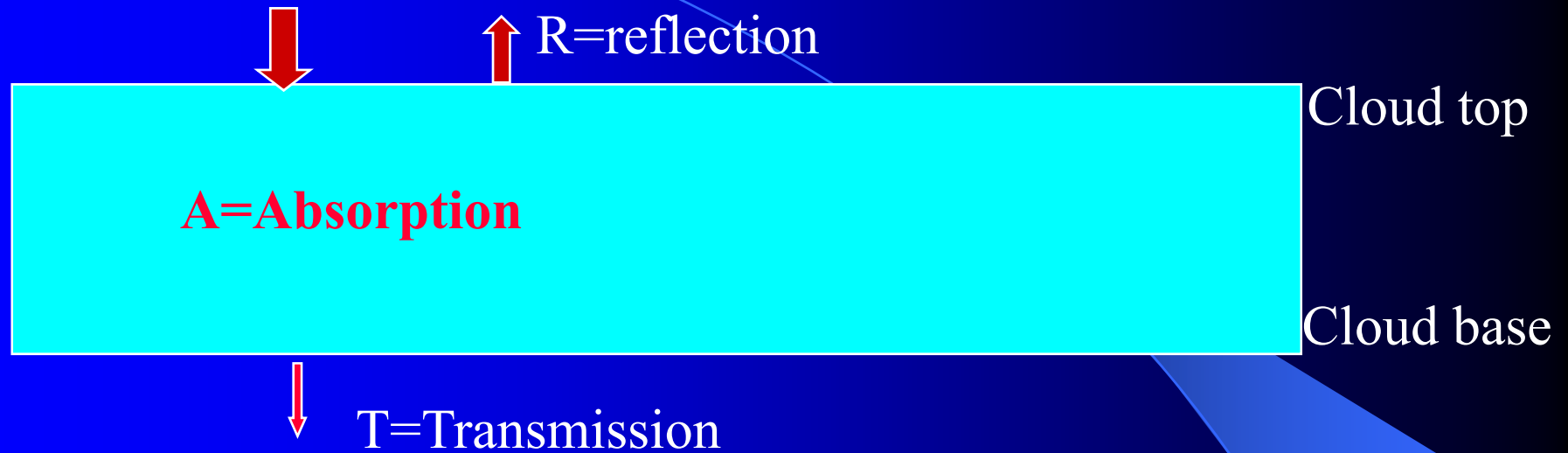


Cloud Radiative Properties and Remote Sensing of Cloud Parameters

4/17/2012

1

For solar radiation in cloud



$$R+T+A=1,$$

For visible wavelength:

$$A \approx 0, \text{ so } R+T=1$$

$$R = \tau^* / (2 + \tau^*)$$

$$T = 2 / (2 + \tau^*)$$

$$\tau^* = (1-g)\tau$$

g =asymmetry factor, =0.75 for aerosol, =0.85 for clouds

τ =cloud optical depth for cloud, aerosol optical depth for aerosol

How can we calculate visible tau

- $\tau = 2\pi r_e^2 N \Delta Z$

r_e : cloud-droplet effective radius, μm

N : cloud-droplet number concentration, $1/\text{cm}^3$

ΔZ : Cloud thickness = cloud top - Cloud base, m.

$$\text{LWC} = (4/3) \pi r_e^3 N \Delta Z \rho_w$$

LWC = cloud liquid water content, g/m^3

$$\tau = (3/2) * (\text{LWC} * \Delta Z) / (r_e \rho_w) = (3/2) \text{LWP} / r_e$$

$\text{LWP} = \text{LWC} * \Delta Z$, cloud liquid water path, g/m^2

How can we calculate IR tau

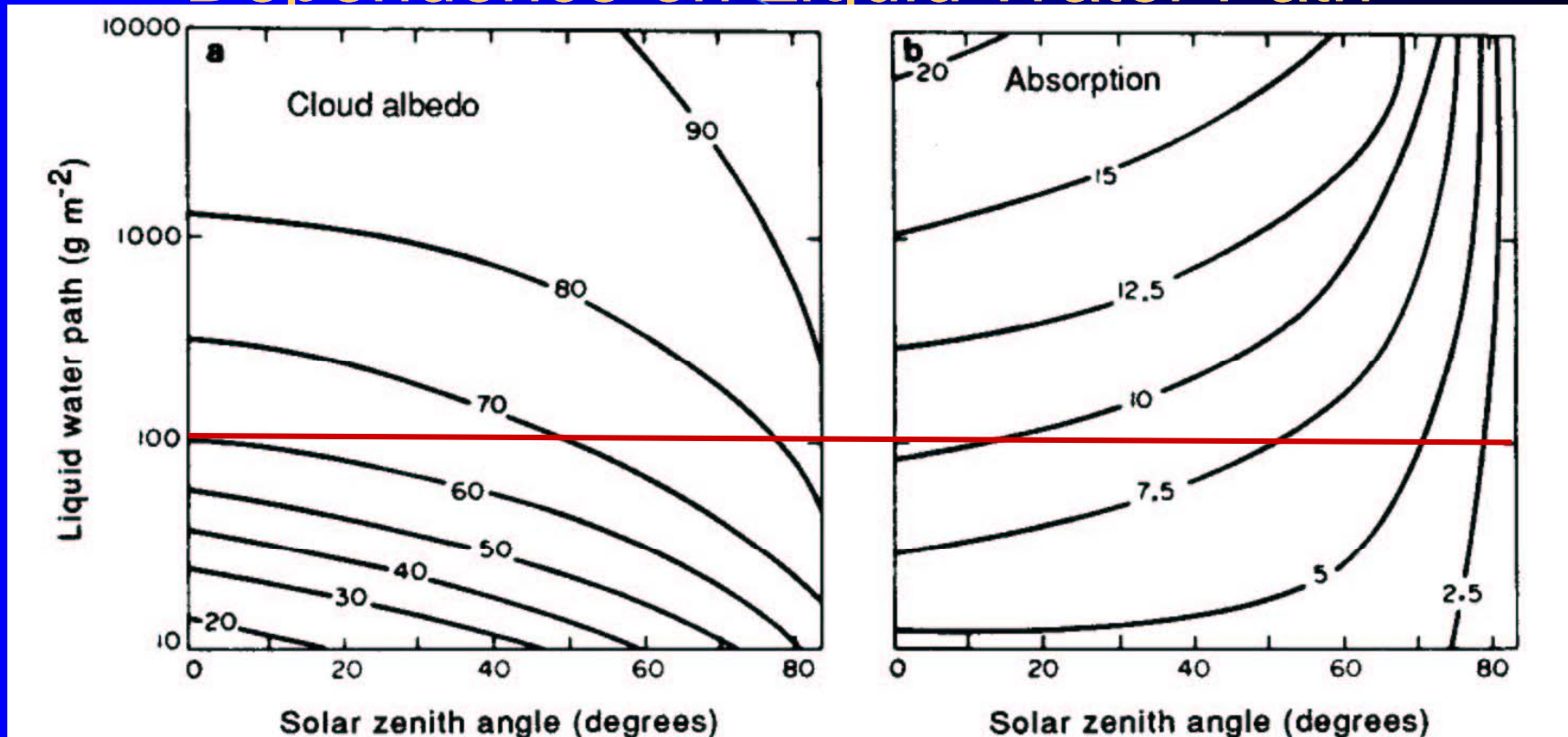
- $\tau_a^* = k_c * LWC * \Delta Z = k_c * LWP$

k_c is the mass absorption coeff for cloud

$k_c \sim 0.12 \text{ m}^2/\text{g}$ for stratus cloud (liquid)

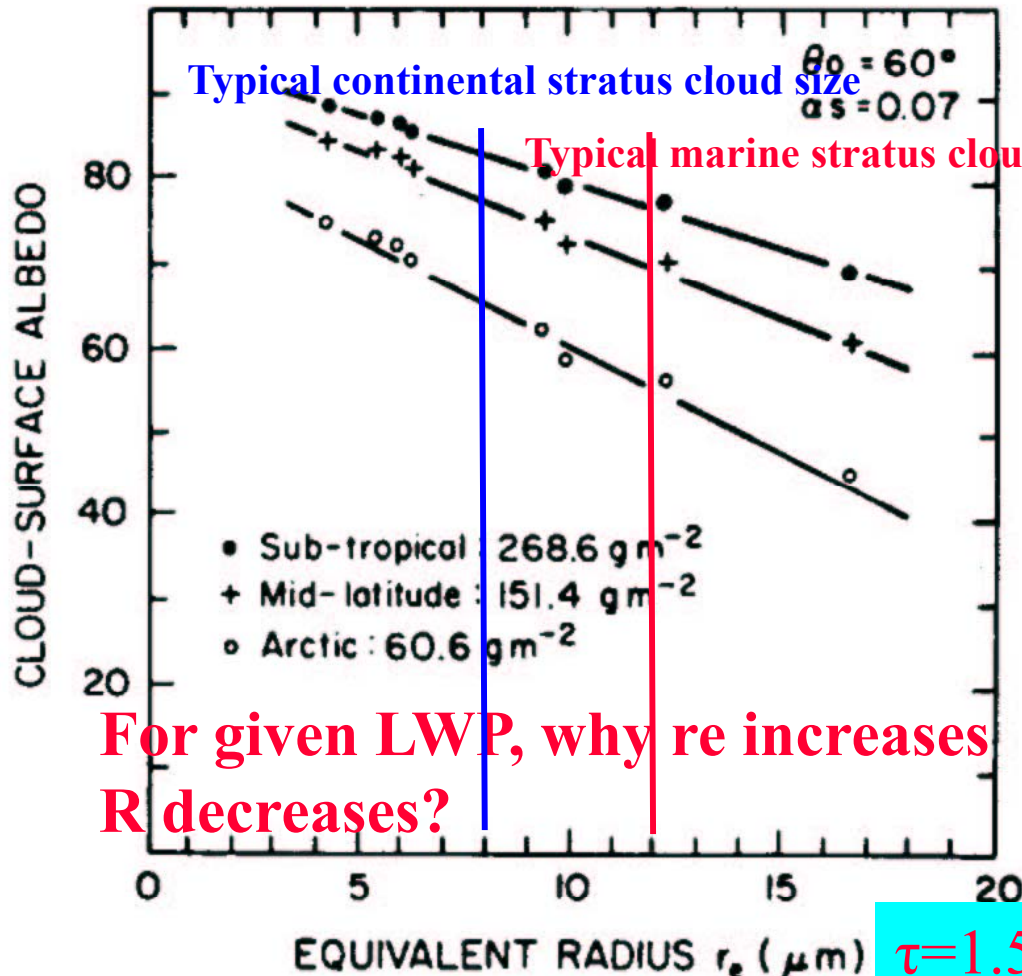
$k_c \sim 0.08 \text{ m}^2/\text{g}$ for cirrus cloud (ice)

Cloud Radiative Properties: Dependence on Liquid Water Path



- Recall $A+R+T = 1$, A =absorption, R =reflection, T =transmission
- Optically thick clouds reflect and absorb more than optically thin
- Generally reflect more than absorb, but less true at low solar zenith angles.
- Question: why absorb more at small solar zenith angle?

