Diurnal Differences in Lidar Ratios for Opaque Water Clouds

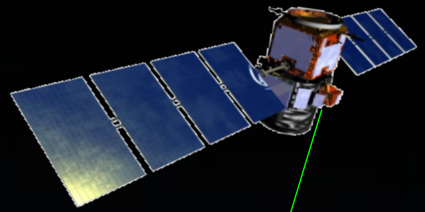

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image source: https://www.nasa.gov/mission_pages/station/multimedia/gallery/iss034e016601.html

Lidar Ratios for Opaque Water Clouds (V4.2)

$$S_c = \frac{1}{2\eta_c \gamma_c'}$$

Platt, 1973

REQUIRES CLEAR SKIES ABOVE

$$\eta_c = \left(\frac{1-\delta_v}{1+\delta_v}\right)^2$$

Hu et al., 20073

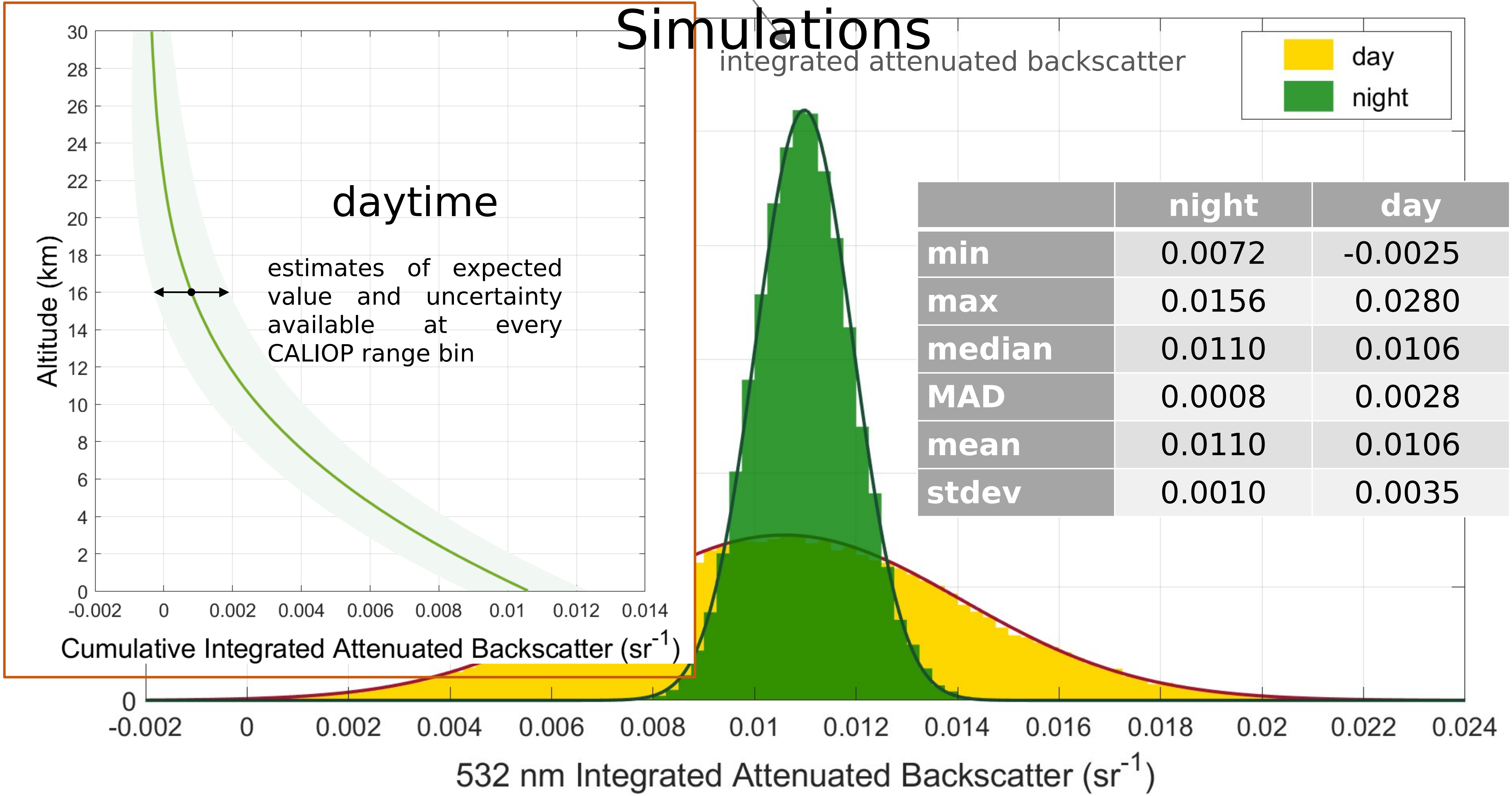
Column Optical Depths Above Opaque Water Clouds (V4.5)

$$\tau_{above} = -\frac{1}{2}\ln\left(2 S_c \gamma_c' \left(\frac{1-\delta_v}{1+\delta_v}\right)^2\right)$$

Hu et al., 2007

Diurnal Variations in the Polarization Gain Ratio Calibration are Accounted for in V4.5

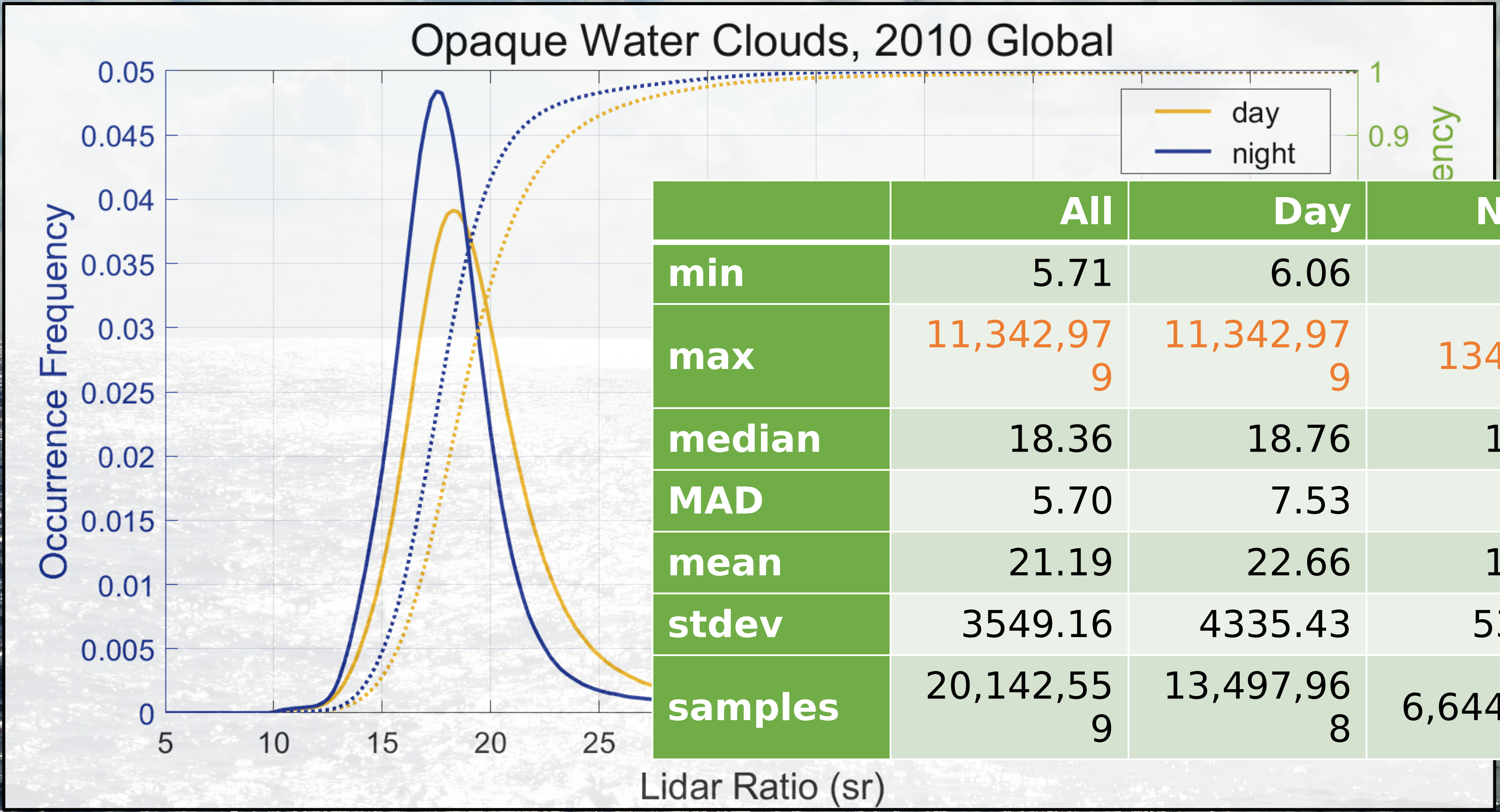
“Clear Skies” Total Column γ' Distributions From Simulations



	night	day
min	0.0072	-0.0025
max	0.0156	0.0280
median	0.0110	0.0106
MAD	0.0008	0.0028
mean	0.0110	0.0106
stdev	0.0010	0.0035

