UNIVERSITÉ DE VERSAILLES SAINT-QUENTIN-EN-YVELINES

LSCE LABORATOIRE DES SCIENCES DU CLIMAT & DE L'ENVIRONNEMENT

cea energie atomique • energies alternatives

DGA DÉLÉGATION GÉNÉRALE POUR L'ARMEMENT

Remote sensing of atmospheric aerosol, clouds and aerosol-cloud interactions.

Bremen, 16-19 December 2013

Satellite analysis of aerosol indirect effect on stratocumulus clouds over South-East Atlantic

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Costantino and Bréon (2011), Geo. Res. Lett.
Costantino and Bréon (2013), ACP
Costantino and Bréon (2013), ACPD

Introduction

Aerosol

AEROSOL: complex and dynamic mixture of **tiny solid and liquid particles** that float in the atmosphere

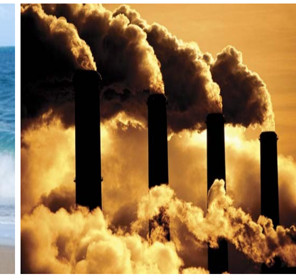

Desert dust

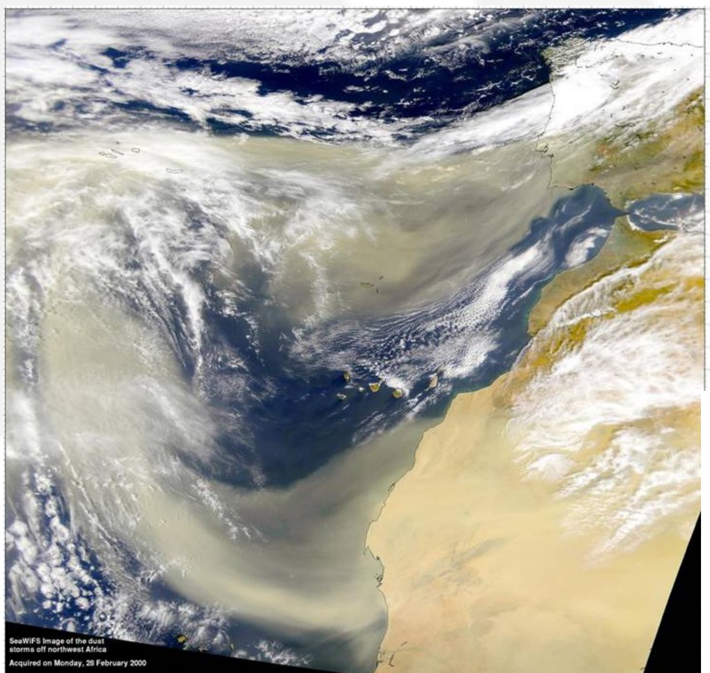

VOC from vegetation


Smoke from fires


Volcanic ash

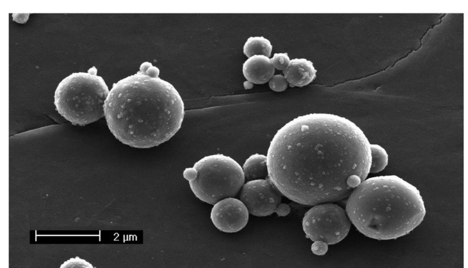

Sea salt

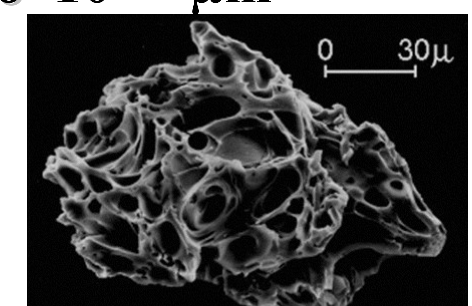

Industrial pollution



- Can be **transported** by wind to very **long distance**
- Strong **temporal** and **spatial variability**, over both land and ocean.

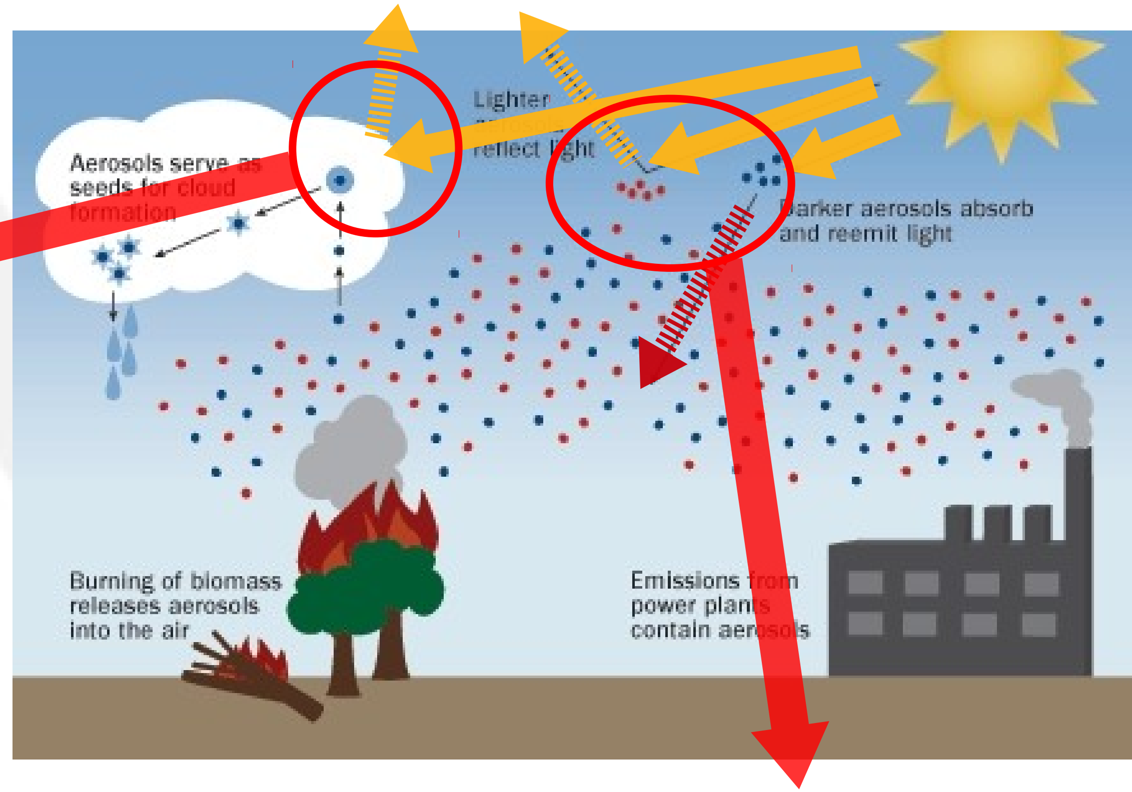
Size down to 10^{-1} µm





Aerosol Impact on Climate

SMOKE and **INDUSTRIAL POLLUTION** **can interact with solar radiation in <u>two</u> ways:**



<u>INDIRECT EFFECT:</u>

Acting as CCN aerosol can

1/ <u>modify cloud microphysics</u> and, in turn, cloud reflectivity (INDIRECT EFFECT #1)

2/ <u>affect cloud structure and life cycle</u> and, in turn, cloud reflectivity + cloud cover (INDIRECT EFFECT #2)

<u>DIRECT EFFECT:</u>

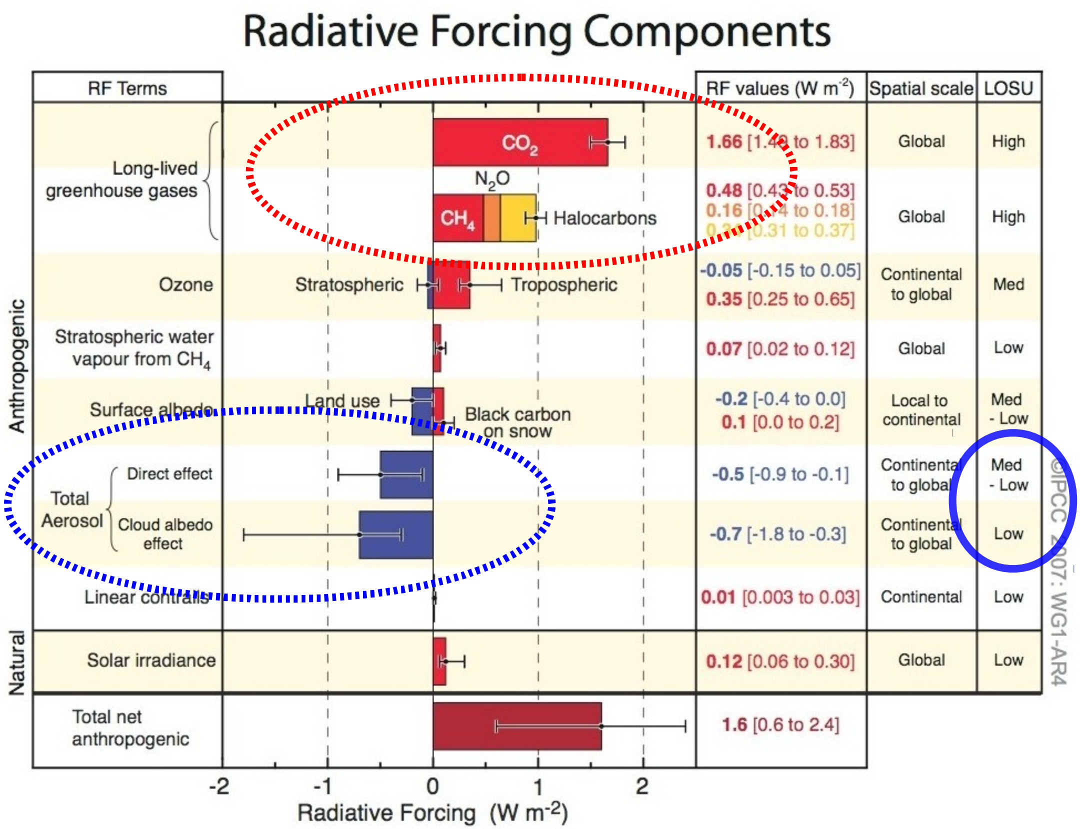
<u>Scattering</u> and <u>absorption</u> of solar radiation

Radiative Forcing

Aerosol impact on climate change:

