Advances in understanding 3D interactions between sunlight and the atmosphere during the SORCE mission

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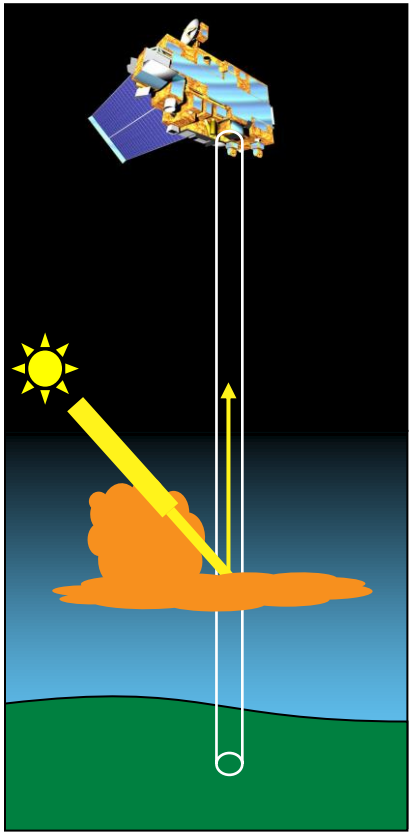
3D radiative effects in the atmosphere

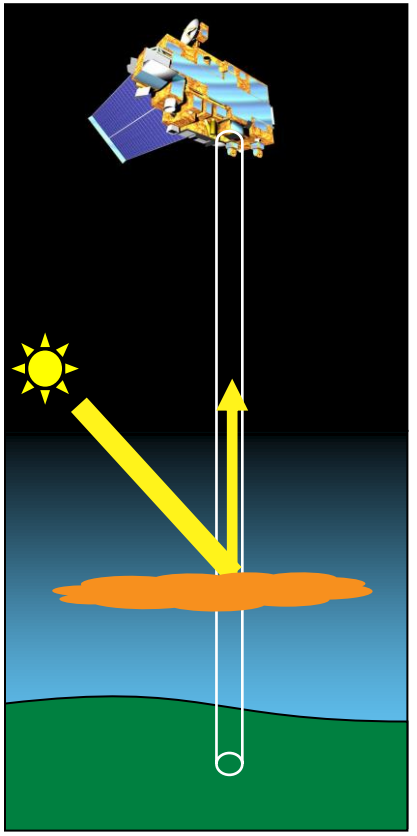
1D approximation:

$$\nabla = \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \frac{\partial}{\partial z} \approx \frac{\partial}{\partial x}$$

3D world



1D approximation



Steps toward 3D radiation in applications

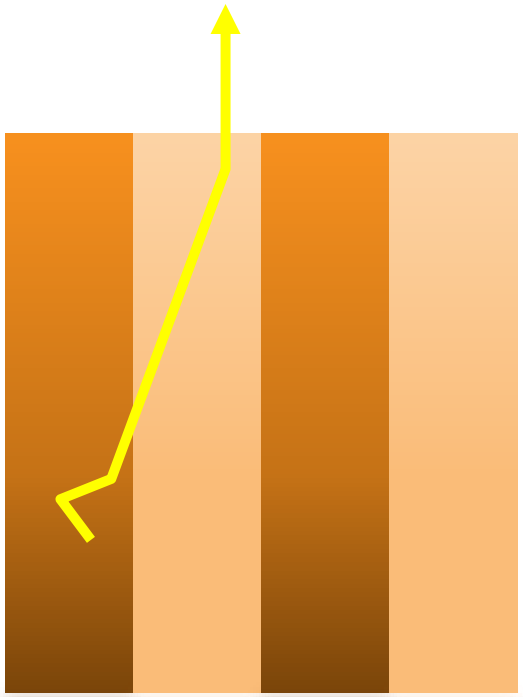
Estimate the impacts of 1D approximation

Mitigate the impacts
(3D corrections or fully 3D calculations)

Develop remote sensing methods that gain new information from 3D radiative processes

Understanding impacts of 1D approx. in 3D world

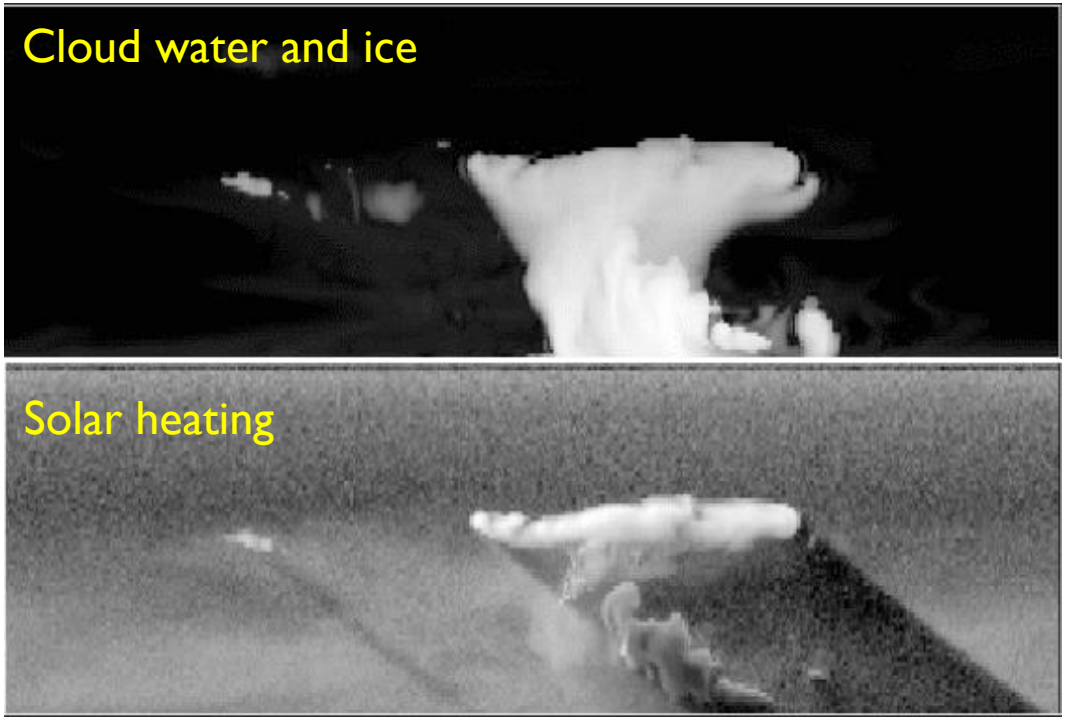
Channeling (Cannon 1970)



Improvements in 3D simulations:
Speed, polarization
Intercomparison of 3D Radiation Codes
(Online 3D calculator, public code, reference results, book)

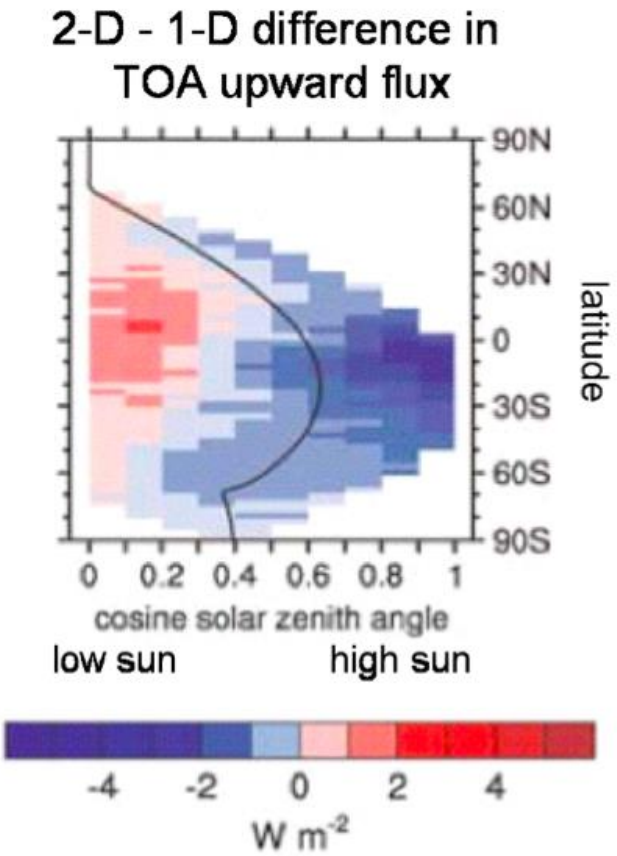
Impacts on deep convective clouds

Modest immediate impact on development of deep convective clouds
(O'Hirok, Frame, Cole)



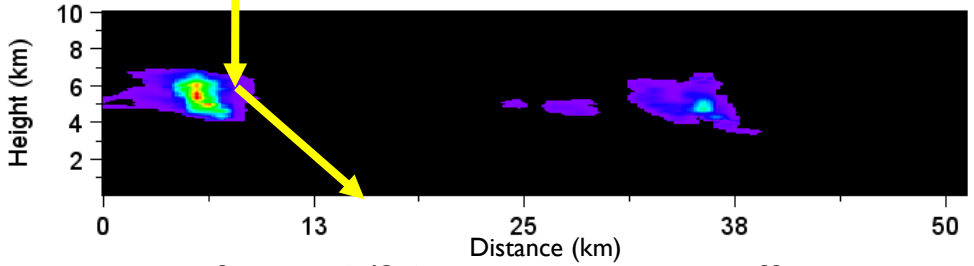
Impacts on large-scale solar heating

All clouds in a monthlong global 4 km-resolution simulation

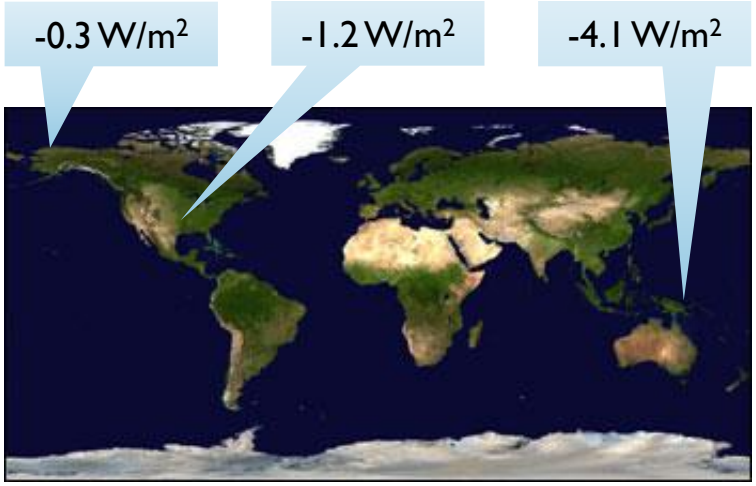


Cole and Barker (2005)

Radar measurements of cloud water content at DOE sites

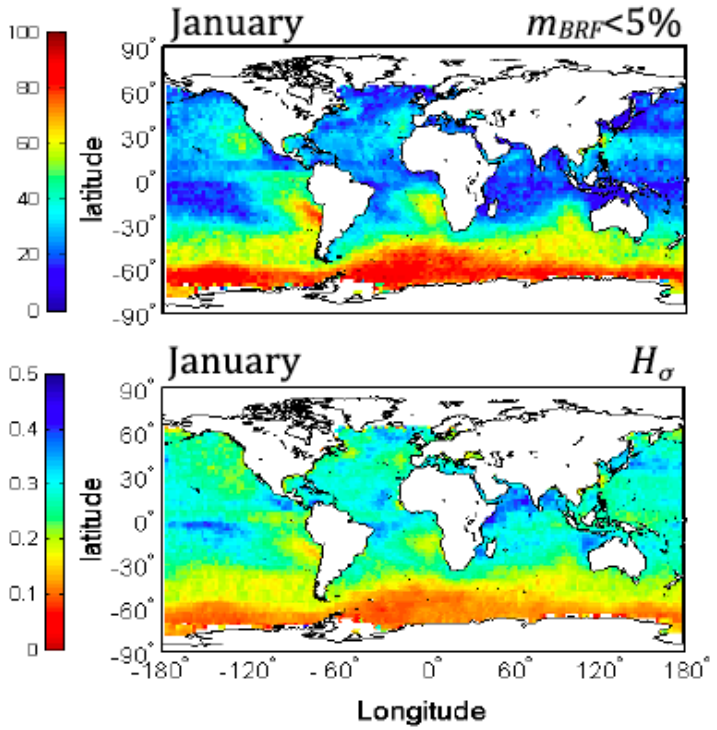


Multiyear full-day (24 hour) average difference between 2D and 1D calculations of reflected sunlight



