Shortwave Direct Radiative Effect (DRE) of Above-cloud Aerosols (ACA) based on 6 years of CALIOP and MODIS observations

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Steamboat Springs, CO

Zhibo Zhang (Physics Dept./UMBC), Kerry Meyer (USRA), Hongbin Yu (ESSIC/UMD), Peter R. Colarco (NASA), Steven Platnick (NASA), Lazaros Oreopoulos(NASA)

zhibo.Zhang@umbc.edu

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6-year (2006~2012) Averaged ACA DRE

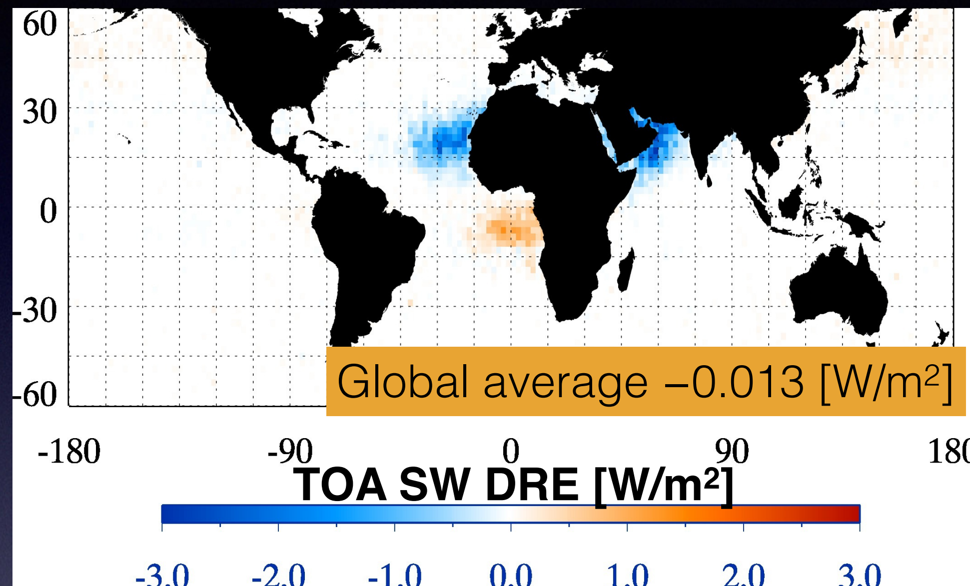
Full column AOT:
CALIOP Daytime ALay5km V3

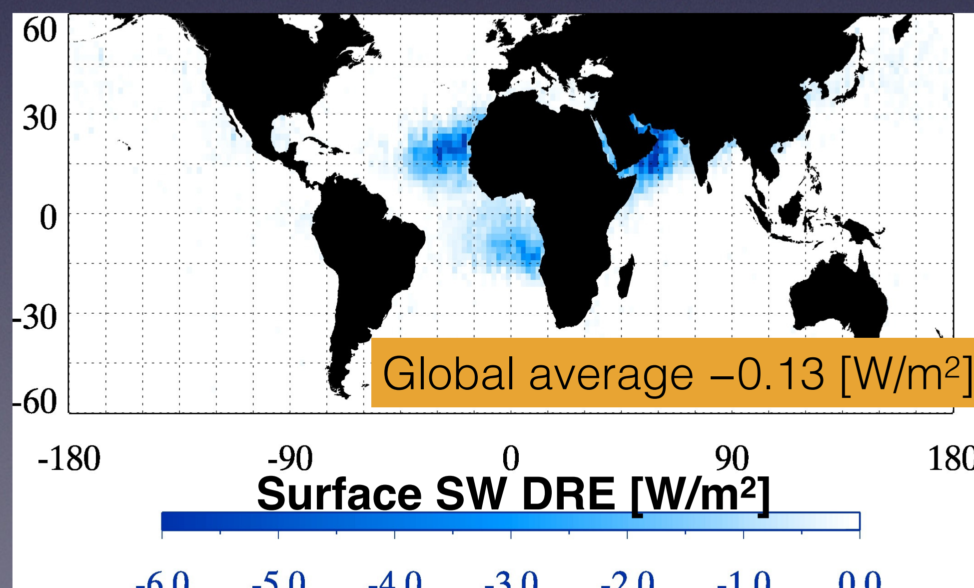
CAD_score:	<-30
Horizontal_avg:	<80km
Extinc_Qc_532:	<2
Feature_OD_unc_532:	<-99.5

COT:
Aqua-MODIS MYD08_D3 V5.1
COT-CTP Joint histograms

Diurnal Average:
Diurnal solar insolation
time-invariant AOT & COT

CALIOP smoke + OBS Dust





Outline

- Methodology
- Results
- Uncertainty Analysis
- Summary and outlook

Methodology

(Zhang et al. AMT 2014)

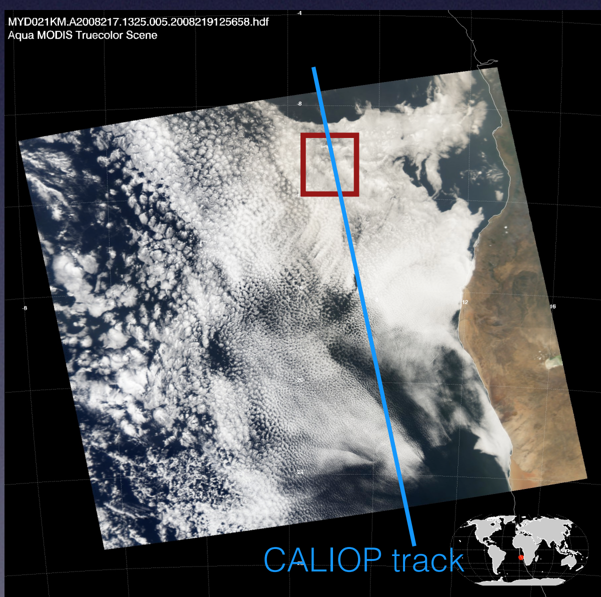
$$\langle DRE \rangle_{ACA} = \int_0^\infty \int_0^\infty DRE(\tau_c, \tau_a) p(\tau_c, \tau_a) d\tau_c d\tau_a$$

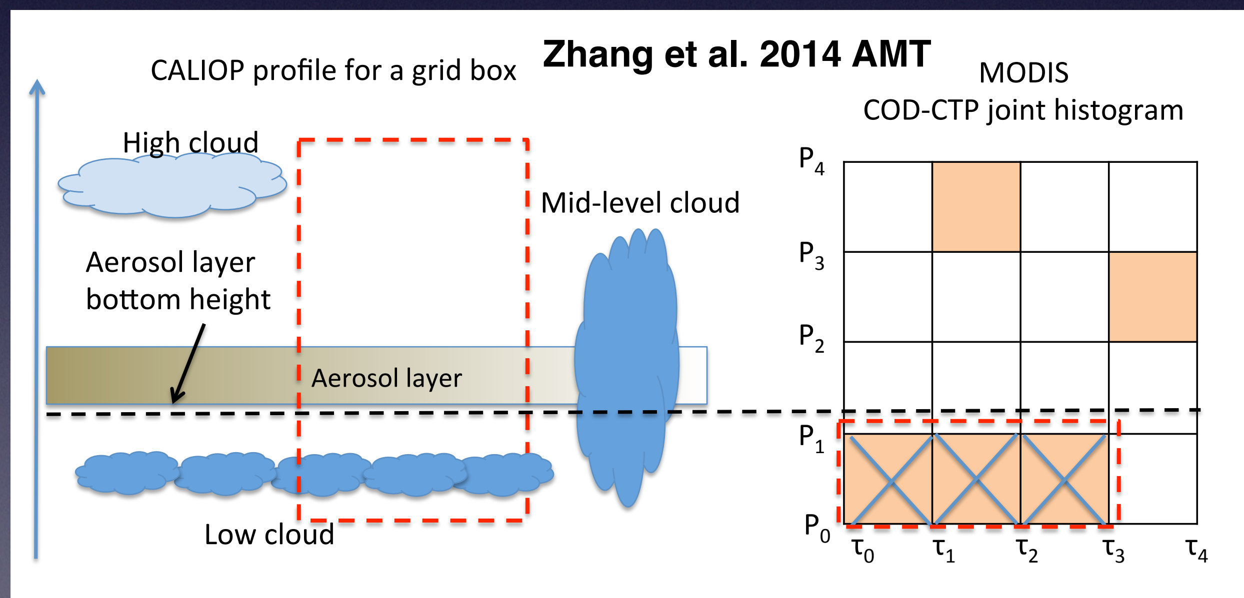
$p(\tau_c, \tau_a)$ joint PDF between AOT and COT

Assuming *random* overlap between AOT and COT

$$\langle DRE \rangle_{ACA} = \int_0^\infty \int_0^\infty \left[DRE(\tau_c, \tau_a) p(\tau_c) d\tau_c \right] p(\tau_a) d\tau_a$$

$p(\tau_c)$ PDF of COT $p(\tau_a)$ PDF of AOT





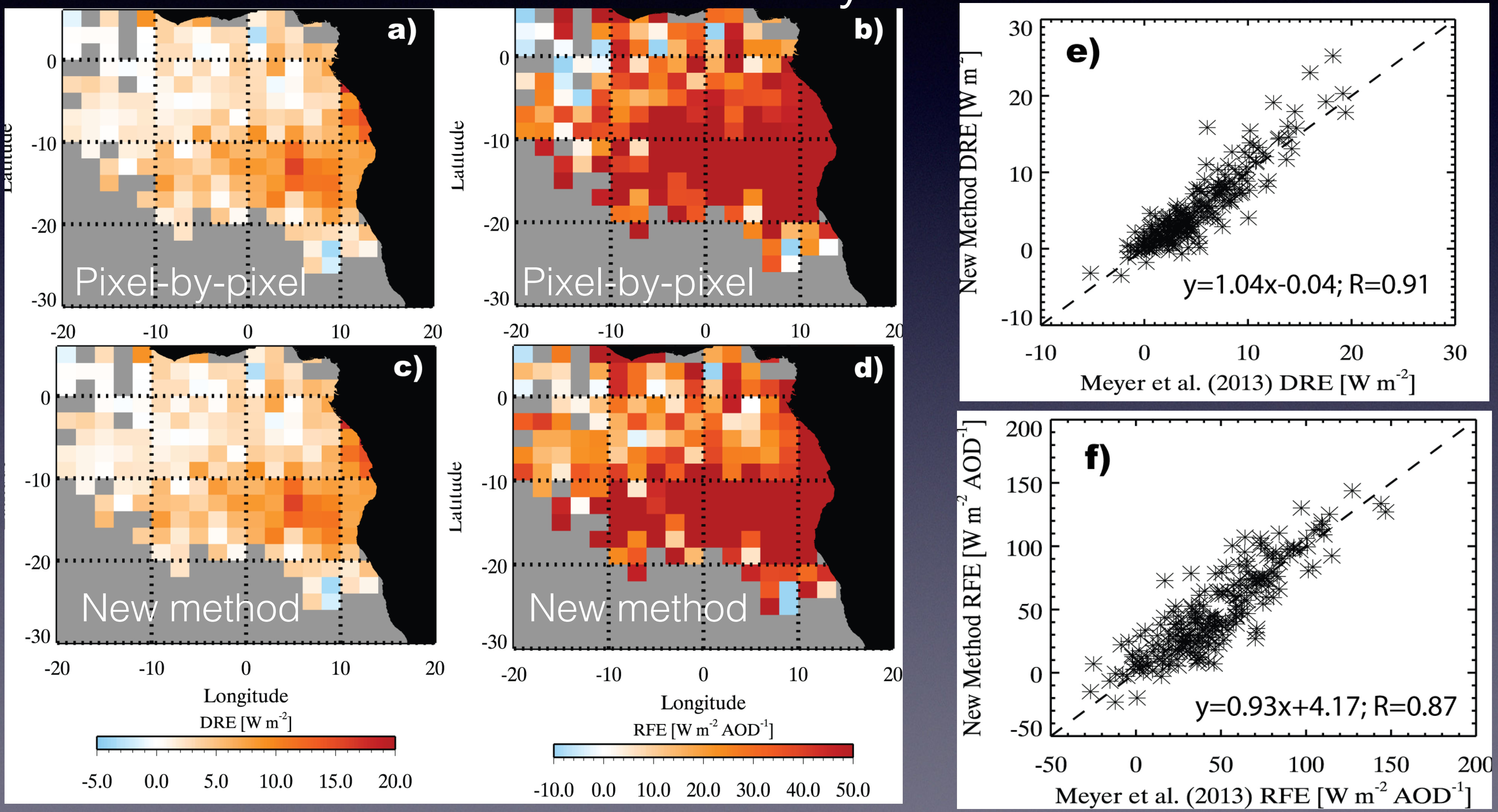
Advantages:

- Efficient (no need for pixel-level collocation)
- Account for COT and AOT variation within grid
- Flexible (applicable to other datasets)
- Facilitate uncertainty analysis

Methodology

(Zhang et al. AMT 2014)

DRE DRE efficiency



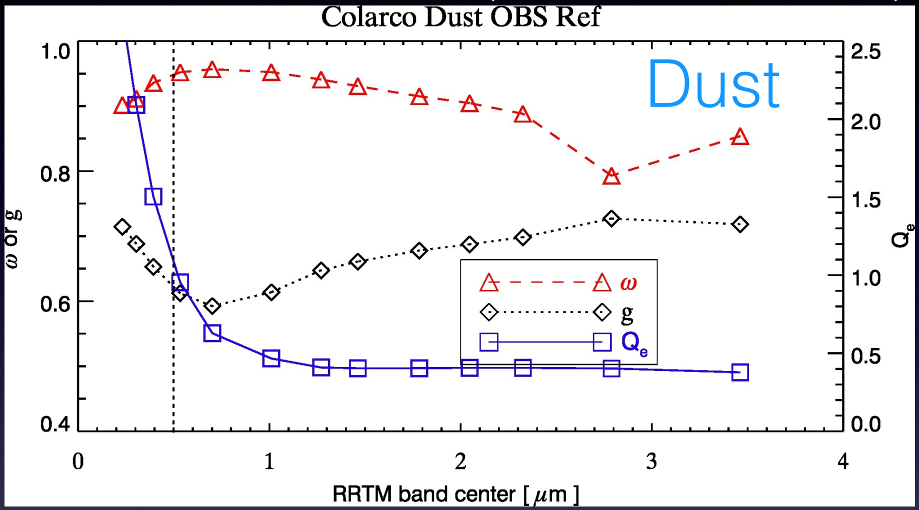
Results

$$\langle DRE \rangle_{all-sky} = (1 - f_c)\langle DRE \rangle_{clear-sky} + f_c \langle DRE \rangle_{ACA}$$

$$\langle DRE \rangle_{ACA} = \int_0^{\infty} \int_0^{\infty} \left[DRE(\tau_c, \tau_a) p(\tau_c) d\tau_c \right] p(\tau_a) d\tau_a$$

