Intercomparison of global aerosol direct radiative effect estimates based on CALIOP

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Estimating aerosol direct radiative effect (DRE)

- **Models: ‘bottom-up approach’**
  - “Infinite” complexity in modeling ERFari from first principles
  - Multiple aerosol emissions sources, secondary production, aerosol nucleation, internal mixing, …

- **Observations: ‘top-down’ constraints**
  - circa 2005: MODIS
    - Clear-sky only, typically ocean-only
  - starting about 2010: CALIPSO
    - Global clear-sky, all-sky

Estimates based on MODIS

- **A number of MODIS-based estimates appeared, circa 2005**
  - Clear-sky only
  - Mostly ocean-only (retrievals over land more uncertain)

MODIS study	DRE (W/m^2)
Remer and Kaufman (2006)	-5.9
Bellouin et al. (2005)	-6.4
Loeb and Manalo-Smith (2005)	-5.5, -3.8
Zhang et al. (2005)	-5.3
Yu et al. (2003; 2004; 2006)	-5.7, -5.1, -5.5
Chou et al. (2002) (SeaWiFS)	-5.4

Global studies based on CALIOP

- **Oikawa, Nakajima, Inoue and Winker, 2013:** A study of the shortwave direct aerosol forcing using ESSP/CALIPSO observation and GCM simulation, JGR 118, 3687–3708, doi:10.1002/jgrd.50227
- **Henderson, L'Ecuyer, Stephens, Partain, and Sekiguchi, 2013:** A Multi-sensor Perspective on the Radiative Impacts of Clouds and Aerosols, JAMC 52, 853–871, doi:10.1175/JAMC-D-12-025.1.
- **Matus, L'Ecuyer, Kay, Hannay and Lamarque, 2015:** The Role of Clouds in Modulating Global Aerosol Direct Radiative Effects in Spaceborne Active Observations and the Community Earth System Model, J. Climate 28, 2986–3003, doi:10.1175/JCLI-D-14-00426.1
- **Oikawa, Nakajima and Winker, 2018:** An evaluation of the shortwave direct aerosol radiative forcing using CALIOP and MODIS observations, JGR 123, 1211–1233, doi:10.1002/2017JD027247.

