



ARM SWS

to study cloud drop size within the clear-cloud transition zone

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Thanks to Peter Pilewskie (UC) and Connor Flynn (PNNL)



Why is the transition zone?

- It is difficult to distinguish between cloudy and cloud-free air in remote sensing observations (e.g., Stevens & Feingold, 2009).
- The regions around clouds are neither precisely clear nor precisely cloudy (Koren et al., 2008).
- This problem has major climatic consequences, in particular on aerosol indirect effect studies, which demand a precise separation of clear and cloudy air (e.g., Charlson et al., 2007).



ARM Shortwave Spectroradiometer



The SWS measures zenith spectral radiance.

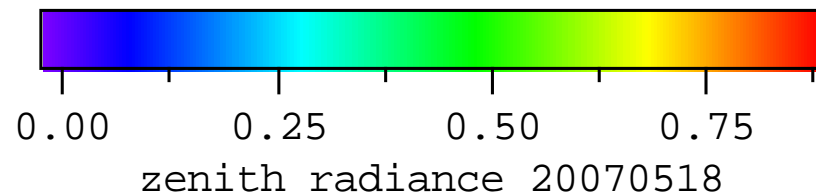
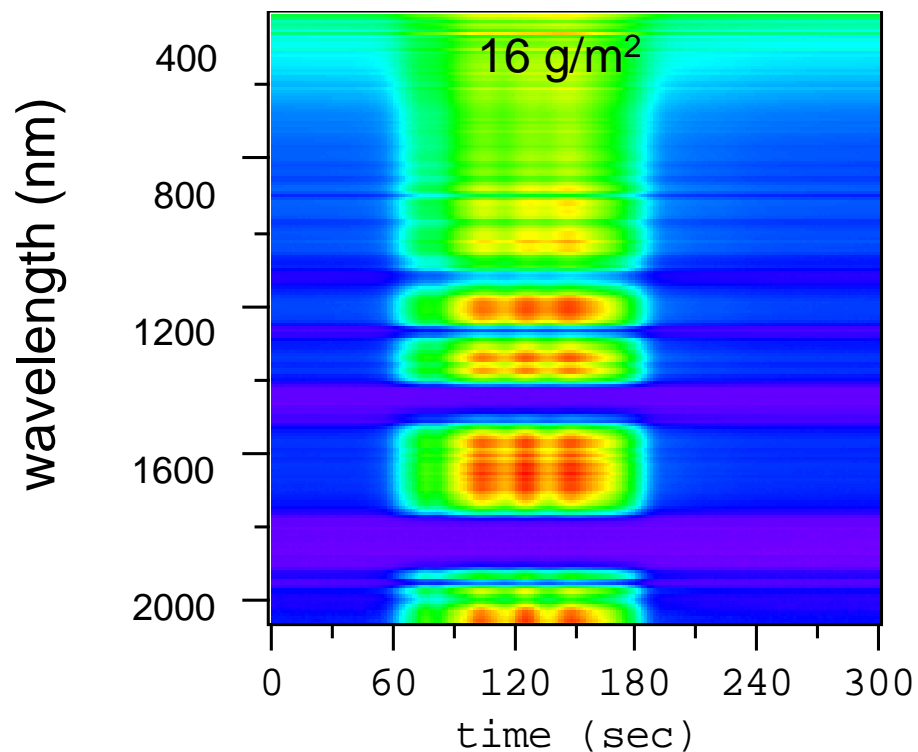
- Spectral Range: **350-2170** nm
- Spectral Resolution
 - 350-970 nm: 8nm
 - 970-2170 nm: 12nm
- Spectral Sampling rate: **1 Hz**
- Field of view: **1.4°**
- **418** wavelengths

(adapted from Pilewskie's presentation at the last ARM STM)



SZA=45°

May 18, 2007



at 250 sec

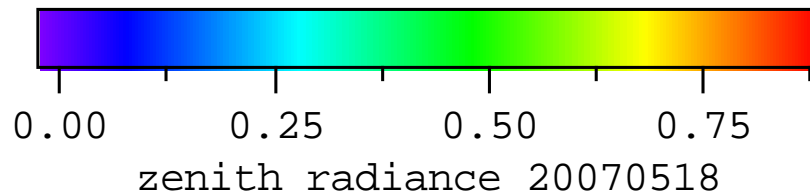
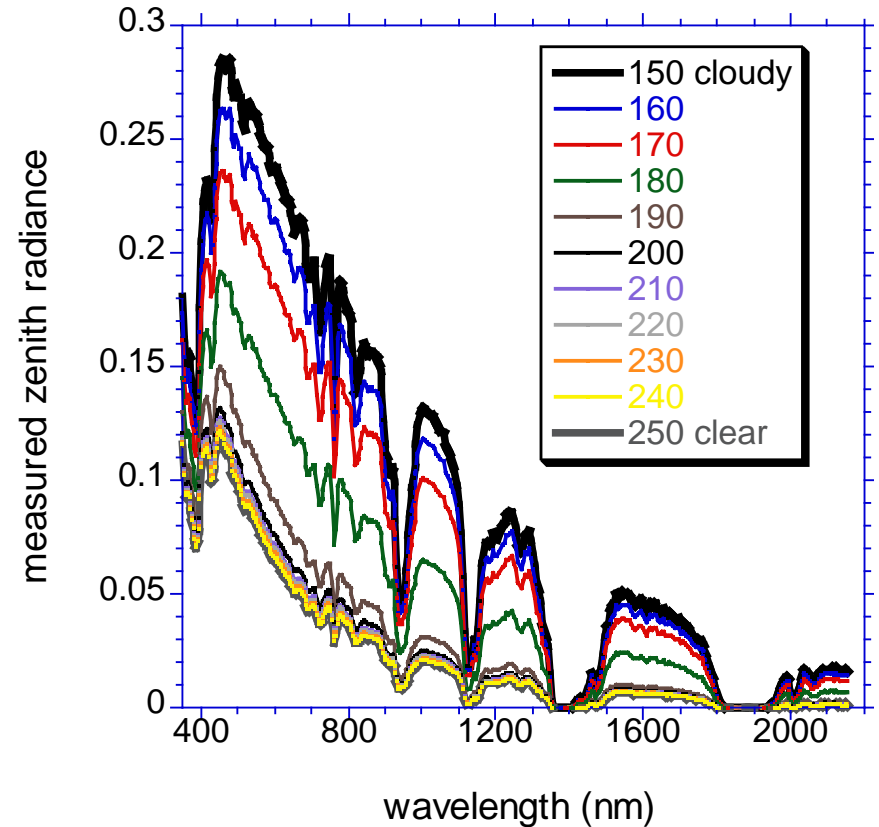
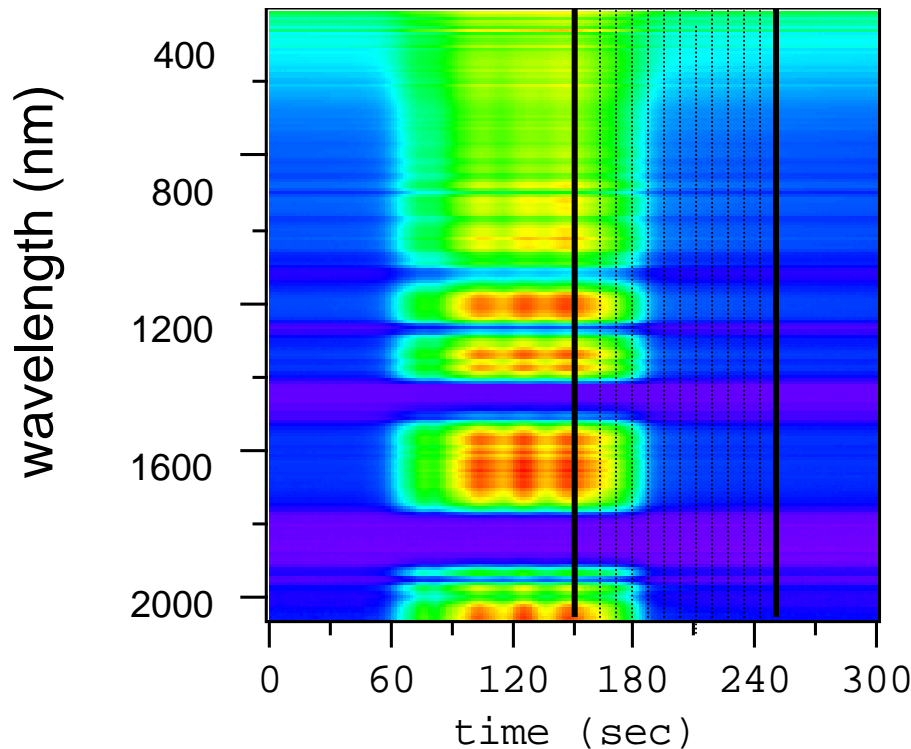
CBH=2km



