Mapping aerosol lidar ratios over ocean for CALIPSO using MODIS AOD-constrained retrievals and a global aerosol model

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Morphing MIRA Webinar

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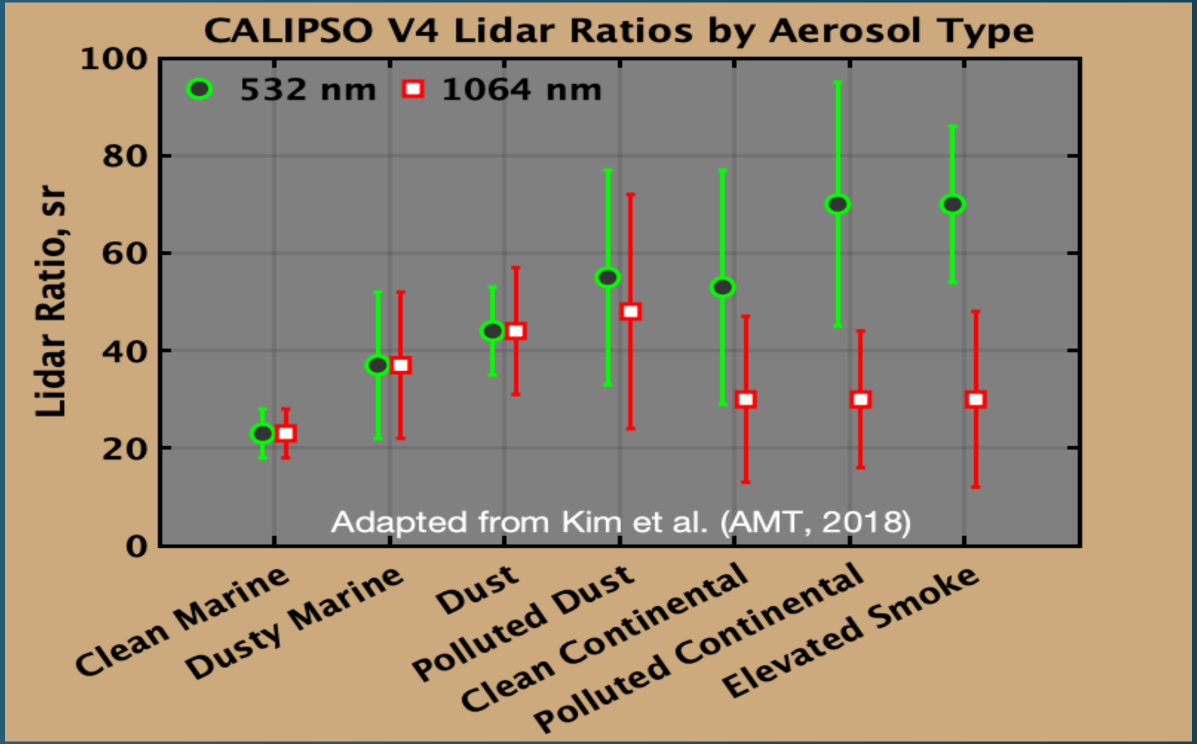
Introduction & motivation for this study

How CALIPSO works:

Aerosol Type → Lidar ratio → Retrieve extinction (*z*)

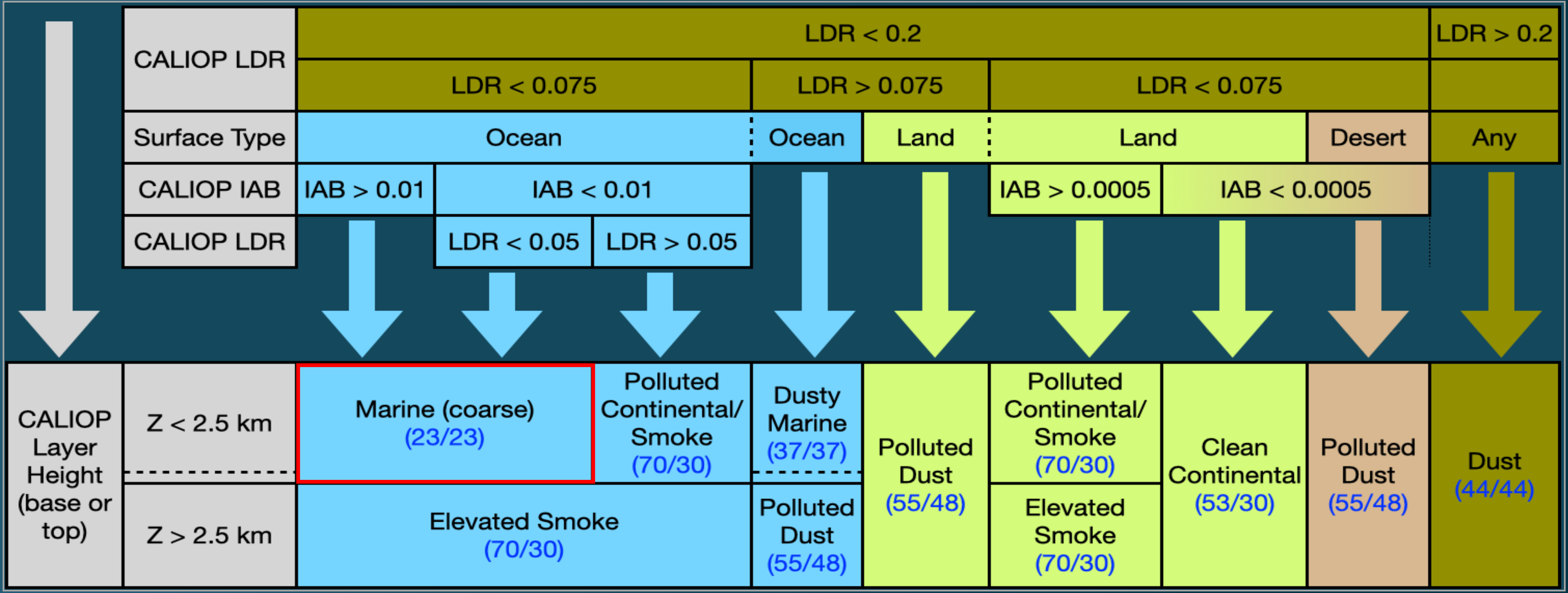
Current CALIPSO lidar ratio selection process uses a single lidar ratio globally for each CALIPSO aerosol type:



- The CALIPSO mission, combined with AOD from a passive sensor, provides a unique long-term global dataset to study the lidar ratio
- Goal of this study: creation of regional and seasonal climatological lidar ratio maps for marine aerosols through a combined observational/model approach by leveraging:
  - Backscatter profiles (CALIOP)
  - Passive aerosol retrievals (Aqua MODIS)
  - NASA global aerosol model simulations (GEOS/GOCART)

CALIPSO Version 4 Lidar Ratio Selection Process

IAB: 532 nm integrated attenuated backscatter (i.e., signal strength) **LDR: 532 nm estimated linear depolarization ratio**
(532/1064) lidar ratios



Adapted from Kim et al. (AMT, 2018)

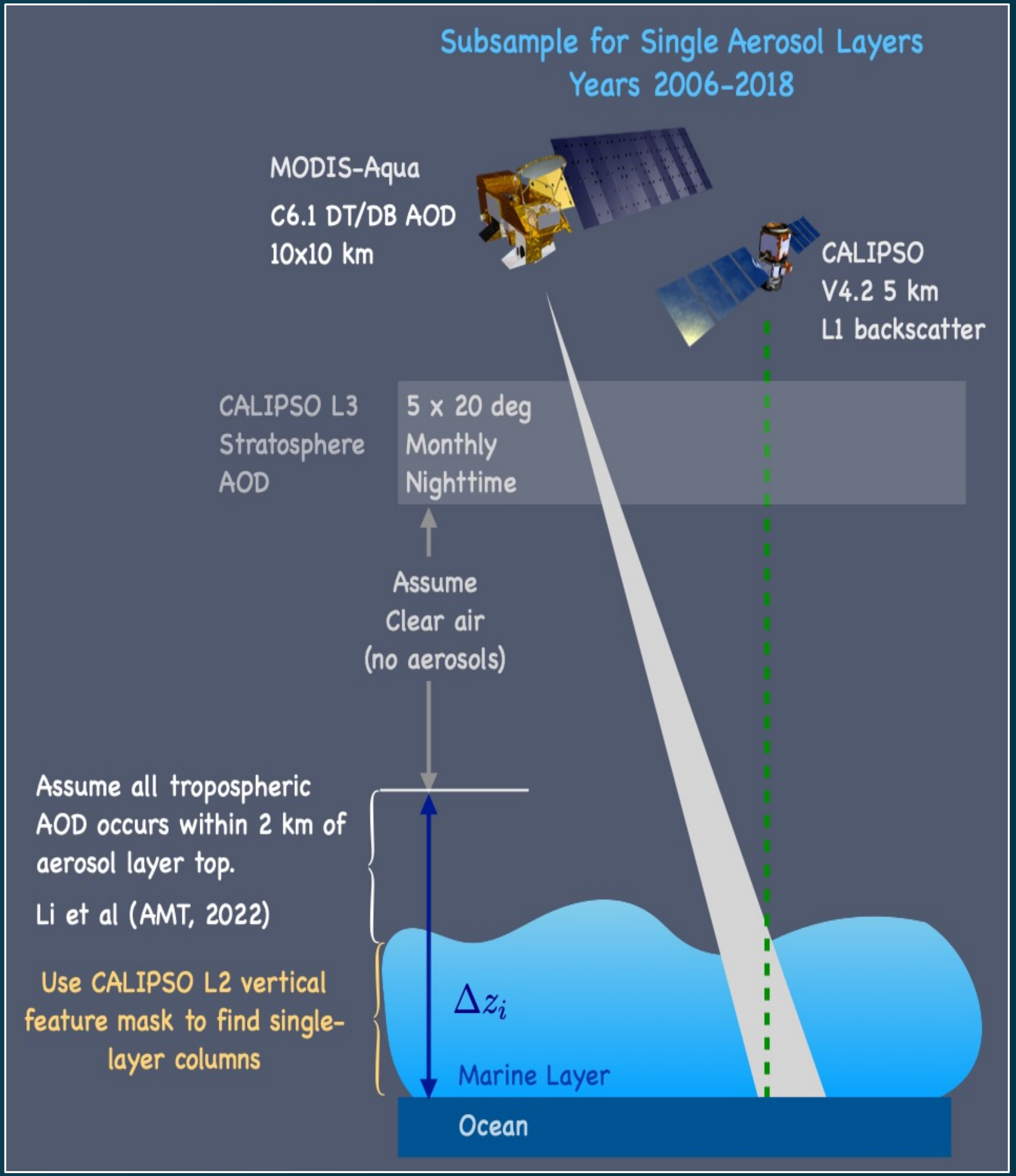
Methods

1. Use MODIS column-integrated AOD to constrain collocated CALIOP backscatter profiles and infer aerosol lidar ratios (Fernald 1972).

