Mapping Modeled Aerosol Species to Measured Lidar Ratios for the MIRA Project

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50 years of lidar observations: the tip of the laser remote sensing iceberg?

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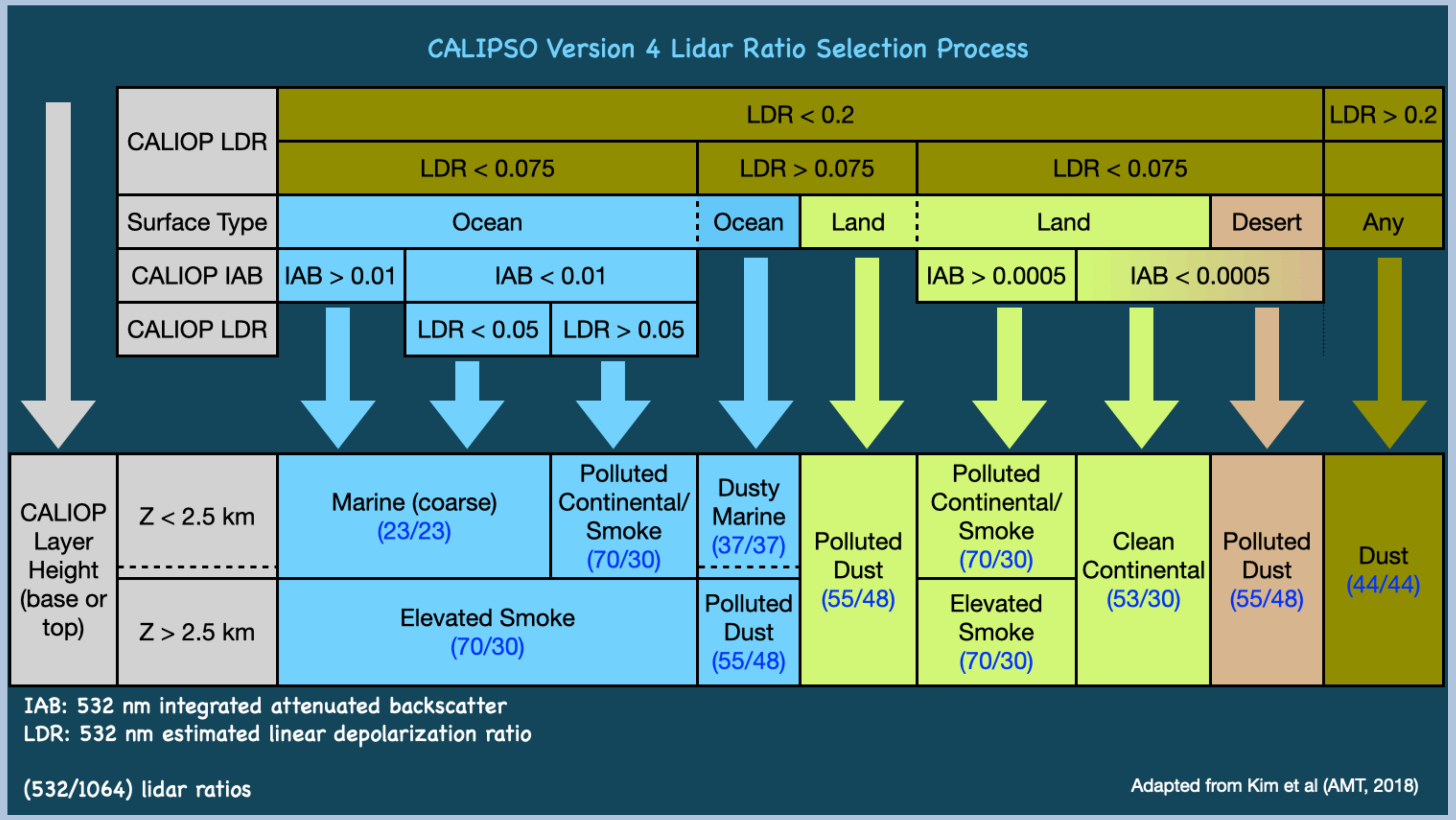
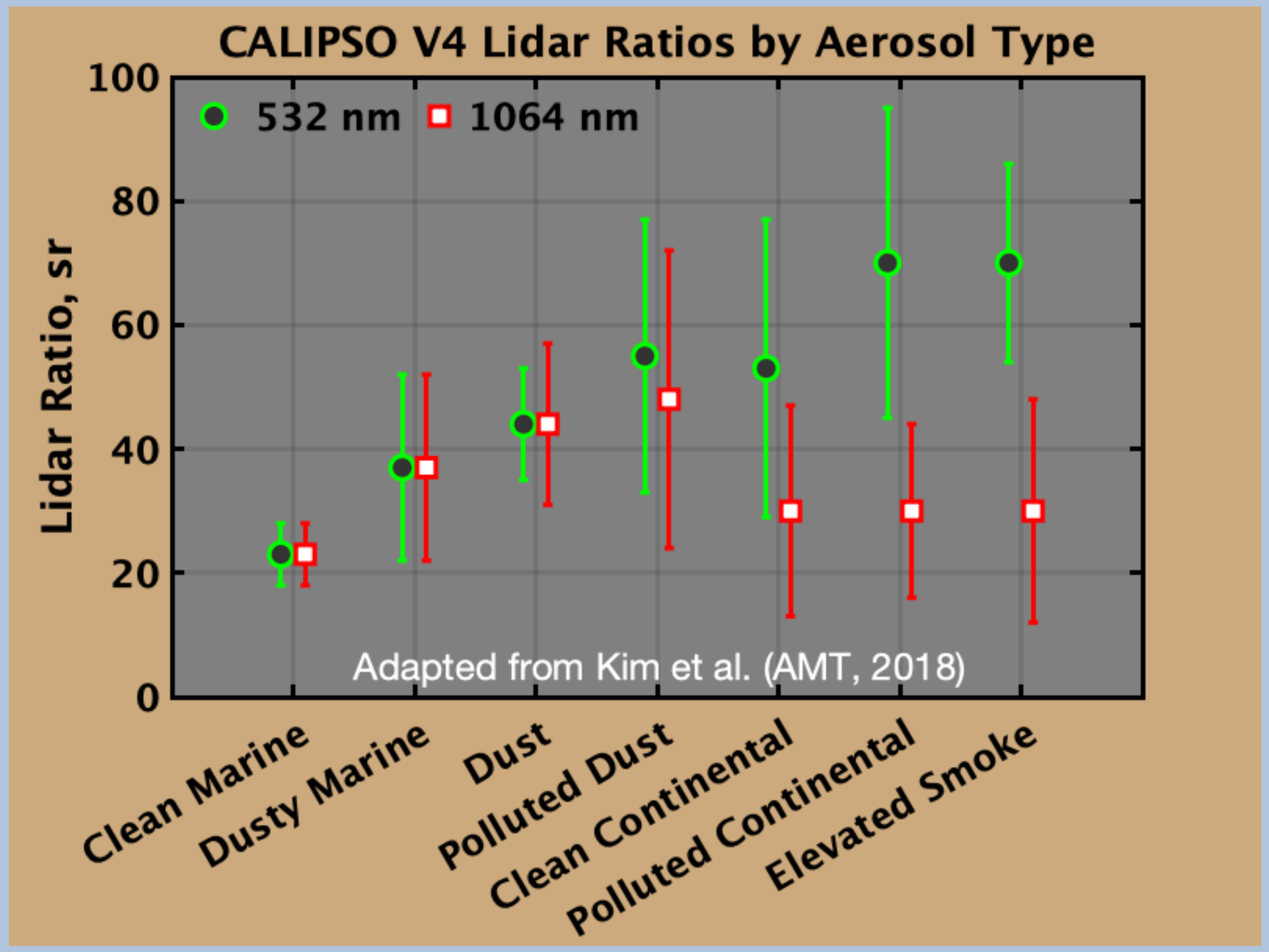
Motivation

