

# Creating Regional and Seasonal Climatologies of Marine and Dusty Marine Aerosol Lidar Ratios using MODIS AOD Constrained Retrievals and GOCART Model Simulations

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# Introduction & motivation for this study

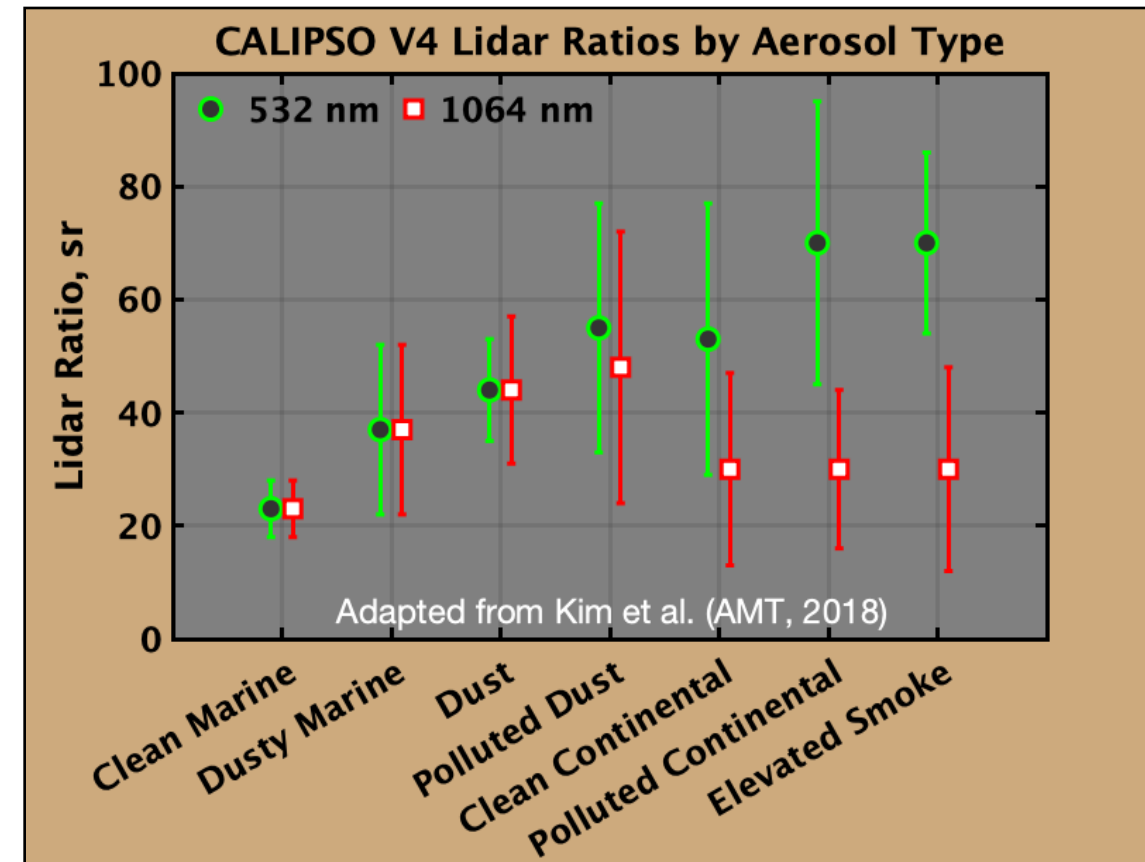
- After 17 years, the NASA CALIPSO mission ceased science operations in August 2023
- For the final CALIPSO data products release (Version 5), the CALIPSO project seeks to improve the accuracy of its aerosol extinction profiles by revising the aerosol lidar ratios (extinction-to-backscatter ratios; LRs) associated with various aerosol types
- For CALIOP, the elastic backscatter lidar aboard CALIPSO:

Aerosol Type → Lidar Ratio → Retrieve Extinction (z)

**\*Goal of this study:** creation of regional and seasonal climatological LR maps for marine and dusty marine aerosols through a combined observational/model approach by leveraging:

- Backscatter profiles (CALIOP)
- Passive aerosol retrievals (Aqua MODIS)
- Global aerosol model simulations (GEOS/GOCART)

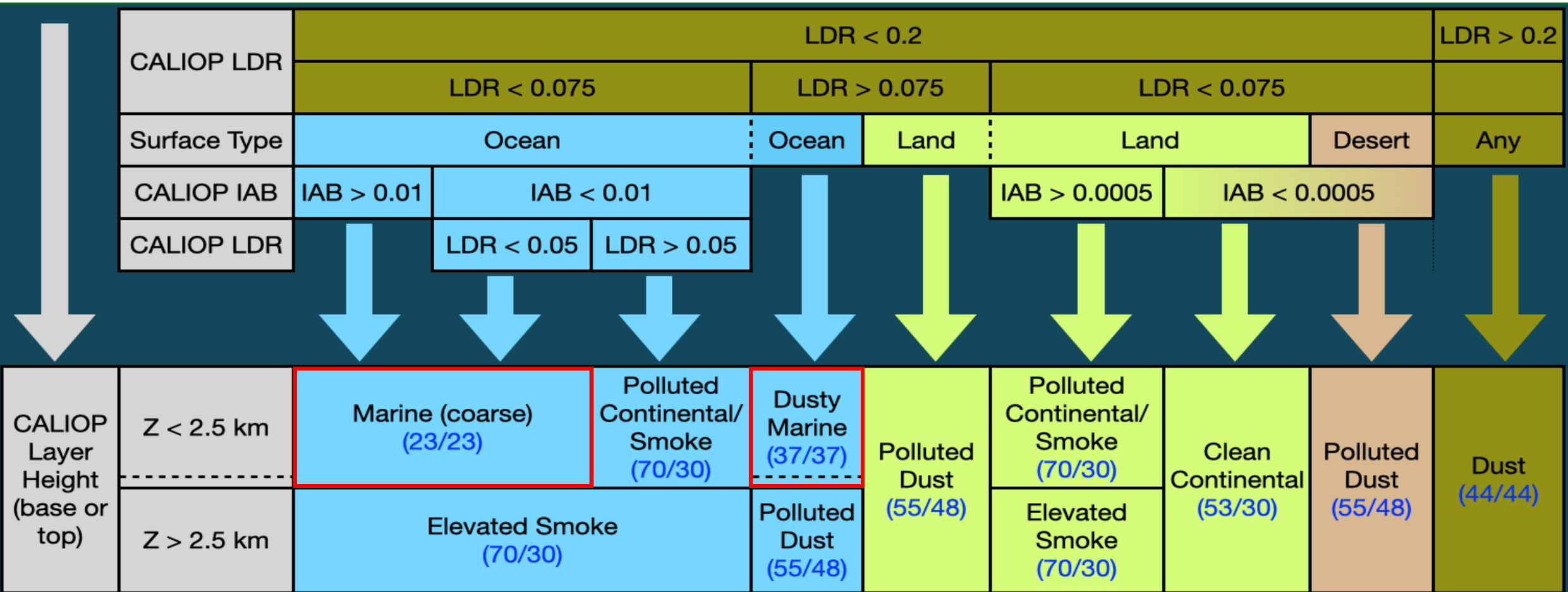
Current algorithm assigns one LR value globally for each of the seven tropospheric aerosol types:



# CALIPSO Version 4 Lidar Ratio Selection Process

IAB: 532 nm integrated attenuated backscatter (i.e., signal strength)  
(532/1064) lidar ratios

LDR: 532 nm estimated linear depolarization ratio



Adapted from Kim et al. (AMT, 2018)