Cloud Radiative Properties: Dependence on Drop Size

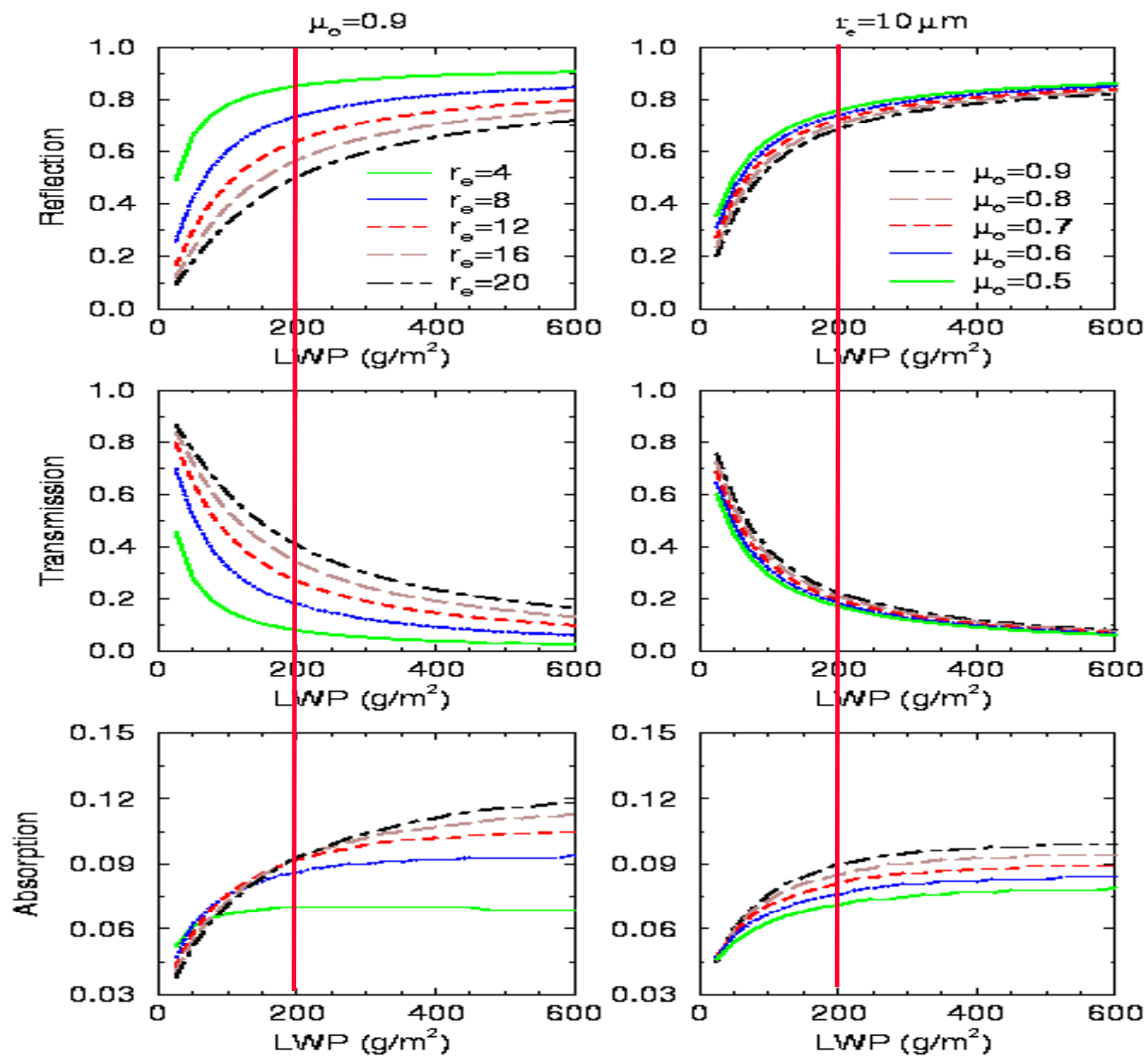


For given LWP, why r_e increases
R decreases?

- Small droplets make brighter clouds
- Larger droplets absorb more
- Dependence on liquid water path at all droplet sizes too

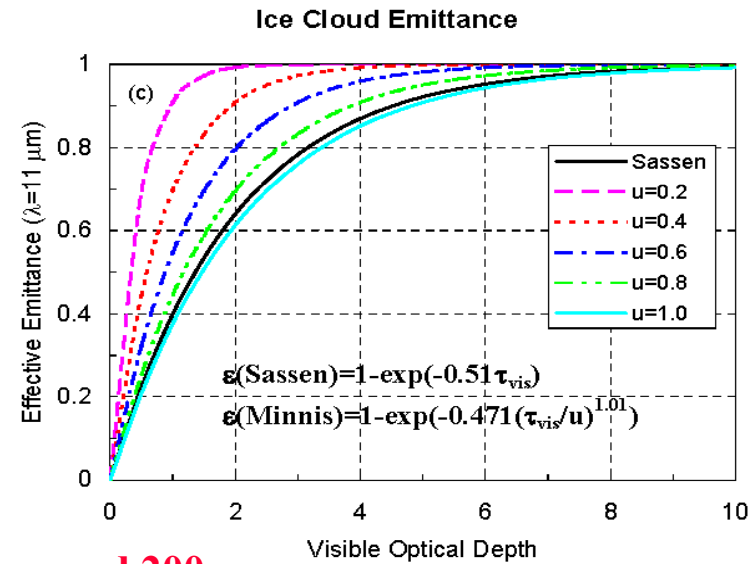
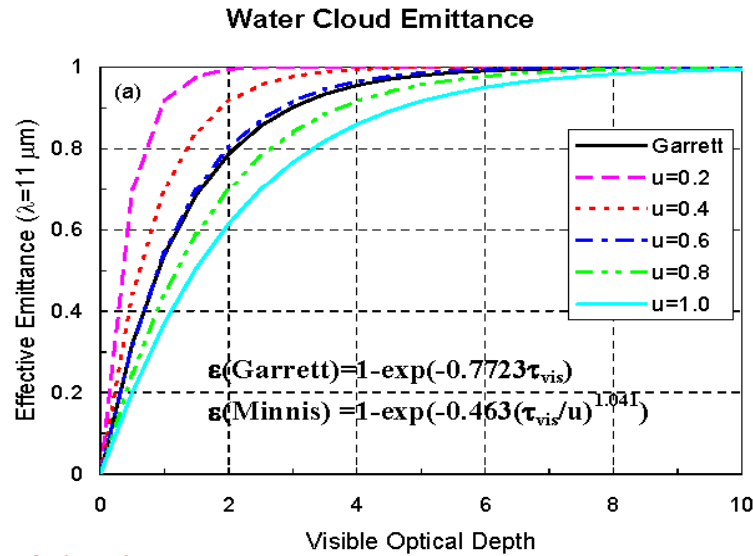
$$\tau = 1.5 * \text{LWP} / r_e$$

τ increases \rightarrow R increases, T decreases

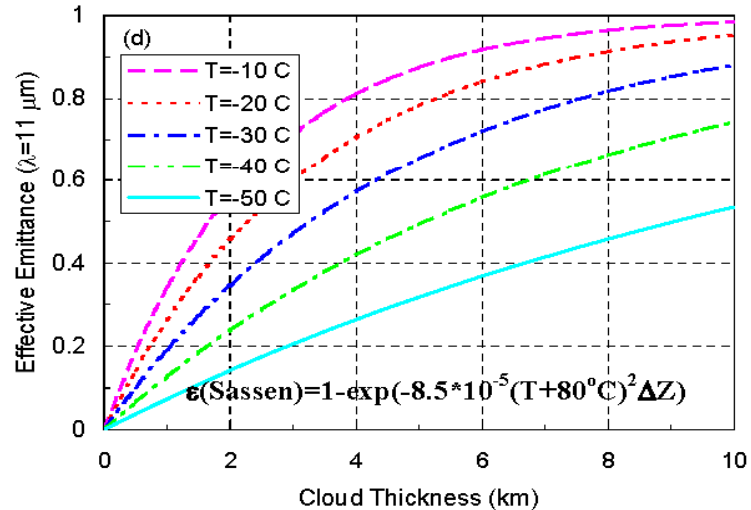
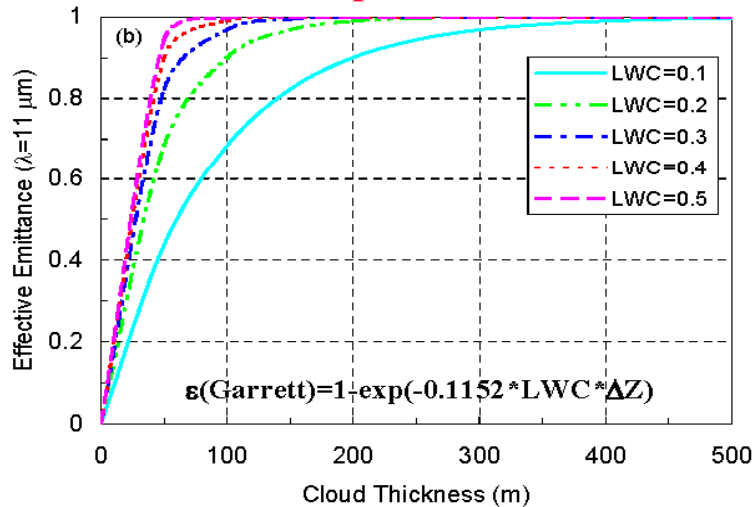


Relation between cloud LW emittance and tau

When emittance = 1, the clouds are called optically thick.
Otherwise, they are called optically thin.



Most of liquid water clouds become saturated at around 200 m, which is where lidar can penetrate into clouds Most



The background is a solid blue color with a subtle gradient. On the right side, there is a white arc that curves from the top towards the bottom, creating a sense of depth or a horizon line. The text is centered in the middle of the image.

