Dynamics of shallow cumulus and stratocumulus clouds in the presence of black carbon aerosol

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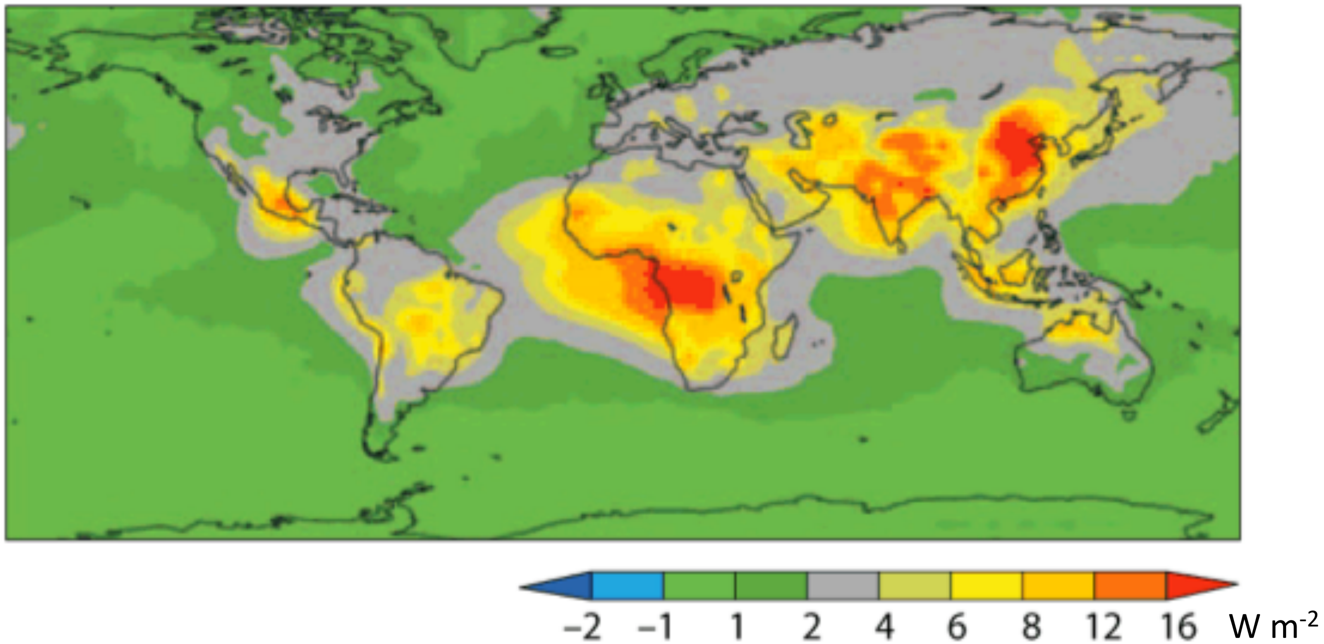
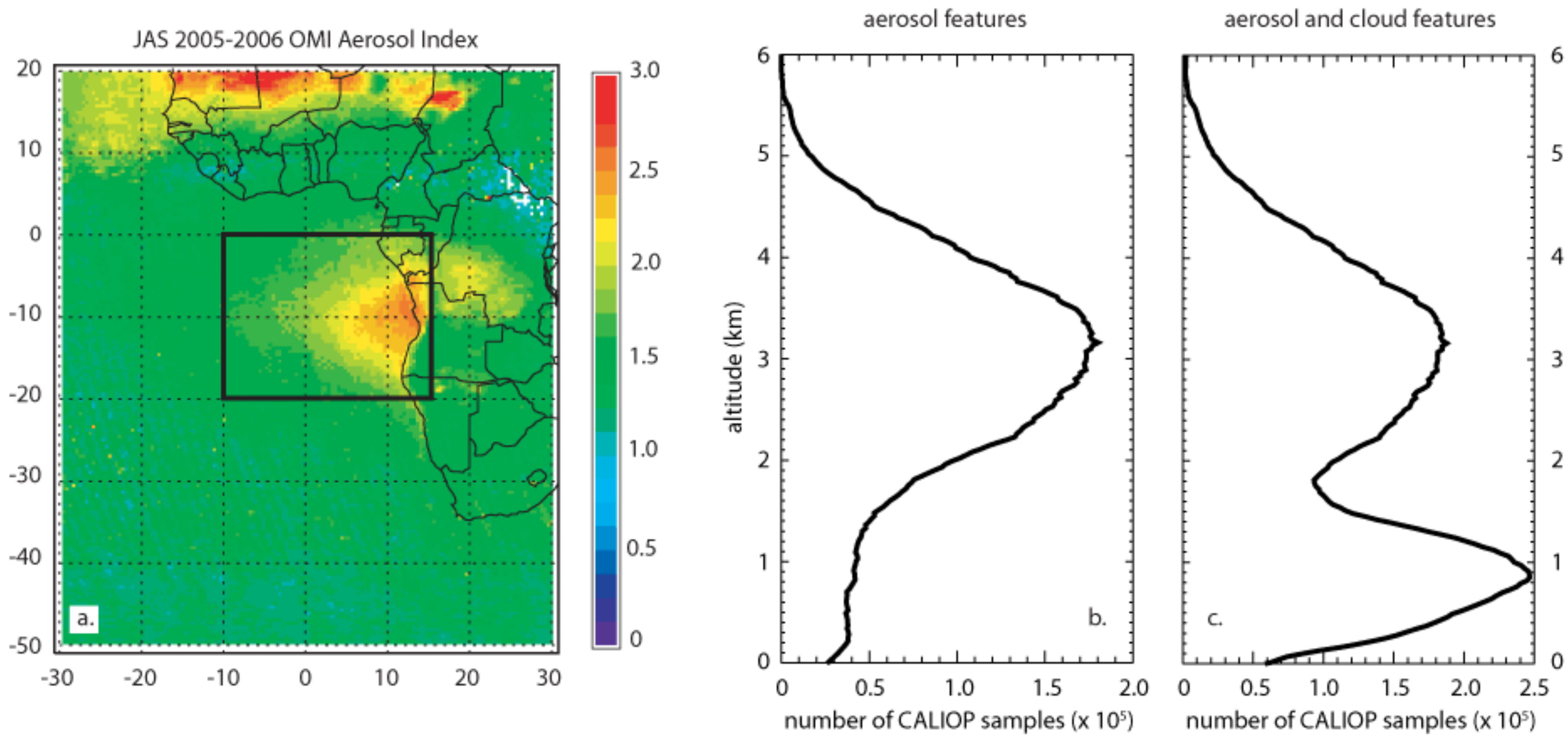
Light absorbing black carbon aerosols