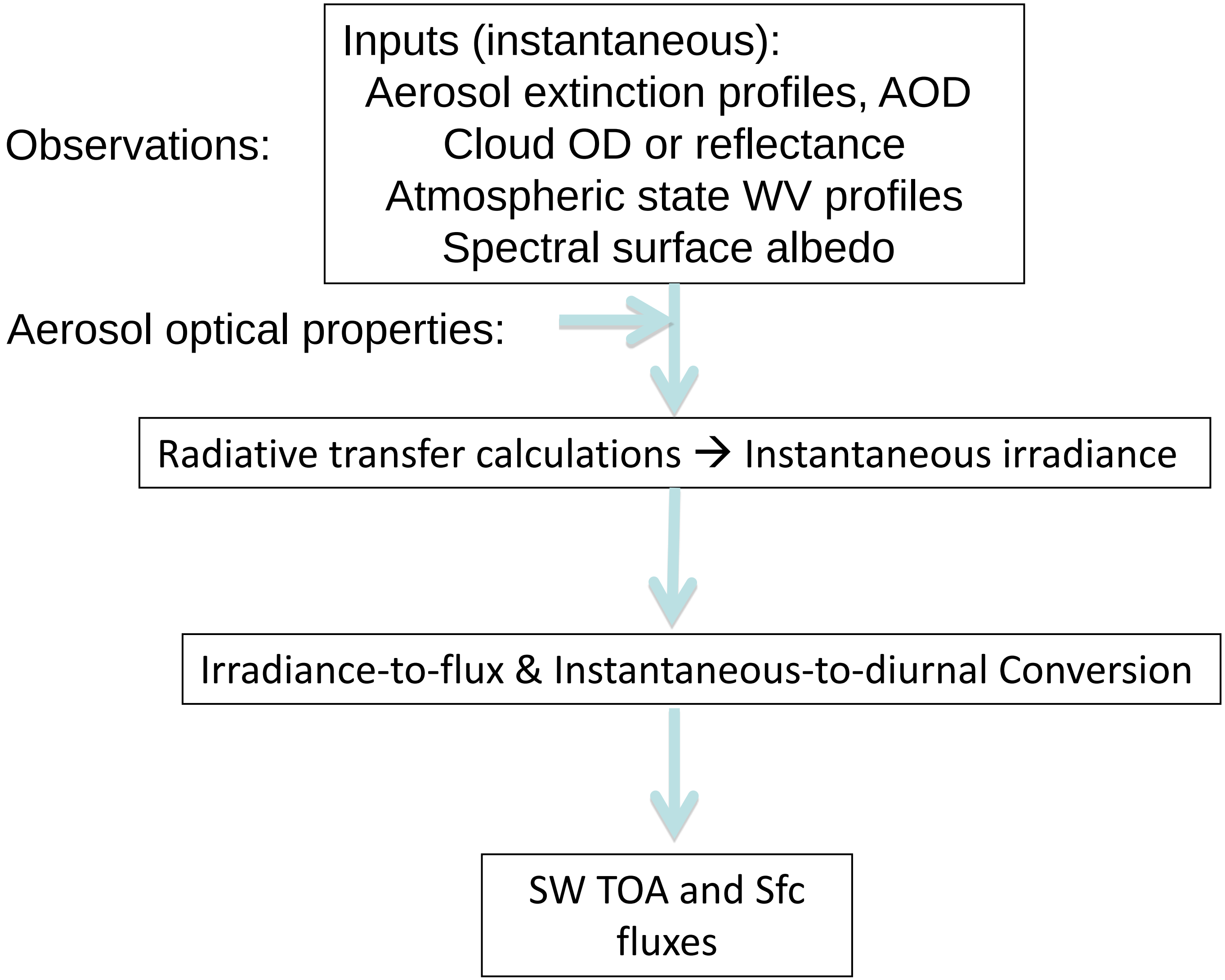
Summary of CALIOP-based Results

Global TOA SW DRE (W/m^2)

	Clear-sky	All-sky	Ratio of All/Clear
Oikawa, 2013	-2.9	-0.8	0.28
Oikawa, 2018	-3.7	-2.0	0.54
Henderson et al, 2013	-2.2	-1.6	0.73
Matus et al, 2015	-2.6	-1.9	0.73
Winker & Kato (C3M)	-3.3	-2.34	0.71

Computing RF_{ari} from Observations

The A-train provides most of the necessary quantities



Points of Difference

- **Data product used**
  - Oikawa et al: MODIS C5 and CALIPSO V2 (2013), V3 (2018)
  - Henderson et al: 2B-FLXHR; Matus et al: 2B-FLXHR-lidar
  - Winker and Kato: C3M
- **Temporal scale of observations**
  - Oikawa et al 2013, 2018: monthly averaged cloud/aerosol data
  - Others: instantaneous cloud/aerosol data
- **Conversion of Irradiance-to-flux & Instantaneous-to-diurnal**
  - Winker and Kato: CERES methodology
  - Others: use more approximate methods
- **Aerosol optical properties**
  - Oikawa et al., Henderson et al, Matus et al. all use CALIOP layer typing and absorption from CALIOP aerosol models
  - Winker and Kato:
    - combination of observed and modeled aerosol type classification
    - Optical properties from OPAC, except for dust