- Since CALIPSO is an elastic backscatter lidar, it is necessary to select *a priori* aerosol lidar ratios prior to computing extinction profiles (see diagram at right for the selection process).
- Presently, the CALIPSO lidar ratio selection process uses *a single lidar ratio* for each of the 7 CALIPSO aerosol types in the troposphere, and the lidar ratio uncertainty is large for most aerosol types.
- Consequently, regional and seasonal variability of the lidar ratio is very limited in the present CALIPSO algorithm.
- Here, we describe an approach for creating new climatological lidar ratio maps for each of the CALIPSO aerosol types using MODIS-CALIPSO constrained retrievals and global model simulations.
- The purpose is to eventually replace the seven single-valued lidar ratios for the CALIPSO types with latitude- and longitude-dependent maps for each of the seven types.

Outline

- The next slide describes how we use Fernald (JAM, 1972) inversions to retrieve new lidar ratios of single-type aerosol layers in clear skies (in lieu of the standard CALIPSO selection process).
- Slide 4 describes how we relate modeled sea salt fraction to lidar ratio for CALIPSO's clean marine aerosol type.
- Slide 5 describes how the technique can be used to create global and seasonal maps of Clean Marine aerosol lidar ratios, even in coastal regions where the CALIPSO selection process can mistype low altitude aerosols.
- Slide 6 presents the conclusions.
- Slide 7 describes MIRA





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Method

- We use MODIS DTDB column Aerosol Optical Depths (AOD) collocated with the CALIPSO backscatter profiles in clear skies.
- We subsample these collocated datasets for cloud-free time periods when a single CALIPSO aerosol type is present in the column (i.e., no multi-layers).
- We use a Fernald (JAM, 1972) inversion to infer the lidar ratios of these single-type layers, assuming that all contributions to AOD occur at altitudes less than 2 km above the CALIPSO aerosol layer top.
- We average the n retrieved lidar ratios S_r in each lat/long grid box for the year 2017, and omit grid boxes where the relative standard error is greater than 10%. That is, we require

$$\frac{\sigma/\sqrt{n}}{\langle S_r \rangle} \le 0.10 \qquad (1)$$

- For the N retrievals that pass this threshold test, we use a global aerosol model (GEOS/GOCART) to estimate the volume fractions F_j of M modeled aerosol components that are collocated with the CALIPSO curtain. Then we assume the retrieved lidar ratio S_r can be empirically represented as a volume average of the lidar ratio for each modeled aerosol component S_c . Thus, for a single retrieval:

