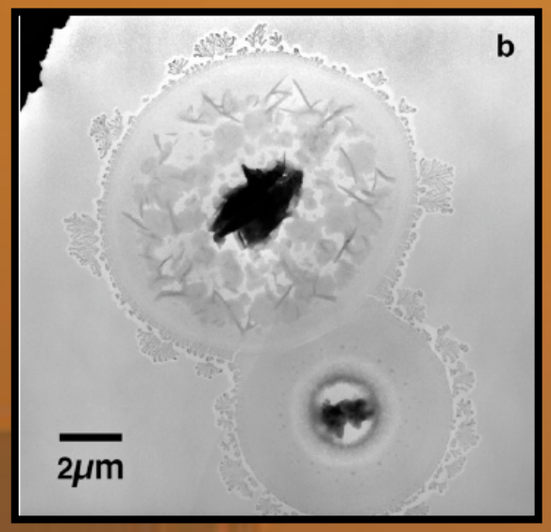
Remote Sensing of Aerosol Water Uptake

Greg Schuster, NASA Langley Research Center



Kojima et al., Atmos. Res. (2006)

Water Uptake

- Ubiquitous
- Can be responsible for 50% of aerosol forcing
- Model calculations of aerosol growth are largely unchecked because of the lack of routinely available data.

Los Angeles, 2006. Photo courtesy of http://npr.org.

3-Component Aerosol Retrieval

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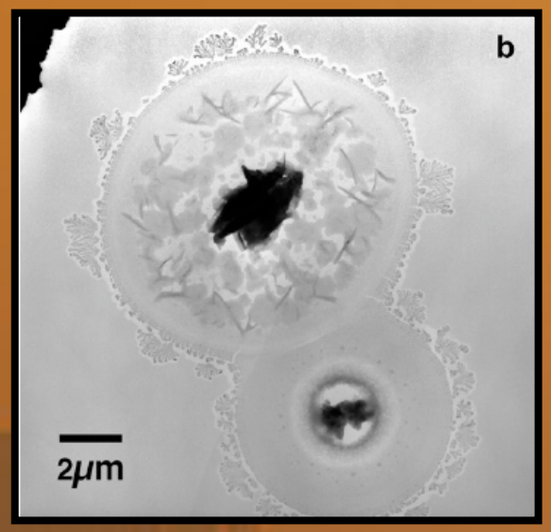

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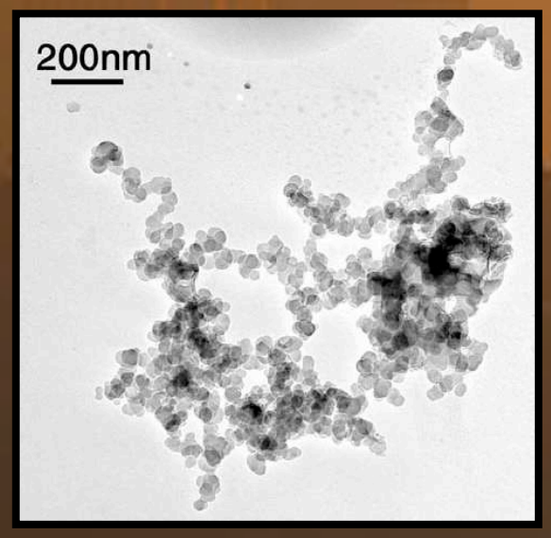

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Black Carbon

- Ubiquitous
- Dominant absorbing aerosol pollutant.
- Modeled missions inventories highly uncertain
- Large source of uncertainty in modeled aerosol forcing

Dry Aerosol

- Need to separate aerosol water from dry aerosol mass

Los Angeles, 2006. Photo courtesy of http://npr.org.

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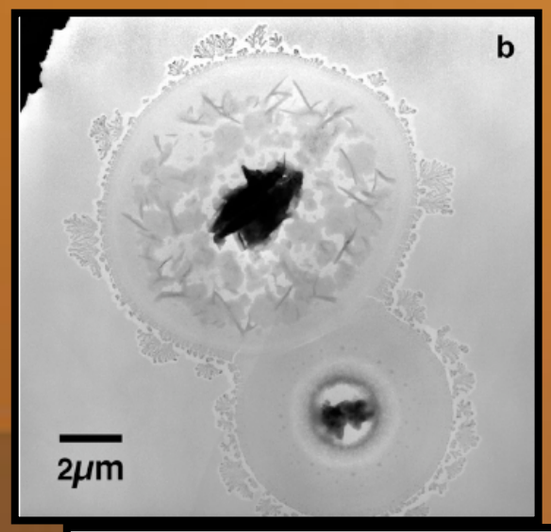
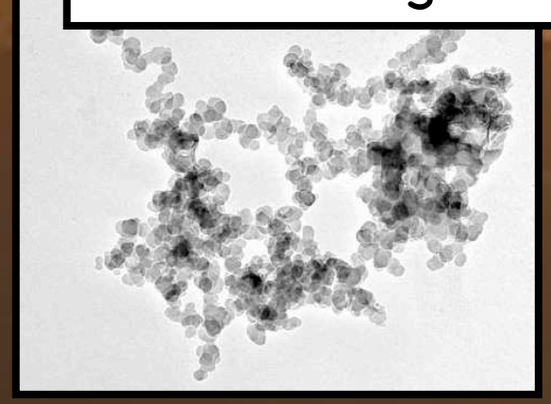


Water Uptake

- Ubiquitous
- Can be responsible for 50% of aerosol forcing
- Model calculations of aerosol growth are largely unchecked because of the lack of routinely available data.

- Results have been applied to the AERONET database of surface instruments.
- Technique is readily adaptable to other instruments that are capable of retrieving refractive index.



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Los Angeles, 2006. Photo courtesy of http://npr.org.

The AERONET Retrieval

AERONET sky scans

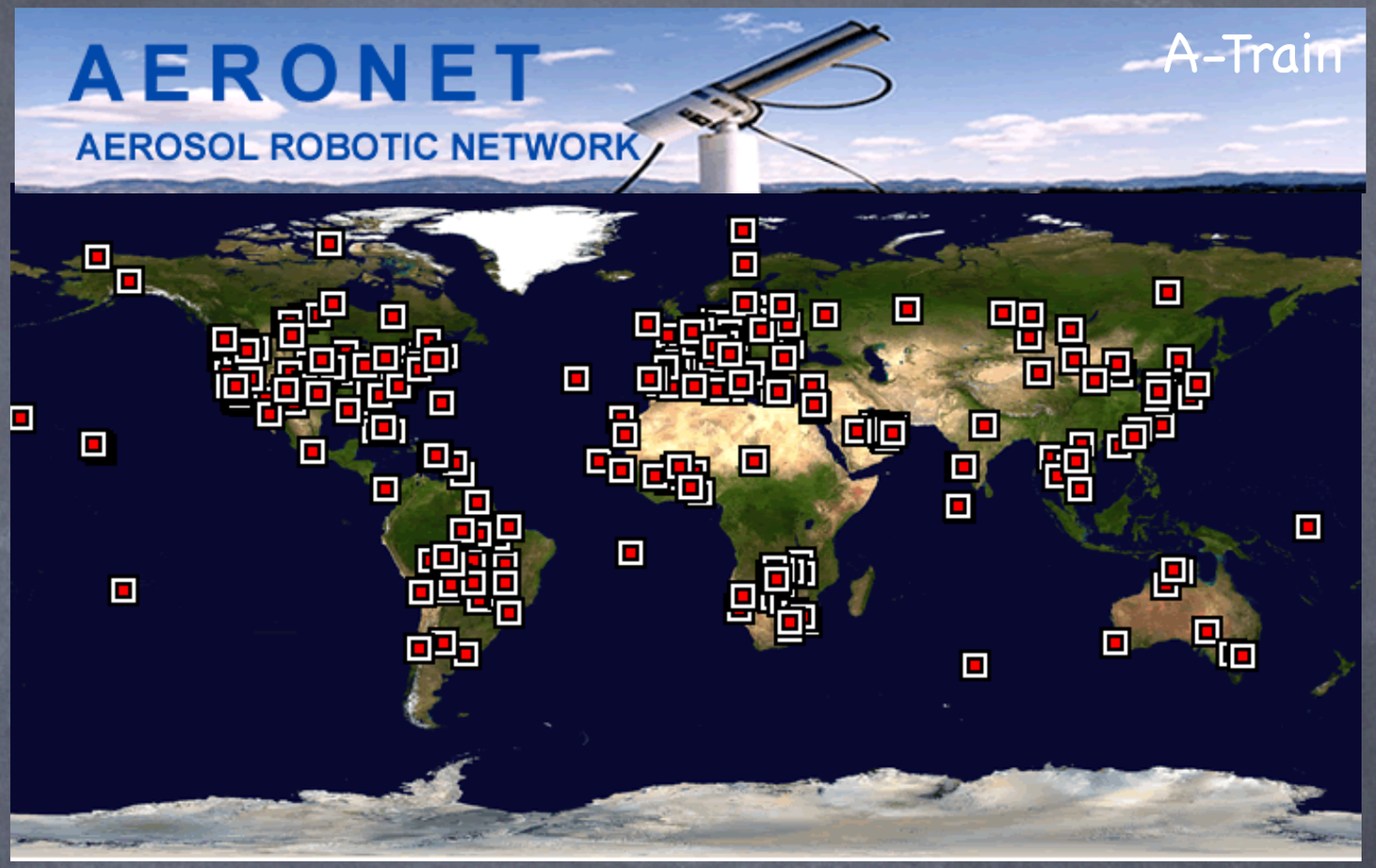
Dubovik Retrieval
+ 100% Internal Mixture
+ Optics independent of size

Complex Refractive Index

Size Distribution

3CA Retrieval

Volume fraction of BC, water, and "dry" aerosol



1. Dry Aerosol Size Distribution
2. Hygroscopic Growth Factor
3. Aerosol Liquid Water Path
4. BC concentration
5. Black Carbon Specific Absorption
6. Dry Aerosol Optical Depth
7. Dry Single Scatter Albedo

