III Conferencia Regional sobre Mudanças Climáticas: América do Sul, São Paulo, 4-8 Novembro de 2007

O Papel dos Aerossóis Atmosféricos no Sistema Climático Regional e Global

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Outline of the presentation

Concept of radiative forcing and aerosol particles role

•Direct effects of aerosol particles in climate

•Indirect effects of aerosols: Changes in cloud microphysics and lifetime

•Biomass burning aerosols and effects on regional and global climate

•Effects of aerosol particles on photosynthesis and carbon uptake in forests

How do aerosols influence climate?

I) Direct Effects (i.e., not involving cloud)

a) Backscattering of sunlight into space

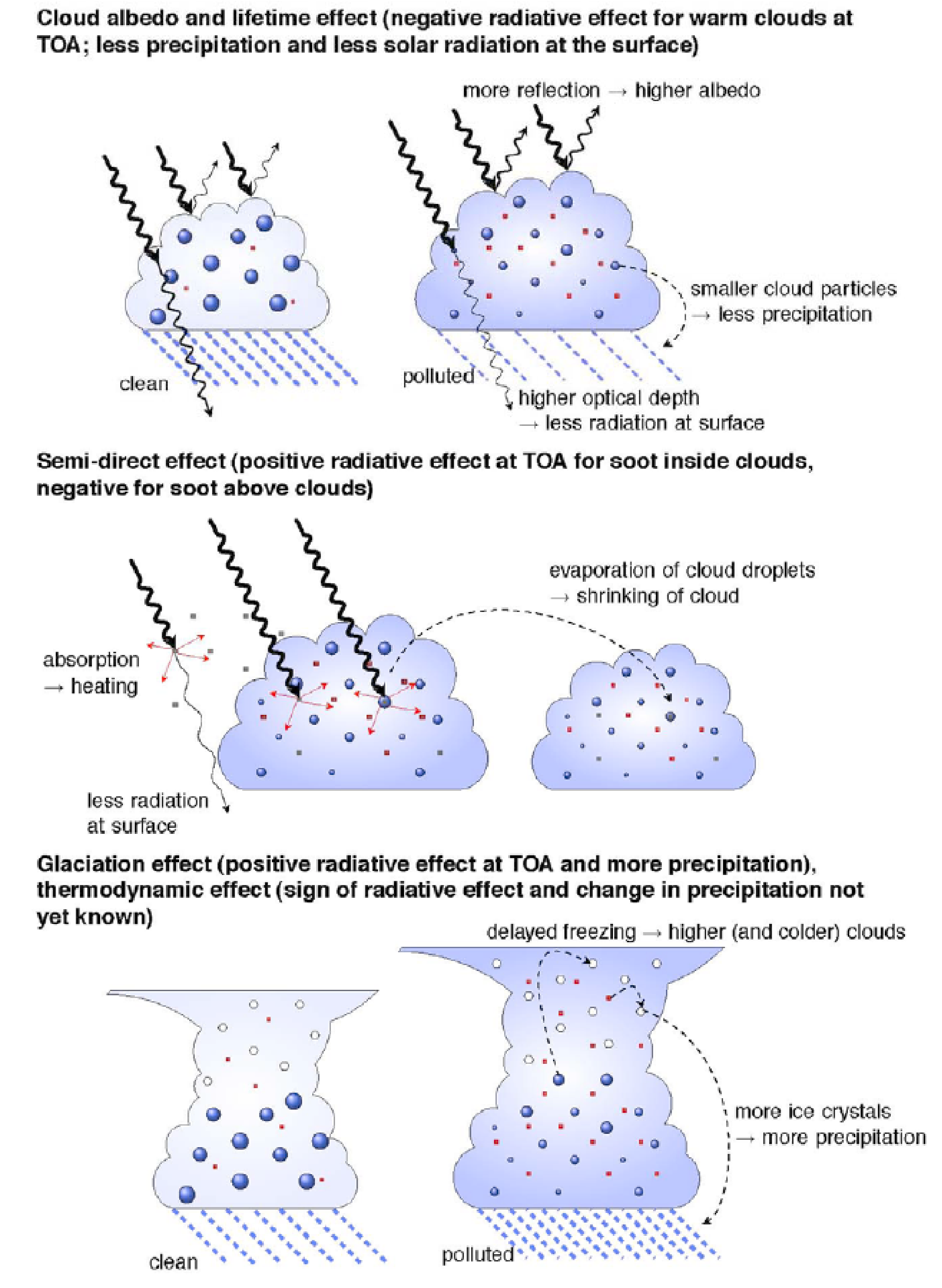
➔ increased albedo ➔ cooling

II) **Aerosol indirect effects**

- Each cloud droplet needs a "seed" or nucleus to be able to form: "Cloud Condensation Nucleus" (CCN)
- For a given cloud, the more CCN in the air, the more droplets
- Since the water supply in a cloud is limited: more droplets means smaller droplets

IIc) Third Indirect Effect: Aerosol Effect on Convection Dynamics

If there is enough latent heat available (tropics), the air will rise to freezing level, and rain-production mechanisms involving ice will replace “warm” processes.



