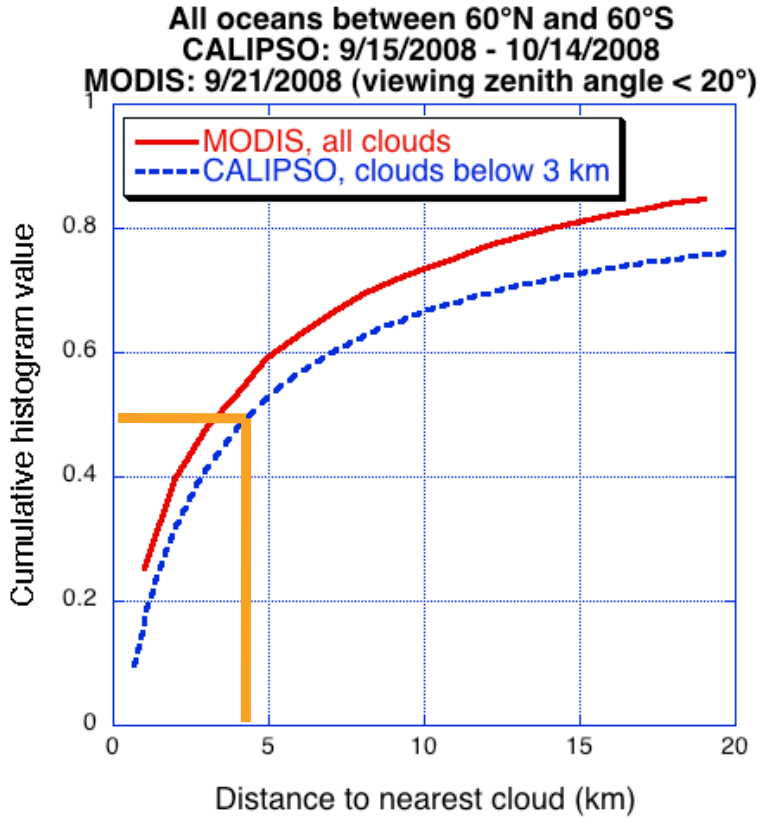
MODIS and CALIOP views of aerosol changes near clouds

T. Várnai[1,2], A. Marshak[2], G. Wen[2,3], W. Yang[2,3], A. Lyapustin[2]

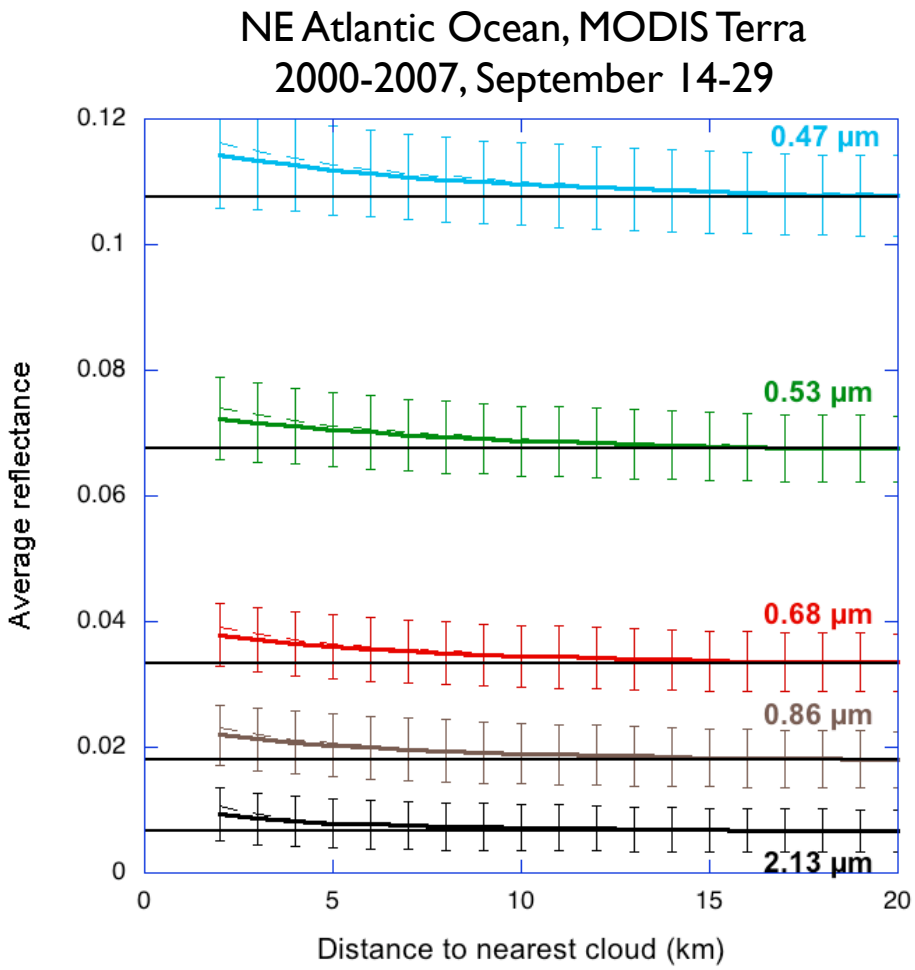
[1]UMBC JCET, [2]NASA GSFC, [3]USRA

Aerosol measurements near clouds are important



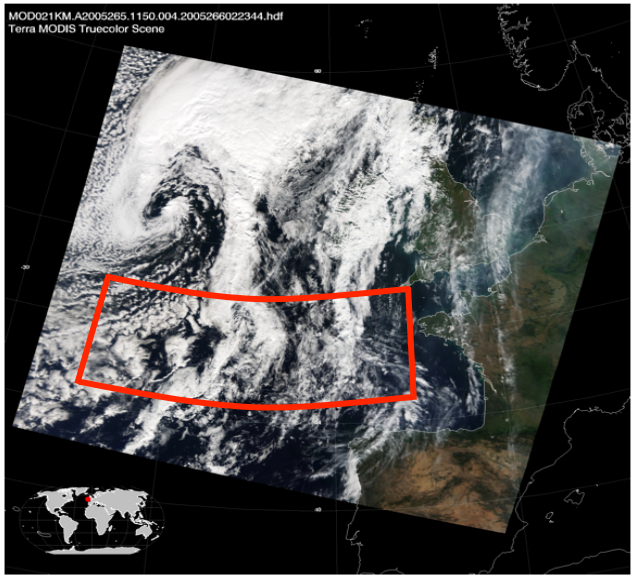
- Aerosol remote sensing near clouds is challenging
- Excluding areas near-cloud risks biases in aerosol data

MODIS reflectances increase near clouds



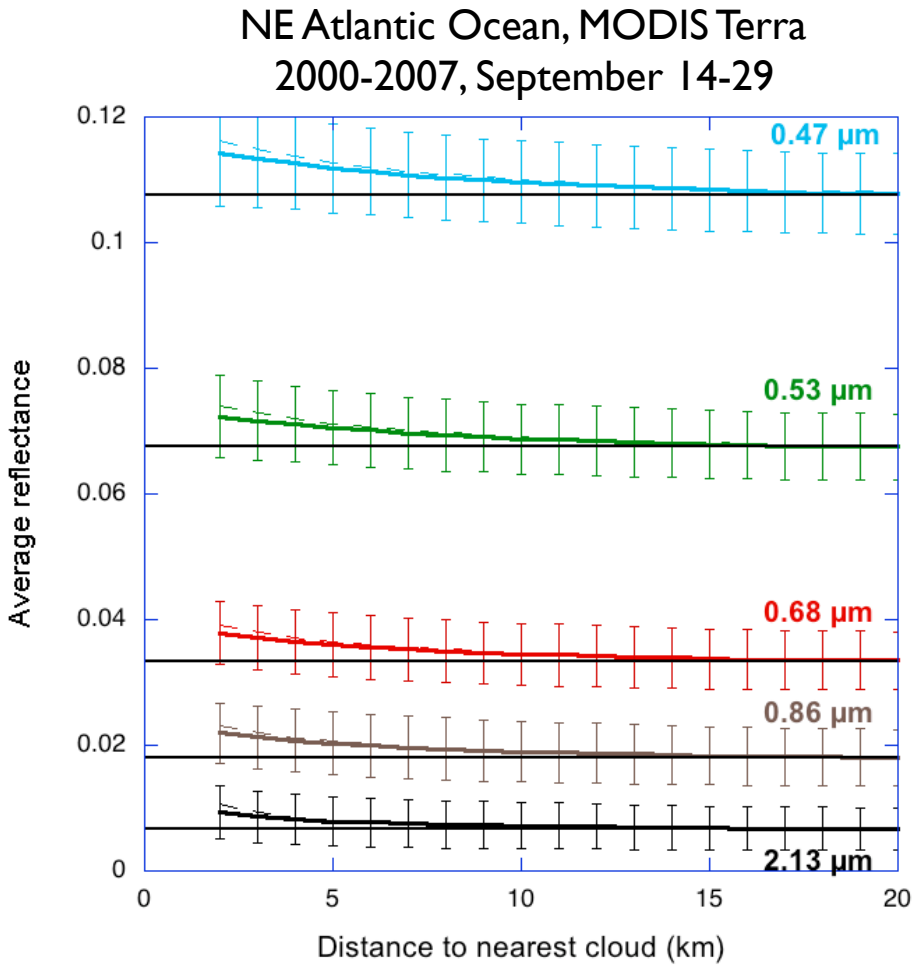
Reflectance increase may come from:

- Aerosol changes (e.g., swelling in humid air)
- Undetected cloud particles
- Instrument imperfections
- 3D radiative effects



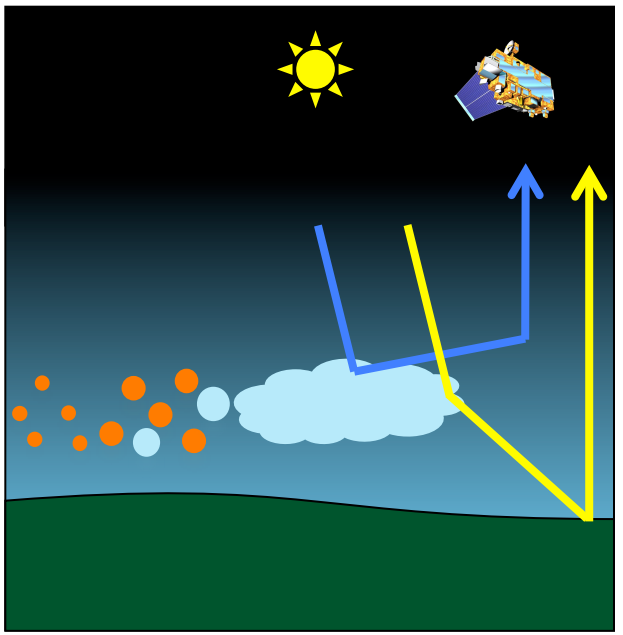
Várnai and Marshak (2009)

MODIS reflectances increase near clouds



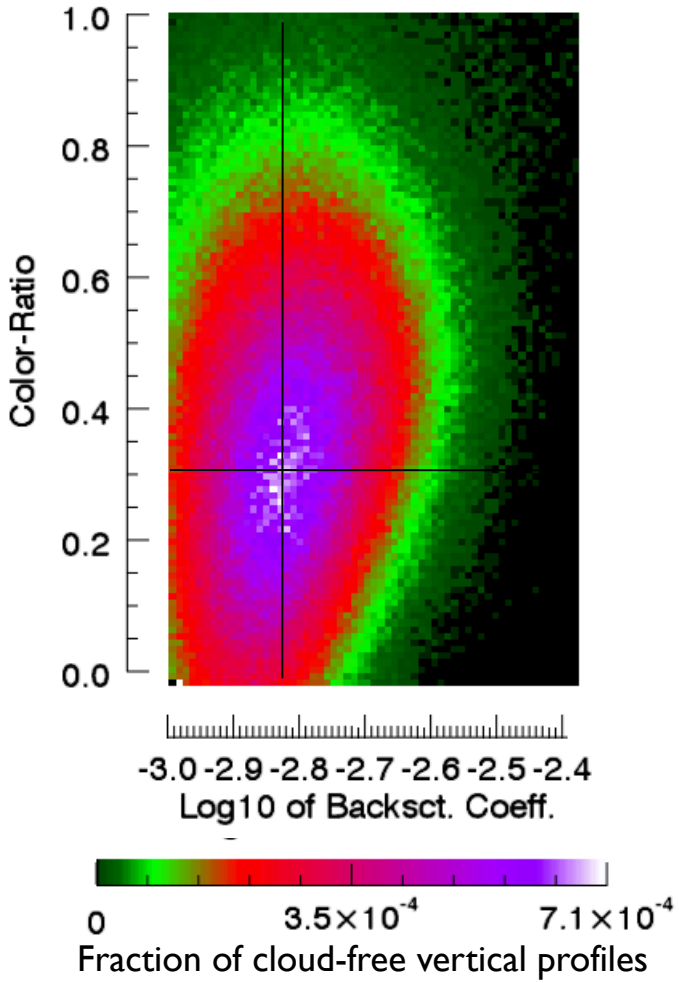
Reflectance increase may come from:

- Aerosol changes (e.g., swelling in humid air)
- Undetected cloud particles
- Instrument imperfections
- 3D radiative effects

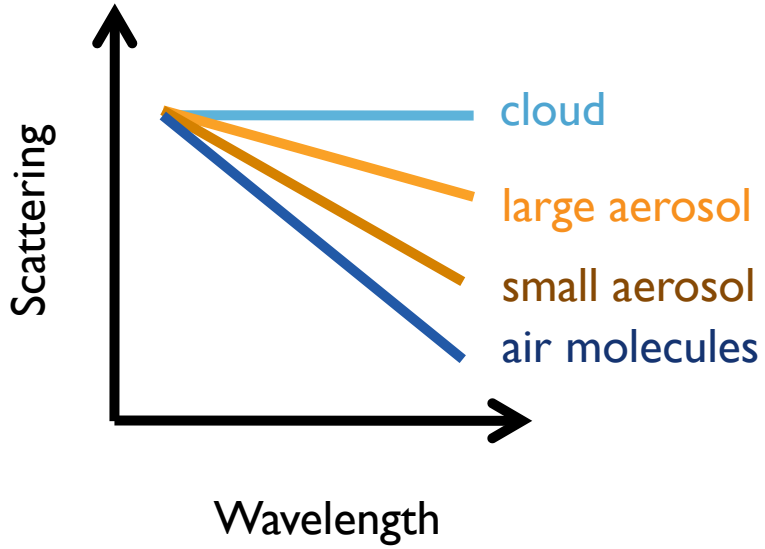


Várnai and Marshak (2009)

CALIOP gives information on aerosol OT, size



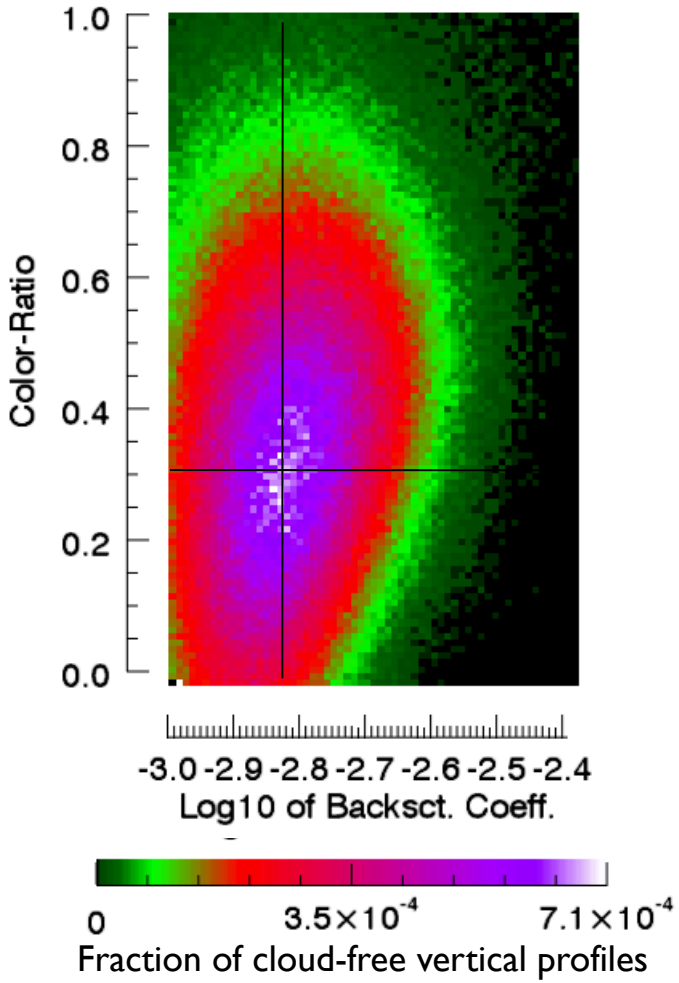
$$\text{Color ratio} = \frac{\text{Backscatter}_{1064\ \text{nm}}}{\text{Backscatter}_{532\ \text{nm}}}$$