Satellite
The ~~AERONET~~ Retrieval

Glory APS measurements

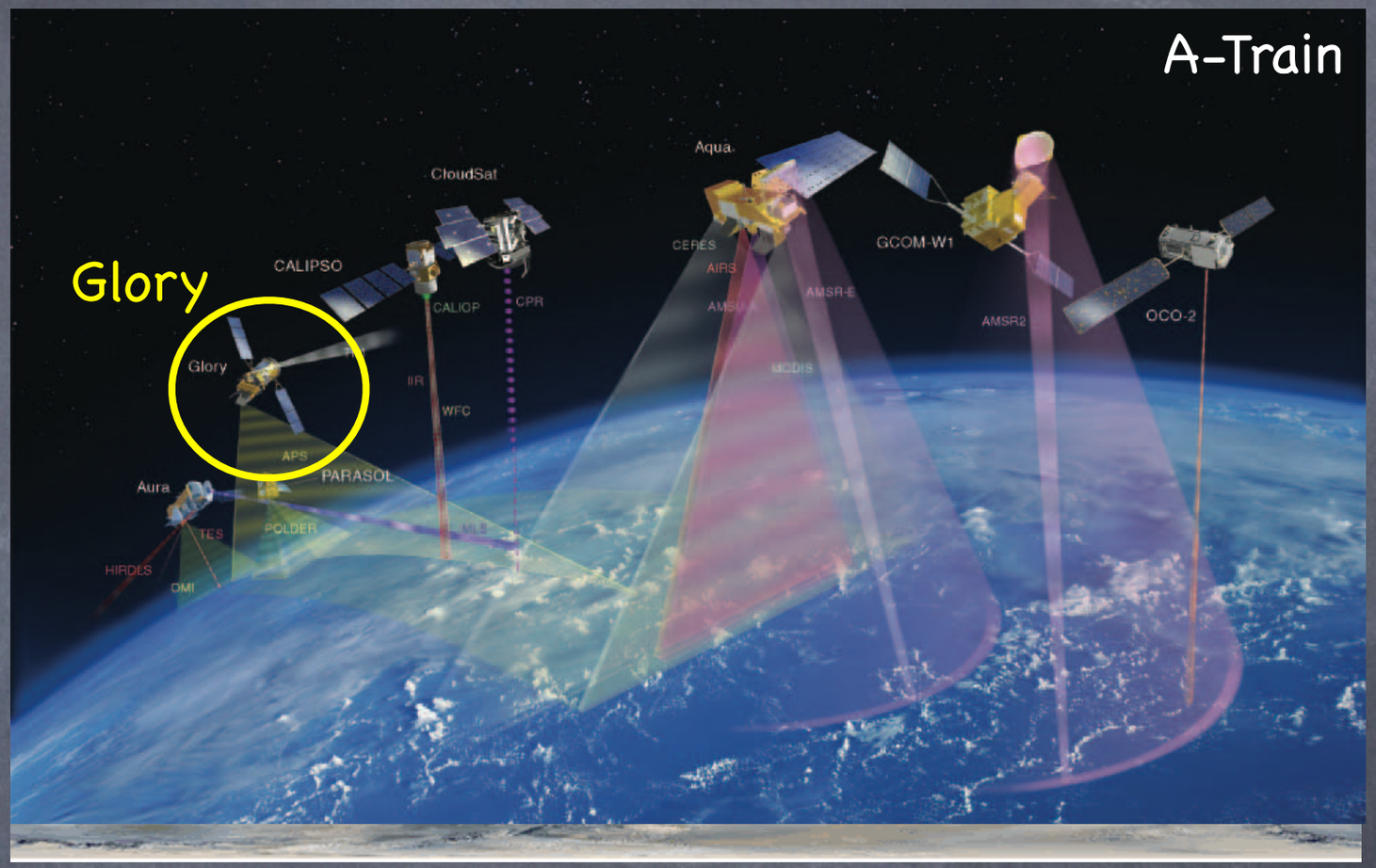
↓

APS Retrieval
+ Bimodal size distribution

↓

Complex Refractive Index

Size Distribution



↓

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} for each mode

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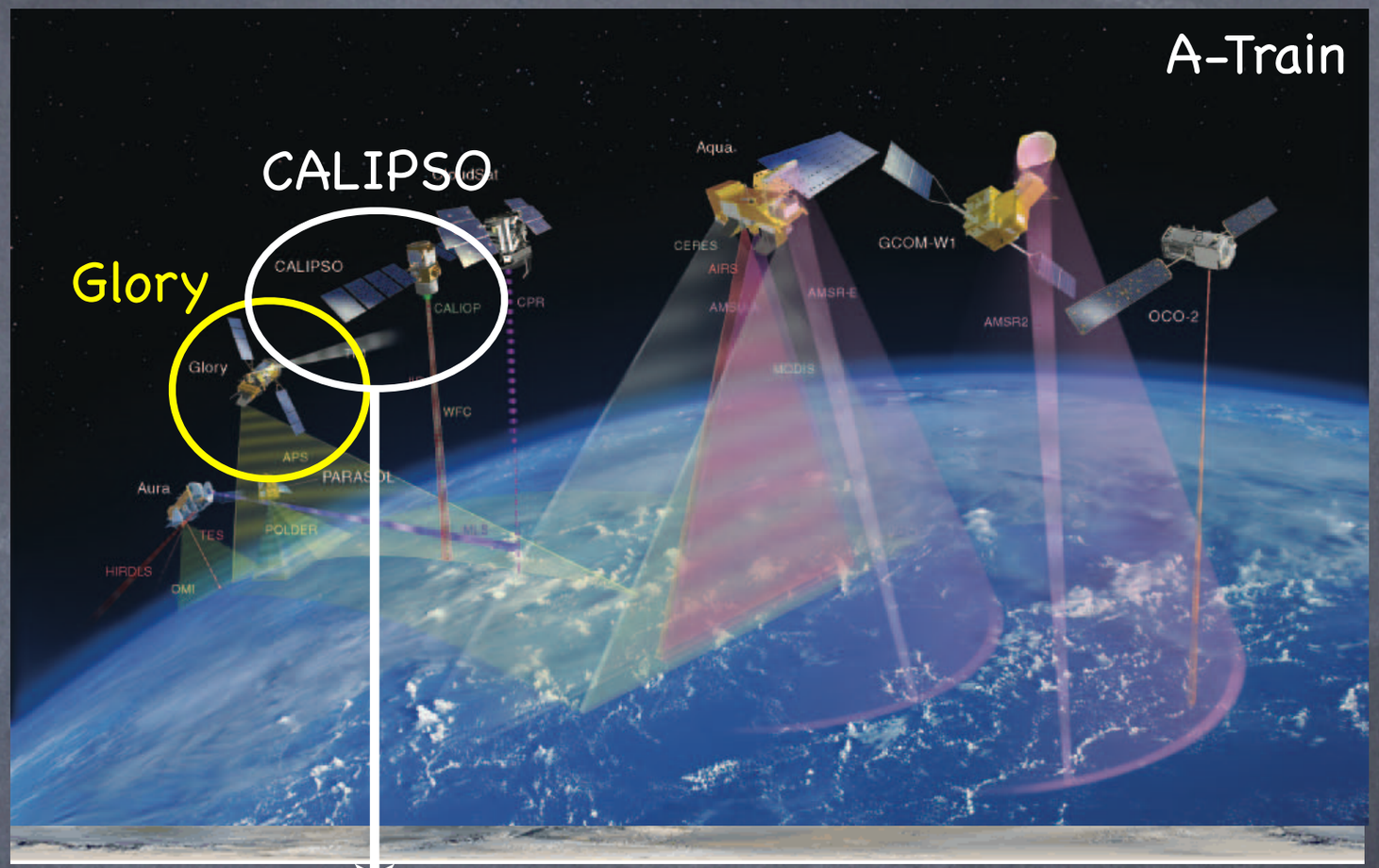

+ Vertical Distribution of Aerosols
+ RH(Z)

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Volume fraction of BC, water, and "dry" aerosol

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In each layer and for each mode

Satellite
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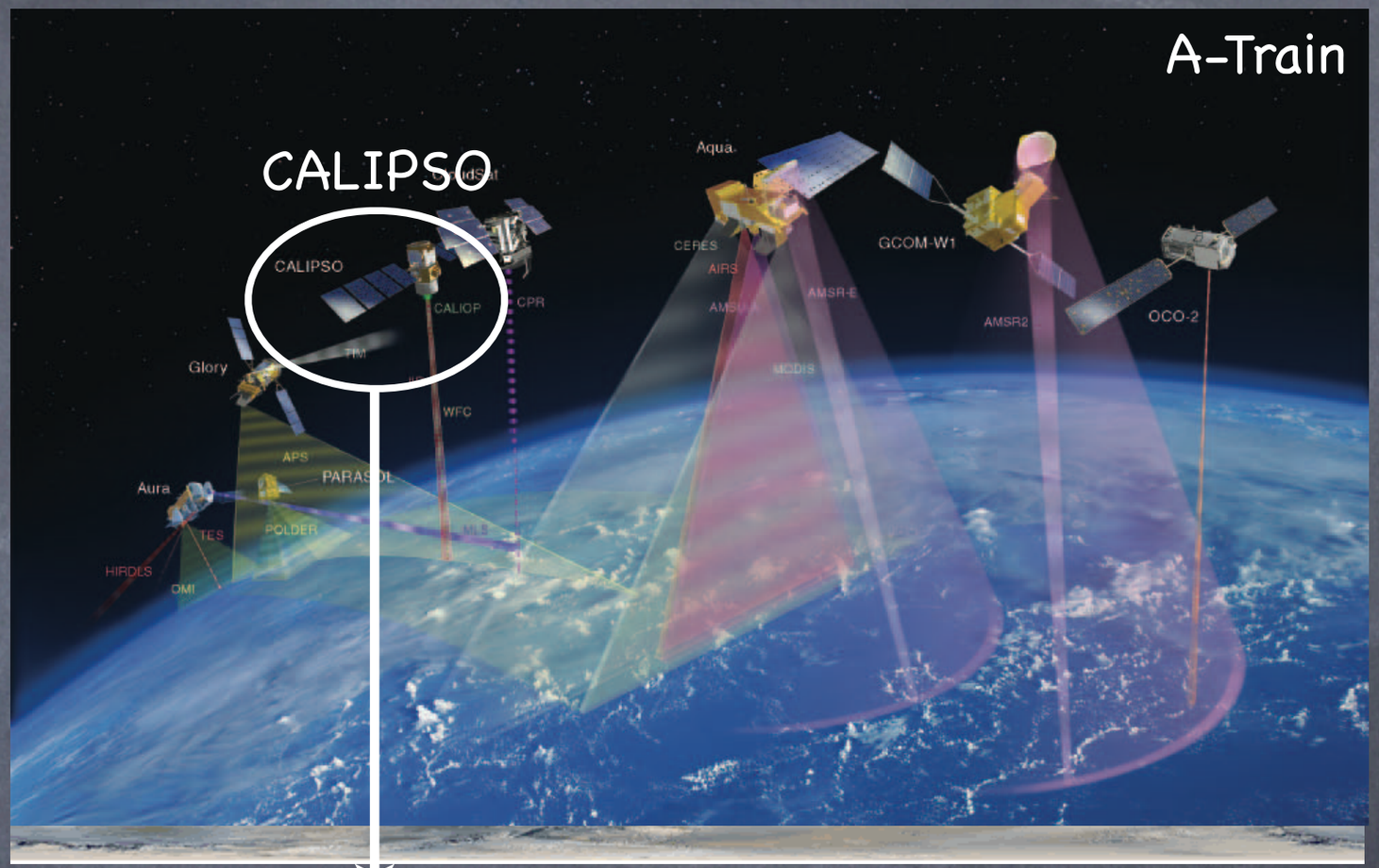

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In each layer and for each mode

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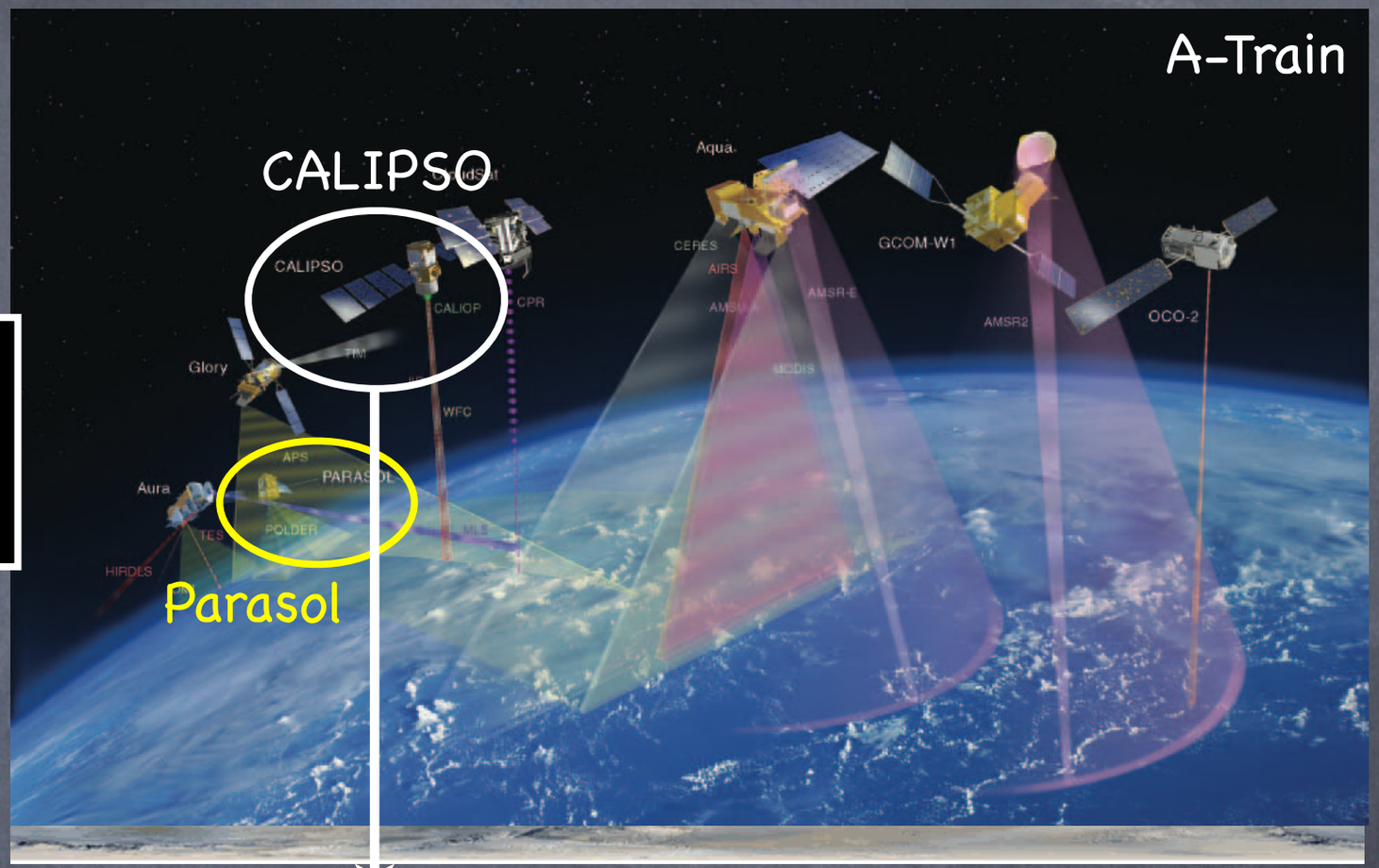
The ~~AERONET~~ Retrieval

POLDER radiances (ugh)

Dubovik's Research Code
+ Bimodal distribution possible

Complex Refractive Index

Size Distribution



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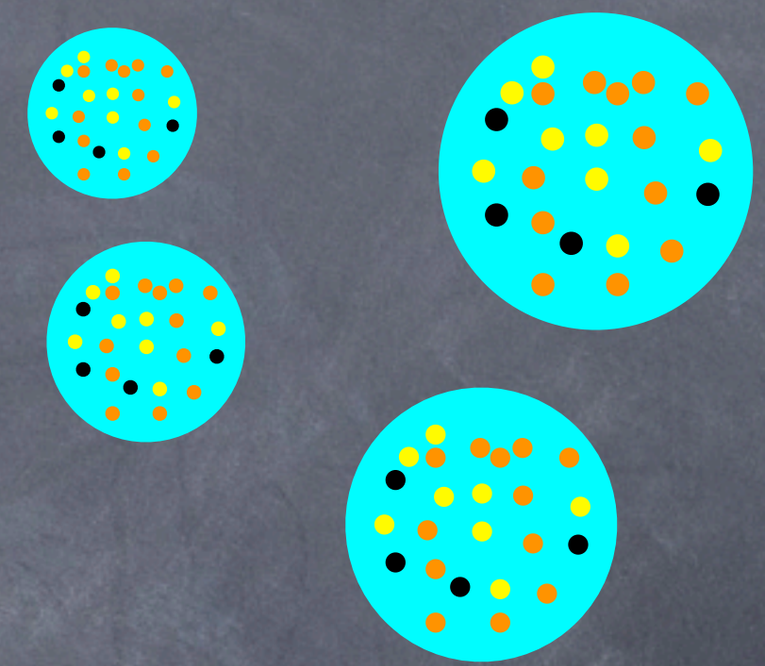
In each layer and for each mode

3-Component Aerosol Retrieval Scheme

- Assume an internal mixture of four aerosol species
  1. Black carbon
  2. Water
  3. Dry Aerosols
     a) Ammonium Nitrate (surrogate for solubles)
     b) Dust (insoluble component)
- Iterate black carbon concentration until imaginary refractive index of the mixture "matches" retrieved values at 670, 870, and 1020 nm for AERONET.
- Iterate the soluble/insoluble concentration until the real refractive index "matches" the retrieved values (at all wavelengths).
- Use an empirical constraint for soluble fraction:



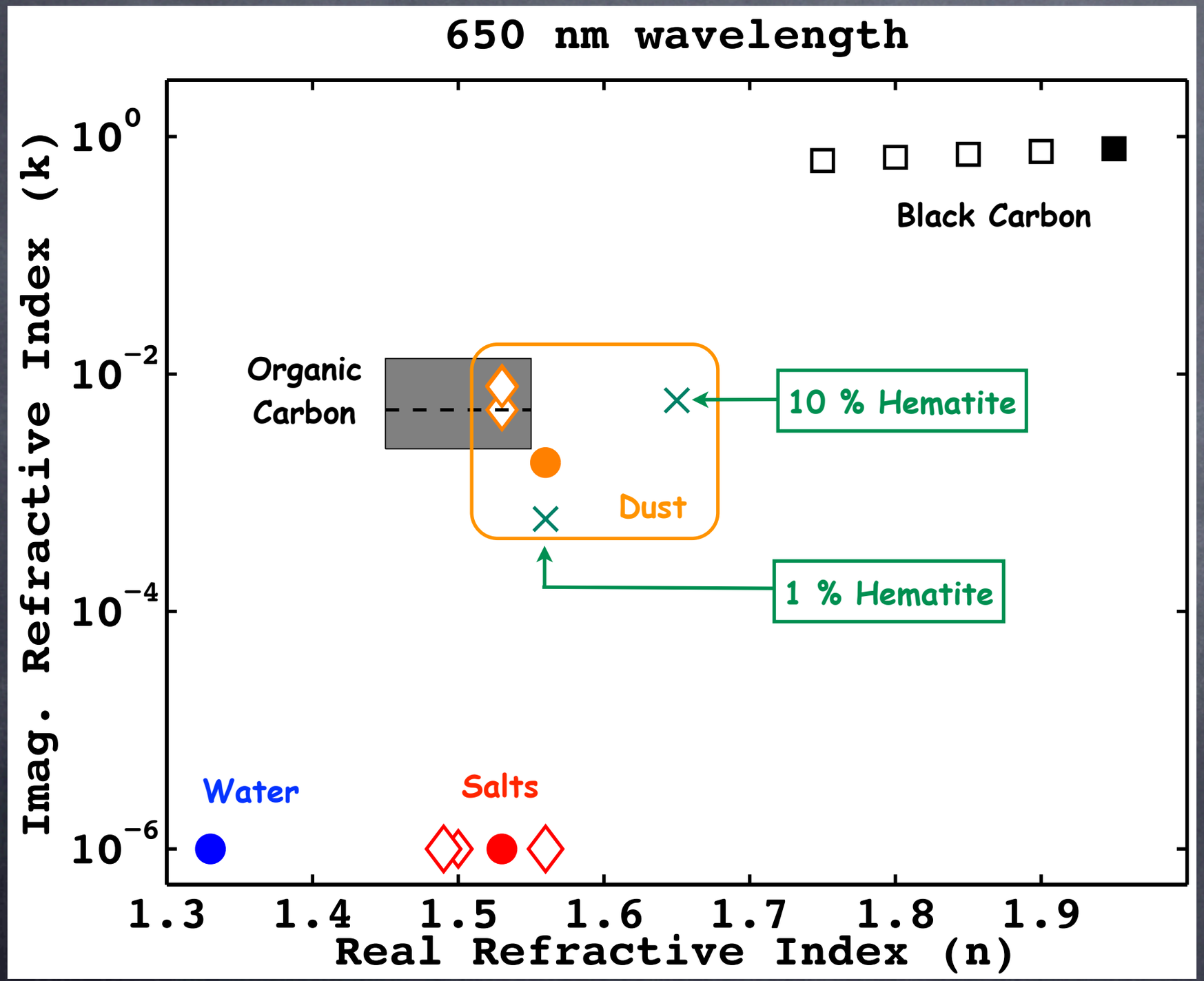
Maxwell-Garnett effective medium approx and Lacis code

$$\frac{inslbl}{slbl} \propto \left(\frac{inslbl}{slbl}\right)_{clmt} (m_r - 1.33)^3$$

