Global Aerosol Direct Radiative Effect from CALIOP and C3M

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Aerosol Radiative Forcing

- One of the key uncertainties in understanding climate change
- Two basic approaches to estimating:
  - Model-based (Aerocom: Schulz et al., 2006)
  - Observation-based (Yu et al., 2006; Bellouin et al, 2008, etc.)
- Both approaches have limitations
  - Observations: limited capabilities to observe and characterize aerosol globally
  - Models: well, they're models
- Comparisons of model-based and observation based estimates show significant differences

DARF vs. DRE

- "Direct aerosol radiative forcing"
  - Net radiative perturbation from anthropogenic aerosol at TOA, relative to pre-industrial

- Aerosol "direct radiative effect"
  - Net radiative perturbation at TOA from the total aerosol (natural + anthropogenic) relative to an aerosol-free atmosphere

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- We focus on aerosol DRE here
  - Can be observed more directly than DARF
  - Radiative effects of natural aerosols also climatically important

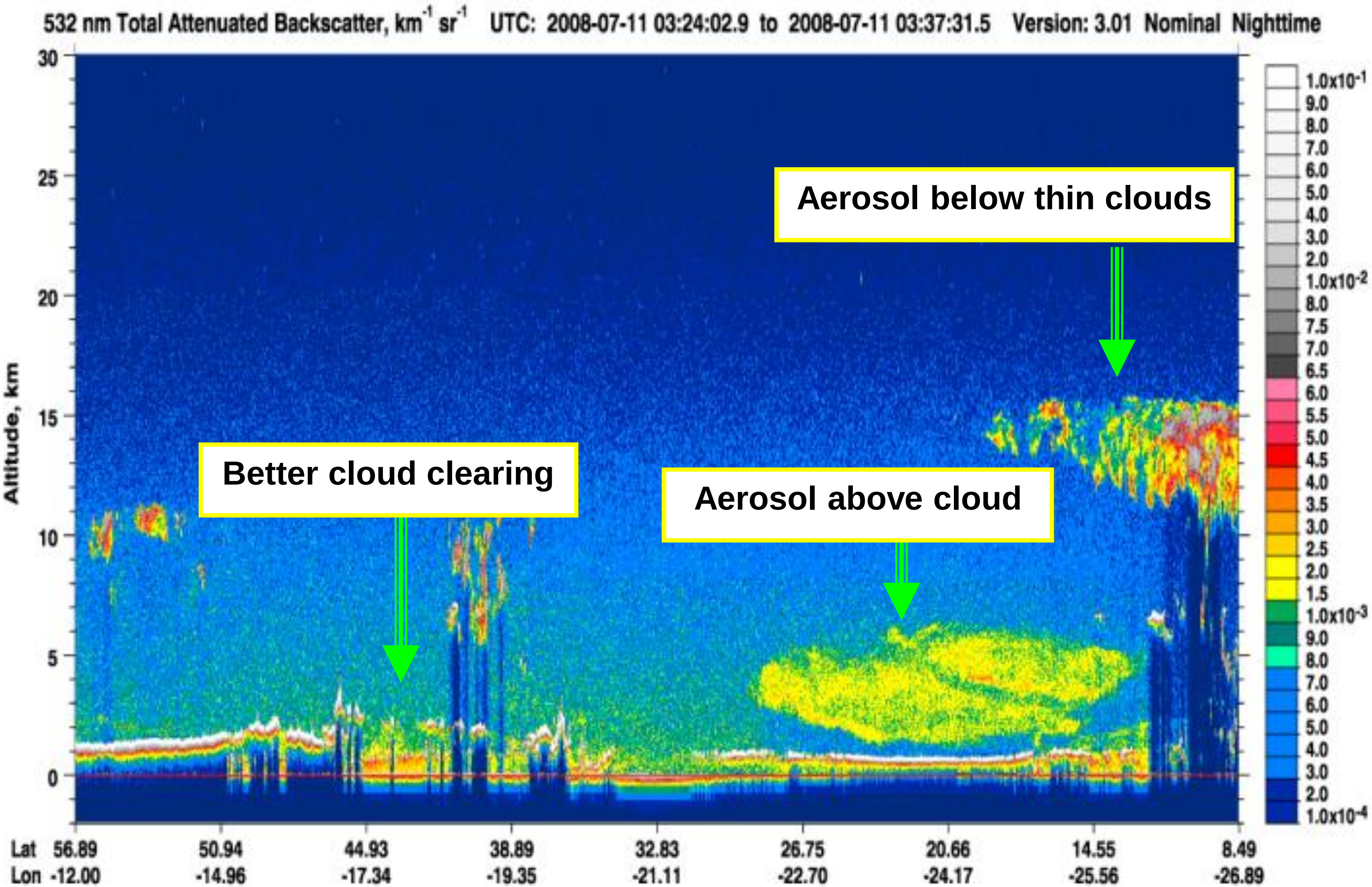
- Chand et al. (2009) and Sakaeda et al. (2011) have performed regional DRE studies based on CALIOP