Atmospheric heating by aerosol absorption



Chung et al. (2005) via Ramanathan and Carmichael (2008)

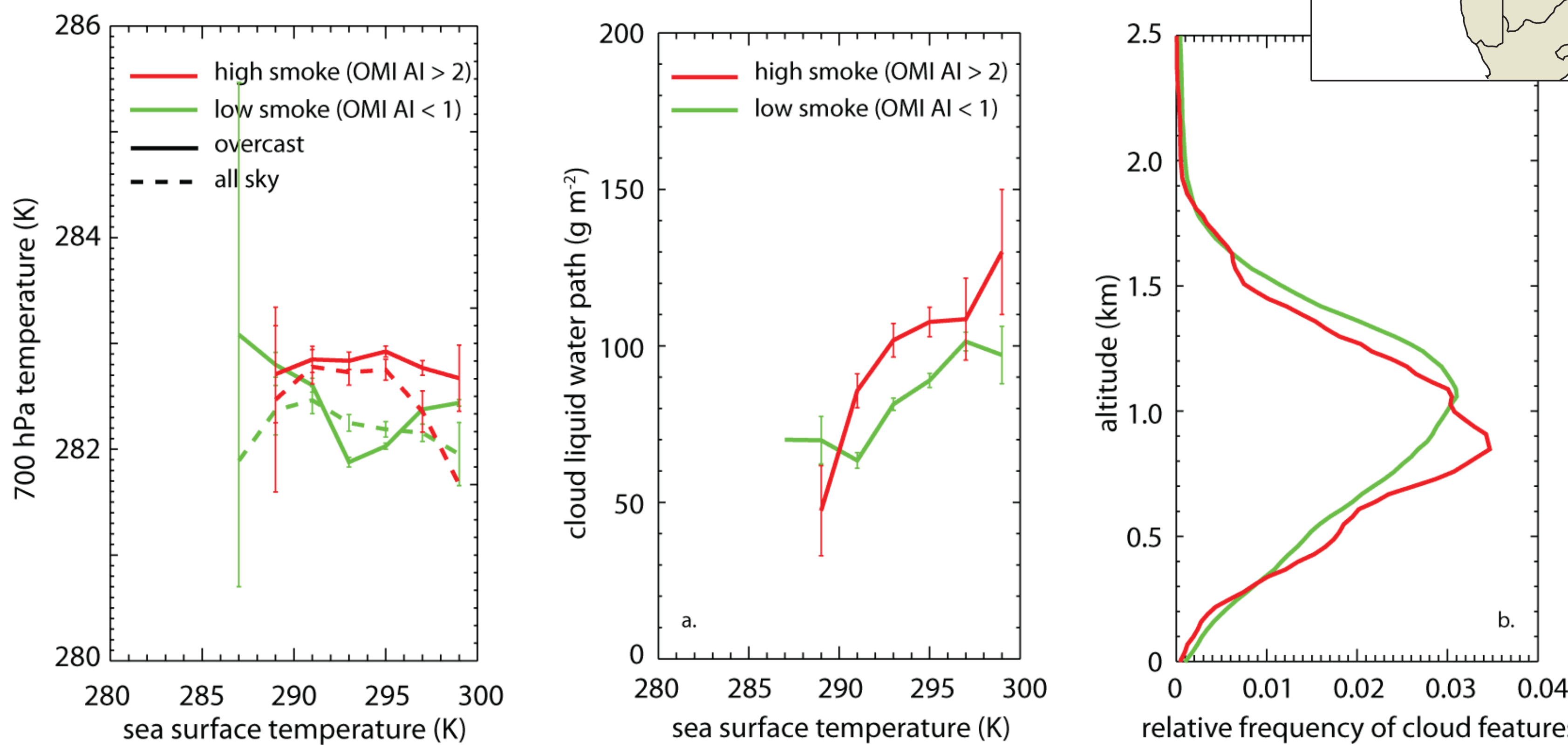
Light absorbing smoke over stratocumulus clouds



- Absorbing smoke aerosols in a deep layer above the boundary layer.
- Stratocumulus cloud deck beneath a capping inversion at the top of the marine boundary layer.

