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Supplement of

MISR research-aerosol-algorithm refinements for dark water retrievals

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Real Refractive Index (n_r) Sensitivity Study

[Figures S1 – S5]

This section expands on the AOD retrieval sensitivity analysis for the real refractive index (n_r), illustrated in Figure 6 of the main paper. It covers a range of particle sizes, and n_r as well as AOD values are varied systematically for the particles assumed in the algorithm comparison space.

For each figure, the simulated atmosphere contains single-mode particles having n_r and effective radius (r_e) given at the top. Comparison-space particles, having varying n_r, are defined above each panel; comparisons are made for three values of AOD and a range of geometries. The geographic placement of the plots is for illustration – over-water conditions are assumed everywhere, with the surface pressure prescribed as 1013.25 mb, and the surface wind speed set to 2.5 m/s.

Parameter Space

Simulated Atmosphere ***r_e* values** (μm): 0.12, 0.26, 0.57, 1.28, 2.80

Simulated Atmosphere ***AOD* values:** 0.1, 0.5, 2.0

Simulated Atmosphere ***n_r* value:** 1.45

Comparison Space ***n_r* values:** 1.35, 1.40, 1.50, 1.55

Input Atmospheric Particles: n_r=1.45, r_e=0.12 µm

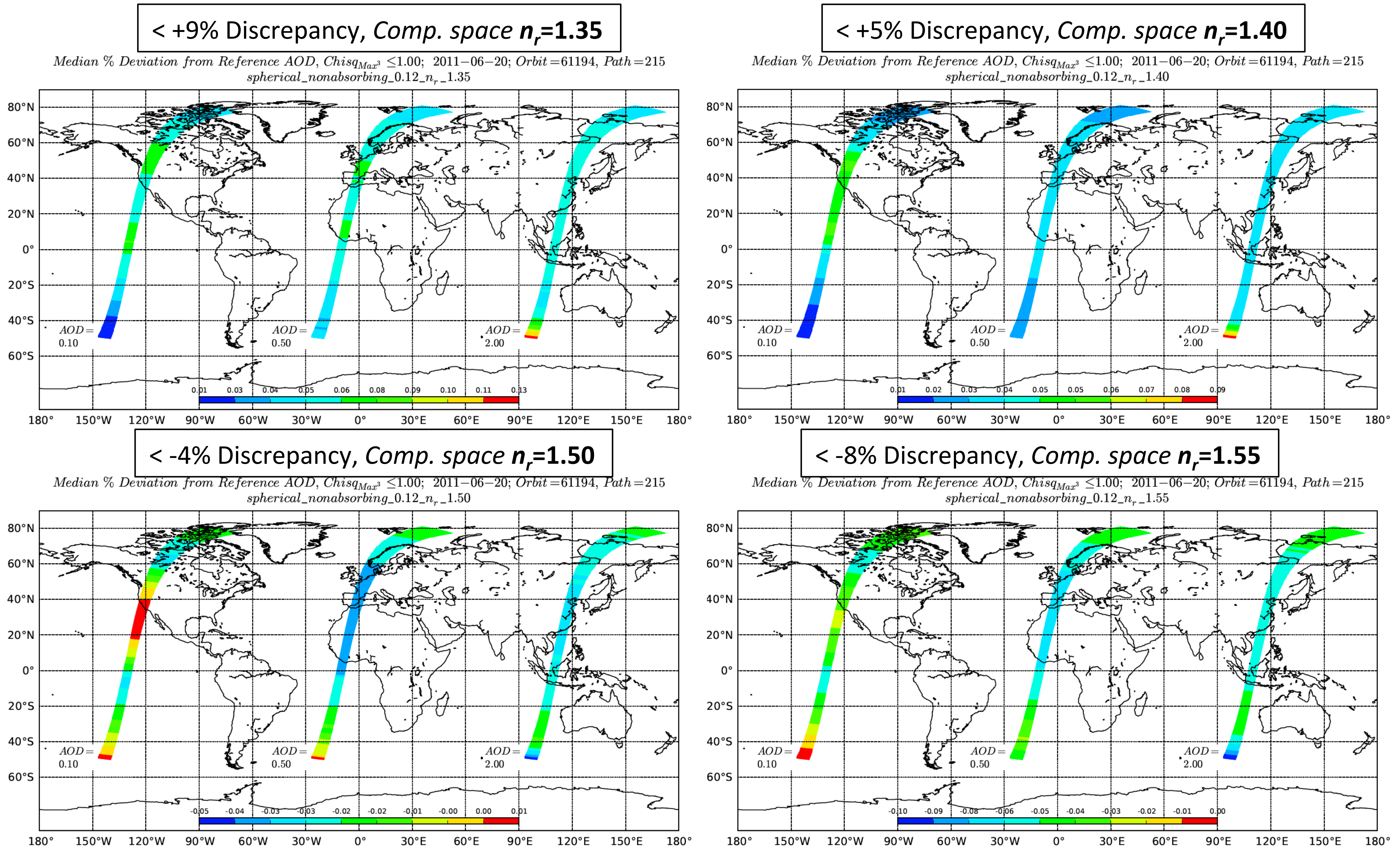
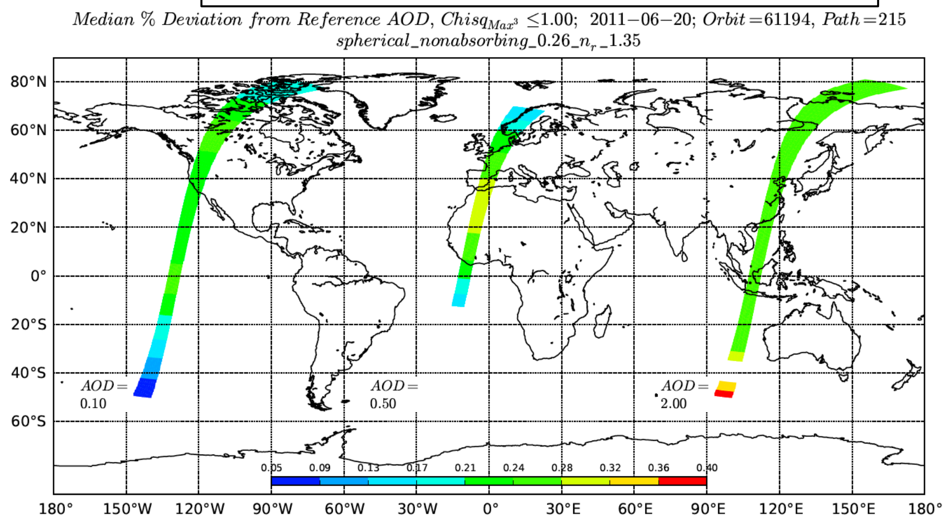


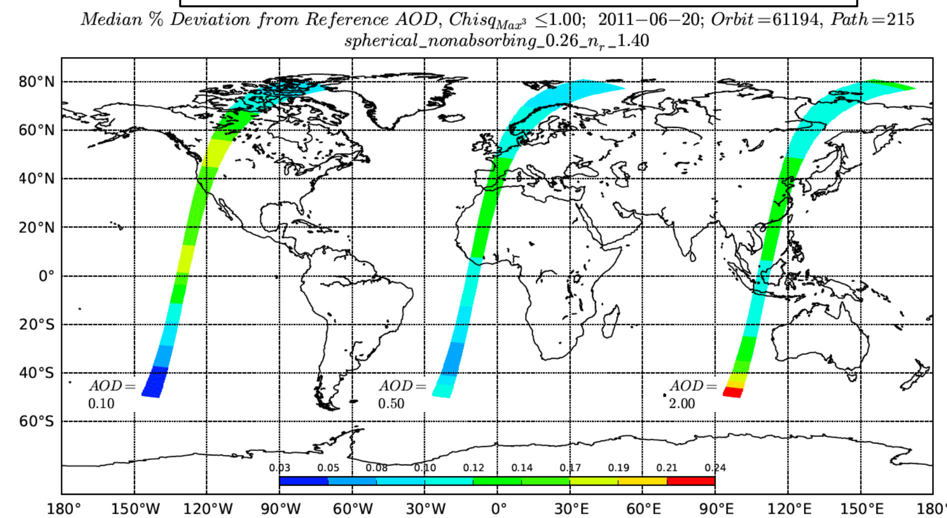
Figure S1

Input Atmospheric Particles: n_r=1.45, r_e=0.26 μm

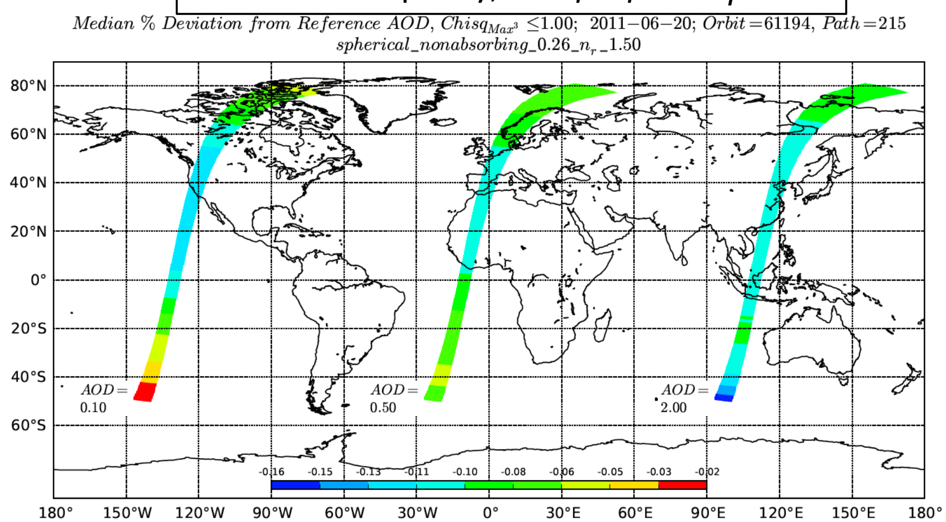
< +32% Discrepancy, *Comp. space* $\boldsymbol{n_r}$**=1.35**