- Following the launch of Terra and Aqua, a number of estimates of aerosol DRE were performed based on MODIS AOD, sometimes also using CERES fluxes

	Clear-sky Ocean DRE (W/m^2)
Yu et al., 2004	**- 5.1, -5.7**
Loeb and Smith, 2005	**- 5.46**
	- 3.8
Remer and Kaufman, 2006	**-5 to - 5.5**
Yu et al, 2006 (review)	**- 5.5 (mean)**

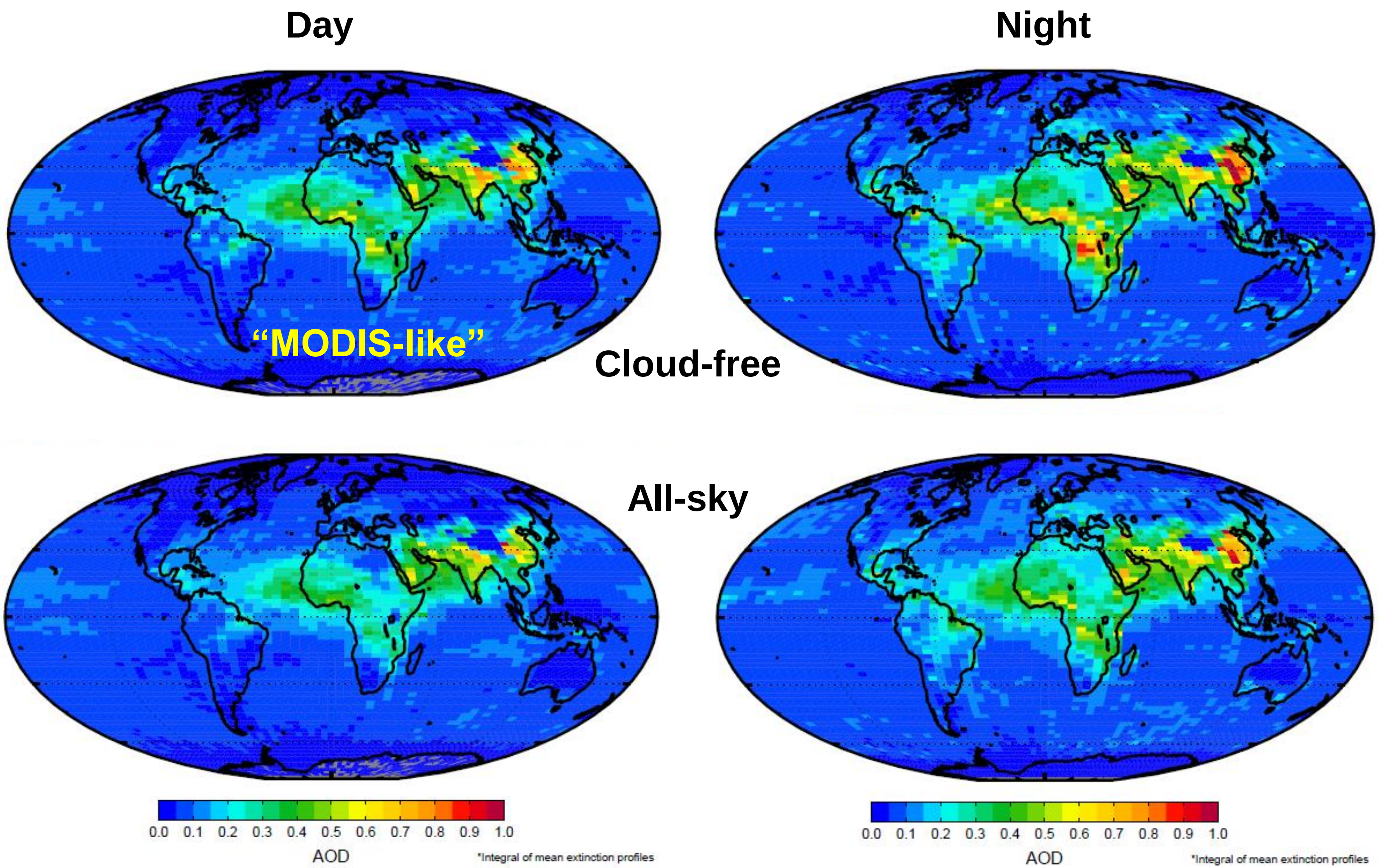
- But: limited to clear skies, usually ocean only
- Various assumptions made to extrapolate to global all-sky
  - Some studies assumed zero aerosol effect in cloudy skies

