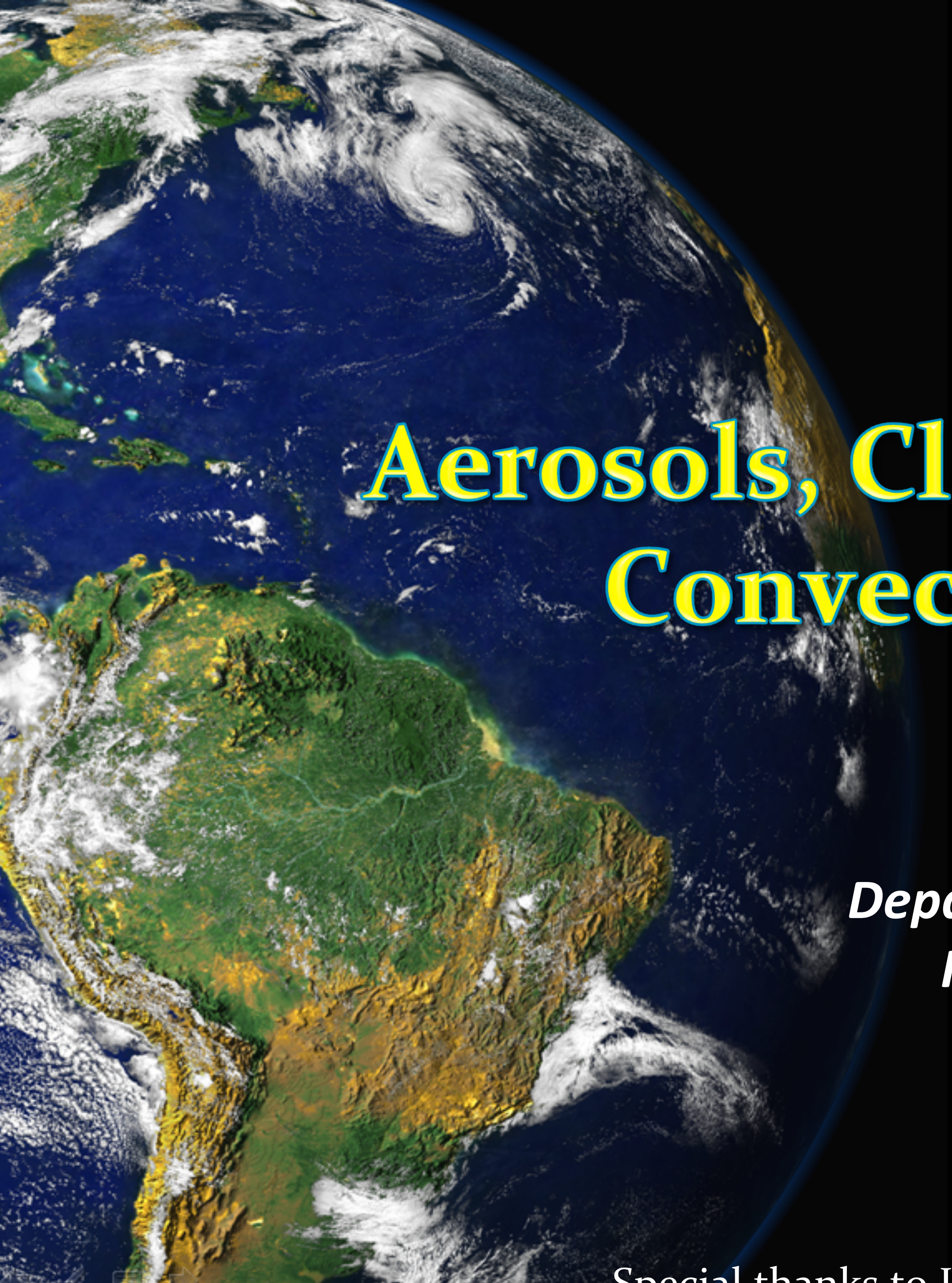

FCM, UFSC
26 de Novembro de 2014

Aerosols, Clouds and Convection

Henrique Barbosa
Departamento de Física Aplicada
Instituto de Fisica da USP
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Special thanks to Ilan Koren for sharing some of the slides

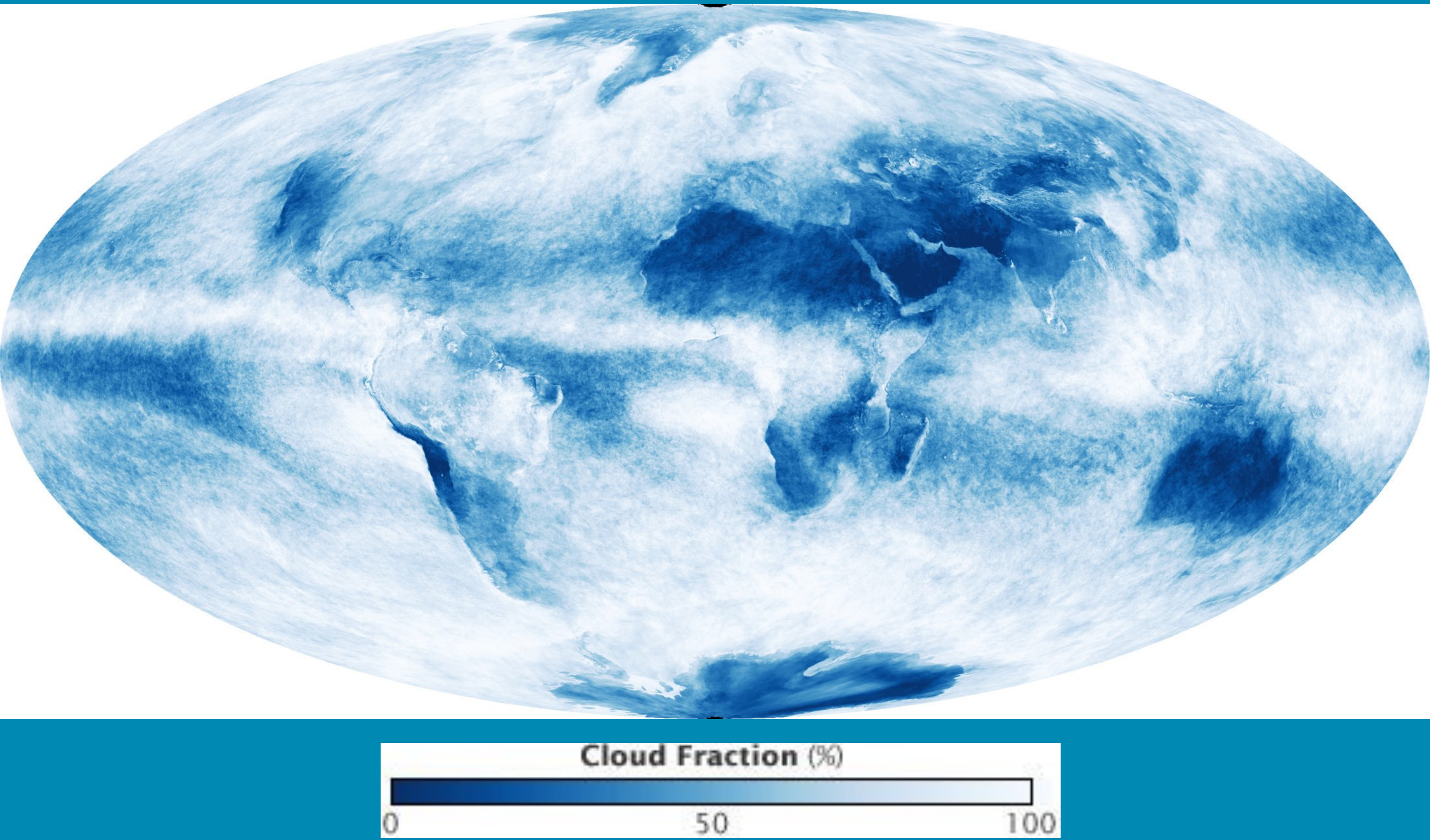
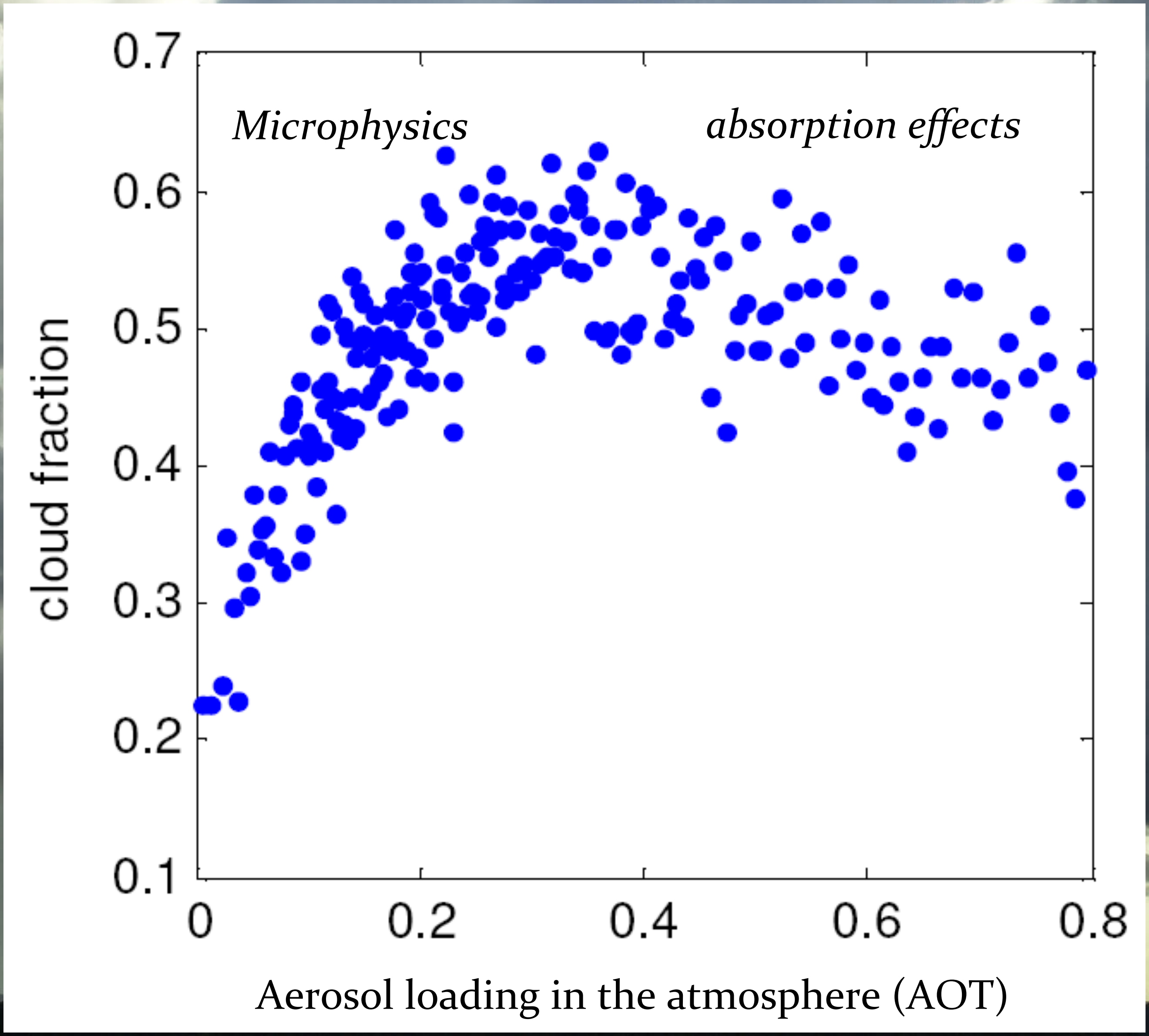
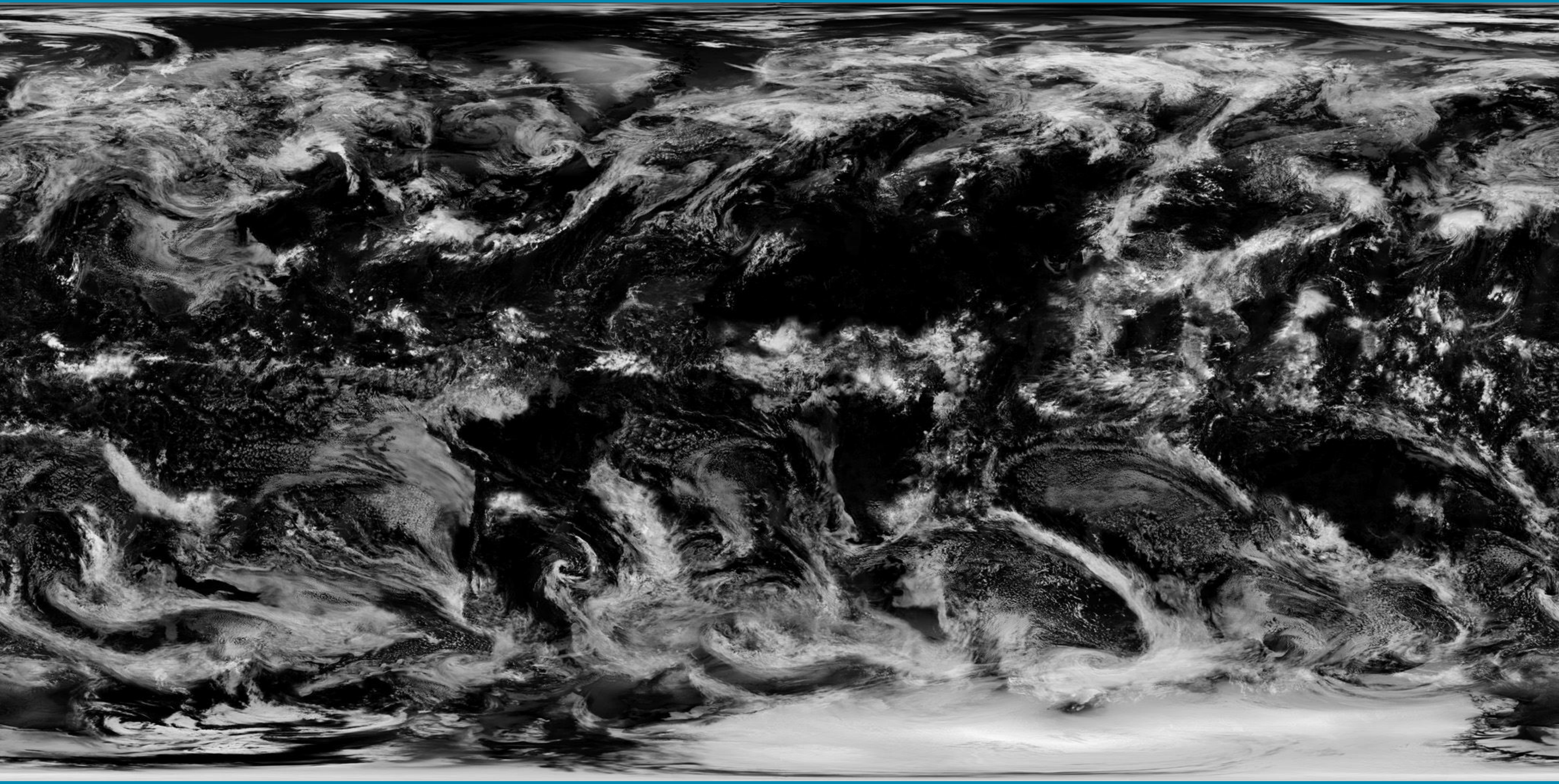

Cloud Fraction (%)
0
50
100


Photo: Ilan Koren

Relationships between cloud properties and aerosol loading in Amazonia

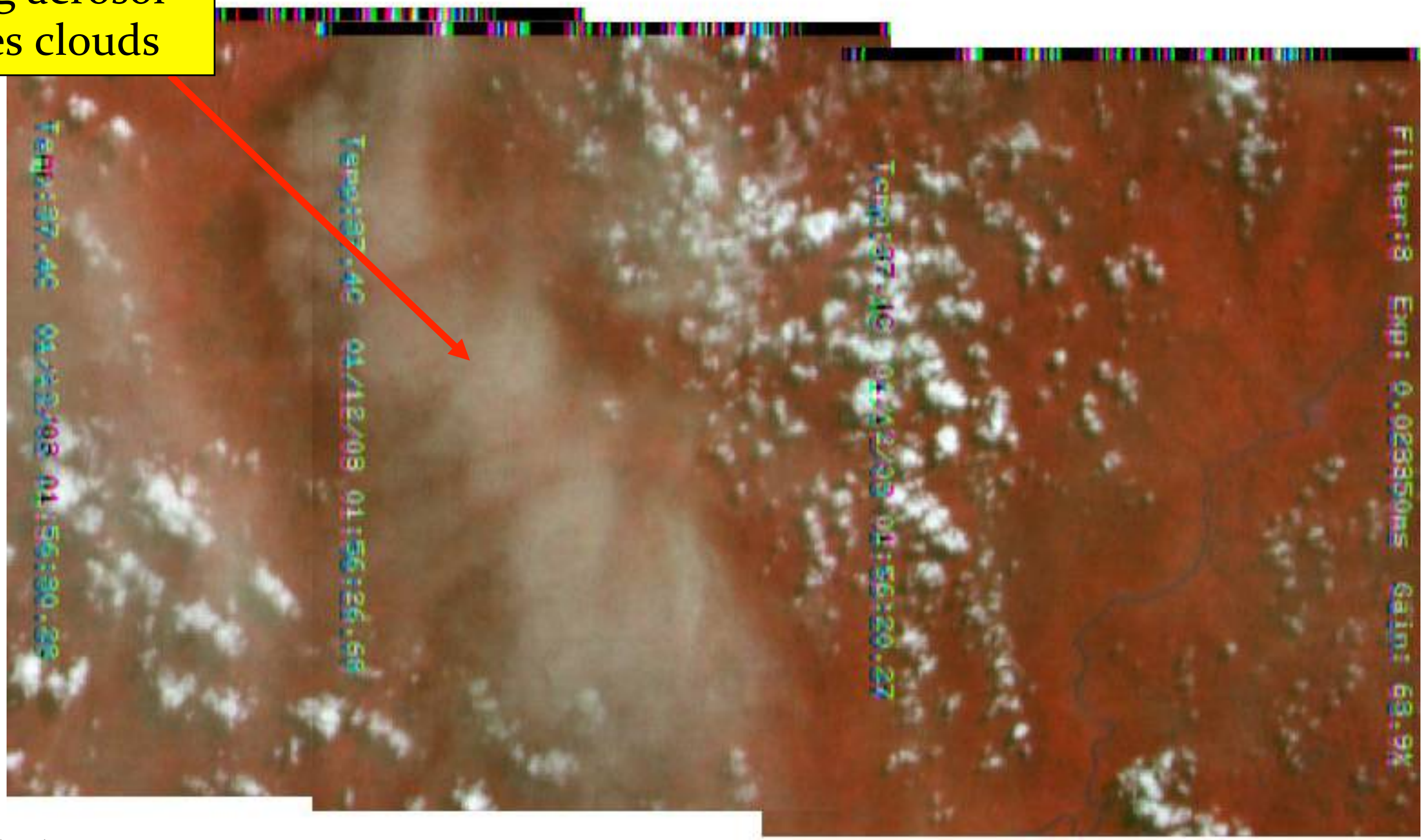


Koren et al., Science 2008



With too much aerosols: Cloud supression

Absorbing aerosol suppresses clouds

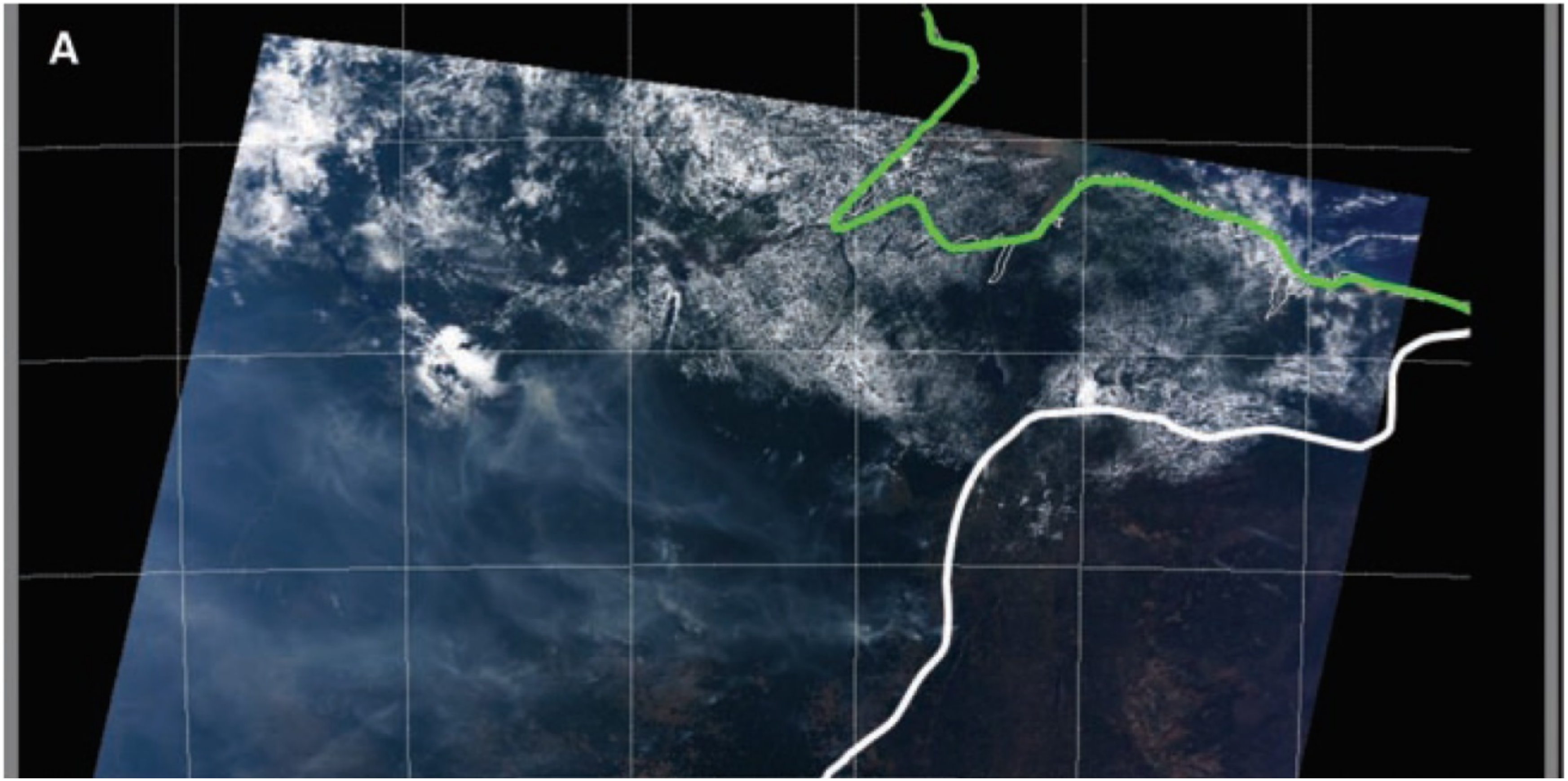


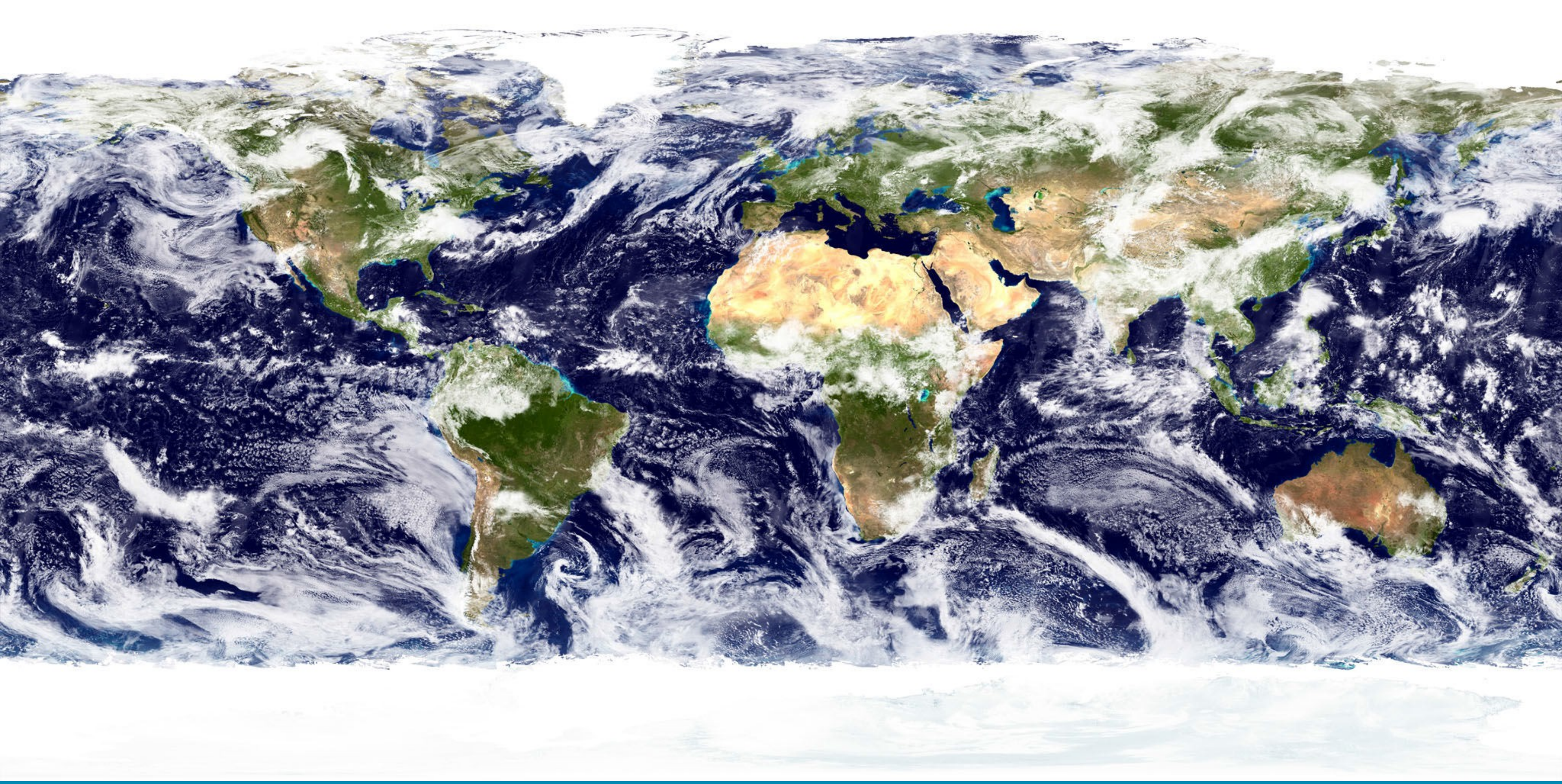
- Stabilization
- Suppression of surface fluxes
- Microphysical influences on droplets

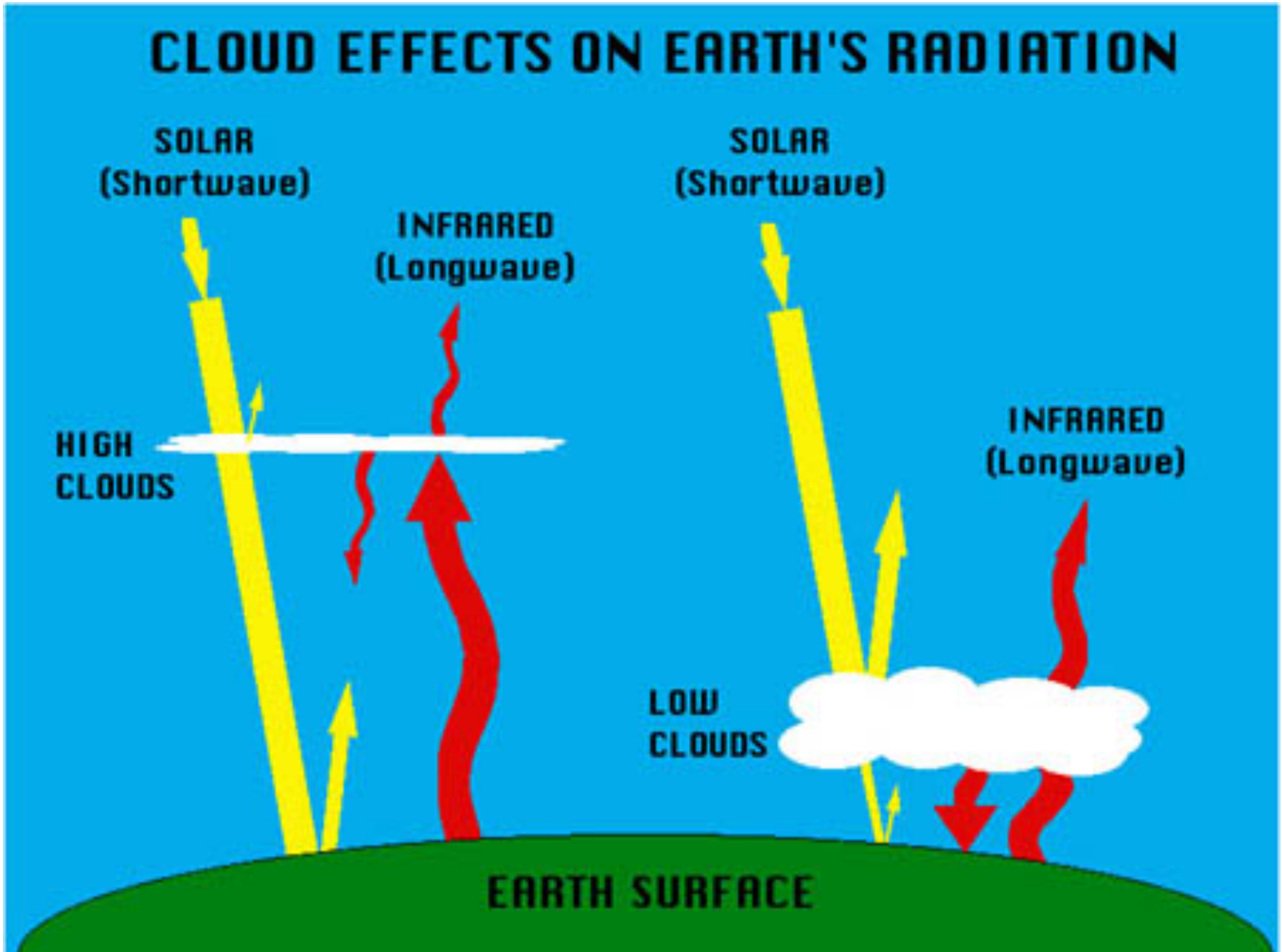
Columbia Shuttle January 2003

Terra and Aqua satellite images of the east Amazon basin, 11 August 2002. *(From Koren et al., 2004)*

Large scale low cloud suppression



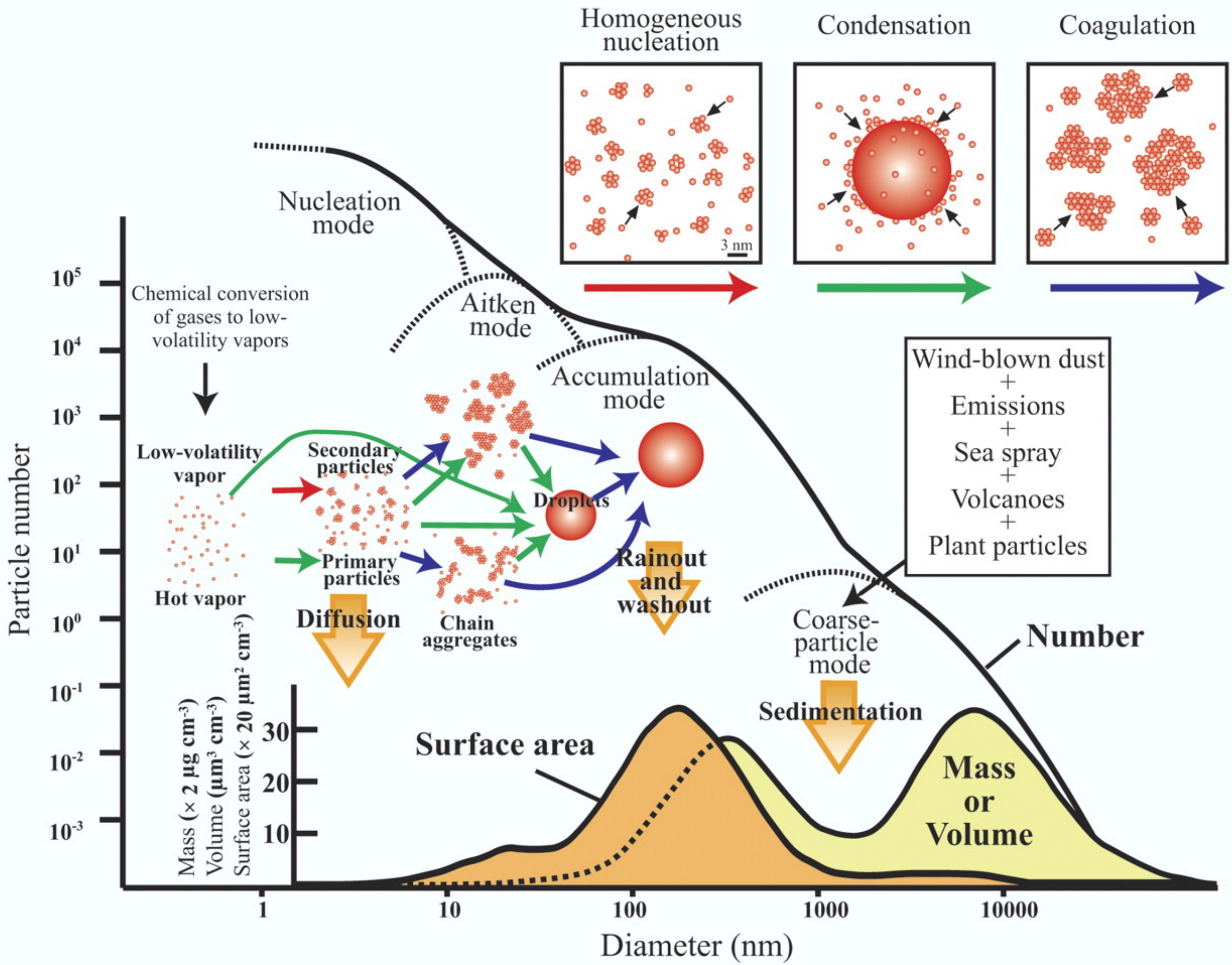



CLOUD EFFECTS ON EARTH'S RADIATION
SOLAR
(Shortwave)
INFRARED
(Longwave)
HIGH
CLOUDS
SOLAR
(Shortwave)
INFRARED
(Longwave)
LOW
CLOUDS
EARTH SURFACE

Key players of basic convectve warm cloud (Cu)