< +19% Discrepancy, *Comp. space* $\boldsymbol{n_r}$**=1.40**



< -13% Discrepancy, *Comp. space* $\boldsymbol{n_r}$**=1.50**



< -27% Discrepancy, *Comp. space* $\boldsymbol{n_r}$**=1.55**

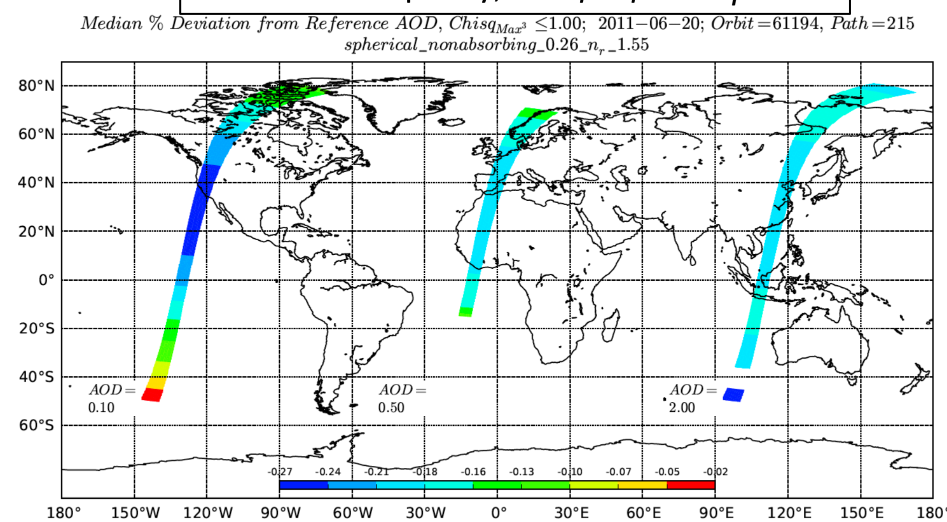


Figure S2

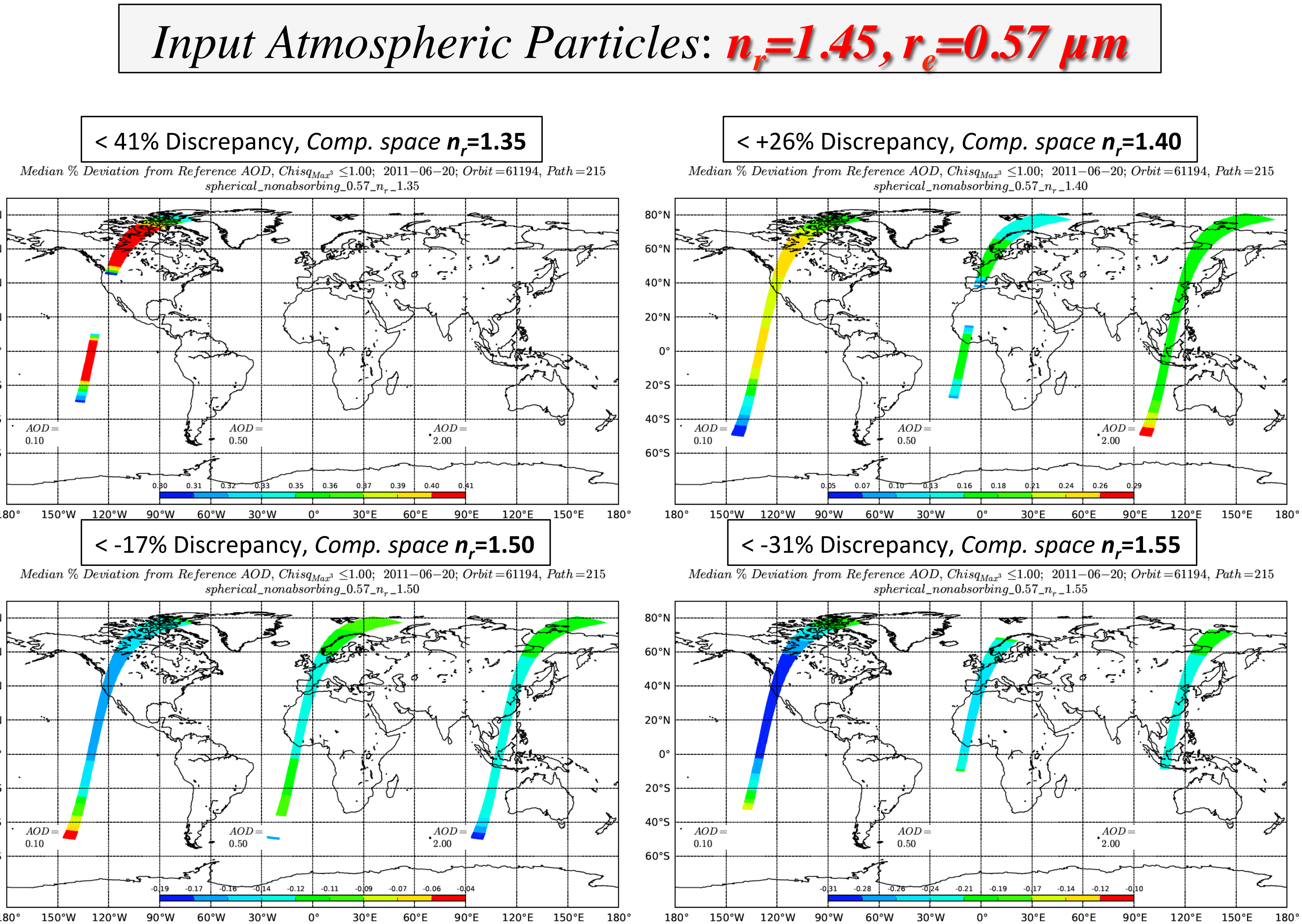

Input Atmospheric Particles: n_r=1.45, r_e=0.57 μm
< 41% Discrepancy, Comp. space n_r=1.35
Median % Deviation from Reference AOD, Chisq_Max^3 ≤1.00; 2011−06−20; Orbit=61194, Path=215
spherical_nonabsorbing_0.57_n_r_1.35
< +26% Discrepancy, Comp. space n_r=1.40
Median % Deviation from Reference AOD, Chisq_Max^3 ≤1.00; 2011−06−20; Orbit=61194, Path=215
spherical_nonabsorbing_0.57_n_r_1.40
< -17% Discrepancy, Comp. space n_r=1.50
Median % Deviation from Reference AOD, Chisq_Max^3 ≤1.00; 2011−06−20; Orbit=61194, Path=215
spherical_nonabsorbing_0.57_n_r_1.50
< -31% Discrepancy, Comp. space n_r=1.55
Median % Deviation from Reference AOD, Chisq_Max^3 ≤1.00; 2011−06−20; Orbit=61194, Path=215
spherical_nonabsorbing_0.57_n_r_1.55
AOD= 0.10
AOD= 0.50
AOD= 2.00
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
180°
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
180°

Figure S3

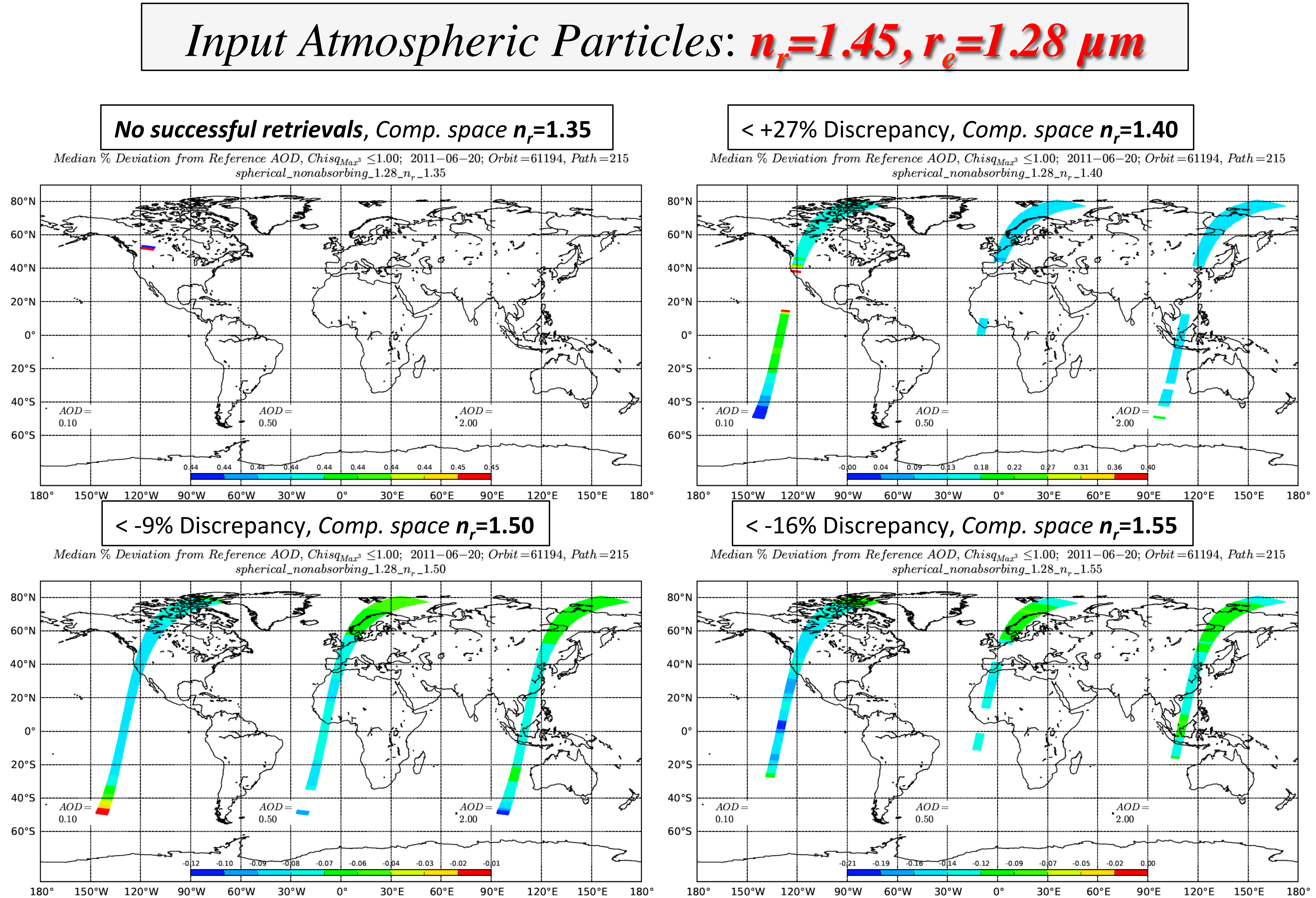
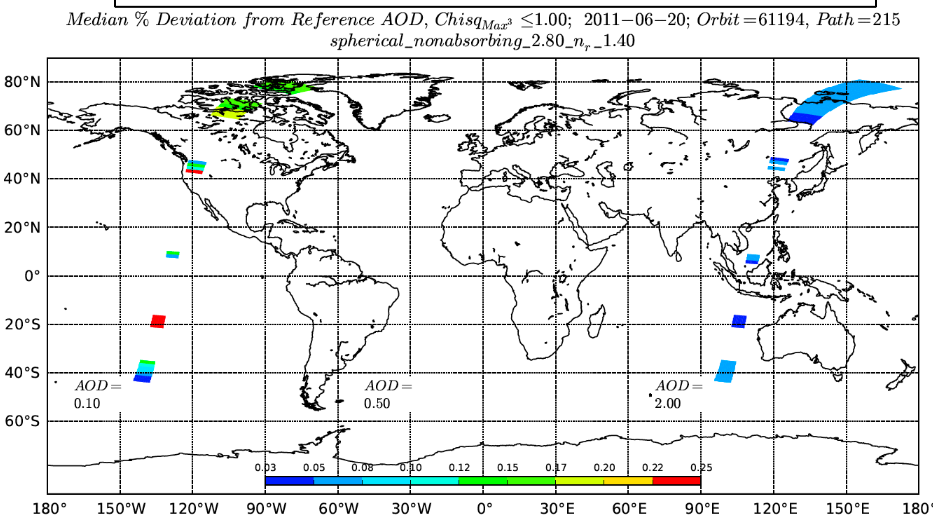