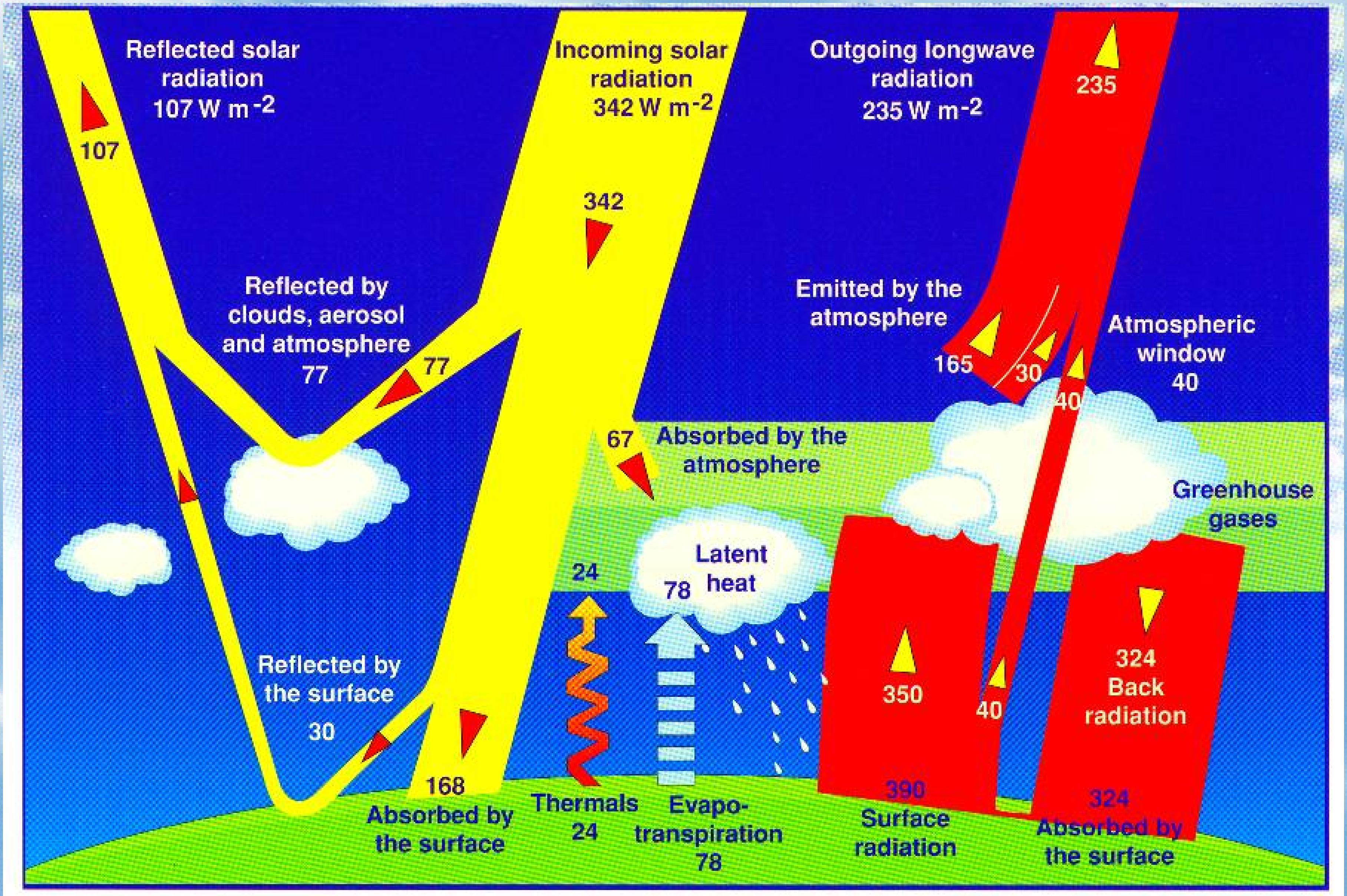
Aerosol-cloud interactions

Only the change of cloud albedo induced by aerosols in the context of liquid water clouds, is considered to be radiative forcing