# Data & Methods

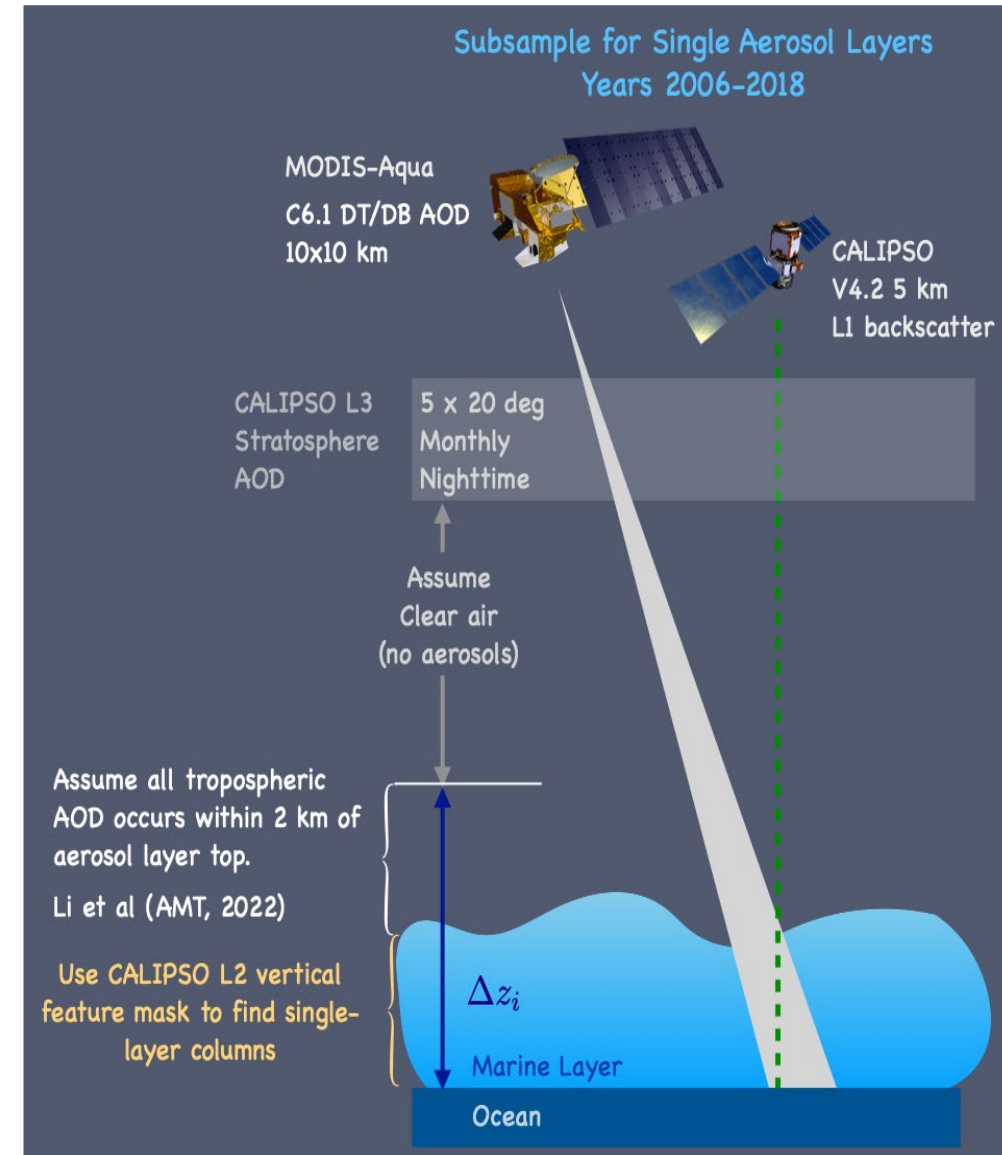
1. Use MODIS column-integrated AOD to constrain collocated CALIOP backscatter profiles and infer aerosol LR (Fernald, 1972); cloud screening; incorporates stratospheric AOD.

2. Create subset of data for profiles with only:
- CALIOP-classified marine and dusty marine aerosols
  - Feature Type QA = 3 (high confidence)
  - Contains 5 km spatial averages

3. Compute sea salt volume fractions (< 2.5 km) from model data.

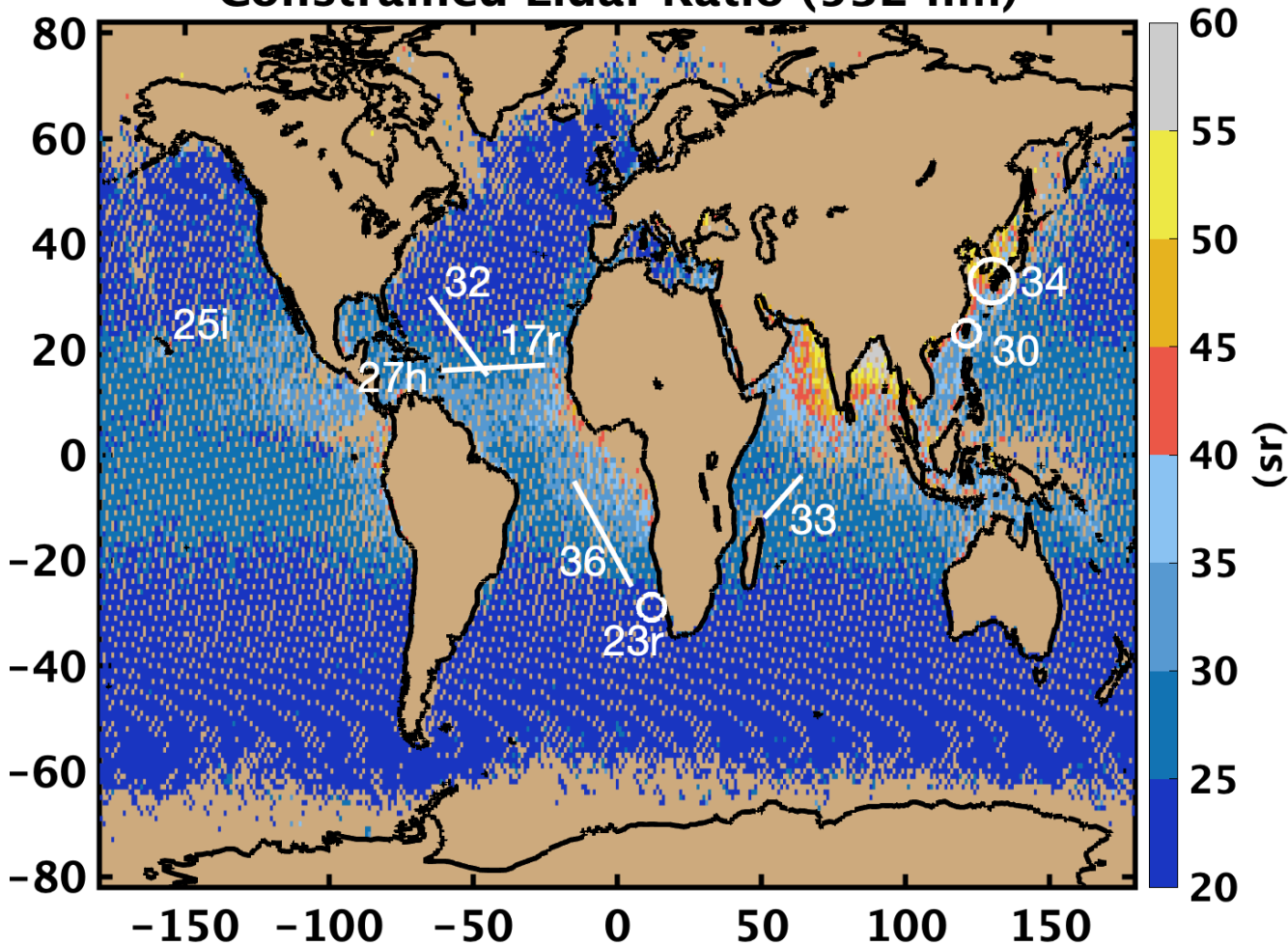
4. Collocate and develop relationship between daily modeled sea salt volume fractions with Fernald-retrieved marine and dusty marine LRs.

5. Use model/retrieval relationship to build seasonal LR maps.



# MODIS AOD-constrained LRs & comparisons with past studies

12-year median (2006-2018) on 1x1 degree grid  
Constrained Lidar Ratio (532 nm)