GHG

Aerosol



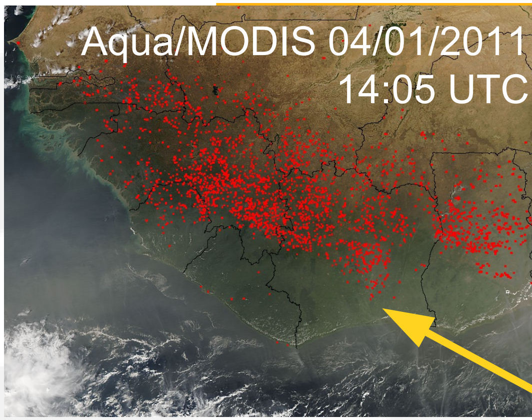
Results of IPCC report 2007

1/ SECOND most impostant ATHROPOGENIC FORCING after GHG (opposite in sign)

2/ The consequence of aerosol-cloud interaction is the PRIMARY UNCERTAINTY

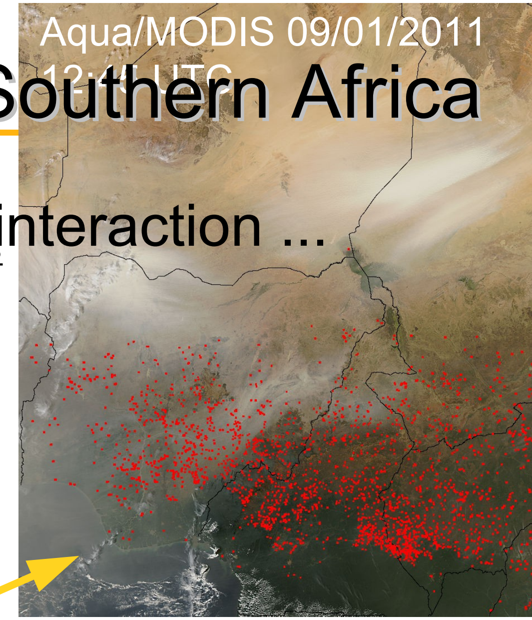
Fires in Central and Southern Africa

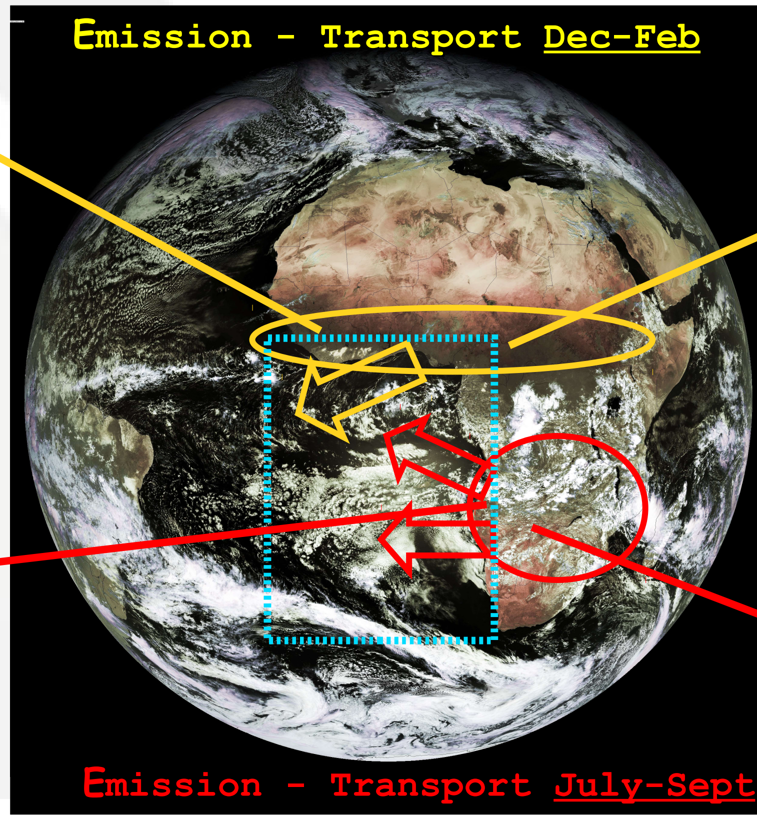
…gions to observe cloud-aerosol interaction …



