National Aeronautics and Space Administration

SAGE III/ISS

Stratospheric Aerosol and Gas Experiment

An Earth Science Mission on the International Space Station

SAGE III/ISS Science Team Meeting

Travis N. Knepp

Mahesh Kovilakam,

Stephan J. Miller,

Larry Thomason

Particle Size Distribution Parameters from SAGE III/ISS Extinction Spectra, with Application to the 2022 Hunga Tonga Eruption

Proposed Work

- Use Mie theory to identify PSD parameters from SAGE III/ISS data
    - Account for measurement error in PSD estimates
    - Provide confidence intervals for PSD estimates
    - Expand to include other microphysical properties (e.g., SAD and VD)
    - Extend analysis to include bimodal distributions

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  - Extend analysis to include bimodal distributions

Algorithm is complete and all objectives met

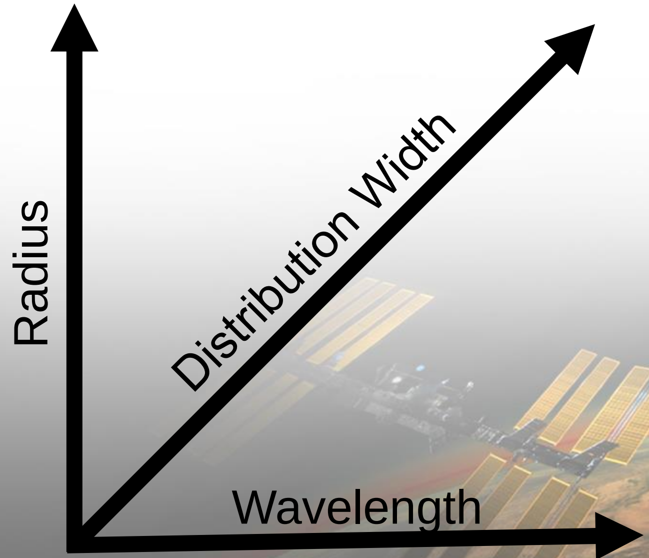
Mie Theory Assumptions

- Invoke standard Mie theory assumptions
  - all particles spherical
  - all distributions are lognormally distributed
  - particles composed of 75% (wt) sulfuric acid, 25% water
    - Palmer and Williams (1975) refractive indices

  - above assumptions used in lookup table (LUT) creation

Lookup Table (LUT)

- Use Mie theory to create lookup tables of extinction coefficients: k(r, λ, σ)
- Tested for series of extinction ratio combinations



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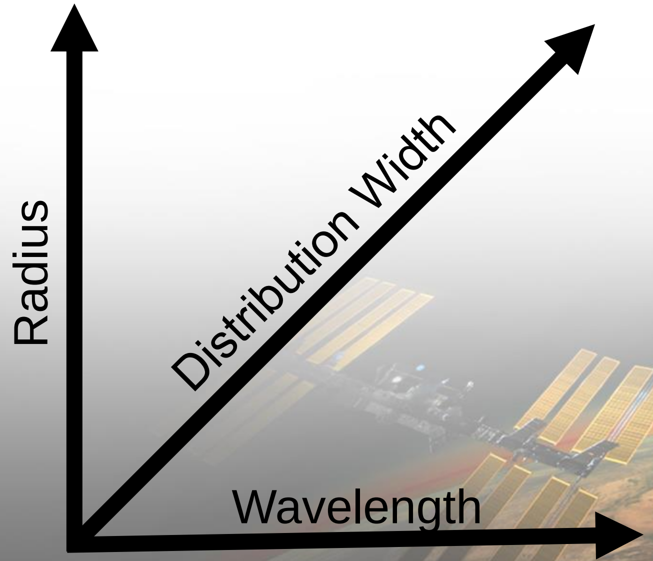
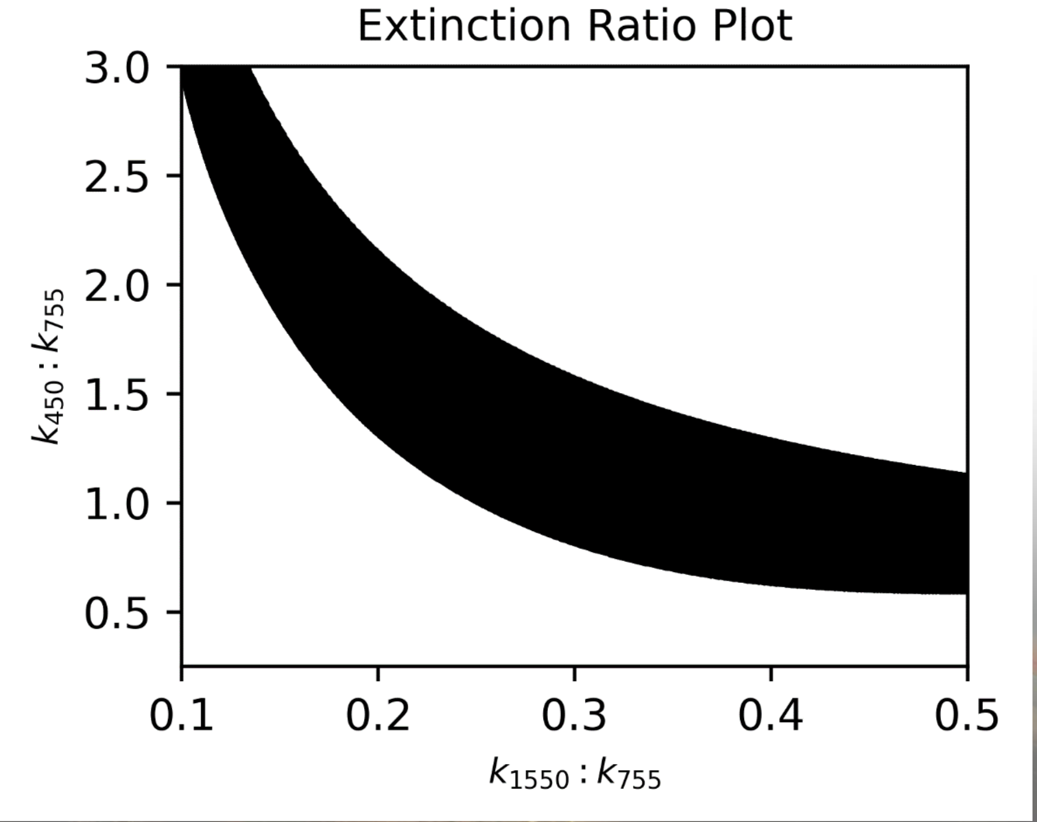
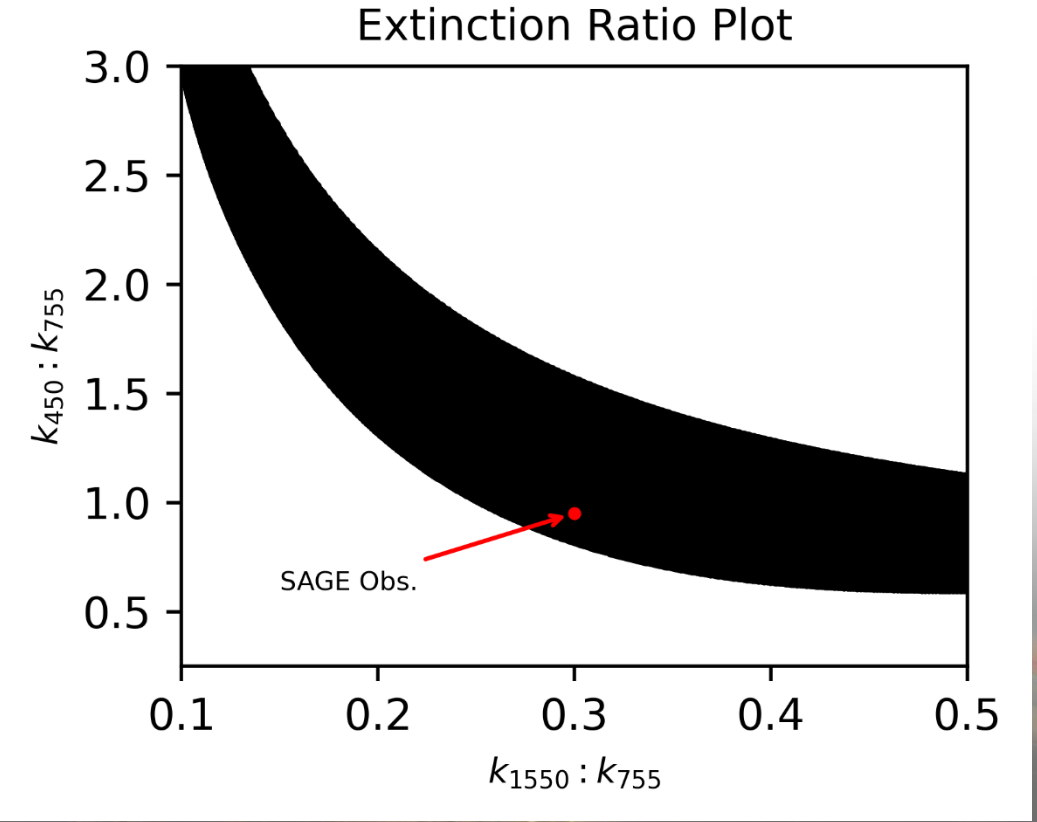


Condition #	Numerator Wavelengths (nm)	Denominator Wavelength (nm)
0	520	1021
1	448, 520	1021
2	448, 520, 755	1021
3	448, 520, 755, 869	1021
4	384, 448, 520, 755, 869	1021
5	384, 448, 520, 755, 869, 1543	1021
6	448, 520, 755, 869, 1543	1021
7	520	1543
8	448, 520	1543
9	448, 520, 755	1543
10	448, 520, 755, 869	1543
11	448, 520, 755, 869, 1021	1543
12	520, 755, 869, 1021	1543
13	384, 448, 520, 755, 869	1543
14	384, 448, 520, 755, 869, 1021	1543
15*	448, 1543	755

Visualizing the Solution Space



Visualizing the Solution Space



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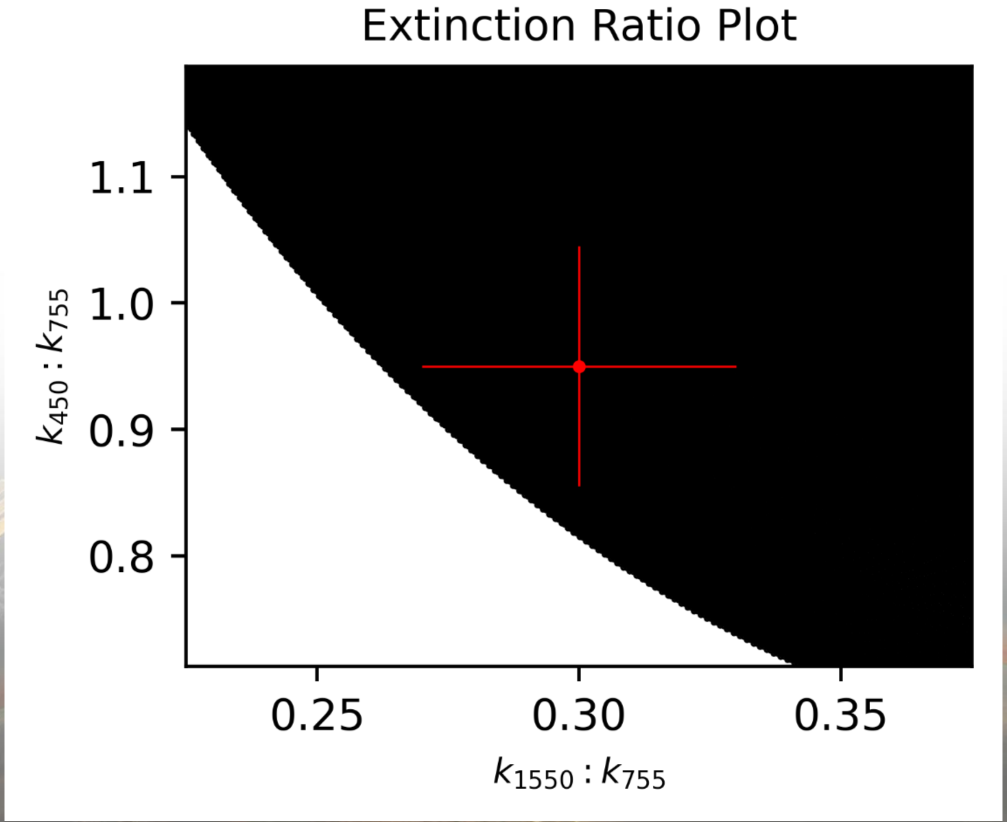