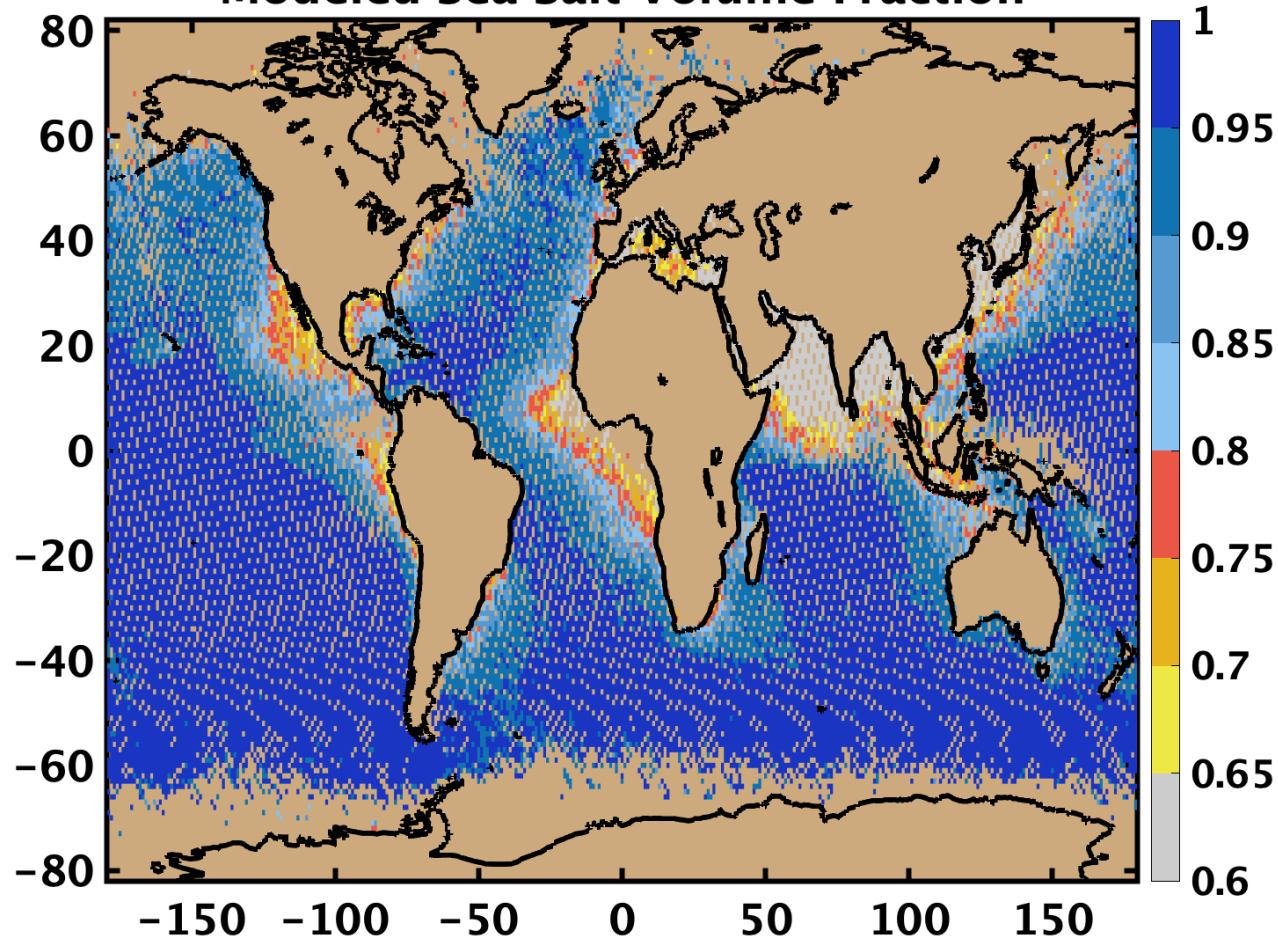


Study	532 nm Lidar Ratio (sr)	Method/Technique
Bohmann (2018)	$23 \pm 1$	Raman
Burton et al. (2012)	$20 \pm 5$	HSRL
Dawson et al. (2015)	26	SODA AOD & CALIOP IAB
Masonis (2003)	$25 \pm 3.5$	<i>In situ</i>
Rittmeister (2017)	$17 \pm 5$	Raman
Rogers et al. (2014)	$27 \pm 14$	HSRL
Schmid (2003)	34	Fernald inversion (MPL)
Voss (2001)	$32 \pm 6$ $36 \pm 16$	Fernald inversion (MPL)
Wang (2020)	$30 \pm 12$	Fernald inversion (MPL)
Welton (2002)	$33 \pm 6$	Fernald inversion (MPL)

# Sea salt volume fractions from GEOS/GOCART

12-year mean (2006-2018) on 1x1 degree grid

## Modeled Sea Salt Volume Fraction

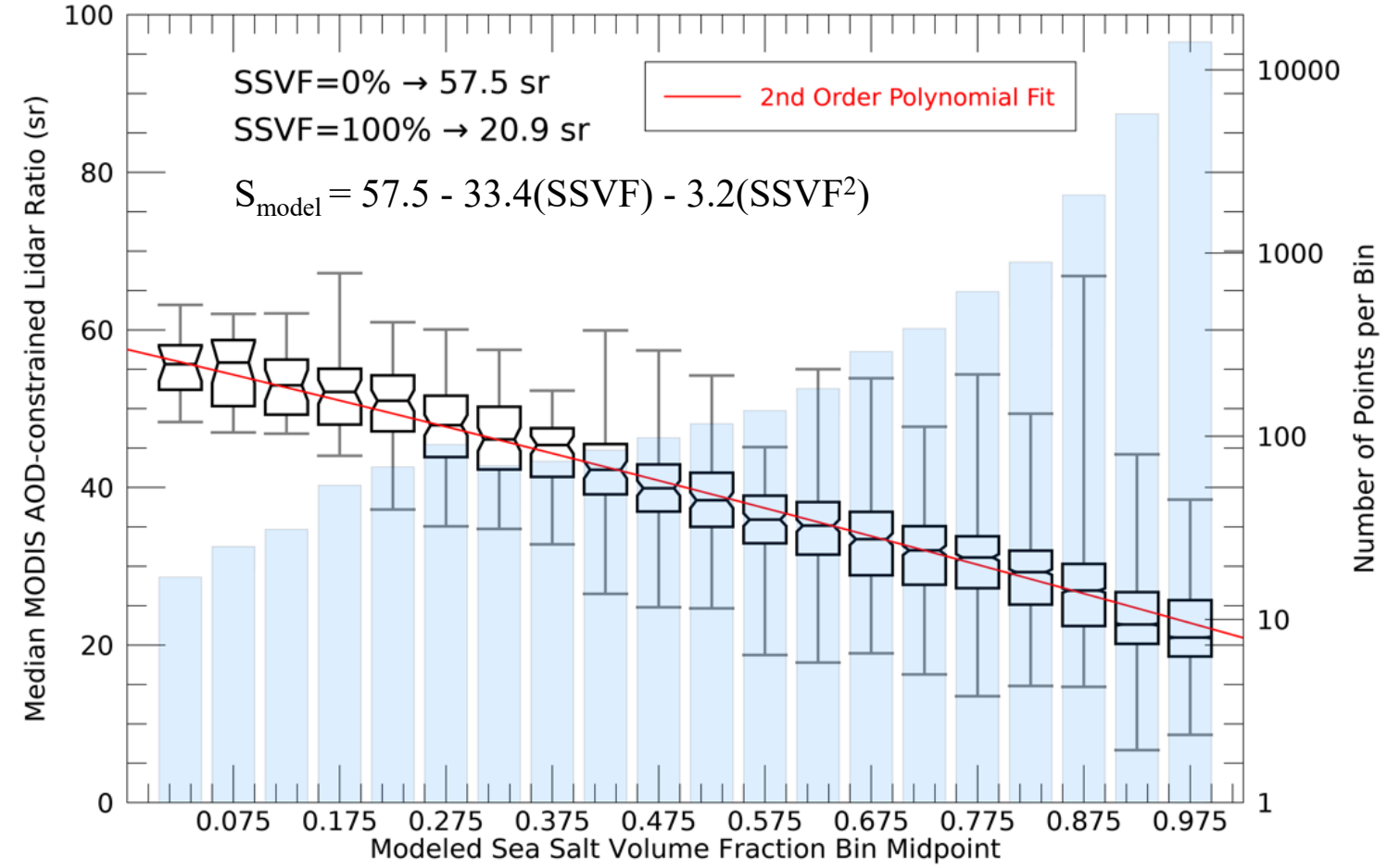
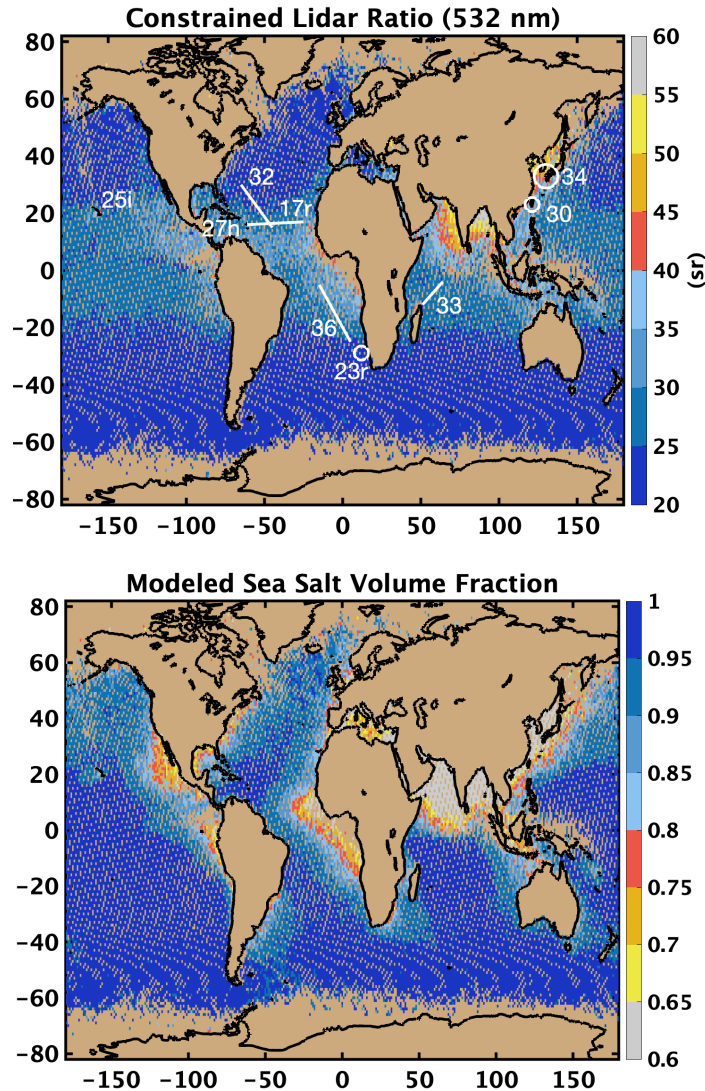


## Computation of Modeled Sea Salt Volume Fractions:

- Aerosol Species:  $\text{SO}_4$ ,  $\text{SO}_4\text{v}$ ,  $\text{NH}_4\text{a}$ ,  $\text{NO}_3$  (3 bins), BC, BrC, OC, Dust (5 size bins), Sea salt (5 size bins), but excluding dust for this analysis (because CALIPSO marine has low linear depolarization ratios)
- Convert mass mixing ratios ( $\text{kg kg}^{-1}$ ) to volumes ( $\text{m}^3$ )
- Below 2.5 km, sea salt volume fraction computed as:

$$\frac{\Sigma(\text{sea salt volume})}{\Sigma(\text{total aerosol volume, no dust})}$$