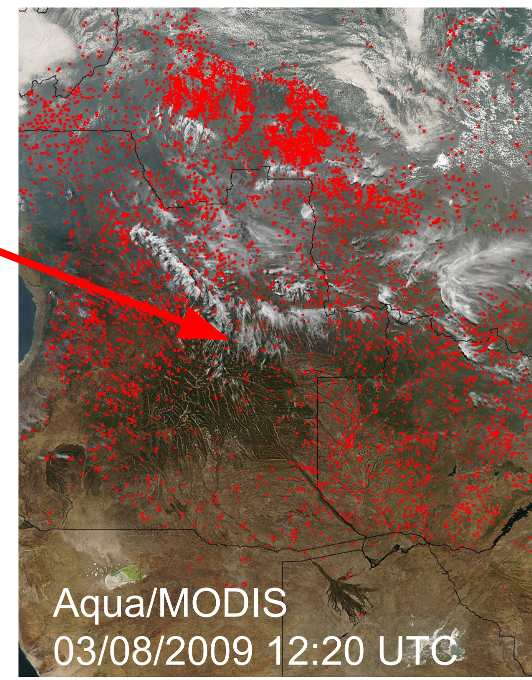
Fires in West Africa

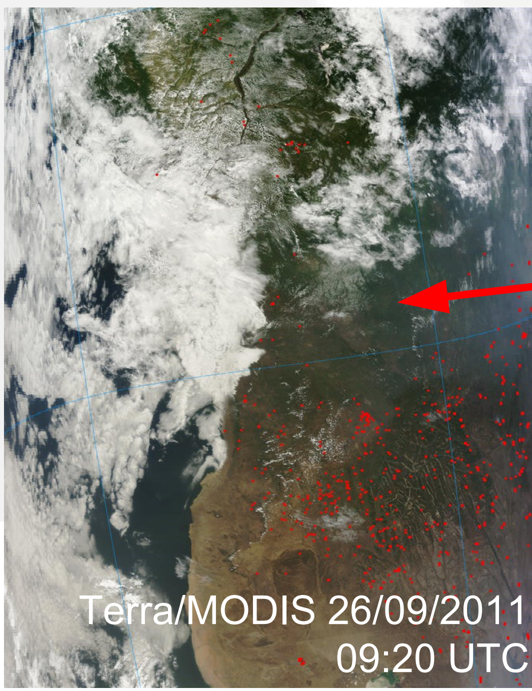
Dust and fires across Sahel





Fires in Southern Africa

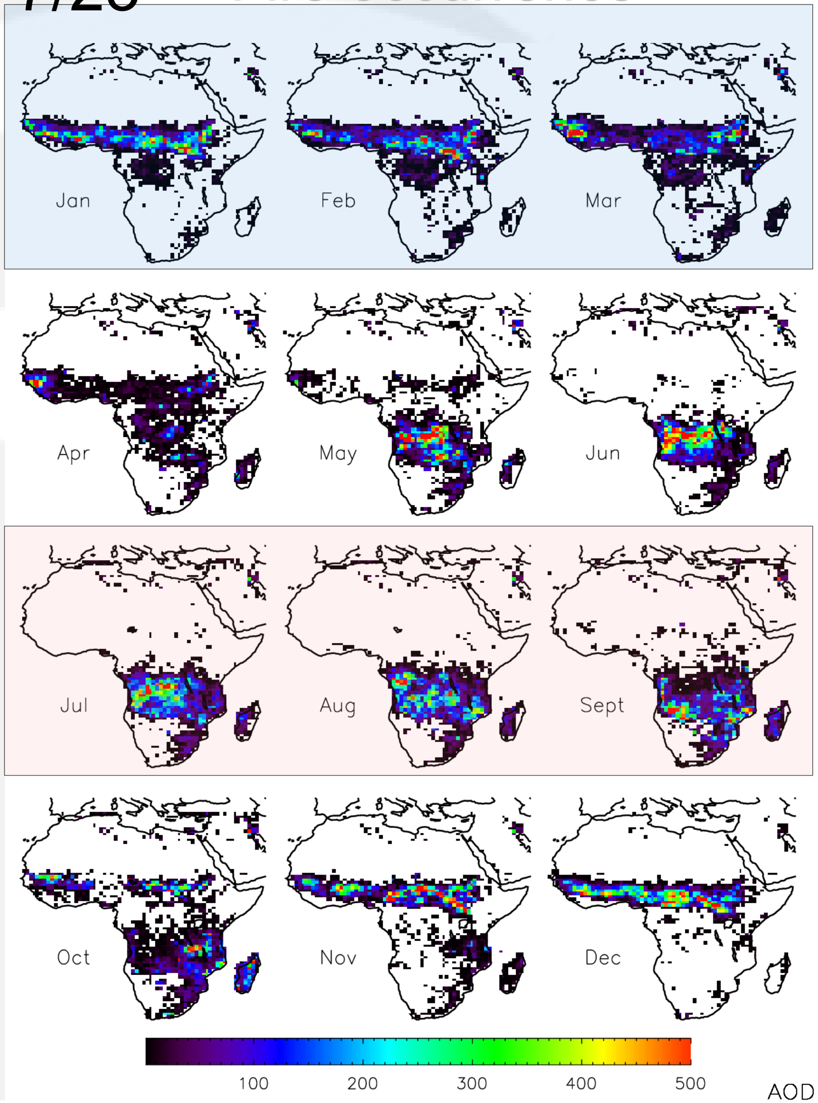




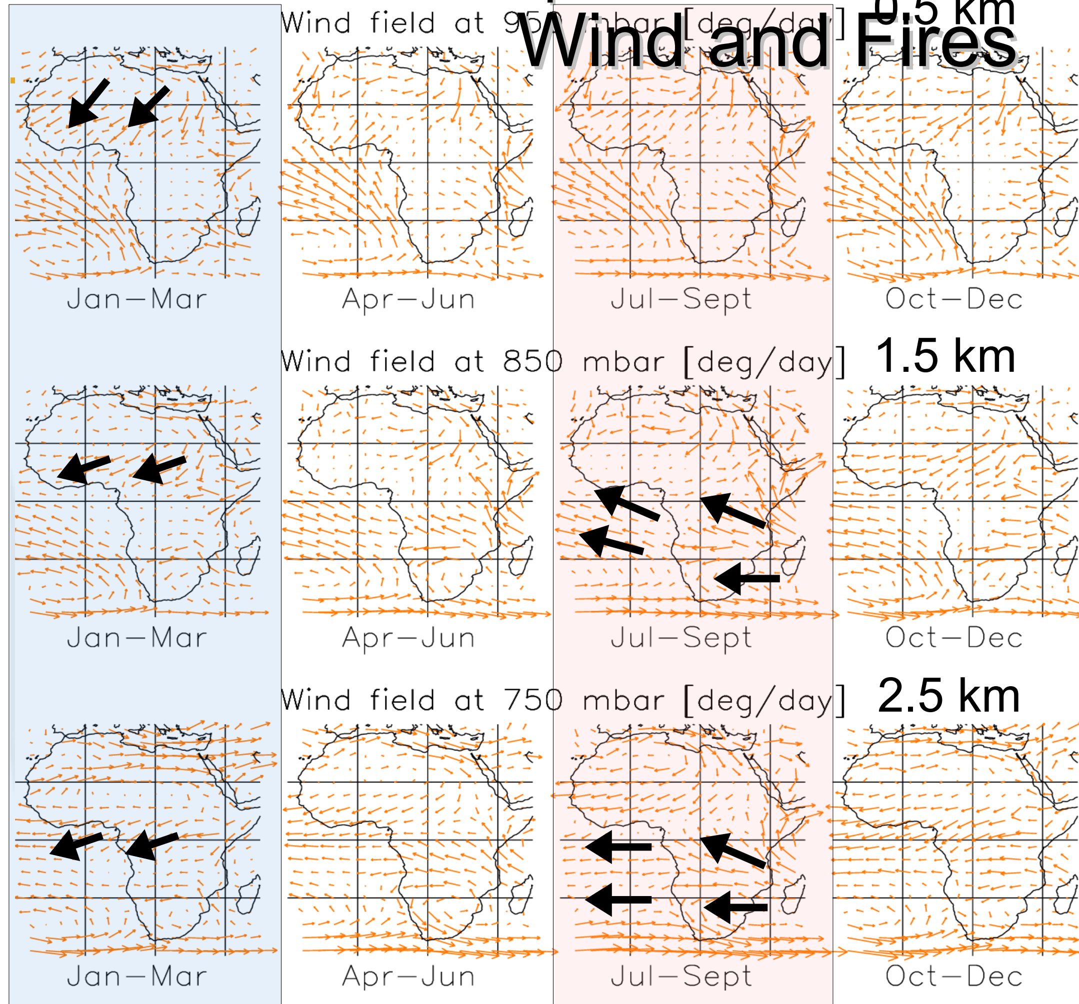
Smoke and clouds over Southern Africa

Wind and Fires

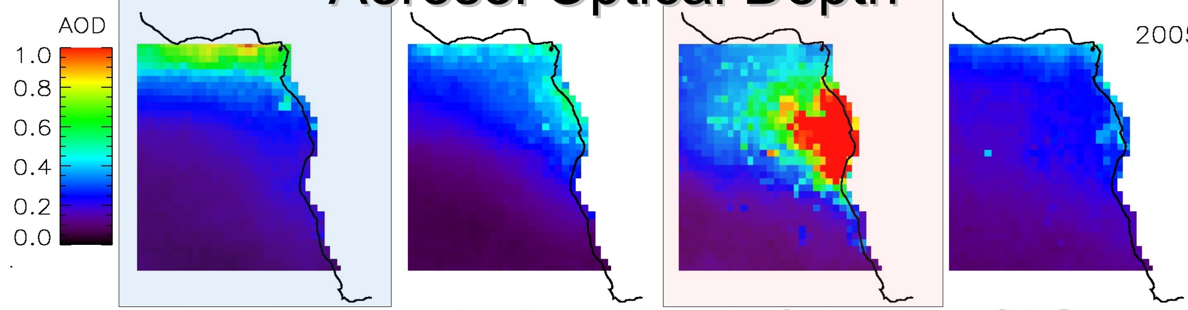
Fire occurrence



Wind speed



Aerosol Optical Depth



<u>Efficient trasport</u> of aerosol particles over the ocean!!!

Costantino and Bréon, 2013

Biomass Burning (BB) aerosol

Produced by:
Savanna and cropland fires.

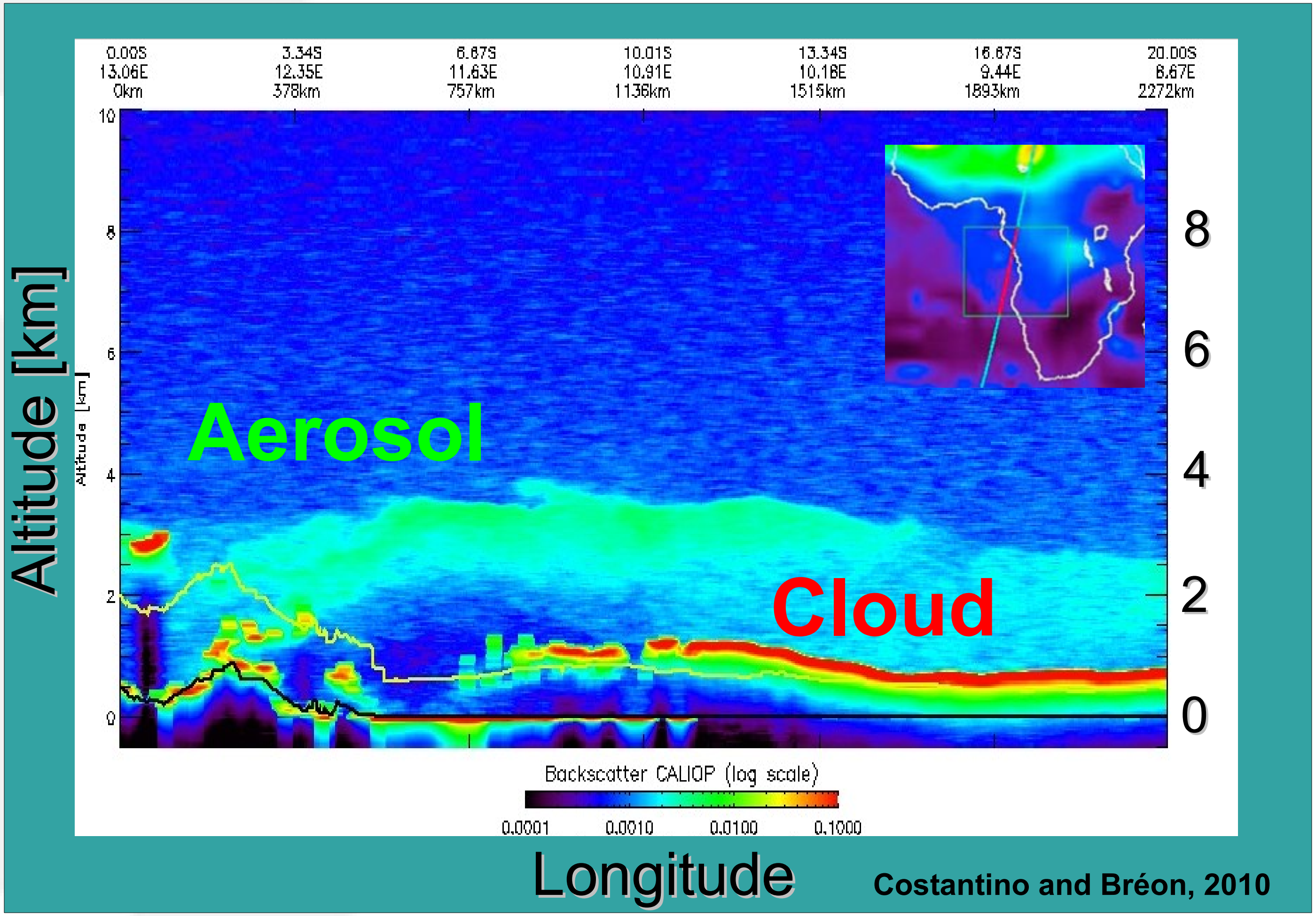
Contain:
OC (Organic Carbon): major component (~50% soluble).

BC (Black Carbon): insoluble dust, ash, soluble salt.
Primary emitted in efficient flaming fires (a more efficient combustion increases soot surface oxidation, that leads to a stronger chemical reactivity and water uptake).

Large fraction of soluble material → already very efficient **CCN** immediately after the fire.