Opaque Water Clouds Detected at 1-km Resolution

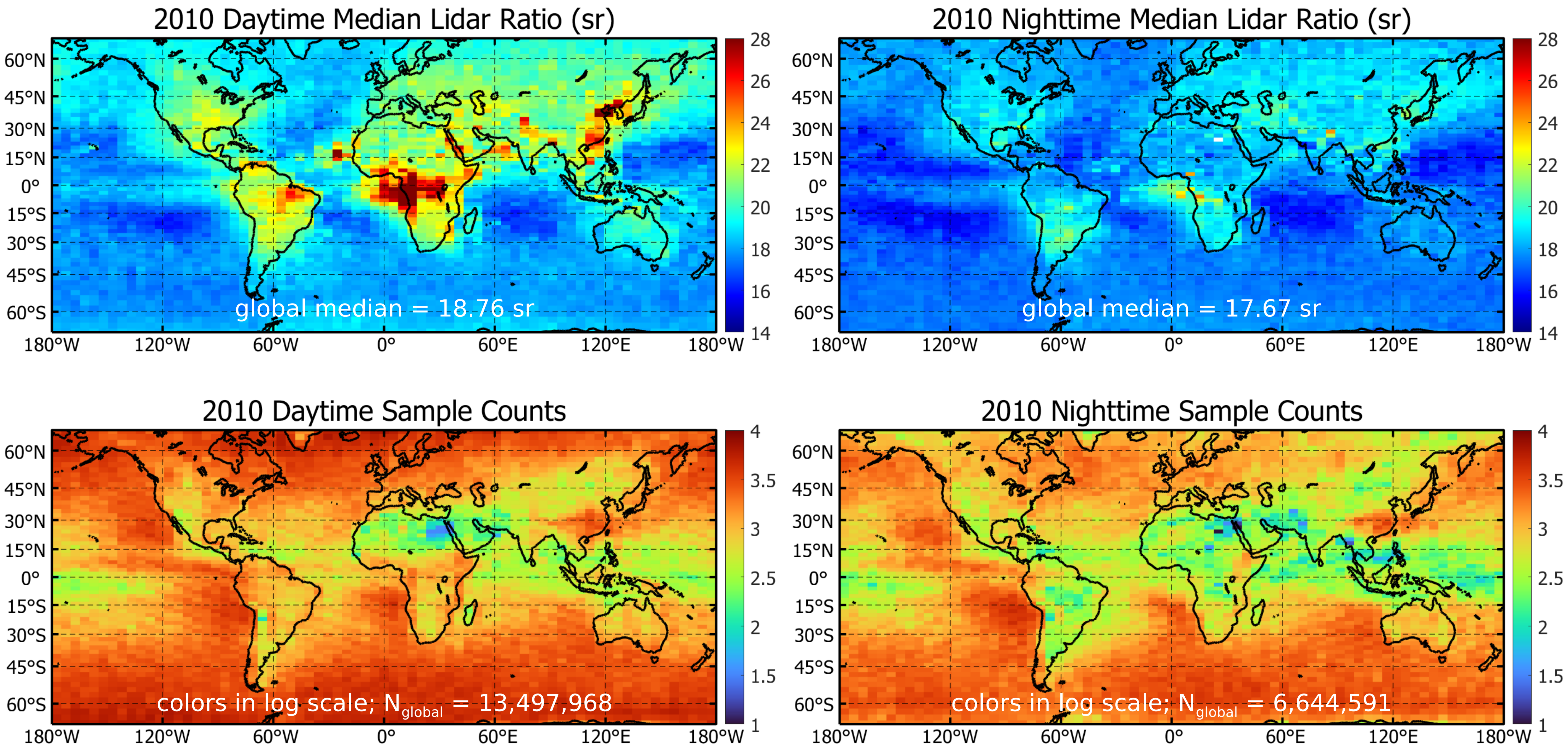
Data Filtering : Accept Only $\gamma'_{clear}(z_{top}) \pm \Delta\gamma'_{clear}(z_{top})$



	All	Day	Night
min	5.71	6.06	5.71
max	11,342,979	11,342,979	134,459
median	18.36	18.76	17.67
MAD	5.70	7.53	2.22
mean	21.19	22.66	18.21
stdev	3549.16	4335.43	53.38
samples	20,142,559	13,497,968	6,644,591

https://earthobservatory.nasa.gov/blogs/fromthefield/files/2012/09/its-a-beautiful-day-in-the-trades-with-typical-cumulus-clouds.jpg

Opaque Water Cloud Lidar Ratios, 2010 Global



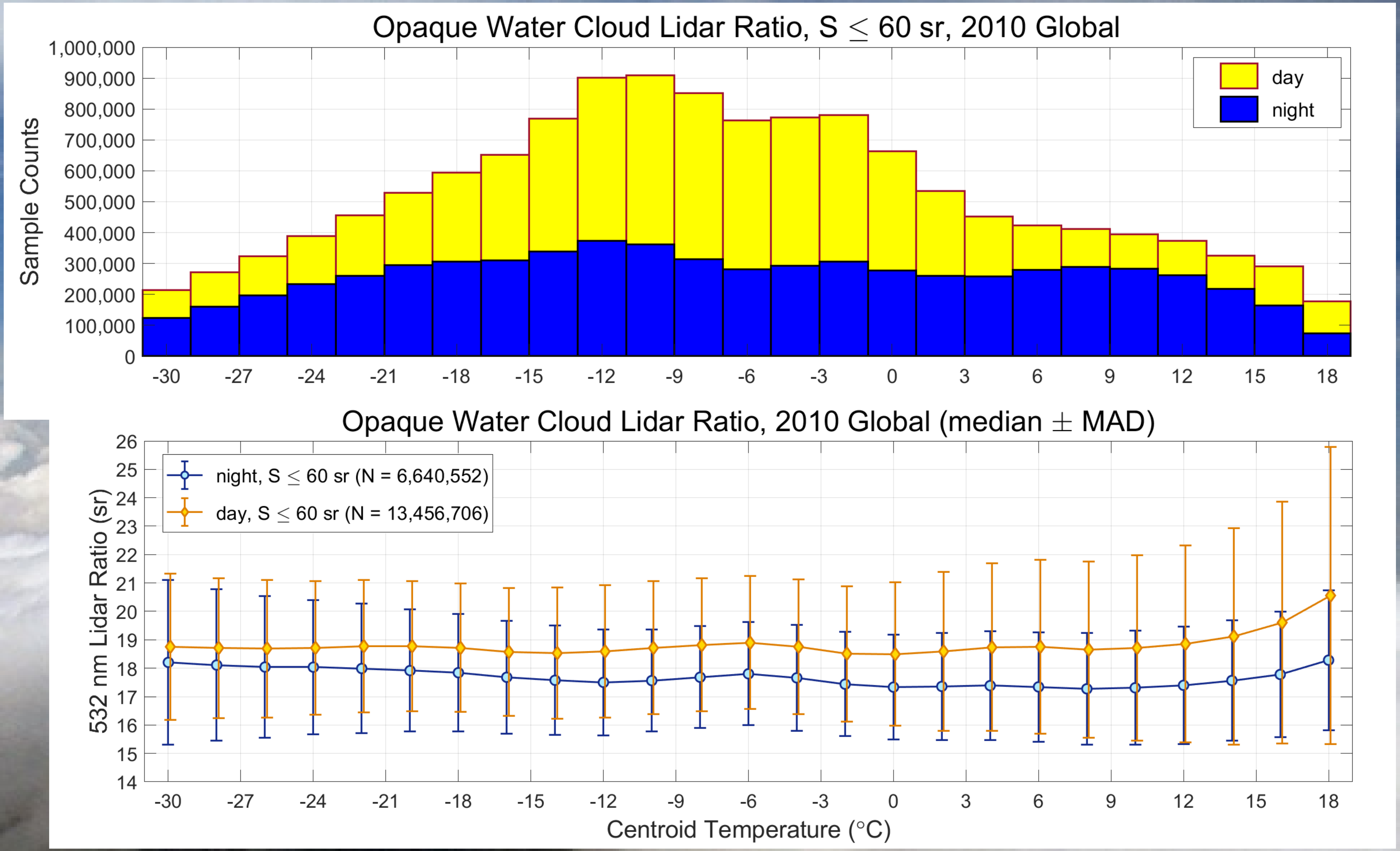


image source: https://www.pnnl.gov/science/images/highlights/atmospheric/tropical-clouds-darwin-lg.jpg

Deirmendjian, 1969

https://www.rand.org/content/dam/rand/pubs/reports/2006/R456.pdf

Mie calculations with C1 cloud distribution yield **S_{532} = 19.3 sr**

O'Conner et al., 2004

https://doi.org/10.1175/1520-0426(2004)021<0777:ATFAOC>2.0.CO;2

The values of *S* at **532** and 355 nm are **18.6 ± 1** and 18.9 ± 0.4 sr, respectively, for the same range of parameters

Wu et al., 2009

https://doi.org/10.1364/AO.48.001218

we find the mean value of [water] cloud lidar ratios at **355 nm** is **18.6 sr** with a standard deviation of 3.9 sr

SODA

Deaconu et al., 2017

https://doi.org/10.5194/amt-10-3499-2017

the median of $S_{c,lat}$ [**at 532 nm**] for the night-time data is **19.36 sr**, which is interestingly close from the theoretical value determined by Hu et al. (2006). For daytime data, $S_{c,lat}$ is sys-tematically higher ~~and with a median of 20.64 sr.~~

Hu et al., ILRC 2006

https://www-calipso.larc.nasa.gov/resources/pdfs/ILRC_2006/Hu-Multiscatter-Depolarization-2O-2.pdf

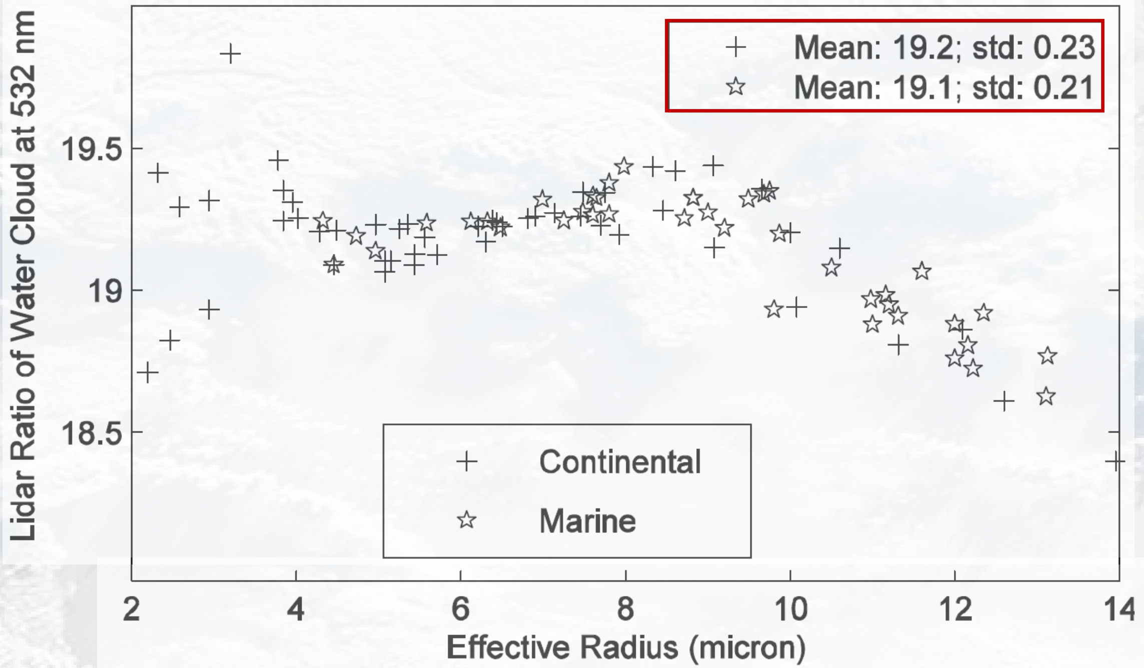


Fig. 3. Extinction-to-backscatter ratios (Sc) calculated using the widths and mode-radii from all historical water cloud particle size distribution observations

