Towards understanding of the transition between low warm clouds and clear air

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Two key issues are that measurements classified as "cloud-free" may not be, and that aerosol measured in the vicinity of clouds is significantly different than it would be were the cloud field, and its proximate cause (high humidity), not present (e.g., Loeb and Schuster, 2008). The latter results from humidification effects on aerosol optical properties (Charlson et al., 2007; Su et al., 2008; Tackett and Di Girolamo, 2009; Twohy et al., 2009; Chand et al., 2012), contamination by undetectable cloud fragments (Koren et al., 2007) and the remote effects of radiation scattered by cloud edges on aerosol retrieval (Wen et al., 2007; Várnai and Marshak, 2009).

What’s the transition zone (TZ)

The TZ between cloudy and clear air is a region of strong aerosol-cloud interactions where aerosol CCN humidify and swell when approaching the cloud, while cloud drops evaporate and shrink when moving away from the cloud.

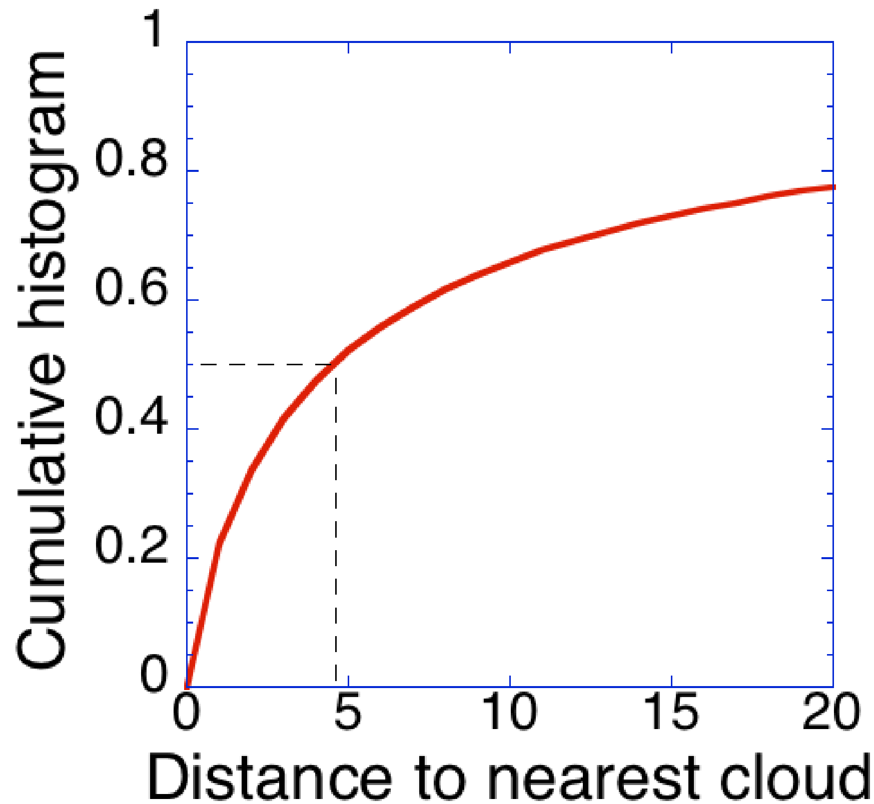
The TZ tends to be contaminated by ‘weak cloud elements’, such as cloud fragments sheared off from adjacent clouds.

More precisely (Koren et al., 2009), the TZ consists of fast-changing particle clumps:
(1) aerosols at various stages of uptake of water vapor;
(2) cloud fragments sheared off from neighboring clouds;
(3) incipient clouds that are forming but are not yet stable entities;
(4) hesitant clouds—pockets of near-saturation humidity.

The TZ is difficult to study with current aircraft and with most surface remote sensors because they just don’t have the time and/or spatial resolution to do so.

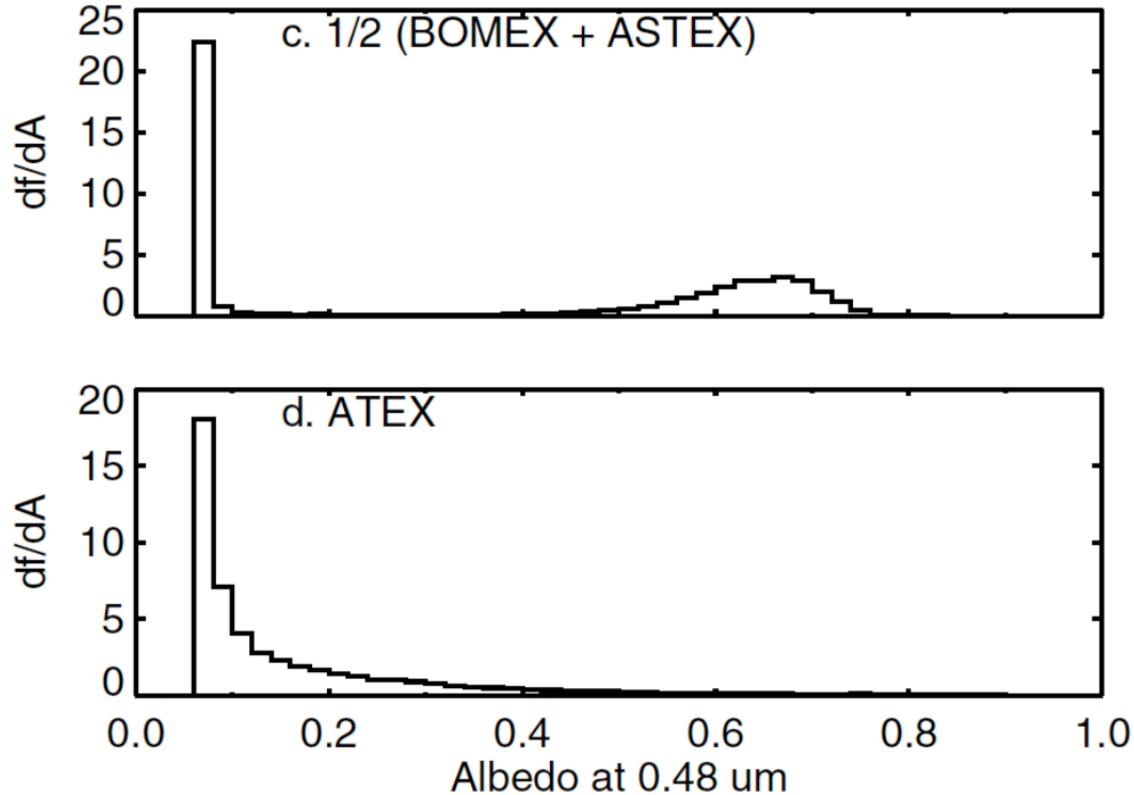
Why to study the TZ

The TZ is ubiquitous: according to CALIPSO observations, about half of all 'clear sky' pixels over ocean are within 5 km of a low cloud (Varnai and Marshak, 2011).



The TZ complicates estimates of the aerosol indirect effect and of aerosol radiative forcing — excluding aerosols near clouds will dramatically reduce the database and **underestimate** the forcing, while including them may **overestimate** it because of unaccounted cloud contamination.

Inseparability of cloudy and clear skies under partial cloud cover (from Charlson et al., 2007)

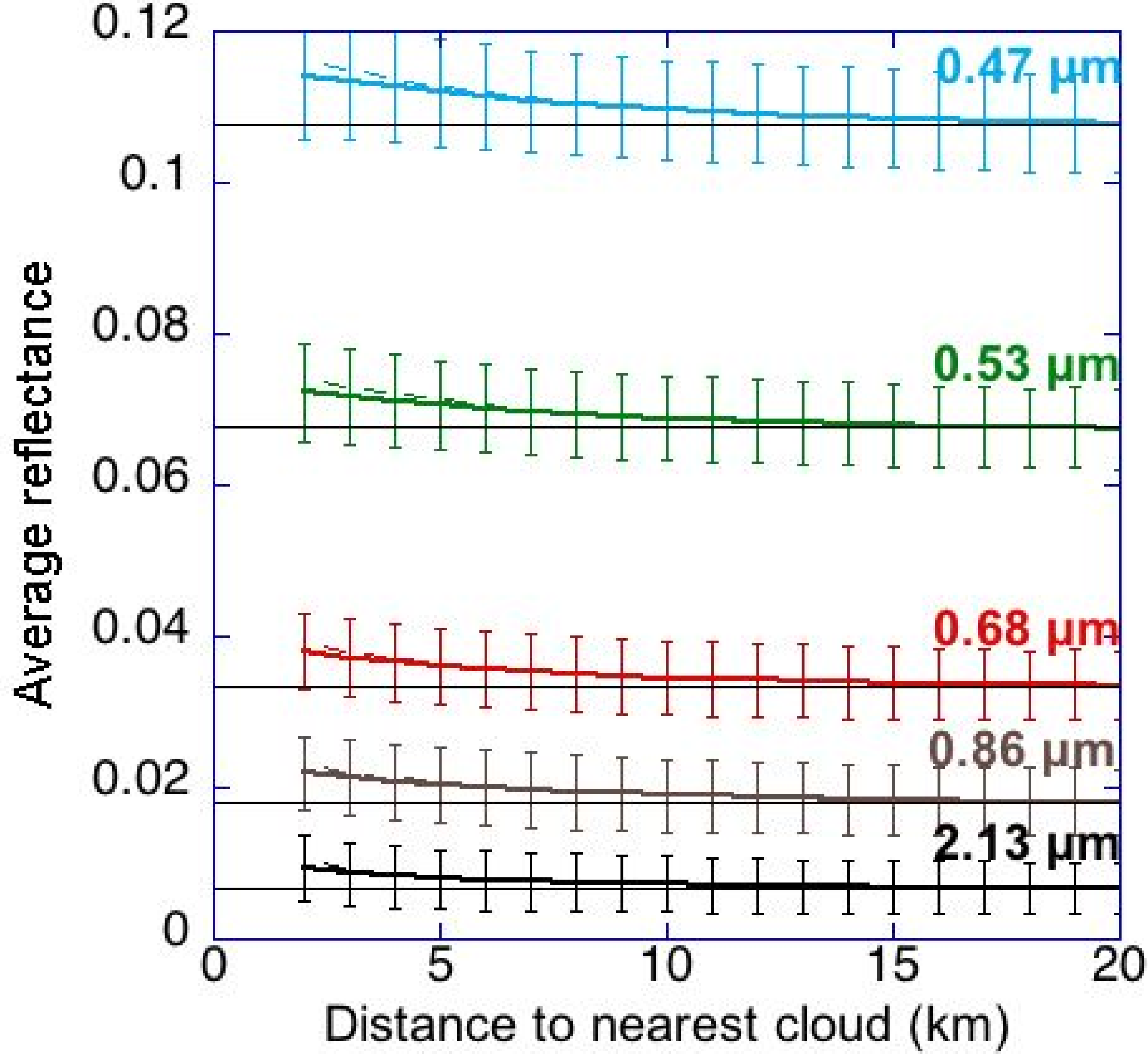


Albedo pdfs from LES of trade Cu and Sc clouds

Upper plot: average of the BOMEX (~10% cloud cover) and ASTEX (overcast) fields; clear and cloudy contributions are nicely separated.
Lower plot: for ATEX trade Cu (~50% cloud cover), with the albedos from clear and cloudy portions inseparable.