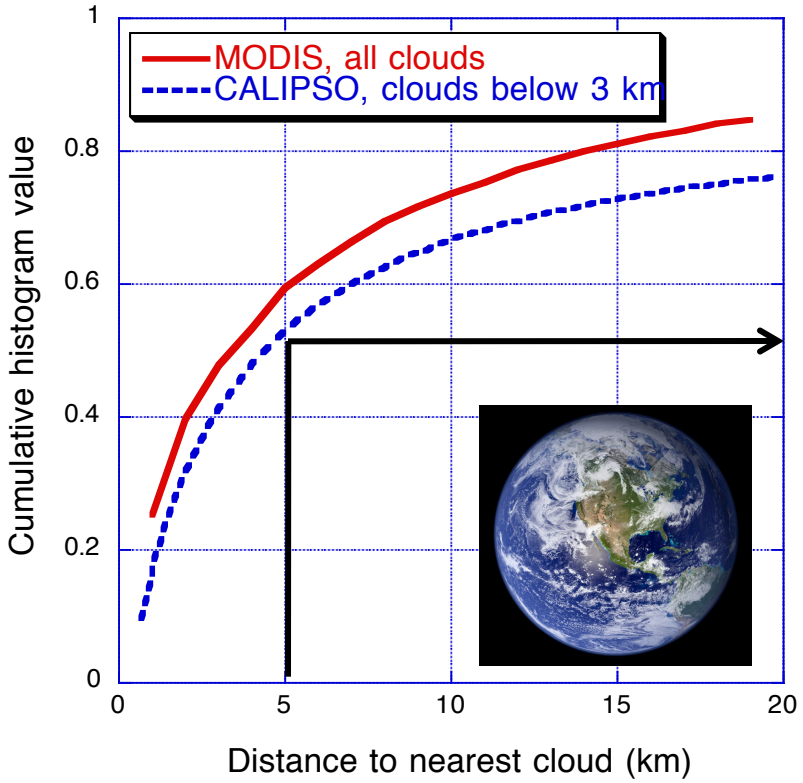


global night data over ocean
July 8 – Aug 7, 2007

CALIOP histogram far from clouds

Far from clouds (> 5km)

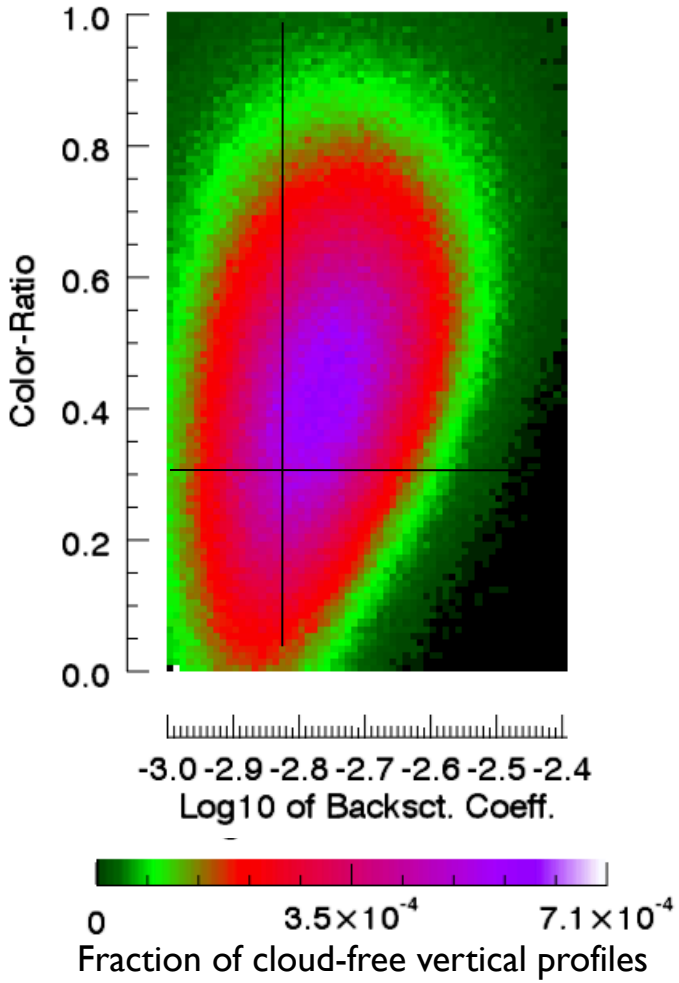


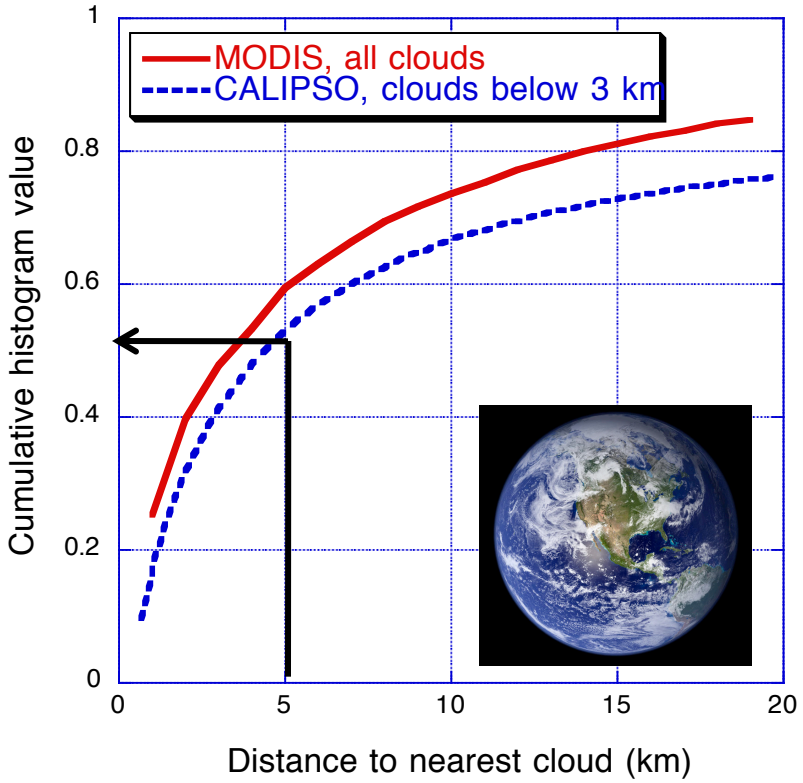


global night data over ocean
July 8 – Aug 7, 2007

CALIOP histogram near clouds

Close to clouds (< 5km)

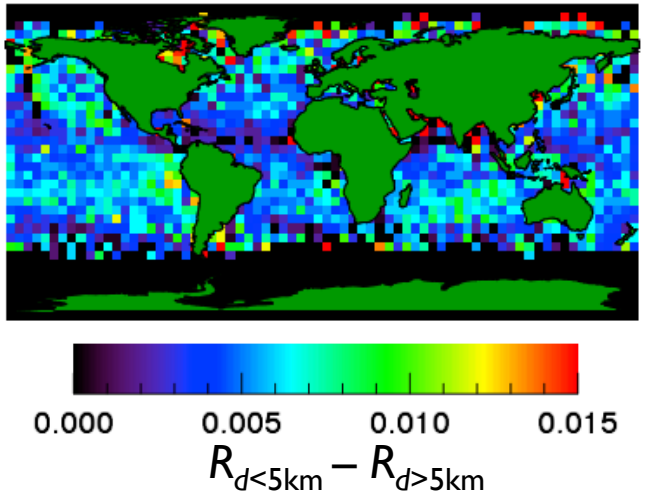




global night data over ocean
July 8 – Aug 7, 2007

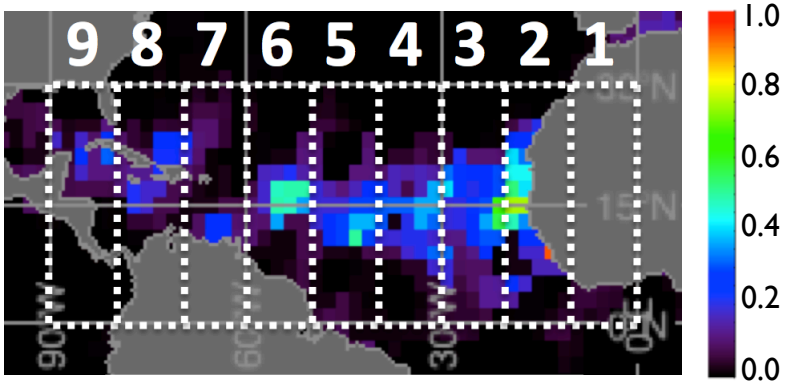
Near-cloud enhancements in Jun-Jul-Aug

Median MODIS 0.55 μm reflectance enhancement

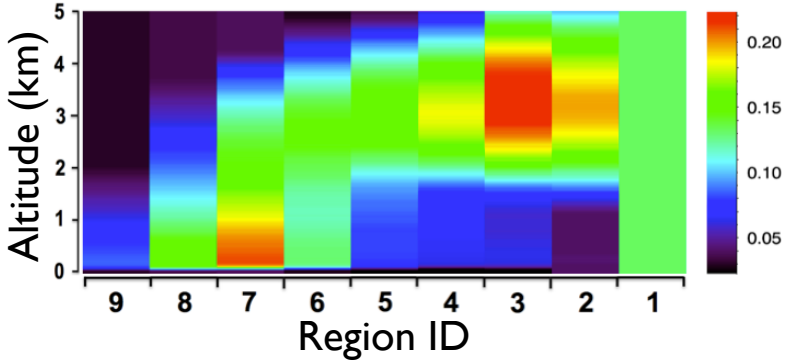


Jun-Jul-Aug, 2007

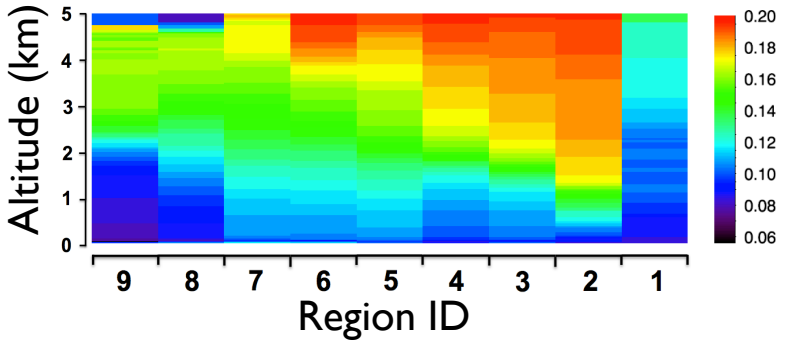
Dust gets lower & more spherical westward