Input Atmospheric Particles: n_r=1.45, r_e=1.28 µm
No successful retrievals, Comp. space n_r=1.35
Median % Deviation from Reference AOD, Chisq_Max³ ≤1.00; 2011−06−20; Orbit=61194, Path=215
spherical_nonabsorbing_1.28_n_r_1.35
< +27% Discrepancy, Comp. space n_r=1.40
Median % Deviation from Reference AOD, Chisq_Max³ ≤1.00; 2011−06−20; Orbit=61194, Path=215
spherical_nonabsorbing_1.28_n_r_1.40
< -9% Discrepancy, Comp. space n_r=1.50
Median % Deviation from Reference AOD, Chisq_Max³ ≤1.00; 2011−06−20; Orbit=61194, Path=215
spherical_nonabsorbing_1.28_n_r_1.50
< -16% Discrepancy, Comp. space n_r=1.55
Median % Deviation from Reference AOD, Chisq_Max³ ≤1.00; 2011−06−20; Orbit=61194, Path=215
spherical_nonabsorbing_1.28_n_r_1.55
AOD=
0.10
AOD=
0.50
AOD=
2.00
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
180°
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
180°

Figure S4

Input Atmospheric Particles: n_r=1.45, r_e=2.80 μm

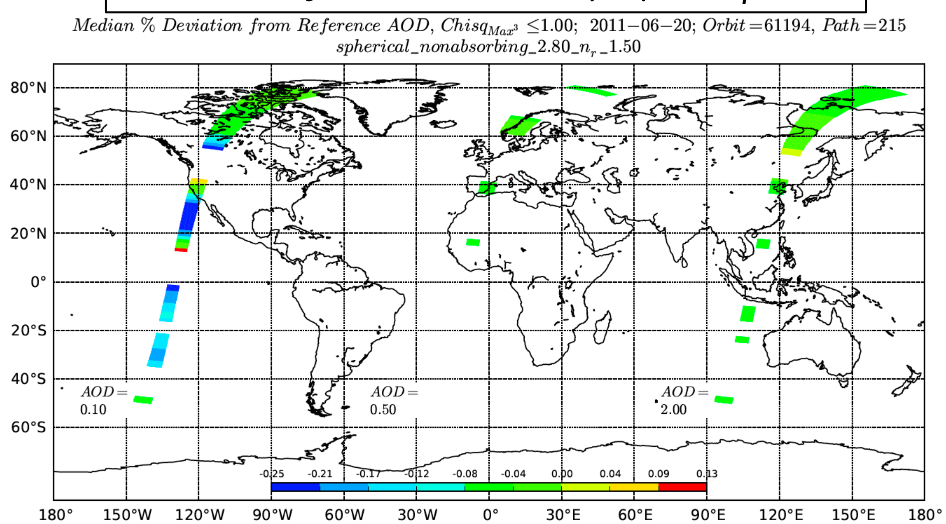
No successful retrievals, *Comp. space* n_r**=1.35**

Few successful retrievals, *Comp. space* n_r**=1.40**



For very large particles,
If n_r ***deviates by 0.05 or more***
no successful retrievals are obtained
(i.e., some retrieval sensitivity to n_r***)***

Few successful retrievals, *Comp. space* n_r**=1.50**



No successful retrievals, *Comp. space* n_r**=1.55**

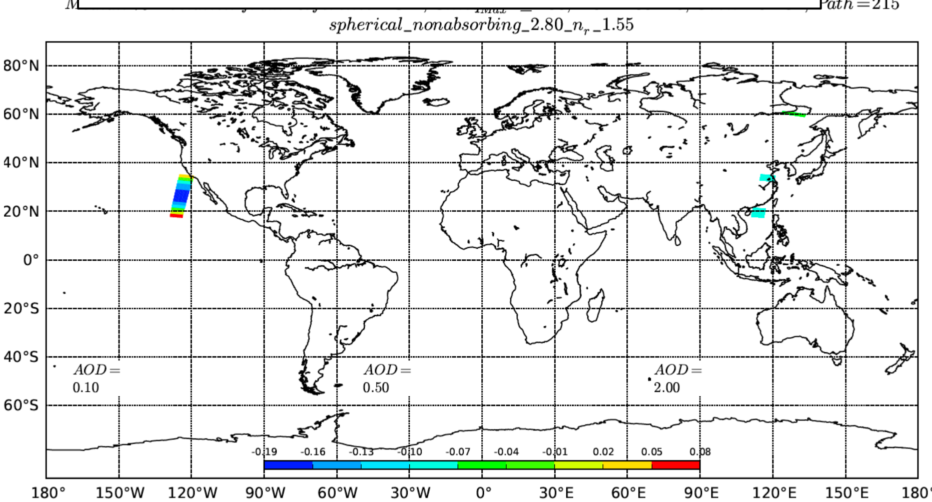


Figure S5

Real Refractive Index Sensitivity Study *Conclusions* [Figures S1 – S5]

- When n_r is ***overestimated***, AOD is systematically ***underestimated***, and conversely
- Generally, retrieved AOD values ***still fall within 0.05 or 20% AOD***, except in extreme cases
- ***Smaller particles*** are affected less by errors in n_r
- ***Very large particles*** are so sensitive to changes in n_r that mixtures ***might not pass*** the algorithm acceptance criteria if n_r deviates too far (~0.05) from the correct value
- ***Medium particles*** (0.26-0.57 μm) produce the largest AOD deviations for ~0.1 n_r error, but are not sensitive enough to n_r to retrieve the correct value. Summary:
  - r_e = 0.12 μm: 5%-7.5% max. deviation for every 0.1 deviation from the correct n_r [Figure S1]
  - r_e = 0.26 μm: 20%-30% max. deviation for every 0.1 deviation from correct n_r [Figure S2]
  - r_e = 0.57 μm: 20%-40% max. deviation for every 0.1 deviation from correct n_r [Figure S3]
  - r_e = 1.28 μm: 15%-40% max. deviation for every 0.1 deviation from correct n_r [Figure S4]
  - r_e = 2.80 μm: variable max. deviation for every 0.1 deviation from correct n_r [Figure S5]
- Distributions having larger effective radii tend to have biases that vary considerably ***depending on viewing/solar geometry***
- Overall, the ***0.57 μm particle tends to perform the worst*** if n_r is incorrect; the 0.26 μm particle is a close second. (Mixtures might still pass, but the retrieved AOD discrepancy can be >0.05/20%.)

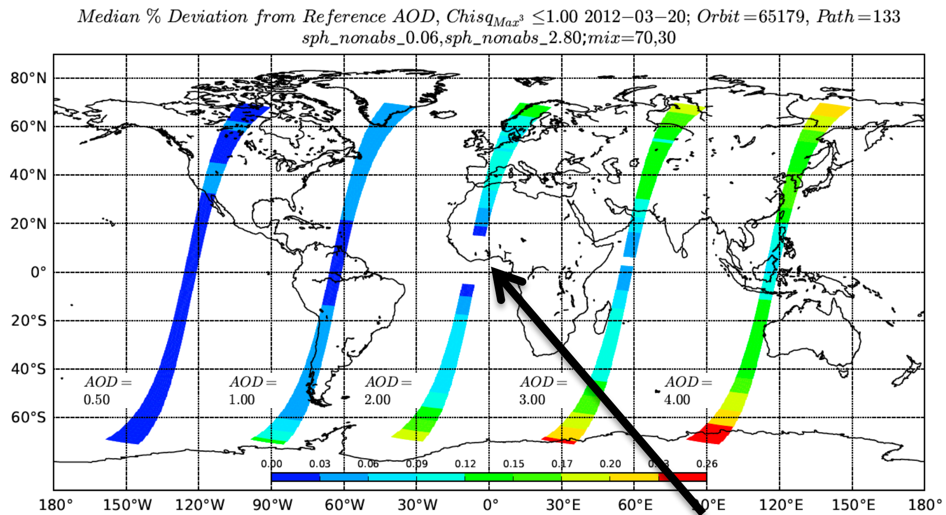
Linear Mixing (LM) & ***Modified-Linear Mixing*** (MLM) Sensitivity Study

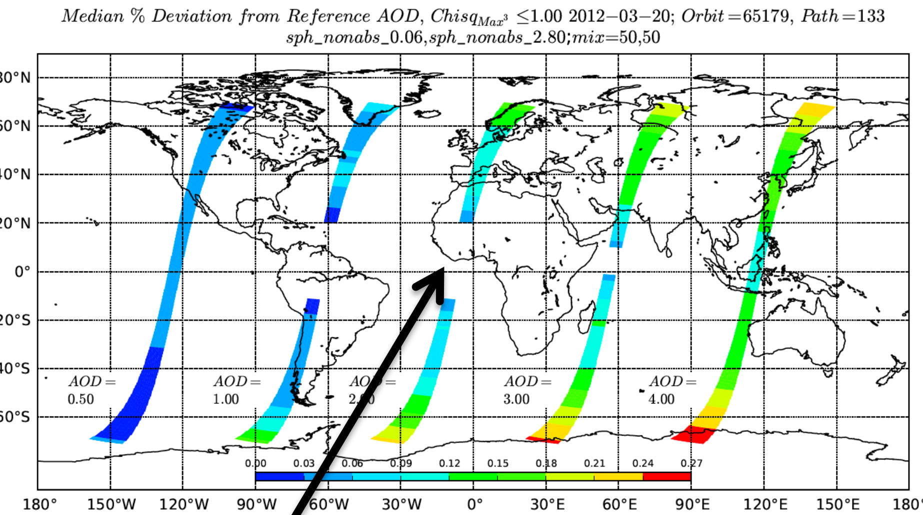
This section expands on the AOD retrieval sensitivity analysis for ***Linear Mixing*** and ***Modified Linear Mixing***, as illustrated in Figure 7 of the main paper. MLM is used to approximate the radiative effects of mixtures containing two or more optically distinct aerosol components, based on pre-run radiative transfer calculations for the components individually [*Abdou et* al., 1997]. This supplement considers bi-modal particle distributions covering a range of particle sizes and SSA values, comparing retrieved AOD results from LM and MLM with those derived from runs of the radiative transfer code using layer-effective phase function (Equs. 3 of the main text).

For each figure in this section, the simulated atmosphere and retrieval climatology contain the same bi-modal mixture of particles, specified in the figure annotation, and taken from the SA climatology [*Kahn et al*., 2010]. Comparisons are made between radiative transfer runs using layer-effective phase function and LM or MLM approximations, for five values of AOD and a range of geometries. (The geographic placement of the plots is for illustration – all retrievals are performed over simulated black surfaces.) Mixture numbers in the figures correspond to the climatology in the MISR V22 SA climatology.