Wilcox (2010)

Light absorbing smoke over stratocumulus clouds



LWP and cloud-top temperature higher for high-smoke cases compared to clean, independent of SST. Cloud tops are lower for high-smoke cases.

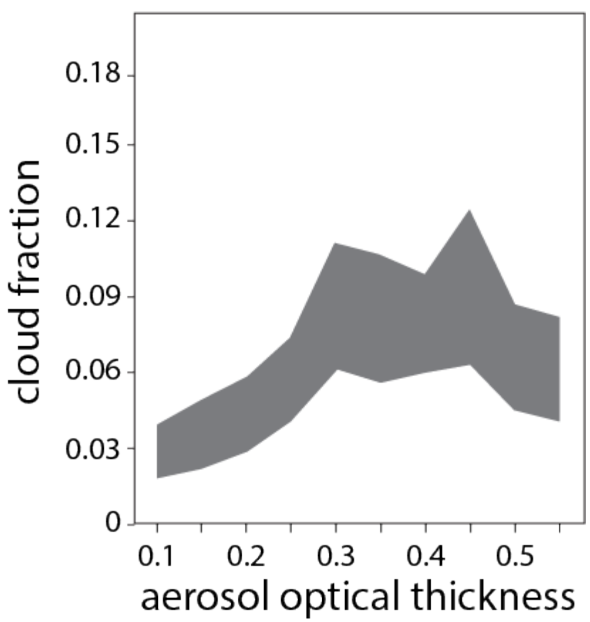
Mechanism: warming of the 700 hPa layer above the cloud-top boundary layer inhibits cloud-top entrainment, (a) preserving boundary layer humidity, (b) enhancing LWP, and (c) promoting subsidence of cloud-top.

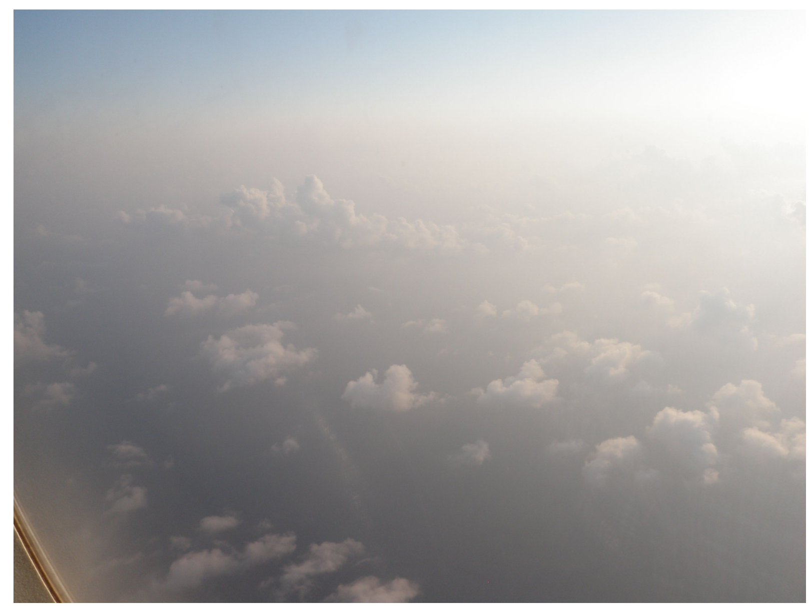
Wilcox (2010)

Light absorbing smoke over cumulus clouds

Satellite (ASTER) cloud observations suggest mainly increasing cloud cover with increasing aerosol.