Input Aerosol Scattering Properties

CALIOP dust PSD (Omar et al. 2009 JAOT)
+ OBS dust refractive index (Colarco et al. 2014 JGR)



CALIOP smoke PSD +
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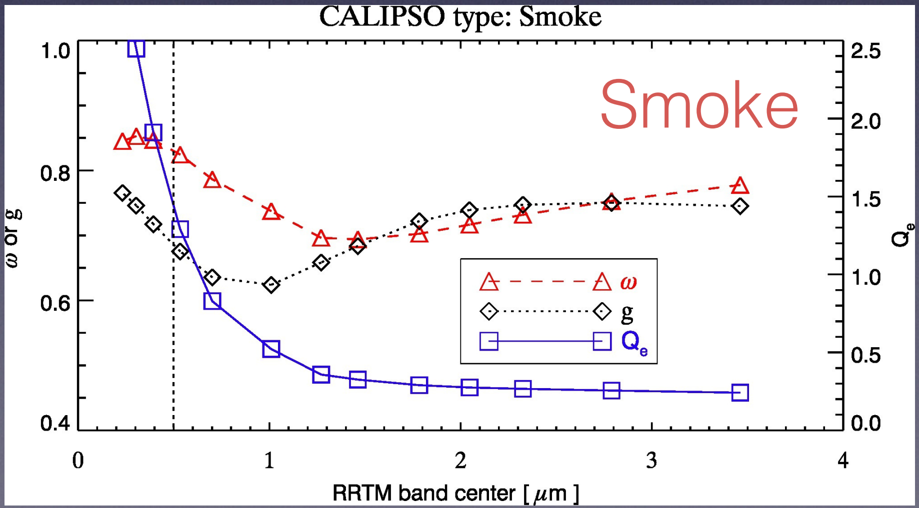
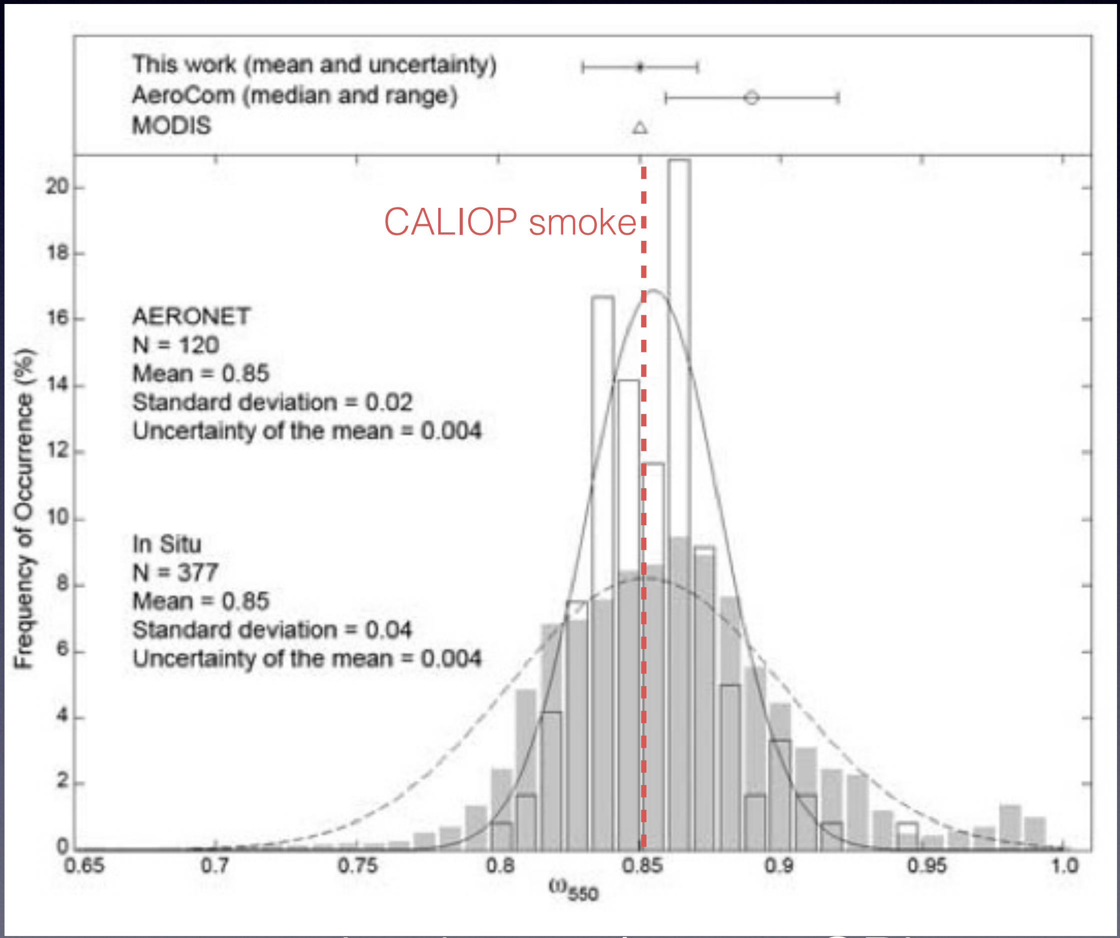


Smoke Albedo from SAFARI 2000 at 550nm



Leahy et al. 2007 GRL

6-year (2006~2012) Averaged ACA DRE

Full column AOT:
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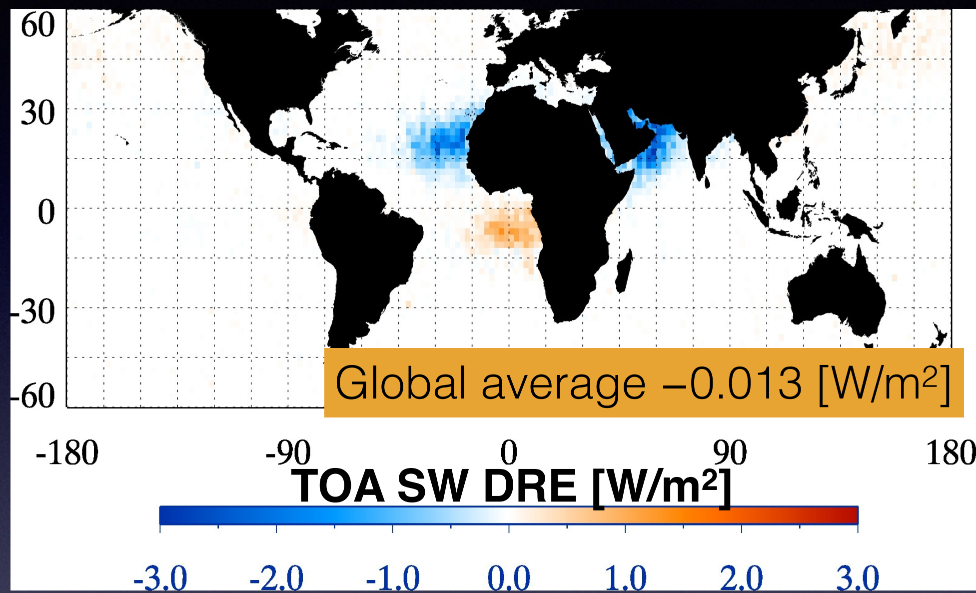
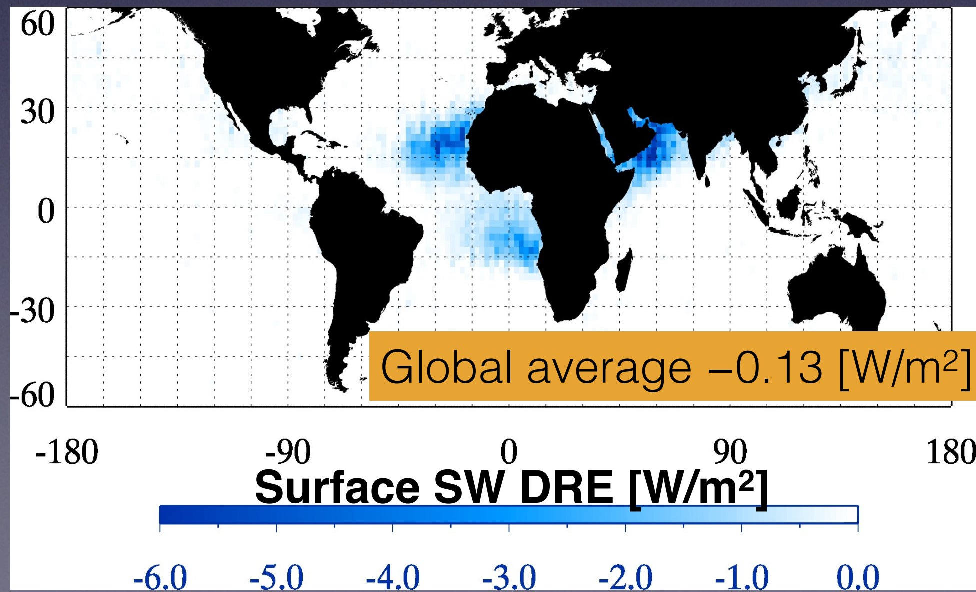
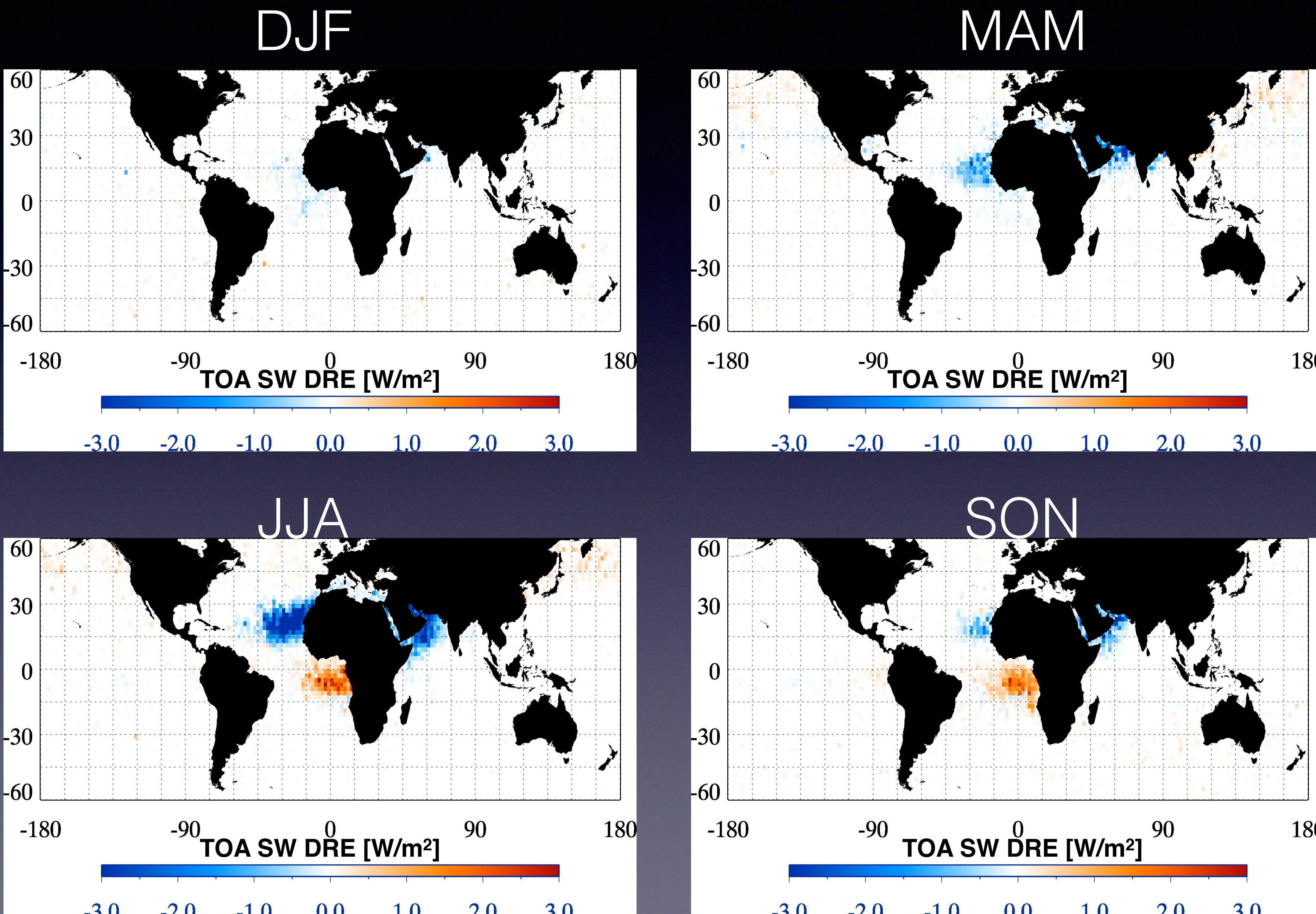




Zhang et al. ACP in preparation

Seasonal Variation



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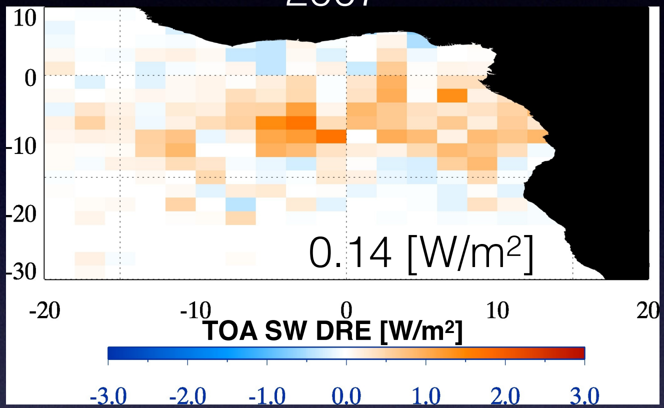
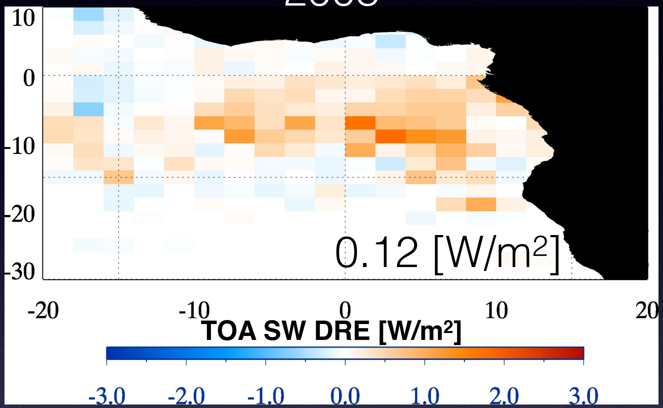
Inter-annual Variation: SE Atlantic Smoke Region