CALIOP's Default Water Cloud Lidar Ratio: 19 sr

image source: https://climatekids.nasa.gov/resources/icons/cloud-formation.jpg

Cirrus Cloud Optical Depths Derived Via Two
ds

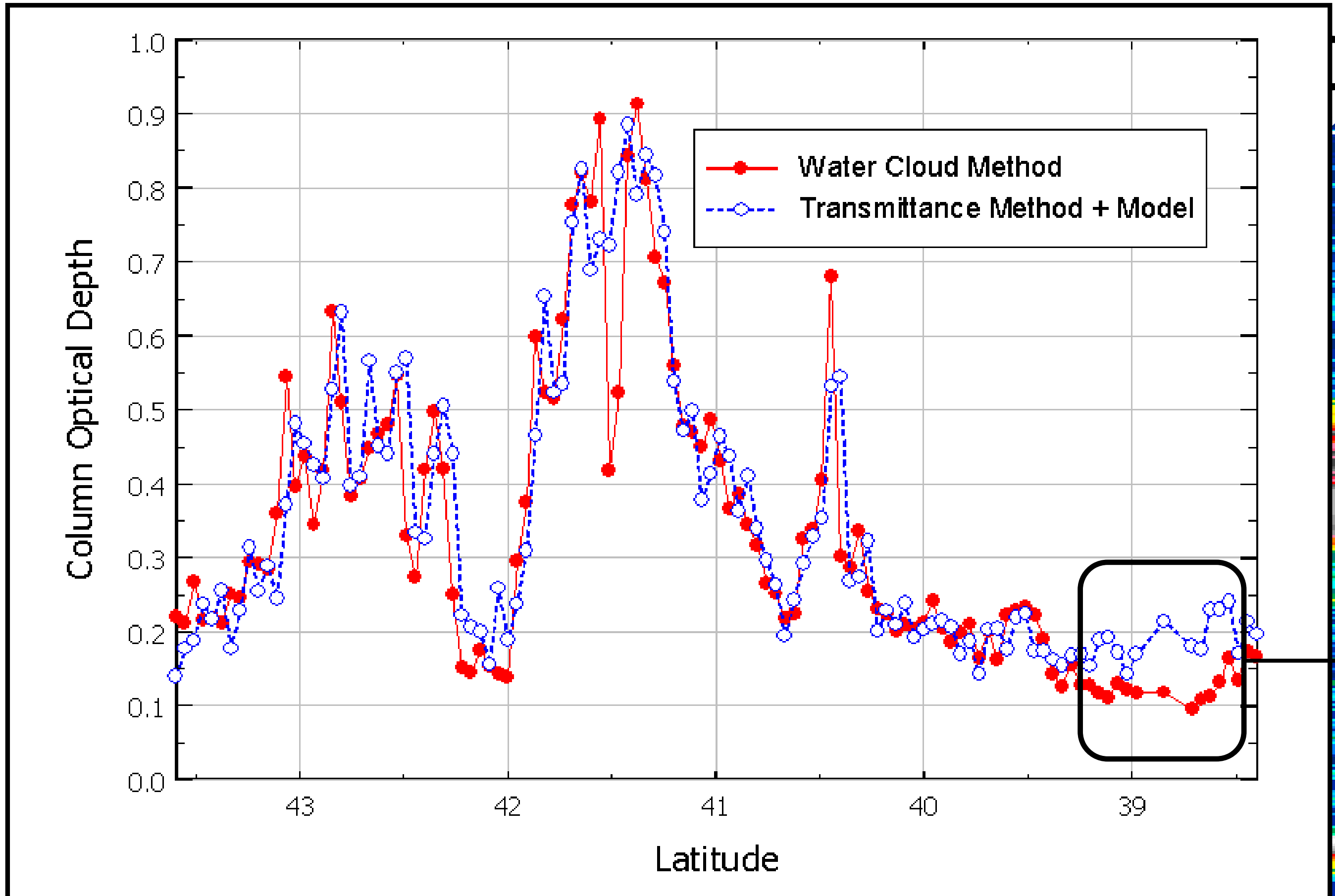


Fig. 3. Cirrus cloud optical depths derived using the water cloud method (solid line) are compared to estimates obtained via the traditional “clear air” technique (dashed line).

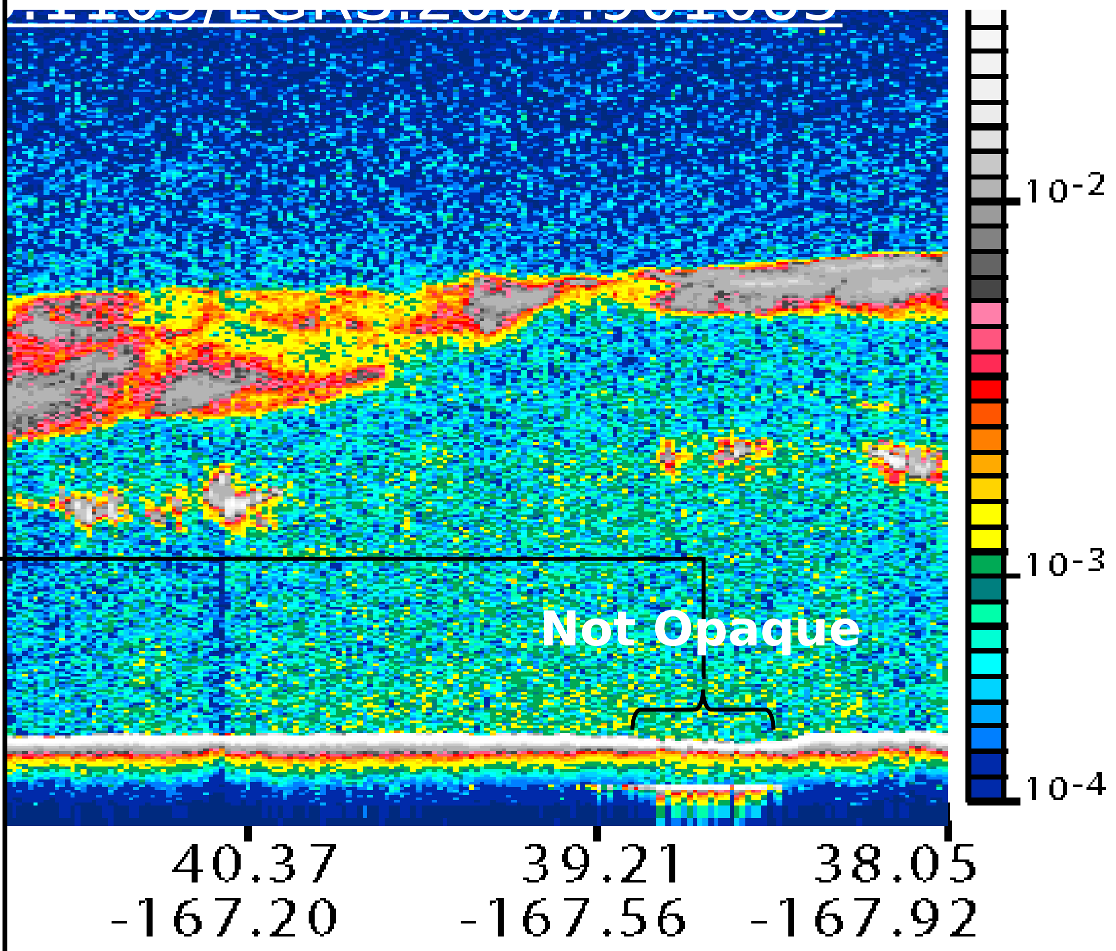
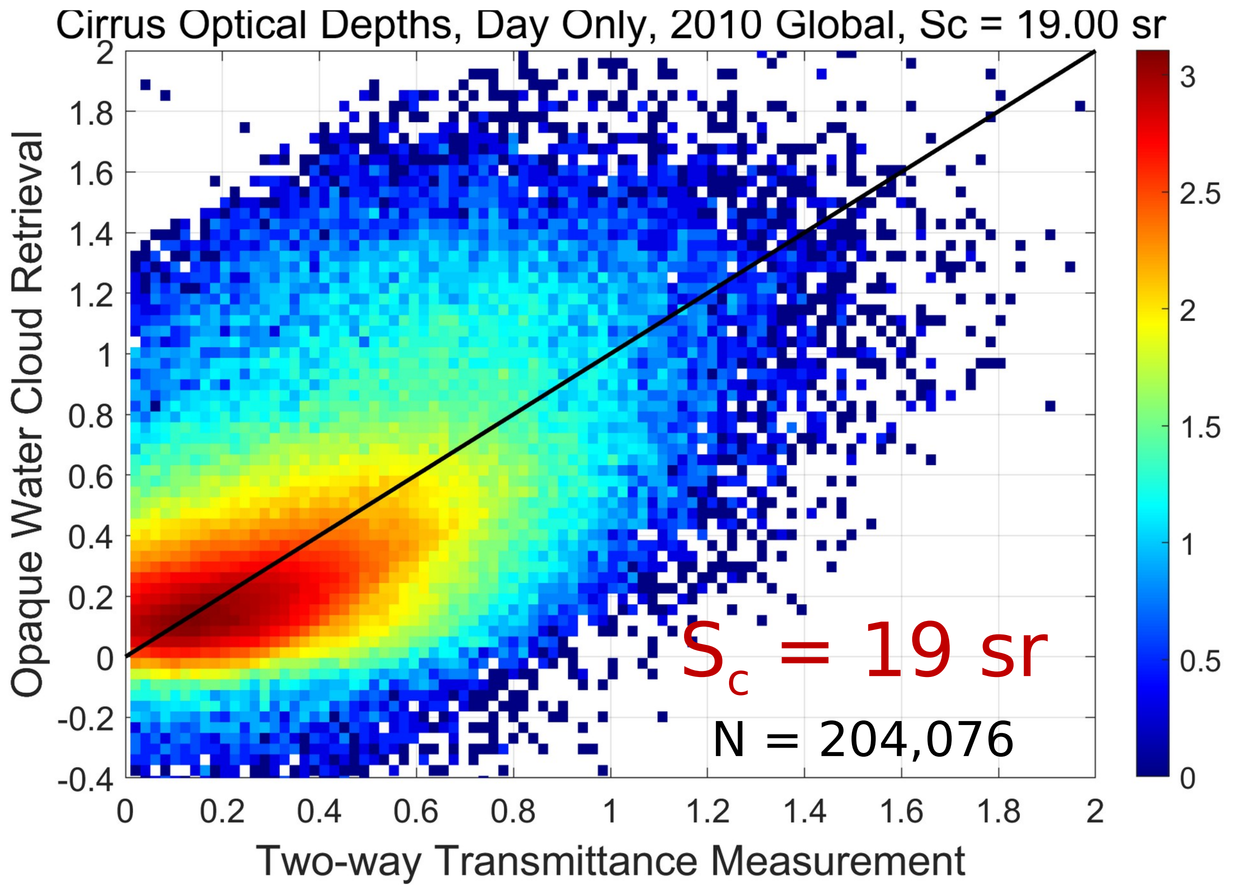


Fig. 2. CALIPSO lidar measurements acquired June 20, 2006 at ~13:20 UTC, showing an extended cirrus layer separated from an underlying opaque water cloud by a region of clear air.