[Note that *MLM* reduces to *LM* when all particles in the mixture are non-absorbing or have the same SSA.]

Impact of *Linear Mixing;* Globally, Non-Absorbing Aerosol

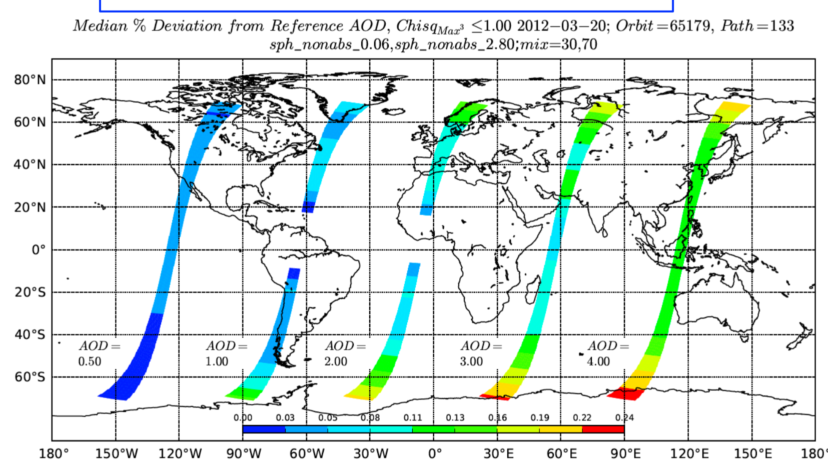




< +17% Discrepancy, ***Mix #5***
70% sph_nonabs_0.06
30% sph_nonabs_2.80

Note: At low lat, moderate AOD →
No mixtures pass when LM is used

< +18% Discrepancy, ***Mix #7***
50% sph_nonabs_0.06
50% sph_nonabs_2.80



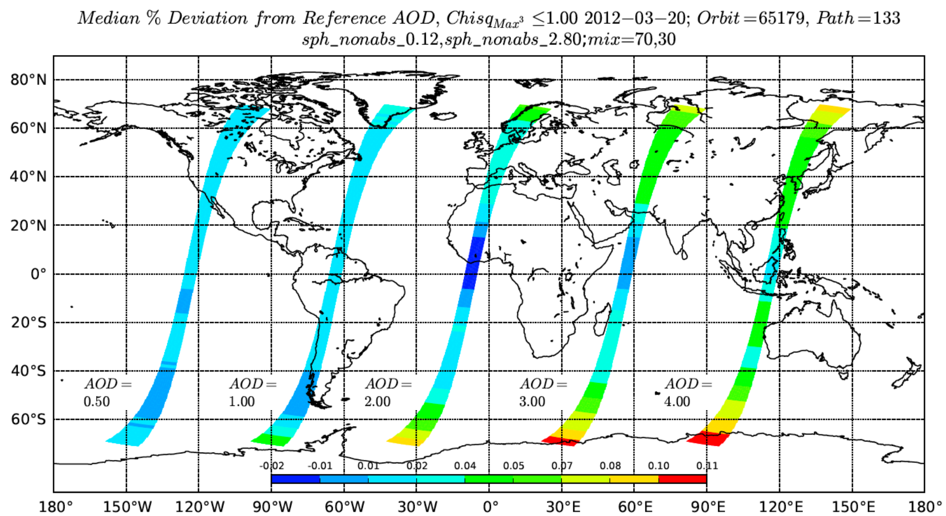
< +16% Discrepancy, ***Mix #9***
30% sph_nonabs_0.06
70% sph_nonabs_2.80

0.06 + 2.80 μm
r_e particles

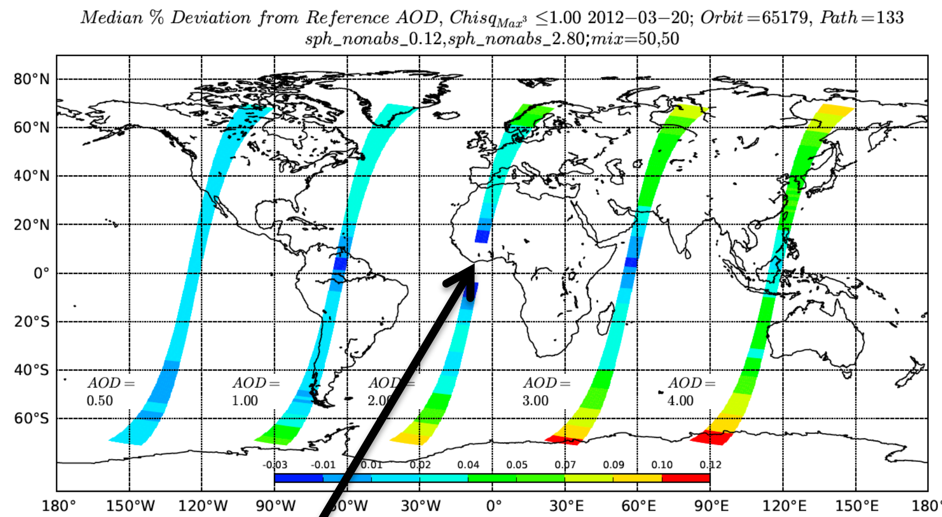
- **Linear mixing *overestimates* AOD with spherical *non-absorbing* particles**
- **A larger particle *size difference* → larger AOD *overestimate***

Figure S6

Impact of ***Linear Mixing;*** Globally, Non-Absorbing Aerosol

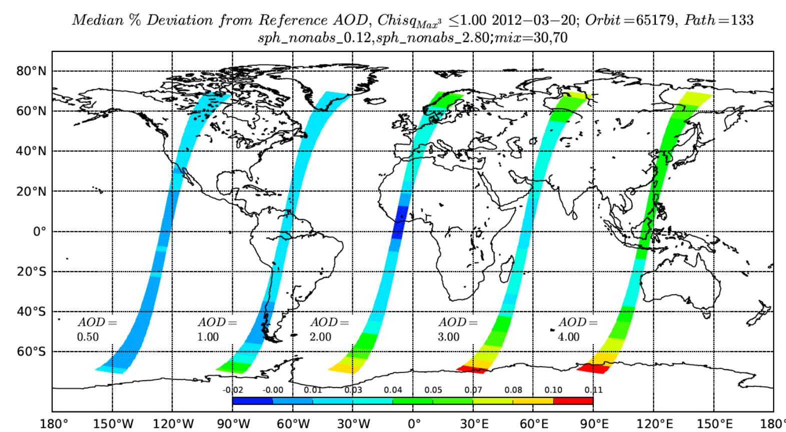


< +7% Discrepancy, ***Mix #15***
70% sph_nonabs_0.12
30% sph_nonabs_2.80



Note: At low lat, moderate AOD →
No mixtures pass when LM is used

< +7% Discrepancy, ***Mix #17***
50% sph_nonabs_0.12
50% sph_nonabs_2.80



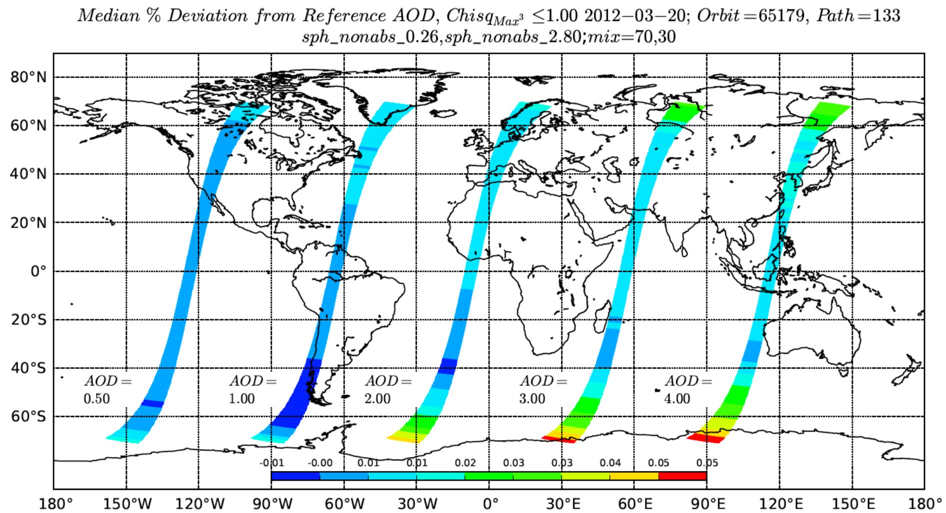
< +7% Discrepancy, ***Mix #19***
30% sph_nonabs_0.12
70% sph_nonabs_2.80

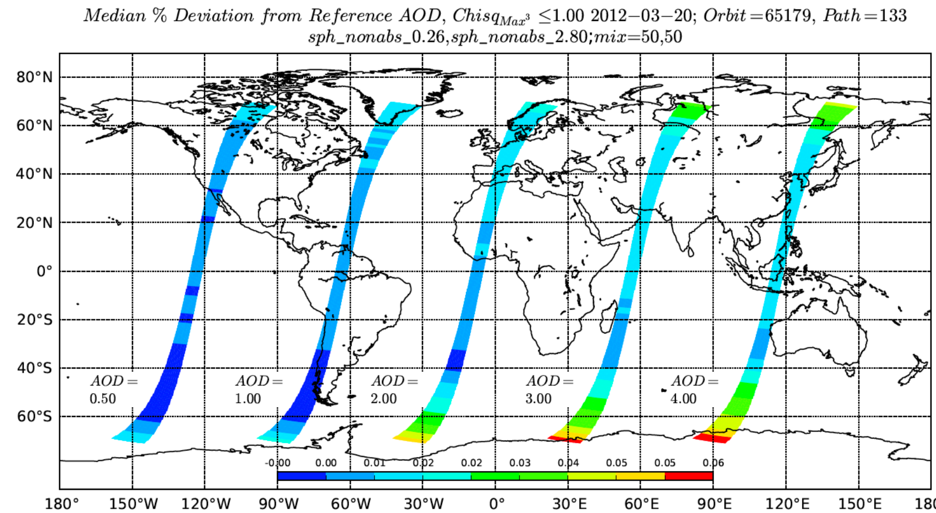
0.12 + 2.80 μm
r_e particles

- **Linear mixing *overestimates* AOD with spherical *non-absorbing* particles**
- **A larger particle *size difference* → larger AOD *overestimate***

