# Validation of CERES-MODIS Cirrus Cloud Properties Using ARM Retrievals

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# Objectives

1. To compare CERES-retrieved cirrus cloud height and temperature with ARM radar/lidar data at SGP site during 2000-2002 period.

2. To compare CERES-retrieved cirrus microphysical properties with ARM retrievals using radar reflectivity and Doppler velocity (For both optically thin and thick, Deng and Mace, 2006)

# CERES-retrieved cloud temp and height

**Step 1:** To get the effective cloud temperature $T_{eff}$ first

$$B(T) = (1- \varepsilon)\, B(T_s) + \varepsilon B(T_{eff})$$

B(T) is the observed 10.8-μm radiance after correction for attenuation and emission of the overlaying atmosphere.

$B(T_s)$ is the upwelling radiance at cloud base, and

ε is the cloud effective emissivity, $\varepsilon = 1-\exp[1-0.471(\tau/\mu_0)^{1.01}]$

As optical depth τ approaches 4 or 5, the emissivity approaches unity and the radiance from the surface has no impact on $B(T_{eff})$

**Step 2:** To convert $B(T_{eff})$ into $T_{eff}$ using Planck function, then the effective cloud height $H_{eff}$ is defined as the lowest altitude having $T_{eff}$ in the GEOS vertical profile of atmospheric temperature.

Note that $H_{eff}$ is the cloud radiative center from satellite point of view, not cloud physical center.

# CERES-retrieved cloud microphysics

**Daytime:** the 4-channel VISST (Visible Infrared Solar-Infrared Split-window Technique).

**Nighttime:** the 3-channel Solar-infrared Infrared Split-window Technique [SIST].

**Effective diameter De**: derived from 3.7-um radiance

**Optical depth $\tau$:** visible (day) and solar-infrared (night)

**IWP** ~ De * $\tau$

**Assumption:** Randomly oriented hexagonal ice crystals

# ARM observations and retrievals

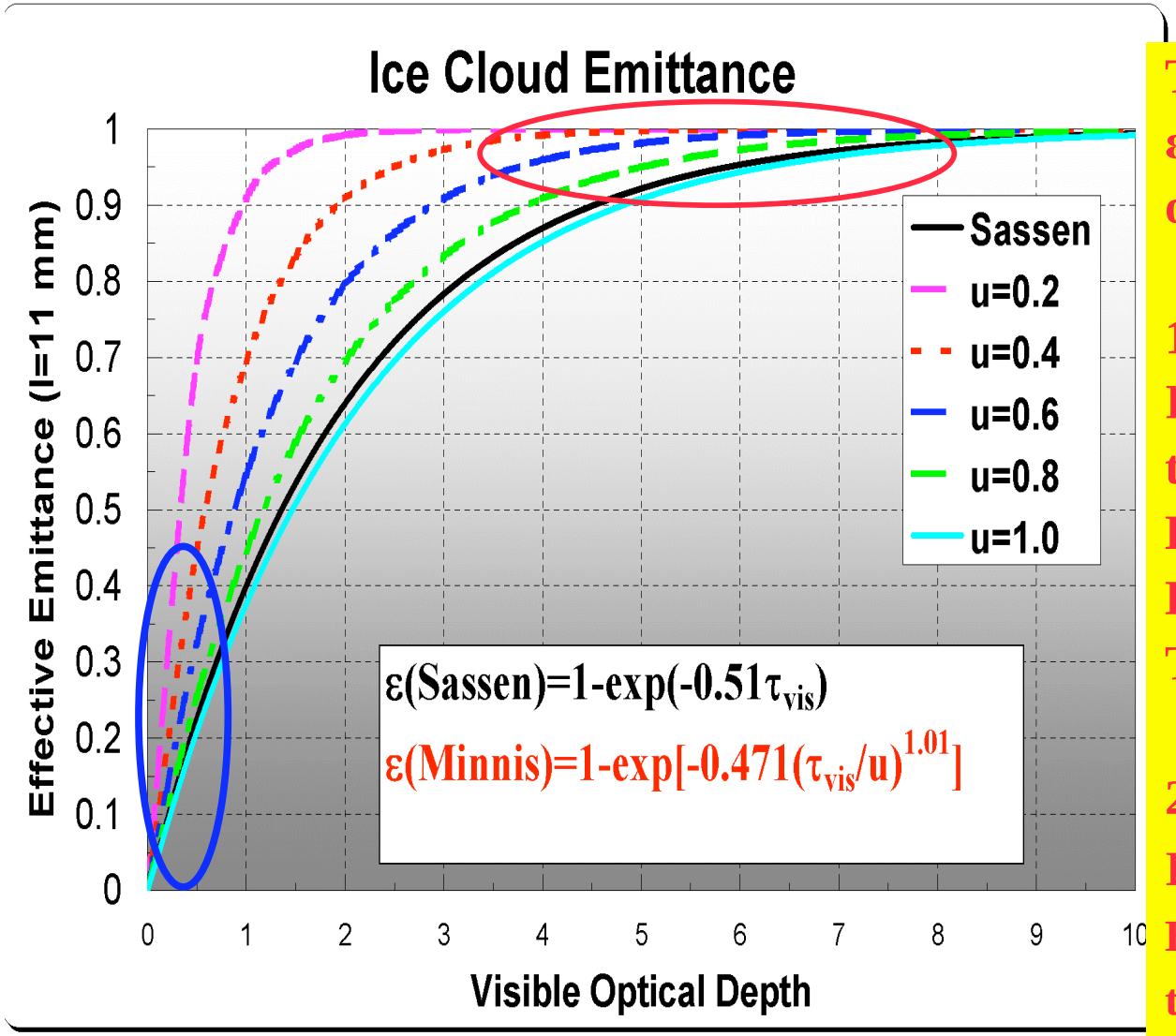
**Cloud base and top heights derived ARM radar-lidar pair measurements.**

**Cloud base and top temperatures inferred from ARM merged sounding after having heights.**

**Cloud microphysical properties:**

**Using ARM radar reflectivity, Mean Doppler velocity, and mass-dimensional power-law relationship to derived $D_e$ and IWC, then infer optical depth.**

As $\tau \sim 5 \rightarrow \varepsilon \sim 1$, the radiance mostly from cloud top $\rightarrow H_{eff} \sim H_{top}$



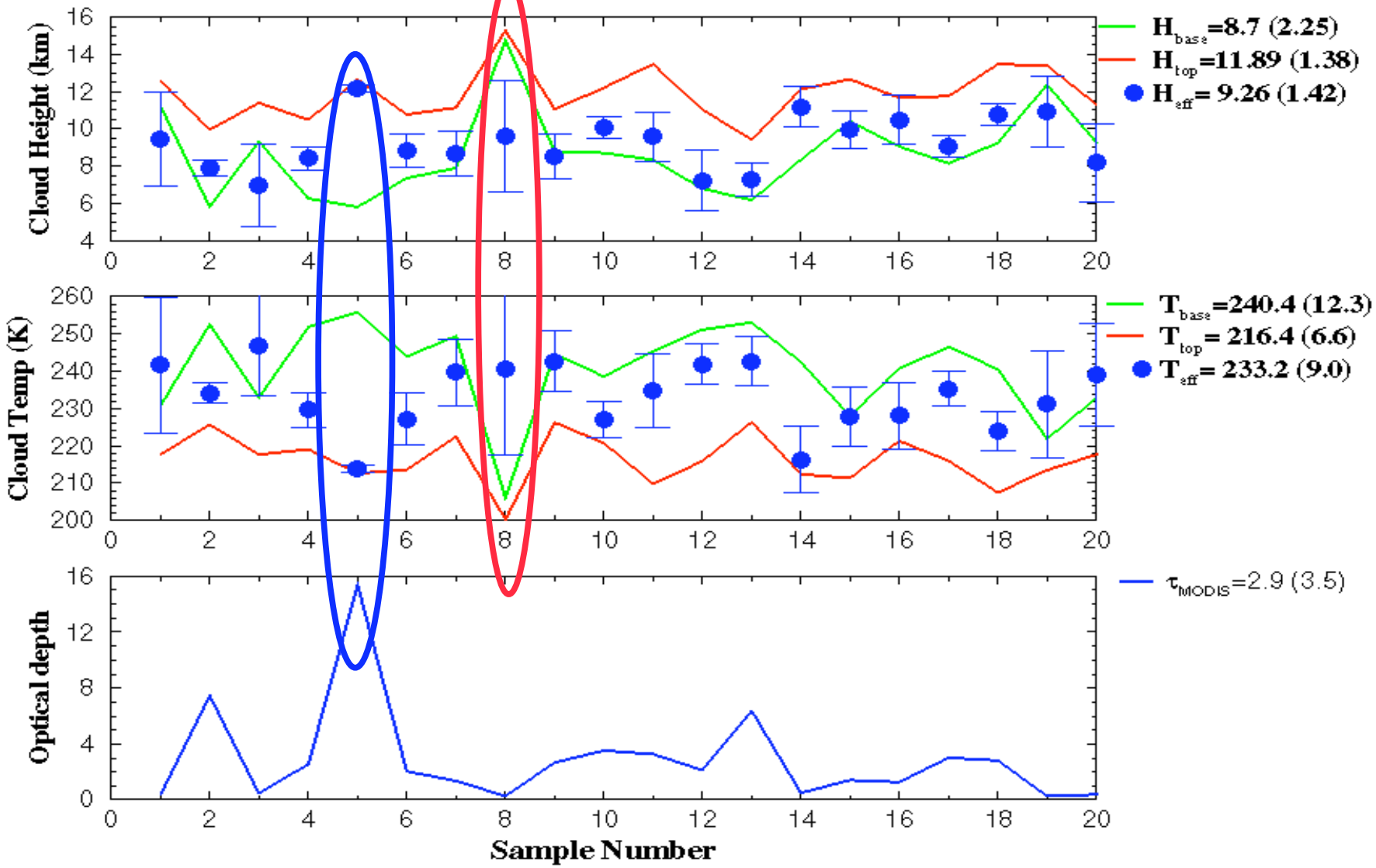

For $\tau < 1$, $H_{eff} \sim H_{base}$

There are 2 error sources, $\varepsilon(\tau)$ and $B(T_s)$, in estimation of $T_{eff}$ and $H_{eff}$.