N. Indian Ocean



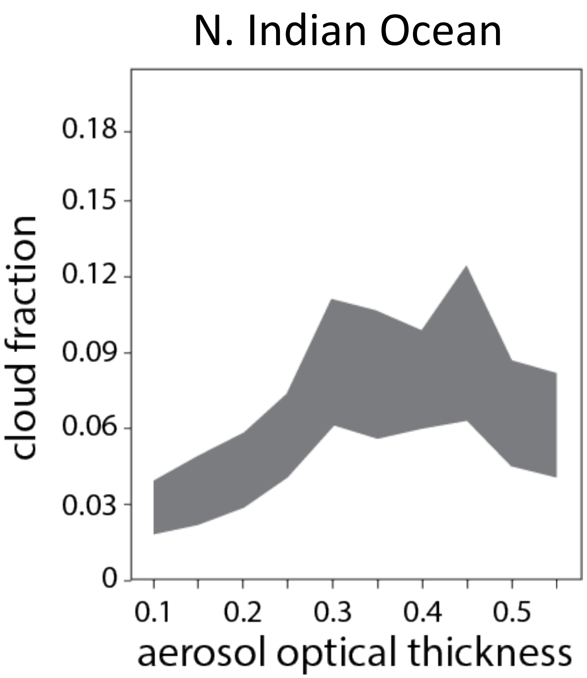


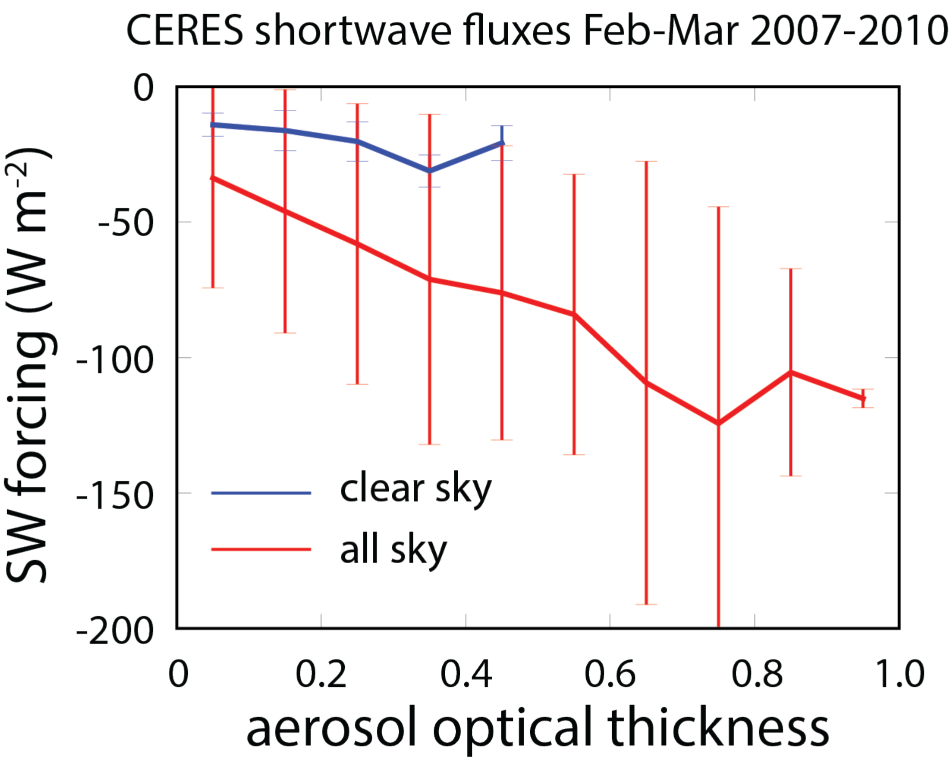
adapted from: Dey et al. GRL (2011)

Light absorbing smoke over cumulus clouds

Satellite (ASTER) cloud observations suggest mainly increasing cloud cover with increasing aerosol.