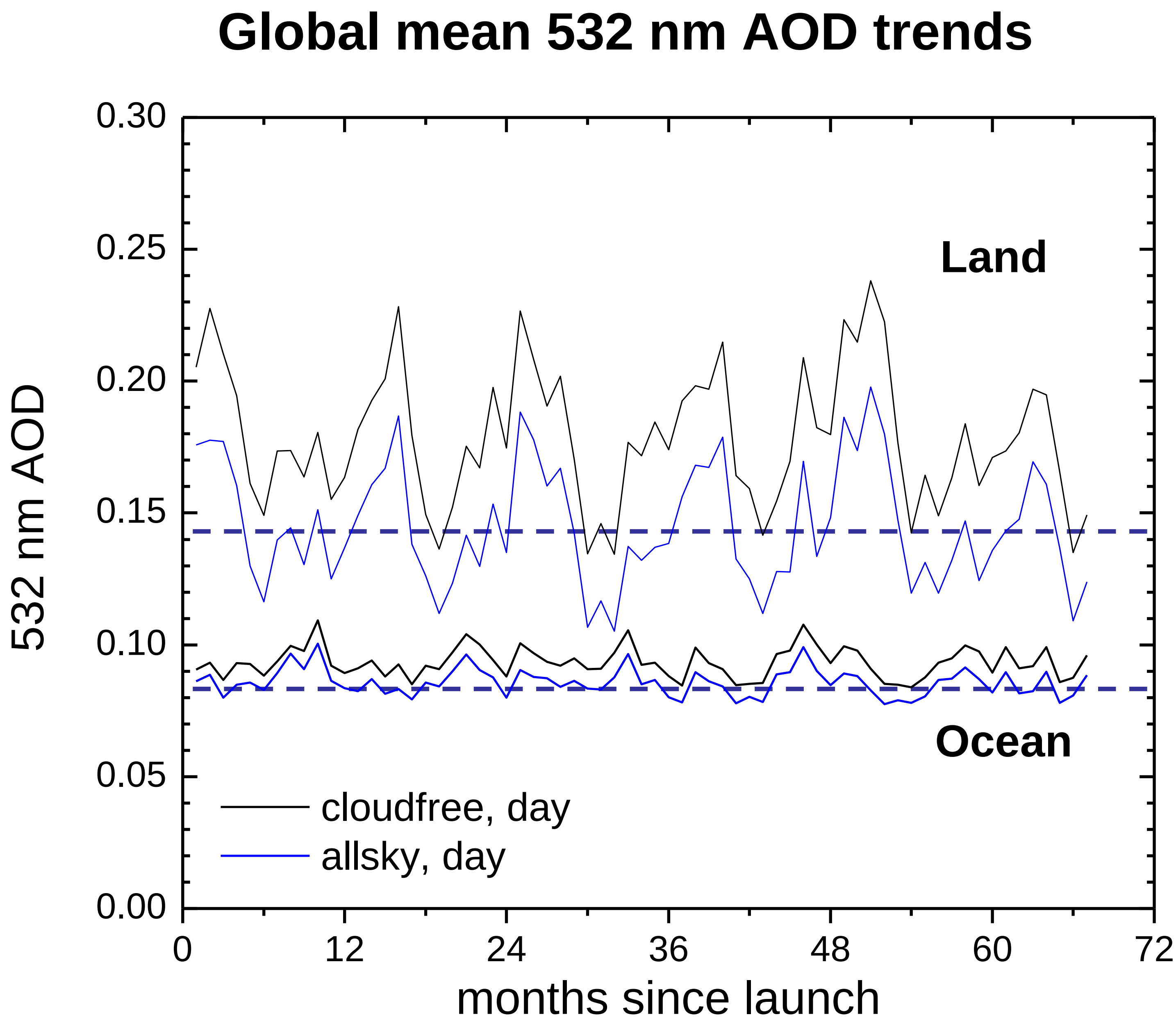
Now: new observing capabilities from CALIOP



2008 Annual Mean AOD from CALIOP

(Winker et al., ACPD, 2012)

