All-Sky Aerosol Radiative Effects

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Looking back

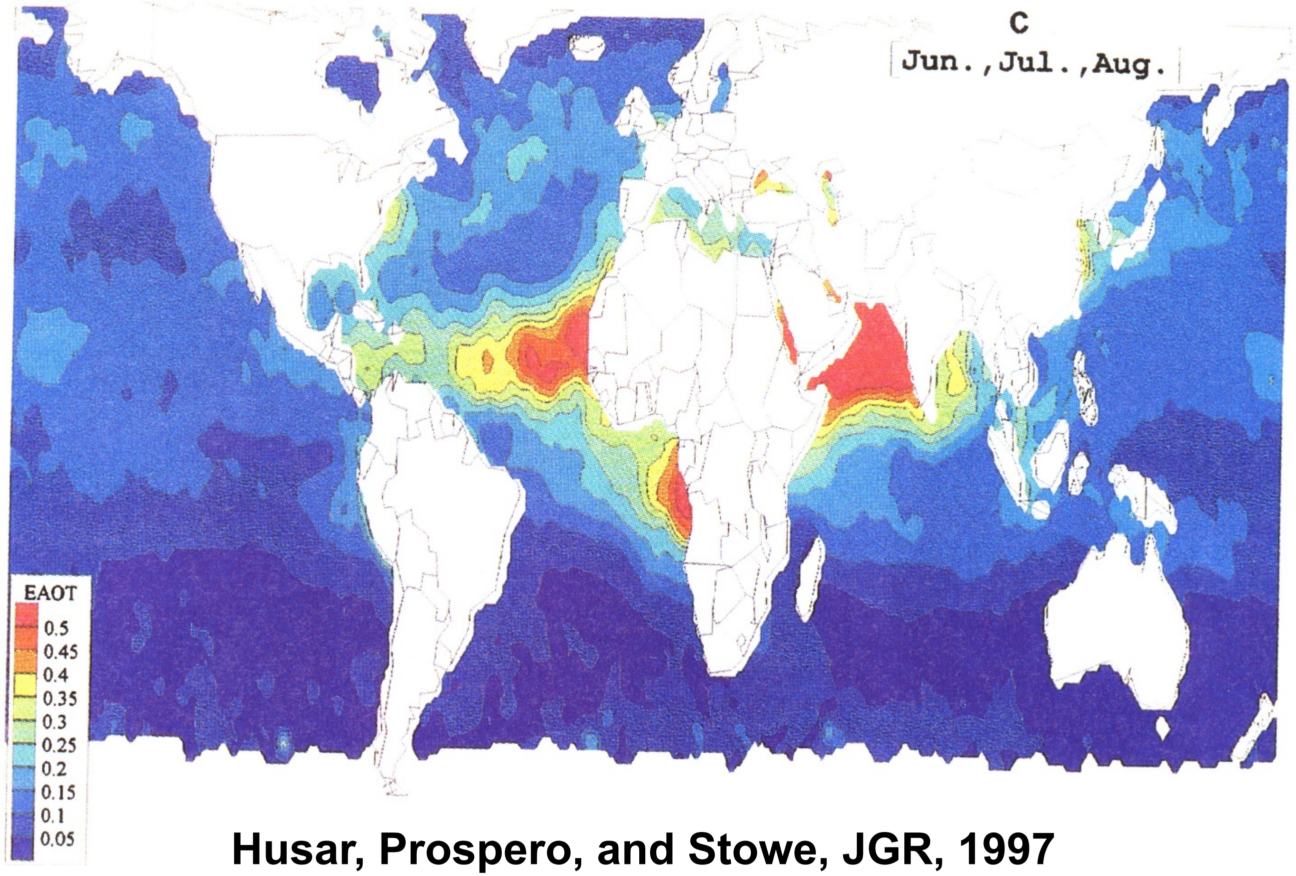
- 1990:
  - First IPCC climate assessment - 3 pages on aerosols
  - Years before the first satellite aerosol climatology
  - Some understanding of sulfate aerosol (from acid rain studies) but little understanding of loading and global distribution of other types

- 1994: LITE – first lidar observations from space

- Today:
  - MODIS, MISR, PARASOL, OMI, CALIOP, AIRS, SEVIRI, …
  - IPCC AR5: 30 pages on aerosol, just in Chapter 7

1997: First global maps

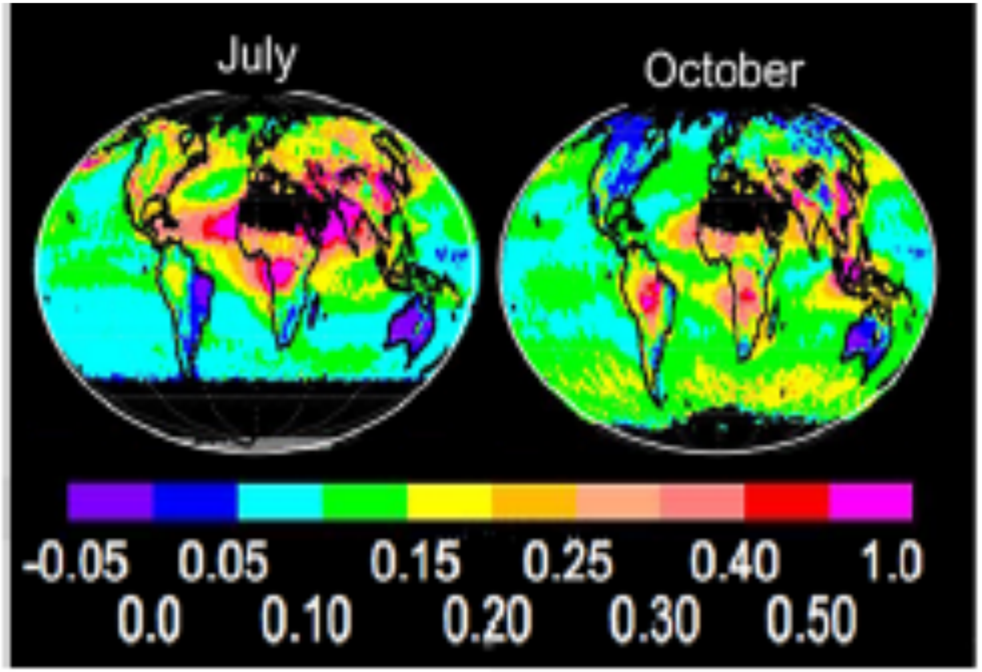
16,892 HUSAR ET AL: AEROSOLS OVER OCEANS WITH AVHRR



Husar, Prospero, and Stowe, JGR, 1997

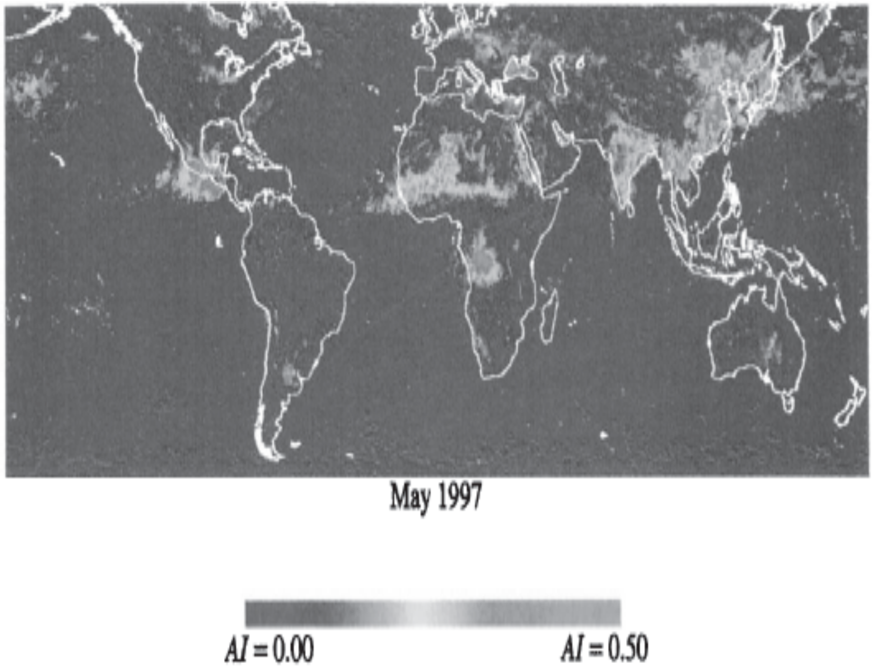
Circa 2000: AOD over land

MODIS



(Remer et al. 2005)