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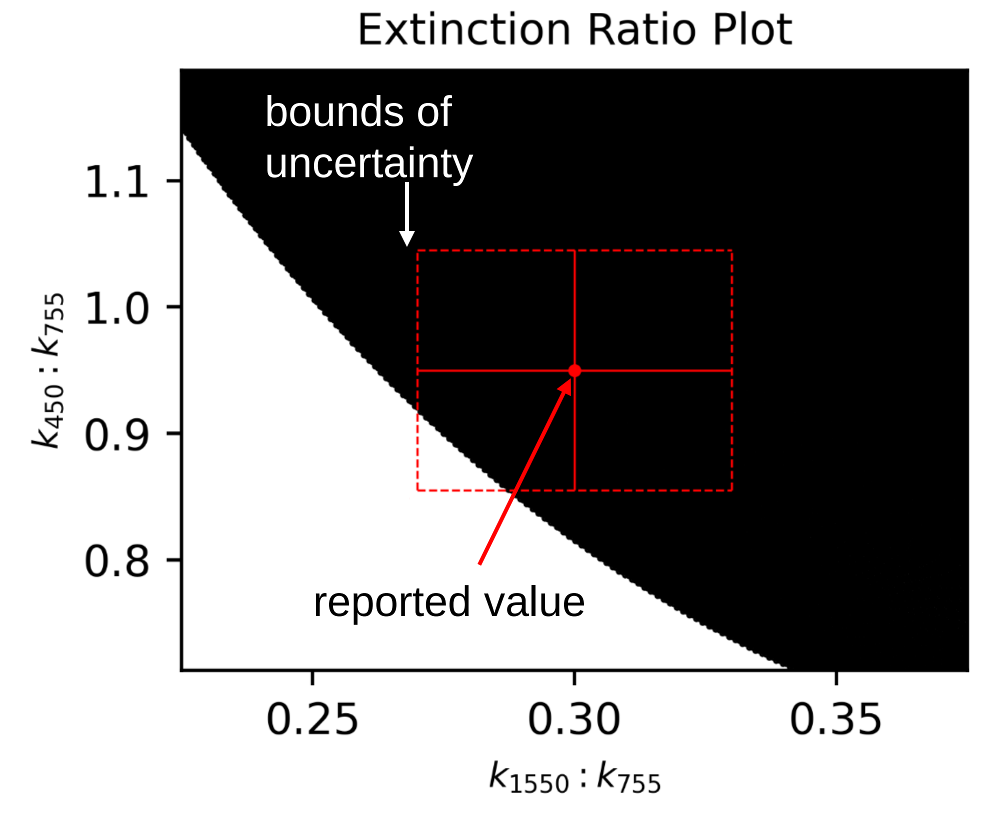
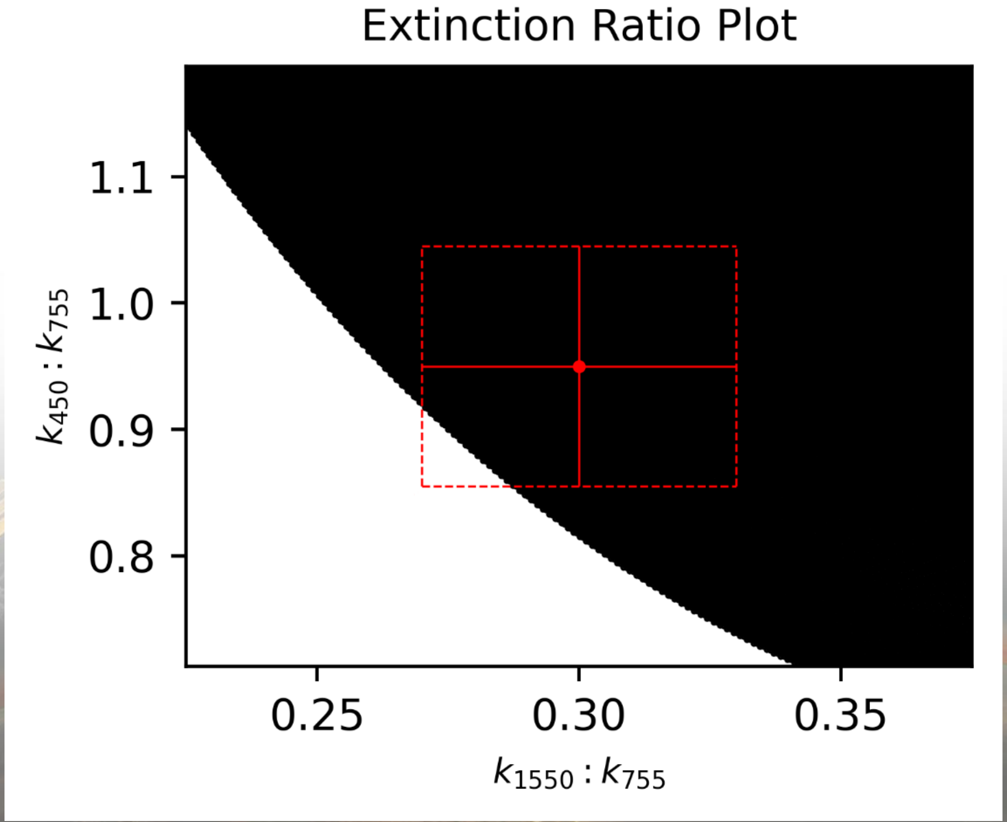


All potential solutions!

Which is right/best?

Visualizing the Solution Space



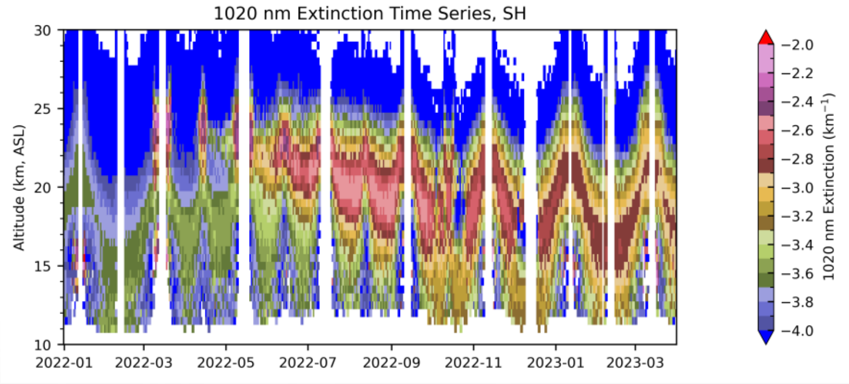
Use distance from central point as weight

Calculate weighted statistics (e.g., median)

2022 Hunga Tonga Eruption

- Hunga Tonga Erupted in January 2022
  - SO_2 injection was modest (~0.5 Tg)
  - H_2O injection was large (3,000 – 13,000 Tg)
    - ~5-10% stratospheric H_2O content
  - Eruption was violent (injection up to 58 km)
    - VEI 6, comparable to Krakatoa?

SAGE III/ISS Observation of HTHH: Aerosol



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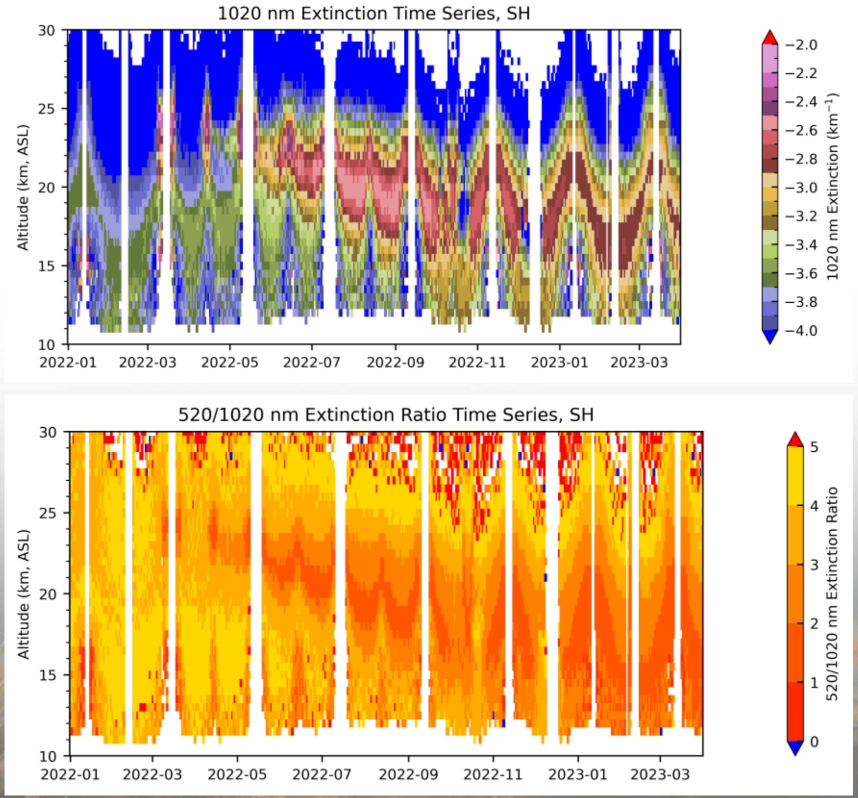
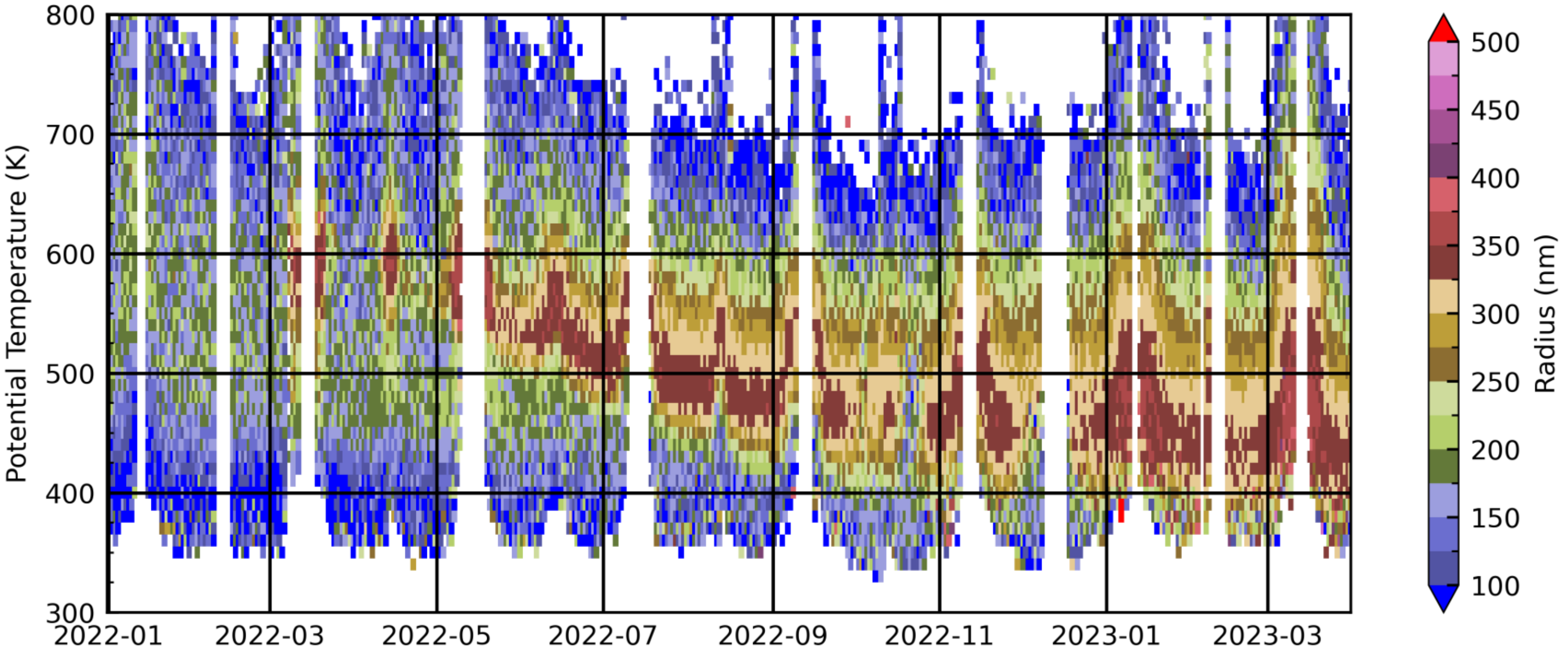
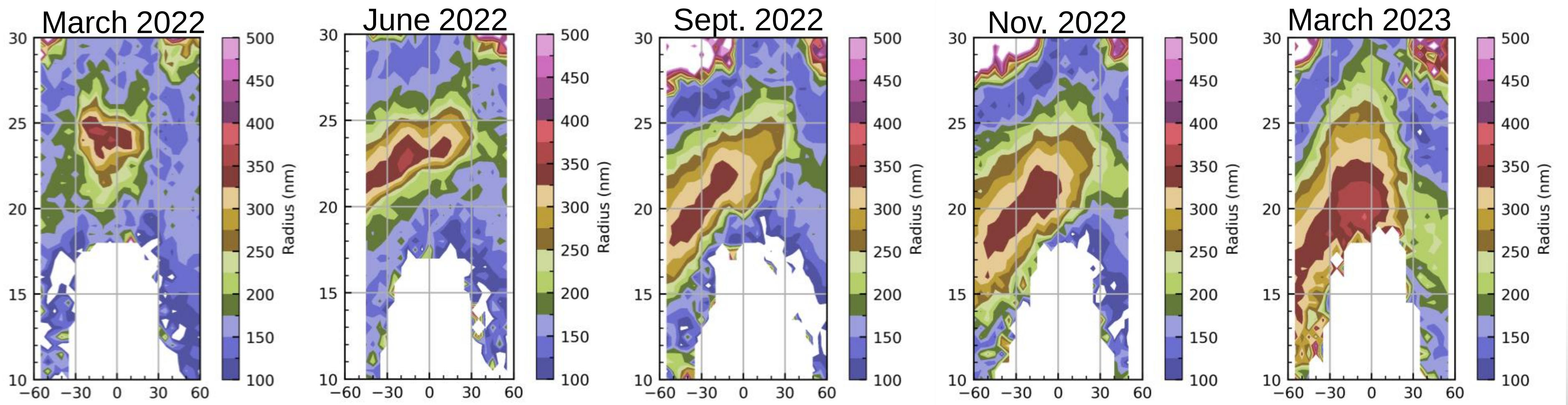