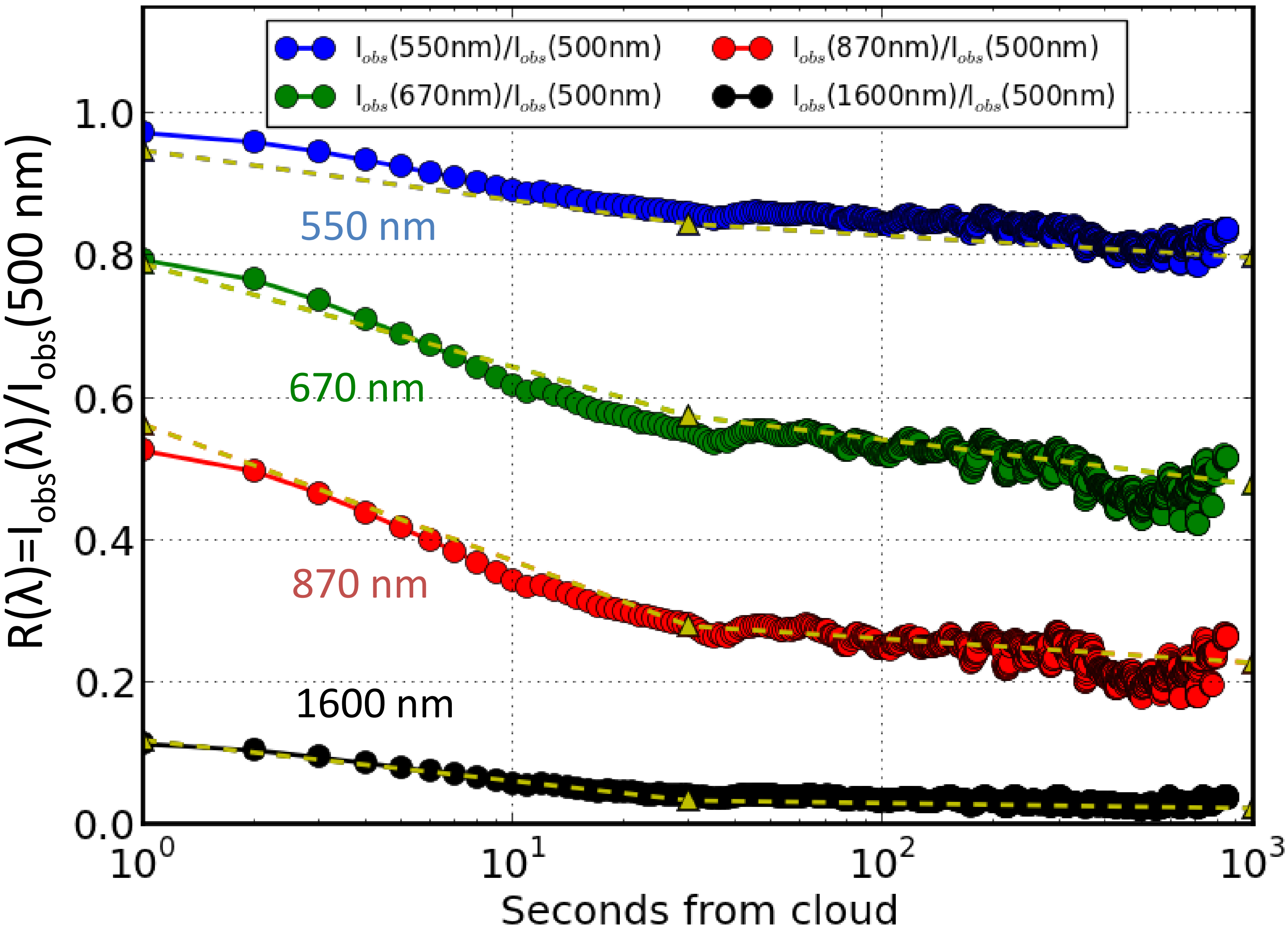
MODIS

Varnai and Marshak, 2009



2 Sep. weeks for 8 years OF MODIS Terra obs.: southwest of UK

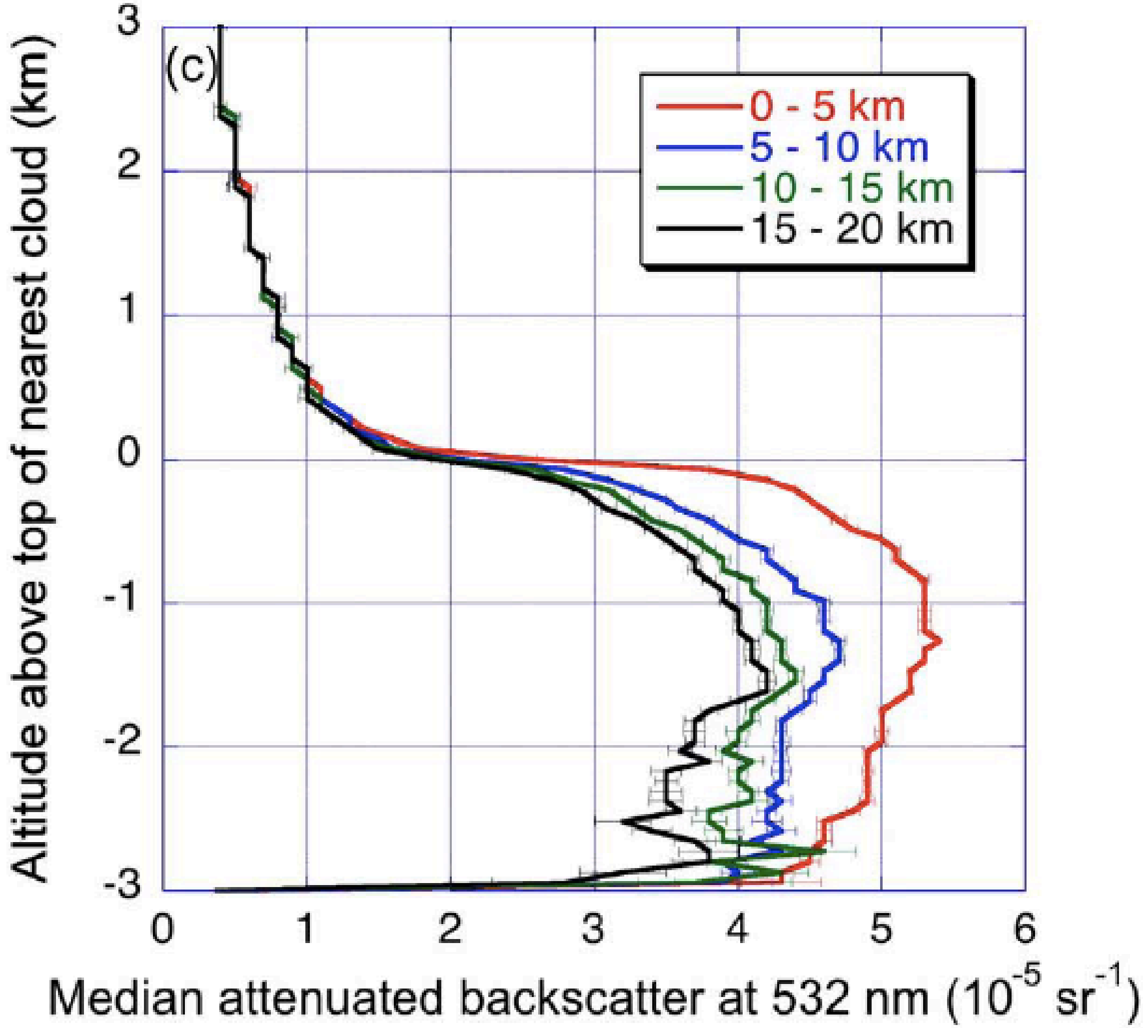
ARM SWS



Measured radiance ratios from 7 months and 208 cases; μ_0=0.6-0.7.

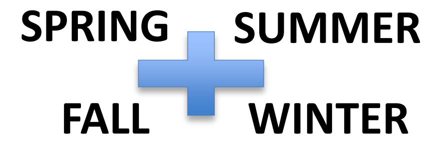
CALIPSO

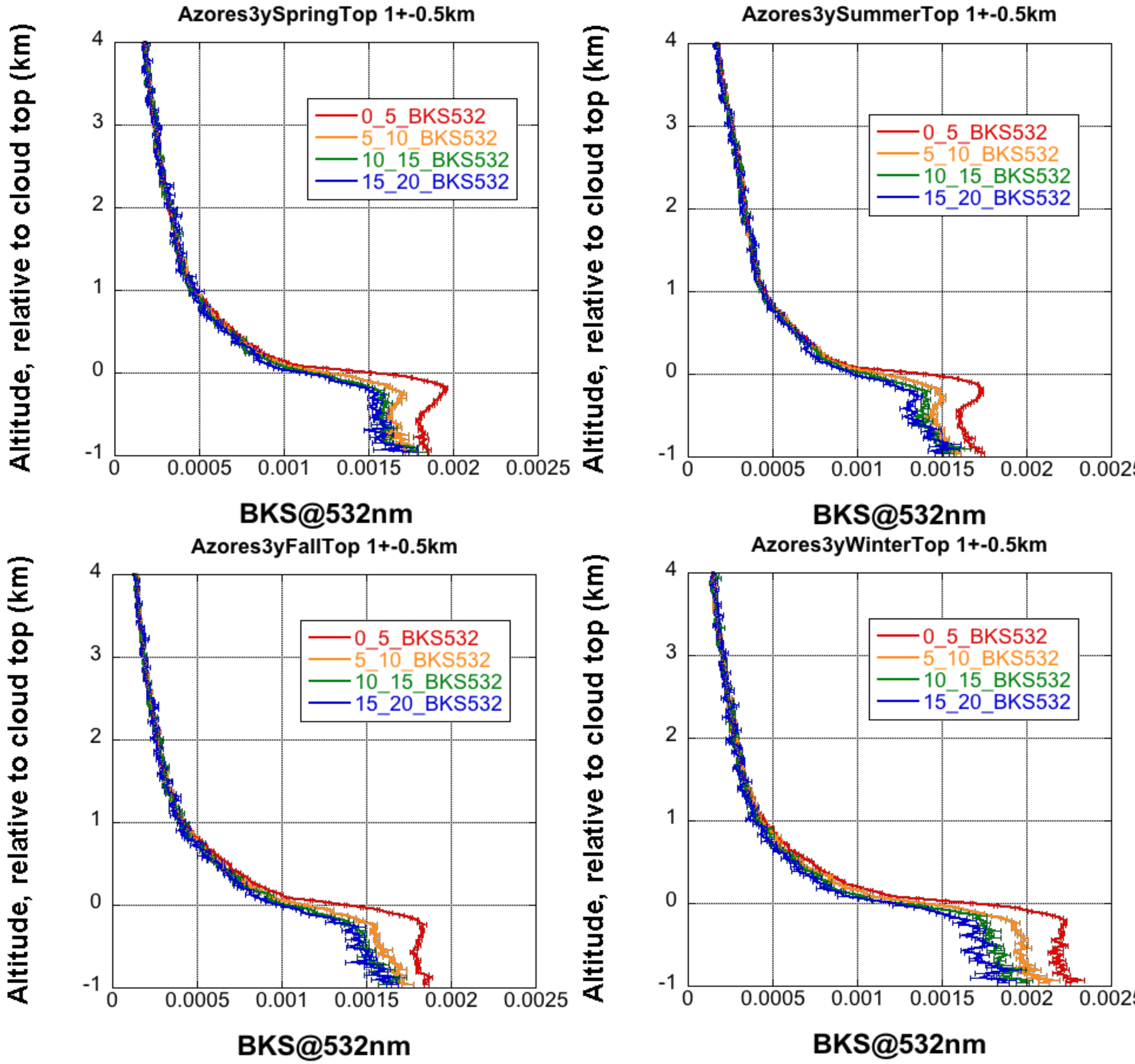
Varnai and Marshak, 2011



Global over ocean data for Sep-Oct 2008

3 year observations for the Azores region: June 06 – June 09
<u>BKS@532nm</u> profiles @ 4 seasons
cloud tops are from 0.5km→1.5km