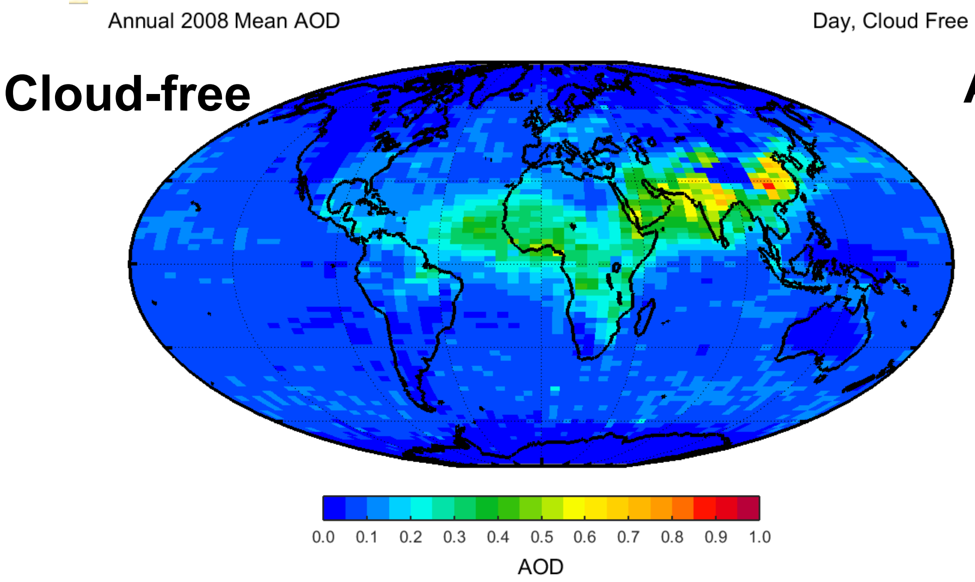
POLDER

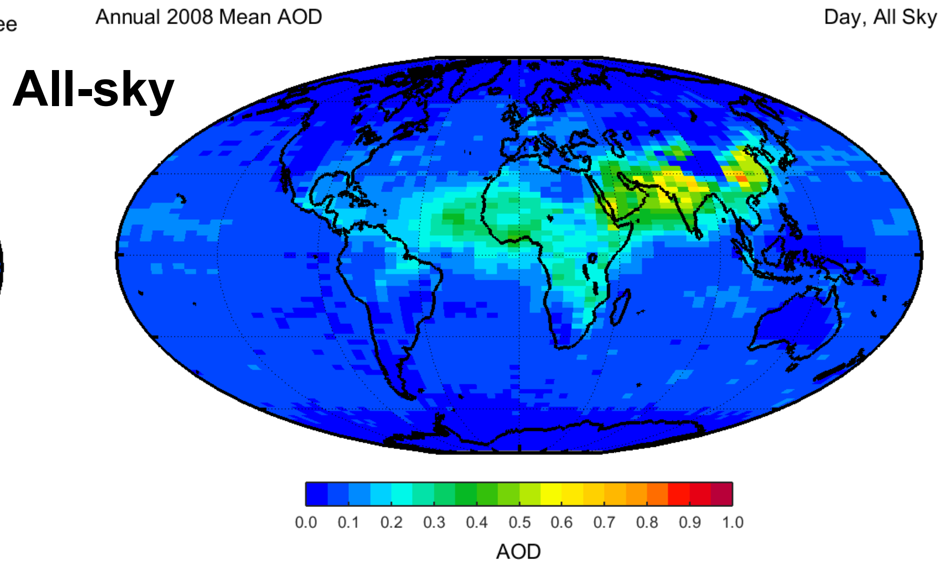


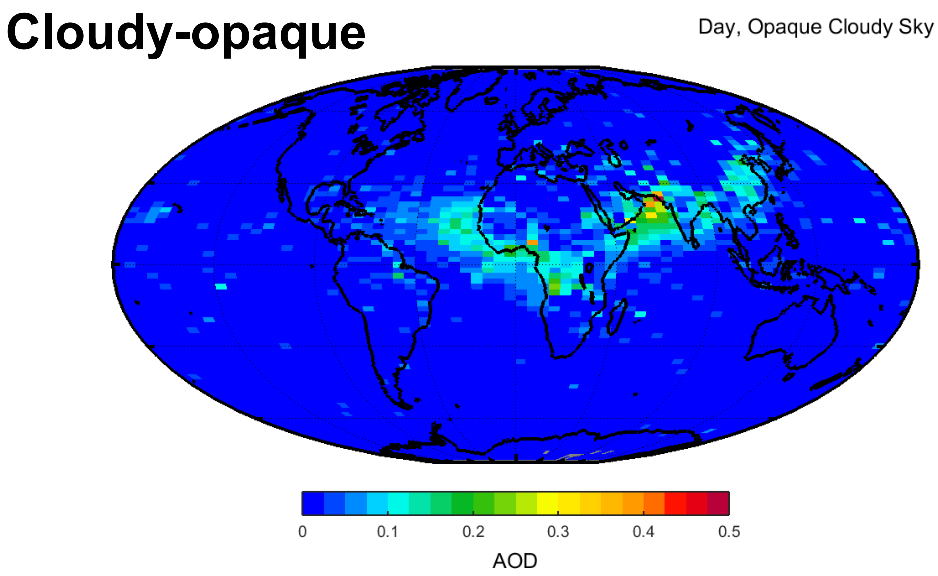
(Deuzé et al. 2001)

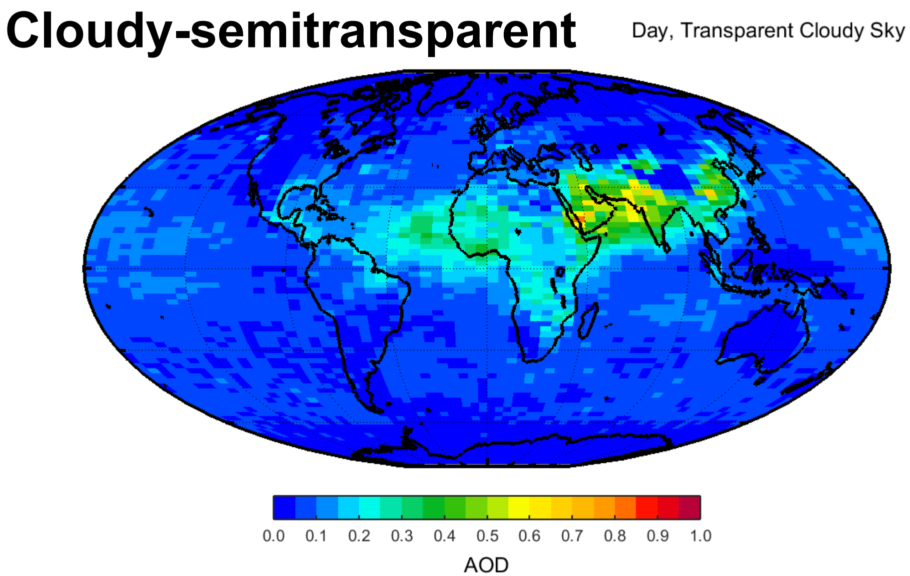
Annual mean AOD

(from CALIOP V3 Level 3 product)