Consider the whole SWS spectrum

SZA=45°

May 18, 2007

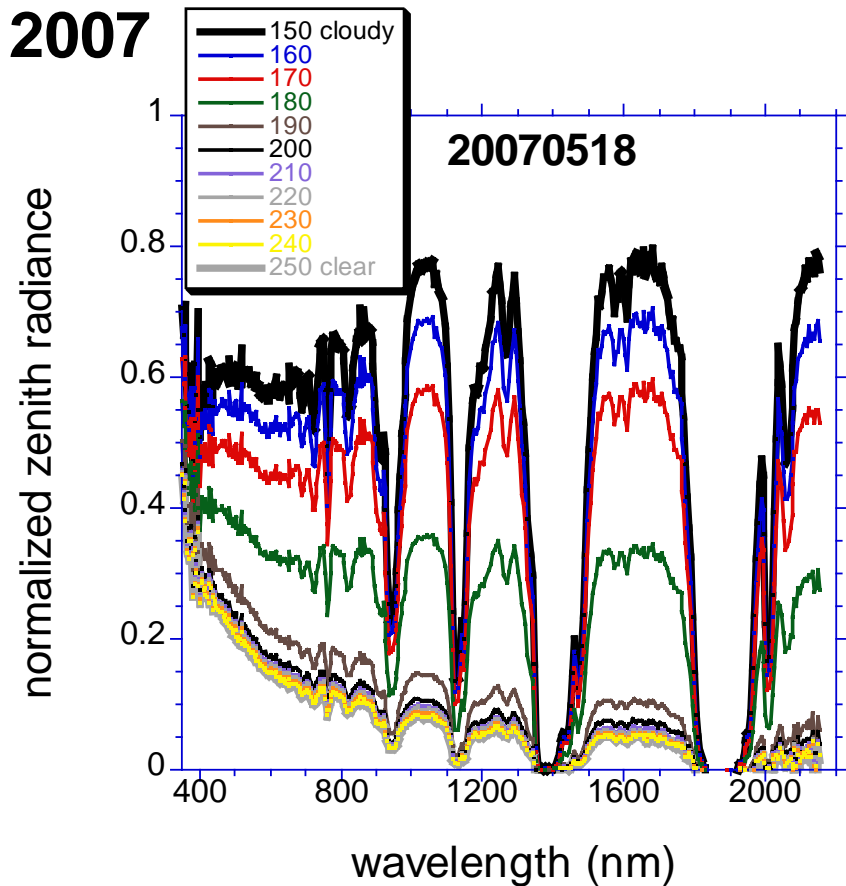
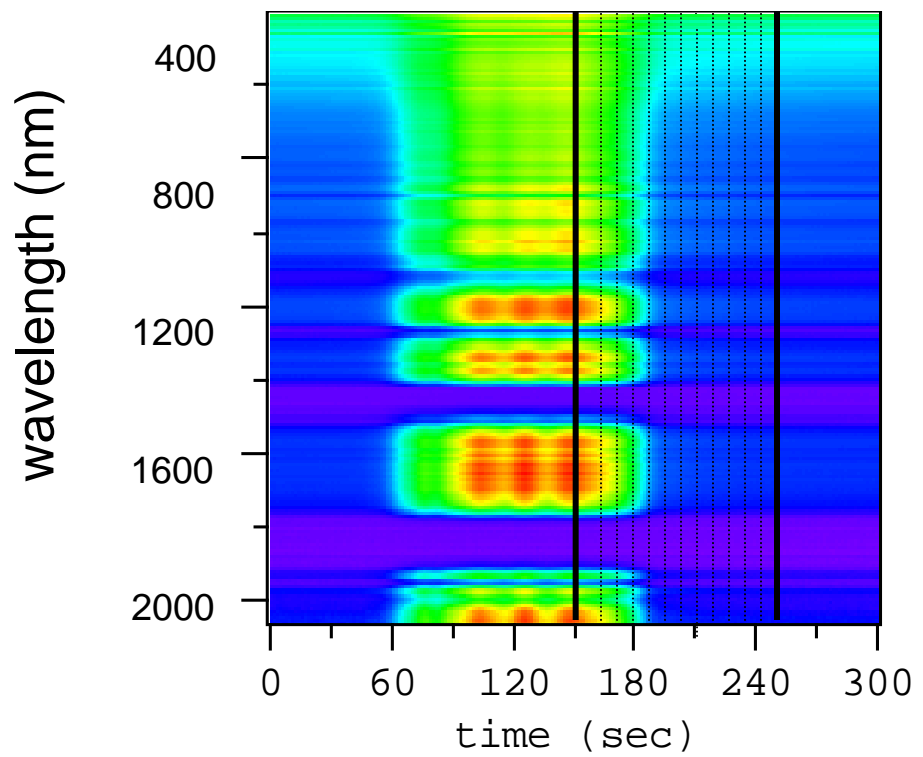




Consider the whole SWS spectrum

SZA=45°

May 18, 2007



Normalized to an extraterrestrial solar spectrum



Spectral-invariant hypothesis

Zenith radiance spectrum in the transition zone is a linear combination of cloudy and clear sky spectra with a wavelength-independent weight

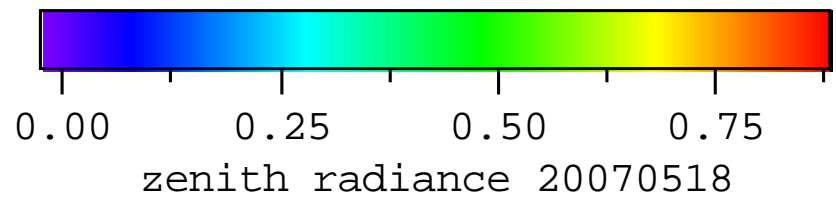
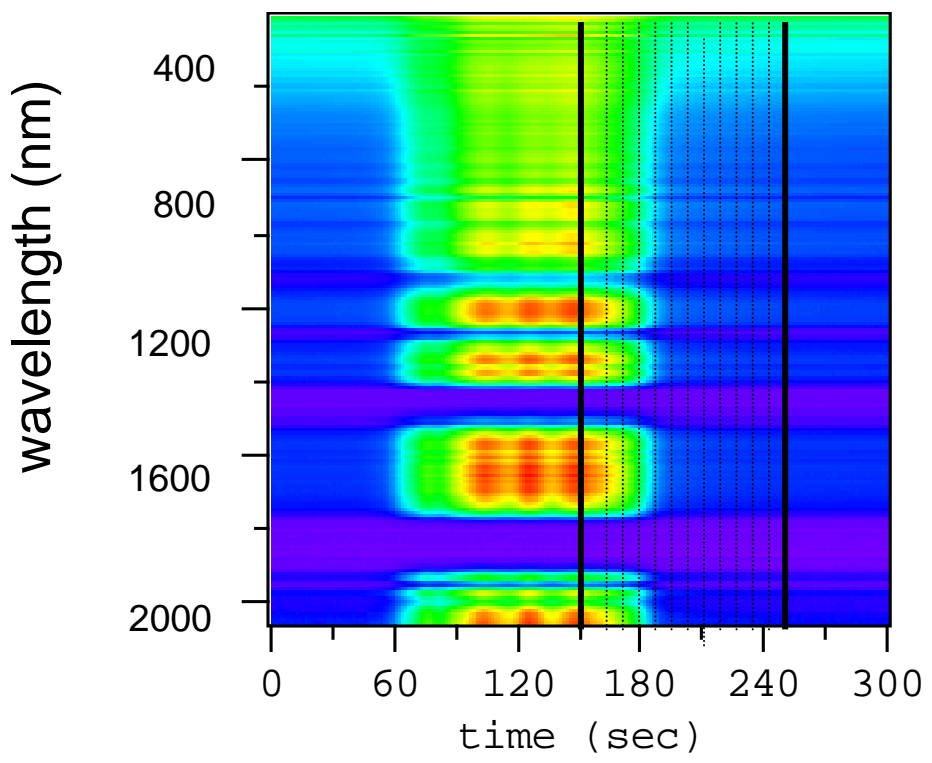
$$I_{transition}(\lambda) = aI_{cloudy}(\lambda) + (1-a)I_{clear}(\lambda),$$
$$a \in (0,1), a \neq a(\lambda)$$

$$\frac{I_{transition}(\lambda)}{I_{clear}(\lambda)} = a \frac{I_{cloudy}(\lambda)}{I_{clear}(\lambda)} + (1-a)$$