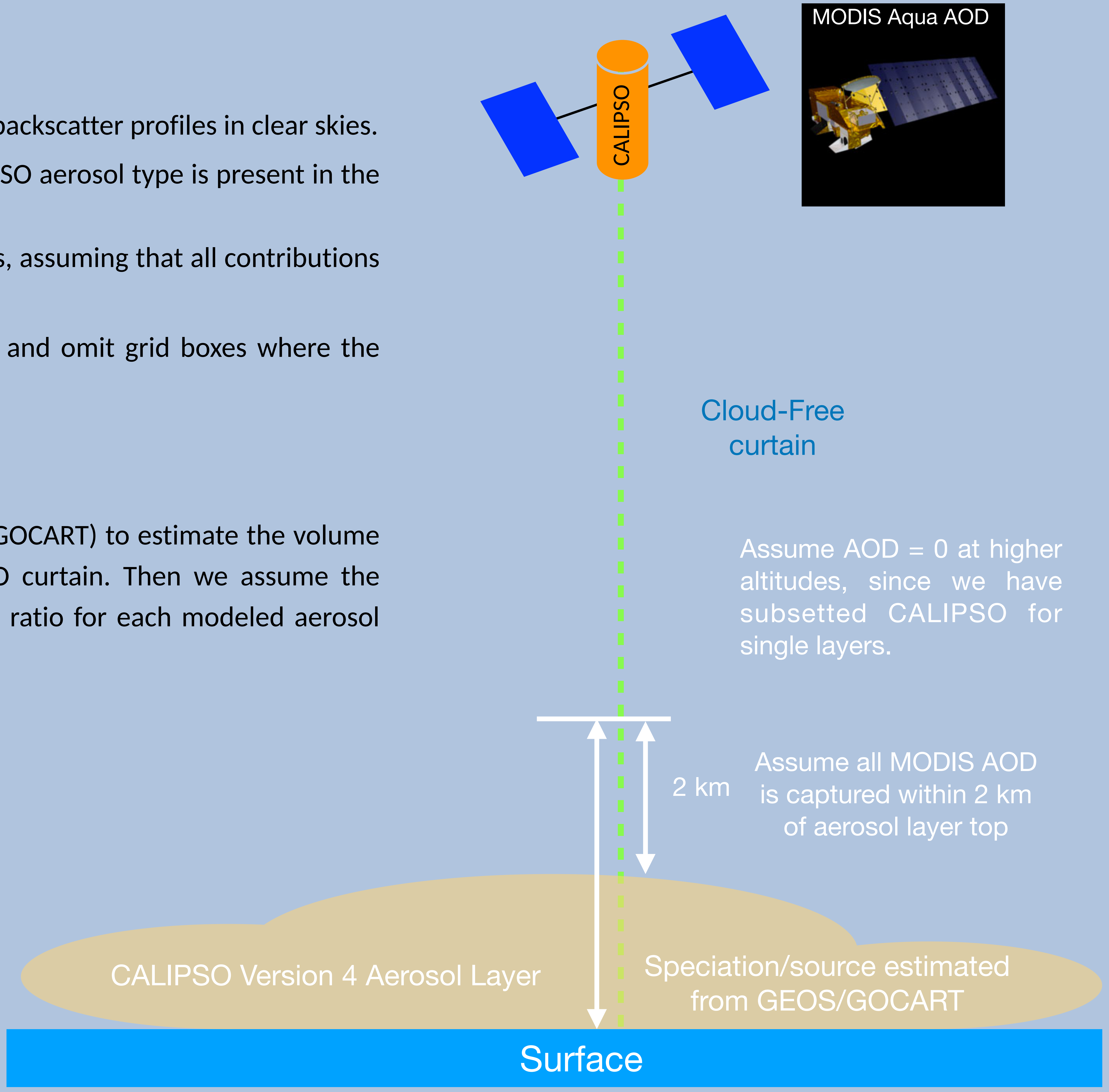
$$S_r \simeq \sum_{j=1}^{M} F_j S_{c,j} \qquad (2)$$

- For N retrievals, S_r can be expressed as a $N \ x \ 1$ vector:

$$\overrightarrow{S_r} \simeq [F]\,\overrightarrow{S_c} \qquad (3)$$

where $[F]$ is now a N x M matrix of modeled mixing ratios and S_c is a $M \ x \ 1$ vector. This can be solved to obtain the lidar ratio of each modeled aerosol component:

$$\overrightarrow{S_c} \simeq (F^t F)^{-1} F^t \overrightarrow{S_r} \qquad (4)$$



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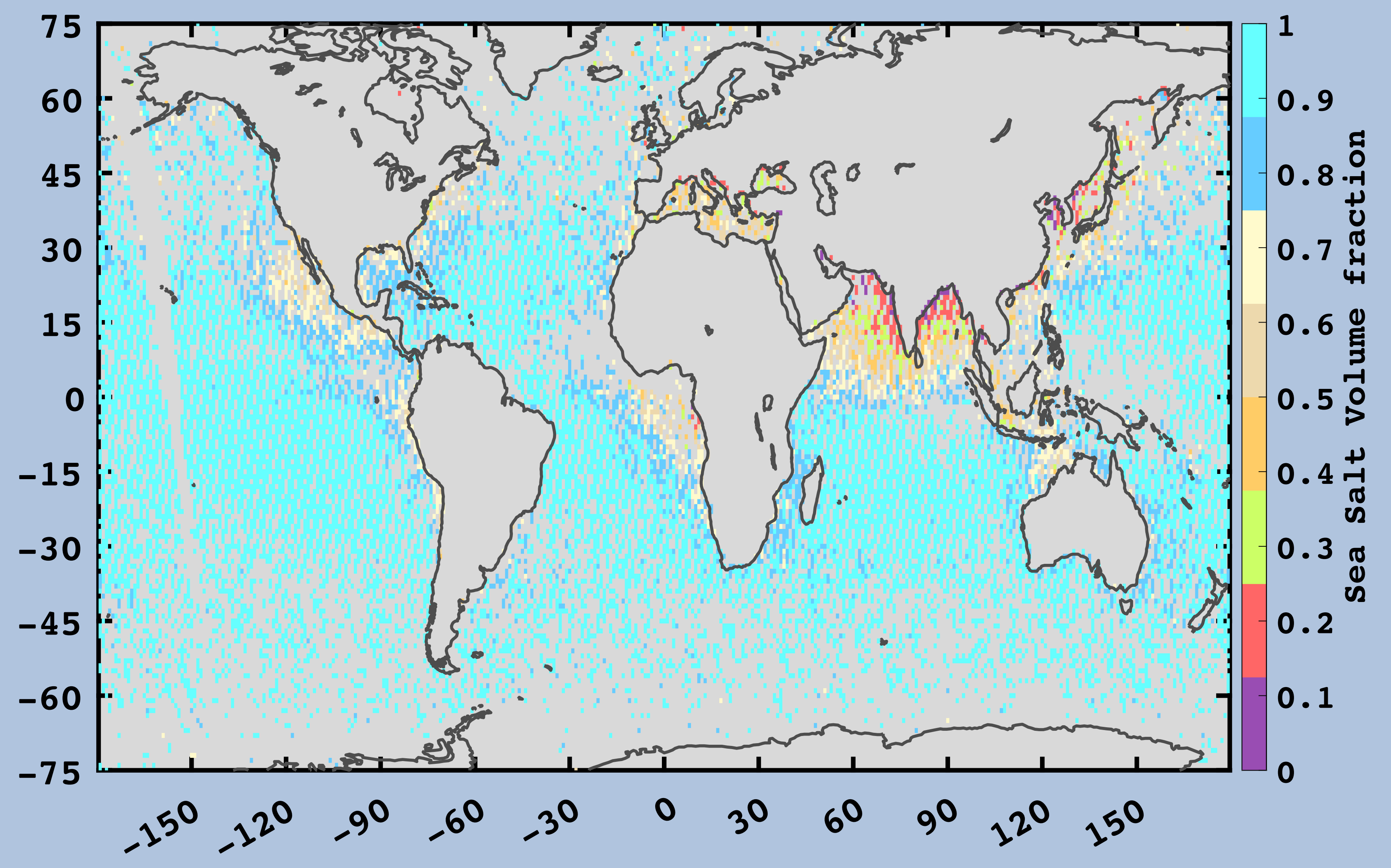
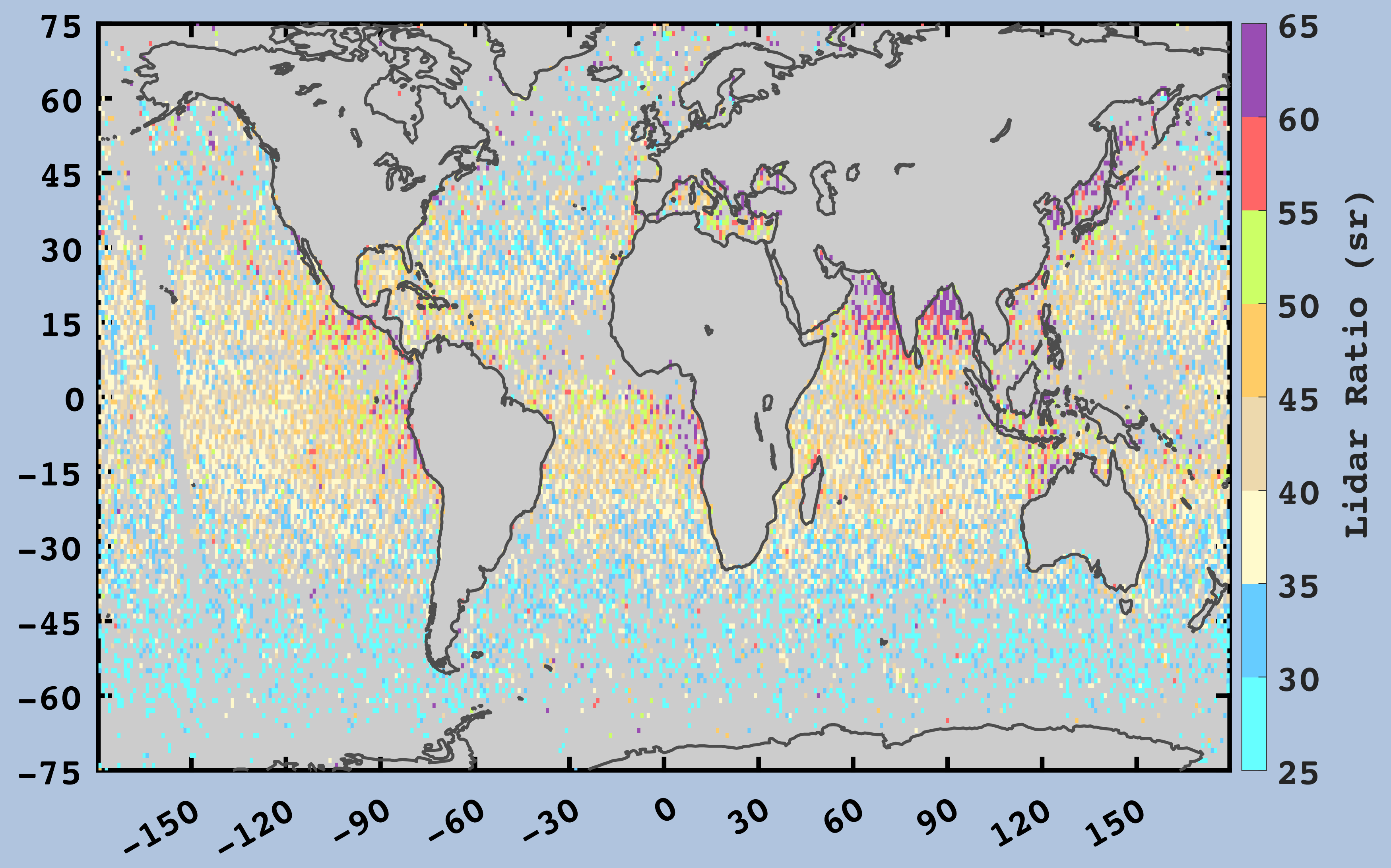
CALIPSO Clean Marine Aerosol Type

