Effects of pollution on low-level maritime cloud properties and the top of atmosphere shortwave albedo

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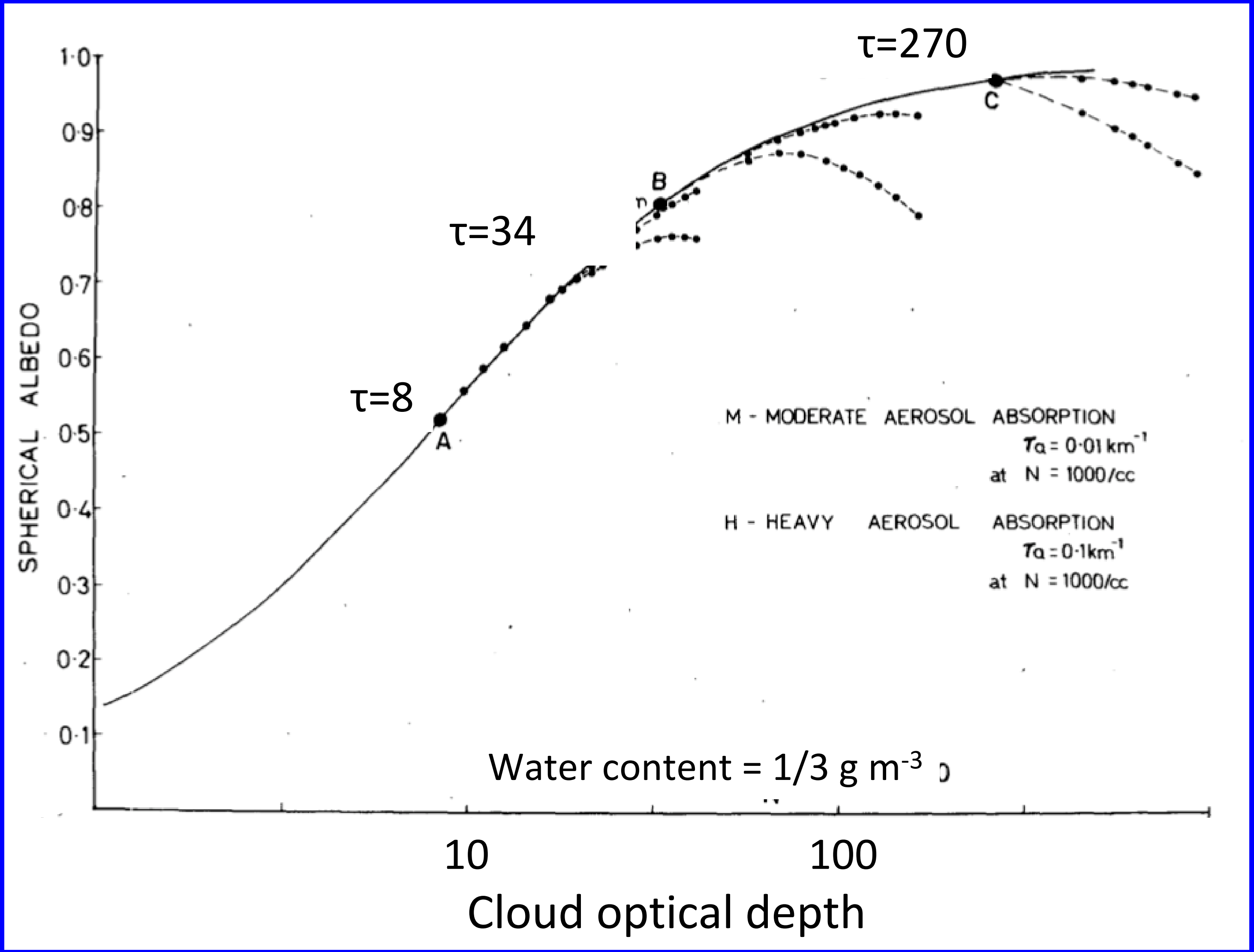
Twomey (1977): The influence of pollution on the shortwave albedo of clouds