Schuster et al, GRL (2009)

Sensitivity studies (Schuster et al, JGR, 2005; Schuster et al, GRL, 2009):
- Black carbon: +/- 50%
- Water: +/- 0.3

The solution is unique because black carbon and water have refractive indices that are significantly different than other common atmospheric aerosols



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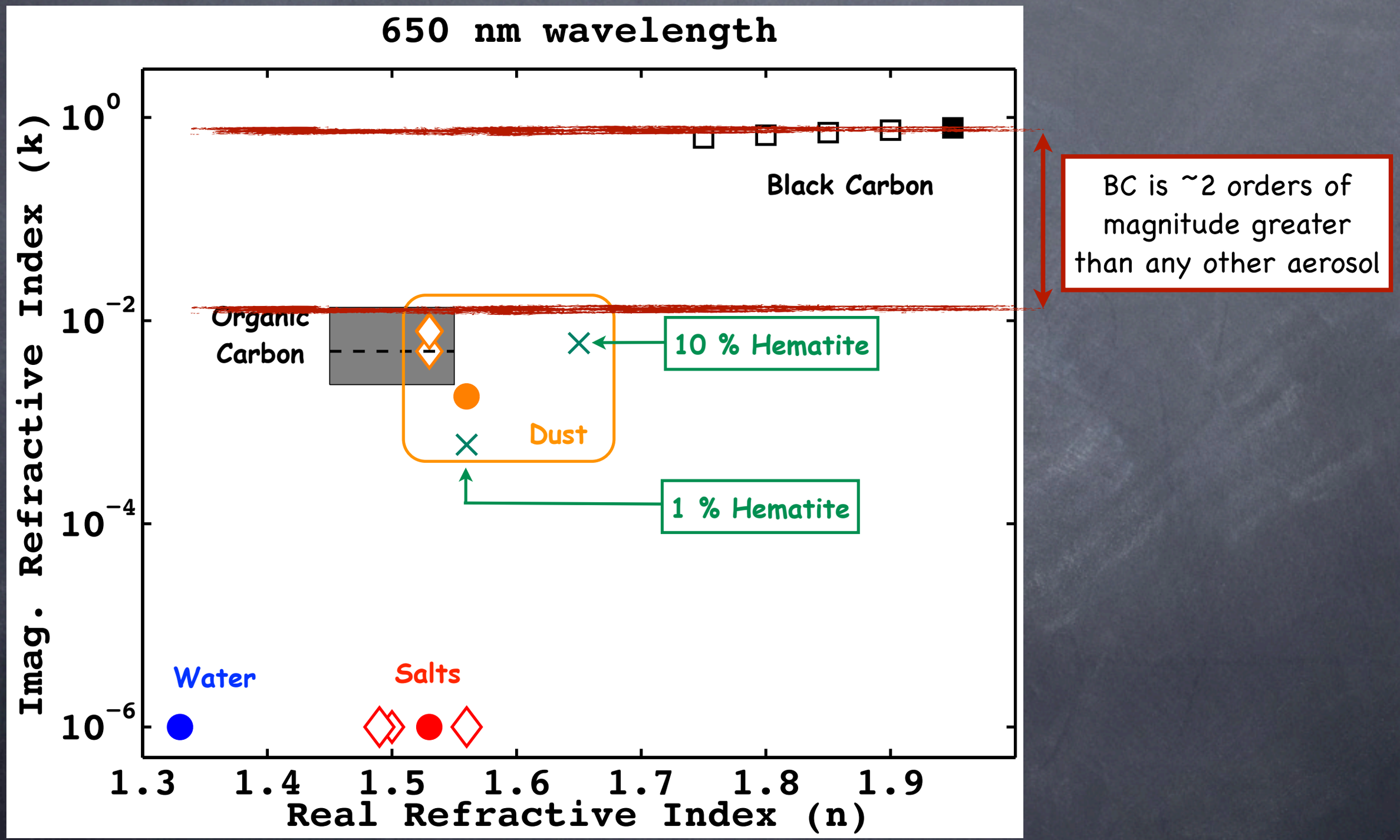

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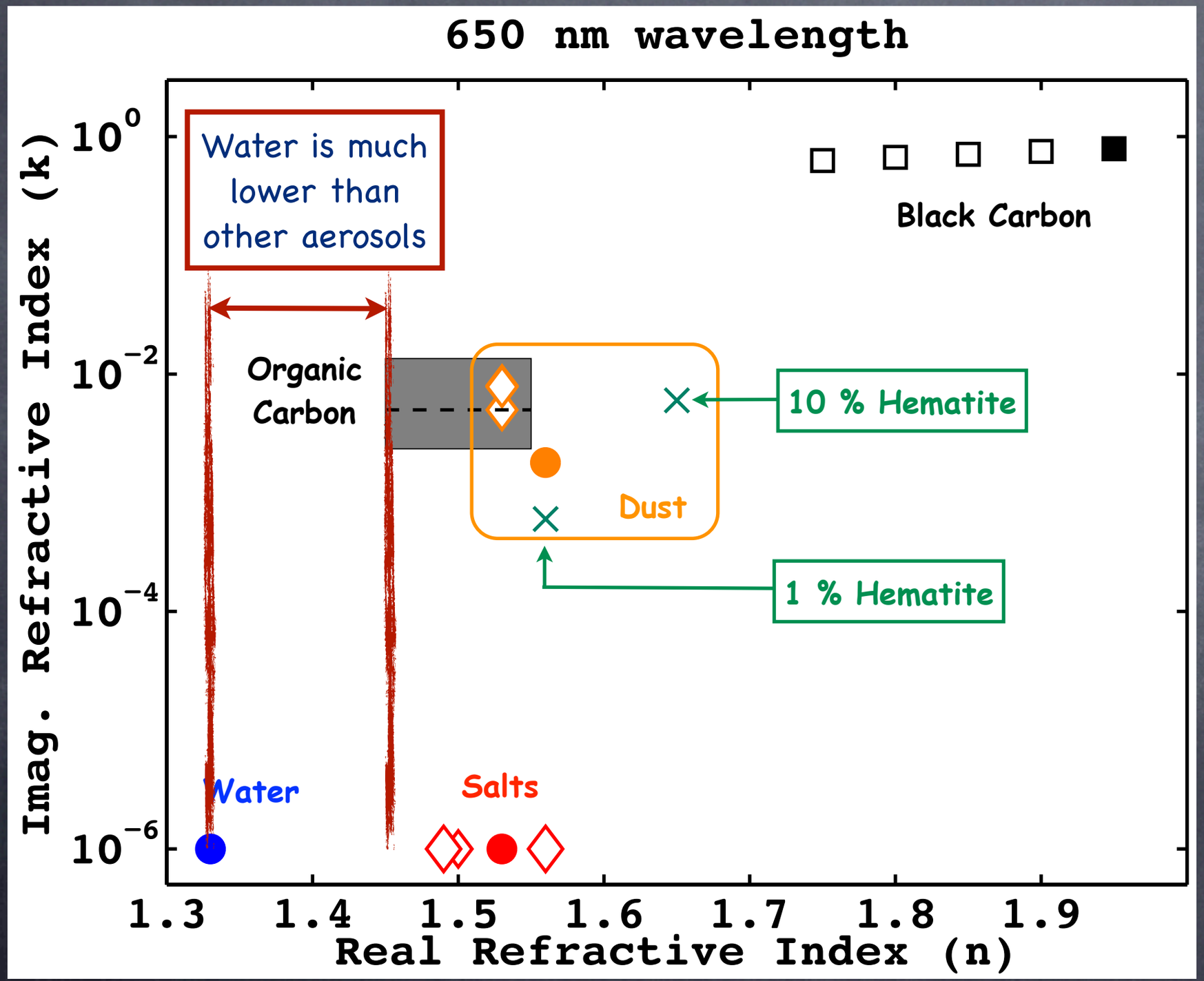
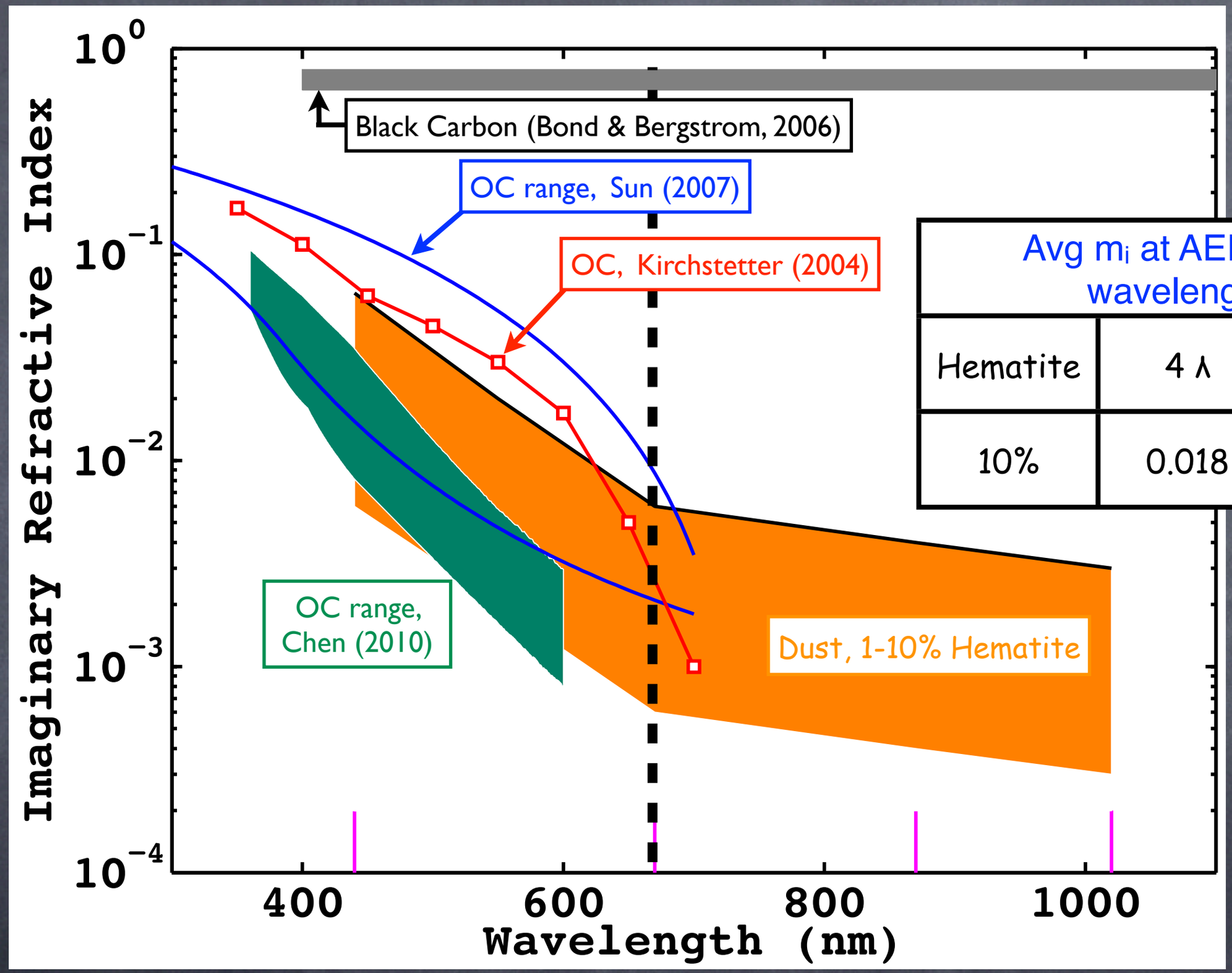