1) assuming $B(T_s)$ is correct.
If $\tau$ is underestimated,
then $\varepsilon$ is underestimated.
$B(T_{eff})=[B(T)-B(T_s)]/\varepsilon+B(T_s)$
$B(T_{eff})$ is higher $\rightarrow$
$T_{eff}$ is higher $\rightarrow H_{eff}$ is lower

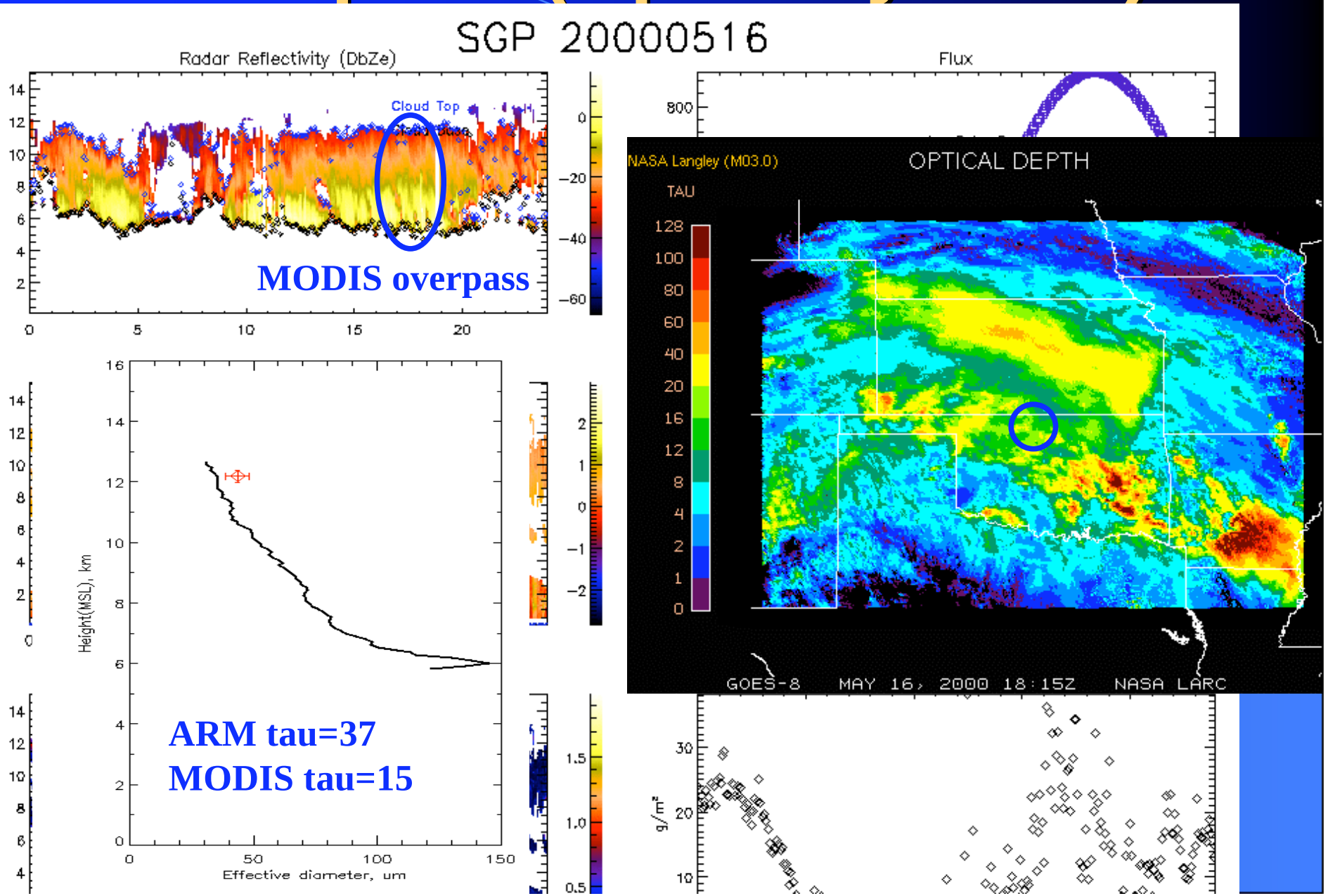
2) Assuming $\varepsilon(\tau)$ is correct.
If $B(T_s)$ is underestimated,
$B(T_{eff})=[B(T)]/\varepsilon - B(T_s)(1-\varepsilon)/\varepsilon$
then $B(T_{eff})$ is higher $\rightarrow$
$T_{eff}$ is higher $\rightarrow H_{eff}$ is lower

# DAY Comparison of cloud height and temperature at ARM SGP site (Day)

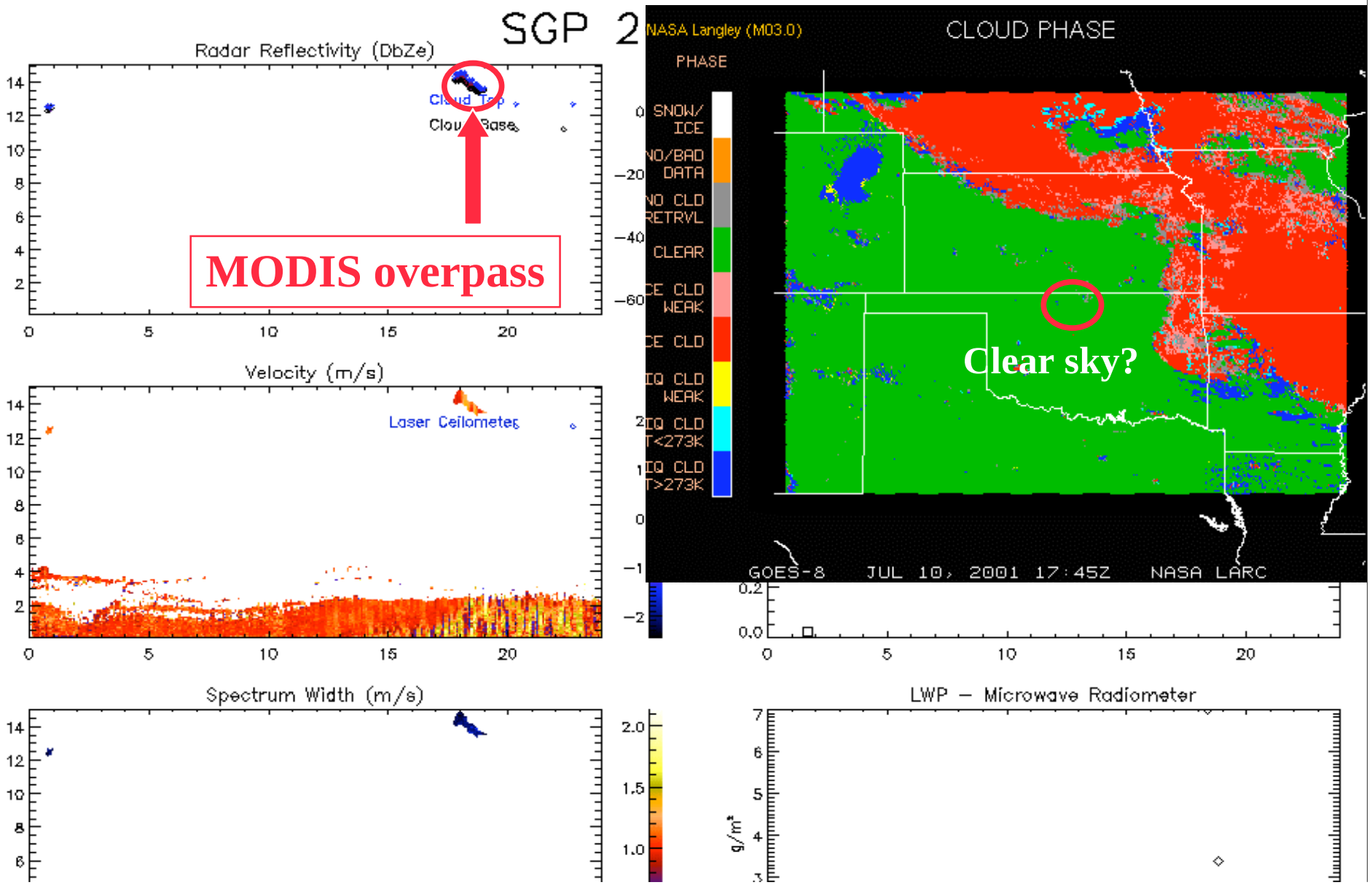



1. We understand $H_{eff} \sim H_{top}$ for sample 5 because of its optically thick.
2. We can explain most of $H_{eff} \leq H_{base}$ because their optical depths are small, but we do not understand sample 8 (lower than $H_{base}$)

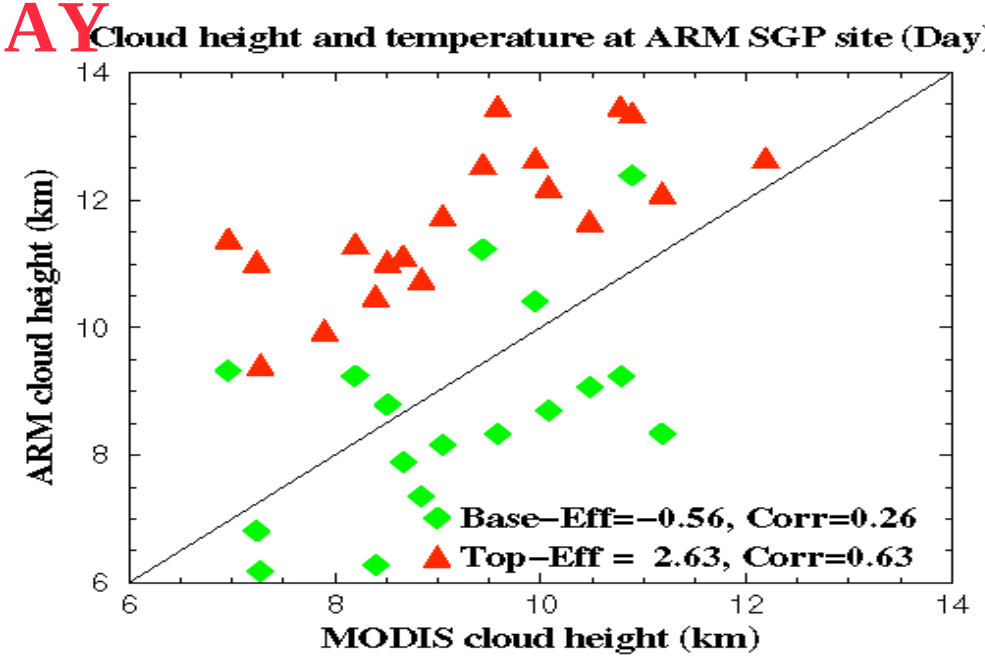
# Sample 5 (Optically thick)