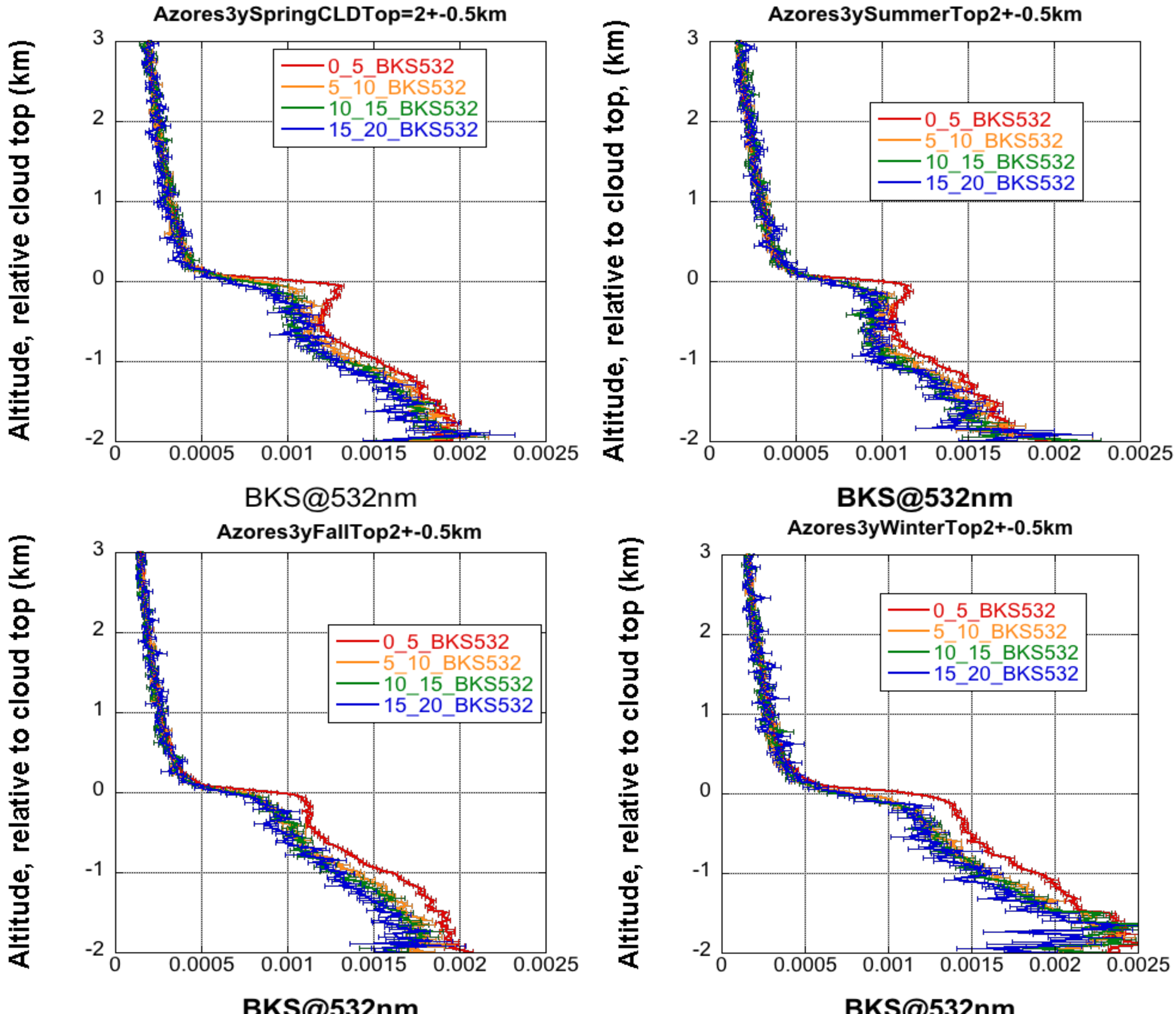




The wintertime max in scattering near the surface is due to increased wintertime sea-salt production.

3 year observations for the Azores region: June 06 – June 09
BKS@532nm profiles @ 4 seasons
cloud tops are from 1.5km→2.5km

SPRING SUMMER
FALL WINTER

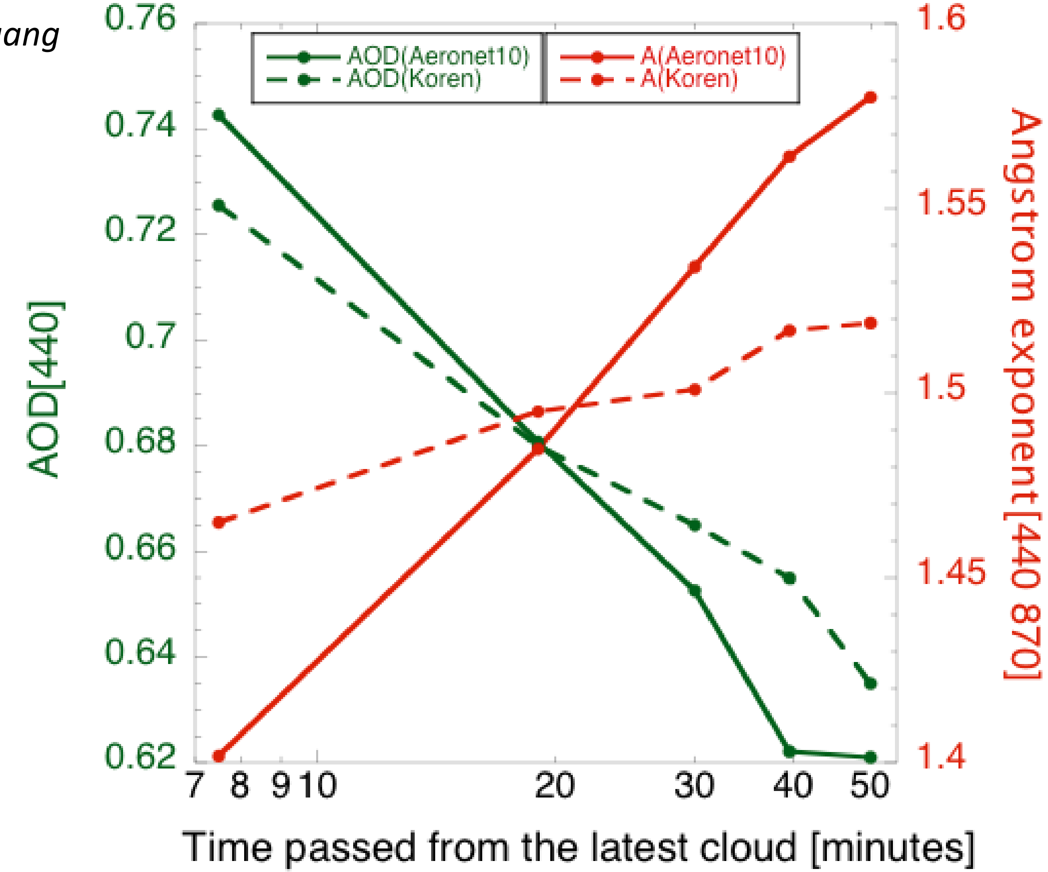


The boundary layer decoupling, with higher backscatter near the surface and then a drop-off in the upper layer containing the clouds

These are Observations. What’s about Products?

AERONET data

Courtesy of Stefani Huang



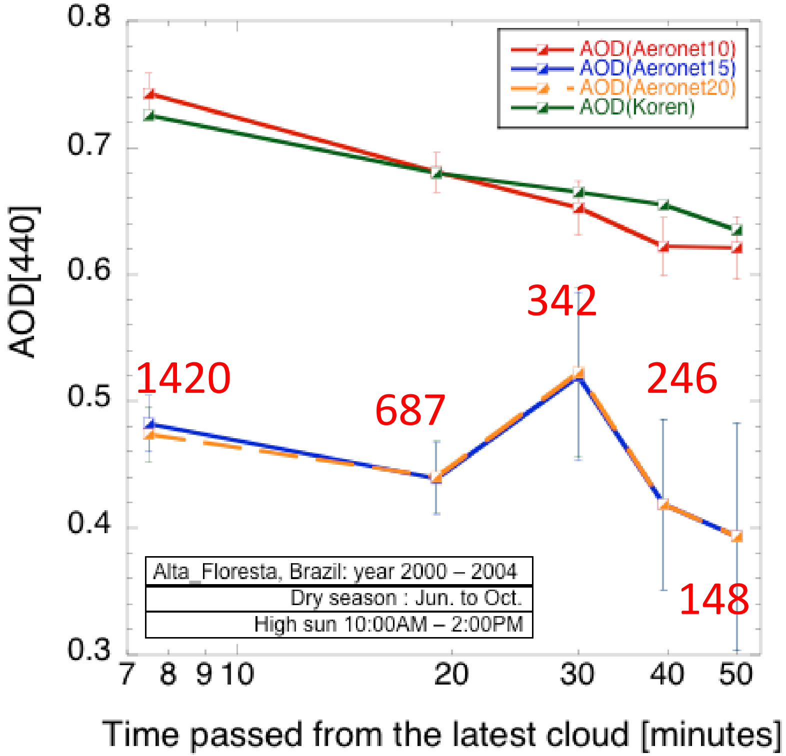
An analysis of AERONET Level 1[1] and Koren et al., (2007)[2] data for Alta-Floresta (Brazil) during the biomass burning (Jun. to Oct., 2000-2004), as a function of the distance from the nearest cloud.