2. Create subset of data for profiles with only CALIOP-classified marine aerosols.

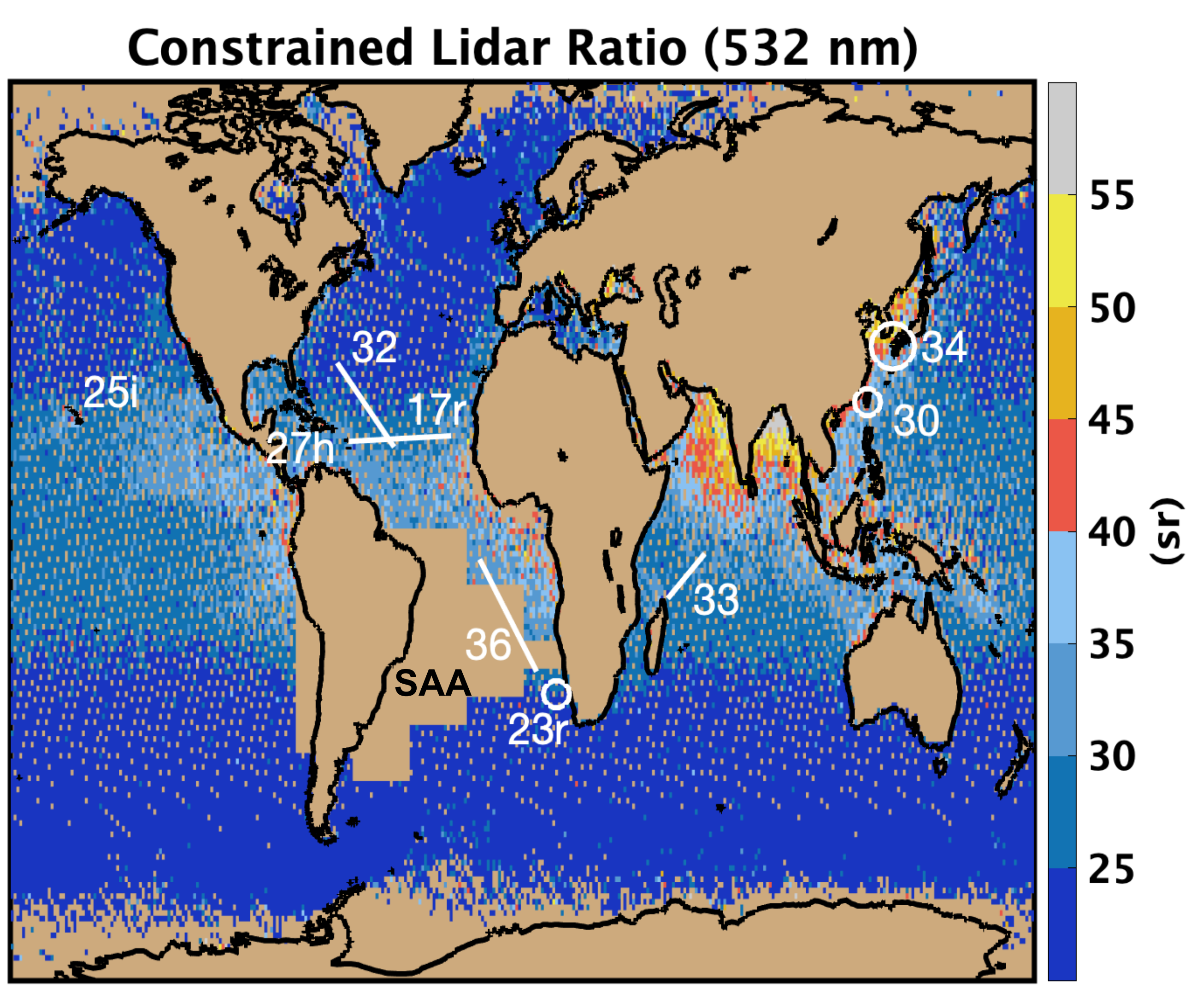
3. Compute sea salt volume fractions (< 2.5 km) from model data.

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



MODIS AOD-constrained lidar ratios & comparisons to past studies

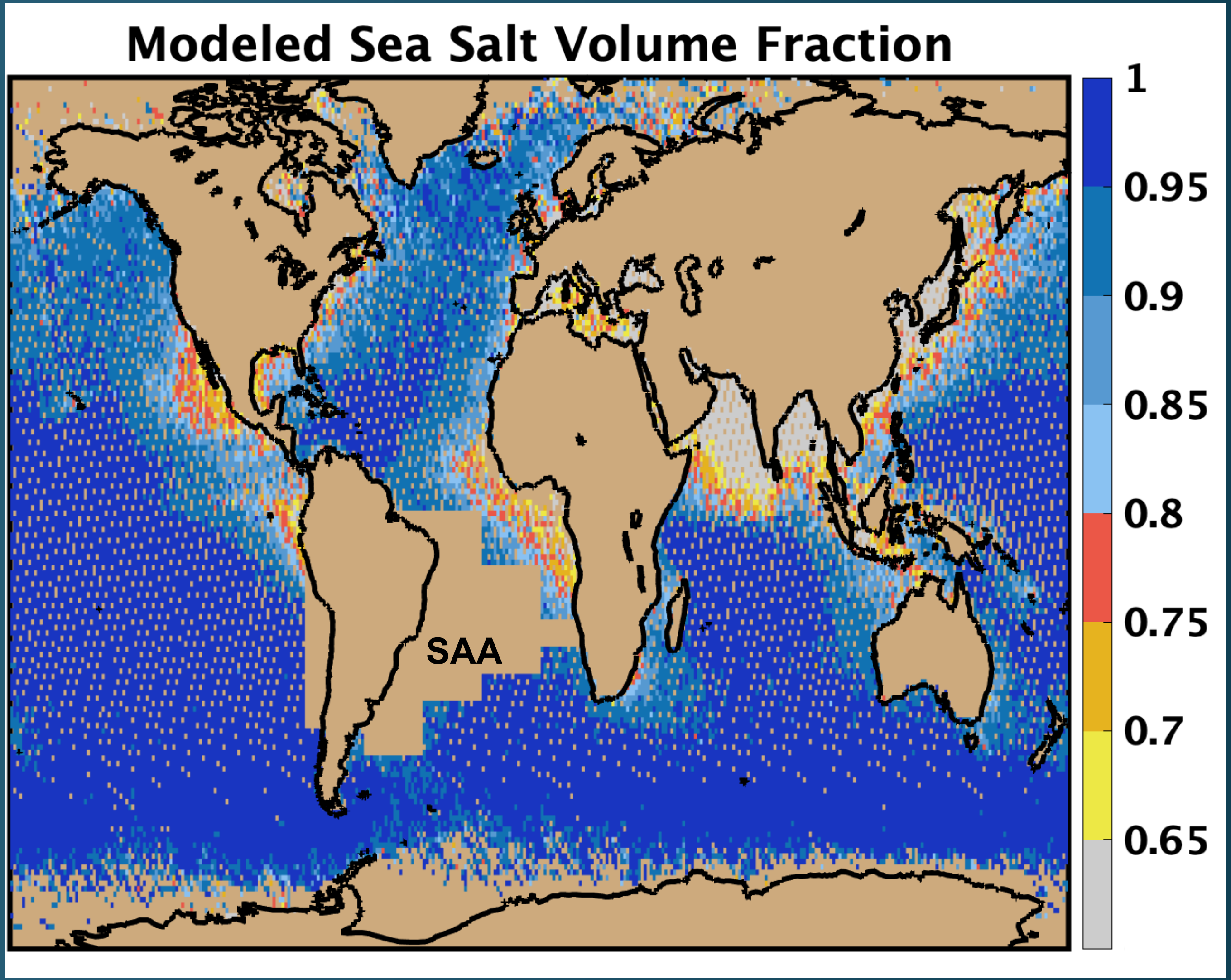
12-year mean (2006-2017) on 1x1 degree grid



Study	Lidar Ratio (sr)	Method/Technique
Bohlmann (2018)	23	Raman
Dawson et al. (2015)	26	SODA AOD & CALIOP IAB
Masonis (2003)	25	*In situ*
Rittmeister (2017)	17	Raman
Rogers et al. (2014)	27	HSRL
Schmid (2003)	34	Fernald inversion
Voss (2001)	32; 36	Fernald inversion
Wang (2020)	30	Fernald inversion
Welton (2002)	33	Fernald inversion

Sea salt volume fractions from GEOS/GOCART

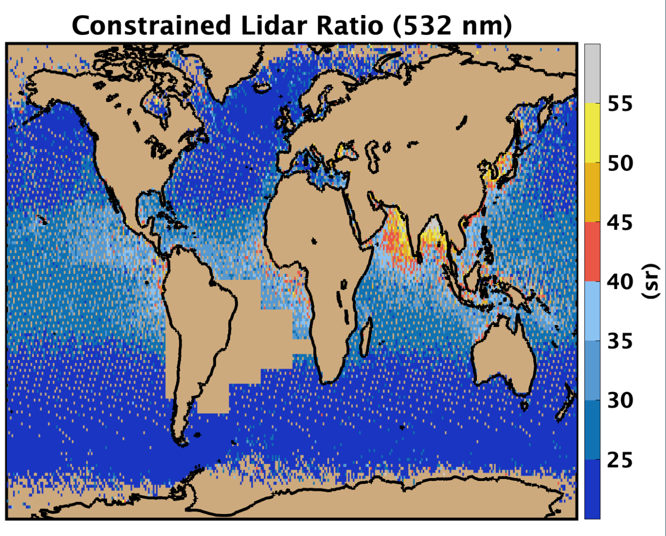
12-year mean (2006-2017) on 1x1 degree grid

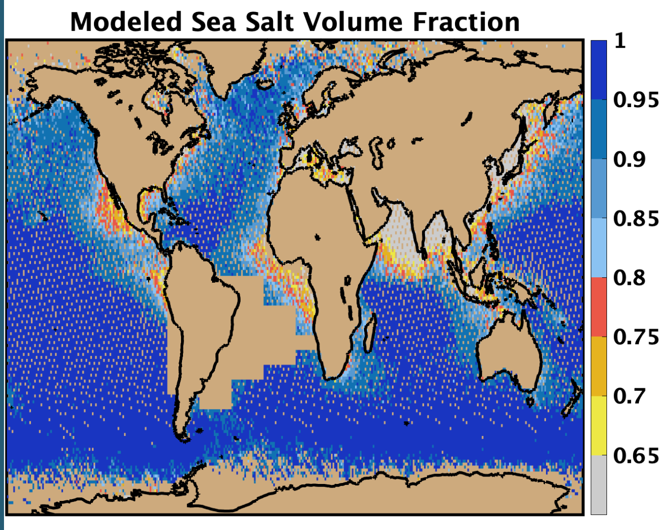


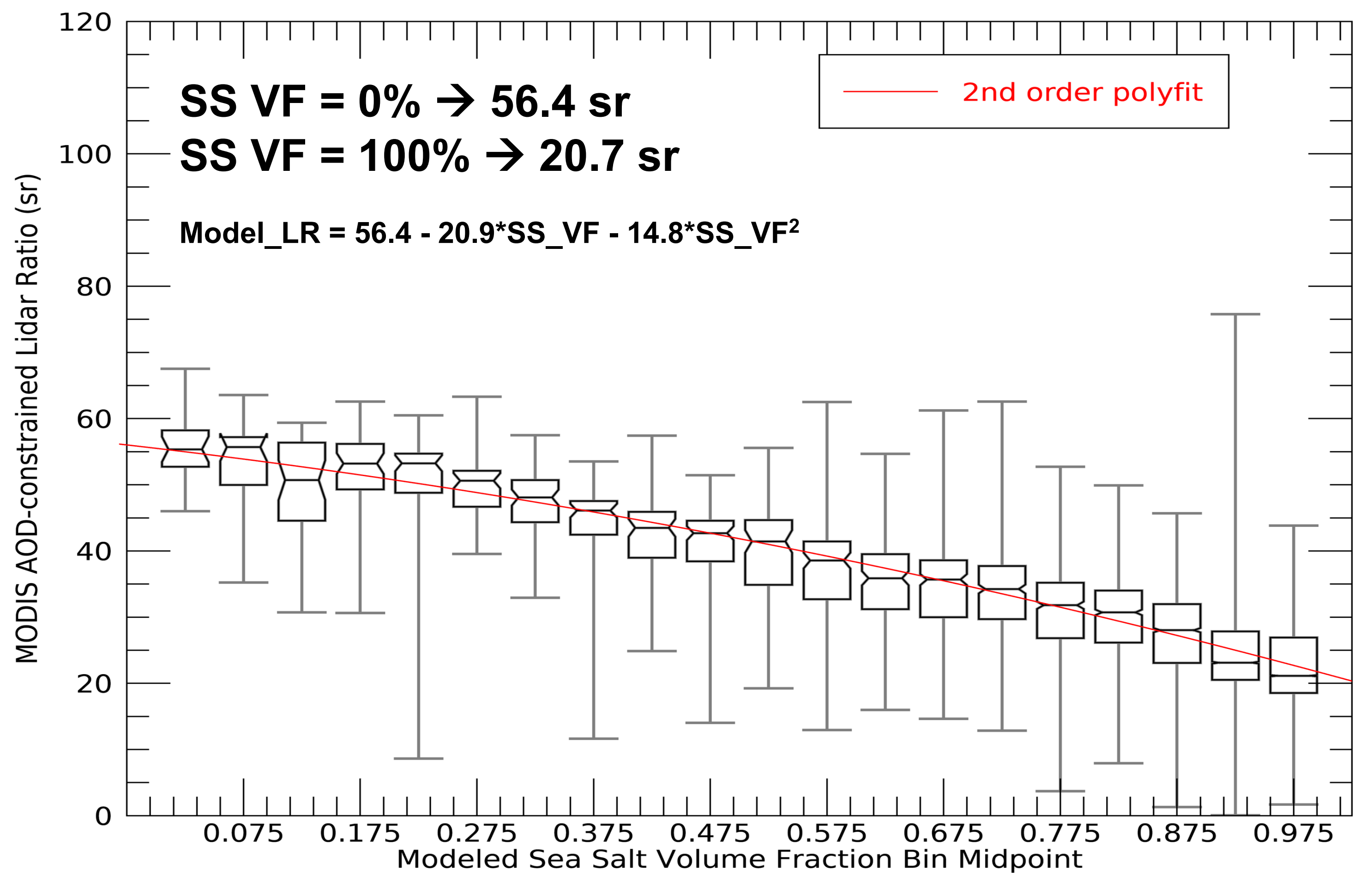
Computation of Modeled Sea Salt Volume Fractions below 2.5 km:

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

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





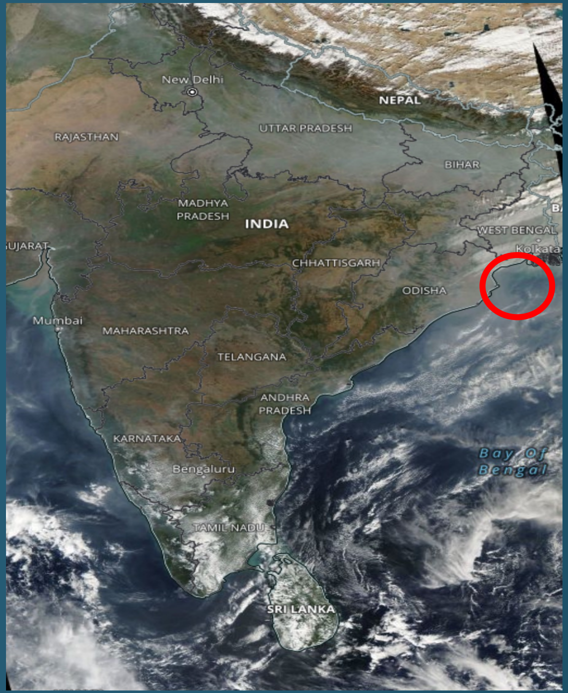


*Will use this relationship to create seasonal maps of lidar ratios...

Investigating seasonal sampling (case study)

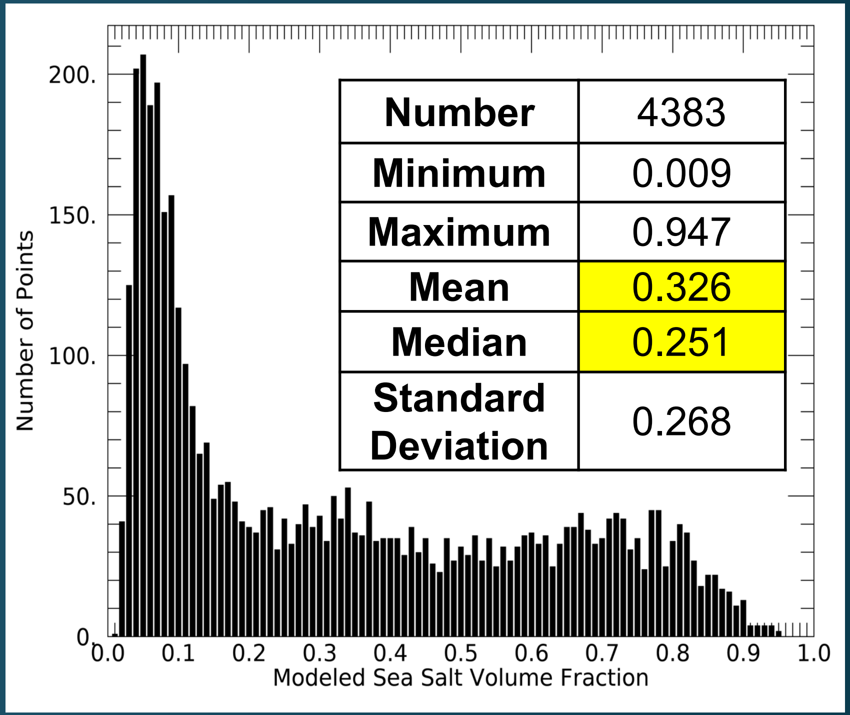
One lat/lon grid box in Bay of Bengal (2006-2017):

Map from NASA Worldview (MODIS visible image)



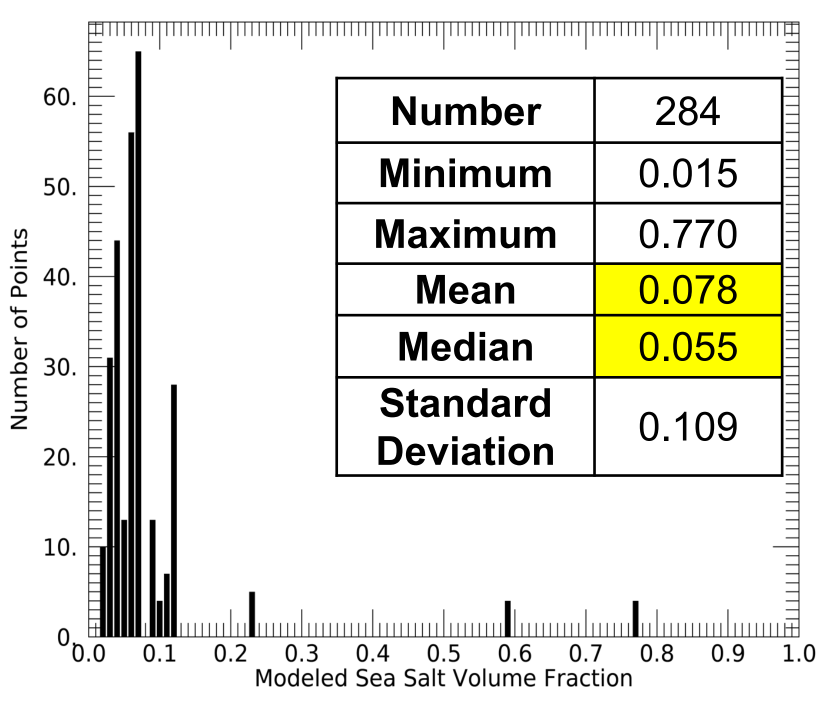
(worldview.earthdata.nasa.gov)

Non-collocated dataset (only model)



Number	4383
Minimum	0.009
Maximum	0.947
Mean	0.326
Median	0.251
Standard Deviation	0.268

Collocated dataset (MODIS/CALIOP + model)



Number	284
Minimum	0.015
Maximum	0.770
Mean	0.078
Median	0.055
Standard Deviation	0.109

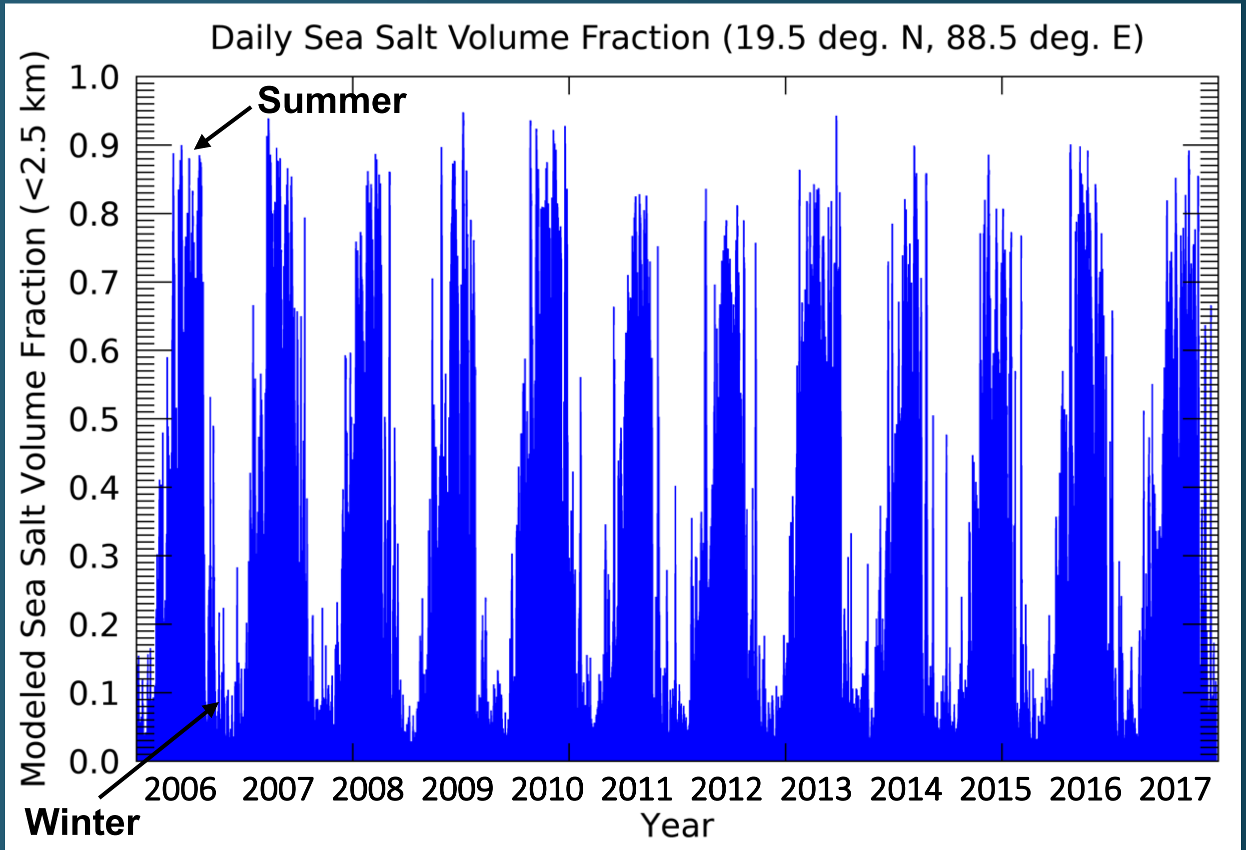
Investigating seasonal sampling (case study)

One lat/lon grid box in Bay of Bengal (2006-2017):				
Season	**Non-collocated (only model)**		**Collocated (with MODIS/CALIOP)**	
	Mean sea salt volume fraction	Counts	Mean sea salt volume fraction	Counts
MAM	0.272	1104	0.051	2
JJA	0.624	1104	NaN	0
SON	0.329	1092	0.135	84
DJF	0.072	1083	0.054	198

Sea salt volume fractions collocated with MODIS/CALIOP are heavily weighted toward DJF

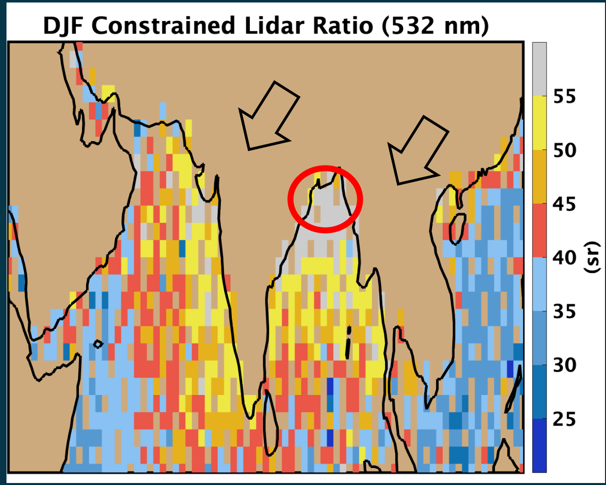
Seasonal variability in modeled sea salt volume fraction is non-trivial

One lat/lon grid box in Bay of Bengal (2006-2017):

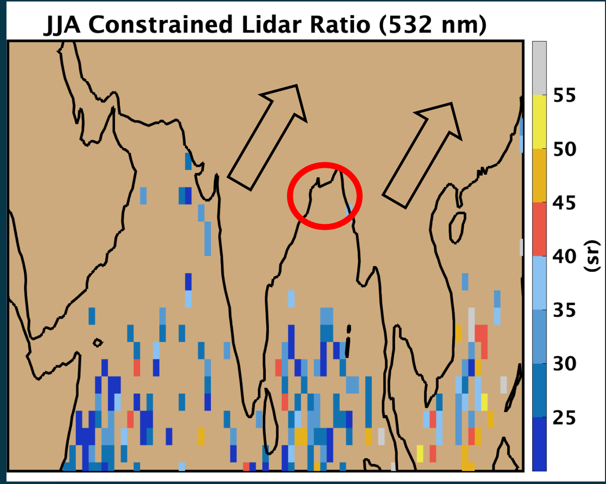


- Wind direction from land in winter (lower wind speeds)
- Wind direction from water in summer (higher wind speeds)