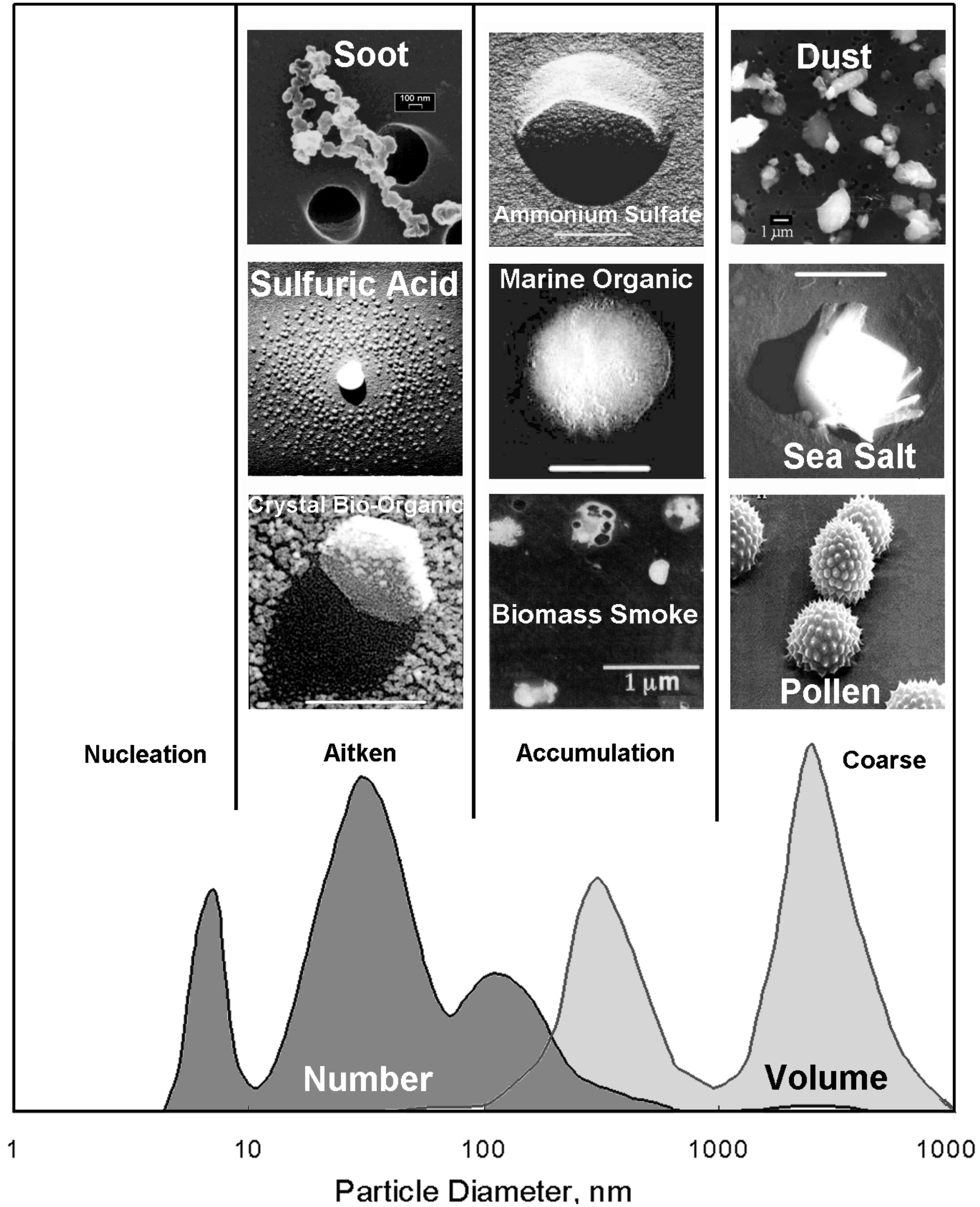
And all clouds need CCN to form

Steffen Schmidt / AP

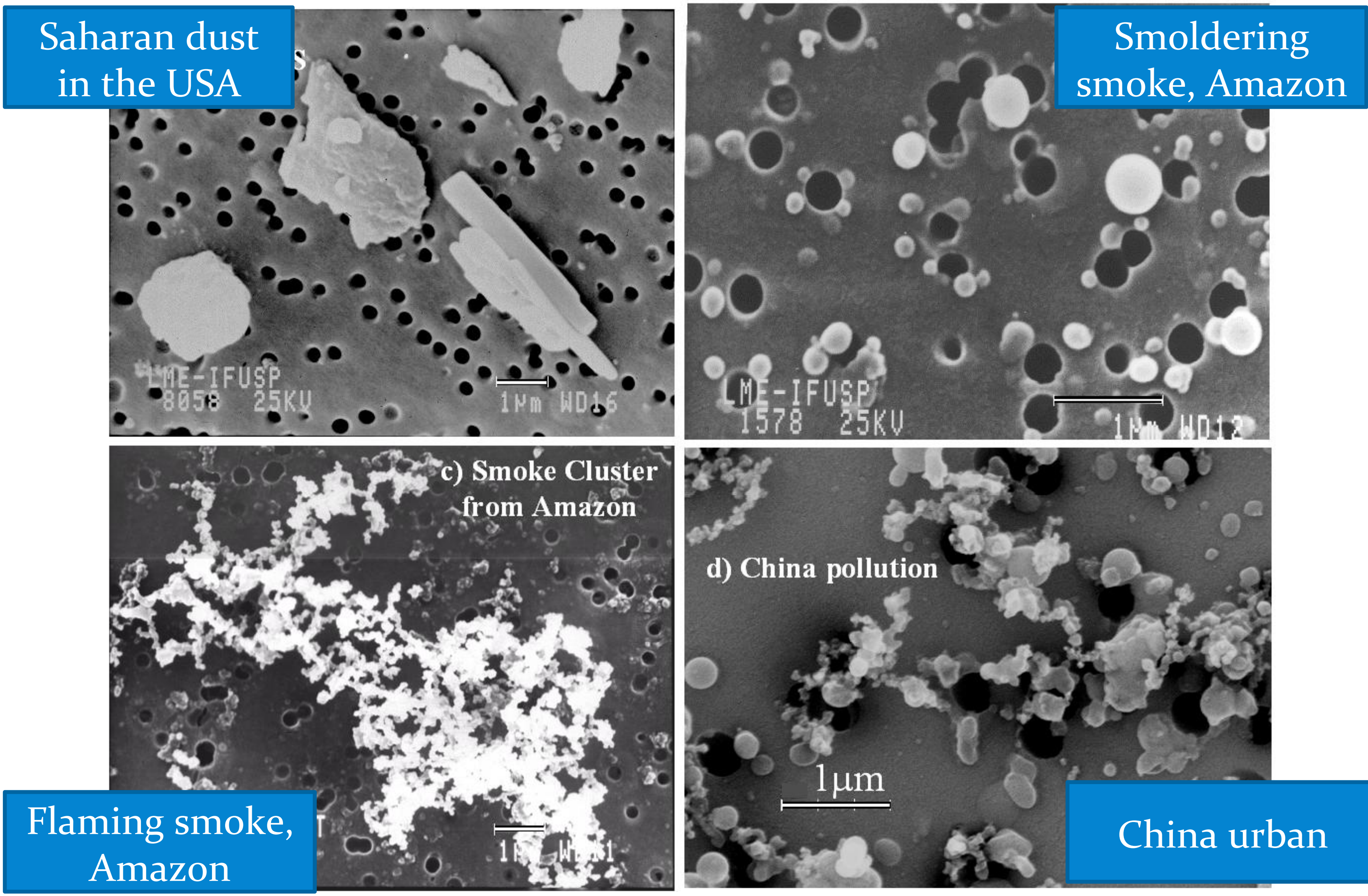

Homogeneous nucleation
Condensation
Coagulation
3 nm
Nucleation mode
Aitken mode
Accumulation mode
Coarse-particle mode
Chemical conversion of gases to low-volatility vapors
Low-volatility vapor
Hot vapor
Secondary particles
Primary particles
Chain aggregates
Droplets
Diffusion
Rainout and washout
Sedimentation
Wind-blown dust + Emissions + Sea spray + Volcanoes + Plant particles
Number
Surface area
Mass or Volume
Particle number
Mass (× 2 μg cm-3) Volume (μm3 cm-3) Surface area (× 20 μm2 cm-3)
Diameter (nm)

Aerosol…

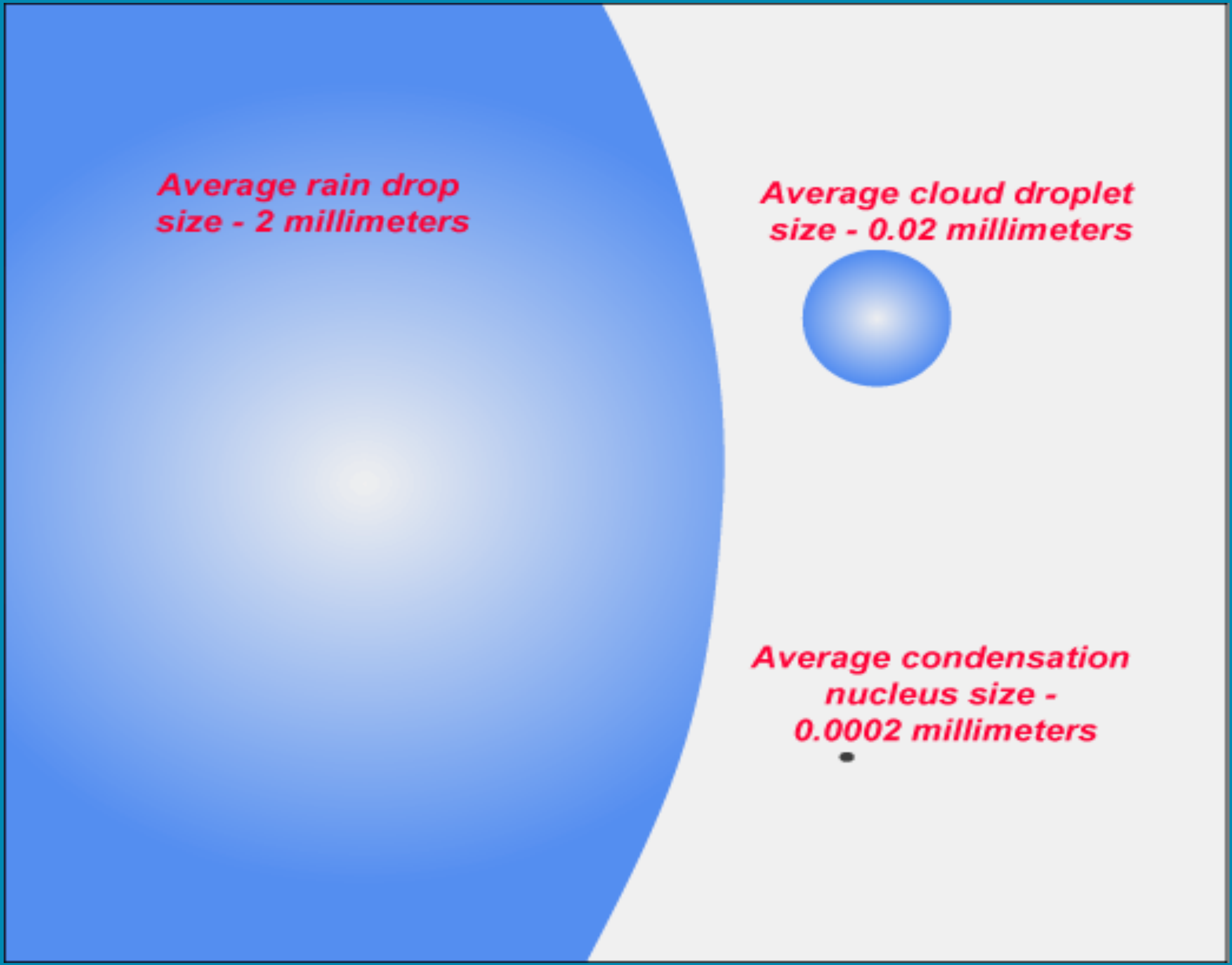
- Interaction with the radiation and CCN property depends:
  - Size
  - Shape
  - Surface properties
  - Chemistry



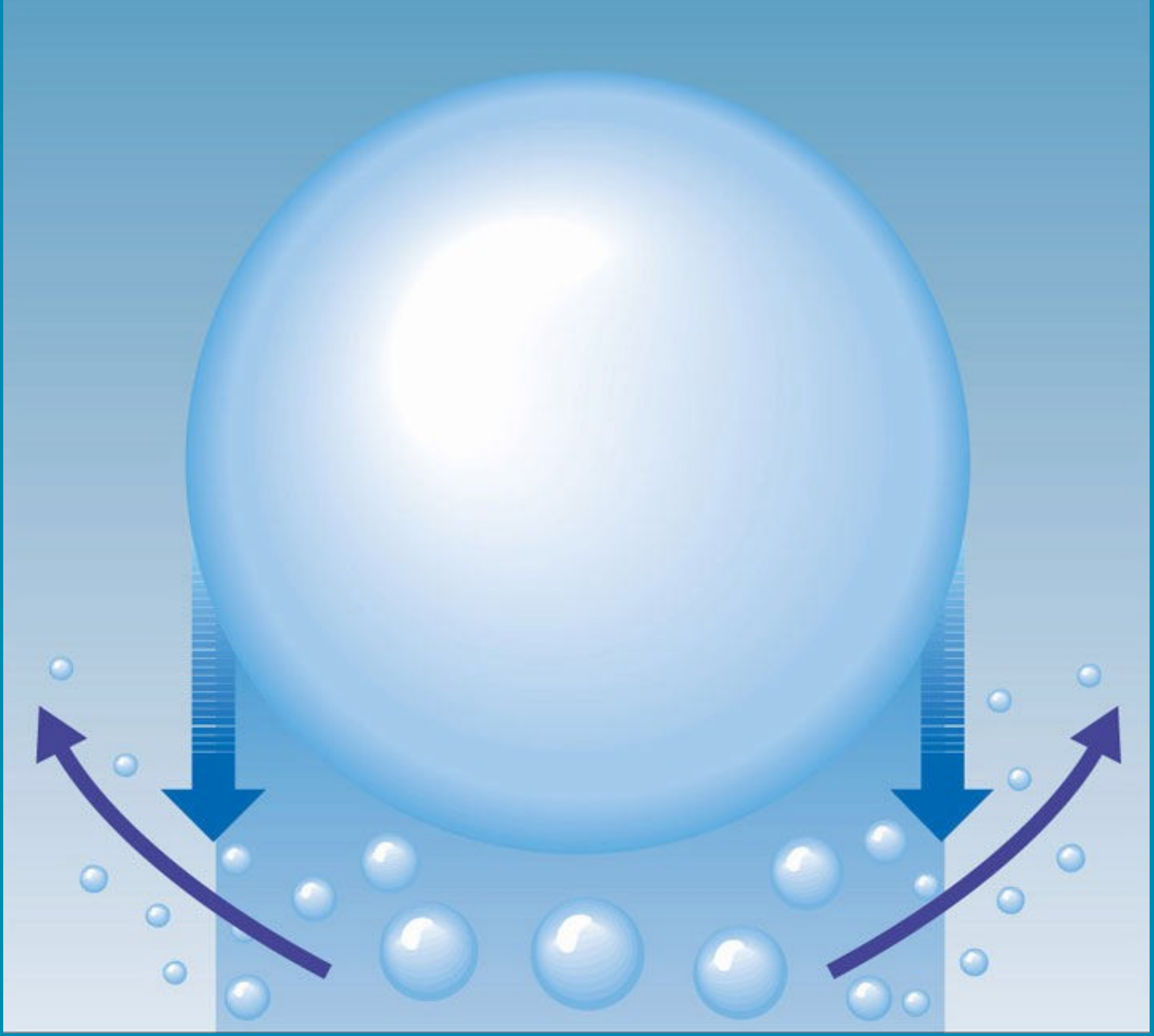
… Aerosols can be very different



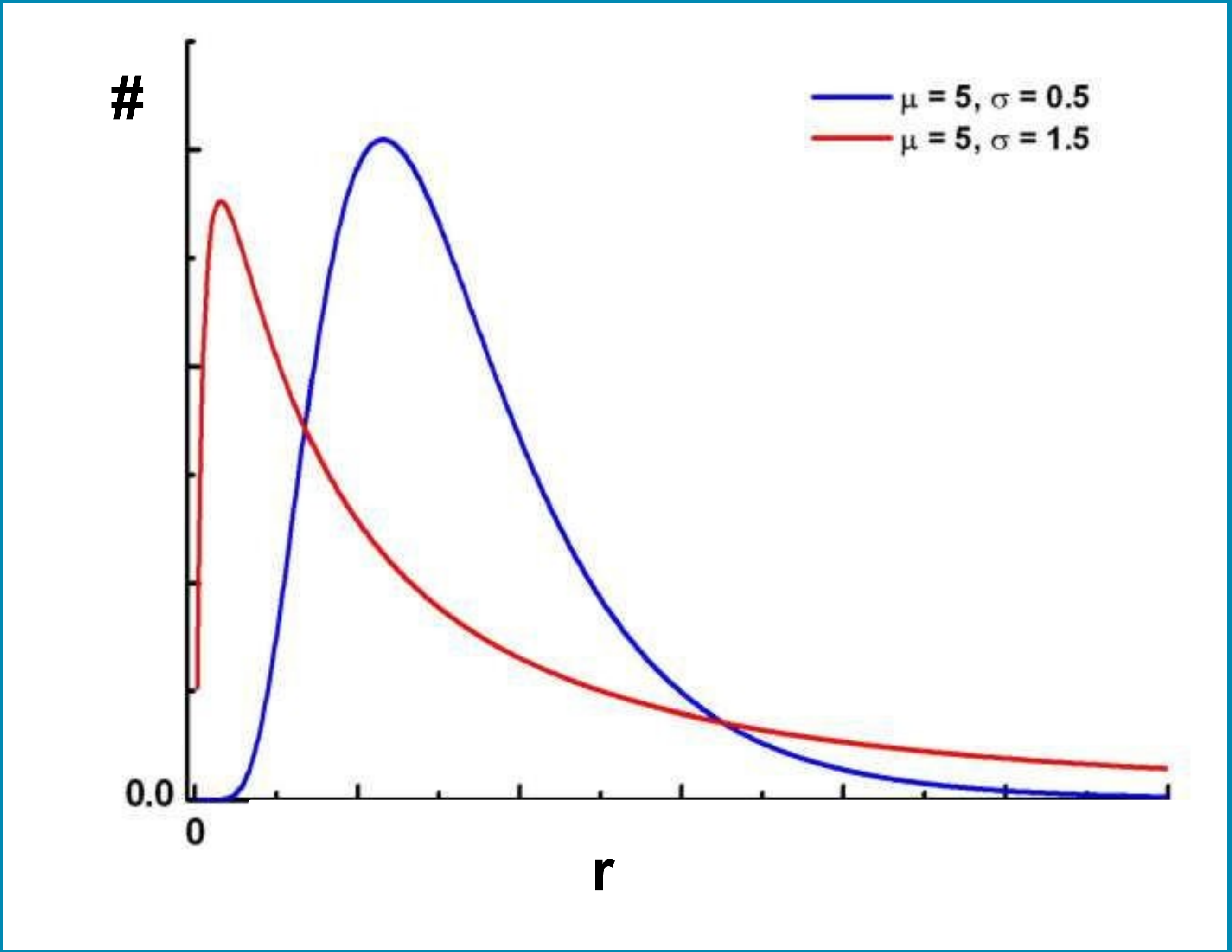
6 orders of magnitude in volume



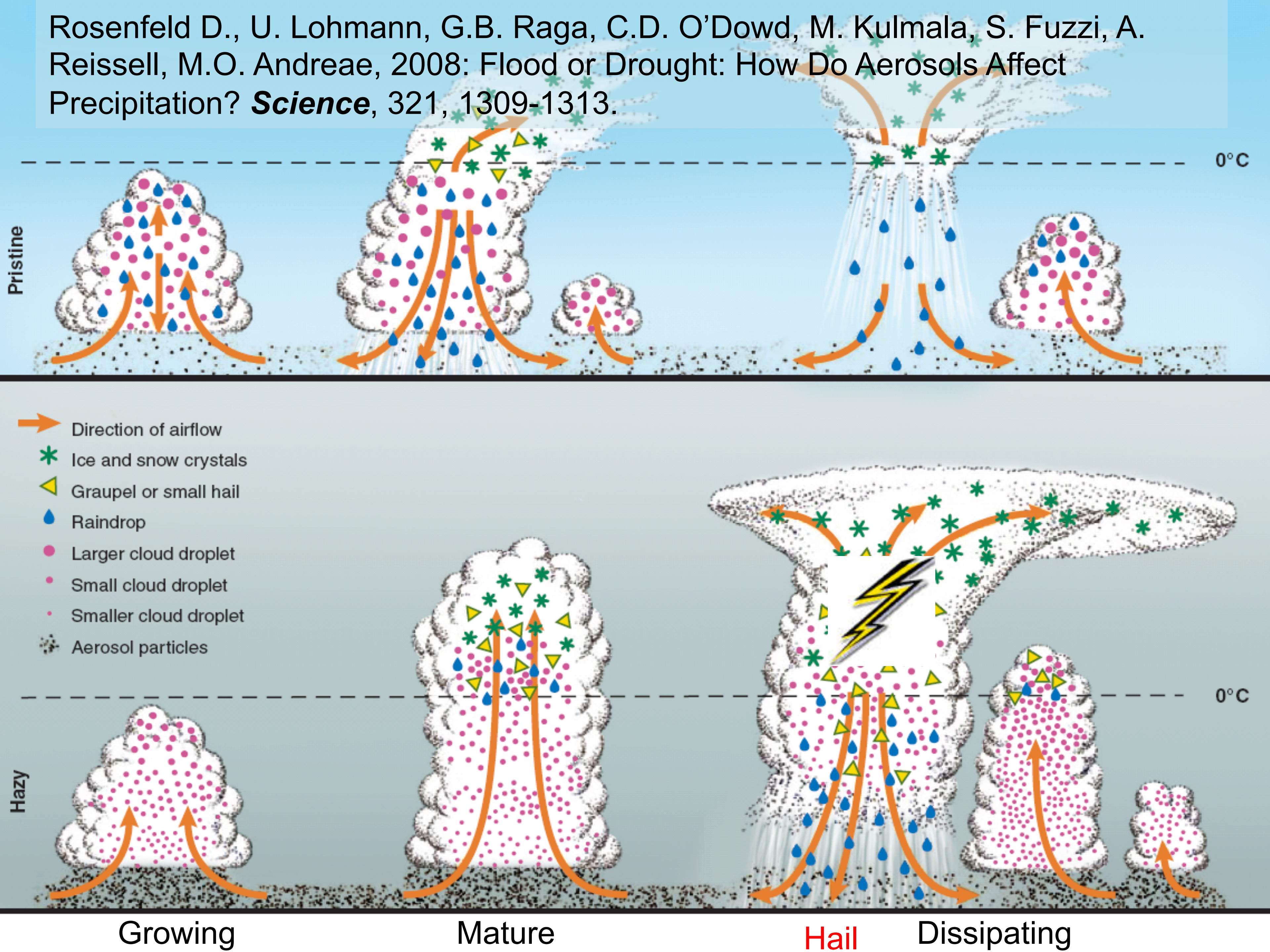
Interactions between different sizes is what makes rain



Polluted x pristine clouds

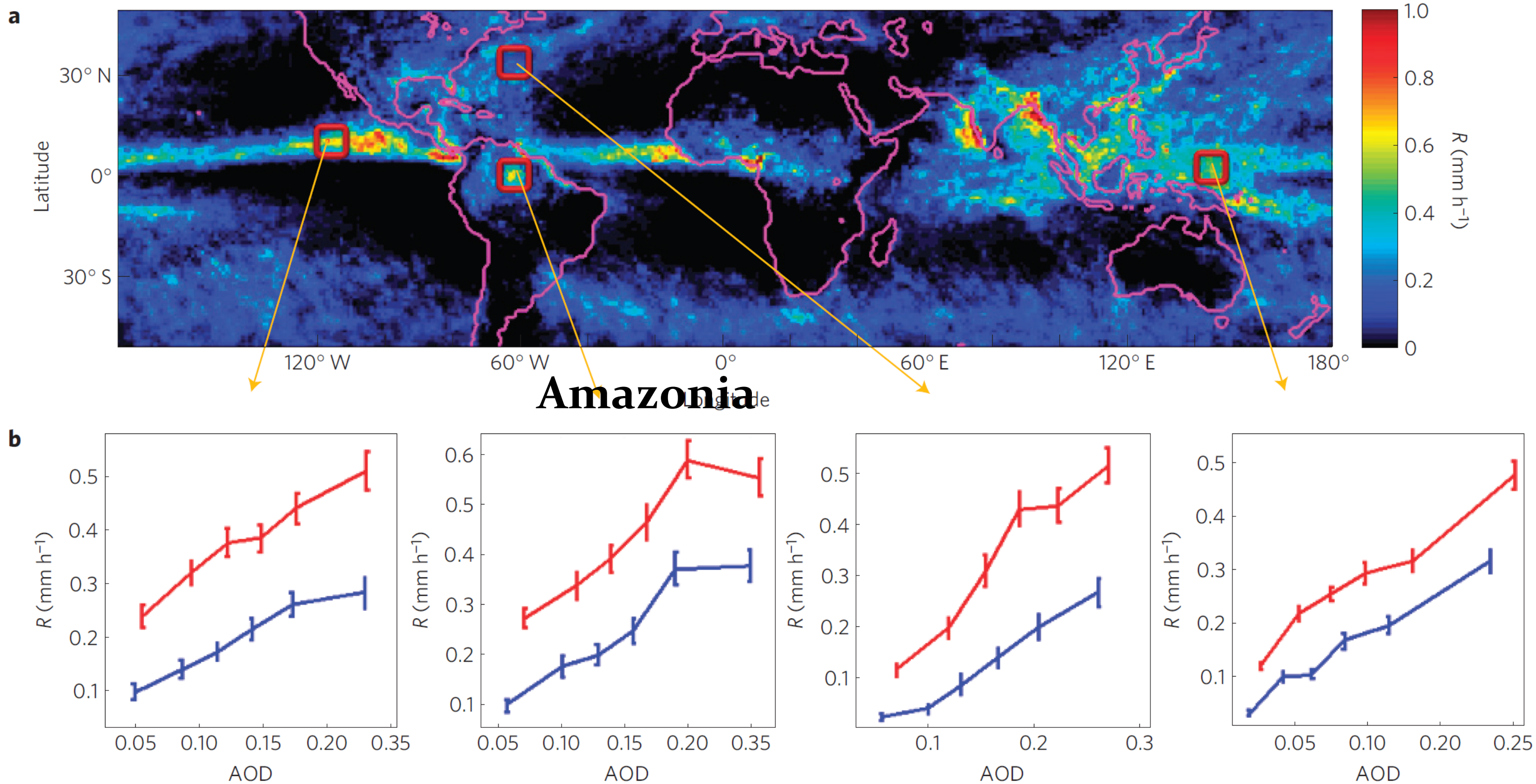


Rosenfeld D., U. Lohmann, G.B. Raga, C.D. O'Dowd, M. Kulmala, S. Fuzzi, A. Reissell, M.O. Andreae, 2008: Flood or Drought: How Do Aerosols Affect Precipitation? ***Science***, 321, 1309-1313.



Rain rate (TRMM) versus Optical Depth (MODIS)

NATURE GEOSCIENCE DOI: 10.1038/NGEO1364 LETTERS



13:30 local-time map of rain rate (*R*) and the observed trend with aerosol loading in four selected regions. Period: July and August 2007. **b**, The average *R* values are plotted for six aerosol-loading sets (blue, including zero *R* grid squares; red, without zero *R* grid squares). Note the *R* intensification as a function of AOD in all cases. (Koren et al., Nature 2012)

Key players of basic convective warm cloud (Cu)

Thermodynamic Profiles

Microphysics - Aerosols

Key players of basic convective warm cloud (Cu)

Thermodynamic Profiles

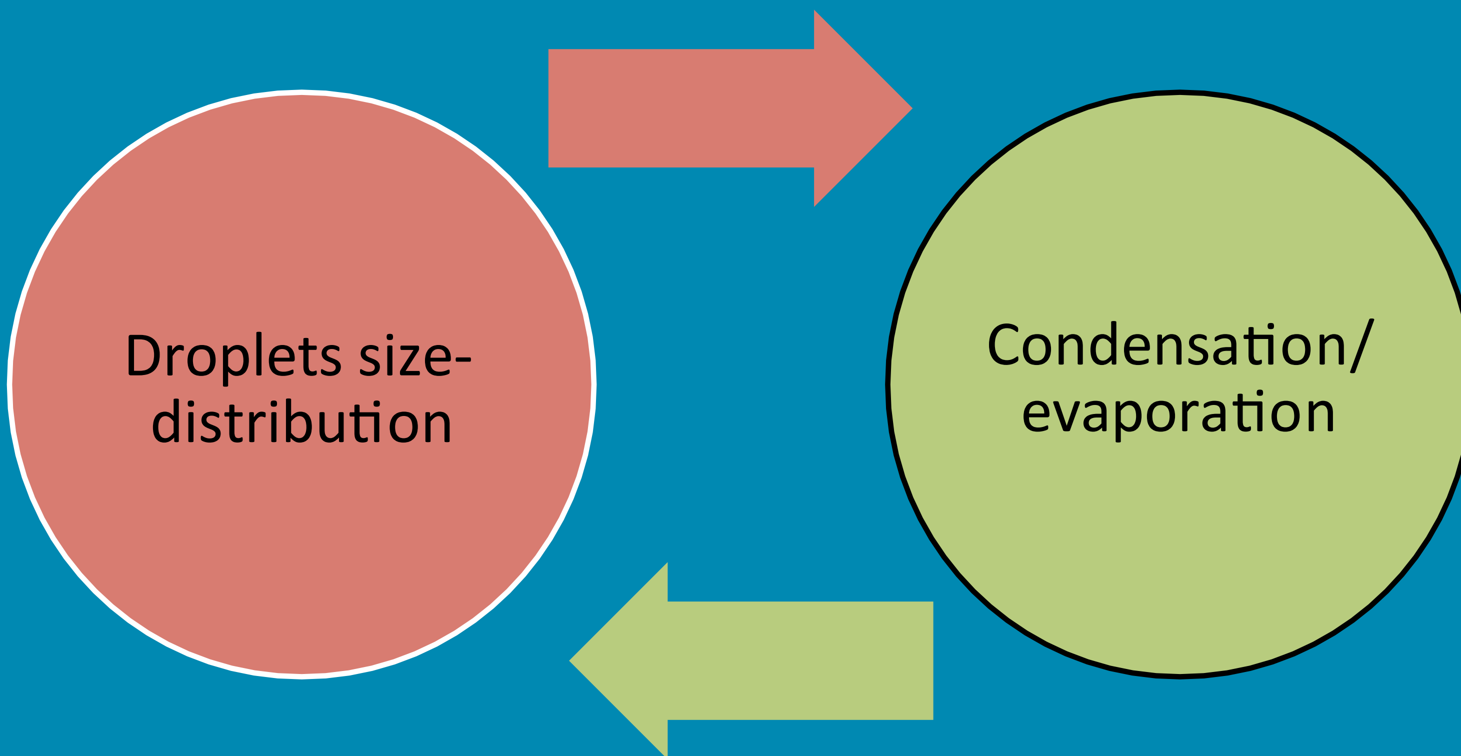
Microphysics - Aerosols

Droplets size-distribution

Key players of basic convective warm cloud (Cu)

Thermodynamic Profiles

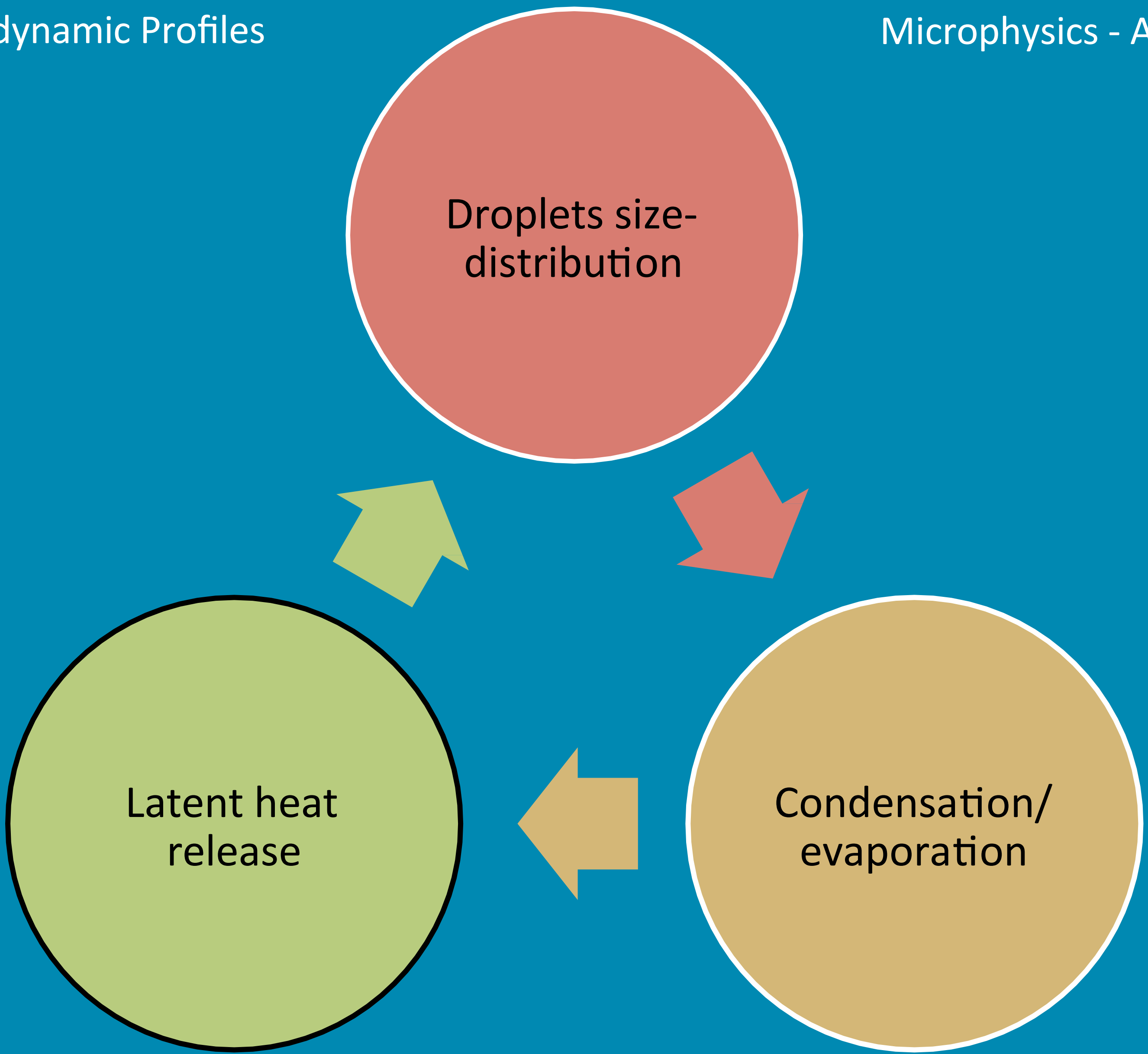
Microphysics - Aerosols



Key players of basic convective warm cloud (Cu)

Thermodynamic Profiles

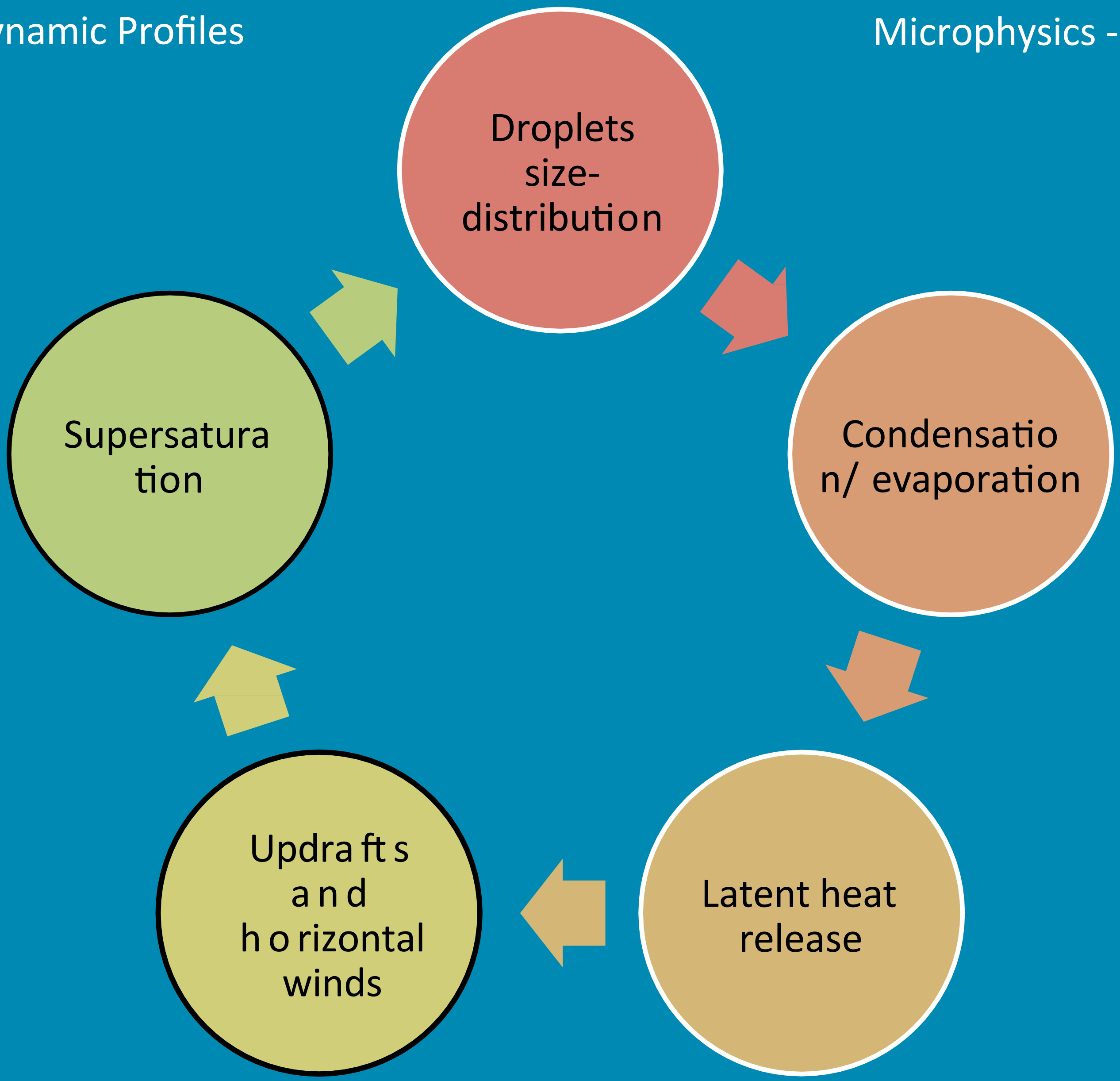
Microphysics - Aerosols



Key players of basic convective warm cloud (Cu)

