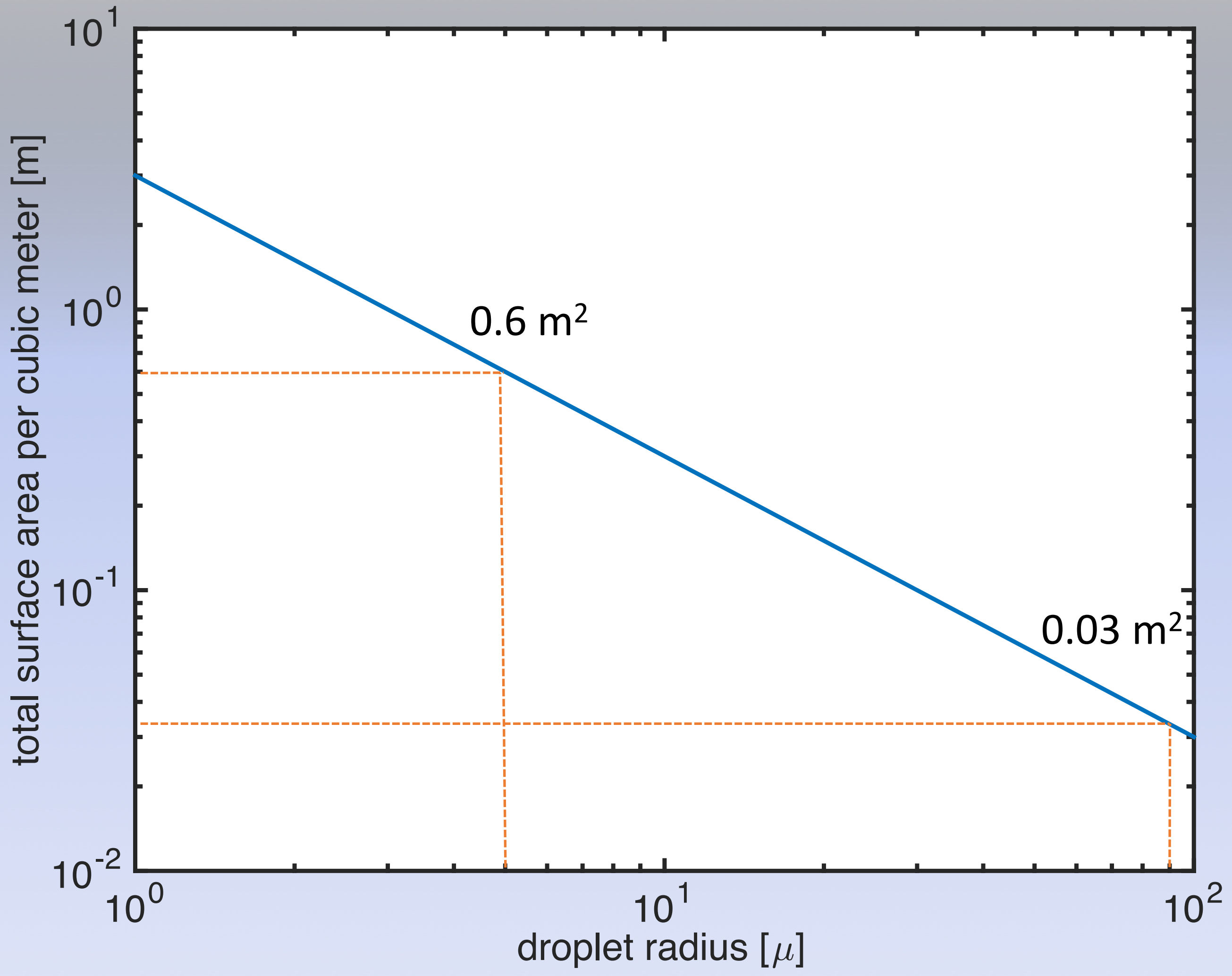
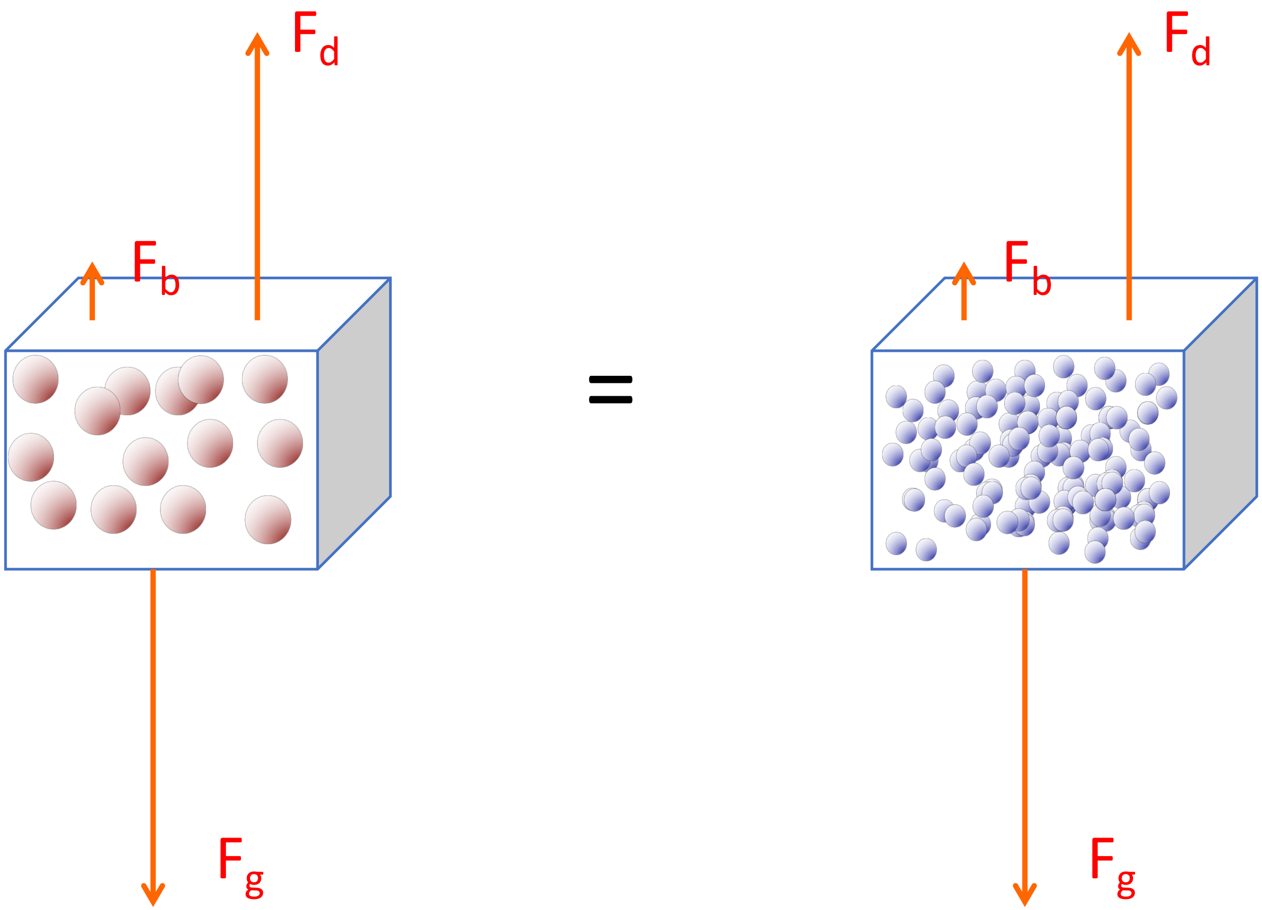
Volume to surface area

In one cubic meter – with 1 g of liquid water:

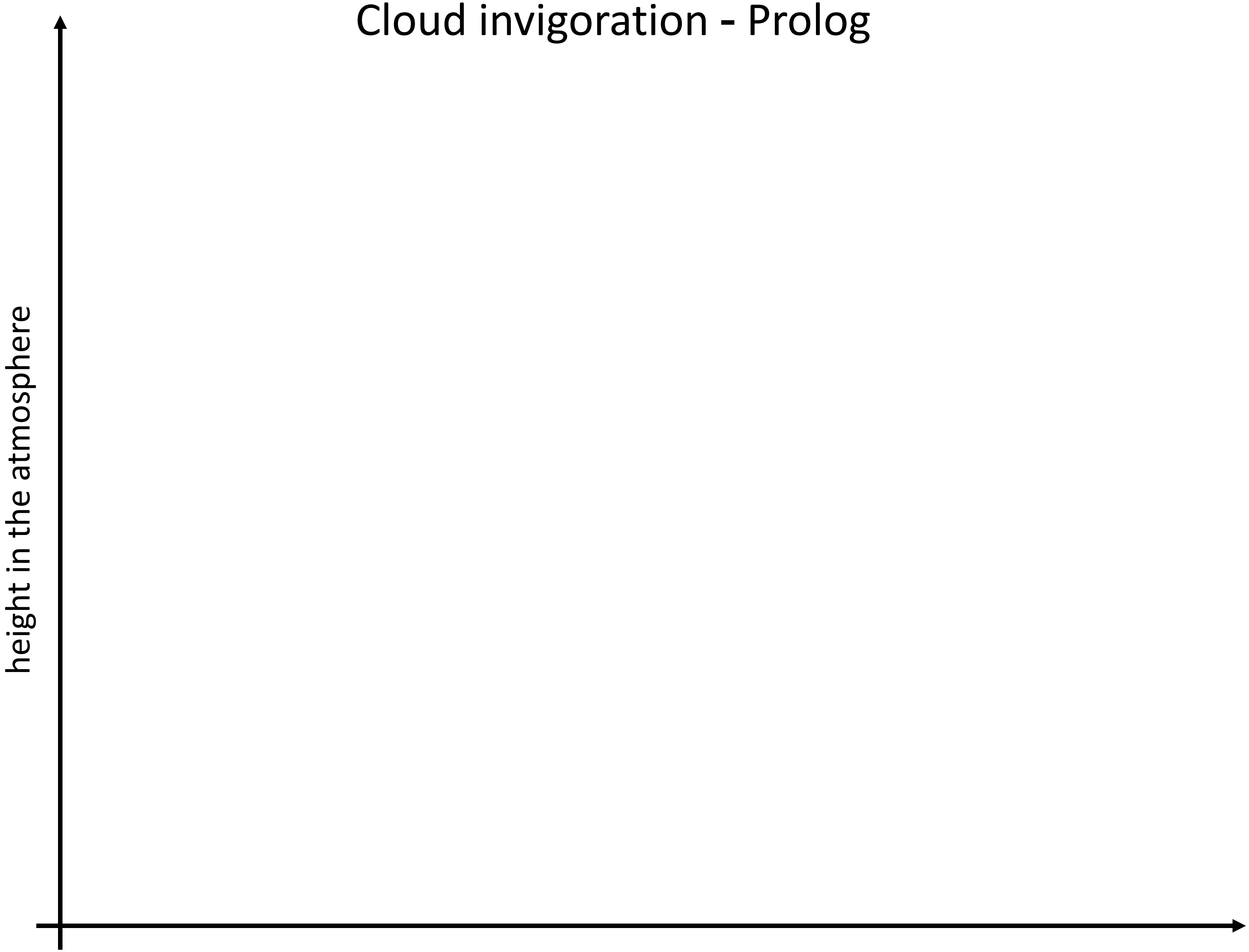




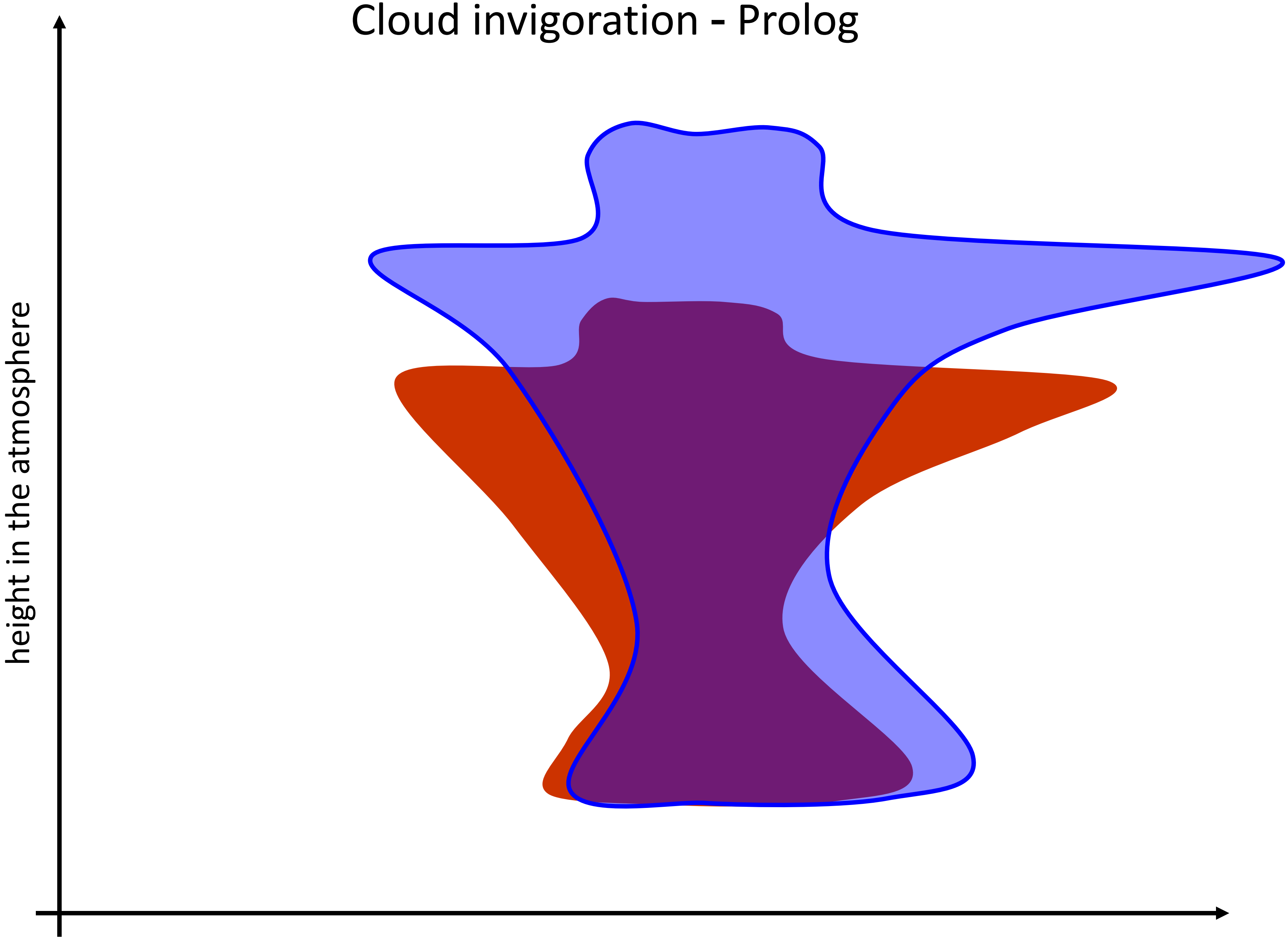
F_d
F_b
F_g
=
F_d
F_b
F_g

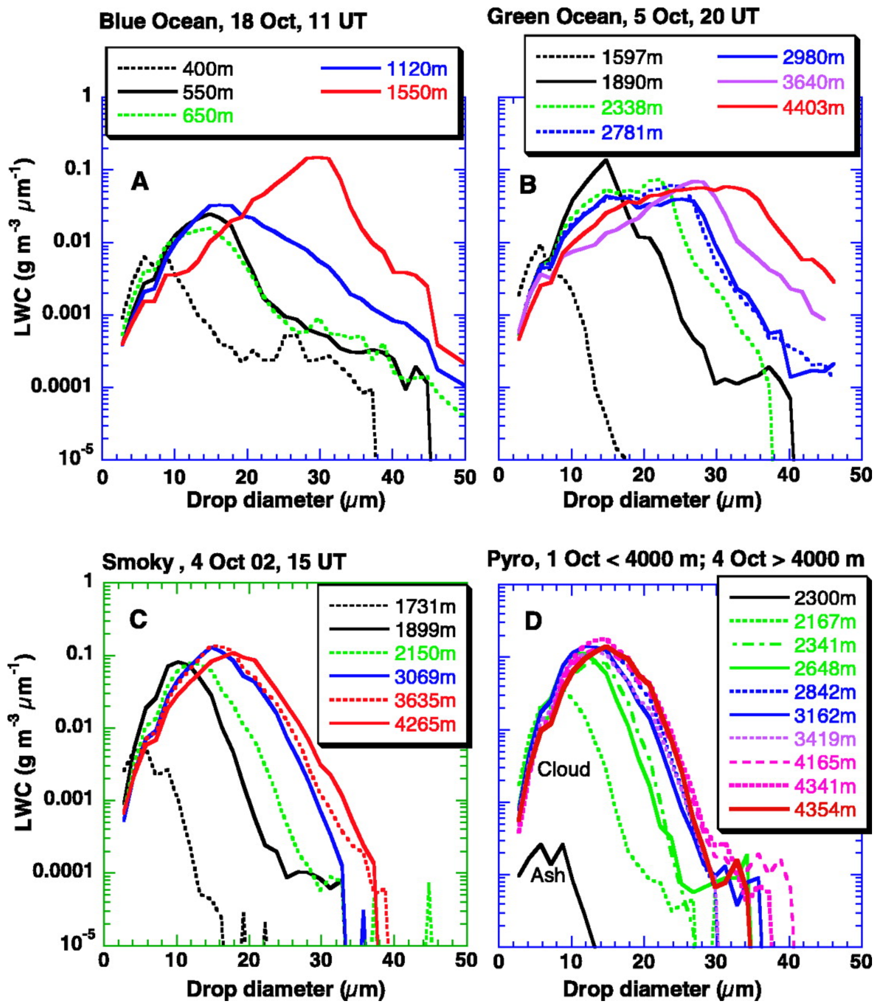
Cloud Core and Margins

Cloud invigoration - Prolog



Cloud invigoration - Prolog

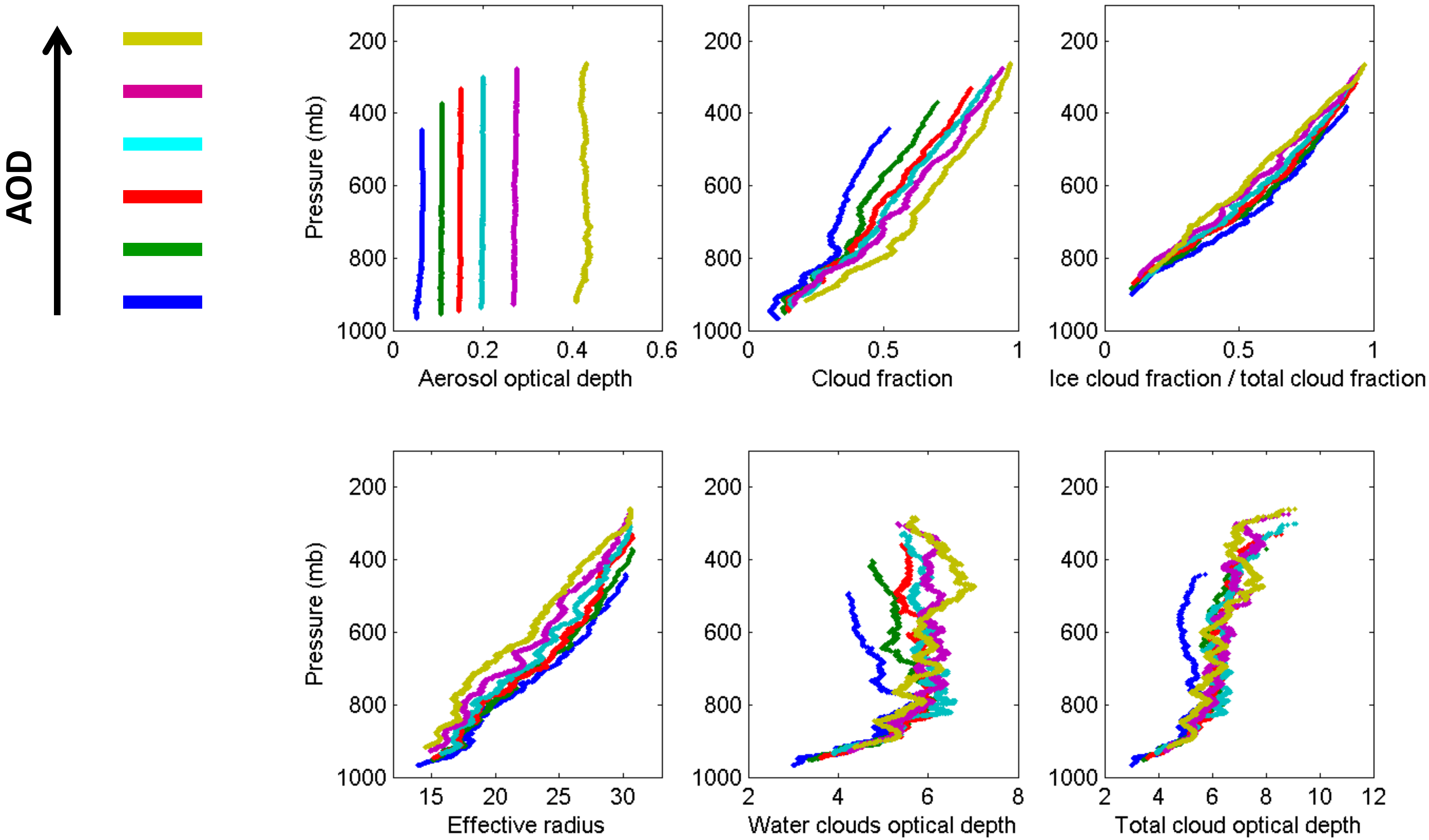




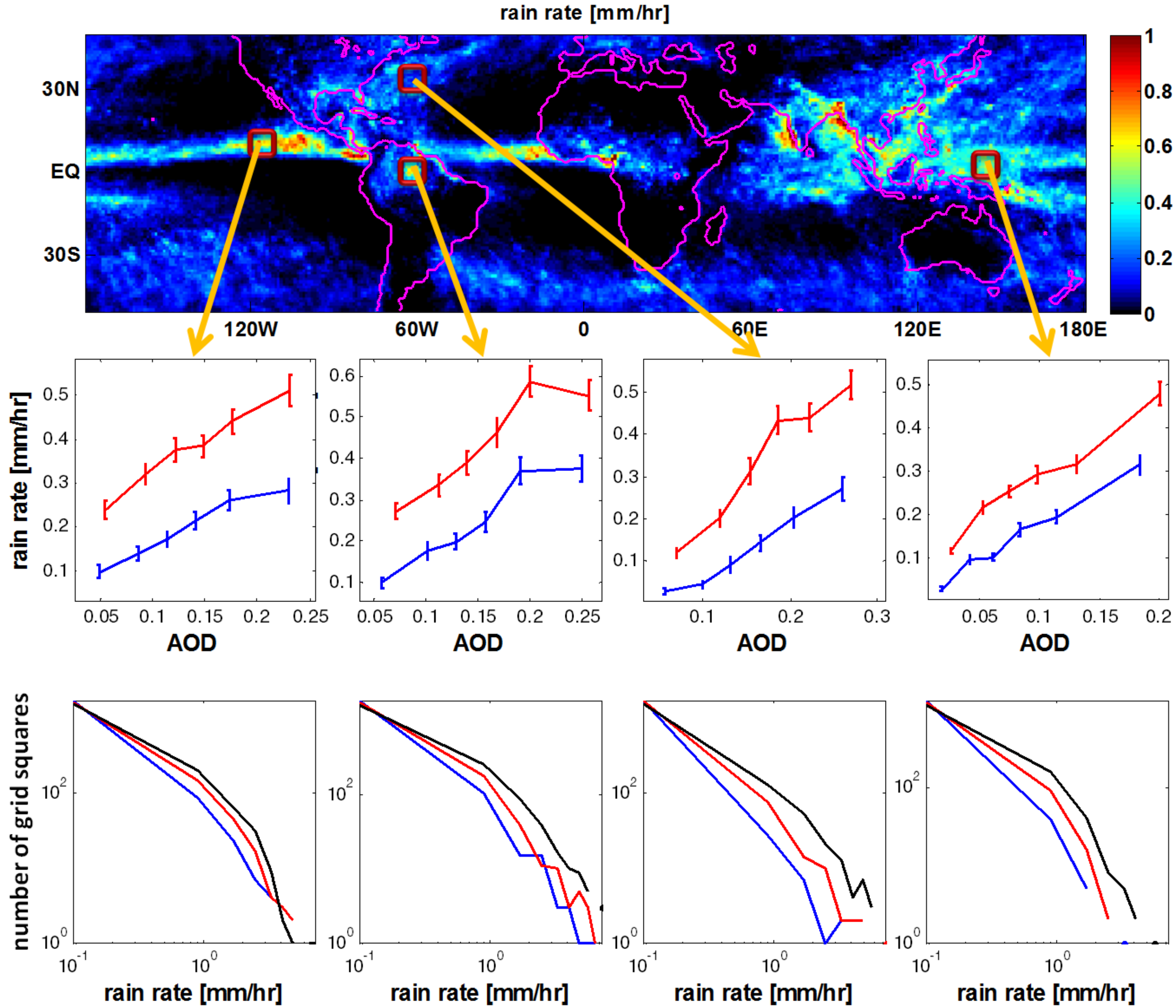
N vs LWC

Andreae et al., 2004

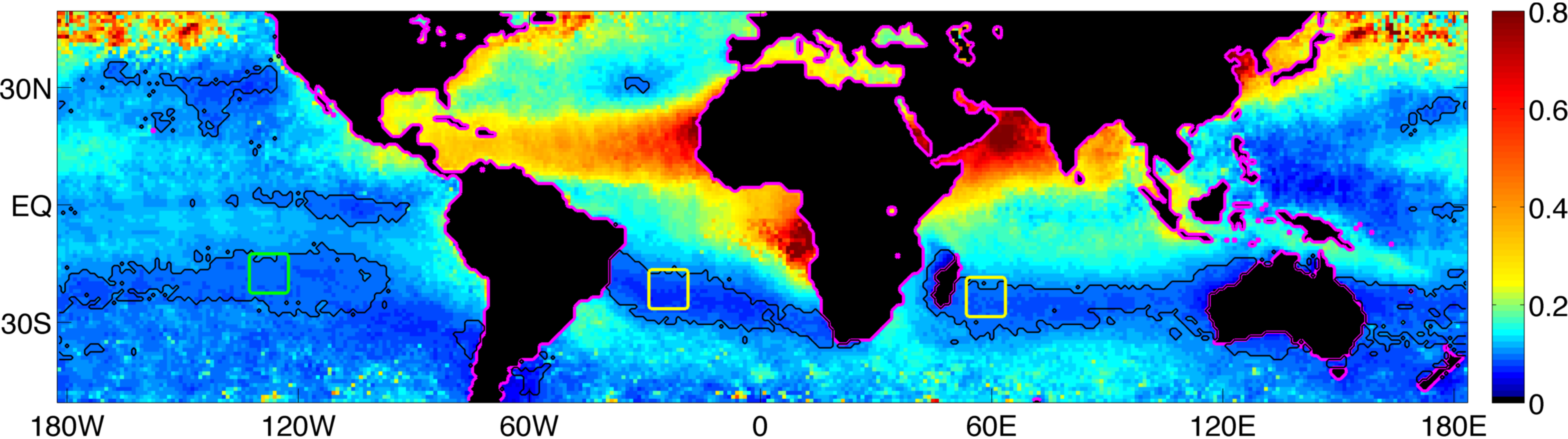
Aerosol invigoration and restructuring of Atlantic convective clouds



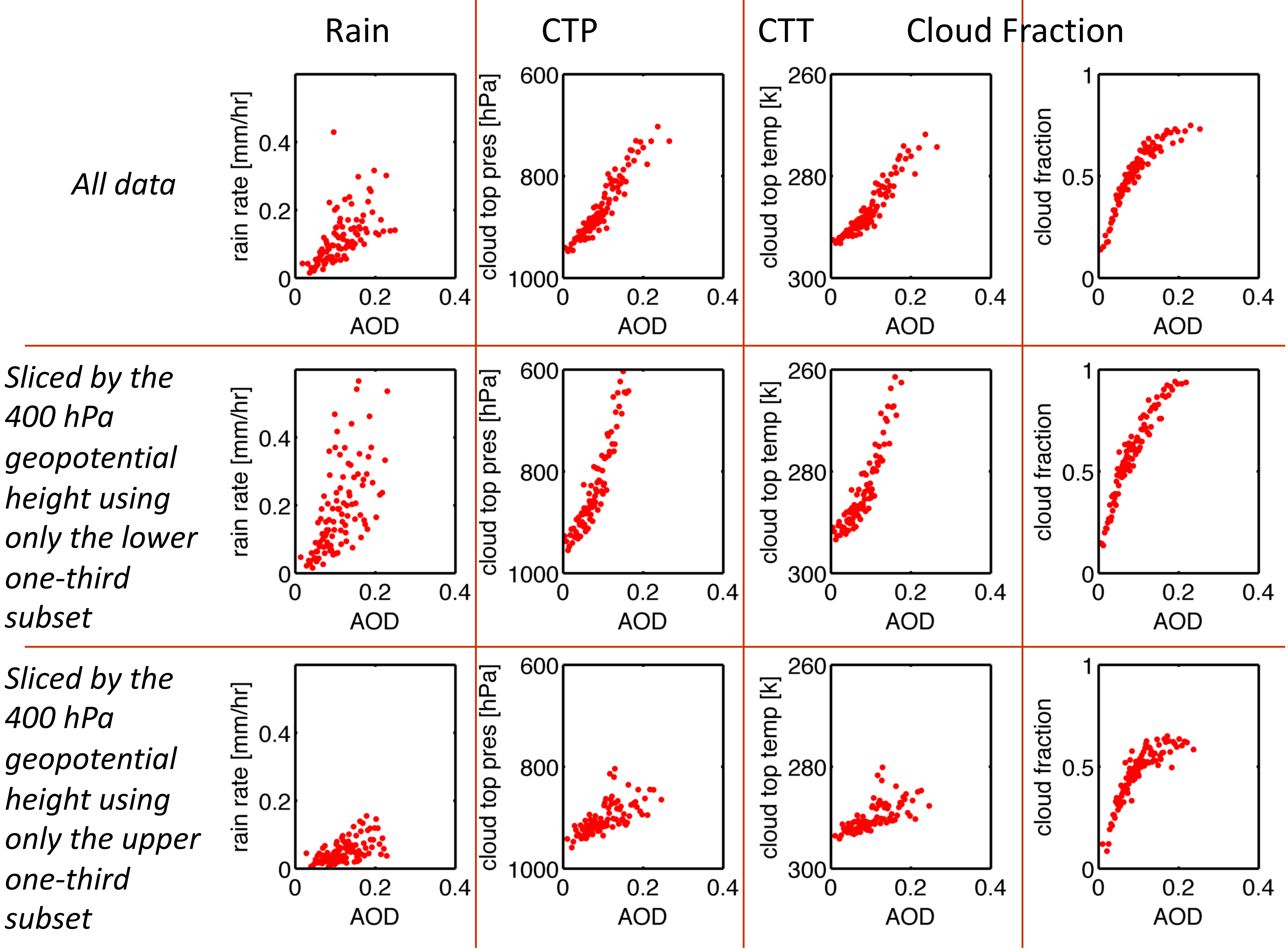
Koren et al, 2005



rain rate [mm/hr]
30N
EQ
30S
120W
60W
0
60E
120E
180E
rain rate [mm/hr]
AOD
AOD
AOD
AOD
number of grid squares
rain rate [mm/hr]
rain rate [mm/hr]
rain rate [mm/hr]
rain rate [mm/hr]



Averaged aerosol optical depth (AOD) over the oceans for JJA 2007. Areas marked by a black contour represent pristine oceanic regions with AOD < 0.1 and warm convective clouds. The green box marks the main study area over the Pacific and the yellow boxes mark the study areas over the Atlantic and Indian oceans (all boxes are 9° by 9°).