Figure S7

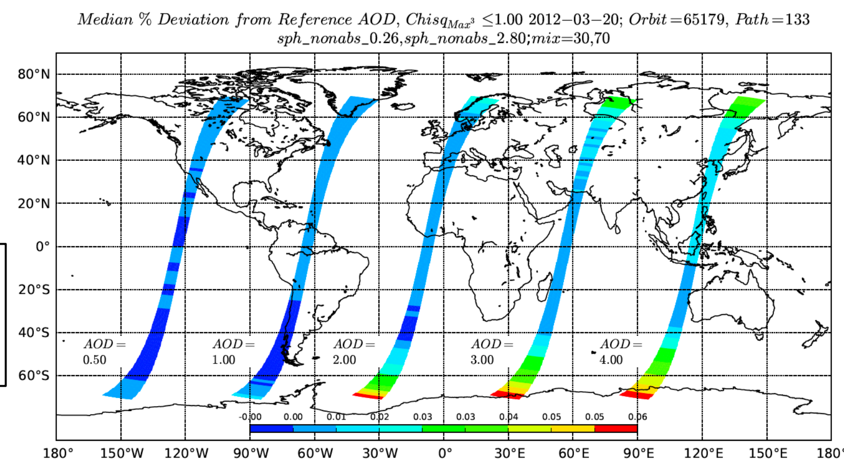
Impact of ***Linear Mixing;*** Globally, Non-Absorbing Aerosol





< +2% Discrepancy, ***Mix #25***
70% sph_nonabs_0.26
30% sph_nonabs_2.80

< +2% Discrepancy, ***Mix #27***
50% sph_nonabs_0.26
50% sph_nonabs_2.80



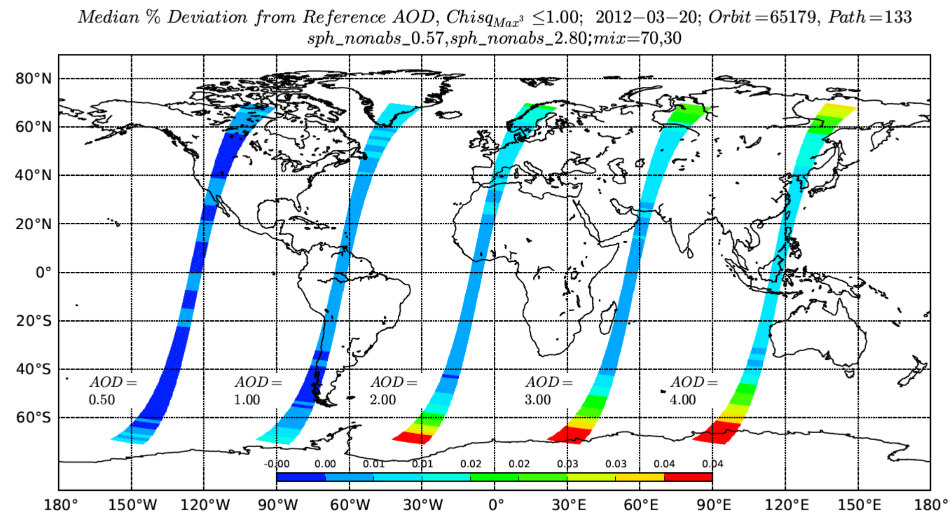
< +3% Discrepancy, ***Mix #29***
30% sph_nonabs_0.26
70% sph_nonabs_2.80

0.26 + 2.80 μm
r_e particles

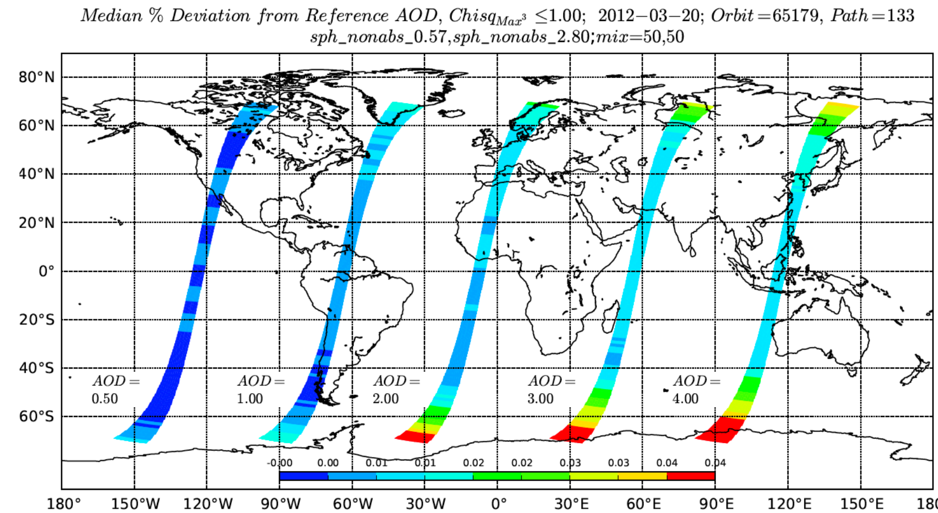
- **Linear mixing *overestimates* AOD with spherical *non-absorbing* particles**
- **A larger particle *size difference* → larger AOD *overestimate***

Figure S8

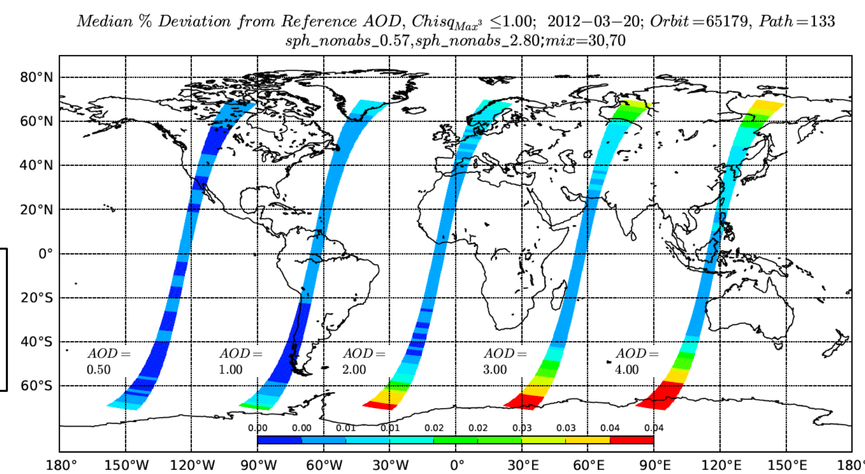
Impact of ***Linear Mixing;*** Globally, Non-Absorbing Aerosol



< +2% Discrepancy
70% sph_nonabs_0.57
30% sph_nonabs_2.80



< +2% Discrepancy
50% sph_nonabs_0.57
50% sph_nonabs_2.80



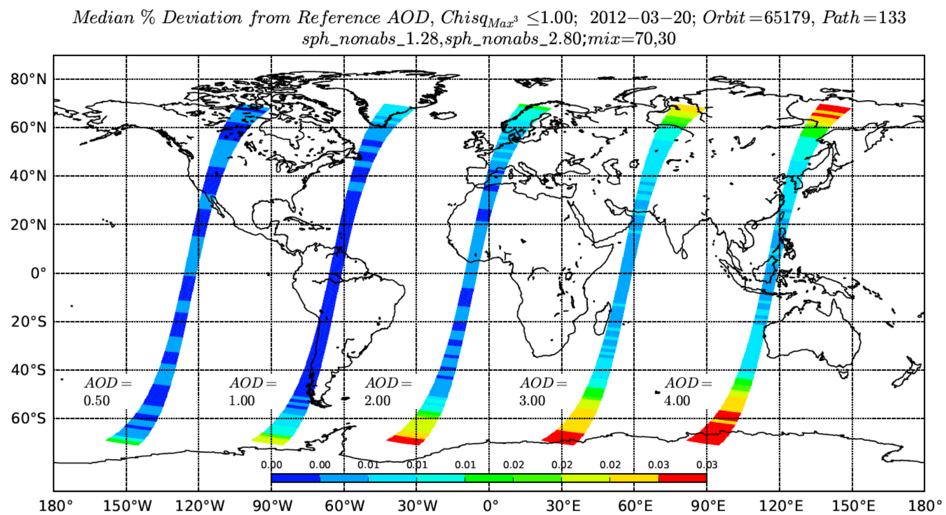
< +2% Discrepancy
30% sph_nonabs_0.57
70% sph_nonabs_2.80

0.57 + 2.80 μm
r_e particles

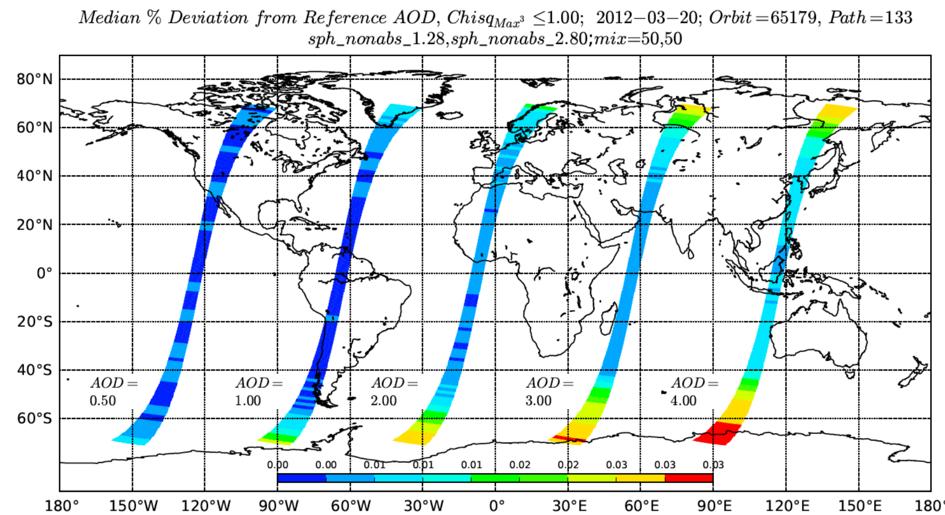
- **Linear mixing *overestimates* AOD with spherical *non-absorbing* particles**
- **A larger particle *size difference* → larger AOD *overestimate***

Figure S9

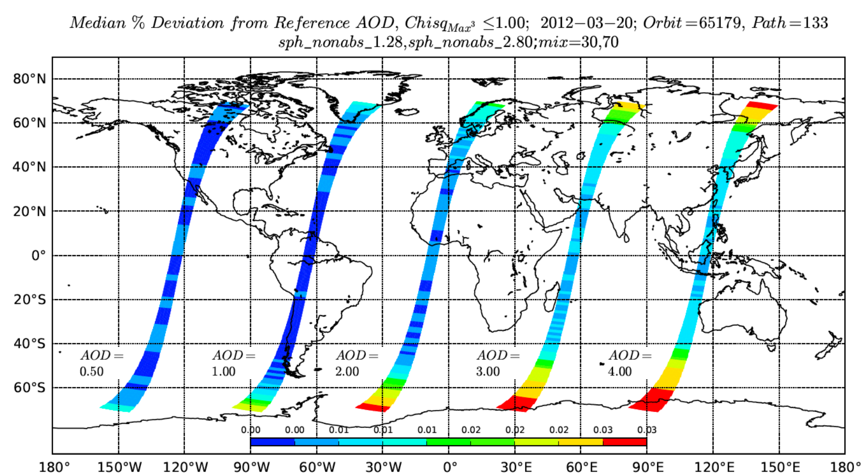
Impact of ***Linear Mixing;*** Globally, Non-Absorbing Aerosol



