Global Aerosol Vertical Profiles from CALIPSO Lidar and GOCART Model

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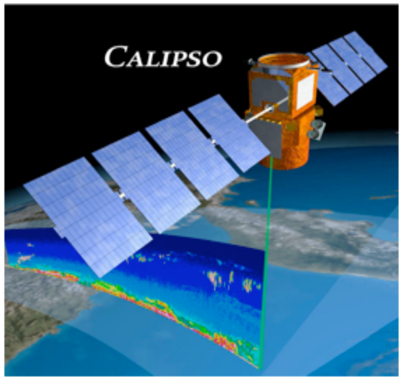
OBJECTIVES

- Derive an annual cycle of aerosol vertical distributions on a global scale through a statistical analysis of CALIPSO observations.
- Examine differences between CALIPSO observations and GOCART simulations.

CALIPSO LIDAR (CALIOP) MEASUREMENTS



- Dave's Overview

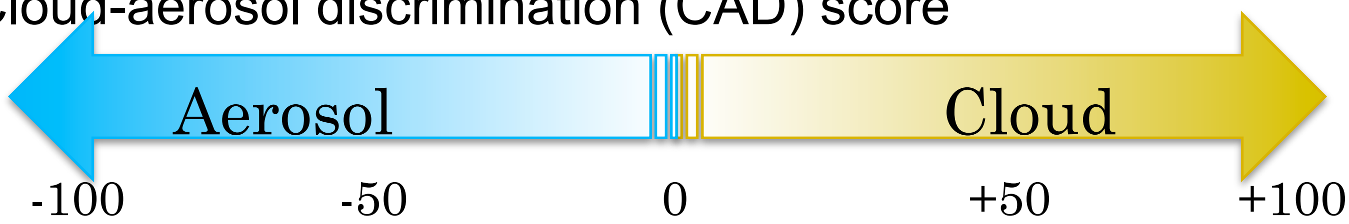
- CALIPSO is providing first-ever, annual cycle of aerosol vertical distributions at high resolution and on a global scale.

- The real strength of CALIPSO is the high-resolution vertical profile information more than AOD.

CALIPSO DATA USED

Level 2, Version 2.01 Aerosol **LAYER** Products

- 18 month (06/2006-11/2007)
- Layer top and base
- Layer extinction & attenuated backscatter
- Volume depolarization ratio (δ_v, molecular + particle)
- Lidar ratios (extinction-to-backscatter ratio)
- Cloud-aerosol discrimination (CAD) score



➢**We derive aerosol profiles at 532 nm from the layer product.**

➢**At altitudes of no aerosol detection, we set extinction & backscatter to ZERO (biased lower because of the detection sensitivity).**

GOCART MODELING

- Offline simulations
  - driven by GEOS-4
  - 2.5°x2°
  - 30 layers
  - outputs every 3hr

- Major components
  - **Sulfate, OC, BC:** from industrial, biomass burning, biogenic, and volcanic sources
  - wind-blown **Dust** & **Sea-salt**

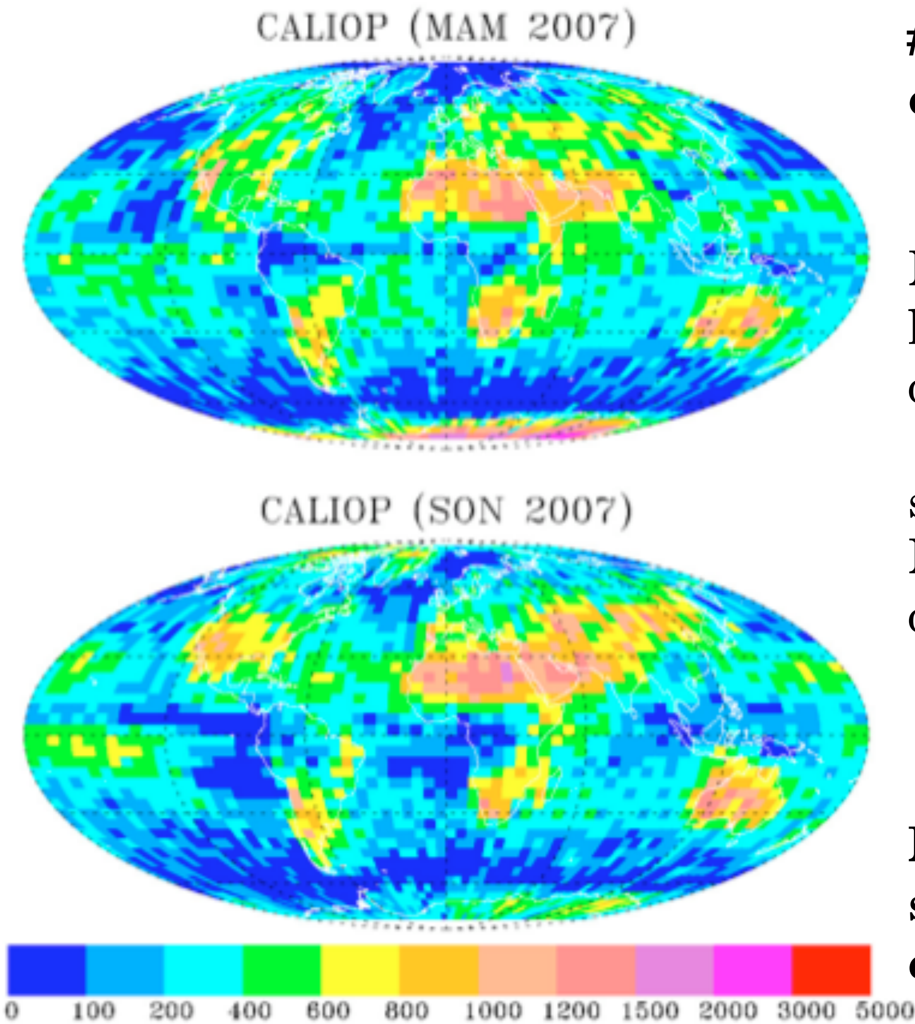
Data Screening & Sampling

- **Data Screening**
  - **Nighttime** (better quality than daytime)
  - **Cloud-free**: Clear column, and high-level, thin clouds (top>7km, OD<0.1) (using CALIOP cloud layer products)
  - **CAD score**: [-50, -100]
  - **Lidar ratio**: initial = final (excluding complex features, e.g., vertically adjacent to or imbedded in other feature)

- **CALIPSO dust/non-dust separating** (simple threshold approach)
  - $\delta_v > 0.06$, dust; $\delta_v < 0.06$, non-dust

- **GOCART and MODIS Sampling**
  - Close to **CALIOP cloud-free** column (<u>spatial proximity</u>)
  - GOCART close to CALIOP overpass time (<u>temporal proximity</u>)

CALIPSO-based "Cloud-Free" Sampling



# of cloud-free samples in each 5°x4° grid

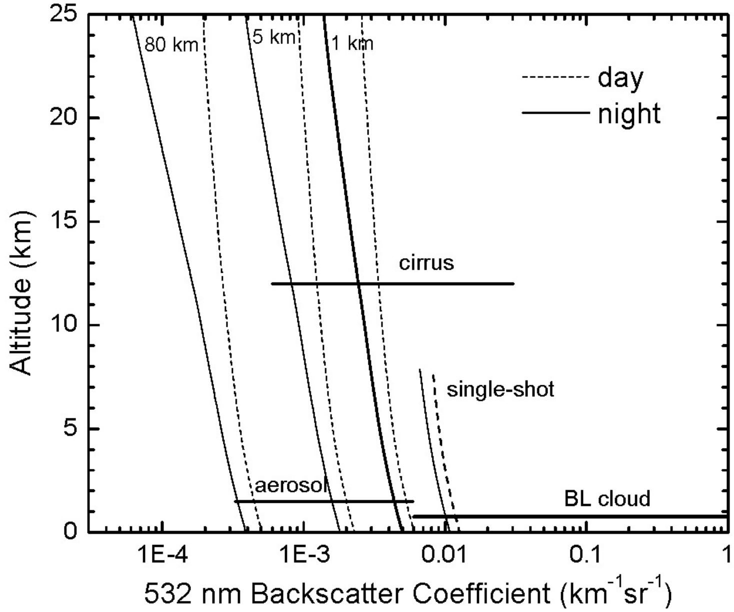
Non-uniform distributions: higher over land than over ocean;

substantial under-sampling in N. pacific, N. Atlantic, tropical oceans, S. Oceans,

MODIS and GOCART are sampled based on CALIPSO cloud-free columns!

