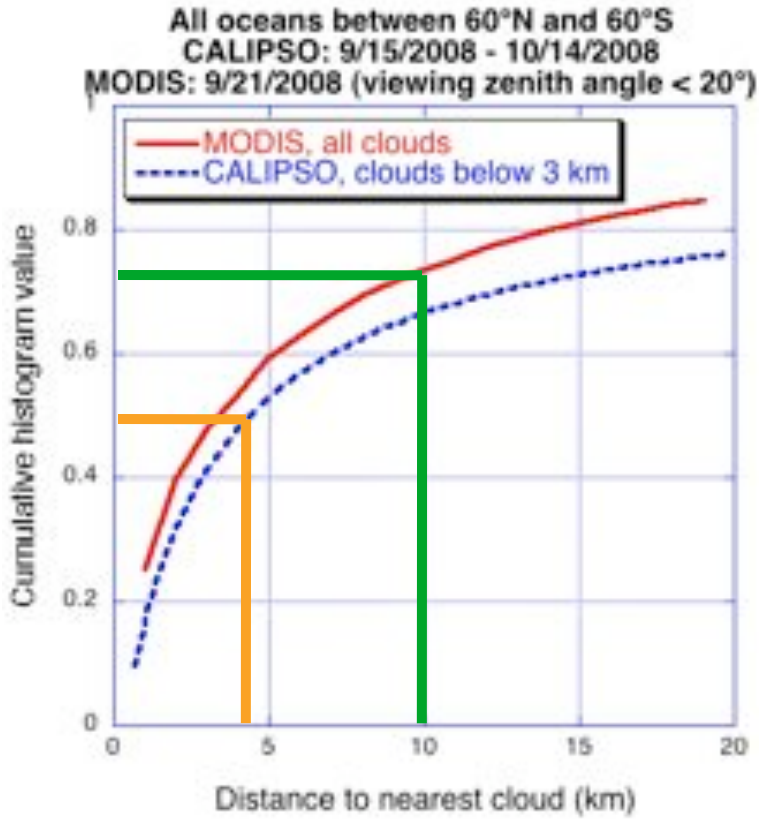
Aerosol properties near clouds

Alexander Marshak and Tamás Várnai

NASA GSFC and UMBC JCET

R. Cahalan, F. Evans, G. Wen, W. Yang

Aerosol measurements near clouds are important

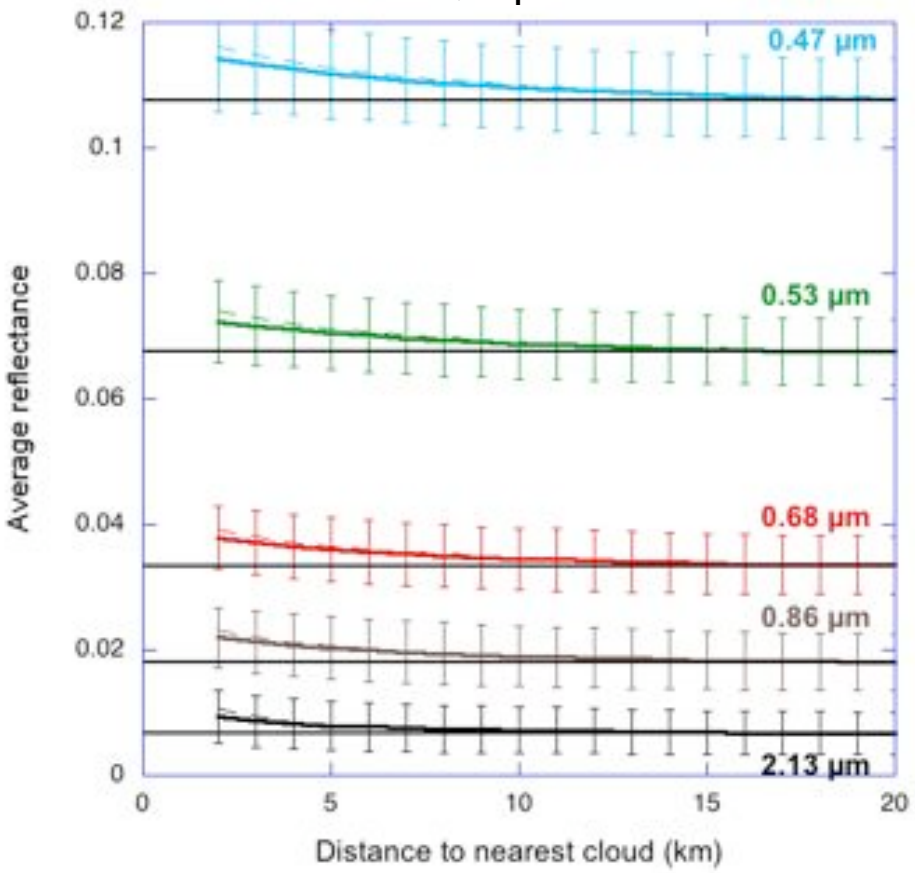


Motivation:

- Help satellite studies of aerosol-cloud interactions
- Aerosol remote sensing near clouds is challenging
- Excluding areas near-cloud risks biases in aerosol data

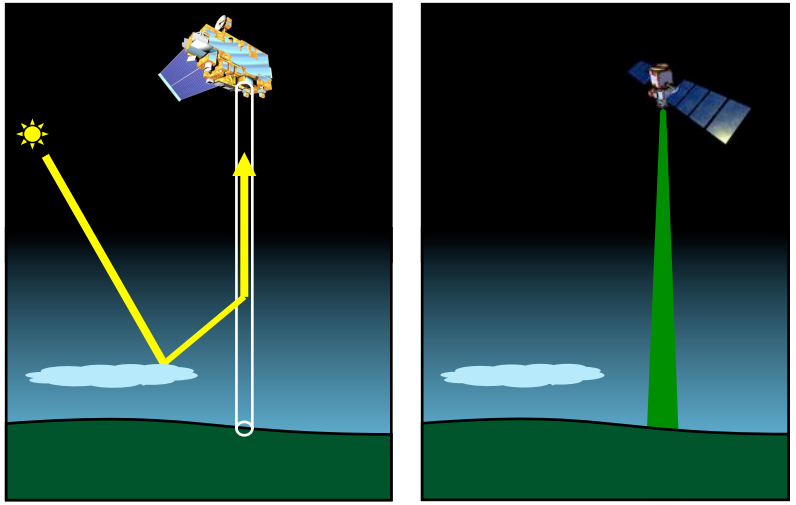
MODIS reflectances increase near clouds

NE Atlantic Ocean, MODIS Terra
2000-2007, September 14-29



Reflectance increase may come from:

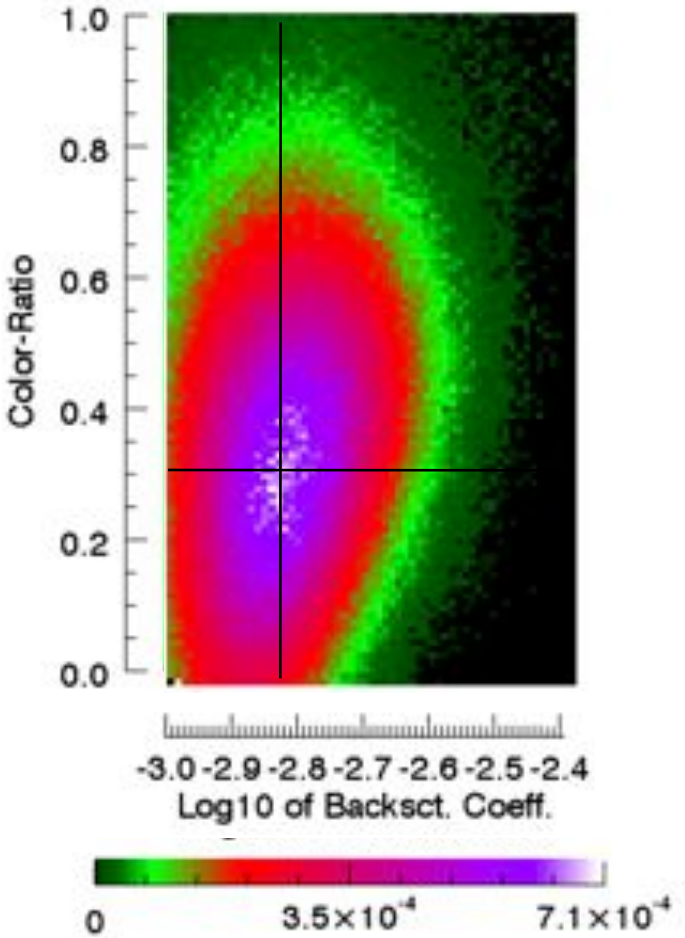
- Aerosol changes (e.g., swelling in humid air)
- Undetected cloud particles
- Instrument imperfections
- 3D radiative effects



