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Atmospheric Measurement Techniques Discussions

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]

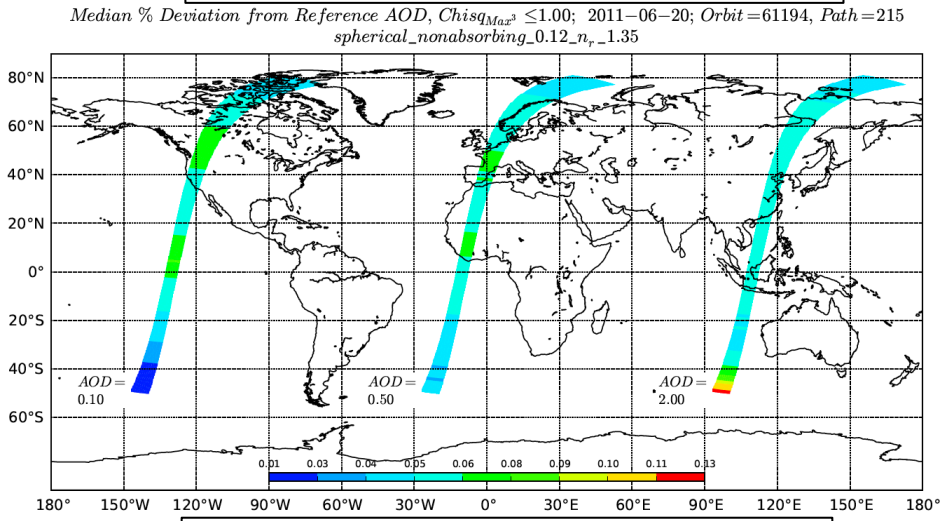
For each figure, the simulated atmosphere contains single-mode particles having n_r and effective radius (r_e) given at the top. Comparison-space particles, having varying n_r, are defined above each panel; comparisons are made for three values of AOD and a range of geometries. (The geographic placement of the plots is for illustration – all retrievals are performed over simulated black surfaces.)

Conclusions

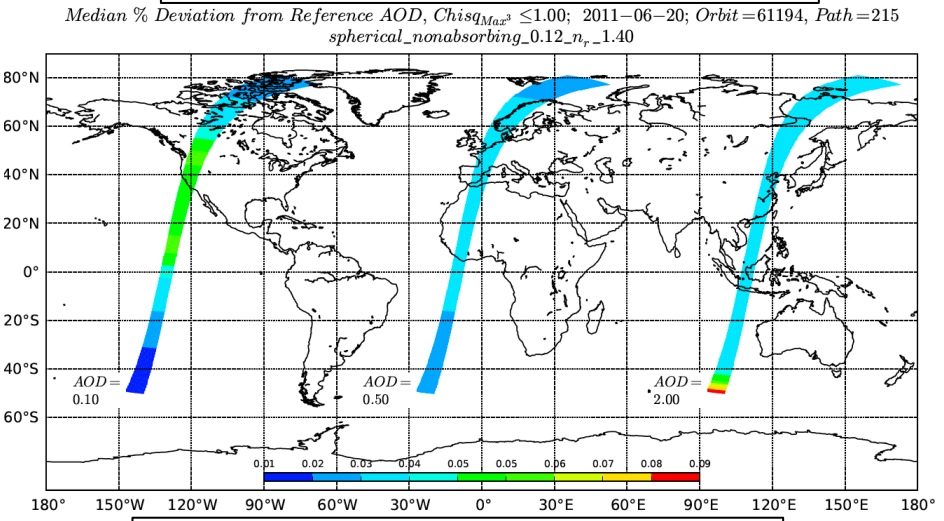
- When n_r is ***overestimated***, AOD is systematically ***underestimated***, and conversely
- Generally, retrieved AOD values ***still fall within 0.05 or 20% AOD***, except in extreme cases
- ***Smaller particles*** are affected less by errors in n_r
- ***Very large particles*** are so sensitive to 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%.)

Geographic distribution: *Input* n_r=1.45, r_e=0.12 µm

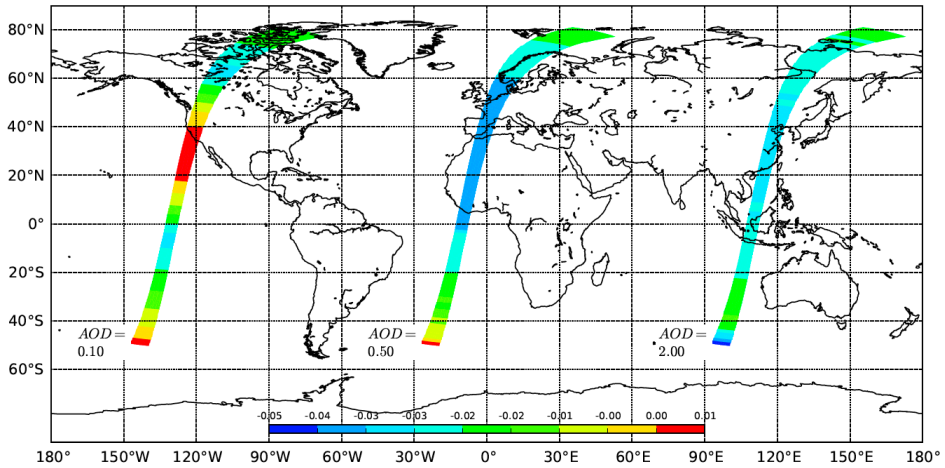
< +9% Discrepancy, *Comp. space* n_r=1.35



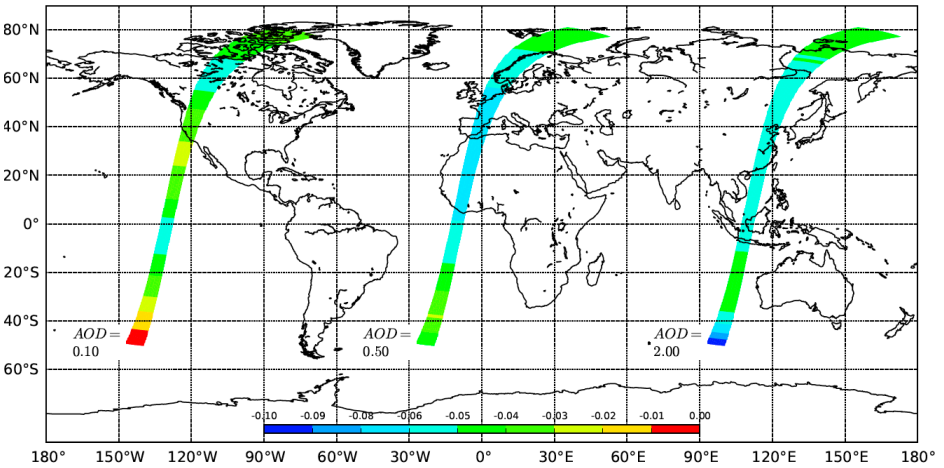
< +5% Discrepancy, *Comp. space* n_r=1.40



< -4% Discrepancy, *Comp. space* n_r=1.50



< -8% Discrepancy, *Comp. space* n_r=1.55

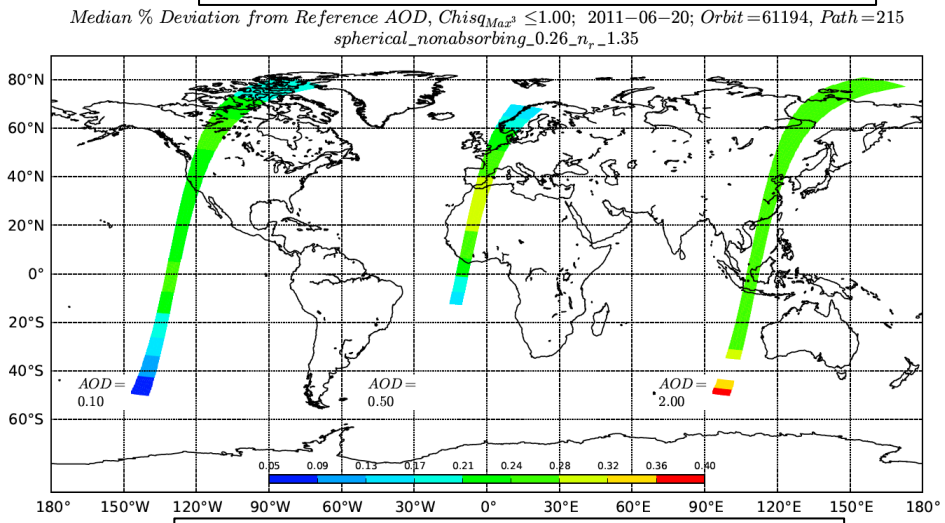


- When n_r is ***overestimated***, AOD is systematically ***underestimated***, and conversely
- In typical cases, the effect is largest for medium particles
- MISR Version 22 SA spherical particles have n_r=1.45; for pure water, n_r=1.33

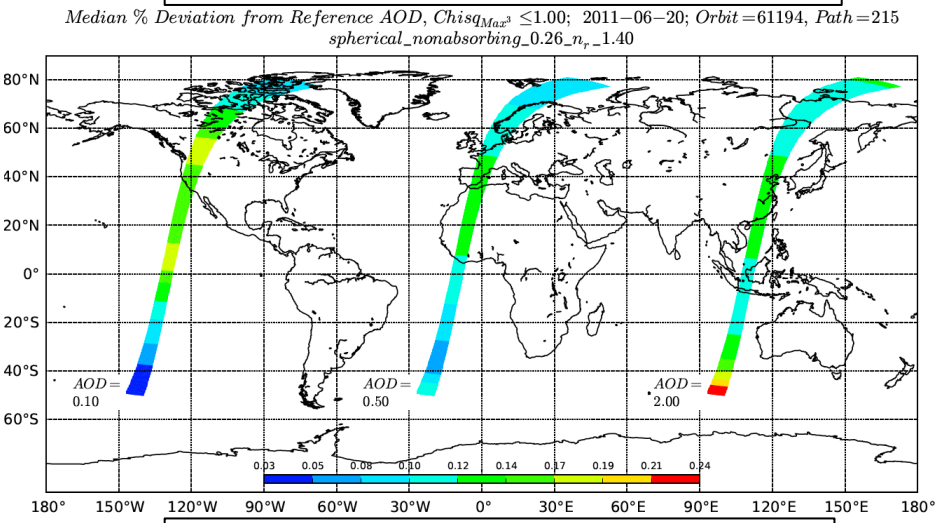
Figure S1

Geographic distribution: *Input* n_r=1.45, r_e=0.26 µm

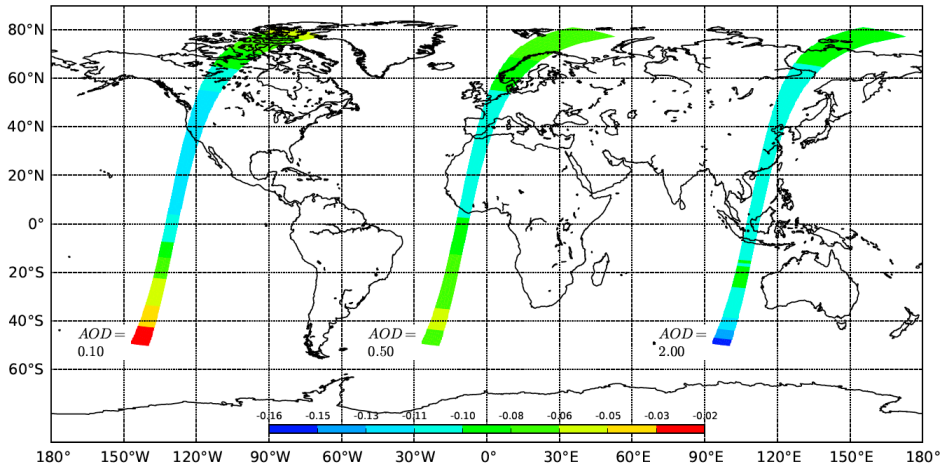
< +32% Discrepancy, *Comp. space* n_r=1.35



