What can be learned from ARM shortwave hyperspectral observations?

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1. Introduction

Understanding the transition zone is necessary to understand fully 3D cloud scenes.

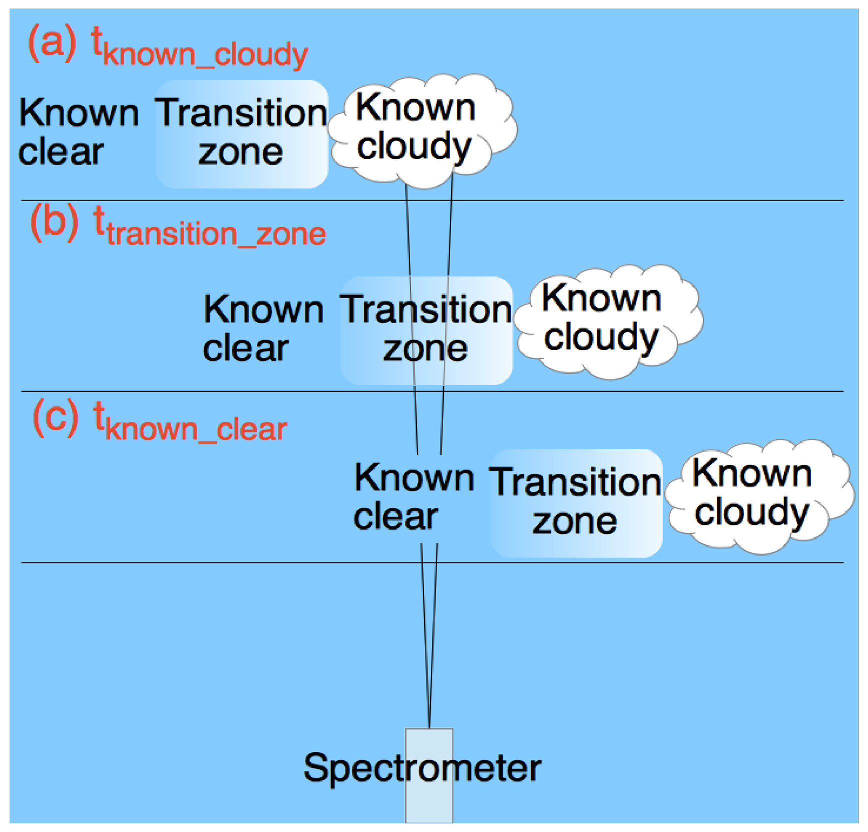
The transition zone is an active region of cloud-aerosol interactions.

Current retrieval algorithms do not perform well for thin cloud that is typical in this transition.

We explore the use of shortwave hyperspectral radiance observations and the spectral invariant relationship (see Section 2) to study the cloud transition zone, the region between cloudy and cloudless skies.

2. Spectral invariant relationship

Three regimes advect over a spectrometer as a cloud edge passes (see figure to the right):
(1) Known cloudy
(2) Transition zone
(3) Known clear