Dust contribution to AOT

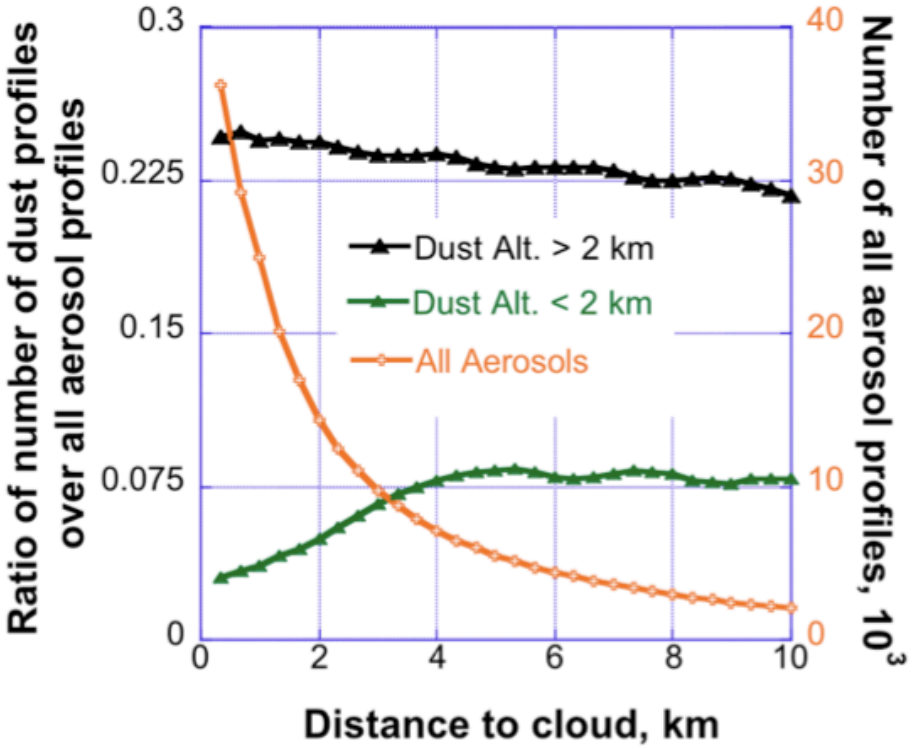


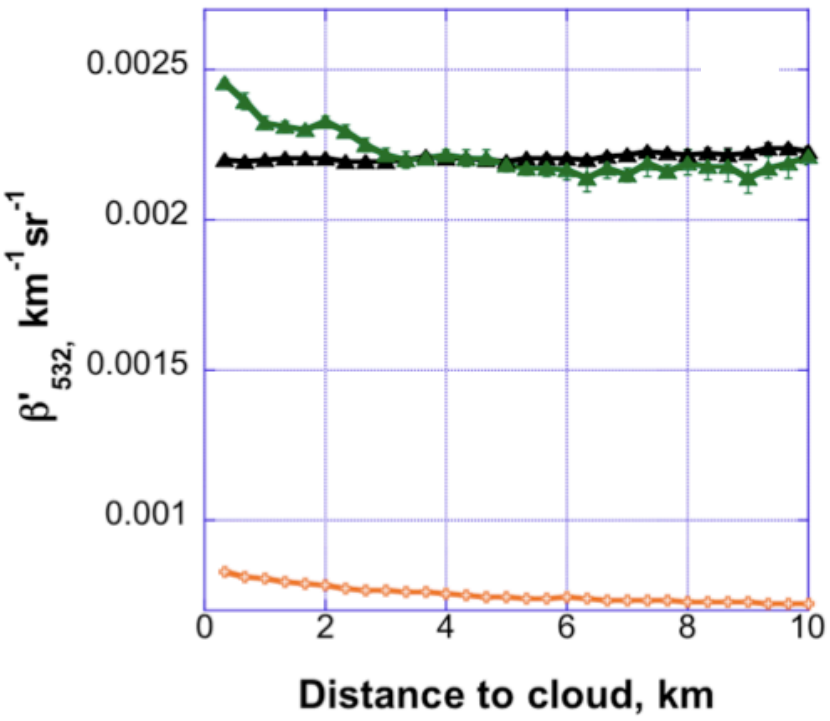
Probability of finding dust



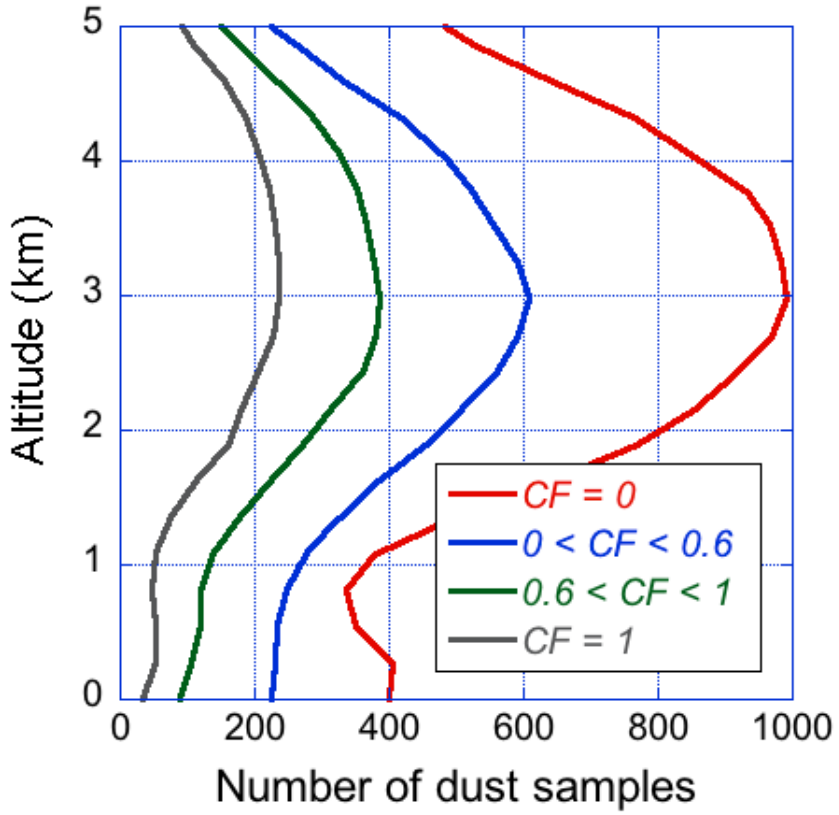
Dust depolarization ratio

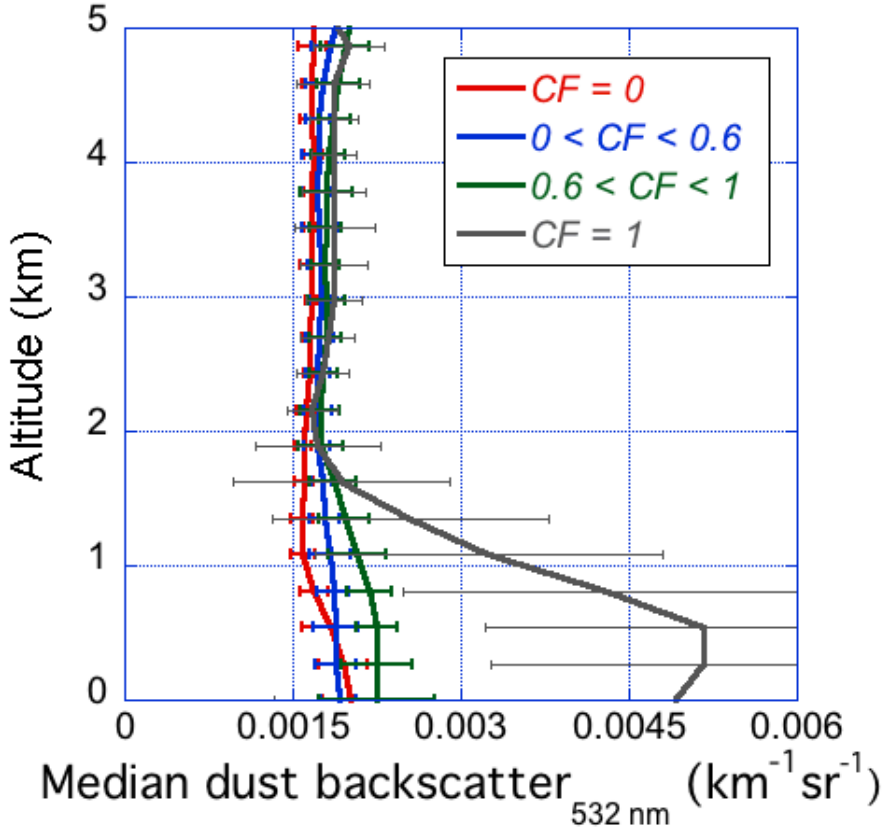
Detection of low dust less frequent near clouds





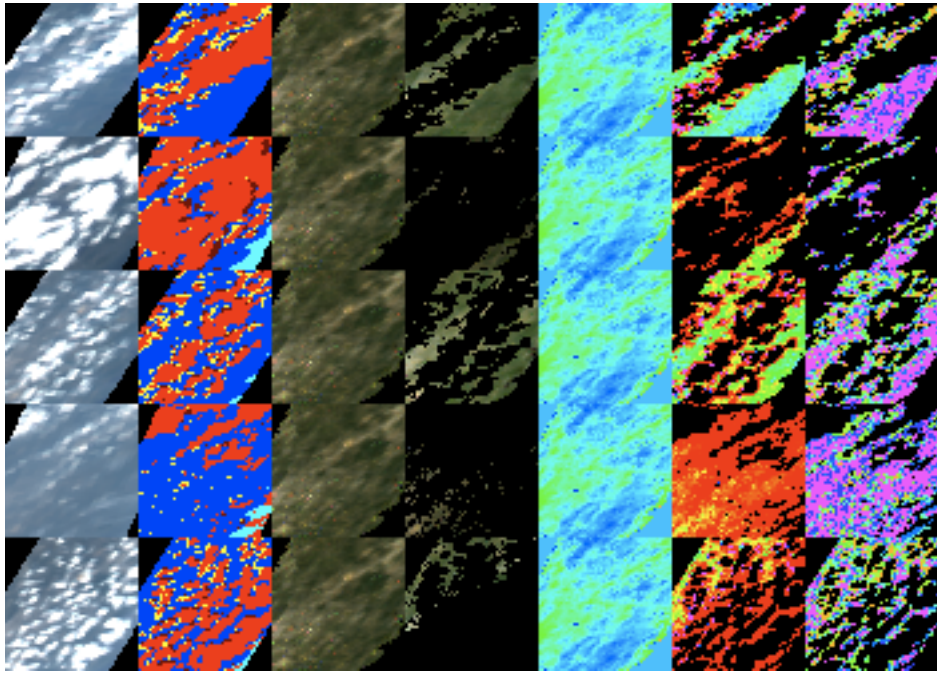
High dust doesn't change much near clouds

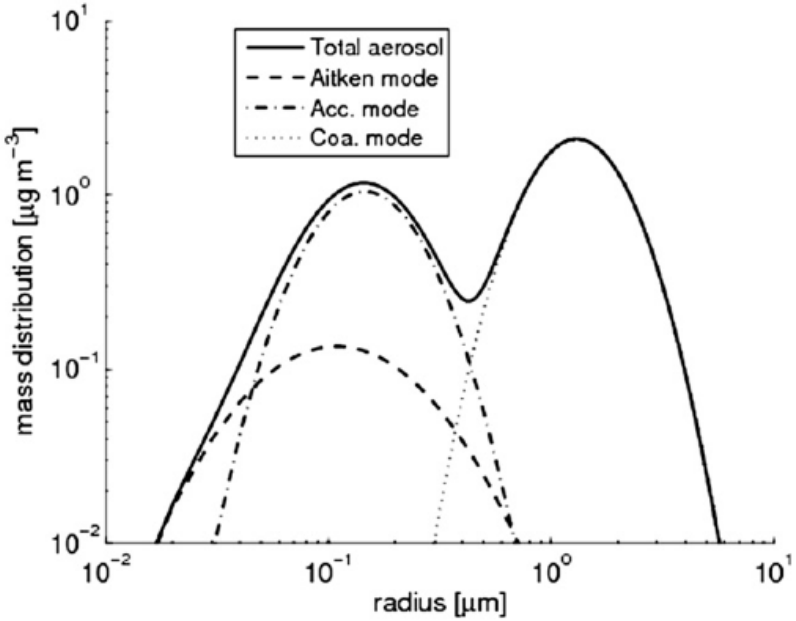




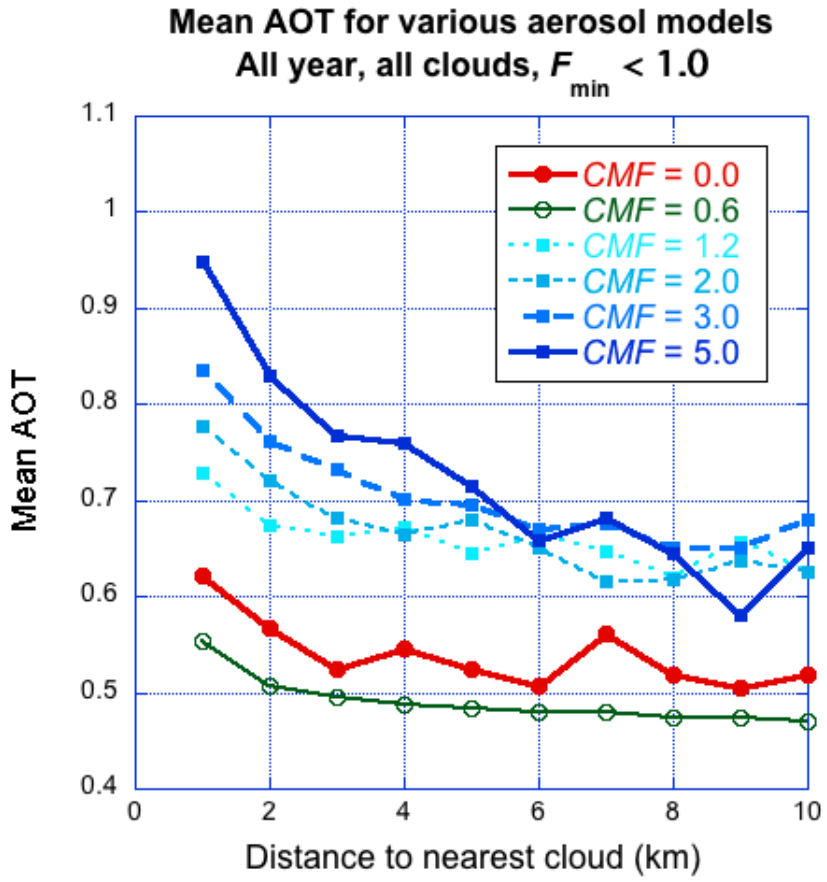
MAIAC gives 1 km-resolution data over land

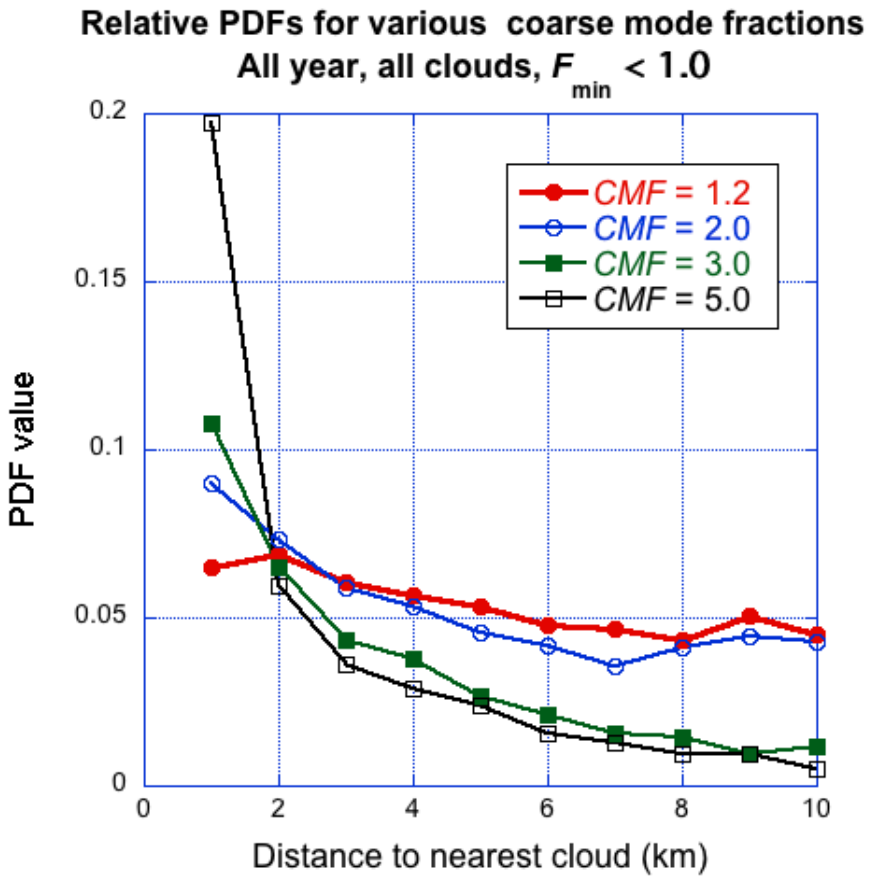
AOT Model (size)





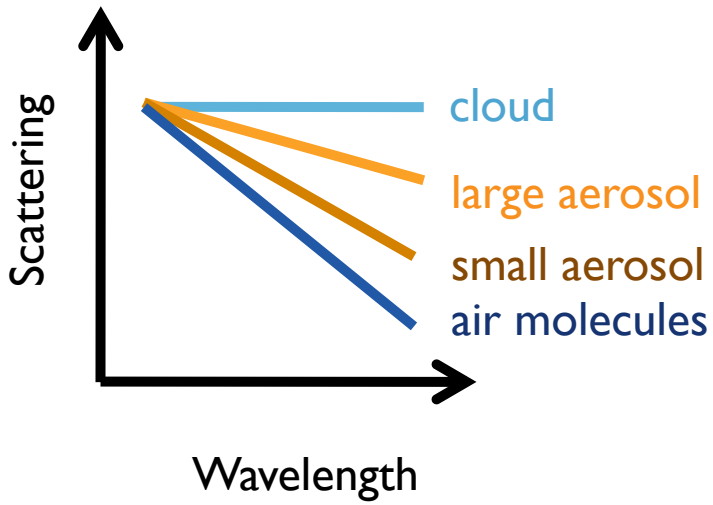
MAIAC: Enhancements larger for larger particles