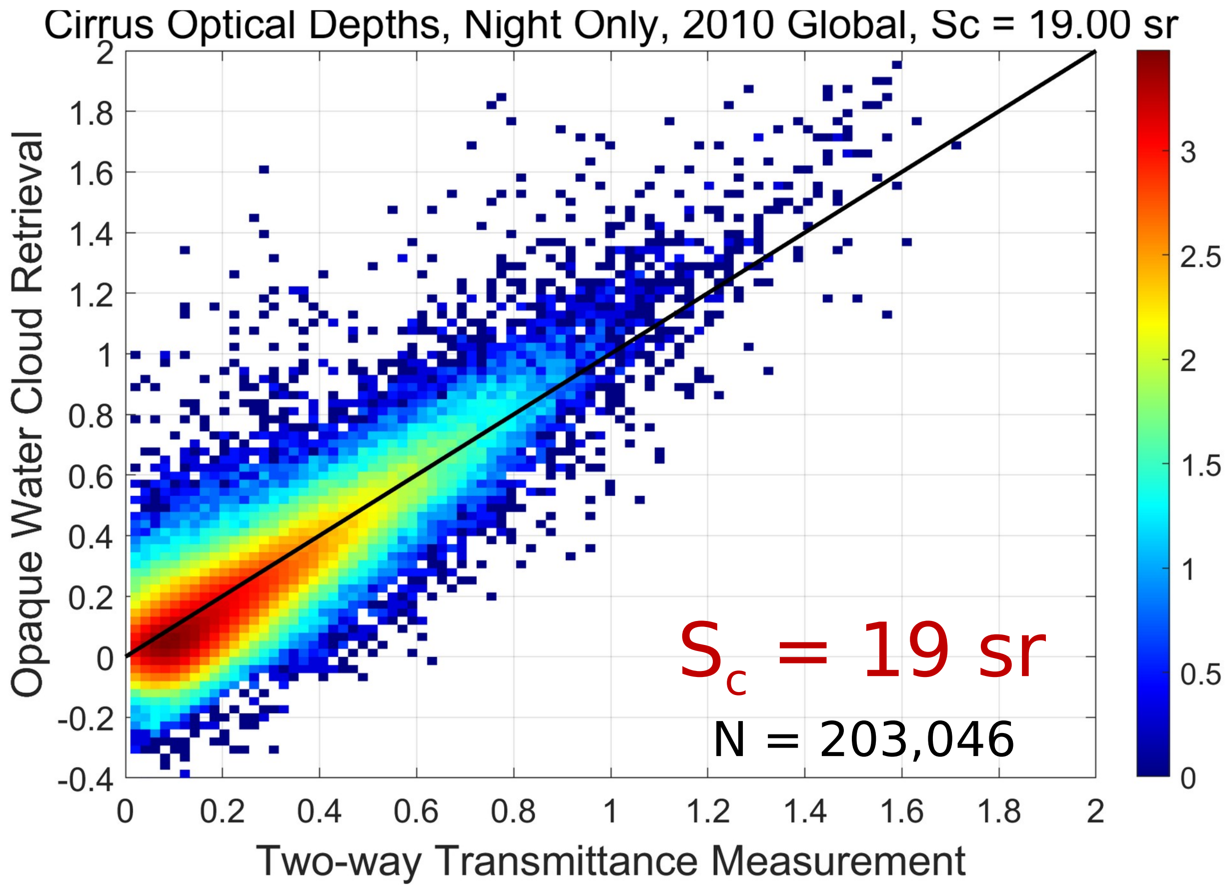
Cirrus Cloud Optical Depths Derived Via Two Methods