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  - Significant biases in AOD and low cloud fraction due to bug in Level 2 code
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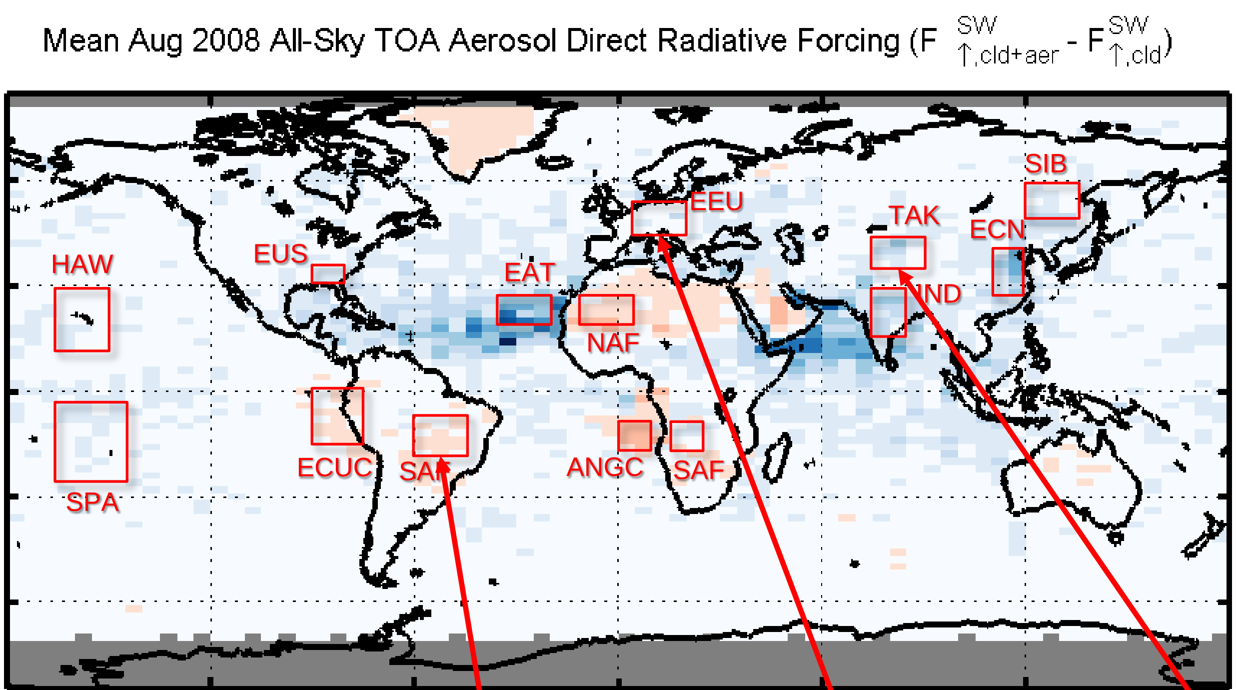
Aerosol optical properties

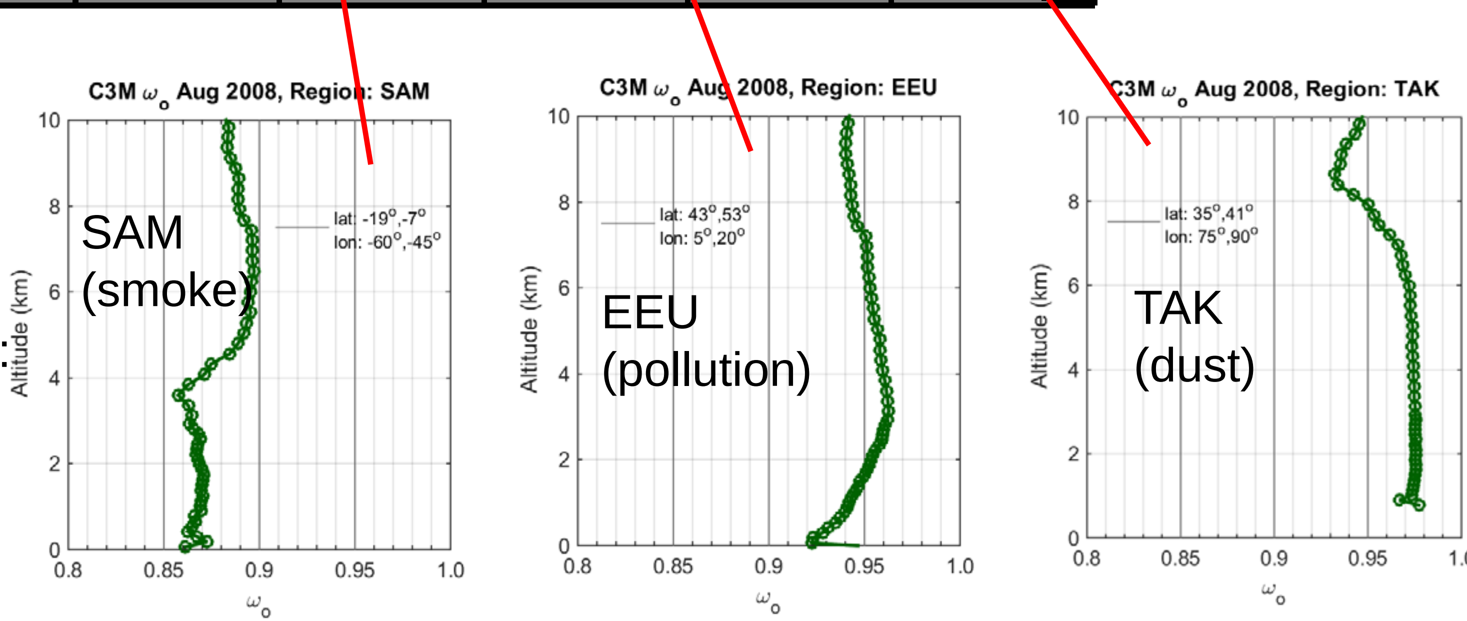
- **Matus and Oikawa**
  - both use aerosol type from CALIOP classification
- **Winker and Kato**
  - Take aerosol type from MATCH, unless CALIOP identifies dust

