Physical Interpretation of the Spectral Radiative Signature in the Transition Zone Between Cloud-free and Cloudy Regions

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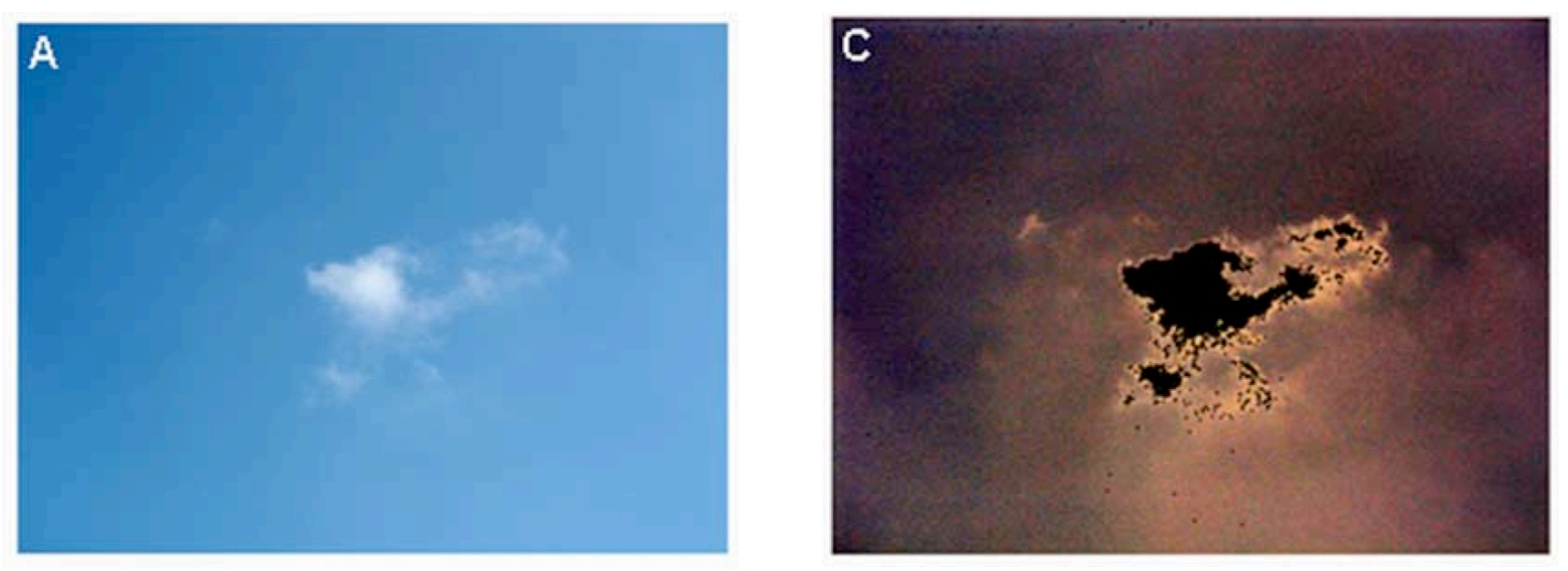
Cloud boundaries are somewhat fuzzy

- Fuzzy cloud boundaries create major headaches for studies of aerosol indirect effect and aerosol radiative forcing.



Captions: Images from Koren et al. (2007) show that separation between cloud-free and cloudy areas is ambiguous.

- Yet it has been difficult to study the transition zone using conventional data; both satellite and in situ aircraft data are inadequate.
- One-sec-resolution zenith radiance data from the ARM shortwave spectrometer (SWS) provide a unique opportunity to study the transition.

