How 3D Science Can Help to Correctly Interpret MODIS Data for Better Understanding of Aerosol-Cloud Interactions

Alexander Marshak (GSFC)

Robert Cahalan (GSFC)

Támas Várnai (UMBC)

Guoyong Wen (UMBC)

Brian Vant-Hull (UMD)

Instead of Intro

clouds are complex and "satellite analysis may be affected by potential cloud artifacts" (Kaufman and Koren, 2006);

- for **aerosol** retrievals:
  - cloud contamination
  - adjacency effect

may significantly overestimate AOT

- for **cloud** retrievals:
  - clear sky contamination (with dark surface)
  - cloud 3D structure (e.g., shadowing)

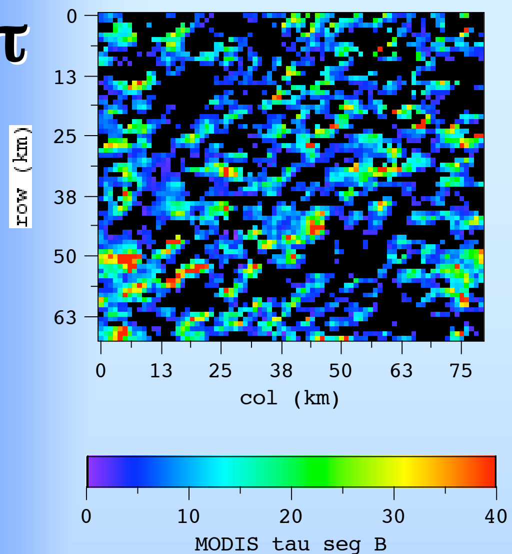
may significantly overestimate droplet size

To study **cloud-aerosol interaction** we need to be sure that retrieved **correlations** between AOT and r_e reflect real physics rather than remote sensing problems