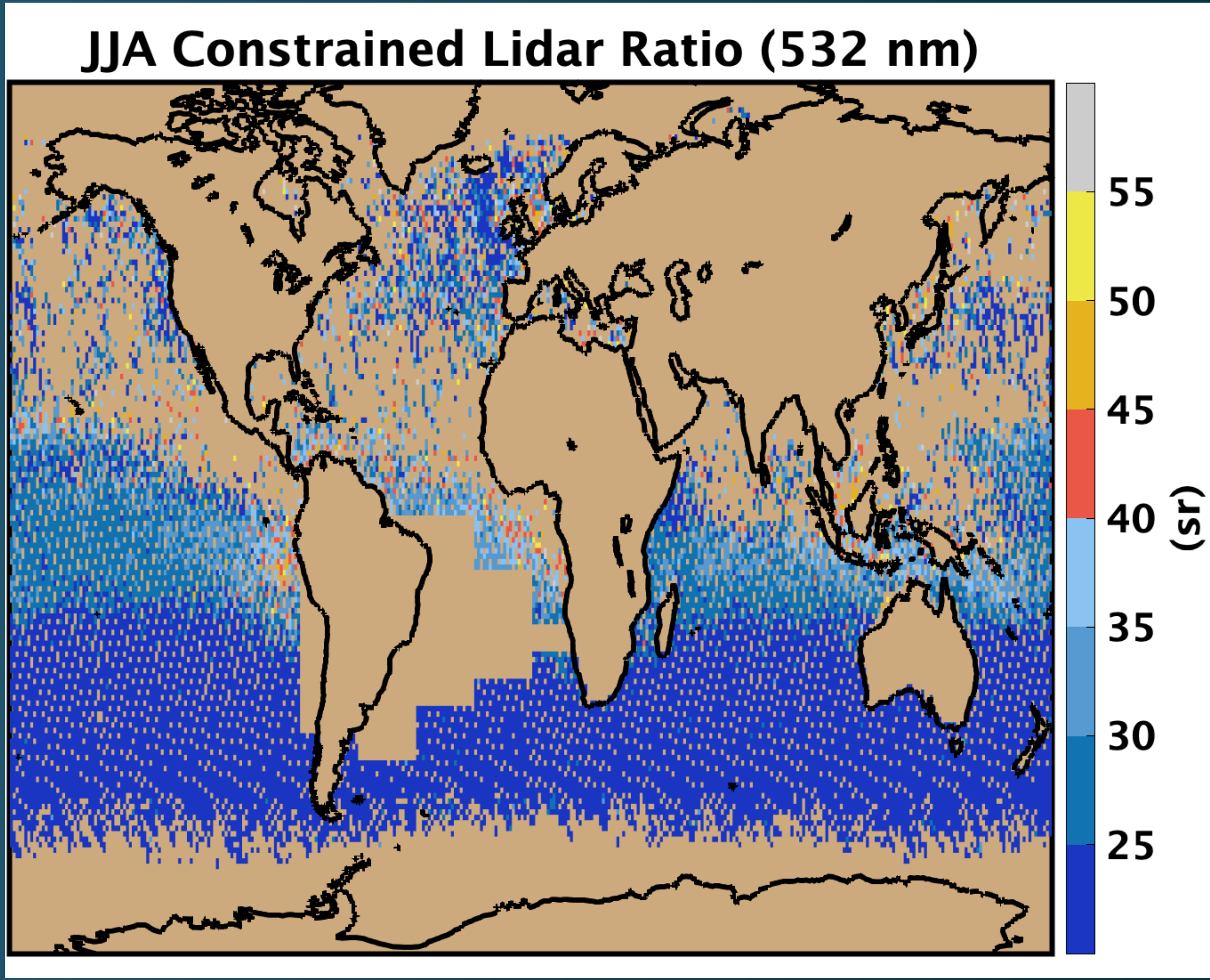
Winter Monsoon (DJF)



Summer Monsoon (JJA)

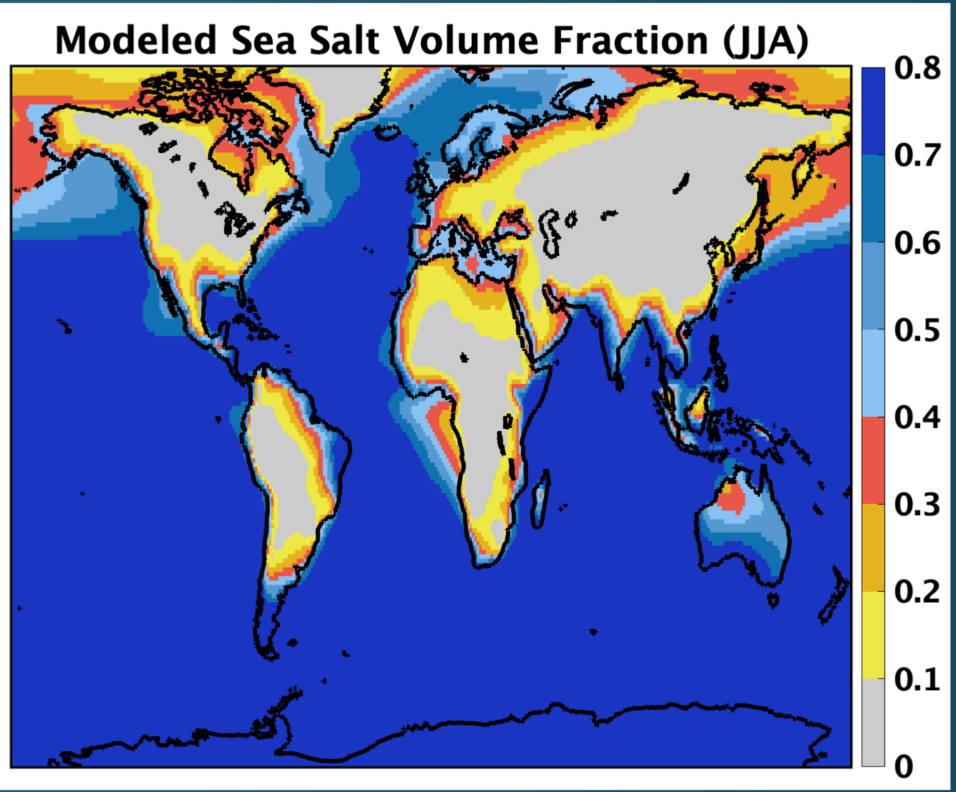


Seasonal coverage (JJA; 2006-2017): Global

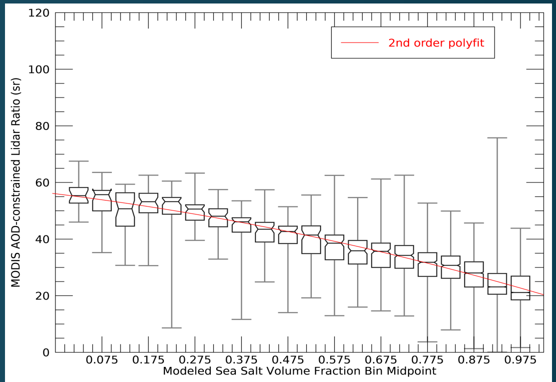


Initial results of seasonal model-assisted lidar ratios (JJA)

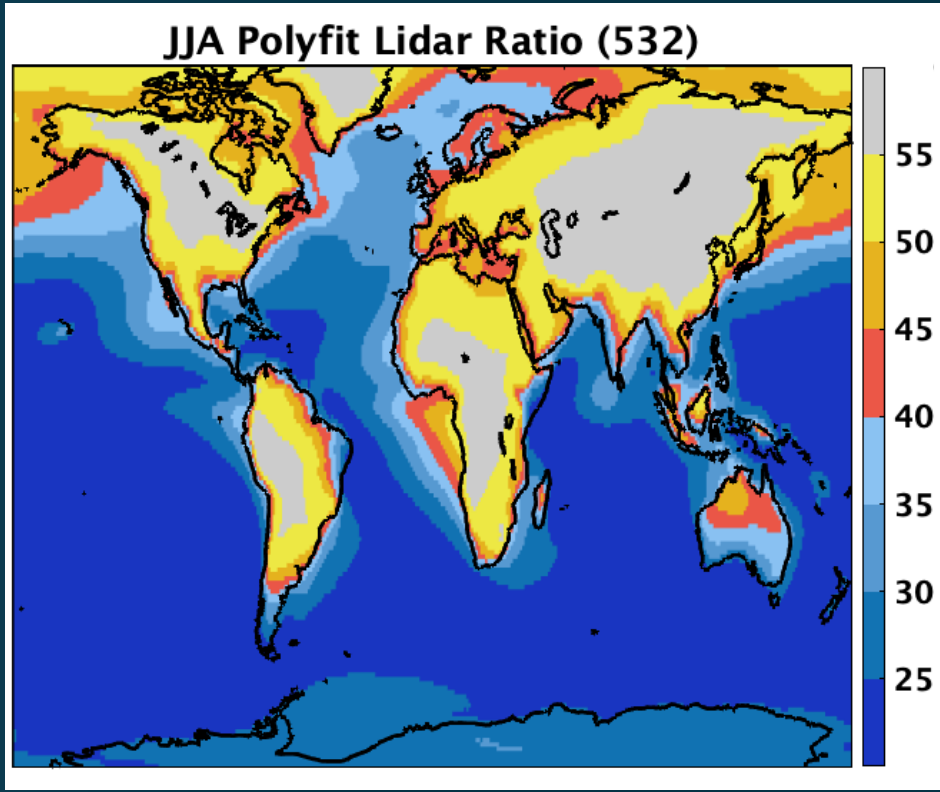
Sea salt volume fractions (SSVF) from the model



2nd order polynomial equation (from SSVF vs. lidar ratio relationship)



Model-assisted lidar ratios



<u>***Current work**</u>: comparisons of constrained lidar ratio retrievals and model-assisted lidar ratios (i.e., evaluating the skill in our method for creating these seasonal maps)*

Preliminary results: Dust

Retrieved lidar ratios of source regions (S_t)

Tags	Lidar Ratio (sr)
WAF	48
EAF	56
BOD	38
CAS	52
MDE	43
EAS	51
TAK	45
NAM	62
SOH	49

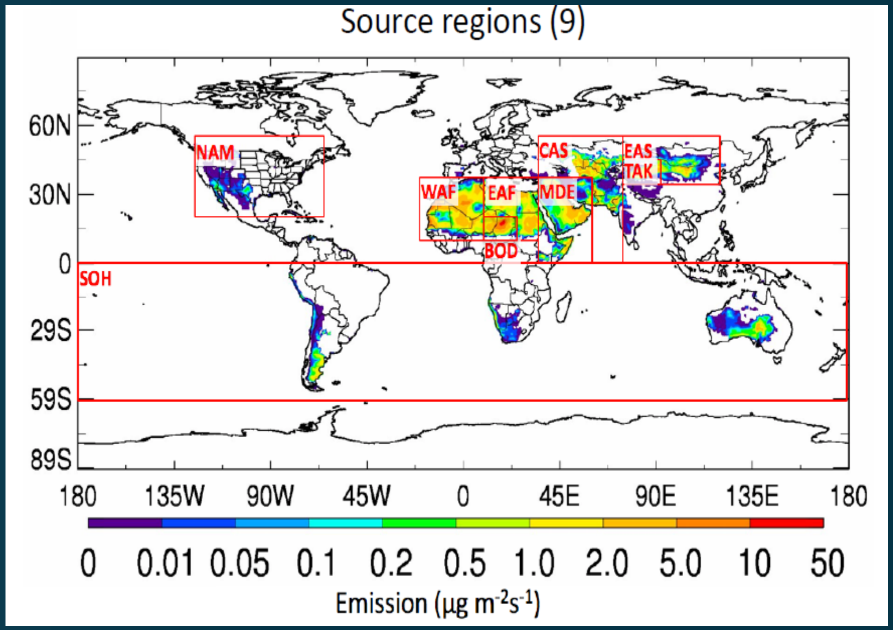
Figures/analysis courtesy Jay Kar

Lidar ratios of dust using S_t and climatological source fractions from model (2009-2012):