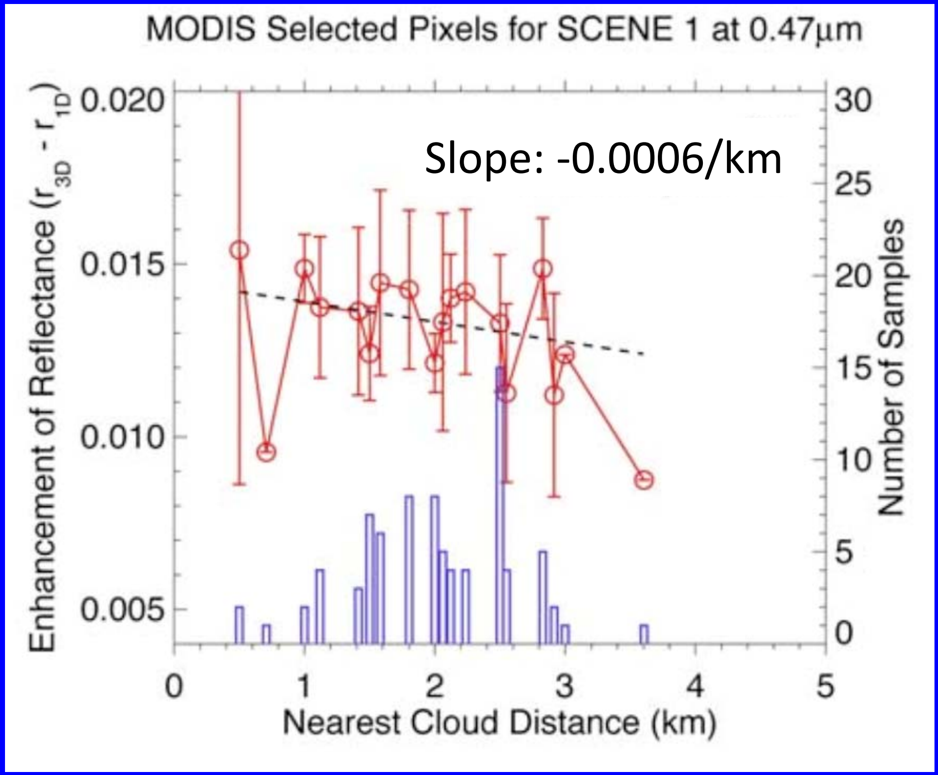


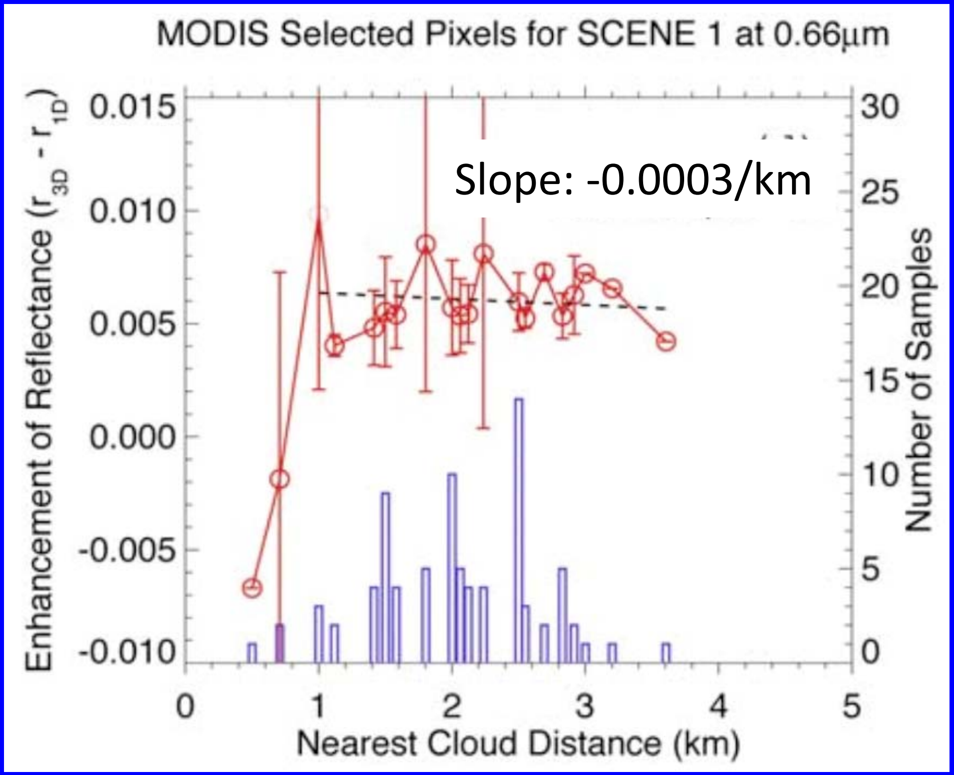
Satellite data have been used to study the correlations between aerosol and cloud properties ……

However, satellite retrievals have biases. These biases when not accounted for can be misleading.

Bias #1: cloud adjacency effect

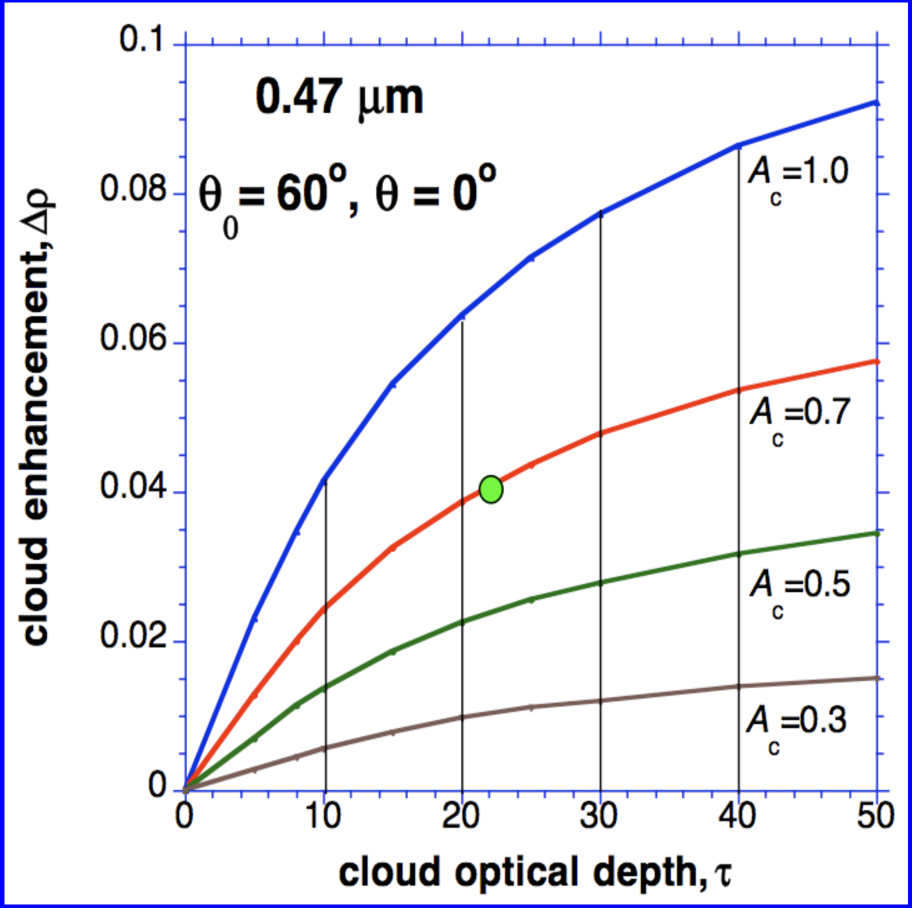
- AOD increases as cloud optical depth (COD) and cloud cover (Wen et al, 2006, 2007, Varnai &Marshak, 2009);