Thermodynamic Profiles

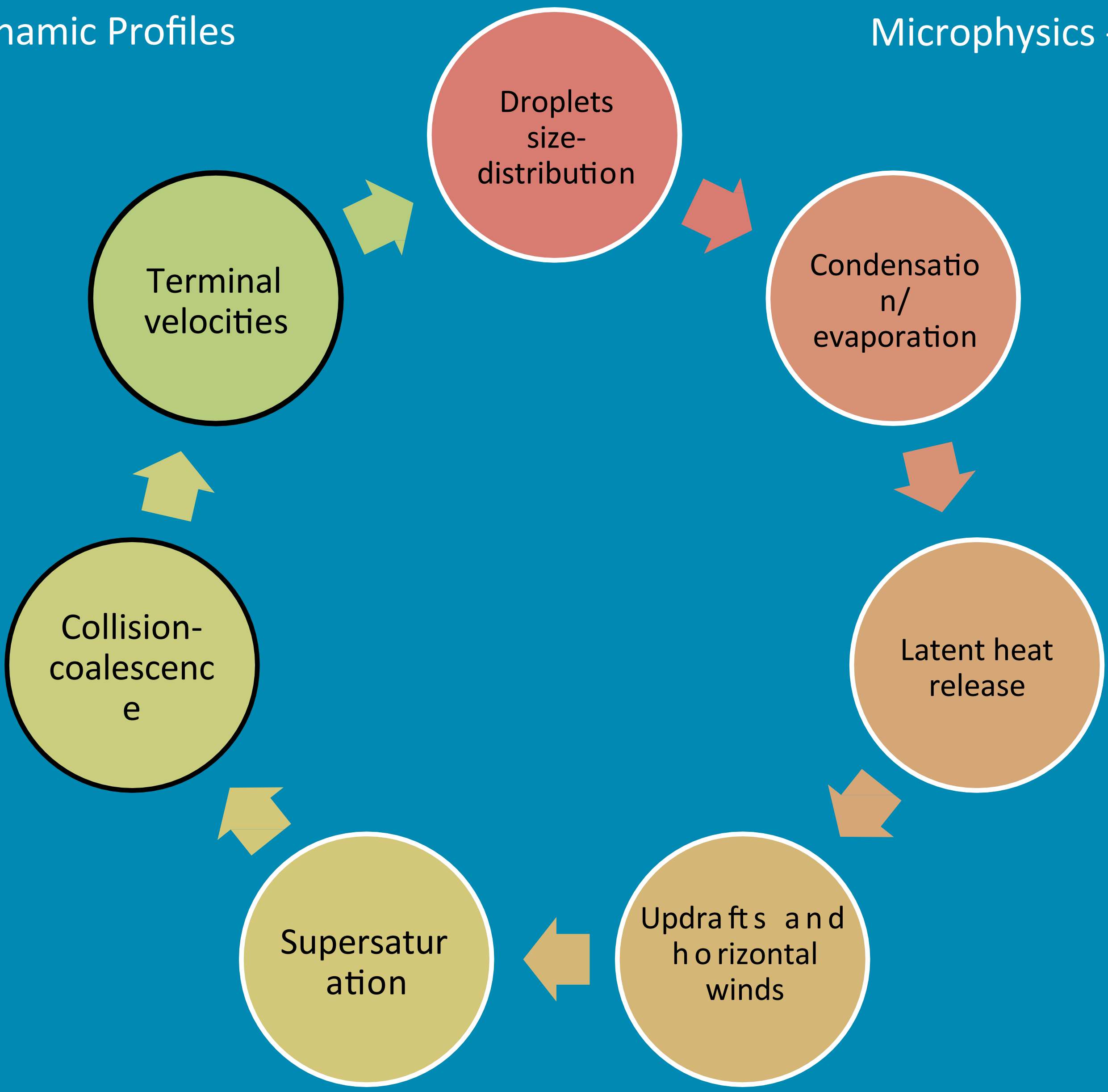
Microphysics - Aerosols



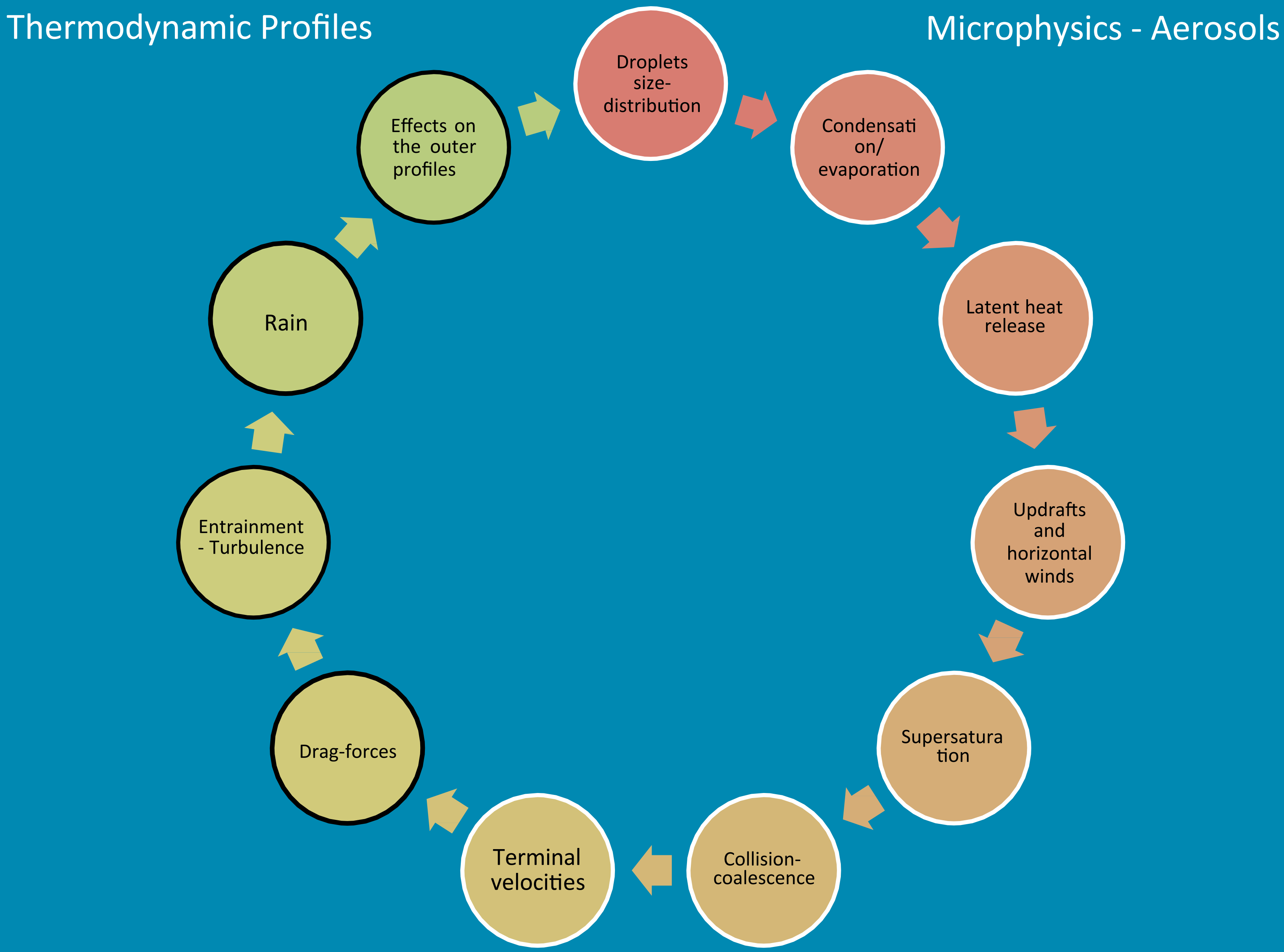
Key players of basic convective warm cloud (Cu)

Thermodynamic Profiles

Microphysics - Aerosols



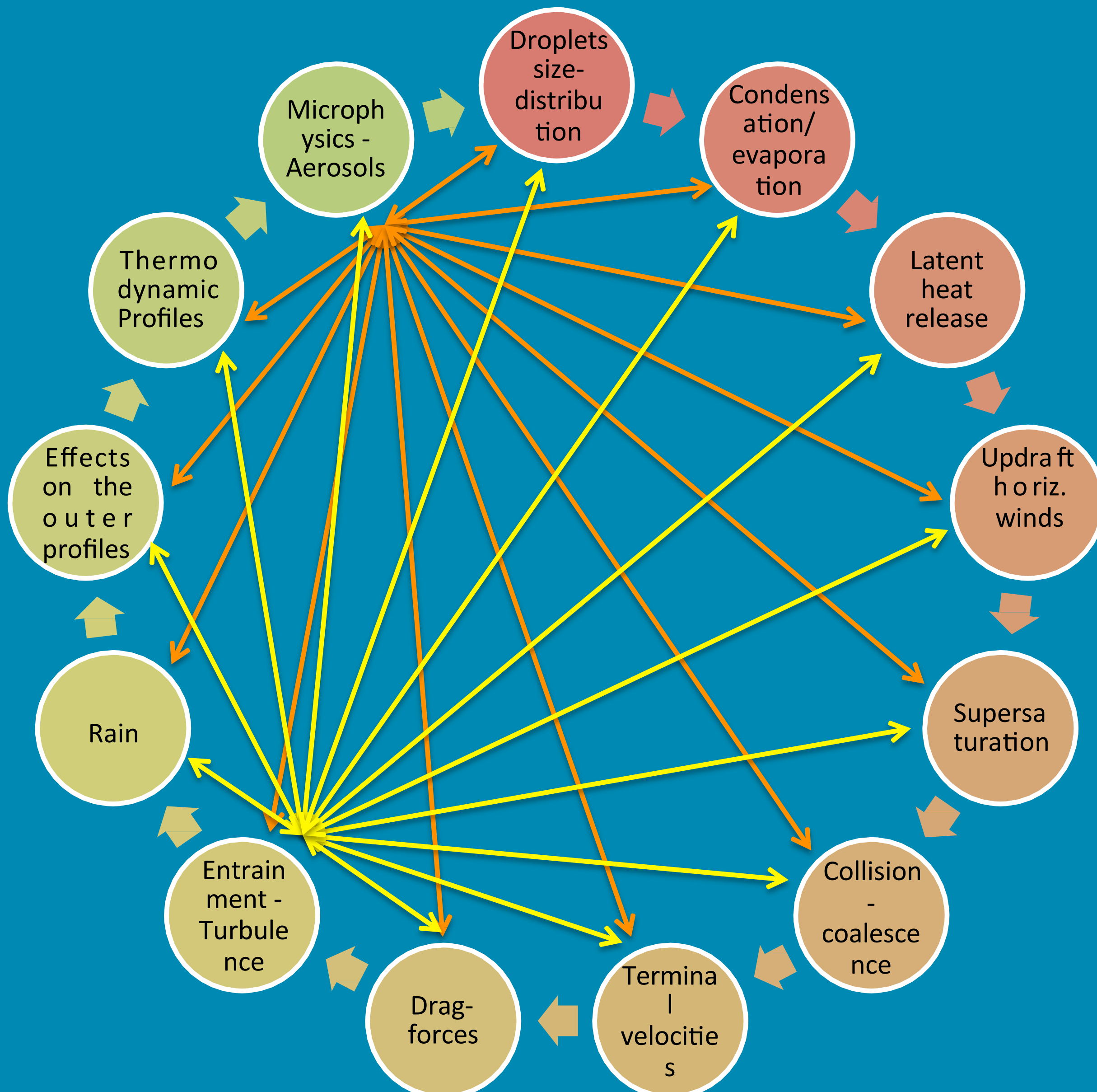
Key players of basic convective warm cloud (Cu)



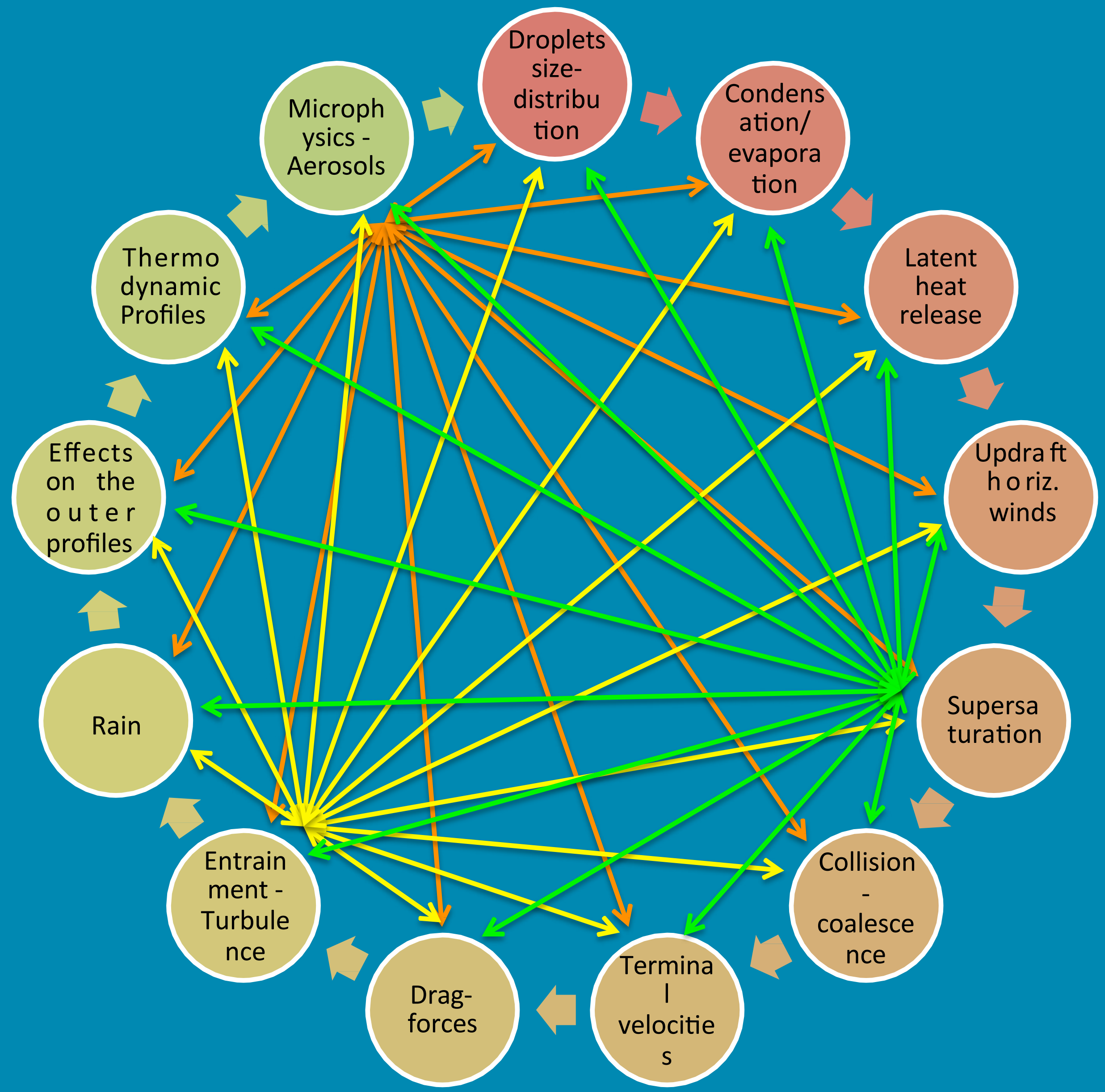
Key players of basic convective warm cloud (Cu)

Key players of basic convective warm cloud (Cu)

Key players of basic convective warm cloud (Cu)



Key players of basic convective warm cloud (Cu)




Clouds and Aerosols
after the
1st, 2nd, 3rd,…,Nth
indirect effect

To further study the cloud (and cloud field) system

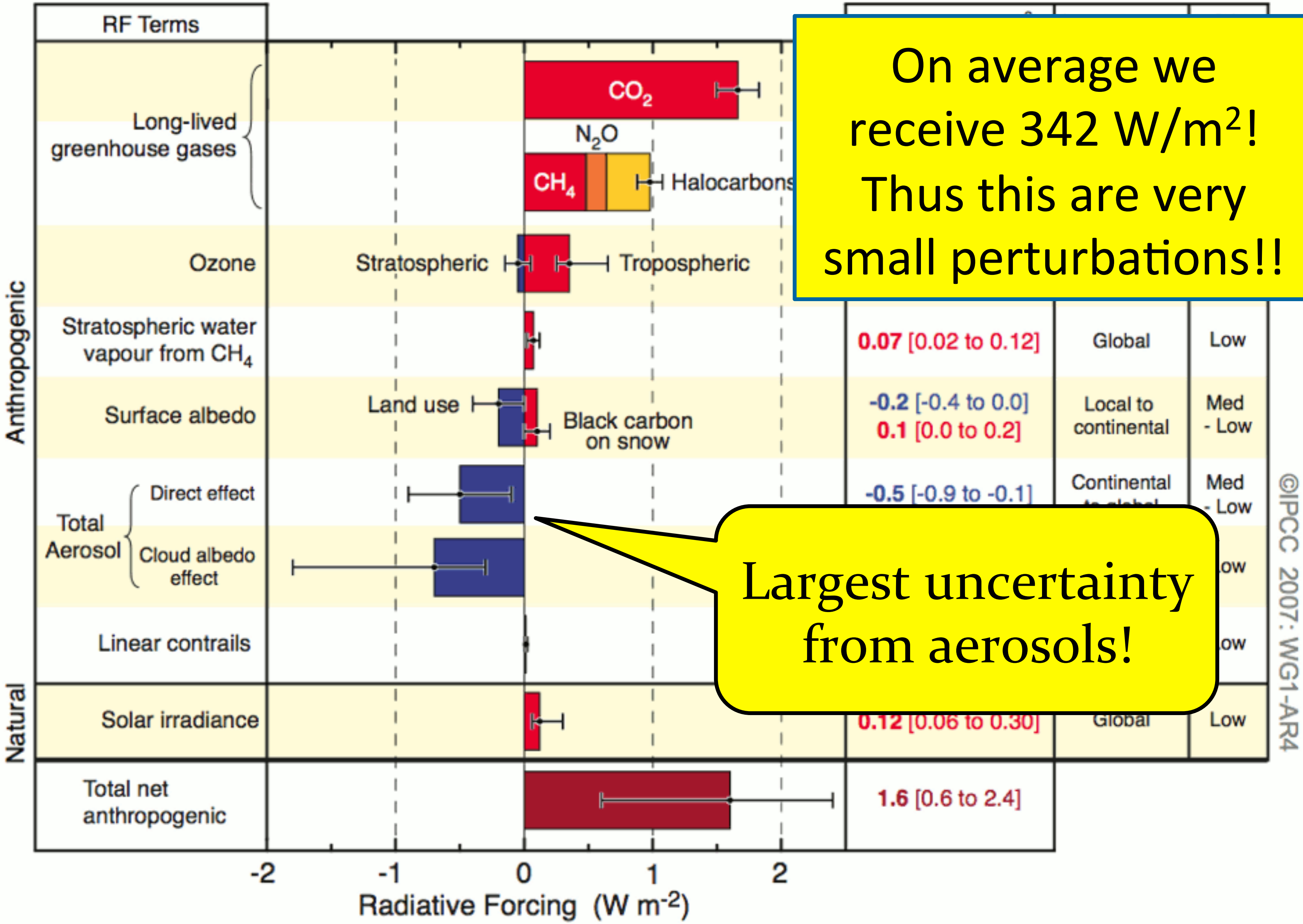
1) Not only microphysics – dynamics and microphysics are coupled (you can measure the coupling strength). Hence changes in aerosol properties affect cloud dynamics

2) Not only Marine Stratocumulus – strong aerosol signature in convective clouds

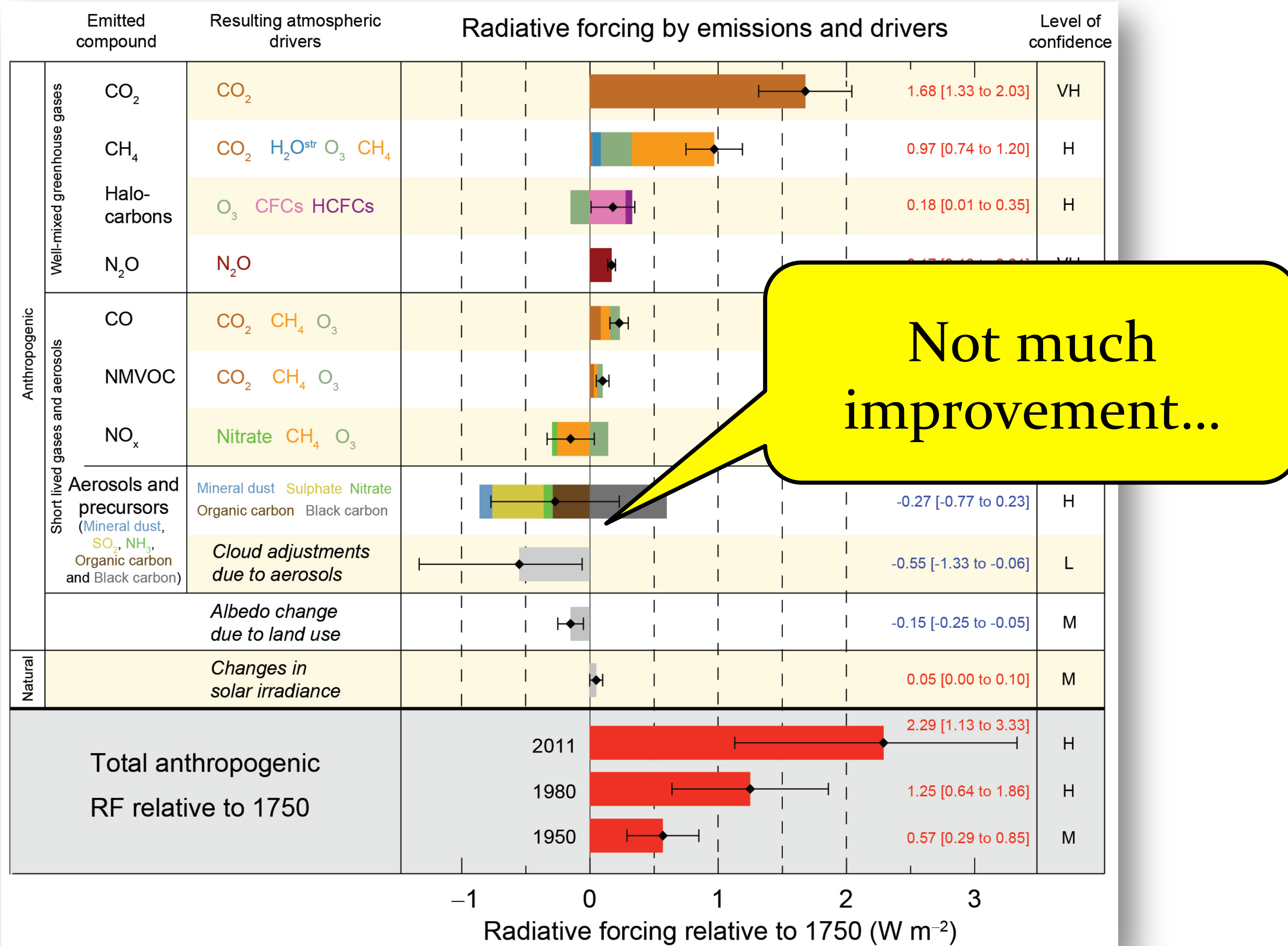
3) We do not understand well the warm phase and therefore how changes in aerosol properties affect it (many dynamical regimes)

4) Observations – models – theoretical analysis (toy models)

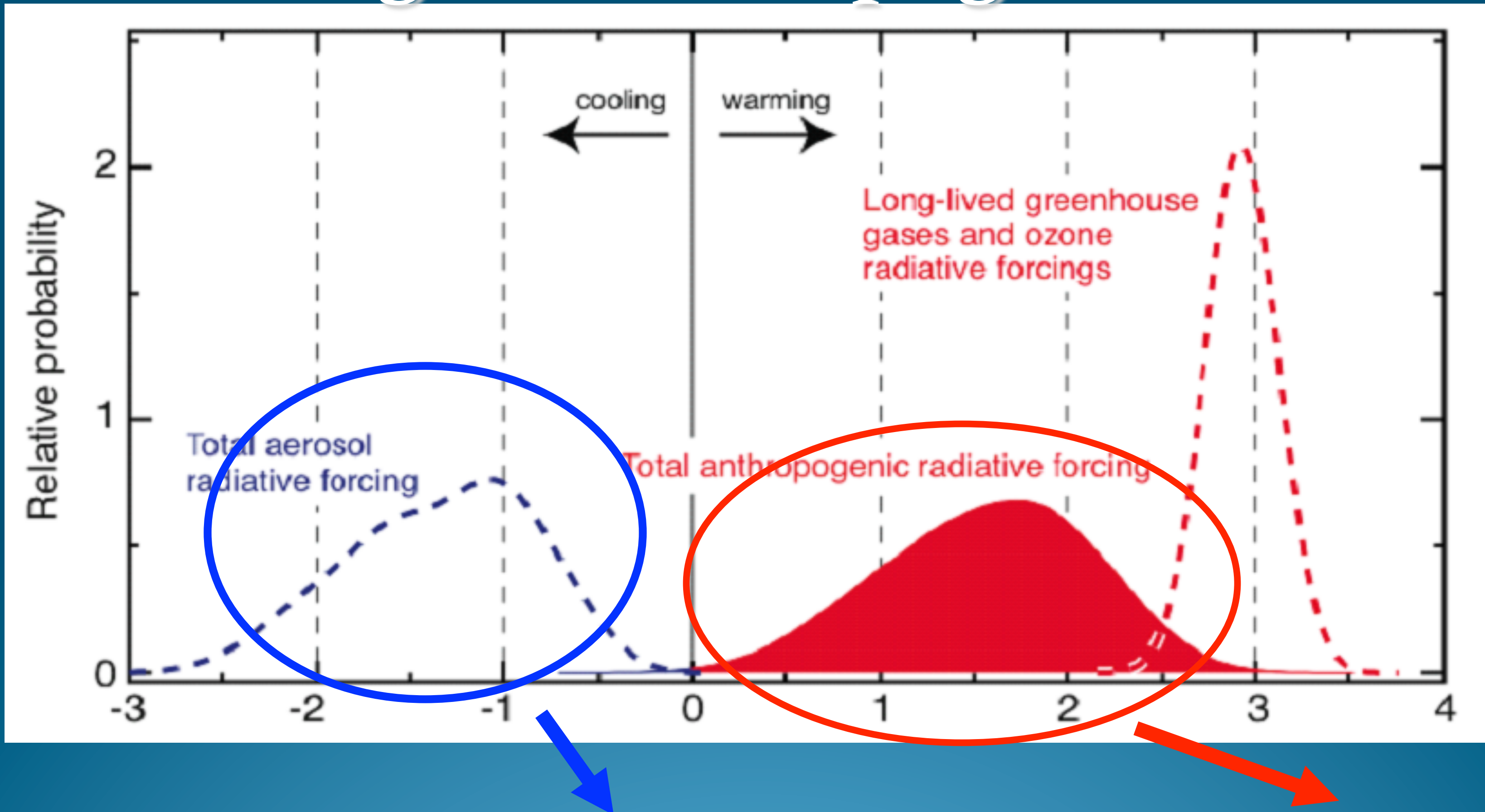
Radiative forcings of the global climate system IPCC 2007



Forçante radiativa do sistema climático global (IPCC 2013)



Combining all anthropogenic effects



What is being doing to this component is critical to the final forcing

- *Combined anthropogenic forcing* is not straight sum of individual terms.
- Tropospheric ozone, cloud-albedo, contrails → asymmetric range about the central estimate
- Uncertainties for the agents represented by normal distributions except: contrail (lognormal); discrete values → trop. ozone, direct aerosol, cloud albedo
- Monte Carlo calculations to derive probability density functions for the combined effect

What about convection?

1. Sophisticated dynamics with parameterized convection (climate models)

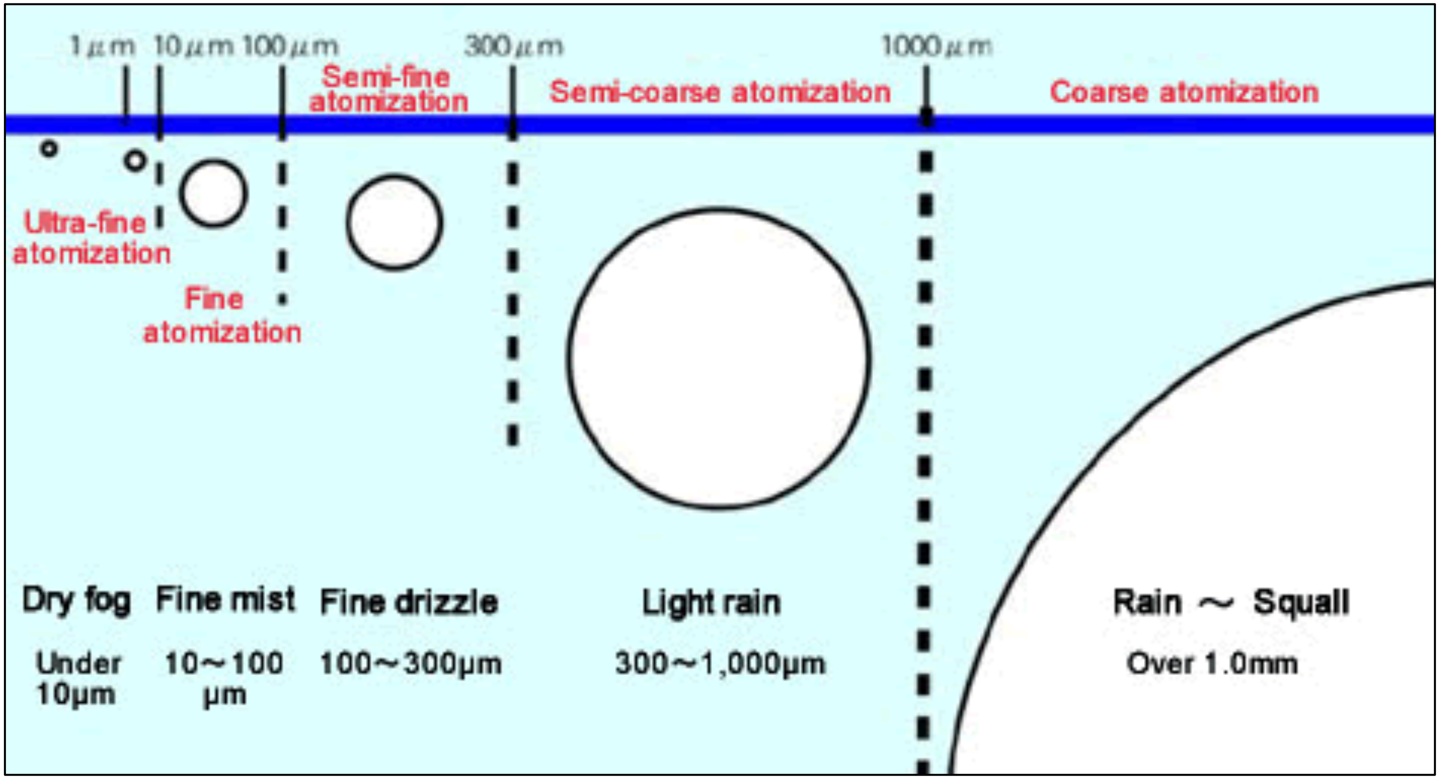
2. Sophisticated dynamics with some microphysics (regional models): bulk microphysics (N-moments)

3. Simplified dynamics with sophisticated microphysics (LES/CRM): bin microphysics

4. No dynamics with explicity condensation equations (parcel models): single particle microphysics

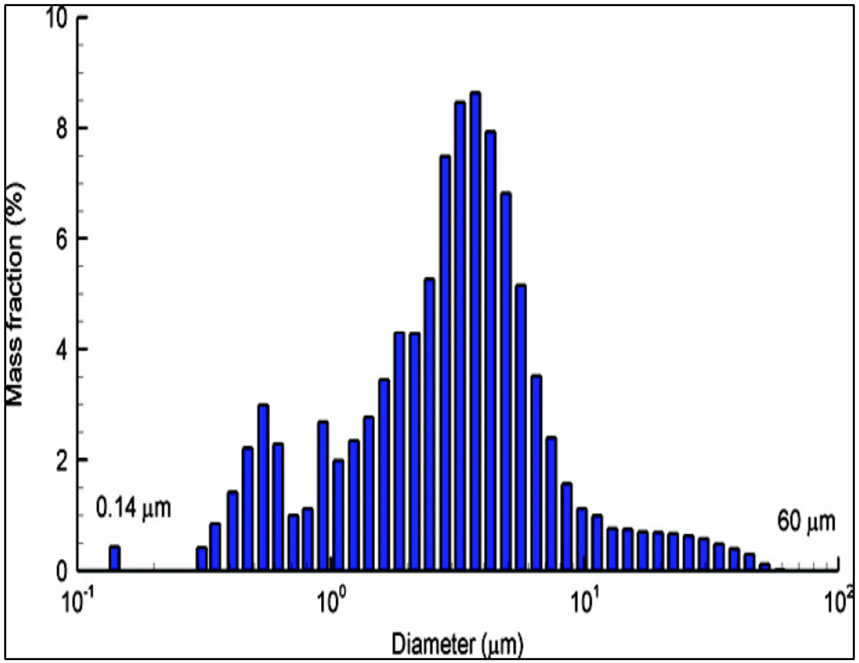
4 Single Particle Microphysics

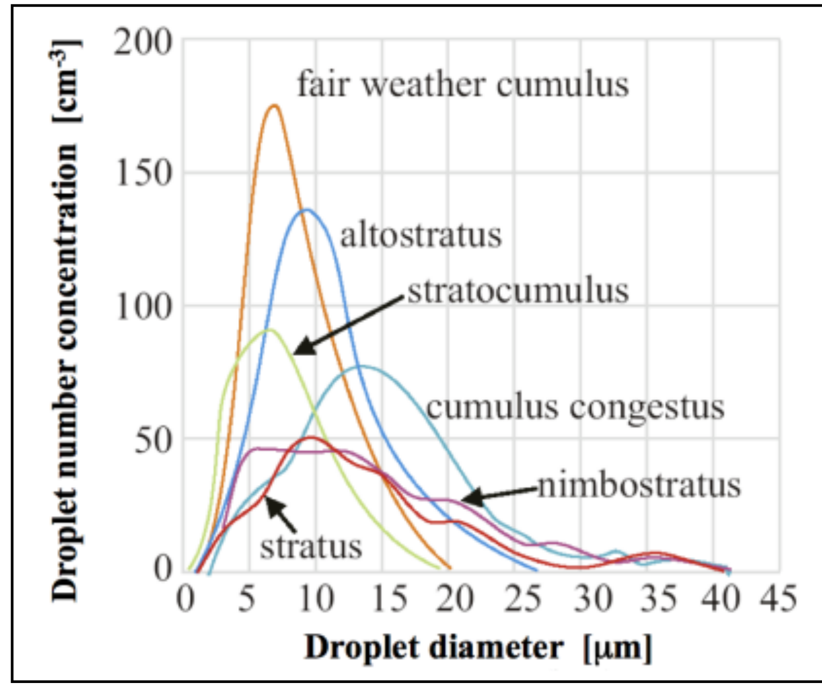
- Parcel models with no dynamics, no mixing, that solve the diffusion equation explicitly for the growth of particles into droplets.



