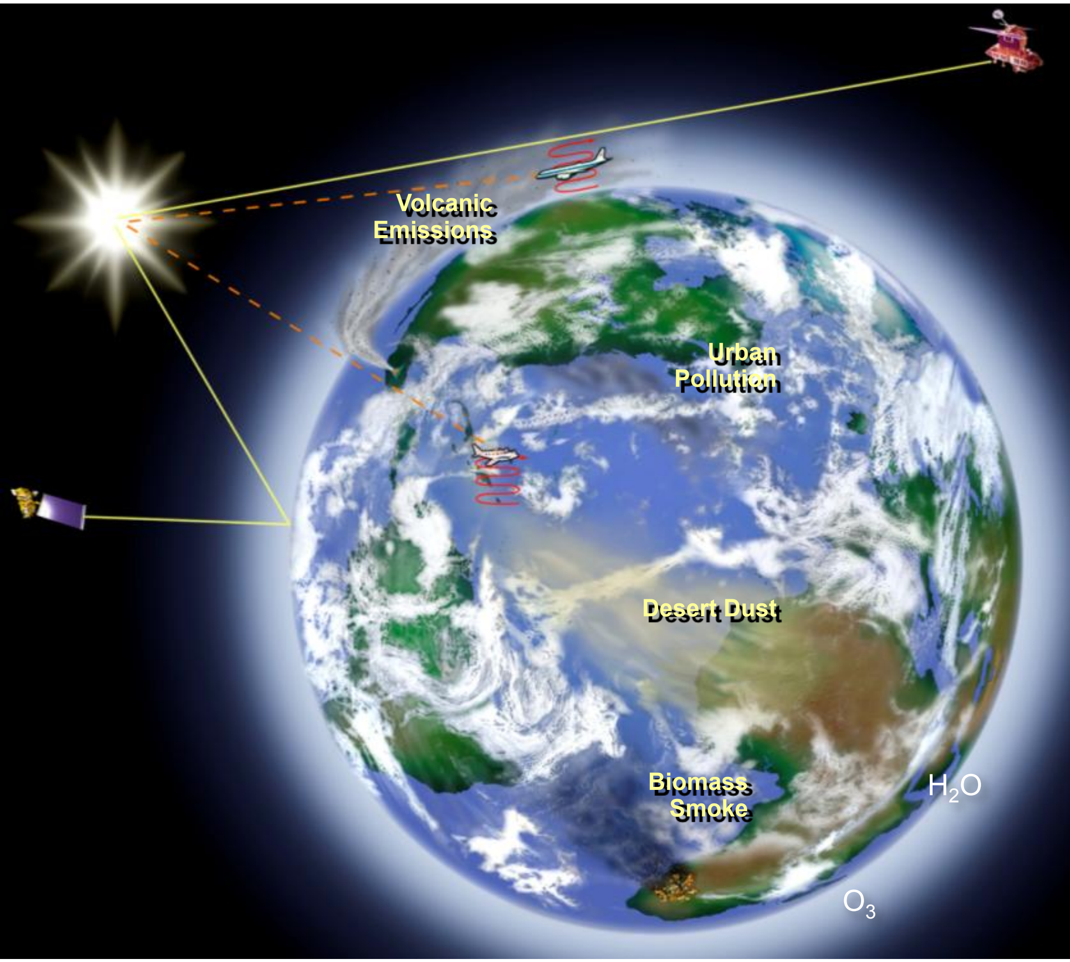
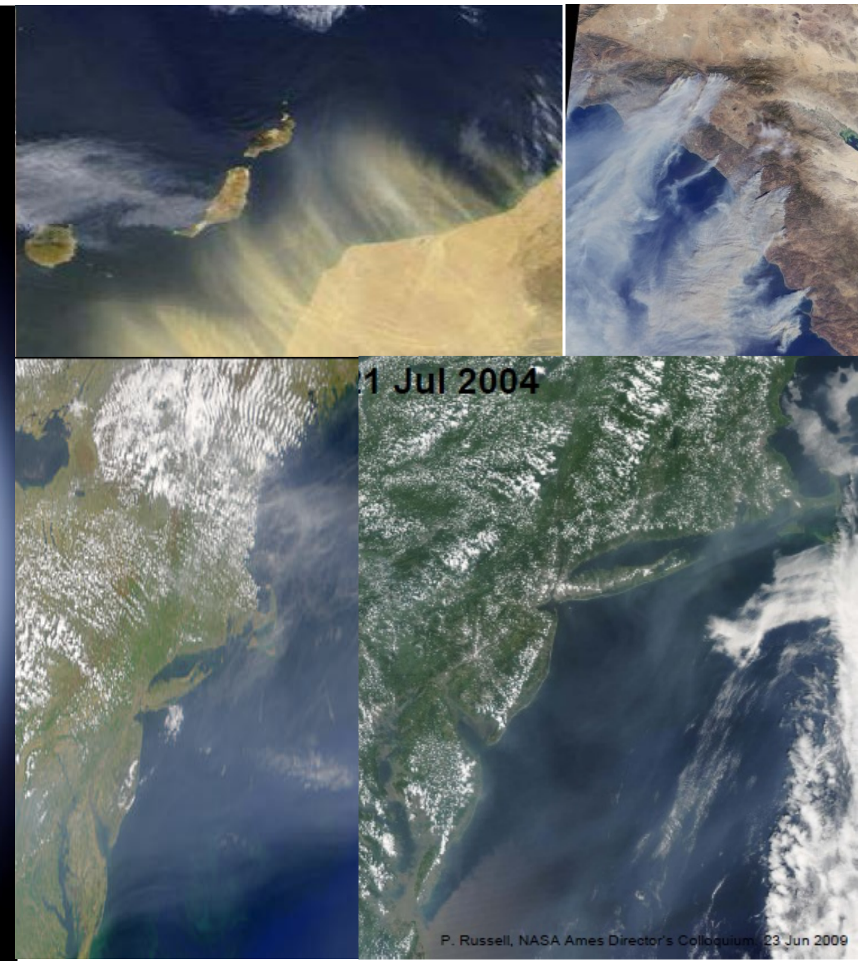
Identifying Aerosol Type from Space:

Absorption Wavelength Dependence as a Foundation for Multidimensional Specified Clustering and Mahalanobis Classification

Phil Russell* & the Glory Aerosol ClassificationTeam#

*NASA Ames Research Center #SJSU, SRI, BAER, NASA LaRC, NASA GISS, U. Hawaii, …





LOA-CNES Workshop on Aerosol & Cloud Properties for Climate Studies, Paris, FR, Sep 2011

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The Glory Aerosol Classification Team

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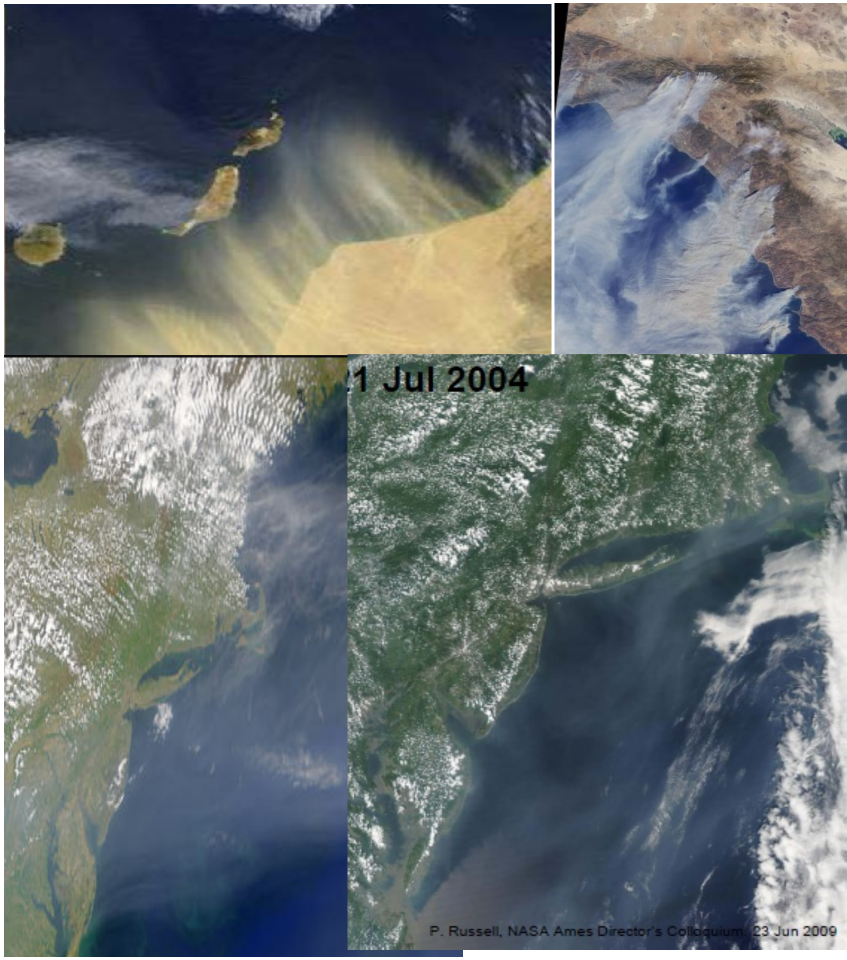

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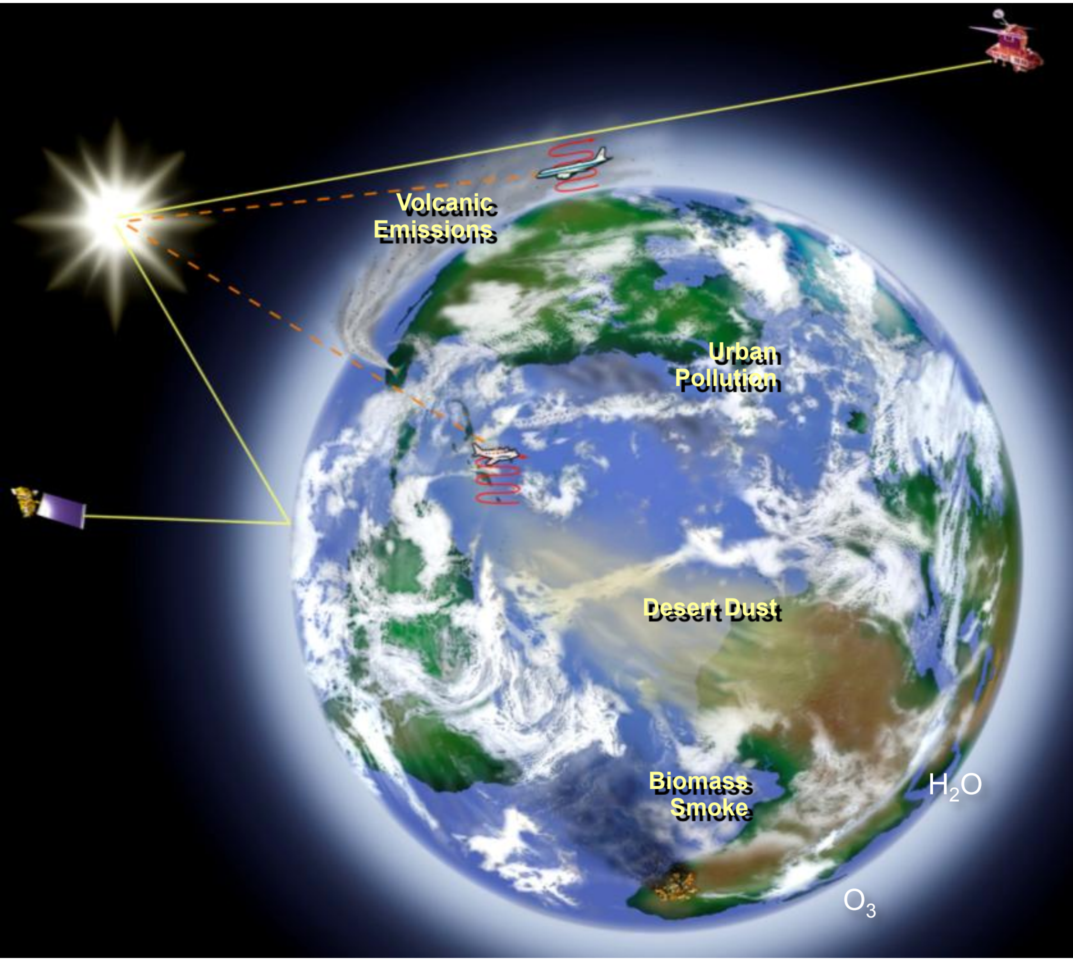
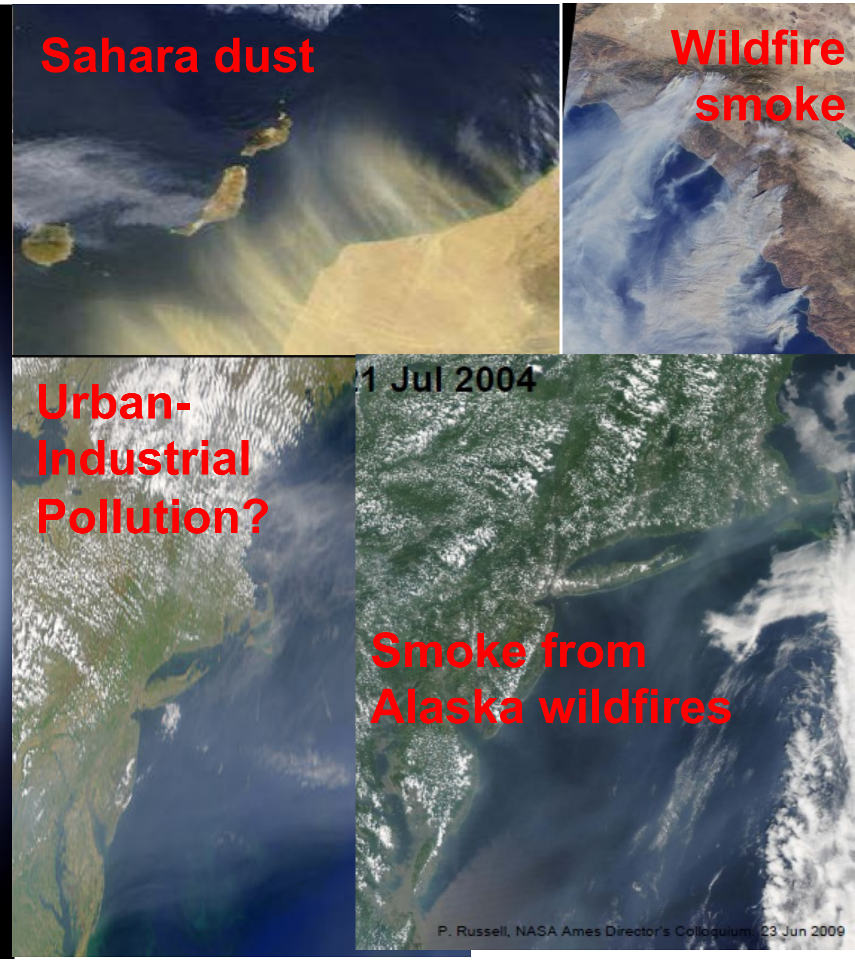
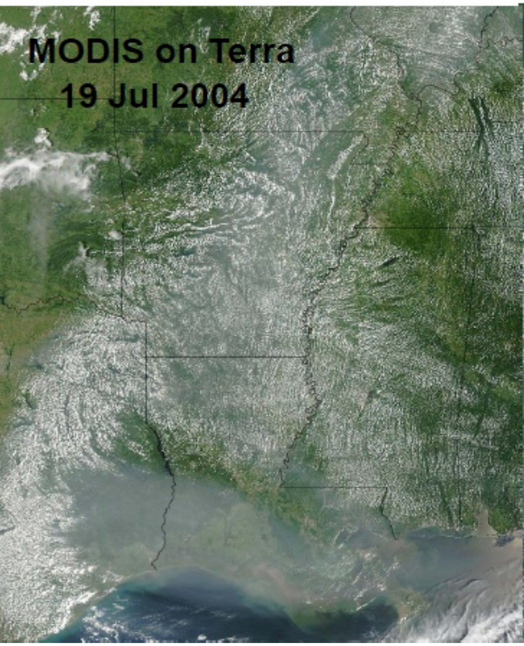


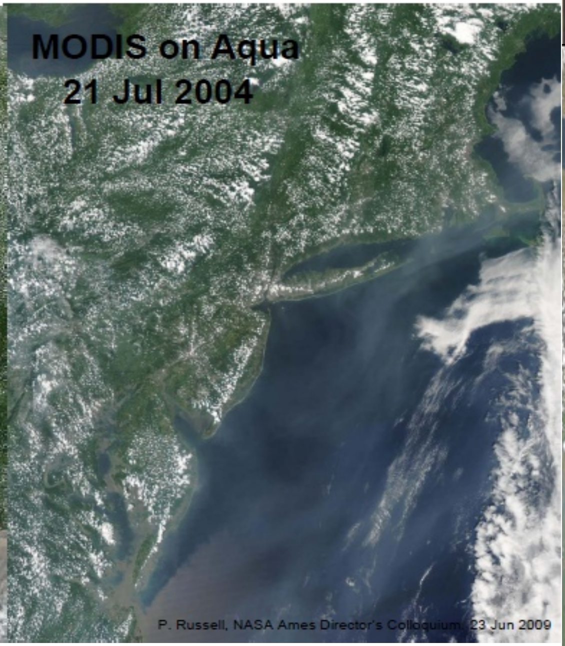


Goal of this work:

Identify aerosol type using only the opto-physical* information retrieved from a single data grid box*

*But the algorithm can be trained using other information (e.g., trajectories, accompanying trace gases, …)





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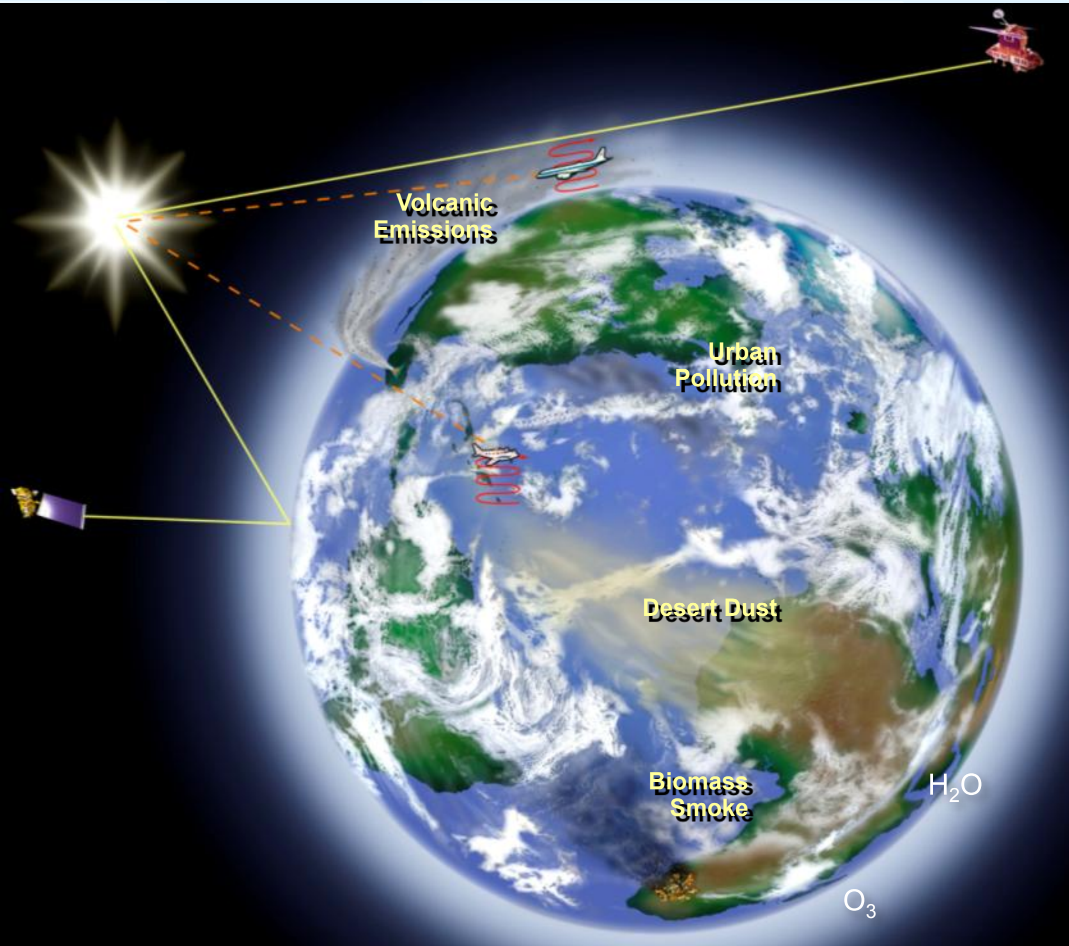
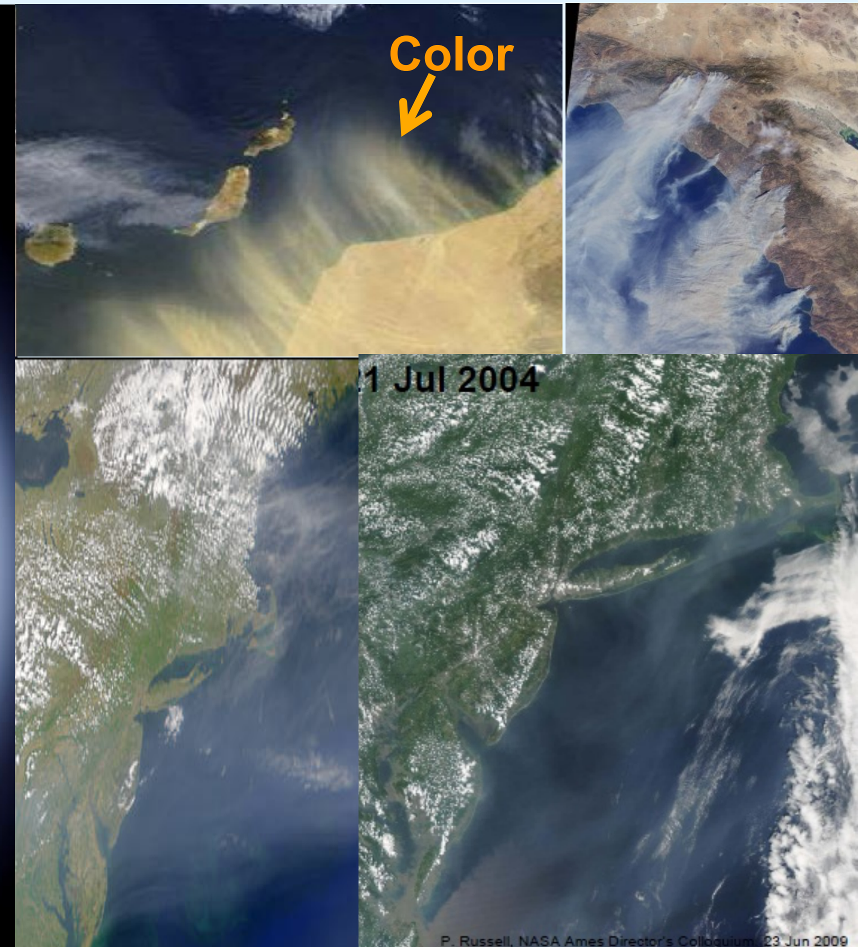




Background on Radiative Flux Divergence & Closure, Absorption Spectra, etc.

Downwelling Flux: F↓

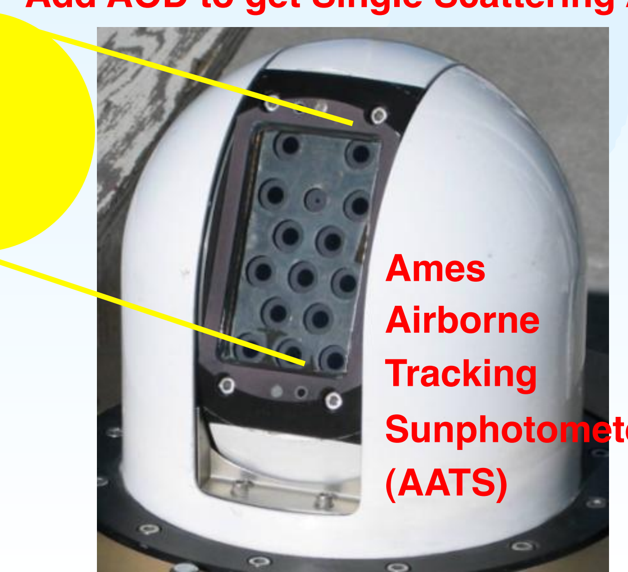
Upwelling Flux: F↑

Net Flux: F↓- F↑

Flux Divergence (absorption):

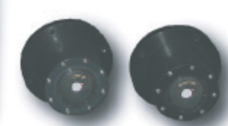
$$(F\downarrow - F\uparrow)_{2000m} - (F\downarrow - F\uparrow)_{43m}$$

Add AOD to get Single Scattering Albedo (SSA)

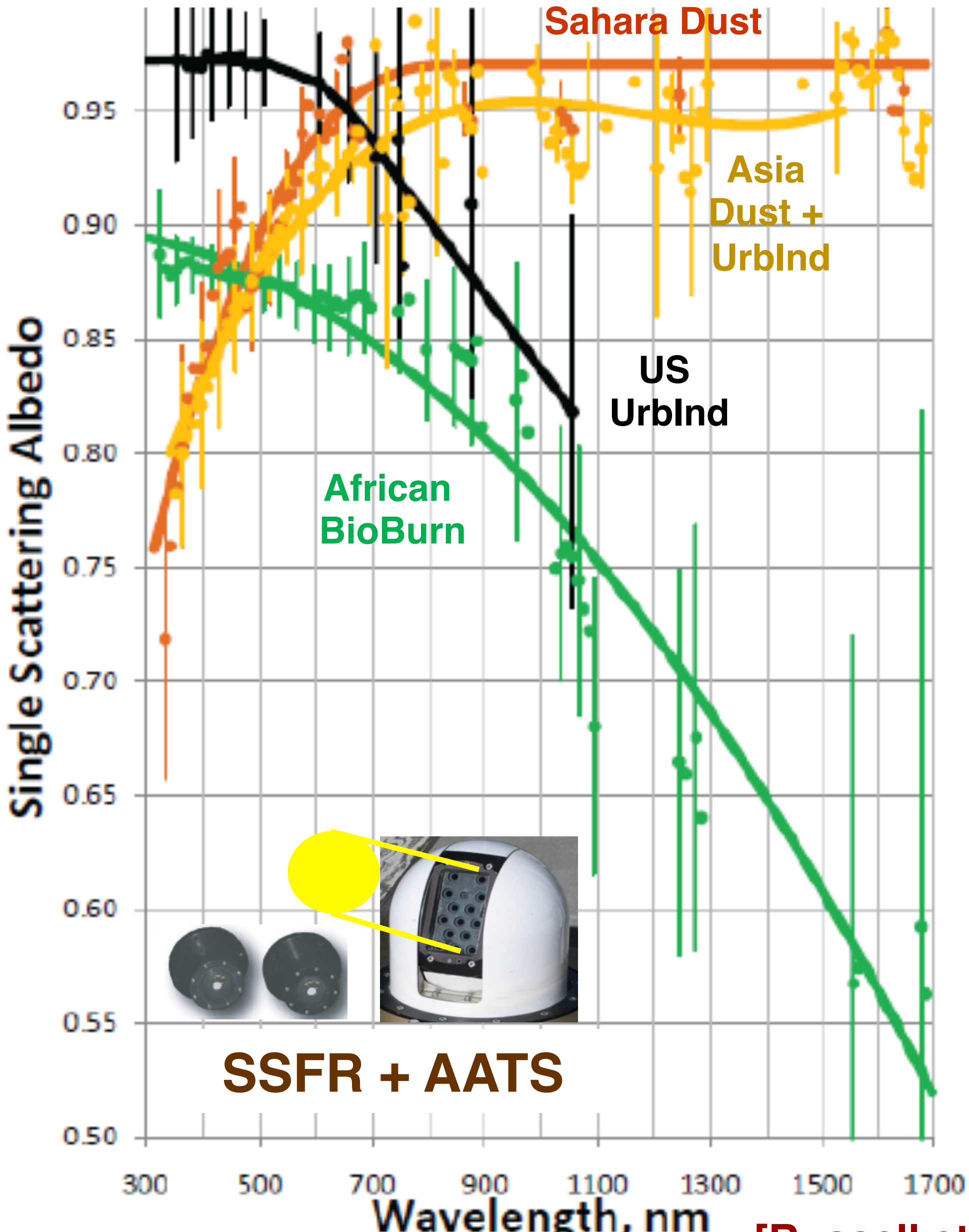


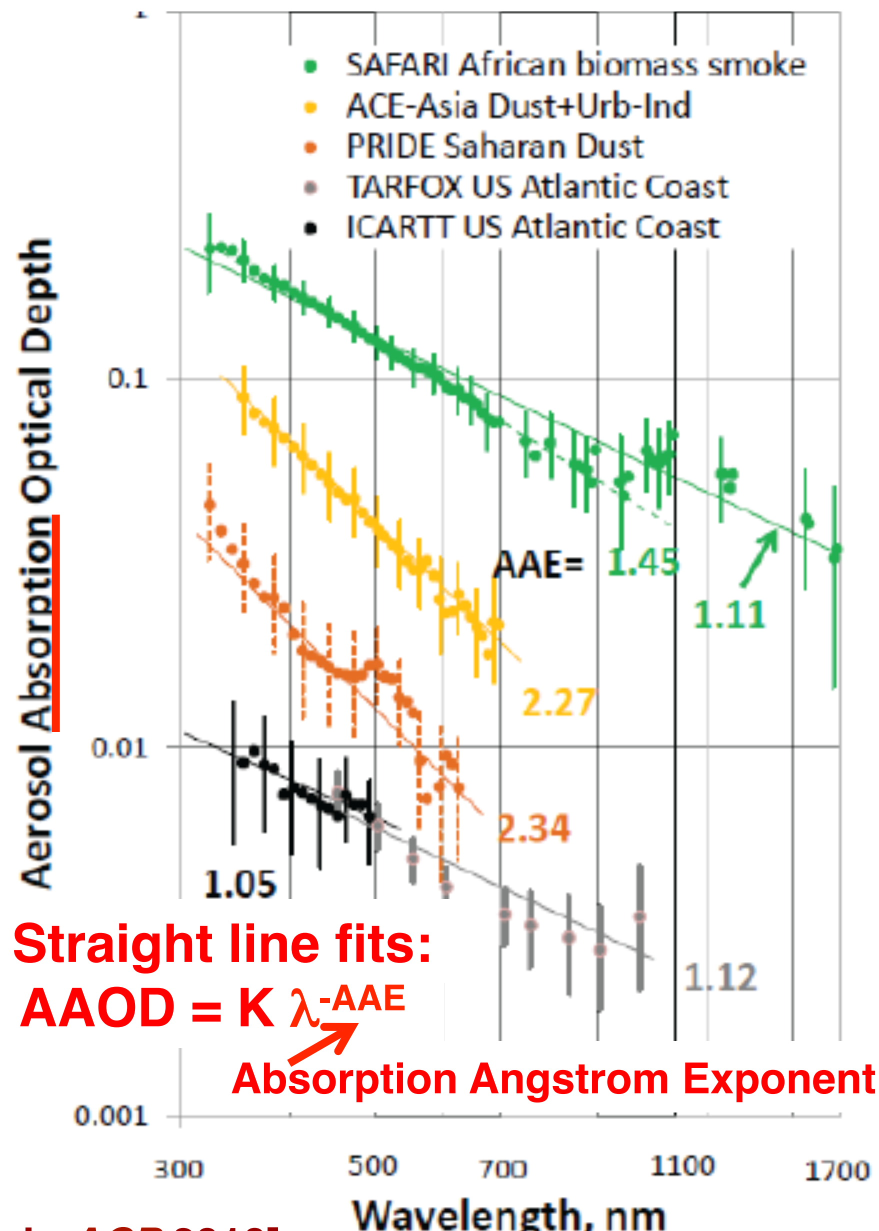
Solar Spectral Flux Radiometer (SSFR)
Pilewskie & Gore, NASA Ames