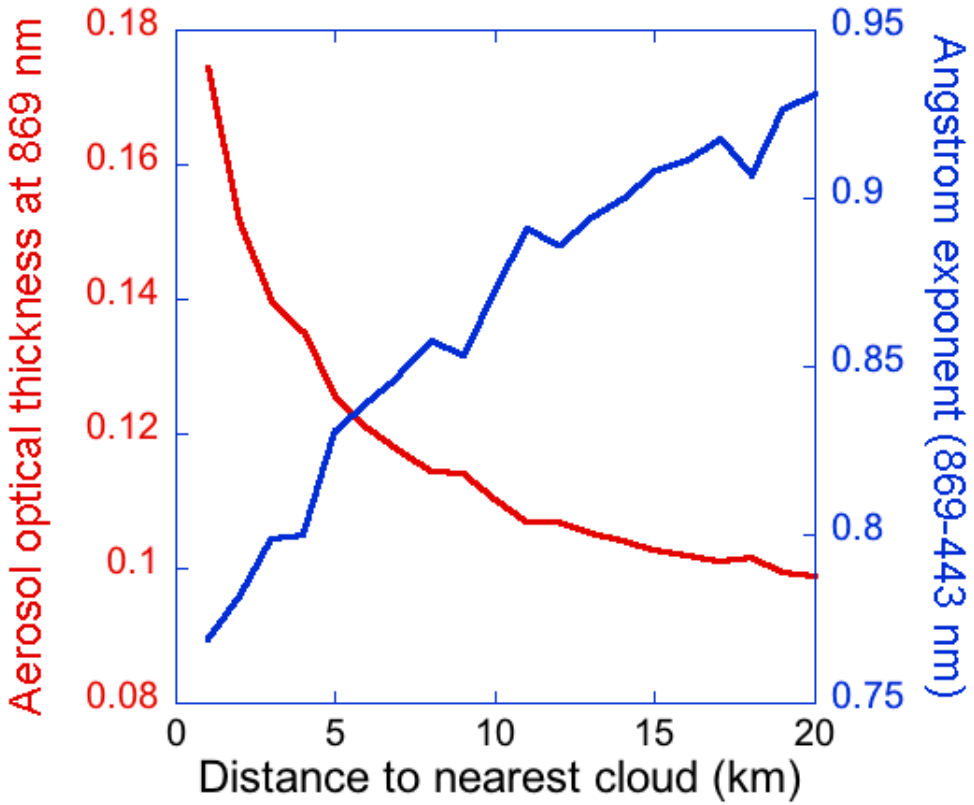




Near-cloud aerosol in ocean color atm. correction

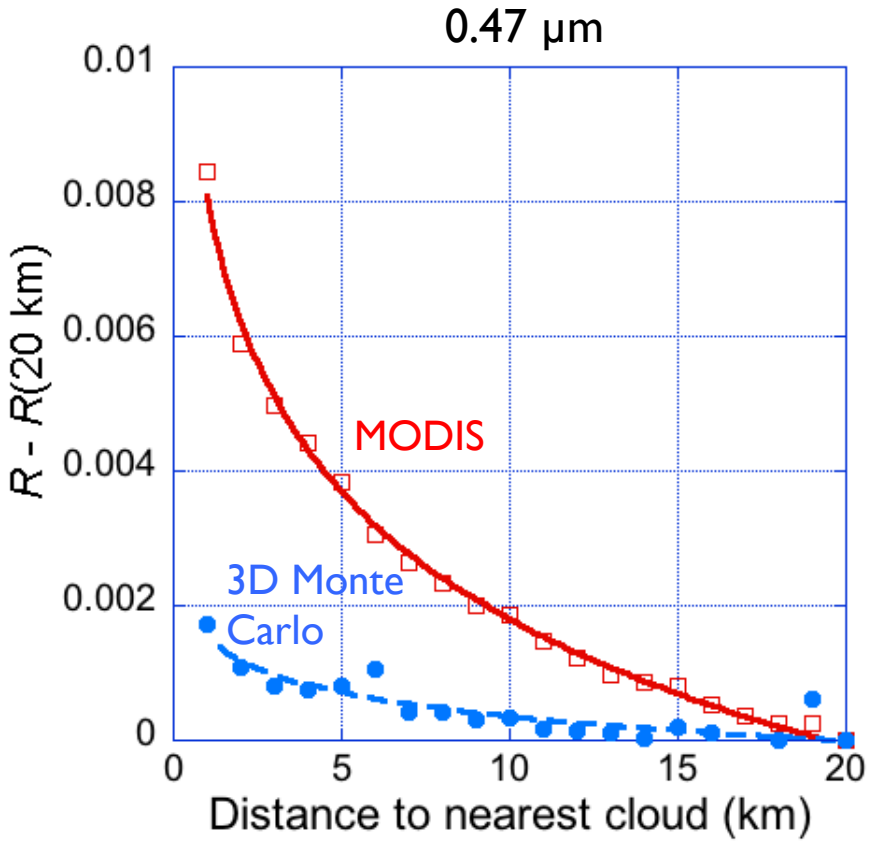
$$\tau_\lambda = \tau_{\lambda_0}\left(\frac{\lambda}{\lambda_0}\right)^{-\alpha}$$

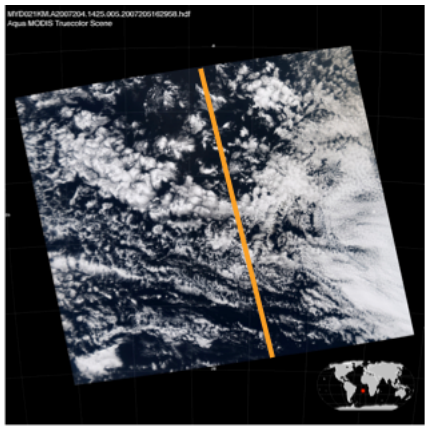


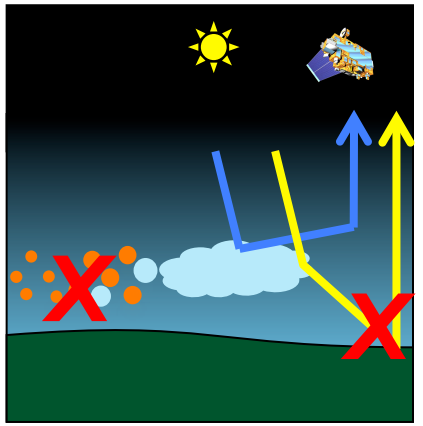


Aqua along CALIOP track, All oceans, 11/06-10/07

MODIS data vs. simulations of 3D enhancement





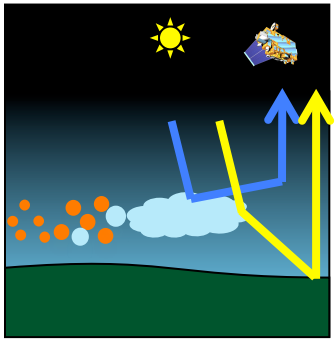


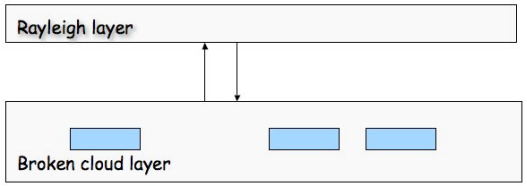
3D Monte Carlo:

- MODIS cloud products
  (τ, cloud top pressure)
- No aerosol
- No surface

All oceans, Aqua along CALIOP track, 11/06-10/07

Correction for 3D effect is being developed





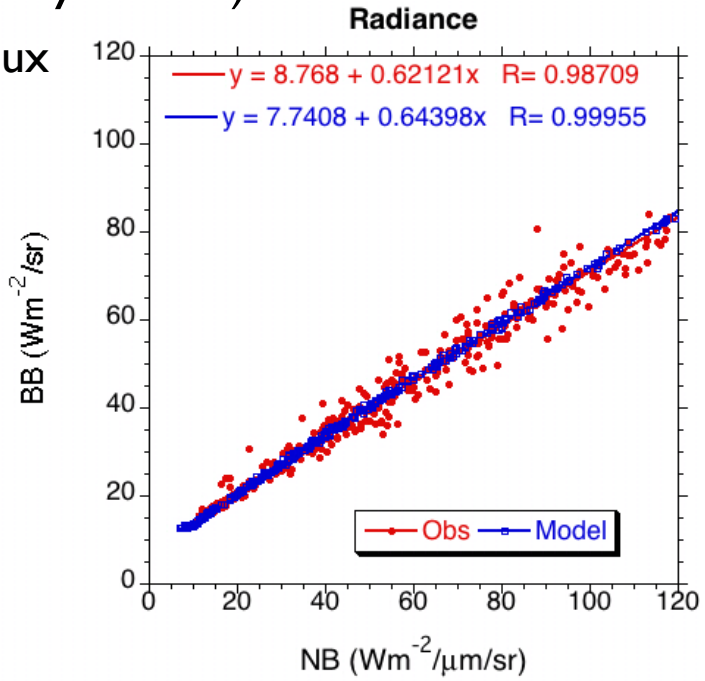
$$R_{corr} = R_{MODIS} - \Delta R$$

$$\Delta R = \frac{\alpha_c T_m(\tau_m, \Omega_0)}{1 - \alpha_c R_{m,diff}(\tau_m, \Omega)} [t_{m,diff}(\tau_m, \Omega) - e^{-\frac{\tau_m}{\mu_0}}]$$

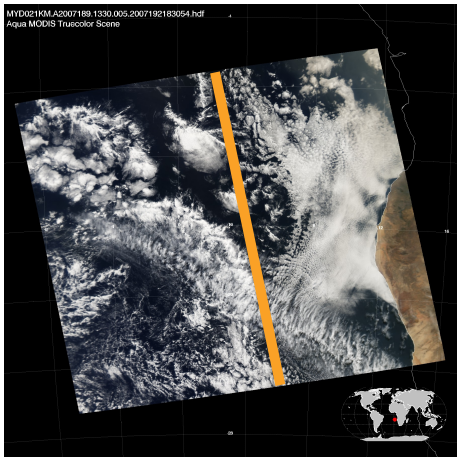
CERES can help get α_c (narrow band flux reflected by clouds):

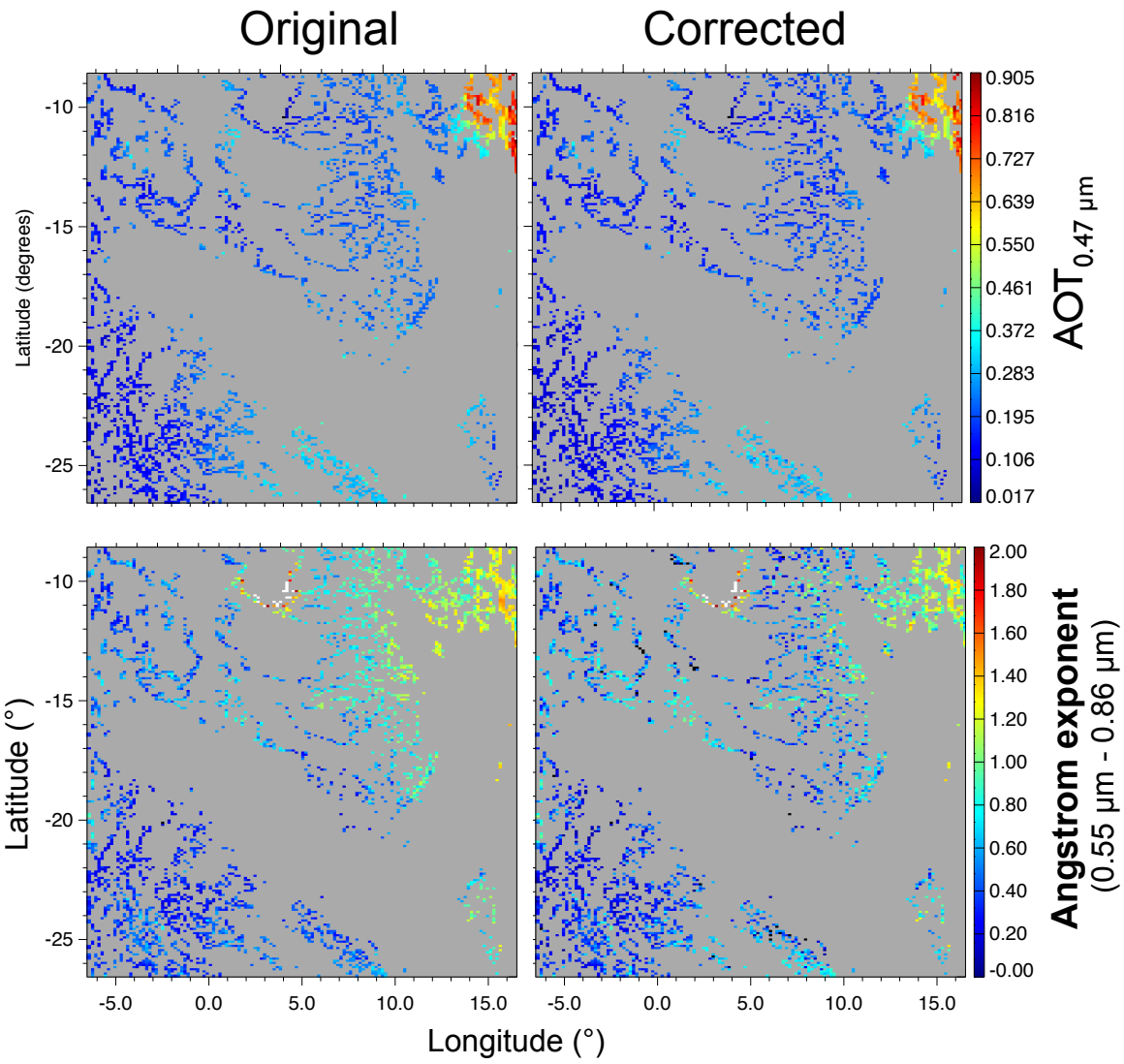
- Broadband radiance + angular model ➔ broadband flux
- Convert to narrowband flux by assuming that

$$\frac{F_{obs}^{NB}}{F_{obs}^{BB}} \approx \frac{F_{model}^{NB}}{F_{model}^{BB}}$$



Aerosol retrievals using corrected radiances

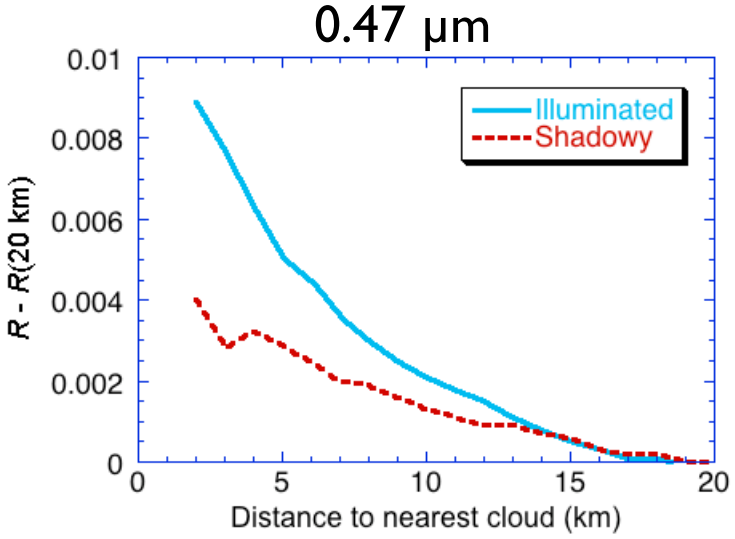


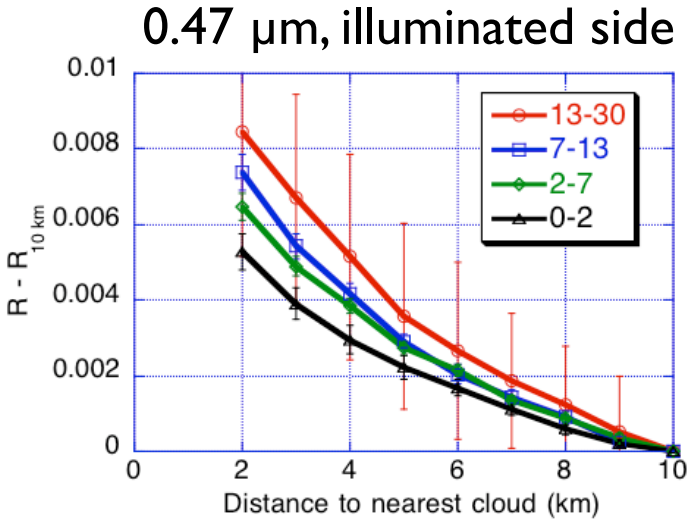


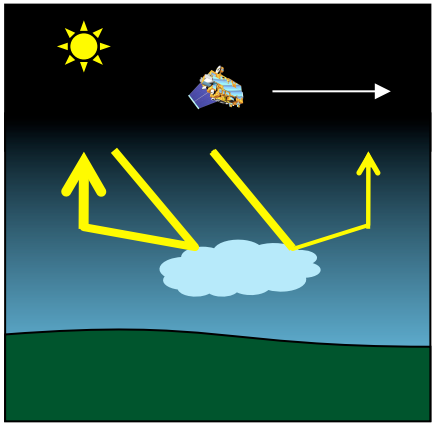
Summary

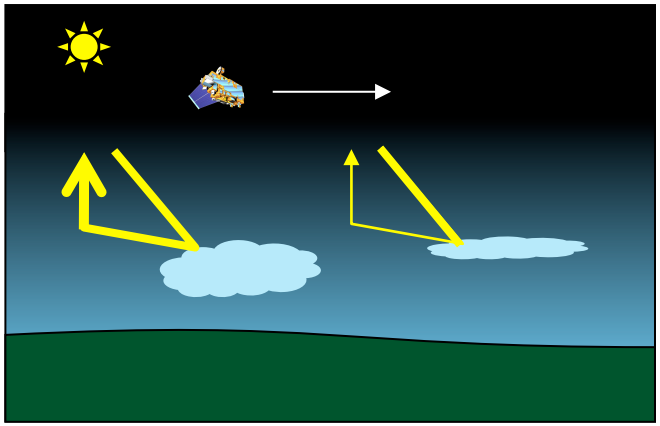
- Clouds are surrounded by a wide zone of increased particle size optical thickness.
- Near-cloud enhancements vary with aerosol properties, they are small for high dust and large for large particles near Washington, DC.
- 3D radiative processes play an important role in shaping radiance fields around clouds.