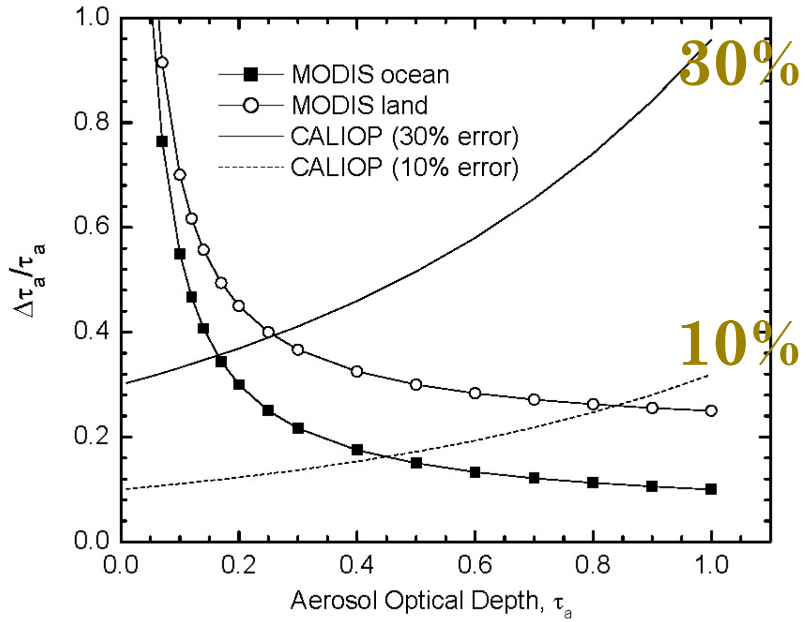
MAJOR UNCERTAINTIES IN CALIPSO AEROSOL

- Detection sensitivity



Night > Day; FA > ABL

- Lidar Ratio selection



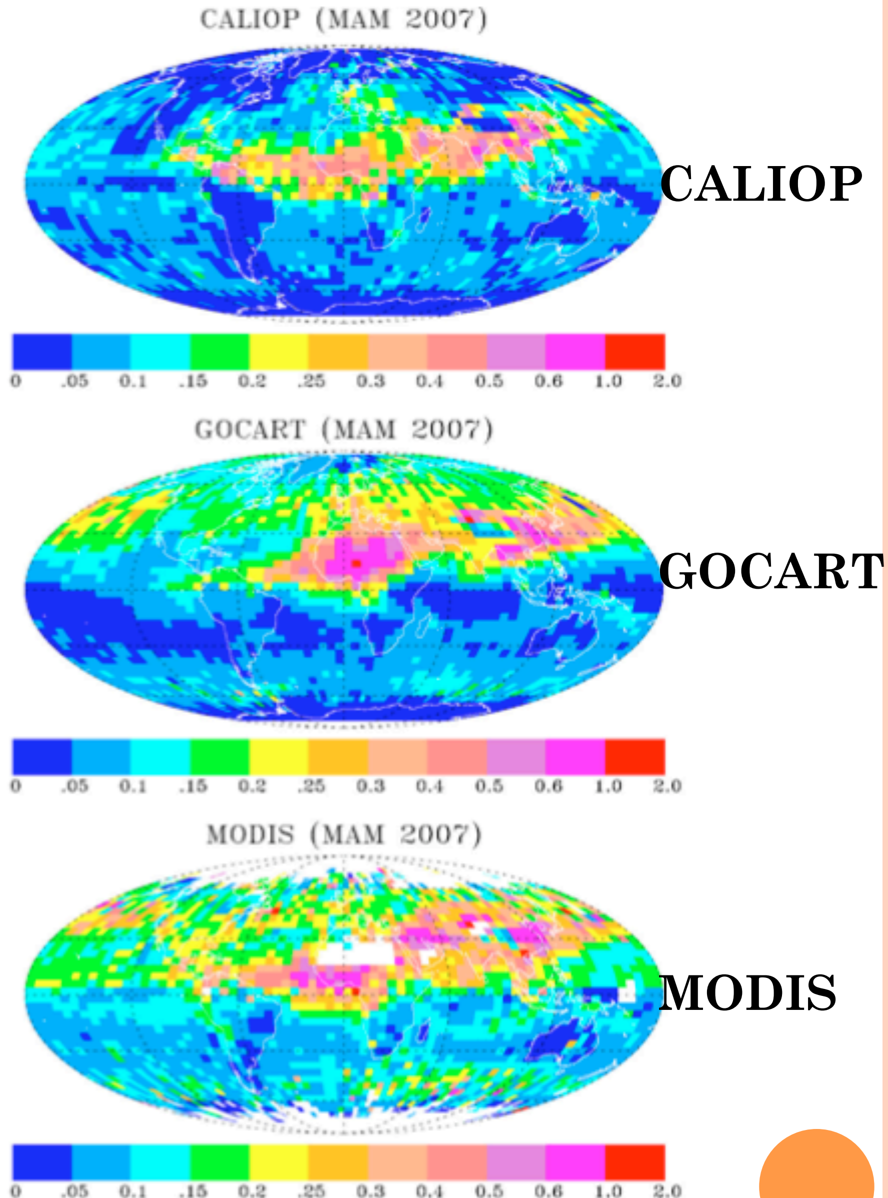
Despite AOD error, **the shape of the profile** (in particular upper portion) is fairly <u>representative.</u>

- Incorrect identification of the base (e.g., attenuation of signal)
- Aerosol/clouds misclassifications

[from Winker et al., JTECH, 2009]

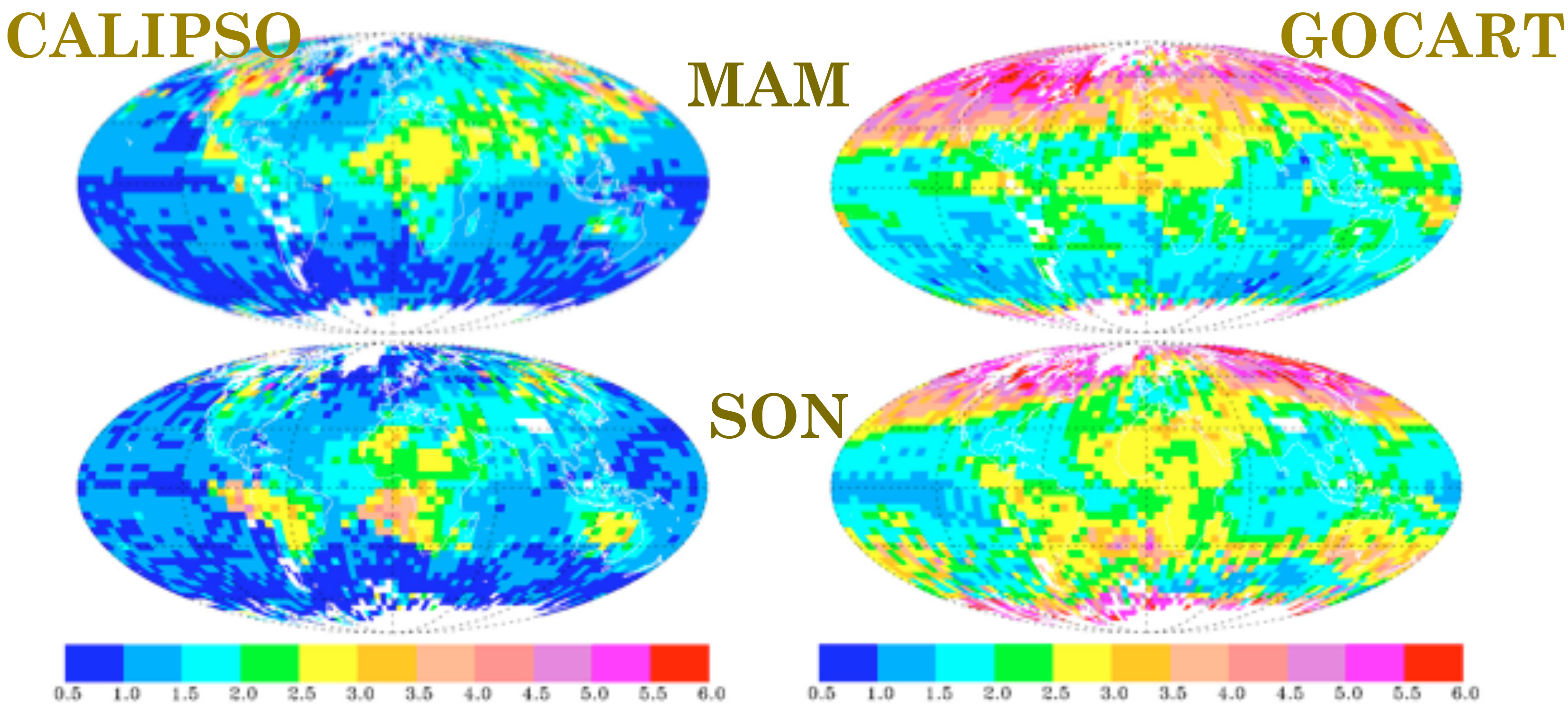
CLOUD-FREE AOD

- General consistency in **patterns** (and seasonal variations).
- CALIOP AOD generally lower than MODIS.
- But the real strength of CALIPSO is the high resolution vertical profile information more than AOD!



Scale height (H) for Extinction

$$\int_{z=0}^{z=H} \sigma dz = (1 - e^{-1})AOD = 63\% AOD$$

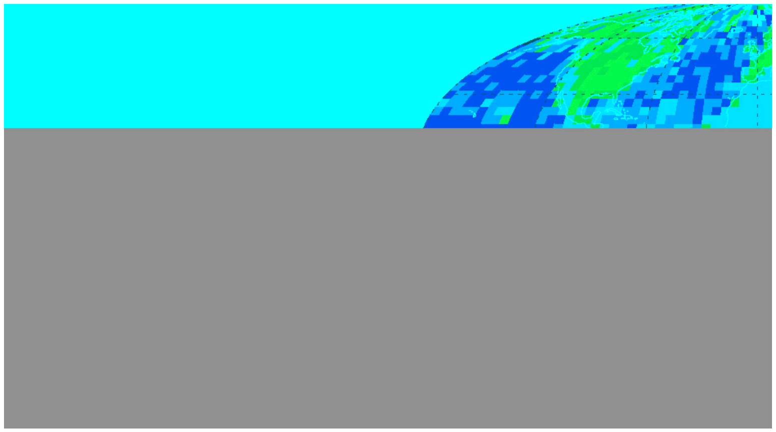


- CALIPSO < GOCART consistently;
- Better agreement over dust and biomass burning region;
- Largest differences in mid- and high-latitudes.