Black Carbon is much more absorbing than anything else



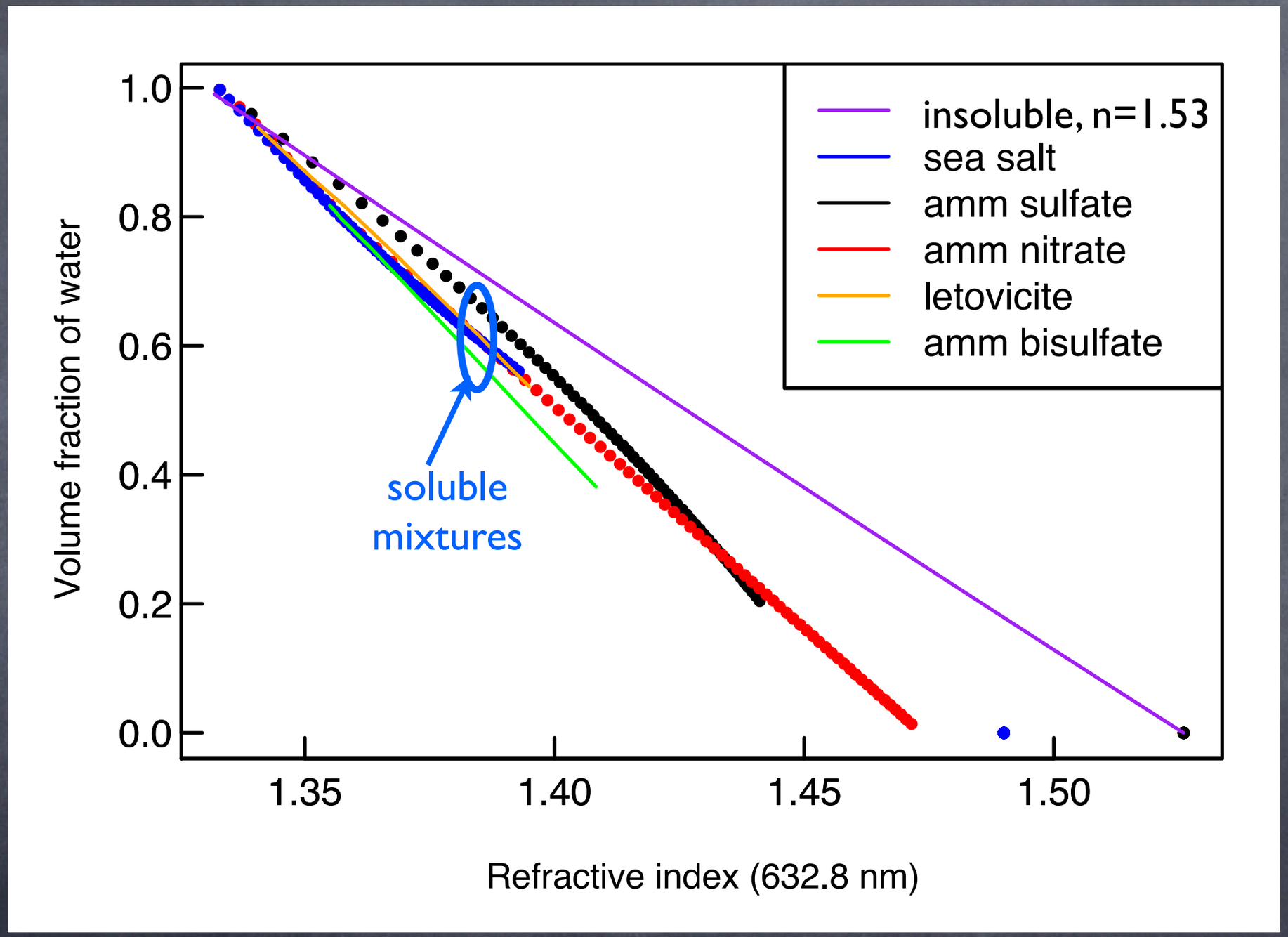
Avg m_i at AERONET wavelengths		
Hematite	4 λ	3 λ
10%	0.018	0.0045

See

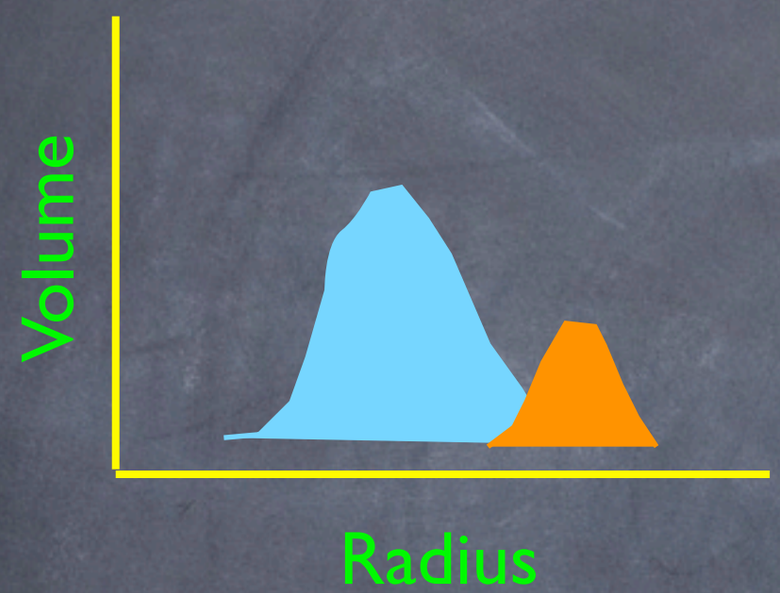
Arola, A., G. Schuster, G. Myhre, S. Kazadzis, S. Dey, and S. N. Tripathi (2011), Inferring absorbing organic carbon content from AERONET data, Atmospheric Chemistry and Physics, 11(1), 215–225.

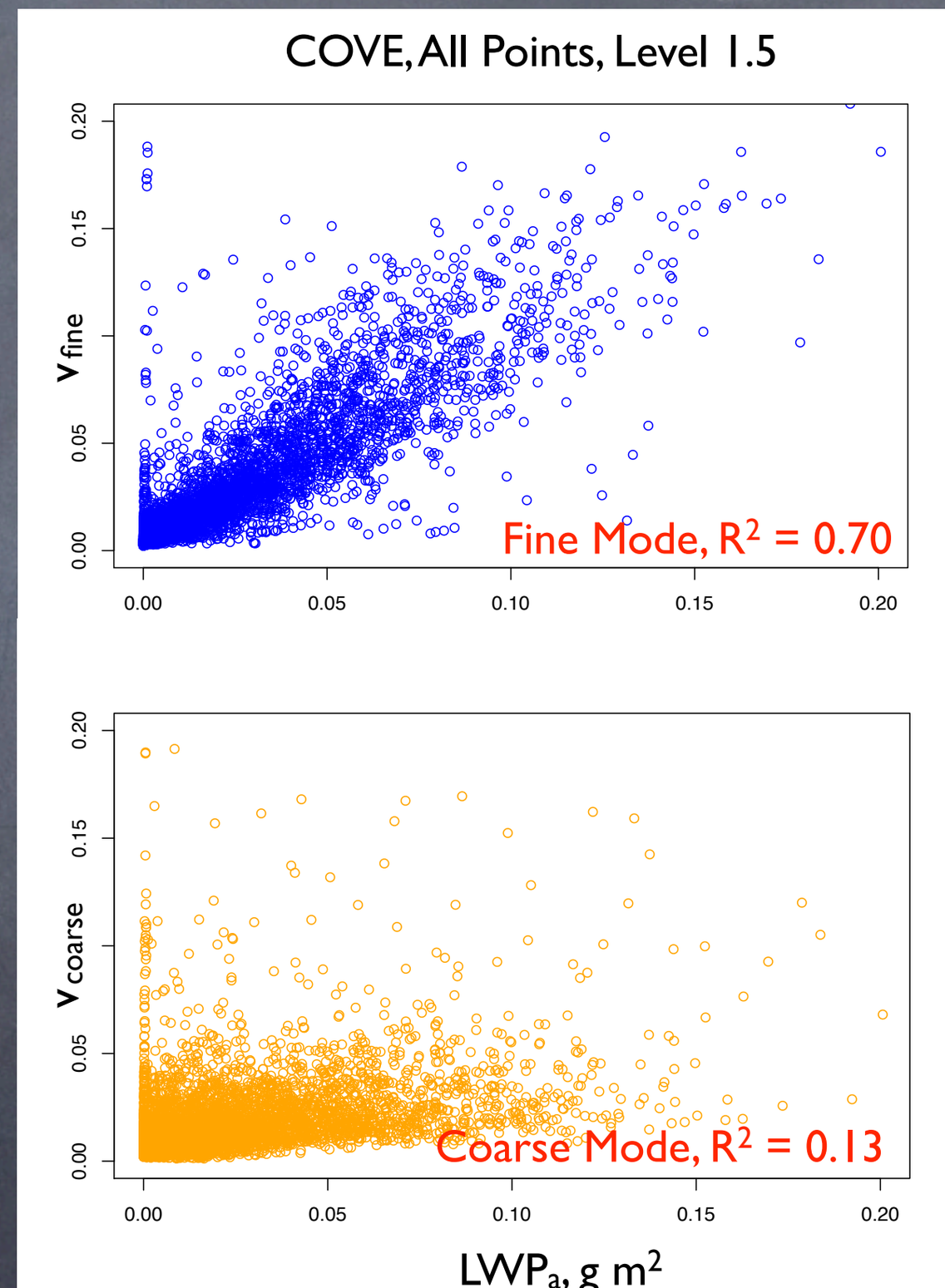
Koven and Fung (2006), Inferring dust composition from wavelength- dependent absorption in Aerosol Robotic Network AERONET data, J. Geophys. Res., 111, D14205, doi:10.1029/2005JD006678.

Soluble aerosol mixtures have similar water fractions for a given refractive index



Water uptake of fine and coarse modes





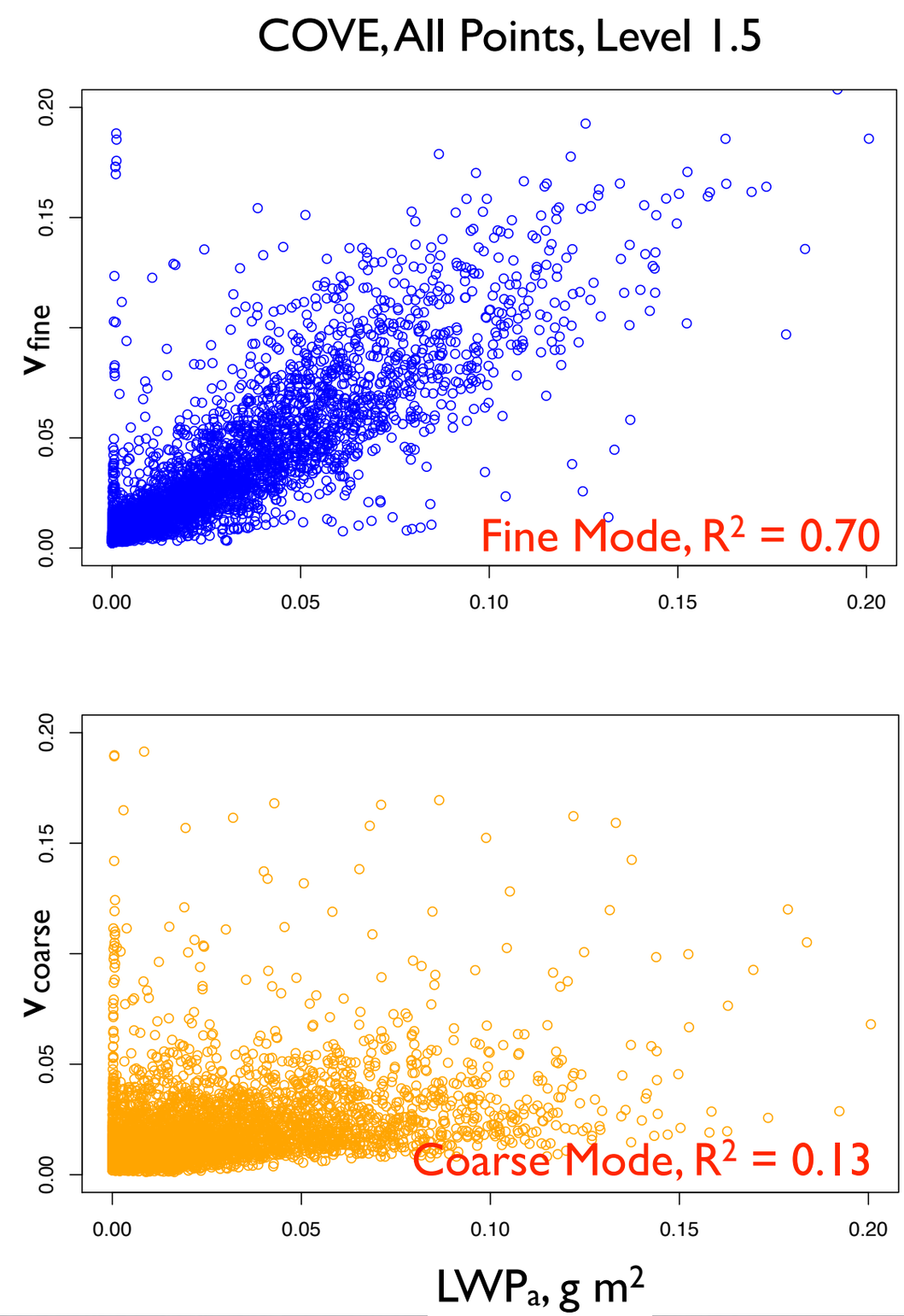
Water uptake of fine and coarse modes

Table 1. Coefficient of determination (R^2) of aerosol liquid water path with fine mode concentration and coarse mode concentration. The ratio of average fine volume fraction to total volume fraction is also shown. (AERONET all-points, level 1.5 dataset.)

	Location	Lon.	Lat.	R^2_{fine}	R^2_{crs}	$\overline{V_f}/\overline{V_T}$
D	Solar Village	46.4	24.9	0.323	0.046	0.10
D	Sede Boker	34.8	30.9	0.476	0.059	0.20
D	Cairo EMA	31.3	30.1	0.646	0.006	0.29
P,D	Boulder (BSRN)	-105.0	40.0	0.613	0.017	0.38
P,D	Beijing	116.4	40.0	0.458	0.001	0.40
B	Cuiaba-Miranda	-56.0	-15.7	0.489	0.030	0.54
P	Bondville	-88.4	40.0	0.721	0.068	0.55
B	Mongu	23.2	-15.3	0.311	0.154	0.60
P	COVE	-75.7	36.9	0.704	0.132	0.62
P	GSFC	-76.8	39.0	0.734	0.089	0.64

Schuster et al., GRL (2009)

R^2_{fine} is greater than R^2_{crs} at 96% of 351 AERONET sites (minimum of 100 retrievals each).