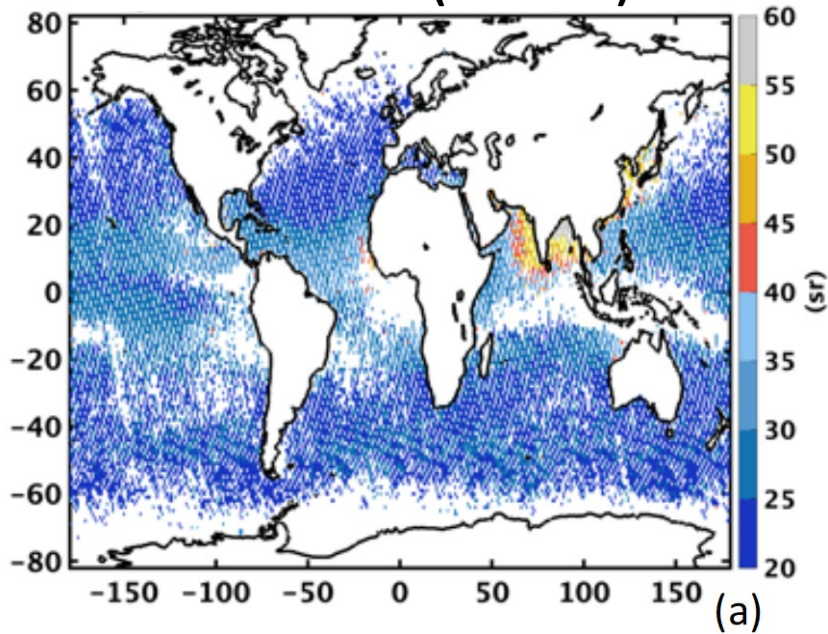
# Developing the relationship between modeled sea salt volume fraction & MODIS AOD-constrained lidar ratio retrievals\*



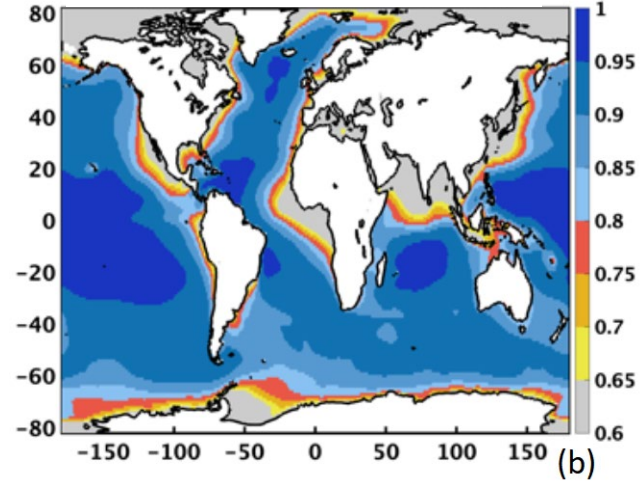
\*Will use this relationship to create seasonal maps of lidar ratios...

# Building the seasonal LR Maps (DJF)

LR Retrievals (medians)



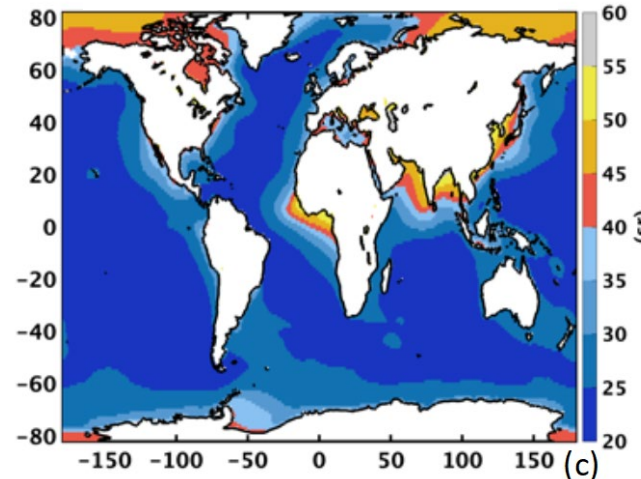
Modeled Sea Salt Volume Fraction



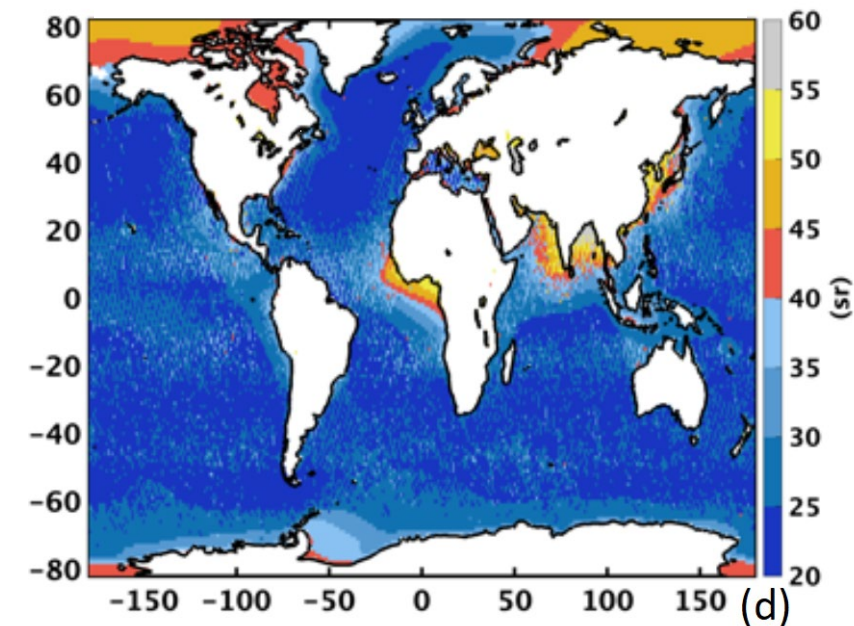
$$S_{\text{model}} = 57.5 - 33.4(\text{SSVF}) - 3.2(\text{SSVF}^2)$$



Modeled-assisted LRs



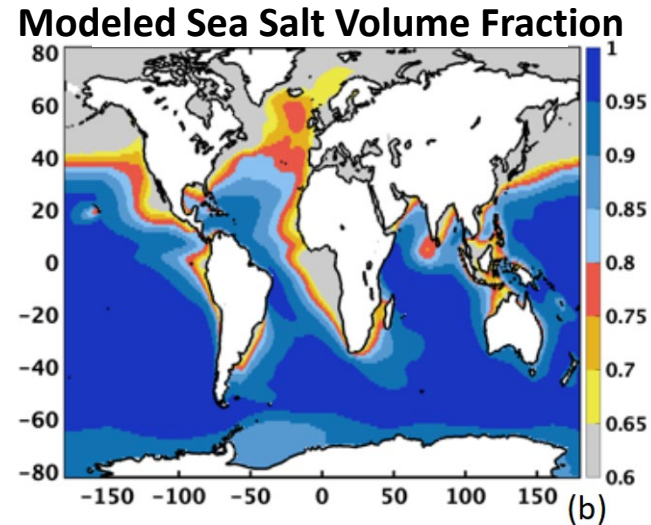
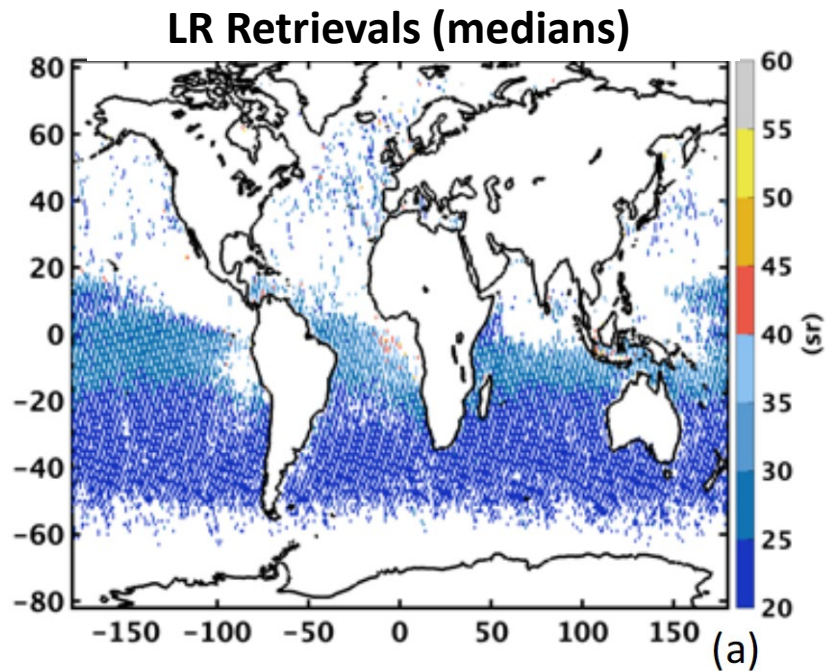
Hybrid LRs (Retrieval+Model)