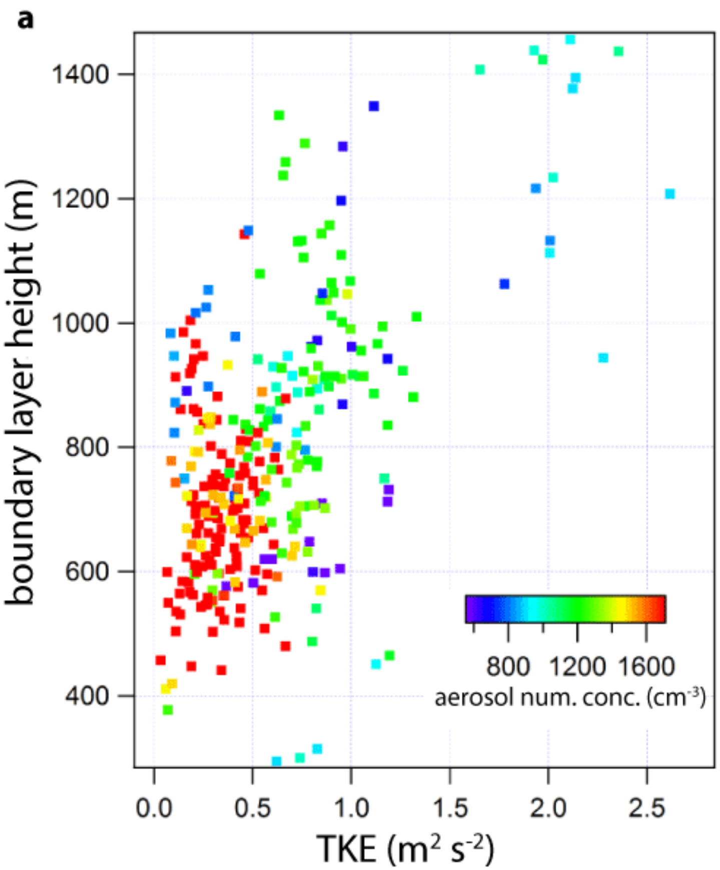
CERES indicates brighter clouds

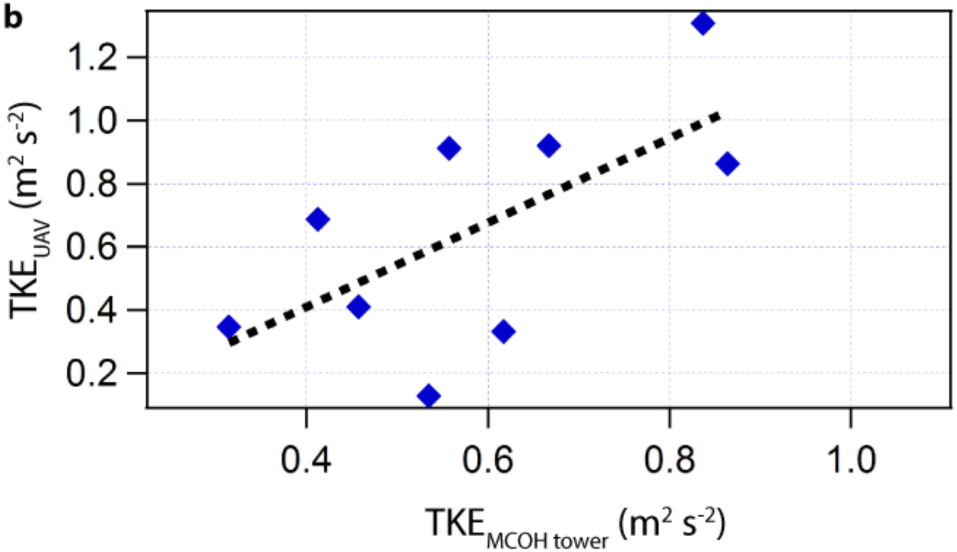




adapted from: Dey et al. GRL (2011)

Black carbon suppresses turbulence in the boundary layer



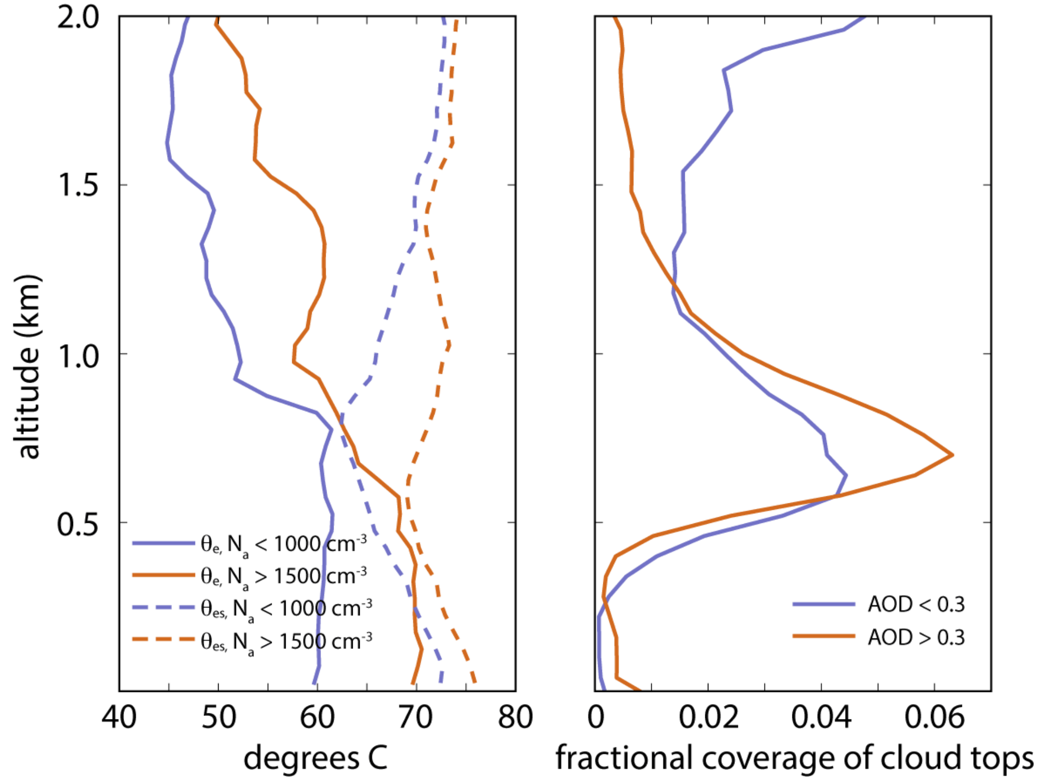


As the aerosol number concentration in the boundary layer increases:

- turbulent kinetic energy is reduced,
- boundary layer top is lower,
- latent heat flux from surface reduced from 99 to 61 W m^{-2}.

Wilcox et al., PNAS (2016)

Semi-direct effect for shallow cumulus clouds



Profiles with UAV aircraft show that more polluted boundary layer is:

- warmer (+1 K),
- more humid (+8% RH),
- has a thicker saturated cloud layer, and
- has cloud tops that penetrate deeper into the free troposphere.