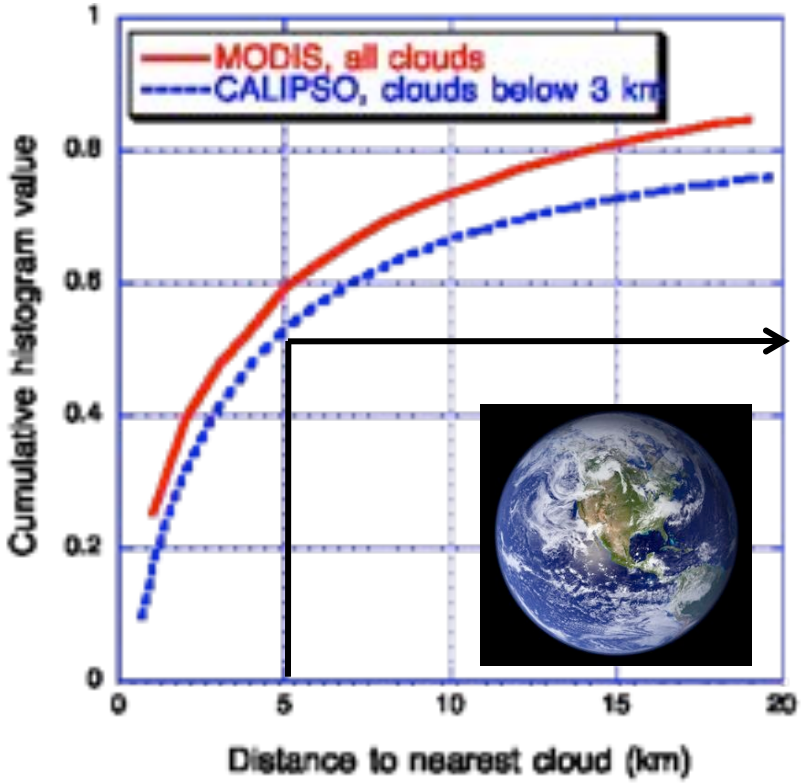
Várnai and Marshak (2009)

CALIOP backscatter and particle size

Far from clouds (> 5km)



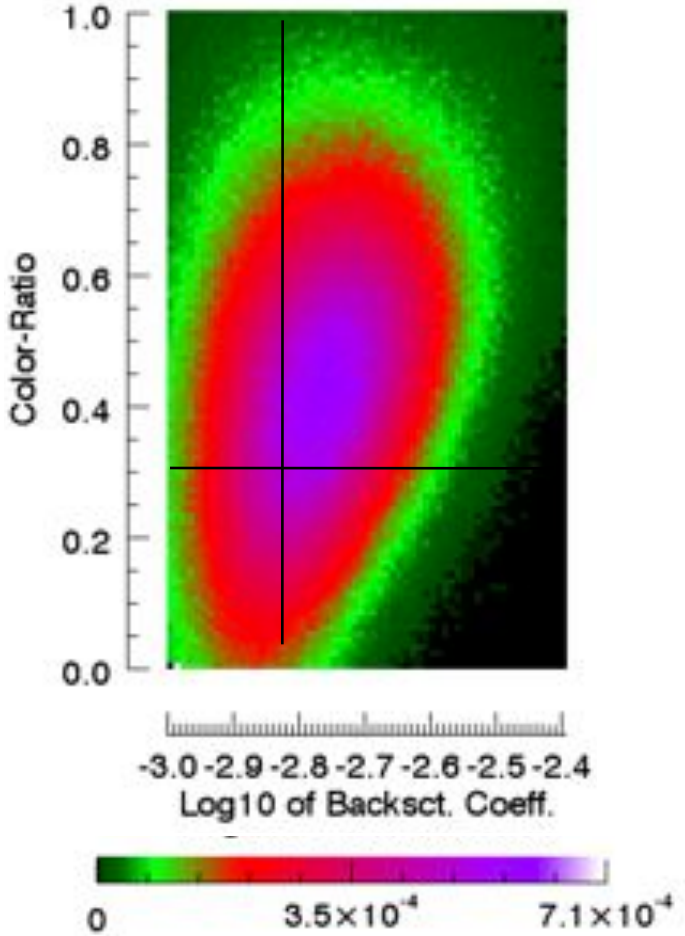
Fraction of cloud-free vertical profiles

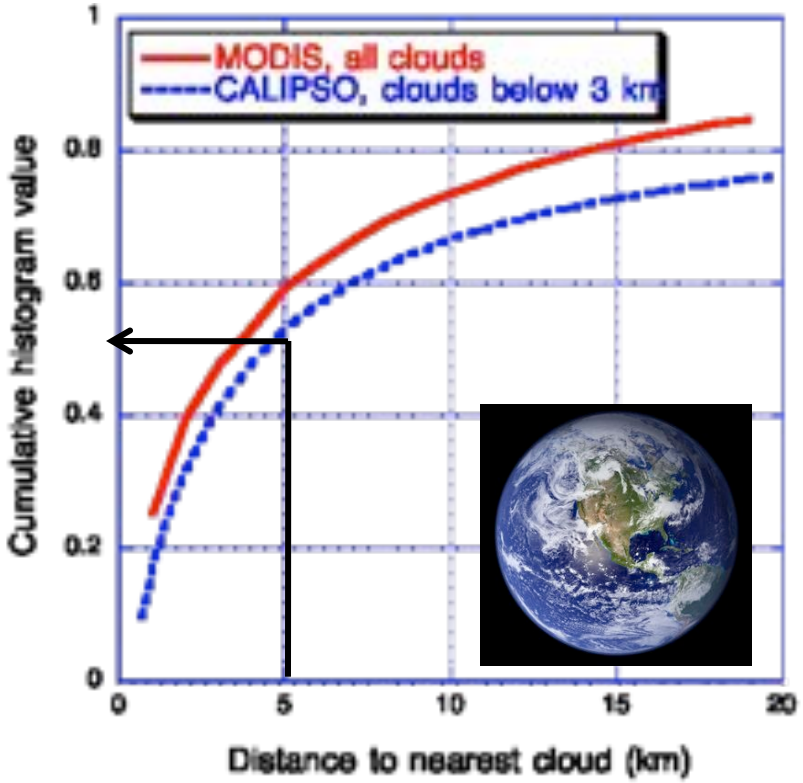


global night data over ocean
July 8 – Aug 7, 2007

CALIOP backscatter and particle size

Close to clouds (< 5km)