Remote Sensing of Cloud Parameters

Input Data and Procedures for R/S of Cloud

Cloud mask

Cloud thermodynamic phase

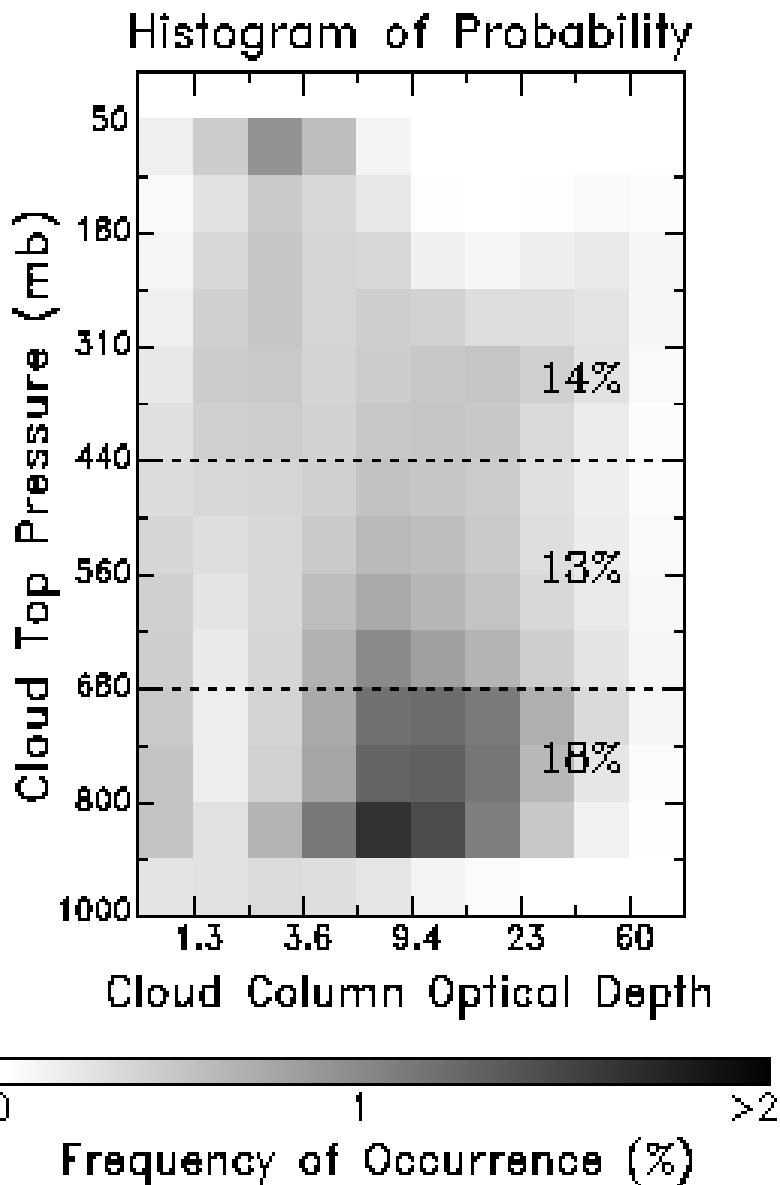
Cloud top properties

Atmospheric correction

Surface albedo

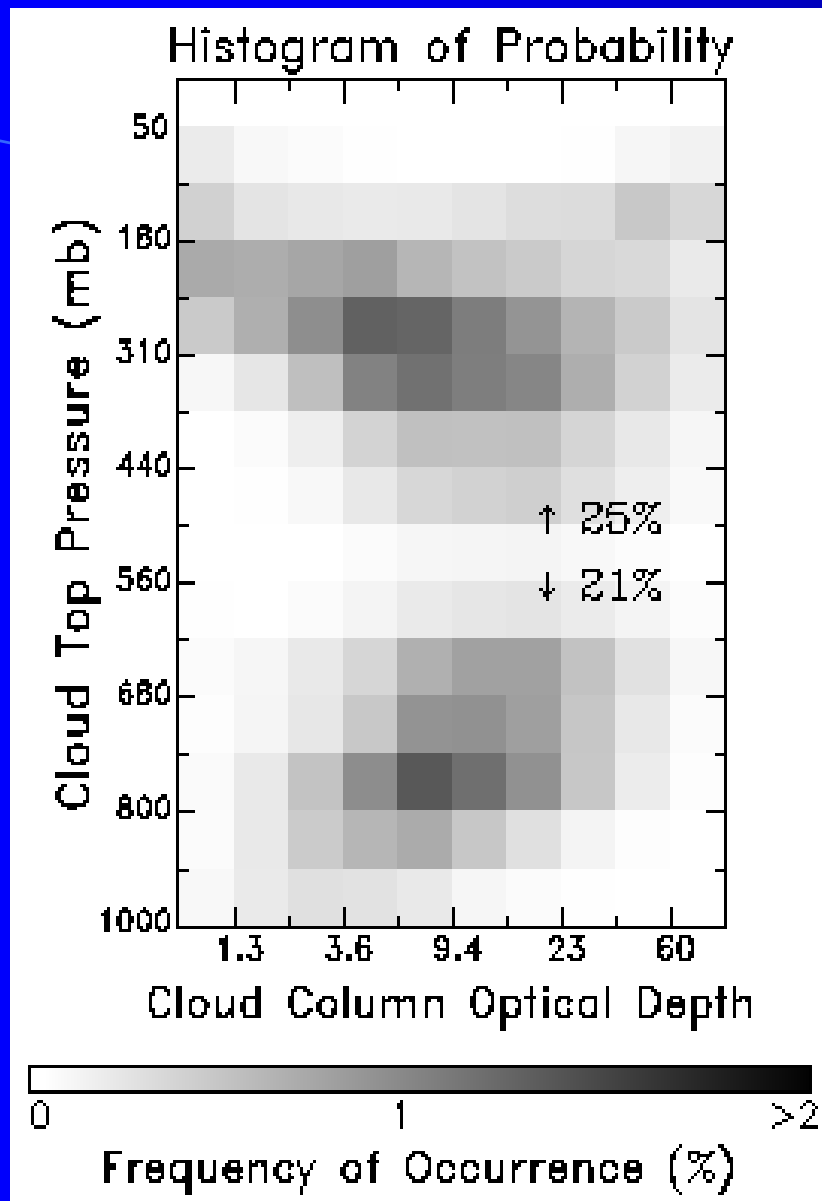
Ancillary data: atmo $T(p)$, $w(p)$;
surface temperature, etc.

The ISCCP-like Bispectral Visible/Infrared Method



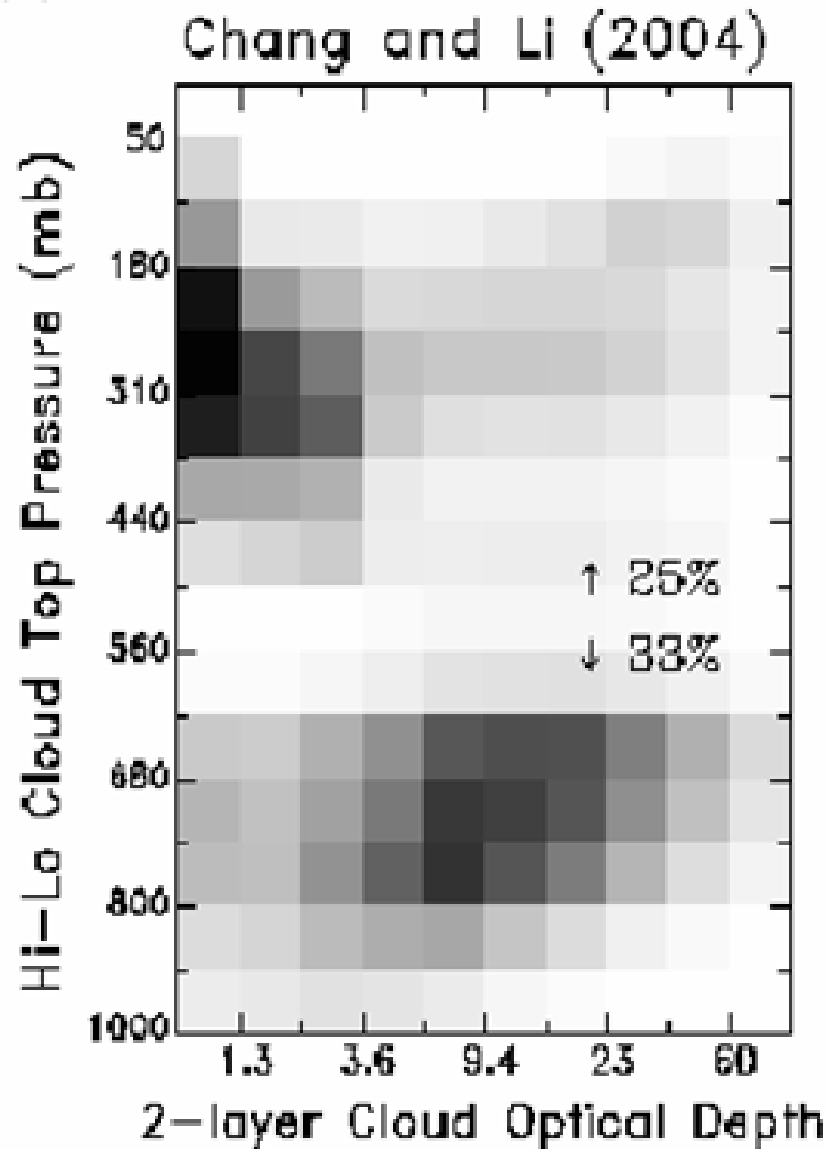
- ✓ Cloud top pressure is retrieved from the infrared ($\sim 11 \mu\text{m}$) channel and
- ✓ Cloud column optical depth is retrieved from the visible ($\sim 0.6 \mu\text{m}$) channel (ISCCP, Rossow and Schiffer 1999)
- Single layer cloud is assumed in retrievals.

MODIS Cloud Top Pressure and Optical Depth Products



- ✓ Cloud top pressure:
 - < 700 mb is retrieved from the CO₂-slicing channels (Menzel et al. 2002) and
 - > 700 mb is from the 11- μ m channel (Platnick et al. 2003).
- ✓ Cloud column optical depth is from the visible channel.
- Single layer cloud is assumed in retrievals.

The Overlapped Retrieval Scheme (Chang and Li, 2005a)



- ❑ Two or multi-layer clouds can be detected by using CO₂ slicing channel and IR channels.
- ❑ Retrieve high-cloud optical depth from infrared radiative transfer model
- ❑ Retrieve low-cloud optical depth from visible radiative transfer model
- ❑ Iterate between steps 1 and 2 to fit best high and low cloud optical depths to the observed radiances at both visible and infrared channels.