V4.5 Test Data – **Default** Water Cloud Lidar ratio = 19

Daytime



Nighttime

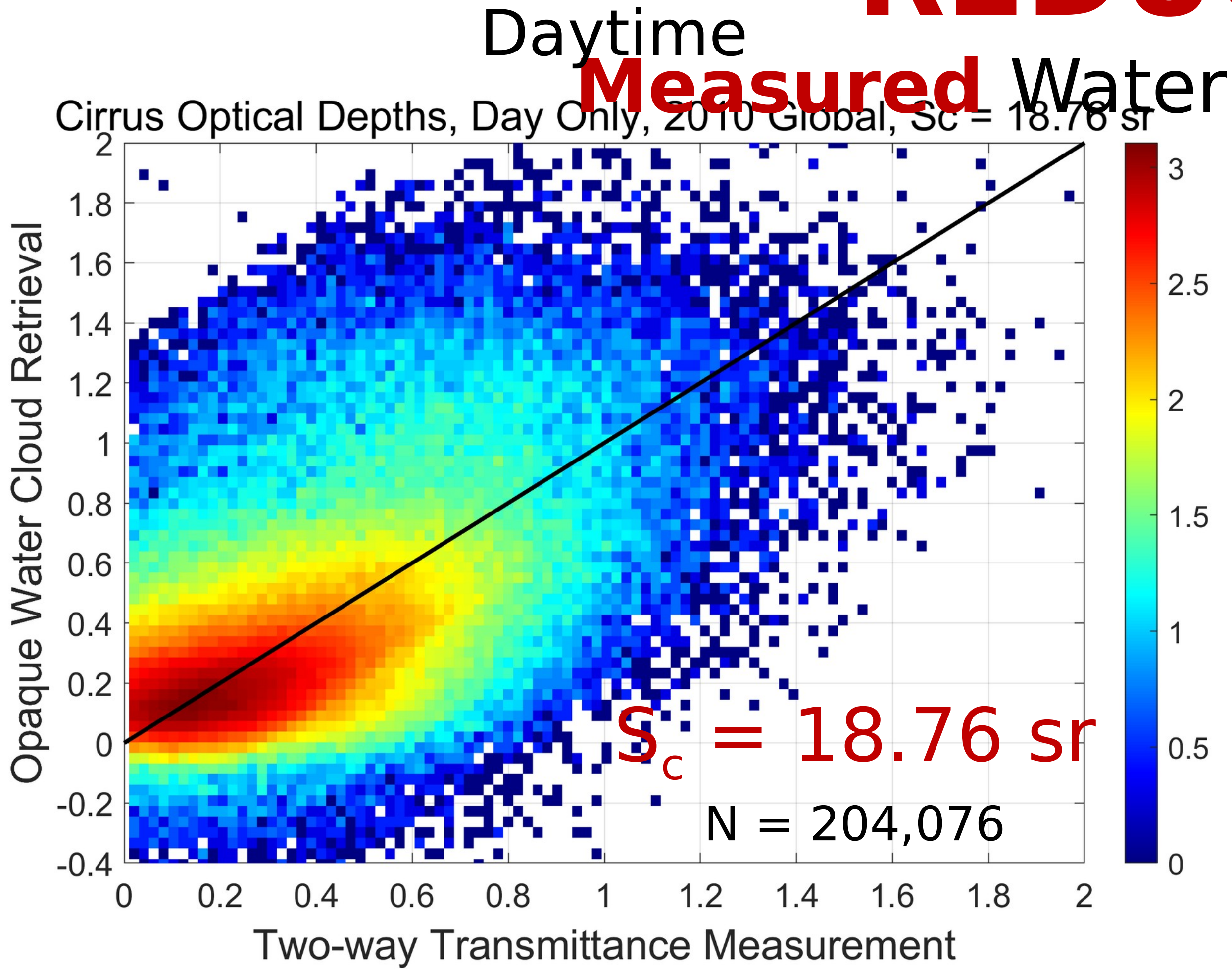


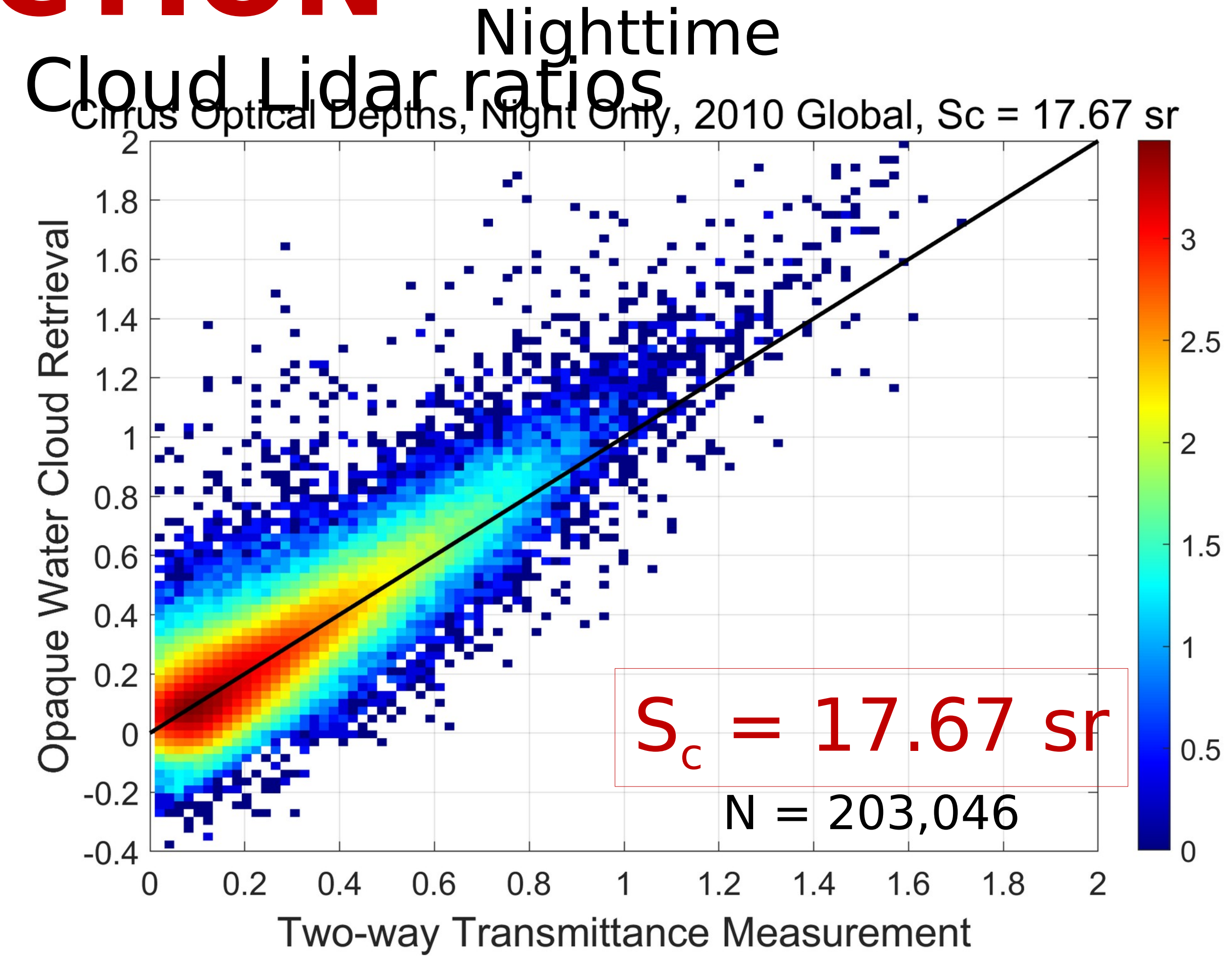
OWC_method = 0.7016 × T^2_method + 0.0674

OWC_method = 1.0132 × T^2_method – 0.0349

NOTICEABLE NIGHTTIME BIAS REDUCTION

Measured Water Cloud Lidar ratios





OWC_method = 0.7016 × T2_method + 0.0737
mean optical depth increase = 0.006

OWC_method = 1.0132 × T^2_method + 0.0013
mean optical depth increase = 0.036

DISCUSSION

- Instrumental day-night differences are deemed well characterized in V4.5, and we are reasonably confident that there are lidar ratio differences in the water clouds themselves.
- **PHYSICAL EXPLANATIONS?**
  - The day-night difference may reflect diurnal changes due to radiative heating/cooling of cloud top, a key part of the water cycle that might not be properly captured in the current models.
  - .....
- V4.5 Recommendation: default lidar ratios for ALL water clouds

	Daytime	Nighttime
V4.2	19 sr	19 sr
V4.5	**18.8 sr**	**17.7 sr**

Image source: https://www.arm.gov/research/highlights/489

Thank You For Your Attention

CALIPSO & CloudSat Science Team Meeting 2022

image source https://www.weather.gov/jetstream/clouds_intro

CALIOP PGR Corrections: Take Home Message for Data Users

Level 2 demo: characteristics of opaque water clouds

integrated volume depolarization ratio

$$\delta_v = \frac{\overline{X_\perp}}{PGR \times \overline{X_\parallel}} = \delta_v(PGR)$$

integrated attenuated backscatter

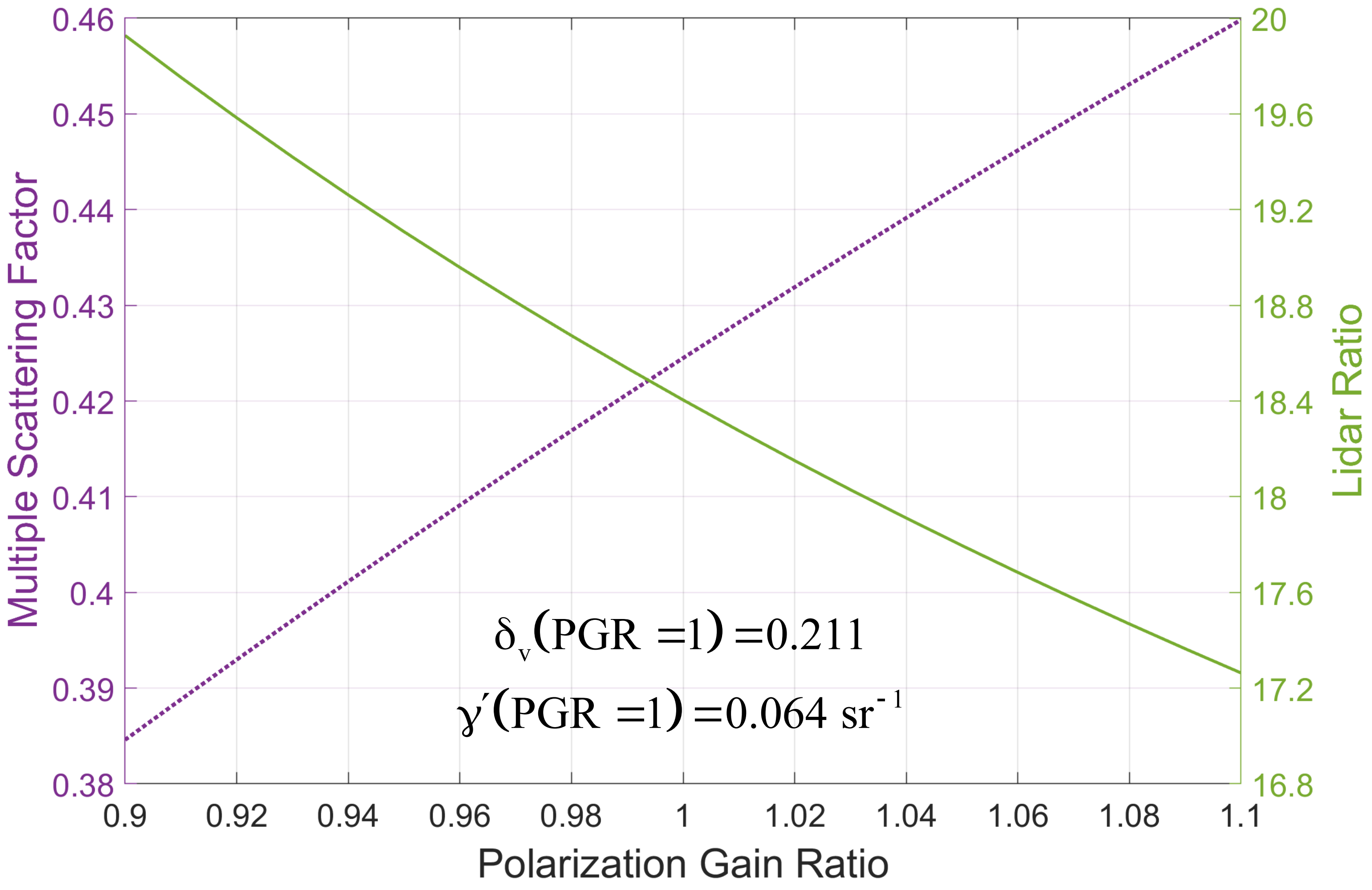
$$\gamma'(PGR) = \frac{1}{C_\parallel}\left(\int_{top}^{base} X_\parallel(z) + \frac{X_\perp(z)}{PGR}\, dz \right)$$

multiple scattering factor

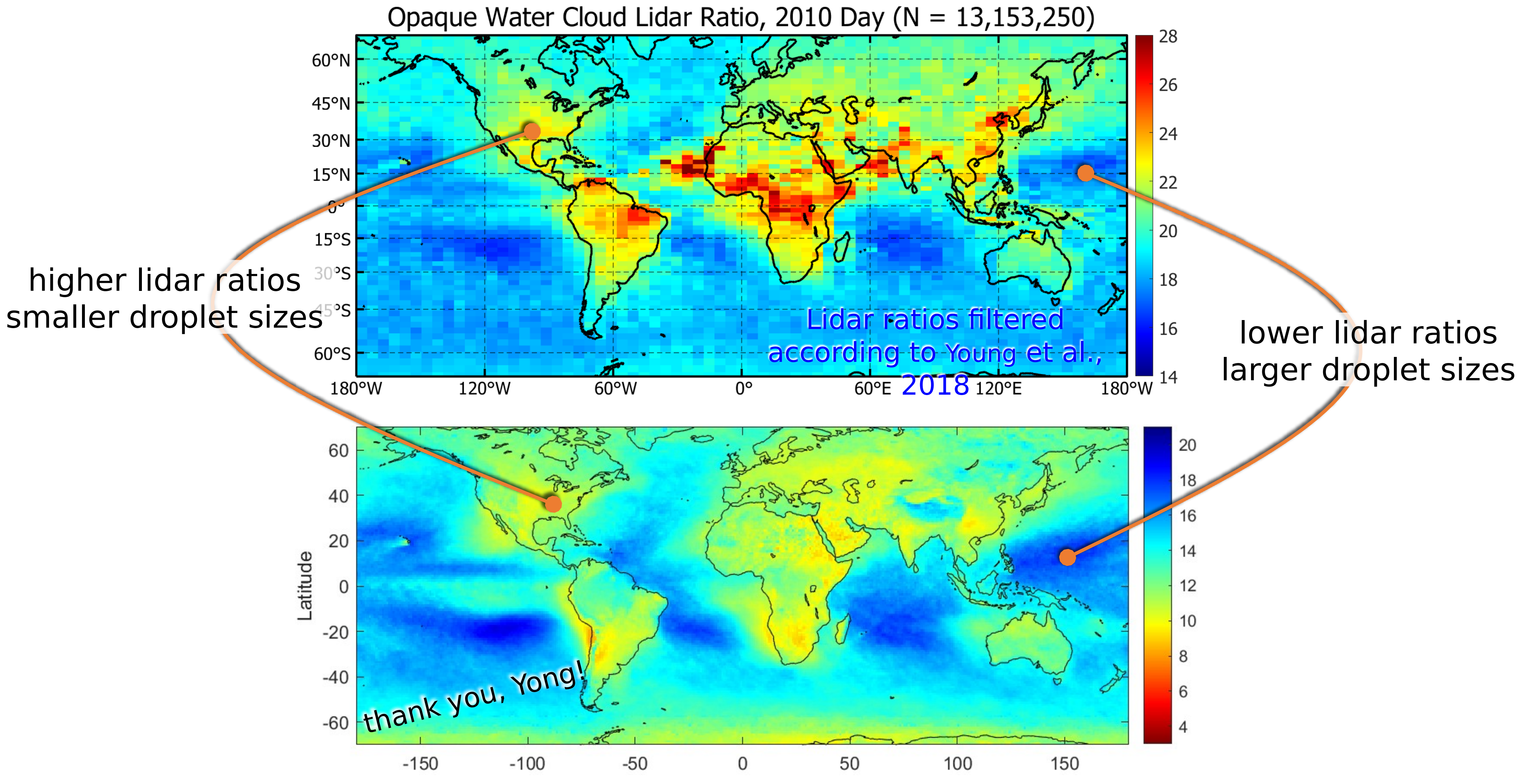
$$\eta = \left(\frac{1-\delta_v}{1+\delta_v} \right)^2 = \eta(PGR)$$