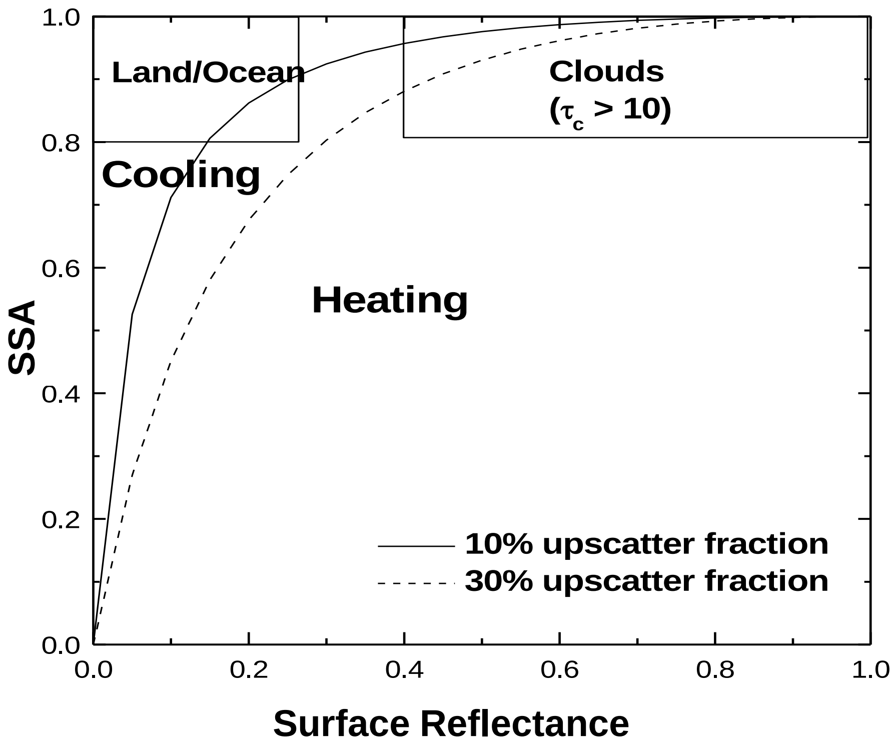


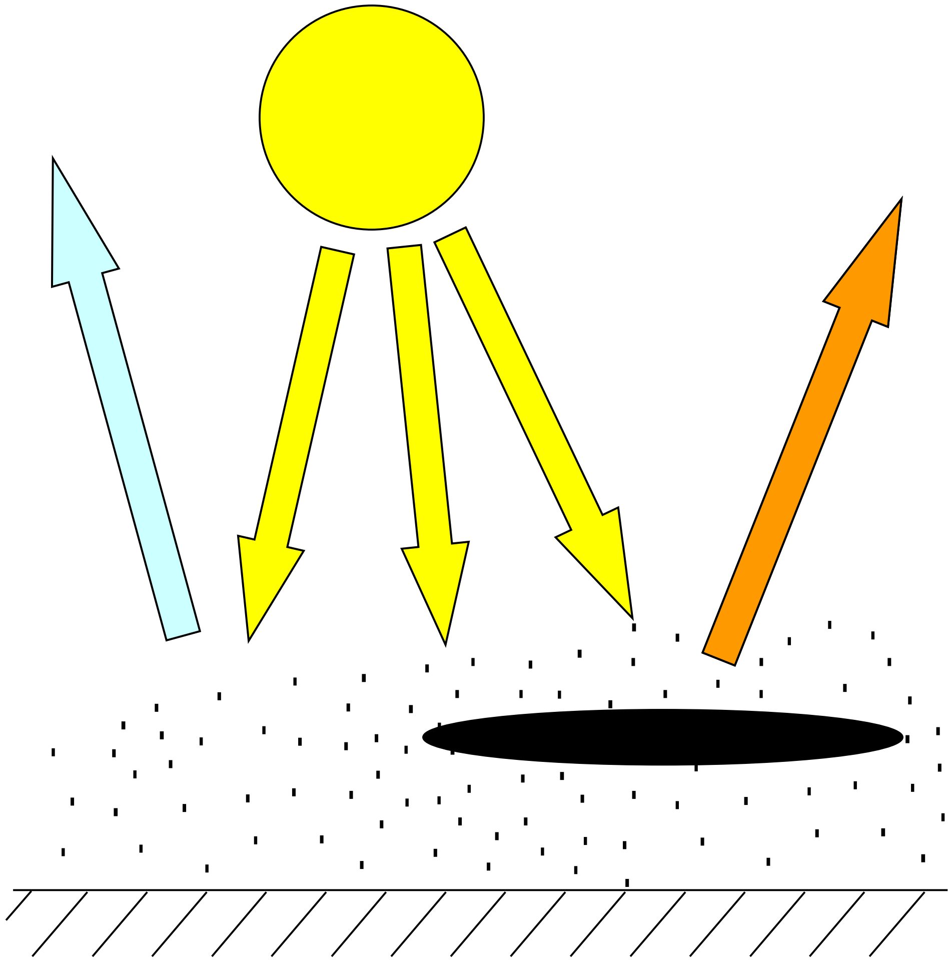

Global mean 532 nm AOD trends
Land
Ocean
cloudfree, day
allsky, day
532 nm AOD
months since launch
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
12
24
36
48
60
72

- Non-absorbing aerosol has a cooling effect
- But the effect of absorbing aerosol depends on the underlying albedo

(Chylek and Coakley, 1974)

