MODIS and CALIPSO observations of aerosol properties in partly cloudy conditions

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From Chapter 7 of IPCC AR5 report

"*… aerosol measured in the vicinity of clouds is significantly different than it would be were the cloud field … not present*". …Thus "*ascribing changes in cloud properties to changes in the aerosol remains a fundamental challenge*."

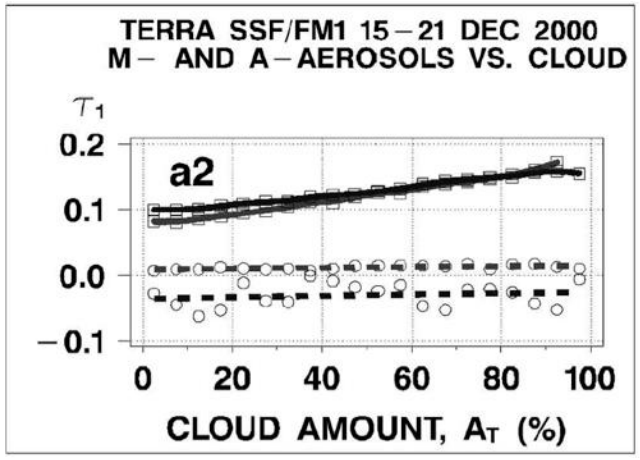
What happens to aerosol in the vicinity of clouds?

All observations show that aerosols seem to grow near clouds

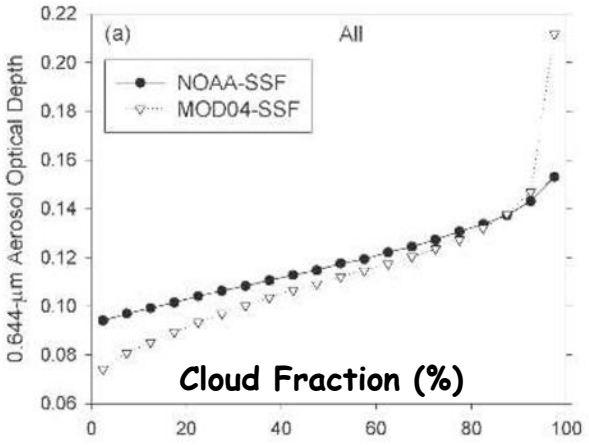
or

(to be safer) "*most satellite observations show a positive correlation between retrieved AOT and cloud cover*", e.g.,

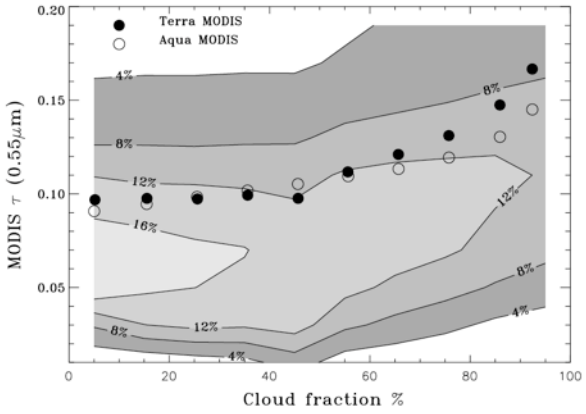
Chand et al. (2012) using MODIS data found a 25% enhancement in AOT between CF 0.1-0.2 and CF 0.8-0.9.



from Ignatov et al., 2005



from Loeb and Manalo-Smith, 2005



from Zhang et al., 2005

What happens to aerosol in the vicinity of clouds?

However, it is not clear yet how much grows comes from (e.g., Quaas et al., 2010)

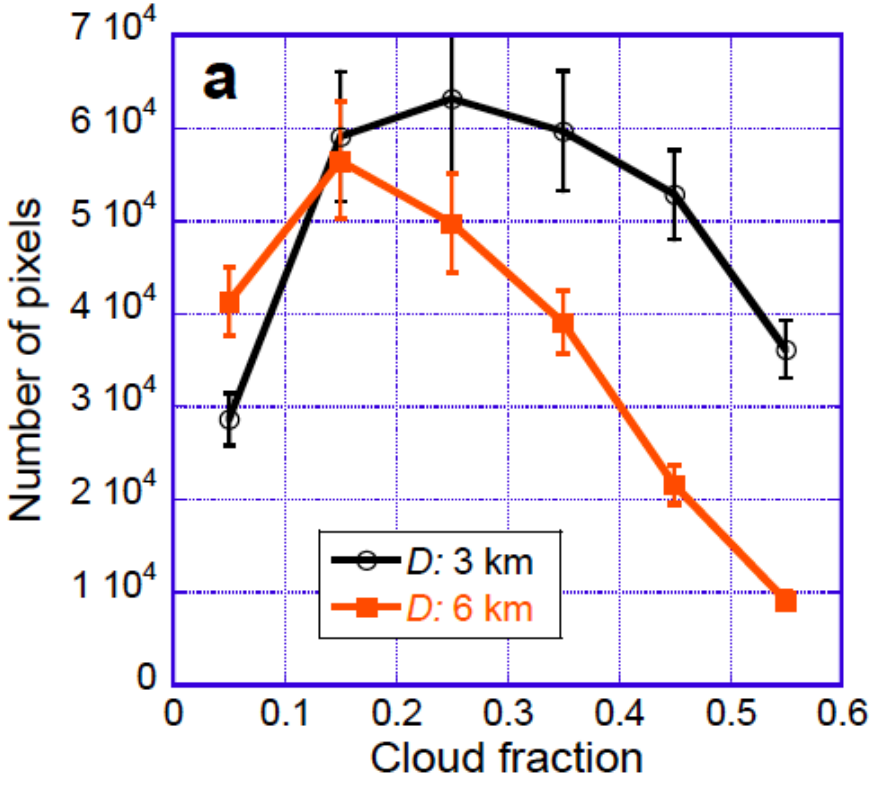
(i) aerosols swelling in the humid air surrounding clouds;
(ii) cloud processing that enhances the number of aerosol particles through chemical or microphysical processes;

(i) undetected cloud particles;
(ii) clouds scattering sunlight into nearby clear areas;

(i) instrument issues.

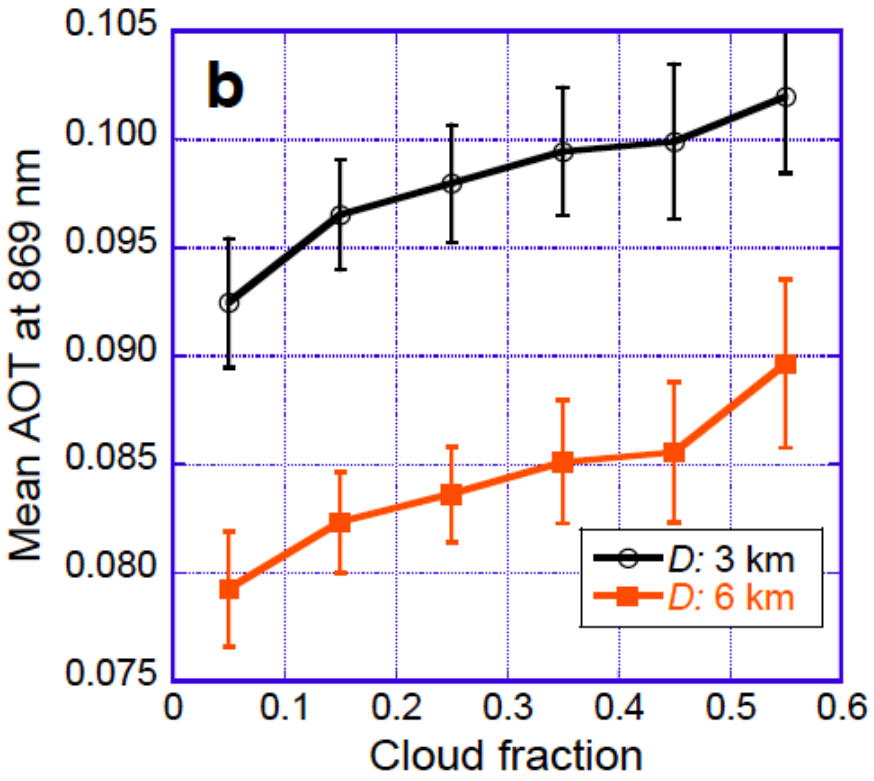
MODIS
(South of UK)

Number of pixels



- for high CF: N(3km) > N(6km)
- for low CF: N(3km) < N(6km)
- N(CF=0.5) < N(CF=0.3)

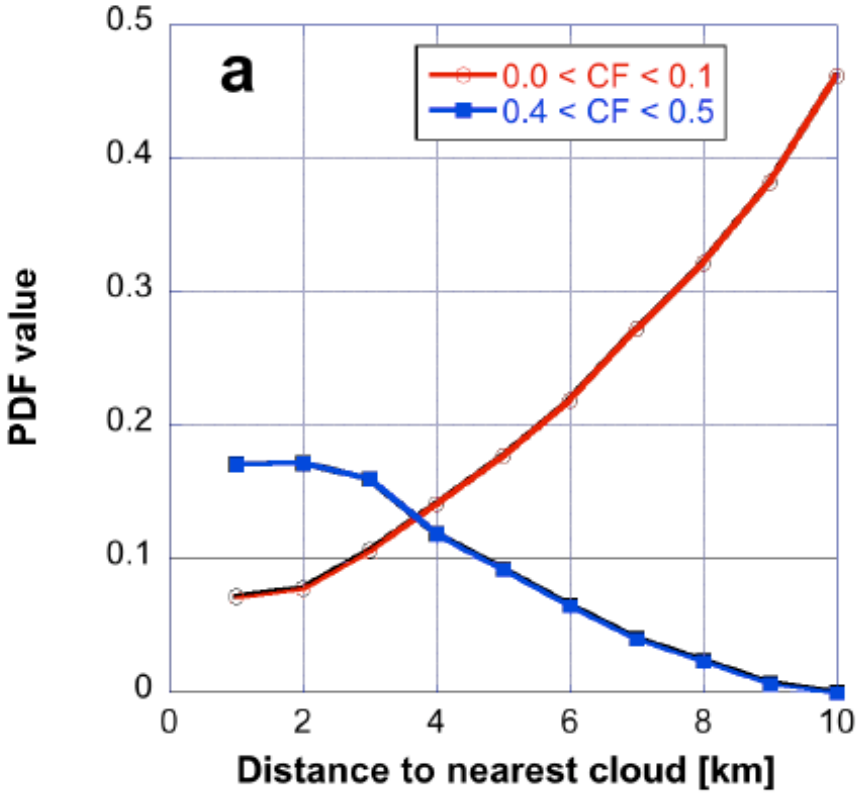
AOT



- AOT(3km) > AOT(6km)
- AOT(CF=0.5) > AOT(CF=0.1)