Aerosol Transport over SE-Atlantic

North-East ◄ 2300 km ► South-West

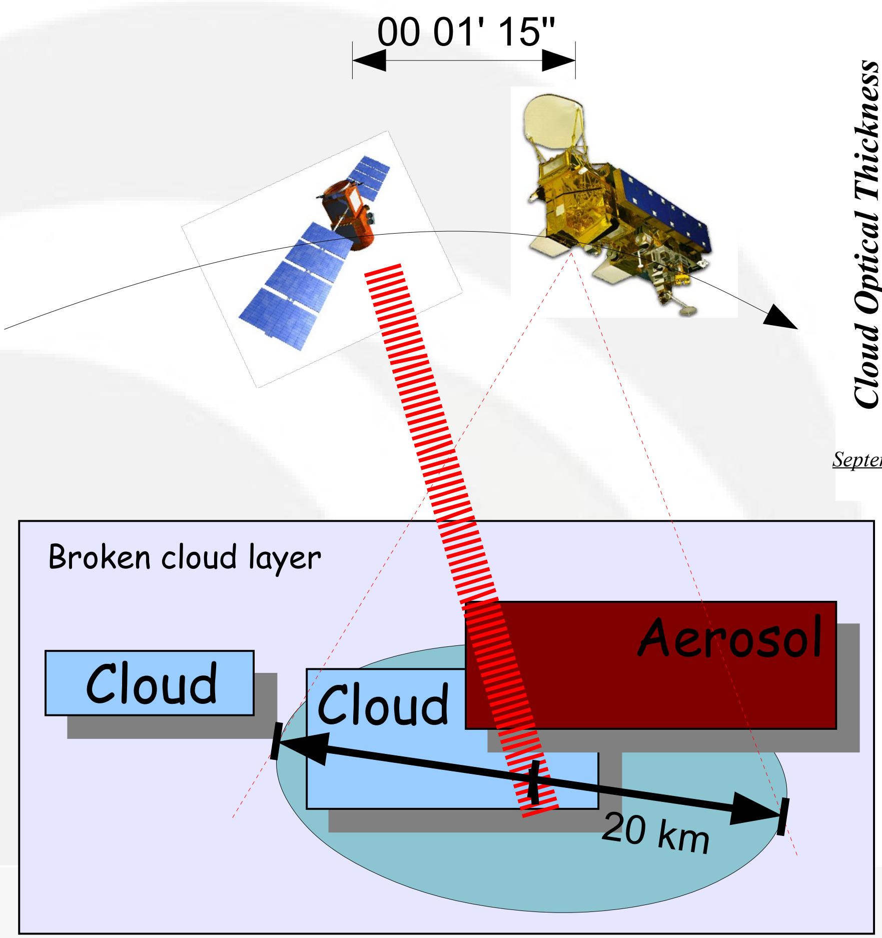


Costantino and Bréon, 2010

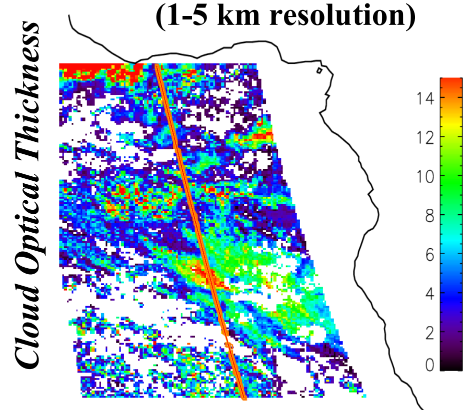
Land

Ocean

Multisensor Monitoring

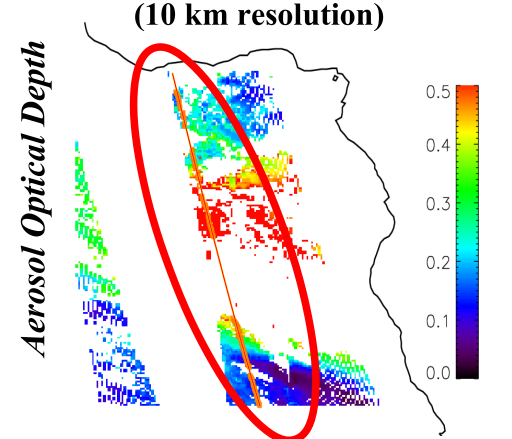


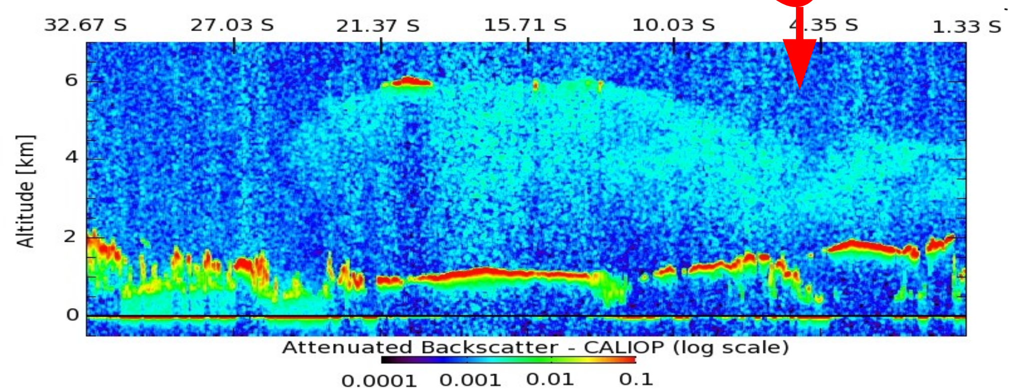
MODIS L2 CLOUD product
(1-5 km resolution)

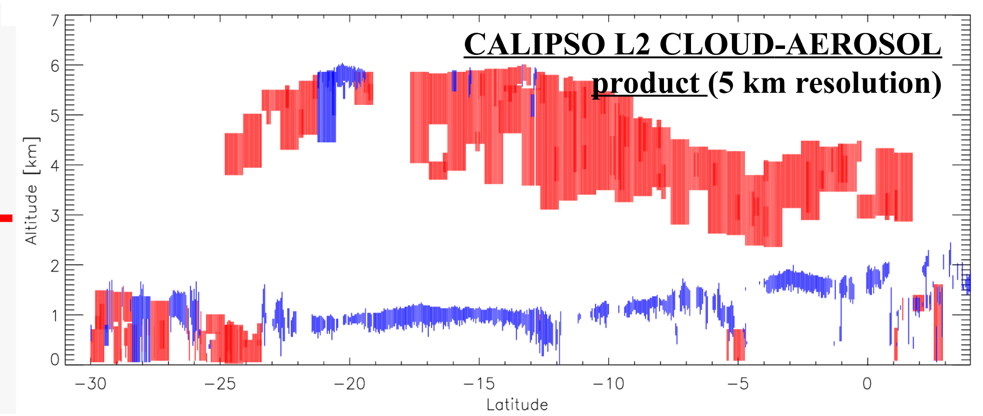


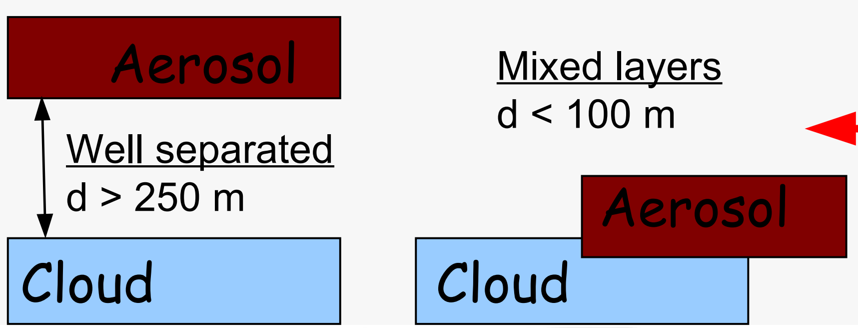
September, 14, 2010, from 13:55 to 14:04 UTC

MODIS L2 AEROSOL product
(10 km resolution)





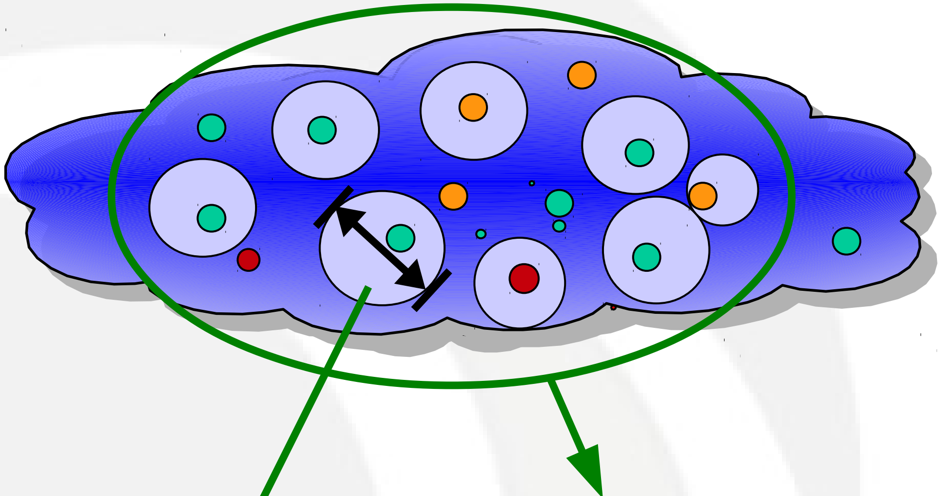




INDIRECT EFFECT #1: Impact on Cloud Microphysics

INDIRECT EFFECT #1: Impact on Cloud Microphysics

Assuming a constant liquid water content



$$\Delta \log r_e = -\frac{\Delta \log N_c}{3}$$

$$N_c \propto N_a^{0.7}$$

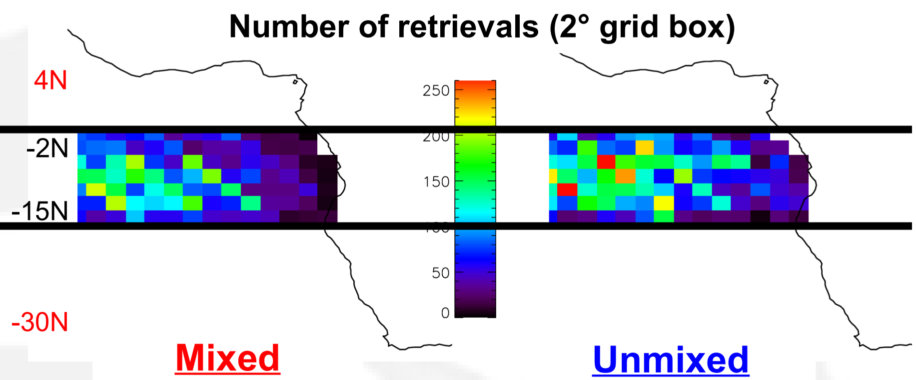
Satellite-derived relationship (Kaufman et al., 1997)

$$N_a \propto AI$$

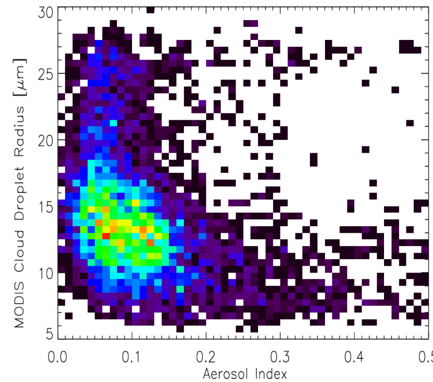
$$\Delta \log r_e = -0.23\ \Delta \log AI$$

CDR – AI relationship

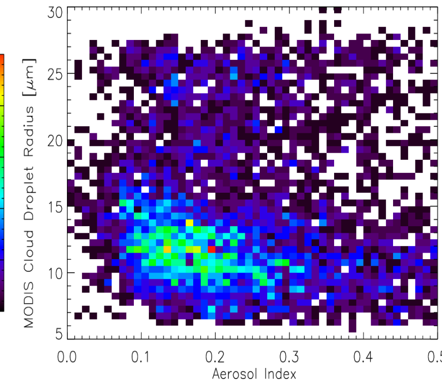
June 2006 – Decembre 2010 (~ 33 000 coincidences)