(i) $y(\lambda) = ax(\lambda) + b$
(ii) $b = 1 - a$

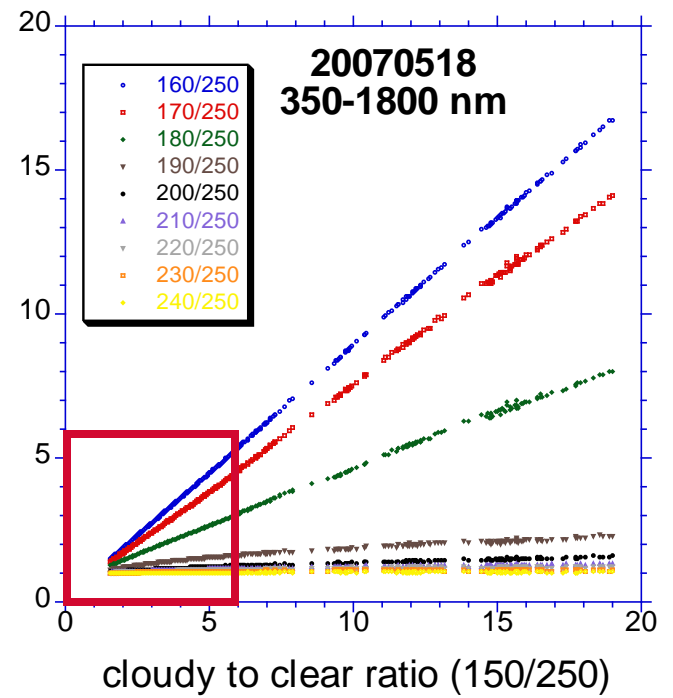


Checking spectral-invariance

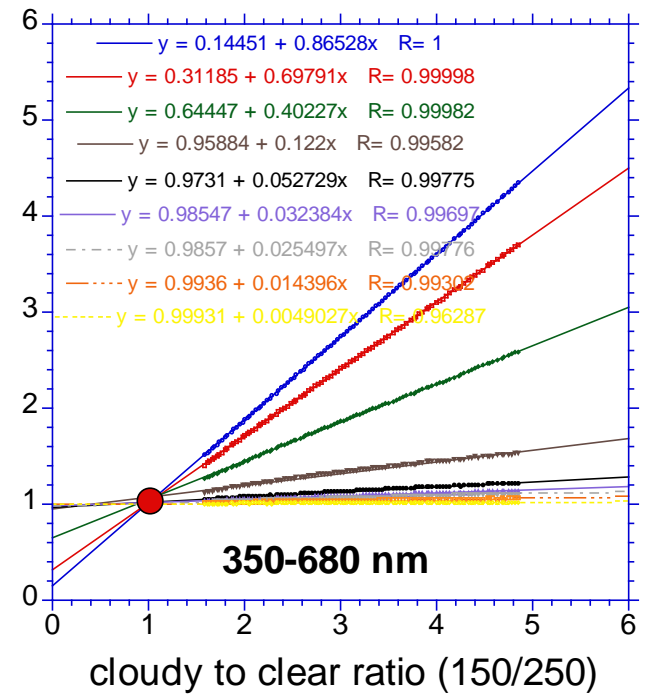


$$\frac{I_{transition}(\lambda)}{I_{clear}(\lambda)} = a \frac{I_{cloudy}(\lambda)}{I_{clear}(\lambda)} + (1-a)$$

ratios to clear

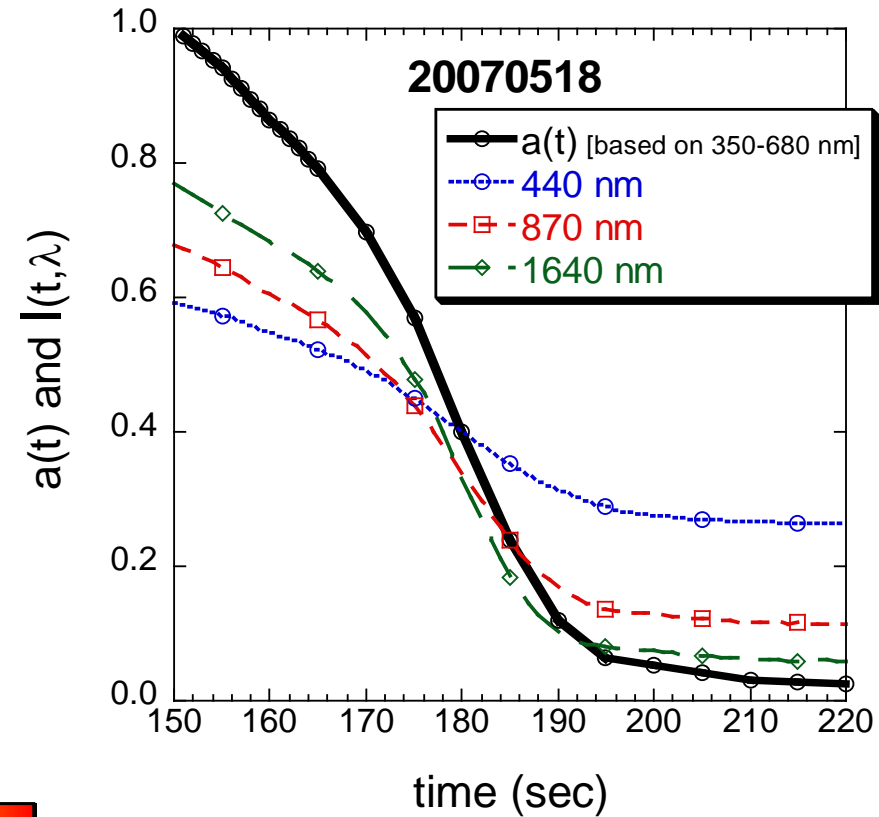
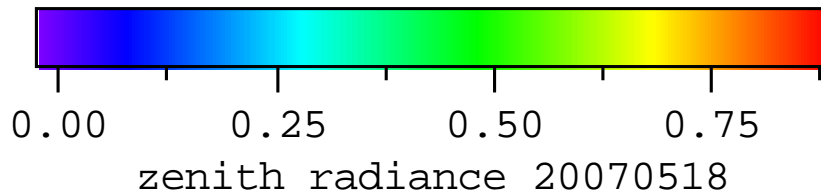
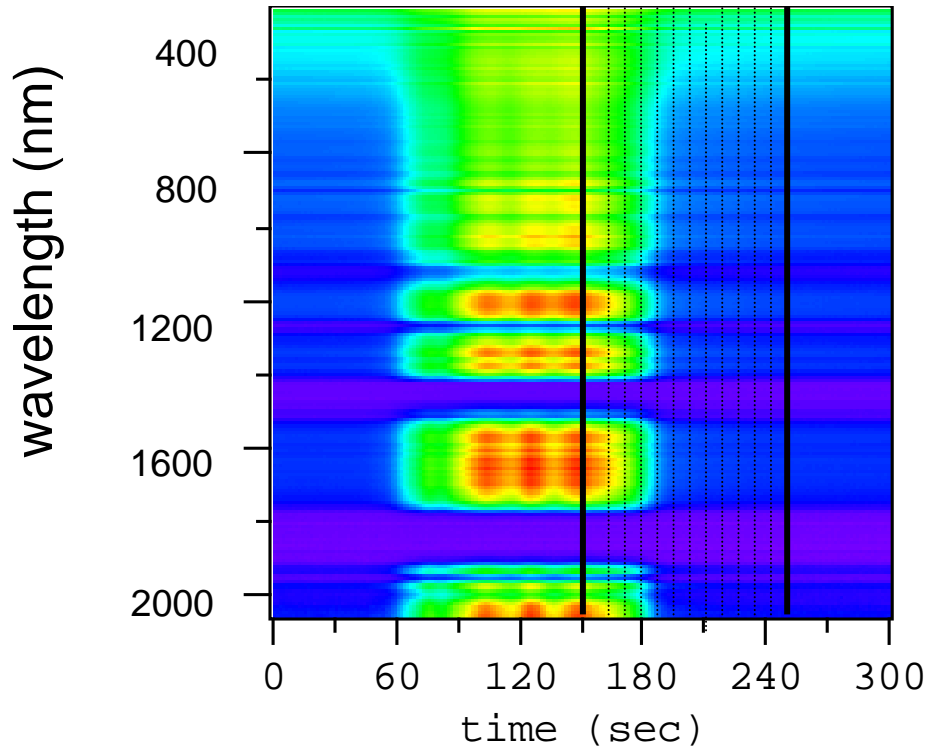