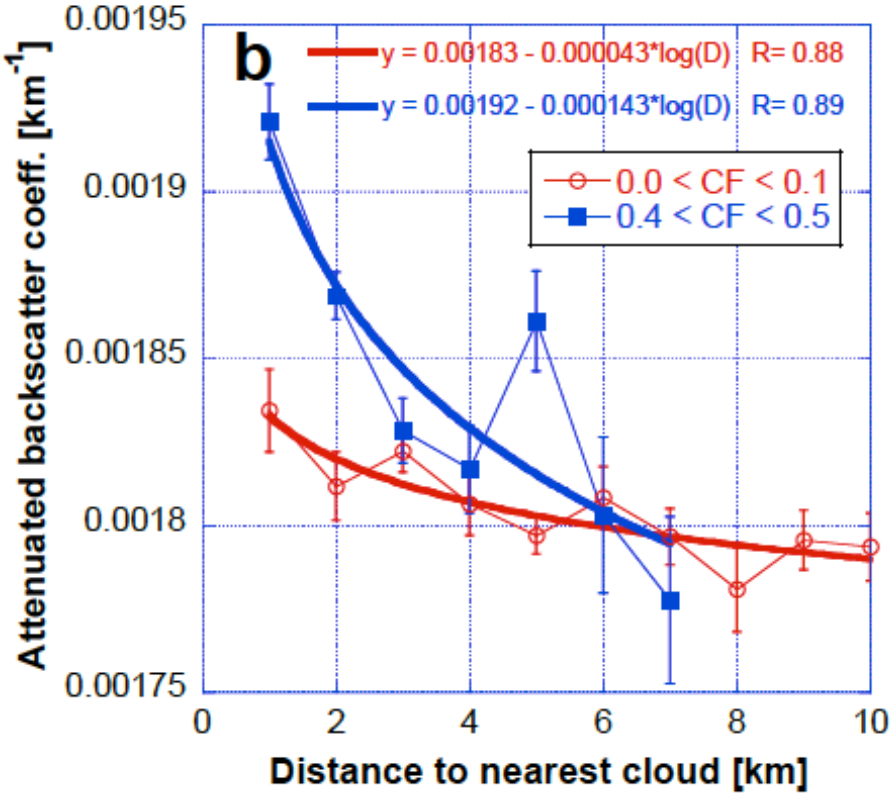
CALIPSO
(around the Azores)

Normalized number of samples



- for high CF: N(3km) > N(6km)
- for low CF: N(3km) < N(6km)
- far from clouds: N(CF=0.5) << N(CF=0.1)

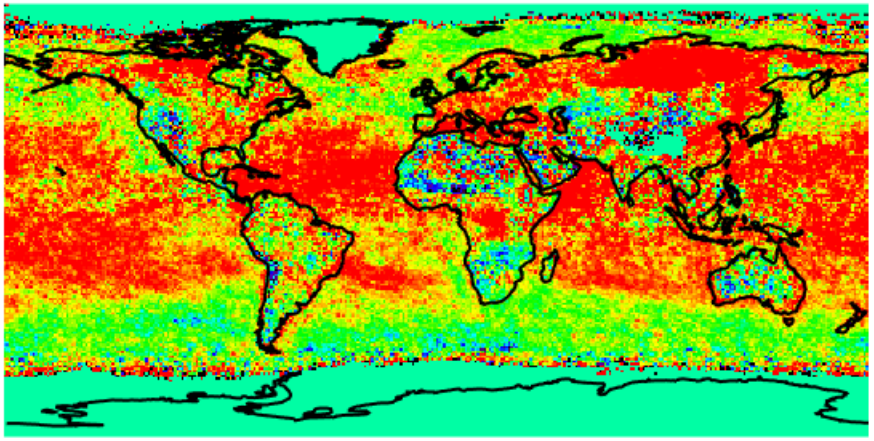
Backscatter

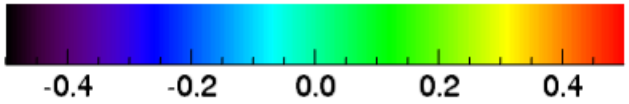


- Backsct(2km) > Backsct (6km)
- Backsct(CF=0.5) > Backsct(CF=0.1)