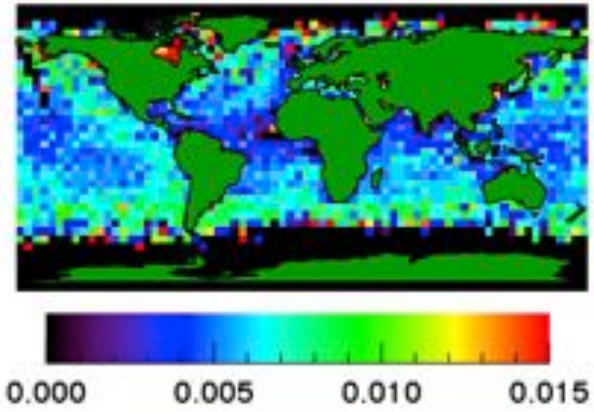


global night data over ocean
July 8 – Aug 7, 2007

Enhancements occur over all oceans

MODIS 0.47 μm reflectance (R) enhancement

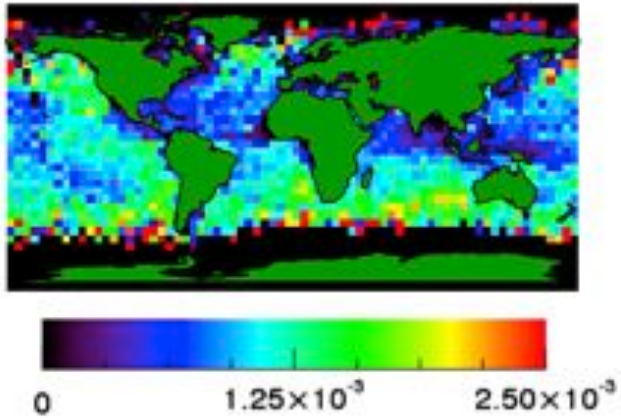
$R_{d<5km} - R_{d>5km}$



Median reflectance enhancement

CALIOP 532 nm backscatter (β) enhancement

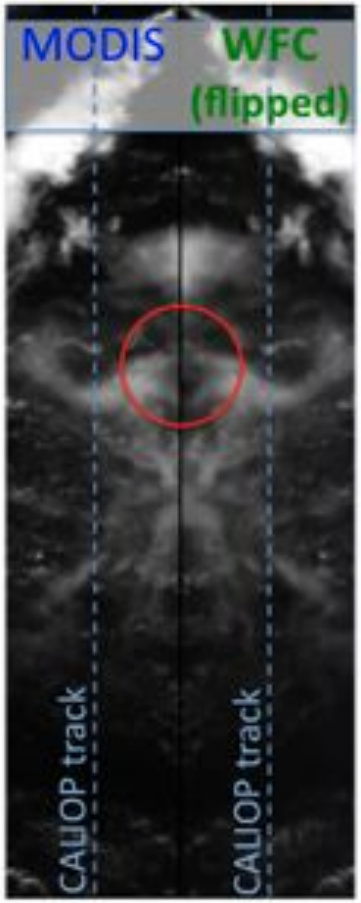
$\beta_{d<5km} - \beta_{d>5km}$

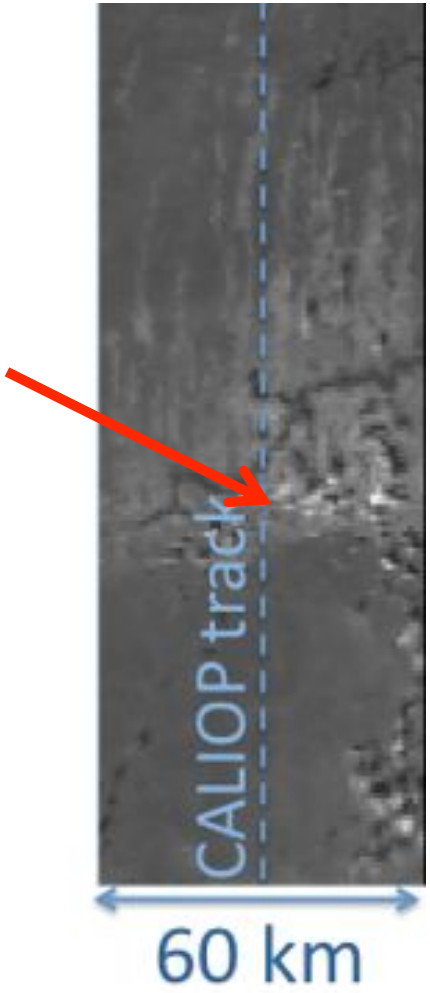


Enhancement of median backscatter integrated up to 3 km (sr^{-1})

One year, 11/06 – 10/07

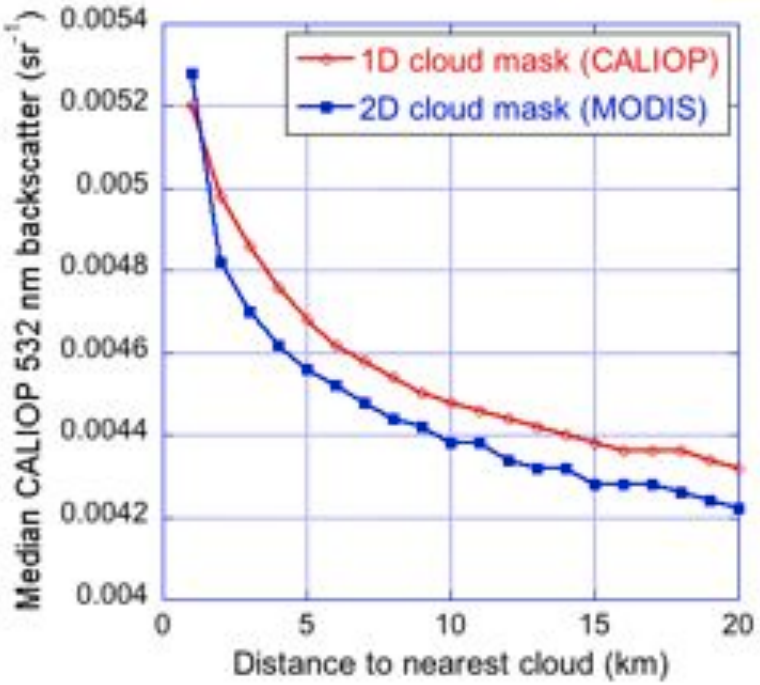
MODIS can add cloud information



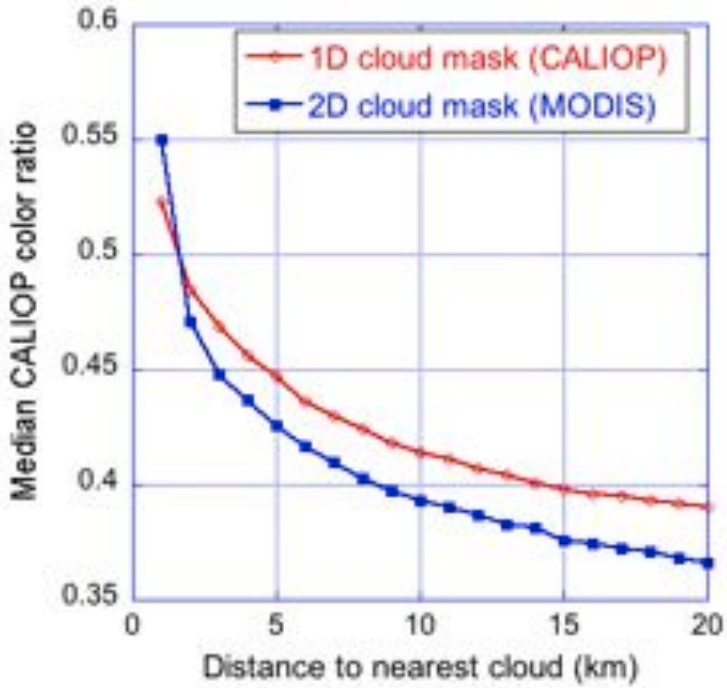


1D & 2D cloud masks yield similar enhancements

CALIOP 532 nm backscatter (β_{532}) integrated up to 3 km altitude

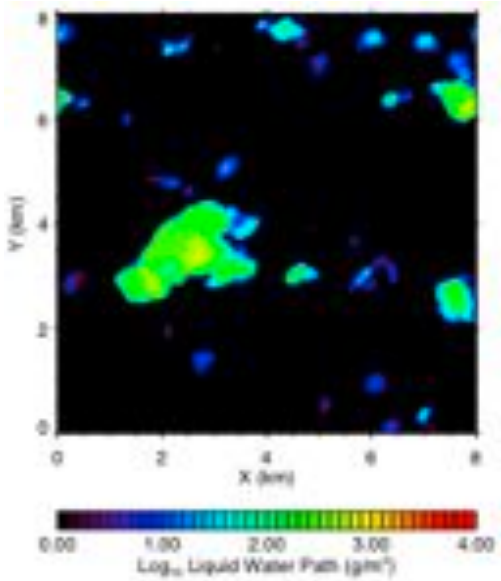


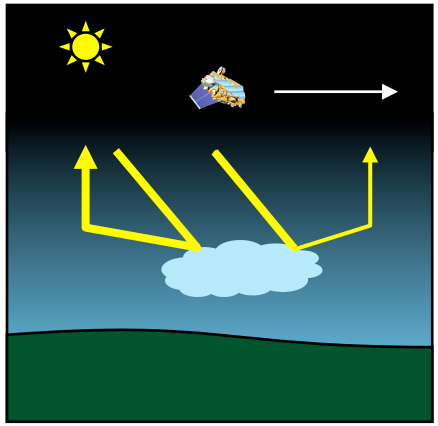
CALIOP color ratio (β_{1064} / β_{532}) (closely related to particle size)



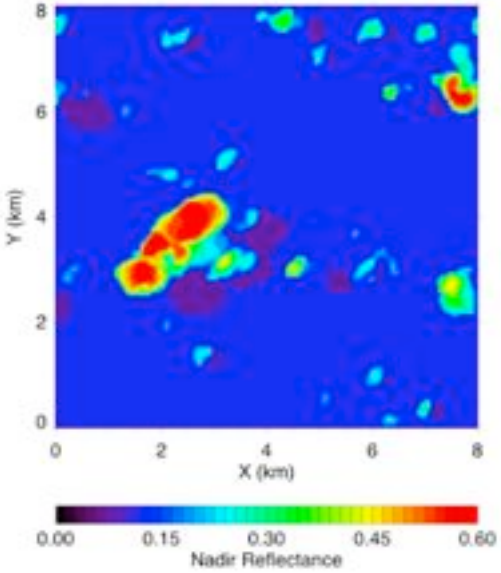
3D-related increases should be asymmetric

LES liquid water path

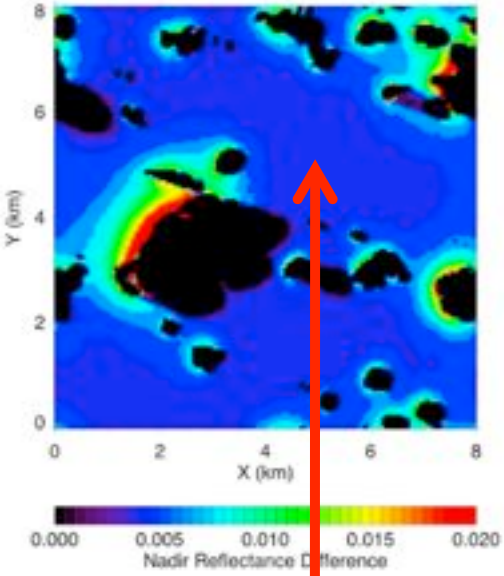




R_{3D} (0.47 μm)