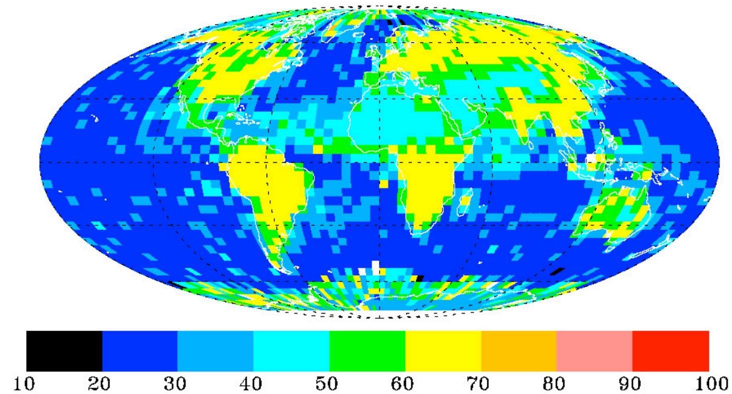
LIDAR RATIO

CALIOP lidar ratio (ABL)

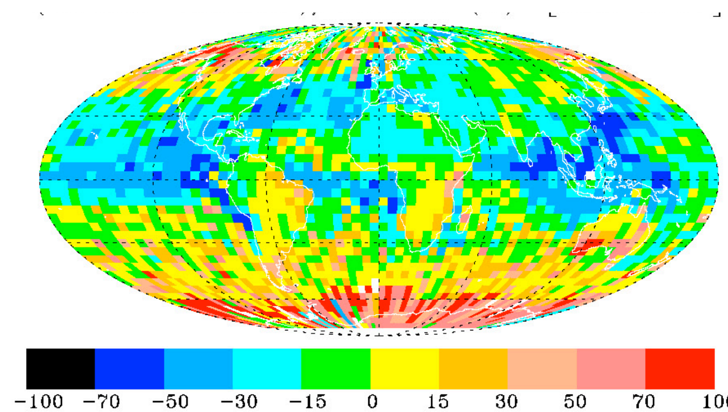
MAM



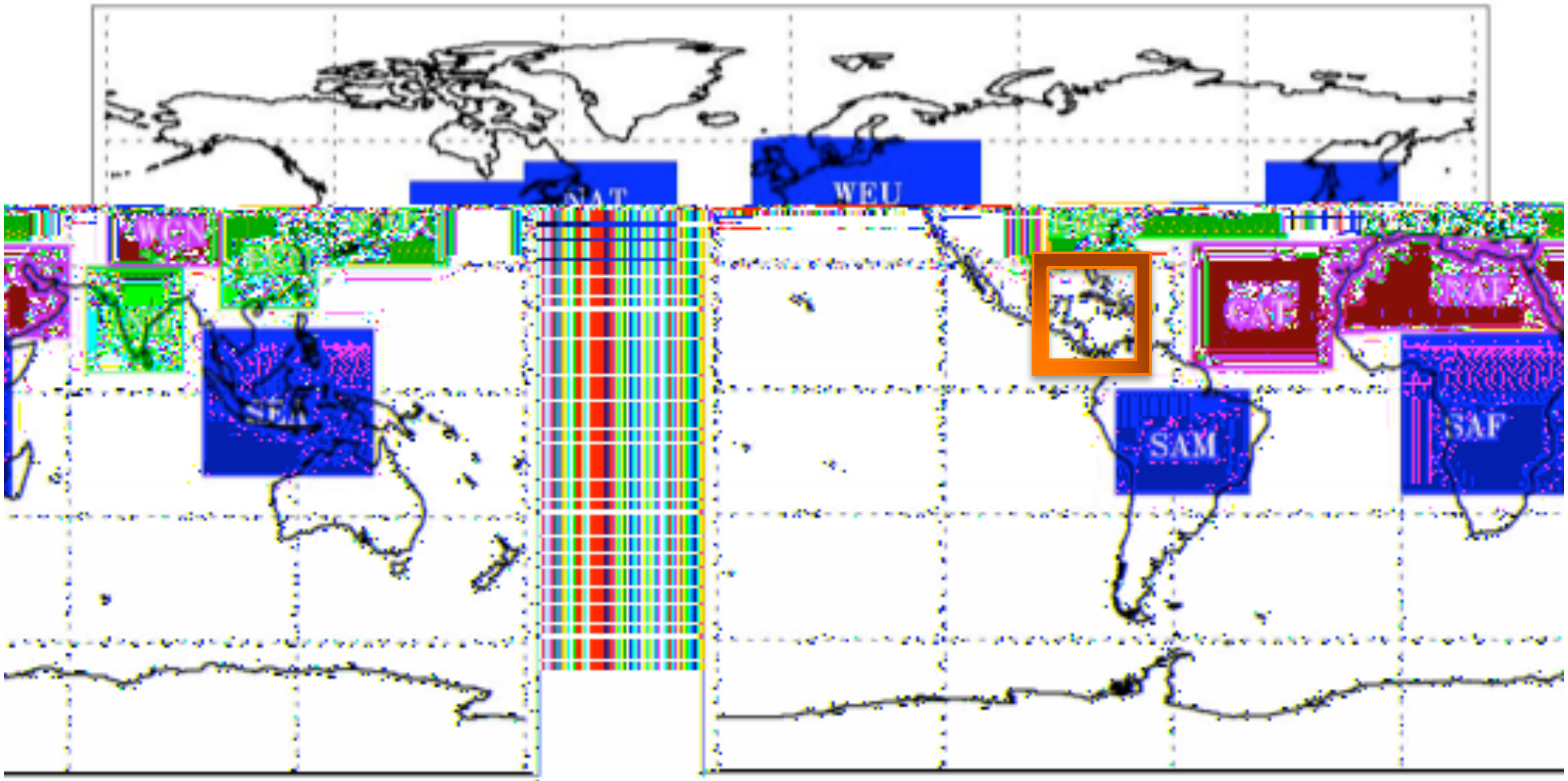
SON



Relative Difference: [CALIOP - GOCART] / GOCART (%)

