MISR:
A Prototype New Product

Michael J. Garay
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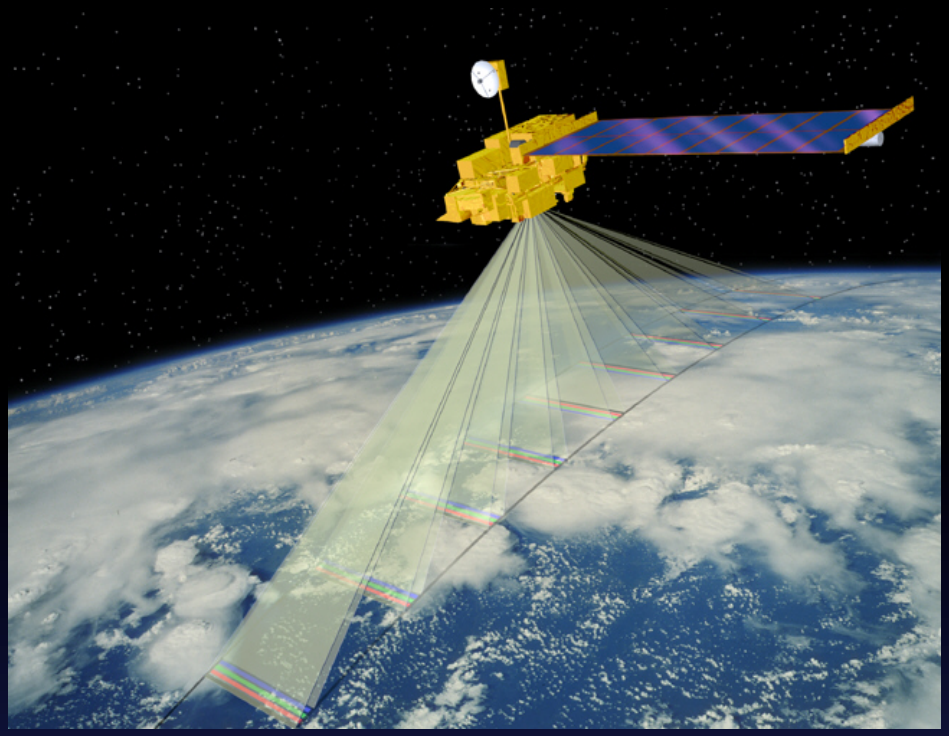

Nine view angles at Earth surface:
70.5° forward to 70.5° backward

Nine 14-bit pushbroom cameras

275 m - 1.1 km sampling

Four spectral bands at each angle:
446, 558, 672, 866 nm

400-km swath: 9-day coverage
at equator, 2-day at poles

7 minutes to observe each scene
at all nine angles

International Cooperative for Aerosol Prediction (ICAP)
Boulder, Colorado

23 October 2014

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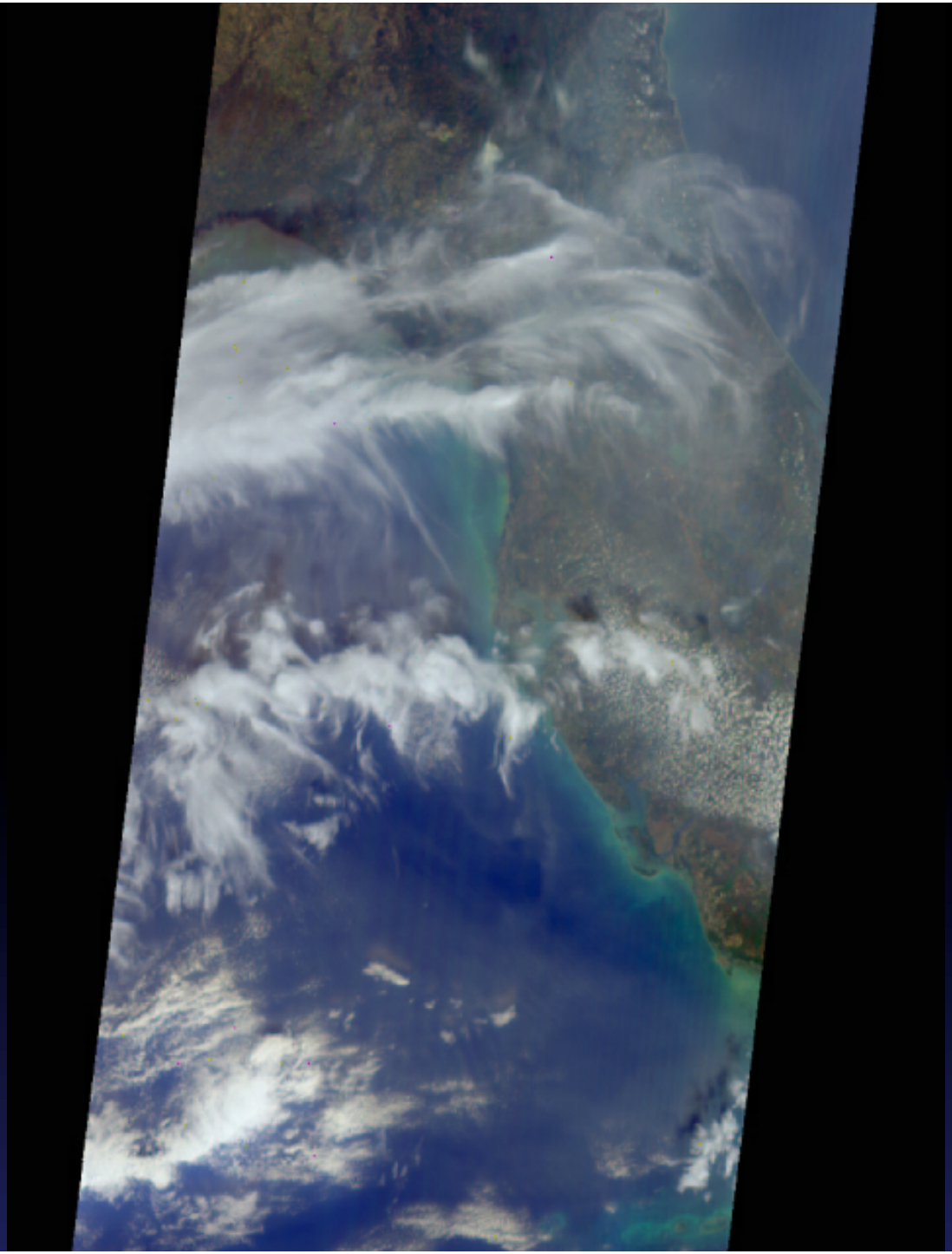
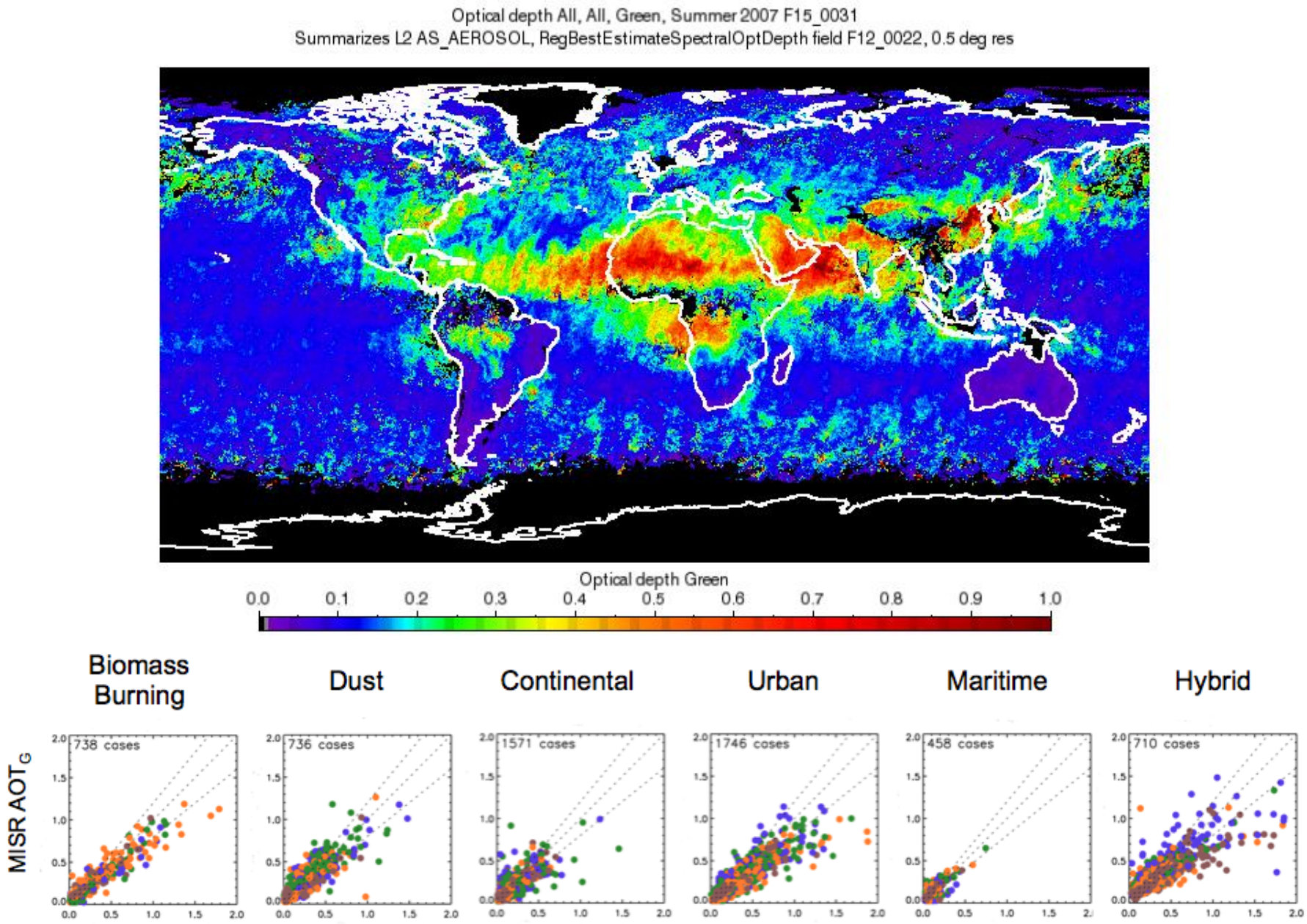


Menu

- Appetizer
  - About the current MISR product
- Salad
  - Moving to 4.4 km resolution
  - NRT?
- Main
  - The MISR retrieval algorithm
- Dessert
  - Benford's Law

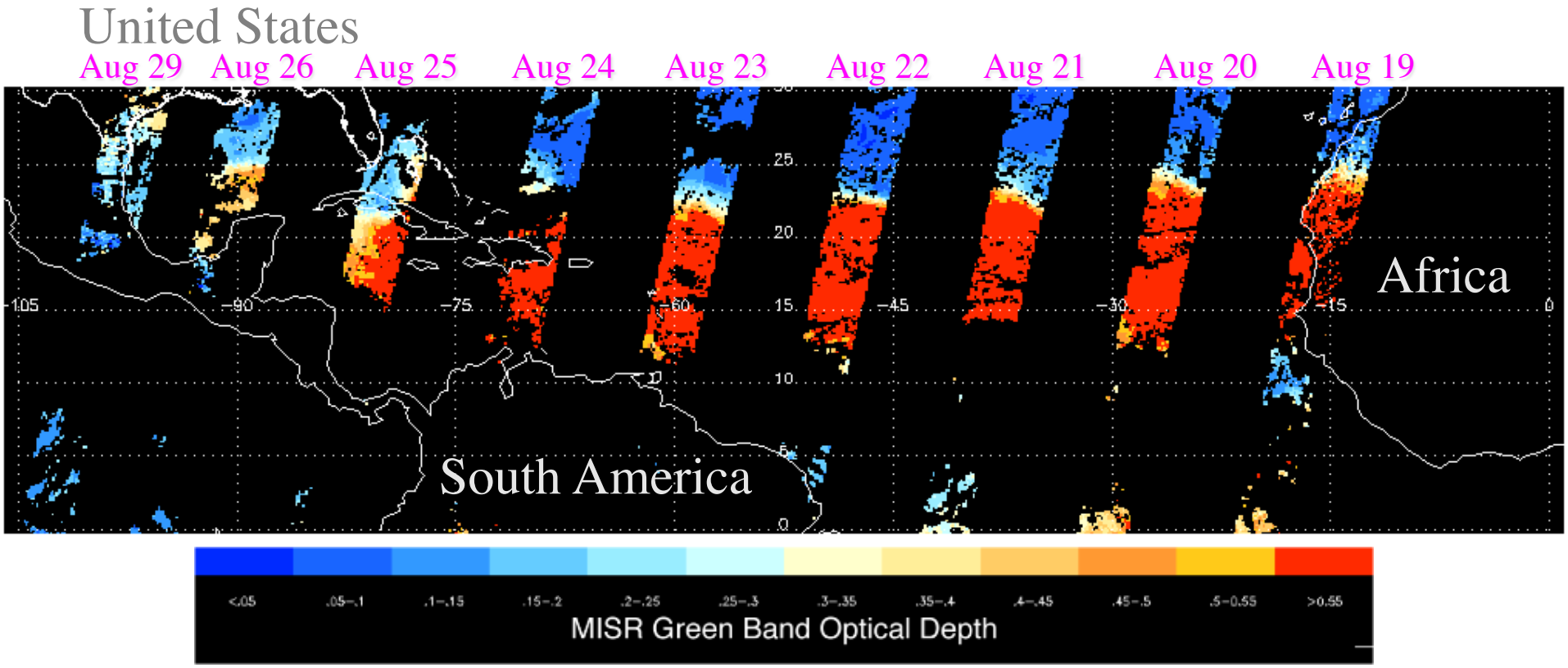
Appetizer


THE JOURNEY OF A THOUSAND MILES
BEGINS WITH BUT A SINGLE STEP
OFF A THOUSAND-MILE-HIGH CLIFF.



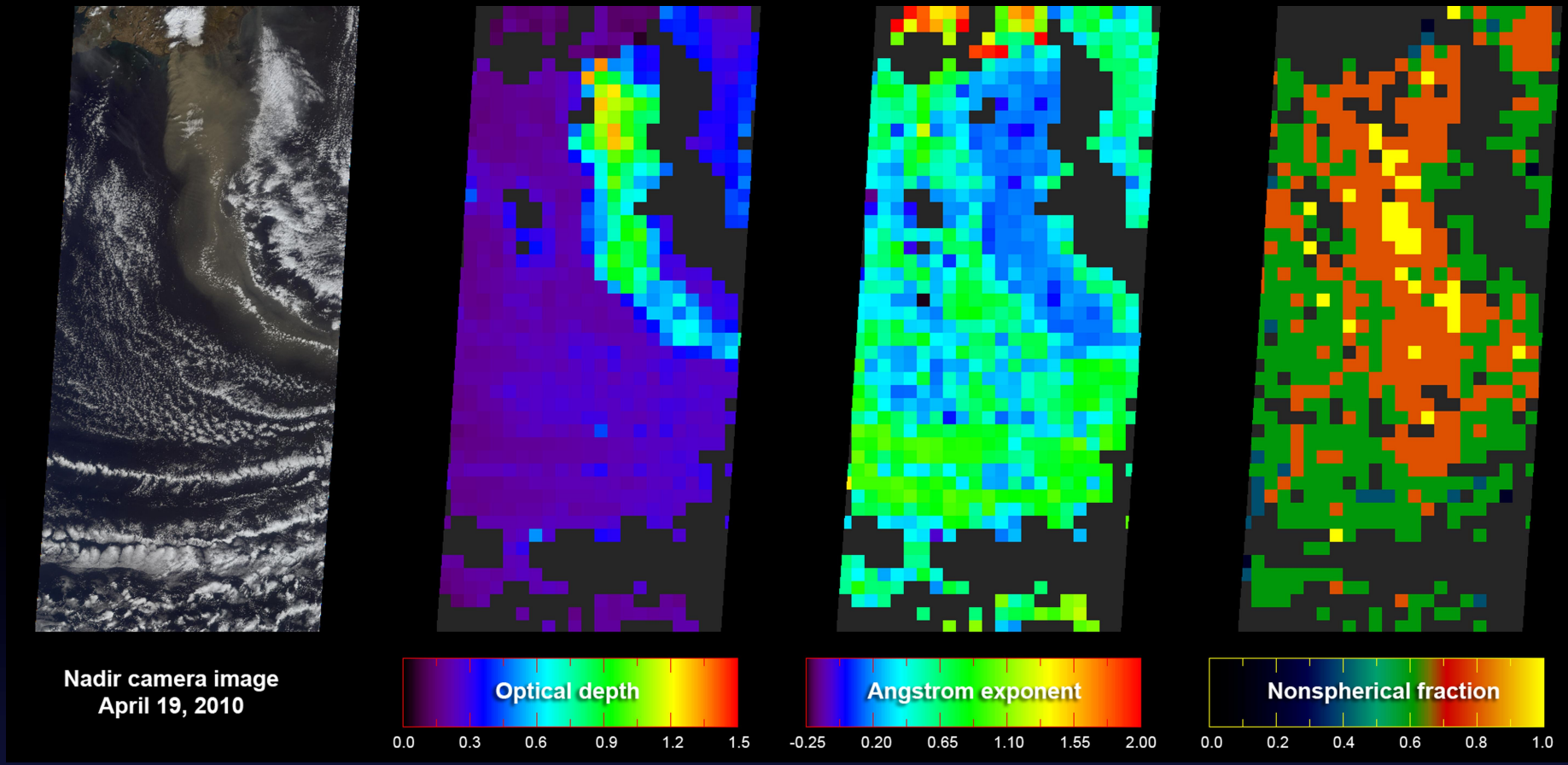
Kahn et al. (2010). Multiangle Imaging SpectroRadiometer global aerosol product assessment by comparison with the Aerosol Robotic Network, *Journal of Geophysical Research – Atmospheres*

Dust from the Sahara Desert Reaches Houston, Texas



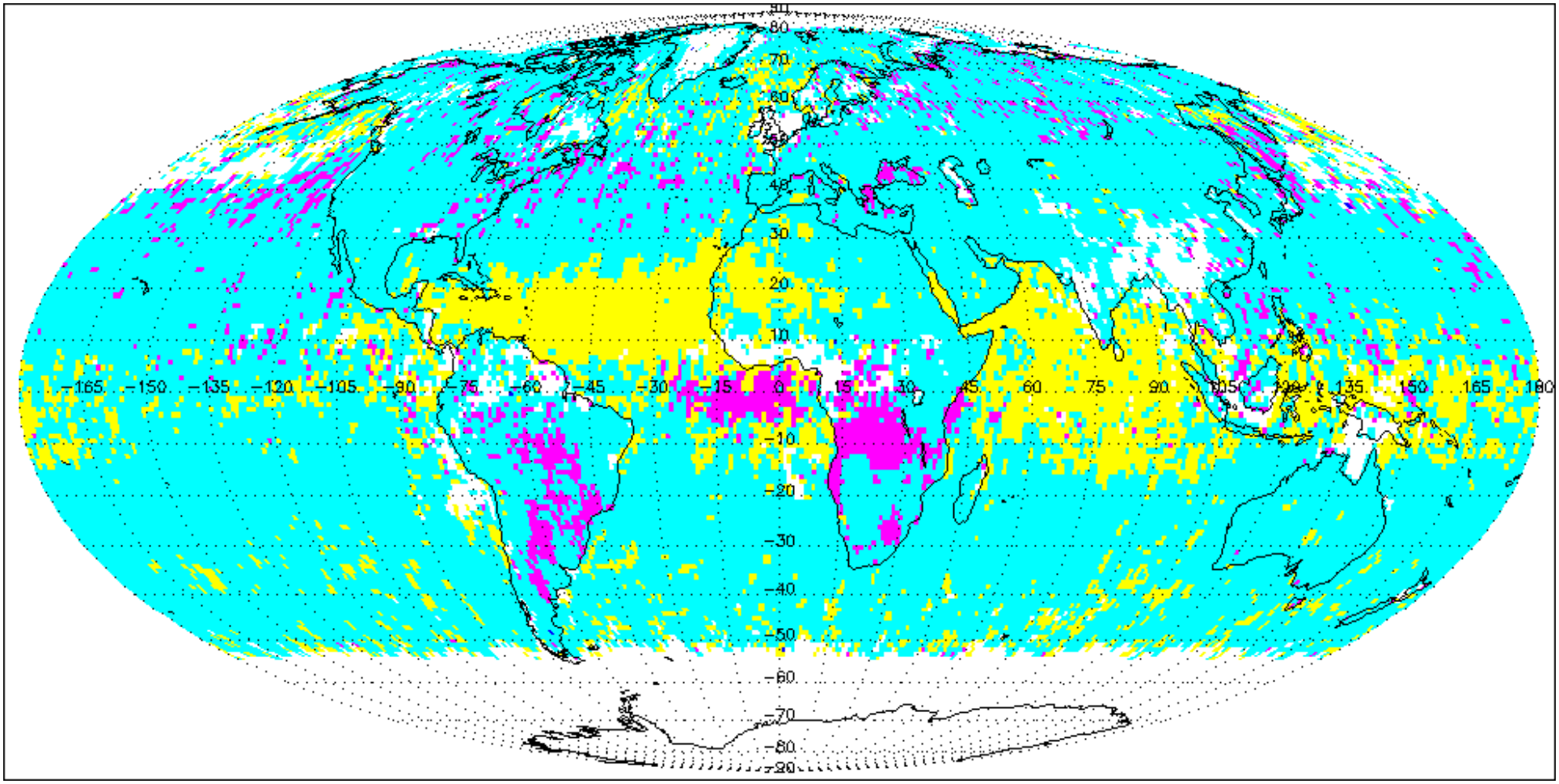
Observations from the Multi-angle Imaging SpectroRadiometer (MISR) Instrument on NASA's EOS Terra Satellite

Aerosol particle properties from MISR



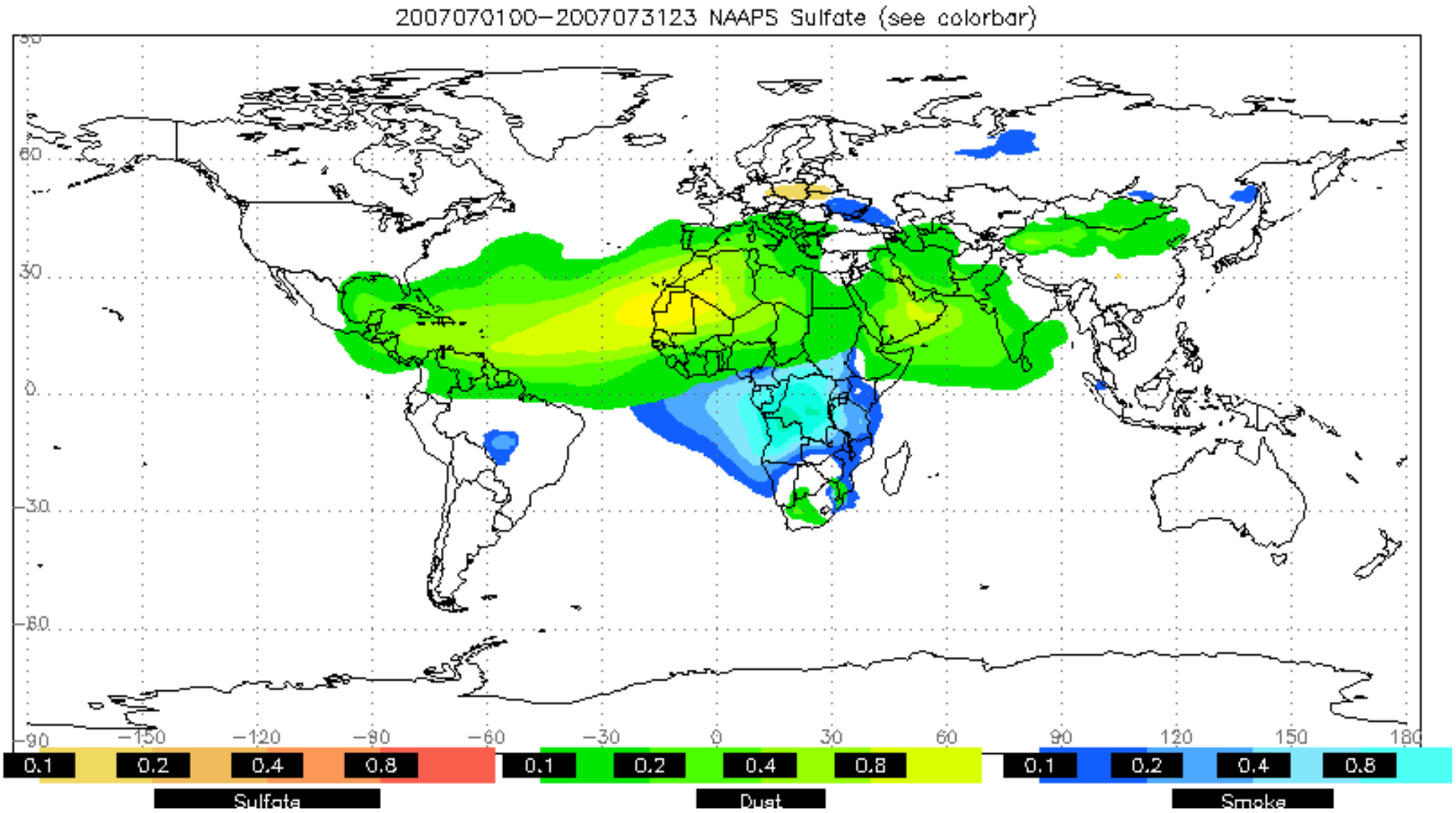
MISR views of Eyjafjallajökull – 4/19/2010

MISR Version 22 Operational Aerosol Product for July 2007



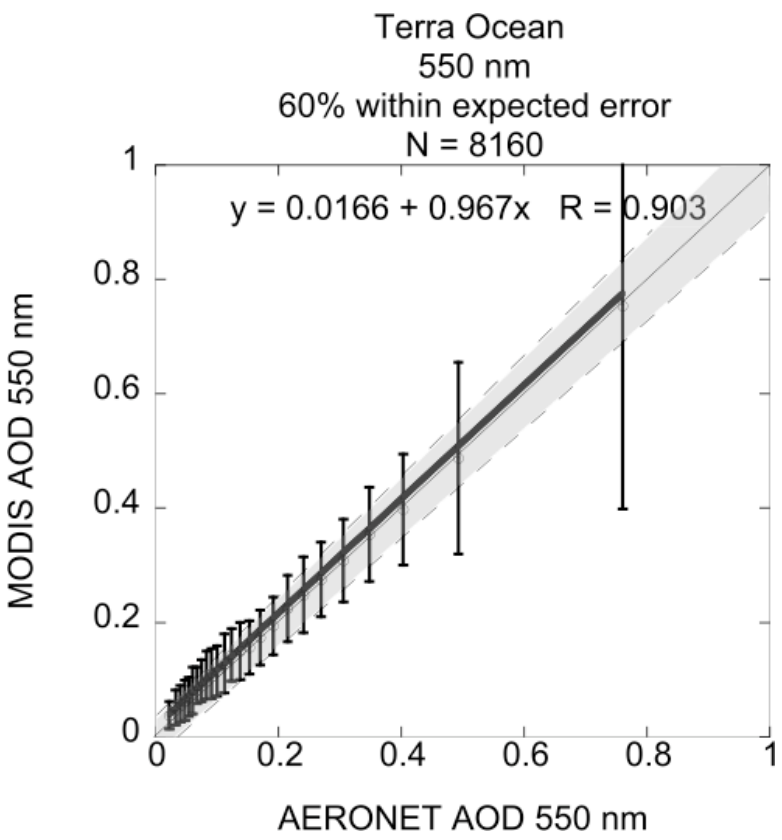
Key

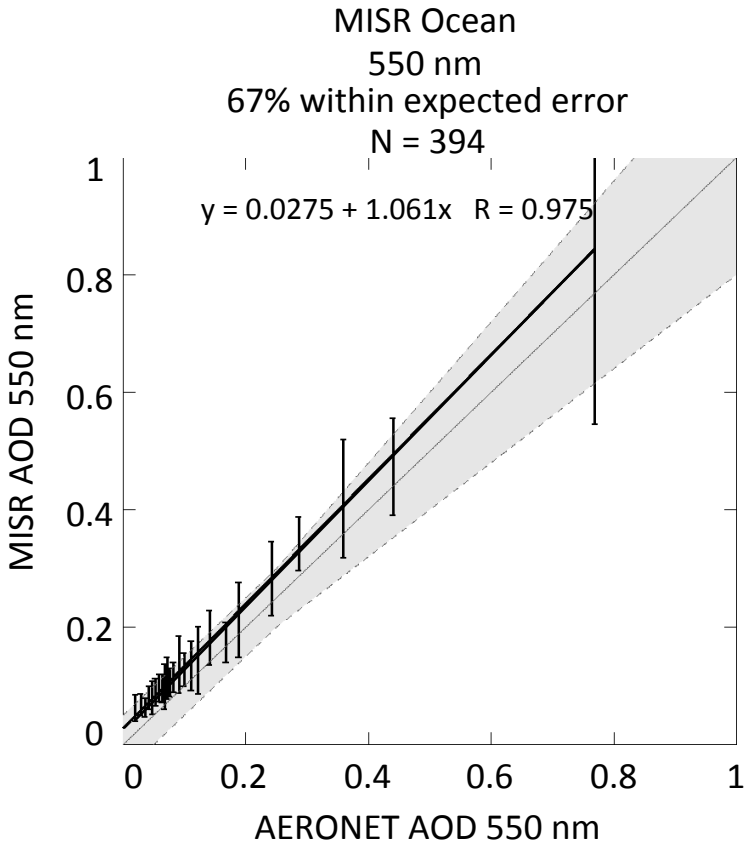
- Spherical Non-Absorbing
- Spherical Absorbing
- Non-Spherical



Aerosol climatology from NAVY Aerosol Analysis and Prediction System (NAAPS) for July 2007

Note: AOT < 0.1 not shown


Terra Ocean
550 nm
60% within expected error
N = 8160
y = 0.0166 + 0.967x R = 0.903
MODIS AOD 550 nm
AERONET AOD 550 nm
0
0.2
0.4
0.6
0.8
1


MISR Ocean
550 nm
67% within expected error
N = 394
y = 0.0275 + 1.061x R = 0.975
MISR AOD 550 nm
AERONET AOD 550 nm
0
0.2
0.4
0.6
0.8
1

Salad

Motivation?

