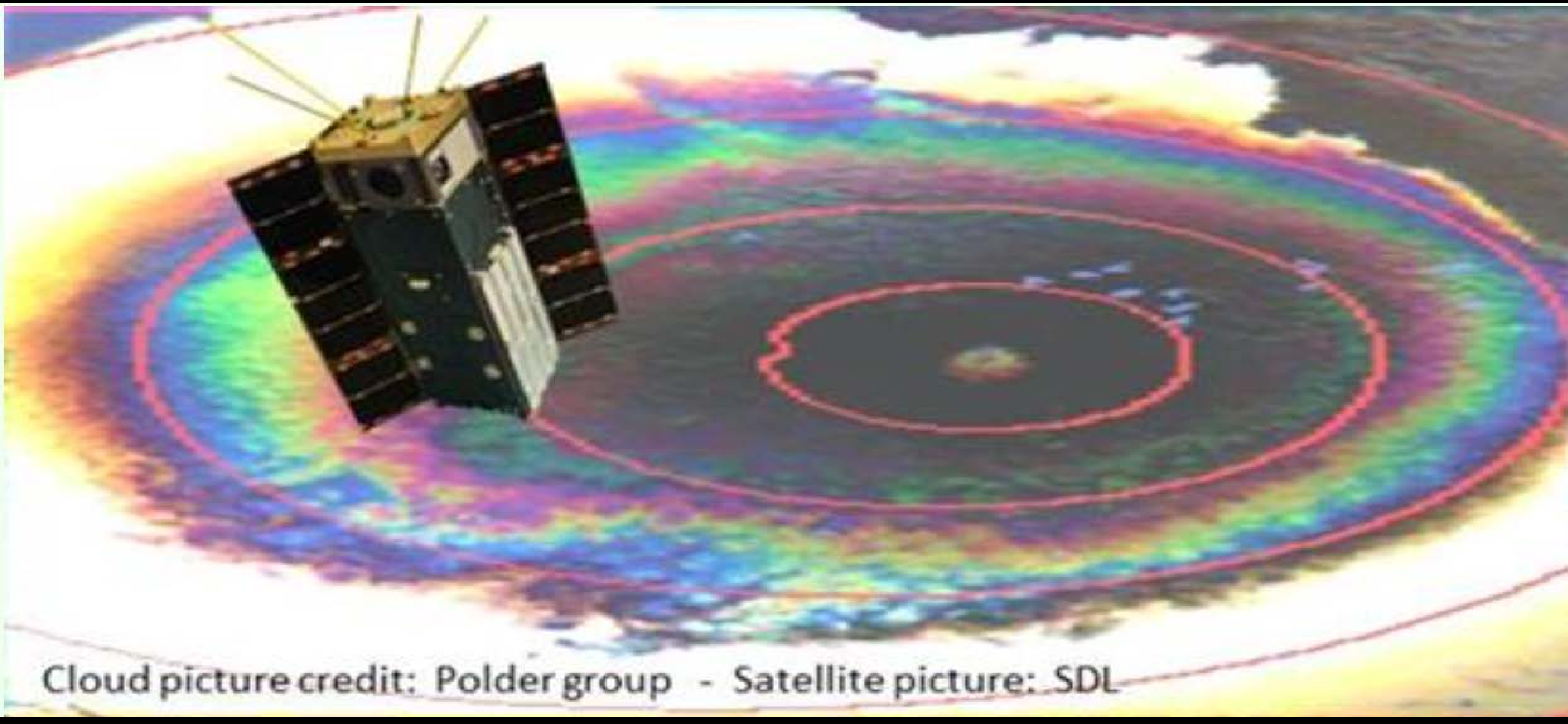
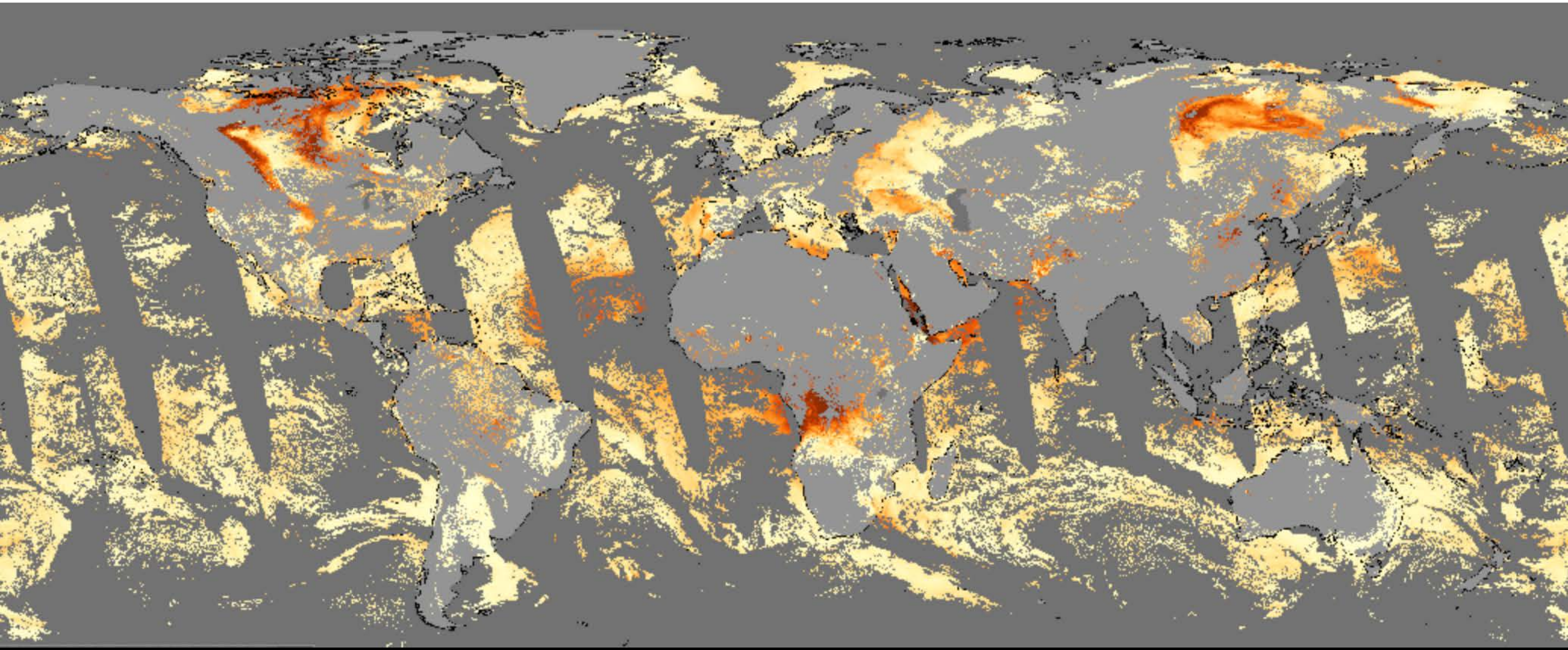
Aerosol Remote Sensing and Atmospheric Correction Beyond VIIRS: What will Expanded Wavelengths, Hyperspectral, Multi-angle, and Polarization Bring to the Table

Lorraine A. Remer
JCET-UMBC



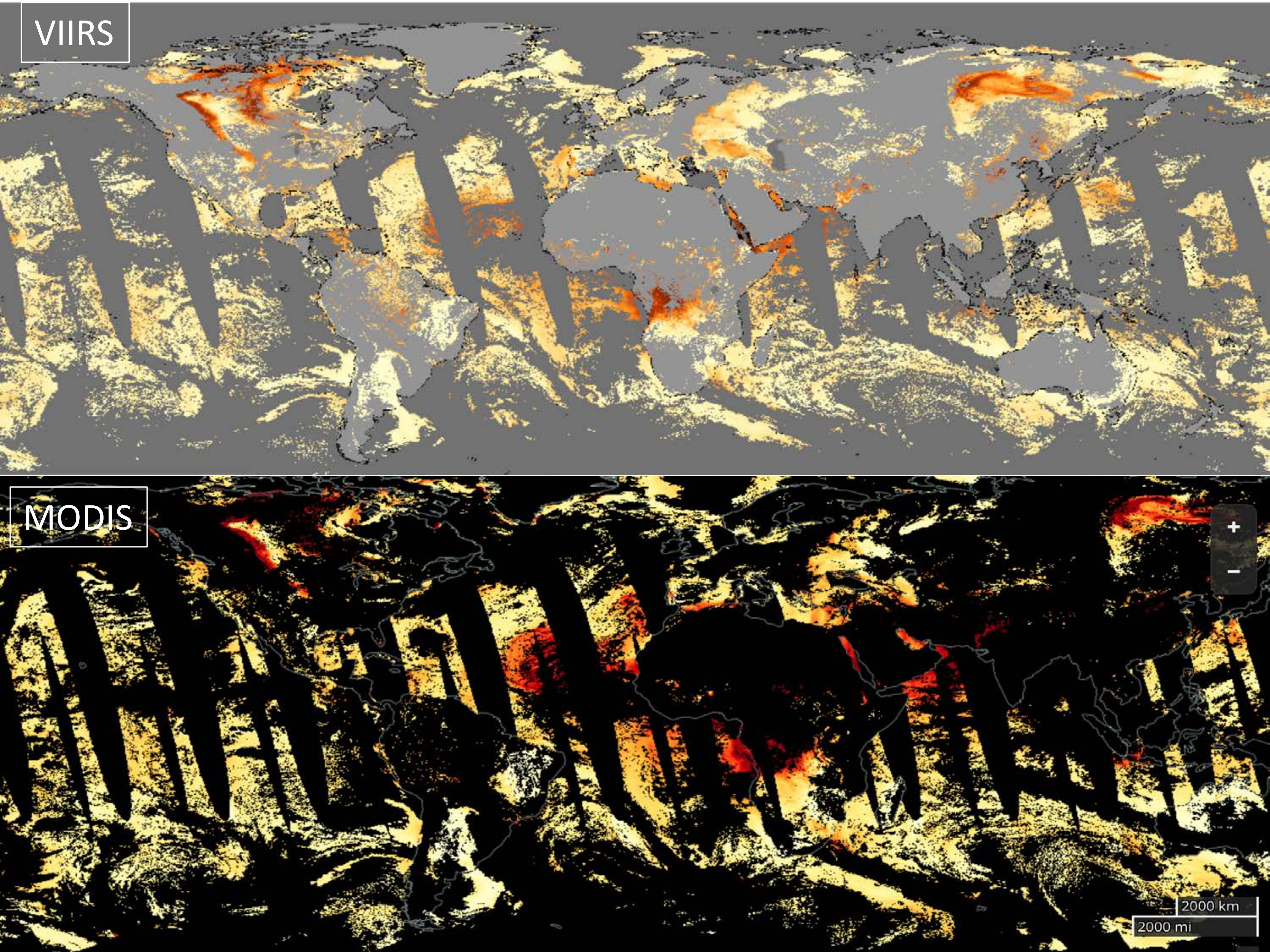
Global Aerosol Optical Depth at 550 nm from VIIRS (IDPS)
13 August 2017



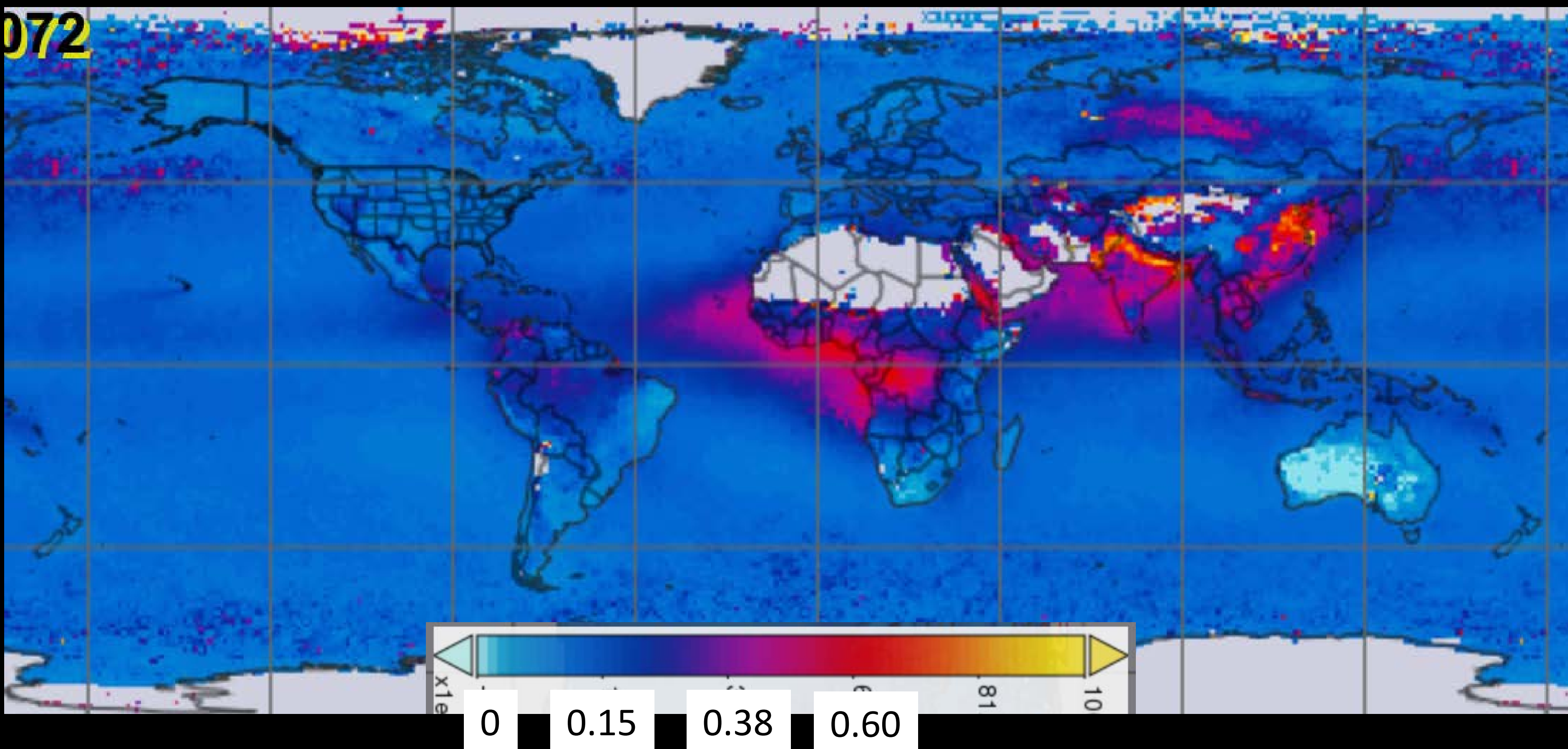
NOAA Global View

Global Aerosol Optical Depth at 550 nm from Aqua MODIS (DT)
13 August 2017

NASA World View


VIIRS
MODIS
+
−
2000 km
2000 mi

Global Aerosol Optical Depth at 550 nm from Aqua MODIS (DT)
2016 Annual Mean



NASA Giovanni

$$\underbrace{L(\tau^{*}, \mu_o, \mu, \varphi)}_{\text{Radiance measured at satellite}} = \underbrace{L_o(\tau^{*}, \mu_o, \mu, \varphi)}_{\text{Radiance from atmosphere}} + \underbrace{\frac{R E_o T_t(\tau^{*}, \mu)}{1 - RS}}_{\text{Radiance from surface}}$$

μ_o = cos(solar zenith angle)

μ = cos(sensor zenith angle

φ = relative azimuth

τ^* = aerosol optical thickness

R = surface reflectance

E_o = extraterrestrial irradiance

T_t = total transmission

S = spherical albedo

$$\underbrace{L(\tau^{*}, \mu_{o}, \mu, \varphi)}_{\text{Radiance measured at satellite}} = \underbrace{L_{o}(\tau^{*}, \mu_{o}, \mu, \varphi)}_{\text{Radiance from atmosphere}} + \underbrace{\frac{R E_{o} T_{t}(\tau^{*}, \mu)}{1 - RS}}_{\text{Radiance from surface}}$$

μ_o = cos(solar zenith angle)
μ = cos(sensor zenith angle
φ = relative azimuth
τ^* = aerosol optical thickness

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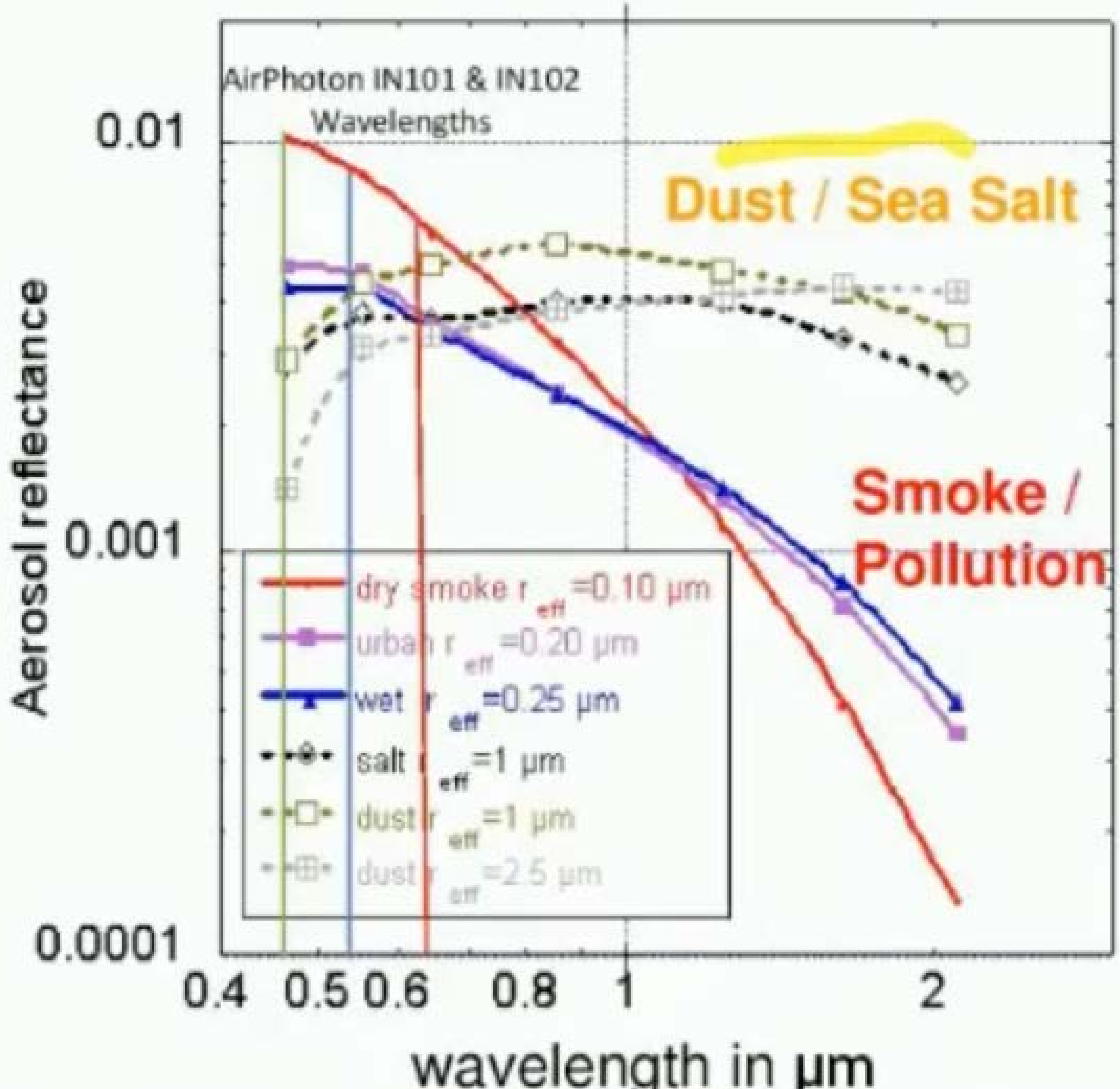
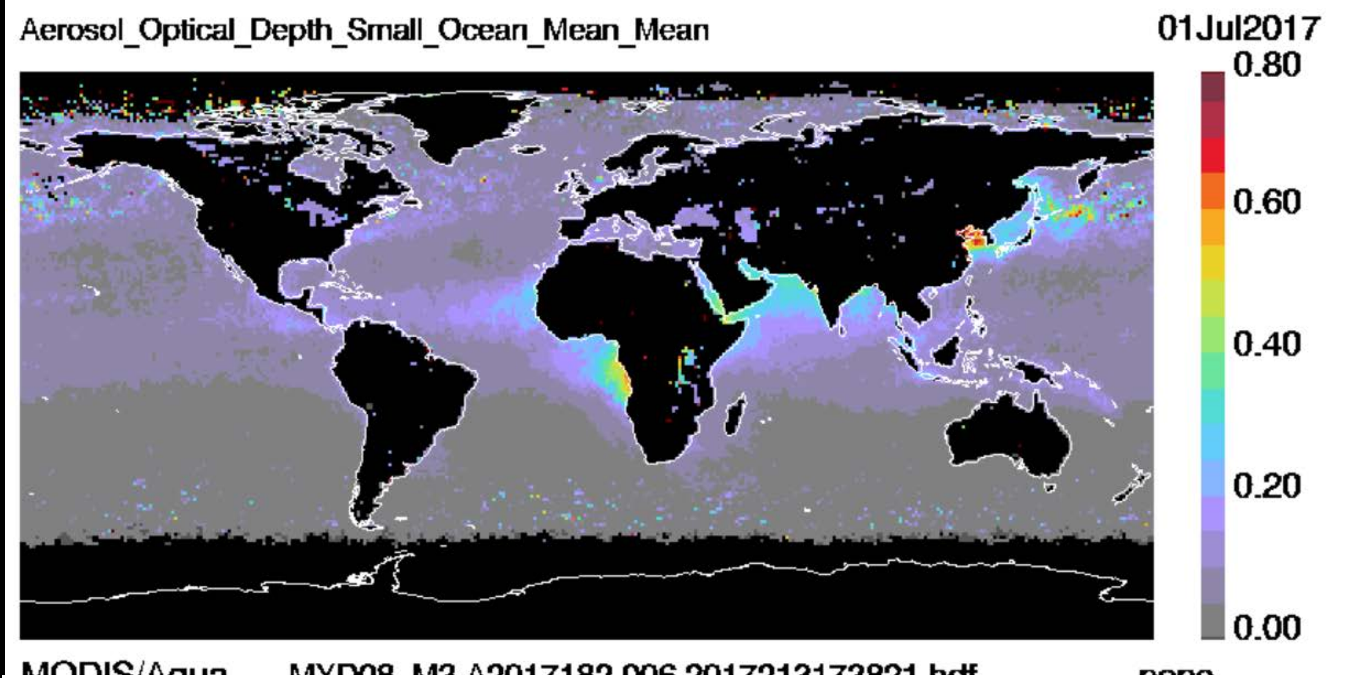
T_t = total transmission
S = spherical albedo

This is a single channel Dark Target retrieval.
(one wavelength at a time)

Requires assumptions of particle size and refractive index, as well as surface reflectance

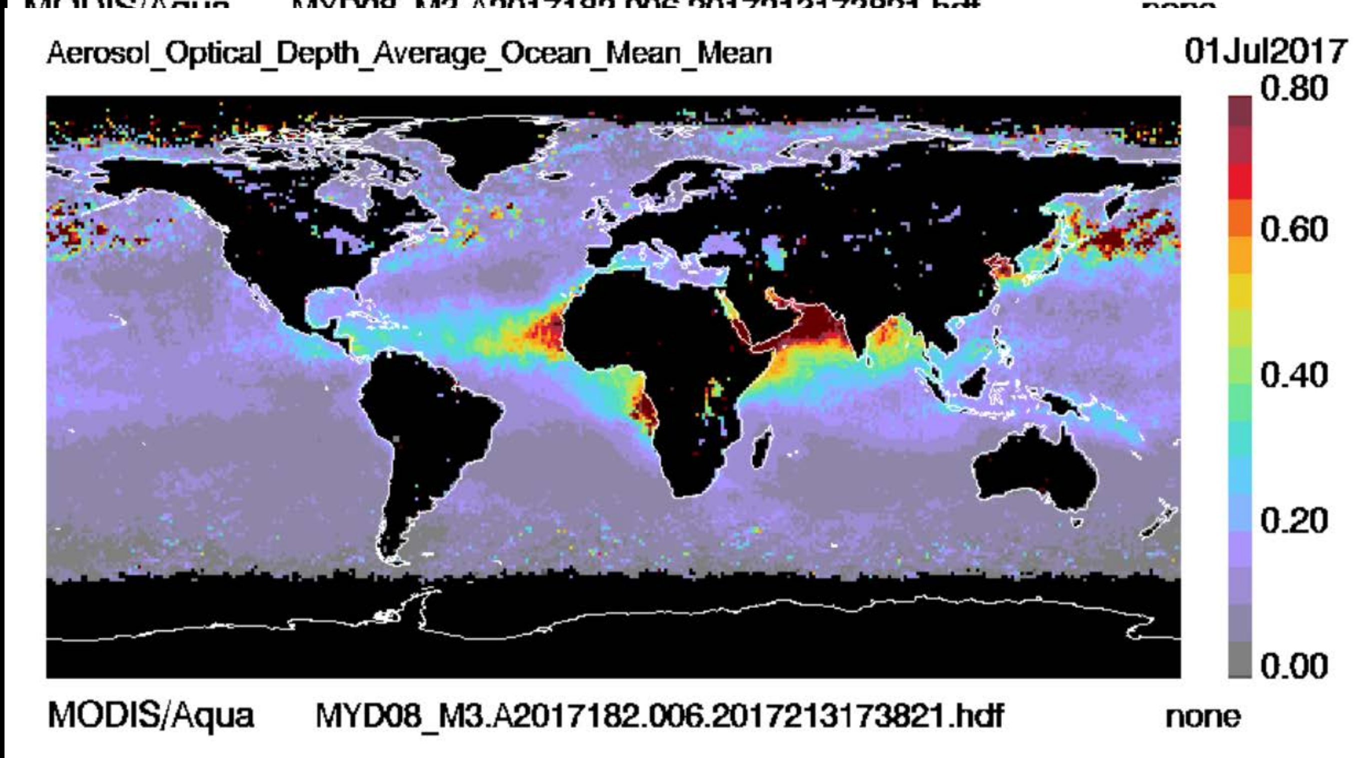
Returns 1 piece of information: τ^*


AirPhoton IN101 & IN102
Wavelengths
Dust / Sea Salt
Smoke /
Pollution
Aerosol reflectance
0.01
0.001
0.0001
0.4
0.5
0.6
0.8
1
2
wavelength in µm
dry smoke r eff =0.10 µm
urban r eff =0.20 µm
wet r eff =0.25 µm
salt r eff =1 µm
dust r eff =1 µm
dust r eff =2.5 µm



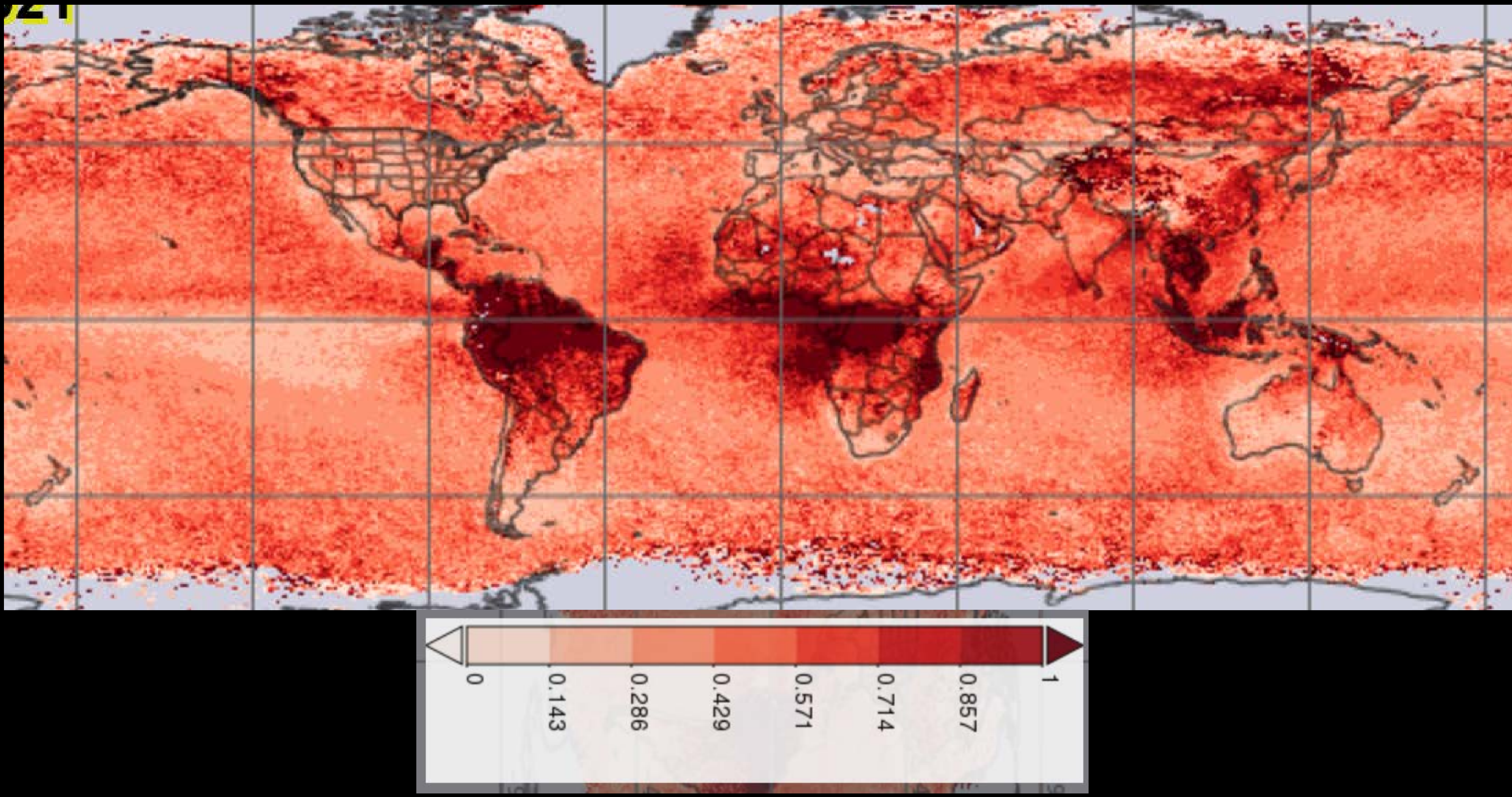
AOD 550 nm
Aqua MODIS
Monthly mean
July 2017

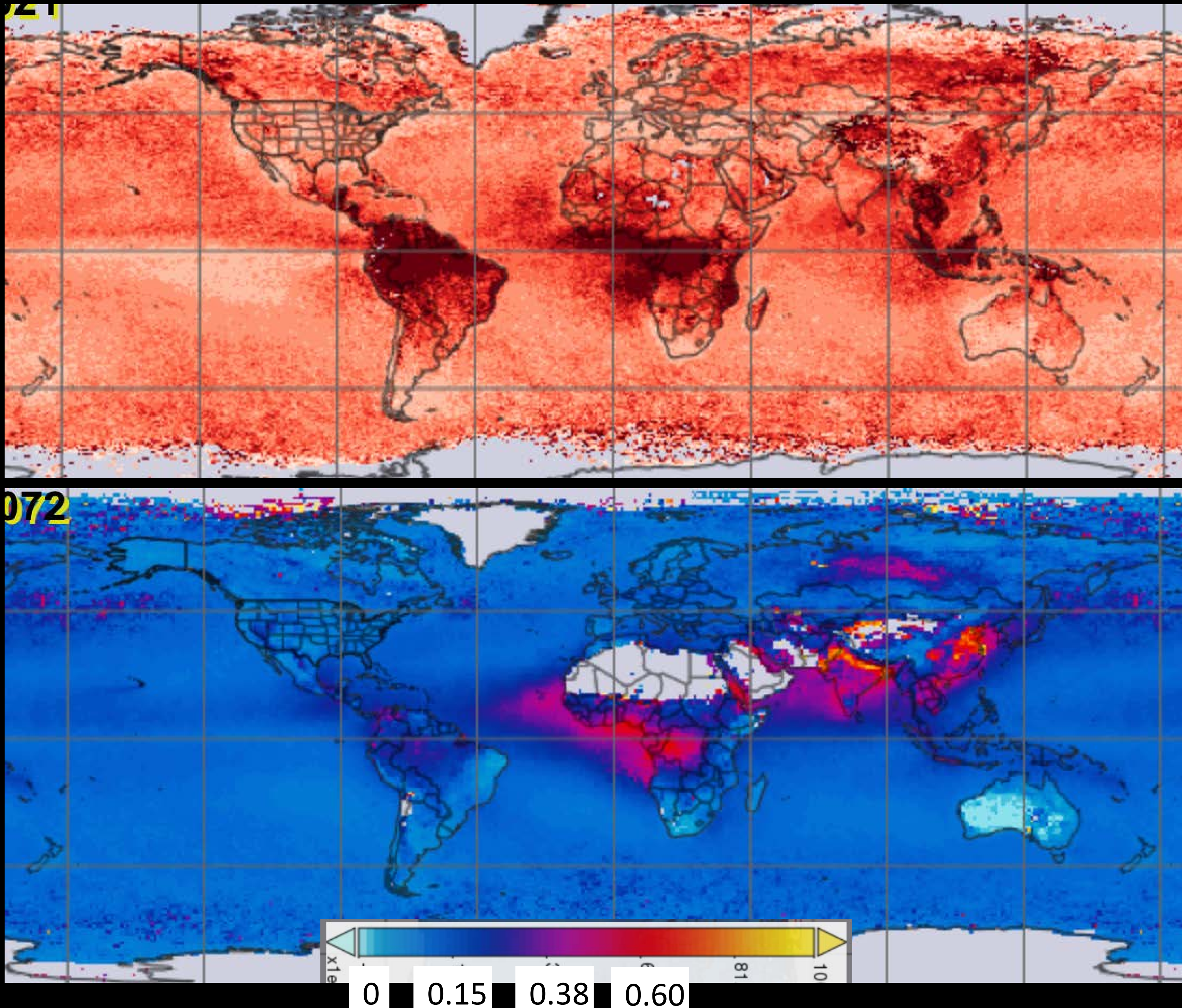
Fine mode only



Total AOD

Global Aerosol Optical Depth at 483 nm from Aura OMI
2016 Annual Mean




0
0.15
0.38
0.60

Radiative transfer in the near UV

$$\underbrace{L^{*}(\Omega,\mu,\mu_0,\varphi,p_0)}_{\text{Radiance measured at satellite}} = \underbrace{L^{0}(\Omega,\mu,\mu_0,\varphi,p_0)}_{\text{Radiance from atmosphere}} + \underbrace{\frac{RT_t(\Omega,\mu,\mu_0,p_0)}{1-RS(\Omega,p_0)}}_{\text{Radiance from surface}}$$

Ω = ozone content

p_o = surface pressure

Note: no dependence on aerosol in the equation

Radiative transfer in the near UV

$$L^{*}(\Omega,\mu,\mu_0,\varphi,p_0) = L^{0}(\Omega,\mu,\mu_0,\varphi,p_0) + \frac{RT_t(\Omega,\mu,\mu_0,p_0)}{1 - RS(\Omega,p_0)}$$

$$R_{\lambda_0} = \frac{L^{*}_{\lambda_0} - L^{0}_{\lambda_0}}{T_{t\_\lambda_0} + S_{\lambda_0}(L^{*}_{\lambda_0} - L^{0}_{\lambda_0})}$$

Reflectance of the lower surface in one wavelength.

If no aerosol, and ozone absorption is minimal (330-390 nm), then <u>just Rayleigh scattering</u>.

Radiative transfer in the near UV

L^0, T_t and S are obtained from Rayleigh scattering calculations

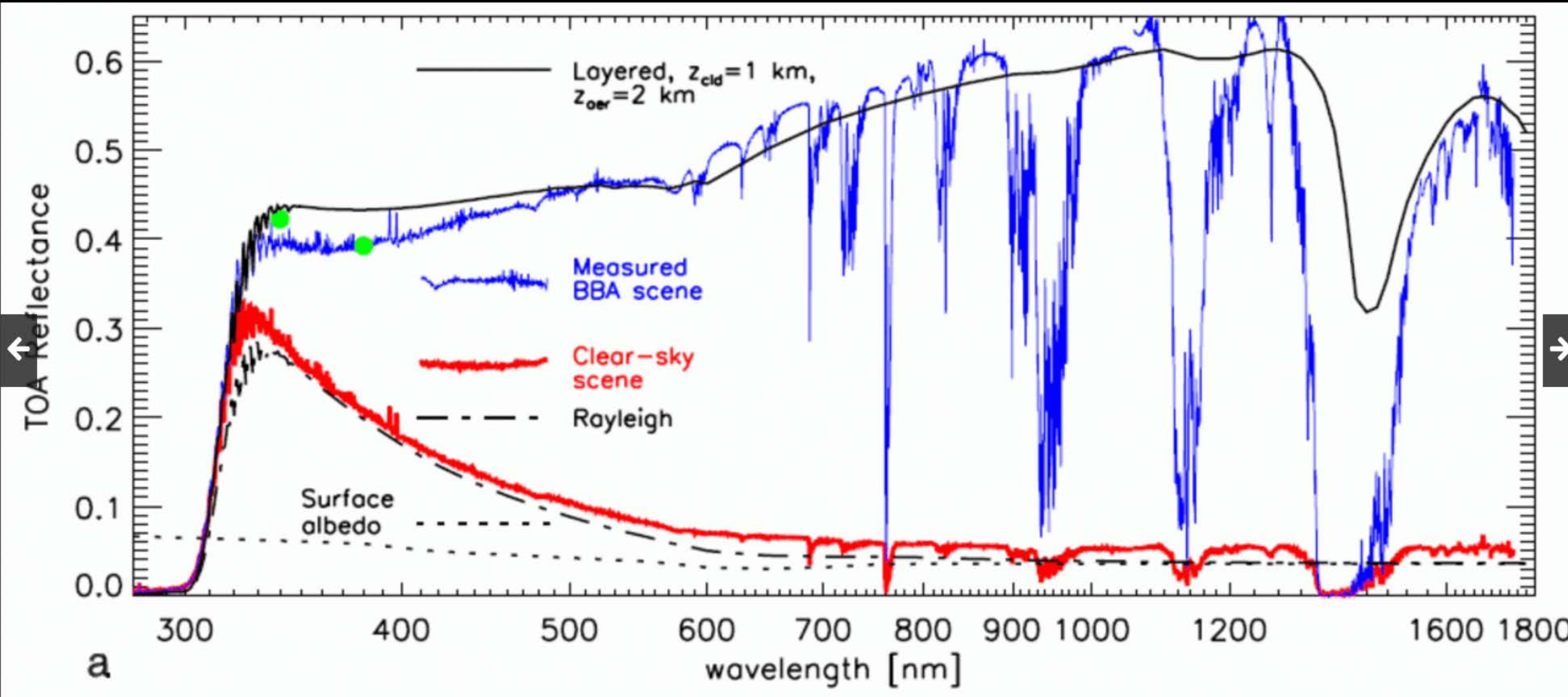
$$R_{\lambda_0} = \frac{L^*_{\lambda_0} - L^0_{\lambda_0}}{T_{t\_\lambda_0} + S_{\lambda_0}(L^*_{\lambda_0} - L^0_{\lambda_0})}$$

Assume lower surface reflectance has NO spectral dependence.

Calculate R at two wavelengths.

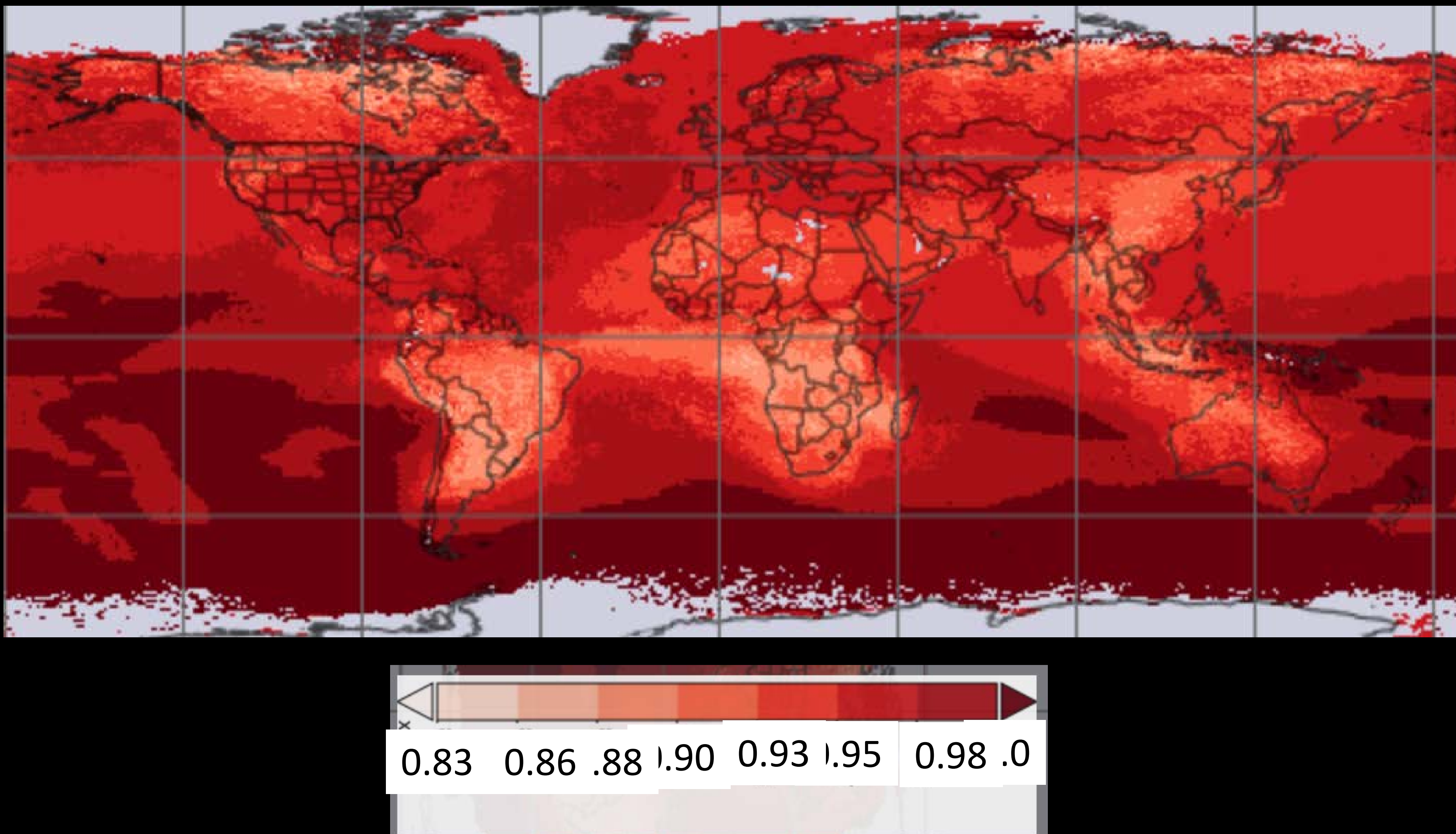
All spectral dependence should match Rayleigh expectations. If not then**, AEROSOL**.

Another SCIAMACHY scene of smoke over broken clouds over ocean



Measurements deviate from Rayleigh-only expectations,
In **magnitude** and in **spectral dependence**.

Global Aerosol Single Scattering albedo at 483 nm from Aura OMI
2016 Annual Mean



One additional problem with the UV approach…

In the UV, deviation from Rayleigh depends on the height of the aerosol.

2 pieces of information/ 3 important parameters:

- Loading (AOD)
- Absorption (SSA)
- Height (h)

The dark target VNIR-SWIR approach…

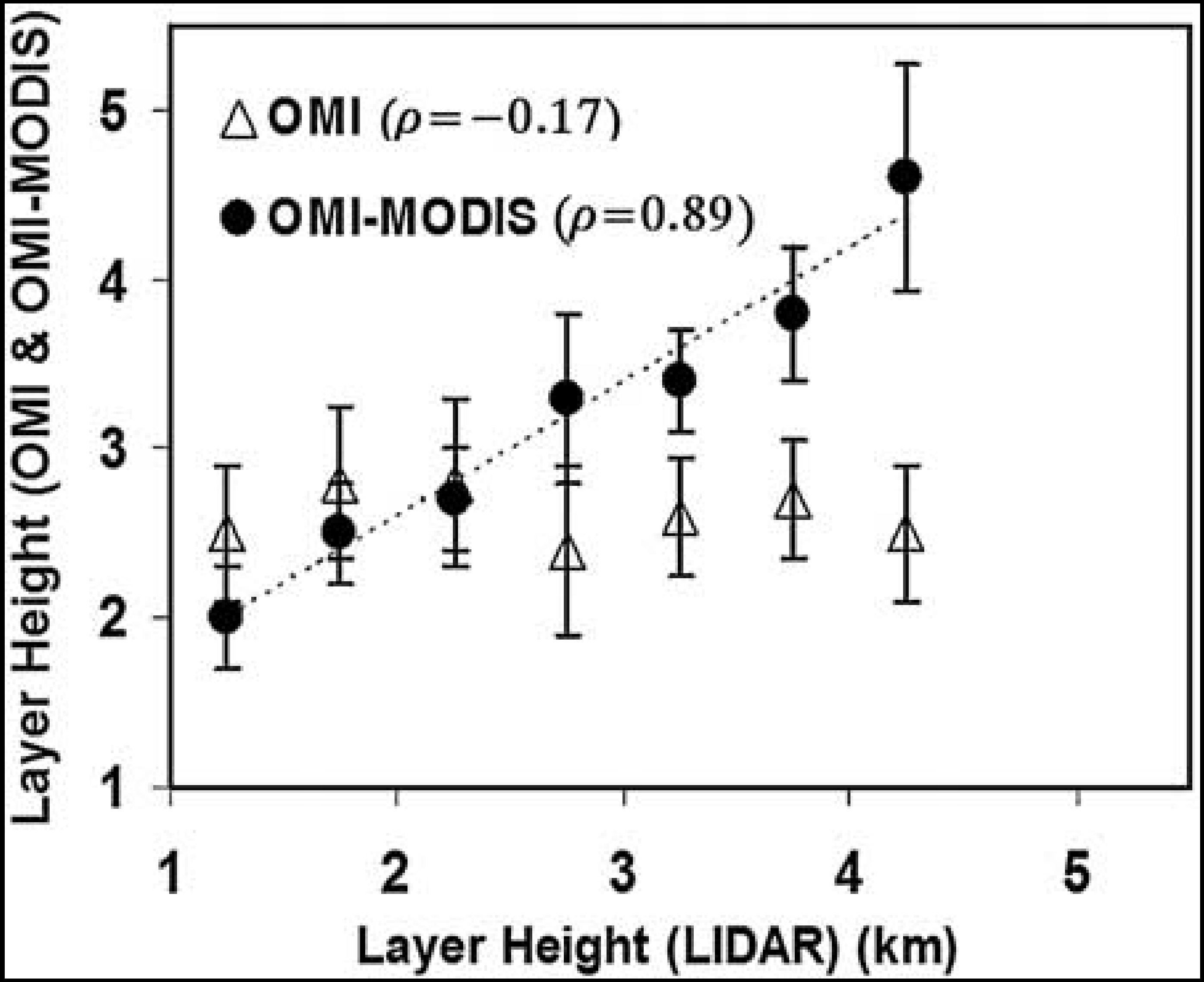
- Quantify the deviation from background radiance
- Spectral dependence gives size.

The UV approach…

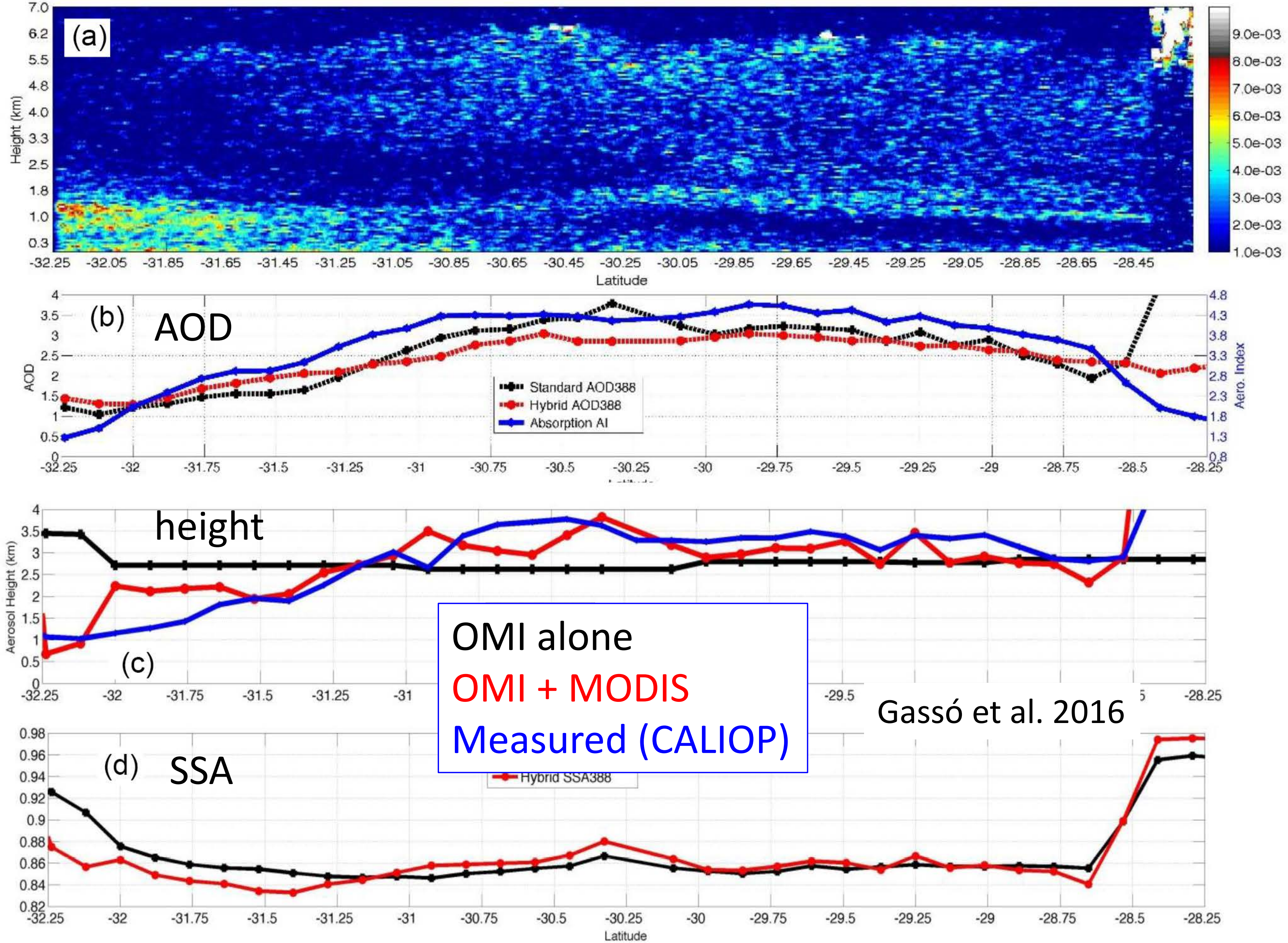
- Quantify the deviation from Rayeigh scattering
- Spectral dependence gives absorption

Combining approaches (MODIS + OMI) we should be able to retrieve **all 3 parameters: AOD, SSA and h**

Retrieval of aerosol height (combined L2 products, not radiances)

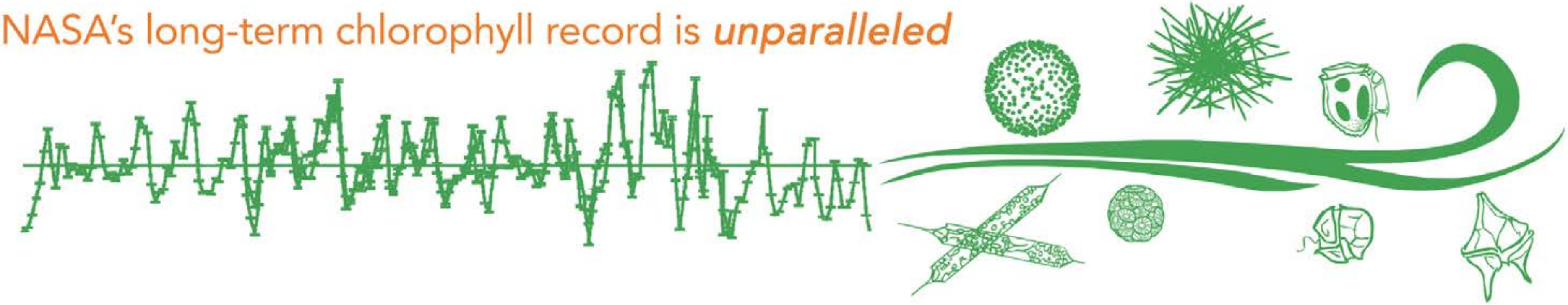


Satheesh, Torres, Remer et al., JGR, 2009


(a)
Height (km)
Latitude
(b)
AOD
Standard AOD388
Hybrid AOD388
Absorption AI
Aero. Index
height
Aerosol Height (km)
(c)
OMI alone
OMI + MODIS
Measured (CALIOP)
Gassó et al. 2016
(d)
SSA
Hybrid SSA388
Latitude

Plankton, Aerosol Cloud ocean Ecosystems
NASA mission for 2022

NASA's long-term chlorophyll record is ***unparalleled***



PACE will show ***all chlorophyll is not created equal***

Primary instrument : Ocean Color Instrument (OCI)

OCI Specifics:

- Single detector, rotating telescope scanner (like SeaWiFS)
- 20-degree tilt to avoid sun glint
- Monthly lunar calibration of all science detectors
- Ground sample distance ~ 1 square kilometer at nadir

- 5 nanometer (nm) resolution from 350 to 890 nm
- Plus short-wave infrared (SWIR) bands centered on 940, 1240, 1380, 1640, 2130 & 2250 nm

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1 km

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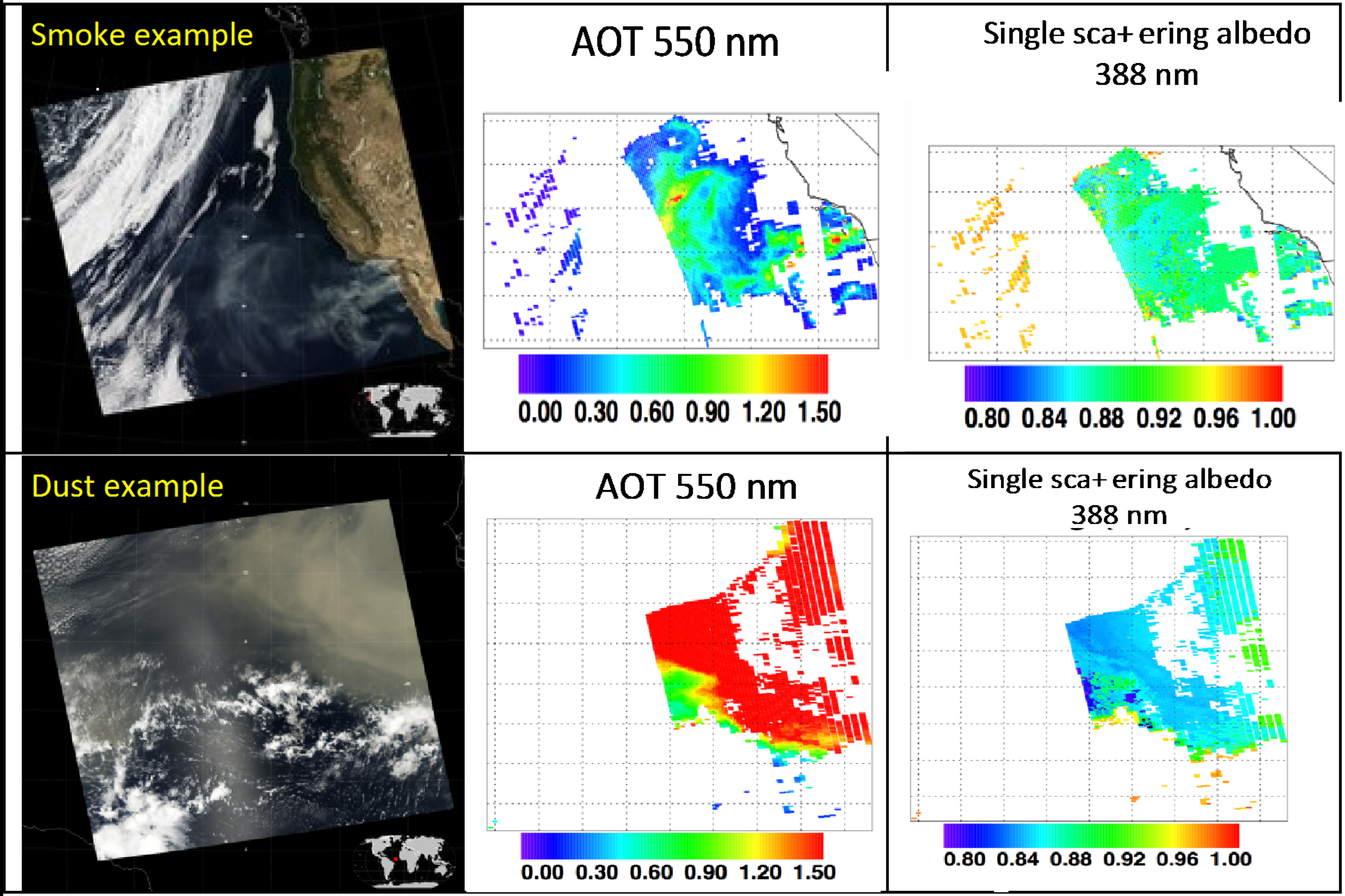

Mattoo and Remer (in progress)

Expected for PACE from OCI

Spectral AOD, SSA and height over oceans (when AOD_550 is sufficiently high ~0.30)

Land not yet explored.

In forward processing, at 3 to 10 km, Across the OCI swath (2-day coverage)

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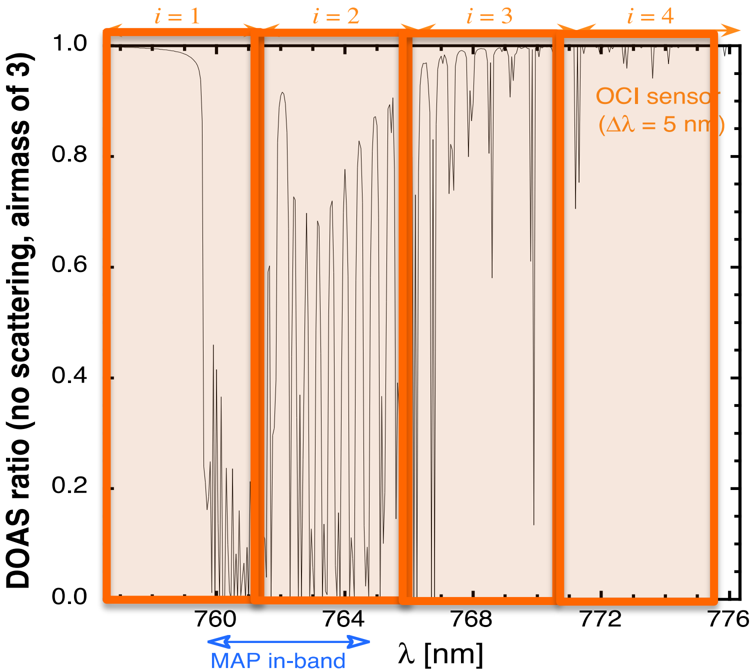


Using Oxygen A-band to retrieve aerosol height

DOAS = differential optical absorption spectroscopy

O_2 : both the amount and cross-section of the gas are accurately known.

DOAS then tells us about the height of the scattering layer (0-2 km vs. 3-5 km)

Davis, Kalashnikova, in progress

Plankton, Aerosol Cloud ocean Ecosystems
NASA mission for 2022

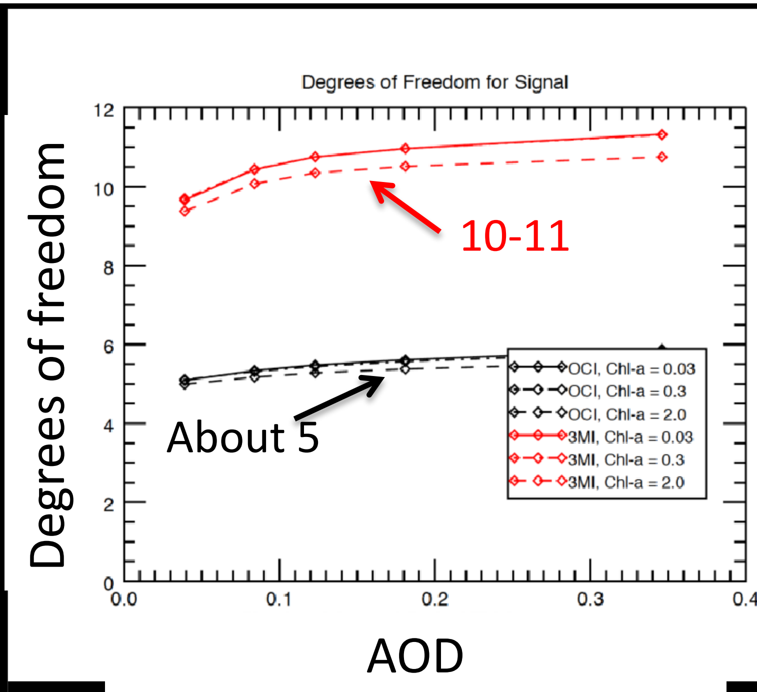
Primary instrument: OCI for ocean color,

but also **an excellent aerosol instrument**:

- Everything for aerosol that MODIS and VIIRS offers
- Except the thermal channels for cloud mask
- Plus, UV channels at 1 km
- And Oxygen A-band at 5 nm

New opportunities for aerosol absorption and height

Secondary instrument: Multi-angle imaging polarimeter

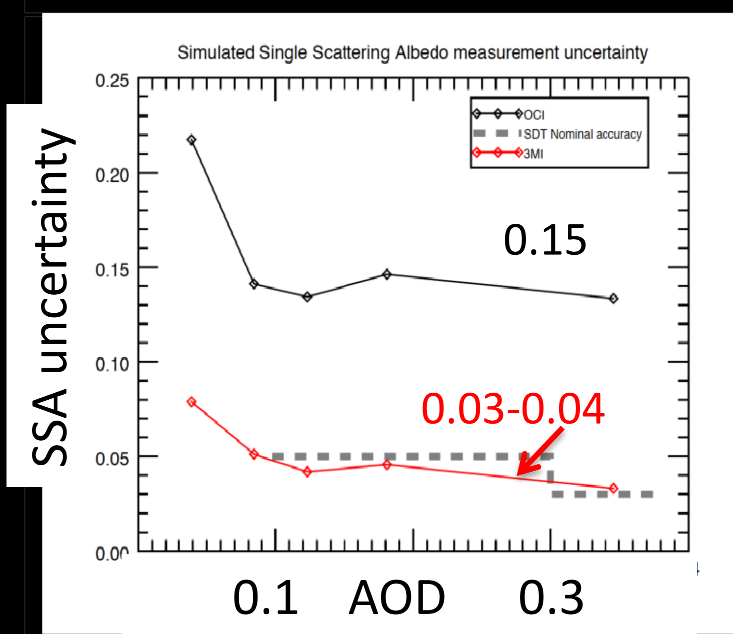


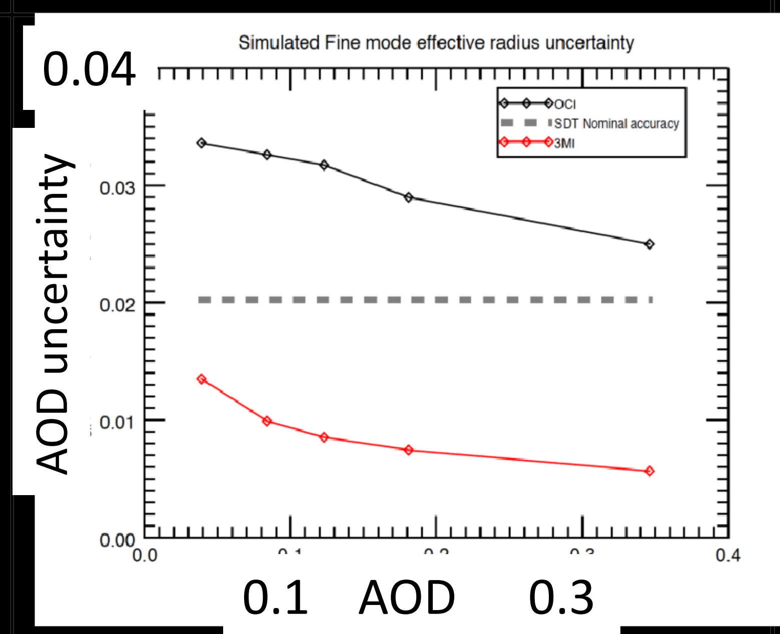
From K. Knobelspiesse

Theoretical calculations

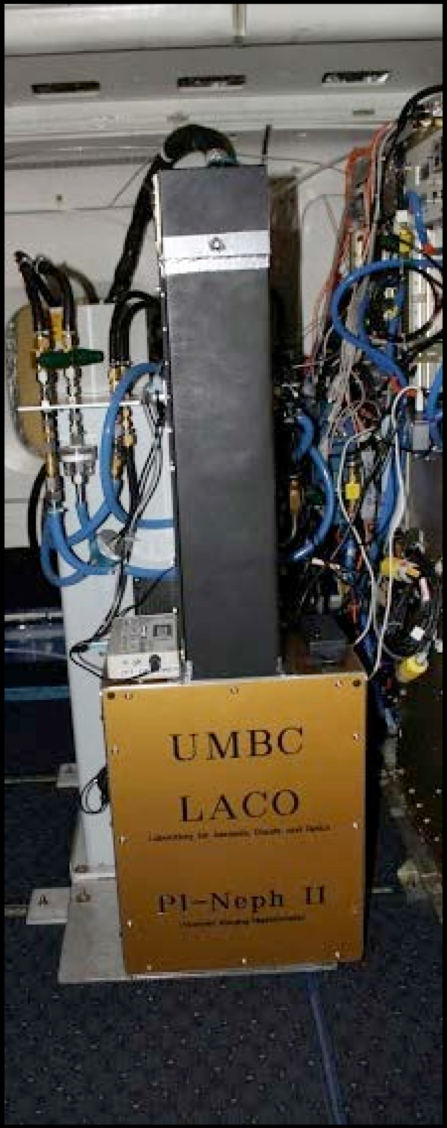
OCI (single angle radiometer) in black

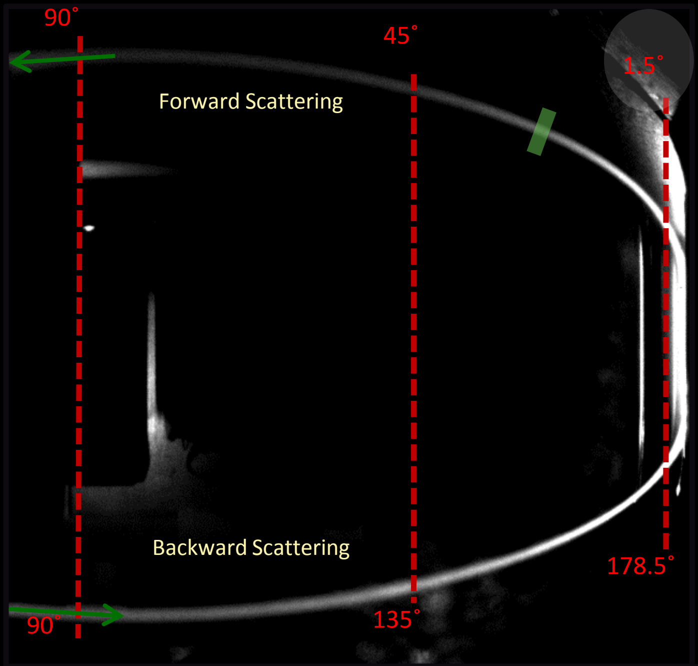
3MI (multiangle polarimeter) in red

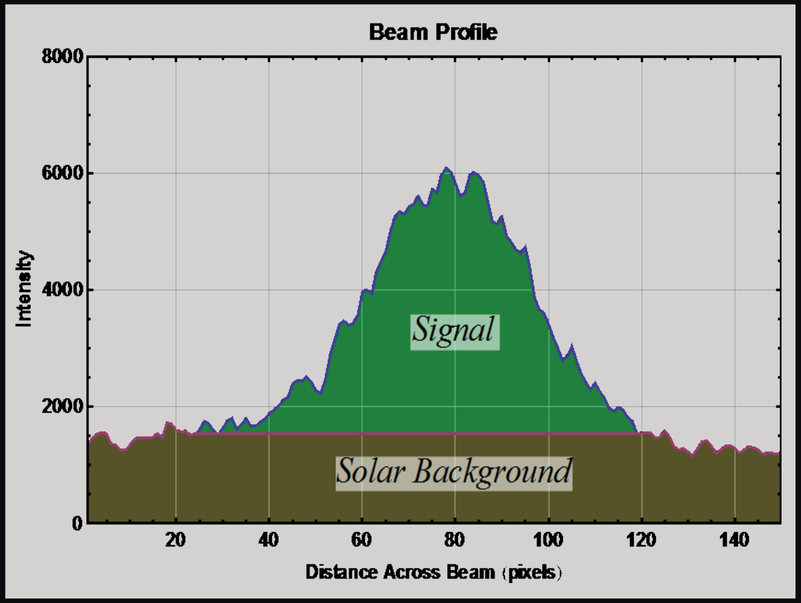




UMBC PI-Neph

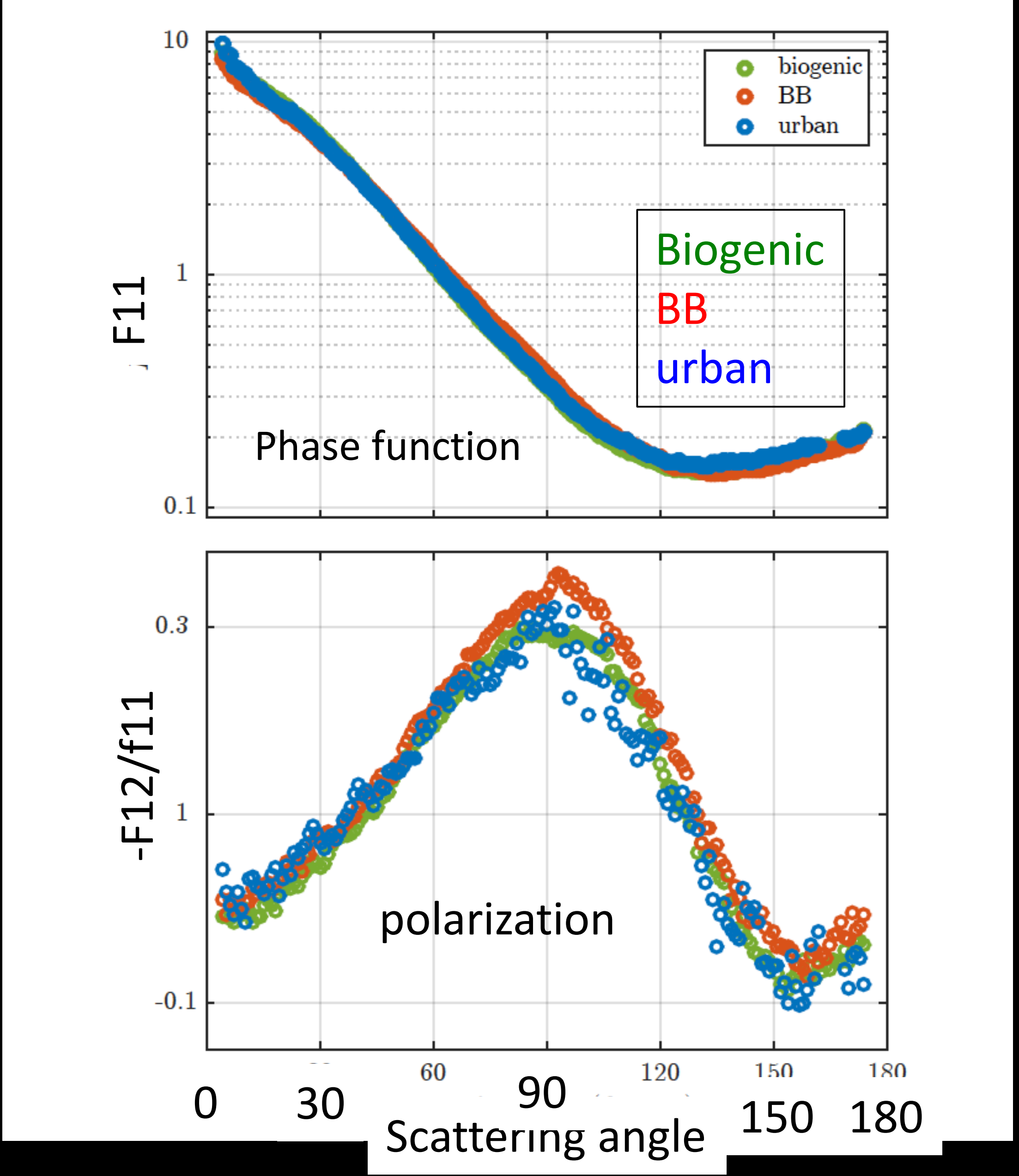




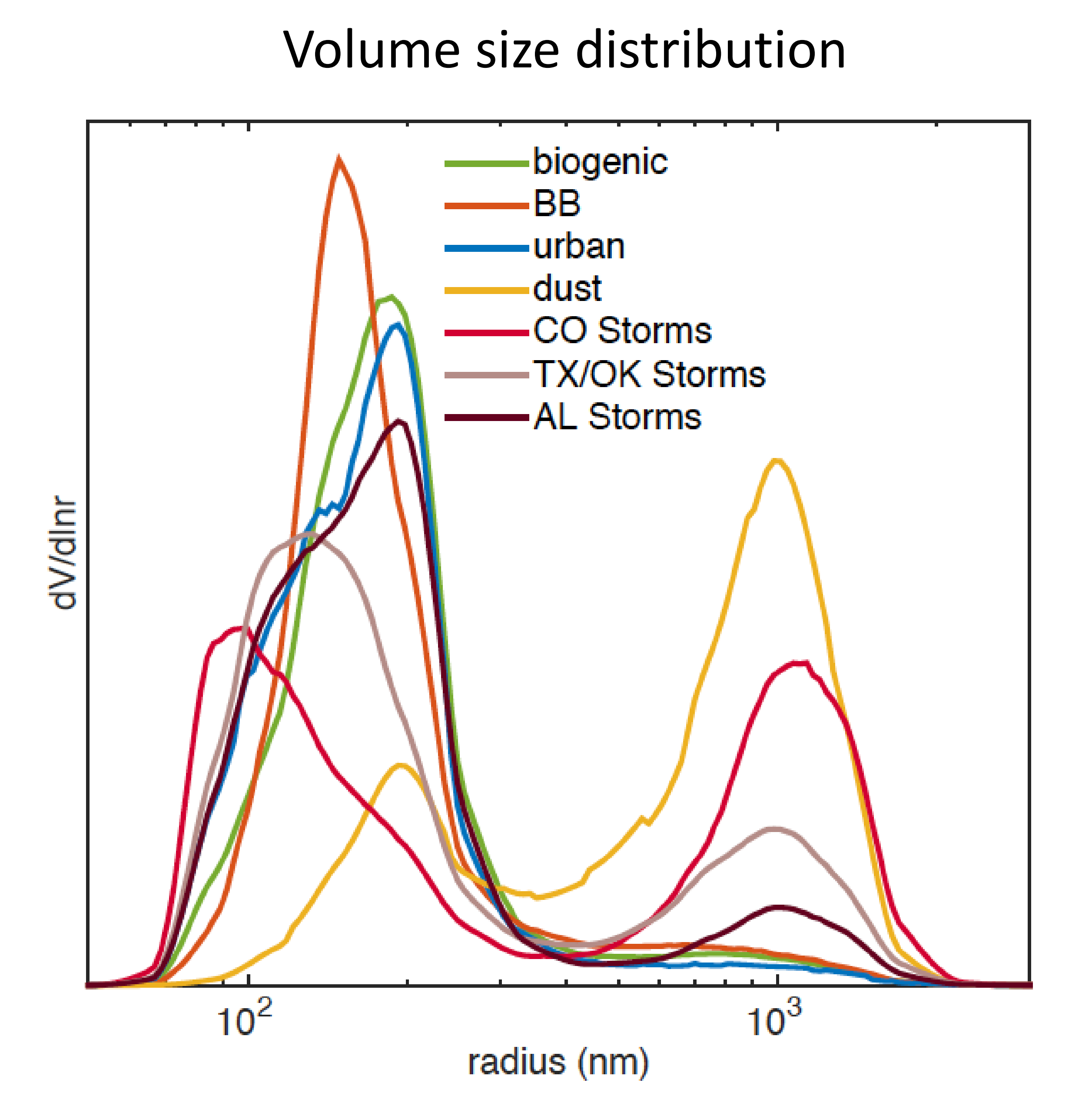


Espinosa, Dolgos and the UMBC team

UMBC PI-Neph measurements of 3 different fine mode aerosols from SEAC4RS



Espinosa et al., 2017

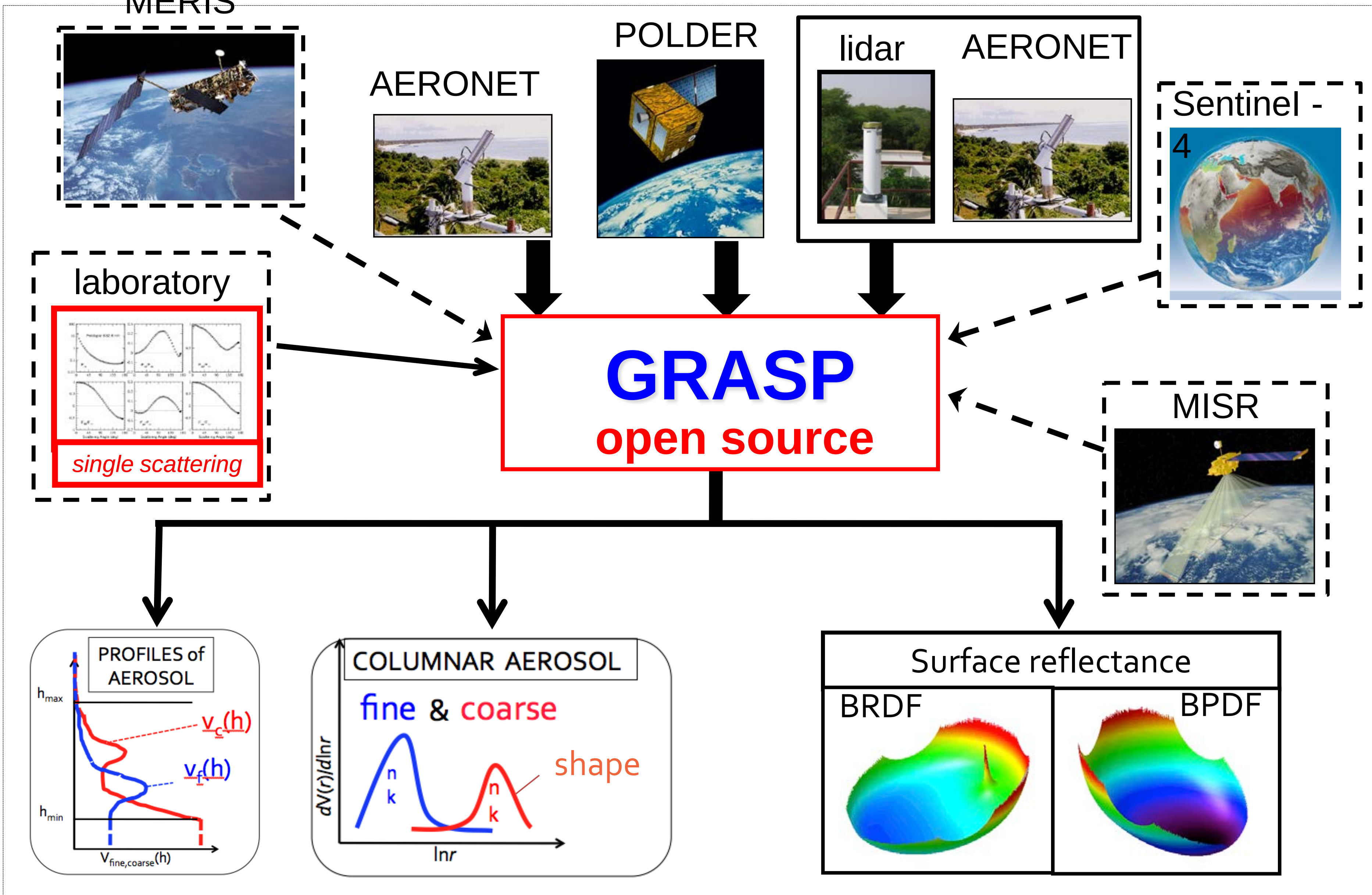


GRASP retrieval applied to PI-Neph measurements

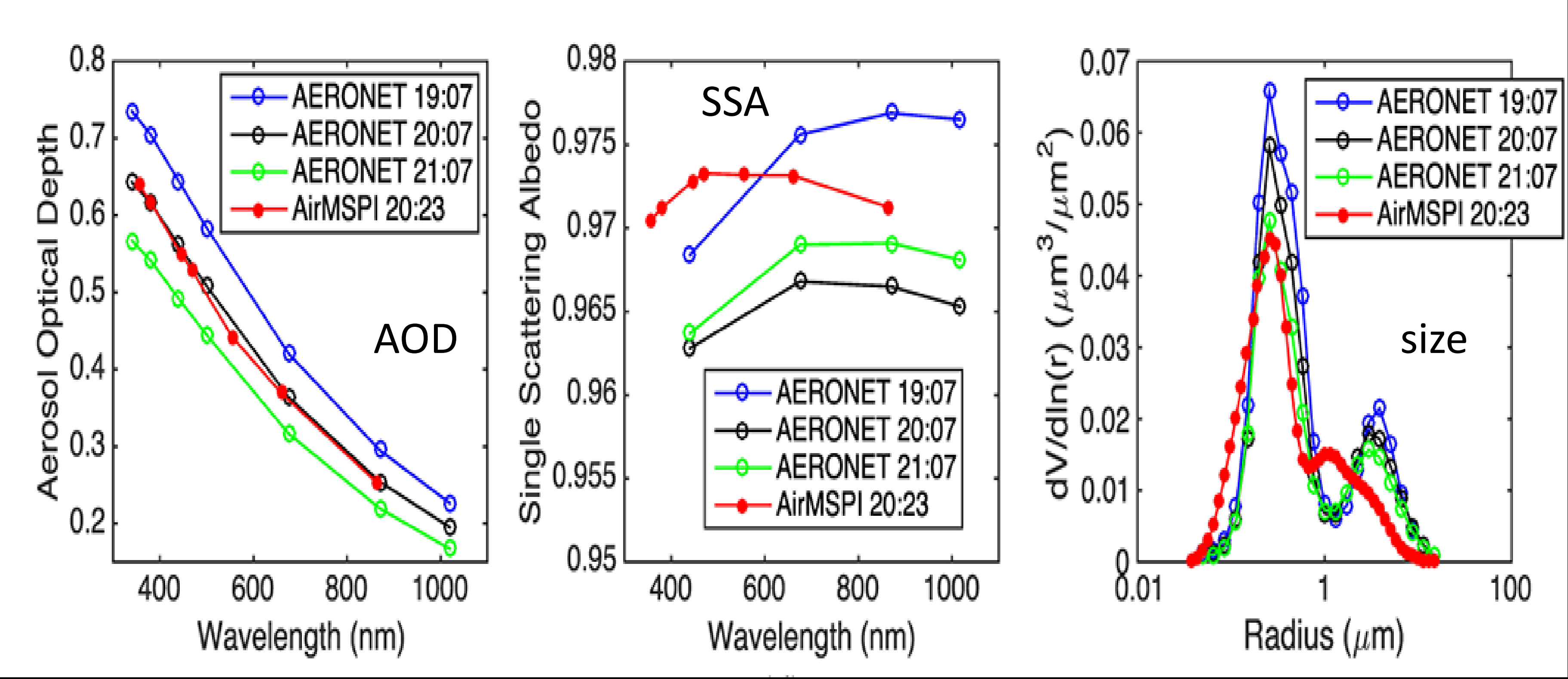
Espinosa et al. (to be submitted)

GRASP: Generalized Retrieval of Aerosol and Surface Properties

Dubovik et al.