opaque layer lidar ratio

$$S = \frac{1}{2\eta\gamma'} = S(PGR)$$

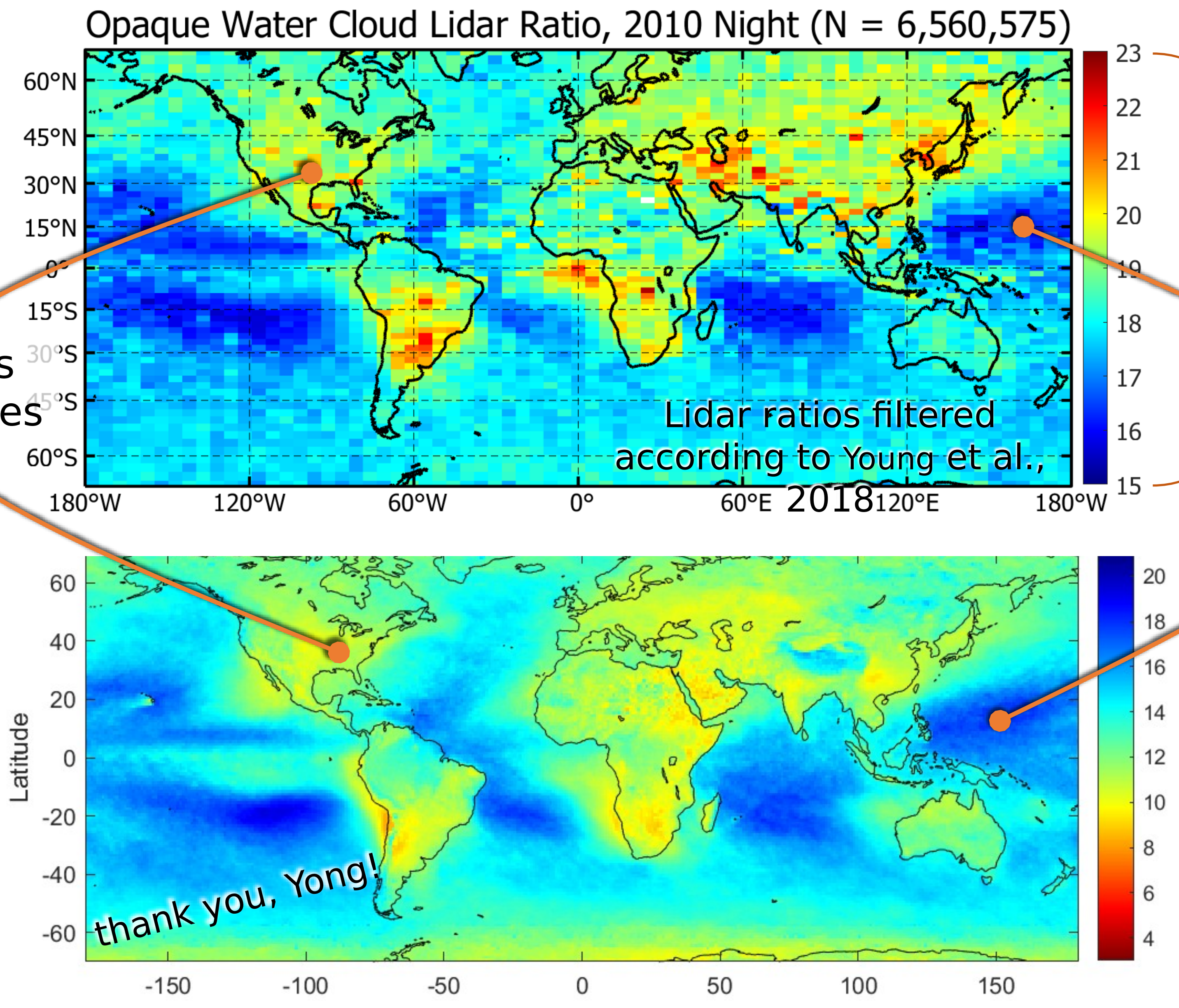


Correlation with MODIS Effective Radius Estimates (Day)



MODIS Effective Radius, 2010 Day

Correlation with MODIS Effective Radius Estimates (Night)