PSD Algorithm Applied to SAGE III/ISS



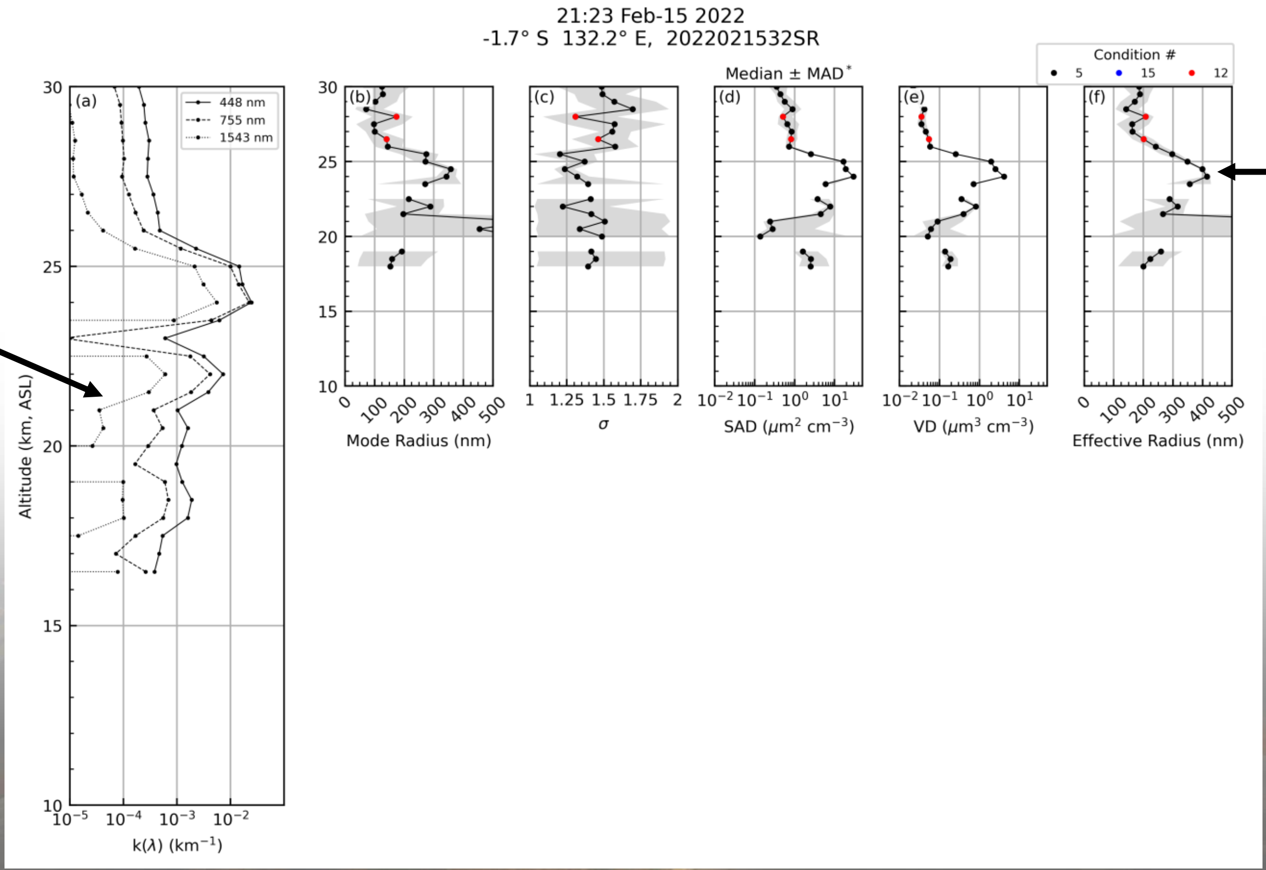
Particle Transport and Descent



All particles moved south

Separation of largest/smallest at high altitude

HTHH Individual Profile



Measurement error large

Comparable to POPS (460 nm)

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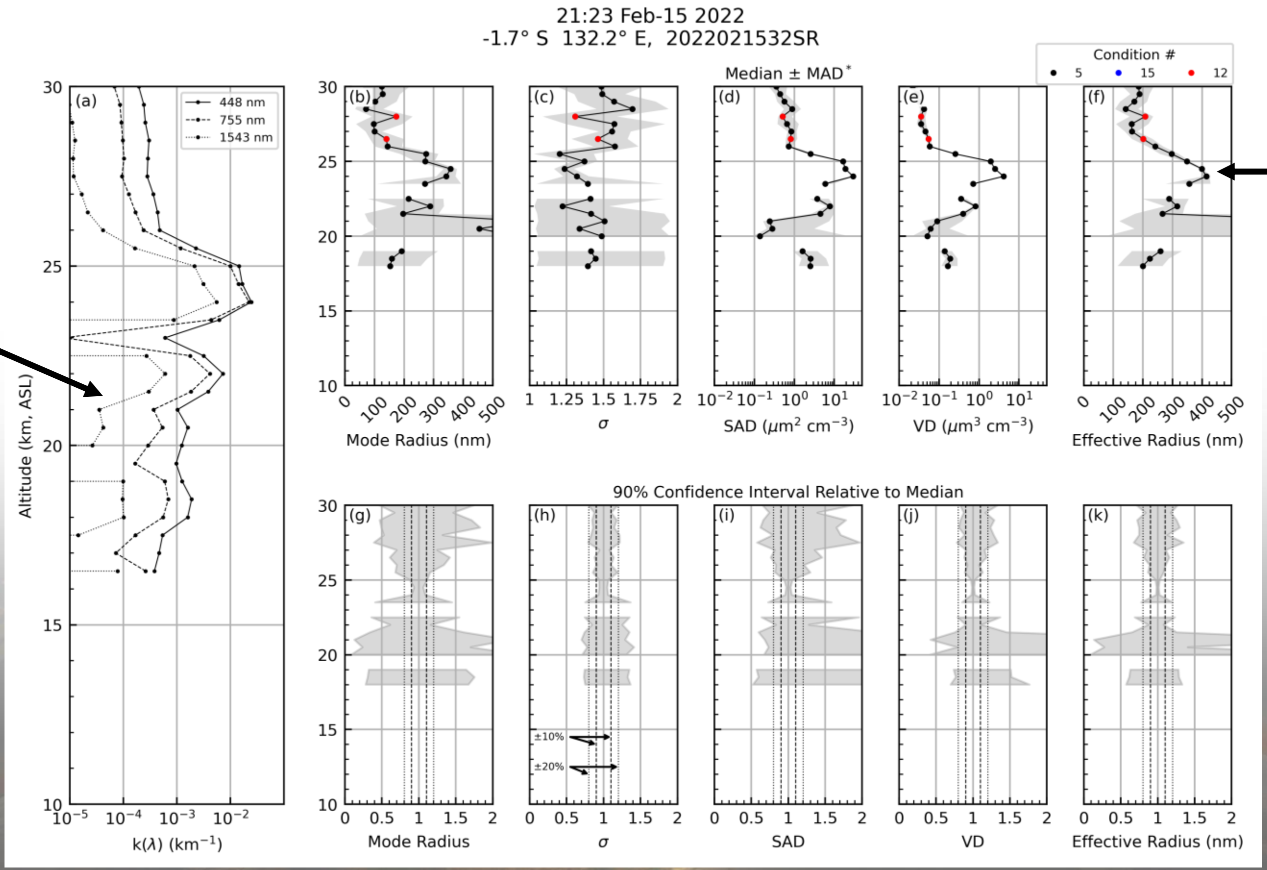