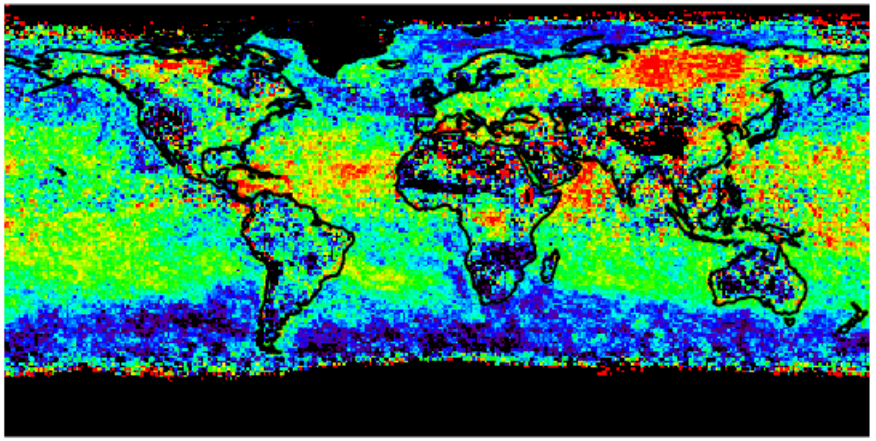
CF-AOD correlation

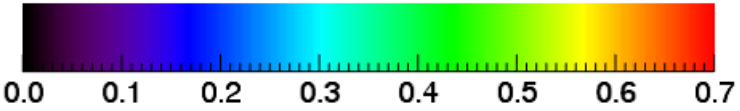
Corr. CF & MODIS AOD, JJA





Corr. of CF & AOD, JJA



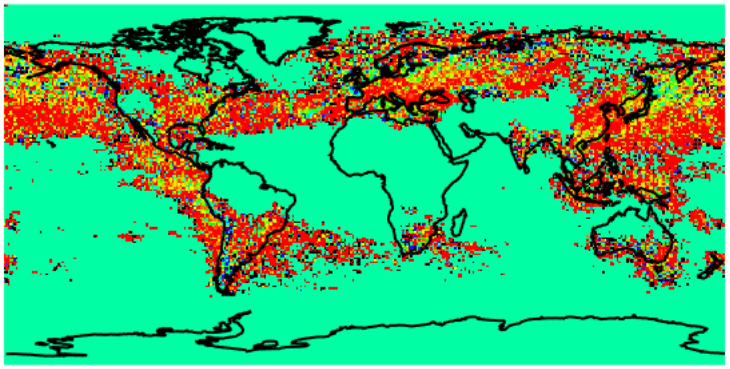


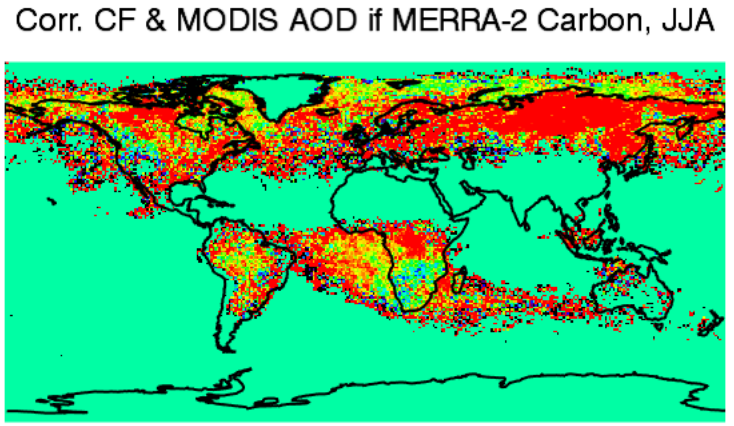
Two options for color scale

Though there are some variations, CF-AOD correlation is **positive** globally

CF-AOD correlation

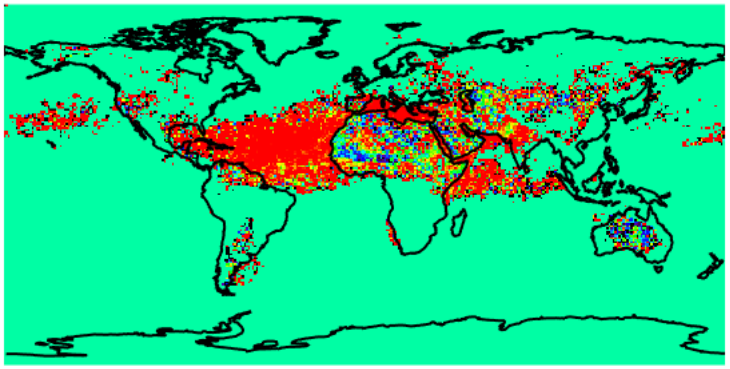
Sulfate

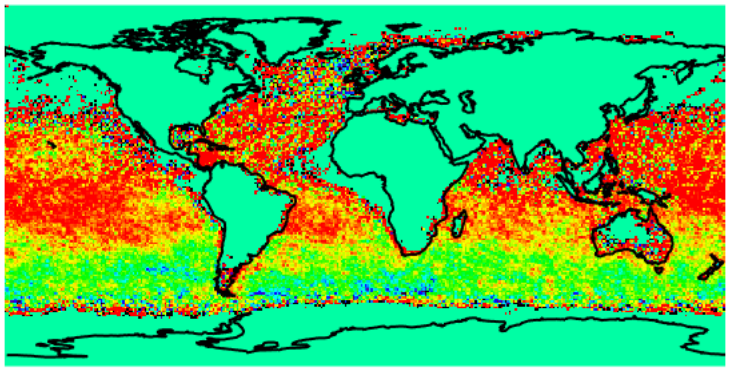




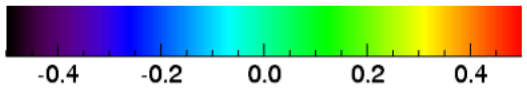
Carbon

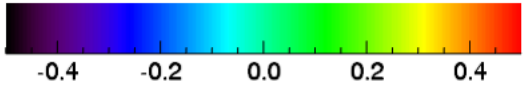
Dust





Sea salt

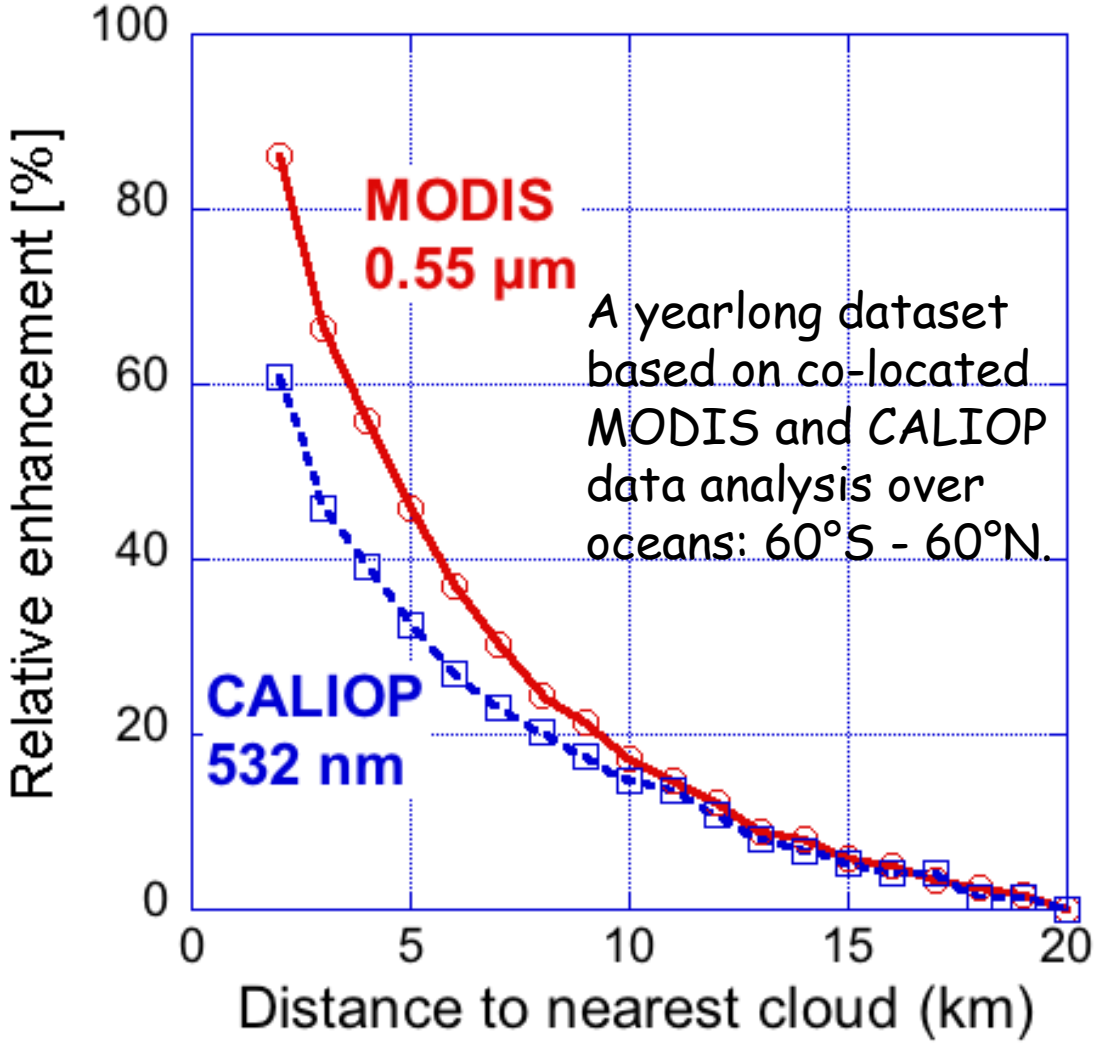




Correlation is positive for all aerosol types

CALIPSO & MODIS
(relative enhancement)

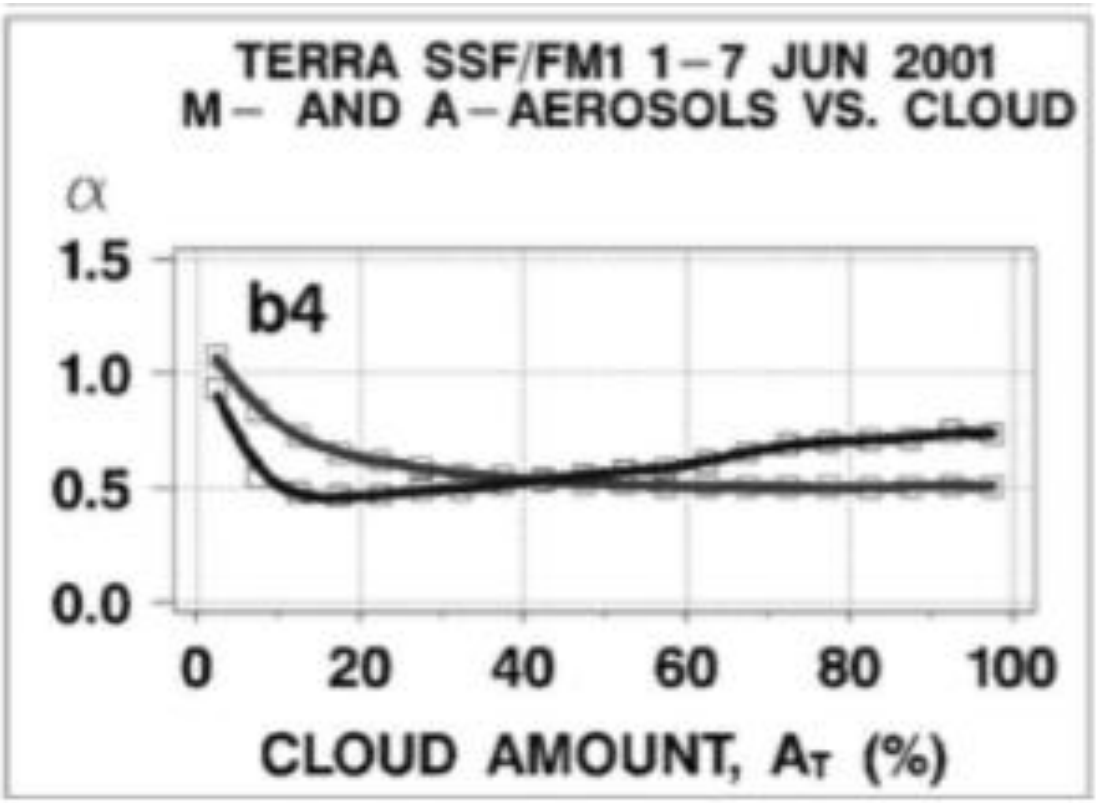
Varnai et al., ACP 2013



Likely due to the 3D radiative effects of clouds (25-30%)

What's about correlation between CF and particle size?