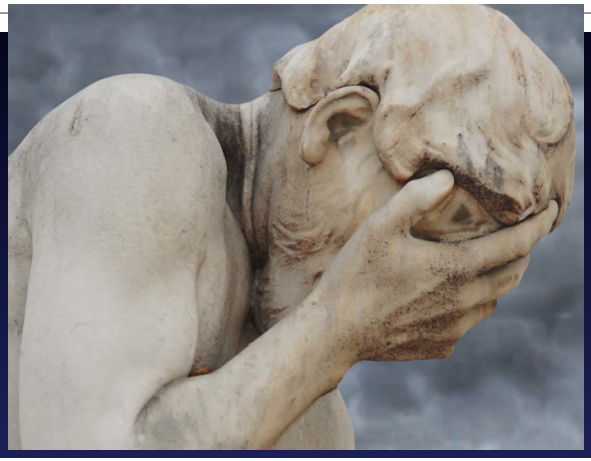
- "Overall, about 70% to 75% of MISR AOD retrievals fall within 0.05 or 20% x AOD of the paired validation data from the Aerosol Robotic Network (AERONET), and about 50% to 55% are within 0.03 or 10% x AERONET AOD…" (Kahn et al., 2010)

CLIMATE SCIENCE

Nature, 7 November 2013

Uncertain then, irrelevant now

Uncertainty in estimates of the effects of aerosols on climate stems from poor knowledge of the past, pristine atmosphere — so getting a better understanding of these effects might not be as useful as was thought. **SEE ARTICLE P.67**



Comparison of MISR and MODIS

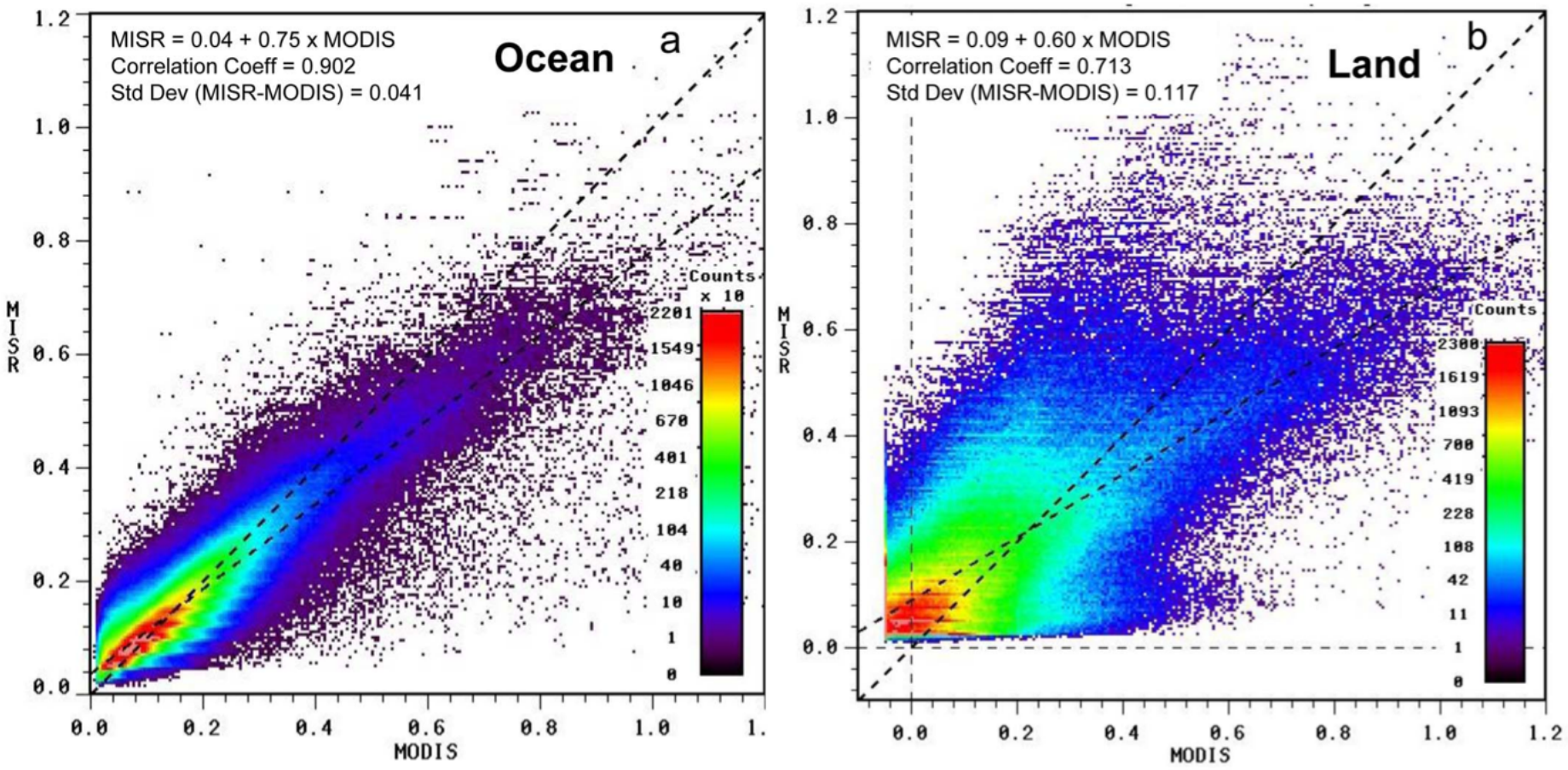
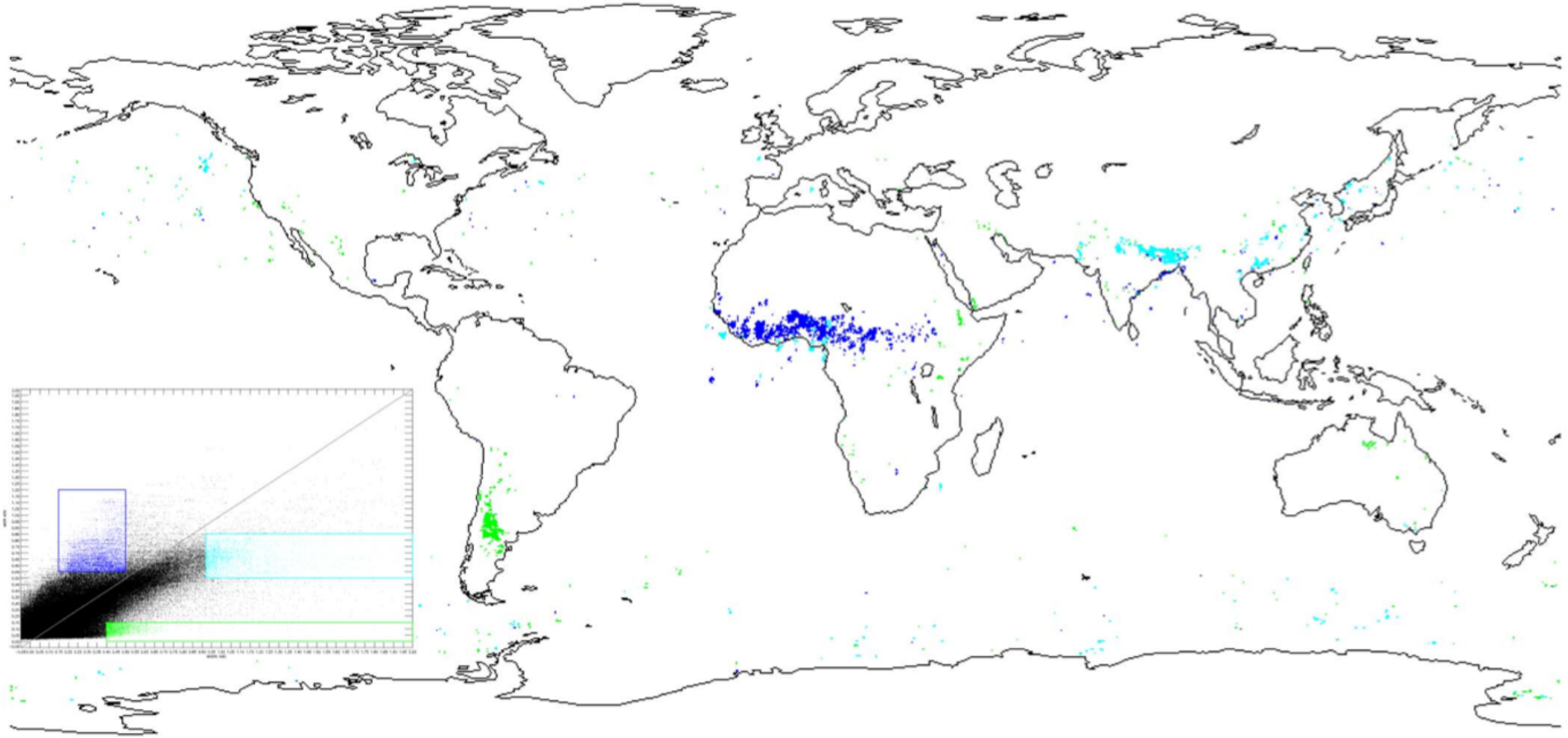
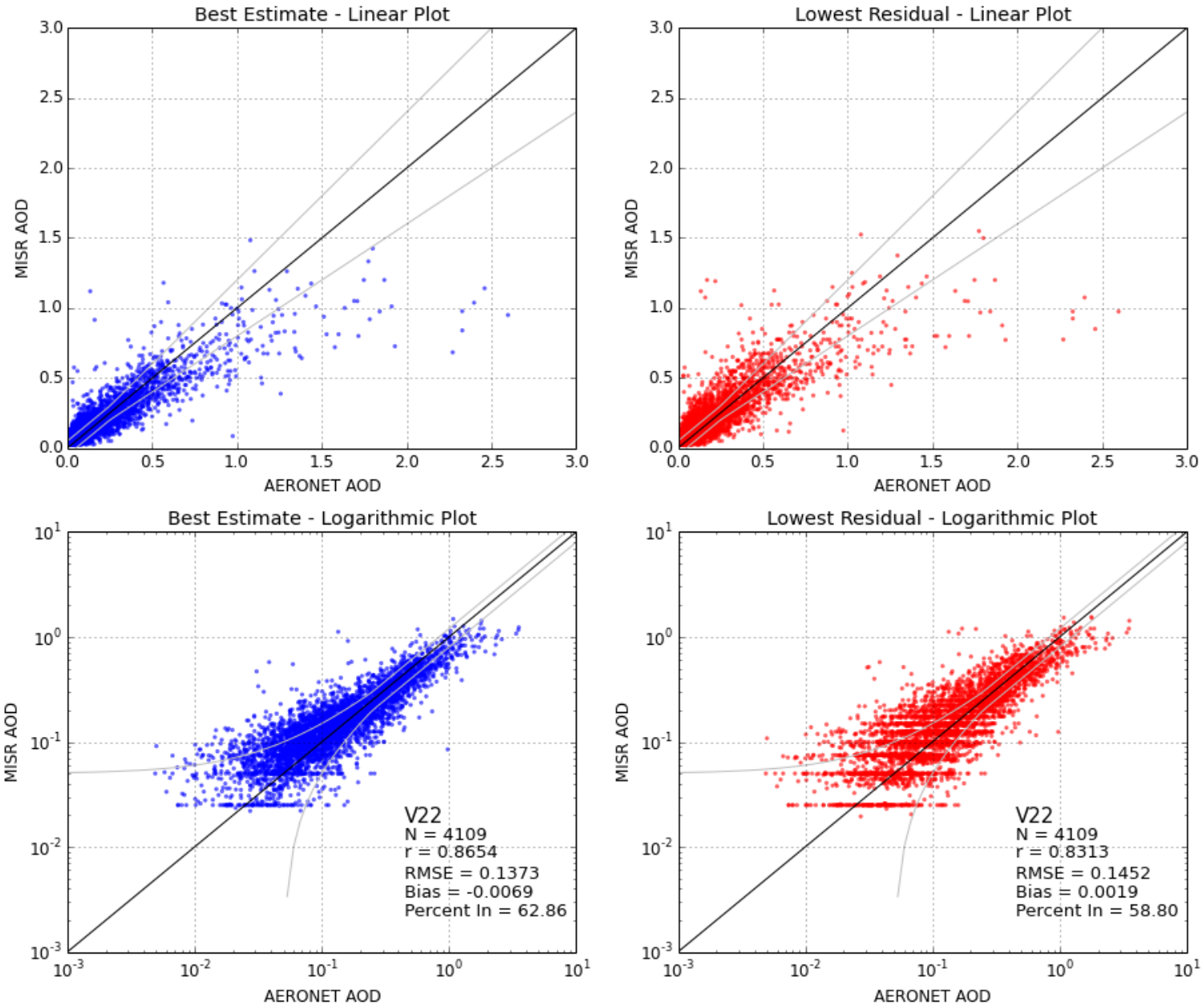
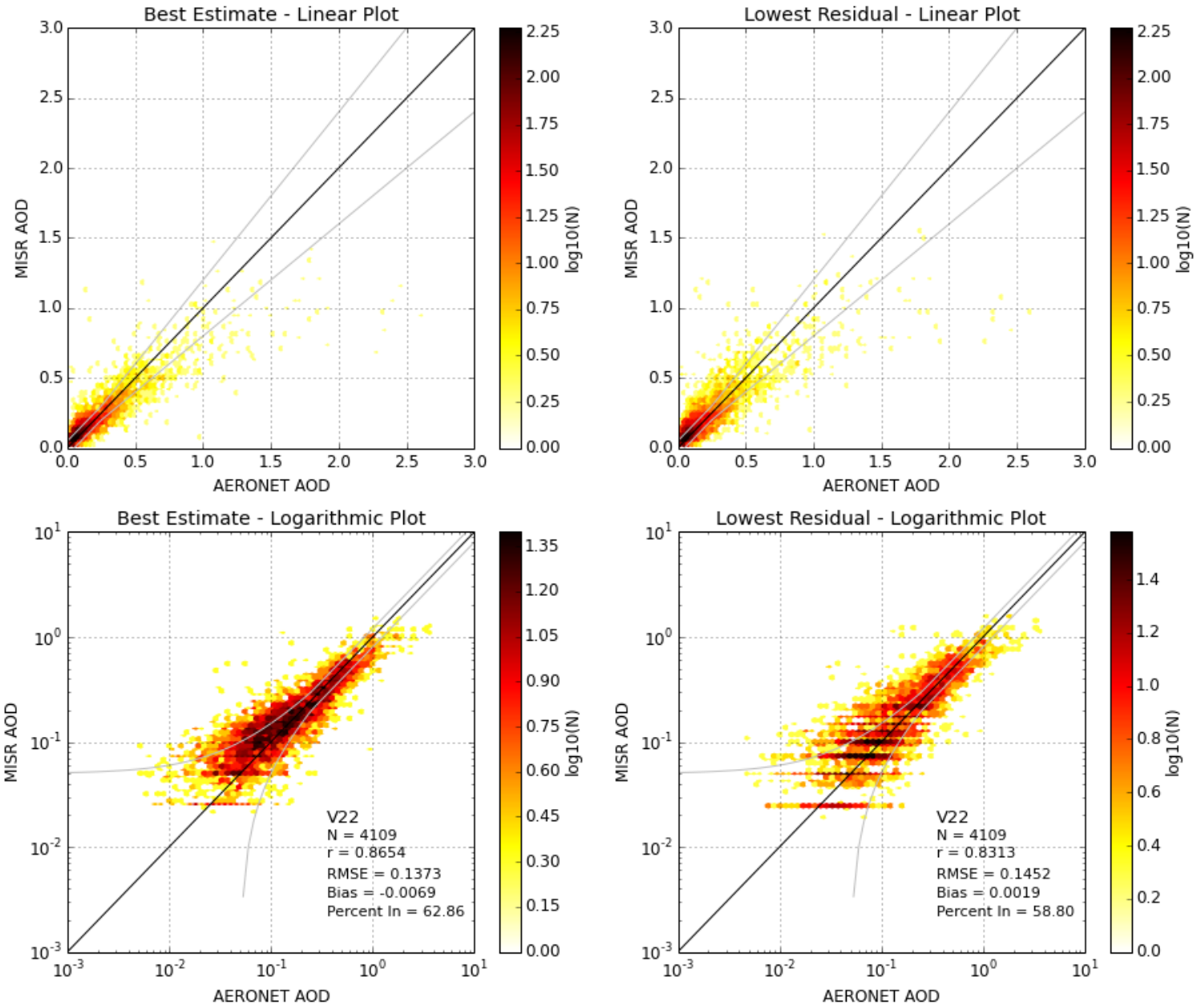


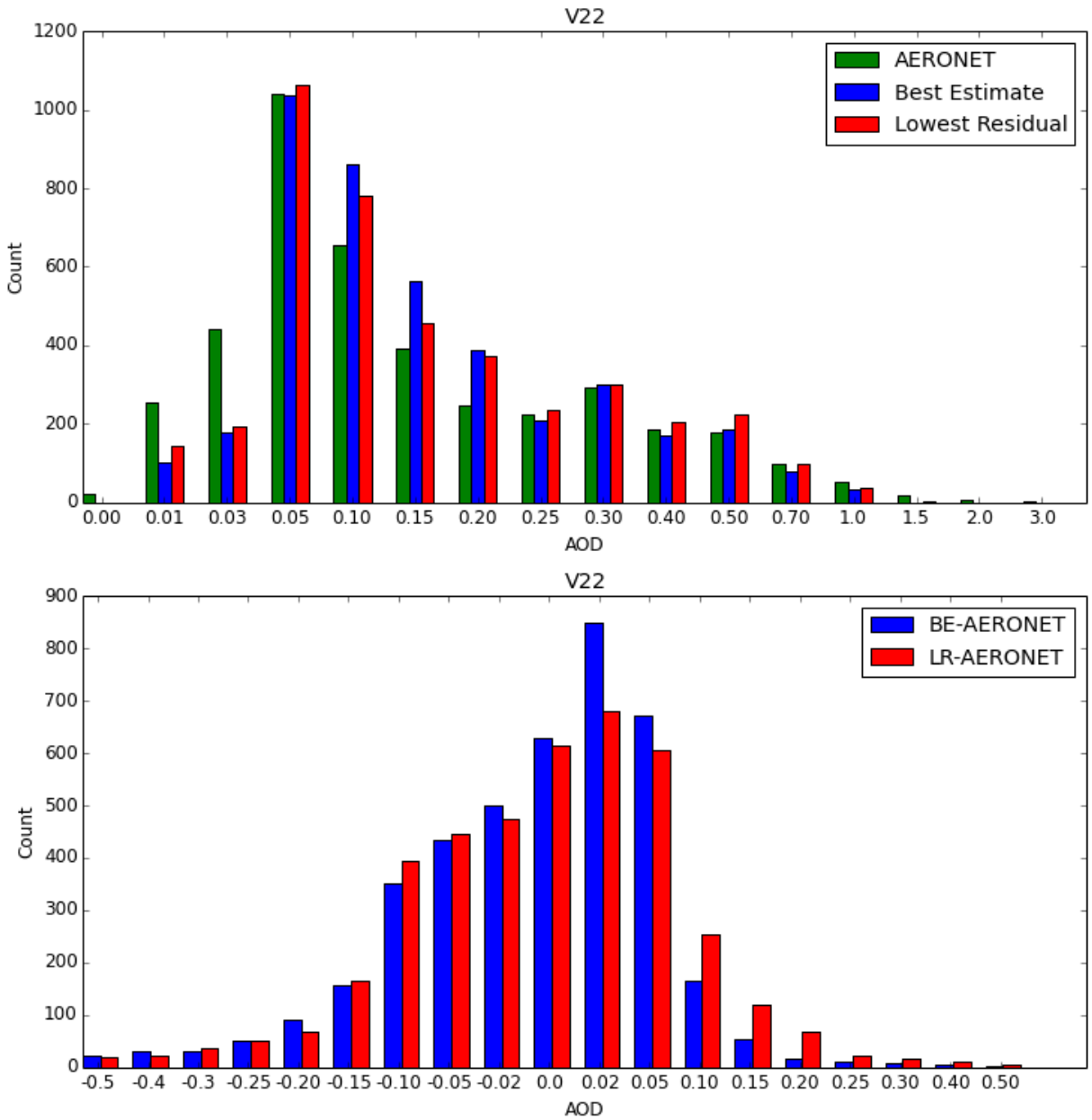
Fig. 5. Scatter plots of MISR versus MODIS coincident mid-visible AOD for January 2006, contoured using a fractional power-law color scale to show the range of point densities. (a) All over-ocean grid points. (b) All over-land grid points. For these plots, MISR Standard aerosol product Version 22 and MODIS/Terra Collection 5 data were used. The regression-line fits, correlation coefficients, and standard deviations are given in the upper left of each plot.

Particle/Mixture Issues

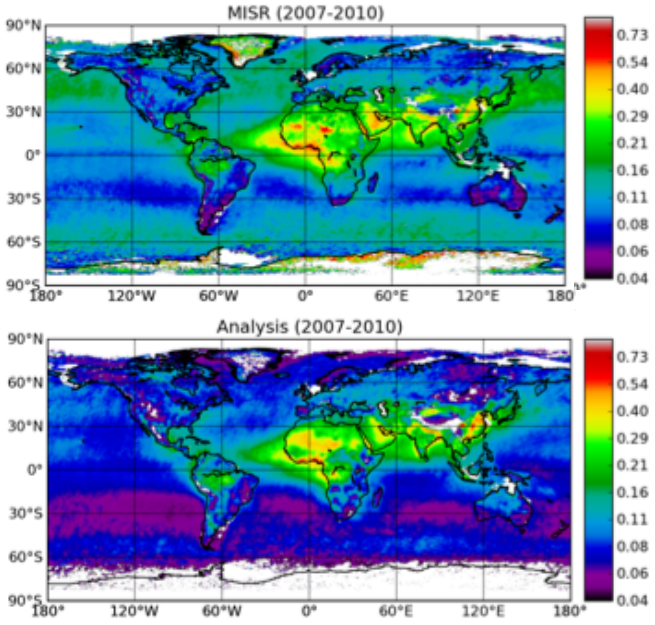


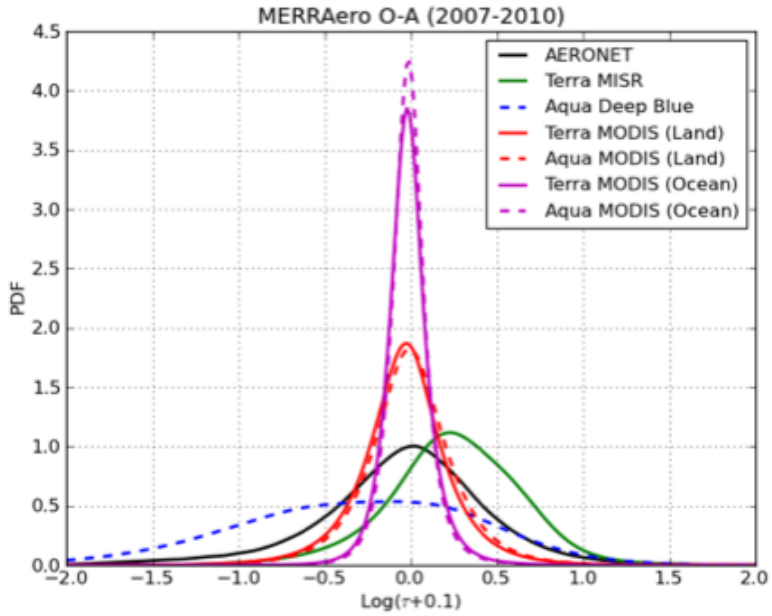

Best Estimate - Linear Plot
MISR AOD
AERONET AOD
Lowest Residual - Linear Plot
MISR AOD
AERONET AOD
Best Estimate - Logarithmic Plot
MISR AOD
AERONET AOD
V22
N = 4109
r = 0.8654
RMSE = 0.1373
Bias = -0.0069
Percent In = 62.86
Lowest Residual - Logarithmic Plot
MISR AOD
AERONET AOD
V22
N = 4109
r = 0.8313
RMSE = 0.1452
Bias = 0.0019
Percent In = 58.80


Best Estimate - Linear Plot
Lowest Residual - Linear Plot
Best Estimate - Logarithmic Plot
Lowest Residual - Logarithmic Plot
MISR AOD
AERONET AOD
log10(N)
V22
N = 4109
r = 0.8654
RMSE = 0.1373
Bias = -0.0069
Percent In = 62.86
V22
N = 4109
r = 0.8313
RMSE = 0.1452
Bias = 0.0019
Percent In = 58.80


V22
AERONET
Best Estimate
Lowest Residual
Count
AOD
0.00 0.01 0.03 0.05 0.10 0.15 0.20 0.25 0.30 0.40 0.50 0.70 1.0 1.5 2.0 3.0
V22
BE-AERONET
LR-AERONET
Count
AOD
-0.5 -0.4 -0.3 -0.25 -0.20 -0.15 -0.10 -0.05 -0.02 0.0 0.02 0.05 0.10 0.15 0.20 0.25 0.30 0.40 0.50

GEOS-5 Reanalysis Activities





Comparison to multi-year satellite data sets

Courtesy of Pete Colarco

Algorithm Updates (Completed)

Algorithm Updates (Completed)

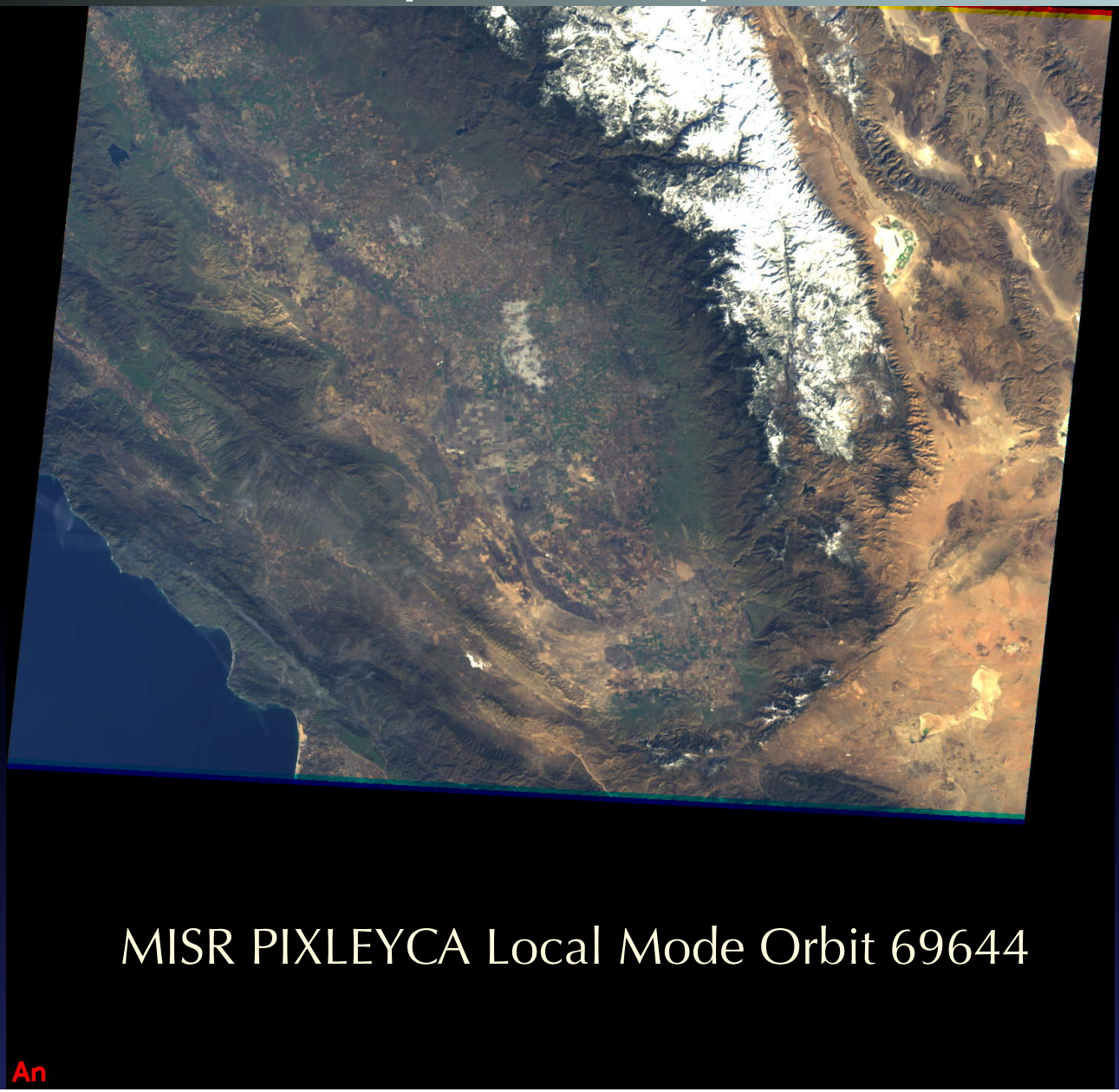
- Match angular resolution to SMART
- Update surface albedo threshold in AOD uppper bound to improve shallow water coverage
- Replace quadratic interpolation with spline in SMART translation
- Enhance HET camera selection code to improve coverage in mountains
- Revised AOD upper bound mask to account for absorbing particles
- Require contiguous grid points in parabolic fit
- Calculate chi-square parameters at retrieved AOD (not on grid)
- Fix error in variance threshold
- Remove log transform in parabolic fit
- Lower floor in chi-square uncertainty
- Use glitter to retrieve windspeed over dark water (when possible)
- Add grid points at low AOD
- Eliminate AOD "uncertainty" as successful mixture criterion
- Increase Mie code iterations for Particle 6