Absorbing aerosol above cloud: more warming than when above ocean

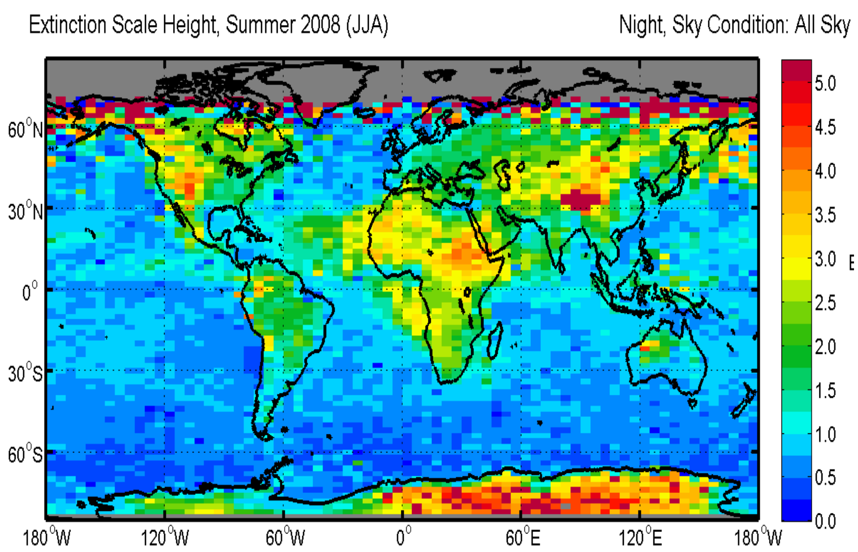


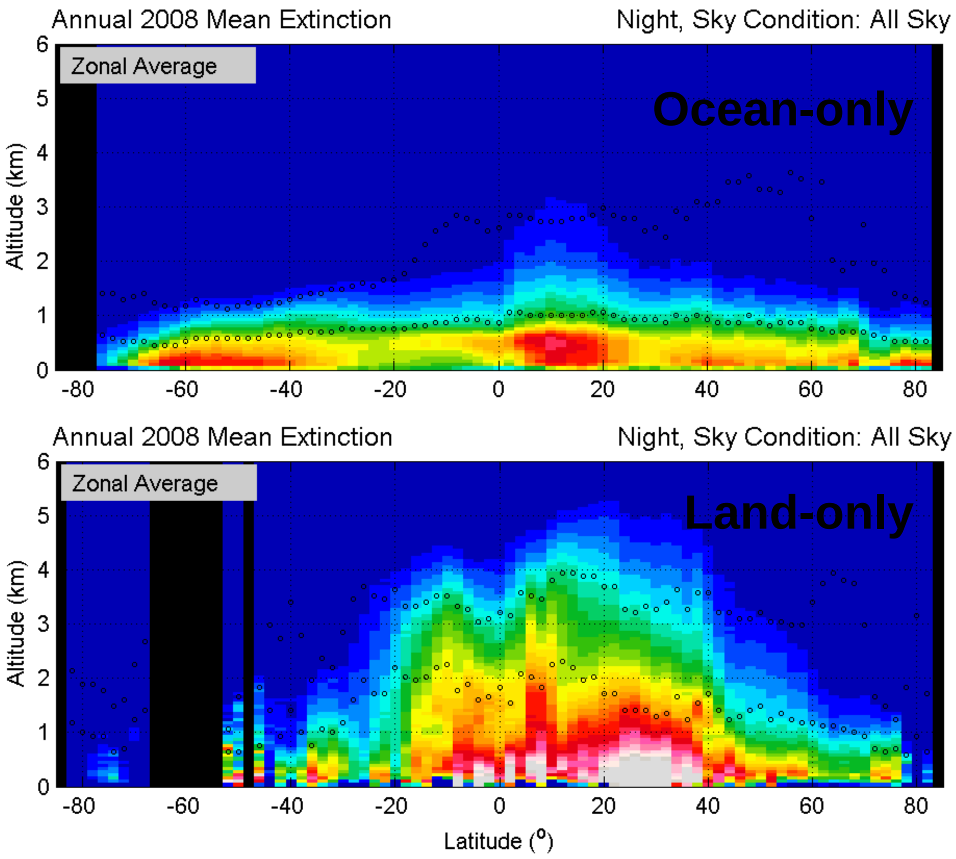


(Haywood and Shine, 1995)

- Aerosol radiative effects depend on the relative vertical locations of aerosol and cloud
- Now have observed profiles rather than model estimates

