Studying the Transition from Cloudy to Clear Skies Using the ARM Shortwave Spectrometer

Alexander Marshak[1], Christine Chiu[2], Yuri Knyazikhin[3], Warren Wiscombe[1,4], and Peter Pilewskie[5]

[1]*NASA/Goddard Space Flight Center* [2]*Joint Center for Earth Systems Technology/UMBC* [3]*Boston University* [4]*Brookhaven national Laboratory* [5]*University of Colorado*

Motivation

- It is difficult to distinguish the transition zone between cloudy and cloud-free air in remote sensing observations. This problem has major climatic consequences, in particular on aerosol indirect effect studies, which demand a precise separation of clear and cloudy air.
- This paper aims to understand the physical processes and radiative signatures in the transition zone using spectral measurements of the ARM shortwave spectrometer (SWS).

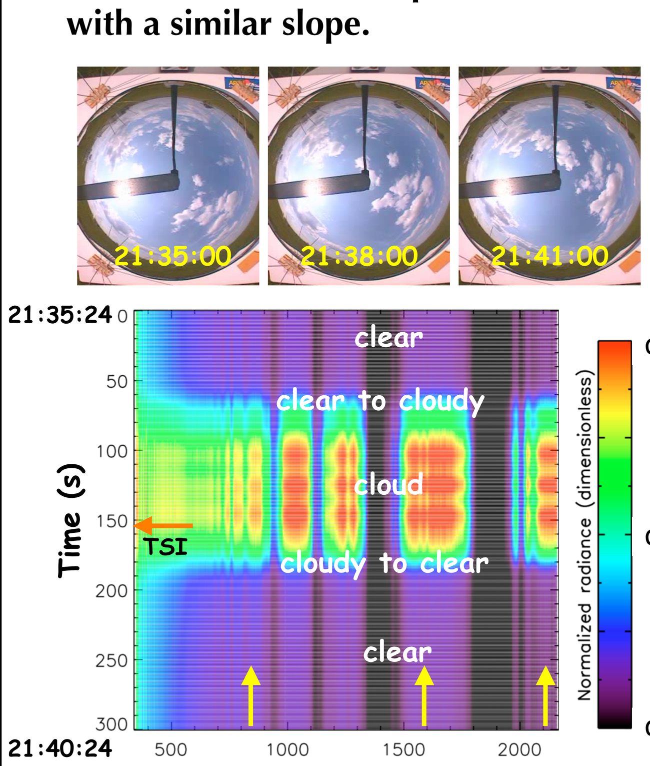
Summary

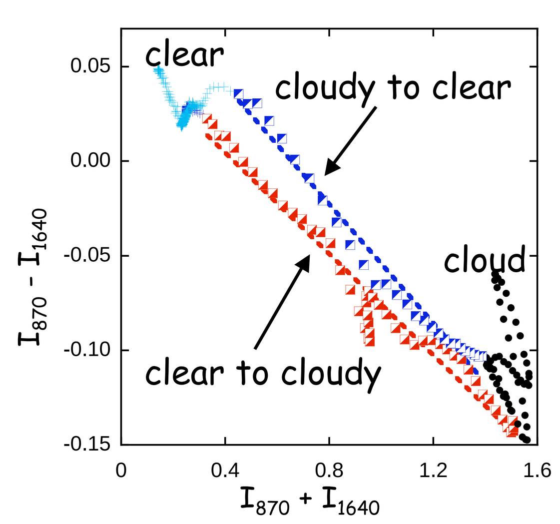
- In the transition zone between cloud-free and cloudy area, we have found a linear relationship between the difference ($I_{870} - I_{1640}$) and sum ($I_{870} + I_{1640}$) in zenith radiances of non (water) absorbing (e.g., 870 nm) and absorbing (e.g., 1640 nm or 2130 nm) wavelengths.
- 5 different regimes are defined based on their distinct spectral signatures and dominant factors:

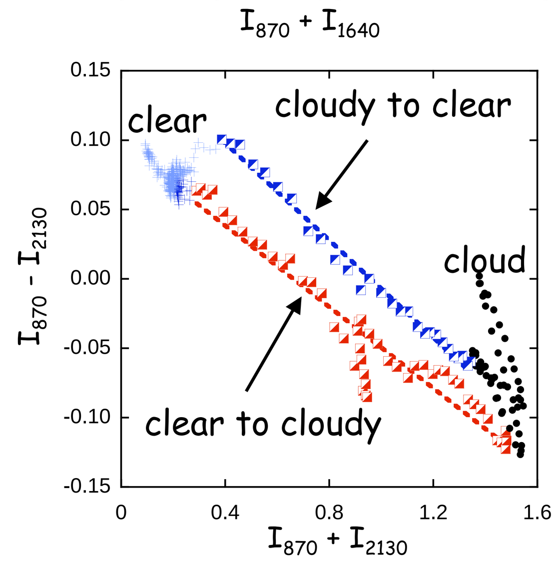
Regime	Descriptions	Radiative signature	Dominant factors
0	cloud-free area	$I_{870}-I_{1640}$ always > 0	Rayleigh and aerosol scattering
1	Transition area	$I_{870}+I_{1640}\uparrow$, $I_{870}-I_{1640}\downarrow$	In-cloud single scattering
2	Thin clouds	$I_{870}+I_{1640}\uparrow$, $I_{870}-I_{1640}\downarrow$	In-cloud single and multiple scattering
3	Very thin clouds	$I_{870}+I_{1640}\uparrow$, $I_{870}-I_{1640}\uparrow$	In-cloud multiple scattering, cloud-surface interaction
4	Thicker clouds	$I_{870}+I_{1640}\downarrow$, $I_{870}-I_{1640}\uparrow$	In-cloud multiple scattering , cloud-surface interaction, transmittance

Shortwave Spectrometer Obs. (418 wavelengths, 1s sampling)

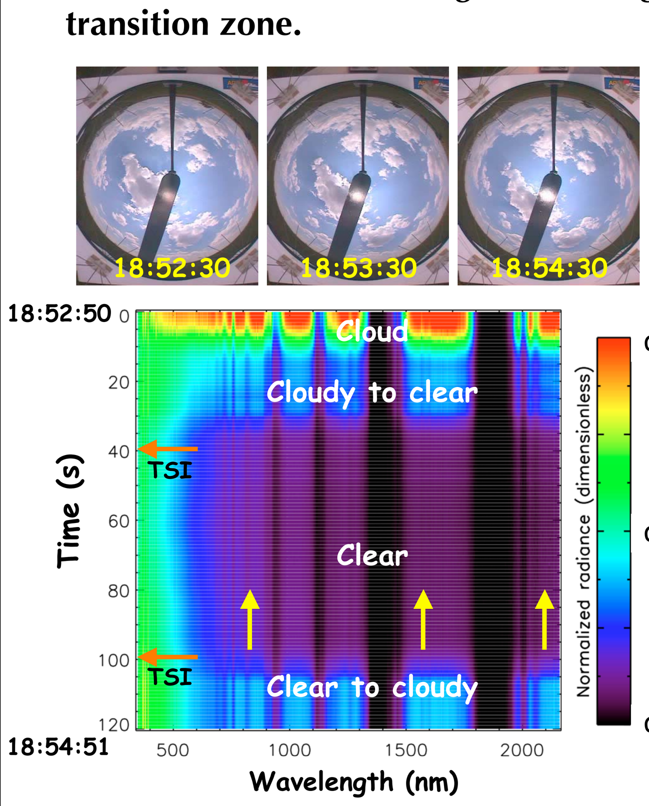
- Case 2007/05/18 helps us to understand the spectral signature on both sides of a cloud.
- In the transition zones (clear-to-cloudy & cloudy-to-clear), SWS spectral signatures show linear relationships on both zones with a similar slope.