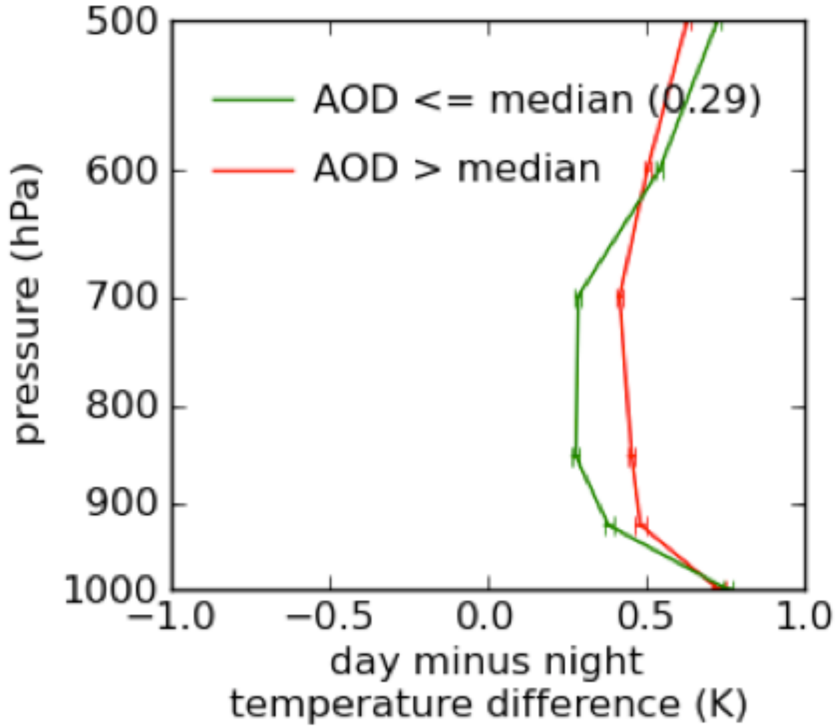
Wilcox et al., PNAS (2016)

Signatures of semi-direct effects in satellite observations

For studies in select locations:

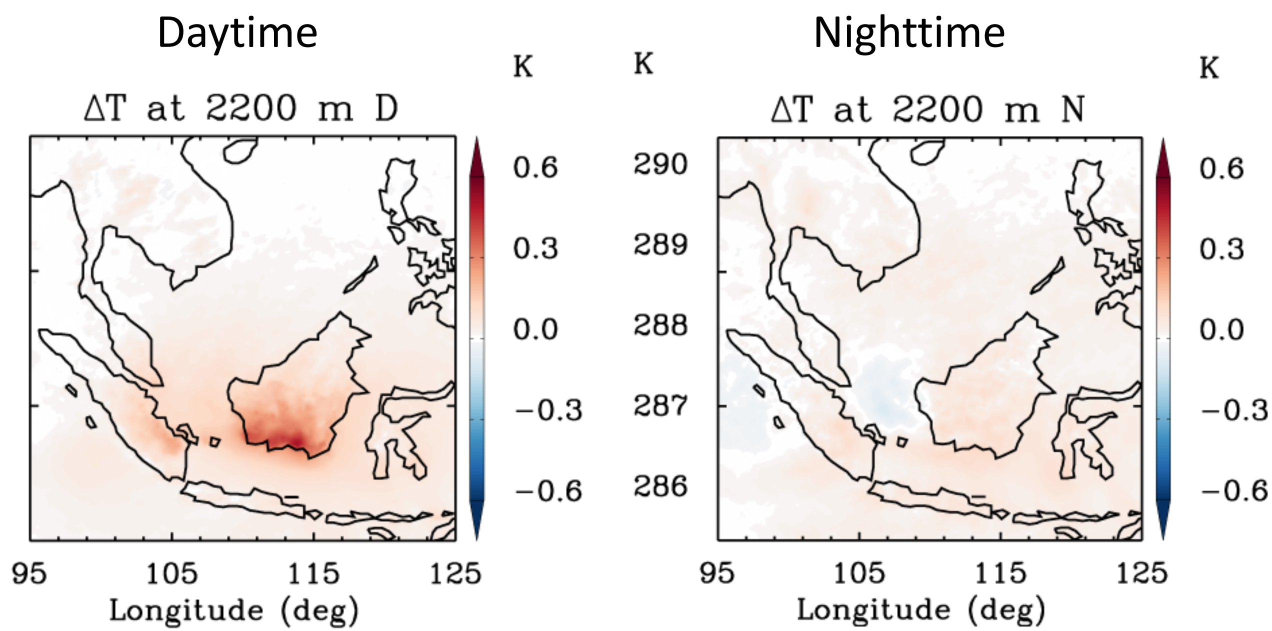
- warmer air temperature in aerosol layer
- greater boundary layer humidity (?)
- greater liquid water path or cloud fraction
- change in cloud tops

AIRS temperature



Signatures of semi-direct effects in satellite observations

In satellite observations of nature the result reflects not just the aerosol effect, but also the response.