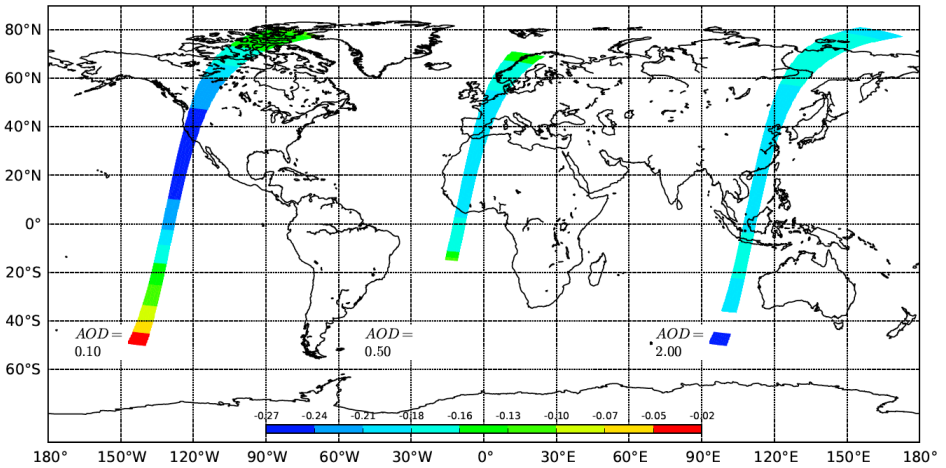
< +19% Discrepancy, *Comp. space* n_r=1.40



< -13% Discrepancy, *Comp. space* n_r=1.50



< -27% Discrepancy, *Comp. space* n_r=1.55

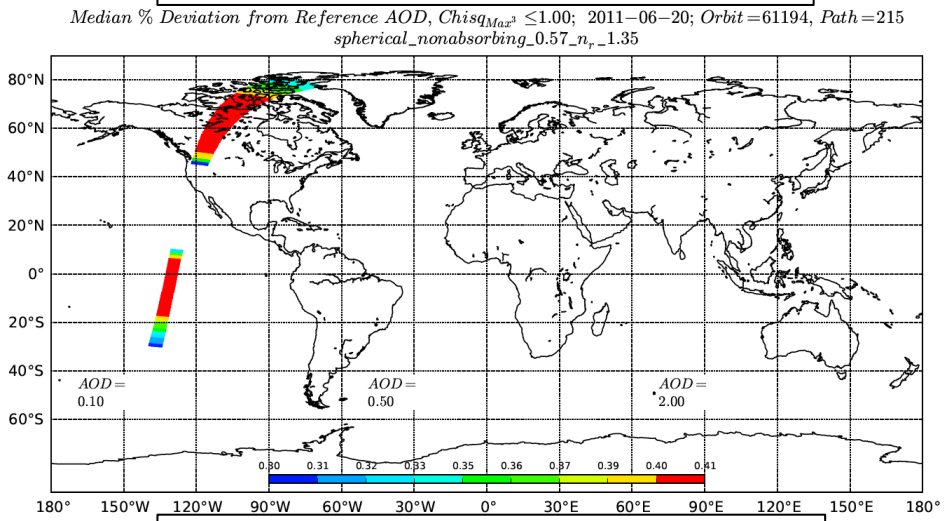


- **When n_r is *overestimated*, AOD is systematically *underestimated*, and conversely**
- **In typical cases, the effect is largest for medium particles**
- **MISR Version 22 SA spherical particles have n_r=1.45; for pure water, n_r=1.33**

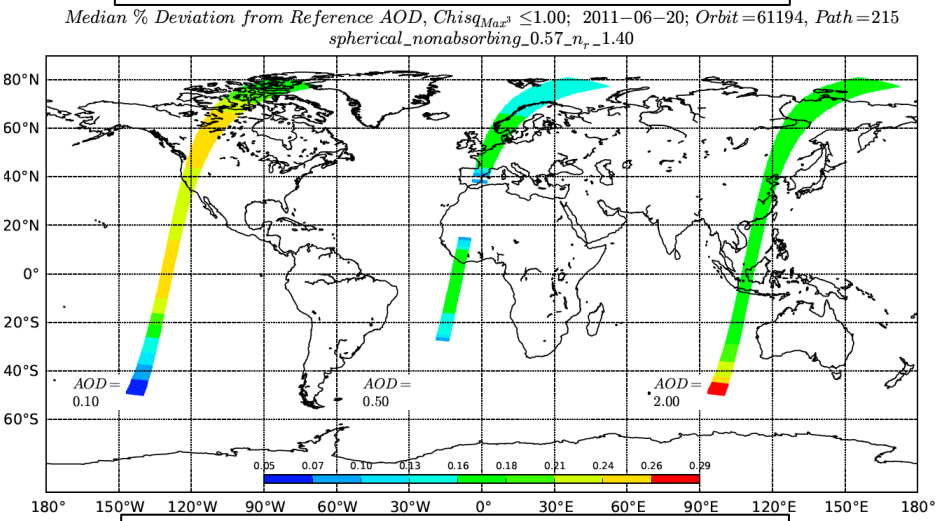
Figure S2

Geographic distribution: *Input* n_r=1.45, r_e=0.57 µm

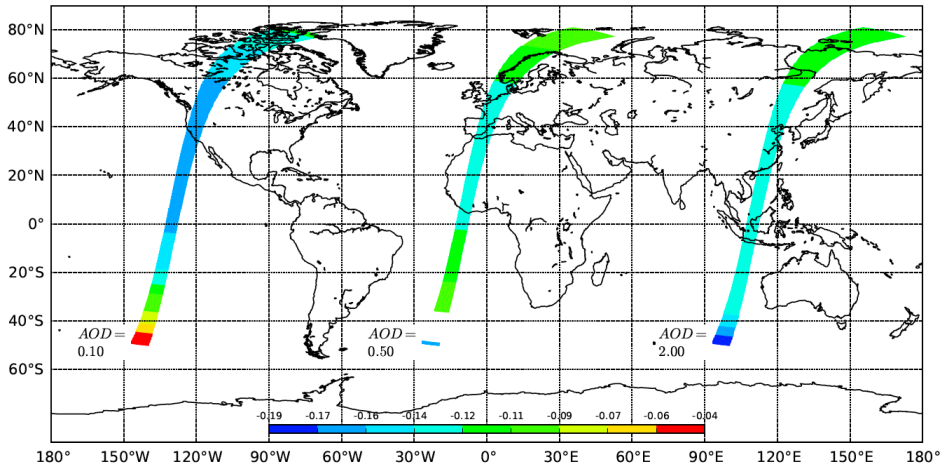
< 41% Discrepancy, *Comp. space* n_r=1.35



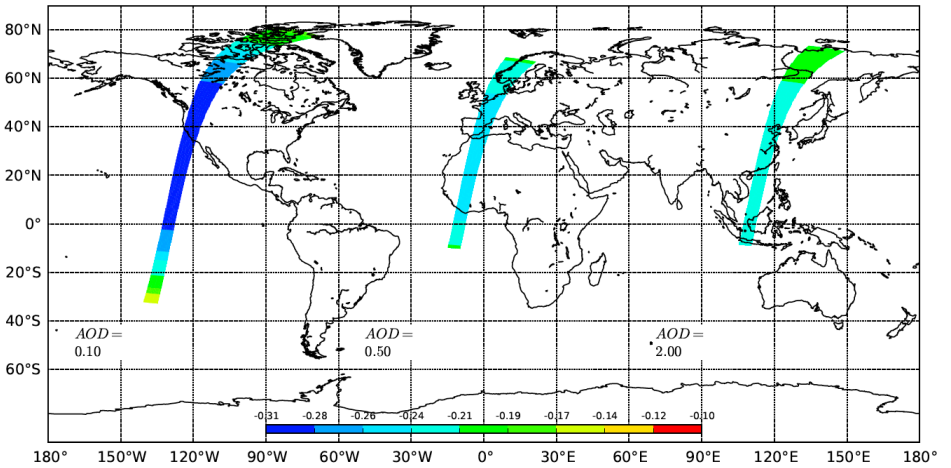
< +26% Discrepancy, *Comp. space* n_r=1.40



< -17% Discrepancy, *Comp. space* n_r=1.50



< -31% Discrepancy, *Comp. space* n_r=1.55

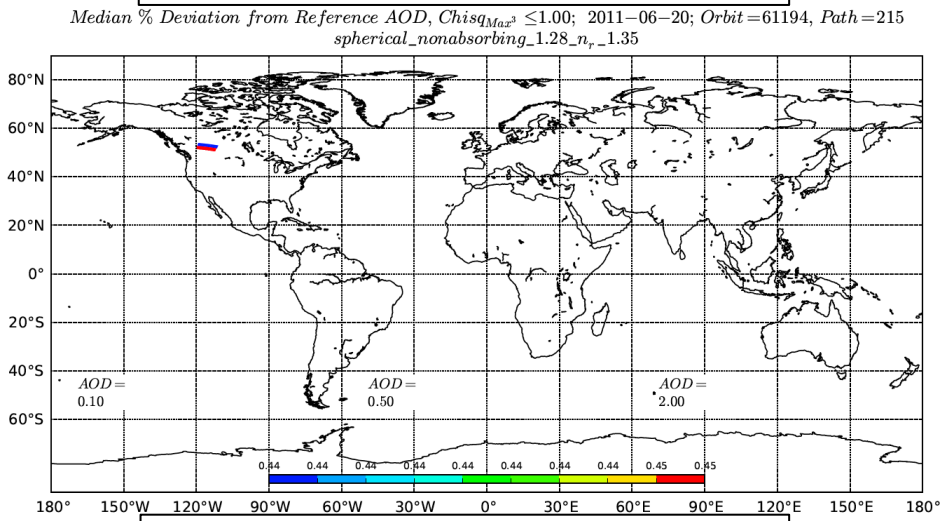


- **When n_r is *overestimated*, AOD is systematically *underestimated*, and conversely**
- **In typical cases, the effect is largest for medium particles**
- **MISR Version 22 SA spherical particles have n_r=1.45; for pure water, n_r=1.33**