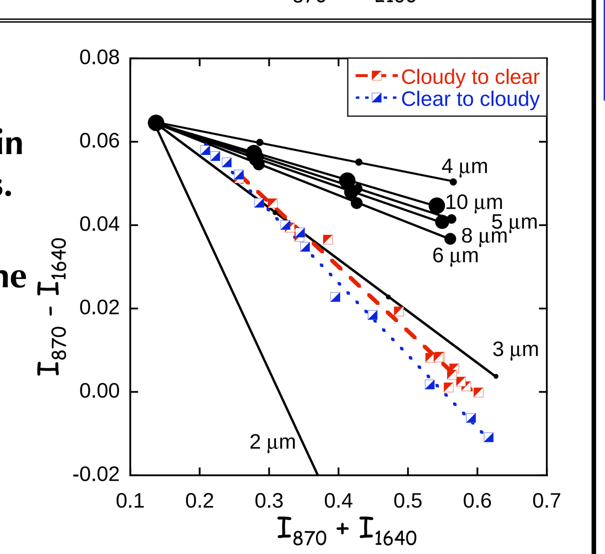


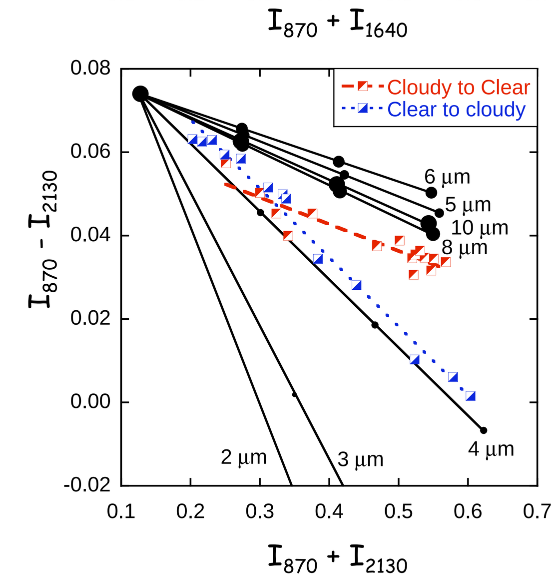




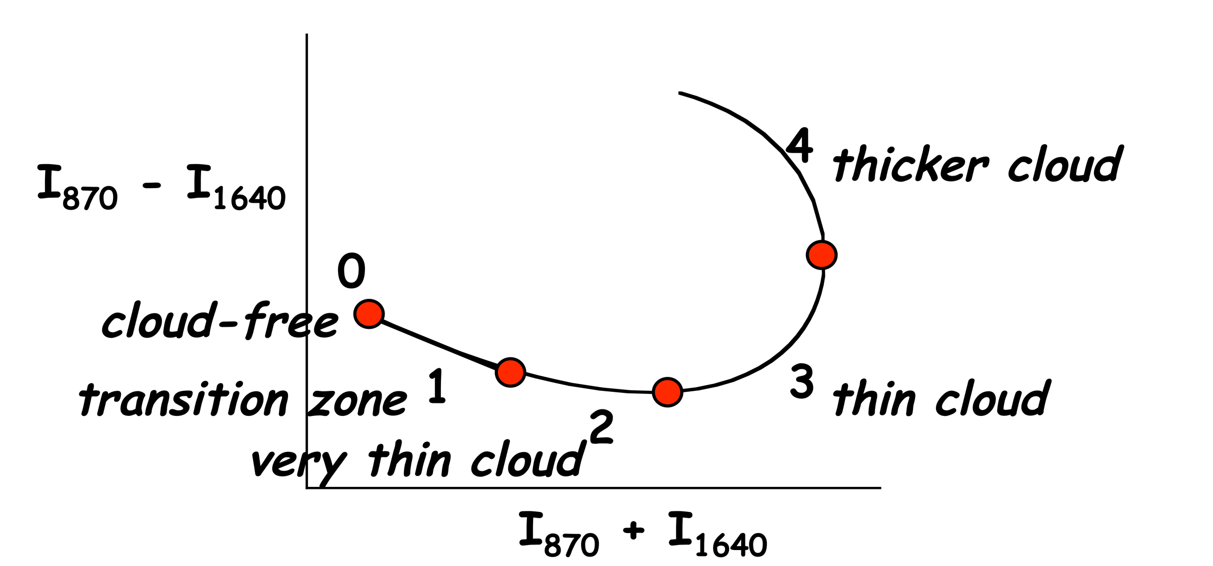
- Case 2006/06/27 helps us to understand the signature on the edges of two different clouds. SWS data show linear relationships in the transition zones but with different slopes.
- 1D radiative transfer calculations seem to work due to dominant single scatterings in the transition zone.