Mixed

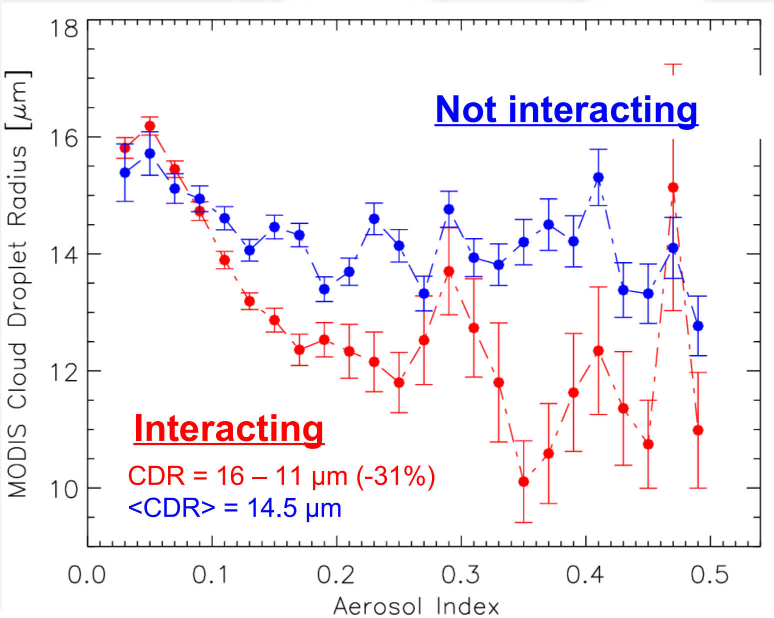


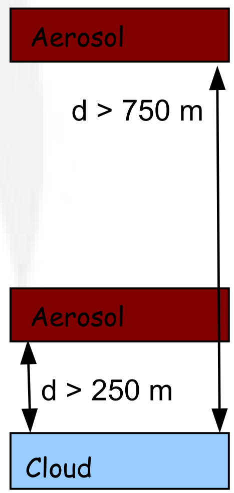
Unmixed

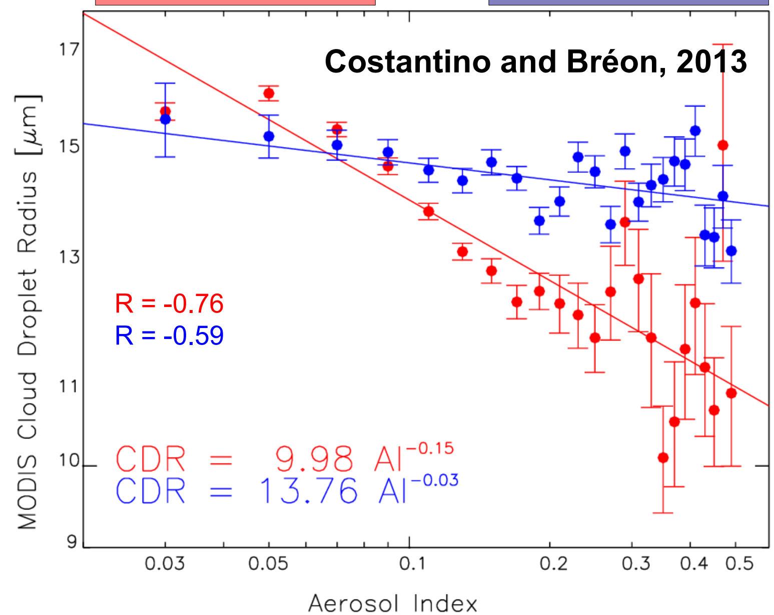


$\Delta \log r_e \propto -0.15\ \Delta \log AI$

$\Delta \log r_e \propto -0.03\ \Delta \log AI$





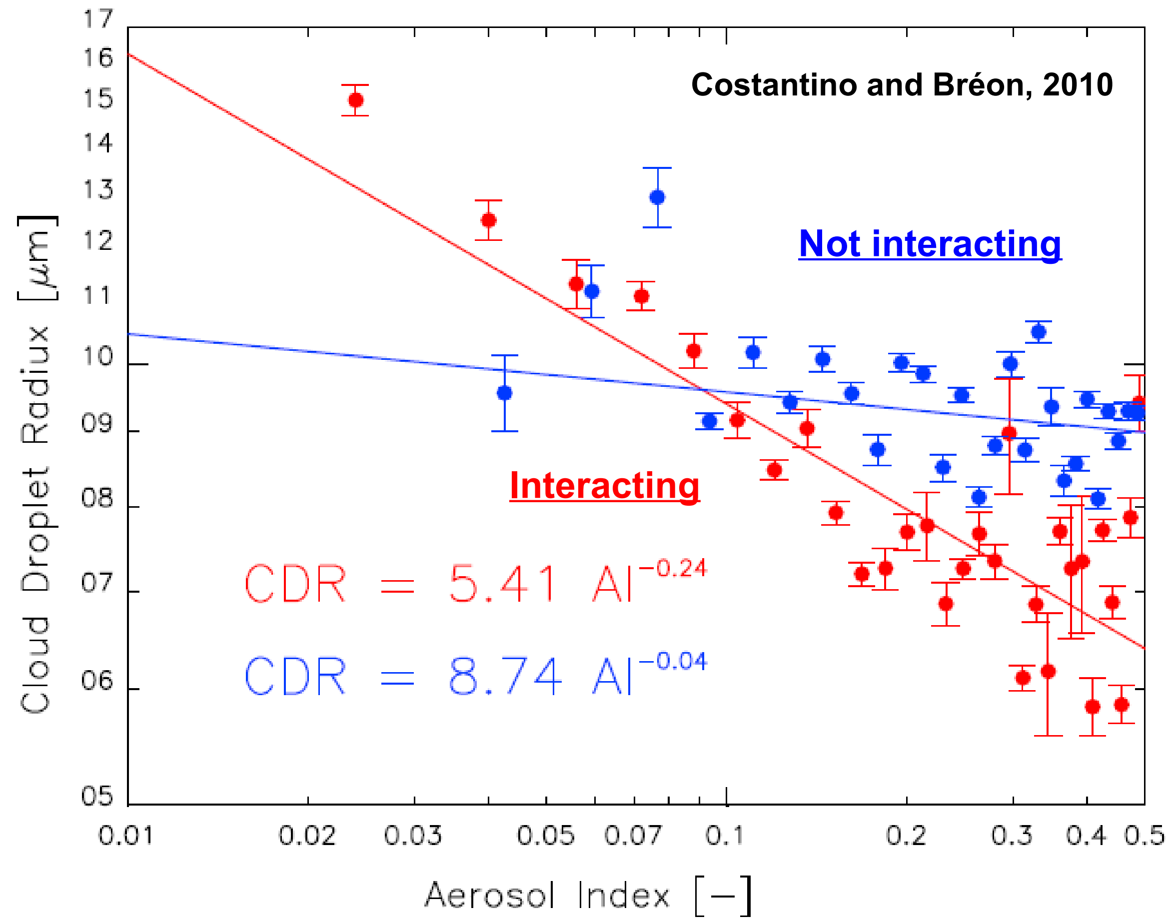


CDR – AI theoretical realtionship:

$\Delta \log r_e = -0.23\ \Delta \log AI$

CDR – AI relationship

PARASOL (CDR) – MODIS (AI) – CALIPSO (vertical position)



June 2006 – Decembre 2008 (~ 10 000 coincidences)

LWP – AI Relationship

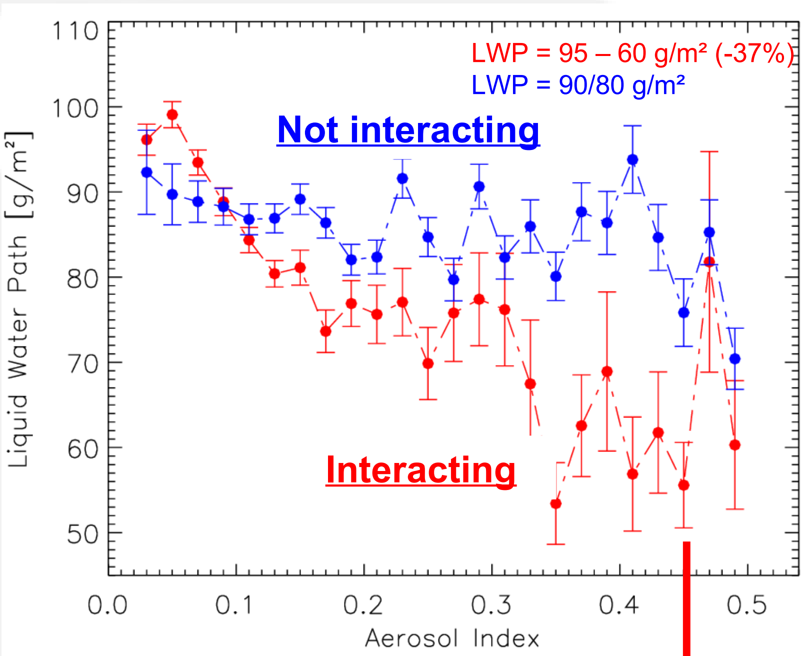
INDIRECT EFFECT #2: Impact on Cloud Water Content

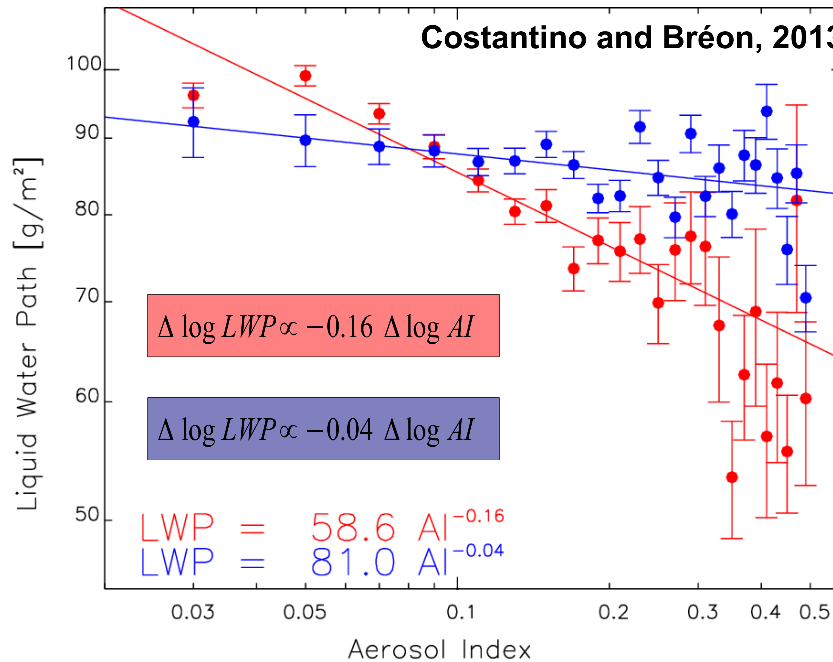
Simple idea (Albrecht's hypothesys):