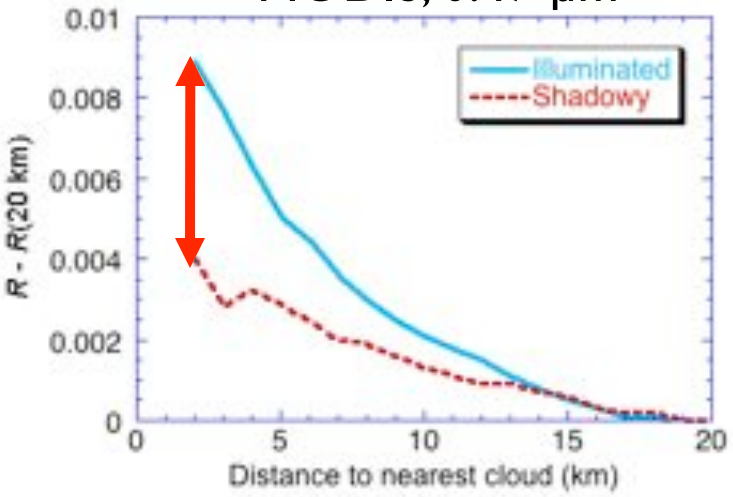
R_{3D}-R_{1D} (0.47 μm)



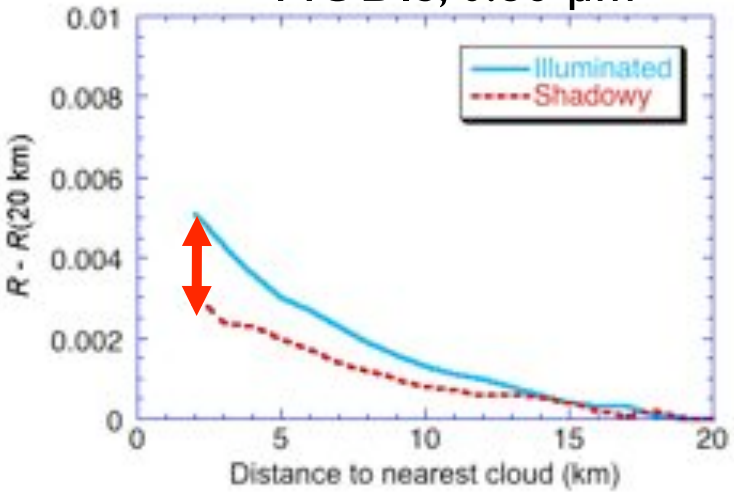
3D effect: enhancement everywhere (outside shadows)

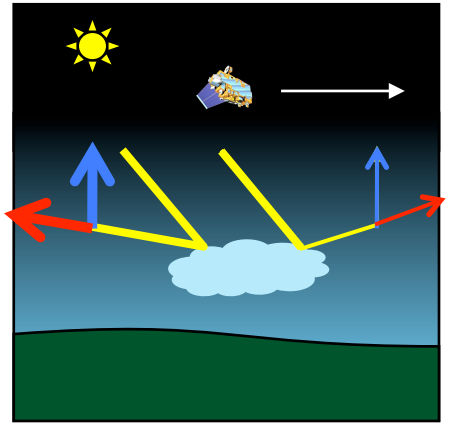
Asymmetry stronger at shorter λ: 3D is important

MODIS, 0.47 μm



MODIS, 0.86 μm

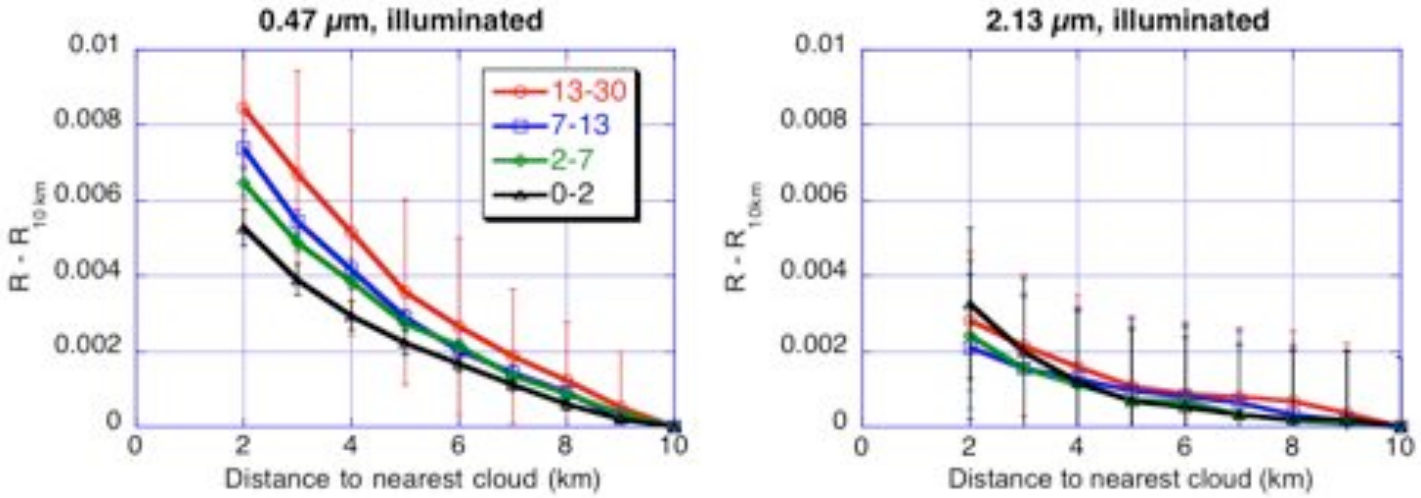




Várnai and Marshak (2009)

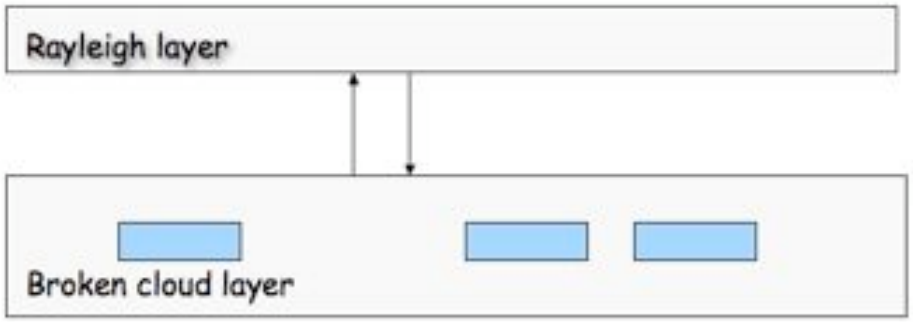
Strong increase near thick clouds agrees with 3D

MODIS reflectances near clouds of various optical thicknesses



Várnai and Marshak (2009)

Simple model to correct for 3D enhancement



$$R_{corrected} = R_{MODIS} - \Delta R(\tau_{Rayleigh}, F_{reflected})$$

Need this

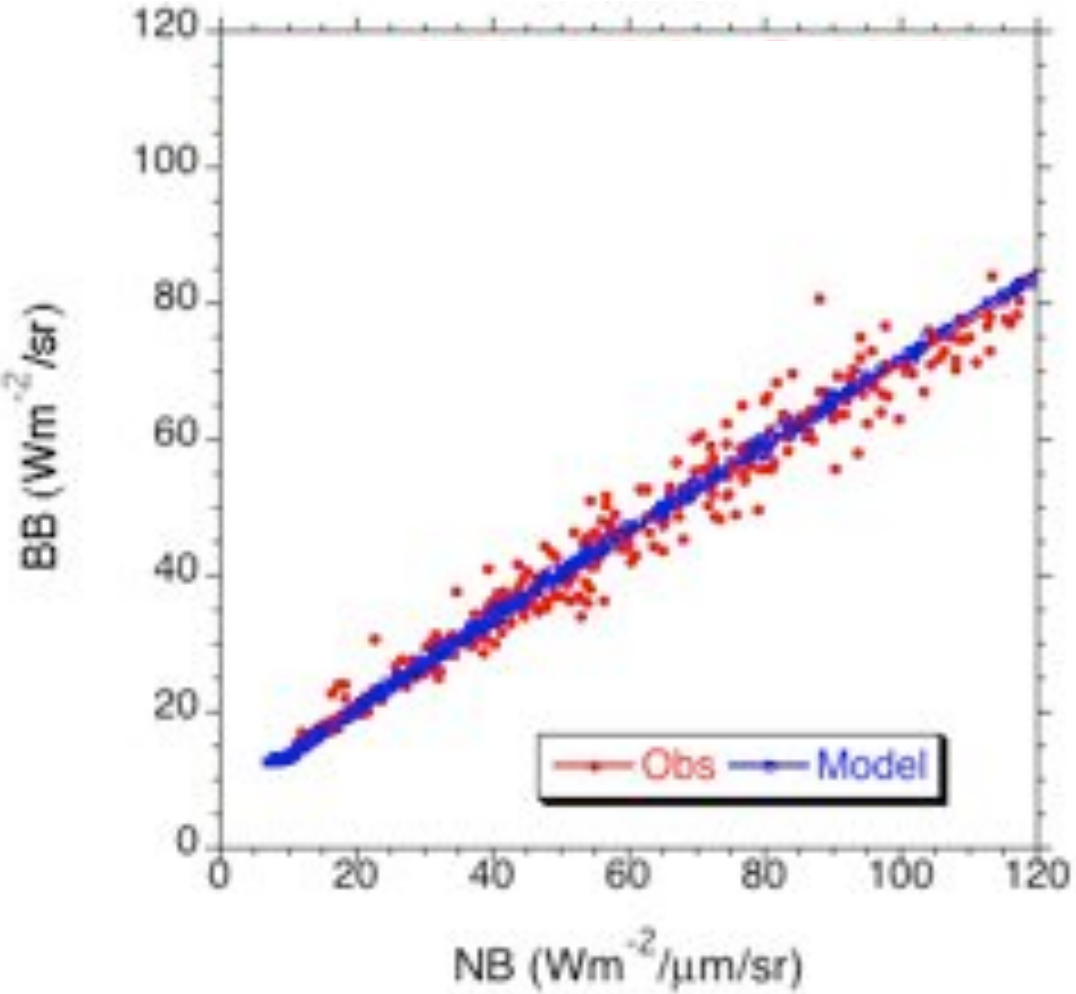
$$\frac{F_{obs}^{NB}}{F_{obs}^{BB}} \approx \frac{F_{model}^{NB}}{F_{model}^{BB}}$$