Behaviors consistent with strong 3D effects



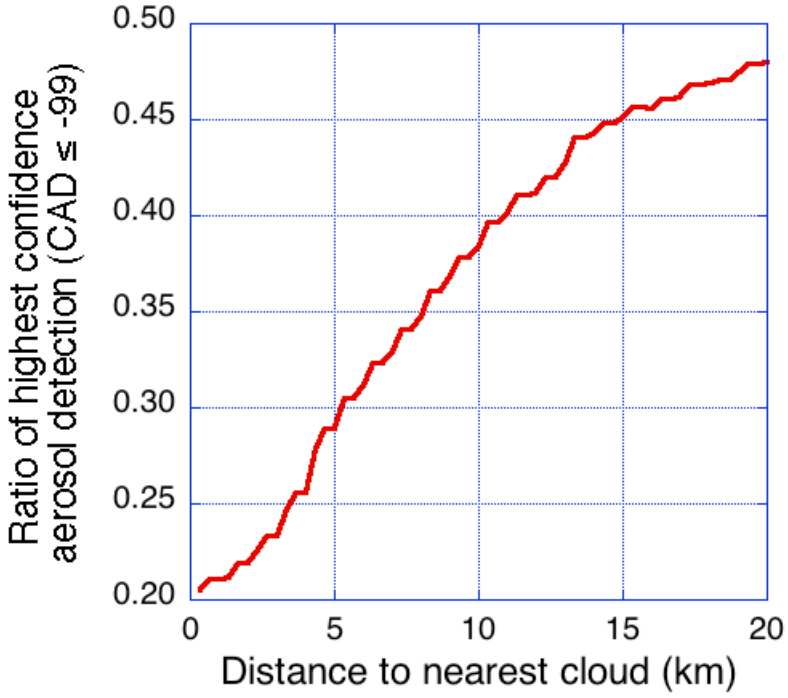


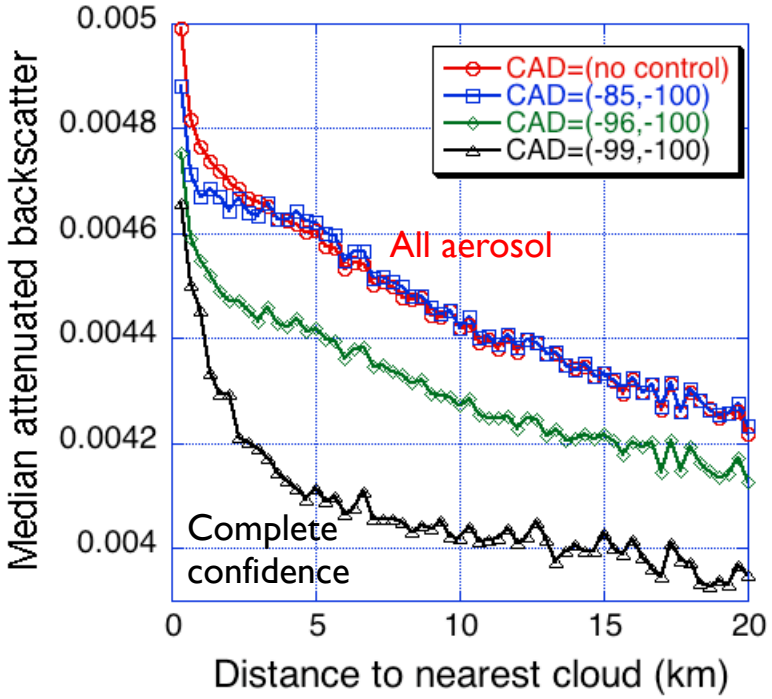




Várnai and Marshak (2009)

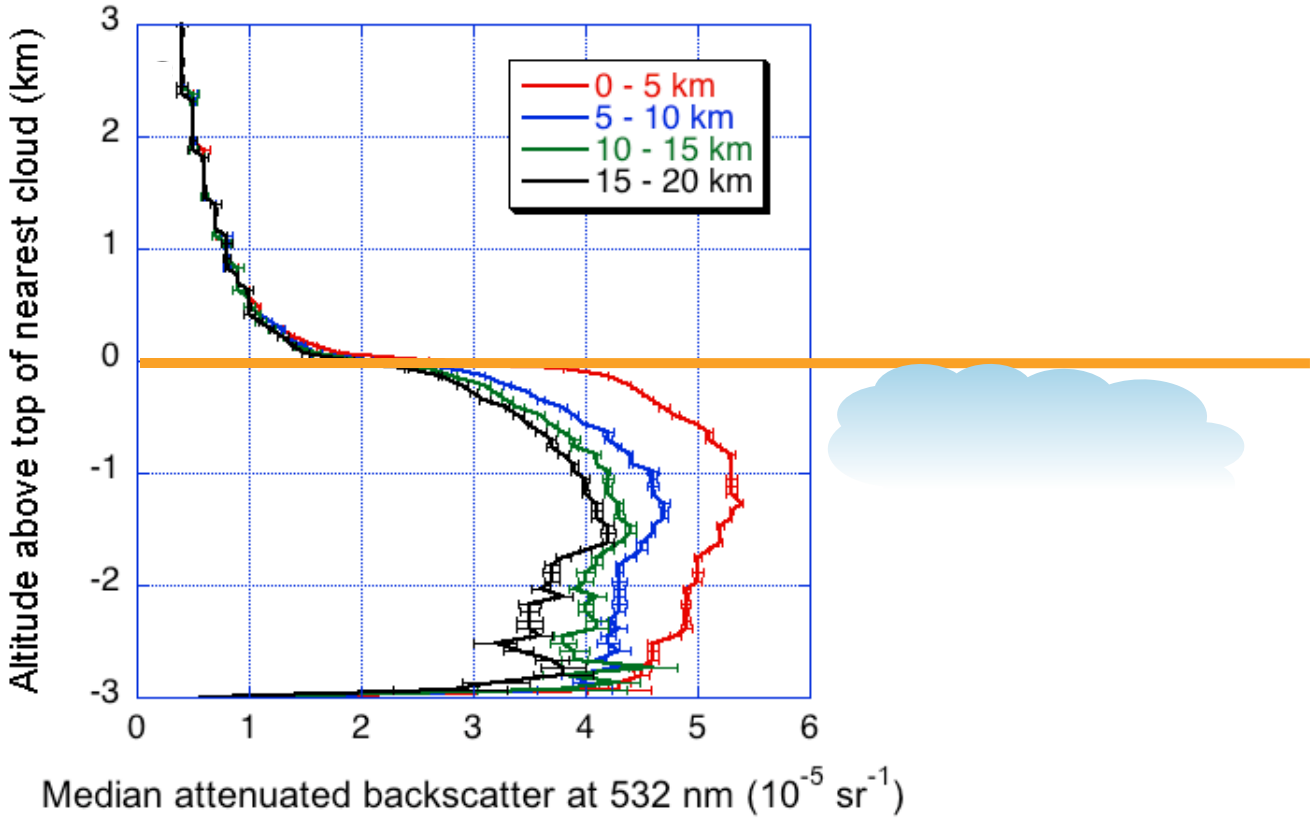
CALIOP confidence changes near clouds





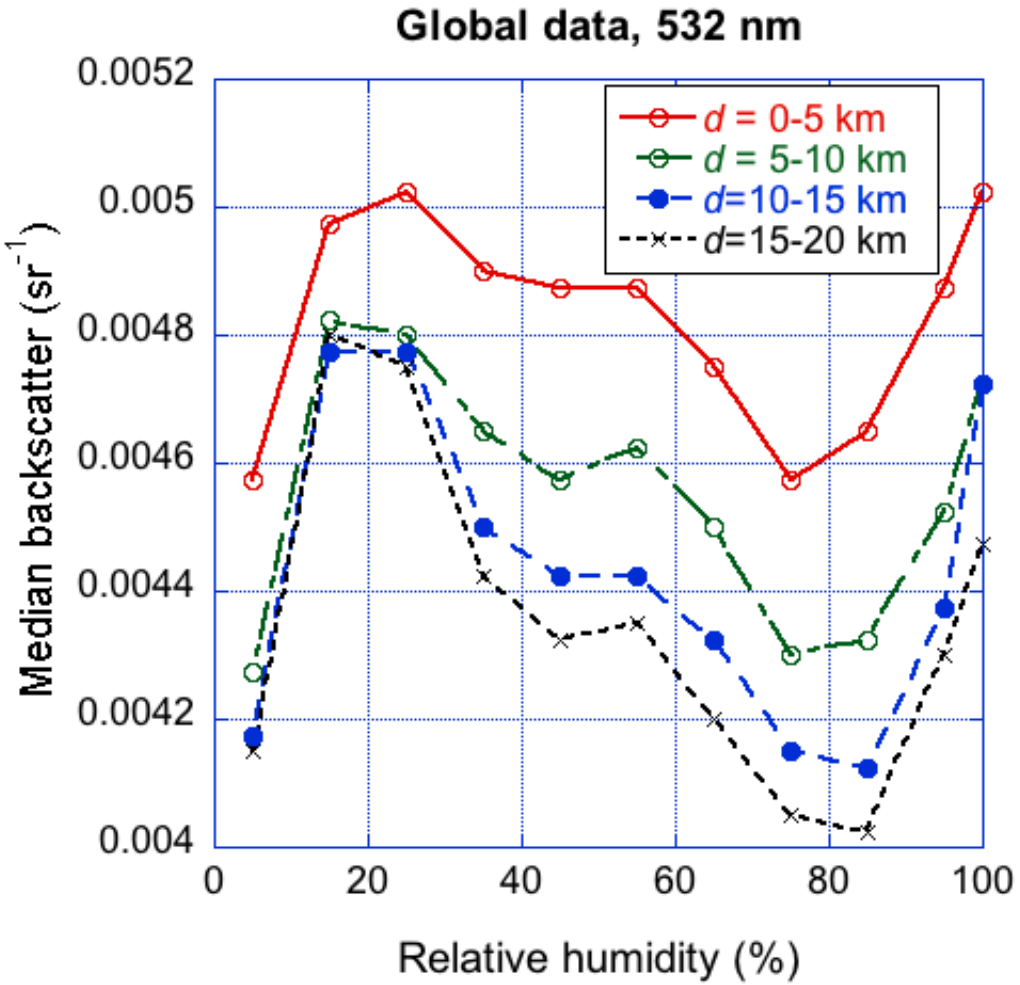
Yang et al. (2011)

CALIOP: increases occur below cloud top



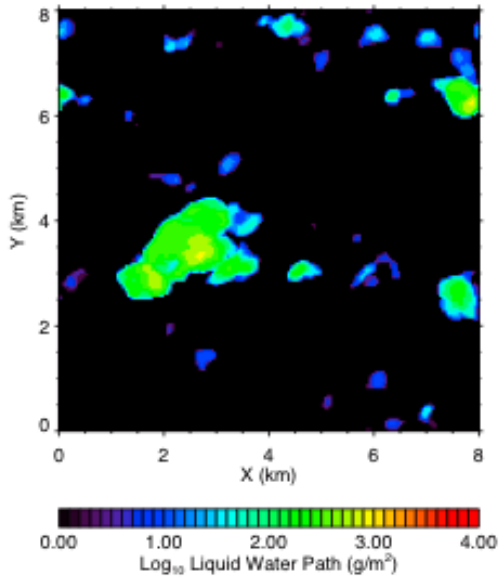
Várnai and Marshak (2010)

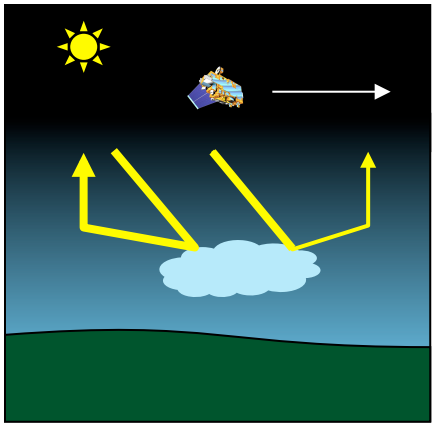
Enhancements smallest for low rel. humidity



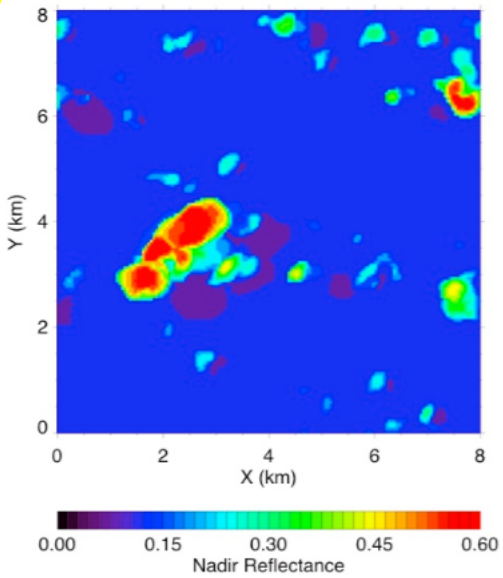
3D-related increases should be asymmetric

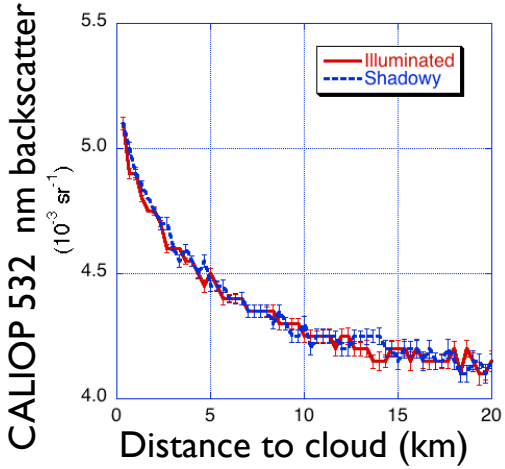
LES liquid water path



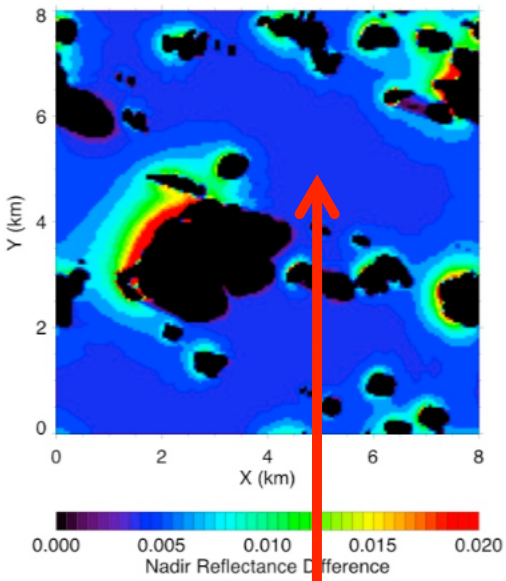


R_{3D} (0.47 μm)





R_{3D}-R_{1D} (0.47 μm)



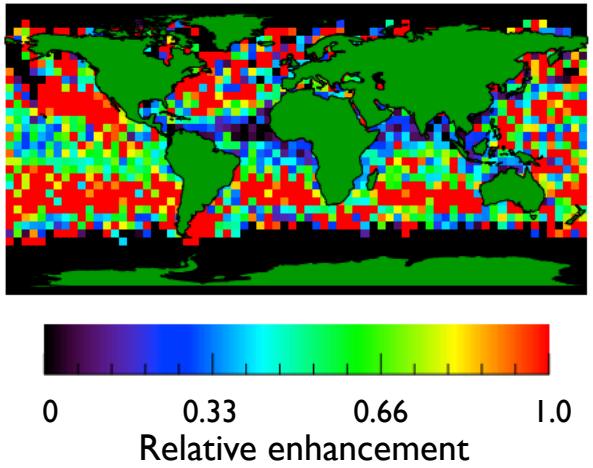
3D effect: enhancement everywhere (outside shadows)

Rel. enhancements: MODIS > CALIOP

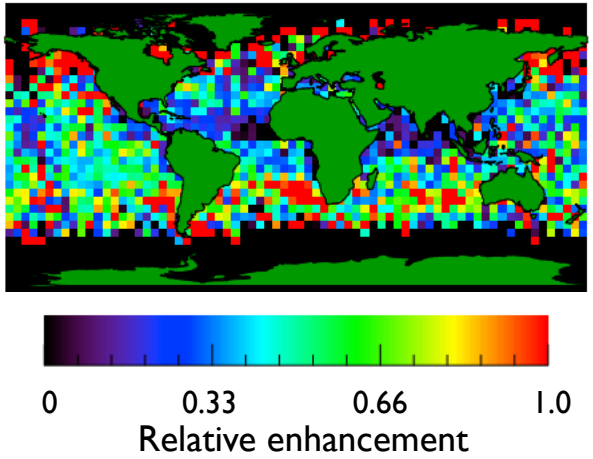
MODIS: $\frac{R_{d<5km} - R_{d>5km}}{R_{d>5km}}$

CALIOP: $\frac{\beta_{d<5km} - \beta_{d>5km}}{\beta_{d>5km}}$

MODIS 0.55 μm refl.