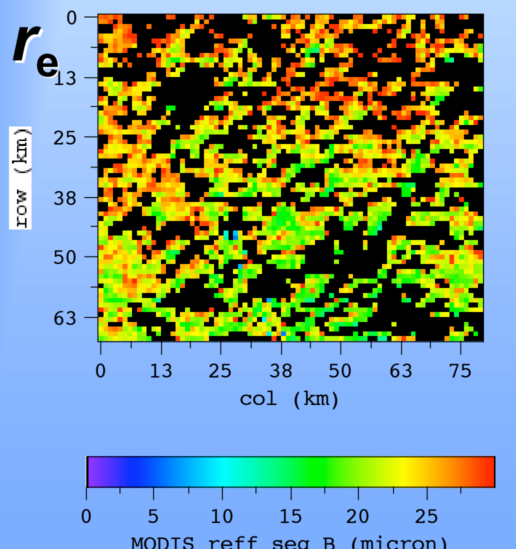
A striking example

Cloud

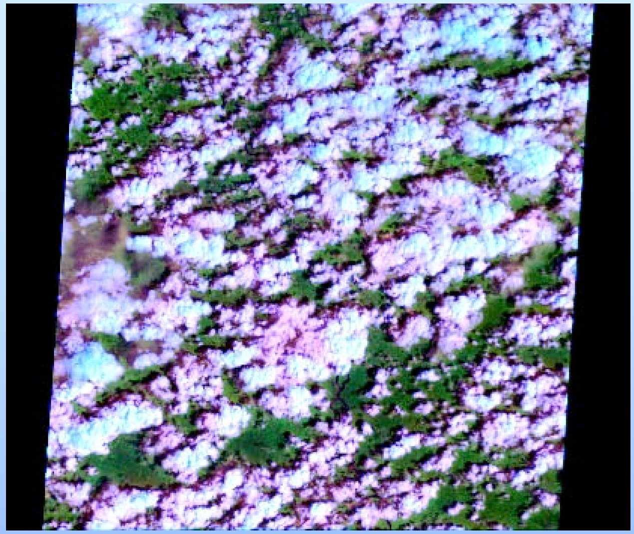
τ



r_e

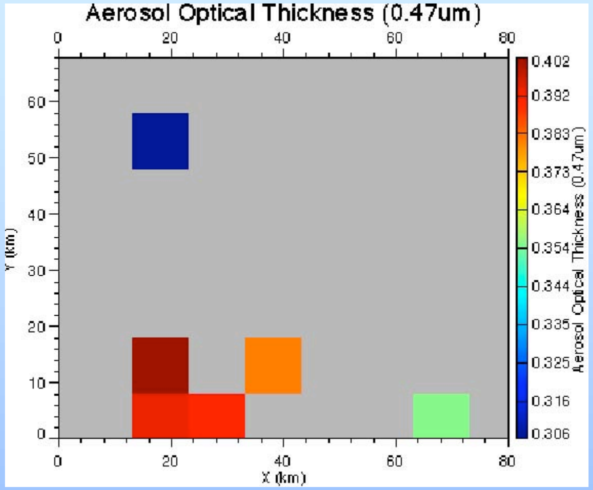


ASTER image

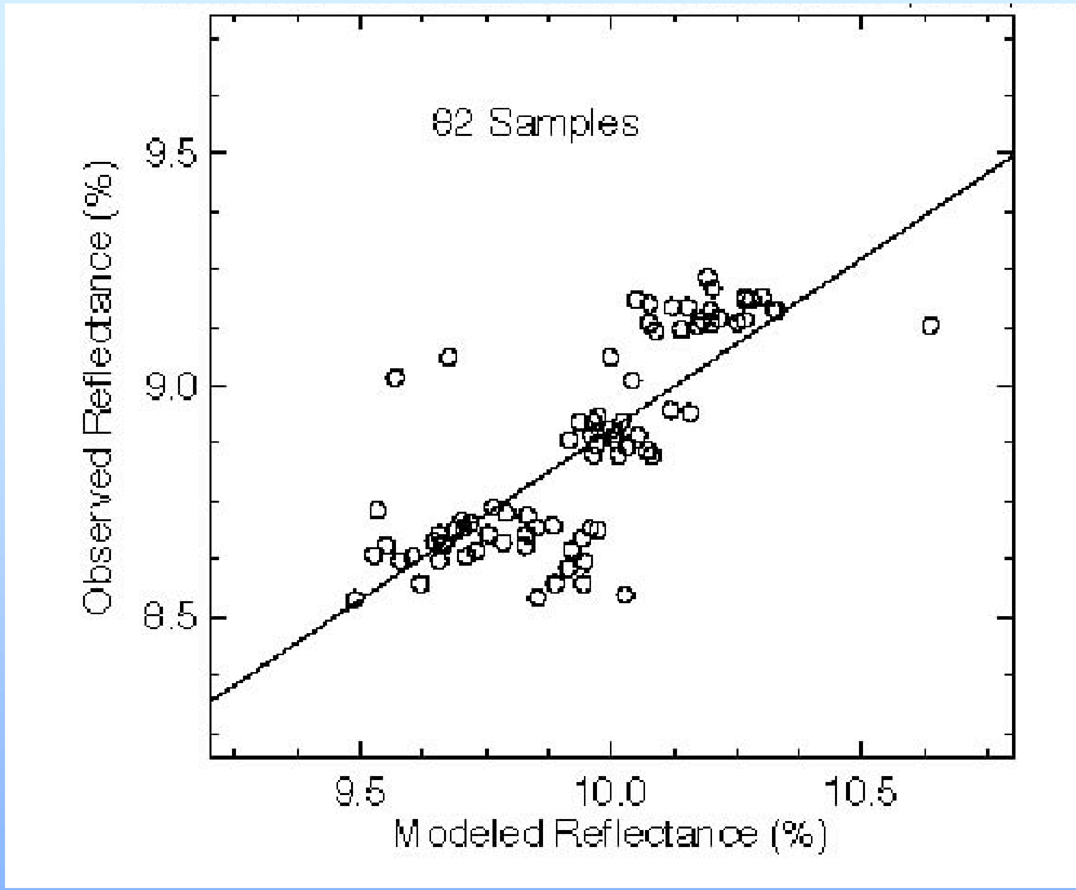


Brazil, Jan. 25, 2003
centered at 0°, 53.78°W

Aerosol



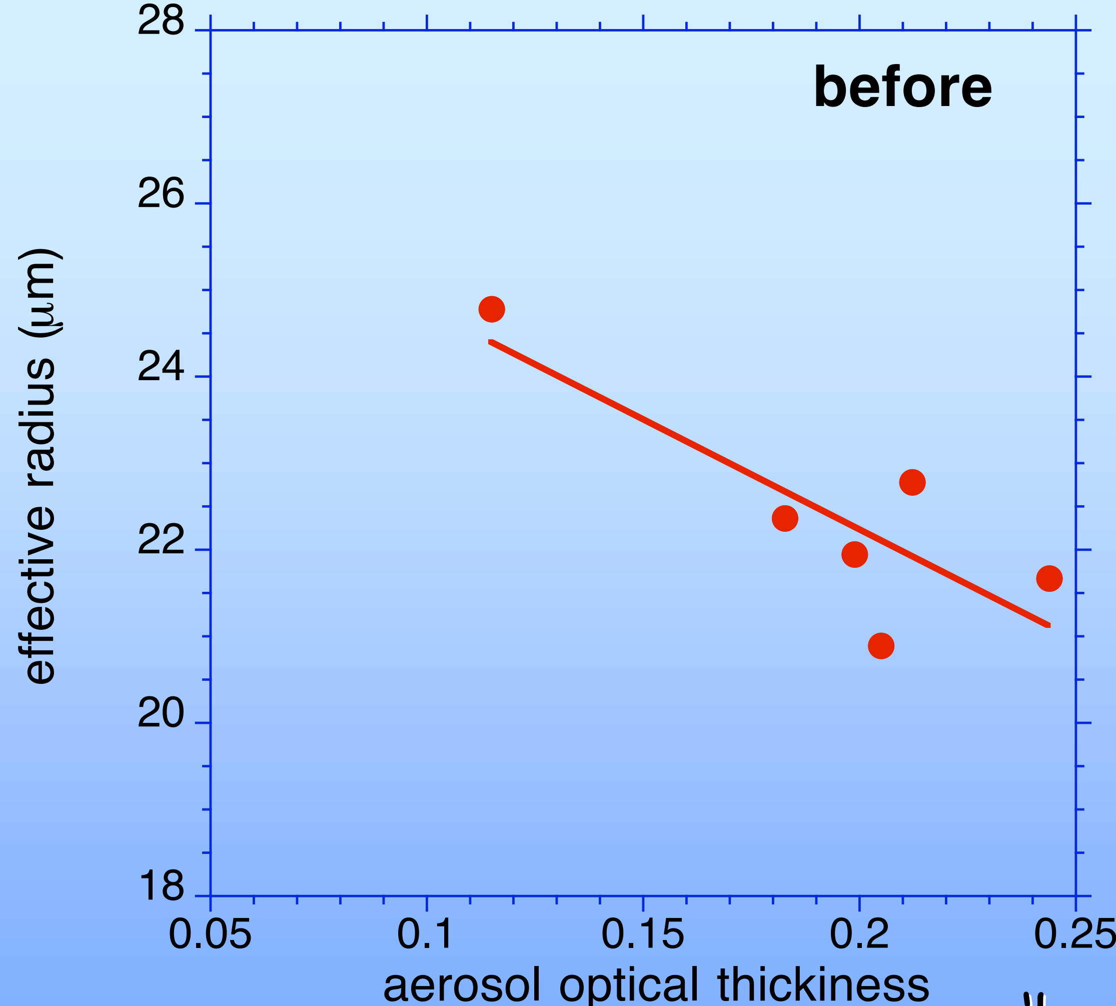
A striking example: const AOT



Modeled (with *const* AOT but MODIS 3D cloud structure) vs. Observed Reflectance.

Cor. coef. = 0.77

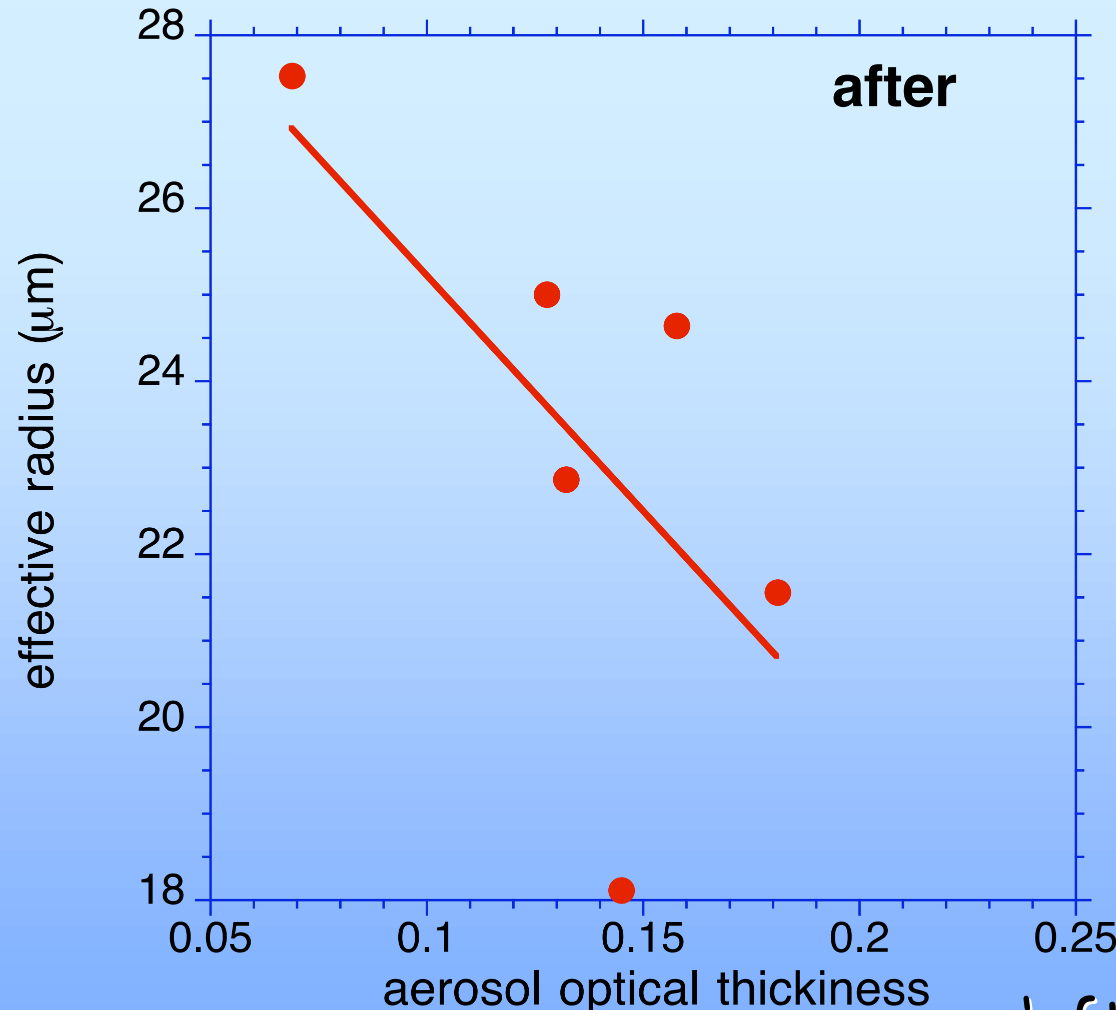
A striking example: 3D corrected vs. 3D uncorrected



r_e vs. AOT

'before' means 3D-uncorrected

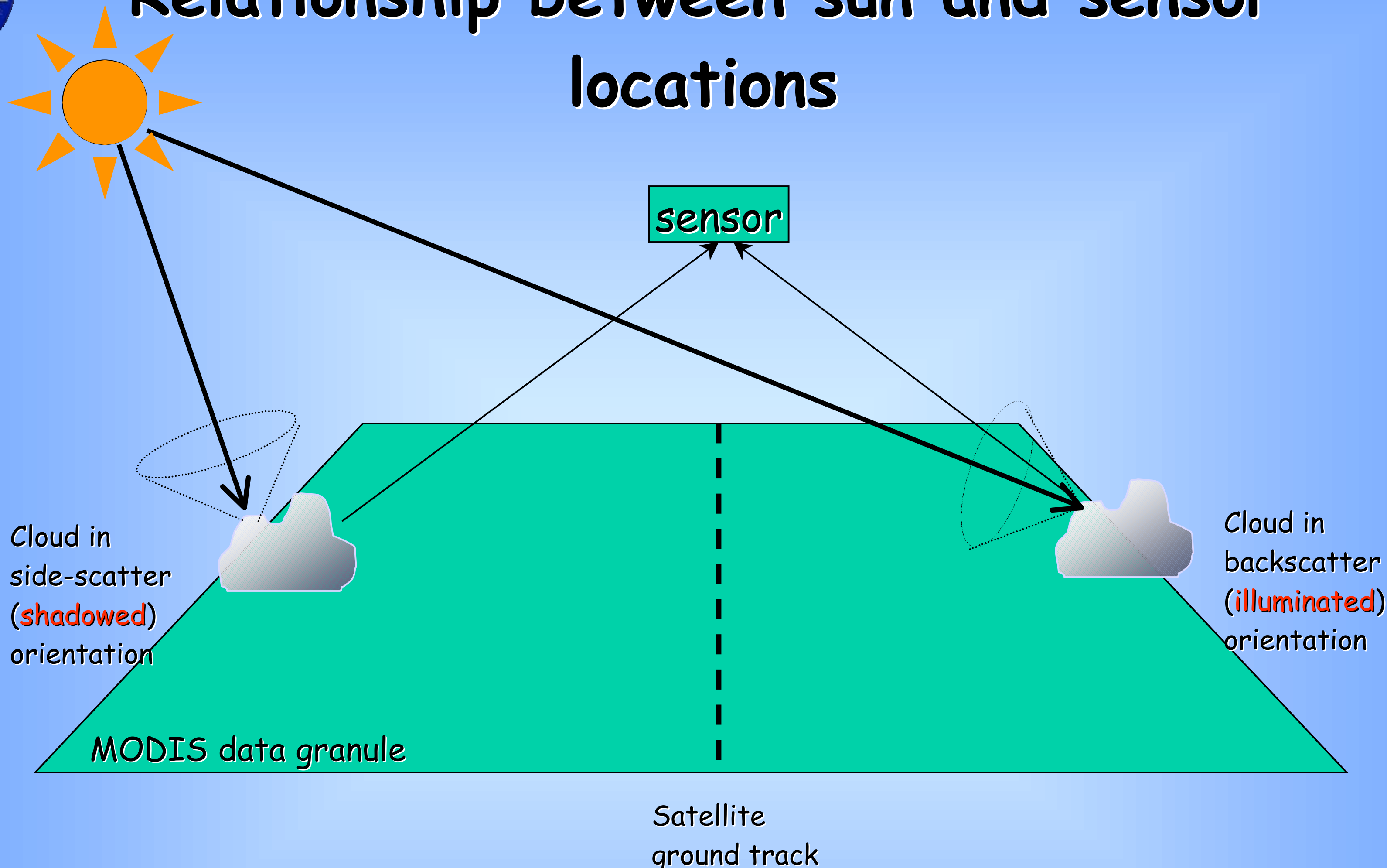
A striking example: 3D corrected vs. 3D uncorrected