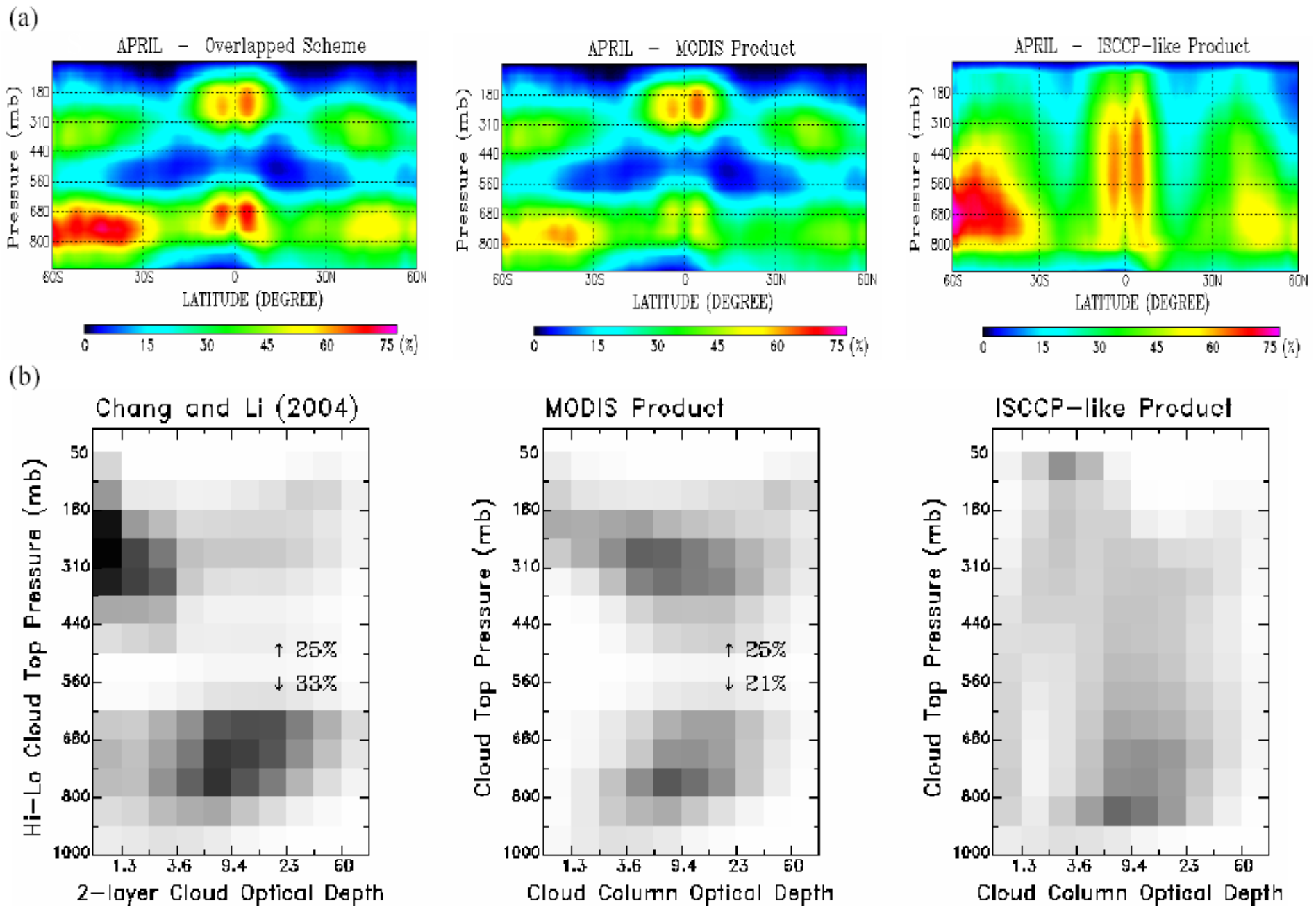
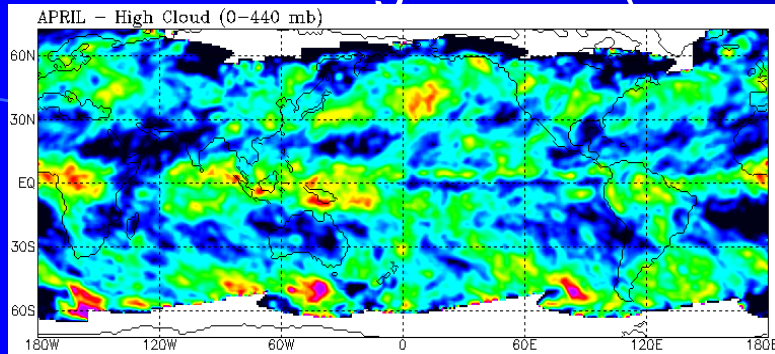


Fig. 6 a) Probabilities of cloud occurrence and b) joined-probabilities of P_c and τ_{VIS} derived from three different satellite inversion algorithms applied to the MODIS pixel data.

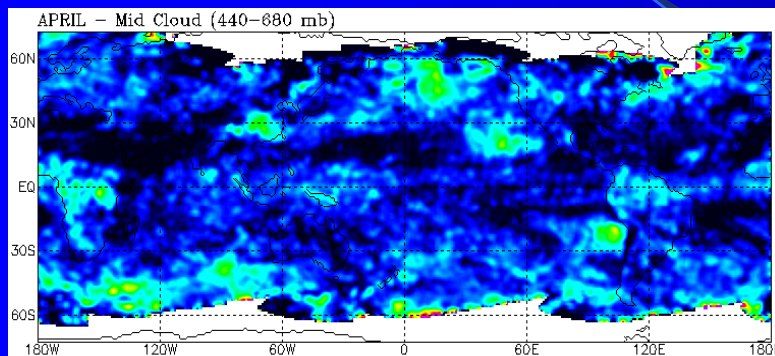
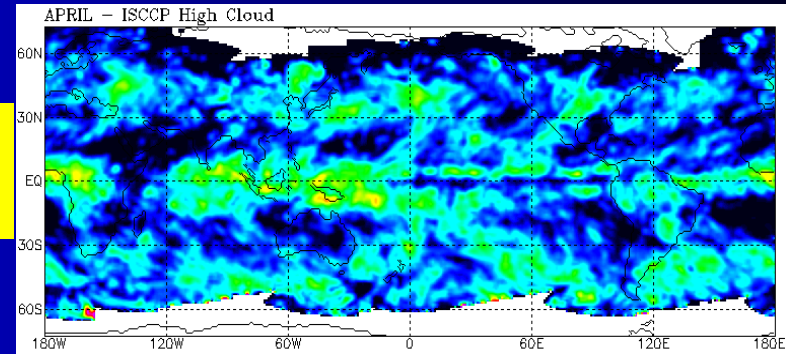
High (< 440mb), Mid (440-680mb), Low (> 680mb) Cloud Amounts

Chang and Li (2005)

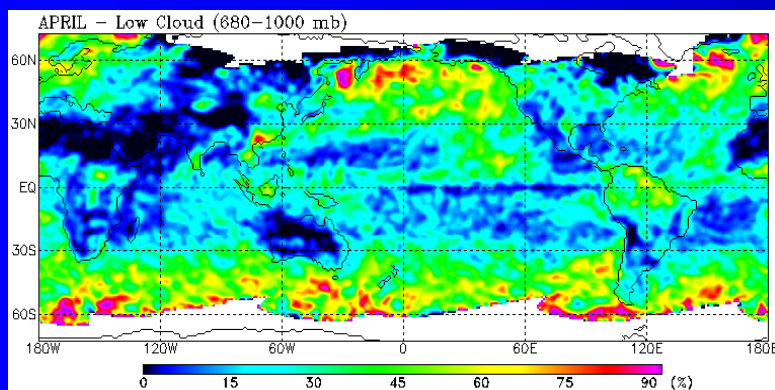
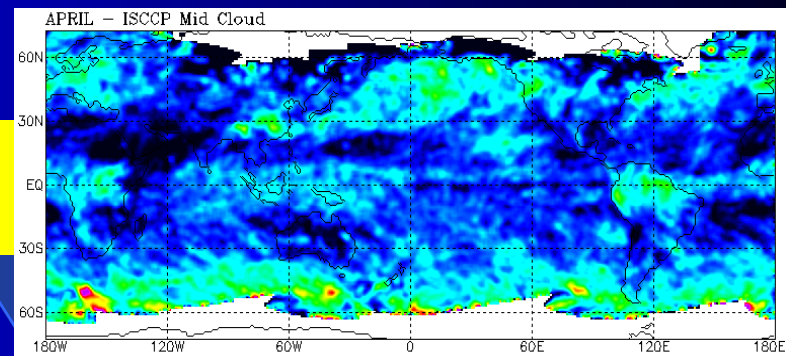
ISCCP-like



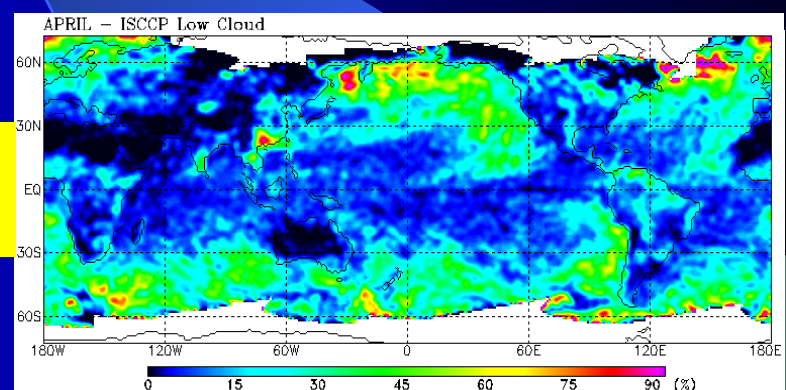
High cloud



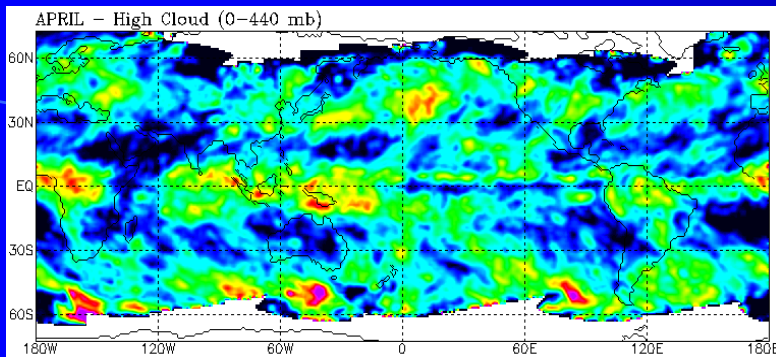
Mid cloud



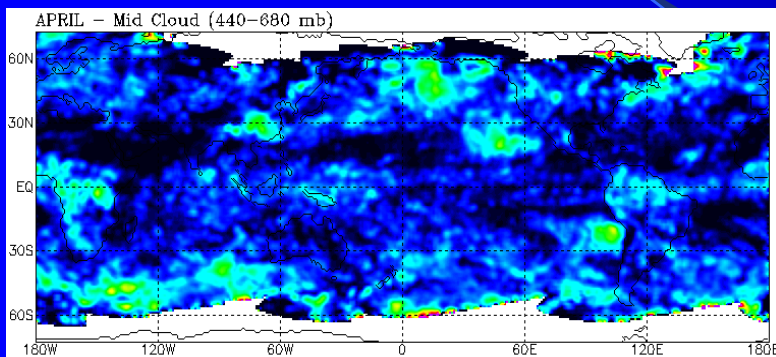
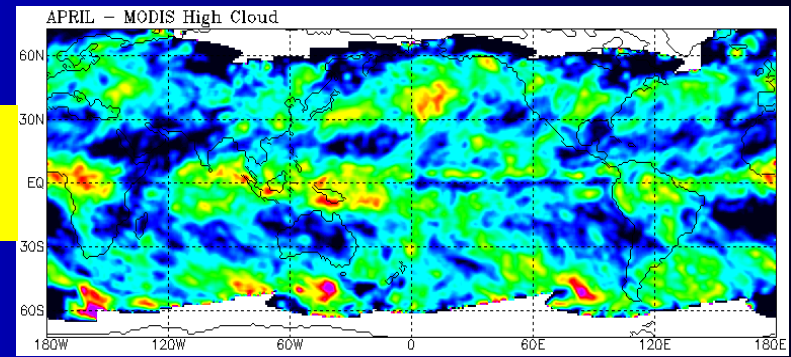
Low cloud



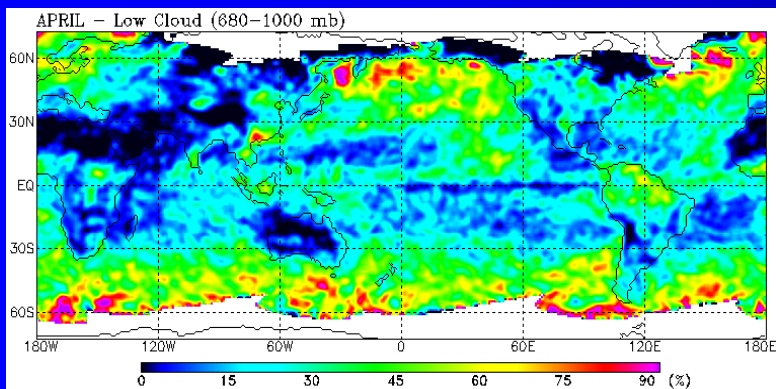
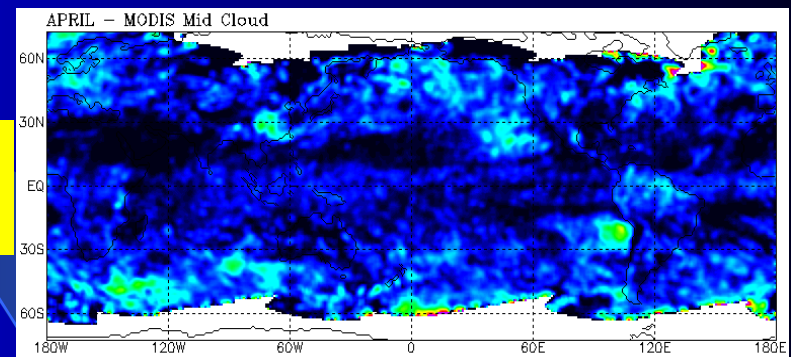
High (< 440mb), Mid (440-680 mb), Low (> 680mb) Cloud Amounts from the Chang and Li (left) and the MODIS Product (right)