< +1% Discrepancy
70% sph_nonabs_1.28
30% sph_nonabs_2.80



< +1% Discrepancy
50% sph_nonabs_1.28
50% sph_nonabs_2.80



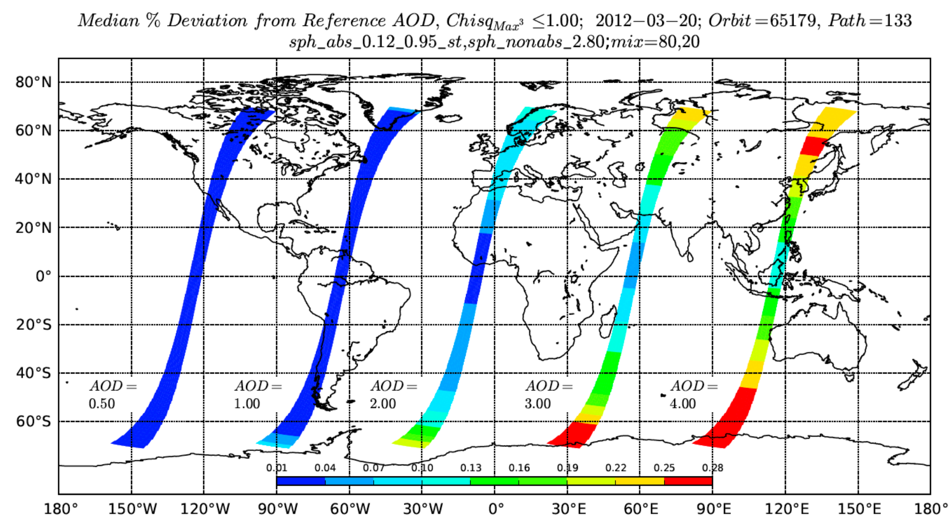
< +1% Discrepancy
30% sph_nonabs_1.28
70% sph_nonabs_2.80

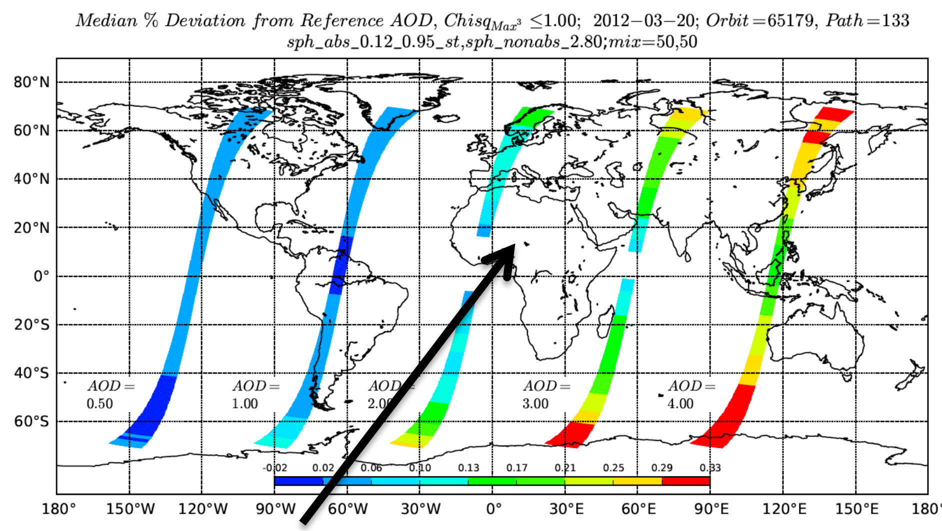
1.28 + 2.80 μm
r_e particles

- **Linear mixing *overestimates* AOD with spherical *non-absorbing* particles**
- **A larger particle *size difference* → larger AOD *overestimate***

Figure S10

Impact of ***MLM;*** Globally, Absorbing Mixtures

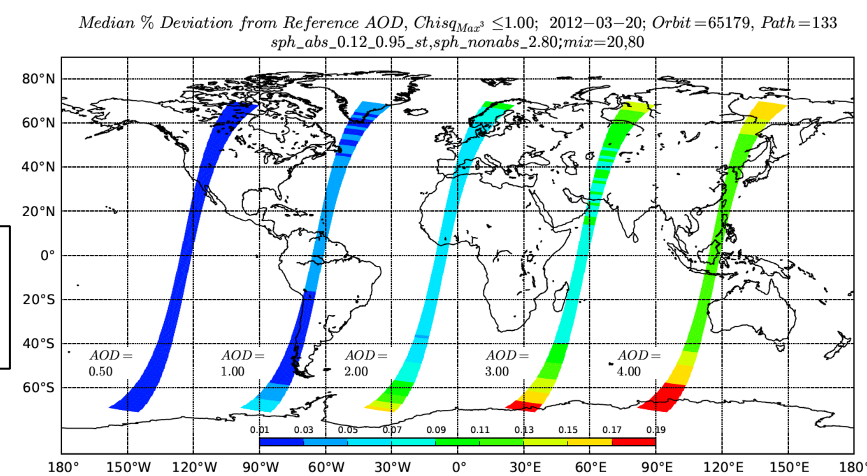




< +25% Discrepancy
80% sph_abs_0.12_SSA-0.95
20% sph_nonabs_2.80

Note: At low lat & moderate AOD →
No mixtures pass when MLM is used

< +29% Discrepancy
50% sph_abs_0.12_SSA-0.95
50% sph_nonabs_2.80



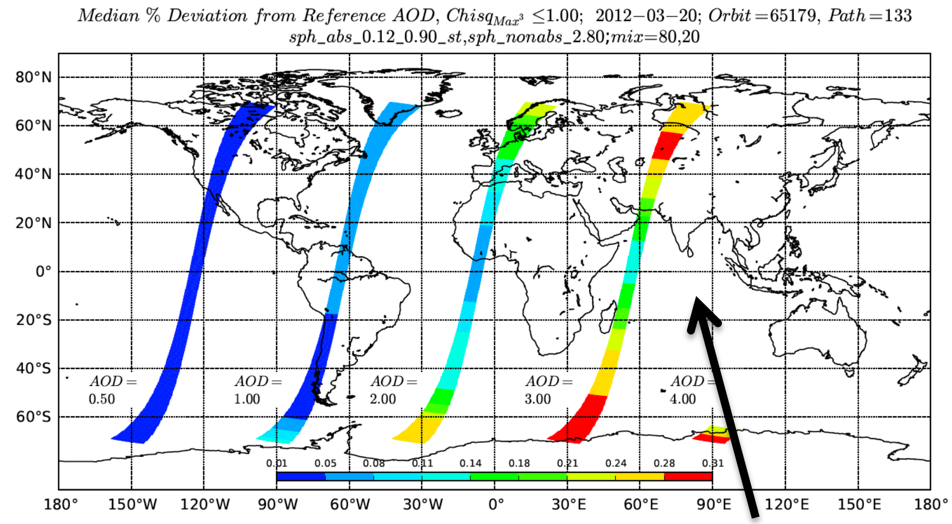
< +13% Discrepancy
20% sph_abs_0.12_SSA-0.95
80% sph_nonabs_2.80

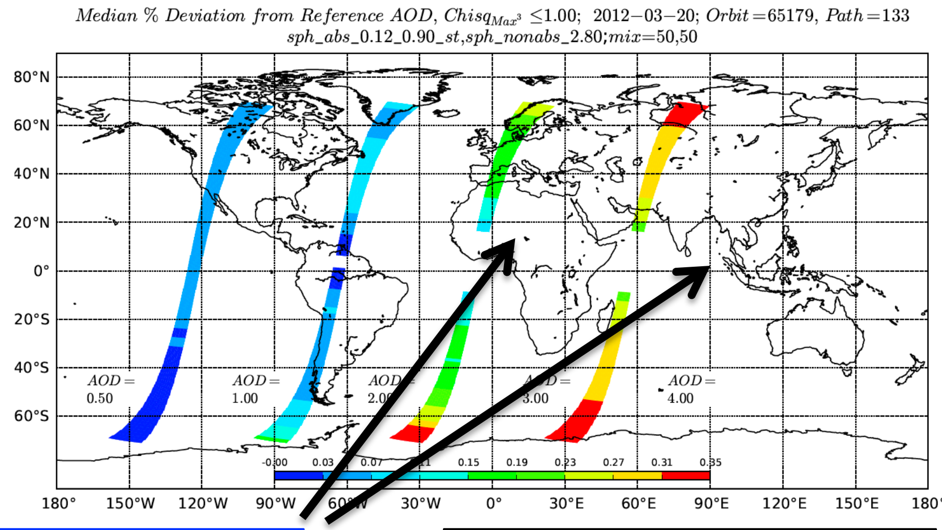
0.12 *SSA_0.95*
+ 2.80 μm
r_e particles

- **MLM *overestimates* AOD with spherical non-absorbing/absorbing particle mixtures**

Figure S11

Impact of ***MLM;*** Globally, Absorbing Mixtures

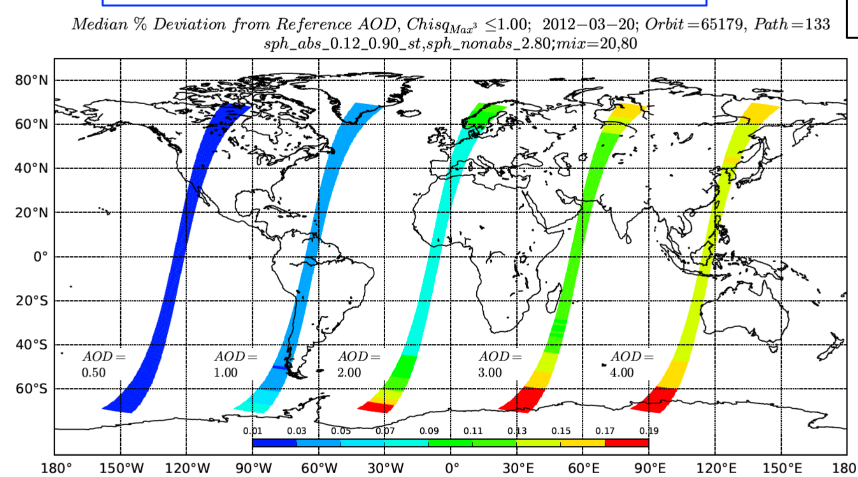




< +28% Discrepancy, ***Mix #34***
80% sph_abs_0.12_SSA-0.90
20% sph_nonabs_2.80

<u>**Note**</u>: At low lat & high AOD →
No mixtures pass when MLM is used

< +31% Discrepancy, ***Mix #37***
50% sph_abs_0.12_SSA-0.90
50% sph_nonabs_2.80



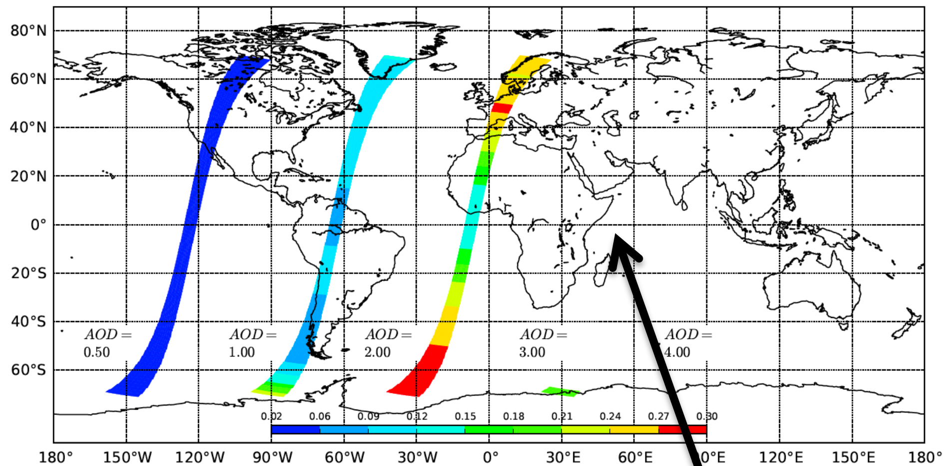
< +17% Discrepancy, ***Mix #40***
20% sph_abs_0.12_SSA-0.90
80% sph_nonabs_2.80