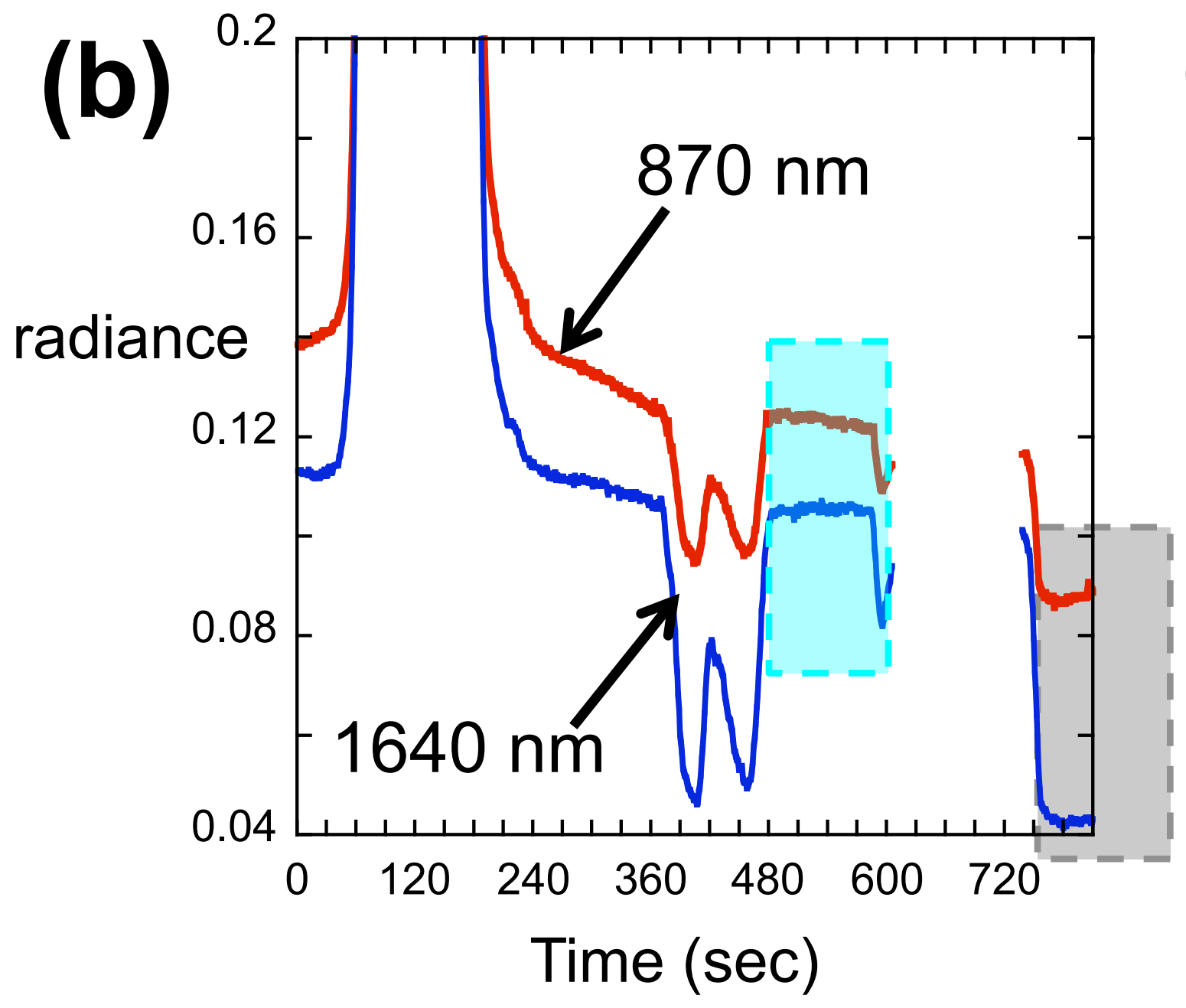
Summary

- In the transition zone, there is a remarkable linear relationship between the sum and difference of radiances at 870 and 1640 nm wavelengths. The intercept of the line is mostly determined by aerosol optical depth and size while the slope is mostly determined by cloud droplet size.
- This linearity can be predicted from simple theoretical considerations and furthermore it supports the hypothesis of inhomogeneous mixing, whereby optical depth increases as a cloud is approached, but the effective drop size remains unchanged.