3 Bin Microphysics

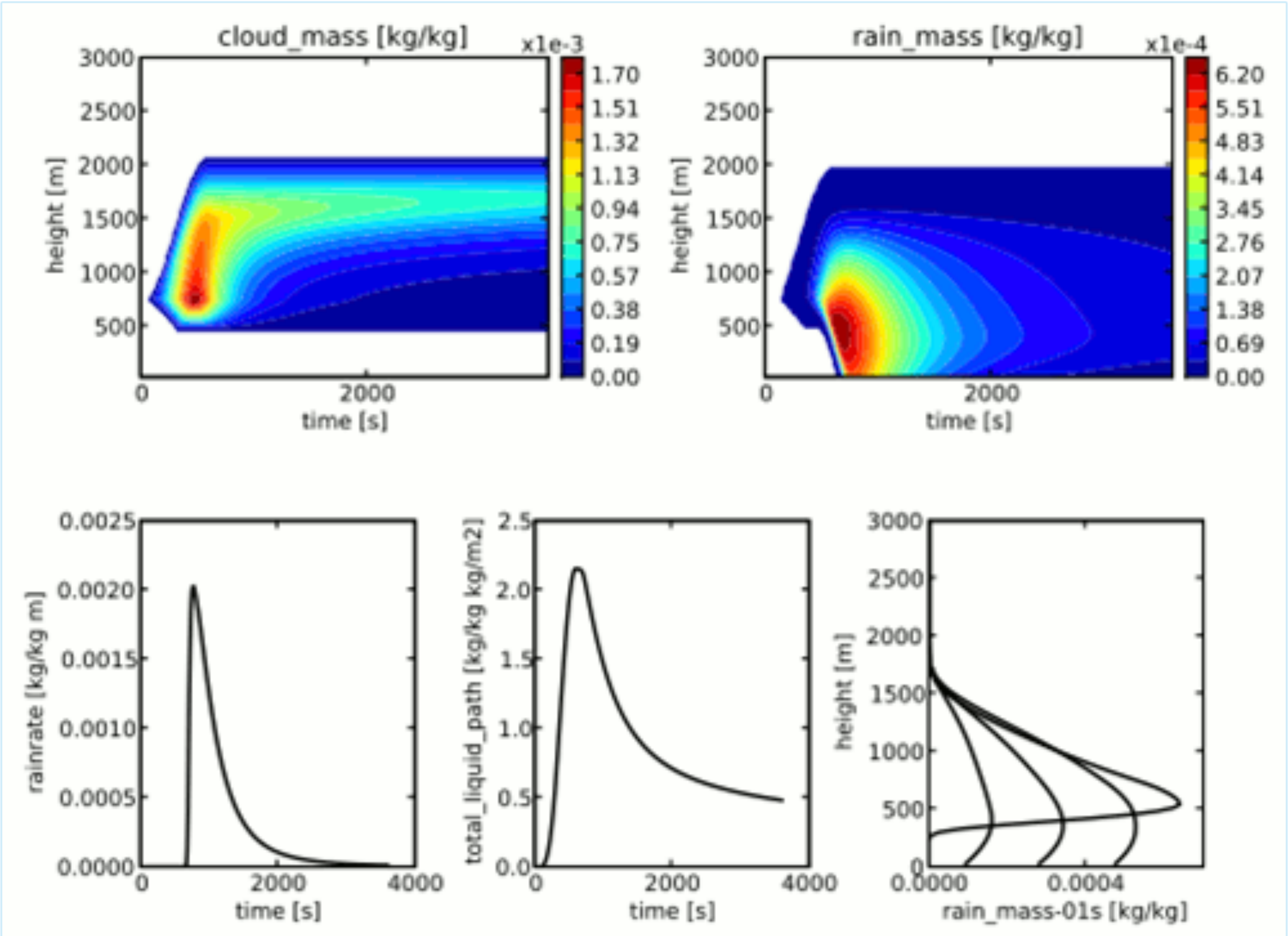
- Models that solve explicitly the size distribution of droplets as they grow, collide, and break.





- Generally used in models with simplified dynamics, typical 1D or 2D frameworks forced by large-scale tendency.

3 Ex.: Taubin – Feingold et al.



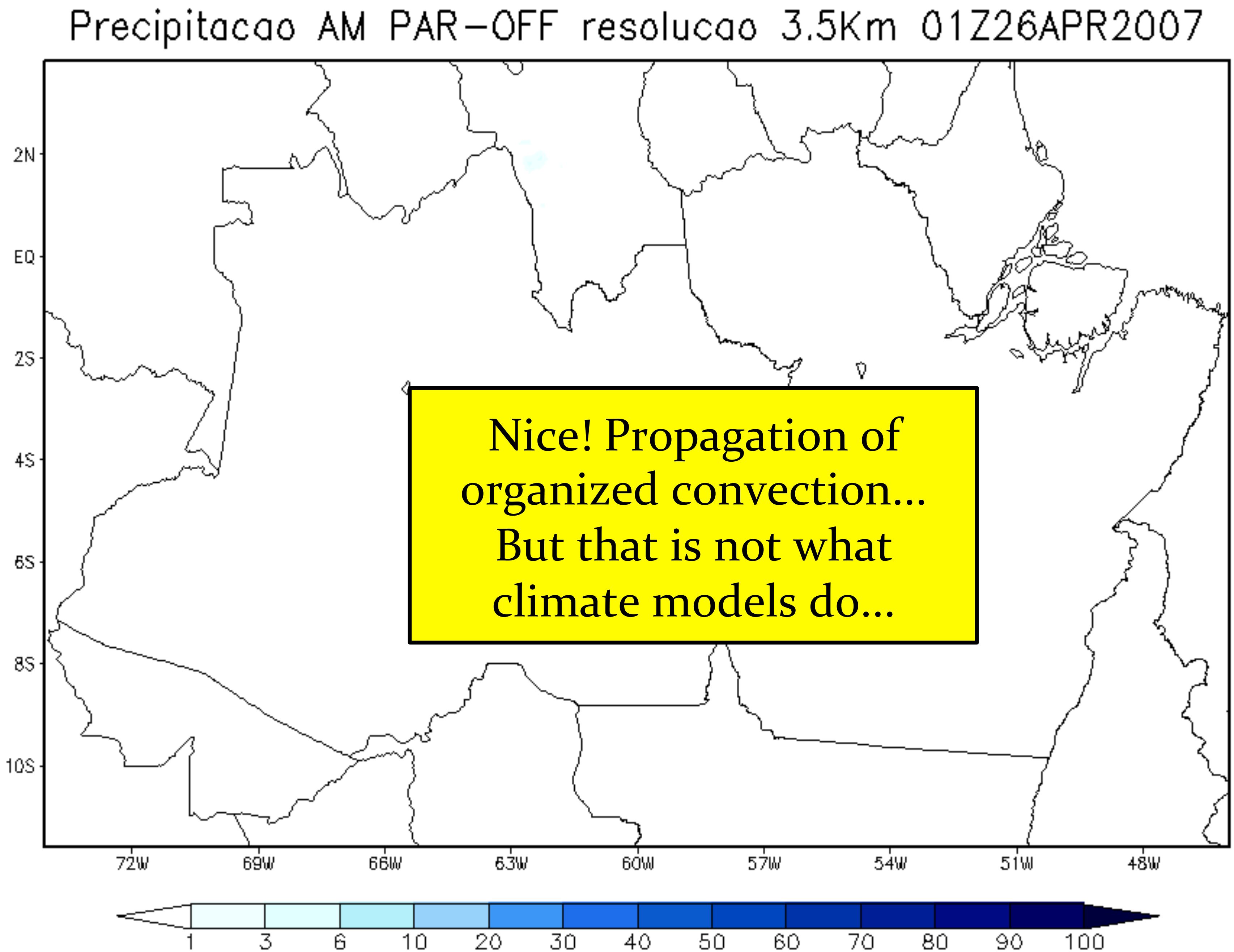
2 Regional Models w/ bulk Micphys

- Typically solve the budget equations for some of the momentums of the size distribution. E.g., first and second momentum (Kessler scheme):
  - Mass concentration (momentum 1)
  - Number concentration (momentum 0)

- Much faster than “bin” schemes, bulk parameterizations have to assume a shape for the size distribution and loose some reality.

00:00:00
26 Apr 2007
1 of 16
Thursday

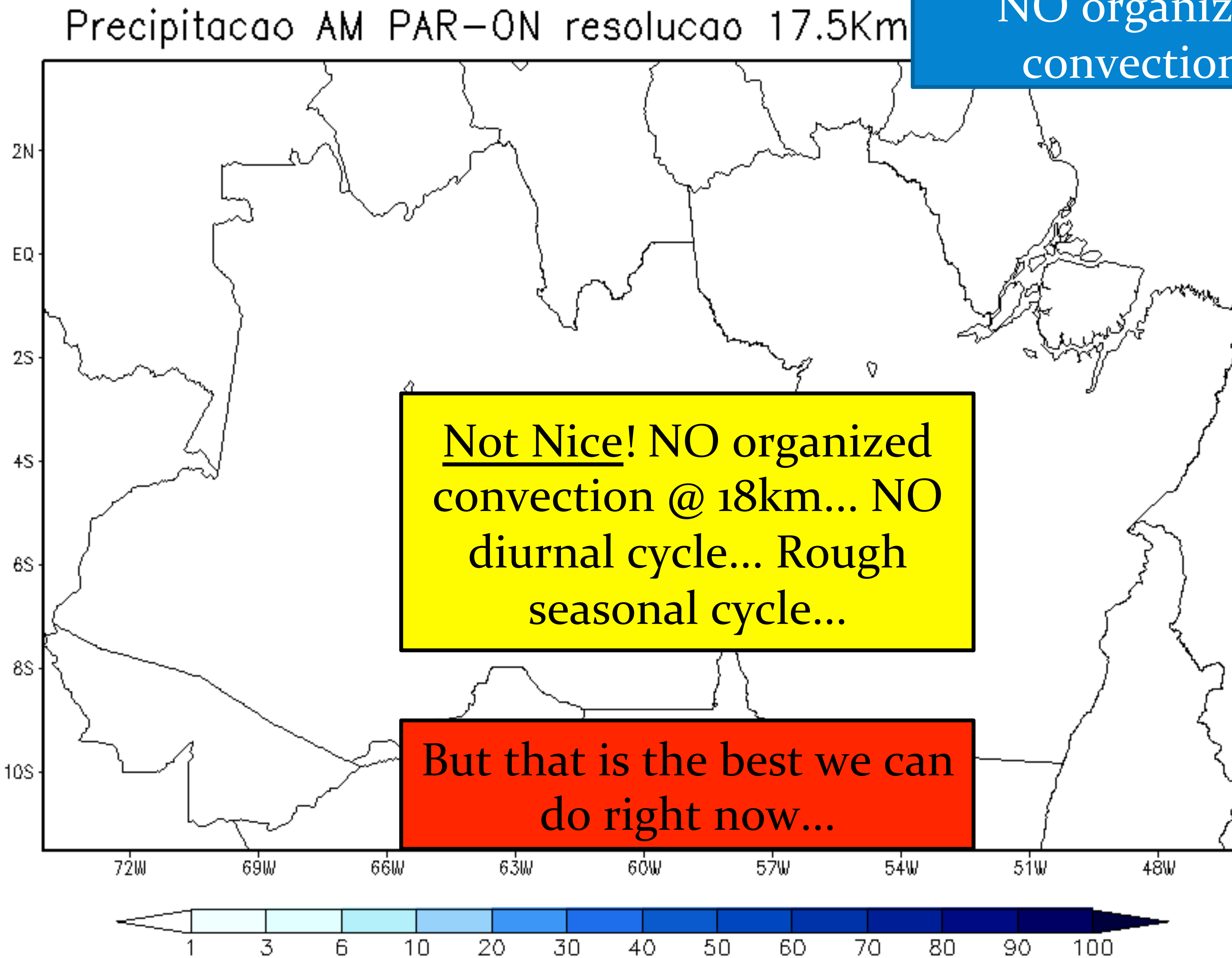
2 RAMS – 1 moment



Nice! Propagation of organized convection… But that is not what climate models do…

M.A.F Silva-Dias et al

Parameterization: NO organized convection!



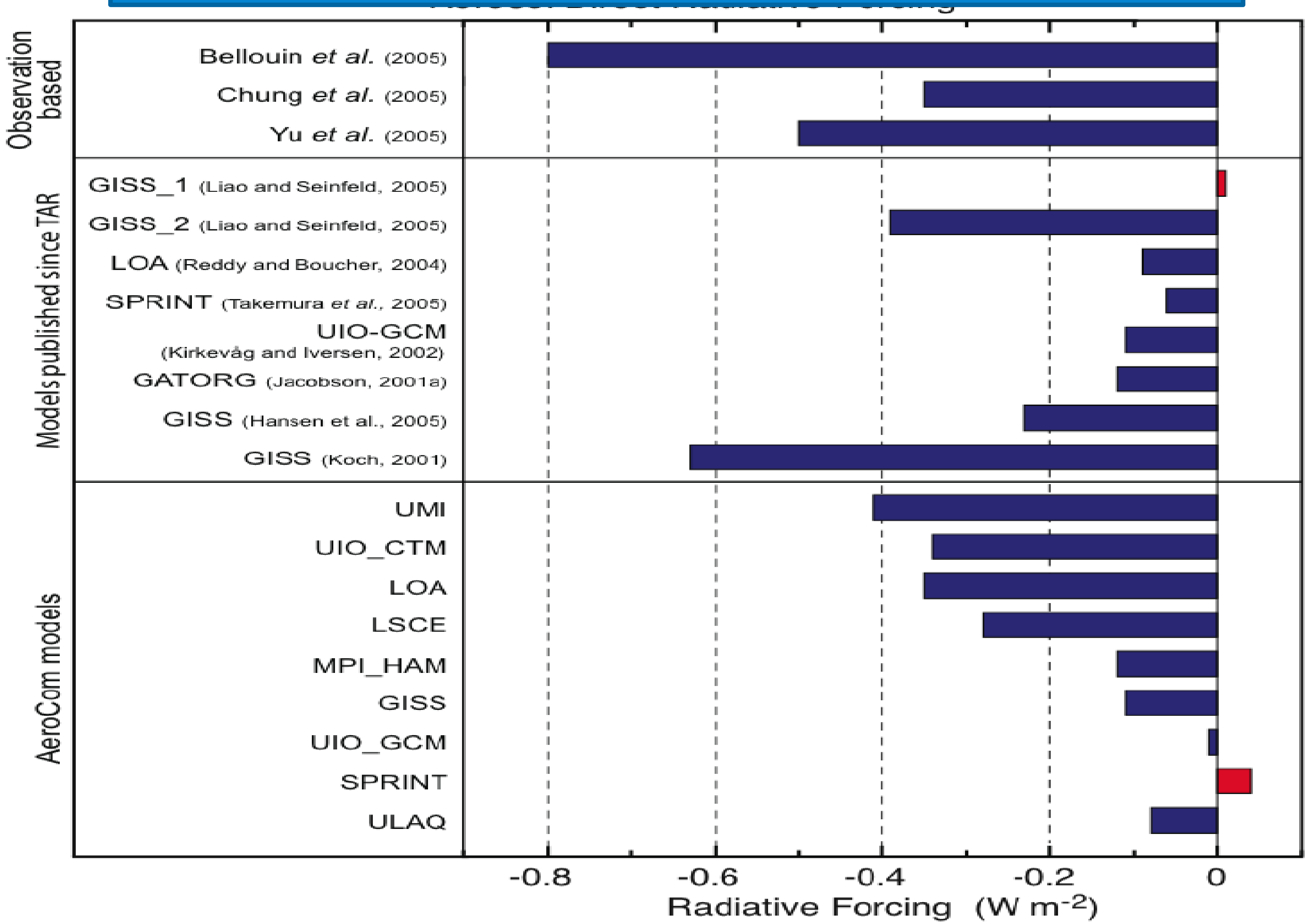
<u>Not Nice</u>! NO organized convection @ 18km… NO diurnal cycle… Rough seasonal cycle…

But that is the best we can do right now…

M.A.F Silva-Dias et al

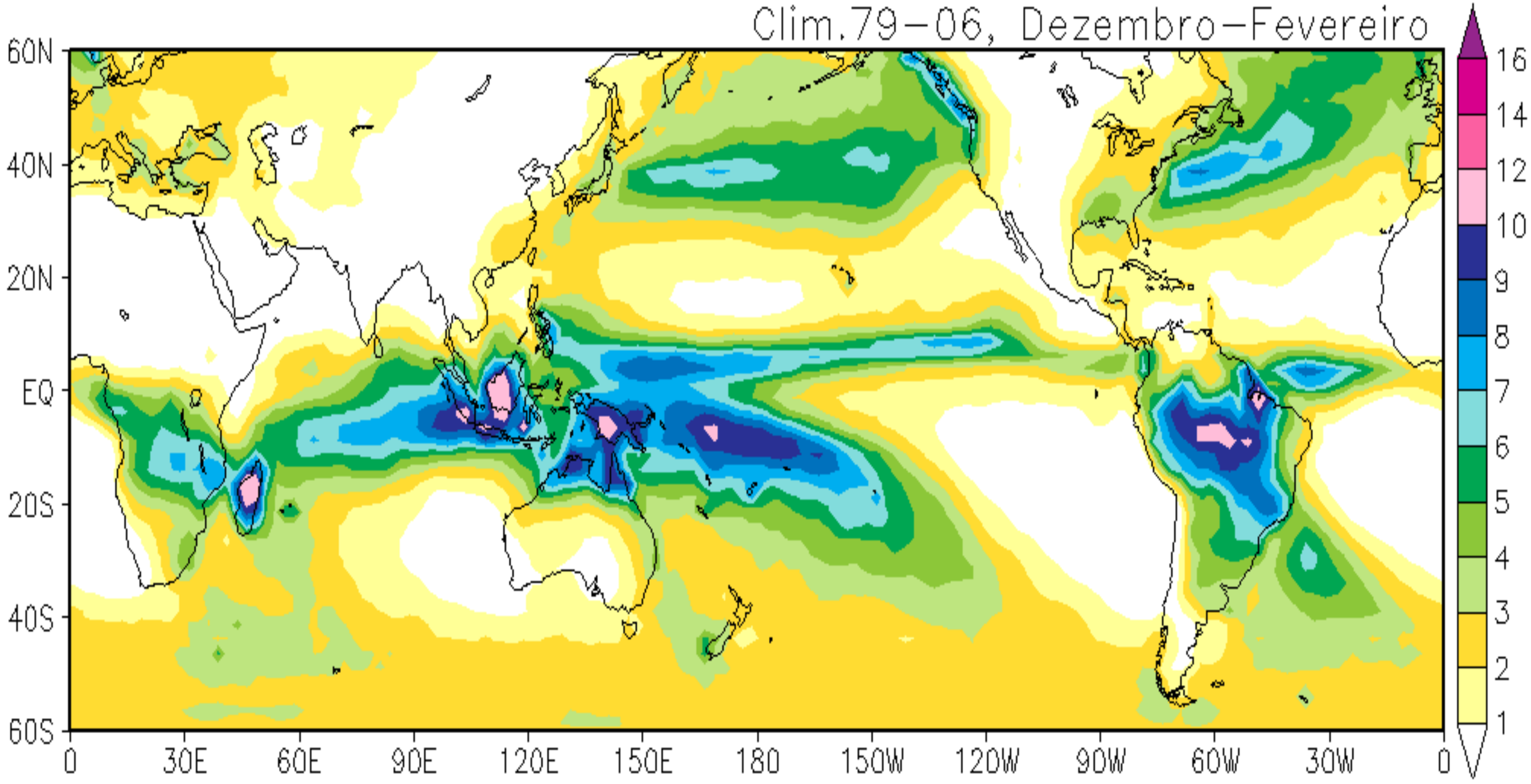
Wait, clouds are complicated but…

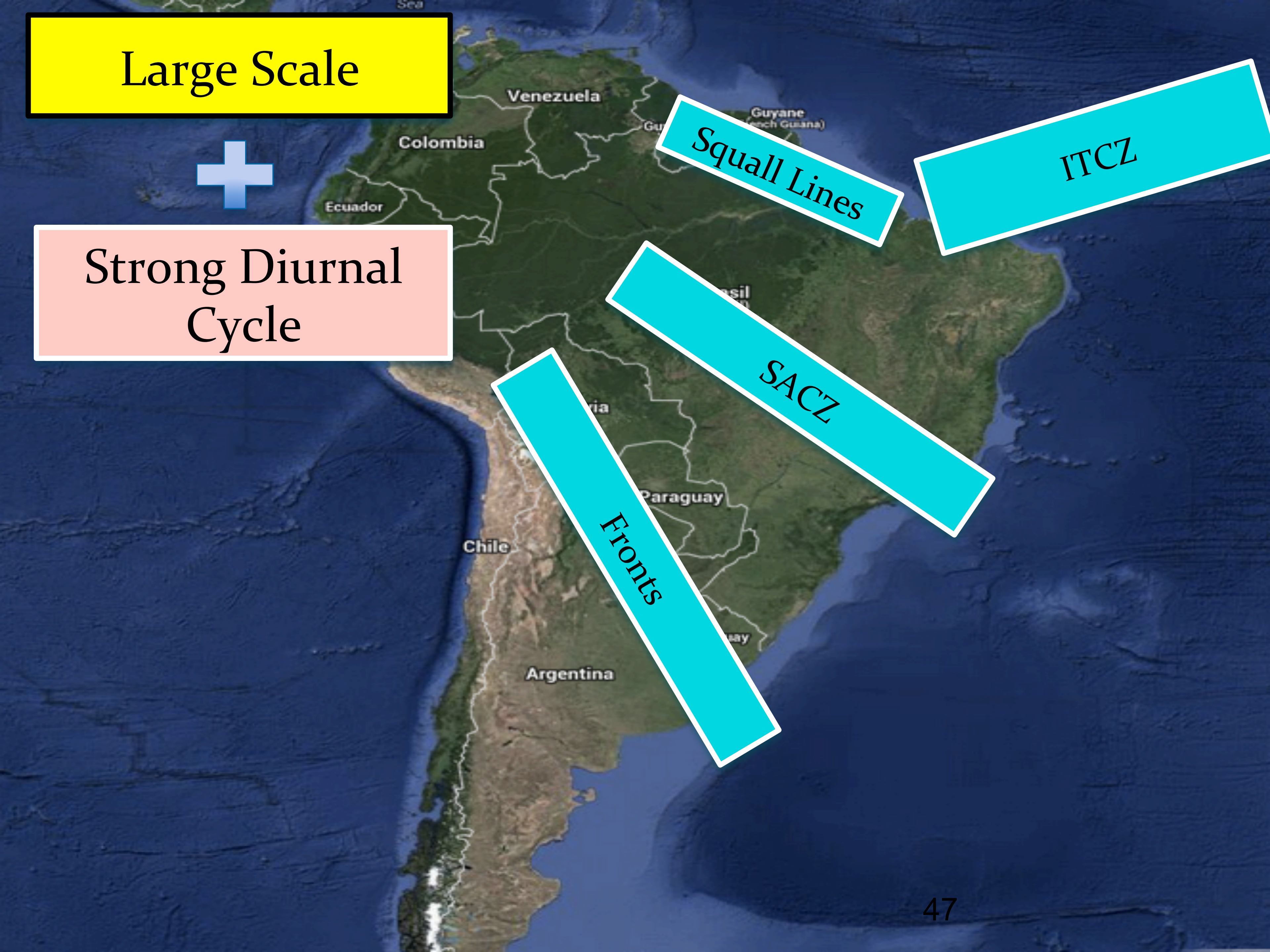
Disagreement between modeled DIRECT aerosol forcing!!!



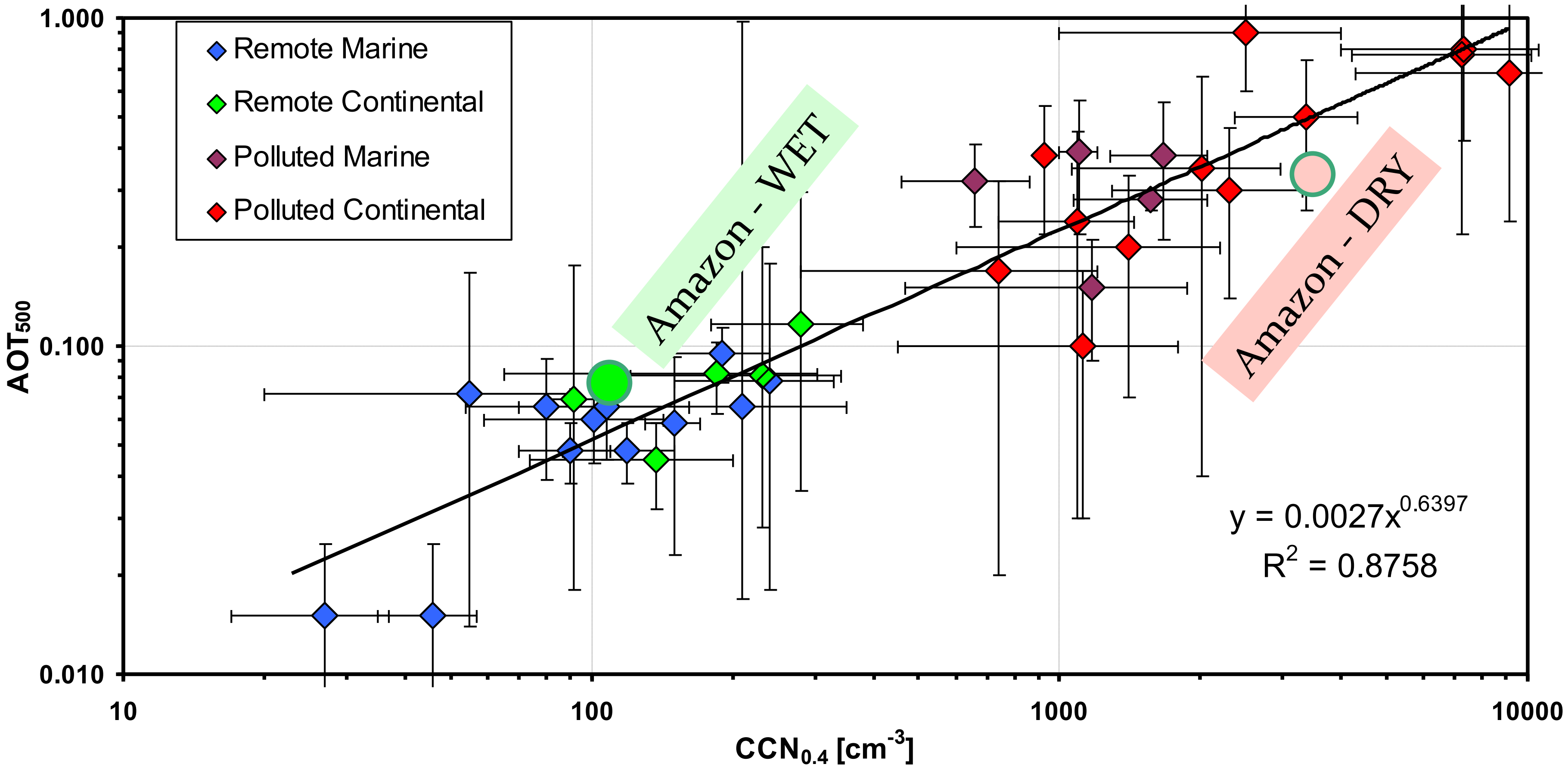

Manaus
Deforestation arch

Global Precipitation




Large Scale
Strong Diurnal Cycle
Squall Lines
ITCZ
SACZ
Fronts
Venezuela
Colombia
Ecuador
Guyane
Paraguay
Chile
Argentina

Observations of CCN and AOT

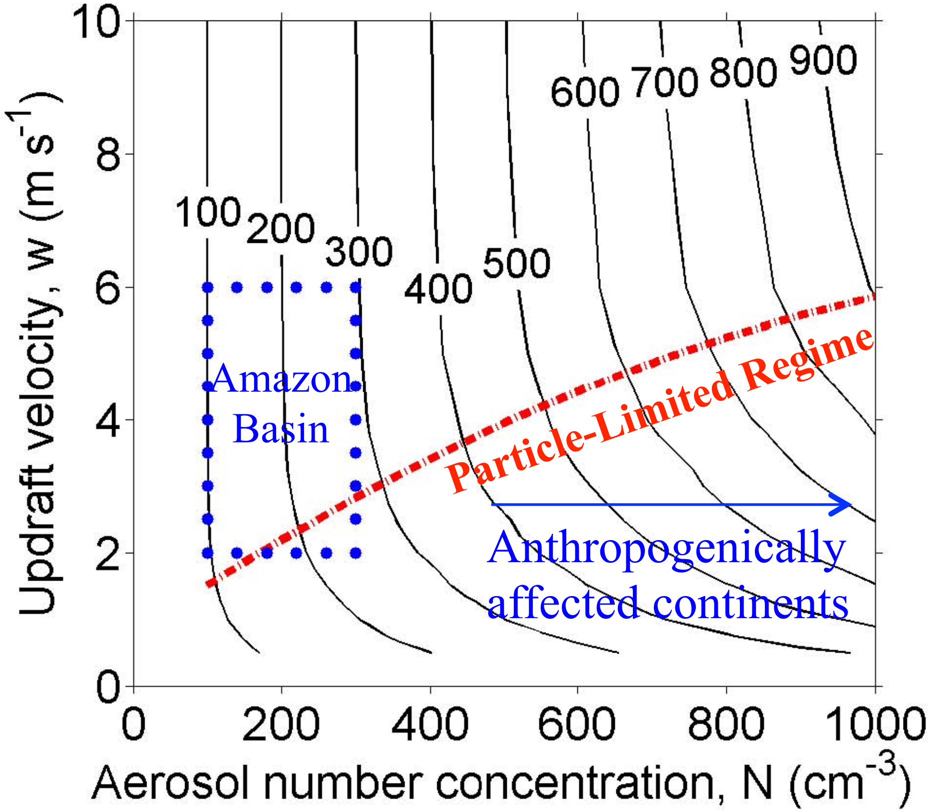


CCN concentrations and AOT over the cleanest continental sites are similar to the cleanest marine sites!

Possible Aerosol Effects

- The Amazon region is particularly susceptible to changes in CN because of the low background concentrations and high water vapor levels, indicating a regime of cloud properties that is highly sensitive to aerosol microphysics.

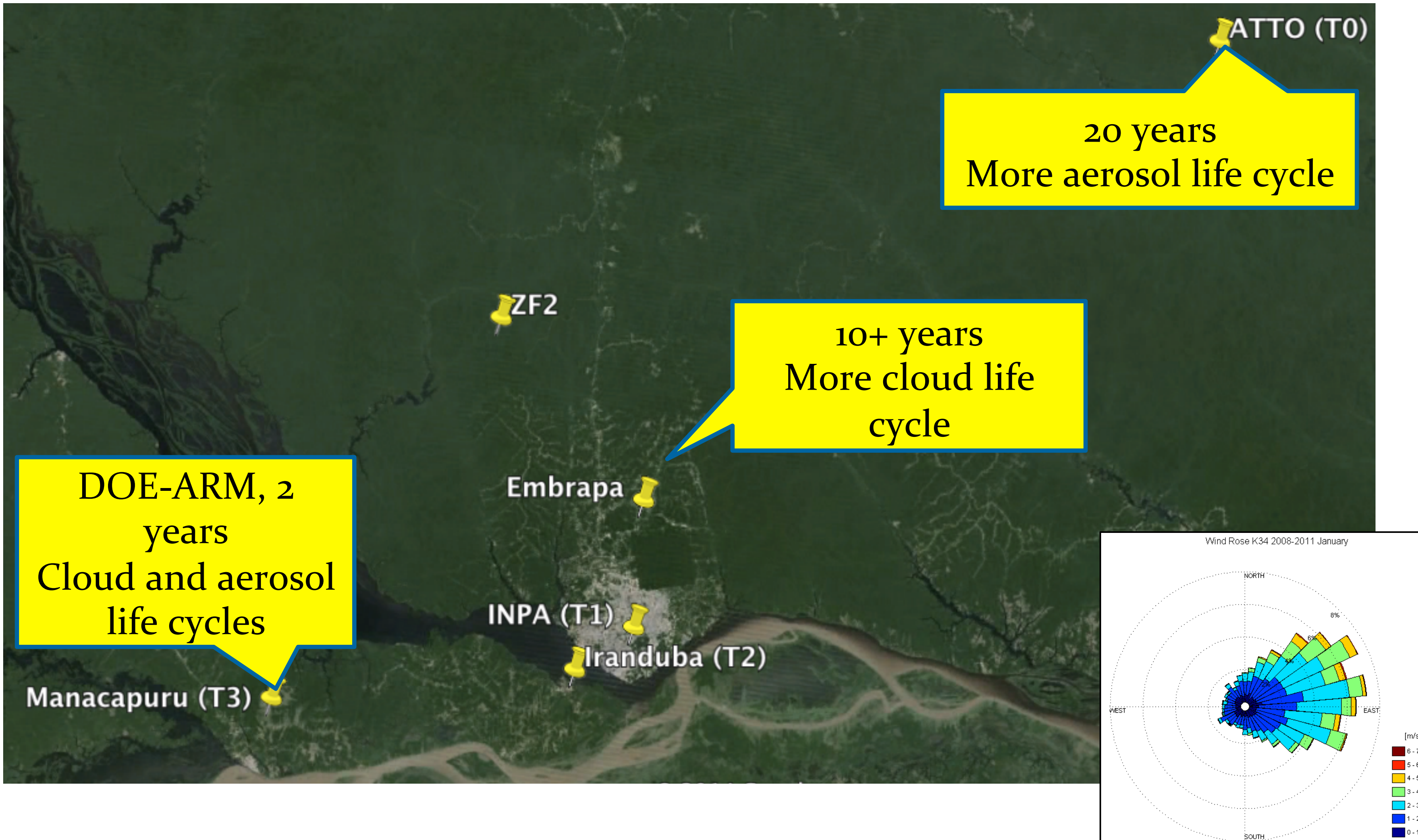
Cloud droplets number concentration



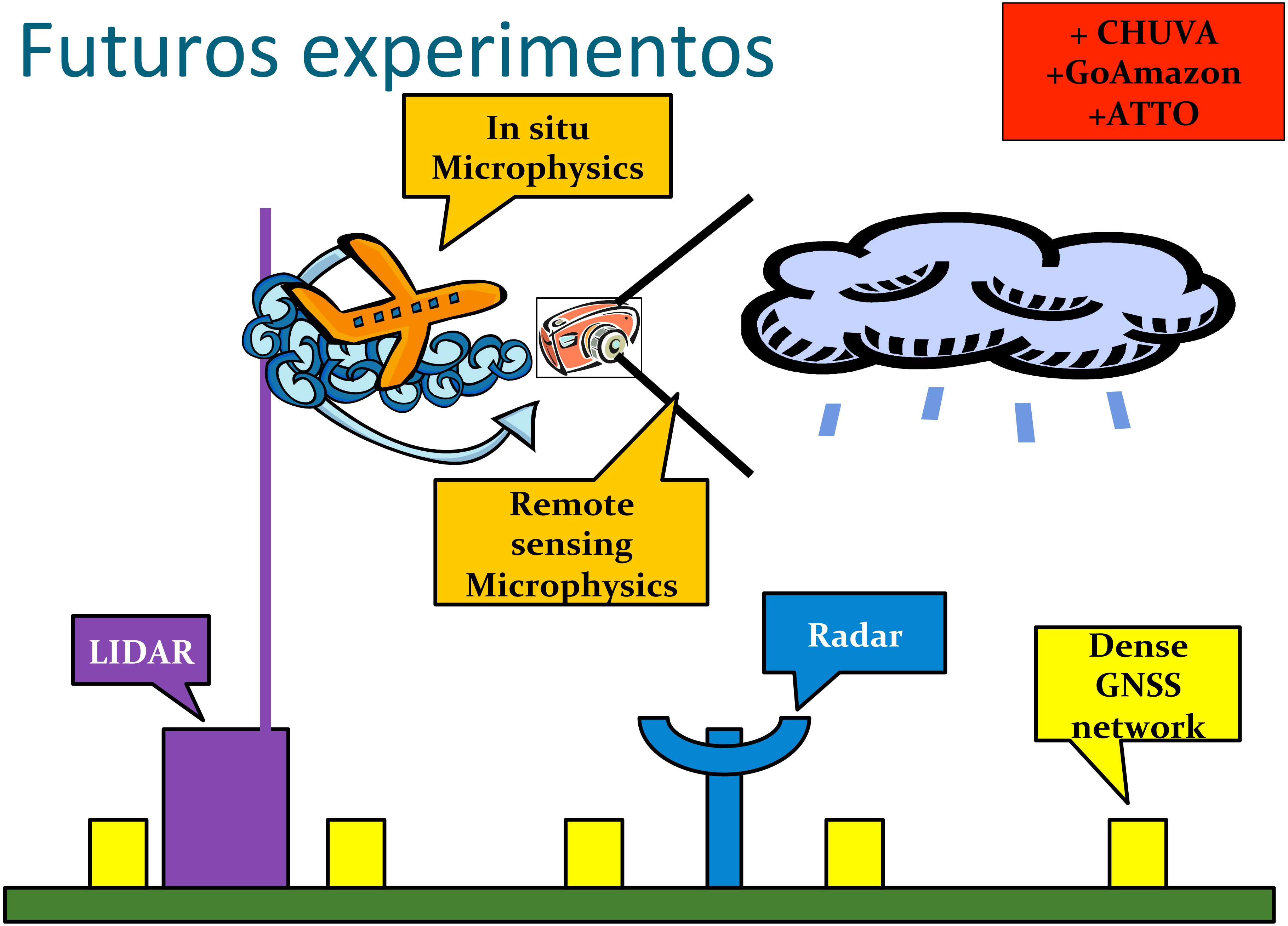
Poschl et al, Science 2010


ATTO
ZF2
Aconvex
GoAmazon
Manaus
Parque Nacional Jaua-Sarisariñama
Canaima
Guyana
Suriname
Guyane (French Guiana)
Oiapoque
Map
Photos
Alto Alegre
Boa Vista
Parque Nacional Parima Tapirapecó
Guiana Amazonian National Park
Roraima
Amapá
Rorainópolis
Parque Nacional Serranía La Neblina
Macapá
Afuá
Chaves
Anajás
Benevides
Almeirim
Breves
Belém
Oriximiná
Alenquer
Óbidos
Monte Alegre
Santarém
Rio Preto da Eva
Fonte Boa
Cametá
Tailândia
Altamira
Tefé
Careiro
Maués
Uruará
Tucuruí
Itaituba
Carauari
Amazonas
Itupiranga
Manicoré
Pará
Marabá
Parauapebas
Eldorado dos Carajás
Novo Progresso
Xinguara
Lábrea
Humaitá
100 mi
200 km
©2011 Google - Imagery ©2011 TerraMetrics, Map data ©2011 Europa Technologies, MapLink - Terms of Use