ratios to clear





Wavelength-independent function $a(\text{time})$ or $a(\text{space})$



from Marshak et al., 2009



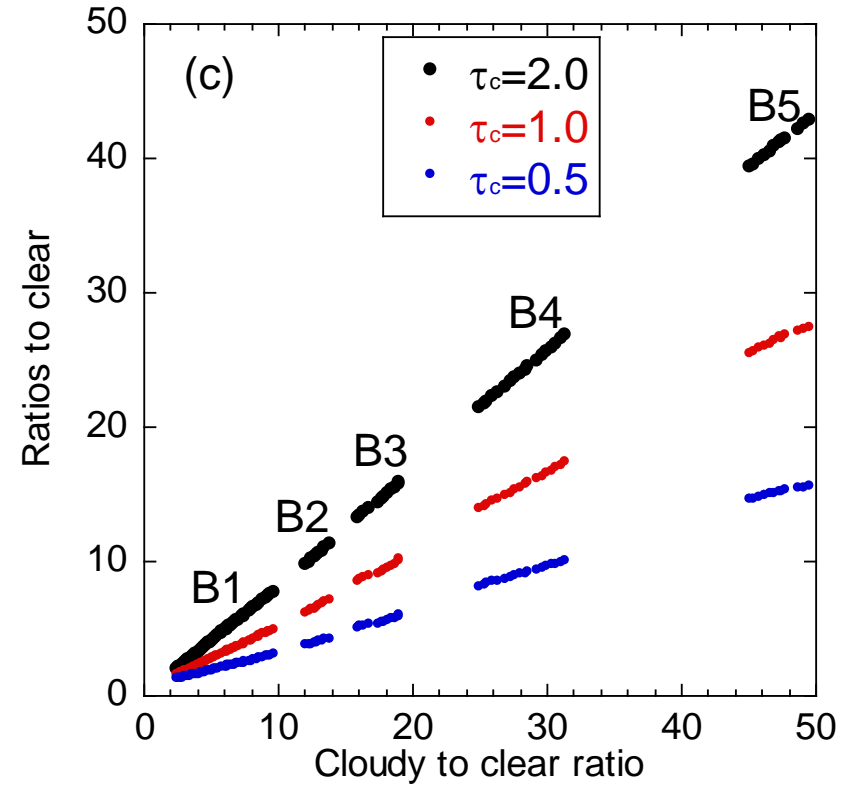
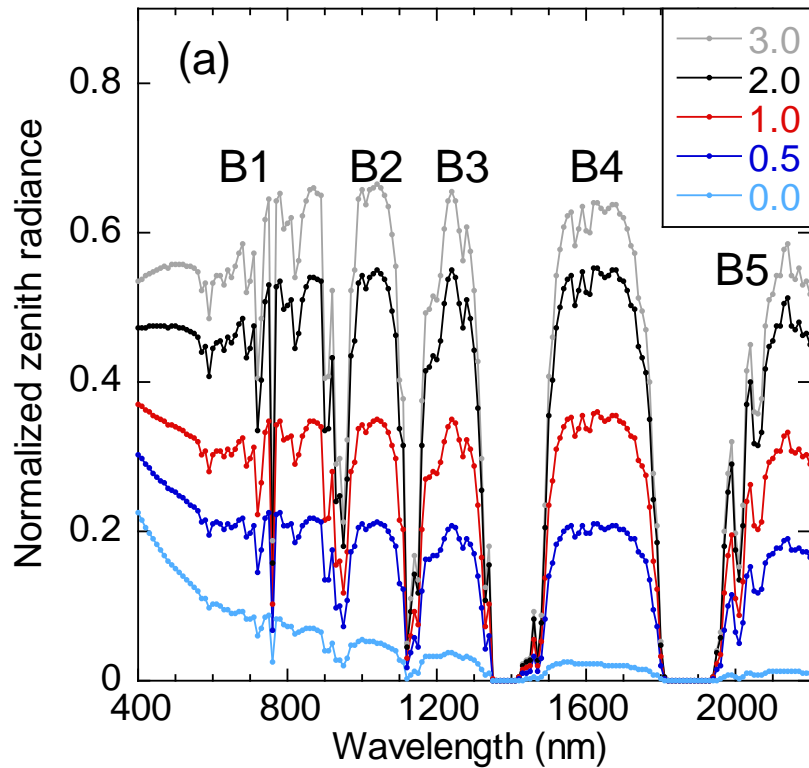
Do radiative transfer calculations confirm this spectral-invariant behavior found in SWS data?

- Use SBDART to calculate zenith radiance at 400-2200 nm wavelengths with a 10 nm resolution
- **Atmosphere**
 - mid-latitude summer atmosphere
 - 3 cm integrated water vapor amount
 - default trace gas amount
- **Aerosol**
 - Rural aerosol type; 0.2 - 1 optical depth at 550 nm
 - 80% relative humidity
- **Cloud**
 - 0-4 cloud optical depth (defined at 550 nm)
 - 1 km altitude

from Chiu et al., ACPD 2010



Modeling: Whole spectrum



SBDARD zenith radiances

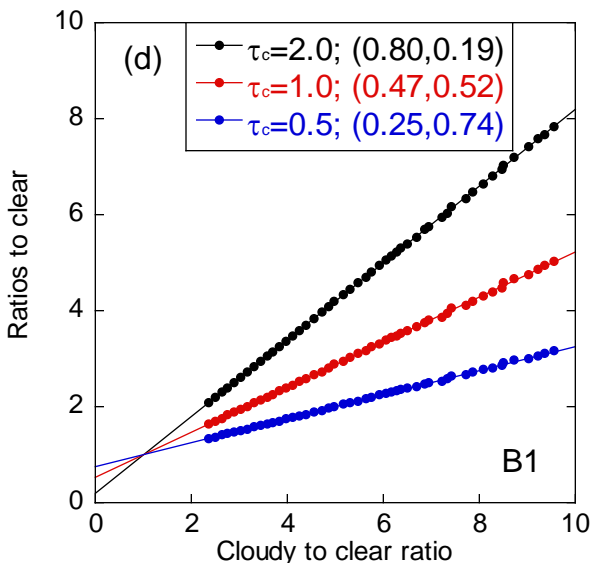
Ratios to clear radiance

$$\frac{I_{transition}(\lambda)}{I_{clear}(\lambda)} = a \frac{I_{cloudy}(\lambda)}{I_{clear}(\lambda)} + b$$

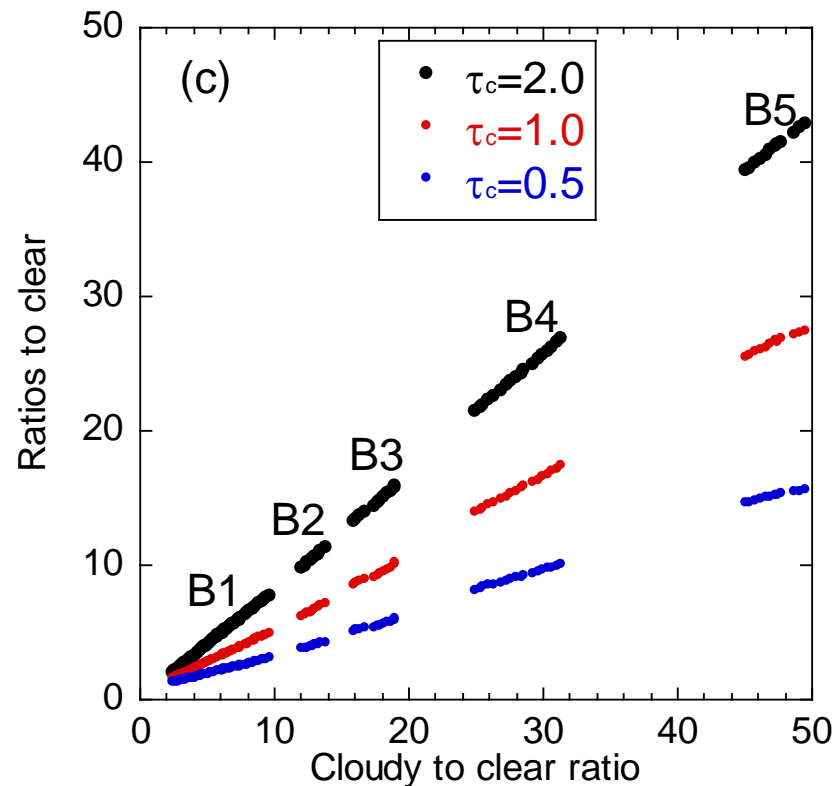
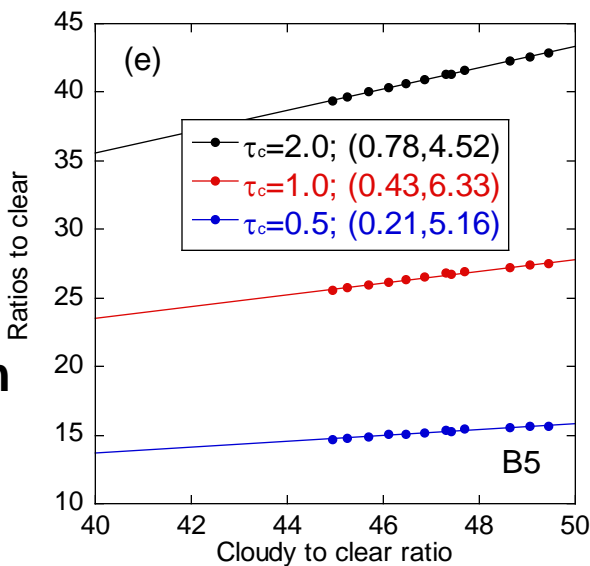