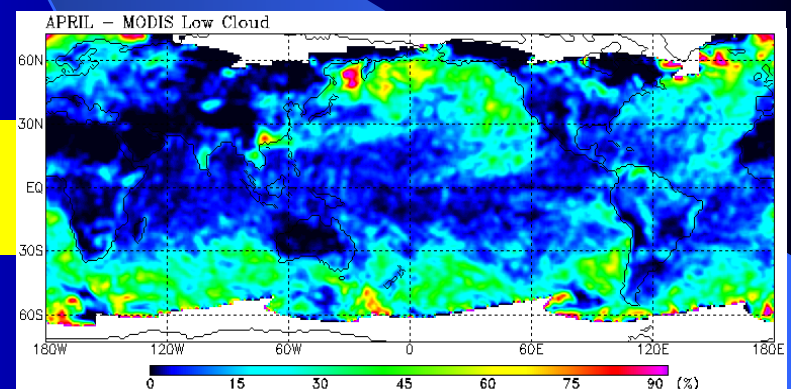
High cloud



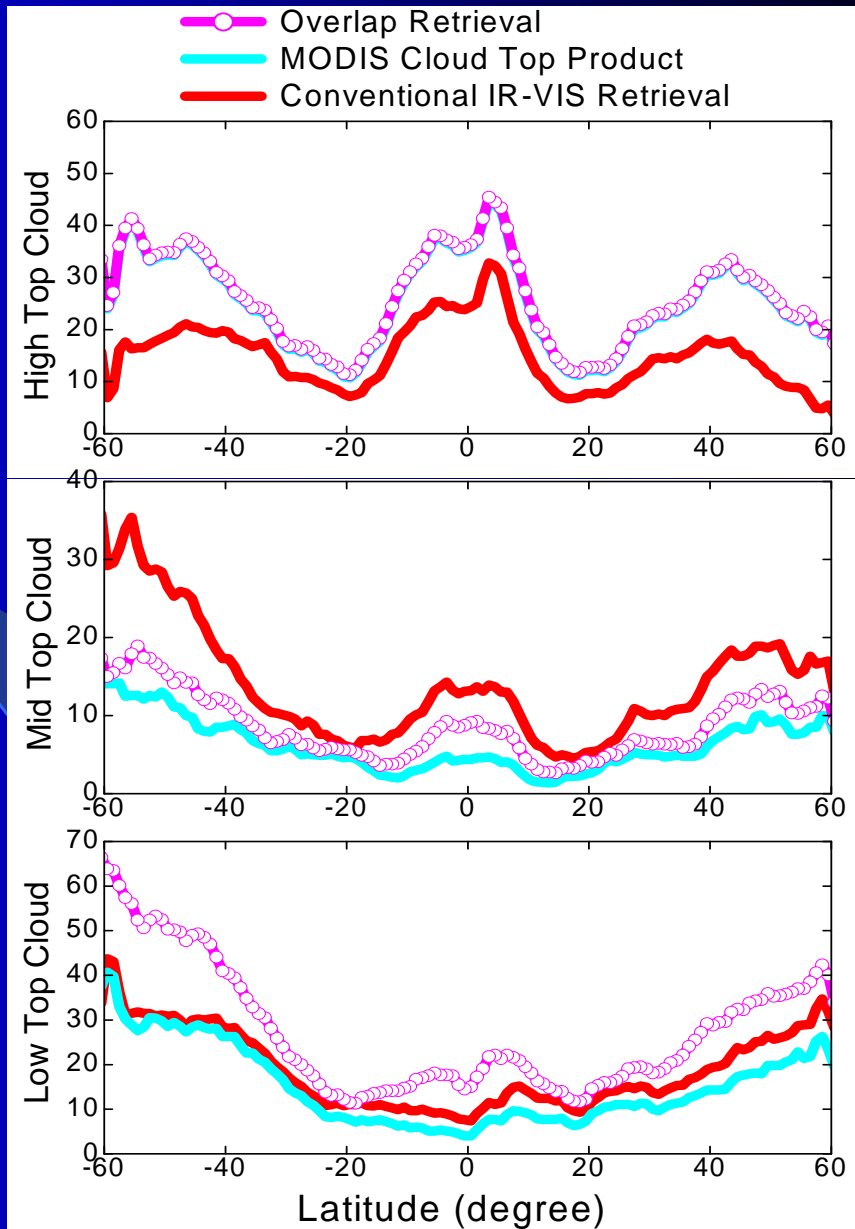
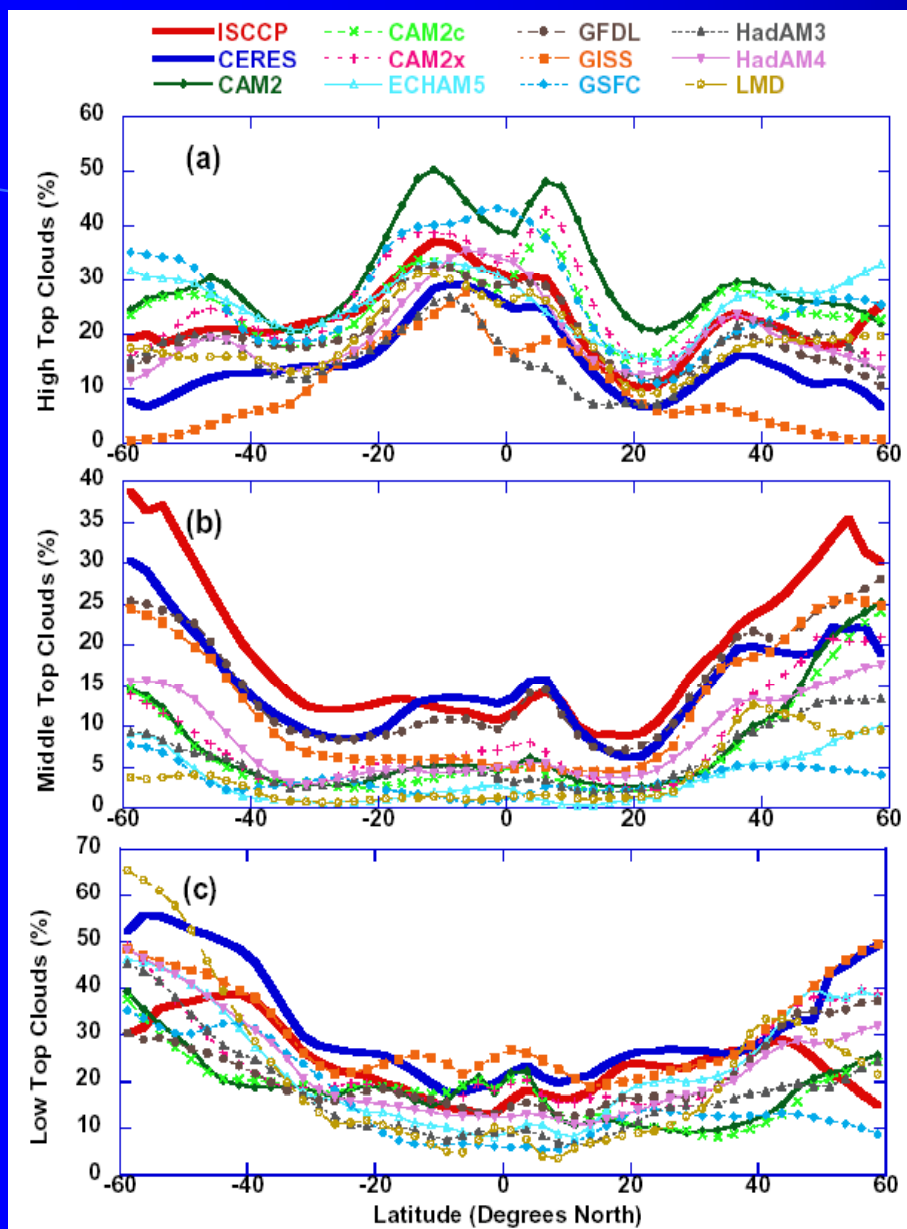
Mid cloud