CERES

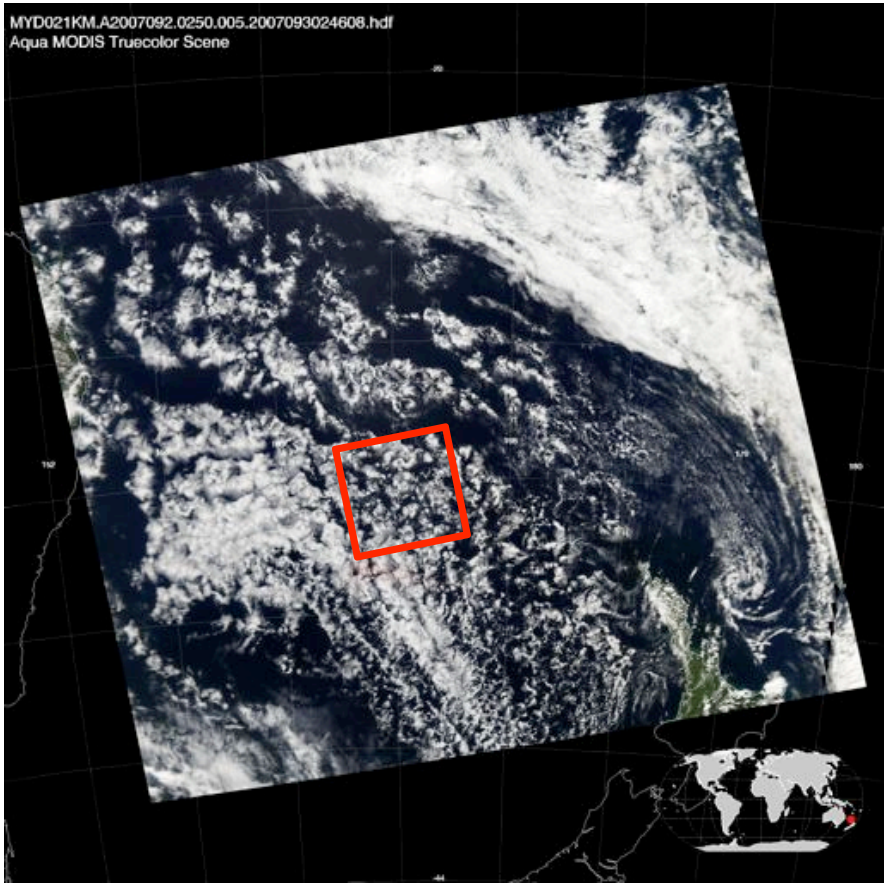
RT model (τ , CF, r_e)
Input from CERES and MODIS
Ocean BRDF
Correlated-*k* for BB

Marshak et al. (2008)

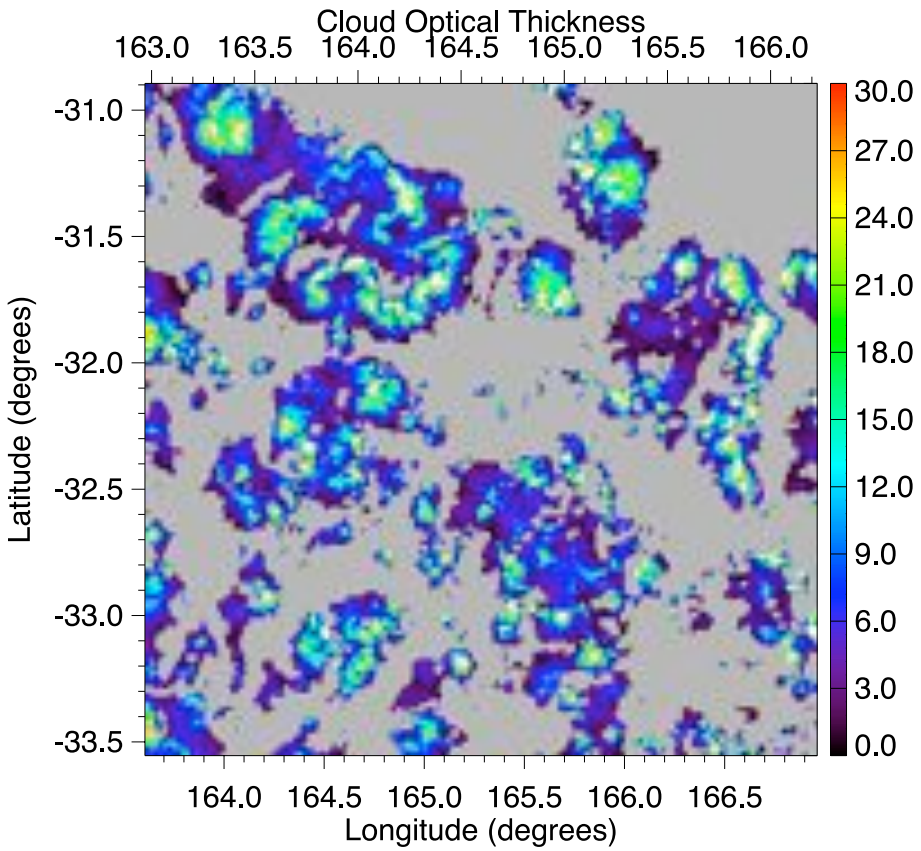
Test shows assumption works for radiances