2017; no dust, Z < 2.5 km, $\frac{\sigma/\sqrt{n}}{\langle S_r \rangle} \leq 0.10$

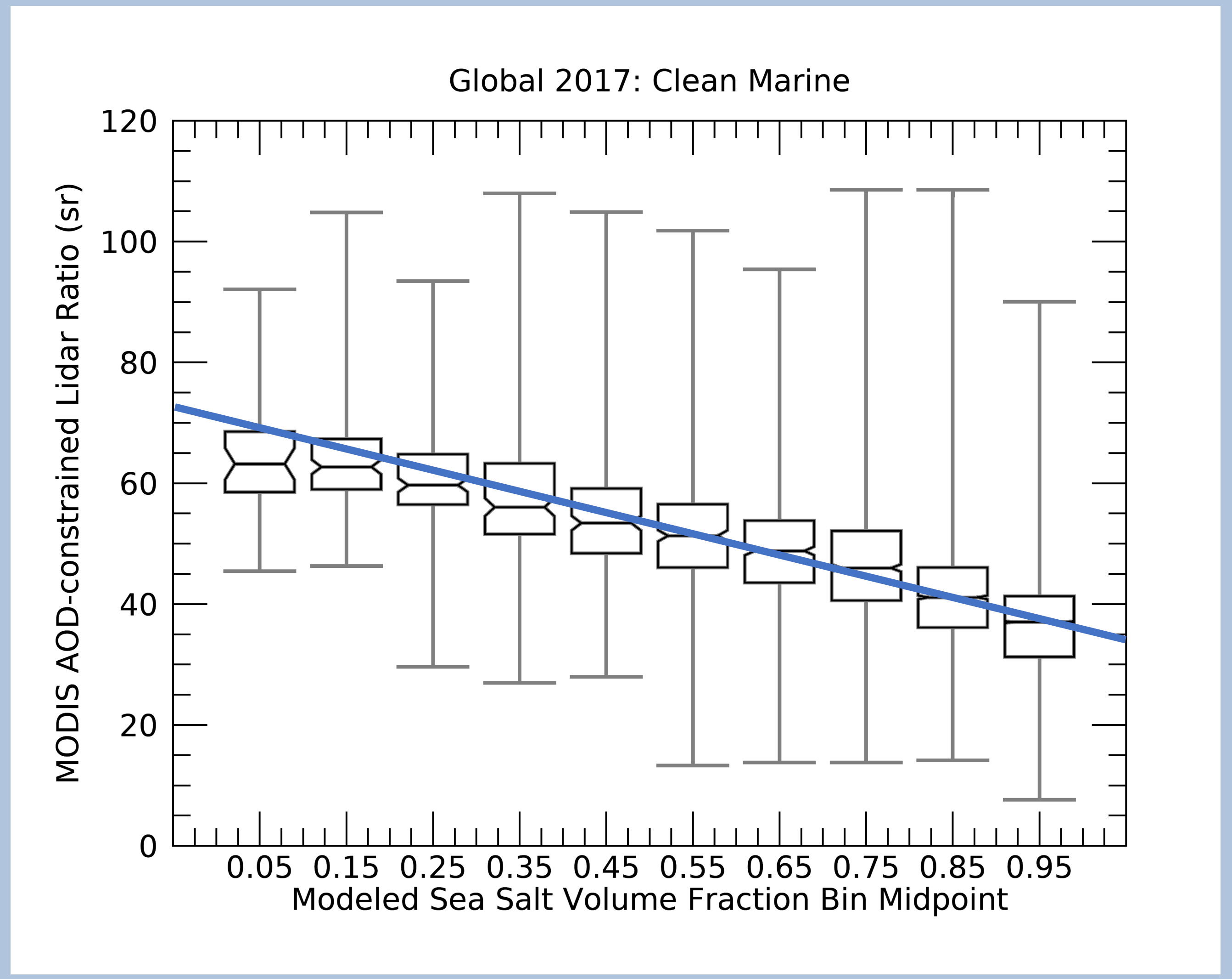
GEOS/GOCART volume fraction of sea salt for the MODIS-constrained lidar ratio retrievals



MODIS-AOD constrained Lidar Ratio (sr)