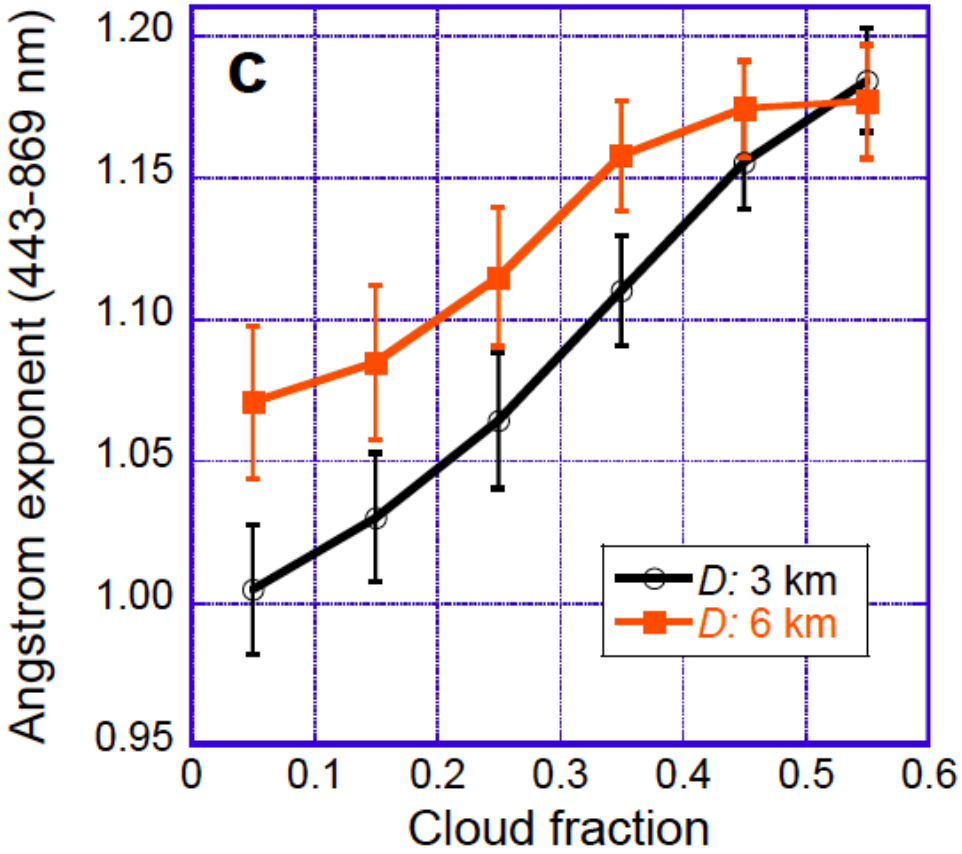
Cloud Fraction vs. Angstrom Exponent



from Ignatov et al., 2005

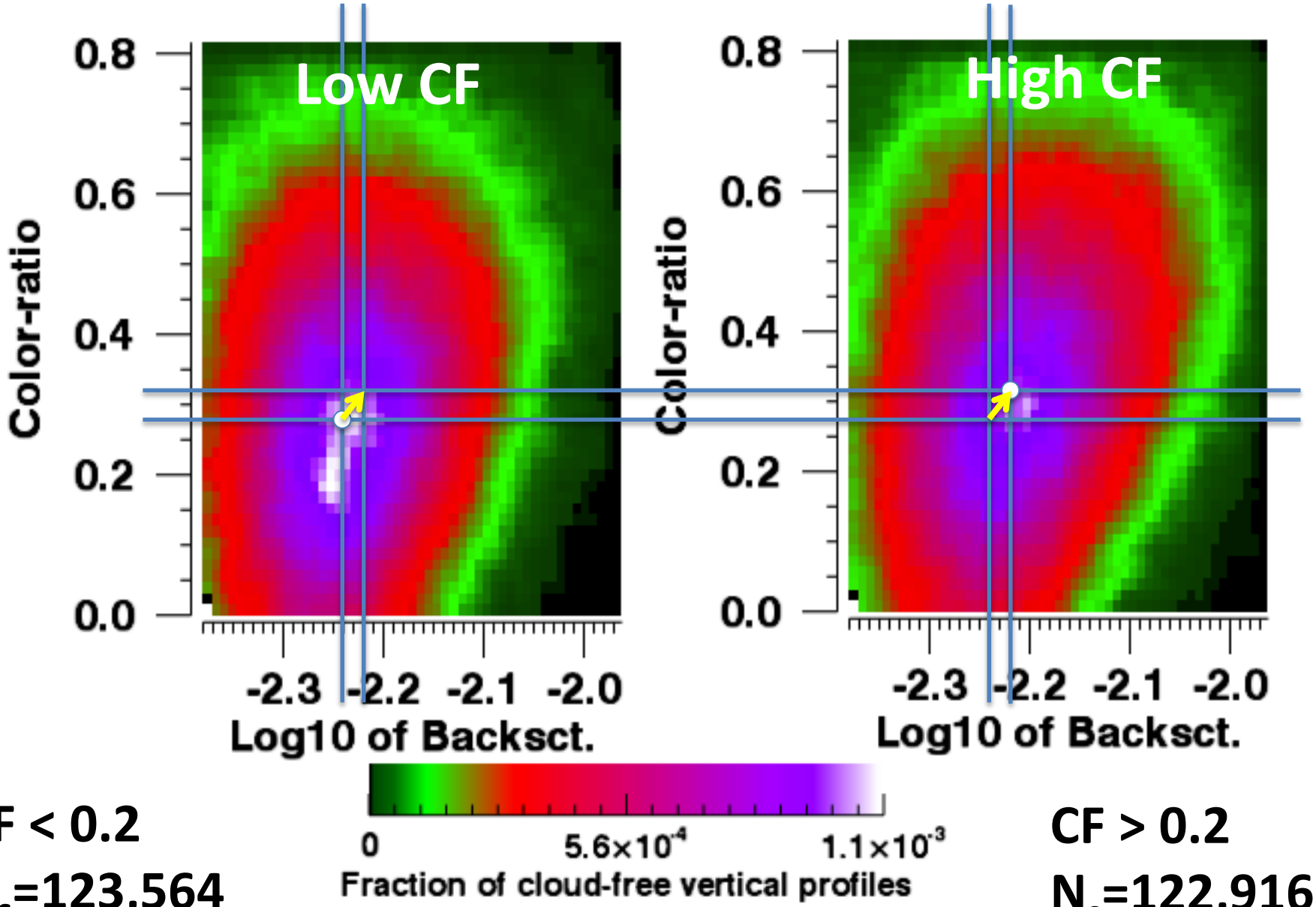
Global statistics included both positive and negative trends. The paper said that the reasons for positive trends were unclear, perhaps caused by artifacts.

MODIS (ocean product): South of UK Angstrom Exponent



- AE(3km) < AE (6km)
- AE(CF=0.5) > AE(CF=0.1)

CALIPSO: Azores area



CF < 0.2

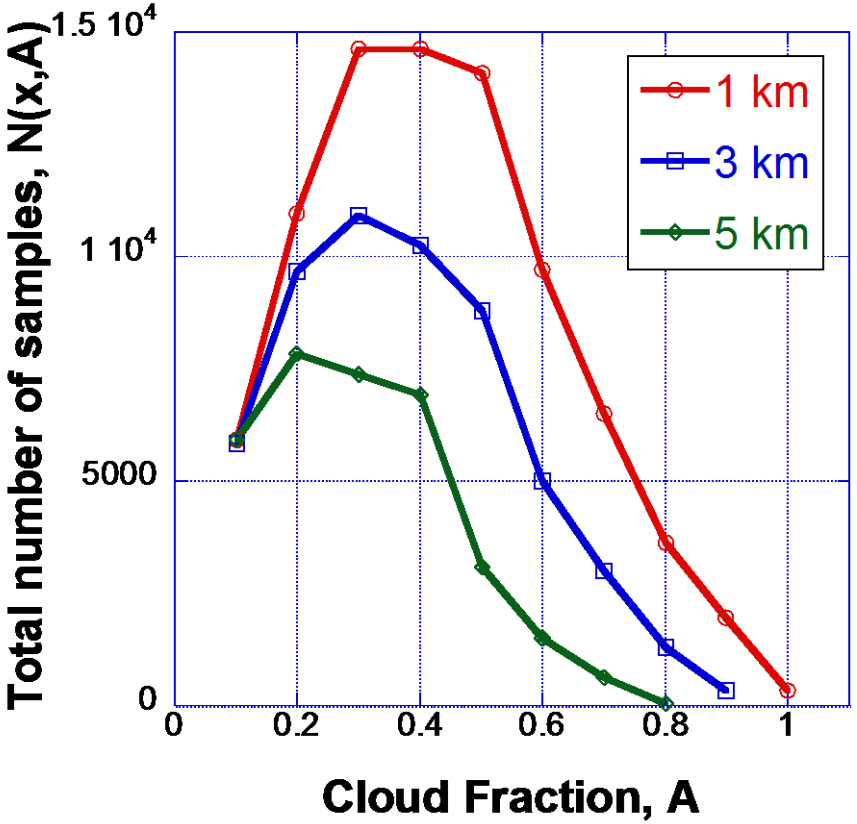
N_s=123,564

CF > 0.2

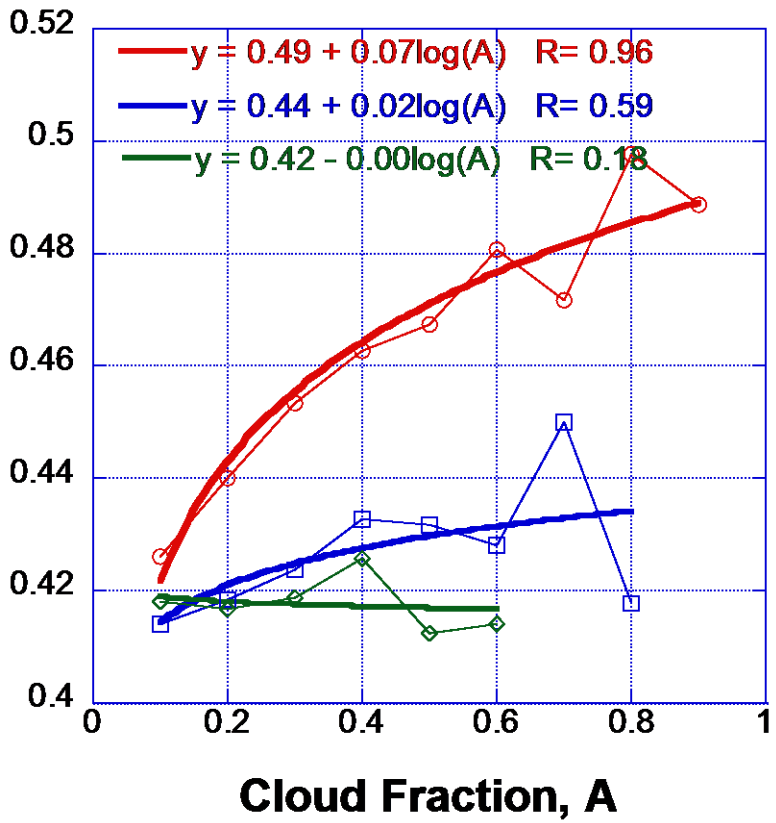
N_s=122,916

CALIPSO
(around the Azores)