Modeling: B1 and B5 bands

B1
0.4-0.8 μm



B5
2.0-2.2 μm

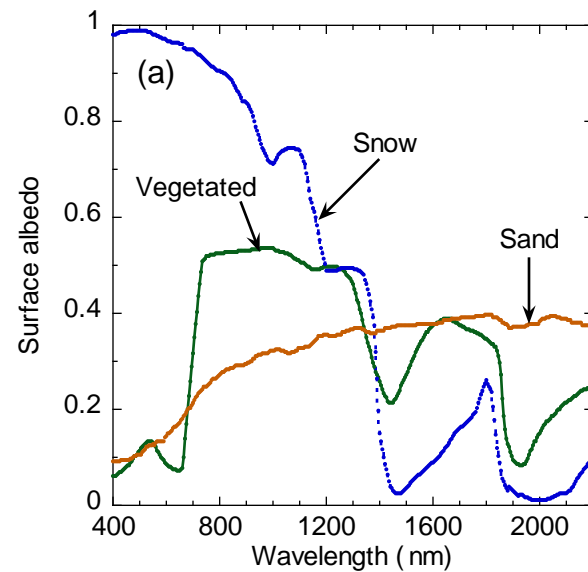
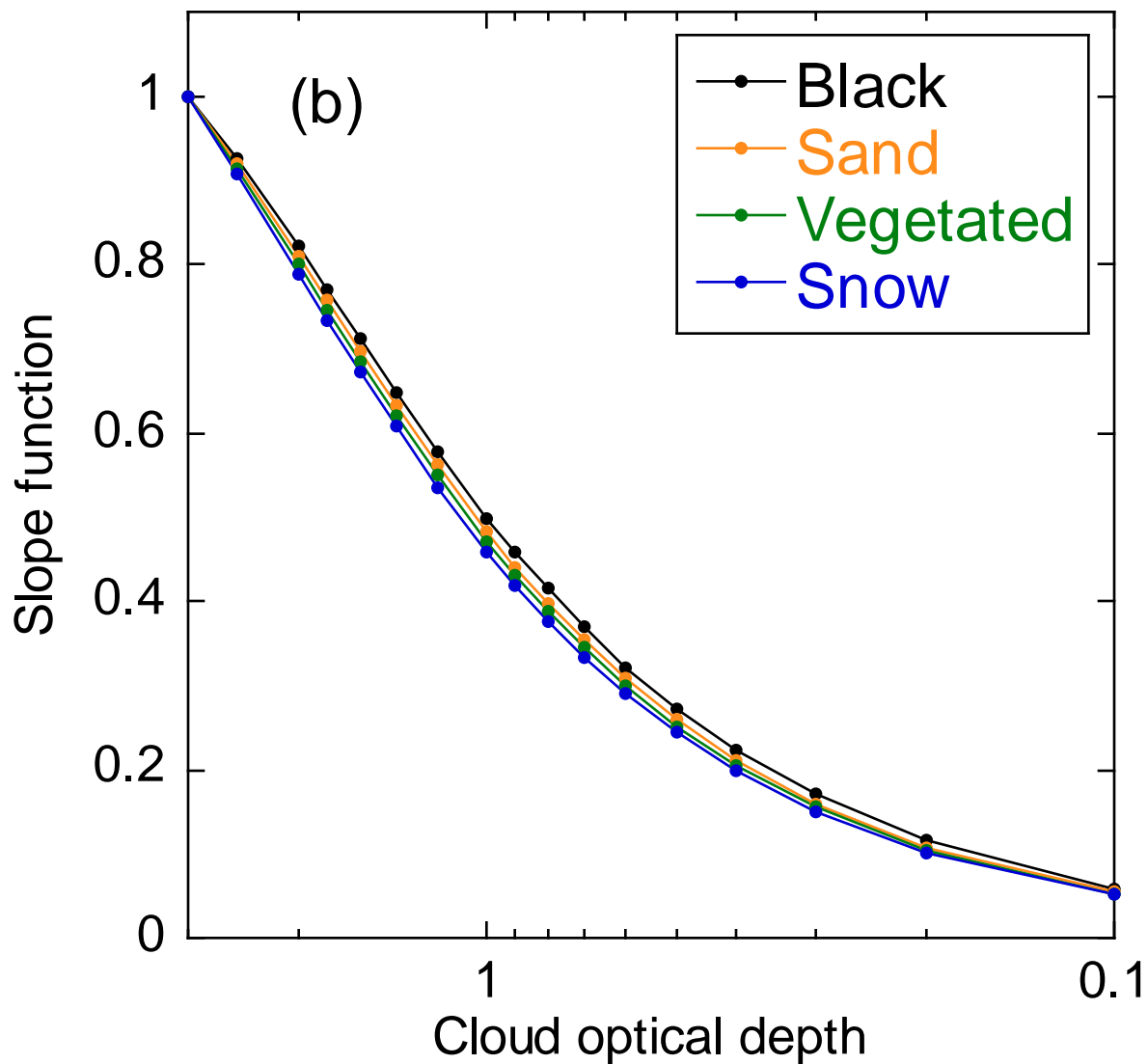


Ratios to clear radiance

$$\frac{I_{transition}(\lambda)}{I_{clear}(\lambda)} = a \frac{I_{cloudy}(\lambda)}{I_{clear}(\lambda)} + b$$