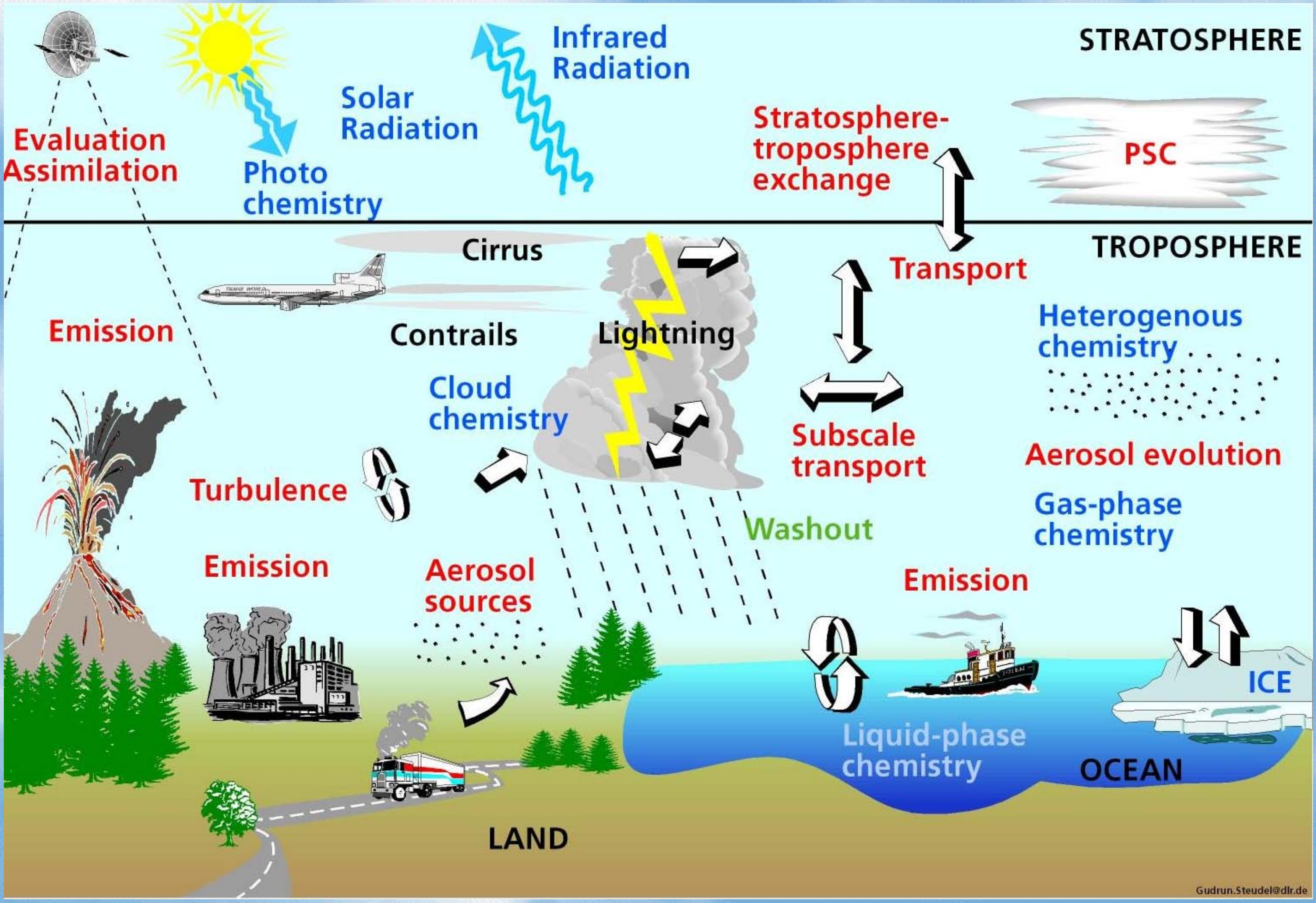
Other processes are not considered as radiative forcings. However, they are included in climate models that explicitly consider the relevant processes