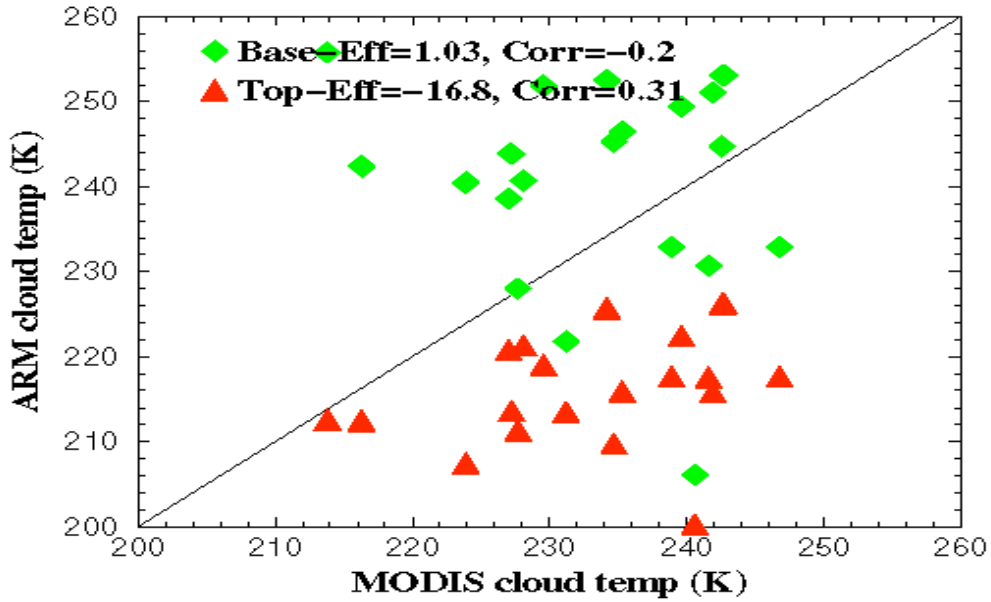


# Sample 8: Local cirrus

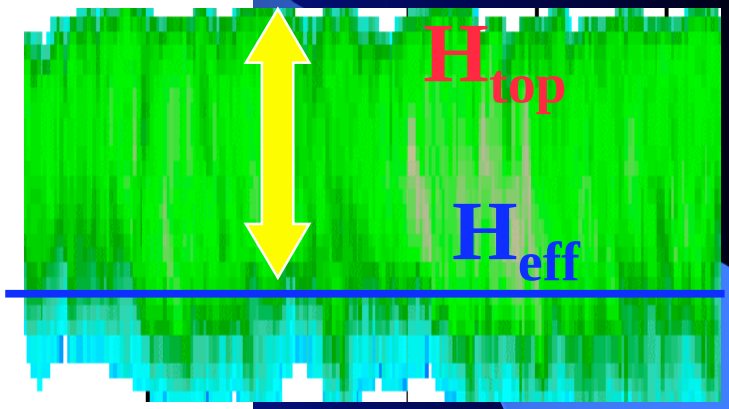


**DAY**



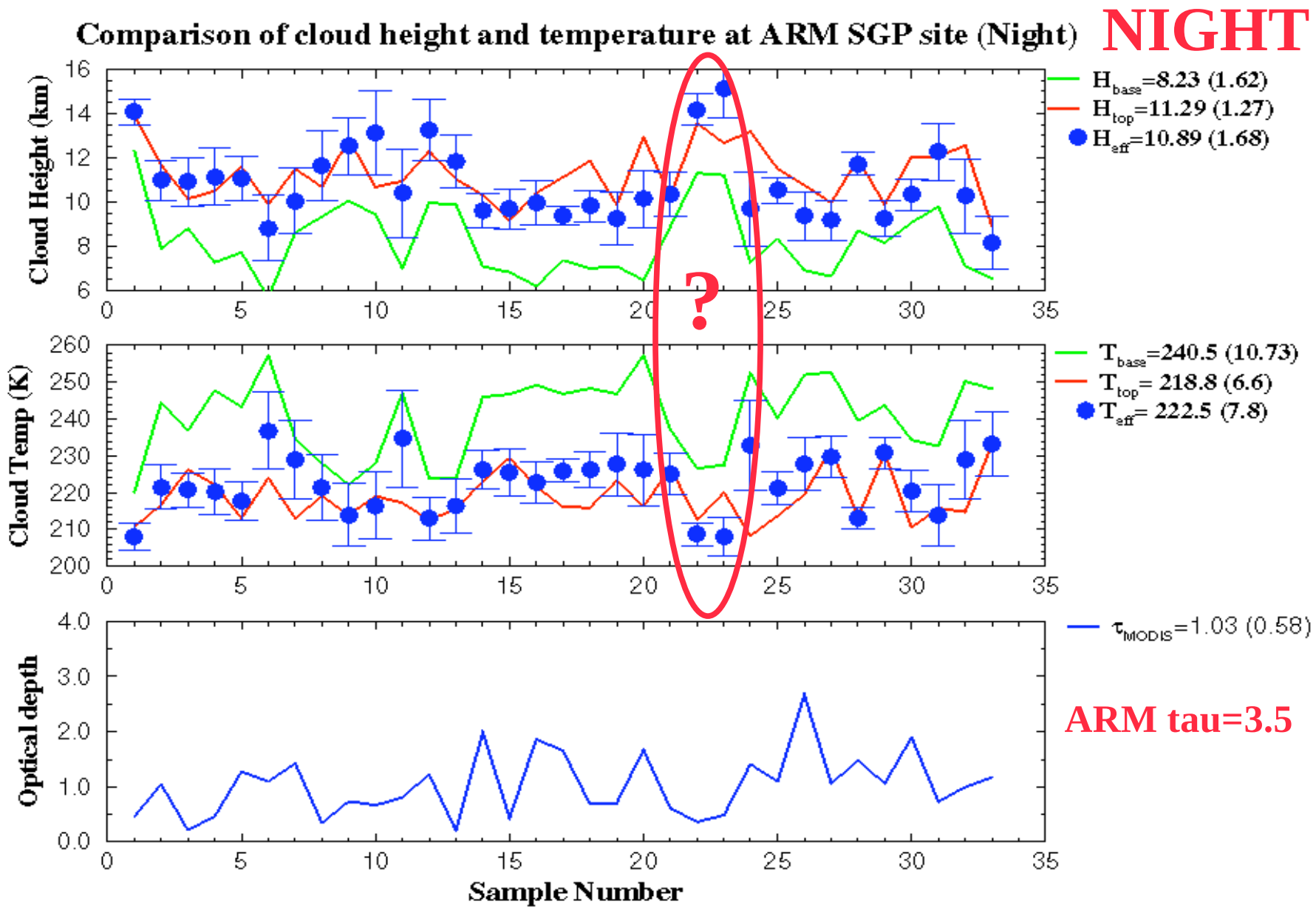




**Most of $H_{eff}$ scatter around $H_{base}$, but have higher correlation with $H_{top}$—very reasonable because satellite-observed radiative centers include ($H_{top}$-$H_{eff}$) information**