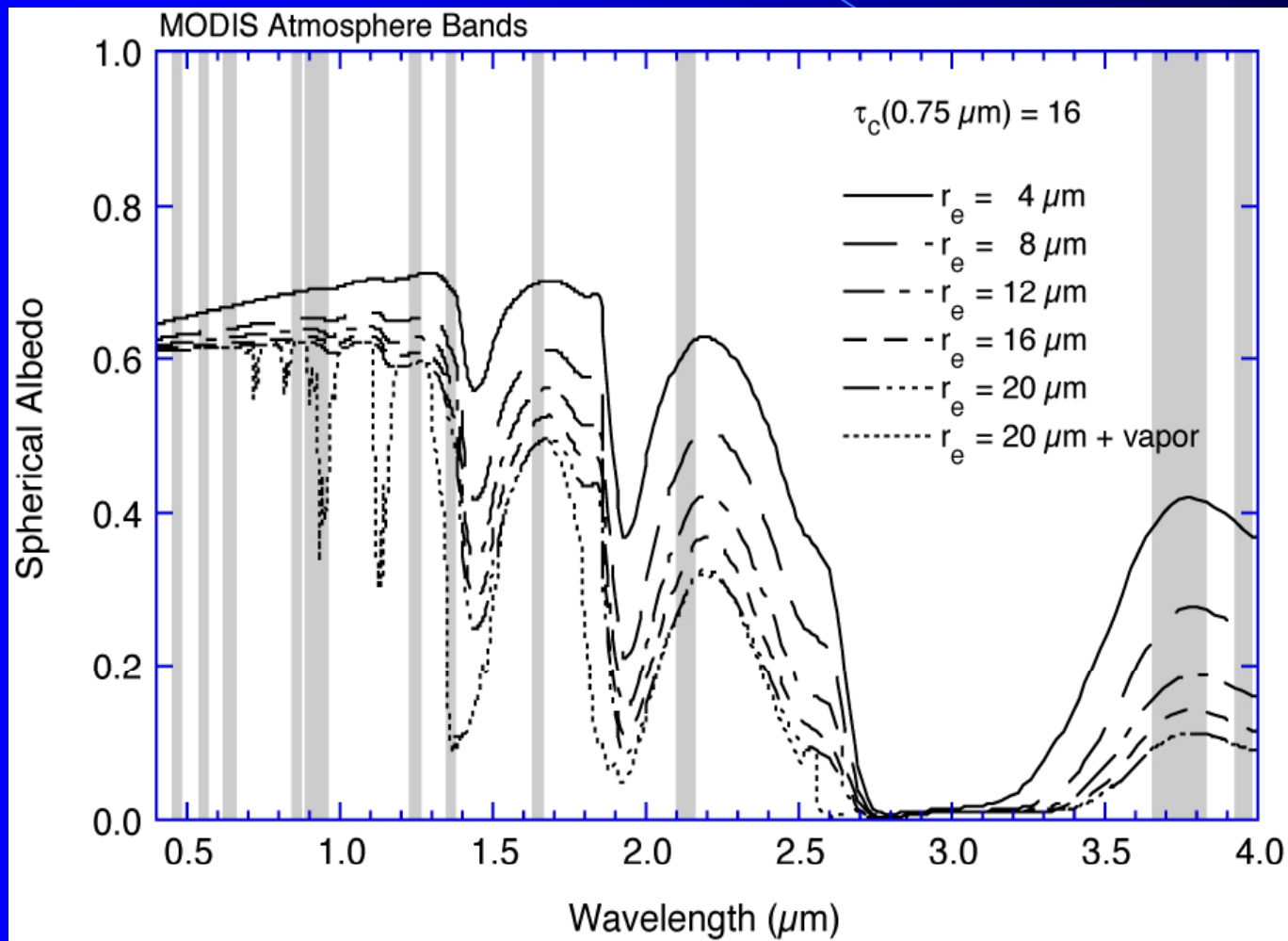
Low cloud



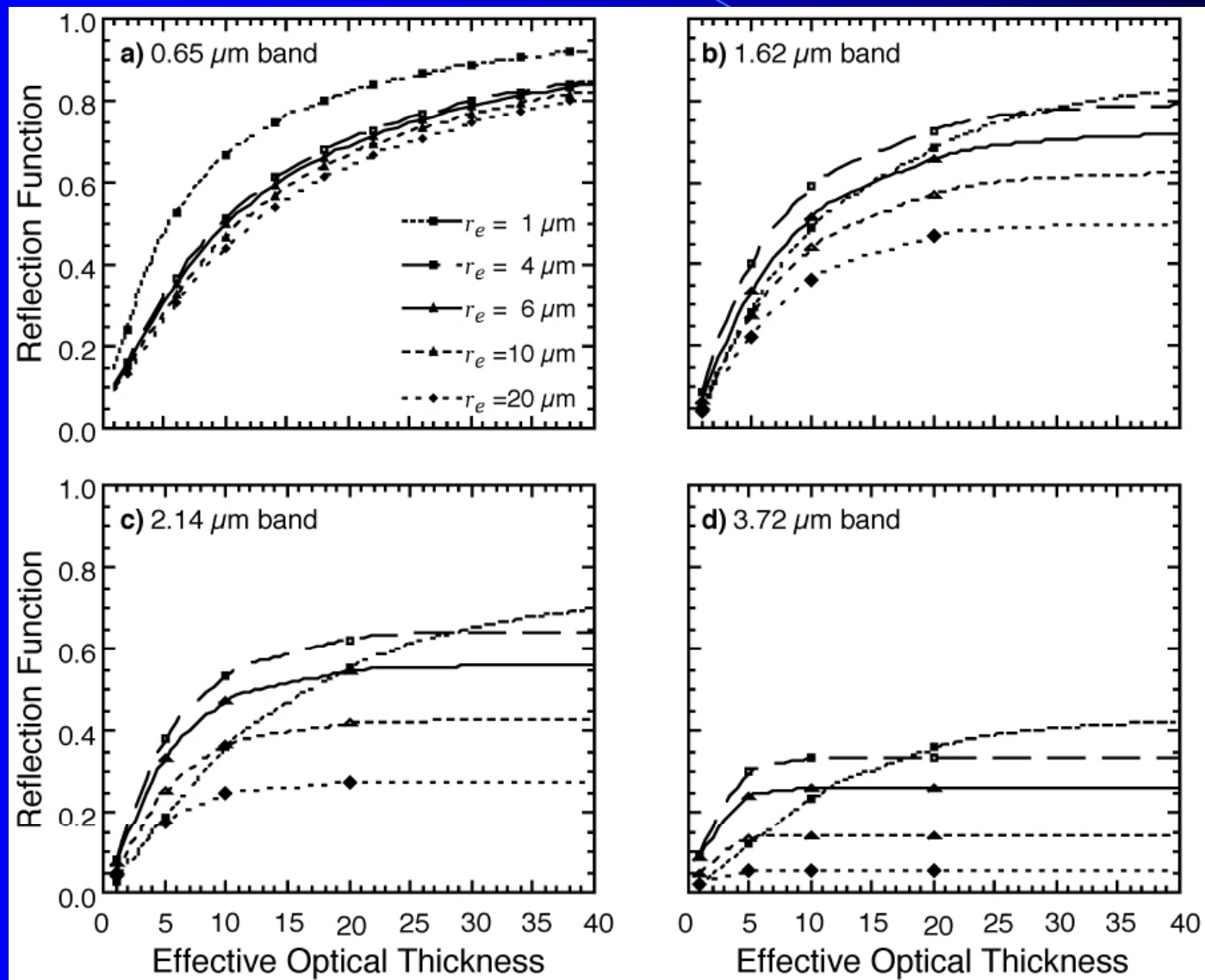
Comparisons of High, Mid, Low Cloud Amounts



Shortwave Properties of Clouds

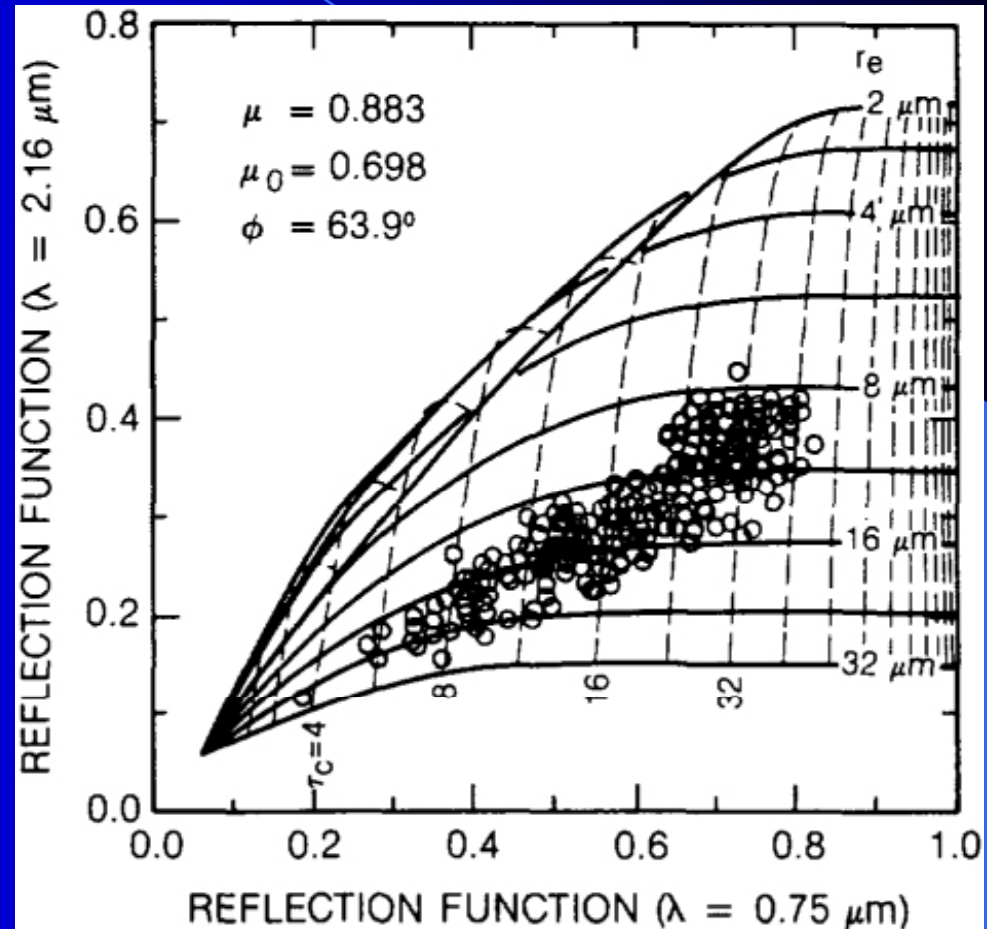


Reflection Function of Clouds as a Function of Cloud Optical Thickness at 0.65 μm



Retrieval of τ_c and r_e

- The reflection function of a nonabsorbing band (e.g., $0.66 \mu\text{m}$) is primarily a function of cloud optical thickness
- The reflection function of a near-infrared absorbing band (e.g., $2.13 \mu\text{m}$) is primarily a function of effective radius
 - clouds with small drops (or ice crystals) reflect more than those with large particles
- For optically thick clouds, there is a near orthogonality in the retrieval of τ_c and r_e using a visible and near-infrared band



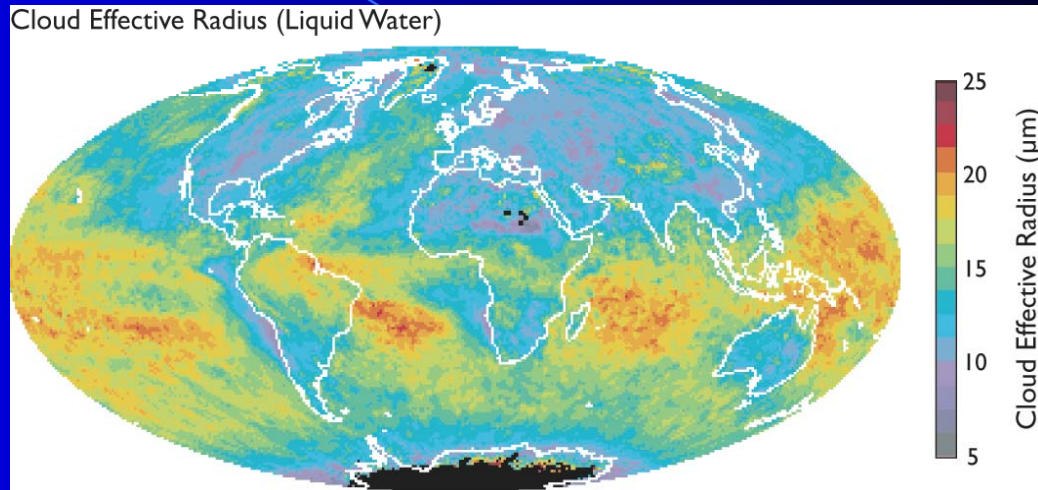
Monthly Mean Cloud Effective Radius

(M. D. King, S. Platnick et al. – NASA GSFC)

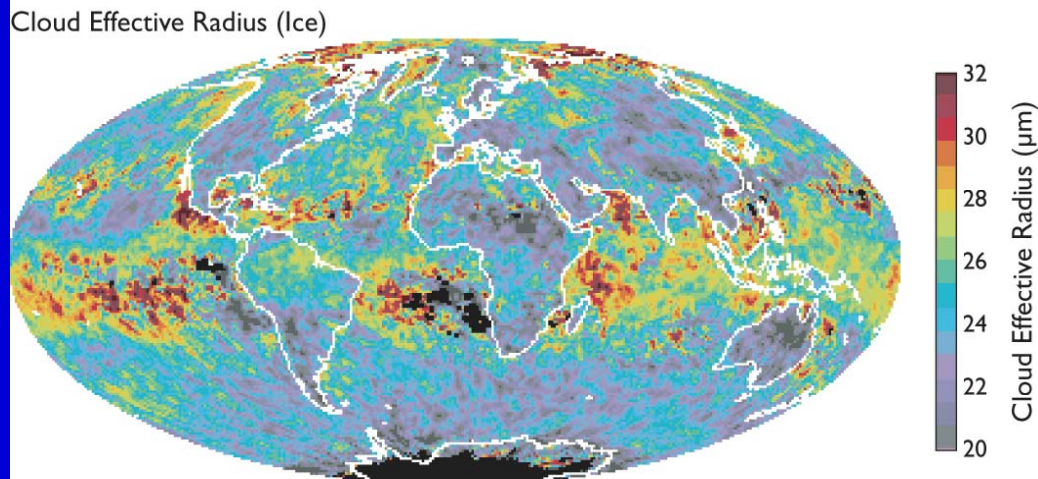
April 2005 (Collection 5)

Aqua (QA Mean)

Cloud_Effective_Radius_Liquid_QA_Mean_Mean



Cloud_Effective_Radius_Ice_QA_Mean_Mean



Vertical variations of cloud droplet sizes and liquid water density for low-level stratiform clouds compiled from various in-situ measurements.