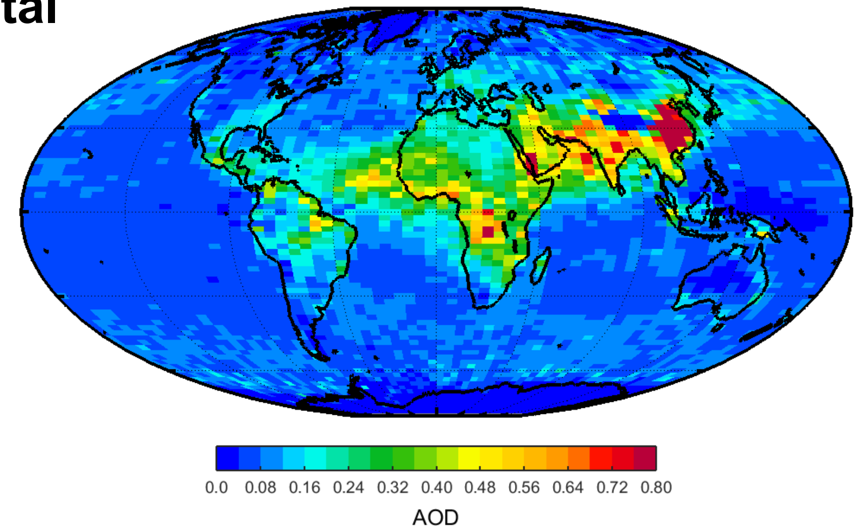




Aerosol Species
(annual mean, cloud-free)

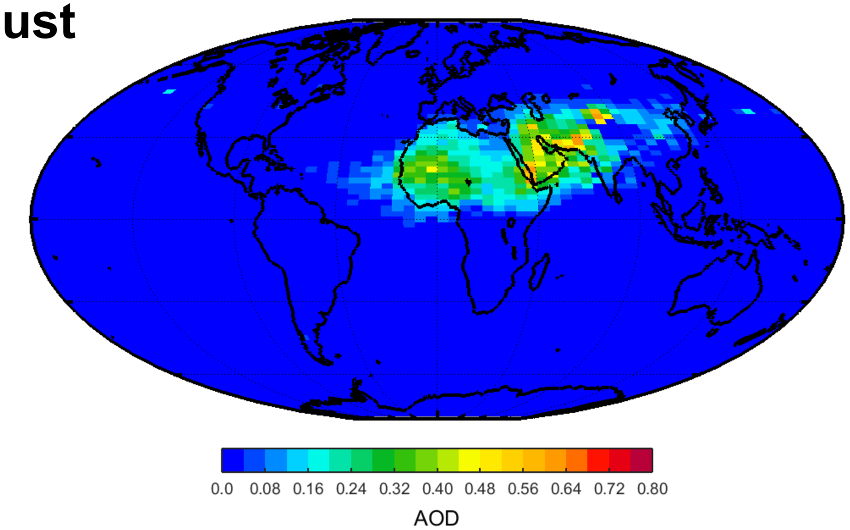
Annual 2008 Mean AOD Night, Cloud Free

Total



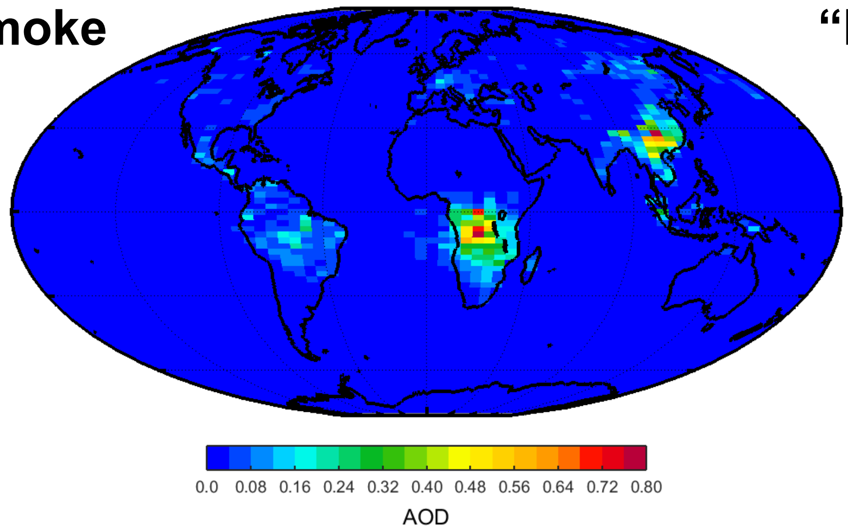
Annual 2008 Mean Dust AOD Night, Cloud Free

Dust



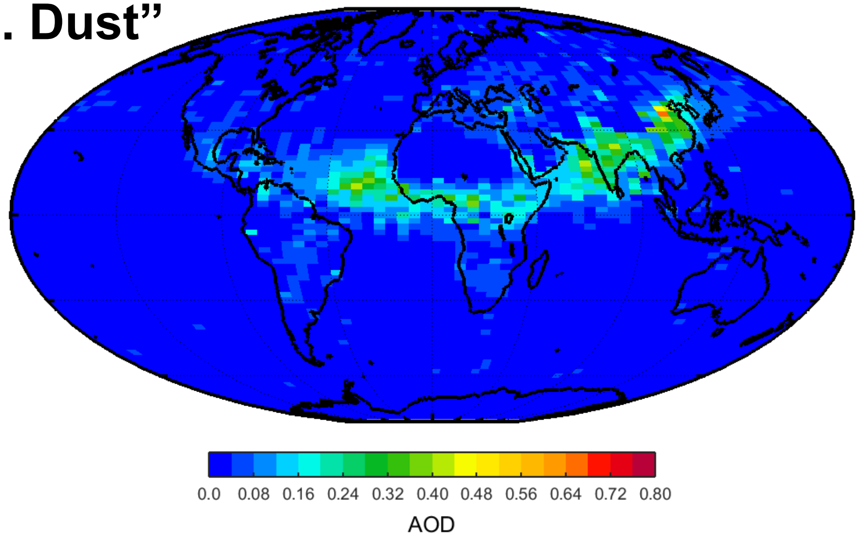
Annual 2008 Mean Smoke AOD Night, Cloud Free

Smoke



Annual 2008 Mean Polluted Dust AOD Night, Cloud Free

“Poll. Dust”



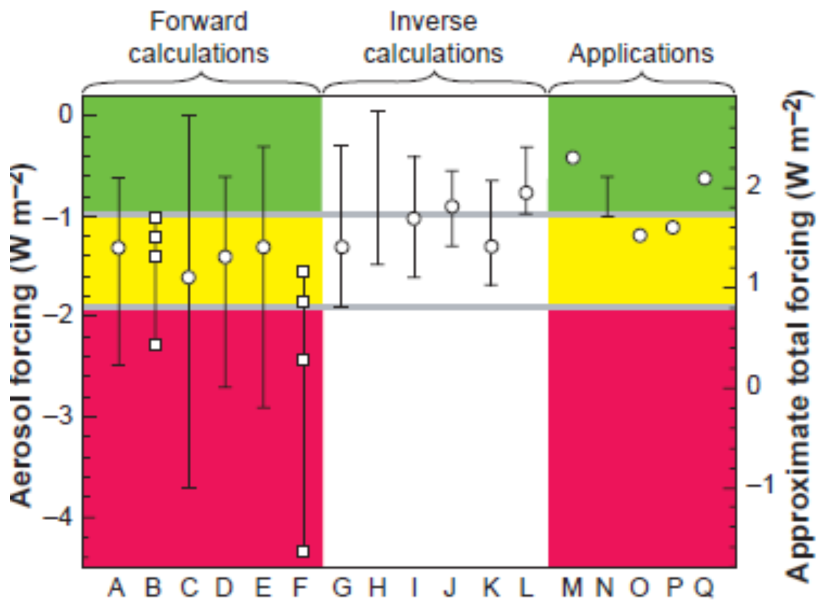
Models vs. Observations

Observation-based estimates are systematically larger than model-based estimates

But:

•Observation-based estimates from passive sensors are clear-sky only

•Models are poor at simulating cloud cover, and the relative vertical locations of aerosol and cloud



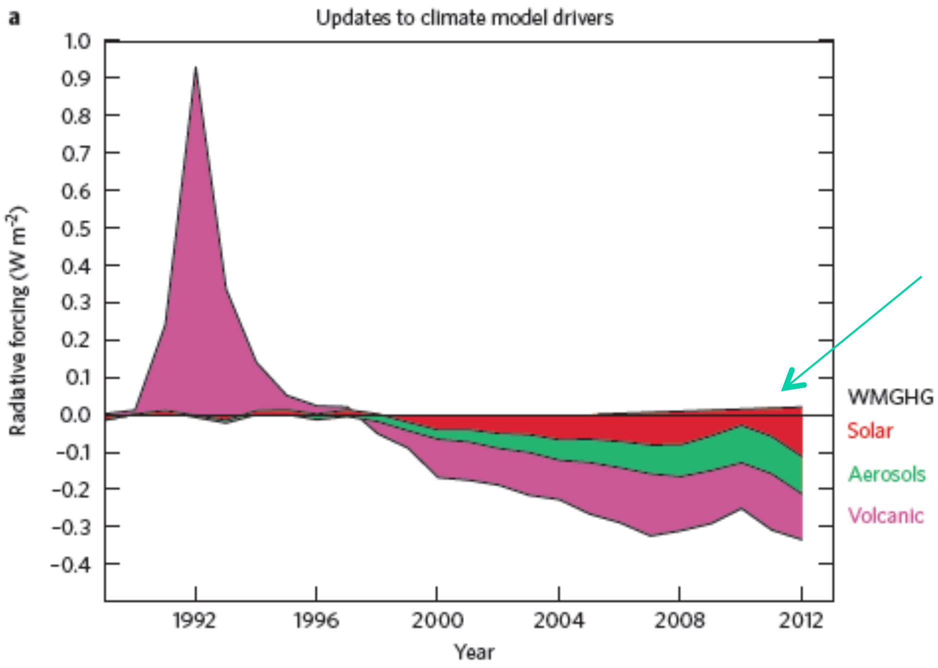
(Anderson et al, Science, 2003)

- *"A recurring question is whether current aerosol models adequately cover the full range of uncertainties" in aerosol radiative forcing*
  - Samset, Myhre, and Schulz, Nat Clim Chng, 2014

Reconciling warming trends

Gavin A. Schmidt, Drew T. Shindell and Kostas Tsigaridis

(Nat Geo, March 2014)

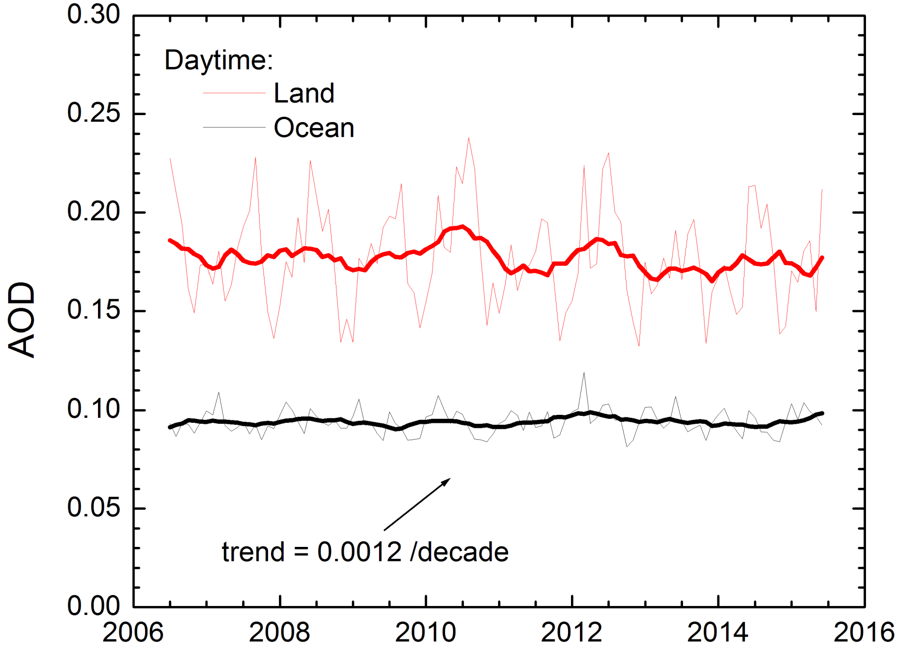


Poses simple explanation for ¾ of the 'hiatus':

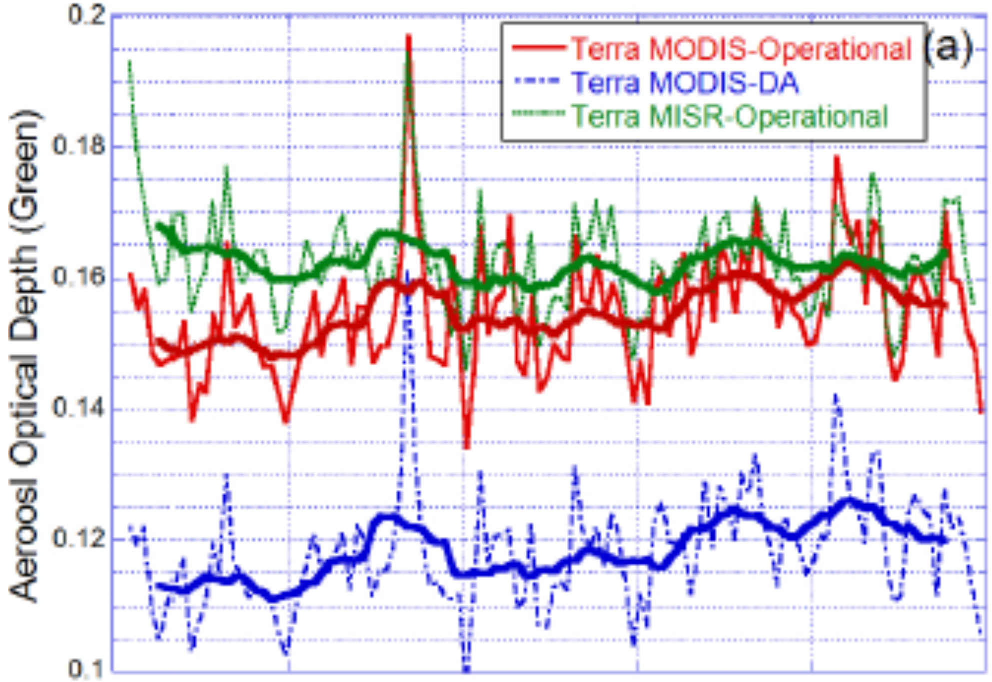
- Solar irradiance and ENSO phasing (1/7)
- Volcanic aerosol (1/3)
- Tropospheric aerosol (1/4)

Attribution of 'hiatus' ?