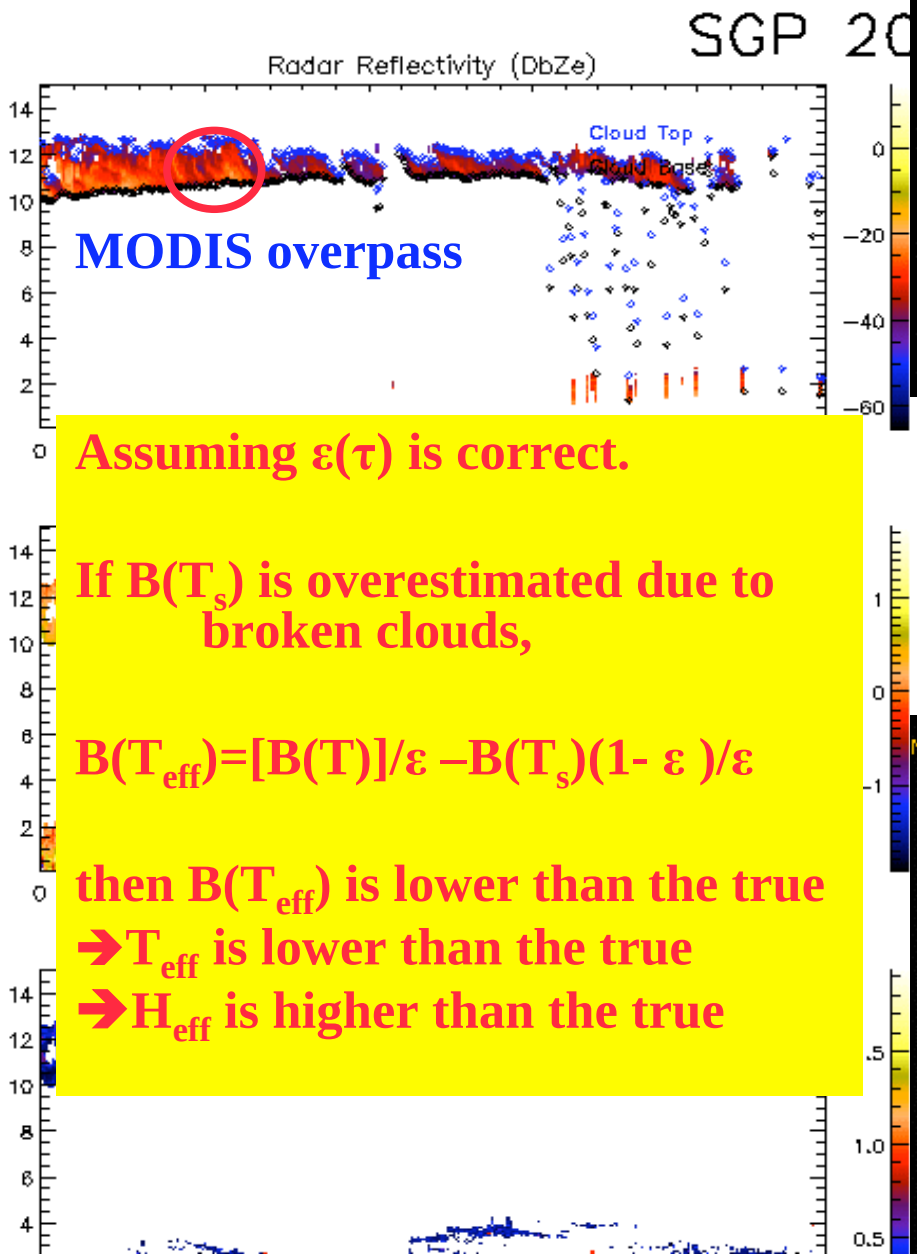

**Most of effective temps also scatter around cloud-base temps with low correlation**

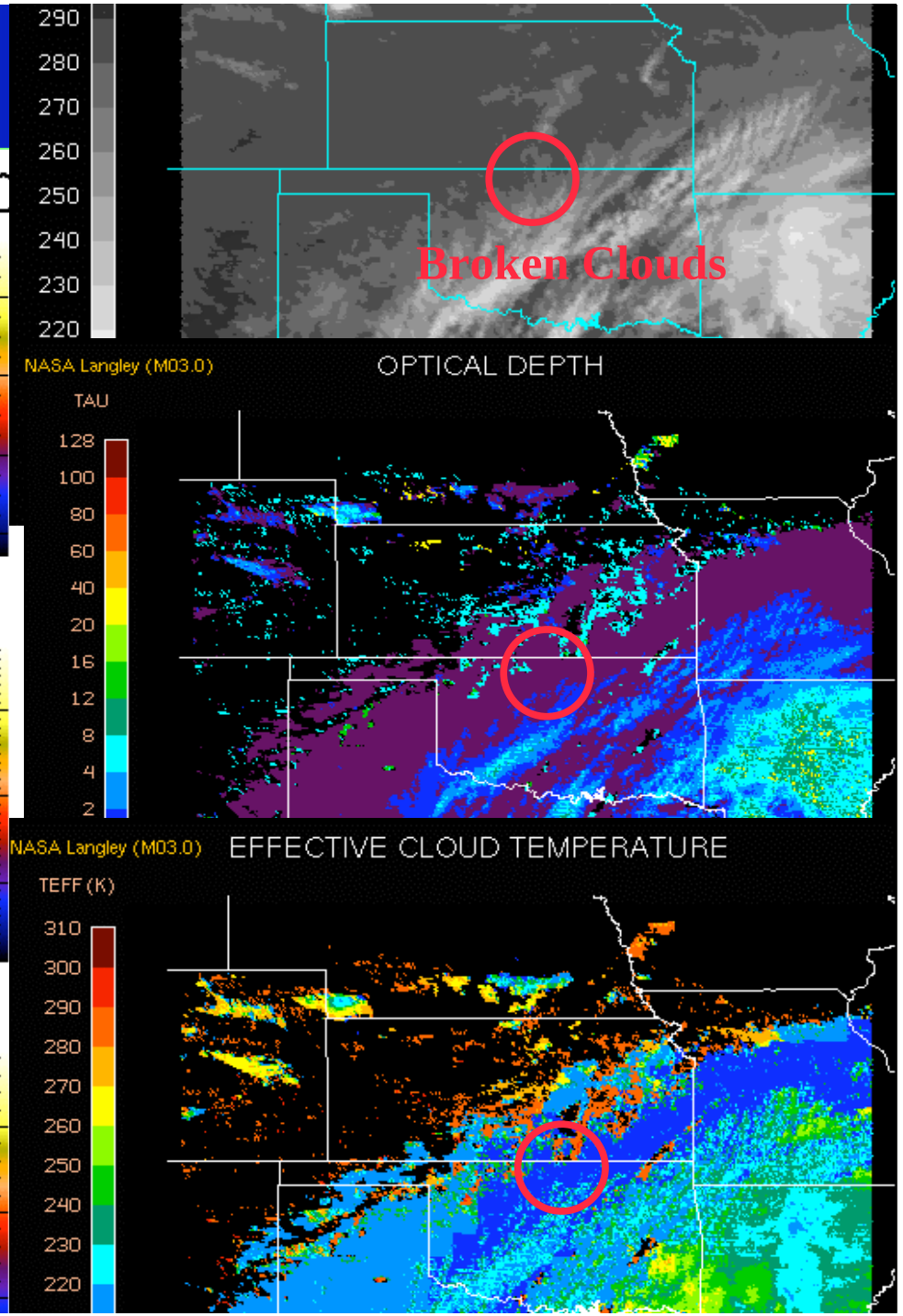
**Conclusion: MODIS-retrieved temp and height are very reasonable.**




**Most of MODIS-derived $H_{eff}$ and $T_{eff}$ are near cloud tops, why?**
**MODIS tau is too low. Using ARM tau➔increases emissivity➔$H_{eff}$.**

# Sample 22




**Assuming ε(τ) is correct.**

**If $B(T_s)$ is overestimated due to broken clouds,**

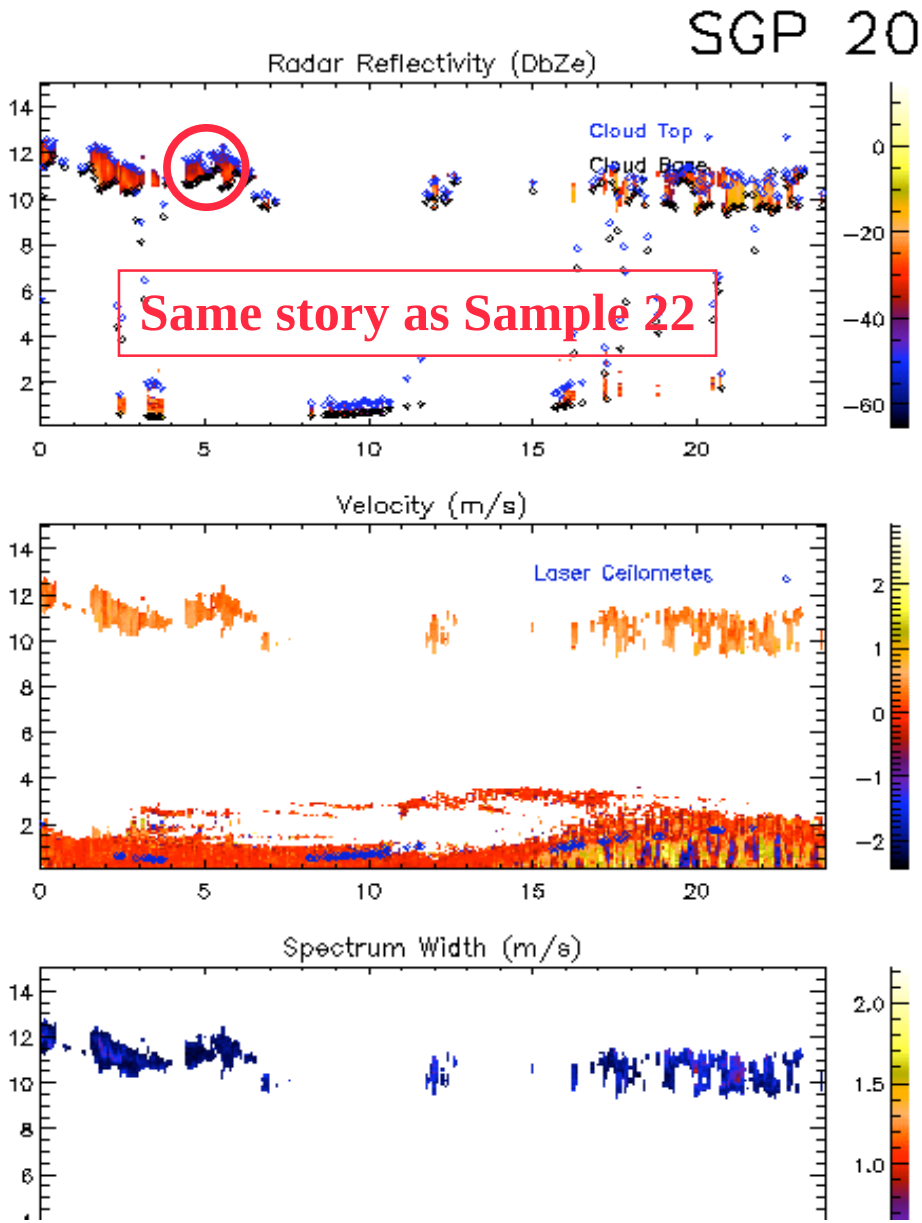
$$B(T_{eff})=[B(T)]/\varepsilon - B(T_s)(1-\varepsilon)/\varepsilon$$

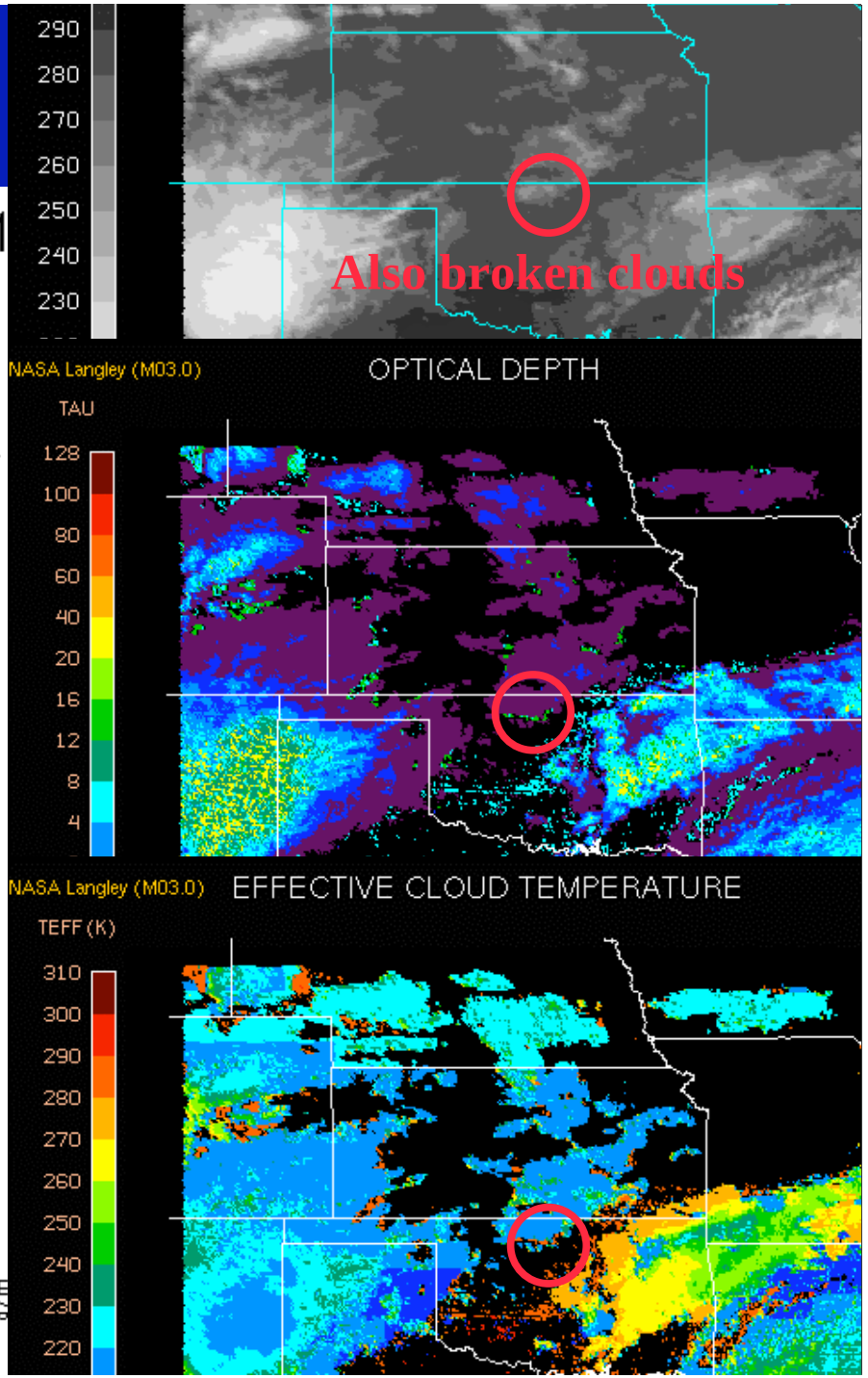
**then $B(T_{eff})$ is lower than the true**