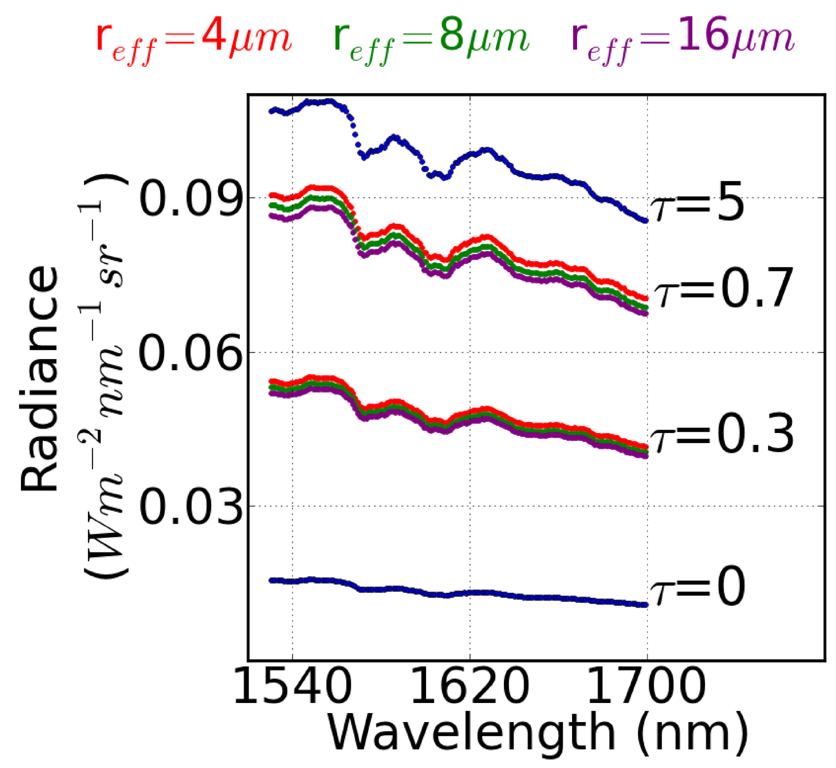
Observed radiance (I_λ) in the transition zone is, to a very good approximation[1,2], a linear combination of a known cloudy and a known clear spectrum with a ***spectral invariant slope (m) and y-intercept (b)***

$$\frac{I_\lambda(t_{\text{transition\_zone}})}{I_\lambda(t_{\text{known\_clear}})}=\frac{I_\lambda(t_{\text{known\_cloudy}})}{I_\lambda(t_{\text{known\_clear}})}m+b$$

where t is time, $\frac{I_\lambda(t_{\text{transition\_zone}})}{I_\lambda(t_{\text{known\_clear}})}=\text{ratio\_to\_clear}$, $\frac{I_\lambda(t_{\text{known\_cloudy}})}{I_\lambda(t_{\text{known\_clear}})}=\text{cloudy\_to\_clear}$

TOP: SBDART modeled NIR radiance for 2 values of cloud optical thickness (τ) and 3 effective radii (r_{eff}). The blue points show the known cloudy (τ=5) and known cloudless spectrum (τ=0).

BOTTOM: Ratio-to-clear, $I(\tau=0.7,0.3)/I(\tau=0)$, versus cloudy-to-clear ratio, $I(\tau=5)/(I(\tau=0))$



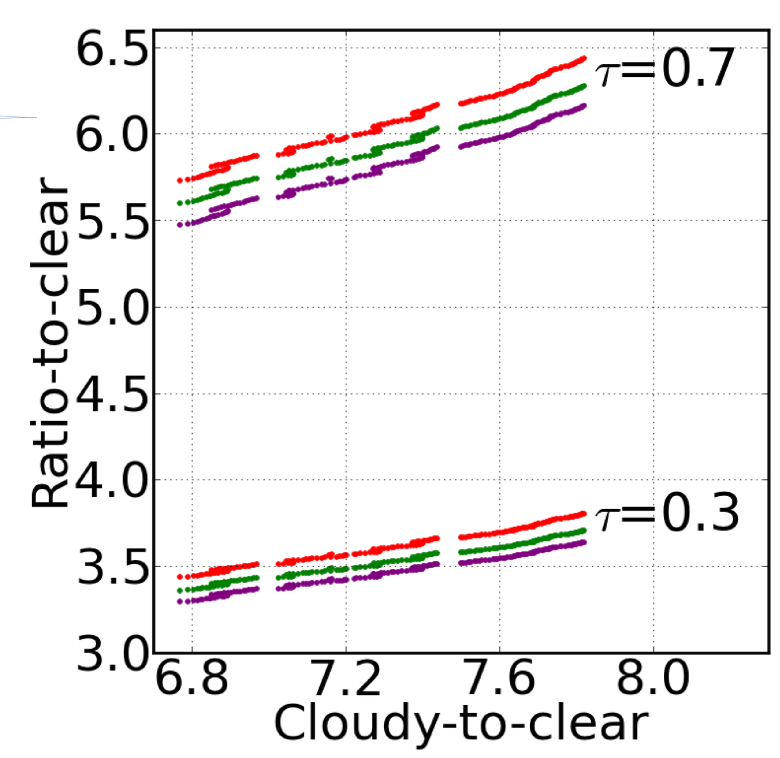
Linear corr. coeff. for modeled ratio-to-clear versus cloudy-to-clear are > 0.994.