F↓, F↑

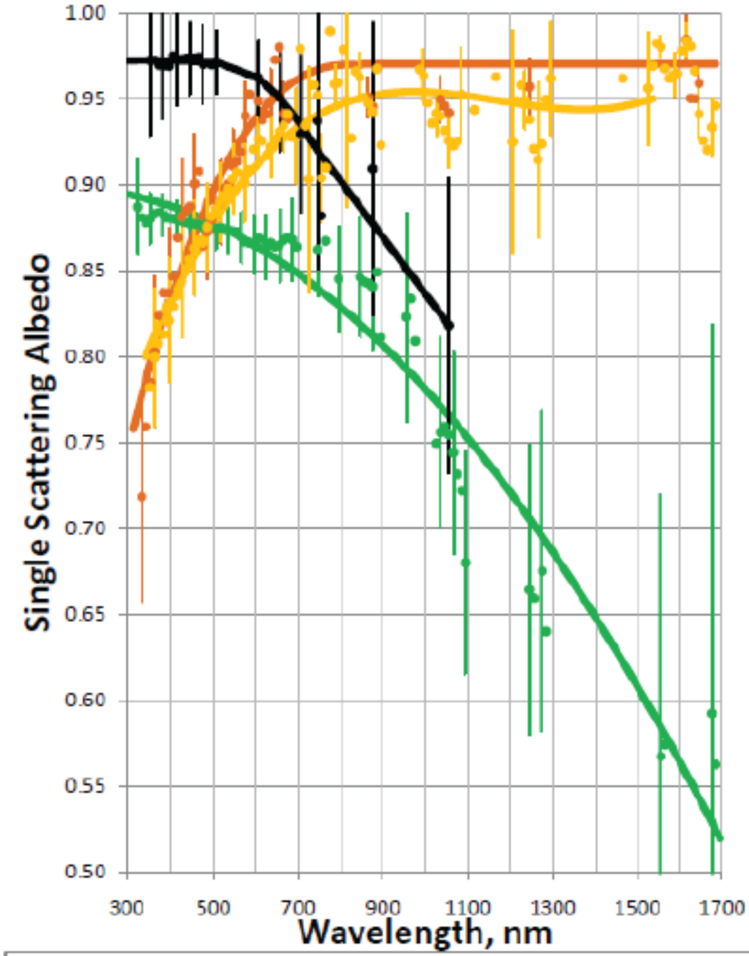


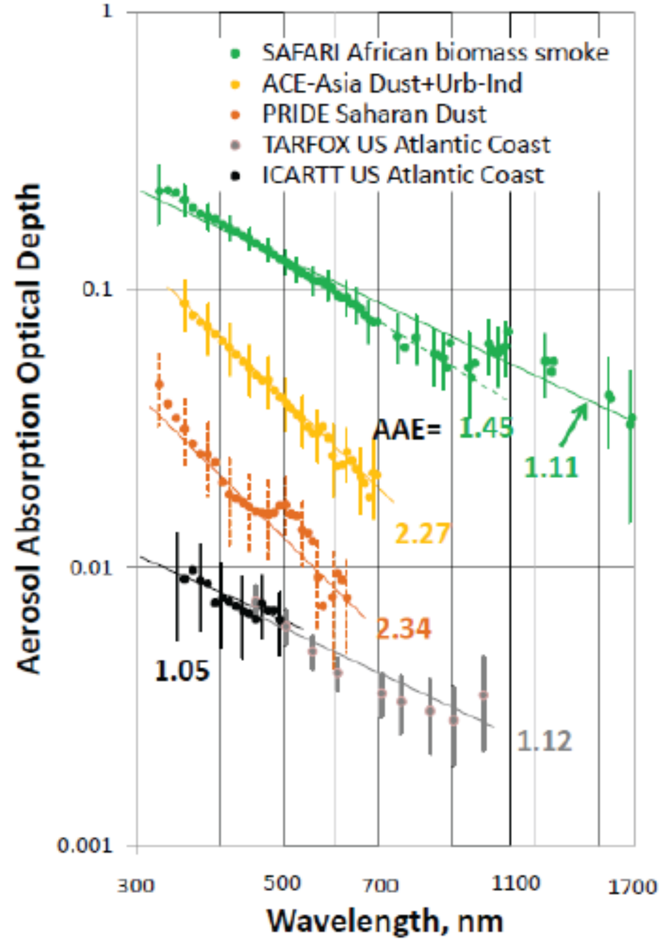
A wide variety of SSA spectra correspond to straight-line (power law) AAOD spectra. AAOD = AOD x (1-SSA)

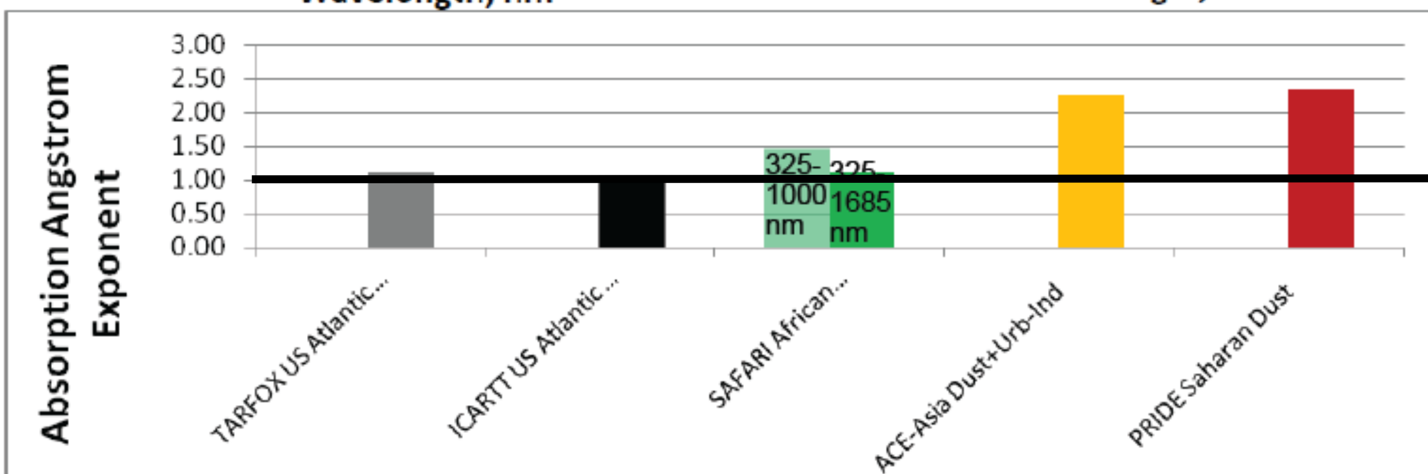




[Russell et al., *ACP* 2010]



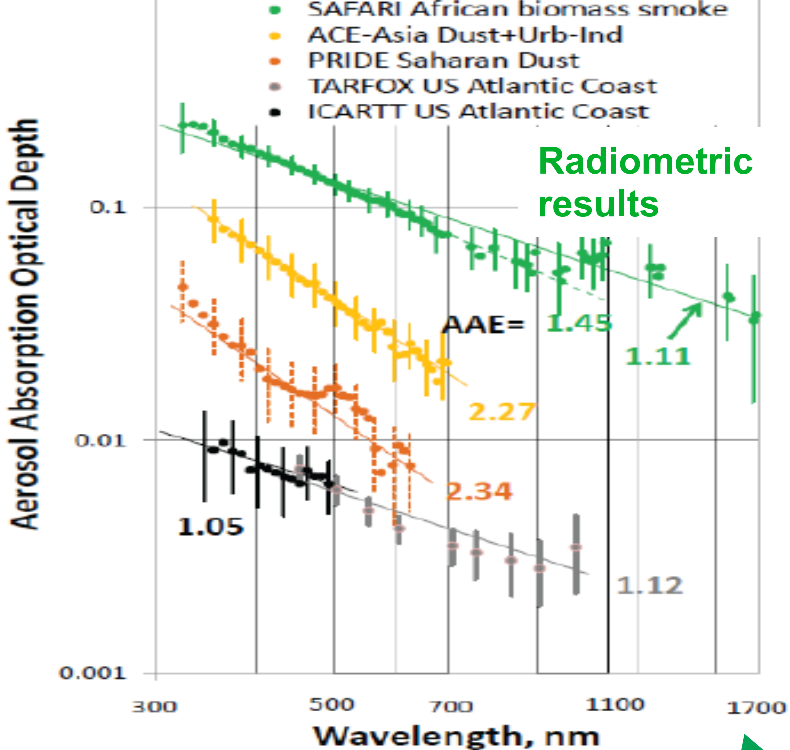


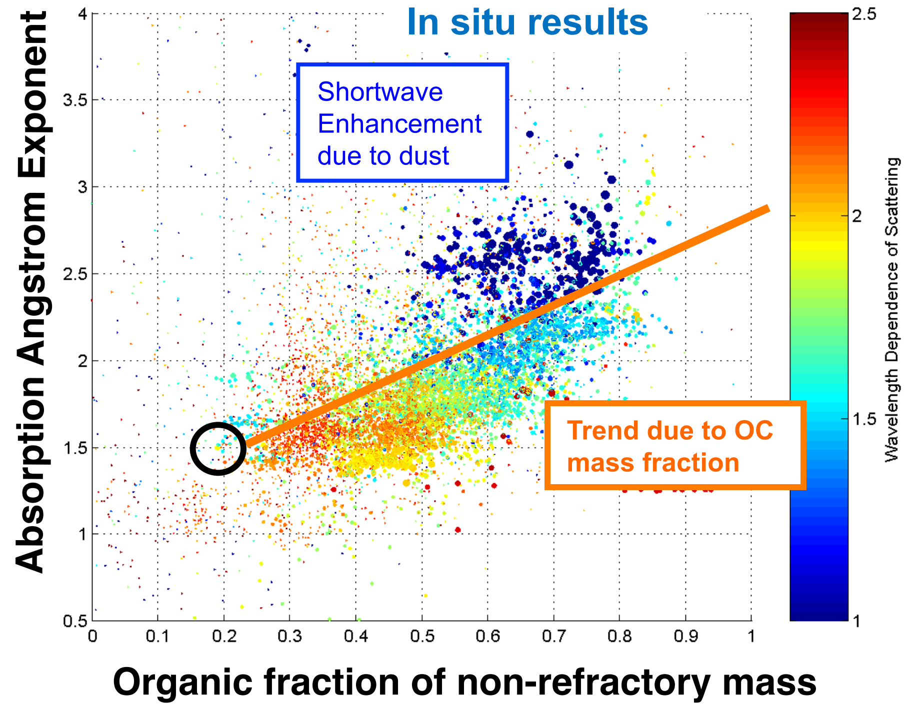


Suggests that knowledge of AAE can help identify aerosol type

Black Carbon: AAE = 1

[Russell et al., *ACP* 2010]



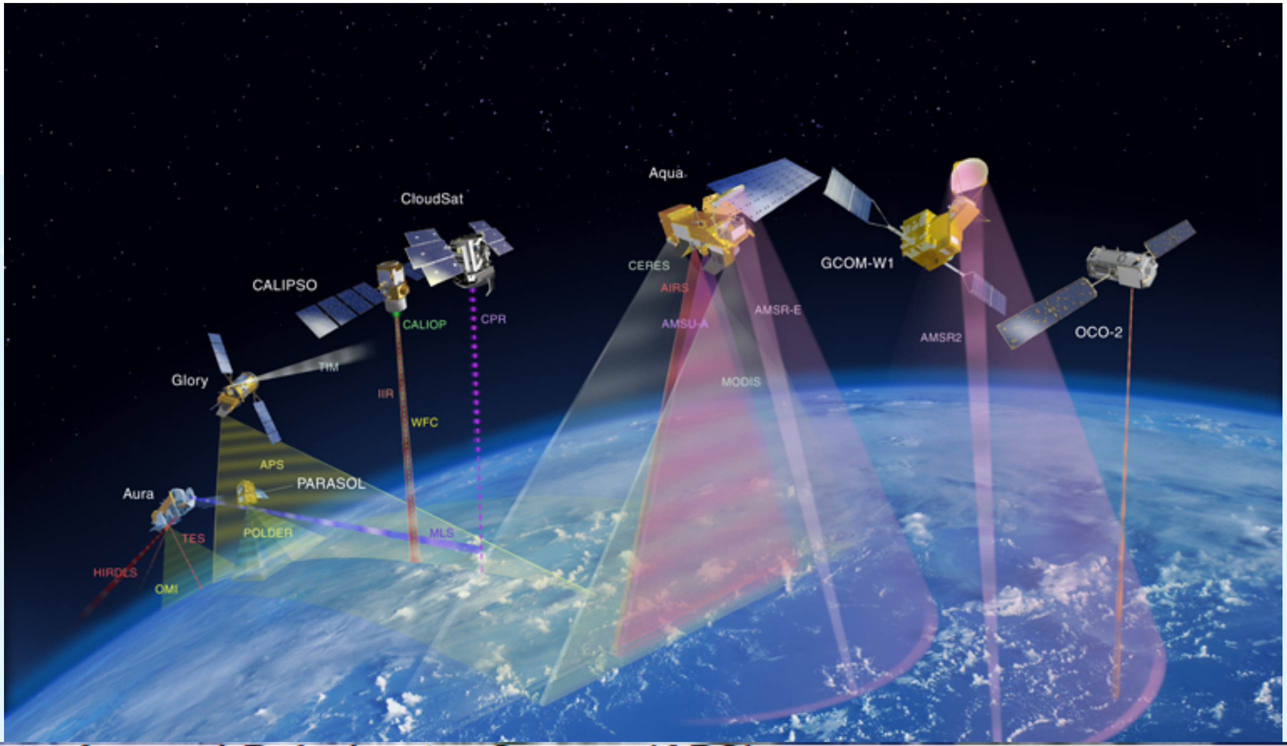


[Russell et al., *ACP* 2010]

These radiometric results are in harmony with in situ results. Both indicate that <u>knowledge of Absorption Angstrom Exponent</u>, plus size (or Extinction or Scattering Angstrom Exponent) <u>can help to determine particle composition</u>.

- This holds out the promise of determining aerosol composition from <u>space</u>, <u>provided Absorption Angstrom Exponent can be determined from space</u>.

1F. The A-Train with Glory



Glory Aerosol Polarimetry Sensor (APS) level-3 data products for aerosol columns

(adapted from Mishchenko et al., 2007)

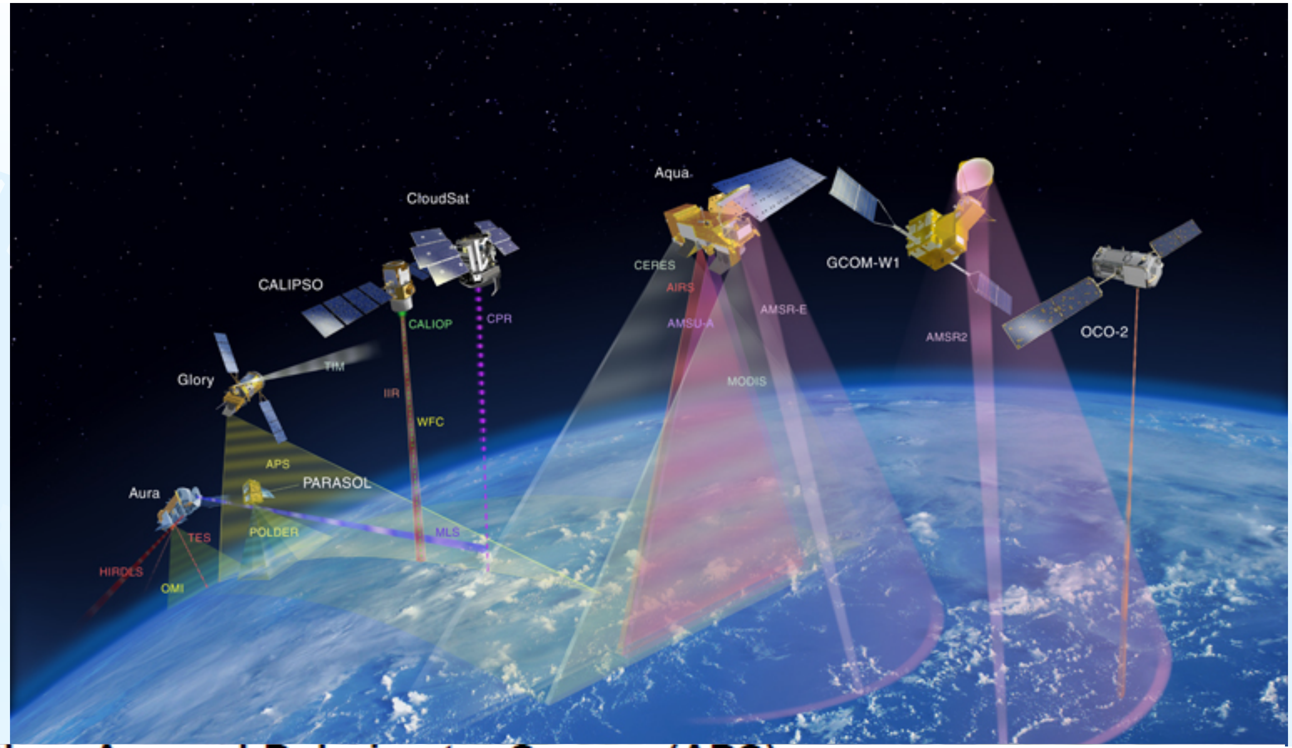
Data product (fine and coarse modes)	Range	Uncertainty
Spectral* aerosol optical depth	0-5	0.02 over ocean 0.04 over land
Aerosol effective radius	0.05-5 µm	10%
Effective variance of aerosol size distribution	0-3	40%
Aerosol spectral* real refractive index	1.3-1.7	0.02
Aerosol spectral* single-scattering albedo	0-1	0.03
Aerosol morphology	Spherical aerosols, irregular dust particles, soot clusters	N/A

*At least in three spectral channels; relative accuracy better where AOD is larger (typically 410-865 nm).

Absorption

AAOD = AOD*(1-SSA)

The A-Train with Glory



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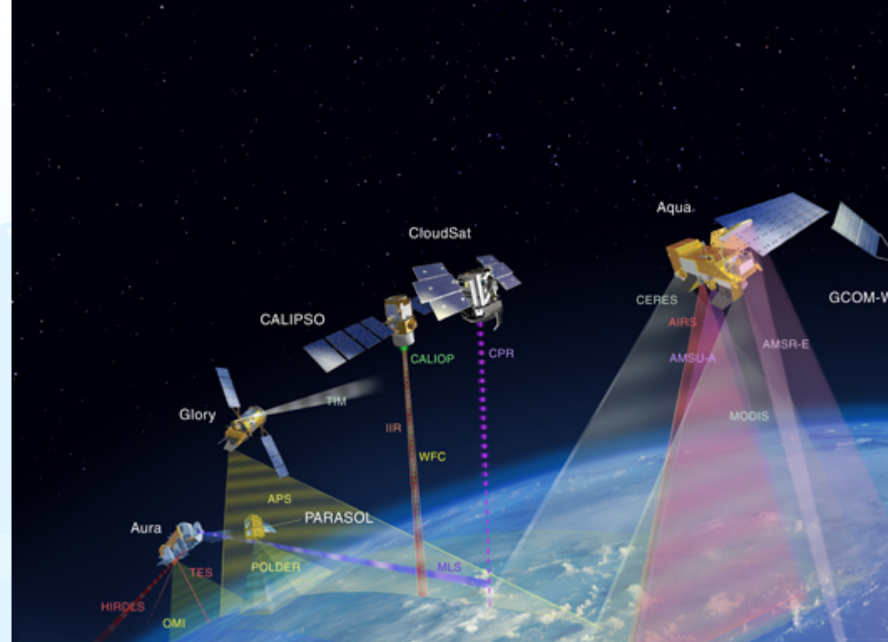
Lost on launch, Mar 2011

- **Possible refly.**
- **Airborne version: RSP**
- **Others: POLDER, PACE, ACE, …**

Question: Do the preceding results, which describe a layer or a point, apply also to the full vertical column viewed by a spacecraft?

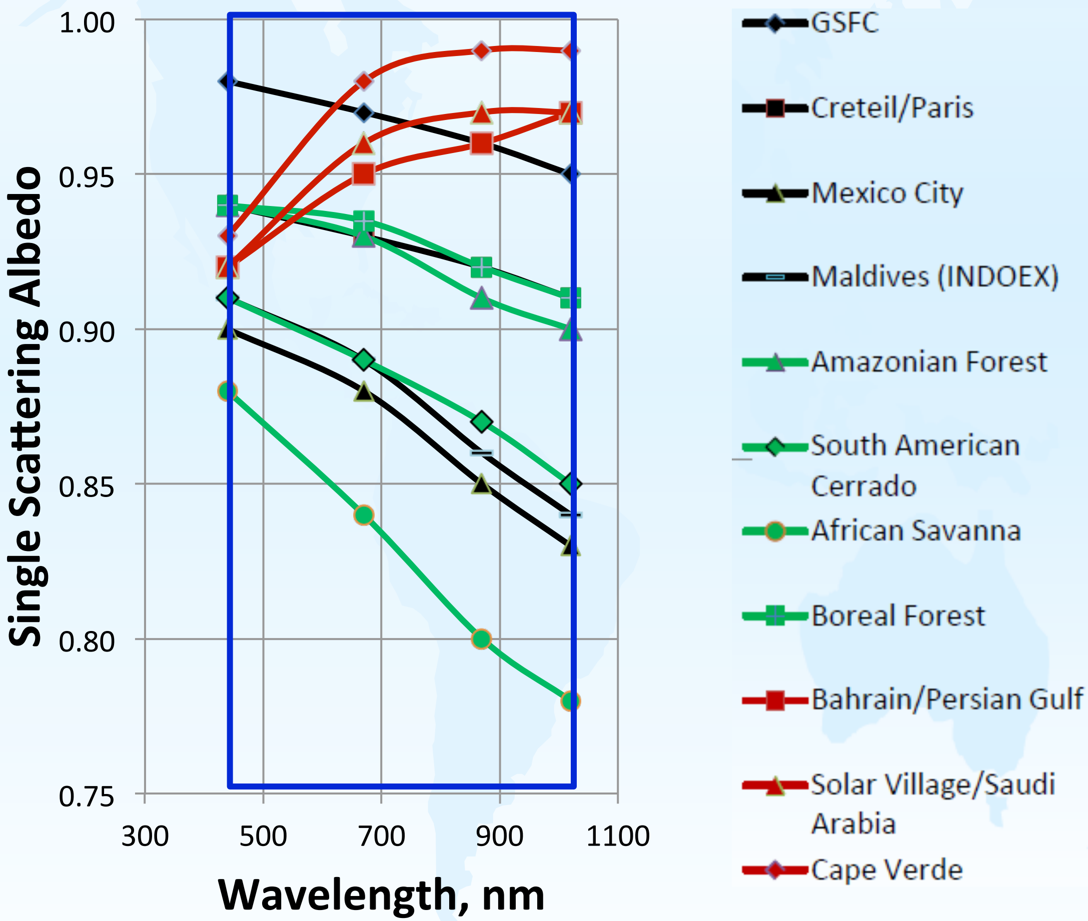


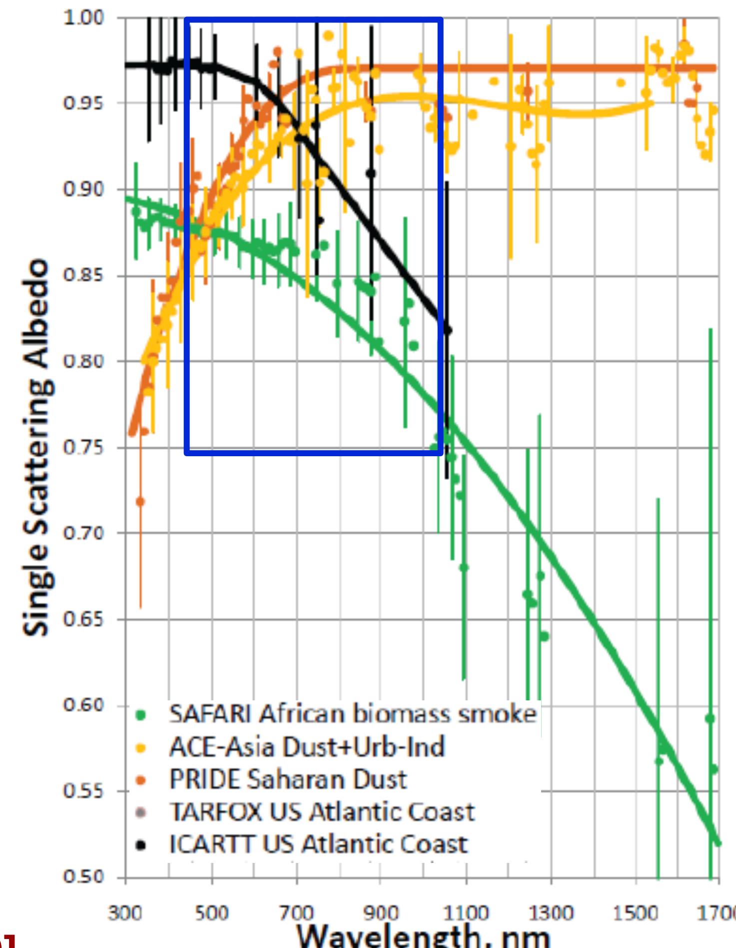
To answer, we looked at many full vertical columns as viewed by AERONET sun-sky photometers (Dubovik et al., 2002)

Question: Do the preceding results, which describe a layer or a point, apply also to the full vertical column viewed by a spacecraft?

AERONET
(Dubovik et al., 2002),
Full Columns

SSFR+AATS
(Bergstrom et al., 2007),
Layers





[Russell et al., *ACP* 2010]

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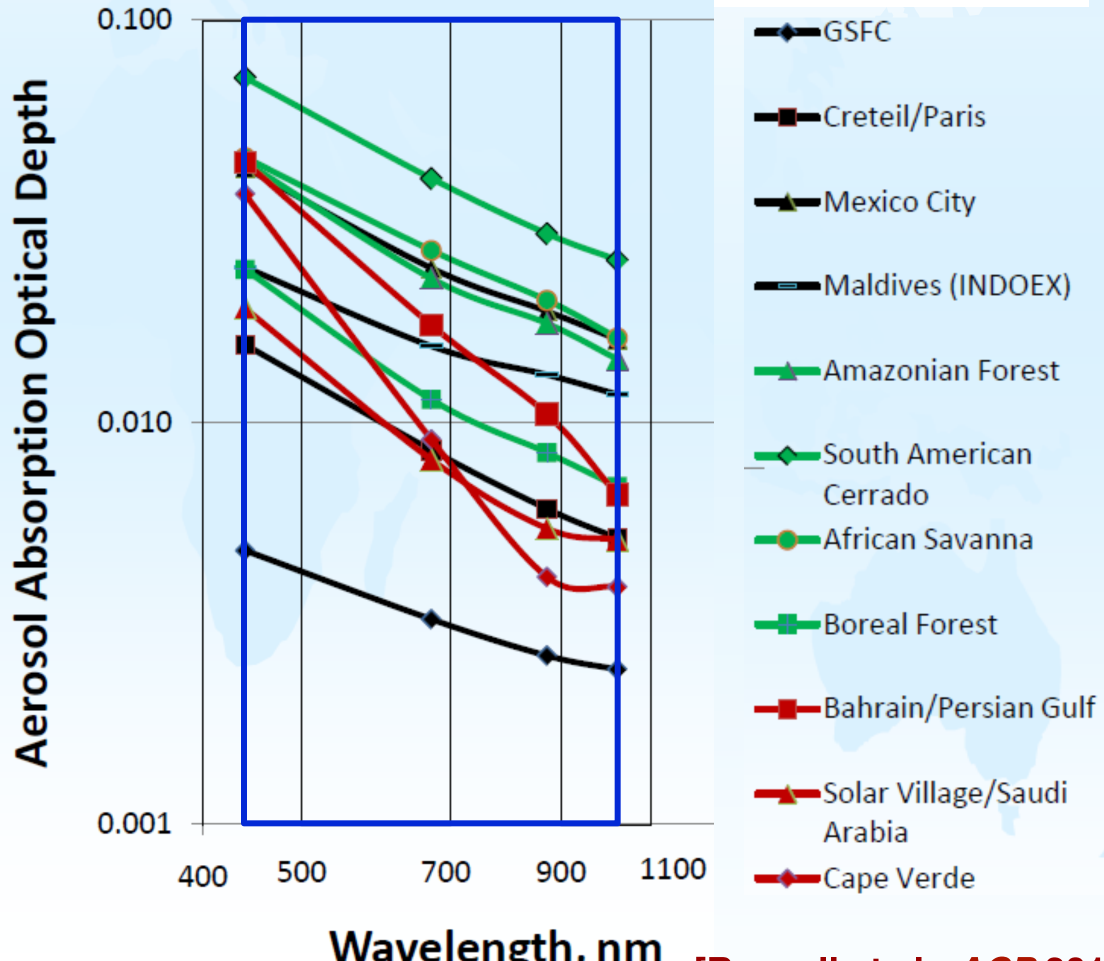
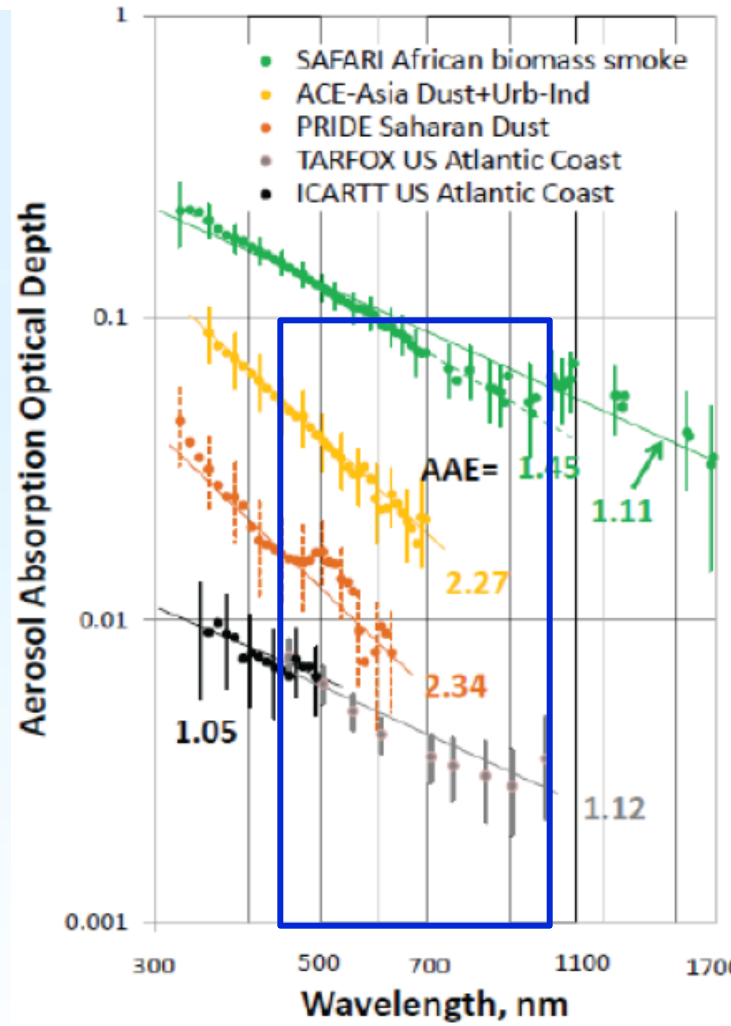
AERONET
Dubovik et al., 2002),
Full Columns