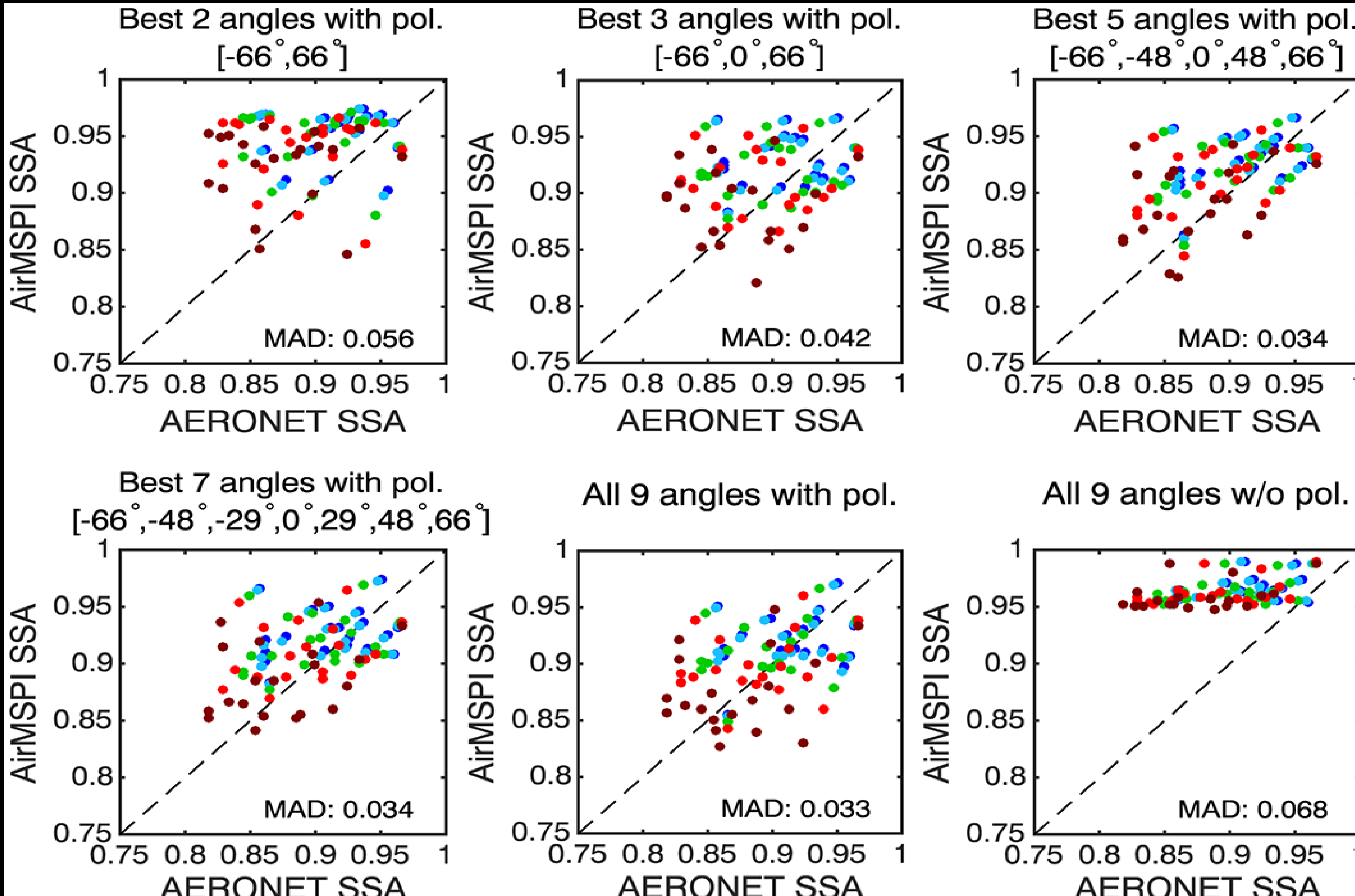


Aerosol retrievals from airborne multi-angle polarimeter (AirMSPI)



AirMSPI on NASA ER-2 over Fresno CA (in red)
Near-time AERONET retrievals at Fresno station (other colors)

Xu et al. (2017)



Best 2 angles with pol.
[-66°,66°]
MAD: 0.056
Best 3 angles with pol.
[-66°,0°,66°]
MAD: 0.042
Best 5 angles with pol.
[-66°,-48°,0°,48°,66°]
MAD: 0.034
Best 7 angles with pol.
[-66°,-48°,-29°,0°,29°,48°,66°]
MAD: 0.034
All 9 angles with pol.
MAD: 0.033
All 9 angles w/o pol.
MAD: 0.068
AirMSPI SSA
AERONET SSA
0.75
0.8
0.85
0.9
0.95
1

Xu et al. 2017

Where are we heading?

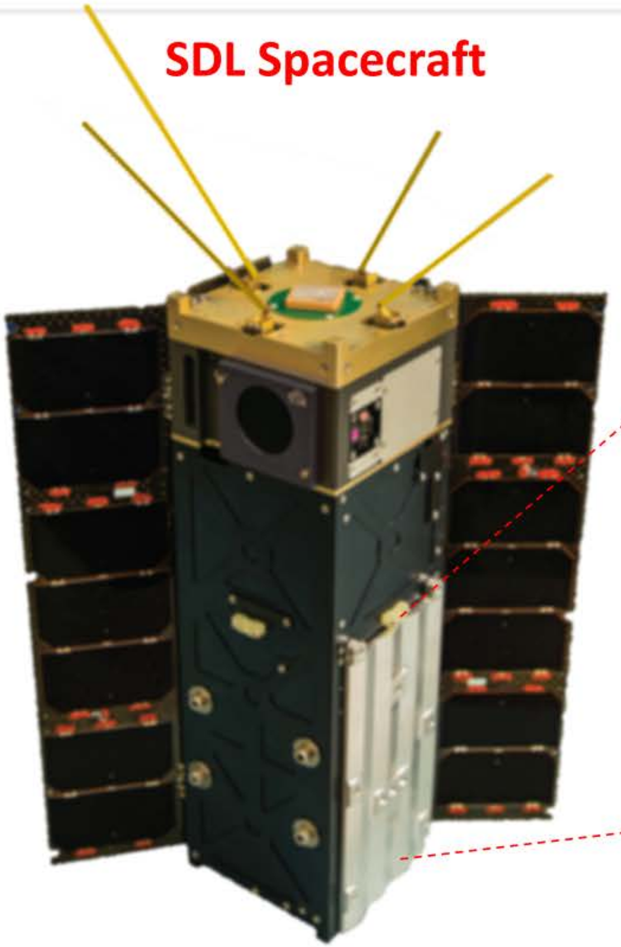
Towards broader aerosol-relevant spectra;
Finer spectral resolution;
Finer spatial resolution for UV;
Multi-angle polarimeters;
Retrievals of more aerosol properties;
With better accuracy;
Expanding retrievals to over clouds and difficult surfaces;
Simultaneous retrievals of aerosol + surface;
Advanced retrieval algorithms that can handle all this information

How will we get there?

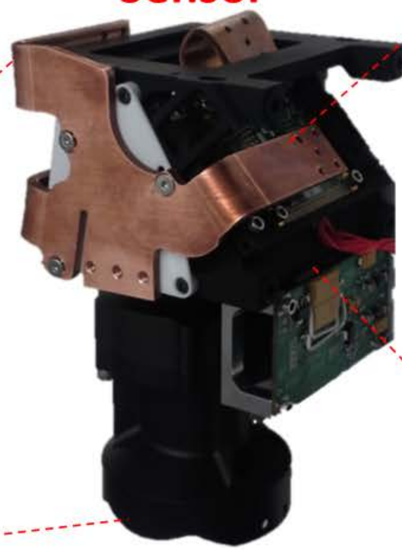
- PACE OCI: 2022, but in political limbo
- PACE polarimeter: even less assured
- MetOP 3MI: 2018 and continuing
- MAIA: an instrument without a launch date
- HARP Cubesat: early 2018

Photos of Actual Instrument & Spacecraft

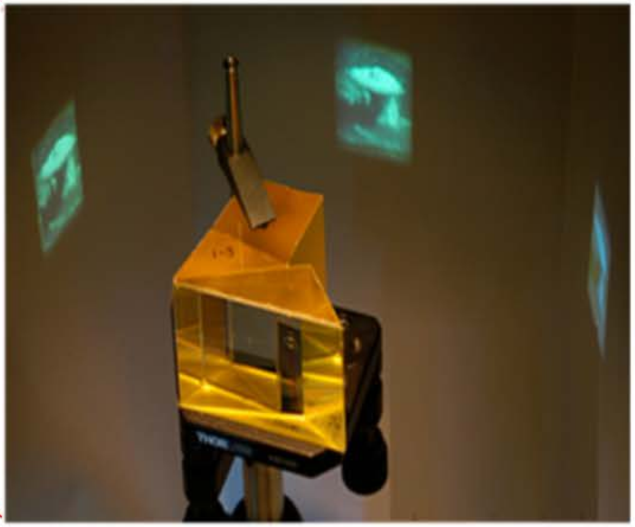
SDL Spacecraft



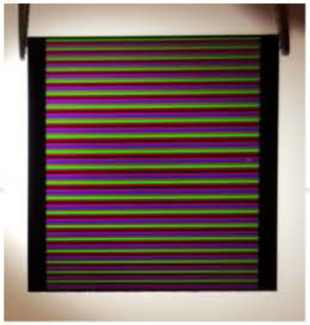
UMBC Sensor



HARP Prism



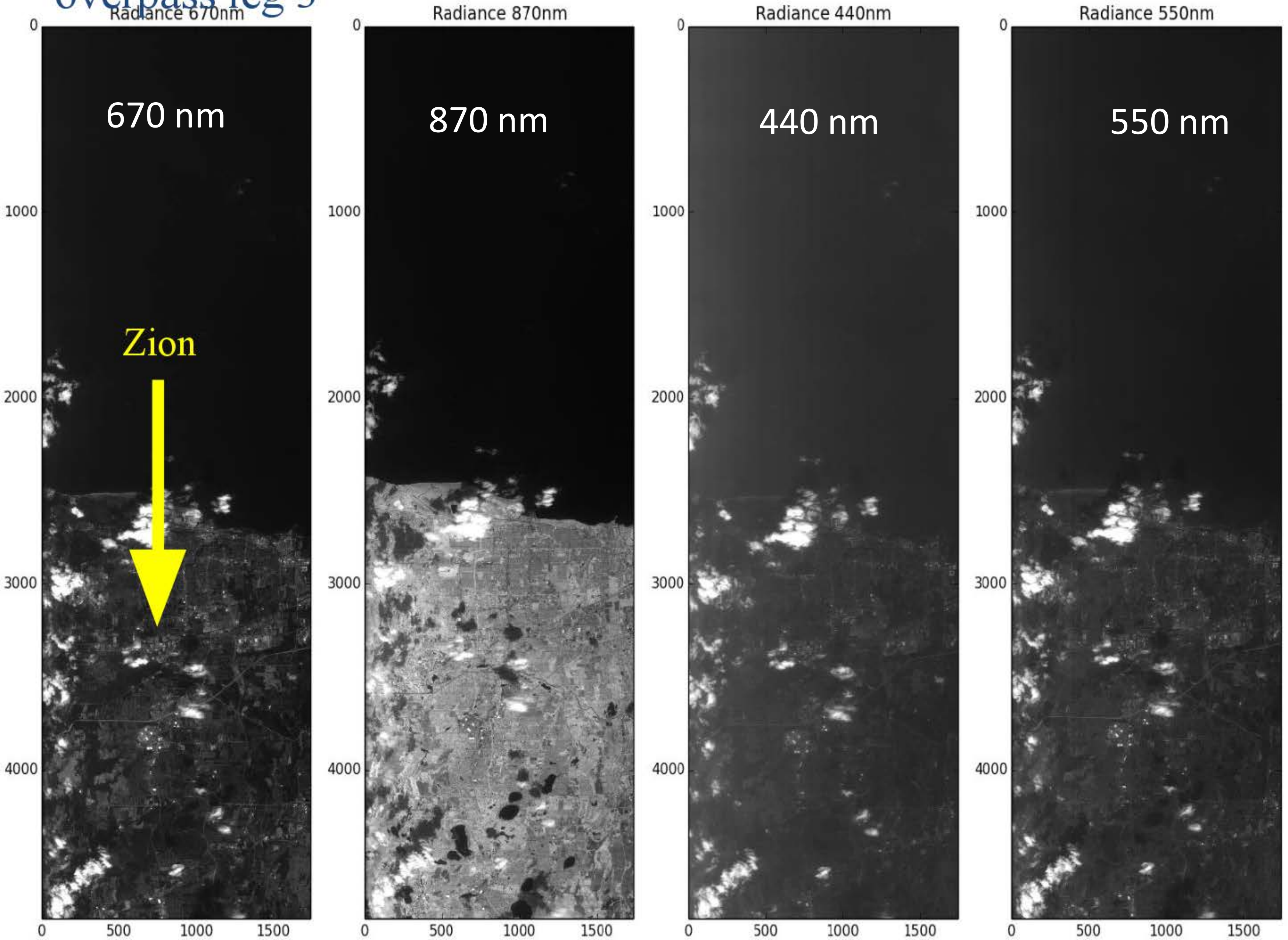
HARP Stripe Filter



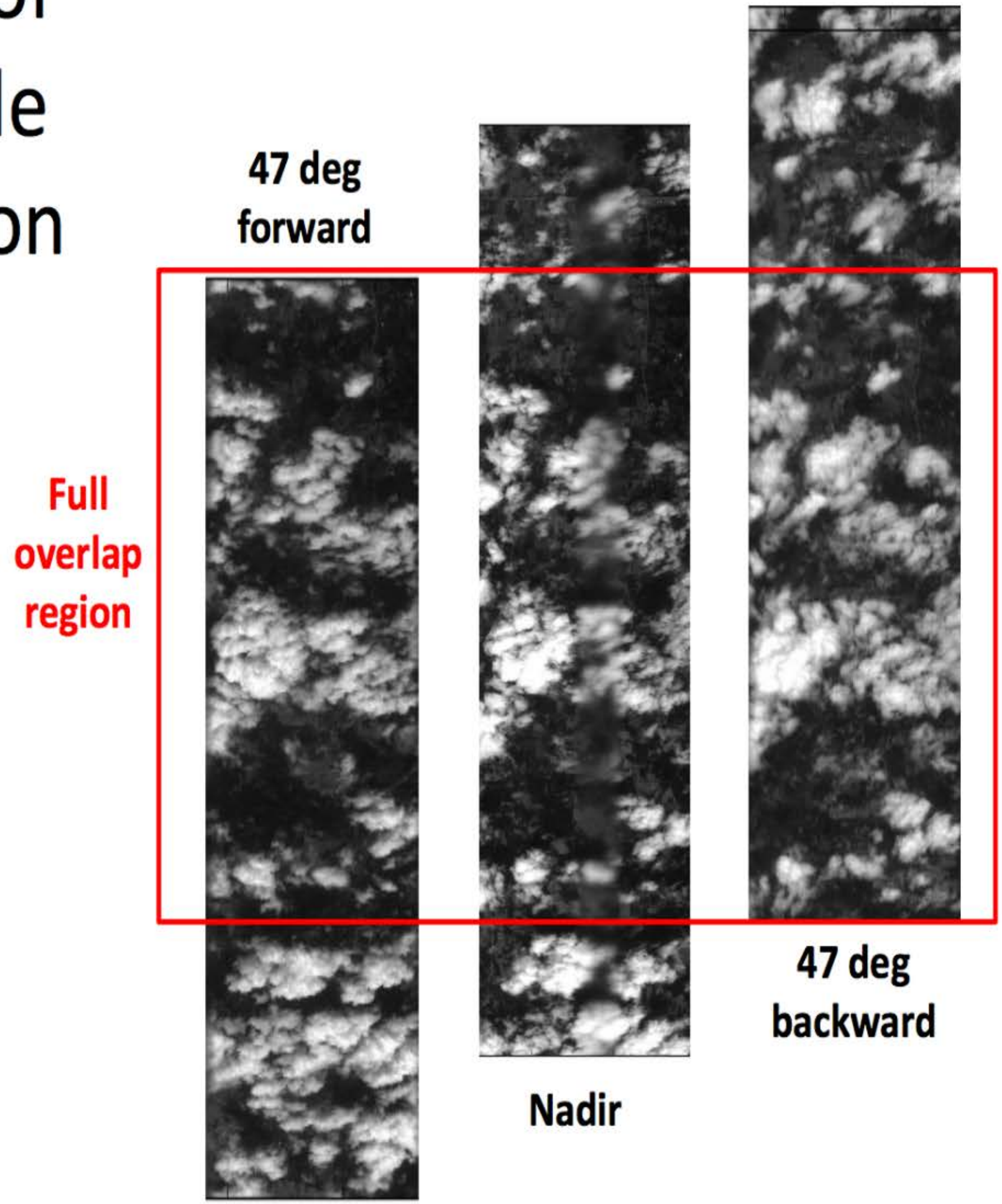
UMBC
Martins et al.

HARP

Preliminary Results from LMOS, 12 June 2017 – AirHARP Zion overpass leg 3

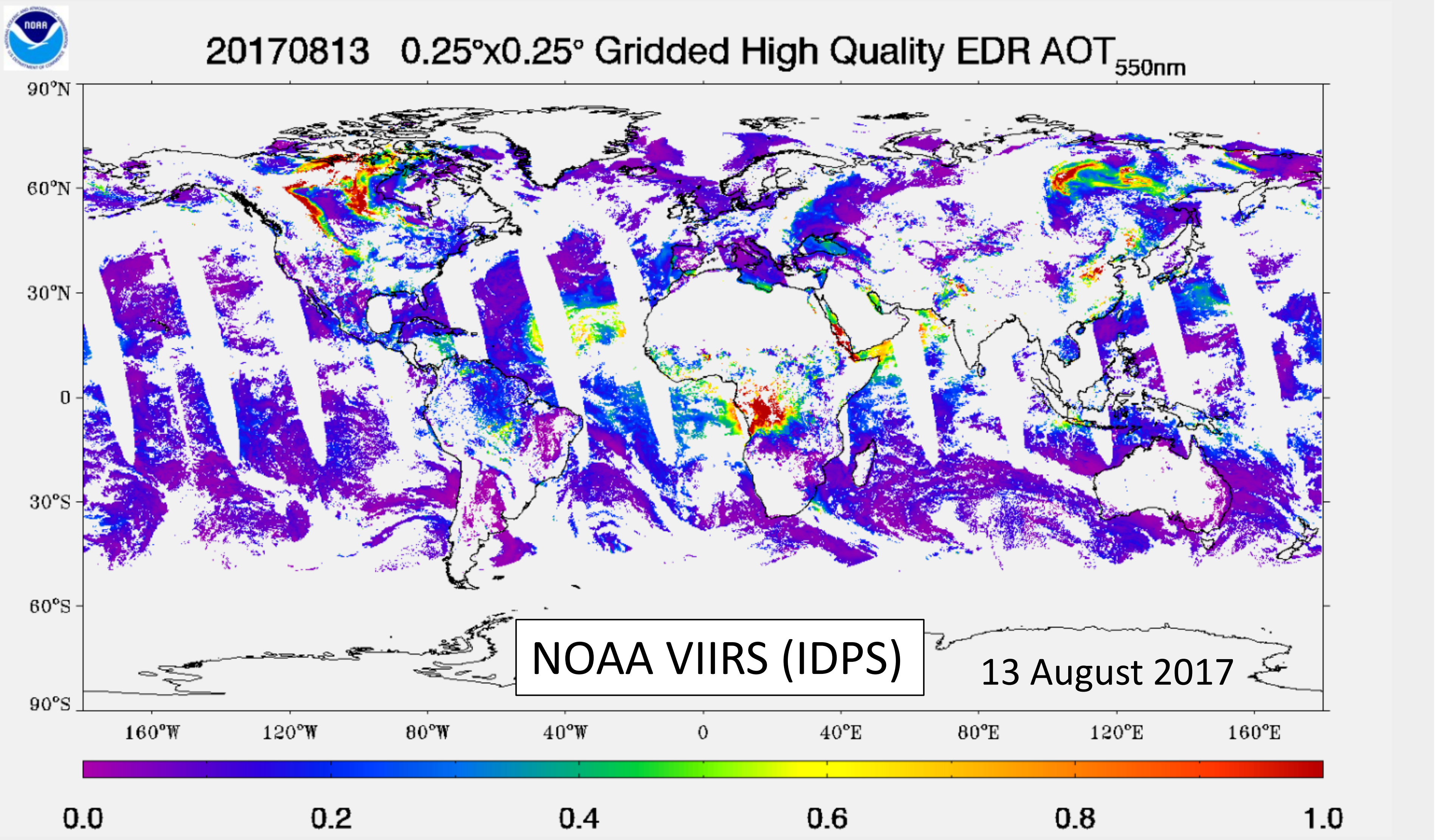


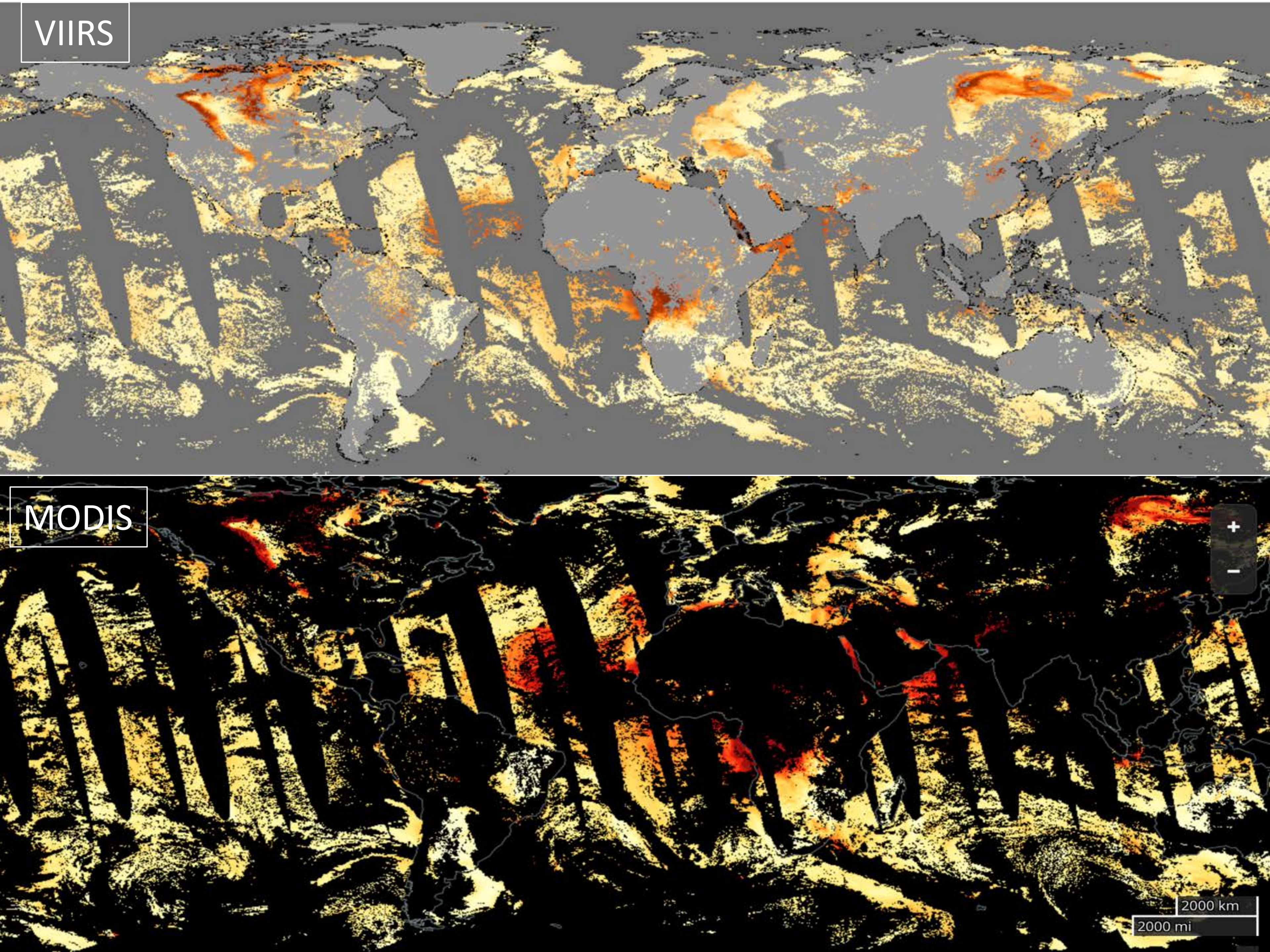
Example of Multiangle observation

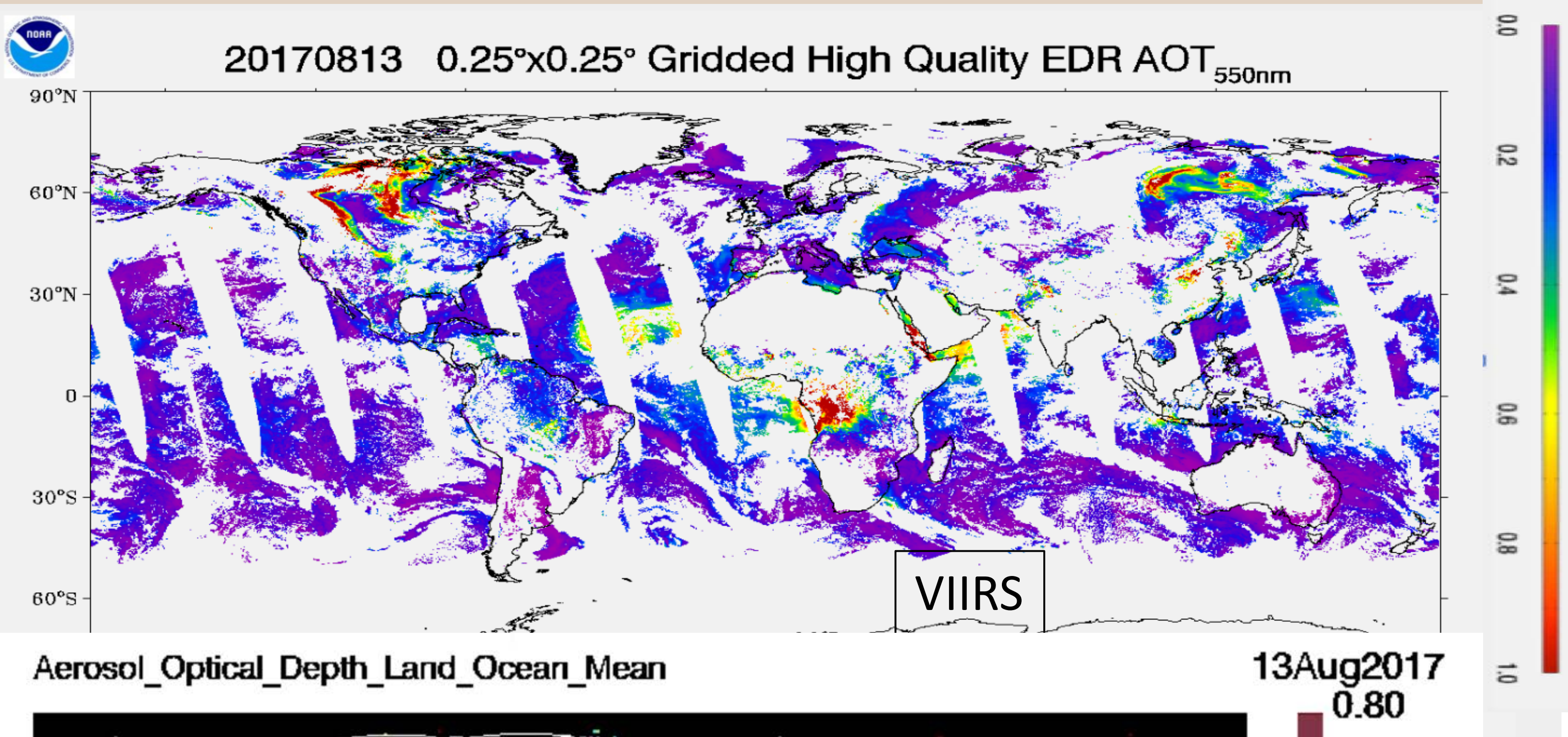


Comparison of NOAA VIIRS and NASA MODIS Aerosol Products

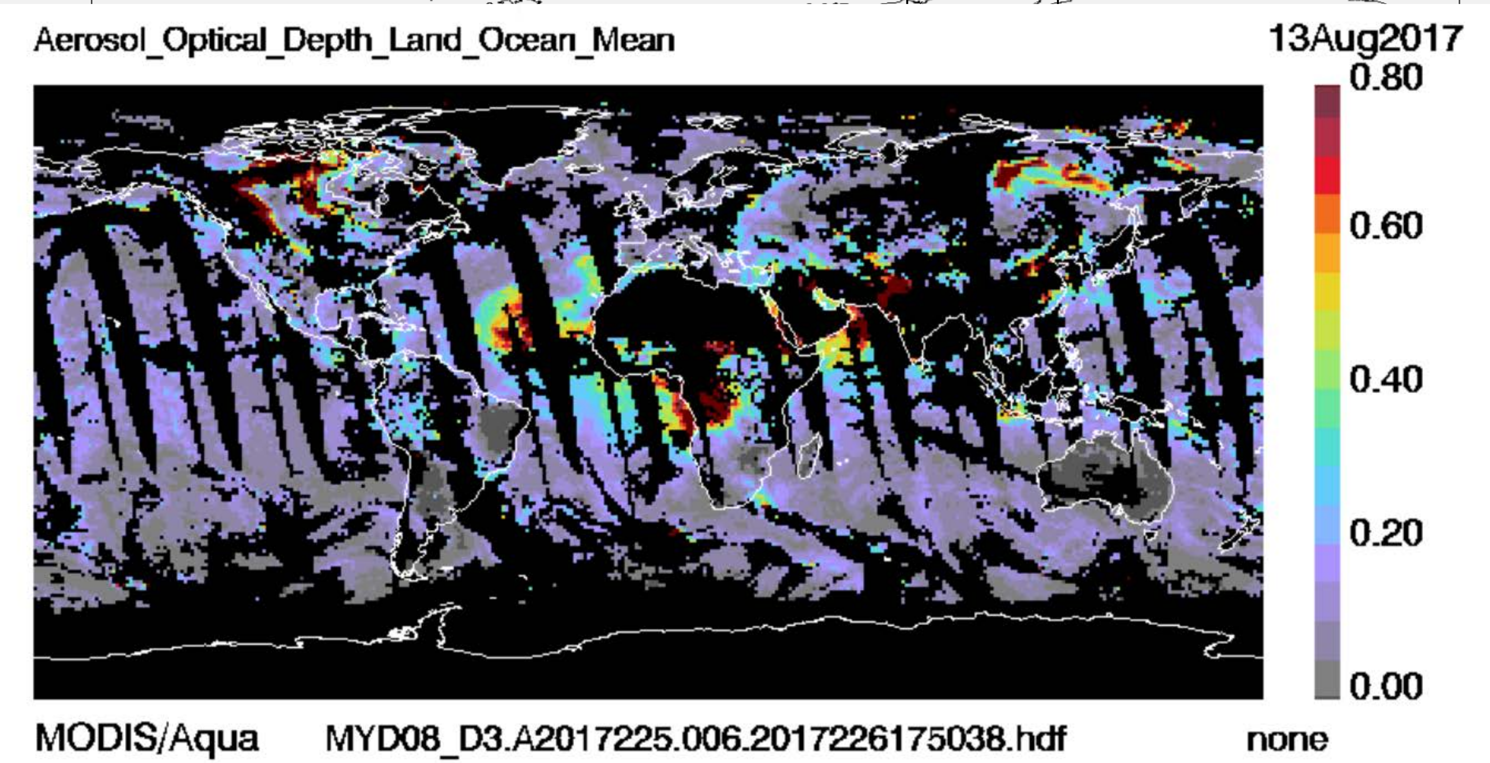
Lorraine A. Remer[1], Jennifer Christhilf[1,2], Robert C. Levy[2]
[1]UMBC, [2]NASA/GSFC




VIIRS
MODIS
+
−
2000 km
2000 mi

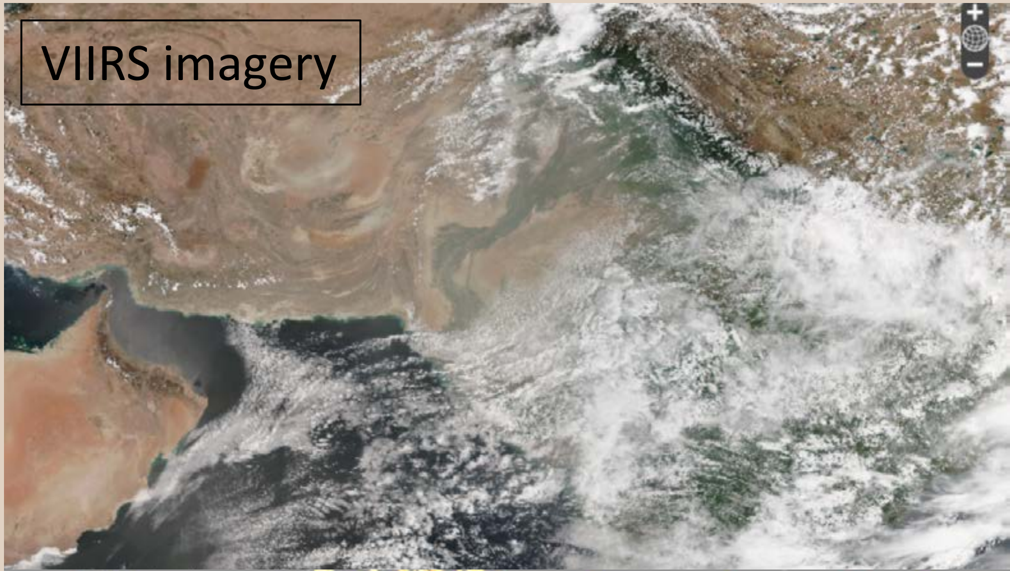


IDPS
Daily
0.25 deg
Gridded
From 6 km
High QA

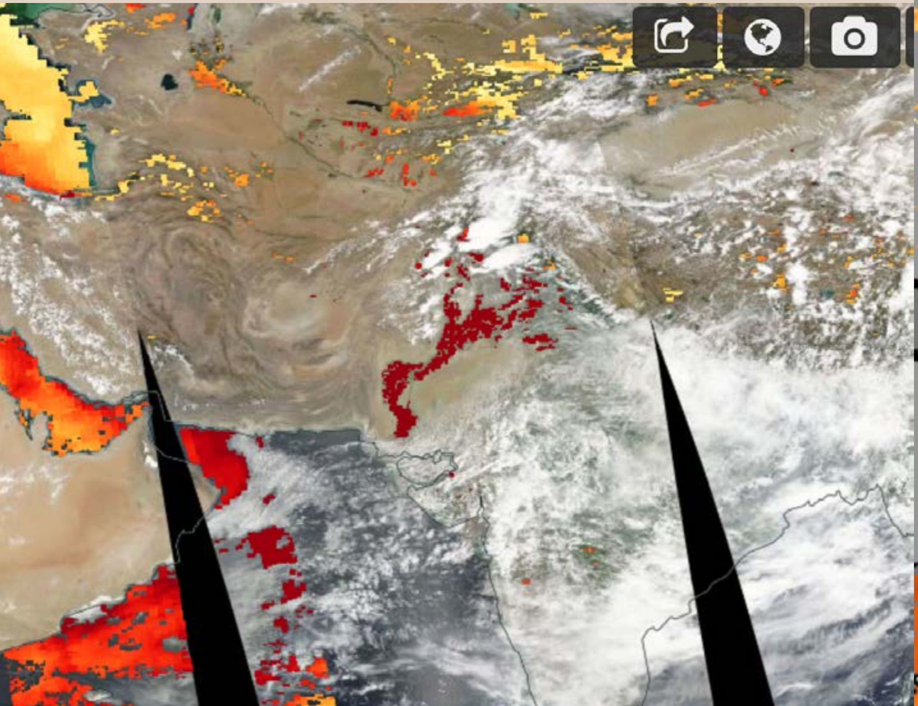


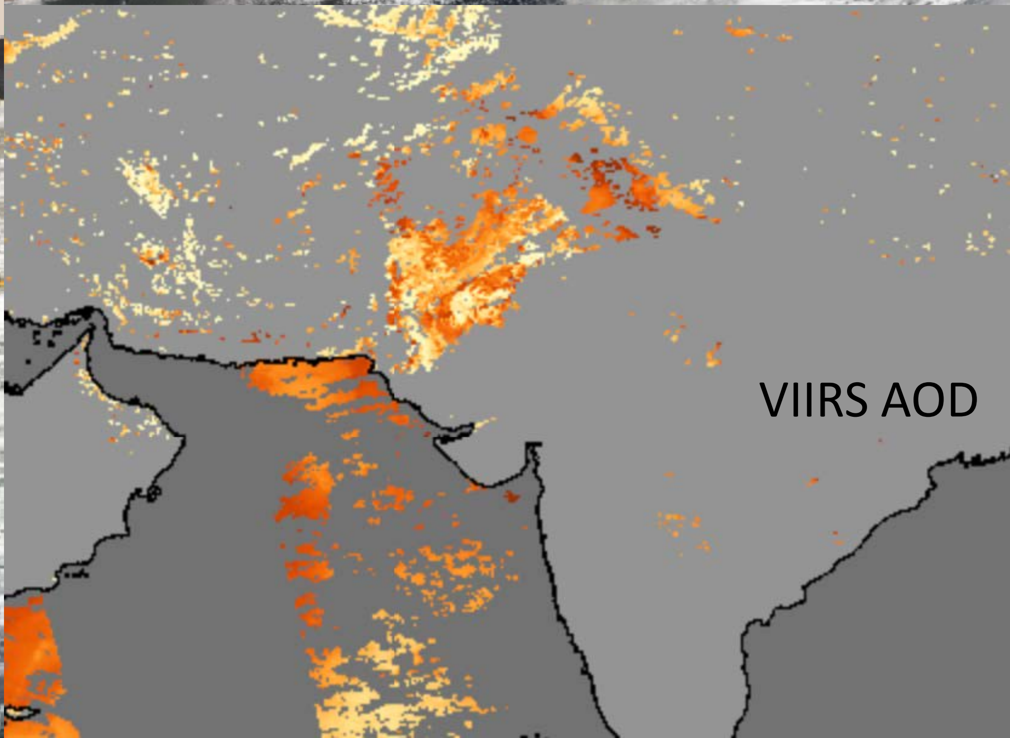
DT
Daily
1 deg
Gridded
From 10 km
High QA

Real color imagery and native resolution AOD
13 August 2017



MODIS Aqua AOD and imagery





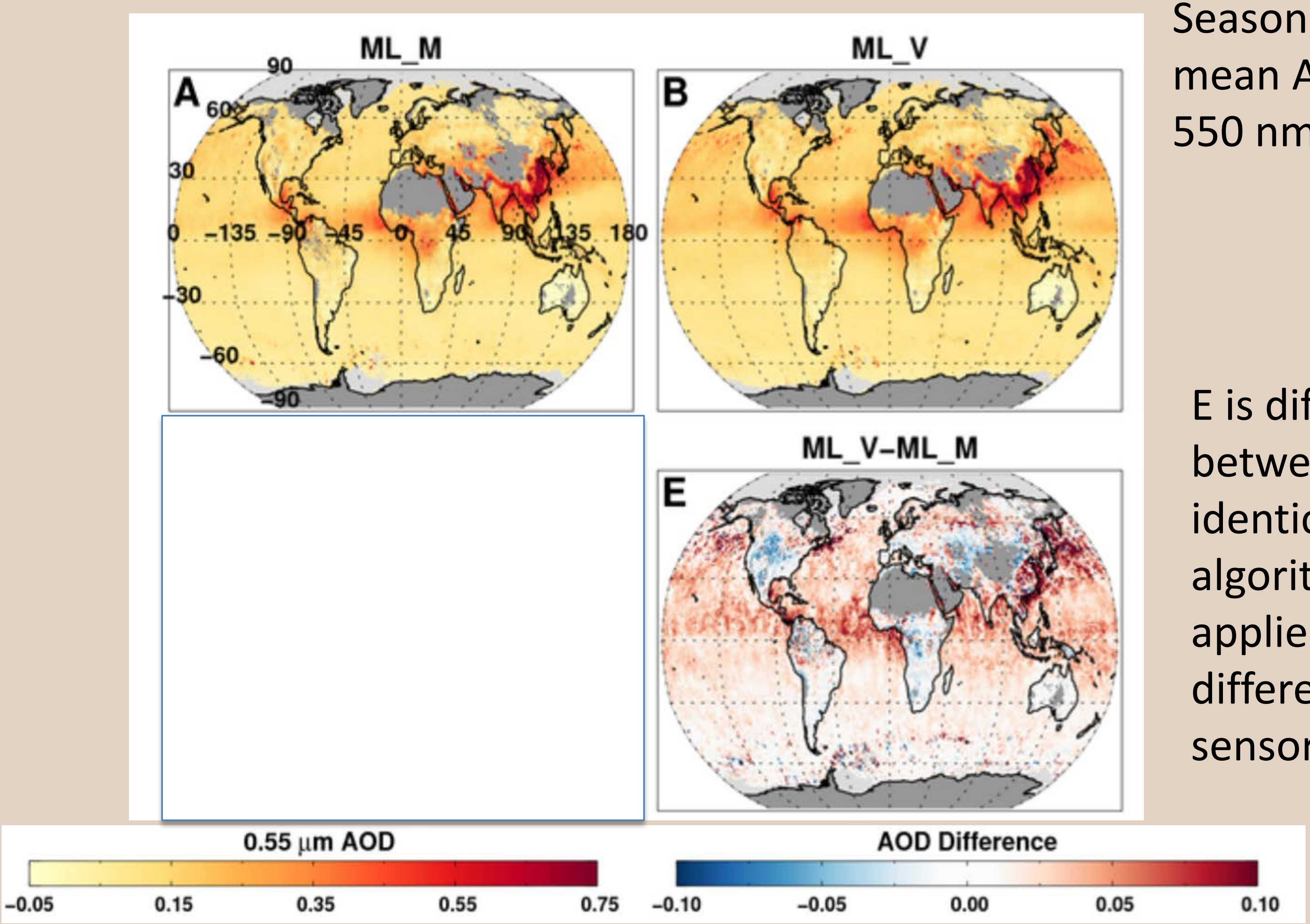
Wavelength differences
Swath differences
Orbit differences
Spatial resolution differences
Calibration differences

Algorithm differences

>>>> Sampling differences
>>>> Retrieval differences

>>>> Differences in means

A & B are identical algorithms

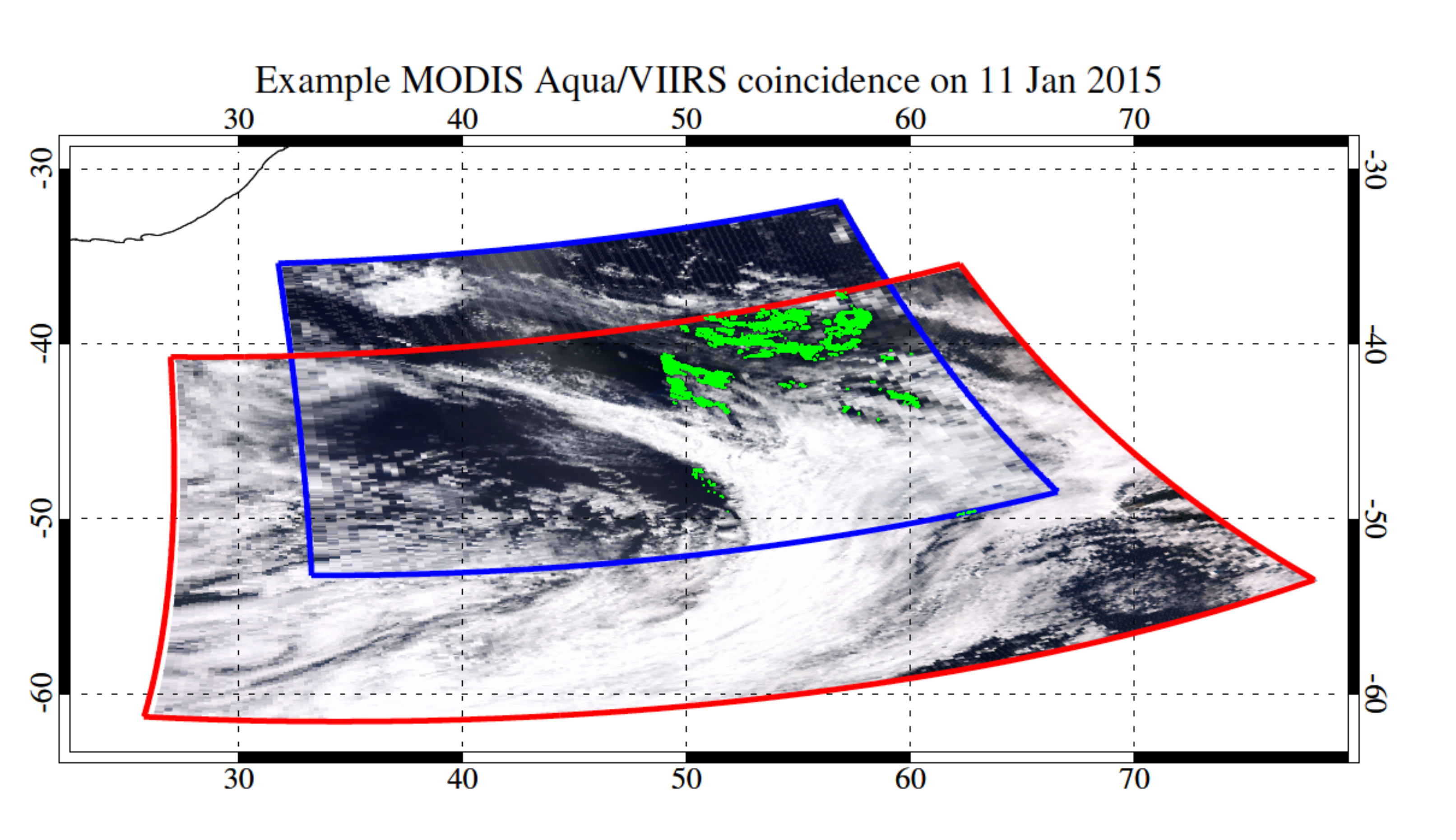


Seasonal (MAM) mean AOD at 550 nm

E is difference between identical algorithms applied to different sensors (B-A)

Levy et al., 2015

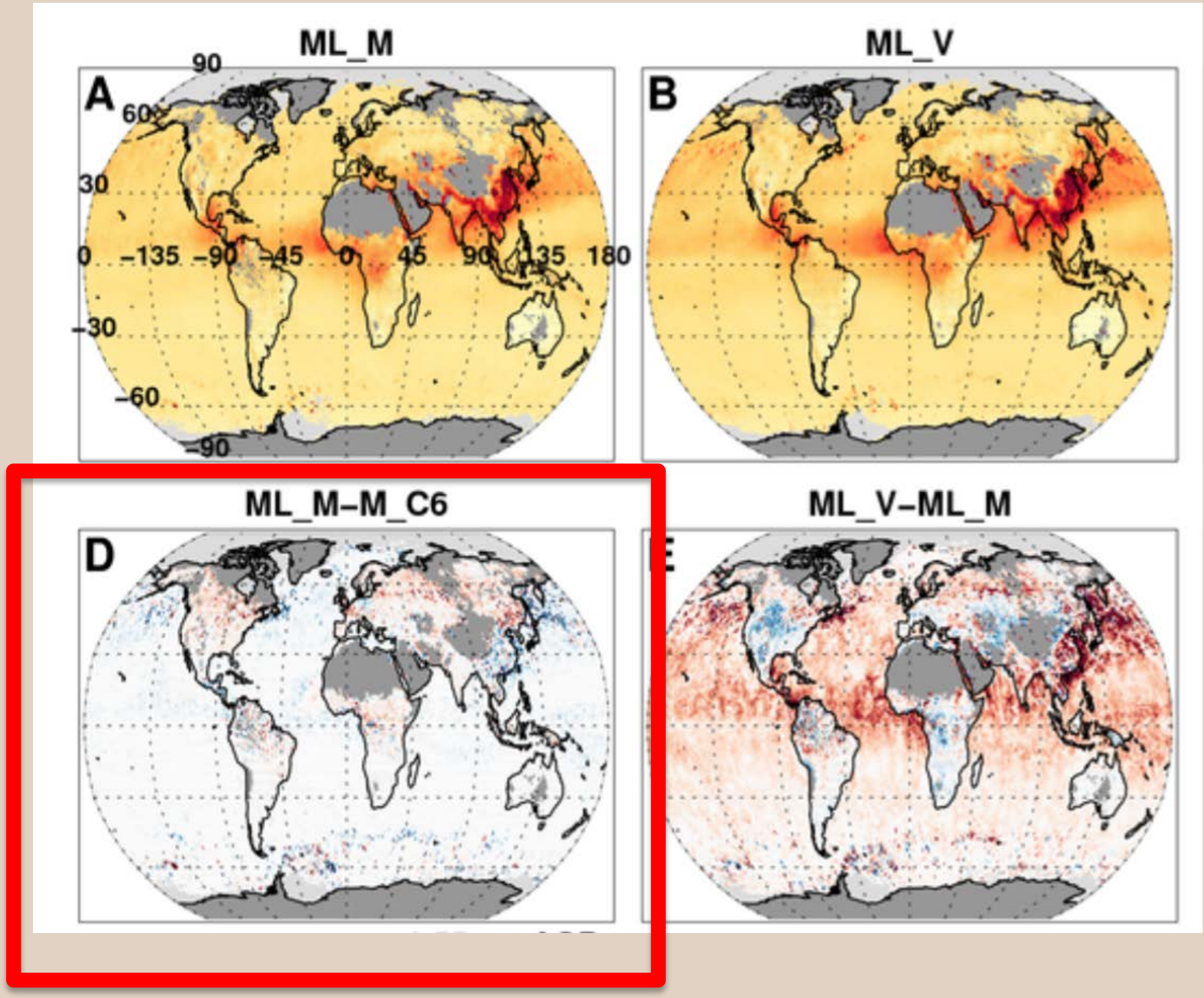
A calibration investigation using “match files” (Sayer et al., 2017)



<u>From SIPS:</u>

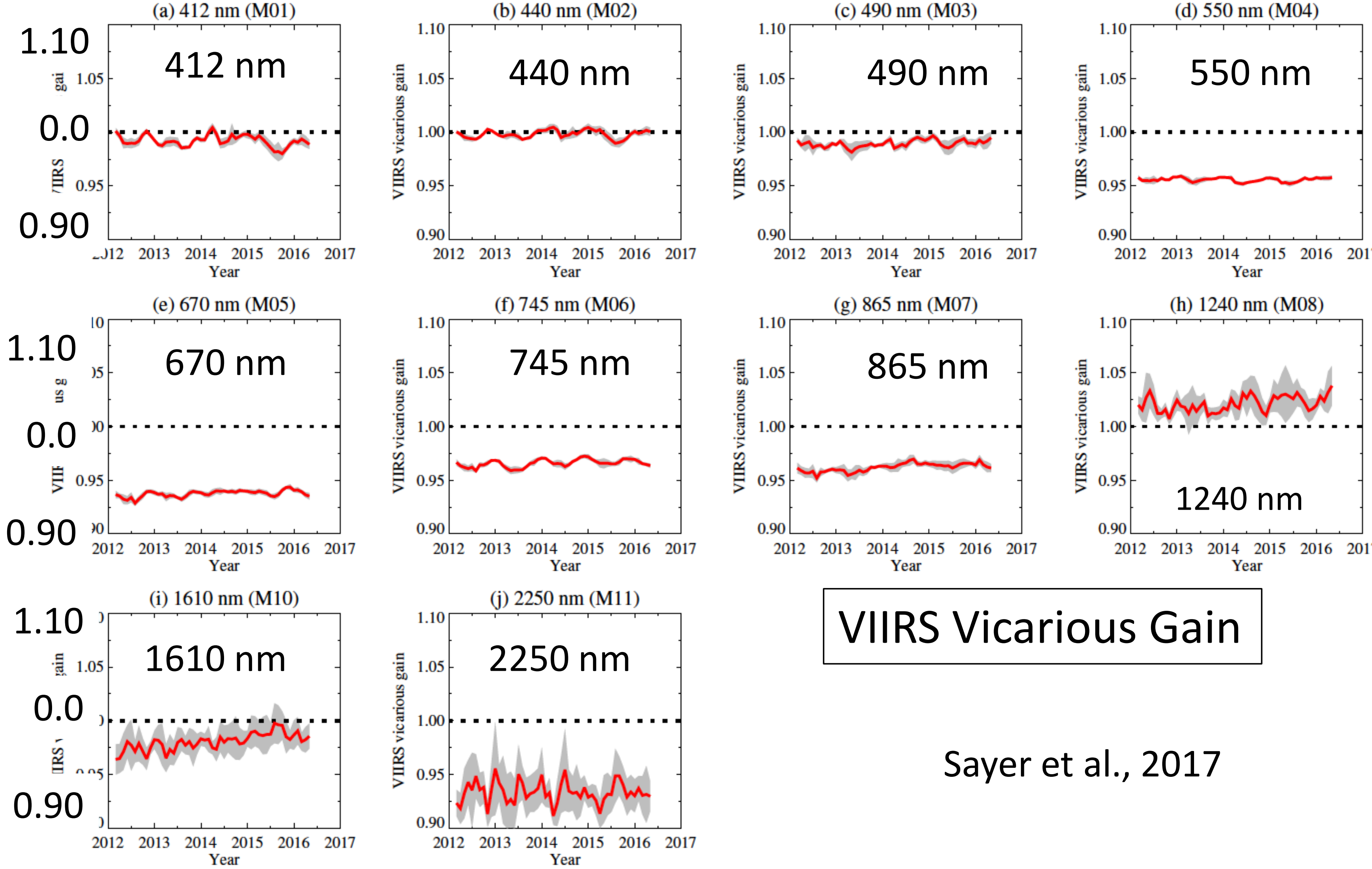
MCST MODIS Aqua Collection 6 data (<u>at 1 km pixel size</u>, the MYD021KM product)

VCST VIIRS Version 1.1 data with Version 1.0.1 calibration (the VL1BM product).



Red box outlines the difference between using the SIPS MODIS input and the operational MODIS product.

Levy et al. (2013)



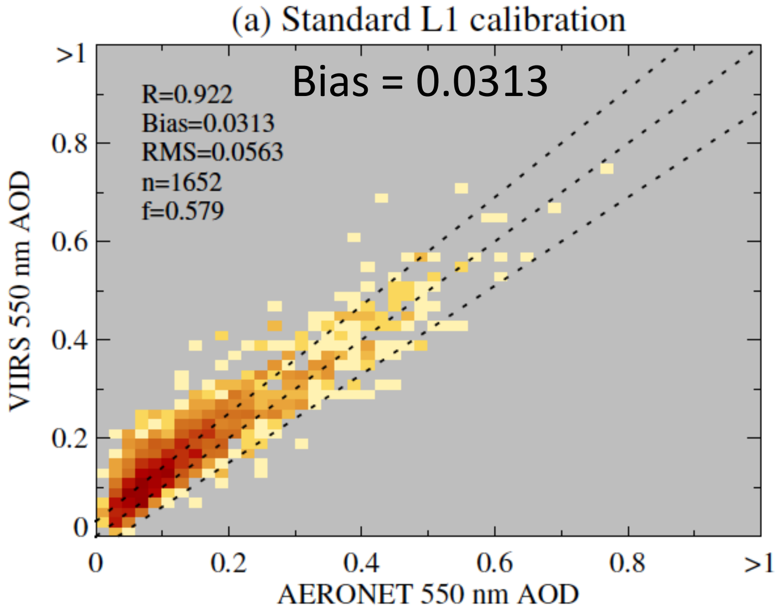
VIIRS Vicarious Gain

Sayer et al., 2017

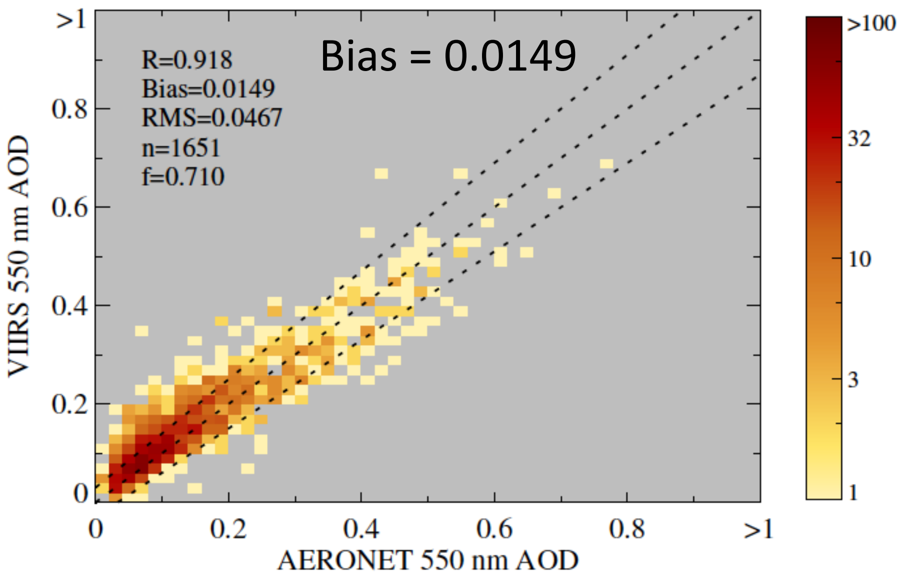
Site	Latitude, °	Longitude, °	Number of matchups
ARM Graciosa	39.091	-28.029	149
Ascension Island	-7.976	-14.415	414
Ersa	43.004	9.359	624
Manus	-2.060	147.425	105
MCO Hanimaadhoo	6.776	73.183	268
Midway Island	28.210	-177.378	89

AOD validation at 6 AERONET island sites

Standard



With vicarious corrections



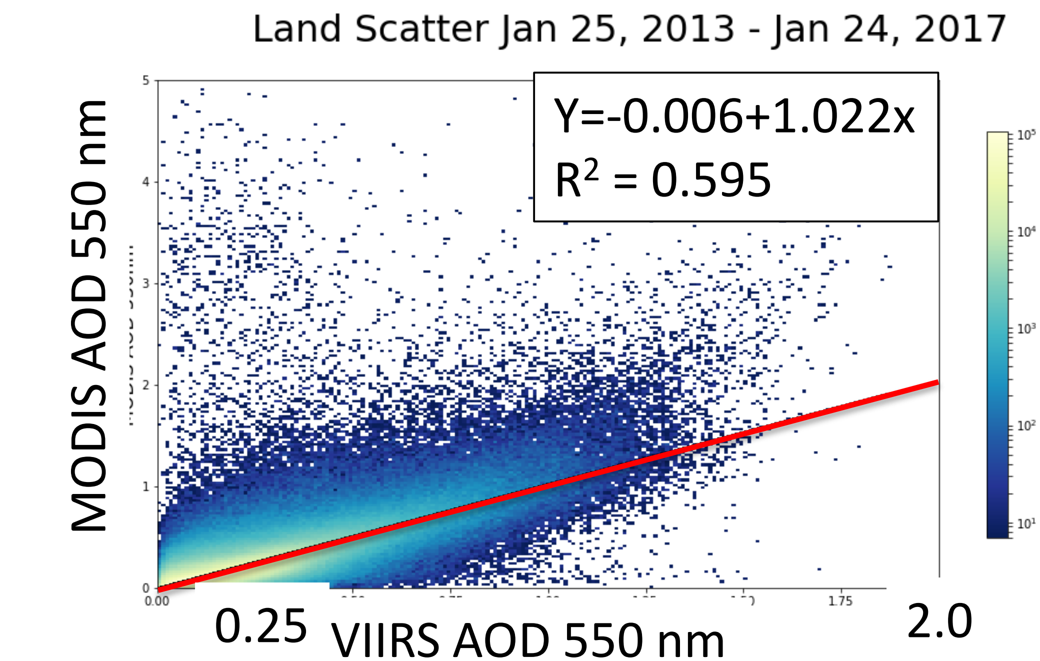
Sayer et al., 2017

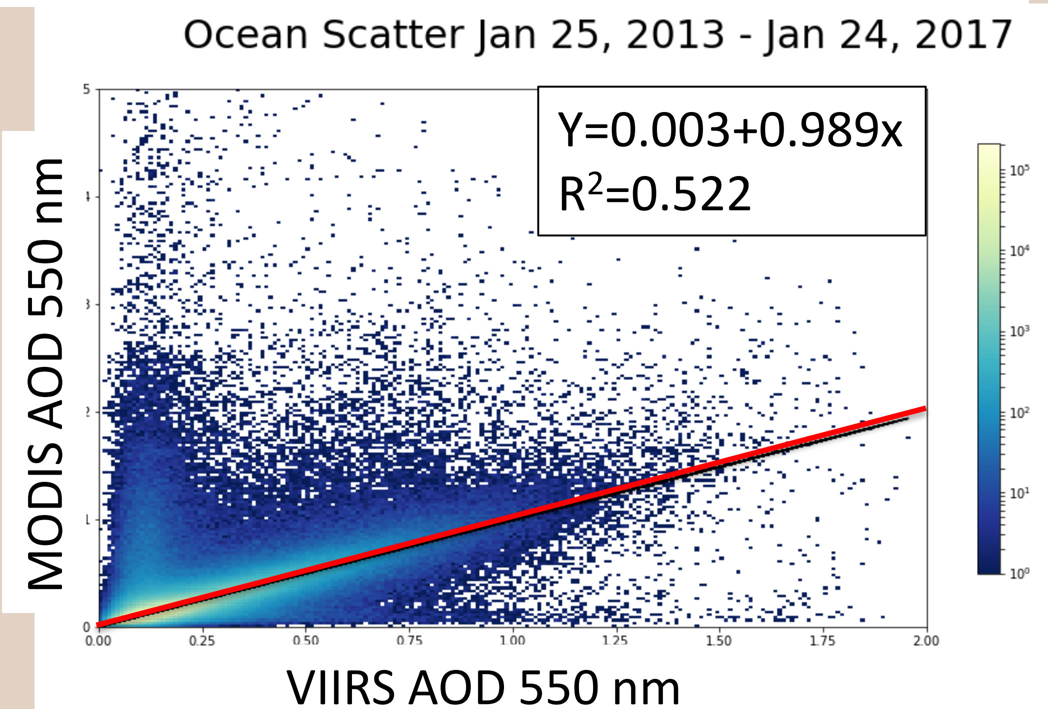
Characterizing MODIS – VIIRS differences

- MODIS Collection 6 Level 3 AOD 550,
- DT land and ocean,
- 1 degree gridded

- VIIRS IDPS AOD550
- 0.25 degree gridded (from VIIRS team web page).
- Aggregated up to 1 degree (if any one of the 0.25 deg squares is populated, the 1 deg square will have a value

- 8-day means created from each.
- Sync-ed
- Start 25 January 2013
- End 24 January 2017



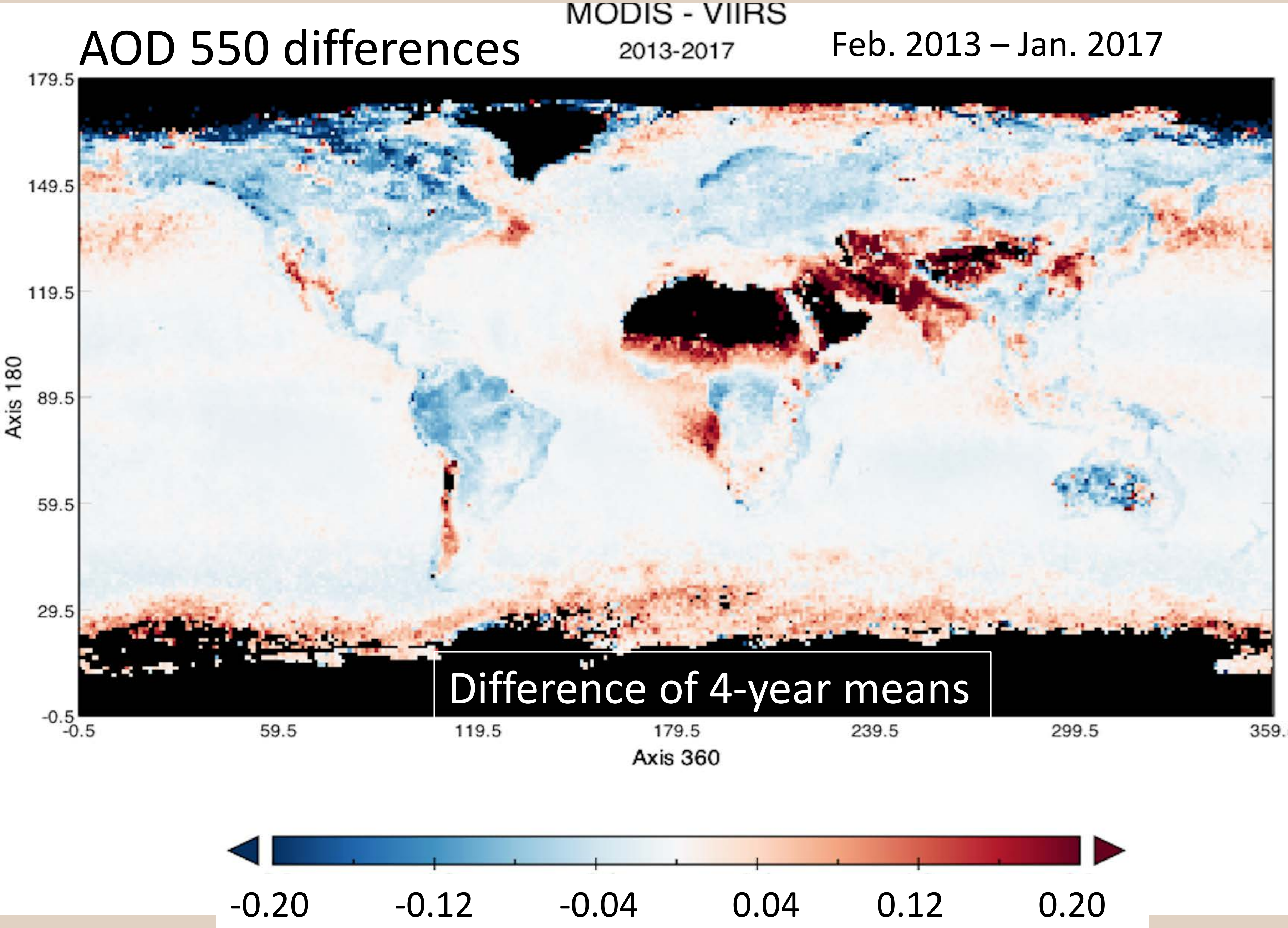


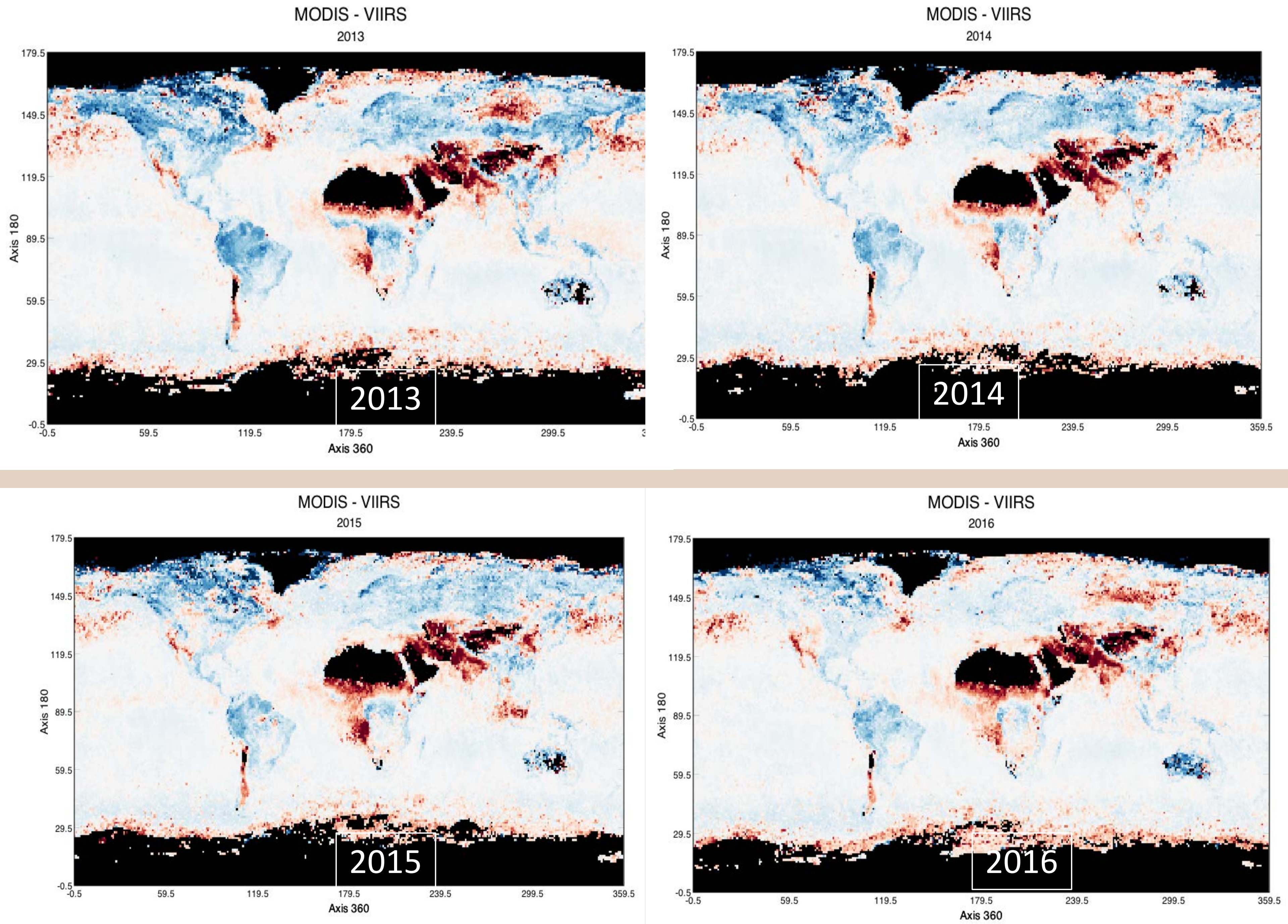
Each ordered pair is an 8-day mean of a 1-degree grid box.

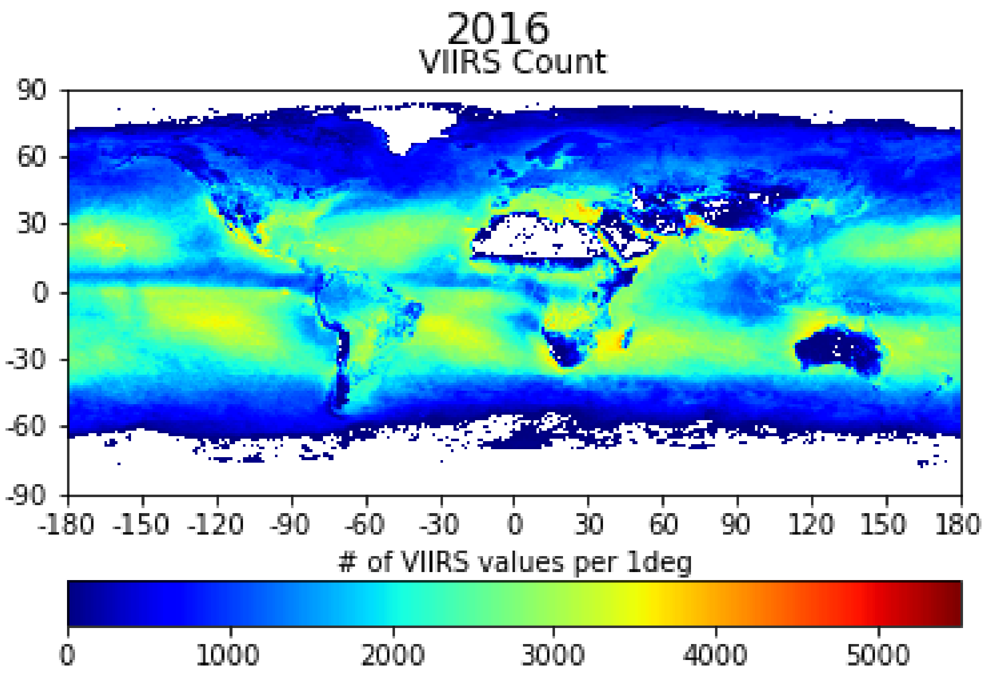
Red line is 1:1 line.

AOD 550 differences

Feb. 2013 – Jan. 2017

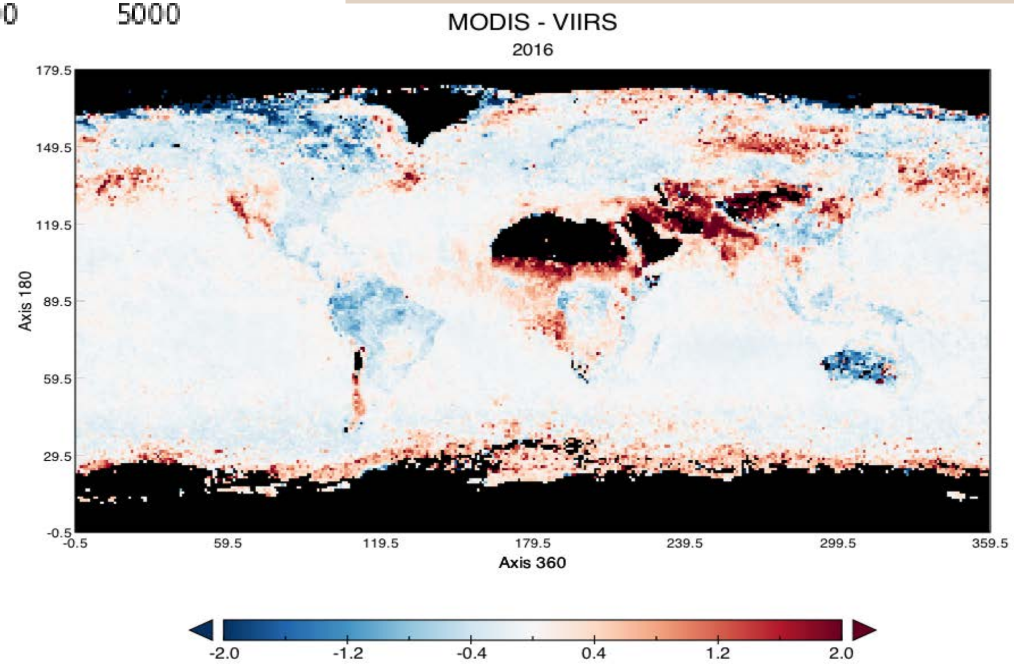


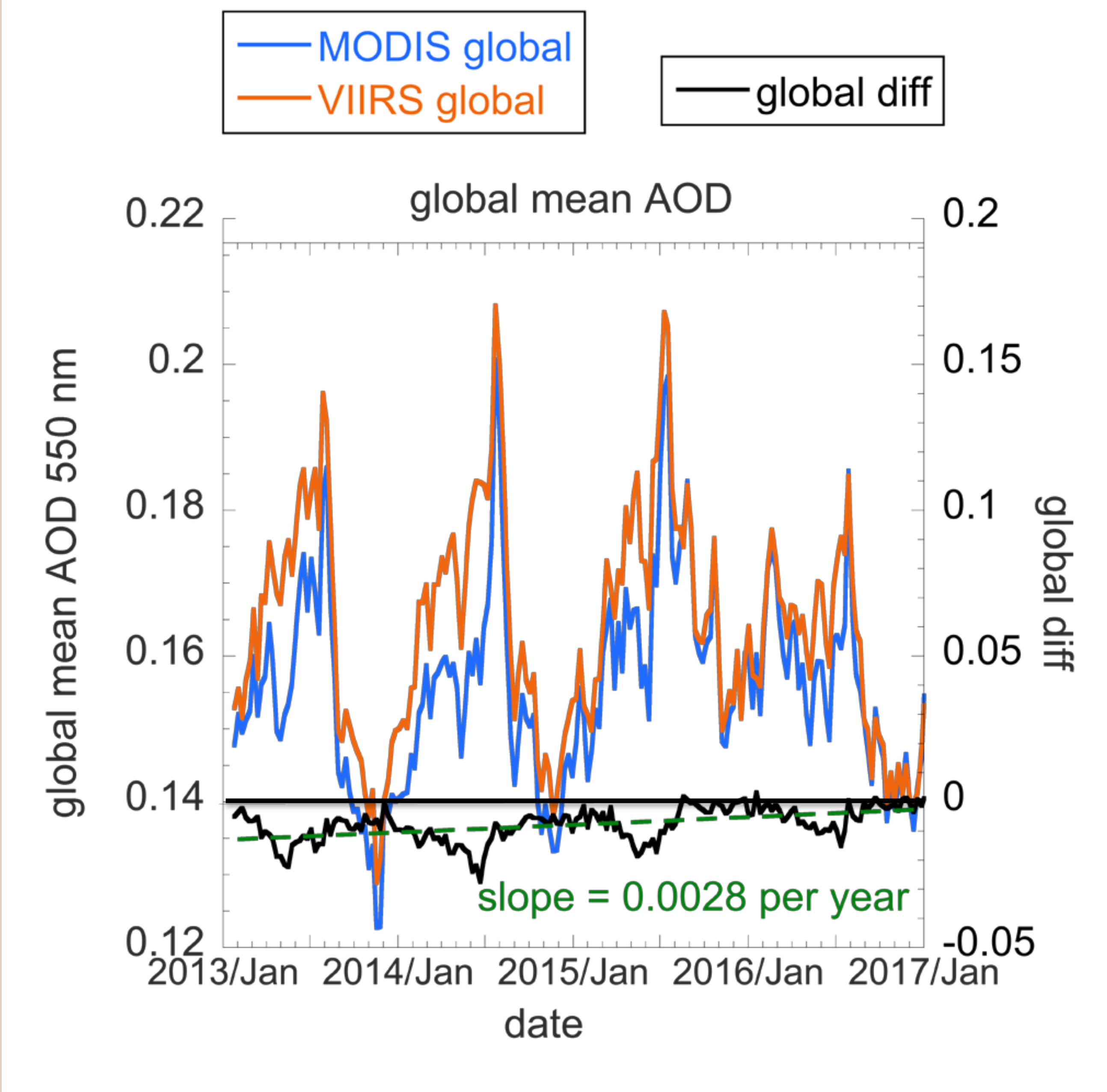

MODIS - VIIRS
2013
179.5
149.5
119.5
89.5
59.5
29.5
-0.5
Axis 180
-0.5
59.5
119.5
179.5
239.5
299.5
Axis 360
2013
MODIS - VIIRS
2014
179.5
149.5
119.5
89.5
59.5
29.5
-0.5
Axis 180
-0.5
59.5
119.5
179.5
239.5
299.5
359.5
Axis 360
2014
MODIS - VIIRS
2015
179.5
149.5
119.5
89.5
59.5
29.5
-0.5
Axis 180
-0.5
59.5
119.5
179.5
239.5
299.5
359.5
Axis 360
2015
MODIS - VIIRS
2016
179.5
149.5
119.5
89.5
59.5
29.5
-0.5
Axis 180
-0.5
59.5
119.5
179.5
239.5
299.5
359.5
Axis 360
2016



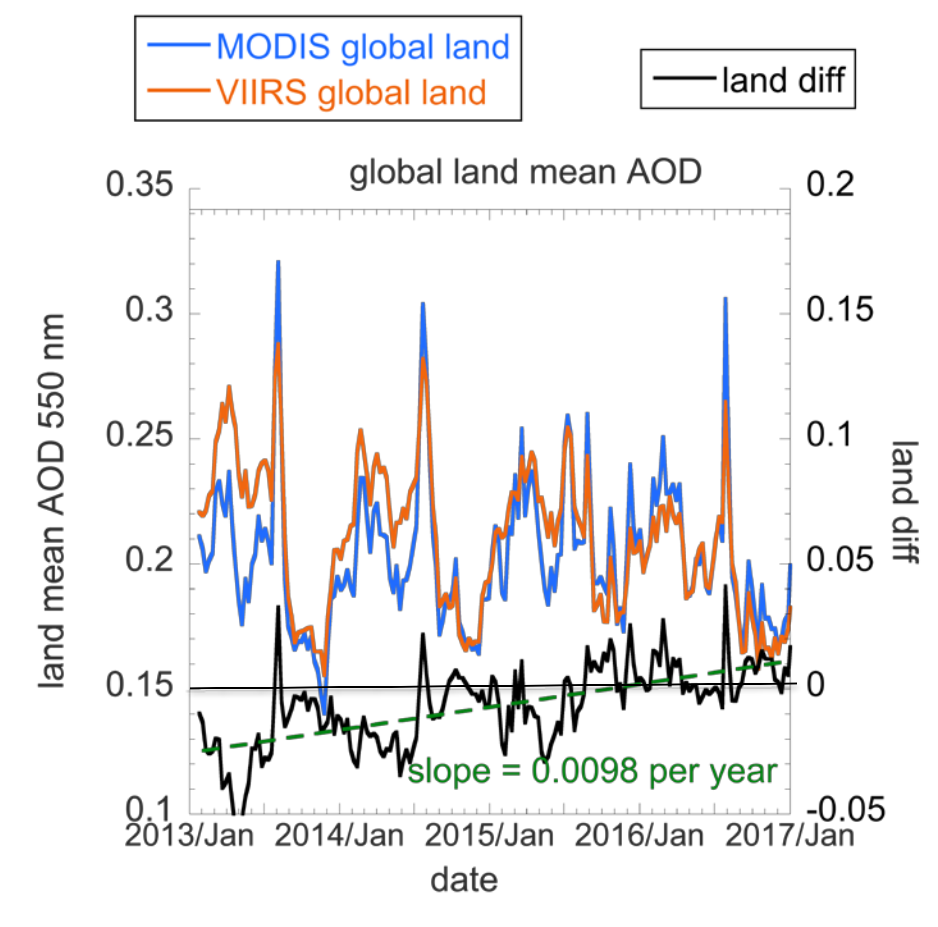
VIIRS count is the number of 0.25 deg squares in each 1 degree box for the entire period. (5840 max for 1 year).

Shown are 2016 counts and differences.