**➔$T_{eff}$ is lower than the true**

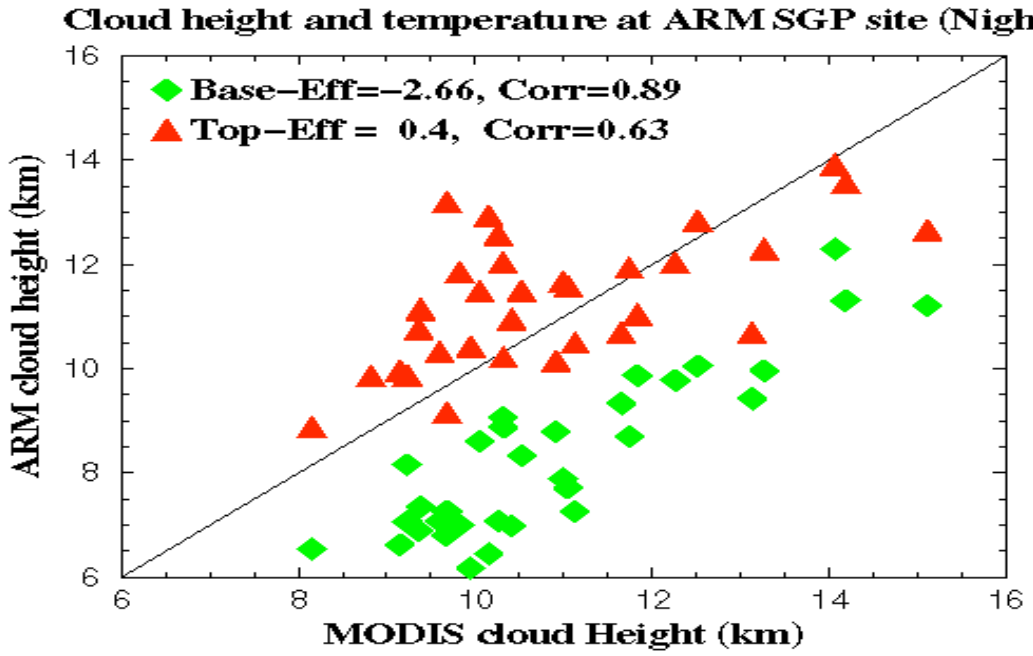
**➔$H_{eff}$ is higher than the true**

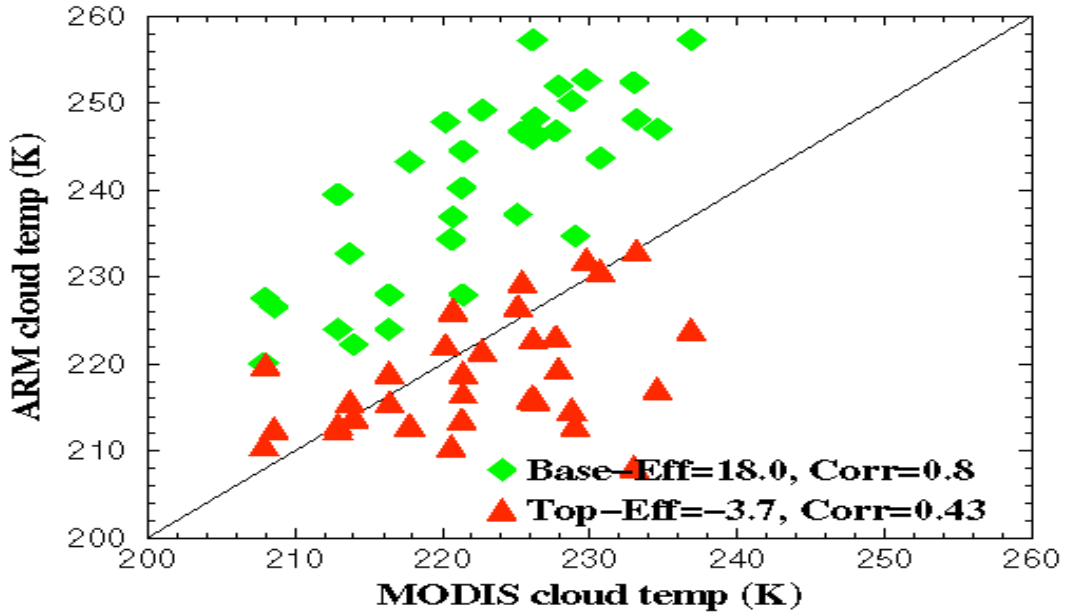
# Sample 23


SGP 2001
Radar Reflectivity (DbZe)
Cloud Top
Cloud Base
Same story as Sample 22
Velocity (m/s)
Laser Ceilometer
Spectrum Width (m/s)


Also broken clouds
NASA Langley (M03.0)
OPTICAL DEPTH
TAU
W/m²
NASA Langley (M03.0)
EFFECTIVE CLOUD TEMPERATURE
TEFF (K)