More aerosol → smaller particles → less collision-coalescence efficiency → less rain → more water in the cloud

LWP – AI relationship

MODIS-CALIPSO concidences (33000)



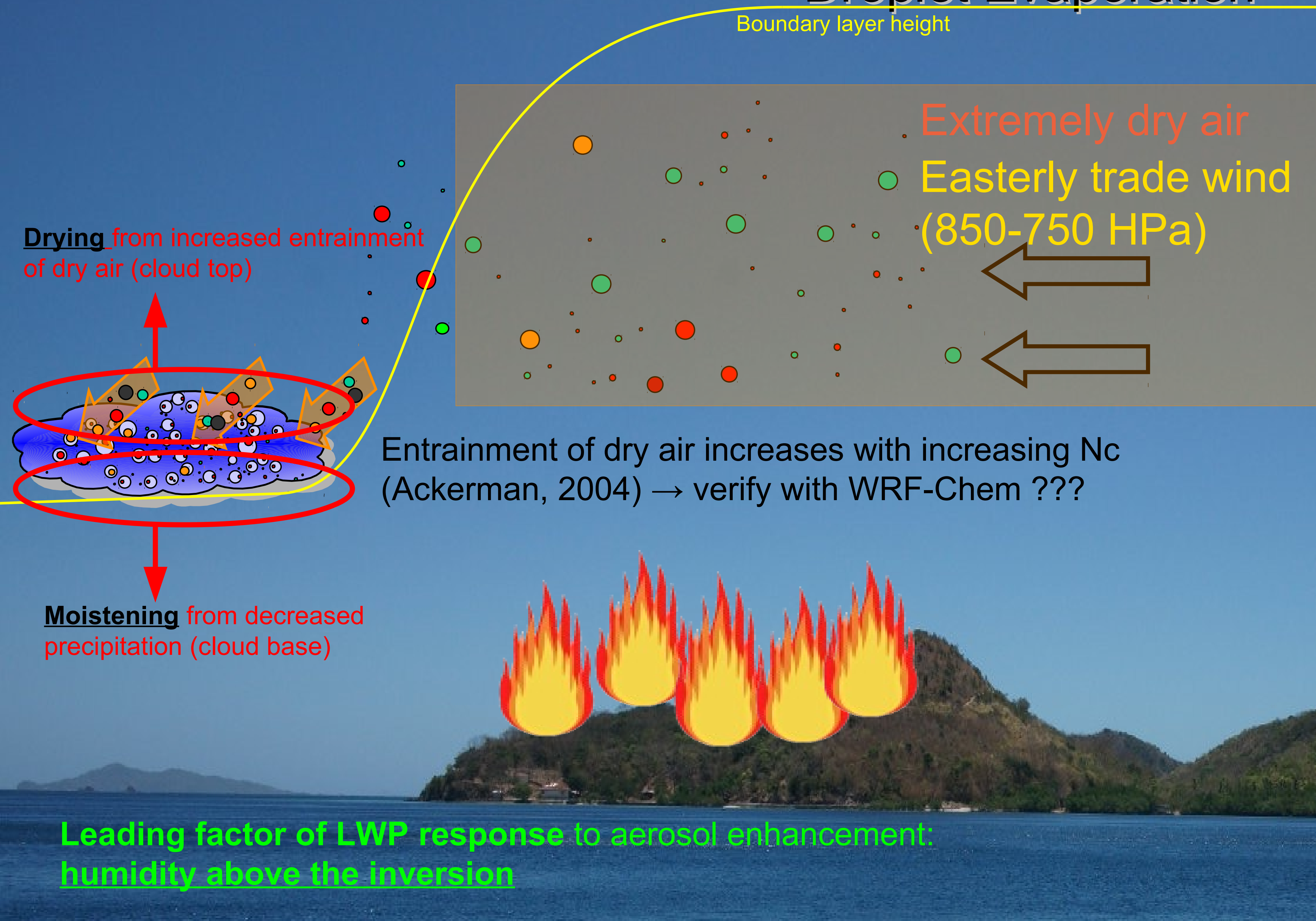


LWP decreases (drying) with increasing aerosol concentration!!

Opposite result with respect to Albrecht's hypothesis (moistening effect)

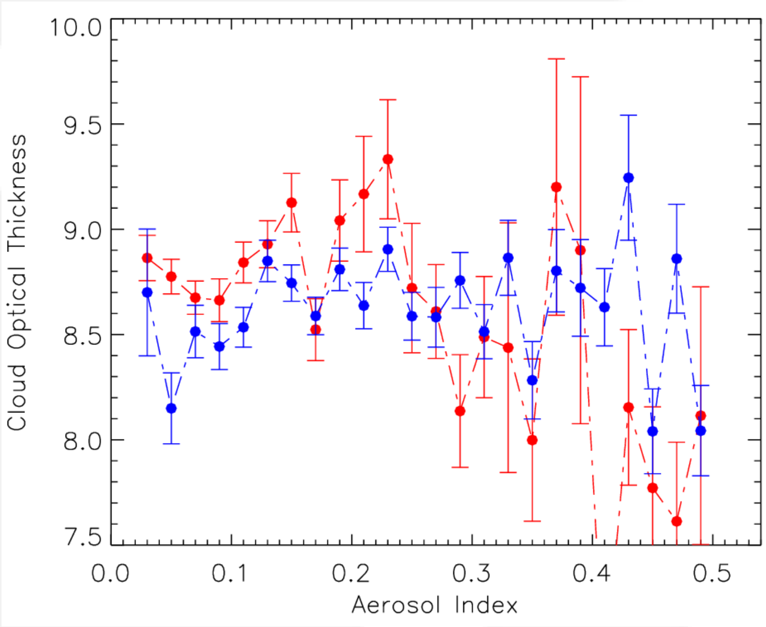
Is this an <u>aerosol-induced effect</u> ?? I am positive, but...

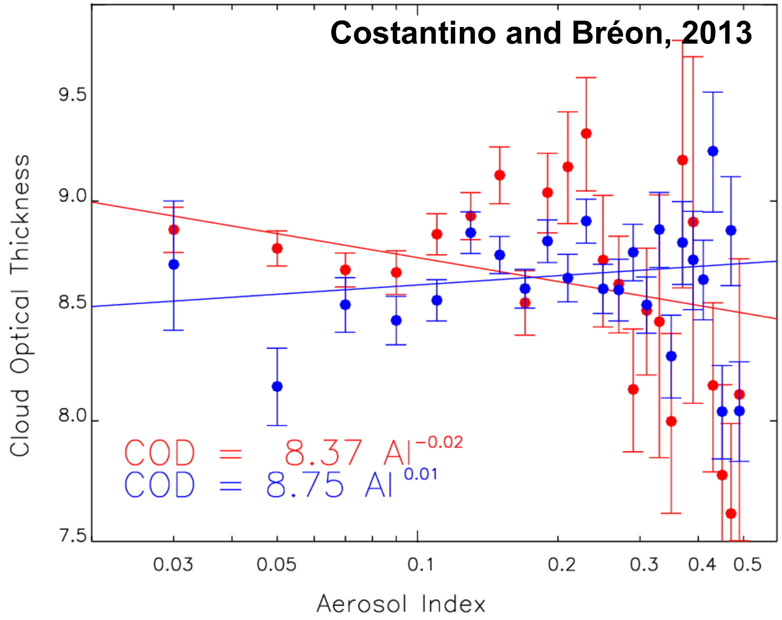
Droplet Evaporation



COT – AI Relationship

Aerosol effect on of cloud reflectance





<u>No evident correlation</u> between COT and AI

AER-CLD interaction: weak radiative impact !!!

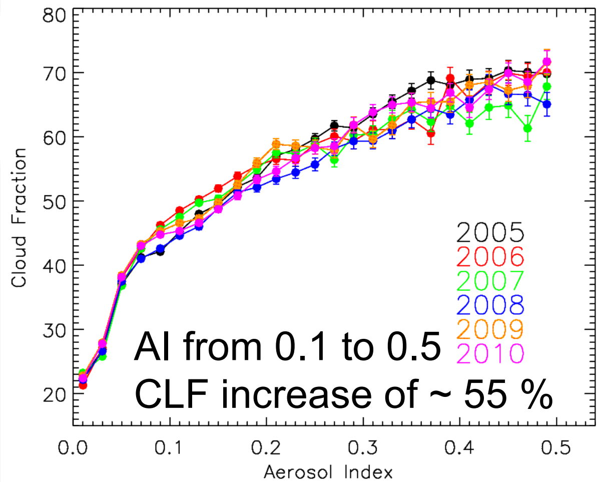
$$\tau_c = \frac{2}{3\rho_w}\frac{LWP}{r_e} \longrightarrow \frac{\Delta \ln \tau_c}{\Delta \ln AI} = \underbrace{\frac{\Delta \ln LWP}{\Delta \ln AI}}_{-0.16} - \underbrace{\frac{\Delta \ln r_e}{\Delta \ln AI}}_{-0.15} = -0.01$$

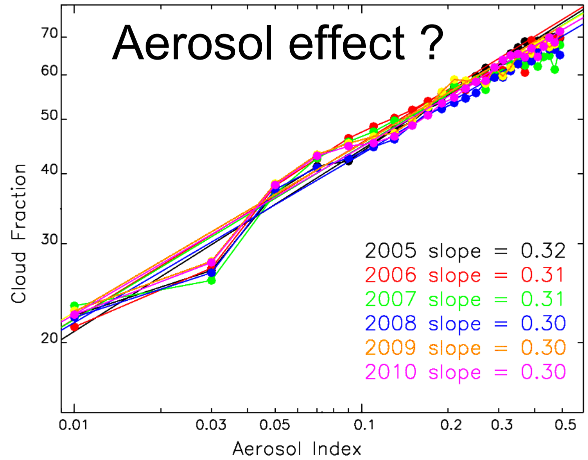
Aerosol impact on Cloud Fraction and Precipitation (... a more difficult issue..)