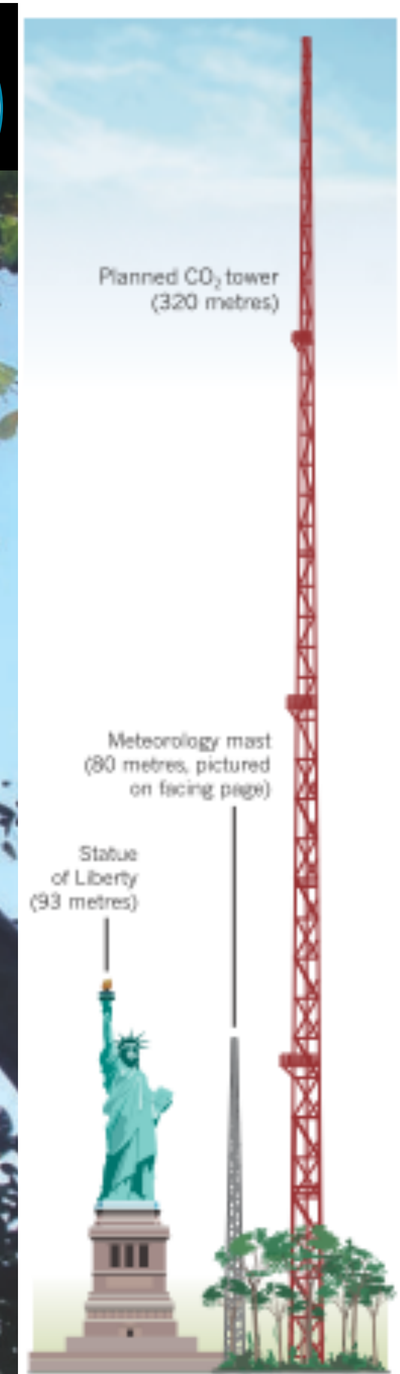
GoAmazon + CHUVA



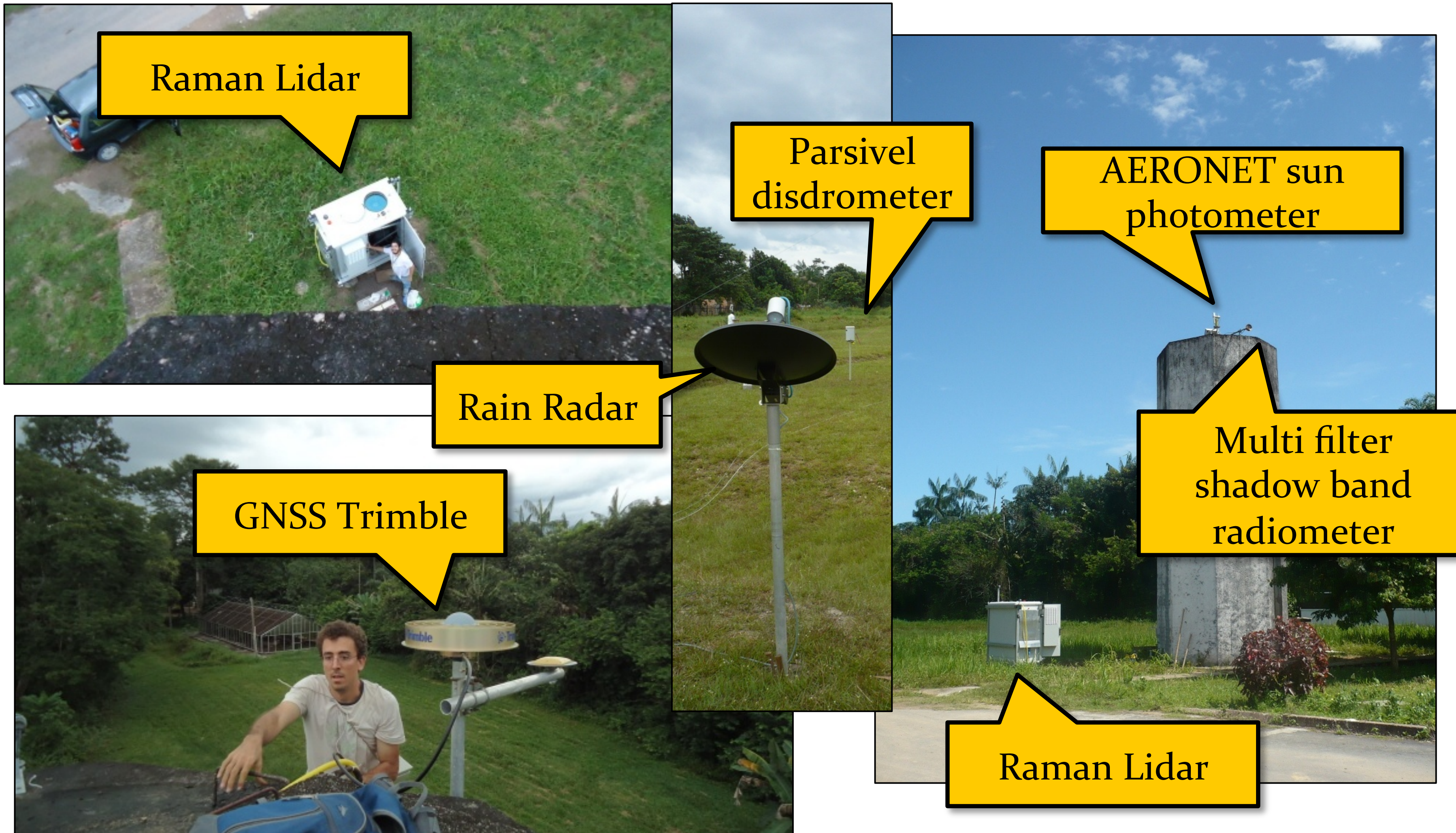
Futuros experimentos



ATTO – Torre pequena (80m)



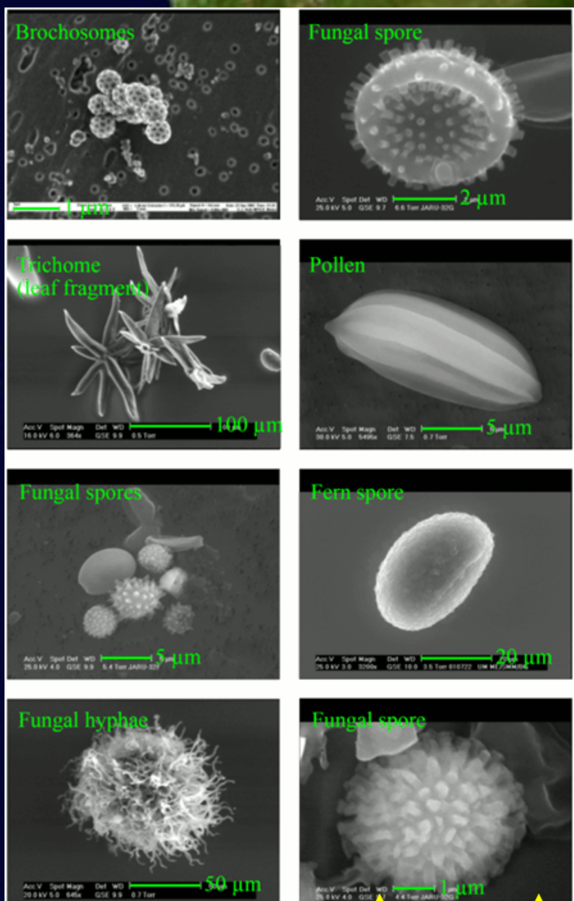
ACONVEX – Aerosols, Clouds, Convection Experiment in Amazon



Manaus ZF2 site

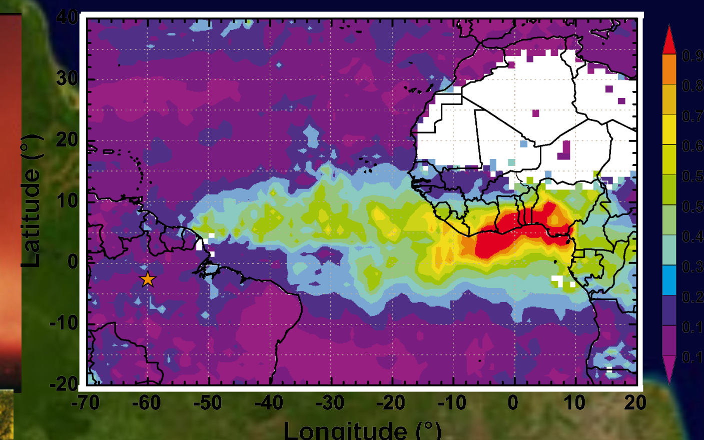
Amazonia: 3 different types of aerosols

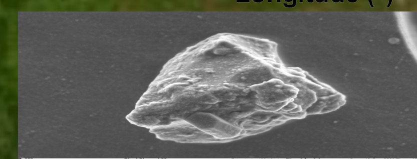
Biogenic (primary and SOA)

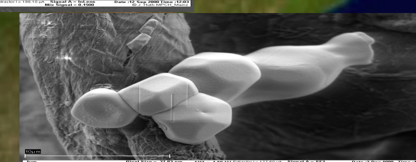


Biomass Burning

Dust from Sahara



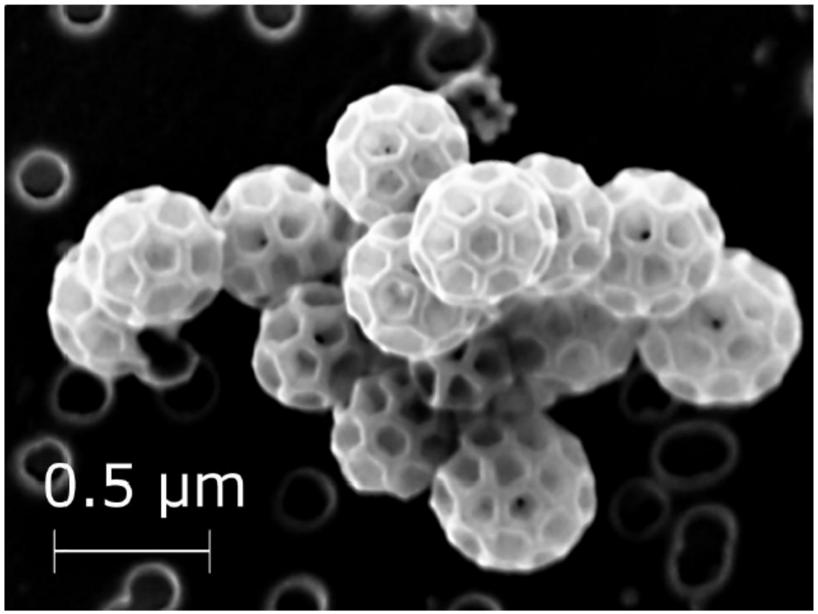




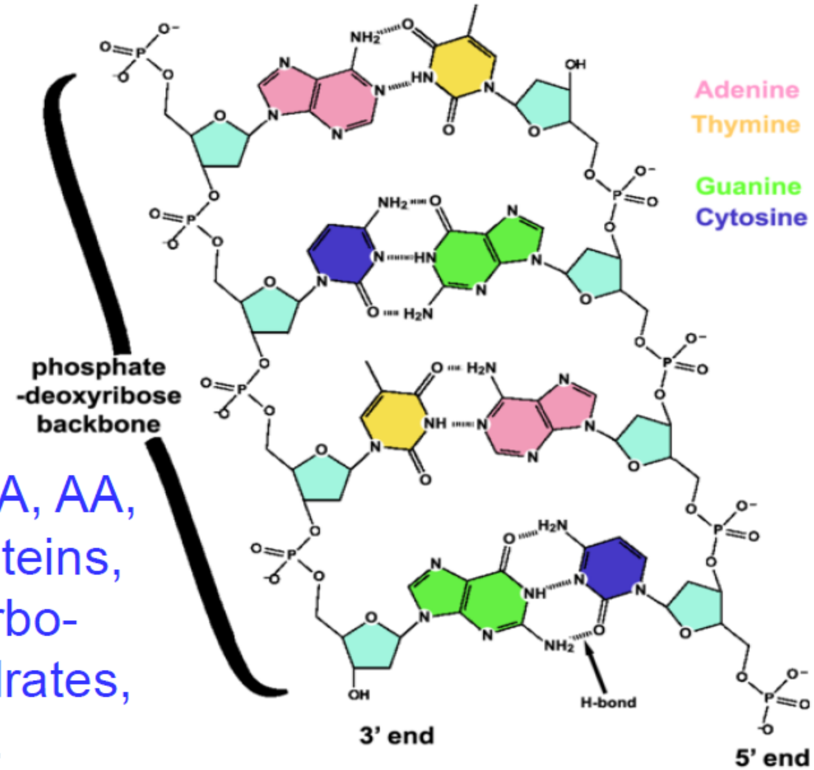
Each with VERY different properties and impacts

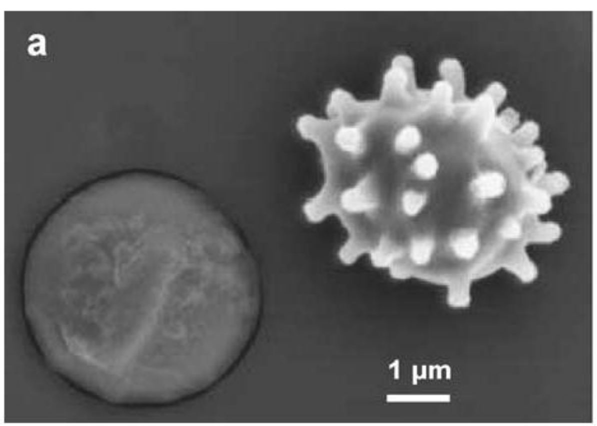
Biological Particles & Molecules

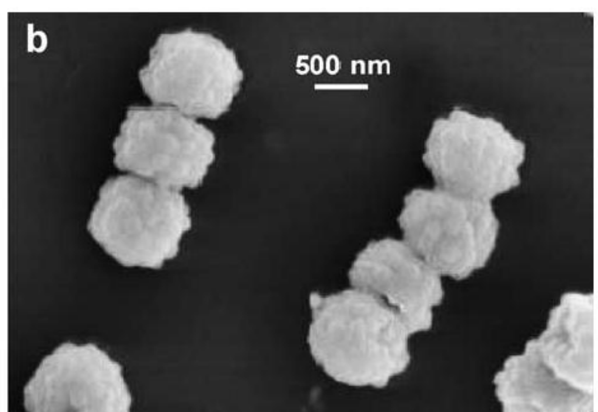
Bacteria, Brochosomes, Spores, Pollen, Plant Debris, etc.

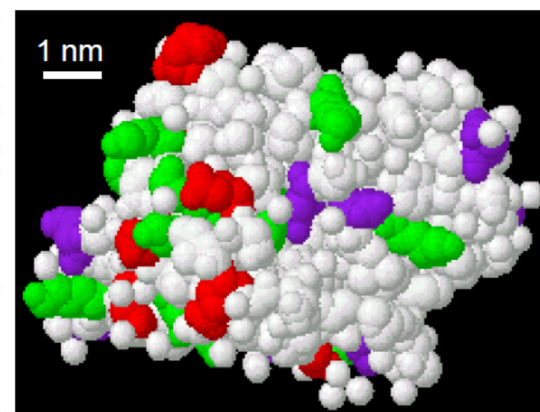


DNA, AA, Proteins, Carbo-hydrates, etc.

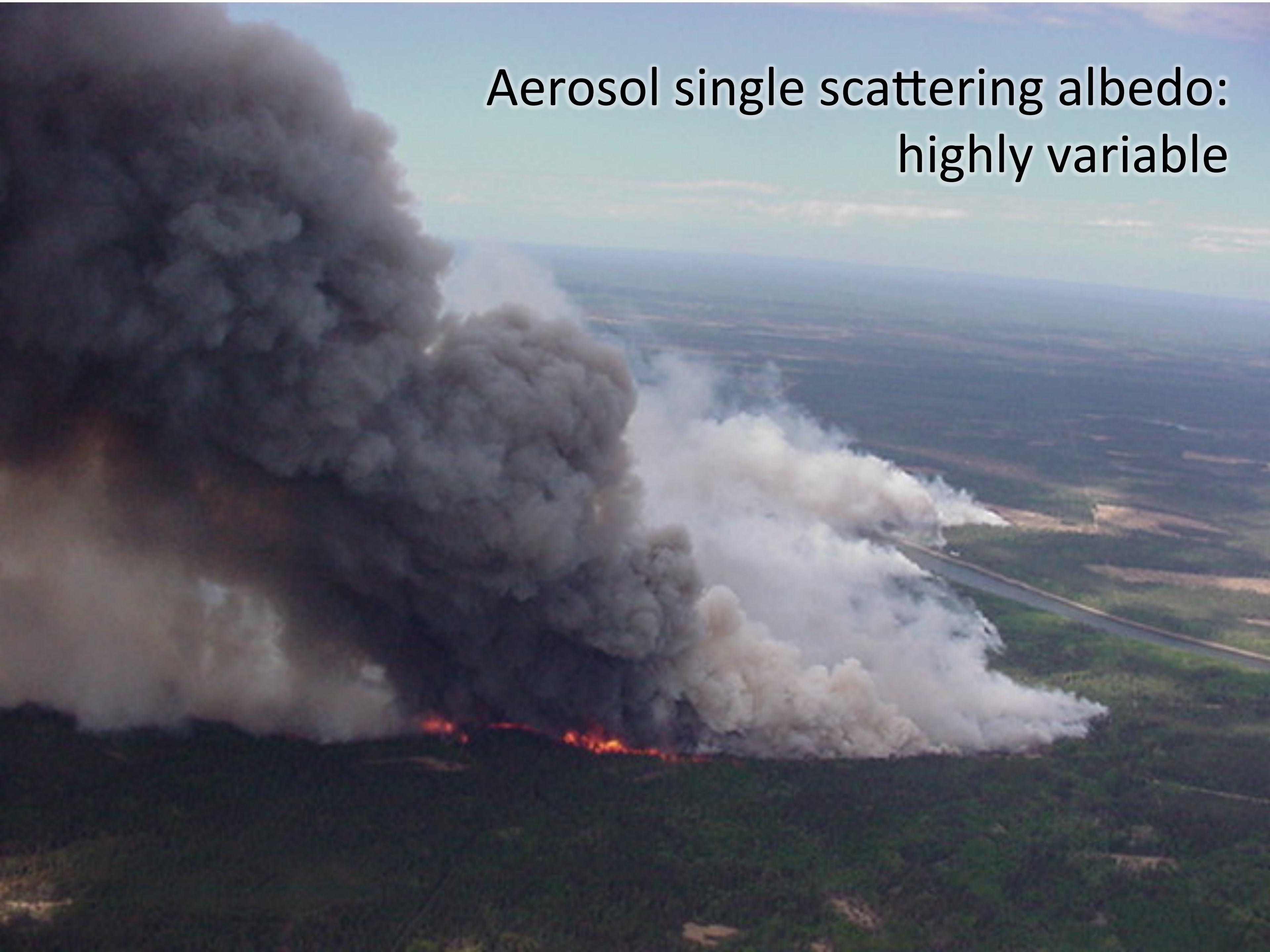






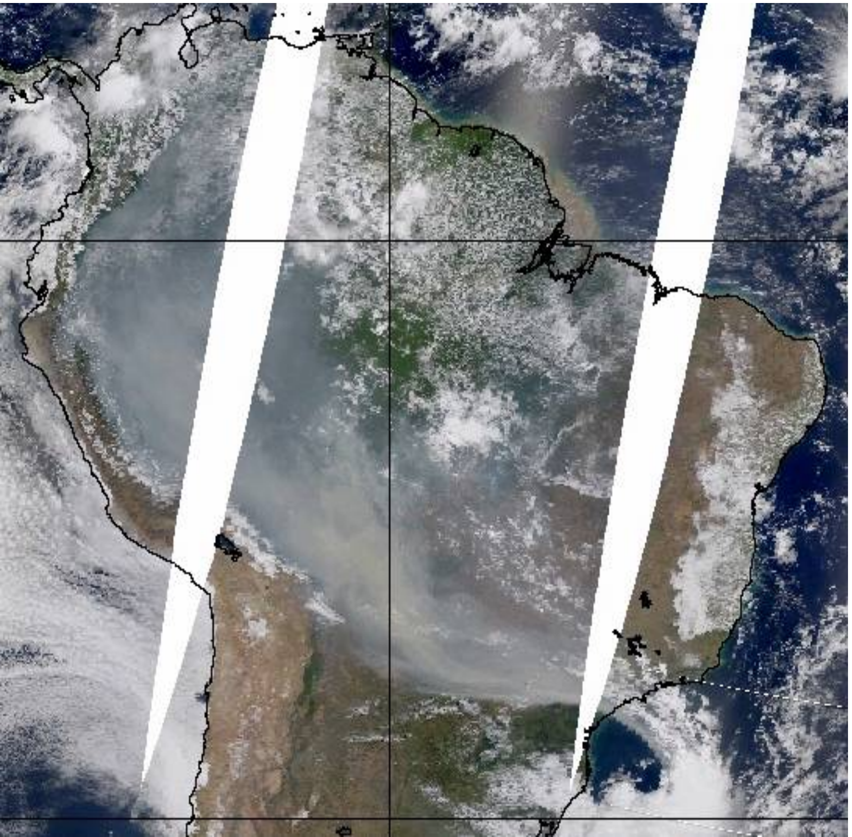


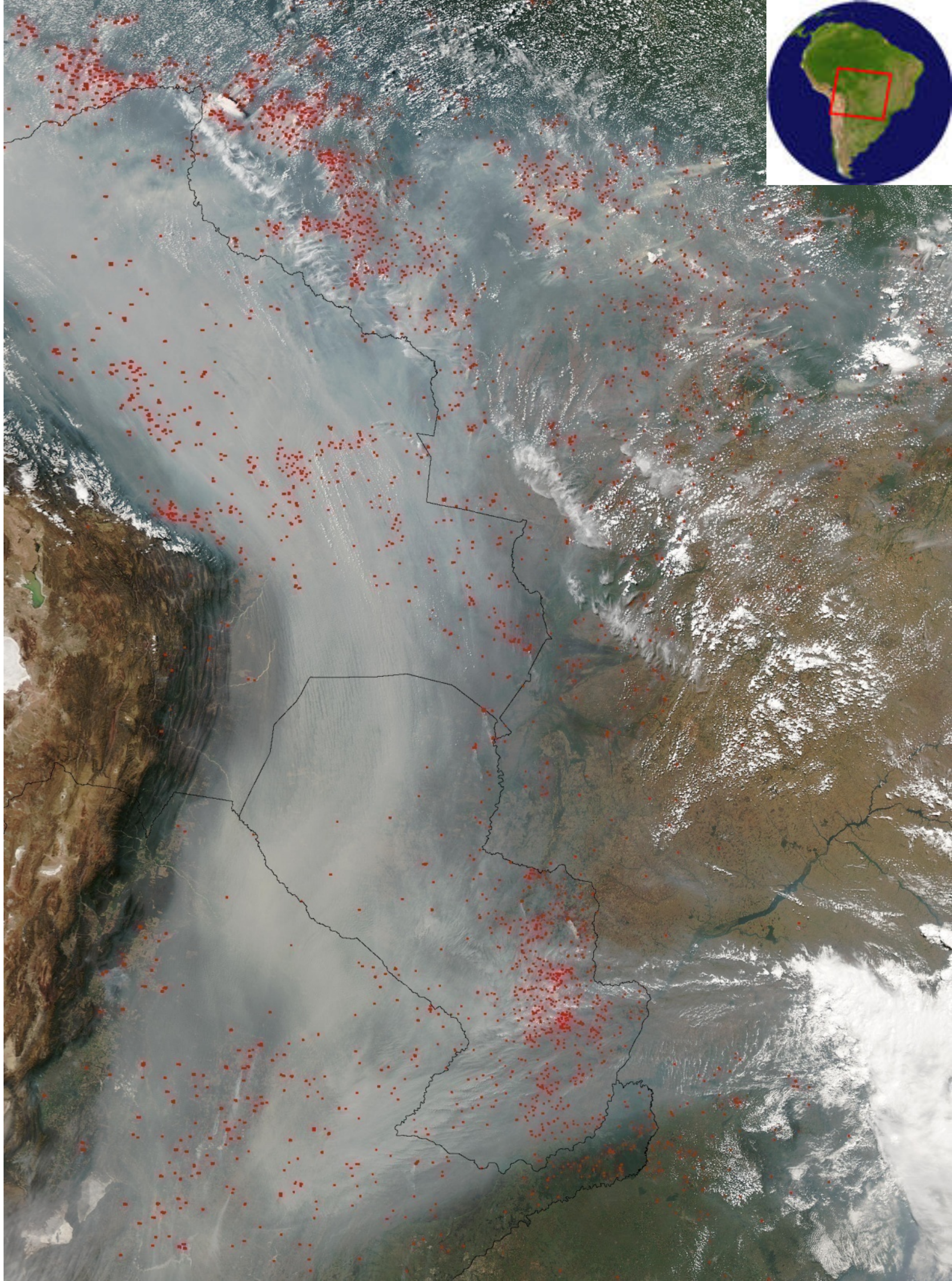
Aerosol single scattering albedo: highly variable



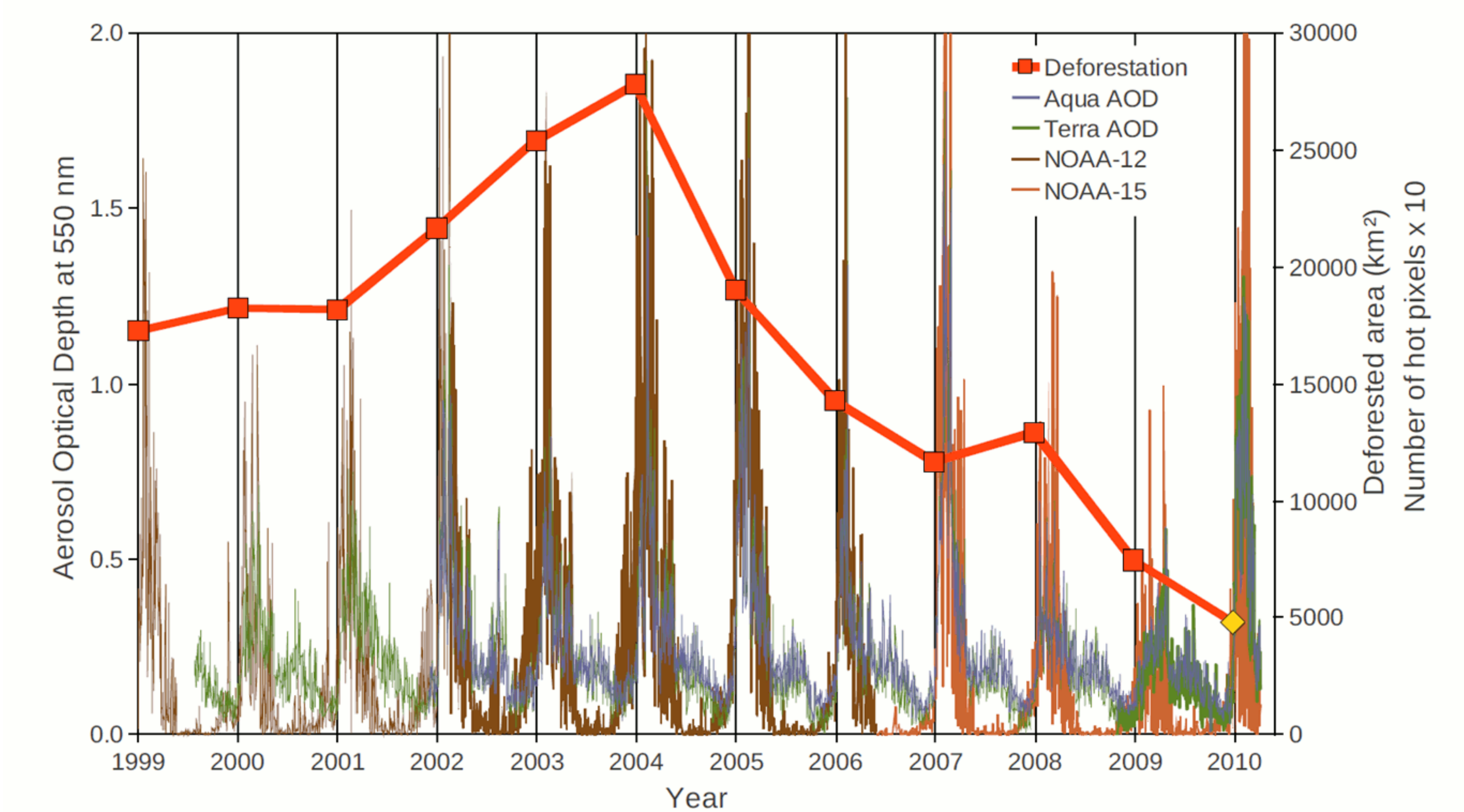
Large scale aerosol distribution in Amazonia

- Severe health effects on the Amazonian population (about 20 million people)
- Climatic effects, with strong effects on cloud physics and radiation balance.
- Changes in carbon uptake and ecosystem functioning





Yearly deforestation with MODIS AOD and hot pixels from NOAA



Yearly deforestation over the Brazilian Amazon region (INPE, 2010) compared to MODIS daily smoke optical depth and the daily number of hot pixels from NOAA-12 and NOAA-15.

Amazonia
Average aerosol forcing clear sky

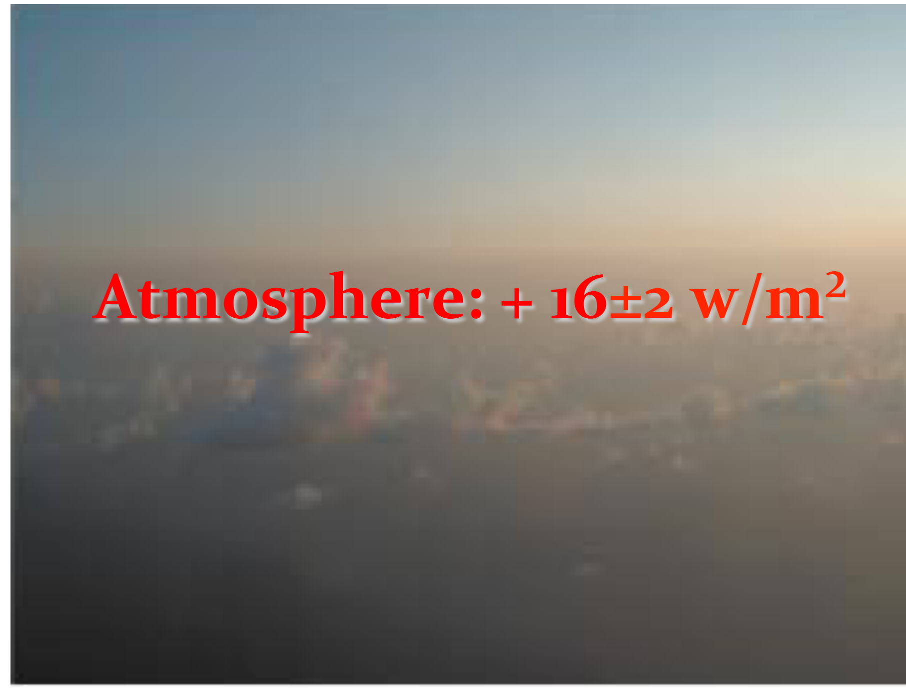
Top: - 10 w/m^2

Surface: - 38 w/m^2

Conditions: surface: forest vegetation
AOT (τ=0.95 at 500nm); 24 hour average
7 years (93-95, 99-02 dry season Aug-Oct)

INDOEX
average aerosol forcing clear sky

Top: - 7±1 w/m^2



Surface: - 23±2 w/m^2

Conditions: surface: ocean
AOT (τ=0.3 at 630 nm); 24 hour average
Jan-Mar 99

Procópio et al. (2004)

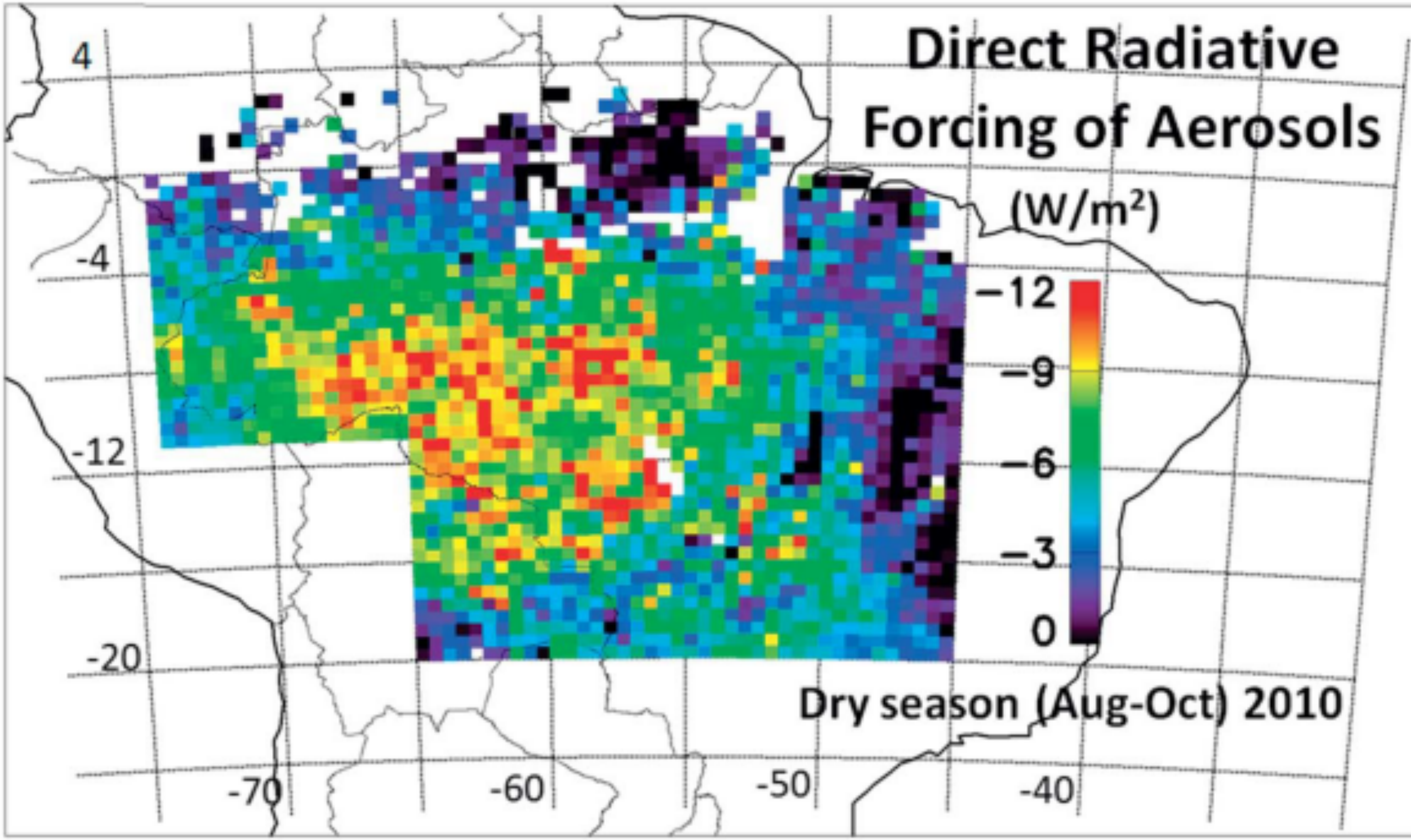
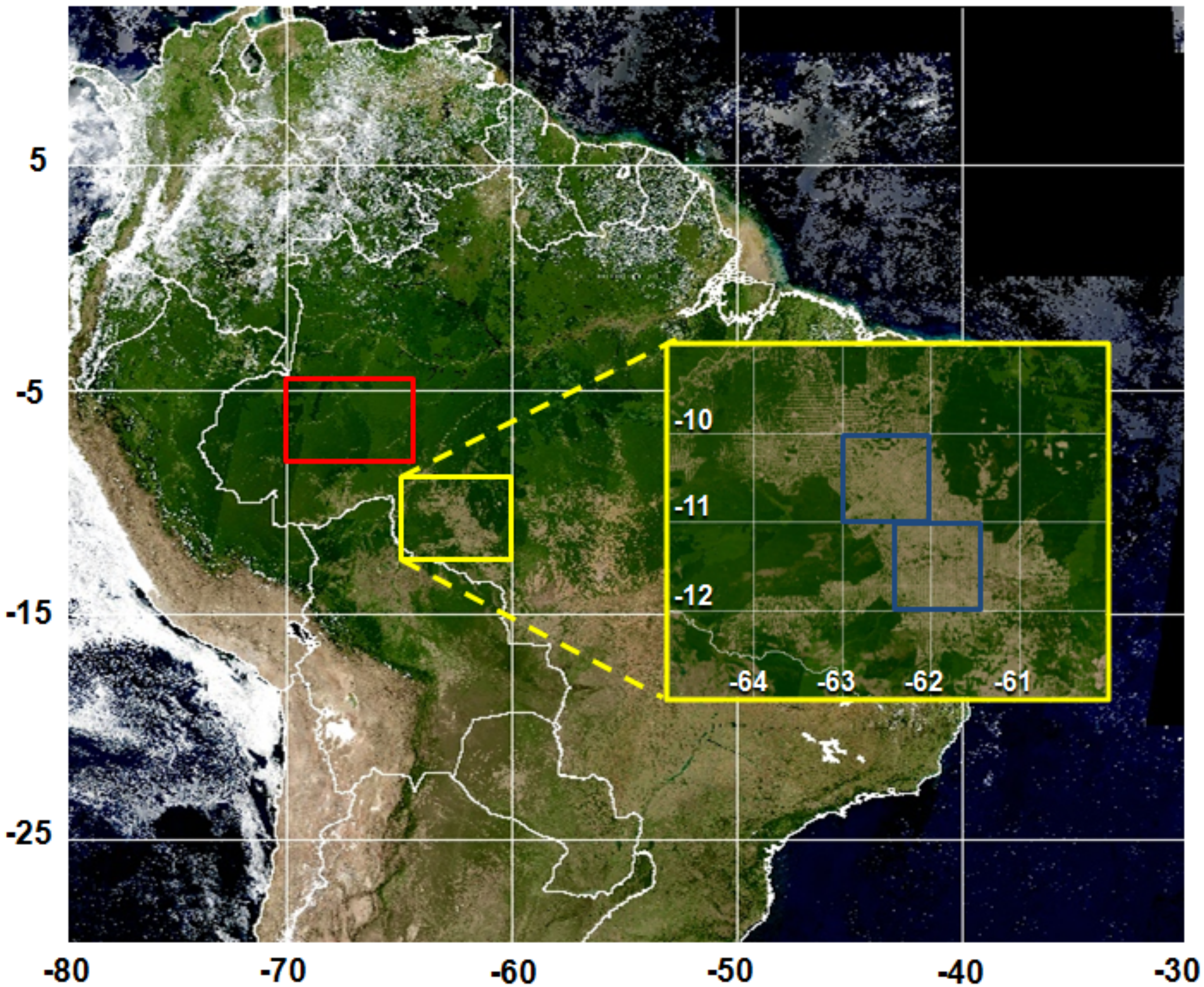


Fig. 18 Average spatial distribution of the direct radiative forcing (DRF) of biomass burning aerosols in Amazonia during the dry season (August to October) of 2010. Forcing derived from calculations using a combination of MODIS and CERES sensors data. During this three-month period, the daily-average radiative forcing of aerosols for the whole area was on average -5.3 ± 0.1 W m^{-2}.