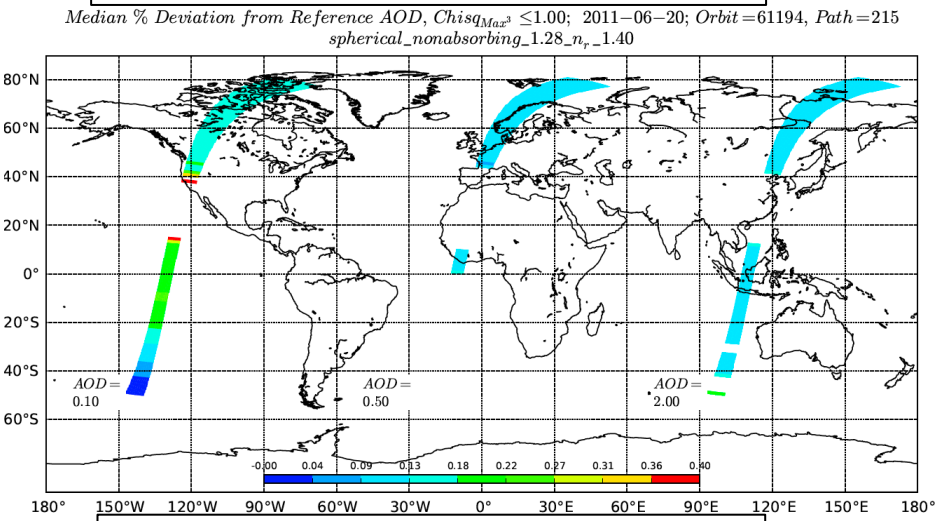
Figure S3

Geographic distribution: *Input* n_r=1.45, r_e=1.28 µm

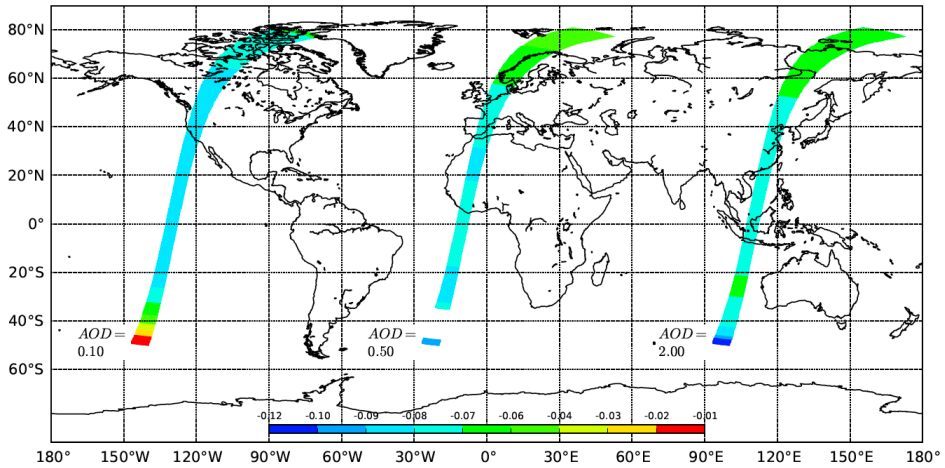
< N/A Discrepancy, *Comp. space* n_r=1.35



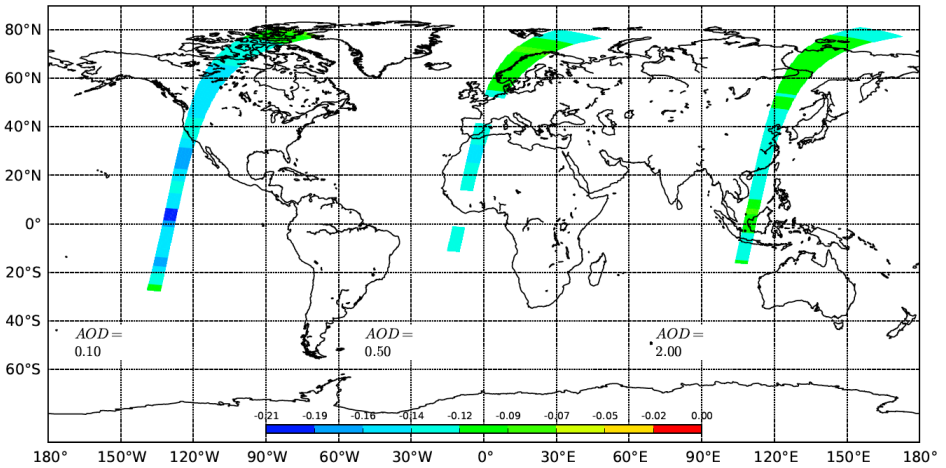
< +27% Discrepancy, *Comp. space* n_r=1.40



< -9% Discrepancy, *Comp. space* n_r=1.50



< -16% Discrepancy, *Comp. space* n_r=1.55



- **When n_r is *overestimated*, AOD is systematically *underestimated*, and conversely**
- **In typical cases, the effect is largest for medium particles**
- **MISR Version 22 SA spherical particles have n_r=1.45; for pure water, n_r=1.33**

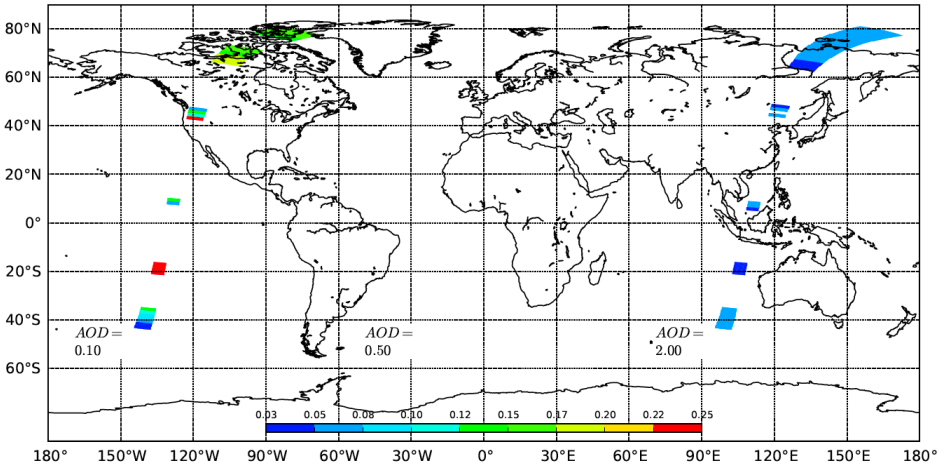
Figure S4

Geographic distribution: *Input* n_r=1.45, r_e=2.80 µm

< N/A Discrepancy, *Comp. space* n_r=1.35

< Variable Discrepancy, *Comp. space* n_r=1.40

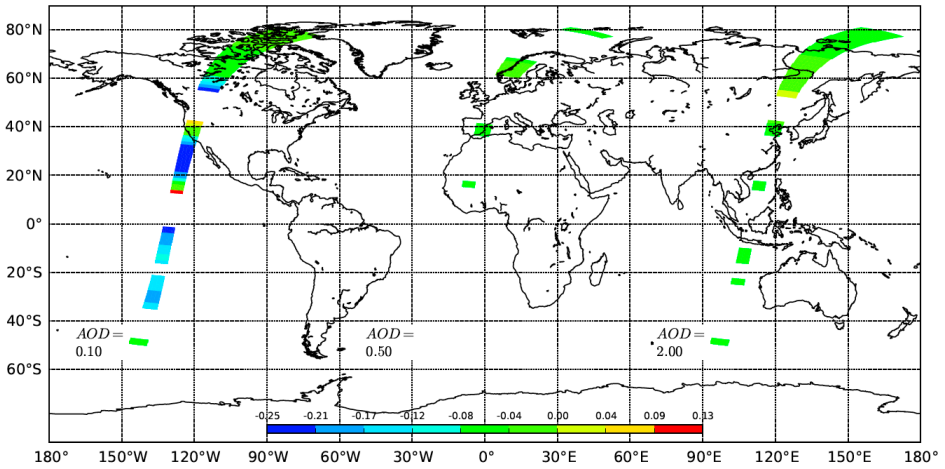
Median % Deviation from Reference AOD, $Chisq_{Max^3} \leq 1.00$; 2011–06–20; Orbit=61194, Path=215
spherical_nonabsorbing_2.80_n_r_1.40



For very large particles, having n_r off by 0.05 or more leads to no successful retrievals (i.e., some retrieval sensitivity to n_r)

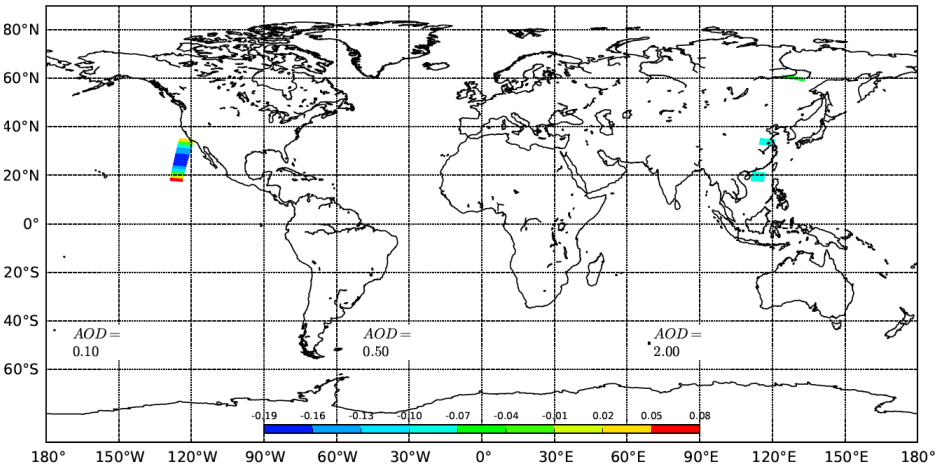
< Variable Discrepancy, *Comp. space* n_r=1.50

Median % Deviation from Reference AOD, $Chisq_{Max^3} \leq 1.00$; 2011–06–20; Orbit=61194, Path=215
spherical_nonabsorbing_2.80_n_r_1.50



< N/A Discrepancy, *Comp. space* n_r=1.55

spherical_nonabsorbing_2.80_n_r_1.55



- **When n_r is *overestimated*, AOD is systematically *underestimated*, and conversely**
- **In typical cases, the effect is largest for medium particles**
- **MISR Version 22 SA spherical particles have n_r=1.45; for pure water, n_r=1.33**

