Smoke over clouds: Response of marine stratocumulus to African savannah burning

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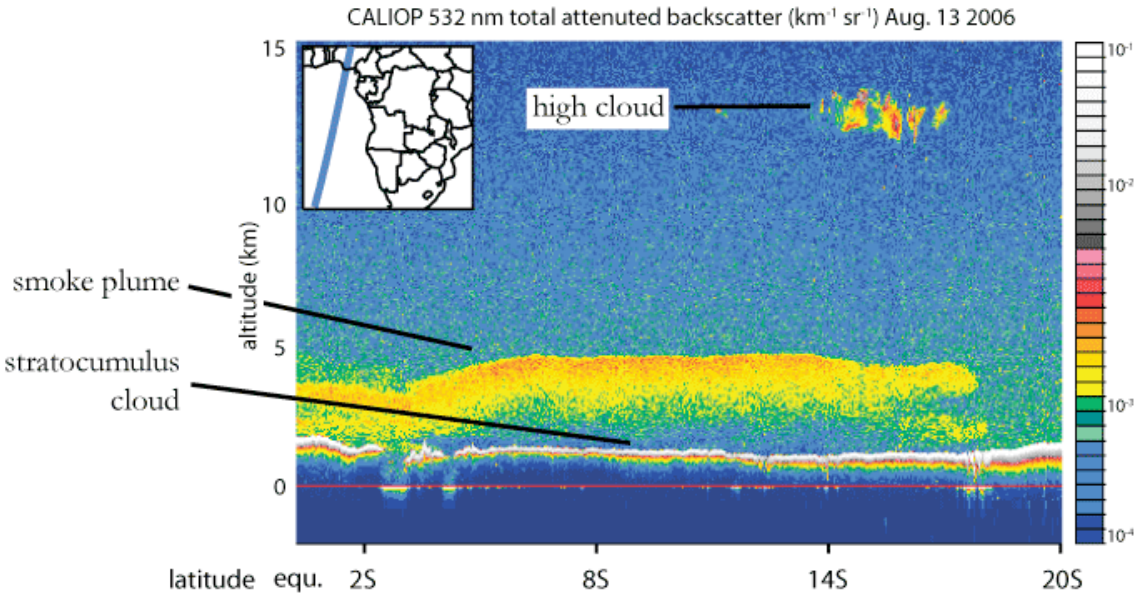
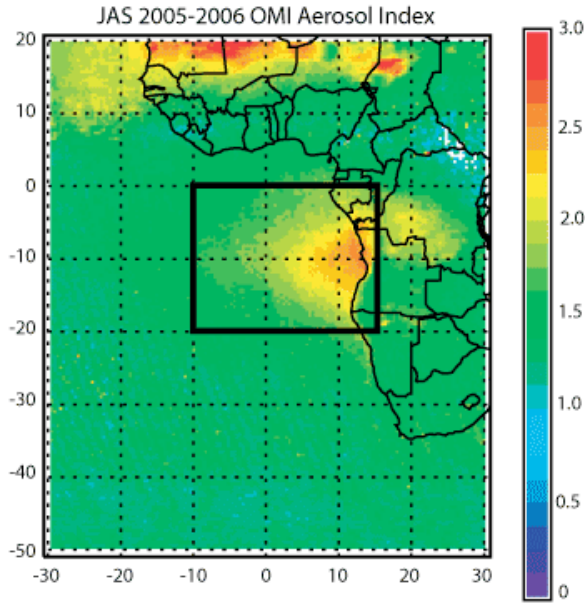


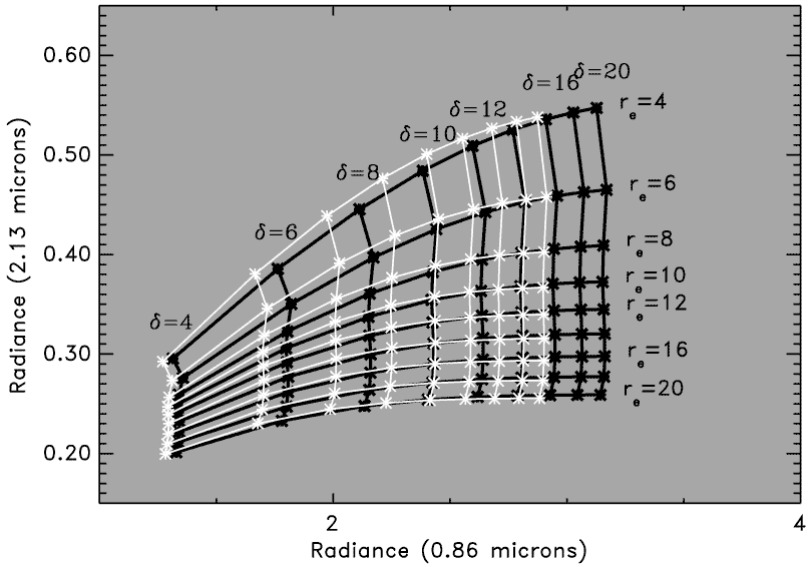


1) Impact on MODIS cloud retrievals.