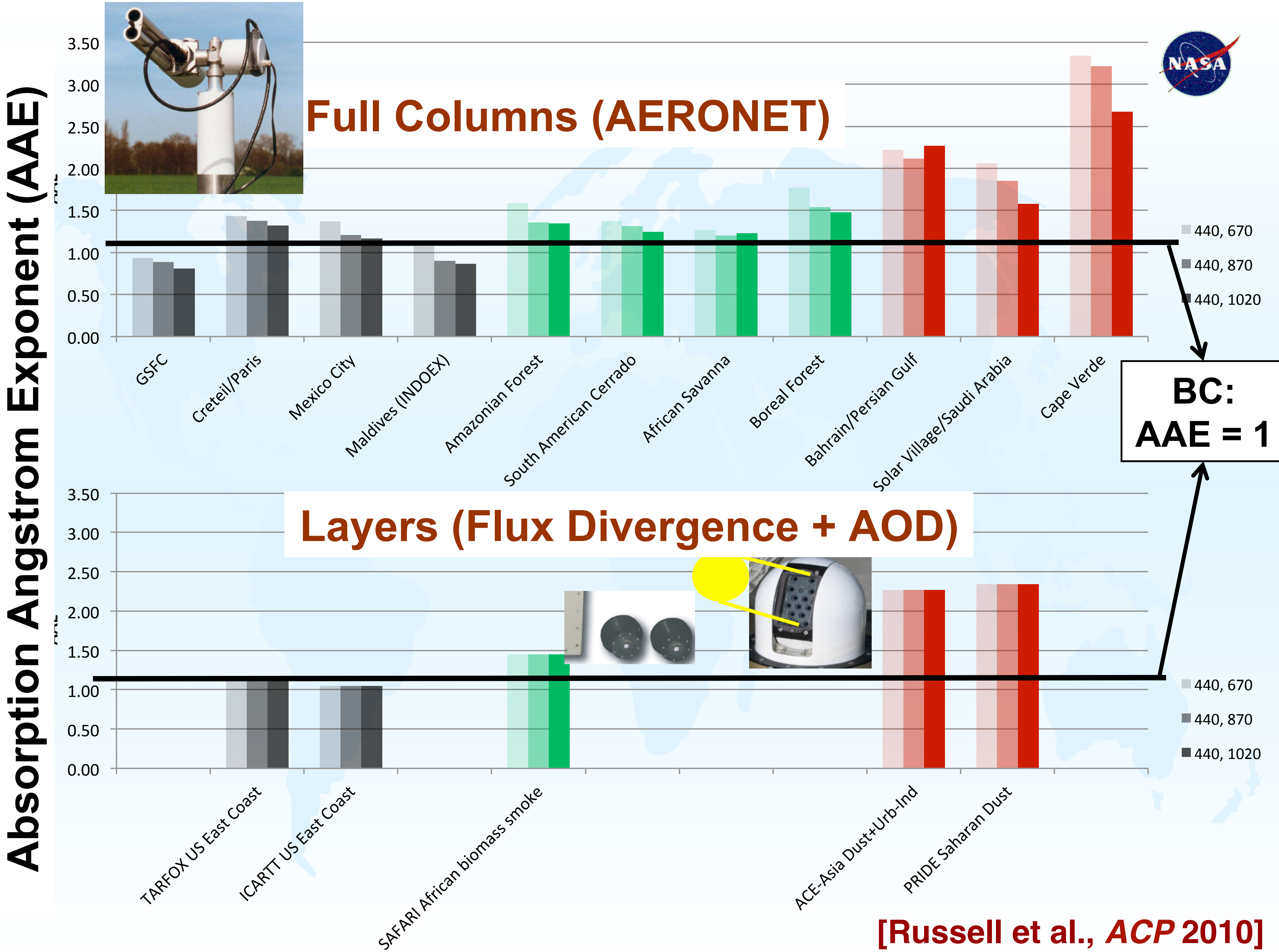


[Russell et al., *ACP* 2010]

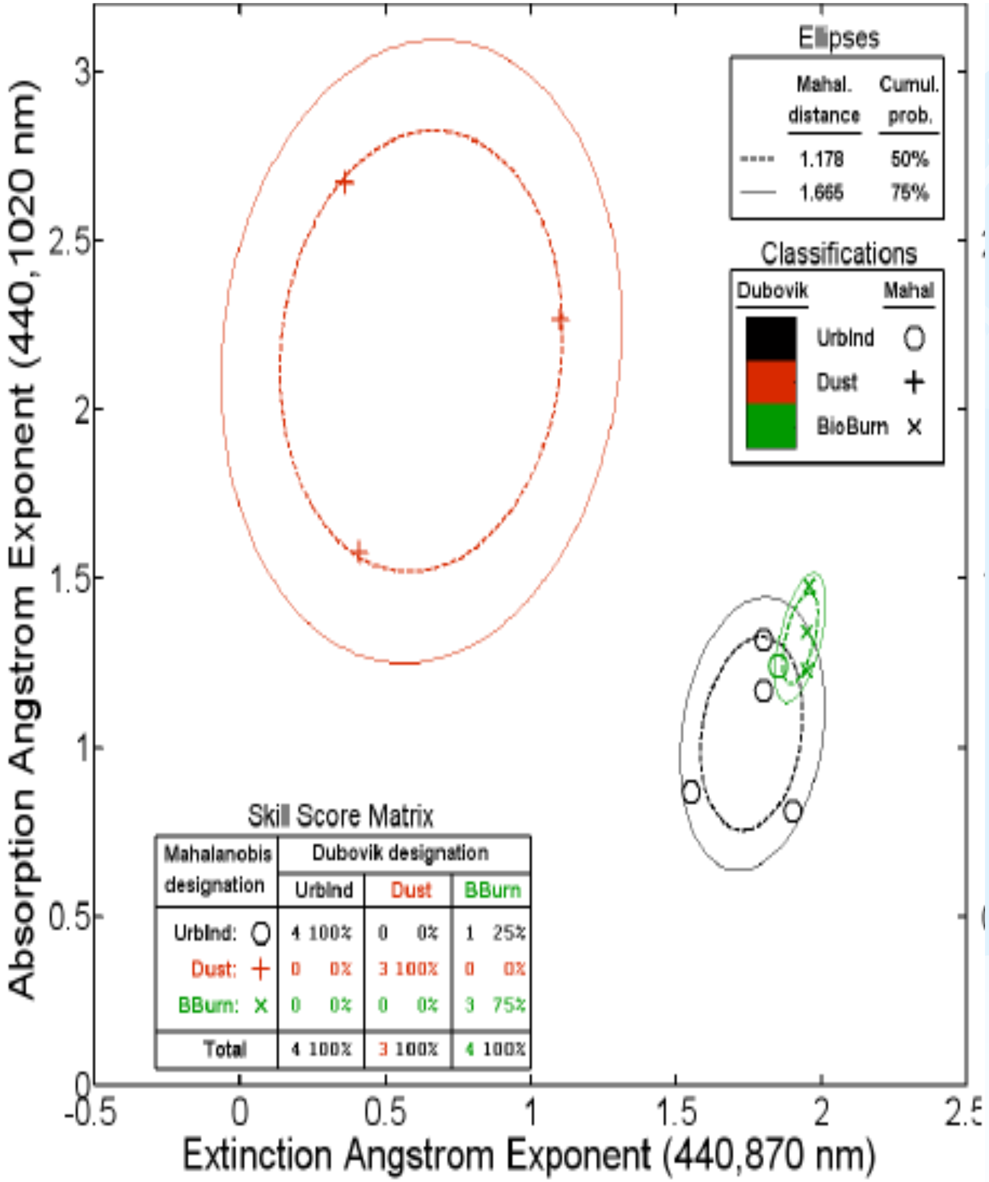
SSFR+AATS

(Bergstrom et al., 2007),
Layers




Absorption Angstrom Exponent (AAE)
Full Columns (AERONET)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
GSFC
Creteil/Paris
Mexico City
Maldives (INDOEX)
Amazonian Forest
South American Cerrado
African Savanna
Boreal Forest
Bahrain/Persian Gulf
Solar Village/Saudi Arabia
Cape Verde
440, 670
440, 870
440, 1020
BC:
AAE = 1
Layers (Flux Divergence + AOD)
TARFOX US East Coast
ICARTT US East Coast
SAFARI African biomass smoke
ACE-Asia Dust+Urb-Ind
PRIDE Saharan Dust
[Russell et al., ACP 2010]

Question: Can we get more separation between types by adding a second parameter and making a 2-D plot?



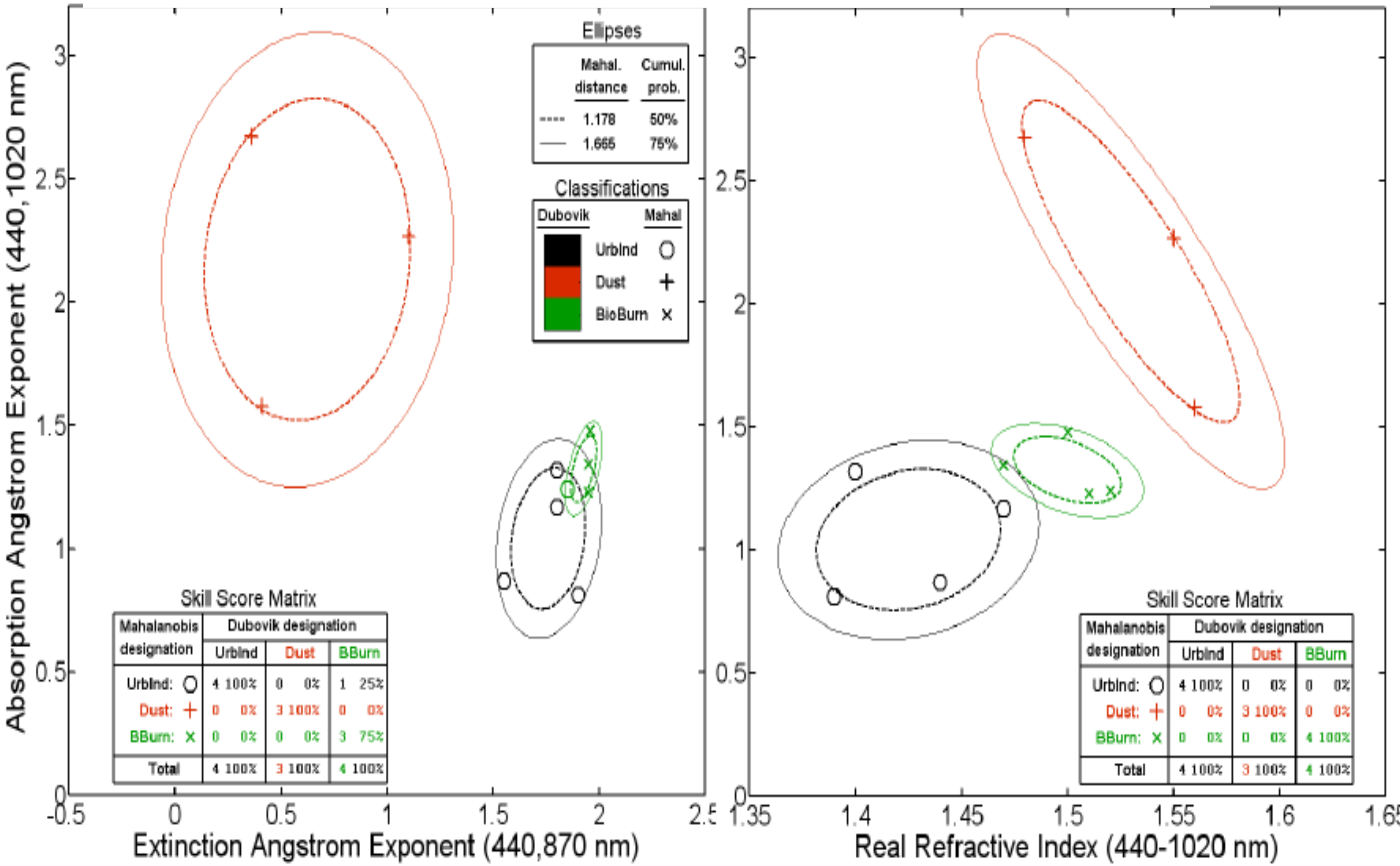
Answers:

1. Adding EAE(440, 870 nm) greatly increases separation between Dust and the others.

2. But it increases separation between the UrbInd & BioBurn clusters only slightly: There is still overlap (ambiguity).

Question: Can we do better by adding more parameters (dimensions)?

2D. Different 2-D plots of Dubovik (2002) AERONET full-column results, showing different separations of clusters

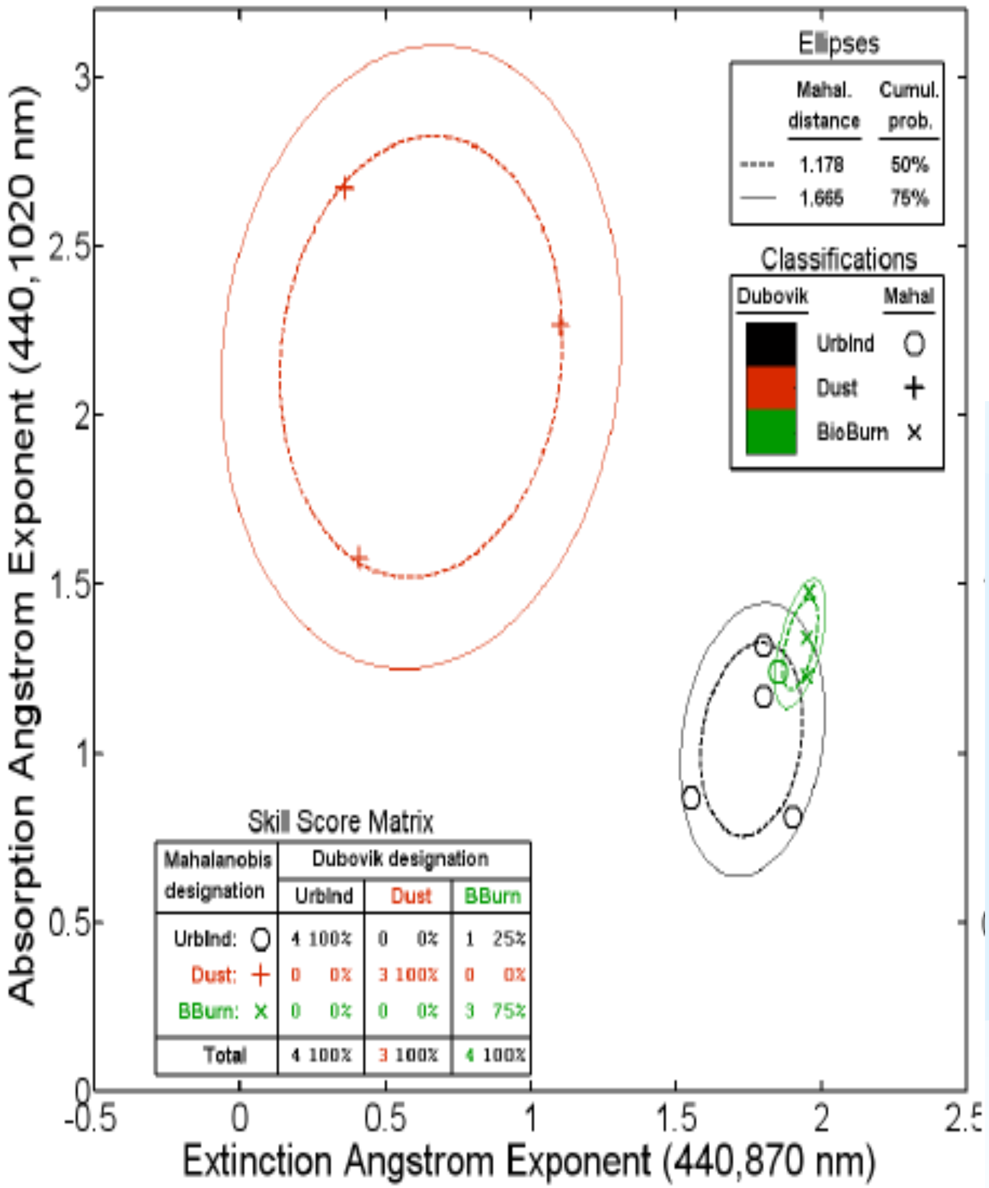


Questions:

1. Can combining all 3 dimensions (AAE, EAE, RRI) produce even better separation between types?
2. Can adding still more dimensions (e.g., SSA, imaginary refractive index [IRI], …, additional λ) improve separation further?
3. Given an individual aerosol observation (point in multidimensional space), is there an objective, quantitative way to measure the multidimensional distance from that point to a cluster (or type)?
   - And hence decide objectively which cluster (aerosol type) the observation best matches?
4. Do the preceding results for the Dubovik et al. (2002) data (AERONET Version 1, site/season means) carry over to individual AERONET retrievals using the Version 2 algorithm?

To answer the above, we followed the example provided by the HSRL aerosol classification technique (Burton et al., *AMTD* 2011) and used Specified Clustering and Mahalanobis Classification

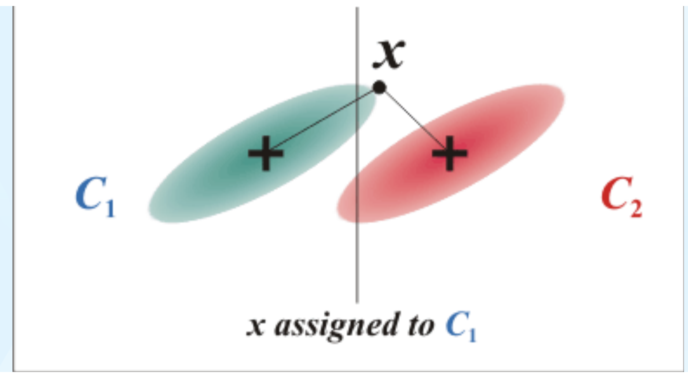
Specified Clustering and Mahalanobis Classification



$$D_M(\mathbf{x}) = \sqrt{(\mathbf{x}-\boldsymbol{\mu})^T S^{-1}(\mathbf{x}-\boldsymbol{\mu})},$$

Mahalanobis Distance, D_M:

The distance between an observation [n-dimensional vector $\mathbf{x}=(x_1,x_2,\ldots x_n)$] and a cluster, taking into account the standard deviations and cross-correlations of the cluster.

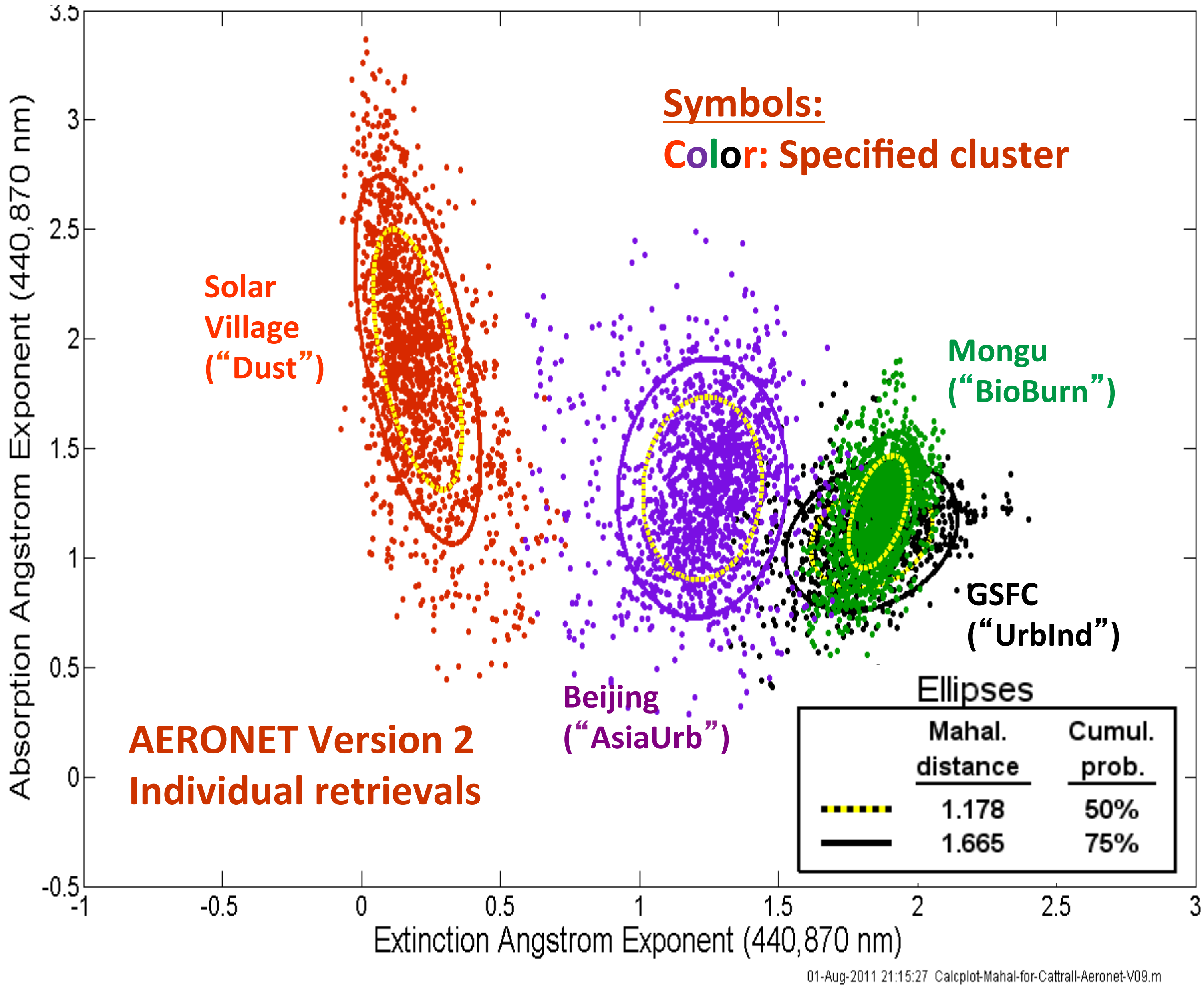


Mahalanobis Classification:

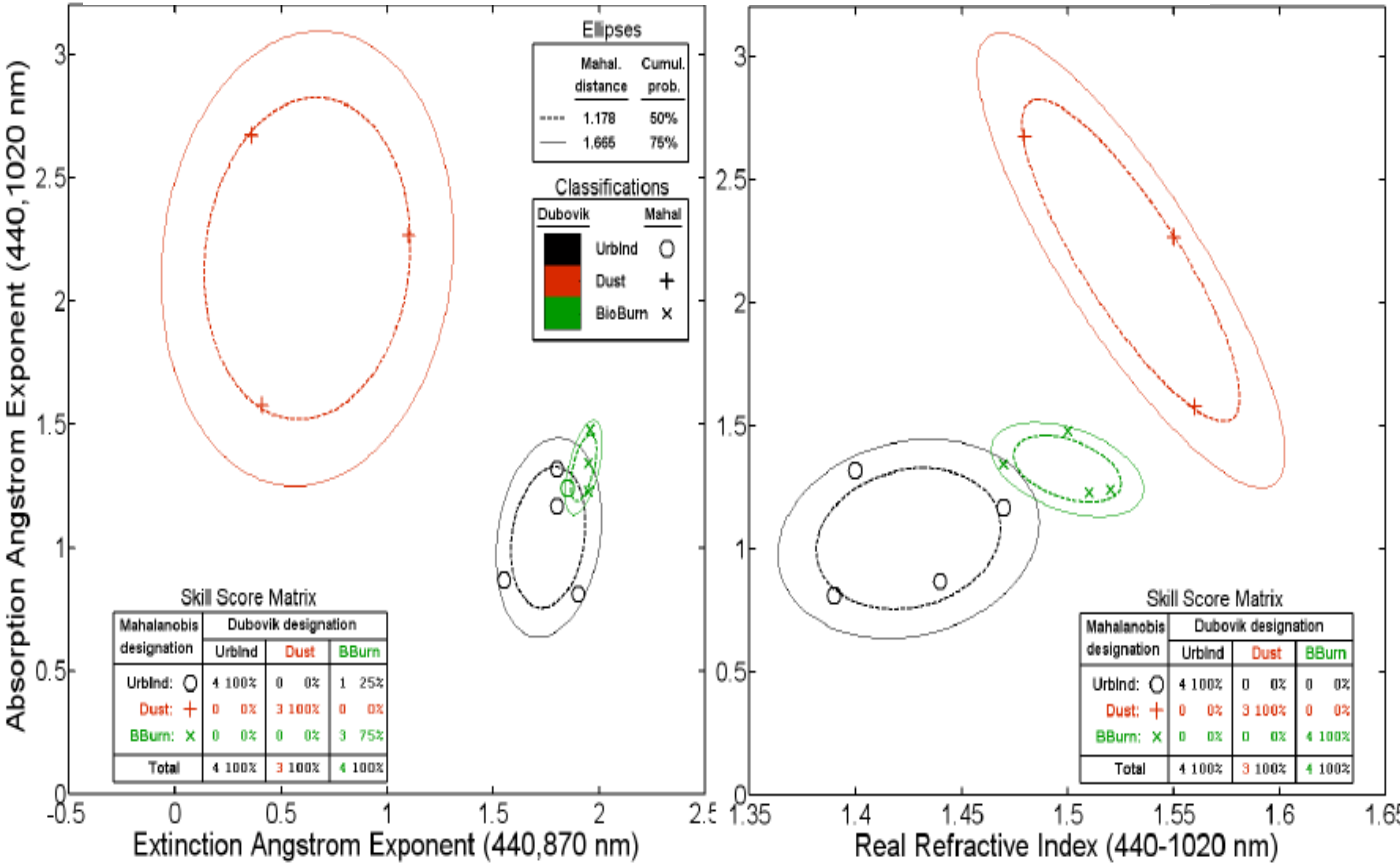
Assigns an observation to the class (cluster) from which it has least D_M. This is also the class for which it has the highest probability density

$$f(D_M) = K \exp\left\{-{D_M}^2/2\right\}.$$

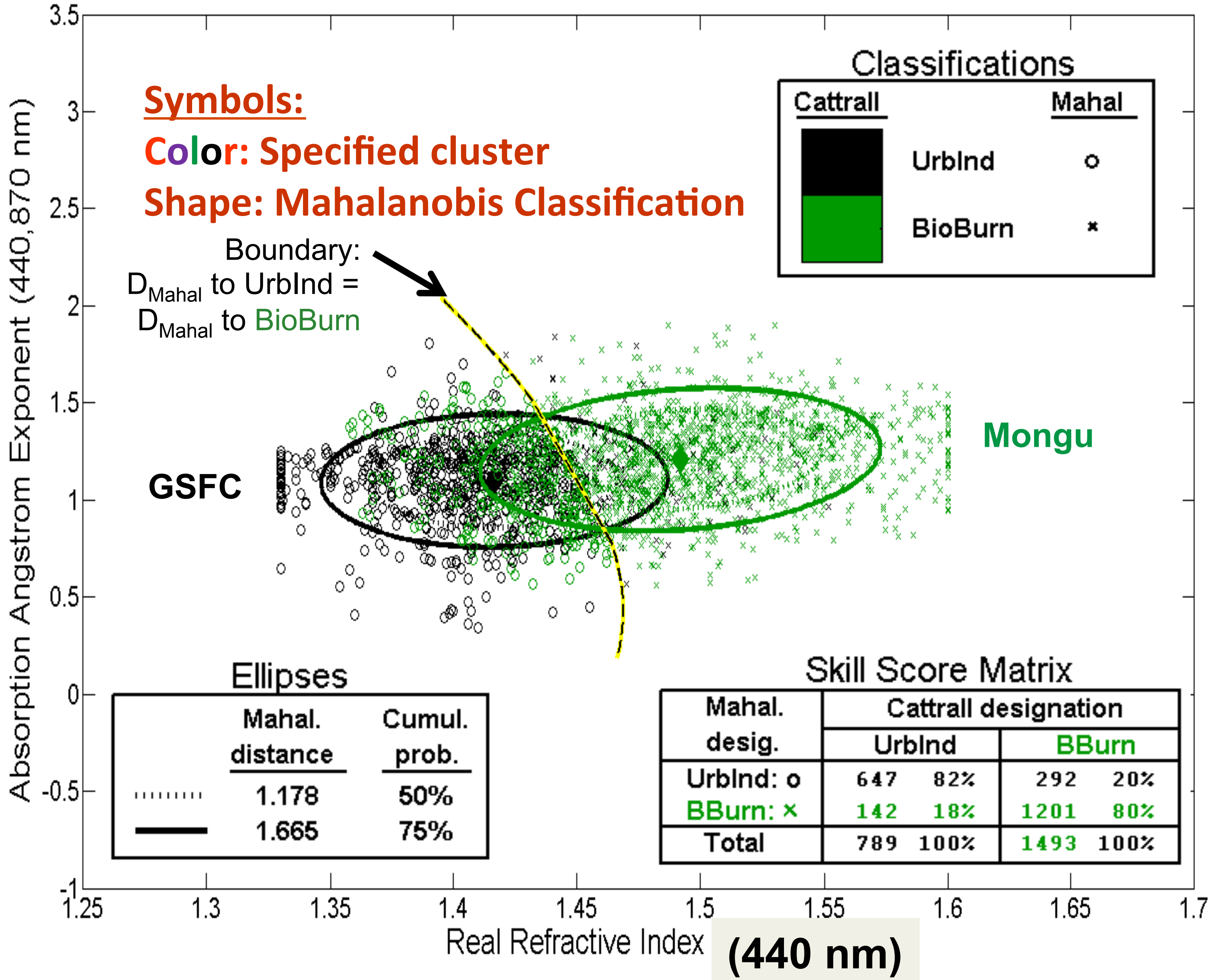
4 AERONET sites/seasons from Cattrall et al. (*JGR*, 2005) selected to illustrate specified clustering and Mahalanobis classification



Different 2-D plots of Dubovik (2002) AERONET full-column results, showing different separations of clusters

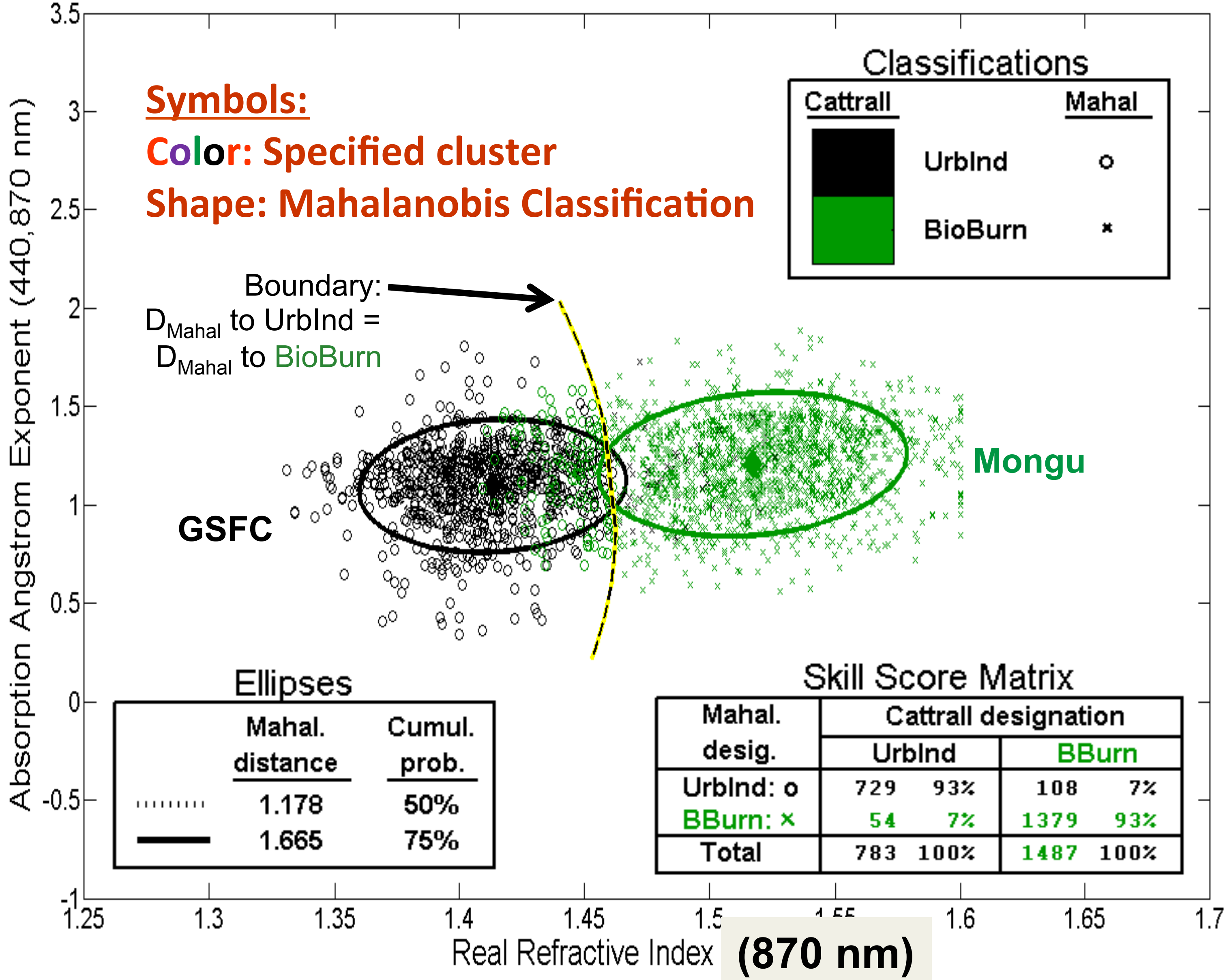


Classification Boundaries and Skill* Scores



*More accurately, "Sameness Scores"