r_e vs. AOT

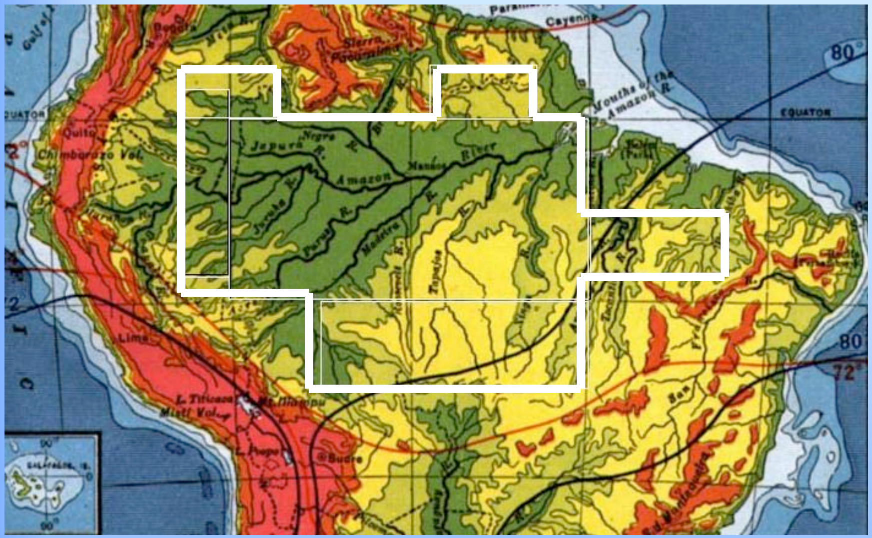
'after' means 3D-corrected

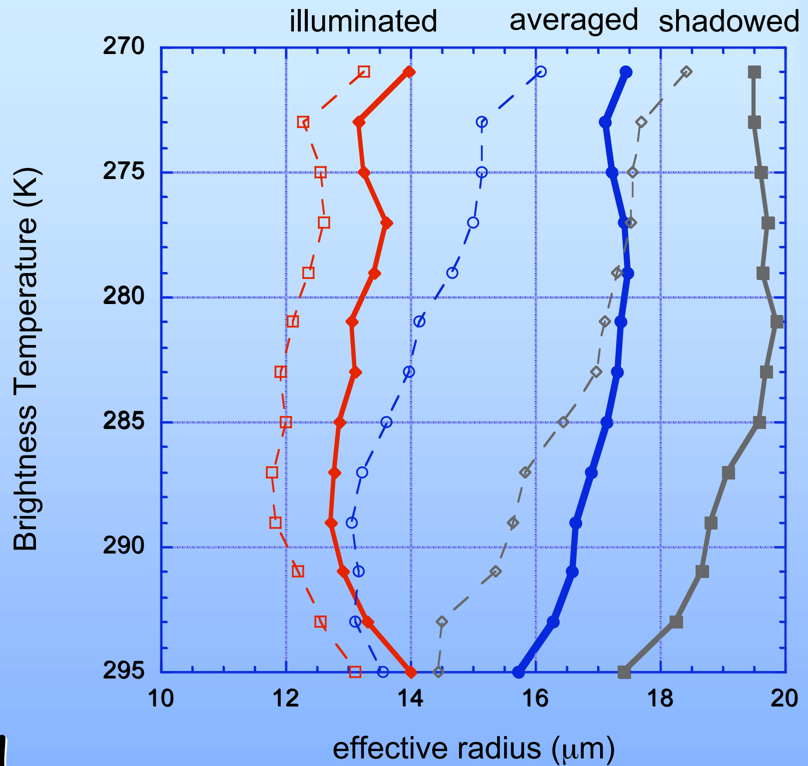
Relationship between sun and sensor locations



The division of the data set into *backscatter* and *side-scatter* geometries.

Cumulus clouds (MODIS, Aug.-Oct. 2002)

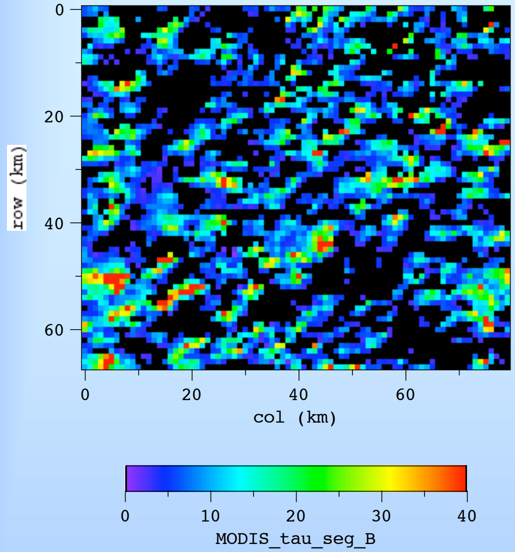




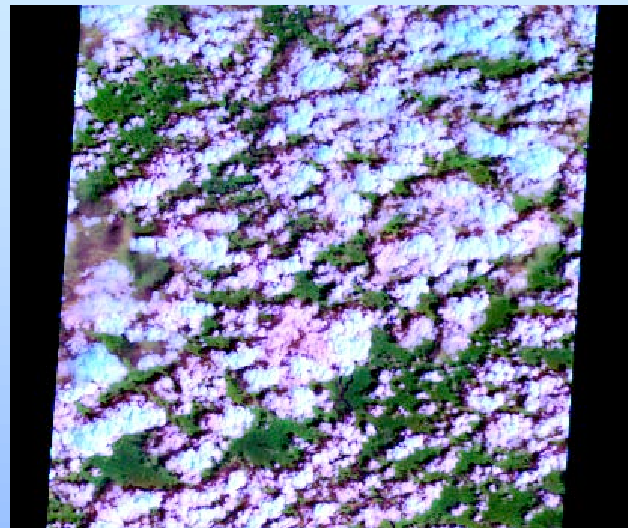
Retrieved r_e for back (illum)- and side (shad)- scattered geometries (col. 4 and "5")

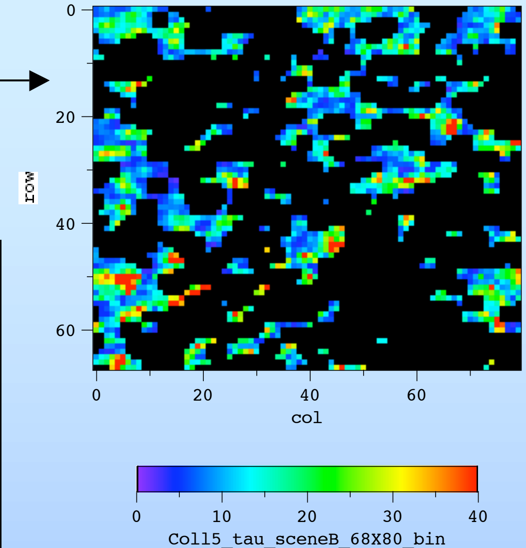
from Vant-Hull et al. (2006)