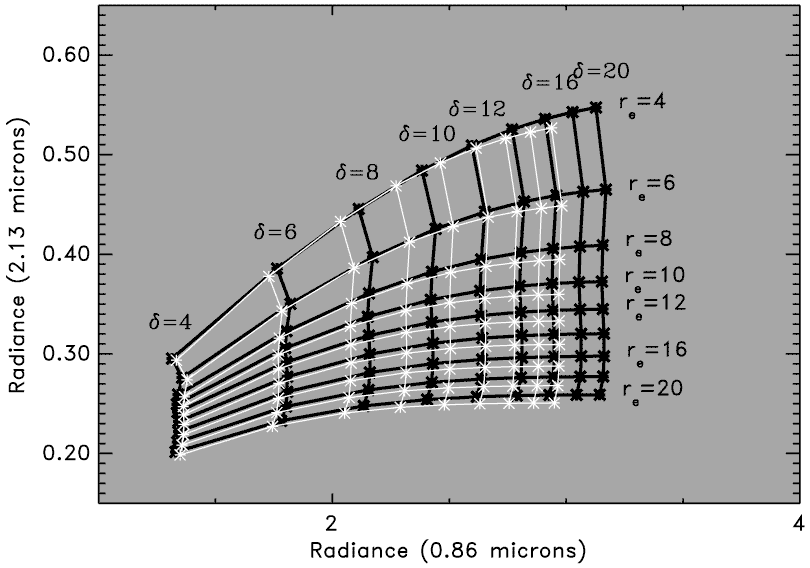
2) Impact on cloud liquid water path.

3) Estimate of radiative forcing.

Smoke over clouds: impact on MODIS retrievals



Biomass burning aerosol over cloud
(mean aerosol $ssa_{0.87\mu m}$=0.86)



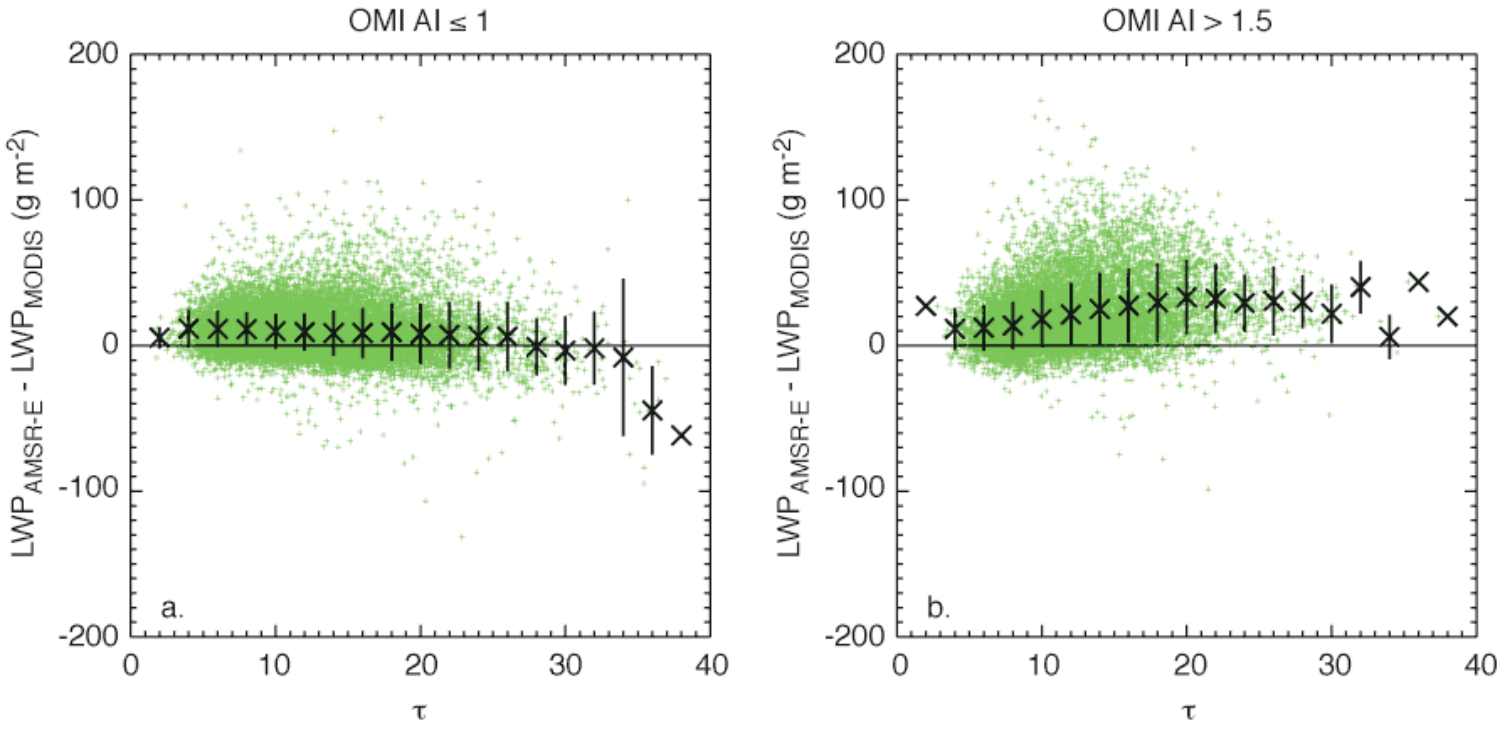
Dust aerosol over cloud
(mean aerosol $ssa_{0.87\mu m}$=0.96)