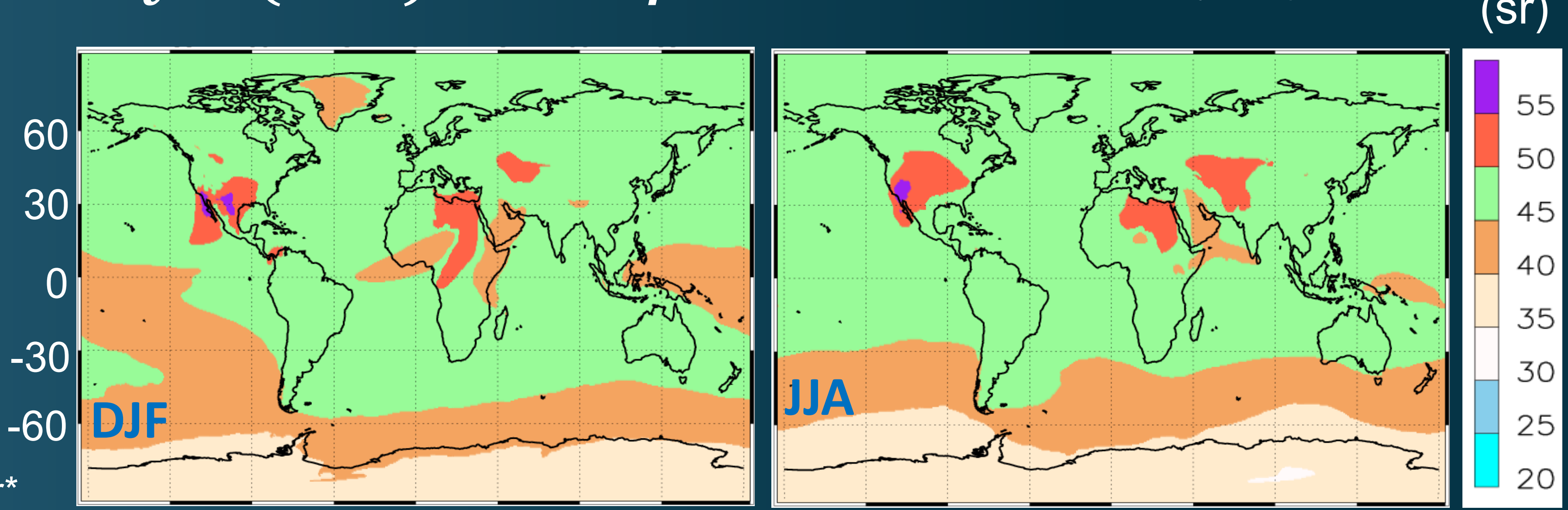
Receptors — Model — From table (tags)

$$\overrightarrow{S_r} = [F]\ \overrightarrow{S_t}$$

$$\overrightarrow{S_t} = (F^t F)^{-1} F^t\ \overrightarrow{S_r}$$



Plot courtesy Dongchul Kim



Summary & next steps

- 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 & help create climatologies that are consistent with MODIS AOD-constrained retrievals
- Maps can provide improved lidar ratio transitions in coastal regions
- Future efforts include other CALIOP aerosol types (e.g., elevated smoke, polluted continental/smoke, dusty marine, etc.)
- Analyses provide new lidar ratio look-up tables that can be used to retrieve aerosol extinction profiles for CALIOP and future space-based elastic backscatter lidars (e.g., AOS)

References

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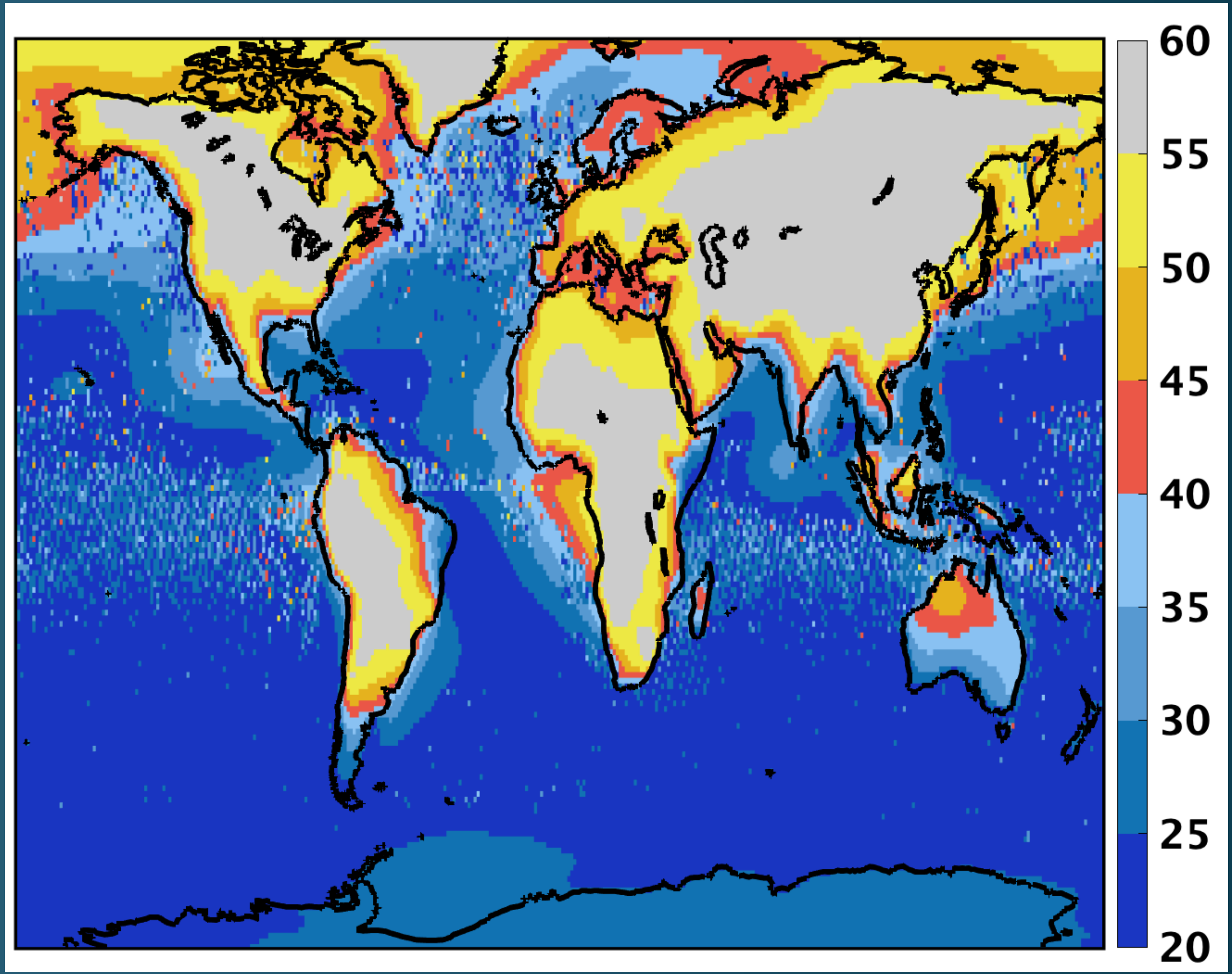
Back up slides

Initial results of seasonal analysis for JJA



5 km JJA (2006-2017): constrained & polyfit LRs

*Using the model to fill gaps when we don't have constrained retrievals available...

Preliminary results: Dust

- Scheme to retrieve lidar ratios of dust ($\overrightarrow{S_t}$) involves two inputs:
  - Lidar ratios from constraining CALIOP backscatter measurements with collocated MODIS AOD ($\overrightarrow{S_r}$)
  - Fractional source contributions from daily 2D GEOS-GOCART dust simulations (F)

Receptors Model Tags

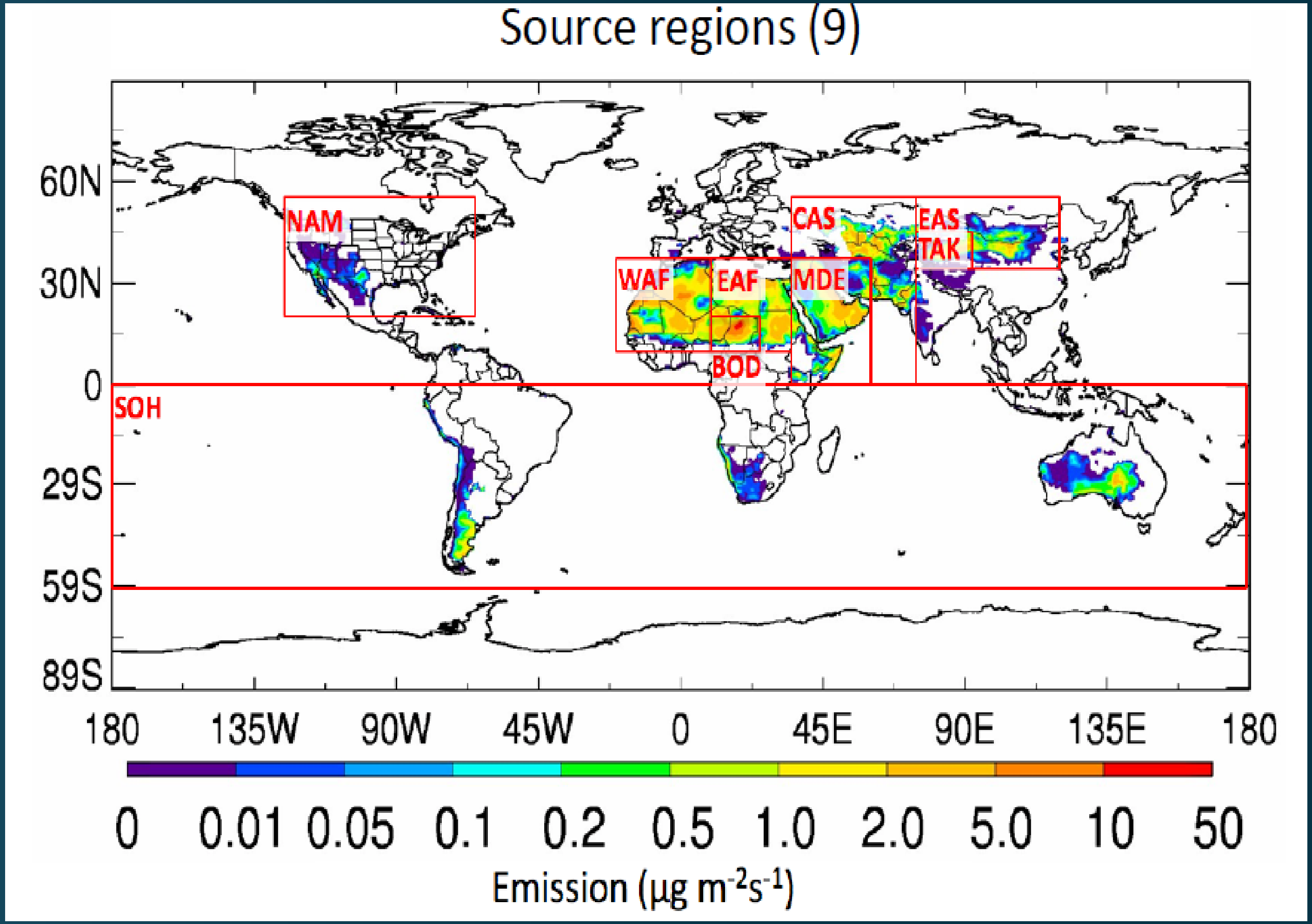
$$\overrightarrow{S_r} = [F]\ \overrightarrow{S_t}$$