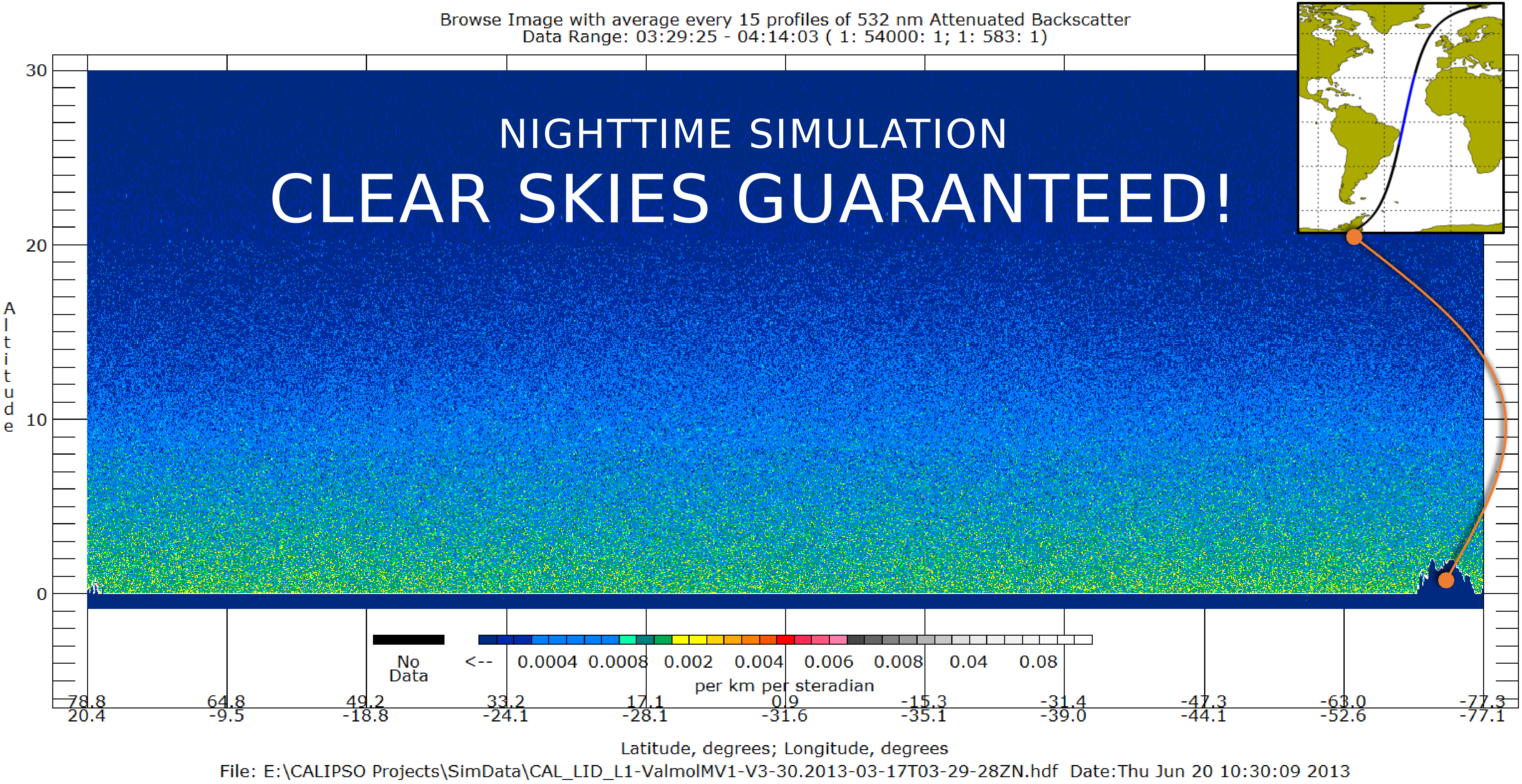


MODIS Effective Radius, 2010 Day

higher lidar ratios
smaller droplet sizes

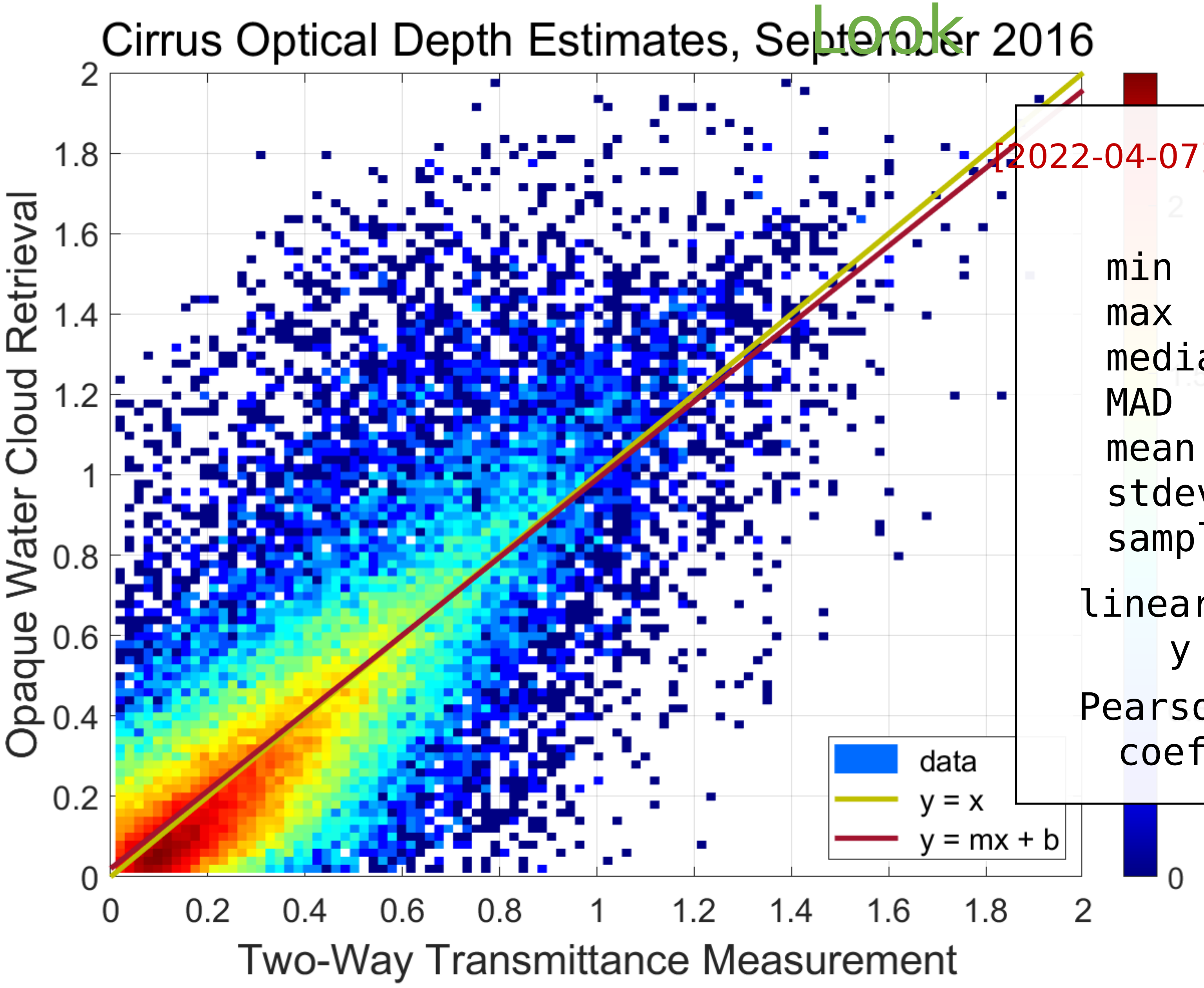
lower lidar ratios
larger droplet sizes

note:
different
color scale!



Output from Kathy Powell’s Super-Duper CALIOP Simulator

Transparent Cirrus Above Opaque Water Clouds: A First Look



[2022-04-07]V4x5Level2BugUpdates[Mark].pptx

	T^2	OWC
min	0.0001	-0.8905
max	1.9289	4.3721
median	0.2446	0.2126
MAD	0.2015	0.2491
mean	0.3175	0.3148
stdev	0.2616	0.3320
samples	44679	44679

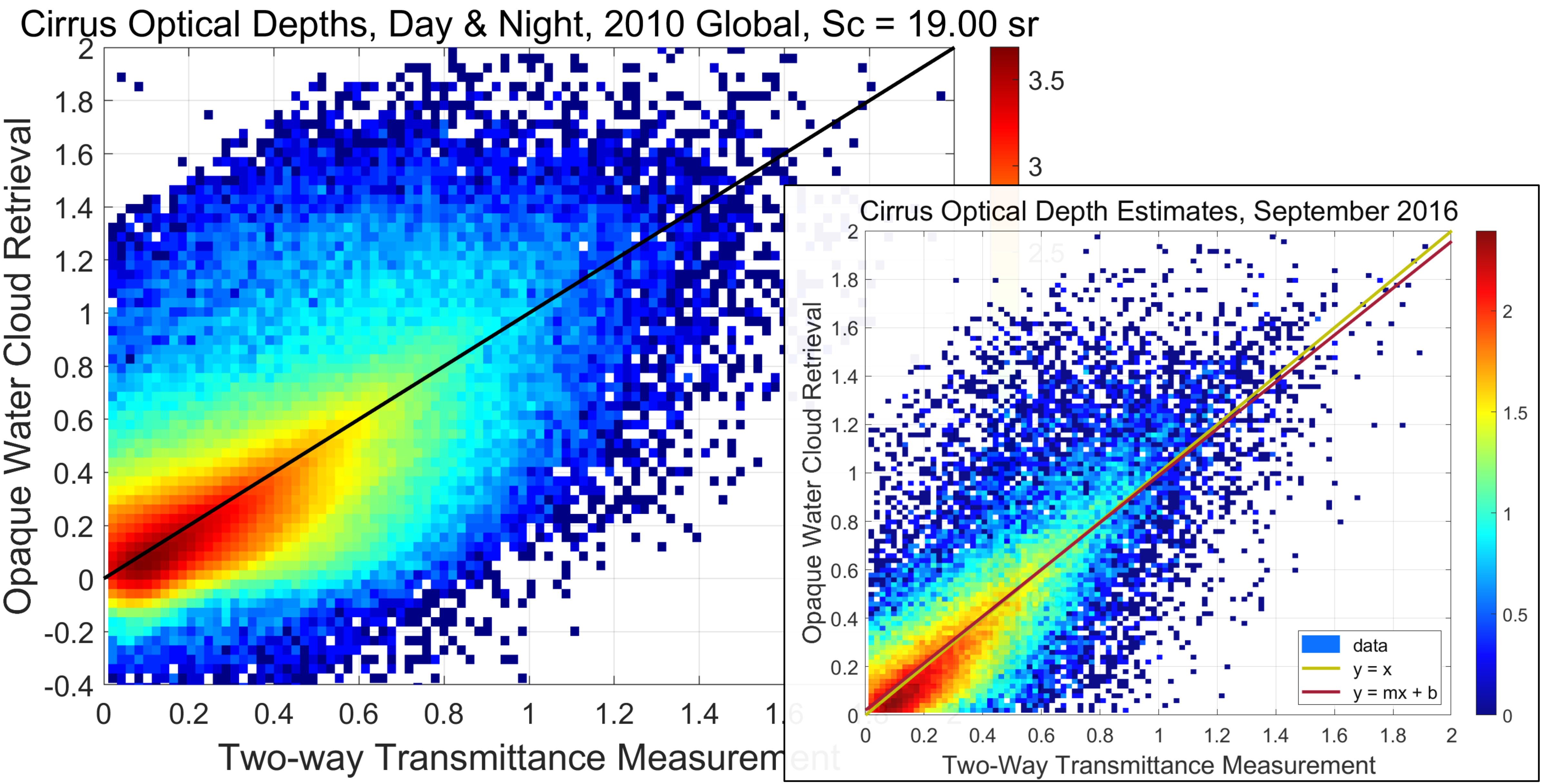
linear fit:

$$y = 0.9680\,x + 0.0206$$

Pearson’s linear correlation coefficient: rho = 0.7797

$S_c = 19$ sr

Transparent Cirrus Above Opaque Water Clouds: 2010



Data filtering as in Young et al., 2018 (https://doi.org/10.5194/amt-11-5701-2018)