Product Updates (Proposed)

Product Updates (Proposed)

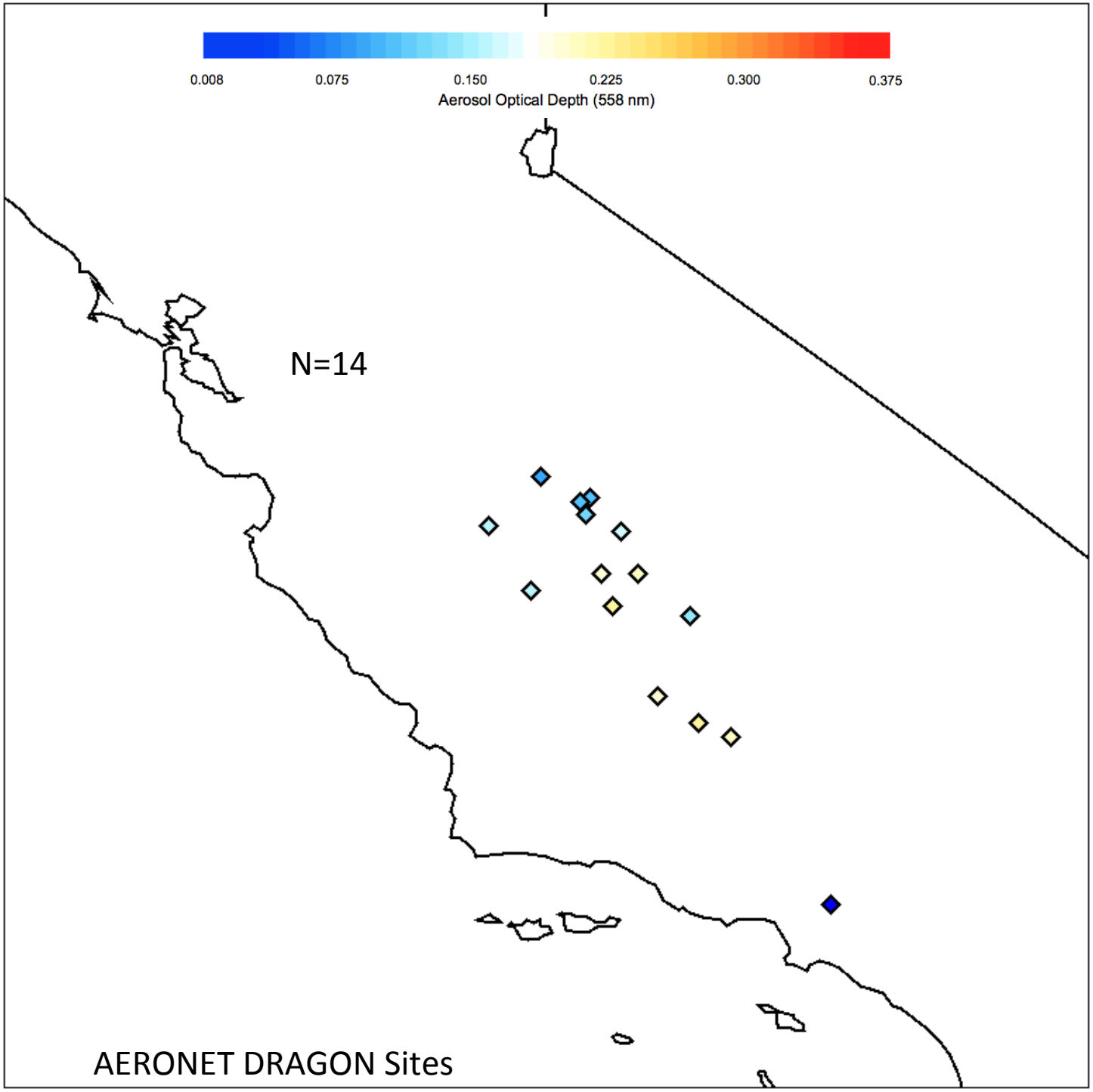
- Move to 4.4 km x 4.4 km spatial resolution
- Separate surface algorithm from aerosol algorithm
- Simplify aerosol product
  - Separate product into (at least) USER and DIAGNOSTIC file
  - Include additional fields (e.g., lat/lon) to make data more user friendly
  - Critically examine contents of current product

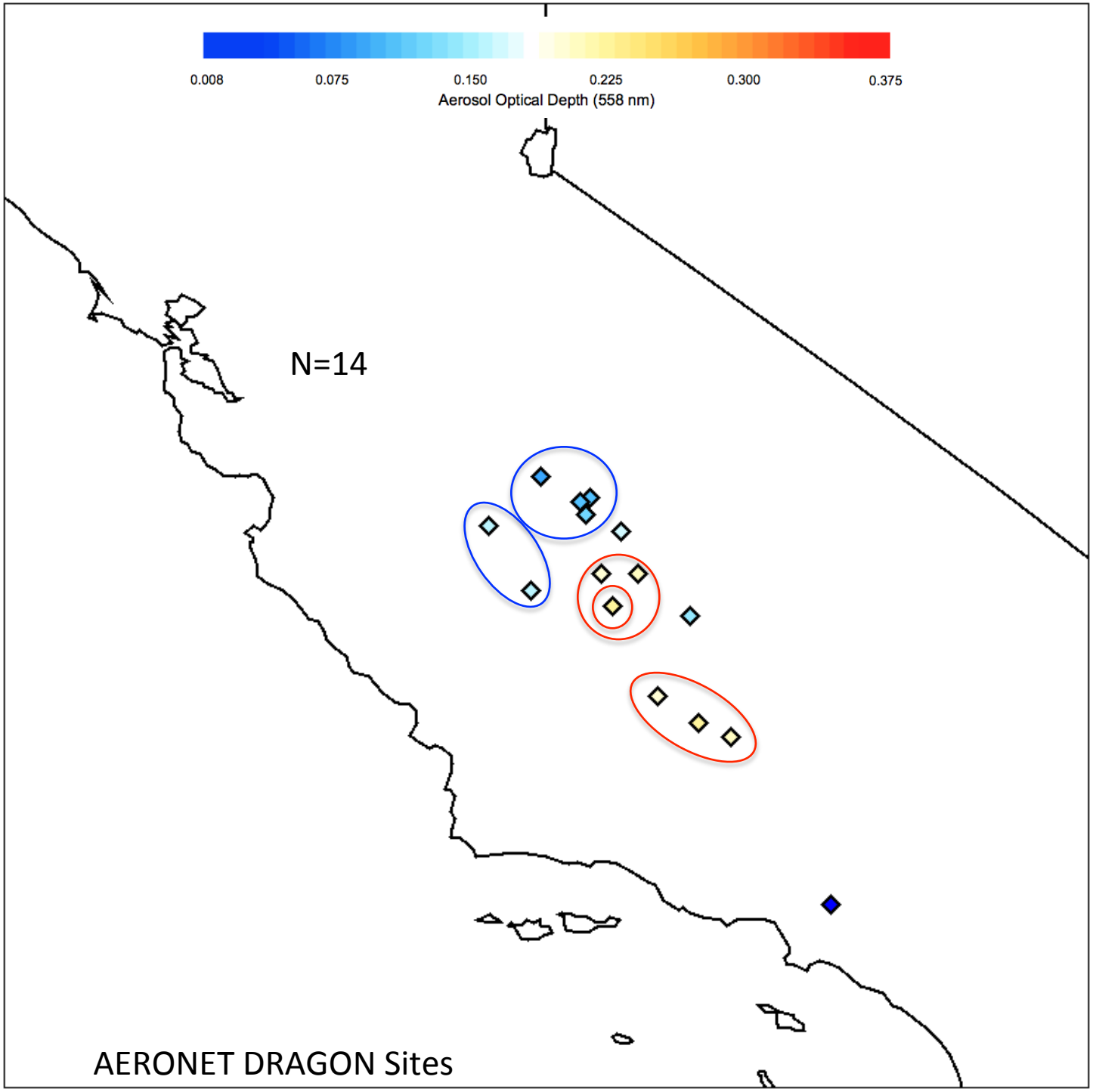
Results – San Joaquin Valley, CA 20 Jan 2013

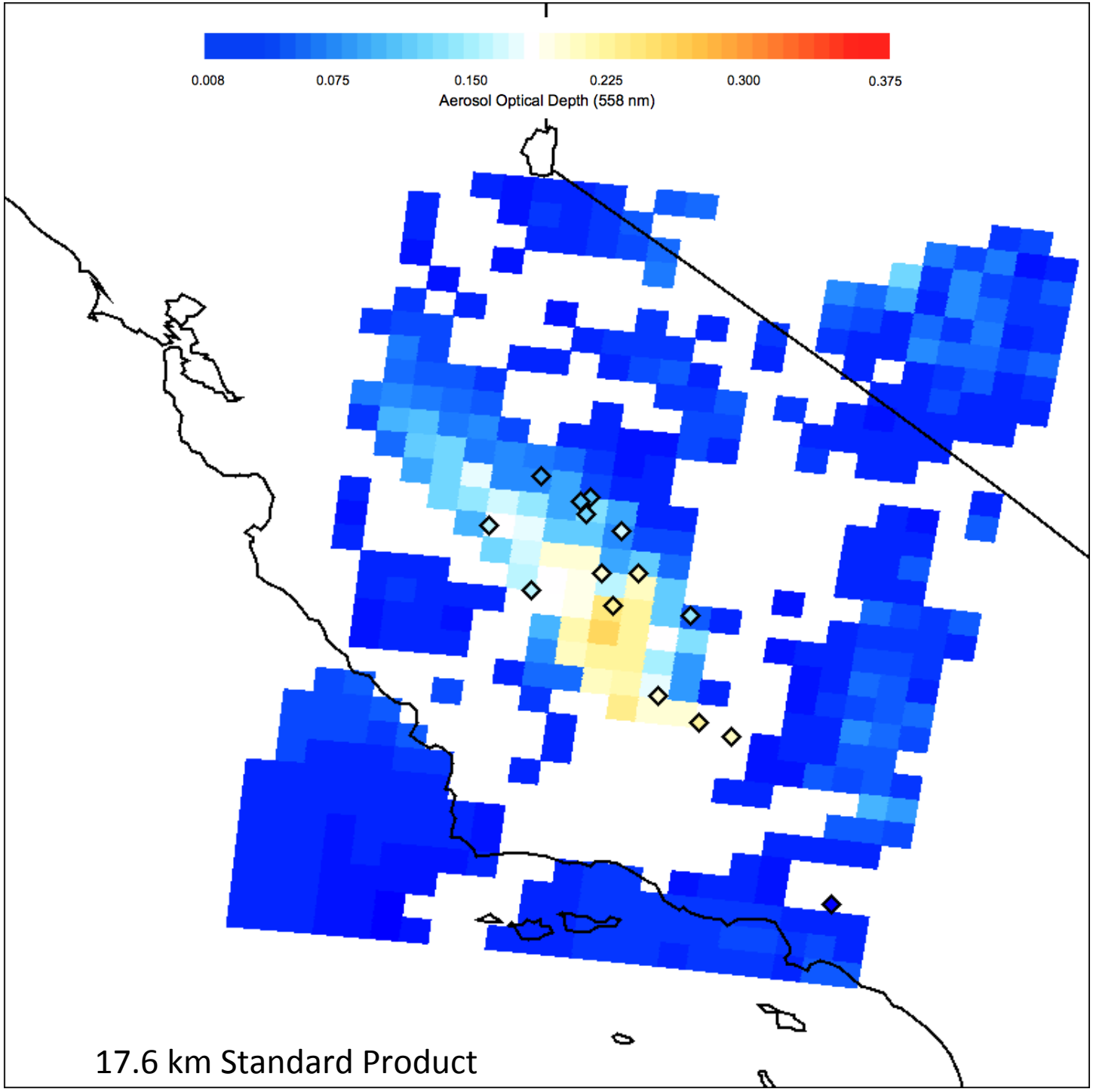


MISR PIXLEYCA Local Mode Orbit 69644

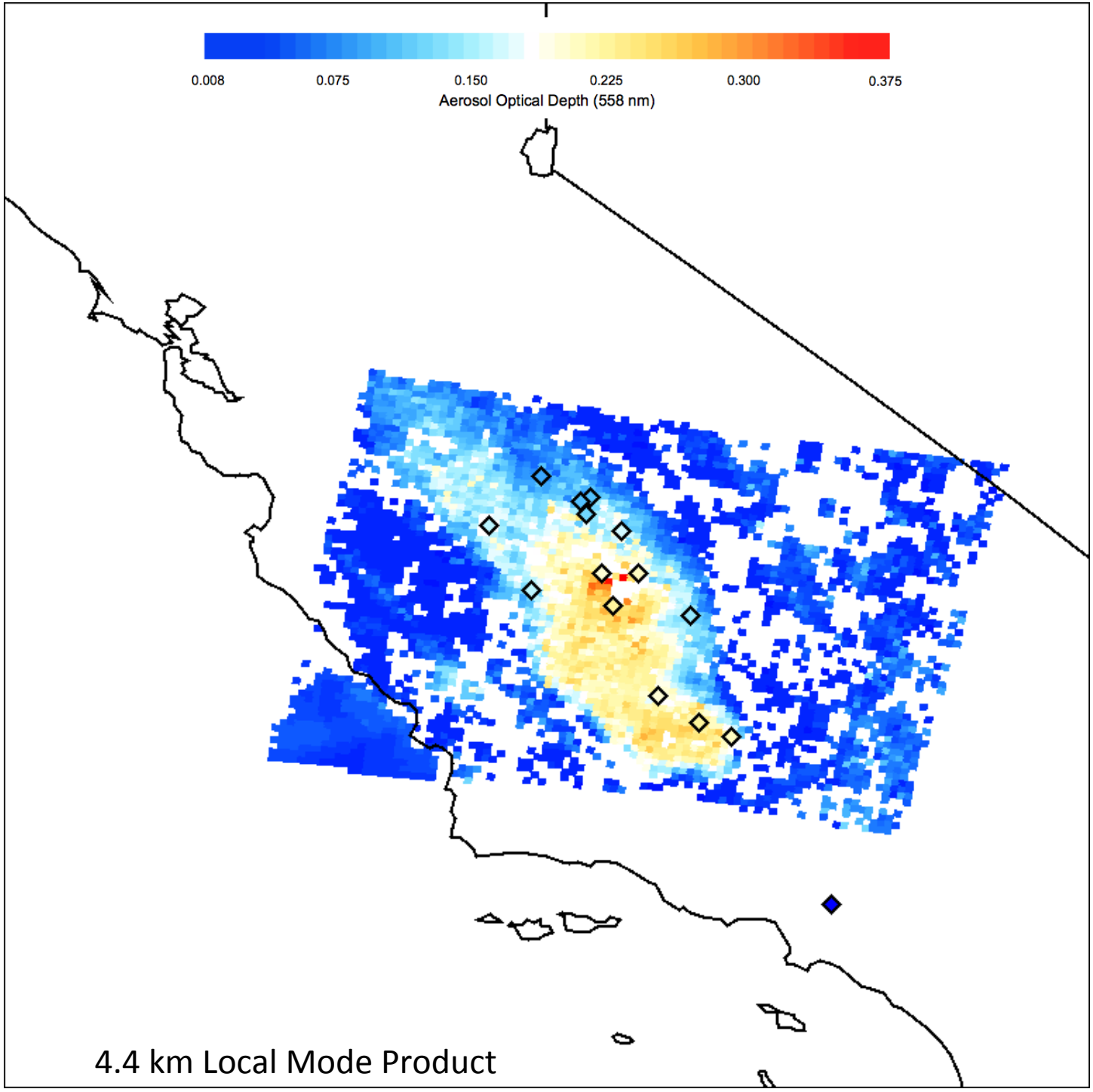
An


0.008
0.075
0.150
0.225
0.300
0.375
Aerosol Optical Depth (558 nm)
N=14
AERONET DRAGON Sites

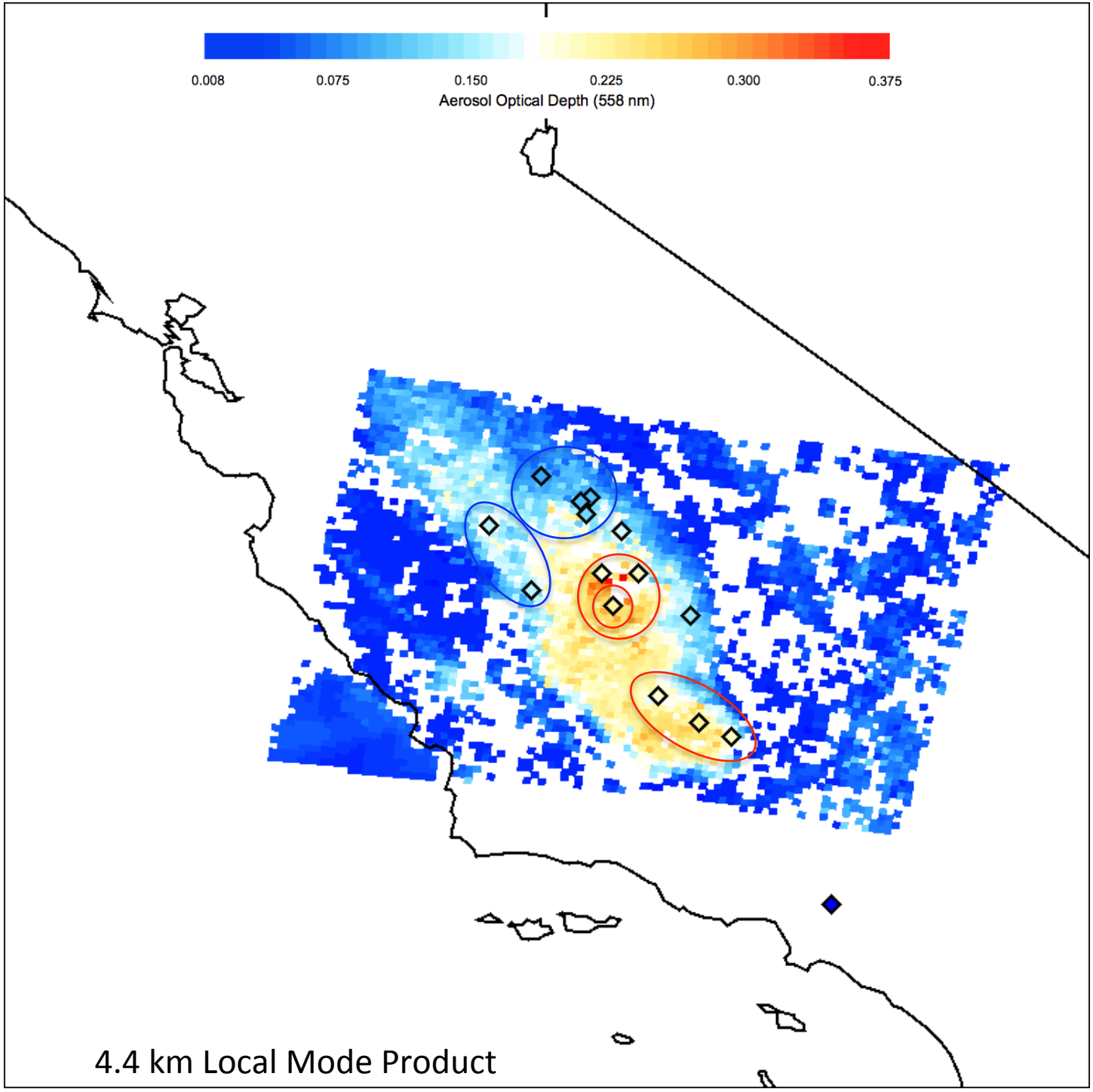

0.008
0.075
0.150
0.225
0.300
0.375
Aerosol Optical Depth (558 nm)
N=14
AERONET DRAGON Sites