Aerosol effects on ice clouds are poorly understood, and are not quantified.

Terrestrial radiation balance



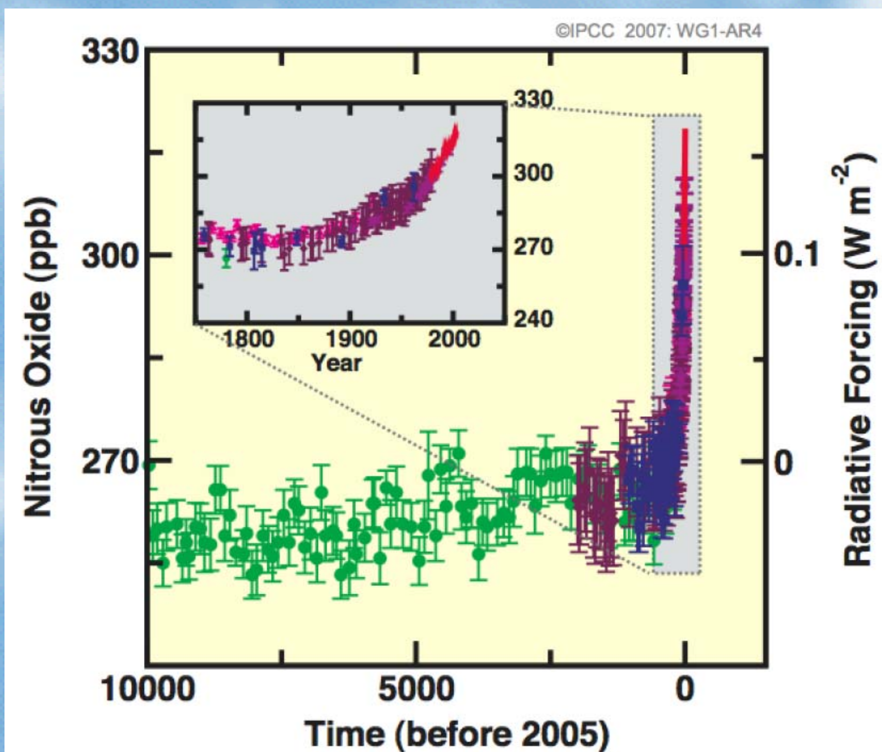
Physical-Chemical process that regulates aerosol and trace gases concentrations in the atmosphere