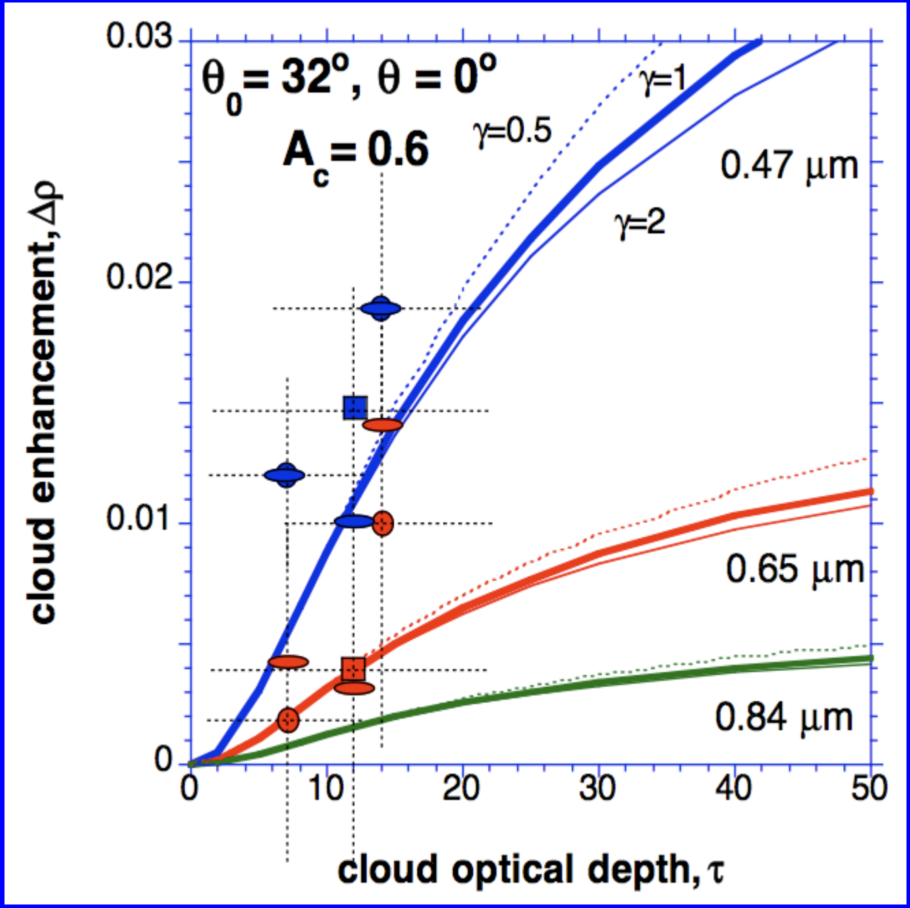




Biases #2: bluing effect

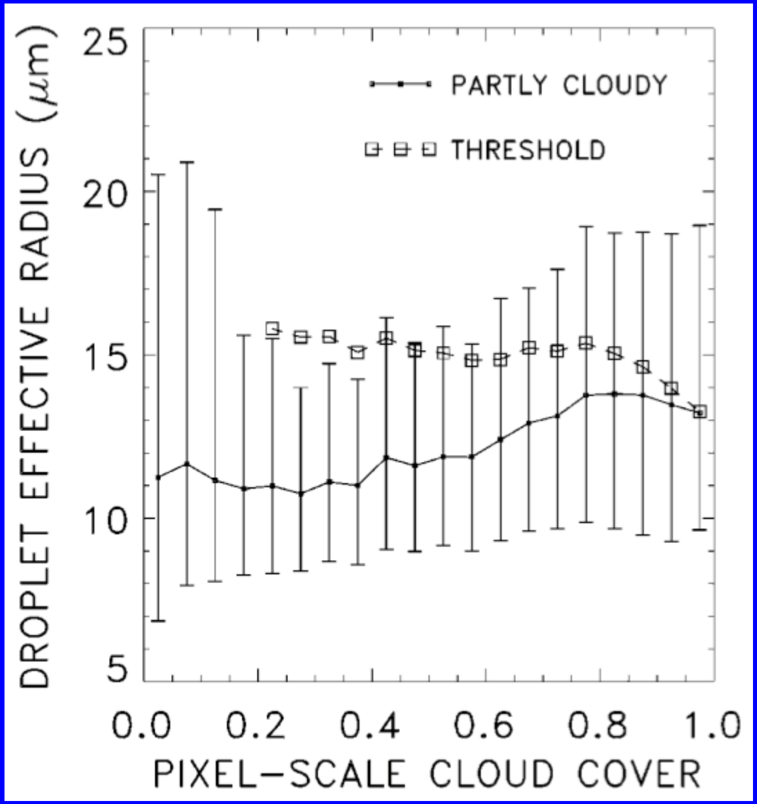
- AOD and Angstrom exponent increases as COD and cloud cover (Marshak et al., 2008);

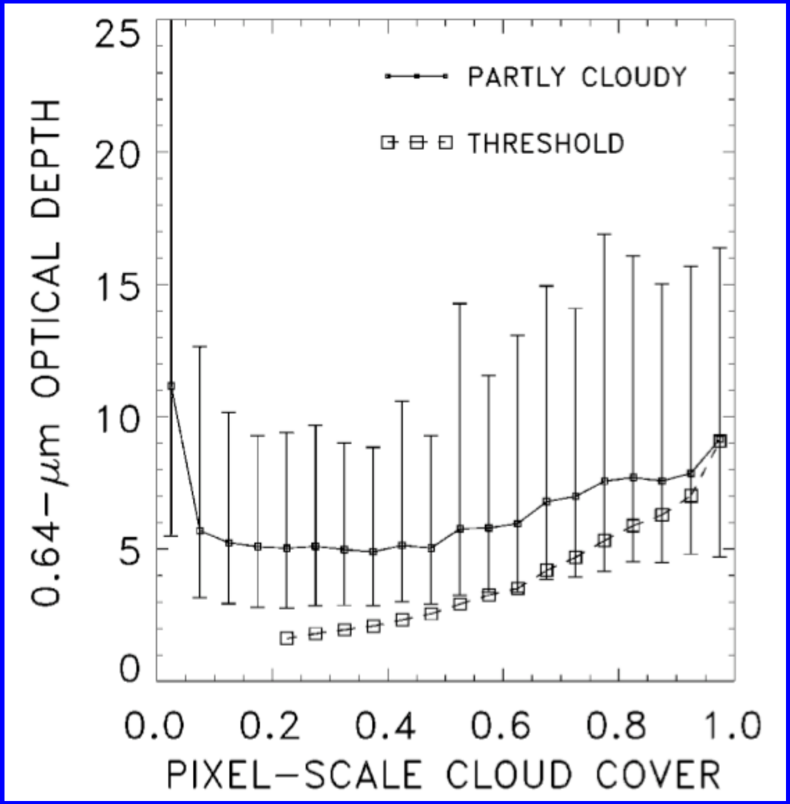




Bias #3: cloud retrieval in partially cloudy pixels

- For partially cloudy pixels, threshold cloud retrievals tend to underestimate COD and overestimate cloud droplet effective radius (Re). These biases decrease as cloud cover increases (Coakley et al., 2005, Matheson et al., 2006);





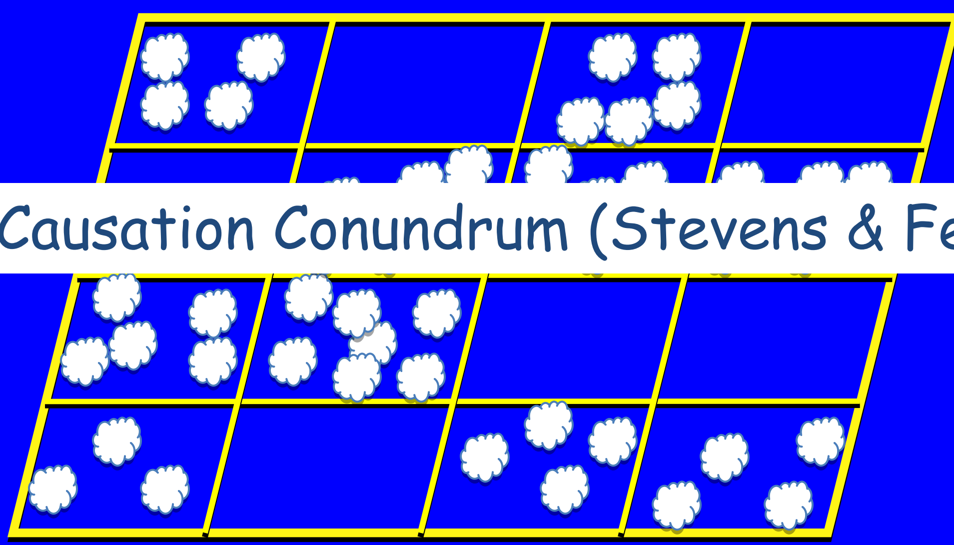
Using AOD to sort clouds, the above mentioned artifacts will be interpreted as aerosol indirect effect

Less cloud fraction, COD is biased low and Re is biased high

Less cloud fraction, smaller 3D/bluing effect, AOD and Angstrom exponent are less biased

More cloud fraction COD and Re are less biased

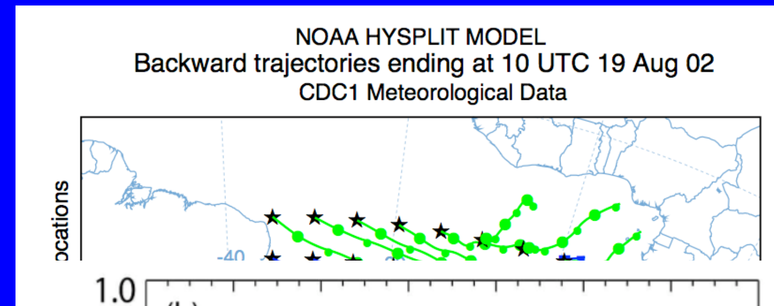
More cloud fraction, larger 3D effect, larger AOD, larger Angstrom exponent