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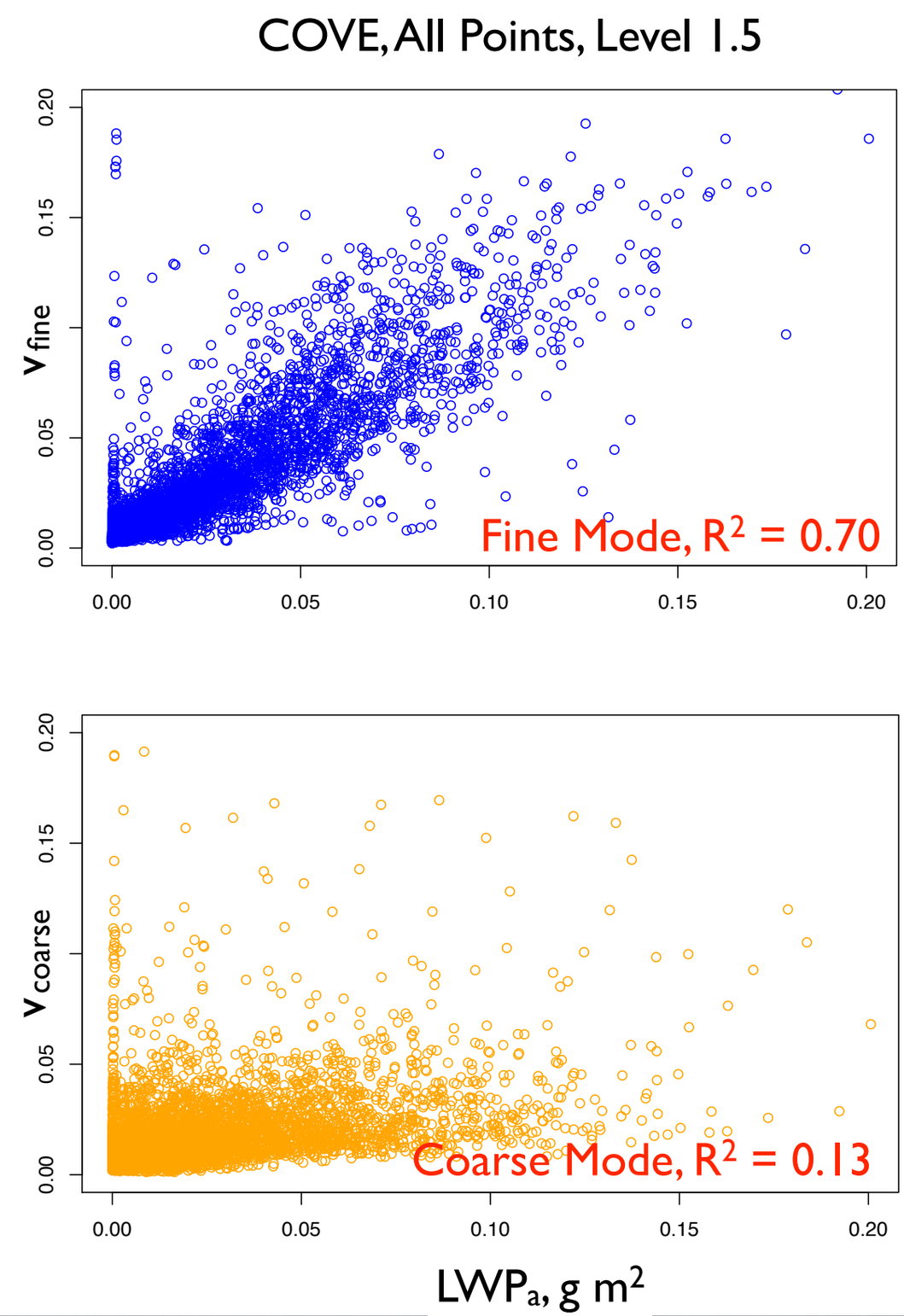
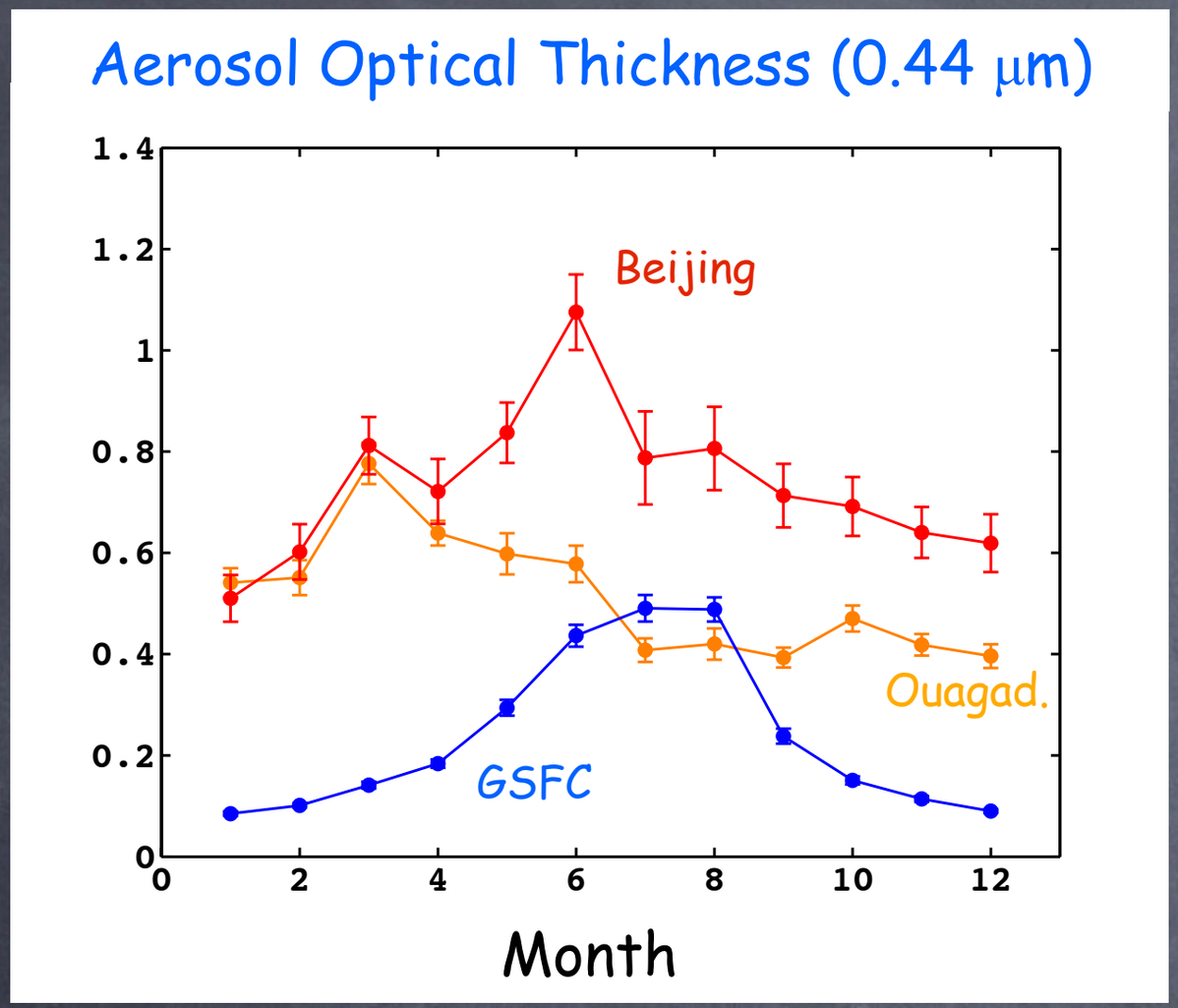
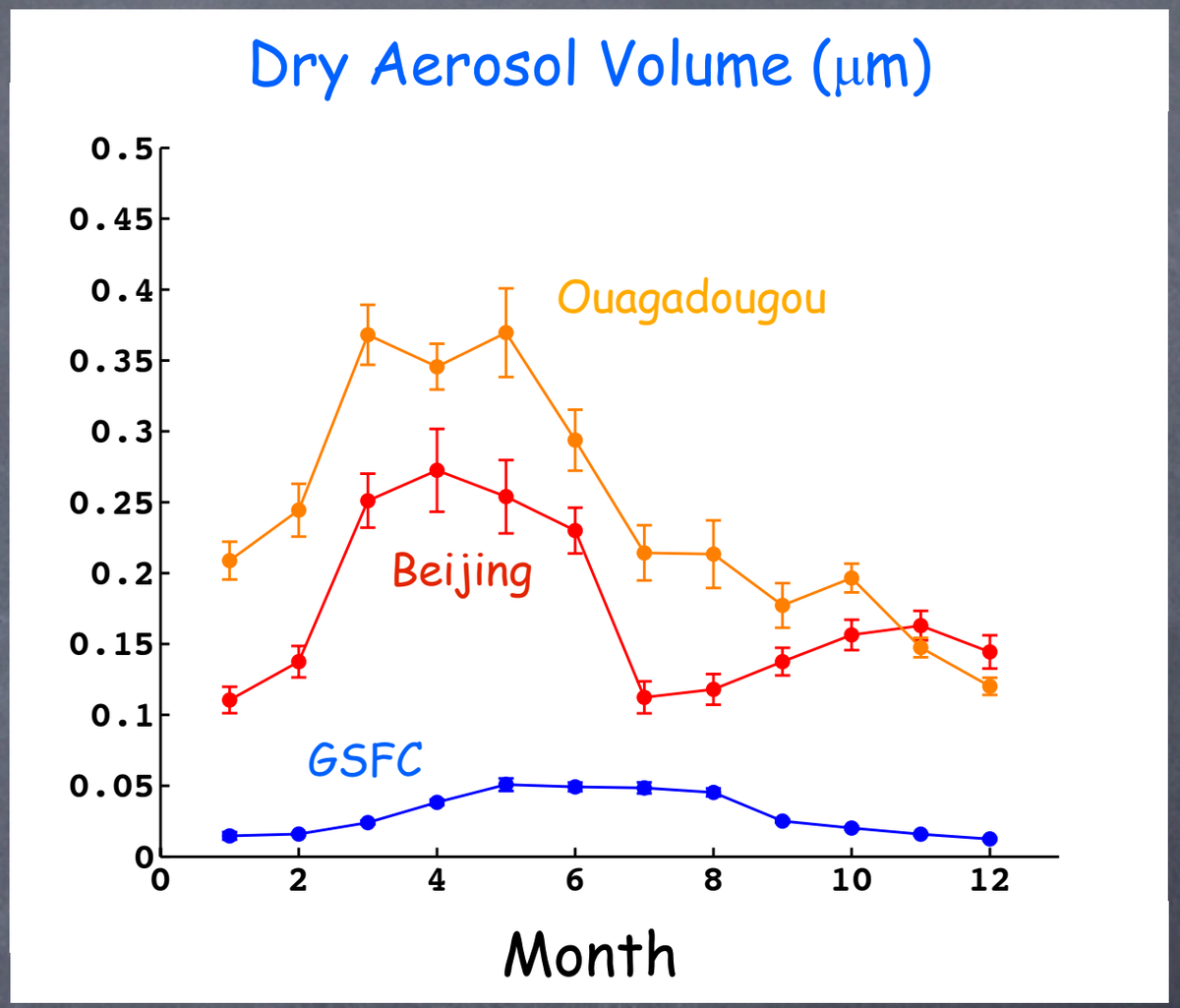


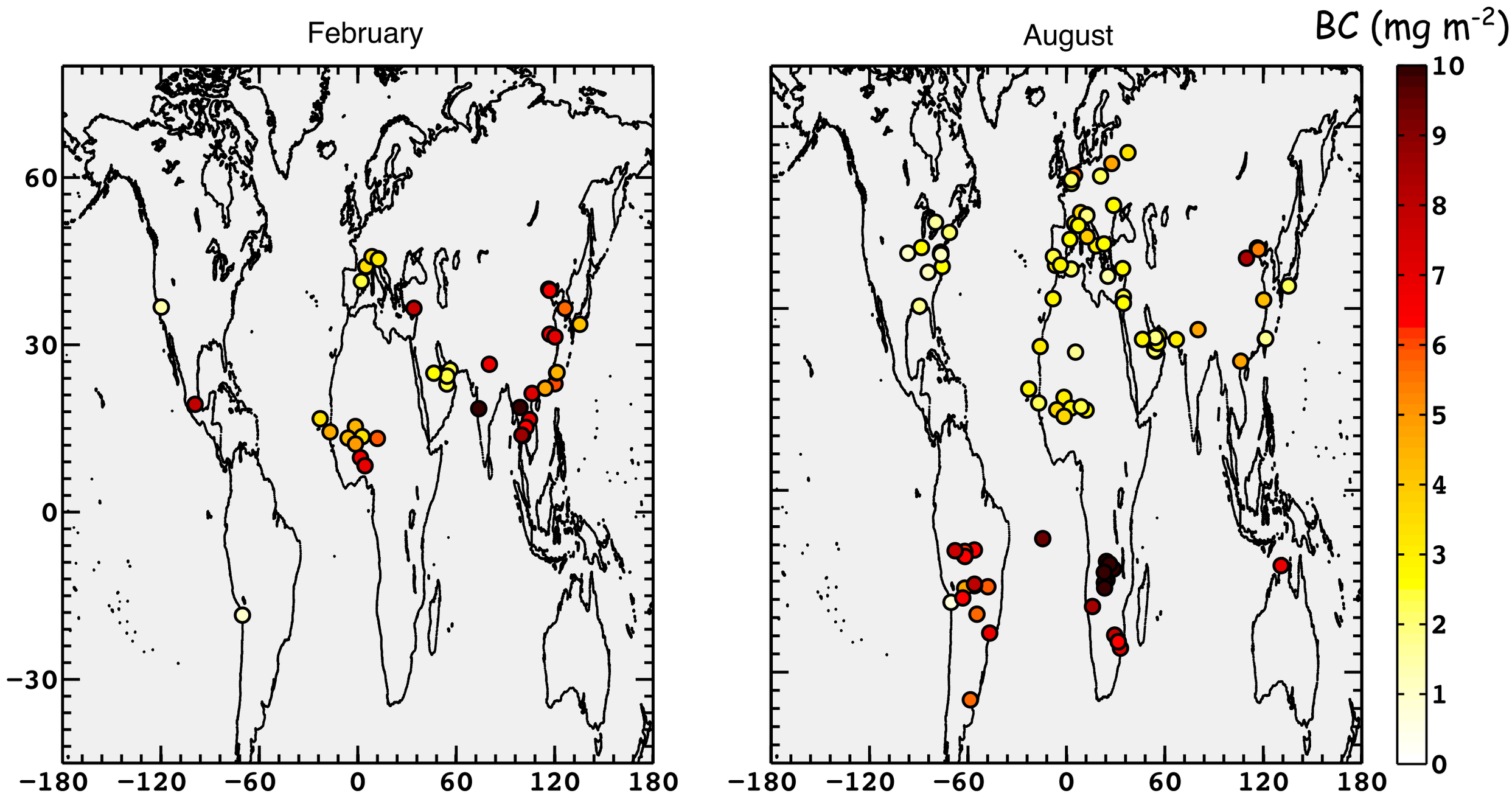
Aerosol Optical Thickness masks the dust signal