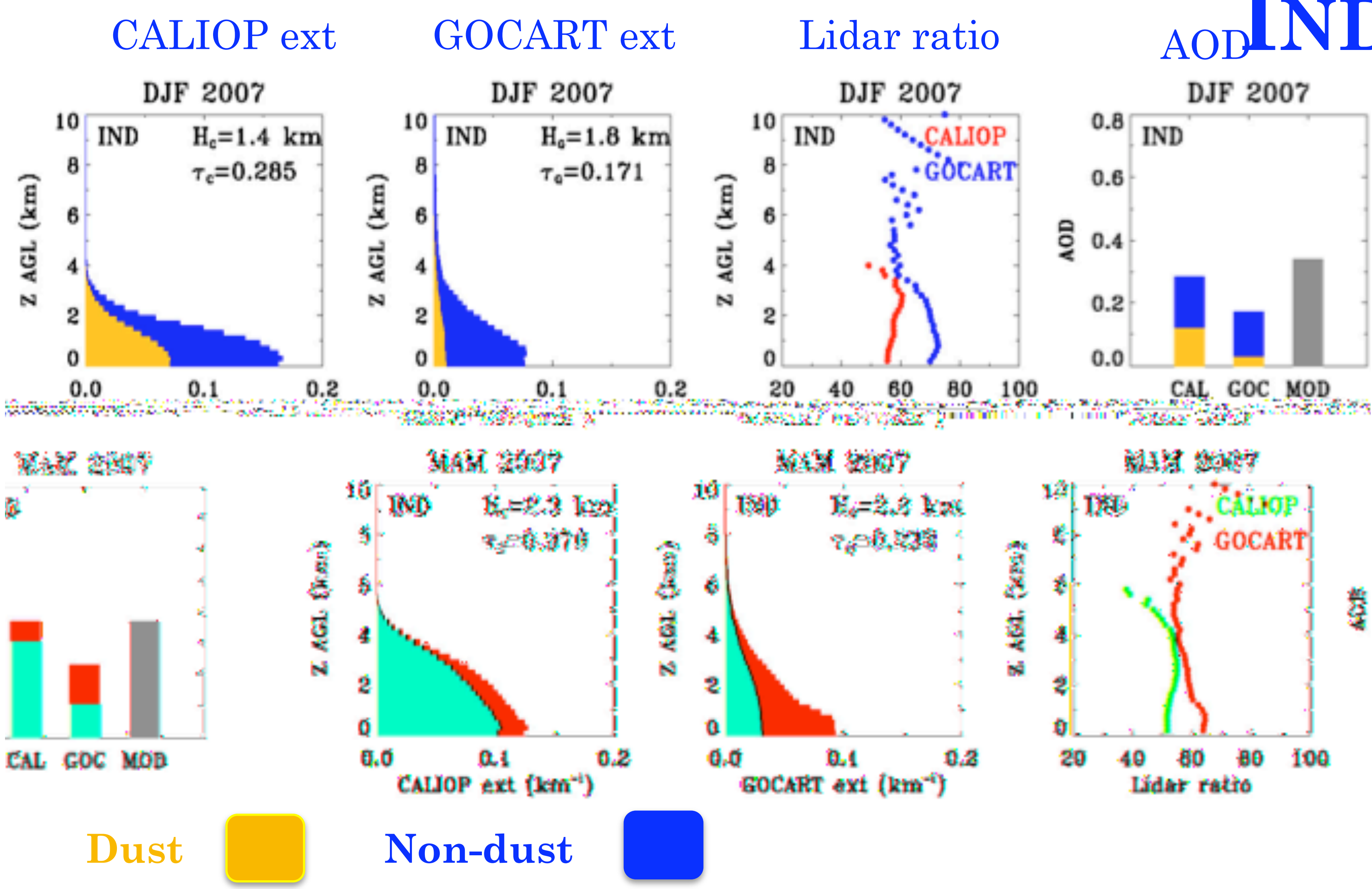


REGIONAL ANALYSIS



Smoke Dust Pollution/ Mixture

INDIA

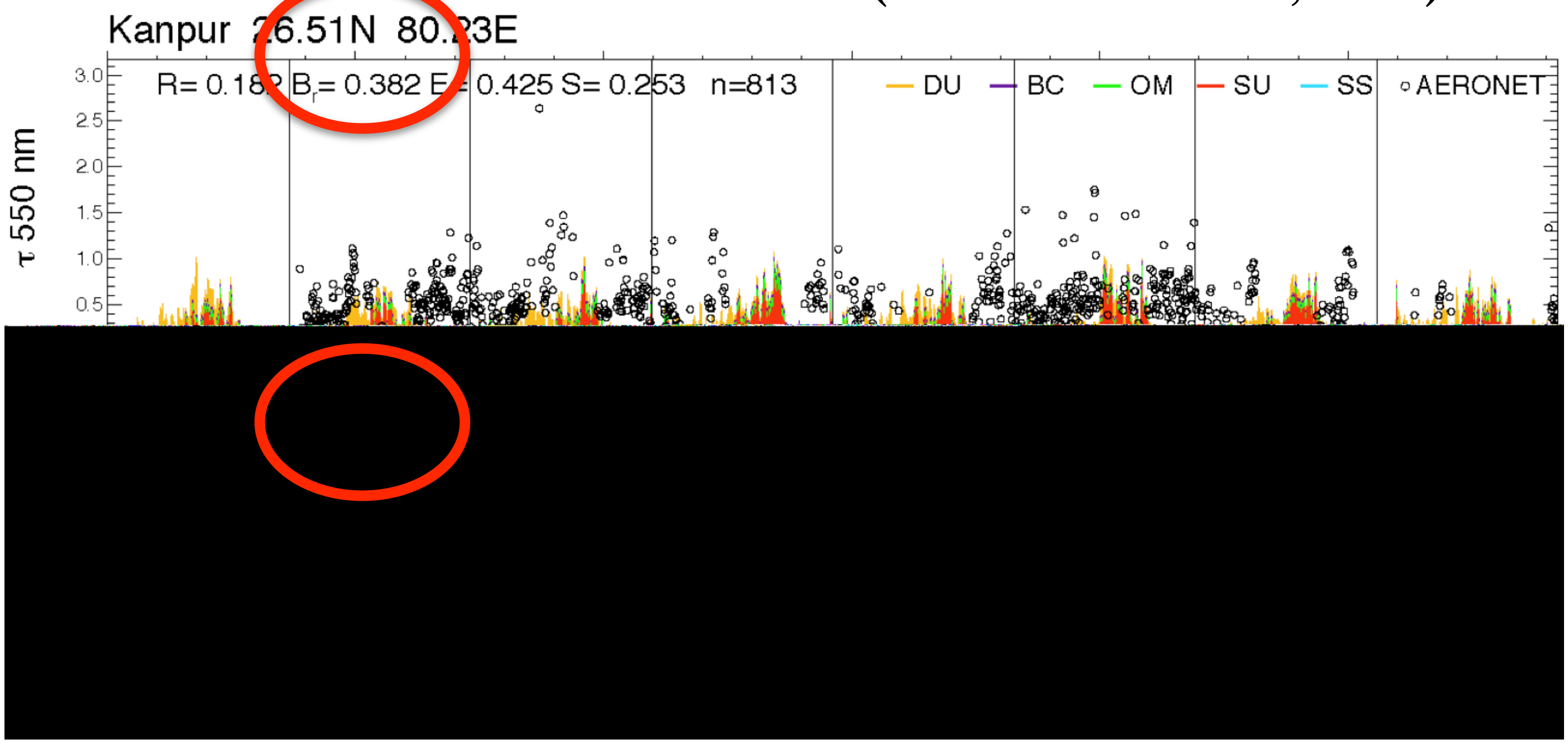


- Good agreement of aerosol top/scale height.
- GOCART has much lower extinction/AOD, which results mainly from dust component.

GOCART VS AERONET

INDIA

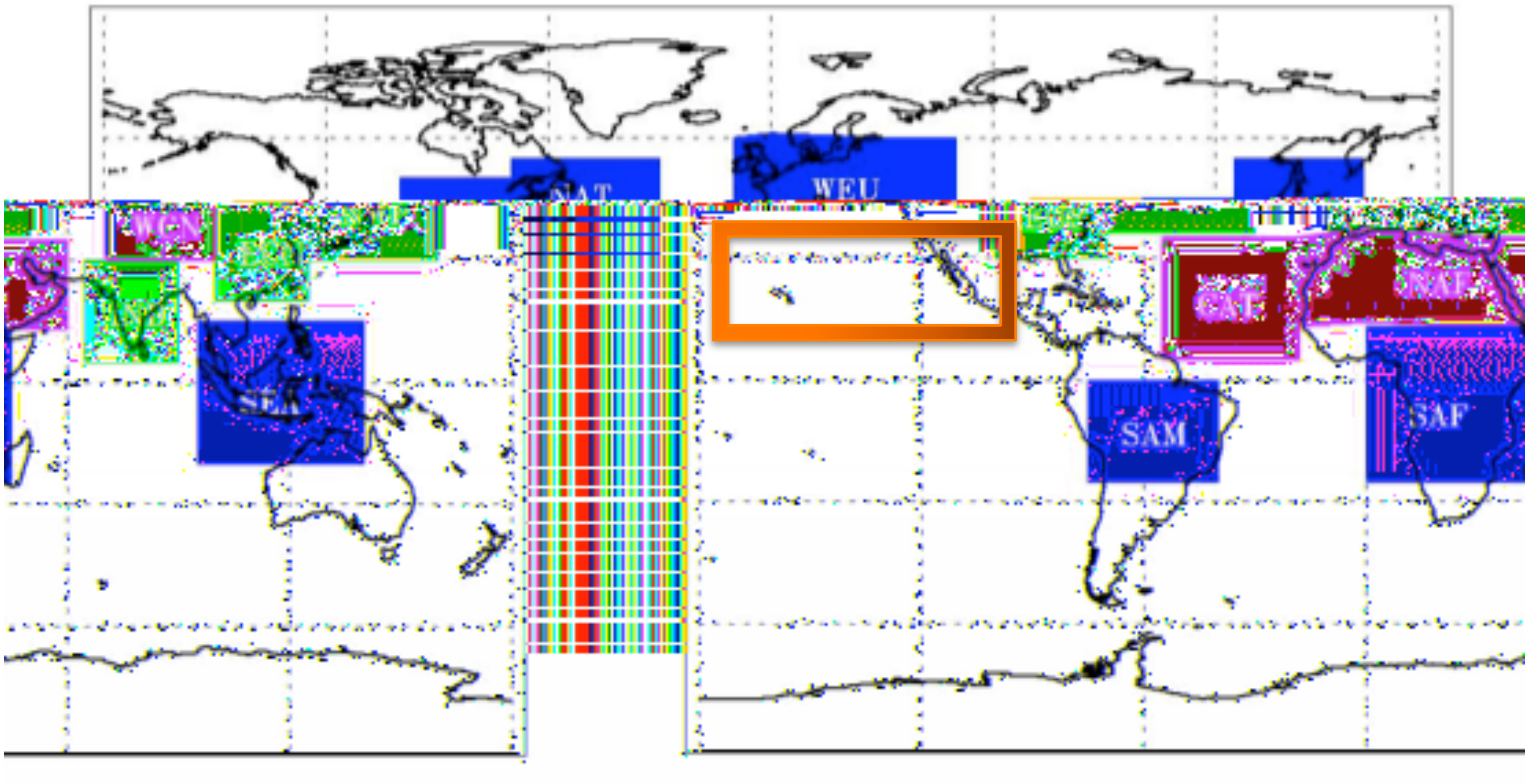
(From Chin et al., 2009)