Várnai (2010)

Impacts in cloud remote sensing

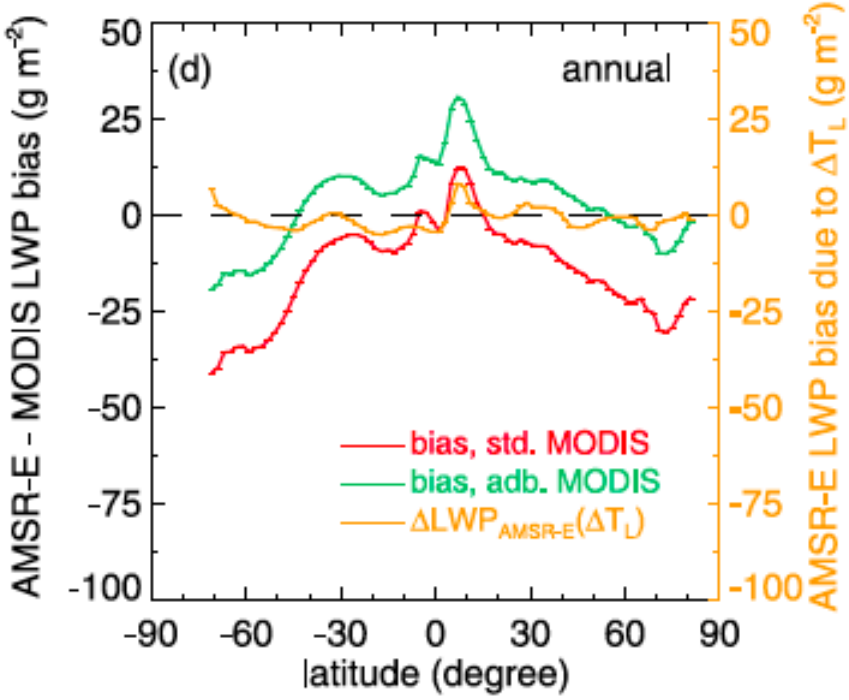


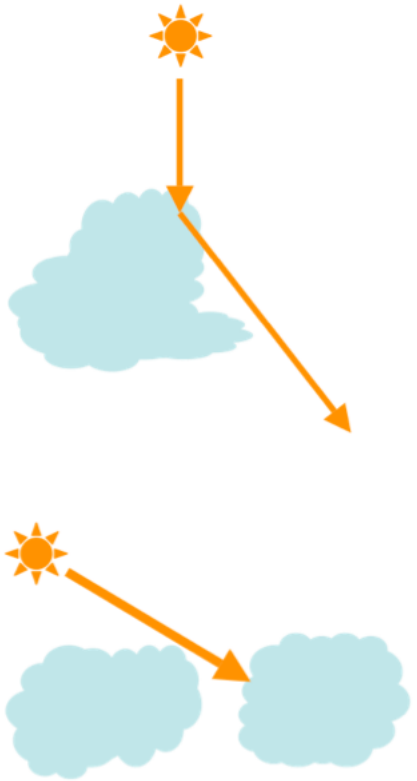
How frequently the observed view-angle dependence of reflected sunlight matches 1D calculations?

How big are the brightness-differences between neighboring pixels?

Di Girolamo, Liang, Platnick (2010)

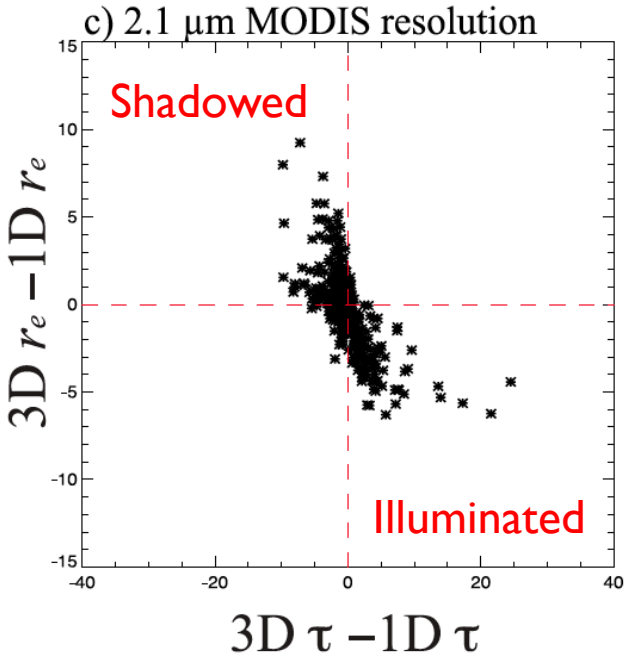
Impacts in cloud remote sensing: water content





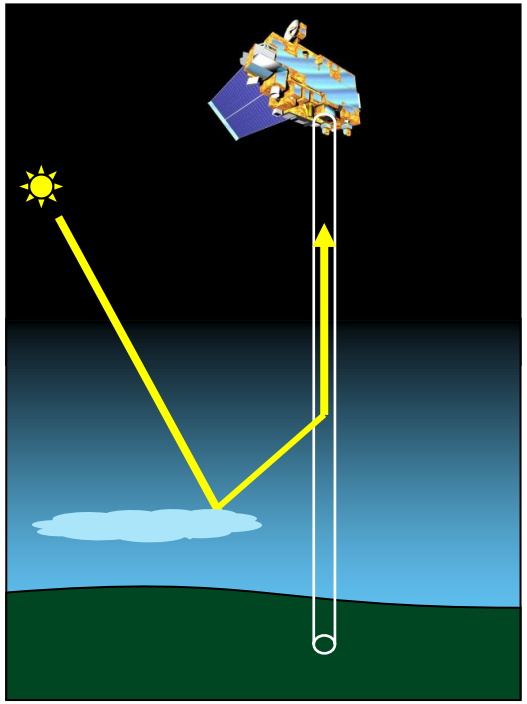
Seethala and Horváth (2010)

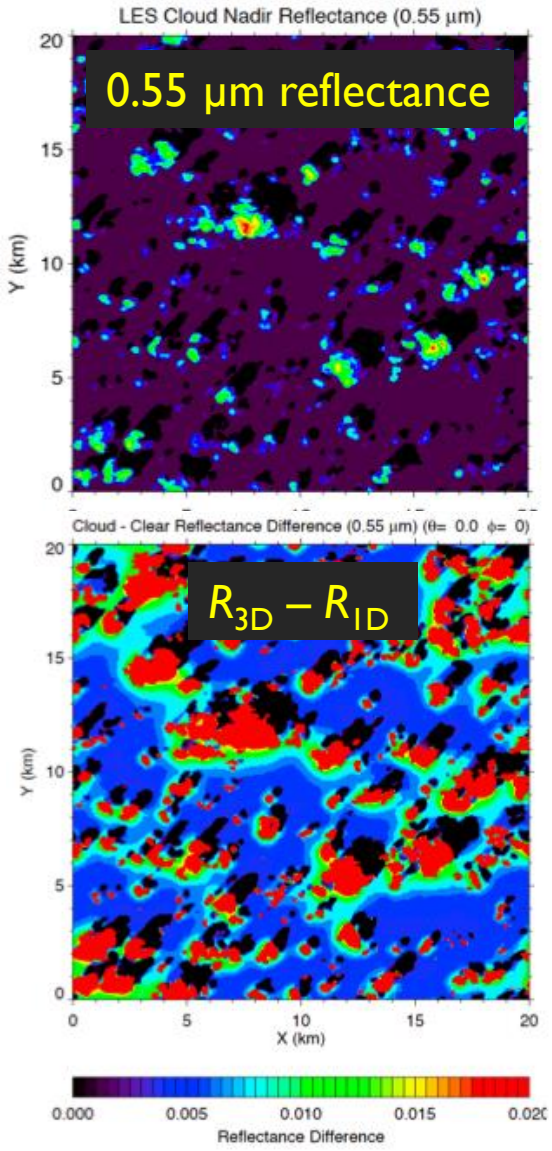
Impacts in cloud remote sensing: droplet size



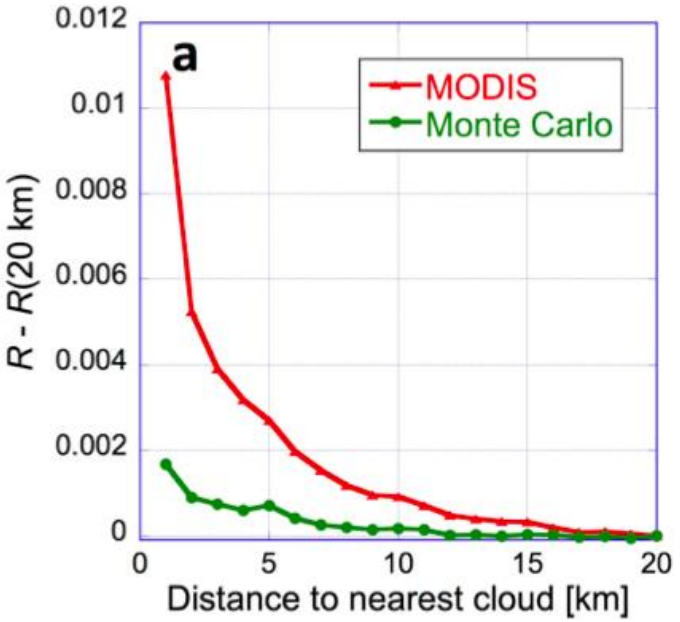
Zhang et al. (2012)

Impacts in aerosol remote sensing





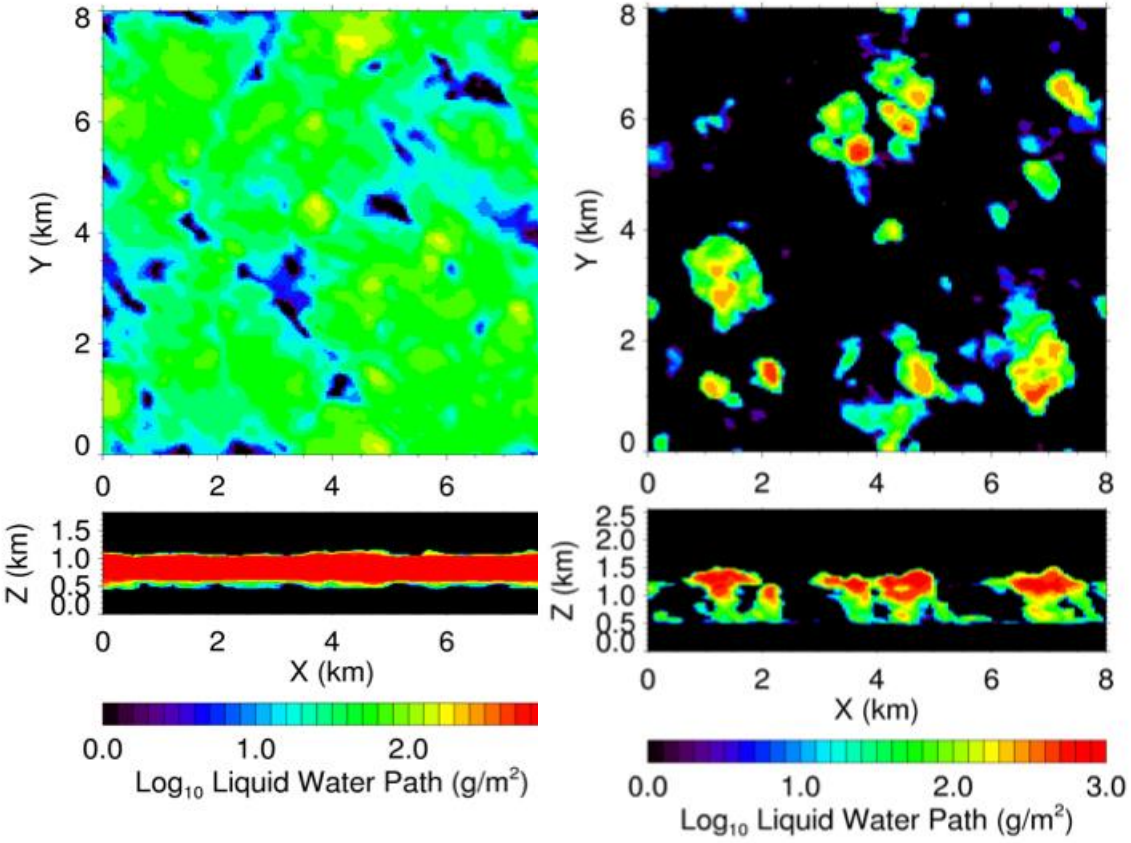
Global yearlong dataset



Várnai et al. (2013)