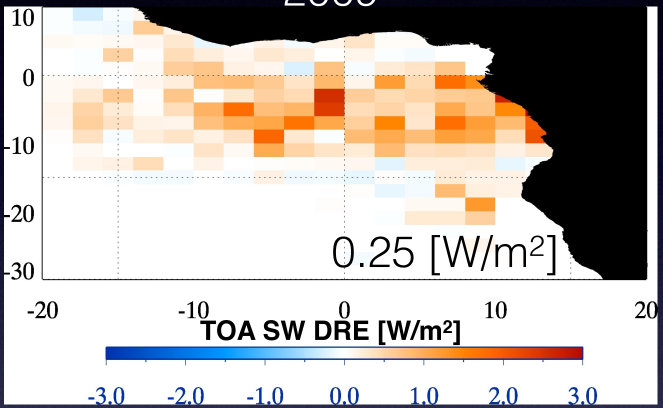
2007



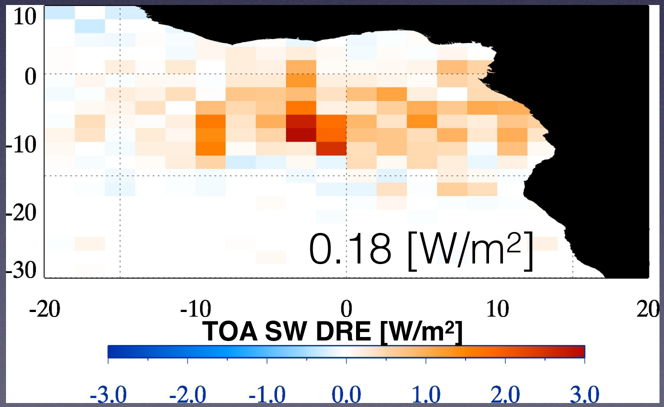
2008



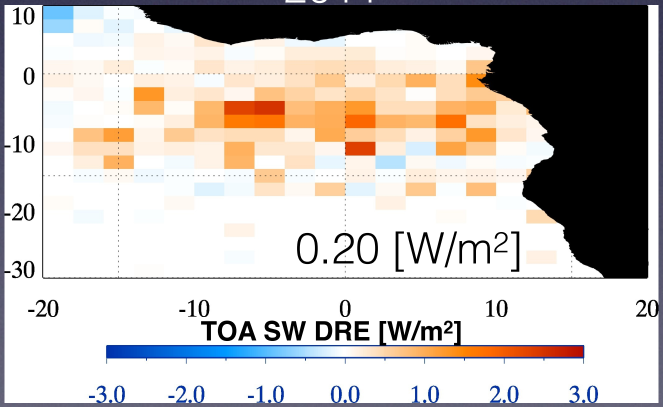
2009



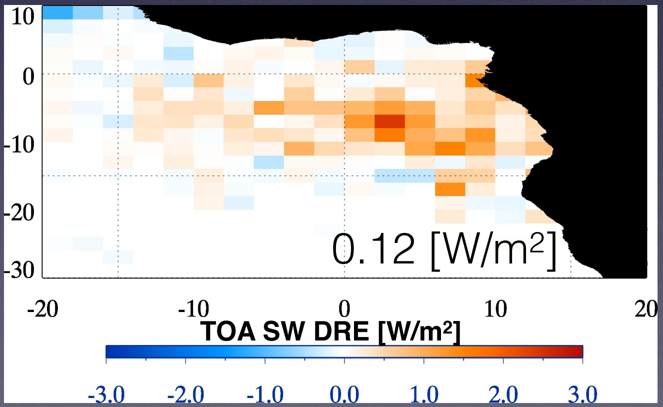
2010



2011



2012



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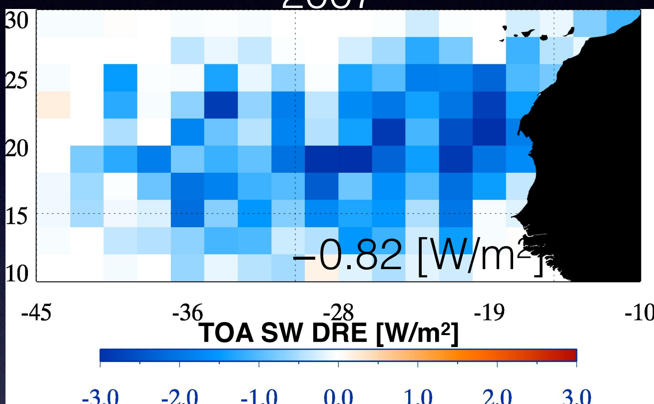
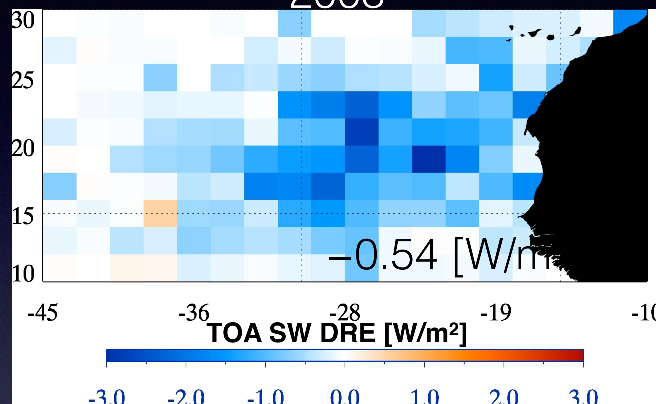
Inter-annual Variation: North Atlantic Dust Transport Region

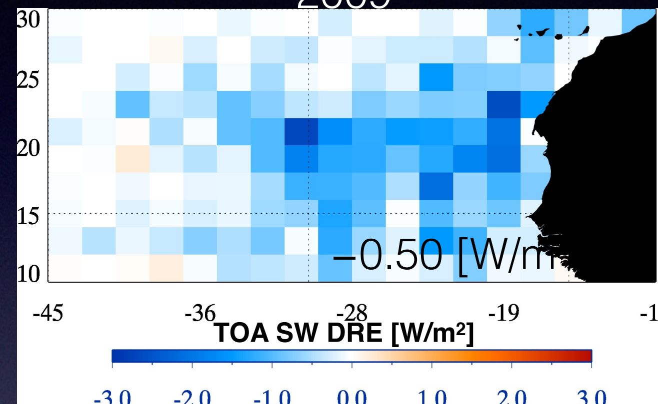
2007



2008



2009



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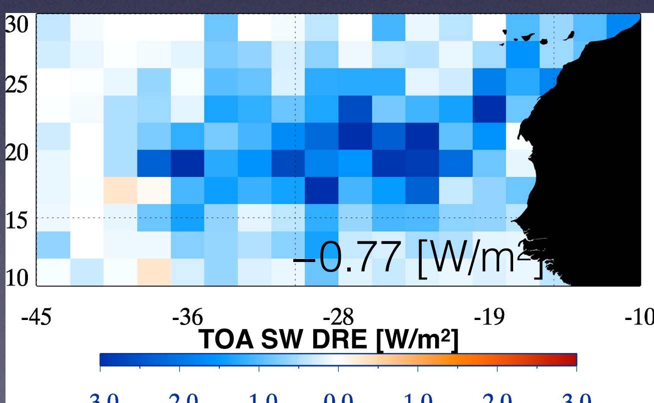

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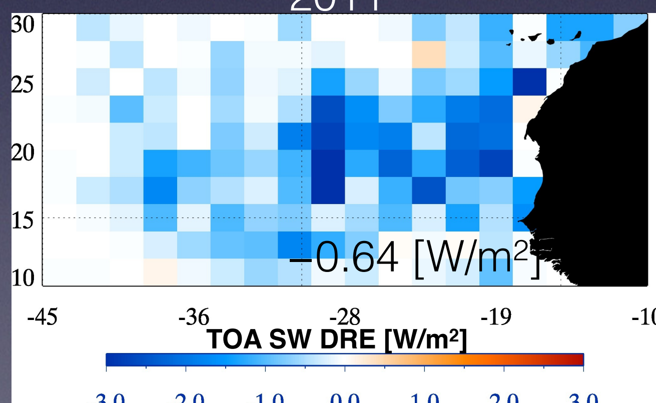
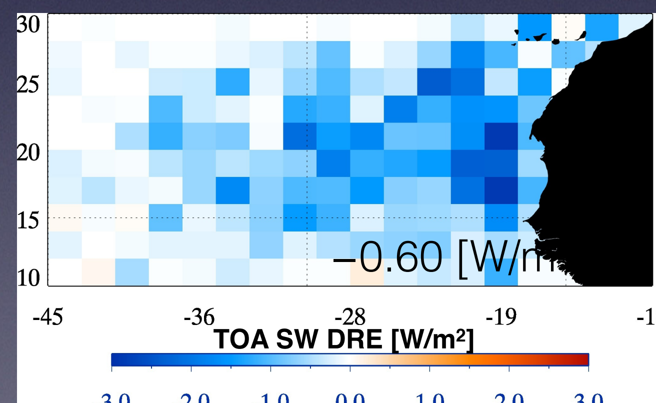


2012



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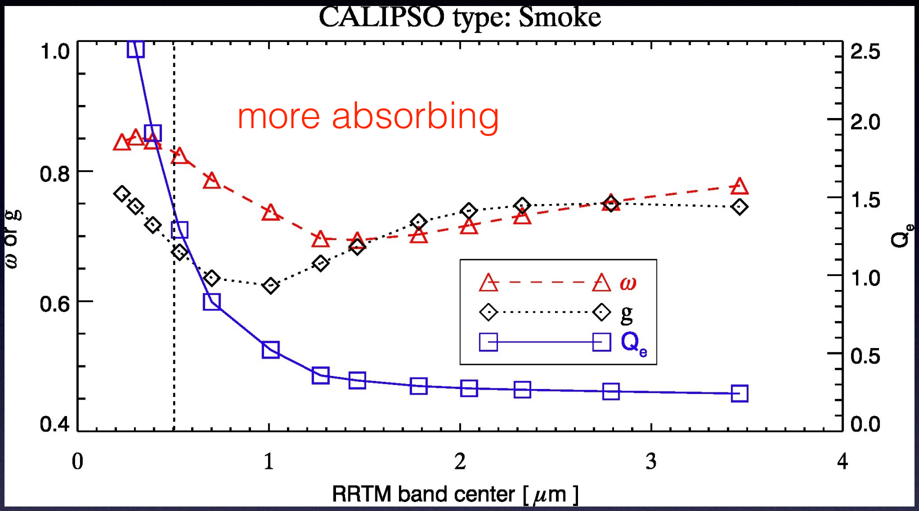
Uncertainty Analysis

- Sensitivity to aerosol model
- Potential CALIOP retrieval bias
    - Aerosol layer thickness uncertainty
    - Daytime noises
- Diurnal cycle of cloud

Uncertainty Analysis I: Sensitivity to smoke aerosol model

CALIOP smoke PSD +
refractive index (Omar et al. 2009 JAOT)



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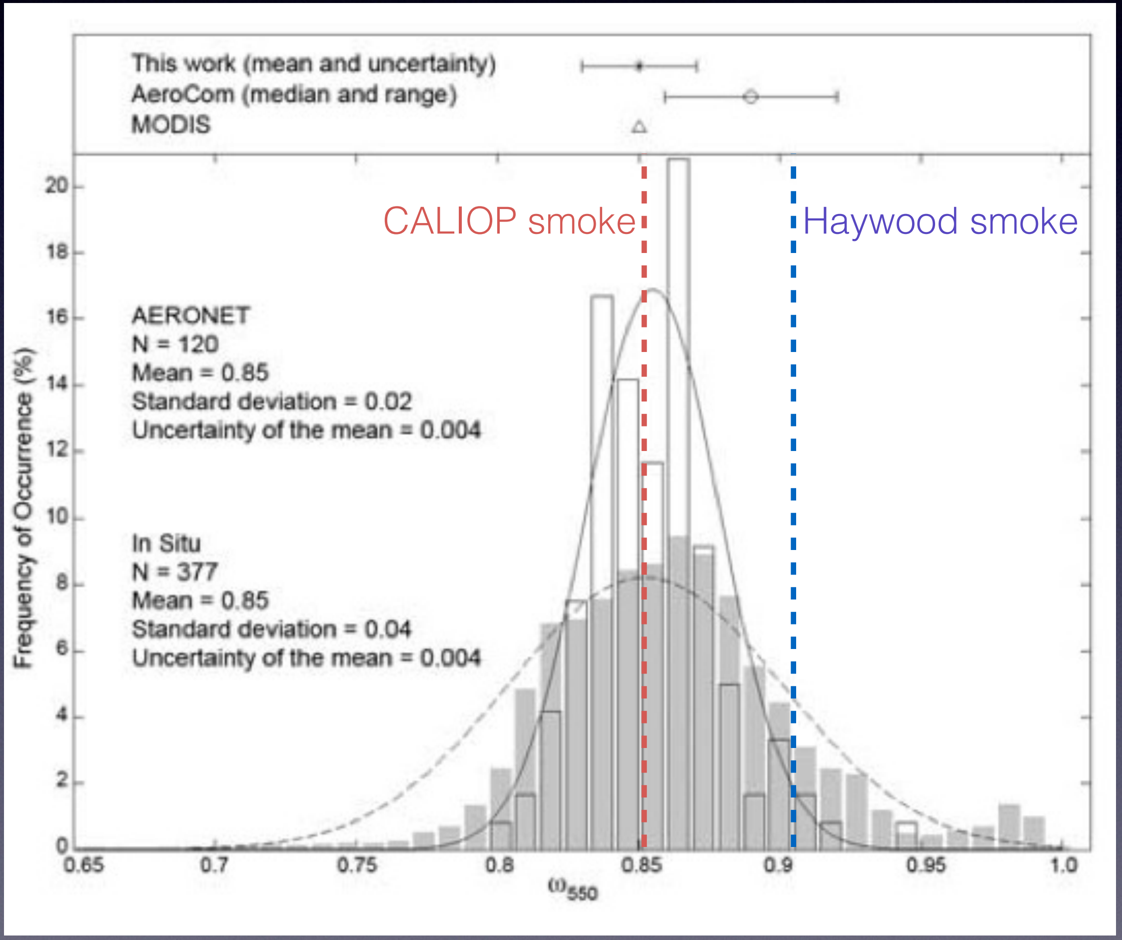
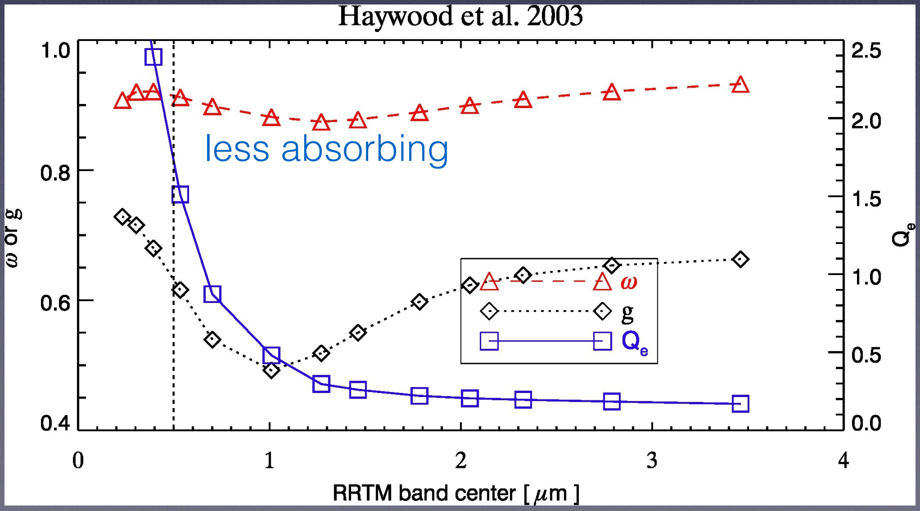