17.6 km Standard Product



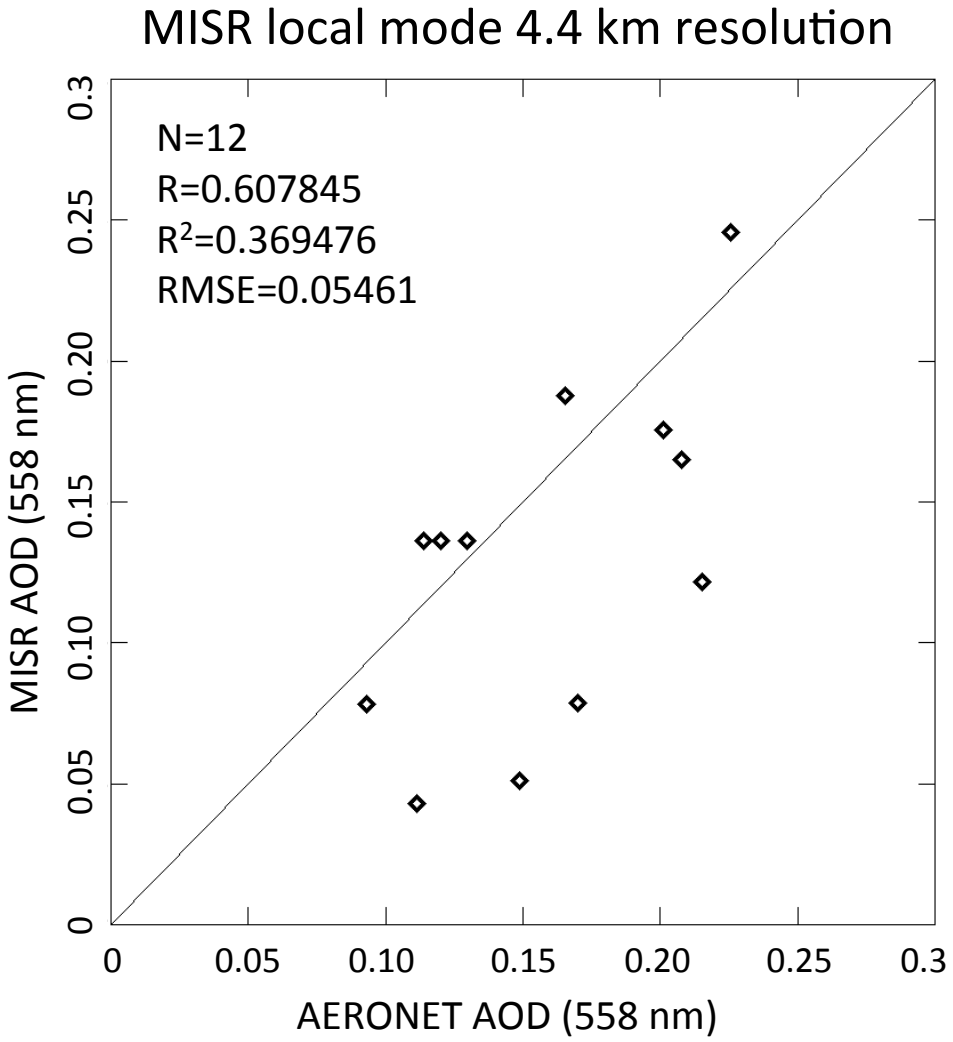
4.4 km Local Mode Product



4.4 km Local Mode Product

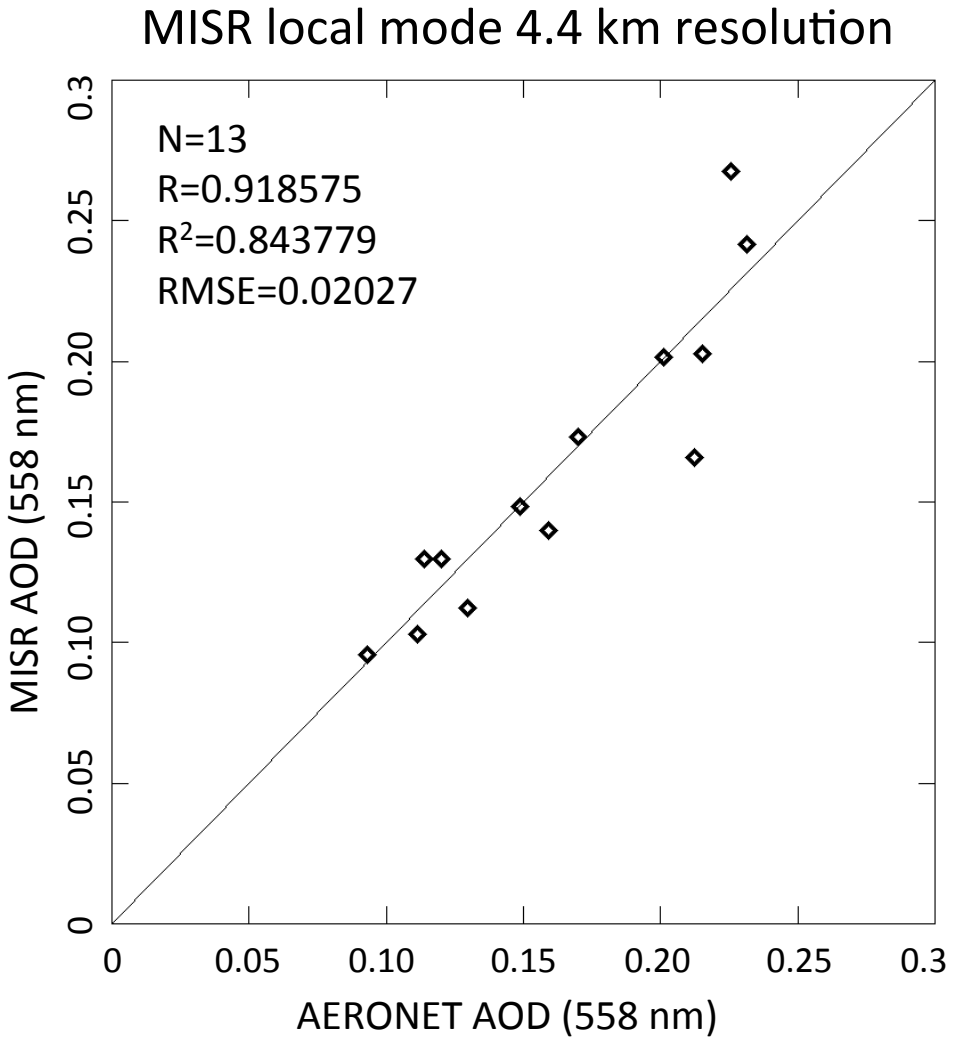
MISR-AERONET

nearest time to MISR overpass

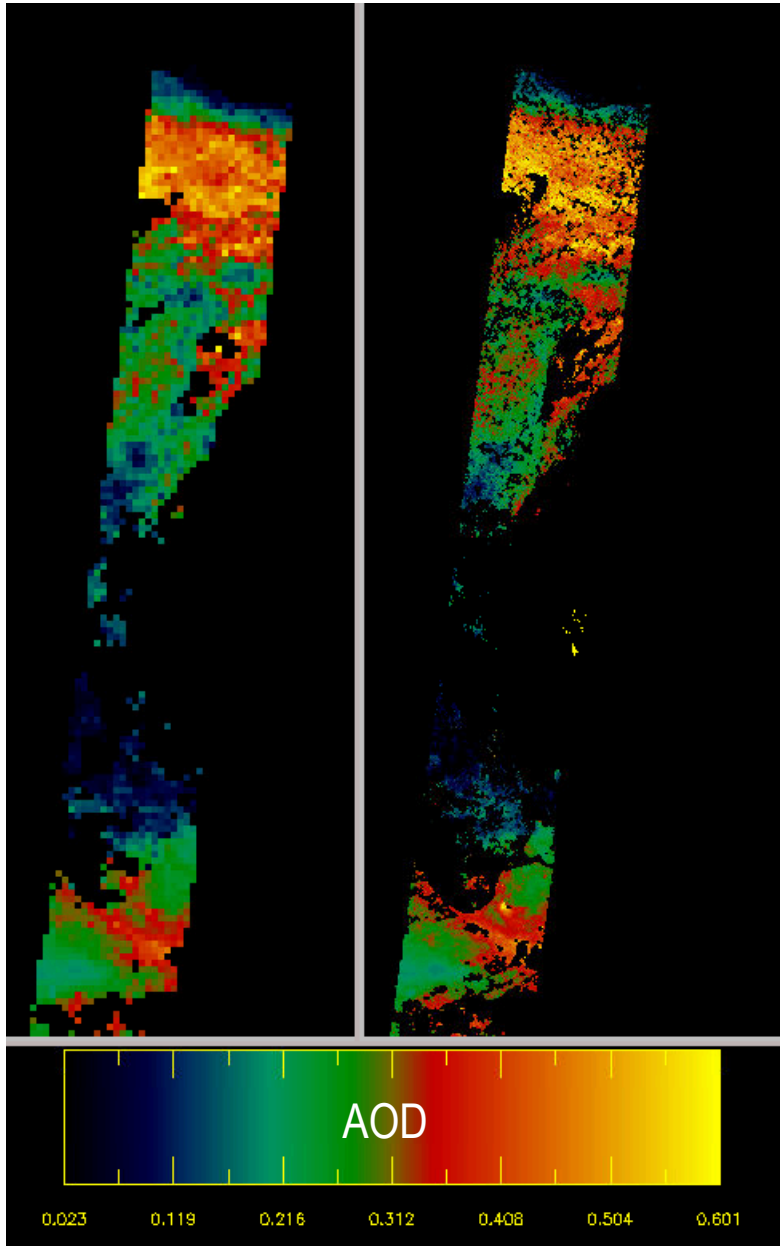


MISR-AERONET

nearest time to MISR overpass



Comparison of 17.6 km and 4.4 km products

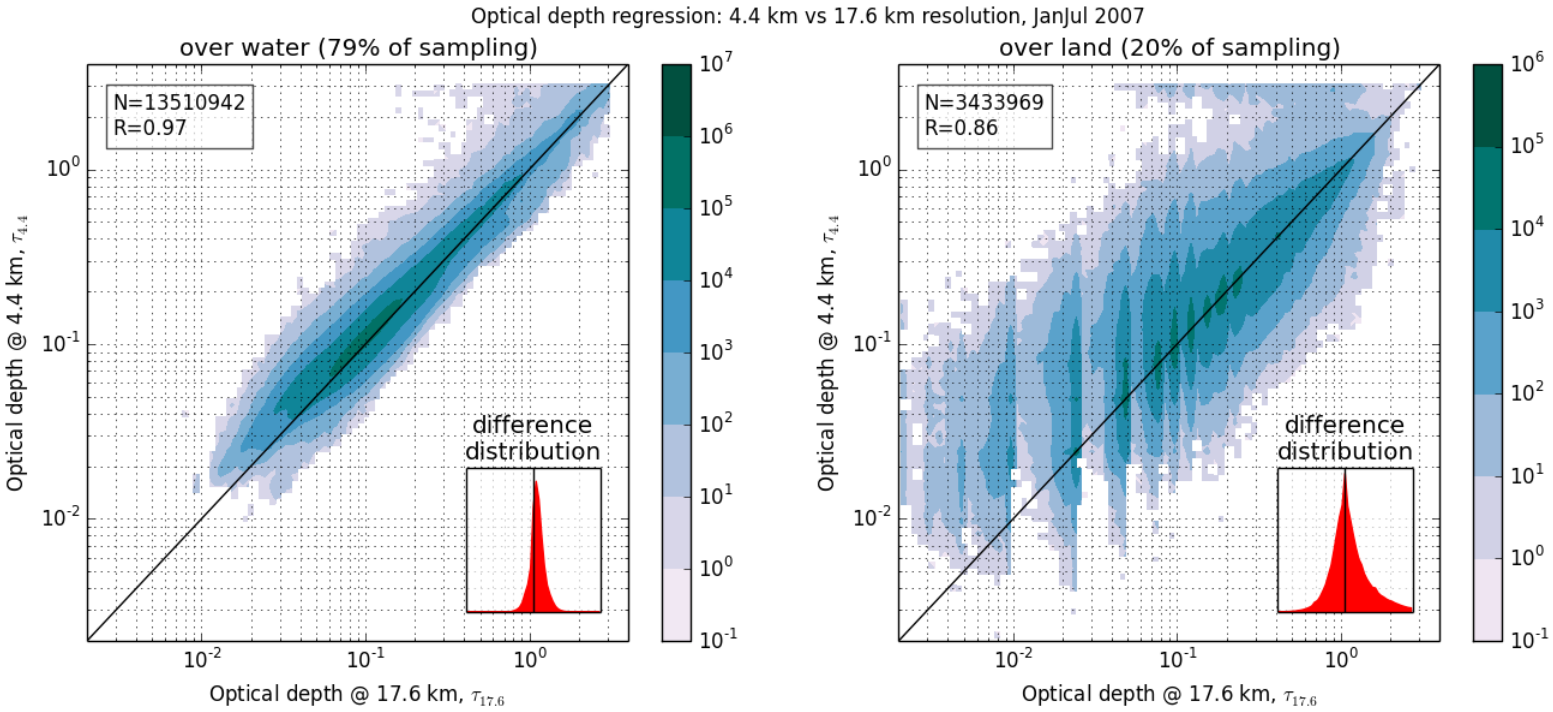


O31948, P143
over India
20 Dec 2005

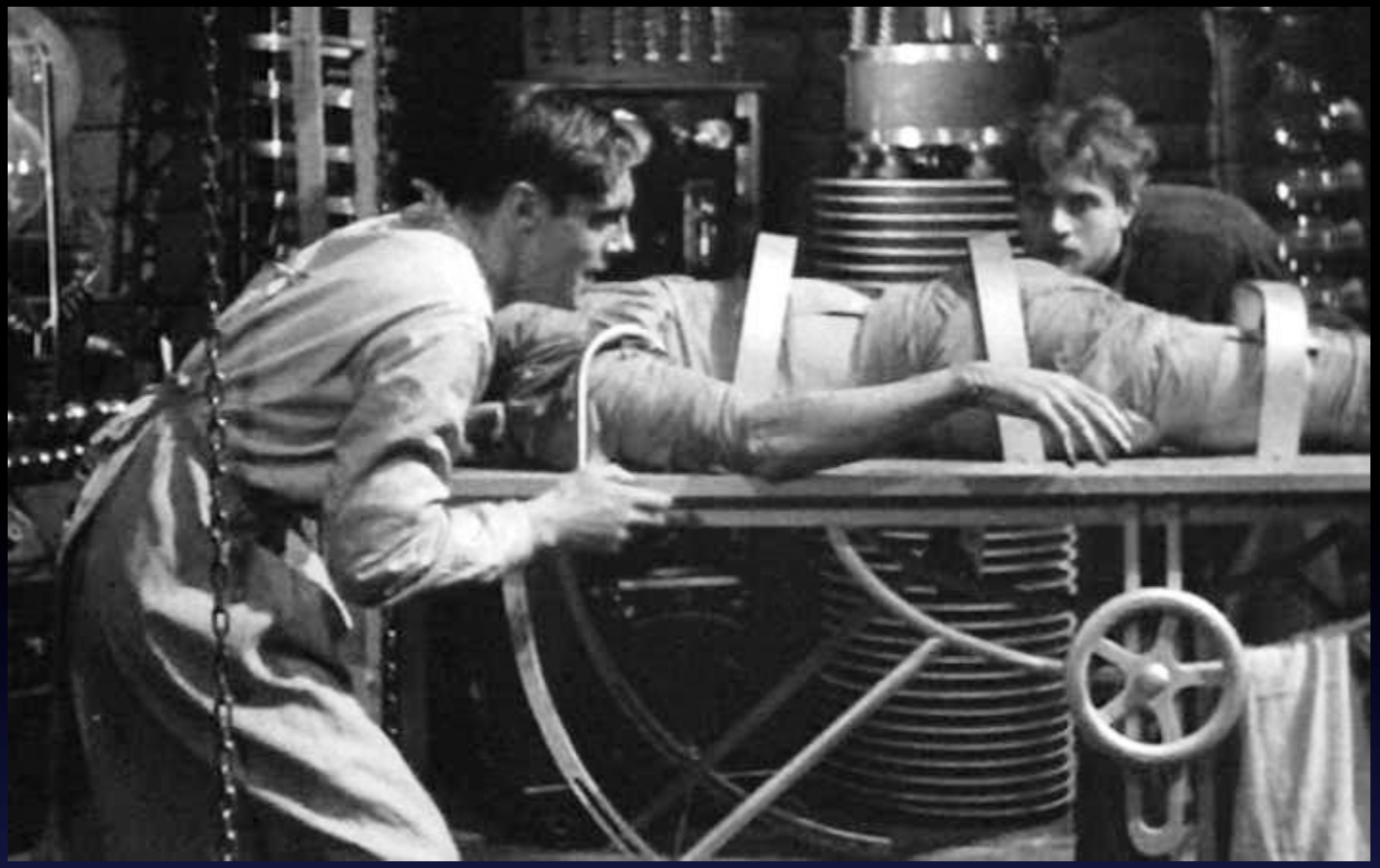
V22 17.6 km
standard product

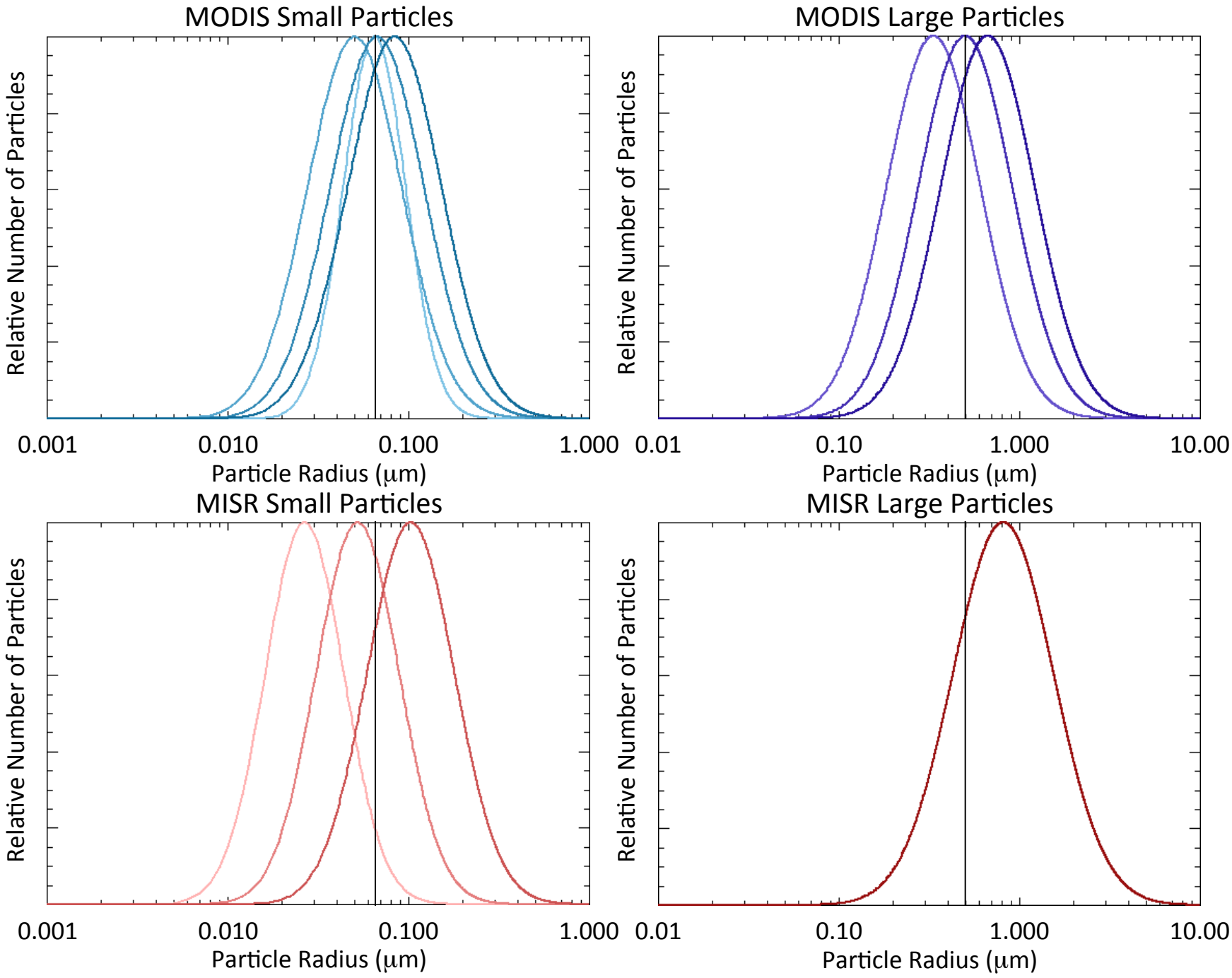
Prototype 4.4 km
product

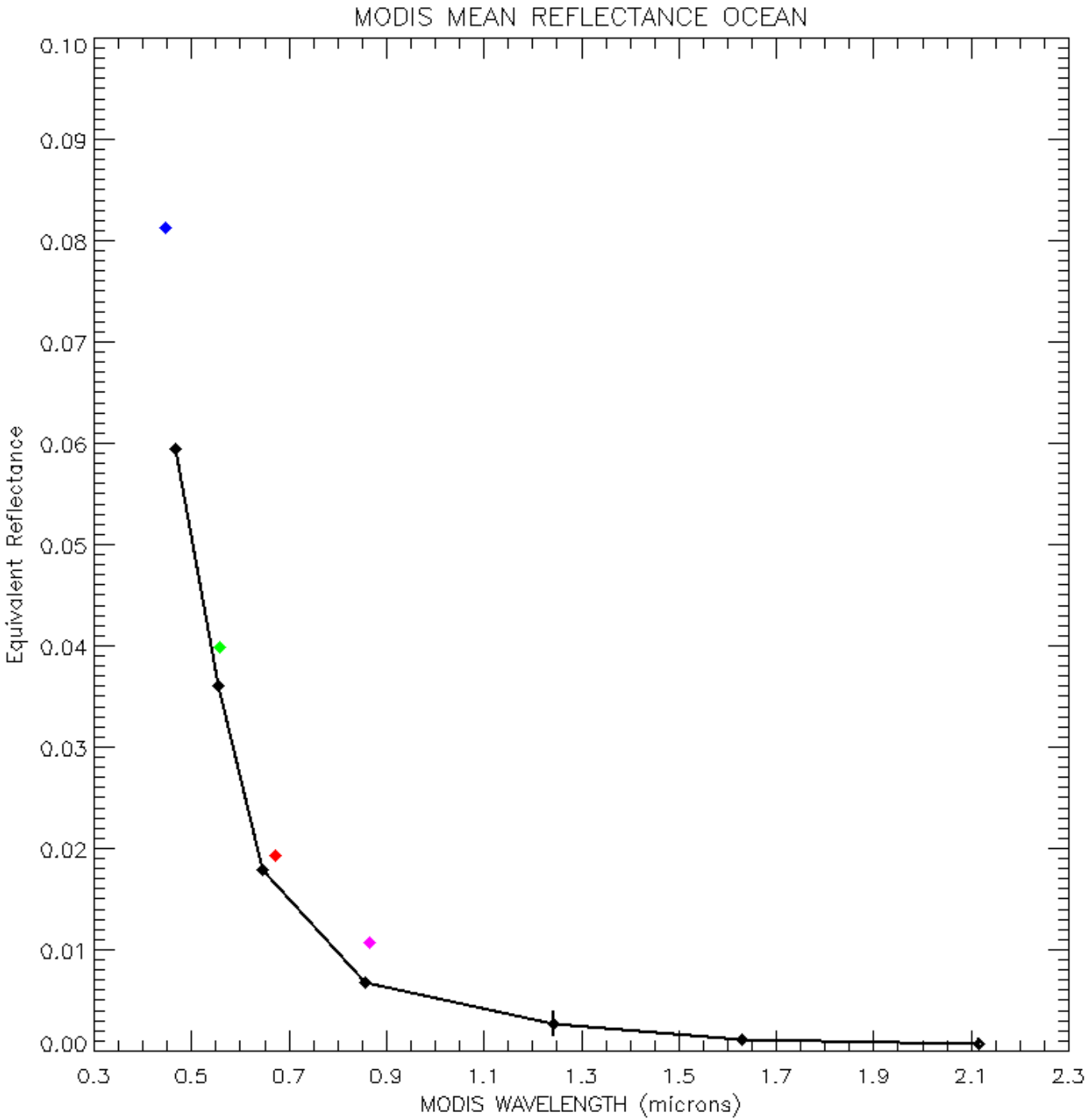
Comparison of 4.4 km prototype AODs with standard 17.6 km aerosol product

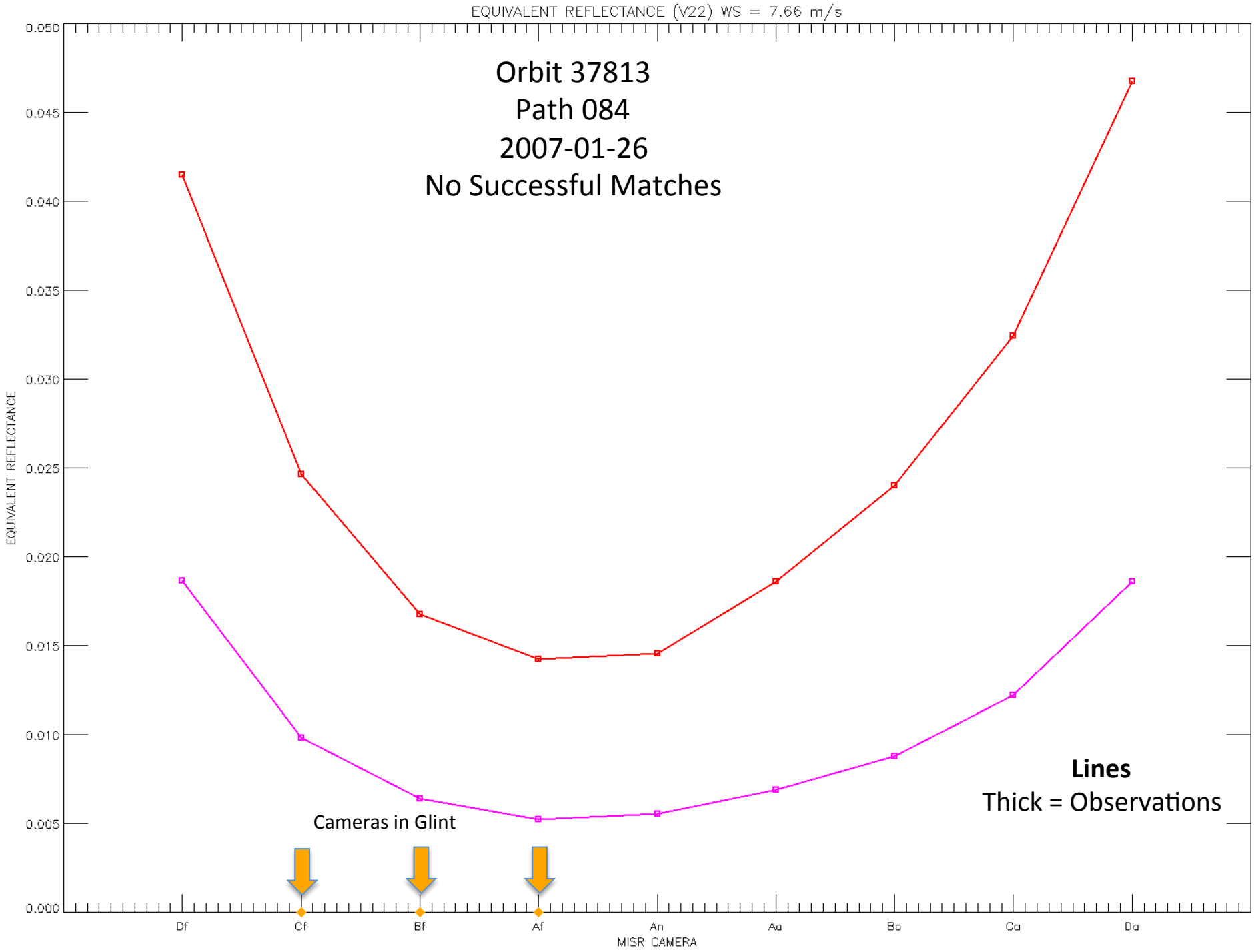


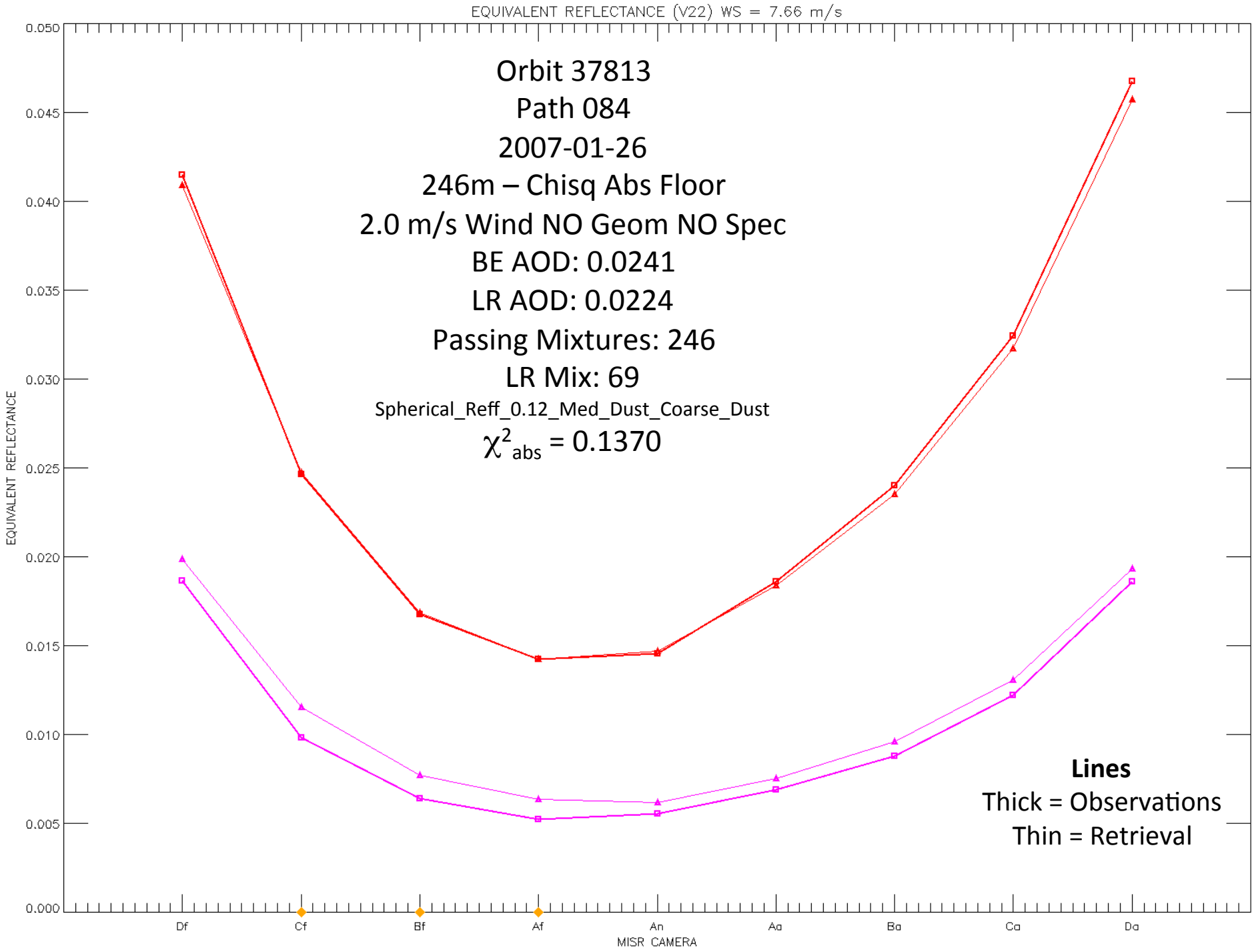
Main

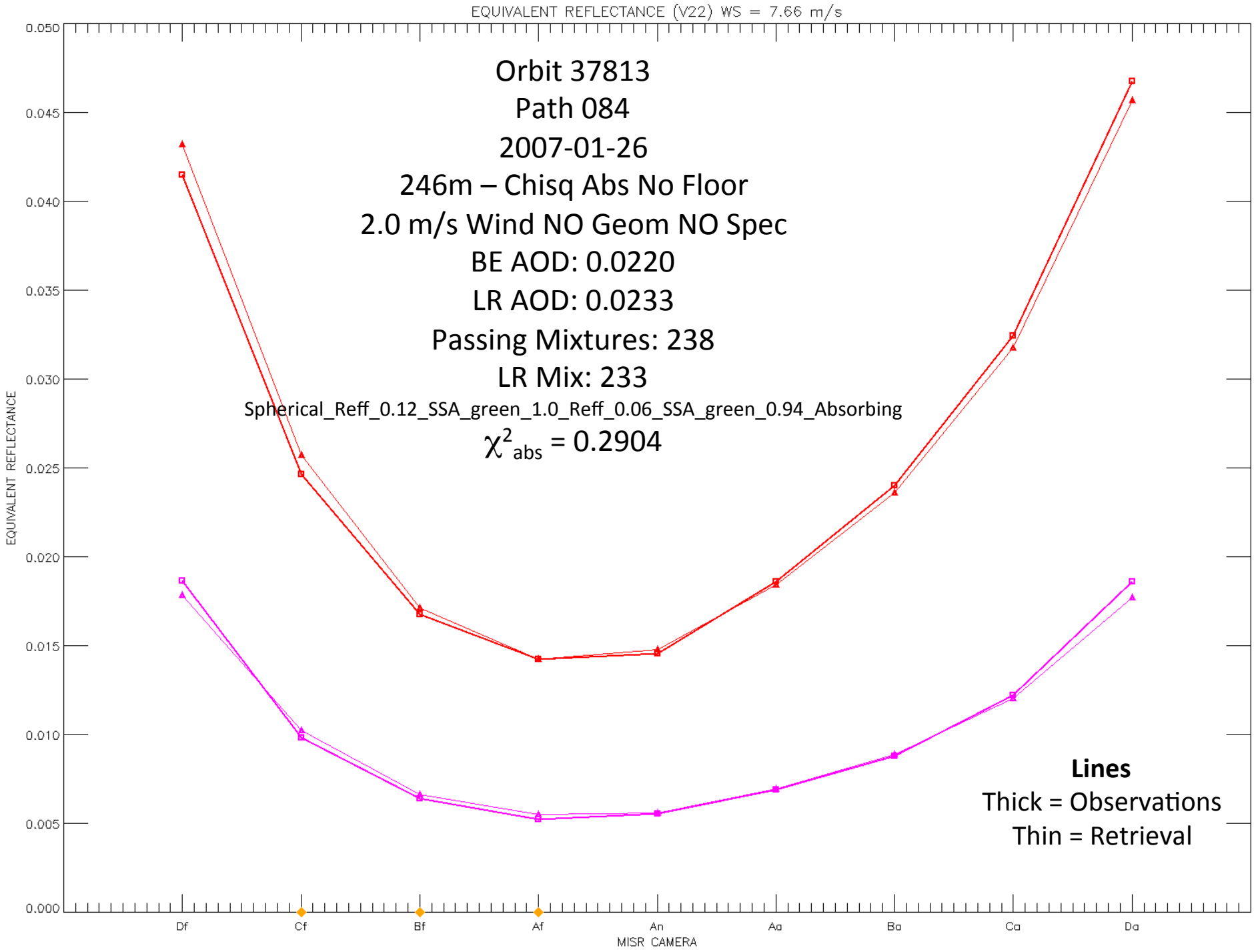


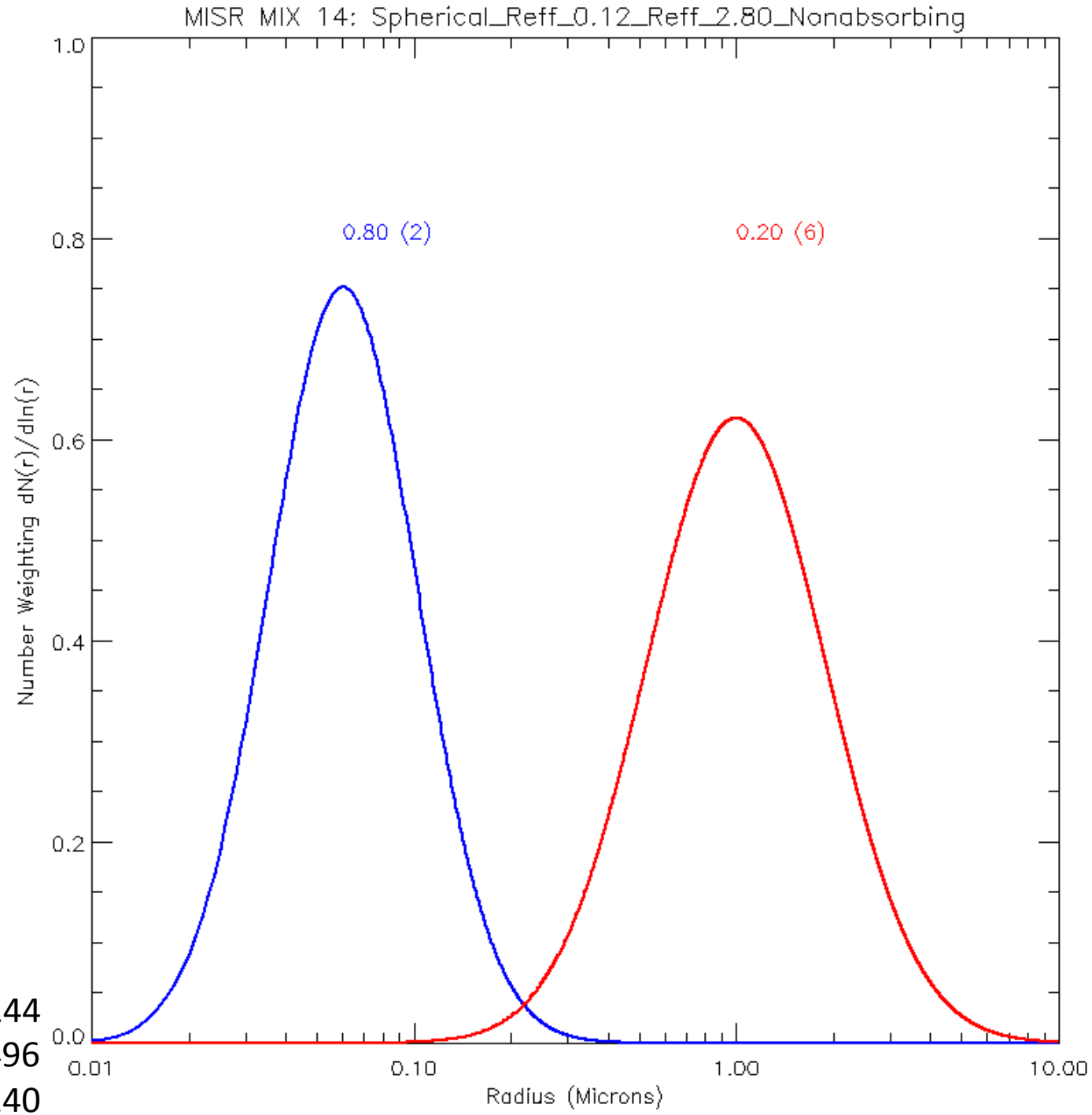

MODIS Small Particles
Relative Number of Particles
0.001
0.010
0.100
1.000
Particle Radius (μm)
MODIS Large Particles
Relative Number of Particles
0.01
0.10
1.000
10.00
Particle Radius (μm)
MISR Small Particles
Relative Number of Particles
0.001
0.010
0.100
1.000
Particle Radius (μm)
MISR Large Particles
Relative Number of Particles
0.01
0.10
1.000
10.00
Particle Radius (μm)