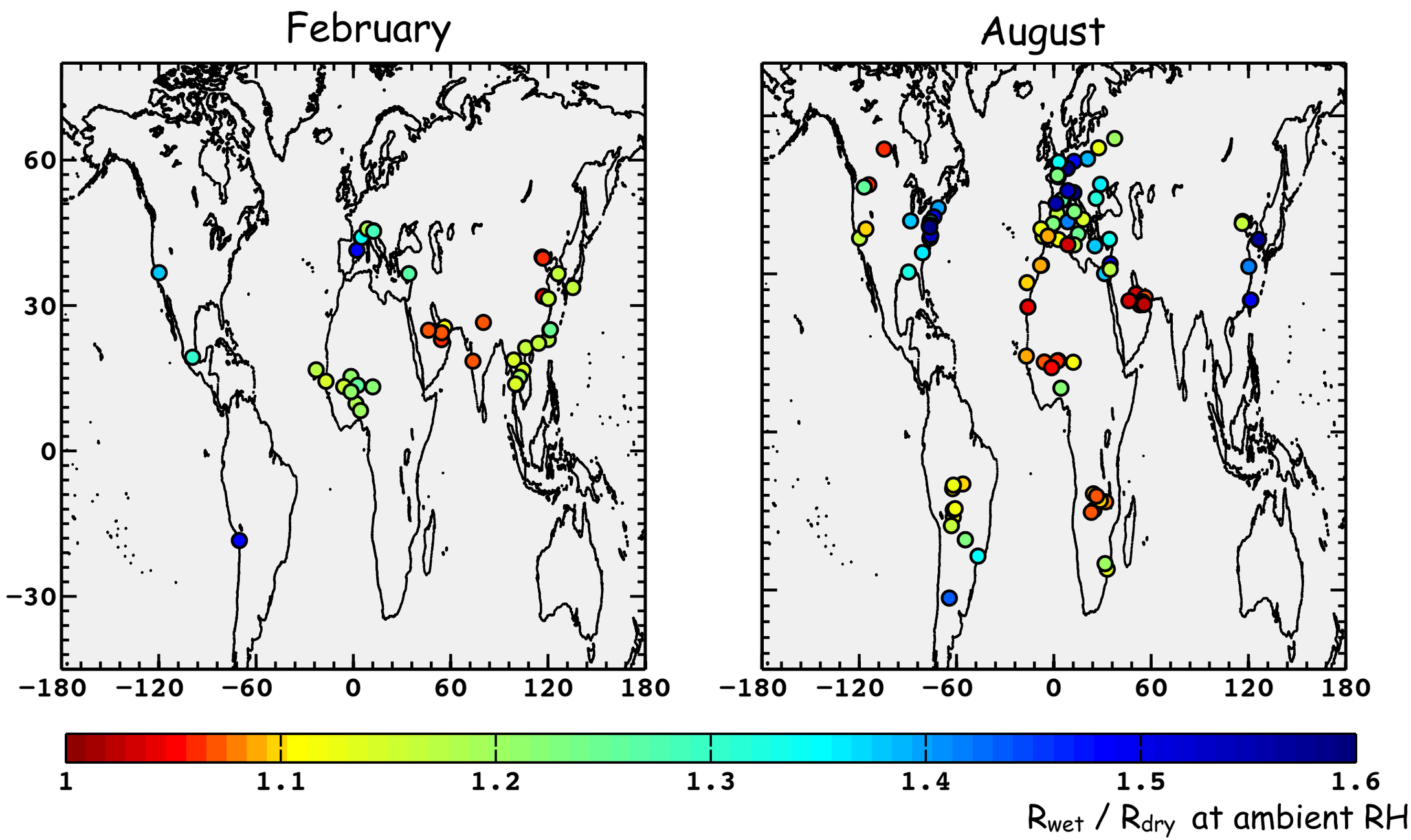
AERONET all-points, level 1.5 dataset, minimum of 10 retrievals

Black Carbon retrieval is consistent with regional and seasonal patterns



AERONET all points level 2.0 dataset, minimum of 20 retrievals

Regional hygroscopic growth is consistent with climate

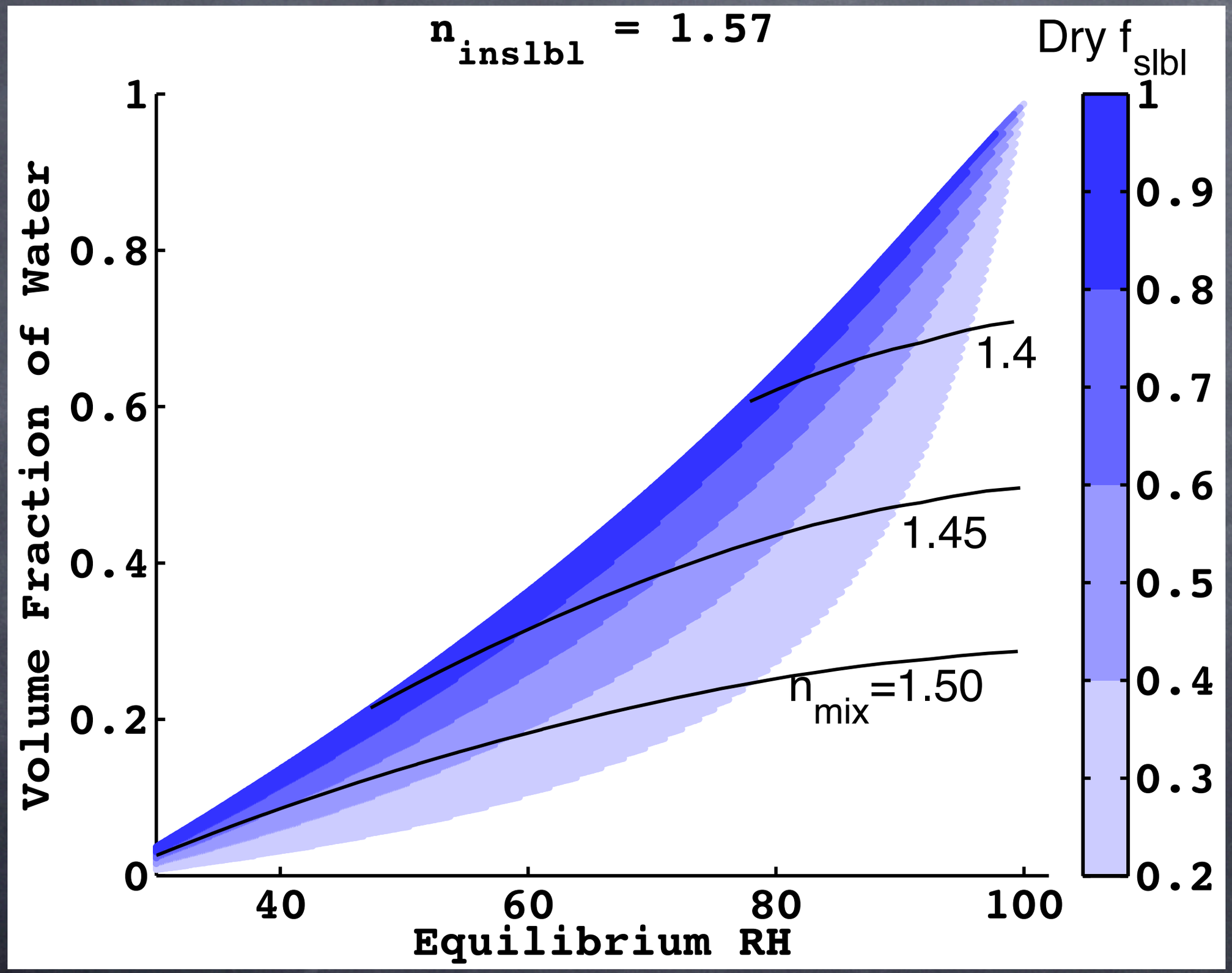


Classifications at 90% RH (Swietlicki et al., 2008):

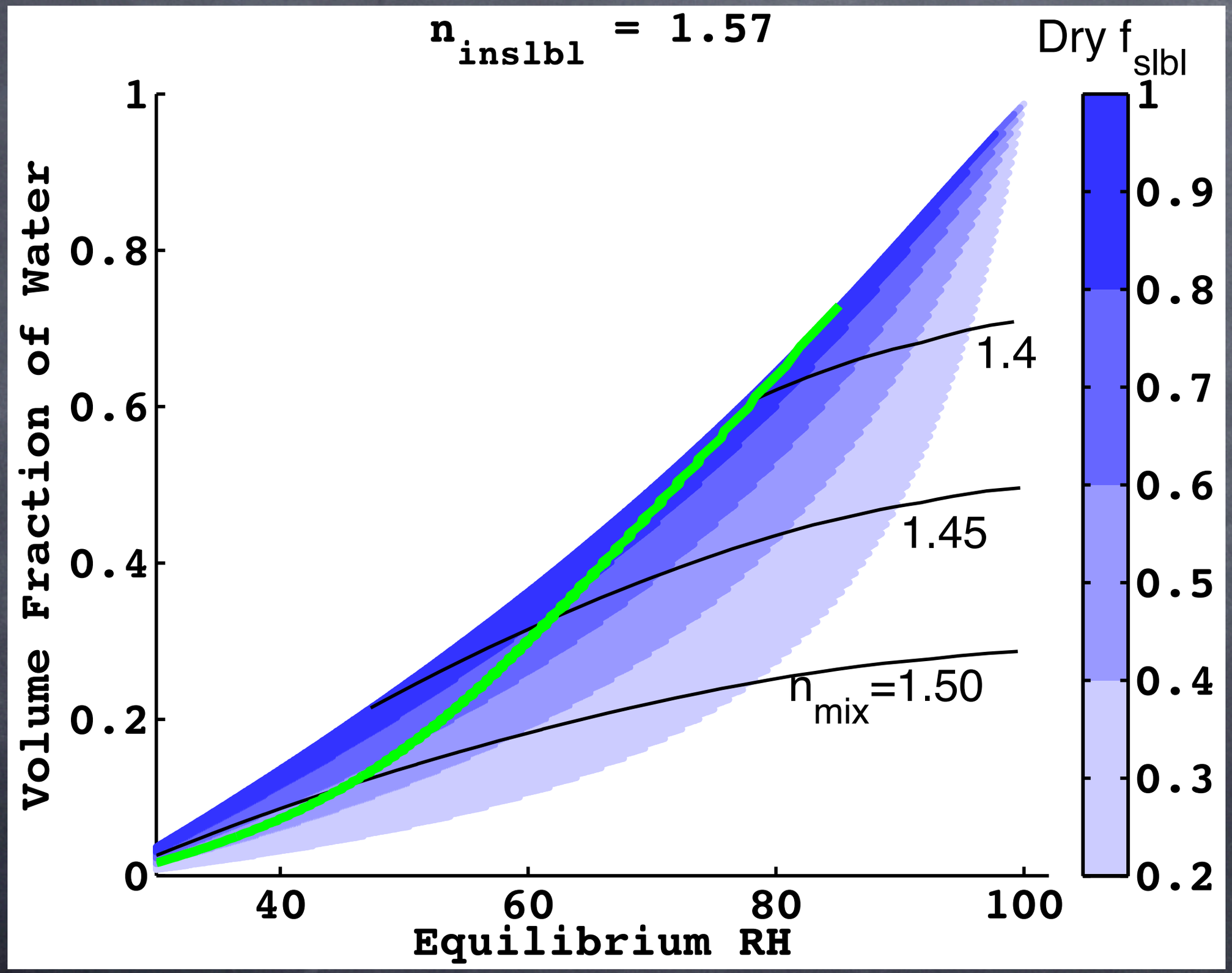
$$R_{wet} / R_{dry} = 1.0 - 1.11 \rightarrow \text{nearly hydrophobic}$$
$$= 1.11 - 1.33 \rightarrow \text{less hygroscopic}$$
$$> 1.33 \rightarrow \text{more hygroscopic}$$

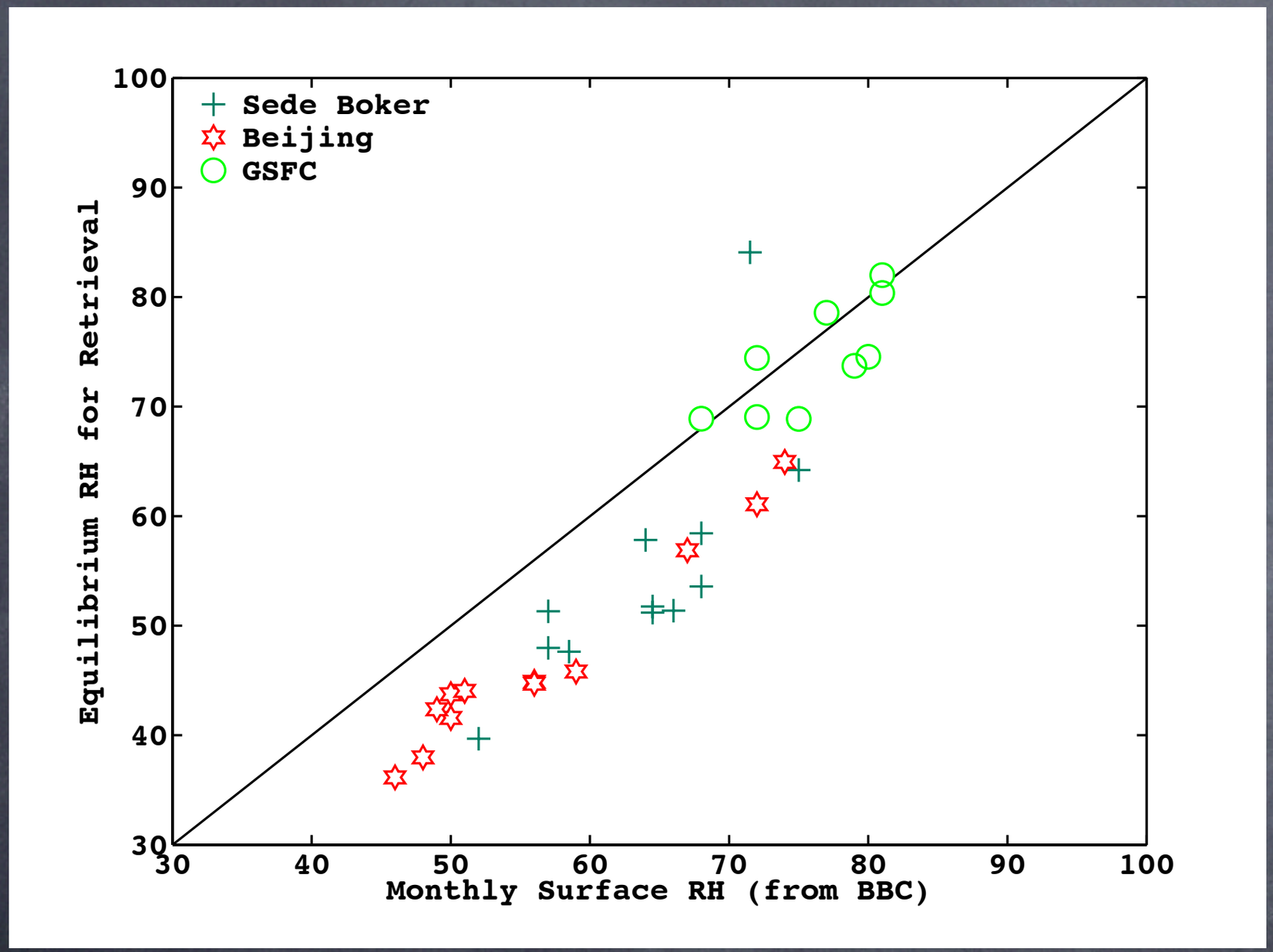
AERONET all-points, level 2.0 dataset, minimum of 20 retrievals