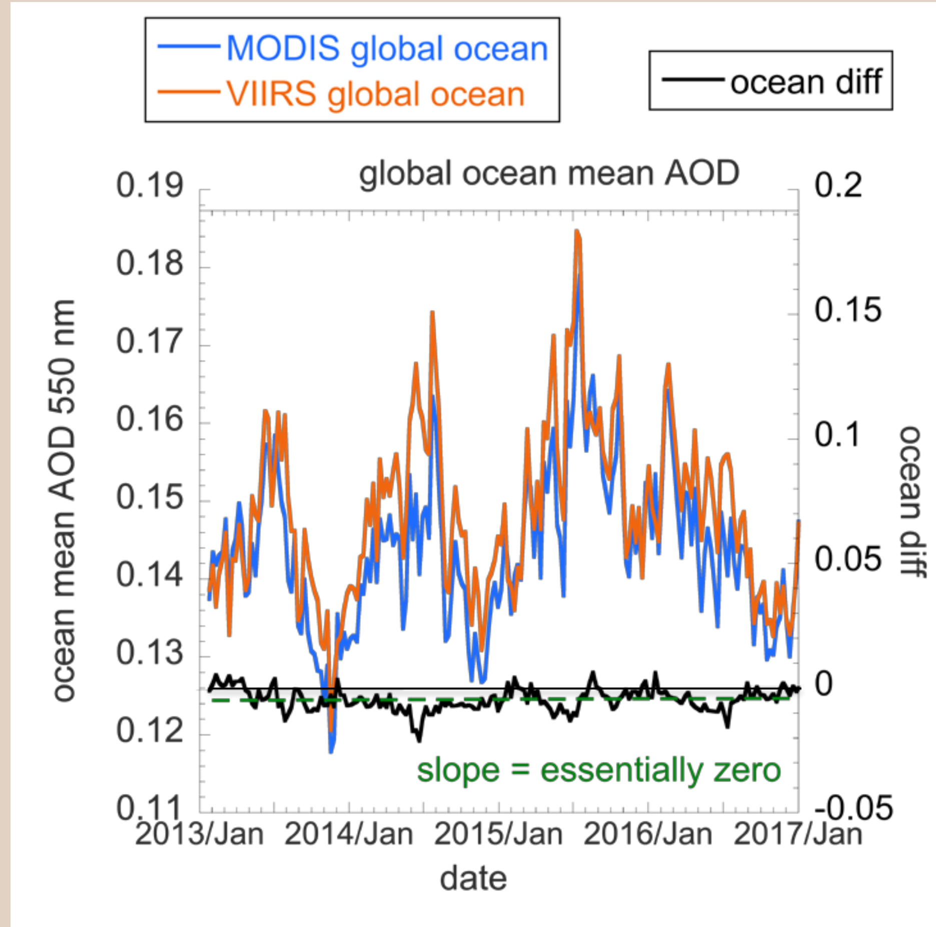




MODIS global
VIIRS global
global diff
global mean AOD
0.22
0.2
0.18
0.16
0.14
0.12
0.2
0.15
0.1
0.05
0
-0.05
global mean AOD 550 nm
global diff
slope = 0.0028 per year
2013/Jan
2014/Jan
2015/Jan
2016/Jan
2017/Jan
date



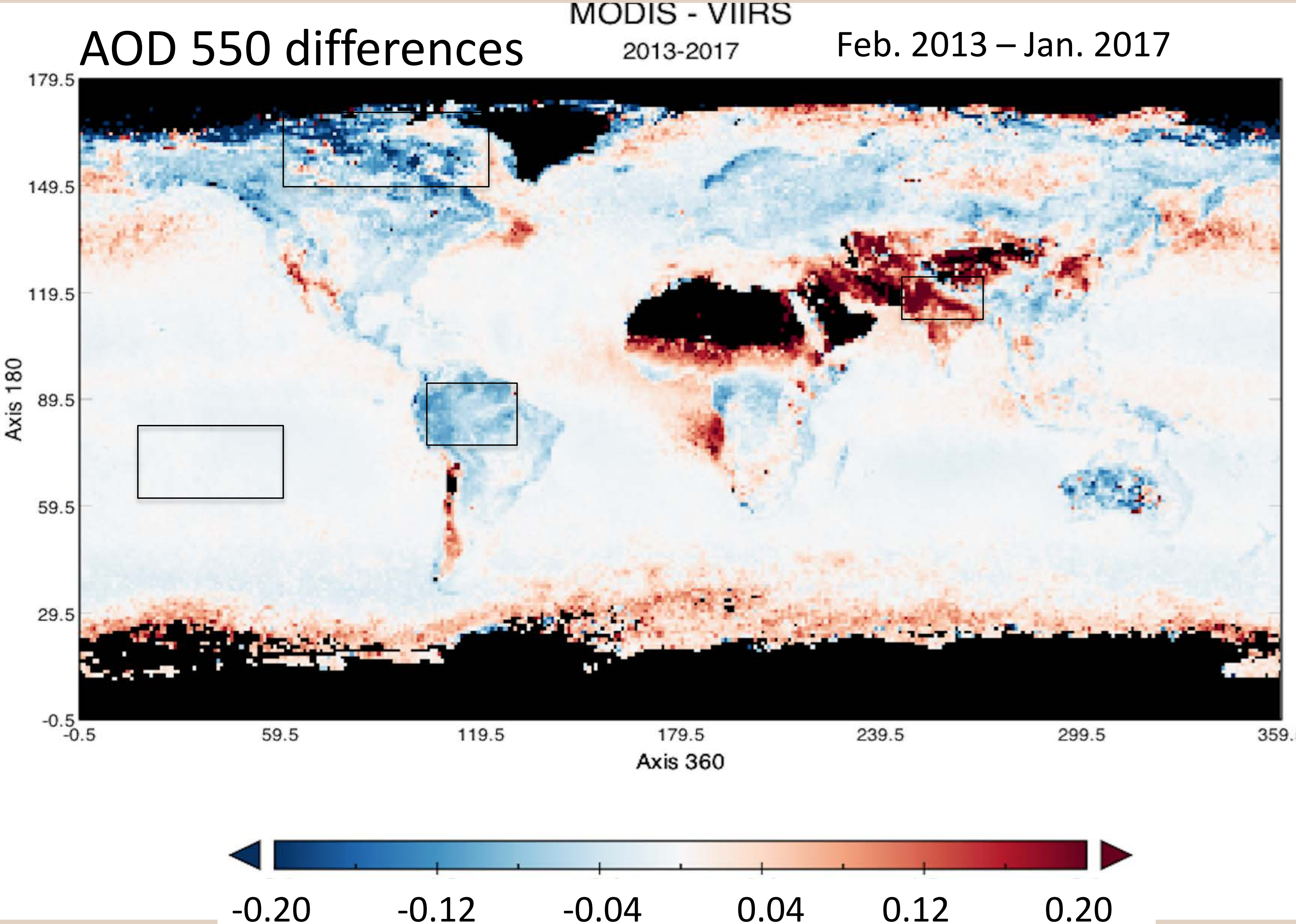
MODIS global land
VIIRS global land
land diff
global land mean AOD
land mean AOD 550 nm
land diff
slope = 0.0098 per year
0.35
0.3
0.25
0.2
0.15
0.1
0.2
0.15
0.1
0.05
0
-0.05
2013/Jan 2014/Jan 2015/Jan 2016/Jan 2017/Jan
date

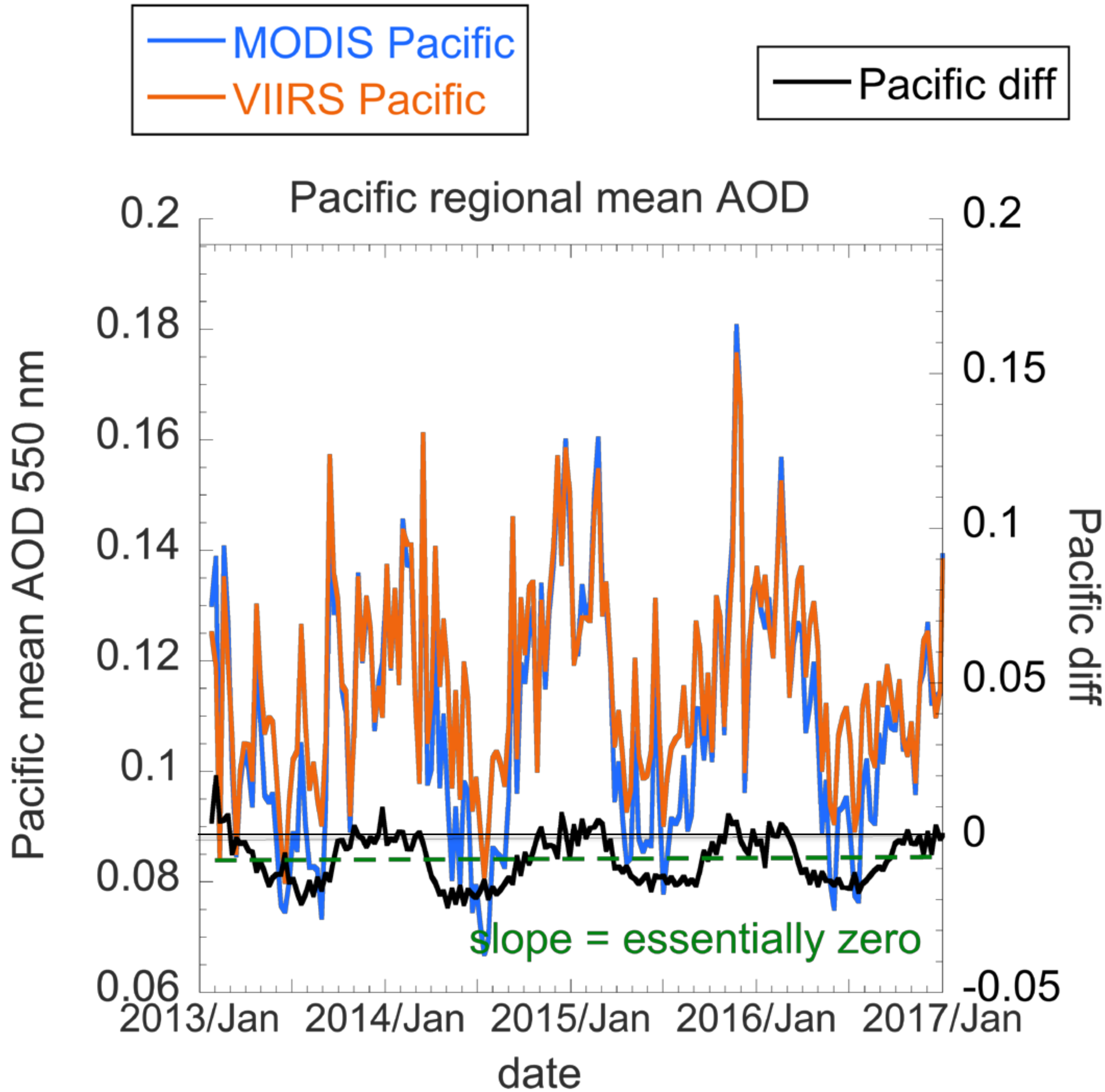


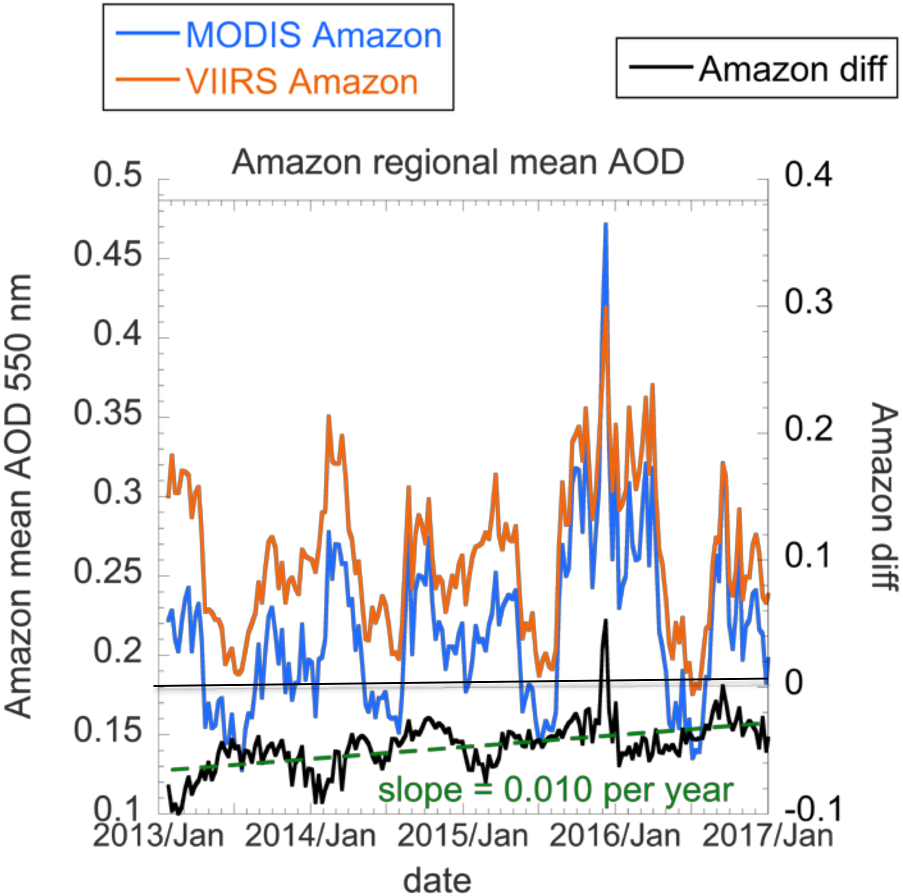
MODIS global ocean
VIIRS global ocean
ocean diff
global ocean mean AOD
ocean mean AOD 550 nm
ocean diff
slope = essentially zero
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.2
0.15
0.1
0.05
0
-0.05
2013/Jan 2014/Jan 2015/Jan 2016/Jan 2017/Jan
date

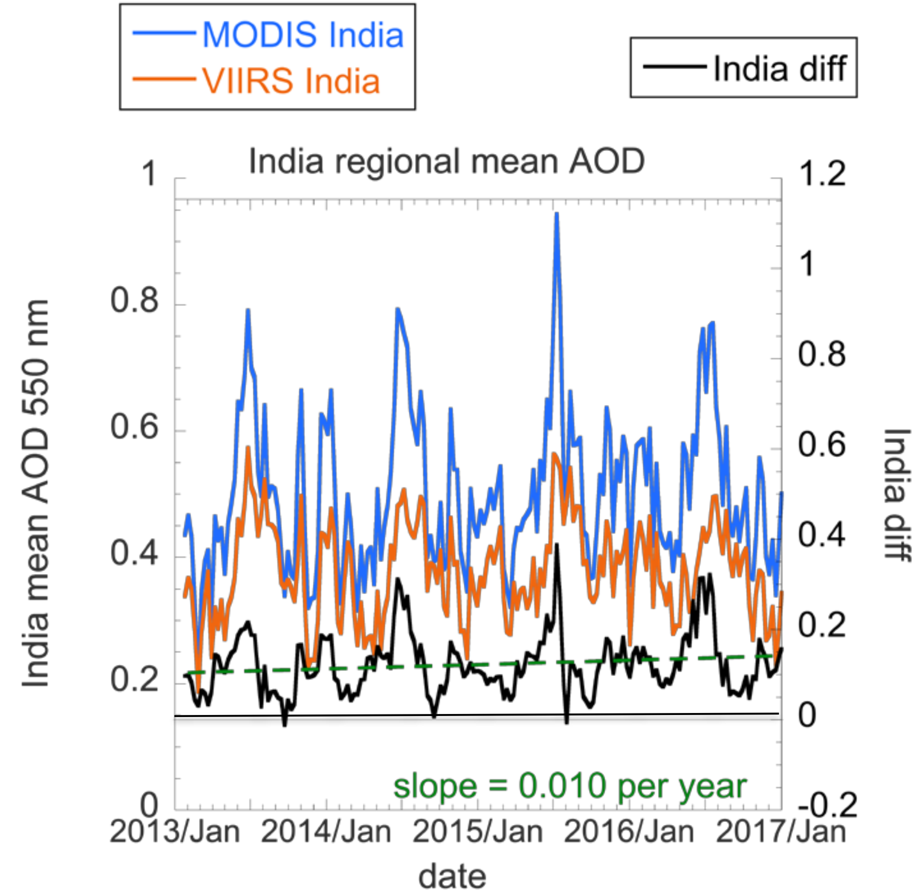
AOD 550 differences

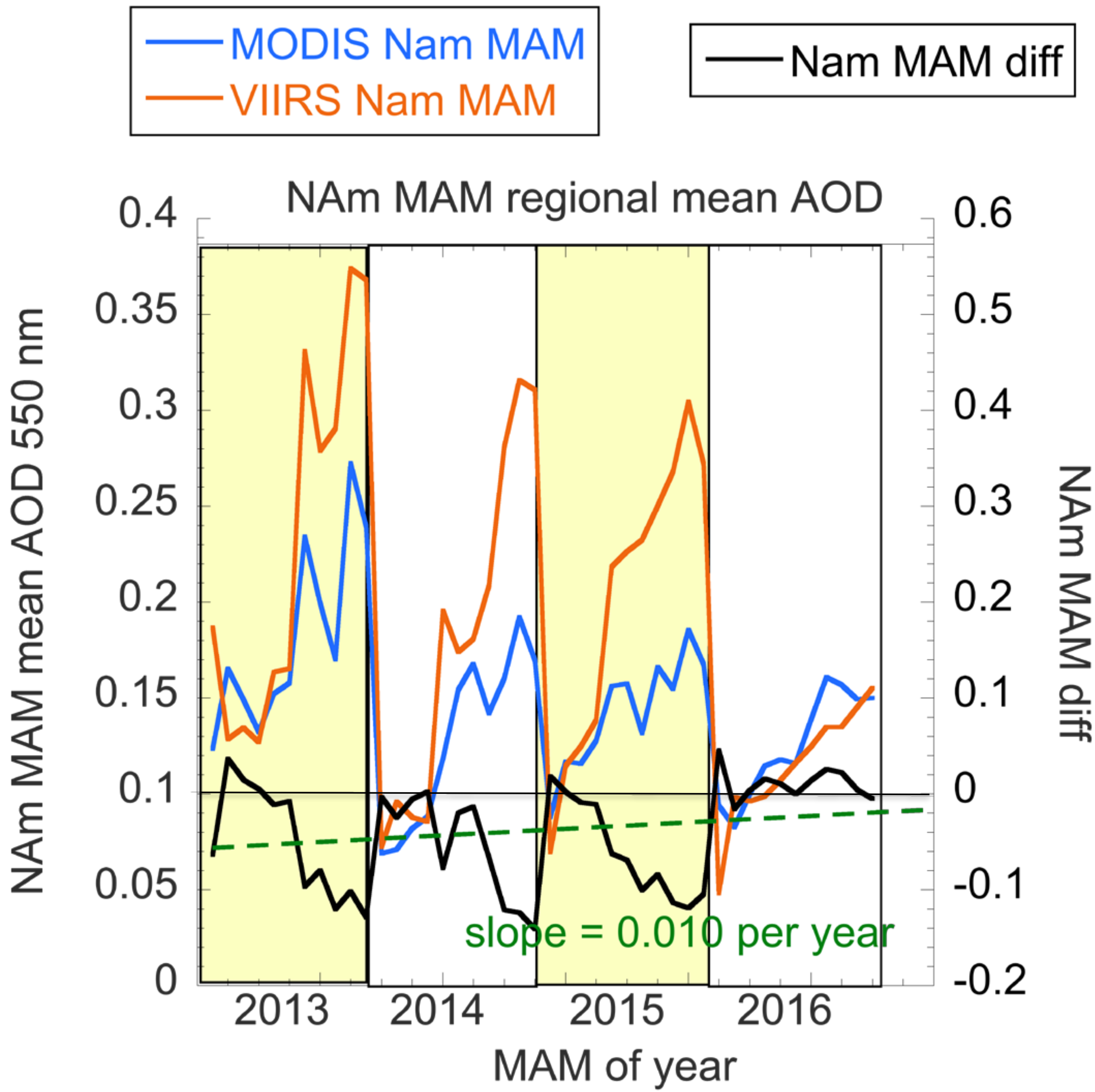
Feb. 2013 – Jan. 2017



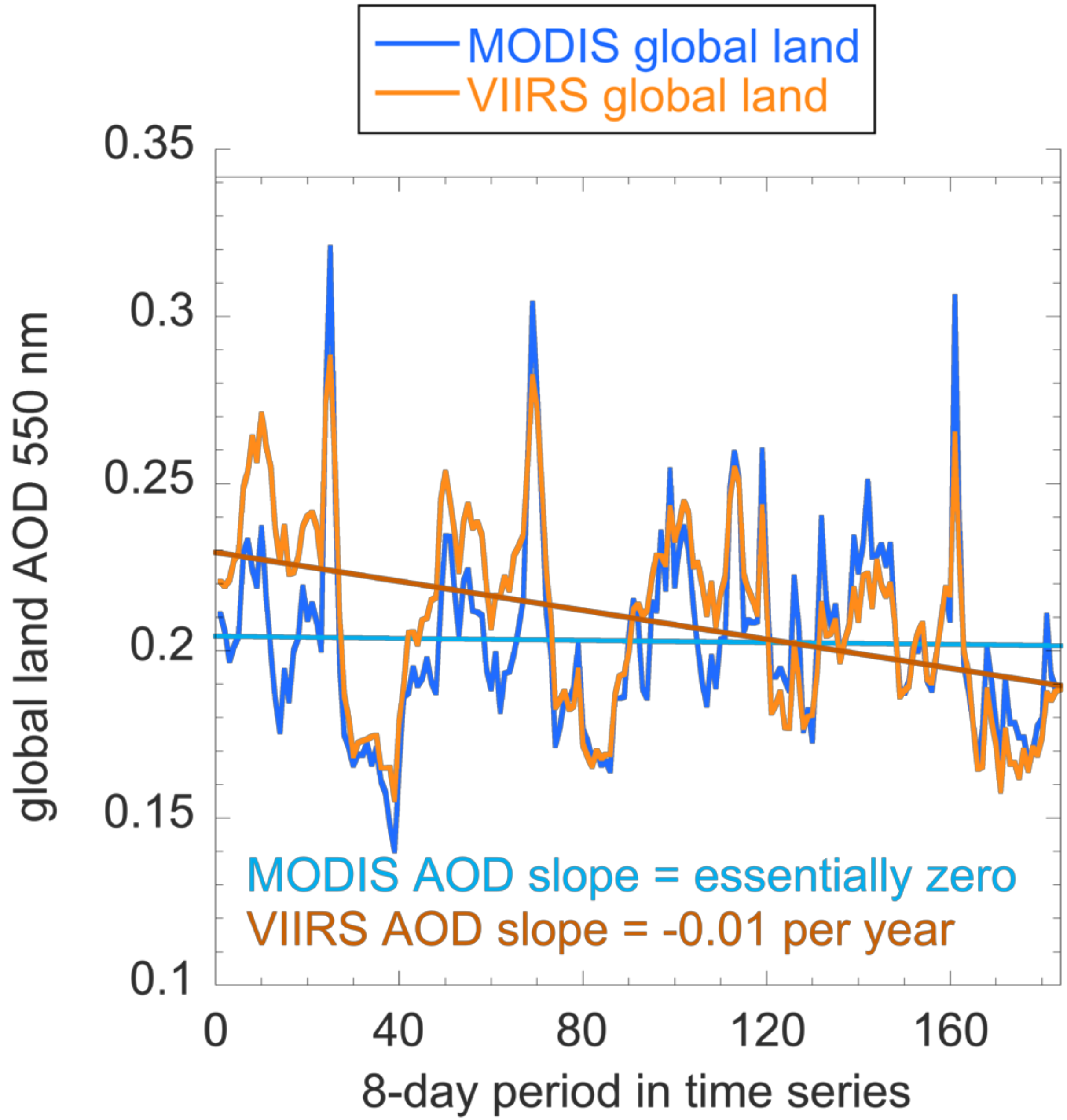

MODIS Pacific
VIIRS Pacific
Pacific diff
Pacific regional mean AOD
Pacific mean AOD 550 nm
Pacific diff
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.2
0.15
0.1
0.05
0
-0.05
slope = essentially zero
2013/Jan
2014/Jan
2015/Jan
2016/Jan
2017/Jan
date


MODIS Amazon
VIIRS Amazon
Amazon diff
Amazon regional mean AOD
Amazon mean AOD 550 nm
Amazon diff
slope = 0.010 per year
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.4
0.3
0.2
0.1
0
-0.1
2013/Jan
2014/Jan
2015/Jan
2016/Jan
2017/Jan
date


MODIS India
VIIRS India
India diff
India regional mean AOD
India mean AOD 550 nm
India diff
slope = 0.010 per year
1
0.8
0.6
0.4
0.2
0
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
2013/Jan
2014/Jan
2015/Jan
2016/Jan
2017/Jan
date



MODIS Nam MAM
VIIRS Nam MAM
Nam MAM diff
NAm MAM regional mean AOD
NAm MAM mean AOD 550 nm
NAm MAM diff
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
slope = 0.010 per year
2013
2014
2015
2016
MAM of year


MODIS global land
VIIRS global land
0.35
0.3
0.25
0.2
0.15
0.1
global land AOD 550 nm
MODIS AOD slope = essentially zero
VIIRS AOD slope = -0.01 per year
0
40
80
120
160
8-day period in time series

Something happened to VIIRS in 2015 that caused land AODs to decrease.

Translates to 0.01 per year, but is really a jump, not linear.

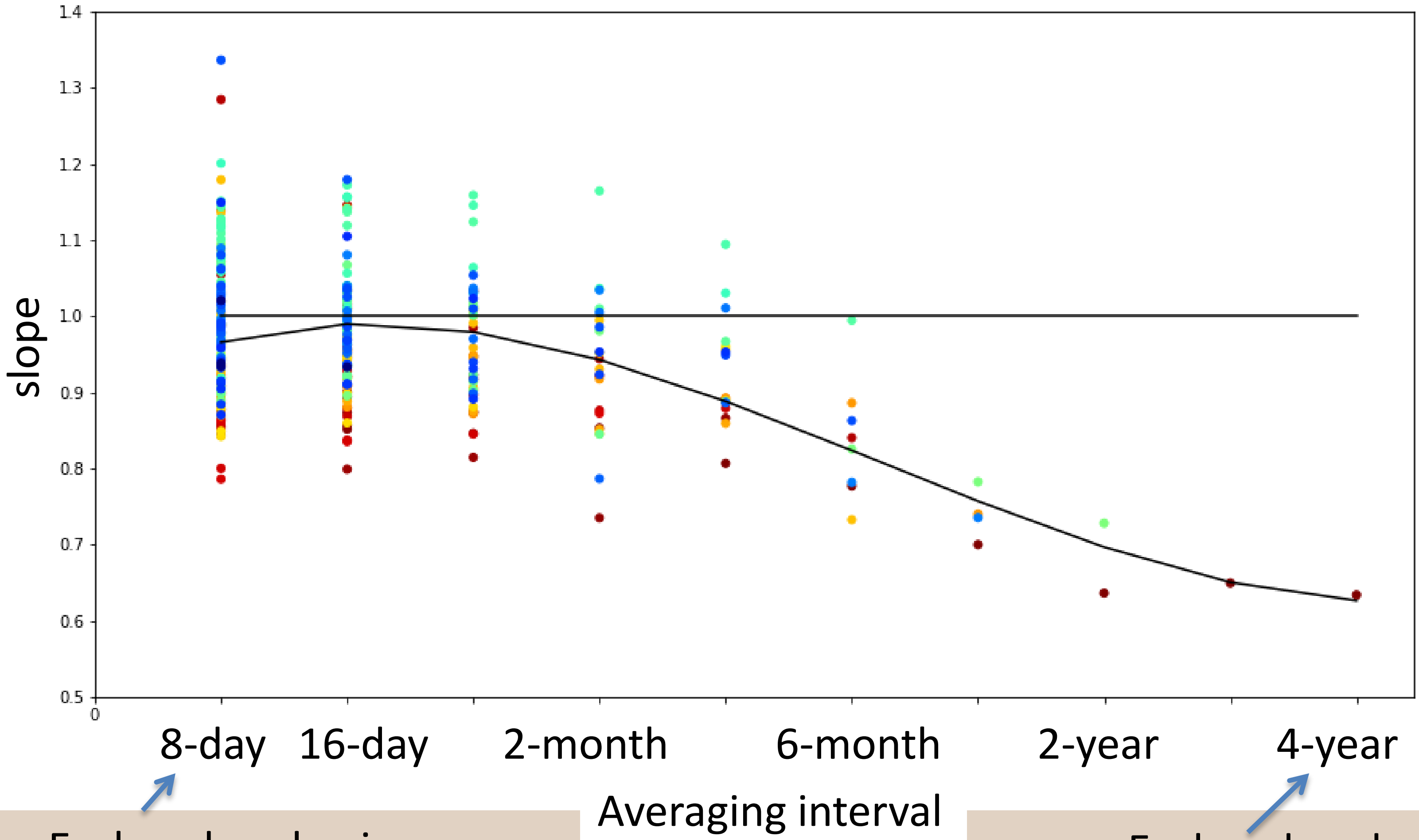
Result over all is to bring VIIRS closer to MODIS.

But not in India, and other land locations where VIIRS is higher than MODIS.

No temporal change to ocean AODs.

VIIRS background ocean AOD still 0.005 higher than MODIS.

Global 4 Years, Slope



Each ordered pair is 8-day mean

Each ordered pair is a 4-year mean

Potential Solution to Resolving Data Artifacts in VIIRS Aerosol Detection Product over Land

Hai Zhang[1], Pubu Ciren[1], Shobha Kondragunta[2], Istvan Laszlo[2], Lorraine A. Remer[3], Hongqing Liu[1], Jingfeng Huang[4], Mi Zhou[1], Ivan Valerio[1]

1. IMSG; 2. NOAA; 3. UMBC; 4. UMD

Outline

- VIIRS Aerosol Detection Product (ADP)
- Demonstration and analysis of the data artifacts in ADP dust detection
- Dust RGB images using IR bands
- Dust detection using IR bands based on dust RGB method

VIIRS Aerosol Detection Product (ADP)

- Detect smoke and dust using two aerosol indices:
  - Absorbing Aerosol Index (AAI)

$$AAI = -100\left[\log_{10}\left(\frac{R_{412}}{R_{440}}\right) - \log_{10}\left(\frac{R'_{412}}{R'_{440}}\right)\right]$$

    - R_{412} and R_{440} : TOA reflectance at 412nm and 440nm bands
    - R'_{412} and R'_{440} : Rayleigh reflectance at 412nm and 440nm bands
  - Dust Smoke Discrimination Index (DSDI)
    - $DSDI = -10\ log_{10}(\frac{R_{412}}{R_{2130}})$
    - R_{412} and R_{2130} : TOA reflectance at 412nm and 2130nm bands

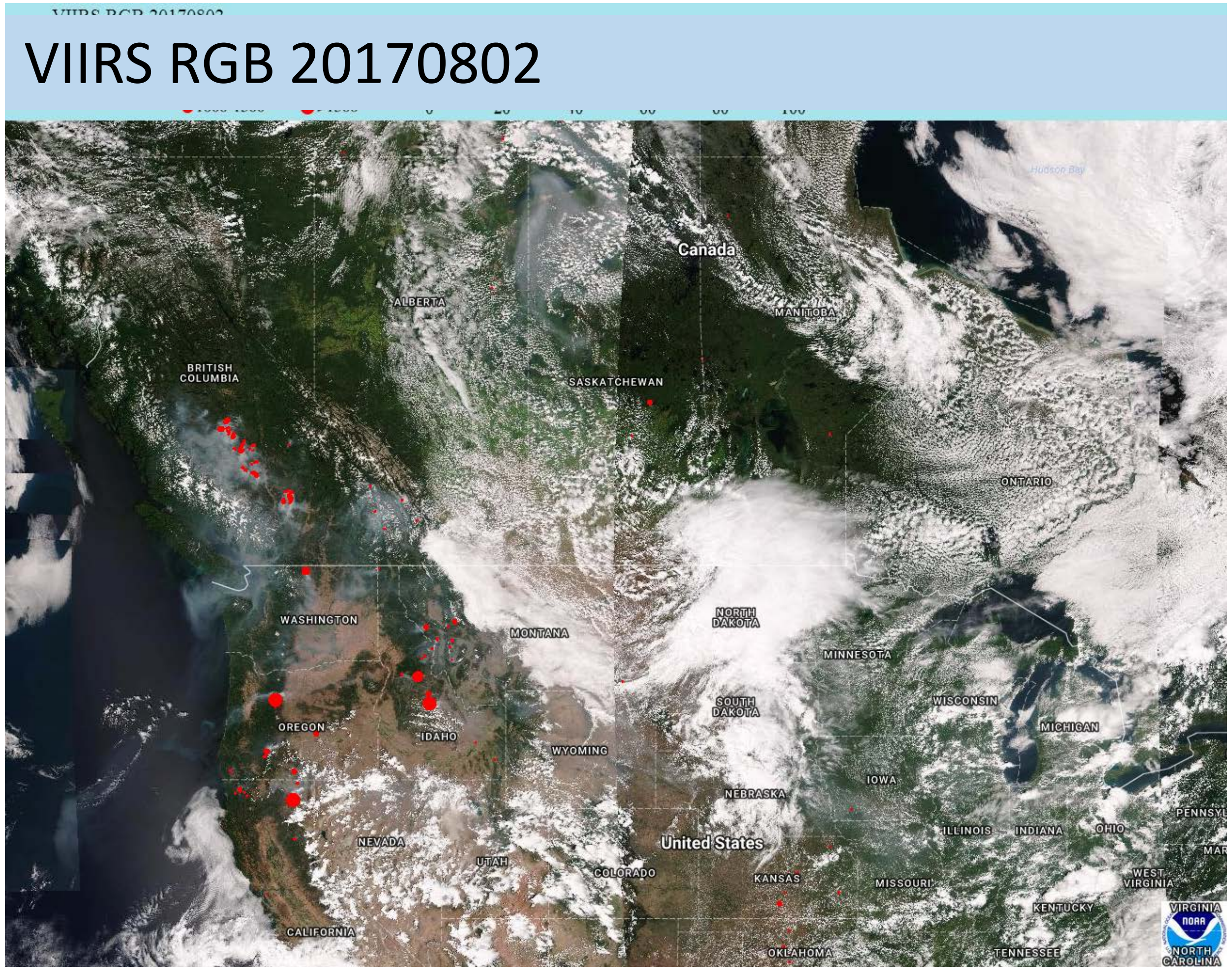
VIIRS Aerosol Detection Product (ADP)

- The detection is based on thresholds of AAI and DSDI, which are different over land and ocean

Surface type	Aerosol type	AAI thresholds	DSDI thresholds	Other
Land	Dust	> 10	≥ 0.0	
	Smoke	≥ 5.0 thin ≥ 9.0 thick	≤ -3.0 thin ≤ -2.0 thick	$0.2<R_{412}<0.4$ thick
Ocean	Dust	> 4.0	≥ -10.0	
	Smoke	≥ 4.5 thin ≥ 10.0 thick	≤ -10.0 thin ≤ -4.0 thick	$R_{2130} < 0.1$ thin

An example of smoke mask shown on eIDEA
(https://www.star.nesdis.noaa.gov/smcd/spb/aq/eidea/)

VIIRS RGB 20170802



VIIRS RGB and smoke mask 20170802

The dust mask is not shown on eIDEA because of the problems in the following slides

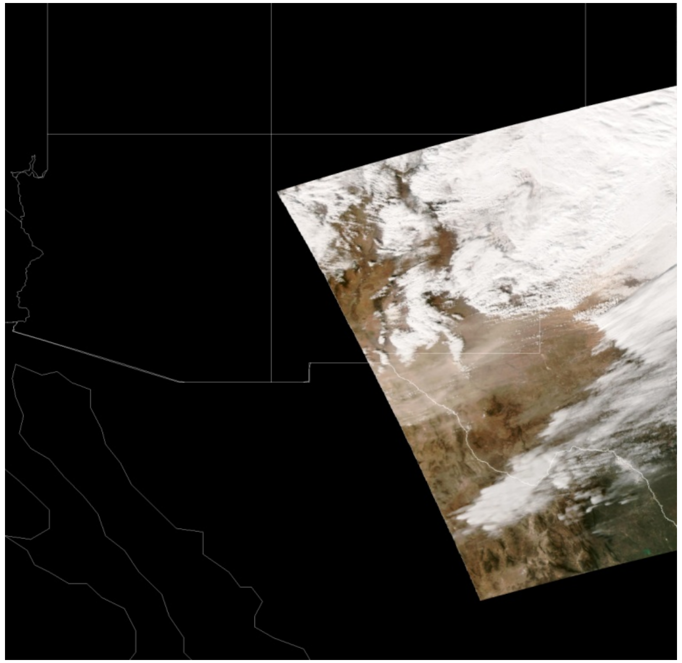
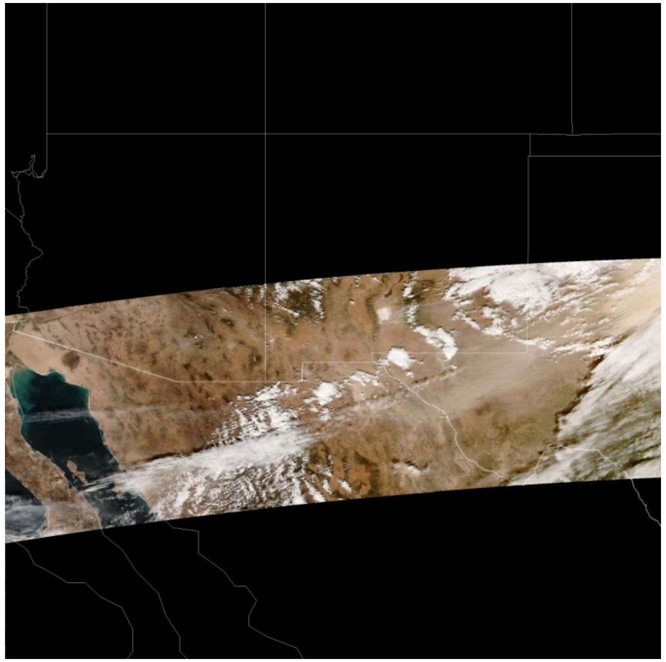
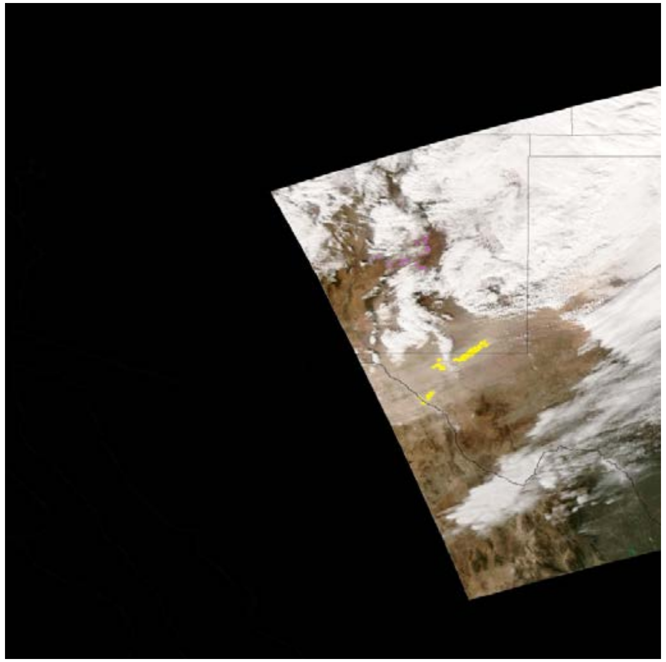
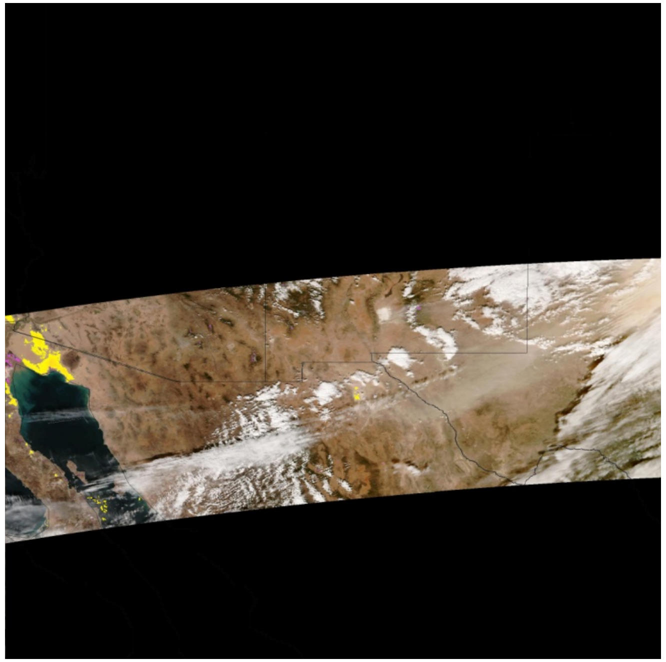
Problems in dust detection over land

- False detection
- Undetected dust
- Geometry dependent
- Demonstrated in the following cases

VIIRS 20161217

Dust storm near Texas/Mexico boundary

Two overpasses

	1902 UTC	2043 UTC
RGB		
RGB and dust mask (yellow)		

VIIRS 20161217

Dust storm near Texas/Mexico boundary

Two overpasses

1902 UTC

2043 UTC

RGB

RGB and dust mask (yellow)

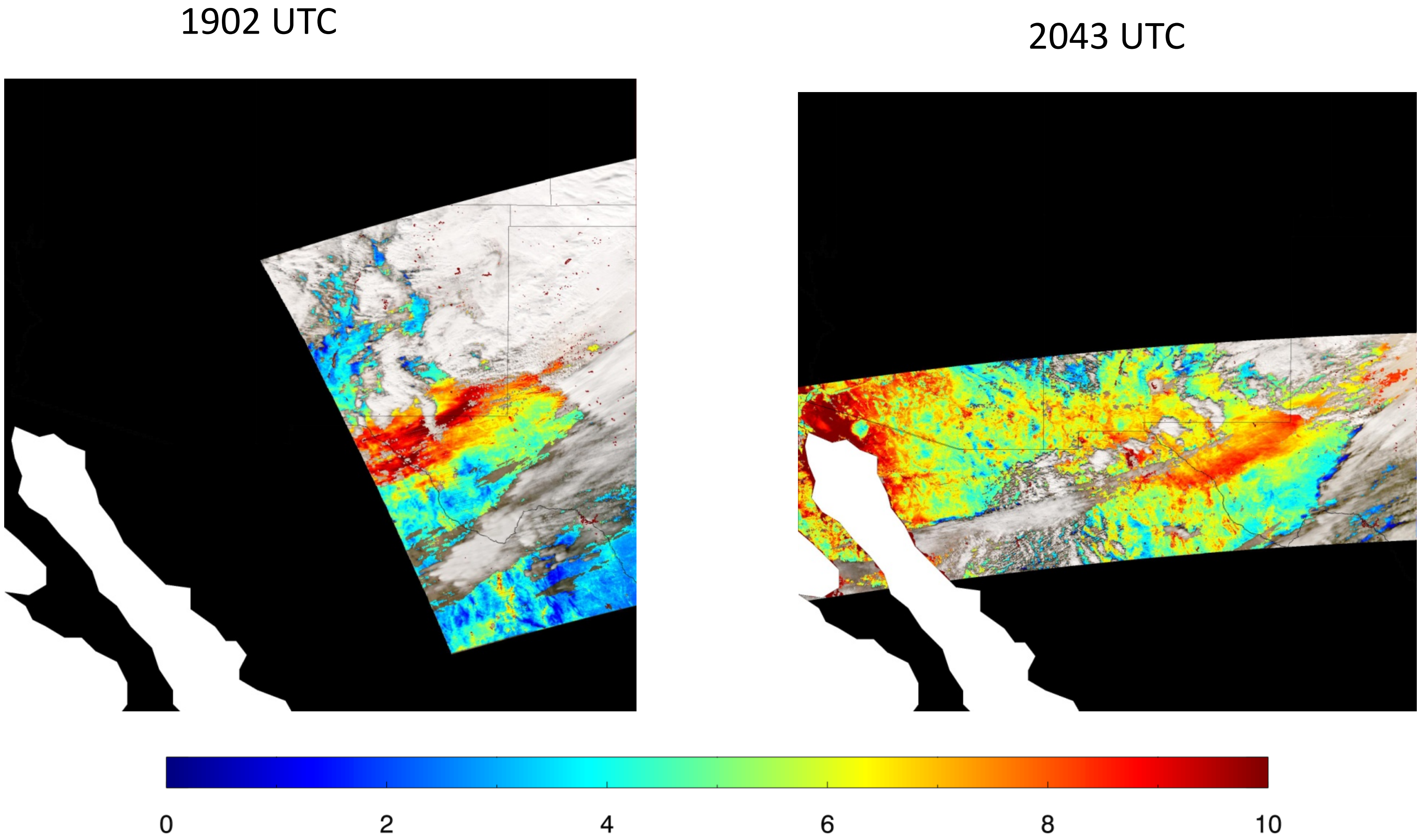
NPP track for 20161217

Since the sun is to the west of the nadir, the overpass at 1902 is in forward reflection geometry and the overpass at 2043 is in backward reflection geometry.

2043 overpass

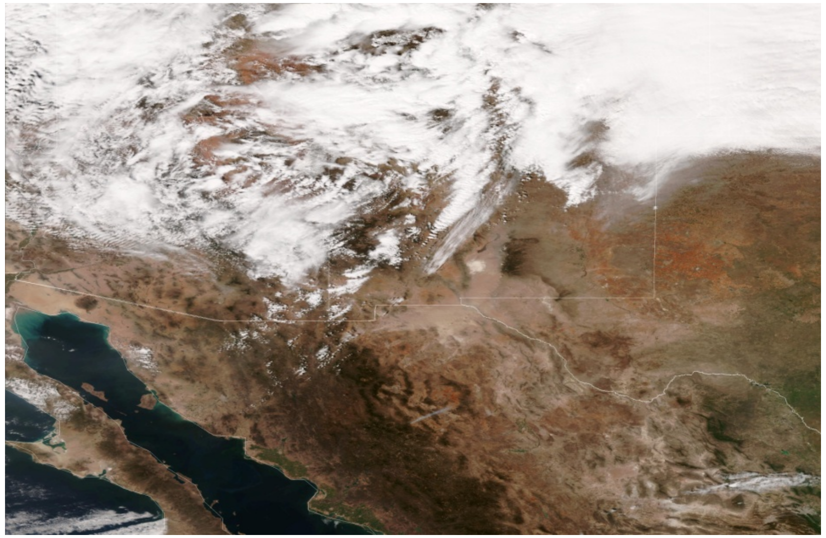
1902 overpass

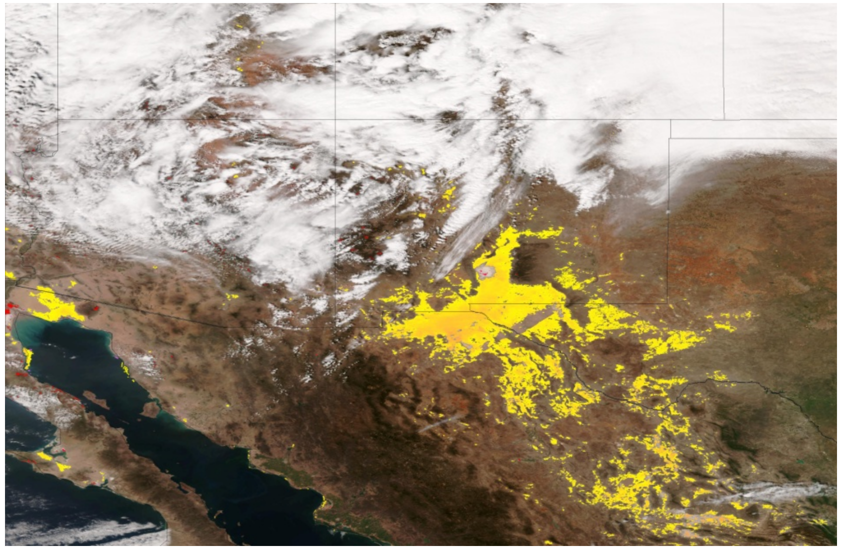
VIIRS AAI 20161217



- AAI is lower in the backward reflection geometry than that in the forward reflection geometry

An example with the area close to the center of the granule (20170331)

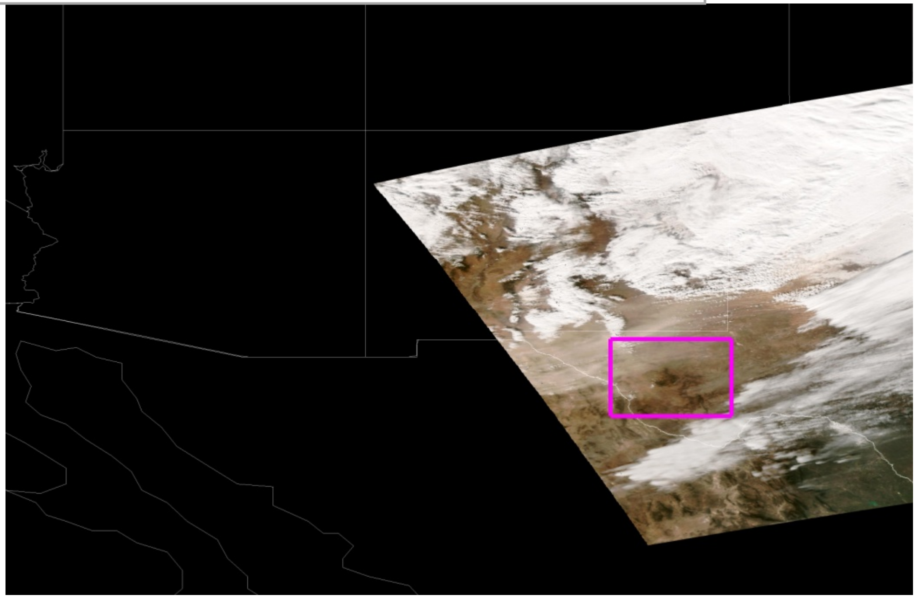


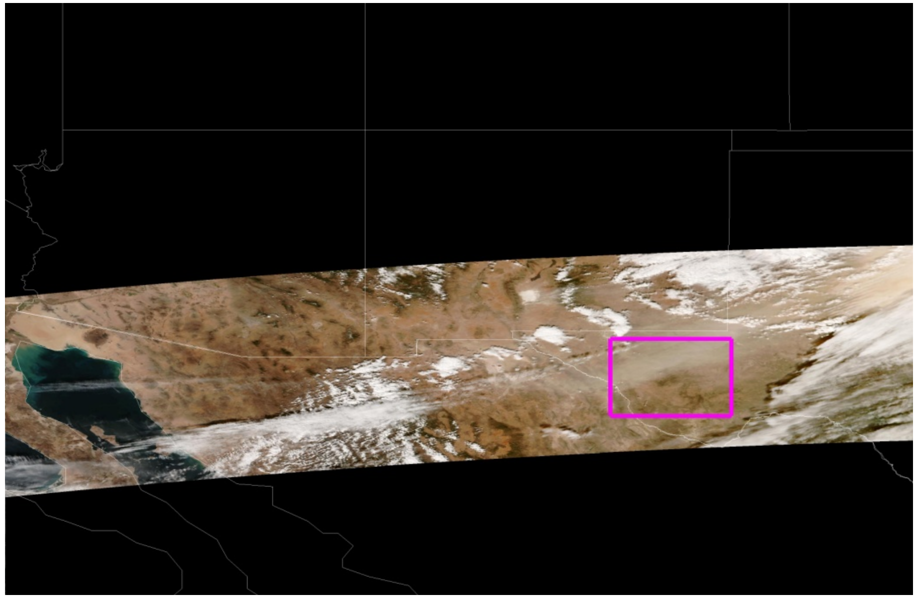


The false detection is more serious in the areas close to the nadir

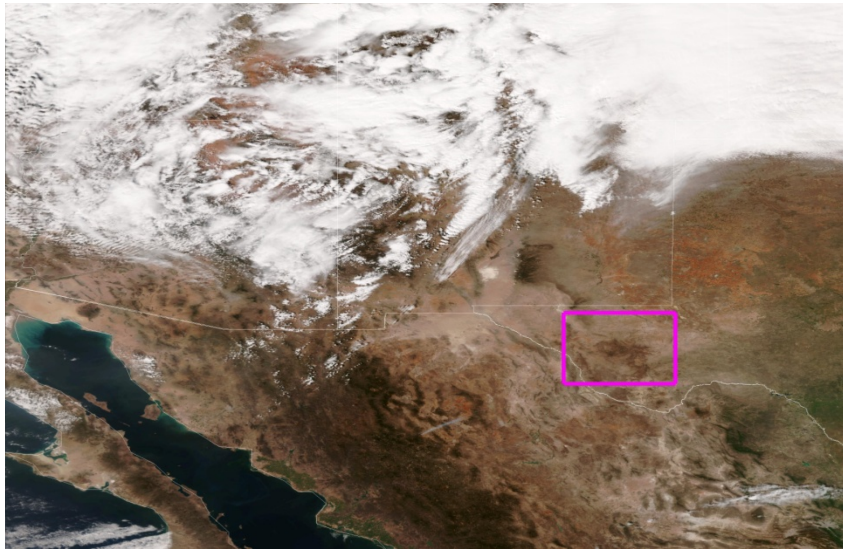
Simulation study of AAI vs aerosol load in the three geometries

20161217





20170331



- Obtain the geometries in the boxes (same area in the three cases)
- Obtain the surface reflectance from surface reflectance database (built from multi-year VIIRS data)

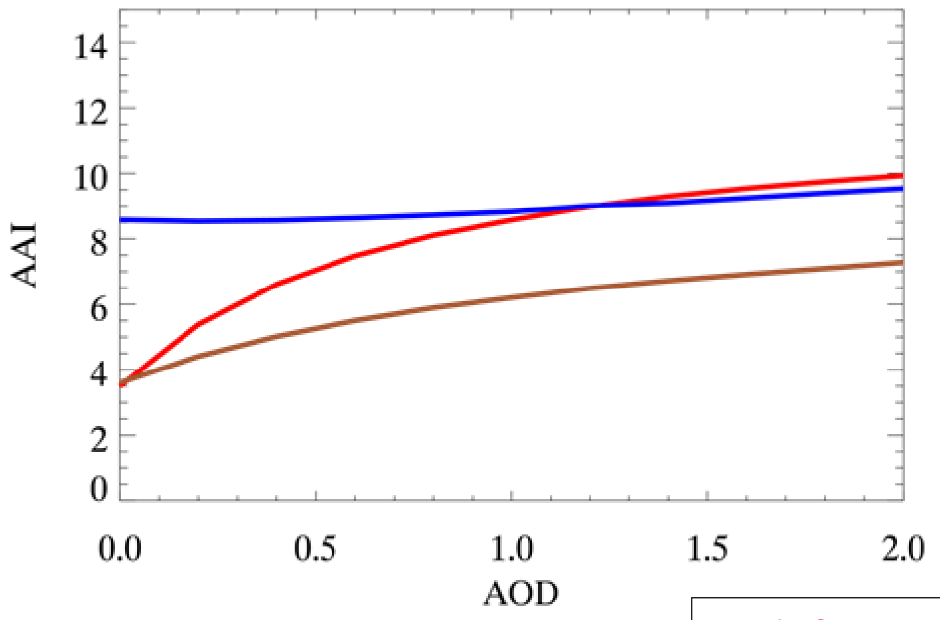
Parameters for the three cases

Case number	description	Lat,lon bound	geometry (sza, vza,azi)	Surface reflectance M1,M2, M3, M5, M11
1	20161217 overpass 1	Lat 29.8N-31.8N Lon 105W-103W	forward (54.27, 65.26, 110.86)	0.05, 0.056, 0.067, 0.126, 0.196
2	20161217 overpass2		backward (60.37, 57.52, 55.80)	0.070, 0.081, 0.098, 0.185, 0.275
3	20170331		nadir (29.11, 13.29, 128.71)	0.076, 0.087, 0.103, 0.182, 0.269

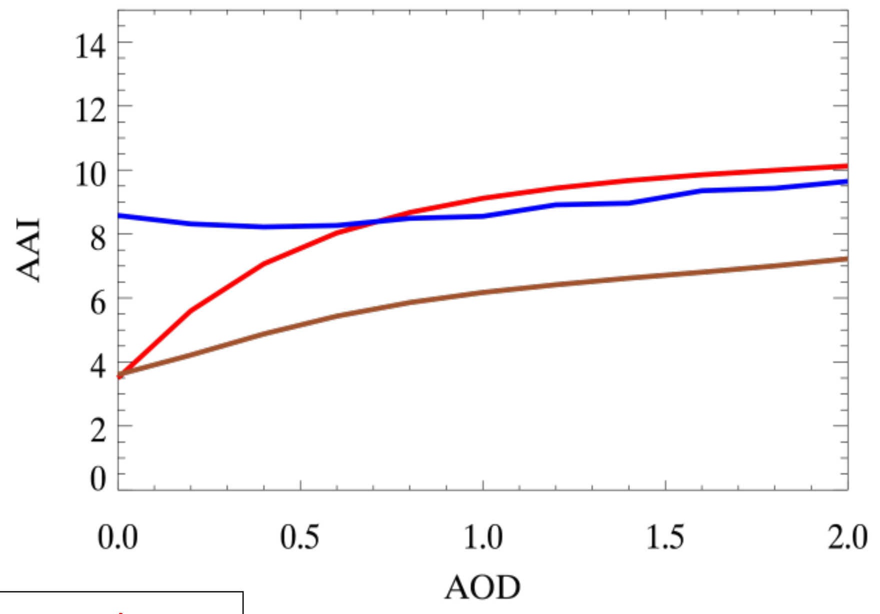
Simulated AAI vs AOD (using LUT in Enterprise AOD algorithm)

$$AAI = -100\left[\log_{10}\left(\frac{R_{412}}{R_{440}}\right) - \log_{10}\left(\frac{R'_{412}}{R'_{440}}\right)\right]$$

Dust



Smoke



Red: forward (20161217 p1)
Brown: backward (20161217 p2)
Blue : nadir (20170331)

- Good sensitivity in forward direction, some sensitivity in backward direction, no sensitivity near nadir
- Dust and smoke are similar in AAI

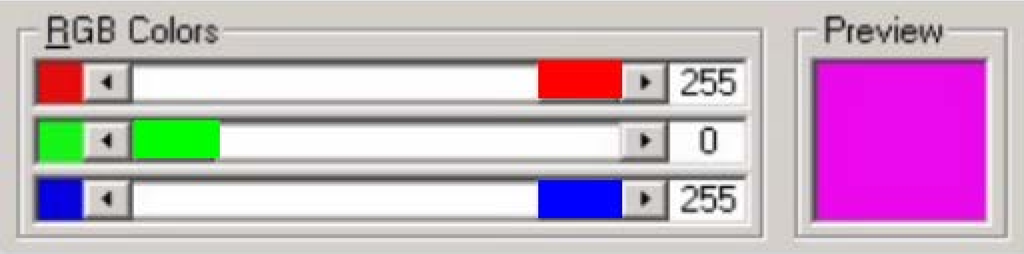
Dust RGB

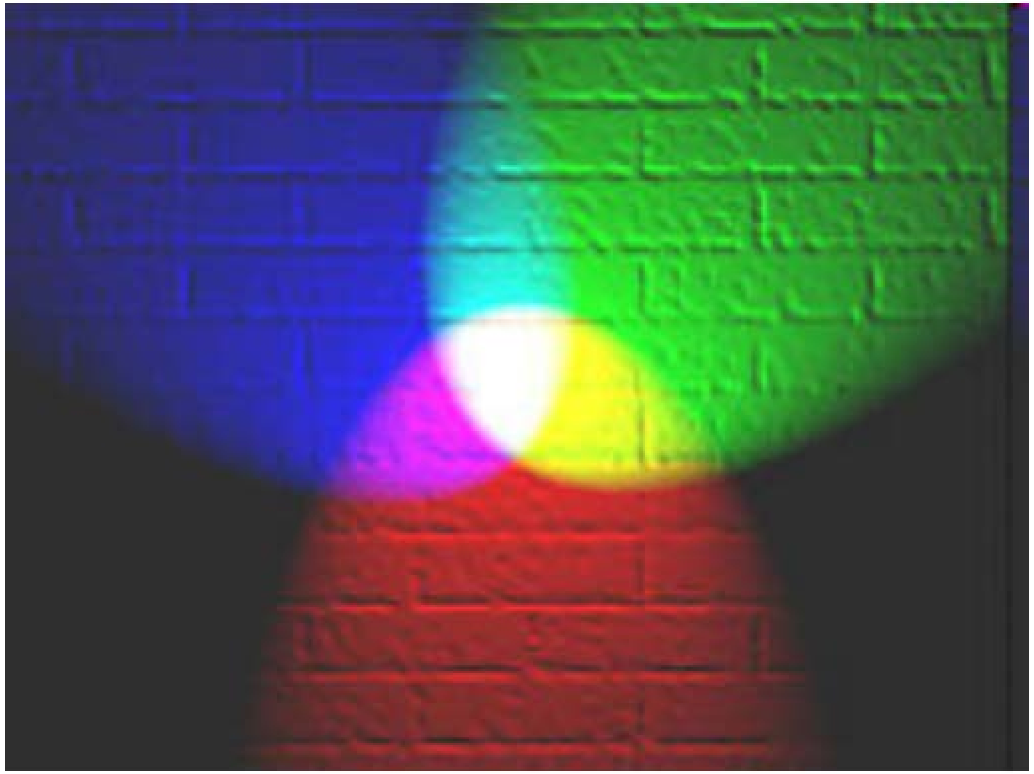
- Used by EUMETSAT (European Organization for Meteorological Satellites) on MSG (Meteosat Second Generation) (https://www.eumetsat.int/website/home/Data/Training/TrainingLibrary/DAT_2042669.html?lang=EN)
- Three IR bands are used: IR8.7, IR10.8 and IR12.0
  - Brightness temperature at IR10.8 is less than that at IR12.0
    - Surface emissivity in 10.8 µm is similar to that in 12 µm
    - More absorption for dust in 10.8 µm than in 12 µm
  - Brightness temperature is close in IR10.8 and in IR8.7
    - Surface emissivity in 10.8 µm is higher than that in 8.7 µm
    - More absorption for dust in 8.7 µm than in 10.8 µm

Dust RGB

- R: bt12 – bt10.8 (bt– brightness temperature)
- G: bt10.8-bt8.7
- B: bt10.8

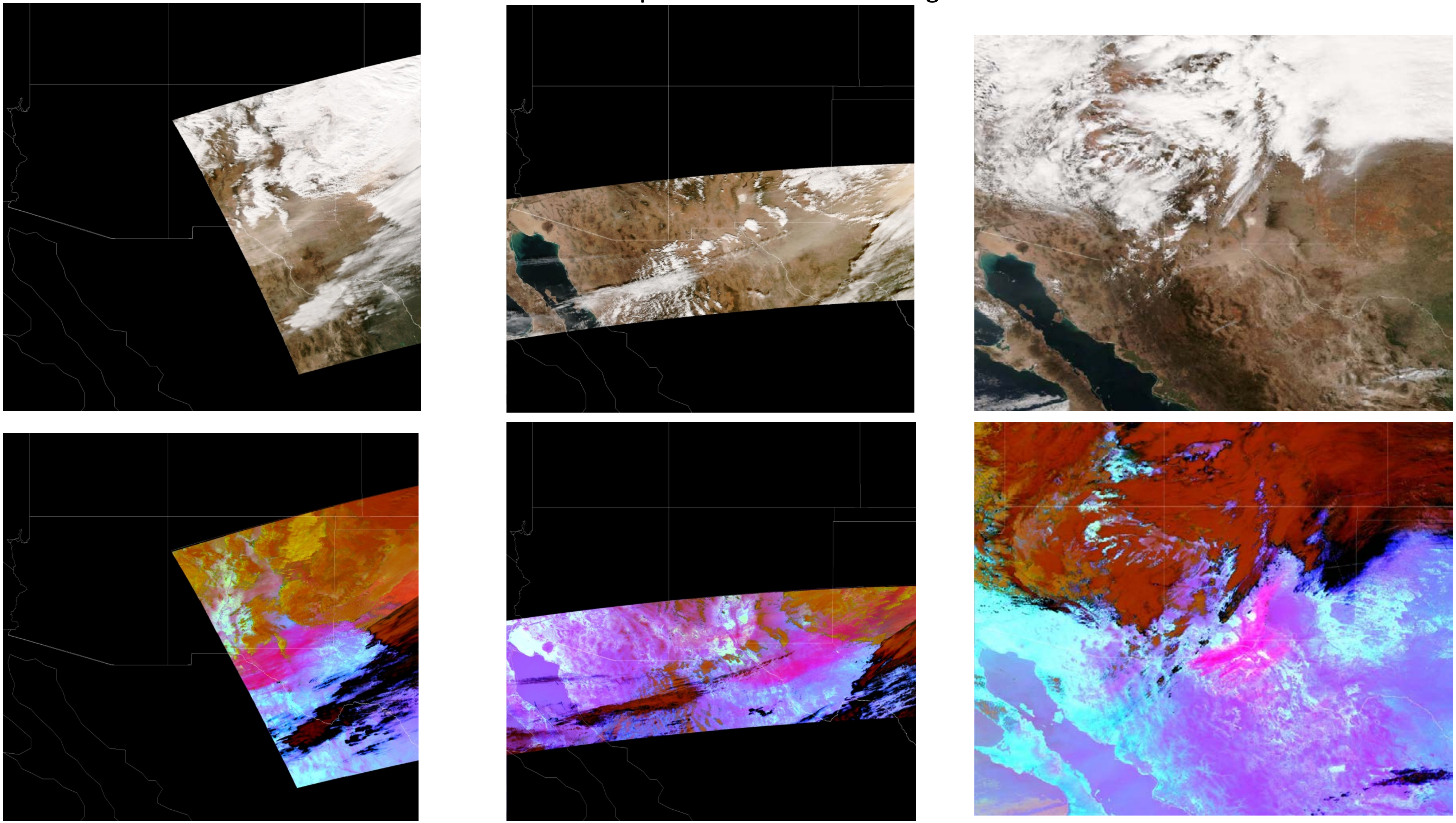
- Using this method, dust shows as magenta color over desert





https://www.eumetsat.int/website/home/Data/Training/TrainingLibrary/DAT_2042669.html?lang=EN

The three cases plotted in dust RGB image

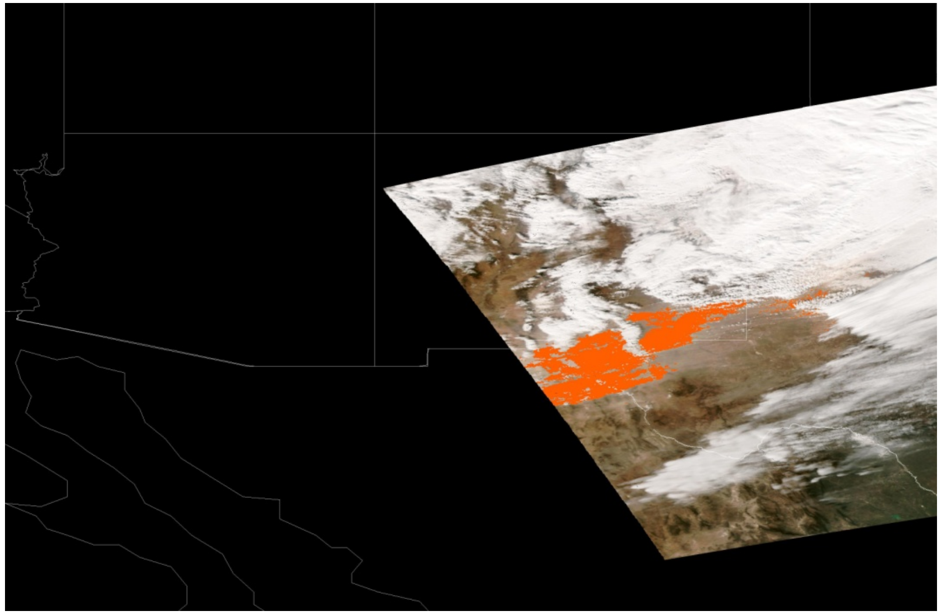


Use thresholds to detect dust in IR bands

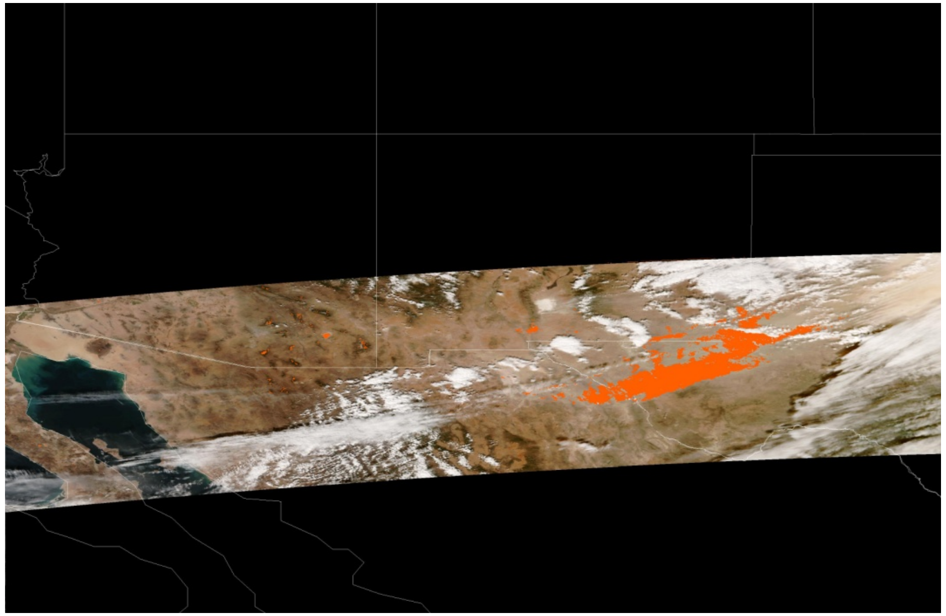
Determine thresholds through visual inspection of the dust cases

	thresholds
R: bt12 – bt10.8	> 0
G: bt10.8-bt8.7	< 0.5 in North America < 4 in North Africa and Arabian Peninsula
B: bt10.8	> 273

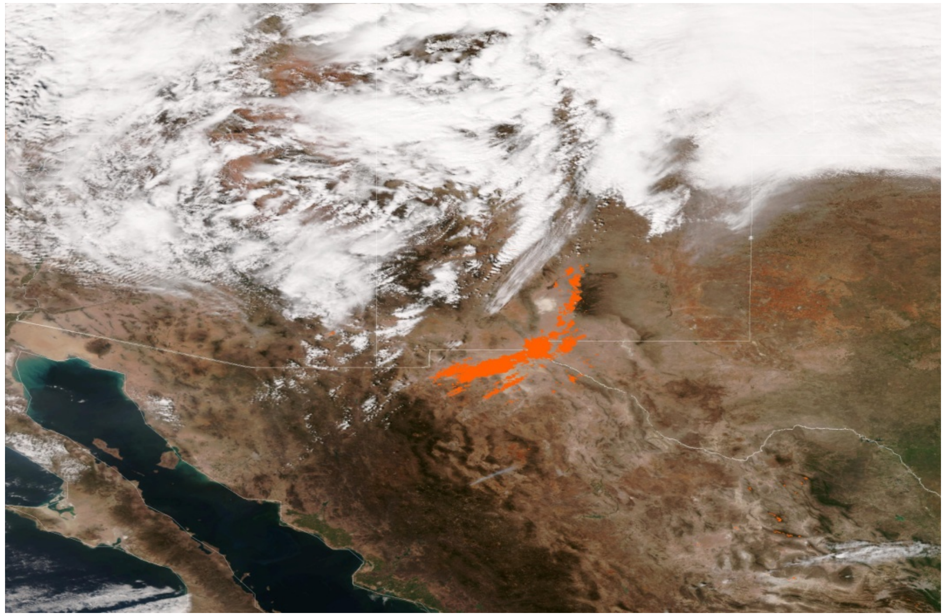
20161217 1902



20161217 2043

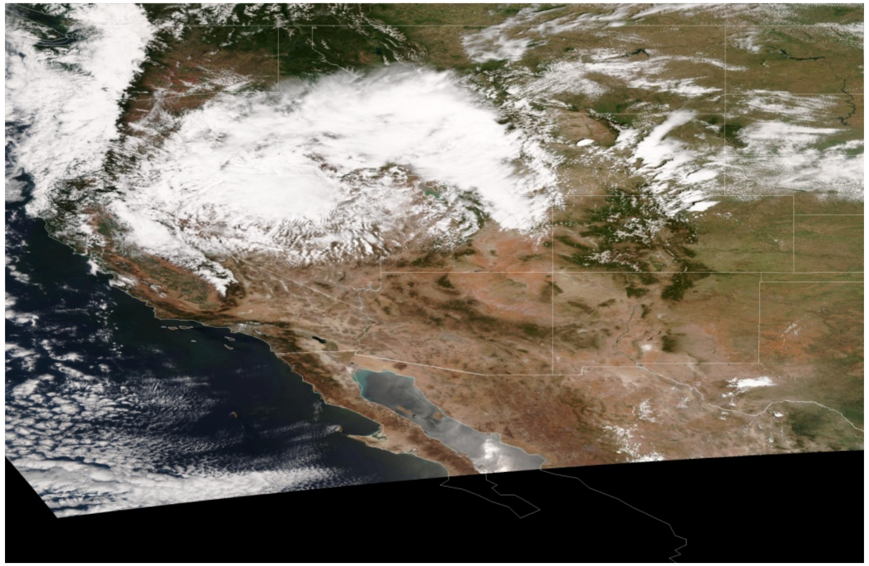


20170331

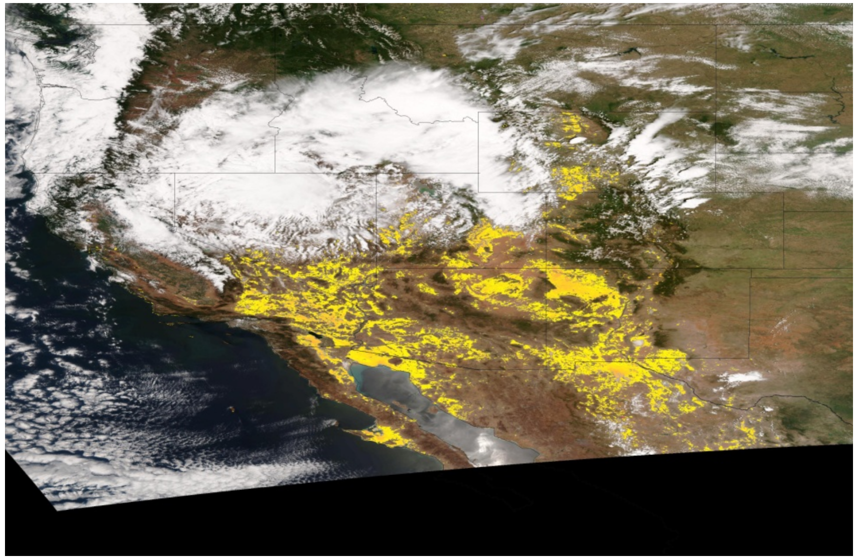


Dust mask (brown color regions) using IR bands for the three cases

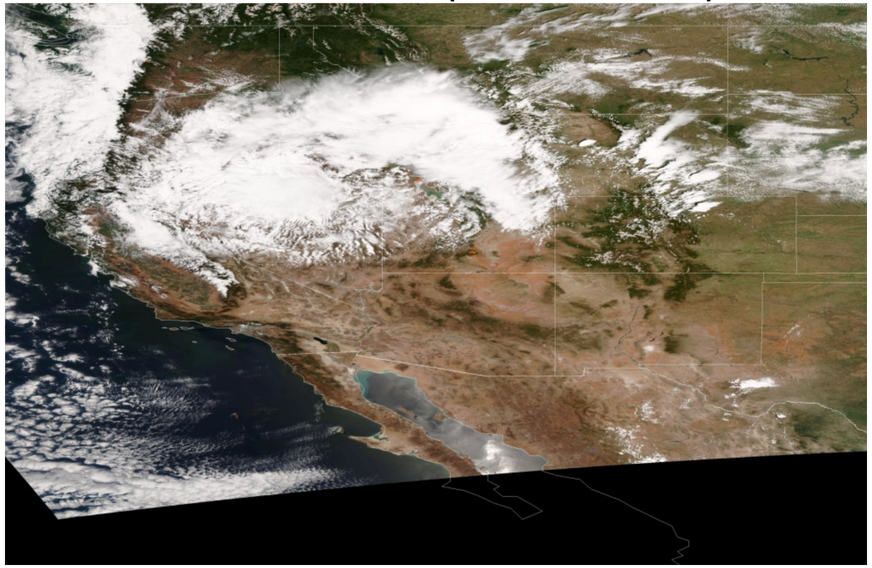
20170612 RGB



20170612 RGB ADP



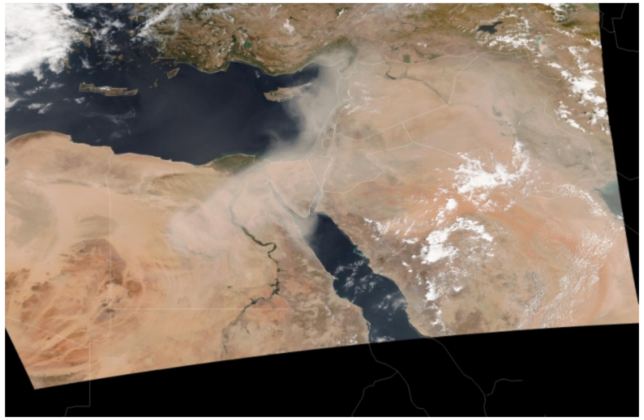
20170612 RGB IRDM (IR dust mask)