MODIS MEAN REFLECTANCE OCEAN
Equivalent Reflectance
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
MODIS WAVELENGTH (microns)

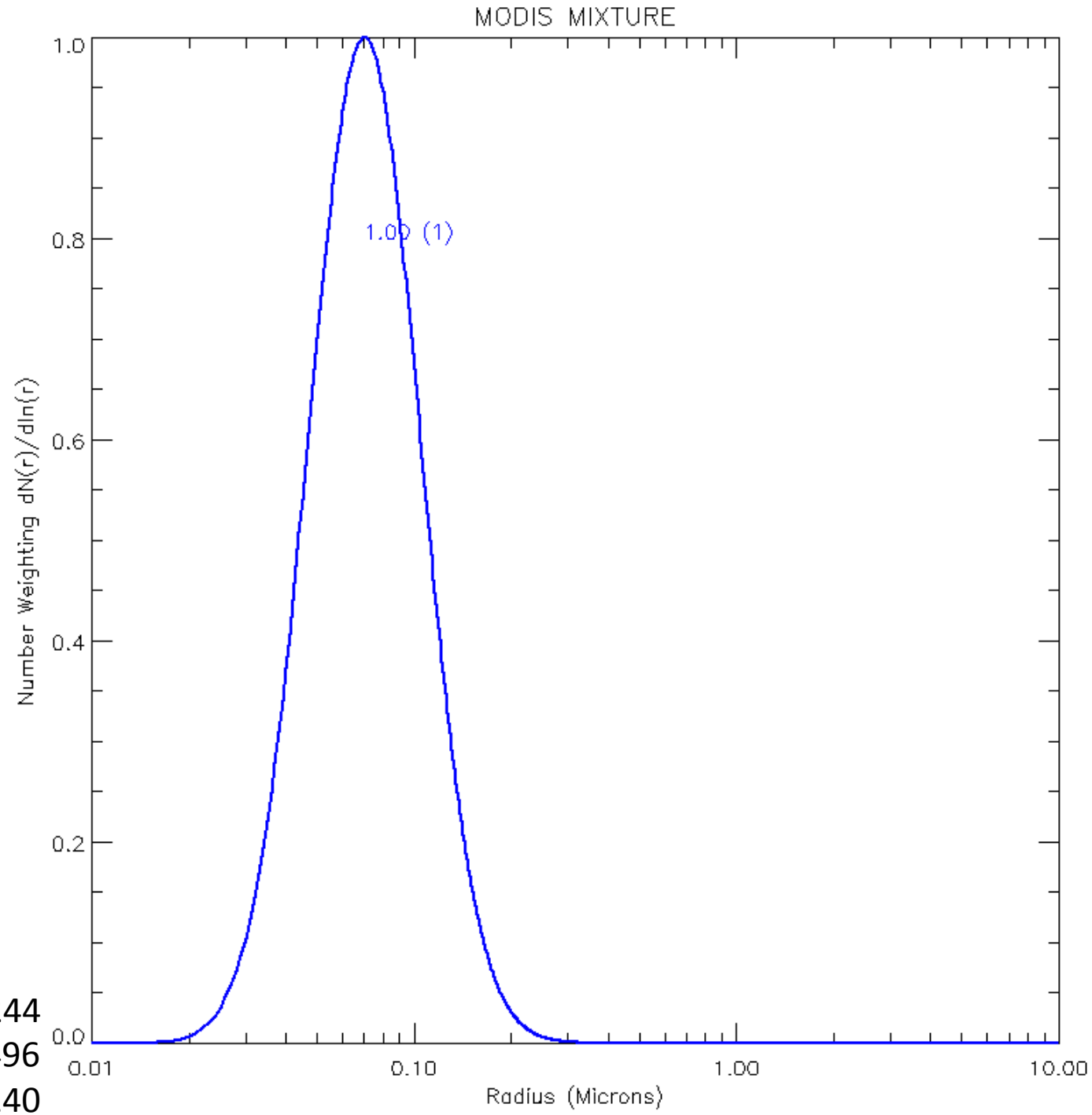

EQUIVALENT REFLECTANCE (V22) WS = 7.66 m/s
Orbit 37813
Path 084
2007-01-26
No Successful Matches
EQUIVALENT REFLECTANCE
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Df
Cf
Bf
Af
An
Aa
Ba
Ca
Da
MISR CAMERA
Cameras in Glint
Lines
Thick = Observations


EQUIVALENT REFLECTANCE (V22) WS = 7.66 m/s
Orbit 37813
Path 084
2007-01-26
246m – Chisq Abs Floor
2.0 m/s Wind NO Geom NO Spec
BE AOD: 0.0241
LR AOD: 0.0224
Passing Mixtures: 246
LR Mix: 69
Spherical_Reff_0.12_Med_Dust_Coarse_Dust
χ^2_{abs} = 0.1370
Lines
Thick = Observations
Thin = Retrieval
EQUIVALENT REFLECTANCE
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Df
Cf
Bf
Af
An
Aa
Ba
Ca
Da
MISR CAMERA

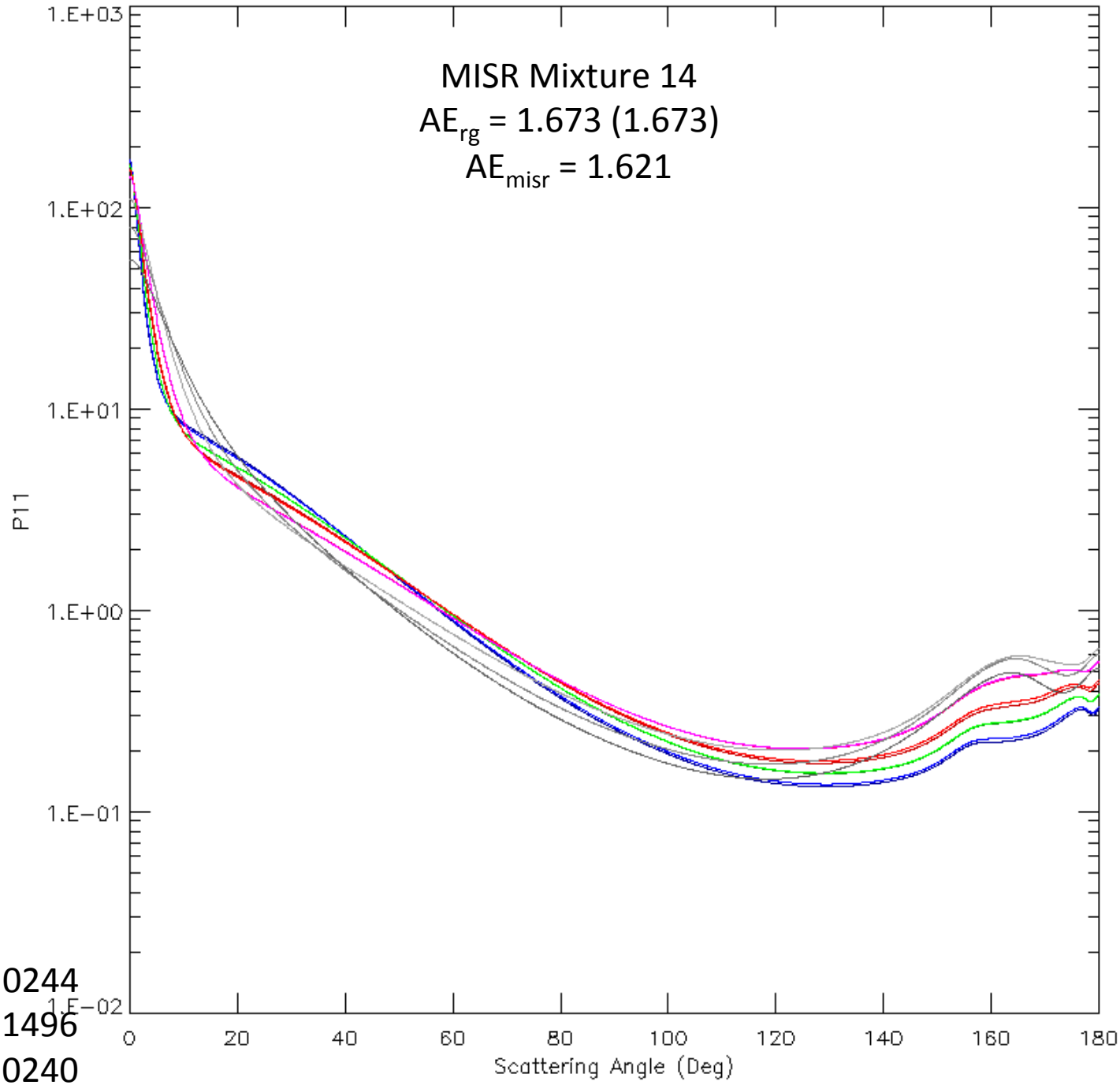

EQUIVALENT REFLECTANCE (V22) WS = 7.66 m/s
Orbit 37813
Path 084
2007-01-26
246m – Chisq Abs No Floor
2.0 m/s Wind NO Geom NO Spec
BE AOD: 0.0220
LR AOD: 0.0233
Passing Mixtures: 238
LR Mix: 233
Spherical_Reff_0.12_SSA_green_1.0_Reff_0.06_SSA_green_0.94_Absorbing
χ^2_{abs} = 0.2904
Lines
Thick = Observations
Thin = Retrieval
EQUIVALENT REFLECTANCE
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Df
Cf
Bf
Af
An
Aa
Ba
Ca
Da
MISR CAMERA



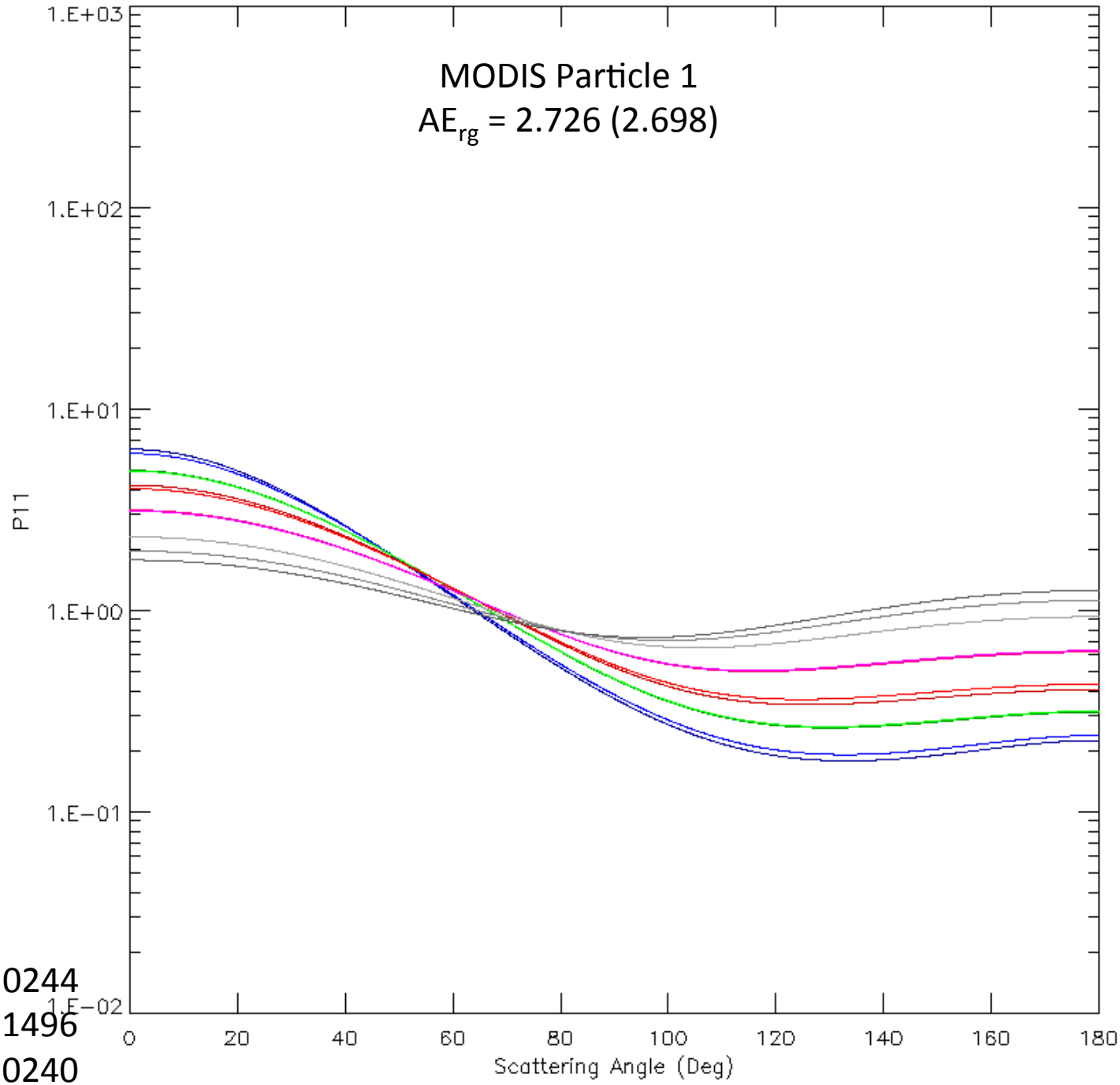
MAN = 0.0244
MISR = 0.1496
MODIS = 0.0240



MAN = 0.0244
MISR = 0.1496
MODIS = 0.0240



MAN = 0.0244
MISR = 0.1496
MODIS = 0.0240

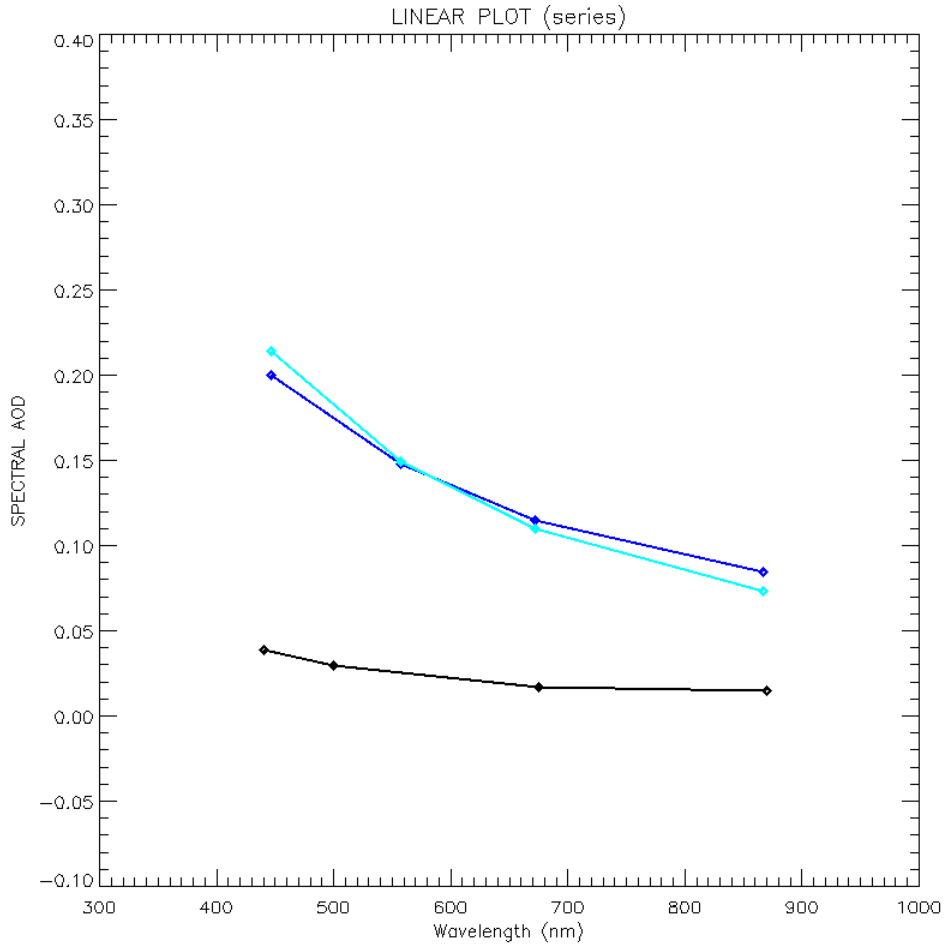


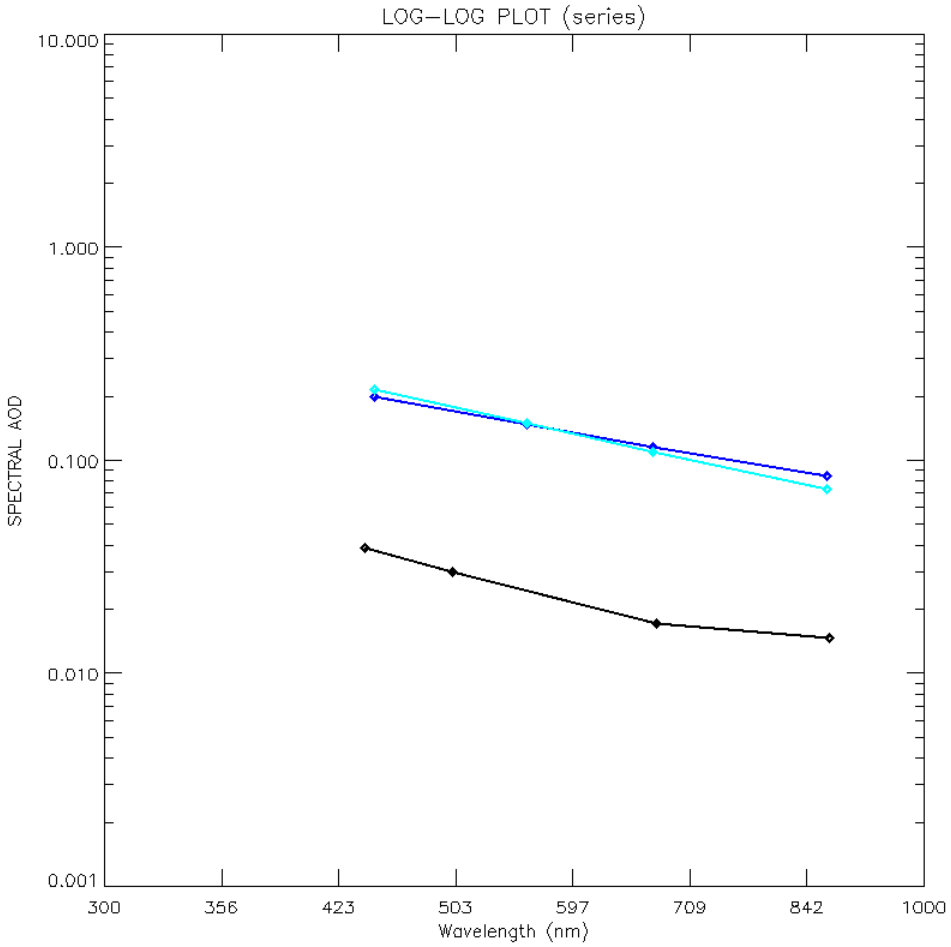
MAN = 0.0244
MISR = 0.1496
MODIS = 0.0240

MISR Mixture 14

AE_{rg} = 1.673 (1.673)

AE_{misr} = 1.621





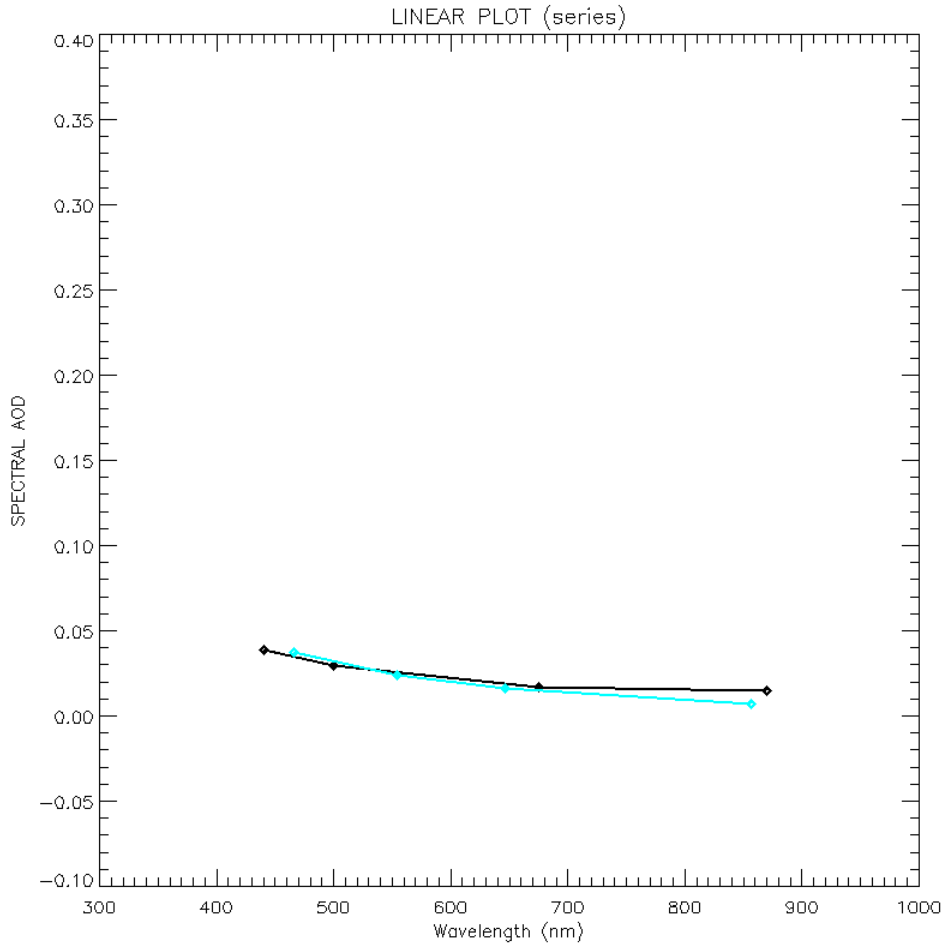
MAN = 0.0244

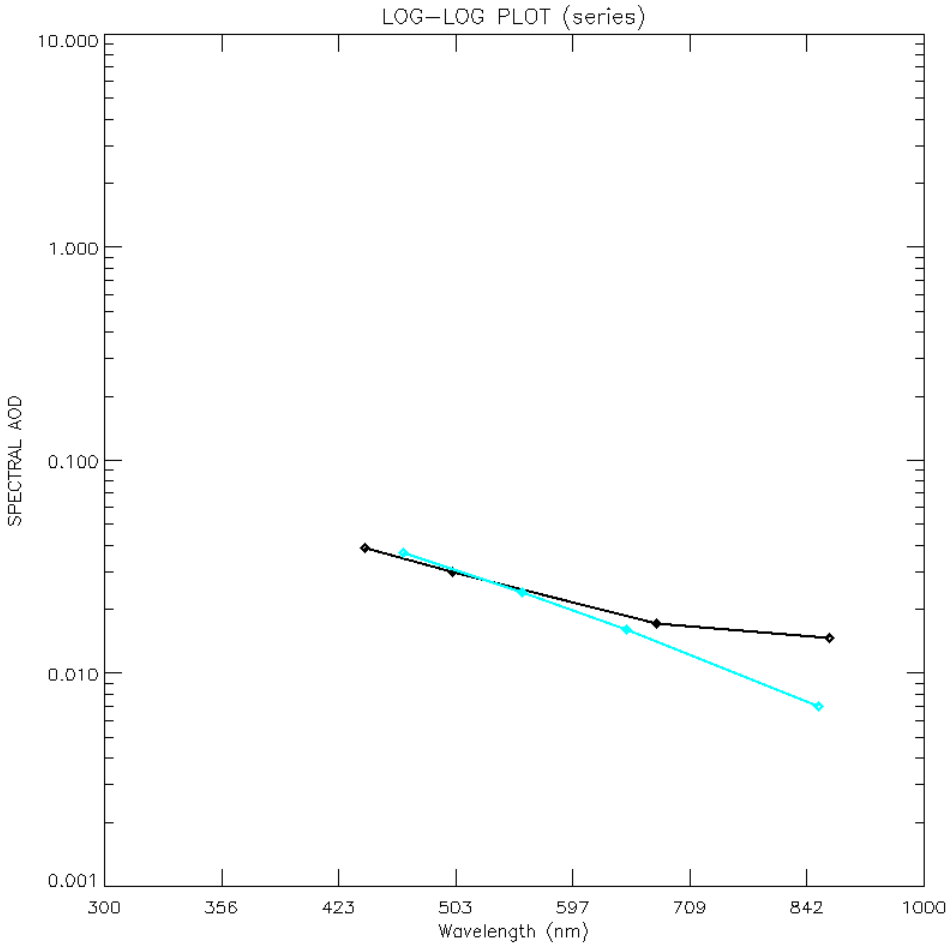
MISR = 0.1496

MODIS = 0.0240

MODIS Particle 1

AE_{rg} = 2.726 (2.698)