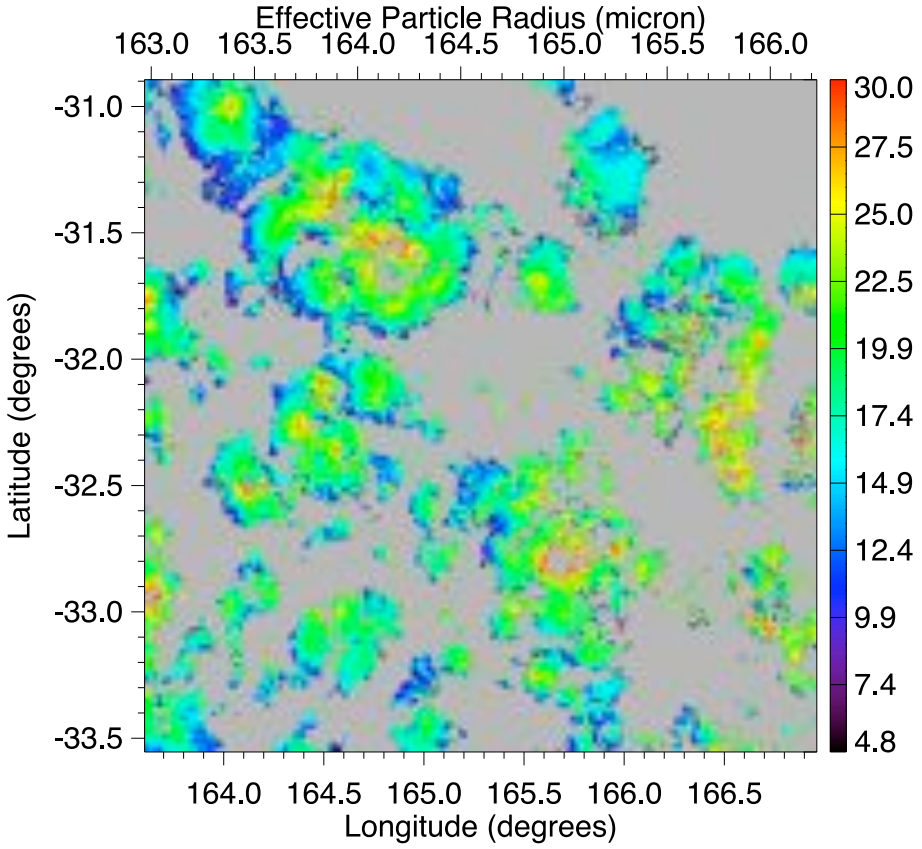


Test scene near New Zealand



MODIS cloud products





← 300 km →

Average(τ)=9

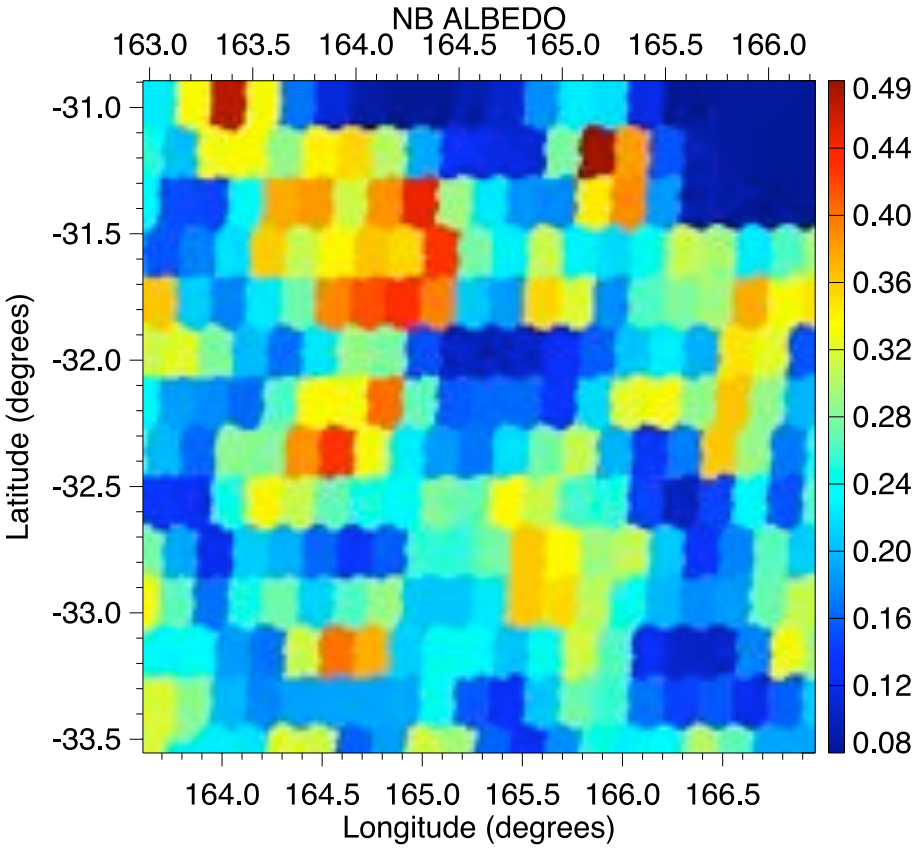
Stddev(τ)=9

← 300 km →

Average(R_e)=18 μm

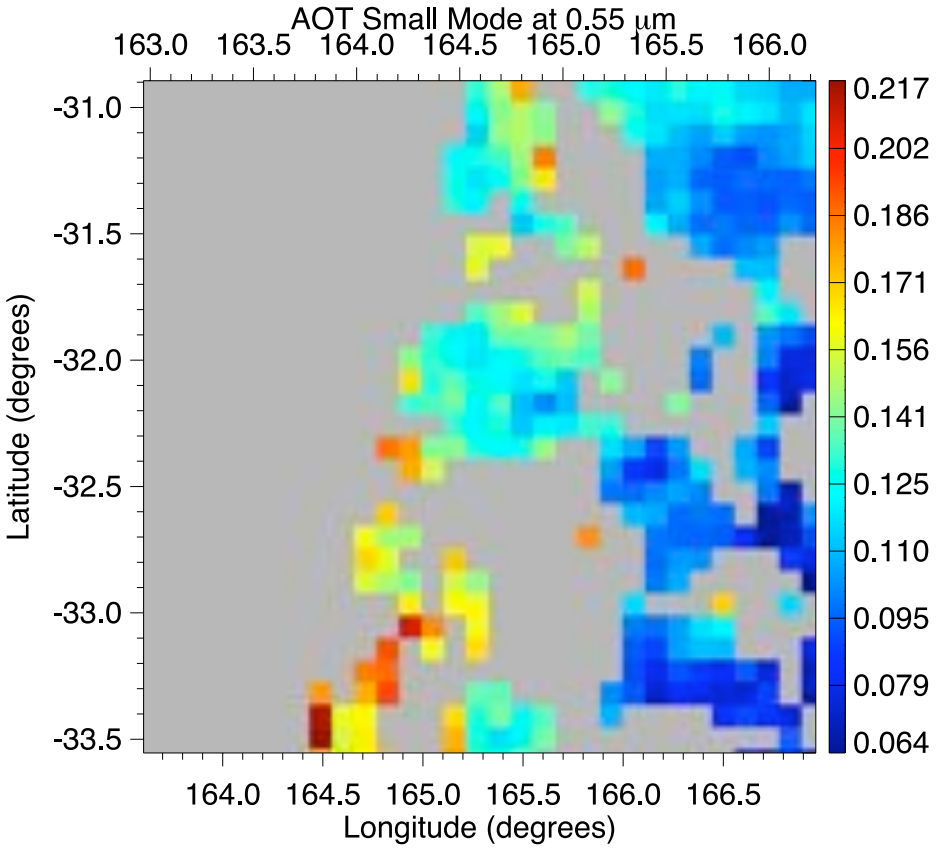
Stddev(R_e) =5 μm

Albedo and AOT



300 km

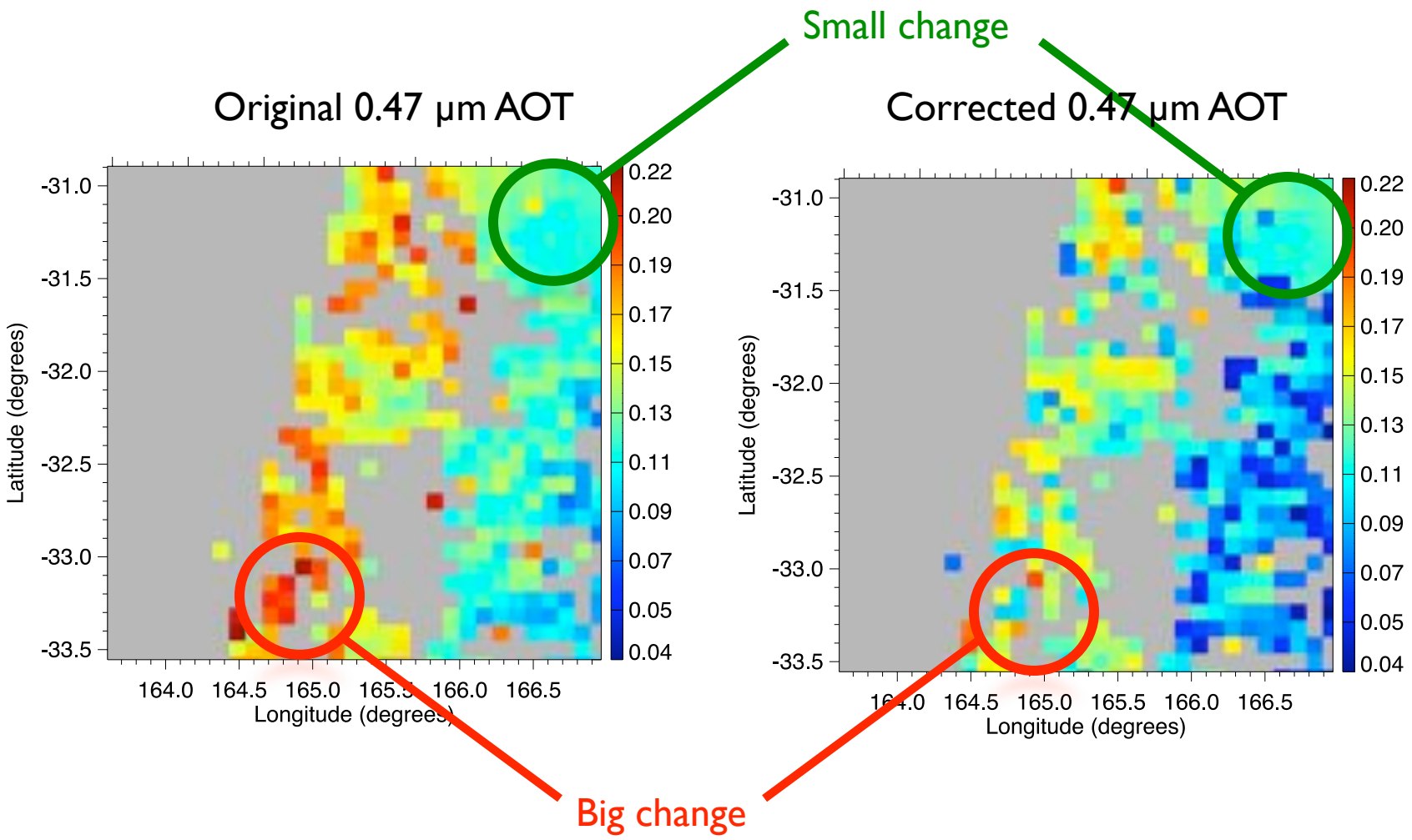
Low level water clouds



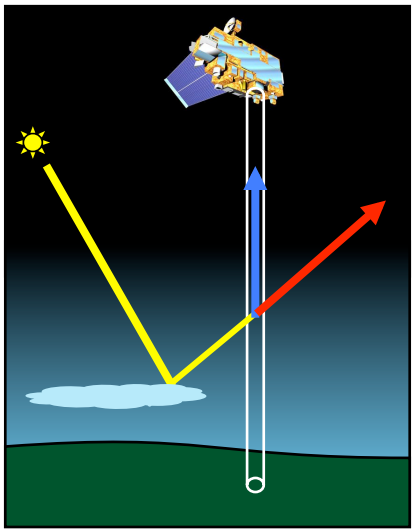
300 km

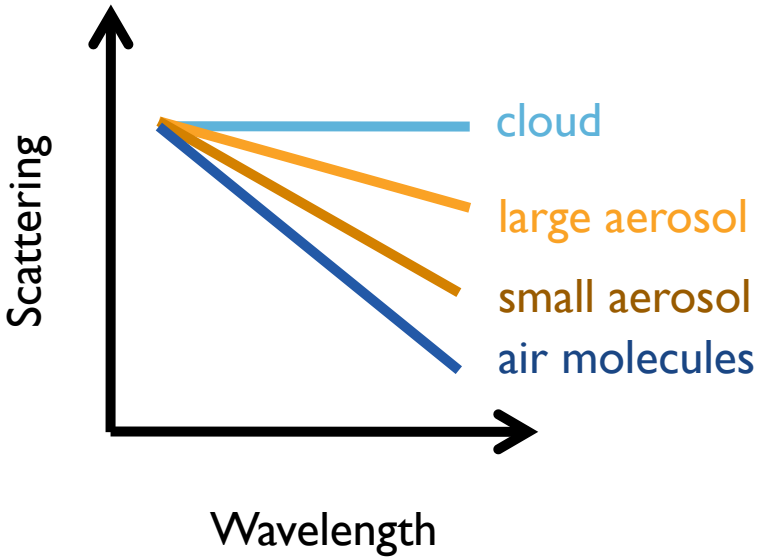
Average AOT ~0.13

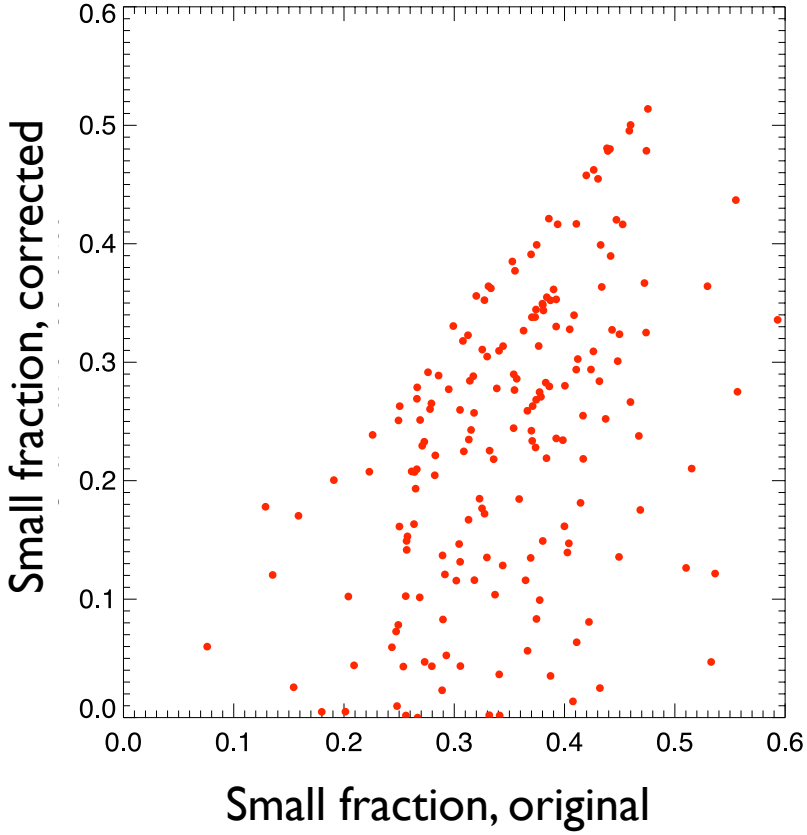
Correction reduces some AOT values



Correction reduces fraction of small aerosols







Summary

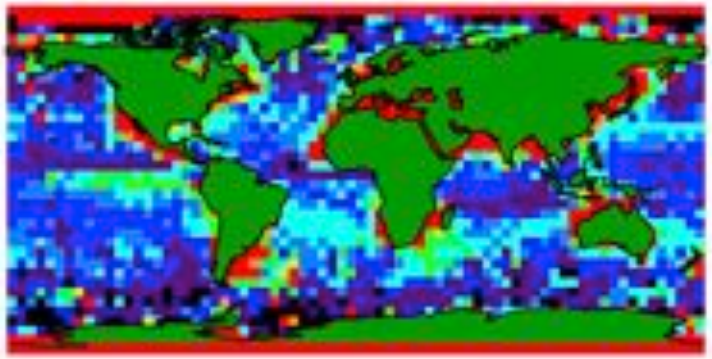