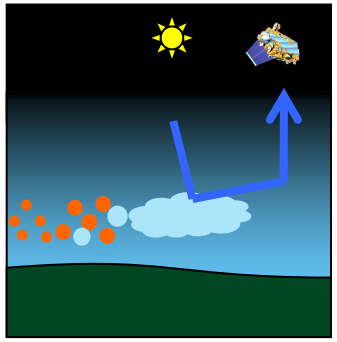
Mitigating 3D impacts: cloud remote sensing

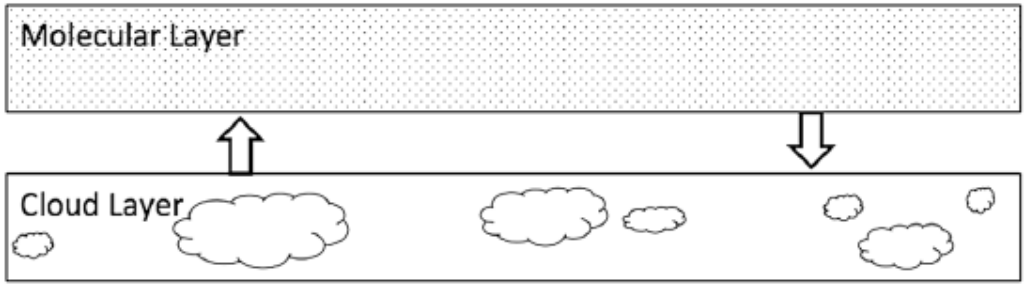
Two sample scenes out of 1000
from dynamical simulations

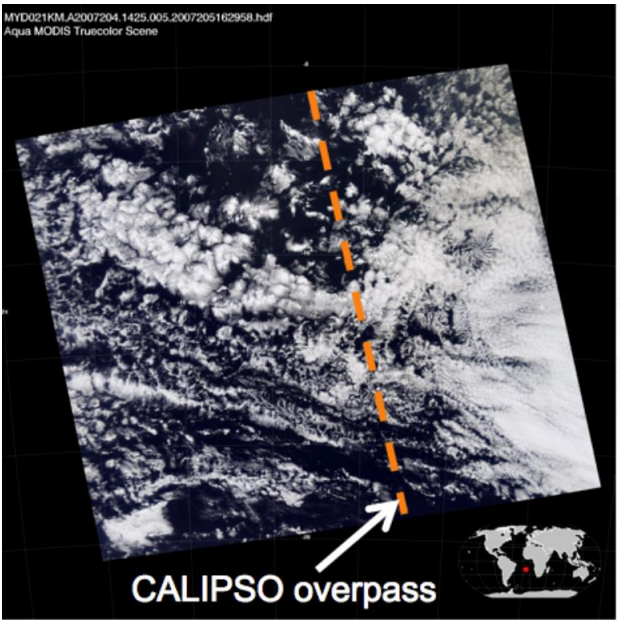


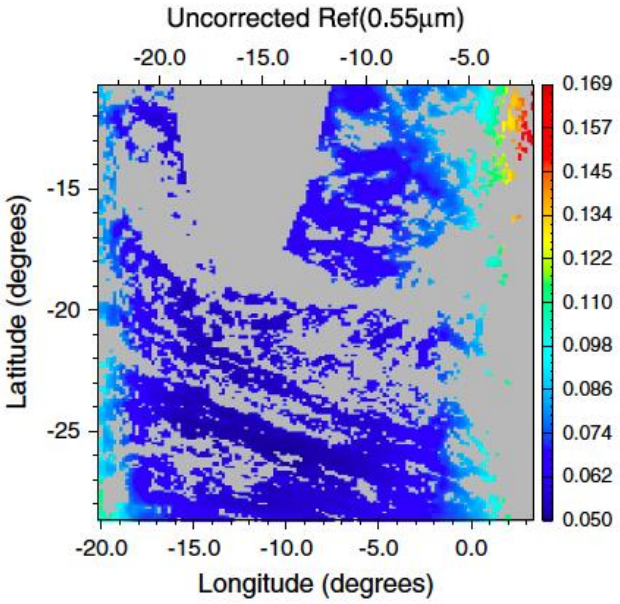
Neural net reduces errors of 1D retrievals by half or even two-thirds by using multiple views and texture

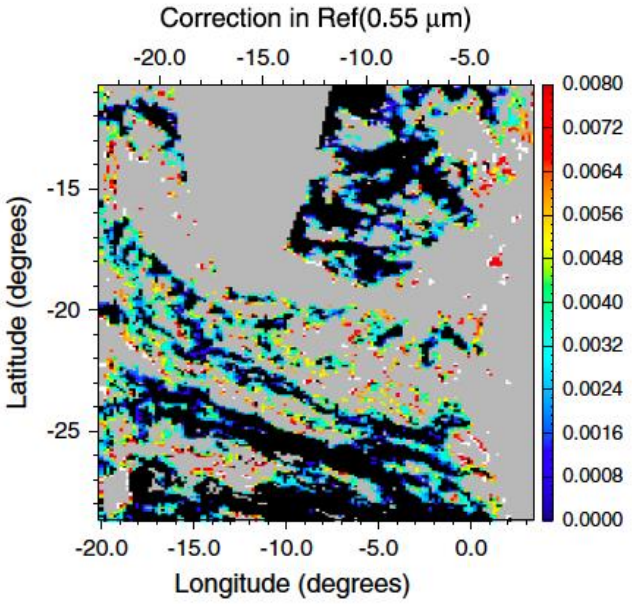
Mitigating 3D impacts: aerosol remote sensing





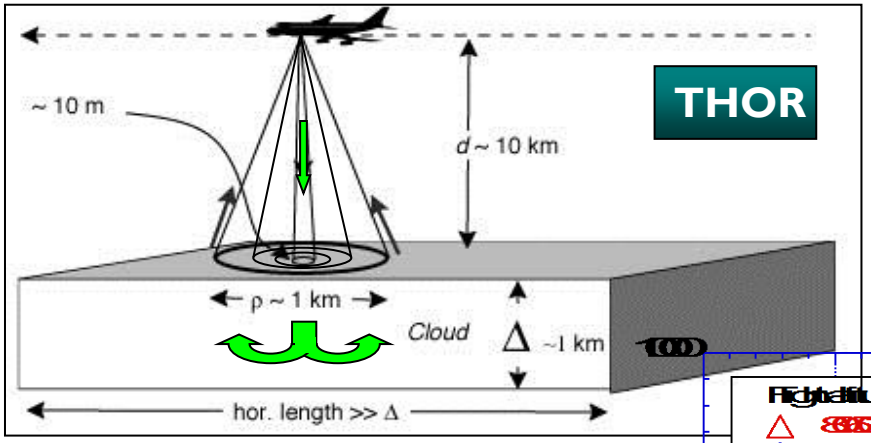


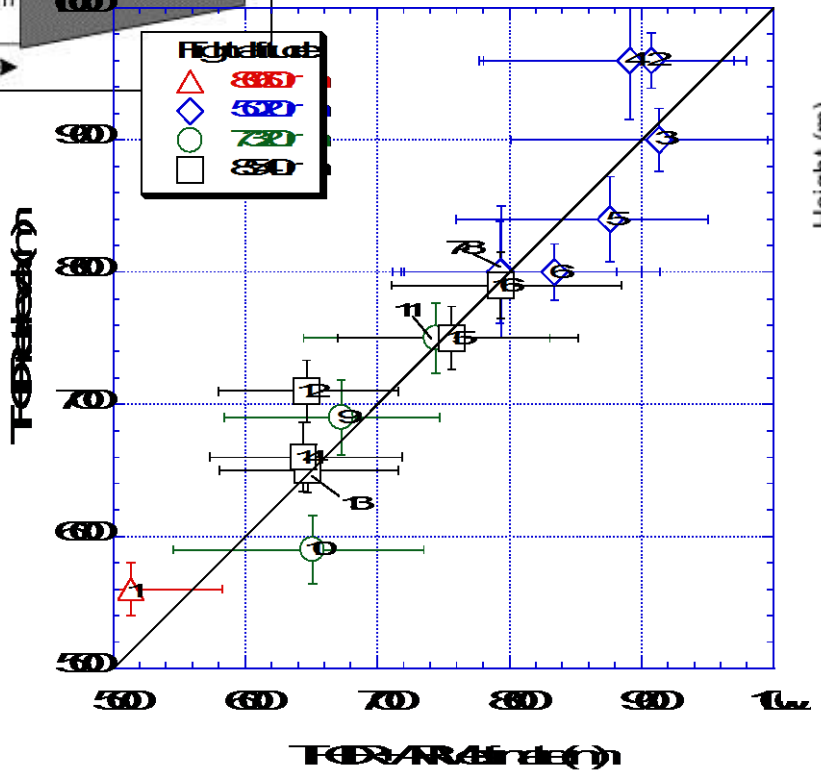


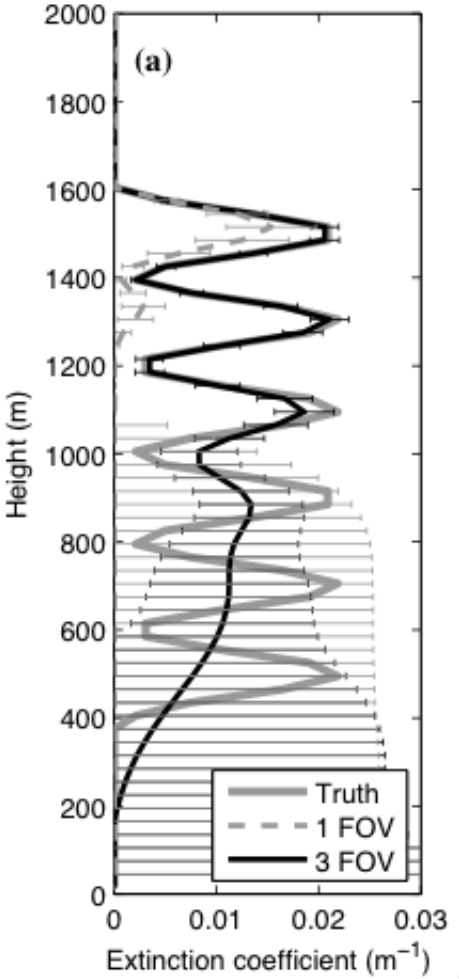


Wen et al. (2005)

Taking advantage of 3D radiative processes



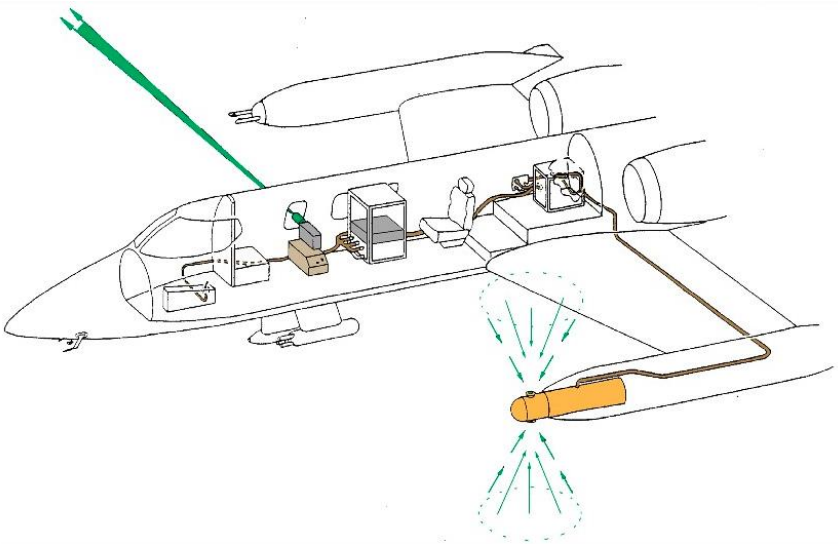


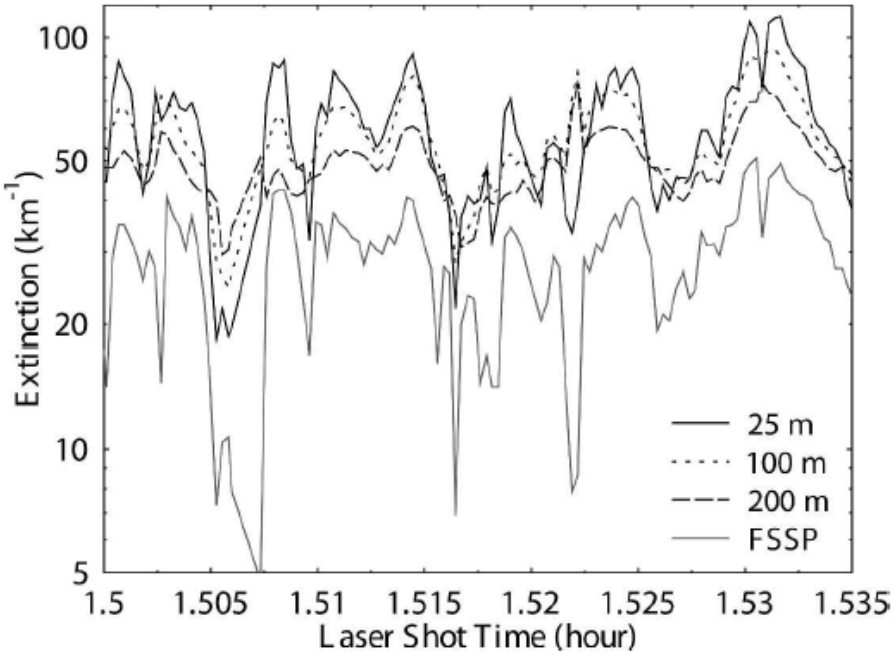


Cahalan et al. (2005)