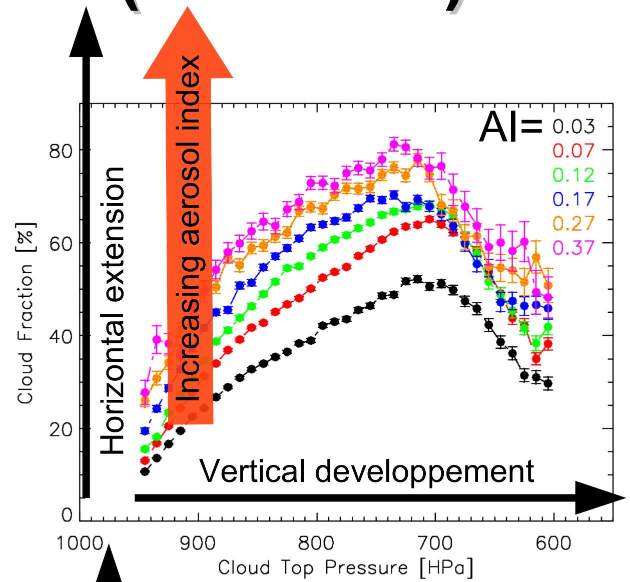
INDIRECT EFFECT #2: Impact on Cloud Lifetime

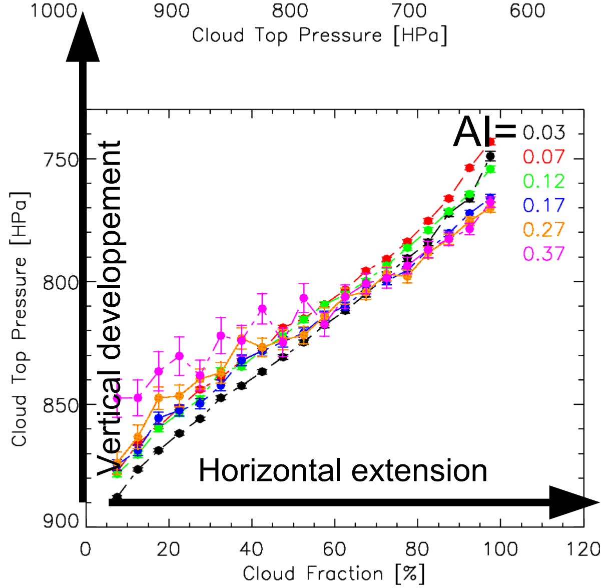
Aerosol effect on of cloud fraction (CLF – AI)

Overestimated (wrt MODELS)









Artifact?
- Aerosol contamination (for AOD > 0.7)
- Adjacent (blueing) effect

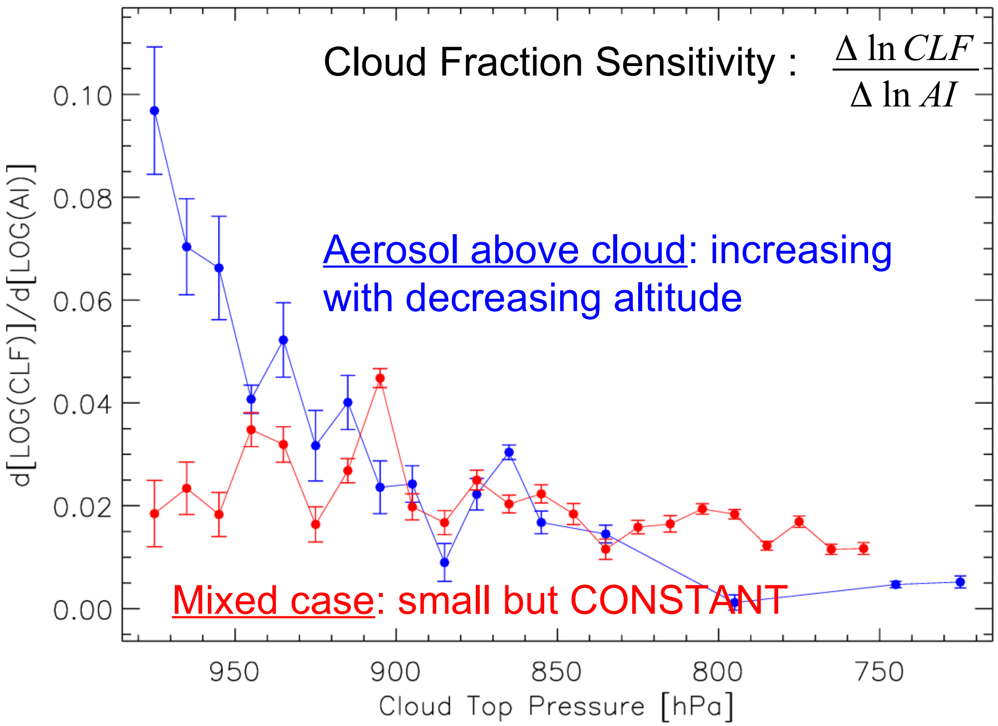
Meteorology?
- Humidity (Swelling effect)
- Surface wind
- Low troposferic stability
- High pressure systems
- Other types of meteorologically driven co-variation of CLF and AI

Costantino and Bréon, 2013

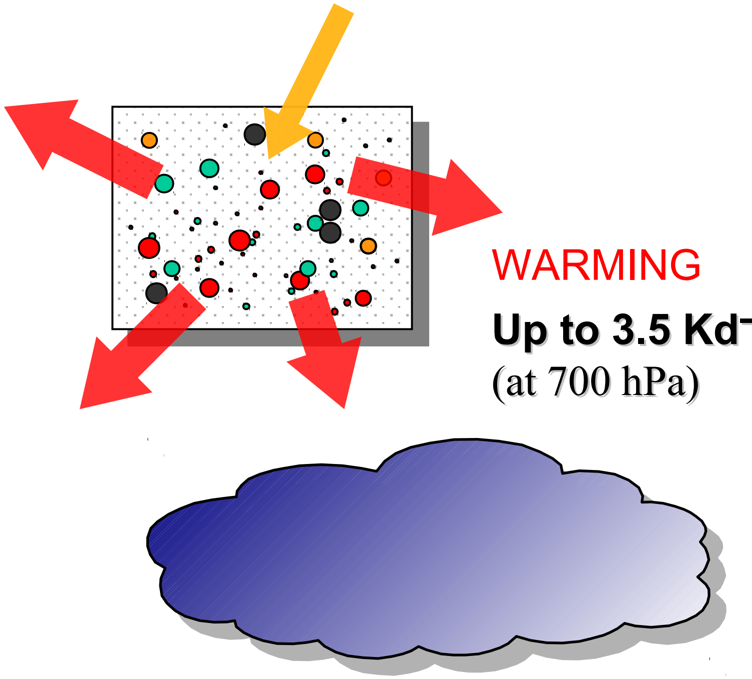
CLF – AI relationship

CONSTANT Cloud Top Pressure

Costantino and Bréon, 2013



Low **cloud cover** increases with increasing **low tropospheric stability** (Klein and Hartmann, 1993)



Data sorted by CTP, from 1000 to 600 HPa, by step of 15 HPa

→ **Cloud cover response to aerosol invigoration seems to depend on aerosol vertical position (and radiative effect)**

Inhibition of Precipitation

PRECIPITATION OCCURRENCE (Lohmann et al., 2000): change in sign of CDR – COT relationship slope from POSITIVE to NEGATIVE

Non precipitating

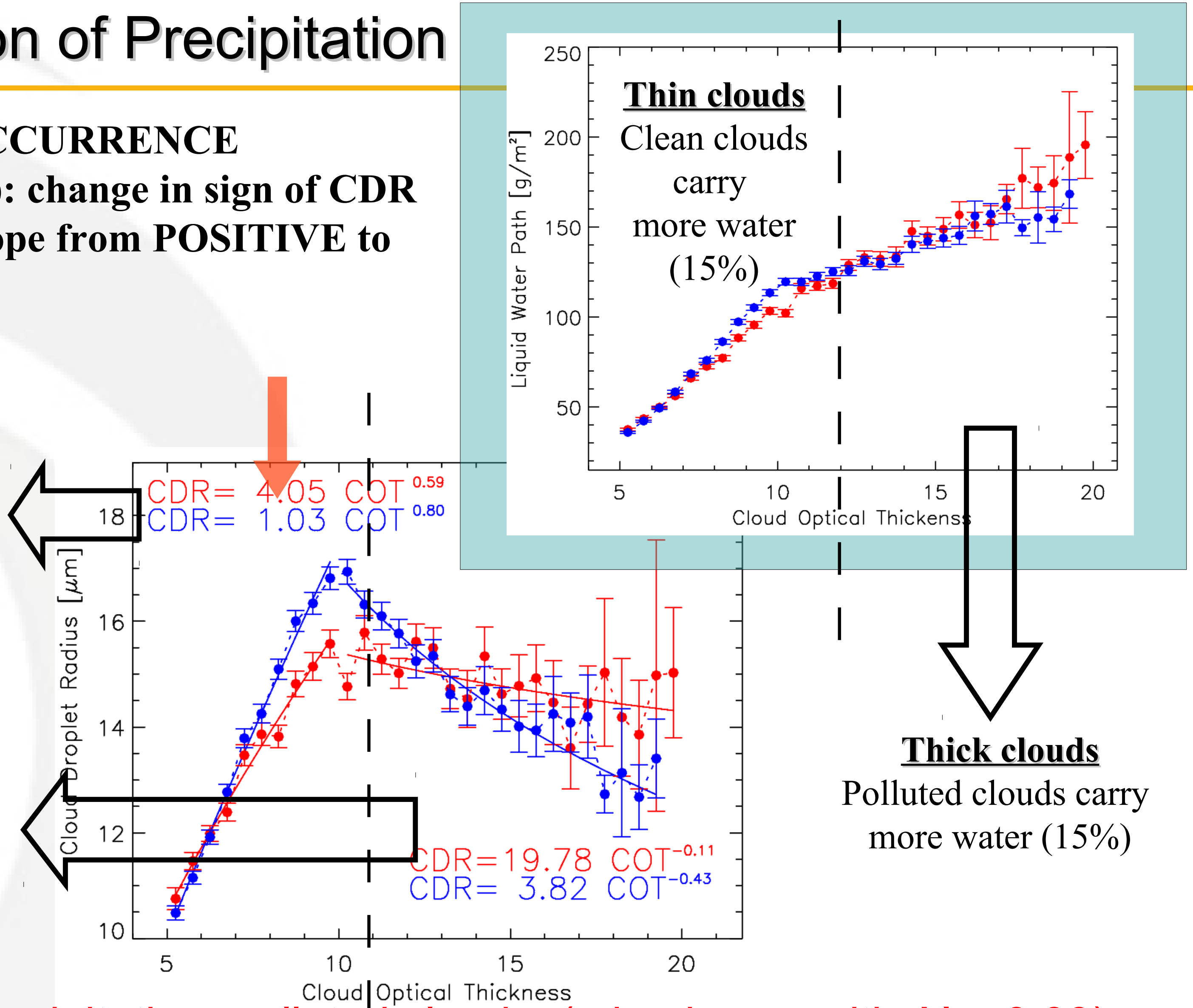
(Adiabatic assumpion)

$$r_e \propto \tau_c^{0.2} N^{0.5}$$

Precipitating

(Constant LWP with increasing COT)

$$r_e \propto \tau_c^{-1}$$



Thick clouds

Polluted clouds carry more water (15%)

$$r_e \propto \tau_c^{-0.11}$$

Less precipitating: polluted clouds (mixed case with AI > 0.09).

$$r_e \propto \tau_c^{-0.43}$$

More precipitating: clean clouds.