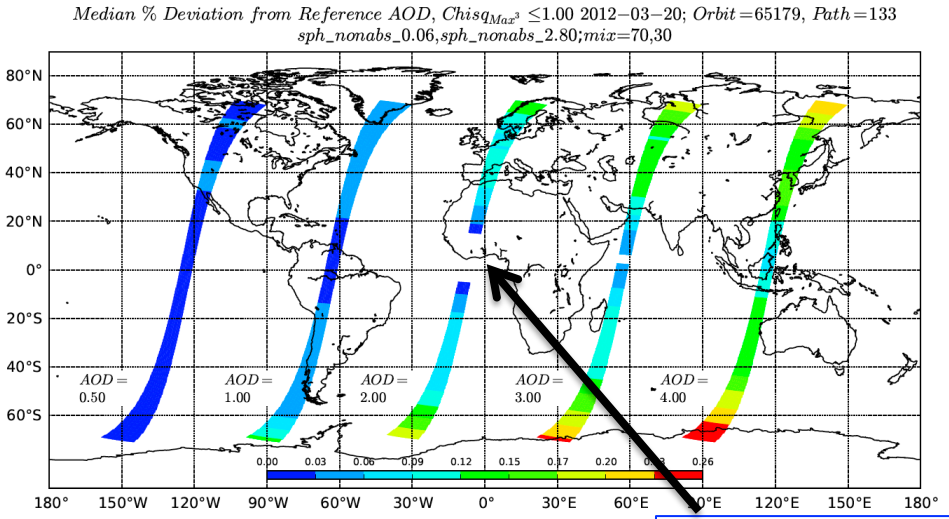
Figure S5

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

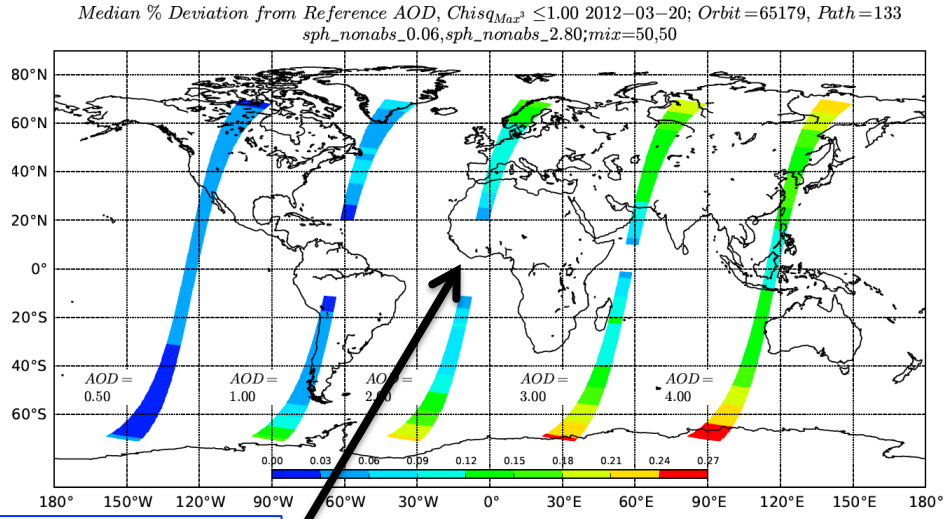
For each figure, the simulated atmosphere and retrieval climatology contain the same bi-modal mixture of particles, specified in the figure annotation, and taken from the SA climatology [*Kahn et al*., 2010]. Comparisons are made between full radiative transfer and LM or MLM approximations, for five 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.)

- 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 **Mixtures #4-10** **(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*]
  - -- **Mixtures #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**
  - -- For **Mixtures #34-40** and **Mixtures #44-49** **(larger fractions 2.80 μm non-abs.)**
    may 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 Version 22 SA climatology

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

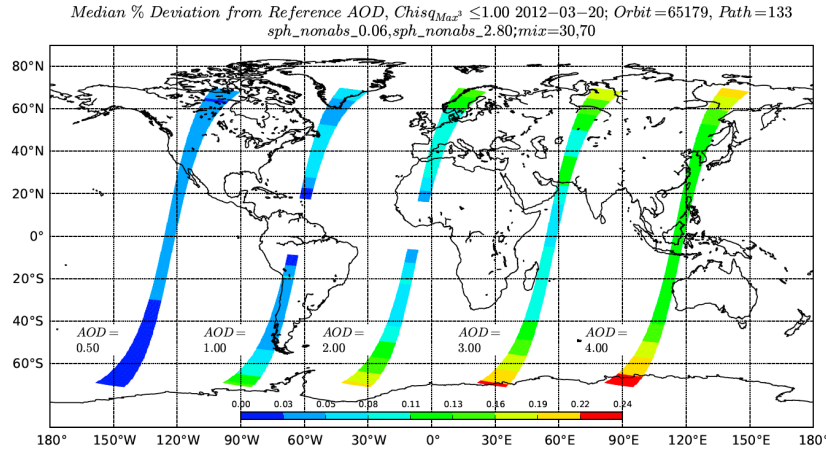


< +17% Discrepancy, ***Mix #5***
70% sph_nonabs_0.06
30% sph_nonabs_2.80



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

<u>Note</u>: At low lat, moderate AOD → ***No mixtures pass*** when LM is used



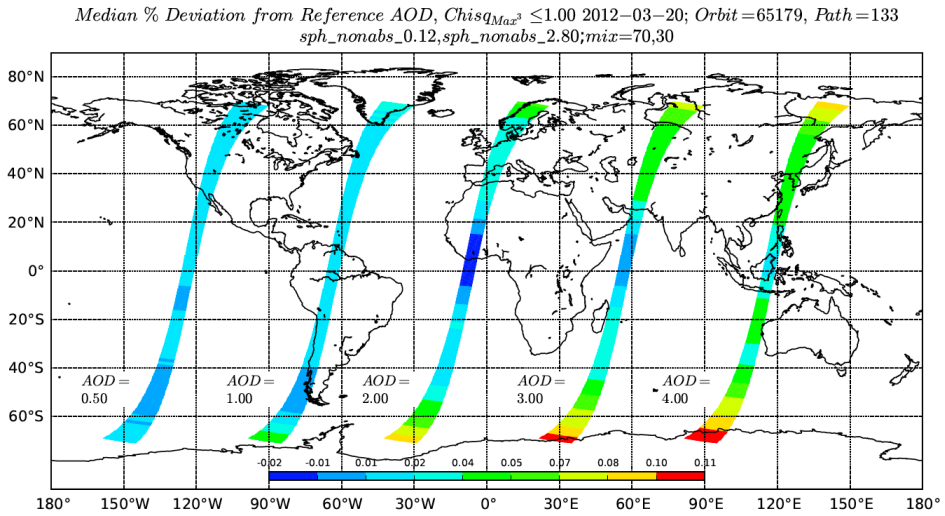
< +16% Discrepancy, ***Mix #9***
30% sph_nonabs_0.06
70% sph_nonabs_2.80

0.06 + 2.80 μm
r_e particles

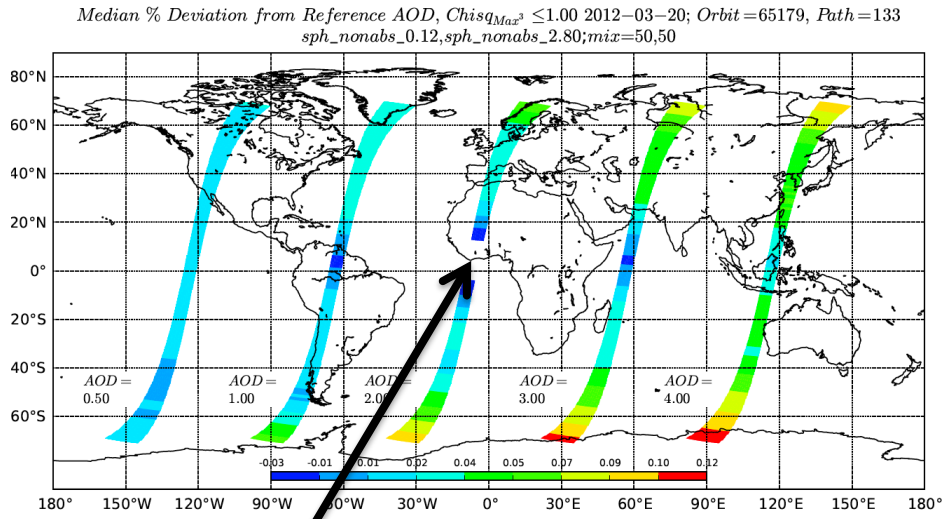
- **Linear mixing *overestimates* AOD with spherical *<u>non-absorbing</u>* particles**
- **A larger particle *size difference* → larger AOD *overestimate***

Figure S6

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

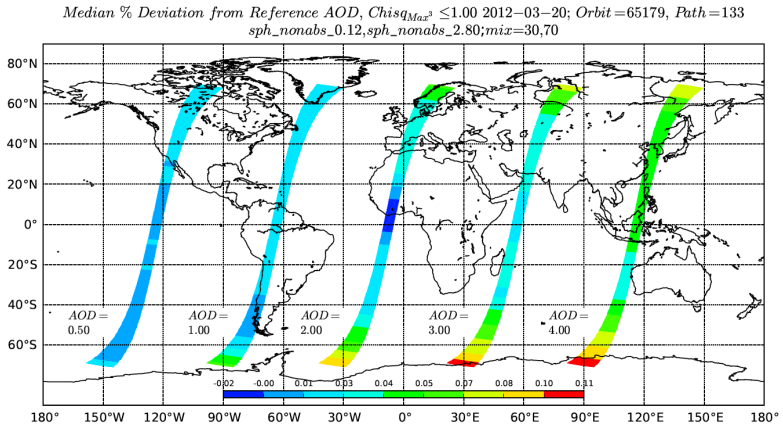


< +7% Discrepancy, ***Mix #15***
70% sph_nonabs_0.12
30% sph_nonabs_2.80



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

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



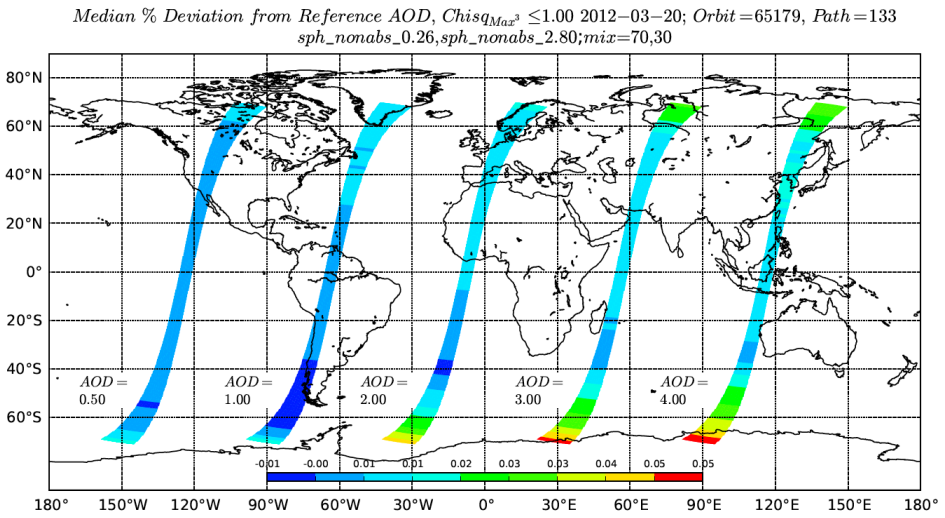
< +7% Discrepancy, ***Mix #19***
30% sph_nonabs_0.12
70% sph_nonabs_2.80