Total number of samples

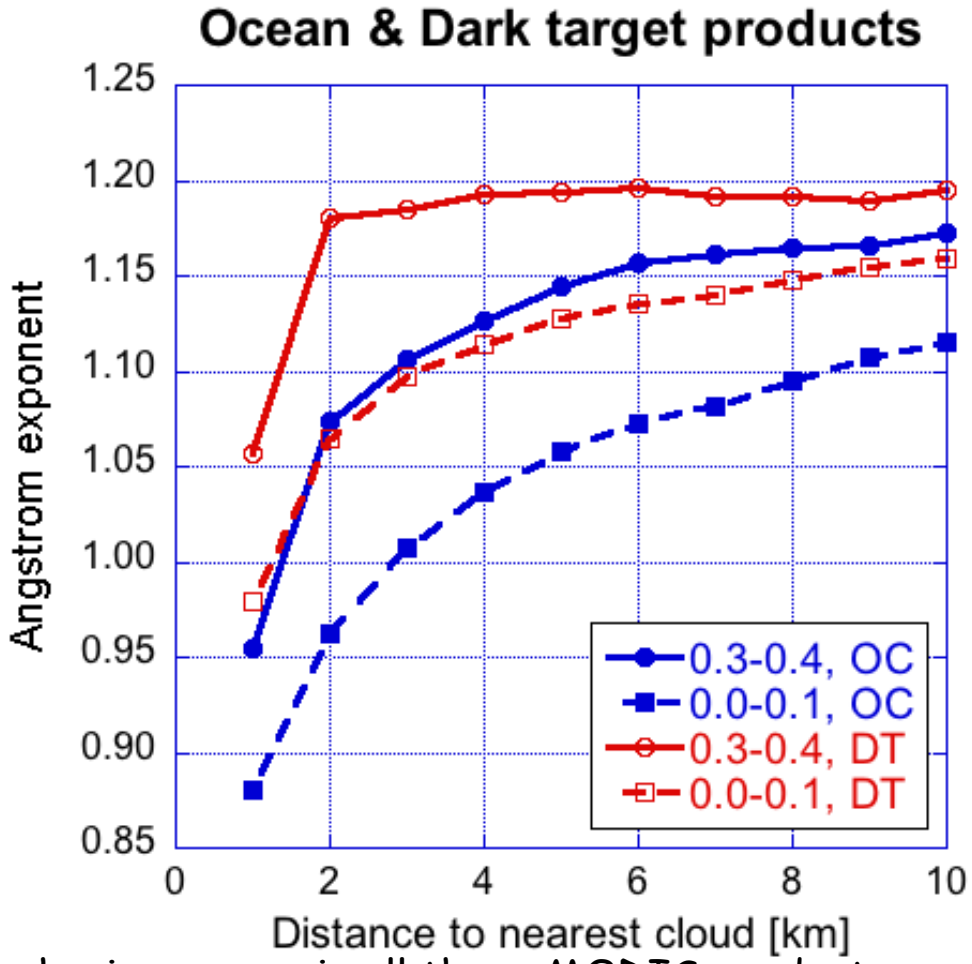


Total color ratio, χ(x,A)



- ColorRatio(1km) > ColorRatio(5km)
- ColorRatio(CF=0.5) > ColorRatio (CF=0.1)

MODIS Angstrom Exponent



The same MODIS behavior occurs in all three MODIS products:

(i) the ocean color,

(ii) the dark target

(iii) the deep blue

though they use dif. wavelengths, cloud masks, data selection methods, and algorithms.

Aerosol size vs. CF in MODIS and CALIPSO products

CALIOP

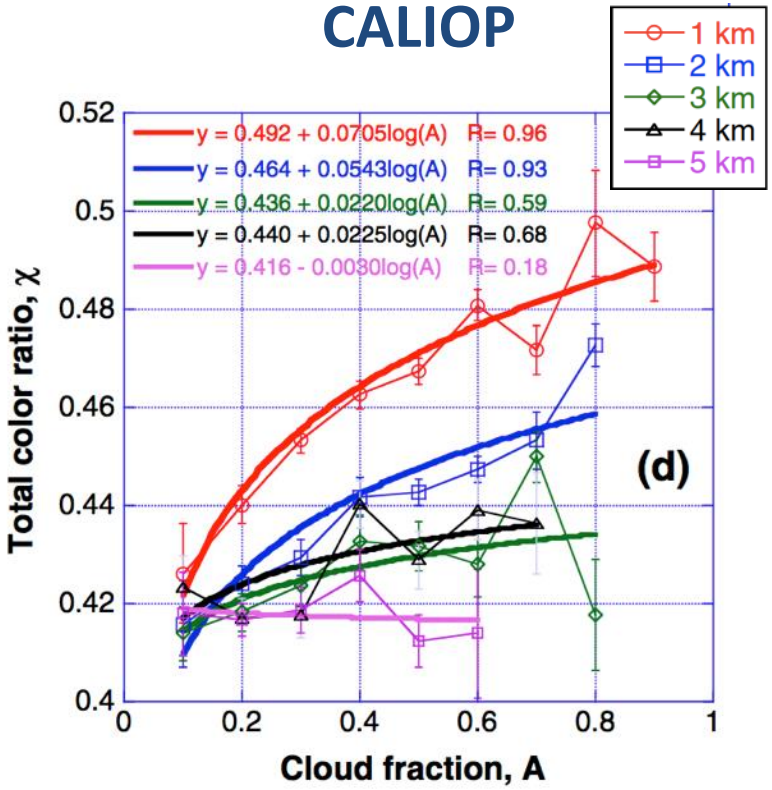


Fig. 3d in Yang et al. (2014)

MODIS

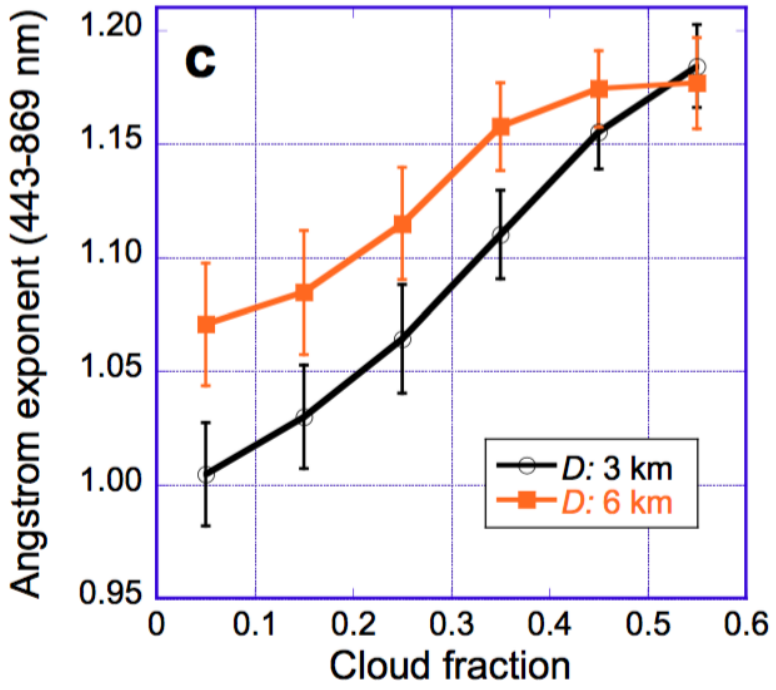
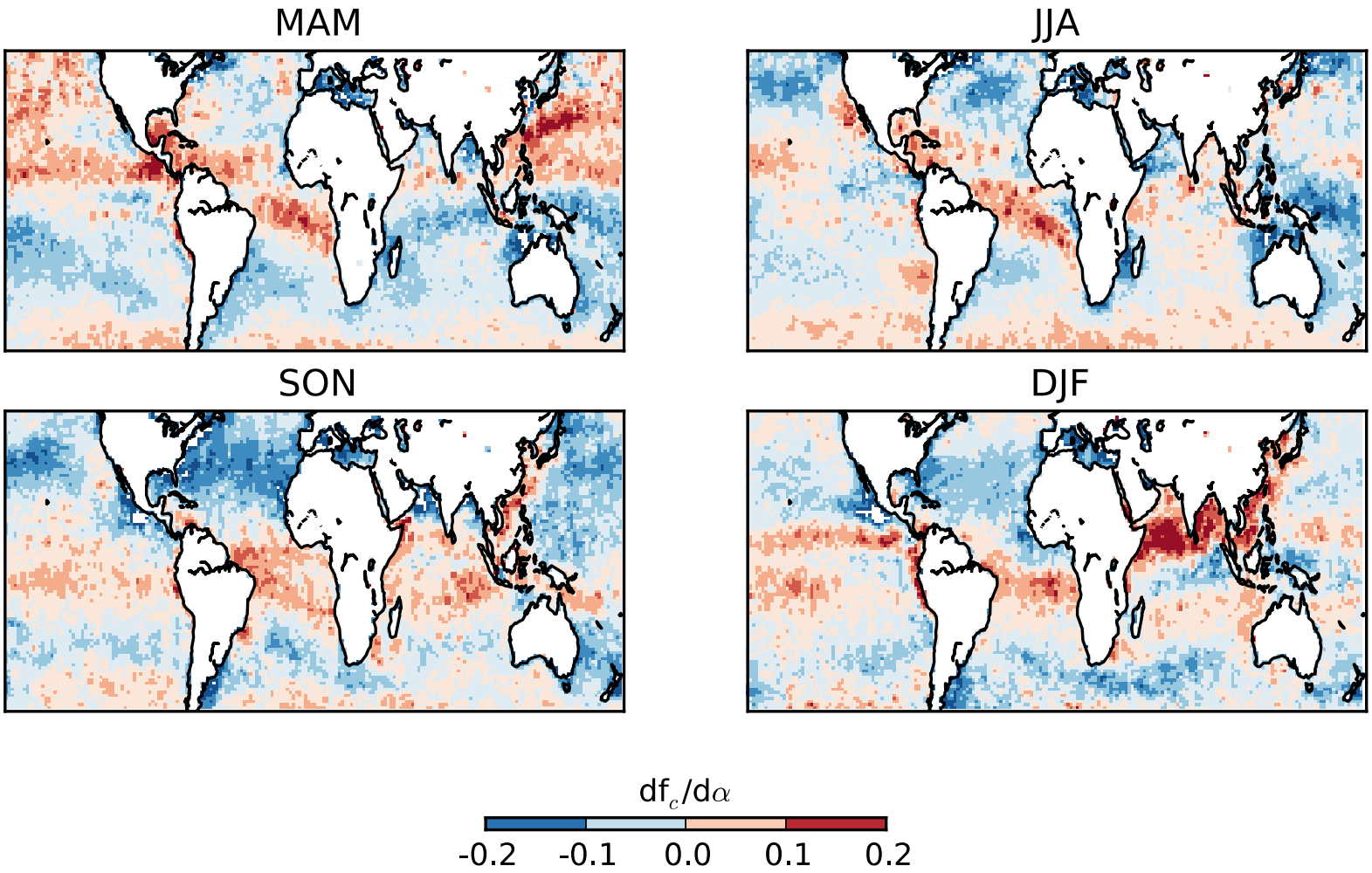


Fig. 4c in Várnai and Marshak (2015)

Why does particle size decrease with CF for MODIS even though it increases for CALIOP?