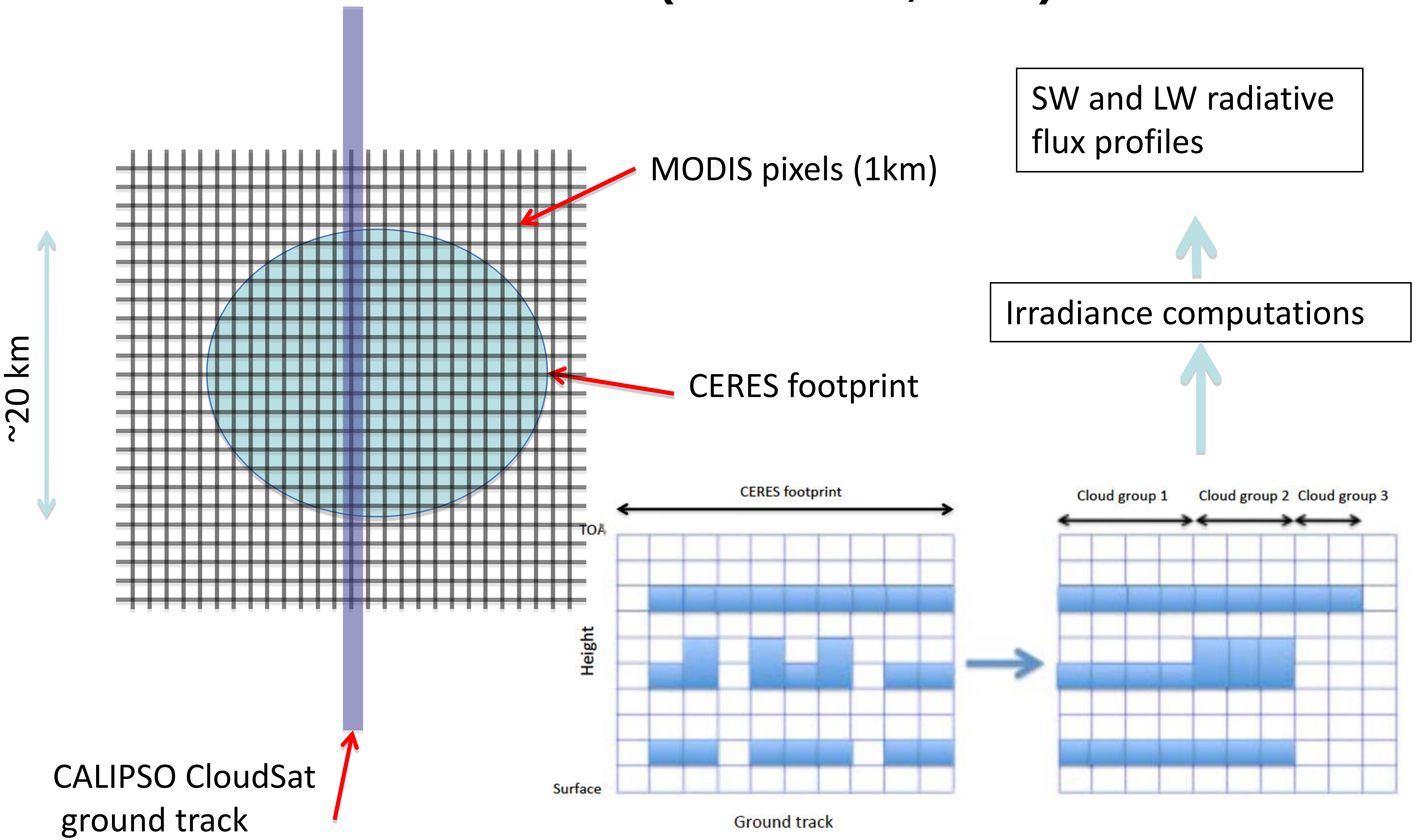
Extinction Scale Height





- To compute DRE, we need CALIOP profiles of 532 nm aerosol extinction, plus:
  - Aerosol single scatter albedo (SSA) and asymmetry parameter
  - Spectral dependence of aerosol optical properties
  - Cloud locations and height, cloud albedo
  - Spectral surface albedo
- We make use of the CERES-CALIPSO-CloudSat-MODIS (C3M) product (Kato et al., 2010)
  - CERES and MODIS data along the CALIPSO groundtrack merged with CALIOP and CPR profile data
  - C3M includes the necessary RT calculations to derive DRE

C3M Product (Kato et al., 2010)



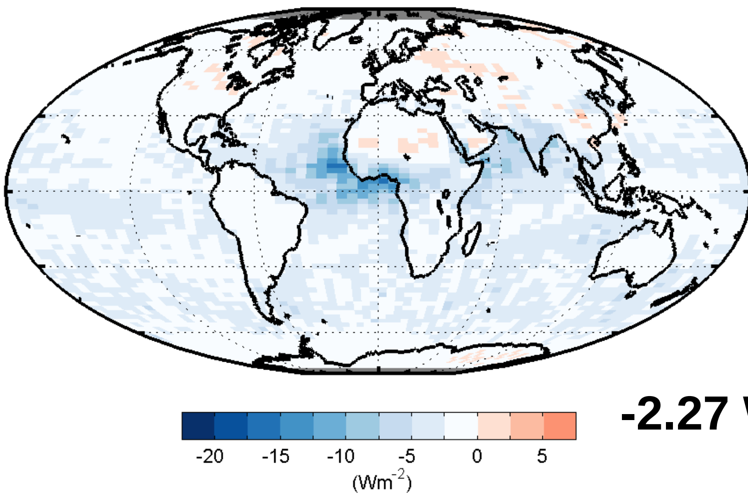
Horizontal resolution of CALIPSO and CloudSat products is maintained
- Similar cloud profiles grouped for the independent column approx