Pounder et al. (2011)

Taking advantage of 3D processes



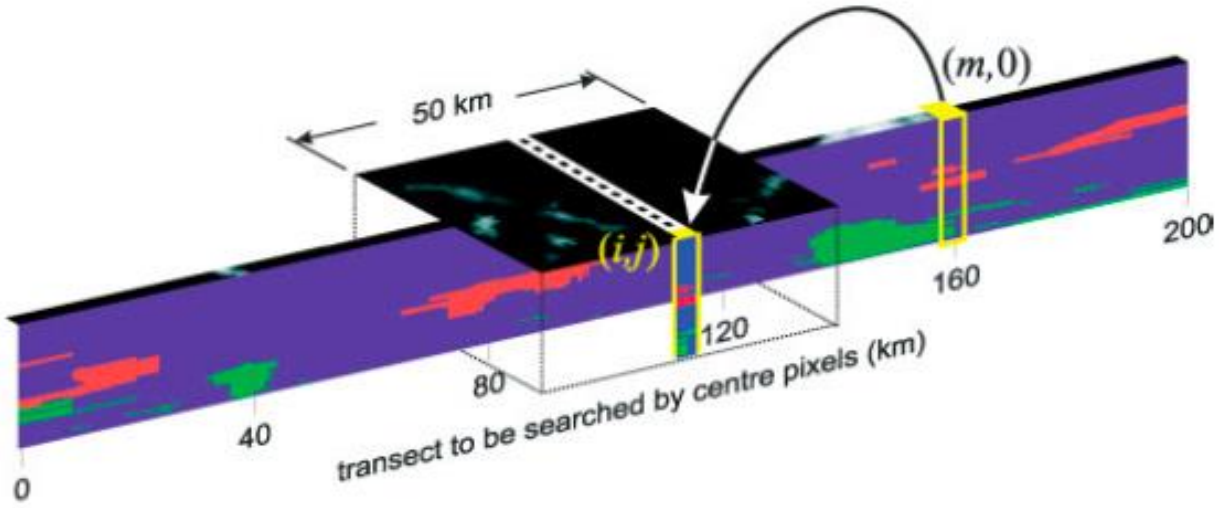


Evans et al. (2006)

Next step: 3D in operational data processing

EarthCARE (launch around 2016)

ATLID – 353 nm high spectral resolution lidar
CPR - W-band radar with Doppler capability
MSI – Multispectral imager
BBR – Solar and thermal broadband radiometer (3 views)

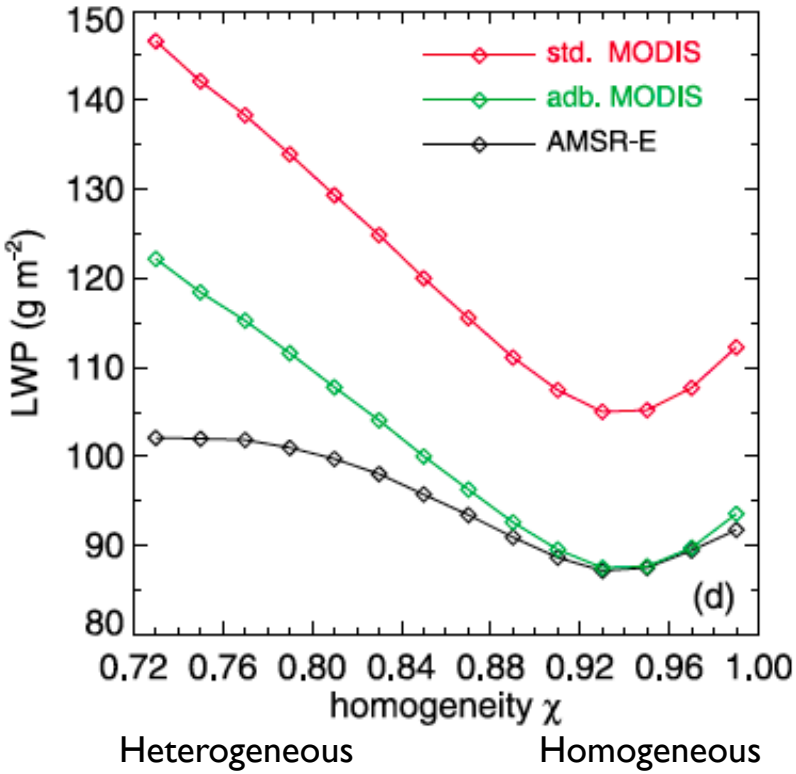


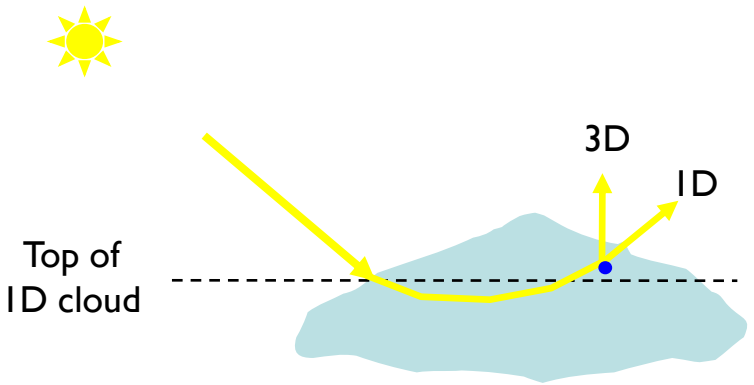
Summary

- Our understanding 3D interactions between sunlight and the atmosphere advanced on many fronts during the SORCE mission.
- Various approaches have been pursued to mitigate the impacts of 3D processes in remote sensing, and even to take advantage 3D radiative processes in lidar probing of thick clouds.
- The EarthCARE mission will be the first to use 3D radiation calculations operationally.

Impacts in cloud remote sensing: water content

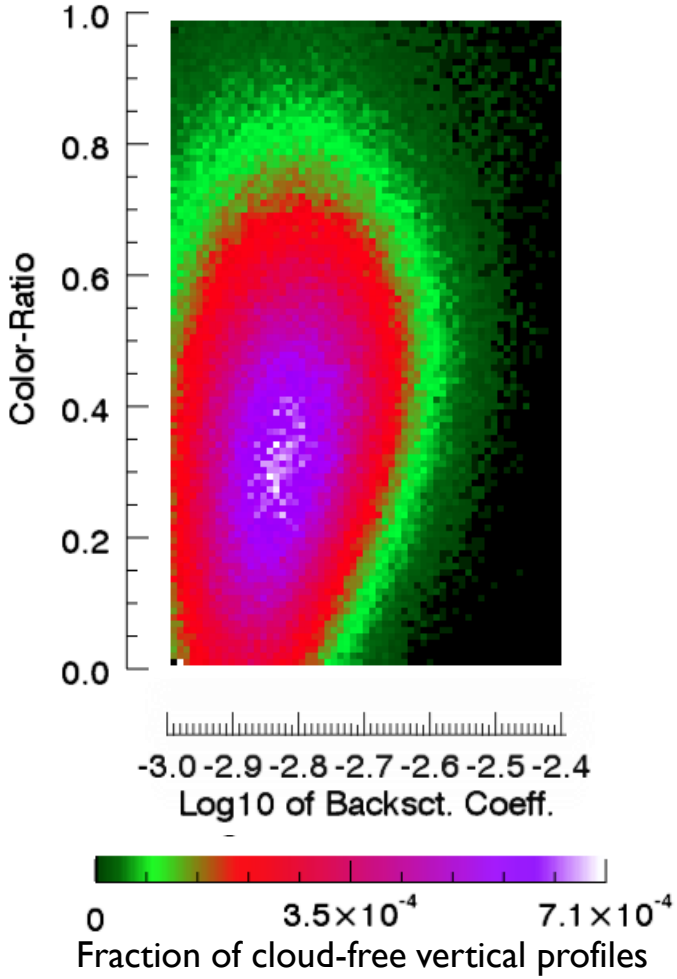
Global annual average for
warm non-precipitating overcast clouds



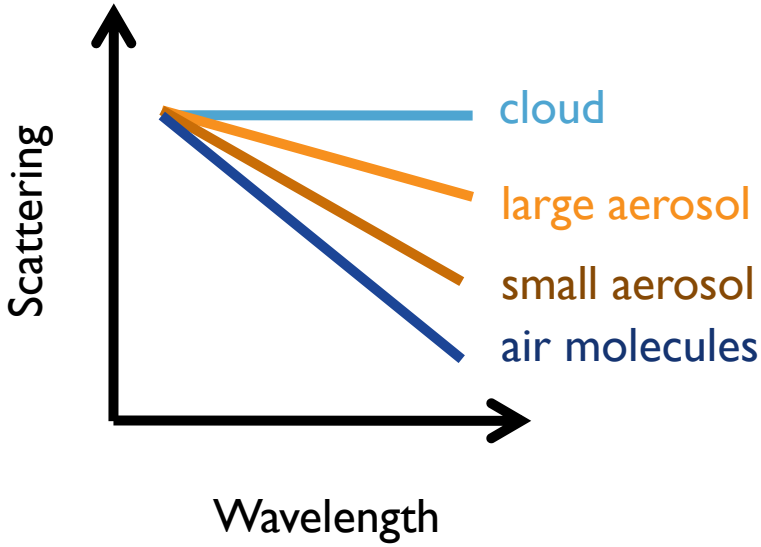


Seethala and Horváth (2010)

CALIOP gives information on aerosol OT, size



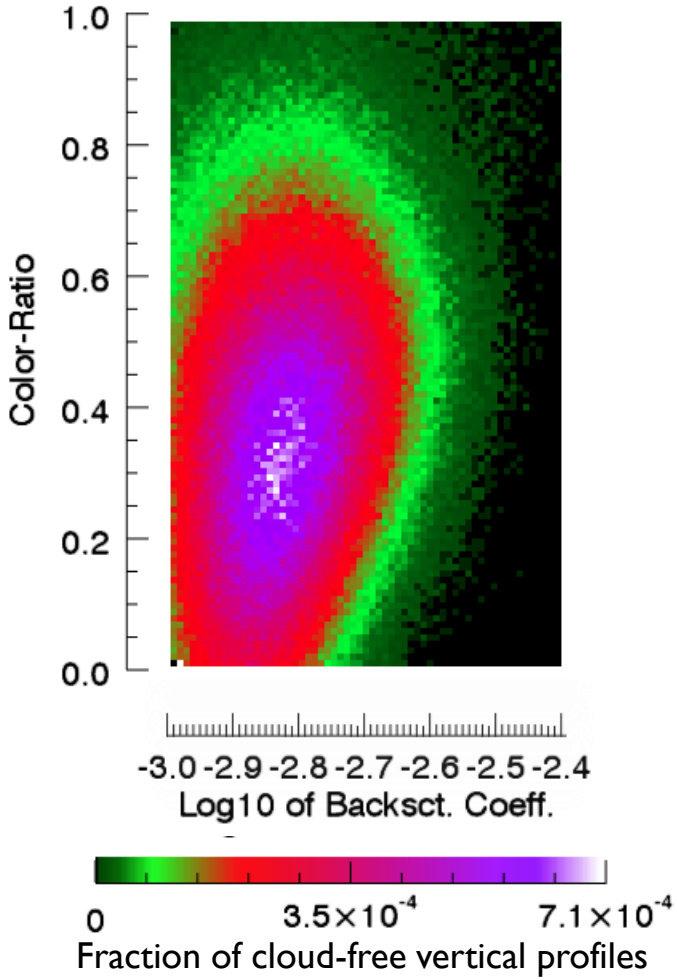
$$\text{Color ratio} = \frac{\text{Backscatter}_{1064\ \text{nm}}}{\text{Backscatter}_{532\ \text{nm}}}$$