- Clouds are surrounded by a wide (>10 km) transition zone of enhanced particle size and light scattering. This transition zone needs to be considered in studies of aerosol radiative effects and aerosol-cloud interactions.

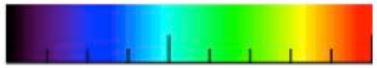
- 3D radiative processes play an important role in enhancing clear sky solar reflectance near clouds. A simple two-layer model shows promise for considering these processes in passive satellite remote sensing.

- A synergy of passive (MODIS, CERES and WFC) and active remote sensing (CALIOP) can help better understand and measure aerosol properties near clouds.

Cloud fraction affects typical distance to clouds

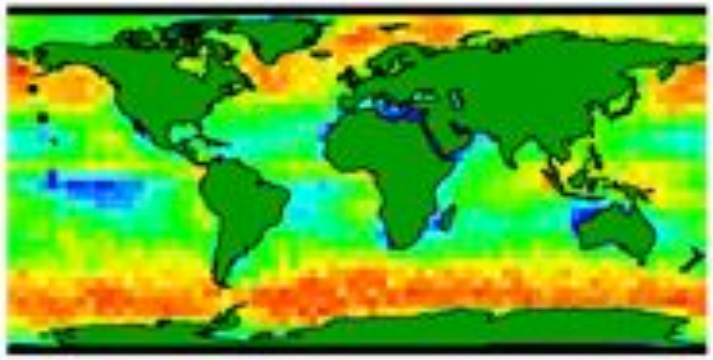
Annual median distance to clouds below 3 km

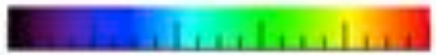




Median distance to clouds (km)