Method

- C3M TOA irradiance calculations based on :
  - CALIOP 532 nm aerosol extinction profiles
    - MATCH profiles used in columns with no CALIOP aerosol
    - MATCH assimilates MODIS AOD
  - Aerosol type from MATCH, except when CALIOP identifies Dust
  - Aerosol optical properties from OPAC
  - Cloud profiles and properties from:
    - CALIOP/CloudSat
    - MODIS
- Broadband RT calculations simulate up & down LW and SW fluxes using CALIPSO/CloudSat vertical structure above CERES footprints
- Instantaneous fluxes converted to diurnal averages using CERES angular distribution models (ADM’s)

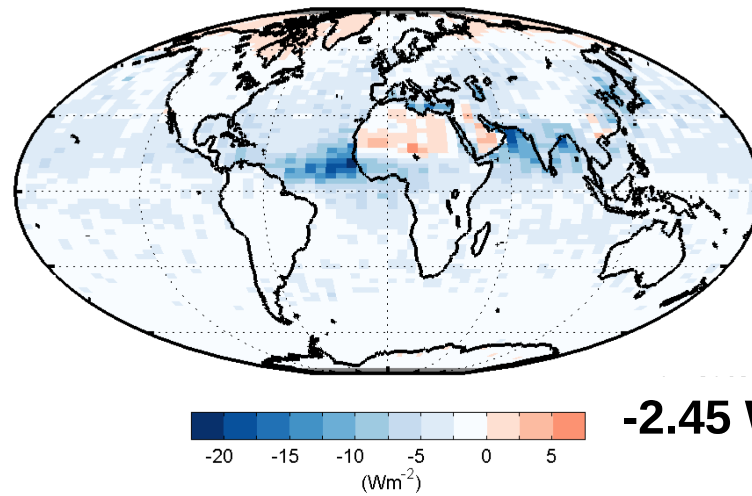
2008 Seasonal All-sky SW TOA DRE

DJF



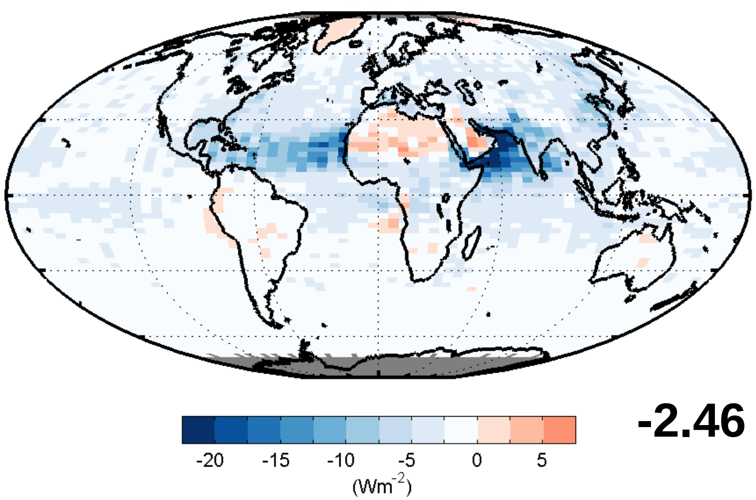
-2.27 W/m^2

MAM



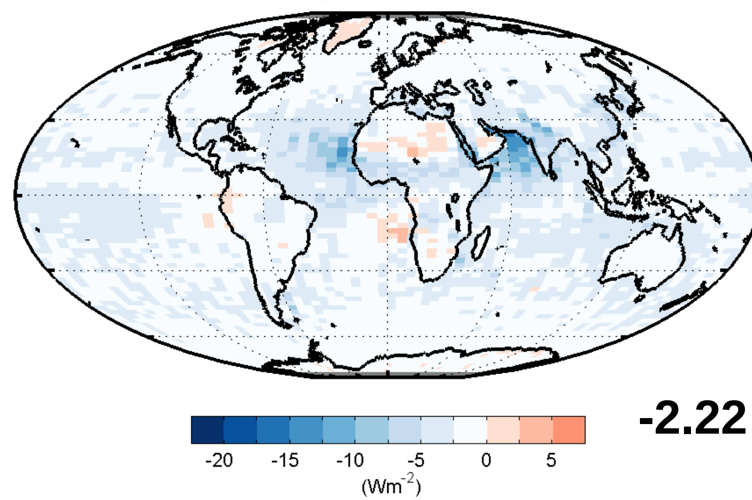
-2.45 W/m^2

JJA



-2.46 W/m^2

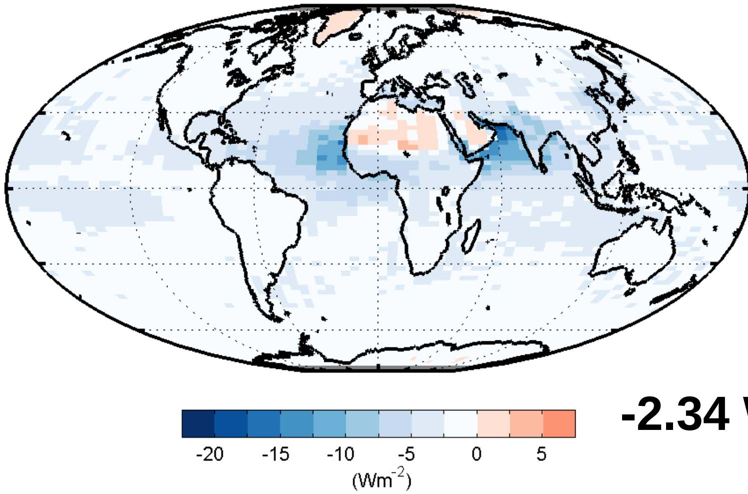
SON



-2.22 W/m^2

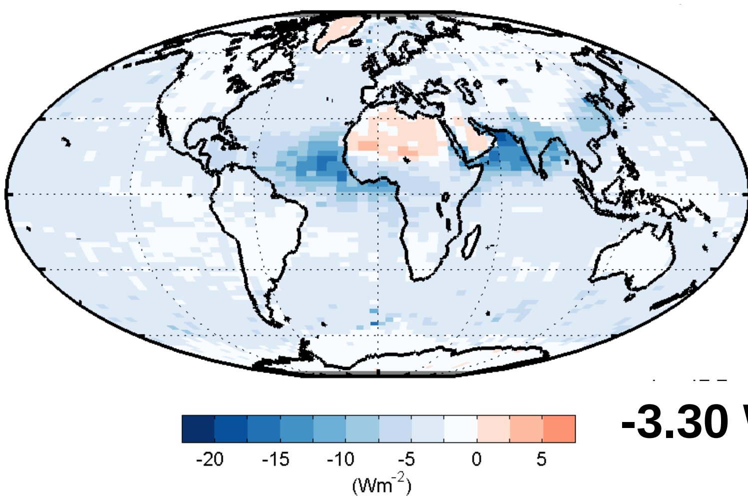
All-sky vs. Clear-sky

All-Sky Aerosol SW DRE



-2.34 W/m^2

Clear-Sky Aerosol SW DRE



-3.30 W/m^2

<u>2008 global annual mean</u>

all-sky	**- 2.34 W/m^2**
clear-sky	**- 3.30 W/m^2**