Haywood et al. (2004)

Smoke over clouds: impact on MODIS retrievals

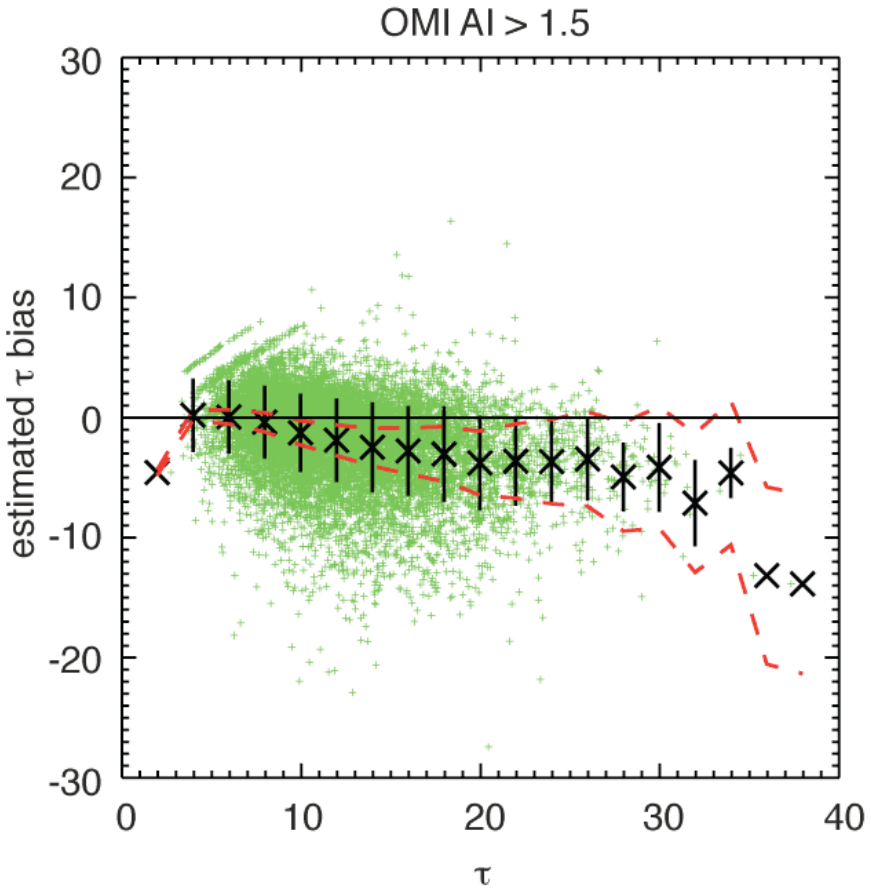
LWP ≈ 5/9tr_e where t and r_e retrieved from MODIS
LWP also proportional to microwave emission observed by AMSR-E

Each sample is an average over 0.25 deg. overcast grid box.