Y-intercept in NIR is dependent on τ and r_{eff}

Slope in the visible is mostly dependent on τ

What are the benefits of hyperspectral obs. compared to dual-channel retrieval?

The slope and y-intercept are **less sensitive to instrument uncertainty** than using radiance alone.



References
[1] A. Marshak, Y. Knyazikhin, J. C. Chiu, and W. J. Wiscombe. Spectral invariant behavior of zenith radiance around cloud edges observed by ARM SWS. Geophysical Research Letters, 36(16):L16802+, August 2009.
[2] C. J. Chiu, A. Marshak, Y. Knyazikhin, P. Pilewskie, and W. J. Wiscombe. Physical interpretation of the spectral radiative signature in the transition zone between cloud-free and cloudy regions. Atmospheric Chemistry and Physics, 9(4):1419–1430, February 2009.

Conclusions

The spectral invariant slope is less affected by instrument uncertainty than the standard dual-channel VIS/NIR method developed for use with cloud reflectance, making it better suited for studying the thin cloud regime of the transition zone.

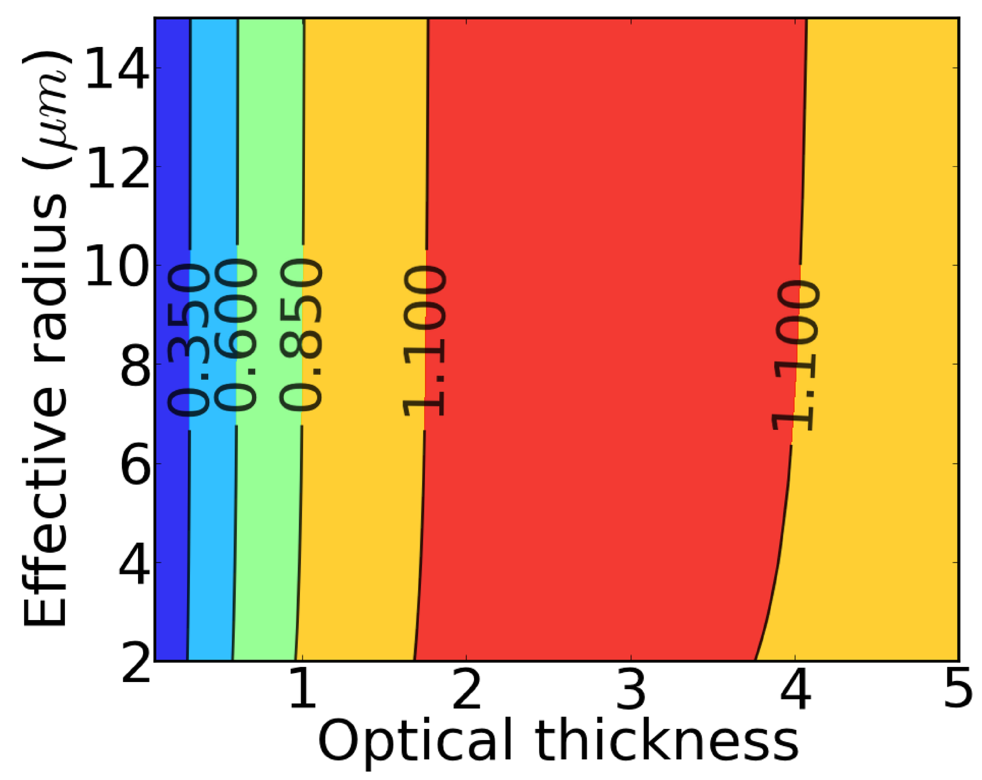
The spectral invariant method predicts the effective radius variation in 70% of the cases.