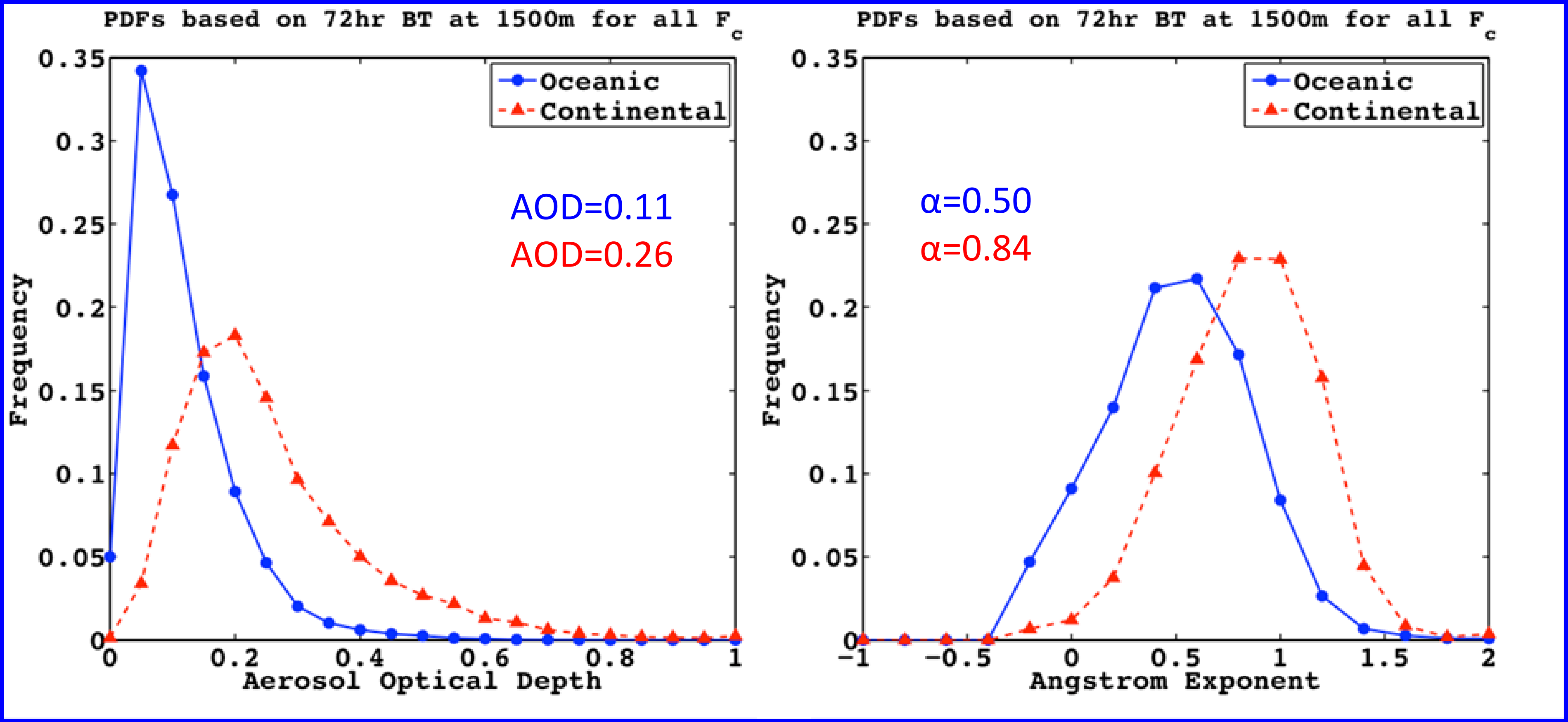
Correlation-Causation Conundrum (Stevens & Feingold, 2009)

Combine satellite, back trajectory, reanalysis data to study aerosol and cloud interactions

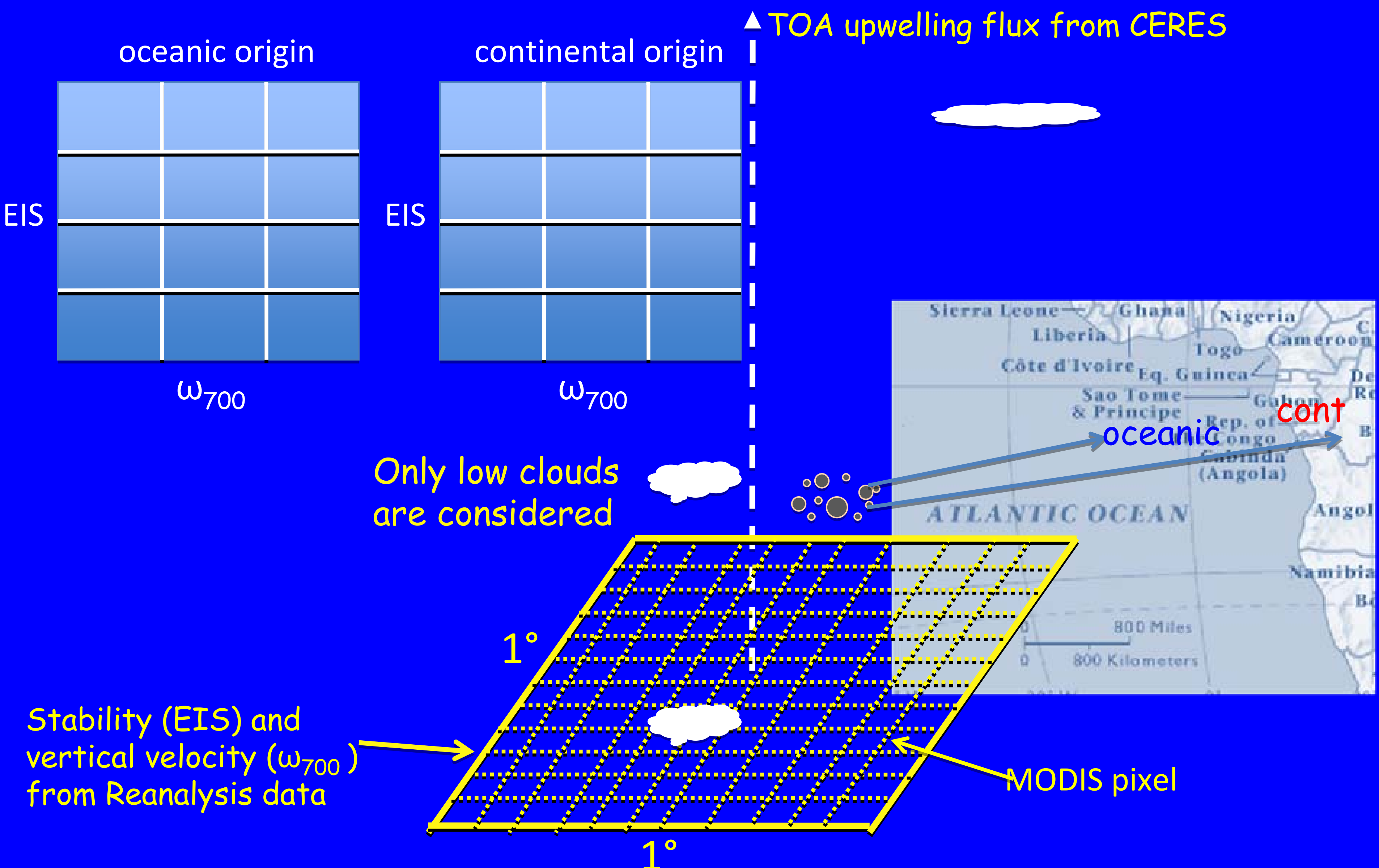
- CERES SSF daily mean data
  - Aerosol optical depth (AOD) from MODIS, cloud droplet effective radius (Re), cloud optical depth, liquid water path, cloud fraction, TOA albedo
- Hysplit back trajectory analysis
  - Aerosol origin is identified as continental or oceanic
- ERA interim reanalysis
  - Estimated Inversion Strength (EIS) and vertical velocity at 700 hPa (ω_{700}) to constrain the thermodynamic and dynamic conditions;