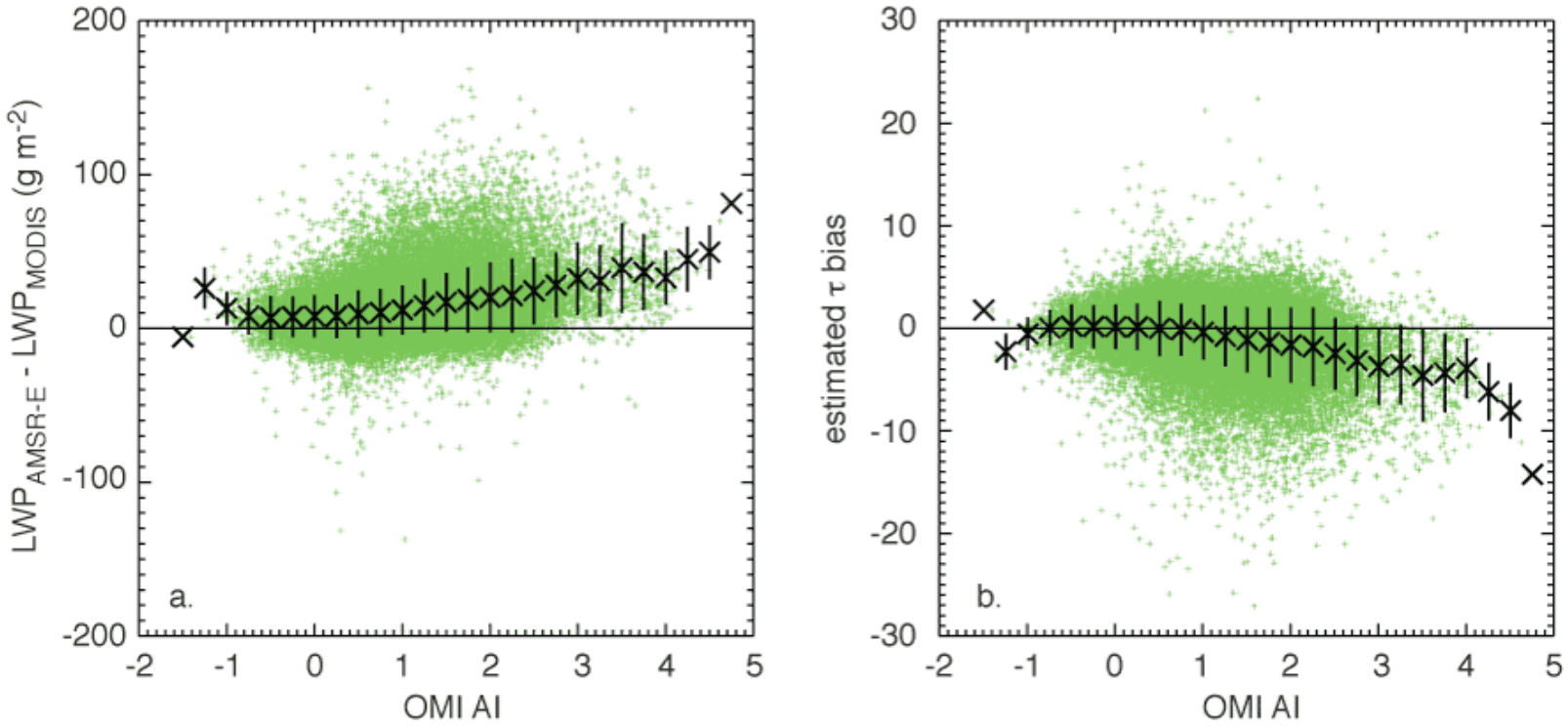
Difference for high OMI AI indicates a bias that increases with cloud optical depth.

Smoke over clouds: impact on MODIS retrievals



If all of the difference is interpreted as bias in cloud optical thickness, then the bias is comparable to estimated uncertainty in instantaneous optical thickness retrieval (red lines) or RMS variability of the LWP difference (vertical black bars).