At λ=870 nm, Skill* Scores have increased to 93%



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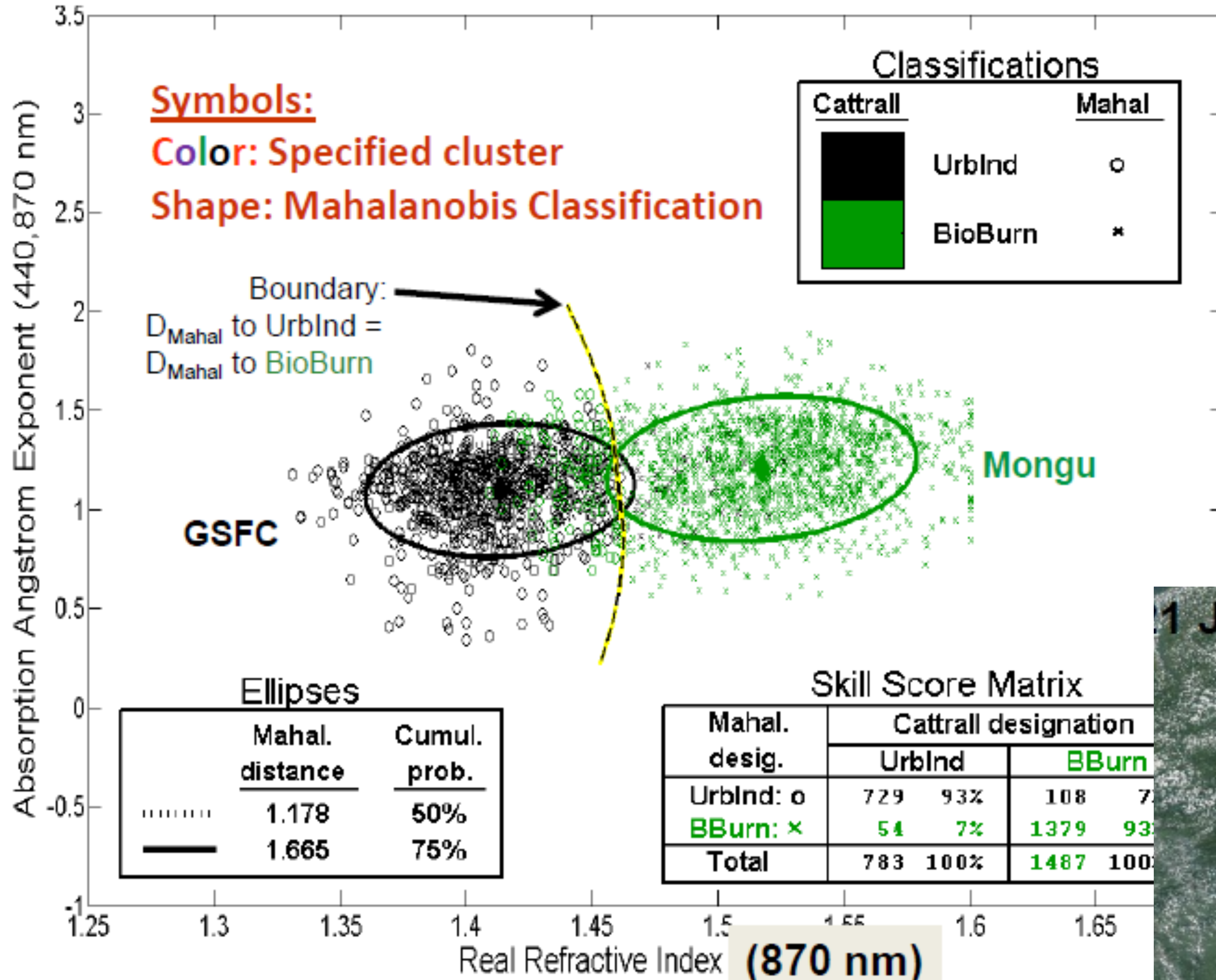
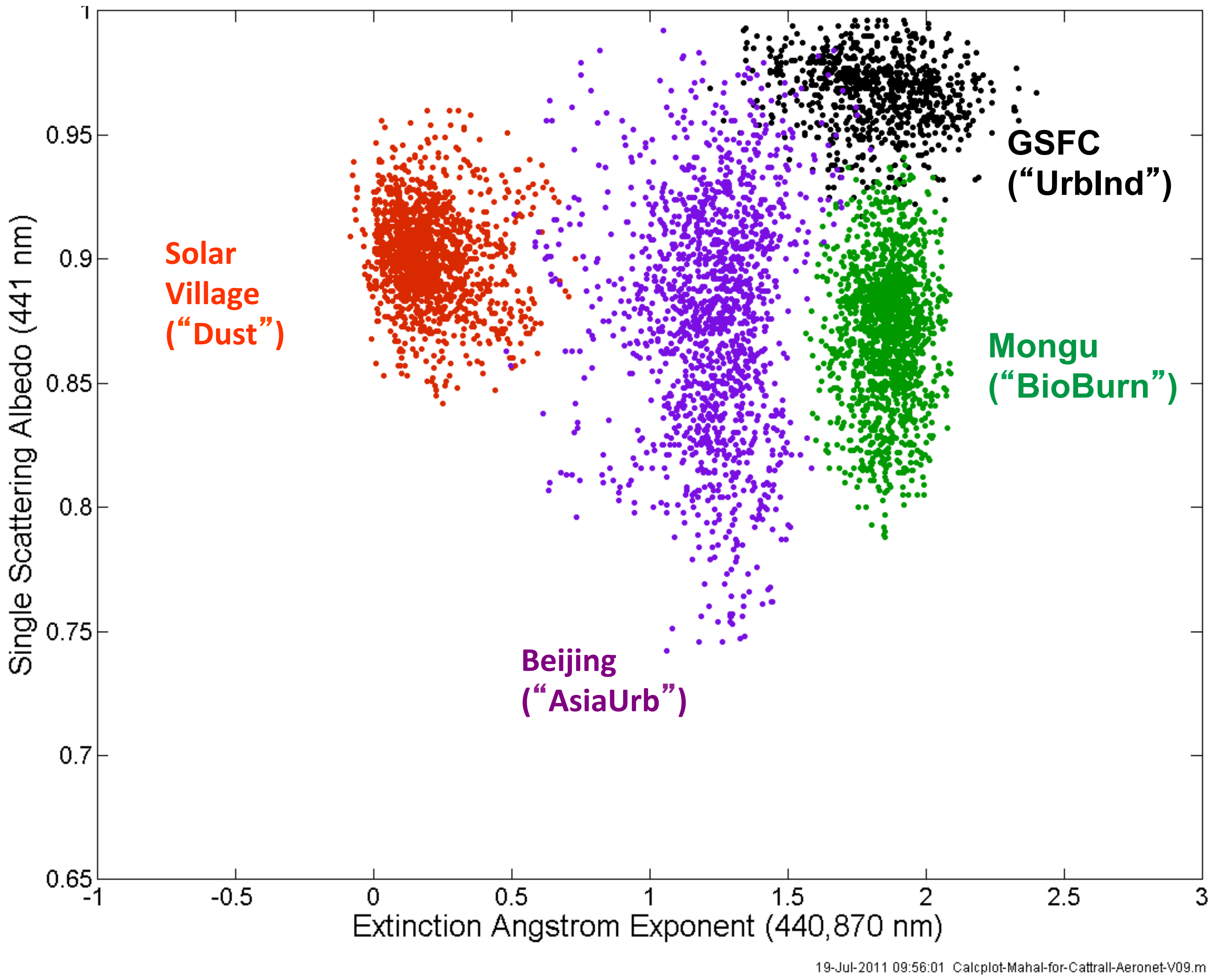


Black "x"s: Mahal. Class. saying a point measured at GSFC is more like BioBurn than a typical day at GSFC

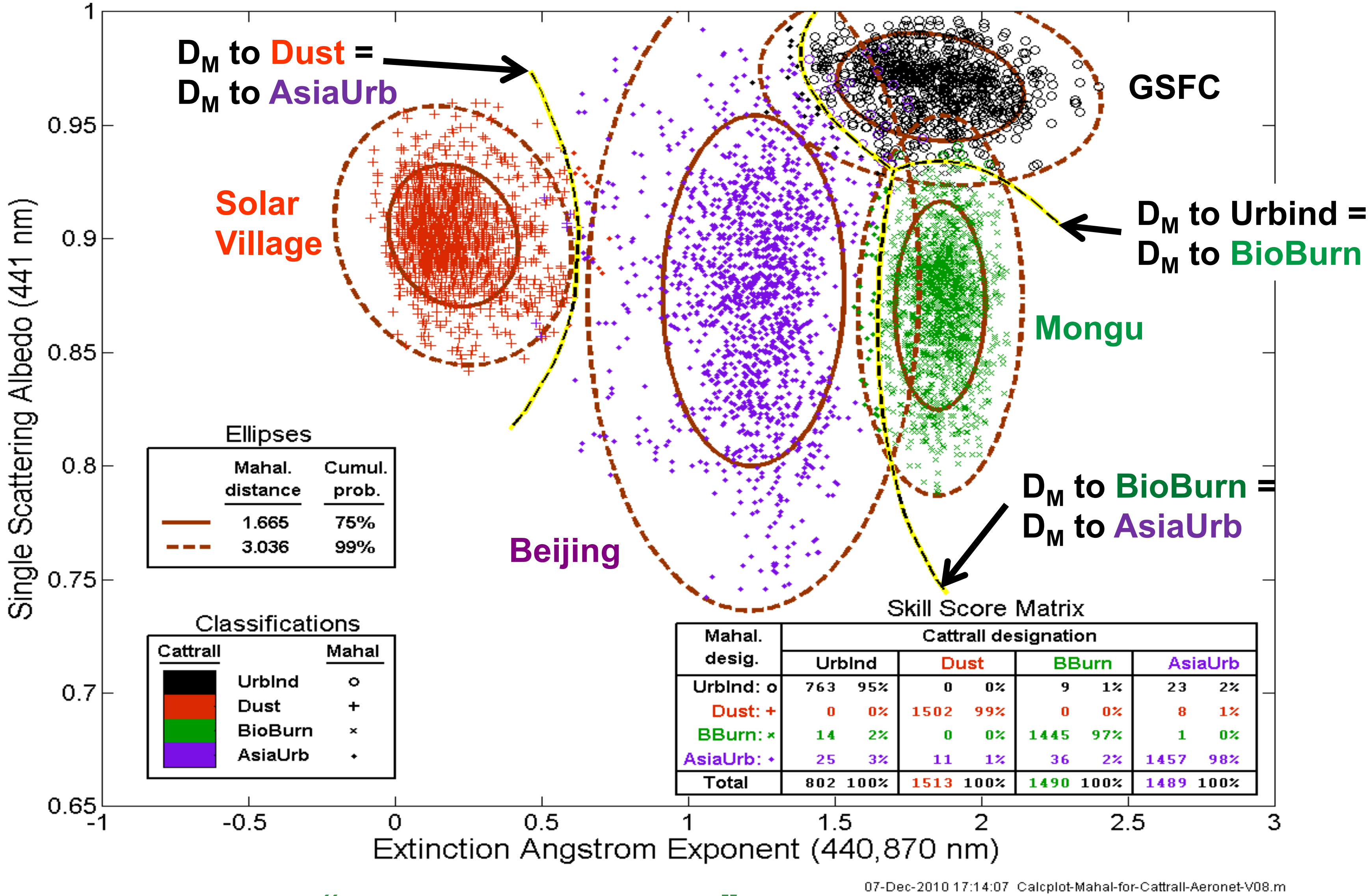
Are these cases of wildfire smoke over GSFC, like the image at right?

Coordinates other than AAE:

SSA(441 nm) vs EAE(440,870 nm)



Skill* scores 95% to 99%

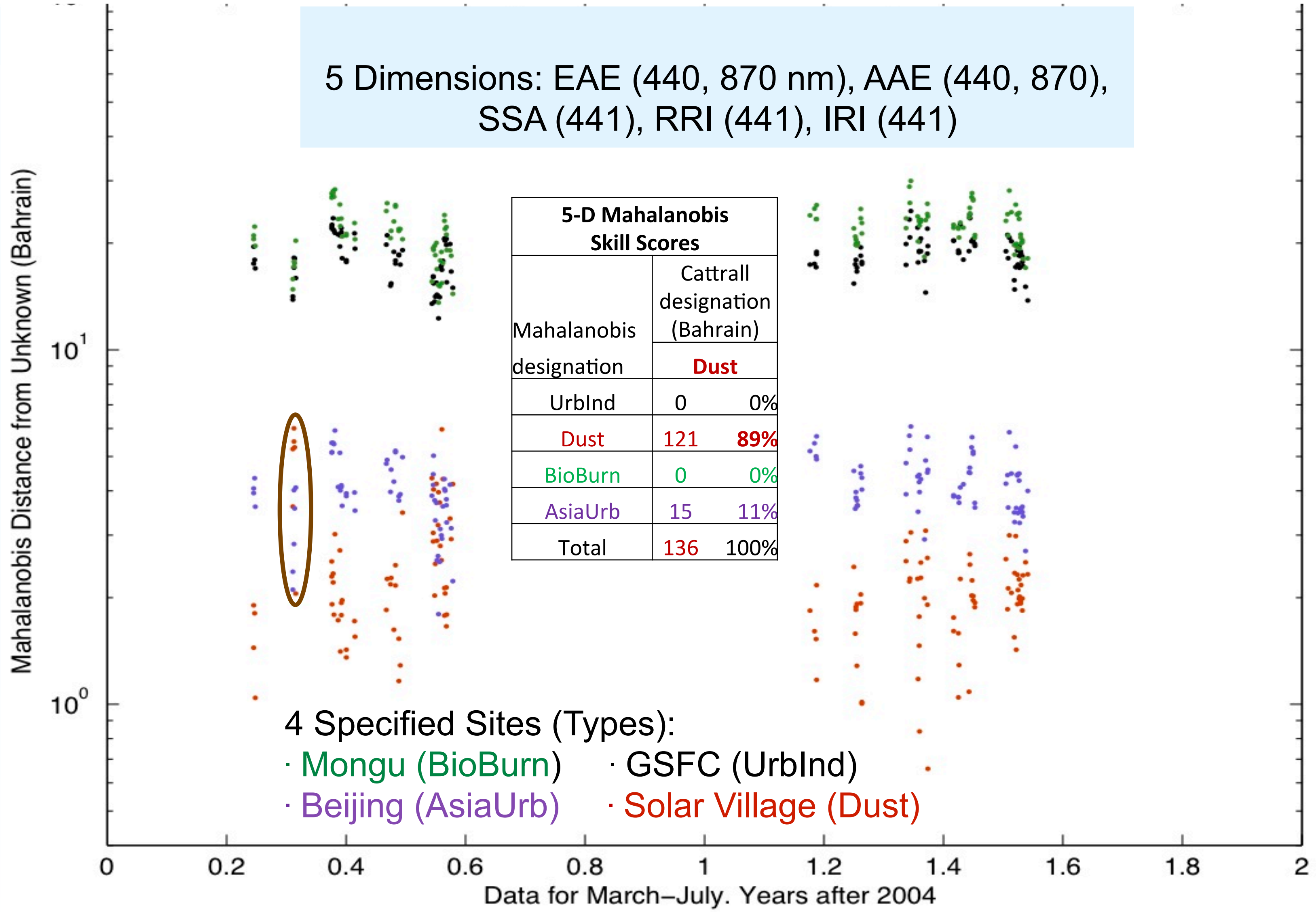


Skill Score Matrix

Mahal. desig.	Cattrall designation							
	UrbInd		Dust		BBurn		AsiaUrb	
UrbInd: o	763	95%	0	0%	9	1%	23	2%
Dust: +	0	0%	1502	99%	0	0%	8	1%
BBurn: ×	14	2%	0	0%	1445	97%	1	0%
AsiaUrb: •	25	3%	11	1%	36	2%	1457	98%
Total	802	100%	1513	100%	1490	100%	1489	100%

*More accurately, “Sameness Scores”

5-D Mahalanobis classification of Bahrain data assigns 89% of Bahrain points to the Solar Village (Dust) cluster and 11% to the Beijing (AsiaUrb) cluster.

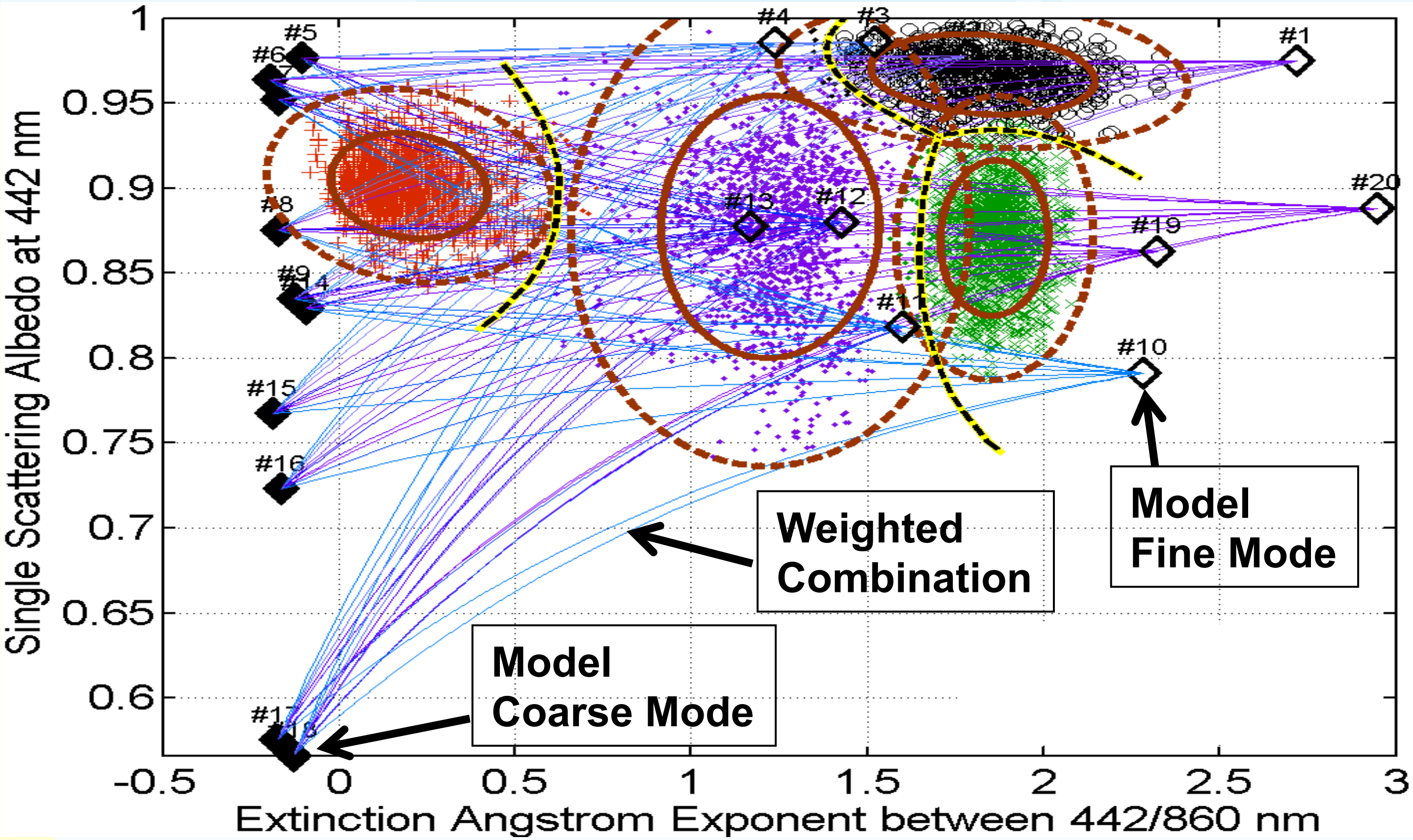


5-D Mahalanobis Skill Scores		
	Cattrall designation (Bahrain)	
Mahalanobis designation	Dust	
UrbInd	0	0%
Dust	121	89%
BioBurn	0	0%
AsiaUrb	15	11%
Total	136	100%

Aerosol models as a path to simulation of Glory APS products

Models used in MODIS retrievals combine a fine mode and a coarse mode (e.g., Remer et al., 2005). Diamonds below show SSA-EAE coordinates of MODIS over-ocean set (modes 1-9), augmented with increased absorption (modes 10-18) and adjusted size (modes 19, 20). Together the lines cover the SSA,EAE space of the AERONET clusters from the 4 Cattrall sites.

To investigate effects of the Glory APS retrieval uncertainties (next slide), we started with an augmented MODIS bimodal model (point on a line) approximating the mean of each cluster. We then added random uncertainties with standard deviations from next slide.



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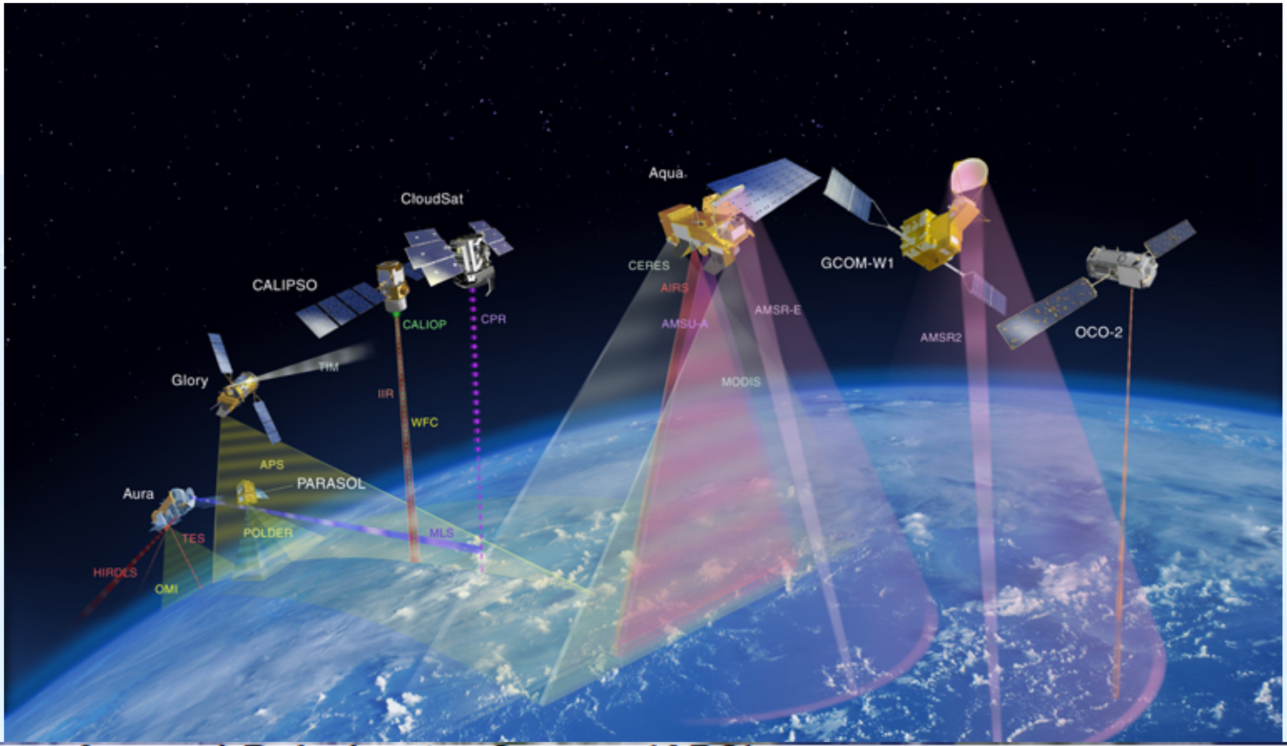

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Data product (fine and coarse modes)	Range	Uncertainty
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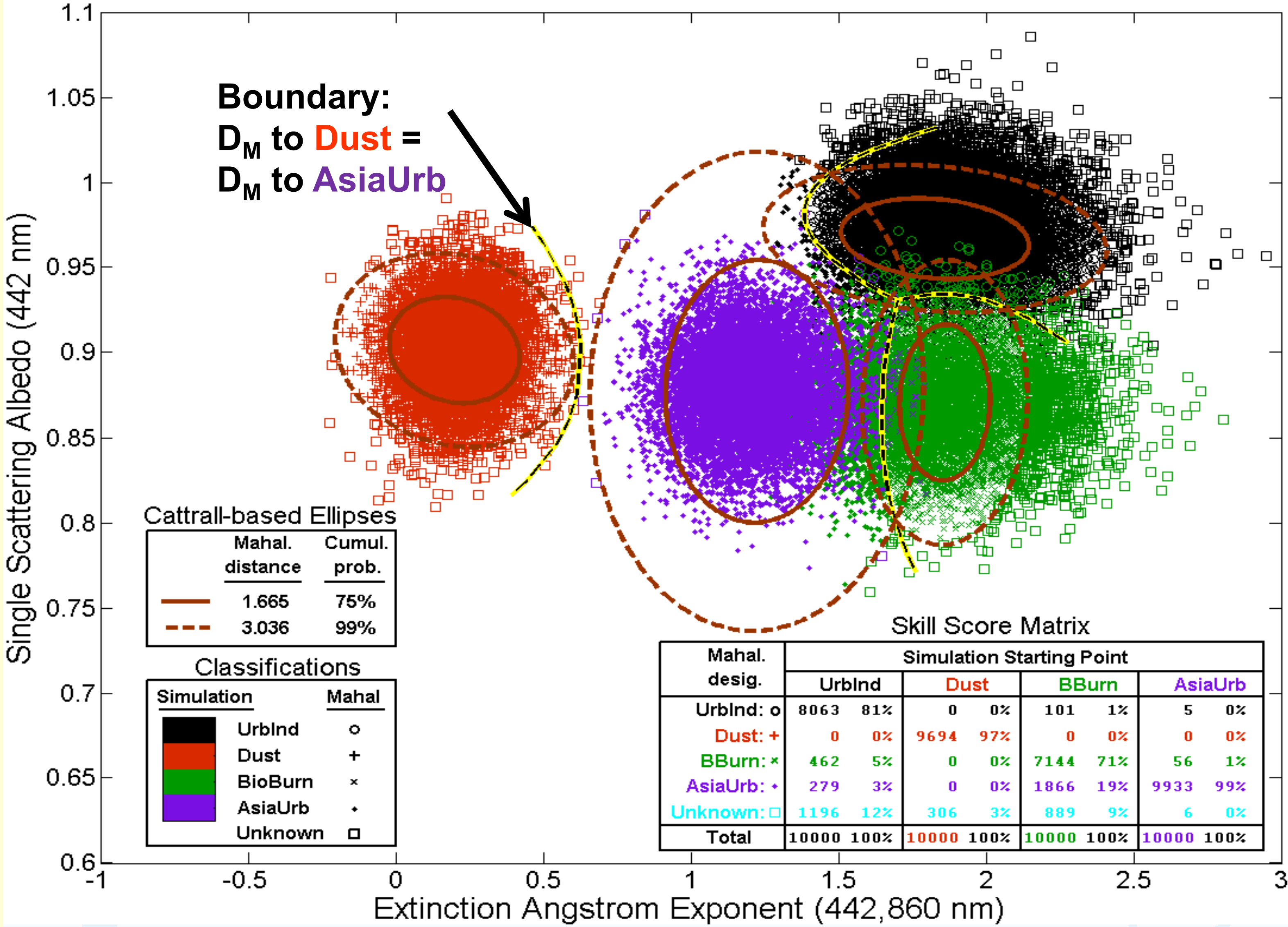
Aerosol morphology	Spherical aerosols, irregular dust particles, soot clusters	N/A

*At least in three spectral channels; relative accuracy better where AOD is larger (typically 410-865 nm).

Uncertainties used in simulations

Simulated measurements and classifications: Skill scores 71-99%

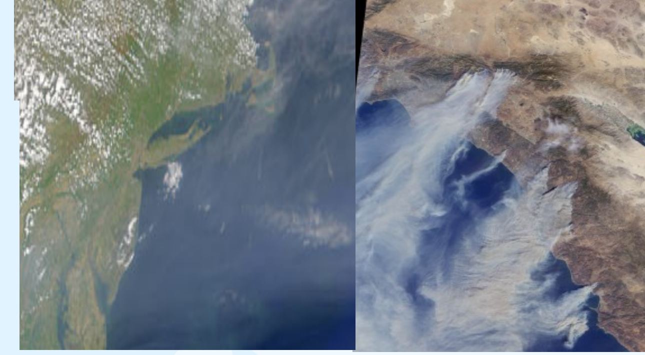
Starting point: an augmented MODIS bimodal model at ~mean of each cluster, normalized to yield AOD(550 nm)=0.5.
Next: added random uncertainties with standard deviations from previous slide.
Results: clusters of 10,000 points each.
Boundaries: from the Cattrall-site clusters



Mahal. desig.	Simulation Starting Point							
	UrbInd		Dust		BBurn		AsiaUrb	
UrbInd: o	8063	81%	0	0%	101	1%	5	0%
Dust: +	0	0%	9694	97%	0	0%	0	0%
BBurn: ×	462	5%	0	0%	7144	71%	56	1%
AsiaUrb: ⋄	279	3%	0	0%	1866	19%	9933	99%
Unknown: □	1196	12%	306	3%	889	9%	6	0%
Total	10000	100%	10000	100%	10000	100%	10000	100%

Mahalanobis classification using those boundaries produces skill scores 71-99%. Points classified as “unknown” have D_M>3 ($P(D_M)$ <1%) for all 4 Cattrall-based clusters.

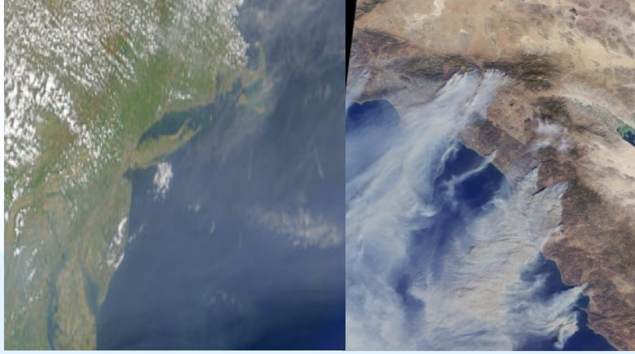
Summary and Conclusions



- Increasingly, aerosol remote sensors (e.g., Glory, RSP, POLDER…) produce multidimensional retrieved aerosol properties [e.g., EAE(λ_1, λ_2), AAE(λ_1, λ_2), SSA(λ_1,...,λ_n), RRI RRI(λ_1,...,λ_n), IRI(λ_1,...,λ_n), several size parameters, shape]—like AERONET.
- Specified clustering and Mahalanobis classification together provide a useful way of combining several dimensions of multiwavelength optical information to assign aerosols to classes (e.g., Urban-Industrial, Biomass-Burning, Mineral Dust, Asian Urban, …).
- The specified or "reference" clusters can be established using information (e.g., trajectories, accompanying trace gases, chemical analyses, prior studies) beyond the optical information that will be available in the general case. These reference clusters can then be used to train and test the classification algorithm.
- Applications of the technique to 2 AERONET data sets and aircraft-sampled aerosols yielded skill* scores ranging from 87% to 100% (diagonal elements of the skill score matrix).

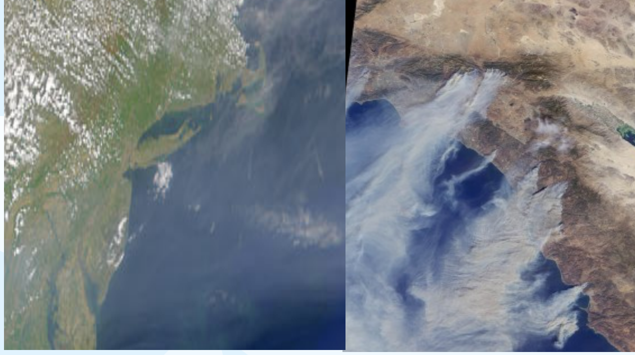
*More accurately, "sameness scores"

Summary and Conclusions (cont'd)



- A first step toward simulating Glory APS data, by using bimodal aerosol models with randomly generated errors based on Glory APS expected uncertainties, yielded skill scores of 71% to 99%, with 0% to 12% of simulated points assigned to an "unknown" class (defined as consisting of points with $D_{Mahal}>3$ from all 4 reference clusters based on 4 AERONET sites and associated seasons).