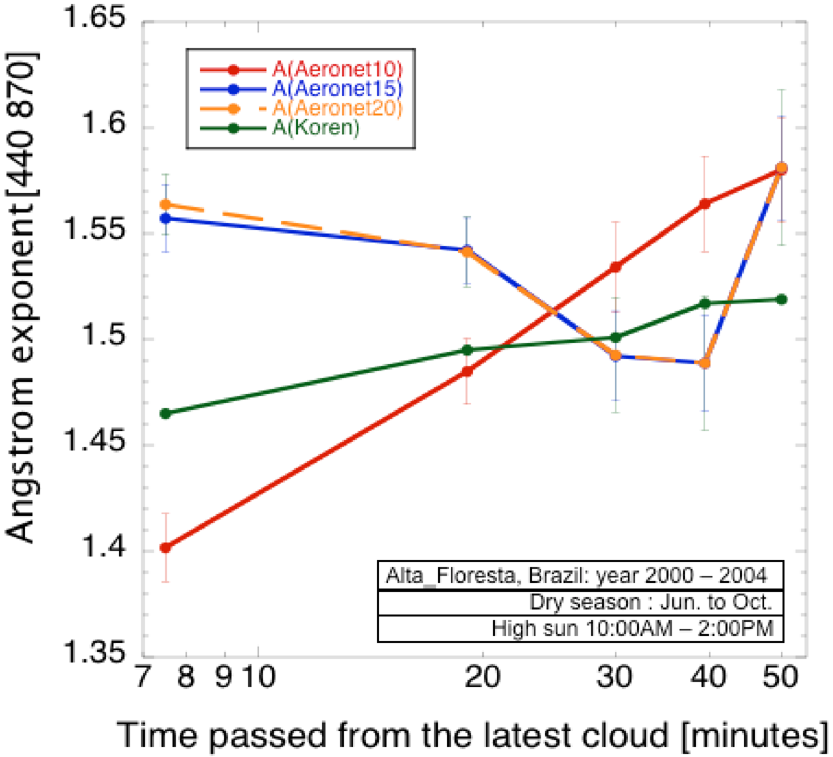
[1] Unscreened data

[2] Applying Kaufman's cloud screening

AERONET data

Courtesy of Stefani Huang

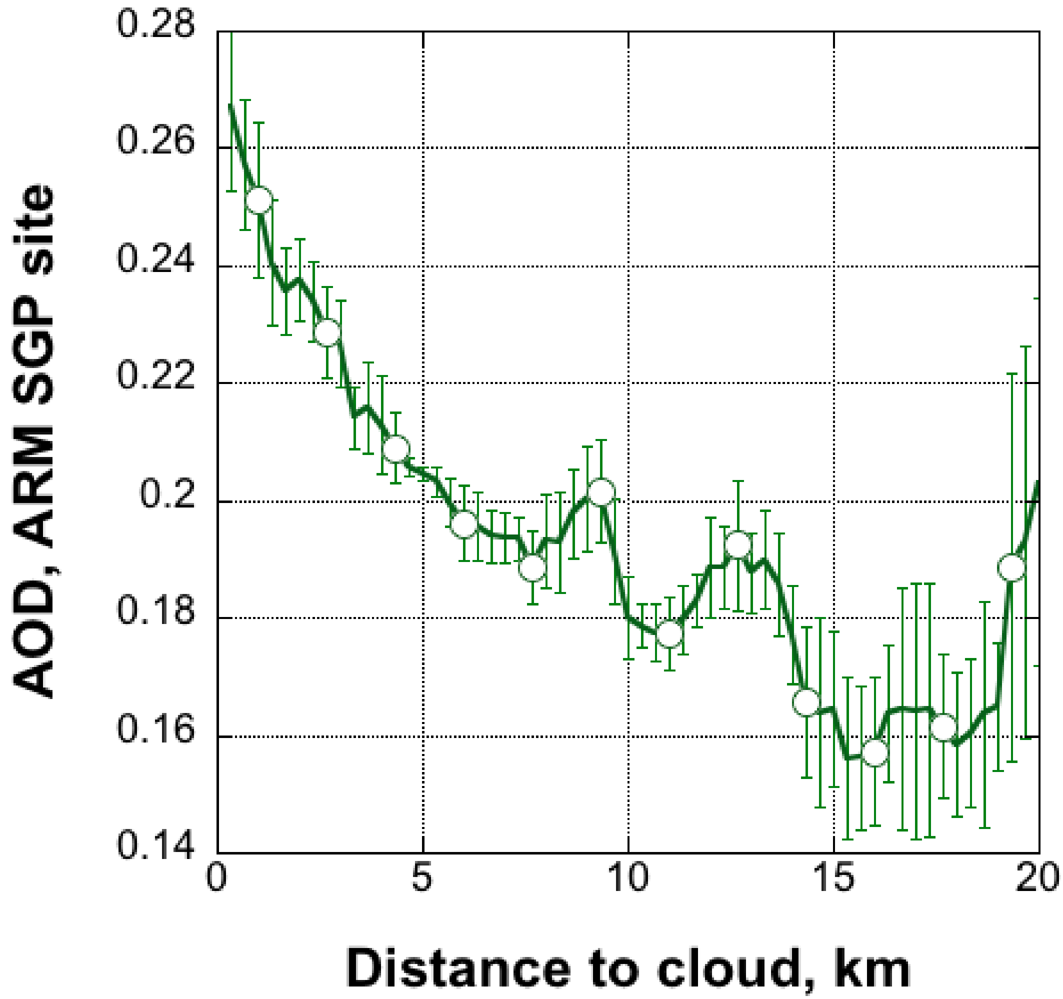




A comparison of different data set: AERONET Leve1[1], Level 1.5[2], Level 2.0[3], and Koren et al., (2007)[4] data for Alta-Floresta during the biomass burning (June to Oct., 2000-2004).

[1] Unscreened data
[2] Cloud-screened data but may not have final calibration applied. These data are not quality assured.
[3] Pre- and post-field calibration applied, cloud-screened, and quality-assured data
[4] Applying Kaufman's cloud screening

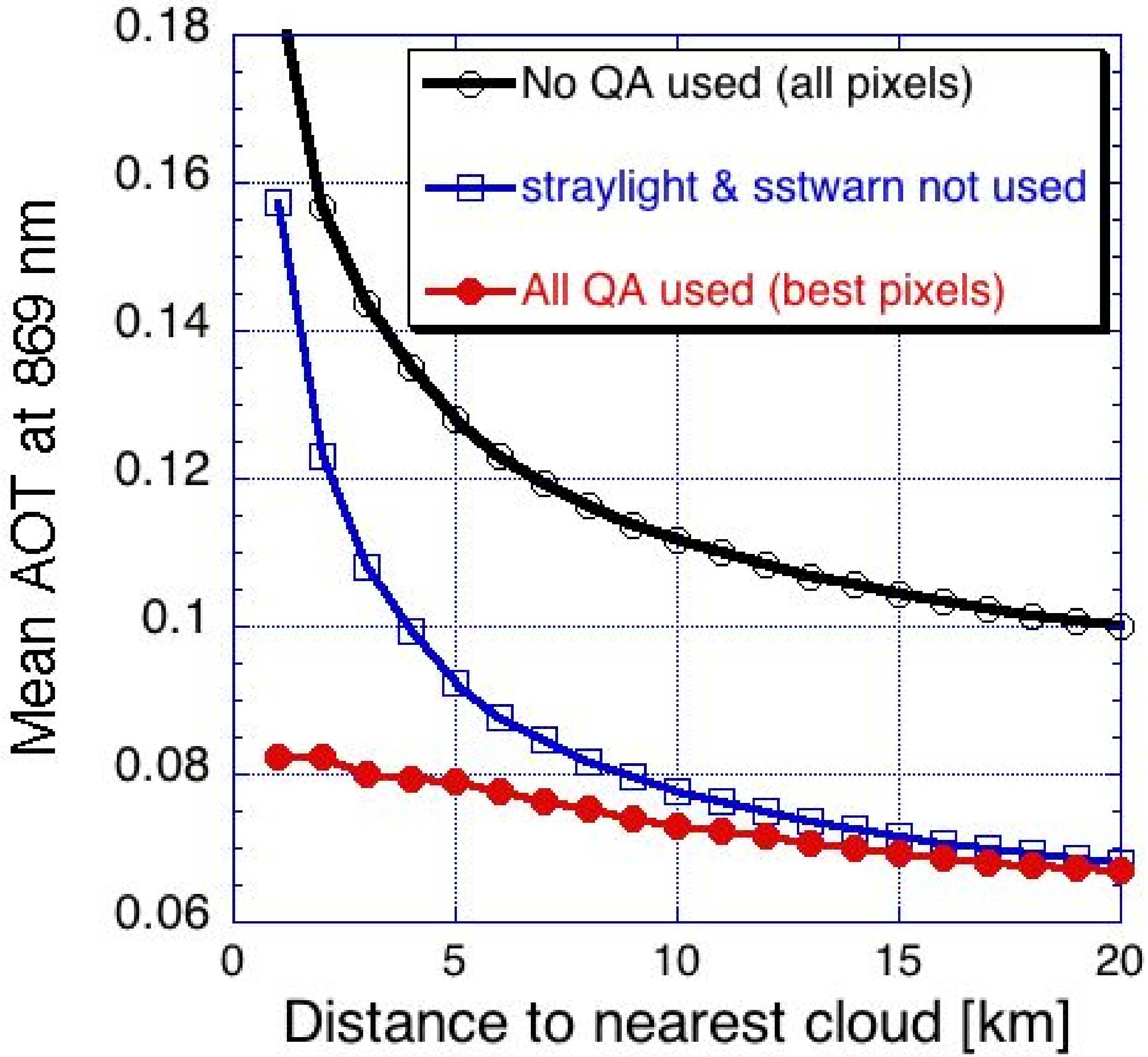
CALIPSO AOD over the ARM SGP site



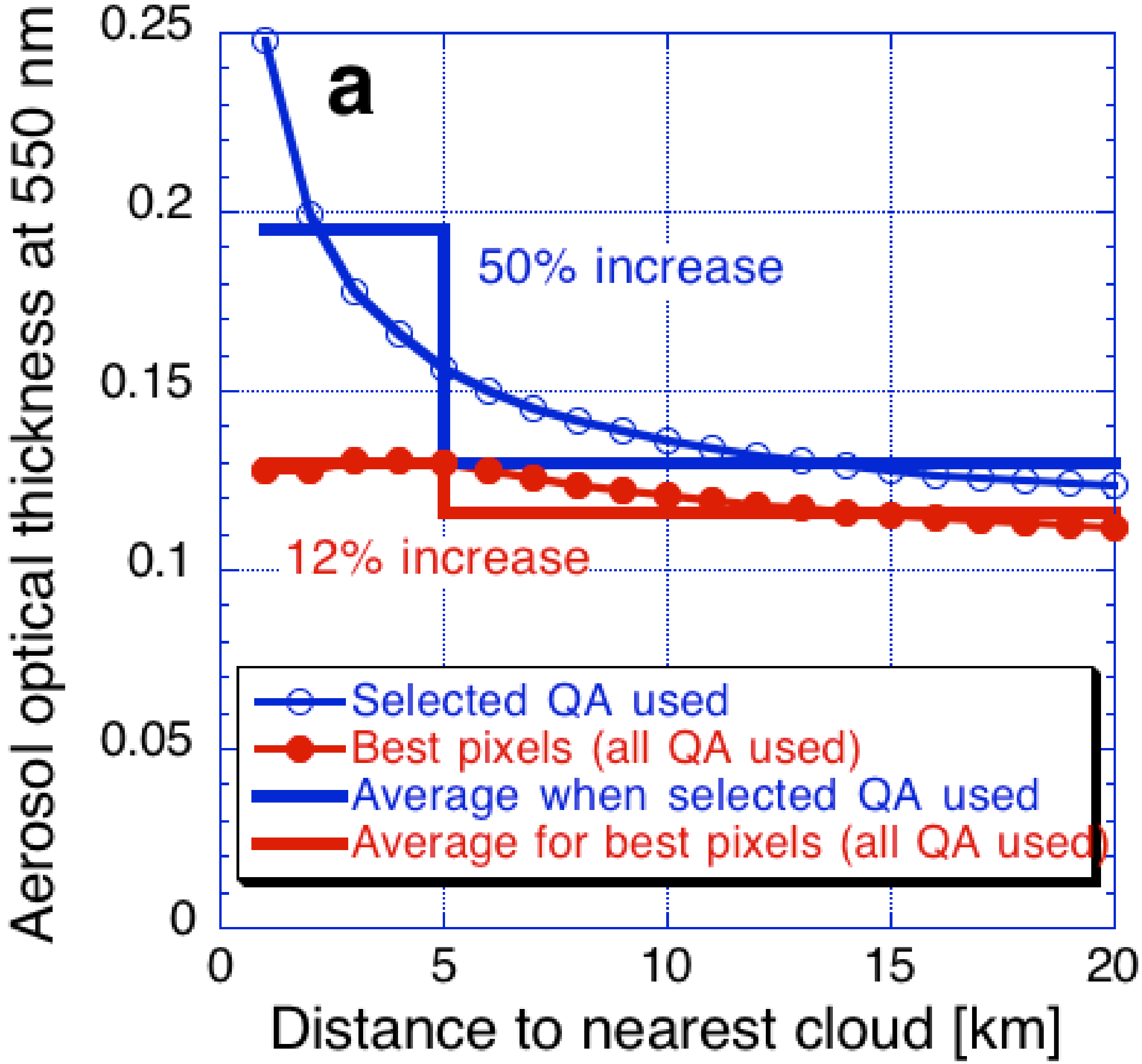
5 years (2007-2011) over a 3° by 3° area around ARM SGP site