Solve for $\overrightarrow{S_t}$ (matrix inversion):

$$\overrightarrow{S_t} = (F^t F)^{-1} F^t\ \overrightarrow{S_r}$$

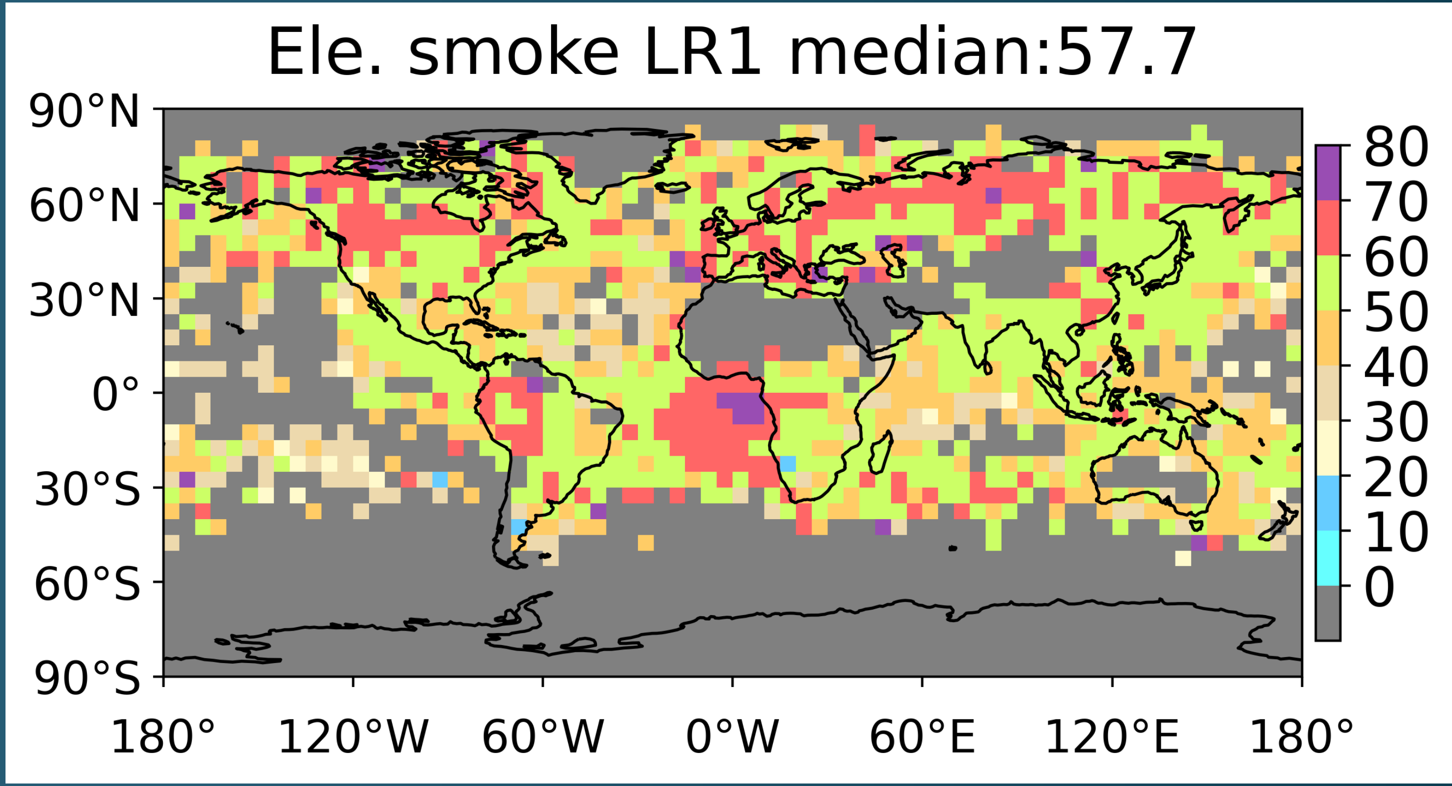
Plot courtesy Dongchul Kim

Tagged source regions modeled by GEOS/GOCART

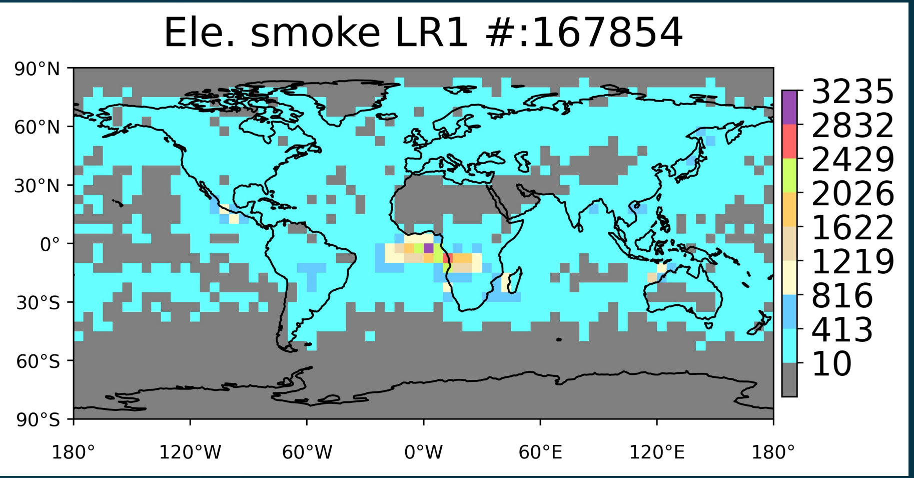


Preliminary results: Elevated smoke (2006-2018)

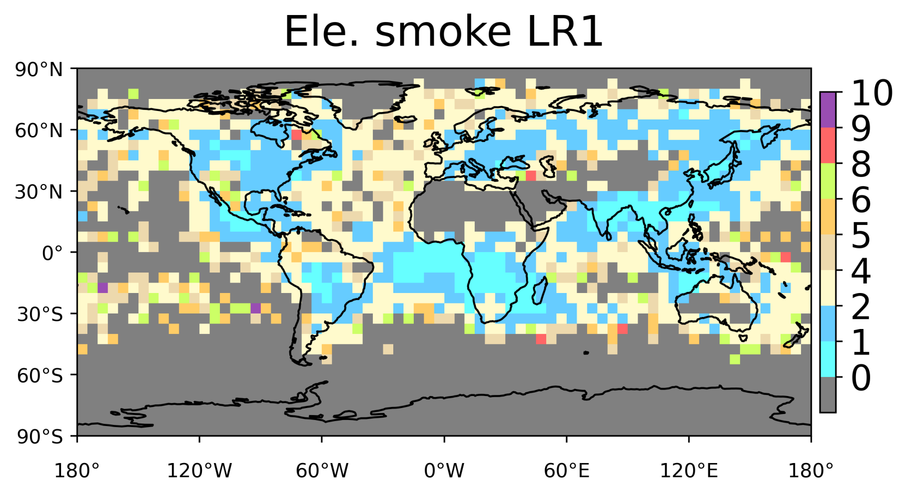
Median Lidar Ratio



Sample Number



Standard Error

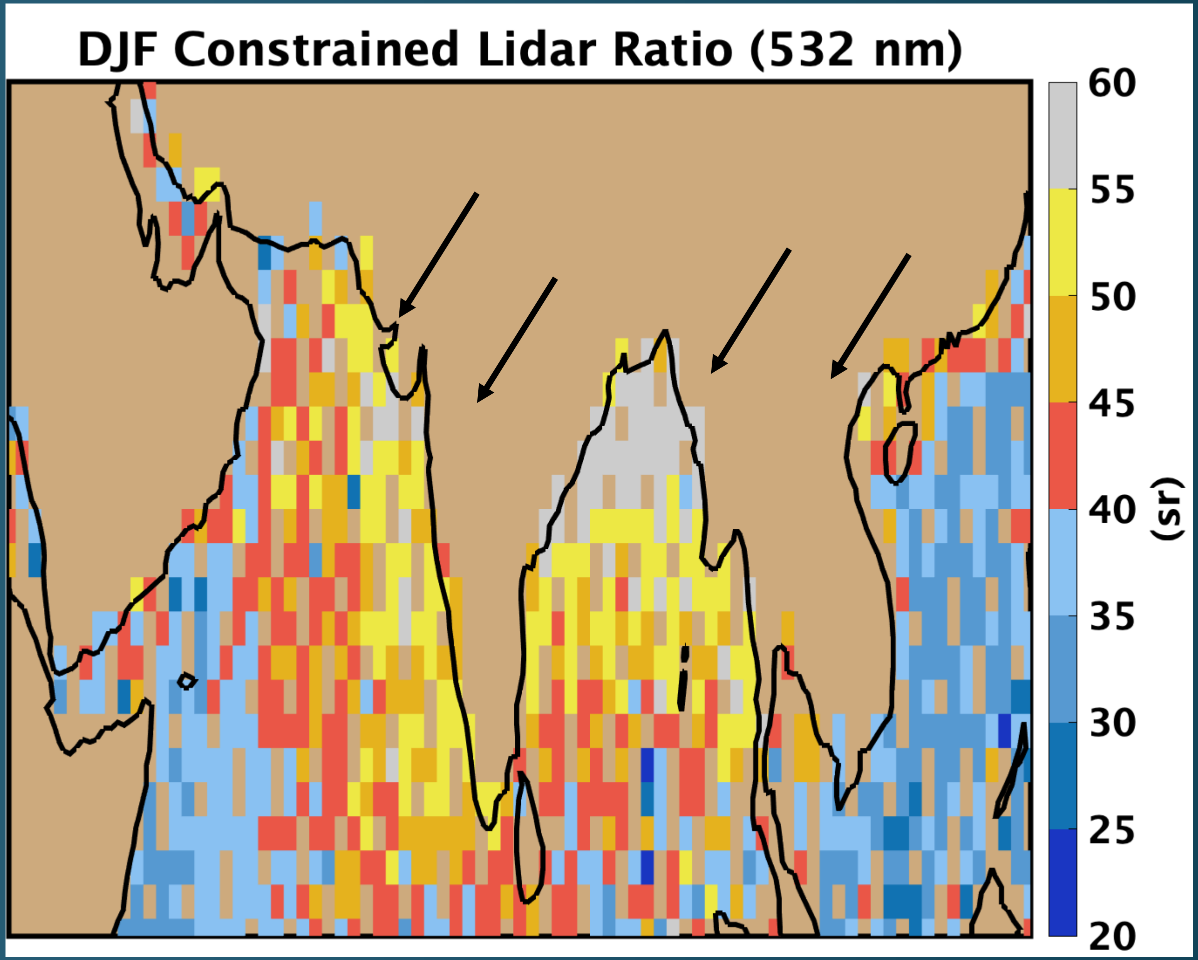


- From MODIS AOD-constrained retrievals
- 5x5 degree latitude/longitude grid

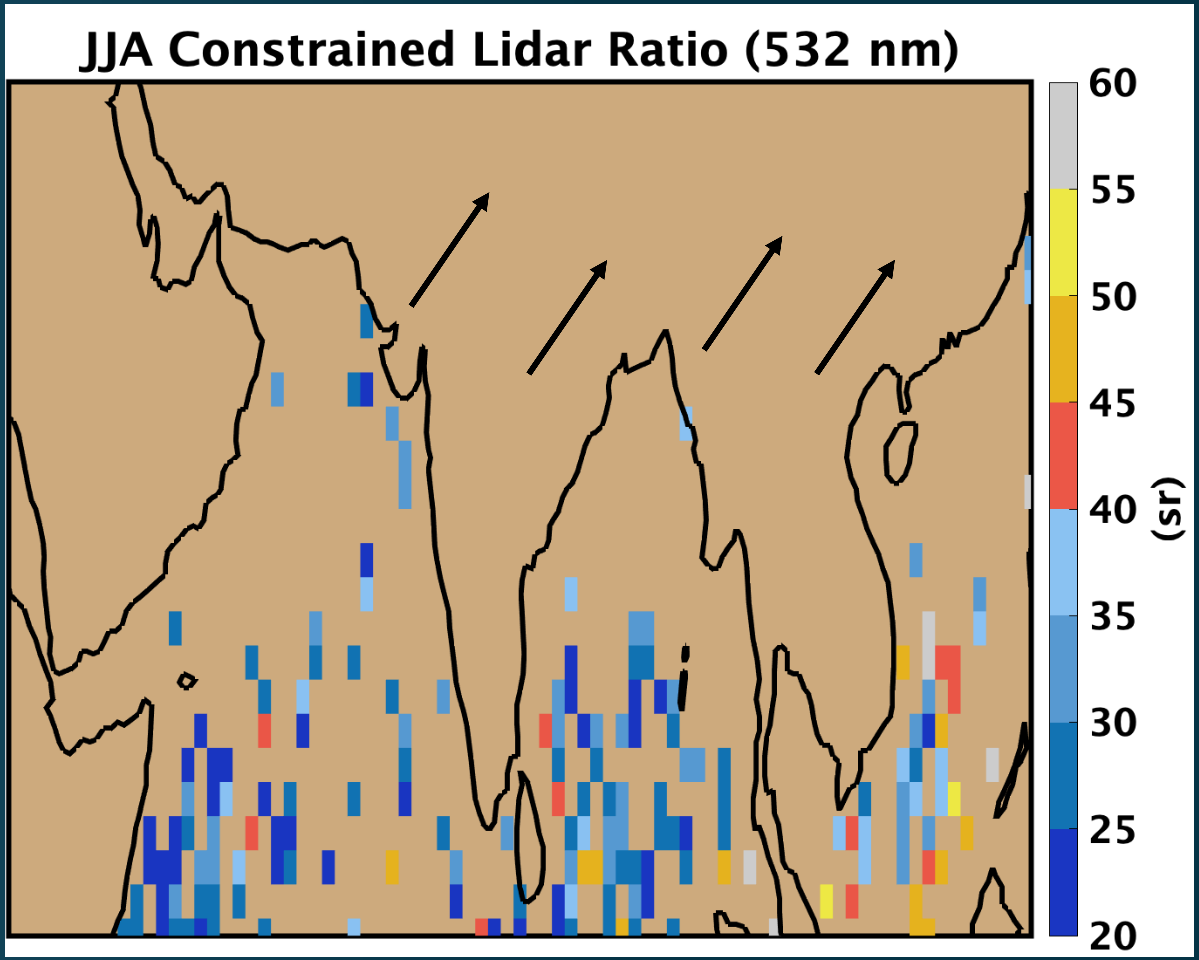
Plots/analysis courtesy Zhujun Li and David Painemal