Smoke over clouds: impact on MODIS retrievals

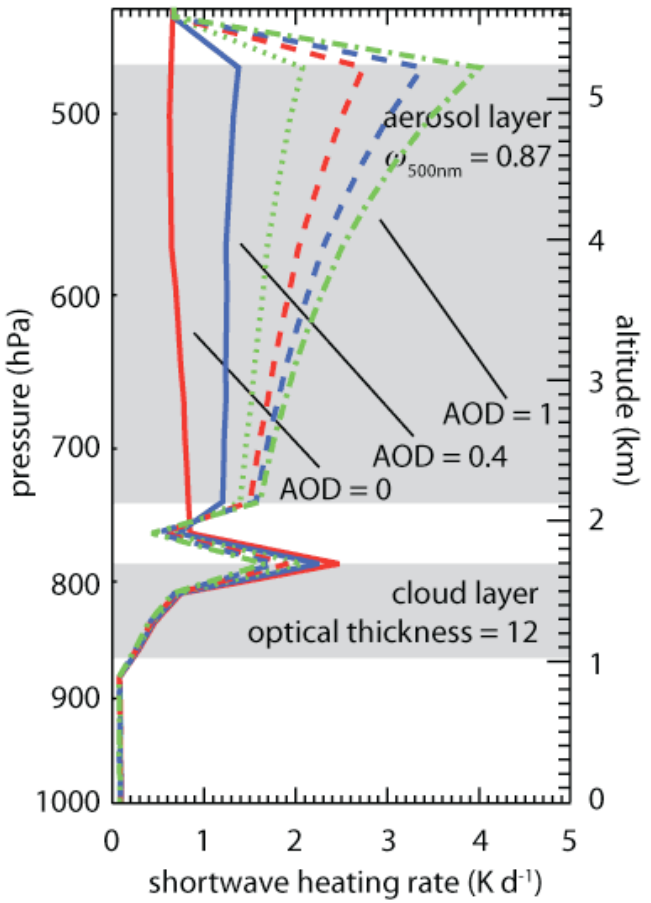


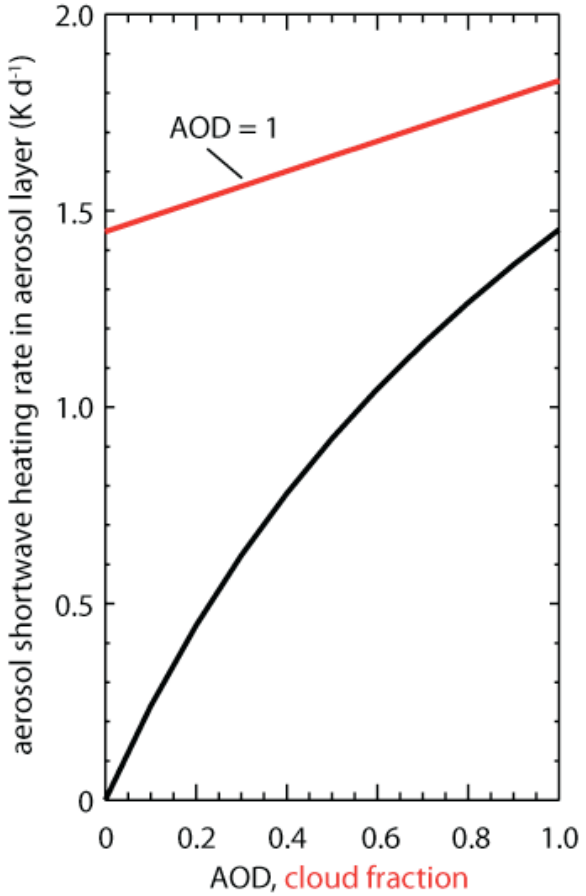
LWP difference increases with OMI AI above cloud. If all of difference interpreted as a bias in cloud optical thickness, then bias only exceeds RMS variability and estimated uncertainty in LWP retrieval for OMI AI>2 (~9% of overcast samples).

Low OMI AI samples indicate a mean bias not attributable to smoke.

Wilcox, E. M., Harshvardhan, and S. Platnick (2009), Estimate of the impact of absorbing aerosol over cloud on the MODIS retrievals of cloud optical thickness and effective radius using two independent retrievals of liquid water path, *J. Geophys. Res.*, **114**, D05210, doi:10.1029/2008JD010589.

Smoke over clouds: impact on clouds



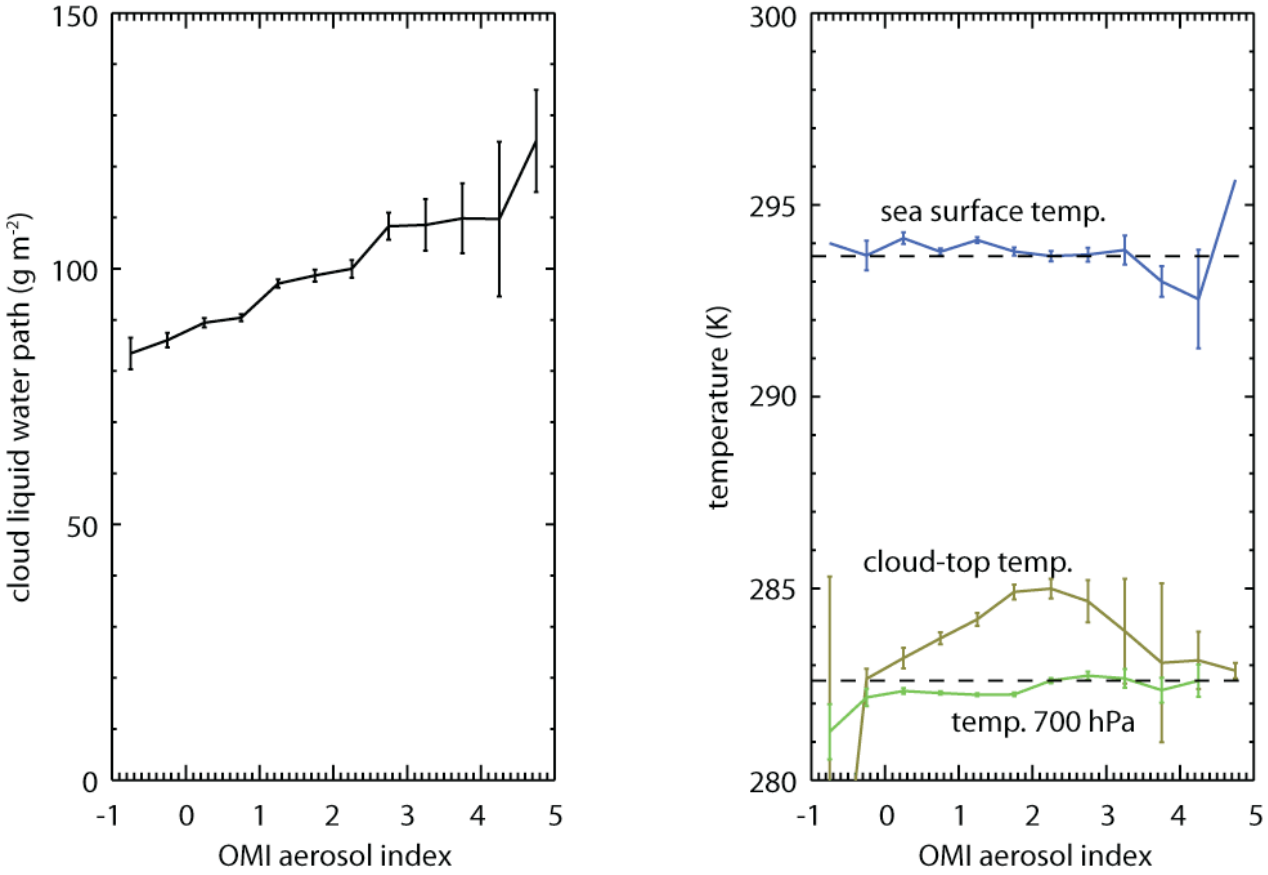


Assuming smoke lies above the cloud, heating in the aerosol layer increases with AOD and cloud-top heating reduced.