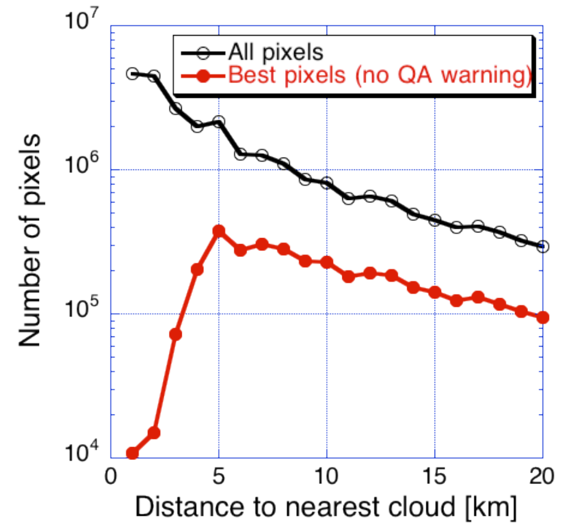
MODIS Ocean AOD @ 869 nm

Varnai and Marshak, 2013



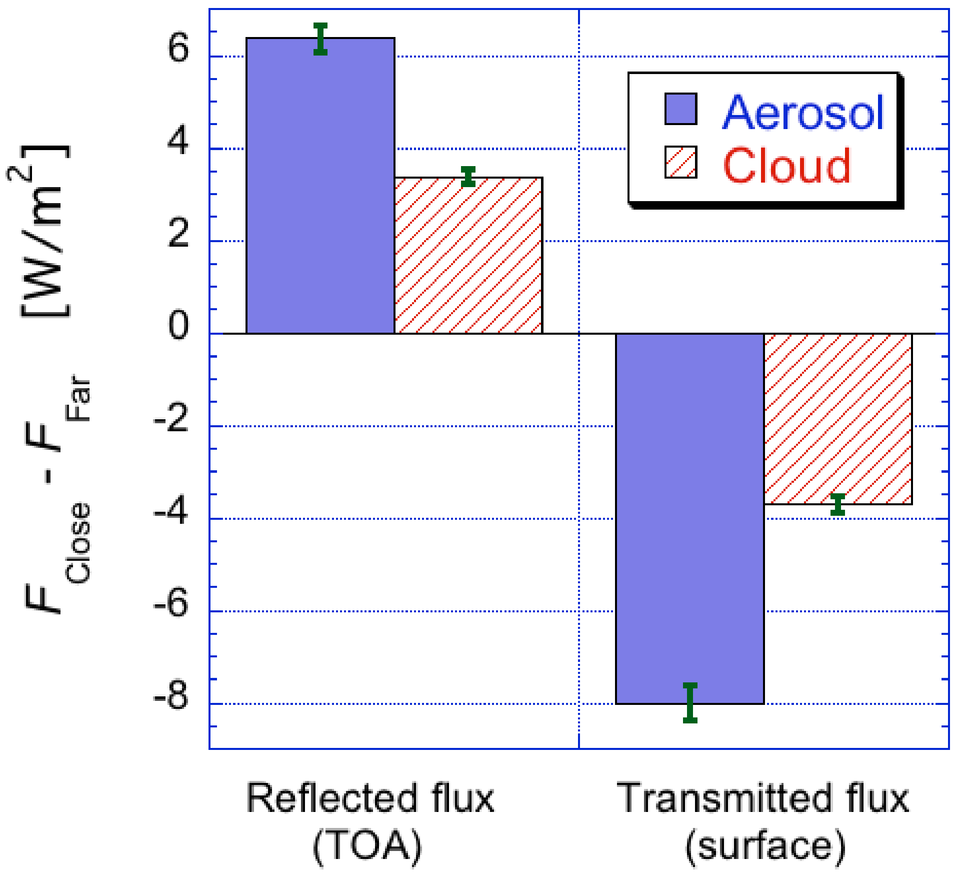
MODIS Ocean AOD @ 550 nm





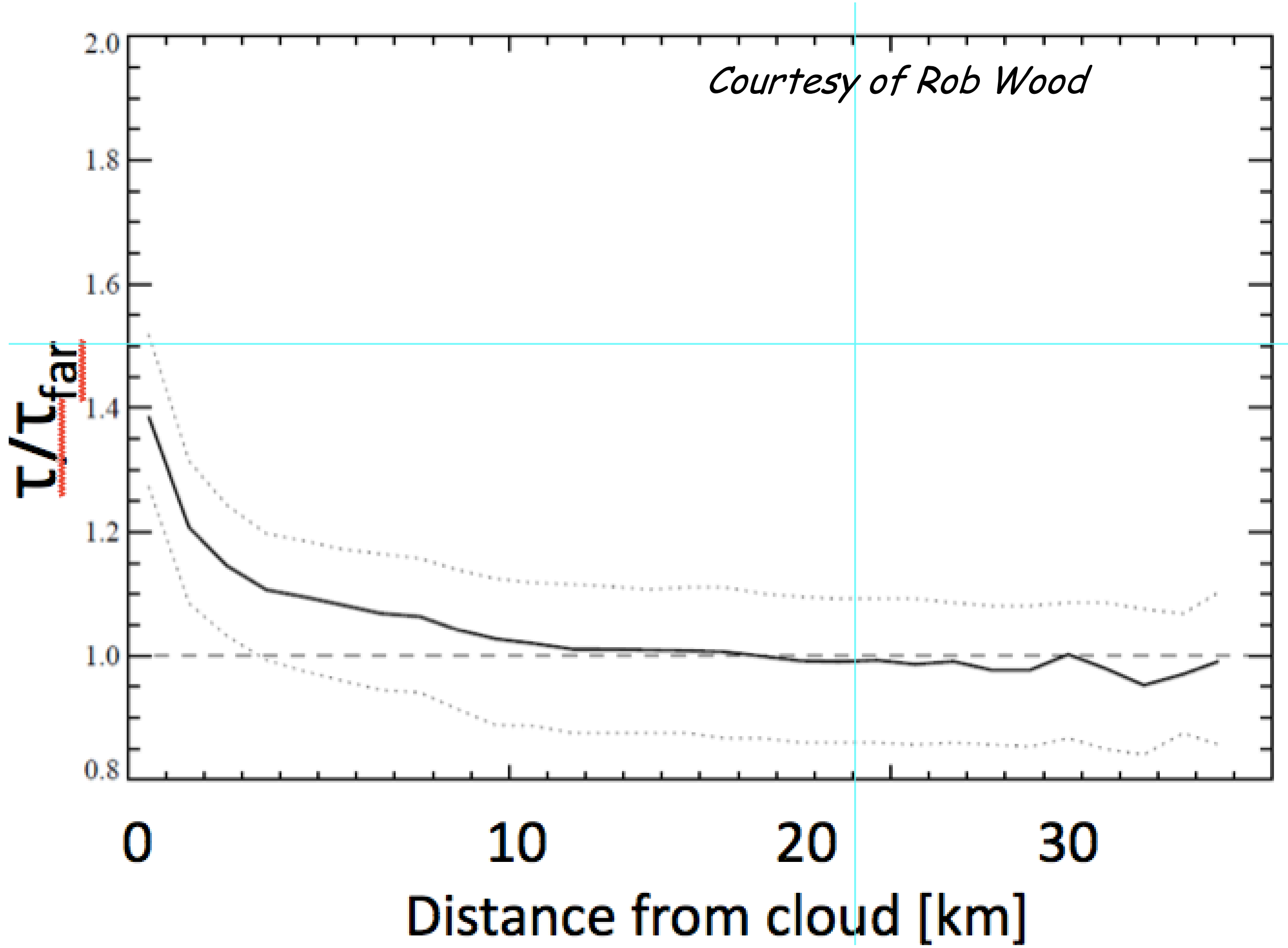
excluding aerosols data near clouds will dramatically reduce the database

Impact of AOD differences on direct RF



Solid blue and red striped bars show the impact for two interpretations of the difference between AOD *close* and *far* from clouds: all near clouds OD changes are attributed to aerosols (blue) and to undetected clouds (red).

Modeling of the AOD Enhancement



Fractalize RH_0 at the surface using bounded cascades (Marshak et al, 1994) and add a vertical structure: $RH(x,z)=RH_0(x)+G(z)$. If RH < 1, AOD is determined as vert. integrated product of RH and dry aerosol extinction (Chand et al., 2012)

Summary

- Aerosol radiative forcing (ARF) cannot be artificially separated into "direct" and "indirect" components. The grey area complicates estimates of ARF – excluding aerosols near clouds dramatically reduces the database and underestimates ARF, while including them may overestimate the forcing;

- Both satellite and ground measured radiation increases as we approach a cloud. But radiation is not identical to AOD. There are other effects that increase *apparent* AOD near clouds, e.g., cloud fragments detrained from a nearby cloud.