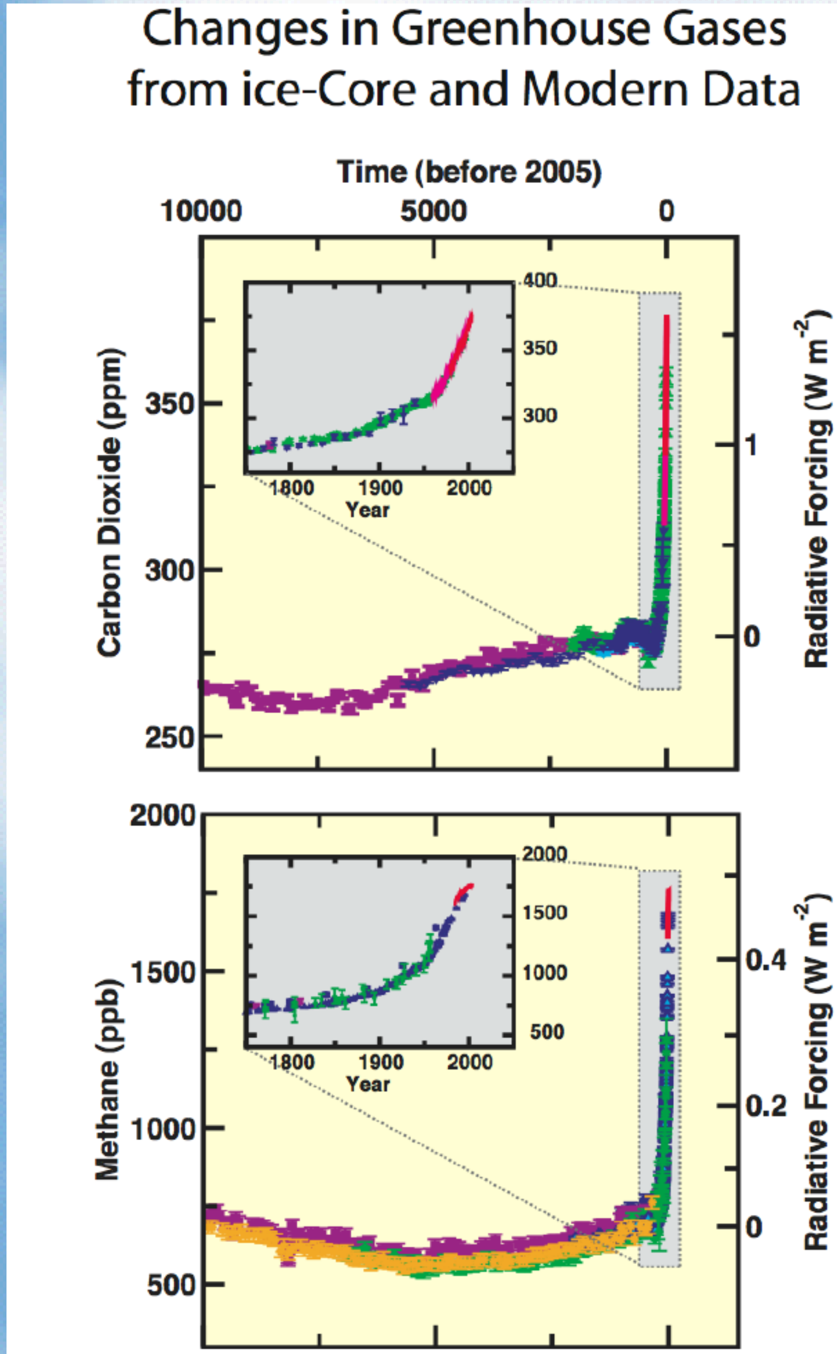


Atmospheric concentrations of CO_2, CH_4 and N_2O in the last 10.000 years.