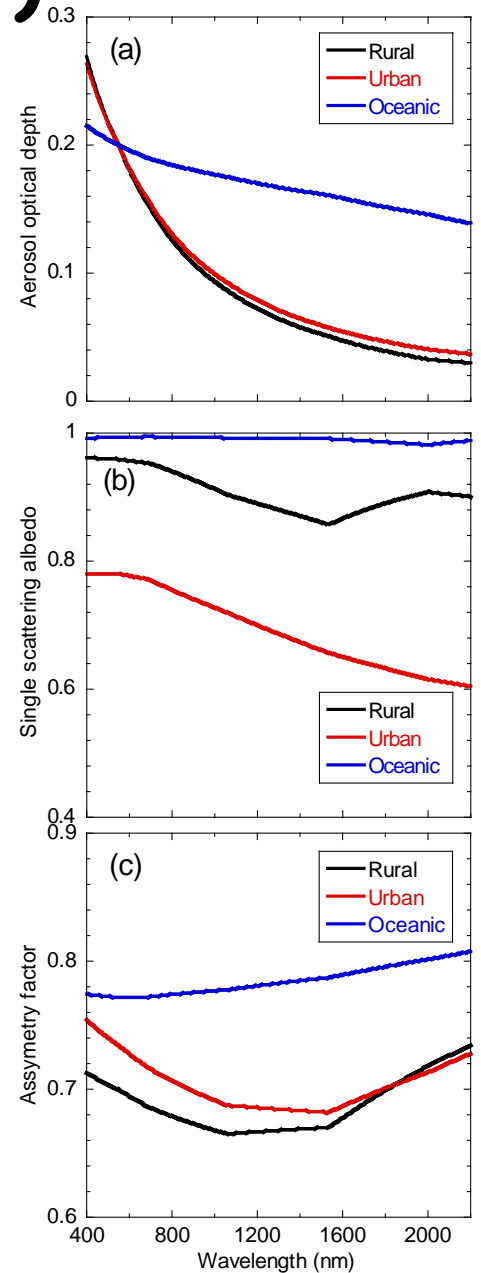
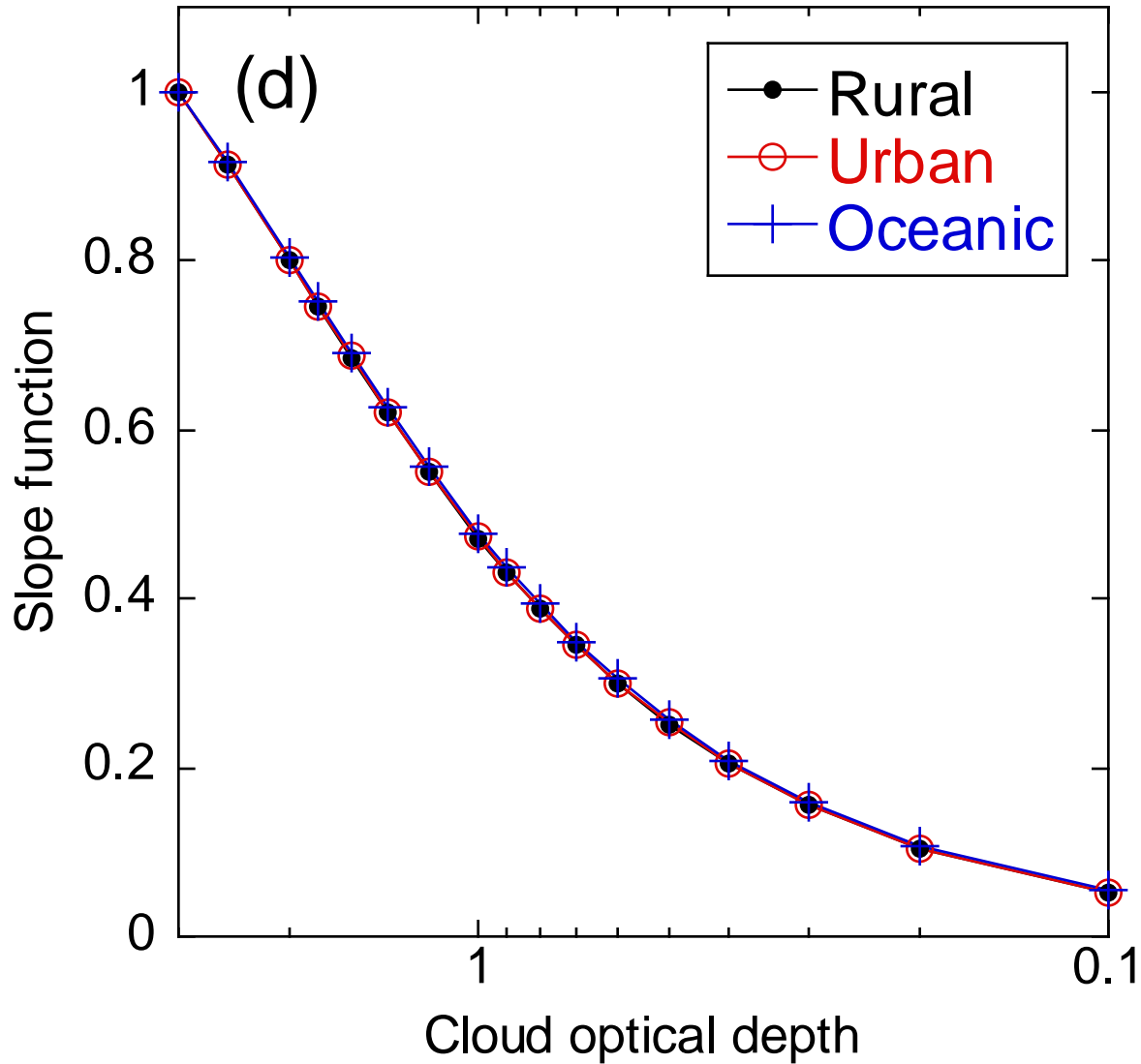


Surface albedo (B1)



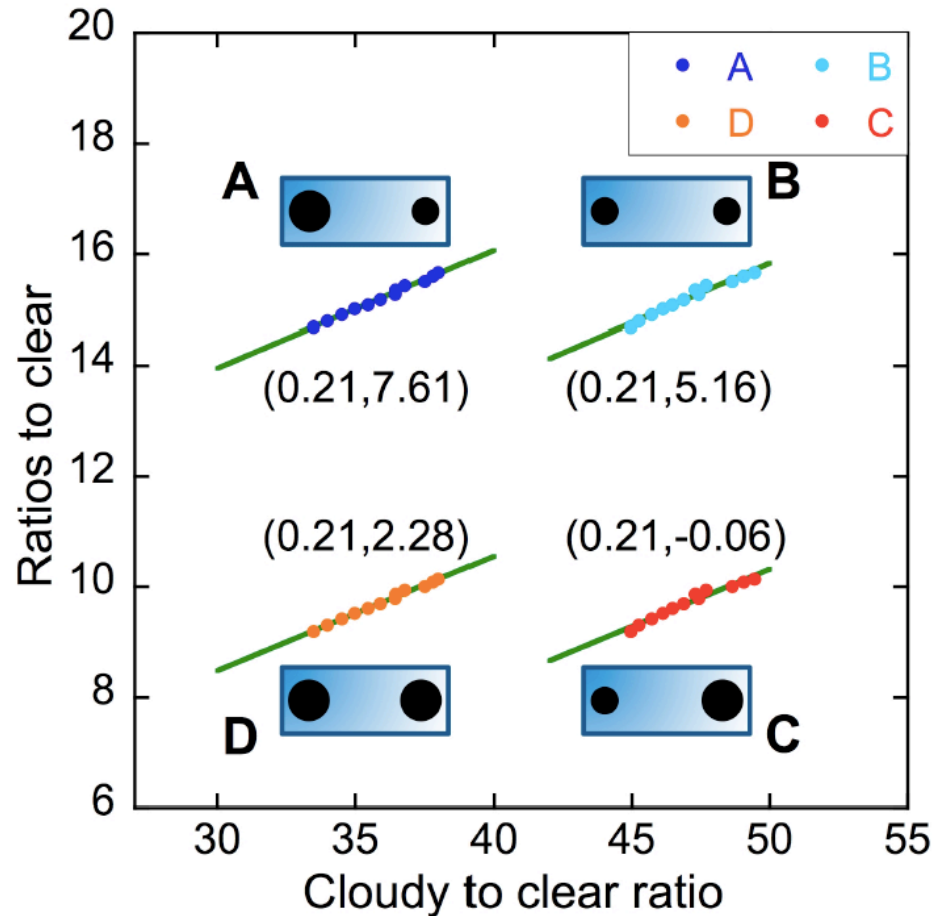
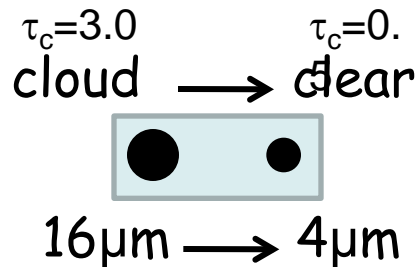
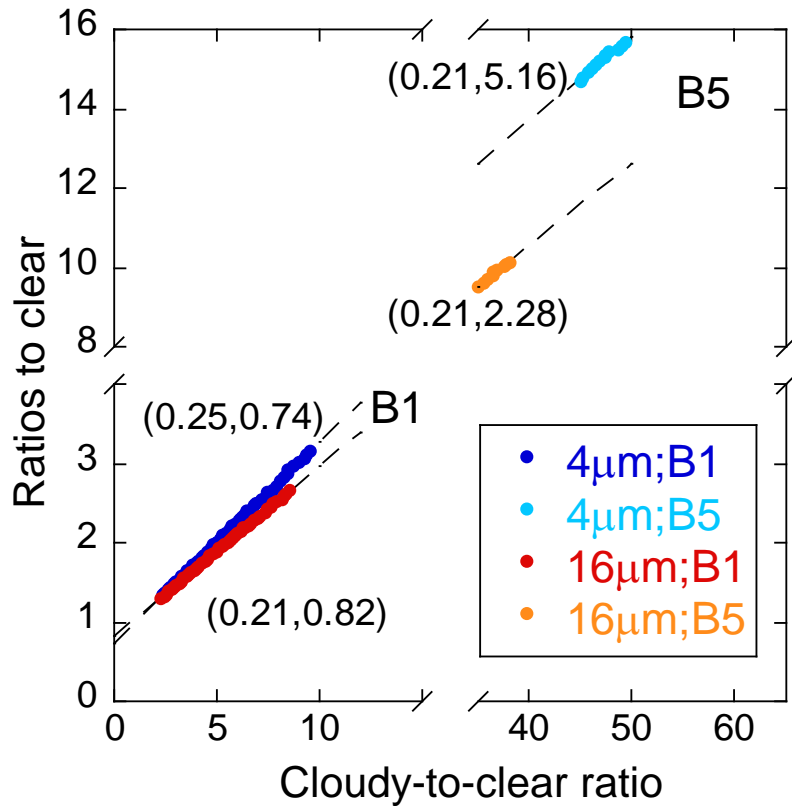