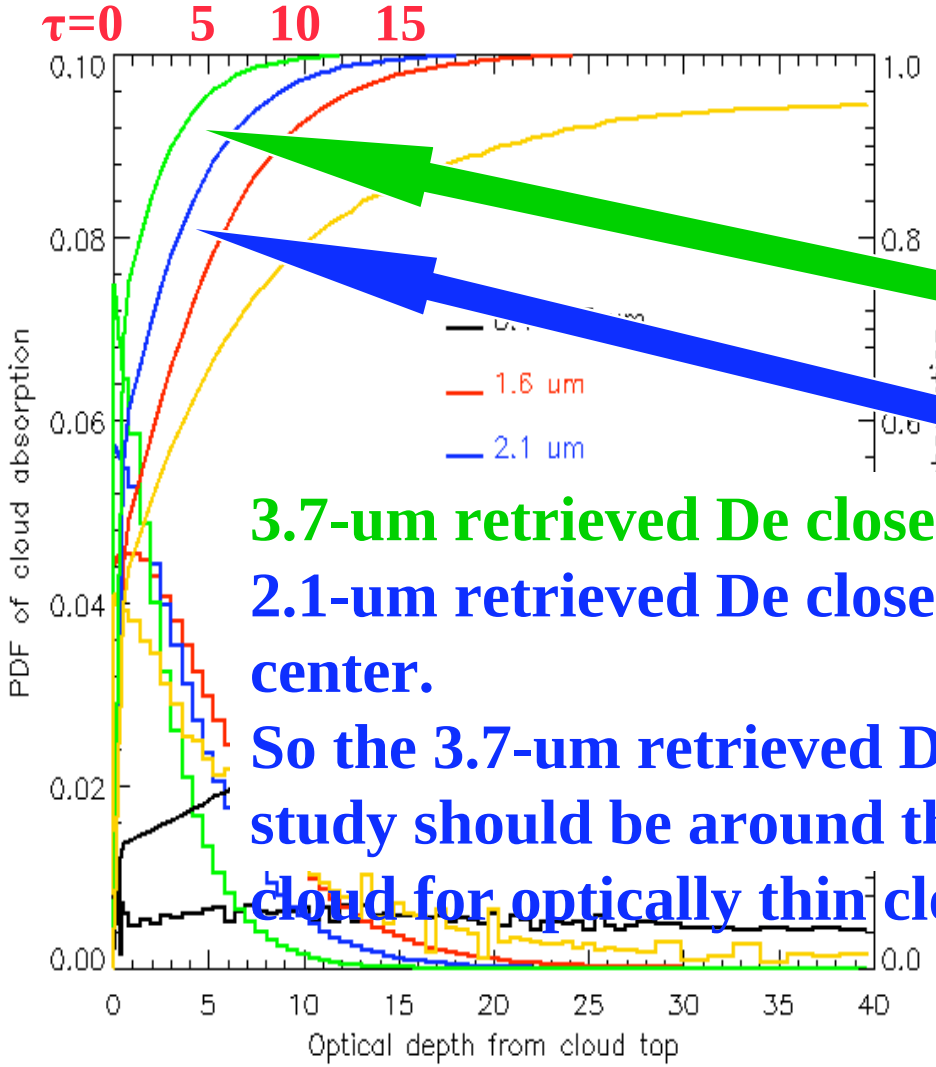
# NIGHT




**Most of $H_{eff}$ and $T_{eff}$ scatter around cloud tops with high correlations**
**This is NOT what we expect.**

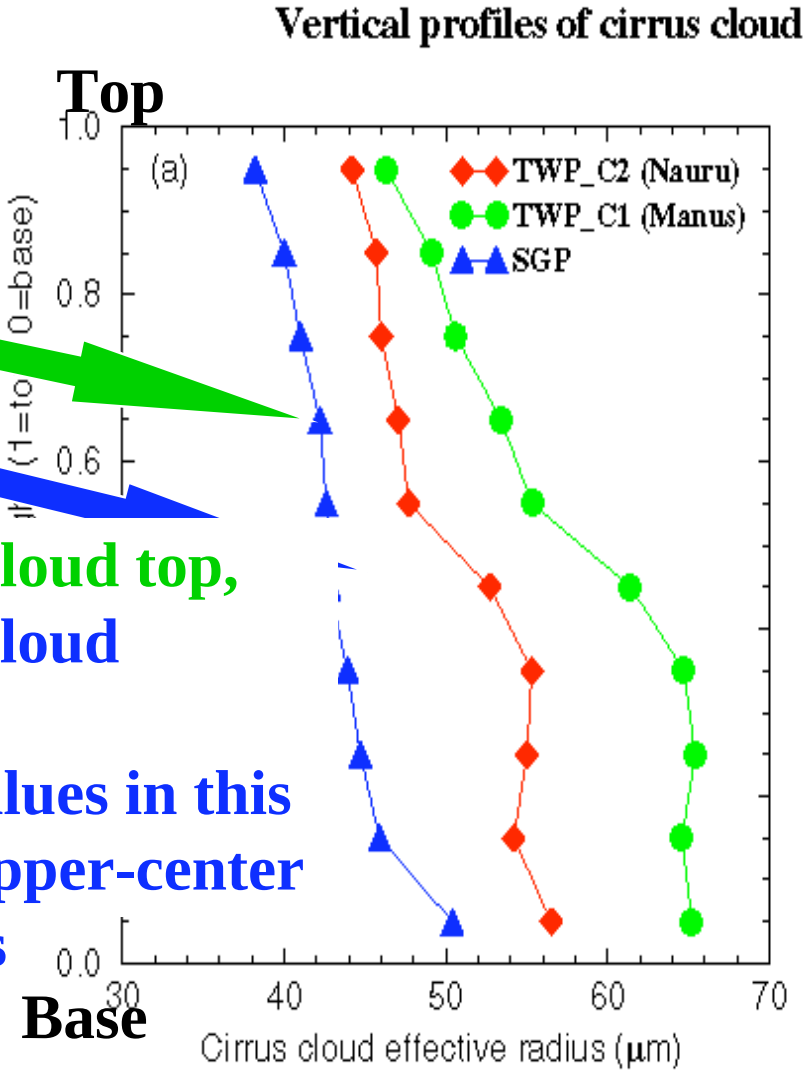
# Cloud Microphysics comparison




Dong et al. JGR 2008

**3.7-um retrieved De close to cloud top, 2.1-um retrieved De close to cloud center.**

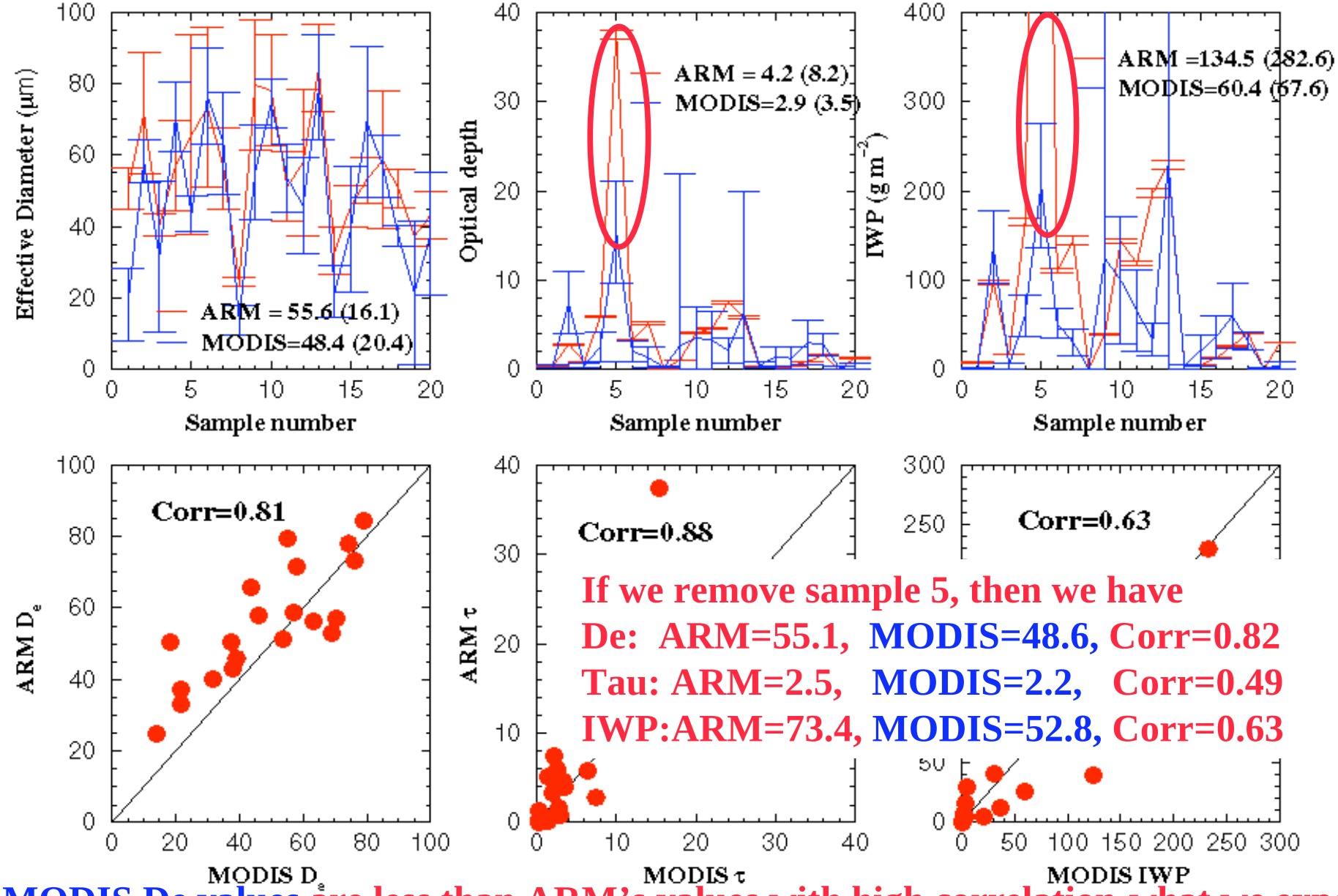
**So the 3.7-um retrieved De values in this study should be around the upper-center cloud for optically thin clouds**




Deng and Mace, 2006

# DAY

## Comparison of Cirrus cloud microphysics at ARM SGP site (Day)




**If we remove sample 5, then we have**

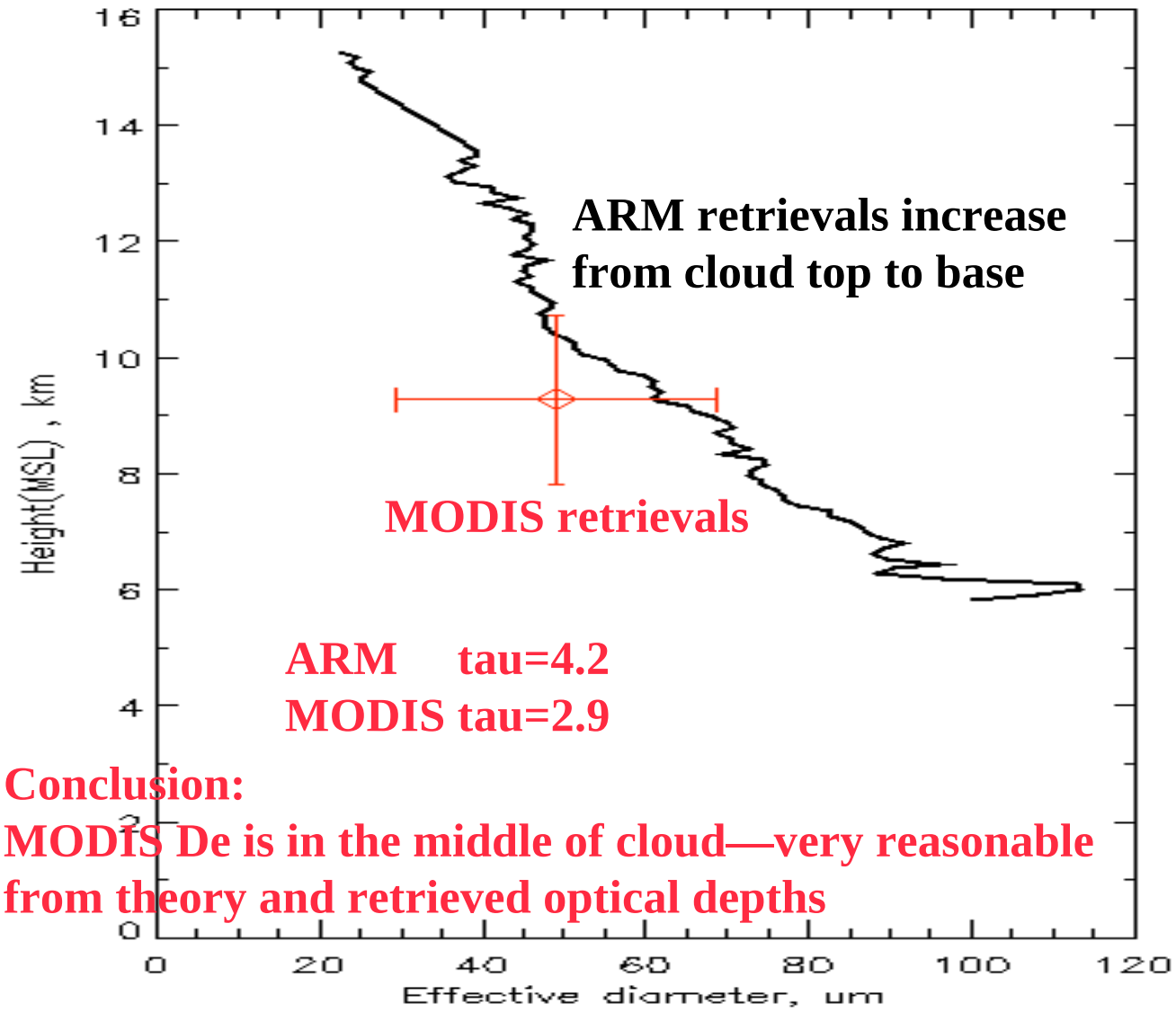
**De: ARM=55.1, MODIS=48.6, Corr=0.82**

**Tau: ARM=2.5, MODIS=2.2, Corr=0.49**

**IWP:ARM=73.4, MODIS=52.8, Corr=0.63**

**MODIS De values are less than ARM's values with high correlation-what we expect but its optical depth and IWP are less than ARM results with high correlations**