Aerosol SSA

	Matus et al, 2015	Oikawa et al, 2018	C3M
Marine	0.99	0.99	0.97- 0.985
Dust	0.99	0.92	0.98
Polluted Continental	0.96	0.93	0.98 - 0.94
Smoke	0.44	0.83	0.87- 0.97
Clean Continental	1.00	0.90	
Polluted Dust	0.96	0.85	

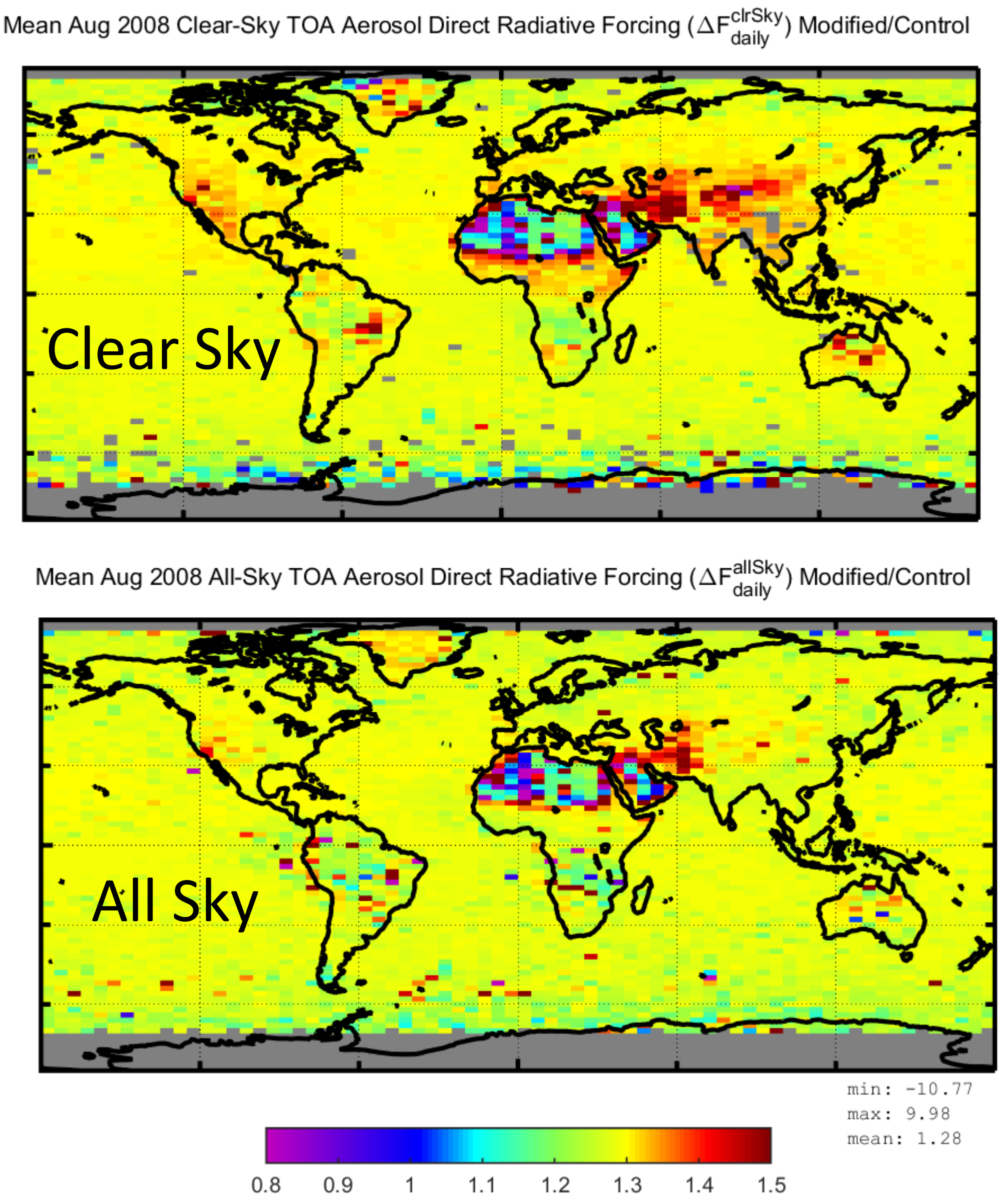


Regional SSA profiles used in C3M:



C3M_regionalSSA_05-Jun-2012.ppt

CALIPSO-based vs MODIS-based Results: AOD biases



CALIOP global AOD is about 30% lower than MODIS C6

Effect of 30% AOD increase

DRE (1.3 x AOD) / DRE (control)

	DRE (W/m^2)	
	C3M	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)

Isn't DRE linear in AOD?

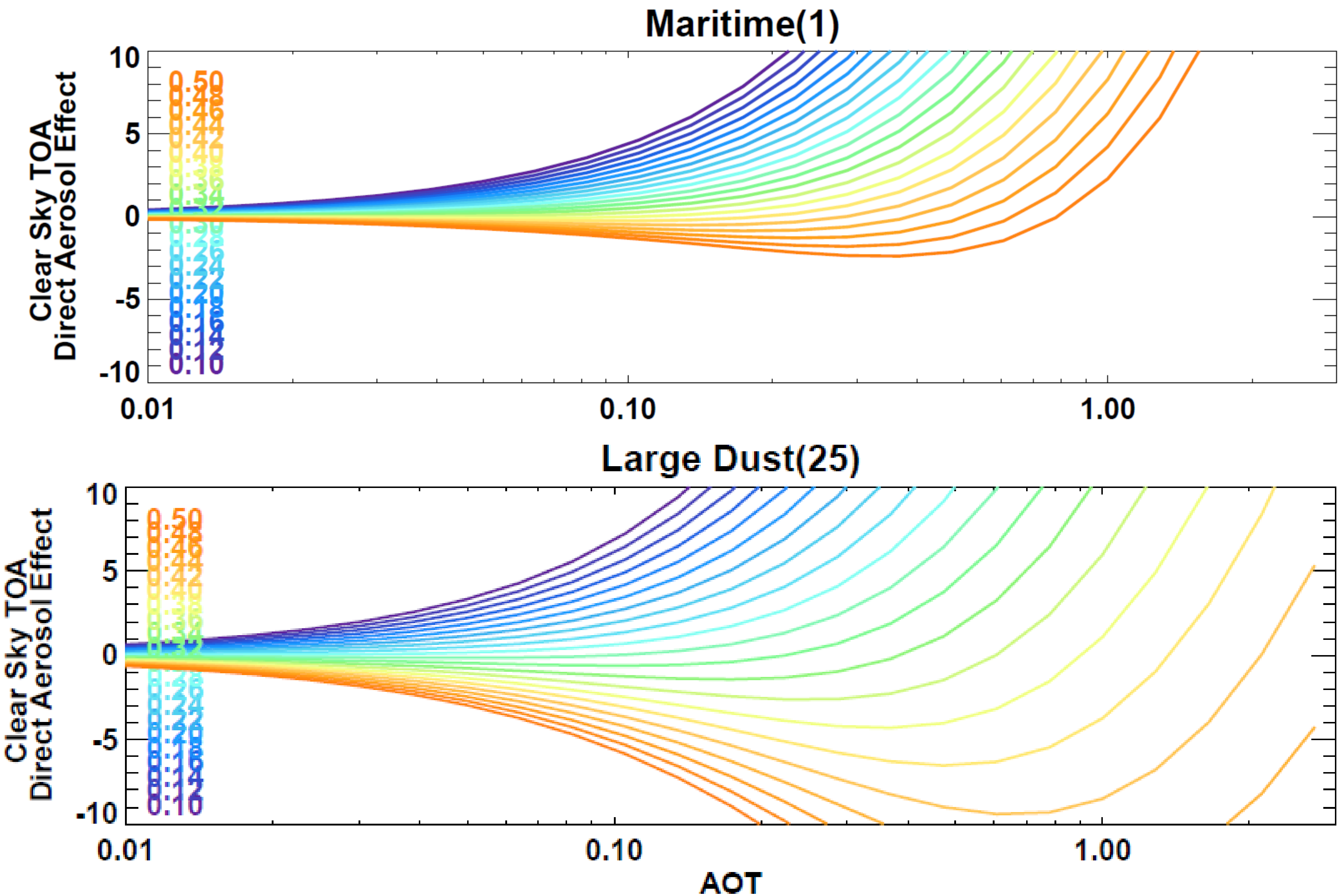
- **Simple relationship predicts DRE is linearly dependent on AOD**