CALIOP, 532 nm bks. (β)



Swelling does not explain curvature of *R*(λ)

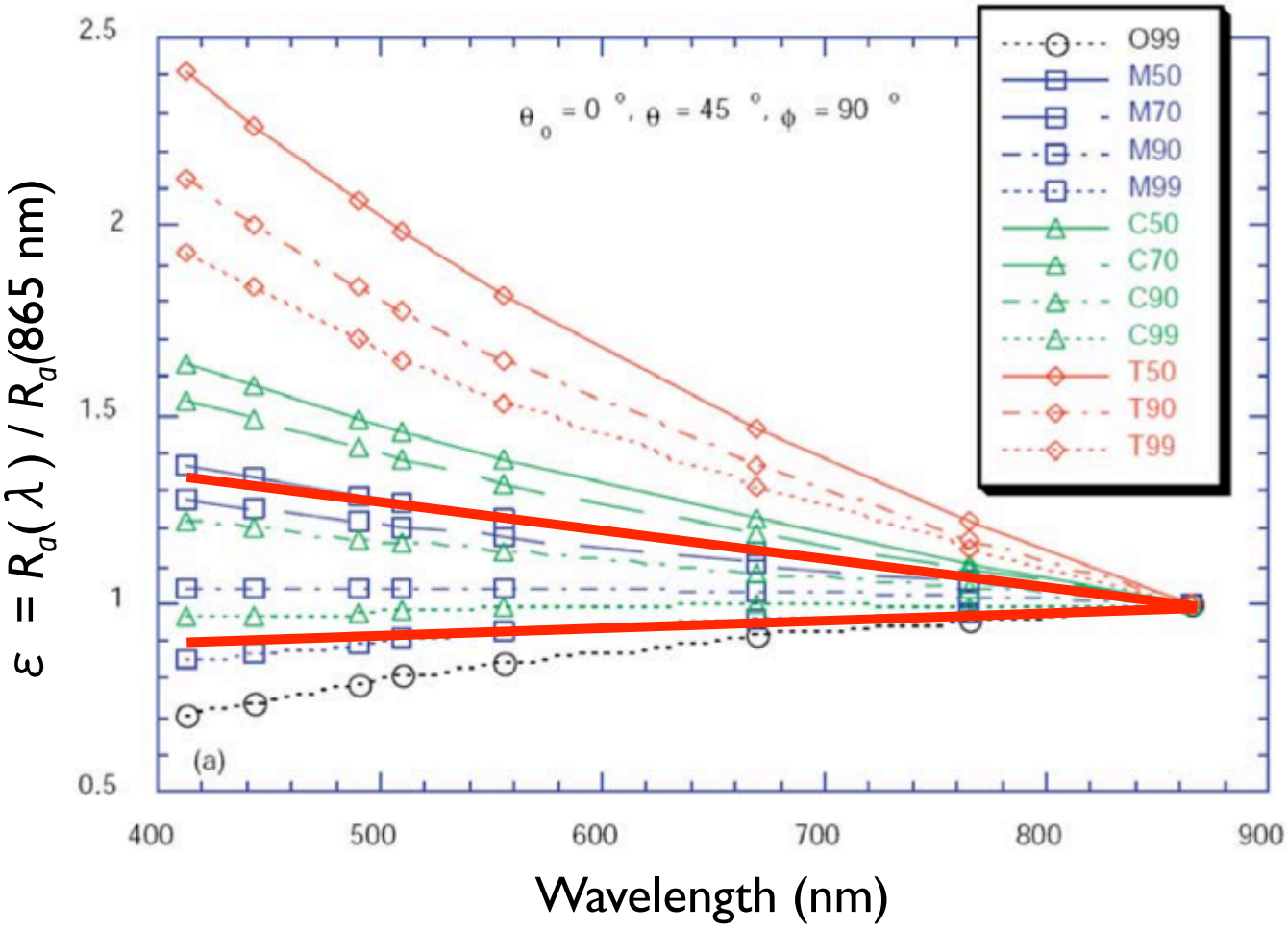
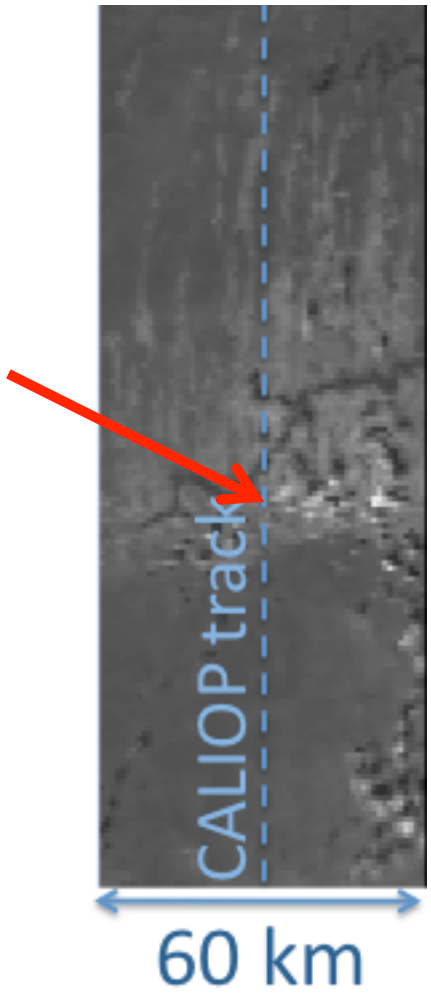
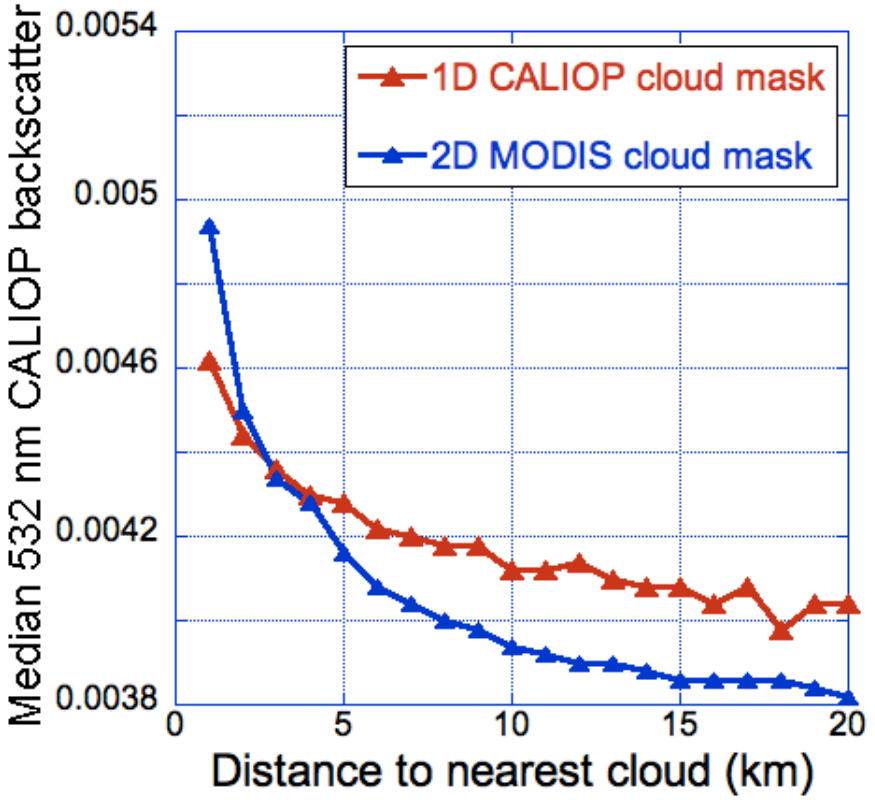


Image from Franz (2007)

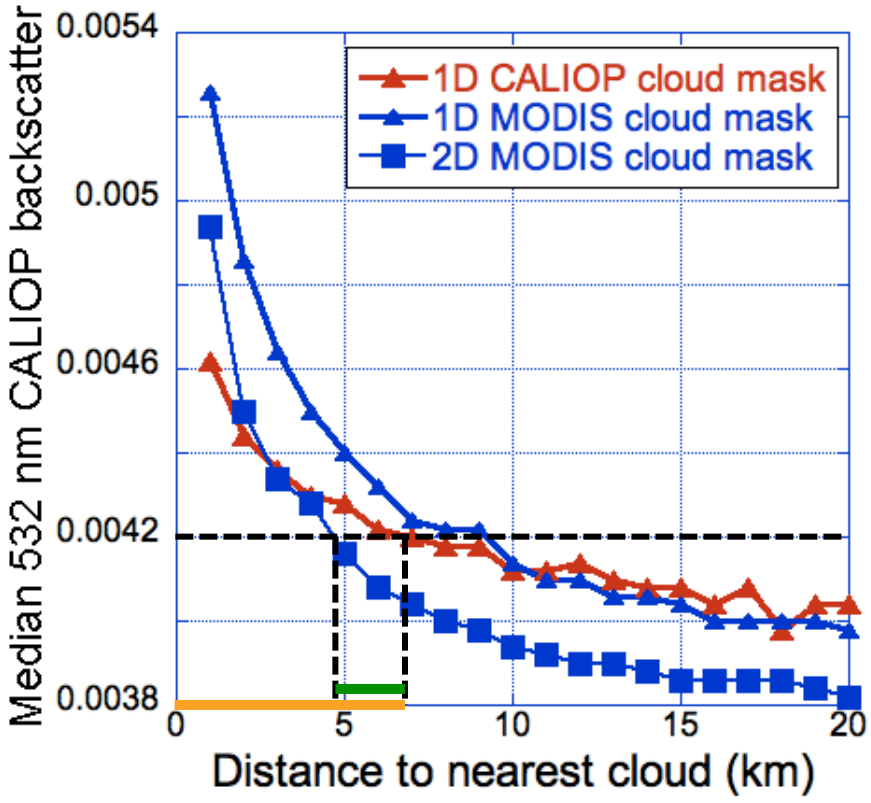
Aerosol models: Maritime, Coastal, Tropospheric (with RH)

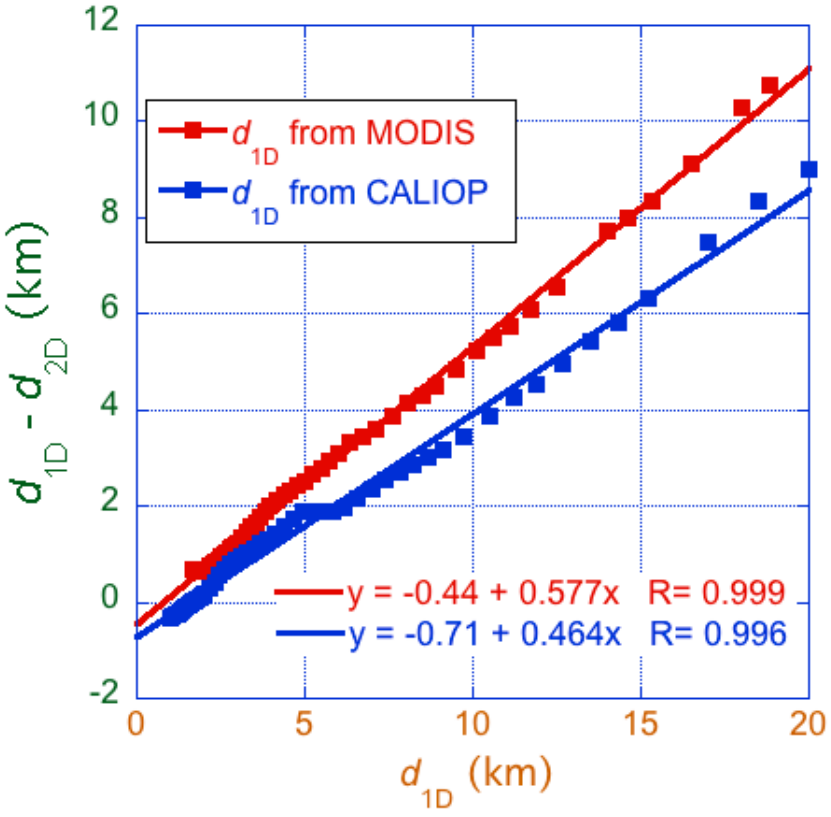
Enhancements greater for MODIS cloud mask