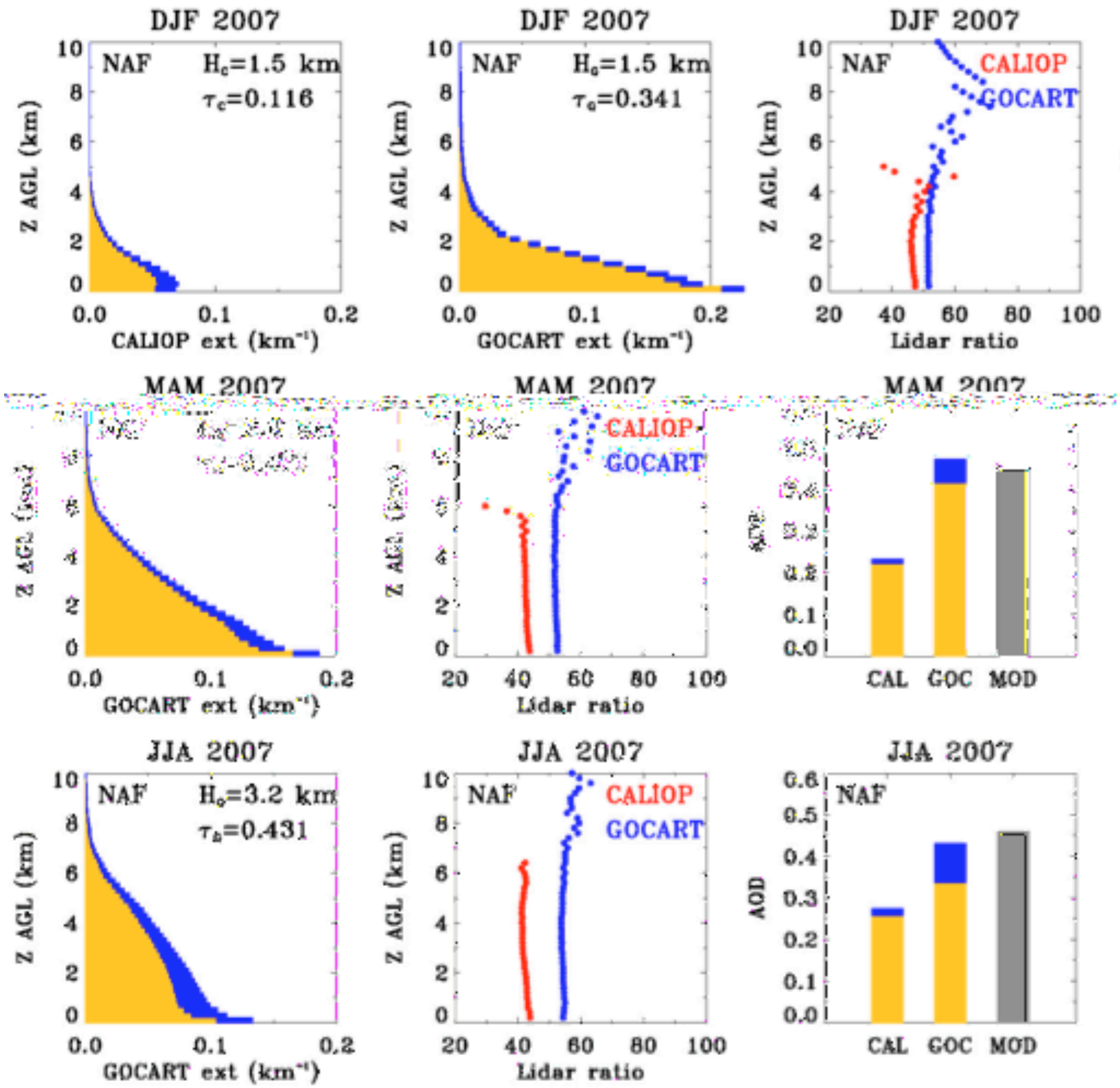
- GOCART underestimates AOD by more than a factor of 2. ☑
- *But is the underestimate due to dust or pollution* ?
- **More work is needed**
  - Better separation of CALIOP dust and non-dust;
  - Improvements of GOCART model (on-going).

DUST SOURCE REGIONS

NORTH AFRICA /ARABIAN PENINSULA



North Africa

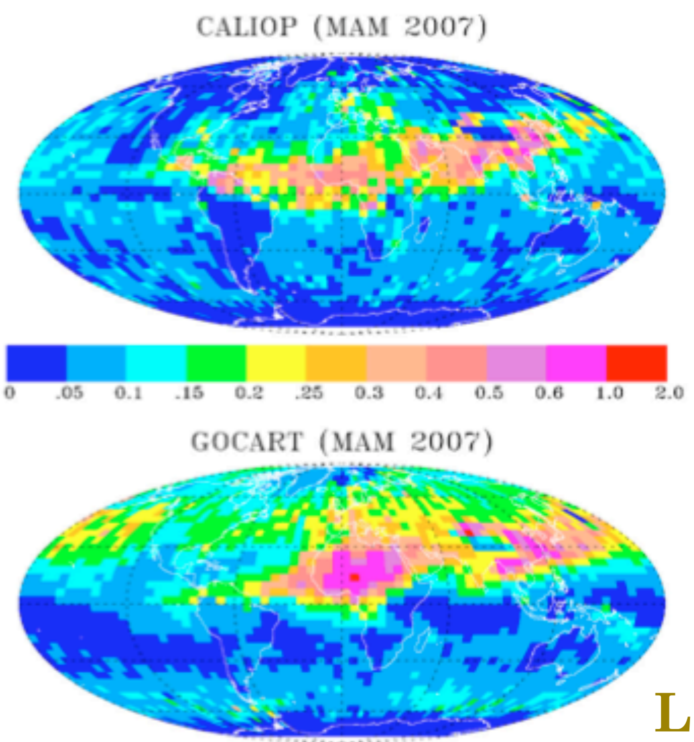


CALIOP ext GOCART ext Lidar ratio

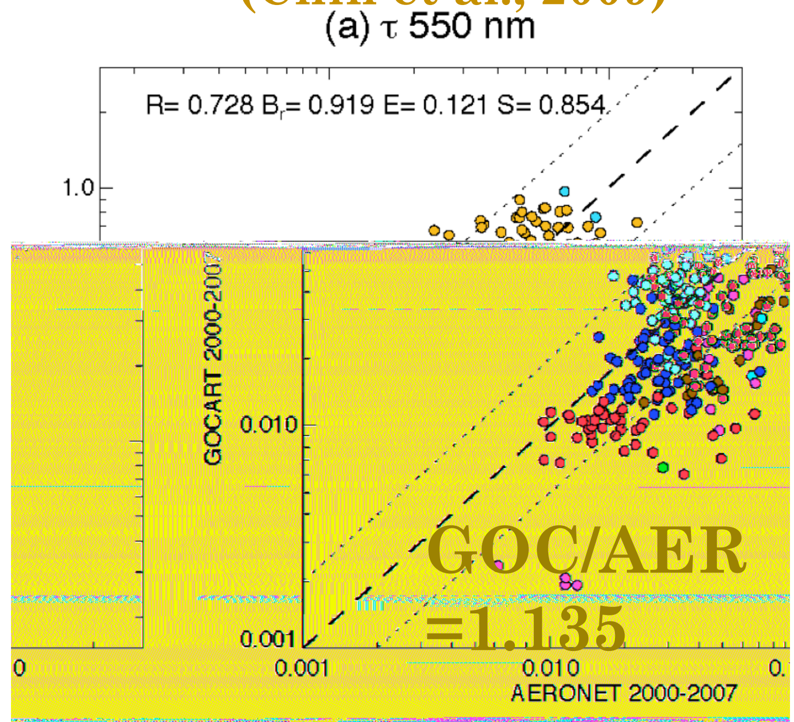
- Good agreement for the top of aerosol layers.
- **Much lower CALIOP extinction, particularly below 2 km.**
- Lidar ratio:
  - CALIOP=43
  - GOCART=52
  - within the observed ranges

Possible Reasons:

- CALIOP
  - may not detect ABL dust due to the attenuation of signal
  - may misclassify dust as clouds
- GOCART overestimate (?)