Constrained Lidar Ratio vs Sea Salt Volume Fraction



N = 14613, R = -0.58, S_{sea} = 34.7 sr, S_{oth} = 73.5 sr

- The left panel shows that modeled sea salt fraction (at altitudes below ~2.5 km) decreases near coastlines that are known for pollution and smoke (e.g., India). Thus, these coastal aerosols are likely misclassified.
- Constrained lidar ratios for the CALIPSO clean marine aerosol type are much higher in these same coastal regions where pollution and smoke is common than over the remote oceans (middle panel), and are actually more consistent with values expected for pollution or smoke (see slide 2).
- We assume that all CALIPSO clean marine layers are composed of up to two aerosol components in the GEOS/GOCART model — marine and other (non-dust). Thus, M = 2 in Equation 2 of previous slide, and we solve Equation 4 to obtain the lidar ratios of our two model components (sea salt and other).
- The result is a clear relationship between the MODIS-constrained lidar ratio and modeled sea salt fraction for the CALIPSO Clean Marine type (right panel).
- Using the GEOS/GOCART sea salt volume fraction can potentially improve upon using a single *a priori* aerosol lidar ratio for CALIPSO Clean Marine layers.

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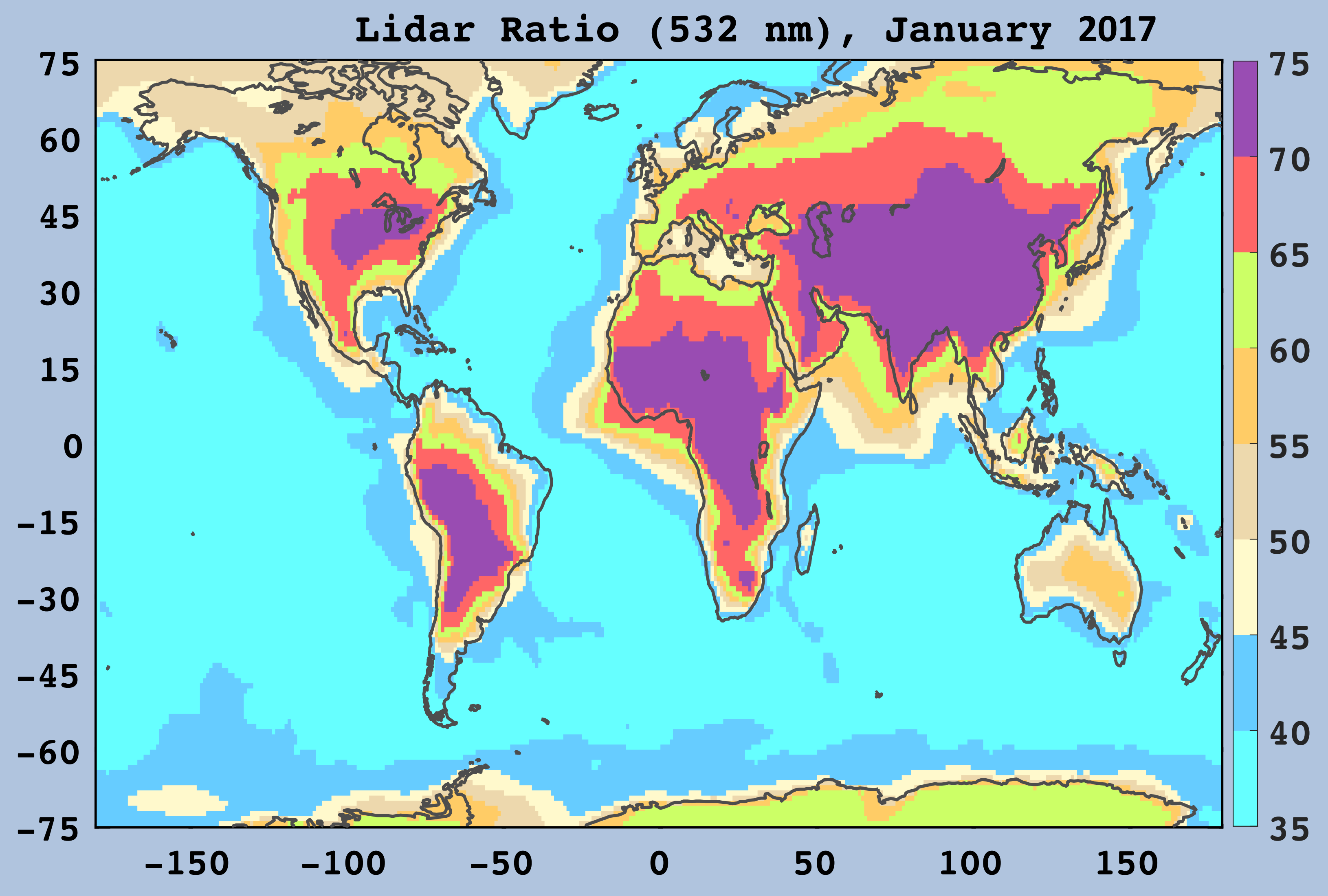
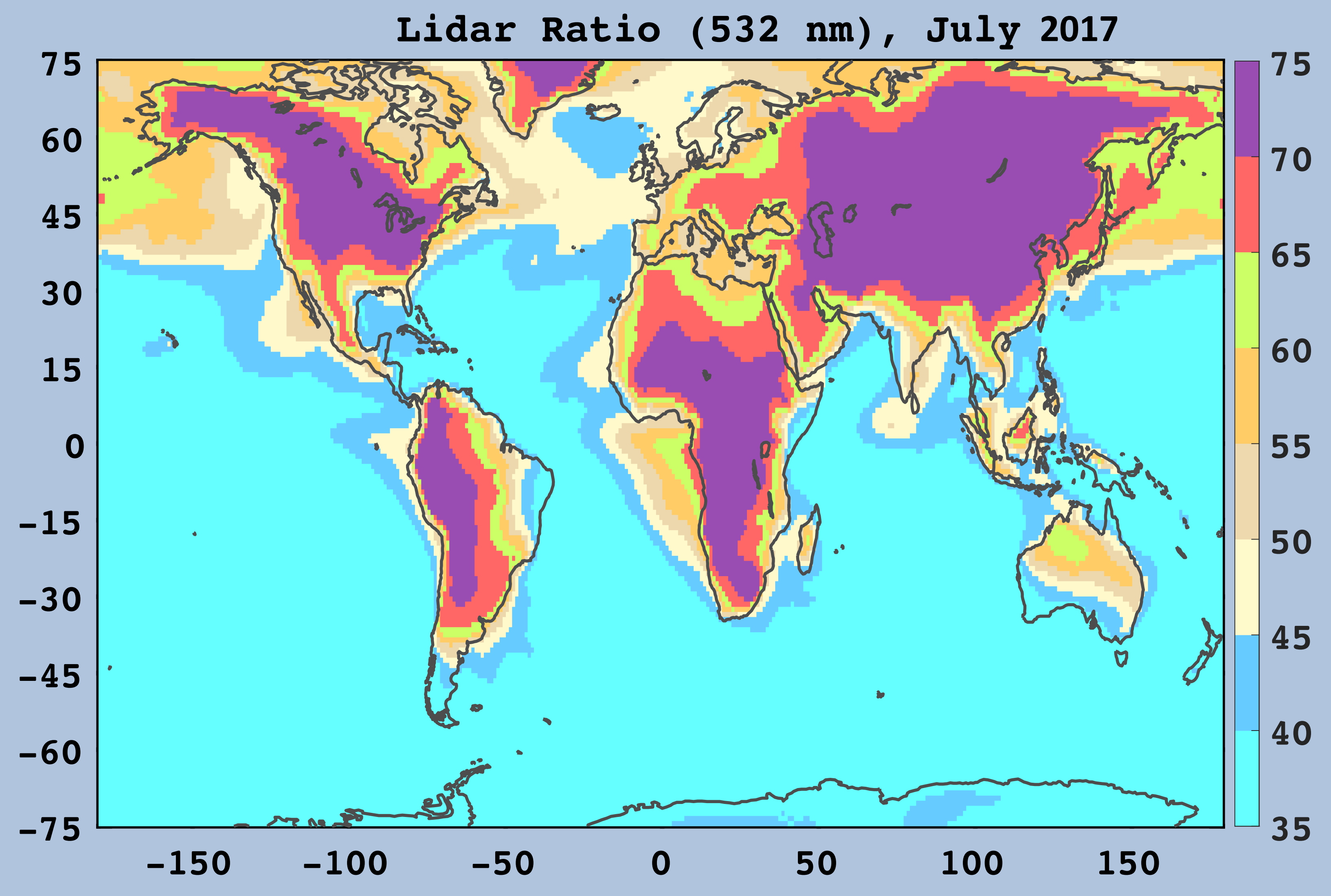
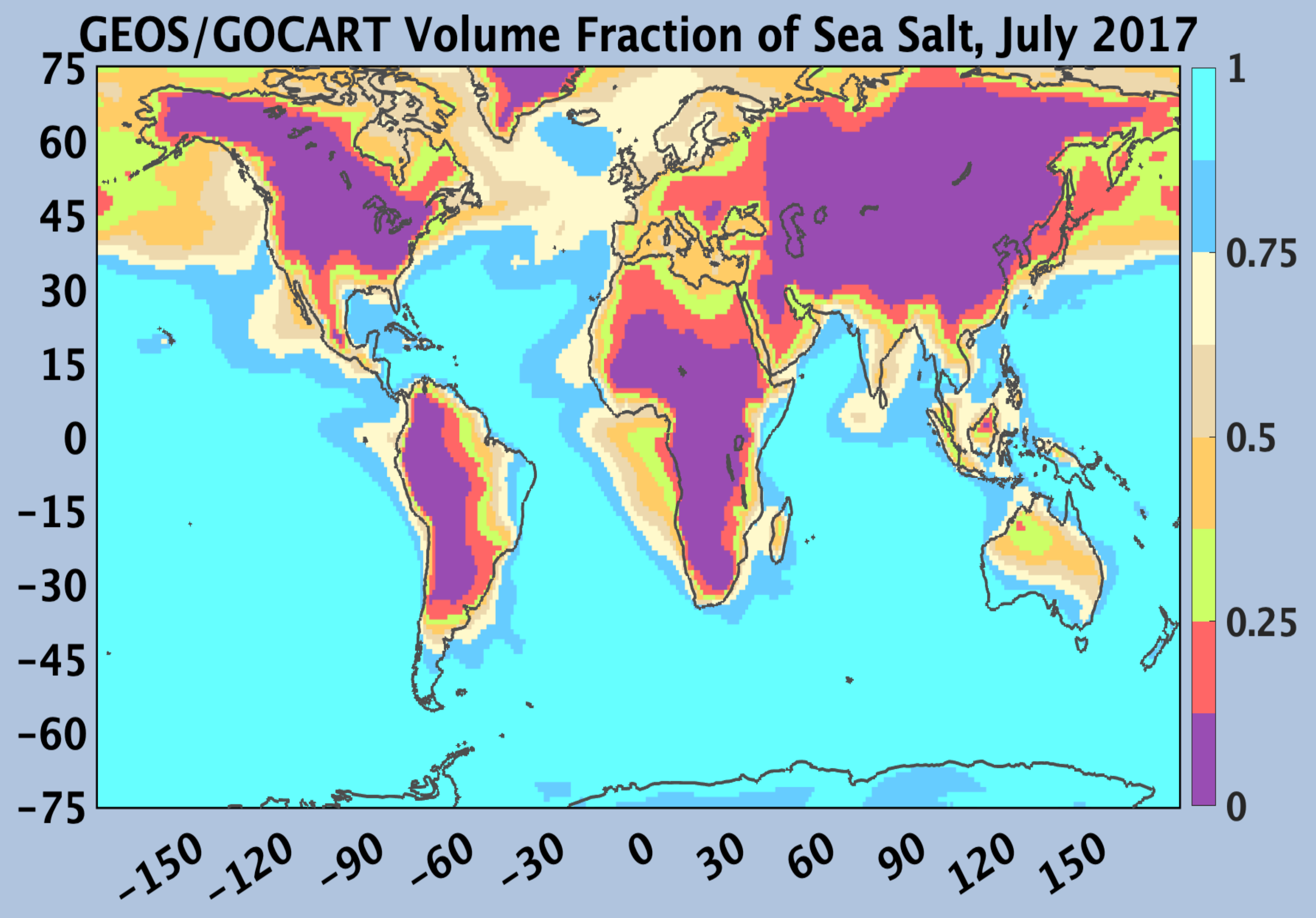
Application