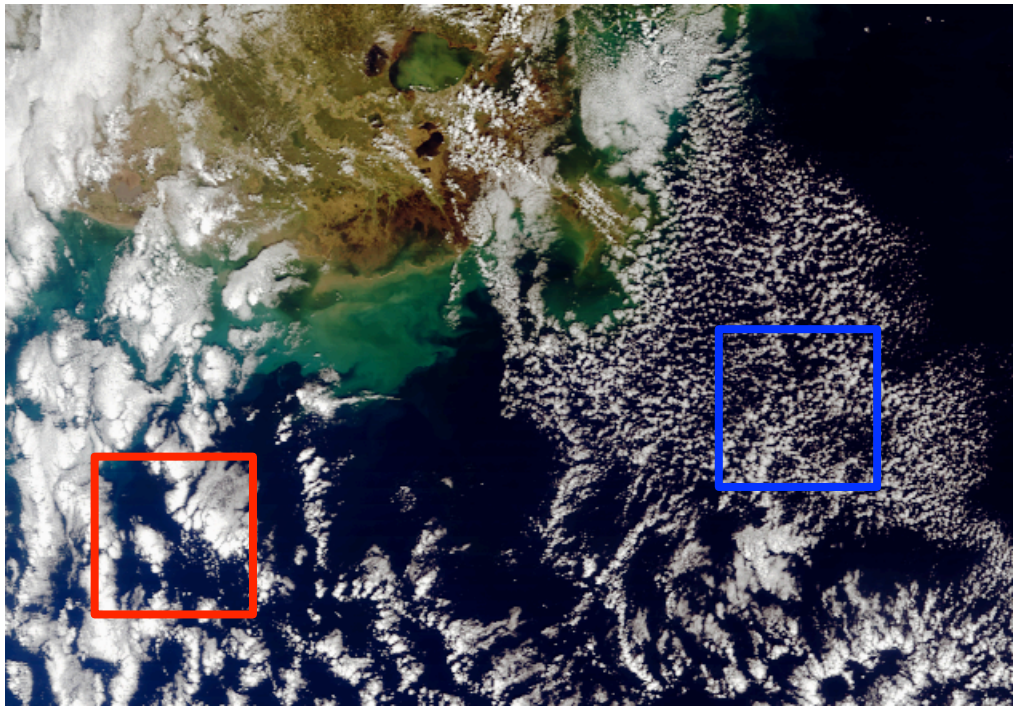


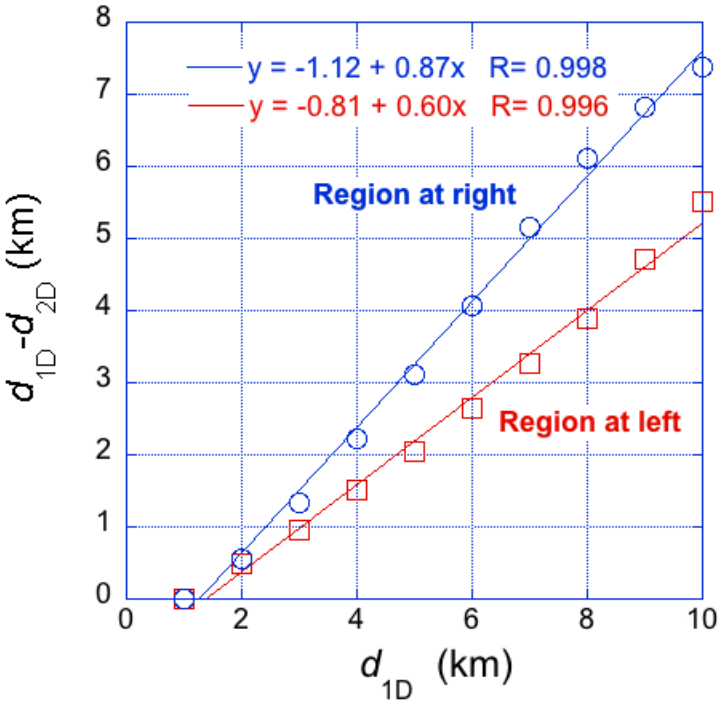
1D & 2D distances to cloud are related



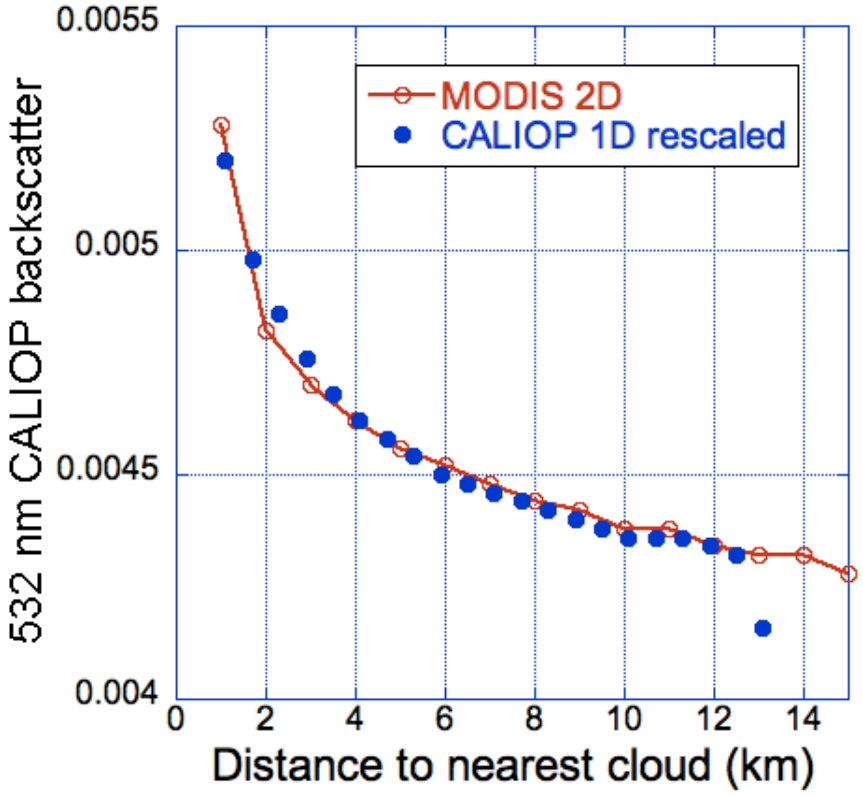


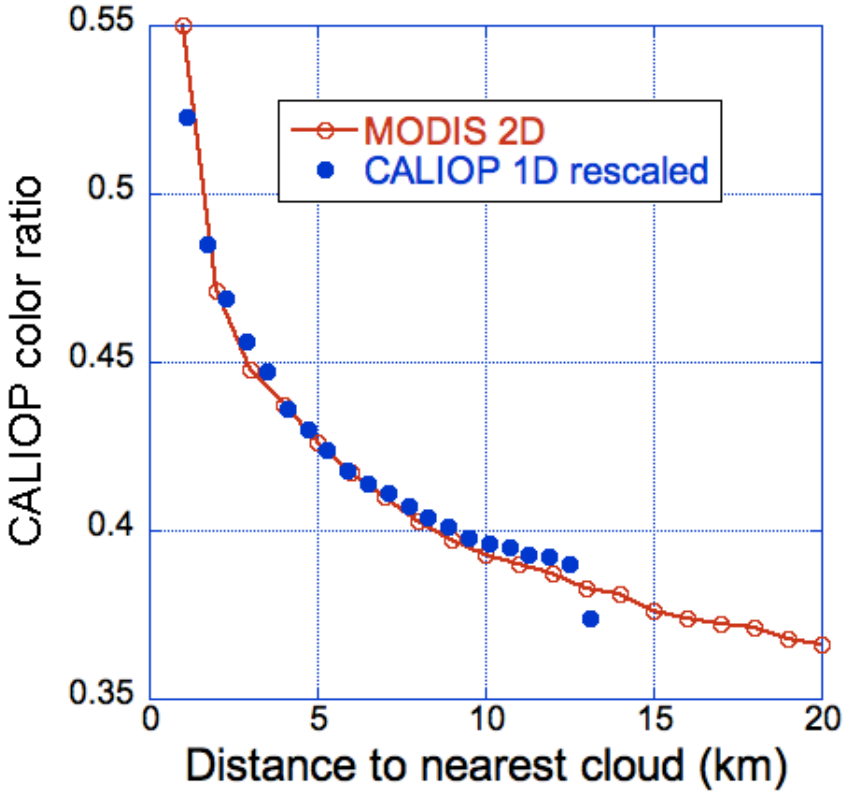
1D & 2D distances to cloud are related



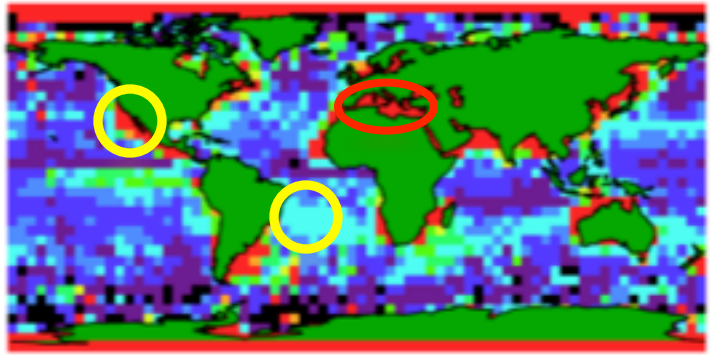


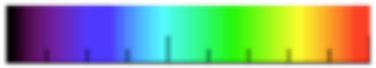
Rescaling CALIOP 1D distances can work





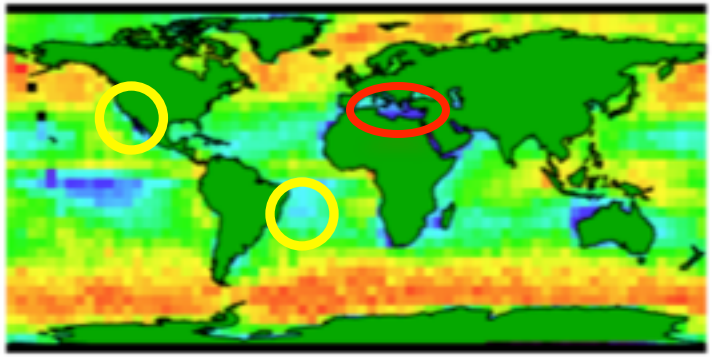
Distance to cloud varies with cloud amount, type

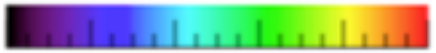




1 5 10

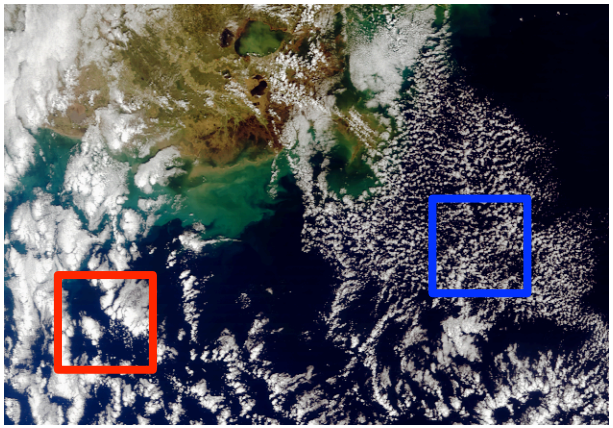
Annual median distance to low clouds (km)



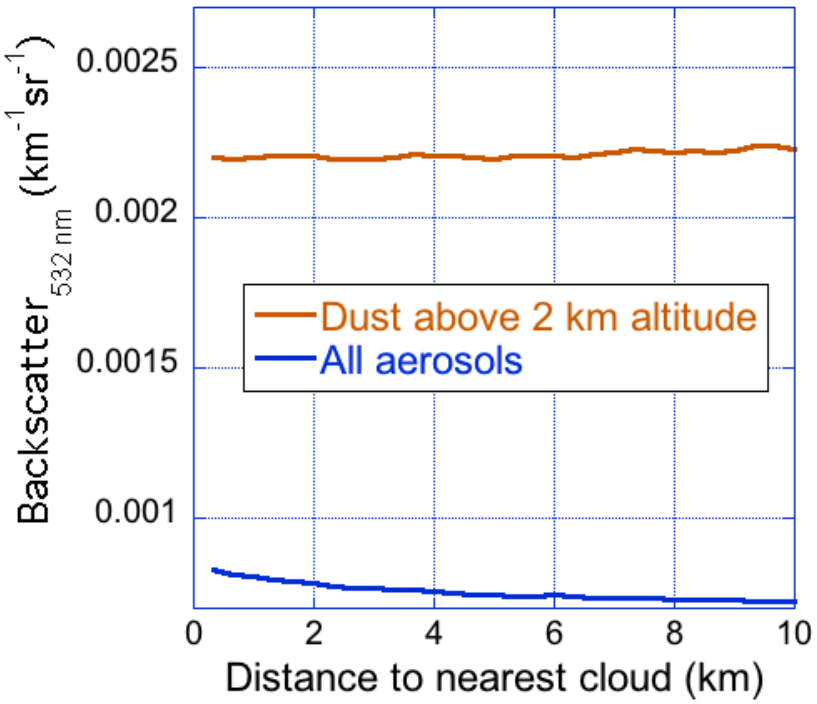


0 0.2 0.4 0.6 0.8 1

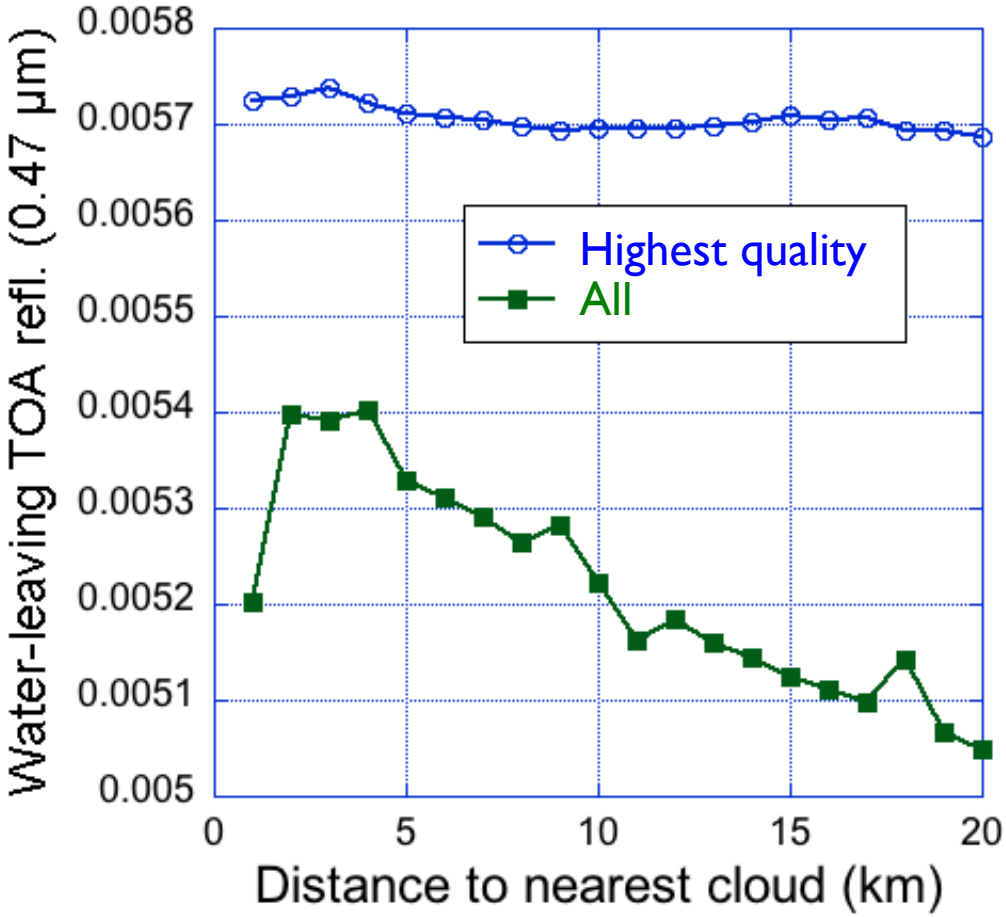
Annual mean cloud fraction



High dust backscatt. doesn't change near clouds



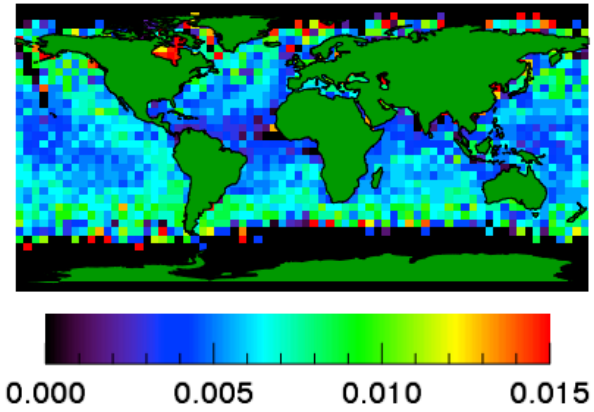
Water leaving radiances near clouds



MODIS & CALIOP enhancements: similar patterns

MODIS 0.47 μm reflectance (*R*) enhancement

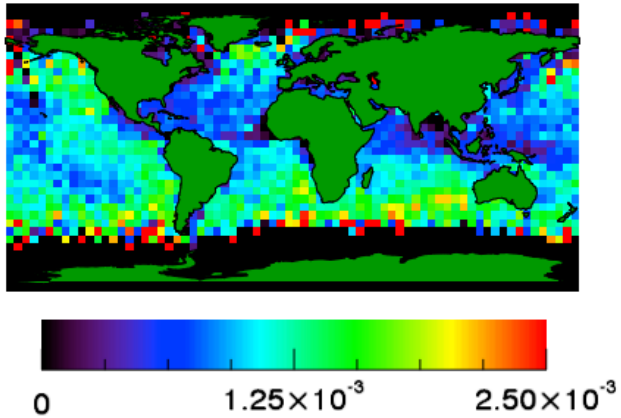
$R_{d<5km} - R_{d>5km}$



Median reflectance enhancement

CALIOP 532 nm backscatter (β) enhancement

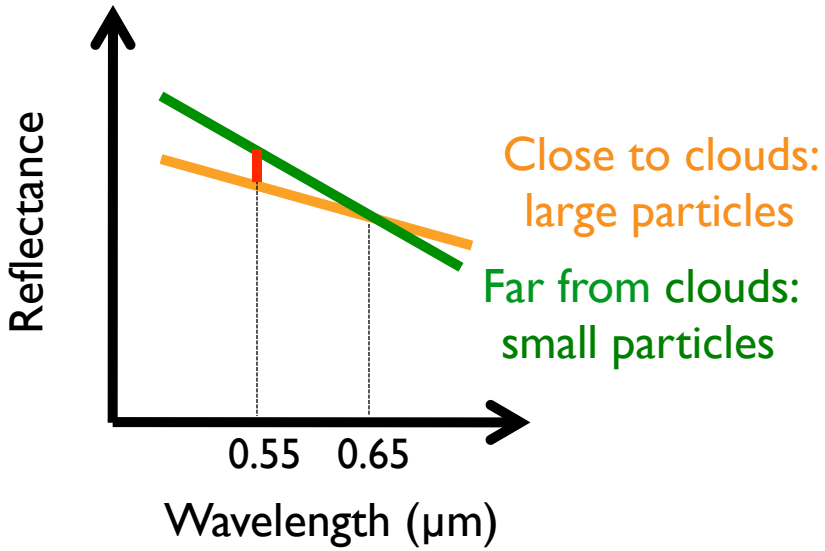
$\beta_{d<5km} - \beta_{d>5km}$



Enhancement of median backscatter integrated up to 3 km (sr^{-1})