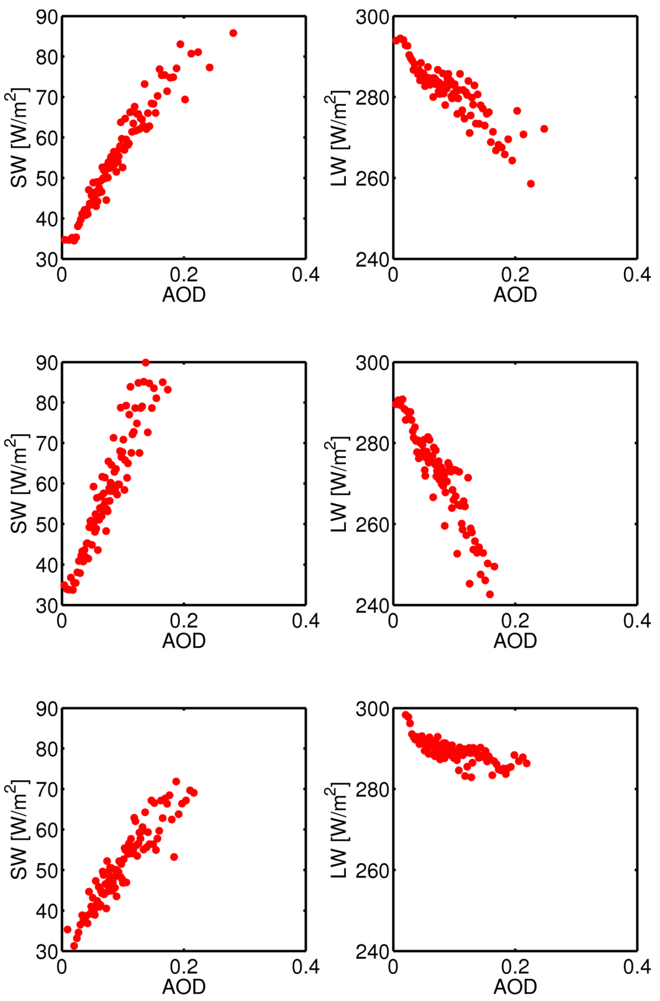


Koren et al, 2014

CERES DATA:

Top-of-atmosphere radiation fluxes in the shortwave (left column) and the longwave range (right). (Top) All-data. (Middle) Data filtered by the 400 hPa geopotential height using only the lower one-third subset. (Bottom) Data filtering by using the upper one-third subset of the 400 hPa geopotential height. Positive flux indicates energy flux to space (cooling effect).

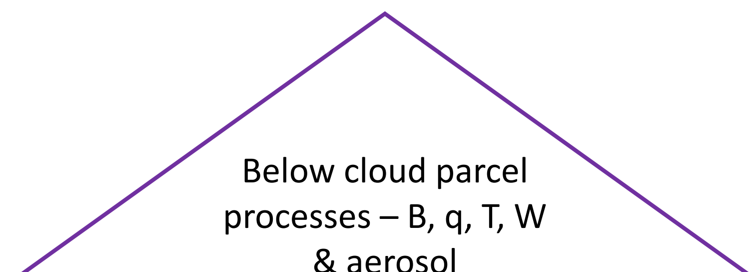
In the all-data case the difference in SW at the top of the atmosphere is cooling of 27 W/m^2 while the LW radiation of the deeper (colder clouds' tops) compensate for half of the forcing (~13 W/m^2) yielding a total of ~14 W/m^2 cooling driven by the aerosol effect on clouds.