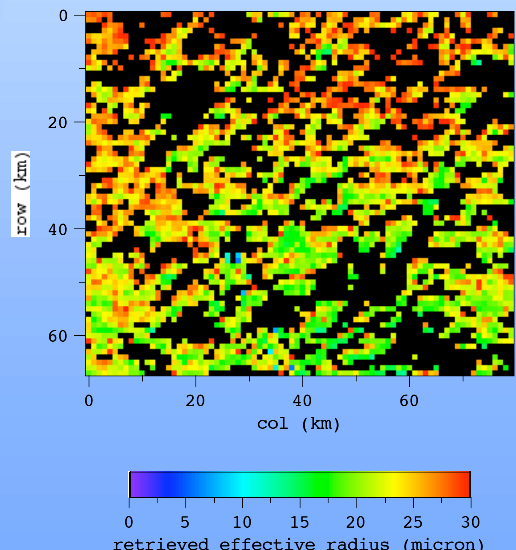
Collection 4 vs. Collection 5



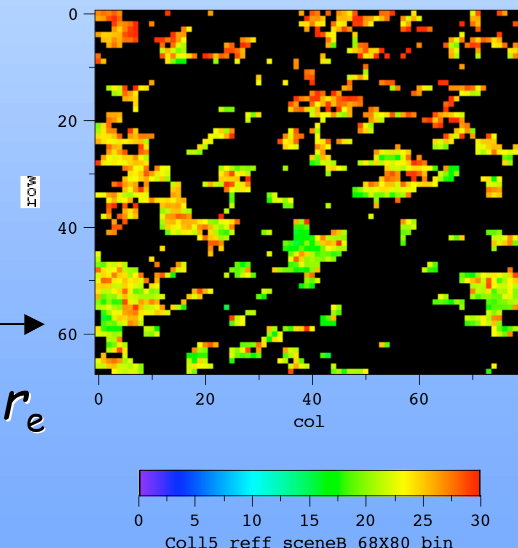
Cloud optical depth, τ



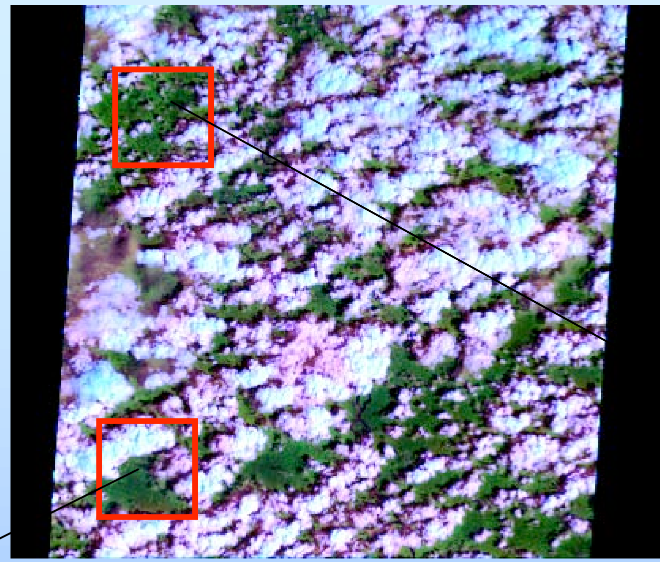




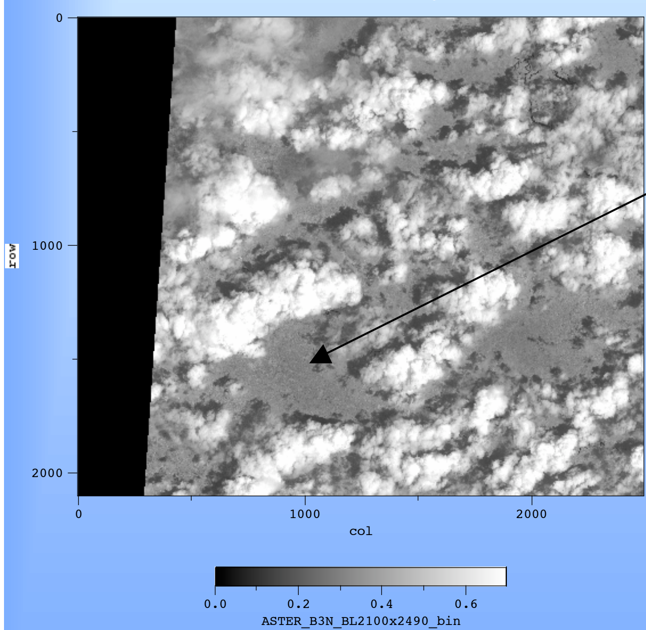
Droplet effective radius, r_e

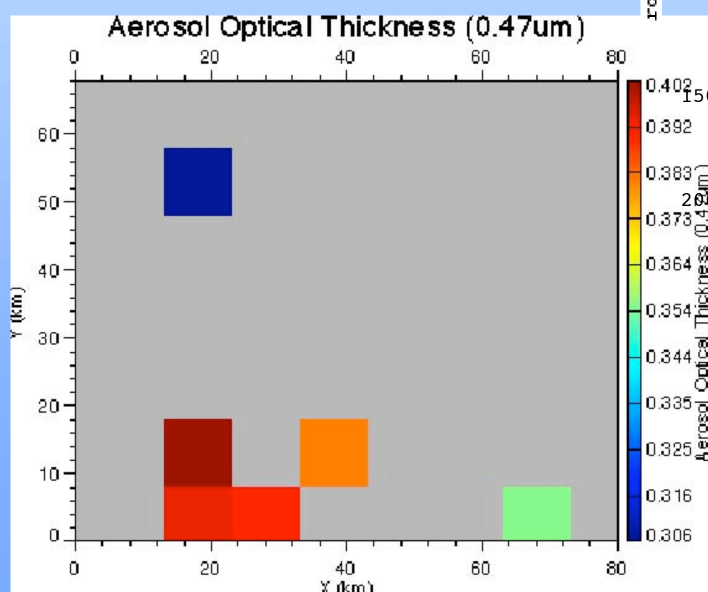


Aerosol-cloud photon interaction

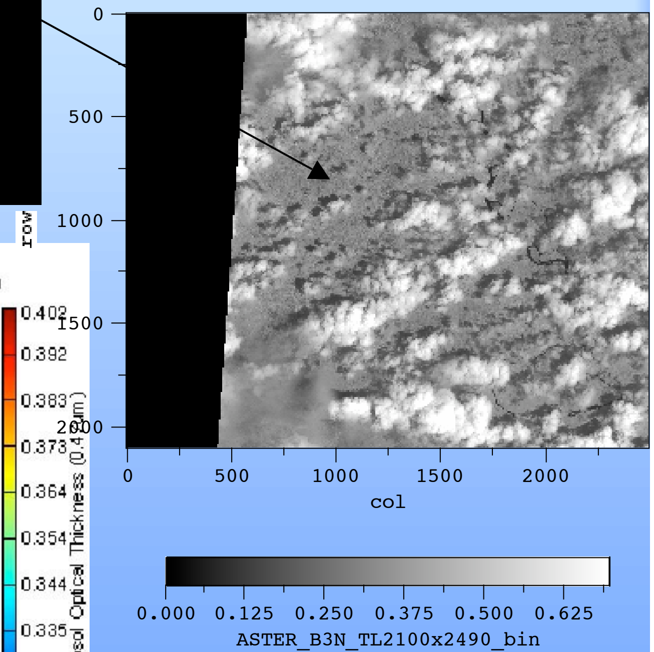


Thick clouds



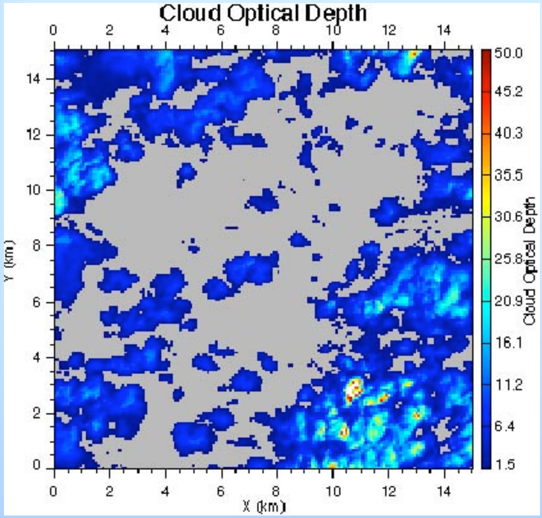


Thin clouds

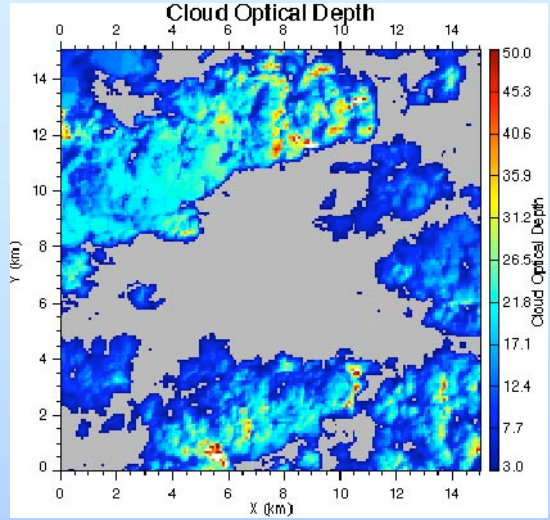


Aerosol-cloud radiative interaction

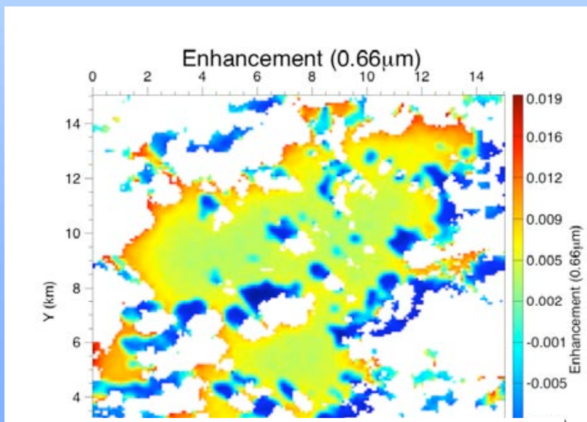
Thin clouds, $\langle\tau\rangle=7$



Thick clouds, $\langle\tau\rangle=15$



$AOT_{0.66}=0.1$

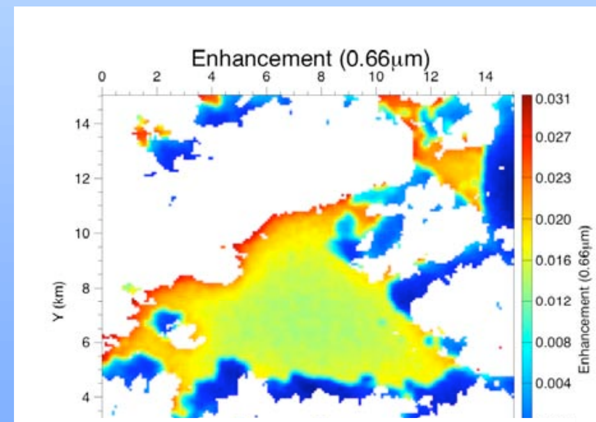


$\Delta\rho \sim 0.004$

$\Delta\tau \sim 0.04$ or ~40%

enhancement:

$\Delta\rho = \rho_{3D} - \rho_{1D}$



$\Delta\rho \sim 0.014$

$\Delta\tau \sim 0.14$ or ~140%

Contributors to 3D cloud effects

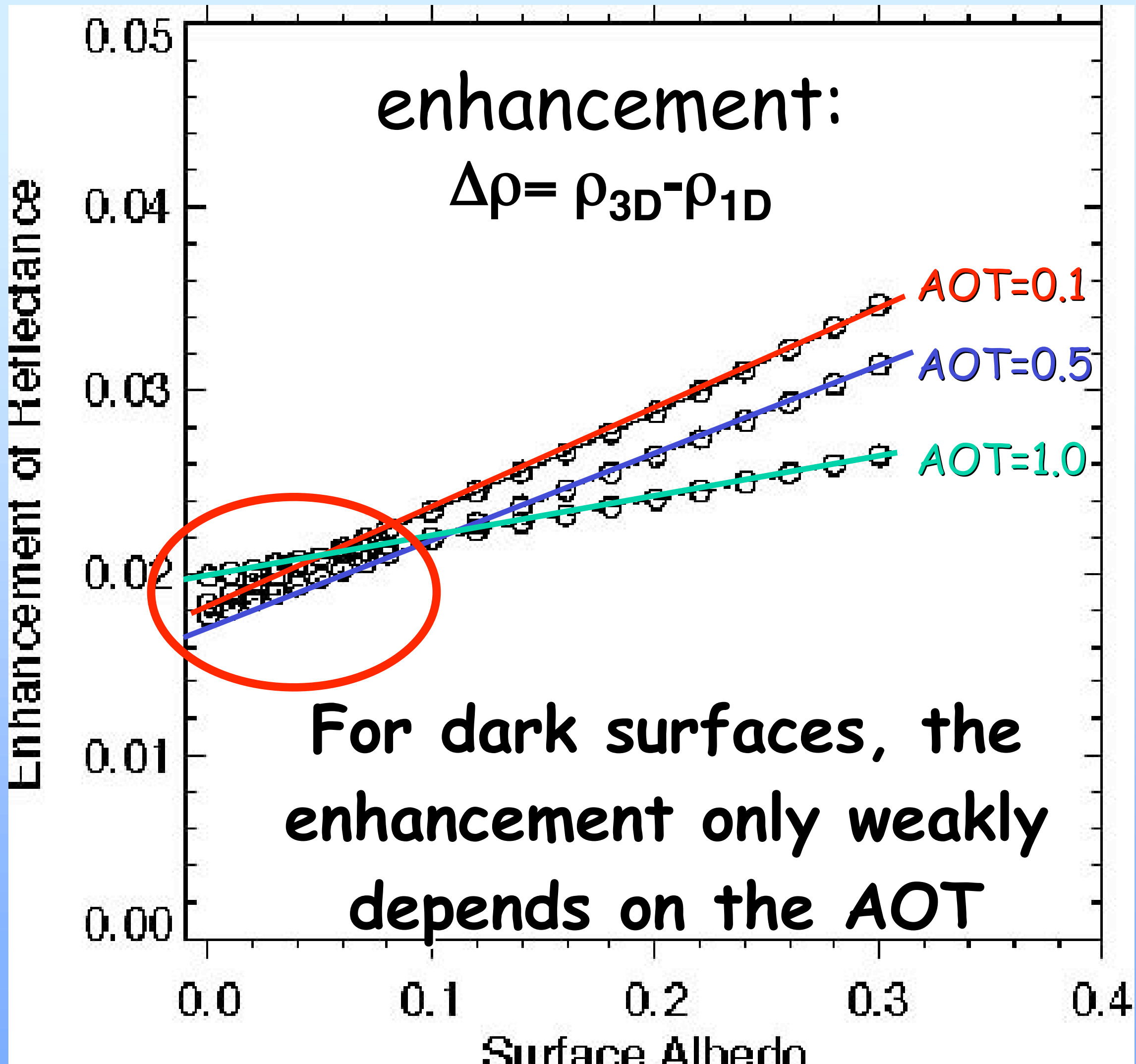
- Rayleigh scattering
- Aerosol amount
- Surface reflectance

What is the relationship between these three factors?