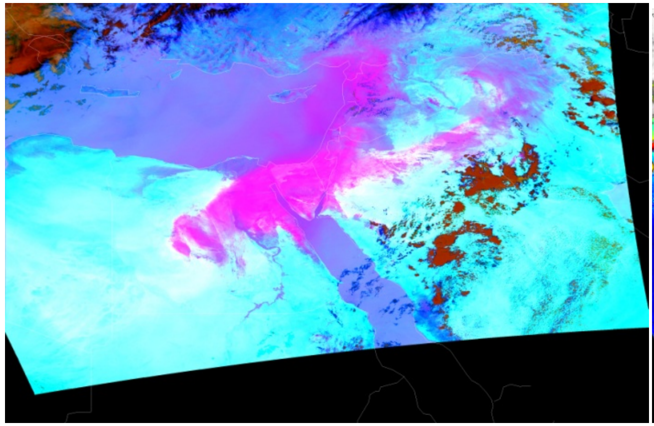
Another case with no dust

20150909 North Africa and Arabian Peninsula

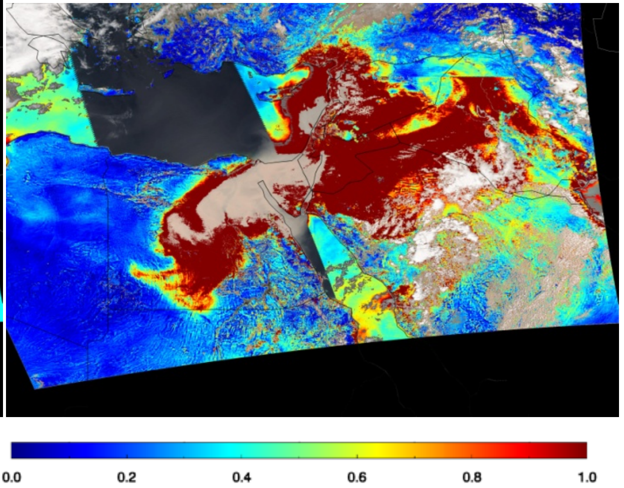
RGB



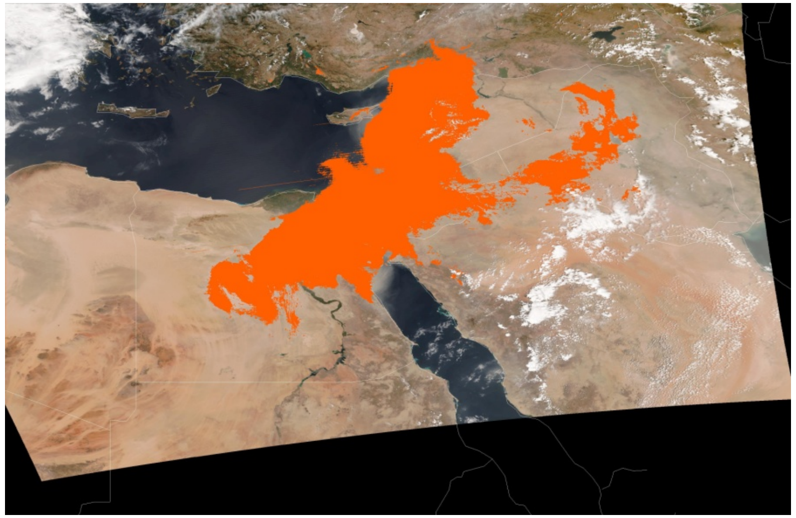
Dust RGB



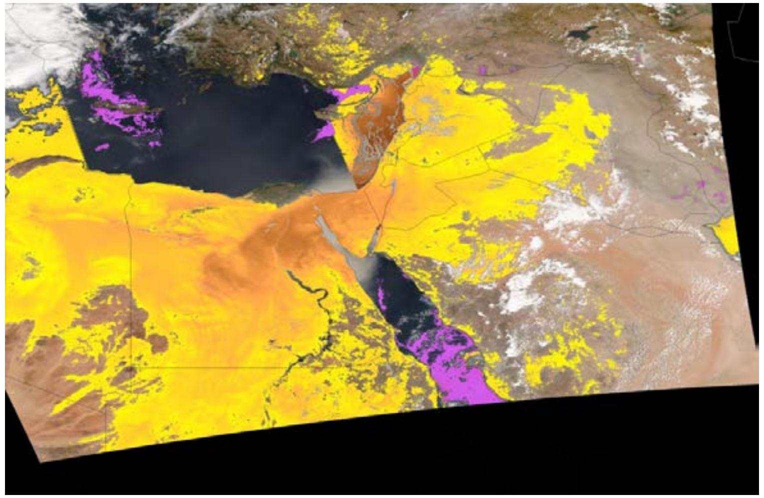
AOD



IRDM

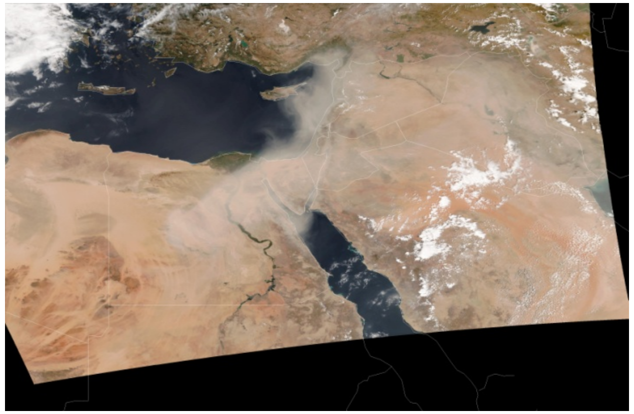


ADP

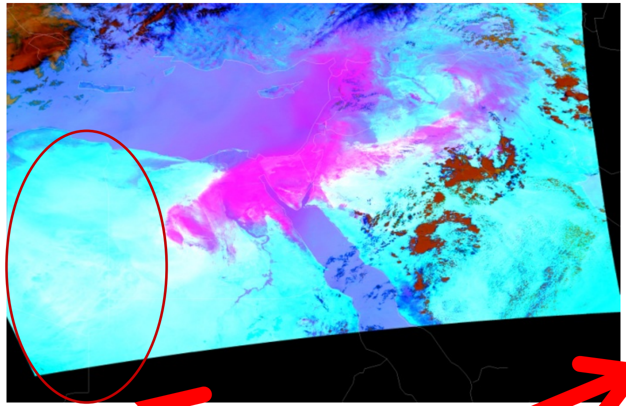


20150909 North Africa and Arabian Peninsula

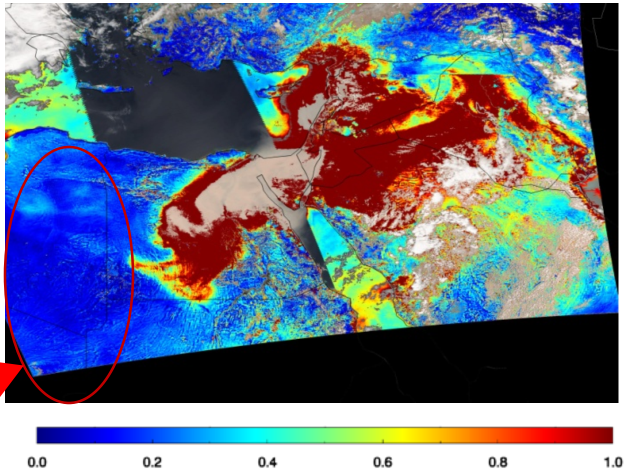
RGB



Dust RGB

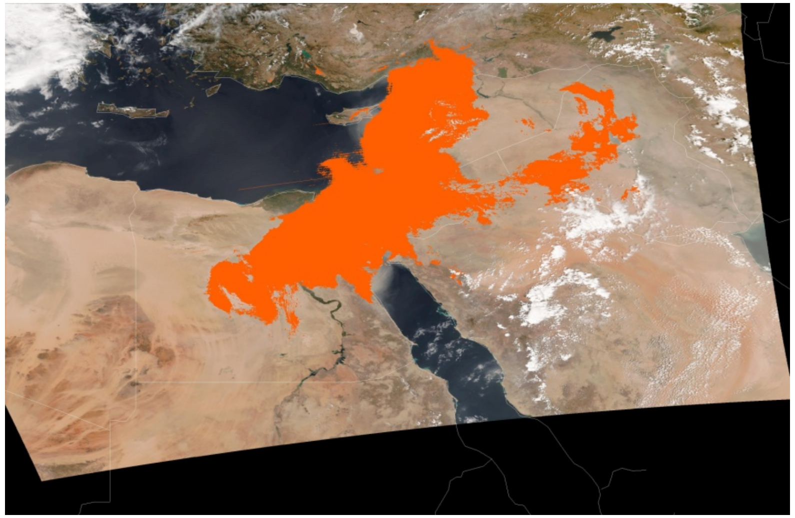


AOD

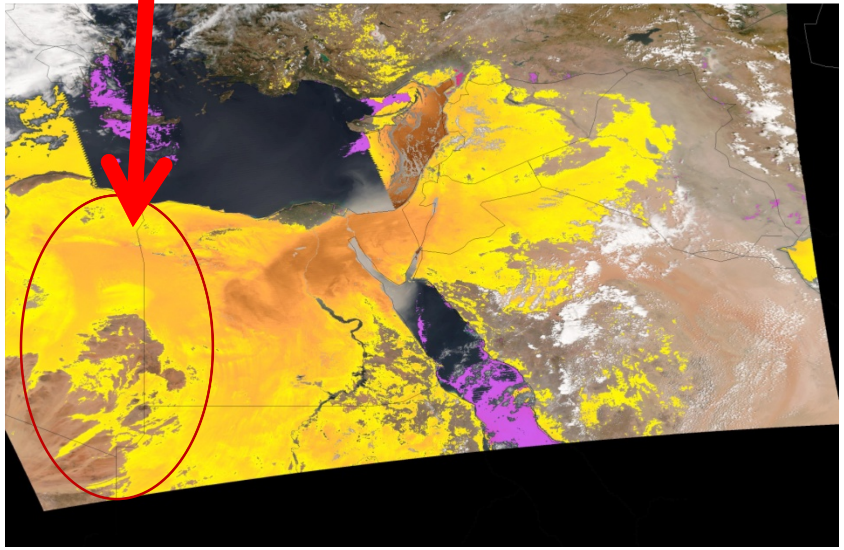


False detection in ADP

IRDM

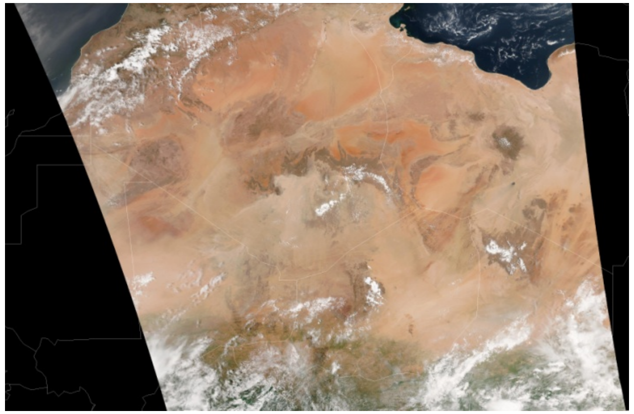


ADP

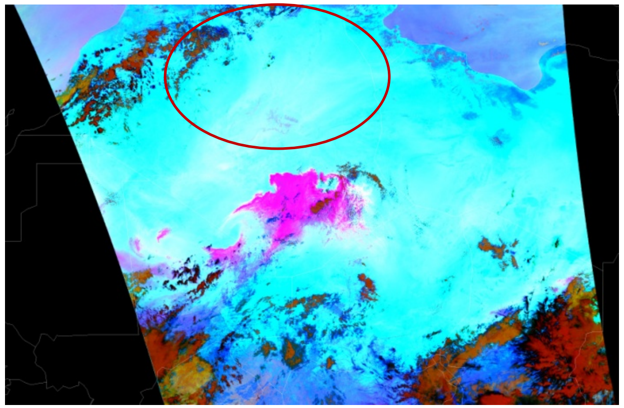


Another case in North Africa 20130823

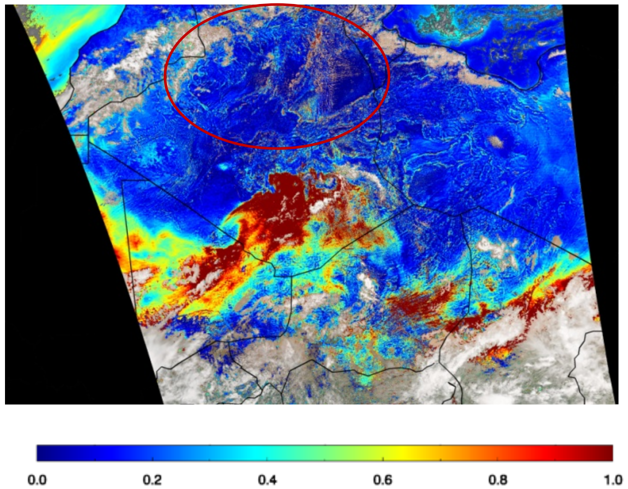
RGB



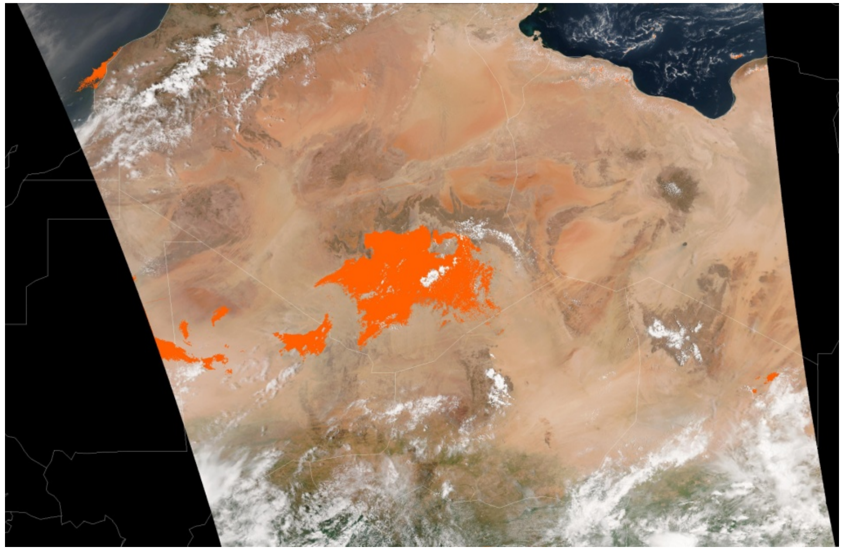
Dust RGB



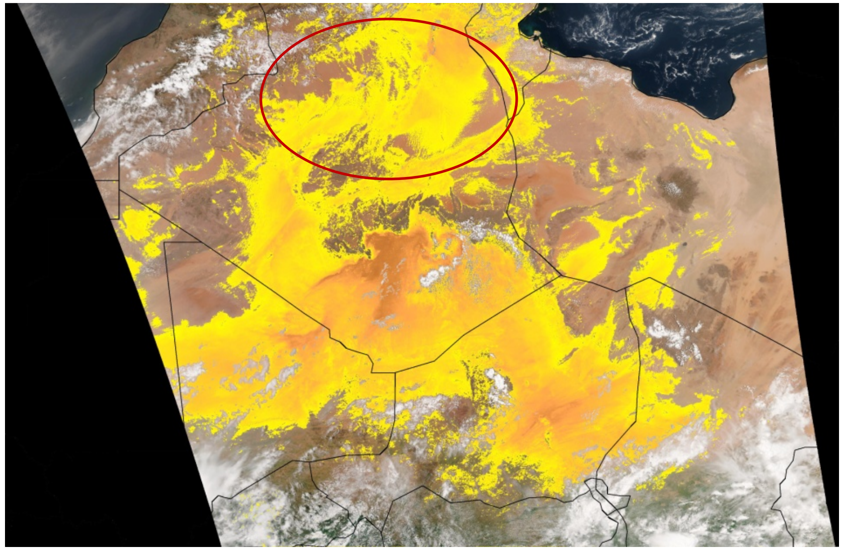
AOD



IRDM

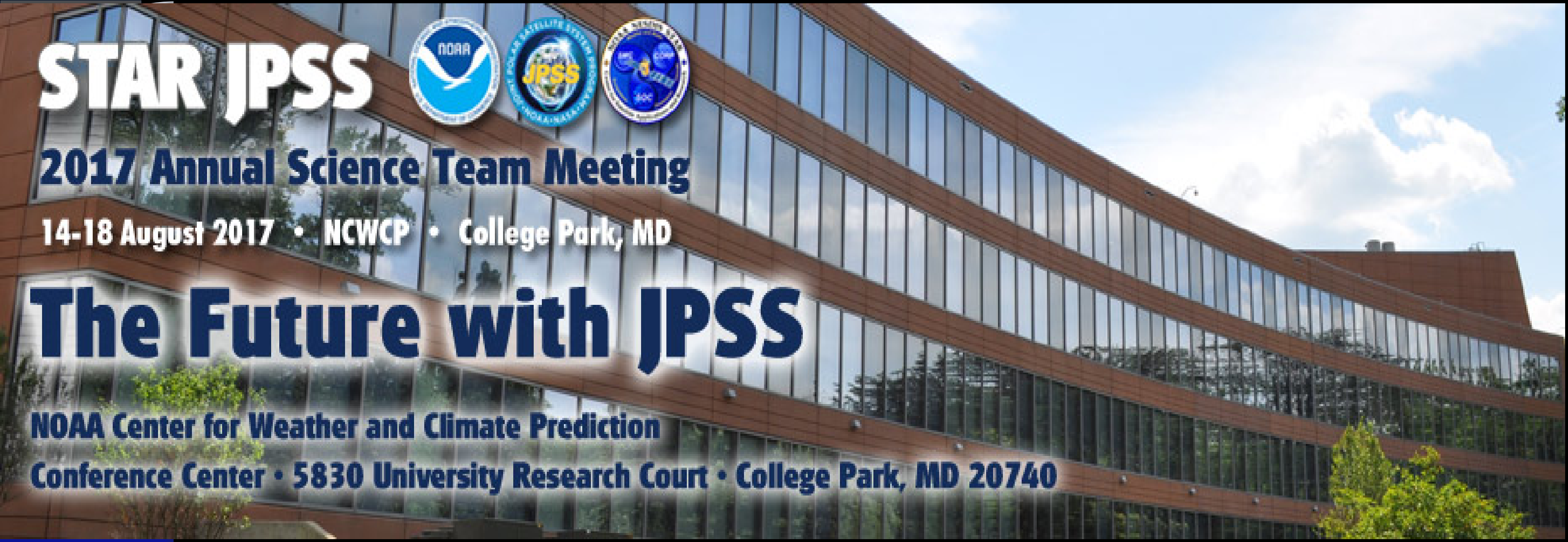


ADP



Summary

- Current ADP dust detection over land using deep blue bands has many areas of false detections
  - Less or no sensitivity of AAI to the aerosol load in some geometries and surface conditions
- An alternative dust detection method based on IR bands is proposed
- Case studies show that using IR bands for dust detection can greatly reduce false detections

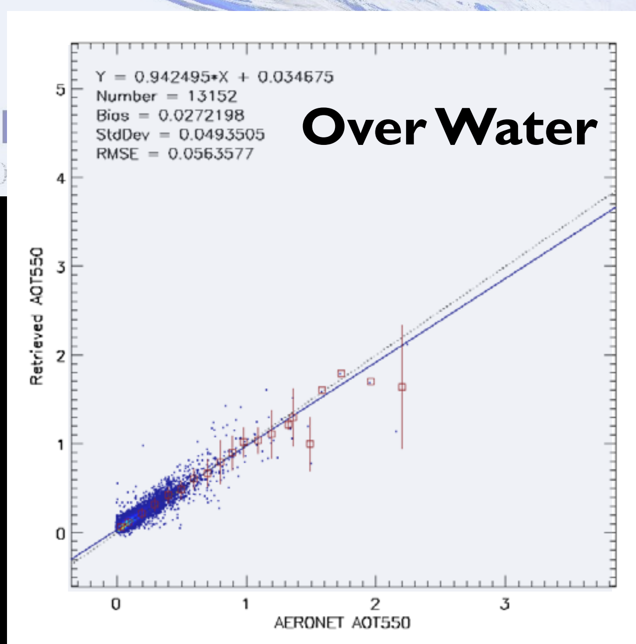


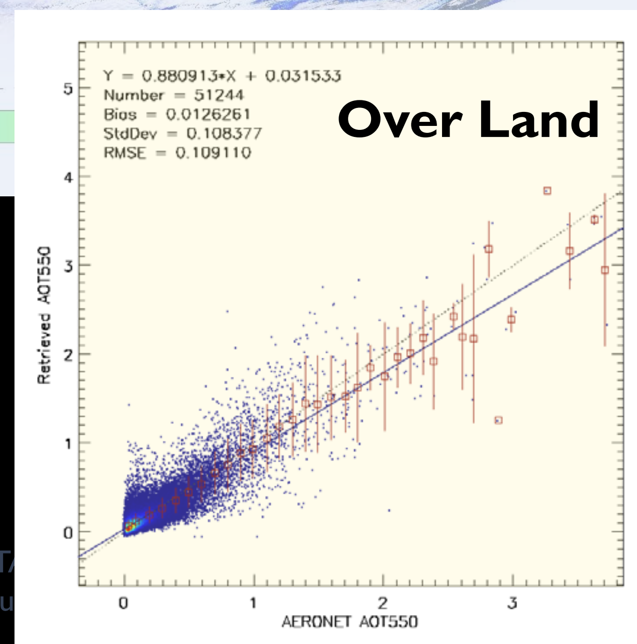
Evaluation of the VIIRS Enterprise Processing System AOD using AERONET over Different Geographic Regions

Hongqing Liu
and NOAA STAR Aerosol Cal/Val Team

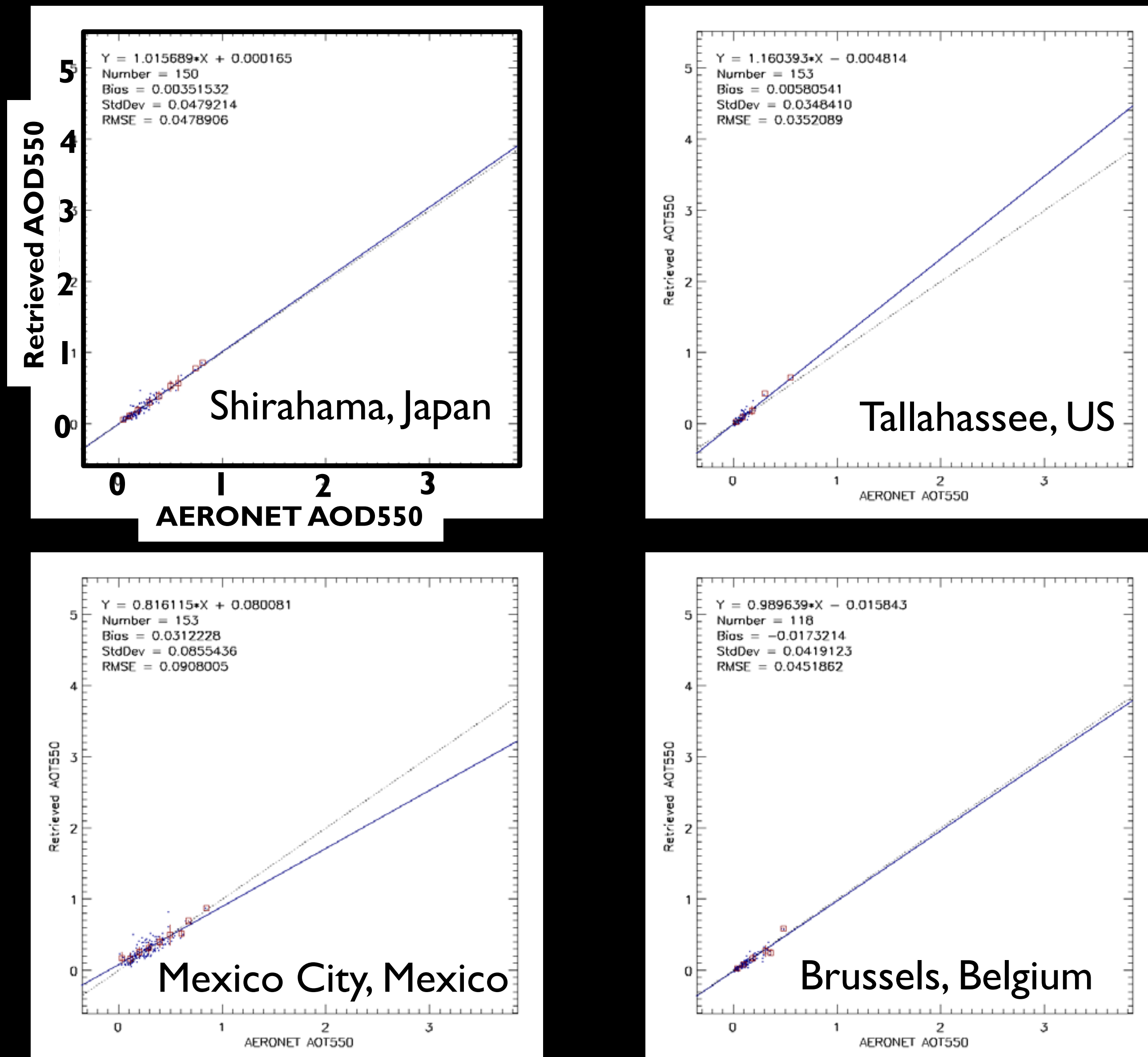
EPS AOD Algorithm

- **Multi-spectral aerosol retrieval**
- **Applied to VIIRS and ABI/AHI at pixel level**
- **Retrieval Coverage**
  - **Daytime cloud and snow/ice-free areas**
  - **Land: dark and bright**
  - **Ocean: non-glint deep water**
  - **AOD at 0.55μm: from -0.05 to 5.0**
- **High-quality retrievals meet requirement**
  - **Larger RMSE over land**

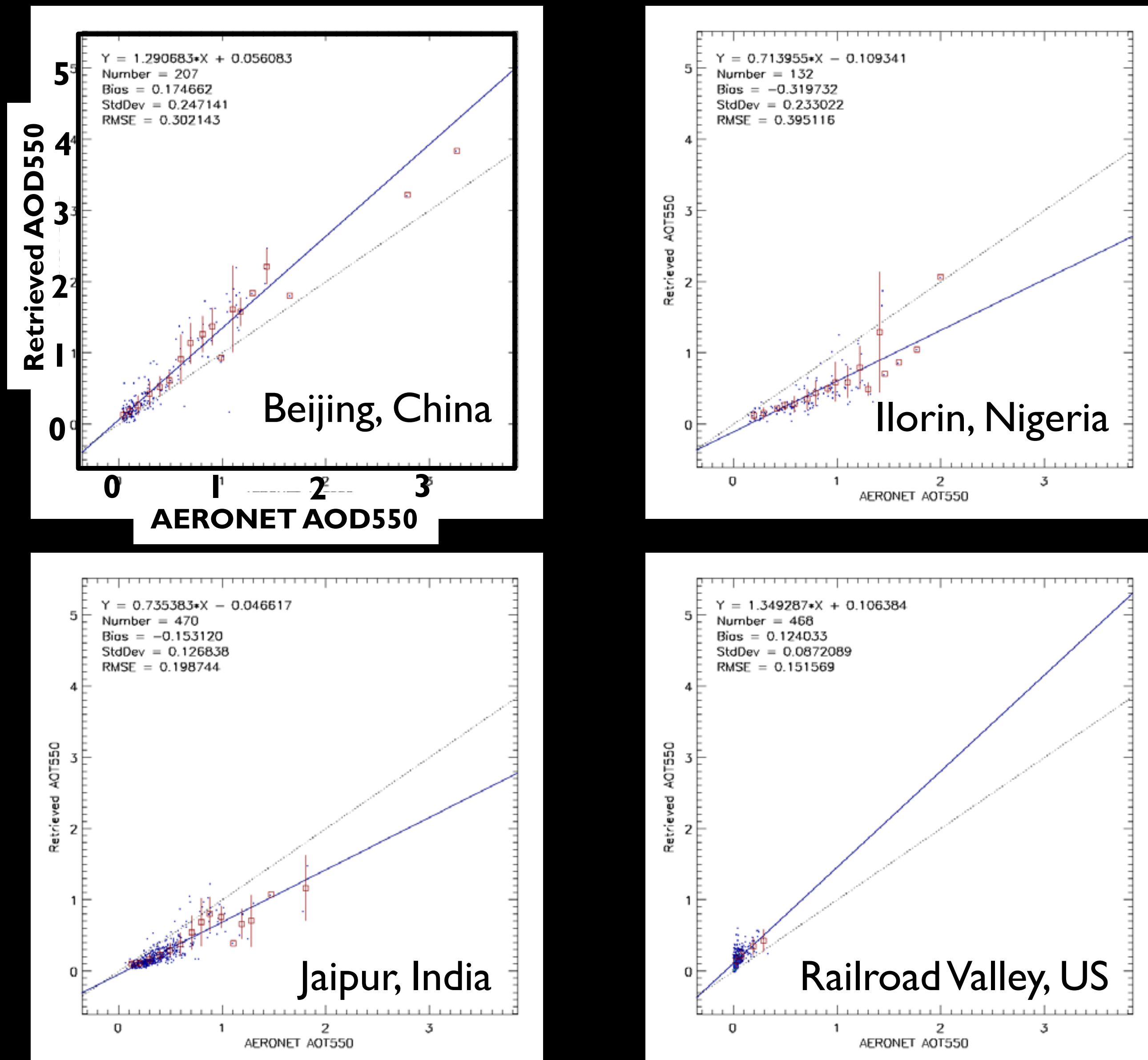




Example of Accurate Regional Retrievals

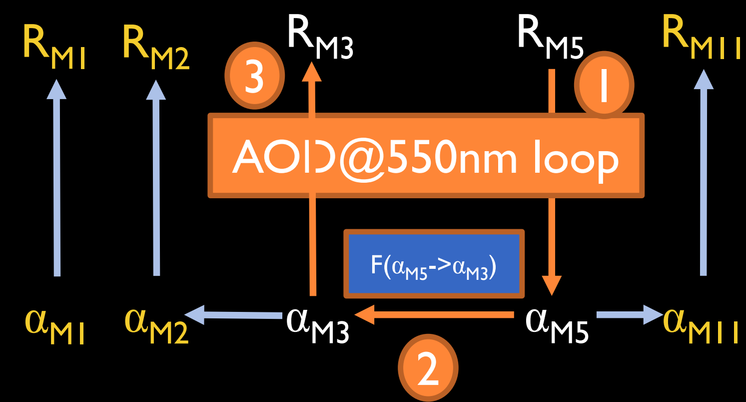


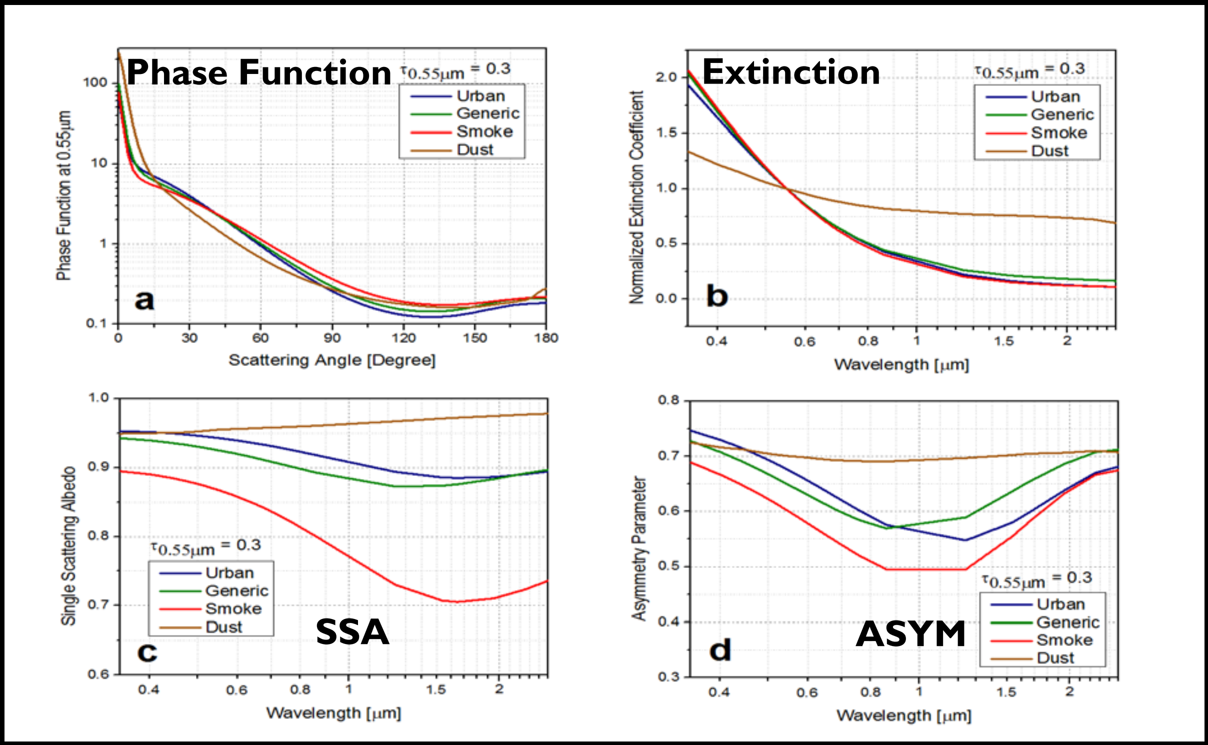
Example of Biased Regional Retrievals



Major Causes of Retrieval Errors over Land

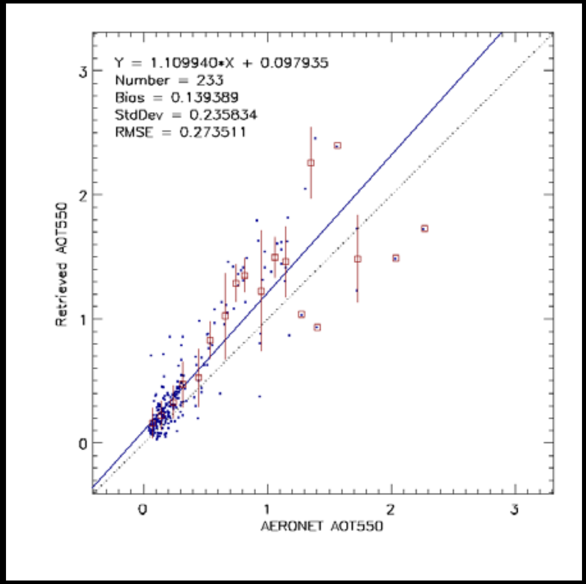
- Surface Reflectance
  - Simultaneous retrieval of AOD@550nm and surface reflectance with two reference channels
- Aerosol Models
  - Once AOD and surface reflectance are determined, difference between calculated and observed reflectance at residual channels are used to select optimal aerosol model from four candidates (urban, generic, smoke and dust)

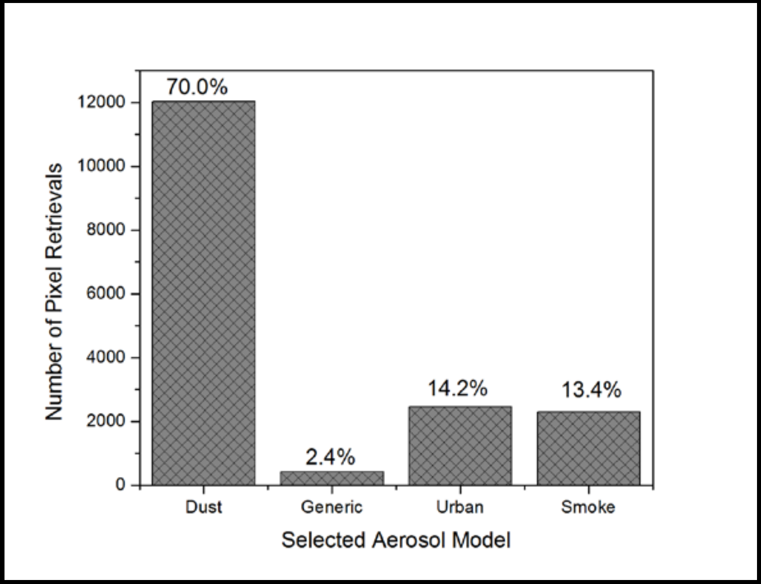


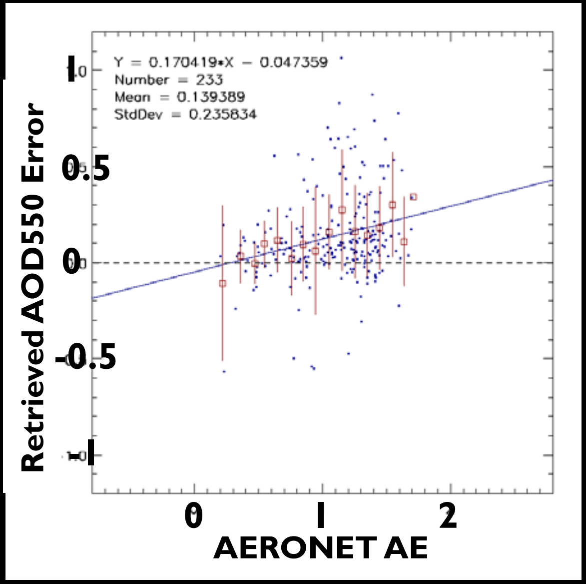


Beijing (1)

- AOD over-estimation
- Higher positive bias for fine-mode aerosol dominated cases (high AERONET AE)
- Majority (70%) of retrievals pick dust model

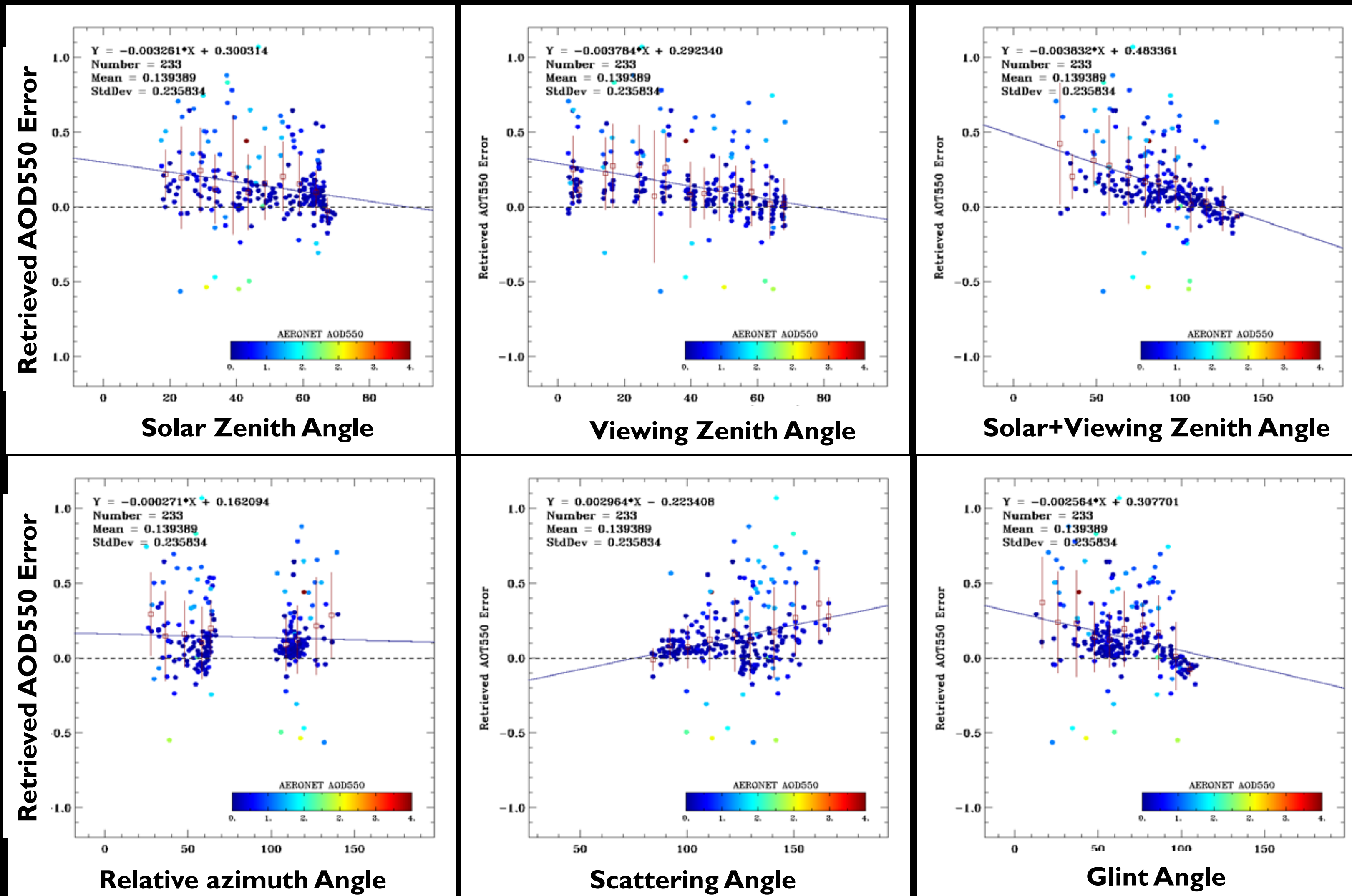






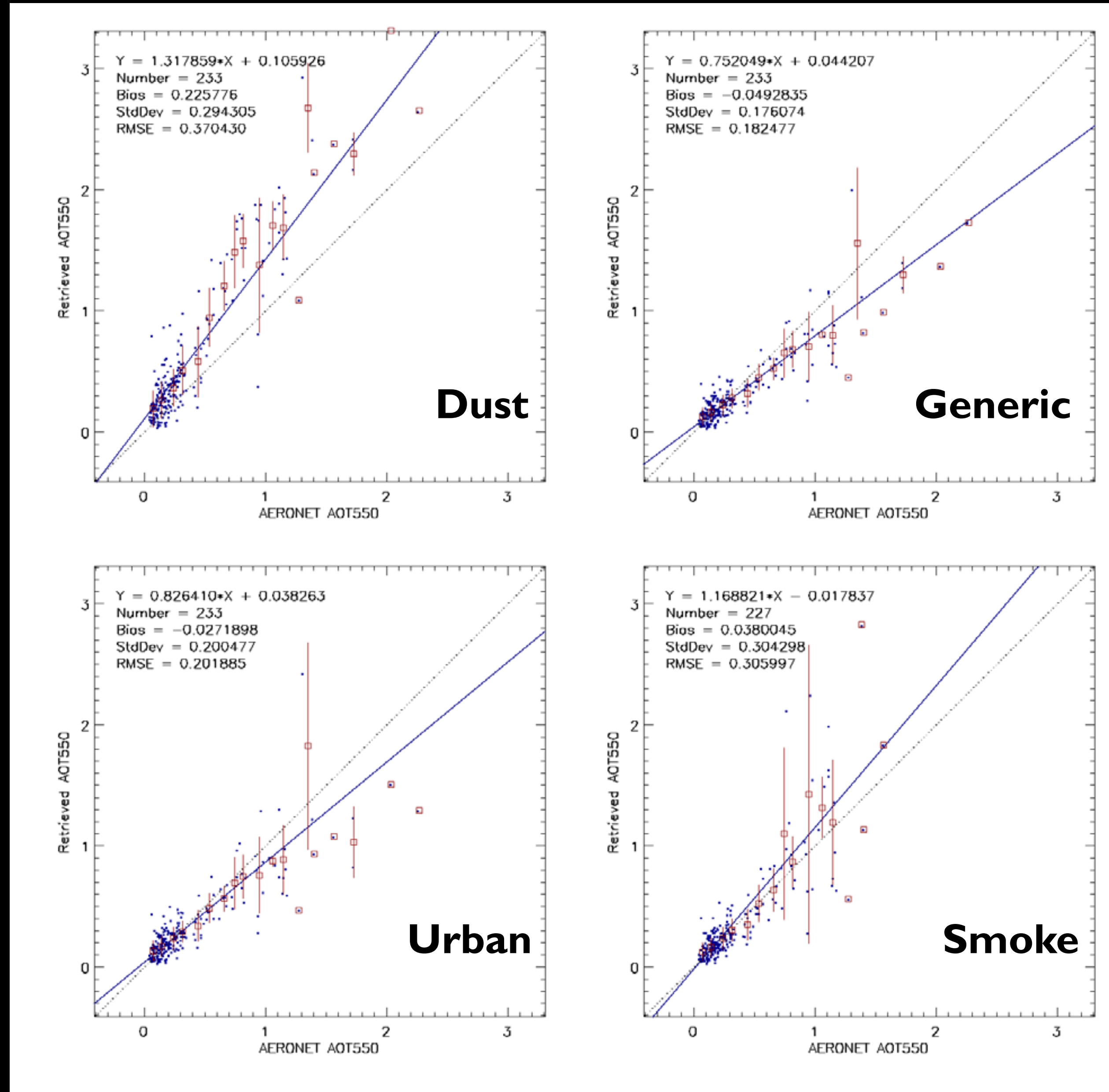
Beijing (2)

- Angular Dependence
  - Retrieval error against zenith, azimuth, scattering and glint angles



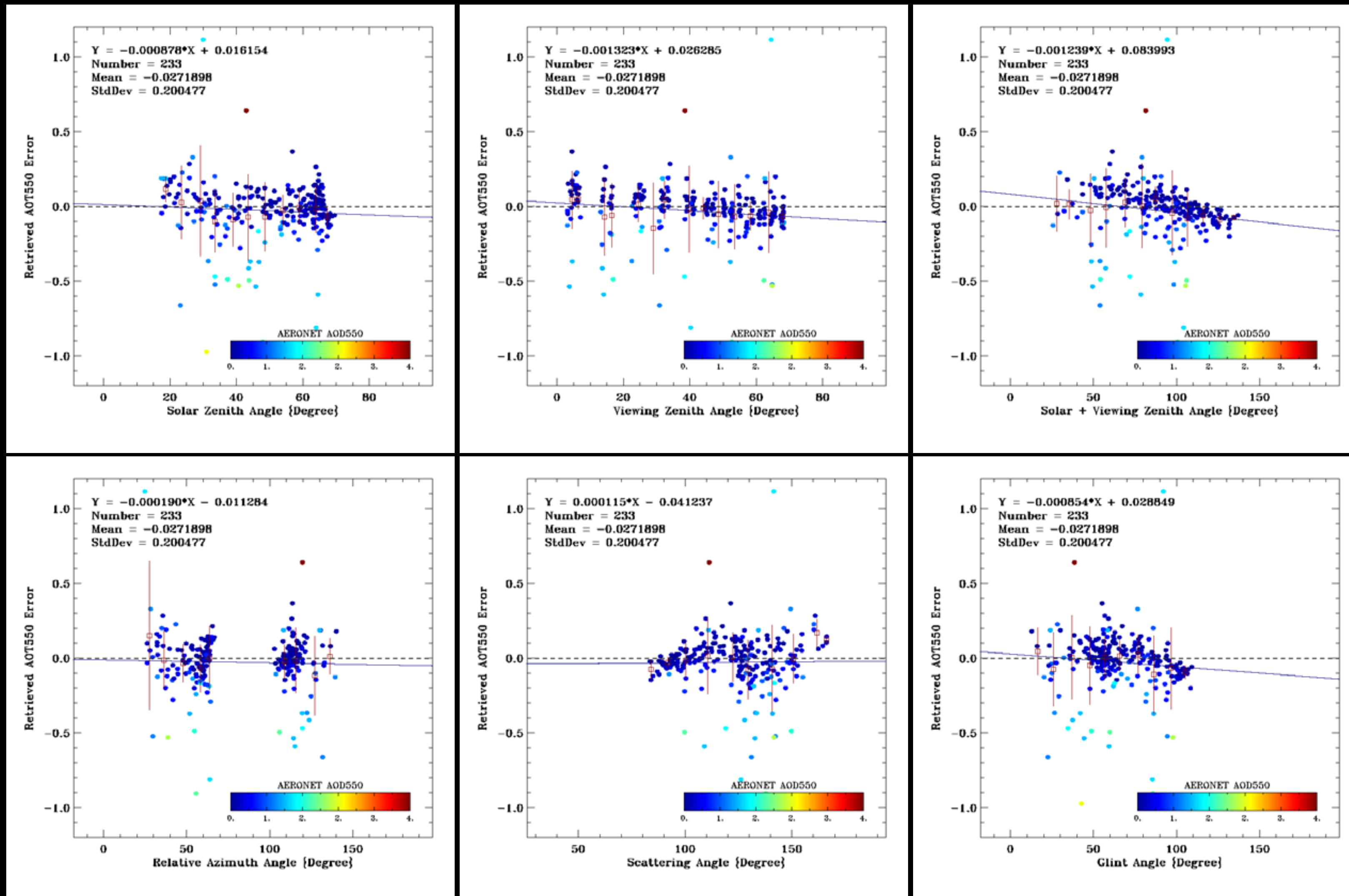
Beijing (3)

- Retrievals with fine-mode dominated aerosols would generate better results
- Problem in aerosol model selection



Beijing (4)

- Retrieval with urban aerosol model
  - Insignificant angular dependence of retrieval errors



Case Study (04/17/2013 05:57GMT)

Beijing (5)

Inputs:

PW	1.14337 cm
OZCONC	0.350851 atm-cm
PSL	1004.41 hpa
SFCTEMP	290.059 K
HGT	13.8458 m
WNDDIR	325.130 degree
WNDSPD	3.28555 m/s
REFLM1	0.322285
REFLM2	0.289493
REFLM3	0.258971
REFLM4	0.227863
REFLM5	0.235482
REFLM6	0.176977
REFLM7	0.282510
REFLM8	0.299651
REFLM9	0.00642178
REFLM10	0.299211
REFLM11	0.243100
BTM12	313.225 K
BTM15	292.967 K
BTM16	291.786
LAT	39.7449
LON	116.487
SOLZEN	37.2535 degree
SATZEN	57.5084 degree
SOLAZI	-134.700 degree
SATAZI	-93.8151 degree
HEIGHT	30.4856 m

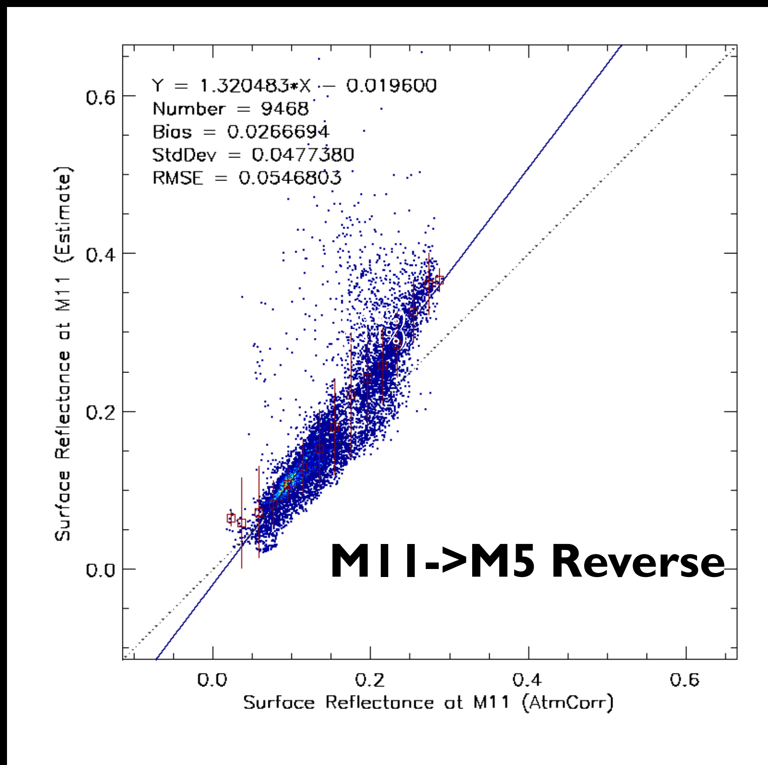
AERONET AOD550 = **0.727** AE=1.25

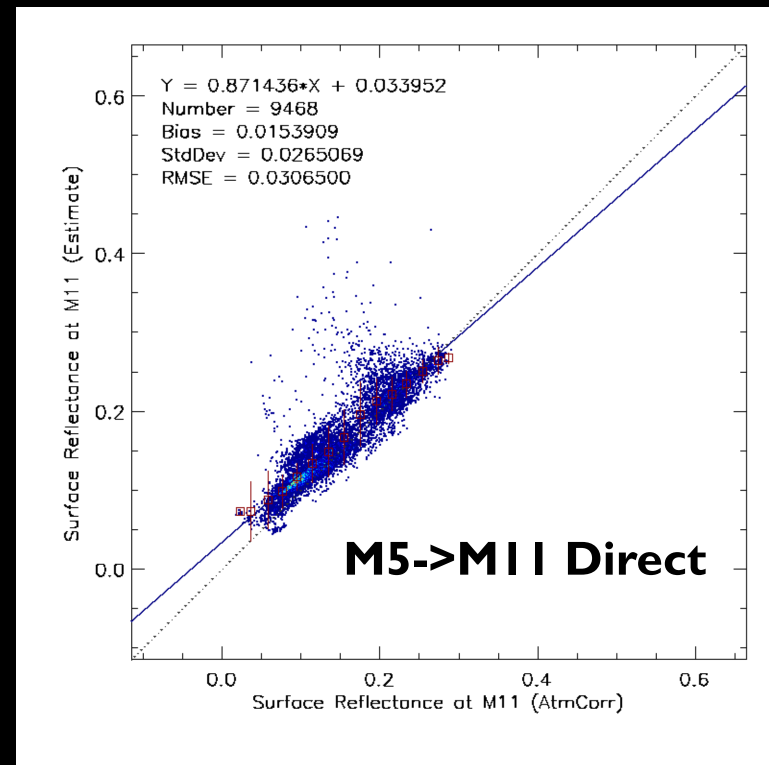
	Dust	Generic	Urban	Smoke
AOD550	**1.079**	**0.498**	**0.507**	**0.769**
Resi@M1	0.035	0.070	0.071	0.021
Resi@M2	0.016	0.038	0.038	0.021
Resi@M11	***0.137***	***0.528***	***0.527***	***0.700***
Residual	**0.082**	**0.309**	**0.308**	**0.404**
SfcR@M1	0.0929	0.1318	0.1304	0.1547
SfcR@M2	0.1030	0.1436	0.1421	0.1675
SfcR@M3	**0.1160**	**0.1577**	**0.1561**	**0.1822**
SfcR@M5	0.1786	0.2304	0.2285	0.2609
SfcR@M11	**0.3202**	**0.4434**	**0.4389**	**0.5160**

Residual dominated by M11 (2.13μm)

Beijing (6)

- Revise the estimation of surface reflectance at M11
  - Current scheme uses the reverse of M11->M5 relationship
  - Derive a new direct relationship from M5 to M11





Beijing (7)

Case Study - Revisit

AERONET AOD550 = **0.727** AE=1.25

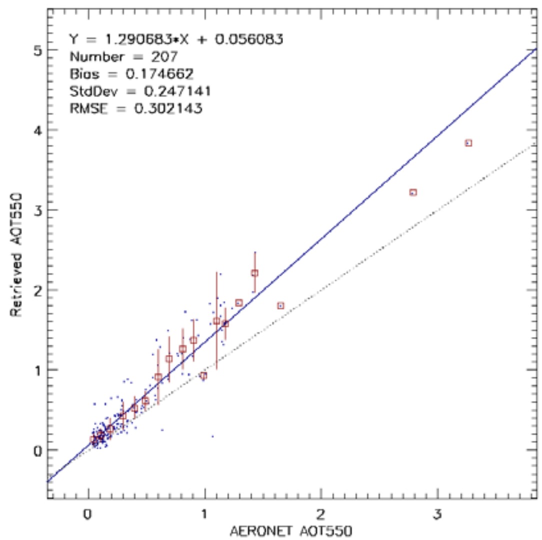
- Compared with current EPS retrieval, estimated surface reflectance at M11 for fine mode aerosols is much closer to the correct value, and the residual is not significantly biased to M11 band.
- Dust is still the best solution.
- Average of two best solutions (dust and generic weighed by residual) 0.794 is closer to the AERONET measurement.

	Dust	Generic	Urban	Smoke
AOD550	**1.079**	**0.498**	**0.507**	**0.769**
Resi@M1	0.035	0.070	0.071	0.021
Resi@M2	0.016	0.038	0.038	0.021
Resi@M11	***0.056***	***0.038***	***0.041***	***0.087***
Residual	**0.049**	**0.051**	**0.052**	**0.053**
SfcR@M1	0.0929	0.1318	0.1304	0.1547
SfcR@M2	0.1030	0.1436	0.1421	0.1675
SfcR@M3	0.1160	0.1577	0.1561	0.1822
SfcR@M5	0.1786	0.2304	0.2285	0.2609
SfcR@M11	**0.2472**	**0.2952**	**0.2934**	**0.3234**

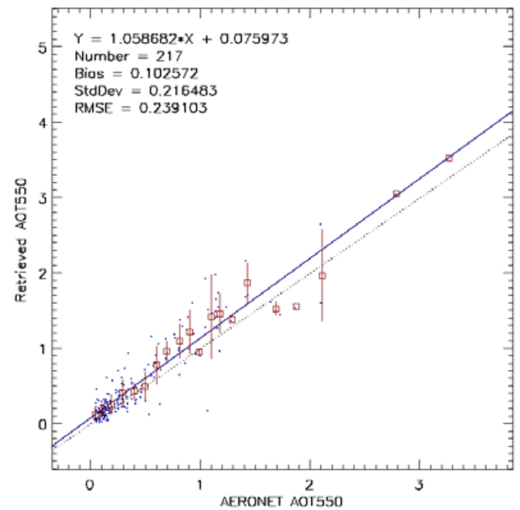
Beijing (8)

- Retrieval with new M5->M11 surface relationship
  - Retrieval over Beijing is slightly improved by using new M5->M11 surface reflectance relationship
  - With modification, less dust retrievals are picked as the best solution: dust 36% (70%); generic 2% (2%); urban 30% (14%); smoke 32% (14%)
  - More improvement is achieved if best two solutions are weighted averaged by the residual

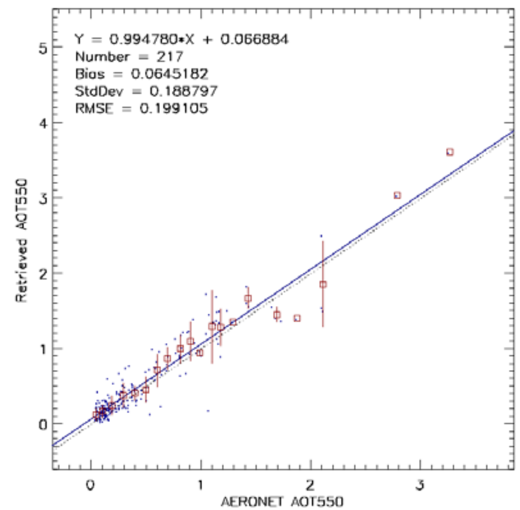
EPS Original Retrieval



New M5->M11 Relationship

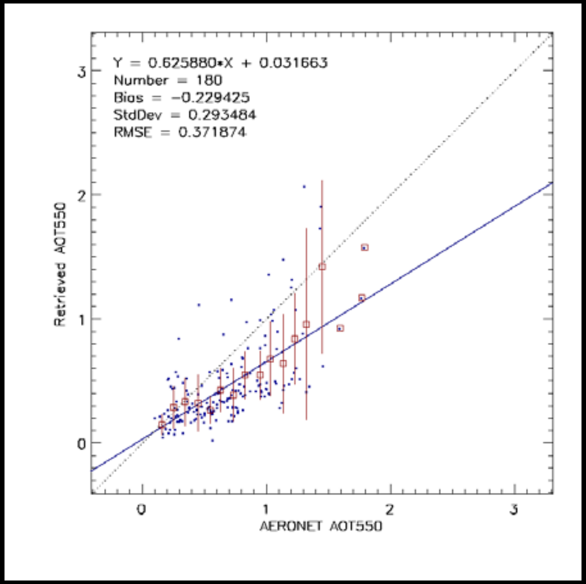


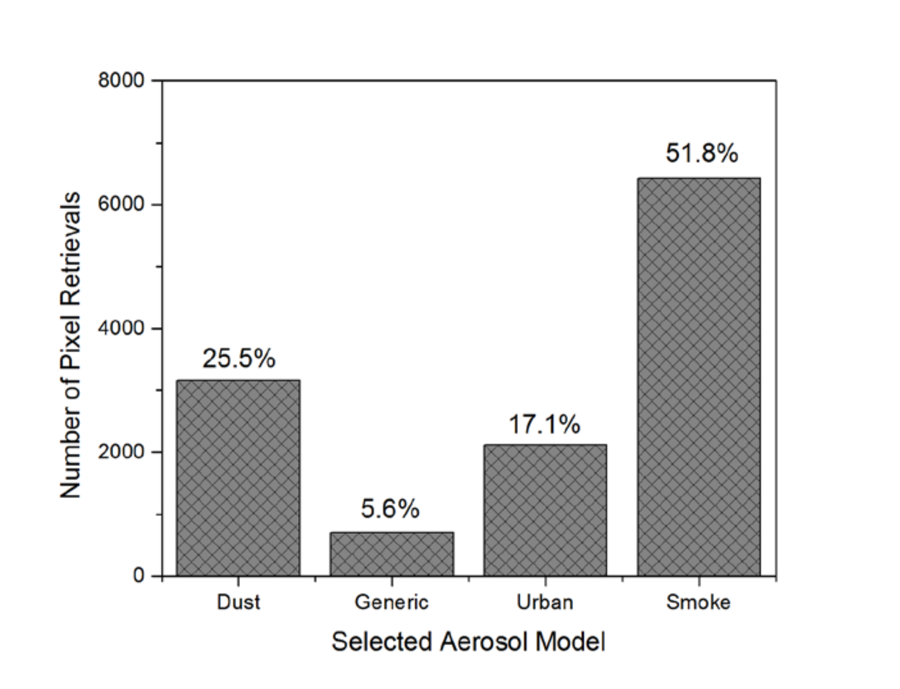
New M5->M11 Relationship Average of best two solutions

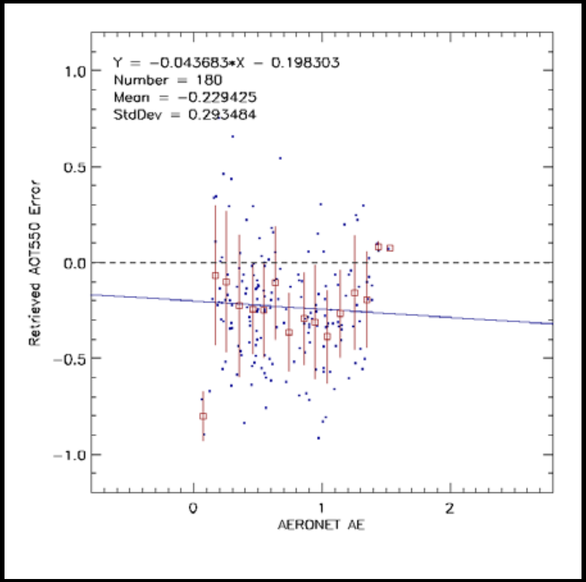


Ilorin (1)

- AOD under-estimation
- Majority (52%) of retrievals pick smoke model, while AERONET Angstrom Exponent shows many dust cases dominated by low AE

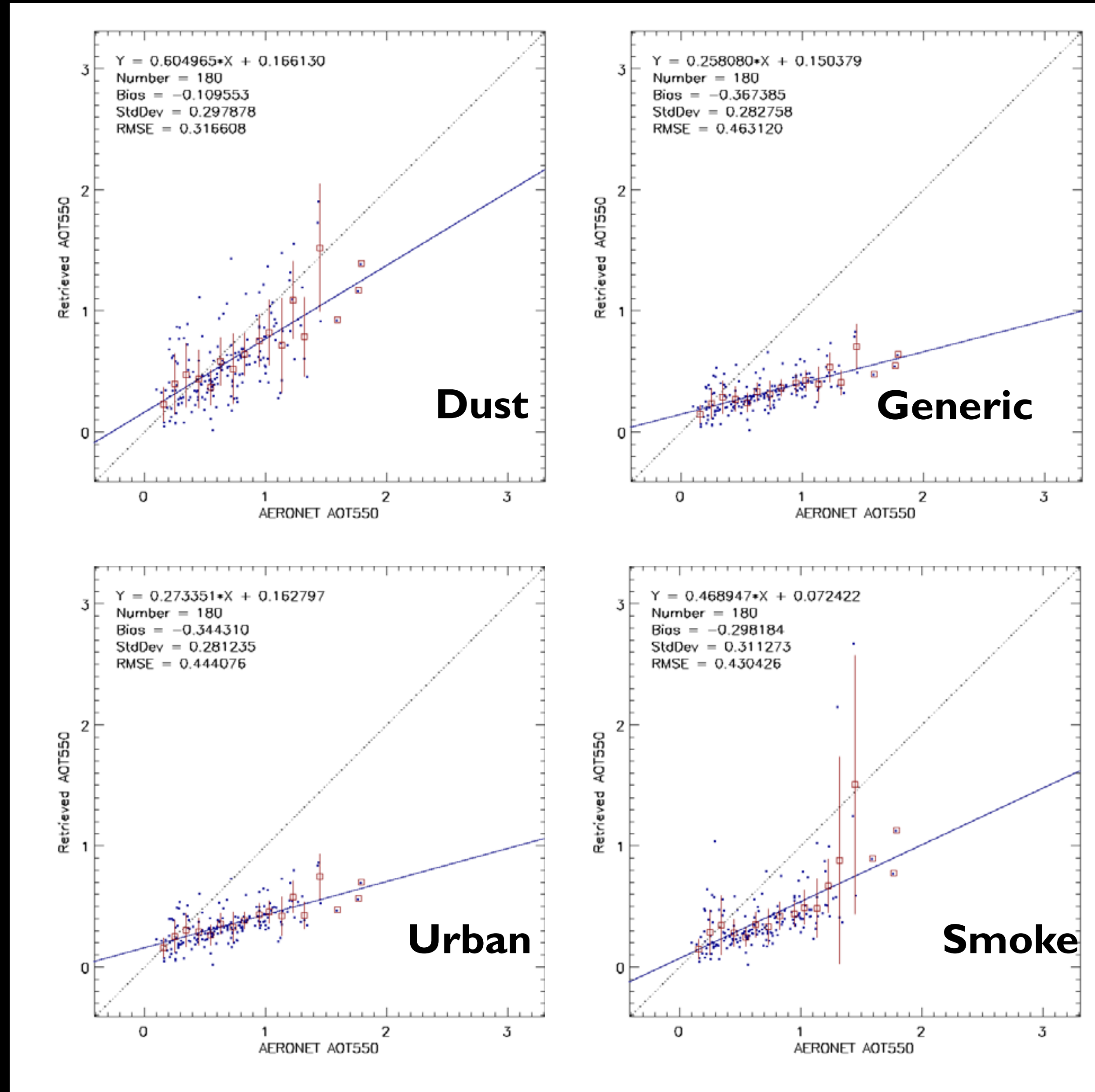






Ilorin (2)

- Retrievals with dust model would generate better results
- Problem in aerosol model selection



Case Study (12/18/2012)

Ilorin (3)

Inputs:

PW	1.51776	cm
OZCONC	0.253983	atm-cm
PSL	966.612	hpa
SFCTEMP	306.494	K
HGT	331.854	m
WNDDIR	212.892	degree
WNDSPD	3.59268	m/s
REFLM1	0.262927	
REFLM2	0.229963	
REFLM3	0.200540	
REFLM4	0.177515	
REFLM5	0.165452	
REFLM6	0.175586	
REFLM7	0.270887	
REFLM8	0.329367	
REFLM9	0.0115250	
REFLM10	0.285928	
REFLM11	0.195022	
BTM12	316.778	K
BTM15	304.850	K
BTM16	303.218	K
LAT	8.28619	
LON	4.16135	
SOLZEN	40.53	degree
SATZEN	40.63	degree
SOLAZI	-141.99	degree
SATAZI	-98.14	degree
HEIGHT	371.975	m

AERONET AOD550 = 1.186 AE = 0.34

	Dust	Generic	Urban	Smoke
AOD550	**1.254**	**0.570**	**0.606**	**0.769**
Resi@M1	0.023	0.035	0.036	0.009
Resi@M2	0.006	0.019	0.019	0.005
Resi@M11	***0.201***	***0.194***	***0.193***	***0.198***
Residual	**0.1167**	**0.1141**	**0.1139**	**0.1143**
SfcR@M1	0.0269	0.0739	0.0738	0.0810
SfcR@M2	0.0289	0.0812	0.0811	0.0891
SfcR@M3	**0.0364**	0.0921	0.0919	0.1005
SfcR@M5	0.0677	0.1355	0.1353	0.1457
SfcR@M11	**0.1320**	**0.1728**	**0.1726**	**0.1789**

Residual dominated by M11, difference is very small, hard to select correct model; dust high AOD associated with low surface reflectance

Ilorin (4)

Case Study (1/9/2013)

Inputs:

PW	2.16383
OZCONC	0.246923
PSL	965.934
SFCTEMP	308.135
HGT	357.818
WNDDIR	217.665
WNDSPD	2.76619
REFLM1	0.206205
REFLM2	0.180127
REFLM3	0.156760
REFLM4	0.141377
REFLM5	0.127727
REFLM6	0.164988
REFLM7	0.249692
REFLM8	0.294279
REFLM9	0.00300334
REFLM10	0.228132
REFLM11	0.133368
BTM12	311.346
BTM15	303.350
BTM16	301.711
LAT	8.08027
LON	4.37263
SOLZEN	36.08
SATZEN	20.74
SOLAZI	--146.94
SATAZI	-97.84
HEIGHT	395.466

AERONET AOD550 = **1.273** AE = 0.578

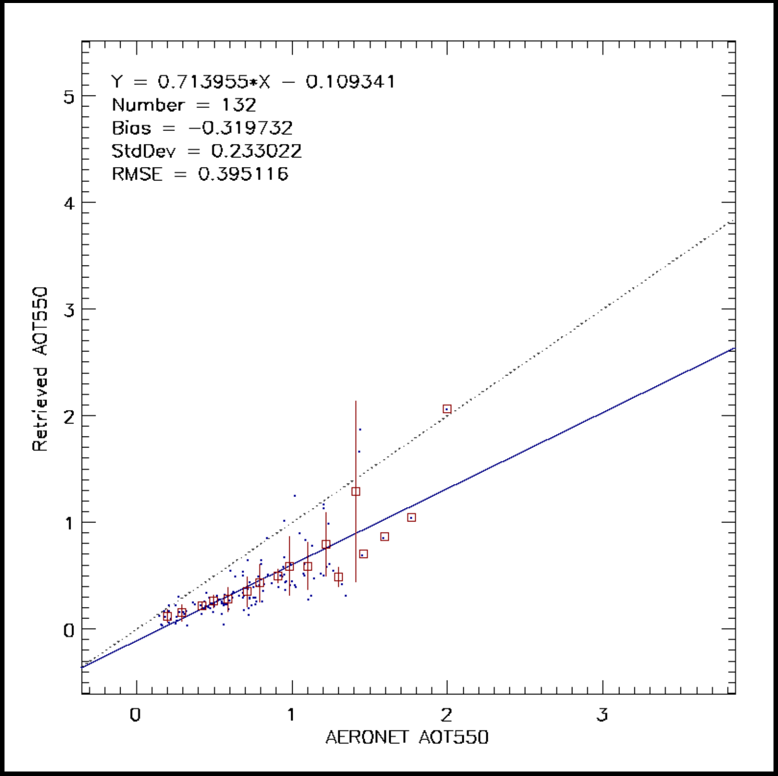
	Dust	Generic	Urban	Smoke
AOD550	**1.232**	**0.620**	**0.679**	**0.700**
Resi@M1	***0.065***	***0.098***	***0.096***	***0.056***
Resi@M2	0.017	0.039	0.037	0.026
Resi@M11	0.015	0.005	0.007	0.014
Residual	**0.040**	**0.061**	**0.060**	**0.036**
SfcR@M1	0.0115	0.0504	0.0499	0.0558
SfcR@M2	0.0136	0.0540	0.0535	0.0596
SfcR@M3	**0.0207**	0.0617	0.0612	0.0673
SfcR@M5	0.0463	0.0968	0.0962	0.1037
SfcR@M11	0.1139	0.1450	0.1446	0.1492

Residual dominated by M1, difference is very small, hard to select correct model; dust high AOD associated with low surface reflectance

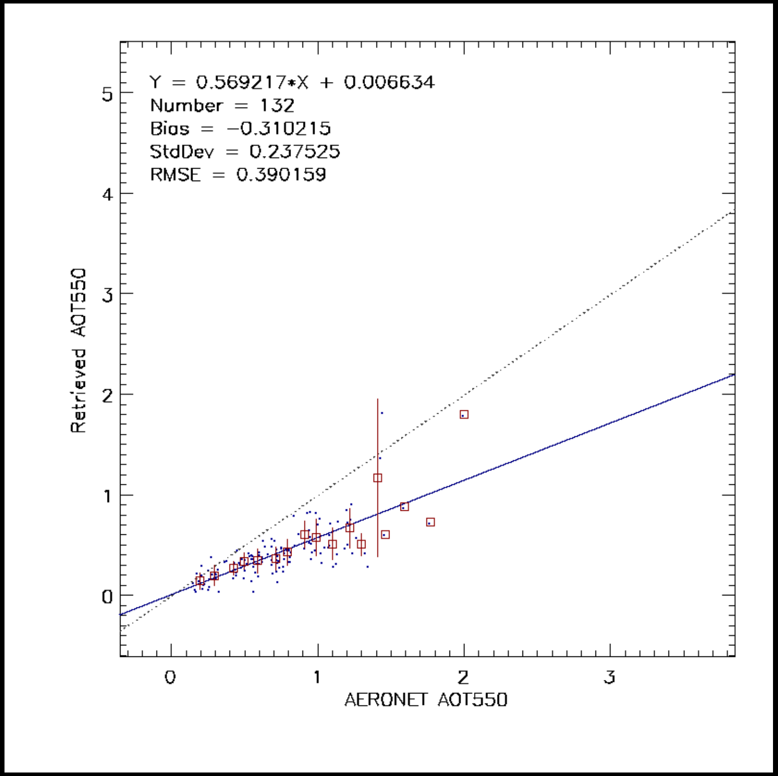
Ilorin (5)

- Retrieval with new M5->M11 surface relationship
  - No improvement

EPS Original Retrieval

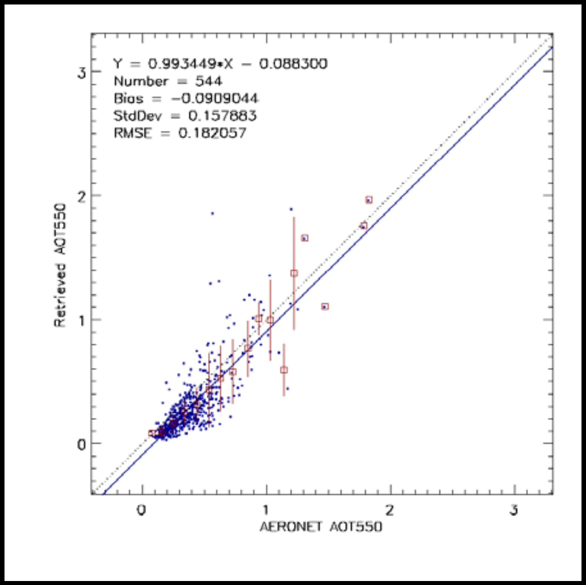


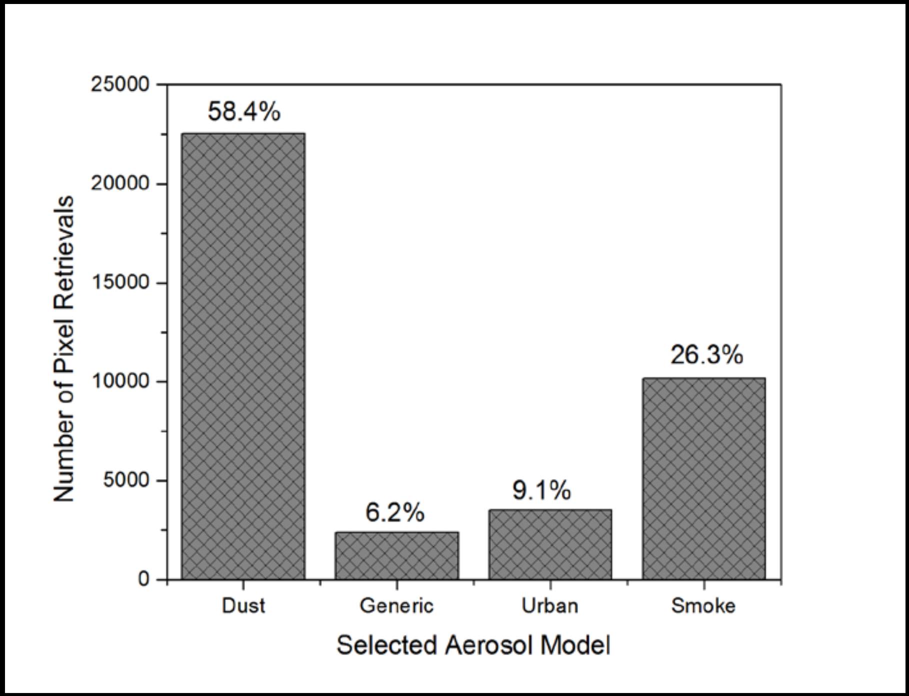
New M5->M11 Relationship

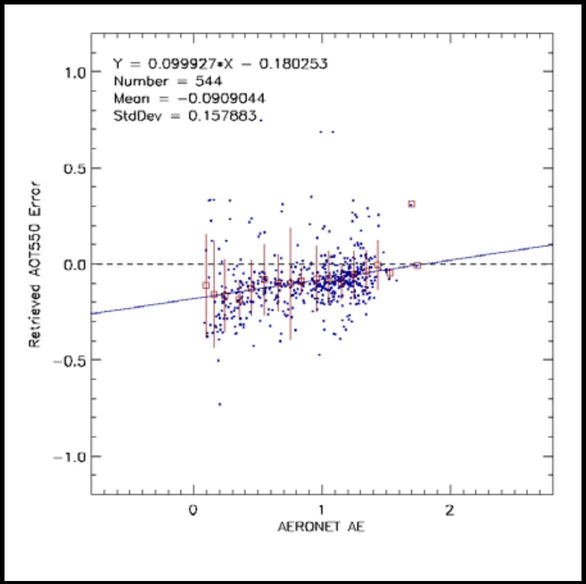


Jaipur (1)

- AOD small under-estimation
- 58% of retrievals pick dust model and 26% of retrievals pick smoke.

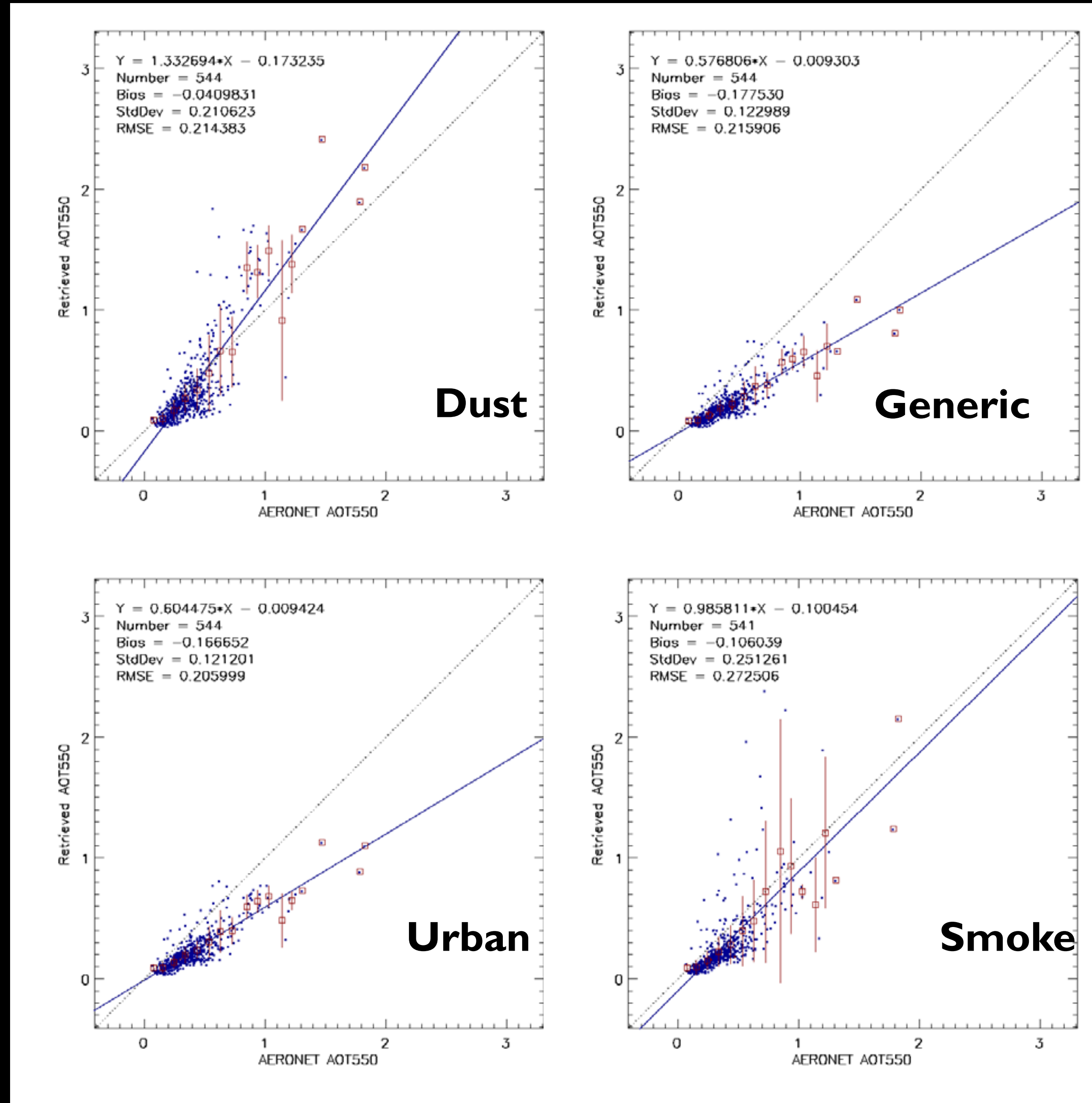






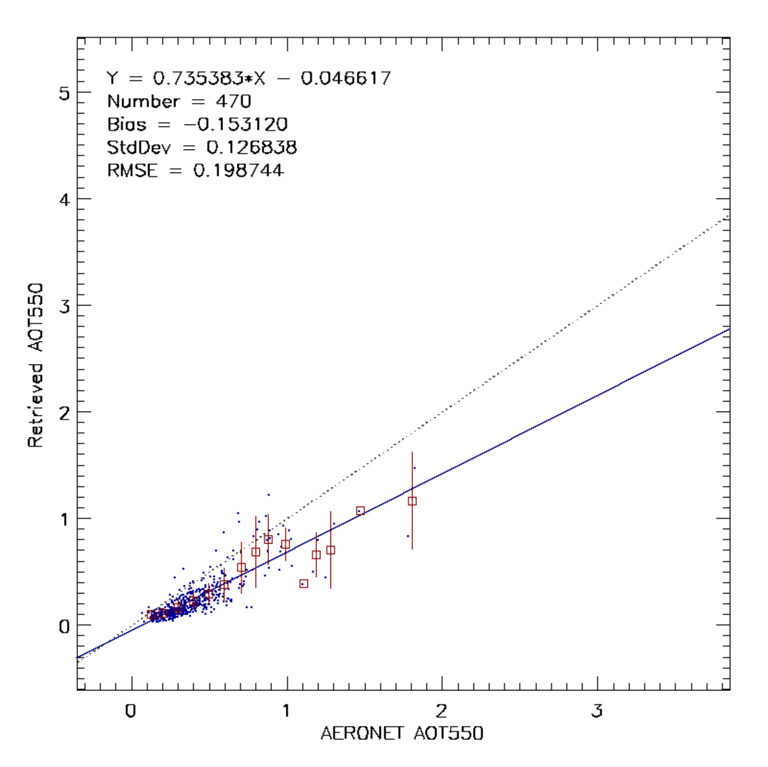
Jaipur (2)

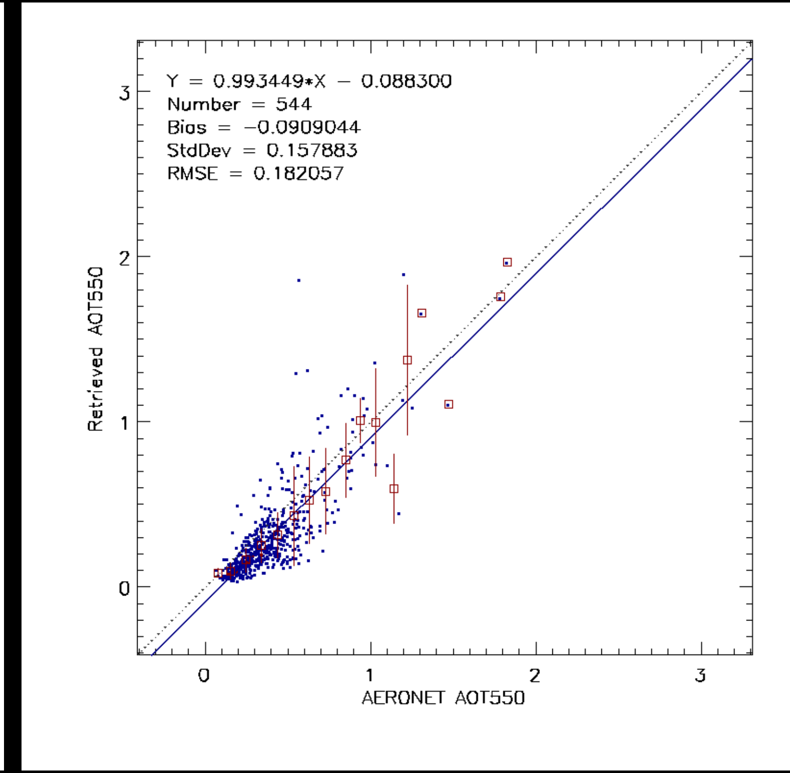
- Dust and smoke models give better results than generic and urban models



Jaipur (3)

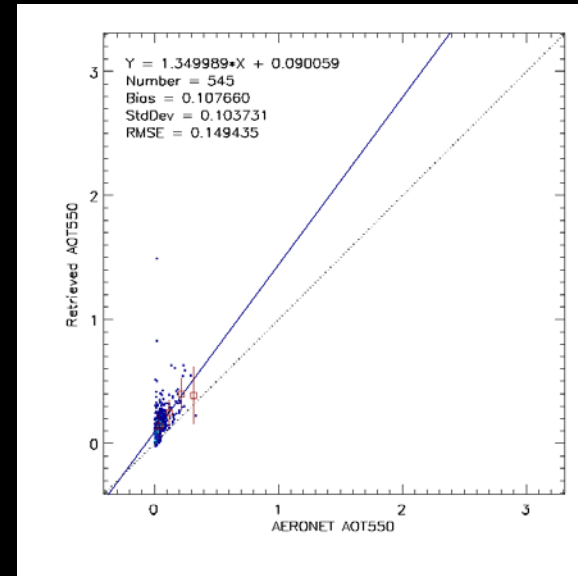
- Validation statistics depend on the satellite-ground matching method
  - Left: 27.5 km radius on satellite retrievals centered on the Jaipur station, at least 750 high quality pixel retrievals
  - Right: 5 km radius, at least 5 high quality retrievals

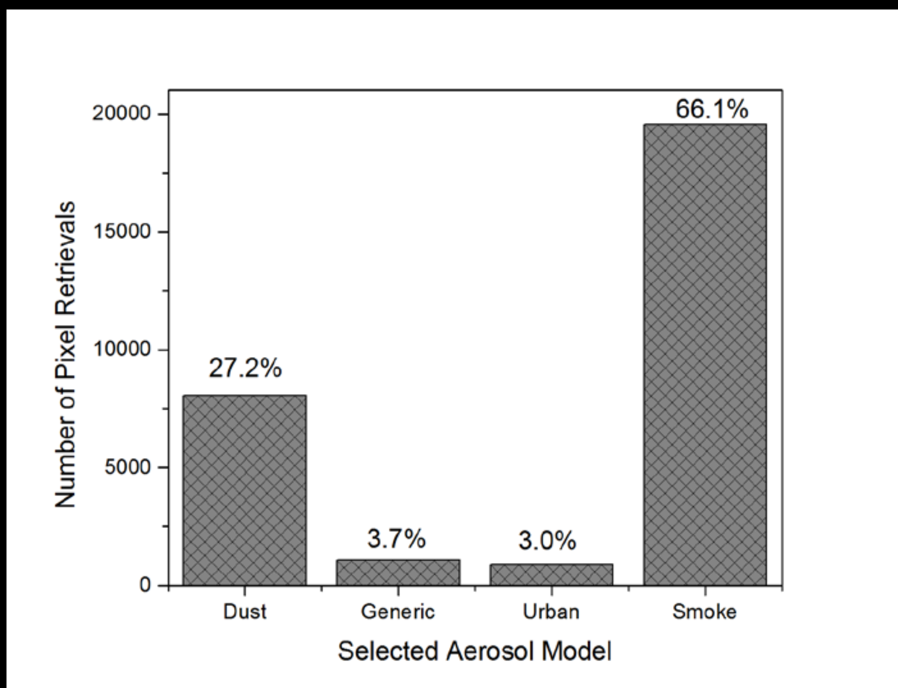


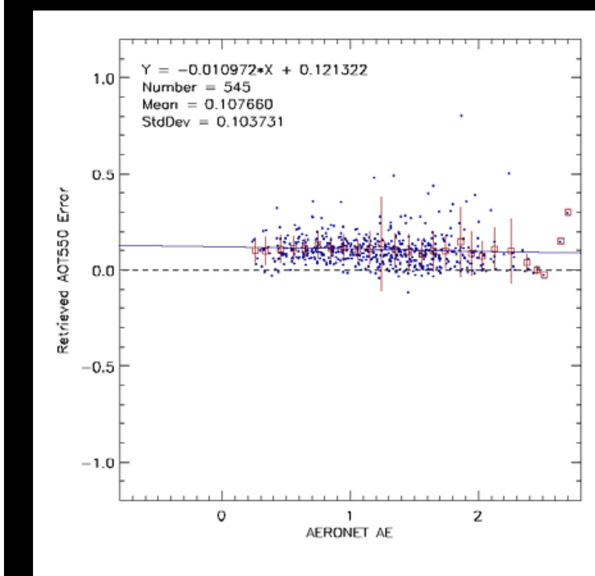


Railroad Valley (1)

- AOD over-estimation
- Low AOD dominated area
- 66% of retrievals pick smoke model and 27% of retrievals pick dust.