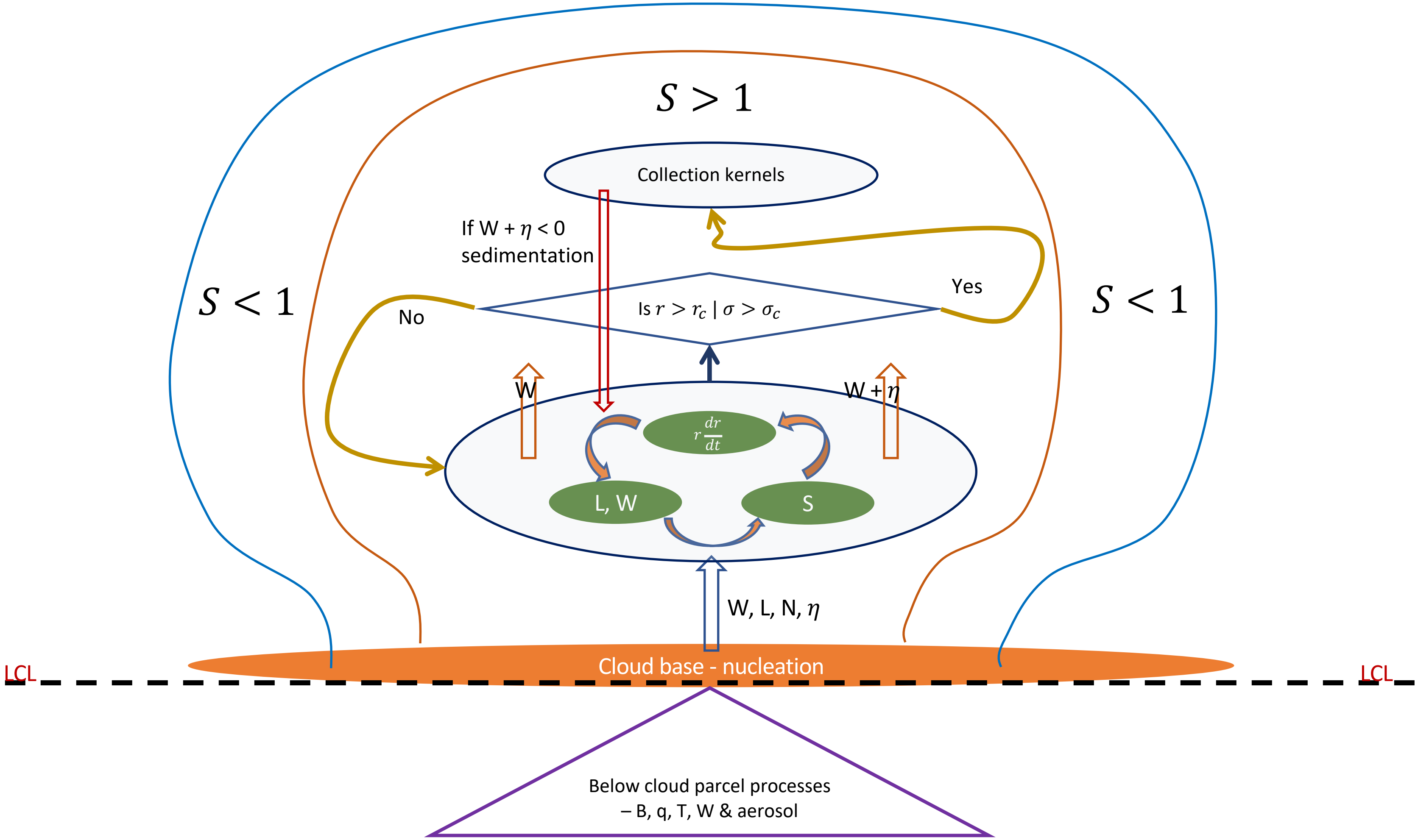
The Grand Cloud Machinery

W	air vertical velocity
N	droplets
L	latent heat
η	effective terminal velocity

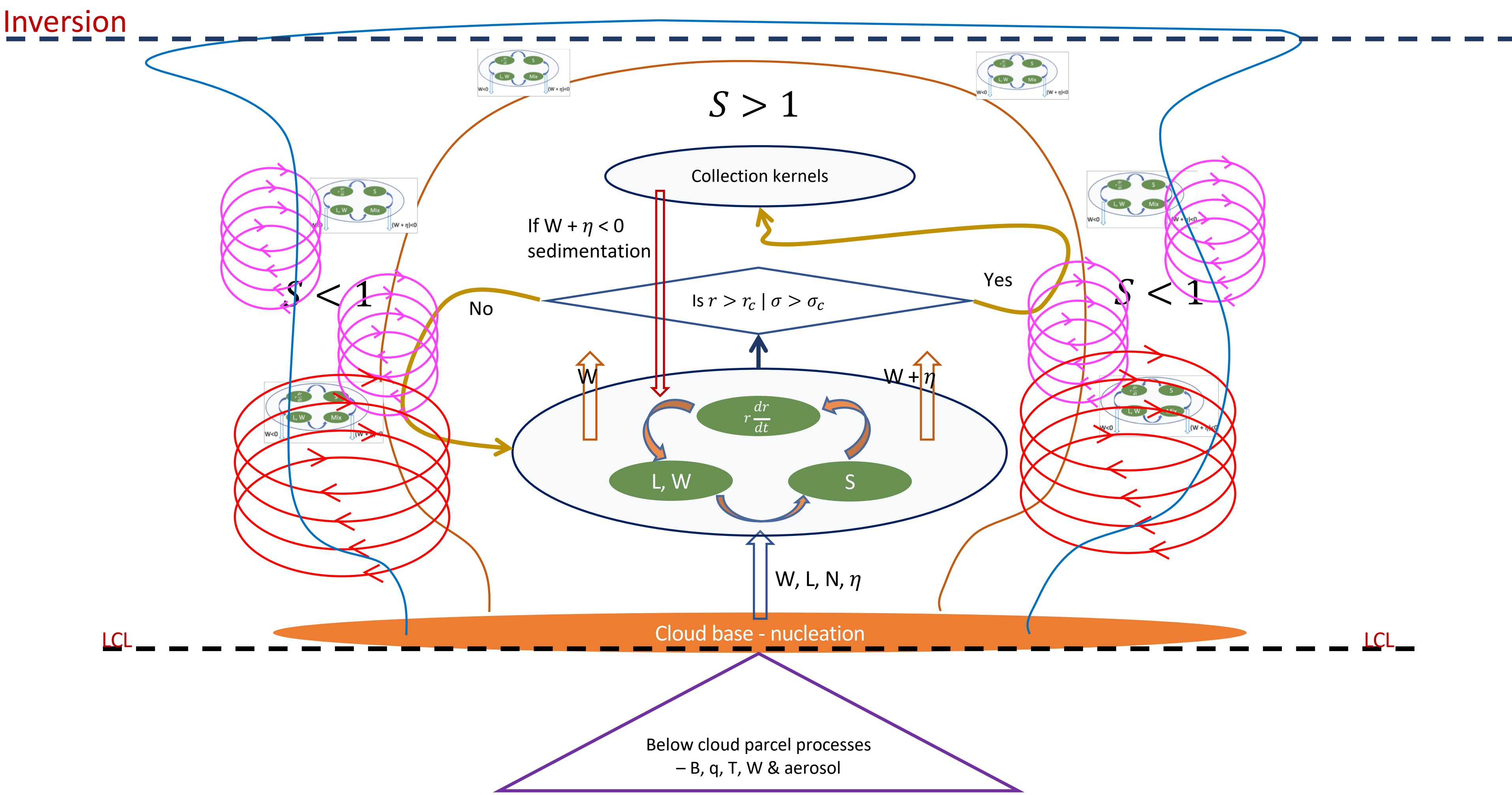
The Grand Cloud Machinery



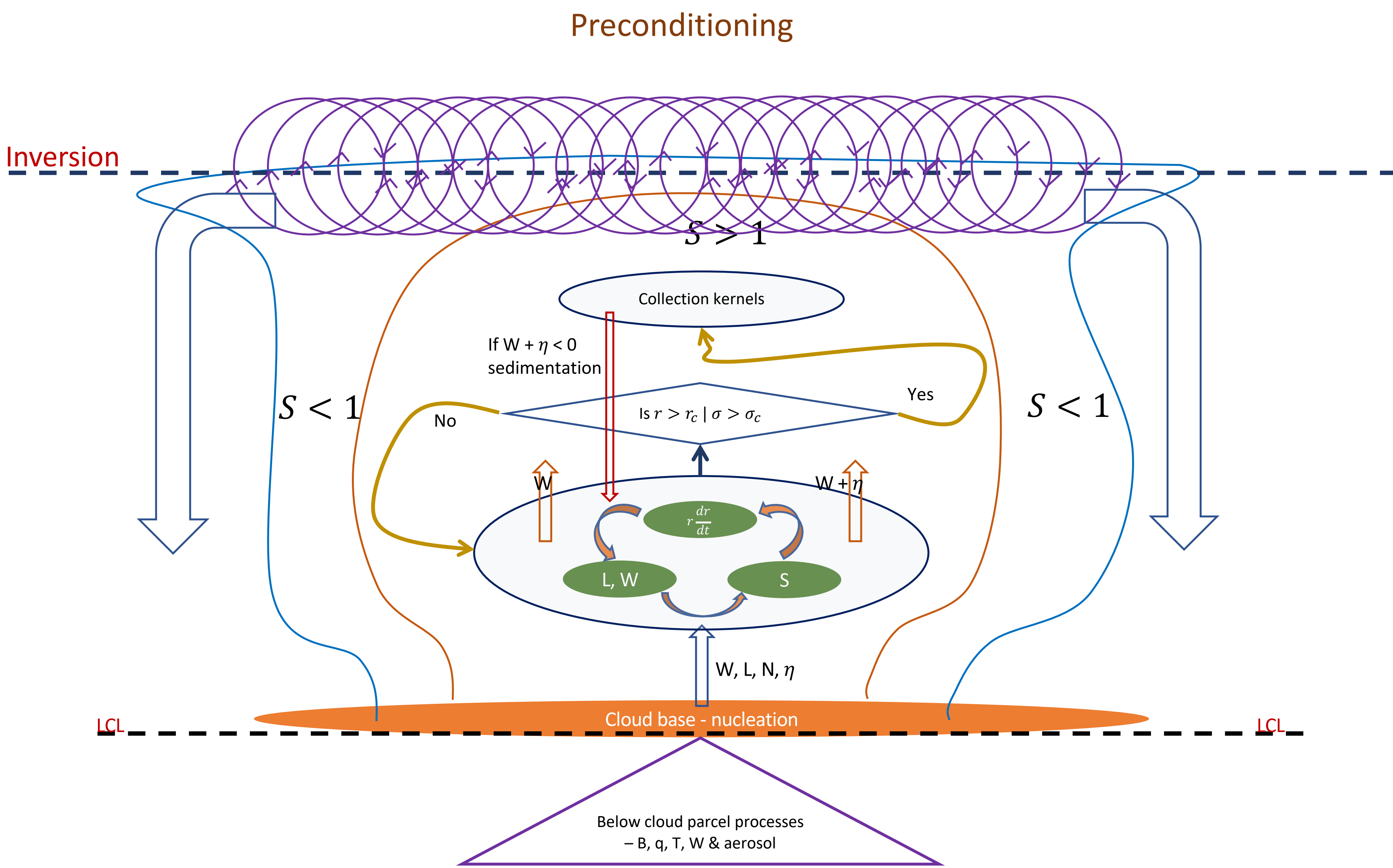
The Grand Cloud Machinery



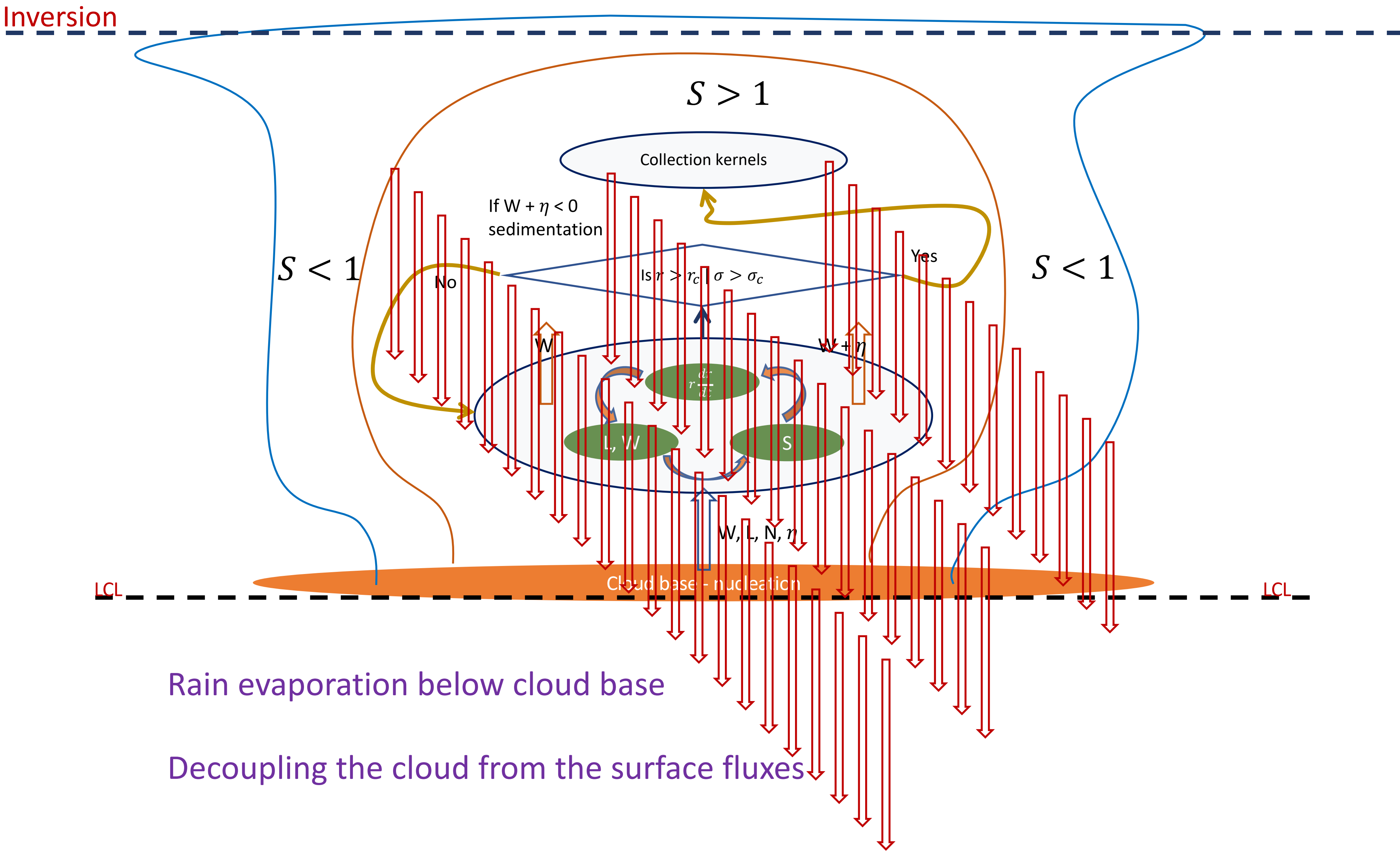
The Grand Cloud Machinery



The Grand Cloud Machinery



The Grand Cloud Machinery



Rain evaporation below cloud base

Decoupling the cloud from the surface fluxes

The Grand Cloud Machinery

On the scale of the cloud field, clouds can precondition the upper cloudy layer
Or rain evaporation below cloud base can decouple the cloudy layer from the surface fluxes

So how changes in aerosol properties can change “the grand cloud machinery”?

We will view this question on the cloud and the cloud-field scales

The Grand Cloud Machinery

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What is cloud invigoration?

Why they were so many contradicting studies on invigoration (still are)?

Is it mixed phase process only?

Is it one process?

When and where should we expect it?

The Grand Cloud Machinery

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What is cloud invigoration? – Pls see the last 1000 slides

Why they were so many contradicting studies on invigoration (still are)?

Is it mixed phase process only? – Of course no. Warm clouds could be invigorated

Is it one process? – No. It is the outcome of interactions between many (sometimes competing) processes

When and where should we expect it?

The Grand Cloud Machinery

On the scale of the cloud field, clouds can precondition the upper cloudy layer
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What is cloud invigoration?

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When and where should we expect it?

Cloud invigoration

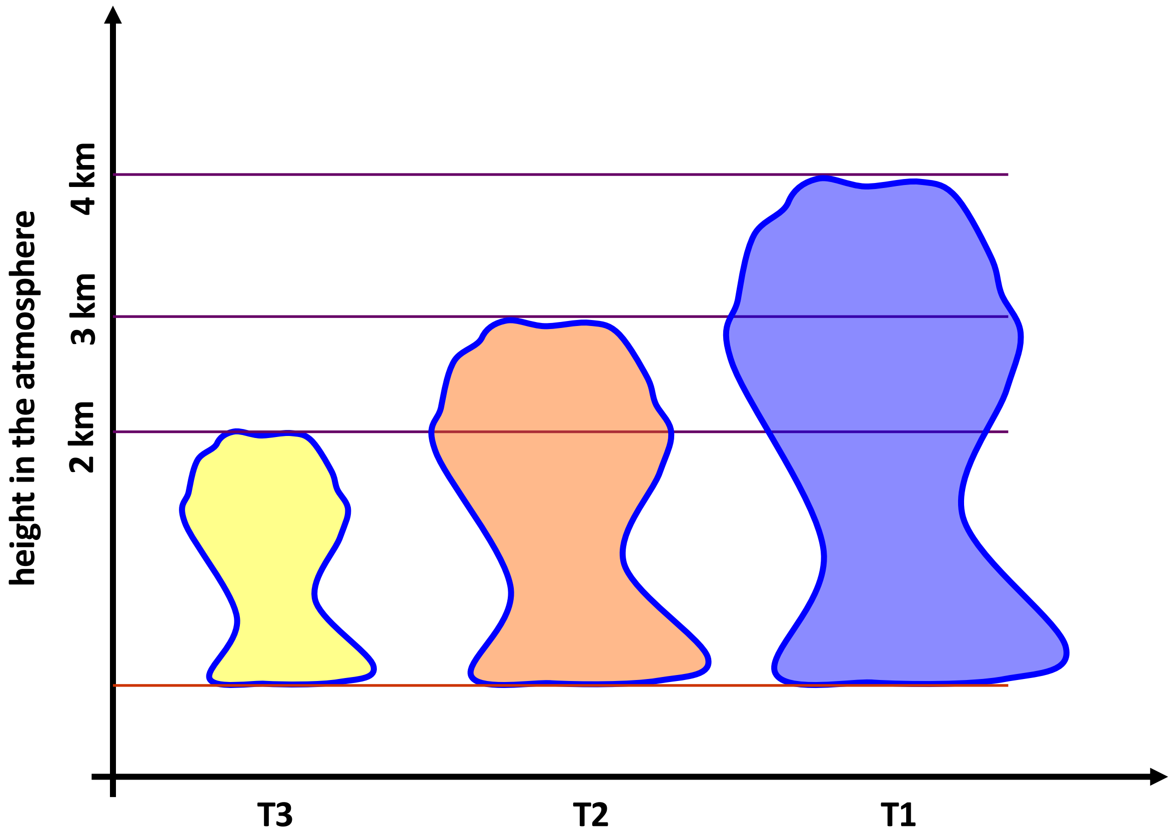
Note: so far all of the described processes and feedbacks are core based

We can define core by RH, B, W and other measures
The core of the cloud will be closer to be adiabatic
Therefore, mixing is expected to be weaker

Away from the core, in the cloud margins the same physics imply opposite trends and feedbacks.

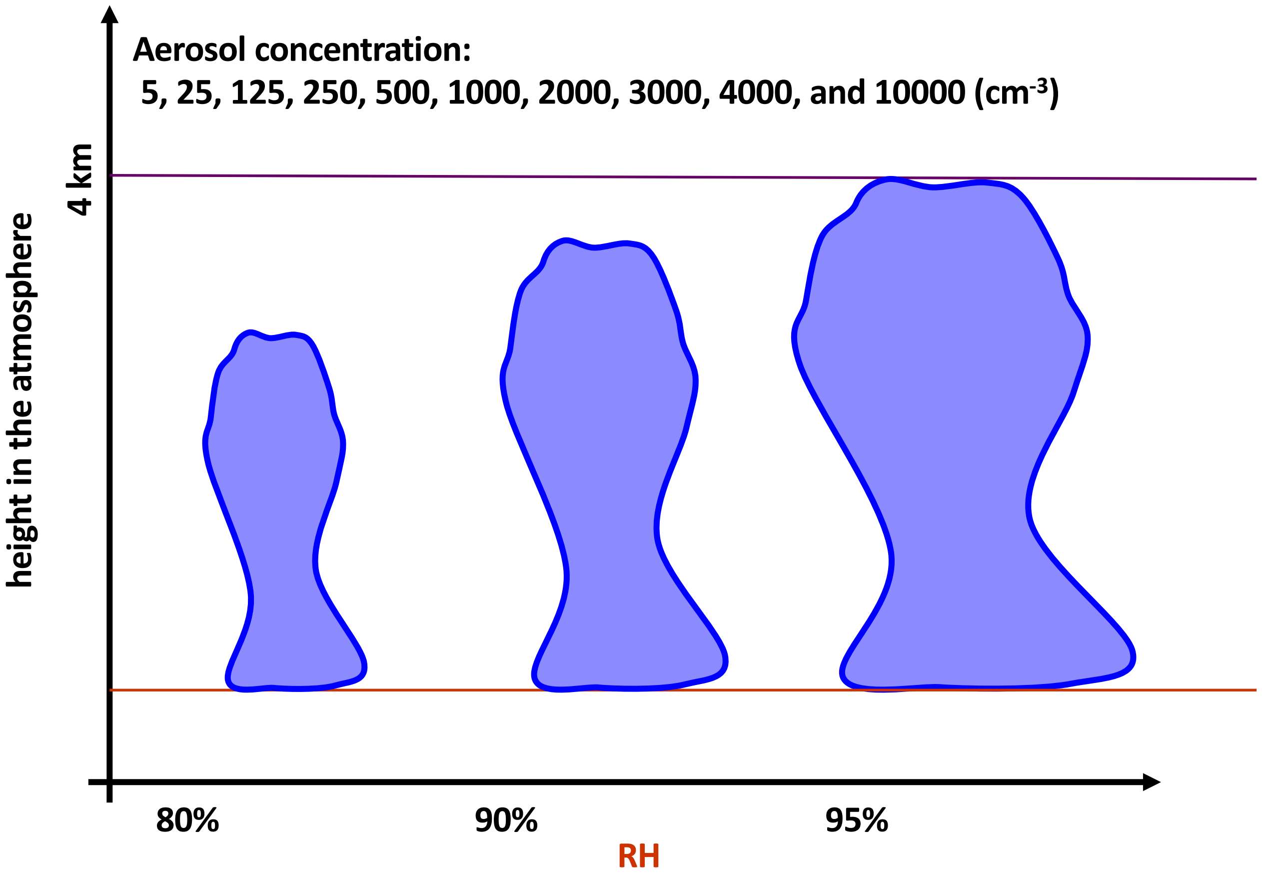
Competition between core based vs margin based processes

Numerical results - Single cloud model set-up

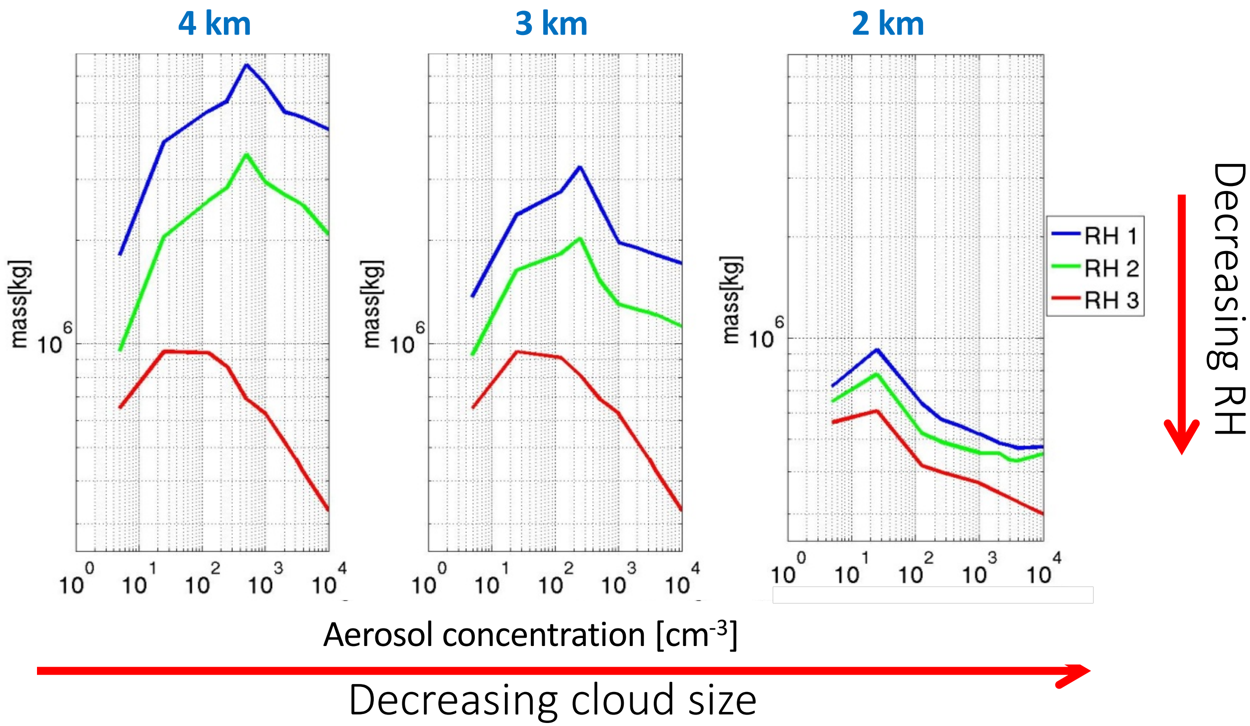


Tel Aviv University axisymmetric cloud model (TAU-CM) with a bin microphysics (Tzivion et al., 1994; Reisin et al., 1996).