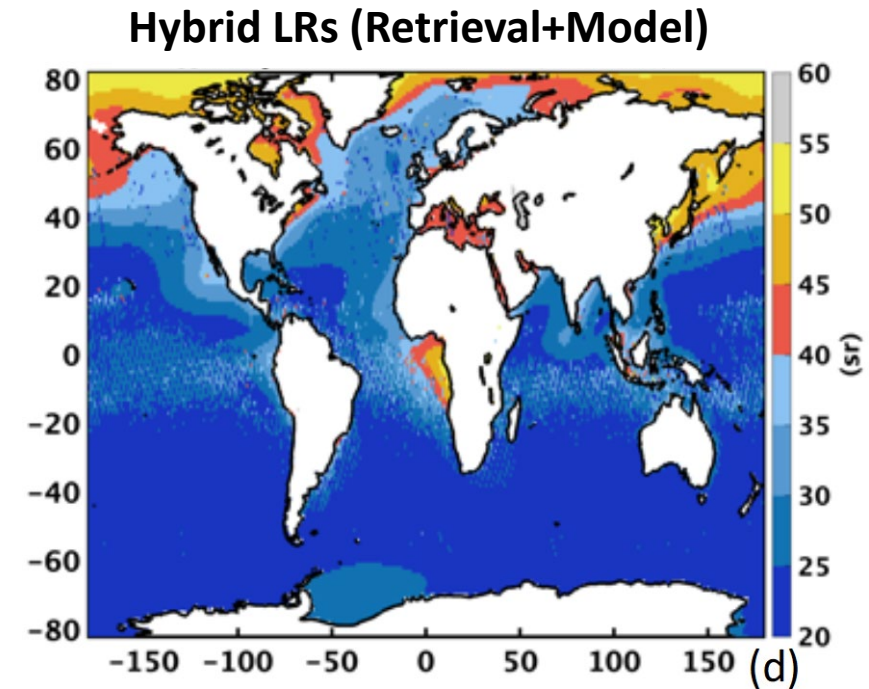
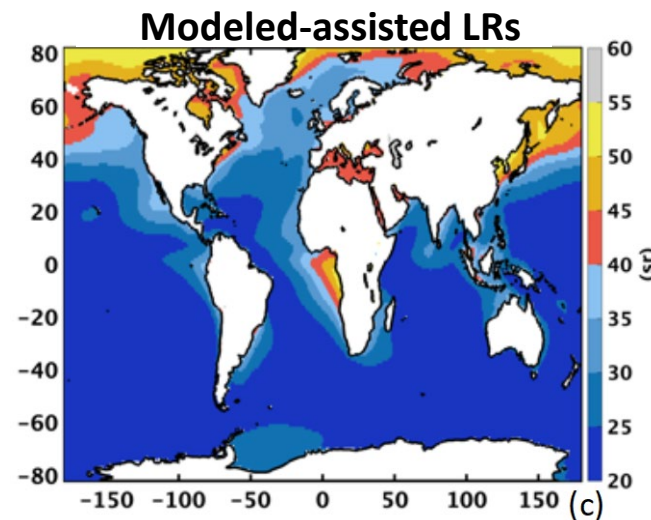
- For retrievals, require  $N \geq 9$  and  $RSE \leq 10\%$  per grid box

- Model helps with lack of retrievals in some regions

# Building the seasonal LR Maps (JJA)



$$S_{\text{model}} = 57.5 - 33.4(\text{SSVF}) - 3.2(\text{SSVF}^2)$$

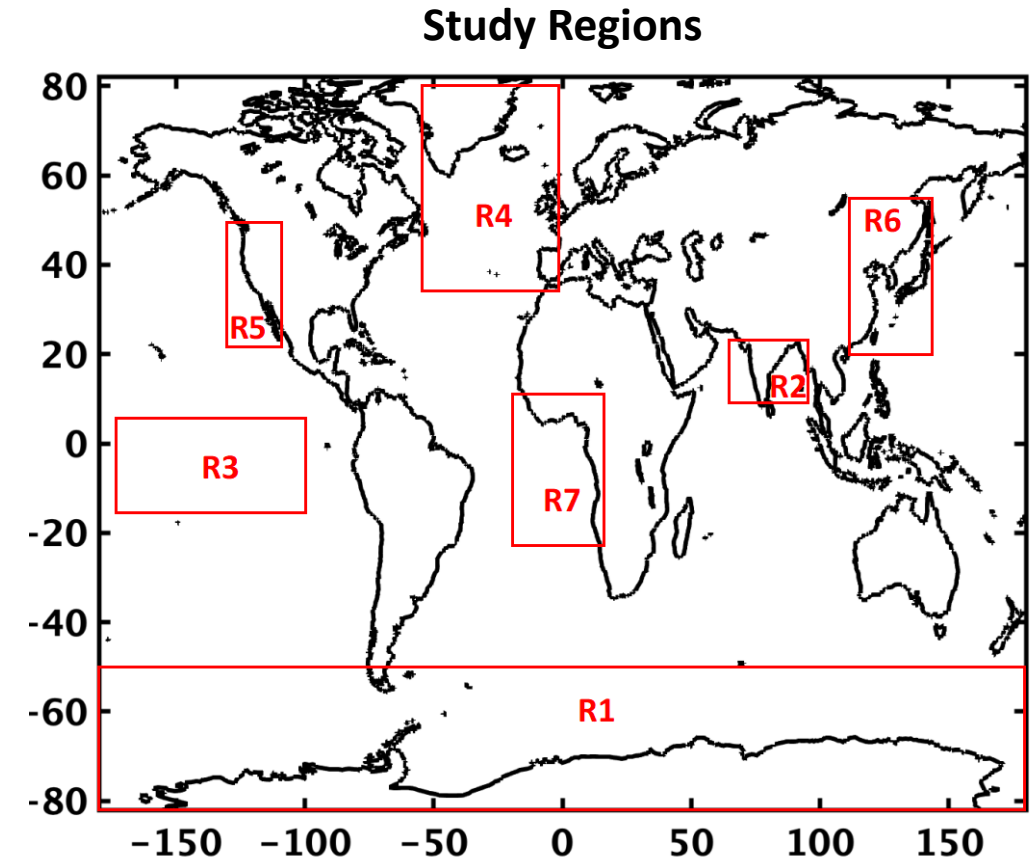


- For retrievals, require  $N \geq 9$  and  $RSE \leq 10\%$  per grid box

- Model helps with lack of retrievals in some regions

# Initial validation efforts: Assessing the impact of the LR maps using standard CALIPSO V4.51 AODs and Ocean Derived Column Optical Depth (ODCOD)

- Lidar ratio LUT:
  - Only modified for marine and dusty marine aerosols
  - Retrieval + Model Hybrid (uses MODIS AOD constrained lidar ratio retrieval when there is one available, otherwise model-assisted (i.e., from model sea salt volume fraction))
- Performed comparisons using:
  - **Standard Version 4.51** 05km\_APro: Column\_Optical\_Depth\_Tropospheric\_Aerosols\_532
  - **New** 05\_km\_Apro: Column\_Optical\_Depth\_Tropospheric\_Aerosols\_532
  - **ODCOD** (minus stratospheric AOD from CALIPSO L3; w/ QA filtering)
- Focused on four months: January, April, July, & October (2014); only daytime & over-ocean
- Eight analyses:
  - Global oceans
  - Seven regions