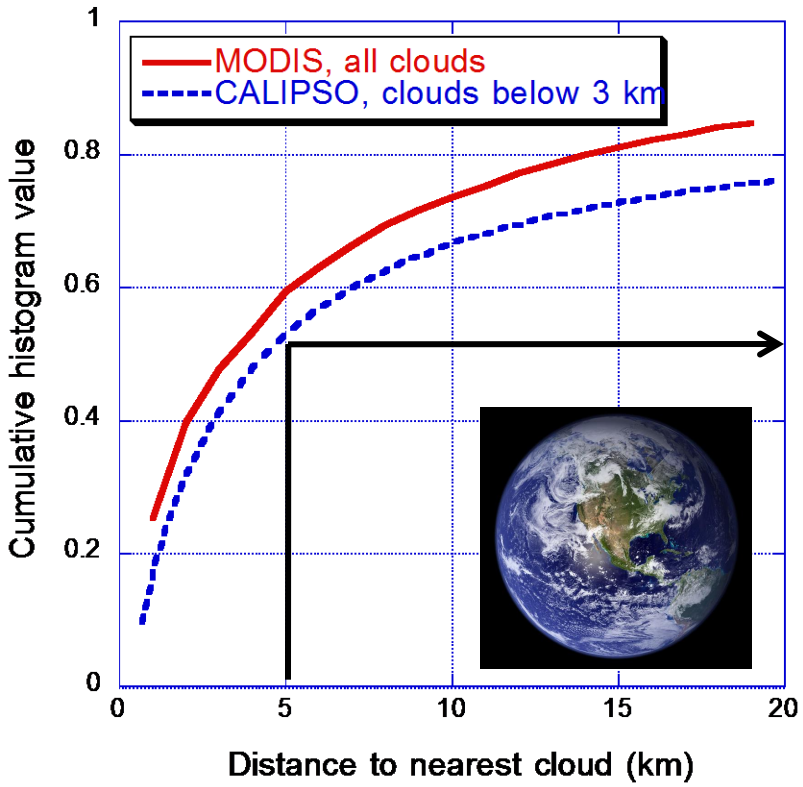


global night data over ocean
July 8 – Aug 7, 2007

CALIOP histogram far from clouds

Far from clouds (> 5km)

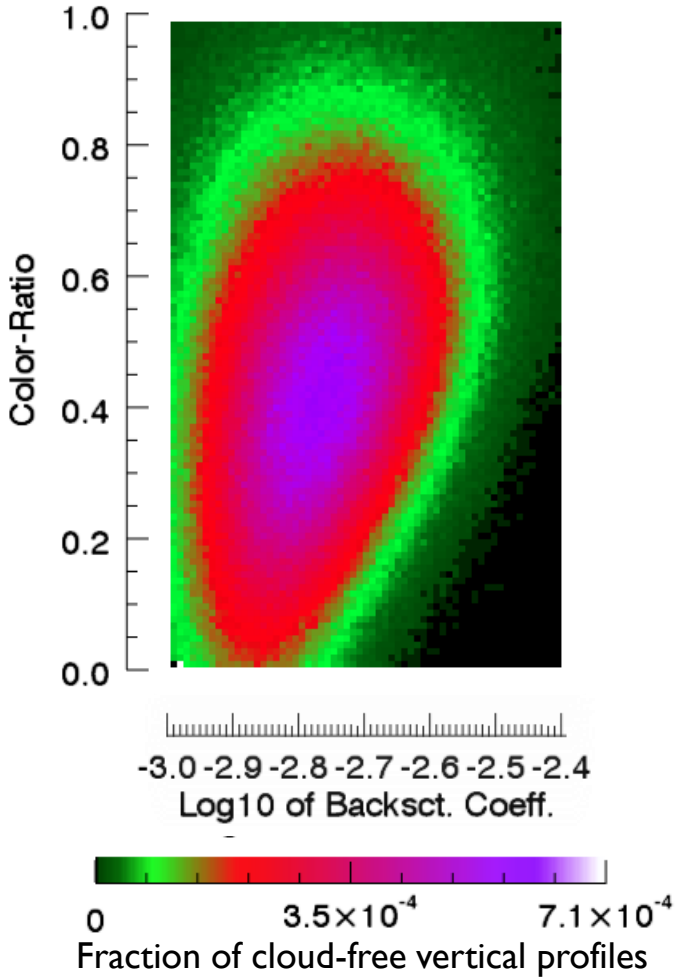


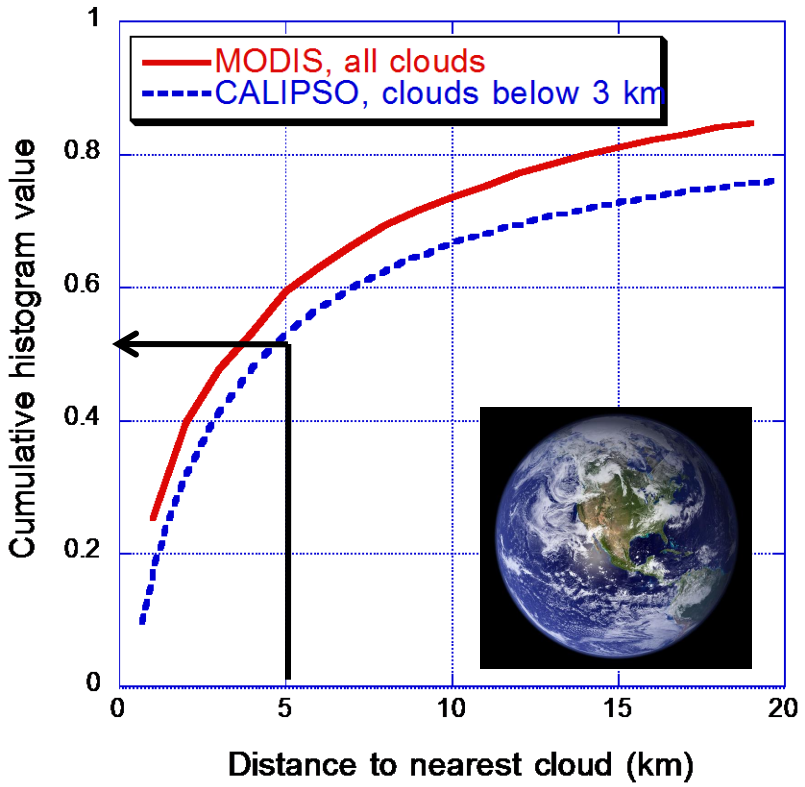


global night data over ocean
July 8 – Aug 7, 2007

CALIOP histogram near clouds

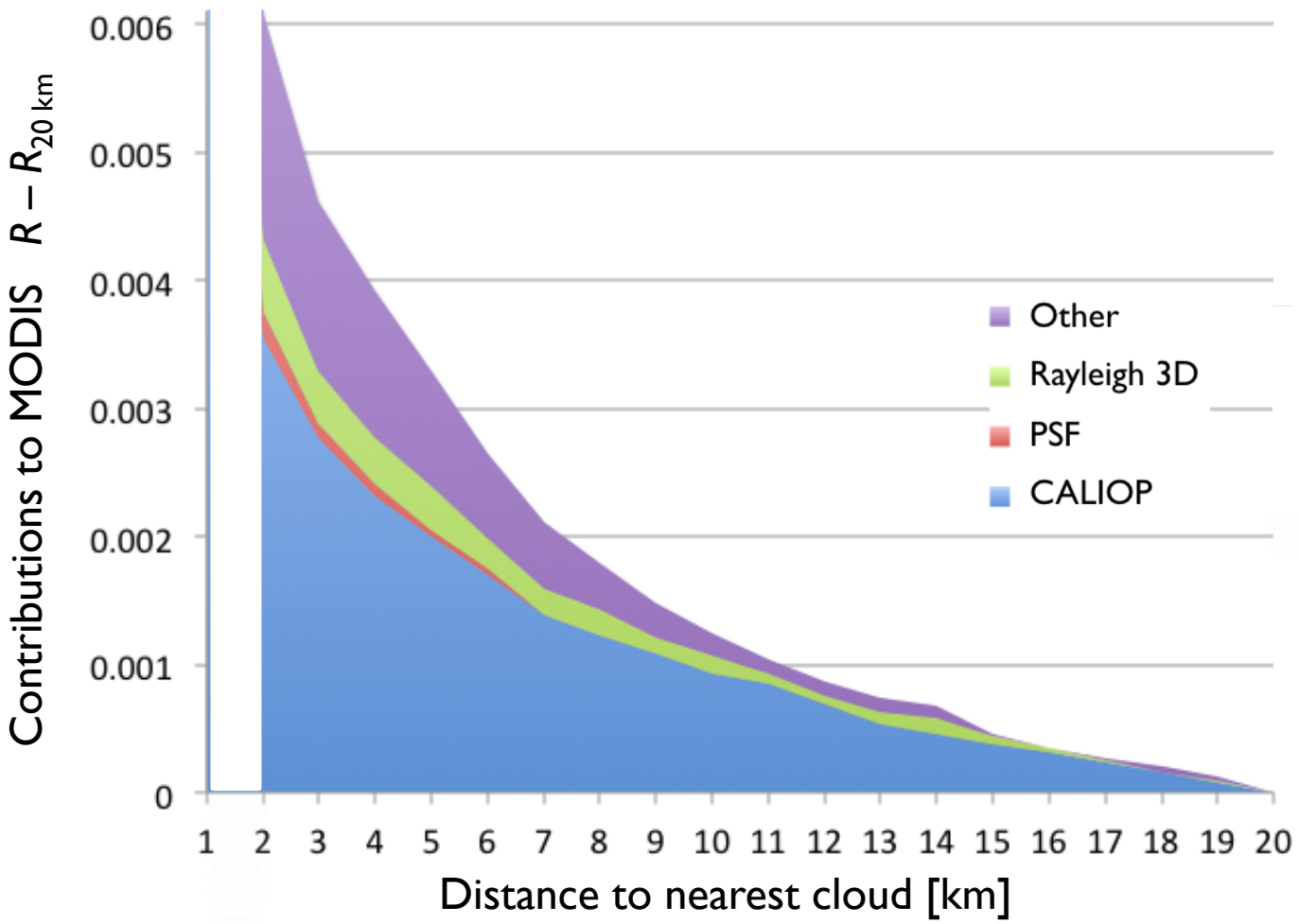
Close to clouds (< 5km)

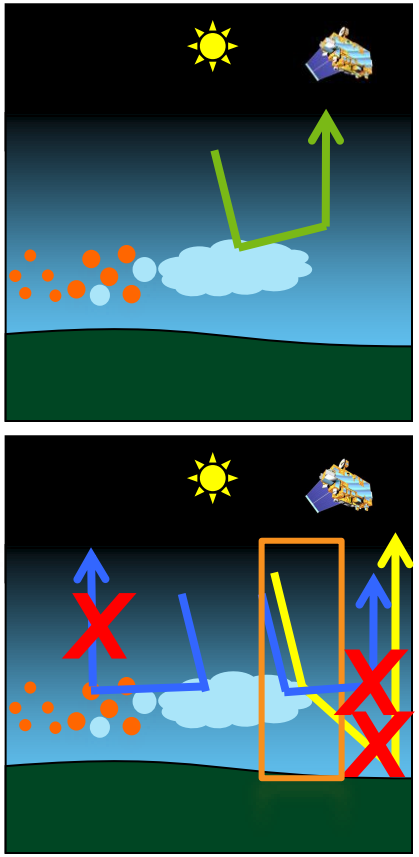




global night data over ocean
July 8 – Aug 7, 2007

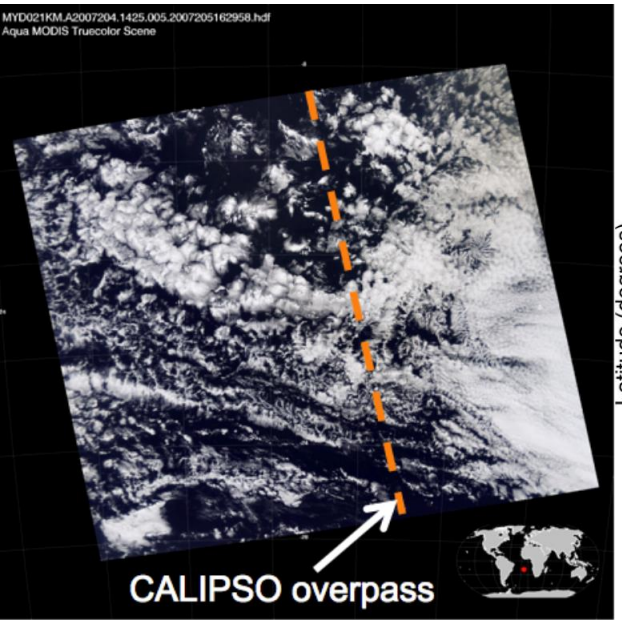
MODIS data vs. simulations of 3D enhancement