Smoke layer heating for high AOD cases increases with cloud fraction.

Diurnal mean calculations using Chou (1992) RT model.

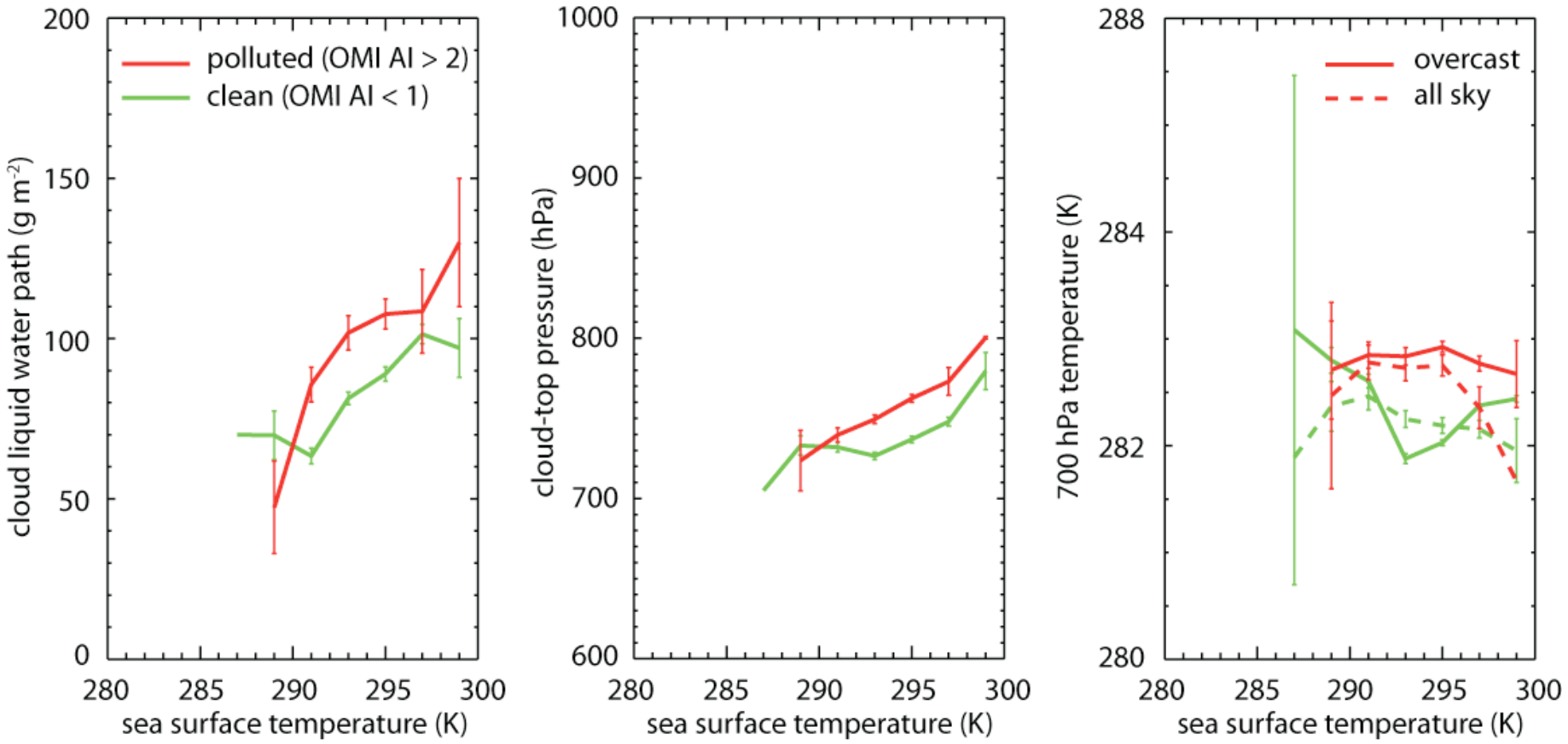
Smoke over clouds: impact on clouds



AMSR-E LWP for overcast samples positively correlated with OMI AI.

AIRS 700 hPa temperature also positively correlated.