0.12 + 2.80 μm
r_e particles

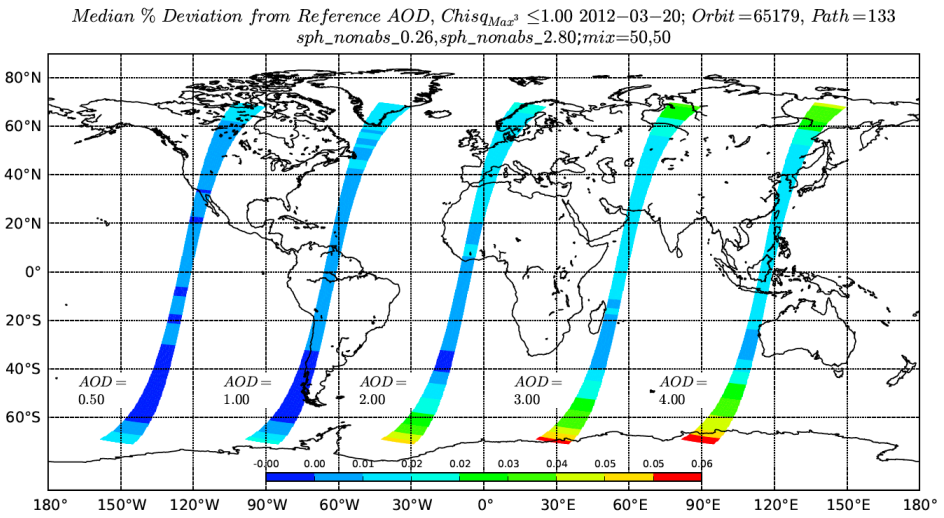
- **Linear mixing *overestimates* AOD with spherical *non-absorbing* particles**
- **A larger particle *size difference* → larger AOD *overestimate***

Figure S7

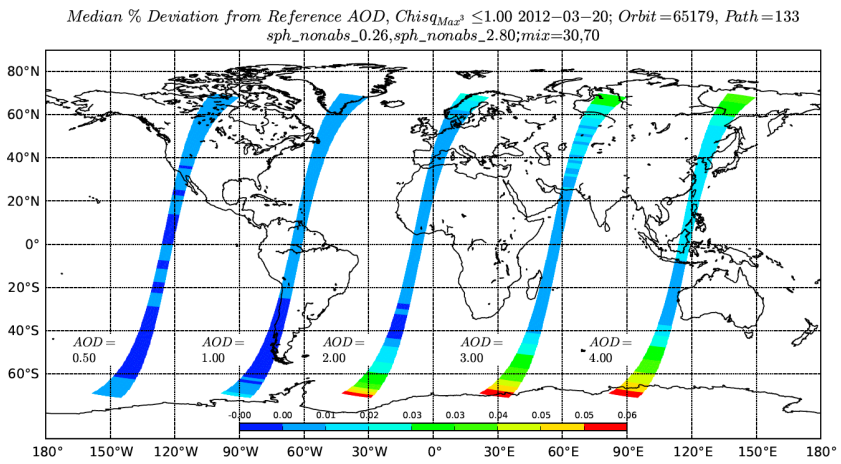
Impact of ***Linear Mixing;*** Globally, Non-Absorbing Aerosol



< +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



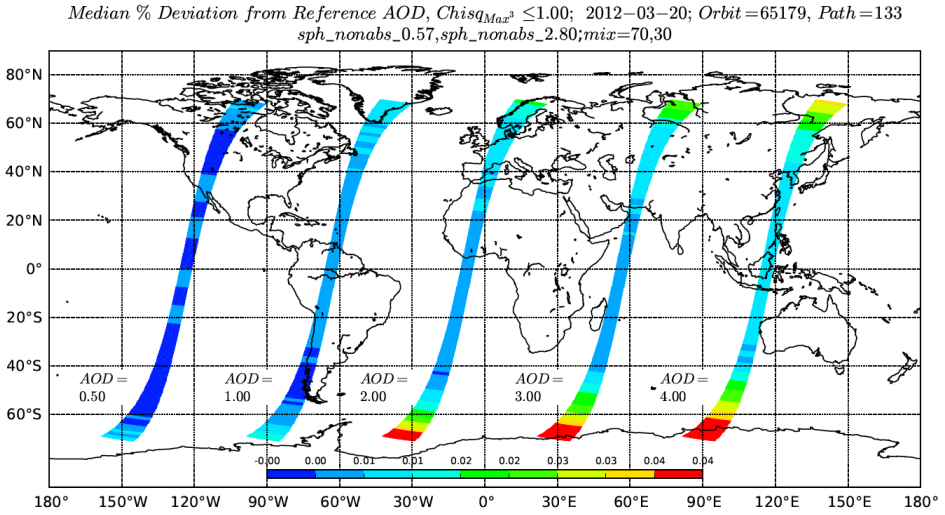
< +3% Discrepancy, ***Mix #29***
30% sph_nonabs_0.26
70% sph_nonabs_2.80

0.26 + 2.80 μm
r_e particles

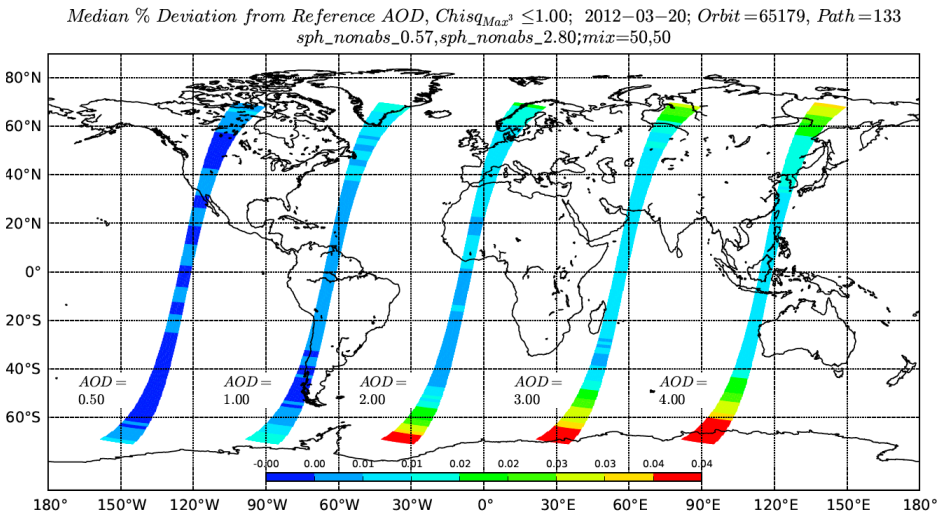
- **Linear mixing *overestimates* AOD with spherical *non-absorbing* particles**
- **A larger particle *size difference* → larger AOD *overestimate***

Figure S8

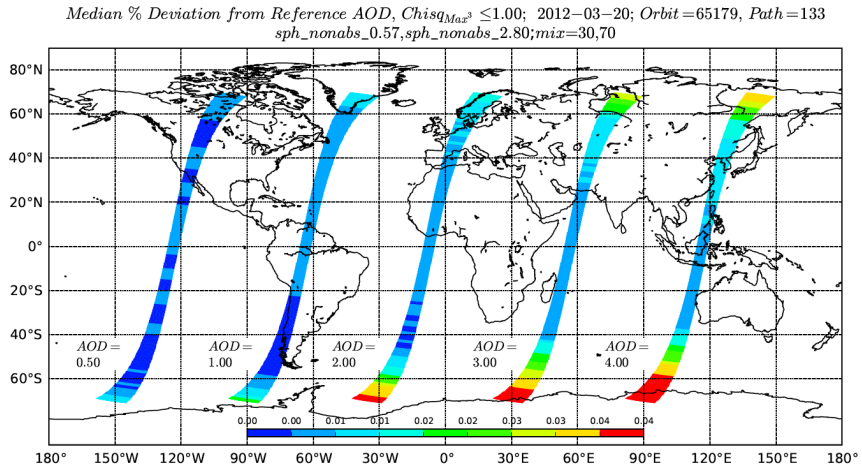
Impact of ***Linear Mixing;*** Globally, Non-Absorbing Aerosol



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



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



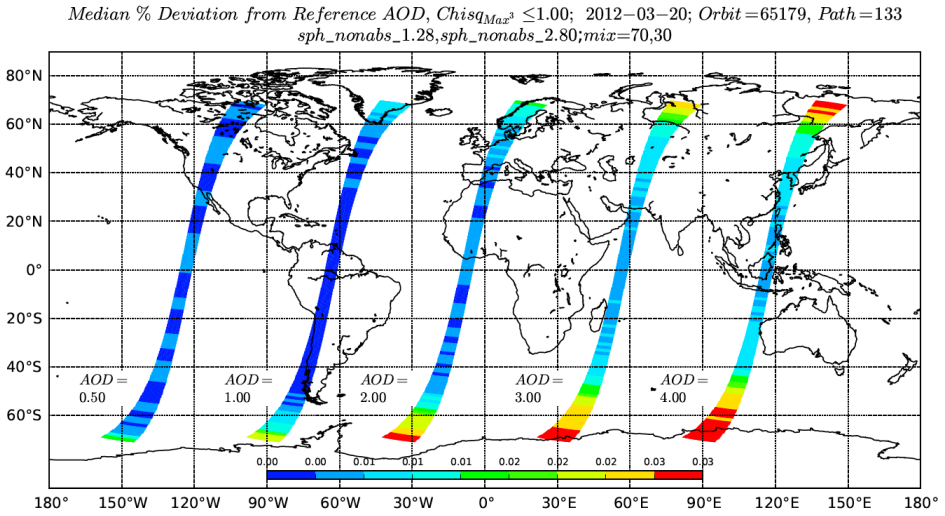
< +2% Discrepancy
30% sph_nonabs_0.57
70% sph_nonabs_2.80