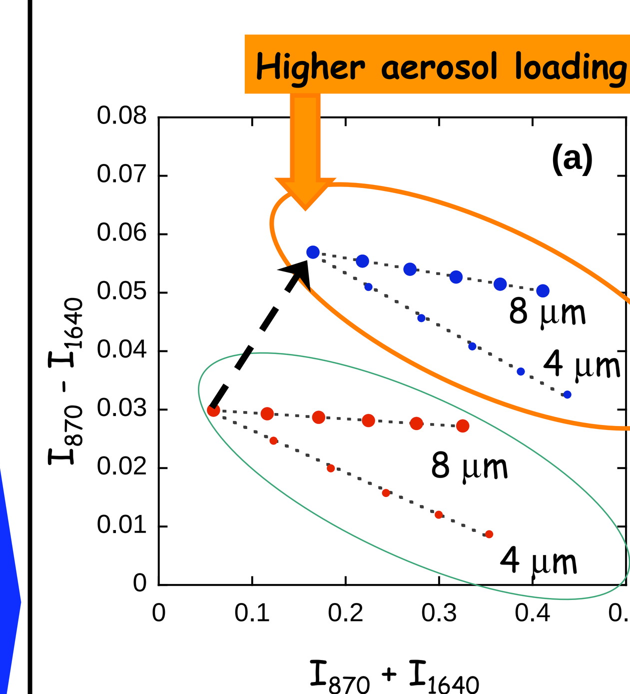
Radiative Signature Regimes



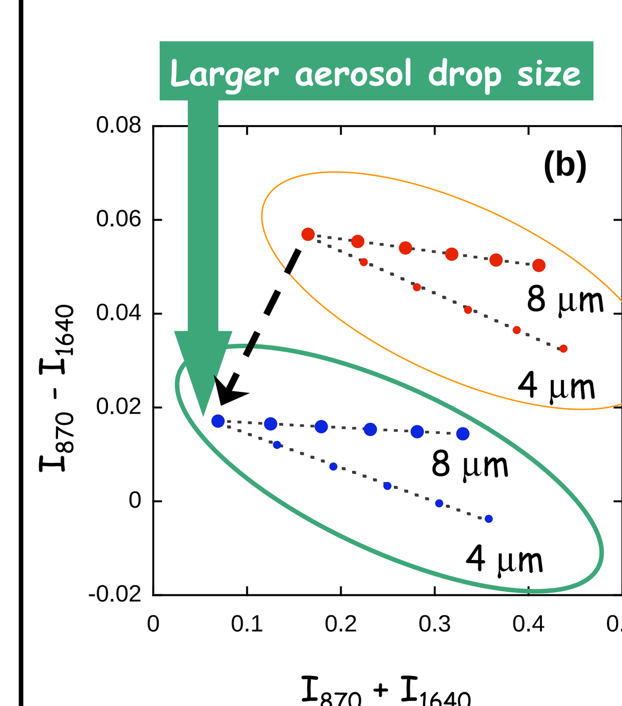
- Generally, we define 5 distinct Regimes on the 'DIF vs SUM' plane (see the schematic plot above).
- Based on 1D radiative transfer calculations and shortwave spectrometer observations (shown at left), we have found a linear spectral signature of the transition zone (Regime 1) between cloud-free (Regime 0) and cloudy areas (Regimes 2-4).
- Spectral signature in zenith radiance is determined by these 4 dominant factors:
  - Rayleigh and aerosol scattering;
  - In-cloud single scattering;
  - In-cloud multiple scattering;
  - Cloud-surface interaction.
- In Regime 1, in-cloud single scattering dominates; this causes a linear relationship between $I_{870} - I_{1640}$ and $I_{870} + I_{1640}$.
- The relationship in Regime 2 to 4 is non-linear due to multiple scatterings and cloud-surface interactions. Surface albedo has been high at the ARM Oklahoma site, and the surface is brighter at 870 nm than at 1640 nm.

Impacts of aerosol properties

1. The spectral signature in cloud-free areas (Regime 0) is <u>strongly sensitive to</u> aerosol properties.
2. In contrast, the slope of the linear relationship in the transition zone (Regime 1) is <u>weakly sensitive to</u> aerosol properties.



3. An increase in aerosol loading moves Regime 0 toward the upper-right direction, meaning that radiances increase at both 870 and 1640 nm and the former increases faster than the latter. In Fig. (a), we increase aerosol optical depth from 0.05 to 0.15, 0.02 to 0.08 for 870 and 1640 nm, respectively. 4 µm and 8 µ m are referred to cloud drop sizes.



4. An increase in aerosol drop size moves Regime 0 toward the lower-left direction, meaning that the radiances decrease at both 870 and 1640 nm and the former decreases faster than the latter. In Fig. (b), we increase aerosol effective radius from 0.25 to 4 µm.