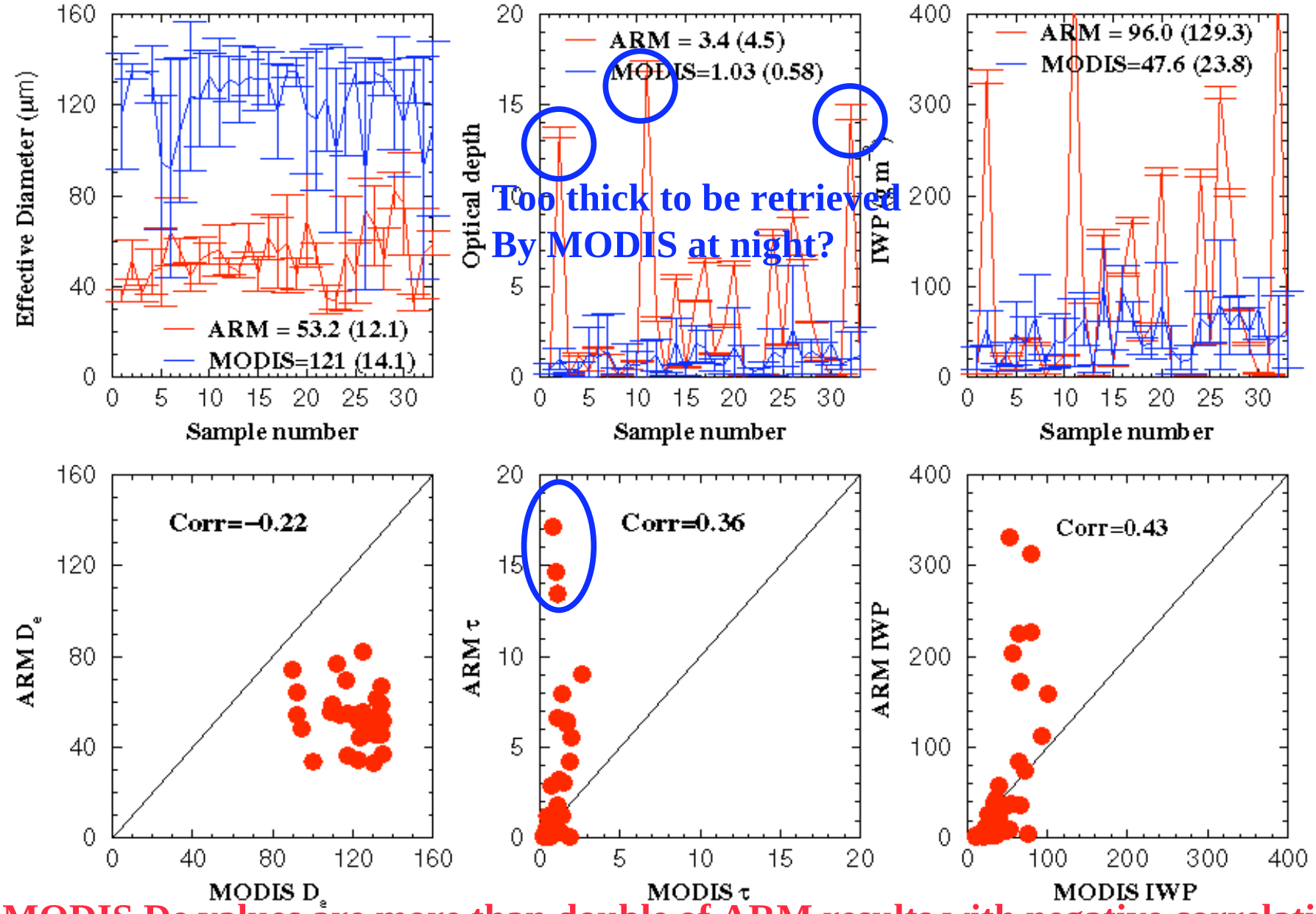
# Mean vertical profile of ARM De




**Conclusion:**
**MODIS De is in the middle of cloud—very reasonable from theory and retrieved optical depths**

## Comparison of Cirrus cloud microphysics at ARM SGP site (Night)

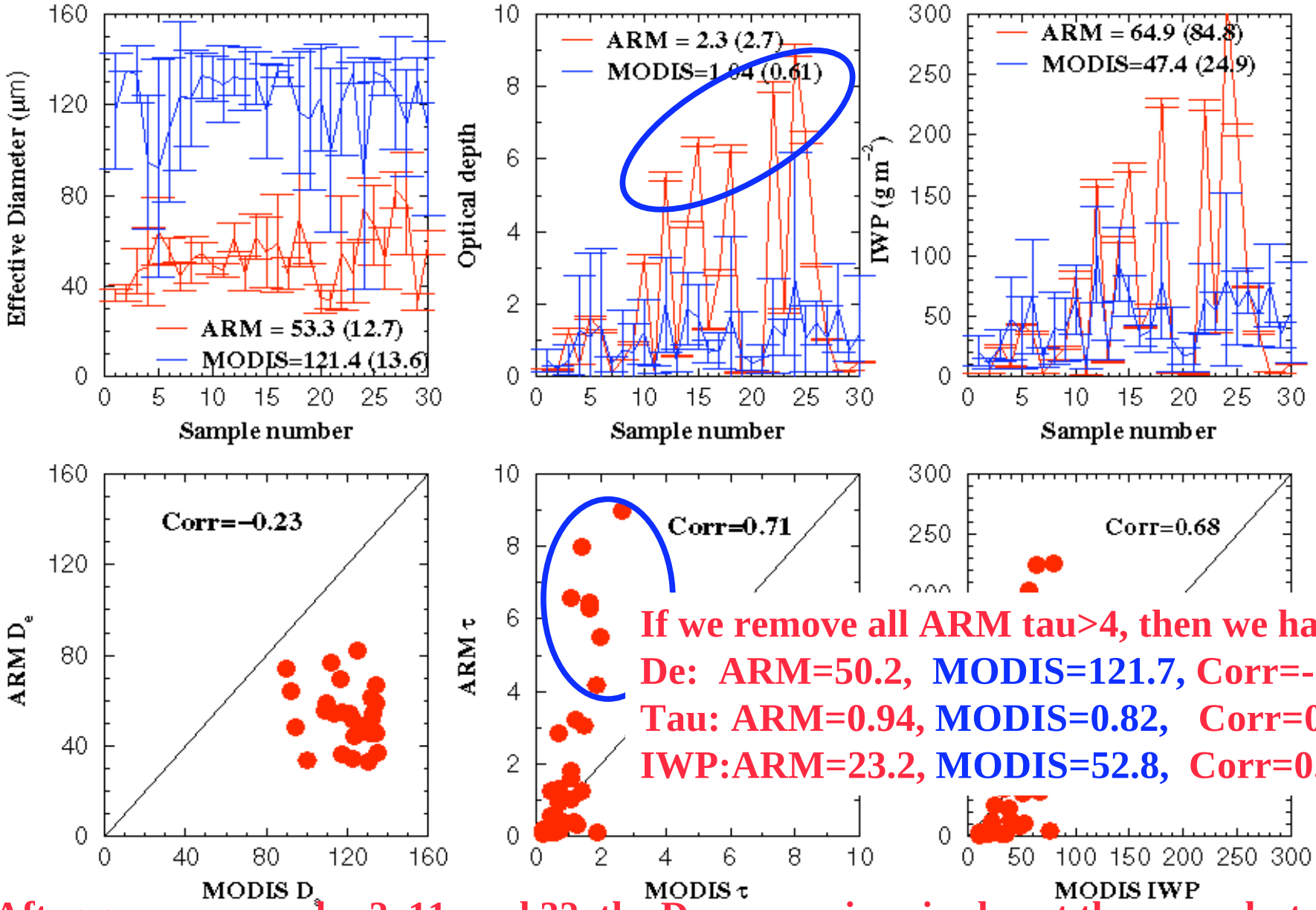
**NIGHT**




**MODIS De values are more than double of ARM results with negative correlation.**

**Tau and IWP are much lower than ARM results with moderate correlations.**

## Comparison of Cirrus cloud microphysics at ARM SGP site (Night) NIGHT




**If we remove all ARM tau>4, then we have**
**De: ARM=50.2, MODIS=121.7, Corr=-0.2**
**Tau: ARM=0.94, MODIS=0.82, Corr=0.4**
**IWP:ARM=23.2, MODIS=52.8, Corr=0.57**

**After remove samples 2, 11, and 32, the De comparison is almost the same, but Tau and IWP agree much better to ARM results with moderate correlations**

# Conclusions

1) Most of MODIS-retrieved daytime cirrus cloud heights and temperatures are close to ARM cloud bases (reasonable for optically thin).

However, their nighttime results are near cloud tops (unreasonable for optically thin clouds)

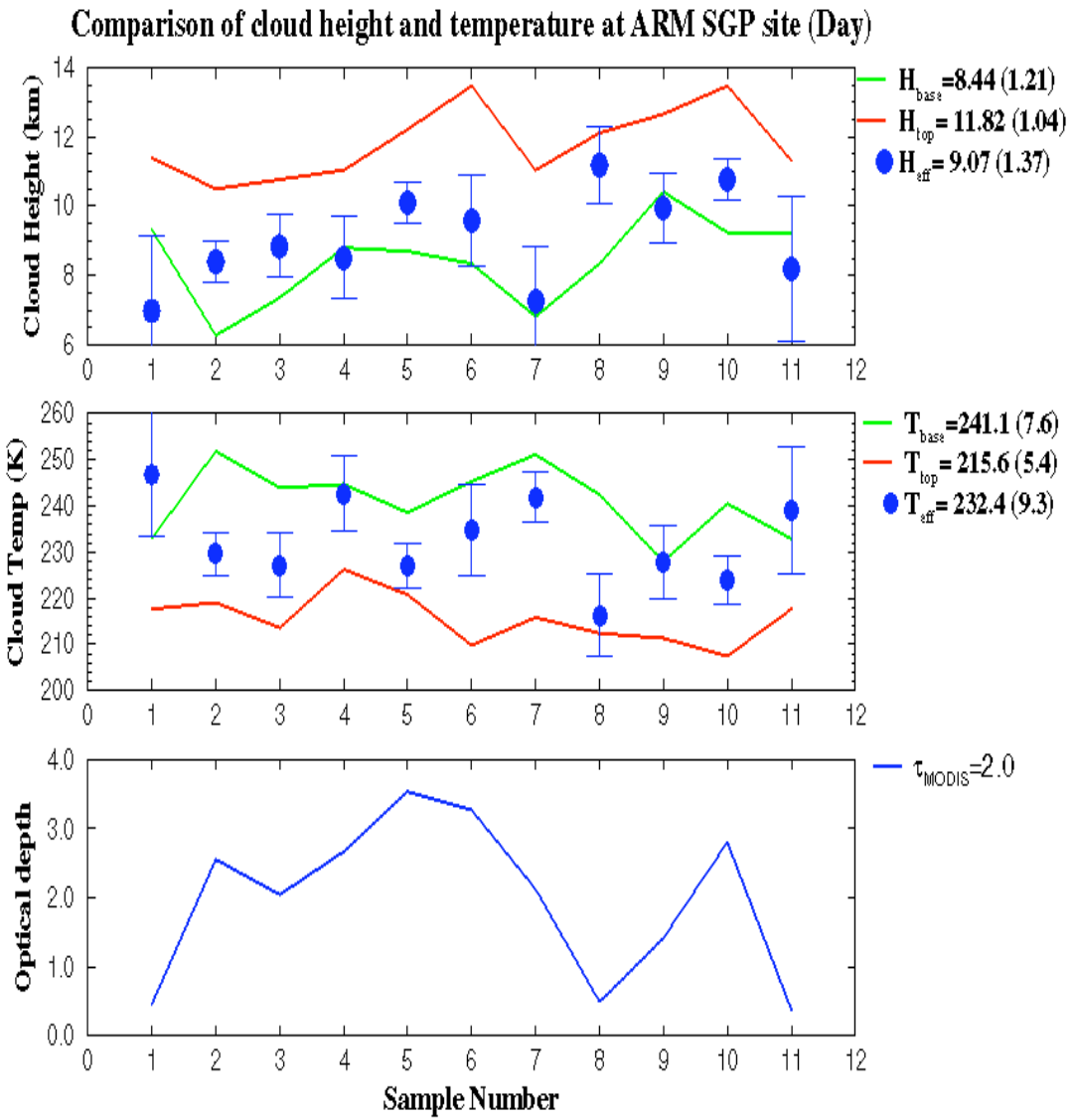
2) The daytime MODIS-retrieved De/tau/IWP values agree well with ARM retrievals with moderate-high correlations, and its De represents the cloud center information.

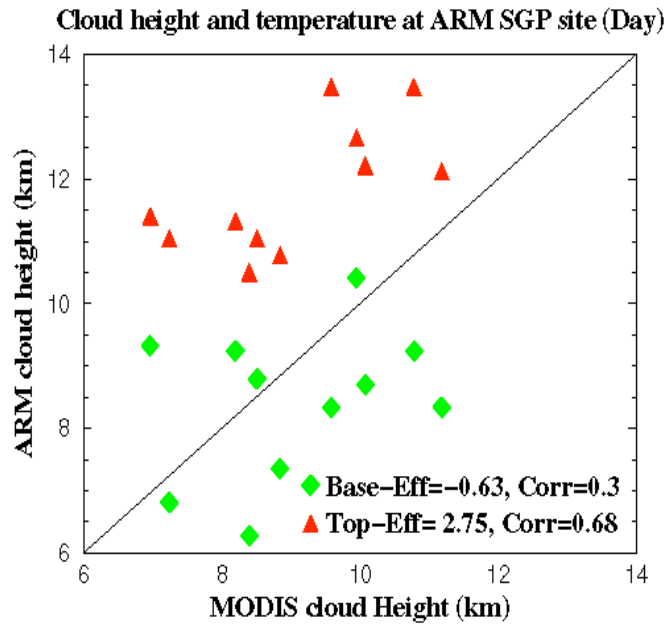
3) The nighttime MODIS De values are double of ARM retrievals with negative correlation, and its Tau and IWP agree much better to ARM results with moderate correlations after removing a few samples.