MODIS Level 3 data

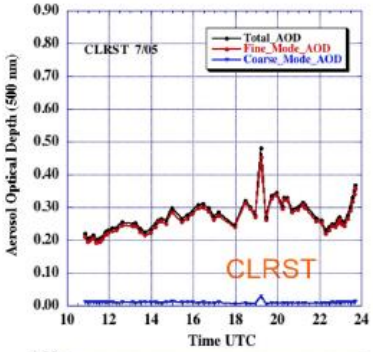


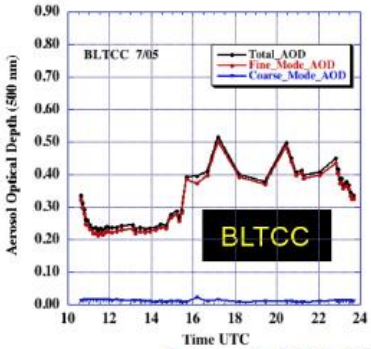
Positive correlation between CF & AE is widespread though not universal

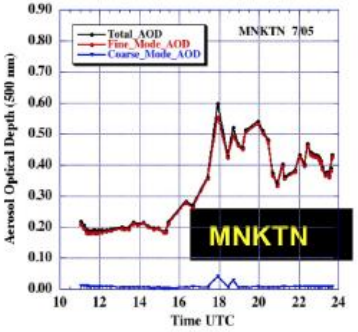
What's about ground-based measurements?

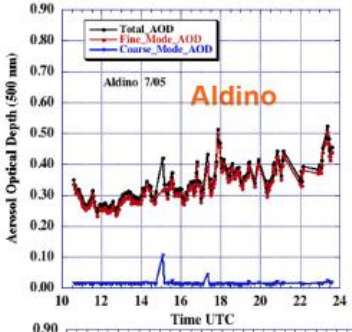
AERONET during DRAGON

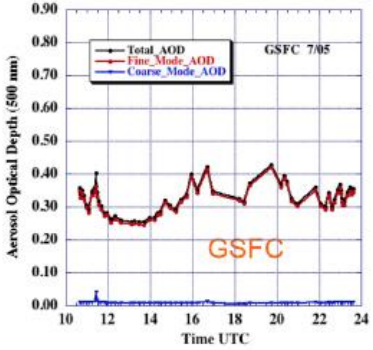
Courtesy of Tom Eck



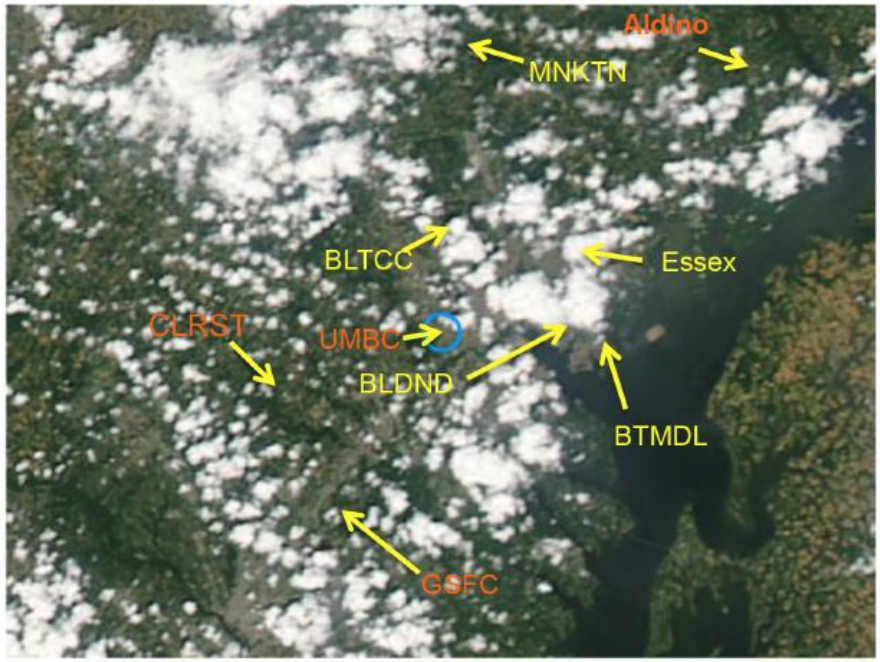


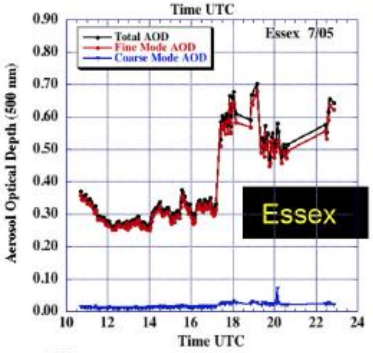


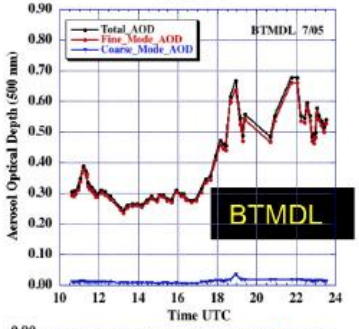


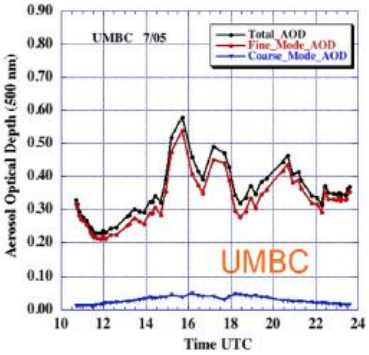


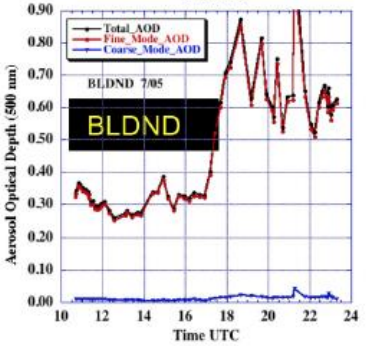
Composite AQUA-MODIS Image on JUL 5 of 2011; Centered on UMBC