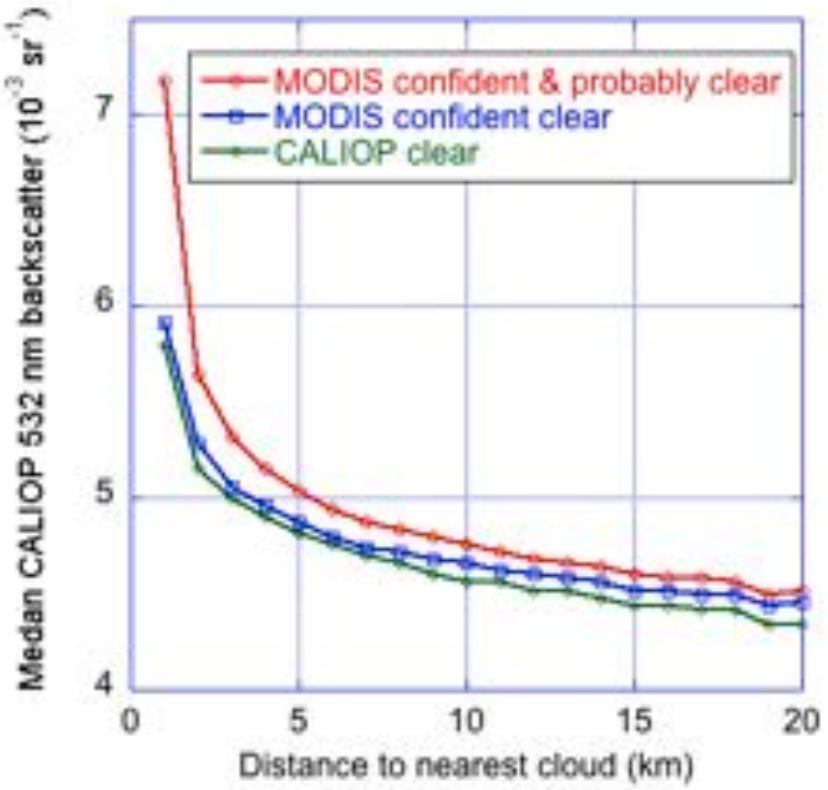
Annual mean cloud fraction





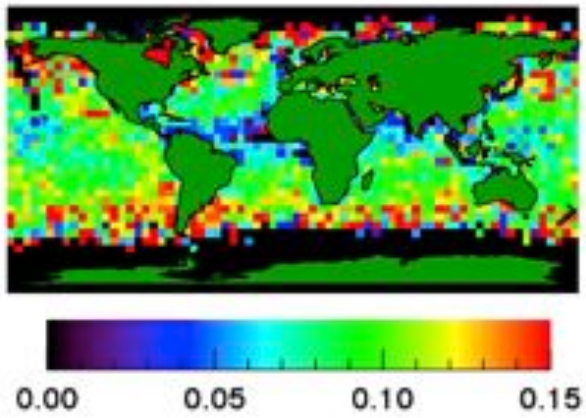
Mean cloud fraction

Cloud mask affects increase mainly near clouds

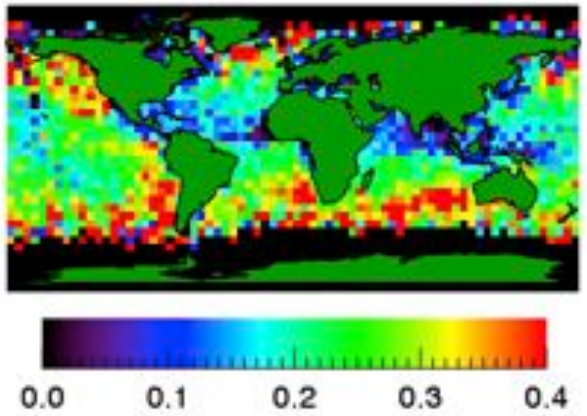


Median relative near-cloud enhancements

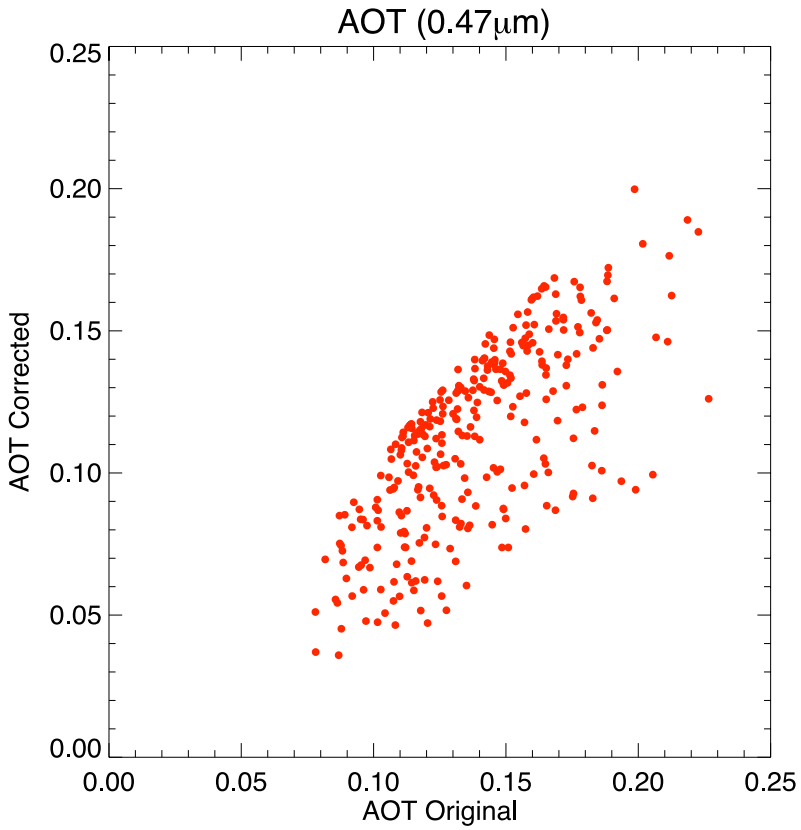
MODIS

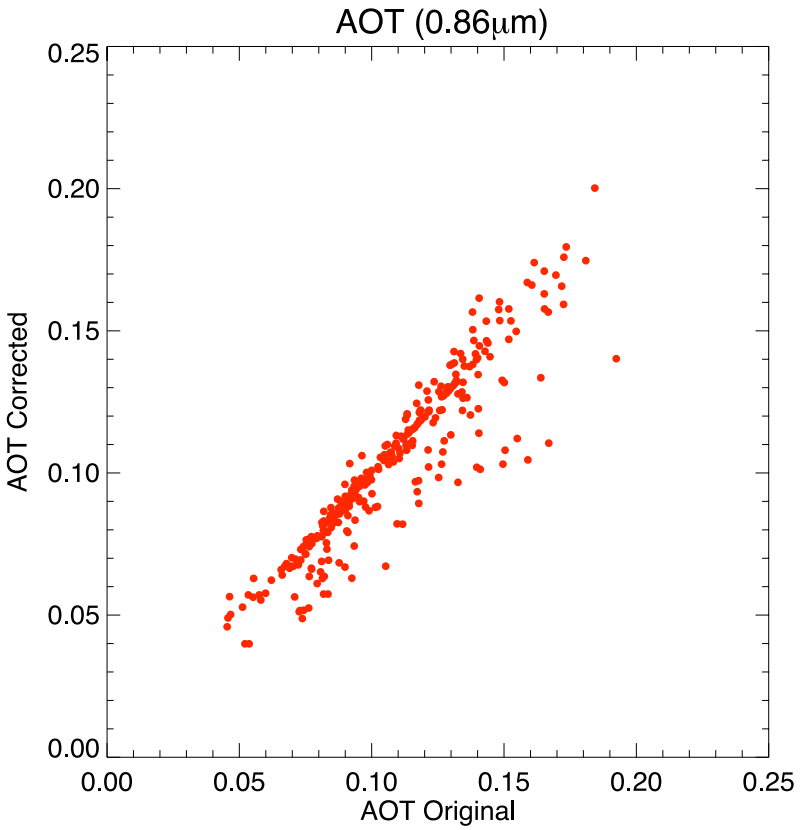


CALIOP

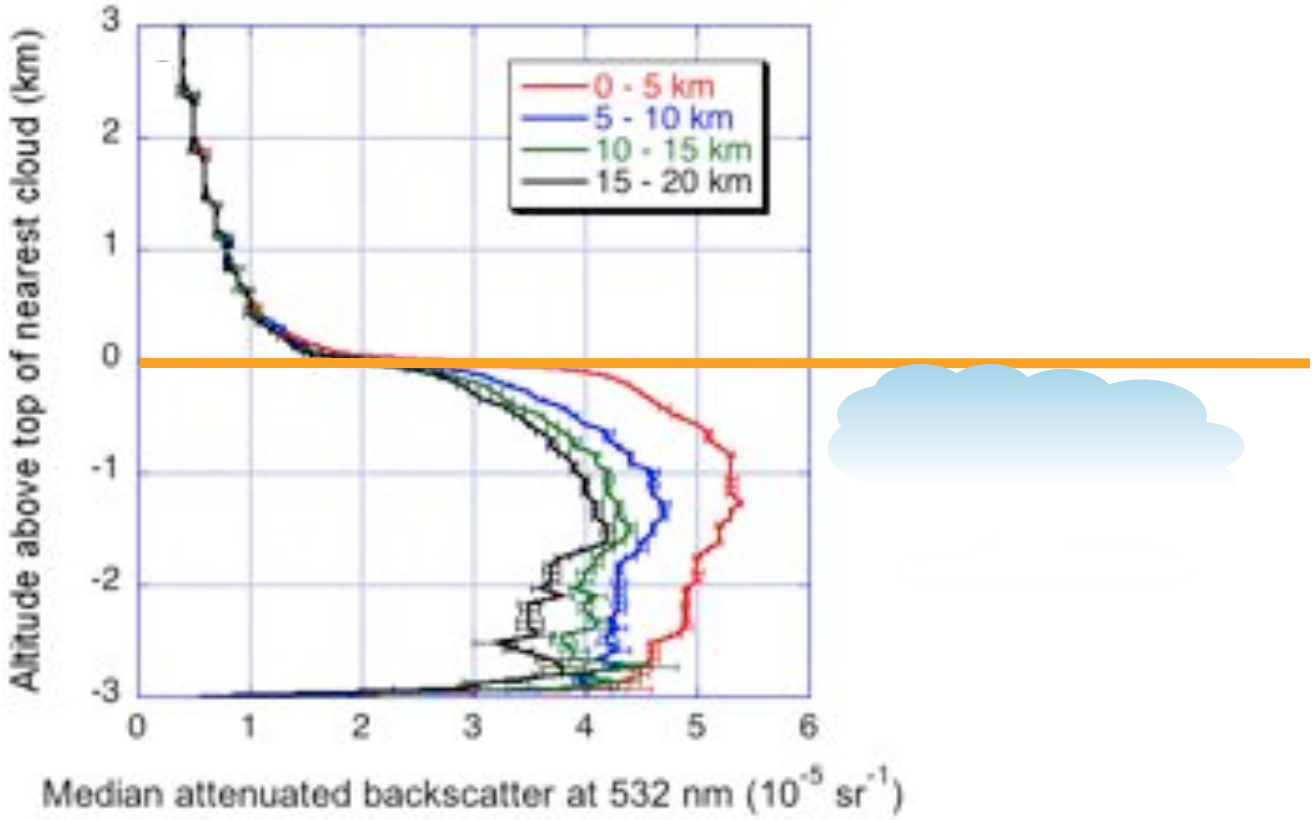


CALIOP: increases occur below cloud top





CALIOP: increases occur below cloud top



Várnai and Marshak (2010)

Increases suggest large changes in AOT

$$R_a(d) = \frac{\bar{\beta}(d) - \bar{\beta}_{Rayleigh}}{\bar{\beta}(20\ \mathrm{km}) - \bar{\beta}_{Rayleigh}}$$