Note the general linear increasing trends!

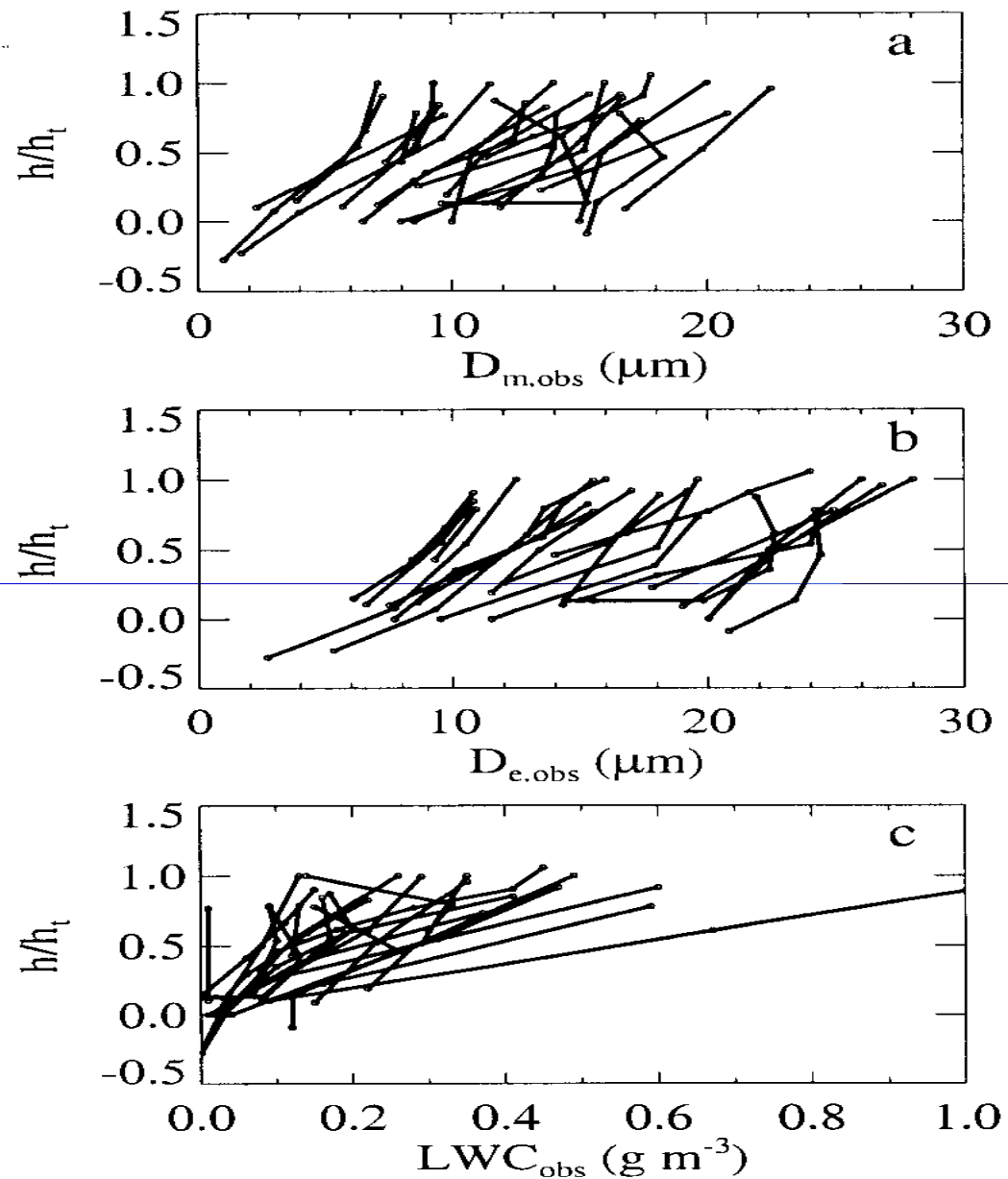
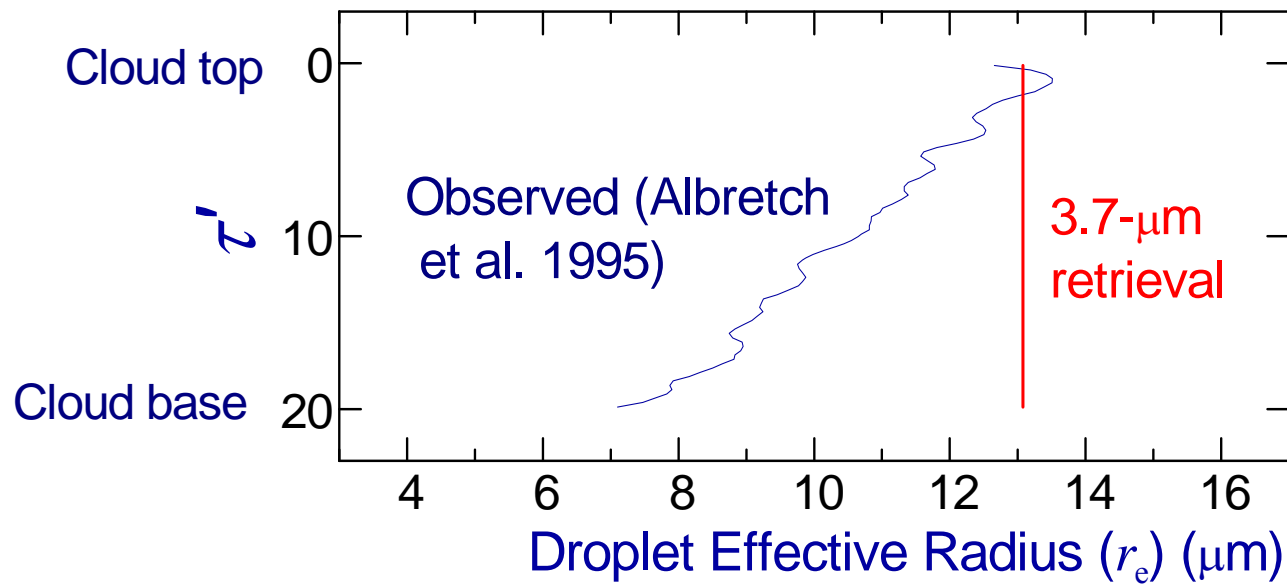


FIG. 2. Vertical profiles of (a) mean diameter, (b) effective diameter, and (c) liquid water content. For all the plots, data points within each cloud are connected. Here, h denotes height and h_t denotes cloud thickness; thus, h/h_t is normalized height within the cloud.

Limitation of Using Single-spectral (3.7- μm) Retrieval

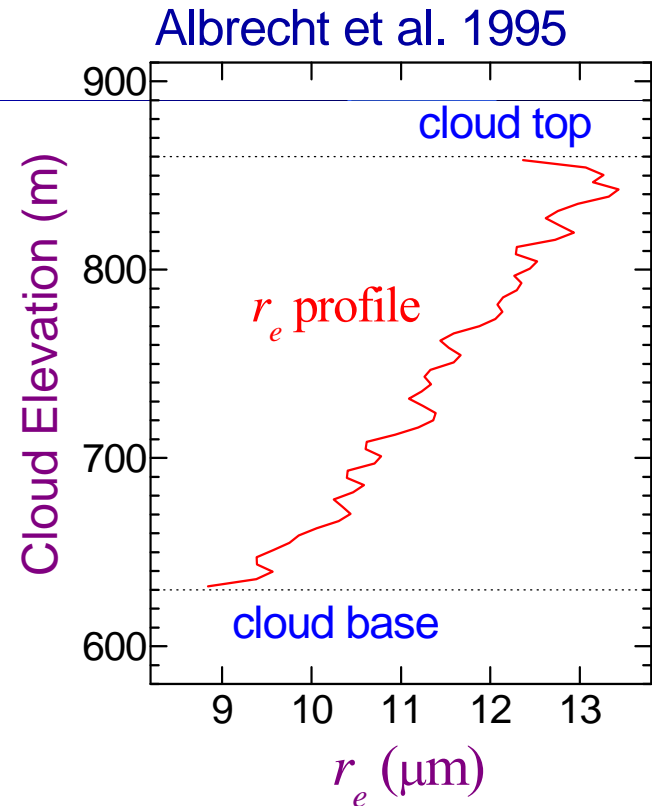
- Because cloud droplets absorb strongly at 3.7 μm , photons rarely transport far inside cloud top before being reflected. The DER (r_e) retrieval may only represent a shallow layer near cloud top.
- The 3.7- μm retrieved DER is biased if the cloud DER has an inhomogeneous vertical variation from cloud top to cloud base.