2017; no dust, Z < 2.5 km







- Now we can use the modeled sea salt fractions to create climatological lidar ratio maps that are consistent with the MODIS-constrained lidar ratio retrievals.
- Note that this procedure does not use Mie Theory or any other single-scatter computations; it is based upon empirically linking retrieved lidar ratios to modeled aerosol components.
- One advantage of this approach is that the model provides values in perpetually cloudy regions where constrained retrievals are rare (e.g., compare to middle panel on slide 4).
- Another advantage of the model is that it provides more realistic transitions at coastlines; note that sea salt fractions can be greater than zero over land and less than 1 over ocean (right panel), which is not allowed in the CALIPSO lidar ratio selection process (see slide 2).
- The smooth coastal transitions of sea salt fractions are also reflected in the lidar ratio maps. However, lidar ratios far from shore are less robust because our dataset is exclusively over ocean (per slide 4).

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Conclusions

- We presented a technique for creating global maps of lidar ratios that is linked to MODIS-CALIPSO Fernald inversions and GEOS/GOCART aerosol speciation, and we applied this technique to CALIPSO's Clean Marine aerosol type.
- The sea salt lidar ratios are higher than expected over the remote oceans (34.7 sr). Some contributing factors that we will explore going forward are:
  - We did not make an AOD adjustment in the Fernald inversions to account for Stratospheric AODs, which will artificially increase the retrieved lidar ratios that we obtain for any tropospheric CALIPSO layer.
  - Thin, tenuous aerosol layers that are below the CALIPSO detection limit and located outside of CALIPSO-detected layers will also artificially increase the retrieved lidar ratios.
  - Sulfate from DMS oxidation is a non-sea salt aerosol source found in remote clean marine layers, and this could also elevate the lidar ratio above the expected value of ~23 sr.
- Advantages of the approach that we described are

1. Empirical method does not require Mie Theory or other single-scatter computations to compute lidar ratios.
2. Model provides results in perpetually cloudy regions where the constrained retrieval fails (middle panel).
3. Model provides smooth transitions at coastlines because sea salt fractions can be non-zero over land and less than 1 over ocean.

Connection to MIRA

- This work is one project within the Models, In situ, and Remote sensing of Aerosols (MIRA) international working group.
- MIRA is a forum that fosters international collaborations amongst the aerosol specialties. https://science.larc.nasa.gov/mira-wg/.
- The purpose of MIRA is to help scientists find potential collaborators in aerosol disciplines that might not be part of their normal research activities.
- Our project is listed as the Mapping Aerosol lidar ratios for CALIPSO (MAC) project in the MIRA federation of projects (https://science.larc.nasa.gov/mira-wg/mac/).
- We seek scientists to provide suborbital lidar ratio data (for verification of our maps) and modelers to provide global output of aerosol speciation for this project.
- ***See description of MIRA on the next slide.***

Acknowledgements

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The Models, In situ, and Remote sensing of Aerosols (MIRA) Working Group

What is MIRA?

MIRA is forum that fos- ters international collaborations amongst the aerosol Modeling, In situ, and Remote sens- ing specialties. MIRA is also a collection of interdisciplinary projects with clear goals that are pursued by small working groups. Finally, MIRA projects are generally char- acterized by requests for additional scientific data (both observational and modeled).

Why?

The purpose of MIRA is to con- textualize both observations and model re- sults through the encouragement of holistic projects and collaborations.

How does MIRA differ from other projects?

MIRA focuses on interdisciplinarity to improve mea- surements and their utility, so MIRA complements the activities of other groups. For example, ensemble model runs of AeroCom could be used in a MIRA project with greater robustness than a similar effort that uses single-model analyses. Other interdisciplinary aerosol groups have different primary foci.

What are MIRA's immediate science goals?

- Encourage projects that facilitate links be- tween modeling and measurements of particu- late pollution.
- Encourage projects that use interdisci- plinary knowledge to develop and improve aerosol remote sensing techniques.
- Encourage a community database of aerosol optical tables that easily allows new contributions and updates.

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