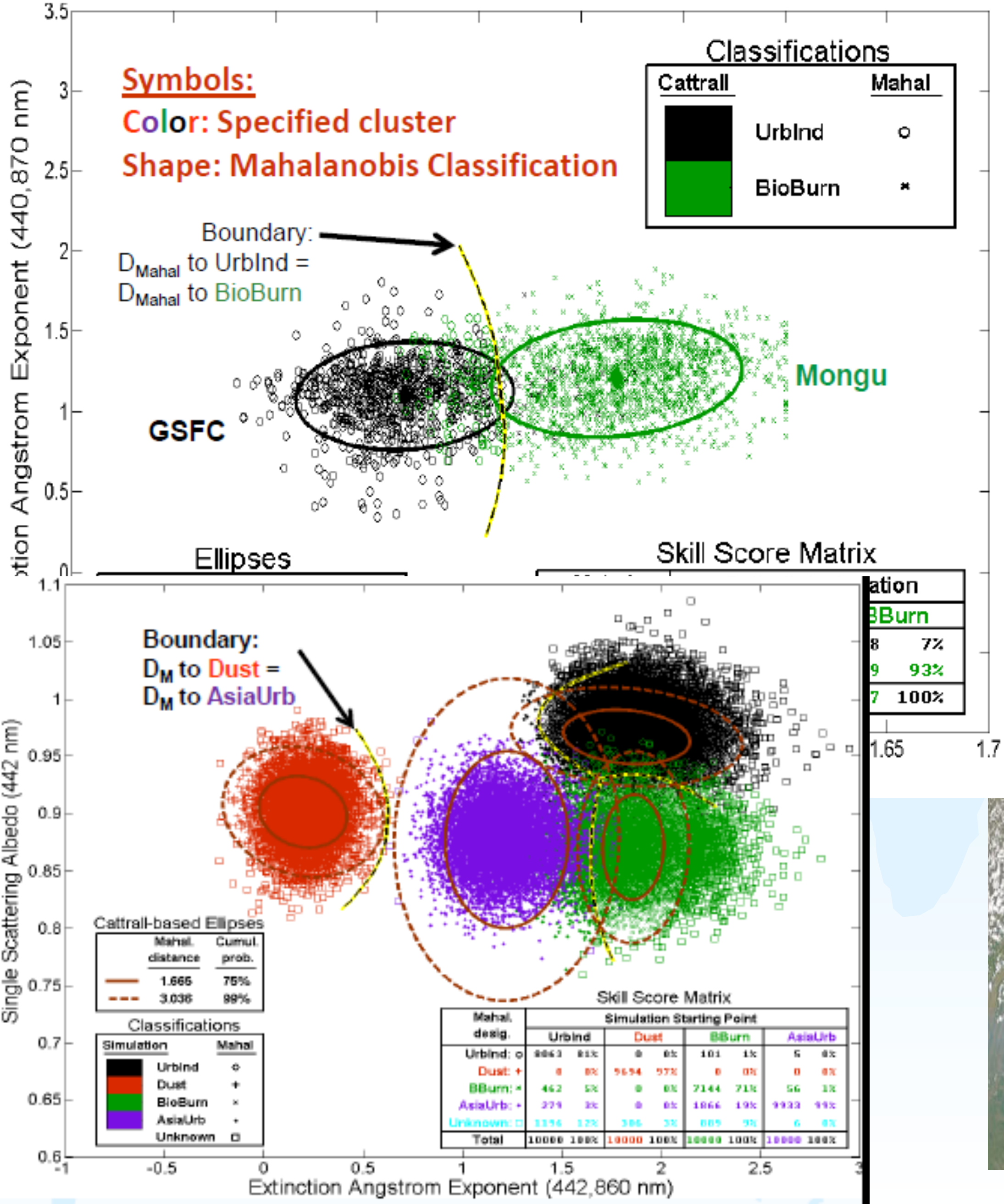
Next Steps



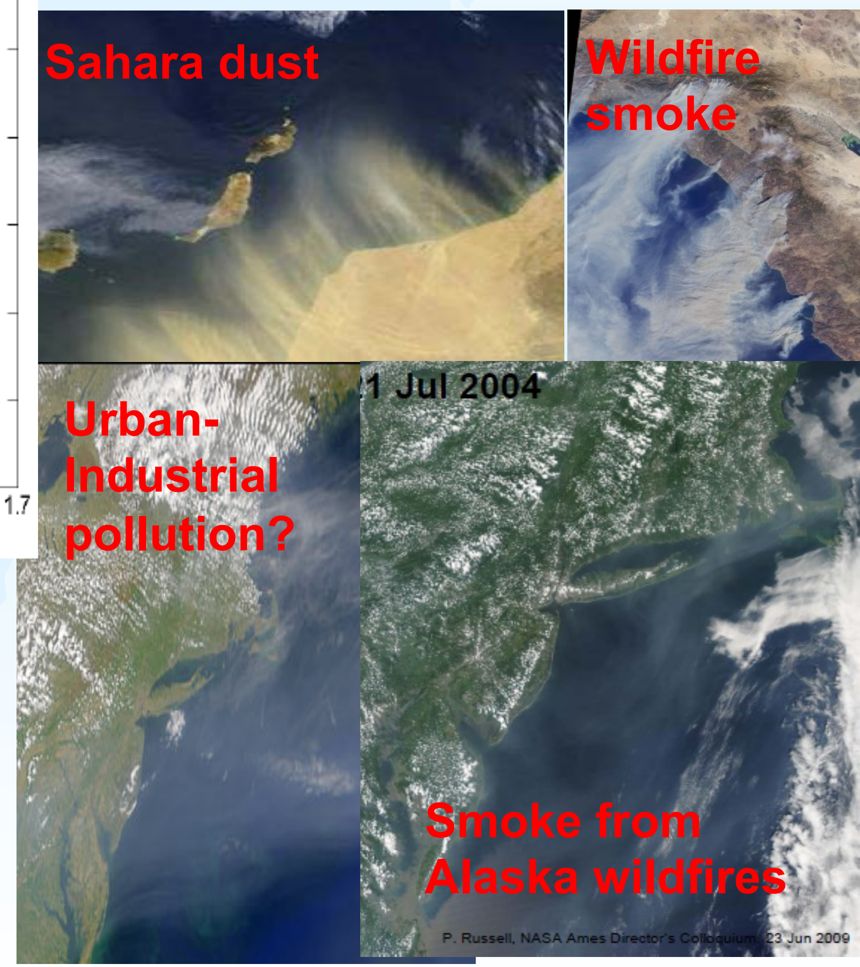
- **Begin to apply technique to other multi-dimensional data sets beside AERONET:**
  - RSP (airborne Glory APS)
  - RSP + HSRLidar
  - POLDER (Dubovik et al. *AMT* 2011)
  - 4STAR* (sun-sky spectrometer: more in Redemann talk later this morning)

***Spectrometer for Sky-Scanning Sun-Tracking Atmospheric Research**

End of Presentation



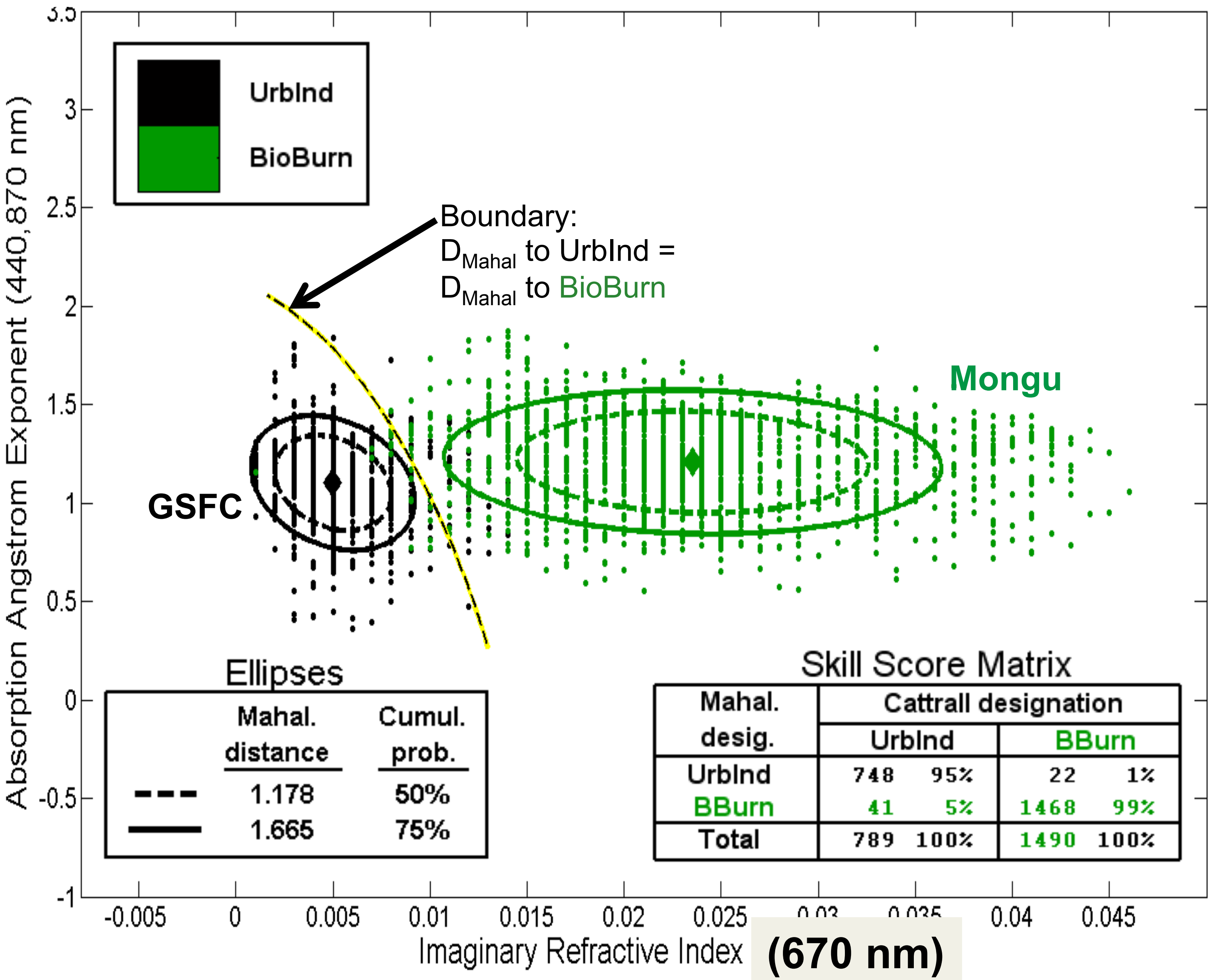
Remaining slides are backup



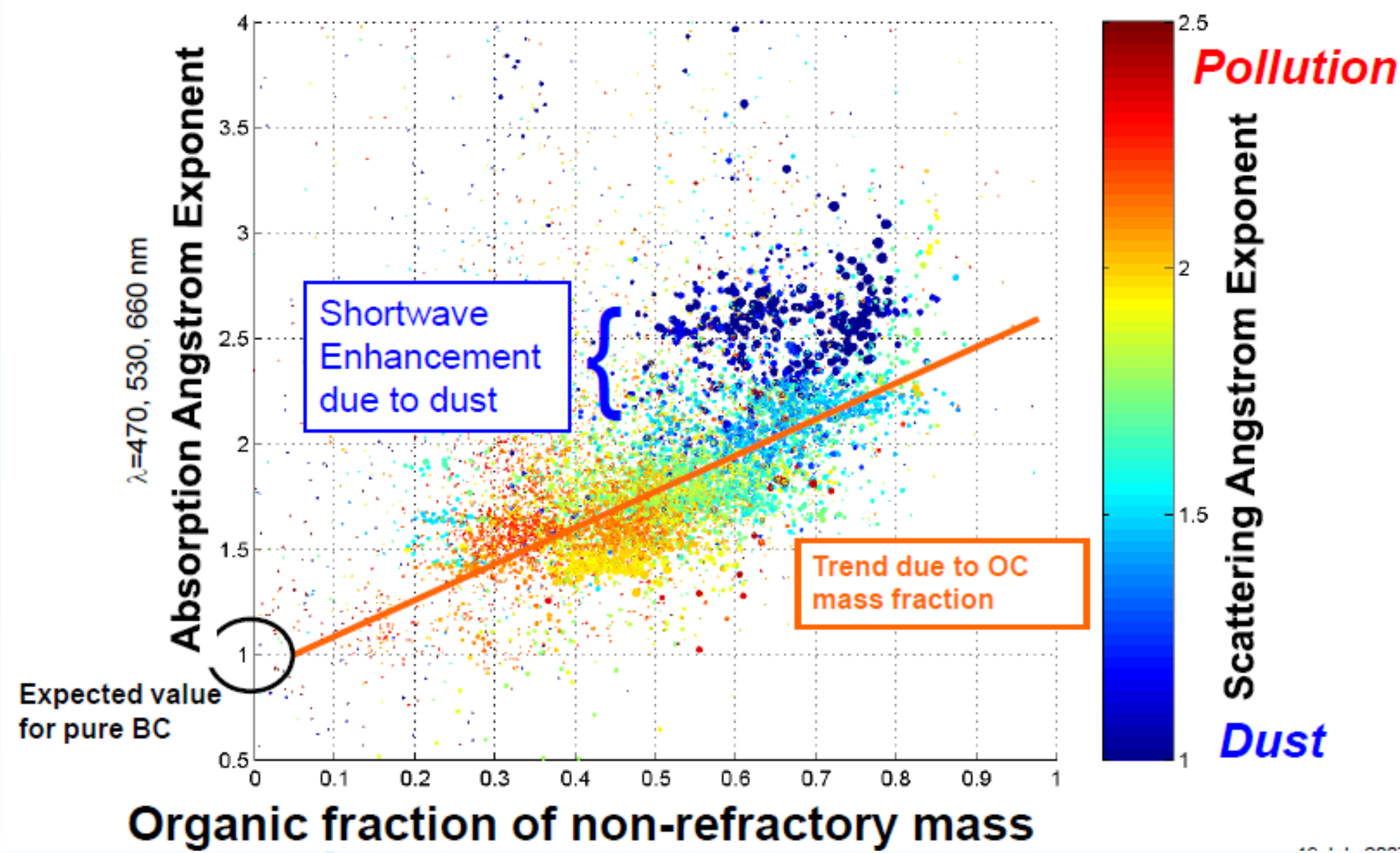
End of Presentation

Remaining slides are backup

Separation also good using Imaginary Refractive Index—Skill Scores 95% and 99%

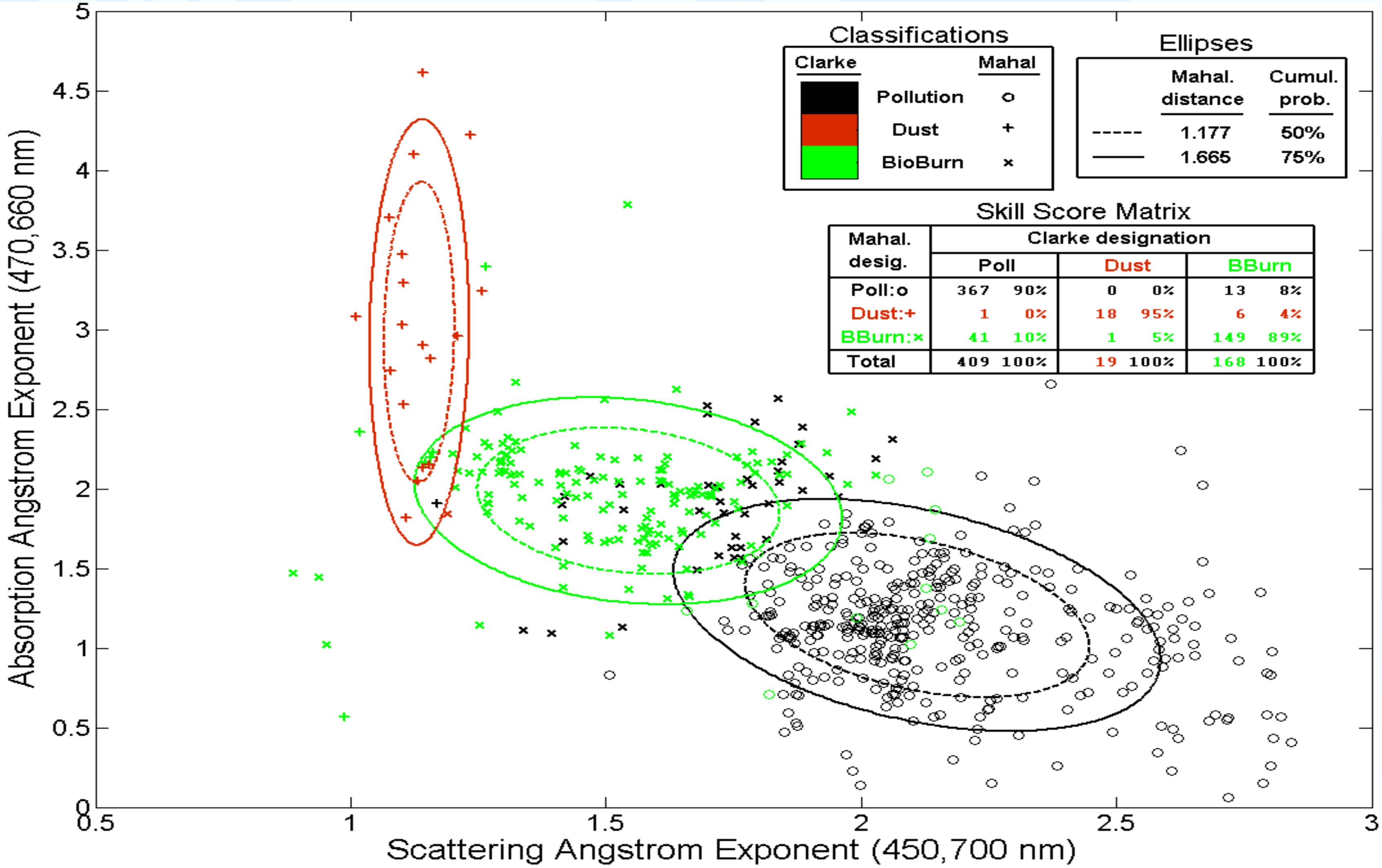


Similar result from very different methods— in situ sampling on C-130 over Mexico

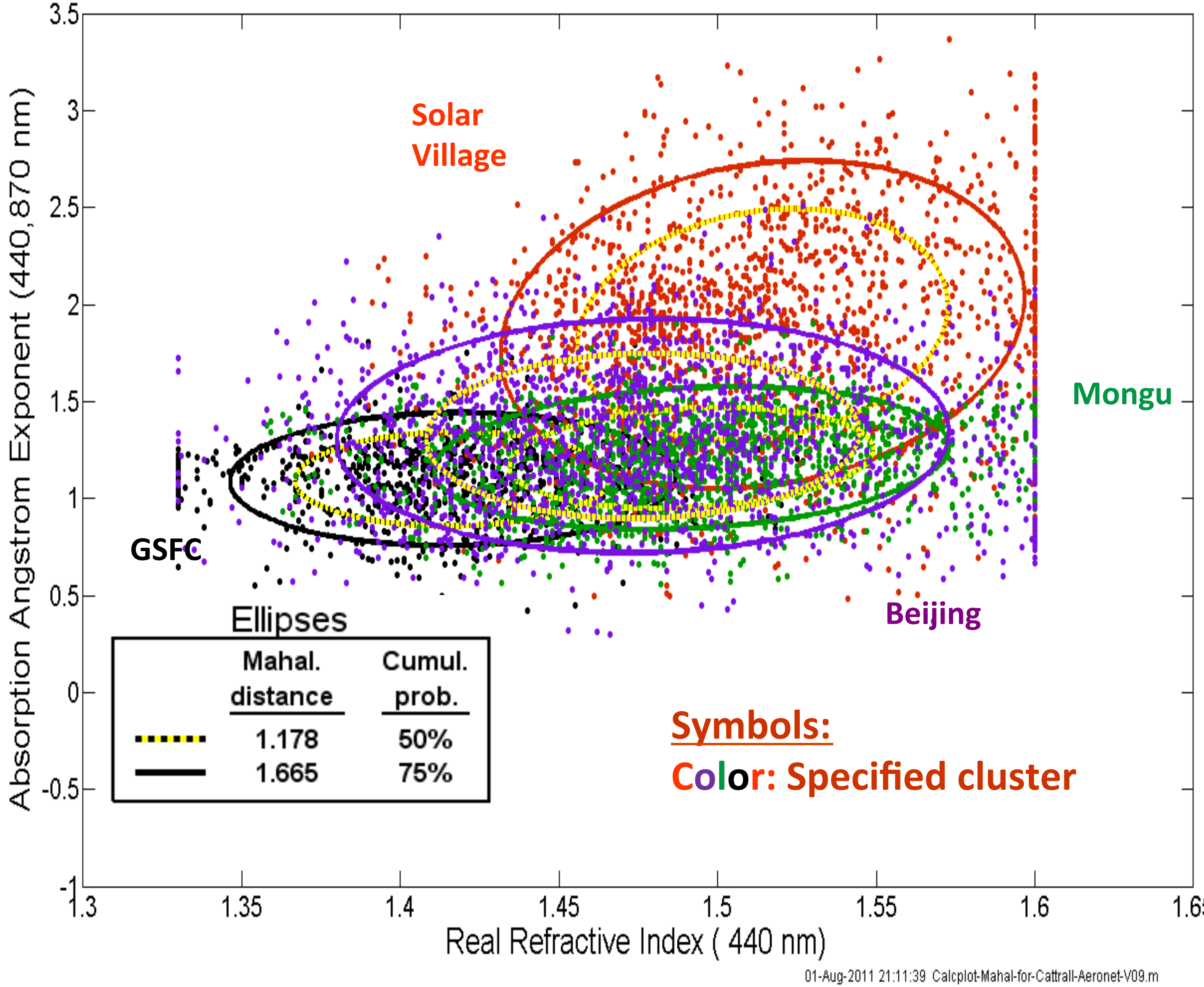


Shinozuka, Clarke, DeCarlo, Jimenez in Russell et al., *ACP* 2010

Specified clustering and Mahalanobis classification can also be applied to in situ data: Aircraft-sampled aerosols [Clarke et al., *JGR* 2007]



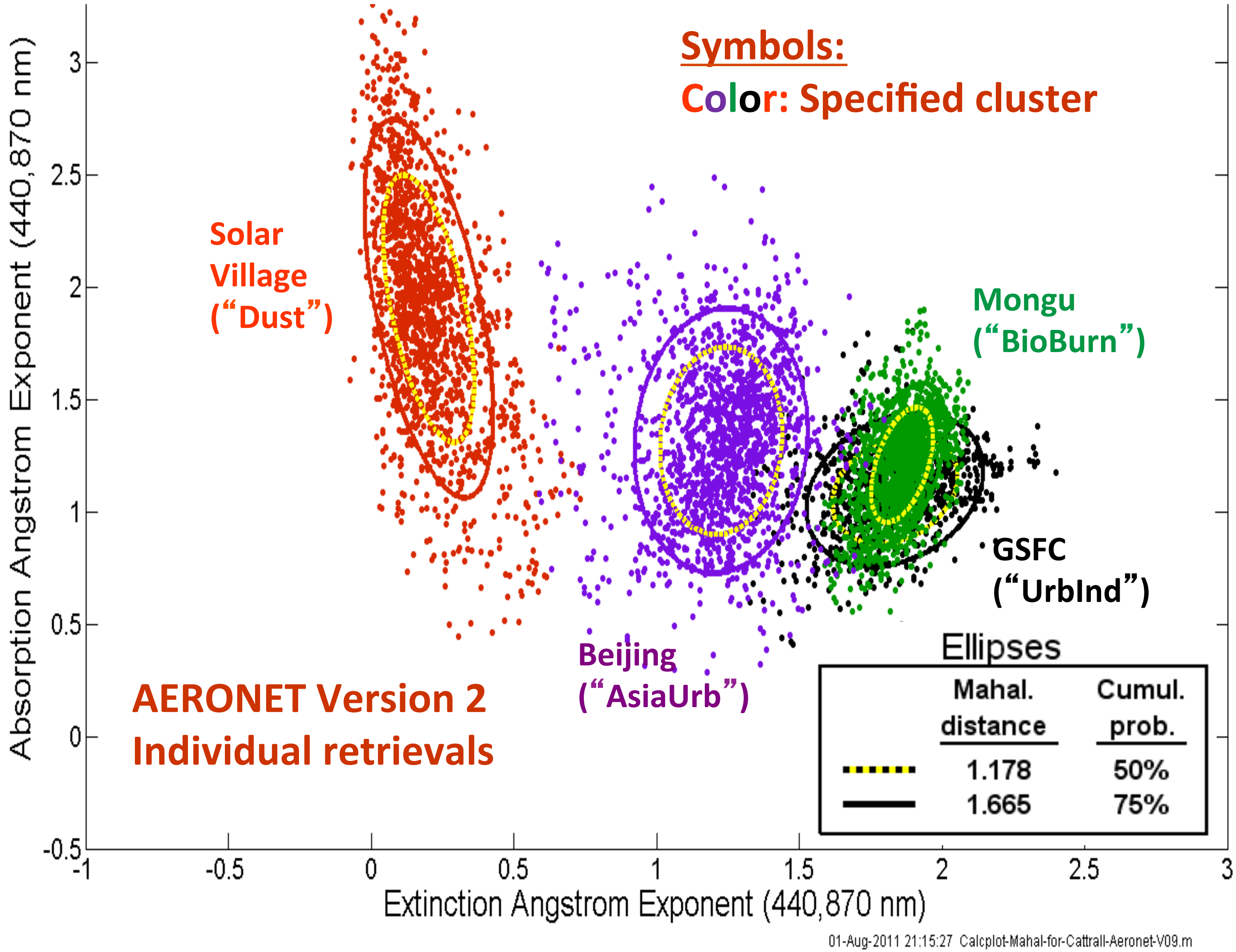
4 AERONET sites/seasons from Cattrall et al. (*JGR*, 2005) selected to illustrate specified clustering and Mahalanobis classification



Symbols:

Color: Specified cluster

Since Dust and AsiaUrb are well separated from BioBurn and UrbInd in AAE-vs-EAE, we can use these 2 dimensions to eliminate them and focus on separating BioBurn and UrbInd from each other.

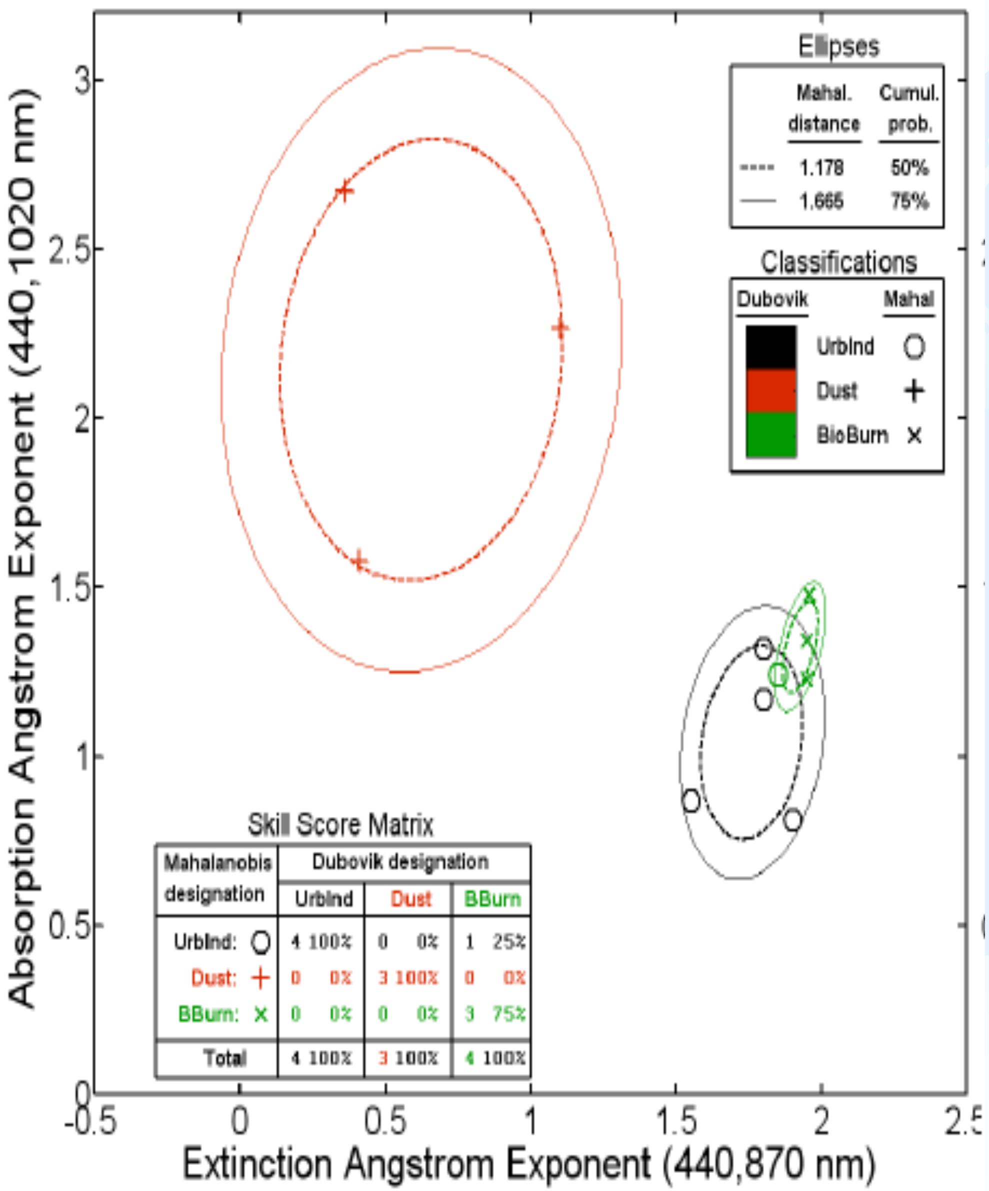


AERONET sites and months from Cattrall et al. (*JGR*, 2005) selected to illustrate specified clustering and Mahalanobis classification

Site Name	Country	Cattrall Desig-nation	Months*	Years#	N_{meas}	
					Raw	Filtered [$D_M \le 3$]
GSFC	USA	UrbInd	Jun-Sep	1992-2009	817	802
Mongu	Zambia	BioBurn	Aug-Nov	1995-2008	1513	1490
Beijing	China	AsiaUrb	Jun-Feb	2000-2009	1538	1489
Solar Village	Saudi Arabia	Dust	Mar-Jul	1999-2008	1573	1513

*Designated by Cattrall et al. #Used by our analyses.

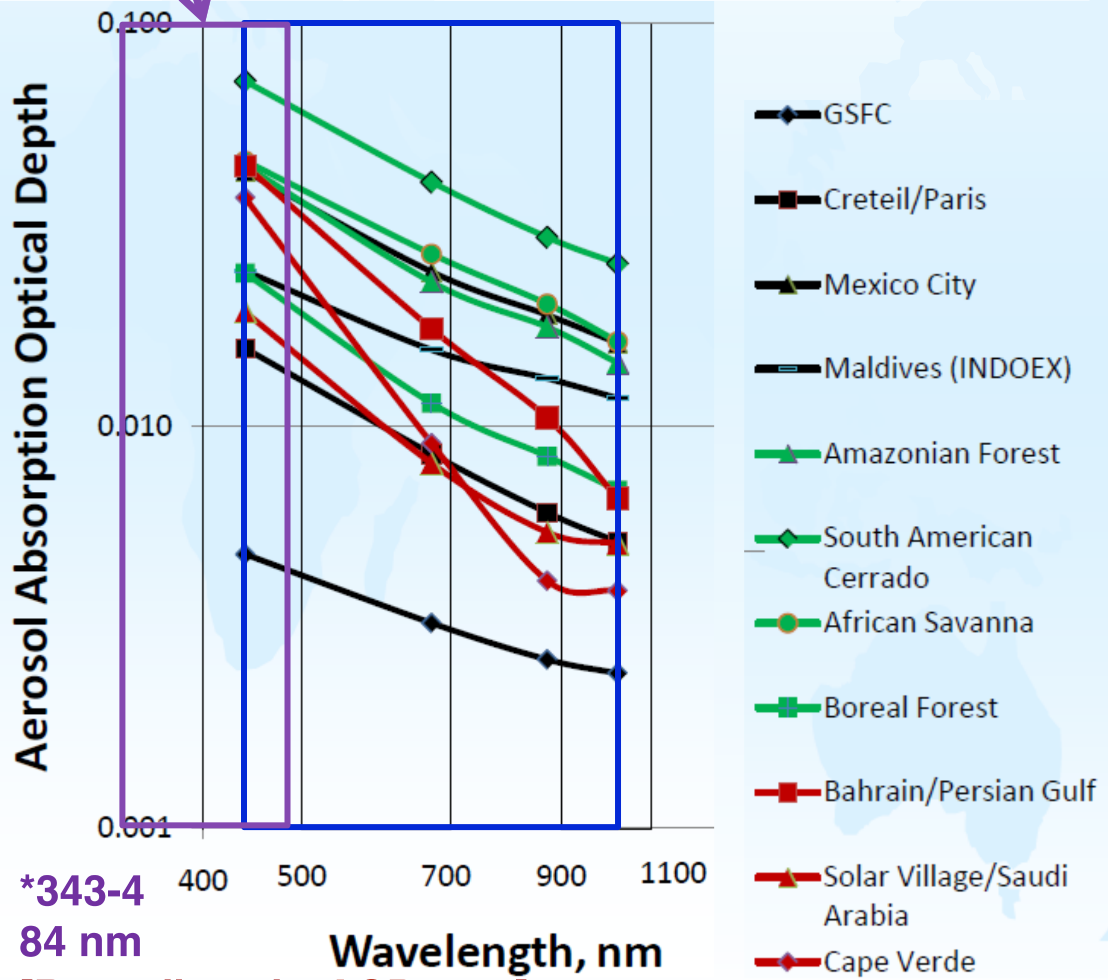
Do the individual, Version 2 retrievals from Cattrall (2005) sites/seasons give results like this from the Dubovik (2002) Version 1 site/season means?