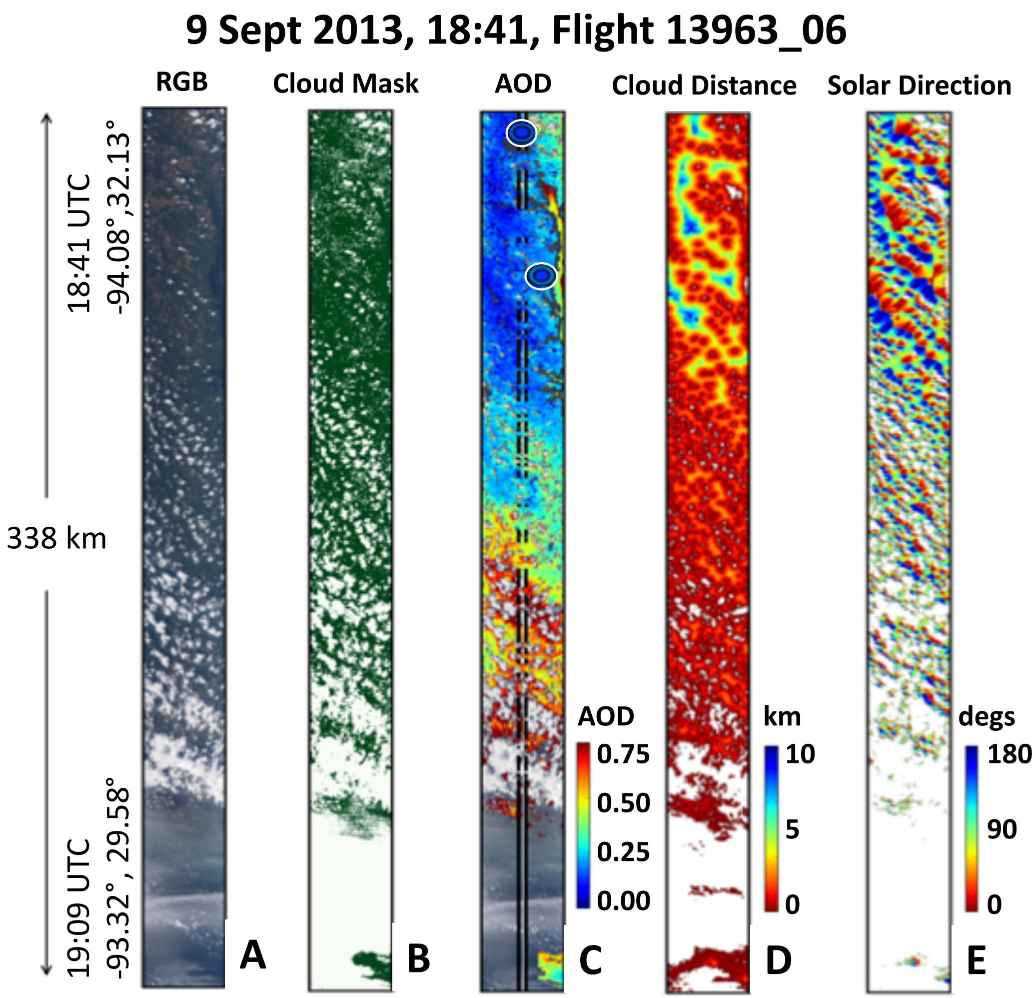
WRFchem simulations: differences between simulation with BC aerosols and simulation without.

Ge et al. (2014)

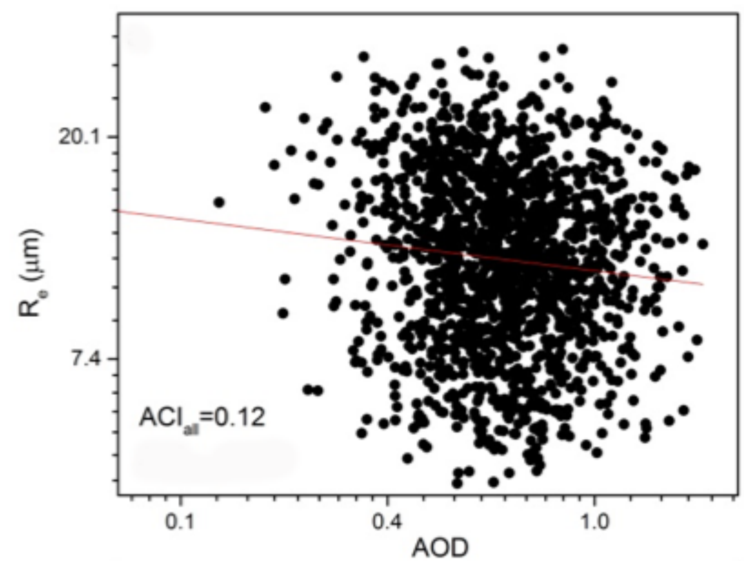
Conclusions so far:

- Over S.E. Atlantic Ocean, absorbing aerosols reduce turbulent entrainment in stratocumulus clouds, leading to thicker clouds and higher albedo.
- Over N. Indian Ocean, similar response is seen for absorbing aerosols over cumulus clouds leading to higher albedo.
- We seek satellite analysis to observe more generally the response to BC aerosols of: Temperature, humidity, boundary layer depth, albedo
- Over Amazon, absorbing aerosols may also reduce turbulence.
- However, boundary layer humidity decreases, rather than increases, so increasing solar radiation due to cloud “burn off” compensates for aerosol reduction in radiation.