Leahy et al. 2007 GRL

Haywood smoke PSD +
smoke refractive index (Haywood et al. 2003 JGR)



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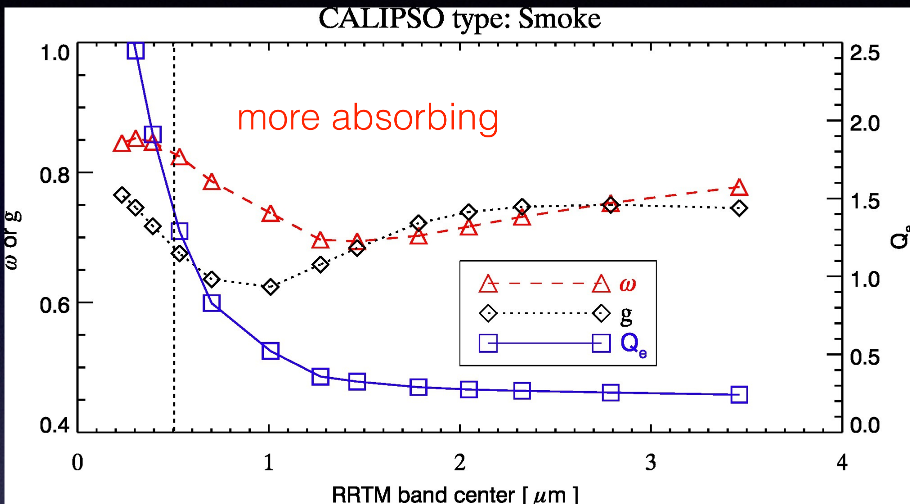

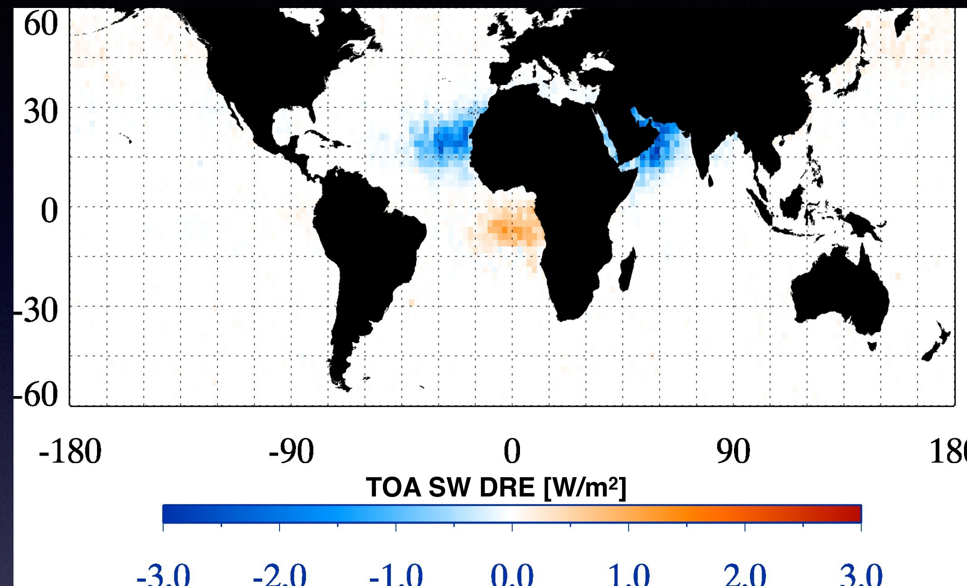

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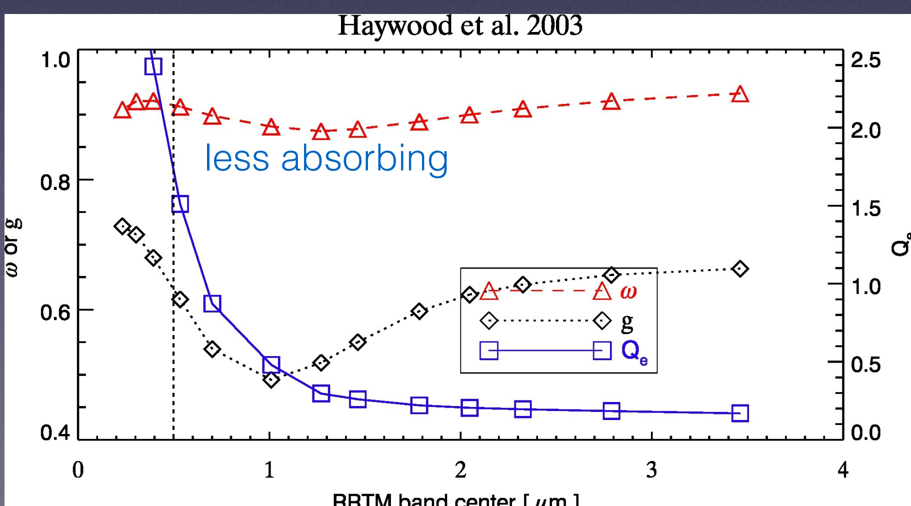
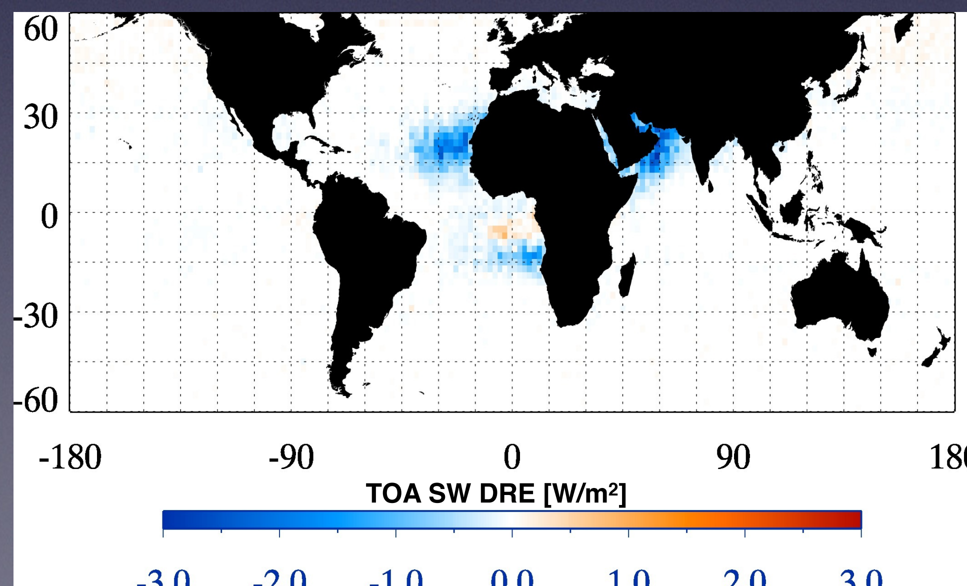
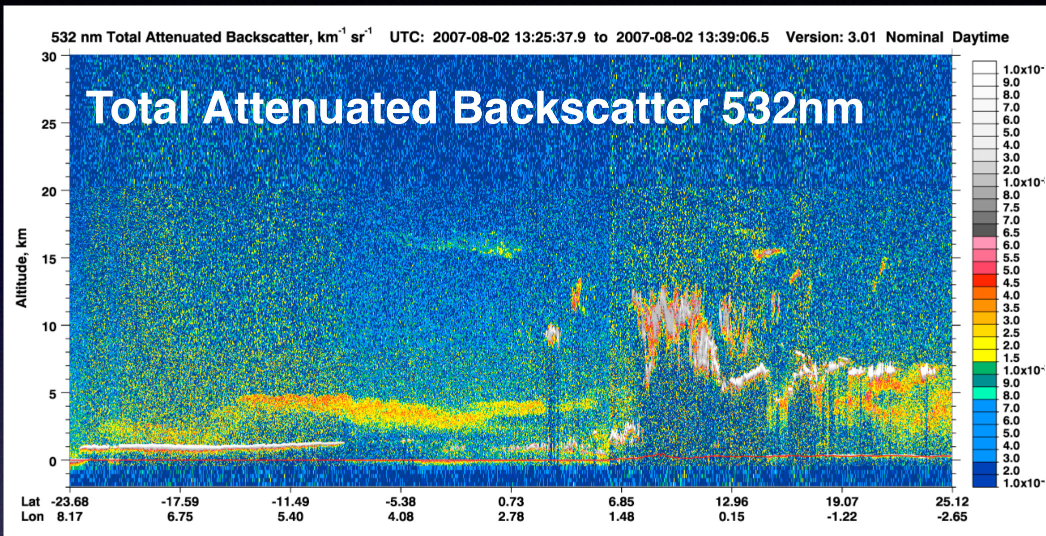
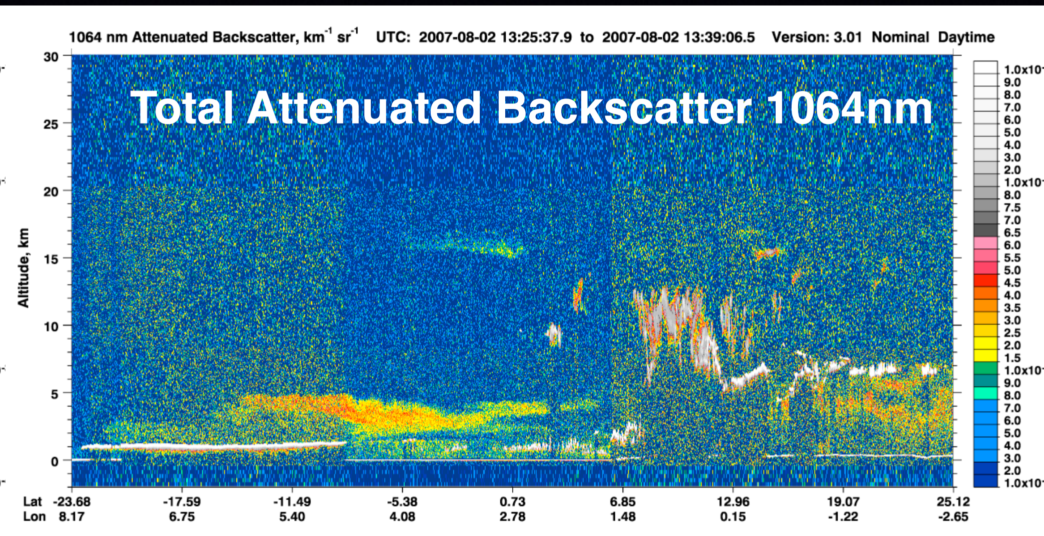


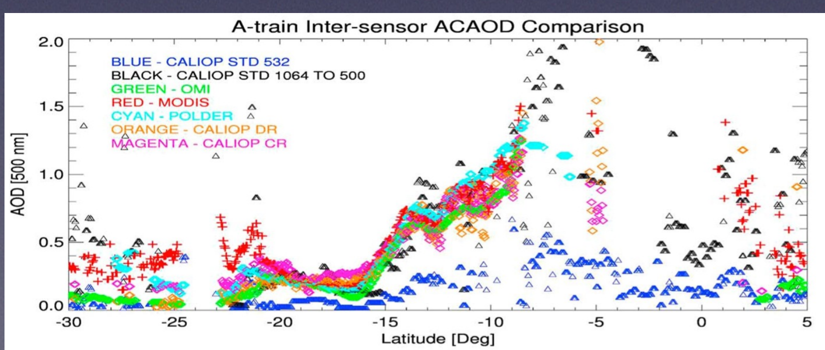


Uncertainty Analysis II:
Aerosol layer thickness uncertainty

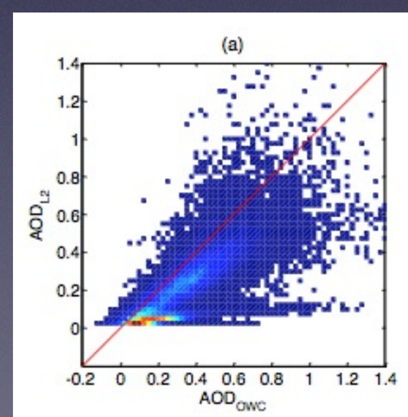




Recent studies suggest CALIOP underestimates ACA AOT
mainly because CALIOP cannot detect the “true” bottom of aerosol layer