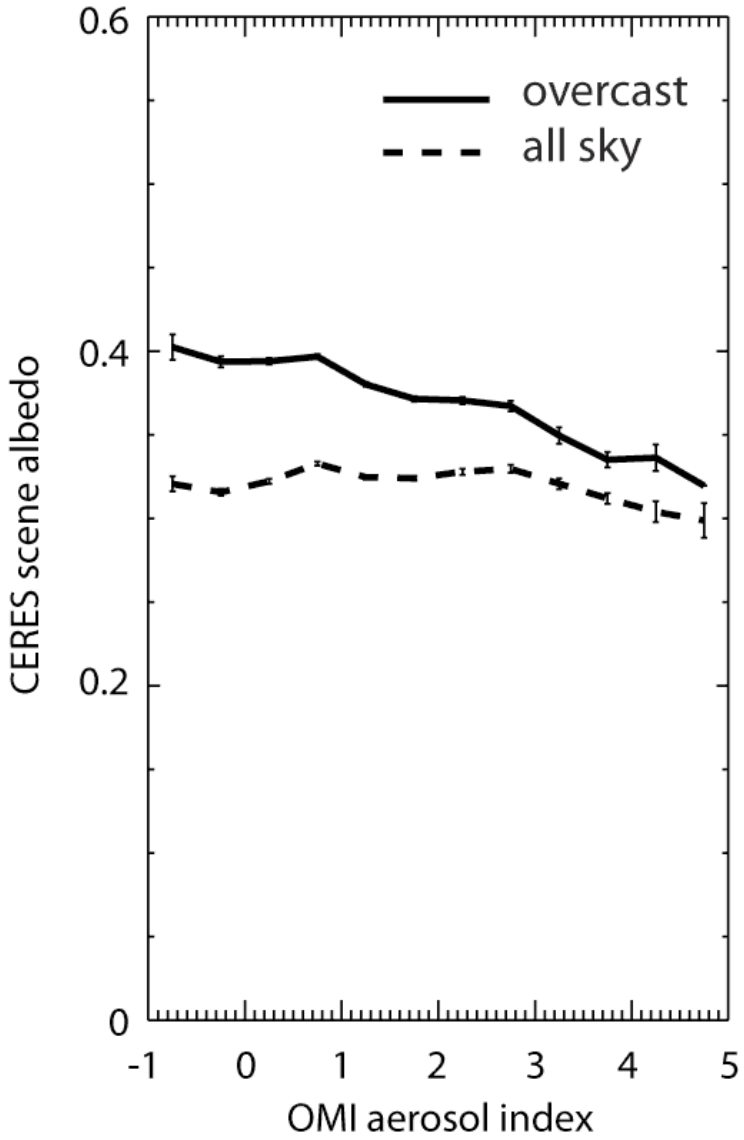
Smoke over clouds: impact on clouds



LWP and cloud-top pressure higher for high-smoke cases compared to clean, independent of SST.

Hypothesis: warming of the 700 hPa layer above the cloud-top boundary layer inhibits cloud-top entrainment, (a) preserving boundary layer humidity, (b) enhancing LWP, and (c) enhancing subsidence of cloud-top (Johnson et al. 2004).

Smoke over clouds: radiative forcing



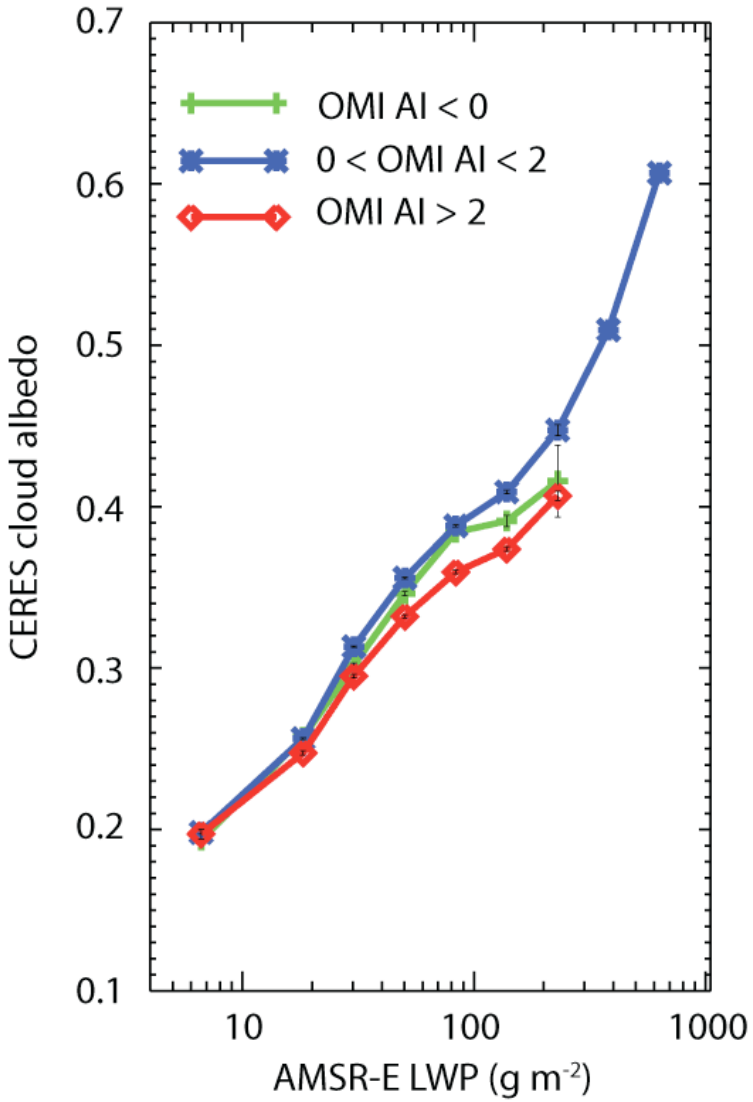
Smoke over clouds darkens the scene. This implies positive radiative forcing.