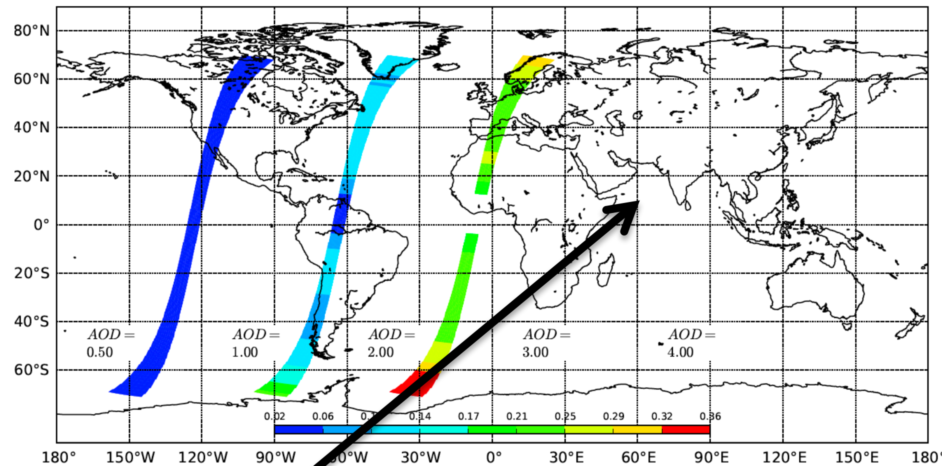
0.12 *SSA_0.90*
+ 2.80 μm
r_e particles

- **MLM *overestimates* AOD with spherical non-absorbing/absorbing particle mixtures**

Figure S12

Impact of *MLM;* Globally, Absorbing Mixtures

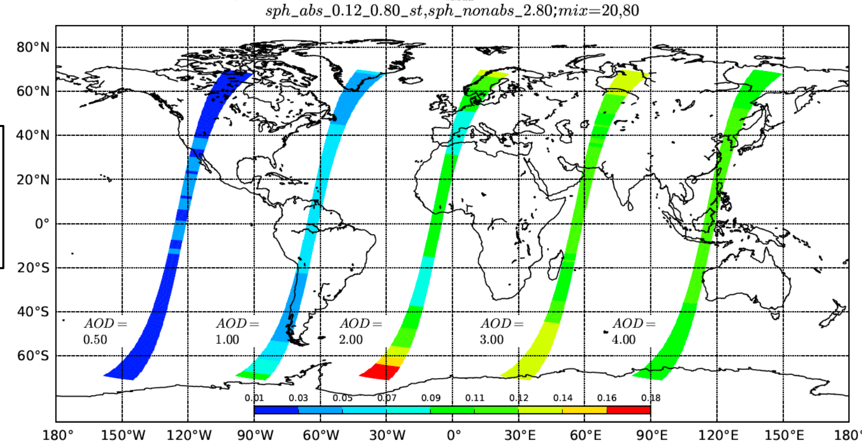




< +27% Discrepancy, ***Mix #44***
80% sph_abs_0.12_SSA-0.80
20% sph_nonabs_2.80

Note: At high AOD →
No mixtures pass when MLM is used

< +29% Discrepancy, ***Mix #47***
50% sph_abs_0.12_SSA-0.80
50% sph_nonabs_2.80



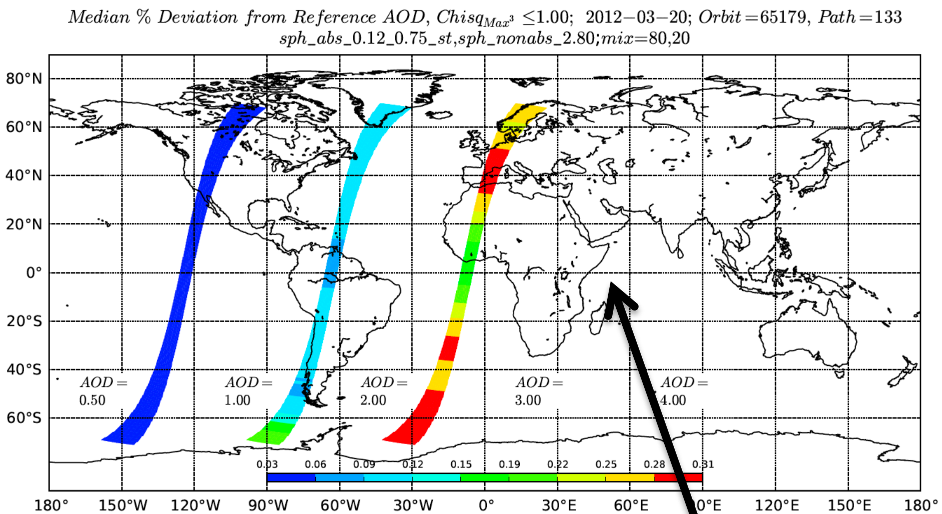
< +12% Discrepancy, ***Mix #50***
20% sph_abs_0.12_SSA-0.80
80% sph_nonabs_2.80

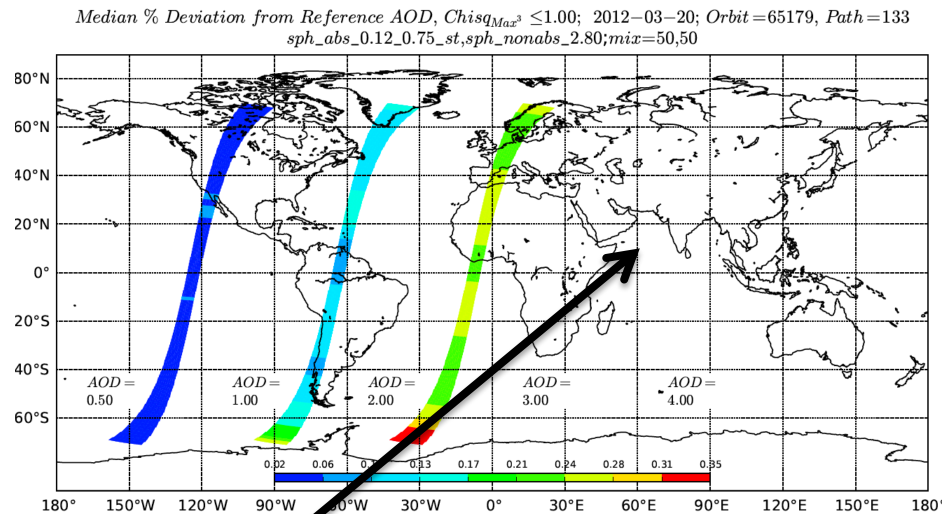
0.12 *SSA_0.80*
+ 2.80 μm
r_e particles

- **MLM *overestimates* AOD with spherical non-absorbing/absorbing particle mixtures**