CALIOP Level 3 AOD



MODIS, MISR: global ocean



(Zhang and Reid, ACP, 2010)

Aerosol DRE

- Aerosol Direct Radiative Effect (DRE)
  - Net radiative perturbation at TOA from the total aerosol (natural + anthropogenic) relative to an aerosol-free atmosphere

DRE = F(AOD) – F(AOD = 0),   F = upward SW flux at TOA

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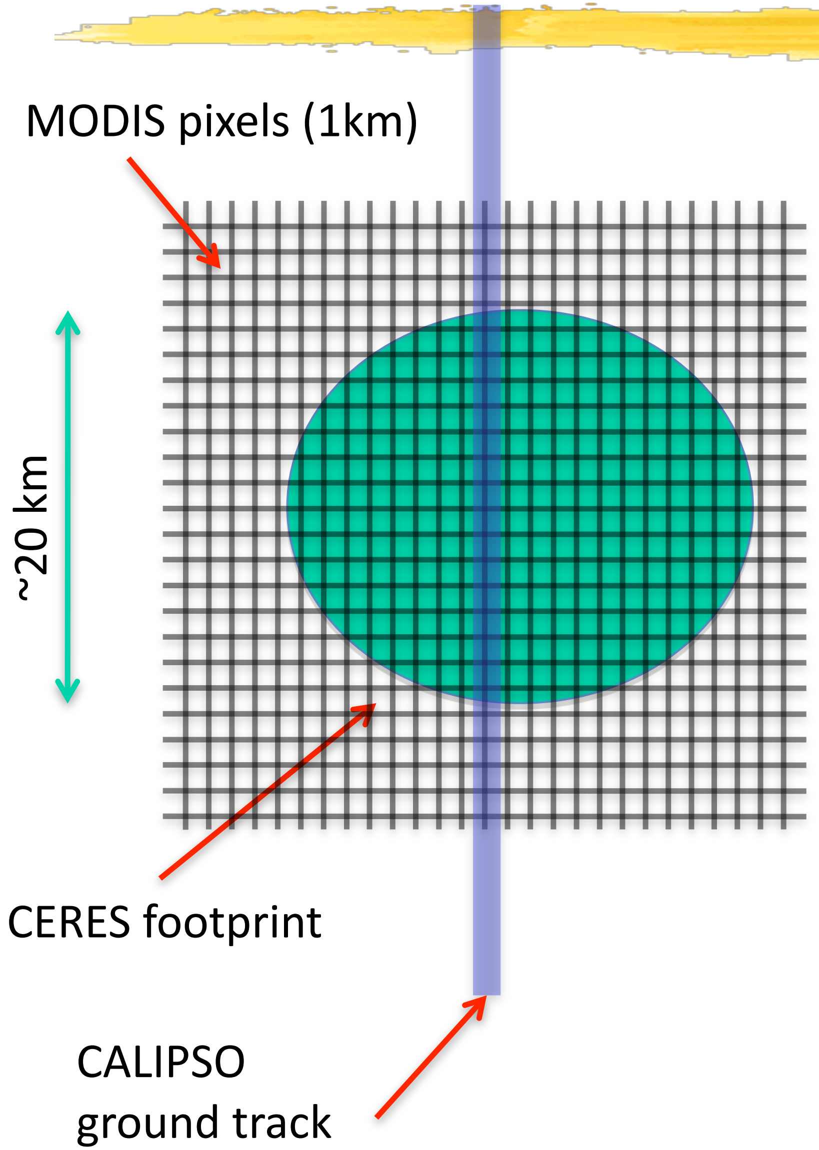
- Have been many observation-based global estimates
  - Most using MODIS (Loeb & Smith, 2005; Yu et al, 2006; Remer and Kaufman, 2006; Bellouin et al. 2005, 2008; etc.)
    - ✓ clear-sky only
    - ✓ Often ocean-only
    - ✓ Often assumed that cloudy-sky DRE = 0
  - Only a few based on CALIOP (Oikawa et al., 2013; Matus et al., 2015)
    - ✓ methodologies not mature yet

C3M Product
(CERES, CALIPSO, CloudSat, MODIS)

C3M provides <u>broadband radiative fluxes</u> along the CALIPSO ground-track based on merged A-train data sets



Aerosol & cloud profiles
TOA radiative fluxes
Spectral surface albedo

↓

Radiative transfer calculations → Irradiance

↓

Instantaneous → Diurnal mean

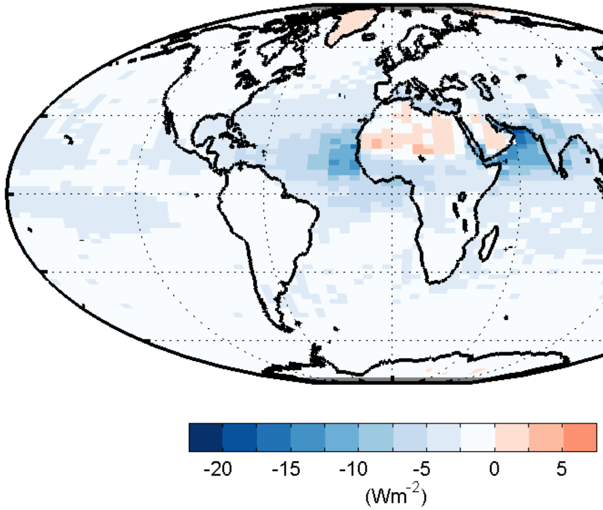
↓

SW and LW radiative flux profiles

(Kato et al., 2010)