★ *Limitation of the 3.7- μm Retrieval Method*

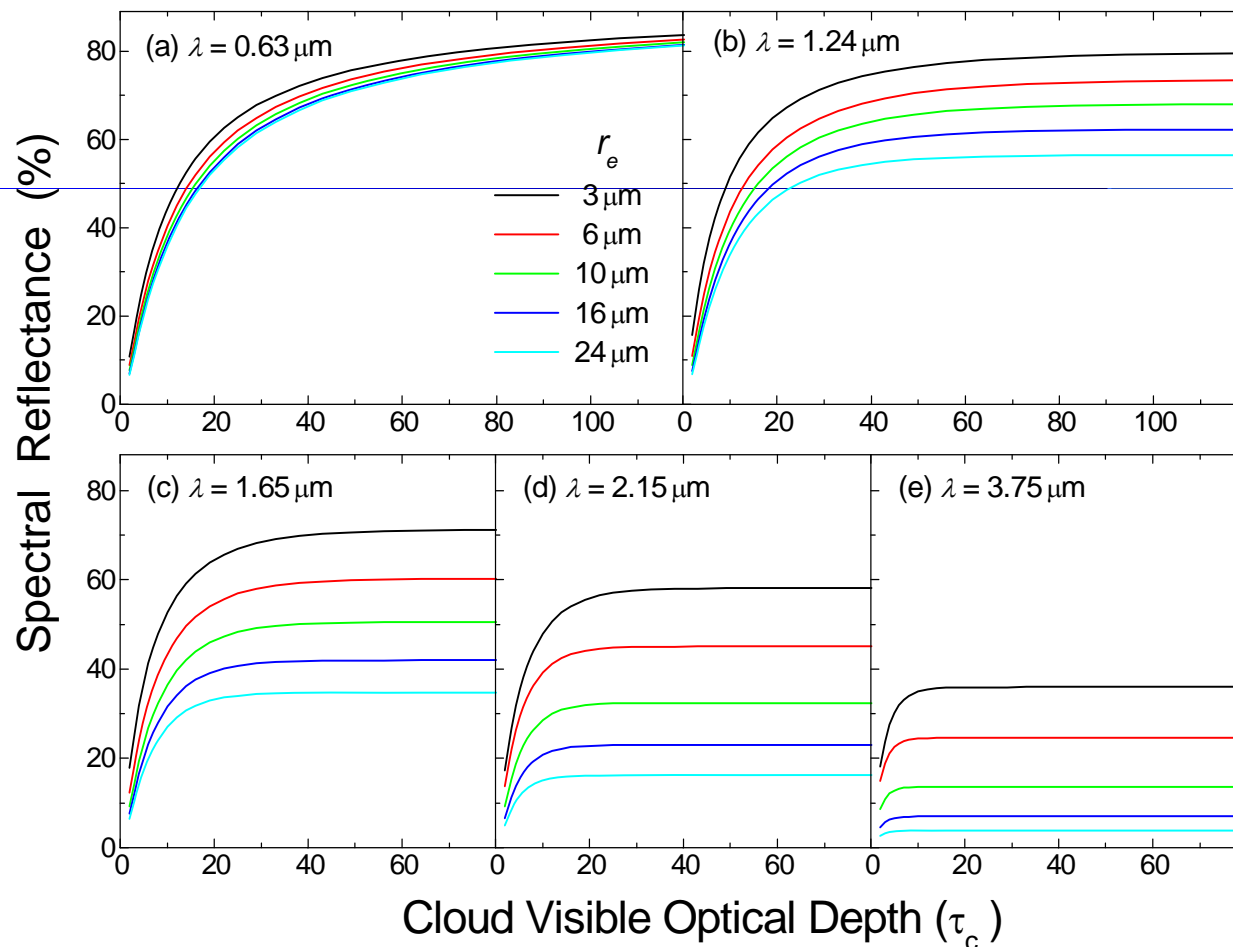
- Due to the significant absorption at 3.7 μm , it is rarely that a photon can transport far beneath cloud top without being absorbed by droplets. Hence, 3.7- μm retrieved r_e can only represent a shallow layer at near the cloud top, which seldom represents the full cloud column.

- *In-situ* observations of stratocumulus cloud often exhibit an increase in r_e with height (Nicholls 1984 at North Sea; Stephens and Platt 1987 at east coast of Australia; Duda et al. 1991 at San Nicholas Island; Martin et al. 1994 at coast of California; Albrecht et al. 1995 and Duynkerke et al. 1995, both at Azores/Madeira Islands).

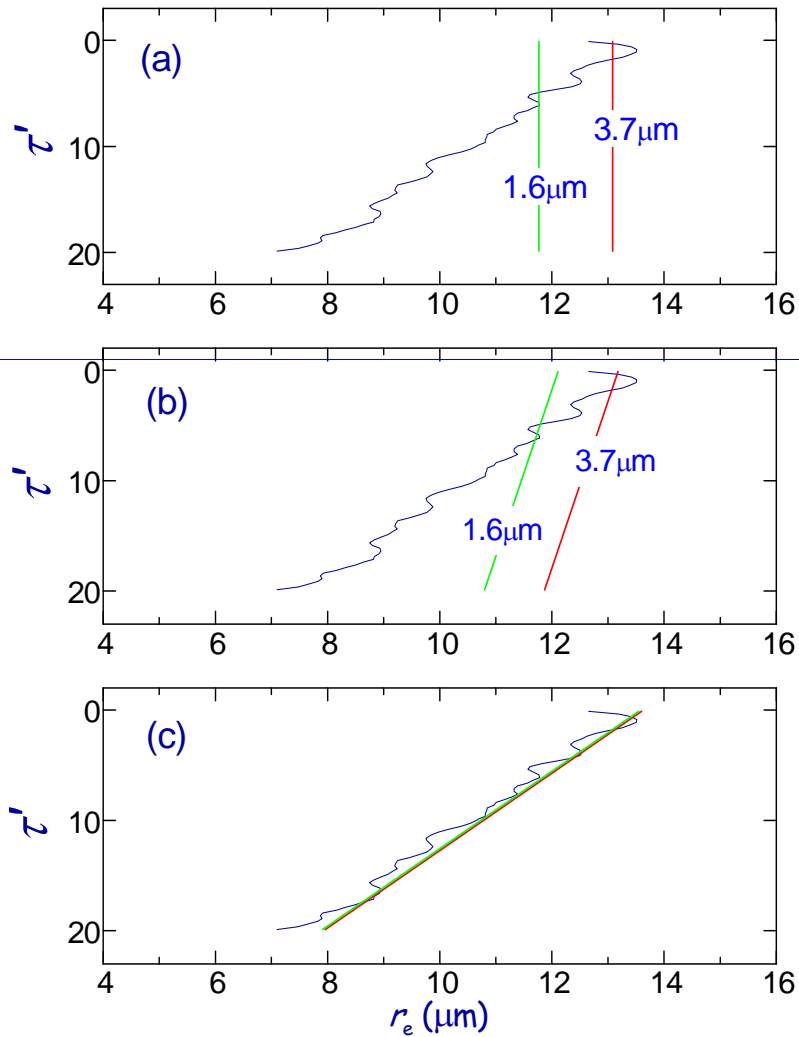


Dependence of Different NIR reflectances on DER

- Multispectral reflectances at distinct near-infrared wavelengths convey certain information on the cloud DER profile because of different photon penetration depths. But, the information alone is not sufficient for retrieving a DER profile.



Schematic Illustration of a Bispectral Retrieval Procedure

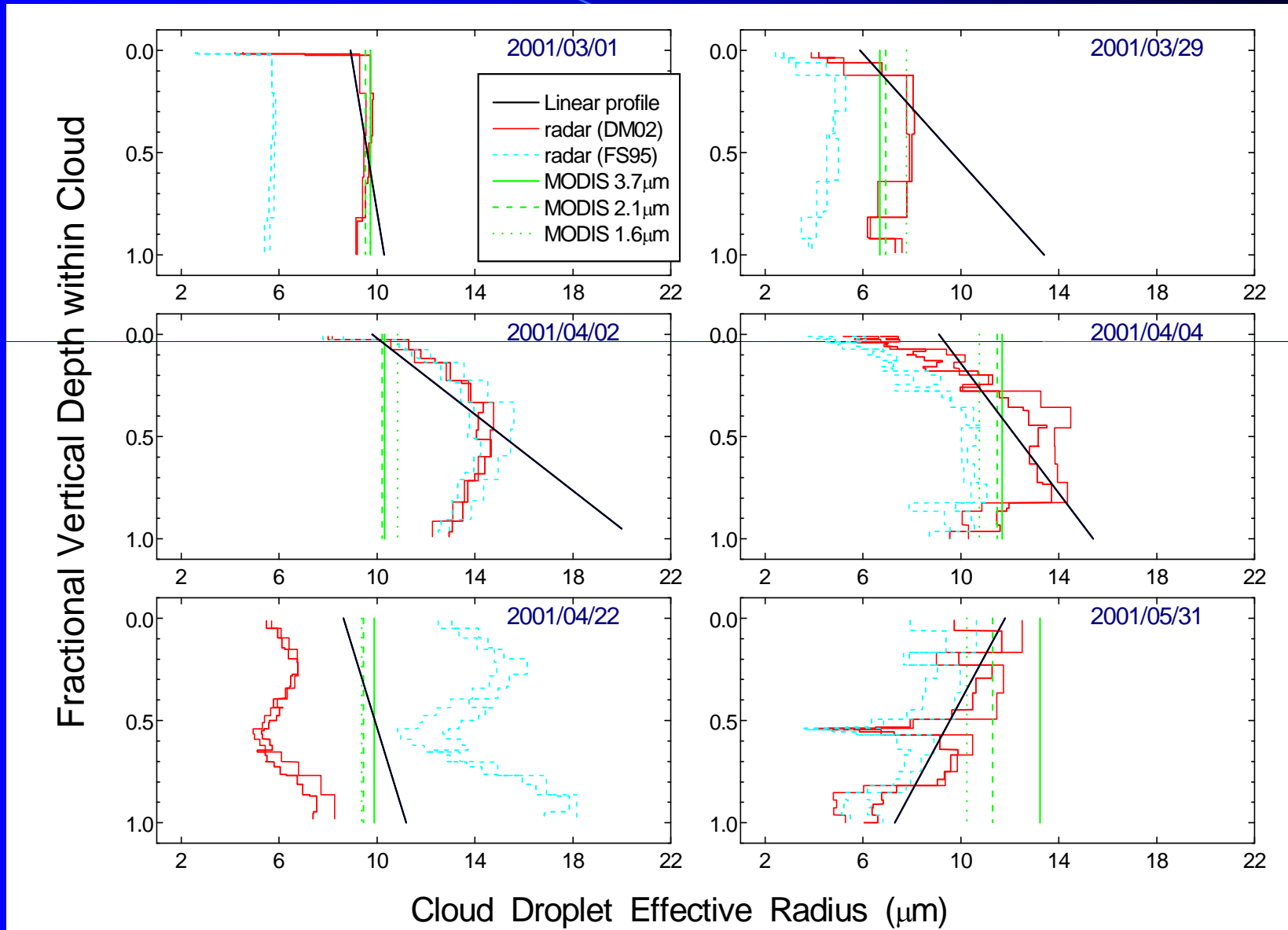


(a) Conventional r_e retrievals by assuming $dr_e/d\tau = 0$.

(b) The linear- r_e retrievals with $dr_e/d\tau = \Delta r_e/\tau_{\text{total}}$, where $\Delta r_e = 13.1 - 11.8 \mu\text{m}$ as obtained from the 3.7- (red) and 1.6- μm (green) retrieved r_e values shown in Figure (a).

(c) The optimal linear- r_e retrieval for the two channels.

DER Vertical Profile from MODIS and Radar Retrievals



Estimating the Cloud Liquid Water Path (LWP)

- In convention, r_e is assumed to be independent of height (z). Thus,

$$\tau(z') \cong \frac{3}{2} \int_0^1 \frac{w(z')}{r_e(z')} dz'$$

$$\Rightarrow LWP = \frac{2}{3} r_e \tau$$

- In this study, an empirical relationship between LWC (w) and r_e is adopted (Bower et al. 1994; Gultepe et al. 1996; Liu and Hallet 1997) by

$$w(z') = c_0 r_e^3(z')$$

$$\Rightarrow LWP = \int_0^1 c_0 r_e^3(z') dz'$$

$$\tau(z') \cong \frac{3}{2} \int_0^1 \frac{w(z')}{r_e(z')} dz' = \frac{3}{2} \int_0^1 c_0 r_e^2(z') dz'$$

where c_0 is determined based on the retrieved values of τ and r_e .

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