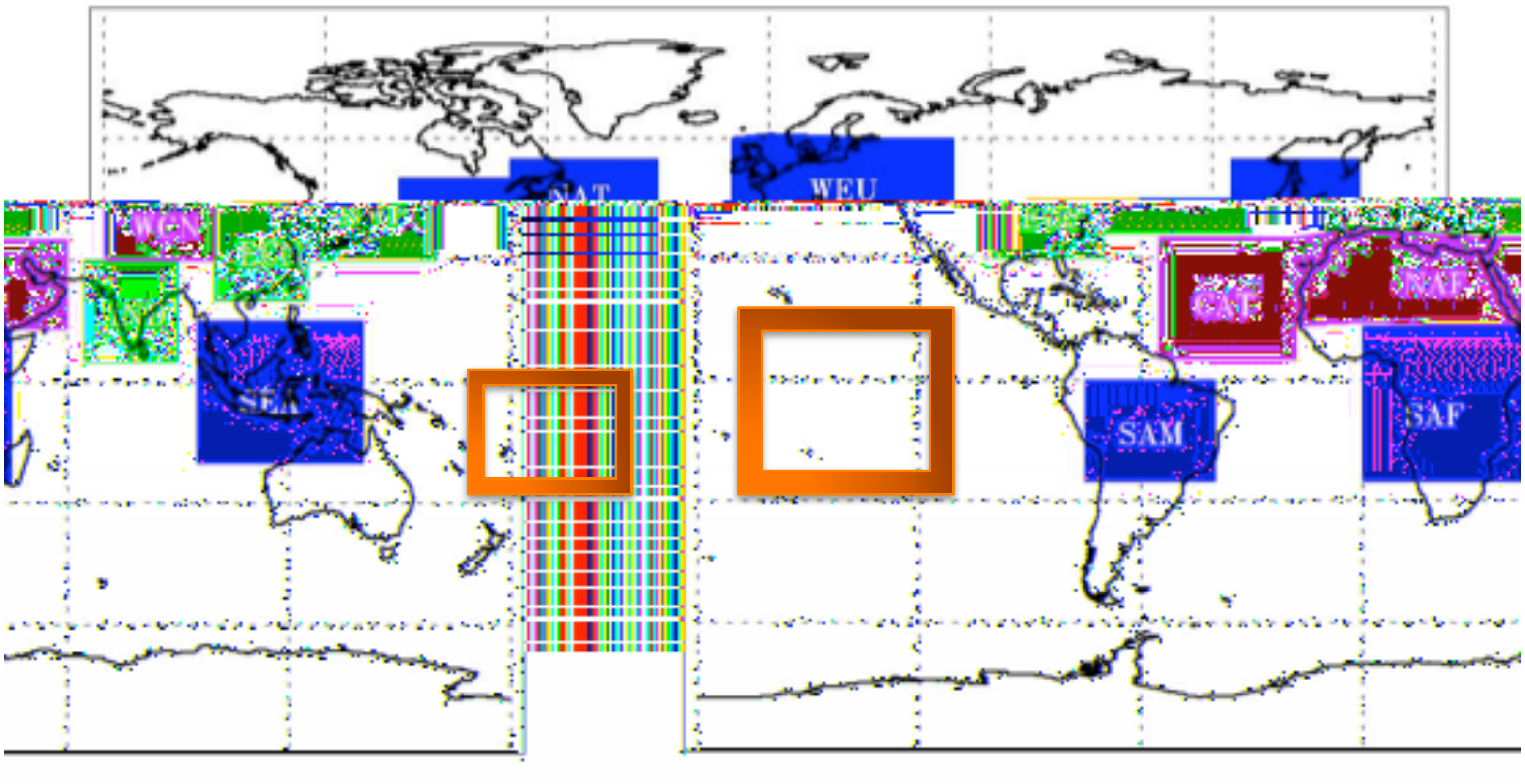
GOCART vs AERONET
(Chin et al., 2009)



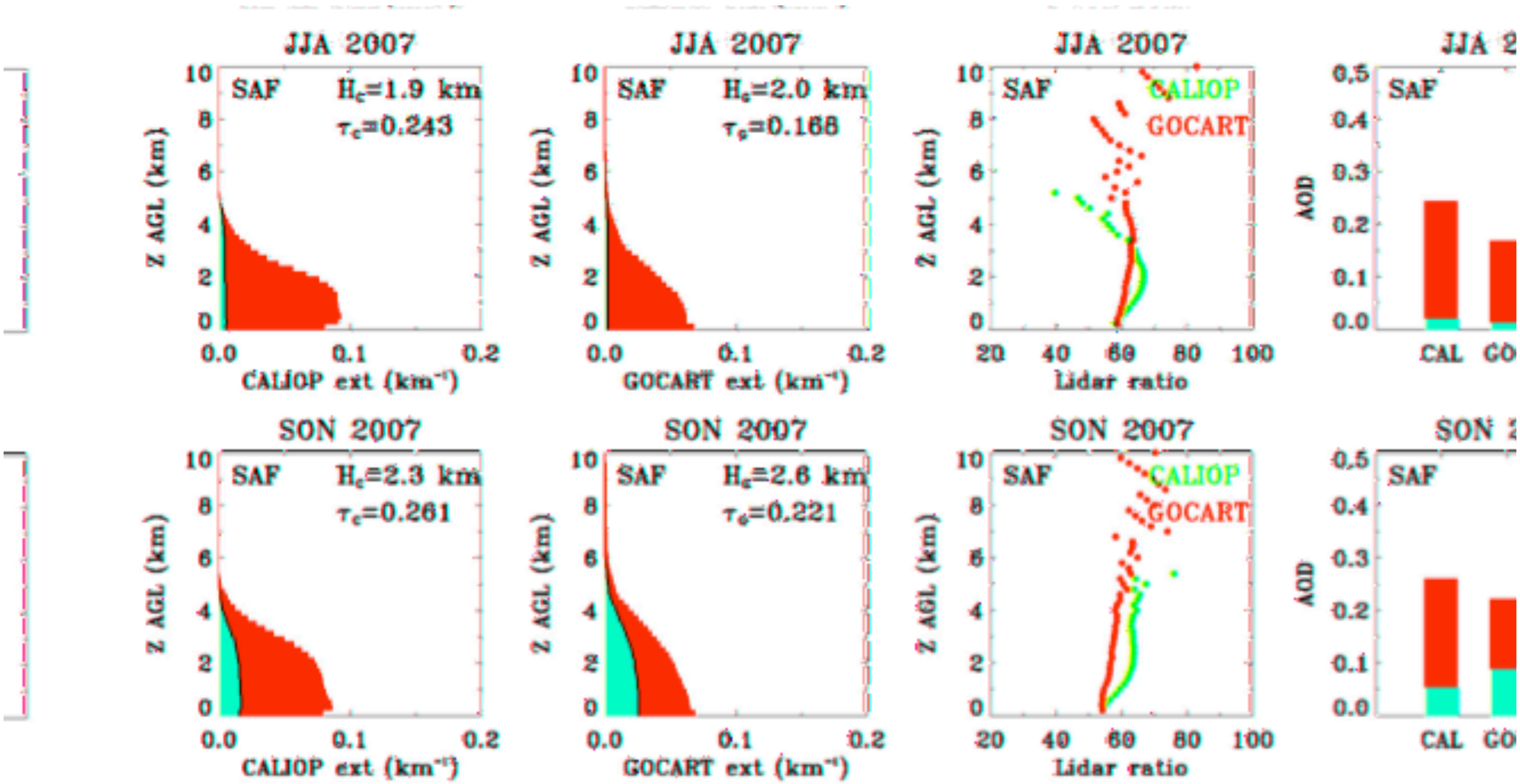
Lack of AERONET sites in the center

BIOMASS BURNING REGIONS

- Southern Africa (SAF)
- South America (SAM)