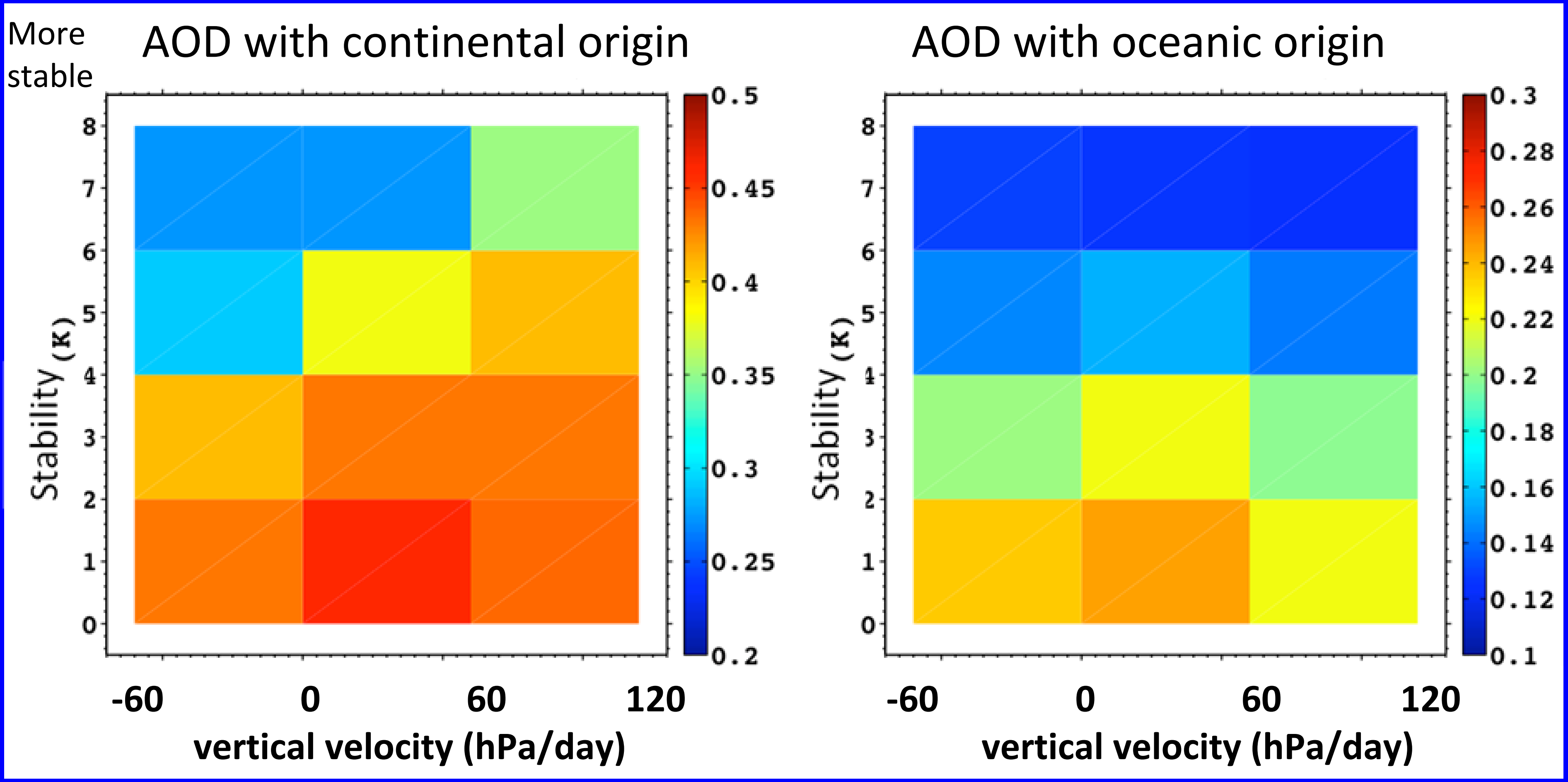
Back trajectory analyses indicate that aerosols with continental origin have higher optical depth and more fine mode particles than aerosols with oceanic origin



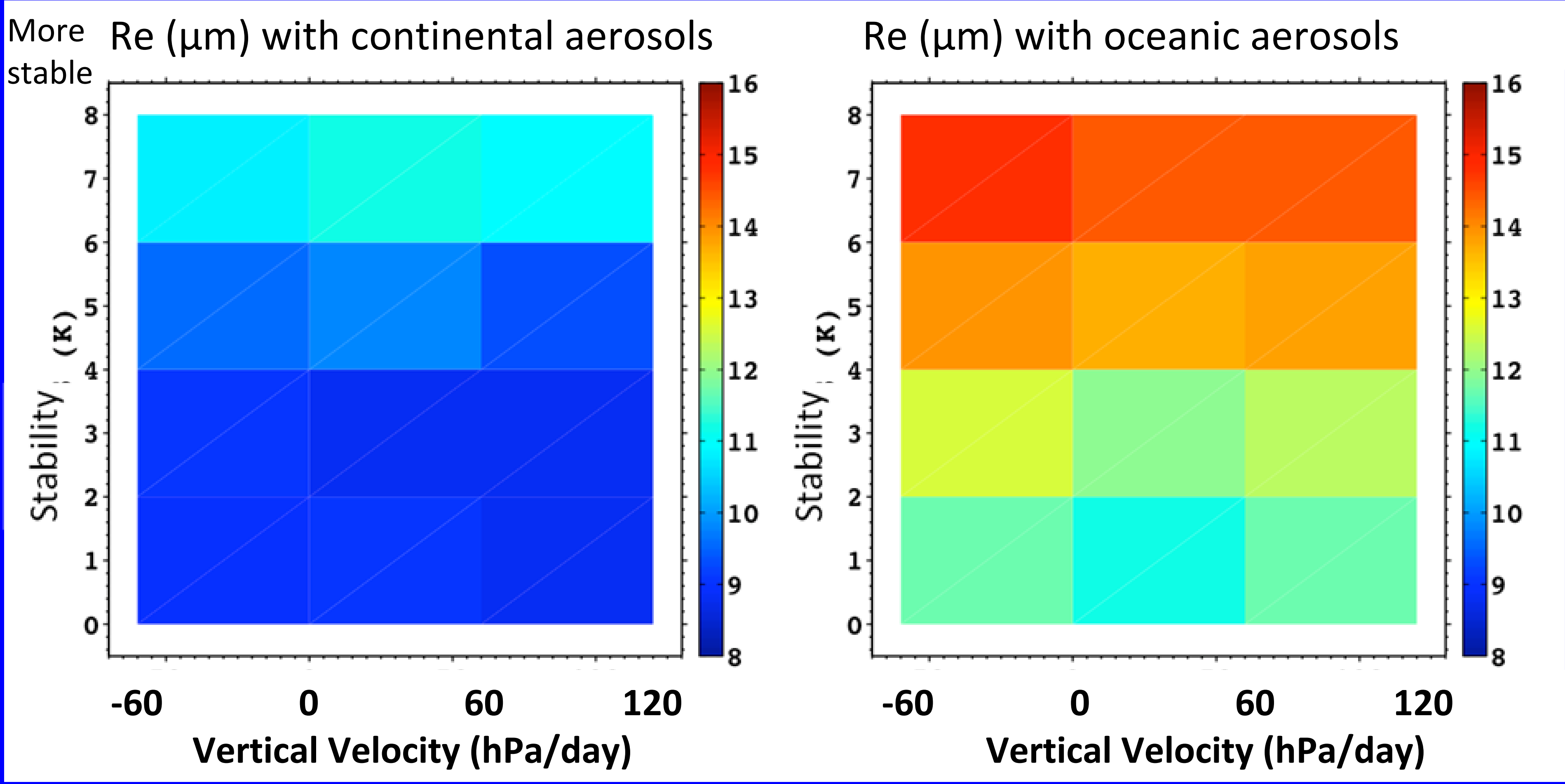
Stratify aerosol and cloud interactions by aerosol type, EIS and ω_{700}