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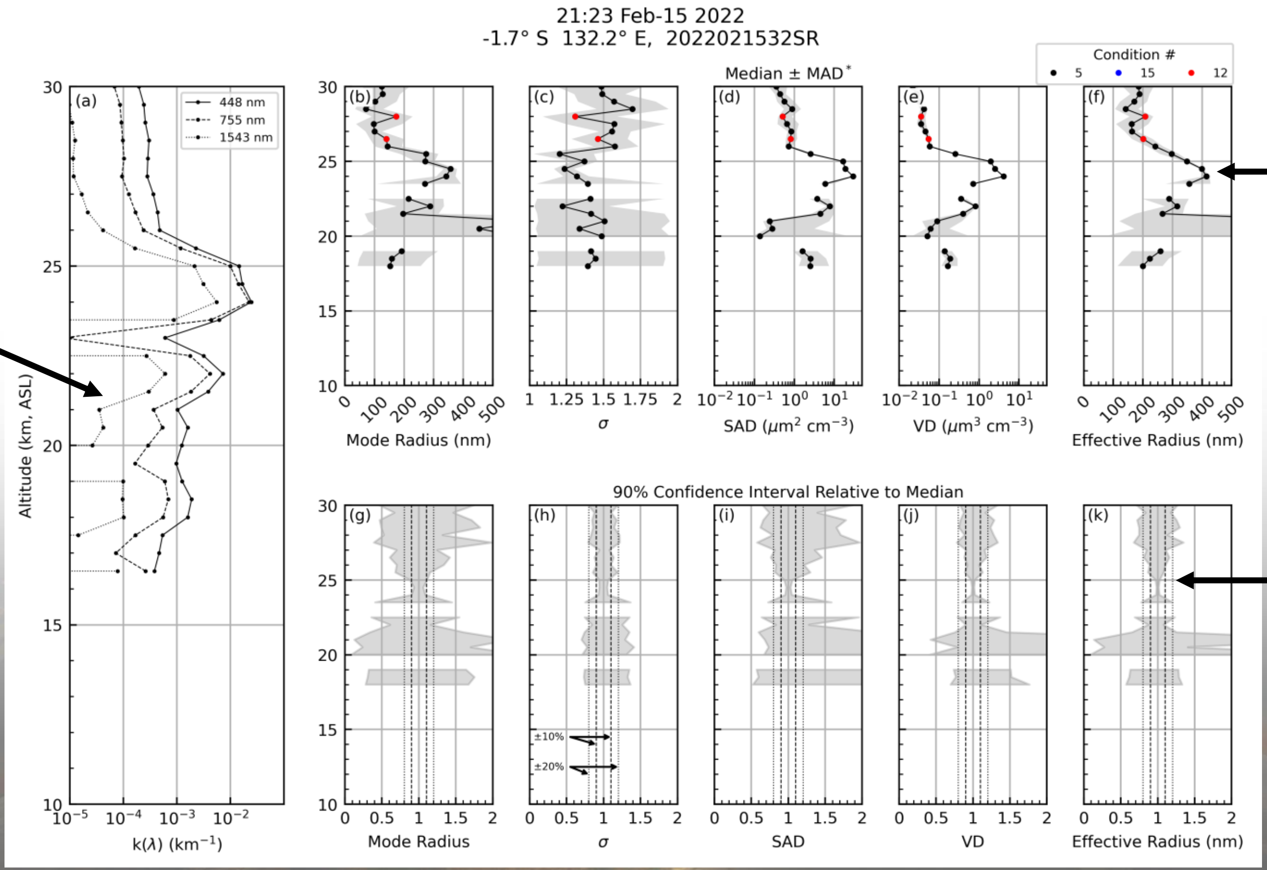
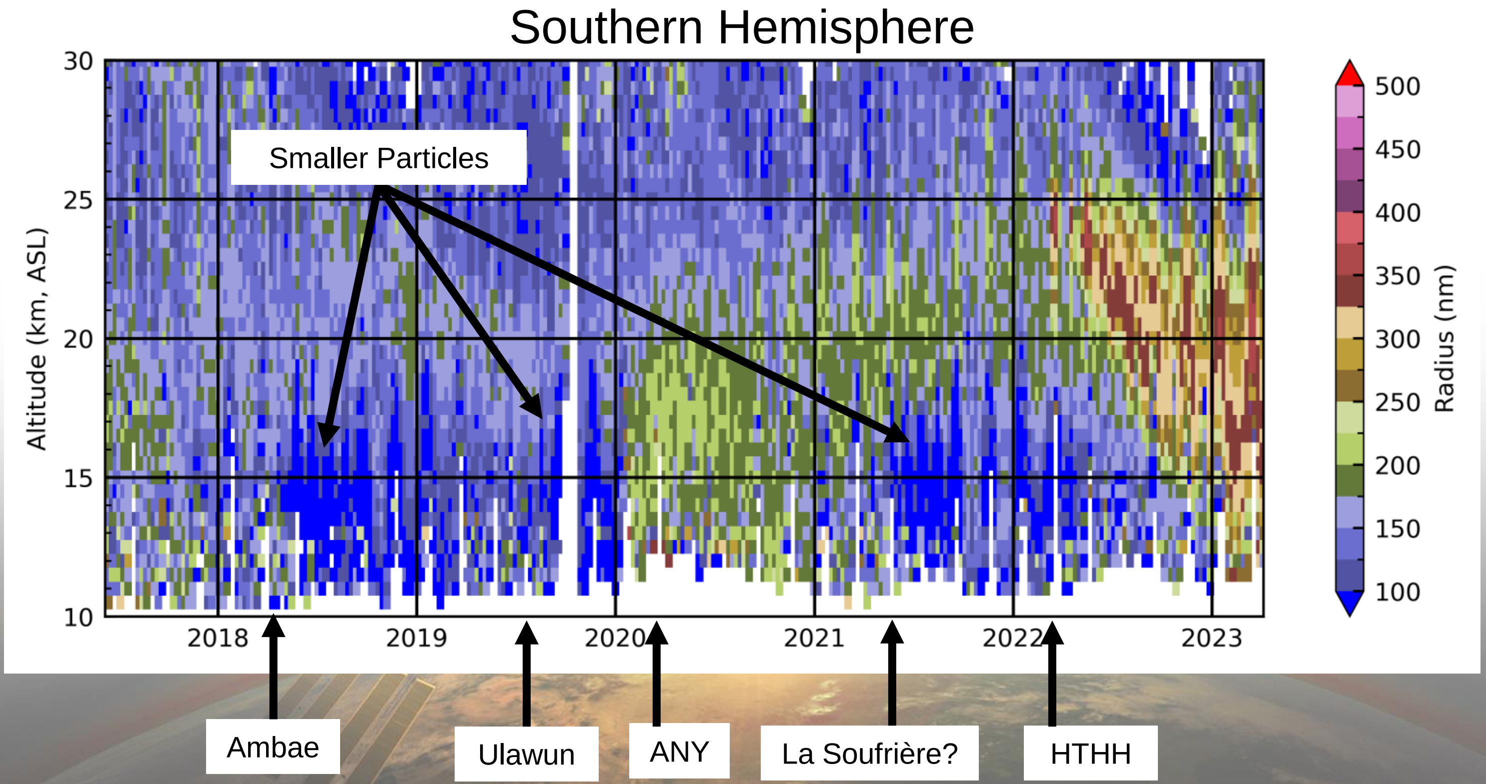


Comparable to POPS (460 nm)

90% confident that PSD estimates are within 10% of median

Other Events



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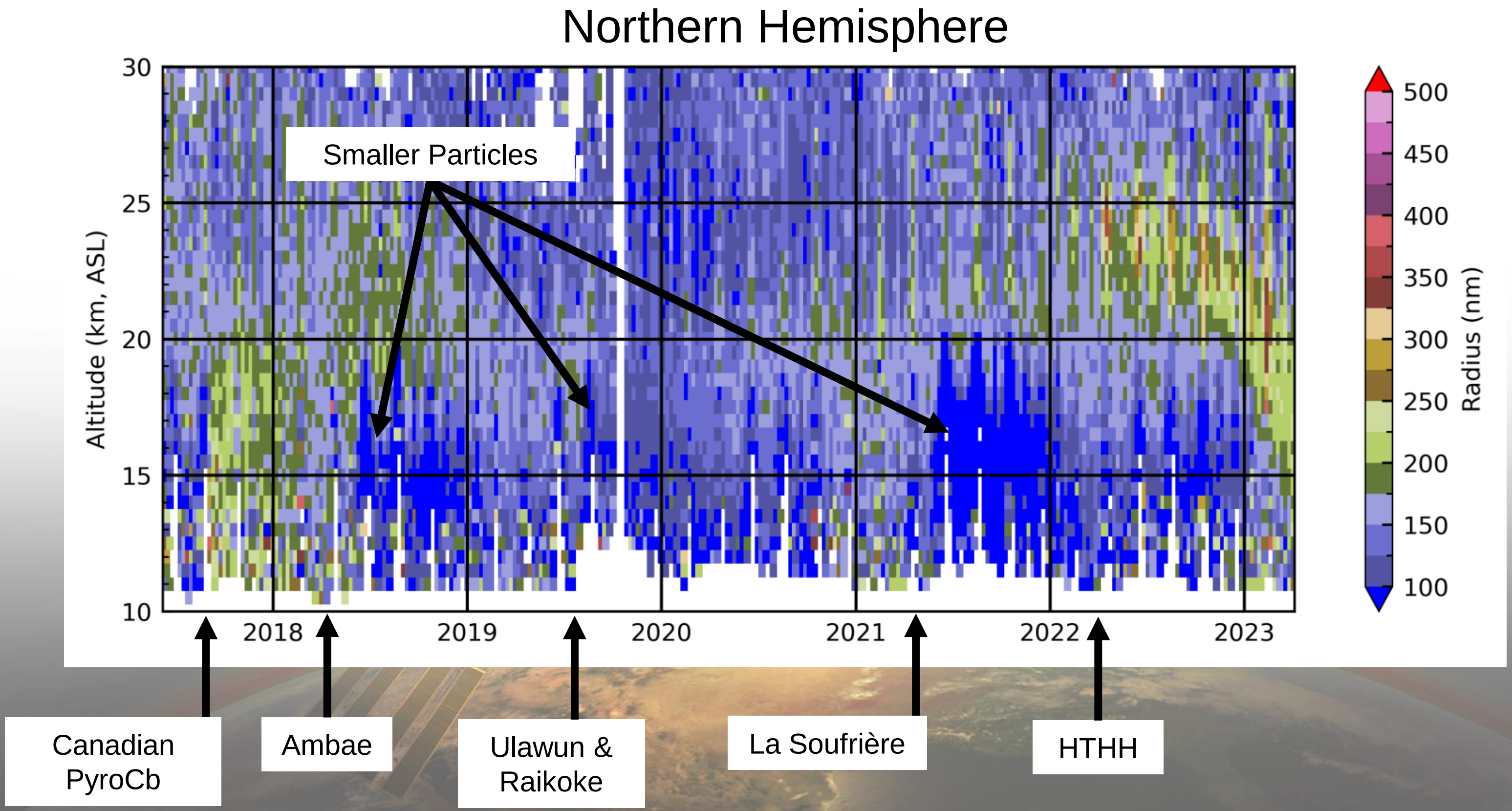
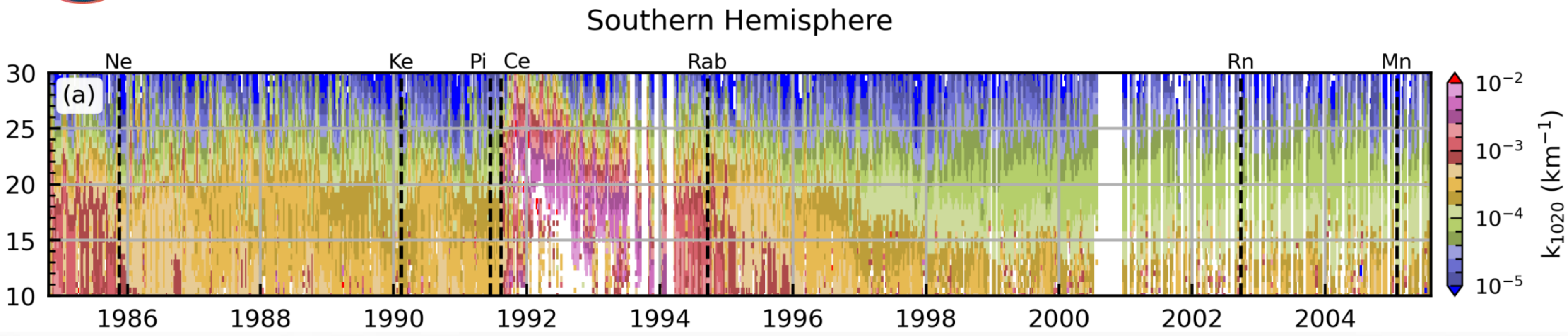


Application to SAGE II



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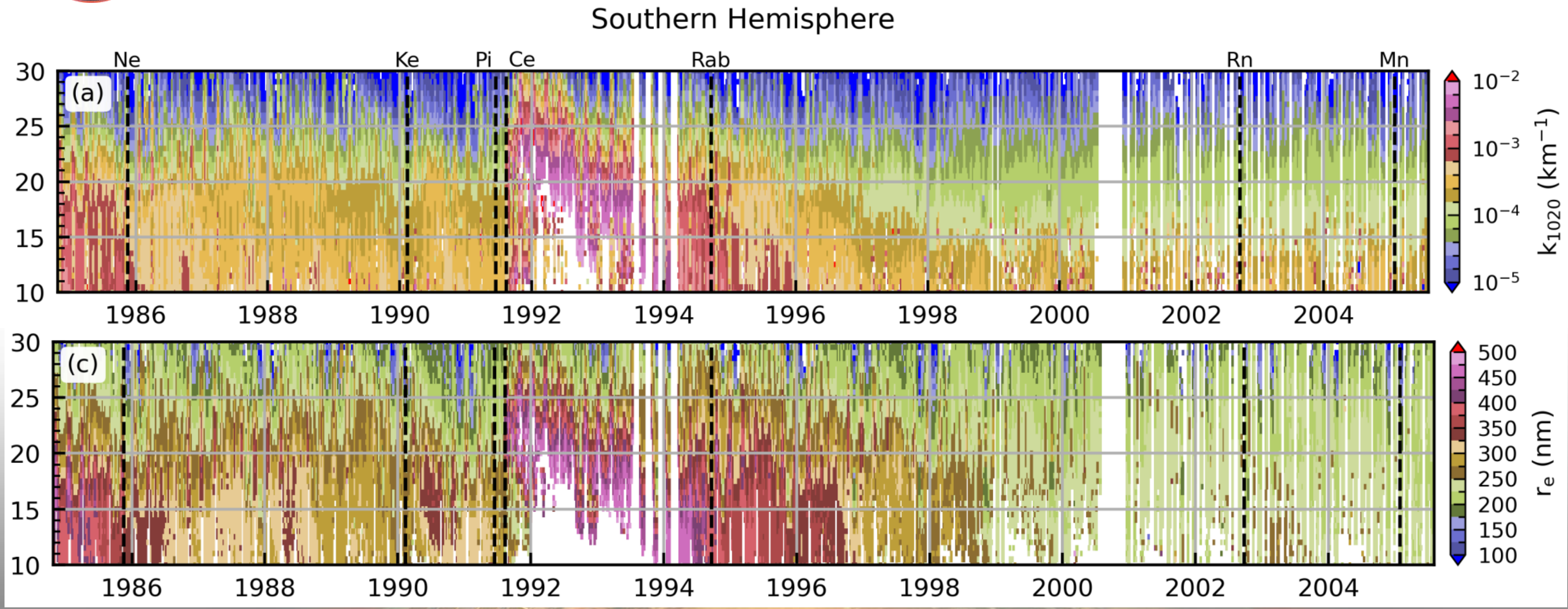
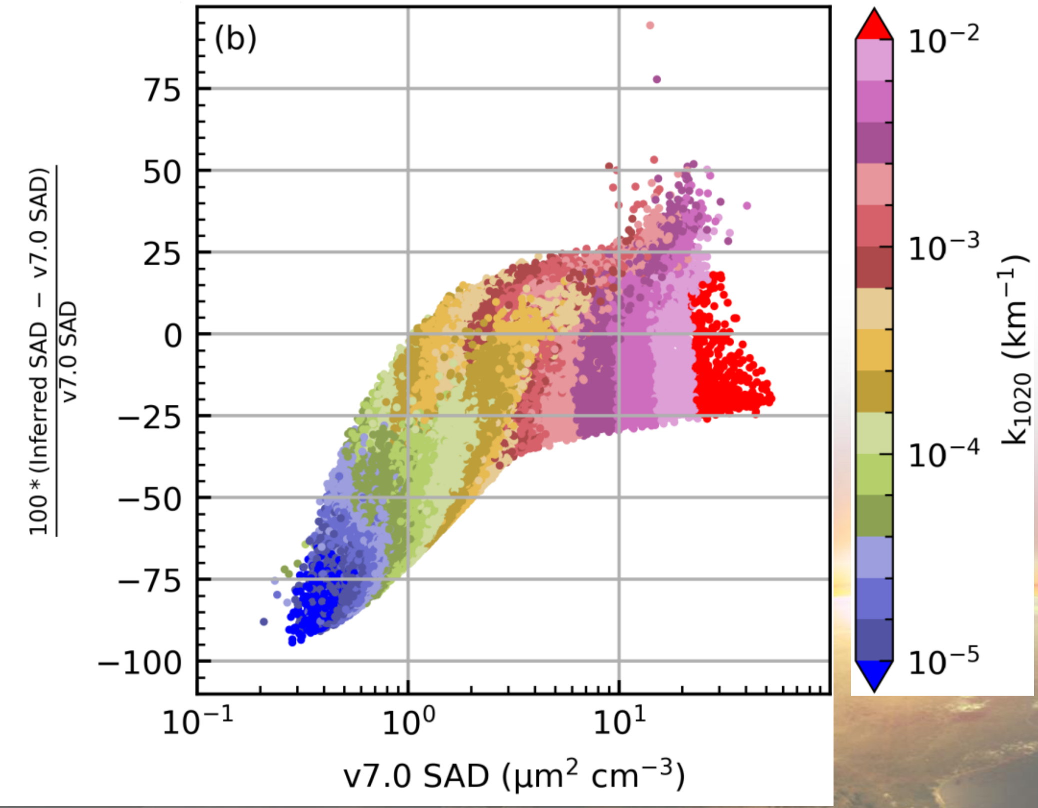