Extending to shorter λ (e.g., the OMI λ range) could help increase differences between UrbInd & BioBurn

AERONET (Dubovik et al., 2002), Full Columns

OMI λ range

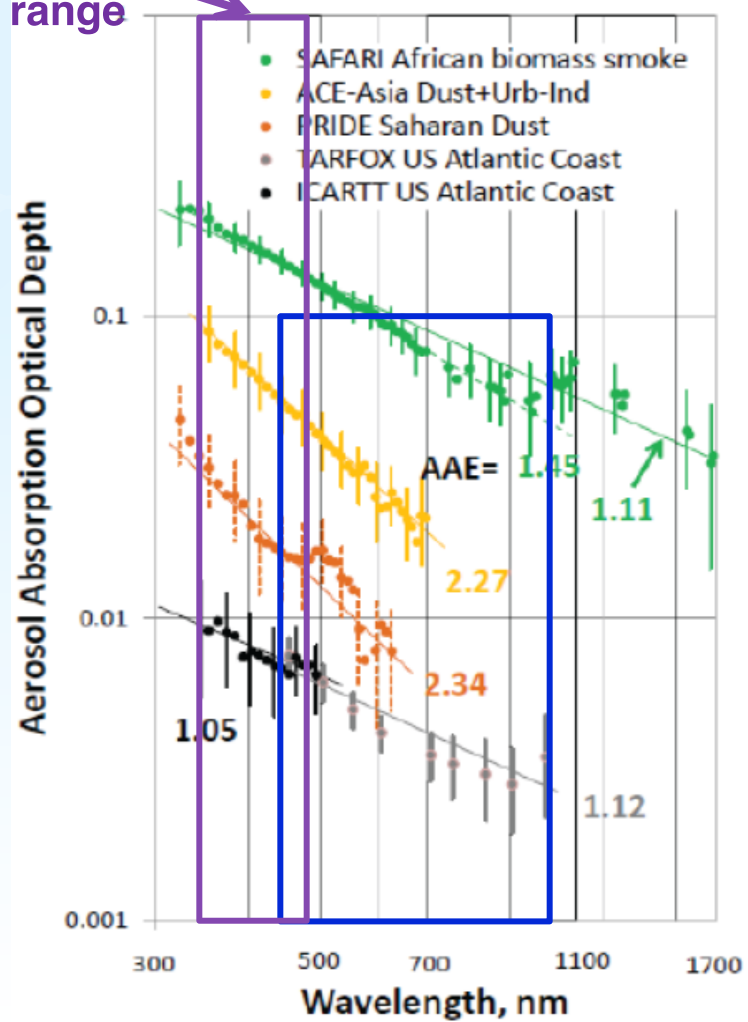


*343-484 nm

[Russell et al., *ACP* 2010]

SSFR+AATS (Bergstrom et al., 2007), Layers

OMI λ range



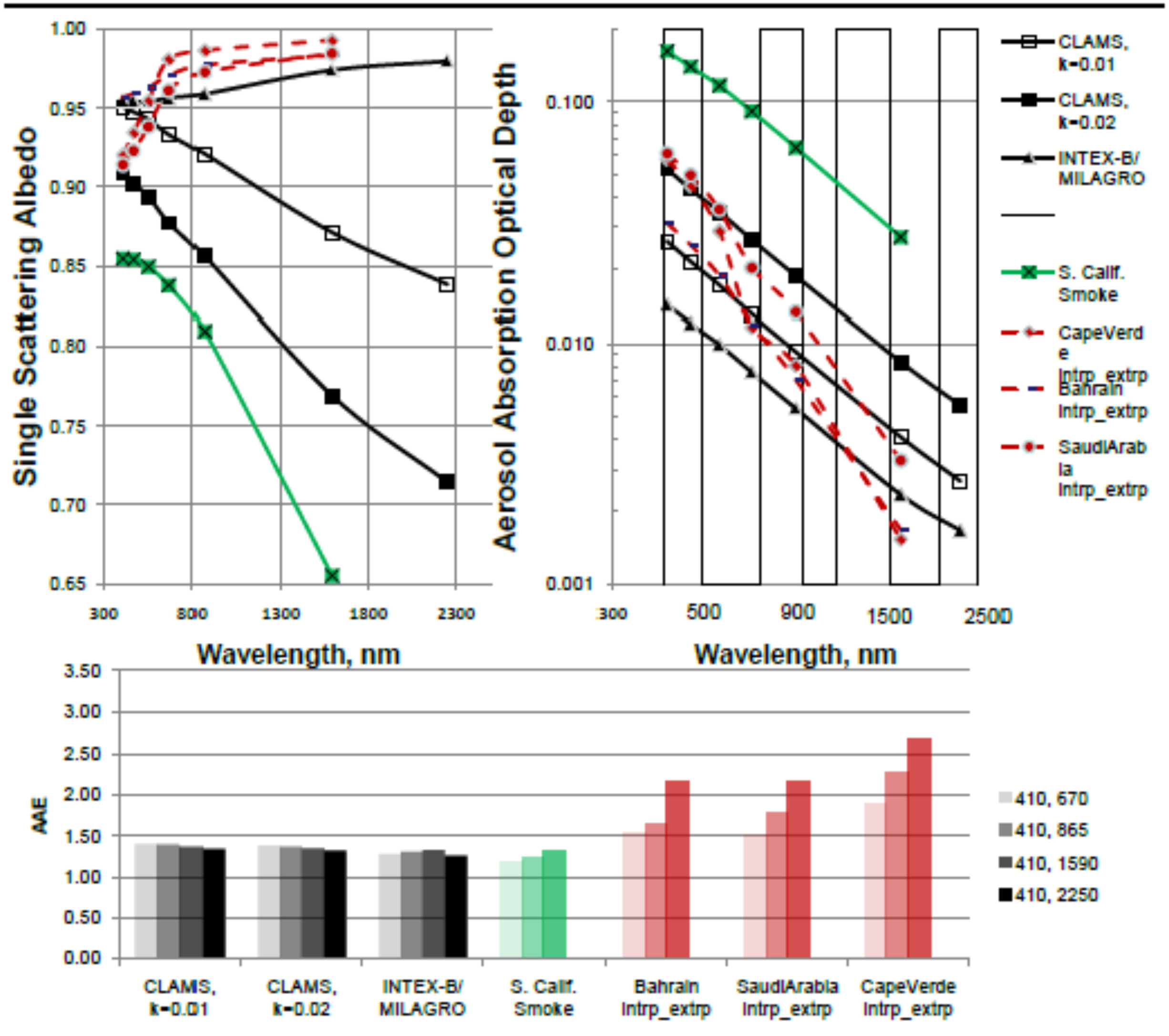
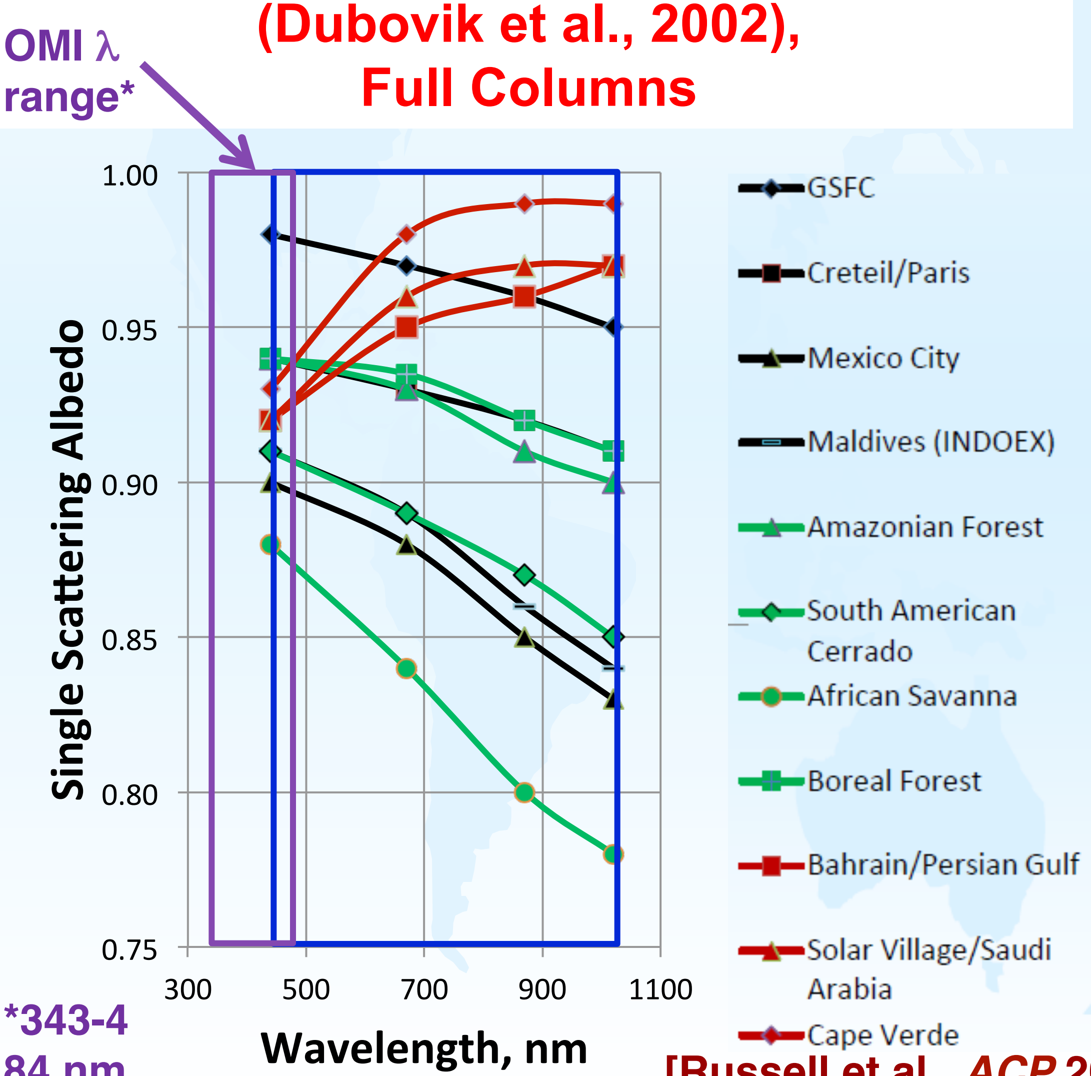


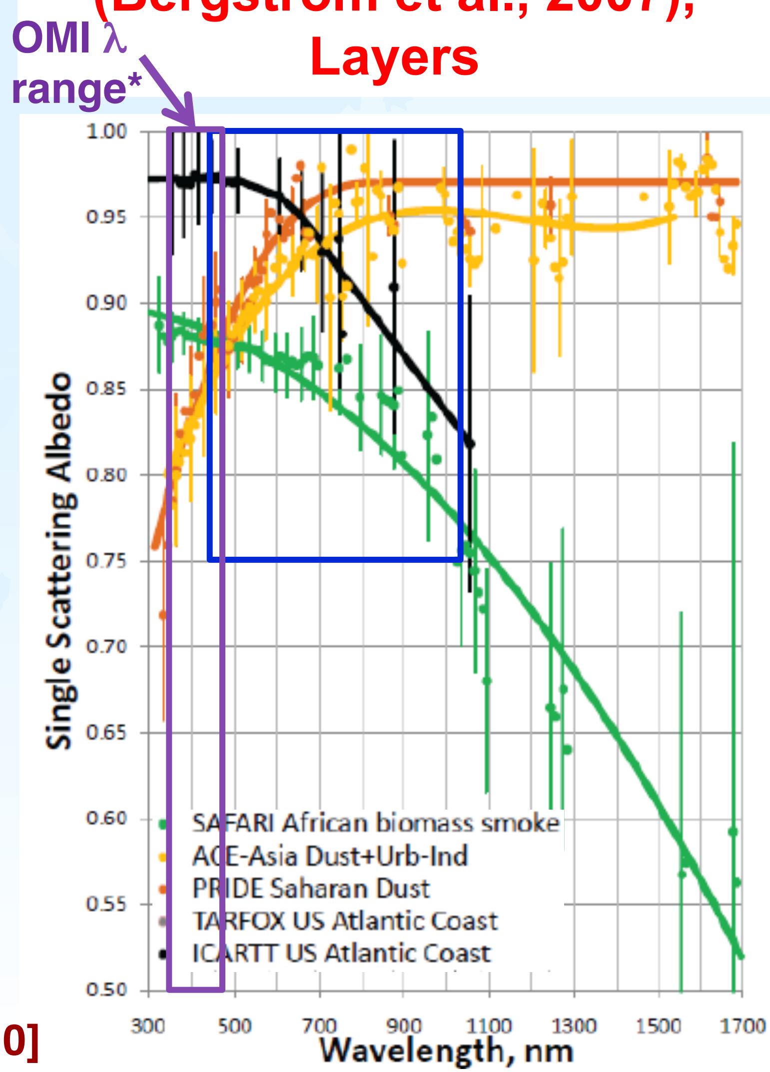
Figure 11. Single Scattering Albedo (SSA) spectra, corresponding AAOD spectra, and Absorption Angstrom Exponent (AAE) values, all at RSP wavelengths. CLAMS, INTEX-B/MILAGRO, and S. Calif results are from RSP measurements described by Chowdhary et al. (2005, 2009) and Waquet et al. (2009). Bahrain, Saudia Arabia, and Cape Verde results are for illustrative purposes only, obtained by interpolating and extrapolating results of Dubovik et al. (2002) to RSP wavelengths. Shading for each location in bottom frame indicates wavelength pair (in nm) for AAE calculation.

OMI λ range (343-484 nm) extends into a region where absorption by organics is strongest.
This may increase distinction between BioBurn & UrbInd classes.

AERONET (Dubovik et al., 2002), Full Columns



SSFR+AATS (Bergstrom et al., 2007), Layers



*343-484 nm

[Russell et al., *ACP* 2010]

Question: Do the preceding results, which describe a layer or a point, apply also to the full vertical column viewed by a spacecraft?

To answer, we looked at many full vertical columns as viewed by AERONET sun-sky photometers (Dubovik et al., 2002)

Background on Radiative Flux Divergence & Closure, Absorption Spectra, etc.

Downwelling Flux: $F\downarrow$

Upwelling Flux: $F\uparrow$

Net Flux: $F\downarrow - F\uparrow$

Flux Divergence (absorption):

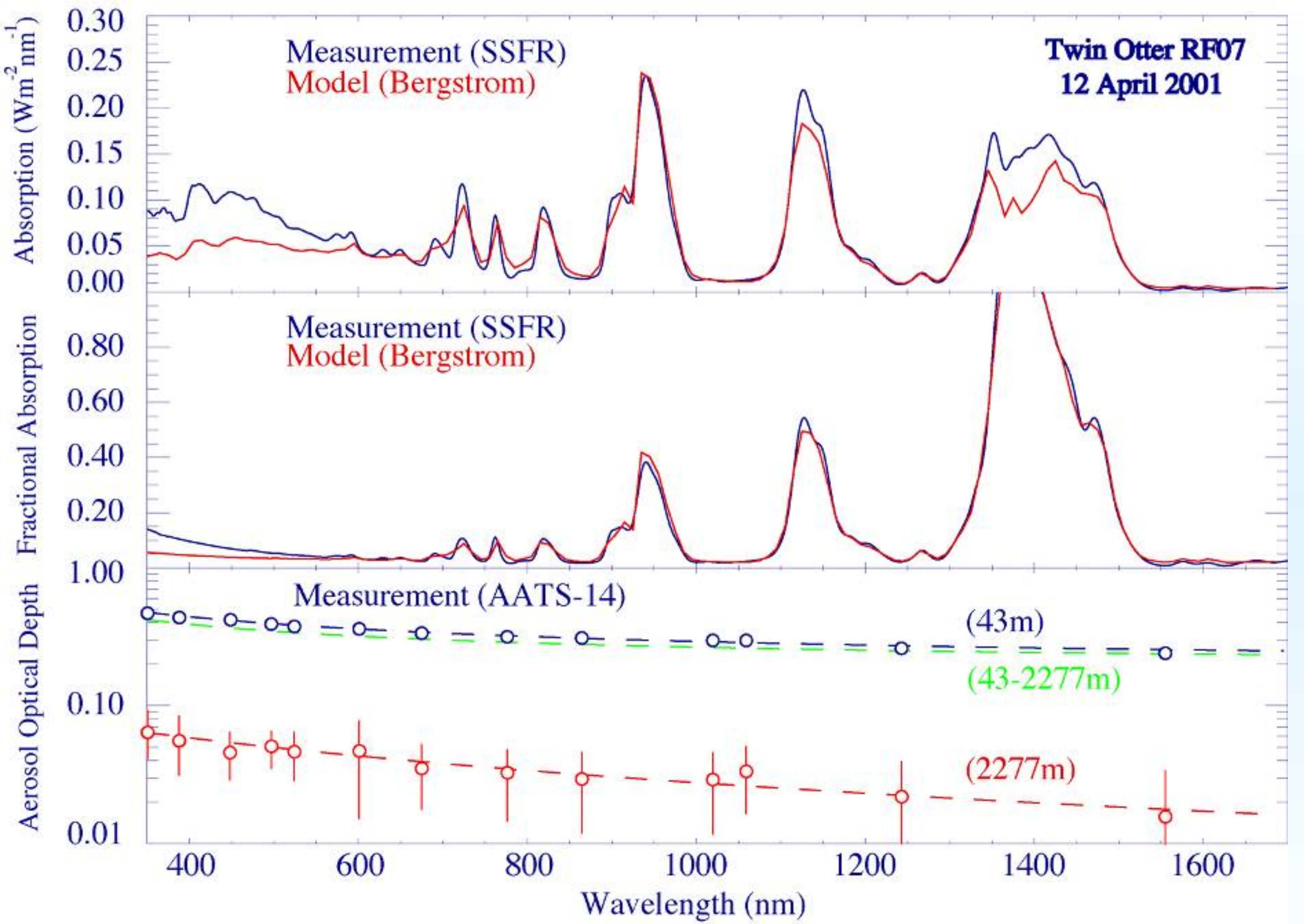
$$(F\downarrow - F\uparrow)_{2000m} - (F\downarrow - F\uparrow)_{43m}$$

Fractional absorption:

$$[(F\downarrow - F\uparrow)_{2000m} - (F\downarrow - F\uparrow)_{43m}] / F\downarrow_{2000m}$$

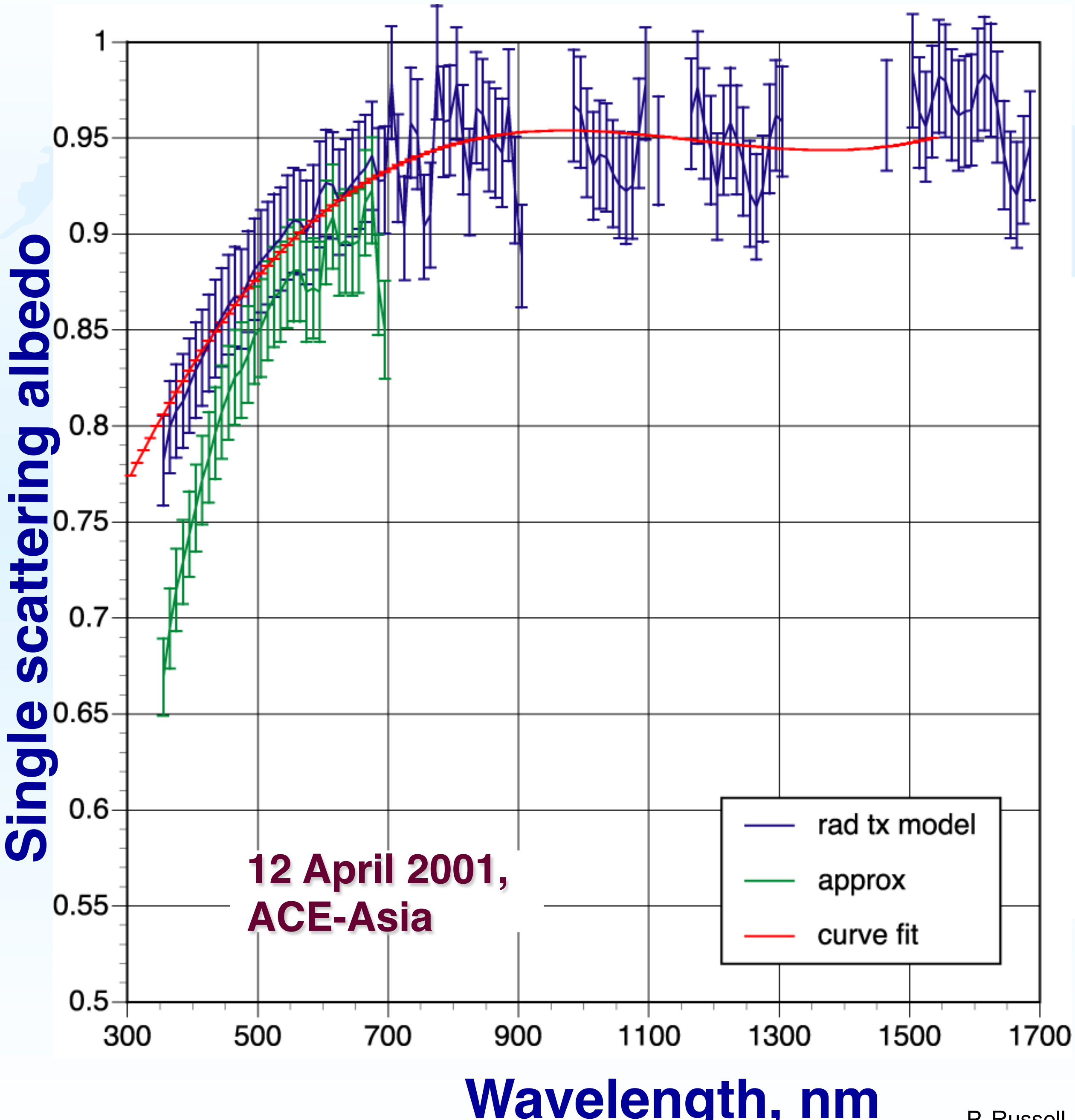
Solar Spectral Flux Radiometer (SSFR)
Pilewskie & Gore, NASA Ames

$F\downarrow$, $F\uparrow$



Pilewskie, Bergstrom, Schmid et al.

Aerosol Single Scattering Albedo Spectrum



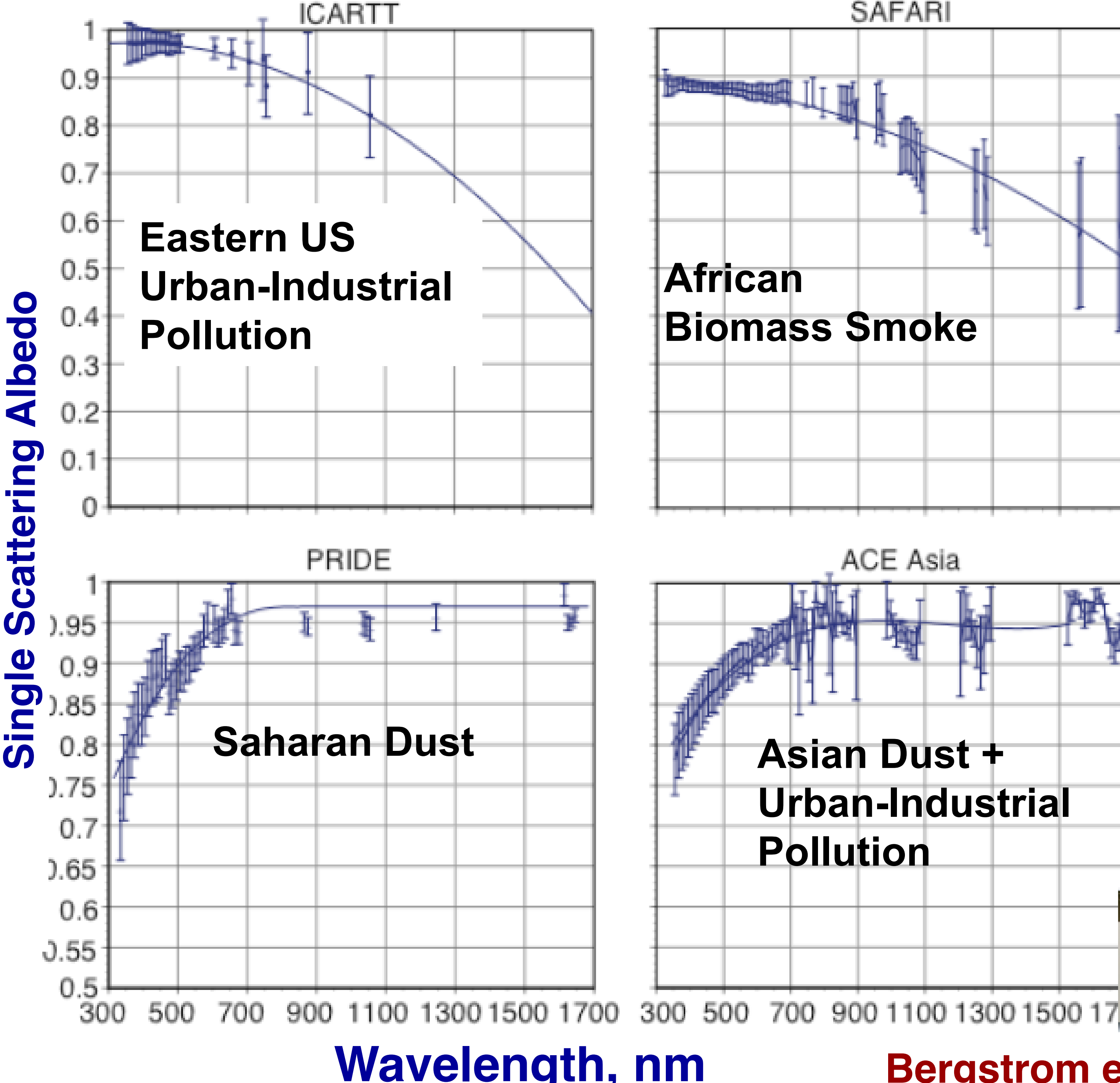
Derived from measured flux and AOD spectra.

Desirable features:

- Describes aerosol in its ambient state (incl volatiles like water, organics, nitrates)
- Wide λ range: UV-Vis-SWIR
- Includes λ range of OMI-UV, OMI-MW, MISR, MODIS, CALIPSO, HSRL, Glory ASP, RSP, POLDER, …
- Coalbedo (1-SSA) varies by factor 4, λ = 350-900 nm

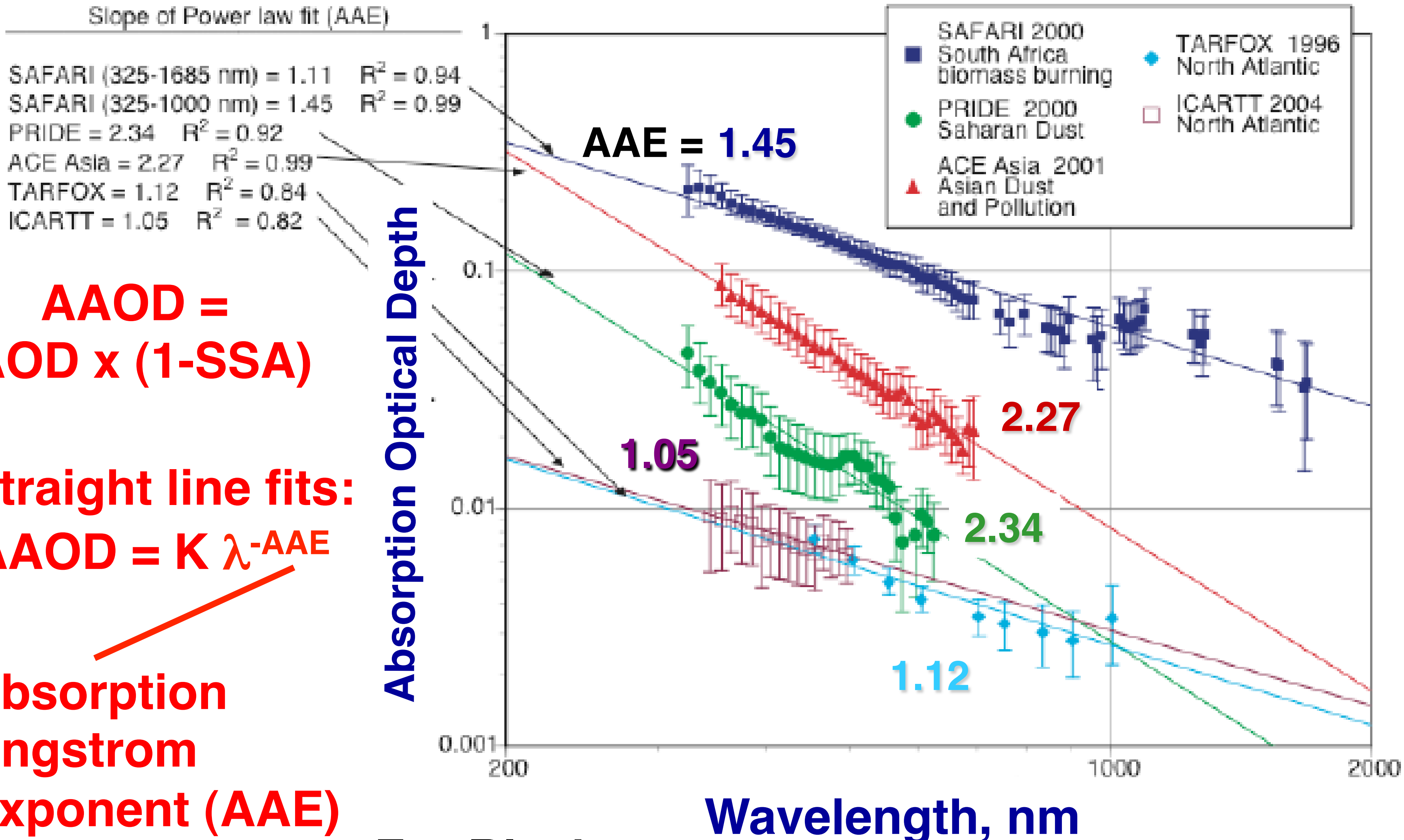
[Bergstrom, Pilewskie, Schmid et al., *JGR* 2004]

SSA Spectra from Expts in 4 Regions of the World Using F (λ) + AOD (λ)



Bergstrom et al., *ACP*, 2007

Aerosol Absorption Optical Depth (AAOD) Spectra from 5 Experiments



AAOD = AOD x (1-SSA)

Straight line fits:

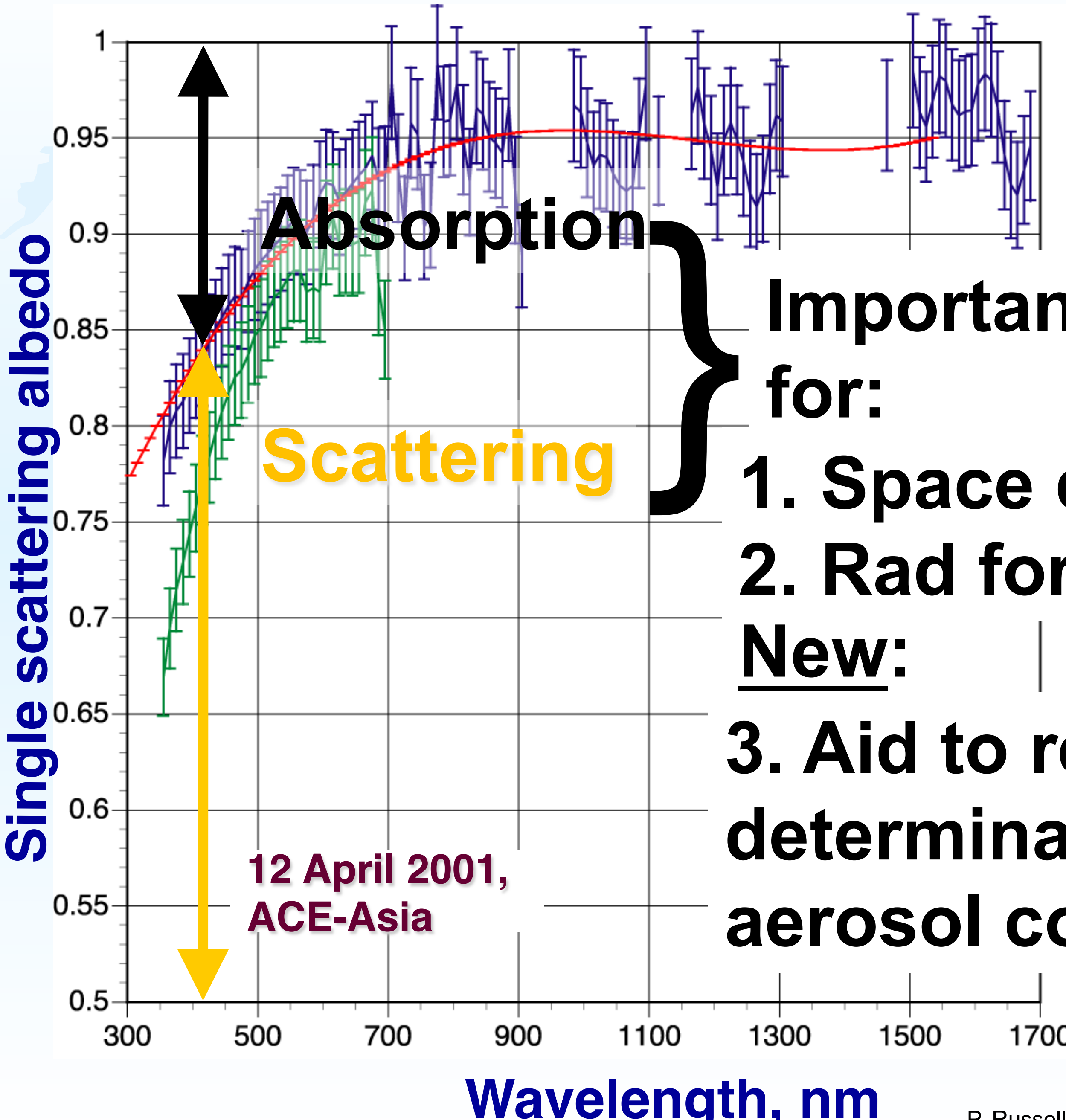
$$AAOD = K \lambda^{-AAE}$$

Absorption Angstrom Exponent (AAE)

For Black Carbon, AAE = 1

Bergstrom et al., *ACP*, 2007

Aerosol Single Scattering Albedo Spectrum



Derived from measured flux and AOD spectra.