AOD Stratified by stability and vertical velocity: aerosols with oceanic origin much smaller than aerosols with continental origin



Cloud droplet effective radius (Re) associated with oceanic origin are larger than Re associated with continental origin



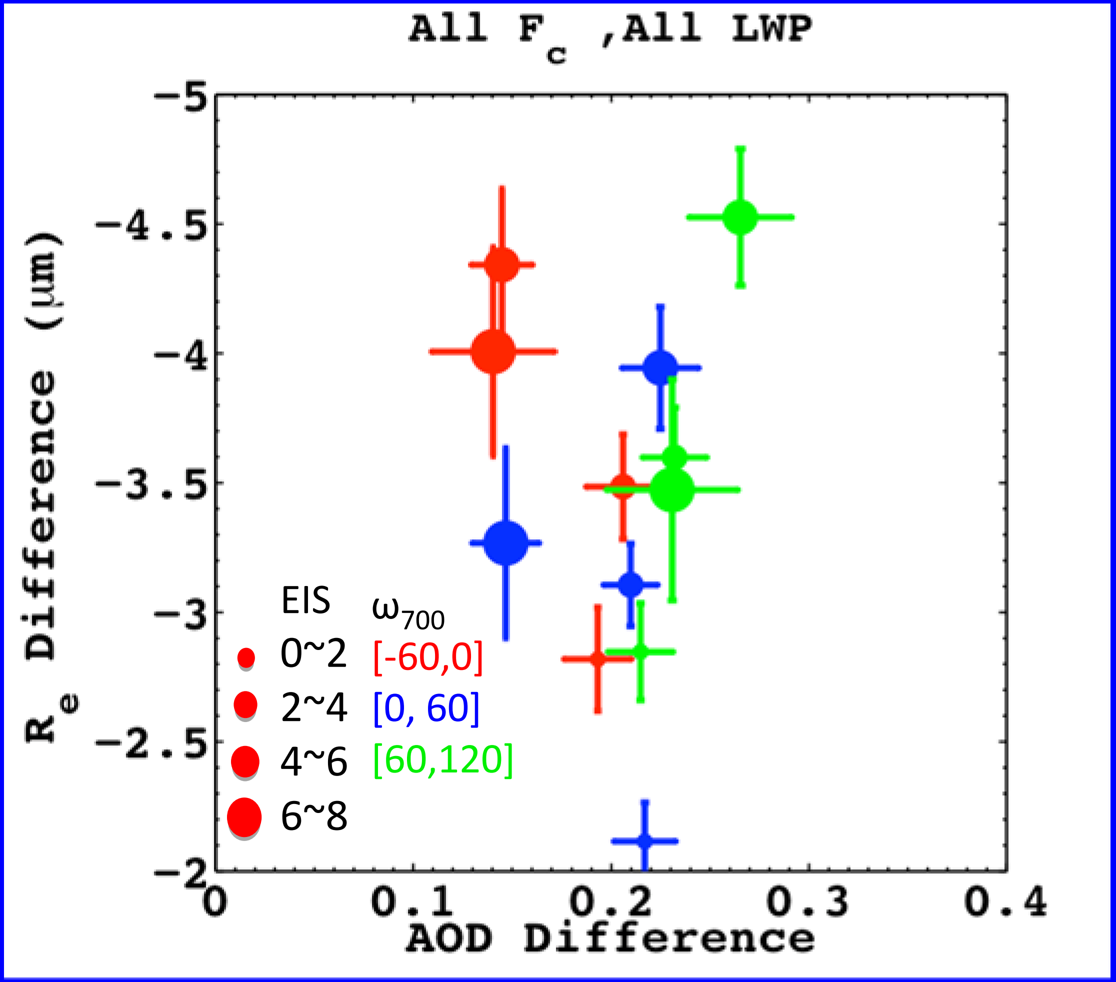
Differences of properties associated with aerosols of continental and oceanic origin: using AOD diagnostically

- Difference and the standard error for a given property are defined as:

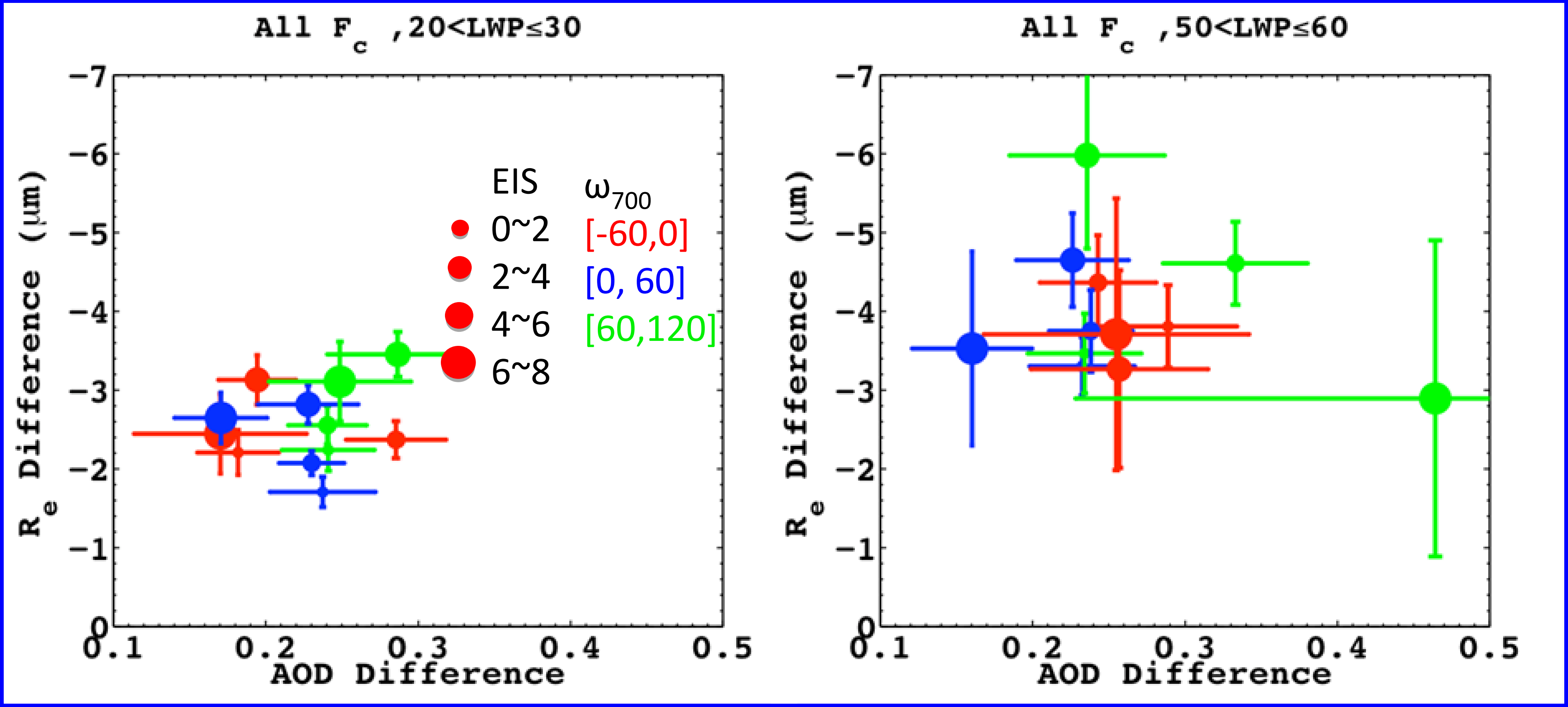
  $\Delta X_i = X_i^c - X_i^o$

  $\sigma_i^2 = (\sigma_i^c)^2 + (\sigma_i^o)^2$

  i is the stability/vertical velocity bin, c and o represent property associated with continental and oceanic aerosols