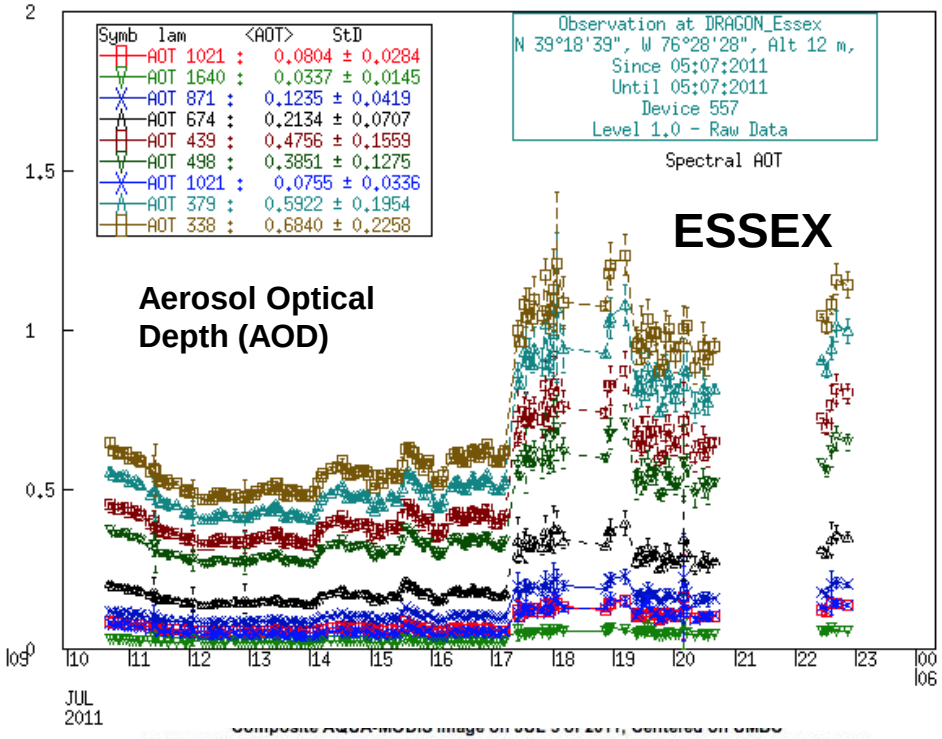


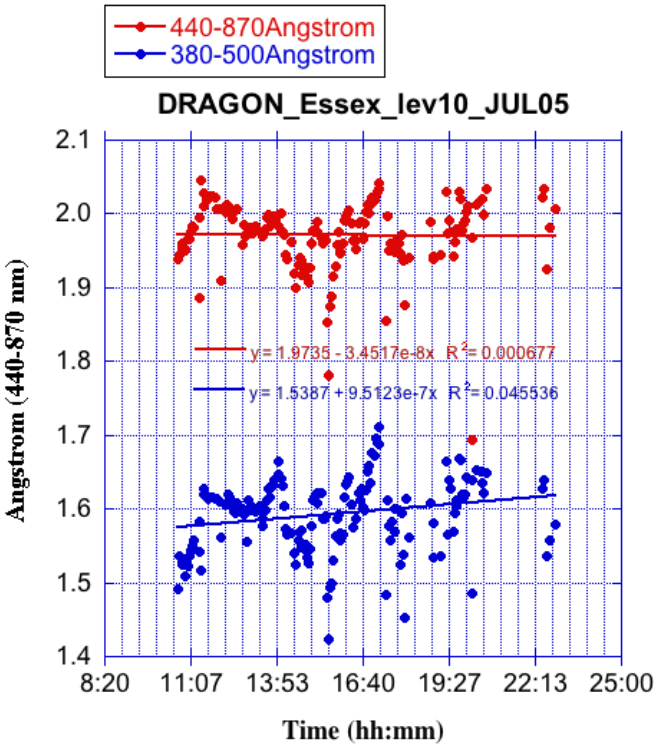
MODIS Images: 2000m 1000m 500m 250m

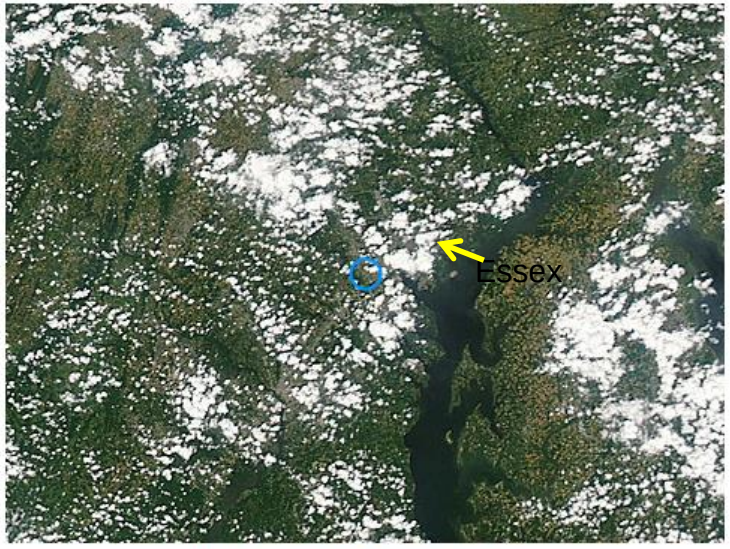
AQUA-MODIS Granule Overpass Times:
16:50, 18:30 UTC

Large increases in AOD are associated with sites that are in close proximity to larger Cu clouds

Courtesy of Tom Eck

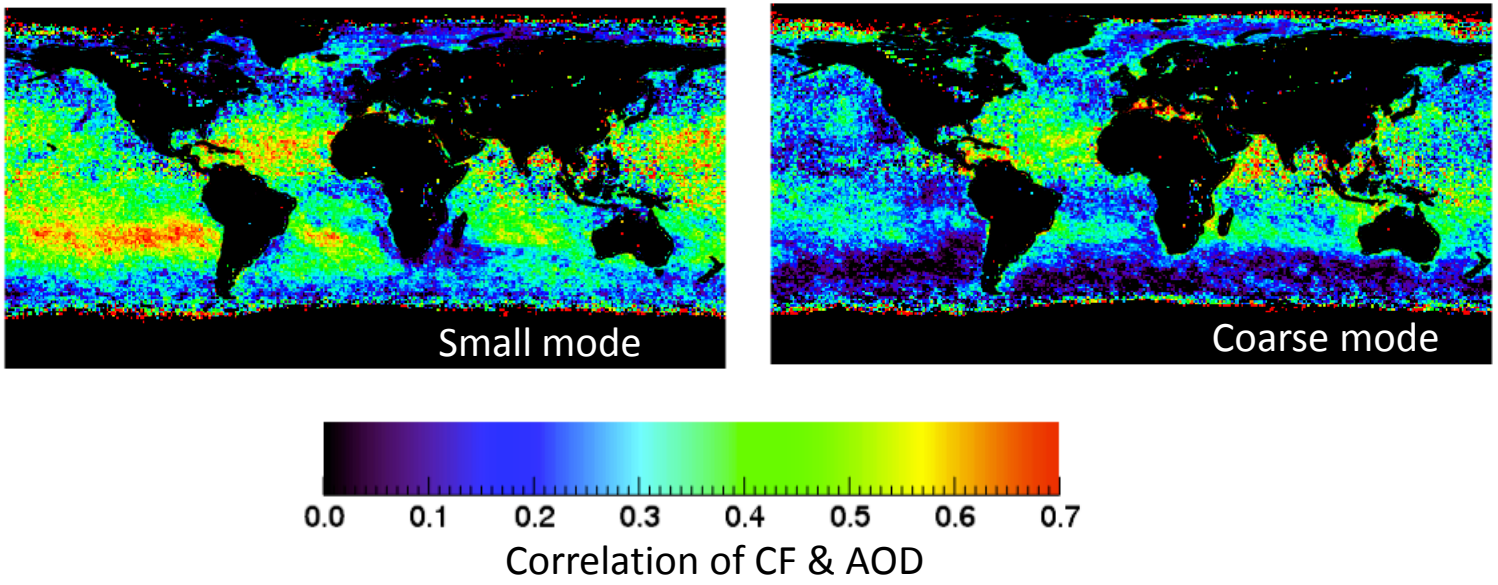






Large jump in AOD (~0.3 at 440 nm) at the DRAGON Essex site occurred just after solar noon on July 5. **However, the AE (440-870 nm) remains very high (>1.9) suggesting possible new particle formation in the cloud environment since a particularly dense cluster of clouds is seen in the vicinity of the Essex site.**

Coarse & small mode AOD vs. CF in Level 3 data



The AOD increase with CF is stronger for ***small*** mode than for ***coarse*** mode

=> AE increases with CF

Why?

- small mode is more hygroscopic,
- coarse mode aerosol is at altitudes less affected by cloud-related humidity increase,
- cloud processing creates small aerosols,

Implication: The primary reason for CF-AOD correlations is NOT cloud contamination

Take home messages

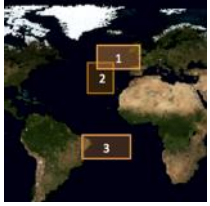
- Both MODIS and CALIOP always show a **positive** correlation between AOD (or BKS) and CF;
- For both CALIOP and MODIS the relationship between particle size (measured by CR and AE, resp.) and CF is much more **complex**;
- All three MODIS products (dark target, ocean color, deep blue) show that in many large regions effective particle size **decreases** with increasing CF;
- CALIOP does not support this relationship; it shows a **positive** correlation between CF and aerosol particle size;
- Possibilities for the opposite behavior of MODIS & CALIOP data include differences in data selection (cloud masking or CAD) or CF calculations.

Acknowledgments:
- NASA Radiation Sciences Program;
- NASA Terra/Aqua Project;
- NASA CALIPSO/CloudSat Project;

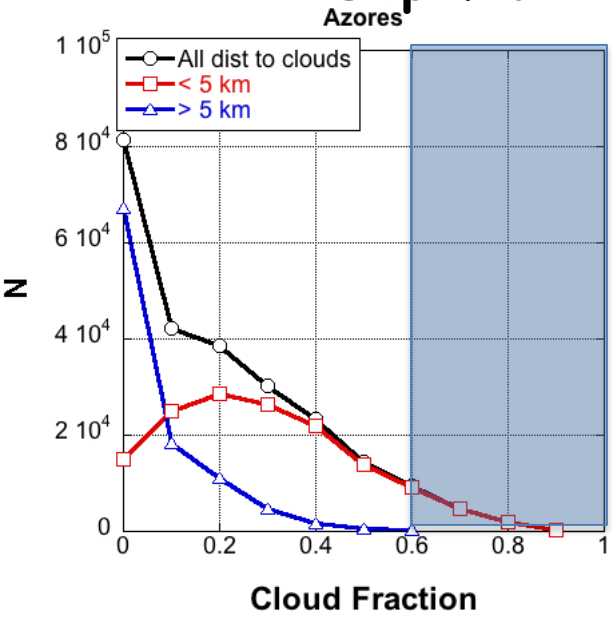
Thank you !