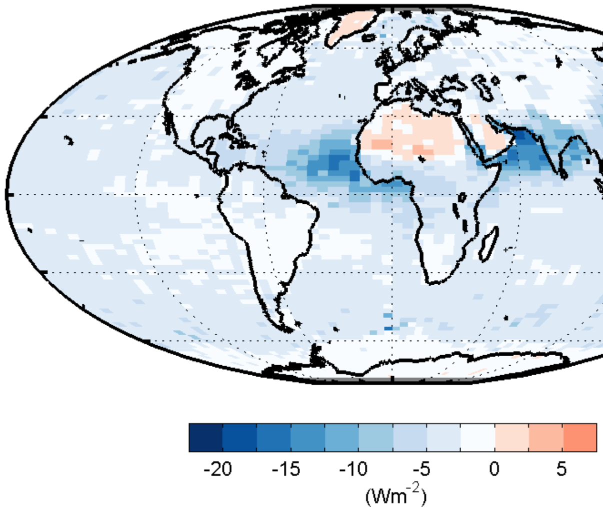
C3M results: closer to model estimates

All-Sky Aerosol SW DRE



-2.34 W/m^2

Clear-Sky Aerosol SW DRE



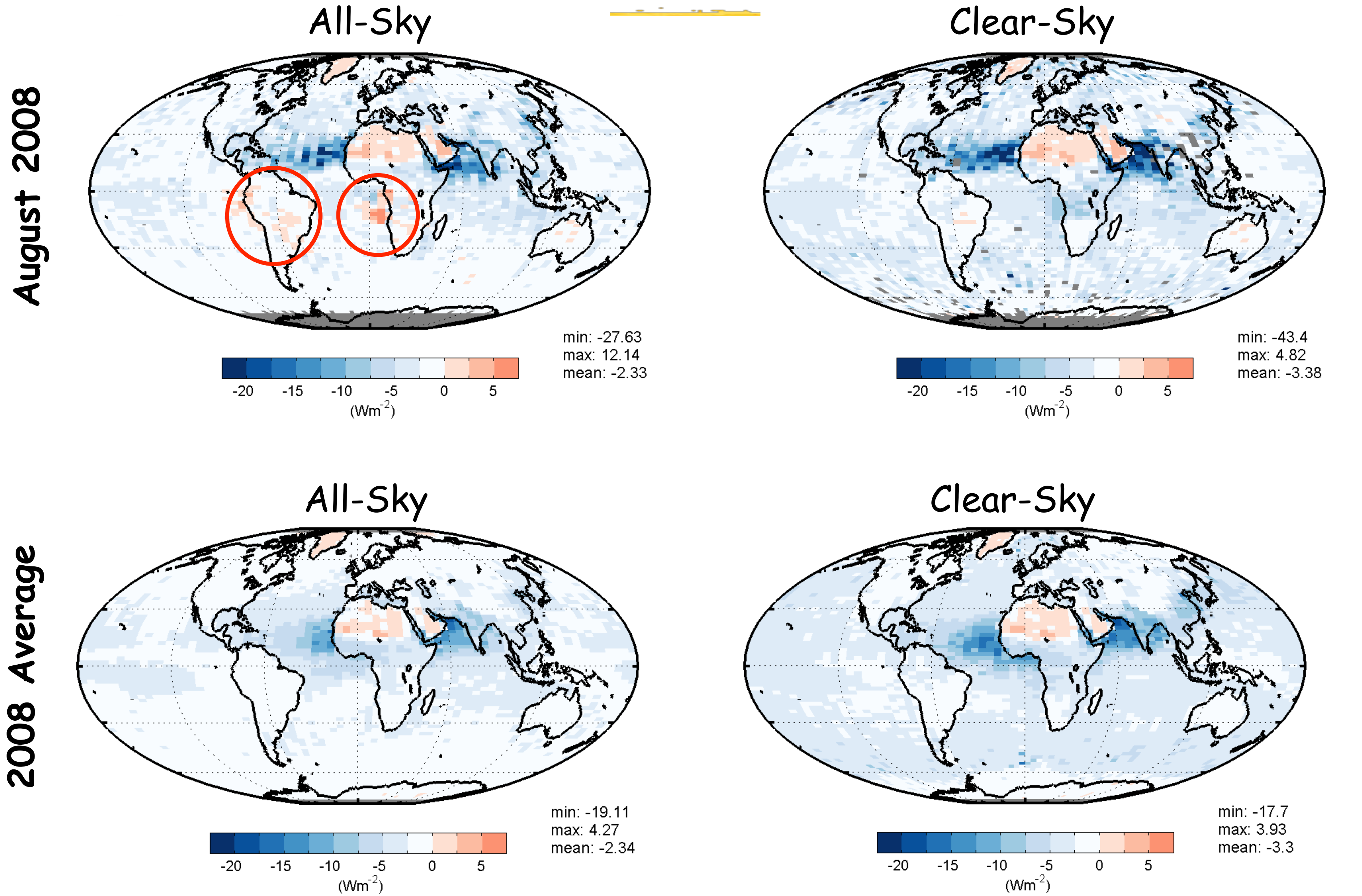
-3.30 W/m^2

<u>2008 global annual mean</u>

all-sky - 2.34 W/m^2

clear-sky - 3.30 W/m^2

2008 seasonal all-sky DRE = -2.22 W/m^2 to -2.46 W/m^2



August 2008
All-Sky
min: -27.63
max: 12.14
mean: -2.33
-20 -15 -10 -5 0 5
(Wm-2)
Clear-Sky
min: -43.4
max: 4.82
mean: -3.38
-20 -15 -10 -5 0 5
(Wm-2)
2008 Average
All-Sky
min: -19.11
max: 4.27
mean: -2.34
-20 -15 -10 -5 0 5
(Wm-2)
Clear-Sky
min: -17.7
max: 3.93
mean: -3.3
-20 -15 -10 -5 0 5
(Wm-2)

	Clear-sky Ocean DRE (W/m^2)
CALIOP & C3M	-3.94 (2008 mean)
Yu et al., 2006	-5.5
Remer and Kaufman, 2006	-5.0 to - 5.5
Loeb and Smith, 2005	- 5.46 (MODIS-ST) - 3.8 (NOAA)
	Global Clear-sky
CALIOP & C3M	-3.30
Aerocom (global models)	-3.3

- C3M clear-sky DRE within ballpark of previous estimates
- MODIS > CALIOP

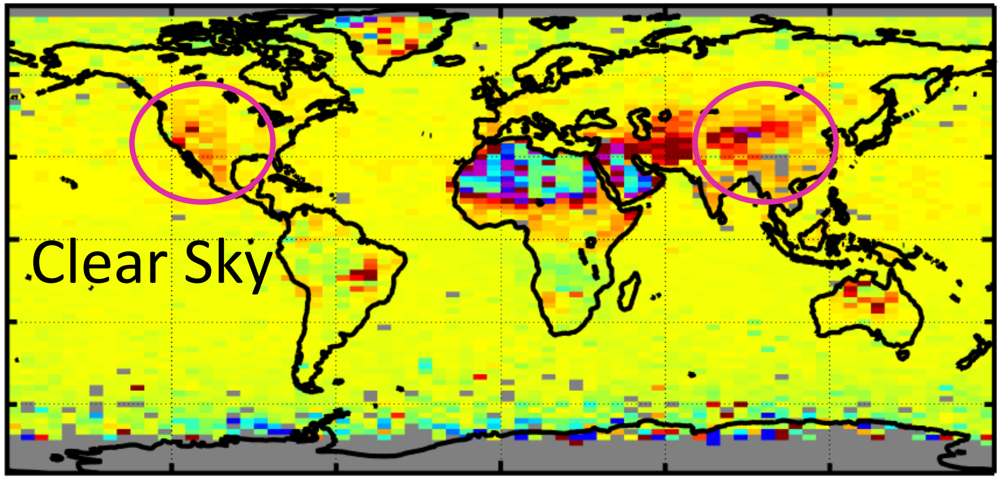
Clear-sky AOD

	CALIOP	MODIS C5
Ocean	0.093	0.13
Land	0.18	0.19

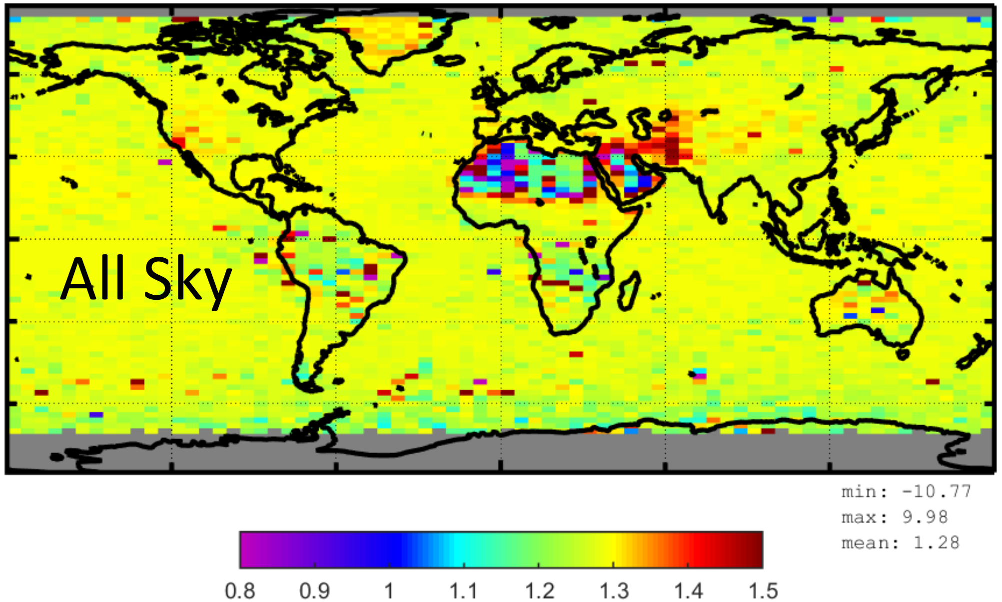
(Winker et al. ACP, 2013)

Uncertainties due to AOD

August 2008: DRE (1.3 x AOD) / DRE (control)



Mean Aug 2008 All-Sky TOA Aerosol Direct Radiative Forcing ($\Delta F^{allSky}_{daily}$) Modified/Control