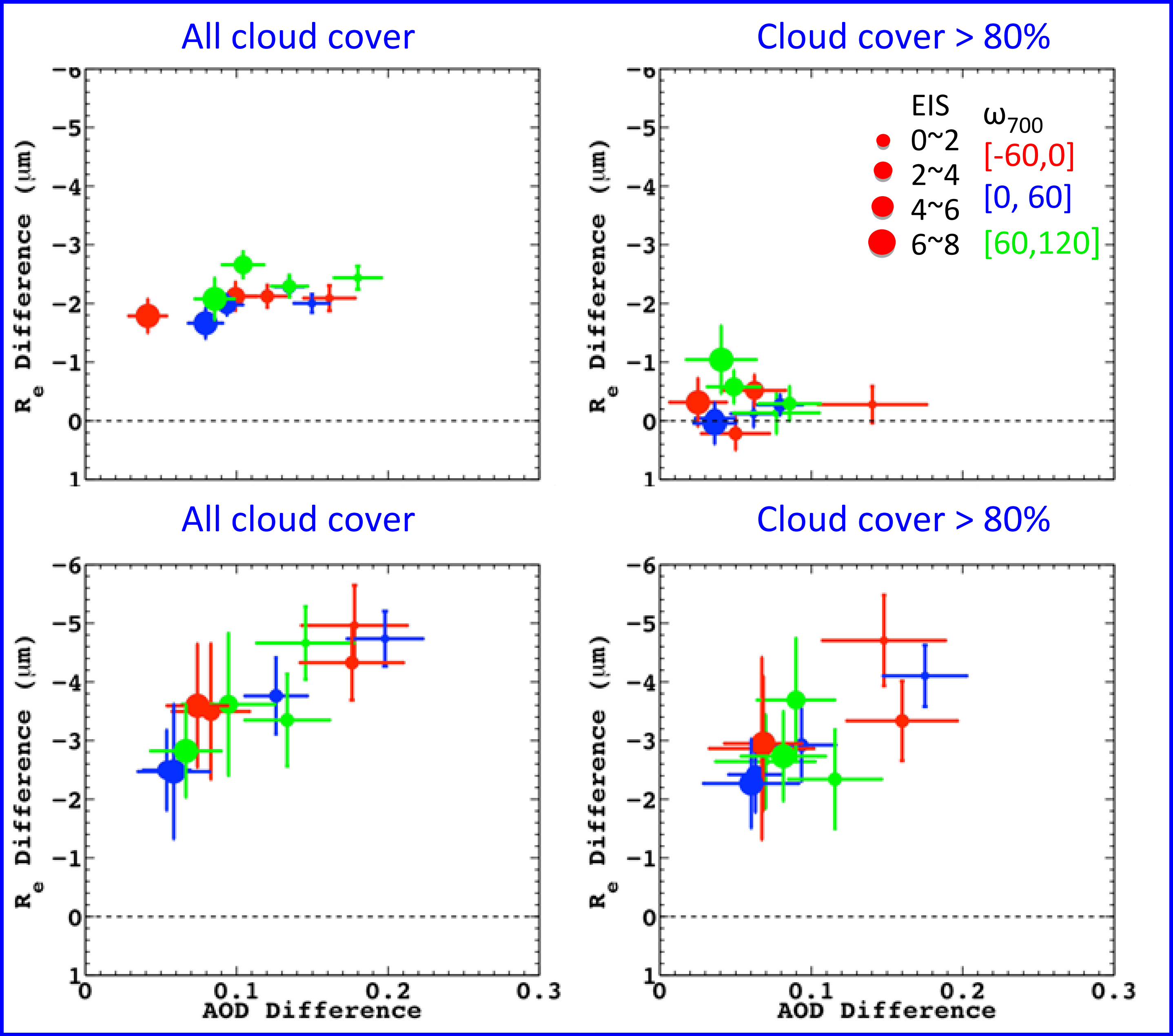
Under constant LWP: Cloud Re associated with continental aerosols are smaller than Re associated with oceanic aerosols