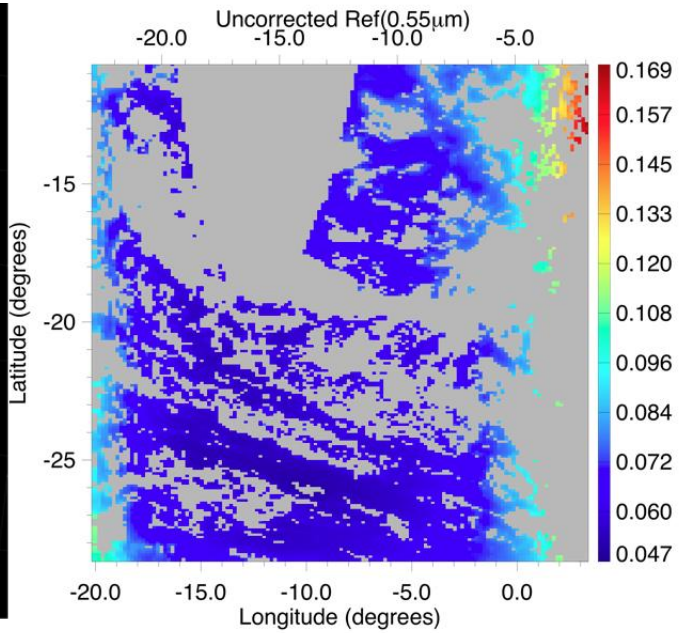


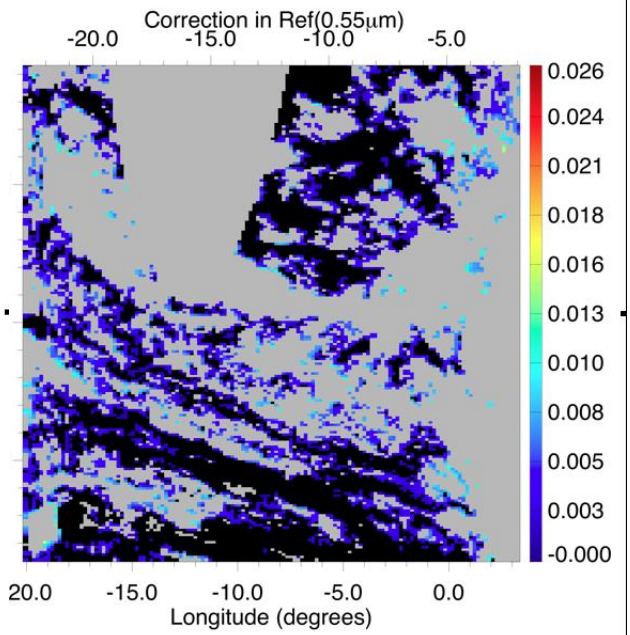


All oceans, Aqua along CALIOP track, 11/06-10/07

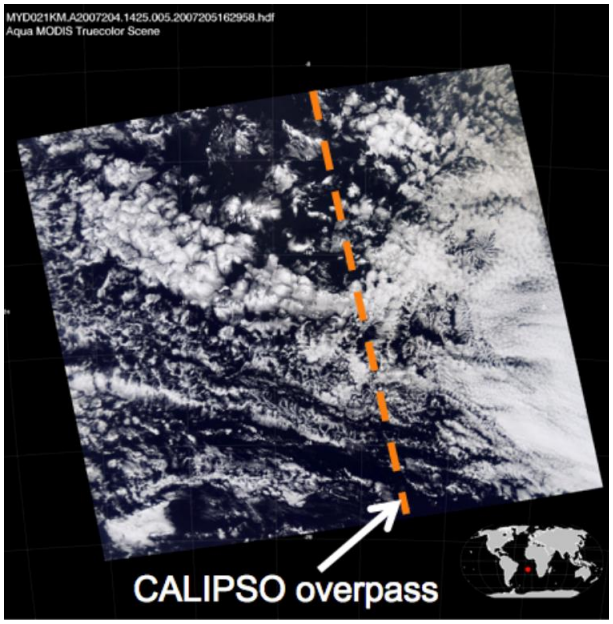
Reflectance corrections for a sample scene