Aerosol effect (B1)





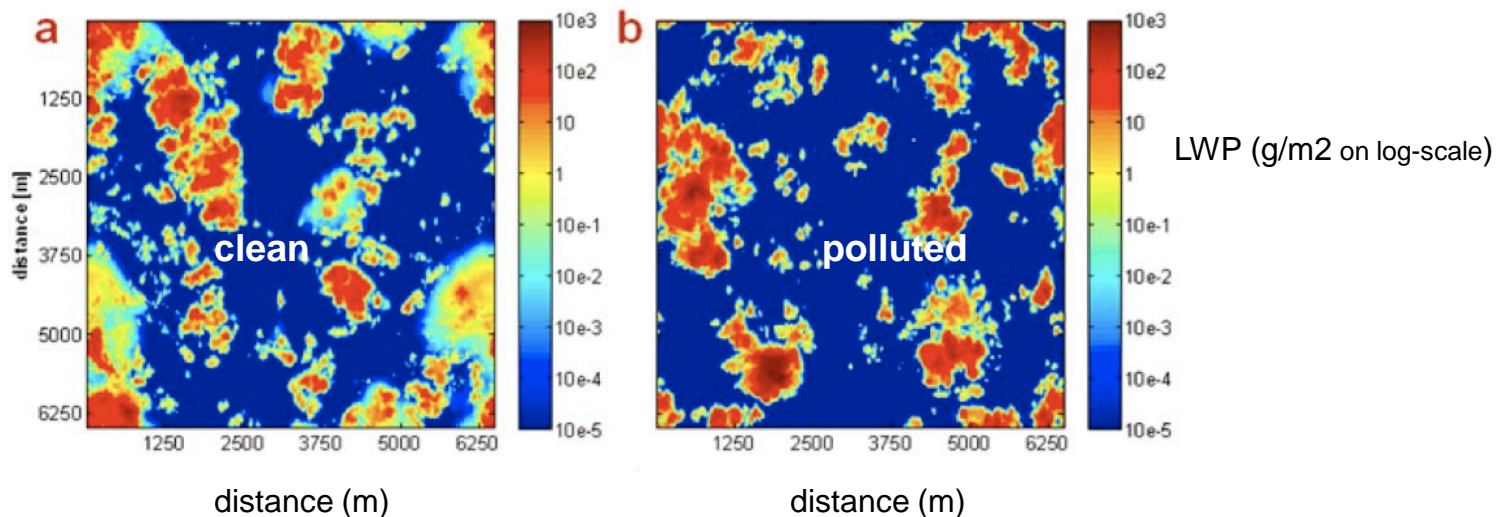
Different drop size in B1 and B5



The high sensitivity of the intercept to cloud drop size can be used to understand cloud growth/evaporation processes in the transition zone

Application to aerosol effect on cloud morphology

KOREN ET AL.: AEROSOL EFFECT ON THE INTER-CLOUD REGION



Koren et al. (GRL, 2009): "The polluted field dries out more rapidly with distance from cloud, and in the cleaner cloud field there are more numerous and larger weak-cloud elements."

Jiang et al. (JGR, 2009) "... these responses are a result of ... stronger evaporation at cloud edges in the case of polluted clouds."



(Potential) observational evidence: 2NFOV

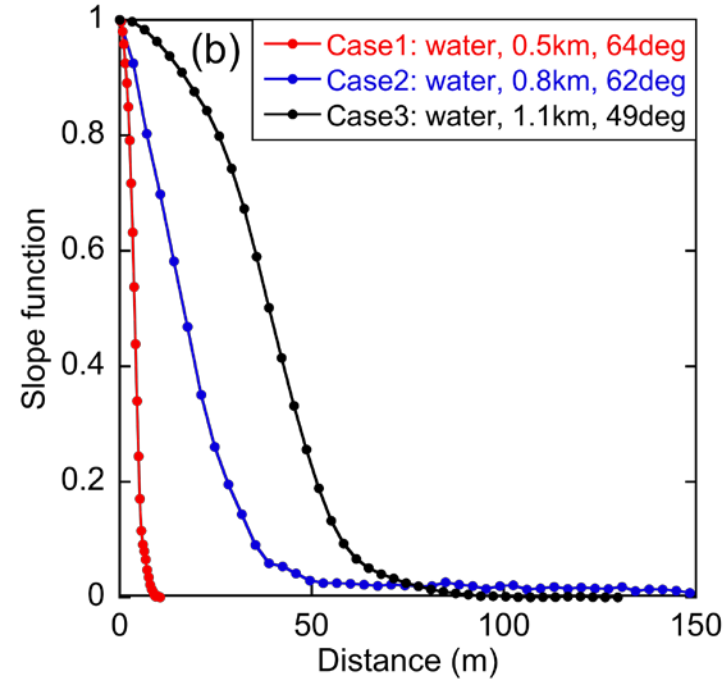
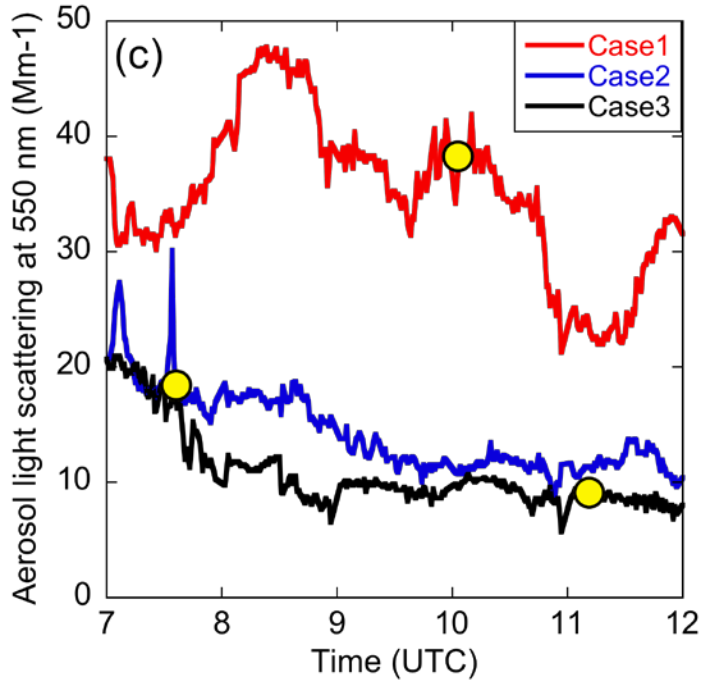
Case 1



Case 2



Case 3



FOV = 1.2°
 wavelengths:
 673 nm (RED)
 870 nm (NIR)