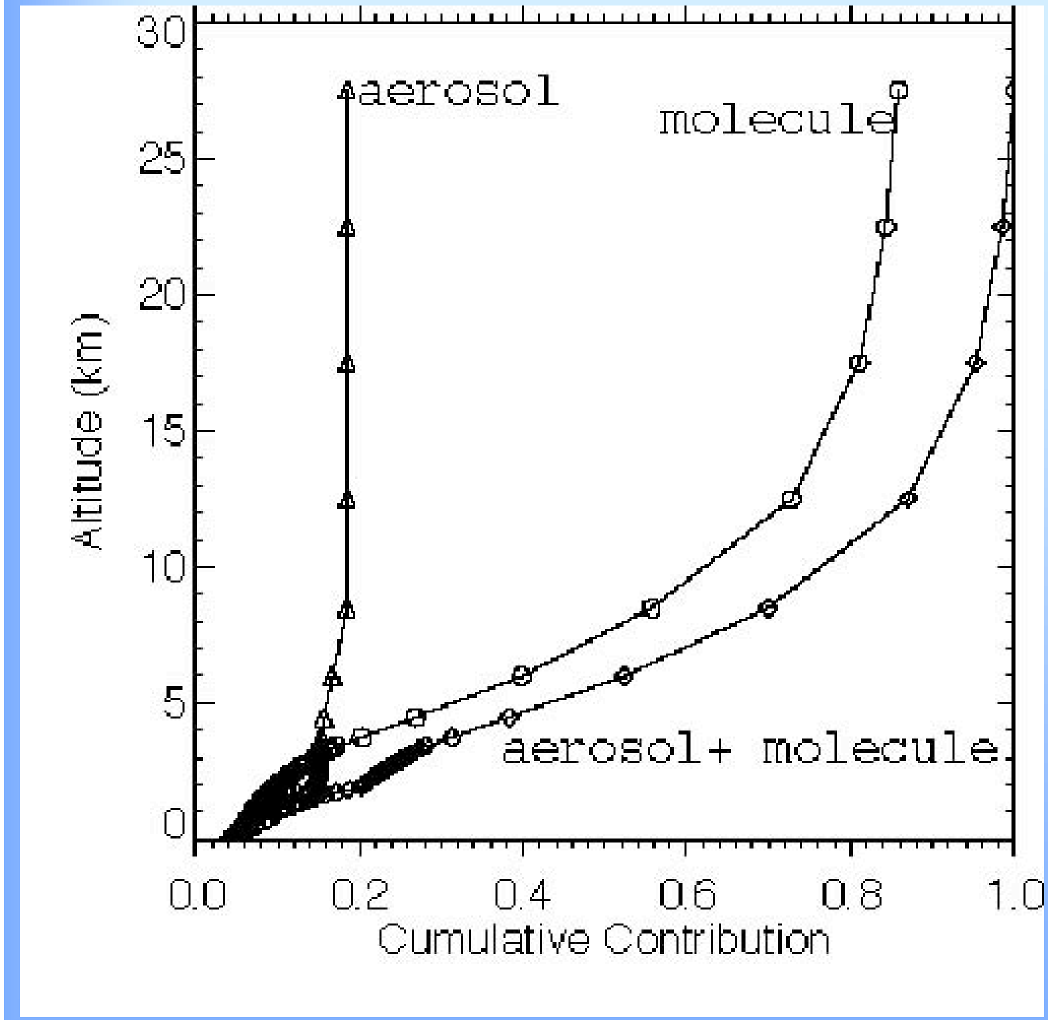
and, of course,

- Distance from cloudy pixels
- Cloud optical thickness

Enhancement of reflectance vs. AOT



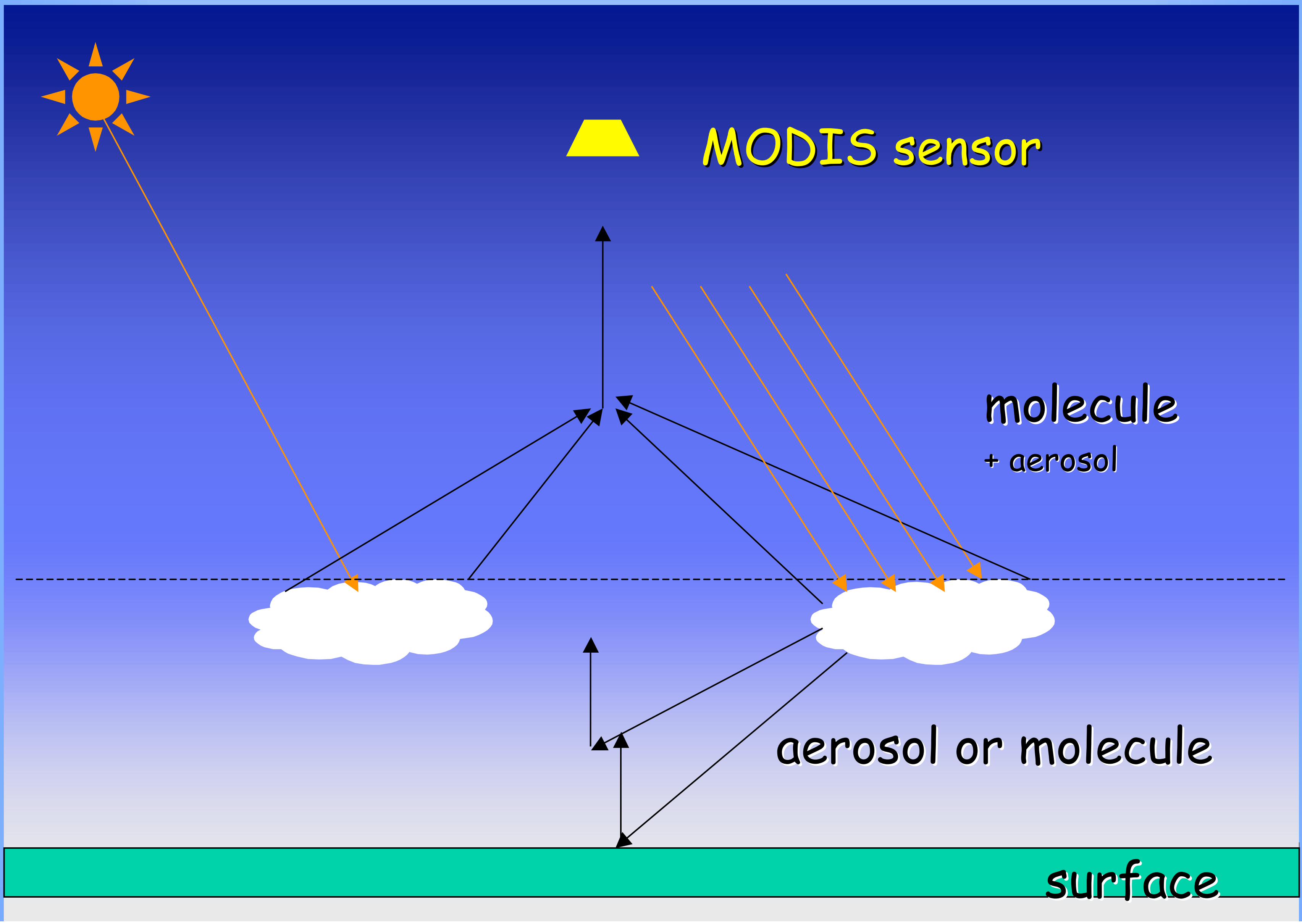
Enhancement of reflectance vs. Rayleigh scattering