Costantino and Bréon, 2013

Summary and Conclusions

- We used satellite data to analyze aerosol-cloud interaction

- and CALIPSO information to distinguish between mixed (interacting) and unmixed (non interaction) layers

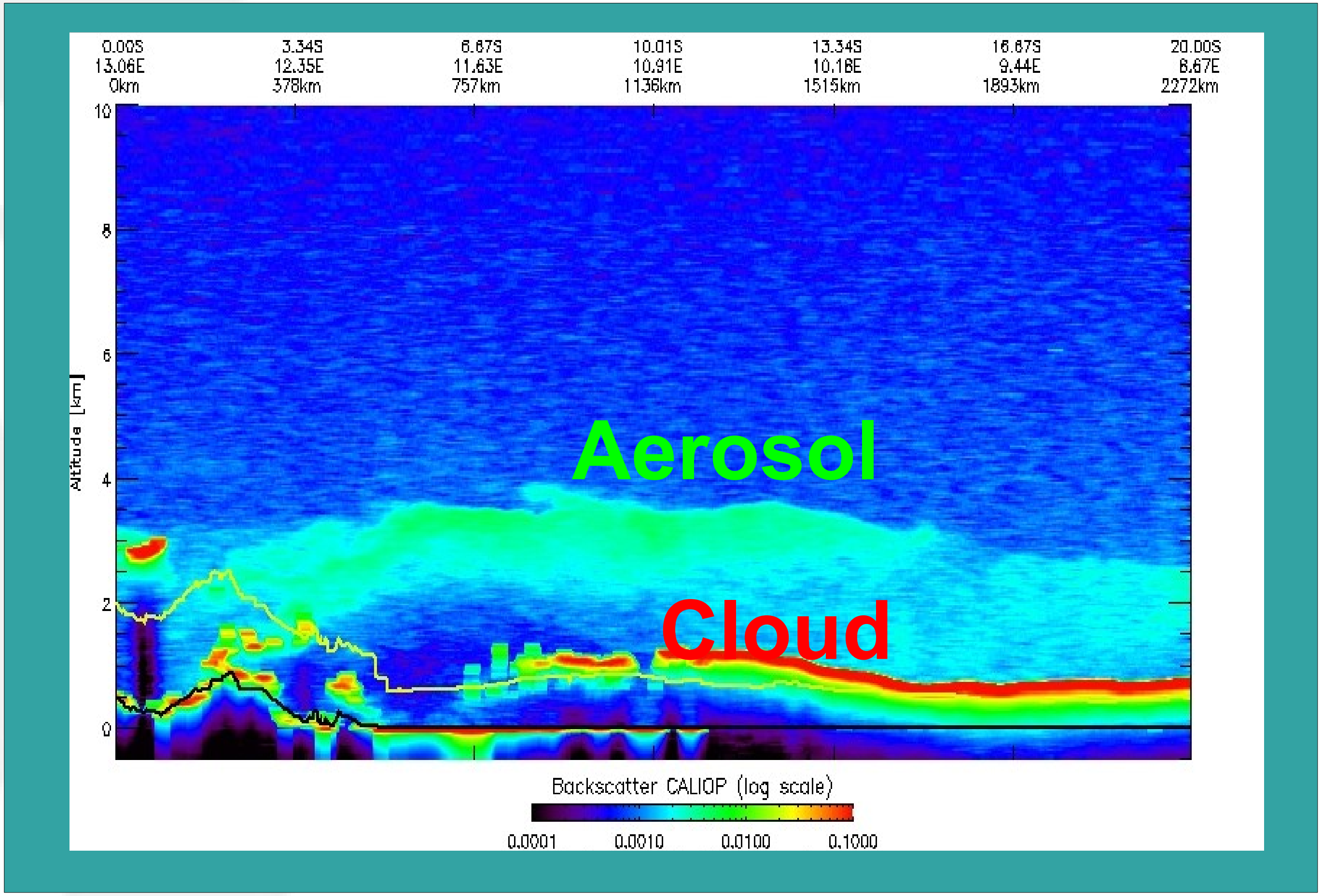
- Large impact of Aerosol on CDR, in-line with theoretical expectations

- No evident Aerosol impact on cloud reflectance (albedo) → SMALL RADIATIVE EFFECT

- Strong correlation between CLF and AI, but further analysis indicates this is probably not an effect due to aerosol-cloud interaction

- Aerosol seems to induces a decrease in precipitation efficiency only in optically thick clouds (tau > 10)

Thank you for your attention ! QUESTIONS ??



<u>For more details:</u>

Costantino and Bréon (2011), Geo. Res. Lett.

Costantino and Bréon (2013), ACP

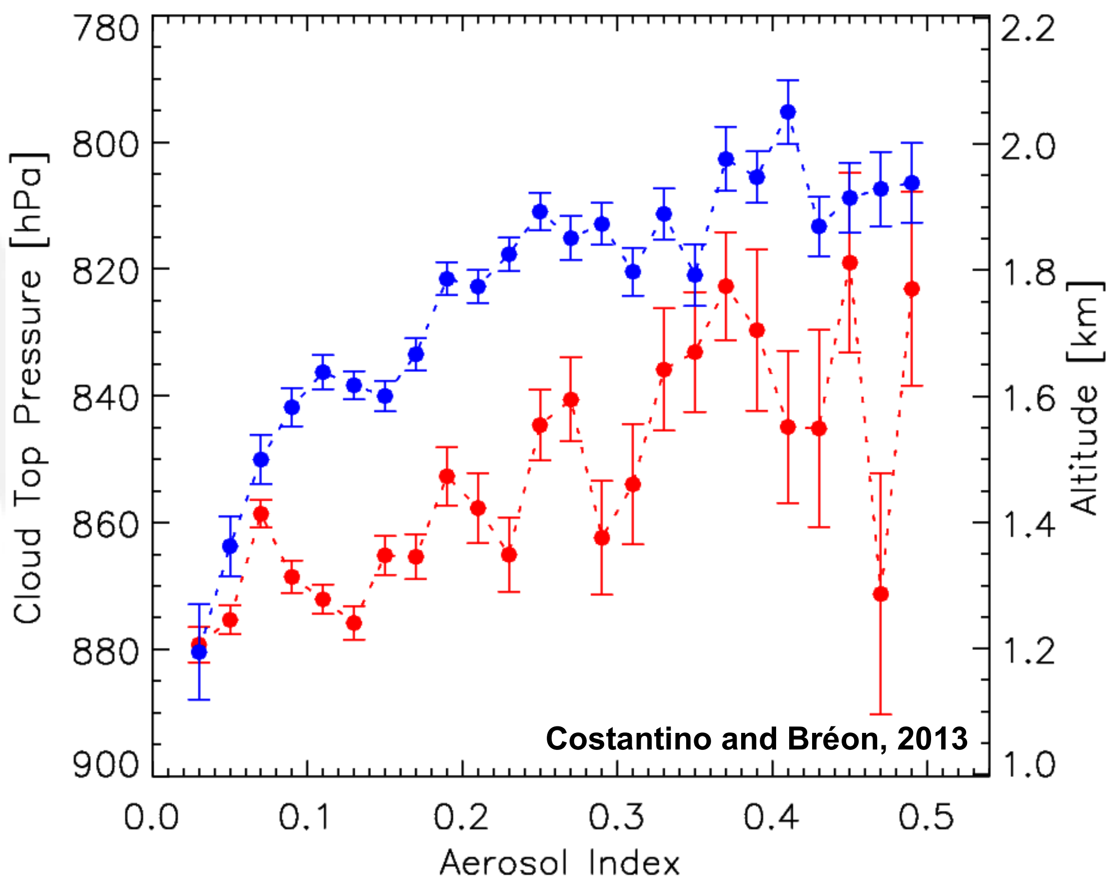
Costantino and Bréon (2013), ACPD

mail to: Lore.costantino@gmail.com

Impact of meteorology

For very low AI, CDR LWP, COT converge to the same values.

In particular mixed and unmixed CTP (the cloud parameter mostly linked to background meteorology) are quite close, for every aerosol regime.



This result suggests a uniform impact of meteorology on both populations: changes in cloud properties (when aerosol and clouds intermingle) are most due to aerosol-cloud interaction.

Impact of aerosol above clouds

Error is may be wavelength dependent:

Haywood et al. (2004): using the 0.86/2.1 μm couple of wavelengths, CDR is very little underestimated (< 1 μm), COT is underestimated by 10-20%.

Cloud dependent:

Coddington et al. (2010): the error in CDR is less than 1 μm and that in COT is within the uncertainties of the instrument (MODIS and SSFS, on board of a airplane flying between the aerosol layer and the cloud top) in regions with small cloud variability (as S-E Atlantic). Errors are much larger in case of strong cloud heterogeneity (up to 10 μm and 10).

Pollution dependent:

Meyer et al. (2013): the error in CDR and COT for polluted clouds is 6% and 18%, and 2.6% and 11% for clean + polluted.

In the present study we use 0.86/2.1 μm, cloud field is supposed to be quite homogeneous (confirmed by PARASOL measurements), and unmixed case is composed only of clean clouds (no multi-layer cloud scenes):

in case of aerosol above clouds CDR, LWP, COT seems to be almost insensitive to large AI variations (while we should expect a decrease in CDR and COT), while mixed CDR variation is about 30%.