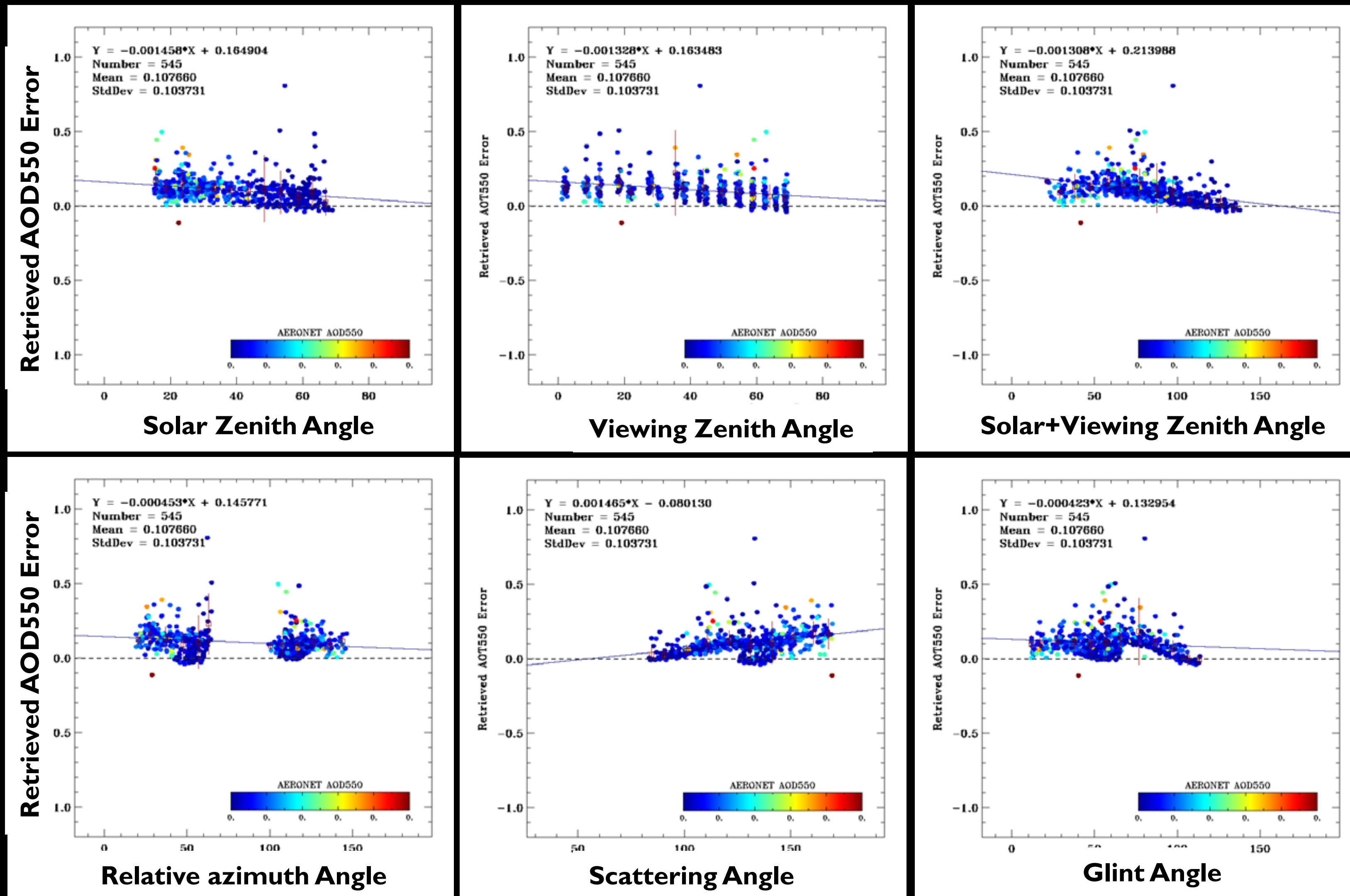






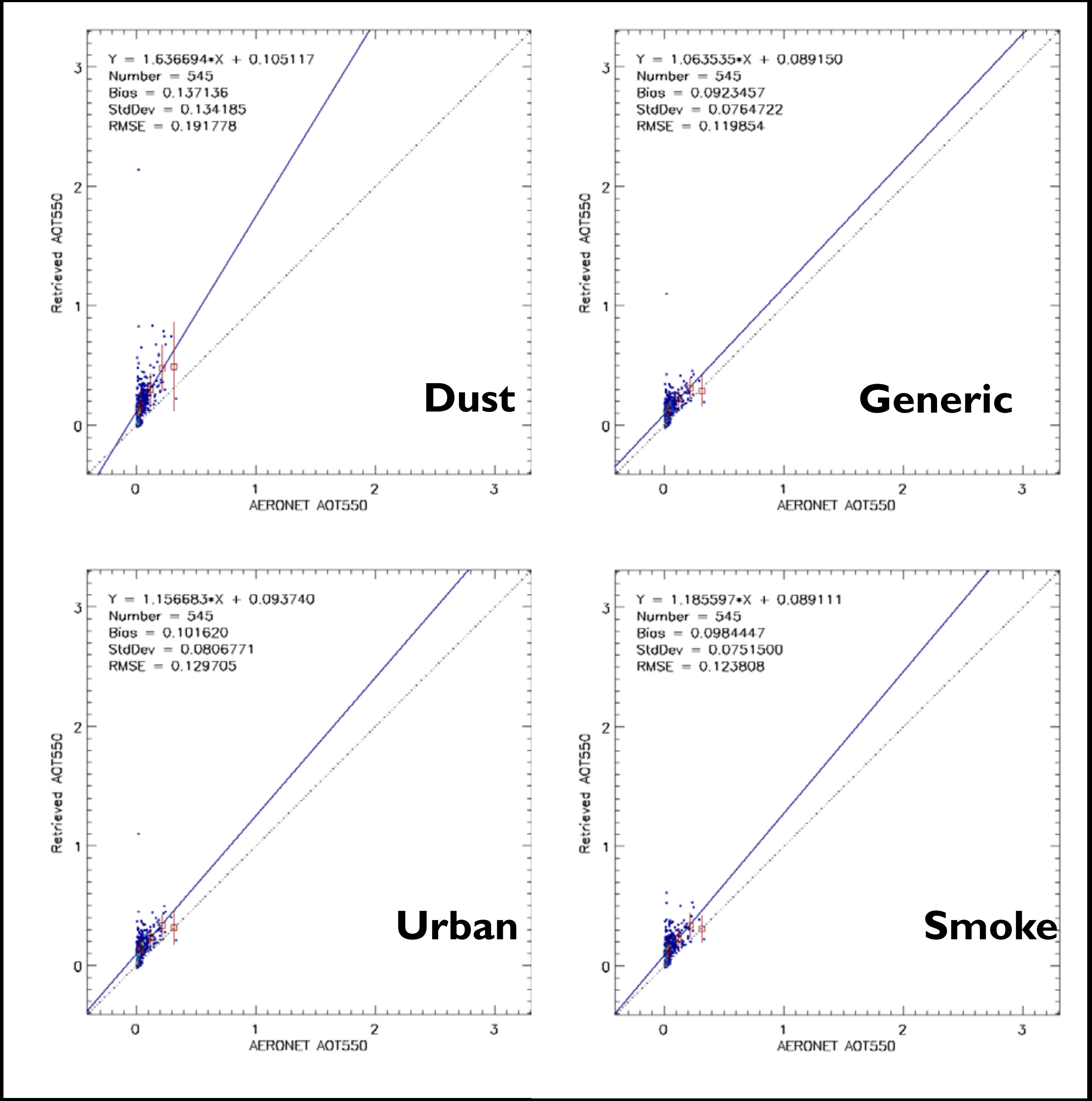
Railroad Valley (2)

- Angular Dependence
  - Retrieval error against zenith, azimuth, scattering and glint angles



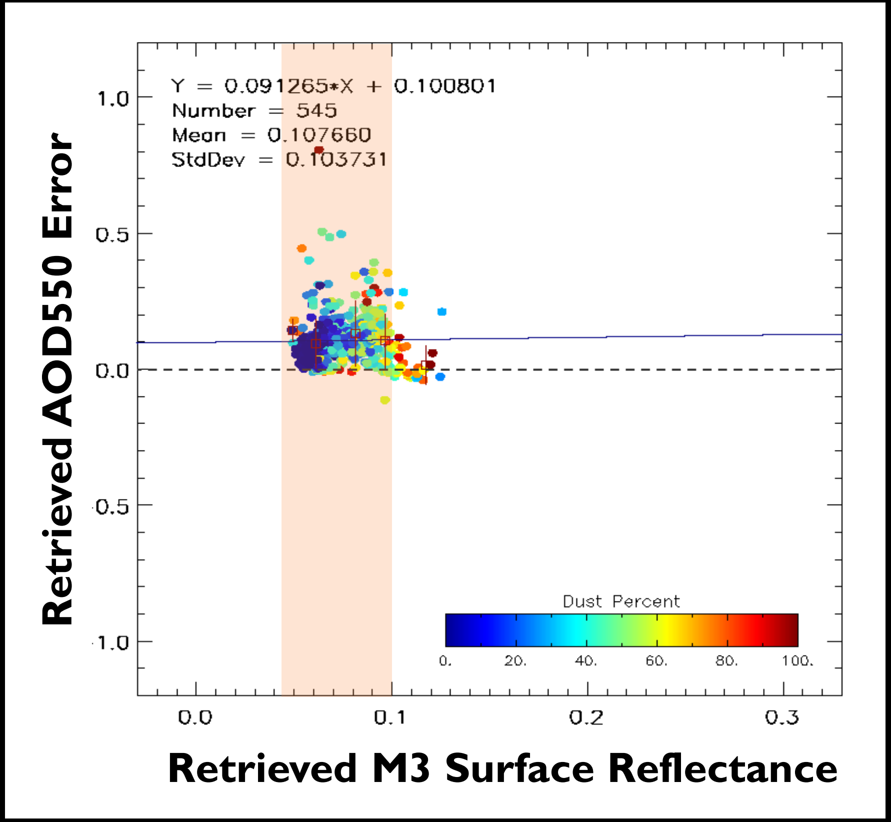
Railroad Valley (3)

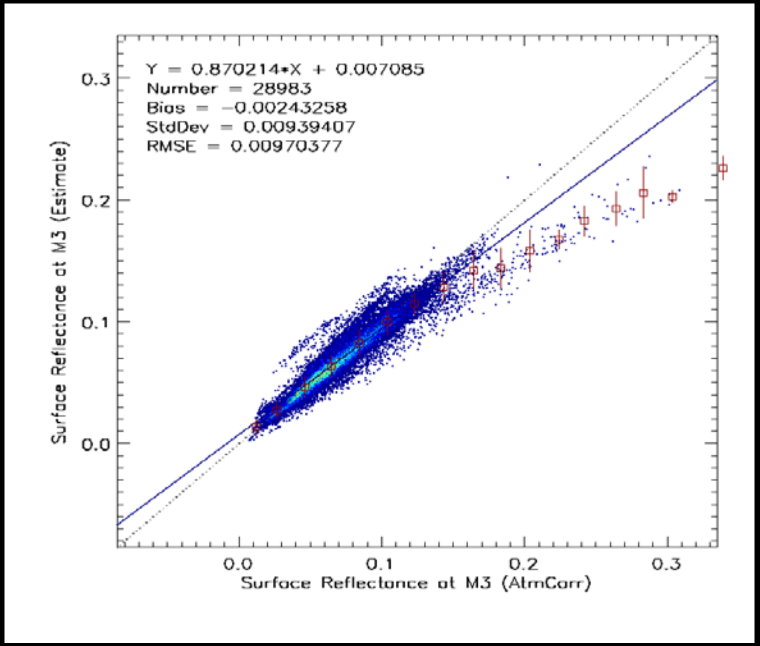
- All aerosol models overestimate.

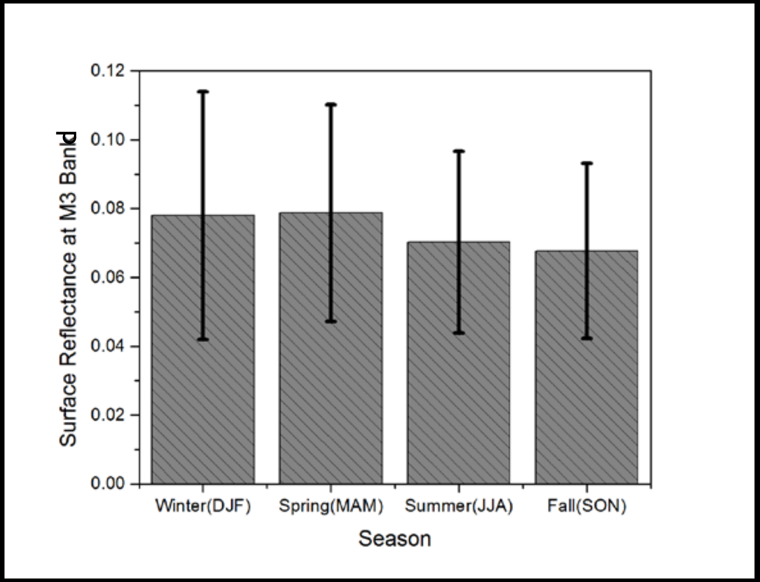


Railroad Valley (4)

- Surface reflectance
  - Retrieve surface reflectance from low AOD cased via atmospheric correction
  - Evaluation of the surface reflectance relationship (M5->M3 derived globally) over this station does not reveal significant error
  - SfcRef@M3 of majority retrievals fall within expected range
  - No significant season variation







SfcRef@M3: 0.072±0.029

Railroad Valley (5)

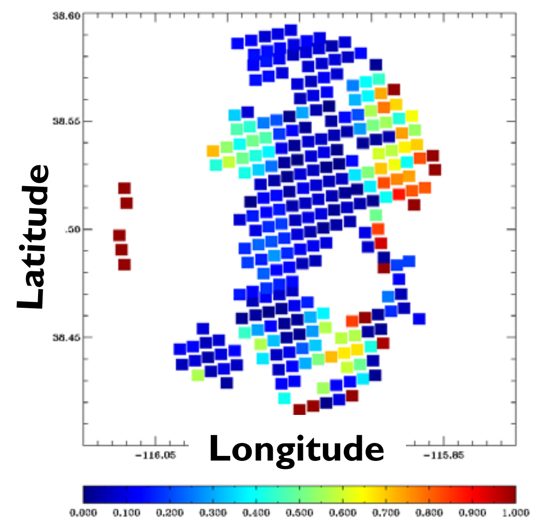
- Rugged terrain

Railroad Valley (6)

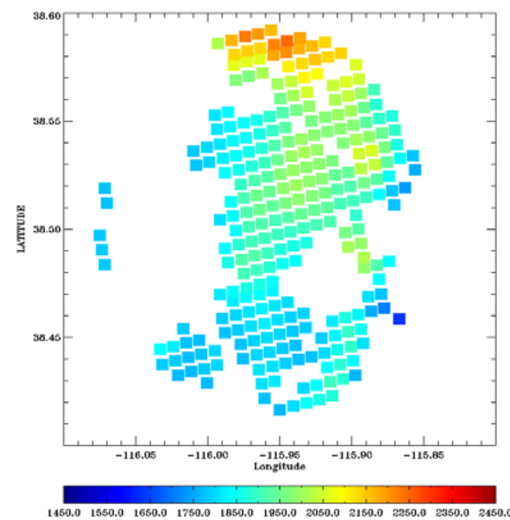
- **Case Study**

Date:	2013.157
AERONET AOD550:	0.052
EPS Mean AOD550:	0.276
Solar Zenith Angle:	19.10°
Viewing Zenith Angle:	11.89°
Solar Azimuth Angle:	-142.06°
Viewing Azimuth Angle:	78.16°
Scattering Angle:	150.83°
Glint Angle:	12.54°

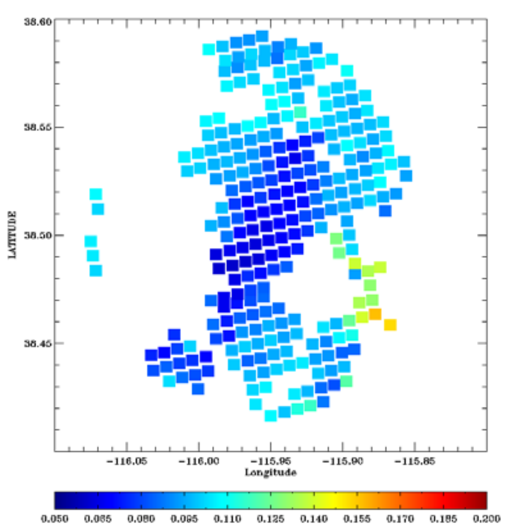
Retrieved AOD550



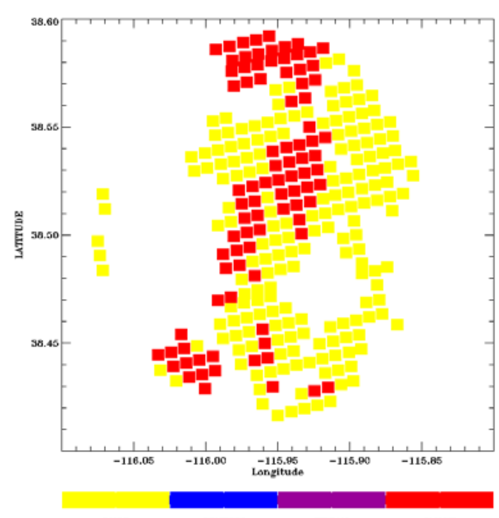
Input Surface Height



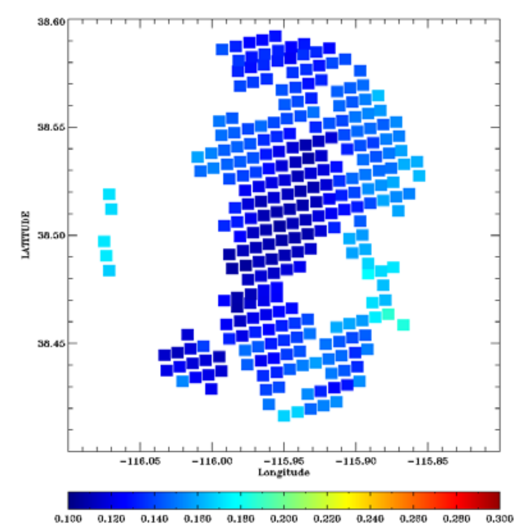
Retrieved SfcRef@M3



Selected Aerosol Model



Input ToaRef@M3

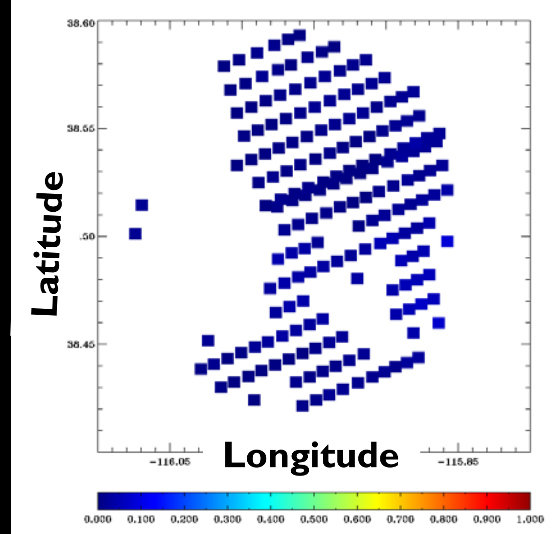


Railroad Valley (6)

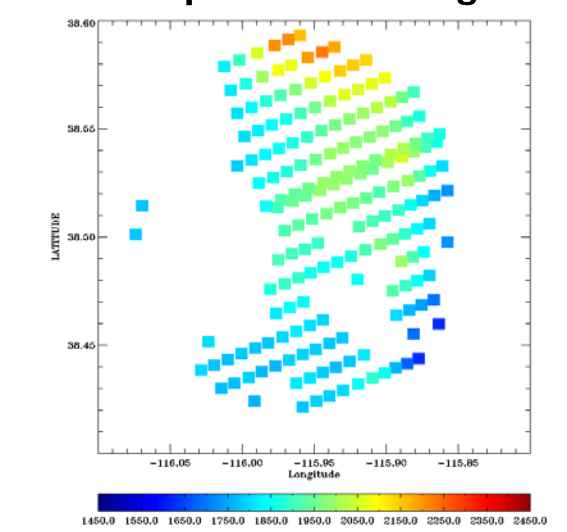
- **Case Study**

Date:	2012.328
AERONET AOD550:	0.009
EPS Mean AOD550:	0.017
Solar Zenith Angle:	59.20°
Viewing Zenith Angle:	59.09°
Solar Azimuth Angle:	-175.33°
Viewing Azimuth Angle:	70.62°
Scattering Angle:	87.87°
Glint Angle:	55.71°

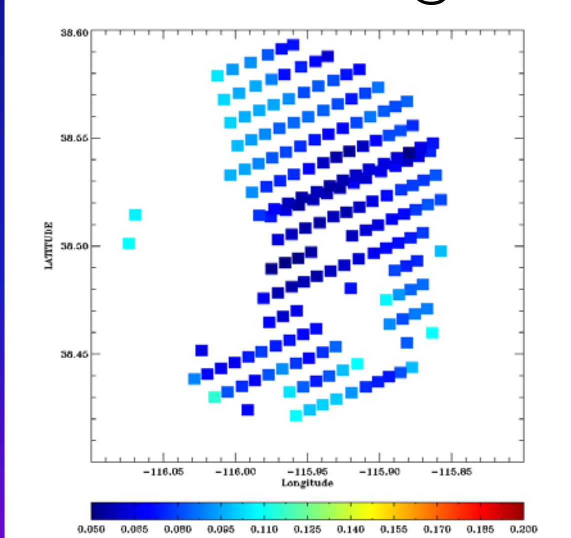
Retrieved AOD550



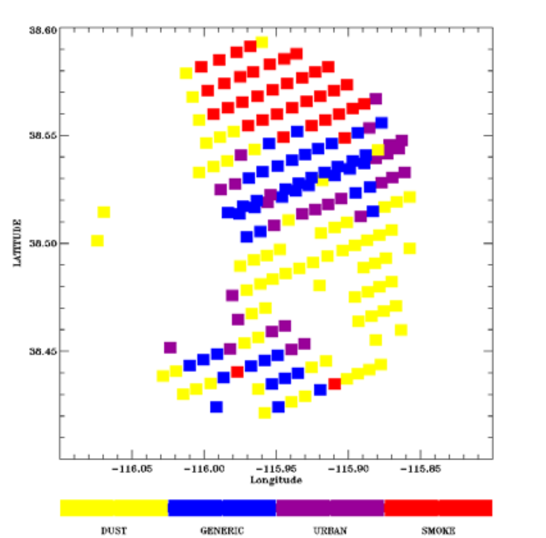
Input Surface Height



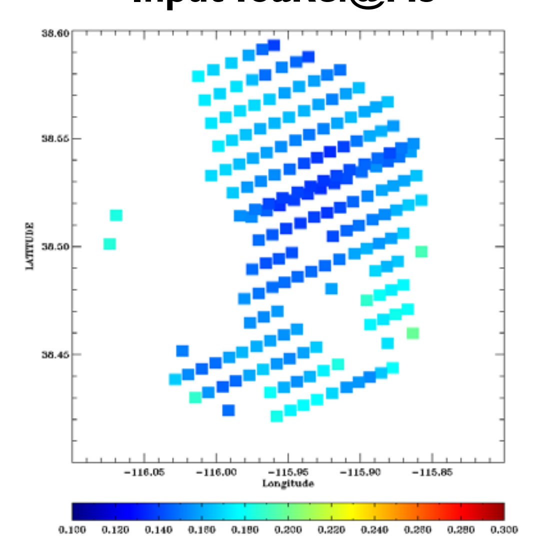
Retrieved SfcRef@M3



Selected Aerosol Model



Input ToaRef@M3

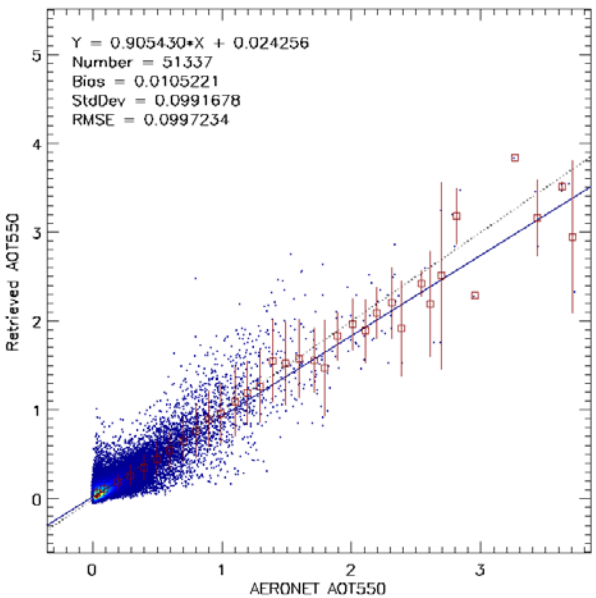


Summary

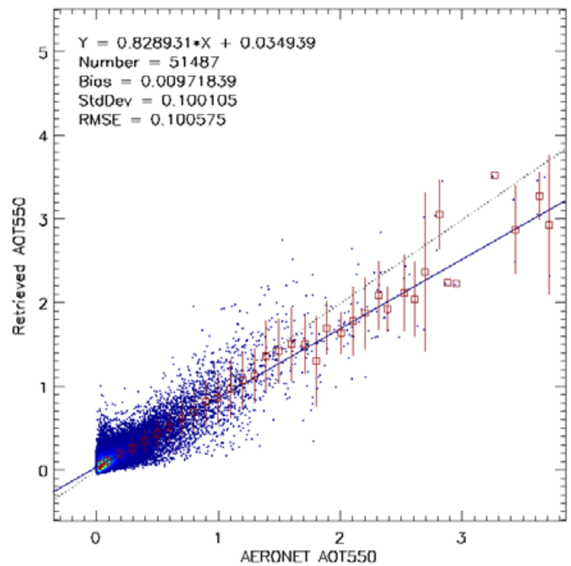
- VIIRS Enterprise Processing System AOD retrieval over land is evaluated using AERONET measurements over different geographic regions.
- Aerosol model selection can be improved by introducing a new set of surface reflectance relationship over East Asia.
- Lack a more absorbing dust model might be the cause of the negative bias over Africa.
- Evaluation of retrieval performance is sensitive to the validation domain selection over certain areas.
- Retrieval would have difficulty over rugged terrain areas.

Global Evaluation

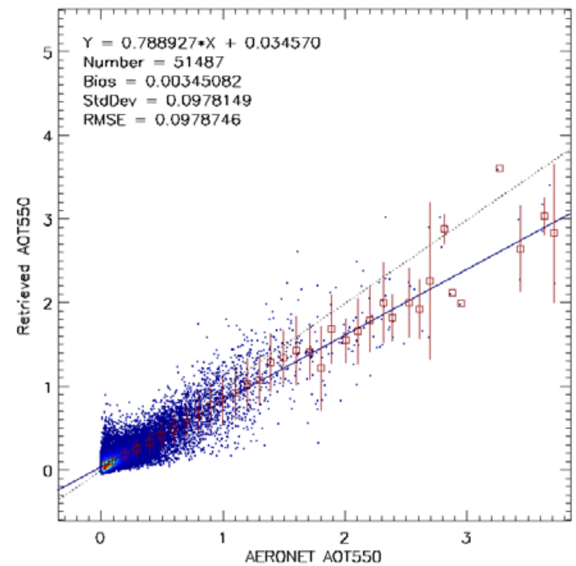
EPS Original Retrieval



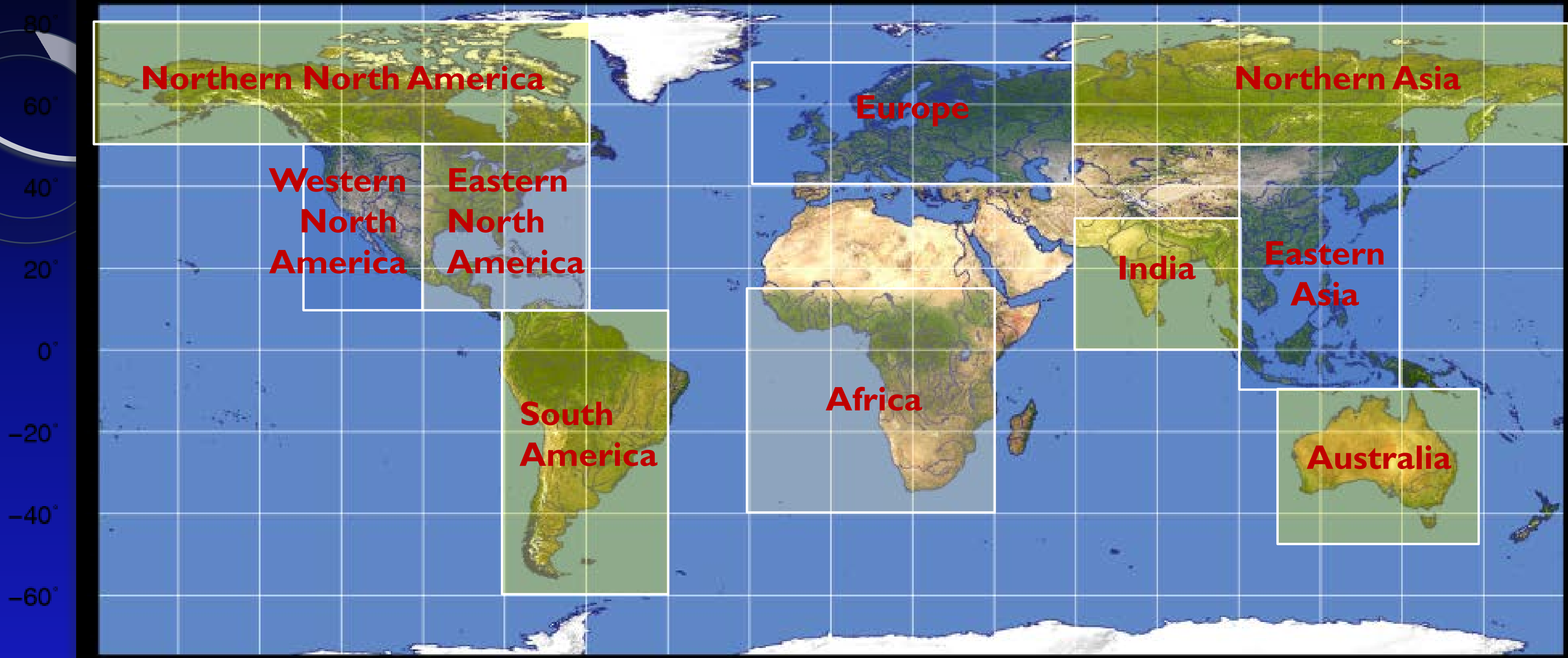
New M5->M11 Relationship



New M5->M11 Relationship
Average of best two solutions



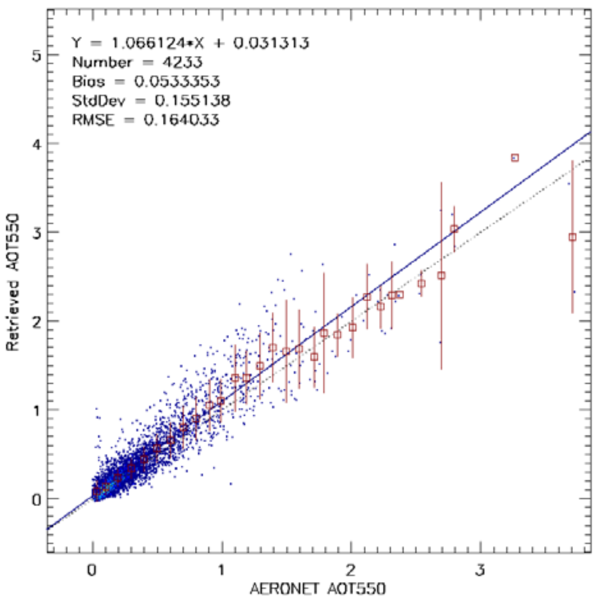
Regional Evaluation



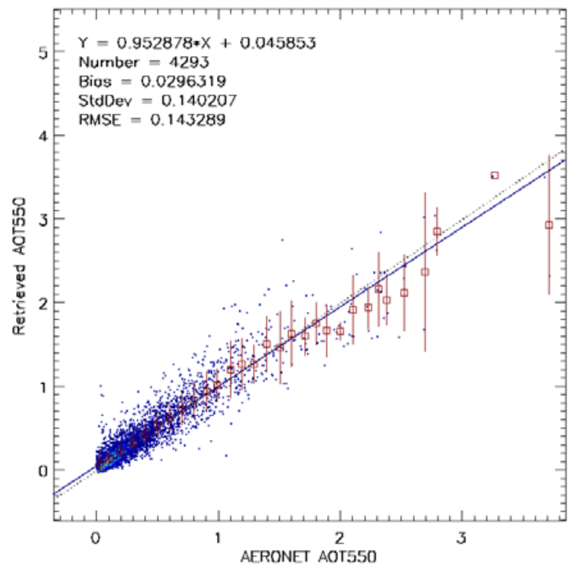
Domain	Longitude	Latitude
Northern North America	180° W - 60° W	50° N - 80° N
Northern Asia	60° E - 180° E	50° N - 80° N
Europe	20° W - 60° E	40° N - 70° N
Western North America	130° W - 100° W	10° N - 50° N
Eastern North America	100° W - 60° W	10° N - 50° N
South America	80° W - 40° W	60° S - 10° N
South Africa	20° W - 40° E	40° S - 15° N
India	60° E - 100° E	0° - 30° N
Eastern Asia	100° E - 140° E	10° S - 50° N
Australia	110° E - 160° E	50° S - 10° S

• Eastern Asia

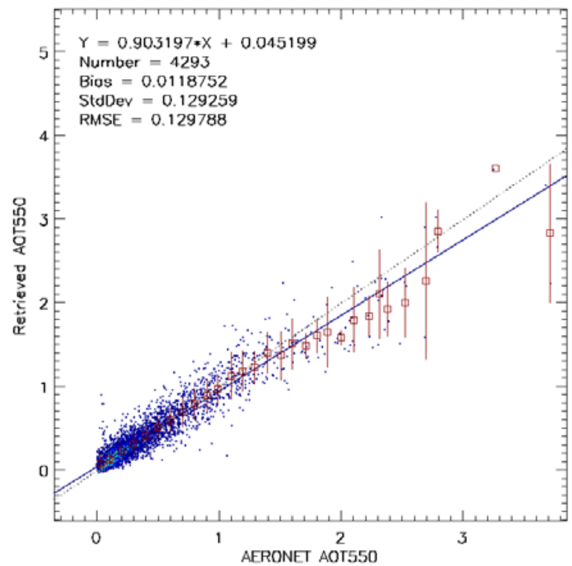
EPS Original Retrieval



New M5->M11 Relationship

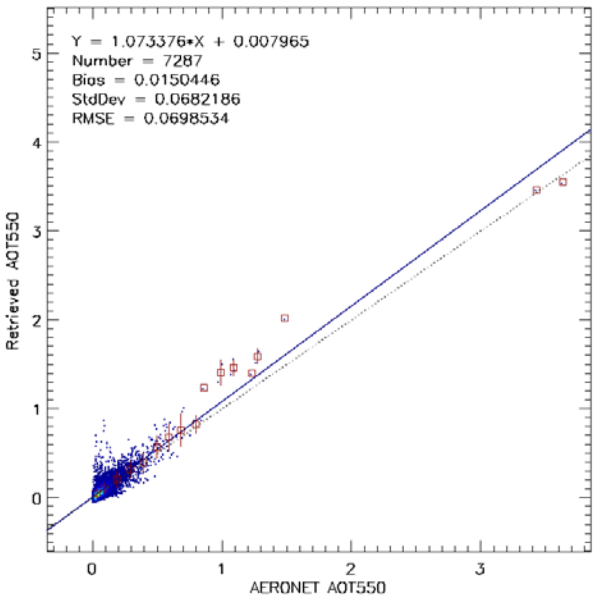


New M5->M11 Relationship
Average of best two solutions

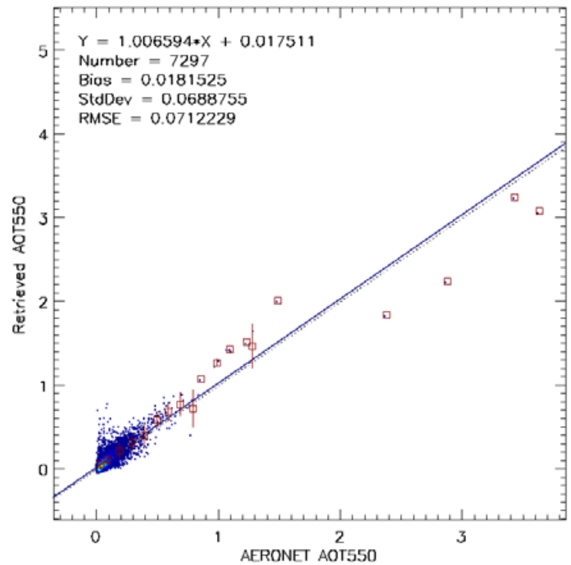


- Eastern North America

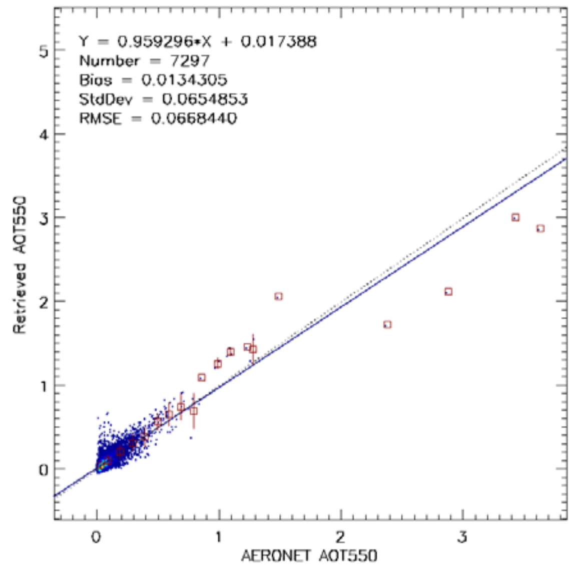
EPS Original Retrieval



New M5->M11 Relationship

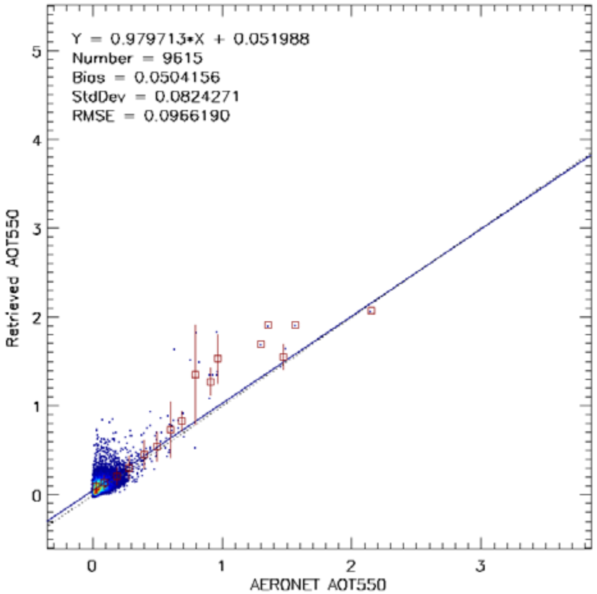


New M5->M11 Relationship
Average of best two solutions

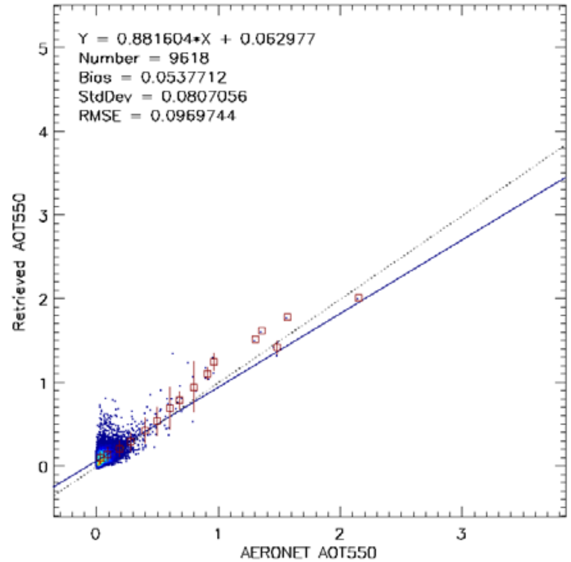


Western North America

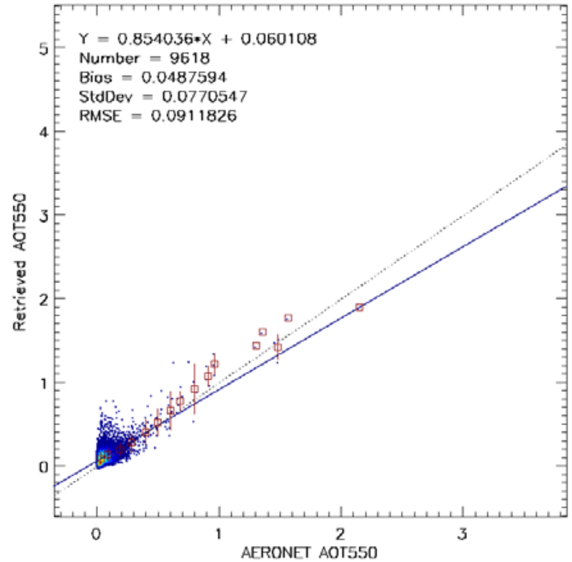
EPS Original Retrieval



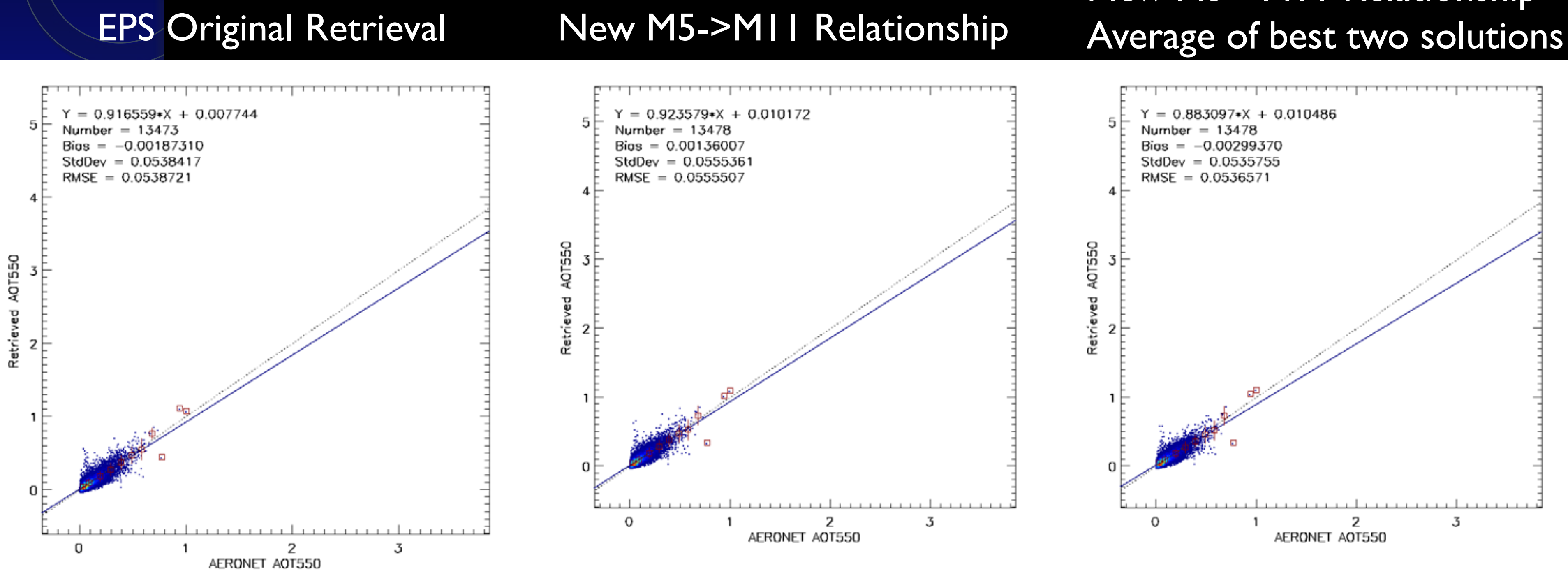
New M5->M11 Relationship



New M5->M11 Relationship
Average of best two solutions

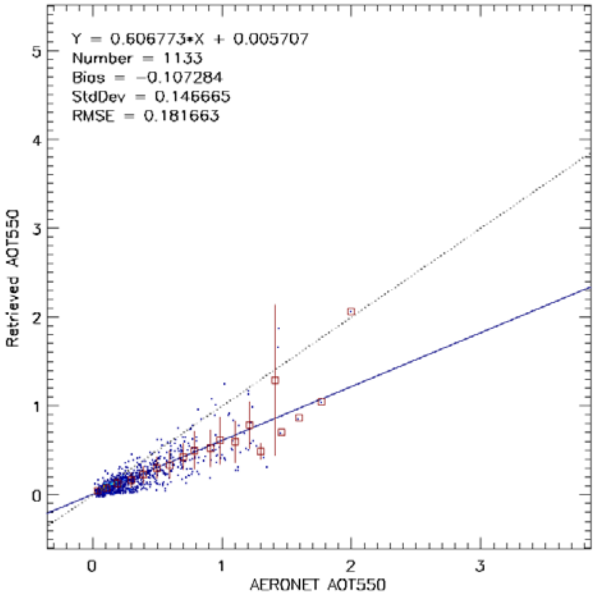


- Europe

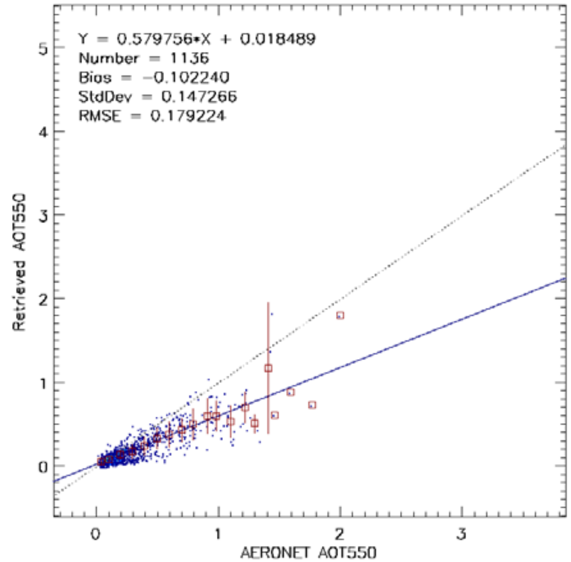

EPS Original Retrieval
New M5->M11 Relationship
New M5->M11 Relationship
Average of best two solutions
Y = 0.916559*X + 0.007744
Number = 13473
Bias = -0.00187310
StdDev = 0.0538417
RMSE = 0.0538721
Retrieved AOT550
AERONET AOT550
Y = 0.923579*X + 0.010172
Number = 13478
Bias = 0.00136007
StdDev = 0.0555361
RMSE = 0.0555507
Retrieved AOT550
AERONET AOT550
Y = 0.883097*X + 0.010486
Number = 13478
Bias = -0.00299370
StdDev = 0.0535755
RMSE = 0.0536571
Retrieved AOT550
AERONET AOT550

- Africa

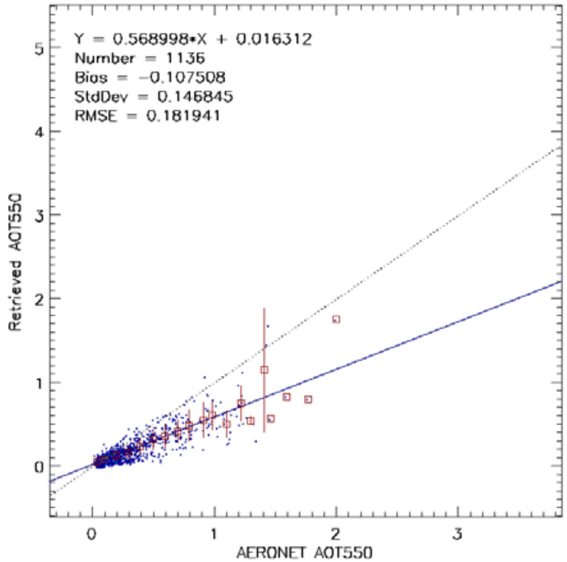
EPS Original Retrieval



New M5->M11 Relationship

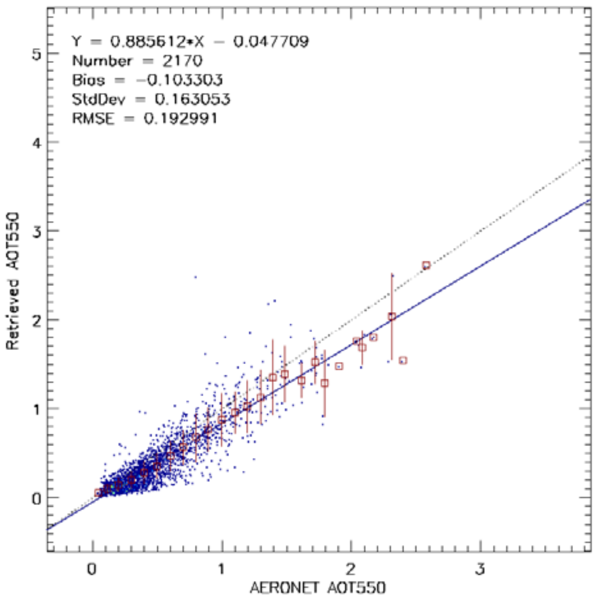


New M5->M11 Relationship
Average of best two solutions

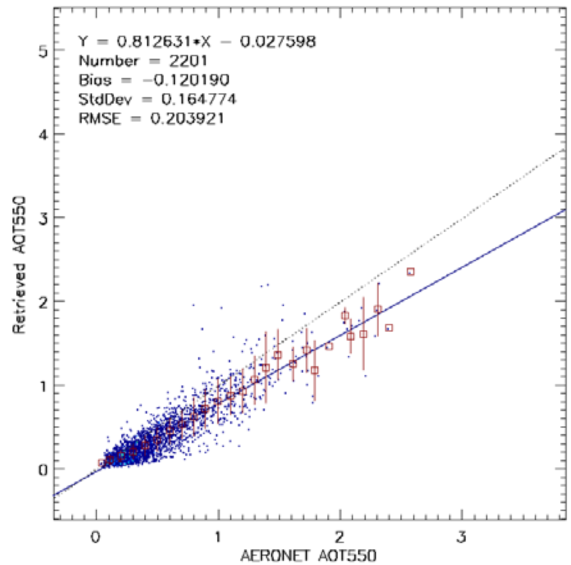


- India

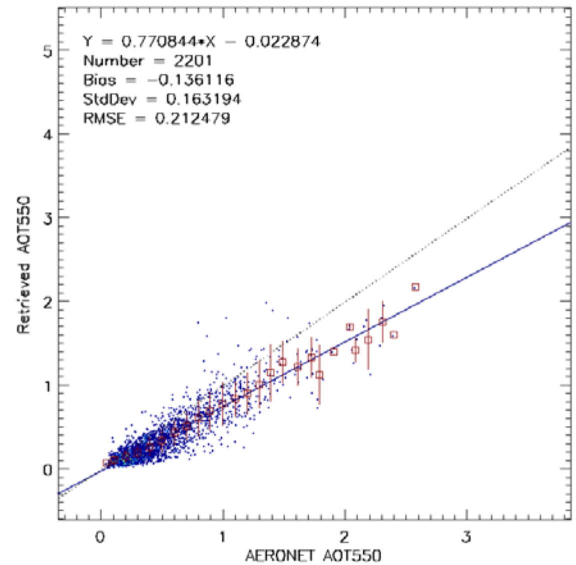
EPS Original Retrieval



New M5->M11 Relationship

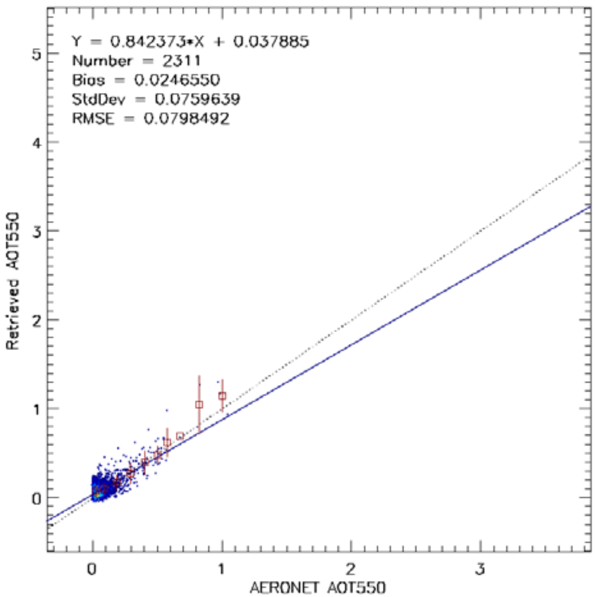


New M5->M11 Relationship
Average of best two solutions

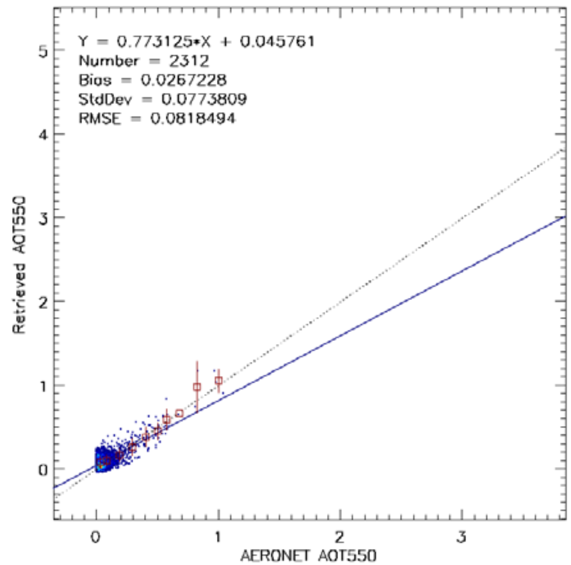


South America

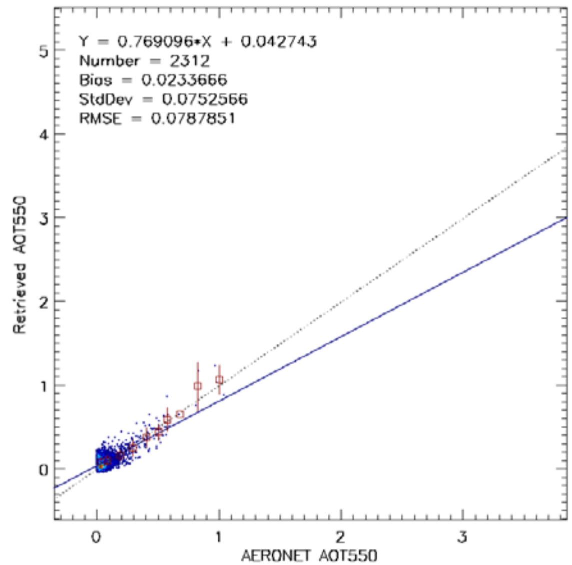
EPS Original Retrieval



New M5->M11 Relationship

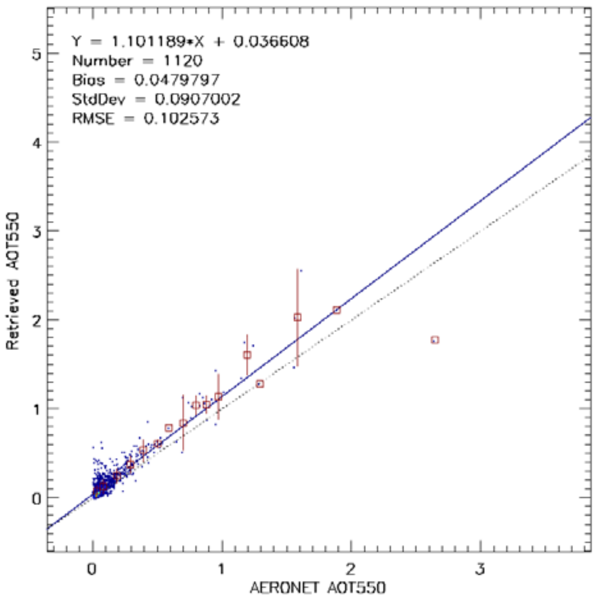


New M5->M11 Relationship
Average of best two solutions

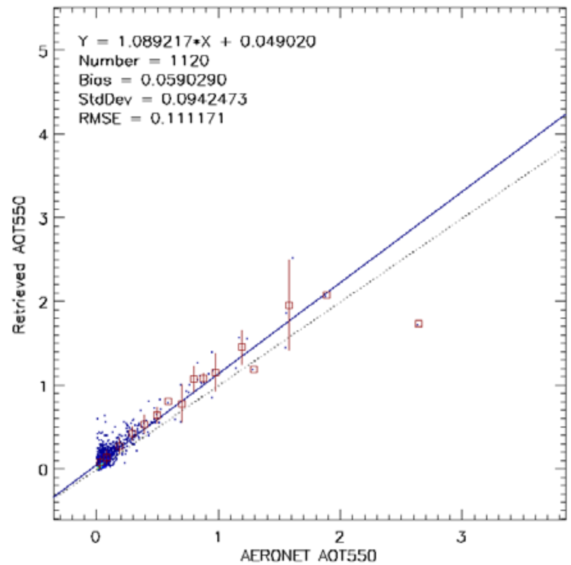


- Northern North America

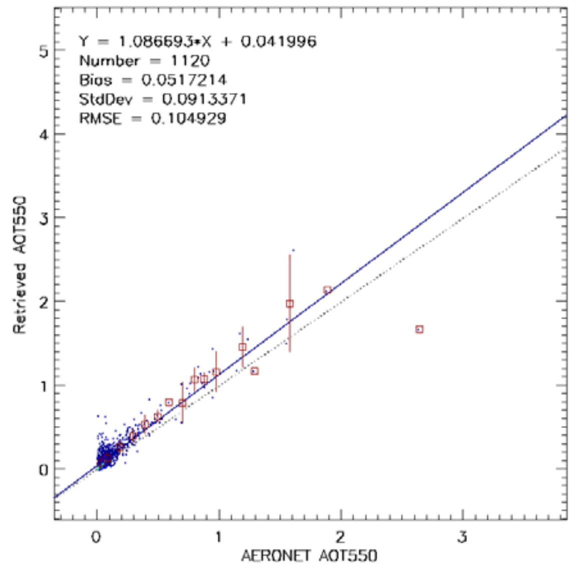
EPS Original Retrieval



New M5->M11 Relationship

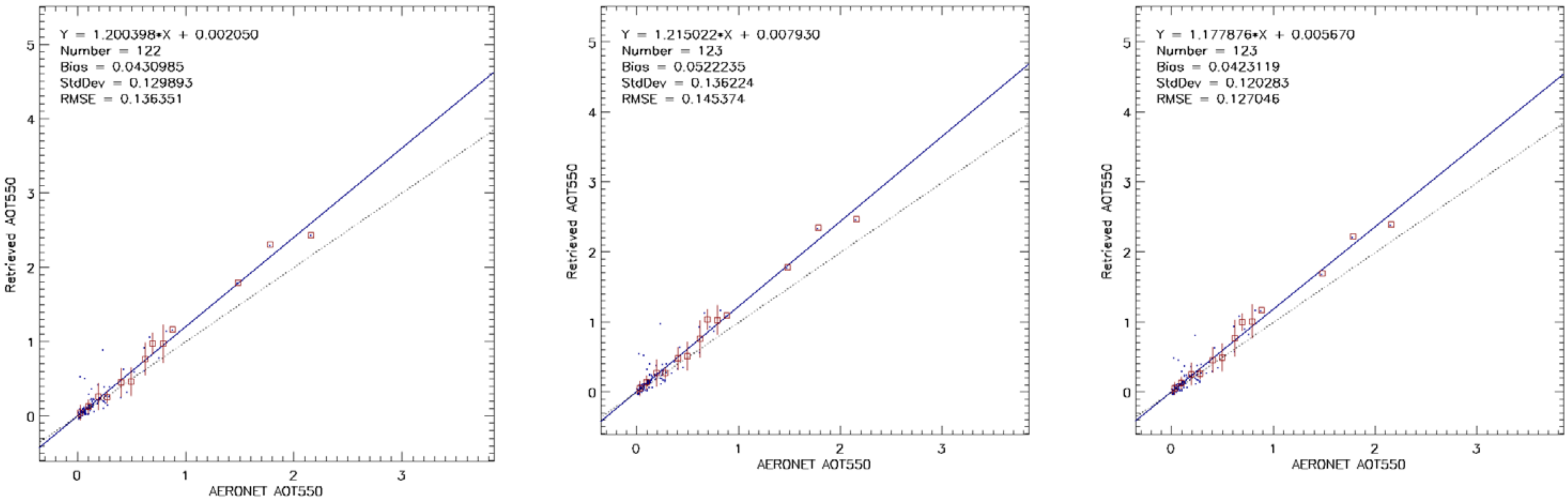


New M5->M11 Relationship
Average of best two solutions



Northern Asia

EPS Original Retrieval | New M5->M11 Relationship | New M5->M11 Relationship Average of best two solutions

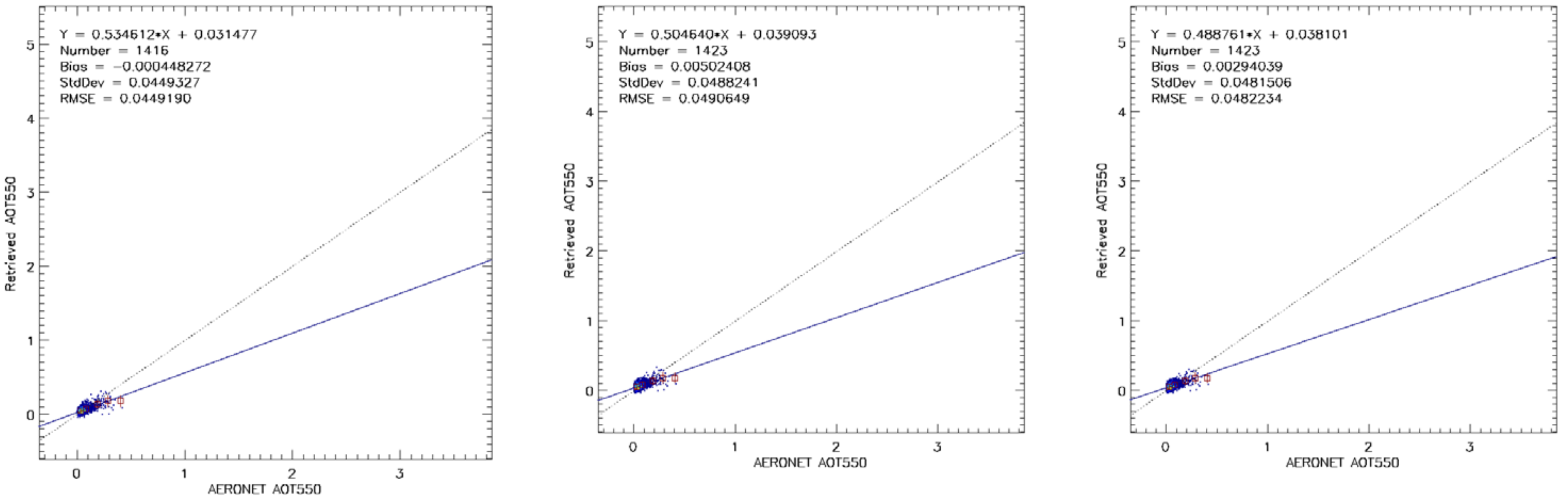


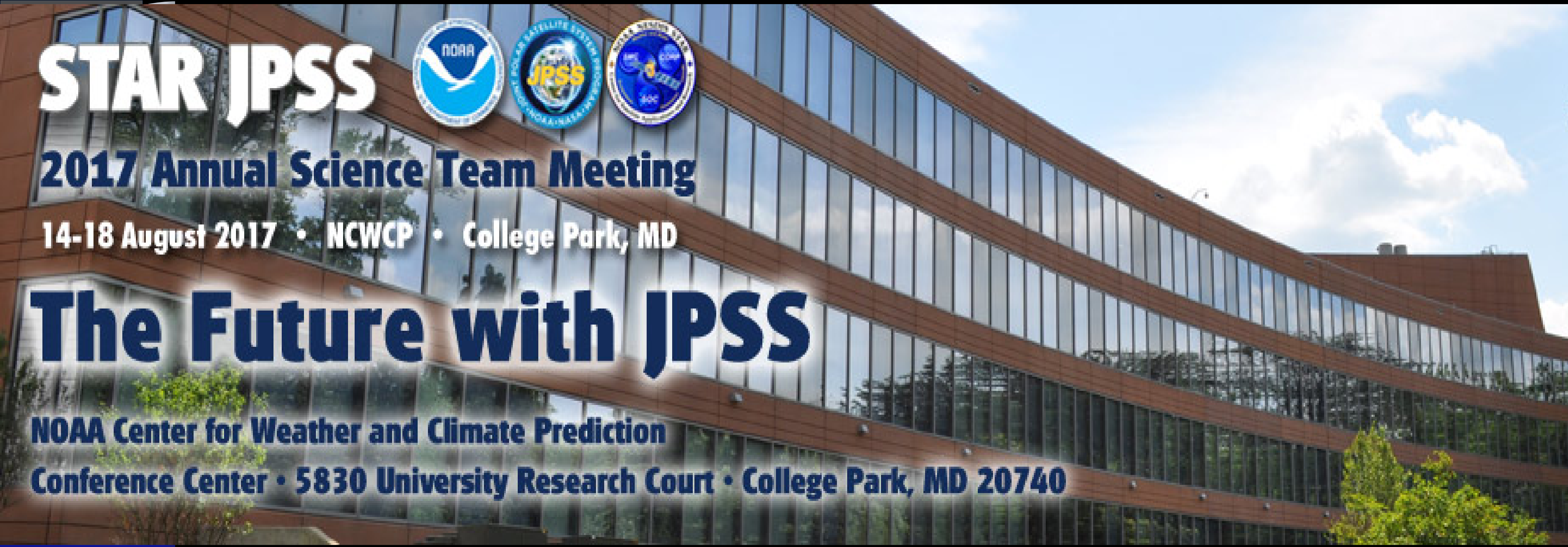
- Australia

EPS Original Retrieval

New M5->M11 Relationship

New M5->M11 Relationship
Average of best two solutions

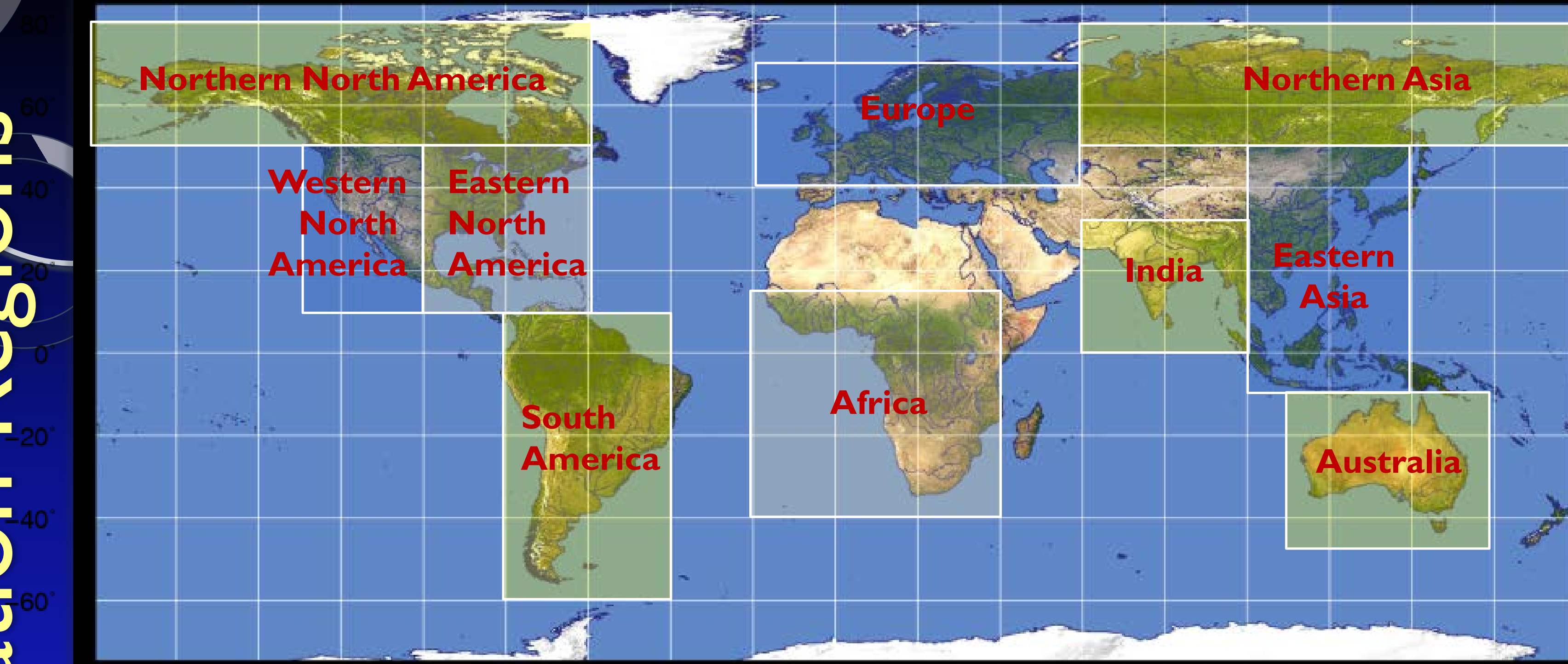




Potential Updates of the Land Aerosol Models for the EPS AOD Algorithm

Hongqing Liu
and NOAA STAR Aerosol Cal/Val Team

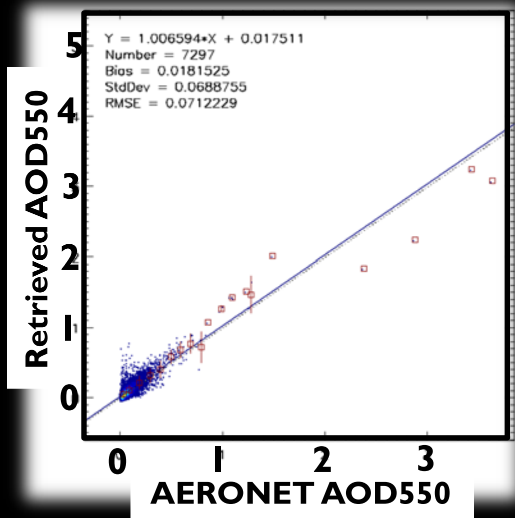
Evaluation Regions



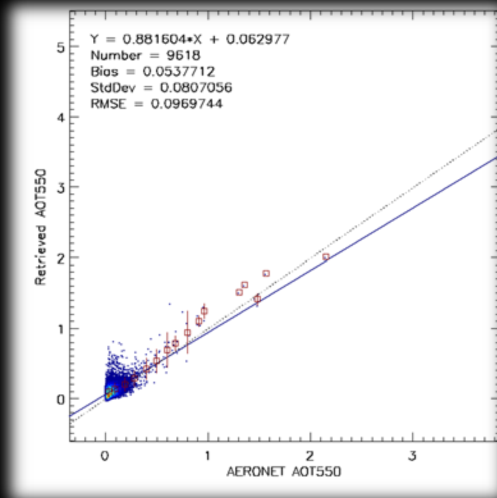
Domain	Longitude	Latitude
Northern North America	180° W - 60° W	50° N - 80° N
Northern Asia	60° E - 180° E	50° N - 80° N
Europe	20° W - 60° E	40° N - 70° N
Western North America	130° W - 100° W	10° N - 50° N
Eastern North America	100° W - 60° W	10° N - 50° N
South America	80° W - 40° W	60° S - 10° N
South Africa	20° W - 40° E	40° S - 15° N
India	60° E - 100° E	0° - 30° N
Eastern Asia	100° E - 140° E	10° S - 50° N
Australia	110° E - 160° E	50° S - 10° S

Regional Performance (I)

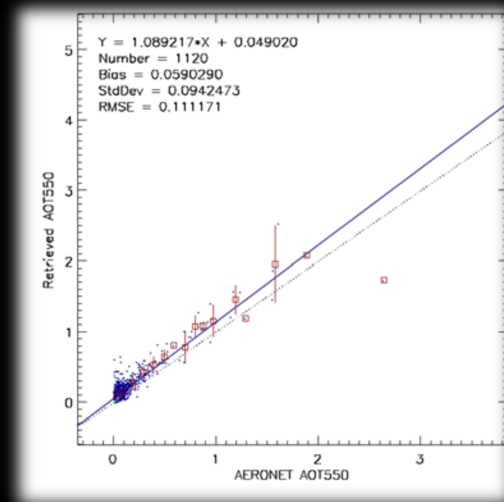
Eastern North America



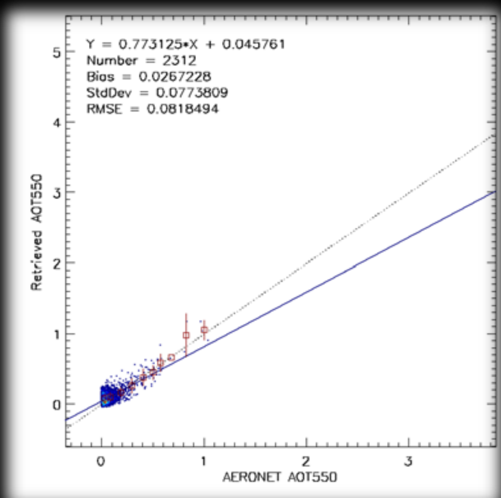
Western North America



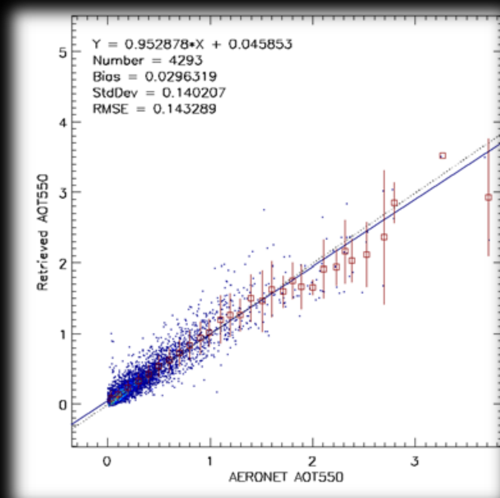
Northern North America



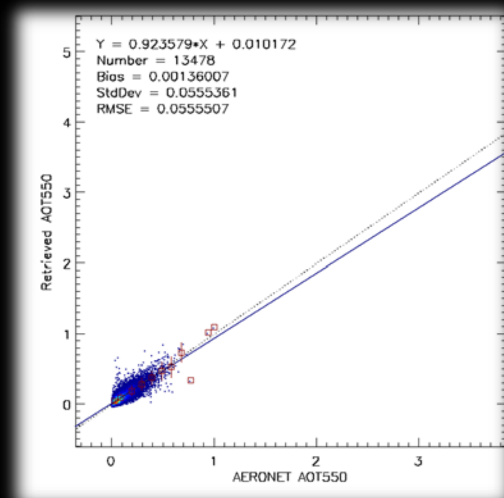
South America



Eastern Asia

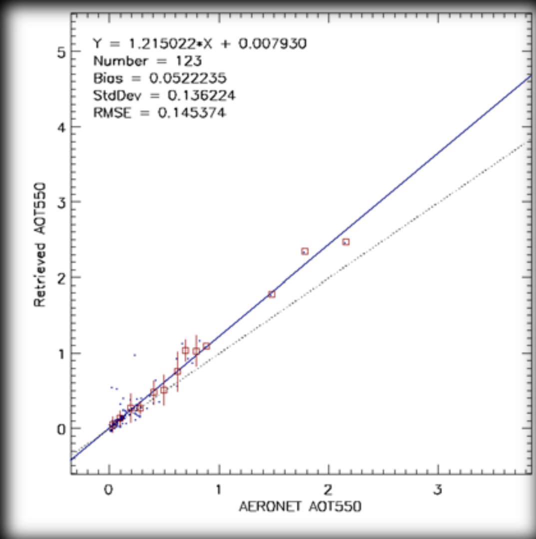


Europe

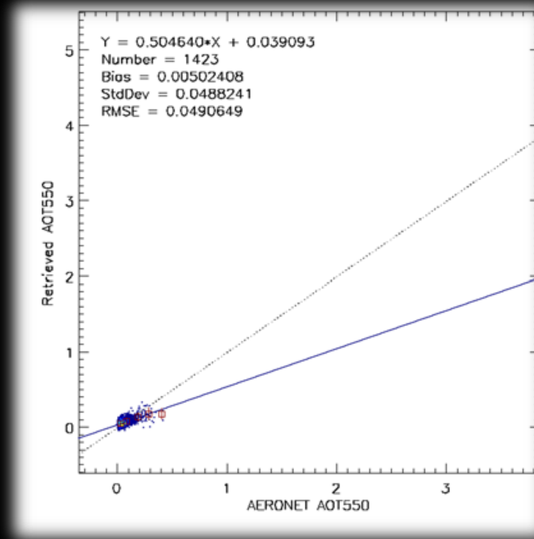


Regional Performance (2)

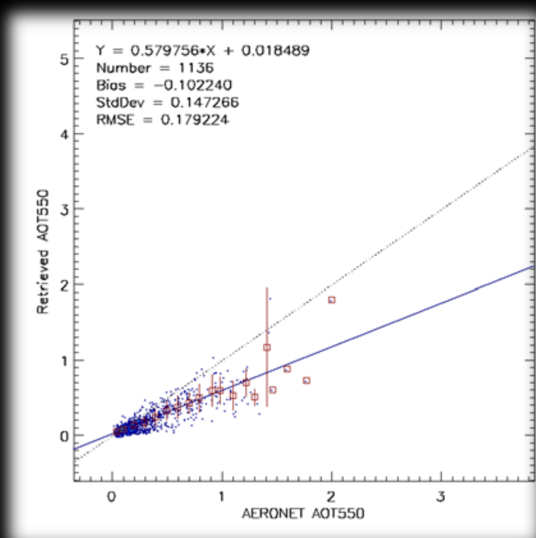
Northern Asia



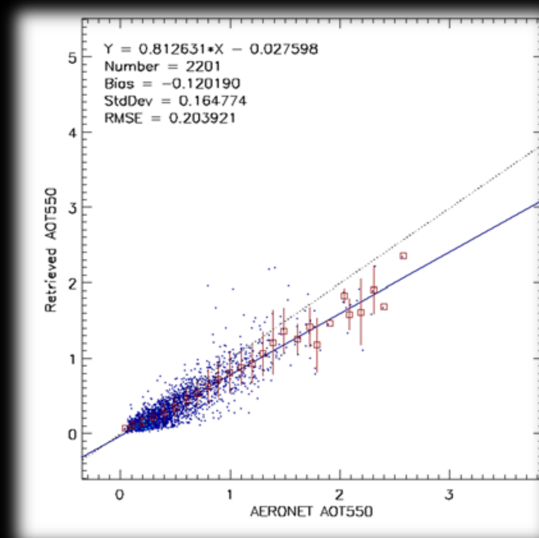
Australia



Africa

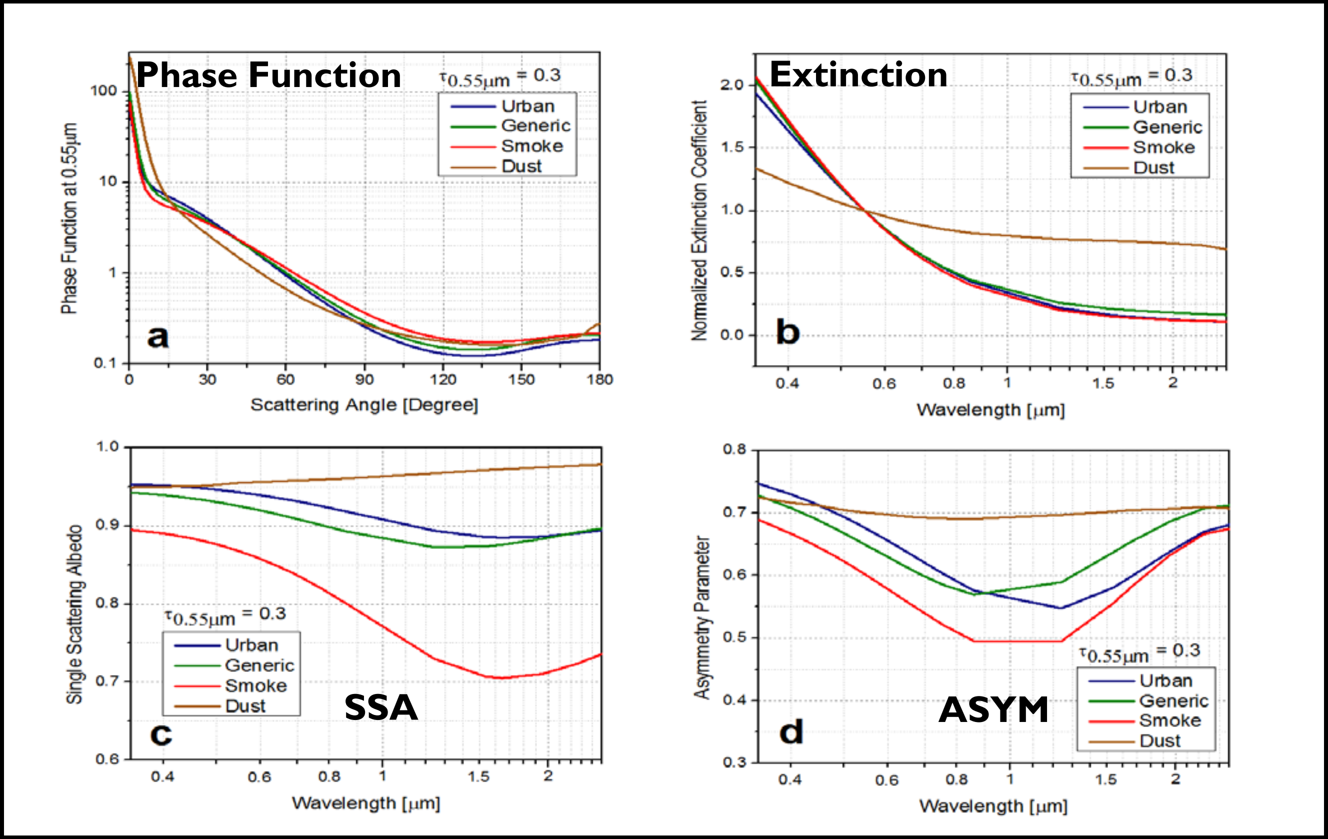


India

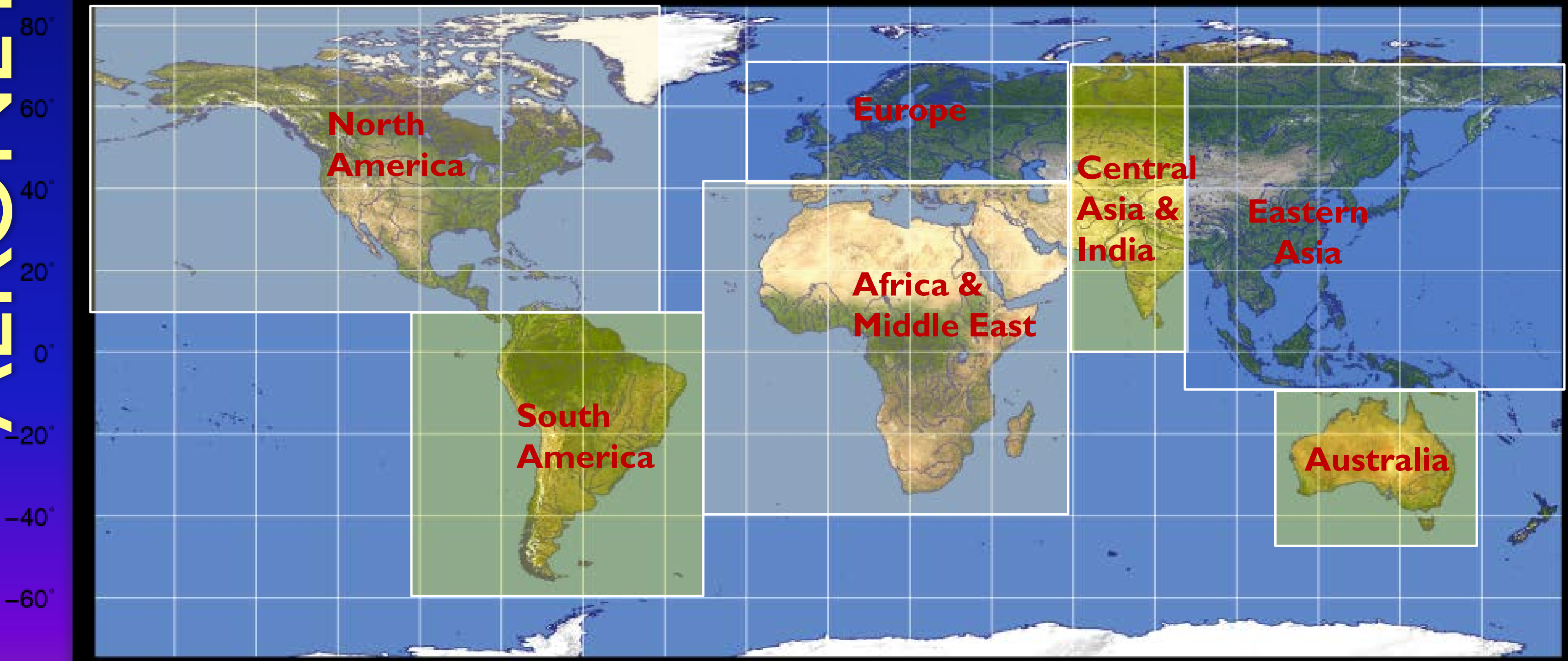


Motivation

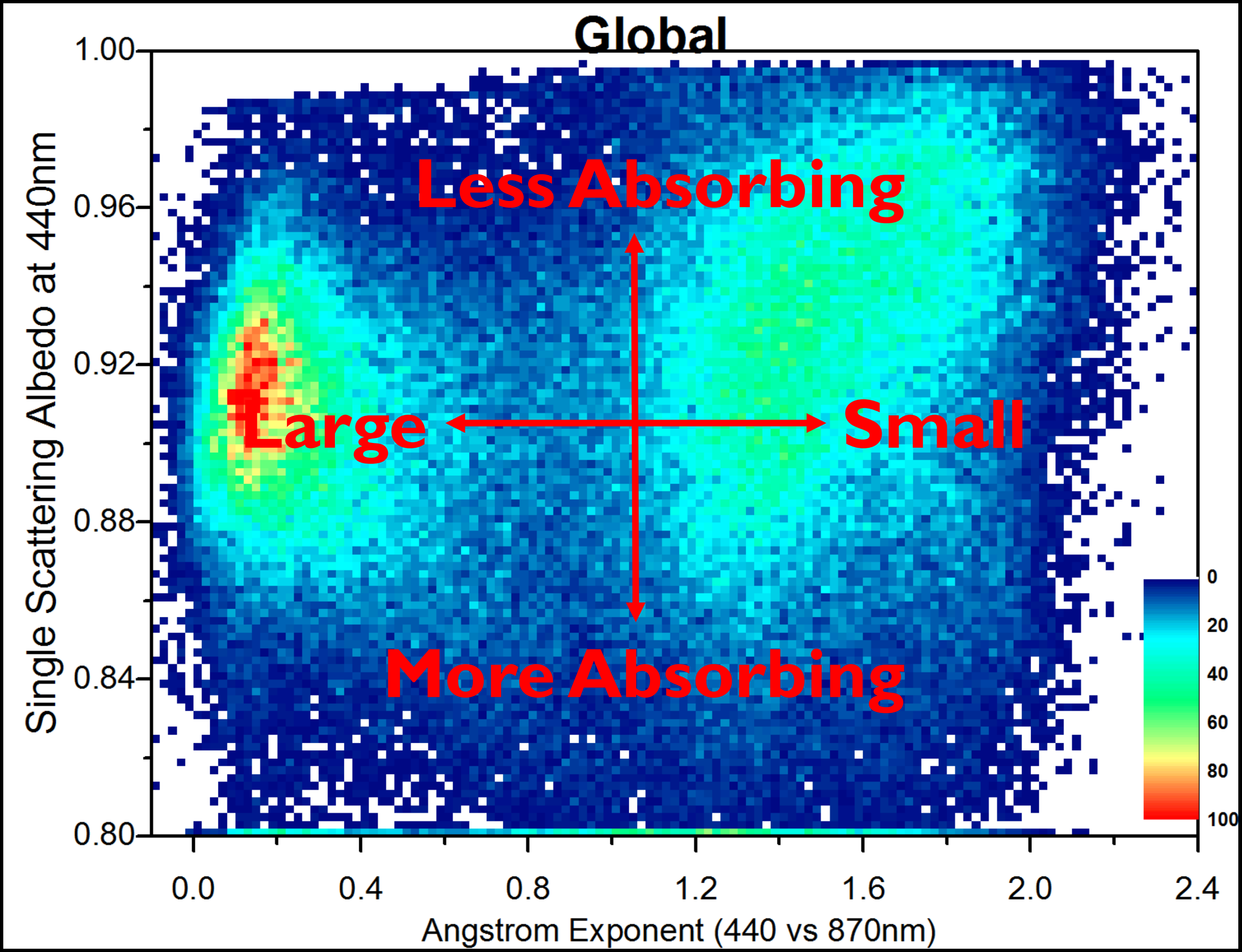
- Current land aerosol models (four types) might not be representative enough for global aerosol retrievals
  - Large errors over Africa and India



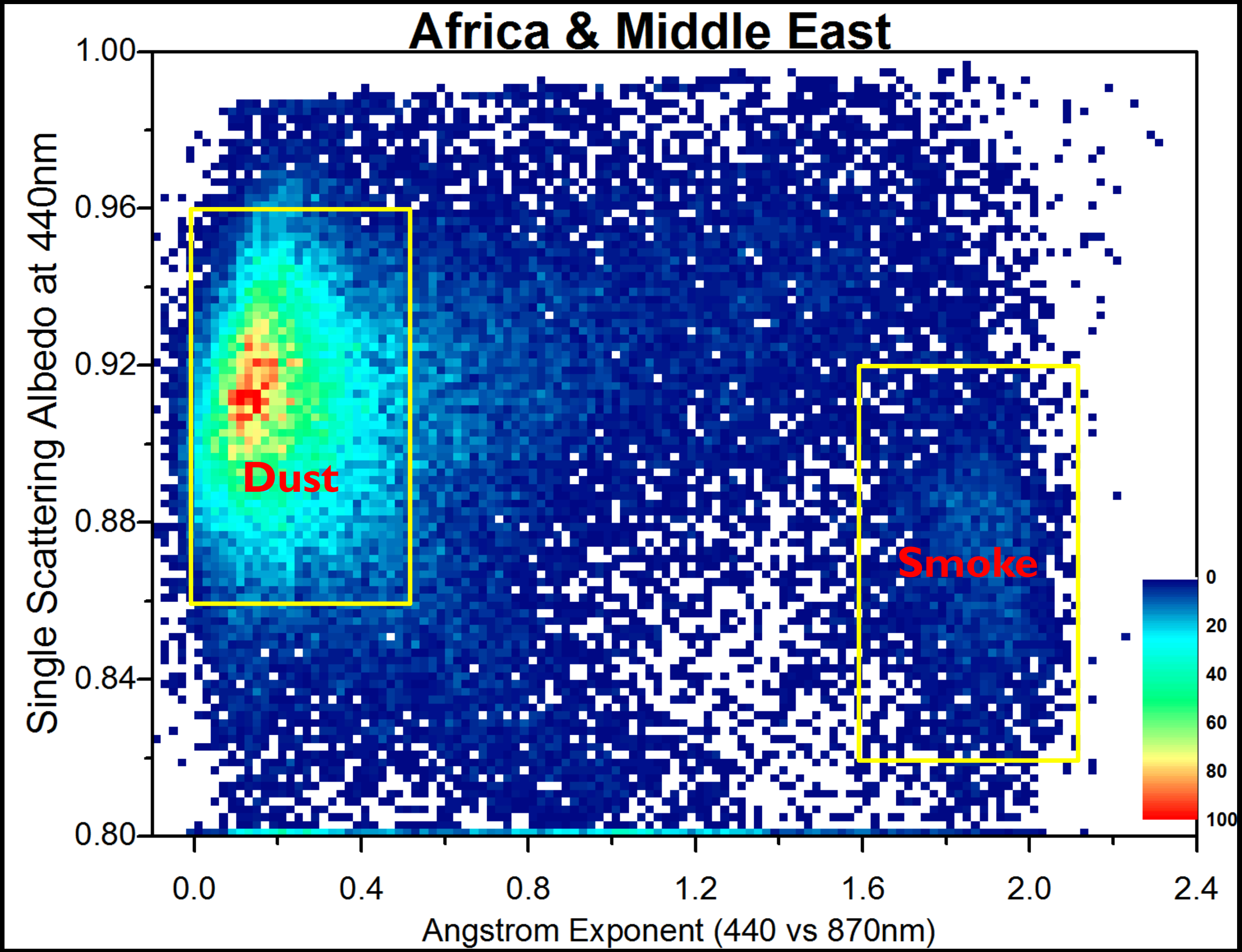
- AERONET Version 2 inversion products
  - Sun photometers measurements in almucantar and principle planes
  - Produce aerosol optical properties: single scatter albedo, size distribution, complex index of refraction, etc.