Single cloud model set-up



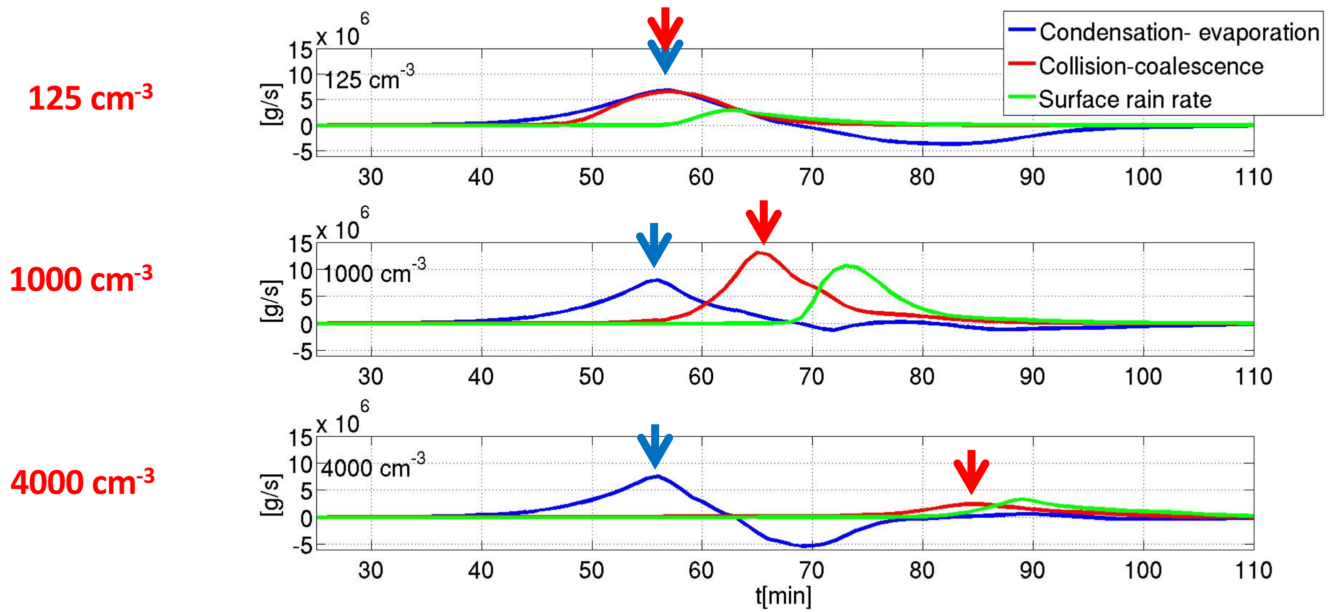
Maximum cloud total mass



Dagan et al., ACP, (2015a)

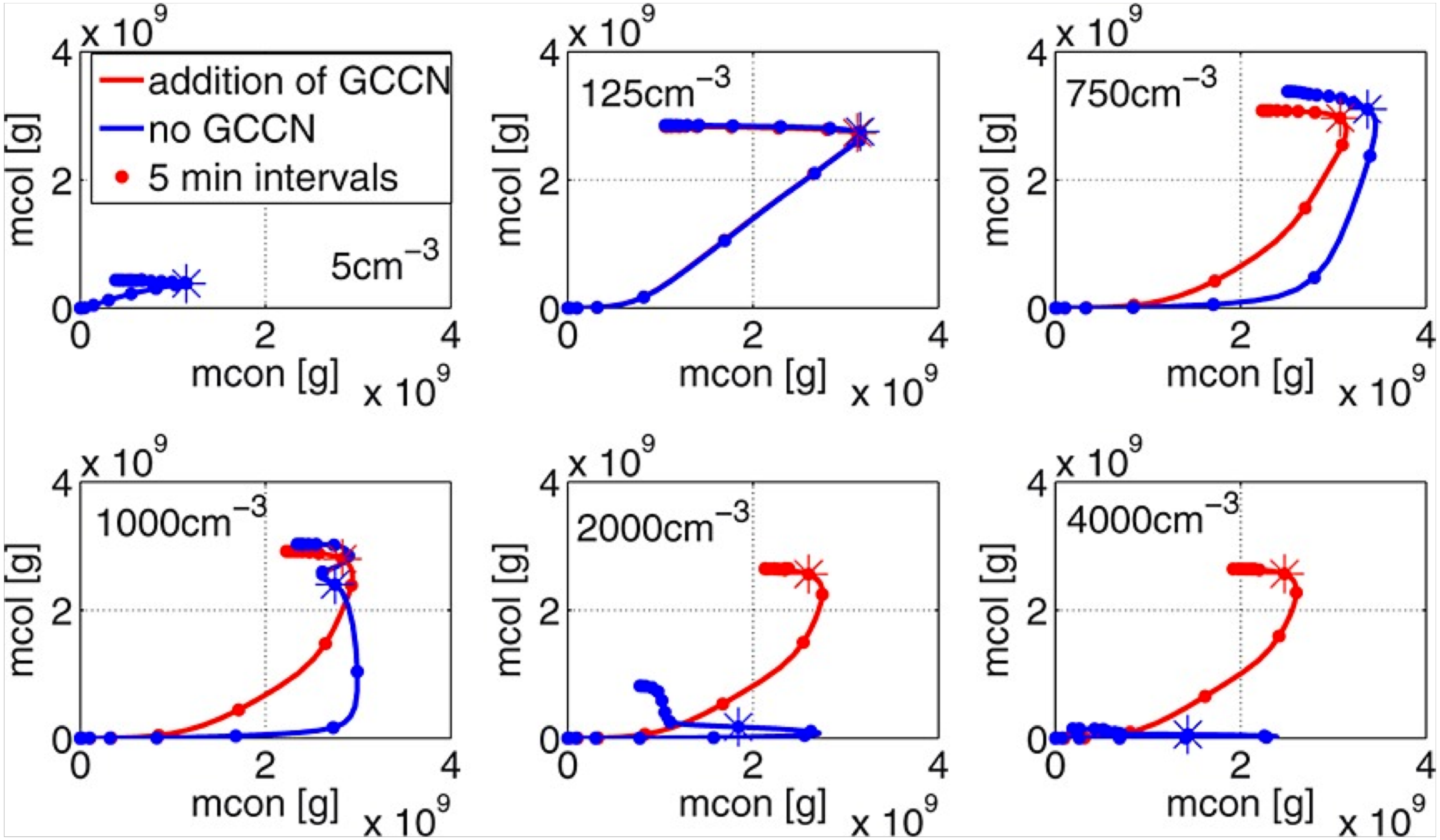
Cloud processes

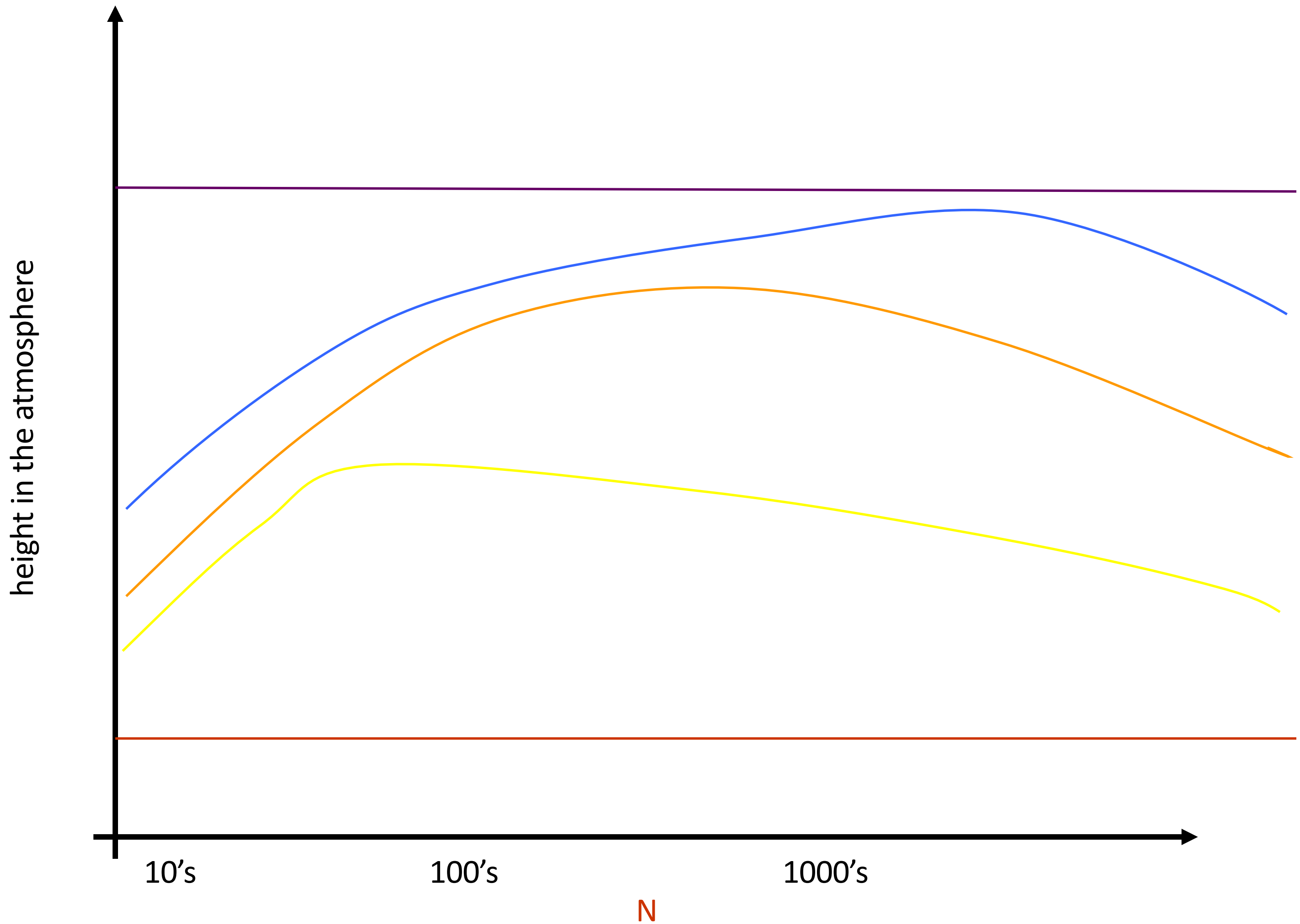
Polluted clouds condense more water vapor due to larger droplets surface area and longer condensation stage



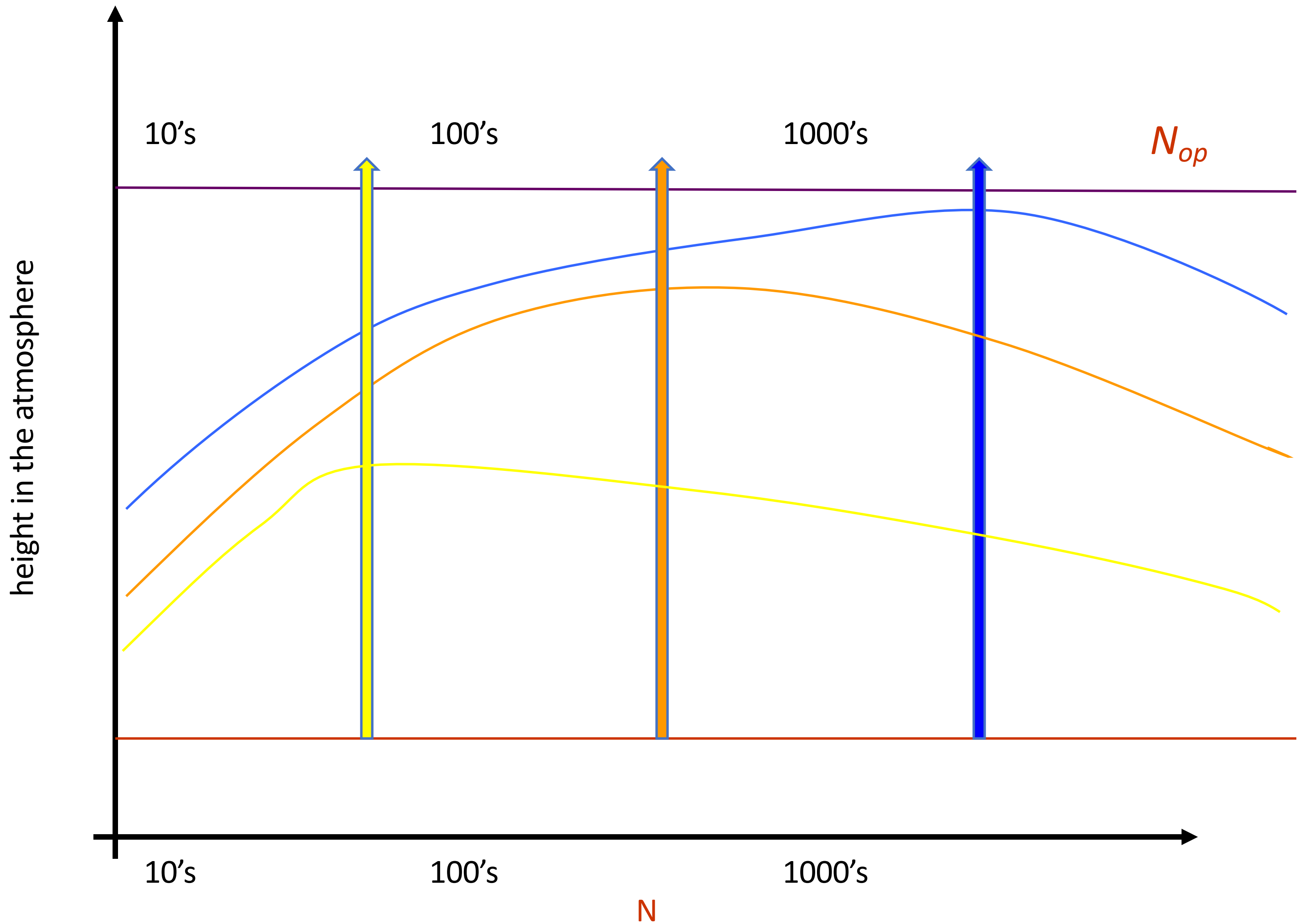
The **early initiation of the collision-coalescence** in clean clouds acts as a **positive feedback** and further reduces the droplets' surface area.