Modeled Water Fraction

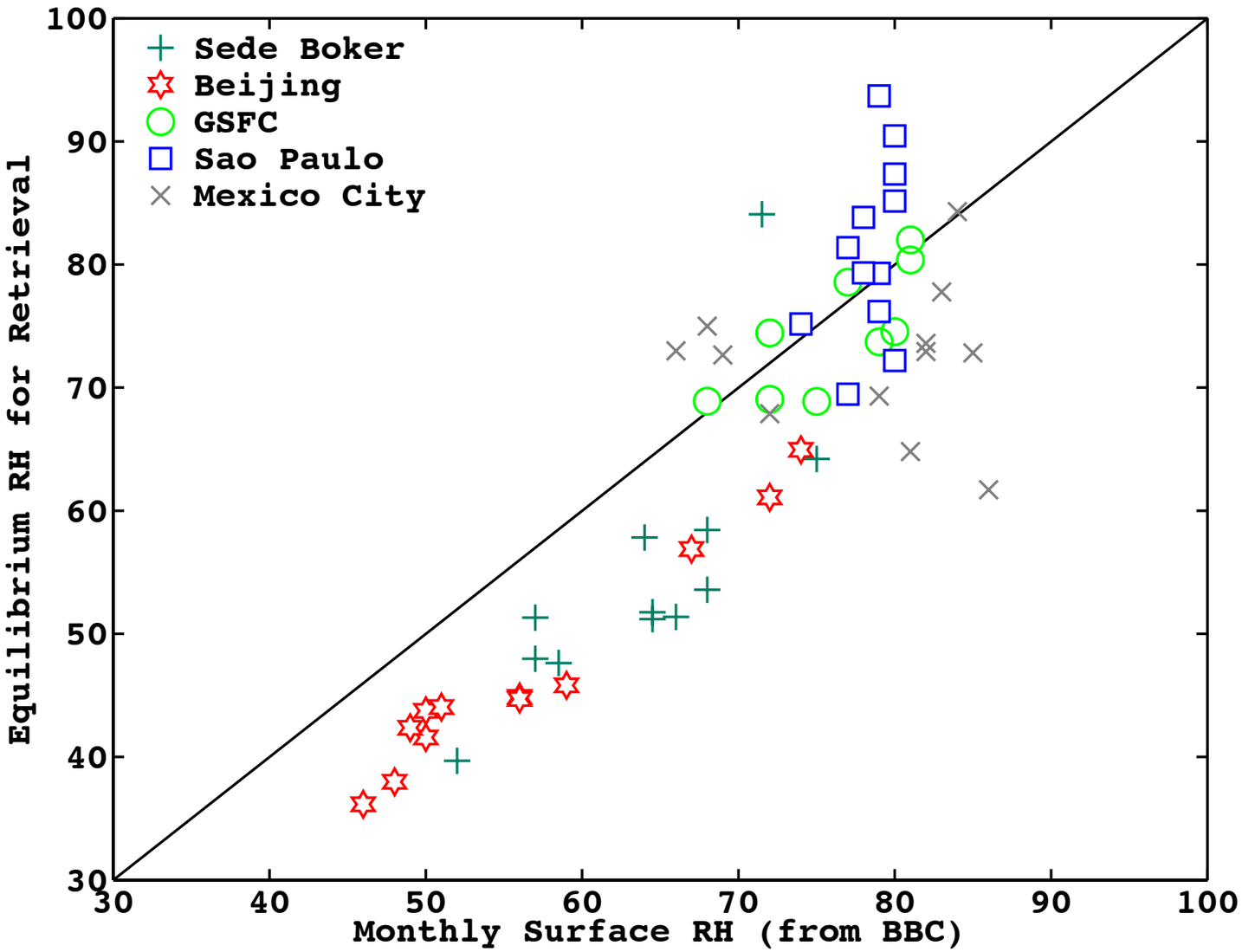


Modeled Water Fraction





Location	R	slope	intercept
Sede Boker	0.76	1.26	-26.04
Beijing	0.98	0.92	-4.84
GSFC	0.76	0.82	12.32



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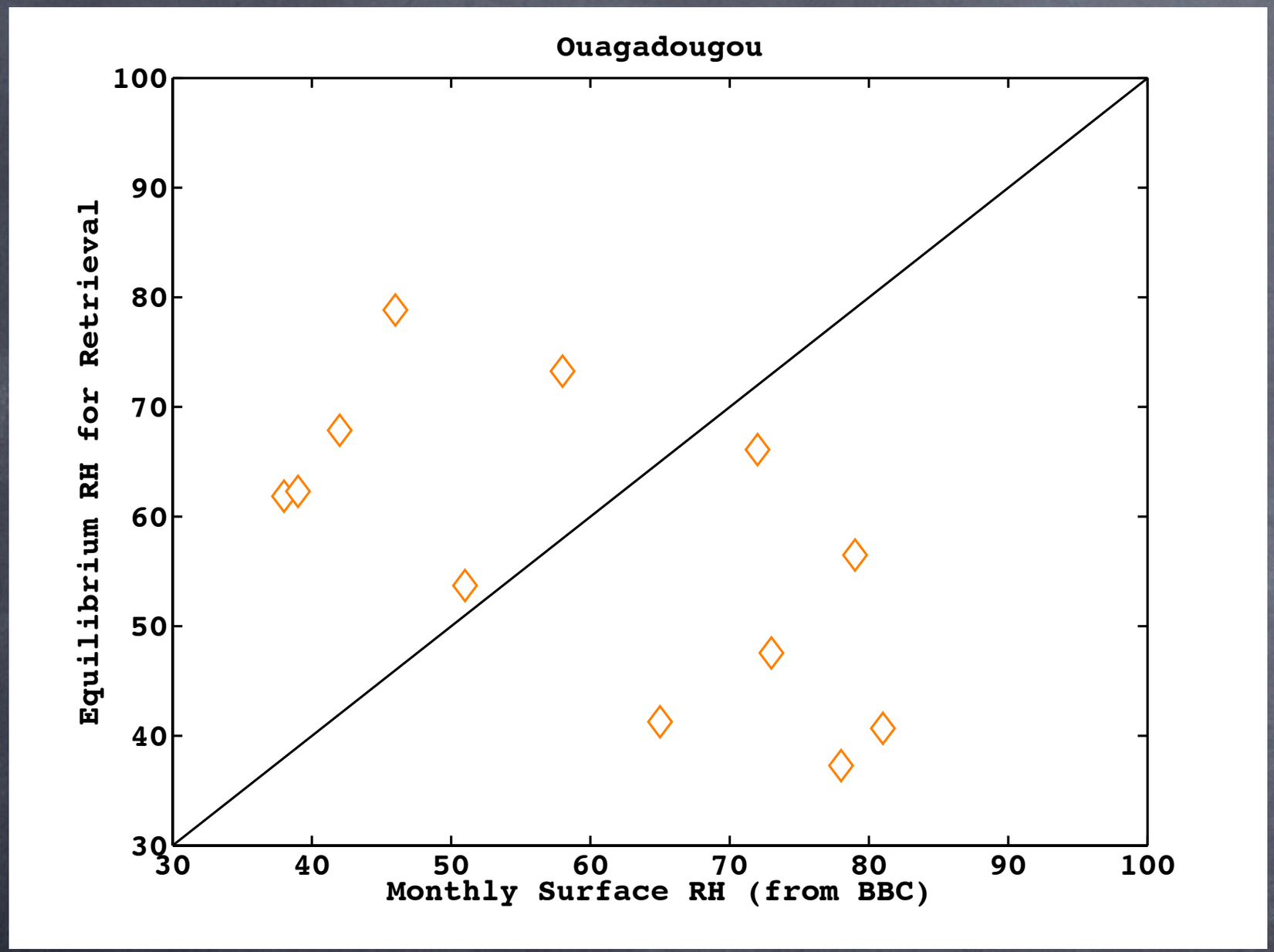
Mexico City	-0.02	-0.02	73.67



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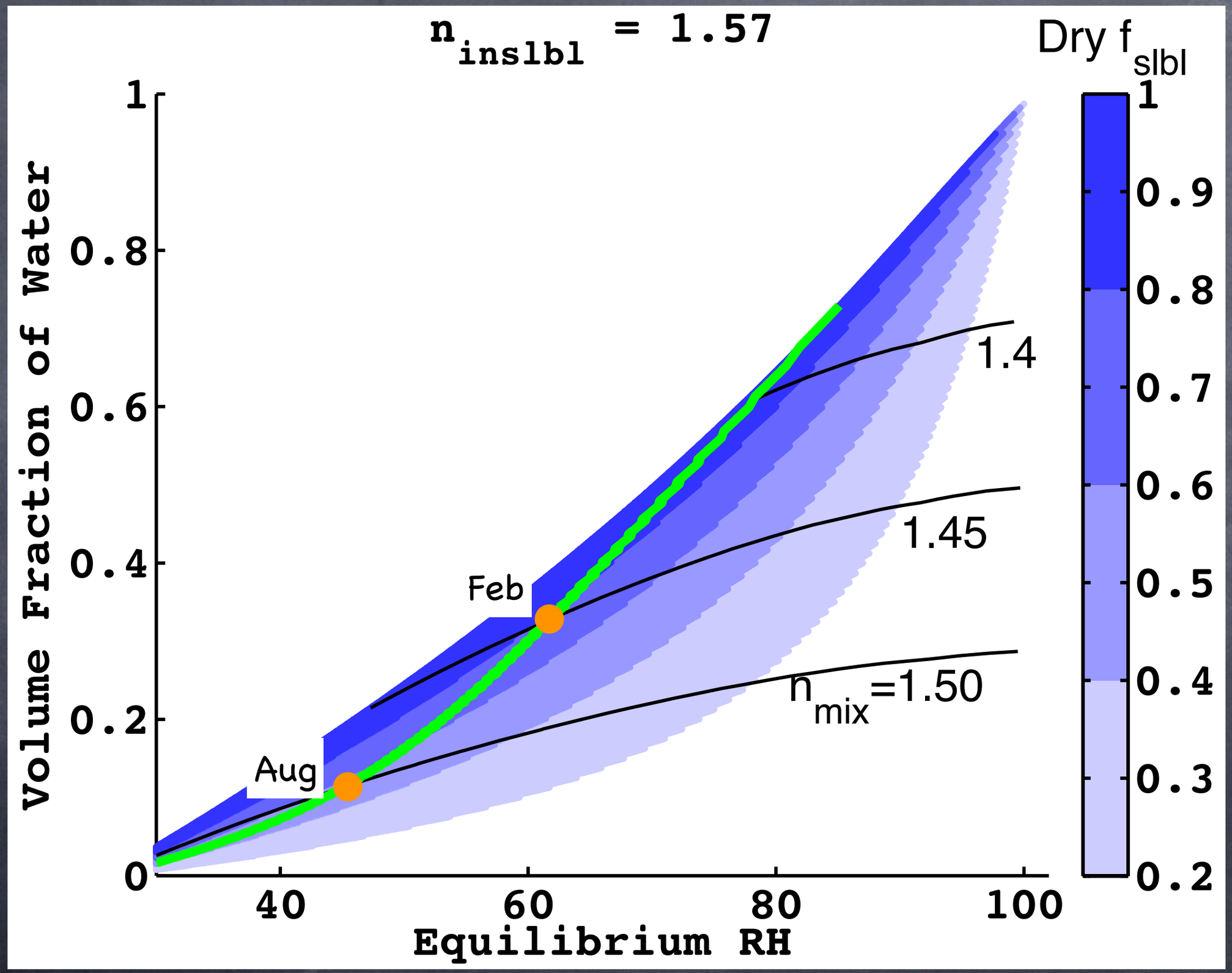
Mexico City	-0.02	-0.02	73.67
Ougadougou	-0.62	-0.51	87.86

Modeled Water Fraction



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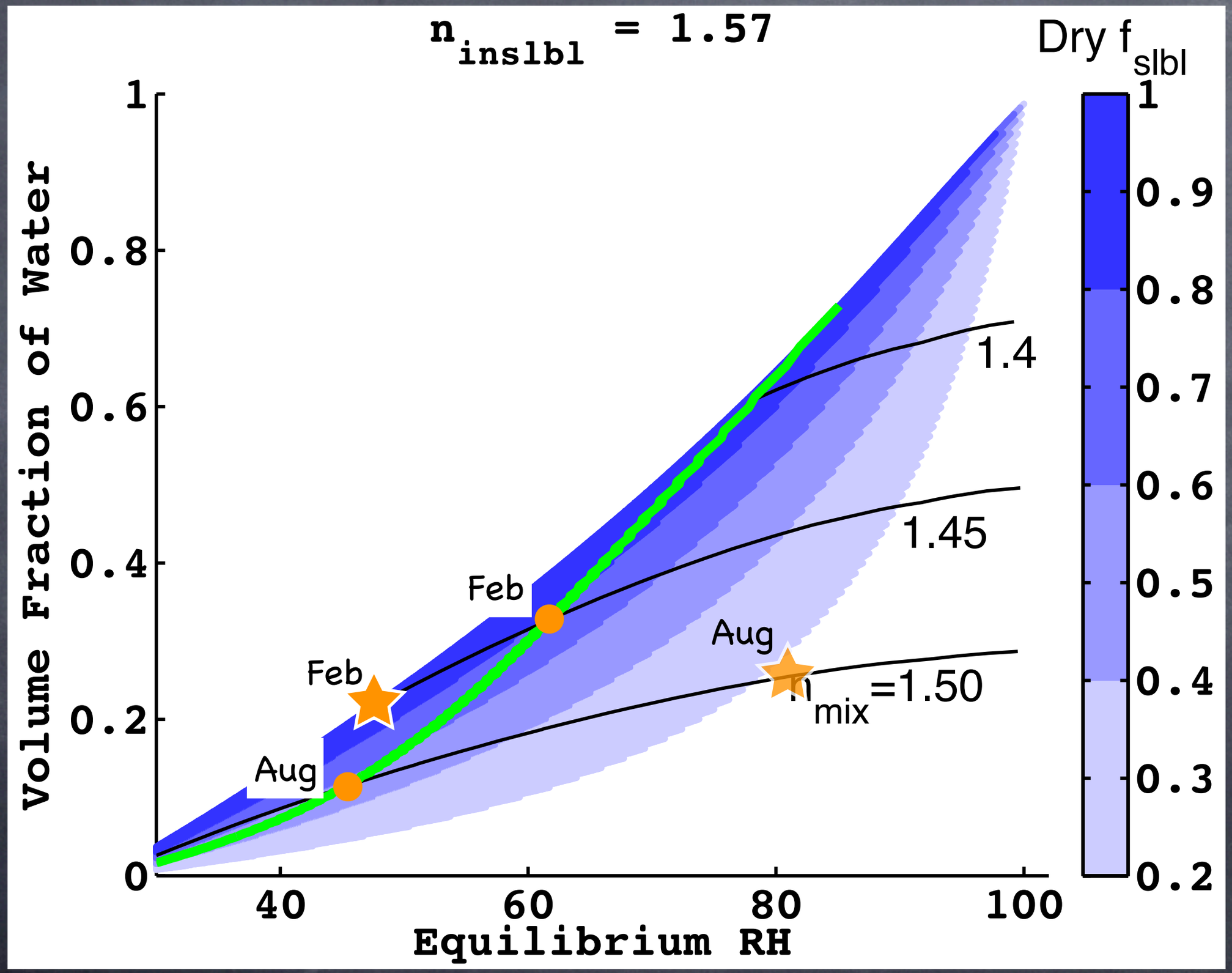