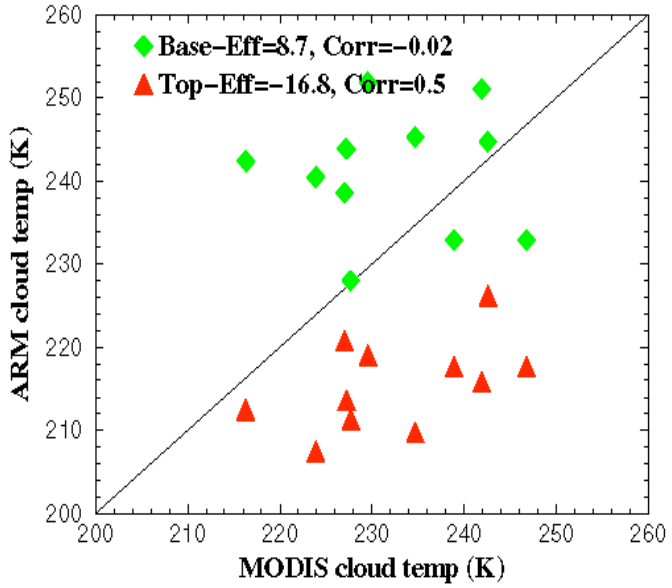
# Commercial Time

- **Dong, X., P. Minnis, B. Xi, S. Sun-Mack, and Y. Chen, 2008: Validation of CERES-MODIS stratus cloud properties using ground-based measurements at the DOE ARM SGP site. *J. Geophys. Res. 113*, D03204, doi:10.1029/2007JD008438.**
- **Dong, X., B., B. Wielicki, B. Xi, Y, Hu, G.G. Mace, S. Benson, F. Rose, S. Kato, T. Charlock, and P. Minnis 2008: Using observations of deep convective systems to constrain atmospheric column absorption in the optically thick limit. *J. Geophys. Res.* doi:10.1029/2007JD009769, in press.**

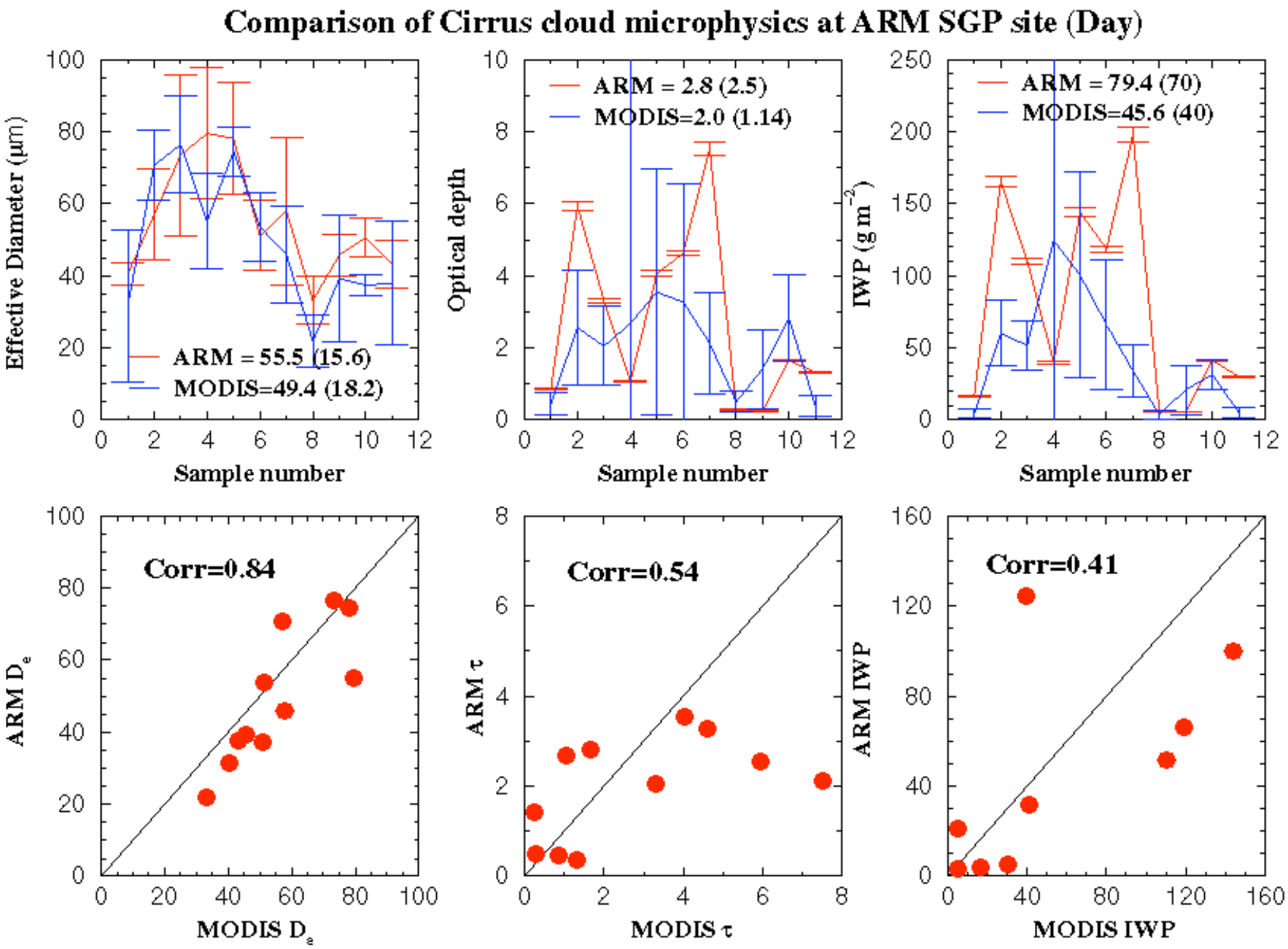
# After removing thos




**There is NO significant improvement for 11 samples**


Comparison of Cirrus cloud microphysics at ARM SGP site (Day)
Effective Diameter (μm)
ARM = 55.5 (15.6)
MODIS=49.4 (18.2)
Sample number
Optical depth
ARM = 2.8 (2.5)
MODIS=2.0 (1.14)
Sample number
IWP (g m$^{-2}$)
ARM = 79.4 (70)
MODIS=45.6 (40)
Sample number
ARM $D_e$
Corr=0.84
MODIS $D_e$
ARM τ
Corr=0.54
MODIS τ
ARM IWP
Corr=0.41
MODIS IWP

# Cloud Microphysics comparison

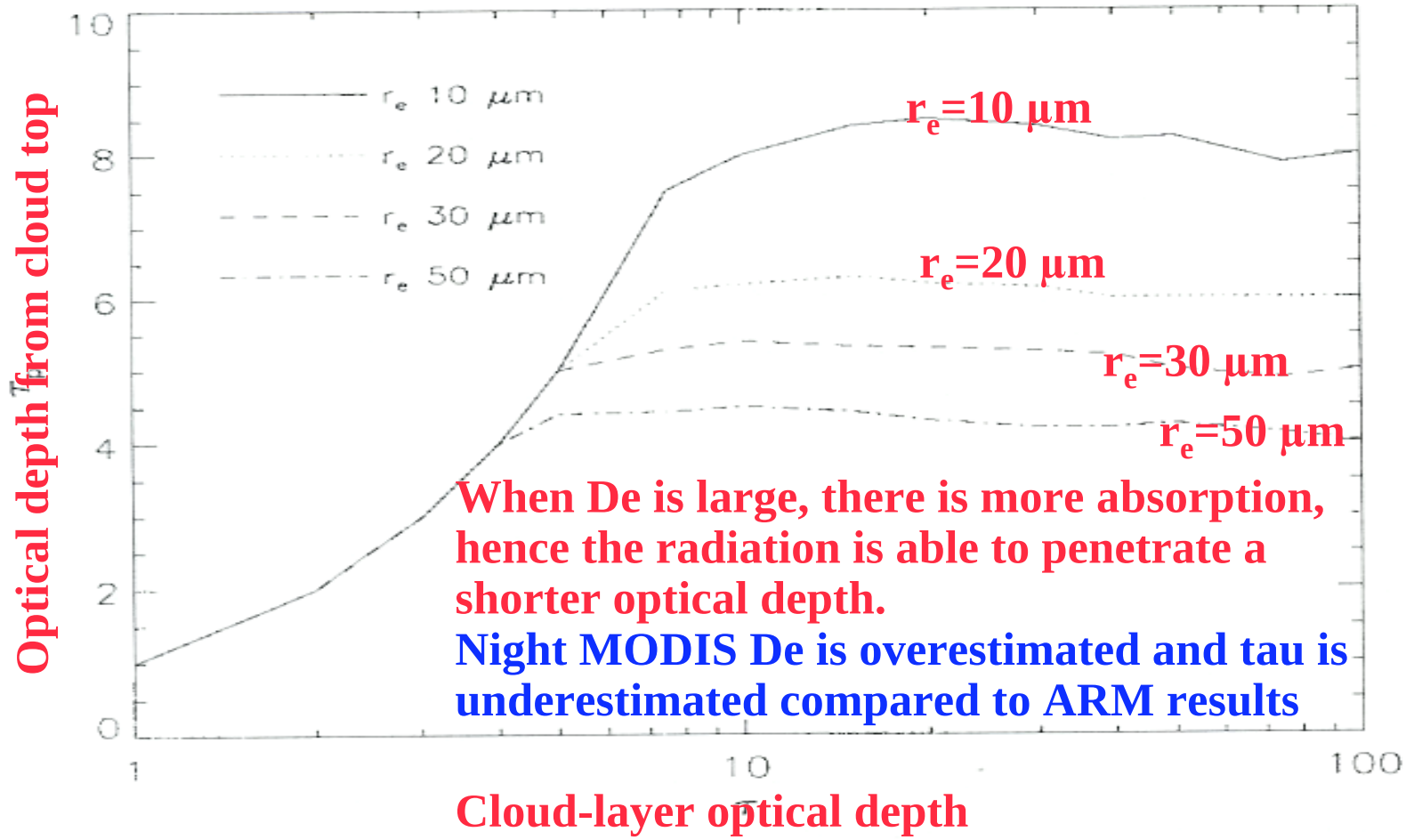



FIG. 7. Optical depth between $z_t$, cloud top, and $z$, where the downward solar radiation in the near-infrared channel is reduced by an exponential factor, against total optical depth $\tau$ for entire cloud for vertically homogeneous clouds with

McFarquhar and Heymsfield, 1998