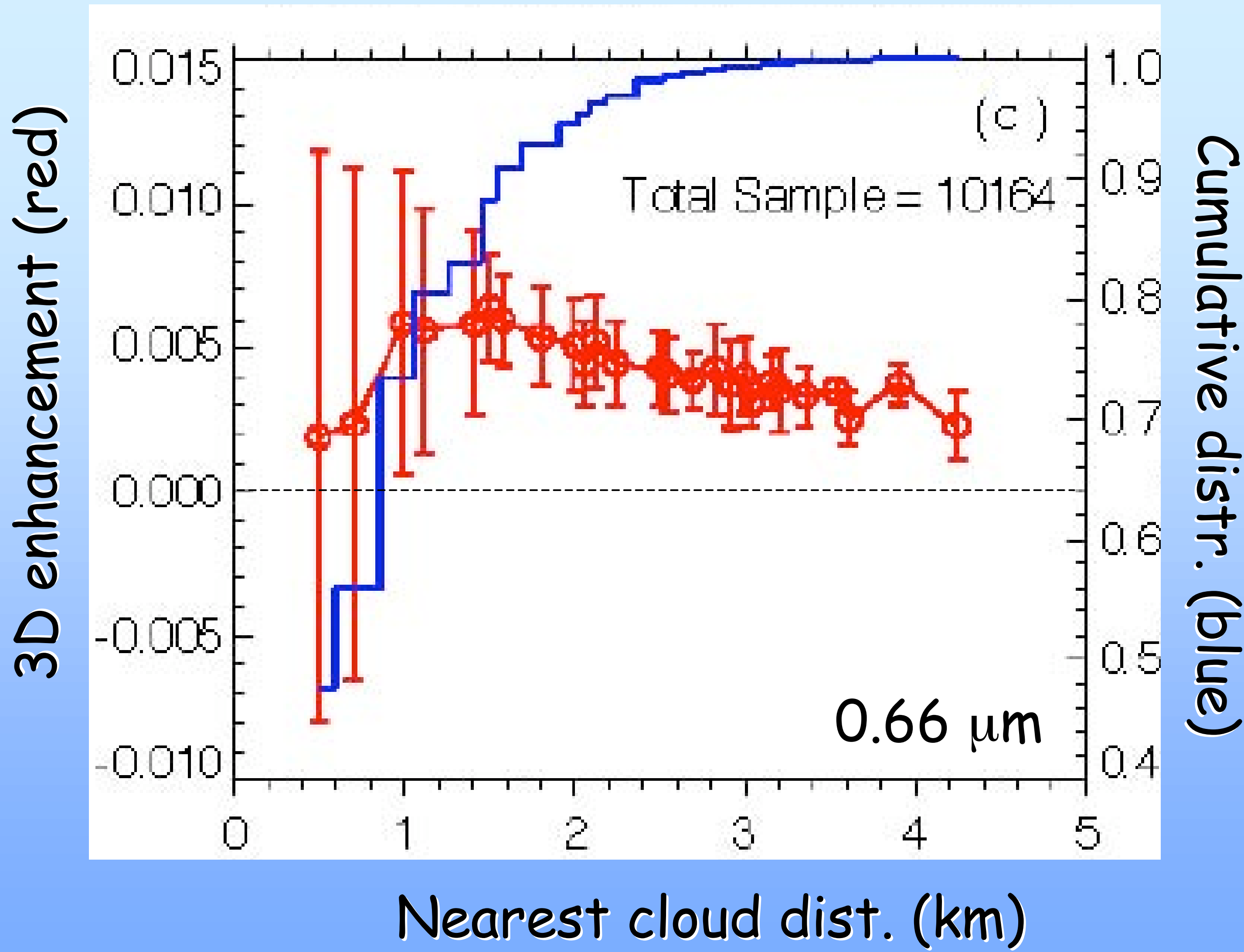
- 3% from surface
- 15% from aerosol
- 82% from molecule

Cloud-molecule scattering is the key process

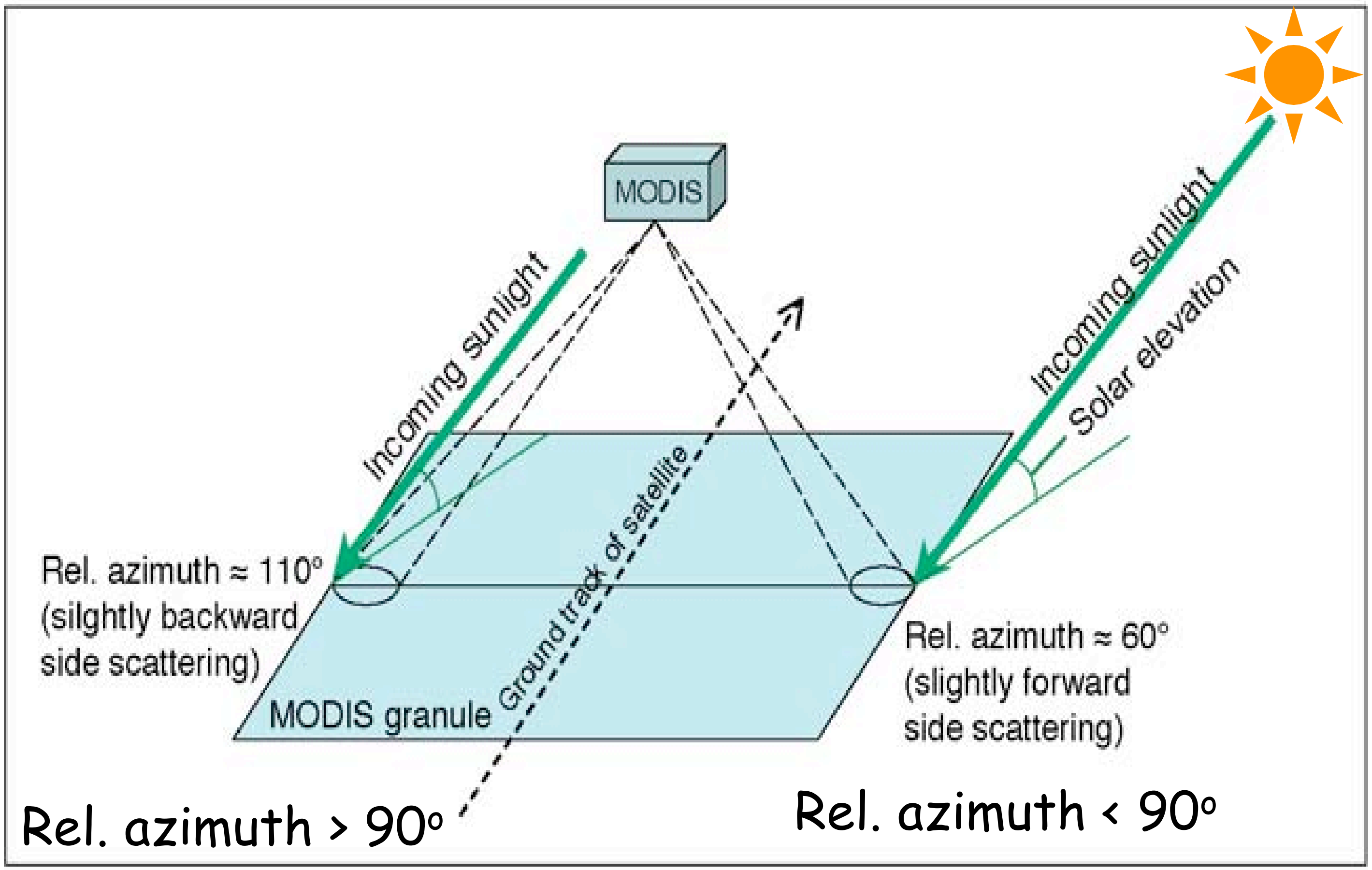
Conceptual model to account for 3D cloud effects



Effect of distance to a cloudy pixel



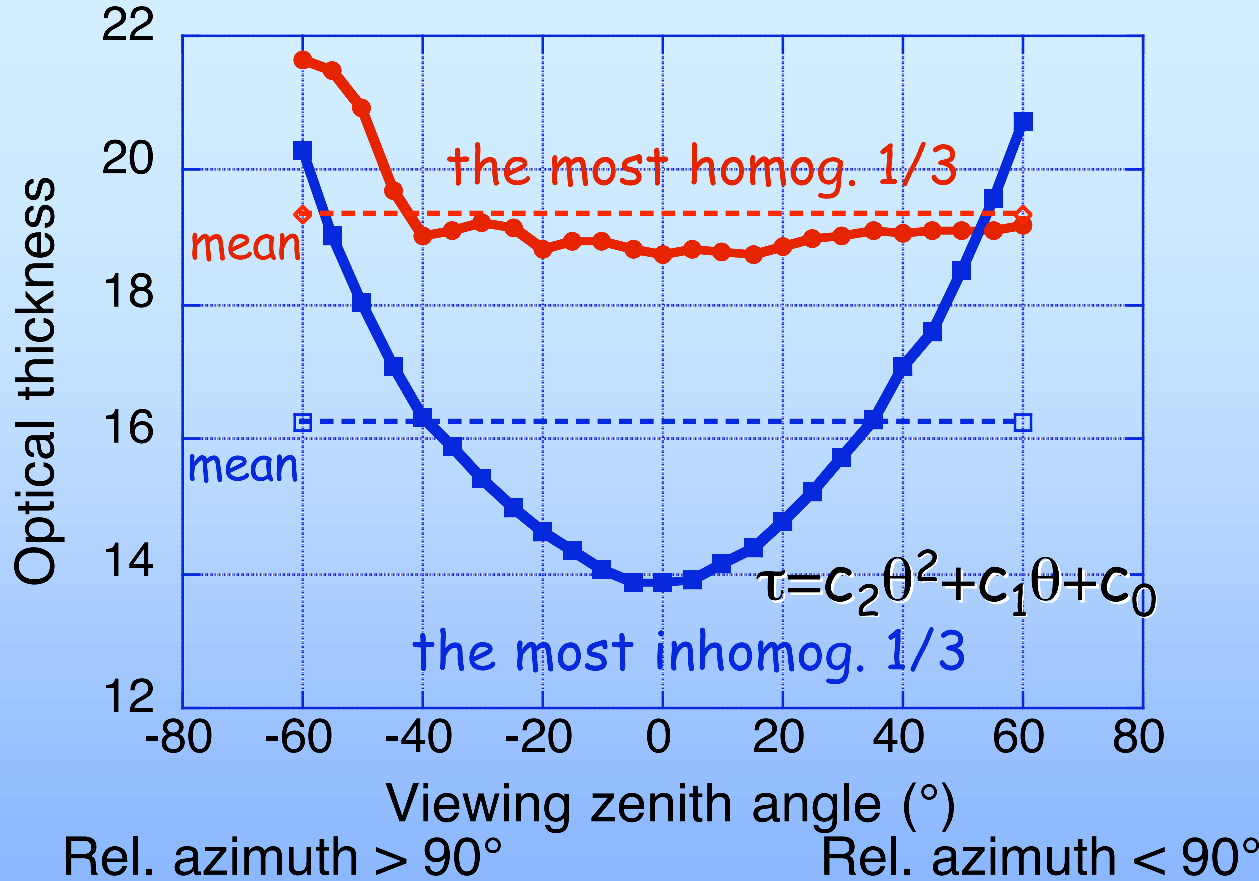
3D radiative effect in Cu clouds. Viewing angle dependence