Mean Diurnal Radiative Forcing due to change in surface albedo: -8.0 ± 0.9 W/m^2

Mean Diurnal Aerosol Forcing Efficiency:

Forest: $-22.5 + 1.4$ W/m^2

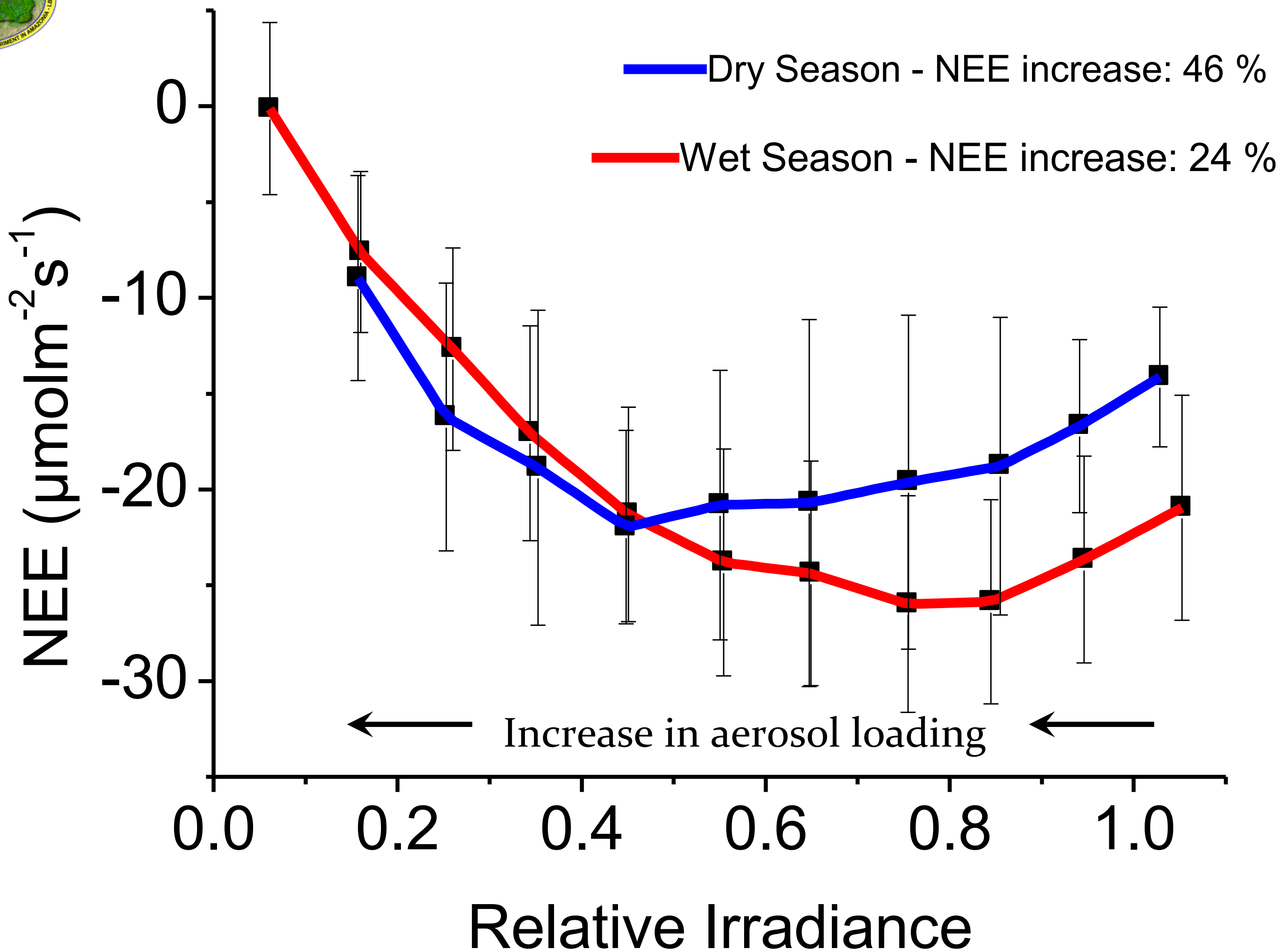
Cerrado: -16.6 ± 1.7 W/m^2

Land-use change radiative forcing. Forested areas are selected in red and deforested areas are selected in blue.

Elisa Sena, Phd Thesis, 2013

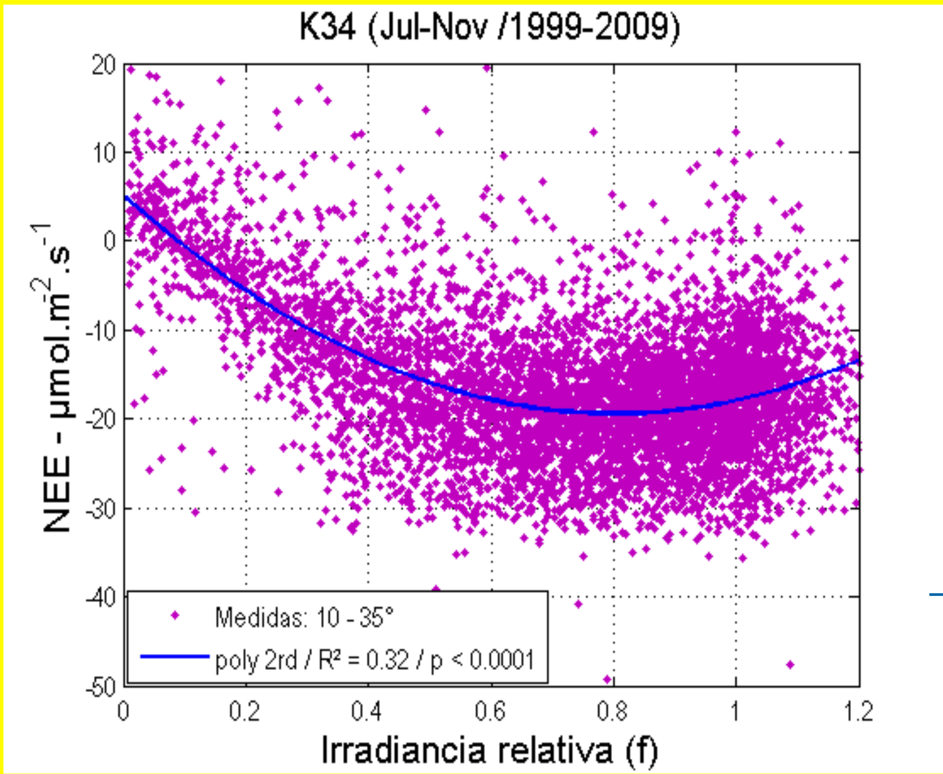
Strong aerosol effect on forest photosynthesis diffuse radiation have a large effect on CO_2 fluxes

Amazonia Rondonia Forest site 2000-2001



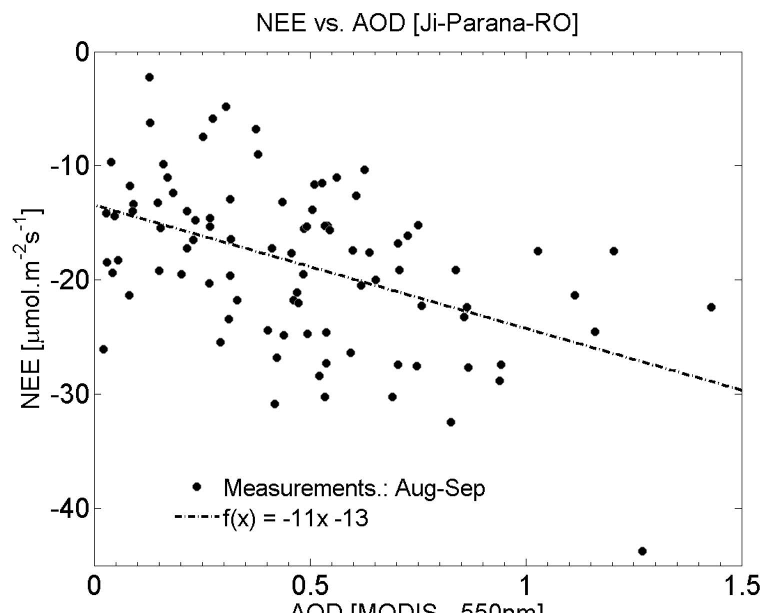
Aerosols effects on NEE – Manaus and

(Glauber Cirino, INPA, 2013)

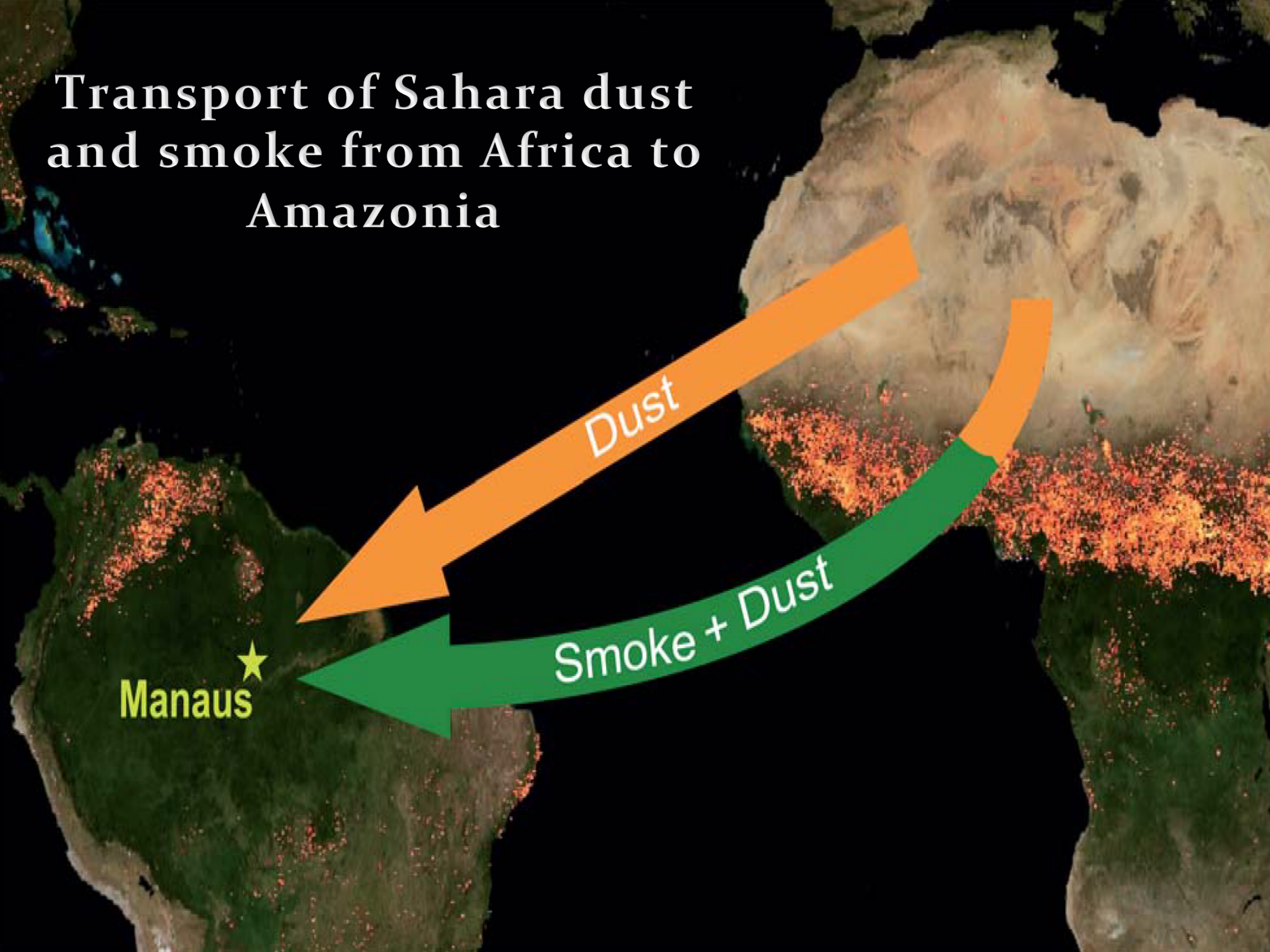


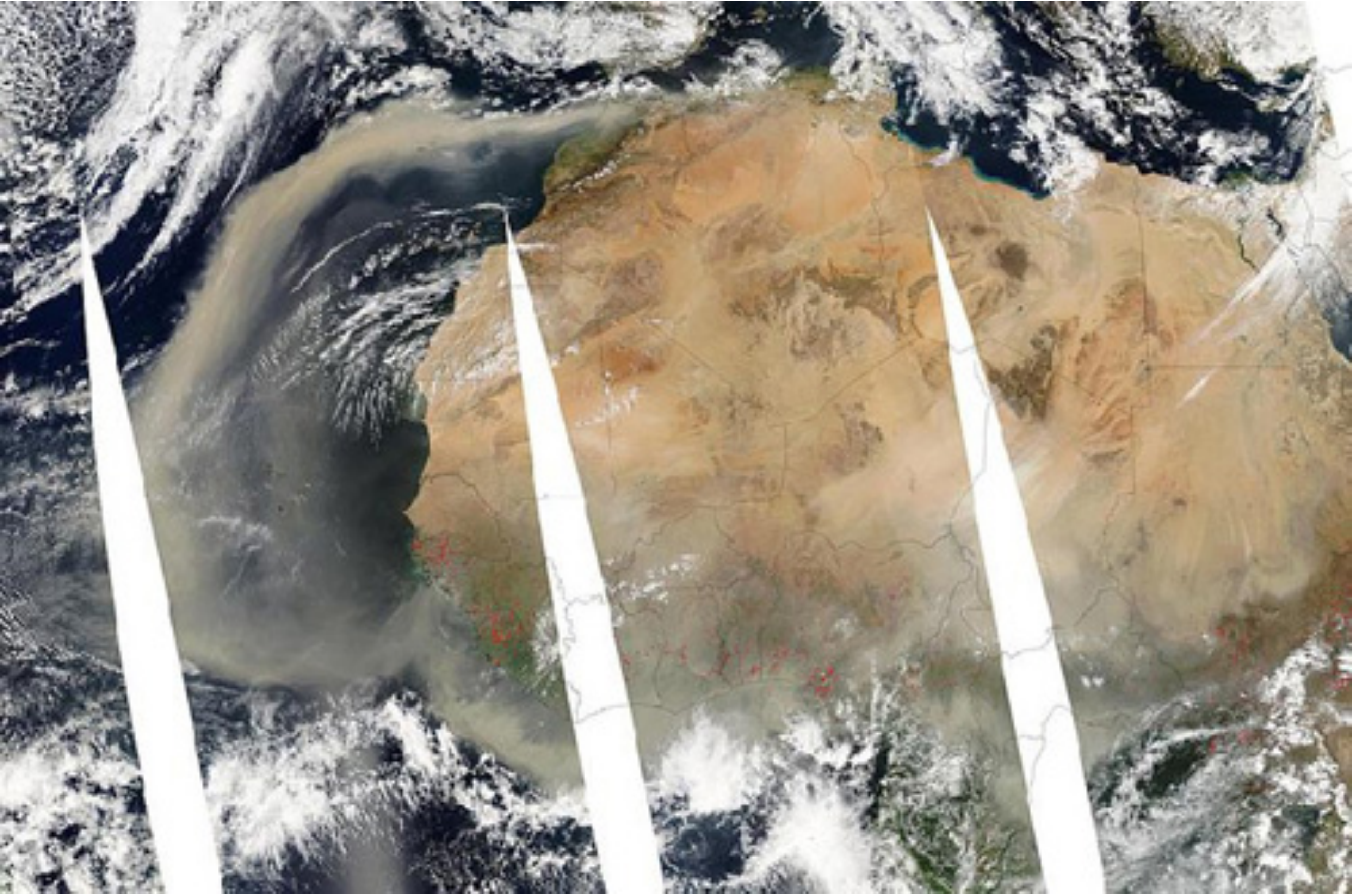
f max: ~ 0,80

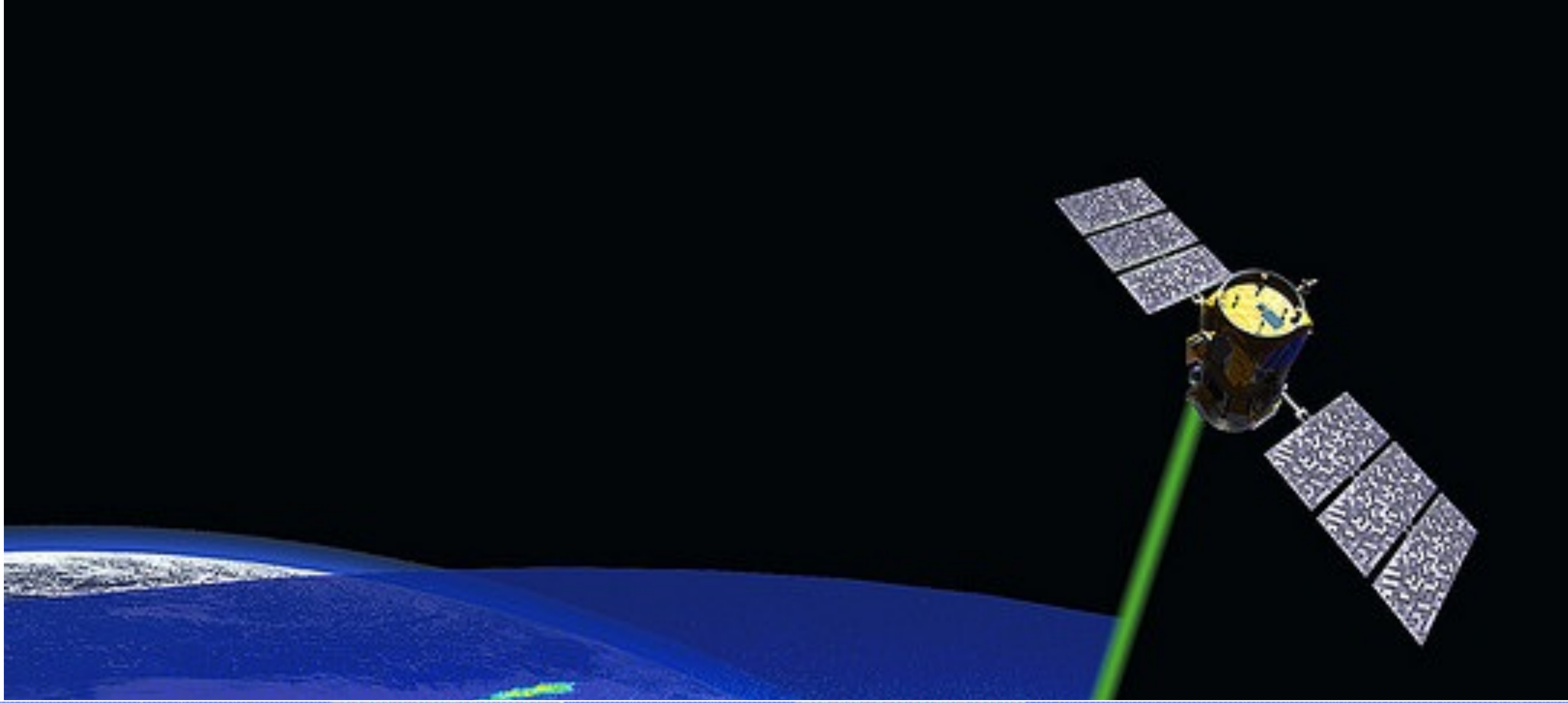
NEE (max): ~ -20 µmol/m²s
AOT: ~ 0,5

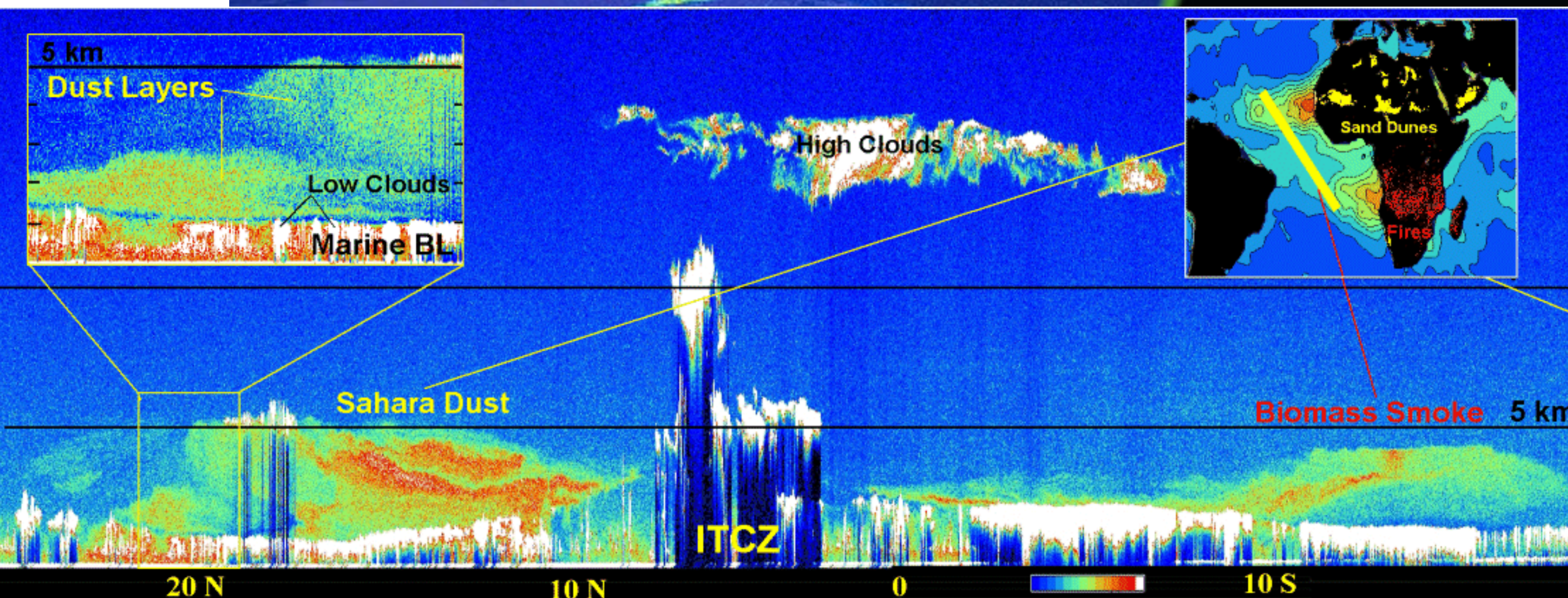


Transport of Sahara dust and smoke from Africa to Amazonia

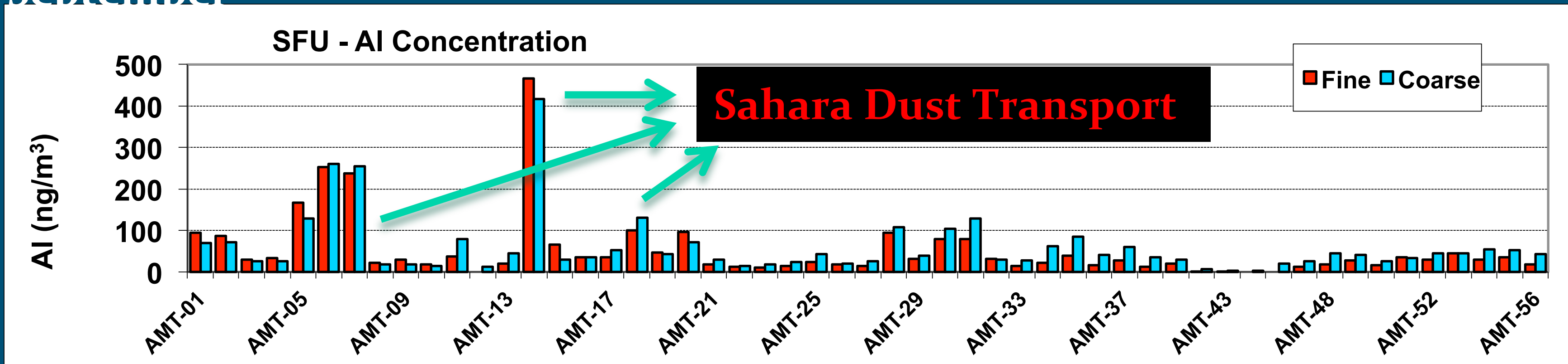


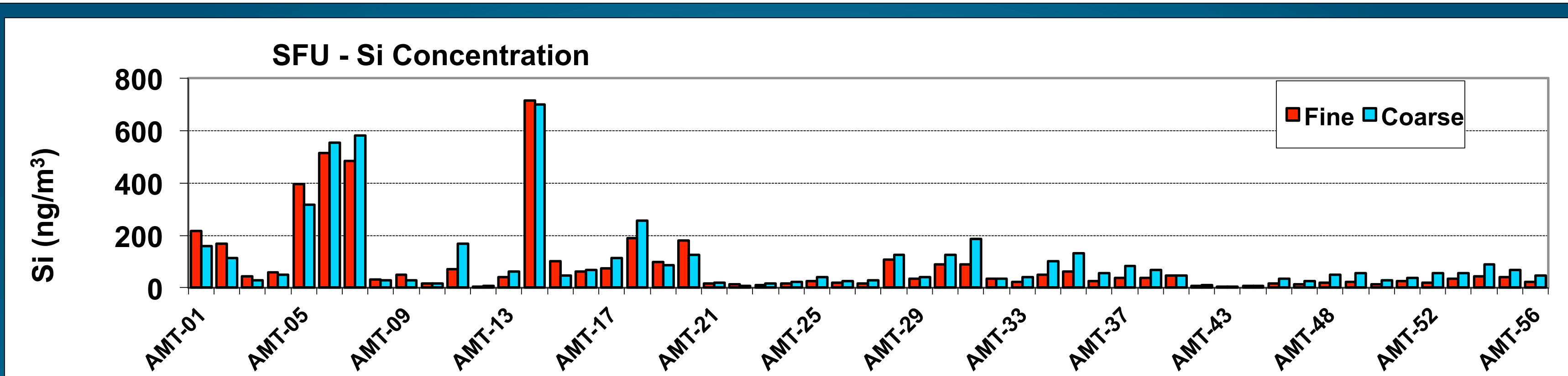


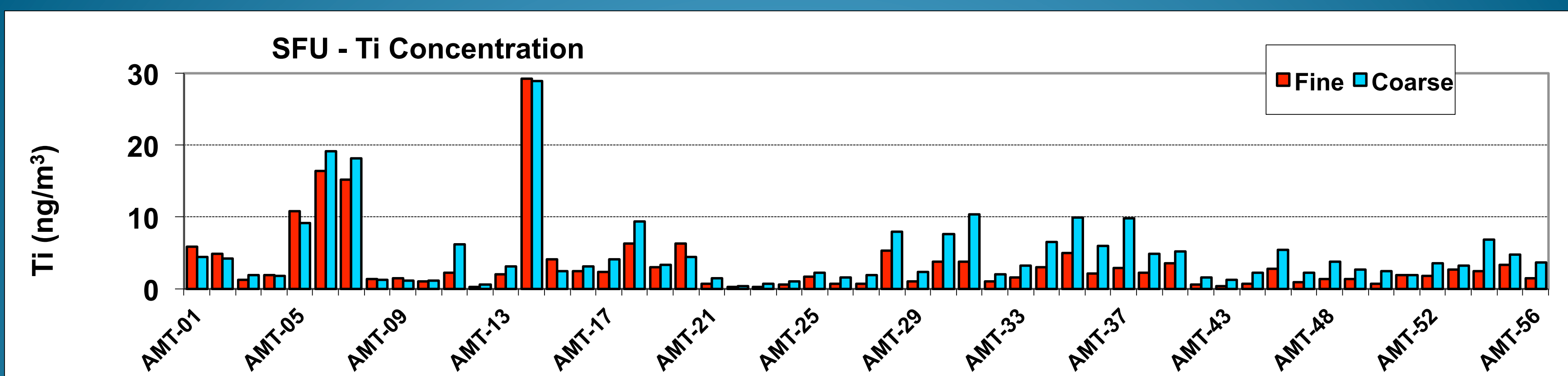



5 km
Dust Layers
Low Clouds
Marine BL
High Clouds
Sand Dunes
Fires
Sahara Dust
Biomass Smoke
5 km
ITCZ
20 N
10 N
0
10 S

Al, Si and Ti elemental Concentration for fine and coarse mode aerosols Feb. to September

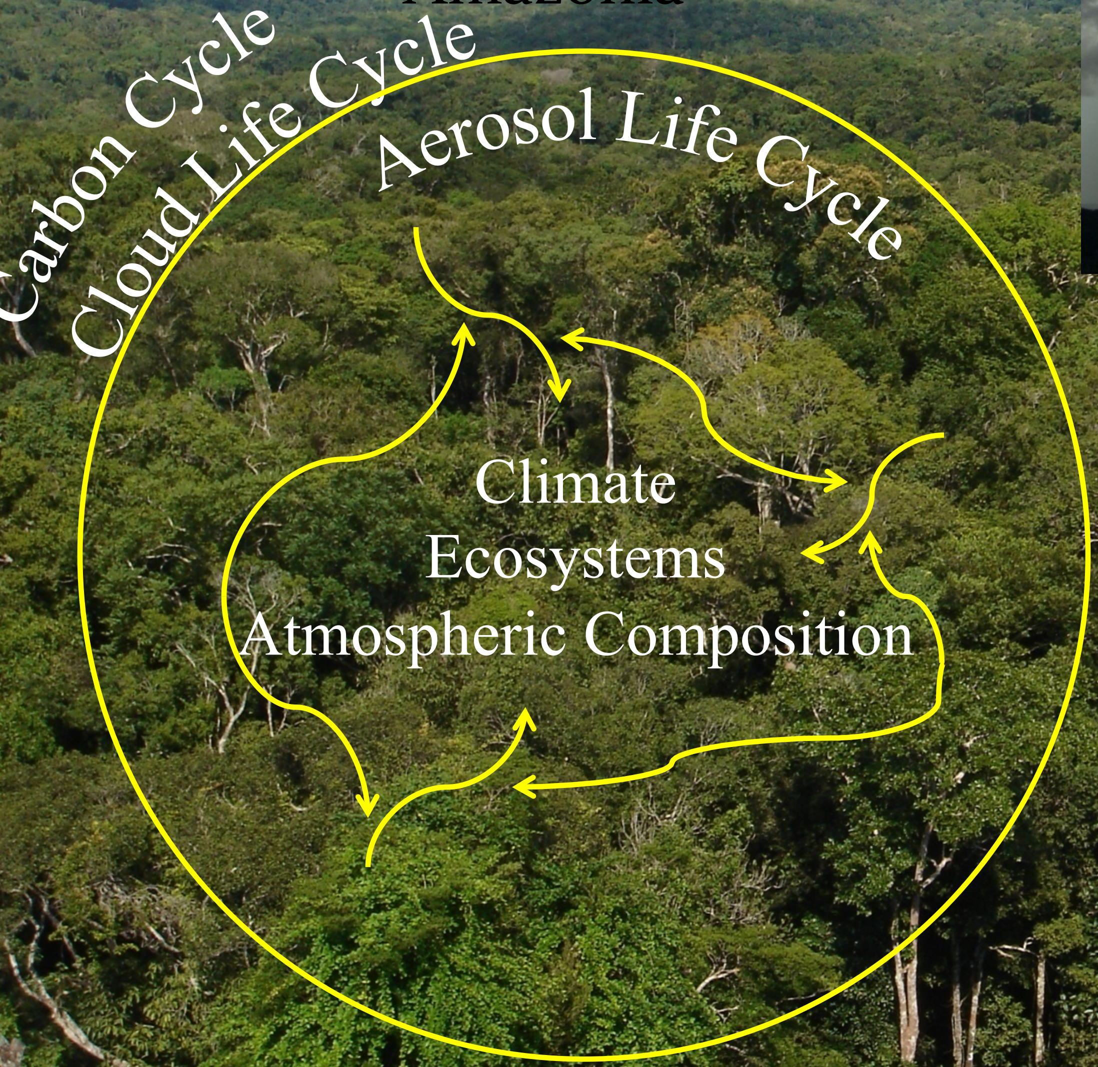




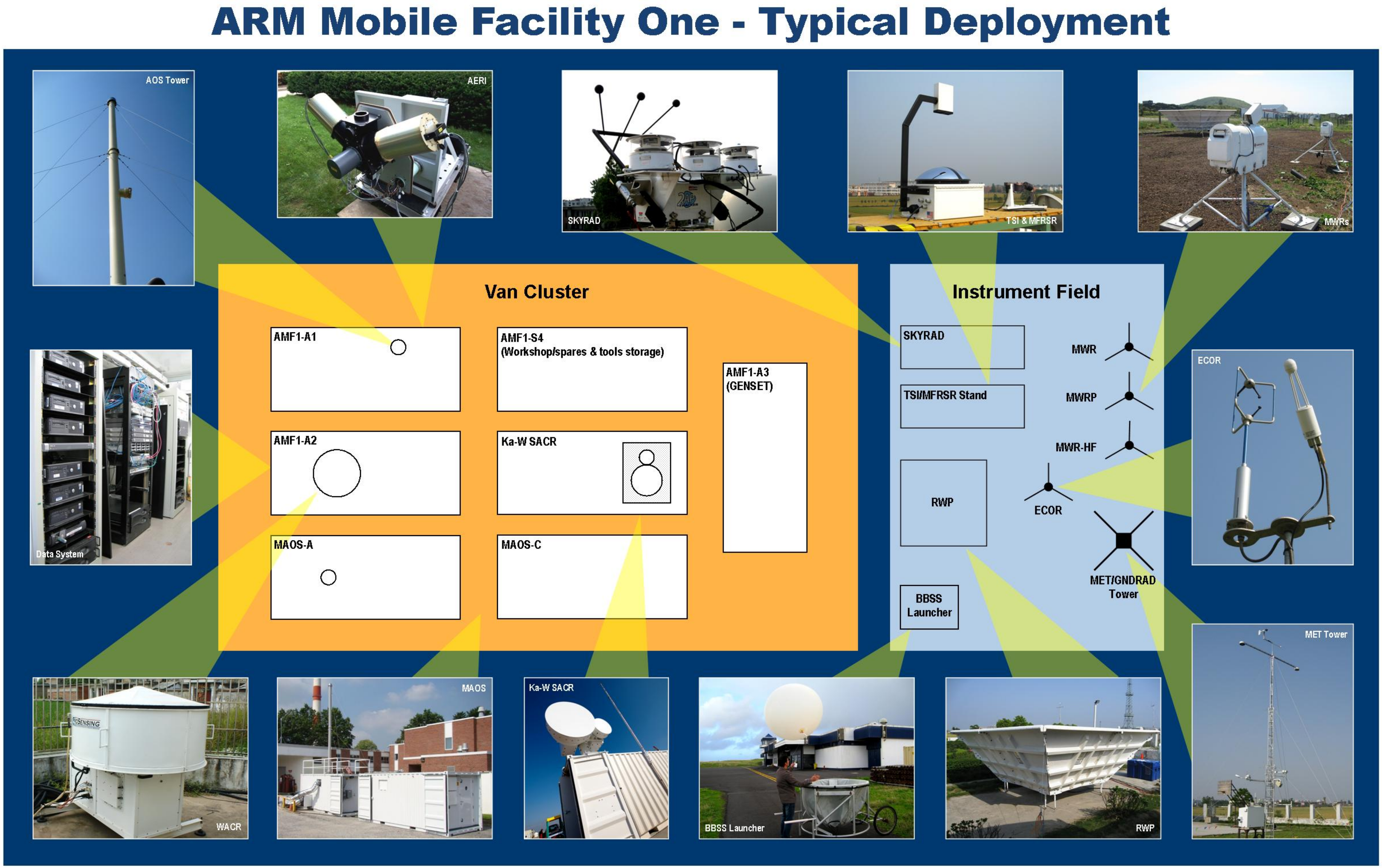


GoAmazon 2014-2015

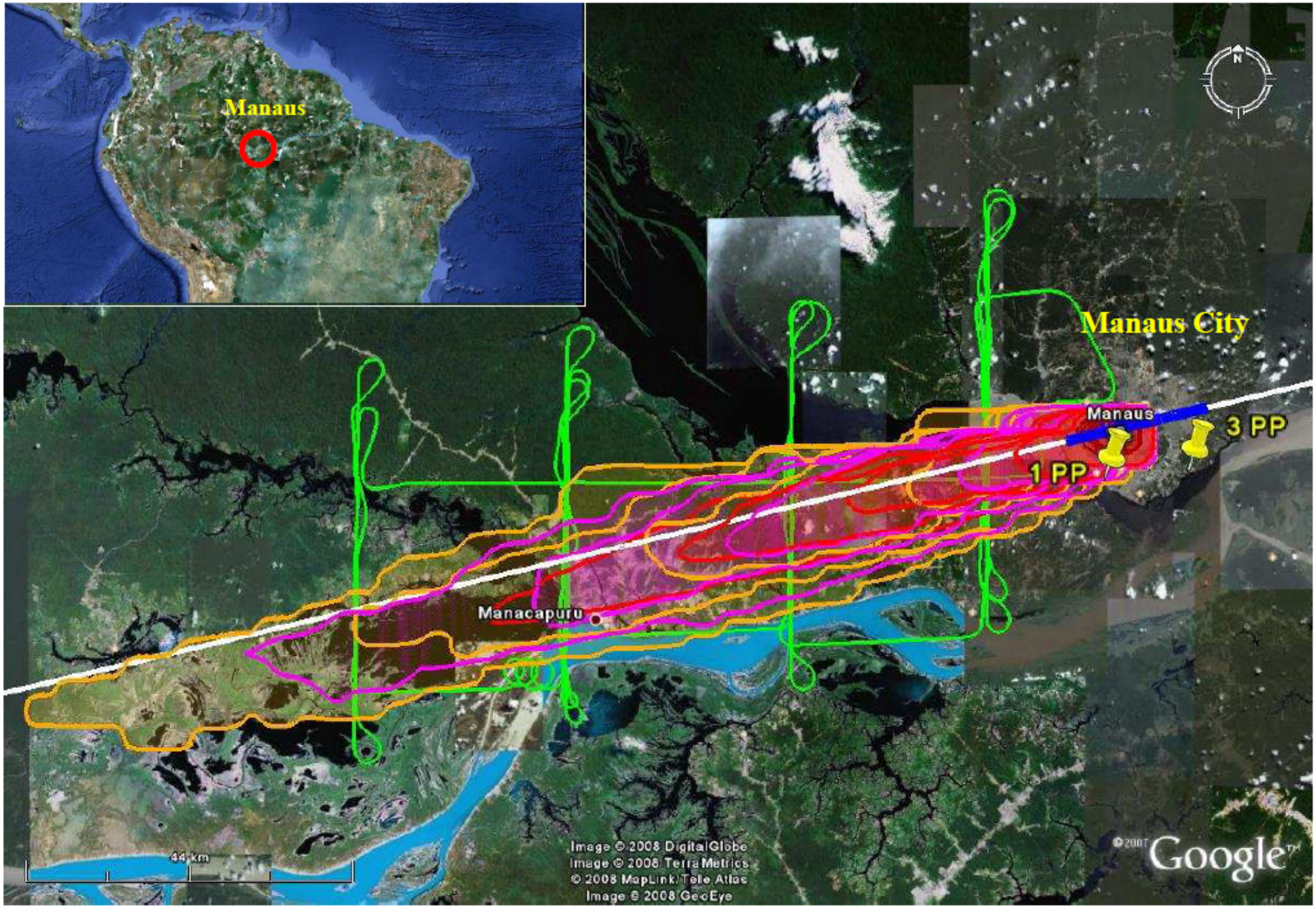
Ecosystems, Atmosphere Composition, and Climate in Amazonia