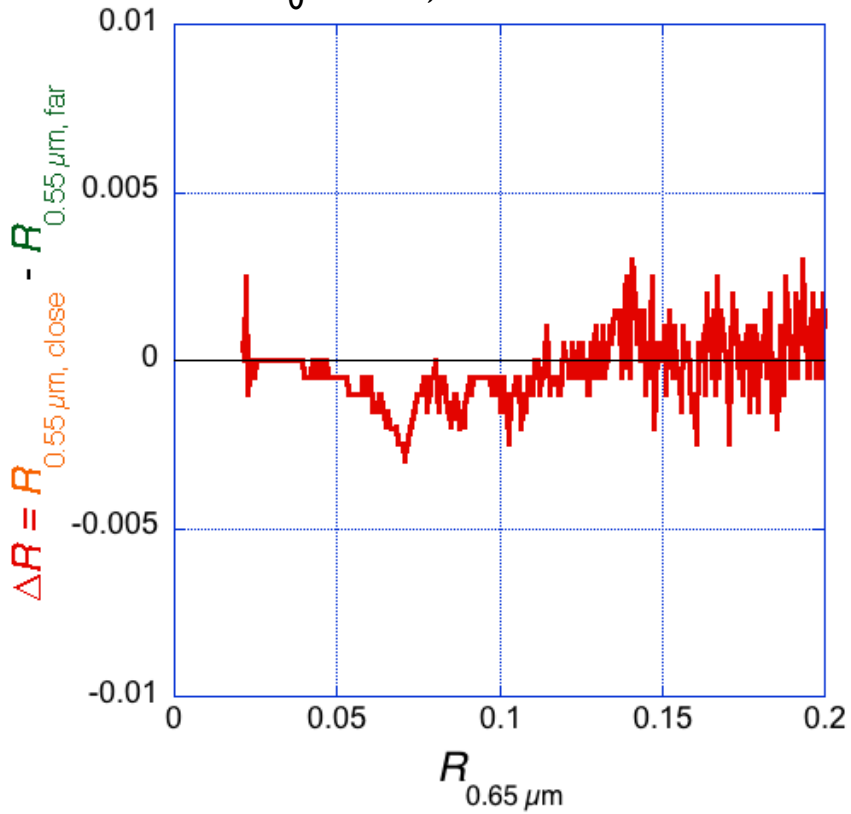
One year, 11/06 – 10/07

MODIS spectral data: particles larger near clouds

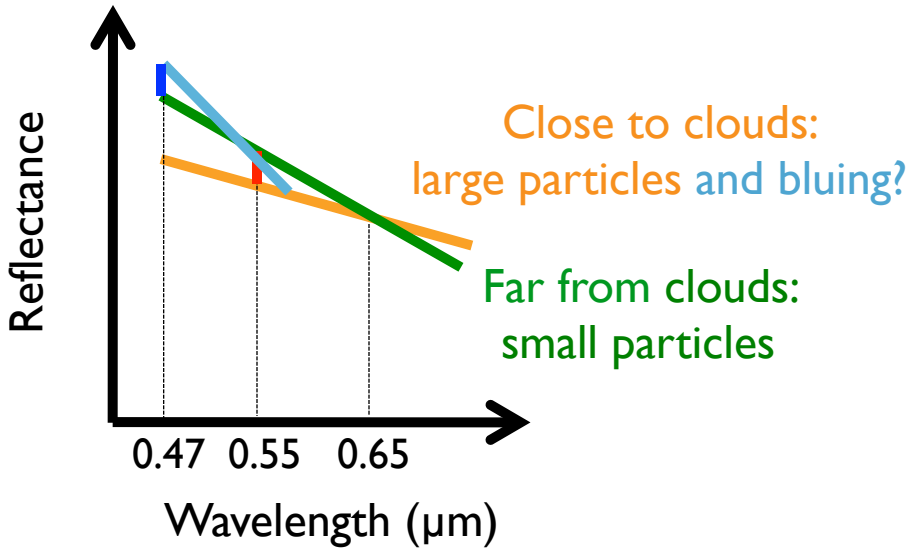


$\Delta R = R_{0.55}$ (d < 5 km) – $R_{0.55}$ (d > 5 km)
should be negative

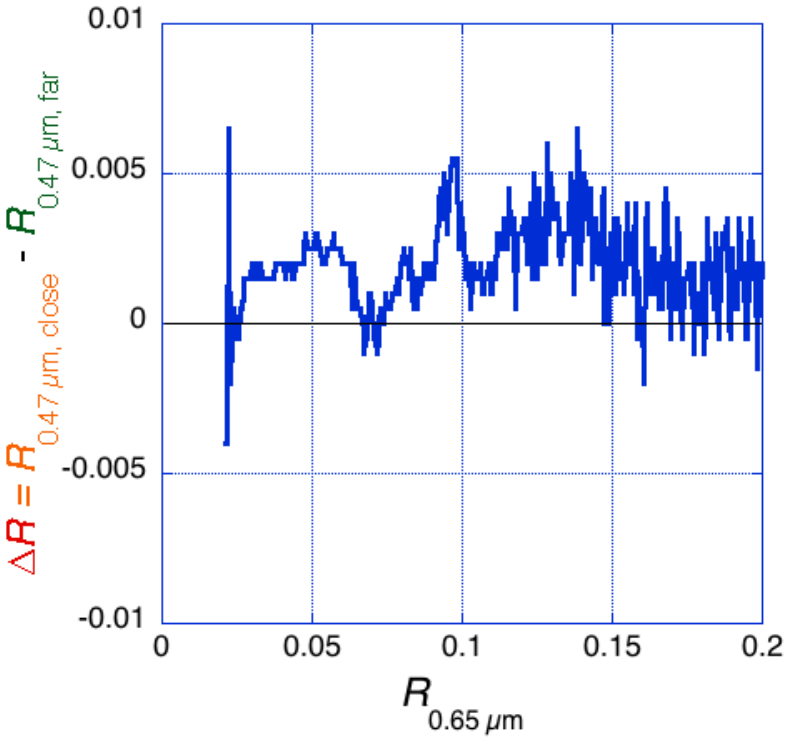
Yearlong MODIS dataset over oceans
$\Theta_0 \approx 30°$, near-nadir view



MODIS spectral data: bluing at short wavelengths



Yearlong MODIS dataset over oceans
$\Theta_0 \approx 30°$, near-nadir view



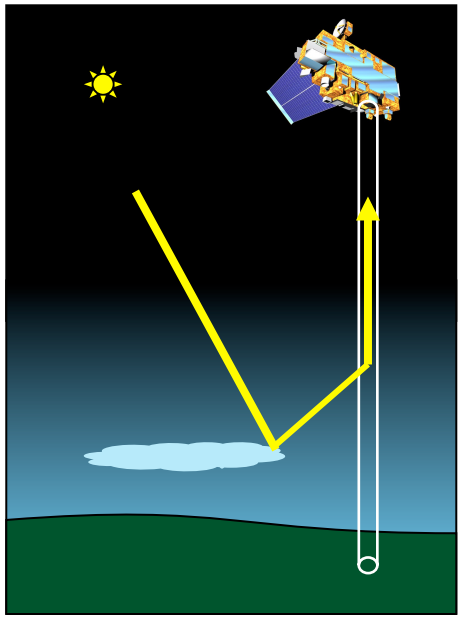
$\Delta R = R_{0.47}$ (d < 5 km) – $R_{0.47}$ (d > 5 km)
is still negative?

MODIS sfc. info can help CALIOP comparisons

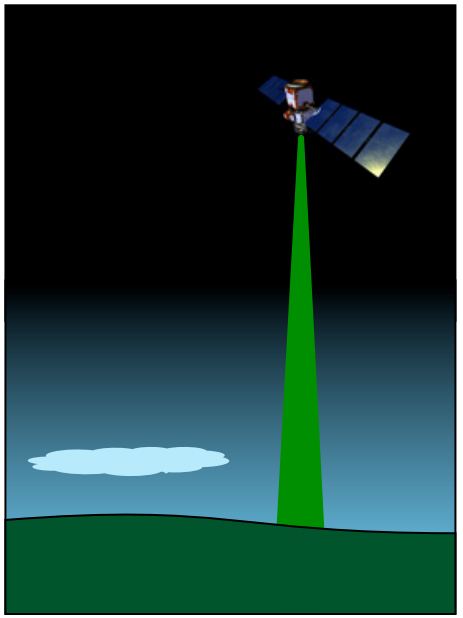
$R_{particle} = R_{obs} - R_{Rayleigh} - R_{sfc}$ $R_{particle} = R_{obs} - R_{Rayleigh}$

Relative increase in $R_{particle}$ near clouds should be similar

MODIS: 3D enhancement

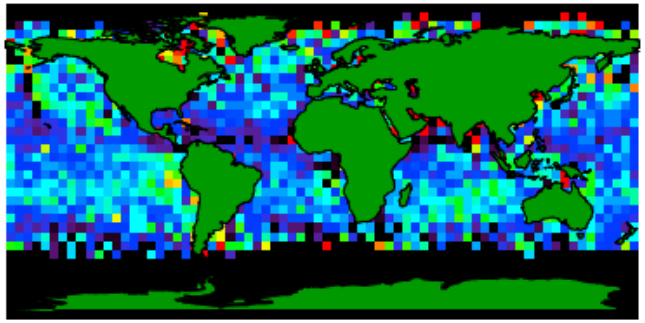


CALIOP: no 3D enhancement



Near-cloud enhancements in Jun-Jul-Aug

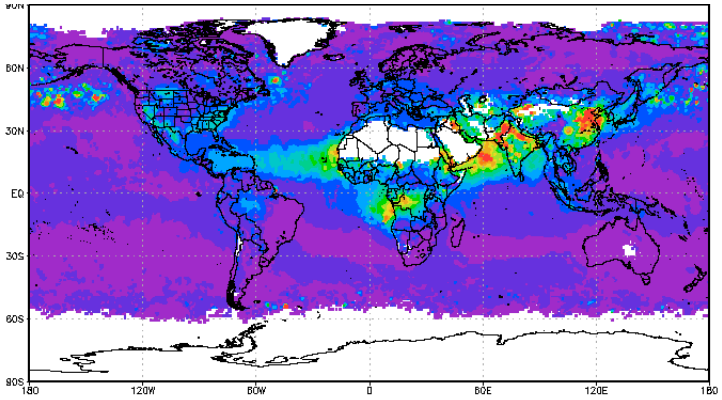
Median MODIS 0.55 μm reflectance enhancement



0.000 0.005 0.010 0.015

$R_{d<5km} - R_{d>5km}$

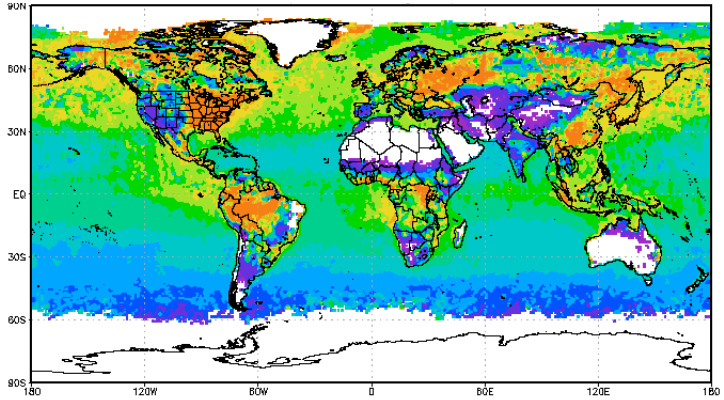
AOT



0.1 0.26 0.42 0.58 0.74 0.9

MODIS AOT at 0.55 μm

Small mode fraction



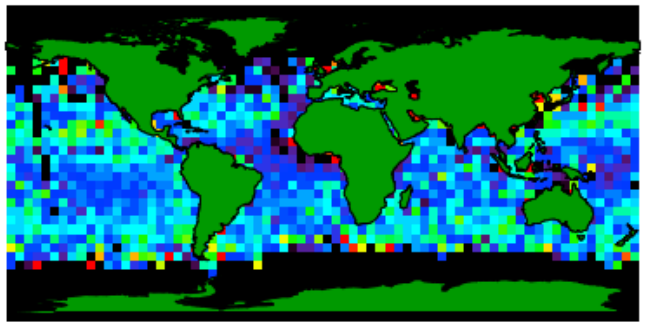
0.0 0.2 0.4 0.6 0.8 1.0

MODIS aerosol small mode fraction

Jun-Jul-Aug, 2007

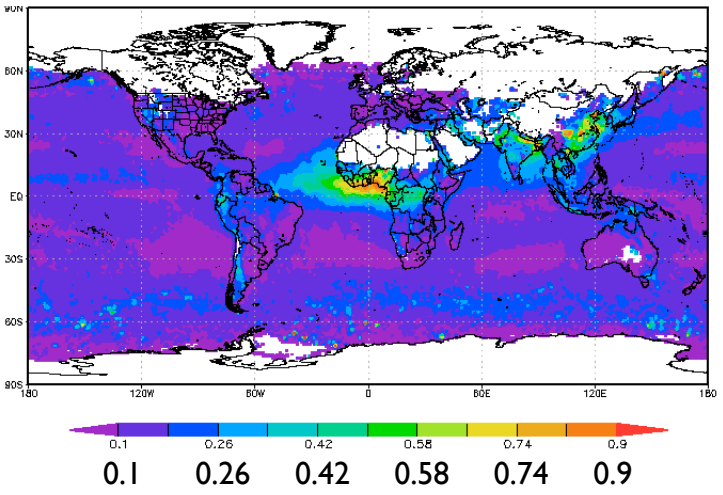
Enhancements in Dec-Jan-Feb

Median MODIS 0.55 μm reflectance enhancement



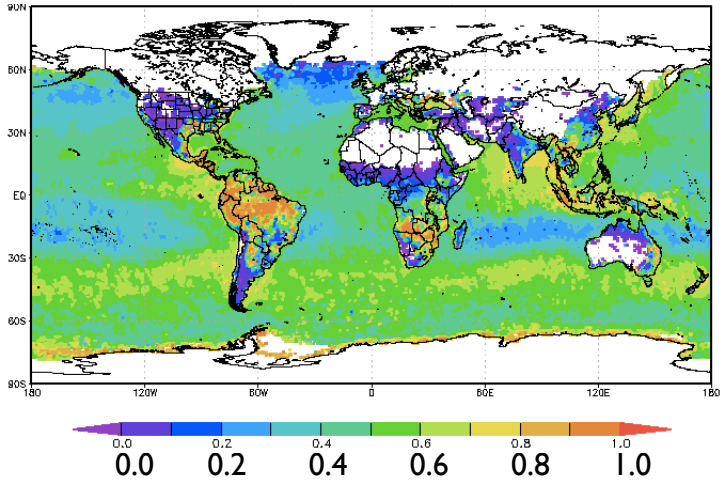
$R_{d<5km} - R_{d>5km}$

AOT



MODIS AOT at 0.55 μm

Small mode fraction



MODIS aerosol small mode fraction

Dec-Jan-Feb