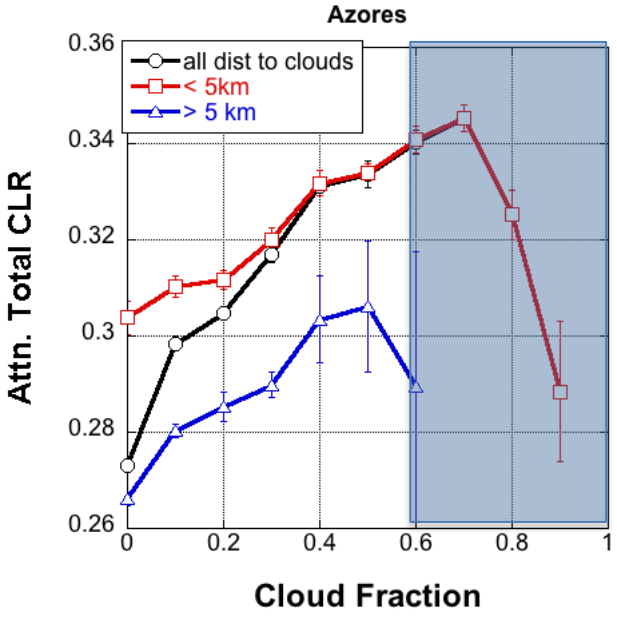
CALIPSO: Azores and South Atlantic

Sep-Nov 2007-2011

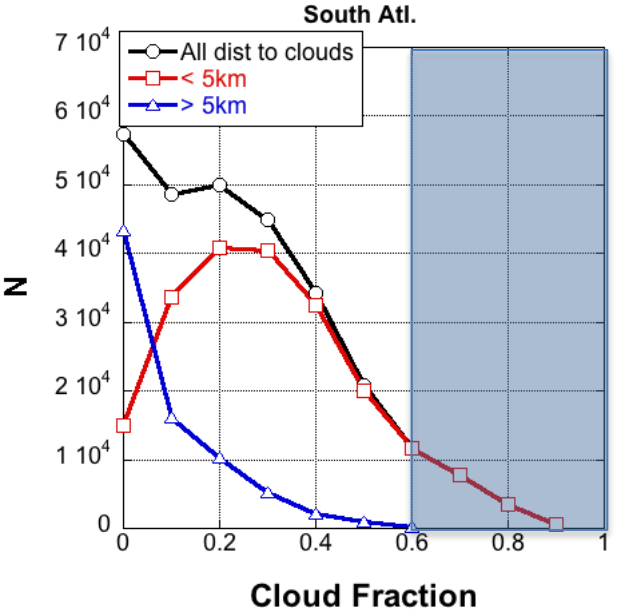


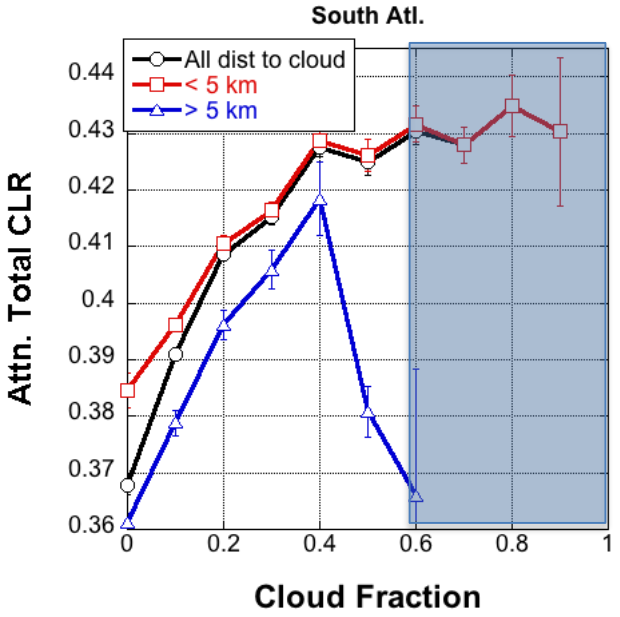
Azores



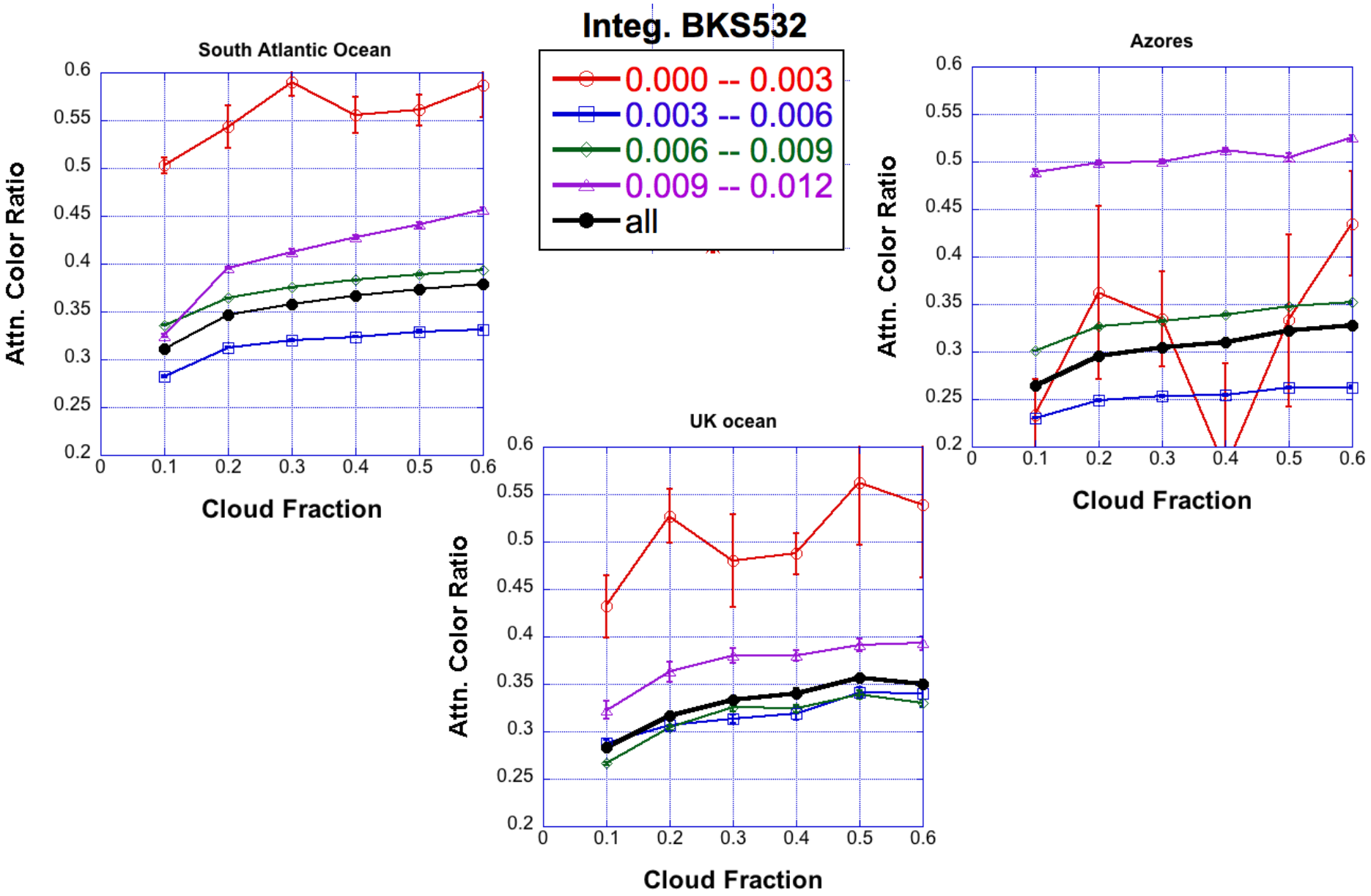


South Atl.

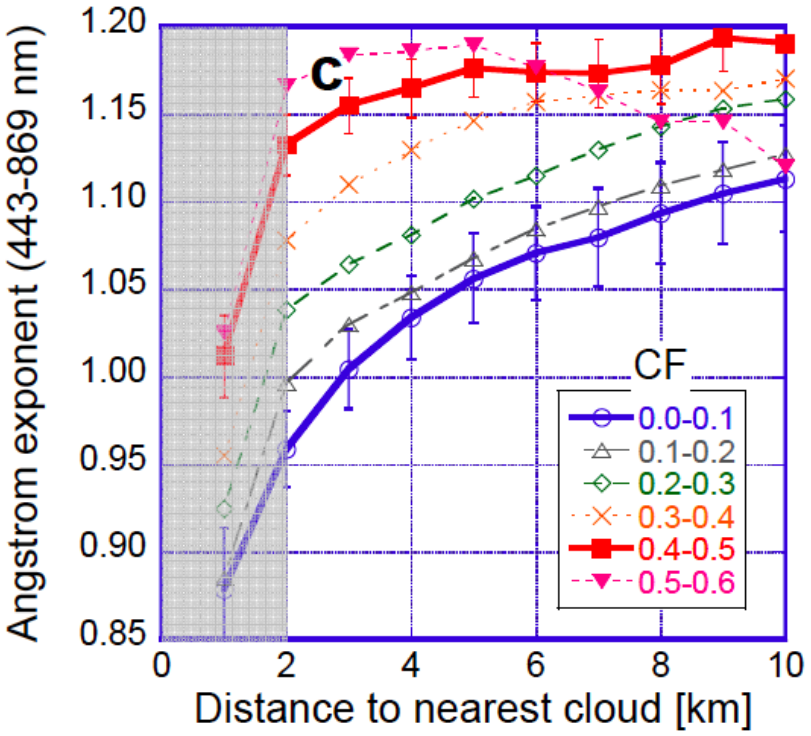


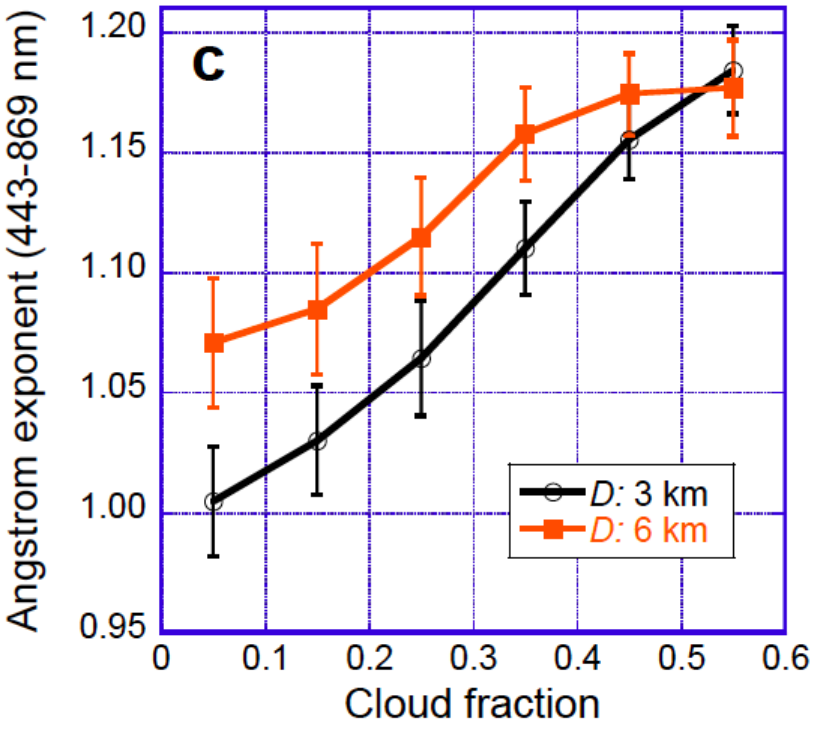


CALIPSO: color ratio for dif. BKS



MODIS (ocean product): South of UK Angstrom Exponent





- AE(dist_to clouds) ↑
- AE(CF) ↑

- AE(3km) < AE (6km)
- AE(CF=0.5) > AE(CF=0.1)