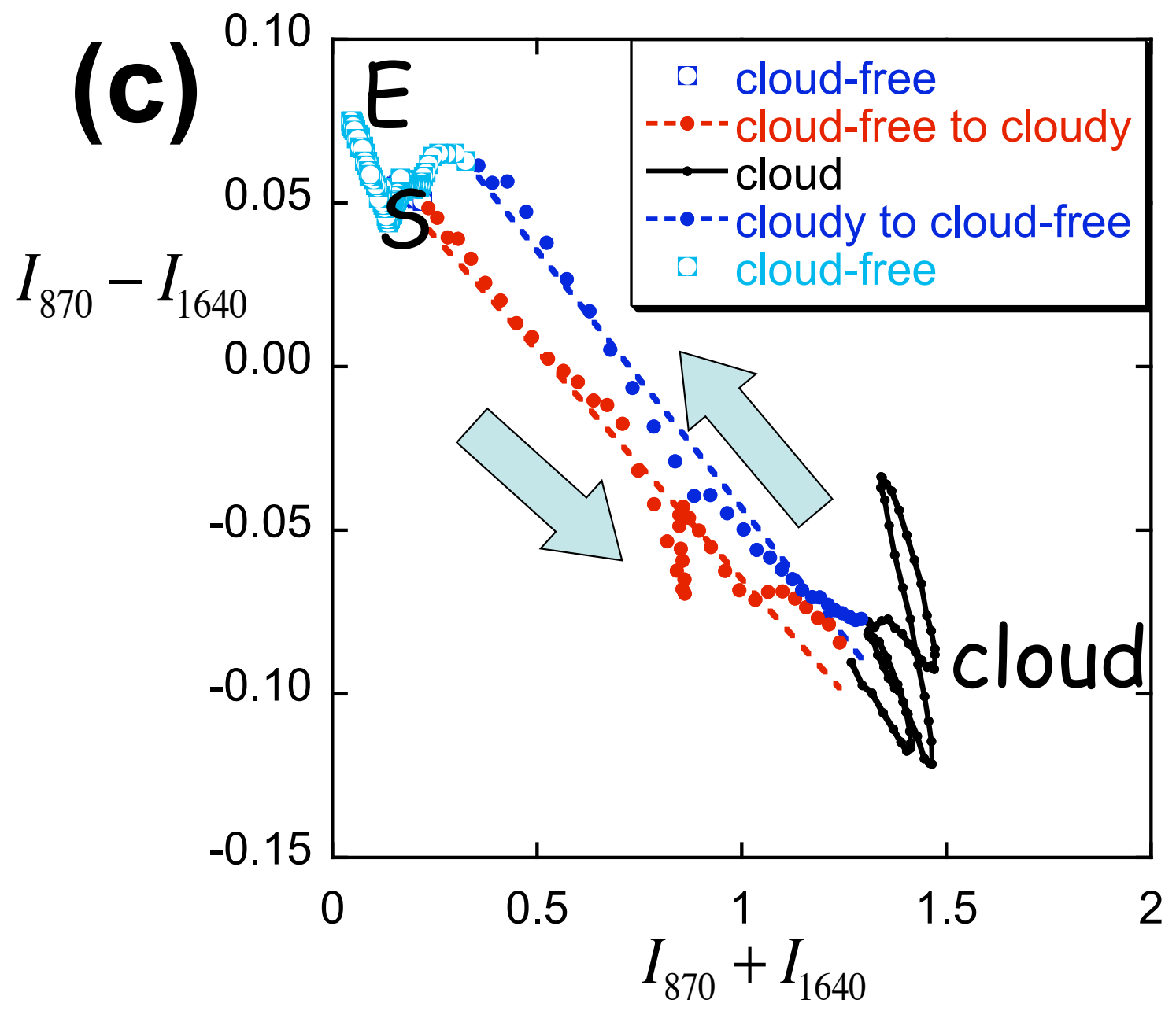
An example shows that in the transition zone, there is a remarkable linear relationship between the sum and difference of radiances at 870 and 1640 nm wavelengths

- We have used two wavelengths, 870 and 1640 nm, from the SWS spectra to study the transition zone between cloudy and clear regions. SWS-observed zenith radiances have been normalized by the extraterrestrial solar spectrum and by cosine of solar zenith angle (SZA).

(a) is total sky images taken on 18 May 2007 with a SZA of 45°.



(b) is time series of uncorrected and normalized radiances at 870 and 1640 nm. We determine stray light contaminations using data from unblocked (cyan) and blocked (grey) time periods. Corrections determined here are then used in next plot.



(c) is the plot of corrected and normalized radiance difference versus sum at wavelengths of 870 and 1640 nm. Letters S and E indicate the start and end of the time series, while two thick arrows indicate the flow of time evolution.

- Note that stray light contaminations in SWS measurements will affect the intercept of the line in the transition zone, but NOT the slope of the line, if the entire time period of interest is completely unblocked or completely blocked.