Cloud absorption can be estimated to within 10%-15% for typical clouds using transmitted zenith radiance observations.

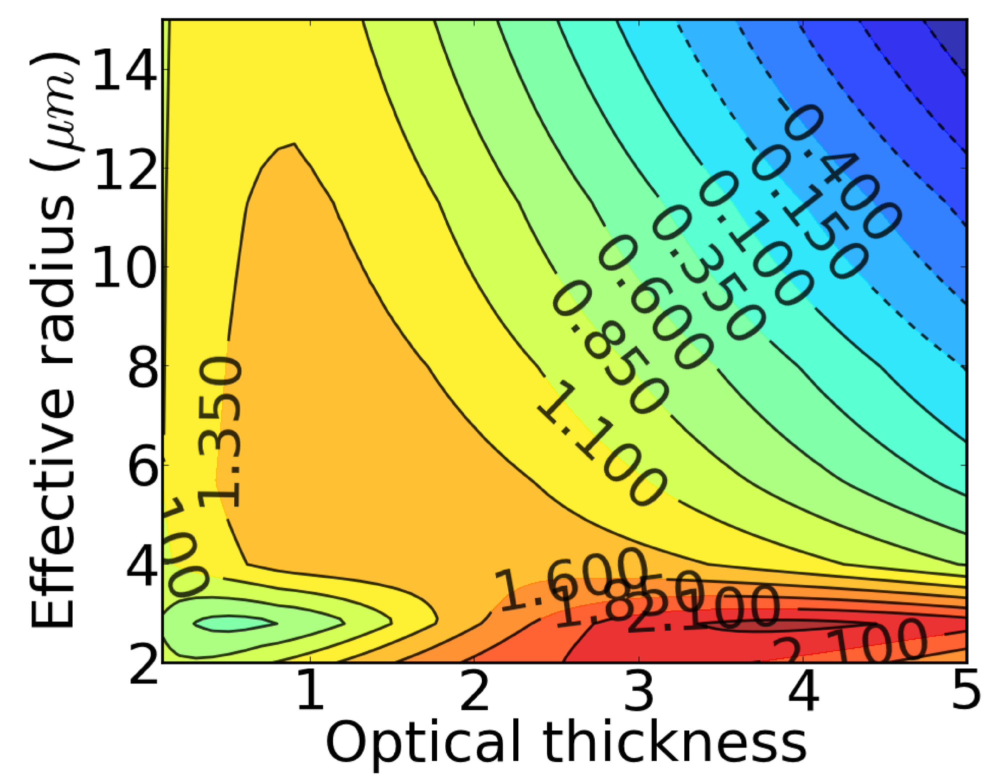
3. Cloud properties retrieved using spectral invariance

1) Find time periods with decreasing optical thickness using the slope, fit over visible wavelengths.

2) Determine the variation in effective radius with the y-intercept (lower figure).



Contour plot of the slope (VIS) (warmer colors=larger slope).



Contour plot of the y-intercept (NIR) (warmer colors=larger y-intercept)

Monte Carlo simulations, choosing two random points in the transition zone, show that the trend in y-intercept correctly predicts the trend in effective radius in 70% of the cases.

4. Cloud absorption estimation

Spectral cloud absorption can be estimated using the simple approximation:

$$A_{\lambda,est}=1-\frac{I_\lambda}{I_{\lambda=500\text{nm}}}$$

This assumes that the transmitted zenith radiance is representative of all energy leaving the cloud.

Estimates of cloud absorption are within 10%-15% for optical thickness between 5 and 20.