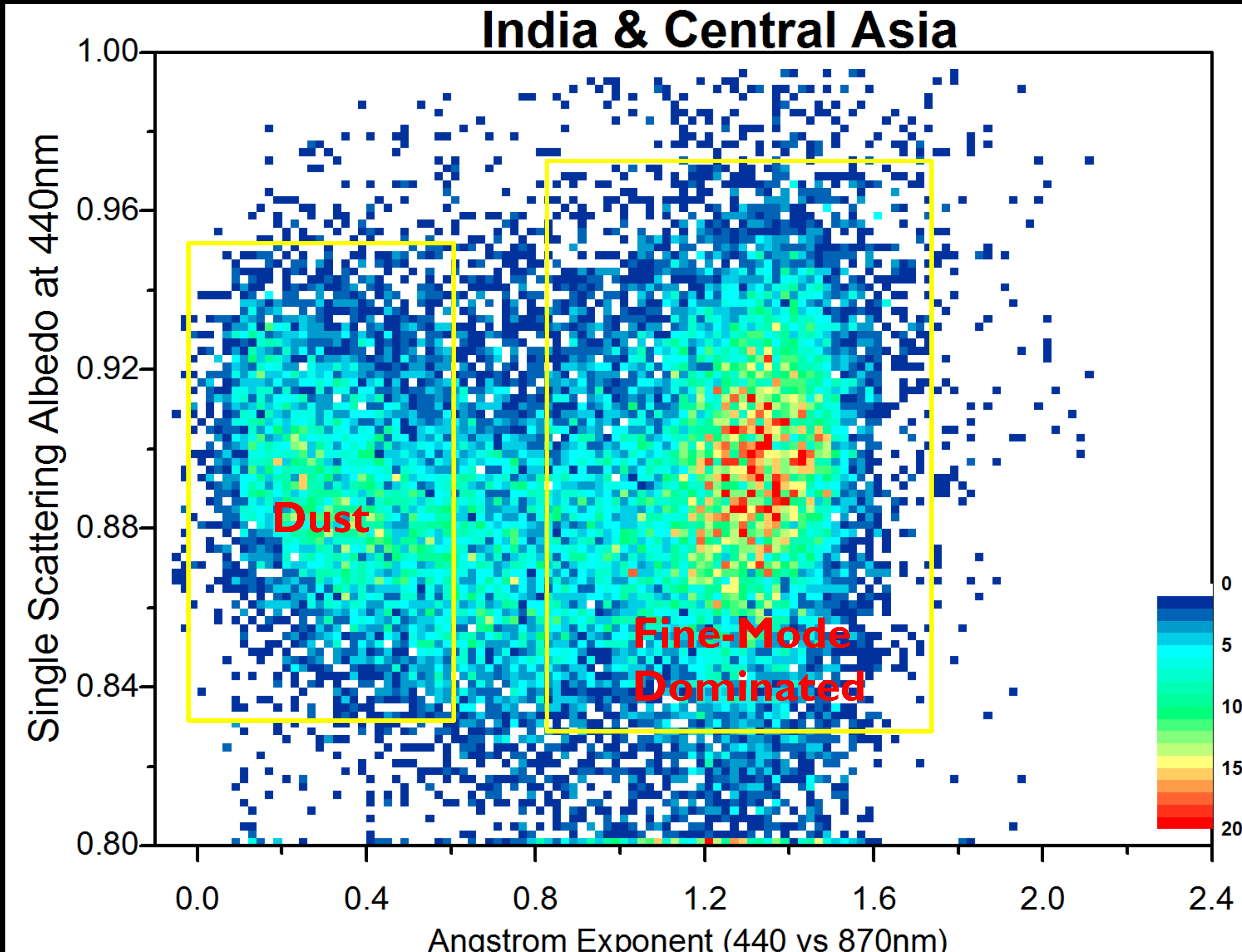
Global Aerosol Properties



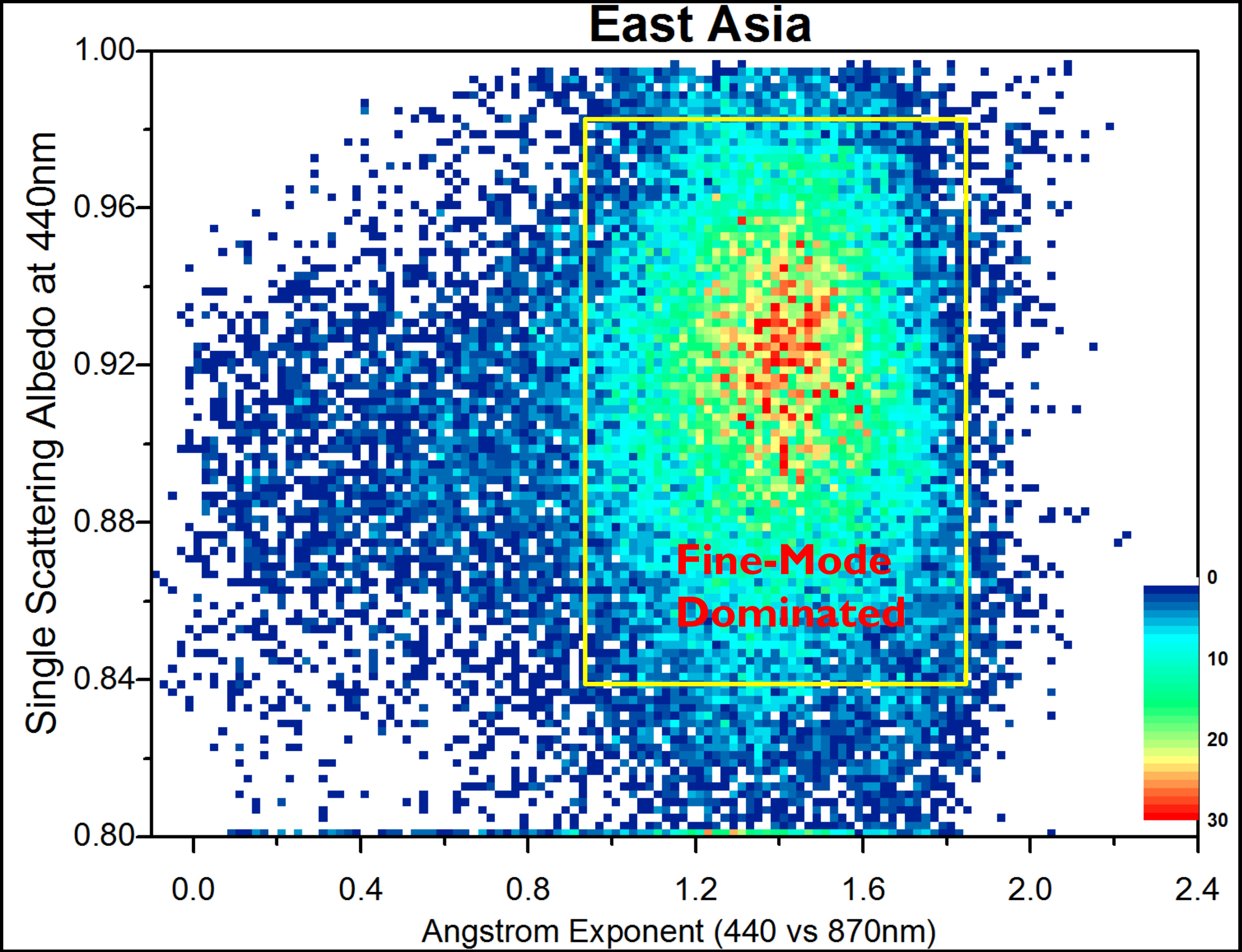
Regional Aerosol Properties (I)



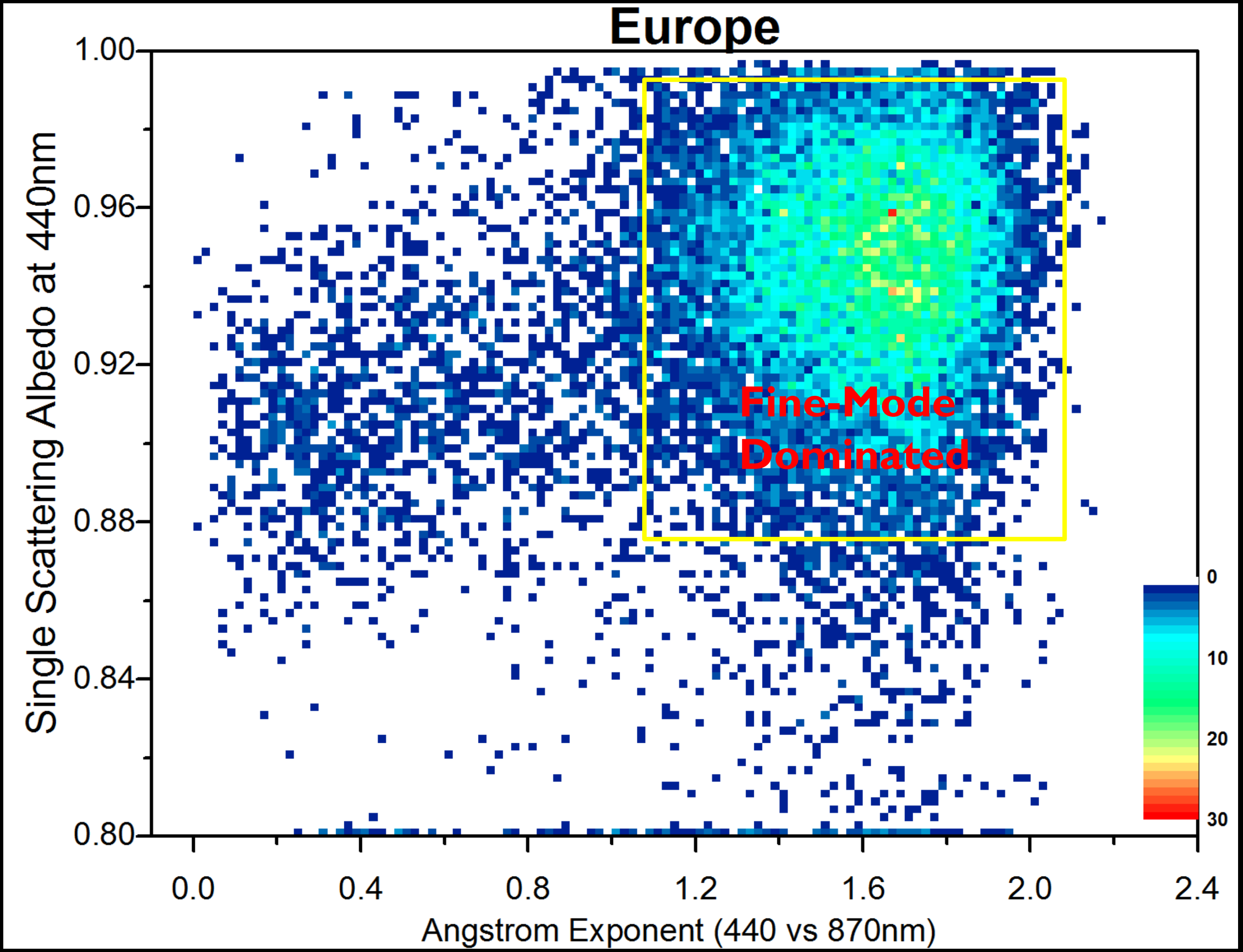
Regional Aerosol Properties (2)



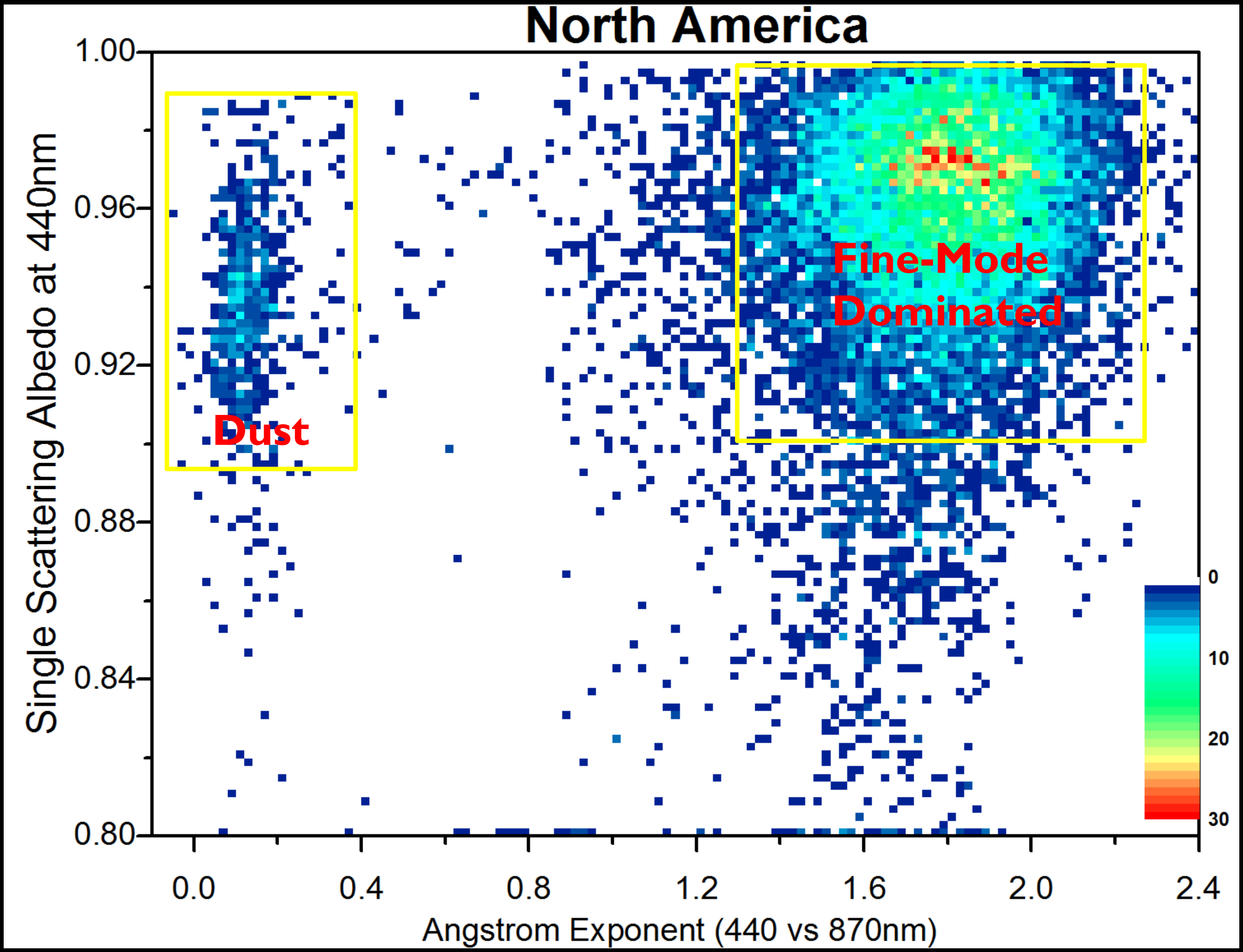
Regional Aerosol Properties (3)



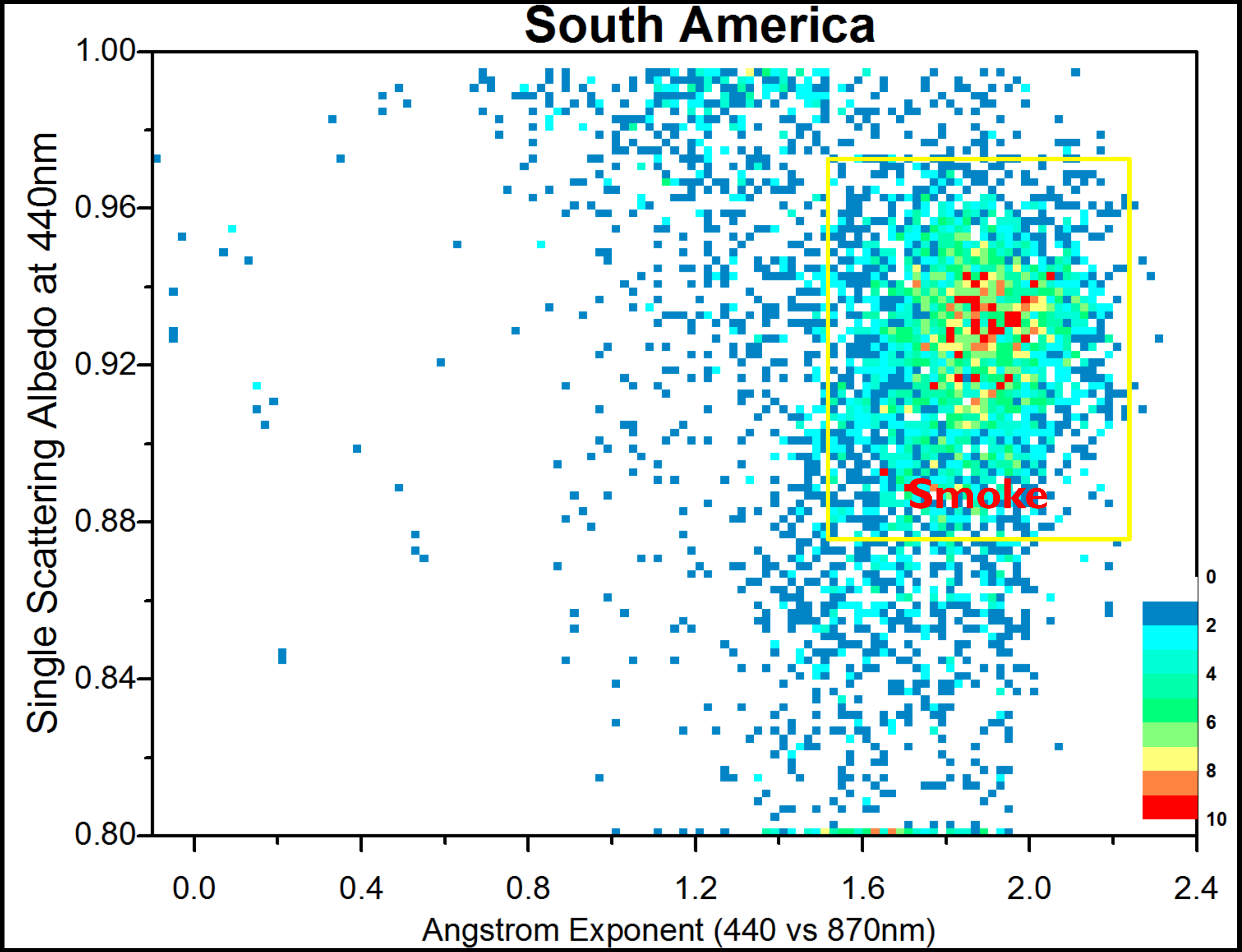
Regional Aerosol Properties (4)



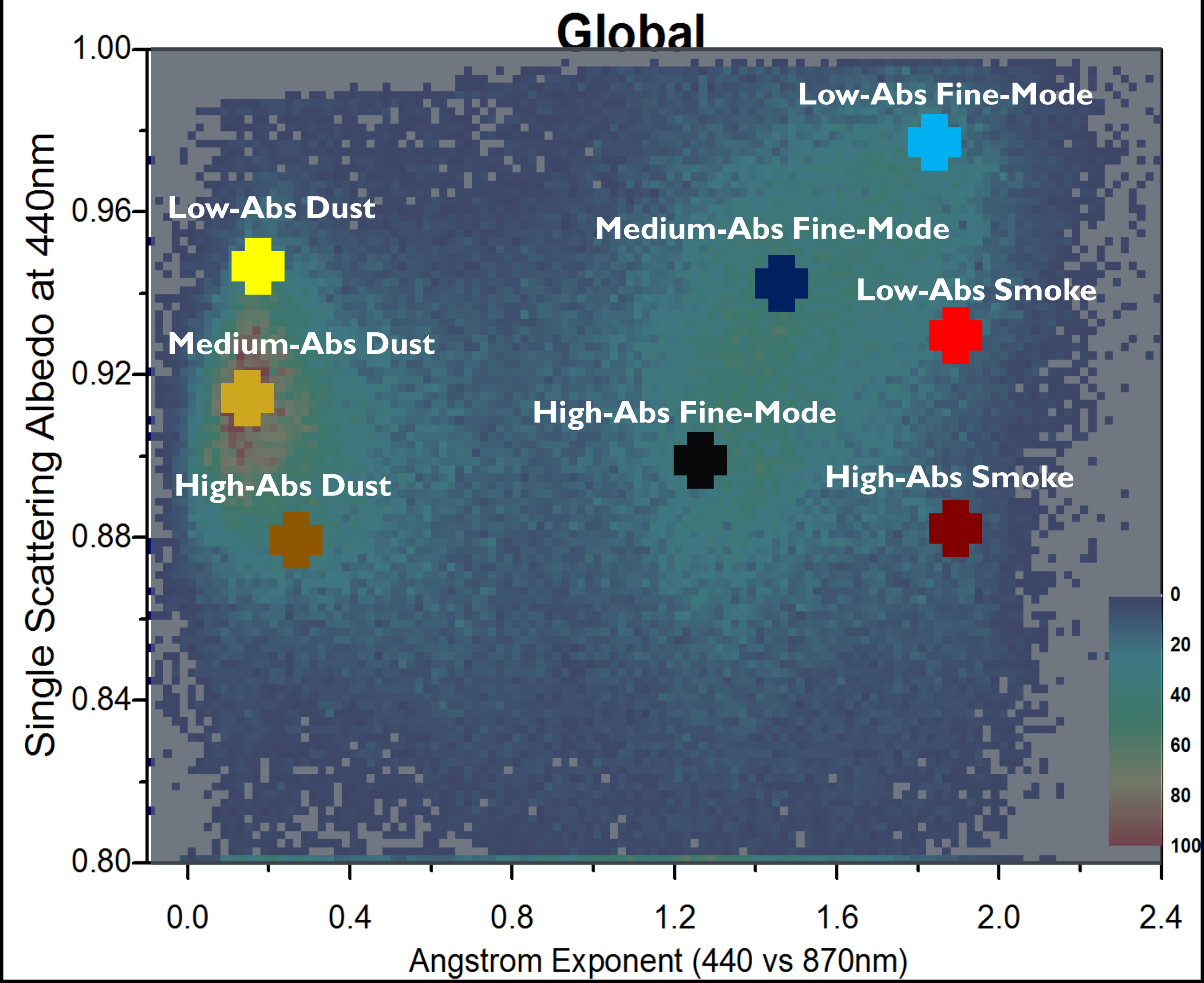
Regional Aerosol Properties (5)



Regional Aerosol Properties (6)



New Aerosol Models

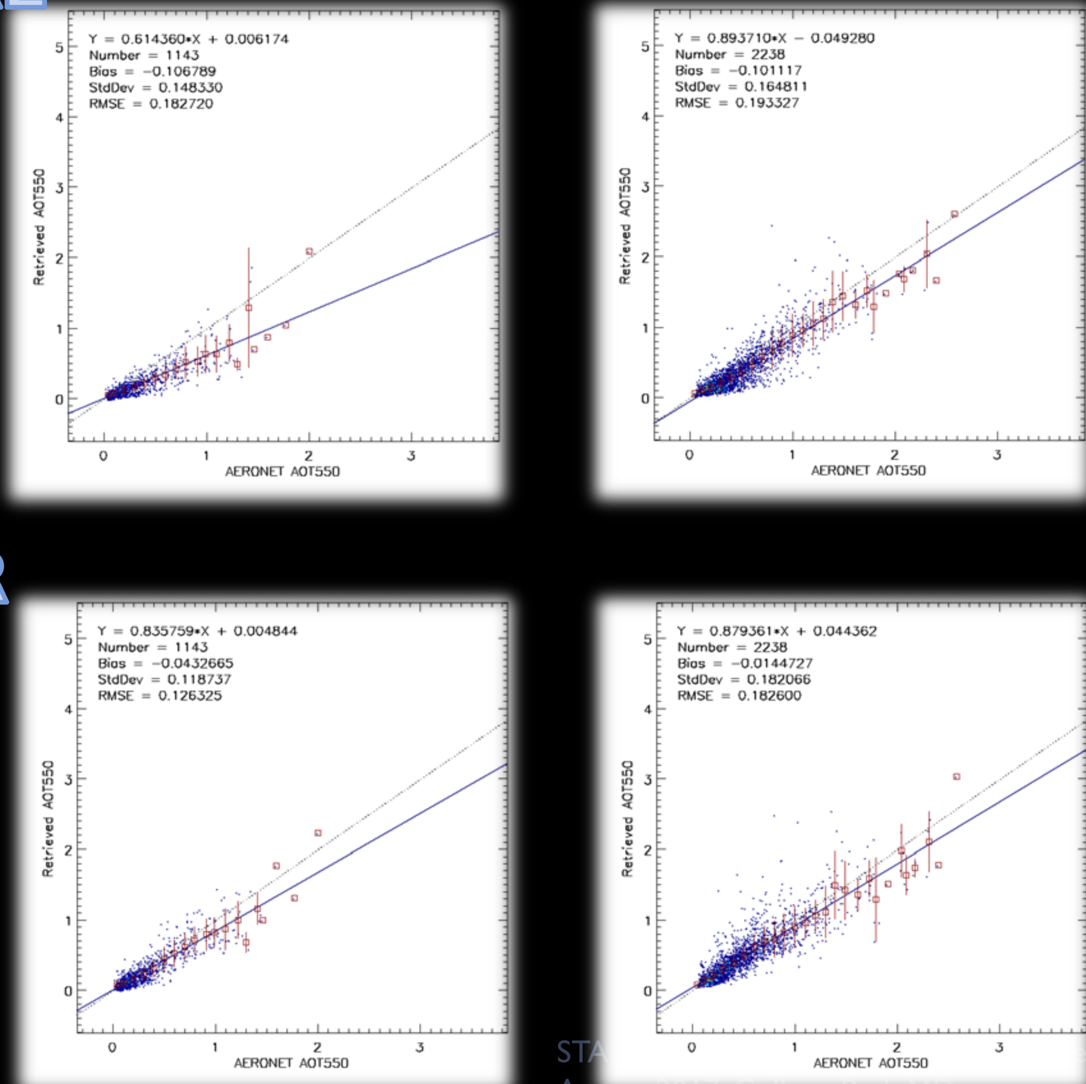


Retrieval (1)

- Generate new lookup table with new land aerosol models and apply to the EPS AOD algorithm
  - Retrieval bias is reduced over Africa and India

BEFORE | **Africa** | **India**

AFTER

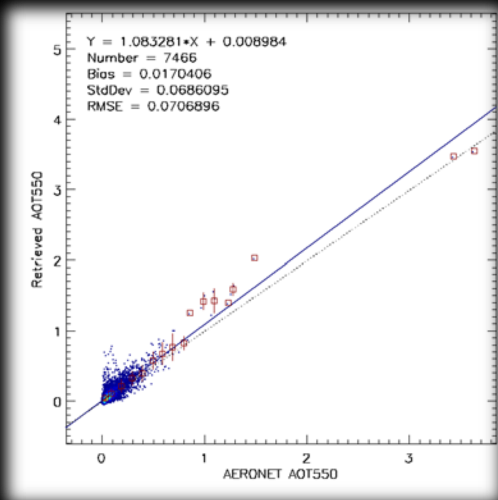


Retrieval (2)

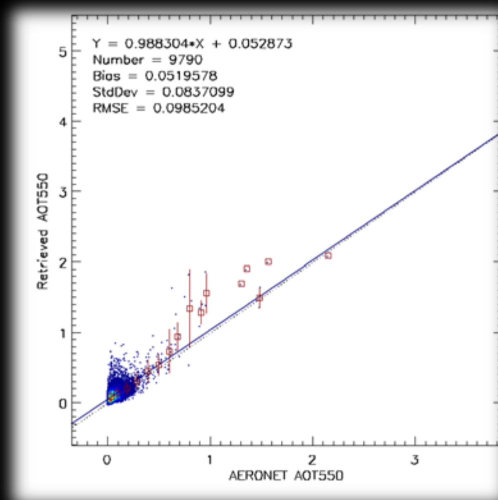
- But not so over other areas
  - Difficulty of picking right aerosol model at low AOD

BEFORE

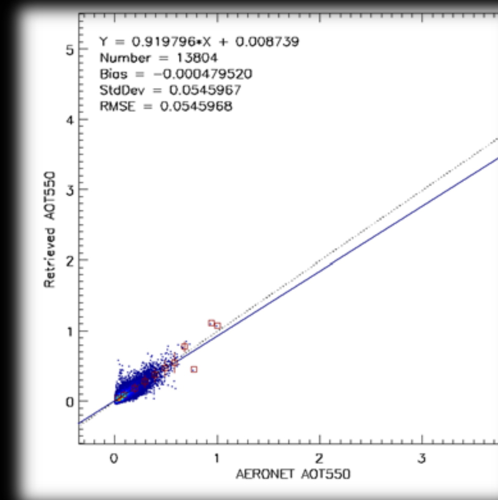
Eastern NA



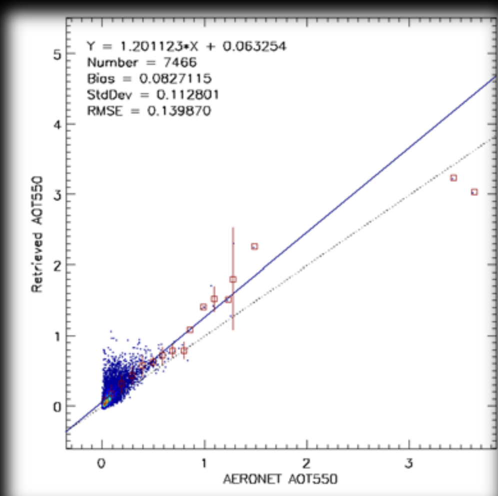
Western NA

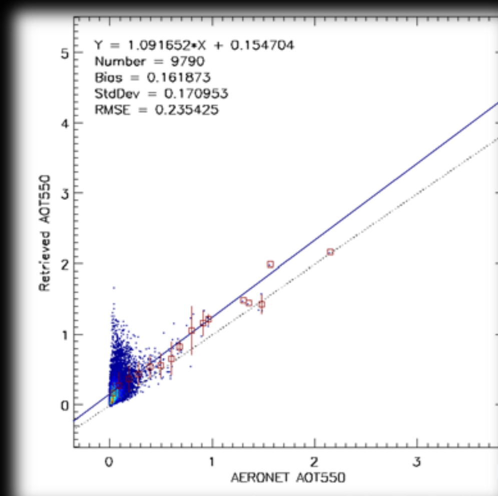


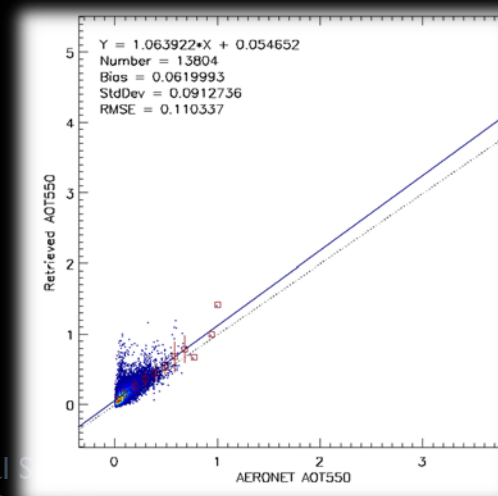
Europe



AFTER

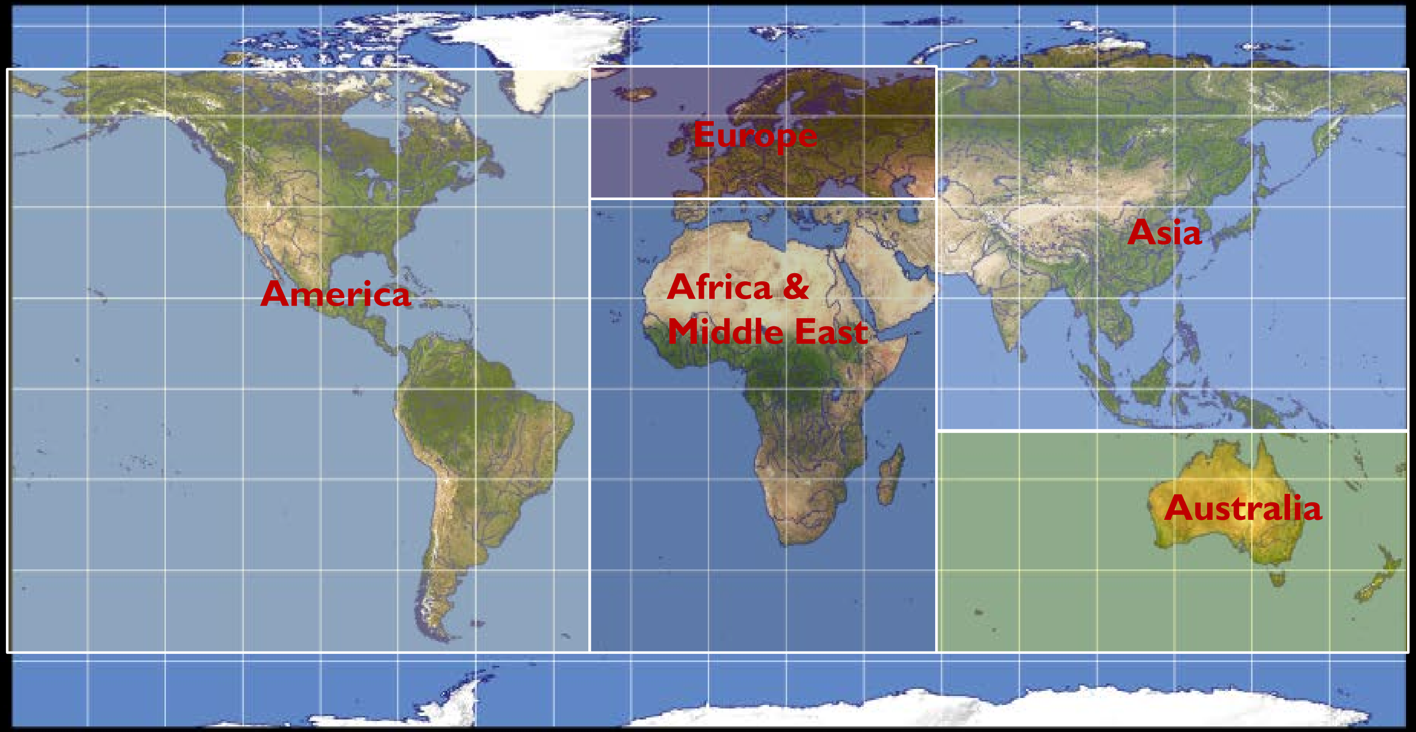






Retrieval (3)

- Candidate aerosol models are specified over land domains.



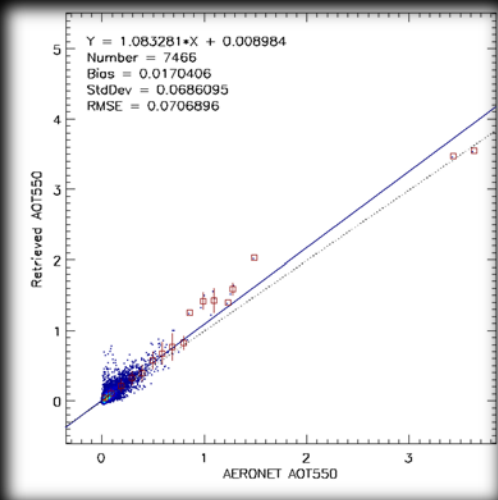
Domain	Longitude	Latitude	Aerosol Models
America	180° W - 30° W	60° S - 70° N	Fine (L,M), Dust (L), Smoke(L)
Europe	30° W - 60° E	40° N - 70° N	Fine (L,M), Dust (L), Smoke(L)
Africa & Middle	30° W - 60° E	60° S - 40° N	Fine(L), Dust(L,M,H), Smoke(L,H)
Asia	60° E - 180° E	10° S -70° N	Fine(L,M,H), Dust(M,H), Smoke(L)
Australia	60° E - 180° E	60° S - 10° S	Fine(L), Dust(L), Smoke(L)
High Latitude	180° W - 180° E	70° N - 90° N 90° S - 60° S	Fine(L)

Retrieval (4)

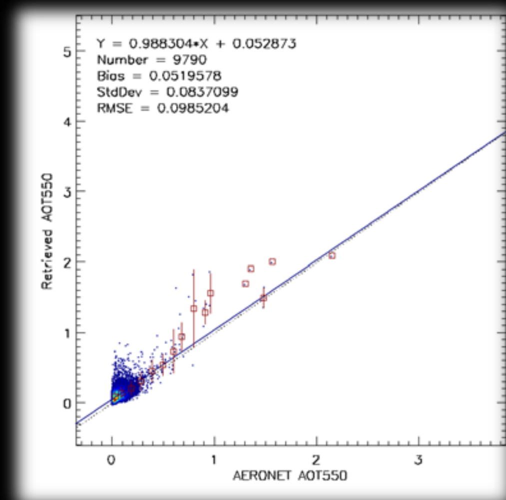
- With regional candidates of aerosol models, improvement is not significant at low AOD

BEFORE

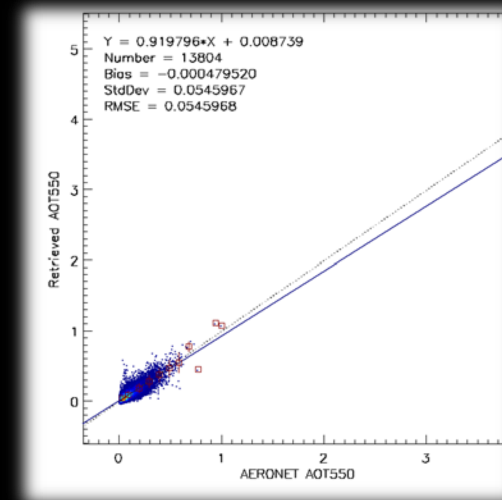
Eastern NA



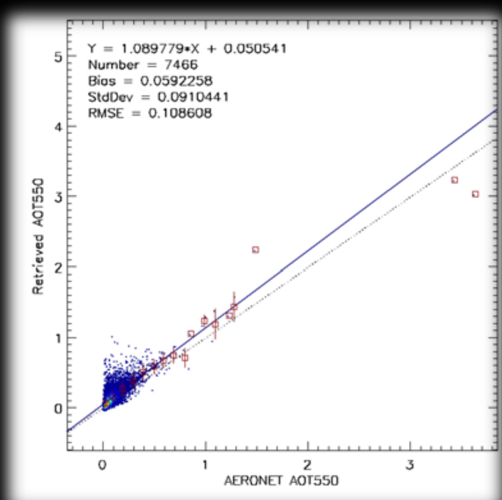
Western NA

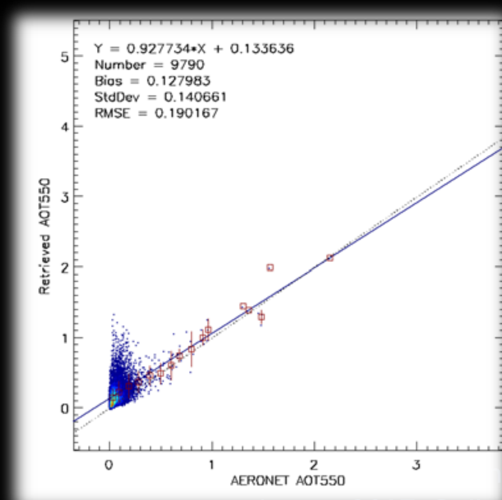


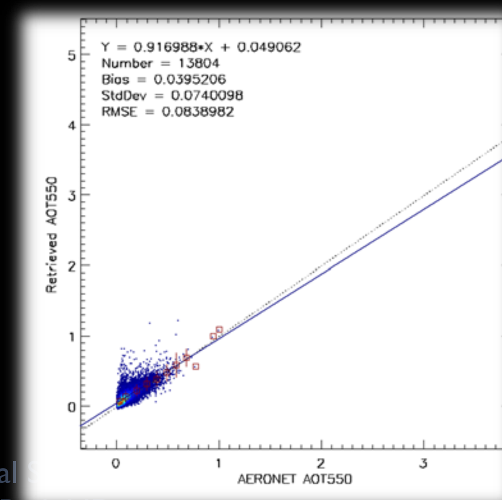
Europe



AFTER





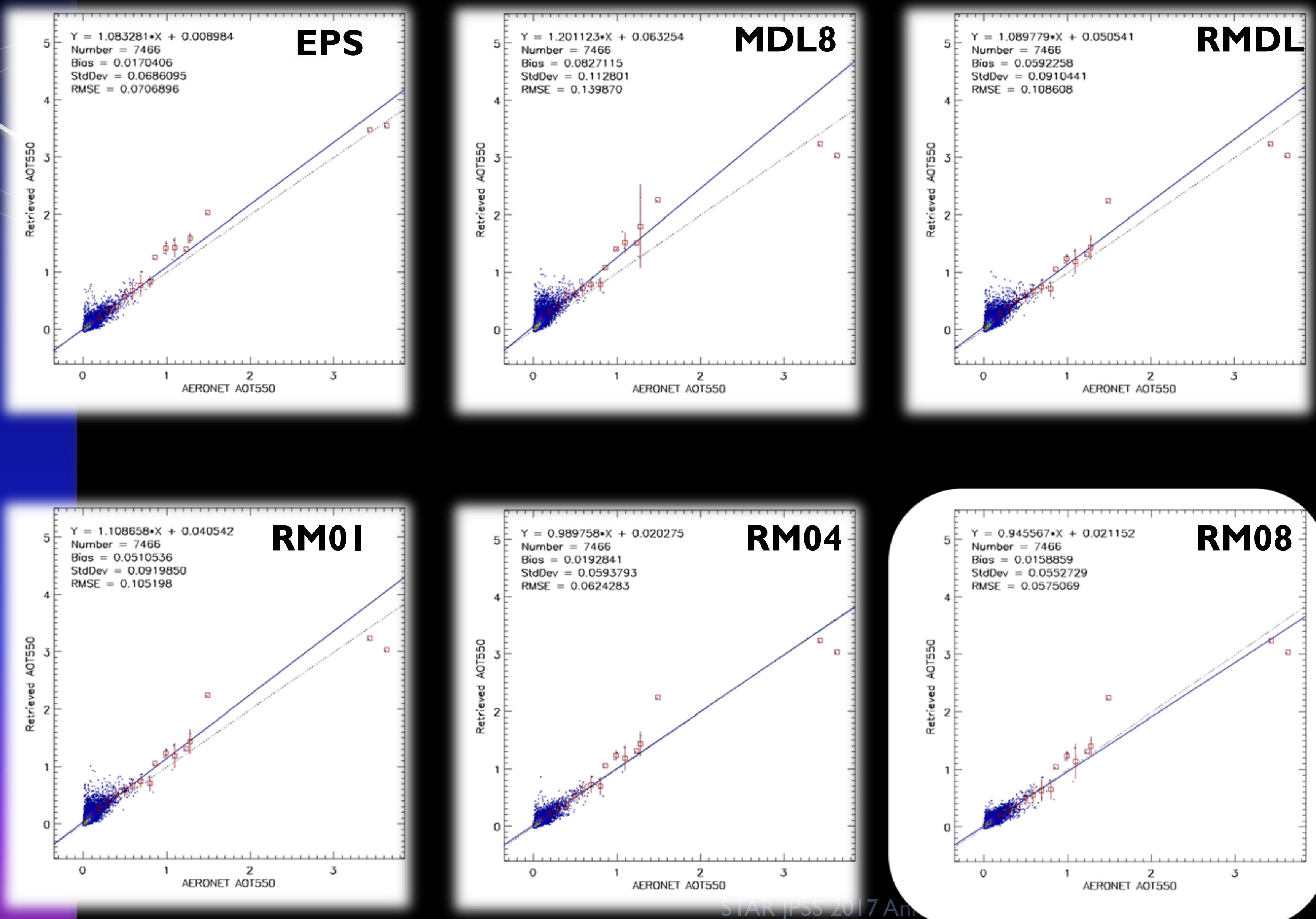


Retrieval (5)

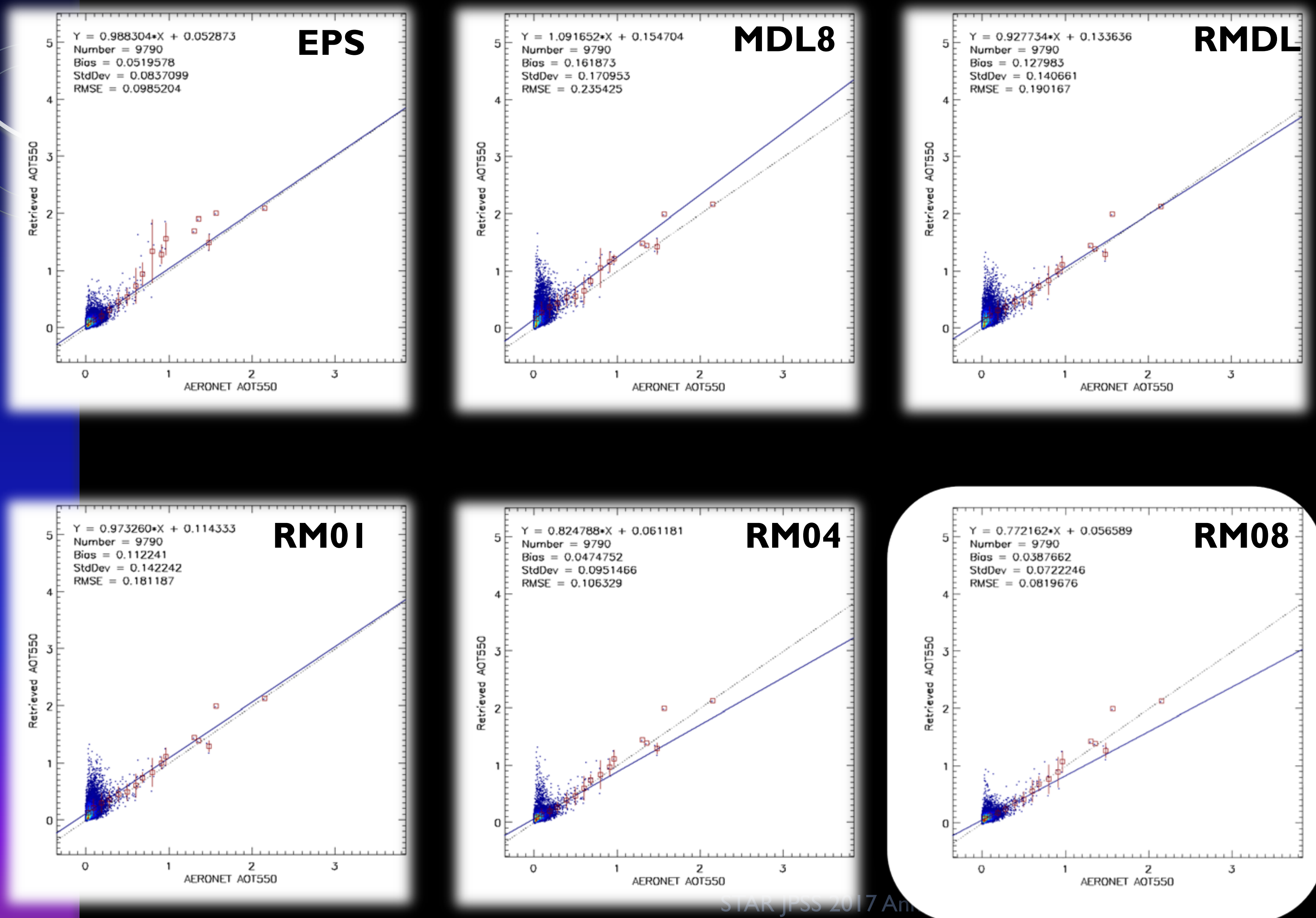
- Over-estimation at low AOD by using new aerosol models
  - Causes: picking absorbing or dust models incorrectly
  - Potential solution: using fine-mode dominated low-absorbing aerosol F(L) model if AOD is low
  - Tests: using F(L) model only if
    - Retrieved AOD < 0.1
    - Retrieved AOD < 0.4
    - Retrieved AOD < 0.8

    Selecting aerosol models only if F(L) AOD is larger than the threshold

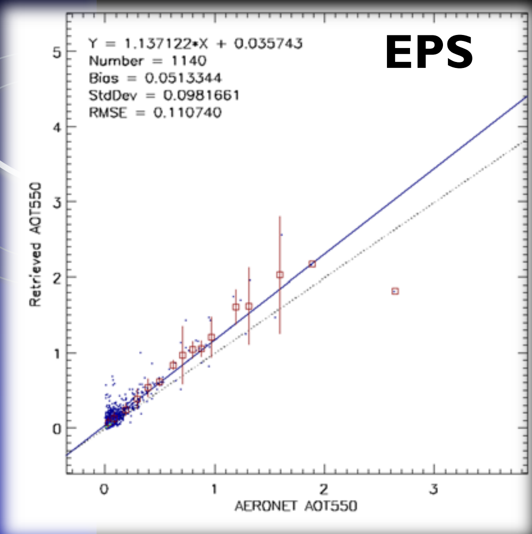
Eastern North America

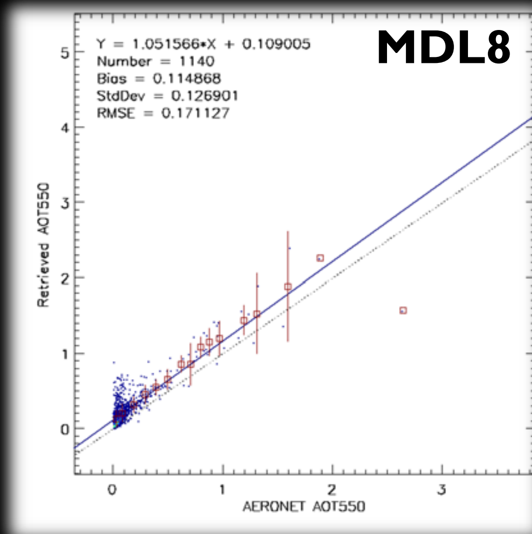


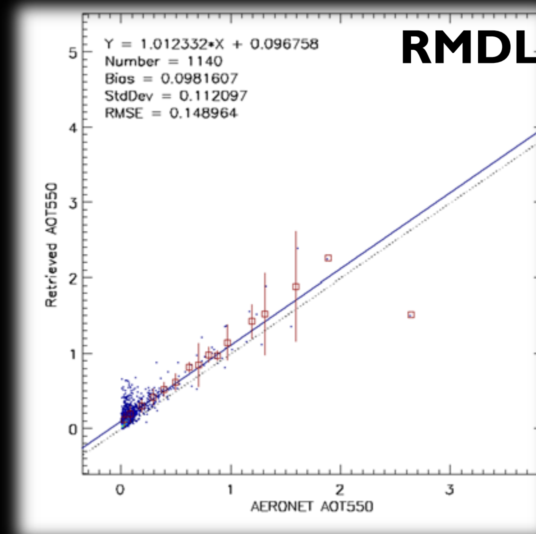
Western North America

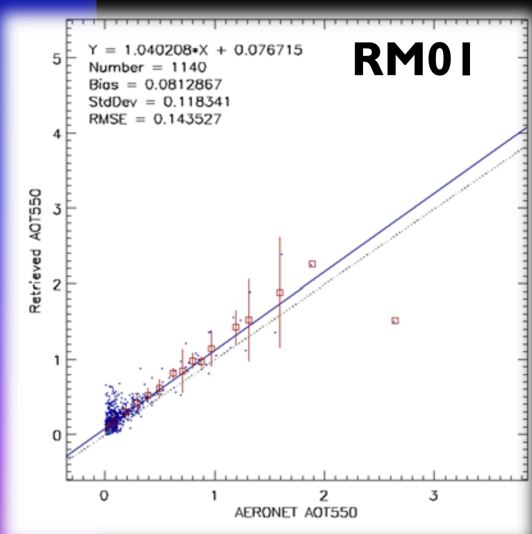


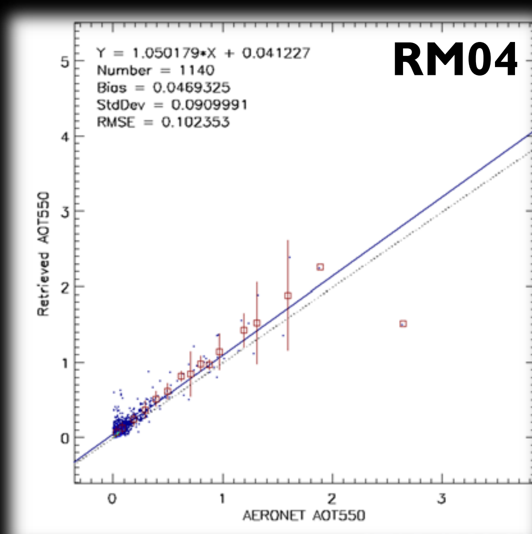
Northern North America

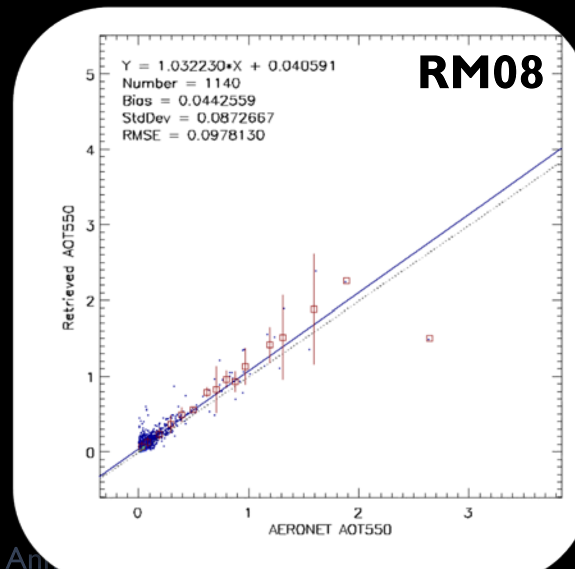




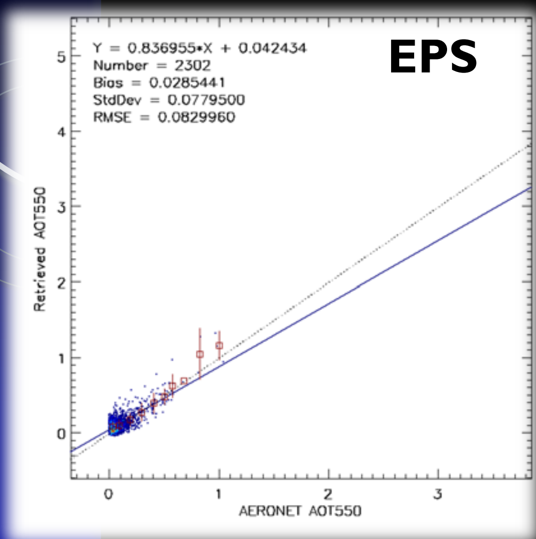


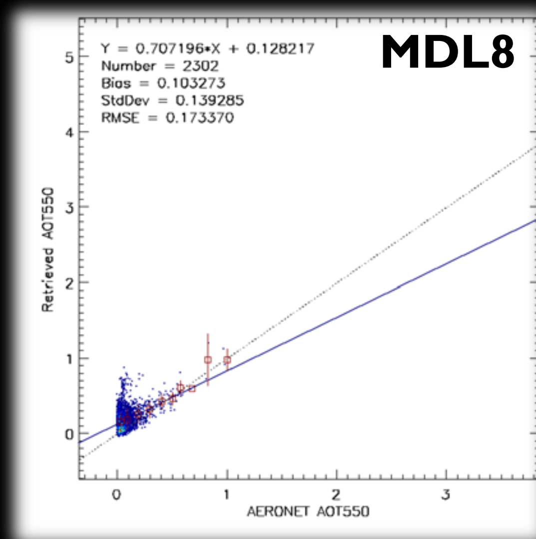


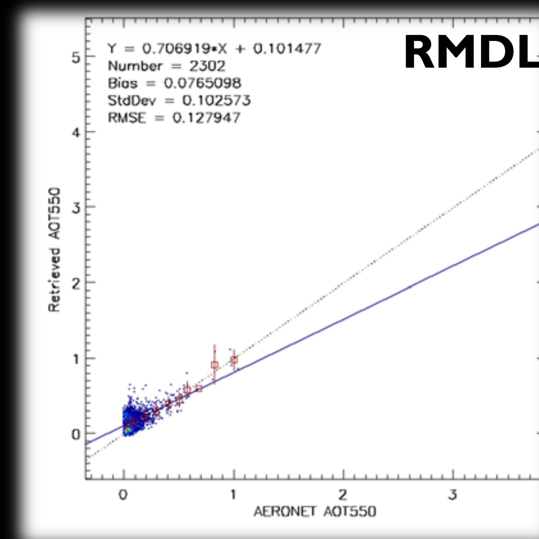


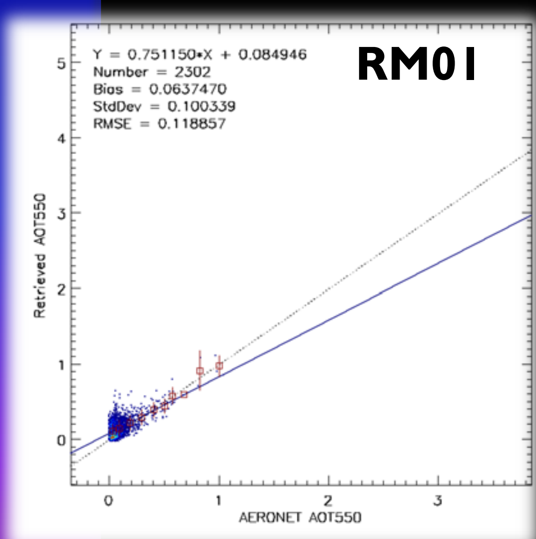


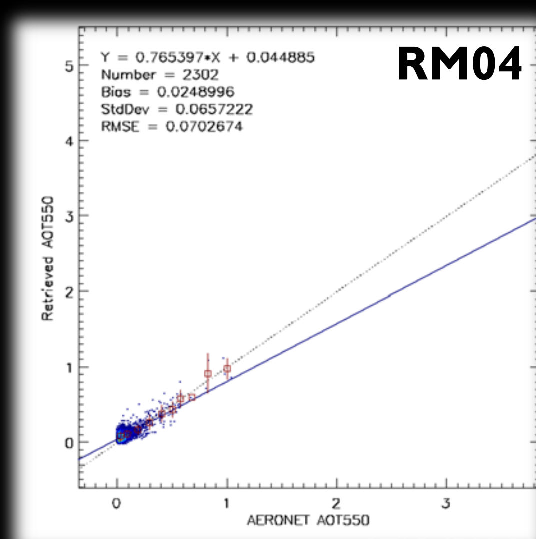
South America

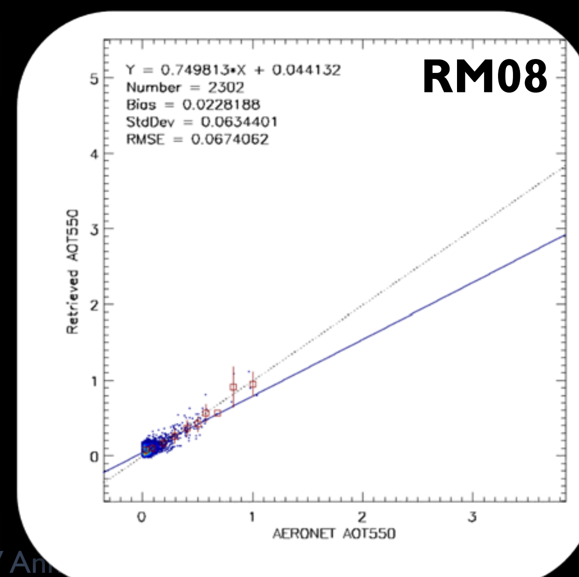




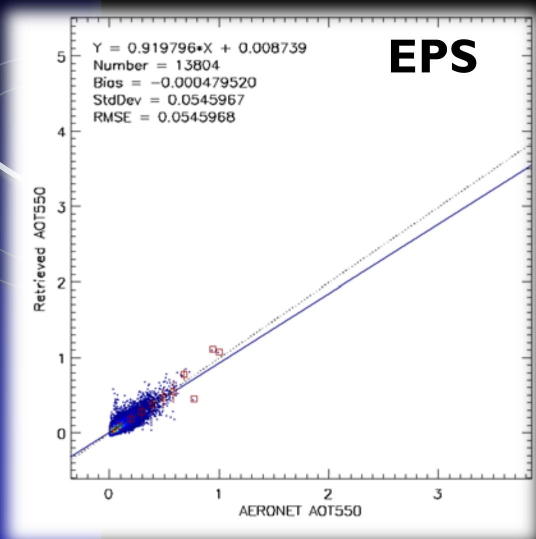


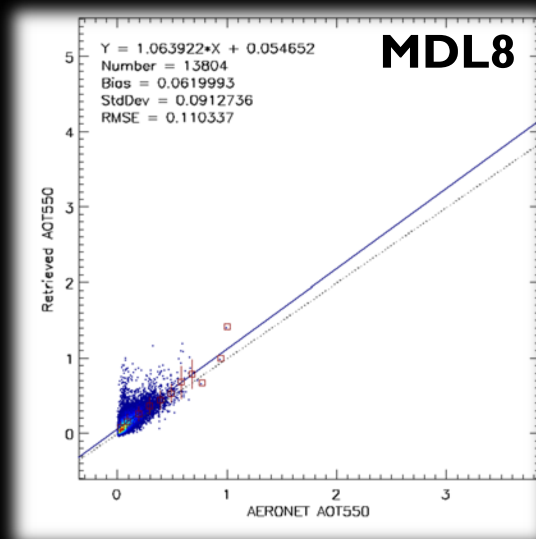






Europe


EPS
Y = 0.919796*X + 0.008739
Number = 13804
Bias = −0.000479520
StdDev = 0.0545967
RMSE = 0.0545968
Retrieved AOT550
AERONET AOT550


MDL8
Y = 1.063922*X + 0.054652
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StdDev = 0.0912736
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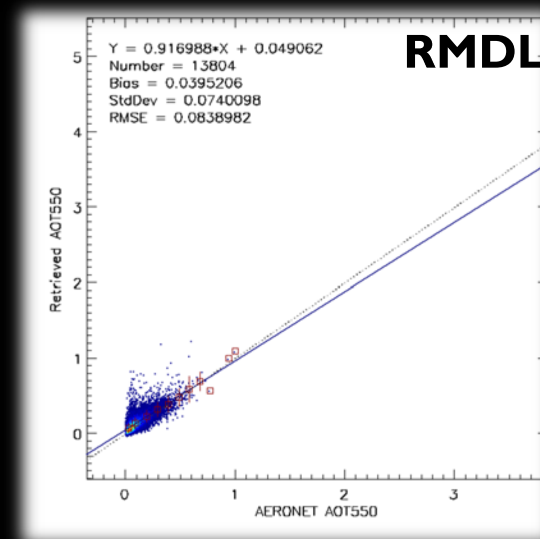
Retrieved AOT550
AERONET AOT550


RMDL
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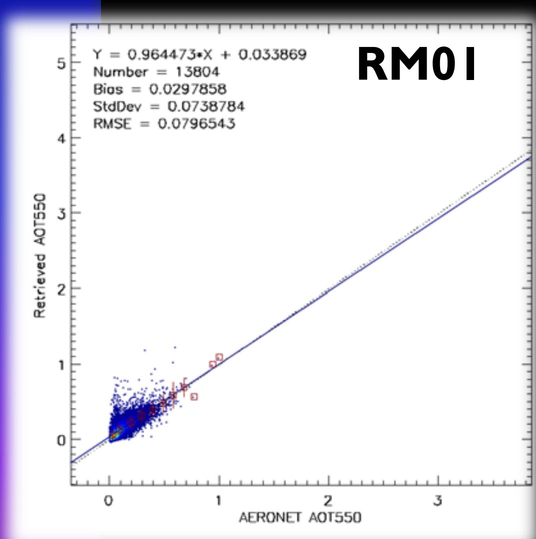
StdDev = 0.0740098
RMSE = 0.0838982
Retrieved AOT550
AERONET AOT550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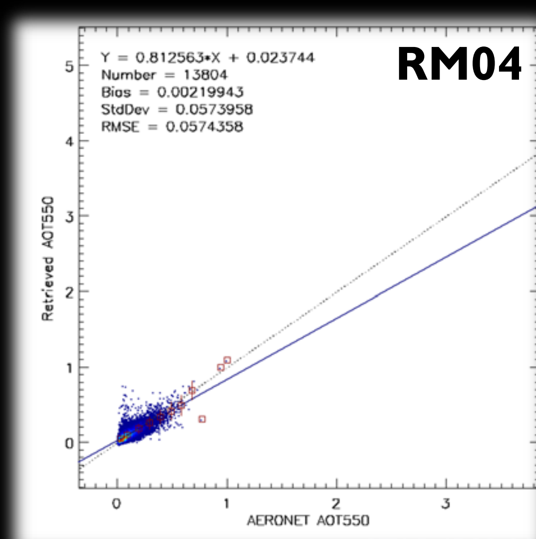
Retrieved AOT550
AERONET AOT550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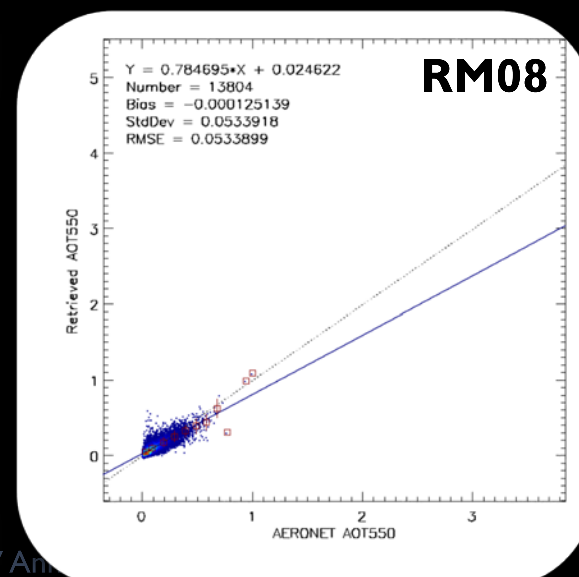
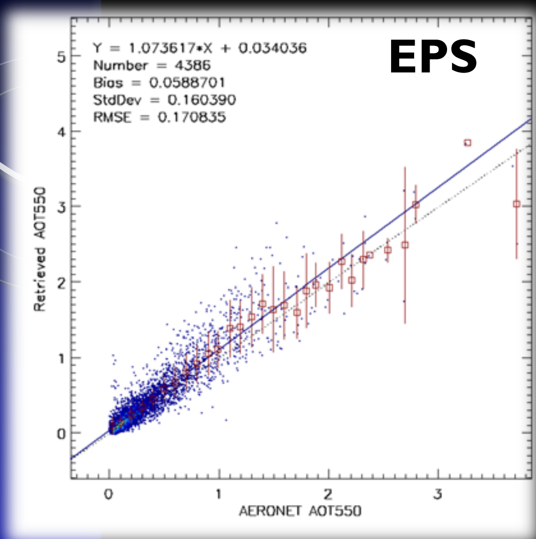
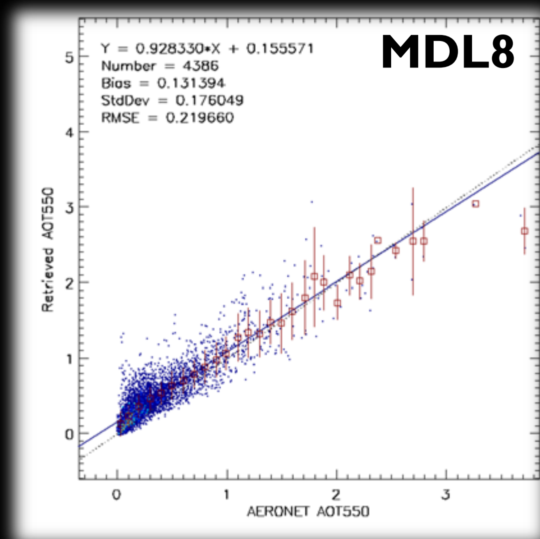
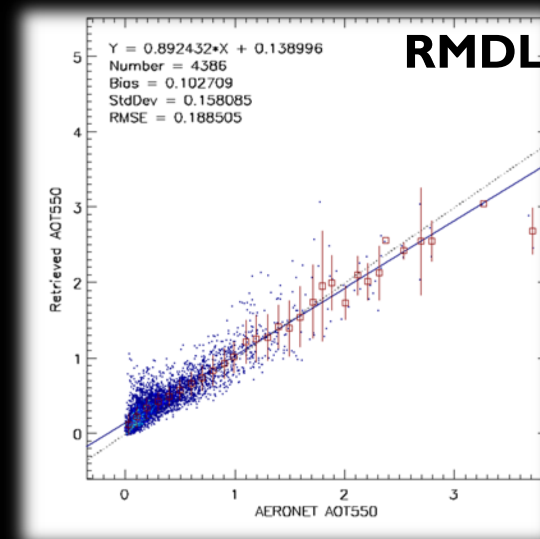
StdDev = 0.0573958
RMSE = 0.0574358
Retrieved AOT550
AERONET AOT550

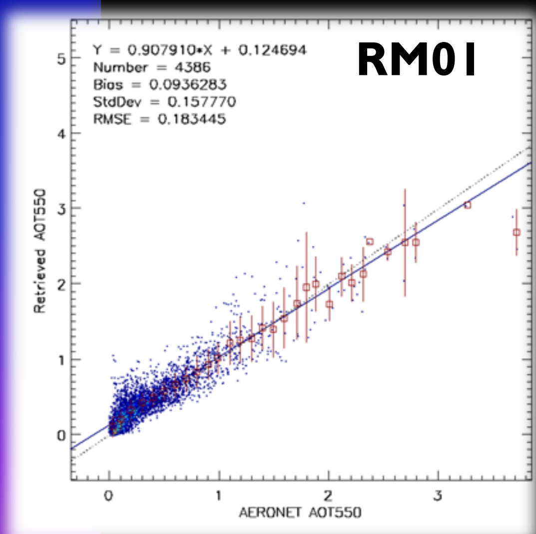

RM08
Y = 0.784695*X + 0.024622
Number = 13804
Bias = −0.000125139
StdDev = 0.0533918
RMSE = 0.0533899
Retrieved AOT550
AERONET AOT550