Seasonal coverage (2006-2017): Regional

DJF



JJA



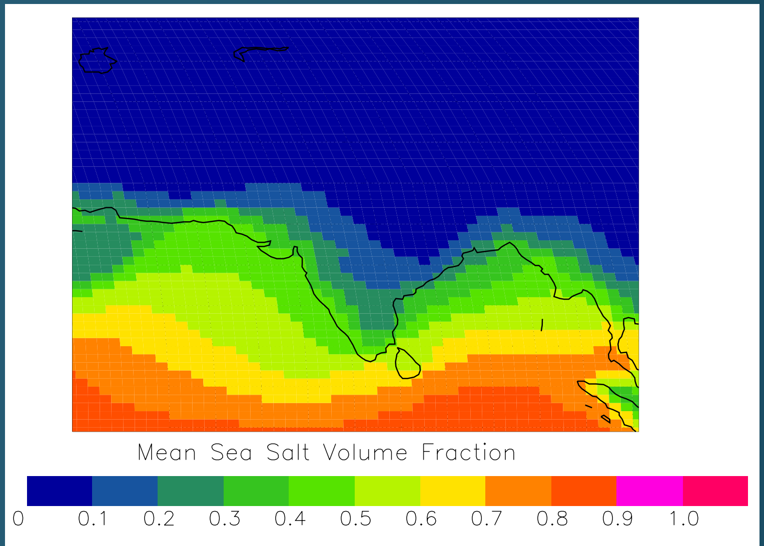
Investigating the differences between modeled sea salt volume fractions with and without a collocated lidar ratio retrieval (CALIPSO marine)

One grid box

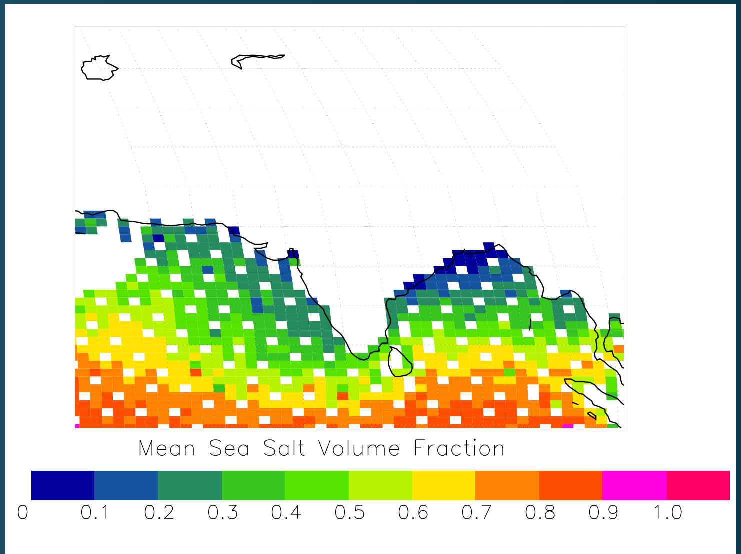
- Focusing on one 1x1 degree latitude/longitude grid box to investigate the values that are going into the means for 2006-2017
  - Latitude: 19-20 deg. N
  - Longitude: 88-89 deg. E

	Non-collocated	Collocated
N =	4383	284
Mean SS VF =	0.326	0.078

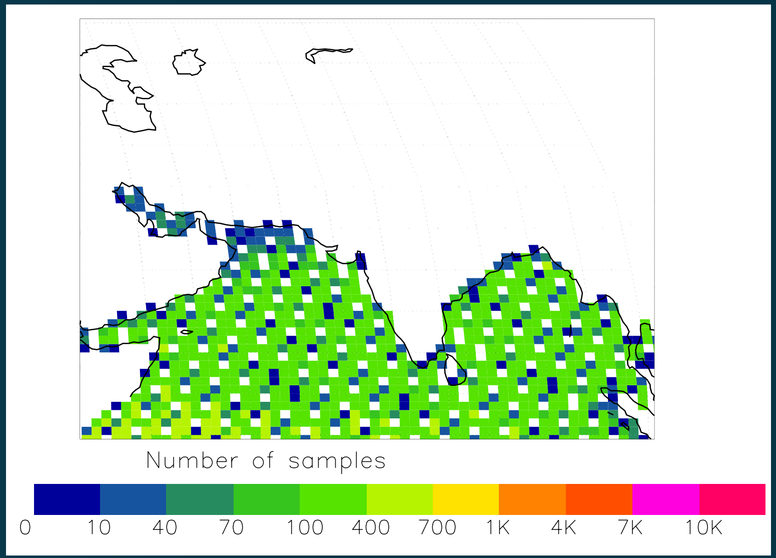
Non-collocated (mean SS VF)



Collocated (mean SS VF)



Collocated (# samples)



Data & methods

1. Collocate CALIOP backscatter profiles and MODIS AOD retrievals.

2. Perform Fernald (1972) inversion algorithm: use MODIS column-integrated AOD to constrain collocated CALIOP backscatter profiles and infer aerosol lidar ratios.

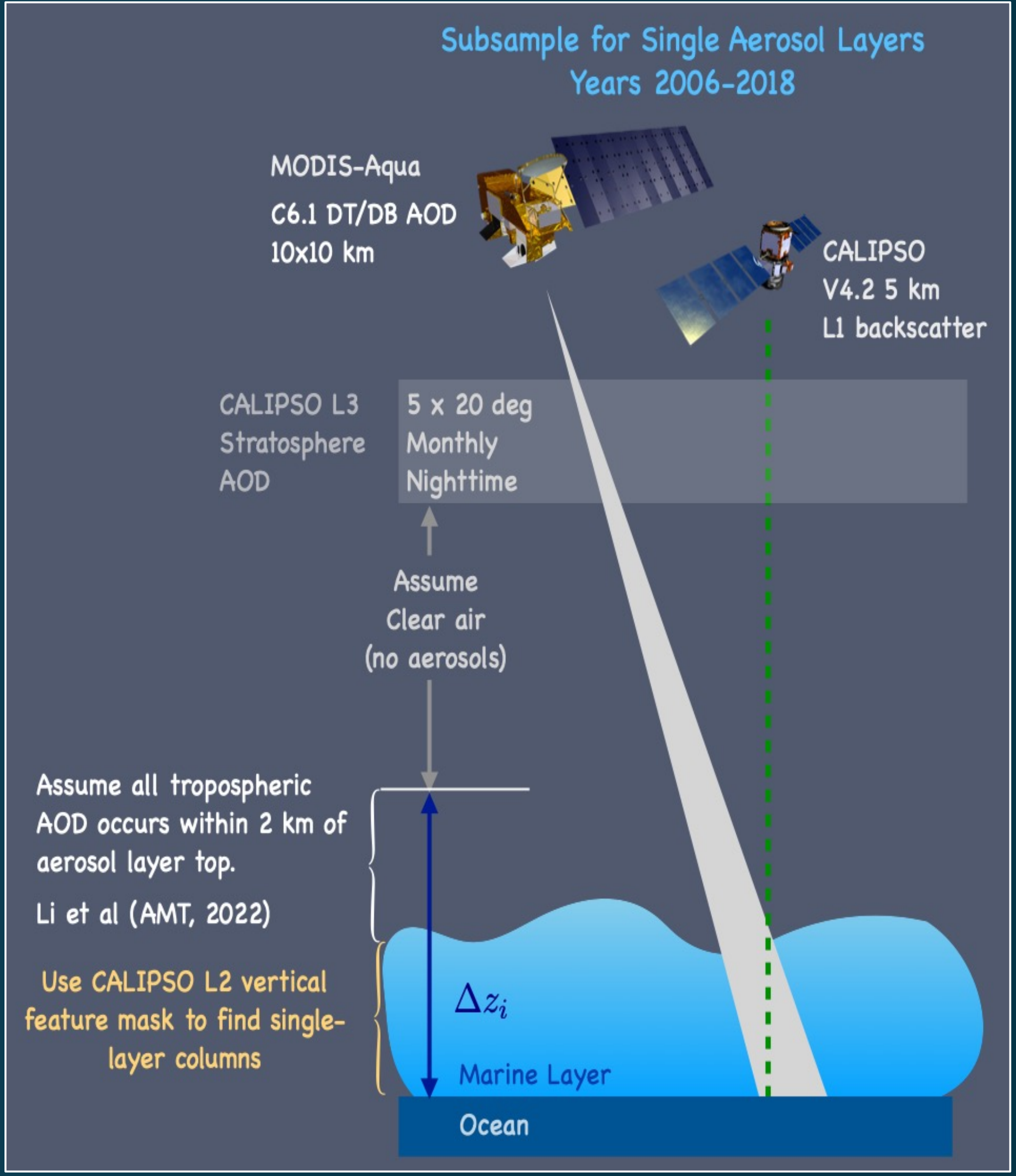
3. Use CALIPSO L3 Stratospheric Aerosol Profile Product to scale lidar ratios to account for stratosphere.

4. Create subset of data for profiles with only CALIOP-classified marine aerosols.

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

6. Collocate daily modeled sea salt volume fractions with Fernald-retrieved marine lidar ratios.

7. Develop relationship between modeled sea salt volume fraction and Fernald-retrieved lidar ratios of marine aerosols.



Horizontal averaging sensitivity study of retrieved lidar ratios
(CALIPSO classified marine aerosols)

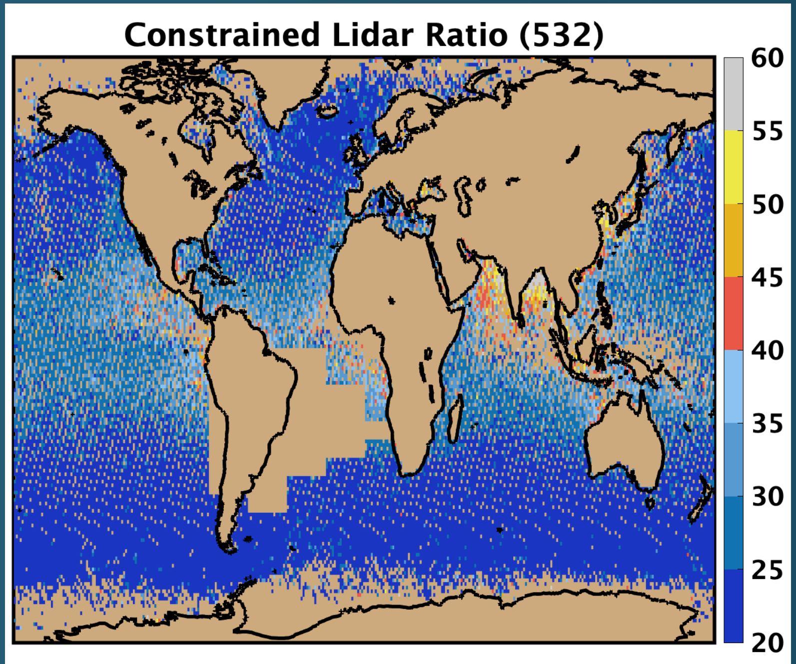
Lidar ratios

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

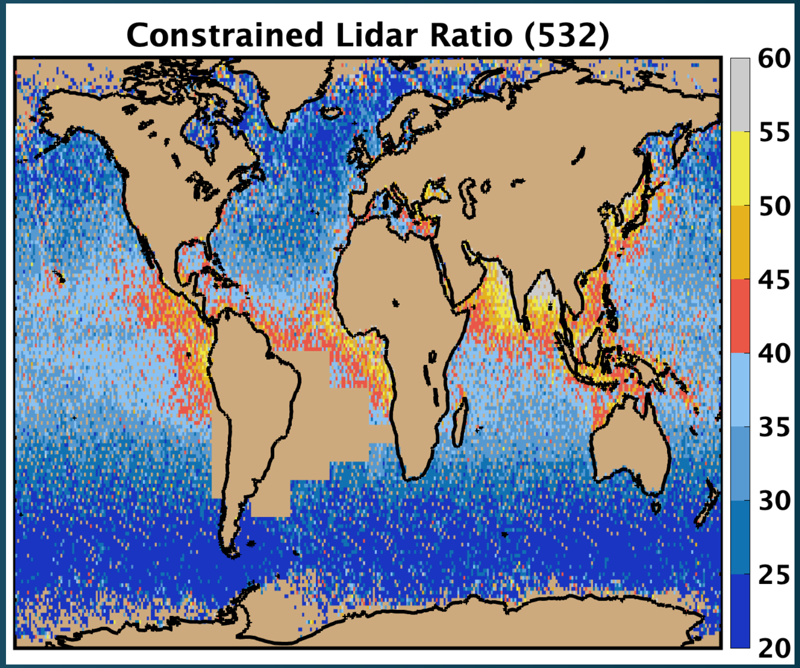
- Longer horizontal averages → larger lidar ratios
- MODIS fine mode fraction increases & sea salt volume fraction decreases
- More influence from non-sea salt aerosols