cloudy-sky	**-1.93 W/m^2**

$$DRE_{total} = (1 - A_c)\, DRE_{clr} + A_c\, DRE_{cldy}$$

$$A_c \sim 0.7$$

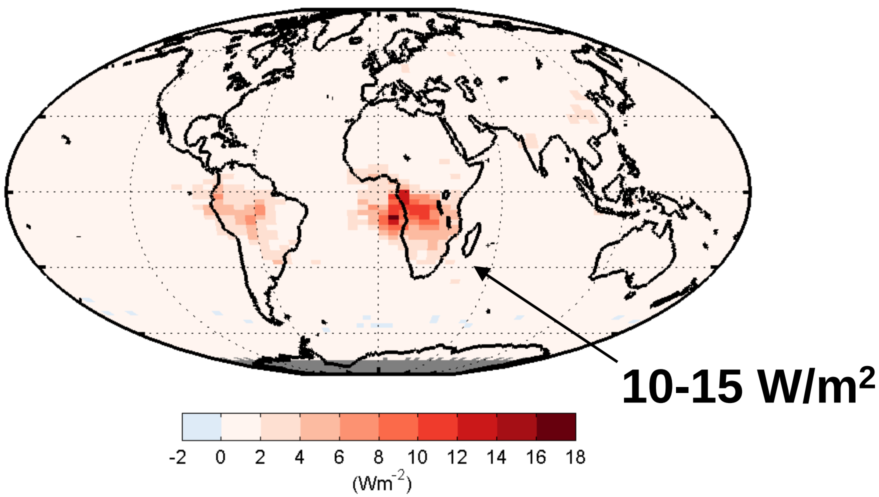
Uncertainties

- Clear-sky ocean DRE within ballpark of previous estimates
- Largest uncertainties probably related to:
  - Magnitude of AOD
    - CALIOP/C3M AOD somewhat less than MODIS Coll. 5
  - Aerosol absorption
    - C3M tends to have too little aerosol absorption

Initial sensitivity study:
SSA of smoke reduced by ~ 0.03

	All-sky TOA DRE (W/m^2) control	reduced ω_o
global	**-2.34**	**-2.06**
ocean	**-2.78**	**-2.57**

DRE difference, Aug 2008
(ω_o reduced − control)



Summary

All-sky CALIOP aerosol profiles offer the opportunity to reduce current uncertainties by quantifying aerosol radiative effects in cloudy skies

Next Steps

- Characterize uncertainties from C3M perturbation runs
  - Estimate DRE uncertainties, measurement requirements
- Compute additional radiation parameters:
  - DRE at surface, atmospheric heating
  - LW DRE
- Compare with other CALIOP-based results
  - Chand et al. (2009)
  - Oikawa et al. (2013)
  - Matus and L'Ecuyer (2015)