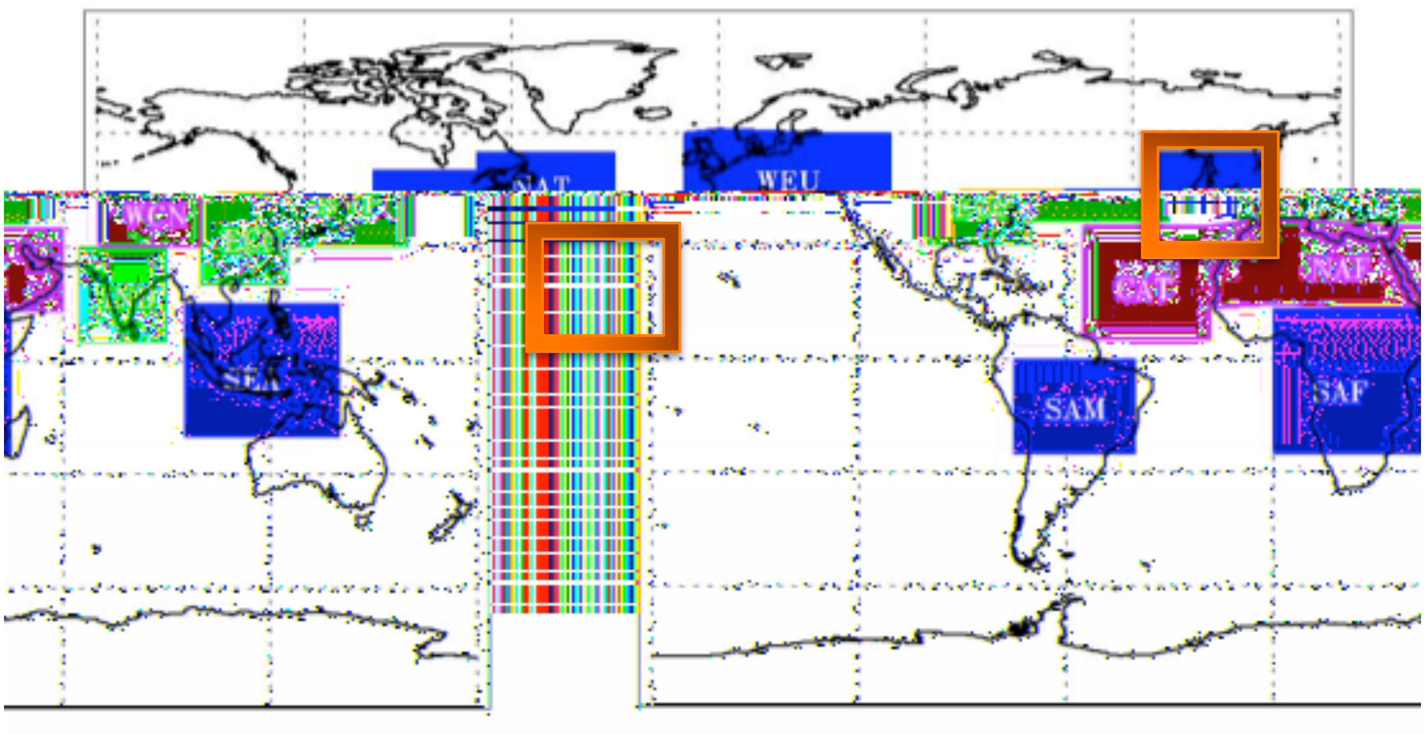
S. Africa



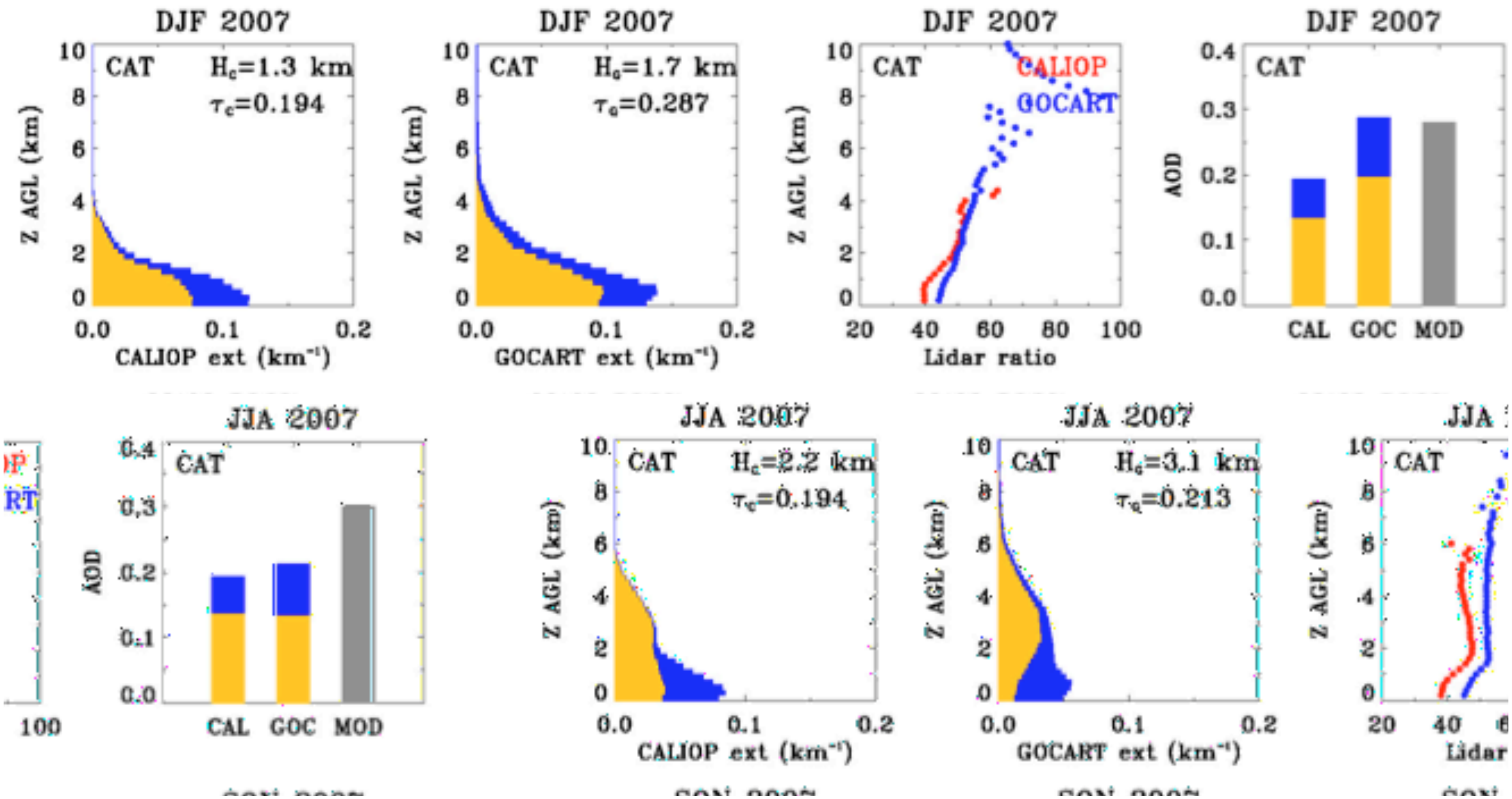
- Good agreements for scale height and lidar ratio
- GOCART smaller extinction (GOC/AER=0.61, Chin et al., 2009) – possible underestimate of emissions.

OUTFLOW REGIONS

- Central Atlantic (CAT)
- Northwestern Pacific (NWP)