0.57 + 2.80 μm
r_e particles

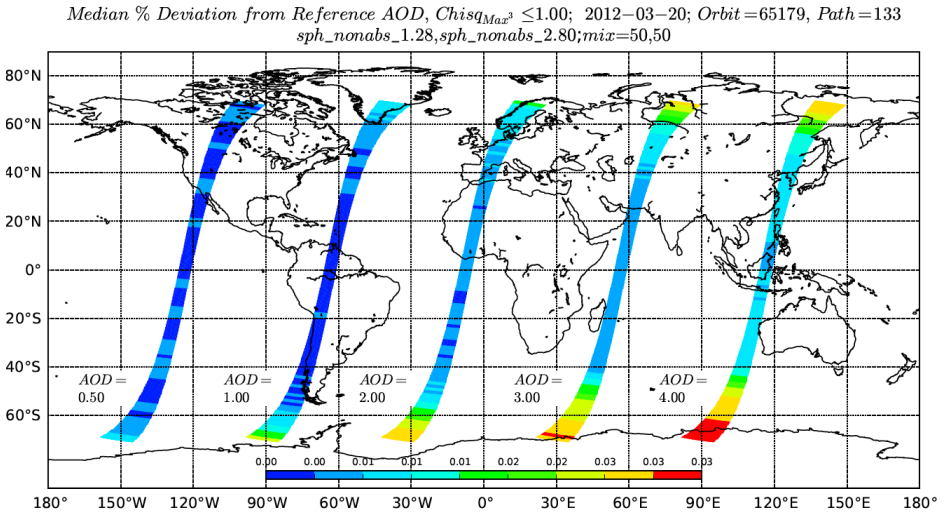
- **Linear mixing *overestimates* AOD with spherical *non-absorbing* particles**
- **A larger particle *size difference* → larger AOD *overestimate***

Figure S9

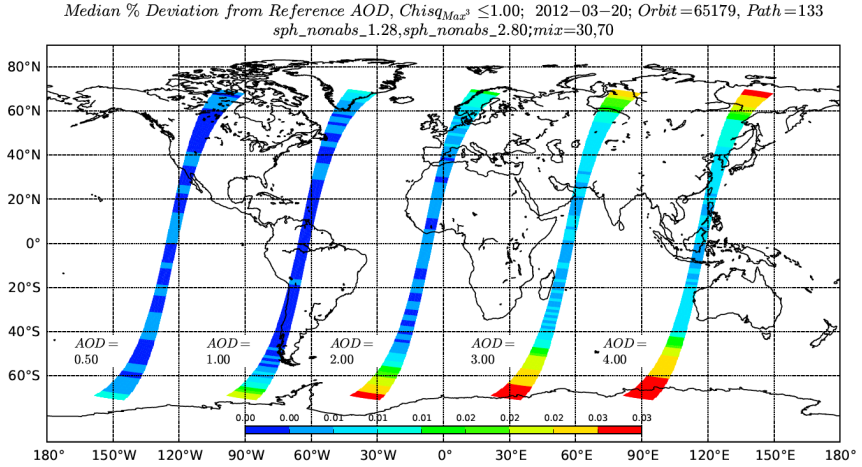
Impact of ***Linear Mixing;*** Globally, Non-Absorbing Aerosol



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



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



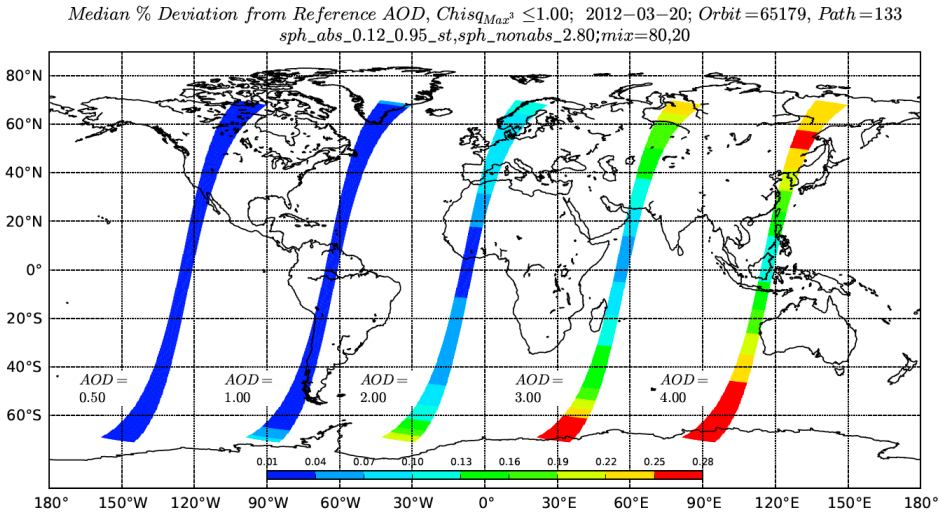
< +1% Discrepancy
30% sph_nonabs_1.28
70% sph_nonabs_2.80

1.28 + 2.80 μm
r_e particles

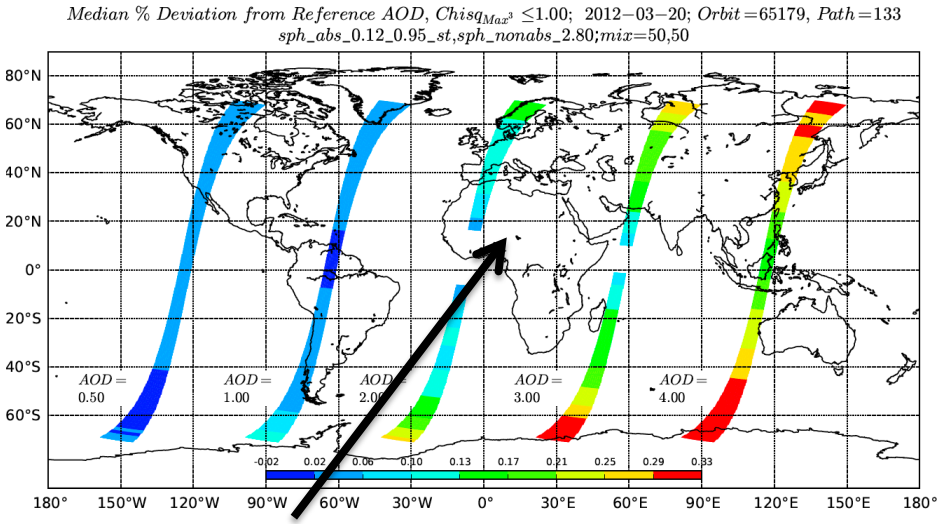
- **Linear mixing *overestimates* AOD with spherical *non-absorbing* particles**
- **A larger particle *size difference* → larger AOD *overestimate***

Figure S10

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

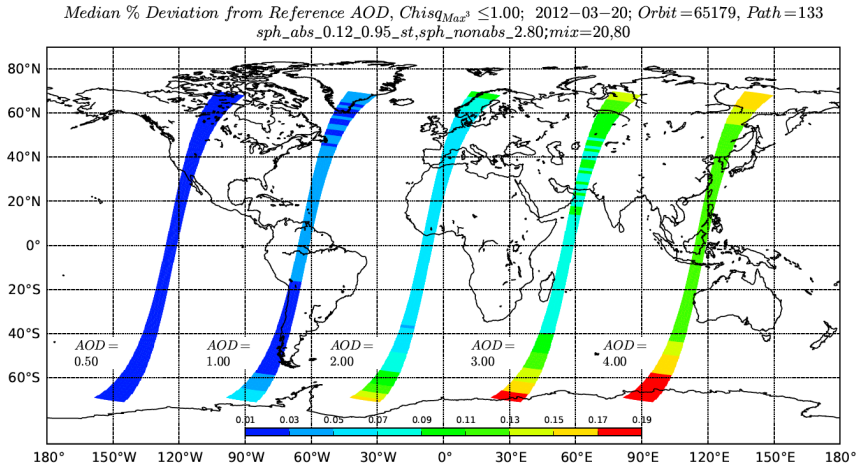


< +25% Discrepancy
80% sph_abs_0.12_SSA-0.95
20% sph_nonabs_2.80



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



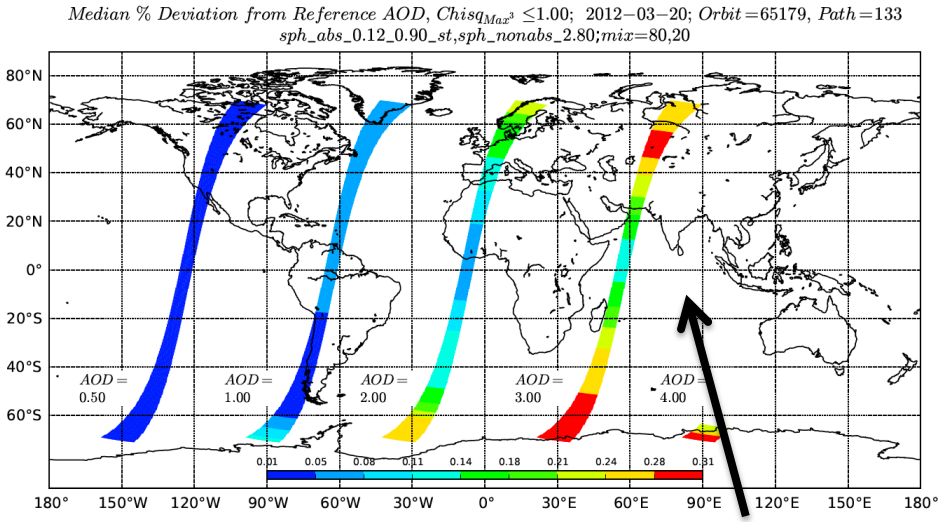
< +13% Discrepancy
20% sph_abs_0.12_SSA-0.95
80% sph_nonabs_2.80

0.12 *SSA_0.95*
+ 2.80 μm
r_e particles

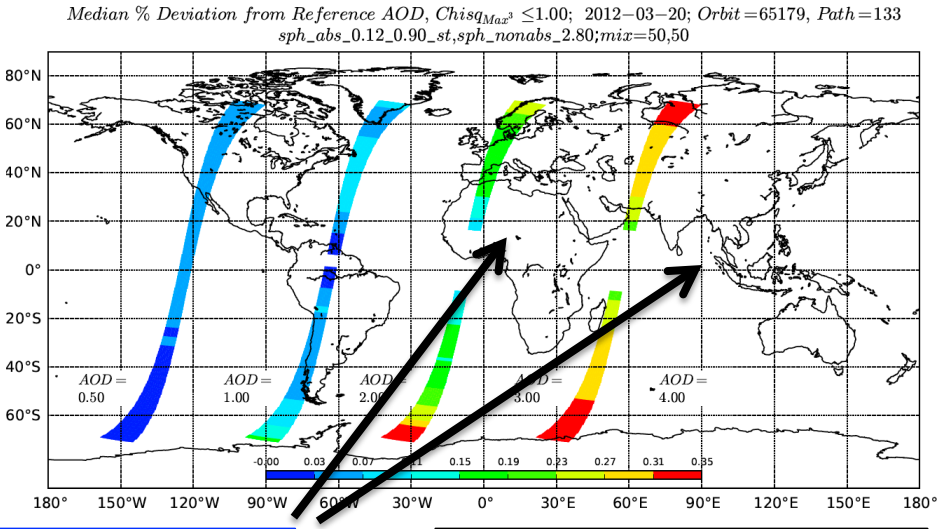
- **MLM *overestimates* AOD with spherical non-absorbing/absorbing particle mixtures**