Competitions between core and periphery processes and N_{opt}




height in the atmosphere
10's
100's
1000's
N

Optimal N, $N_{opt} = N_{opt}(\text{Thermodynamics})$



What about the field scale? – part I

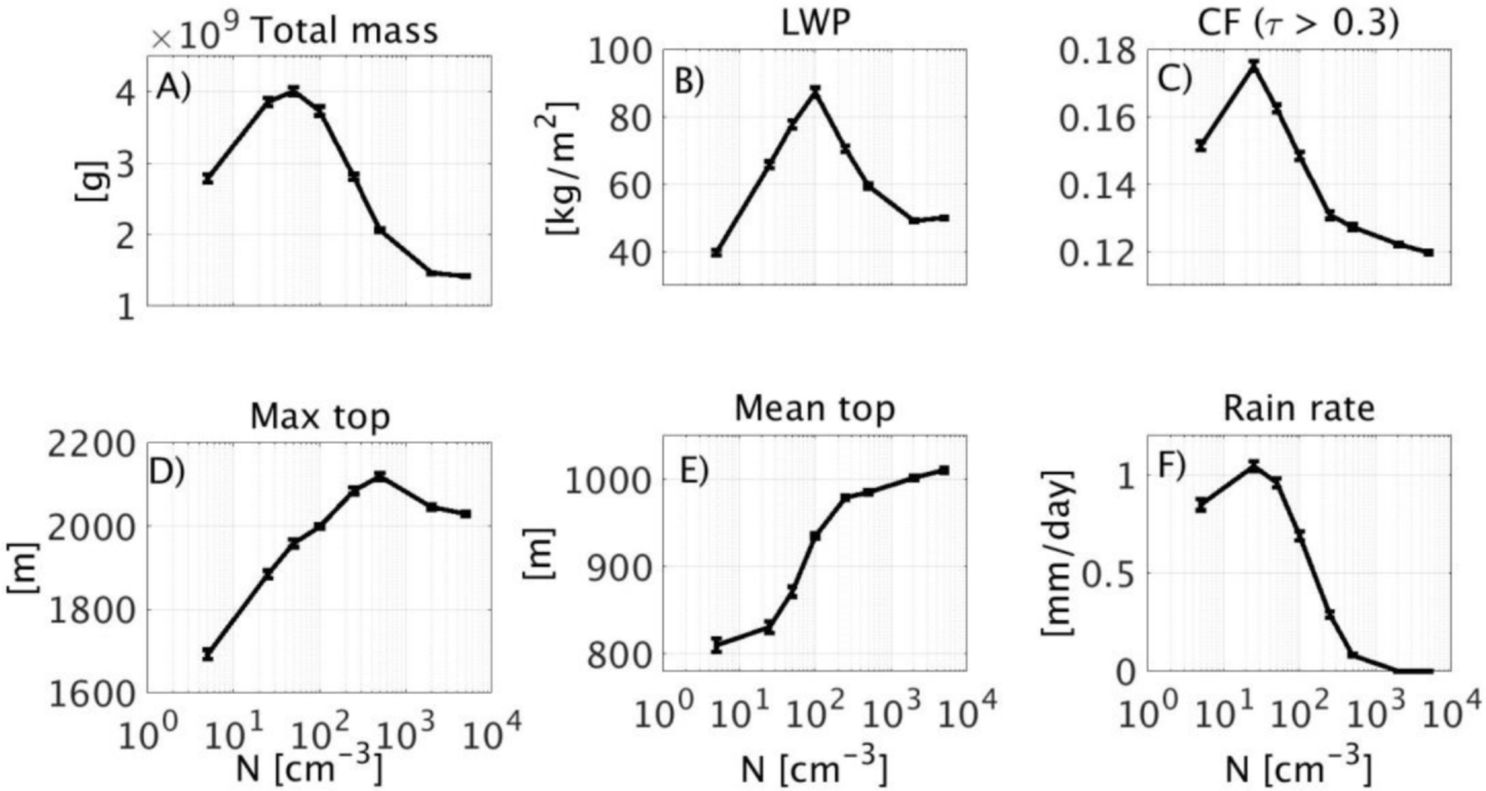
Clouds affect the thermodynamic properties of their field by means of:

Heat and moist distribution

Dynamical partitioning

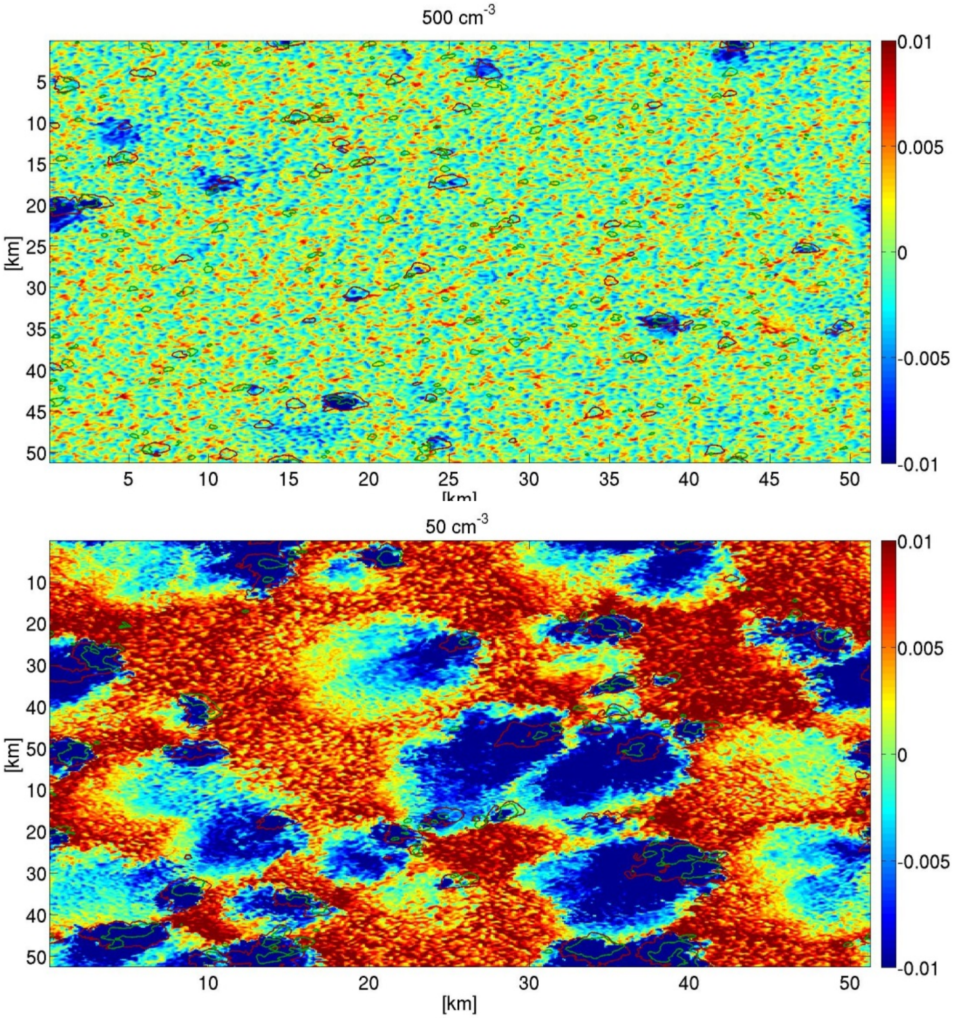
Radiation

On the field scale



Dagan et al., ACPD, (2016)

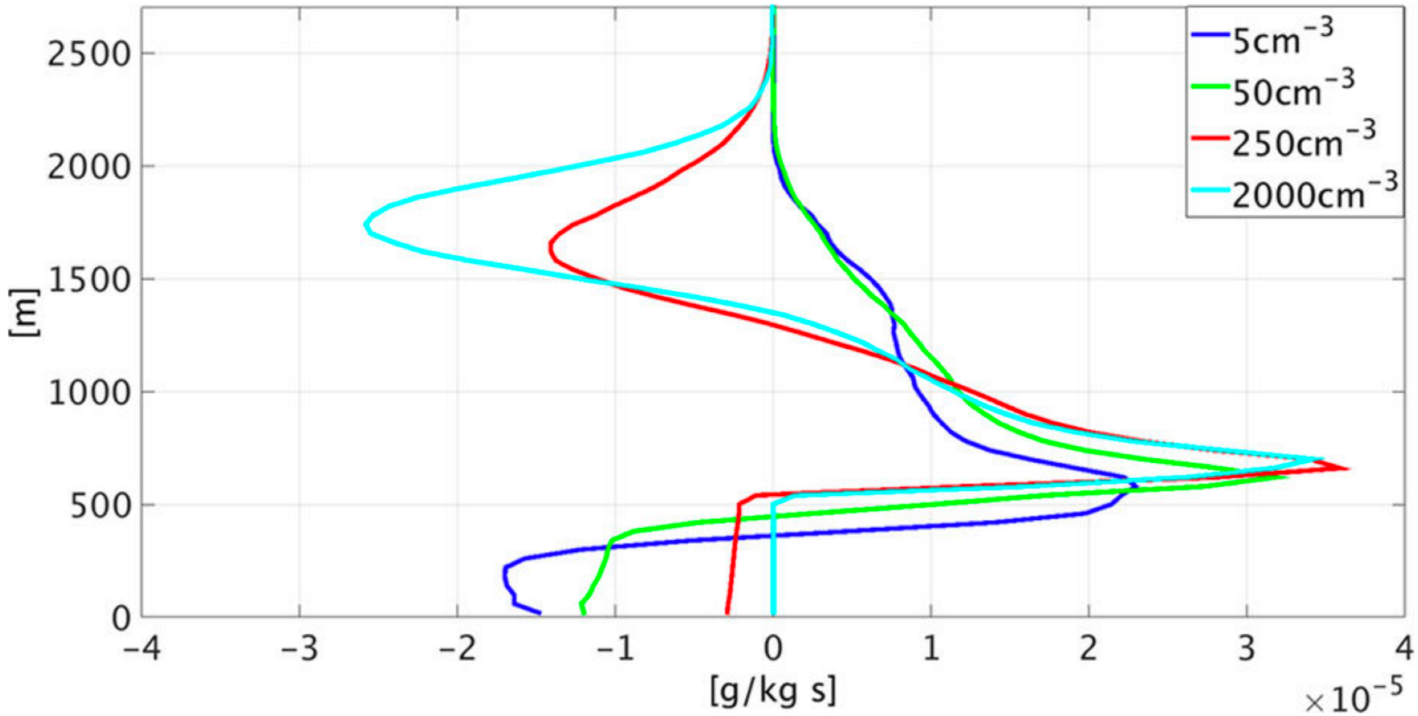
Rain-role in a bistable system



Surface buoyancy (color map [m/s²]) for two large domain LES simulations differ by the aerosol loading used in the simulations after 400 min of simulation. The green contours represents LWP>5kg/m² while the red contours represents surface rain (LWC>0.001g/kg).

Figure 2: Domain's mean condensation-less-evaporation tendencies for four different aerosol loading levels (5 cm^{-3} – blue, 50 cm^{-3} – green, 250 cm^{-3} – red, and 2000 cm^{-3} – cyan).

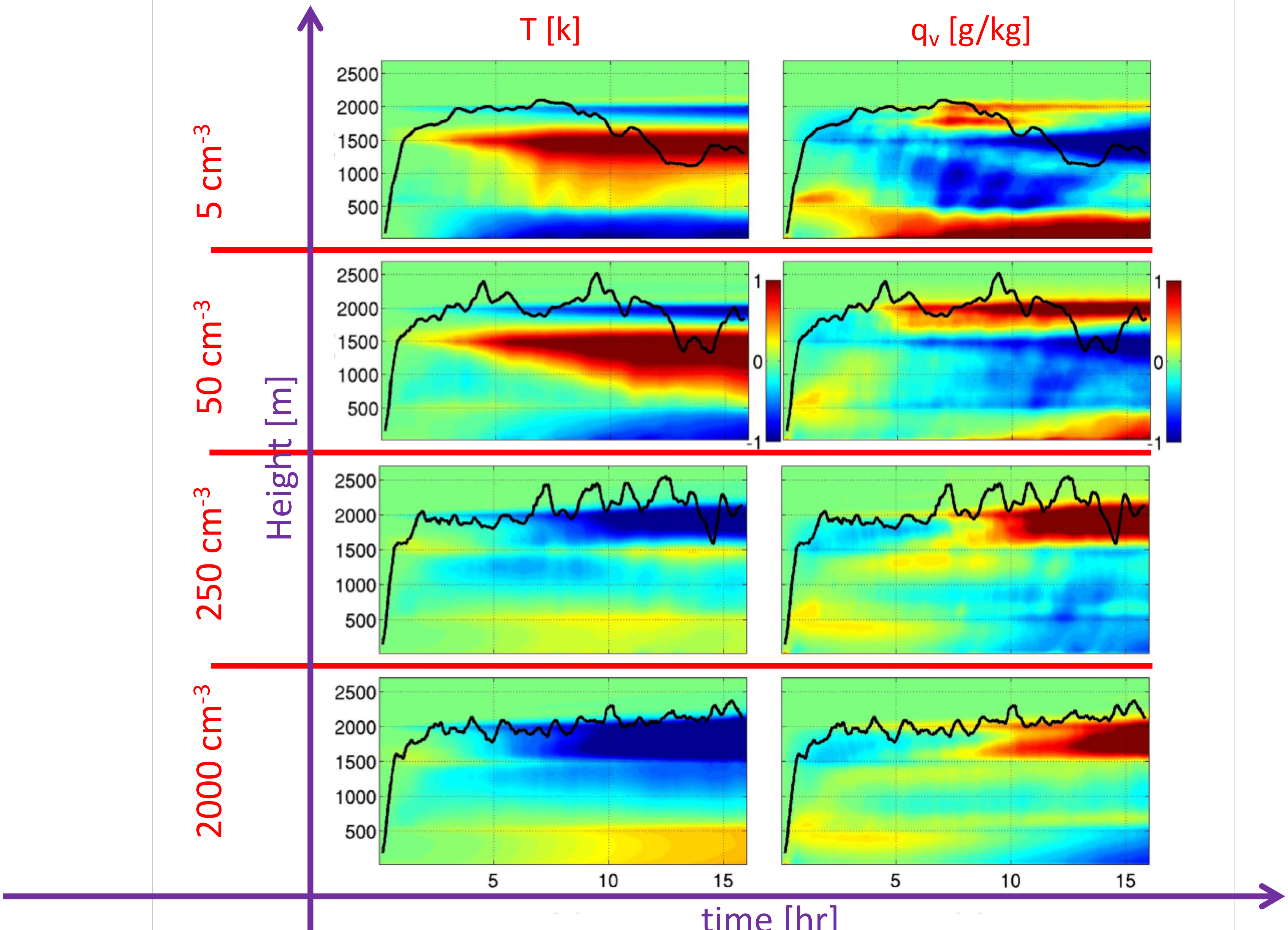
From: Aerosol effect on the evolution of the thermodynamic properties of warm convective cloud fields