The linear behavior allows us to separate radiative signatures of aerosols and clouds

- Denote single scattering albedo, phase function, and optical depth as:

  for aerosols: ϖ_λ^a , P_λ^a, τ_λ^a ; for clouds: ϖ_λ^c , P_λ^c , τ^c
- For a very small optical depth, the downward zenith radiance can be well approximated as:

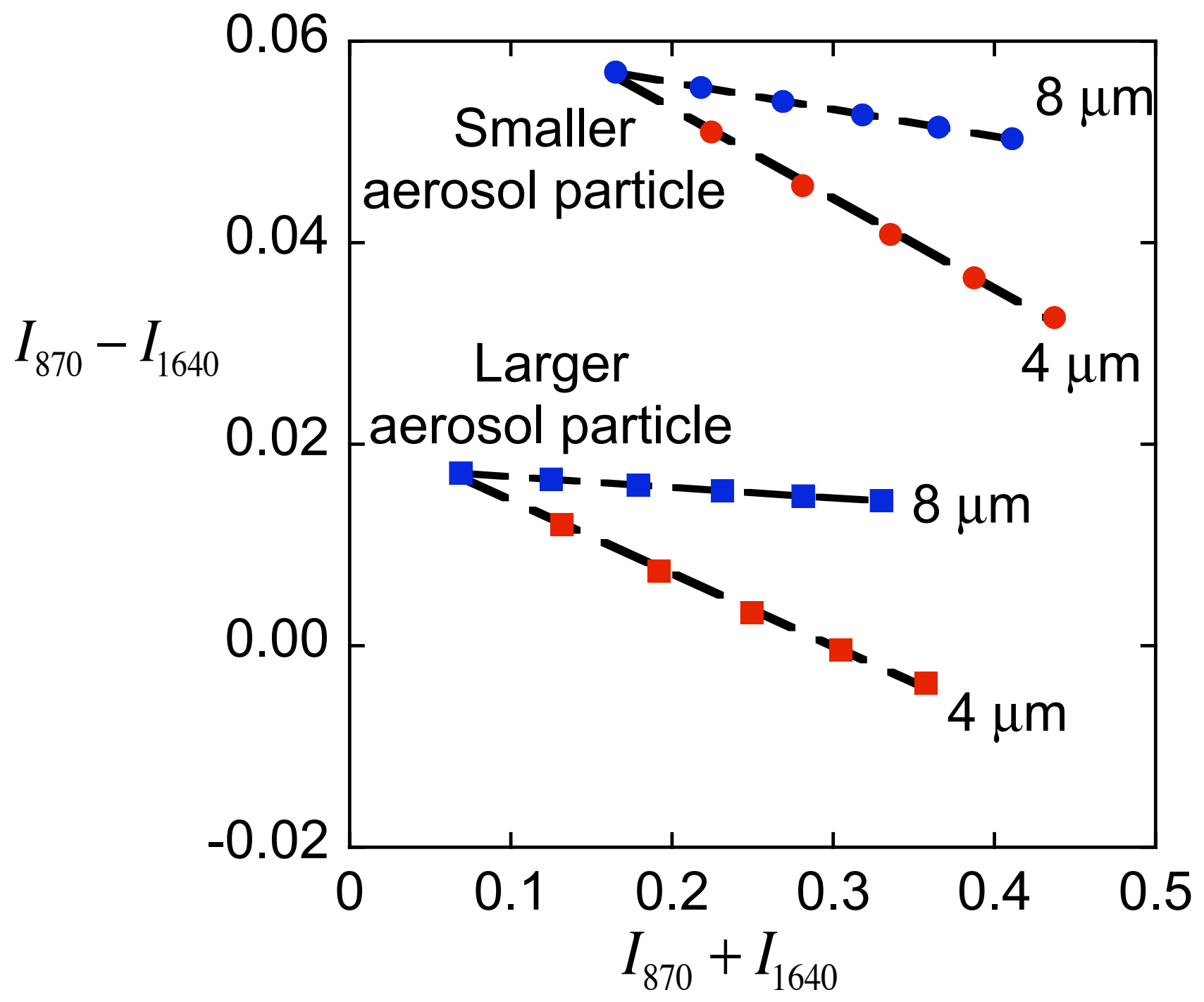
$$I_\lambda \propto \varpi_\lambda \cdot P_\lambda \cdot \tau_\lambda$$

- We then derive :