Re differences are smaller when constrain cloud cover

10<LWP≤20

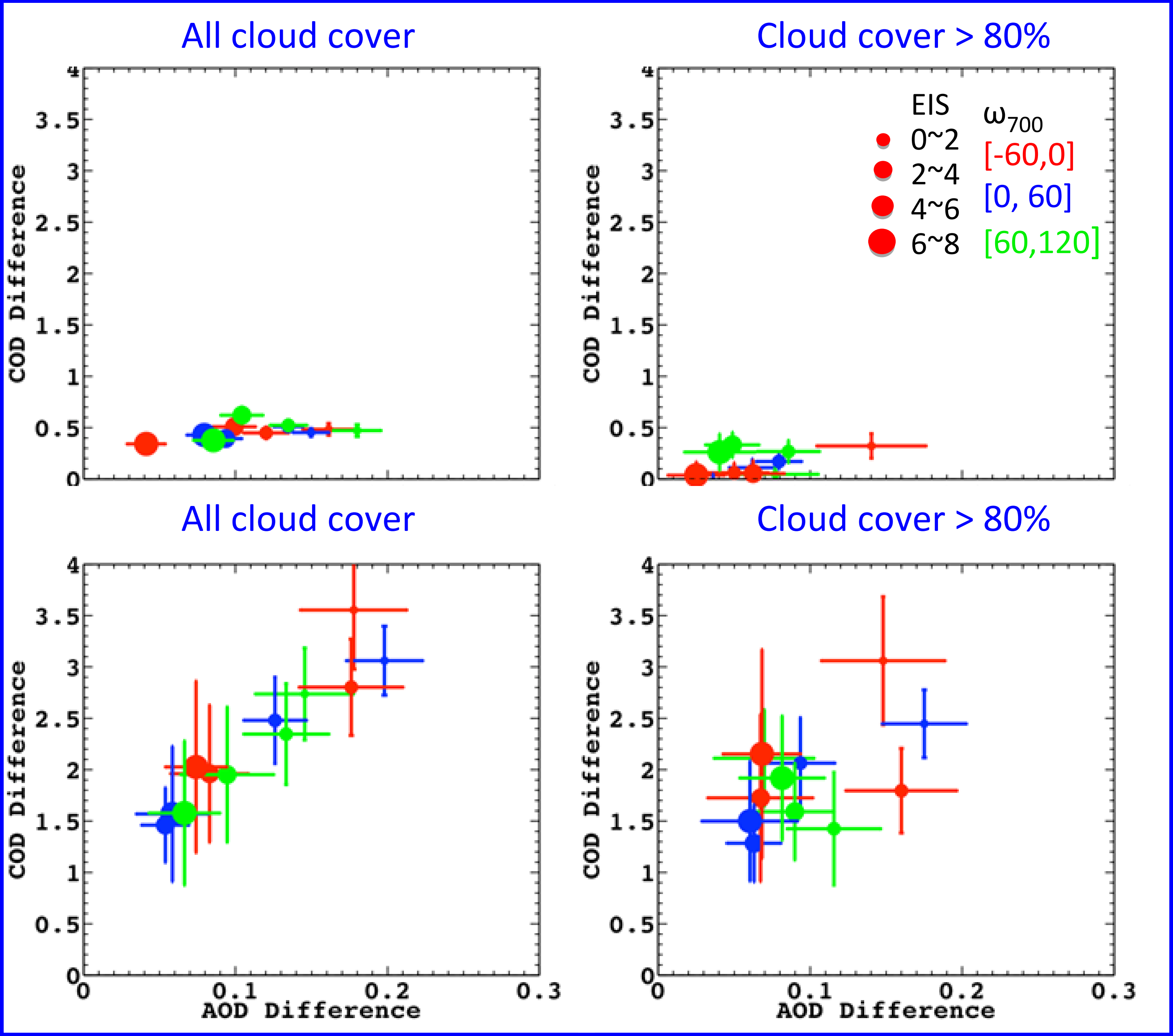
60<LWP≤80



COD differences are smaller when constrain cloud cover

10<LWP≤20

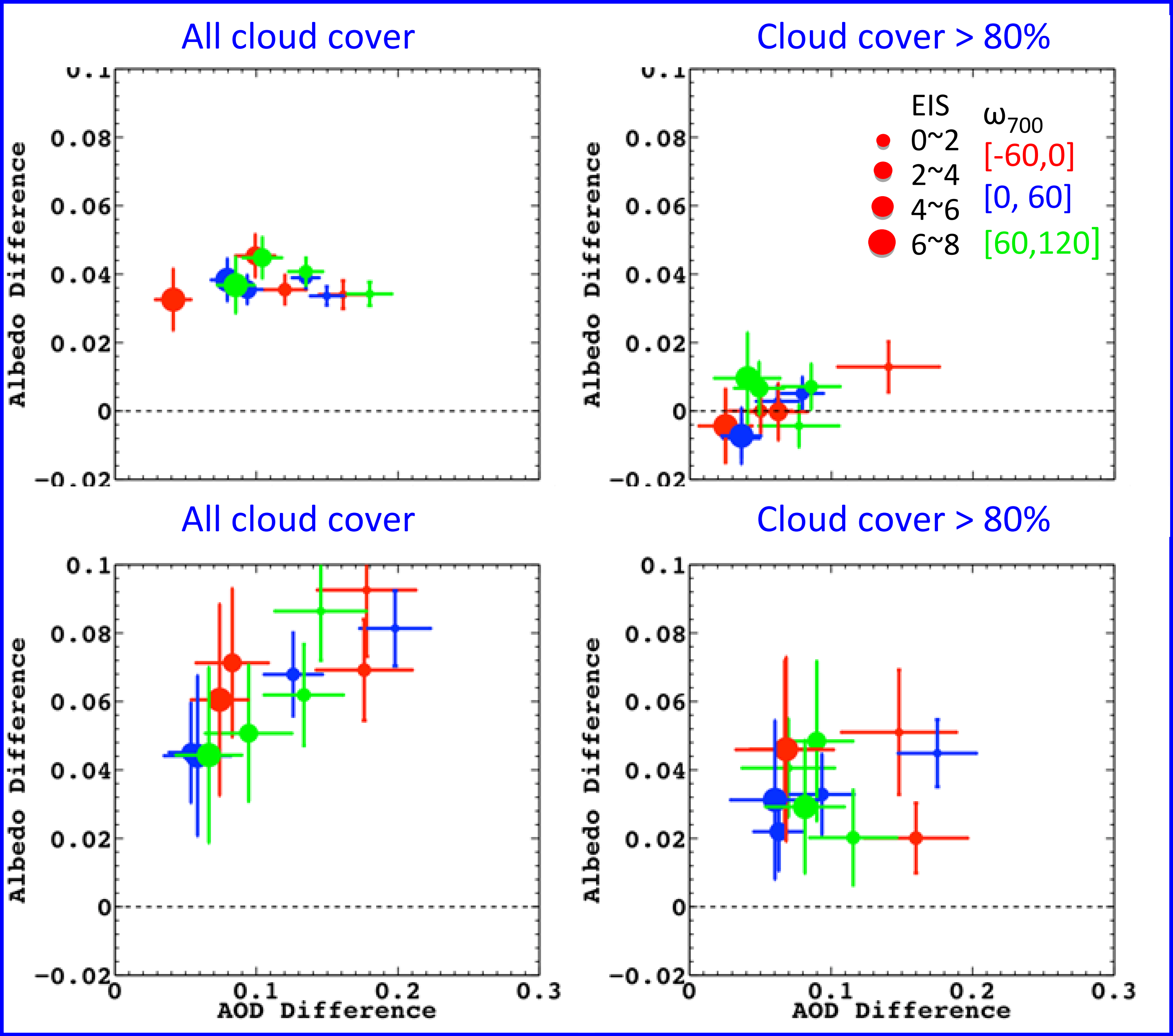
60<LWP≤80



Albedo differences are smaller when constrain cloud cover

10<LWP≤20

60<LWP≤80



Overall differences derived with and without constrained cloud fraction

- All properties are first weighted by the occurrence frequency of each EIS/ω_{700} bin for each LWP interval
- Then weighted by the occurrence frequency of each LWP interval, which is derived using all low cloud retrievals

	All Fc	Fc > 80%
AOD	0.127±0.016	0.081±0.024
Re (μm)	-2.4±0.3	-0.8±0.4
COD	0.9±0.15	0.6±0.18
Fc (%)	19.2±2.9	1.4±1.1
Albedo	0.043±0.006	0.010±0.007

Global cloud albedo effect

$$CAE = \frac{d\alpha}{dln\tau_a} = 0.0272$$

PresDay PreInd

$$\Delta\alpha^o = CAE * (ln0.14 - ln0.109) = 6.8 \times 10^{-3}$$

PresDay PreInd

$$\Delta\alpha^l = CAE * (ln0.22 - ln0.132) = 13.9 \times 10^{-3}$$

Low cld frc over ocean Low cld frc over land

$$\begin{aligned} IRF &= -F^{\downarrow} * [\Delta\alpha^o * 0.47 * 0.7 + \Delta\alpha^l * 0.32 * 0.3] \\ &= -1.2Wm^{-2} \end{aligned}$$

$$\begin{aligned} IRF &= -F^{\downarrow} * [\Delta\alpha^o * 0.47 * 0.7 + \frac{\Delta\alpha^l}{2} * 0.32 * 0.3] \\ &= -1.0Wm^{-2} \end{aligned}$$

Conclusions

- We constrain cloud properties and TOA albedo by thermodynamic (EIS), dynamic (ω_{700}), LWP, cloud fraction, and aerosol types (oceanic vs. continental) to minimize the satellite retrieval artifacts.
- Cloud droplet effective radius associated with aerosols of continental origin is smaller than that with oceanic origin; overall difference is about 0.8 μm, which is about 1/3 the difference when we do not constrain cloud fraction.
- Cloud optical depth associated with aerosols of continental origin are larger than that with oceanic origin; overall difference is about 0.6, which is 2/3 the difference when we do not constrain cloud fraction.
- TOA albedo associated with aerosols of continental origin are larger than that with oceanic origin; overall difference is about 0.010, which is about 1/4 the difference when we do not constrain cloud fraction.