Comparison with SAGE II v7.0 Products



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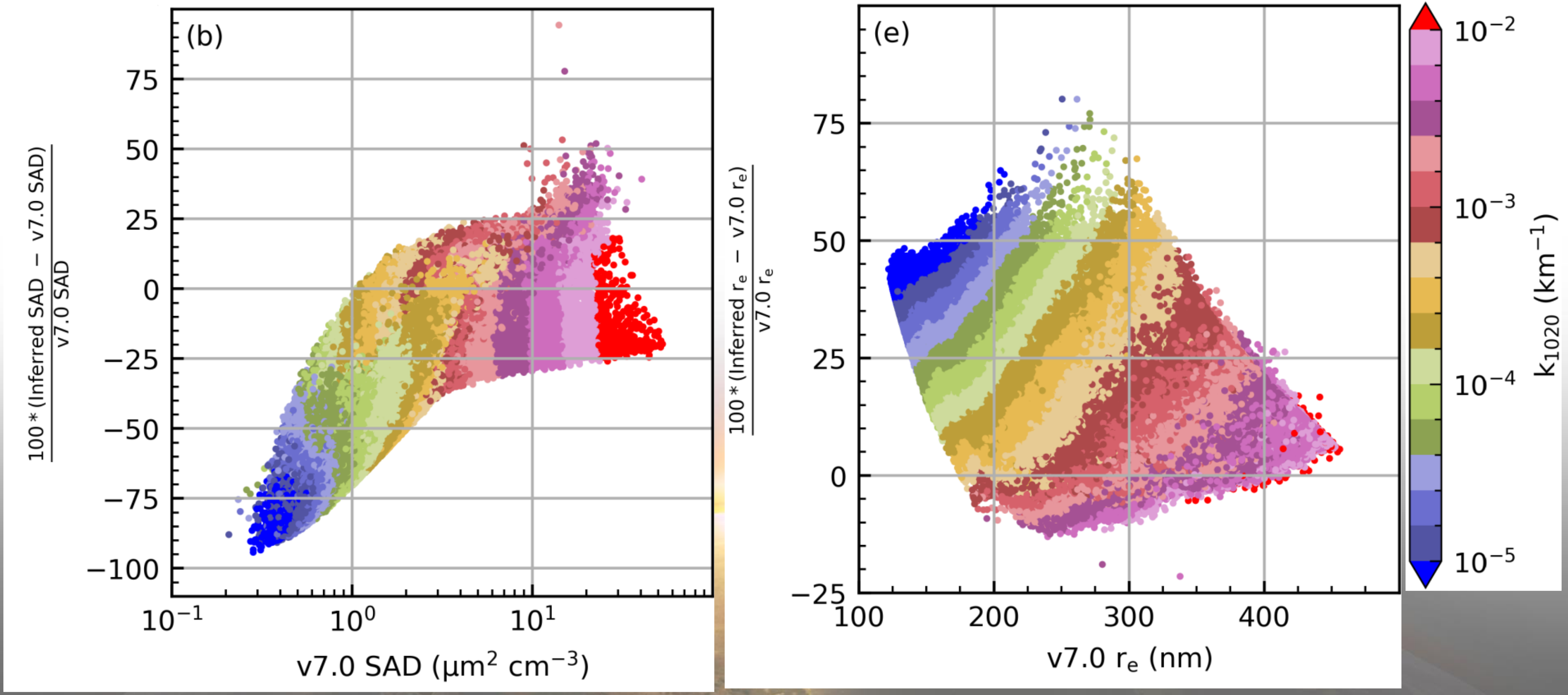


Conclusions from SAGE II comparison

Our products are consistent with the SAGE II products

Recap

- Method to infer PSD parameters from SAGE III/ISS extinction data was developed
    - Method allows computation of confidence intervals

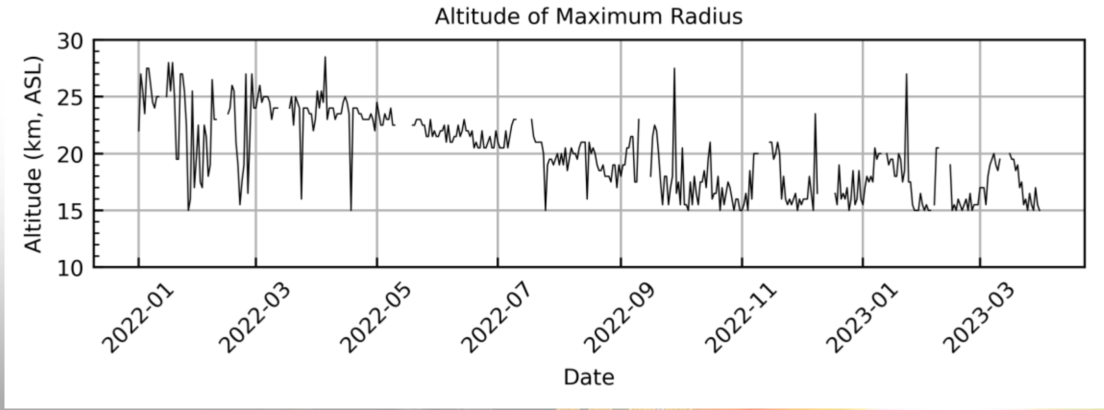
- Hunga Tonga increased particle size >400 nm
    - Good agreement with POPS observations

- Observed smaller particle formation from smaller eruptions

- SAD and r_e products were in good agreement with the SAGE II products

Questions

Sedimentation Rate Estimates



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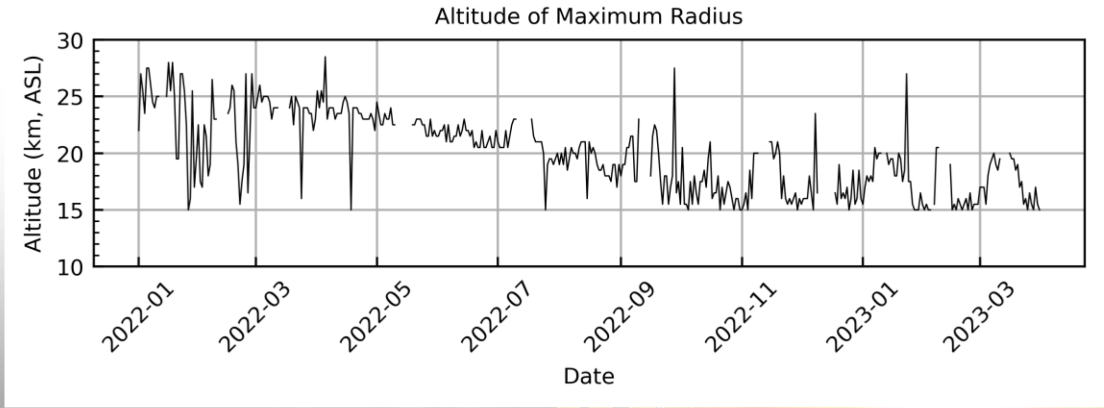
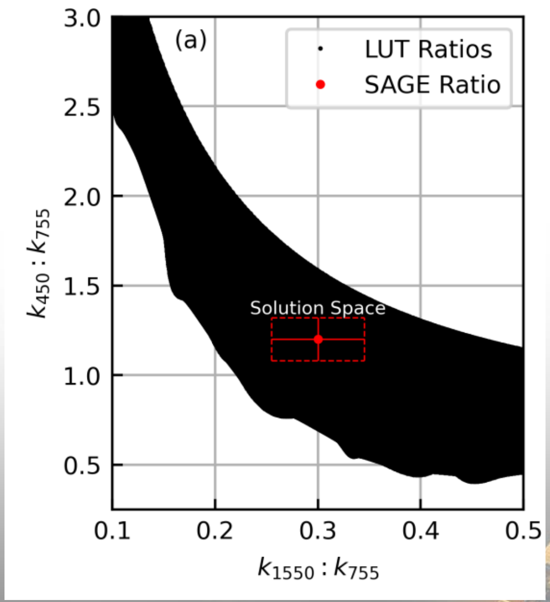


Latitude (S)	Descent Rate (mm/s)
0 - 10	0.1
10 - 20	0.13
20 - 30	0.13
30 - 40	0.23
40 - 50	0.25
50 - 60	0.21
60 - 70	0.32

Estimating Solution Space Variability



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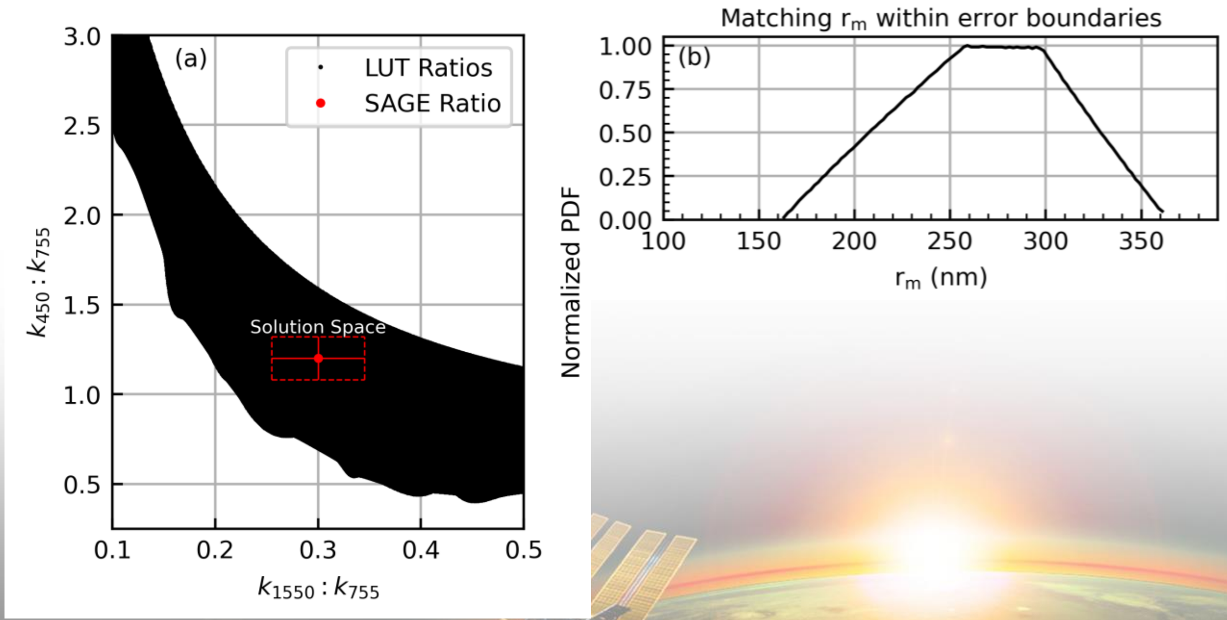