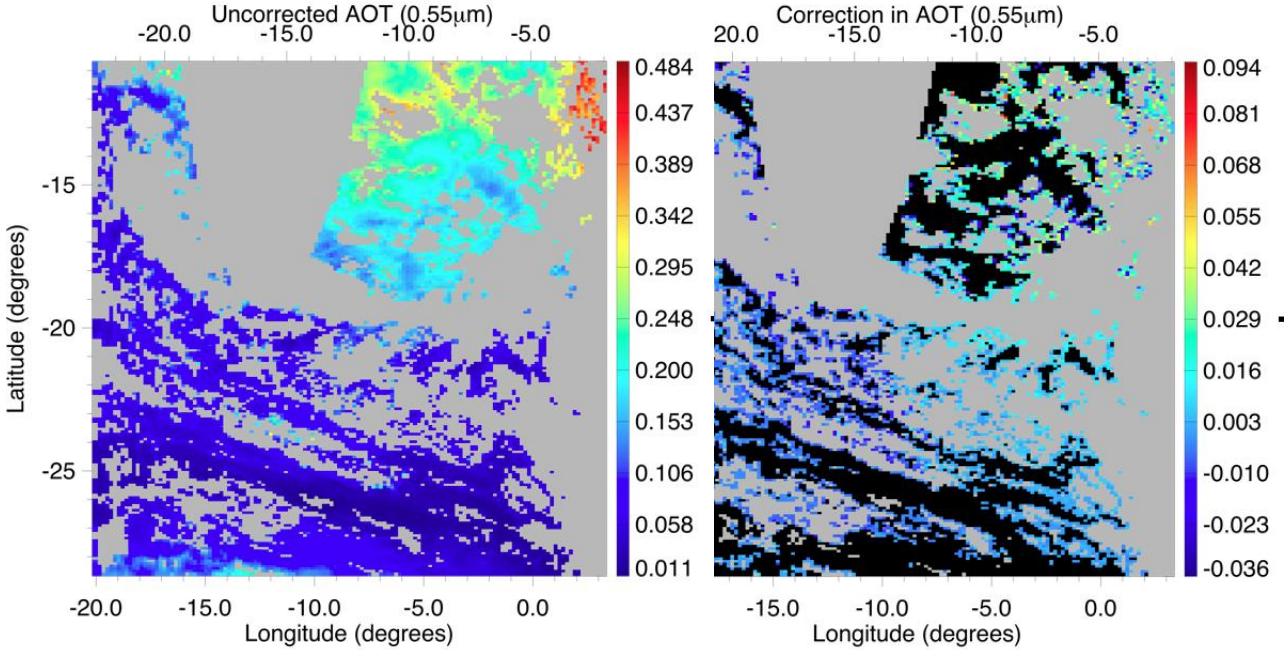




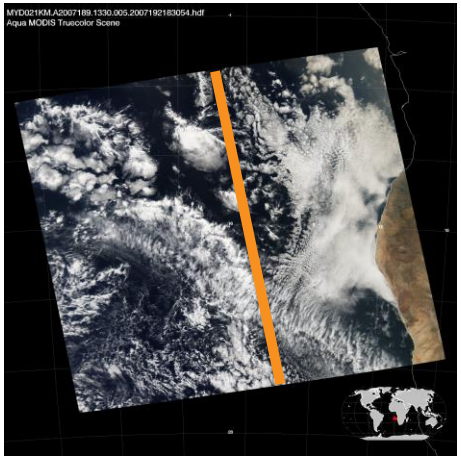


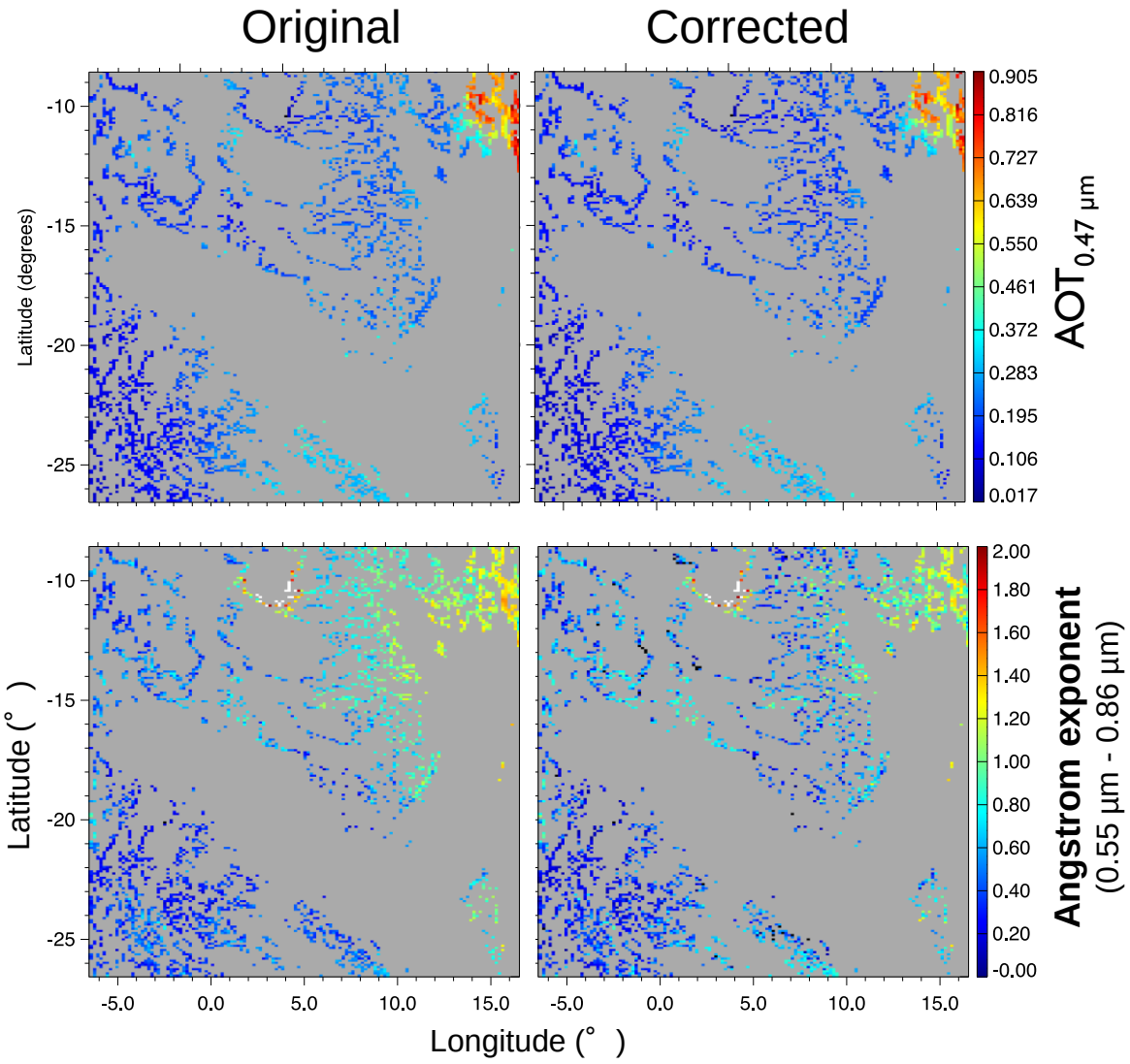
AOT corrections for sample scene





Aerosol retrievals using corrected radiances

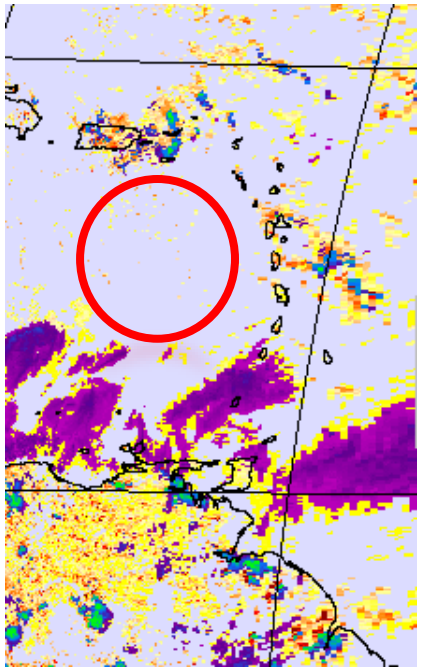


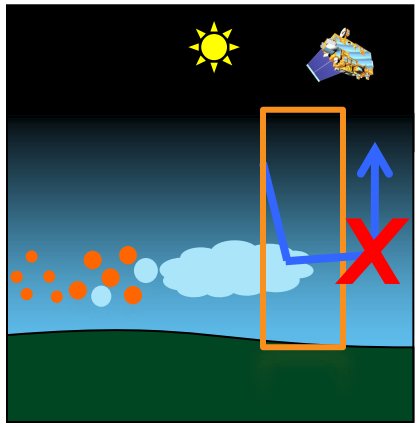


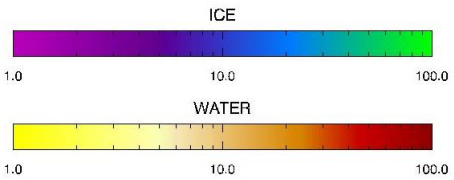
3D effects of Cu not fully present in simulations

RGB image

Cloud product

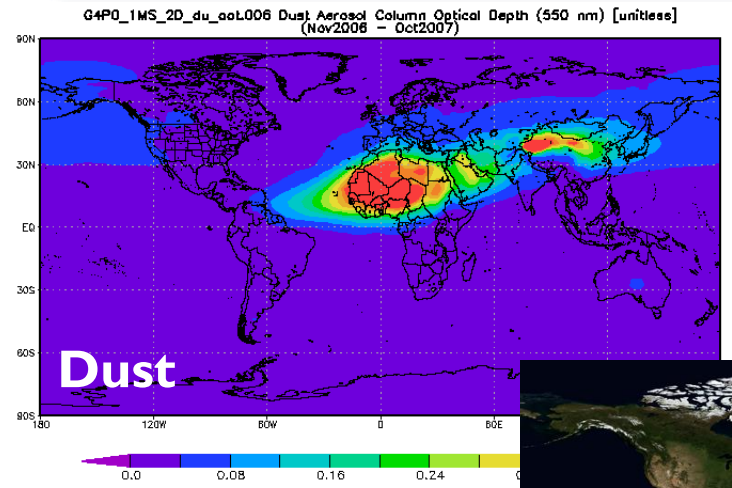




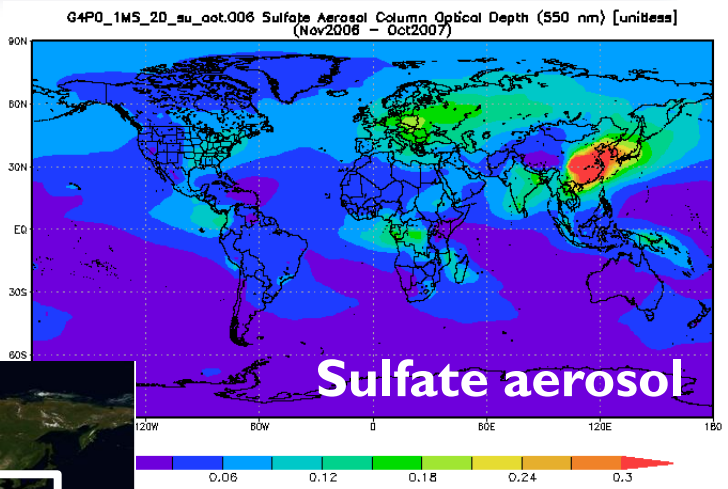


Cloud optical thickness

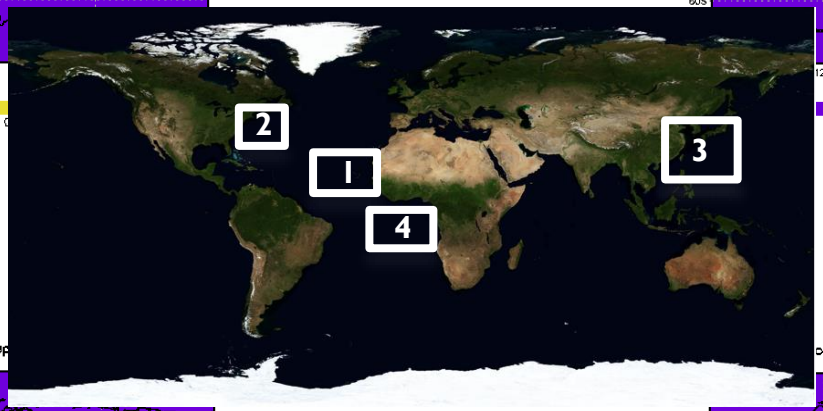
Regions dominated by different aerosols

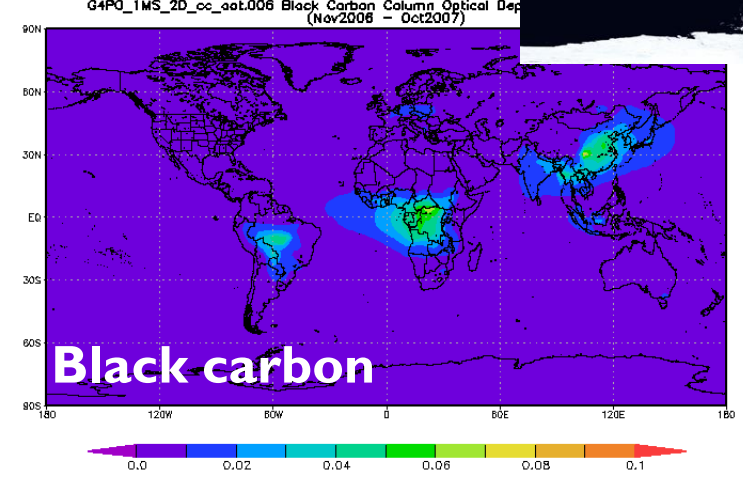


Dust



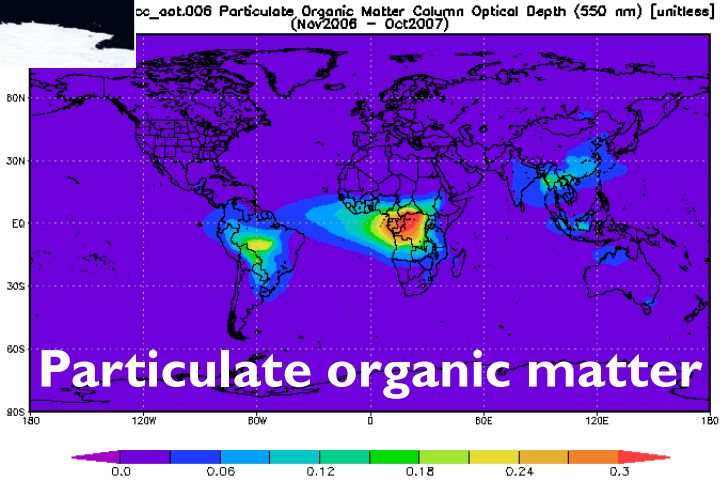
Sulfate aerosol





Black carbon

GOCART data
11/06-10/07



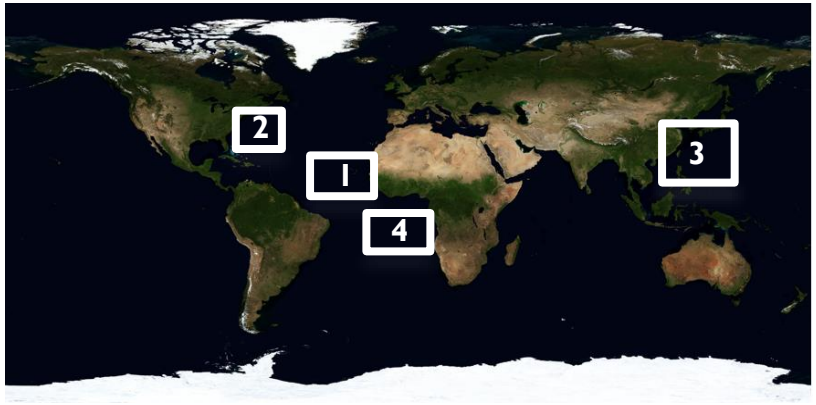
Particulate organic matter

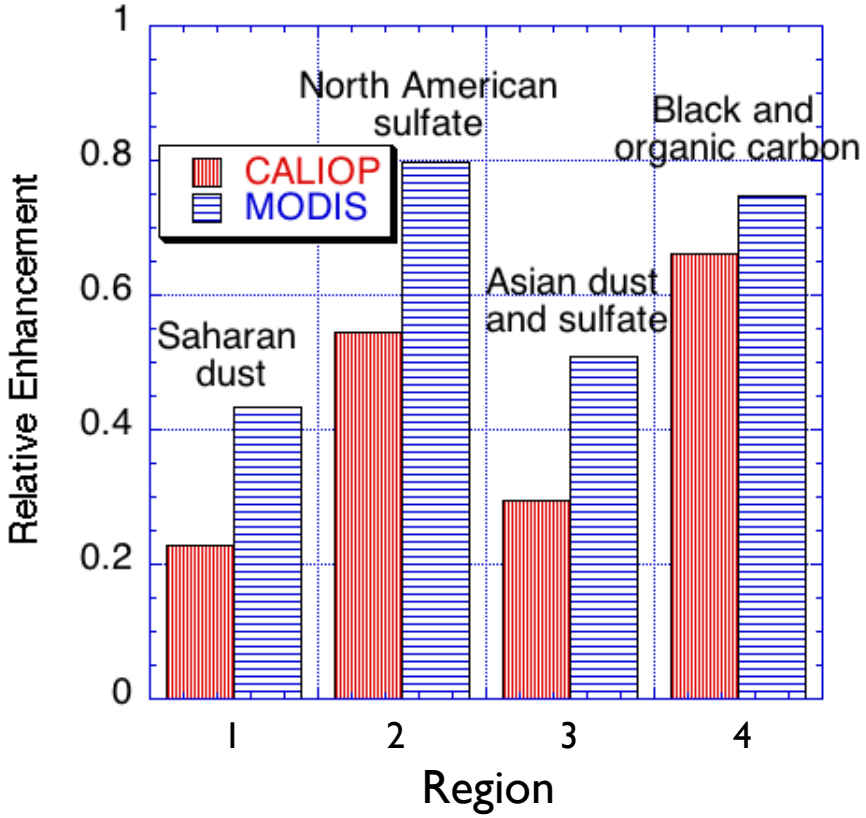
Rel. enhancements are different in each region

$$\text{Rel. enh.} = \frac{R_{close}^{particles} - R_{far}^{particles}}{R_{far}^{particles}}$$

$R^{particles}$ obtained by removing:

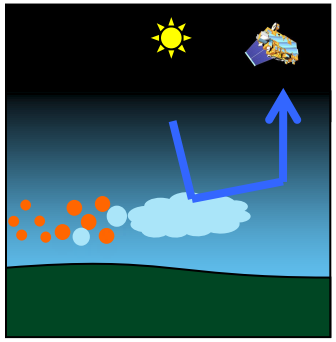
- Rayleigh scattering
- Surface reflection for MODIS
- Ozone absorption for CALIOP