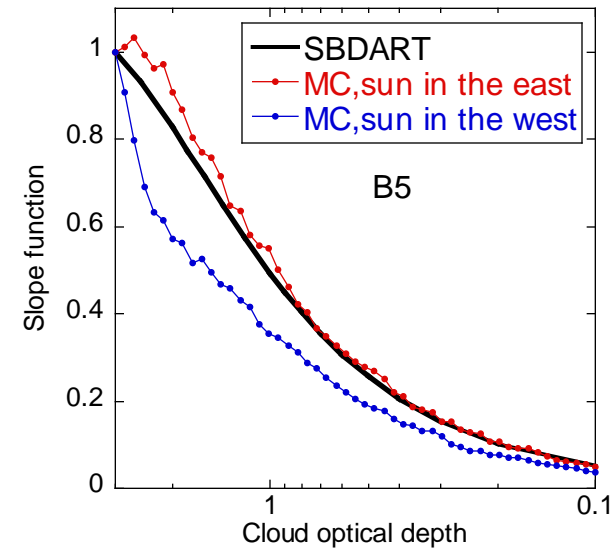
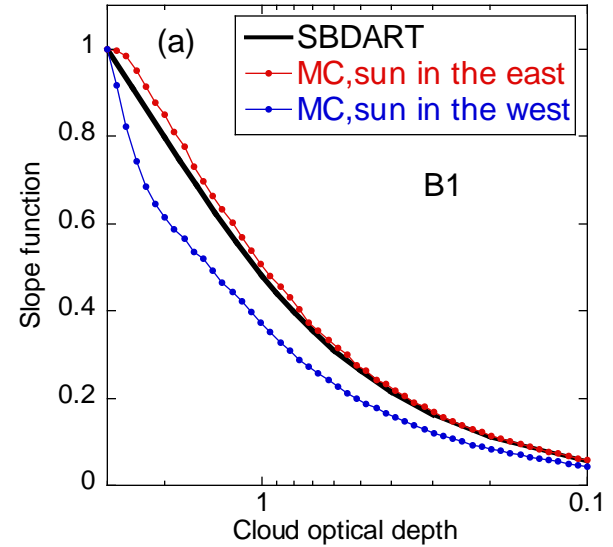
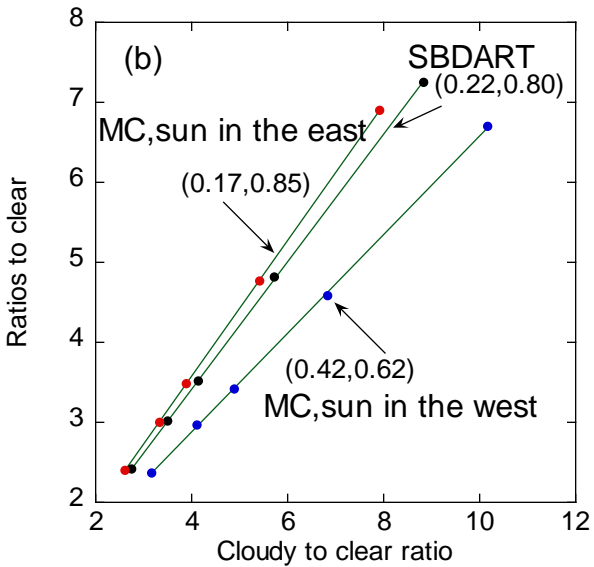
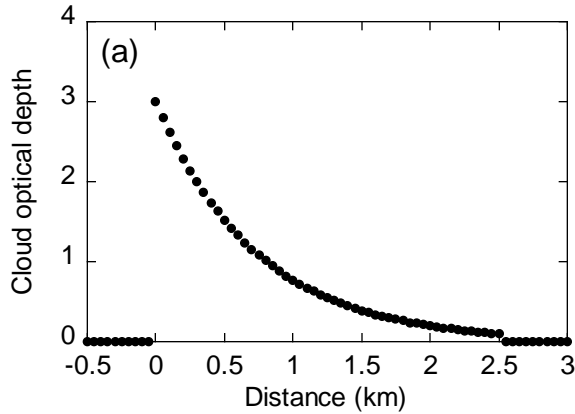


Summary

- The slope and intercept of the spectral-invariant relationship is mostly sensitive to cloud properties and NOT sensitive to surface type and aerosol properties
- At visible wavelengths, both the slope and intercept primarily depend on cloud optical depth; at water-absorbing wavelengths, the intercept depends on cloud absorption properties
- These results suggest a new cloud retrieval method for the transition zone even with insufficient knowledge about spectral surface albedo and aerosol properties



3D effect



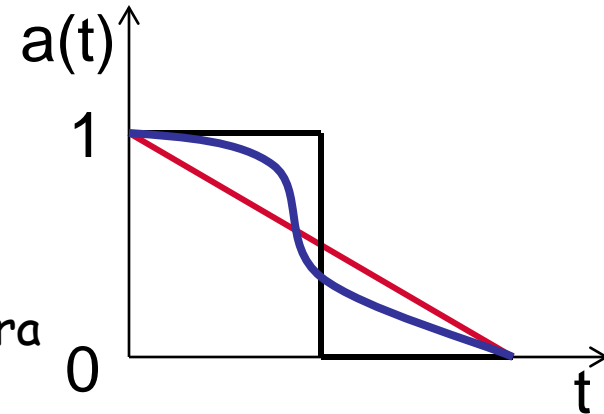


Discussion 1

There is a wavelength-independent function

$a(\text{time})$ or $a(\text{space})$

that characterizes the transition zone (TZ) between cloudy and clear areas. The TZ spectrum is fully determined by this function and zenith radiances spectra of clear and cloudy sky areas.



Model simulations support this statement. However, we do not have yet a clear theoretical understanding of the observed (and simulated) phenomenon.

High temporal resolution meas. in the TZ can be well approx. by the lower temporal resolution plus a linear interpolation.

Missing (or saturated) spectral data in the TZ can be well retrieved using meas. of the whole spectra of clear and cloudy sky areas.



Discussion 2 (applications)

If spectral-invariance of the TZ is established, function $a(\tau)$ can be studied using only two wavelengths, e.g. high temporal resolution 2NFOV (with Red and Near IR channels).

The TZ between *ice* clouds and cloud-free area is longer and smoother than between *water* and cloud-free area.

Koren et al. (2009) and Jiang et al. (2009) found much sharper cloud edges in polluted environments compared to their cleaner counterparts. Thus $a(\tau)$ can serve as a characteristic of pollution in a field with small Cu clouds.

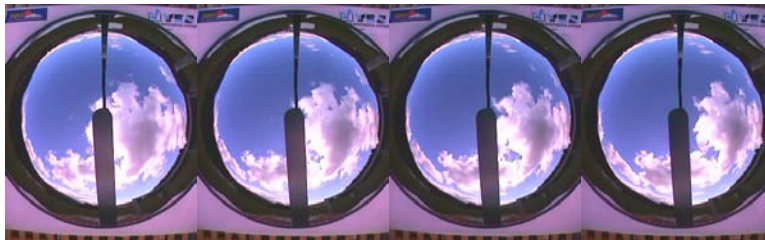


Discussion 3 (remote sensing)

- The slope and intercept of the spectral-invariant relationship is mostly sensitive to cloud properties and not sensitive to surface type and aerosol properties
- At visible wavelengths, both the slope and intercept primarily depend on cloud optical depth; at water-absorbing wavelengths, the intercept depends on cloud absorption properties
- These results suggest a new cloud retrieval method for the transition zone even with insufficient knowledge about spectral surface albedo and aerosol properties



Possible application to cloud thermodynamic phase: 2NFOV



water



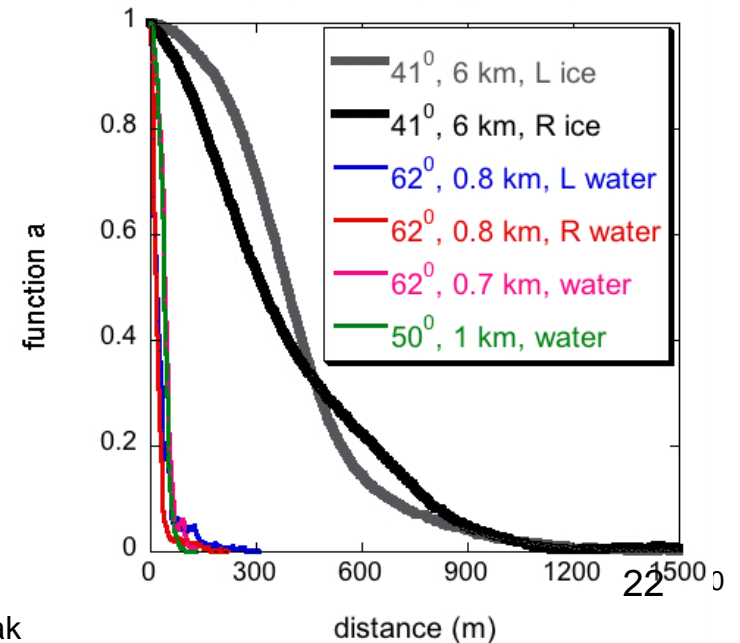
ice

TSI images every 30 sec



FOV = 1.2°
wavelengths:
673 nm (RED)
870 nm (NIR)

Ice vs Water Clouds





Spectral-invariance

$$y(\lambda) = ax(\lambda) + b$$