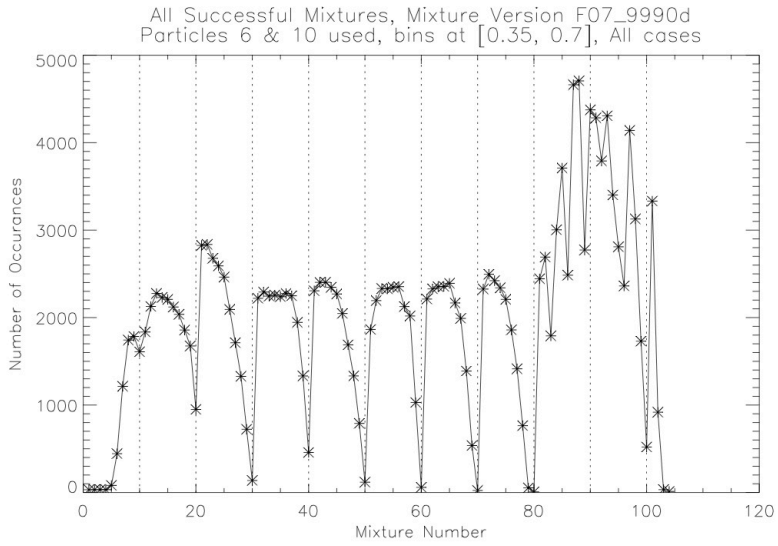


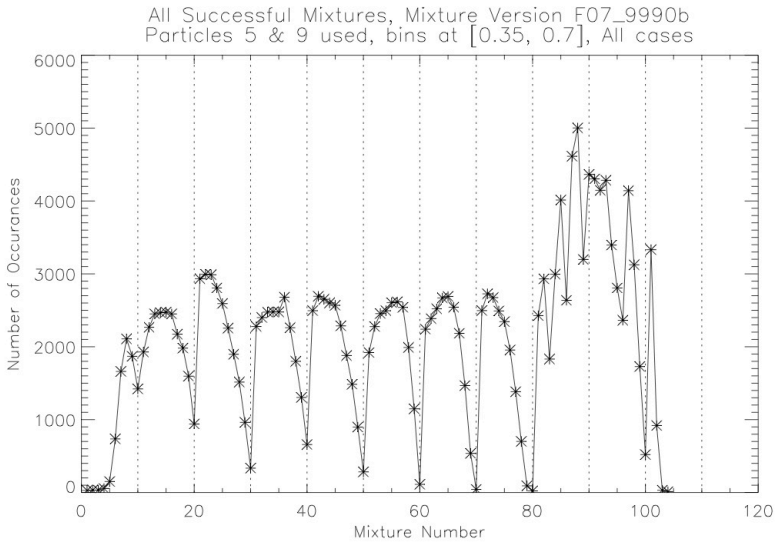


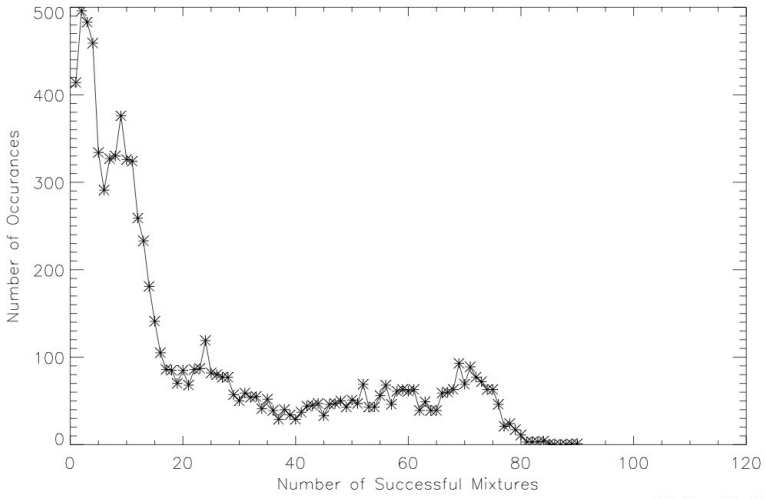
MAN = 0.0244

MISR = 0.1496

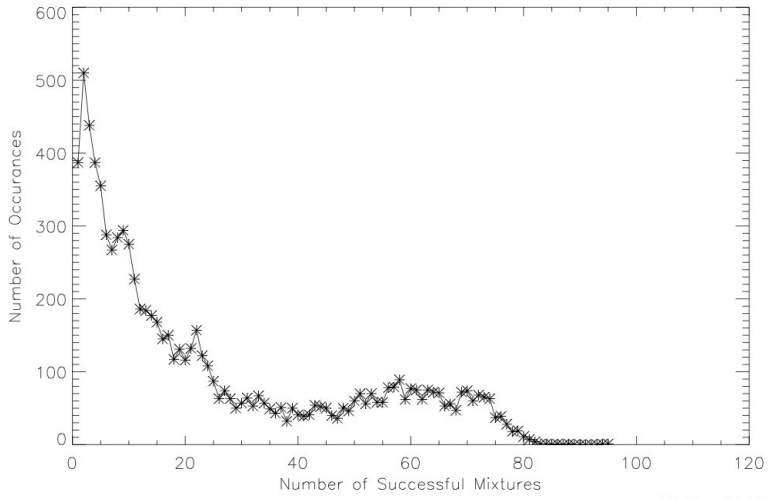
MODIS = 0.0240





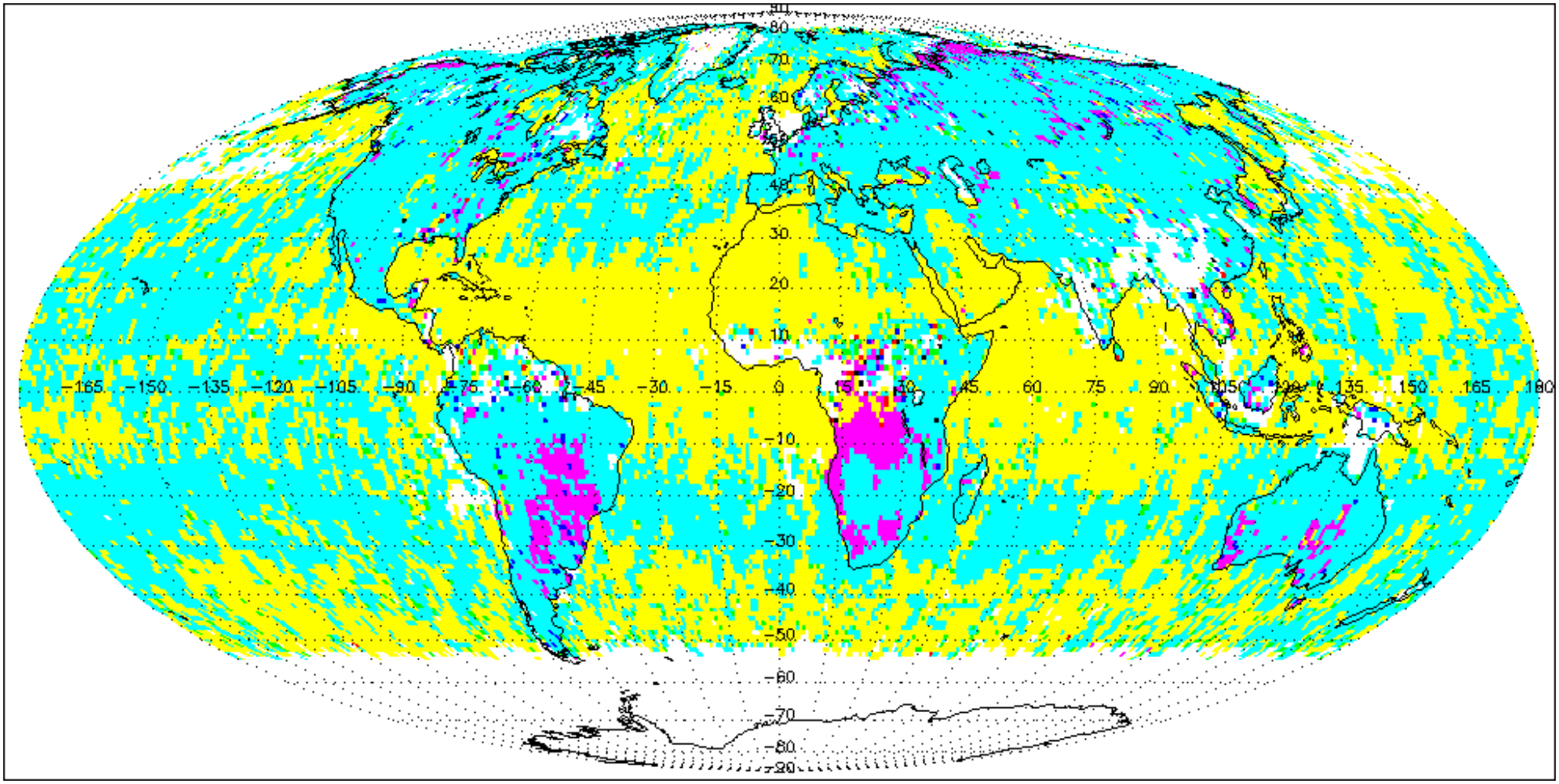


BJGaitley, 17Jun2004



BJGaitley, 10Jul2004

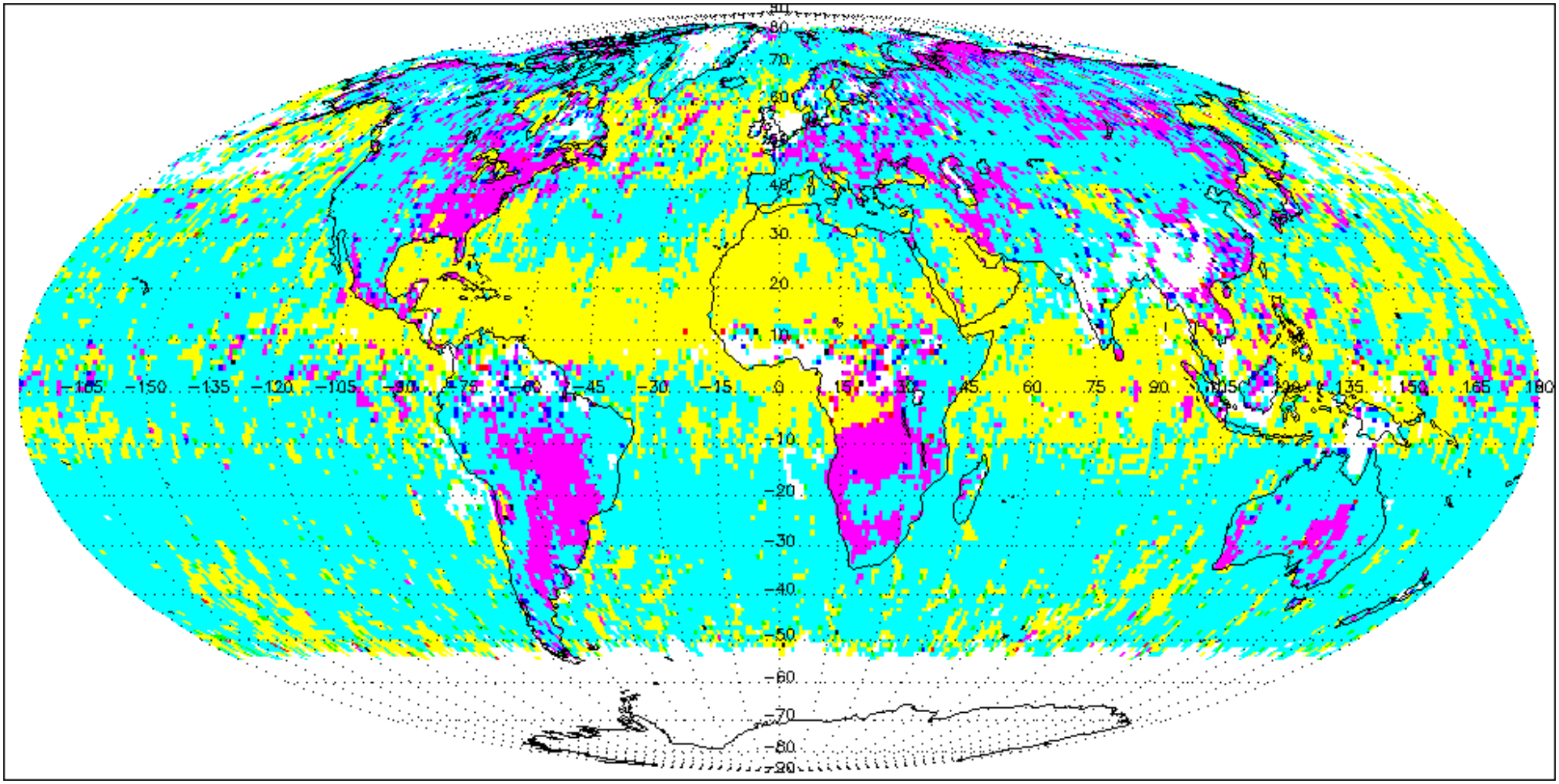
74 Mixtures
(Standard Product)



Key

- Spherical Non-Absorbing
- Spherical Absorbing
- Non-Spherical
- Spherical Absorbing + Non-Spherical (Tie)
- Spherical Non-Absorbing + Non-Spherical (Tie)
- Spherical Absorbing + Spherical Non-Absorbing (Tie)

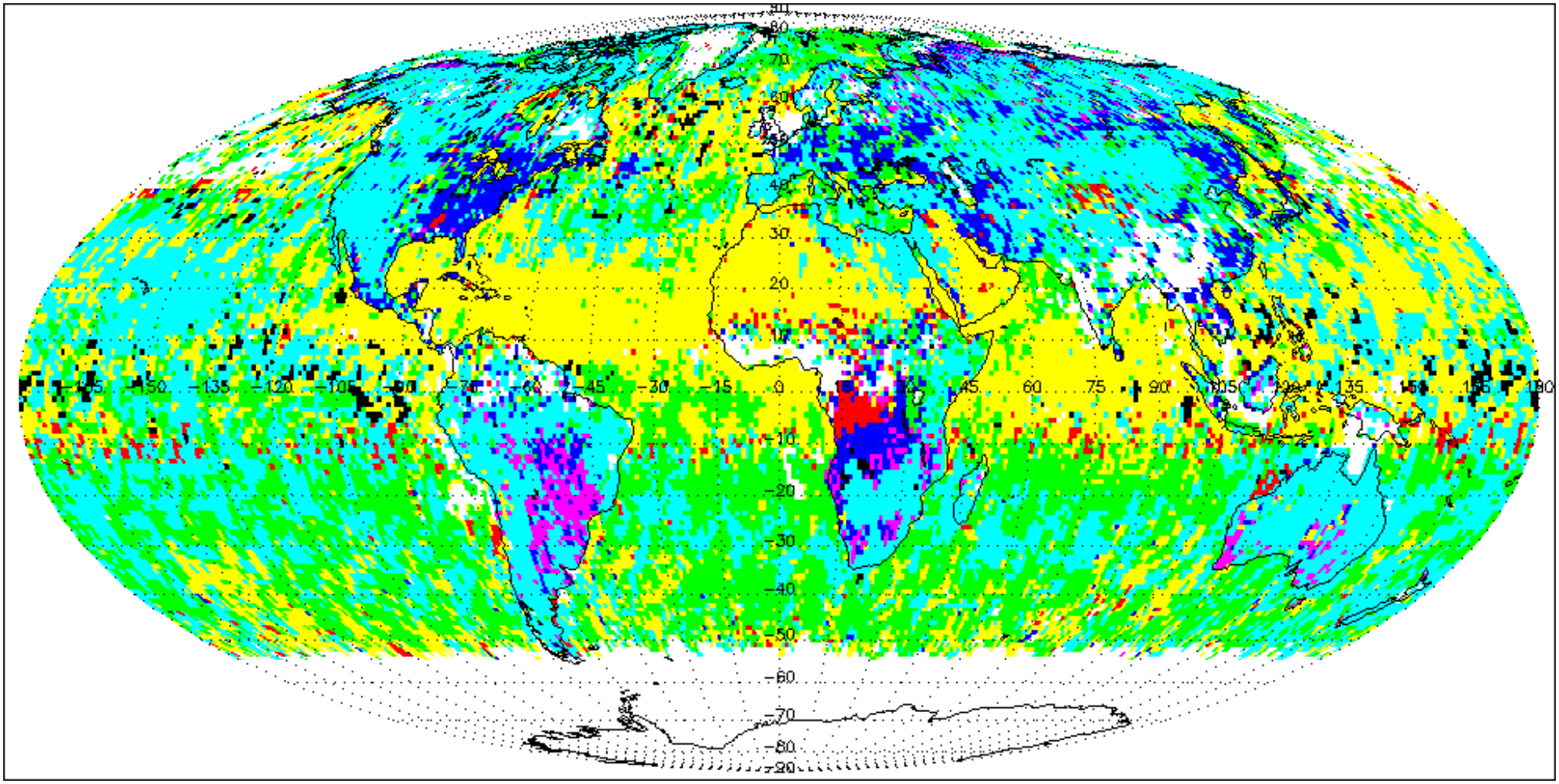
243 Mixtures
(Ralph's Set)



Key

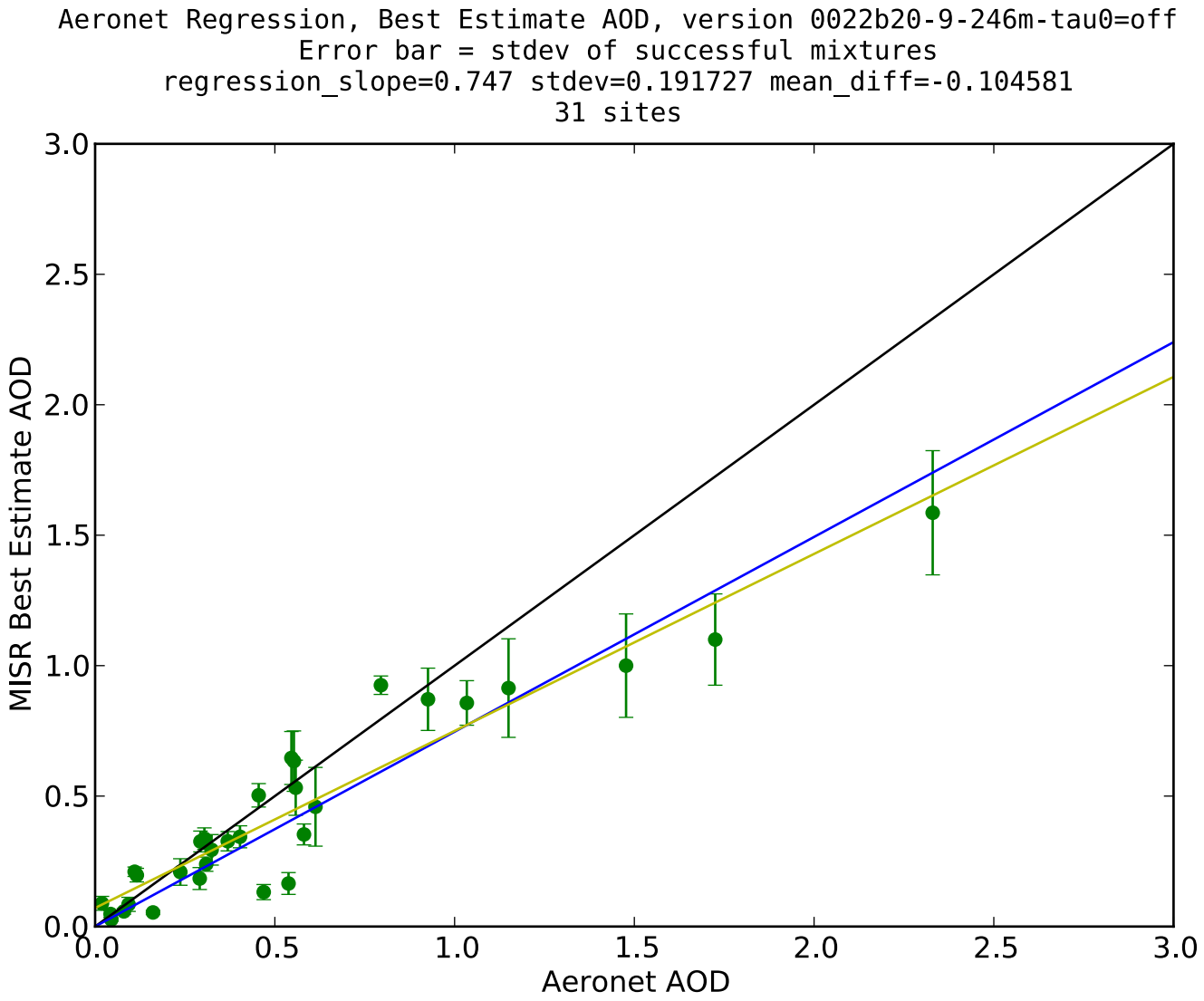
- Spherical Non-Absorbing
- Spherical Absorbing
- Non-Spherical
- Spherical Absorbing + Non-Spherical (Tie)
- Spherical Non-Absorbing + Non-Spherical (Tie)
- Spherical Absorbing + Spherical Non-Absorbing (Tie)

243 Mixtures
(Ralph's Set)

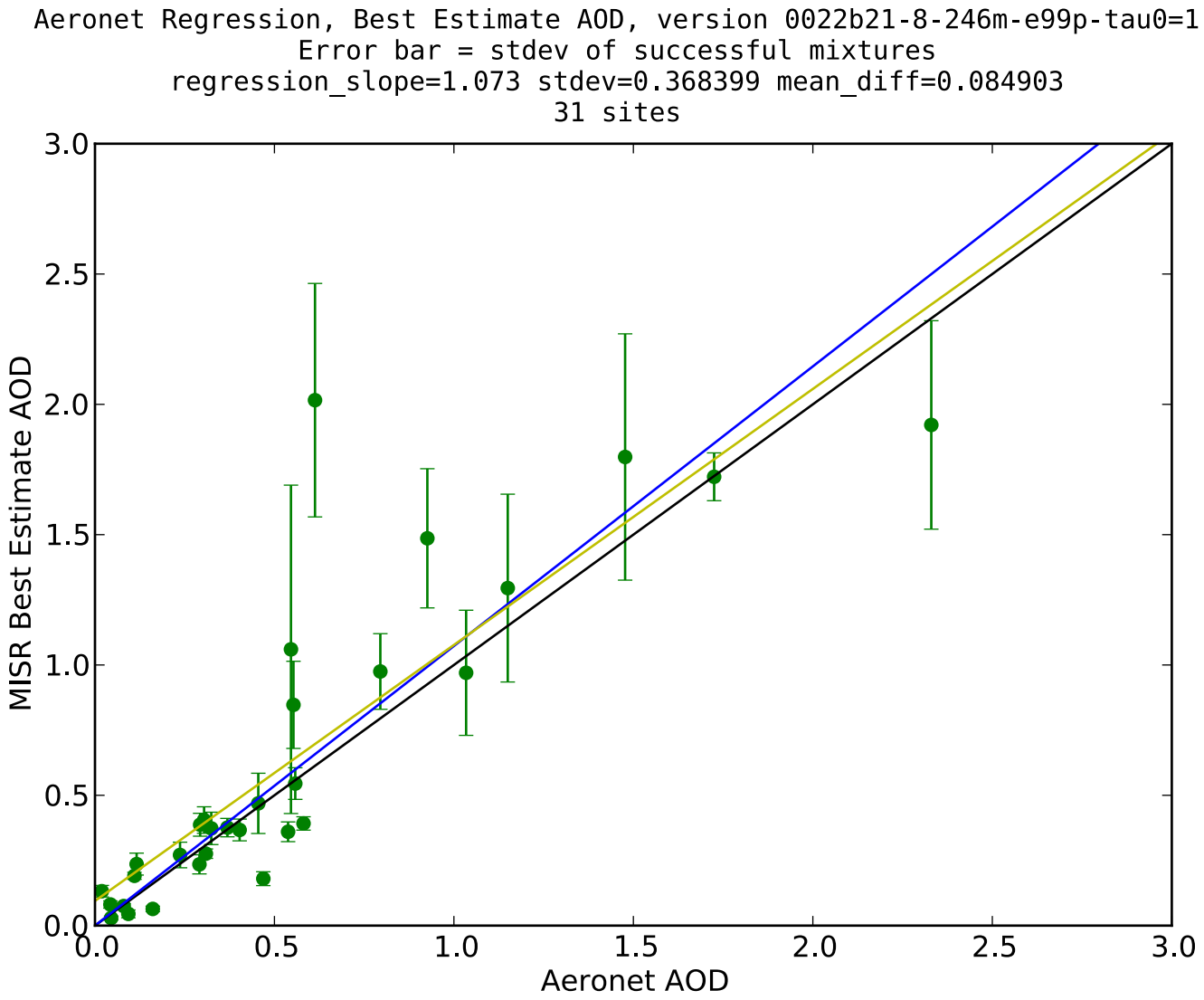


Key

- Spherical Non-Absorbing
- Spherical Absorbing
- Non-Spherical
- Smoke+Dust
- Medium Mode Non-Absorbing
- Medium Mode Absorbing
- Highly Absorbing

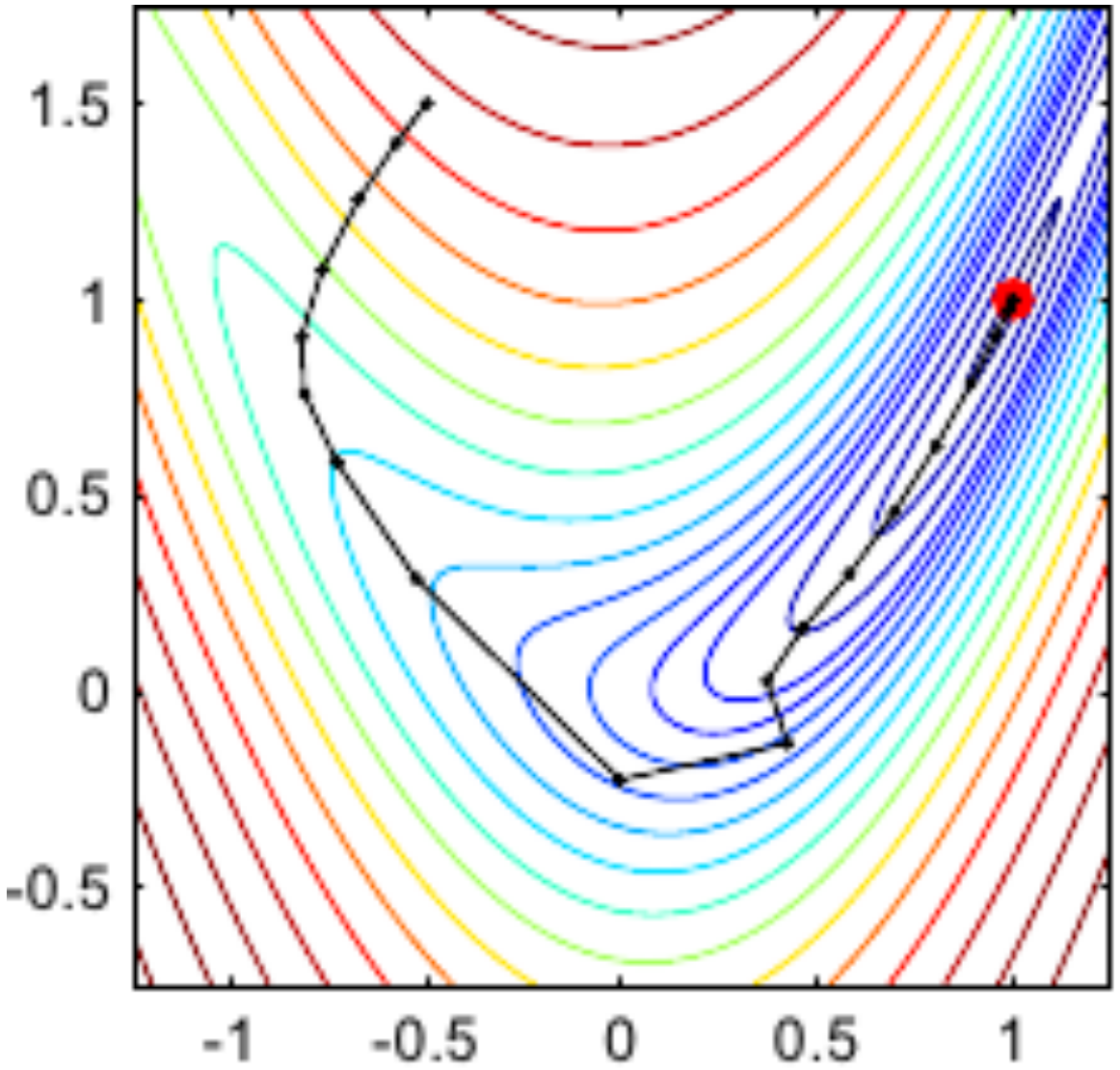


Standard V22 Het + Homog (246 Mixtures)



New Het (99%) + New Homog (Tau0 = 1.0)

Optimization



Chi-Squared Het 2-D Plots

Dimensions:

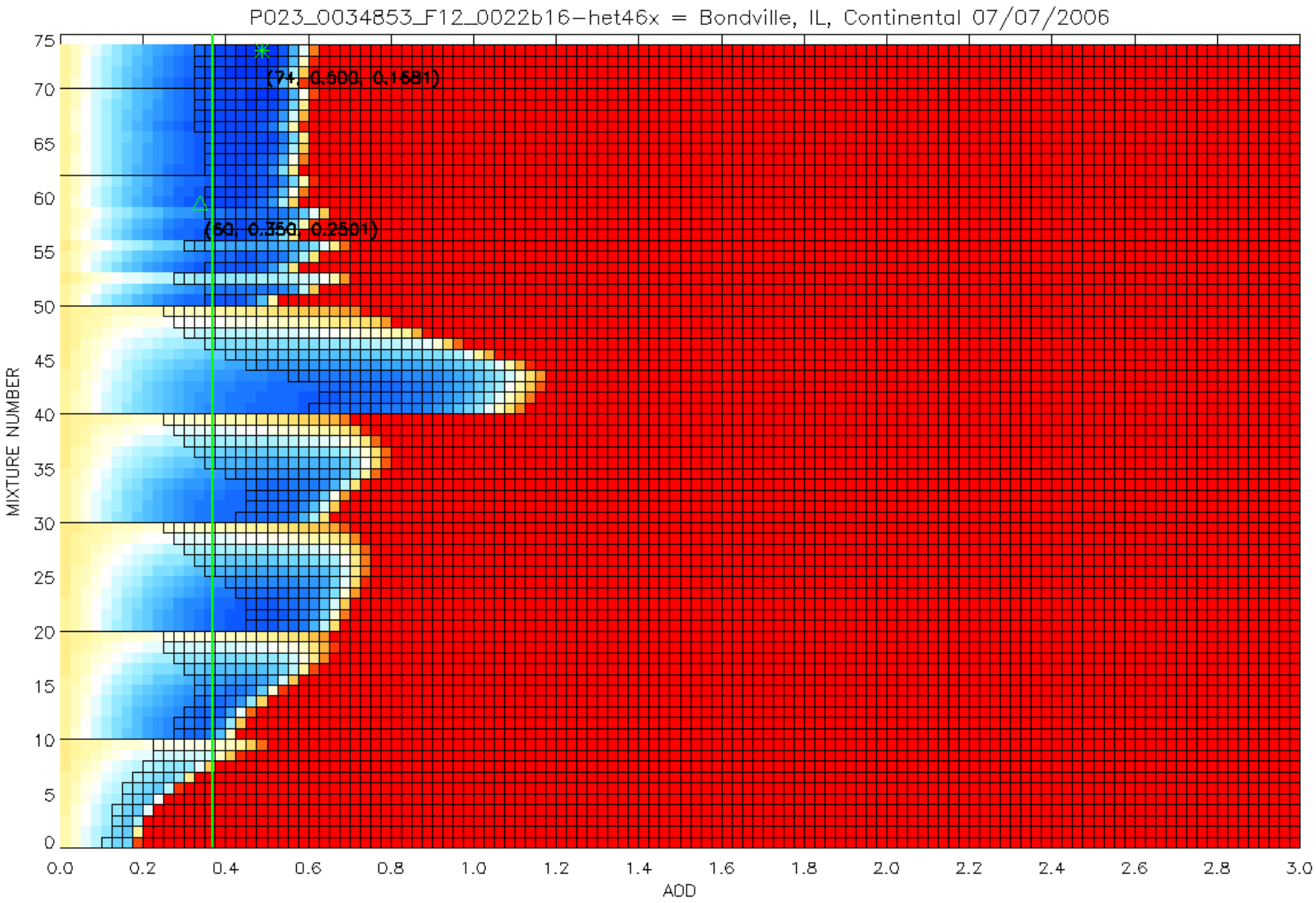
x-axis = AOD

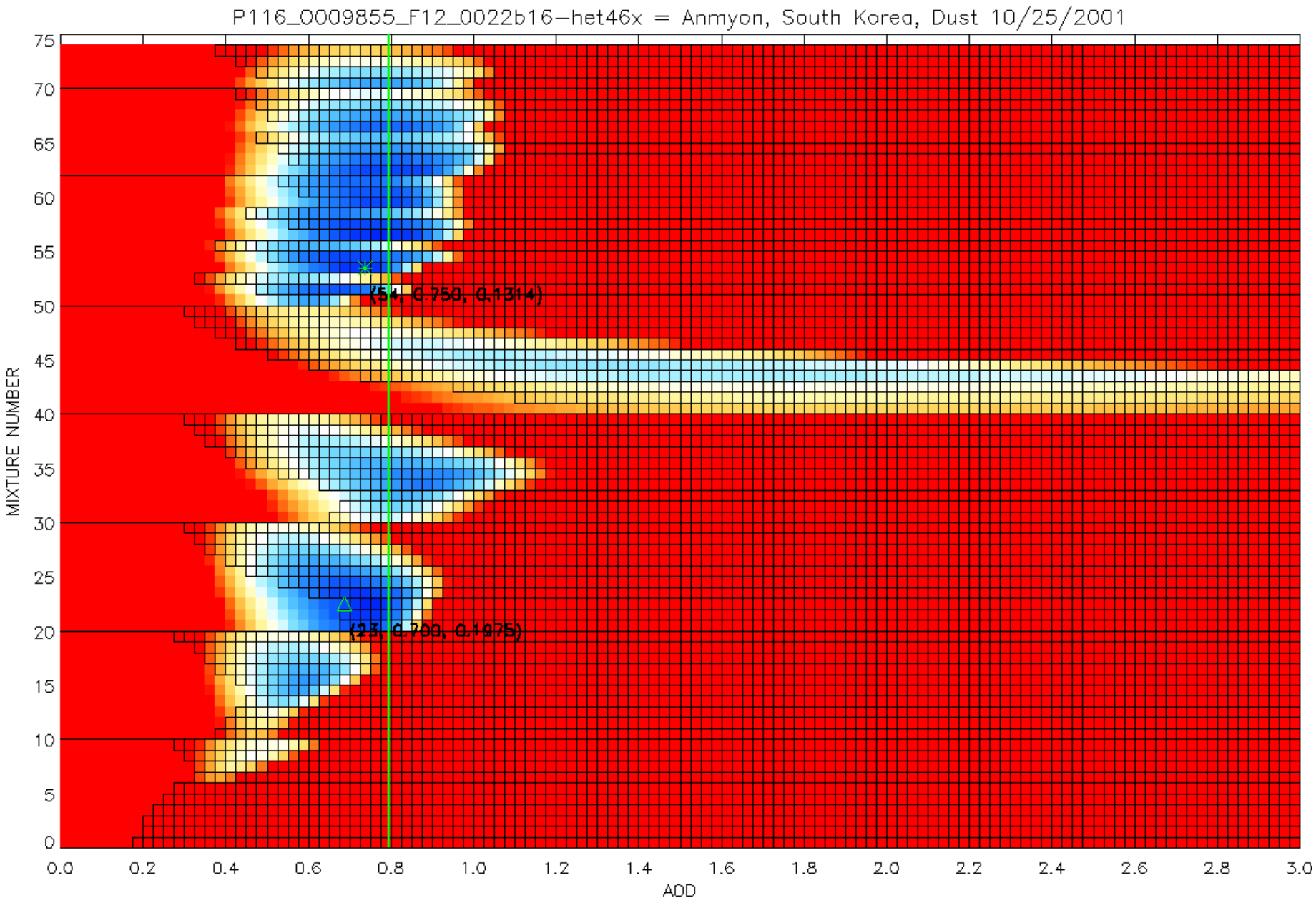
y-axis = Mixture Number (74 mixtures)

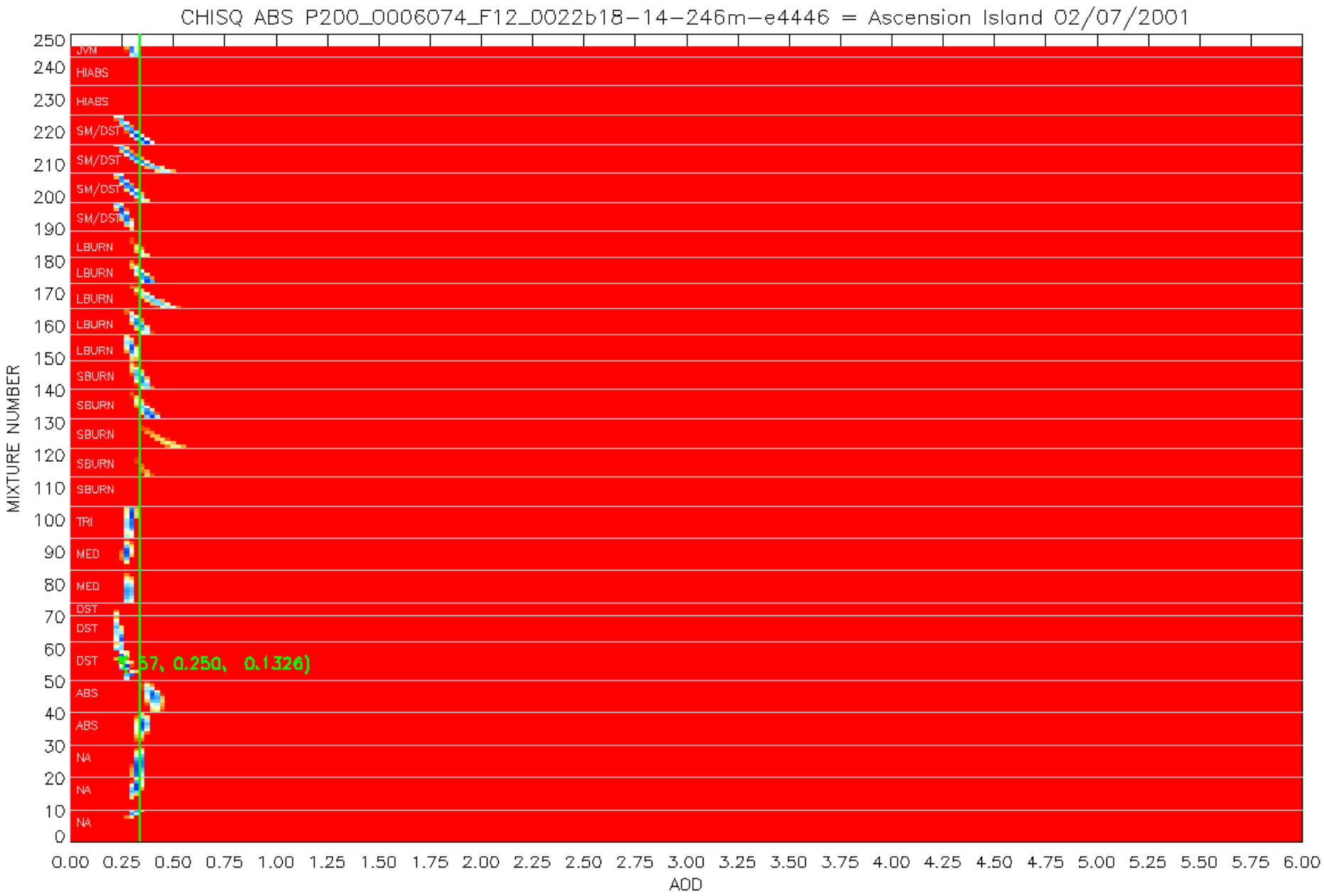
0 Good Fit 1 2 Bad Fit

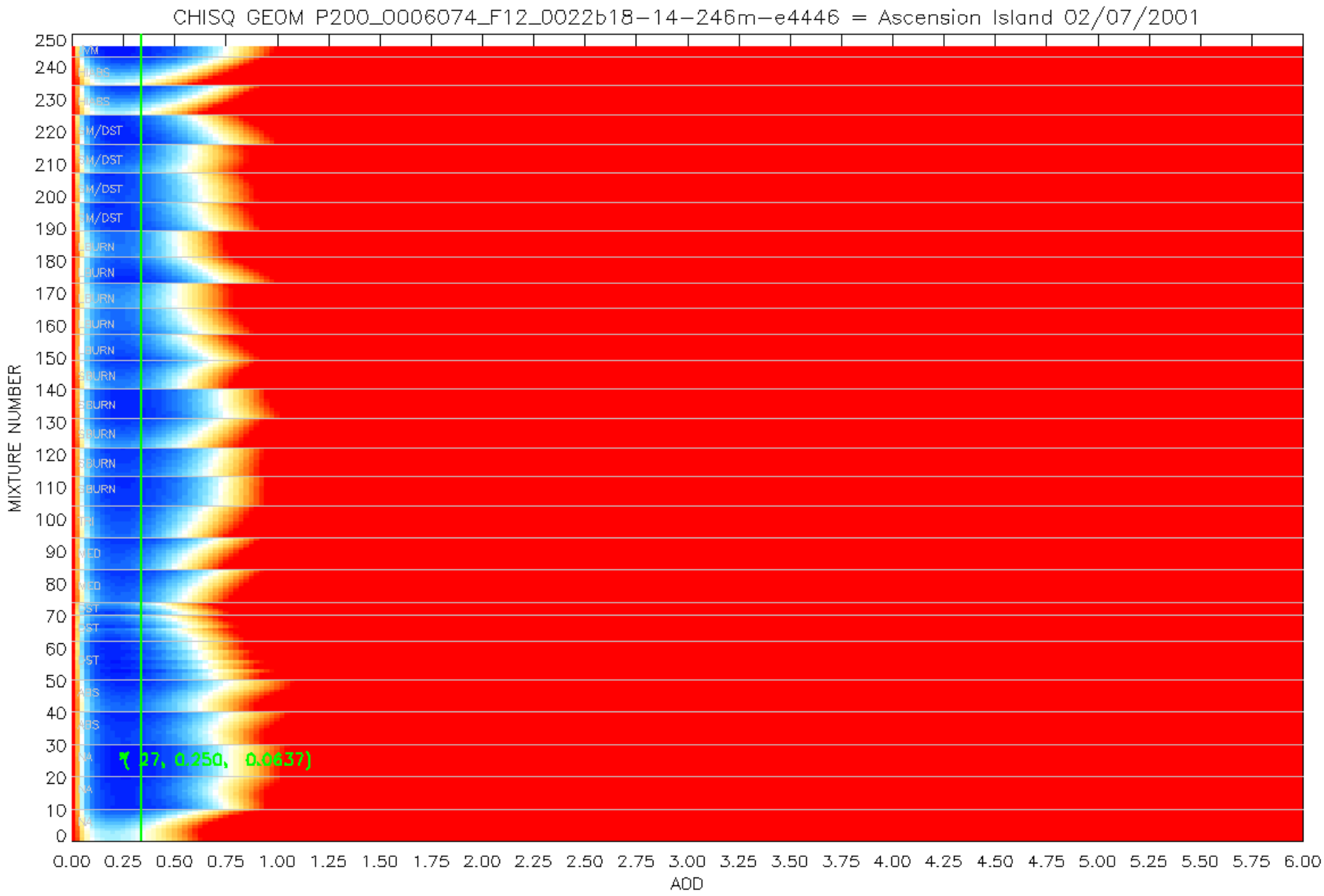
AERONET AOD for these cases is shown as a vertical green line
Lowest Chi-Squared Het value shown as a symbol (Asterisk)
Triplet = (Mixture, AOD, Chi-Squared Het)

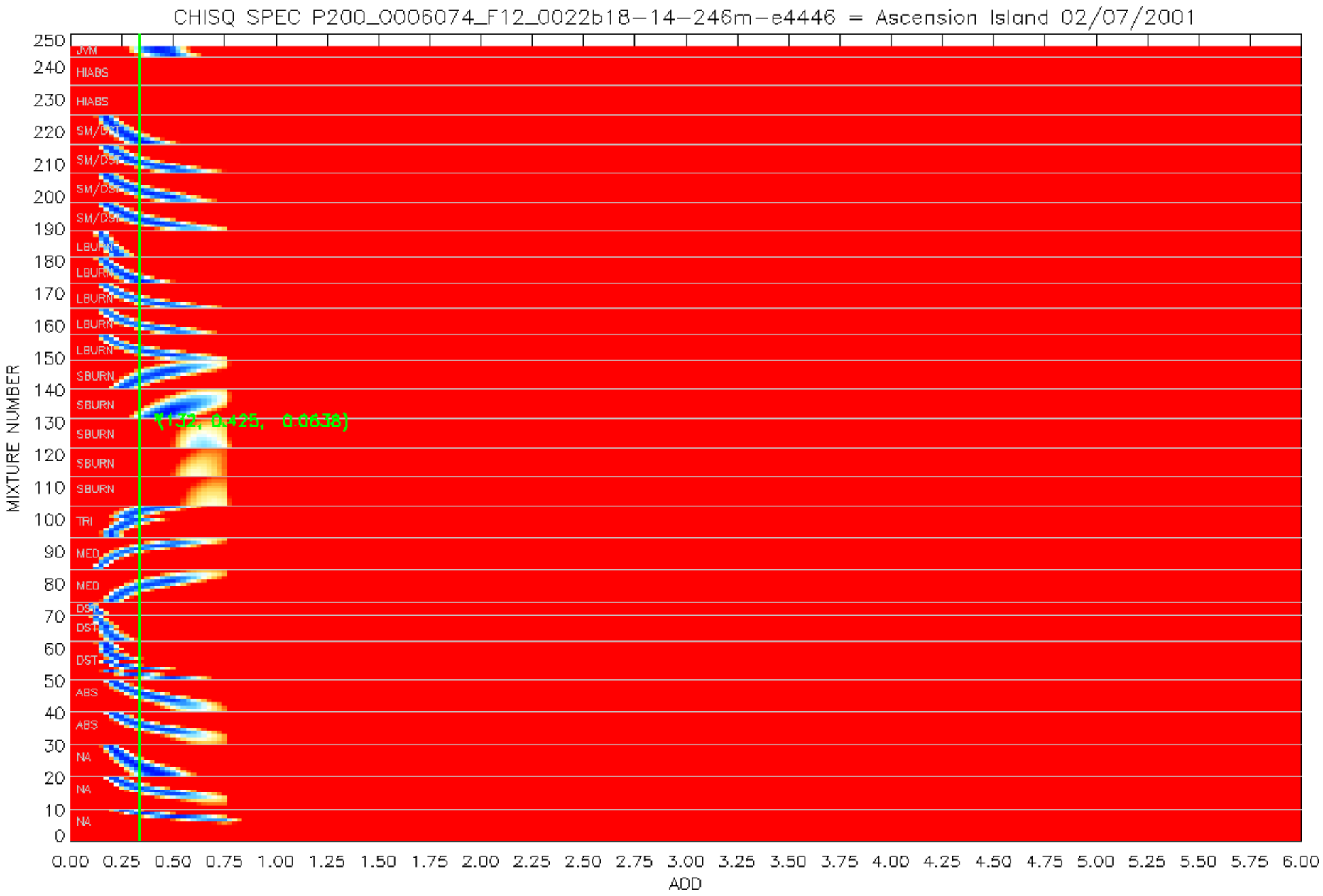
Added Upper Bound Mask and Lowest Chi-Squared Value (Triangle)

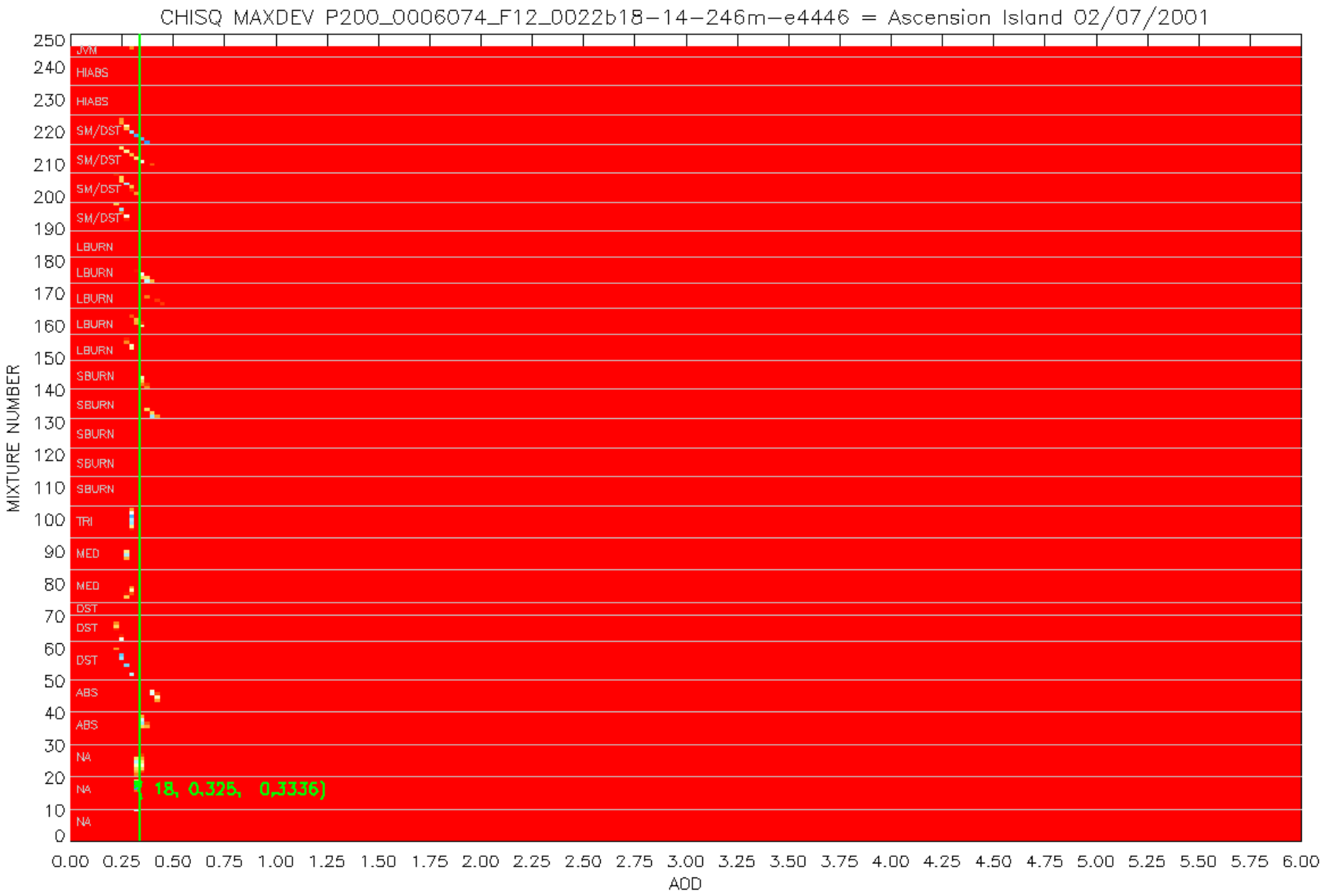

P023_0034853_F12_0022b16-het46x = Bondville, IL, Continental 07/07/2006
(74, 0.500, 0.1581)
(50, 0.350, 0.2501)
MIXTURE NUMBER
AOD
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0

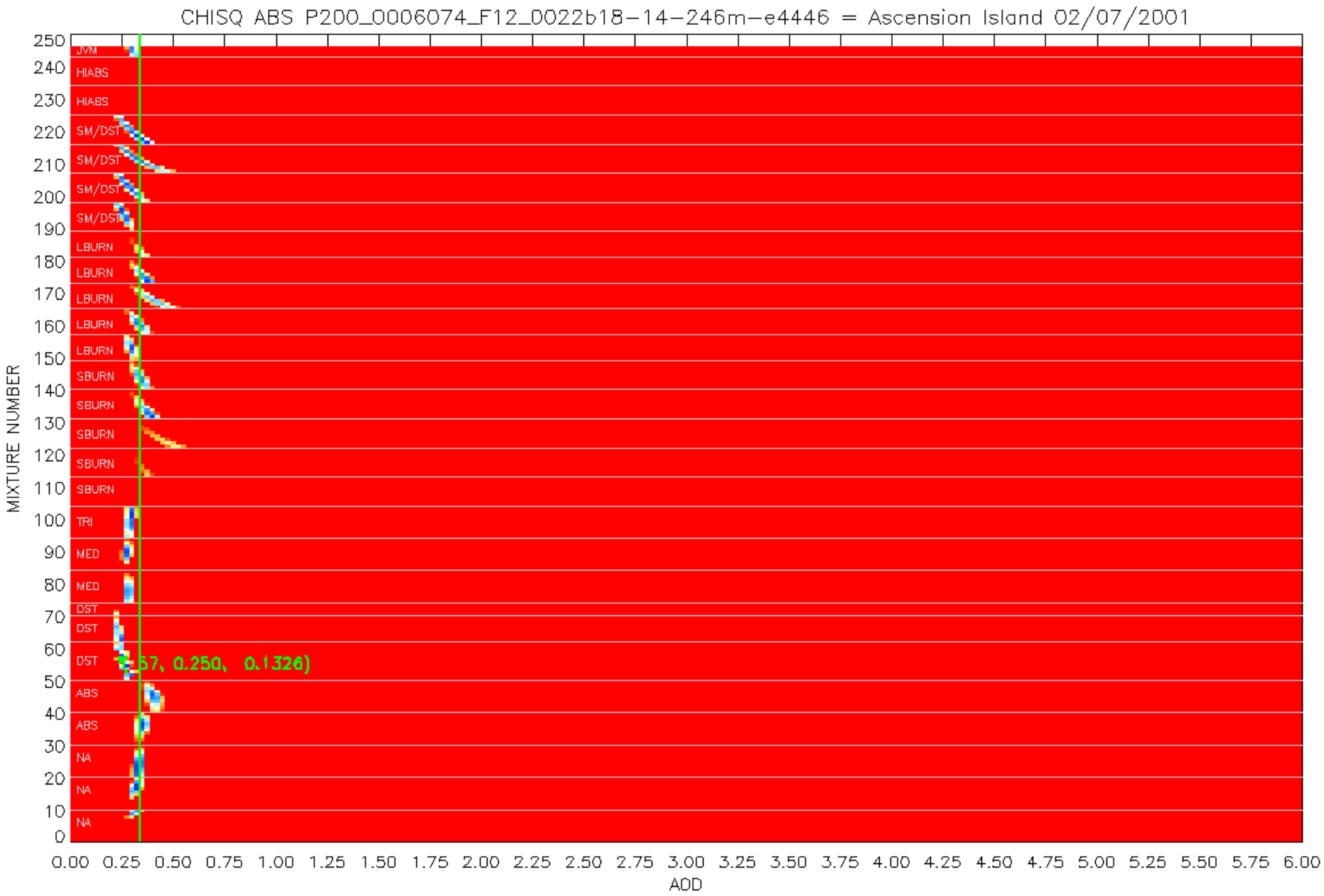

P116_0009855_F12_0022b16-het46x = Anmyon, South Korea, Dust 10/25/2001
MIXTURE NUMBER
AOD
(54, 0.750, 0.1314)
(23, 0.700, 0.1975)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0


CHISQ ABS P200_0006074_F12_0022b18-14-246m-e4446 = Ascension Island 02/07/2001
MIXTURE NUMBER
AOD
JVM
HIABS
HIABS
SM/DST
SM/DST
SM/DST
SM/DST
LBURN
LBURN
LBURN
LBURN
LBURN
SBURN
SBURN
SBURN
SBURN
SBURN
TRI
MED
MED
DST
DST
DST
ABS
ABS
NA
NA
NA
57, 0.250, 0.1326)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00 3.25 3.50 3.75 4.00 4.25 4.50 4.75 5.00 5.25 5.50 5.75 6.00


CHISQ GEOM P200_0006074_F12_0022b18-14-246m-e4446 = Ascension Island 02/07/2001
MIXTURE NUMBER
AOD
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00 3.25 3.50 3.75 4.00 4.25 4.50 4.75 5.00 5.25 5.50 5.75 6.00
(27, 0.250, 0.0637)


CHISQ SPEC P200_0006074_F12_0022b18-14-246m-e4446 = Ascension Island 02/07/2001
MIXTURE NUMBER
AOD
JVM
HIABS
HIABS
SM/DST
SM/DST
SM/DST
SM/DST
LBURN
LBURN
LBURN
LBURN
LBURN
SBURN
SBURN
SBURN
SBURN
SBURN
TRI
MED
MED
DST
DST
DST
ABS
ABS
NA
NA
NA
(132, 0.425, 0.0638)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00 3.25 3.50 3.75 4.00 4.25 4.50 4.75 5.00 5.25 5.50 5.75 6.00


CHISQ MAXDEV P200_0006074_F12_0022b18-14-246m-e4446 = Ascension Island 02/07/2001
MIXTURE NUMBER
AOD
JVM
HIABS
HIABS
SM/DST
SM/DST
SM/DST
SM/DST
LBURN
LBURN
LBURN
LBURN
LBURN
SBURN
SBURN
SBURN
SBURN
SBURN
TRI
MED
MED
DST
DST
DST
ABS
ABS
NA
NA
NA
18, 0.325, 0.3336)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00 3.25 3.50 3.75 4.00 4.25 4.50 4.75 5.00 5.25 5.50 5.75 6.00