Aerosol-cloud interactions from eMAS during SEAC4RS



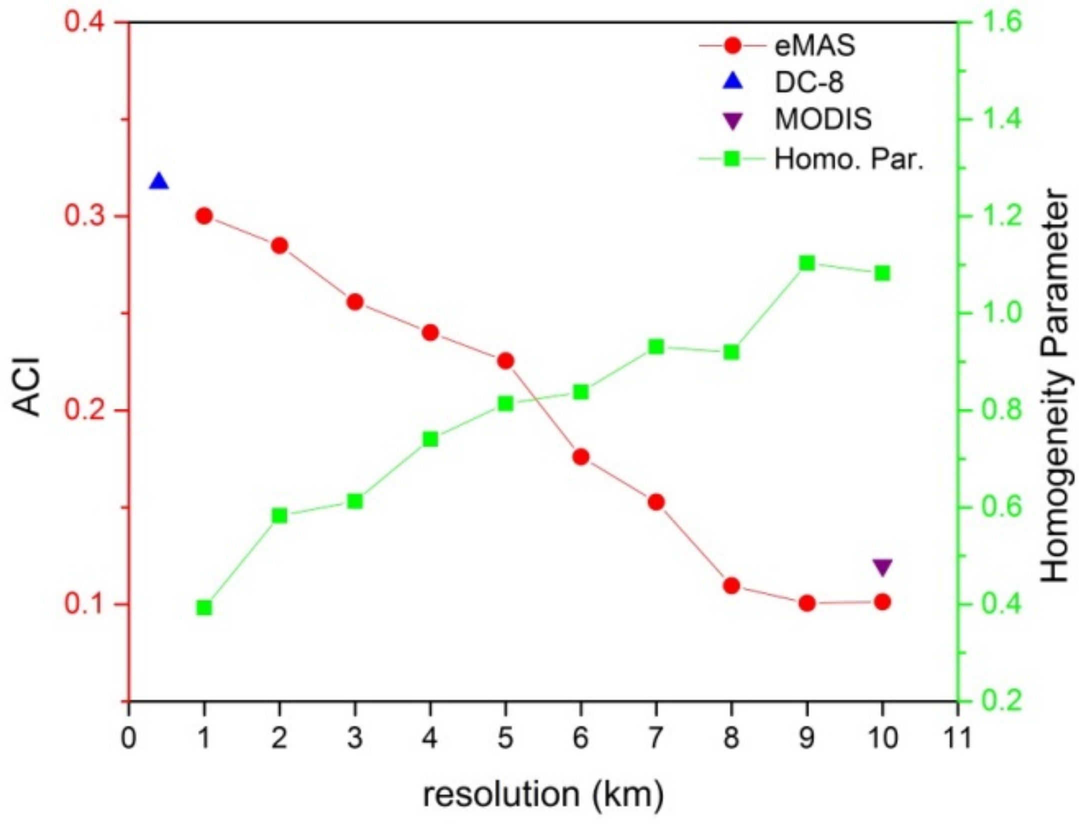
$$ACI = -\frac{dlnR_e}{dlnAOD}$$



Spencer et al. JGR (in review)

Gao et al. (in prep.)

Aerosol-cloud interactions from eMAS during SEAC4RS

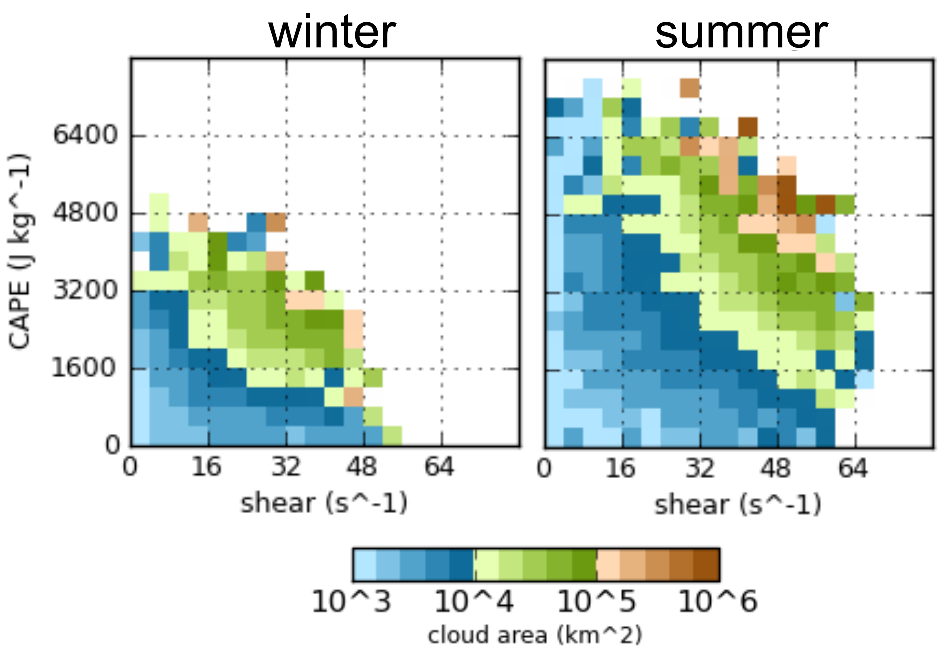


ACI is scale dependent: MODIS systematically underestimates the magnitude of ACI compared to in-situ measurements.

eMAS has allowed us to bridge the gap in resolution and quantify the scale dependence.

Gao et al. (in prep.)

A new climatology of deep convective clouds (DCC) based on an object-oriented approach (see poster)



DCC size depends strongly on CAPE and shear of horizontal wind.

DCC size distribution similar in summer and winter in spite of greater CAPE/shear in summer.

Controlling for CAPE/shear reveals variety of responses of DCC to variations in aerosol (more on poster).

Will be producing a near-global database of millions of DCC over Terra/Aqua period.