**R1:** Southern Oceans

**R2:** Bay of Bengal/Arabian Sea

**R3:** Remote Pacific Ocean

**R4:** North Atlantic Ocean

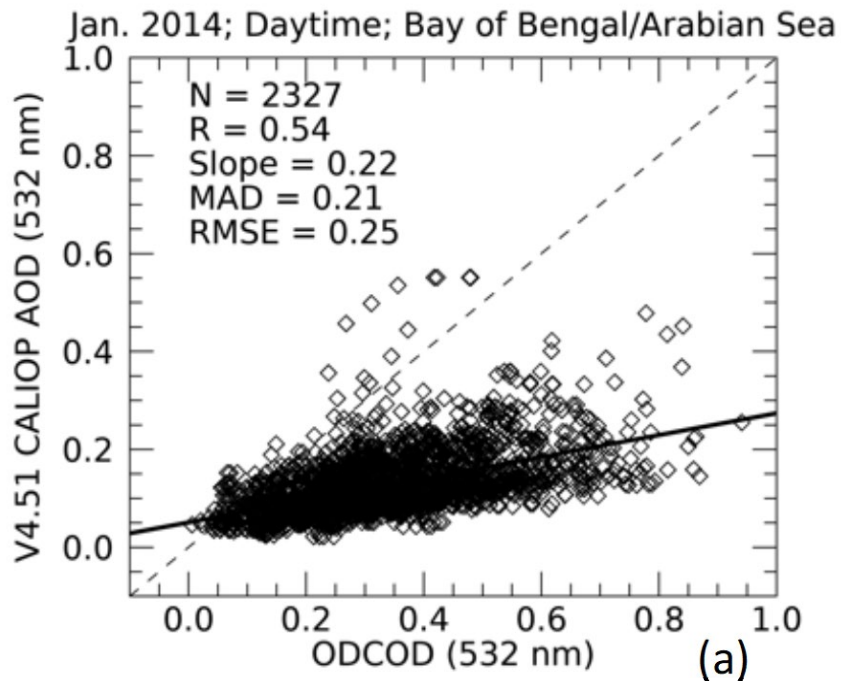
**R5:** West Coast of North America

**R6:** Asia coast

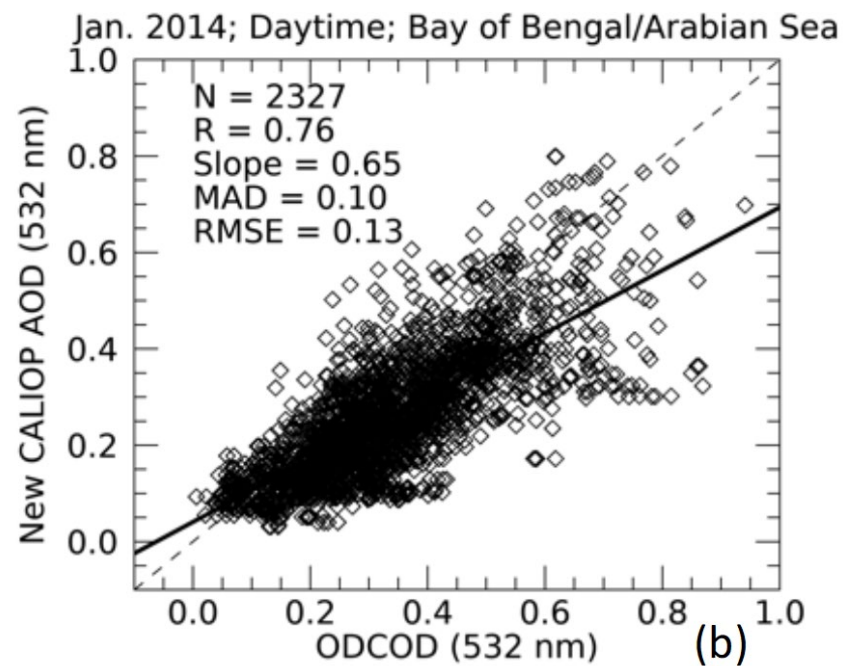
**R7:** West Coast of Africa

# Initial validation efforts: Bay of Bengal and Arabian Sea (January 2014)

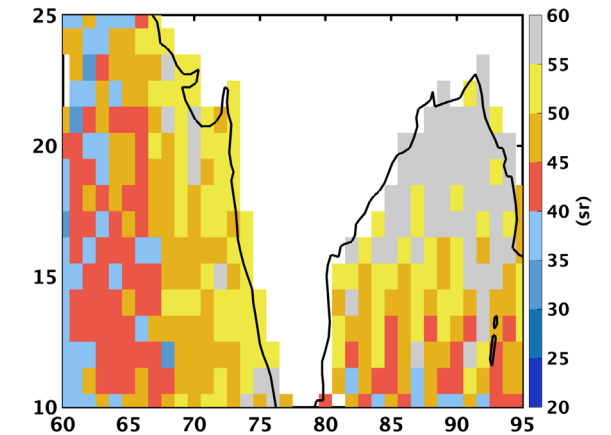
## Using V4.51 Lidar Ratios



## Using new Lidar Ratio LUTs



## DJF Hybrid LRs (Retrieval+Model)



## Mean AOD Differences:

V4.51 – ODCOD	New – ODCOD	AOD Improvement
-0.209	-0.075	0.134

# Summary

- Goal of this study: use the long-term lidar data record from CALIPSO to develop regional and seasonal maps of aerosol lidar ratios over ocean
- Advantage of approach is using a model to fill gaps in the seasonal climatologies, and the maps provide improved lidar ratio transitions in coastal regions
- Technique demonstrated here benefits the final planned CALIPSO data release in 2025 (Version 5)
- Similar methods have been applied to other CALIOP aerosol types (e.g., elevated smoke, polluted continental/smoke, & dust), but will not be included in Version 5 (manuscripts in preparation)
- Future validation efforts for CALIOP marine and dusty marine lidar ratio LUTs for entire data record:
  - Comparisons of new CALIOP AOTs against coastal/island AERONET sites and MAN data
  - Aerosol extinction profile comparisons with coincident airborne HSRL measurements

# Models, In situ, and Remote sensing of Aerosols (MIRA)

*200+ members in 22 countries and growing!*

- MIRA is a forum that encourages interdisciplinary work and fosters international collaborations
- MIRA is also a collection of Topics/Projects (presently we have five):
  - Maps of Aerosol lidar ratios for CALIPSO (MAC)
  - Satellite-Assisted Particulate Matter (SAPM)
  - Tables of Aerosol Optics (TAO)
  - Harmonization of aerosol Assimilation Models and Retrievals (HAMR)
  - Table of Cloud Optics (TaCO)



\*We seek more projects. If you have a multi-disciplinary project, consider contacting the MIRA steering committee at <https://science.larc.nasa.gov/mira-wg/contacts/>

**MIRA webpage**



<https://science.larc.nasa.gov/mira-wg/>

**Join us with these links!**

**MIRA news**

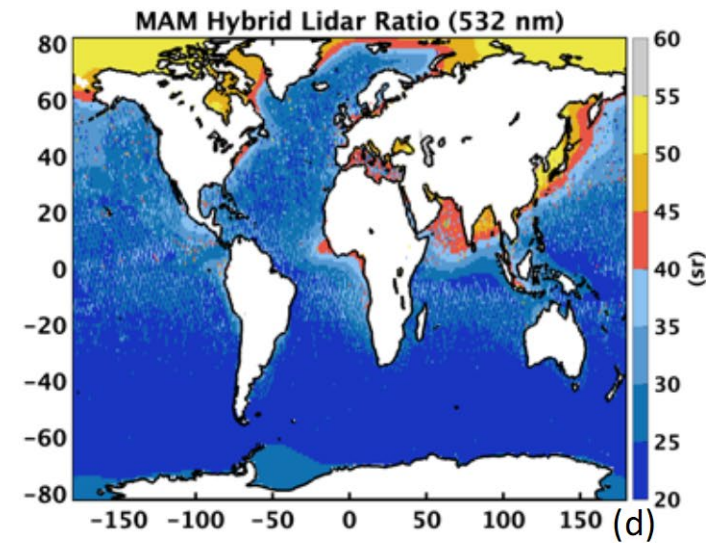
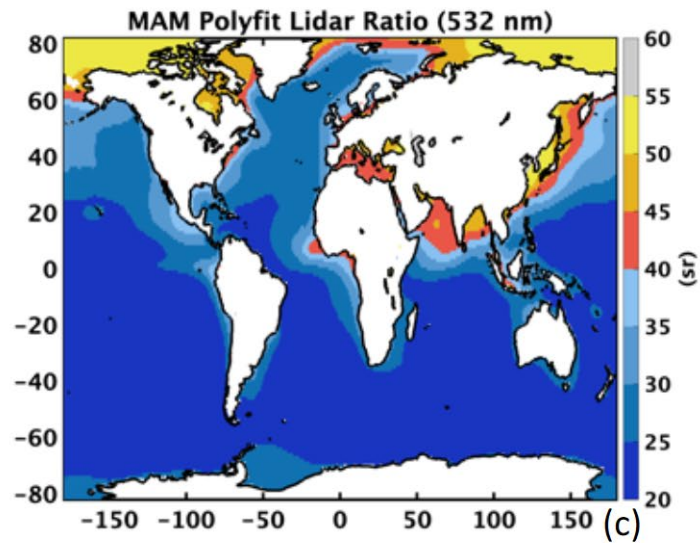
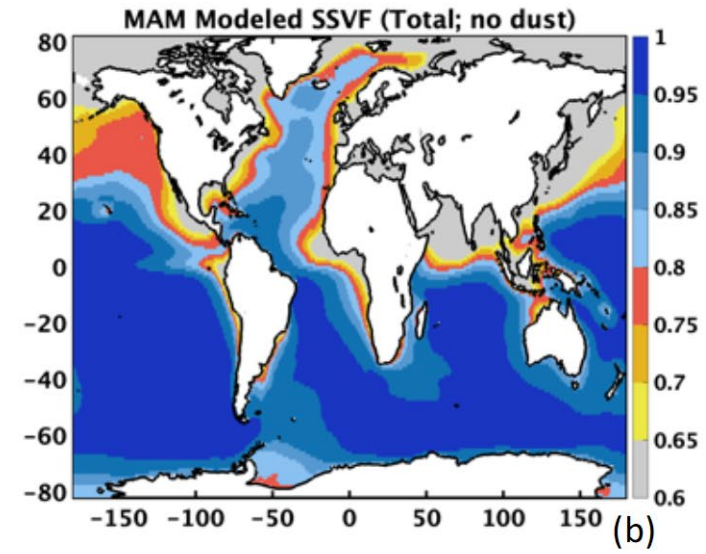
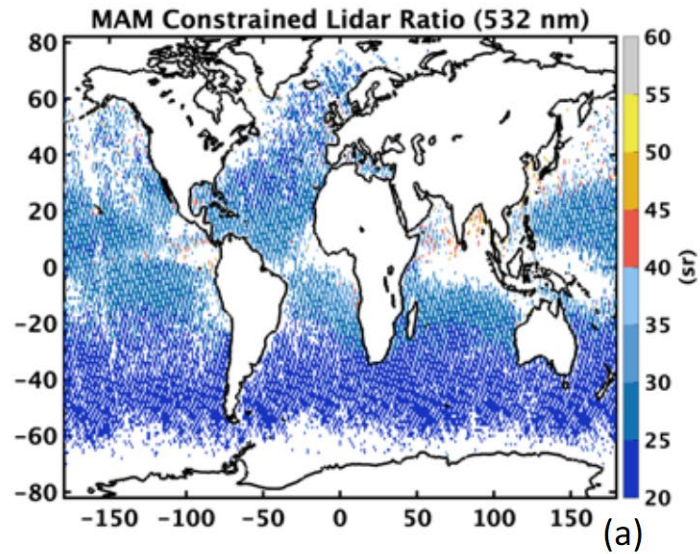