Figure S13

Impact of ***MLM;*** Globally, Absorbing Mixtures



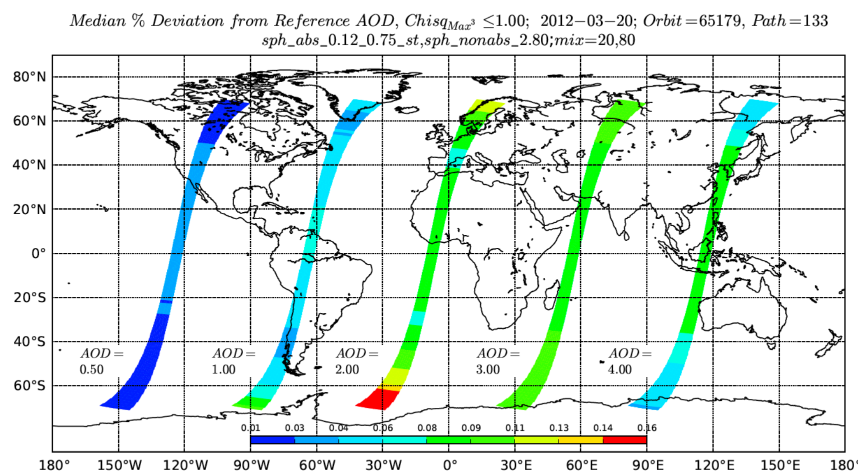


< +31% Discrepancy
80% sph_abs_0.12_SSA-0.75
20% sph_nonabs_2.80

<u>Note</u>: At high AOD →
No mixtures pass when MLM is used

< +28% Discrepancy
50% sph_abs_0.12_SSA-0.75
50% sph_nonabs_2.80

< +11% Discrepancy
20% sph_abs_0.12_SSA-0.75
80% sph_nonabs_2.80

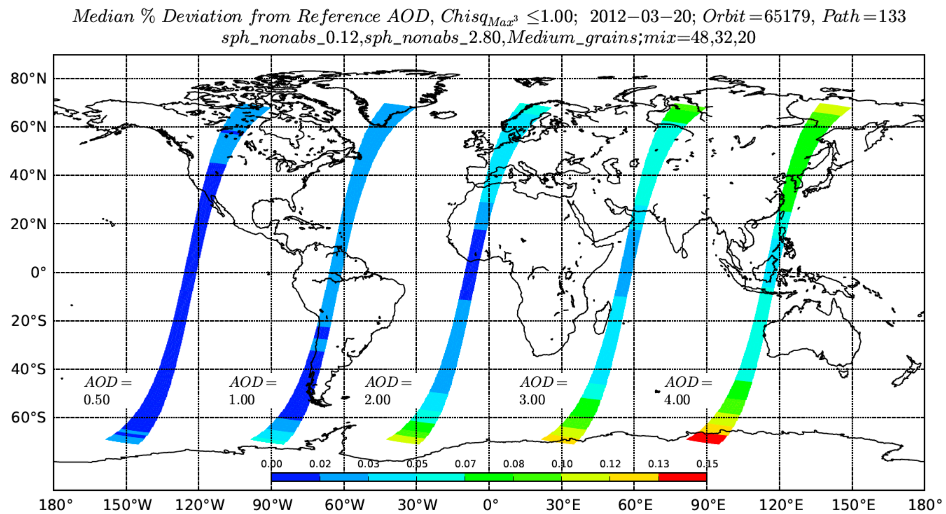


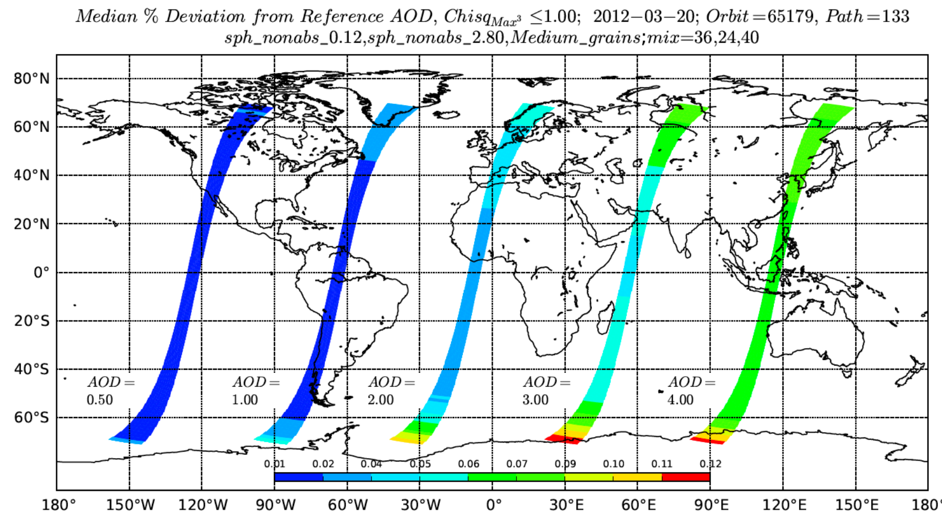
0.12 *SSA_0.75*
+ 2.80 µm
r_e particles

- **MLM *overestimates* AOD with spherical non-absorbing/absorbing particle mixtures**

Figure S14

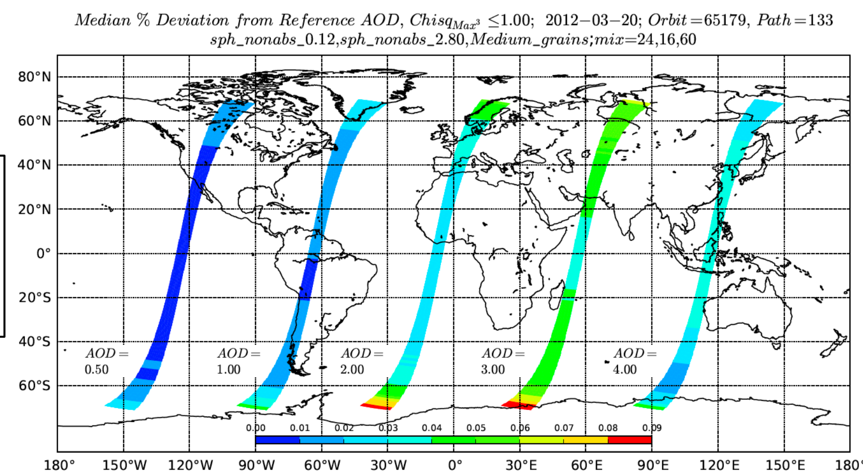
Impact of *MLM;* Globally, Non-Spherical Mixtures





< +10% Discrepancy, ***Mix #52***
48% sph_nonabs_0.12
32% sph_nonabs_2.80
20% Medium Dust Grains

< +9% Discrepancy, ***Mix #55***
36% sph_nonabs_0.12
24% sph_nonabs_2.80
40% Medium Dust Grains



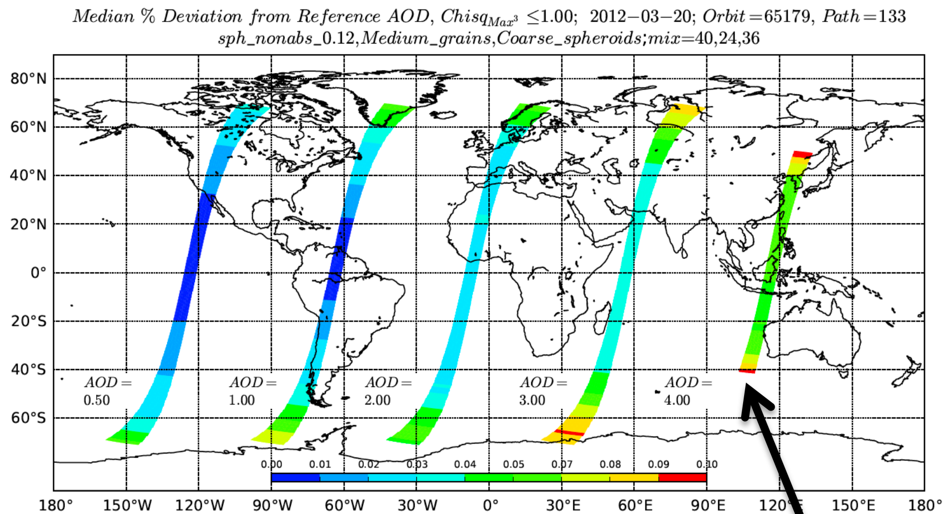
< +6% Discrepancy, ***Mix #58***
24% sph_nonabs_0.12
16% sph_nonabs_2.80
60% Medium Dust Grains

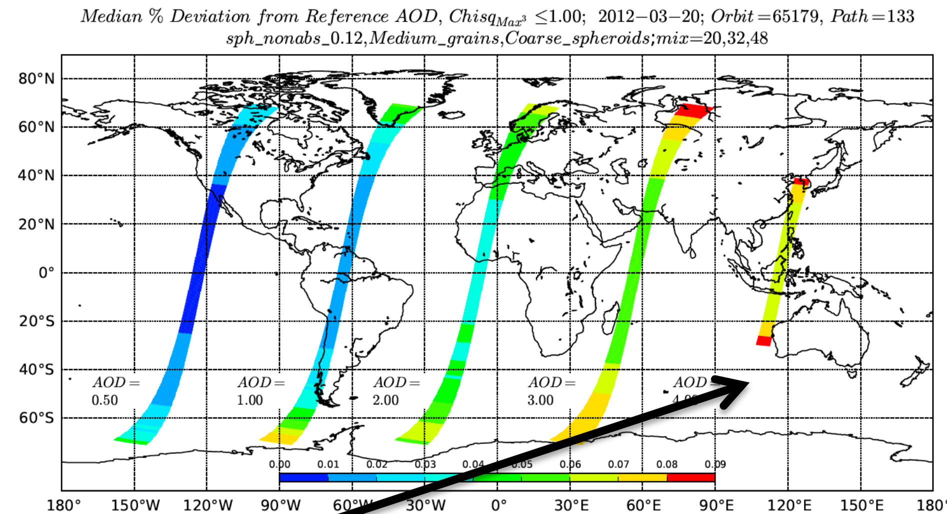
0.12 + 2.80 μm
+ dust grain
r_e particles

- **Modified linear mixing *overestimates* AOD with non-spherical particle mixtures**

Figure S15

Impact of *MLM;* Globally, Non-Spherical Mixtures

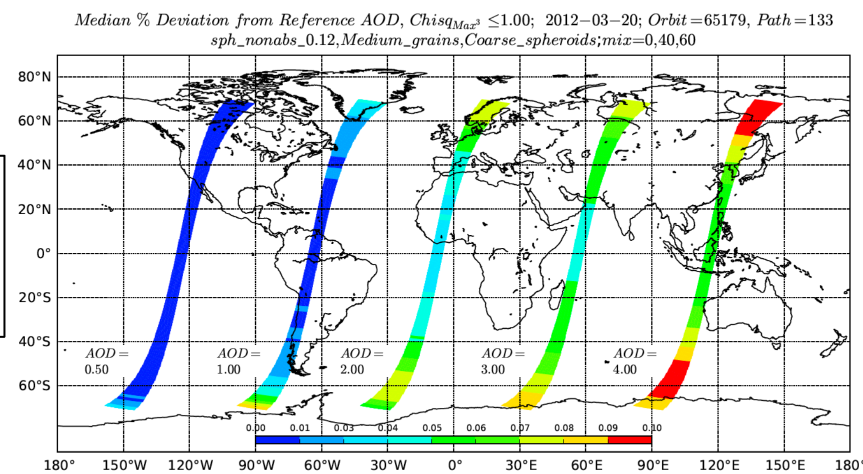




< +10% Discrepancy, ***Mix #65***
40% sph_nonabs_0.12
24% Medium Dust Grains
36% Coarse Dust Spheroids

Note: At high lat & high AOD →
No mixtures pass when MLM is used

< +9% Discrepancy, ***Mix #69***
20% sph_nonabs_0.12
32% Medium Dust Grains
48% Coarse Dust Spheroids



< +9% Discrepancy, ***Mix #73***
0% sph_nonabs_0.12
40% Medium Dust Grains
60% Coarse Dust Spheroids

0.12 μm
+ dust grain
+ dust spheroid
r_e particles

- **Modified linear mixing *overestimates* AOD with non-spherical particle mixtures**

Figure S16

Linear Mixing (LM) & Modified-Linear Mixing (MLM) Sensitivity Study *Conclusions*

- For spherical **non-absorbing** mixtures (Mixtures #1-30) [*LM, Figures S6-S10*]
  - -- Retrieved AOD values ***still fall within 0.05 or 20% AOD***
  - -- ***<5% bias*** for **AOD≤1.0 in all cases**
  - -- **Larger particle *size difference* → larger AOD *overestimate***

    So the **largest bias** is for **[0.06 + 2.80 μm] mixtures**
  - -- The effect becomes more pronounced at ***high AODs*** **(*up to 18%*** *for AOD > 2***)**
- For spherical **absorbing** mixtures, AOD is also ***overestimated*** [*MLM, Figures S11-S14*]
  - -- The mixtures considered here (#31-50) perform reasonably well at low AODs

    [sph_abs_0.12_SSA-0.80 or 90 & + 2.80 μm non-abs.]

    <10% bias for **AOD≤1.0**
  - -- Mixtures having **larger fractions 2.80 μm non-abs. particles** (#34-40 & 44-49)

    can fall outside of ***0.05 or 20% AOD*** for AOD≥2.0 for some geometries
  - -- ***Biases of 10-30%*** for AOD >2.0, ***even when SSA 0.12 μm = 0.95***
- For **non-spherical** mixtures, AOD is also ***overestimated*** [*MLM, Figures S15-S16*]
  - -- But ***<10% bias*** for all non-spherical mixtures in the MISR V22 SA climatology