Important for:

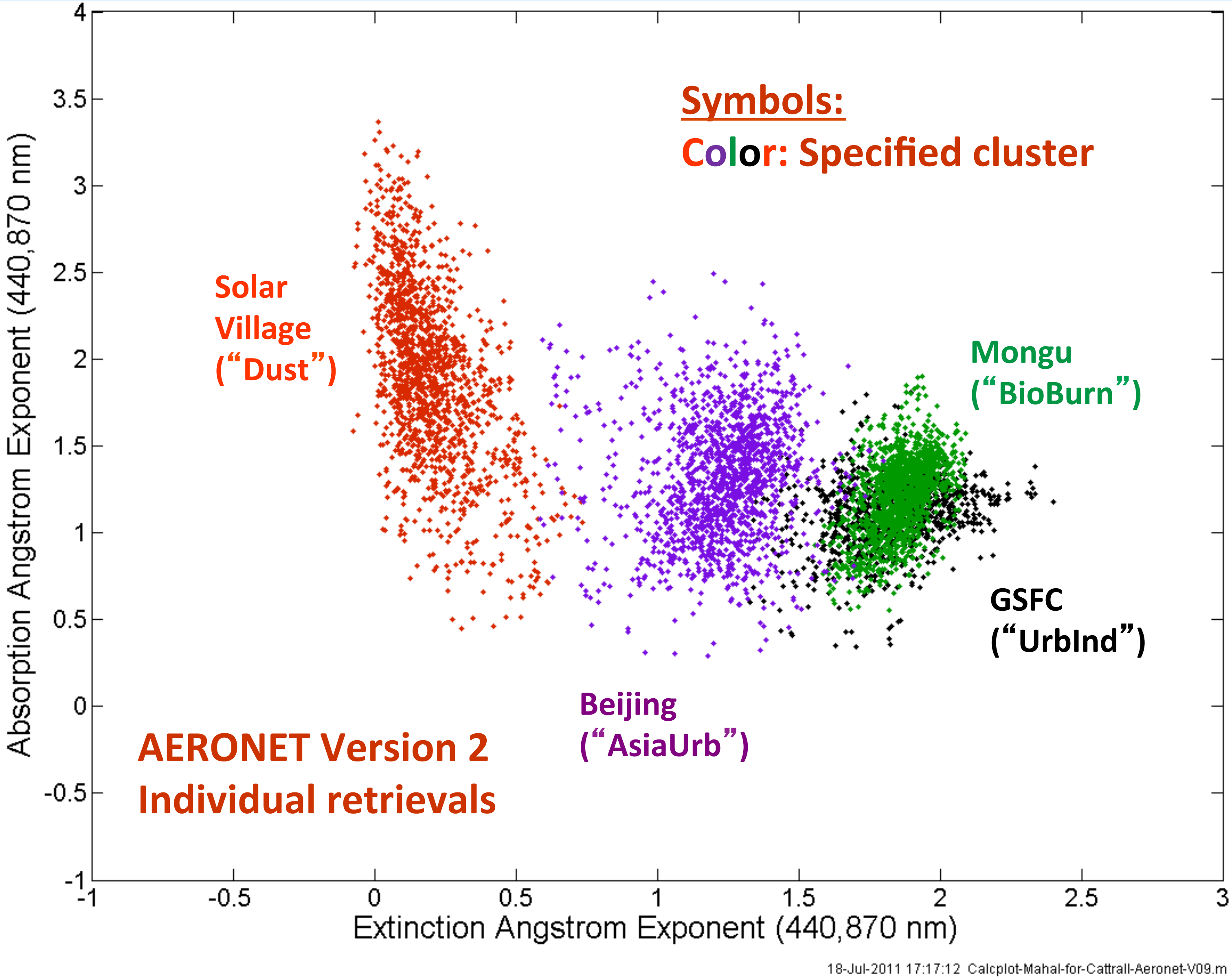
1. **Space determ of AOD**
2. **Rad forc of climate**

New:

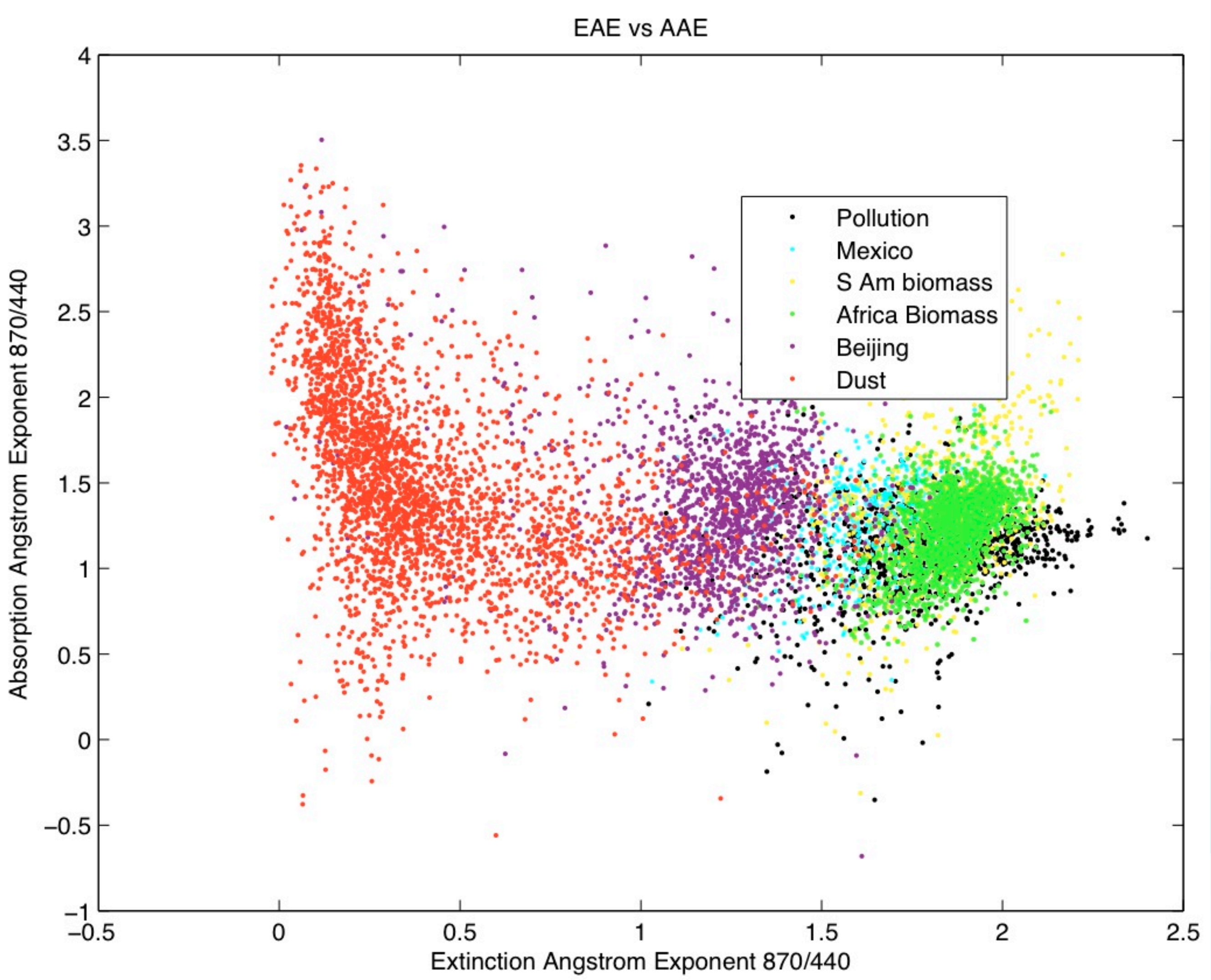
3. **Aid to remote determination of aerosol composition**

[Bergstrom, Pilewskie, Schmid et al., *JGR* 2004]

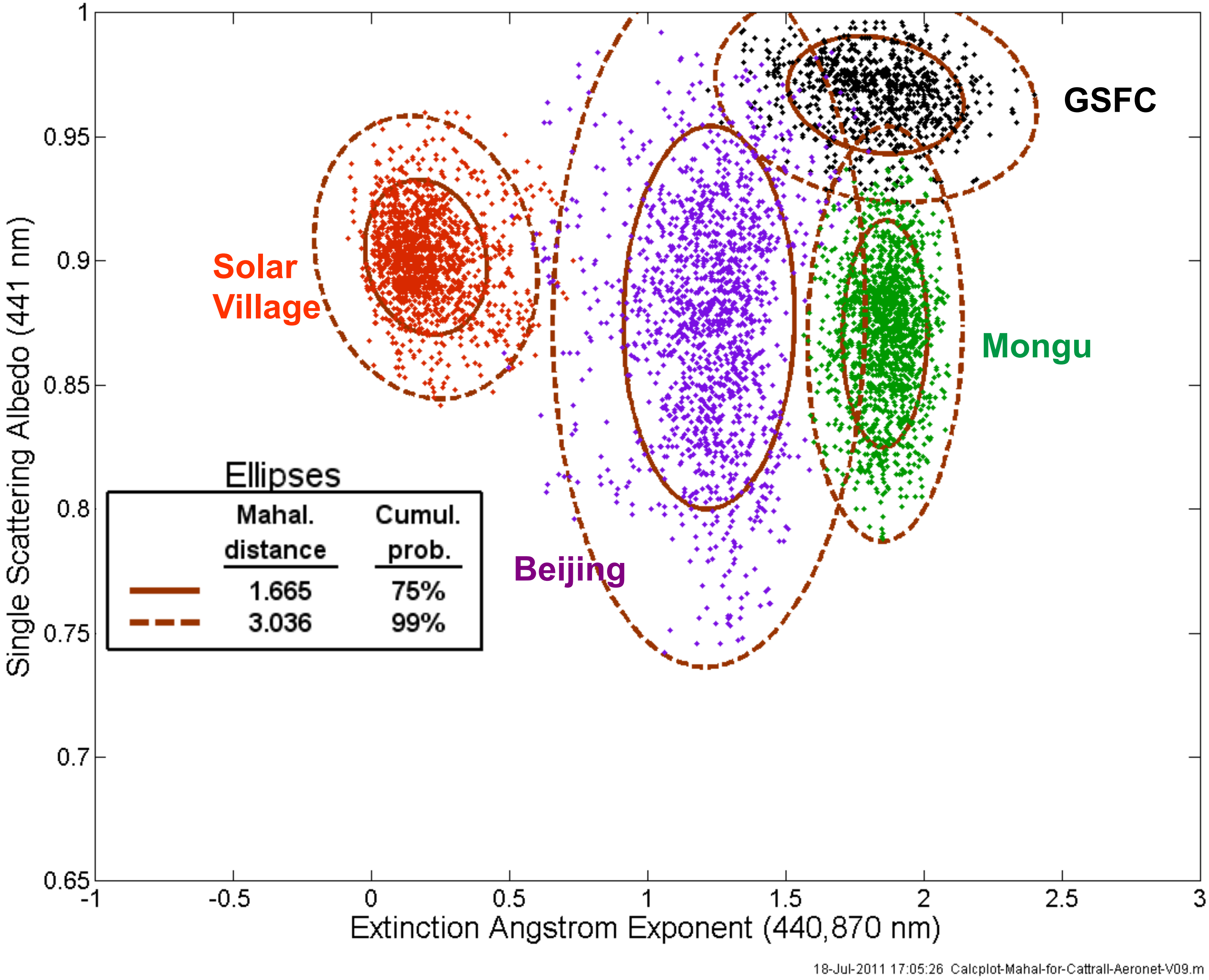
4 AERONET sites/seasons from Cattrall et al. (*JGR*, 2005) selected to illustrate specified clustering and Mahalanobis classification



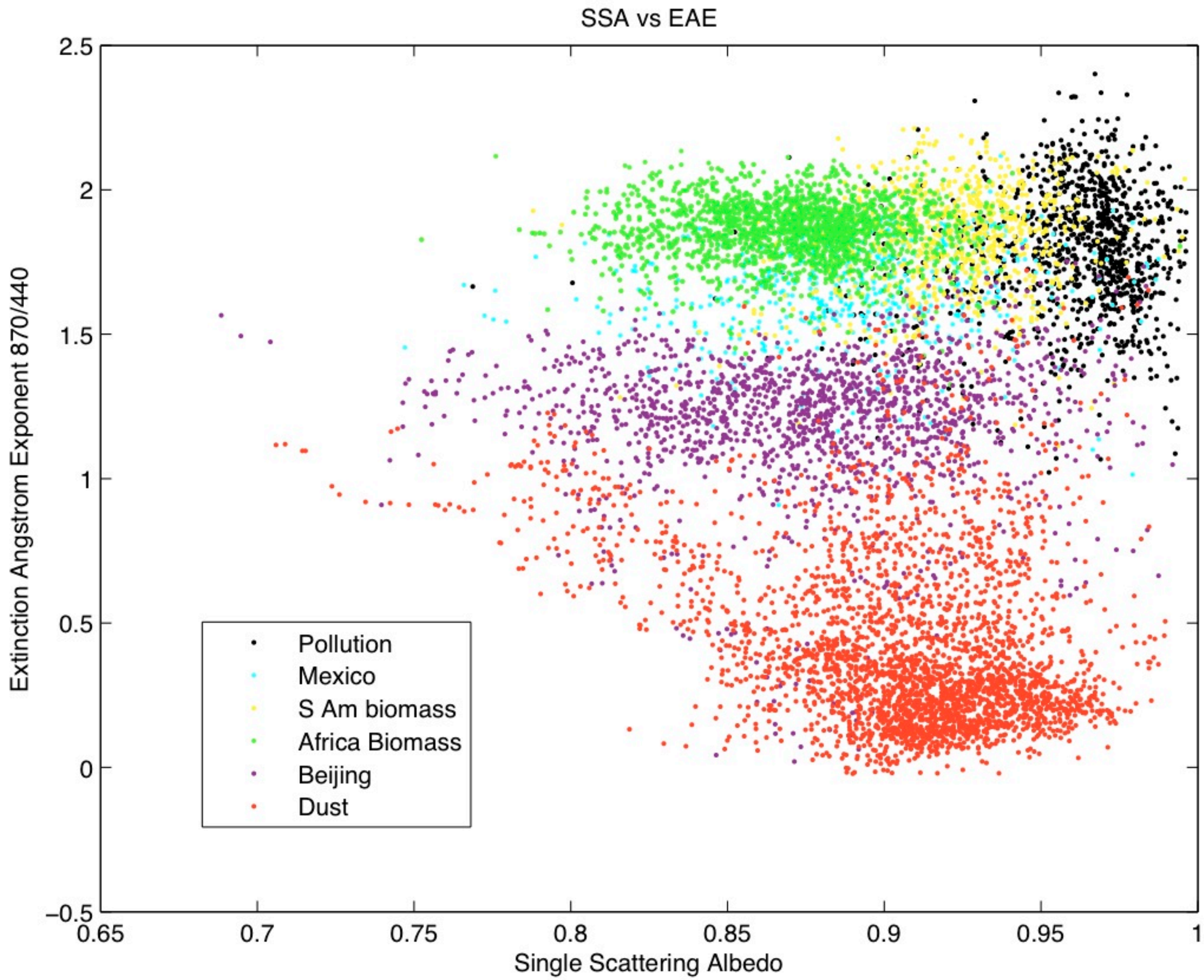
All Cattrall Sites



Coordinates other than AAE: SSA(441 nm) vs EAE(440,870 nm)



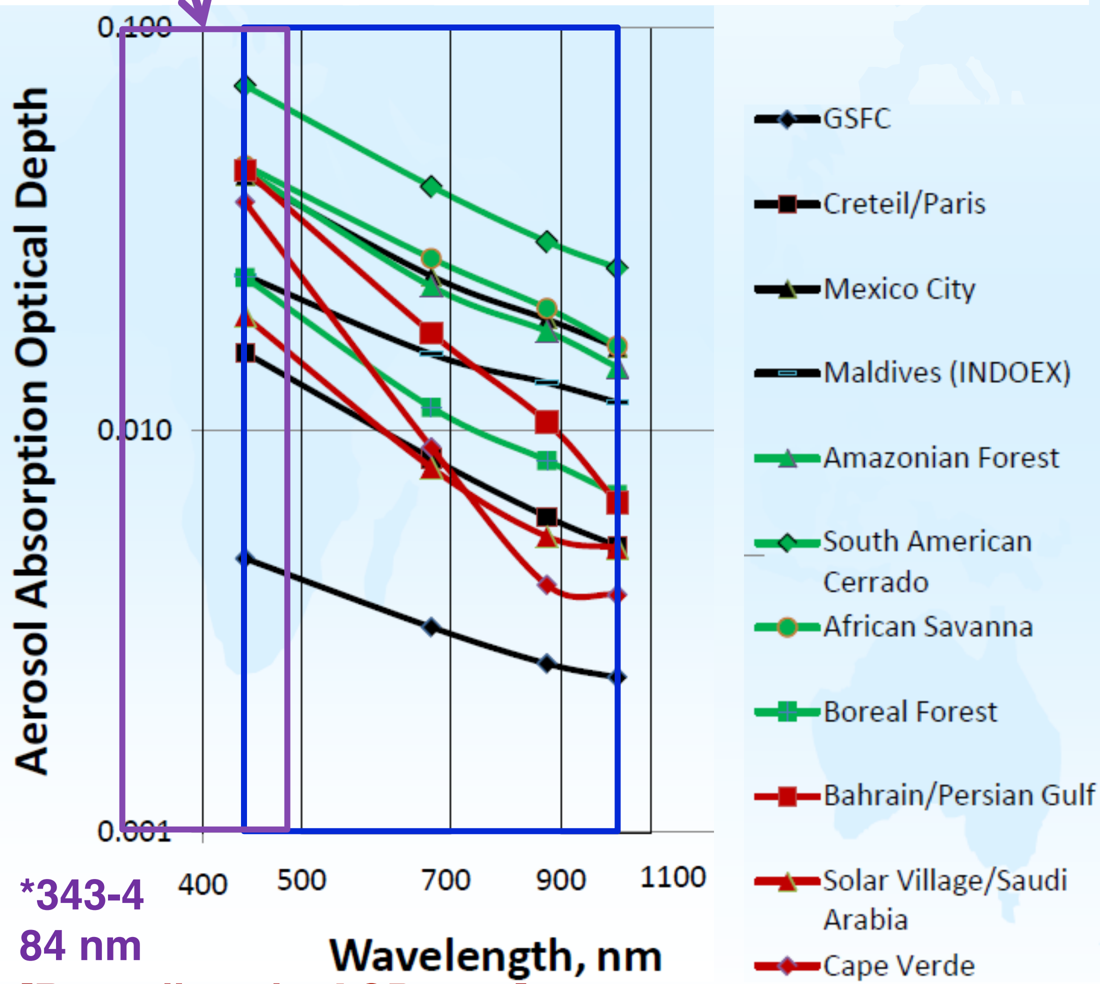
All Cattrall Sites



Question: Do the preceding results, which describe a layer or a point, apply also to the full vertical column viewed by a spacecraft?

AERONET (Dubovik et al., 2002), Full Columns

OMI λ range

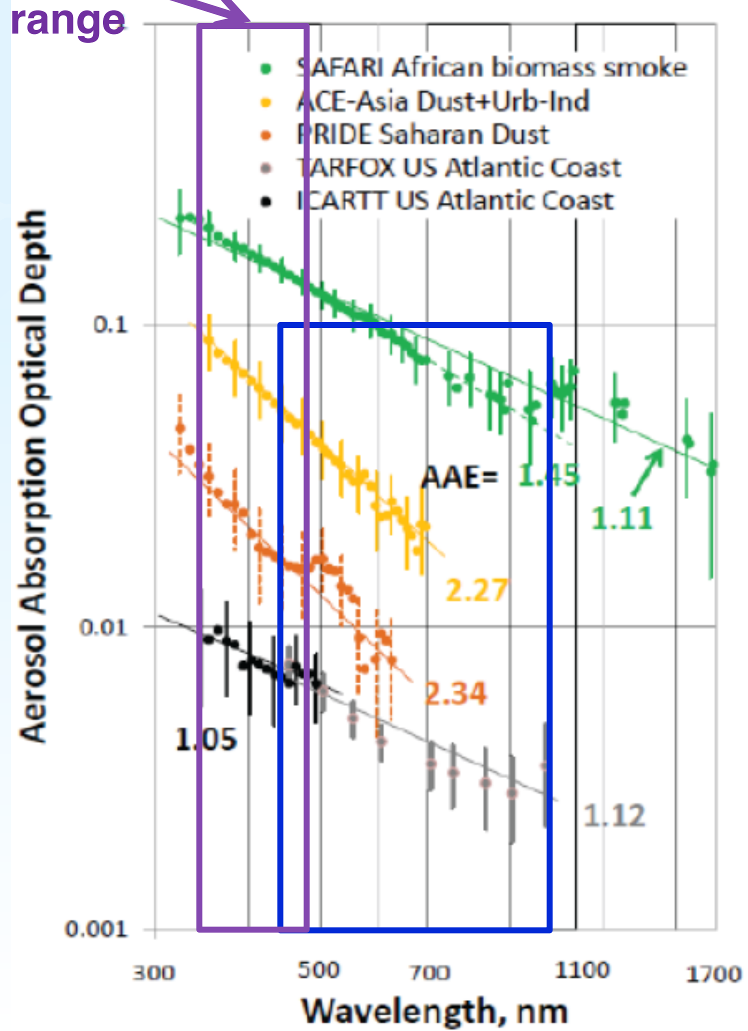


*343-484 nm

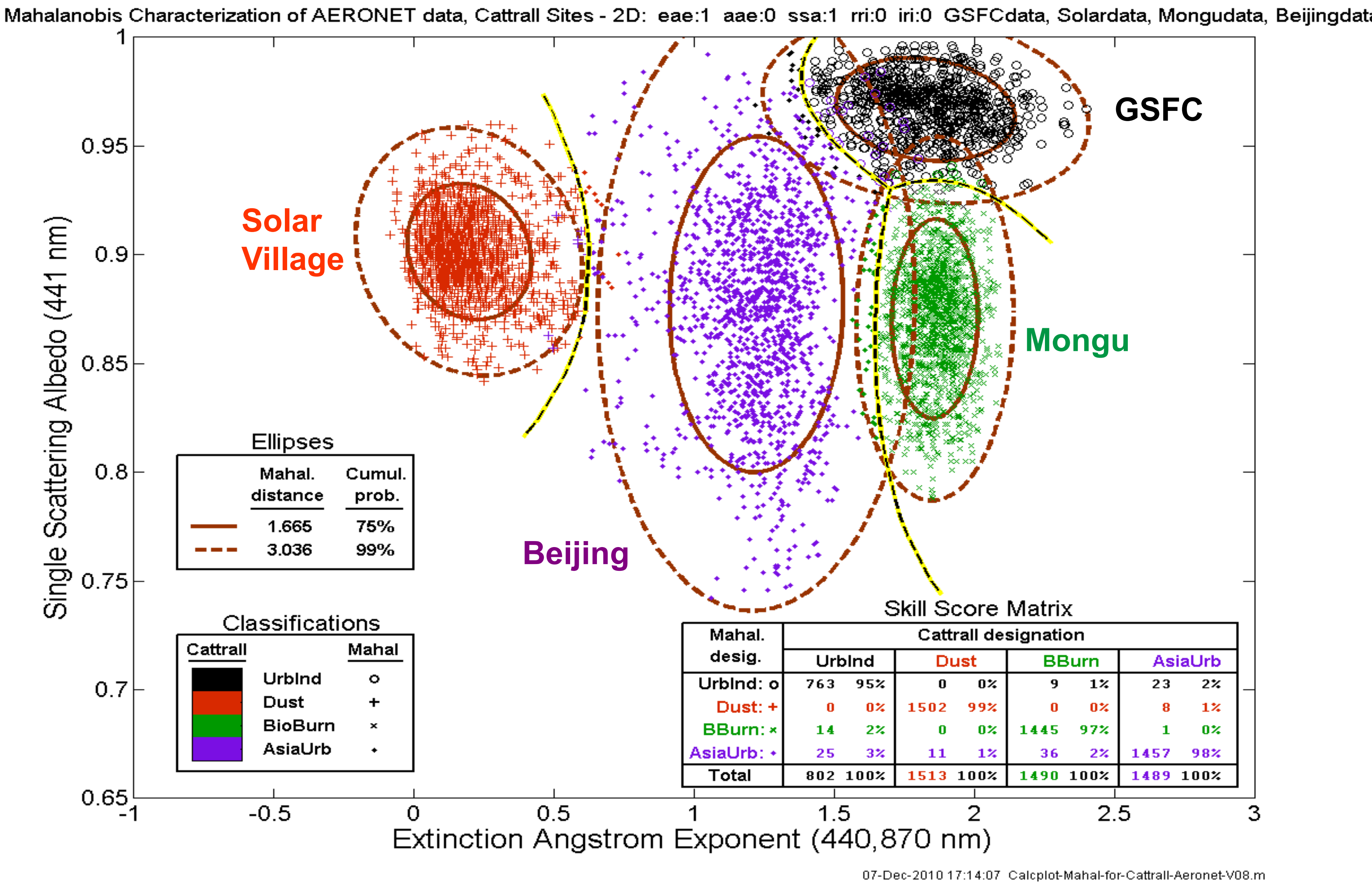
[Russell et al., *ACP* 2010]

SSFR+AATS (Bergstrom et al., 2007), Layers

OMI λ range

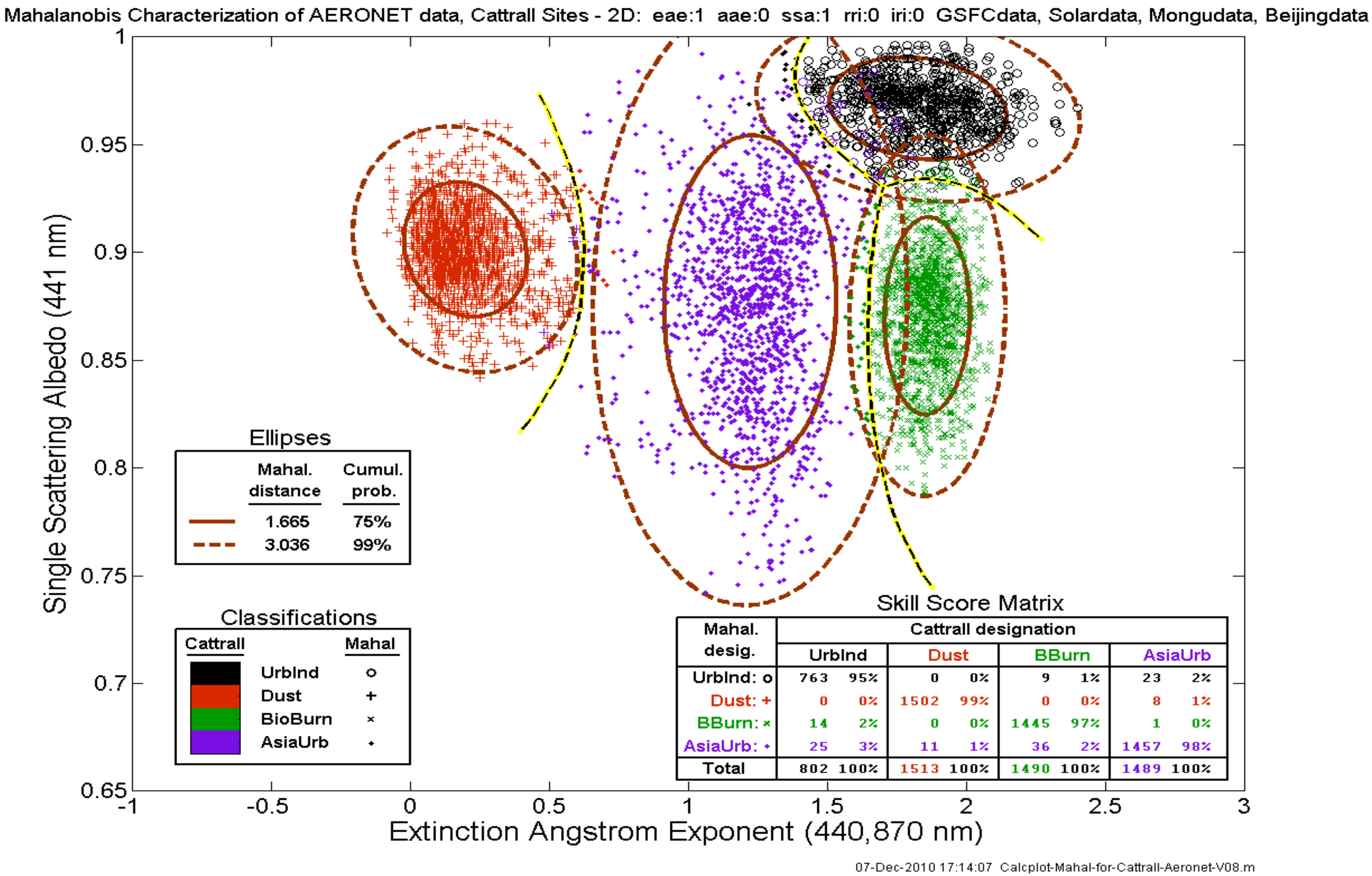


AERONET Version 2, building on Cattrall et al. (2005)



Mahal. desig.	Cattrall designation: UrbInd		Dust		BBurn		AsiaUrb	
UrbInd: o	763	95%	0	0%	9	1%	23	2%
Dust: +	0	0%	1502	99%	0	0%	8	1%
BBurn: ×	14	2%	0	0%	1445	97%	1	0%
AsiaUrb: •	25	3%	11	1%	36	2%	1457	98%
Total	802	100%	1513	100%	1490	100%	1489	100%

4.3A. 2-D Mahalanobis classification for 4 Cattrall sites



Skill Score Matrix

Mahal. desig.	Cattrall designation: UrbInd		Dust		BBurn		AsiaUrb	
UrbInd: o	763	95%	0	0%	9	1%	23	2%
Dust: +	0	0%	1502	99%	0	0%	8	1%
BBurn: ×	14	2%	0	0%	1445	97%	1	0%
AsiaUrb: ·	25	3%	11	1%	36	2%	1457	98%
Total	802	100%	1513	100%	1490	100%	1489	100%