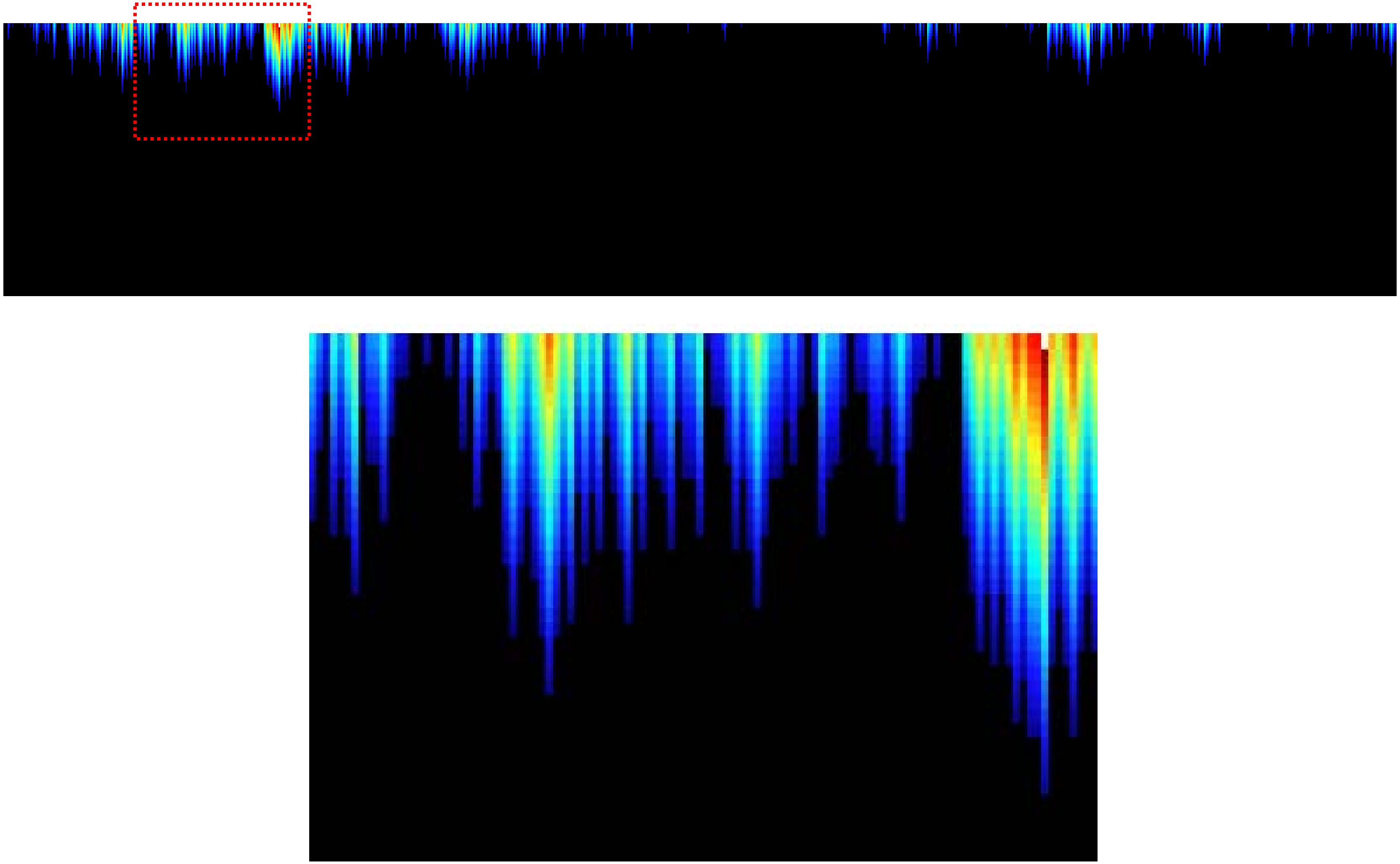
- BB RT calculations indicate that changes of AOD in the TZ affect instantaneous average AF by up to 7 W/m^2. The radiative impact is much larger if near-cloud changes are caused by aerosol particles rather than by undetected cloud droplets.

Heuristic fractal model

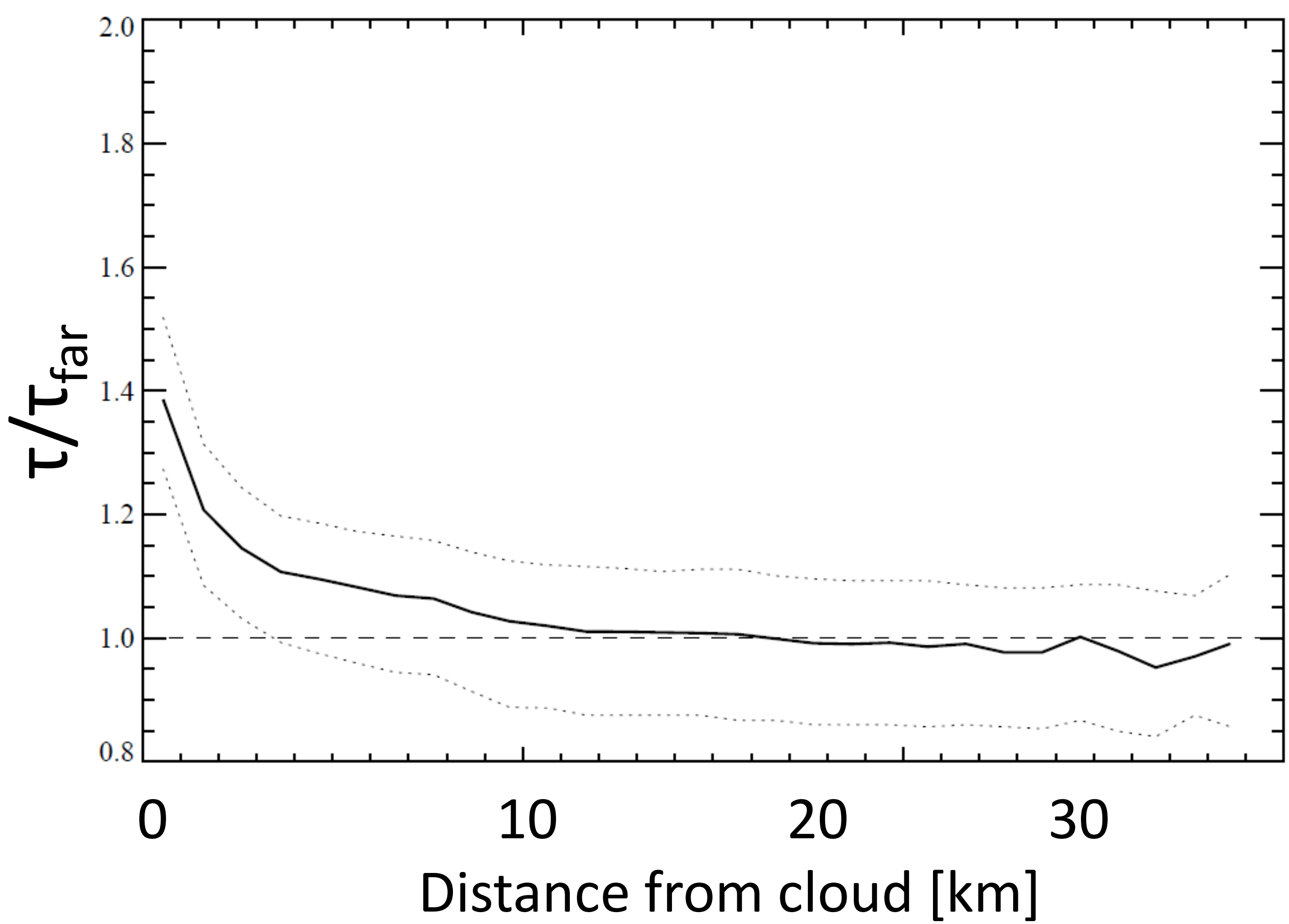
Courtesy of Rob Wood

- Consider local profile as well mixed;
- Saturation ratio S such that dS/dz increases at ~5% per 100 m (T, p dependent);
- Set maximum altitude z_{max} above which RH is small;
- Allow surface RH to be random variable
  - distributed in space according to bounded cascades (Marshak et al. 1994);
  - Specify mean and breadth of RH distribution as inputs;
- Profiles for which $S(z_{max})<1$ are clear; others cloud;
- Cloud condensate from thermodynamics (S-1) is saturation excess = condensate;
- Hygroscopic growth from Kiehl et al. (2000);
- Obtain time/space series of cloud + clear.

Example cloud condensate



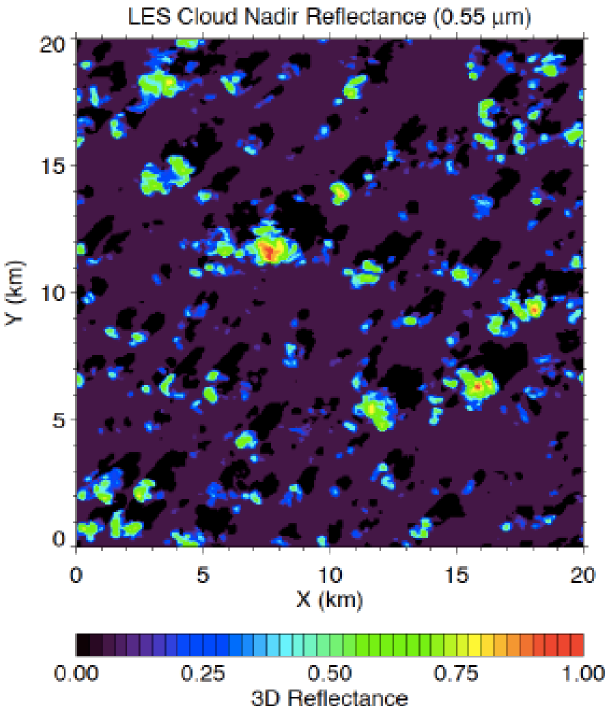
AOD decrease with distance from cloud edge



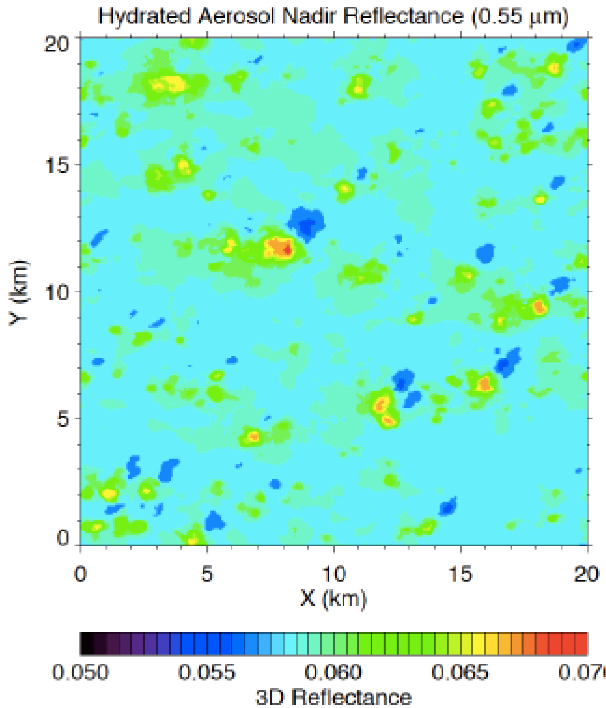
- Example showing mean clear sky AOD decreasing with distance from cloud edge
- Fractal scaling parameters: H=0.1, p=0.1
- RH_0=0.625
- γ_{RH}=0.04
- z_{top}=750 m
- Gives f_c = 0.5

Simulation with LES

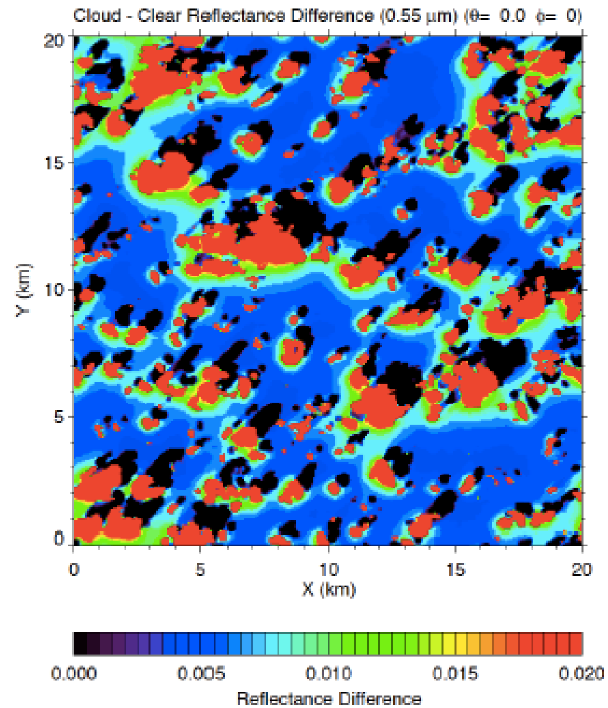
Nadir-view 0.55 μm reflectances for the aerosol-cloud field