MODIS data used

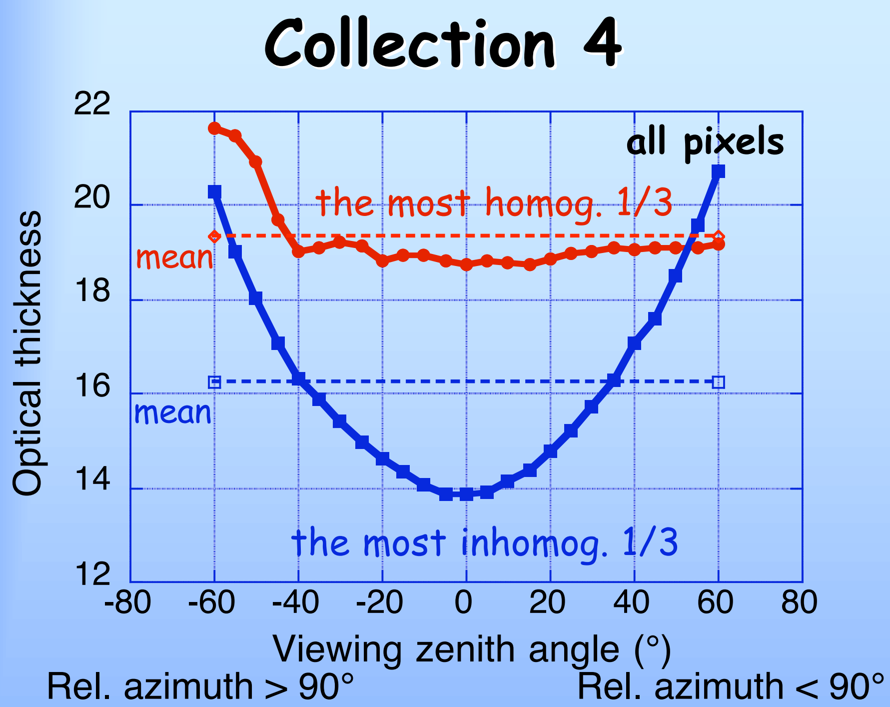
- The whole year: Sept. 2004 - Aug. 2005
- Collection 4
- Liquid phase; high confidence; $\tau \geq 2$
- SZA between 55° and 80°
- Based on local temp. gradient ΔT, all cloudy pixels are divided into 3 **equally populated** categories with thresholds:
  - most homogeneous: 0.3-0.5 C/km (50-80 m)
  - most inhomogeneous: 1.1-1.5 C/km (180-250 m)

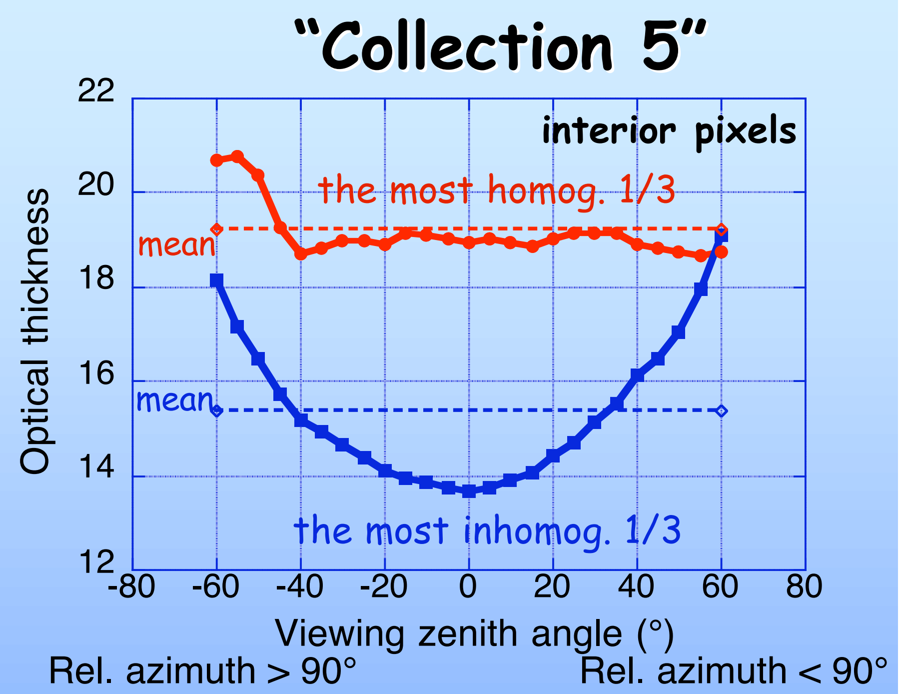
Cloud optical thickness



The most homogeneous (0.3-0.5 C/km) and the most inhomogeneous (1.1-1.5 C/km) cloudy pixels

Cloud optical thickness: col. 4 vs col. 5





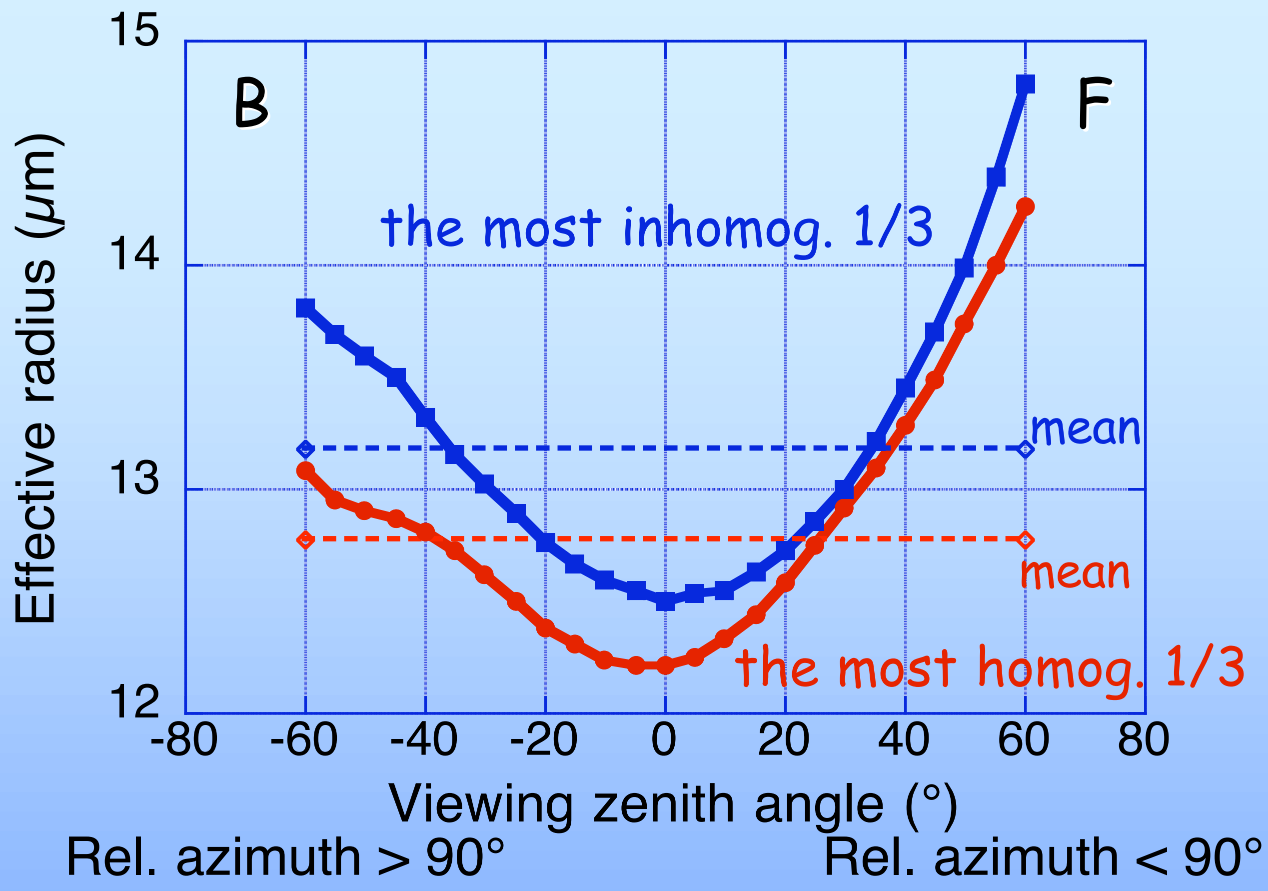
$\tau = c_2\theta^2 + c_1\theta + c_0$

$c_2 = 1.8\ 10^{-3}$ (col.4)

$c_2 = 1.2\ 10^{-3}$ ("col.5")

"Col. 5" shows some improvements for inhomog. clouds; no change for homog. clouds