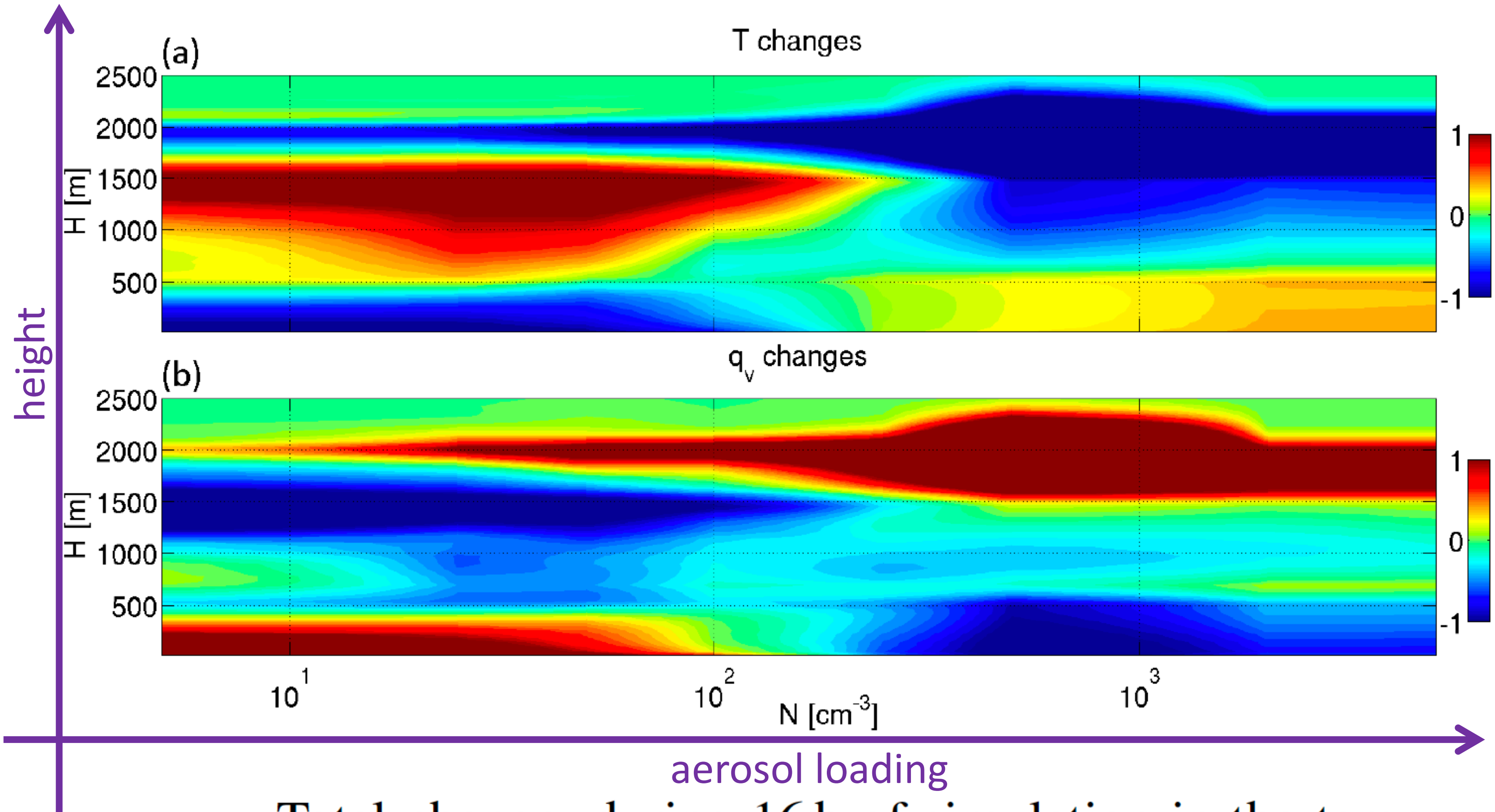
Back to article page »

Dagan et al., SciRep, (2016)

Scientific Reports ISSN 2045-2322 (online)



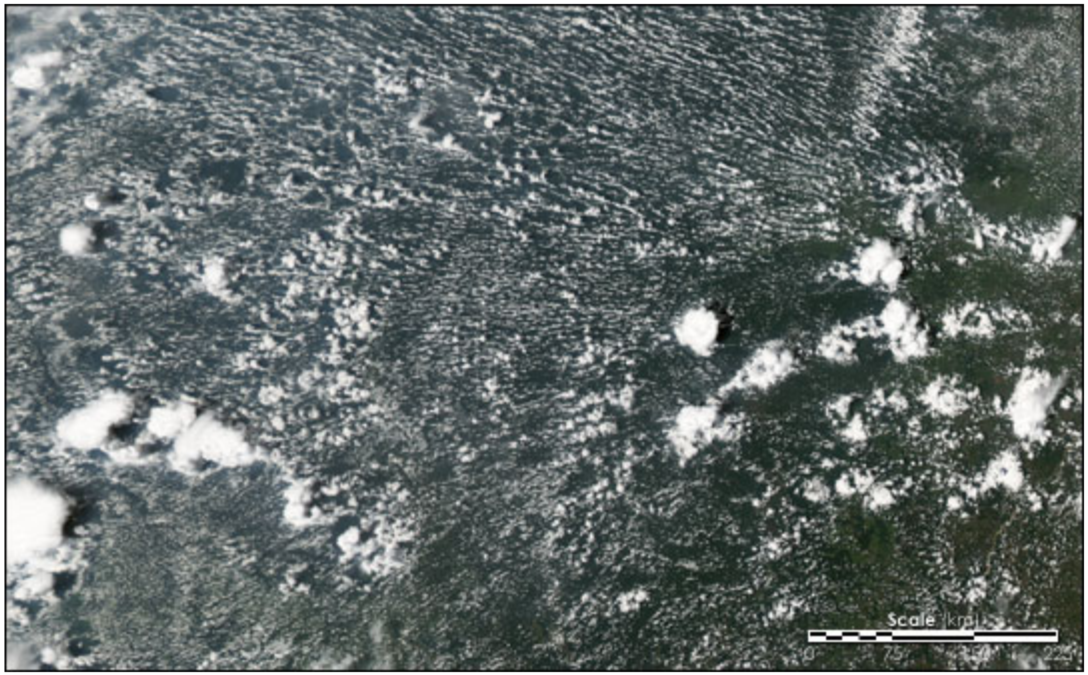
Temporal changes compared to the initial profiles of mean environmental temperature [K] (left column) and mean water vapor mixing ratio [g/kg] (right column). Each row shows the temporal evolution of the differences for a given aerosol concentration (5, 50, 250 and 2000 cm^{-3}). Black lines present the 10 minutes running average of the maximum cloud top height.

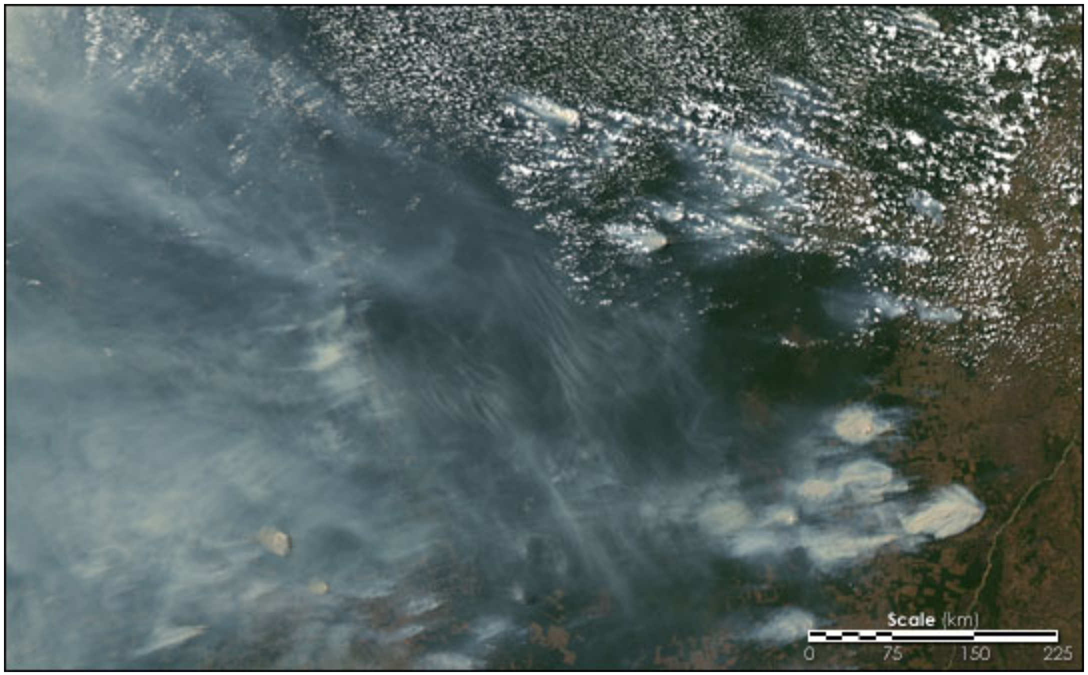


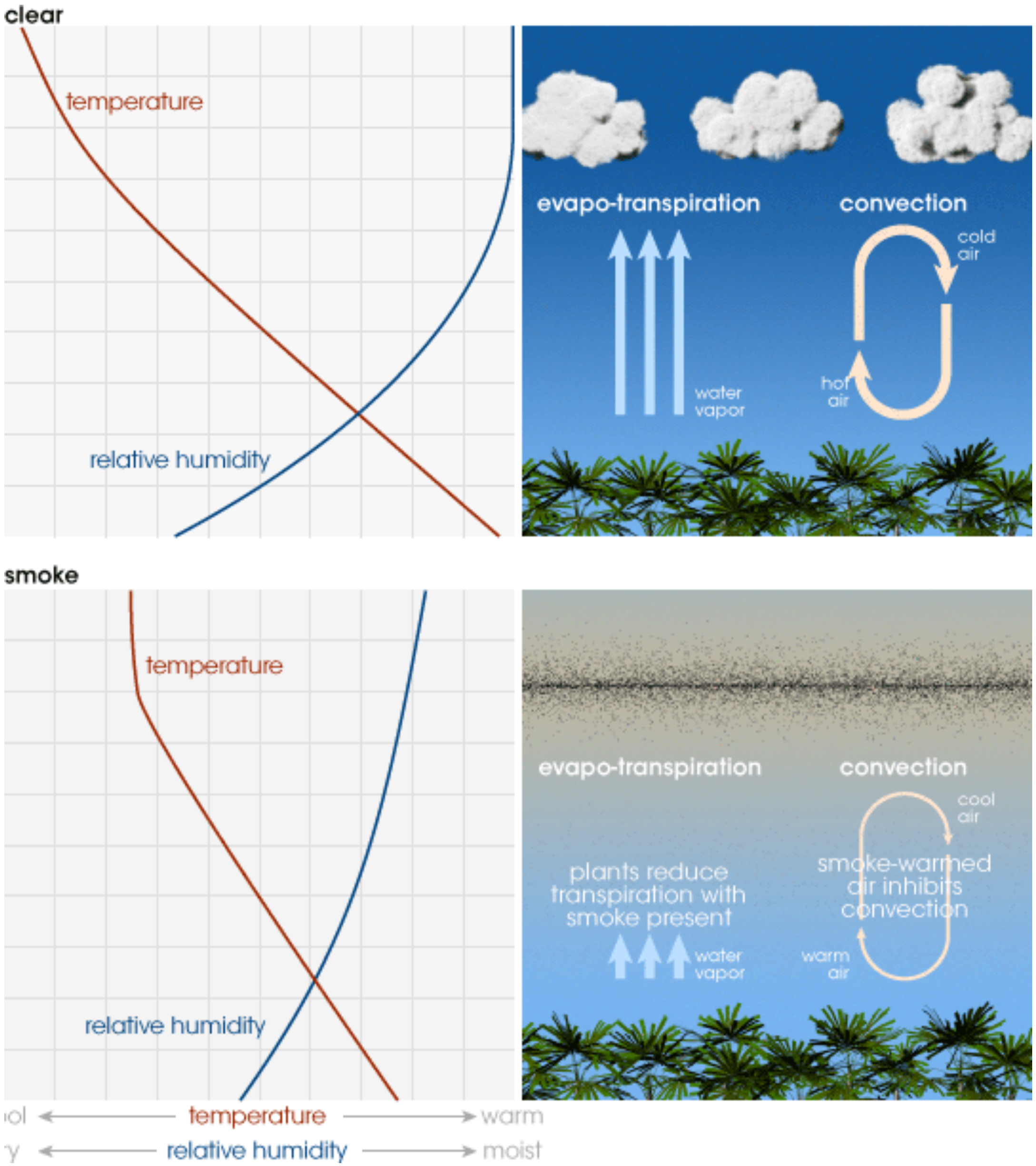
Total change, during 16 h of simulation in the temperature (K; **a**) and water vapor content ($g\,kg^{-1}$; **b**) domain mean vertical profiles as a function of the aerosol concentration used in the simulation.