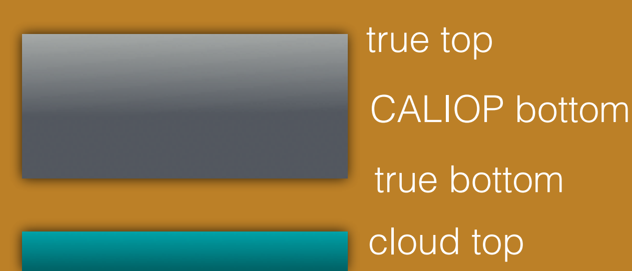


Jethva et al. 2014 GRL



Liu et al. 2014 ACPD

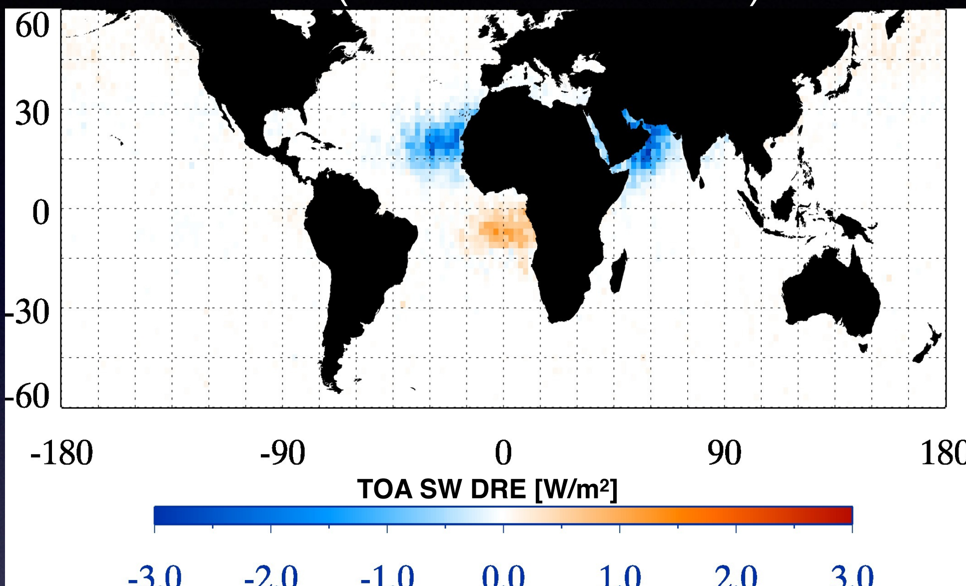
upper limit assessment



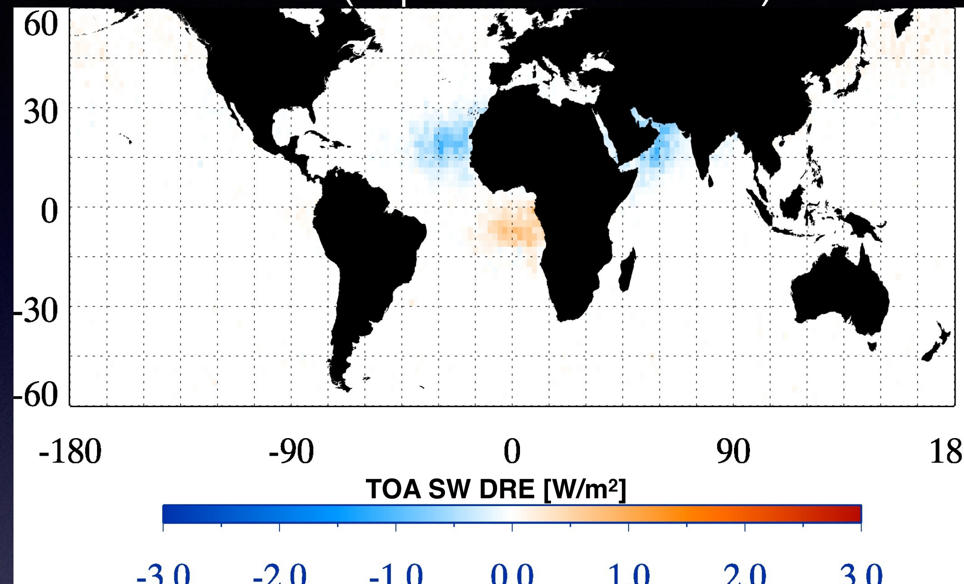
$$AOT_{FC} = AOT_{CALIOP} \frac{h_B(CALIOP) - h_T}{h_T(cloud) - h_T}$$

Uncertainty Analysis II:
Aerosol layer thickness uncertainty

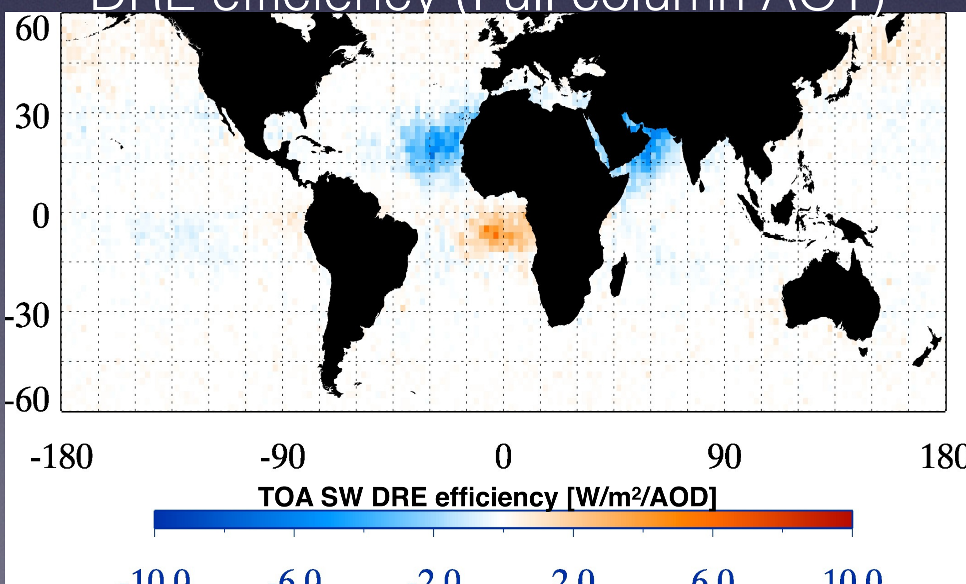
DRE (Full column AOT)



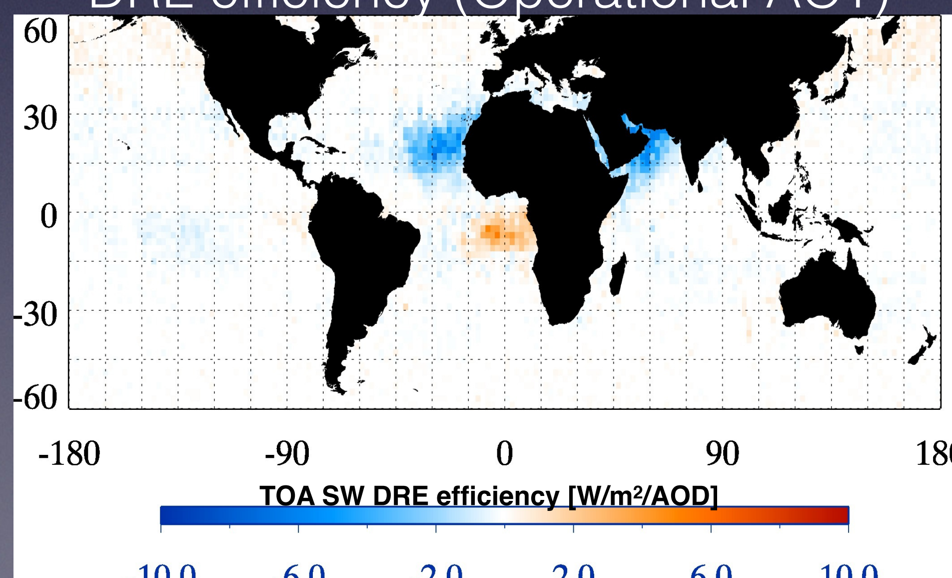
DRE (Operational AOT)



DRE efficiency (Full column AOT)



DRE efficiency (Operational AOT)



Zhang et al. ACP in preparation

Summary

- An efficient, accurate and flexible method to derive the SW ACA DRE has been developed and applied to 6 years of CALIOP and MODIS observations.
- Positive (warming) TOA DRE of above-cloud smoke over SE Atlantic region and negative (cooling) TOA DRE of above-cloud dust over North Atlantic dust transport region and Arabian Sea.
- Above-cloud smoke DRE strongly dependent on smoke bulk scattering properties.
- Uncertainty in CALIOP aerosol layer thickness retrieval has significant impact on ACA DRE, but negligible impact on DRE efficiency.
- Other uncertainties, including CALIOP daytime noises and cloud diurnal cycle, are also found to have impacts on ACA DRE

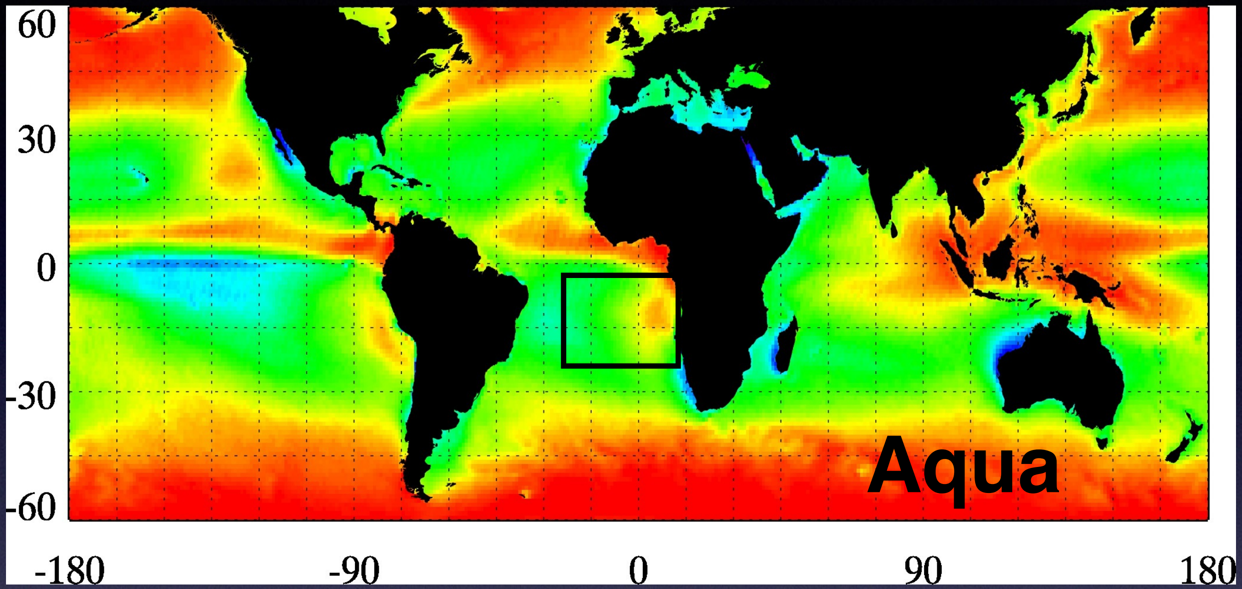
We need a global perspective on ACA DRE

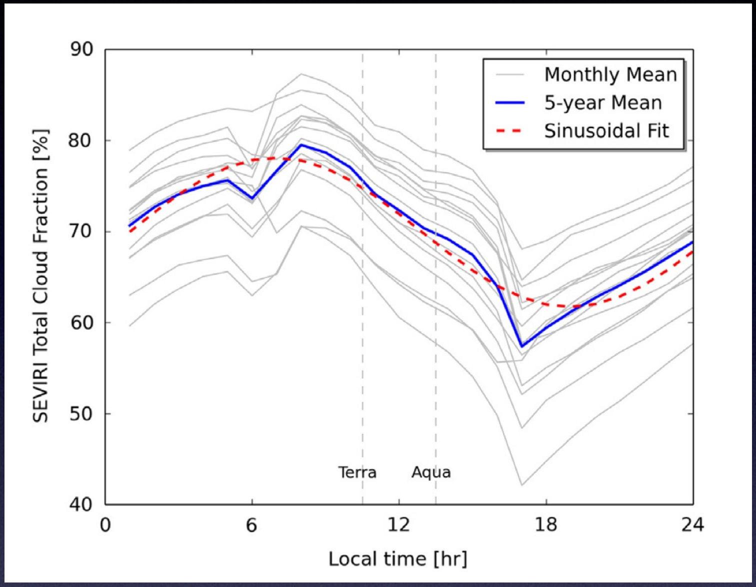
Ongoing Research

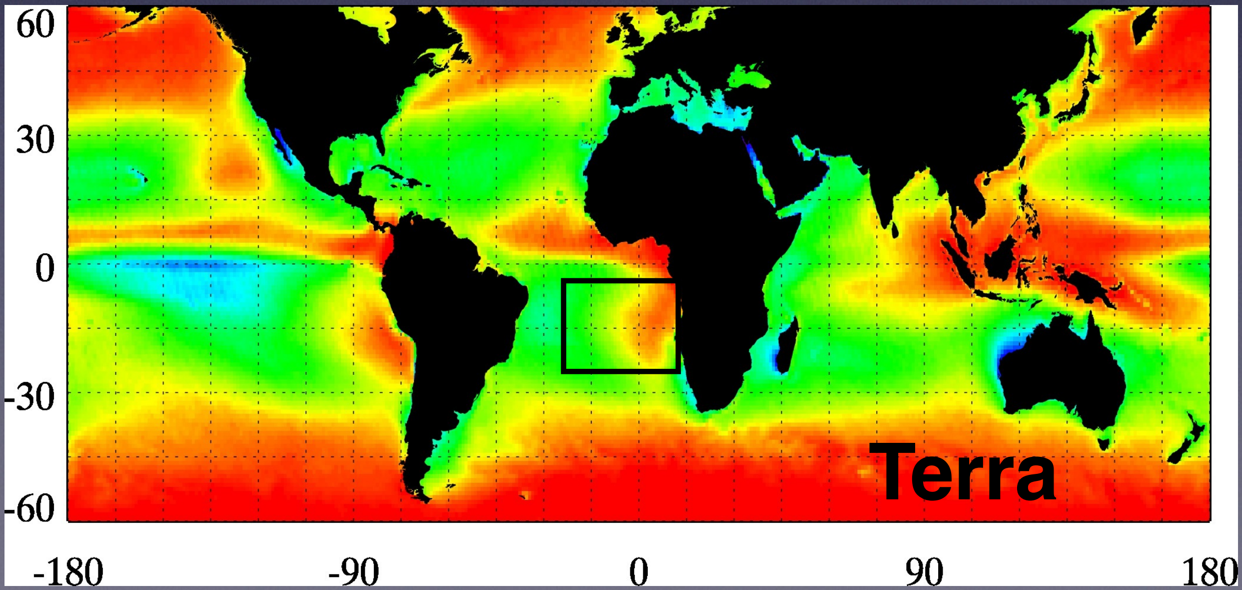
- Comprehensive uncertainty analysis and comparison with results based on other ACA retrieval data sets.
- Investigating the factors influencing the inter-annual variation of ACA DRE.
- Investigating the impact of cloud diurnal variation on ACA DRE.
- Working towards all-sky aerosol direct effects.