Difference between CALIOP and MODIS clear-sky DRE is explained by differences in AOD

Scale CALIOP AOD to MODIS:

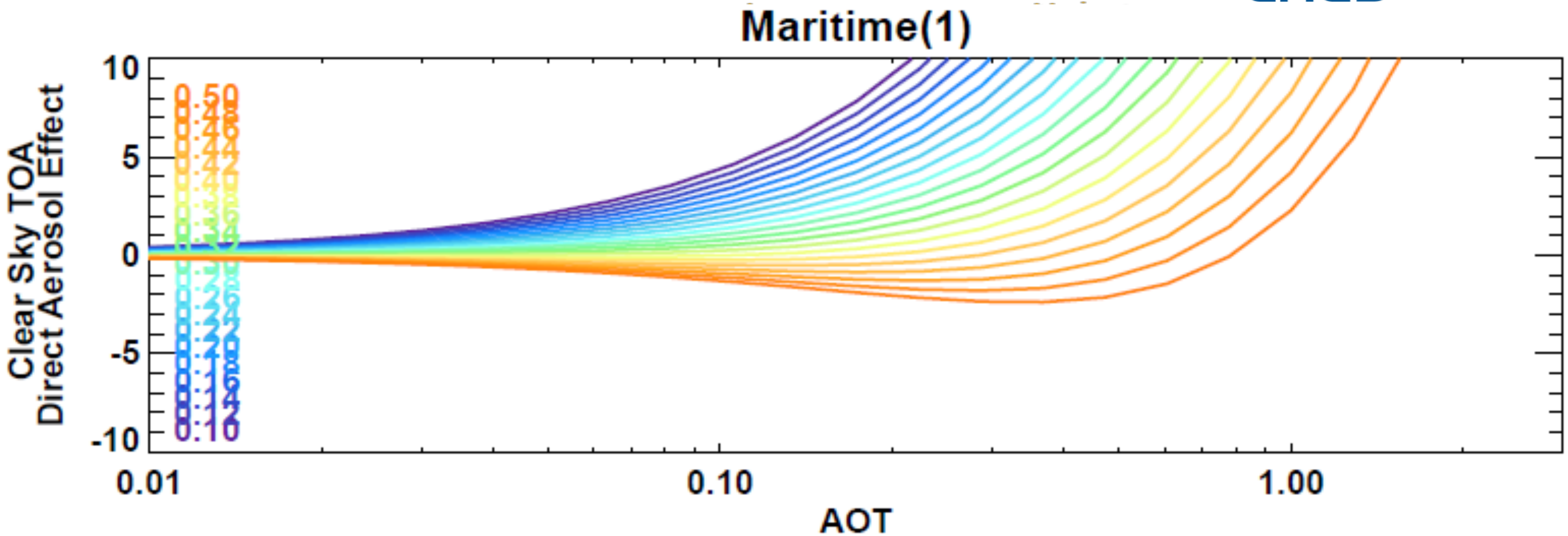
DRE (W/m^2)

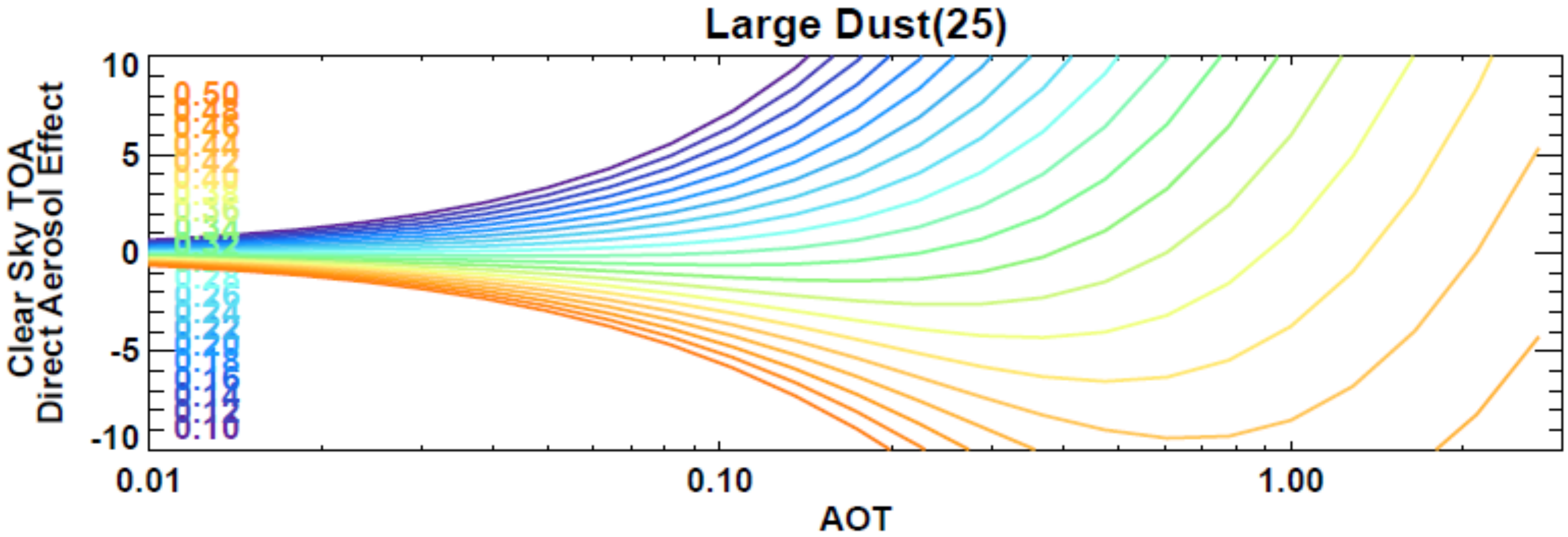
Global:	Control	1.3 x AOD
Clear-sky	-3.44	-4.44
All-sky	-2.18	-2.81

Global mean DRE change ~ 30%

Regional deviations depend on:
- surface albedo
- cloud cover
- aerosol type (absorption)

Clear Sky DRE: scaling with AOD





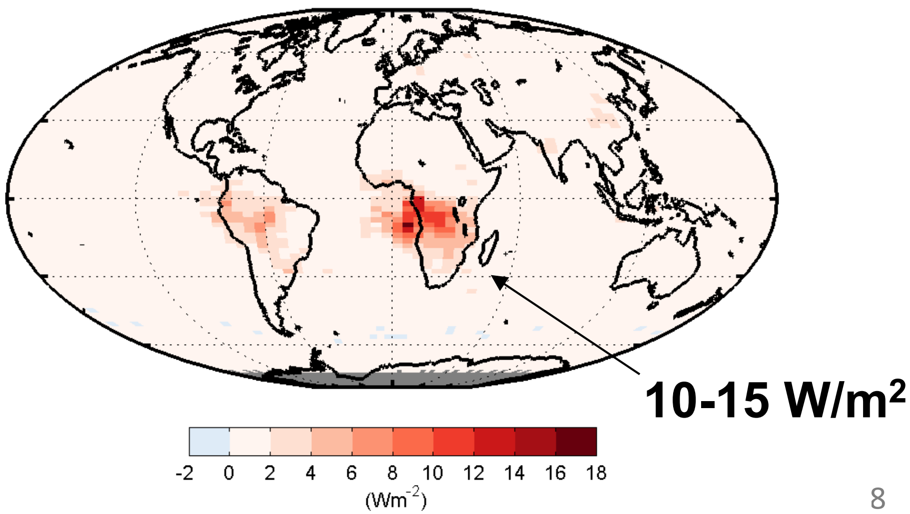
Uncertainties due to aerosol absorption

- Smoke in C3M tends to have too little absorption
- Performed a sensitivity experiment: modify optical properties of smoke to make absorption more realistic
- Produced regional aerosol warming of as much as 15 W/m^2
- Global mean DRE reduced by about 0.25 W/m^2
- Can use this method to define measurement requirements for aerosol absorption and optical depth