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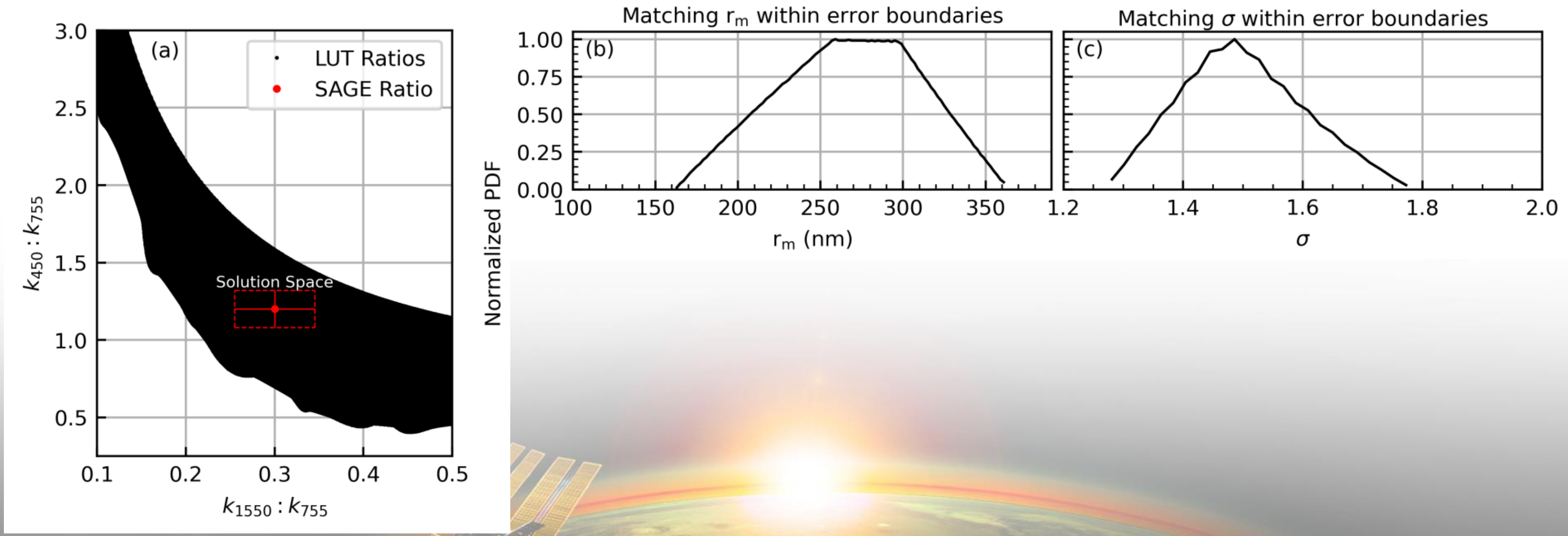

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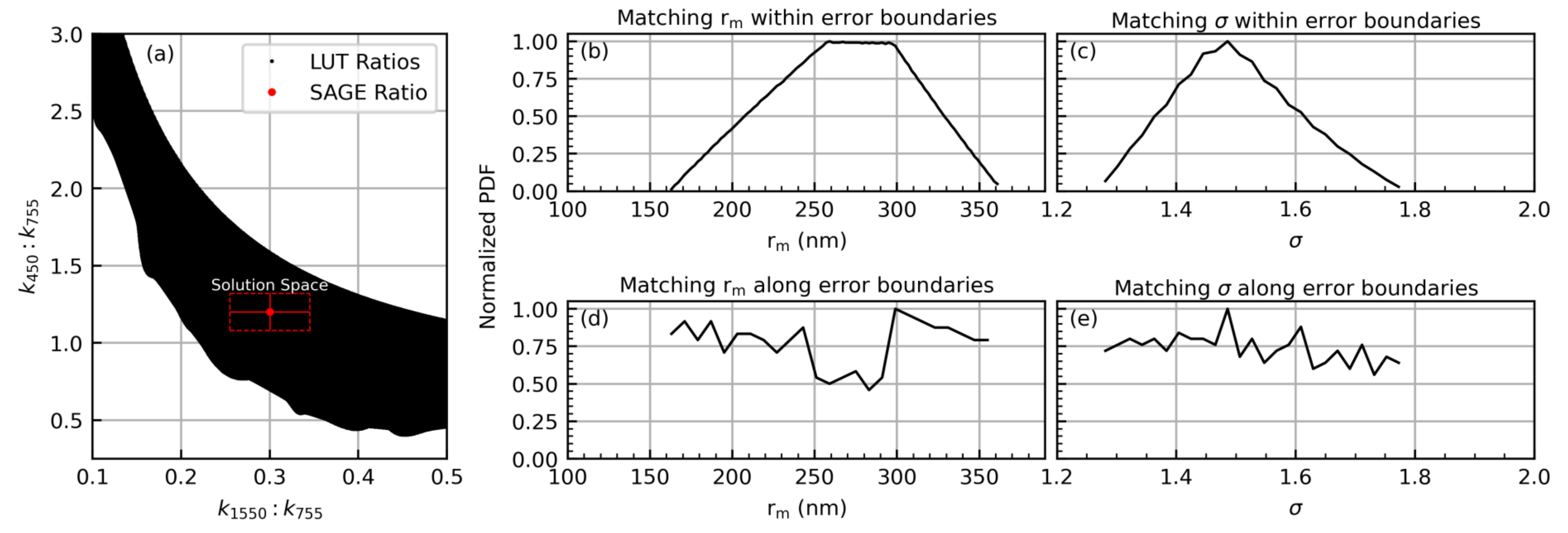
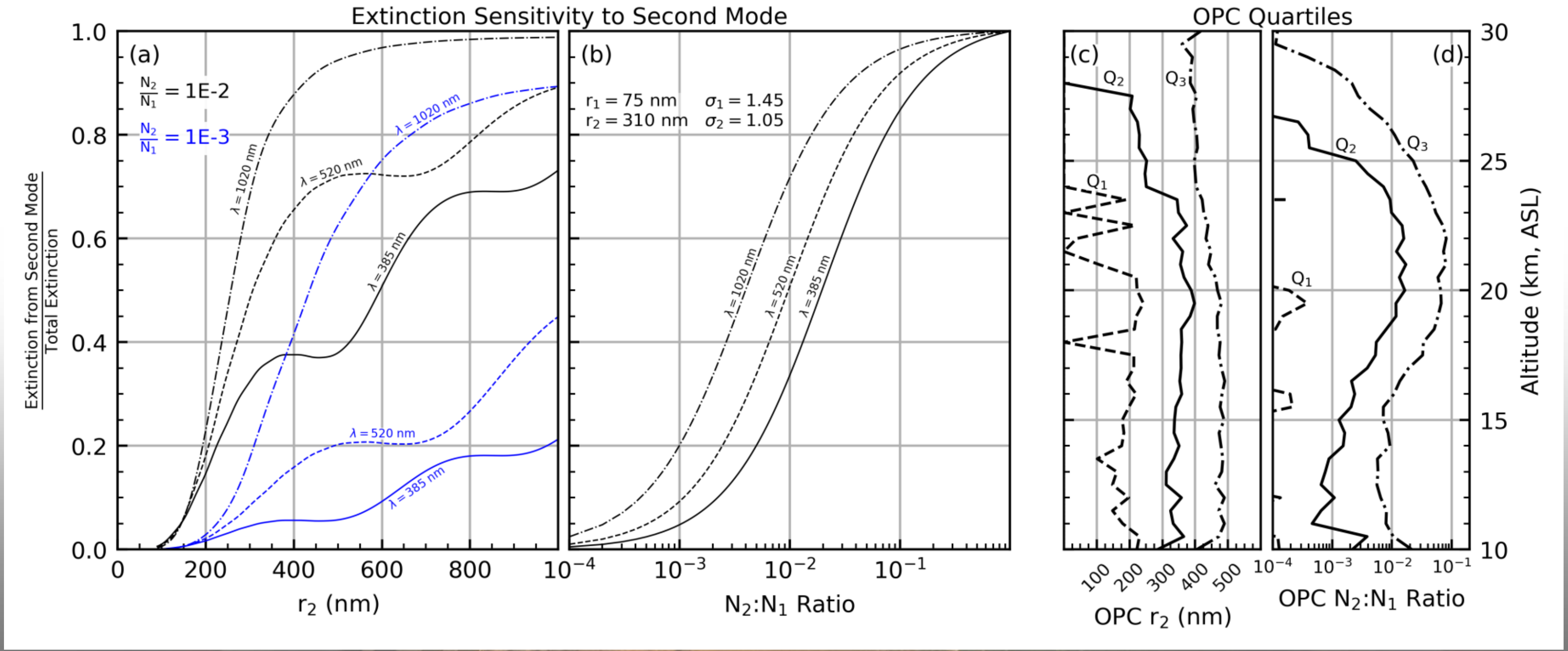
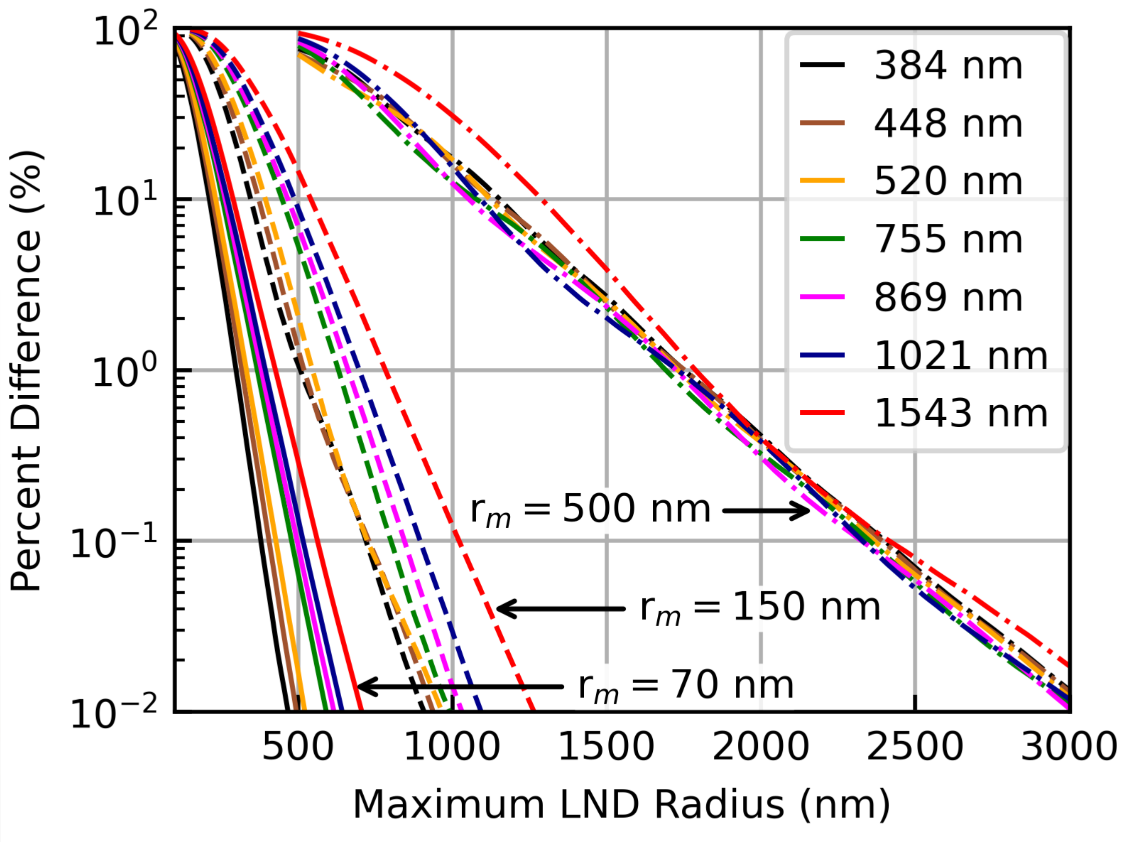