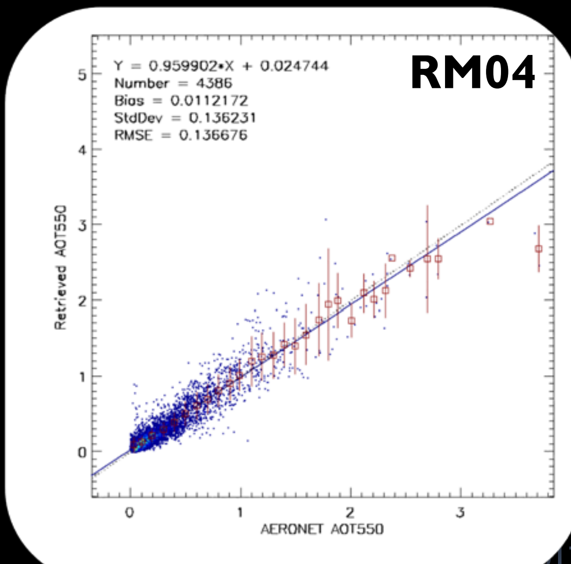
Eastern Asia

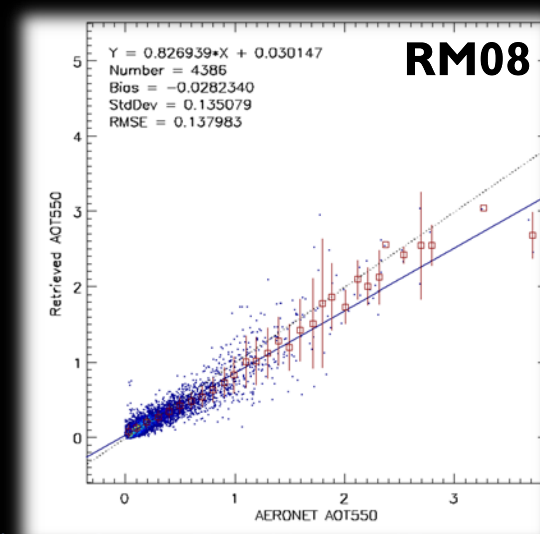




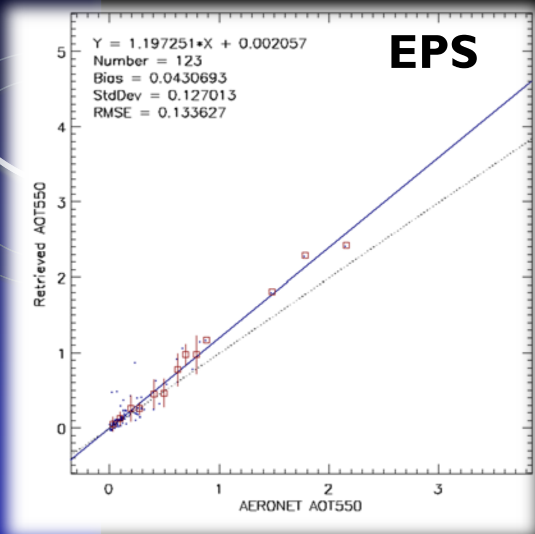


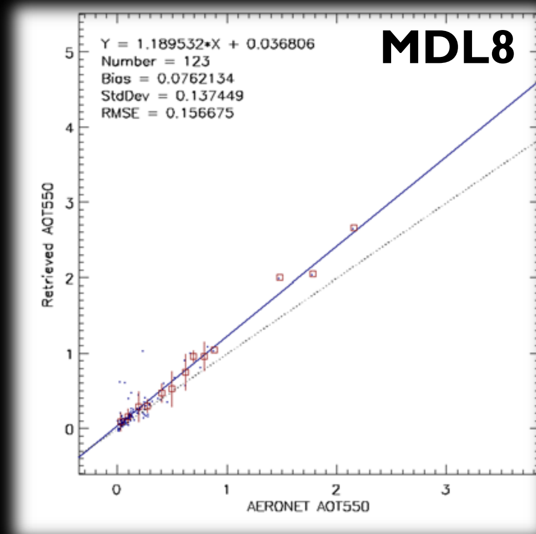


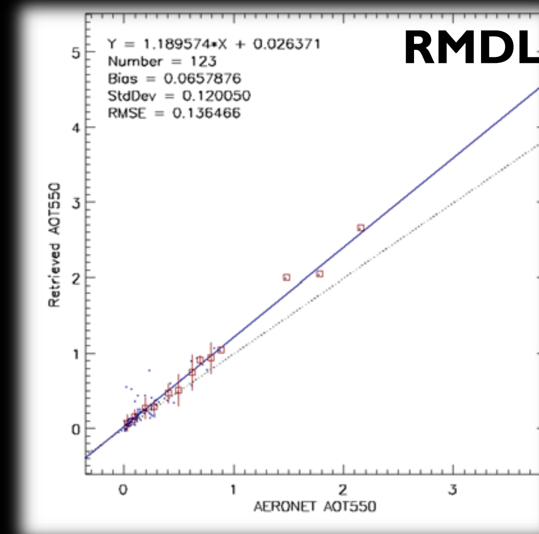


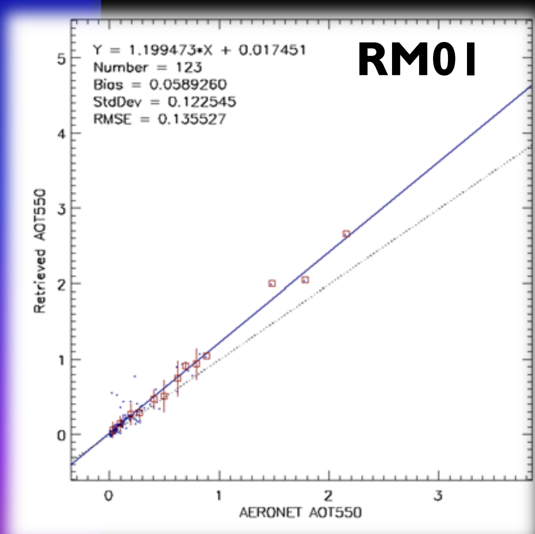


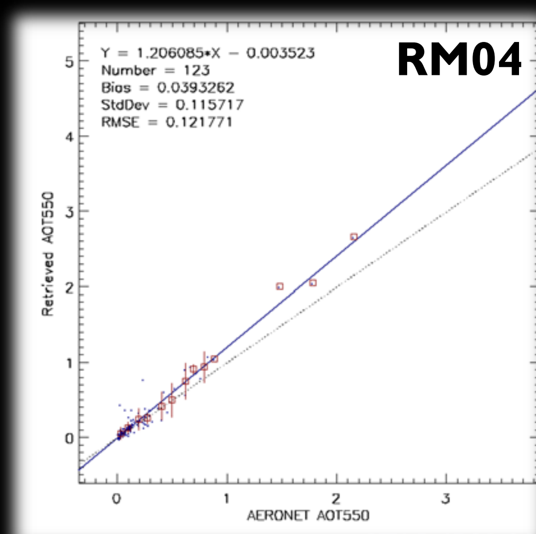
Northern Asia

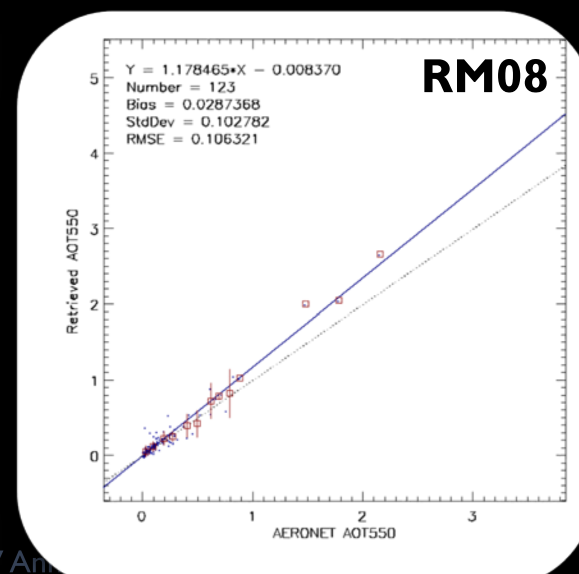




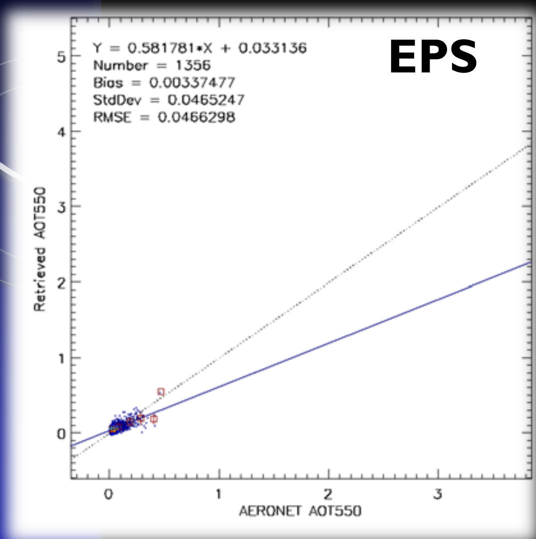








Australia


EPS
Y = 0.581781*X + 0.033136
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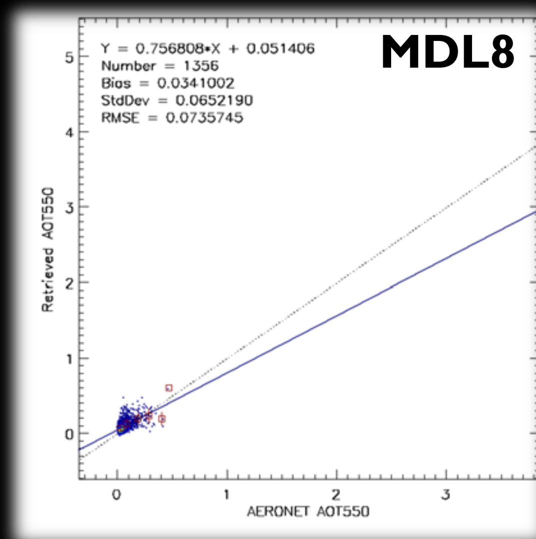
Bias = 0.00337477
StdDev = 0.0465247
RMSE = 0.0466298
Retrieved AOT550
AERONET AOT550


MDL8
Y = 0.756808*X + 0.051406
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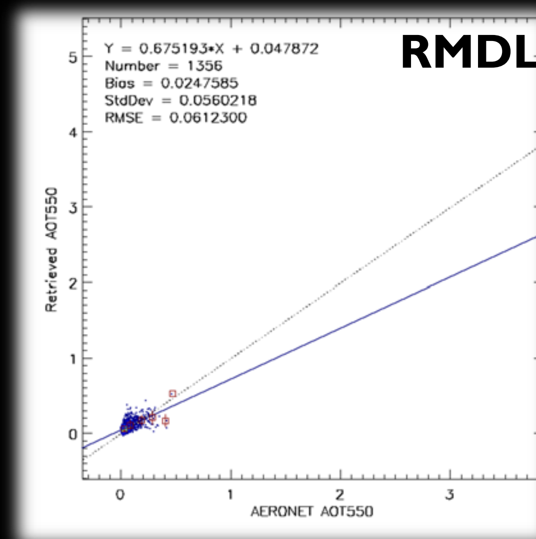
Bias = 0.0341002
StdDev = 0.0652190
RMSE = 0.0735745
Retrieved AOT550
AERONET AOT550


RMDL
Y = 0.675193*X + 0.047872
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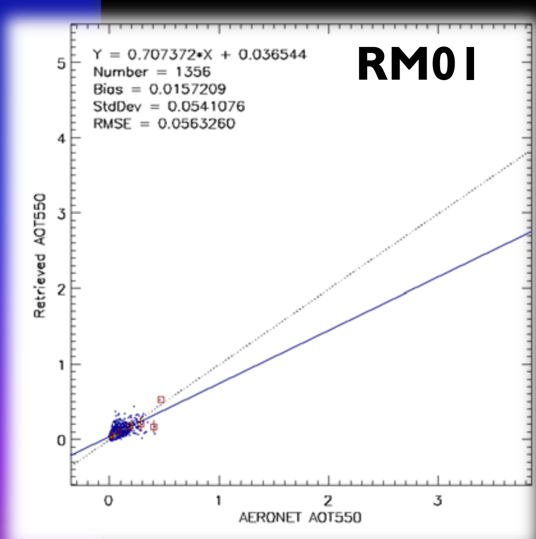
Bias = 0.0247585
StdDev = 0.0560218
RMSE = 0.0612300
Retrieved AOT550
AERONET AOT550


RM01
Y = 0.707372*X + 0.036544
Number = 1356
Bias = 0.0157209
StdDev = 0.0541076
RMSE = 0.0563260
Retrieved AOT550
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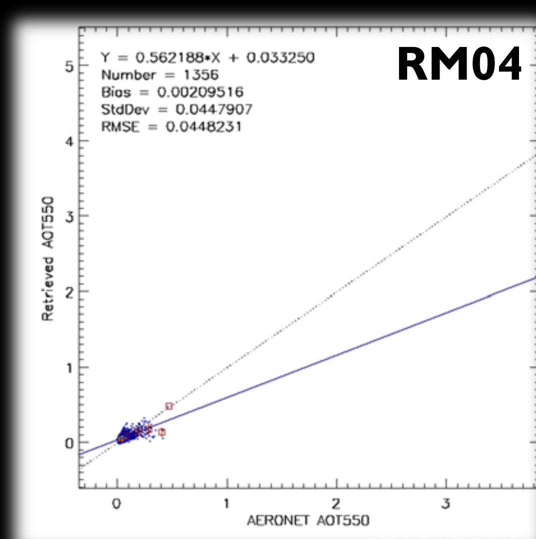
RM04
Y = 0.562188*X + 0.033250
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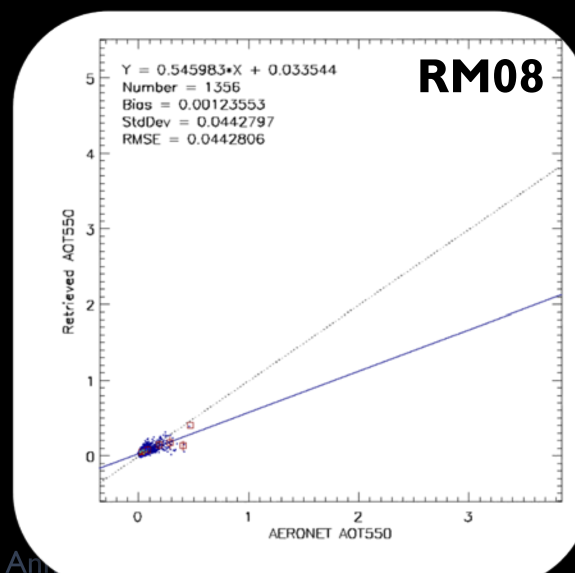
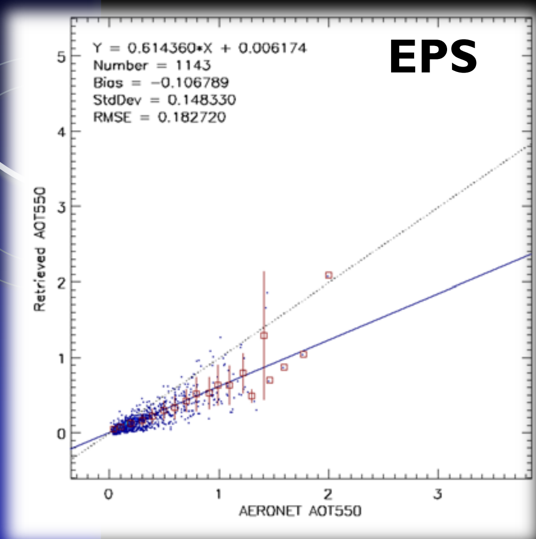
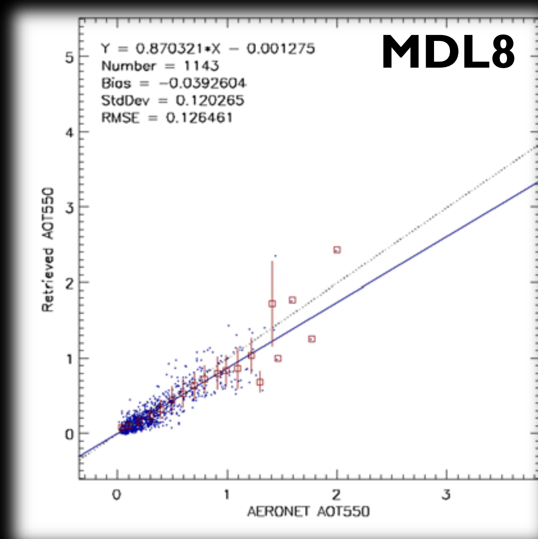
Bias = 0.00209516
StdDev = 0.0447907
RMSE = 0.0448231
Retrieved AOT550
AERONET AOT550


RM08
Y = 0.545983*X + 0.033544
Number = 1356
Bias = 0.00123553
StdDev = 0.0442797
RMSE = 0.0442806
Retrieved AOT550
AERONET AOT550

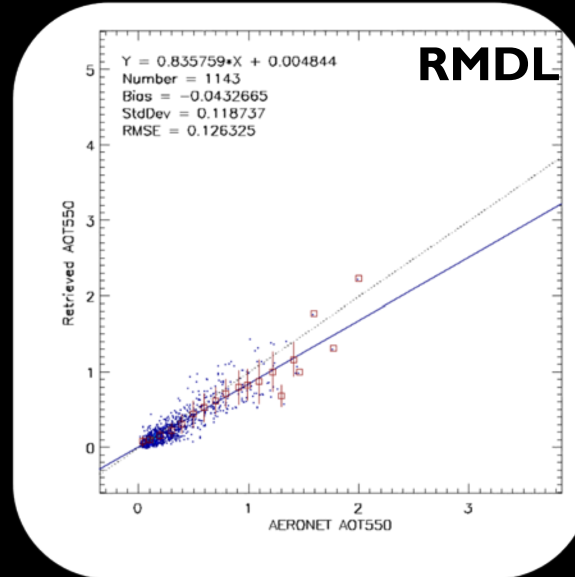
Africa



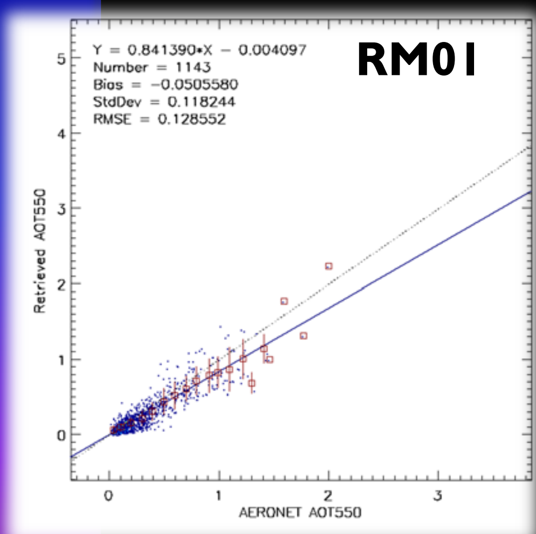
EPS
Y = 0.614360*X + 0.006174
Number = 1143
Bias = −0.106789
StdDev = 0.148330
RMSE = 0.182720
Retrieved AOT550
AERONET AOT550



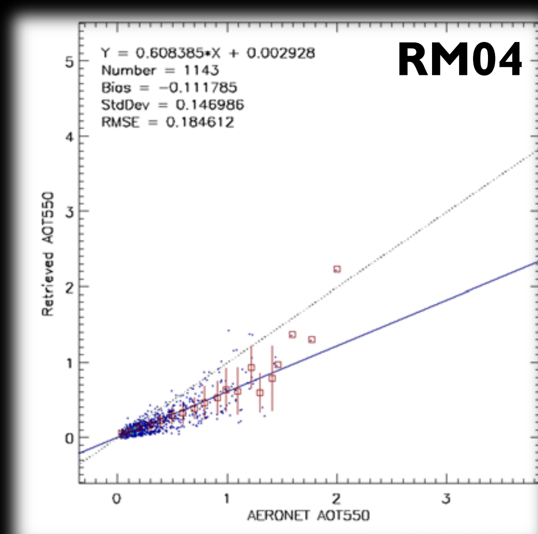
MDL8
Y = 0.870321*X − 0.001275
Number = 1143
Bias = −0.0392604
StdDev = 0.120265
RMSE = 0.126461
Retrieved AOT550
AERONET AOT550



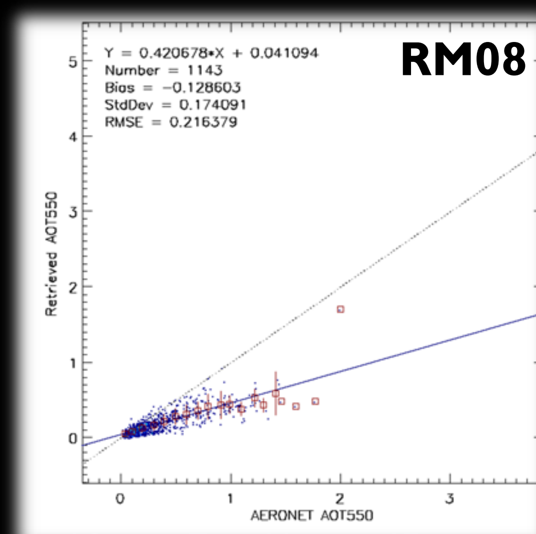
RMDL
Y = 0.835759*X + 0.004844
Number = 1143
Bias = −0.0432665
StdDev = 0.118737
RMSE = 0.126325
Retrieved AOT550
AERONET AOT550



RM01
Y = 0.841390*X − 0.004097
Number = 1143
Bias = −0.0505580
StdDev = 0.118244
RMSE = 0.128552
Retrieved AOT550
AERONET AOT550

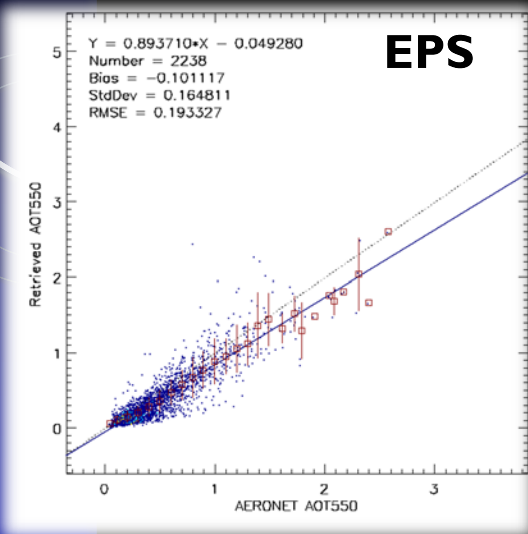


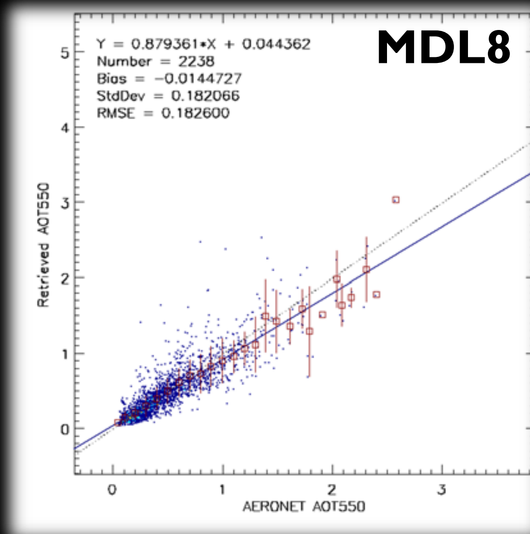
RM04
Y = 0.608385*X + 0.002928
Number = 1143
Bias = −0.111785
StdDev = 0.146986
RMSE = 0.184612
Retrieved AOT550
AERONET AOT550

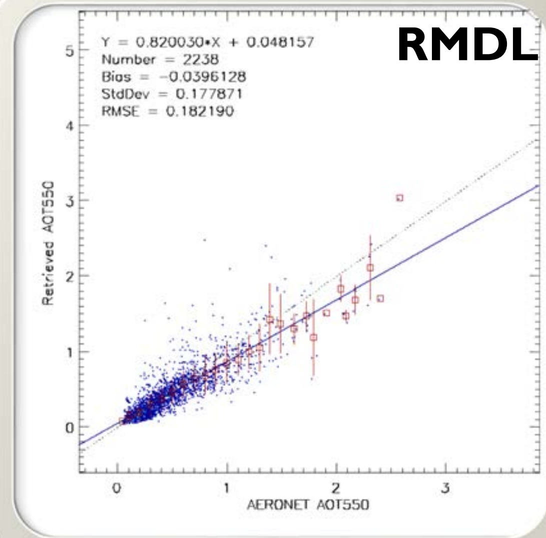


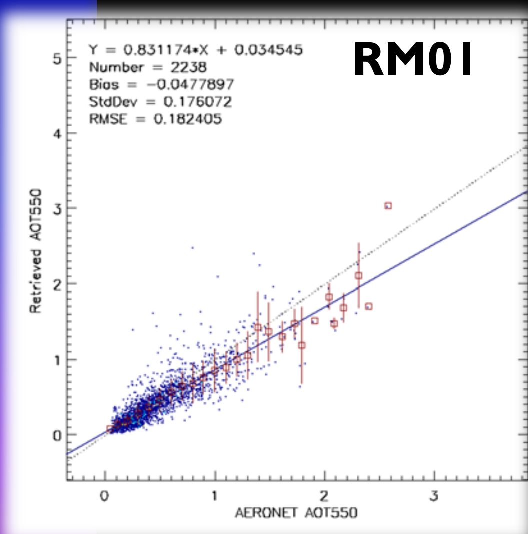
RM08
Y = 0.420678*X + 0.041094
Number = 1143
Bias = −0.128603
StdDev = 0.174091
RMSE = 0.216379
Retrieved AOT550
AERONET AOT550

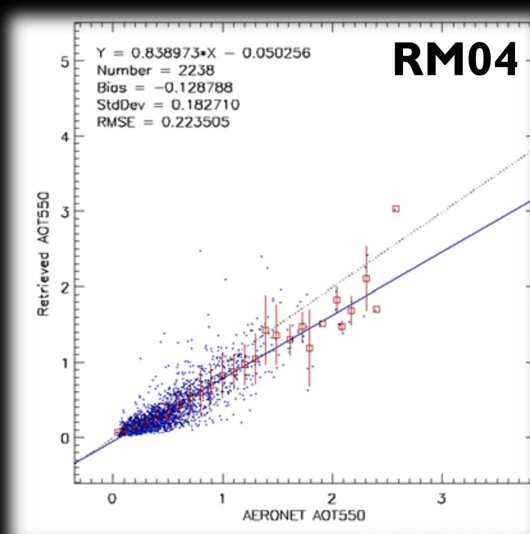
India

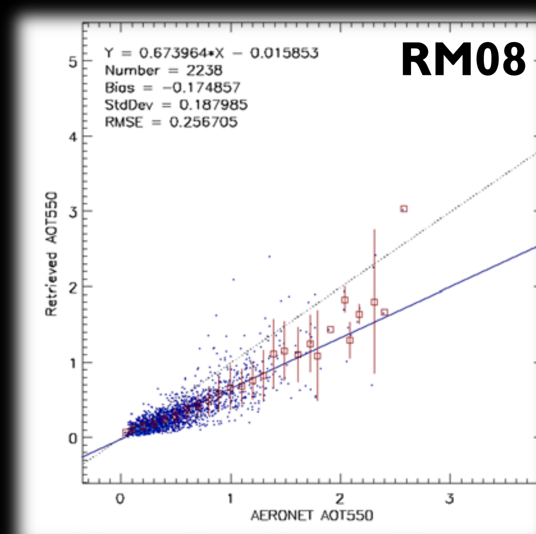

EPS
Y = 0.893710*X − 0.049280
Number = 2238
Bias = −0.101117
StdDev = 0.164811
RMSE = 0.193327
Retrieved AOT550
AERONET AOT550


MDL8
Y = 0.879361*X + 0.044362
Number = 2238
Bias = −0.0144727
StdDev = 0.182066
RMSE = 0.182600
Retrieved AOT550
AERONET AOT550

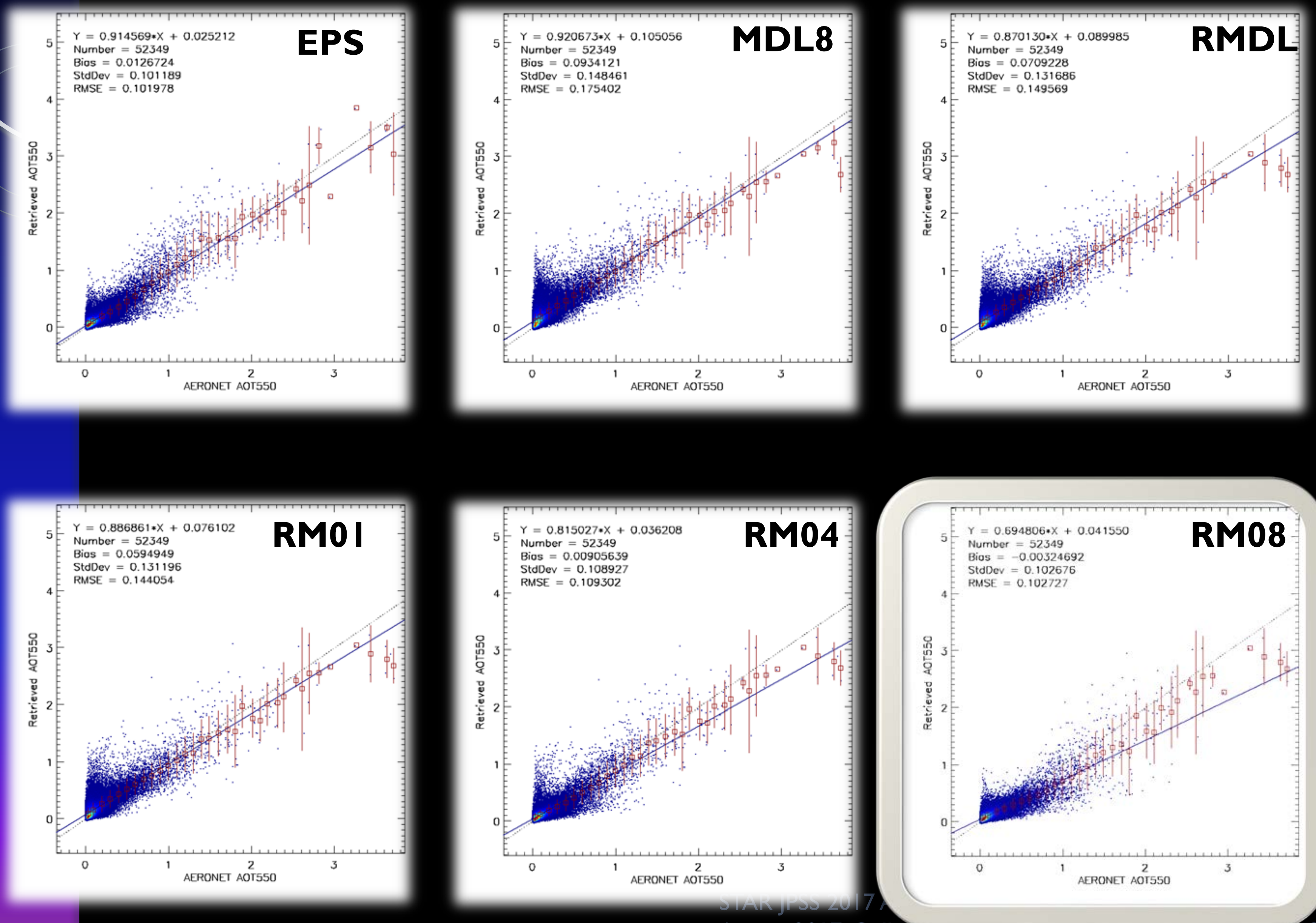

RMDL
Y = 0.820030*X + 0.048157
Number = 2238
Bias = −0.0396128
StdDev = 0.177871
RMSE = 0.182190
Retrieved AOT550
AERONET AOT550


RM01
Y = 0.831174*X + 0.034545
Number = 2238
Bias = −0.0477897
StdDev = 0.176072
RMSE = 0.182405
Retrieved AOT550
AERONET AOT550


RM04
Y = 0.838973*X − 0.050256
Number = 2238
Bias = −0.128788
StdDev = 0.182710
RMSE = 0.223505
Retrieved AOT550
AERONET AOT550

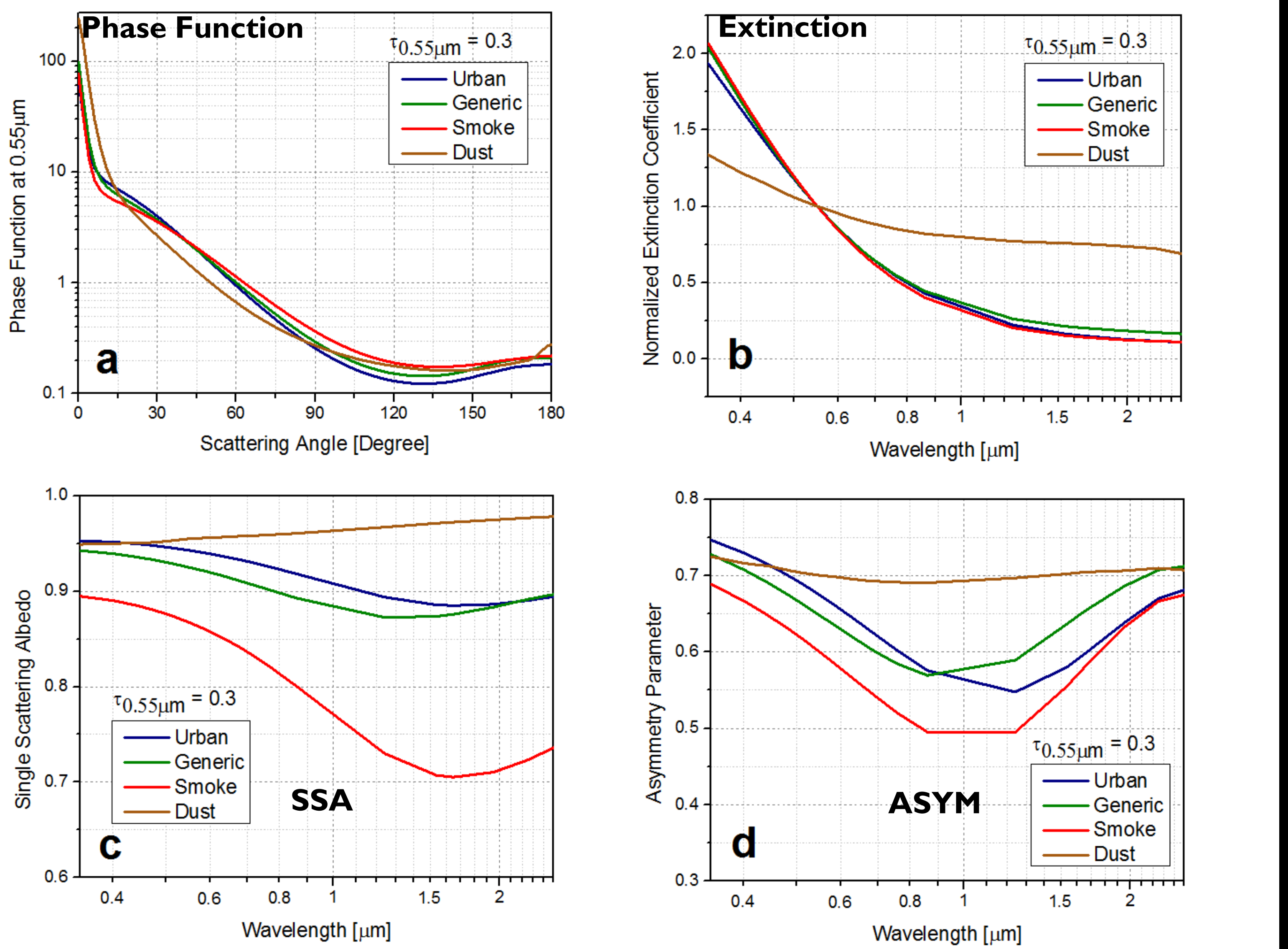

RM08
Y = 0.673964*X − 0.015853
Number = 2238
Bias = −0.174857
StdDev = 0.187985
RMSE = 0.256705
Retrieved AOT550
AERONET AOT550

Global

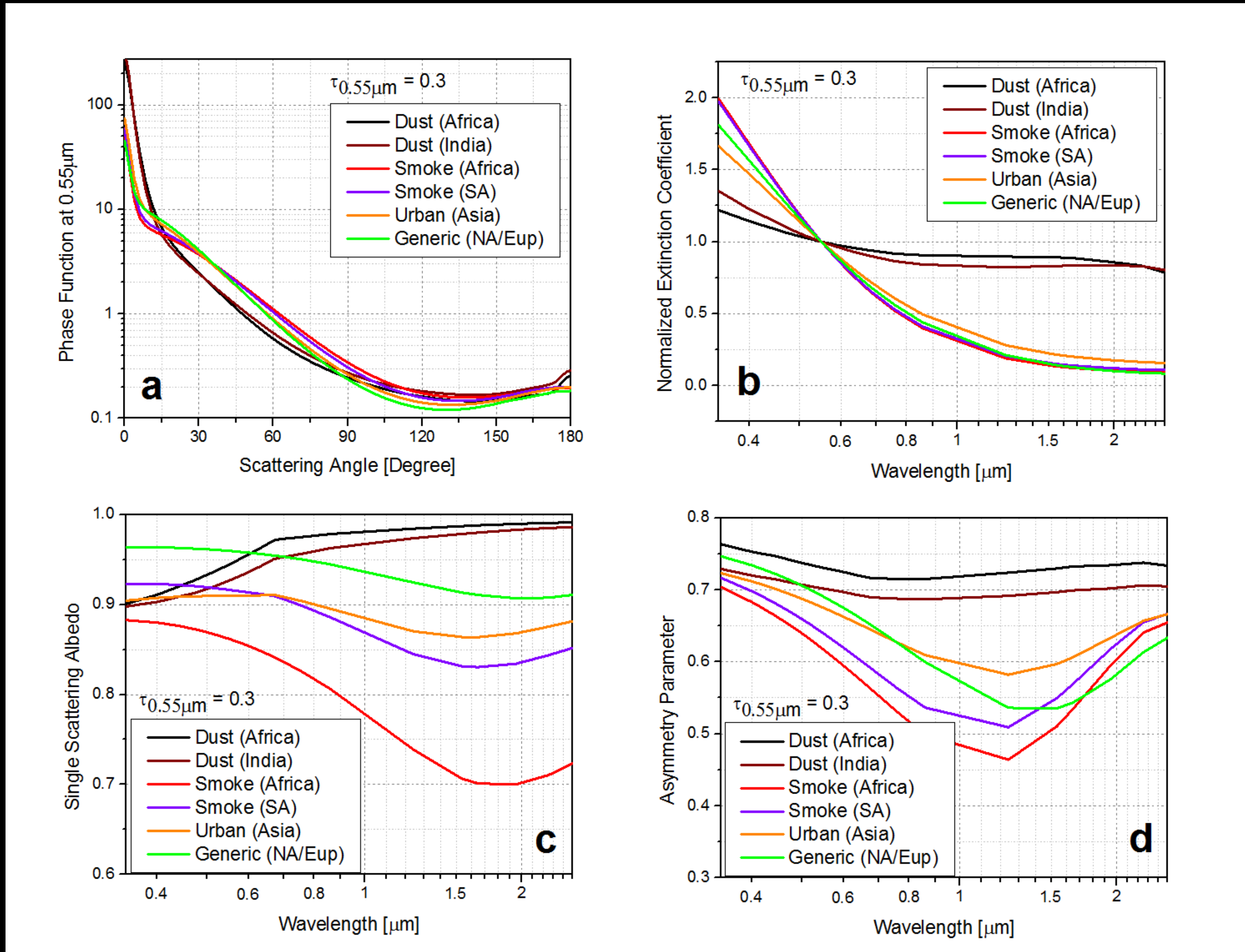

EPS
Y = 0.914569*X + 0.025212
Number = 52349
Bias = 0.0126724
StdDev = 0.101189
RMSE = 0.101978
MDL8
Y = 0.920673*X + 0.105056
Number = 52349
Bias = 0.0934121
StdDev = 0.148461
RMSE = 0.175402
RMDL
Y = 0.870130*X + 0.089985
Number = 52349
Bias = 0.0709228
StdDev = 0.131686
RMSE = 0.149569
RM01
Y = 0.886861*X + 0.076102
Number = 52349
Bias = 0.0594949
StdDev = 0.131196
RMSE = 0.144054
RM04
Y = 0.815027*X + 0.036208
Number = 52349
Bias = 0.00905639
StdDev = 0.108927
RMSE = 0.109302
RM08
Y = 0.694806*X + 0.041550
Number = 52349
Bias = -0.00324692
StdDev = 0.102676
RMSE = 0.102727
Retrieved AOT550
AERONET AOT550

Summary

- New land aerosol models are derived from AERONET inversions
  - Dust: low/medium/high absorbing
  - Smoke: low/high absorbing
  - Fine-mode Dominated: low/medium/high absorbing
- Potential updates on the EPS AOD algorithm is investigated
  - Dynamic selection among all/subset of aerosol models at all/high AOD cases
  - Algorithm has the difficulty to pick the right aerosol model at low AOD cases



Phase Function
$\tau_{0.55\mu m}$ = 0.3
Urban
Generic
Smoke
Dust
a
Phase Function at 0.55µm
Scattering Angle [Degree]
Extinction
$\tau_{0.55\mu m}$ = 0.3
Urban
Generic
Smoke
Dust
b
Normalized Extinction Coefficient
Wavelength [µm]
$\tau_{0.55\mu m}$ = 0.3
Urban
Generic
Smoke
Dust
SSA
c
Single Scattering Albedo
Wavelength [µm]
$\tau_{0.55\mu m}$ = 0.3
Urban
Generic
Smoke
Dust
ASYM
d
Asymmetry Parameter
Wavelength [µm]



$\tau_{0.55\mu m}$ = 0.3
Dust (Africa)
Dust (India)
Smoke (Africa)
Smoke (SA)
Urban (Asia)
Generic (NA/Eup)
a
Phase Function at 0.55µm
Scattering Angle [Degree]
b
Normalized Extinction Coefficient
Wavelength [µm]
c
Single Scattering Albedo
Wavelength [µm]
d
Asymmetry Parameter
Wavelength [µm]

Entangling Snow/Snowmelt Screening and Smog AOT Retrievals in the VIIRS Aerosol Algorithm

Jingfeng Huang

UMD/ESSIC/CICS @ NOAA/NESDIS/STAR

Shobha Kondragunta, Istvan Laszlo, Hongqing Liu, Hai Zhang, Pubu Ciren, Lorraine A. Remer

Outline

- Part 1: Towards a Better Snow/Snowmelt Screening in the IDPS VIIRS Aerosol Algorithm
- Part 2: The missing China Smog AOT Retrievals in the IDPS VIIRS AOT Product
- Part 3: Balance Snow/Snowmelt Screening and China Smog Detection in the EPS Aerosol Algorithm
- Summary

The Two VIIRS Aerosol Algorithms

1. The Two S-NPP VIIRS AOT Algorithms
   - IDPS: Interface Data Processing Segment (Current Operational VIIRS Aerosol Algorithm)
   - EPS: Enterprise Processing System (Currently under testing and will replace IDPS in operation soon)
2. Improvements in EPS:
   1. Pixel screening procedures – *eliminate artifacts*
   2. New algorithm science – *provides enhanced spatial coverage*
3. EPS: Characterization of China Smog Events

IDPS vs. EPS: Main Differences

- **Detection, observation and quantification of global aerosol outbreaks is one of many important applications of the global satellite aerosol products**

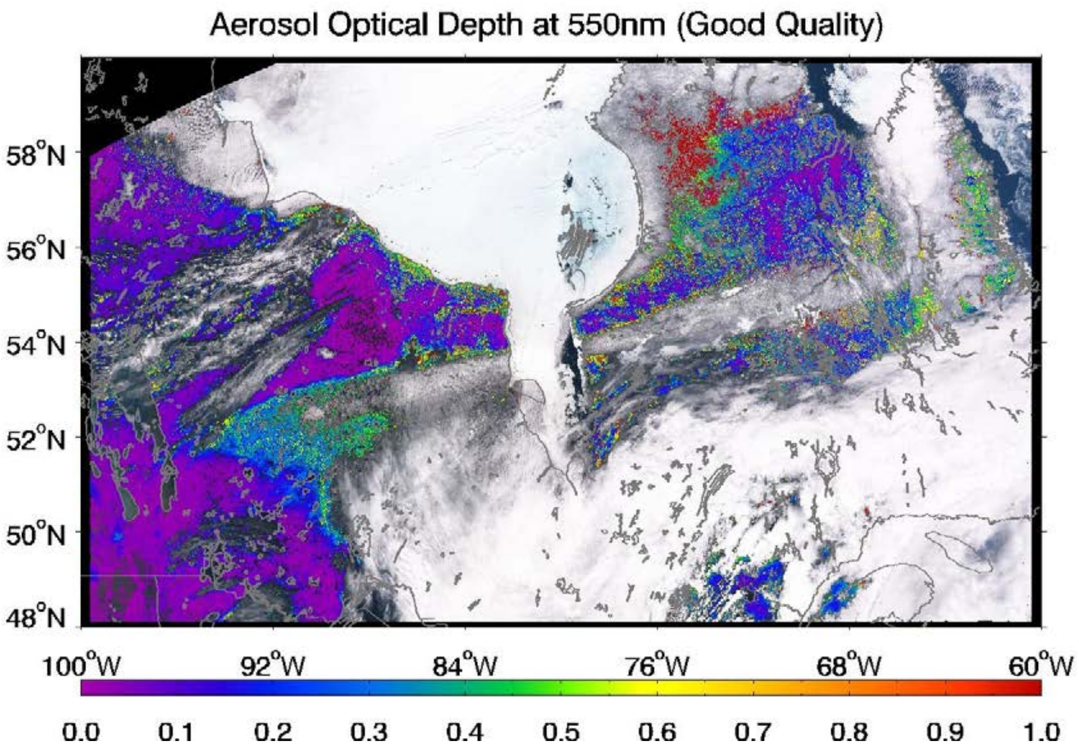
	IDPS Aerosol Algorithm (Current Operational)	EPS Aerosol Algorithm (Upcoming Operational)
AOT range	[0, 2.0]	[-0.05, 5.0]
Retrieval surfaces over land	Dark surface only	Both dark and bright surfaces
Cloud overscreening	Heavy aerosol mis-identified as clouds in some pixels	internal heavy aerosol callback test
Internal snow test over land	Smog mis-identified as snow in some pixels	Improved snow test
Internal Ephemeral Water Test	Aerosol mis-identified as ephemeral water in some pixels	Improved ephemeral water test

PART 1:

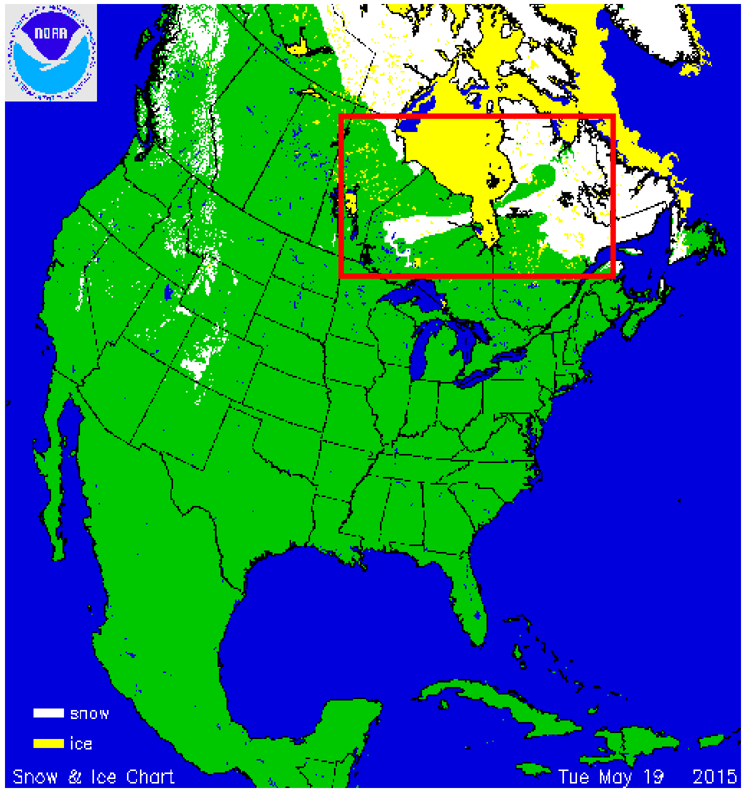
TOWARDS A BETTER SNOW/SNOWMELT SCREENING IN THE IDPS VIIRS AEROSOL ALGORITHM

Problem: Snow/Snowmelt Underscreening (regional)

May 19, 2015

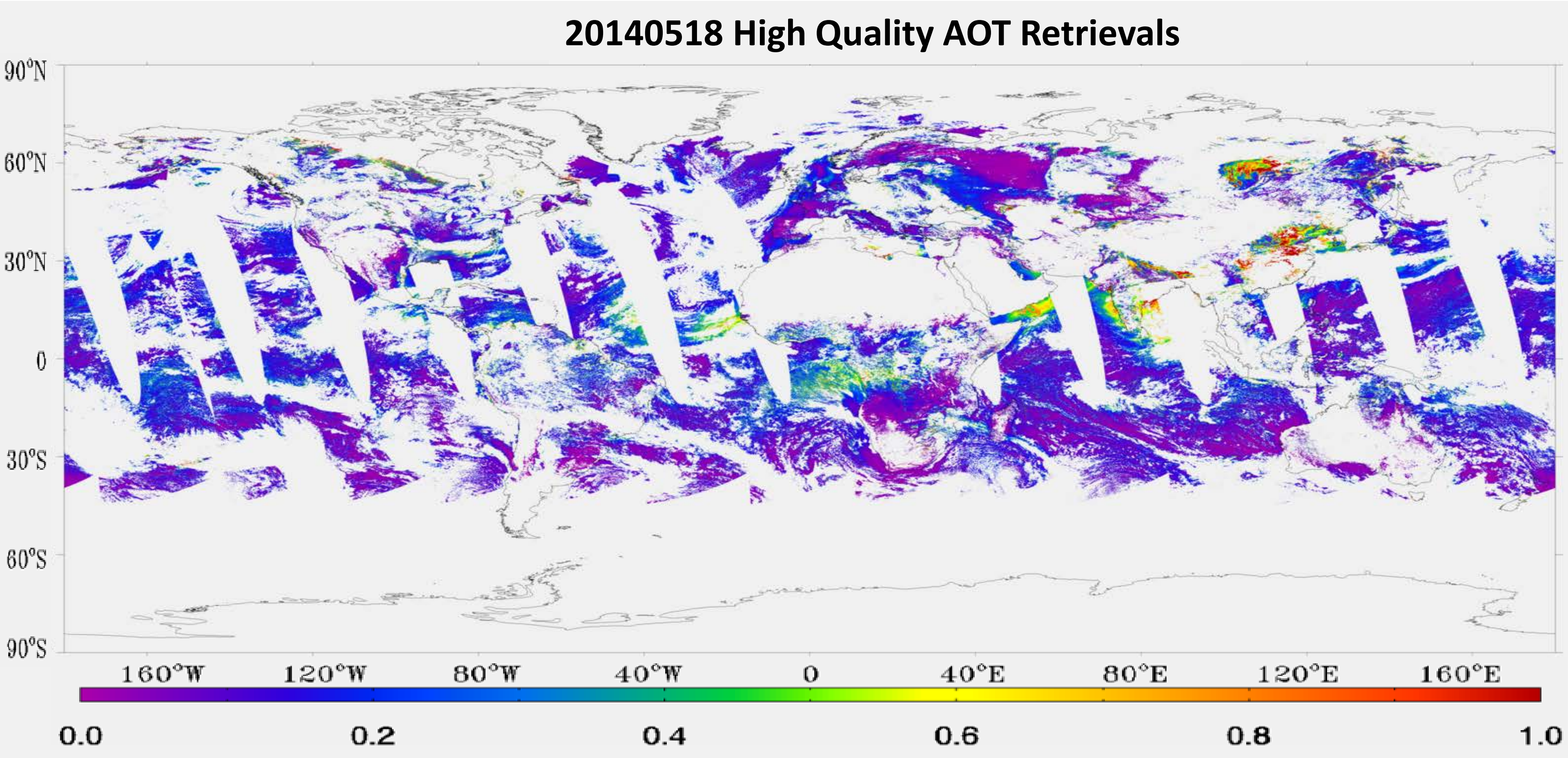


IDPS VIIRS 'Good' quality AOT retrievals on May 19, 2015

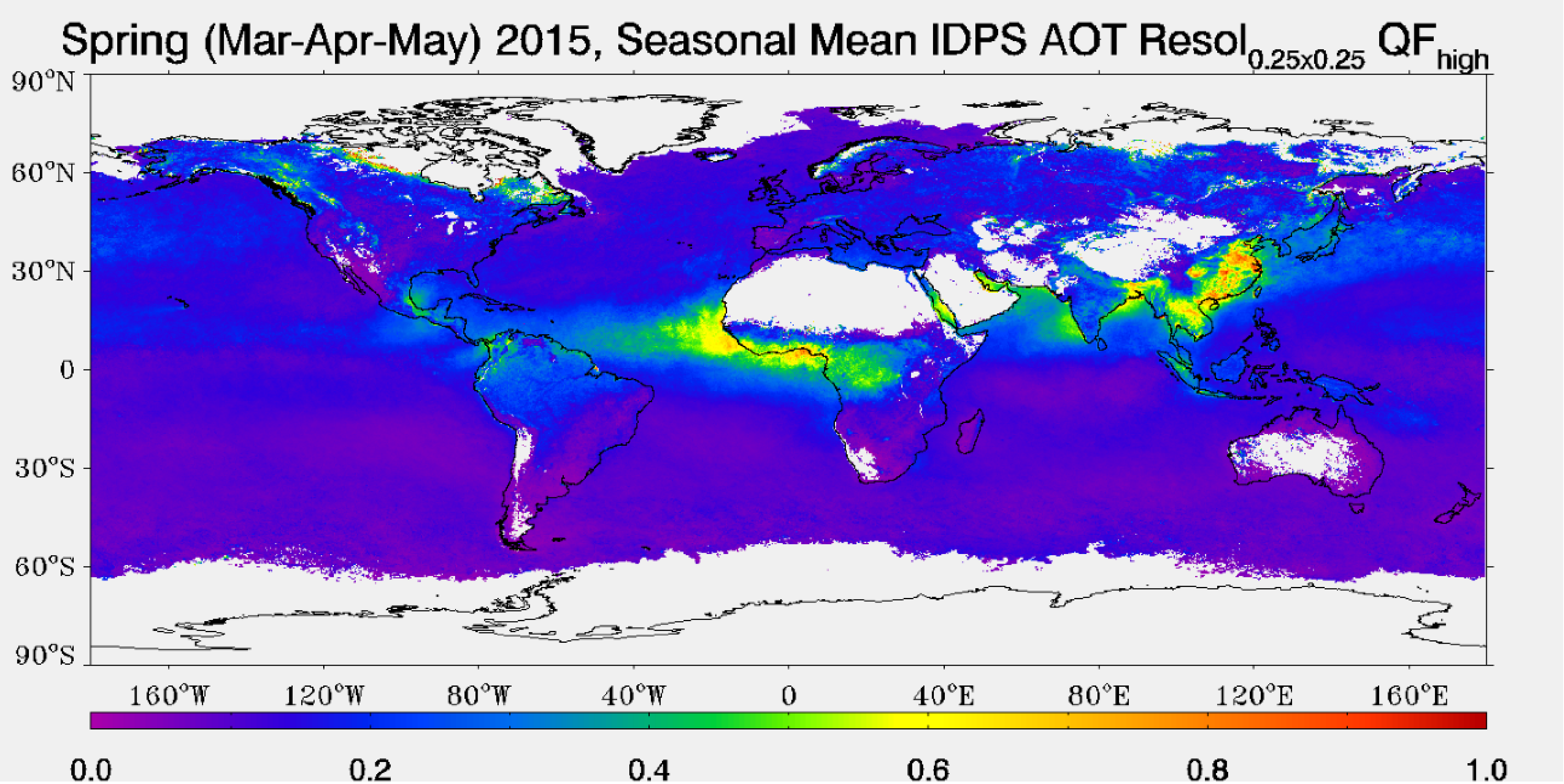


the snow cover map produced by NOAA National Centers for Environmental Information (NCEI) (https://www.ncdc.noaa.gov/snow-and-ice/snow-cover/us/20150519).

Problem: Snow/Snowmelt Underscreening (Global, Daily)



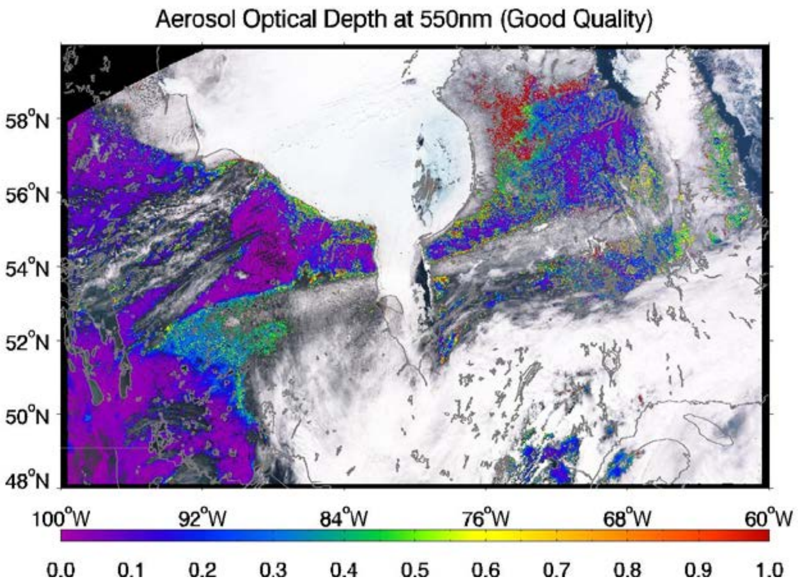
Problem: Snow/Snowmelt Underscreening (Global, Seasonal)

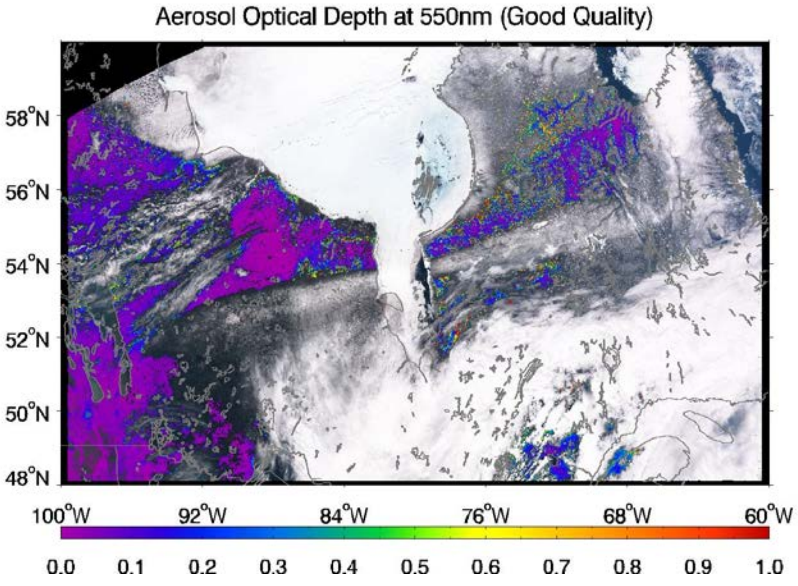


New NDSI and BT11 based Snow Test

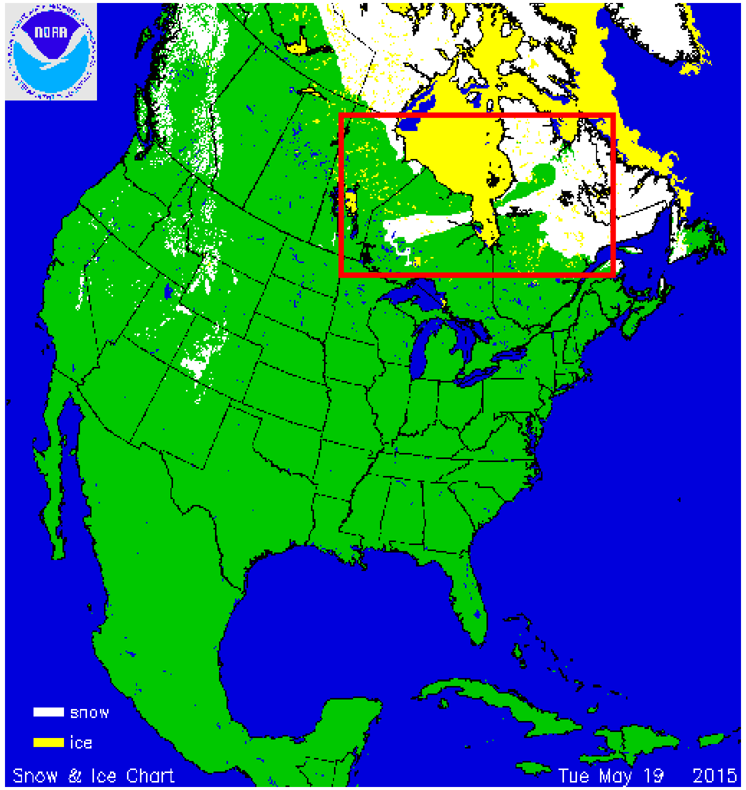
Tests	Old VRA Based Test	New NDSI Based Snow Test	Snow Adjacency Test	Spatial Filter
Criteria	1. VRA > 0.02; 2. rM8/rM7 < 0.9; 3. Surface Temperature (ST) < 278 K	1. NDSI > *C*; 2. $BT_{10.76\ \mu m}$ < 285 K	If any of 7x7 surrounding pixels is snow	If the standard deviation of 3x3 M1 is higher than 0.05
Quality	Not Produced	Not Produced	Degraded to Medium	Degraded to Medium
Notes	1. VRA = crM3 – 0.5*crM5; 2. ST derived from $BT_{10.76\ \mu m}$ and $BT_{12.01\mu m}$	1. NDSI = (rM7-rM8)/(rM7+rM8); 2. C=0.01 for IDPS; 3. C=0.10 for EPS	Check high quality AOT retrievals at central pixel only	Check high quality AOT retrievals at central pixel only

Better Snow/Snowmelt Screening

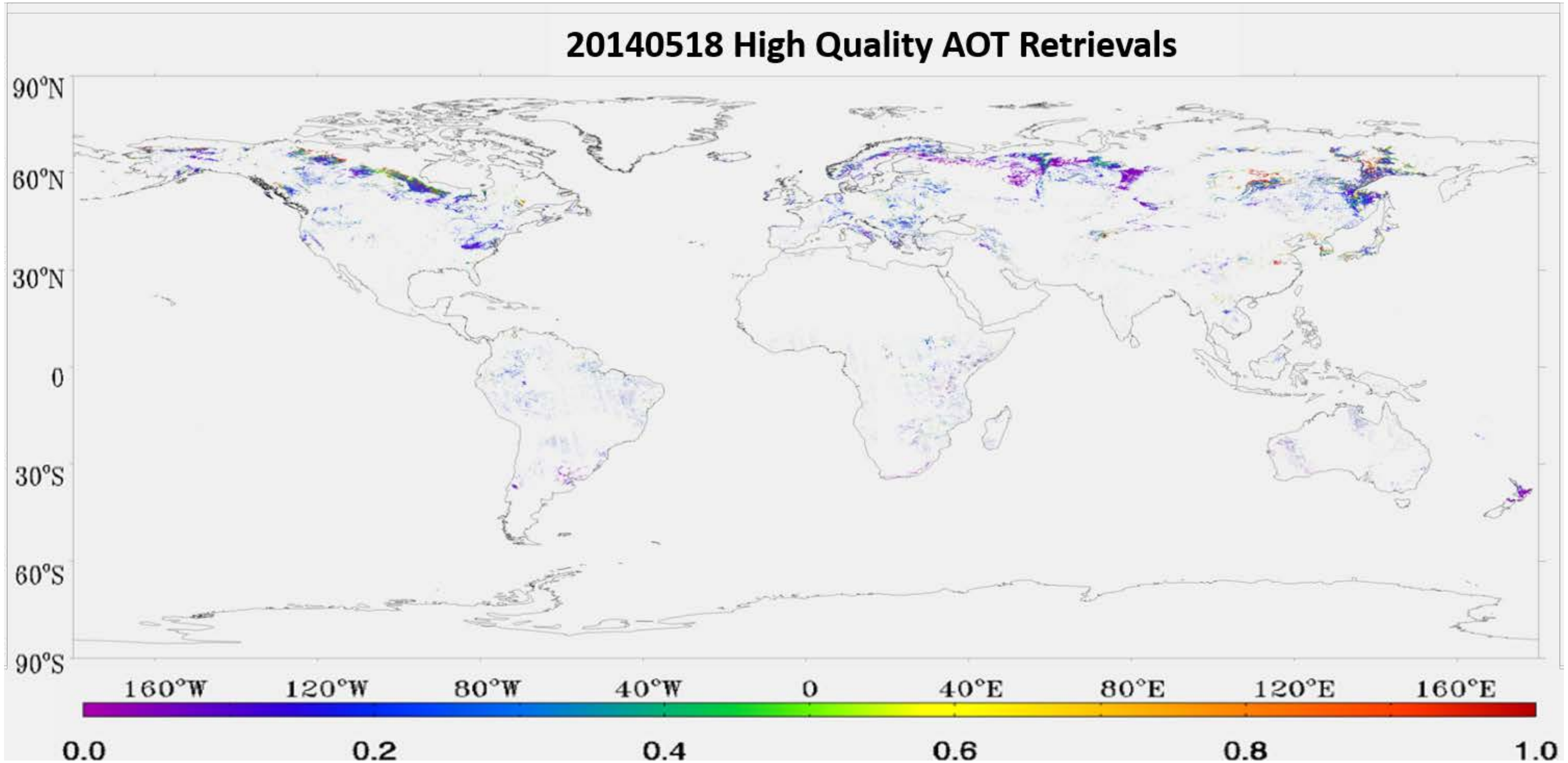




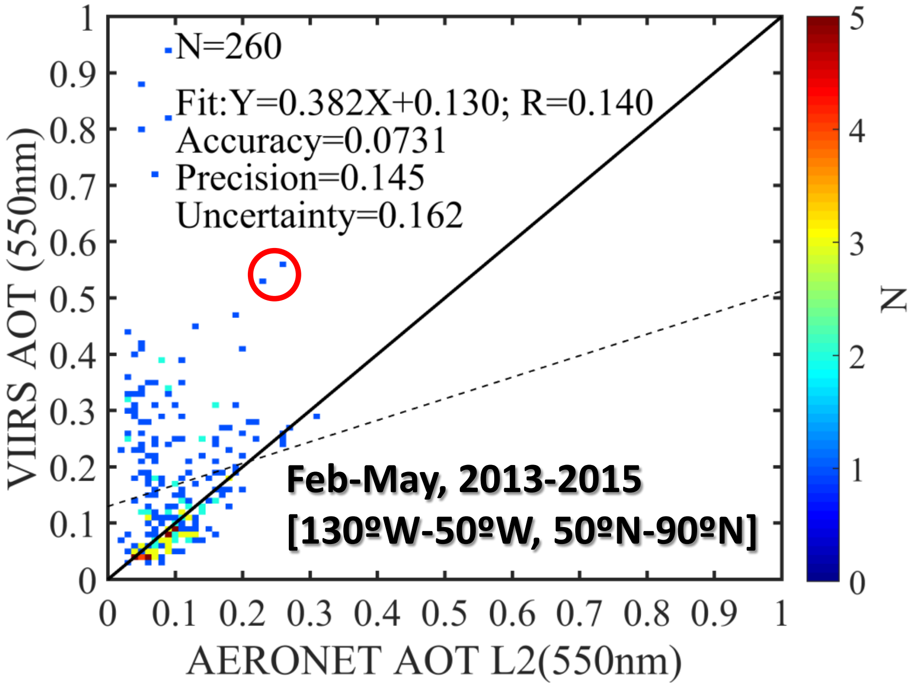
'Good' quality AOT retrievals on May 19, 2015

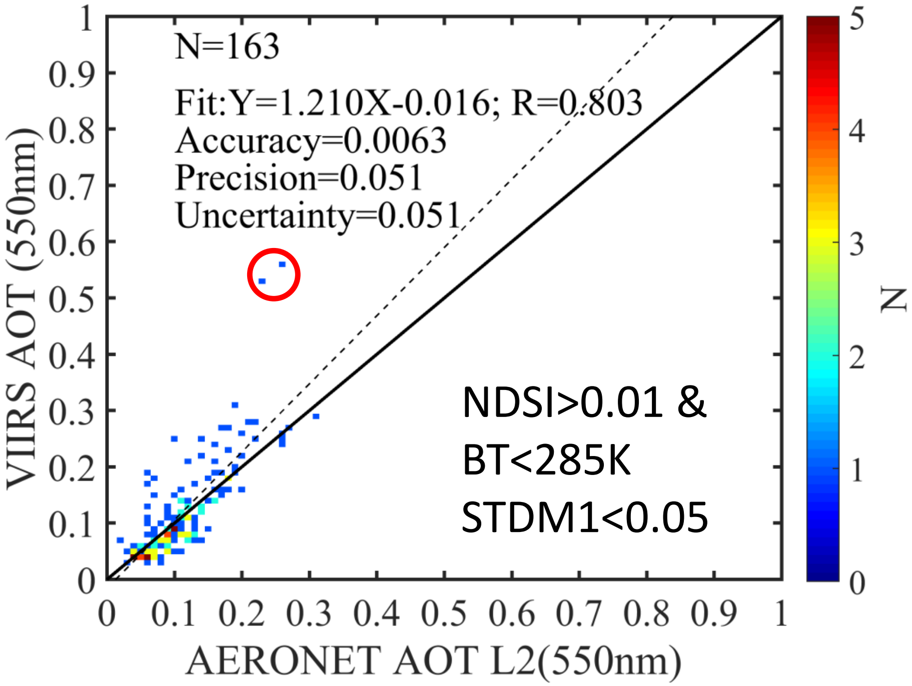


Better Snow Screening



Better Snow/Snowmelt Screening



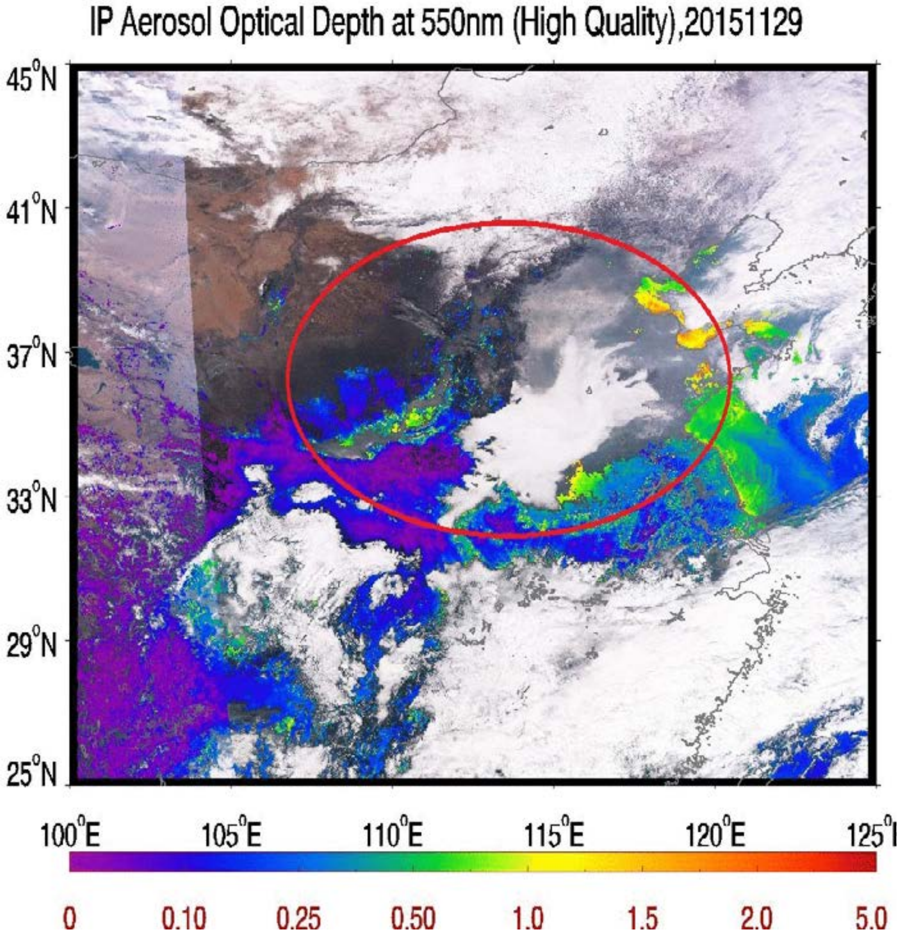


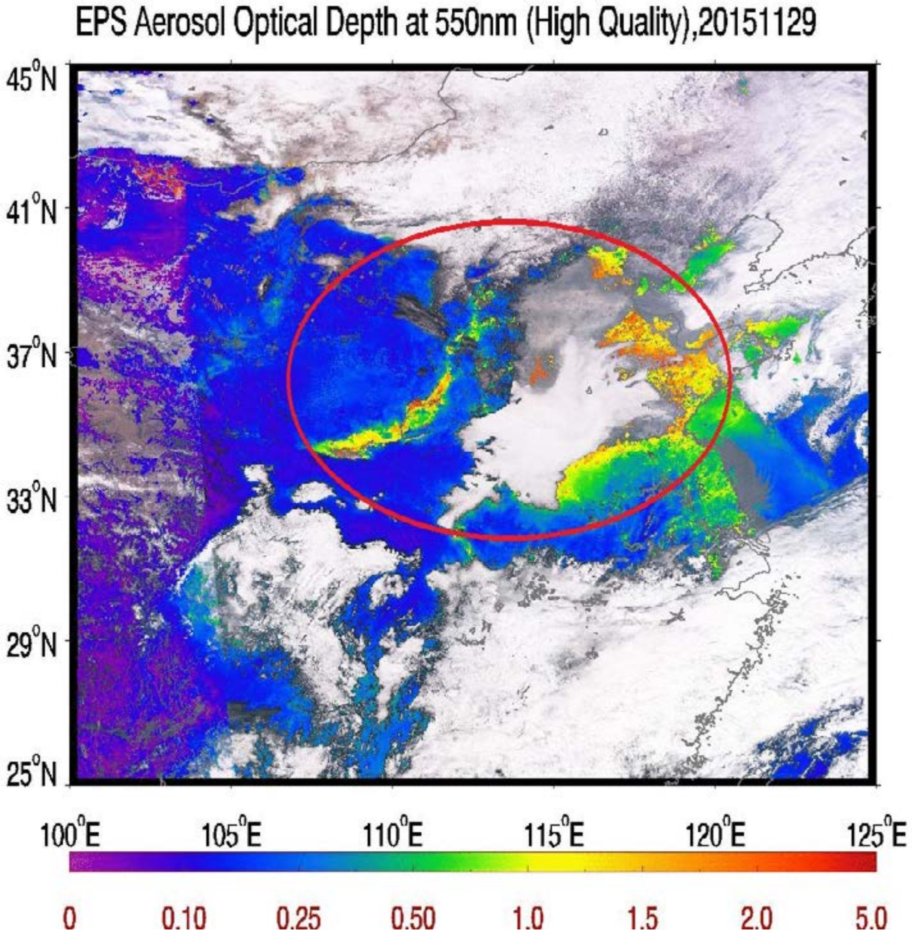
	N	Snow	SnowAdj	SpaFil	N’
Case1	260	43	94	0	163

PART 2:

THE MISSING CHINA SMOG AOT RETRIEVALS IN THE IDPS VIIRS AOT PRODUCT

IDPS vs. EPS: Best Quality AOT Animation



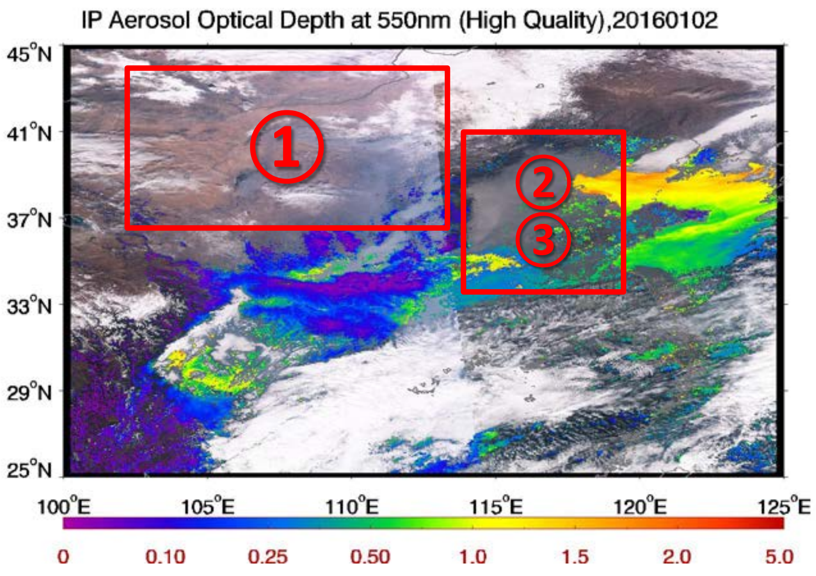


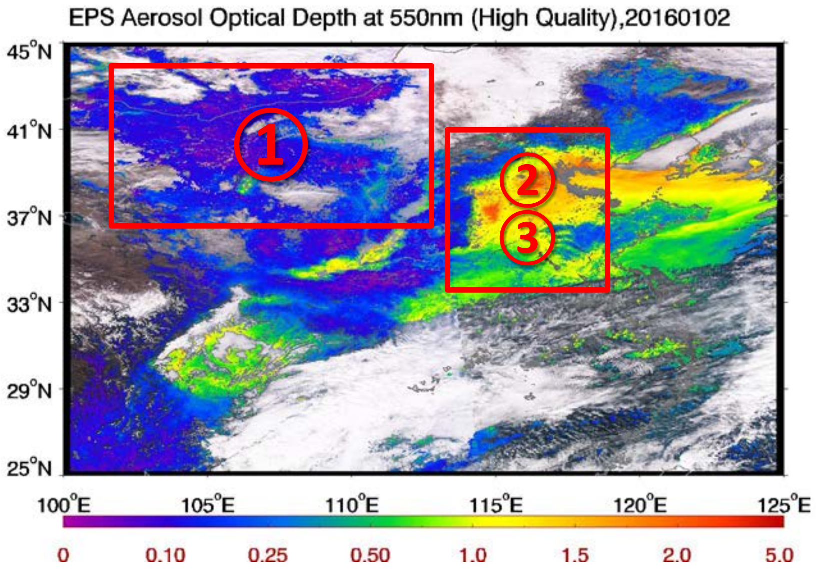
IDPS vs. EPS Best Quality AOT, 2016-01-02

① IDPS only has dark surface retrieval over land; EPS has both dark and bright surface retrievals over land.

② IDPS had AOT retrieval up to 2.0; EPS had AOT retrieval higher than 2.0 and up to 5.0

③ Main Focus: IDPS missed heavy smog AOT retrievals; EPS regained these retrievals.

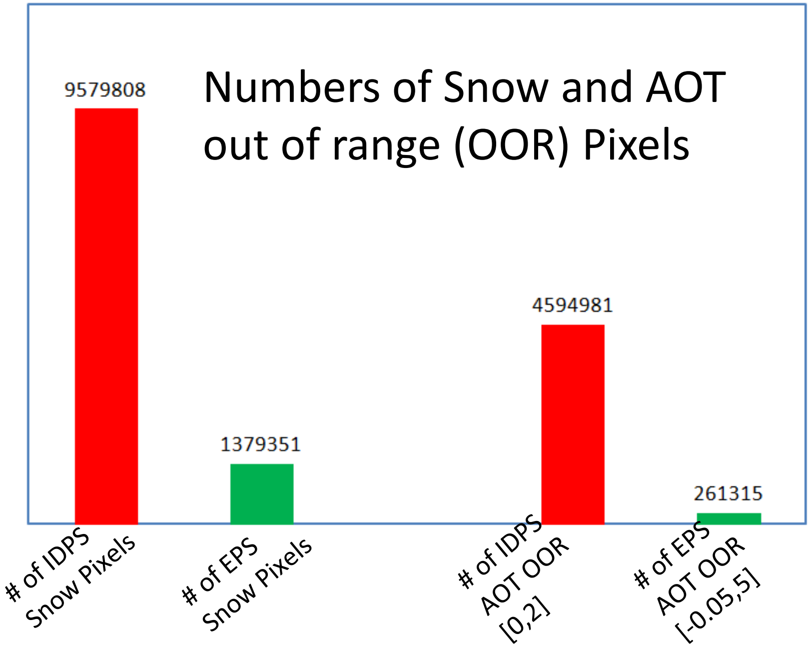




Why did IDPS miss the smog AOT retrievals?