What about the field scale? – part II

Aerosol absorption

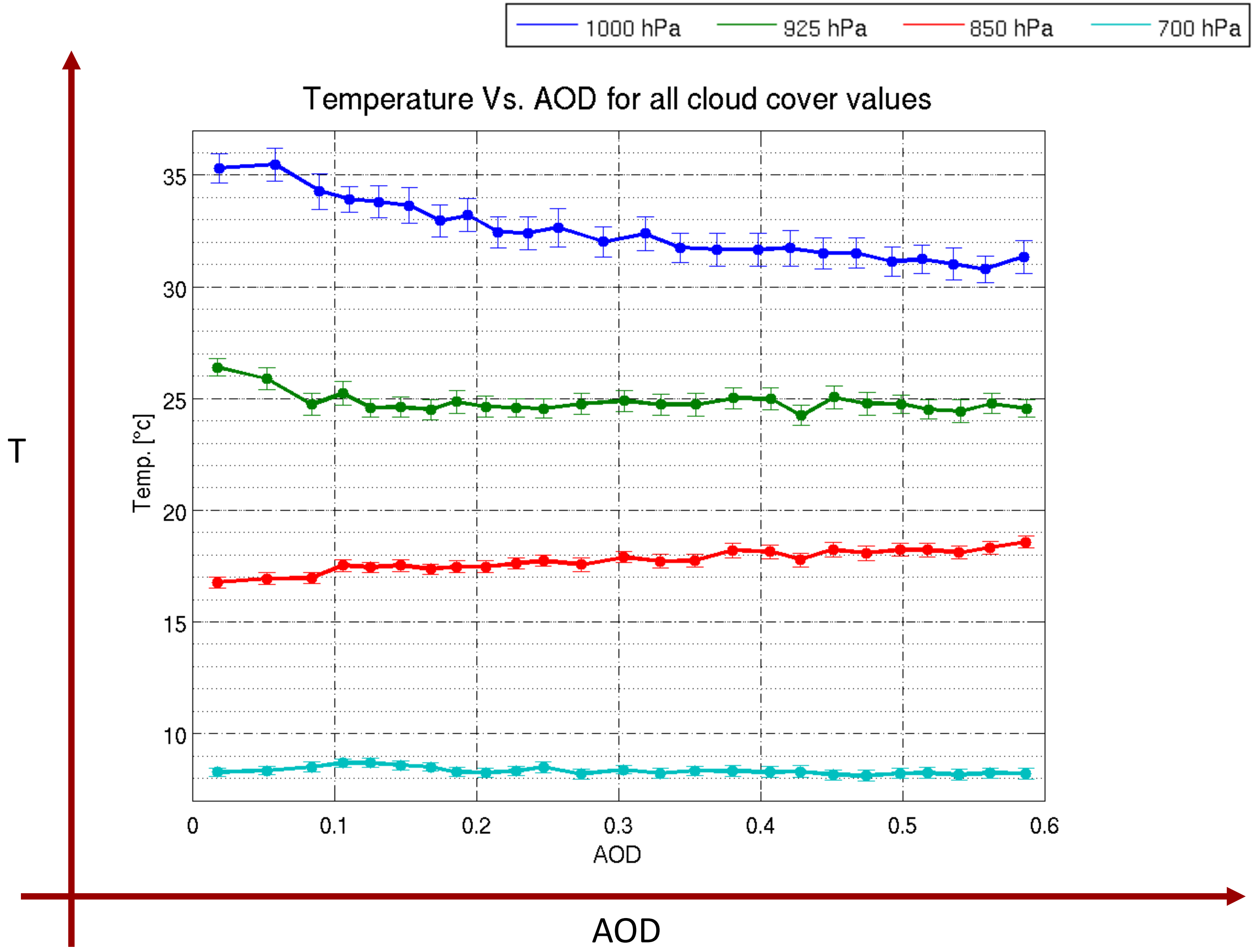

Scale (km)
0
75
150
225


Scale (km)
0
75
150
225

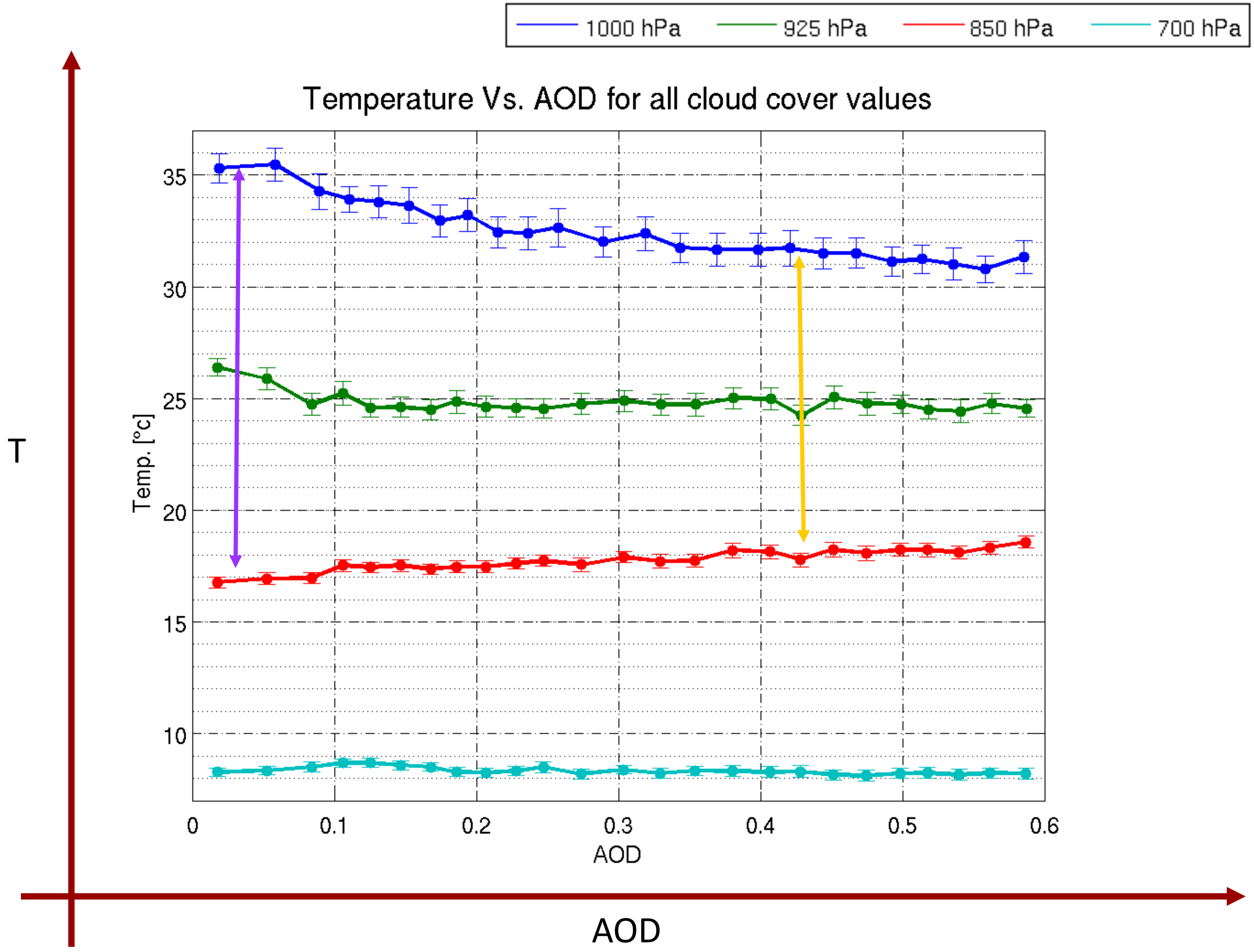


http://earthobservatory.nasa.gov/Study/SmokeClouds/

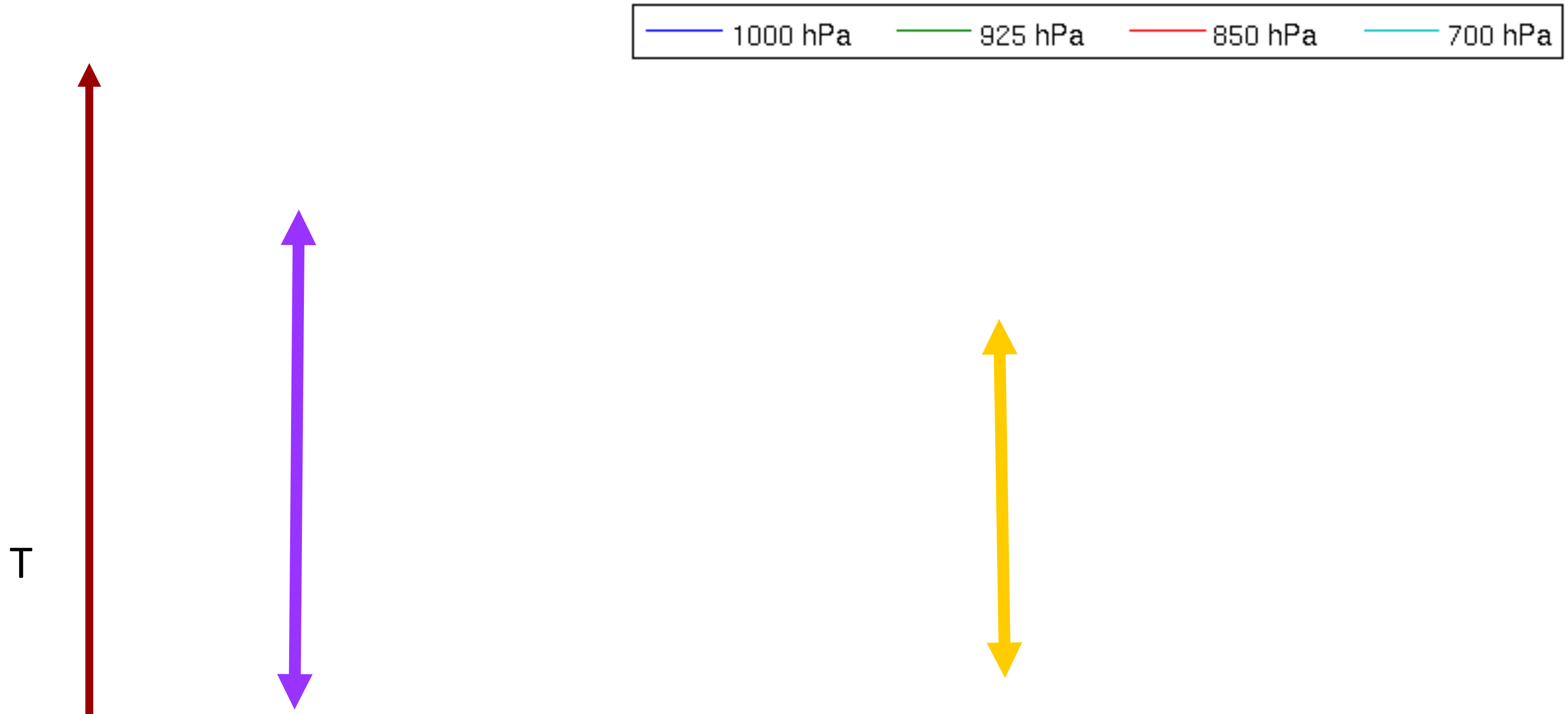
Direct measurements of the effect of biomass burning over the Amazon on the atmospheric temperature profile (Davidi et al, 2009)



Direct measurements of the effect of biomass burning over the Amazon on the atmospheric temperature profile



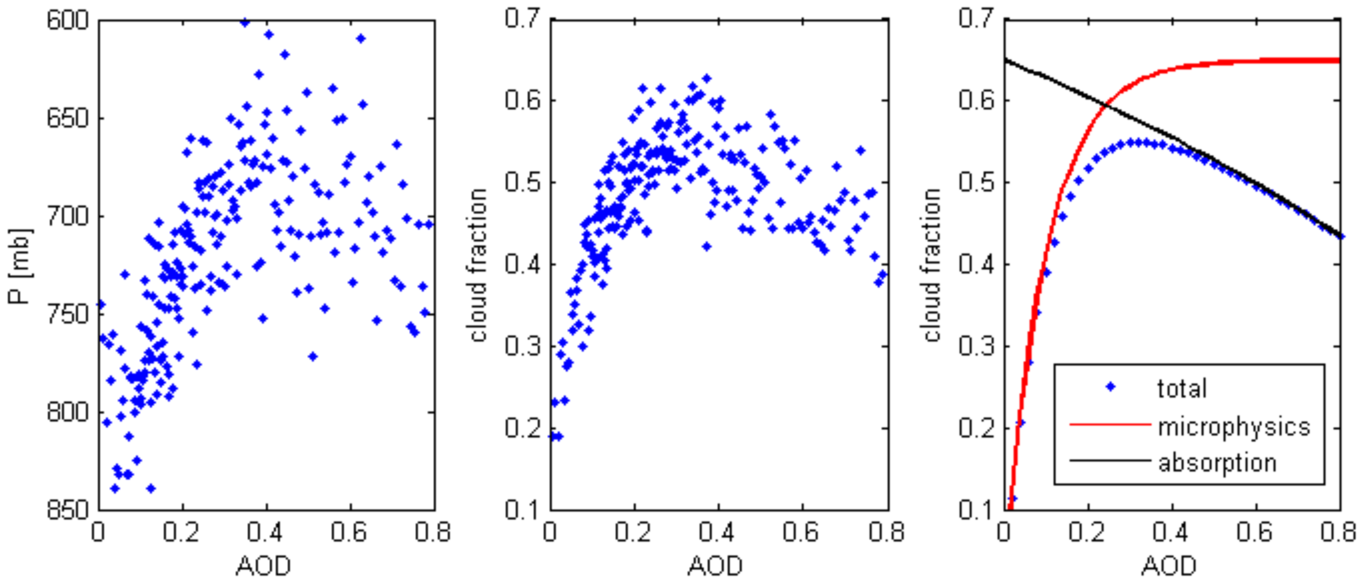
Direct measurements of the effect of biomass burning over the Amazon on the atmospheric temperature profile



DT = T(1000hPa) - T(850hPa), can serve as an indication of the stability of the atmosphere. The dry adiabatic lapse rate is about -1°C per 100m therefore, yields a decrease of ~14°C.

Here it shows that for the clean atmosphere (AOD<0.1) DT ~ 18.5°C indicating average unstable atmosphere, but for the more smoky situations (AOD>0.5) DT ~ 12.5°C, suggesting a transition to a stable atmosphere.

AOD



P [mb]
AOD
cloud fraction
AOD
cloud fraction
AOD
total
microphysics
absorption

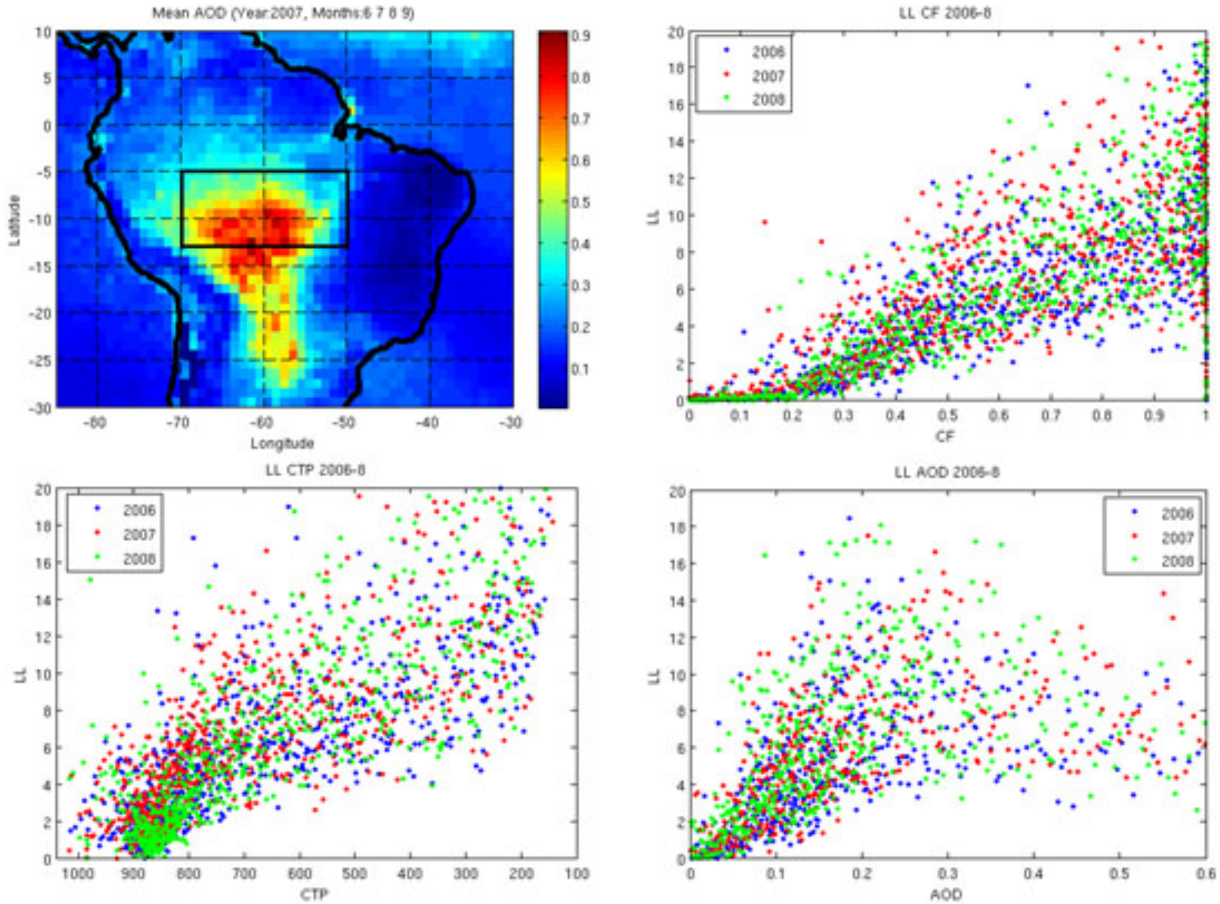


Figure 1: (a) Mean AOD for Jun-Sep, 2007 over the Amazon Basin. The region of interest is marked on the figure. Relationship between number of lightning flashes and (b) cloud fraction (c) cloud top pressure and (d) aerosol loading. 2006 data is marked in blue, 2007 in red and 2008 in green.

Altaratz et al 2009

What was not covered:

Anvils
Self organization and clustering
Mulitstable systems, hysteresis & sharp transitions
Chaotic system & clouds
Randomicity
Polar clouds
Cirrus
Twilight
Spectral inversion of cloud properties
Rain & rain measurements
Electricity – in clouds and the fair weather circuit
…