Horizontal averaging sensitivity study of retrieved lidar ratios
(CALIPSO classified marine aerosols)

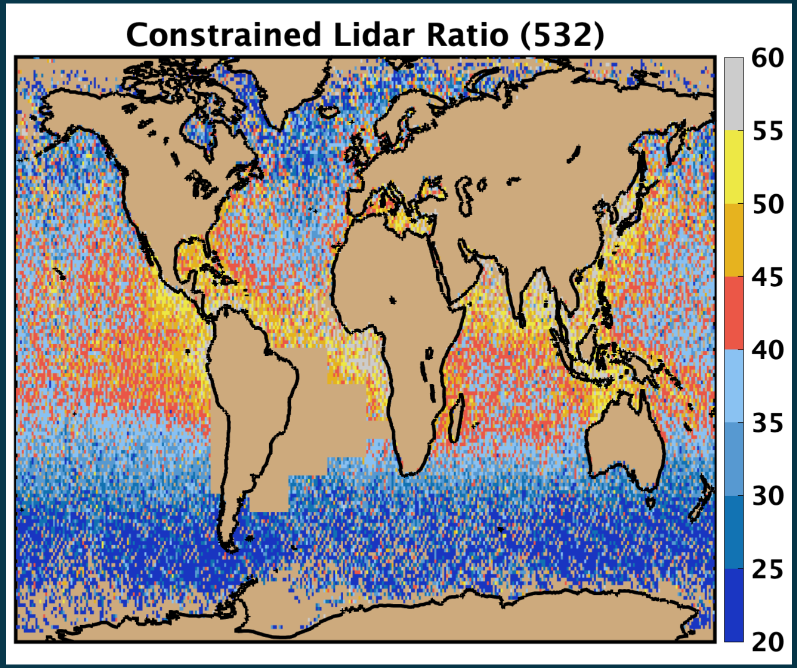
Only 5 km



Only 20 km

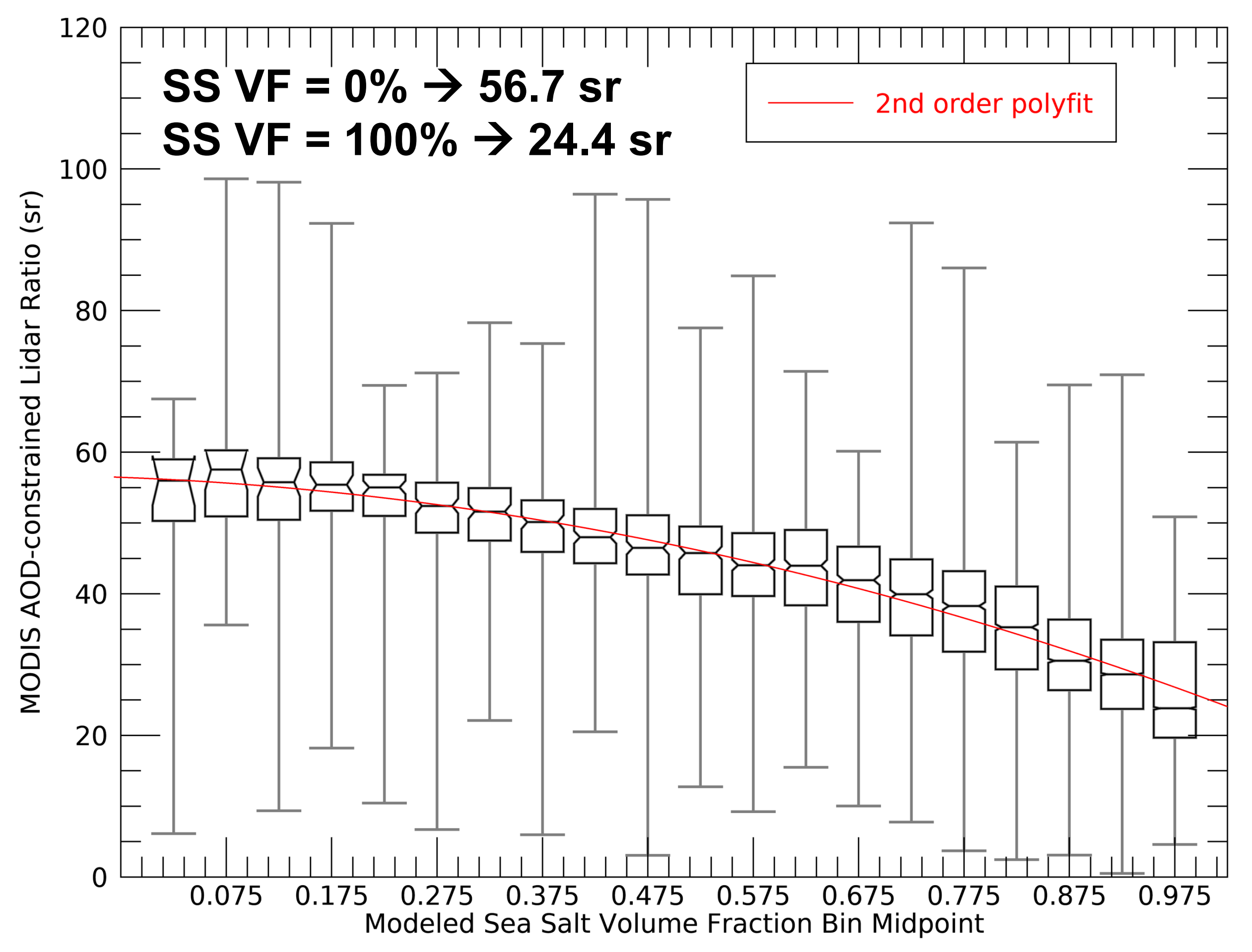


Only 80 km

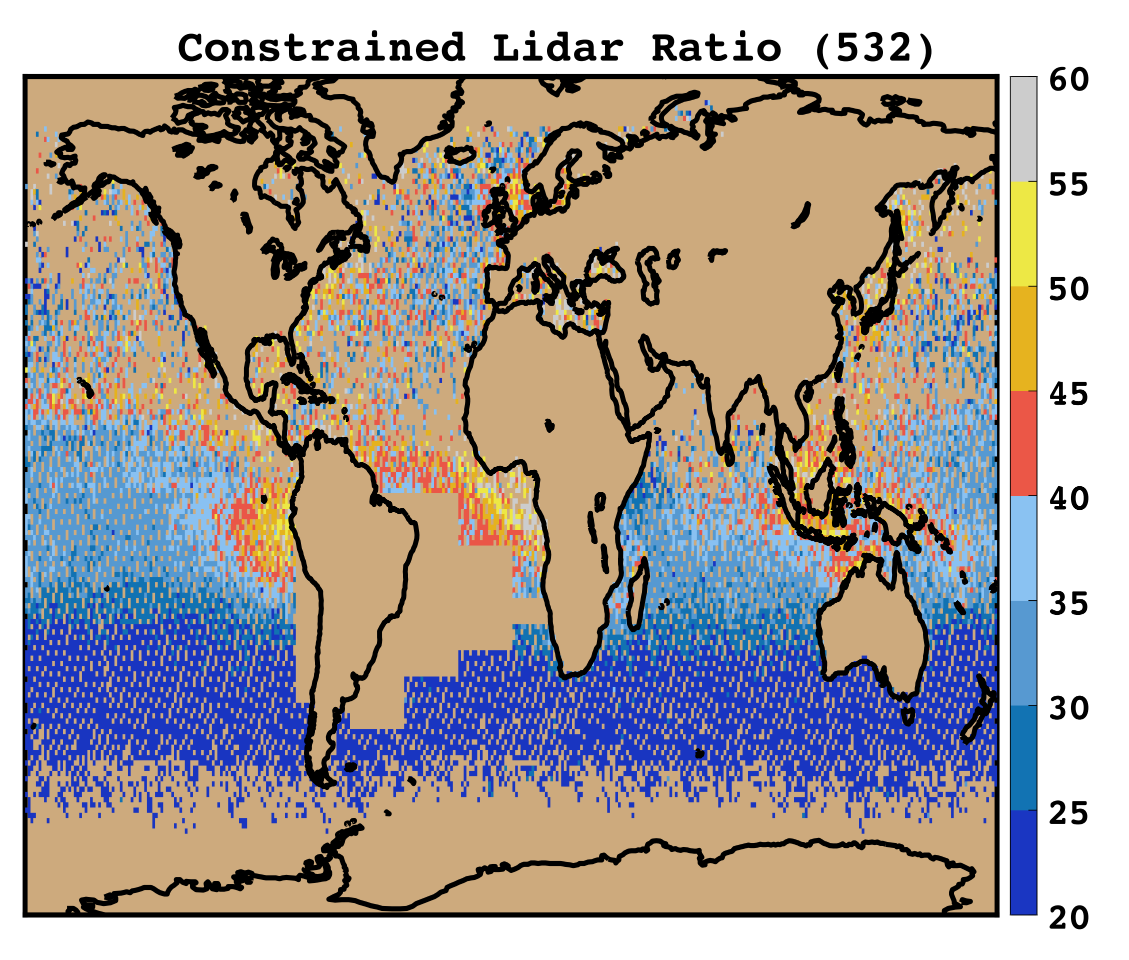


Using the model to help construct seasonal lidar ratio maps

Marine lidar ratios as a function of modeled sea salt volume fraction (2006-2017)



Seasonal analysis: 2006-2017 (JJA) lidar ratios (RSE ≤ 10%)



The MAC Project for the MIRA Working Group

- **MIRA**: Models, In situ, and Remote Sensing of Aerosols
  - A new forum that encourages interdisciplinary work and fosters international collaborations
  - 200+ members in 22 countries and growing
  - Currently consists of 4 projects but are seeking new projects. If interested, please contact the MIRA steering committee at https://science.larc.nasa.gov/mira-wg/contacts/

- **MAC:** Mapping Aerosol lidar ratios for CALIPSO
  - Lead: Greg Schuster (NASA LaRC)
  - Uses lidar ratio retrievals and measurements with aerosol types provided by global aerosol models to build global lidar ratio maps that can vary by season
  - These maps will be pertinent to the CALIPSO Version 5 extinction profile products

MIRA webpage

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

Join us with these links!

MIRA news

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

Using CALIPSO Level 3 Stratospheric Aerosol Product to scale the lidar ratios from constrained retrievals

a. Find CALIOP/MODIS points that fall within each 5 x 20 degree latitude/longitude bin for each month and pull the stratospheric AOD
b. Use the following equation to get the scaled lidar ratio that accounts for stratospheric aerosol loading:

$$S_{scaled} = \frac{\tau_{nostrat}}{\tau_{clmn}} S_{clmn}.$$

$$\tau_{nostrat} = \tau_{clmn} - \tau_{strat}$$

Sensitivity Study: Aerosol Top Height

Aerosol Top Height	≤ 0.5 km	≤ 1.0 km	≤ 1.5 km	≤ 2.0 km
Number	616,498	5,511,503	10,003,988	12,065,528
Minimum	0.002 sr	0.001 sr	0.000 sr	0.000 sr
Maximum	117.53 sr	117.53 sr	117.53 sr	117.53 sr
Mean	37.00 sr	33.29 sr	31.54 sr	31.19 sr
Median	33.25 sr	29.85 sr	28.44 sr	28.25 sr
Standard Deviation	20.30 sr	17.84 sr	16.63 sr	16.22 sr

Lidar ratio vs. MODIS Fine Mode Fraction