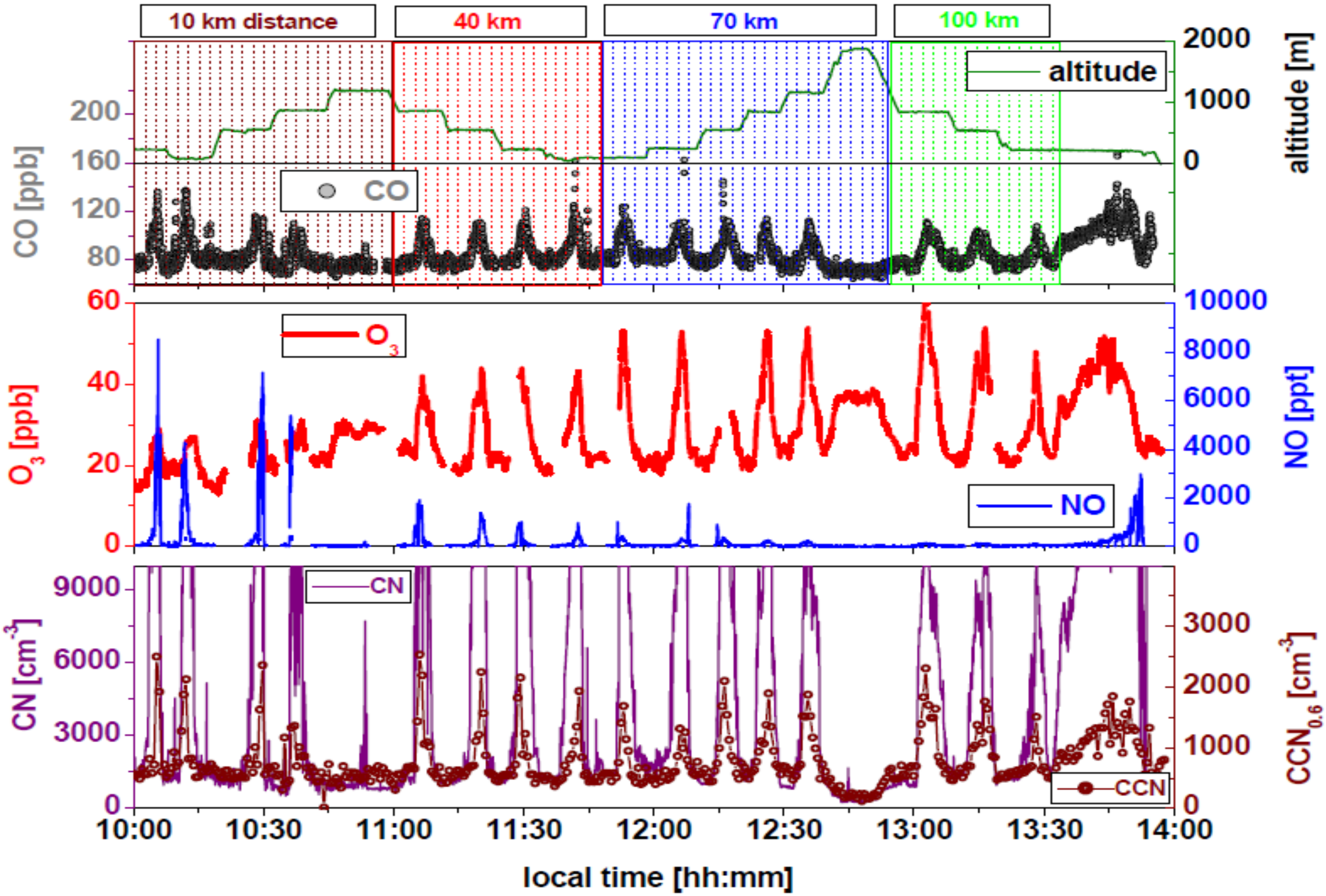


“ARM Mobile Facility in Amazônia” (AMFA2014/5)



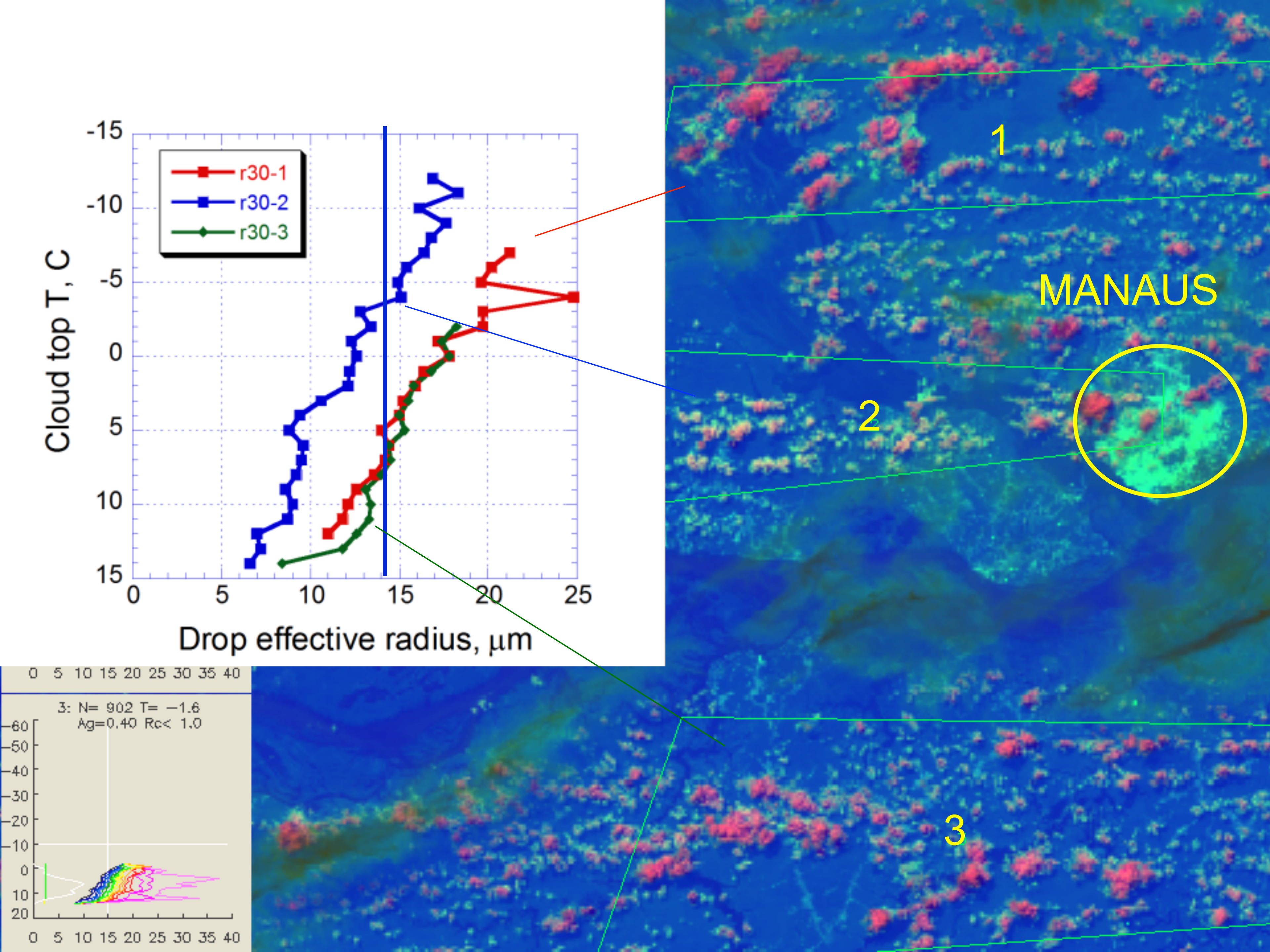
Experimento GoAmazon 2014





Reference: Kuhn, U.; Ganzeveld, L.; Thielmann, A.; Dindorf, T.; Welling, M.; Sciare, J.; Roberts, G.; Meixner, F. X.; Kesselmeier, J.; Lelieveld, J.; Ciccioli, P.; Kolle, O.; Lloyd, J.; Trentmann, J.; Artaxo, P.; Andreae, M. O., "Impact of Manaus City on the Amazon Green Ocean atmosphere: Ozone production, precursor sensitivity, and aerosol load," *Atmos. Chem. Phys.* **2010**, *10*, 9251-9282.

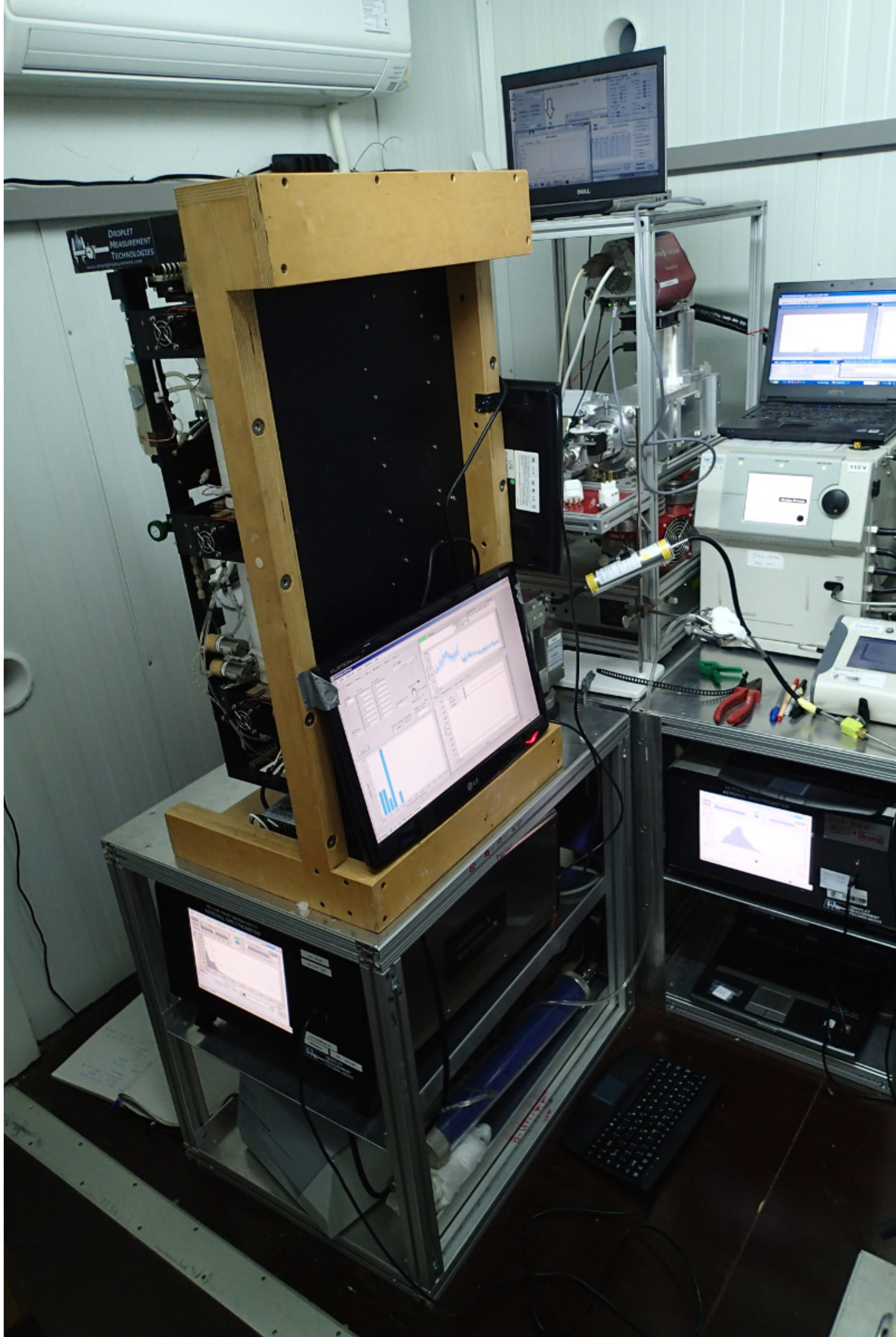

MANAUS

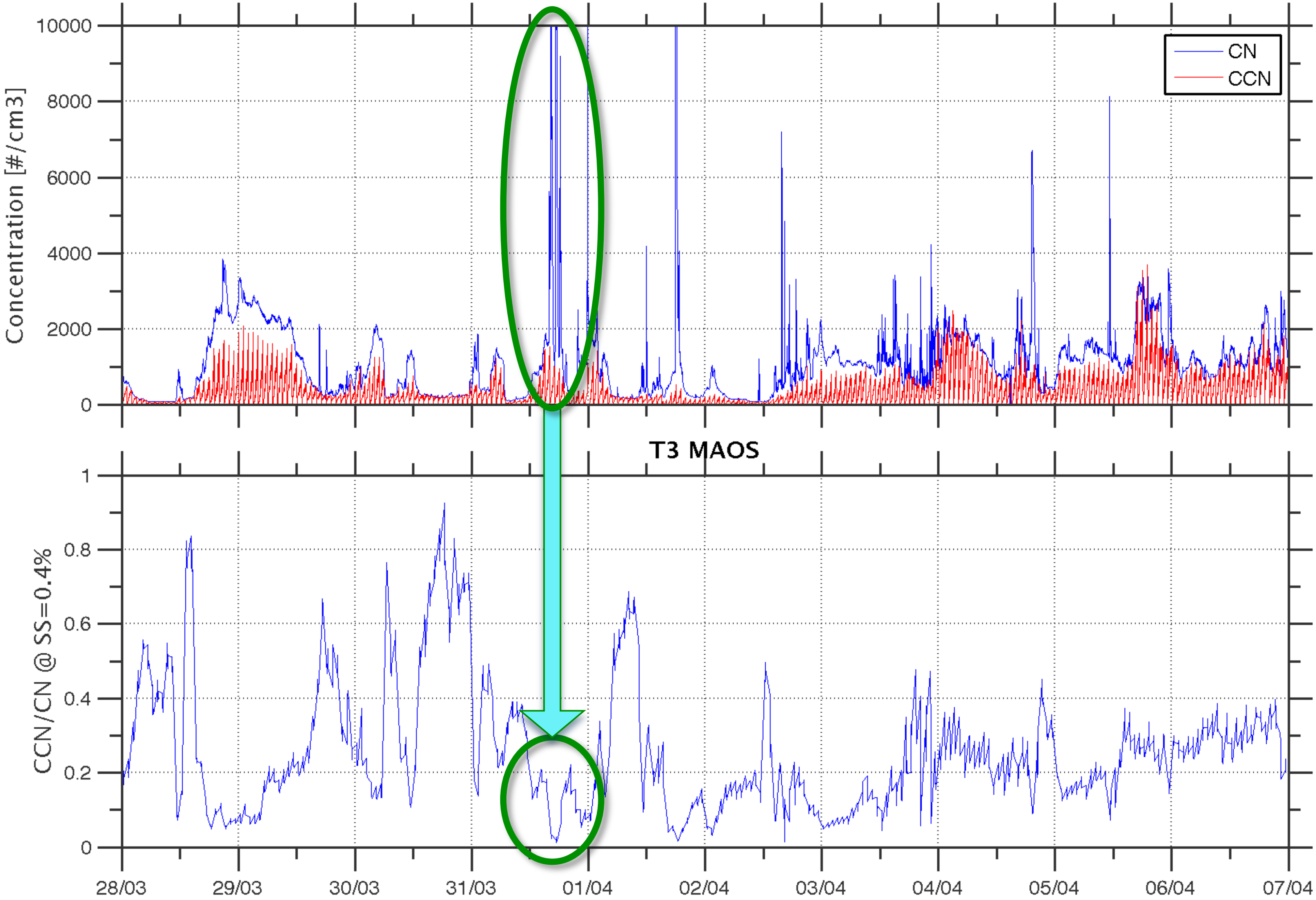


Cloud top T, C
-15
-10
-5
0
5
10
15
0 5 10 15 20 25
Drop effective radius, μm
r30-1
r30-2
r30-3
1
2
3
MANAUS
3: N= 902 T= −1.6
Ag=0.40 Rc< 1.0
0 5 10 15 20 25 30 35 40
-60
-50
-40
-30
-20
-10
0
10
20

Mira's measurements

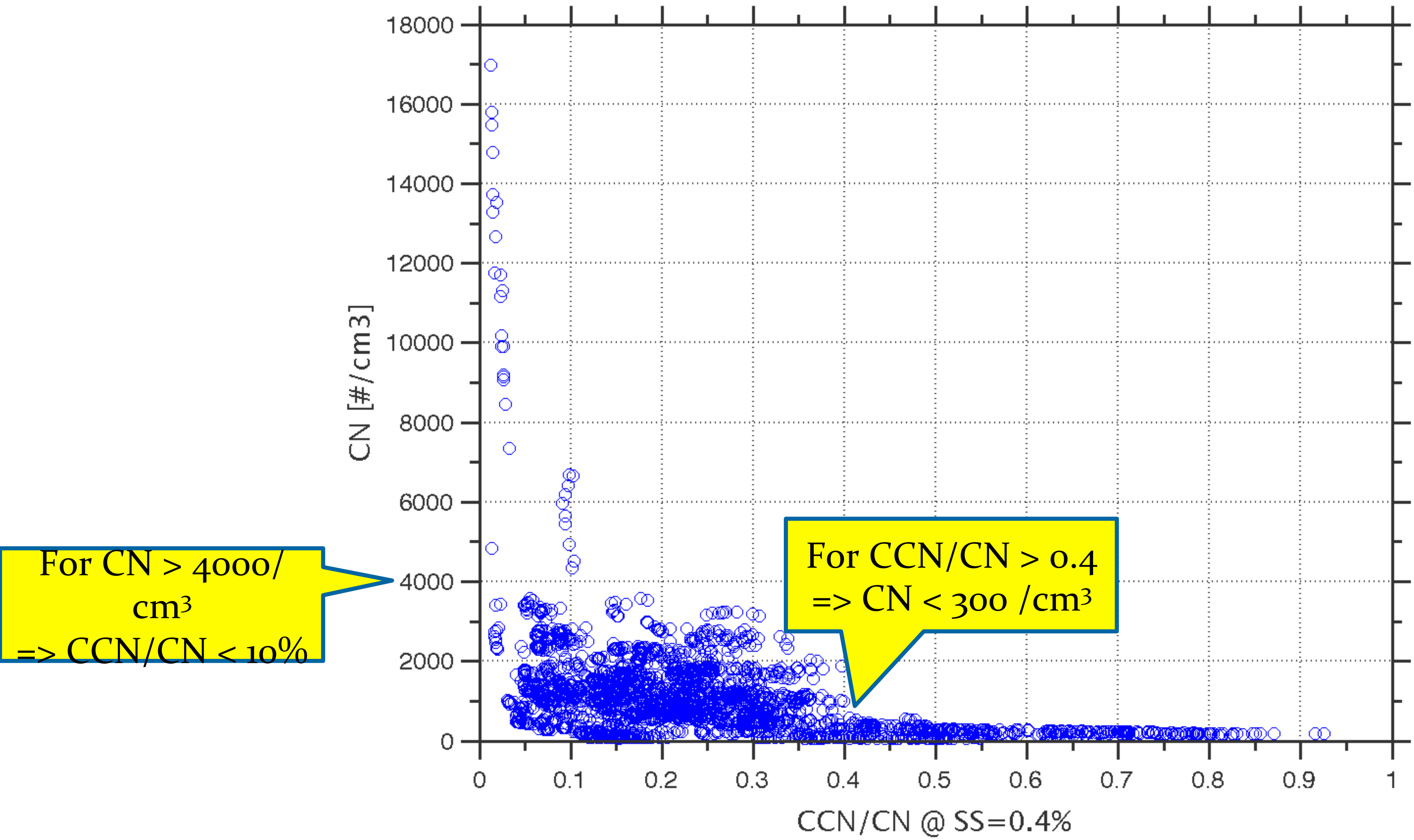
- 17-21 March
  - Initial setup
  - Calibration
  - Intercomparison w/ J. Wang at T3
- 22-26 March
  - Moved to ATTO
  - CCNC calibration
  - DMA/UHSAS calibration with PSL's
  - Started data acquis…





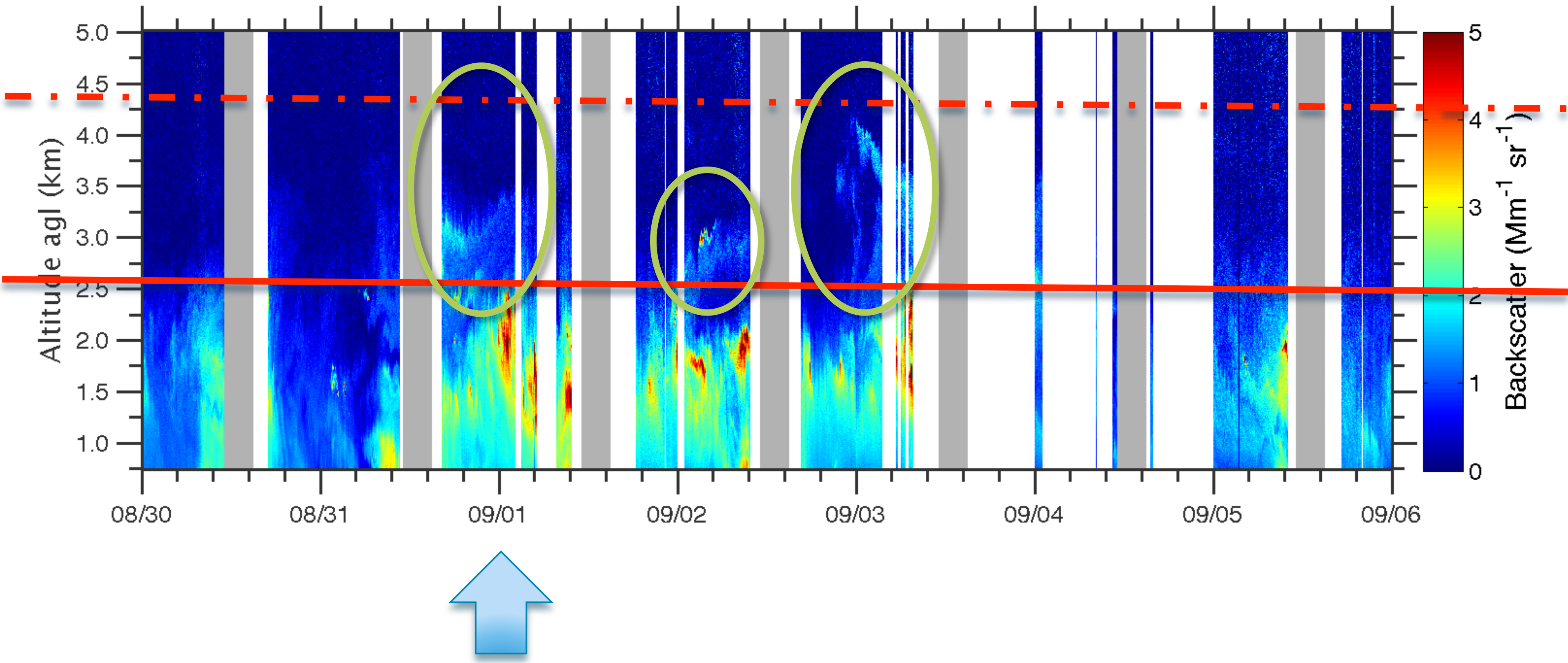
Concentration [#/cm3]
10000
8000
6000
4000
2000
0
CN
CCN
T3 MAOS
CCN/CN @ SS=0.4%
1
0.8
0.6
0.4
0.2
0
28/03
29/03
30/03
31/03
01/04
02/04
03/04
04/04
05/04
06/04
07/04

CCN/CN Measurements at ATTO

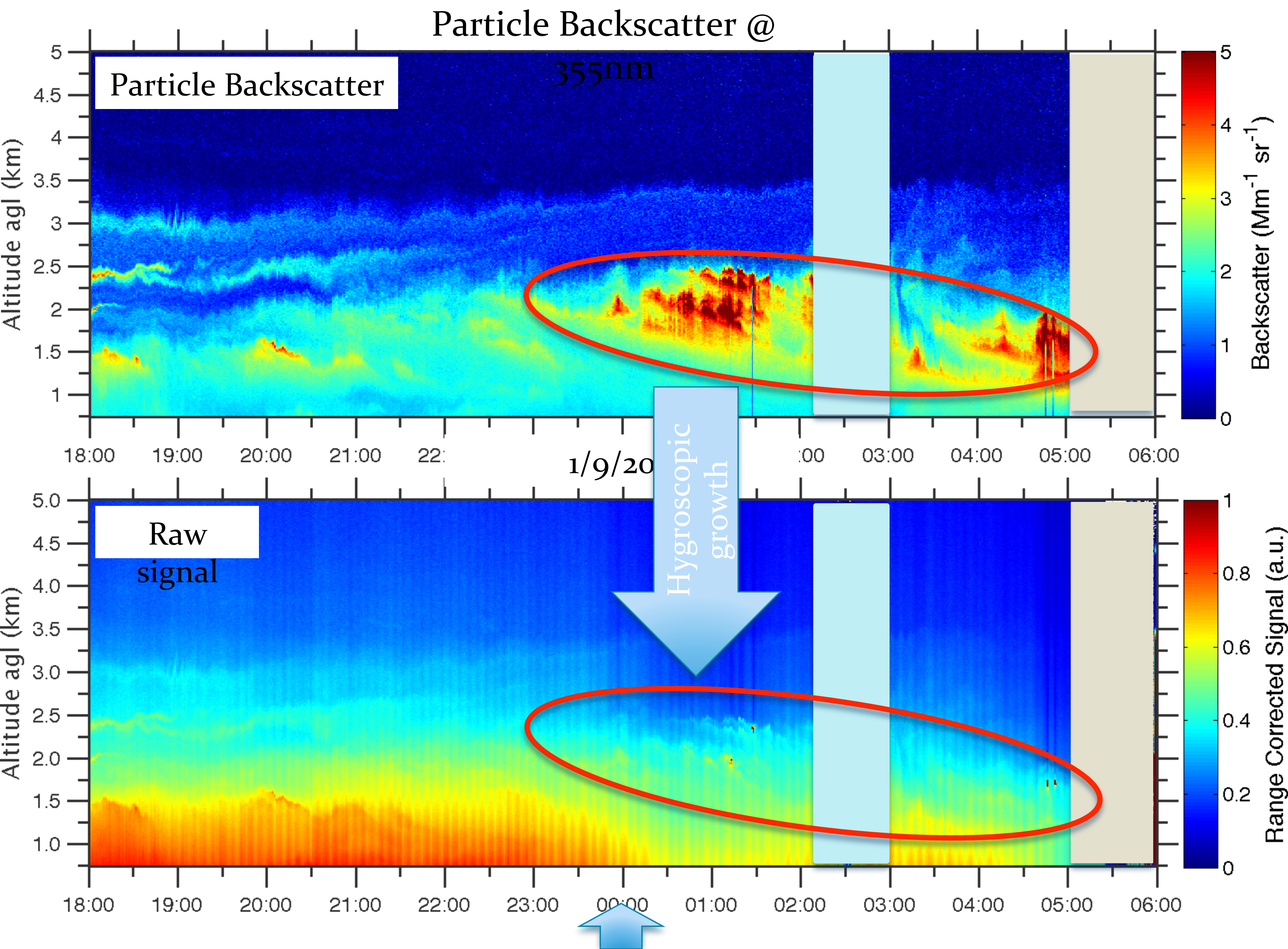


Example of Lidar Measurements

- Particle backscatter coefficient @ 355nm



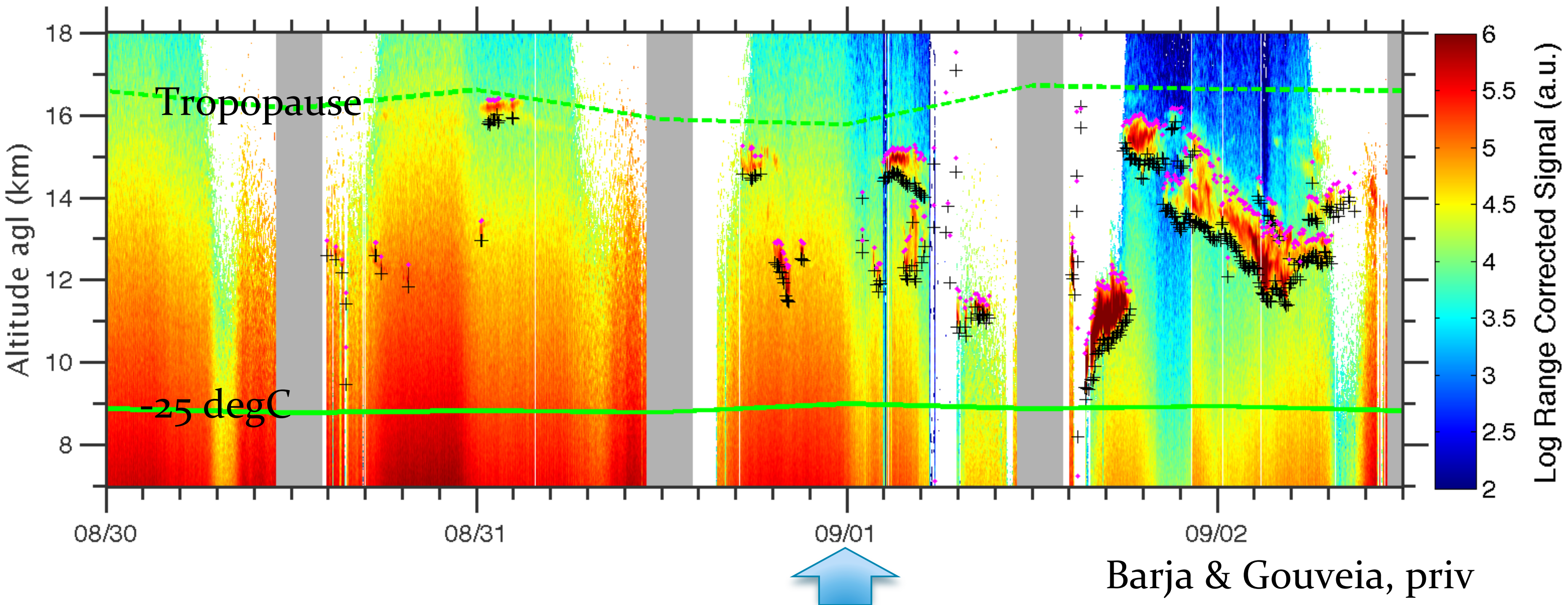
Barbosa et al., AMTD 2014



Particle Backscatter @ 355nm
Particle Backscatter
Altitude agl (km)
Backscatter (Mm-1 sr-1)
1/9/20
Hygroscopic growth
Raw signal
Range Corrected Signal (a.u.)
18:00
19:00
20:00
21:00
22:00
23:00
00:00
01:00
02:00
03:00
04:00
05:00
06:00