CHISQ ABS P200_0006074_F12_0022b18-14-246m-e4446 = Ascension Island 02/07/2001
MIXTURE NUMBER
AOD
JVM
HIABS
HIABS
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SM/DST
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SM/DST
LBURN
LBURN
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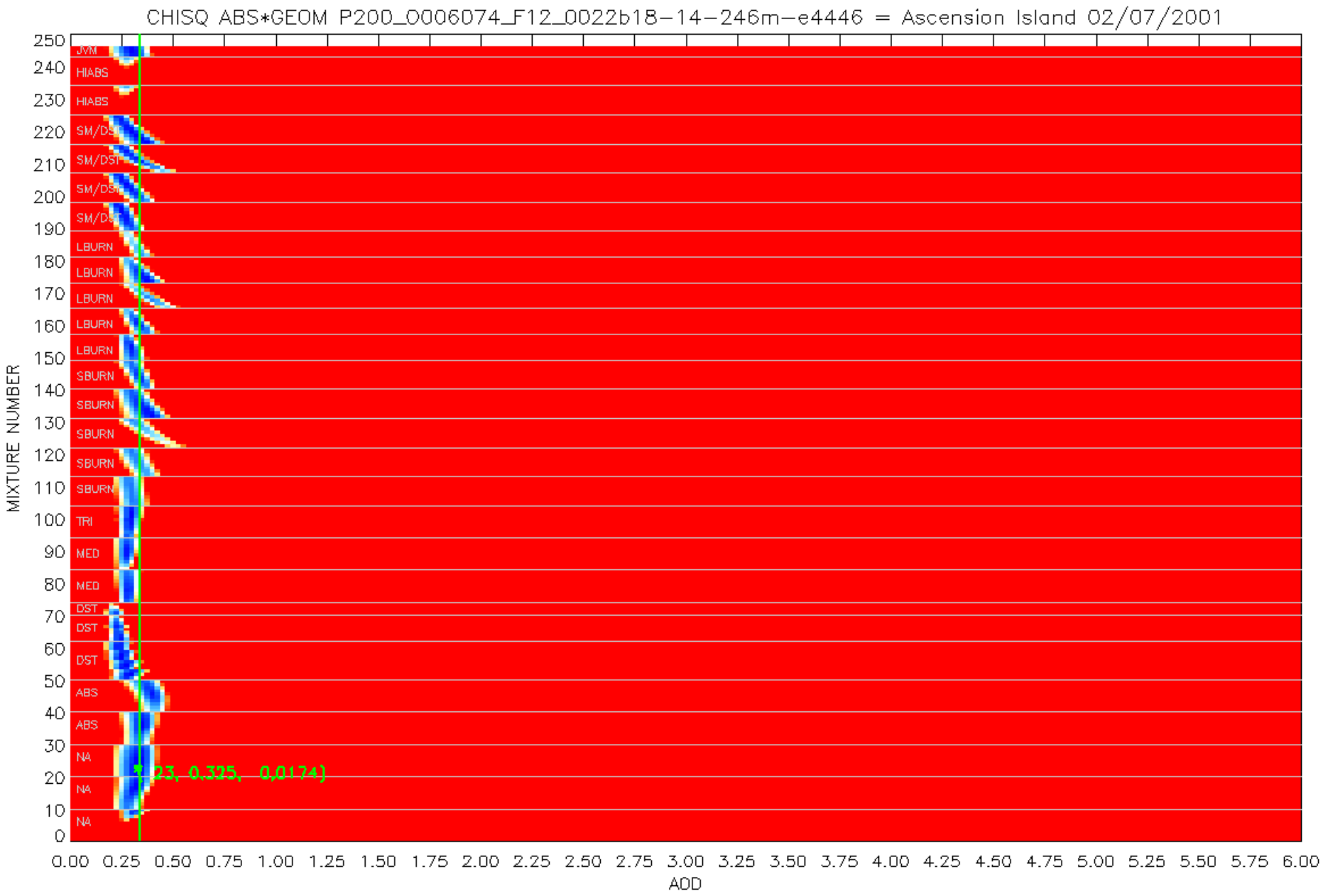
SBURN
SBURN
SBURN
SBURN
SBURN
TRI
MED
MED
DST
DST
DST
ABS
ABS
NA
NA
NA
57, 0.250, 0.1326)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00 3.25 3.50 3.75 4.00 4.25 4.50 4.75 5.00 5.25 5.50 5.75 6.00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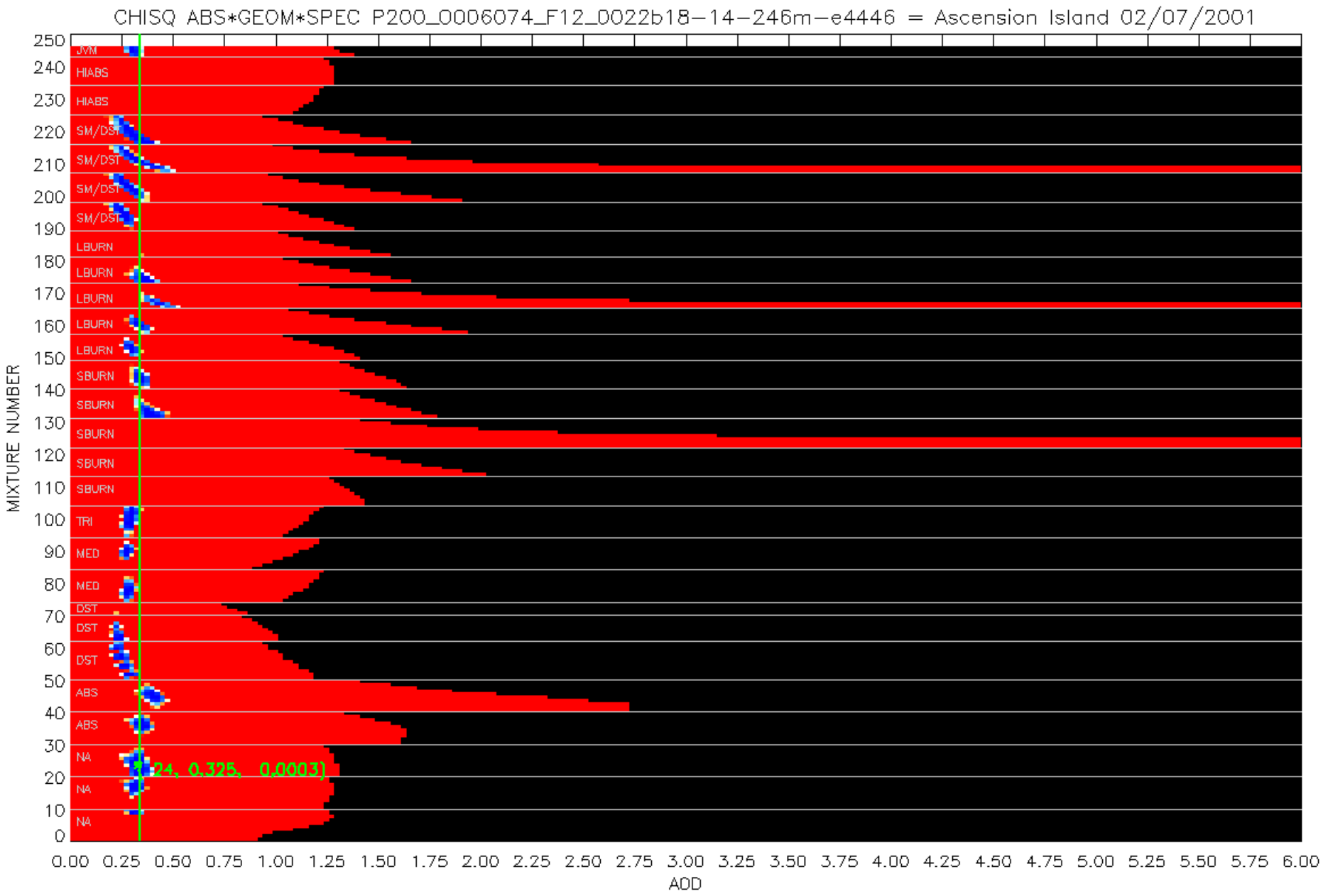
MIXTURE NUMBER
AOD
JVM
HIABS
HIABS
SM/DST
SM/DST
SM/DST
SM/DST
LBURN
LBURN
LBURN
LBURN
LBURN
SBURN
SBURN
SBURN
SBURN
SBURN
TRI
MED
MED
DST
DST
DST
ABS
ABS
NA
NA
NA
0.23, 0.325, 0.0174)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00 3.25 3.50 3.75 4.00 4.25 4.50 4.75 5.00 5.25 5.50 5.75 6.00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MIXTURE NUMBER
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HIABS
SM/DST
SM/DST
SM/DST
SM/DST
LBURN
LBURN
LBURN
LBURN
LBURN
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SBURN
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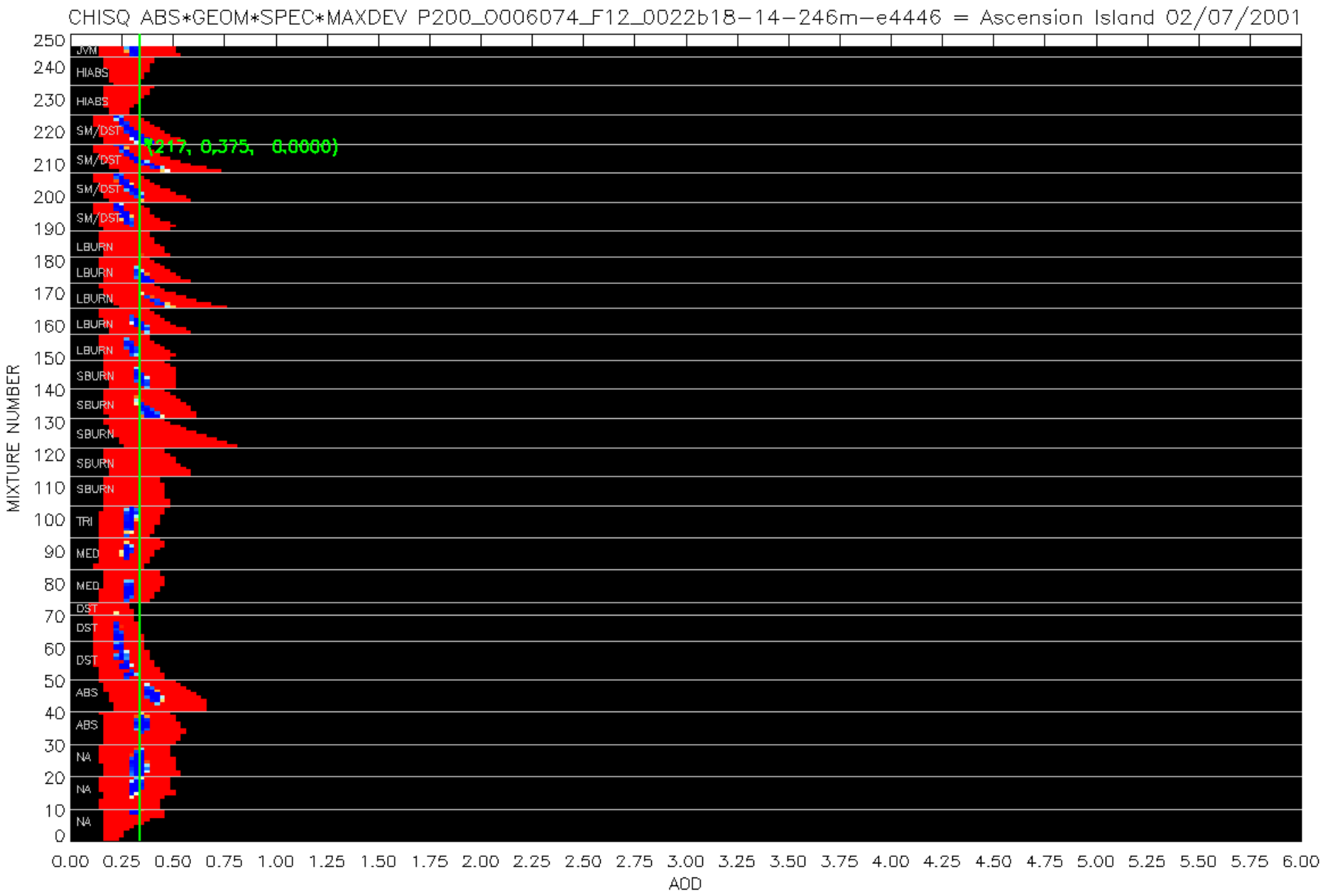
SBURN
TRI
MED
MED
DST
DST
DST
ABS
ABS
NA
NA
NA
(24, 0.325, 0.0003)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00 3.25 3.50 3.75 4.00 4.25 4.50 4.75 5.00 5.25 5.50 5.75 6.00


CHISQ ABS*GEOM*SPEC*MAXDEV P200_0006074_F12_0022b18-14-246m-e4446 = Ascension Island 02/07/2001
(217, 0.375, 0.0000)
JVM
HIABS
HIABS
SM/DST
SM/DST
SM/DST
SM/DST
LBURN
LBURN
LBURN
LBURN
LBURN
SBURN
SBURN
SBURN
SBURN
SBURN
TRI
MED
MED
DST
DST
DST
ABS
ABS
NA
NA
NA
MIXTURE NUMBER
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00 3.25 3.50 3.75 4.00 4.25 4.50 4.75 5.00 5.25 5.50 5.75 6.00
AOD

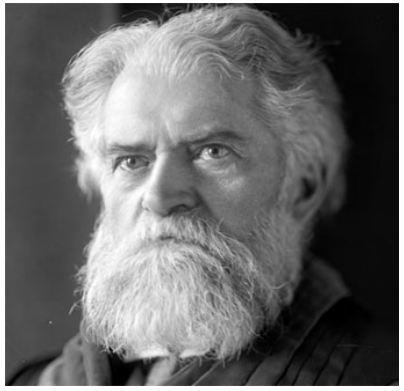
Dessert

Benford's Law

- Simon Newcomb (pictured) published an article in the American Journal of Mathematics in 1881 after noticing that books of logarithms in the library were more used at the beginning and progressively lesser used. He inferred that scientists were looking up numbers starting with 1 more often and less often for later numbers. He expressed this mathematically with the equation:

$$P_D = \log_{10}\left(1 + 1/D\right)$$

- Frank Benford (not pictured) rediscovered this law by making exactly the same observation about books of logarithms and found many other data sets that followed the law. He published his results in a paper in the Proceedings of the American Philosophical Society in 1938.



Benford's Law

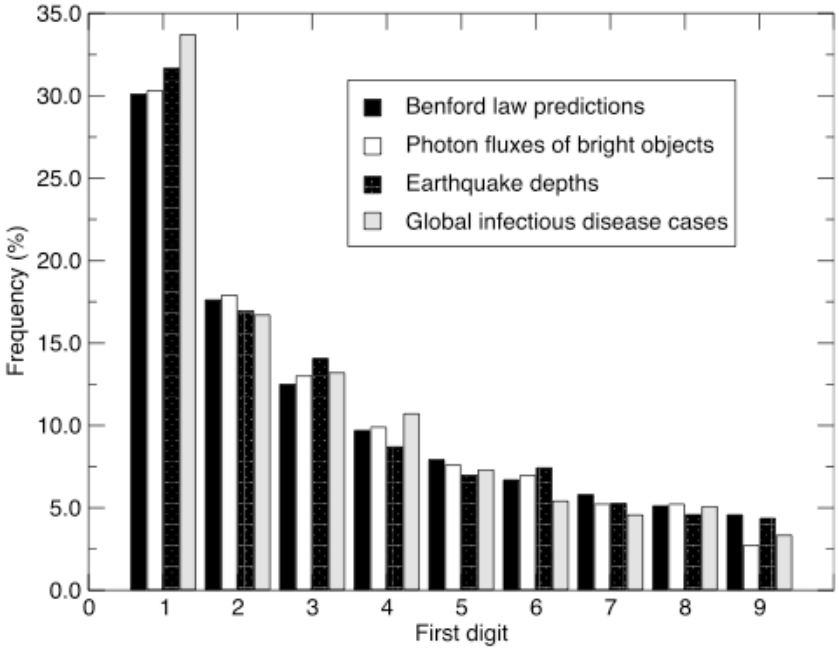
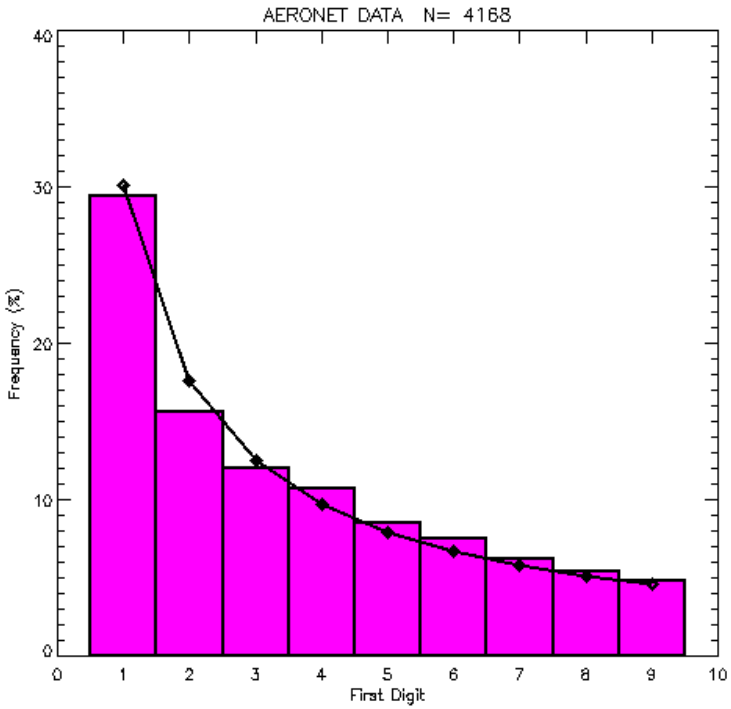
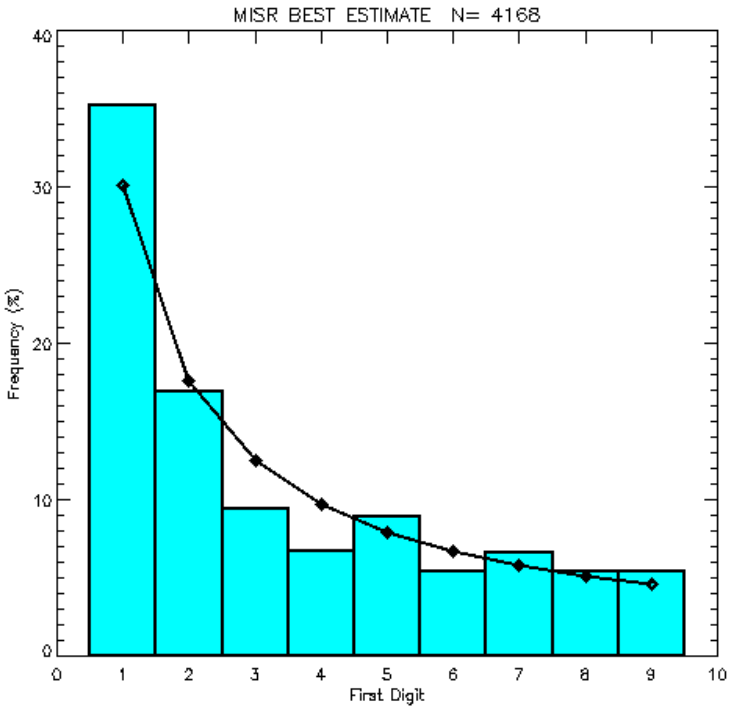
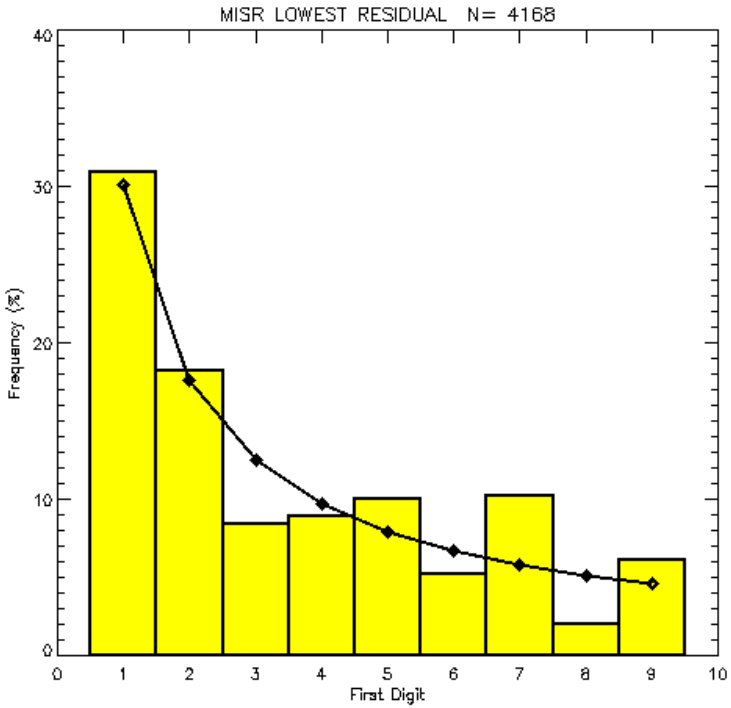


Figure 1. Benford's law predictions according to (1) for distributions of 1st digits compared to three data sets from Table 1. Columns represent eighth row of Table 1, photon fluxes for 1452 bright objects identified by the Fermi space telescope, ninth row of Table 1 depths of 248915 globally distributed earthquakes in the period 1989–2009, and fourteenth row of Table 1 987 reports of infectious disease numbers to World Health Organization in 2007. See Caption of Table 1 for full details. The 1st digit distributions from a wide variety of data sets appear to fit the predictions of the 1st digit law well.

Sambridge et al., GRL, 2010

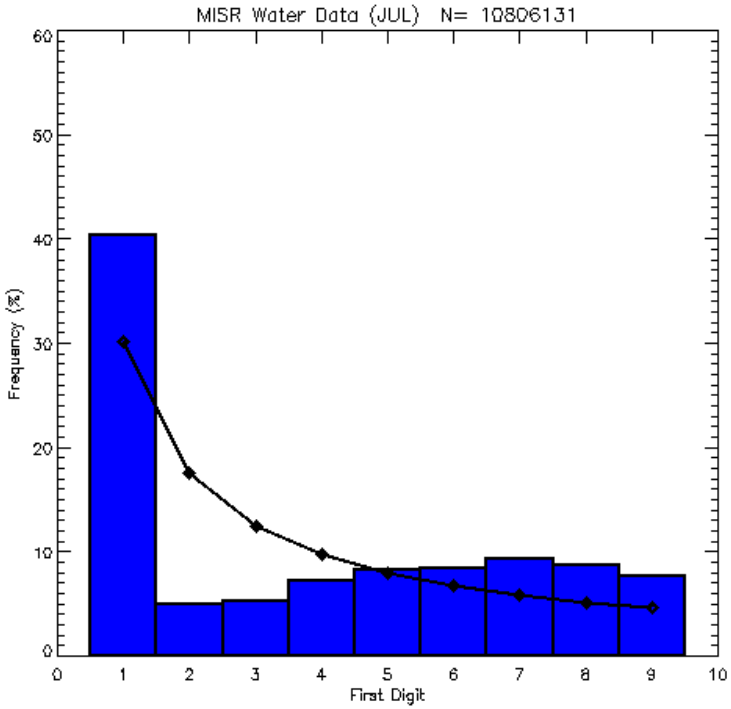


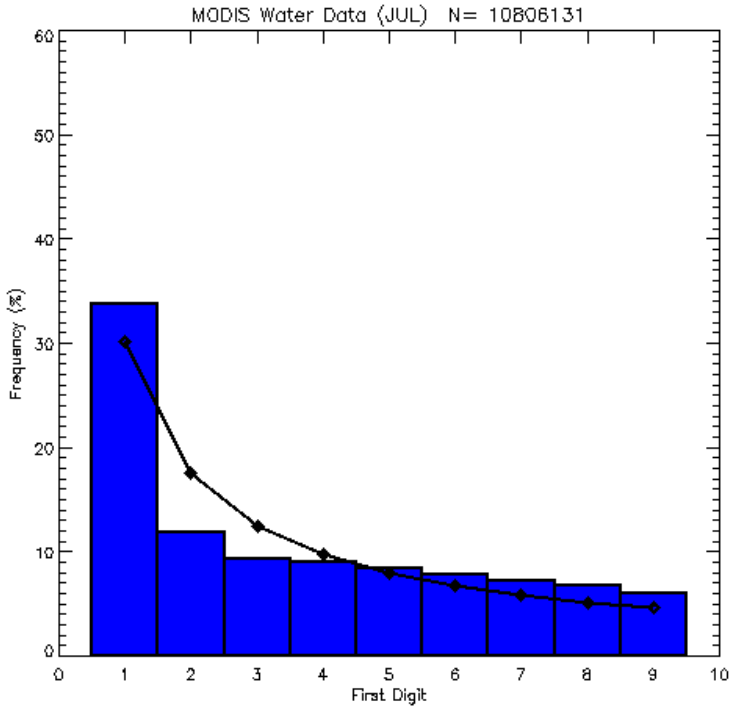


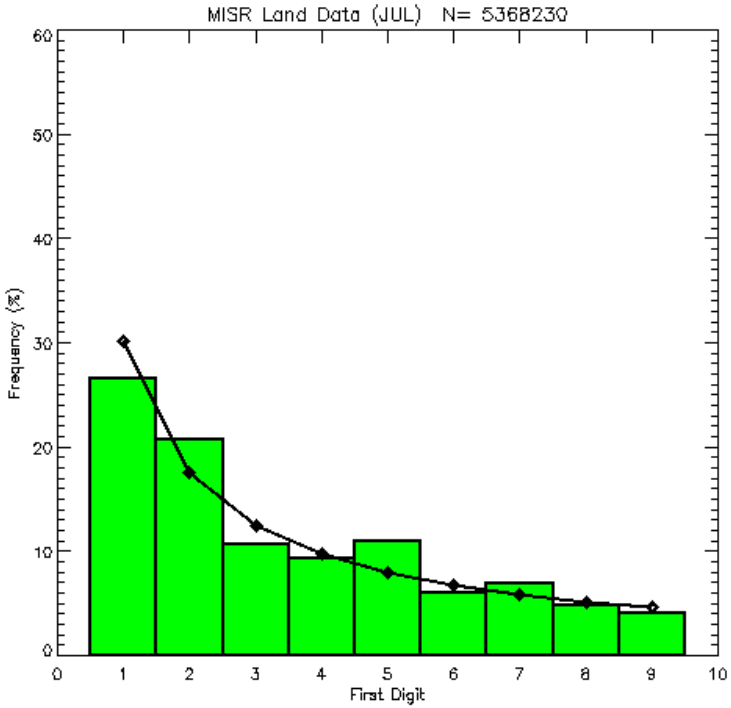


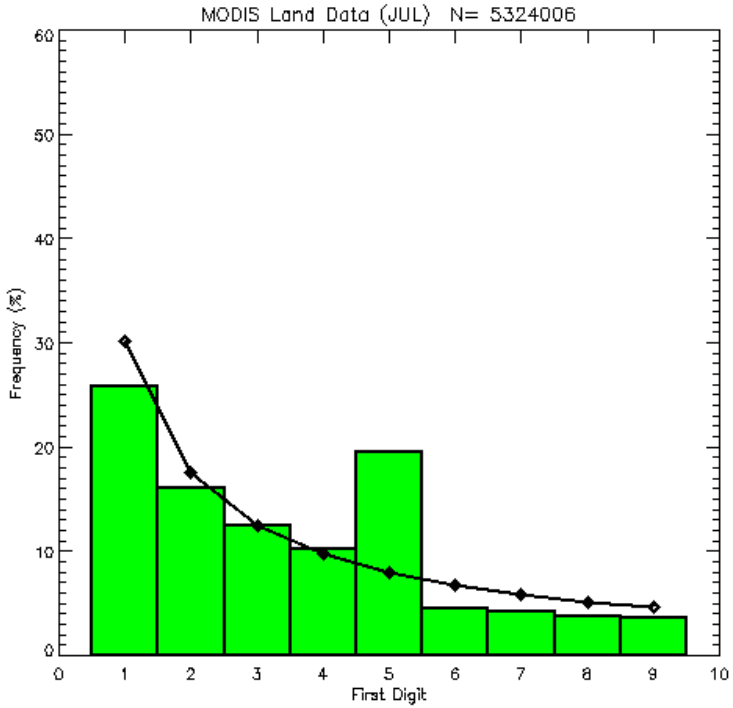
Line shows predictions from Benford's Law

Matched MISR V22/AERONET Data









Matched MISR V22/ MODIS Data

References

Diner, D. J., et al. (2005), Using angular and spectral shape similarity constraints to improve MISR aerosol and surface retrievals over land, *Remote Sens. Environ., 94*, 155-171.

Kahn, R. A., et al. (2009), MISR aerosol product attributes and statistical comparisons with MODIS, *IEEE Trans. Geosci. Remote Sens., 47*, 4095-4114.

Kahn, R. A., et al. (2010), Multiangle Imaging SpectroRadiometer global aerosol product assessment by comparison with the Aerosol Robotic Network, *J. Geophys. Res., 115*, D23209, doi:10.1029/2010JD014601.

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