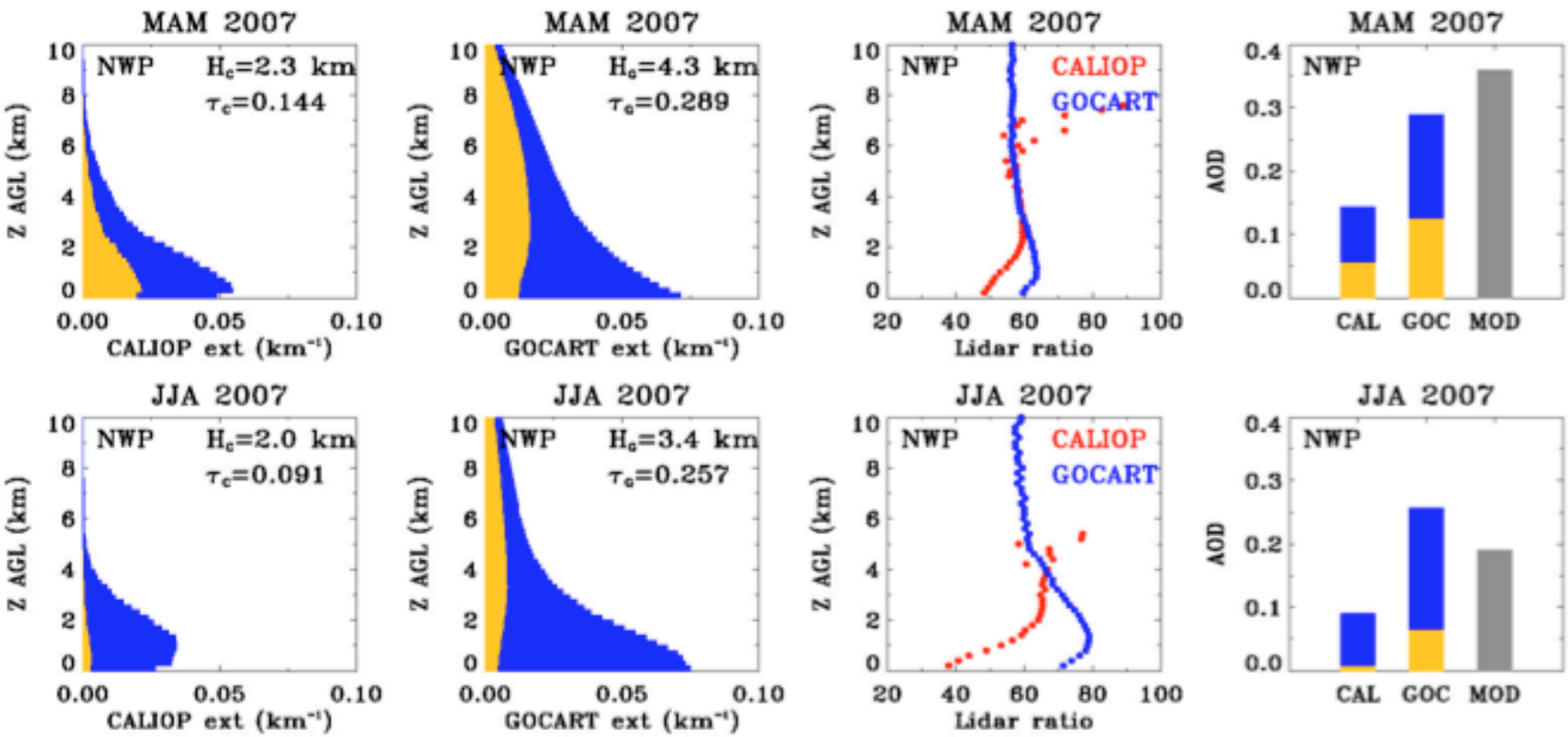
CENTRAL ATLANTIC – DUST OUTFLOW



CALIOP ext GOCART ext Lidar ratio AOD

➢ Much better agreements than in source regions

NW Pacific

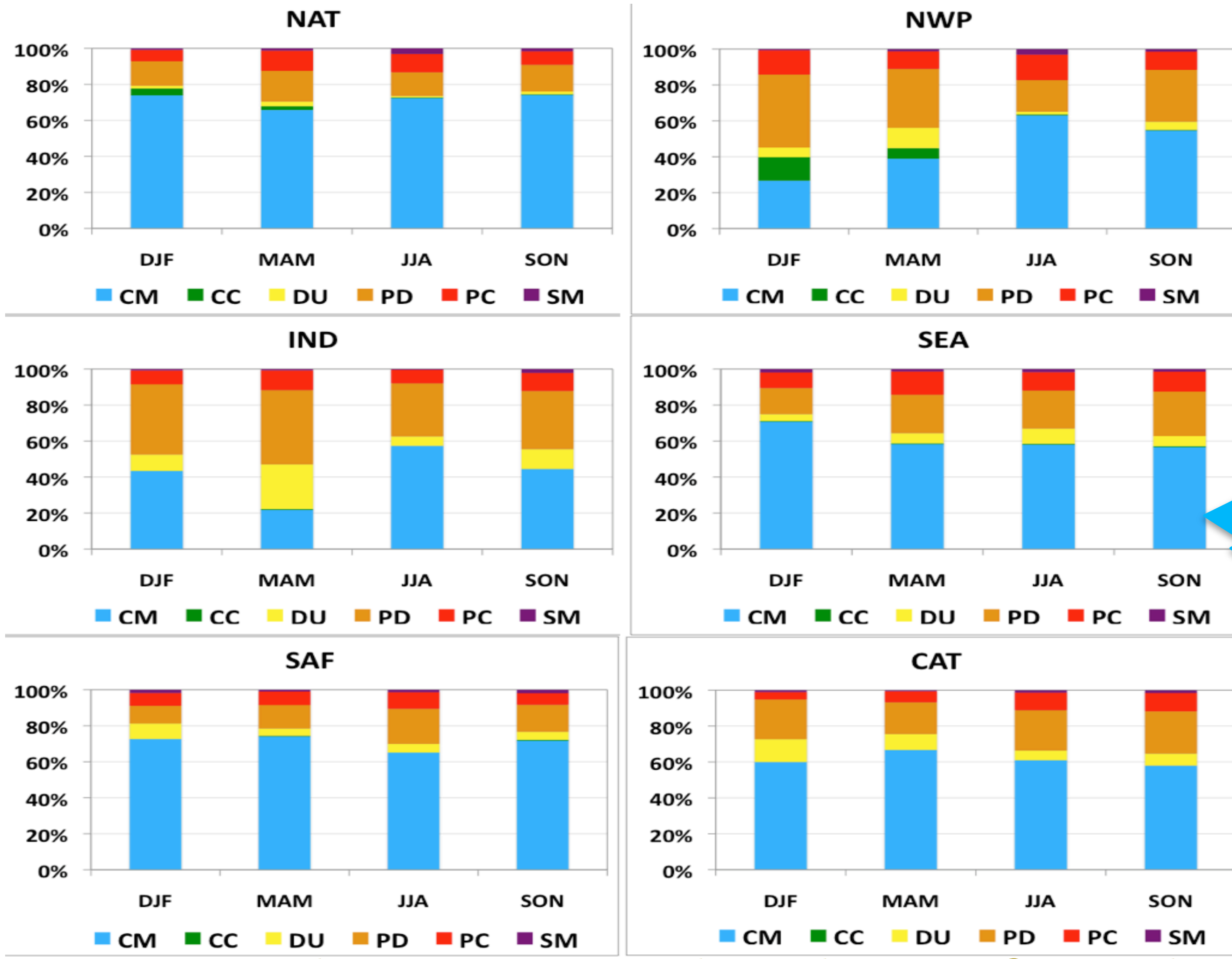


- Large differences in the FA: GOCART>CALIOP
- In the ABL, CALIOP lidar ratio much smaller than GOCART

Possible Reasons

- CALIOP **cloud-free** vs GOCART **cloudy**;
    - Strong outflows are usually associated with cloud systems (so CALIOP sampling may bias lower)
- MODIS could overestimate AOD, because of cloud contamination & presence of non-spherical dust;
- GOCART may overestimate vertical transport;
- CALIOP has detection limit;
- CALIOP algorithm may favor the selection of Clean-Marine aerosol type; and the marine aerosol lidar ratio is a factor of 2-3 smaller than dust and pollution.

In the marine ABL of outflow regions, CALIOP favors selection of **CLEAN-MARINE** type



Percentage of CALIOP selected aerosol types in the marine ABL of major outflow regions

Clean Marine

How are these compared with AeroCom climatology?

SUMMARY

- **AOD:** CALIPSO observations are consistent with GOCART model and MODIS retrieval in geographical patterns and seasonal variations, but not the magnitude.

- **SCALE HEIGHT:** CALIPSO observation is consistently lower than GOCART model, especially in mid- and high-latitudes. But both CALIPSO and GOCART show higher scale height in major dust and smoke source regions than in industrial pollution regions.

- **LIDAR RATIO:** CALIPSO generally agrees with GOCART model within 30%; but in some major ABL outflow regions CALIPSO tends to favor the selection of clean-marine aerosol type and gives much lower lidar ratio than GOCART model.

SUMMARY – CONT'D

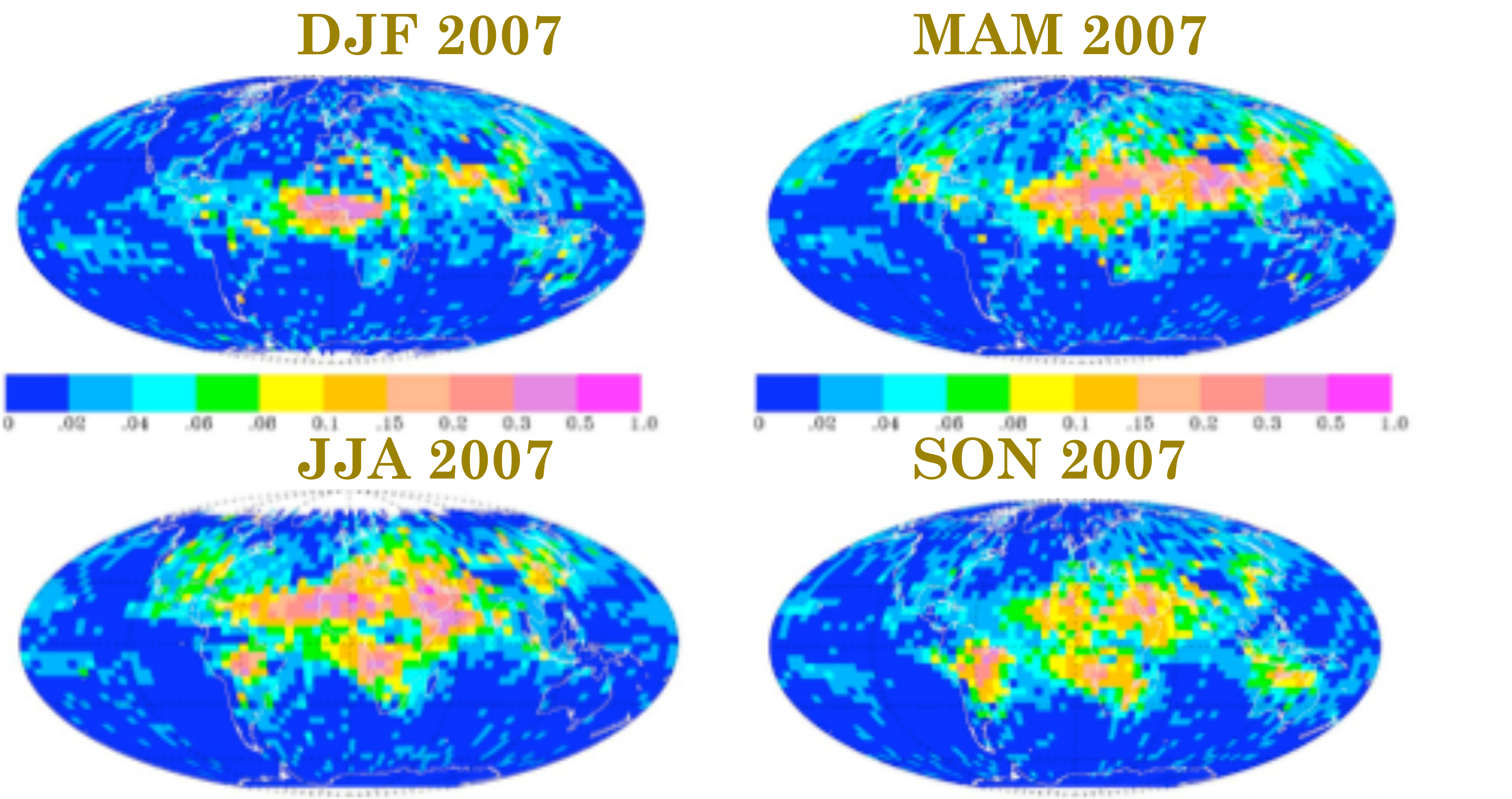
- Over **Indian** sub-continent, GOCART model tends to substantially underestimate aerosol extinction. More work is needed to determine relative contributions by dust and pollution.
- In **dust** source regions, CALIOP extinction is much smaller than GOCART.
- In biomass burning regions (S. Africa and Amazon), GOCART tends to underestimate emissions.
- While CALIPSO and GOCART give a consistent characterization of Sahara dust outflow, CALIPSO observations of East Asia (and North America) outflows are much weaker in magnitude and much more concentrated in the ABL than that suggested by GOCART model.

Above-Cloud AOD from CALIOP

- CALIOP has a capability of detecting aerosol layers above clouds;

- The above-cloud AOD is an important parameter for assessing the aerosol direct forcing in cloudy conditions.

CALIOP AOD above Low-Clouds [Z_{TOP} < 4km]



Higher above-cloud AOD in dust/biomass burning regions, and in industrial regions in summer.

72 (=12 regions x 6 seasons) data points