Meet the family…

And what we do with these beautiful instruments…

NASA

Pacific Northwest
NATIONAL LABORATORY

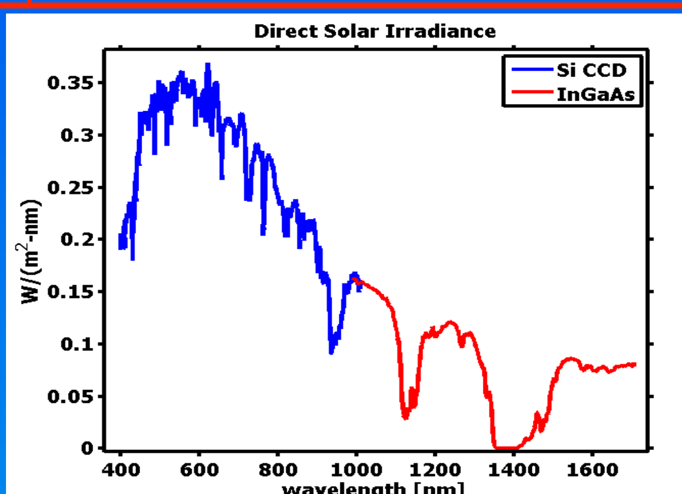
4STAR:
Spectrometer for Sky-Scanning, Sun-Tracking

Atmospheric Research

AERONET-like

- Phase function
- Size mode distributions
- $n_{re}(\lambda)$, $n_{im}(\lambda)$
- Single-scattering albedo
- Asymmetry parameter
- Shape
- Hence aerosol type

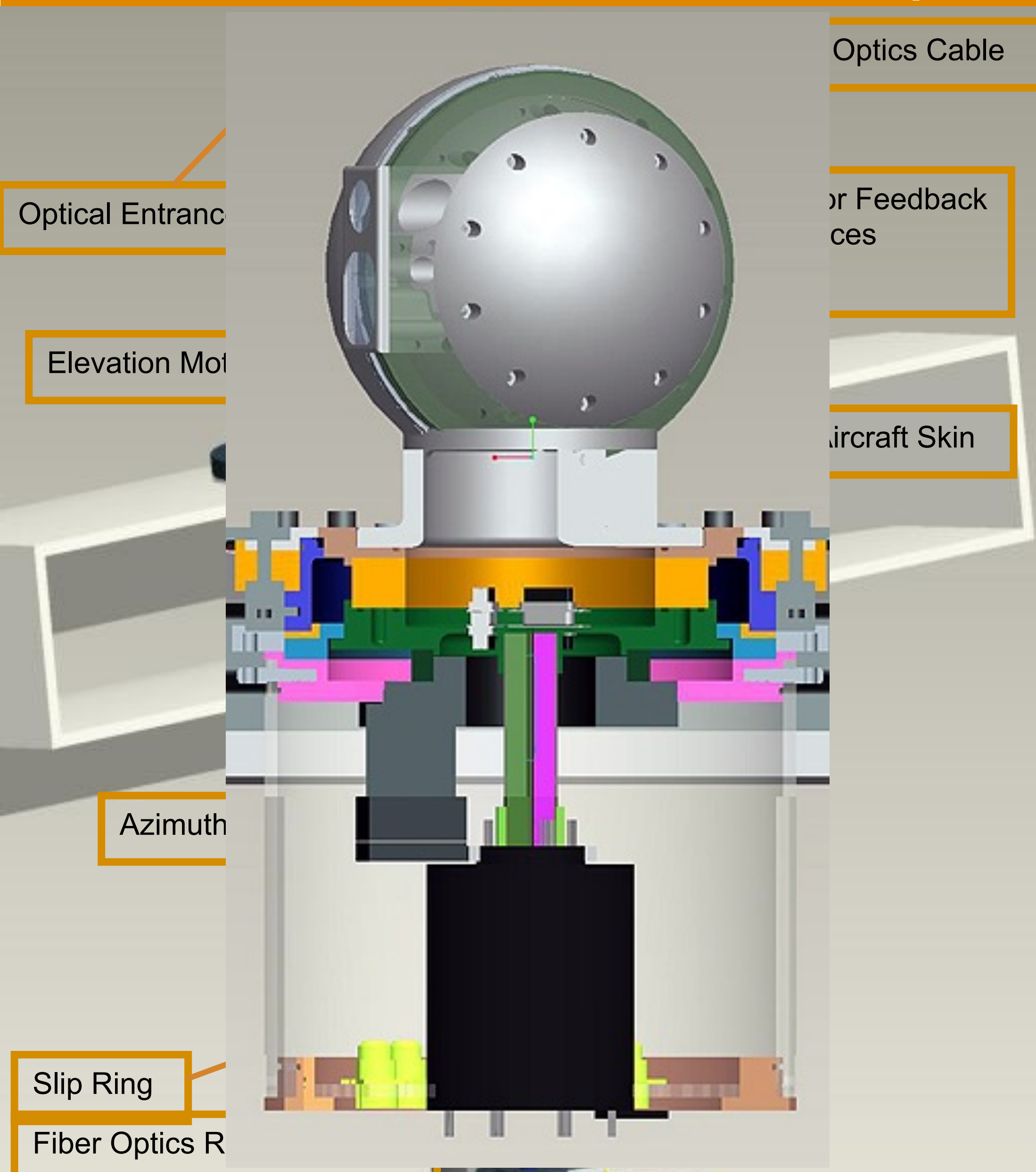
AATS-14 like retrievals of column amount and profiles of aerosol, H_2O and O_3



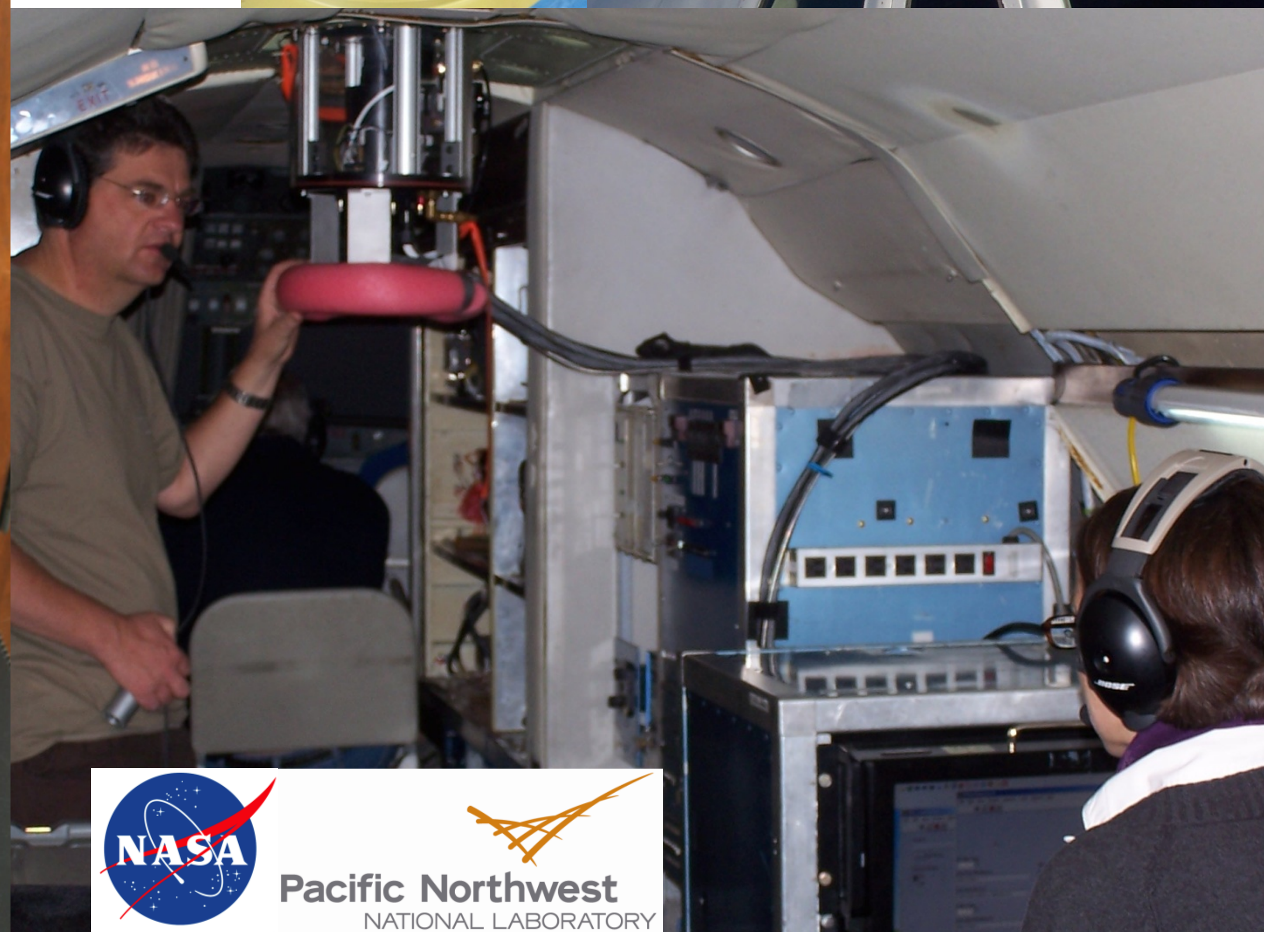
Improve H_2O, O_3
Add NO_2
Thus improve AOD

Simultaneous spectra yield airborne profiles of aerosol type via Aeronet-like retrievals

Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research (4STAR)



4STAR Integration on PNNL/Battelle G-1
Aug-Sep 2010



NASA

Pacific Northwest
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4STAR Test flights on PNNL/Battelle G-1 Sep 2010

3 flights:

1. Pilots only: Airworthiness certification
2. Science ops: Pasco, WA to San Jose, CA
3. Science ops: San Jose local

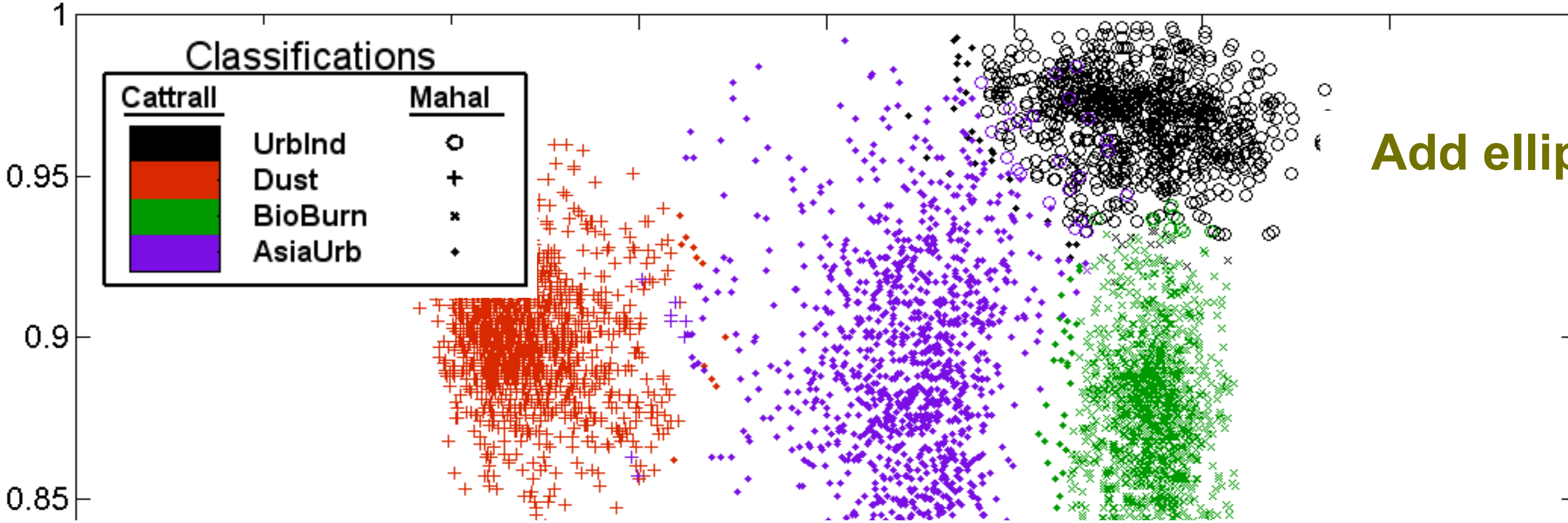
Flights met all goals (sun tracking only).

Large data set to guide improvements & test/demo flights in 2011.

NASA

Pacific Northwest
NATIONAL LABORATORY

Skill* Scores



Add ellipses

Skill Score Matrix

Mahal. desig.	Cattrall designation							
	UrbInd		Dust		BBurn		AsiaUrb	
UrbInd: o	763	95%	0	0%	9	1%	23	2%
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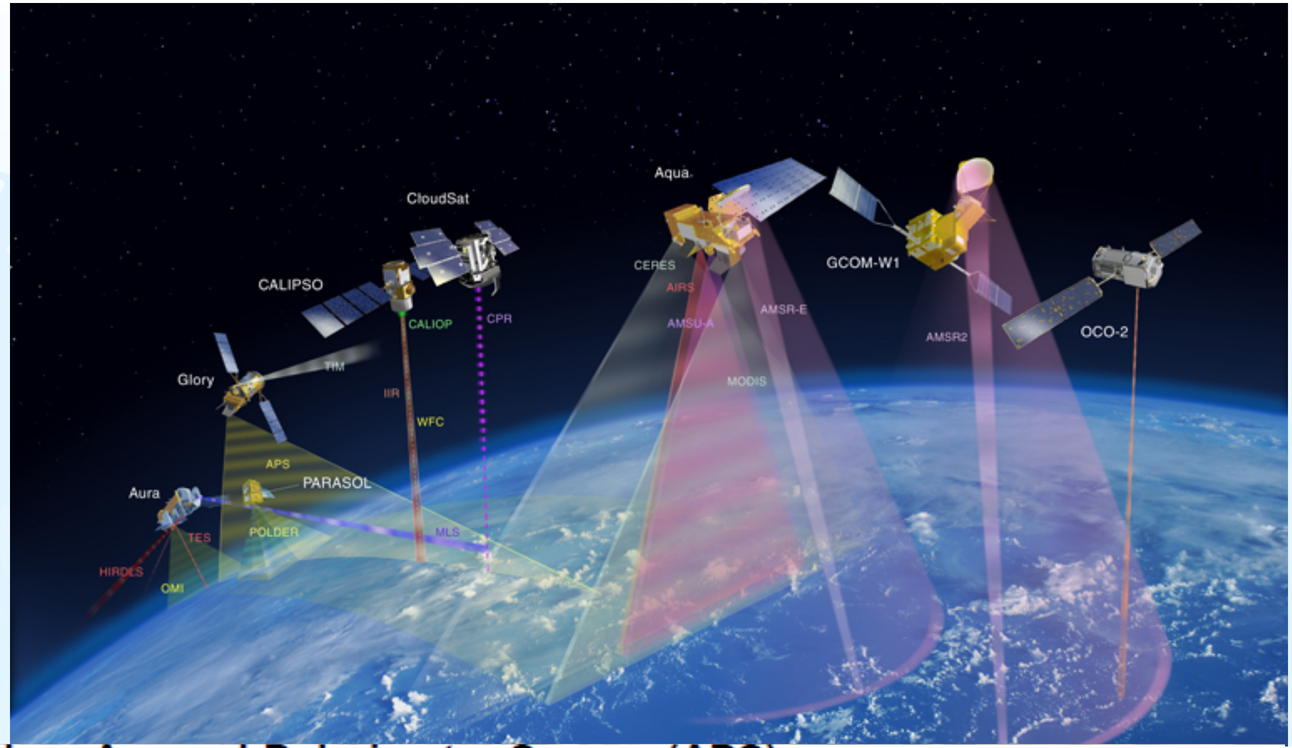
BBurn: ×	14	2%	0	0%	1445	97%	1	0%
AsiaUrb: •	25	3%	11	1%	36	2%	1457	98%
Total	802	100%	1513	100%	1490	100%	1489	100%

*** More accurately, “Sameness Scores”**

The A-Train with Glory



Glory Aerosol Polarimetry Sensor (APS) level-3 data products for aerosol columns

(adapted from Mishchenko et al., 2007)

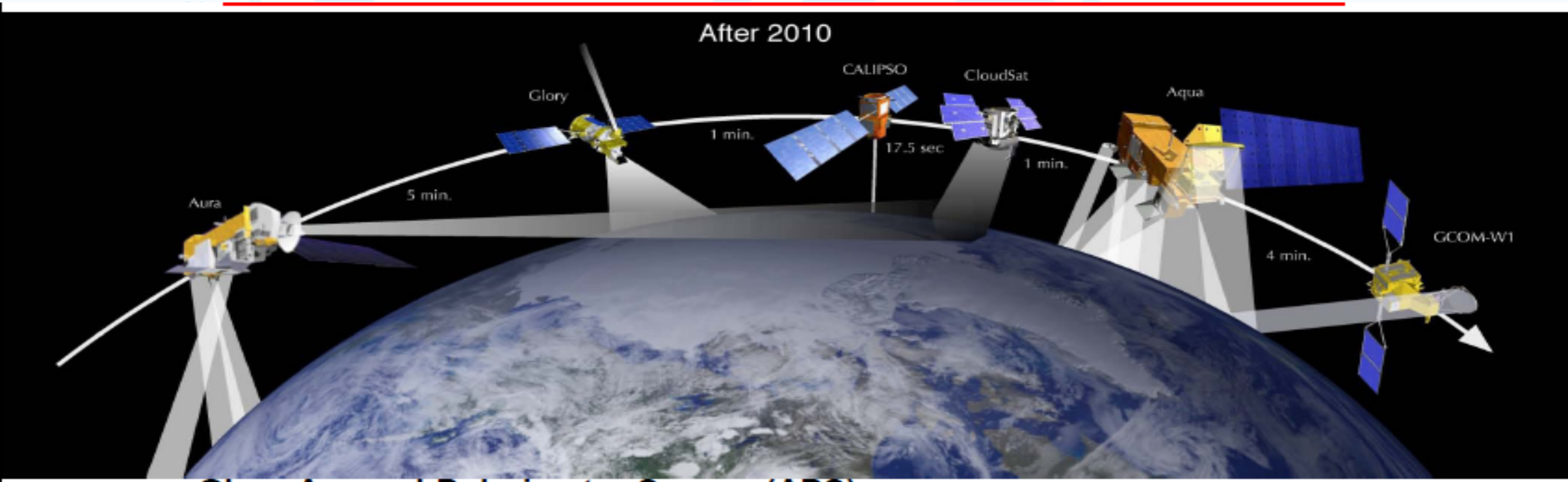
Data product (fine and coarse modes)	Range	Uncertainty
Spectral* aerosol optical depth	0-5	0.02 over ocean 0.04 over land
Aerosol effective radius	0.05-5 μm	10%
Effective variance of aerosol size distribution	0-3	40%
Aerosol spectral* real refractive index	1.3-1.7	0.02
Aerosol spectral* single-scattering albedo	0-1	0.03
Aerosol morphology	Spherical aerosols, irregular dust particles, soot clusters	N/A

*At least in three spectral channels; relative accuracy better where AOD is larger (typically 410-865 nm).

Lost on launch, Mar 2011

- **Possible refly.**
- **Airborne version: RSP**
- **Others: POLDER, PACE, ACE, …**

1F. The A-Train with Glory



Glory Aerosol Polarimetry Sensor (APS) level-3 data products for aerosol columns

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Data product (fine and coarse modes)	Range	Uncertainty
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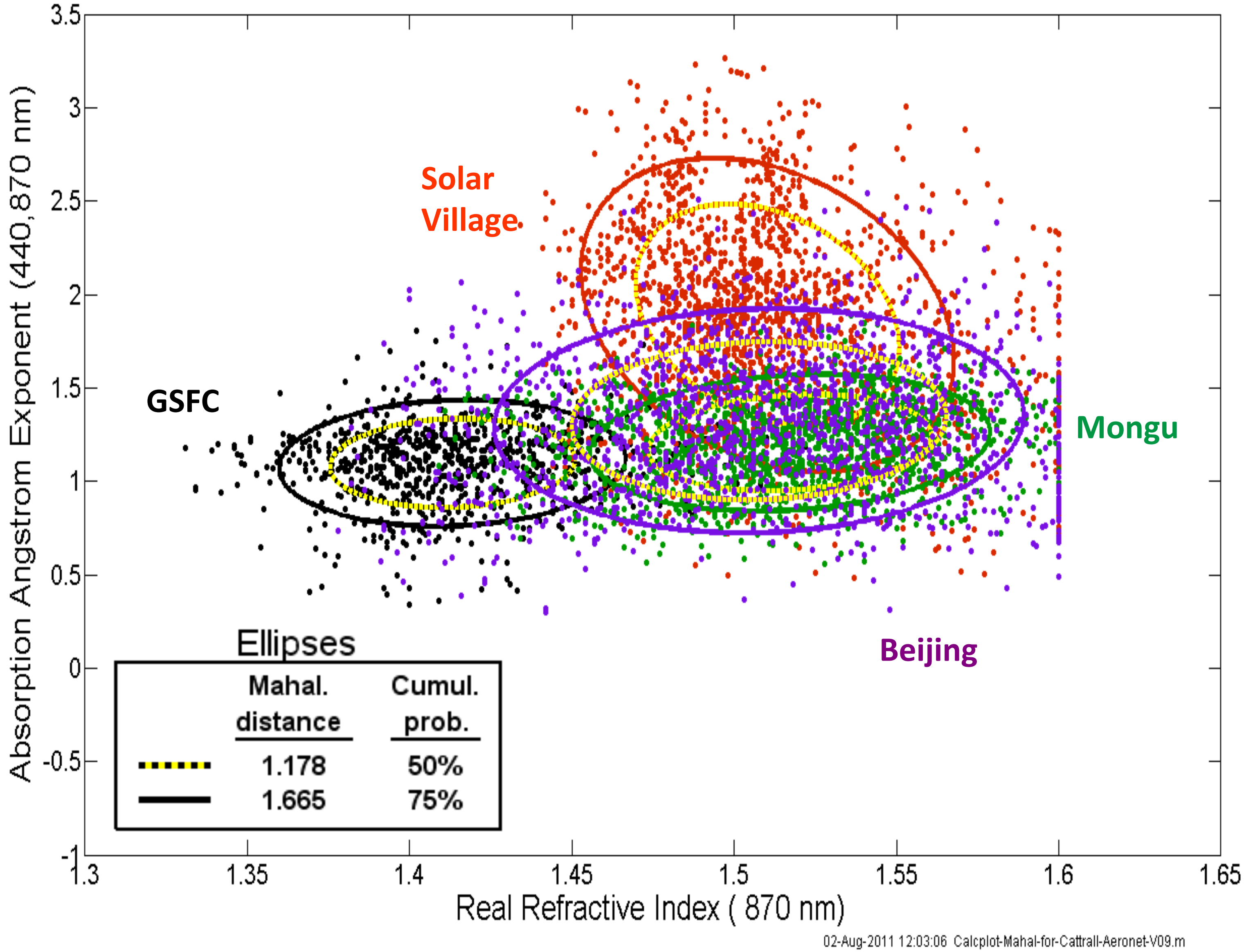
Effective variance of aerosol size distribution	0-3	40%
Aerosol spectral* real refractive index	1.3-1.7	0.02
Aerosol spectral* single-scattering albedo	0-1	0.03
Aerosol morphology	Spherical aerosols, irregular dust particles, soot clusters	N/A

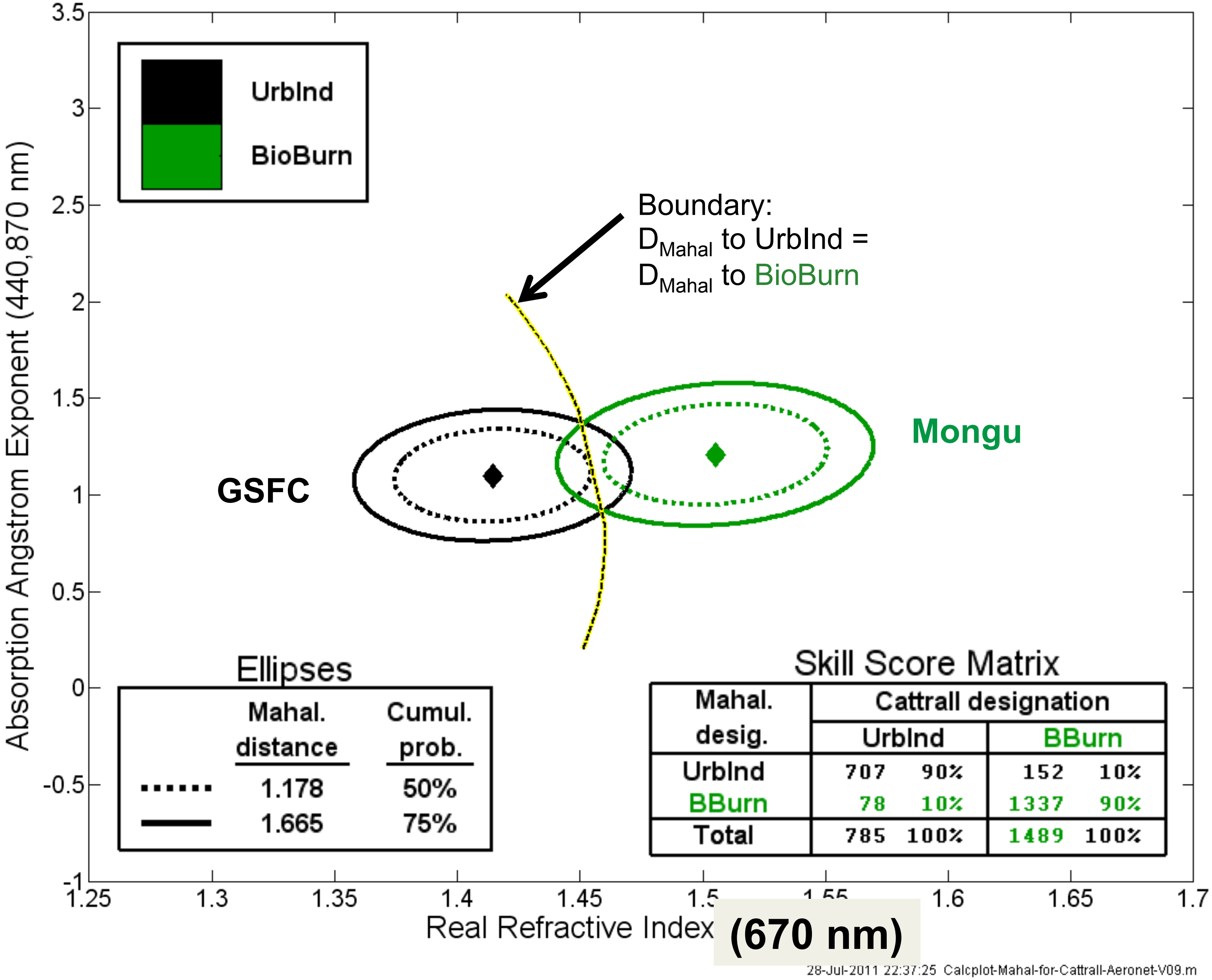
*At least in three spectral channels; relative accuracy better where AOD is larger (typically 410-865 nm).

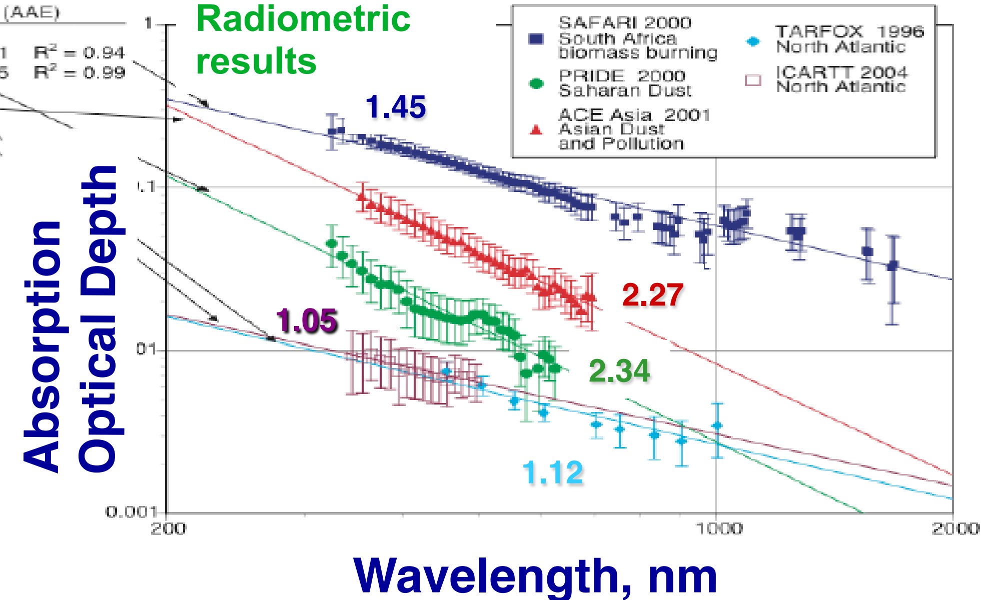
Absorption

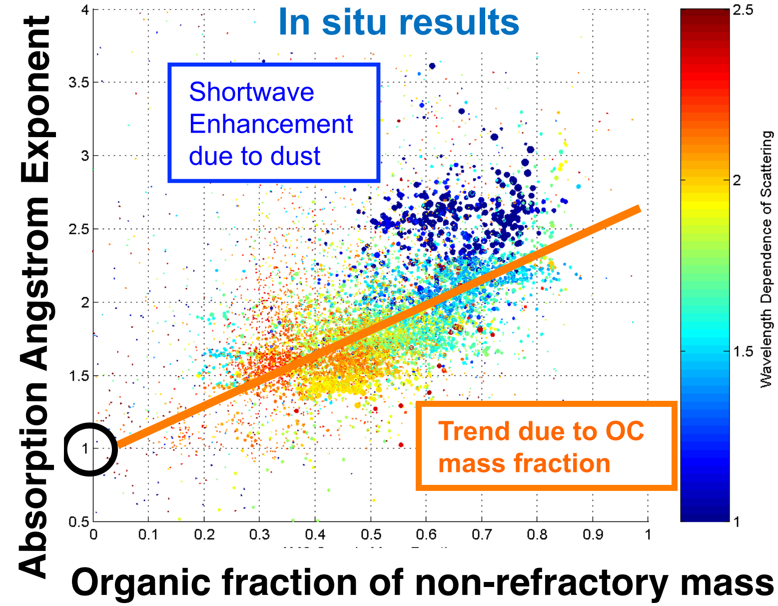
AAOD = AOD*(1-SSA)


Solar Village
GSFC
Mongu
Beijing
Ellipses
Mahal. distance
Cumul. prob.
1.178
50%
1.665
75%
Absorption Angstrom Exponent (440,870 nm)
Real Refractive Index (870 nm)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
1.3
1.35
1.4
1.45
1.5
1.55
1.6
1.65
02-Aug-2011 12:03:06 Calcplot-Mahal-for-Cattrall-Aeronet-V09.m

For RRI, separation increases with λ, and so do Skill Scores





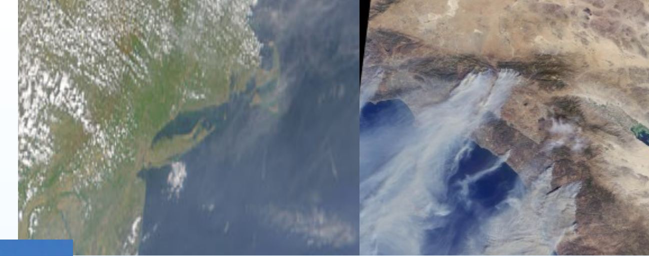


Significance: Both the radiometric and the in situ results indicate that knowledge of Absorption Angstrom Exponent, plus size (or Extinction or Scattering Angstrom Exponent) can help to determine particle composition.

- This holds out the promise of determining aerosol composition from space, provided Absorption Angstrom Exponent can be determined from space.

- Glory APS promised to do this. The airborne version, RSP, continues to do so.

Next Steps



- Begin to apply techr … AERONET:
  - RSP
  - RSP + HSRL
  - POLDER (Dubovik
  - 4STAR

Improve realism of Gl… h airborne <u>RSP data</u> and also <u>enhanced F</u>…

- <u>Extend tests</u> to more … RONET sites and retrieved parameters … and the <u>generality of aerosol type assign</u>… —the news is good!]

- Extend input data sets to parameters from other sensors (e.g., CALIOP layer heights, OMI UV absorption).