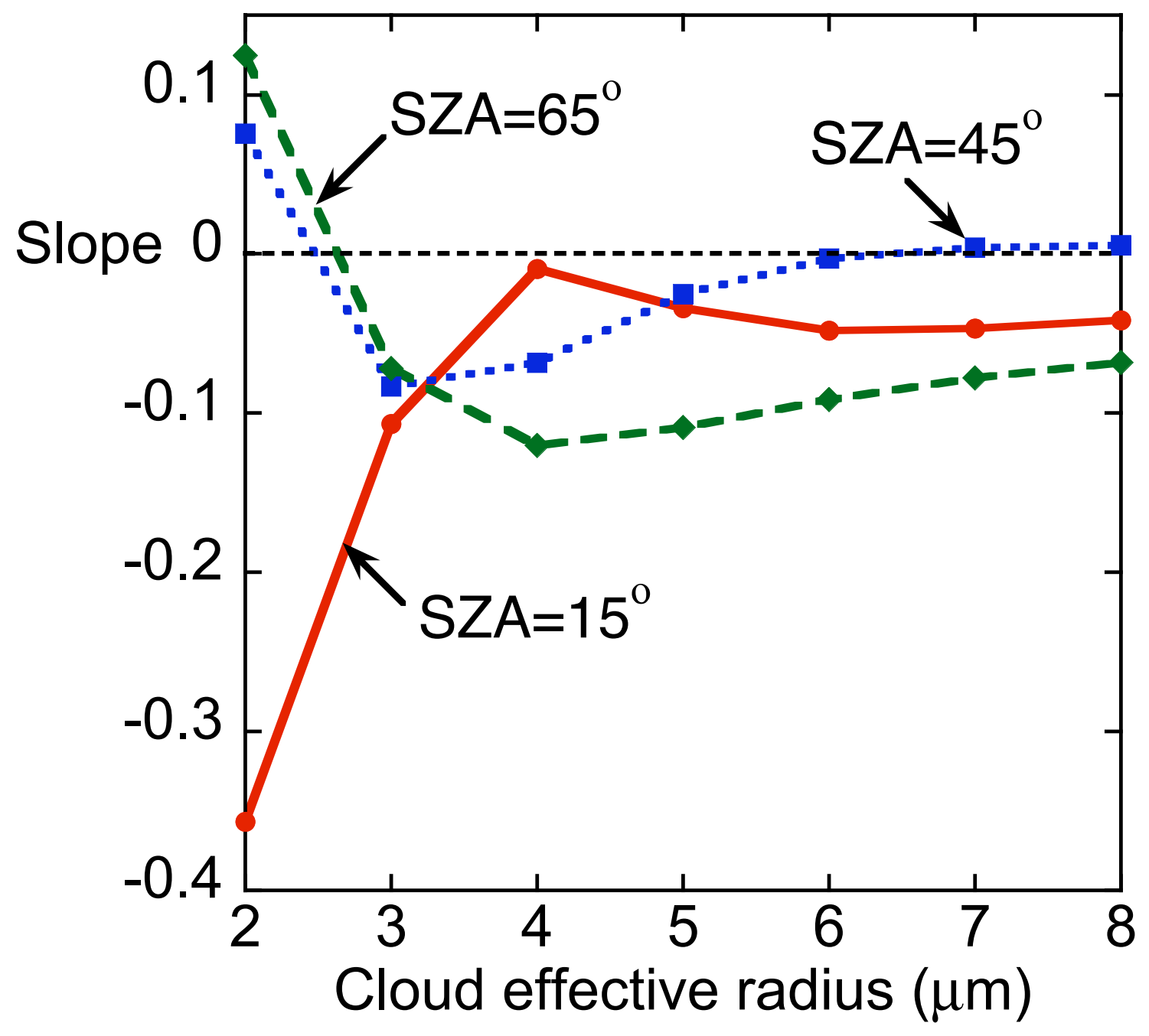
$$\frac{I_{870}-I_{1640}}{I_{870}+I_{1640}}=\frac{a_- + (P_{870}^c-\varpi_{1640}^c P_{1640}^c)\cdot\tau^c}{a_+ + (P_{870}^c+\varpi_{1640}^c P_{1640}^c)\cdot\tau^c}$$

$$a_\pm=\varpi_{870}^a P_{870}^a \tau_{870}^a \pm \varpi_{1640}^a P_{1640}^a \tau_{1640}^a$$

$$\textbf{Slope}=\frac{P_{870}^c-\varpi_{1640}^c P_{1640}^c}{P_{870}^c+\varpi_{1640}^c P_{1640}^c}$$



- The intercept of the linear relationship depends on aerosol properties. Aerosol optical depths are 0.15 and 0.08 for 870 and 1640 nm, respectively. Data points correspond to cloud optical depth from 0 to 0.5 for cloud effective radius (4 and 8 µm).



- The slope of the linear relationship is a function of cloud droplet size. For small droplets less than 4 µm, the slope is very sensitive to droplet size while it asymptotes for larger droplets.