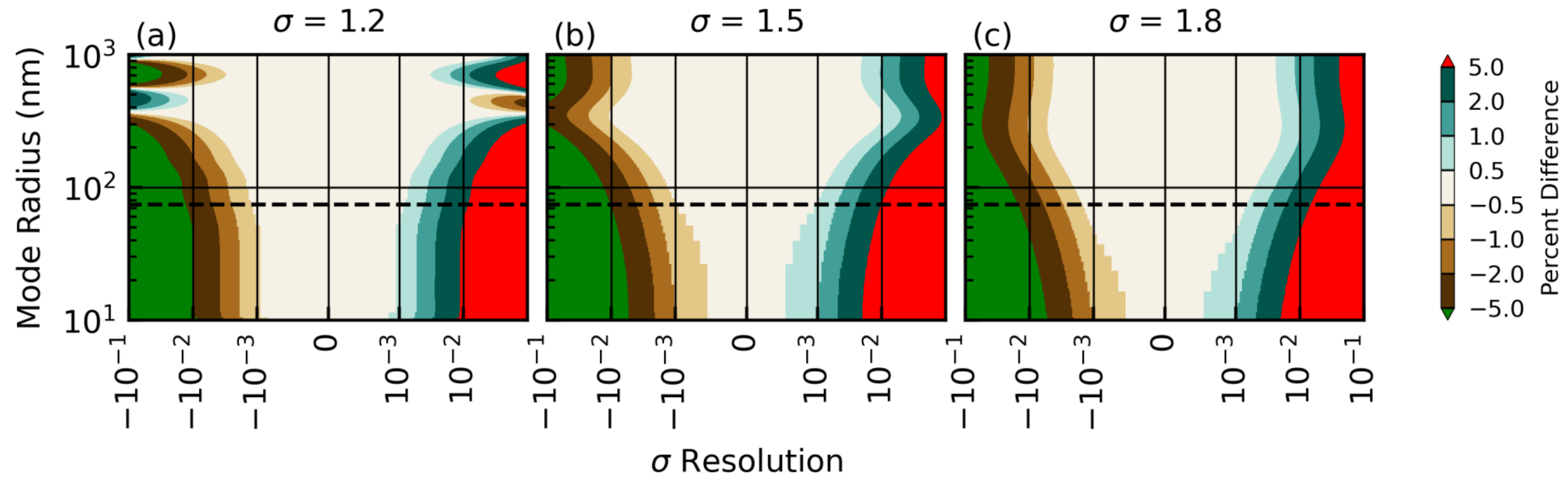
Influence of Second Mode on Extinction



Justification of LUT PSD Radius Range



Justification of LUT PSD sigma Resolution



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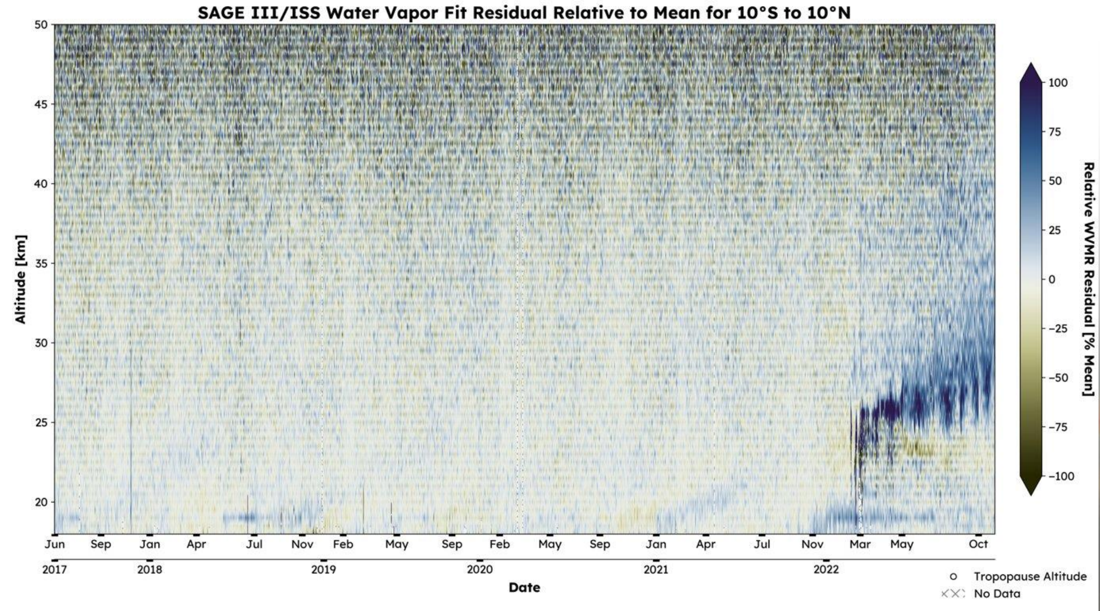
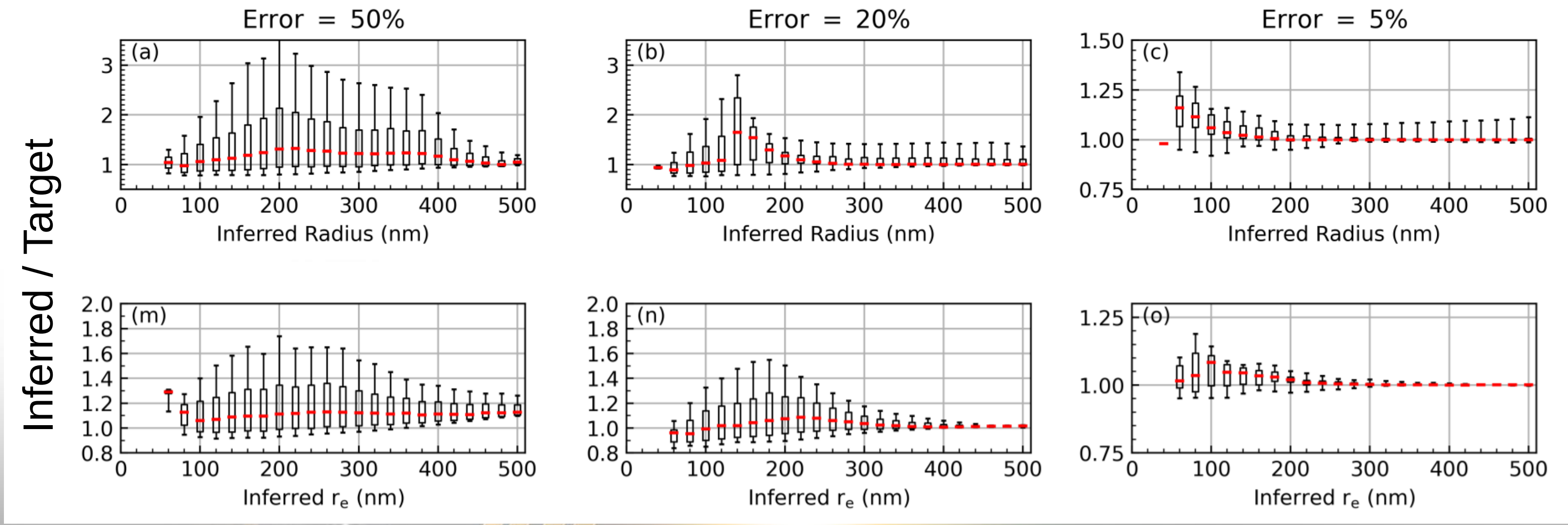


Sensitivity Study Continued
Influence of Error



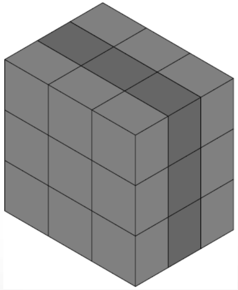
Sensitivity Study Continued
Influence of Error

PSD estimates are LARGER than target values

- higher moments have better agreement

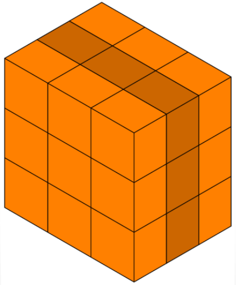
Sensitivity Study: Incorrect Composition

Imaginary atmosphere
NOT 75% H_2SO_4



$k(r, \lambda, \sigma)$ + err

Find matches in 75%
H_2SO_4 LUT



Stats (S_1)

Sensitivity Study: Incorrect Composition

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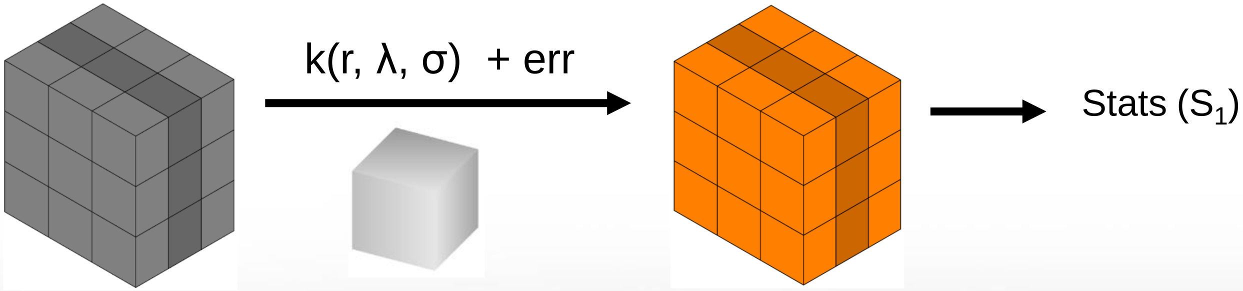
Find matches in 75%
H_2SO_4 LUT



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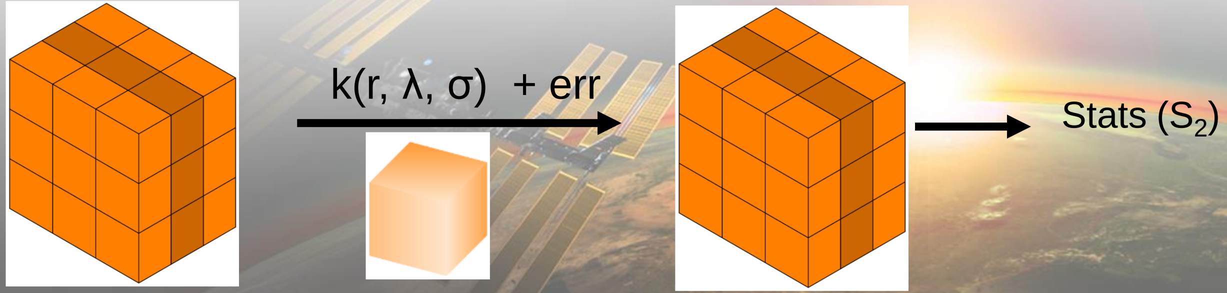