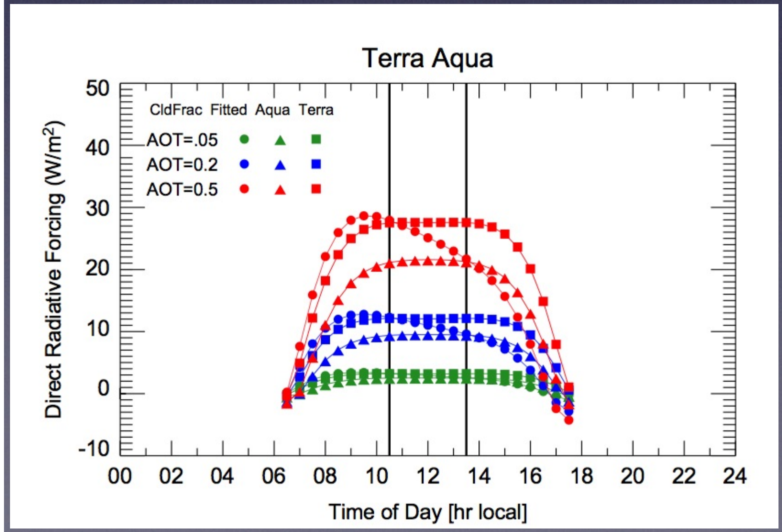
Cloud diurnal variation important for all-sky DRE

Min and Zhang 2014 JQSRT









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Thanks!

- Discussions/suggestions are highly welcome!

Methodology

(Zhang et al. AMT 2014)

Cloud scattering properties

Aerosol scattering properties

NCEP reanalysis atmos. profiles

RRTMG

DRE look-up-table

$$\langle DRE \rangle_{ACA} = \int_0^\infty \int_0^\infty \left[DRE(\tau_c, \tau_a) p(\tau_c) d\tau_c \right] p(\tau_a) d\tau_a$$

Below-aerosol COT PDF

Above-cloud AOT PDF

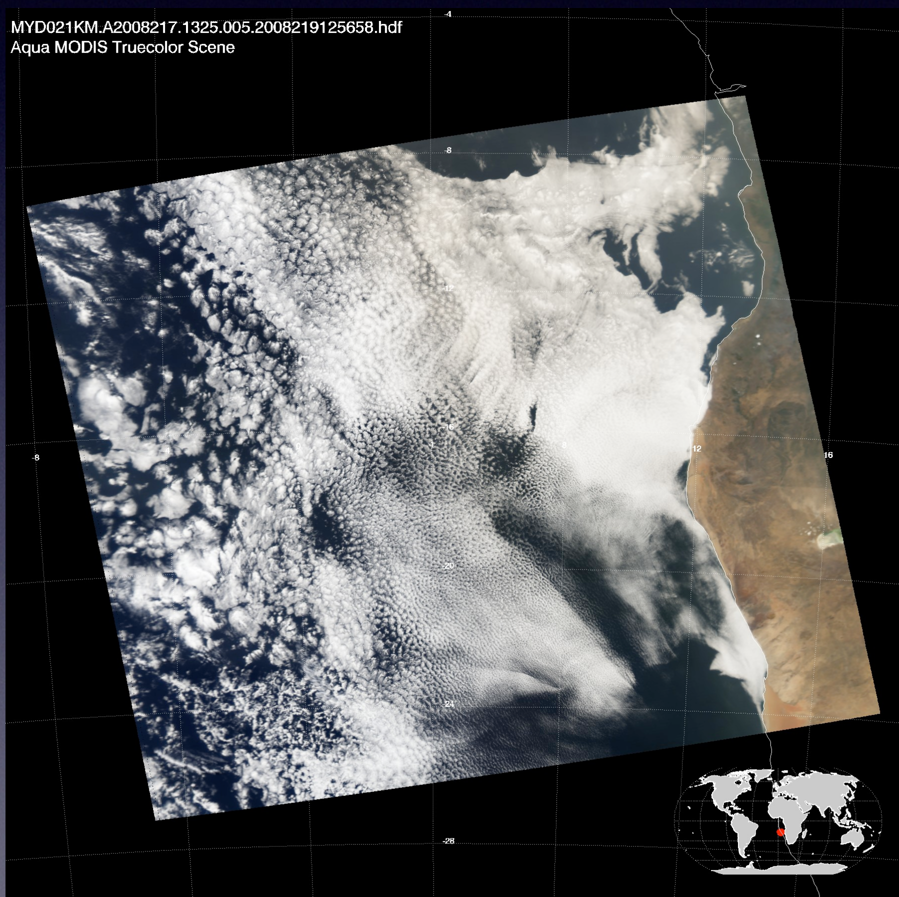
MODIS Level-3 Daily cloud product

CALIOP cloud layer products

CALIOP aerosol layer products

Methodology

COT correction



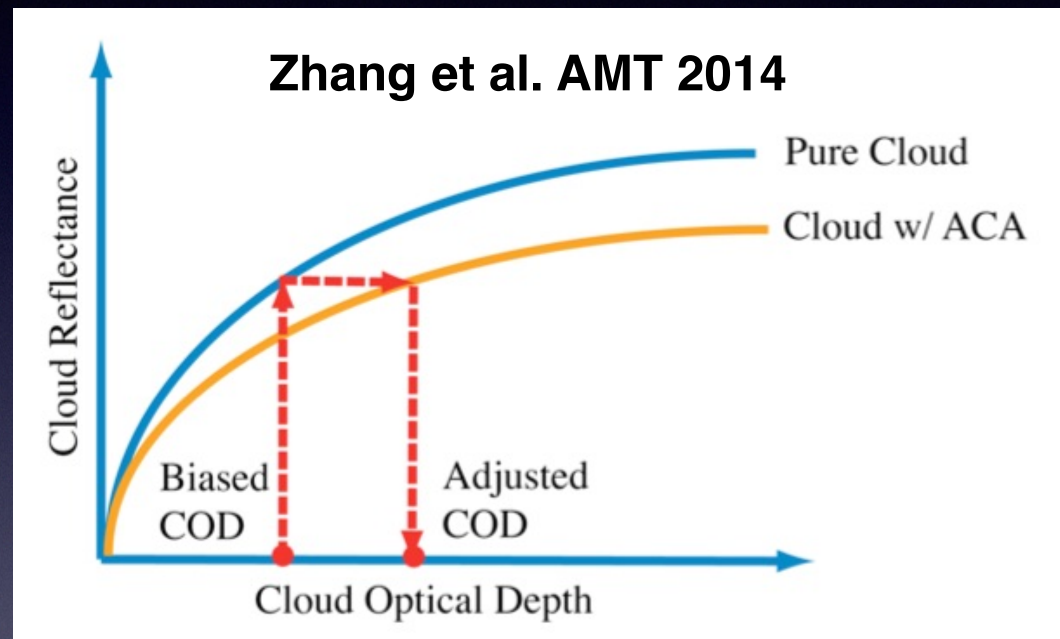
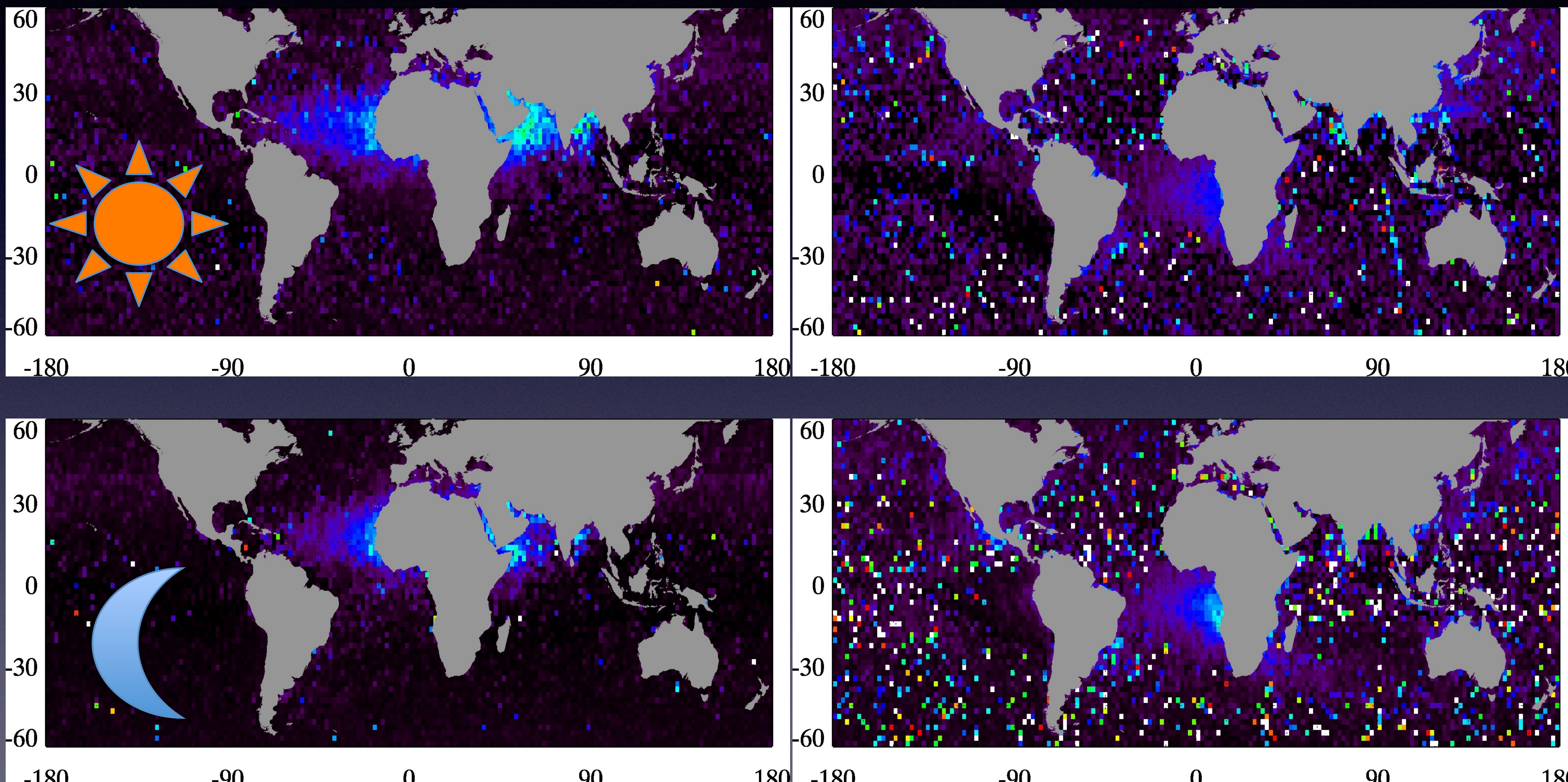


Table 2. Regional and seasonal mean values of instantaneous DRE and RFE based on the pixel-level computation and the new method.

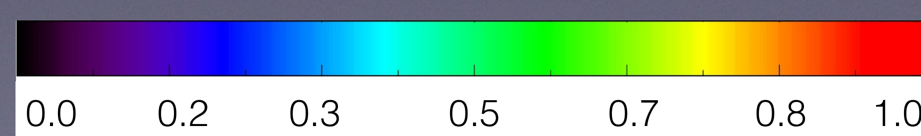
	DRE $[\mathrm{W\,m^{-2}}]$ Bias adjusted (unadjusted)	RFE $[\mathrm{W\,m^{-2}\,AOD^{-1}}]$ Bias adjusted (unadjusted)
Pixel computation	6.6 (5.92)	56.0 (50.3)
New method	6.4 (5.77)	53.8 (50.2)