$$0.021\ sr^{-1} \leq \gamma'_{532} \leq 0.111\ sr^{-1}$$

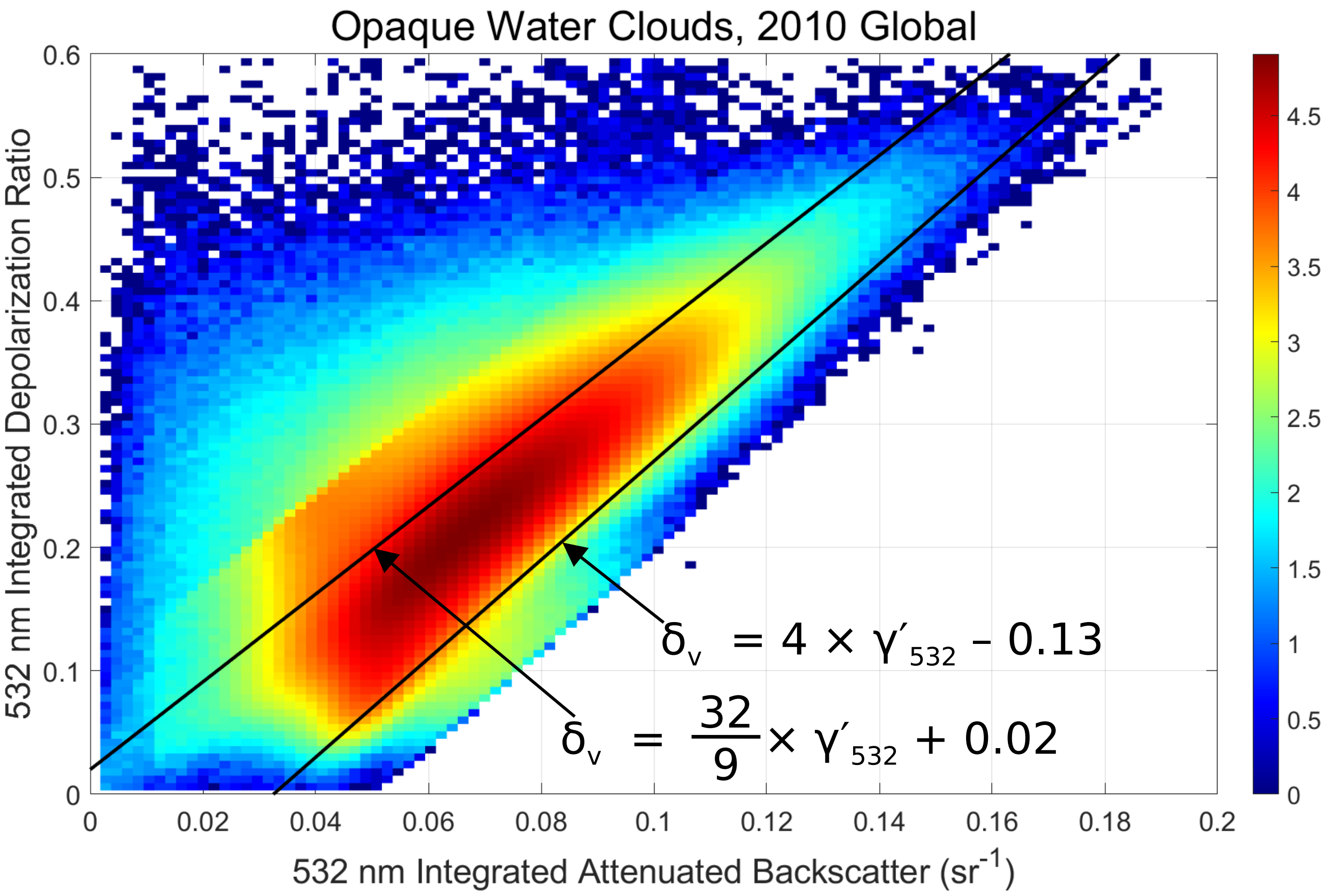
$$0.03 \leq \delta_v \leq 0.39$$

$$0.90 \leq \chi' \leq 1.50$$

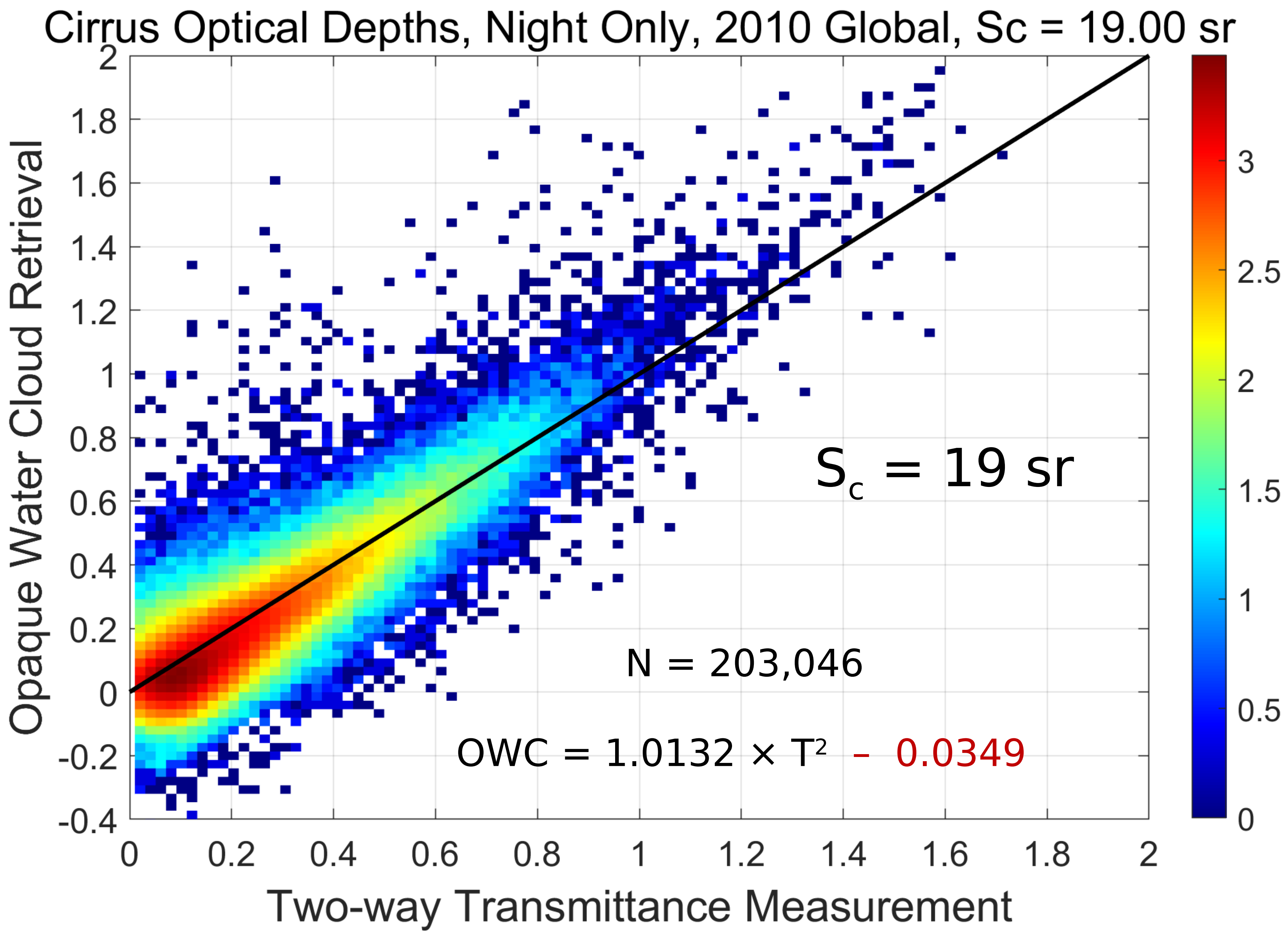
	Day (all)	Day (filtered)	Night (all)	Night (filtered)
min	6.06	9.77	5.71	9.78
max	11,342,979	118.75	134,459	91.4
median	**18.76**	**18.71**	**17.67**	**17.65**
MAD	7.53	2.48	2.22	2.00
mean	22.66	19.25	18.21	18.01
stdev	4335.43	3.55	53.38	2.91
samples	13,497,968	13,153,250	6,644,591	6,560,575

Young et al. 2008-2010 **5-km** , V4.2 median Day: 18.27 median Night: 16.89

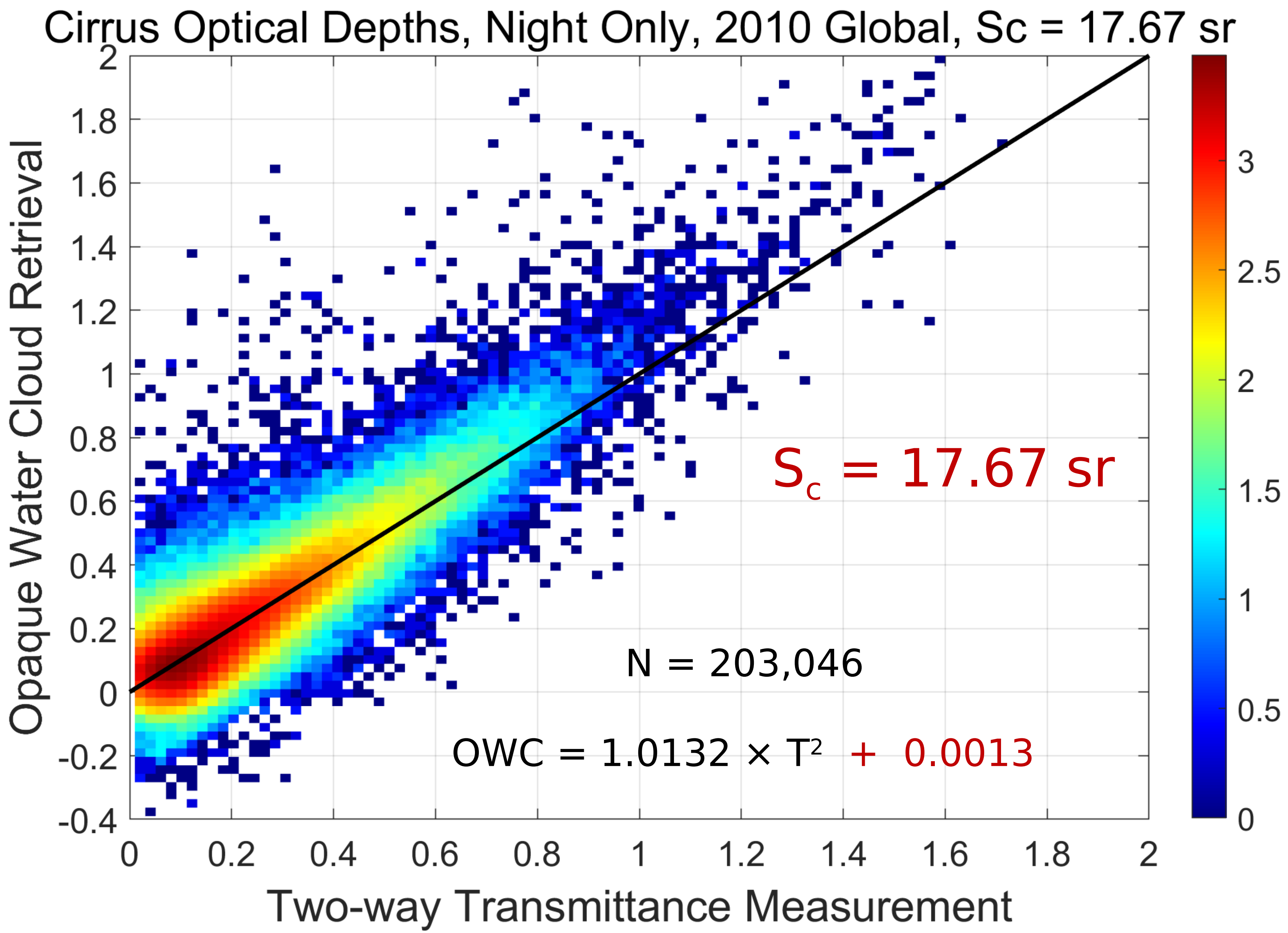
Mace, Benson, and Hu, 2020: On the Frequency of Occurrence of the Ice Phase in Supercooled Southern Ocean Low Clouds Derived From CALIPSO and CloudSat, https://doi.org/10.1029/2020GL087554



	Day (all)	Night (all)
min	12.96	12.96
max	4096.08	659.49
median	**18.29**	**17.54**
MAD	1.71	1.57
mean	18.35	17.62
stdev	3.50	2.87
samples	11,306,800	6,140,160



Cirrus Optical Depths, Night Only, 2010 Global, Sc = 19.00 sr
Opaque Water Cloud Retrieval
Two-way Transmittance Measurement
S_c = 19 sr
N = 203,046
OWC = 1.0132 × T² – 0.0349
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
3
2.5
2
1.5
1
0.5
0



Cirrus Optical Depths, Night Only, 2010 Global, Sc = 17.67 sr
Opaque Water Cloud Retrieval
Two-way Transmittance Measurement
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
3
2.5
2
1.5
1
0.5
0
S_c = 17.67 sr
N = 203,046
OWC = 1.0132 × T^2 + 0.0013