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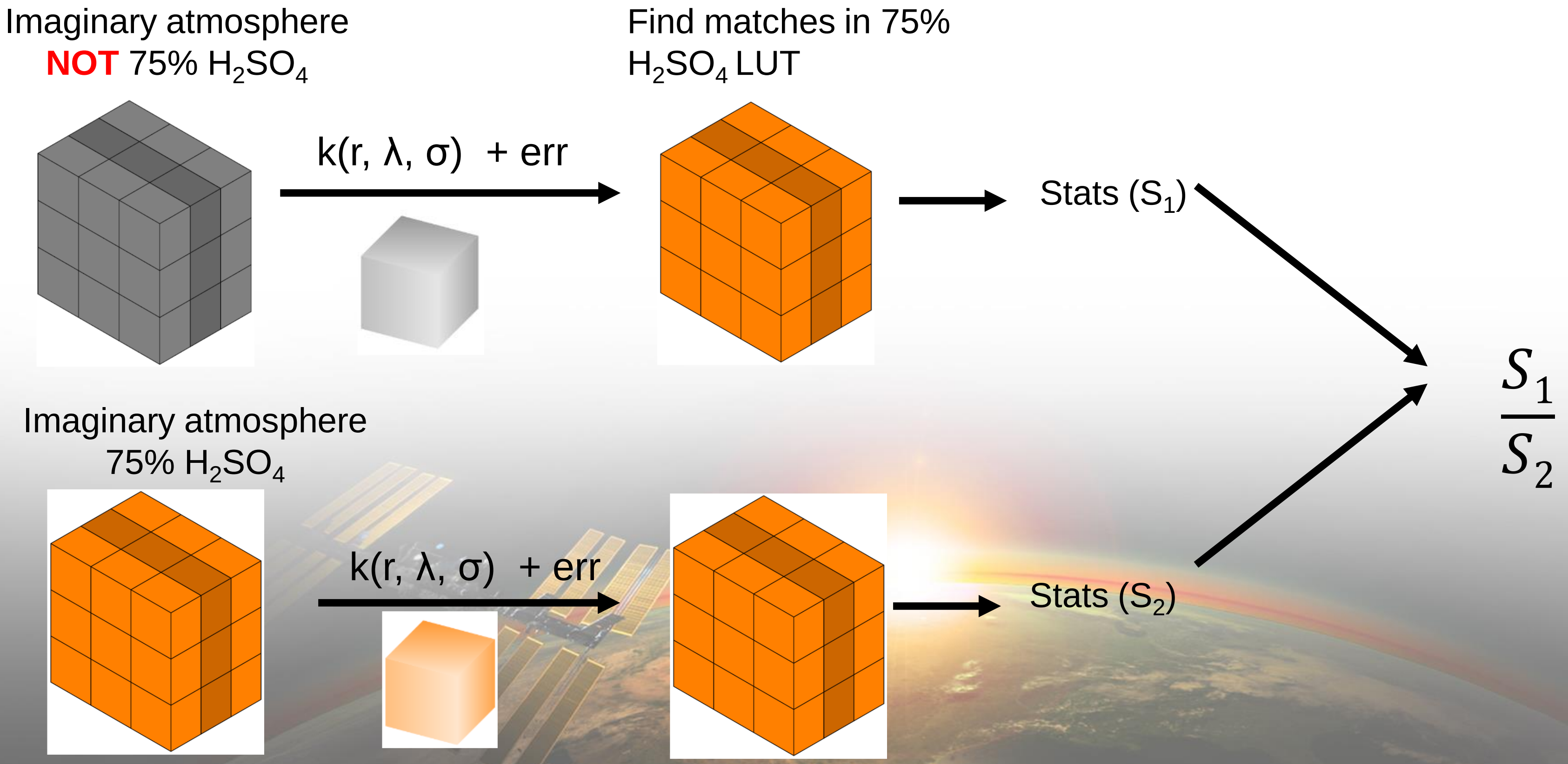
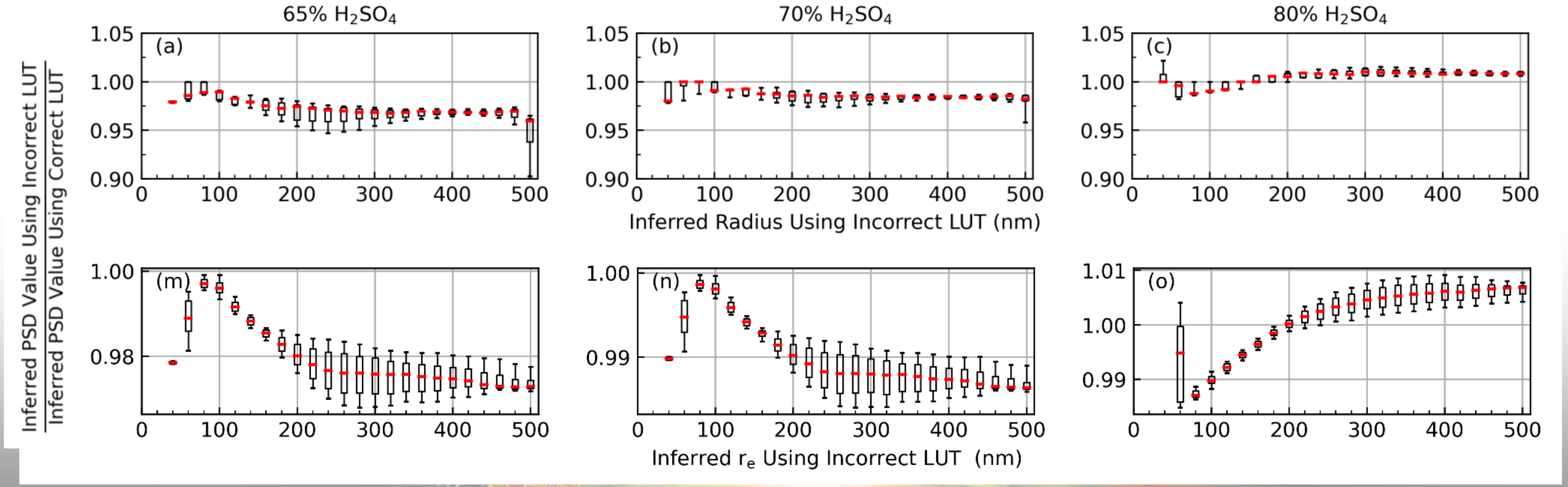


Sensitivity Study Continued
Wrong H_2SO_4 Composition

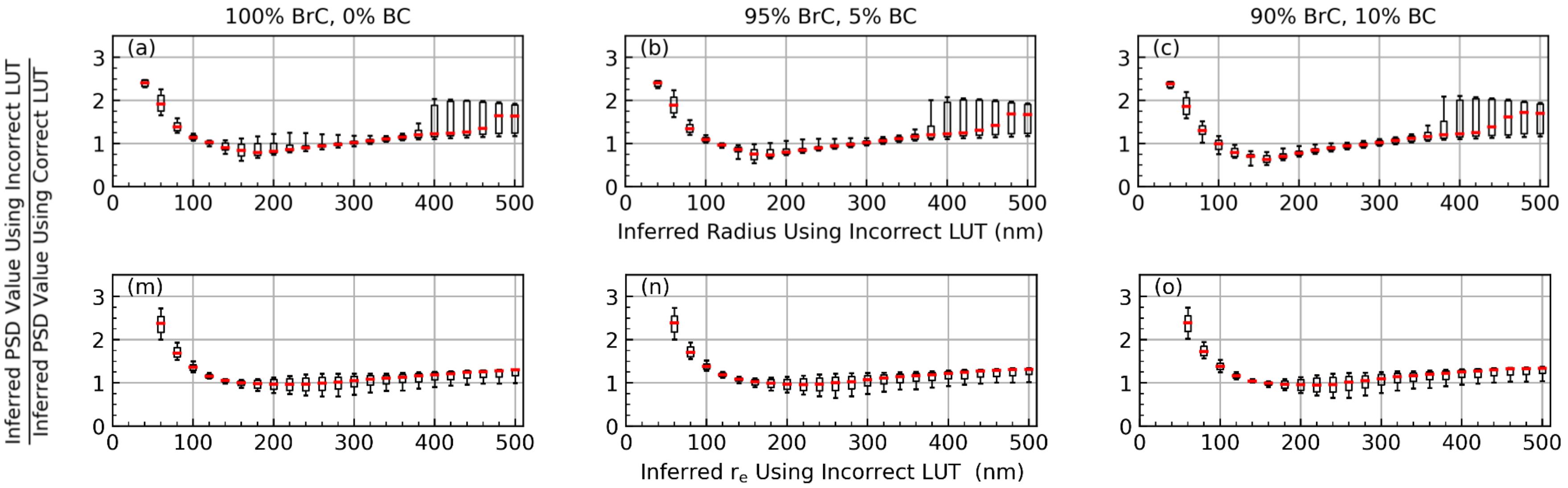


Sensitivity Study Continued
Wrong H_2SO_4 Composition

Almost no difference compared to getting composition correct

- PSD estimates are SMALLER than target values
- higher moments have better agreement

Sensitivity Study Continued
Wrong Composition: With smoke



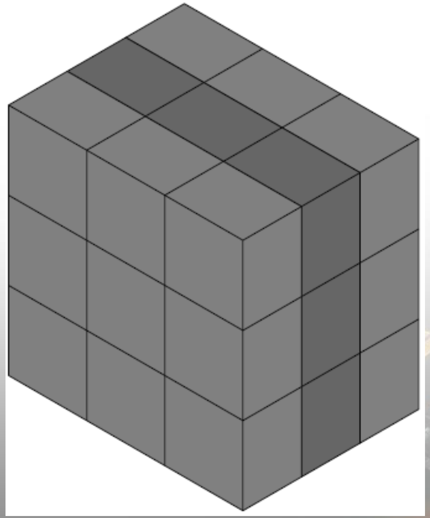
Sensitivity Study (Abridged Edition)

- How accurately can we reproduce “known” values?
  - How does this change as a function of measurement uncertainty?

- Evaluate under 2 scenarios:
  - We get the composition correct
  - We get the composition wrong

Sensitivity Study (Abridged Edition)

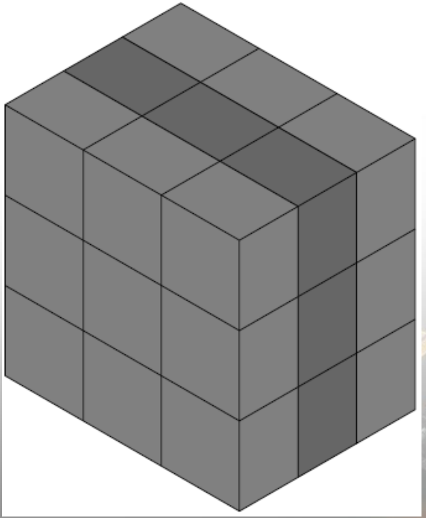
Imaginary atmosphere
Variable Composition



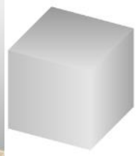
Sensitivity Study (Abridged Edition)

Imaginary atmosphere
Variable Composition

Pull out single
extinction ratio of
known r, λ, σ



k(r, λ, σ) + err



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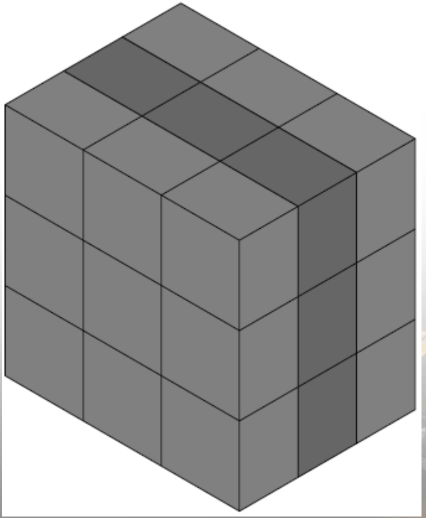
Pull out single extinction ratio of known r, λ, σ

Find matches in 75% H_2SO_4 LUT



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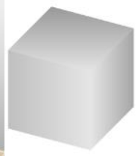
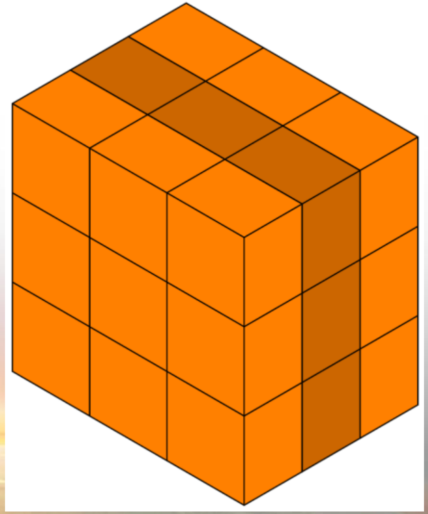




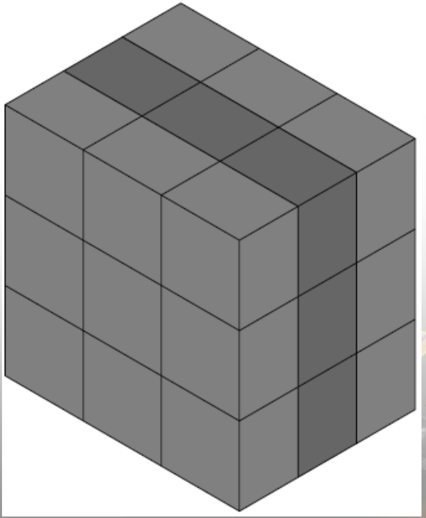
Sensitivity Study (Abridged Edition)

Imaginary atmosphere
Variable Composition

Pull out single extinction ratio of known r, λ, σ

Find matches in 75% H_2SO_4 LUT

Calculate statistics for inferred values



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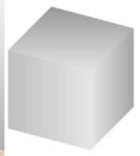

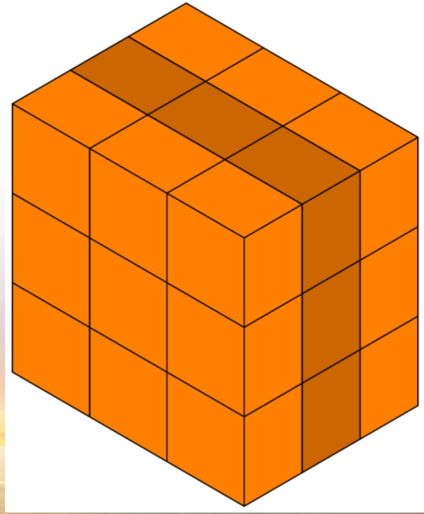

mean
median
Q1, Q3,
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Sensitivity Study: Summary

- Correct composition:
    - overestimated PSD parameters by ~20%

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  - When smoke particles are small: ~300% worse than correct composition

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Higher moment parameters are less impacted in each scenario