Uncertainty Analysis III: CALIOP daytime retrieval noises

Above-cloud dust | Above-cloud smoke



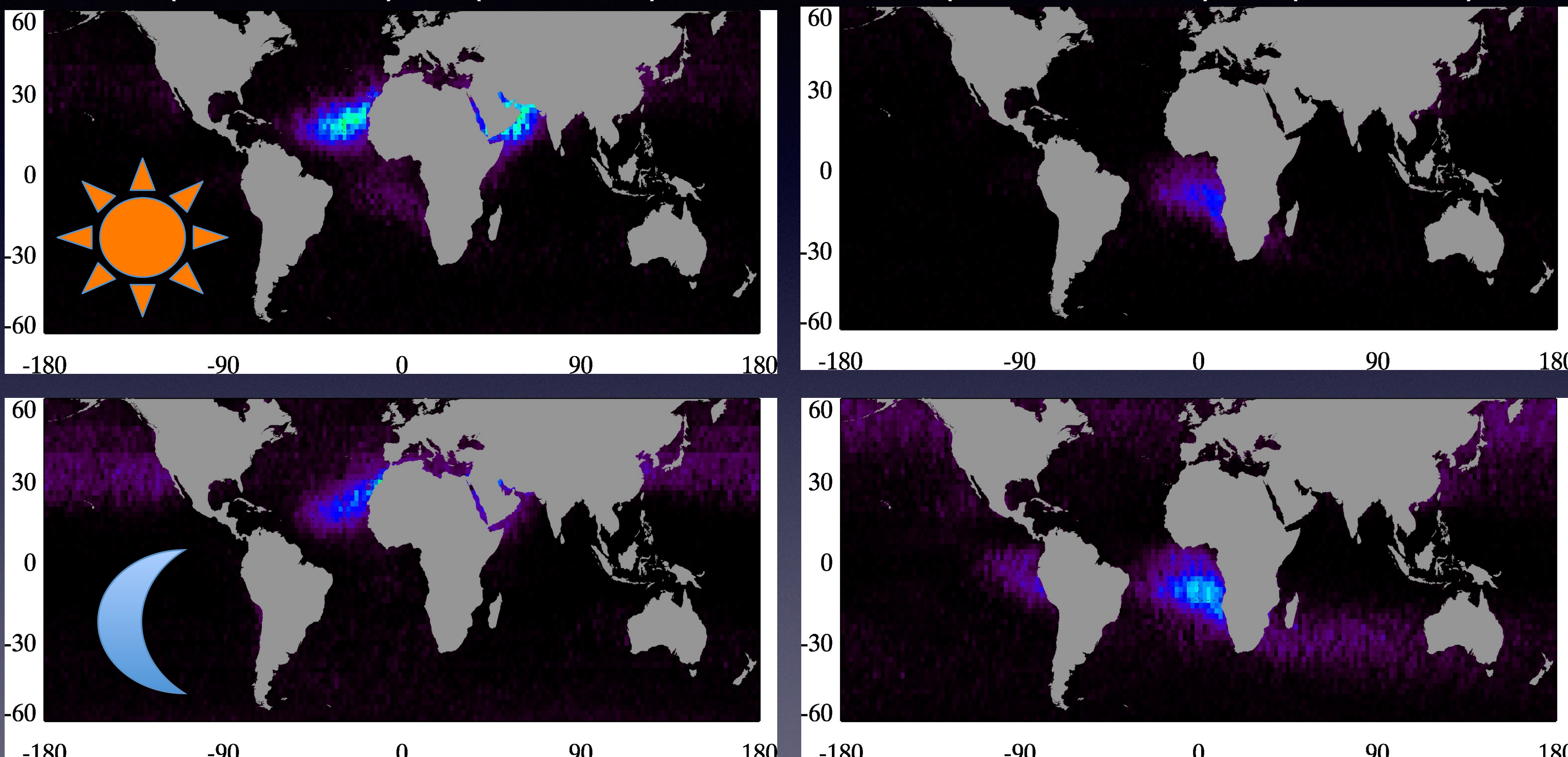
CALIOP seems to “see” thinner dust and thicker smoke during nighttime than daytime



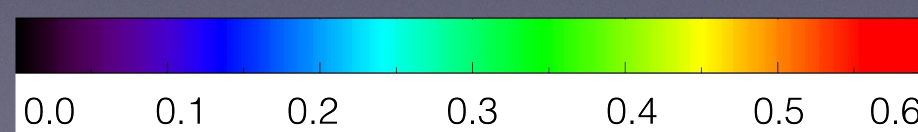
Annual mean ACA AOT 532nm

Uncertainty Analysis III: CALIOP daytime retrieval noises

$N(ACA_{dust})/N(Cloud)$ $N(ACA_{smoke})/N(Cloud)$



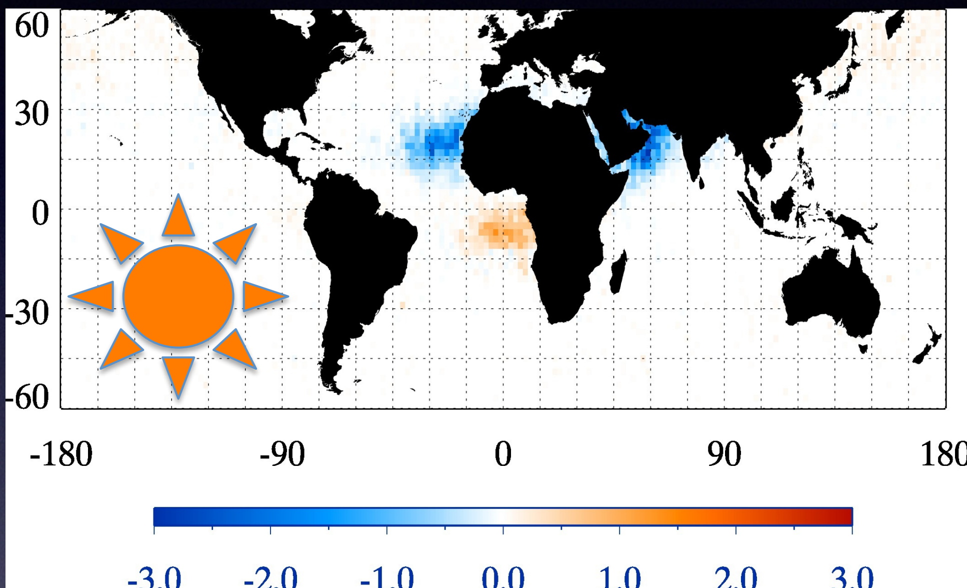
CALIOP seems to "see"
less dust and more smoke over cloud
during nighttime than daytime



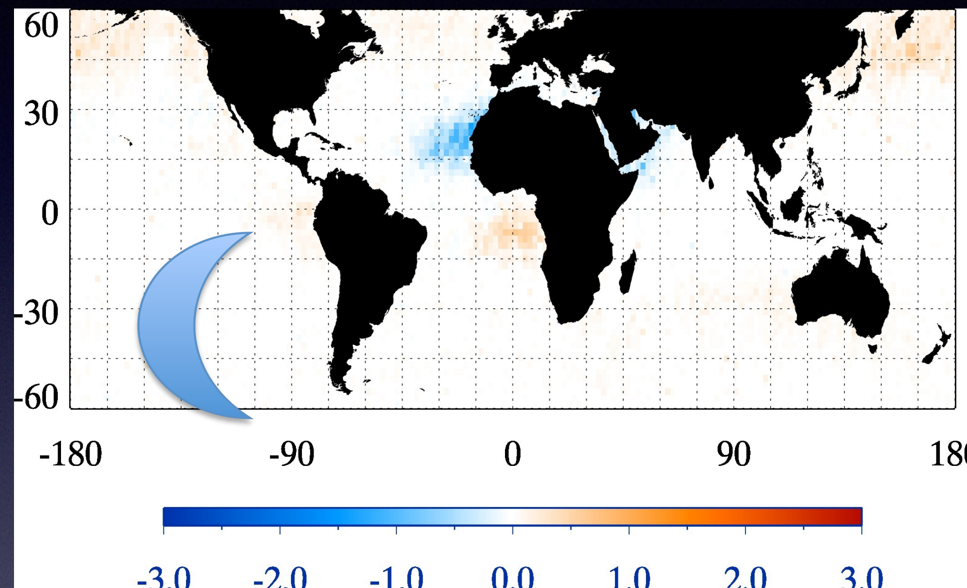
ACA Cloud Overlapping Freq.

Uncertainty Analysis III: CALIOP daytime retrieval noises

Daytime AOT (FC)

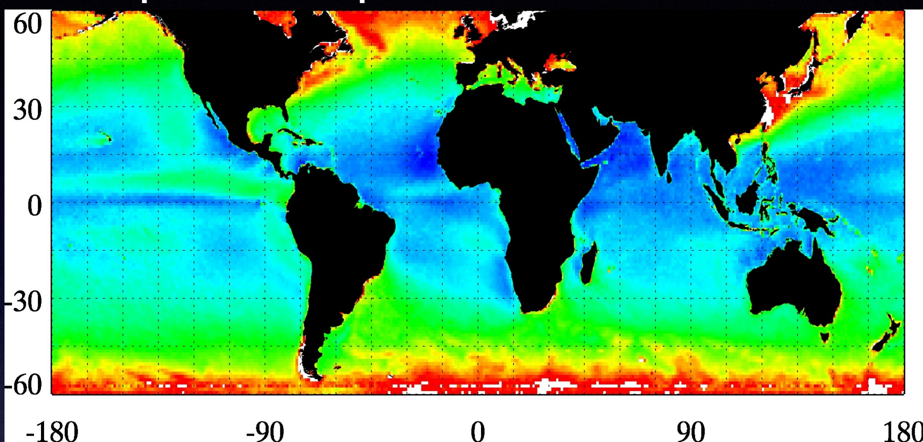


Nighttime AOT (FC)