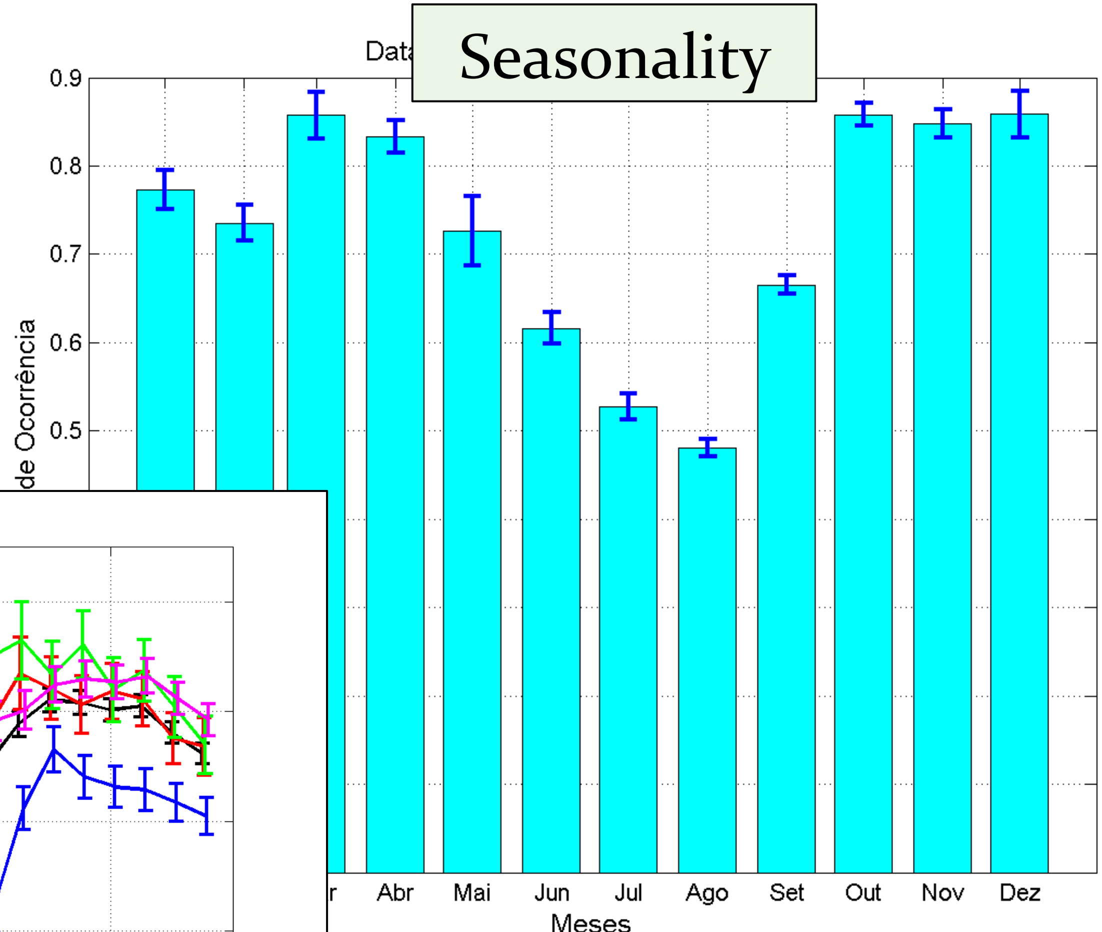
Cirrus Clouds

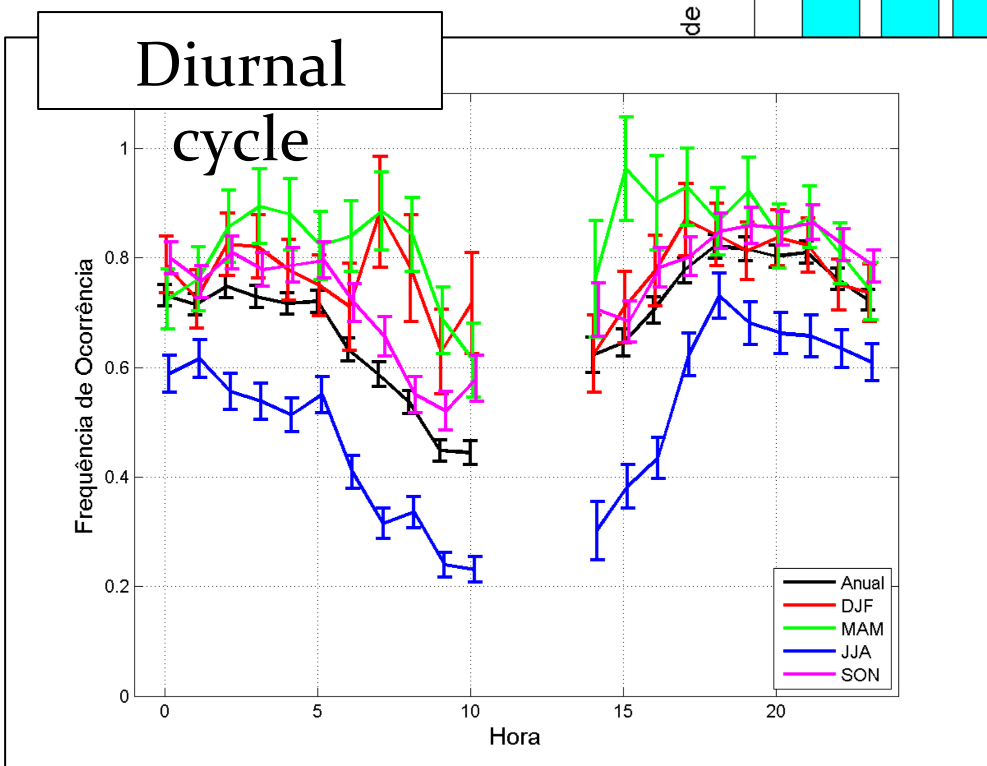
- Cirrus found from 8 to 19.6km
  - Base 12.5±2.4 km
  - Top 14.2±2.2 km



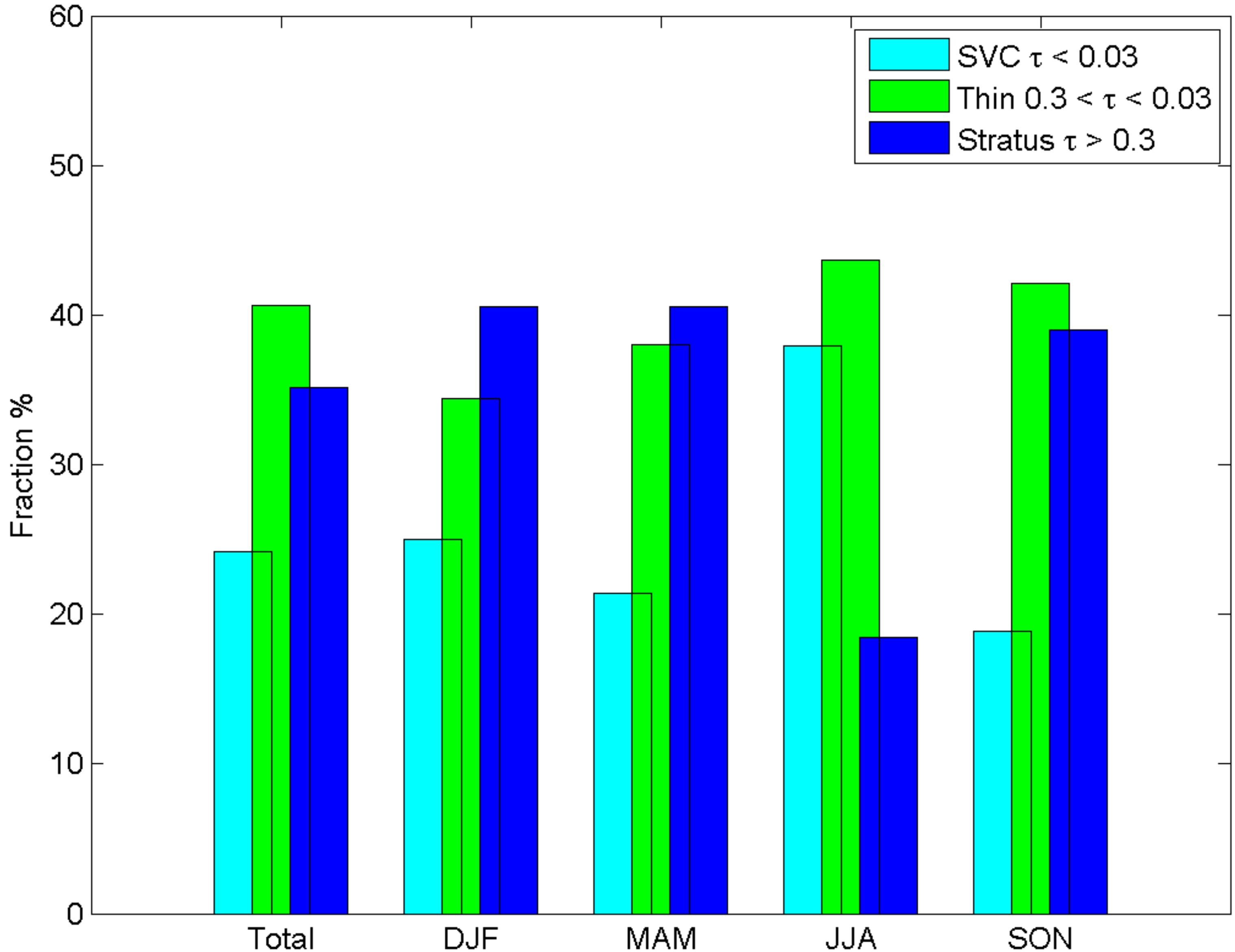
Barja & Gouveia, priv

- Cirrus cloud cover at Manaus
  - 83% MAM
  - 52% JJA



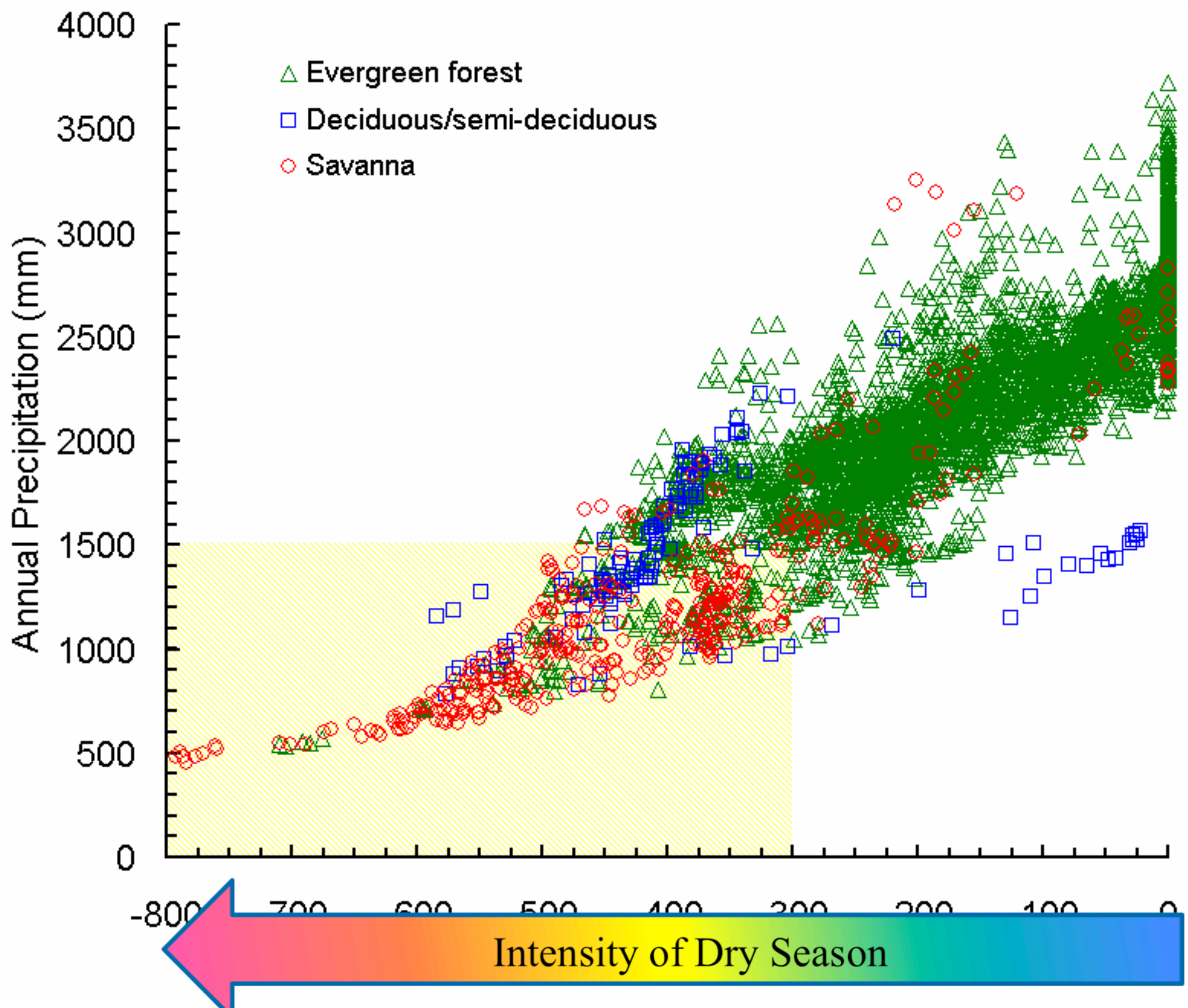


D. Gouveia, Msc dissertation, USP



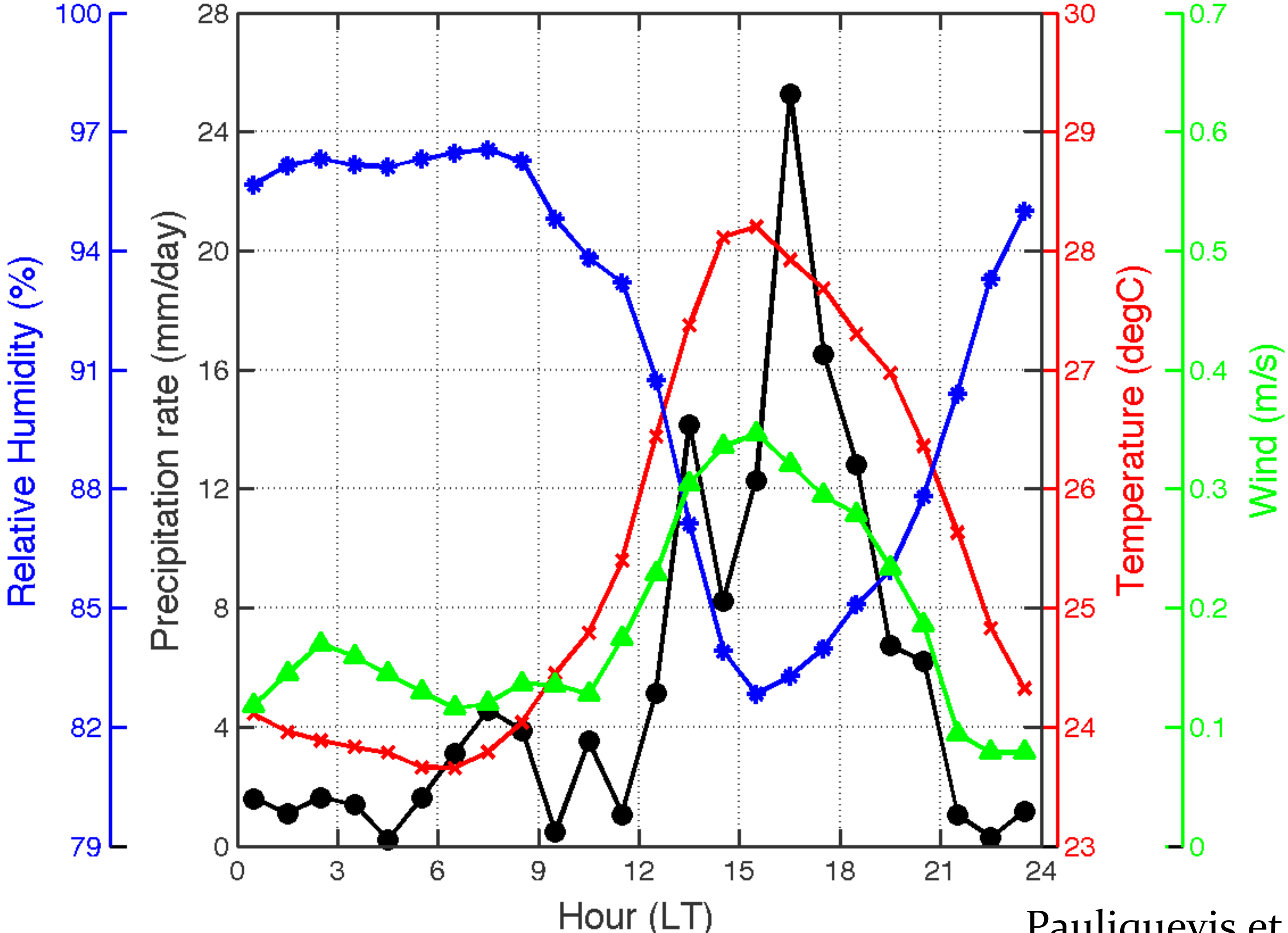
Frequency 78 % 83 % 52 % 77 %

A Rainfall Biogeography of Amazonia



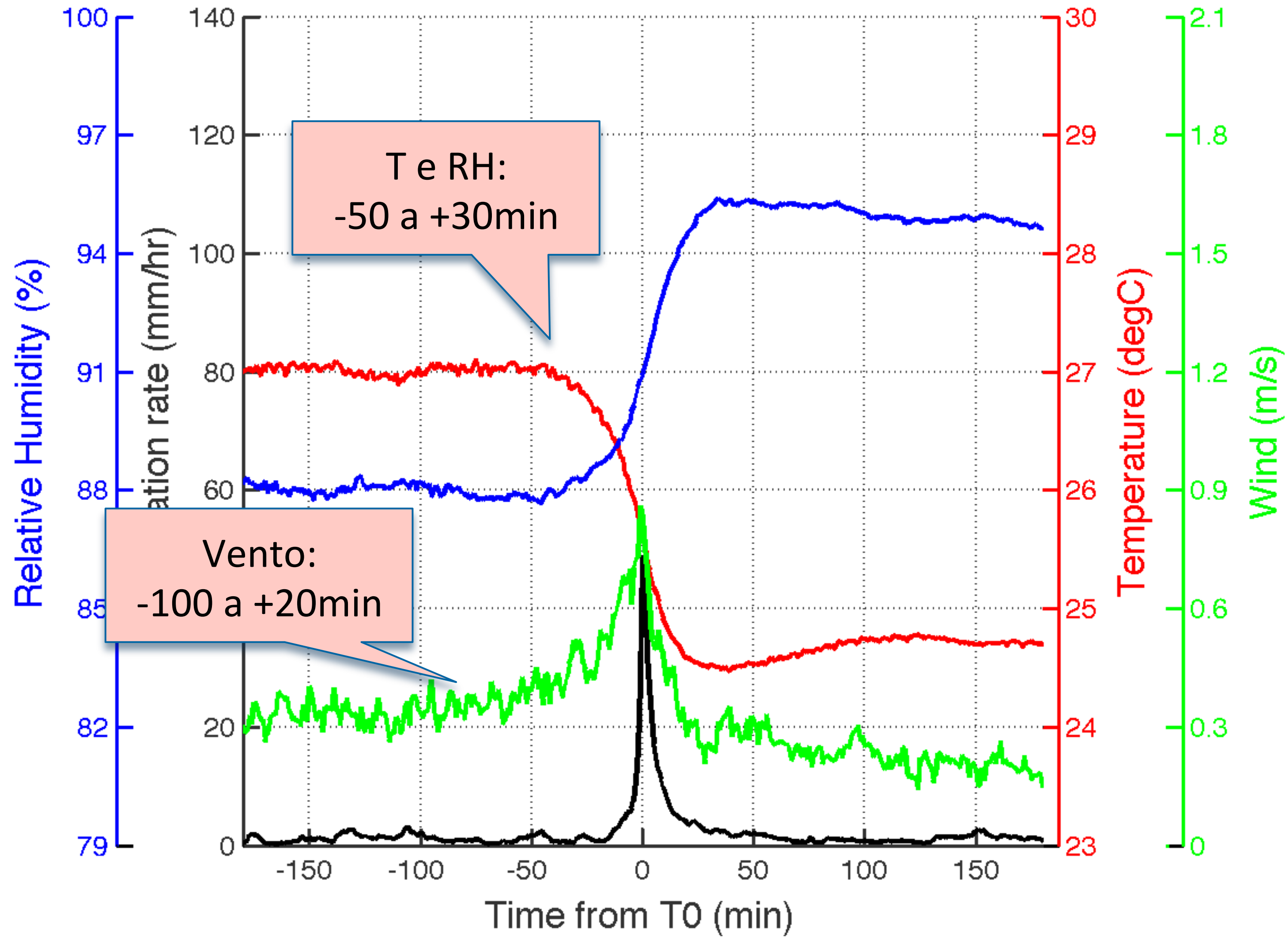
Source: Malhi *et al.*, **Exploring the likelihood and mechanism of a climate-change induced dieback of the Amazon rainforest,** *Proceedings of the National Academy of Sciences*, 2010

Diurnal Cycle @ Embrapa

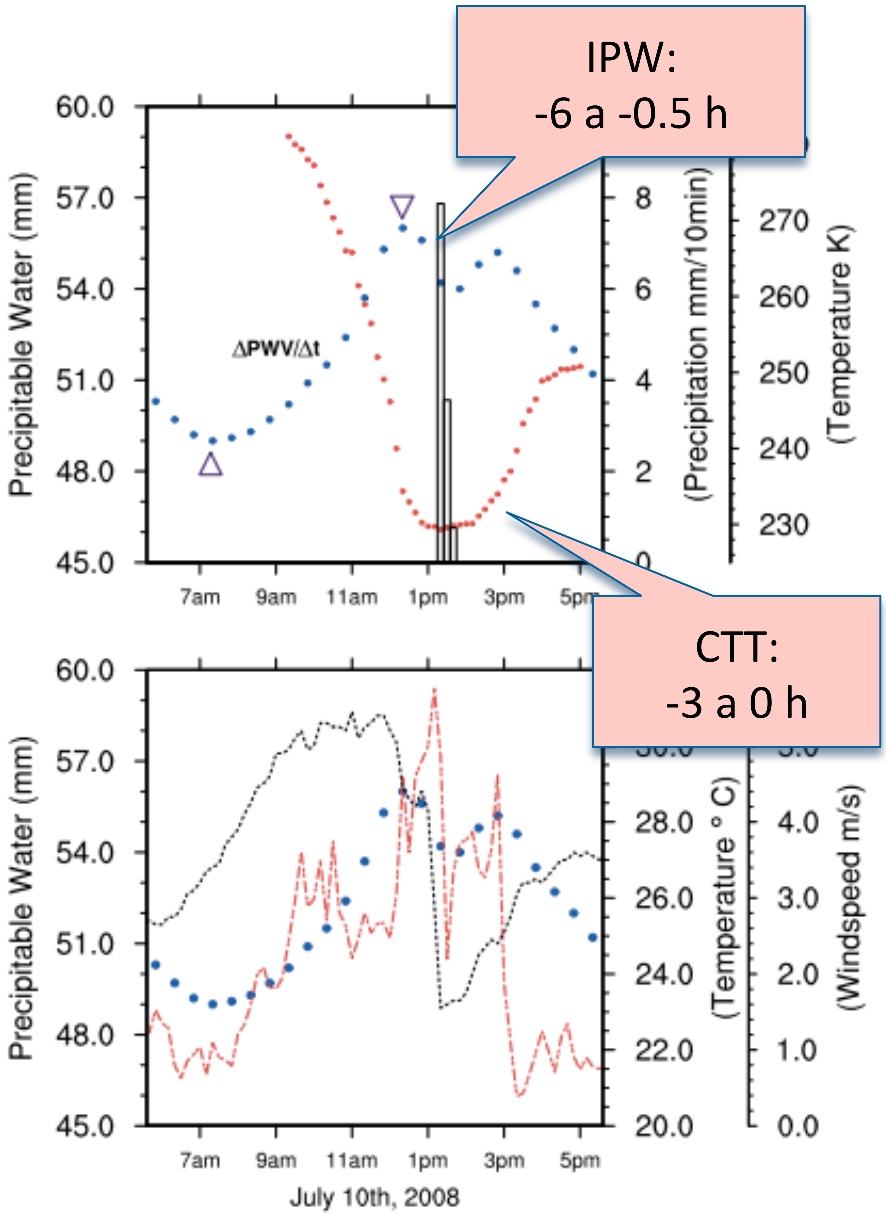


Pauliquevis et al., in

@ Embrapa, T0= time of max precip



GNSS Dense Network



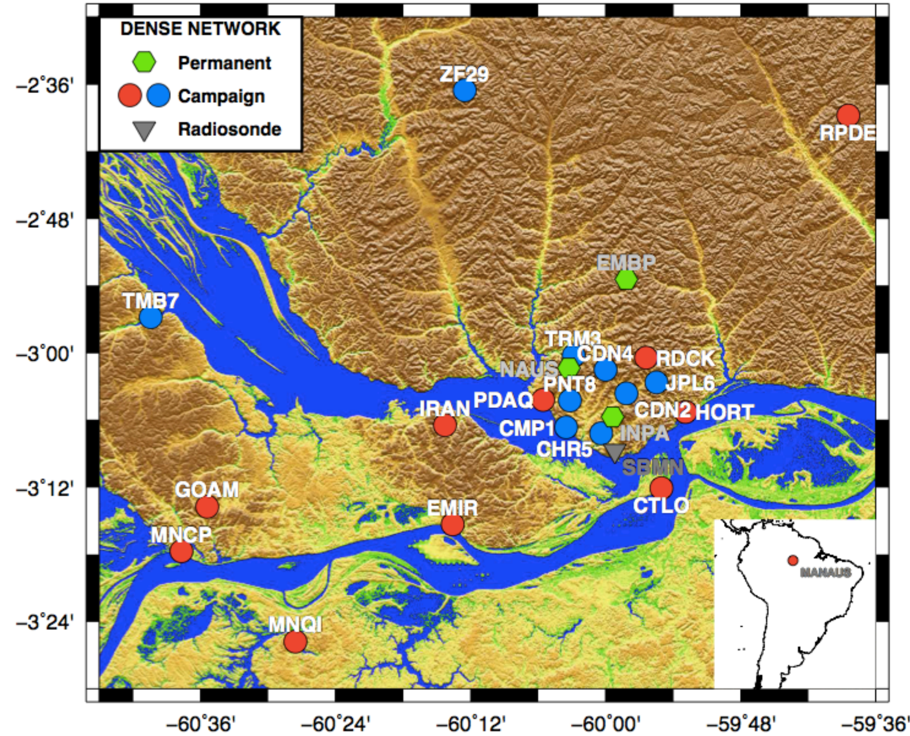


Figure 3. A typical afternoon deep convective event over INPA GNSS/meteorological station. The upper plot contains PWV (blue dots) *versus* average cloud top temperature (red) and precipitation rate (bars). The 'ramp-up' time calculated for the average $\Delta PWV/\Delta t$ (between triangles) represents the timescale of column convergence (see Equation (2) and text for discussion). The bottom graph plots wind speed (red), temperature (black) and PWV(blue) for the deep convective event.

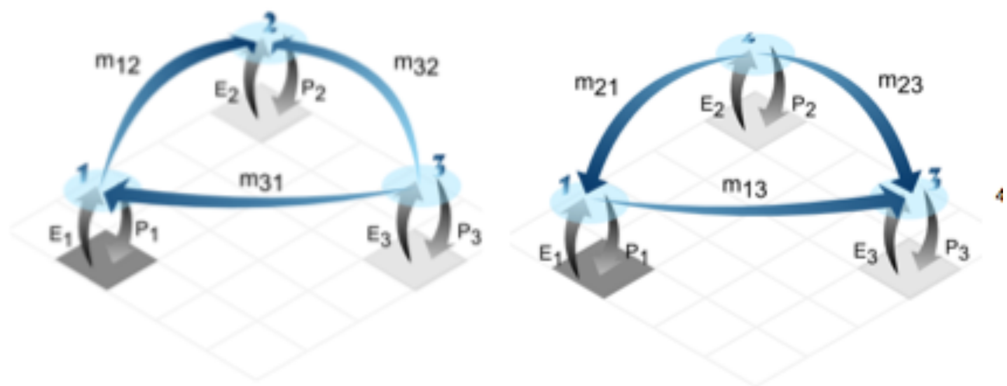
- Adams et al, Atmos. Sci. Let. 2011
- Adams et al, BAMS 2014 (accepted)

Arraut et al, J. Clim 2012

Amazonia is critical for water vapor transport over South America

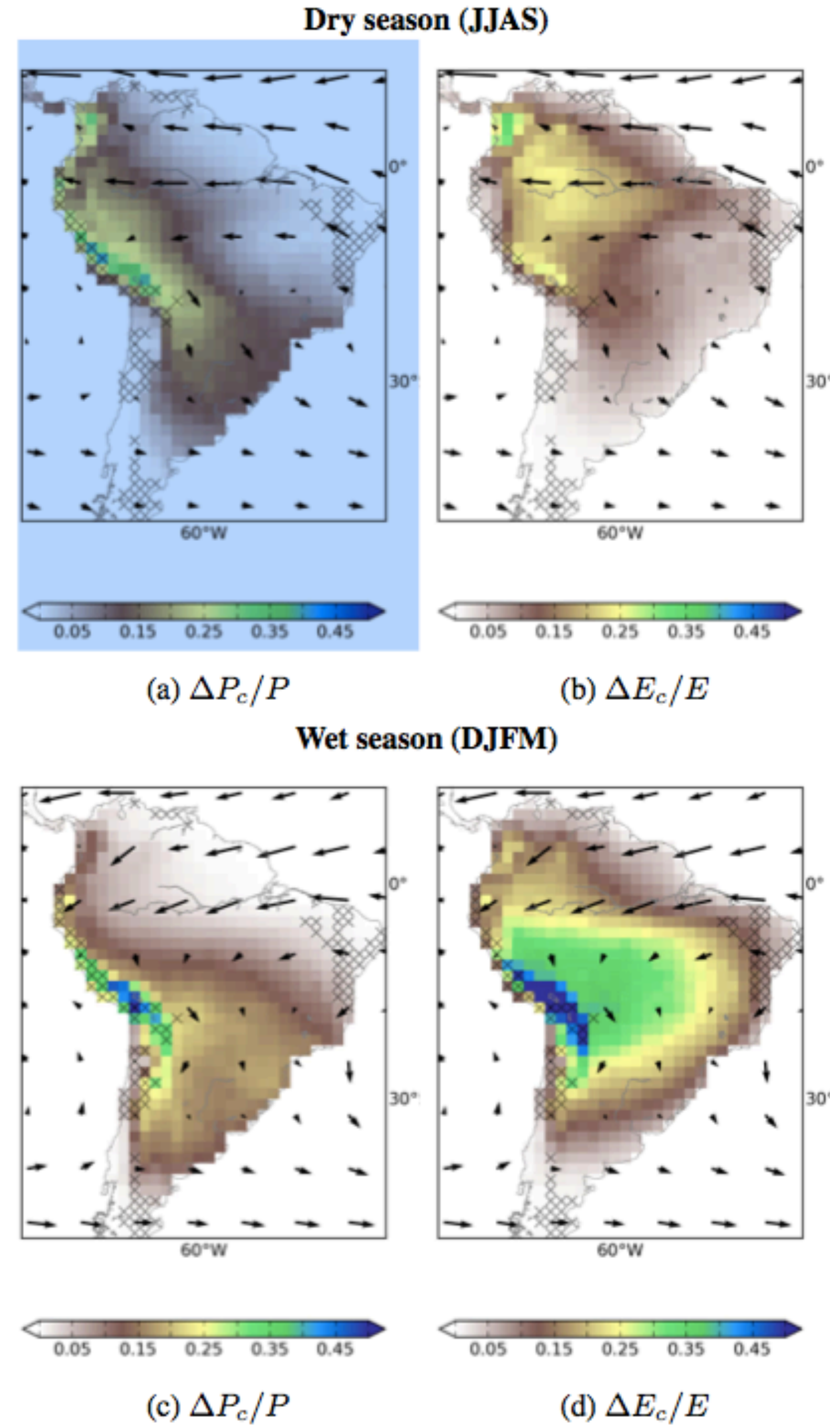
What processes controls these fluxes?

- Zemp et al, ACP 2014

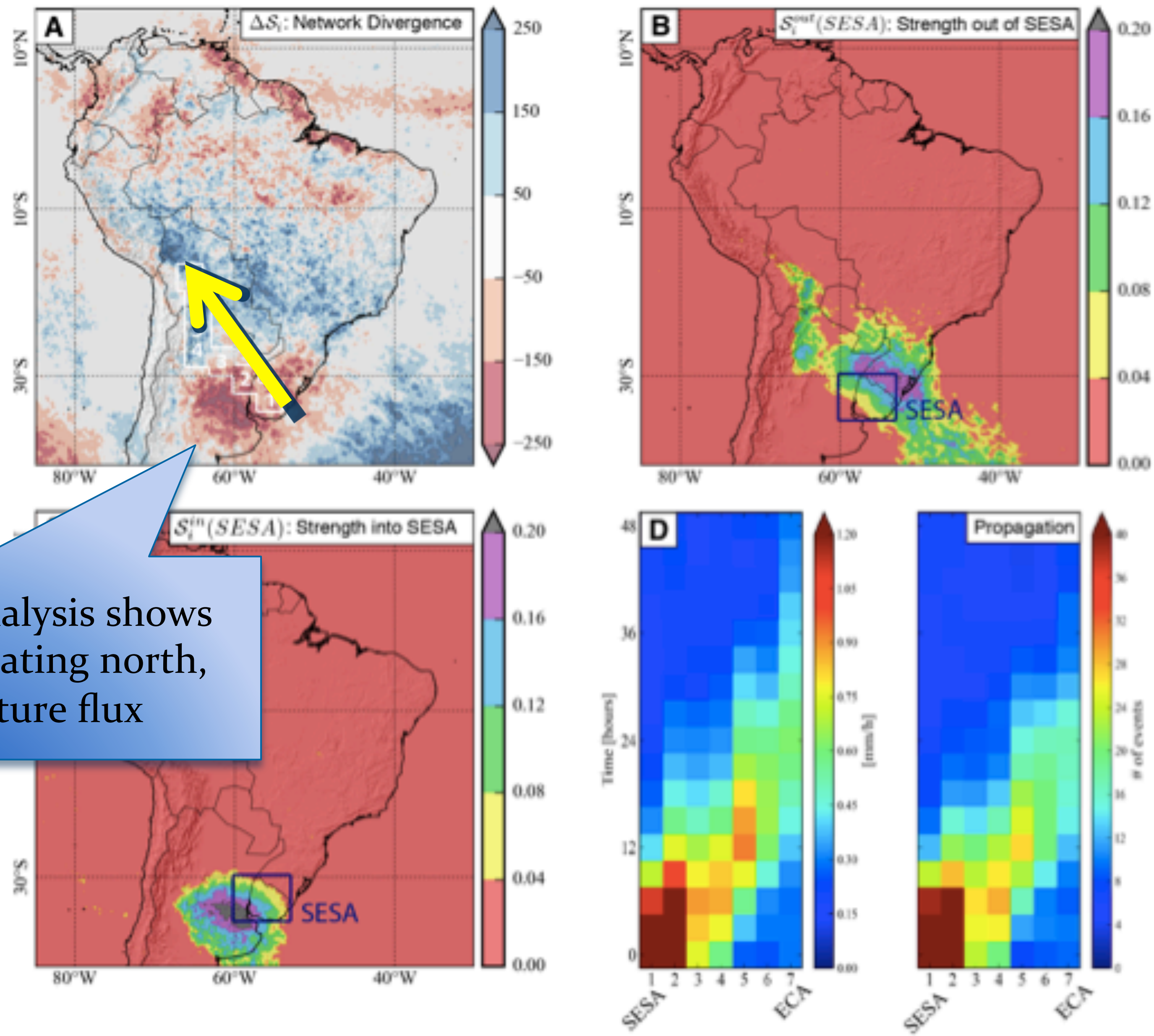


(a) Pattern 1 (b) Pattern 2

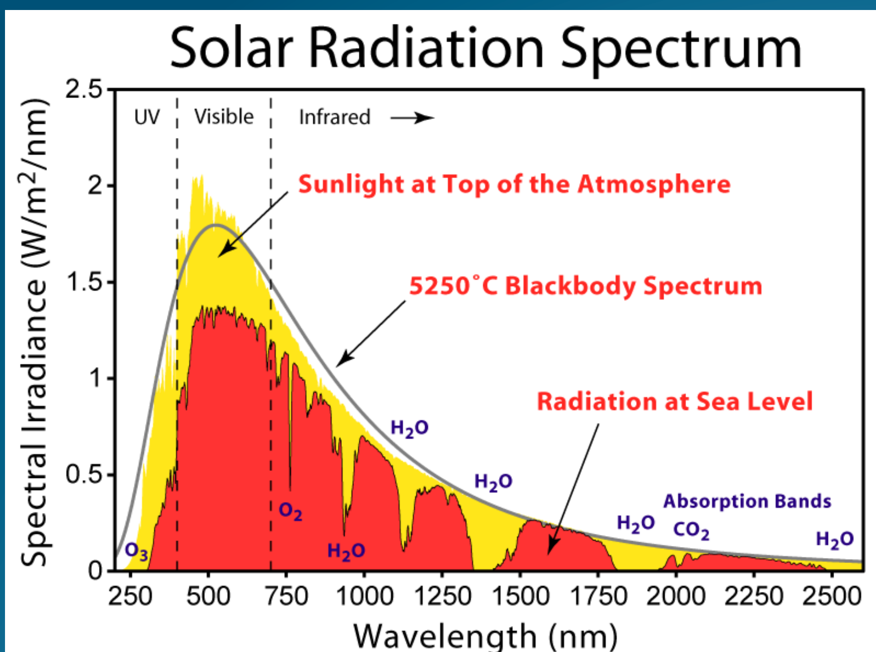
Fig. 5: Fraction of total precipitation originating from cascading moisture recycling ($\Delta P_c/P$) (a,c) and fraction of total evapotranspiration that is involved in cascading moisture recycling ($\Delta E_c/E$) (b,d). While high values of $\Delta P_c/P$ indicate regions which are dependent of cascading moisture recycling for local rainfall, high values of $\Delta E_c/E$ indicate regions which contribute to cascading moisture recycling.



- Boers et al, Nature Comm. 2014



Complex network analysis shows precipitation propagating north, contrary to moisture flux



Thanks!

hbarbosa@if.usp.br

www.fap.if.usp.br/~hbarbosa