Figure S11

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

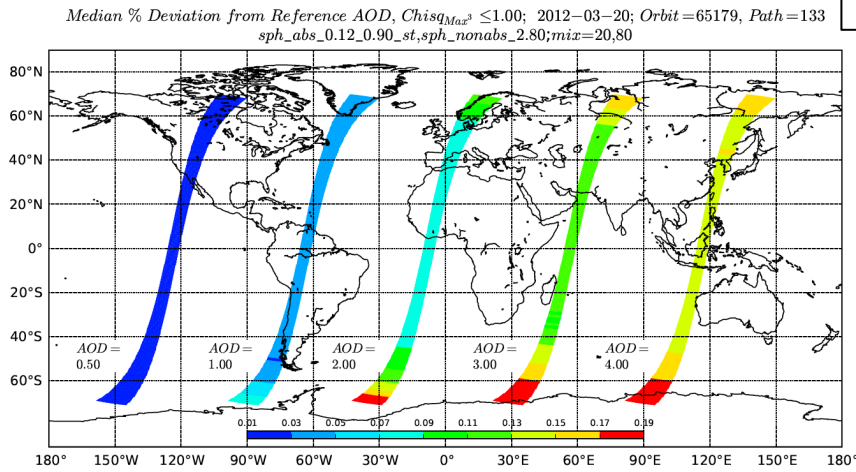


< +28% Discrepancy, ***Mix #34***
80% sph_abs_0.12_SSA-0.90
20% sph_nonabs_2.80



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

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



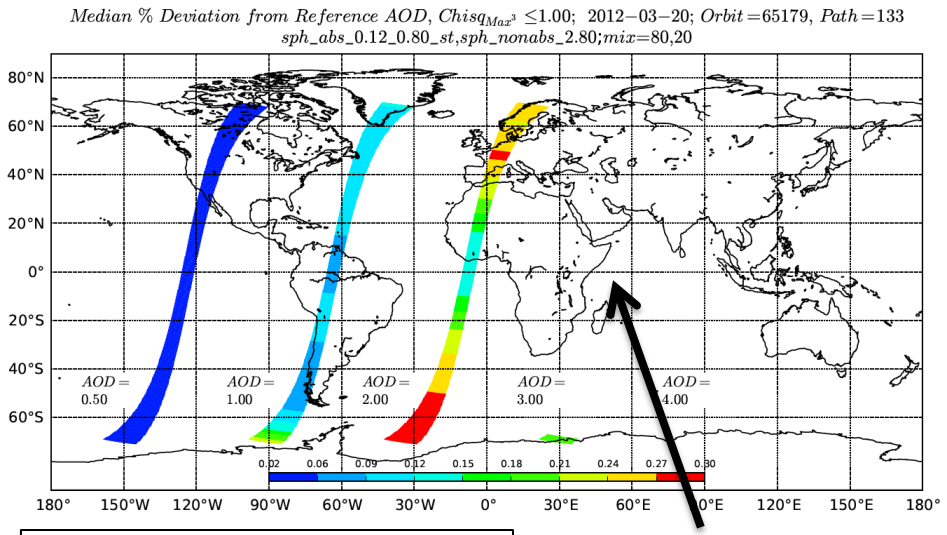
< +17% Discrepancy, ***Mix #40***
20% sph_abs_0.12_SSA-0.90
80% sph_nonabs_2.80

0.12 *SSA_0.90*
+ 2.80 μm
r_e particles

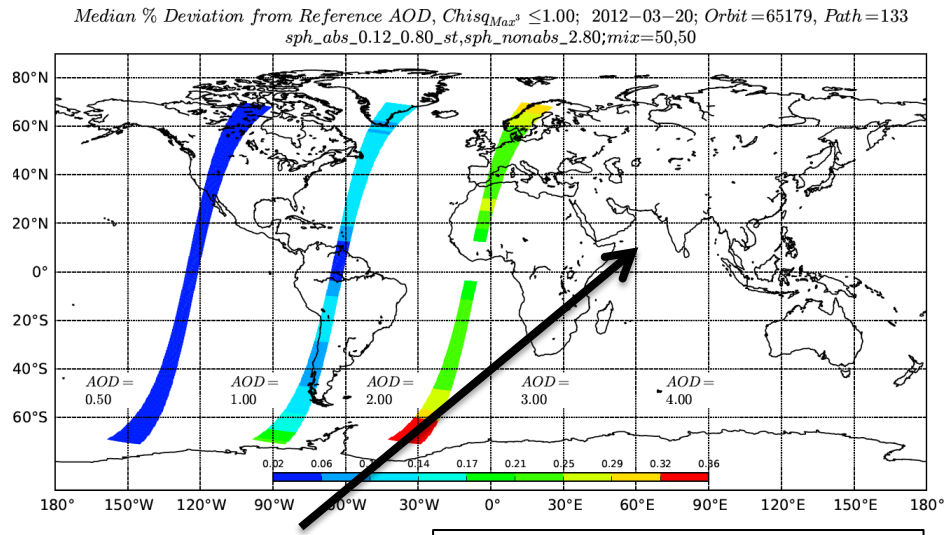
- **MLM *overestimates* AOD with spherical non-absorbing/absorbing particle mixtures**

Figure S12

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

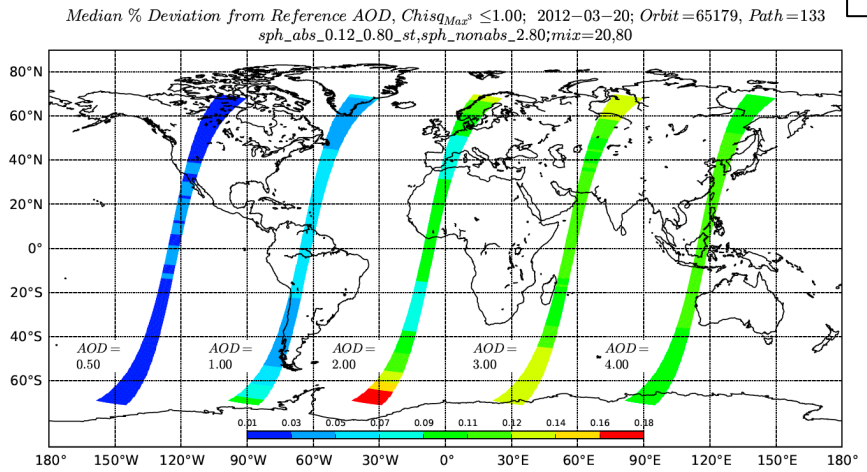


< +27% Discrepancy, ***Mix #44***
80% sph_abs_0.12_SSA-0.80
20% sph_nonabs_2.80



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

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



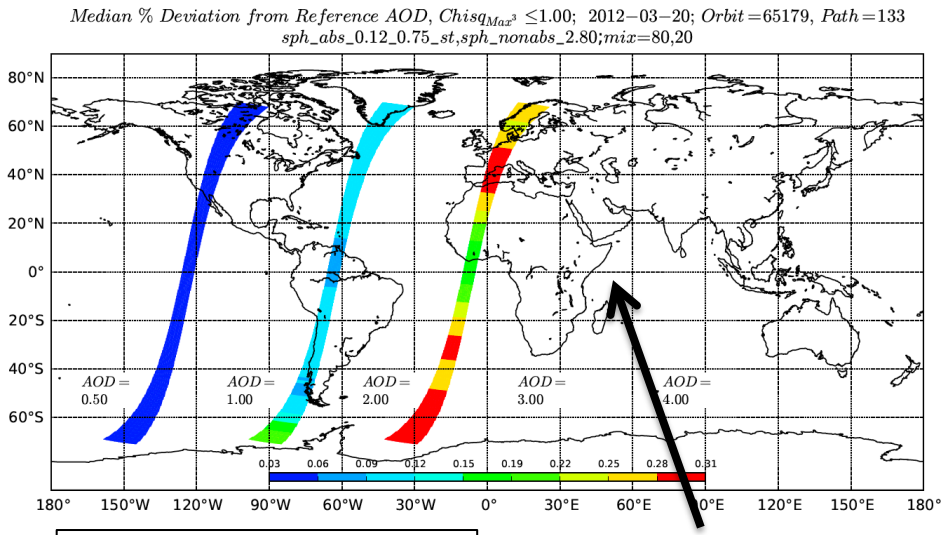
< +12% Discrepancy, ***Mix #50***
20% sph_abs_0.12_SSA-0.80
80% sph_nonabs_2.80

0.12 *SSA_0.80*
+ 2.80 μm
r_e particles

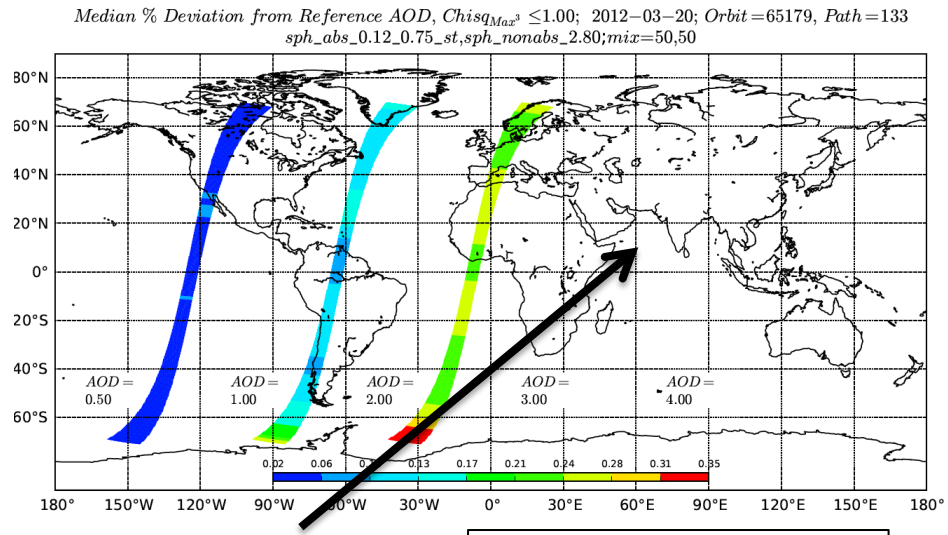
- **MLM *overestimates* AOD with spherical non-absorbing/absorbing particle mixtures**