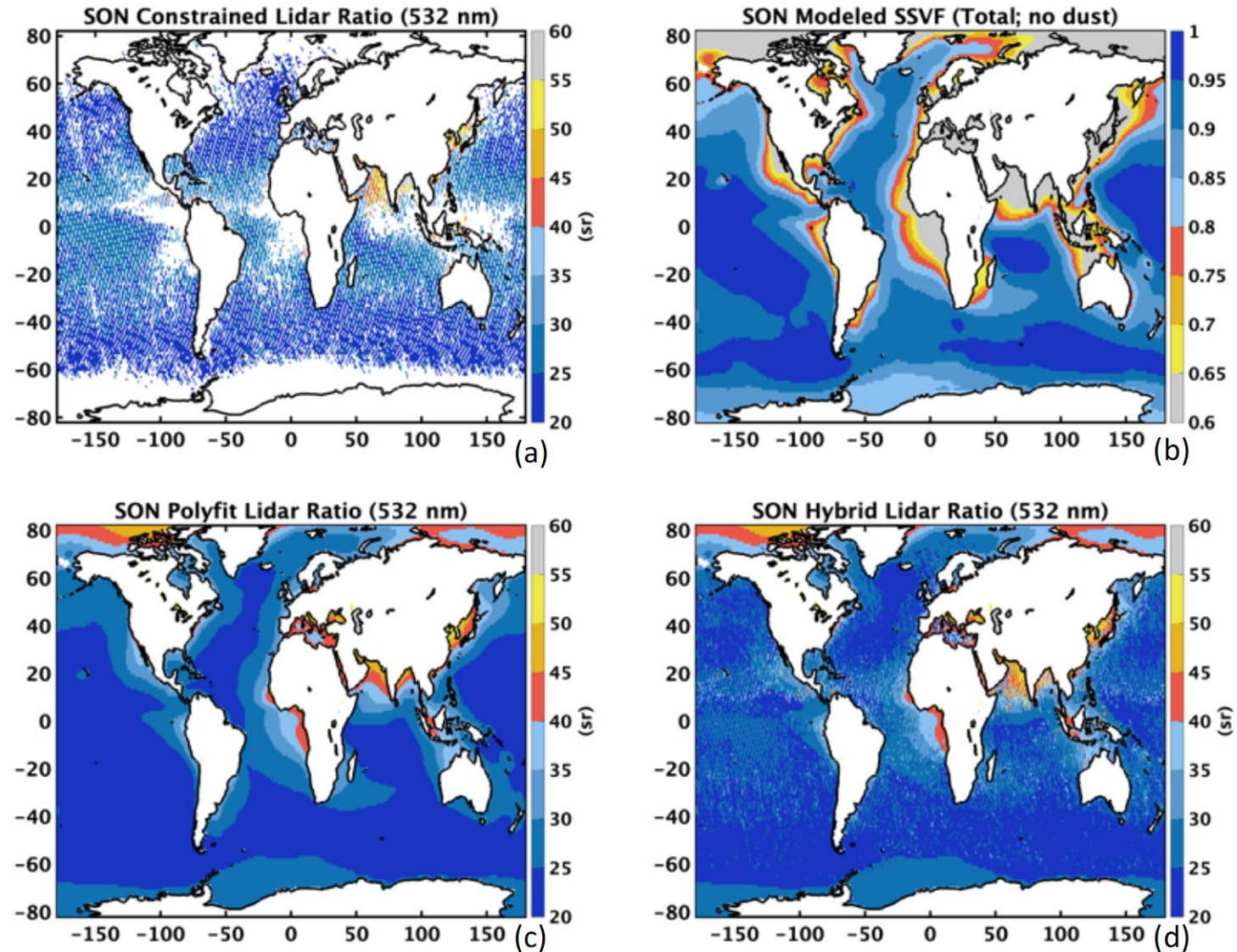
<https://espo.nasa.gov/lists/listinfo/mira>

# Acknowledgements & References

- Funding through support of the NASA CALIPSO Project
- CALIPSO data obtained from the NASA LaRC ASDC
- References:
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  - MODIS data obtained from NASA GSFC
  - Model data obtained from NASA Discover server (NCCS)

# Backup slides





# Initial validation efforts: Assessing the impact of the LR maps using standard CALIPSO V4.51 AODs and ODCOD

$\bar{\tau}_1$	$\bar{\tau}_2$
V4.51	ODCOD
MIRA	ODCOD

Statistically significant differences if:

$$|t| \geq 2$$
$$(p \leq 0.05)$$

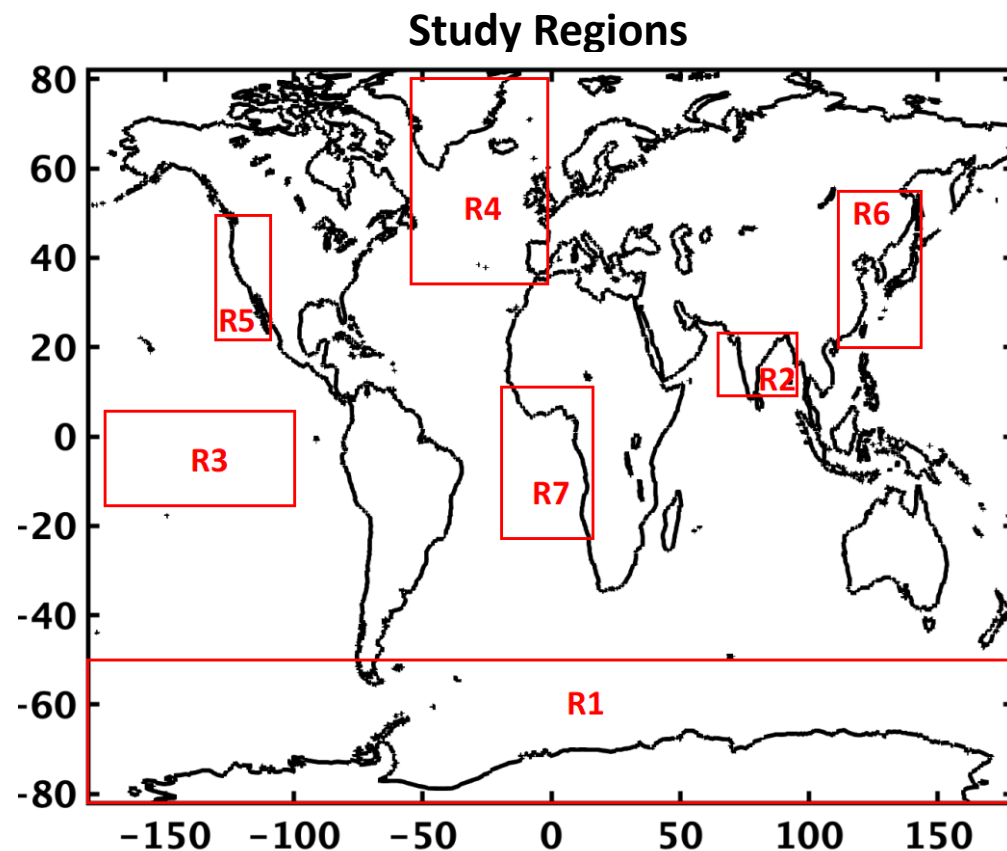
t = t-score

$$B_a = \bar{\tau}_1 - \bar{\tau}_2$$

$B_a$  = absolute bias

$$t = \frac{B_a}{\sigma_a}$$

$\sigma_a$  = standard error of  $B_a$



**R1:** Southern Oceans

**R2:** Bay of Bengal/Arabian Sea

**R3:** Remote Pacific Ocean

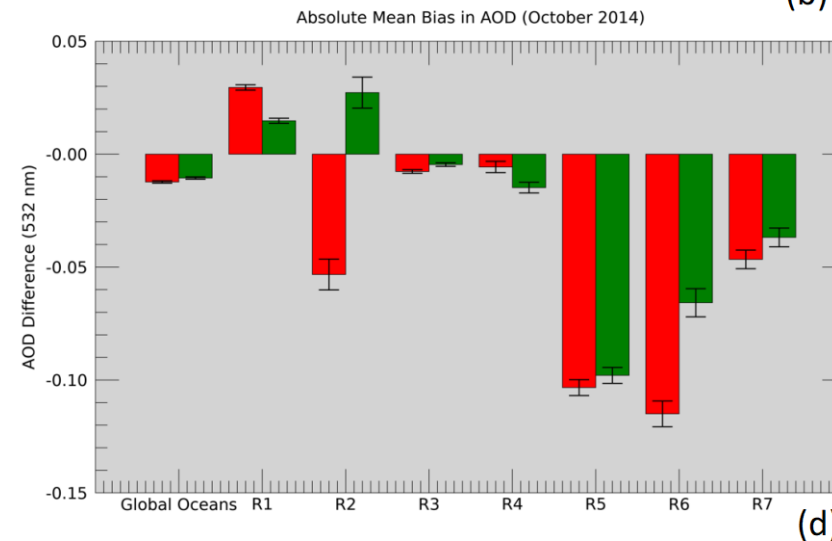
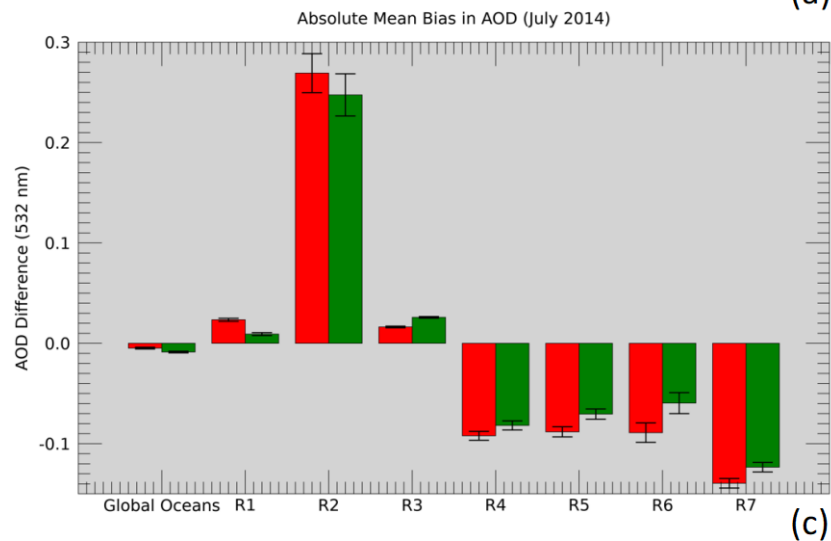
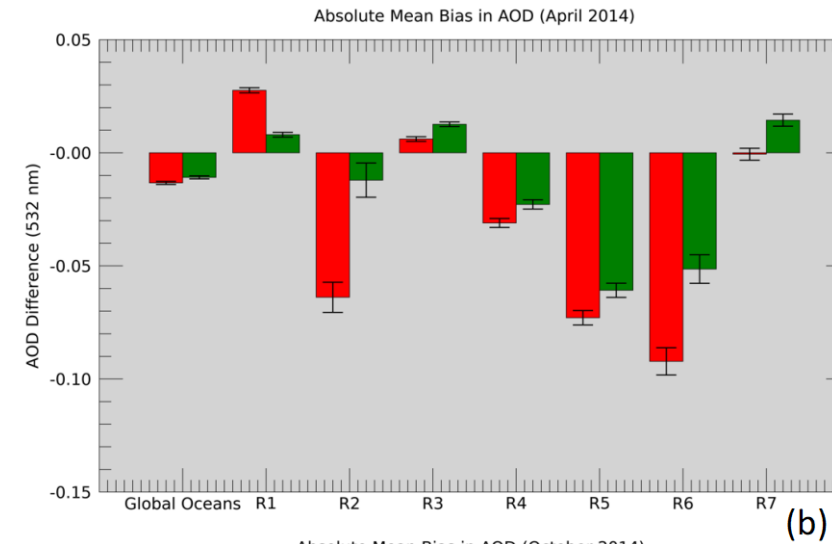
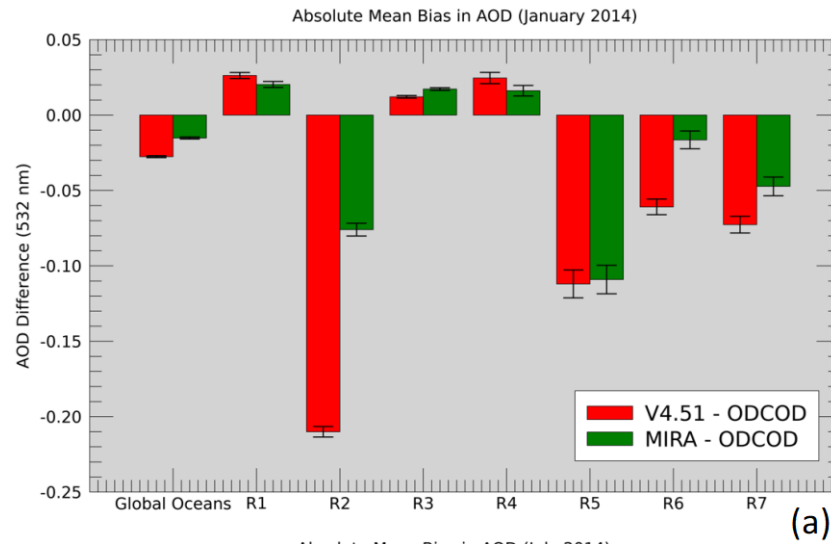
**R4:** North Atlantic Ocean

**R5:** West Coast of North America

**R6:** Asia coast

**R7:** West Coast of Africa

# Initial validation efforts: Assessing the impact of the LR maps using standard CALIPSO V4.51 AODs and ODCOD



# Initial validation efforts: Assessing the impact of the LR maps using standard CALIPSO V4.51 AODs and ODCOD

**Mean AOD Differences**

Region	Region Lat./Lon. Boundaries (°)	January 2014	April 2014	July 2014	October 2014
Global Oceans	-90 to 90; -180 to 180	0.012	0.002	<b>0.004</b>	0.002
Southern Oceans (R1)	-90 to -50; -180 to 180	0.006	0.020	0.014	0.015
Bay of Bengal/Arabian Sea (R2)	10 to 25; 60 to 95	0.134	0.052	0.022	0.026
Remote Pacific Ocean (R3)	-15 to 5; -175 to -105	<b>0.005</b>	<b>0.007</b>	<b>0.010</b>	0.003
North Atlantic Ocean (R4)	35 to 90; -60 to 0	0.008	0.008	0.010	<b>0.009</b>
West Coast of North America (R5)	25 to 50; -128 to -110	0.003	0.012	0.018	0.005
Asia Coast (R6)	20 to 55; 110 to 140	0.044	0.041	0.029	0.049
West Coast of Africa (R7)	-25 to 15; -15 to 15	0.025	<b>0.014</b>	0.016	0.010

Bold values indicate those analyses (month/region) for which the new AOD is further from ODCOD. All other analyses exhibit new AODs closer to ODCOD (i.e., improvement compared to V4.51).

# GO CART model aerosol species

<b>Aerosol Species</b>	<b>Dry size (radius; <math>\mu\text{m}</math>)</b>	<b>Particle Density (kg <math>\text{m}^{-3}</math>)</b>
<b>Sulfate &amp; Volcanic Sulfate</b>	0.35	1700
<b>Ammonium ion</b>	0.2695	1769
<b>Nitrate (size bin 1)</b>	0.2695	1725
<b>Nitrate (size bin 2)</b>	2.1	2200
<b>Nitrate (size bin 3)</b>	7.57	2650
<b>BC, BrC, OC</b>	0.35	1800
<b>Dust (size bin 1)</b>	0.73	2500
<b>Dust (size bin 2)</b>	1.4	2650
<b>Dust (size bin 3)</b>	2.4	2650
<b>Dust (size bin 4)</b>	4.5	2650
<b>Dust (size bin 5)</b>	8.0	2650
<b>Sea Salt (size bin 1)</b>	0.079	2200
<b>Sea Salt (size bin 2)</b>	0.316	2200
<b>Sea Salt (size bin 3)</b>	1.119	2200
<b>Sea Salt (size bin 4)</b>	2.818	2200
<b>Sea Salt (size bin 5)</b>	7.772	2200

# Horizontal averaging sensitivity study of retrieved lidar ratios (CALIOP-classified marine aerosols)

*\*Uses older version of dataset\**

<b>Horizontal Averaging</b>		5 km	20 km	80 km	All
Lidar ratios	<b>Number</b>	1,137,052	4,018,977	1,768,727	11,419,789
	<b>Mean</b>	23.05 sr	32.35 sr	38.71 sr	31.27 sr
	<b>Median</b>	21.57 sr	29.91 sr	35.07 sr	28.34 sr
	<b>Standard Deviation</b>	10.58 sr	16.02 sr	20.65 sr	16.24 sr
	<b>Mean MODIS Fine Mode Fraction</b>	0.40	0.45	0.54	0.45
	<b>Mean Modeled Sea Salt Volume Fraction</b>	0.94	0.92	0.88	0.92
	<b>Mean MODIS AOD</b>	0.13	0.10	0.07	0.10

- Longer horizontal averages → larger lidar ratios
- MODIS fine mode fraction increases & sea salt volume fraction decreases
- More influence from non-sea salt aerosols