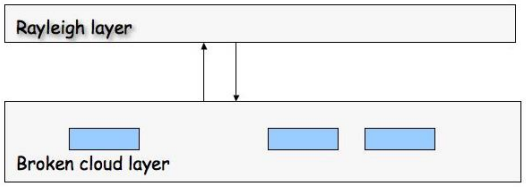




CALIOP & Aqua along CALIOP track, 11/06-10/07

Correction for 3D effect is being developed





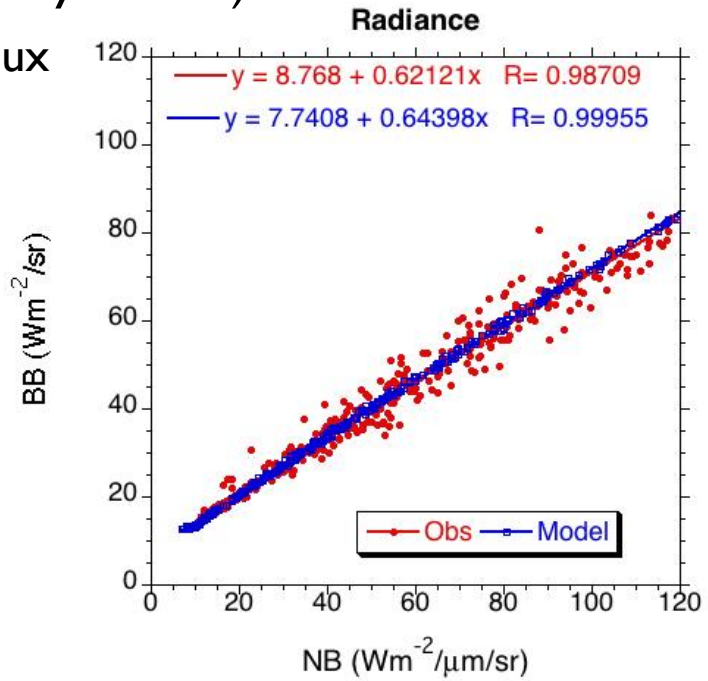
$$R_{corr} = R_{MODIS} - \Delta R$$

$$\Delta R = \frac{a_c T_m(t_m, W_0)}{1 - a_c R_{m,diff}(t_m, W)} [t_{m,diff}(t_m, W) - e^{-\frac{t_m}{m_0}}]$$

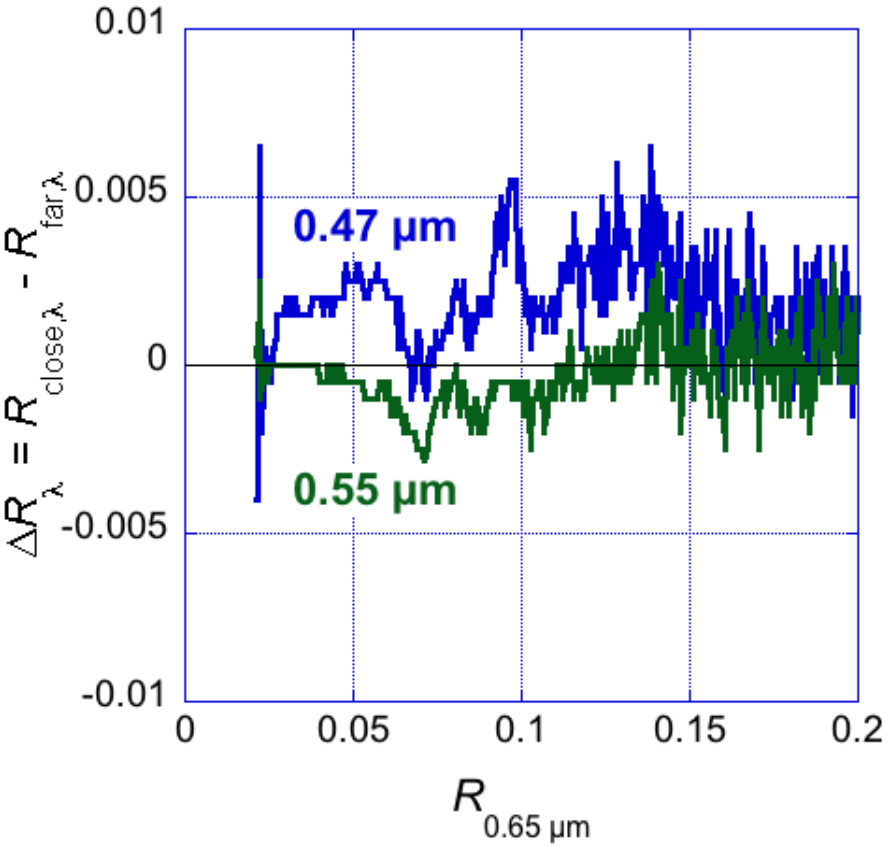
CERES can help get α_c (narrow band flux reflected by clouds):

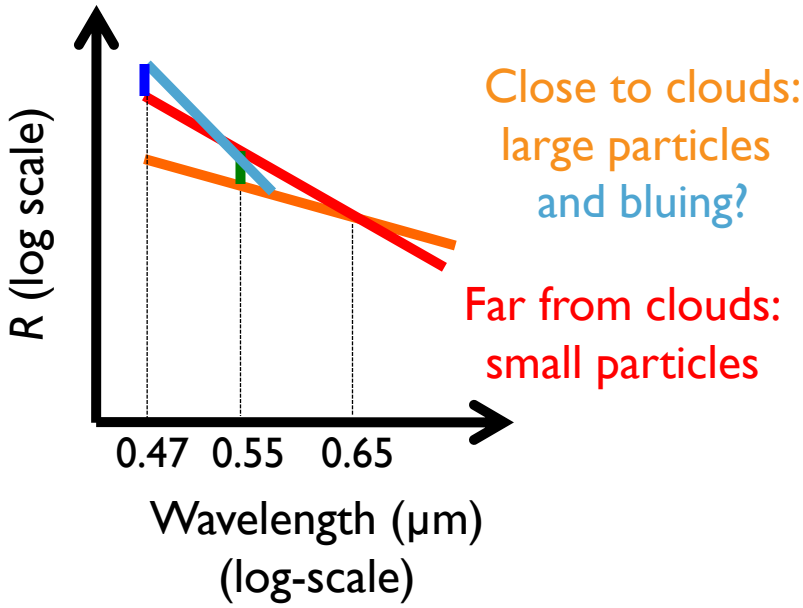
- Broadband radiance + angular model ➔ broadband flux
- Convert to narrowband flux by assuming that

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

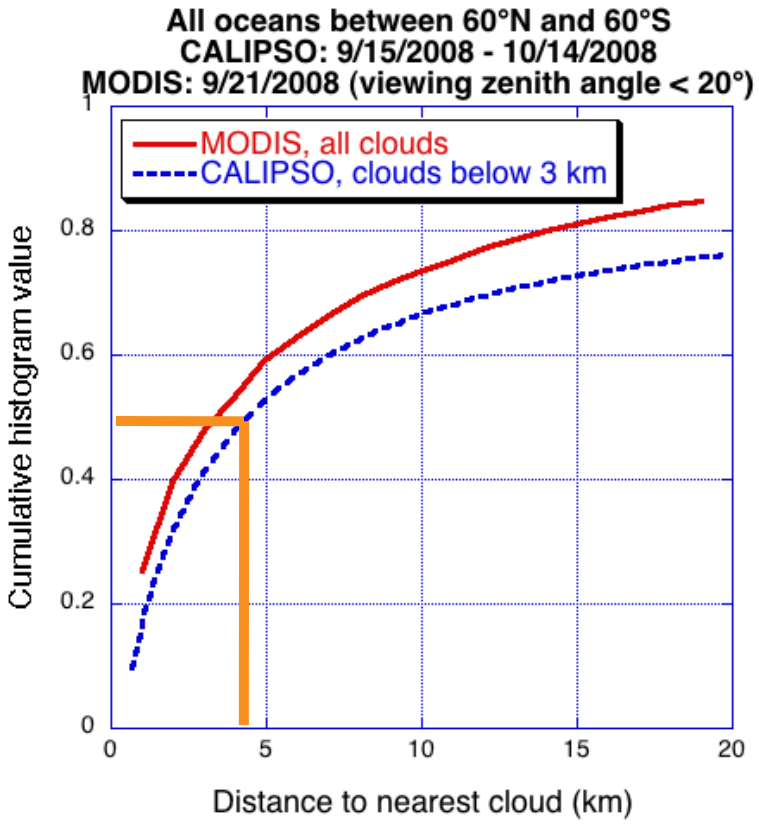


MODIS spectral data consistent with 3D bluing



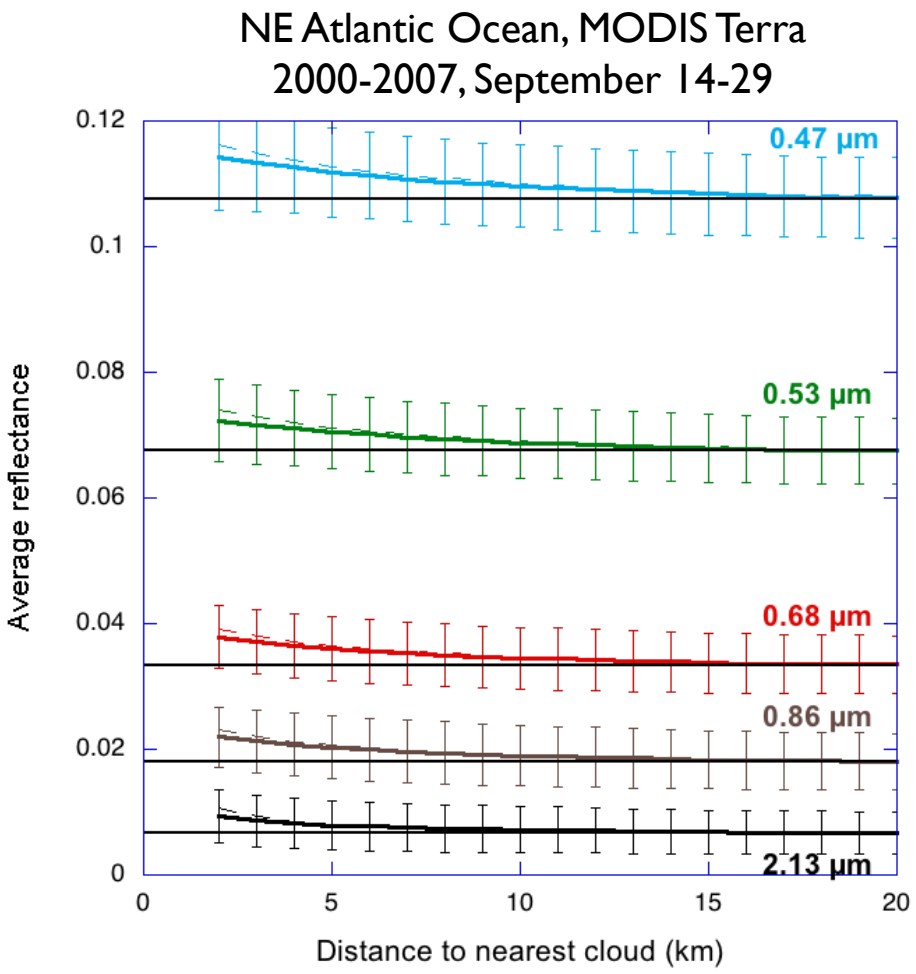


Aerosol measurements near clouds are important



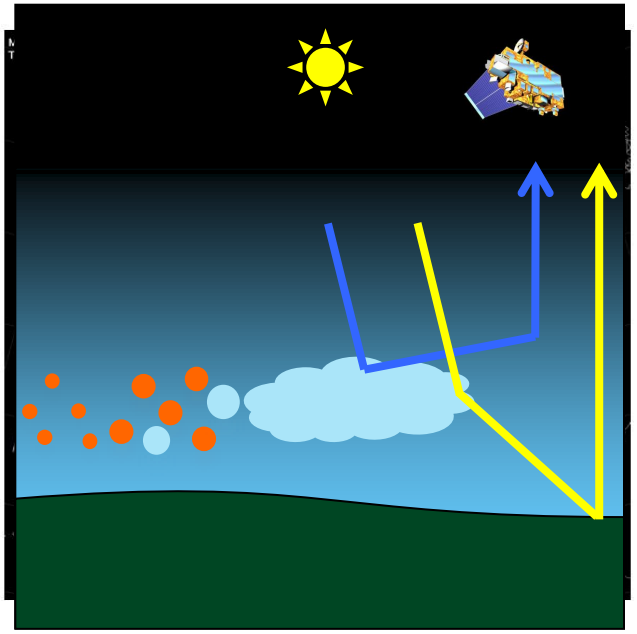
- Aerosol remote sensing near clouds is challenging
- Excluding areas near-cloud risks biases in aerosol data

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)