Same but with no clouds



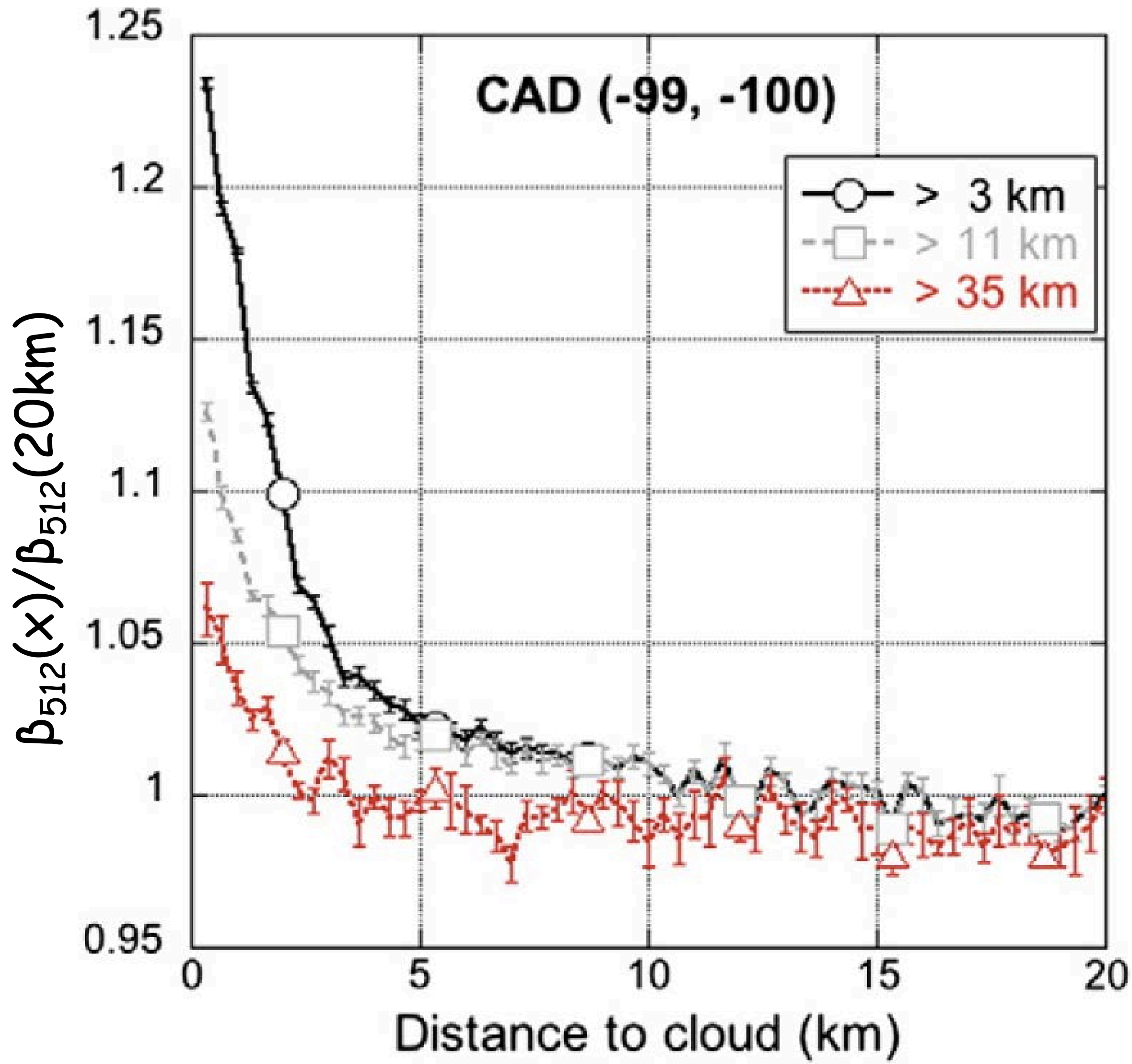
Difference between left and middle panels



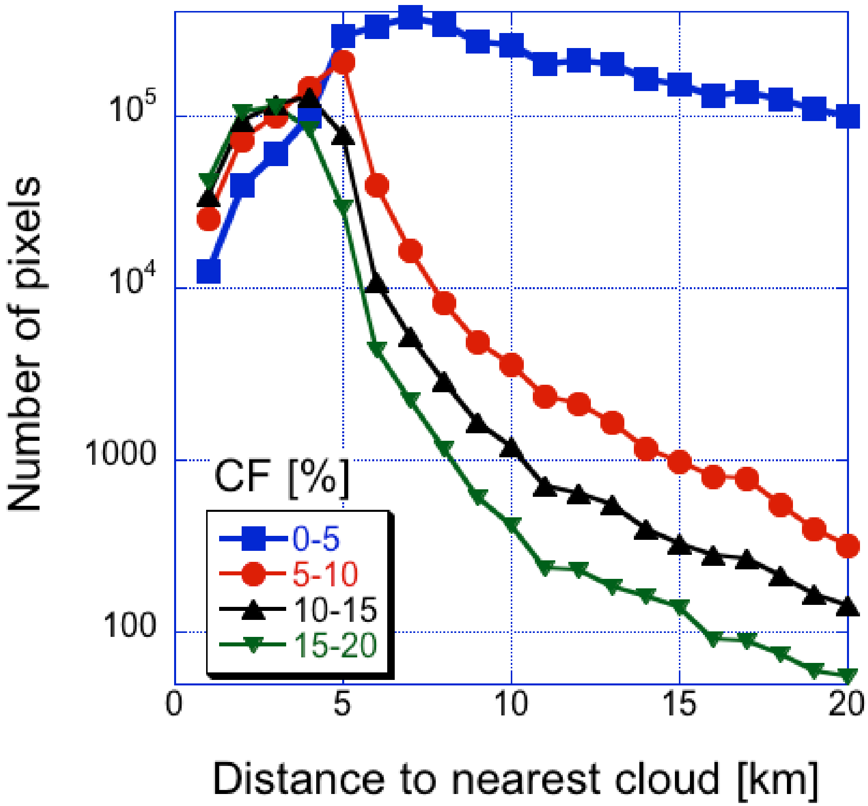
Reflectances for the broken cloud field

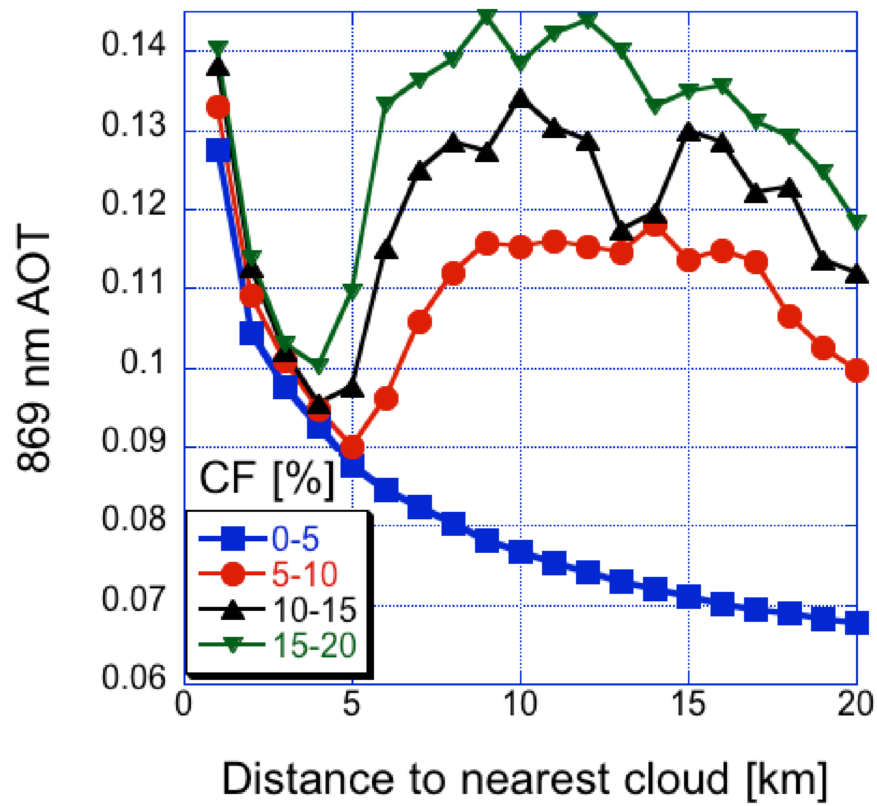
Courtesy of Frank Evans

CALIPSO: Effect of the gaps between clouds on normalized backscatter



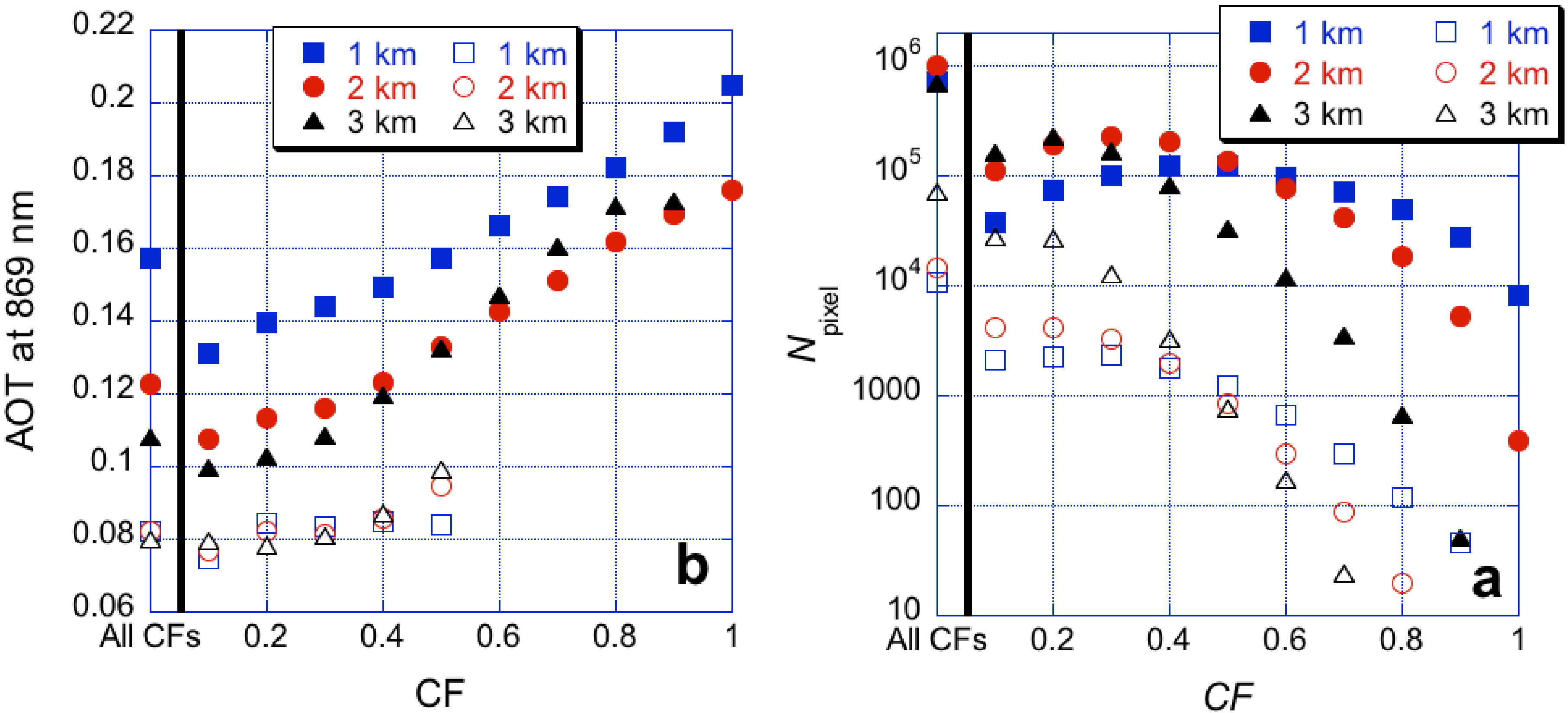
Effect of CF





Close to cloud the main contribution comes from more cloudy areas while far from clouds the contribution comes from predominantly clear areas.