Little dependence of scene albedo on OMI AI for all-sky conditions, but clear negative correlation for overcast conditions.

There is a critical cloud fraction above which the radiative forcing of the aerosol turns from negative to positive (Chand et al. 2009; Podgorny and Ramanathan 2001).

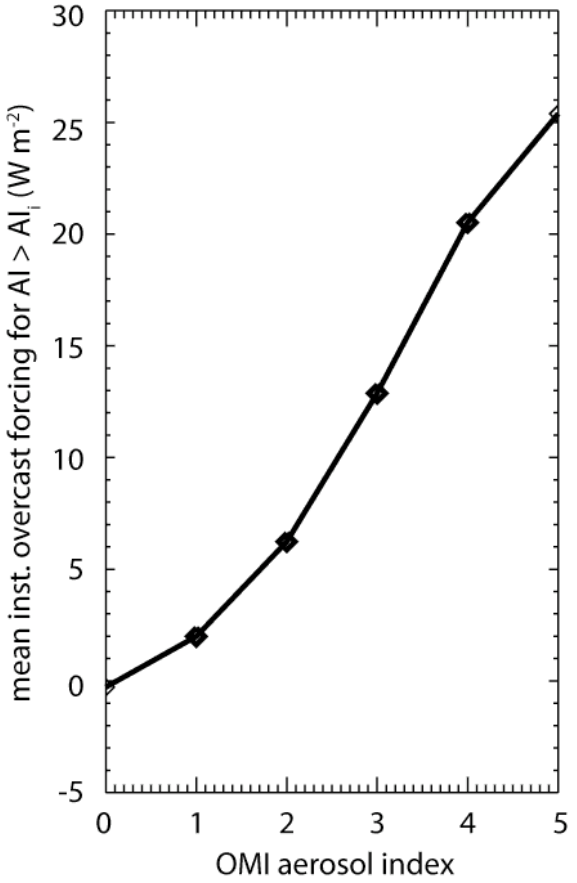
About 0.4 for SE Atlantic (Chand et al.) but depends on ssa of aerosol and optical thickness of the cloud.

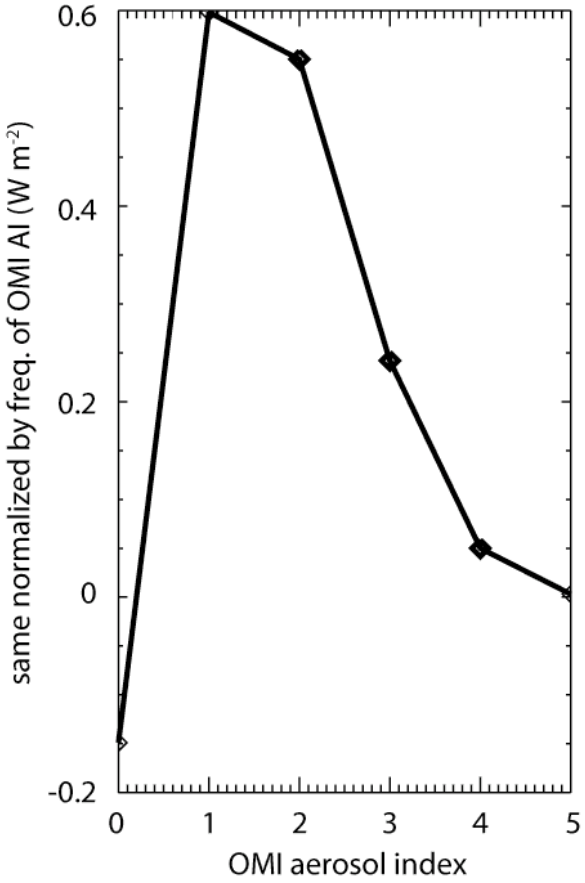
Smoke over clouds: radiative forcing



For overcast conditions the CERES albedo for a given LWP is lower for higher OMI AI.

Smoke over clouds: radiative forcing





$$\frac{1}{N_{AI>AI_i}} \sum_{AI>AI_i} S_o\left(a_{AI<0}^{LWP} - a^{LWP}\right) \qquad S_o\left(\frac{\Delta a}{\Delta \log(LWP)} \Delta \log(LWP)_{AI>2}\right) \approx -15 Wm^{-2}$$

Negative radiative forcing of enhanced LWP may more than cancel positive direct radiative forcing of smoke.

Smoke over clouds: summary

When smoke lies over clouds, the scene darkens the scene.

This leads to a bias in MODIS cloud optical thickness.

Bias only exceeds RMS variability and estimated uncertainty in LWP retrieval for OMI AI>2 (~9% of overcast samples).

LWP and cloud-top pressure higher for high-smoke cases compared to clean, independent of SST.

Hypothesis: warming of the 700 hPa layer above the cloud-top boundary layer inhibits cloud-top entrainment, (a) preserving boundary layer humidity, (b) enhancing LWP, and (c) enhancing subsidence of cloud-top (Johnson et al. 2004).

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