Initial sensitivity study:
SSA of smoke reduced by ~ 0.03

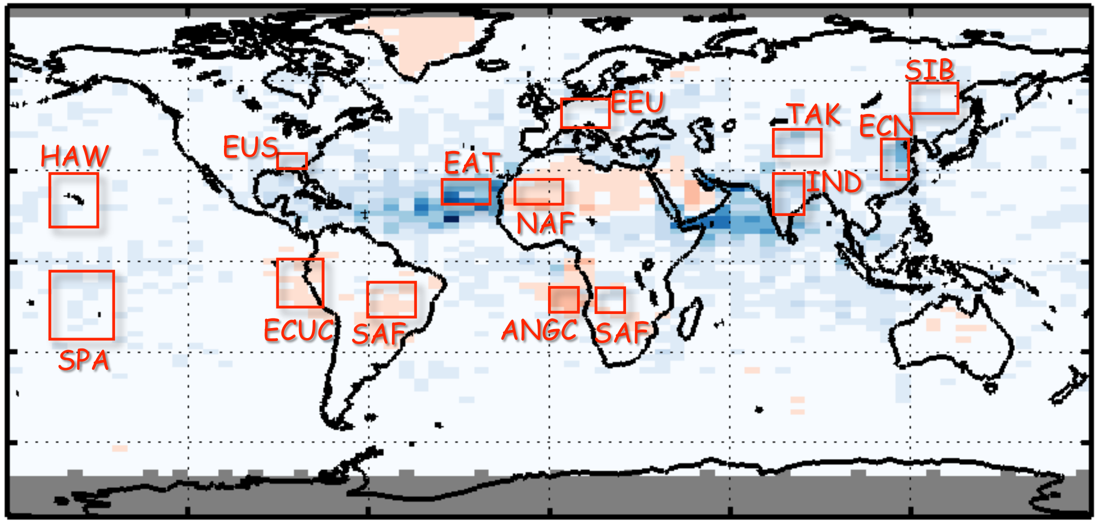
	All-sky TOA DRE (W/m^2) control	reduced ω_o
global	-2.34	-2.06
ocean	-2.78	-2.57

DRE difference, Aug 2008
(ω_o reduced − control)

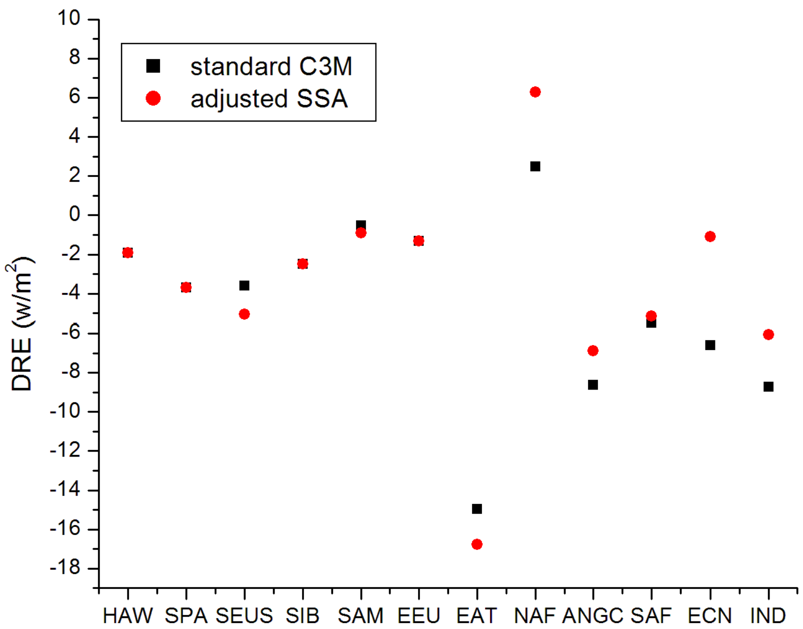


Relation of clear-sky to cloudy-sky aerosol forcing

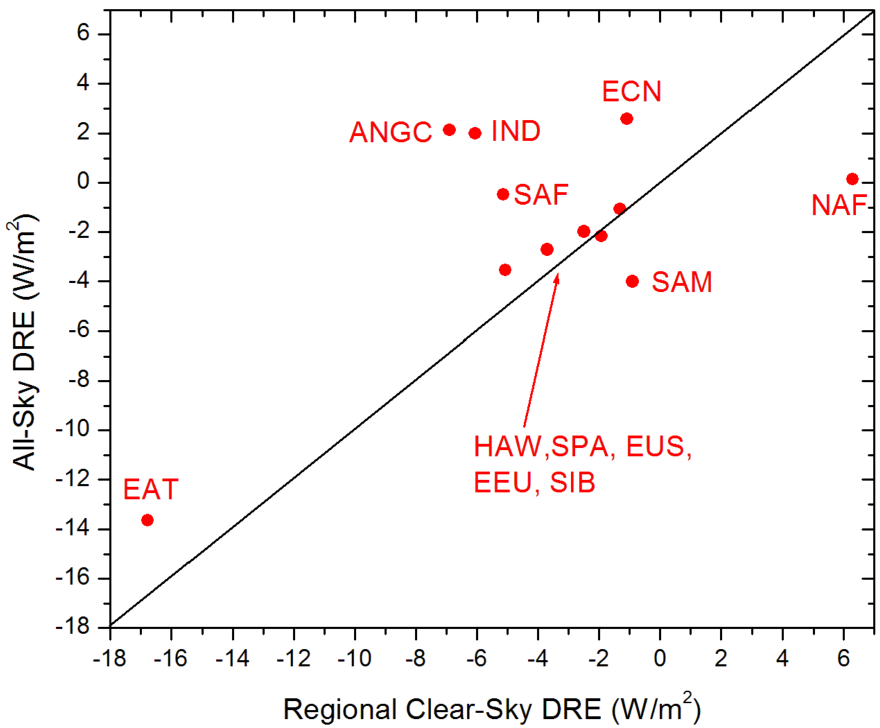
Mean Aug 2008 All-Sky TOA Aerosol Direct Radiative Forcing ($F^{SW}_{\uparrow,cld+aer} - F^{SW}_{\uparrow,cld}$)



Clear-sky Regional DRE



all-sky vs. clear-sky DRE



Several CALIOP-based estimates …
all different

	Clear-Sky Ocean	Clear-Sky	All-Sky
C3M	-3.94	-3.3	-2.34
Oikawa et al (2013)	-4.24	-3.79	---
Matus et al (2015)	-2.6	-2.6	-1.9

	Data Sources	Aerosol Type	Aerosol Optics
C3M	CALIOP-V3, MODIS-CERES CERES ADM	MATCH CALIOP	OPAC (modified)
Oikawa	CALIOP-V2, MODIS-ST	CALIOP	CALIOP
Matus	FLXHR-lidar (Geoprof-lidar, MODIS 2B-TAU)	CALIOP	CALIOP

Where do we need to go?

- Improve methodologies for CALIOP-based methods
- Current AOD estimates not accurate enough to sufficiently constrain aerosol DRE
  - Current passive retrievals:
    - multiple issues related to cloud masking
    - Calibration drifts difficult to remove
  - CALIOP:
    - Standard products underestimate AOD in many (not all) places, mostly due to layer detection issues
      - opaque-cloud retrievals help (Lui et al., 2015; Kacenelenbogen, ..)
    - Extinction/AOD are rather imprecise – uncertainties are largest in the boundary layer
- Other issues:
  - Aerosol absorption
  - Aerosol type (constraining optical models)
  - Anthropogenic fraction