Figure S13

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

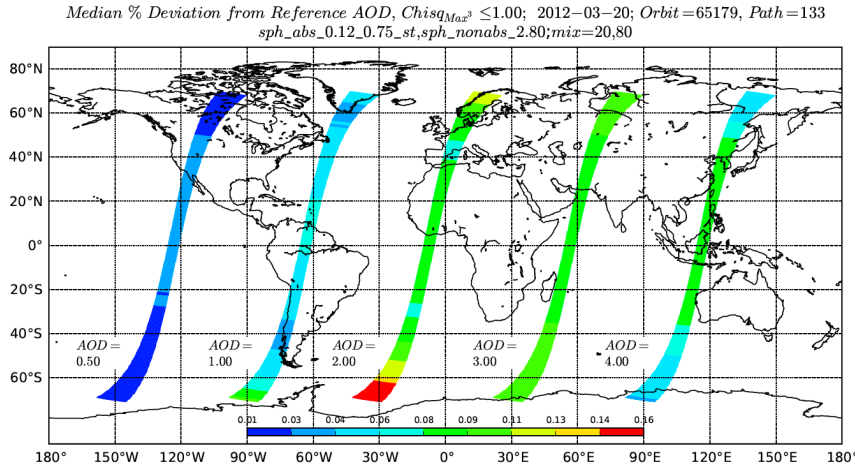


< +31% Discrepancy
80% sph_abs_0.12_SSA-0.75
20% sph_nonabs_2.80



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

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



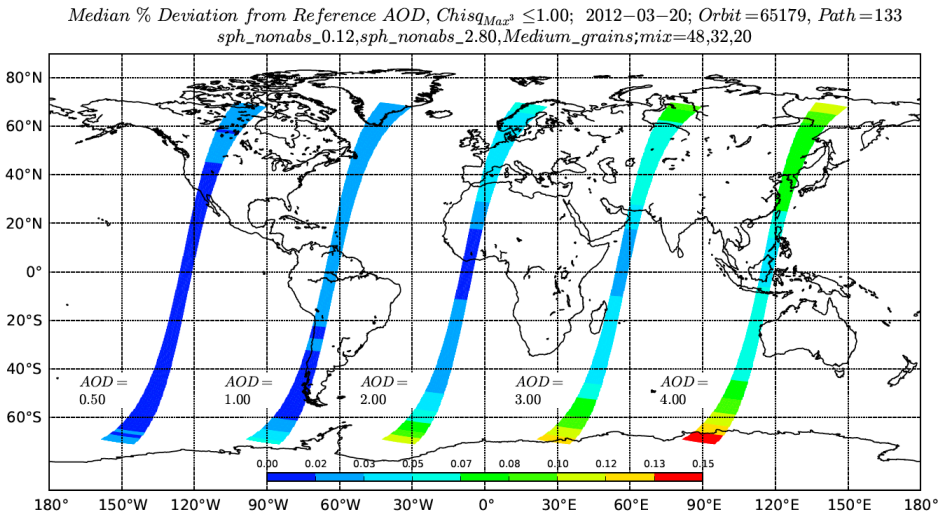
< +11% Discrepancy
20% sph_abs_0.12_SSA-0.75
80% sph_nonabs_2.80

0.12 *SSA_0.75*
+ 2.80 μm
r_e particles

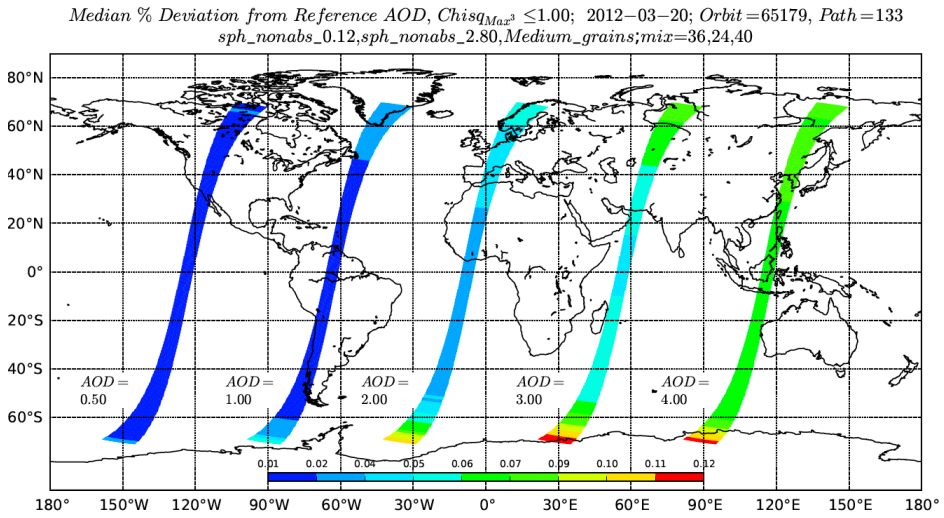
- **MLM *overestimates* AOD with spherical non-absorbing/absorbing particle mixtures**

Figure S14

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

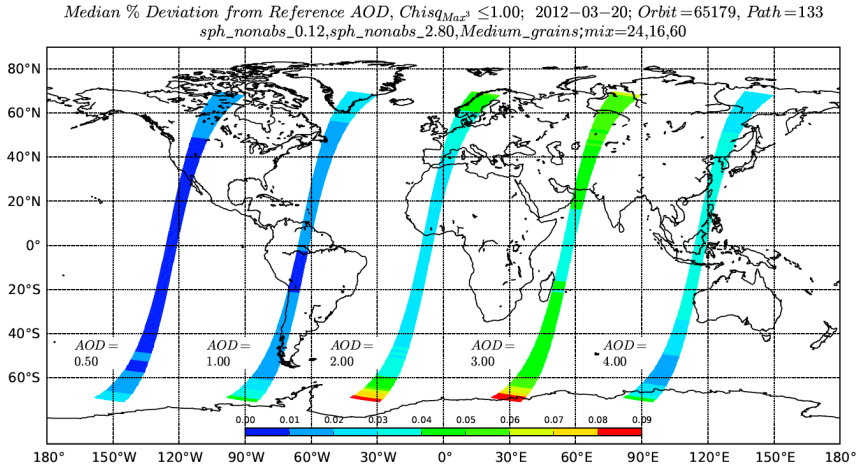


< +10% Discrepancy, ***Mix #52***
48% sph_nonabs_0.12
32% sph_nonabs_2.80
20% Medium Dust Grains



< +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

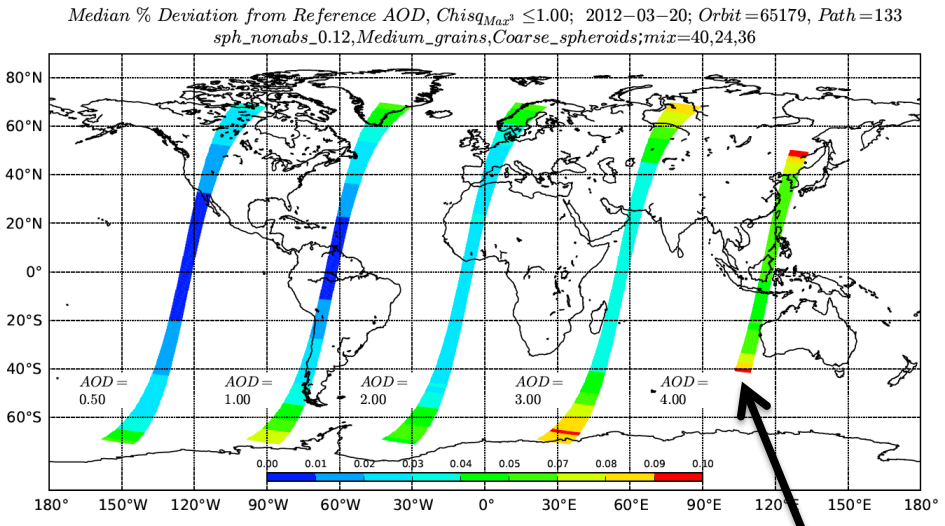


0.12 + 2.80 μm
+ dust grain
r_e particles

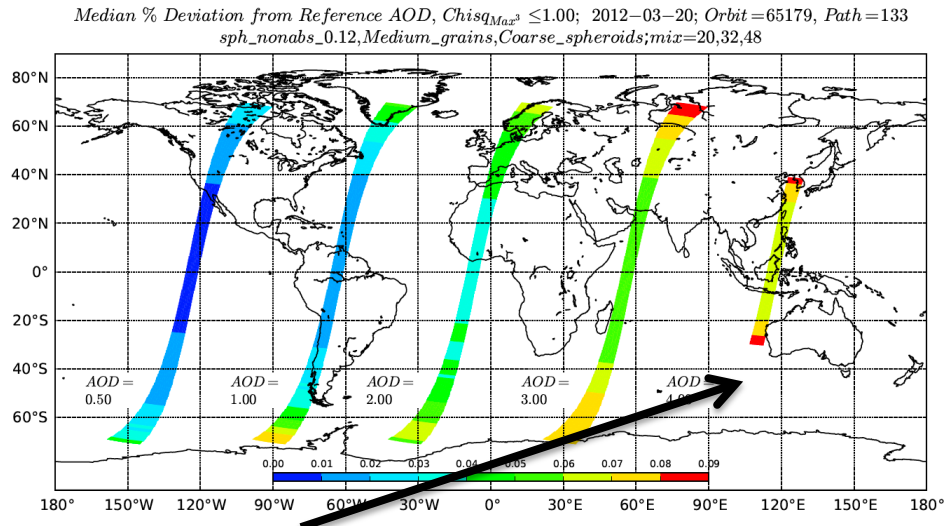
- **Modified linear mixing *overestimates* AOD with non-spherical particle mixtures**

Figure S15

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

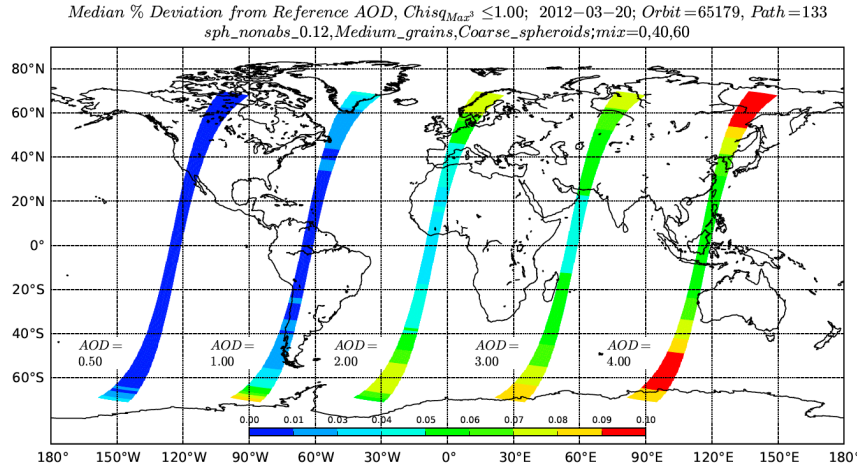


< +10% Discrepancy, ***Mix #65***
40% sph_nonabs_0.12
24% Medium Dust Grains
36% Coarse Dust Spheroids



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

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



< +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