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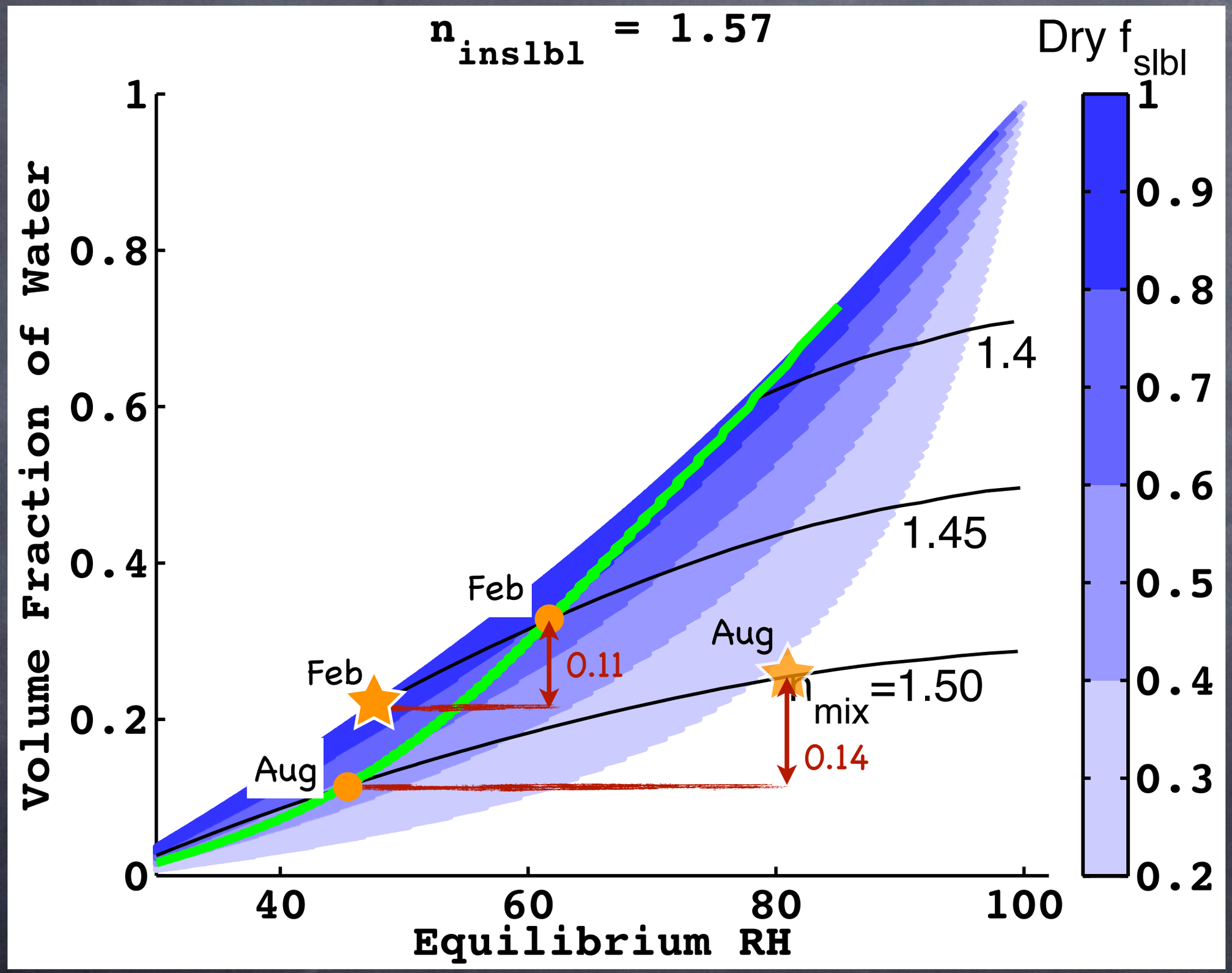

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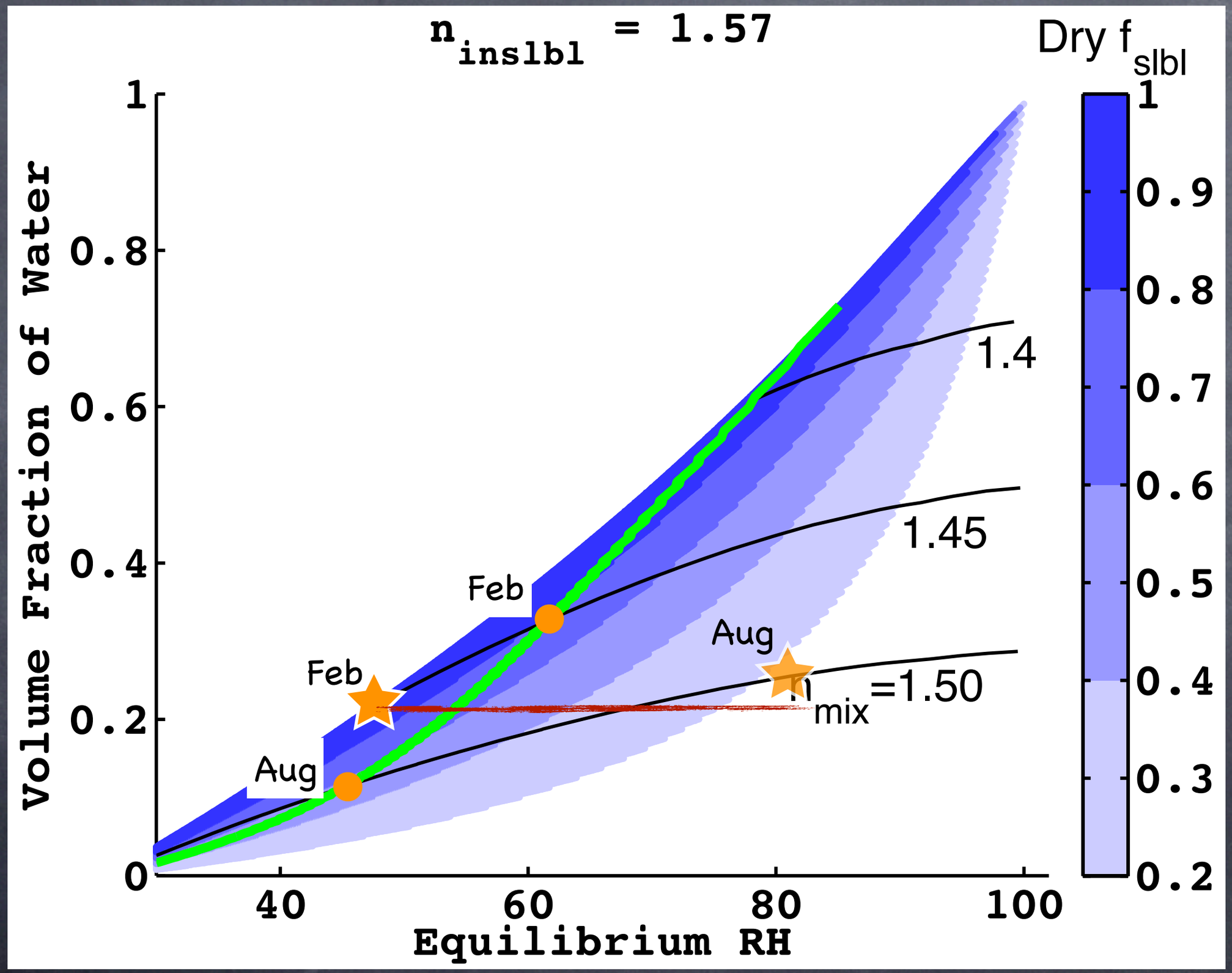
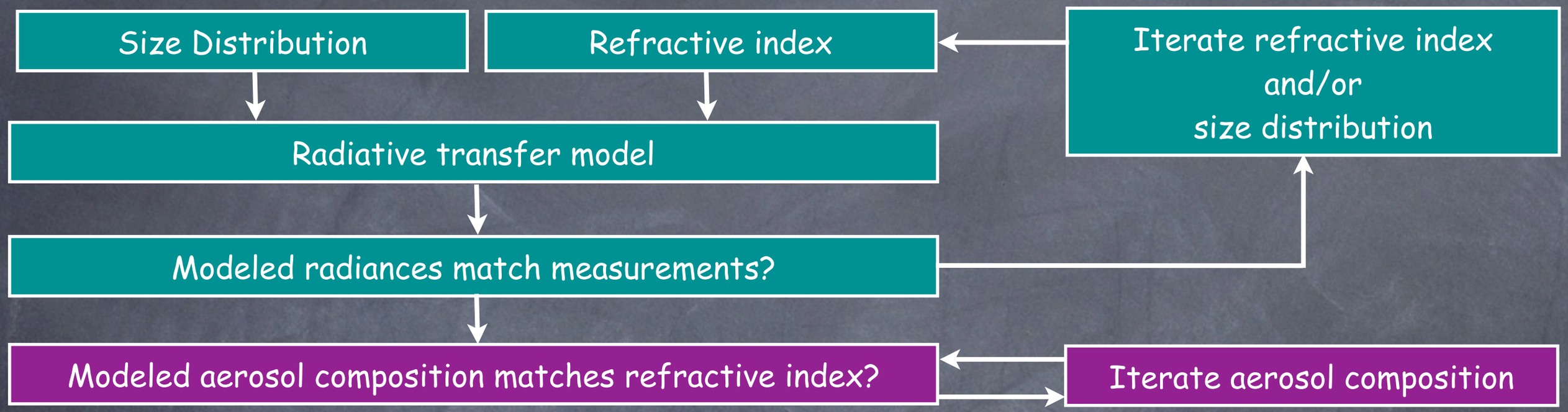


Retrieval Schematic

Old Way: Retrieval from a retrieval



Green: AERONET
Plum: My code

Retrieval Schematic

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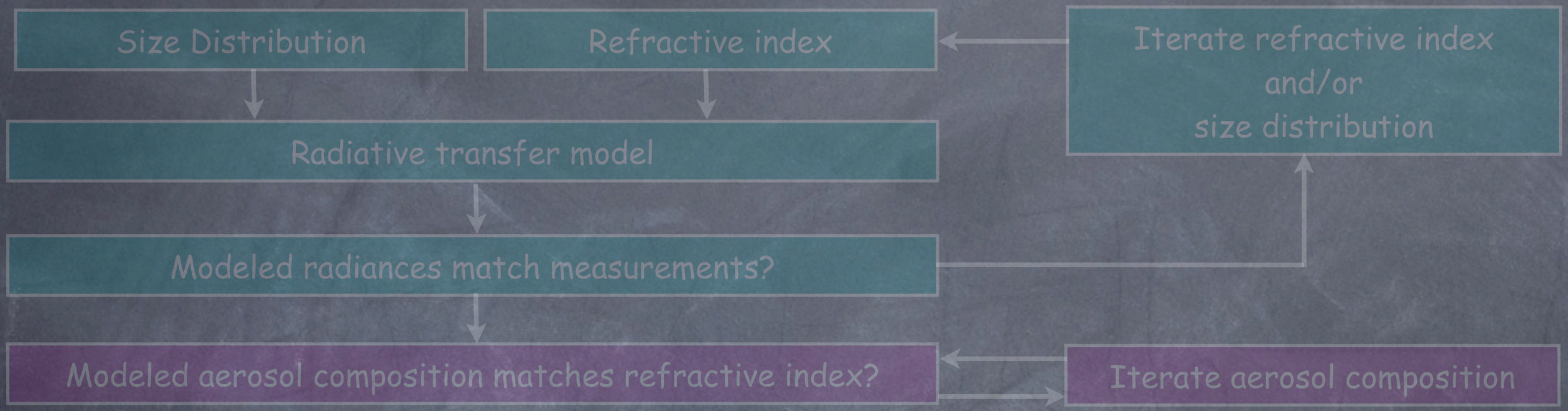
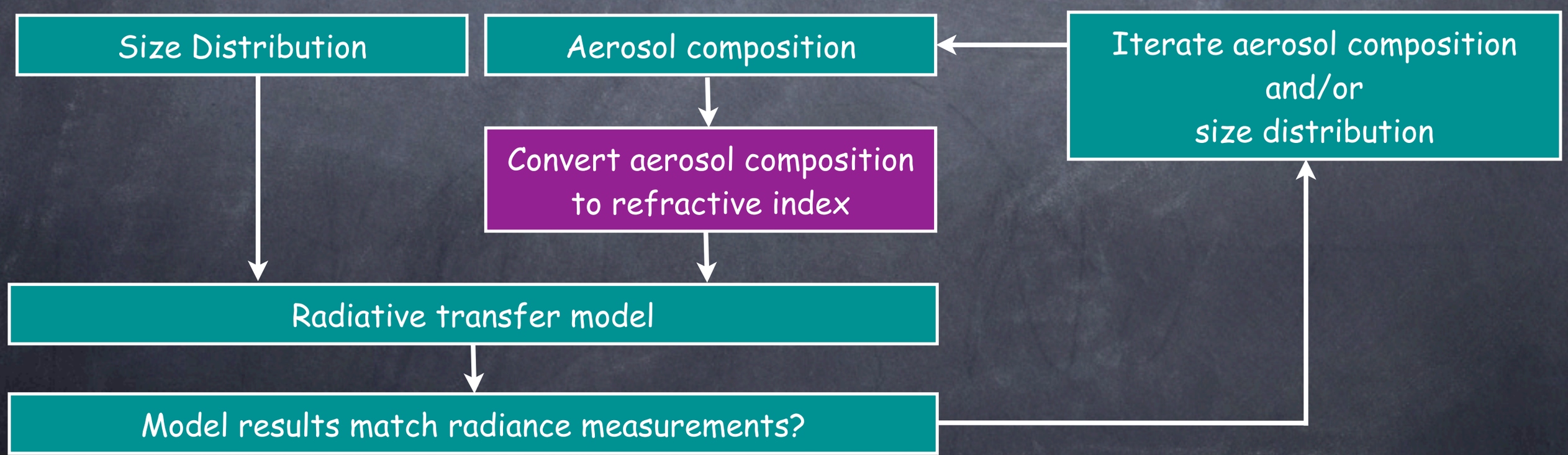


Next Generation: "Bottom up"



Conclusions

- ✓ Real refractive index provides information about the aerosol water content.
- ✓ Black carbon can be uniquely determined from the aerosol imaginary index because it is so much more absorbing than any other aerosol at wavelengths greater than 650 nm.
- ✓ 3CAR provides reasonable results for all regions and seasons (except water over west Africa).

Data: http://asd-www.larc.nasa.gov/~gregs/

Acknowledgments:

We appreciate the efforts of the AERONET and PHOTONS (Service d'Observation from LOA/USTL/CNRS) principal investigators and the entire AERONET/PHOTONS teams.

Thank You!