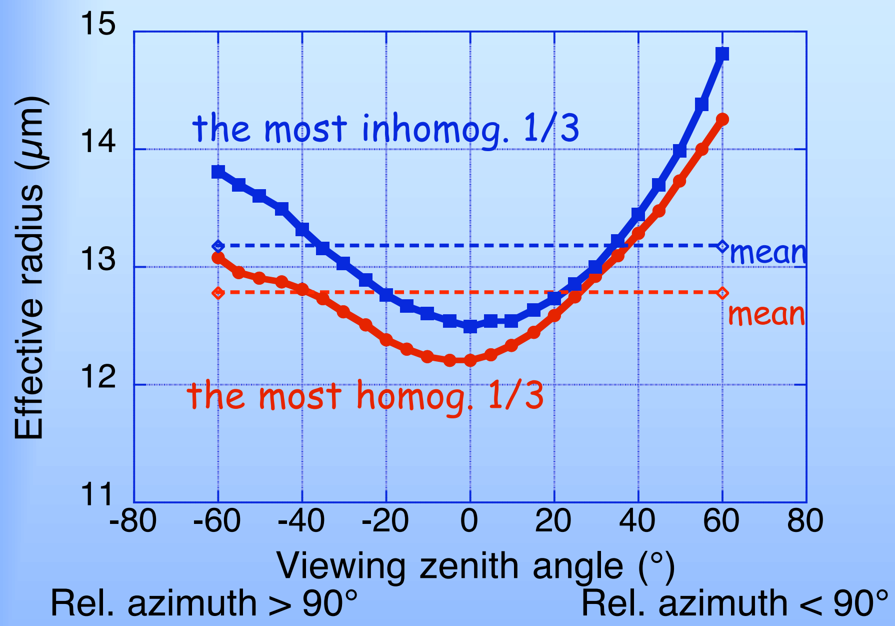
Cloud effective radius, r_e



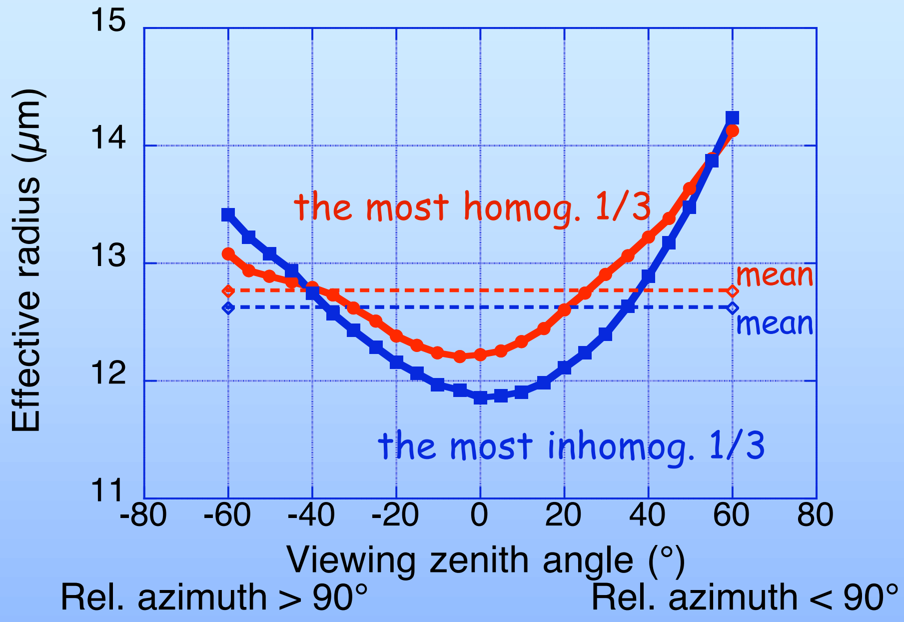
The most homogeneous (0.3-0.5 C/km) and the most inhomogeneous (1.1-1.5 C/km) cloudy pixels

Cloud effective radius: col. 4 vs col. 5

Collection 4



"Collection 5"



The homog. clouds show no changes (mean±1.5 μm) while there are some improvements for the inhomog. clouds

Conclusions

- For study aerosol-cloud interaction in Cu environment, 3D cloud effects cannot be ignored;

- 3D cloud enhancement only weakly depends on AOT; molecular scattering is the key source for the enhancement;

- Retrieved AOT can be corrected for the 3D rad. effects;

- Both cloud τ and r_e show strong dependence on VZA;

- For study aerosol-cloud interaction, a difference of 2-3 μm in r_e doesn't necessarily mean the effect of aerosols on clouds but rather can be a remote sensing problem.

How 3D Science Can Help to Correctly Interpret MODIS Data for Better Understanding of Aerosol-Cloud Interactions

Alexander Marshak (GSFC)

Robert Cahalan (GSFC)

Támas Várnai (UMBC)

Guoyong Wen (UMBC)

Brian Vant-Hull (UMD)

Example of corrected AOT

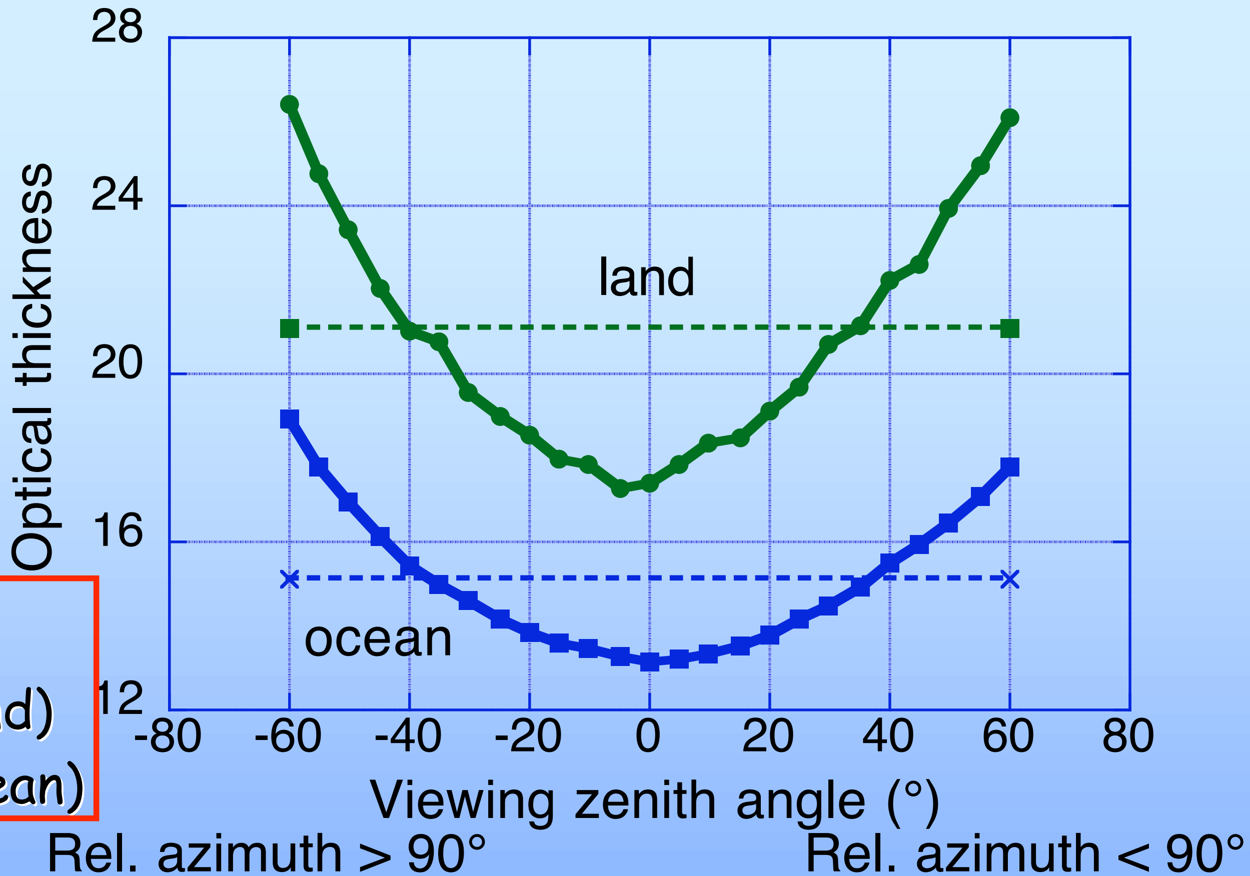
Thin clouds

λ	True	MODIS	$\Delta\tau(\%)$
0.47 μm	0.18	0.30	40%
0.66 μm	0.08	0.12	33%

Thick clouds

λ	True	MODIS	$\Delta\tau(\%)$
0.47 μm	0.21	0.40	48%
0.66 μm	0.08	0.22	64%

Cloud optical thickness: land and ocean



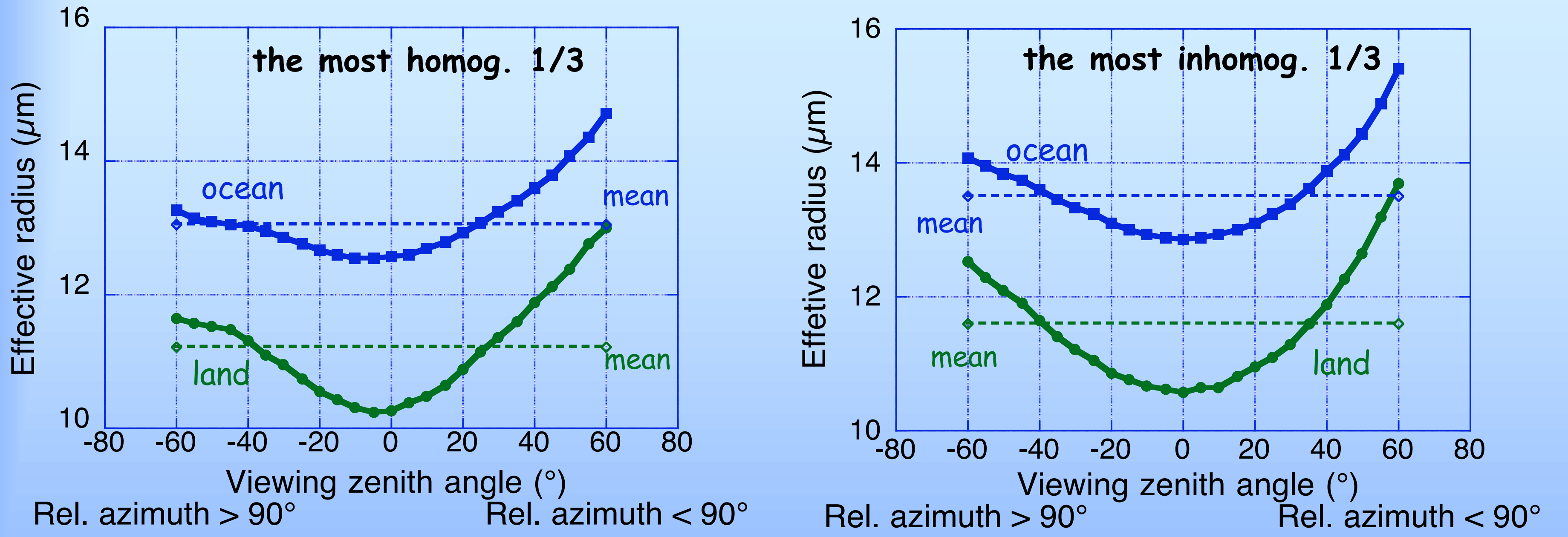
$\tau = c_2\theta^2 + c_1\theta + c_0$

$c_2 = 2.4\ 10^{-3}$ (land)

$c_2 = 1.4\ 10^{-3}$ (ocean)

The most inhomog. (1/3) fraction of cloudy pixels over land and ocean; Liquid clouds over ocean are more homogeneous

Cloud effective radius: land and ocean



Droplet sizes retrieved over ocean are less sensitive to VZA (for all clouds)