$$DRE = F \propto \omega\beta\tau(1 - \alpha)^2 - 2\alpha\tau(1 - \omega)$$

  - (Coakley and Chylek, 1975; Haywood and Shine,1995; Charlson et al., 1991)

- **But misses some aspects of a broadband RT calculation which accounts for trace gas absorption**

From 4-stream Fu-Liou RT



Summary

- **Differences between CALIOP-based DRE estimates largely explained by differences in data products used and optical properties used**
- **Current uncertainties in AAOD are reflected in DRE diversity**
- **Current biases between satellite AOD products result in significant differences in DRE estimates**

- **But … anthropogenic fraction is likely the largest uncertainty in estimating RF_{ari}**

Finally … a comment on Aerosol Indirect Effects

ARTICLE

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OPEN

Observational constraint on cloud susceptibility weakened by aerosol retrieval limitations

Po-Lun Ma [1], Philip J. Rasch [1], Hélène Chepfer [2,3], David M. Winker [4] & Steven J. Ghan [1]

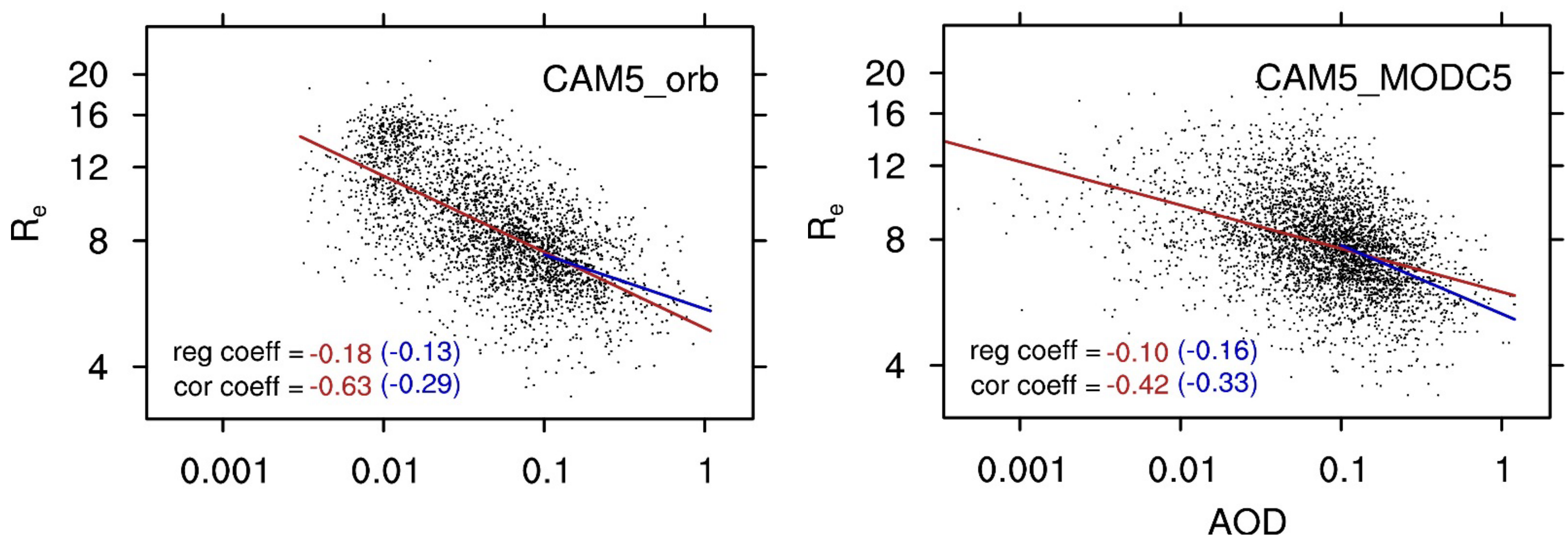

Figure S6