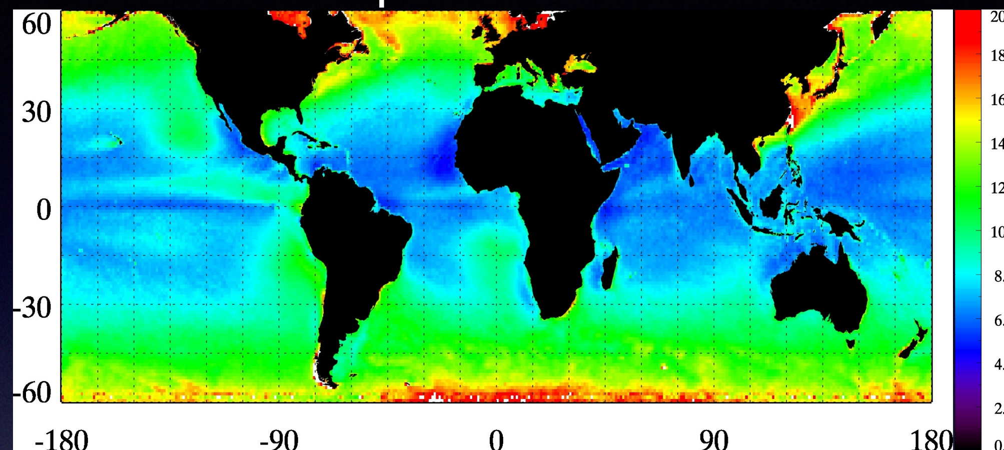


Cloud Diurnal Cycle uncertainty

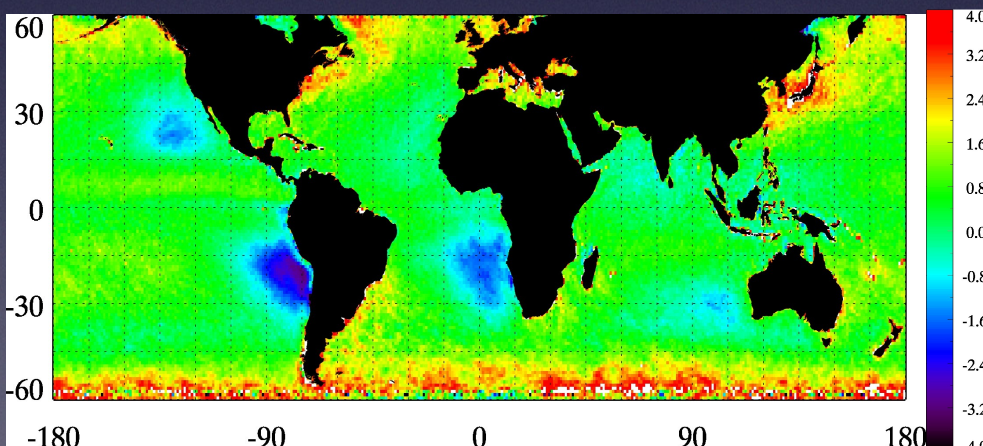
Aqua Liquid Cloud COT

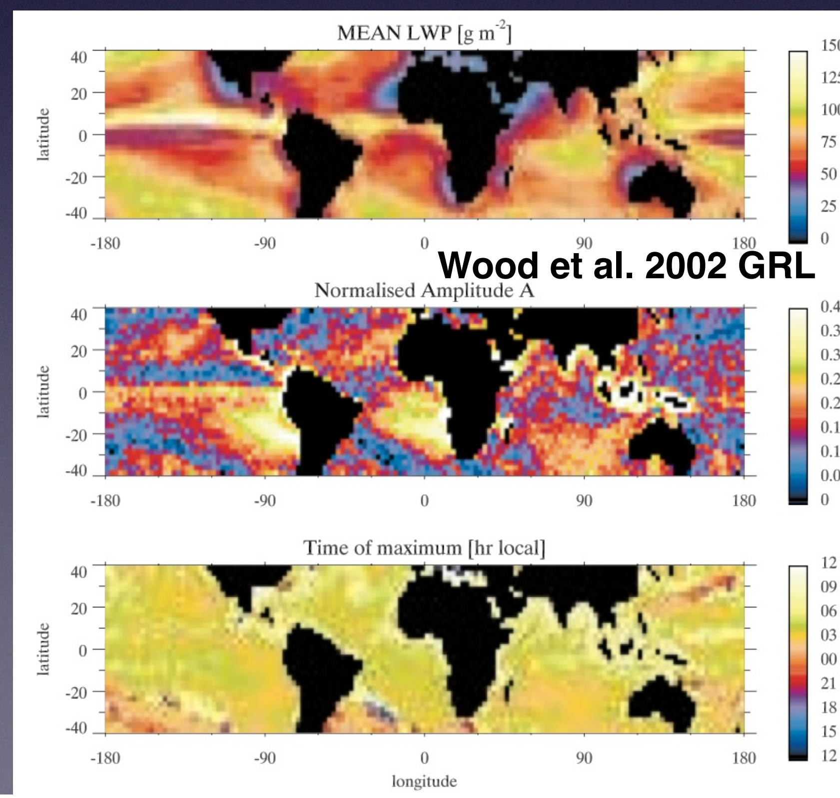


Terra Liquid Cloud COT



Aqua - Terra

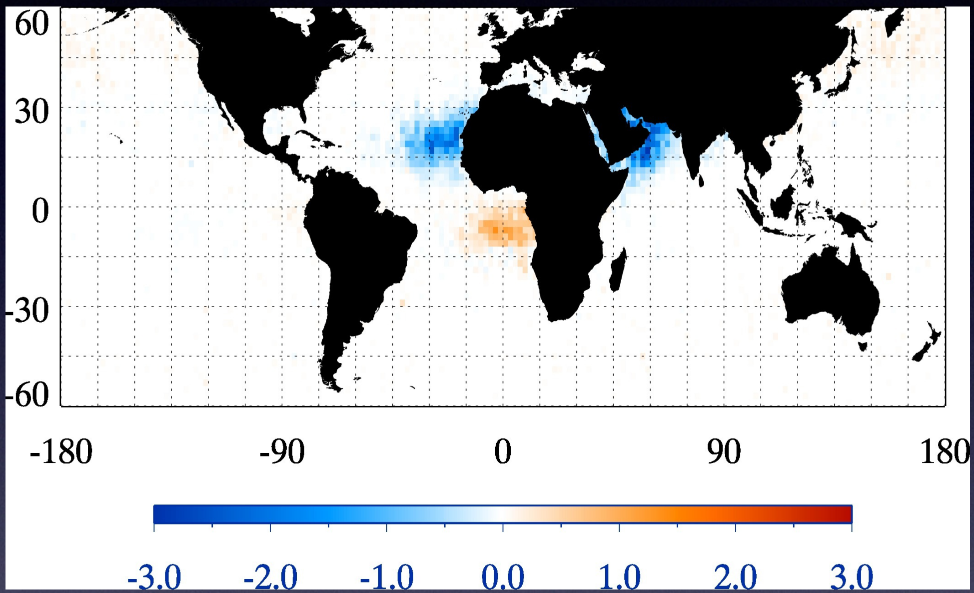




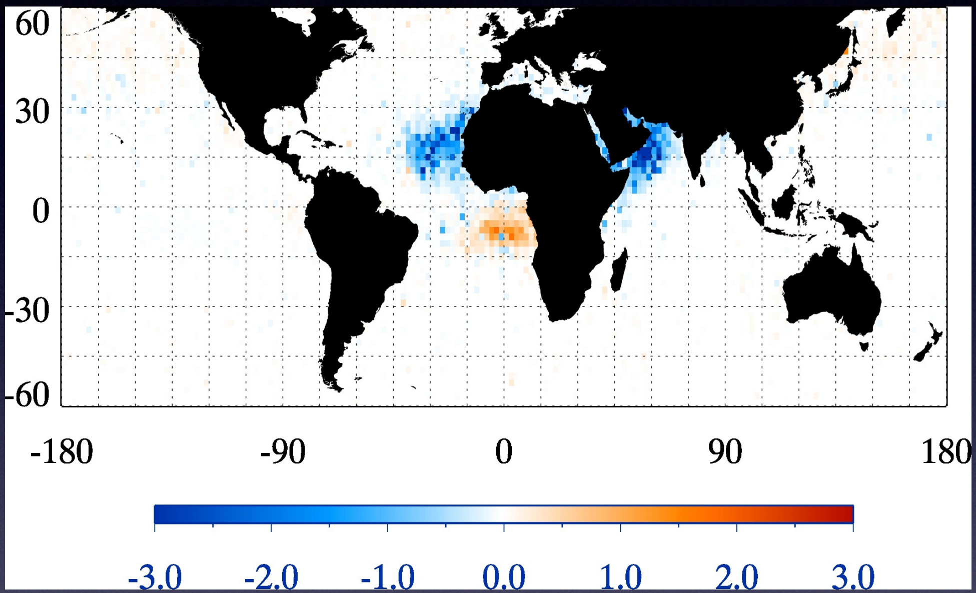
Aqua COT is about 20% thinner than Terra over smoke region due to the strong MBL cloud diurnal cycle

Cloud Diurnal Cycle uncertainty

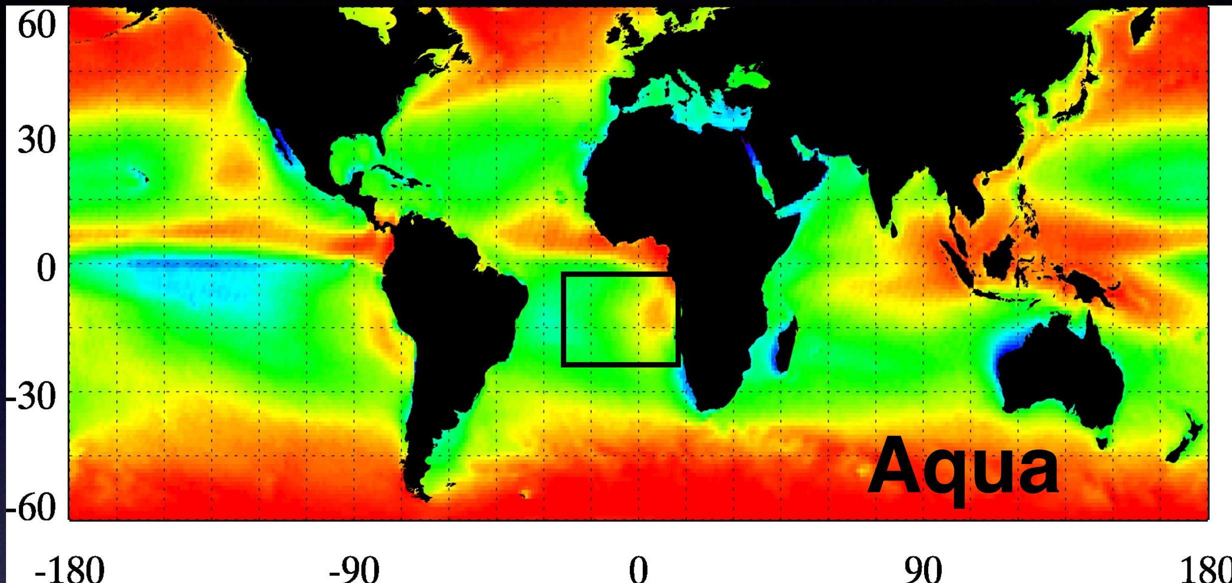
Aqua COT (thinner)

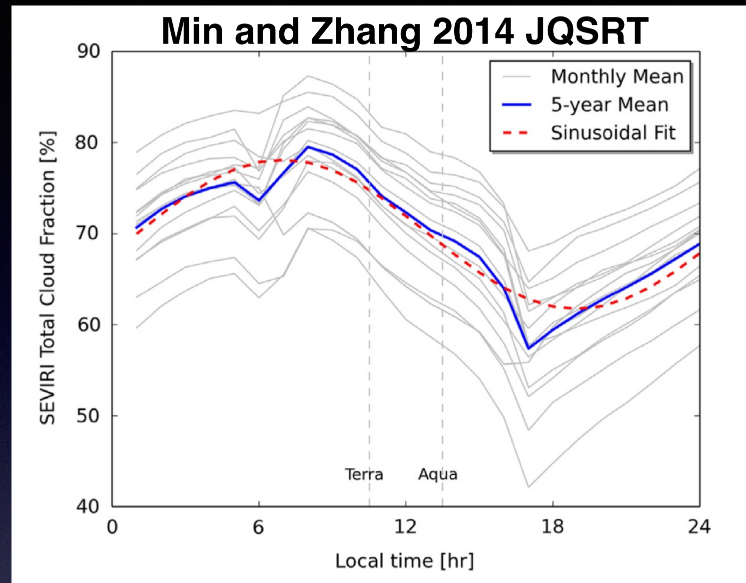


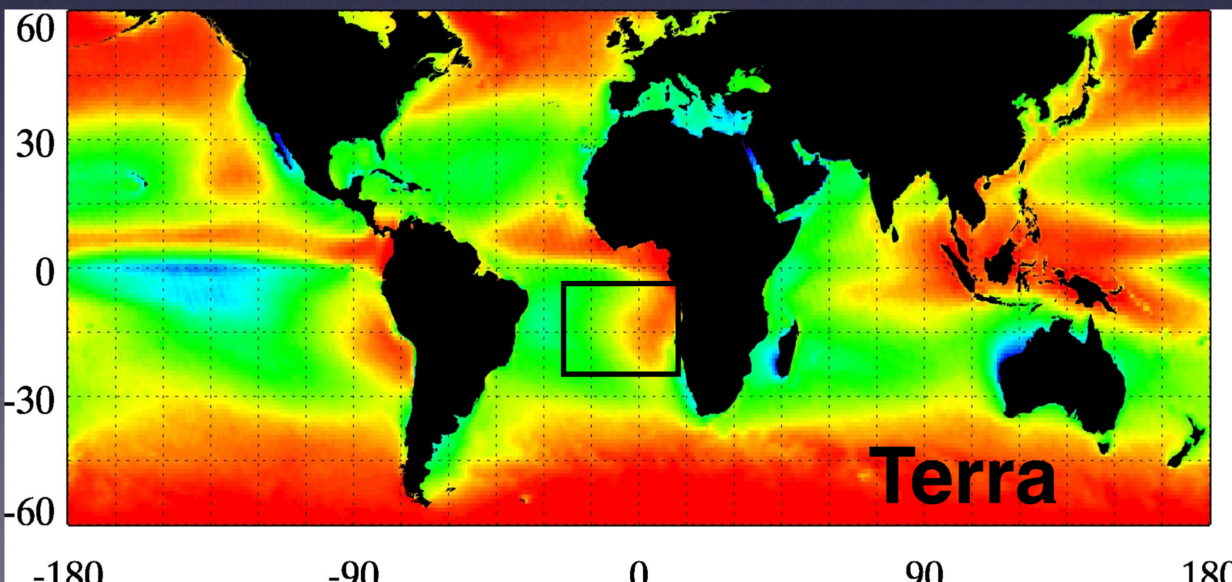
Terra COT (thicker)

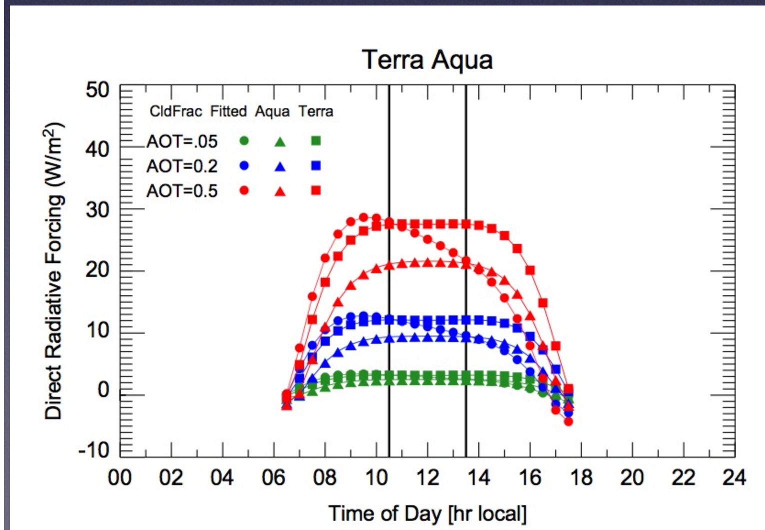


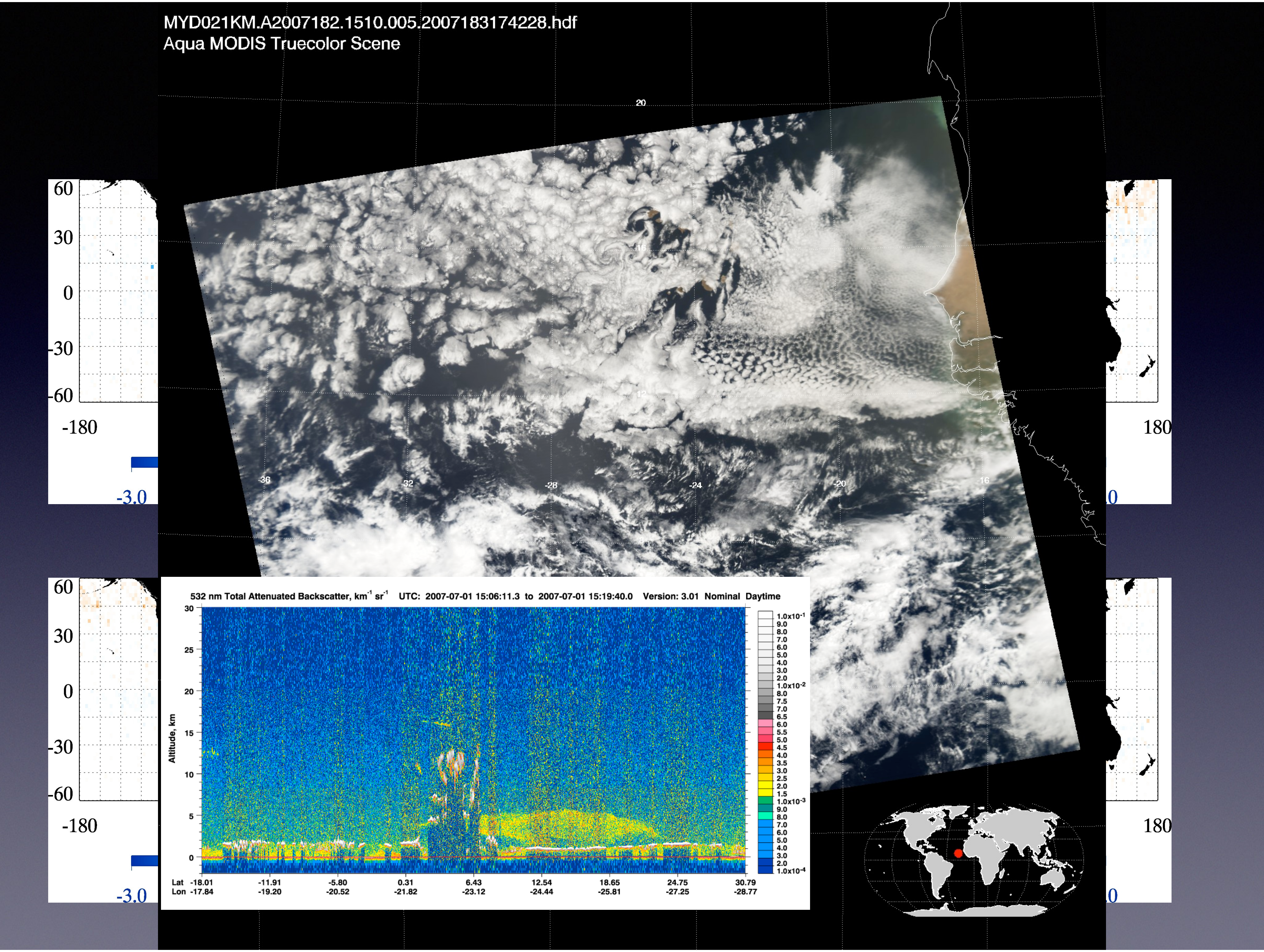
Cloud Diurnal Cycle uncertainty











MYD021KM.A2007182.1510.005.2007183174228.hdf
Aqua MODIS Truecolor Scene
532 nm Total Attenuated Backscatter, km^{-1} sr^{-1} UTC: 2007-07-01 15:06:11.3 to 2007-07-01 15:19:40.0 Version: 3.01 Nominal Daytime
Altitude, km
Lat -18.01 -11.91 -5.80 0.31 6.43 12.54 18.65 24.75 30.79
Lon -17.84 -19.20 -20.52 -21.82 -23.12 -24.44 -25.81 -27.25 -28.77
1.0x10^{-1}
1.0x10^{-2}
1.0x10^{-3}
1.0x10^{-4}
-180
180
-3.0