Data Collection:
- ✓ 13 smog events ([25-45N, 100-125E], Winter 2015-2016)
- ✓ IDPS AOT with QF not produced or excluded
- ✓ EPS AOT (Best Quality) > 0.5
- ✓ 448881 Pixels In Total

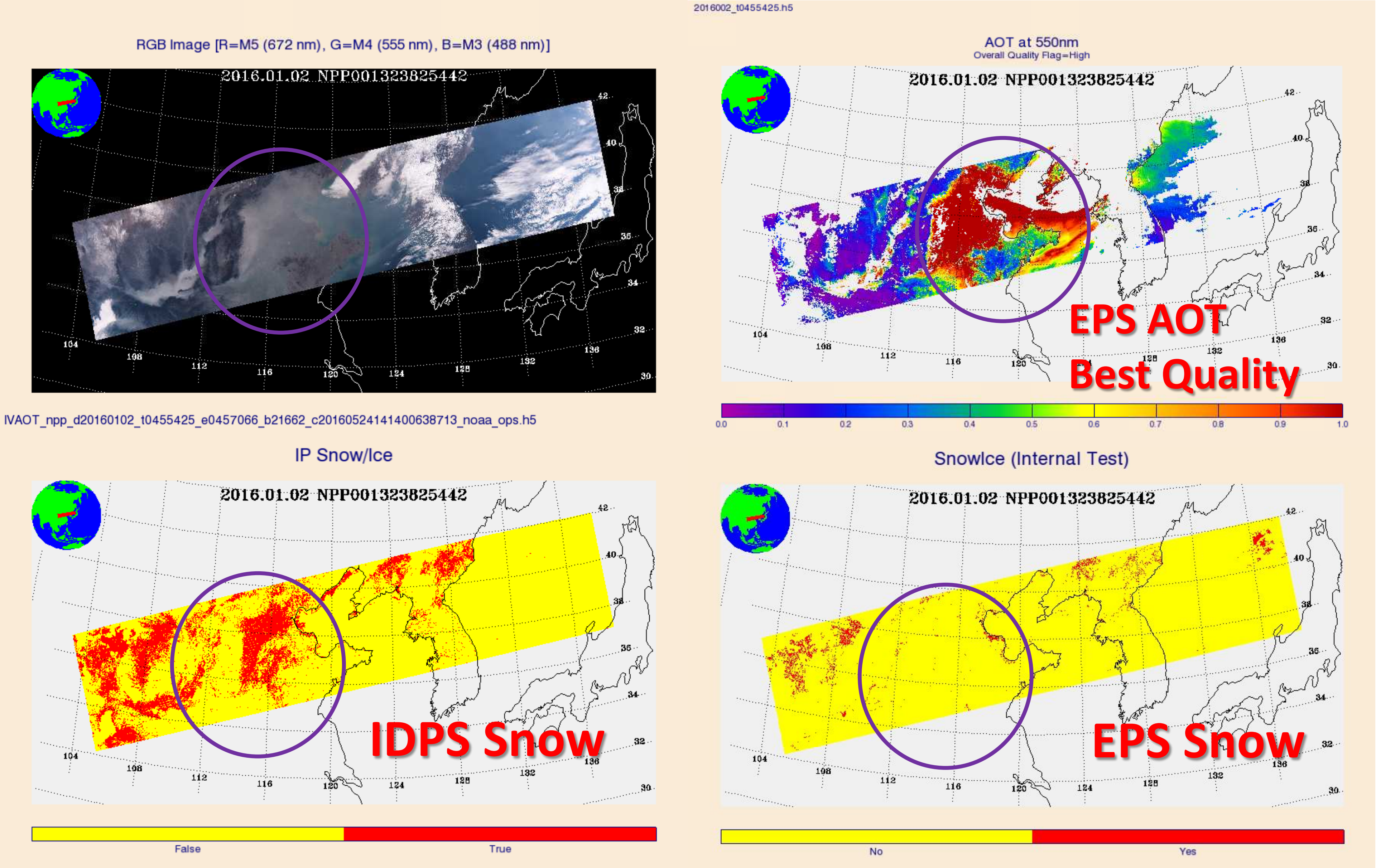
Statistical Results:
- ✓ **49.7% had smog mis-identified as snow**
- ✓ **43.7% had IDPS AOT retrievals out of range [0.0, 2.0]**



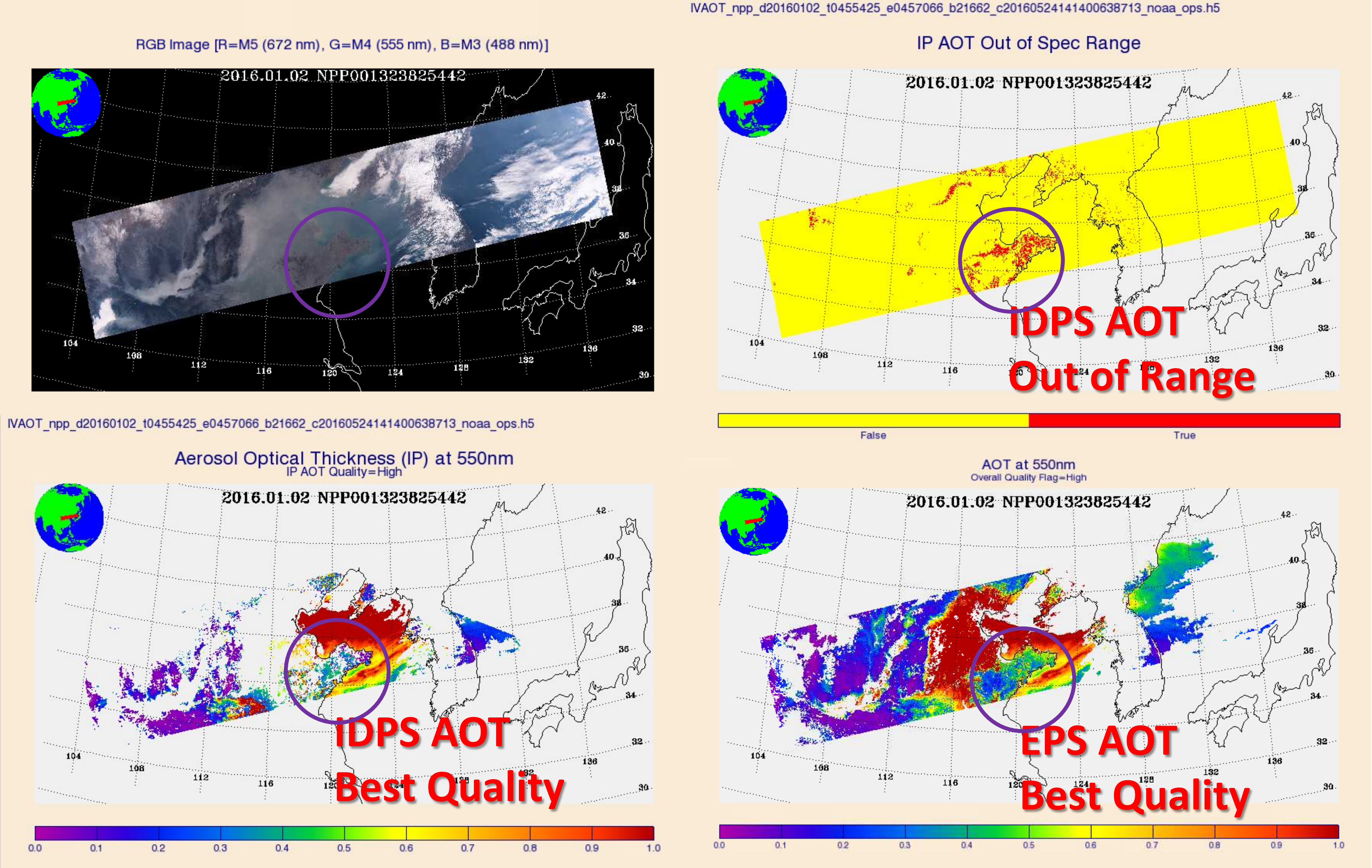
- ➢ Internal Snow Over Screening and AOT Out Of Range (OOR) were identified as the Top Two factors that prevented IDPS best quality AOT retrievals over smog pixels;
- ➢ EPS /IDPS Snow Pixels: 14.4%
- ➢ EPS/IDPS AOT OOR pixels: 5.7%

(Note: EPS has larger AOT range than IDPS)

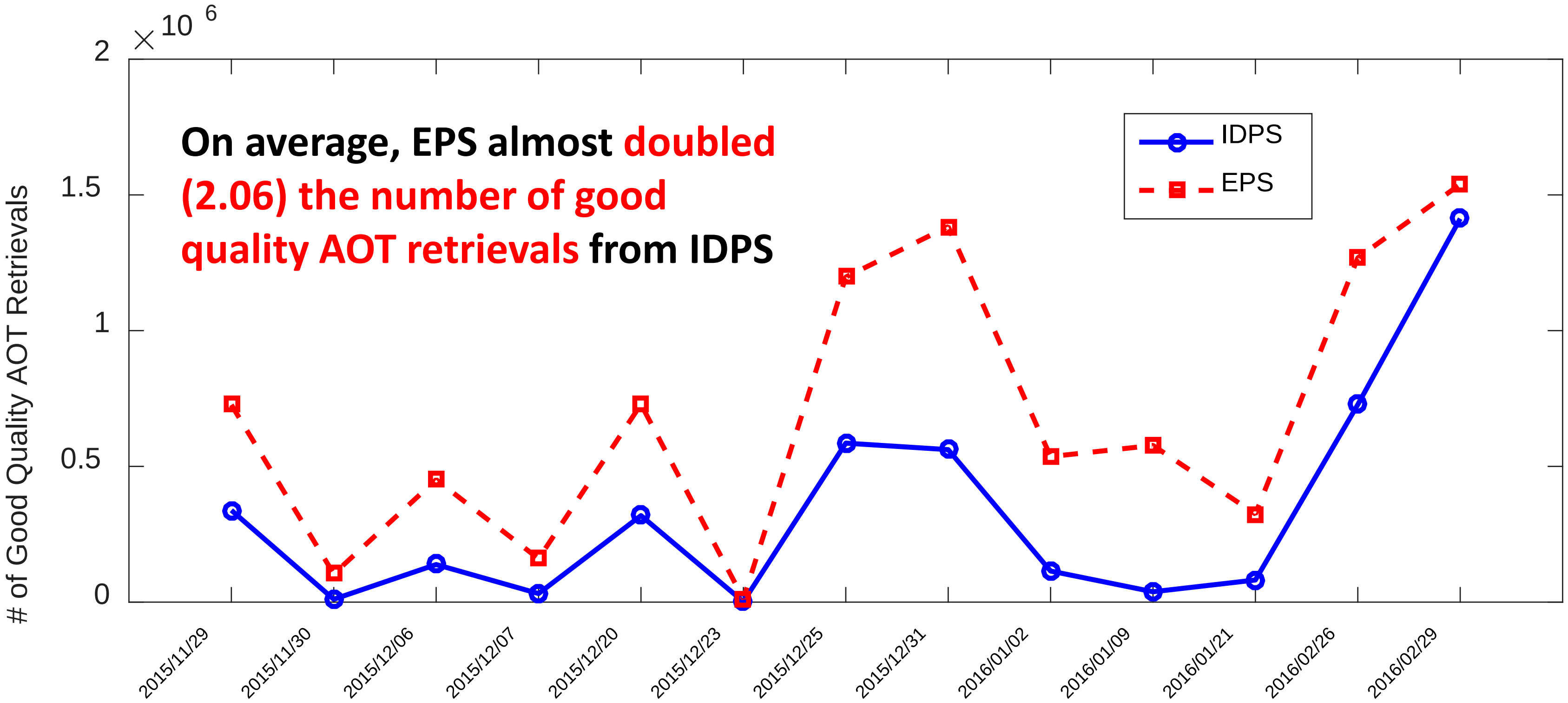
IDPS vs. EPS: Internal Snow Test



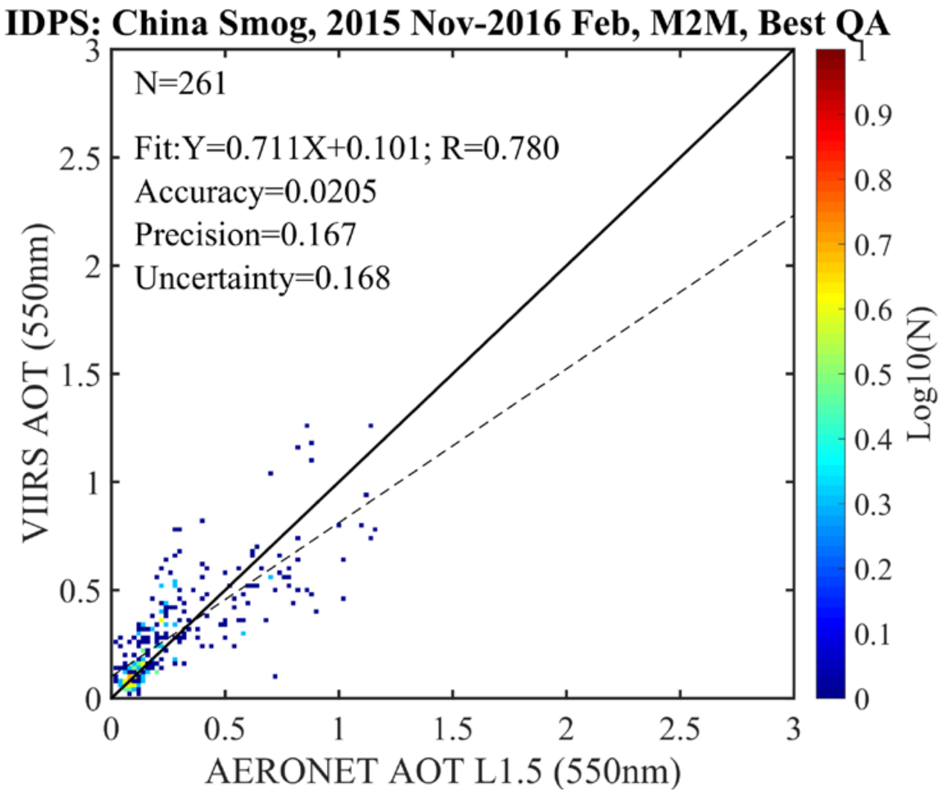
IDPS vs. EPS: AOT Out Of Range (OOR)

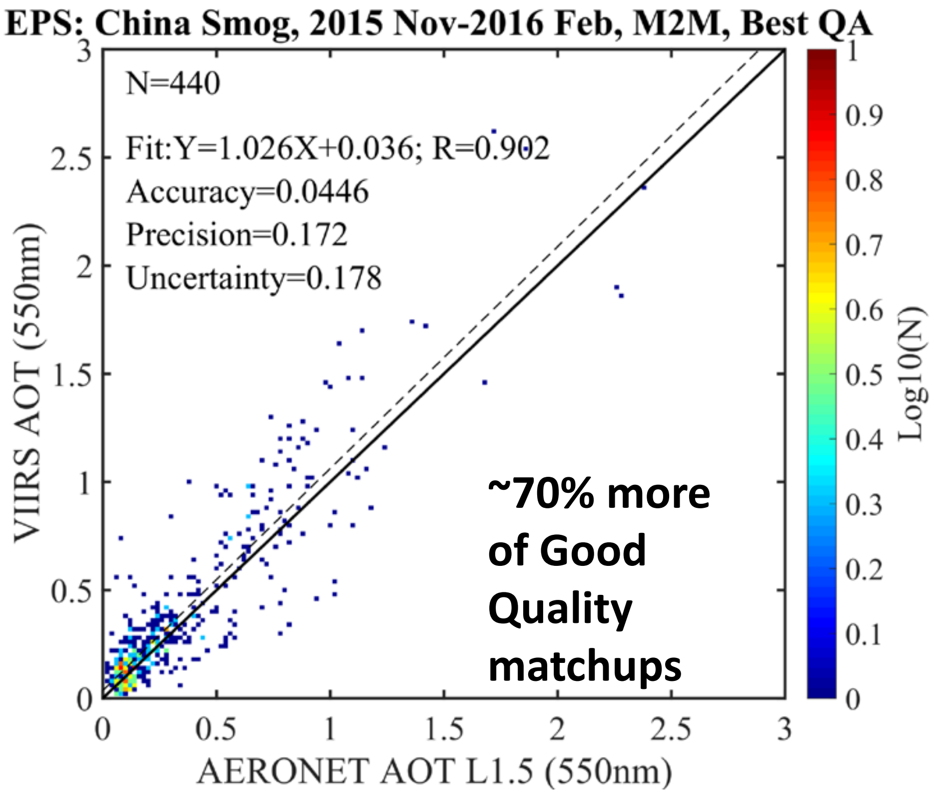


IDPS vs. EPS: Number of Good Quality AOT



IDPS vs. EPS: Comparison to AERONET



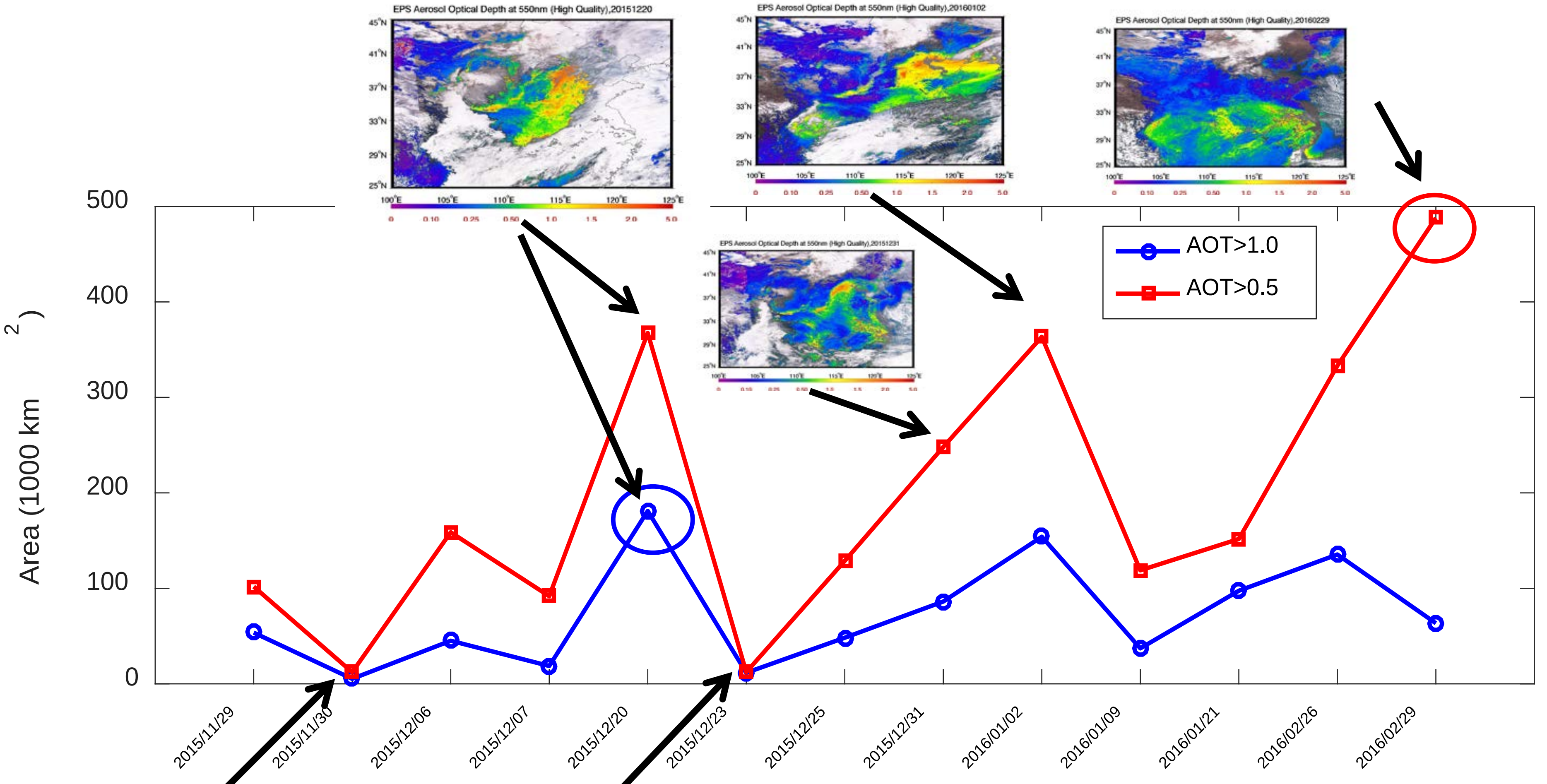


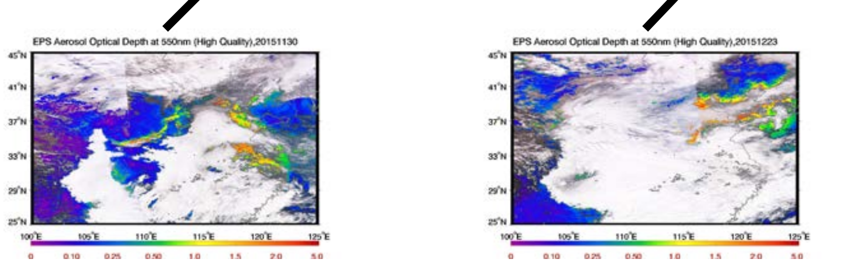
IDPS vs. AERONET L1.5

EPS vs. AERONET L1.5

In the matchup with AERONET L1.5, EPS VIIRS Aerosol Algorithm increased best quality AOT matchups by ~70% more than IDPS

EPS evaluated Smog Spatial Coverage

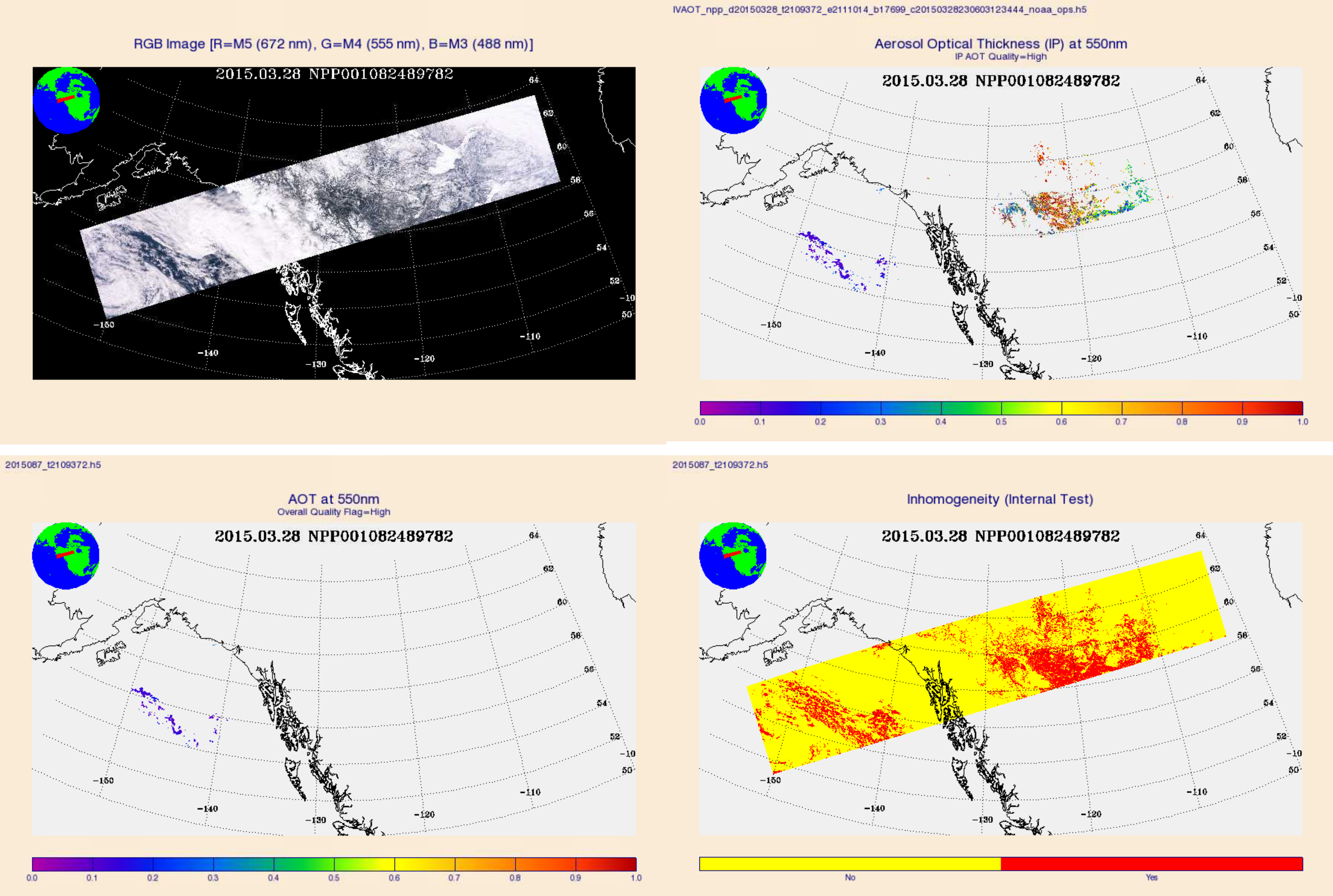


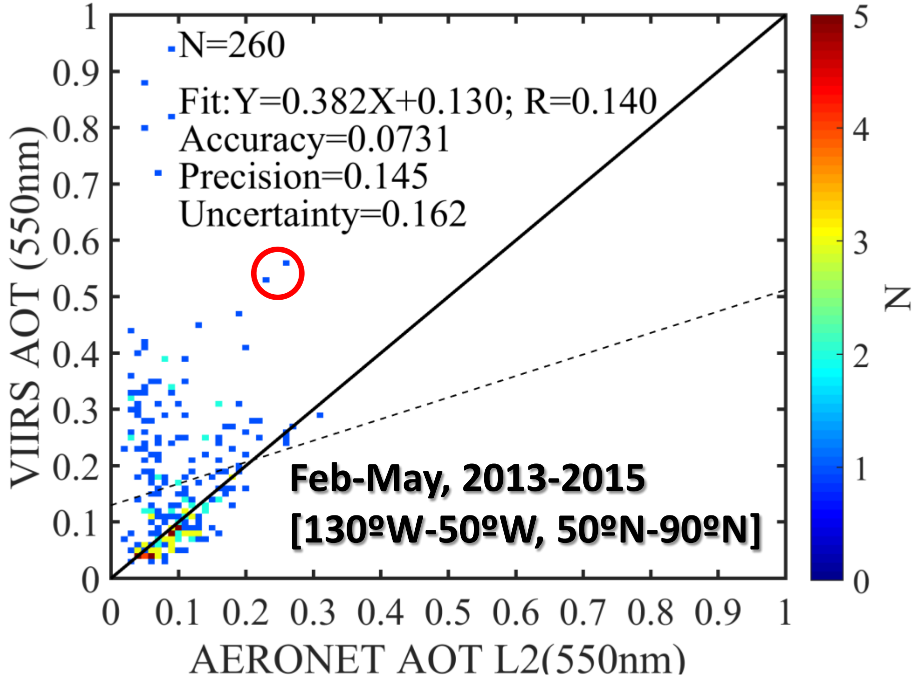


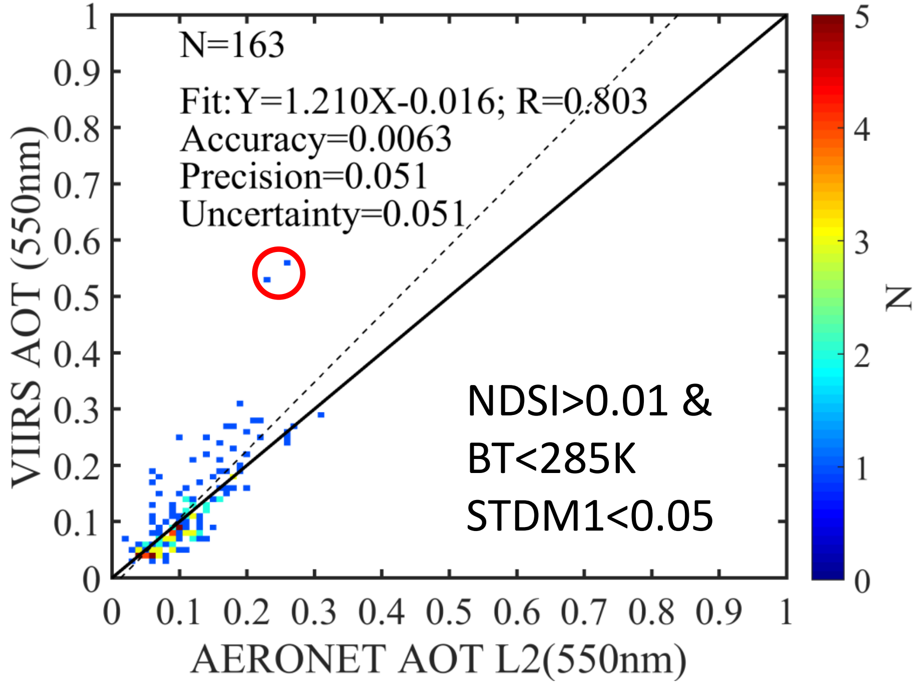
Even without considering under-cloud smog:

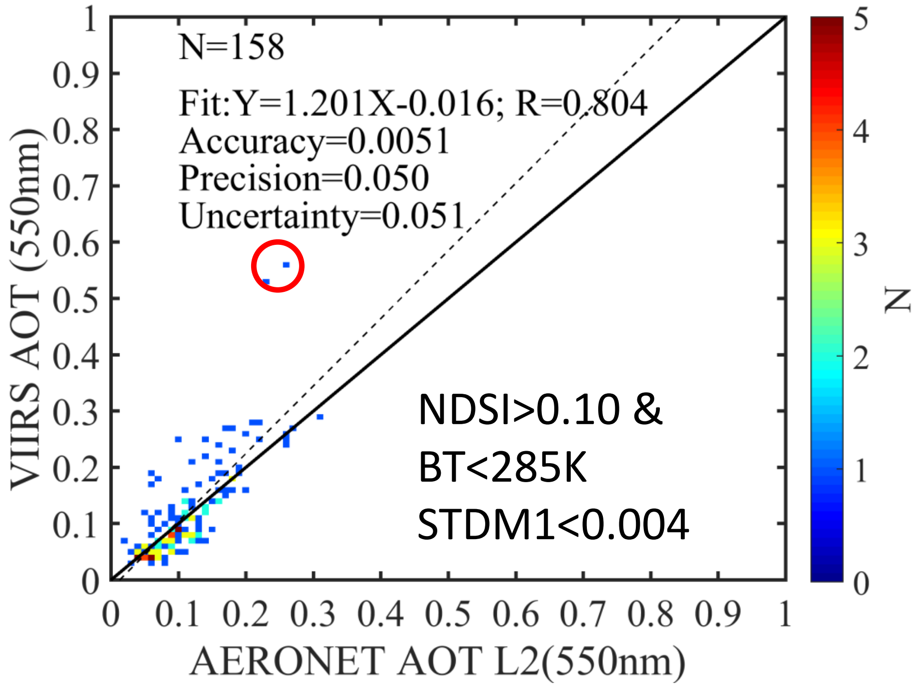
- AOT > 1.0: can be as large as 200,000 km^2
- AOT > 0.5: can be as large as 500,000 km^2

Fine Tuned Spatial Filter in EPS



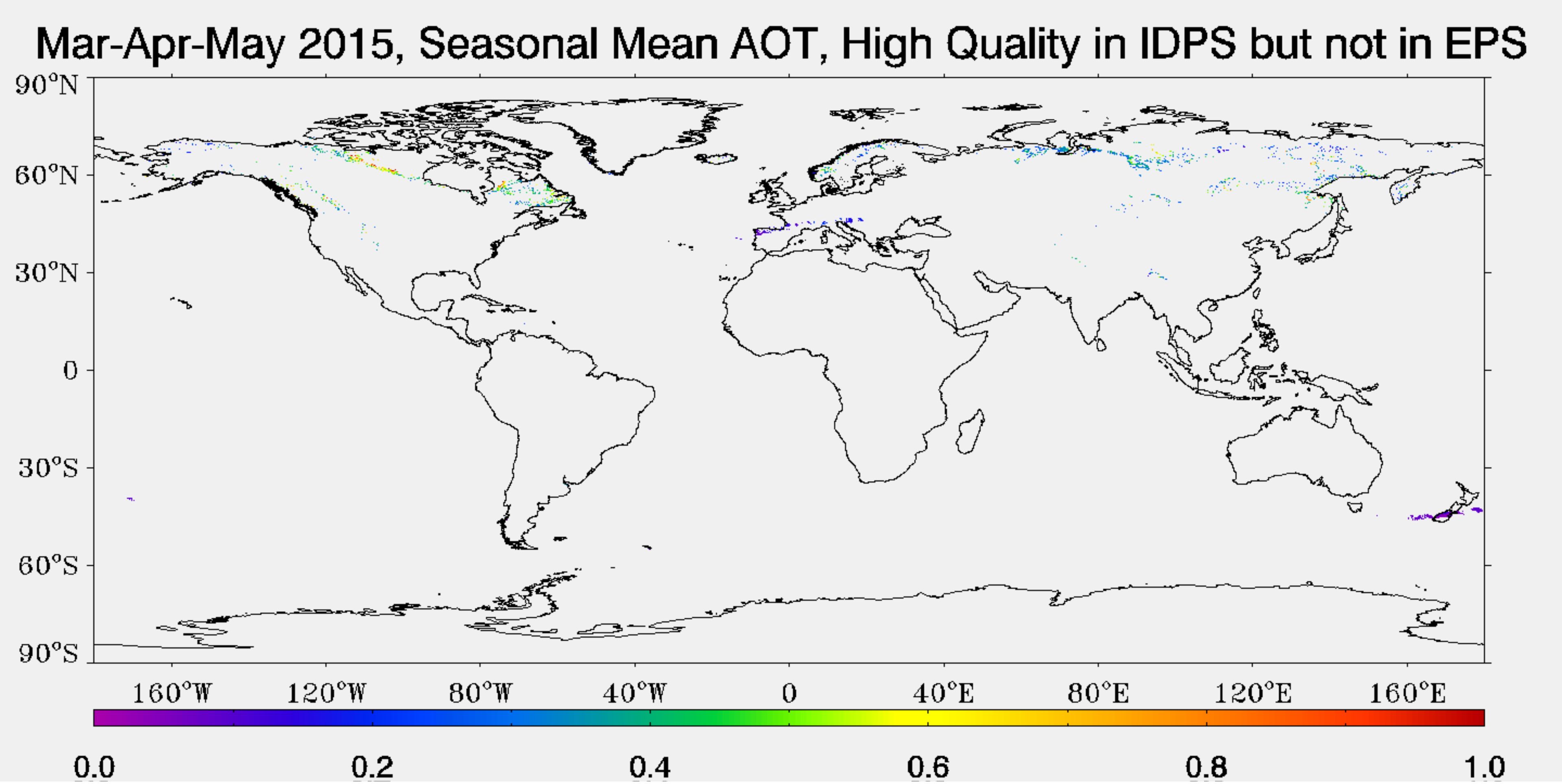






	Initial N	Snow	SnowAdj	SpaFil	New N
IDPS Thresholds	260	43	94	0	163
EPS Thresholds	260	30	94	81	158

IDPS vs. EPS: Boreal Spring AOT



Summary

- The NDSI and BT11 based snow test, combining with the complement snow adjacency test and spatial filter, improves the snow/snowmelt screening in the IDPS VIIRS aerosol products;
- However, AOT retrievals in heavy China Smog events were found missing in the IDPS aerosol product;
- The main reason for the missing smog AOT retrievals is snow over screening, followed by AOT out of range;
- The snow test and spatial filter were fine tuned to regain the missing China Smog AOT retrievals and to keep the same level of snow/snowmelt screening;
- With the new tests, EPS VIIRS Aerosol Algorithm has much more smog AOT retrievals than IDPS; and with more retrievals, EPS AOT also demonstrated better correlation with AERONET than IDPS; and yet, the high biases in the snow/snowmelt region remain screened.
- The EPS VIIRS aerosol algorithm will replace the IDPS algorithm and become operational in 2017

A New Dust Dataset from the IMPROVE Ground Network

Daniel Tong, Julian Wang, Hang Lei and Barry Baker
NOAA Air Resources Laboratory, College Park, MD

Thomas Gill
University of Texas at El Paso, TX

Binyu Wang
Goerge Mason University, Fairfax, VA

(JPSS Science Meeting 2017, College Park, MD)

The "Dust Bowl" During the Great Depression (1930s)

- **Dust Bowl: A period of severe dust storms during the 1930s;**
- **Causes: Extended droughts and poor land management;**
  - ✓ **Homestead Acts:** settlement over the Plains for agriculture **;**
  - ✓ **"Rain follows the plow":** unusually wet climate**;**
  - ✓ **New agricultural machinery:** Deep plowing, eliminating native grass;
  - ✓ **Favorable dust storm conditions during 1930s drought;**

The "Dust Bowl"

Impacts:

- ✓ Stripped 75% of top soils over thousands of farms;
- ✓ Destroyed agriculture and ecosystem (~1950s);
- ✓ > 500,000 lost homes and communities;

"And then the dispossessed were drawn west--from Kansas, Oklahoma, Texas, New Mexico; from Nevada and Arkansas, families, tribes, dusted out, tractored out... They streamed over the mountains, hungry and restless--restless as ants, scurrying to find work … anything, any burden to bear, for food. The kids are hungry. We got no place to live…"

-- John Steinbeck in the Grapes of Wrath

Hundreds of thousands fled the 1930s US Dust Bowl; more drought-spurred migrations are expected.

Another “Dust Bowl”?

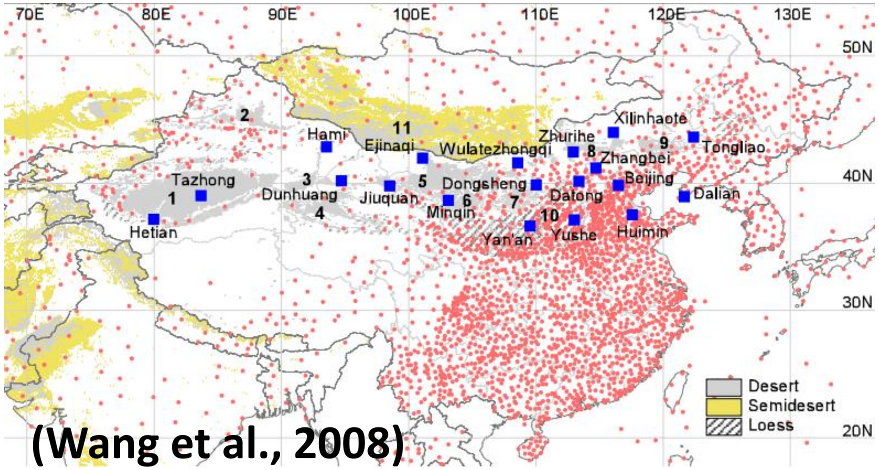
- Central U.S. plains saw severe droughts about once or twice a century over the past 400 years (Woodhouse & Overpeck, 1998).
- This recurring trend may be enhanced global climate change (Schubert et al., 2004).
- Global warming → Precipitation shift from subtropics, greater evaporation, less snow/ice, and earlier spring → amplify the effects of natural climatic variations → intensified droughts and “dust-bowlification” (Romm, 2011).

(Source: Romm, 2011)

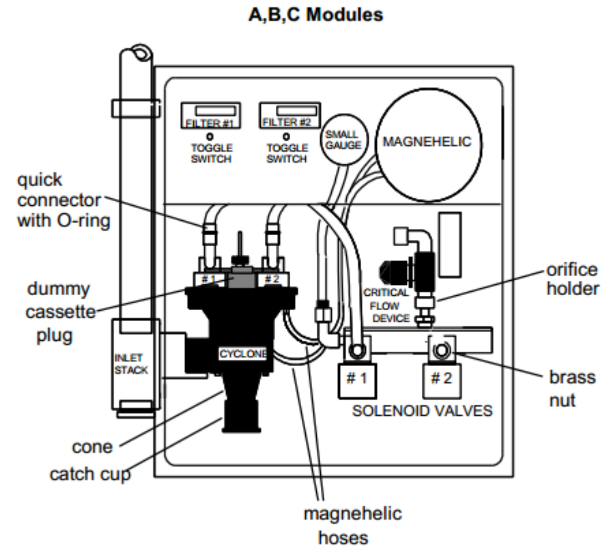
Then and now: sun-baked dry soils kick up clouds of dust in the 1930s (left) and in the modern United States (right).

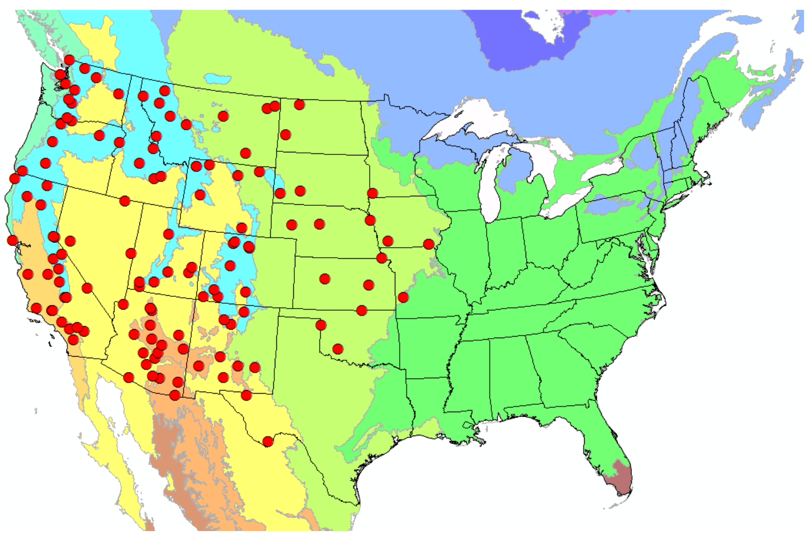
How to Monitor Dust Storms

Chinese Sand and Dust Network

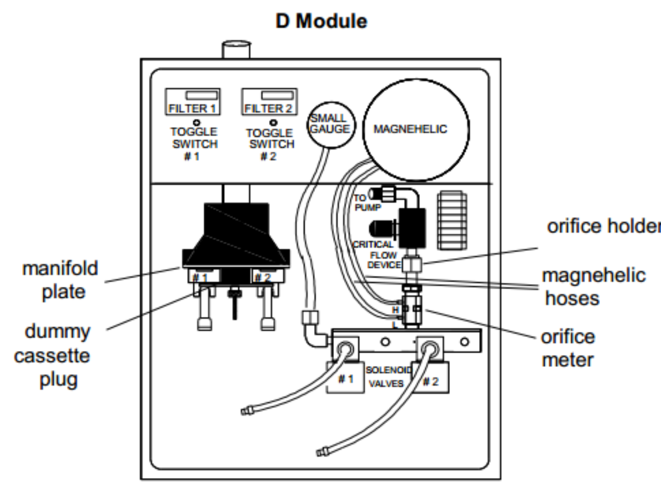


(Wang et al., 2008)



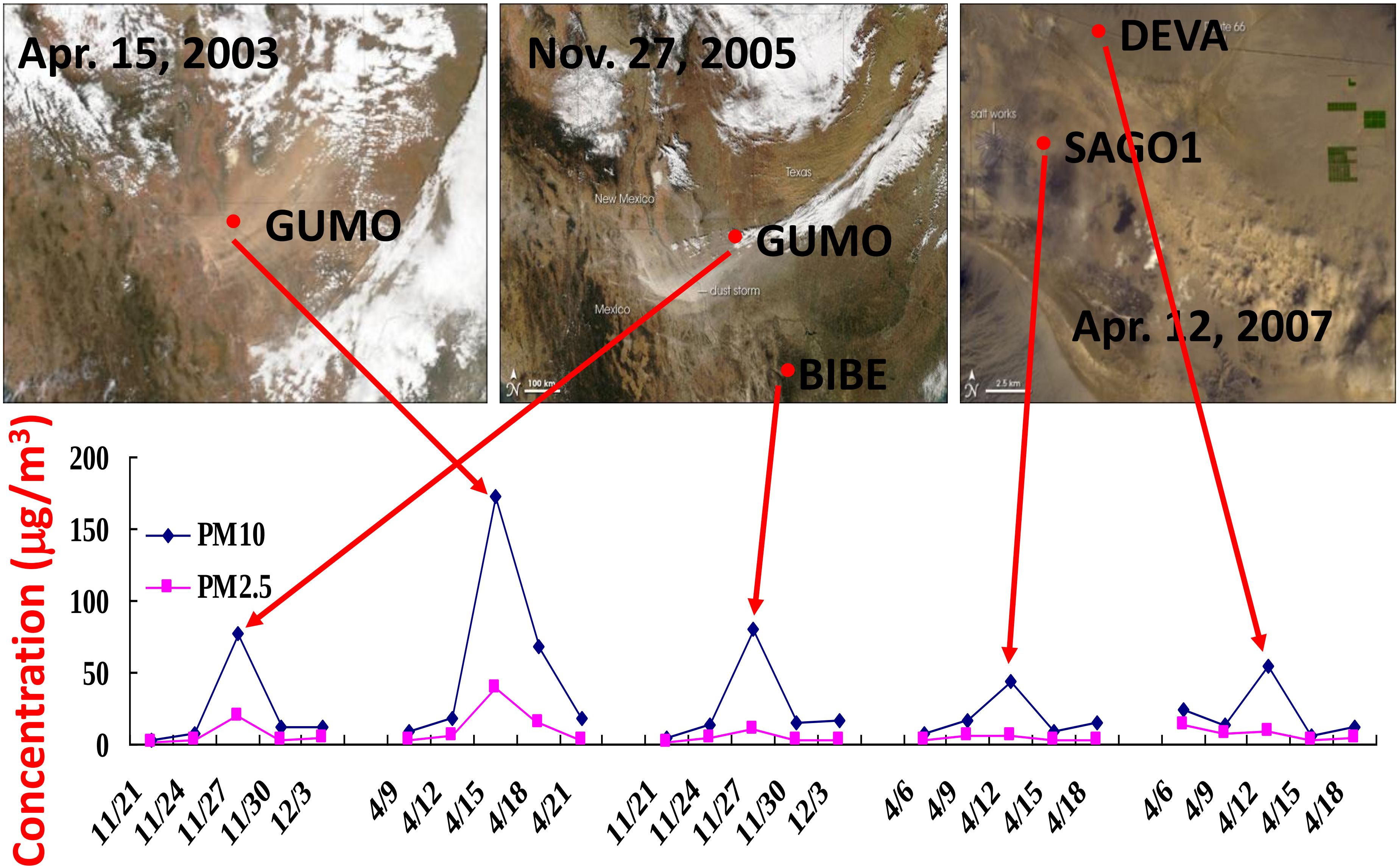


The US Aerosol Network IMPROVE



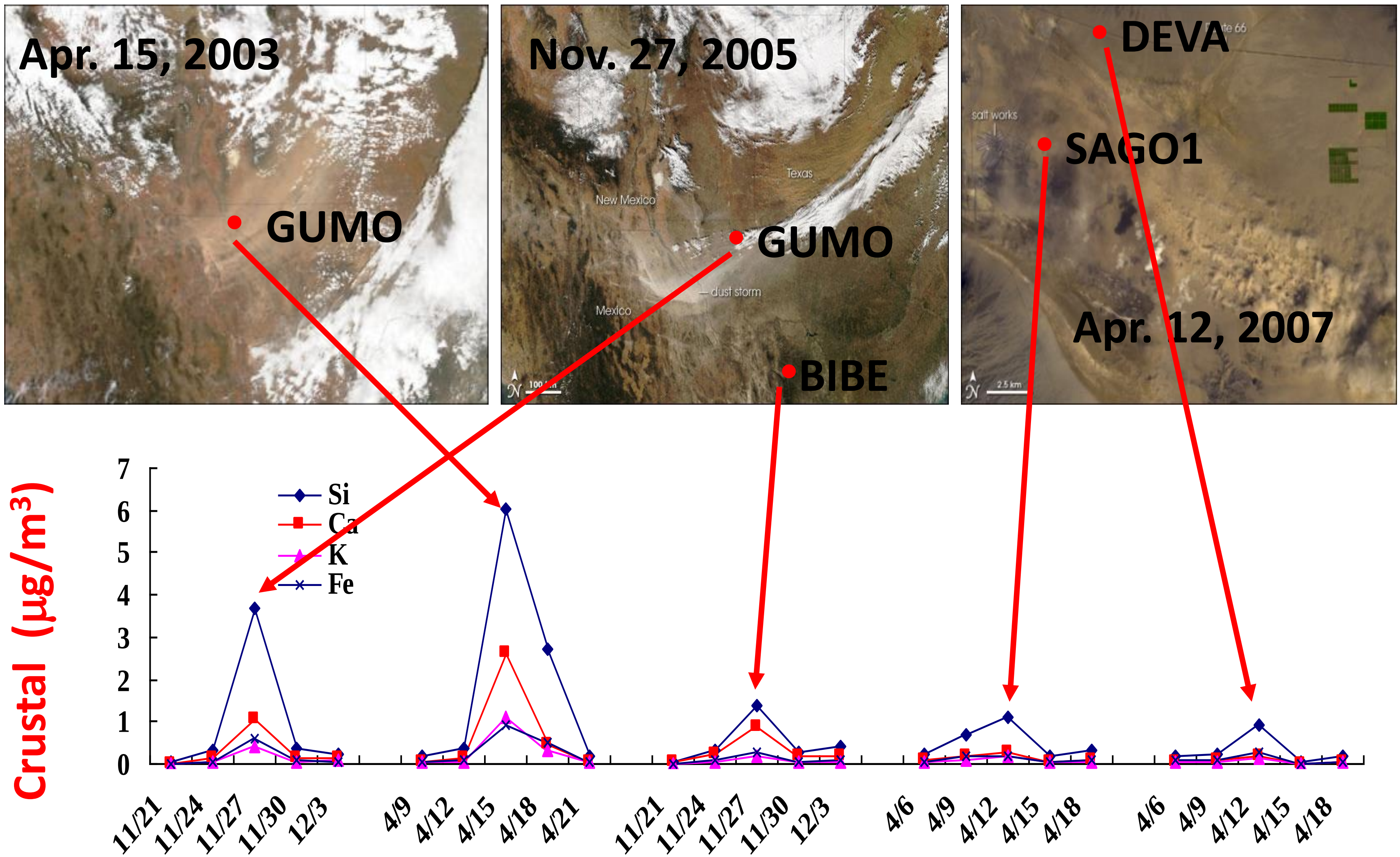
IMPROVE Samplers
Samples Analyzed at UC-Davis

Satellite-aided Algorithm Training



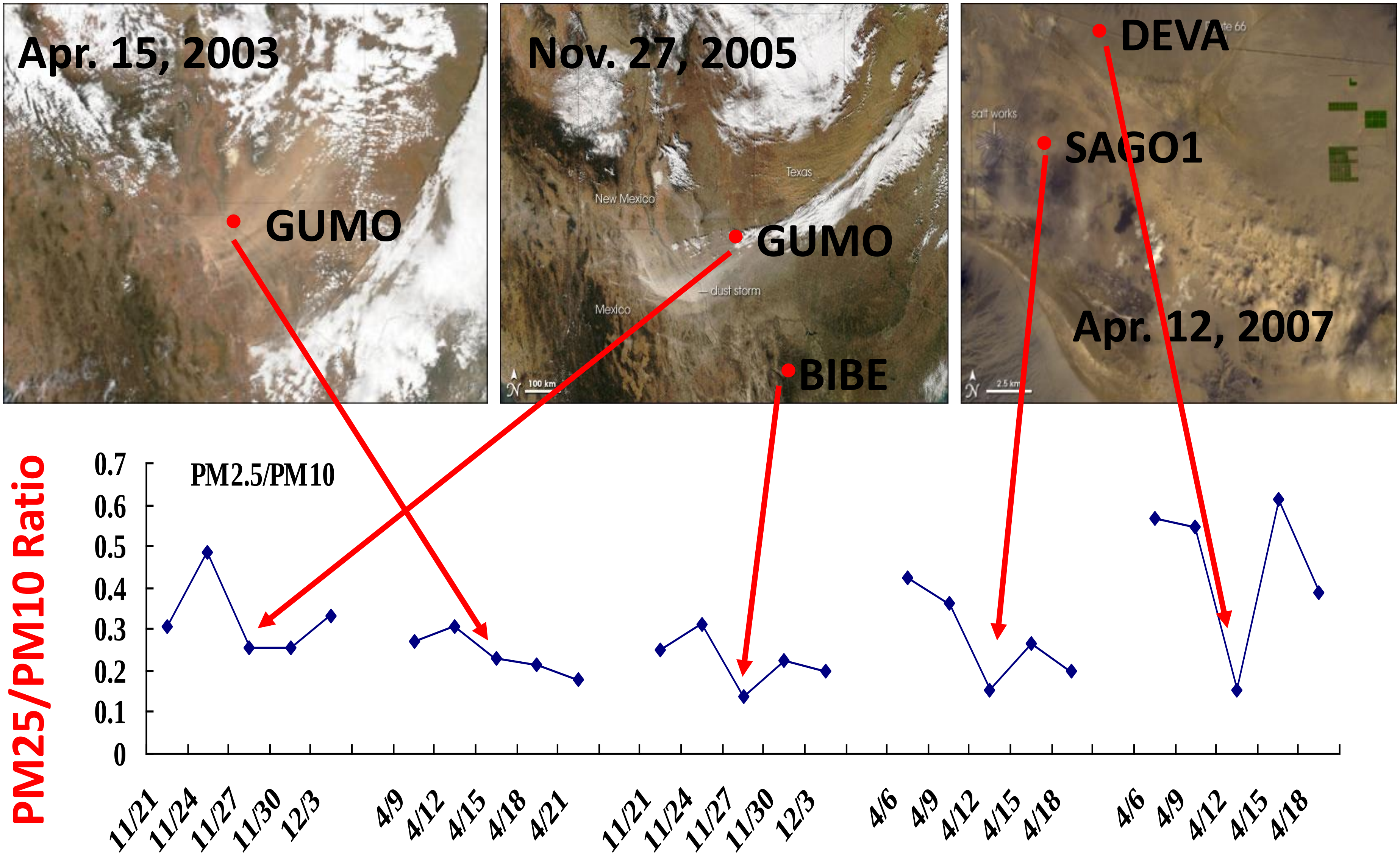
PM10: Particulate Matter < 10 µm PM2.5: Particulate Matter < 2.5 µm

Satellite-aided Algorithm Training



Si – Silicon; Ca – Calcium; K – Potassium; Fe – Iron

Satellite-aided Algorithm Training

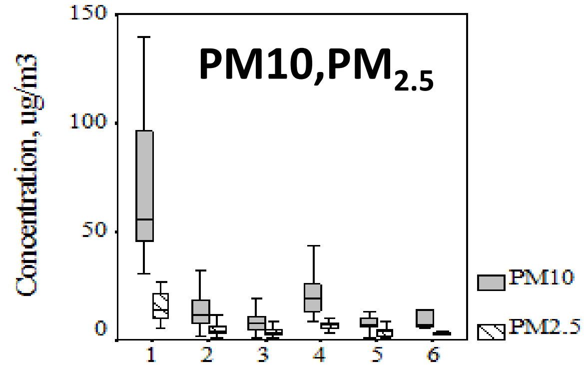


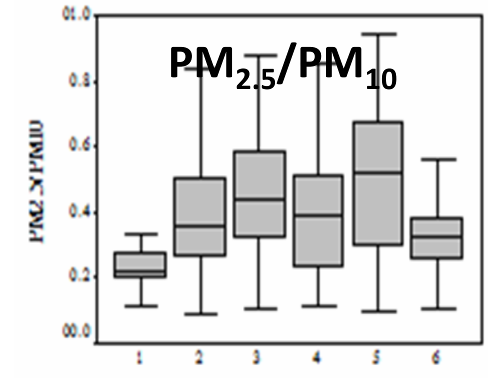
Dust Identification through Cluster Analysis

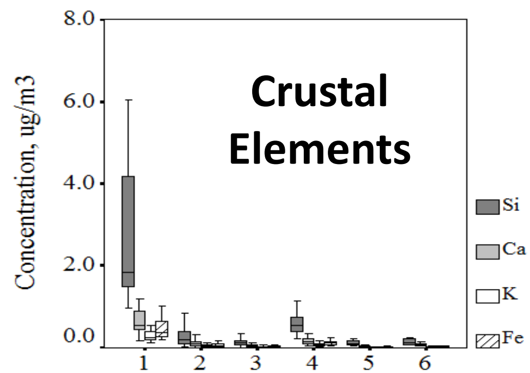
Five Dust Indicators:

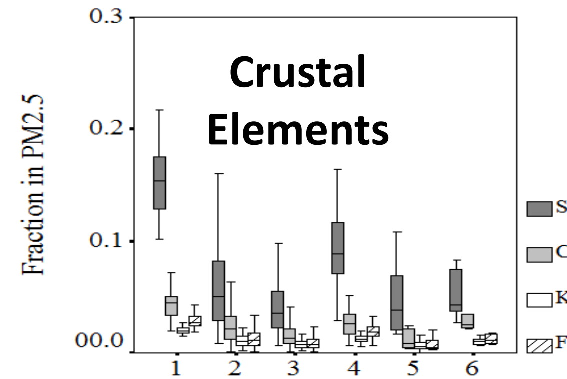
- ❖ High PM_{10}, $PM_{2.5}$;
- ❖ Low $PM_{2.5}/PM_{10}$ ratio
- ❖ High Crustal Fraction
- ❖ Low anthropogenic Fraction;
- ❖ Low Enrichment Factor;

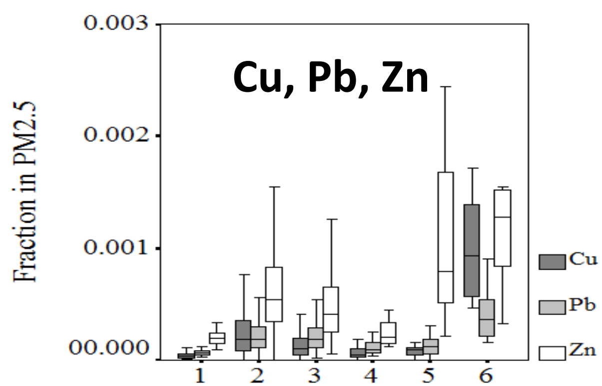
Cu– Copper
Pb – Lead
Zn – Zinc

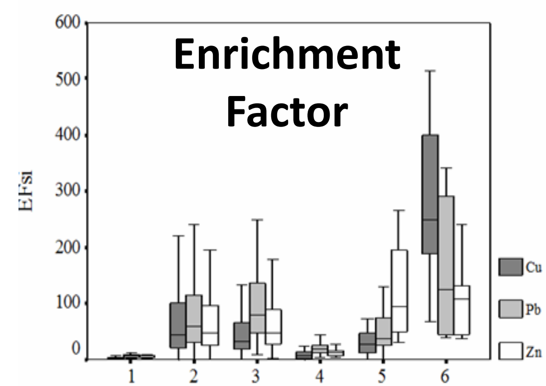






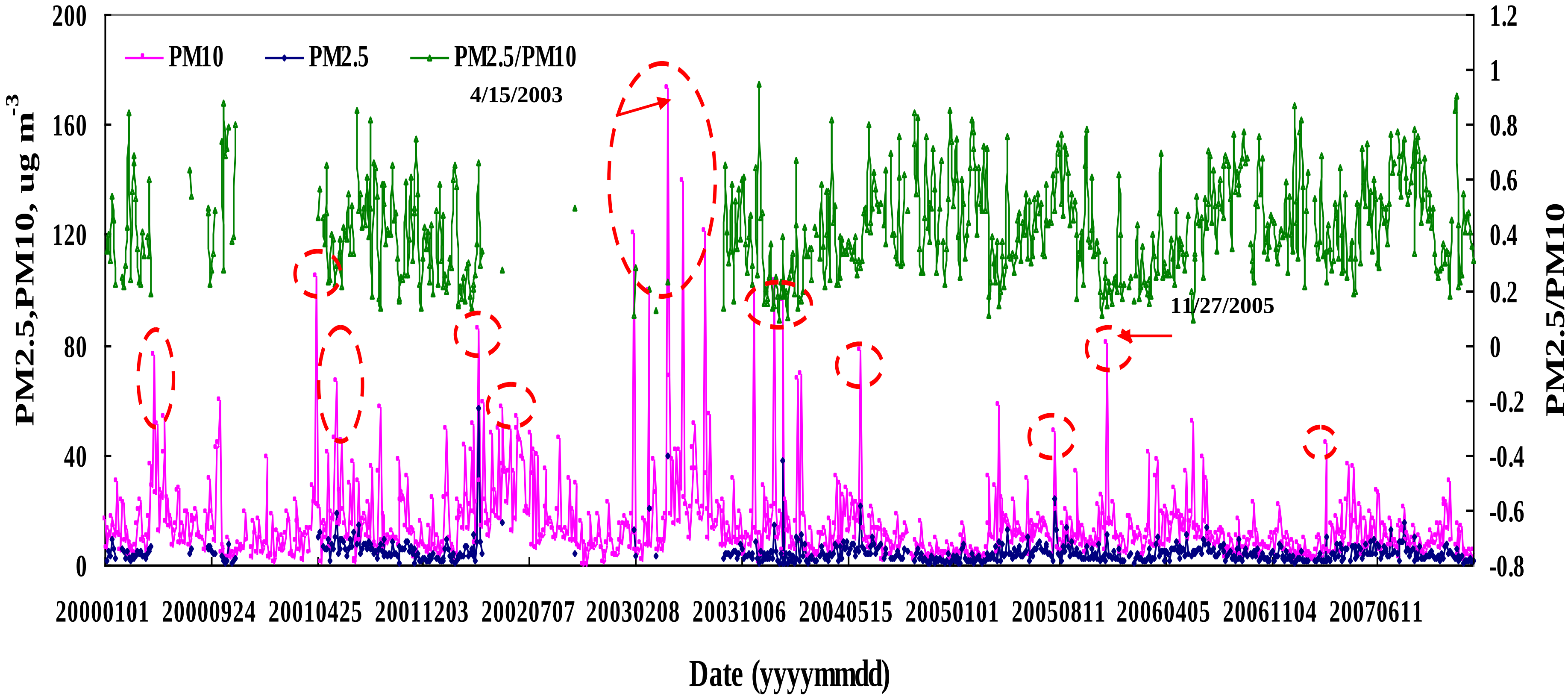






Detecting Dust Storms

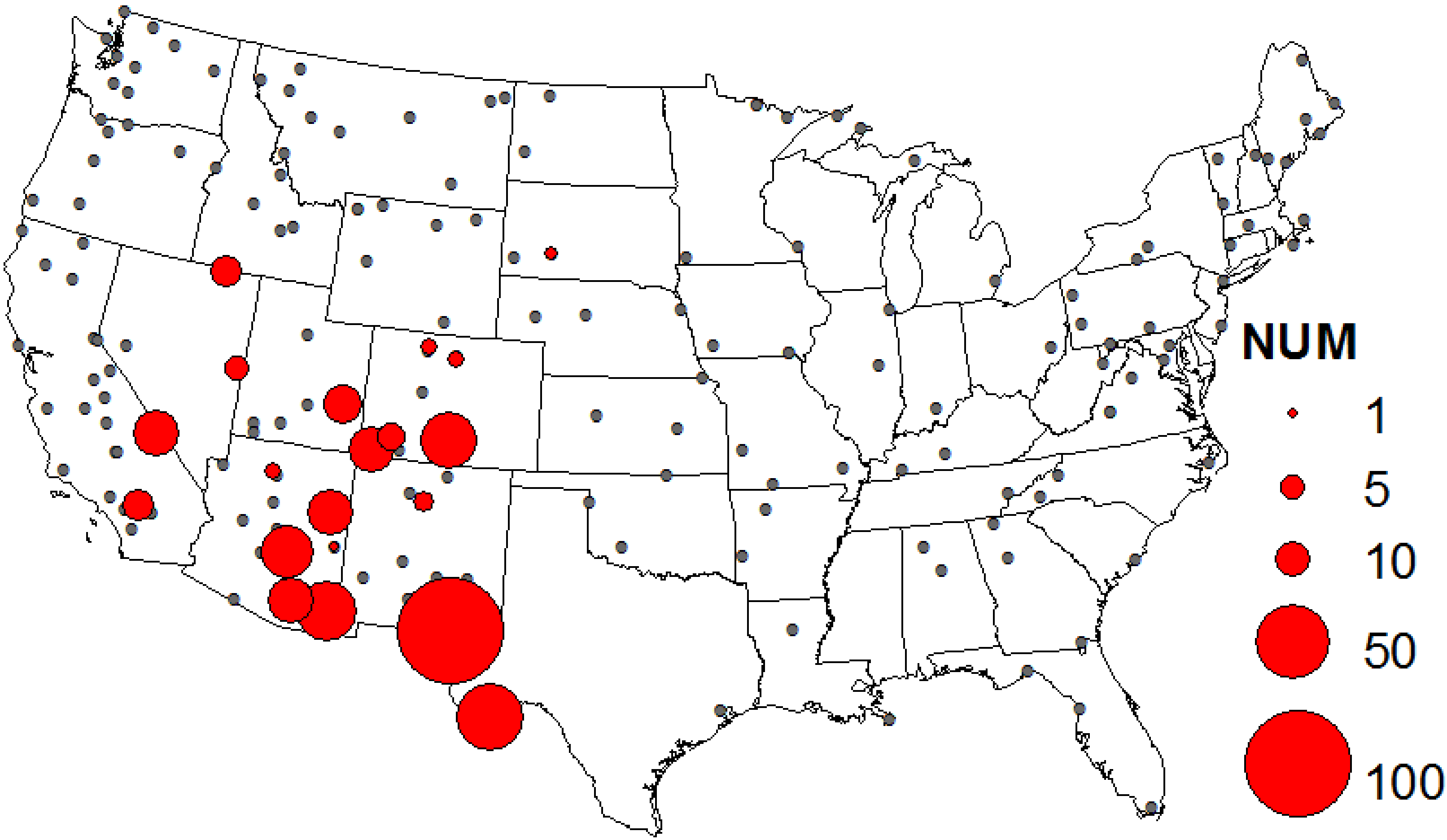
Guadalupe Mountains National Park



(Source: Mo Dan)

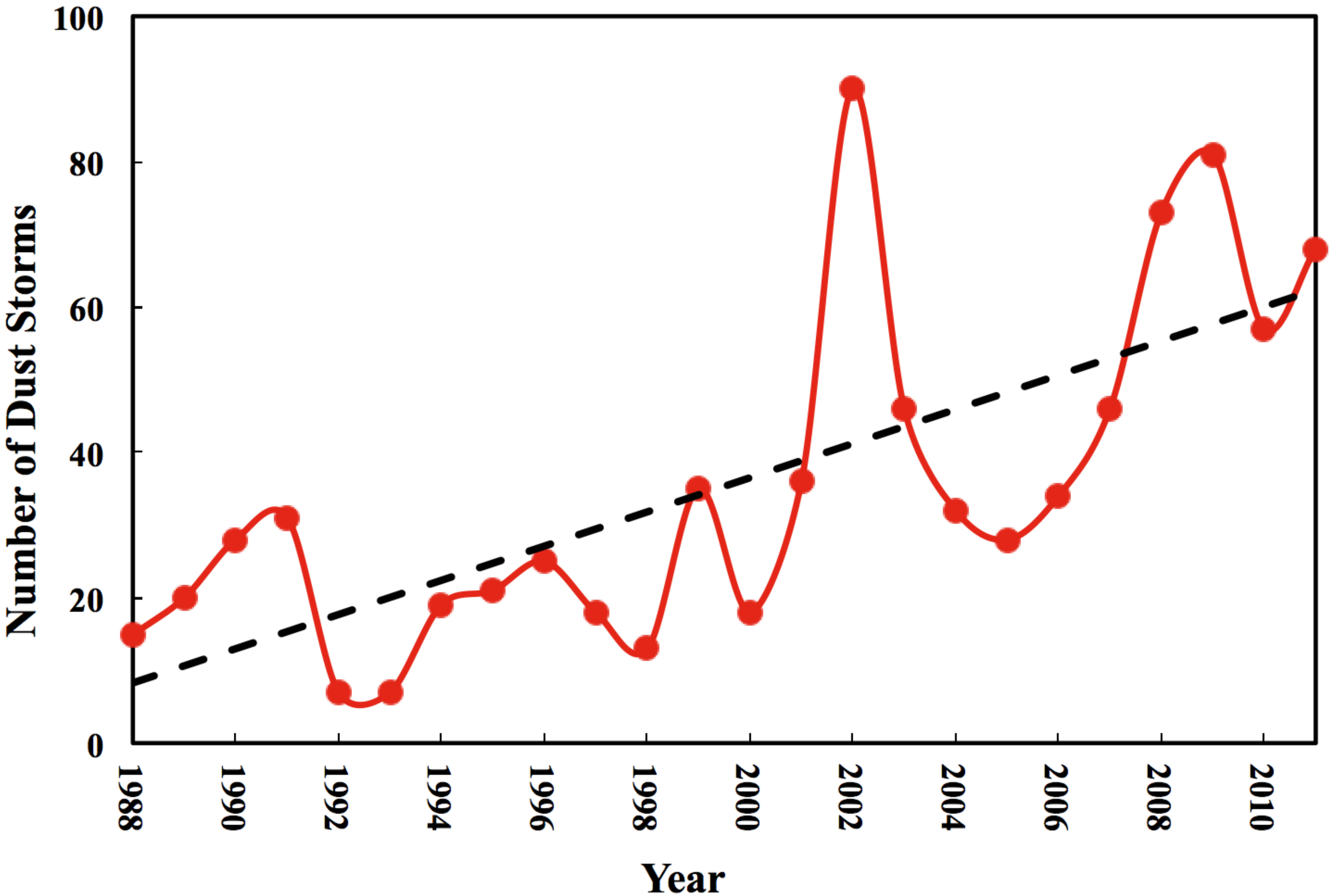
This algorithm, combined with cluster analysis, can pin-point dust.

Locations of Dust Storms



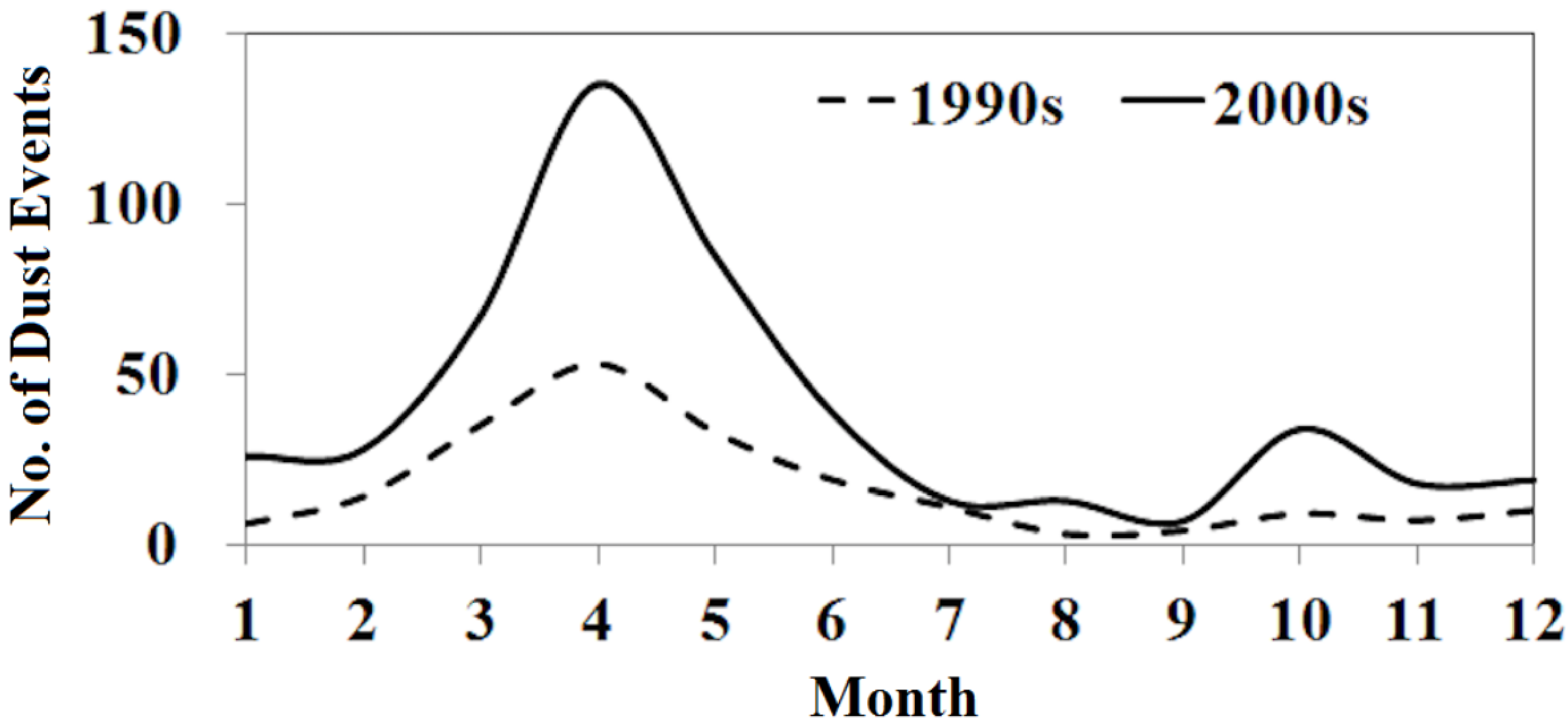
Dust storms detected at 29 sites with continuous data records.

Long-term Dust Trend



20 Giant Storms in 1990s → 48 Storms in 2000s;

Seasonal Variation

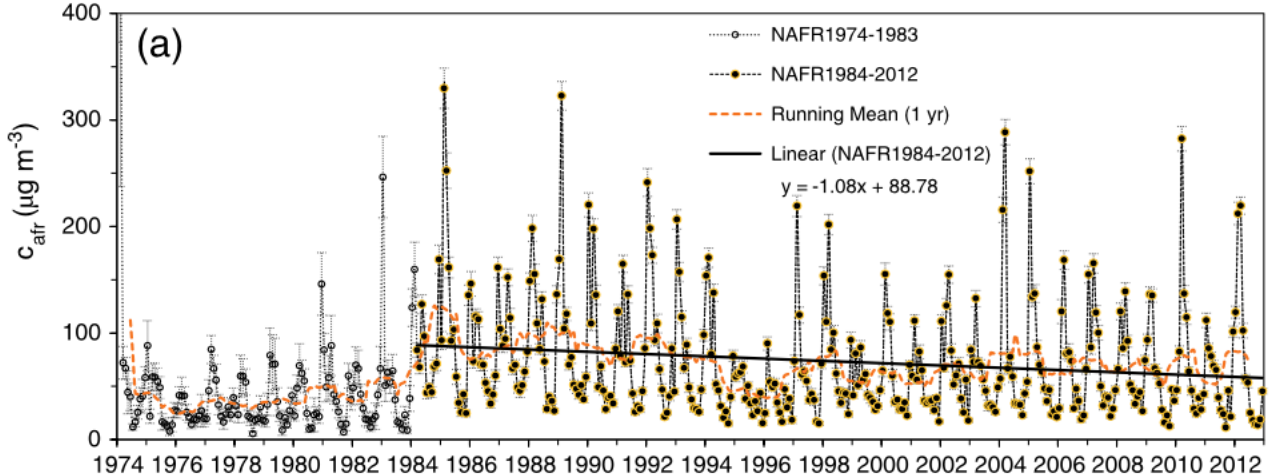


Increase in Spring (mostly) and Fall;

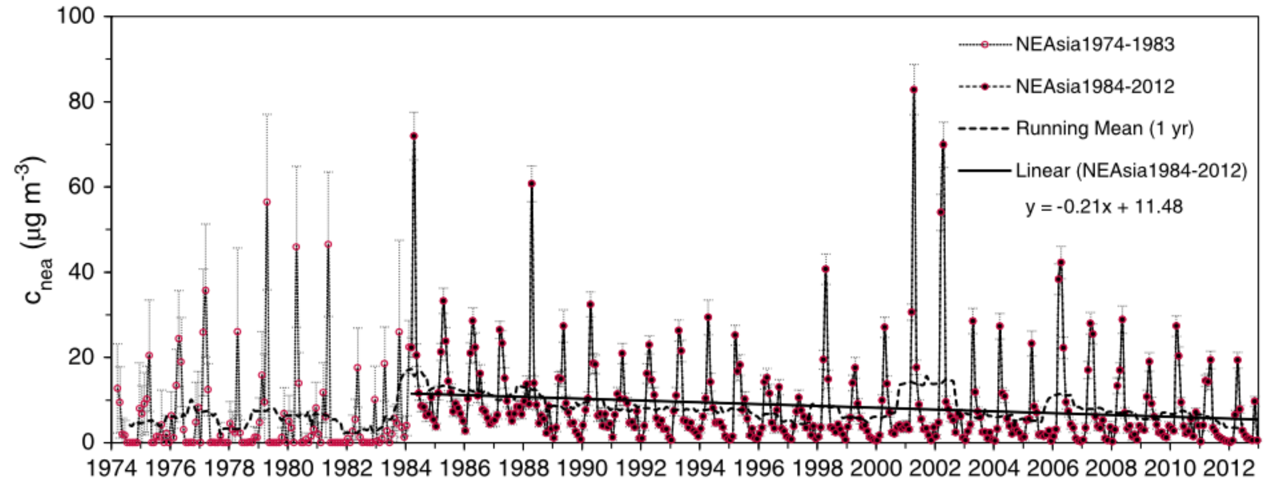
Almost no change in Summer/Wet Season;

Decreasing Dust Trends in Asia and Africa

(Shao et al., 2013)



Northern Africa

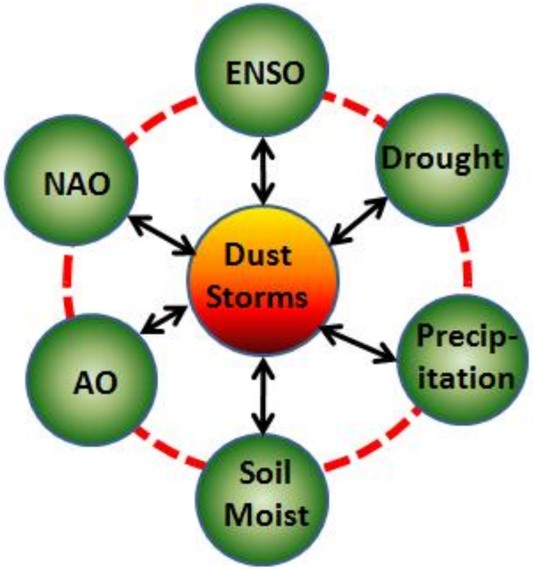


Northern Asia

Global dust concentration decreased at 1.2%/yr from 1984 –2012

What Drives the Dust Trend?

(Contributed by Hang Lei)

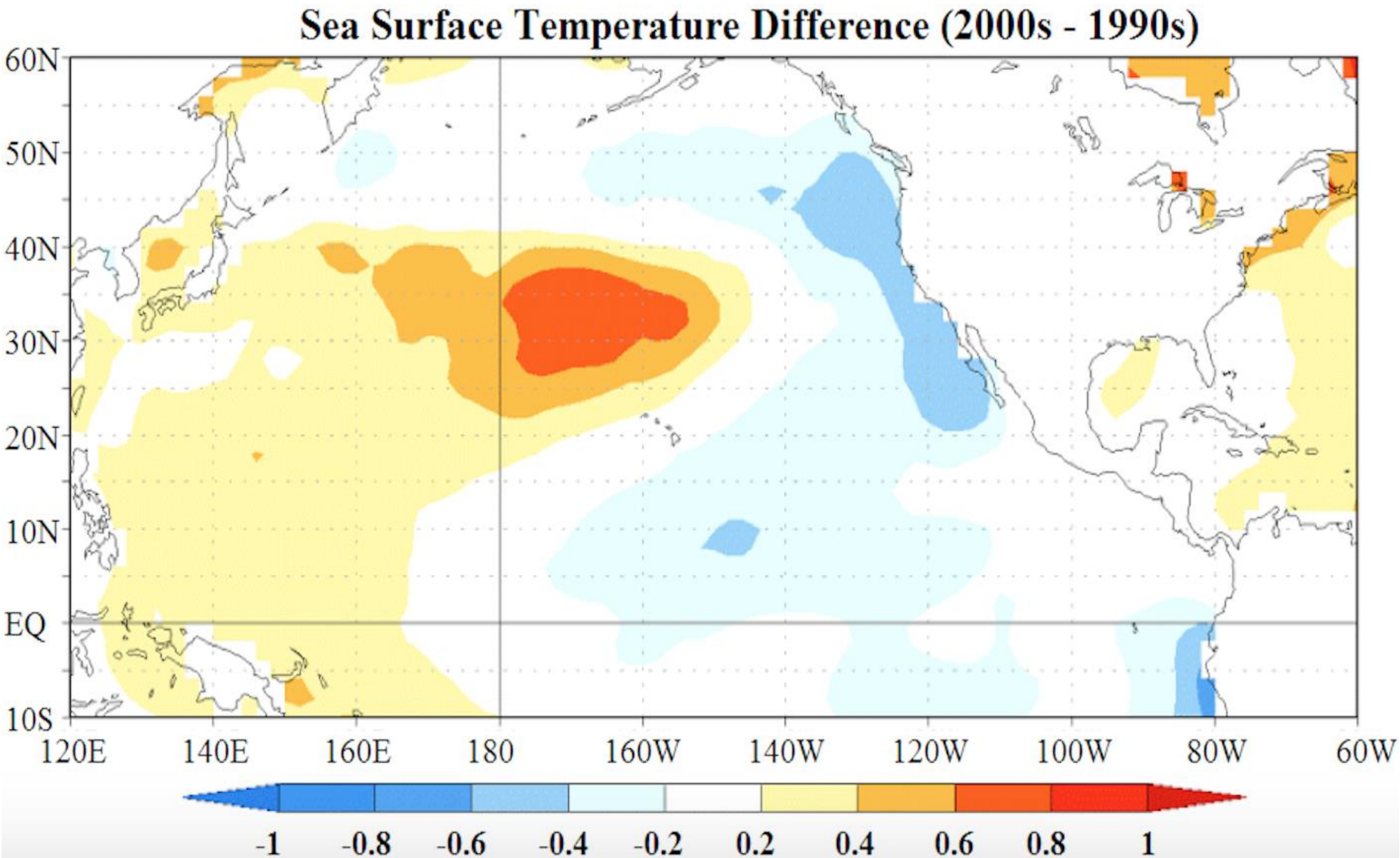


ENSO - El-Nino Southern Oscillation
PDO - Pacific Decadal Oscillation
NAO - North Atlantic Oscillation
PNA - Pacific/North American Oscillation
AO - Arctic Oscillation

	ENSO	PDO	NAO	PNA	AO
LL-dust	-0.44	-0.62	-0.41	-0.33	0.38
HL-dust	-0.32	-0.73	-0.40	-0.56	0.33

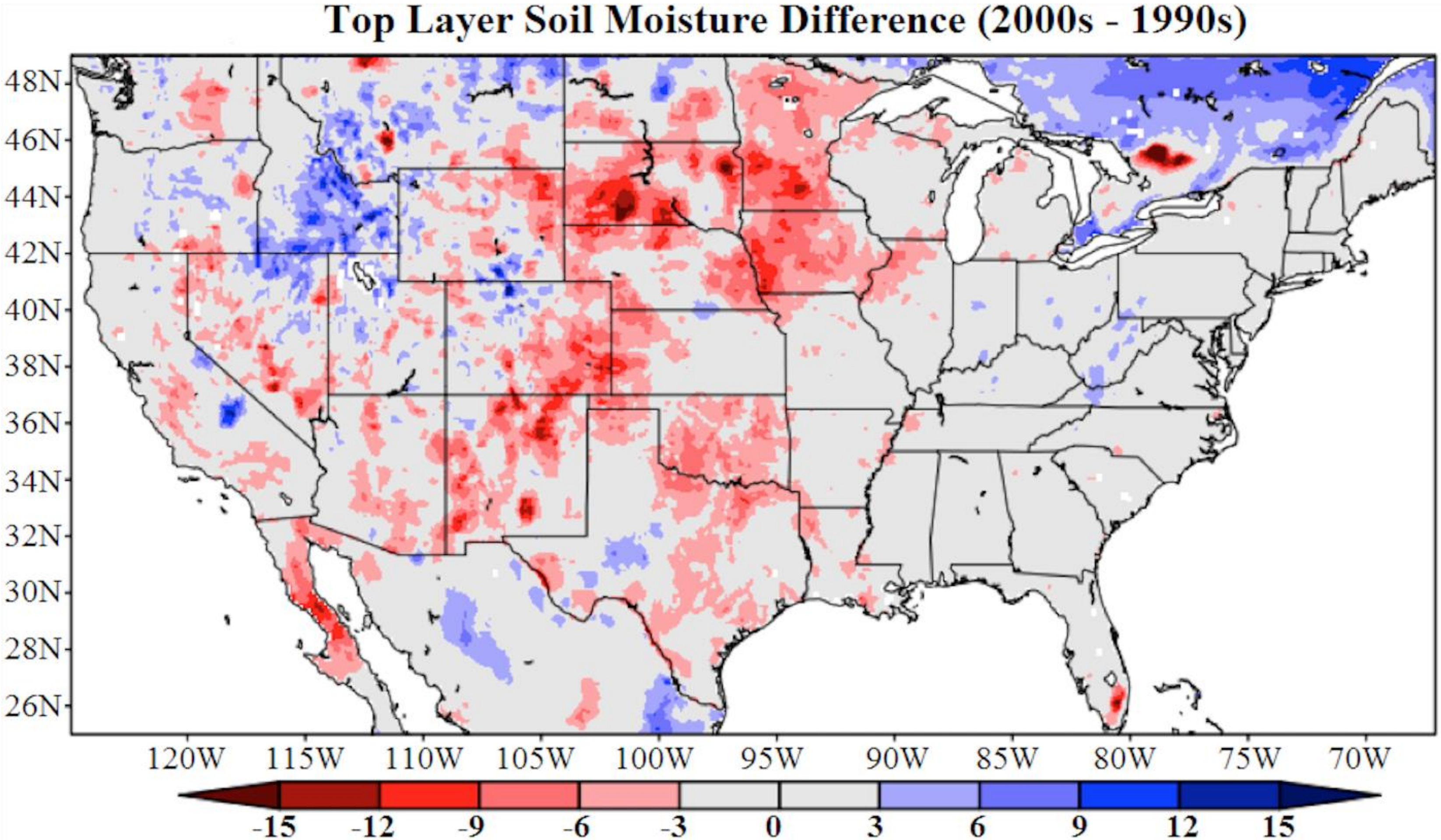
LL – Low Latitude North American deserts (Chihuahua, Mojave, and Sonoran);
HL – High Latitude Deserts (Great Basin and Colorado Plateau)

Changes in Sea Surface Temperature



(Contributed by Julian Wang)

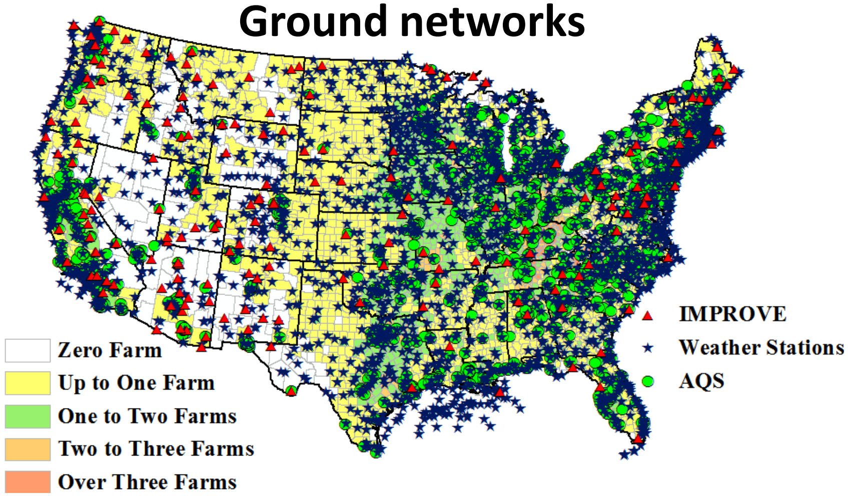
Changes in Soil Moisture



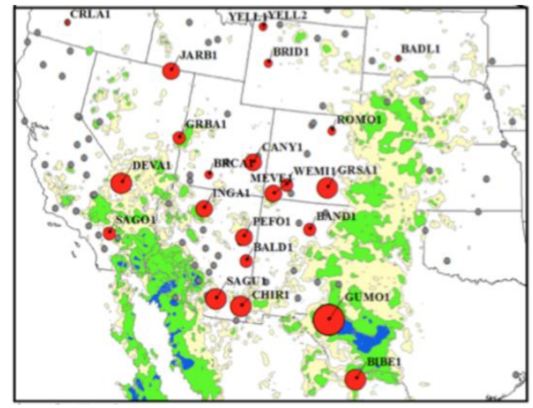
(Contributed by Julian Wang)

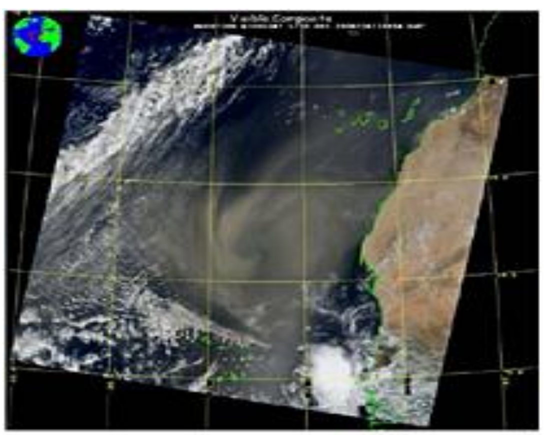
What's Next?

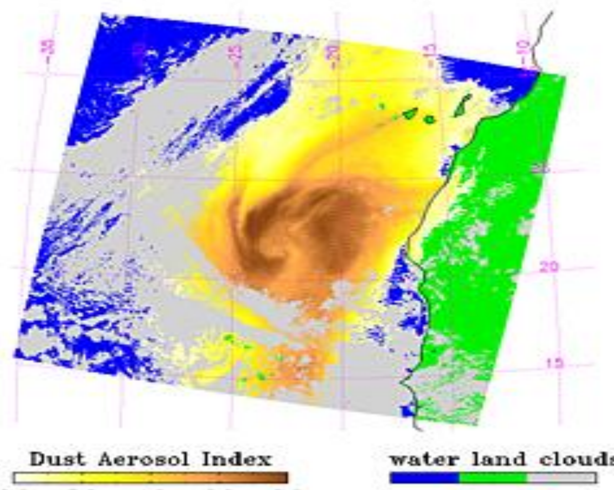
Ground networks



IMPROVE vs MODIS Dust Frequency (MODIS data - Ginoux et al., 2012)







(source: Ciren and Kondragunta, 2014)

- Build community consensus on the long-term trend;
- Use ground data for satellite product validation.

Summary

◆ **We developed a new dust identification method for IMPROVE dataset for VIIRS Dust validation**

◆ **The frequency of dust storms more than doubled from 1990s to 2000s in the Southwest United States.**

◆ **The dust trend is likely driven by large-scale variations of sea surface temperature in the Pacific Ocean.**

- **Further information:**

Tong et al., Atmospheric Chemistry & Physics, 2012;

Lei et al., Climate Dynamics, 2016;

Tong et al., Geophysical Research Letter, 2017;

Acknowledgment & Data Access

- **Funding Support: NASA ROSES and NOAA USWRP;**
- **Data: EPA, NOAA, NASA, CDC and Arizona DHS;**
- **Many colleagues for inspiring discussion.**

- **Data Access: Email qtong@gmu.edu**
- **Project Website: http://ws.laits.gmu.edu/nca**