Effect of CF

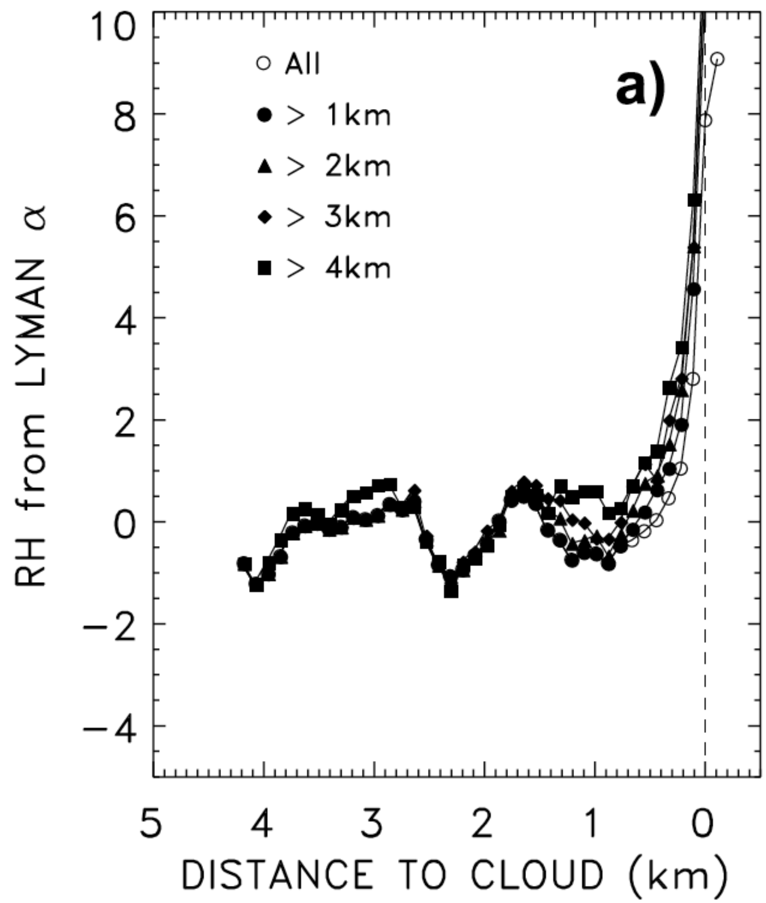


Empty symbols: All QA flags used

Solid symbols: All QA flags used except 'straylight' and 'sstwarn'

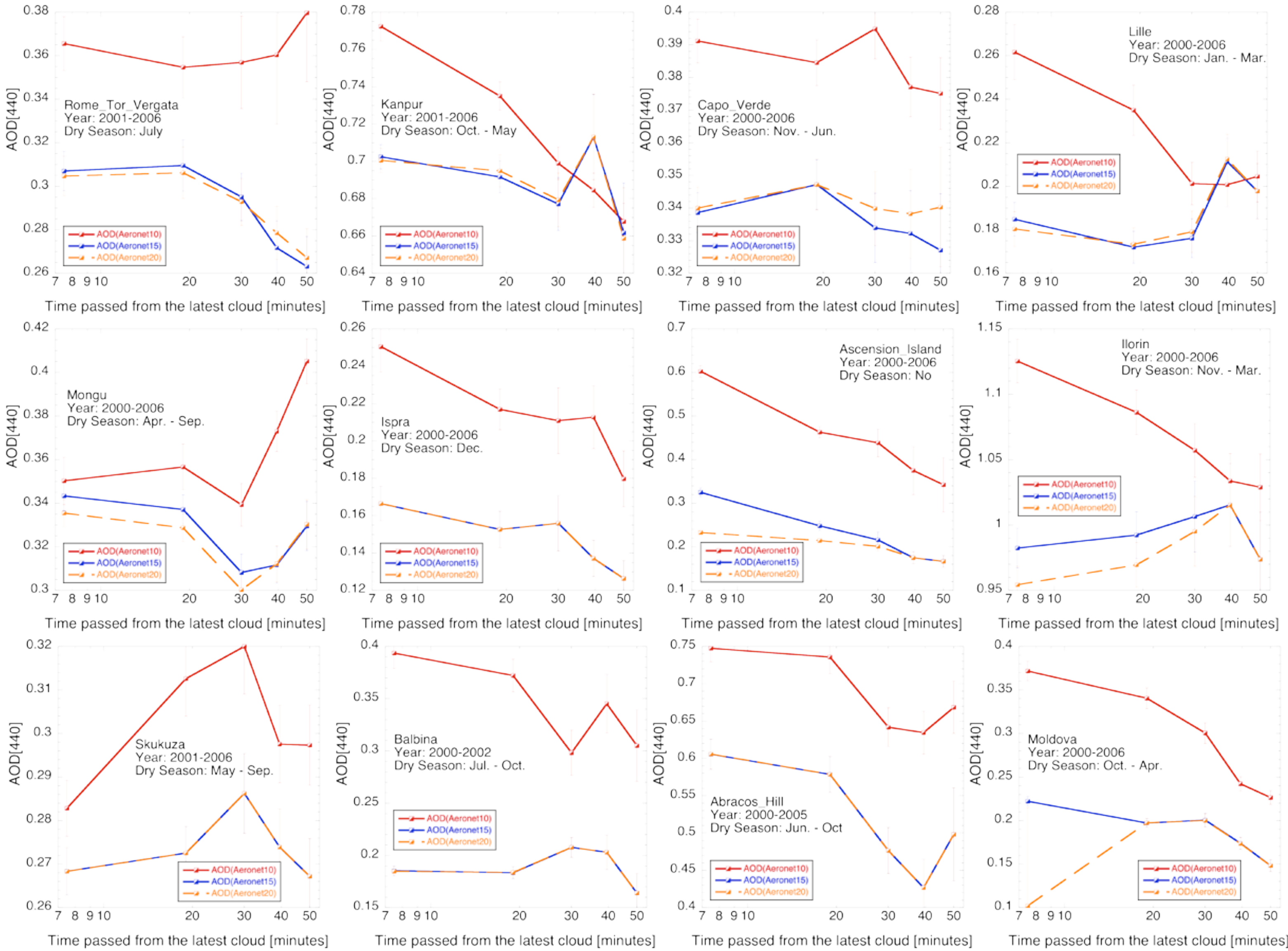
Effect of Relative Humidity

Twohy et al., 2009



Exponential increase in RH near clouds with e-folding distance of 90-300 m (Bar-Or et al., 2012). Aerosol humidification can explain only 25% of the correlation between AOD and cloud cover (Jeong and Li, 2010).

12 other AERONET stations around the globe: AOD (440 nm)

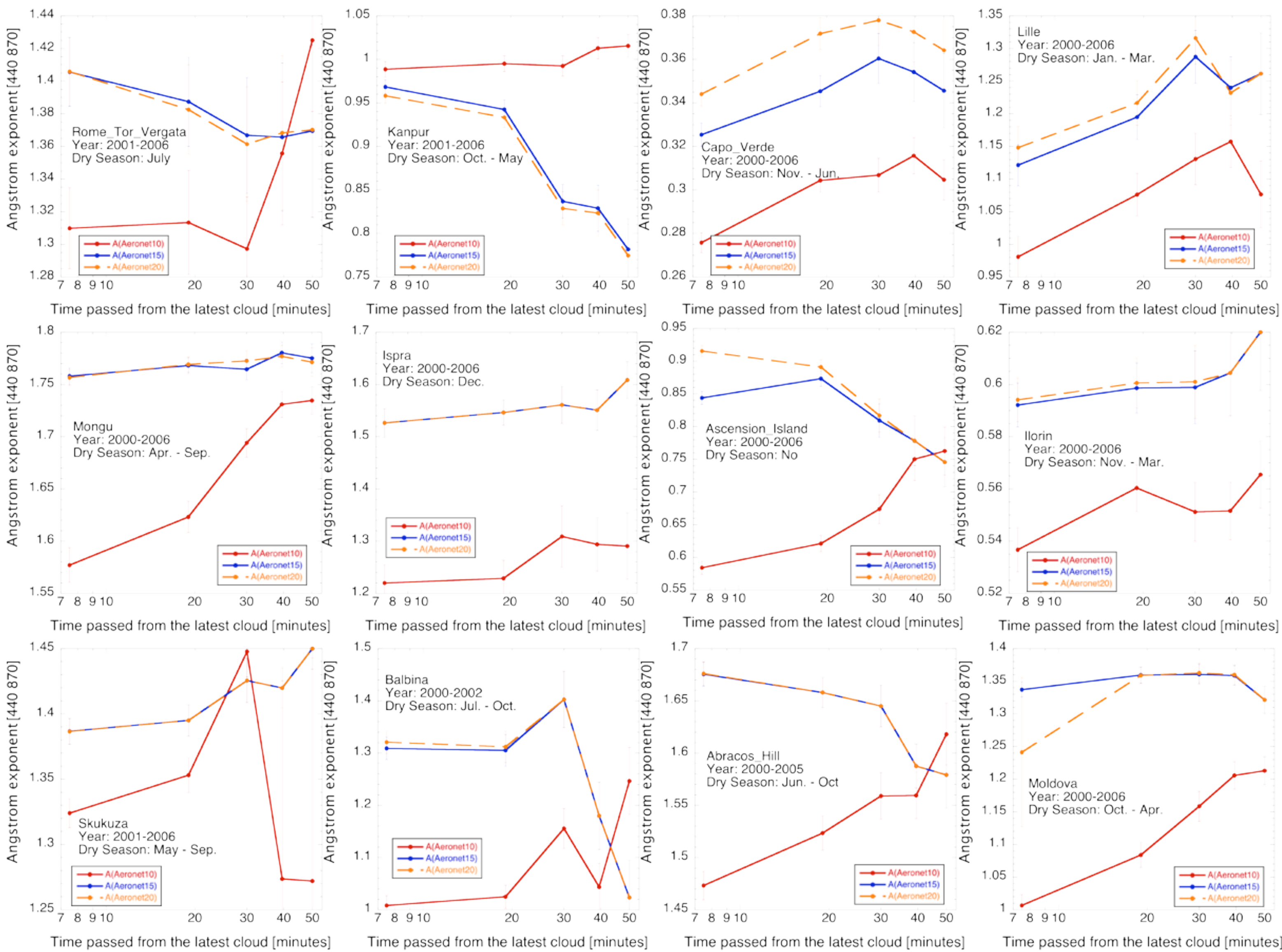


Capo_Verde
Level10: 3127, 2410, 1257,1119, 846
Level15: 2367, 1650,700, 542, 317
Level20: 2181, 1519, 658, 509, 295

Ilorin
Level10: 1757, 1510, 938, 861, 632
Level15: 1700, 1251, 556, 381, 203
Level20: 1677, 1233, 550, 381, 203

Moldova
Level10: 1079, 814, 446, 413, 374
Level15: 906, 683, 347, 264, 175
Level20: 882, 639, 345, 263, 175

12 other AERONET stations around the globe: AE (440-870 nm)



E-folding distance decreases with cloud fraction