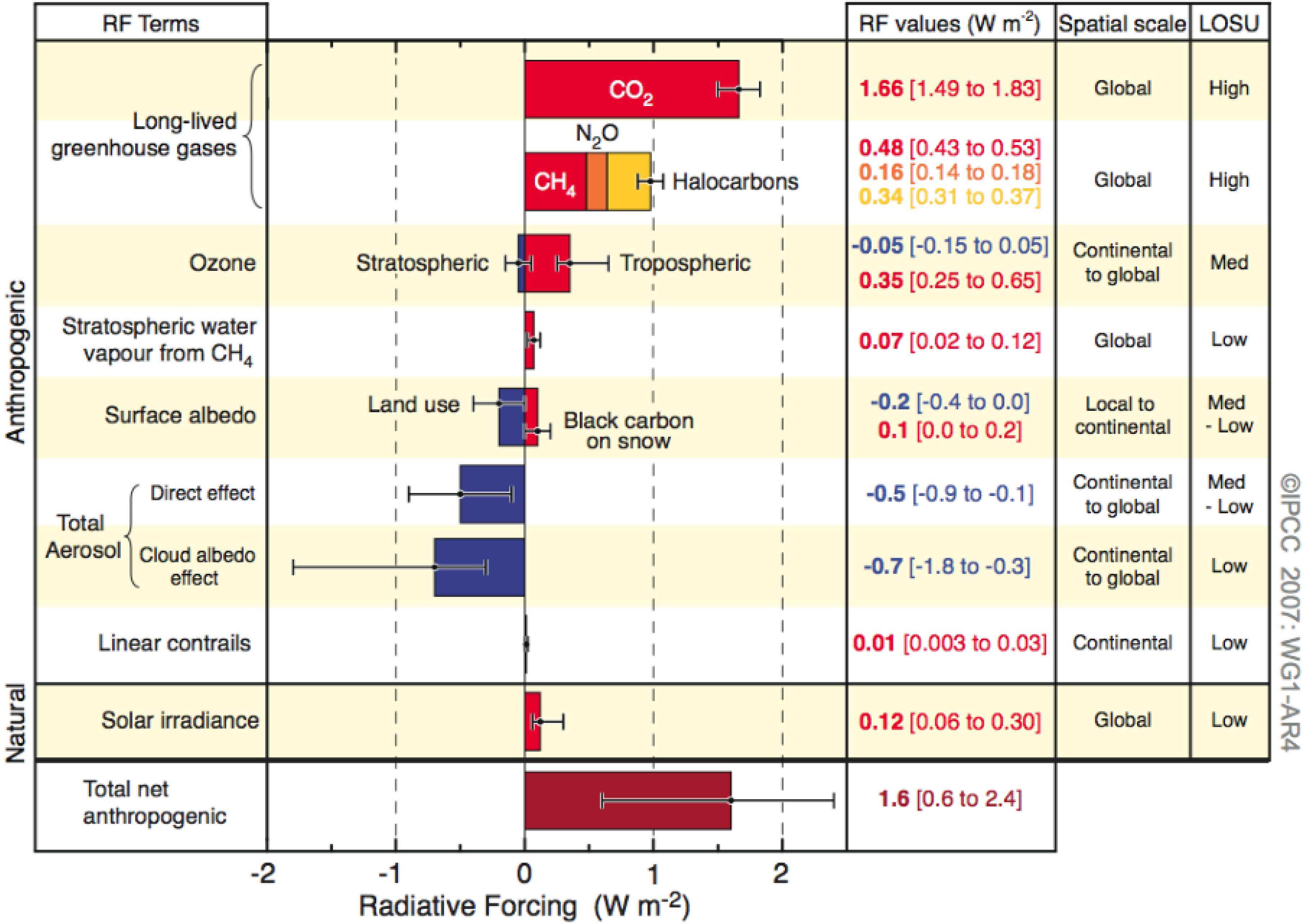
Radiative forcings are on the right scale.

IPCC AR4, 2007

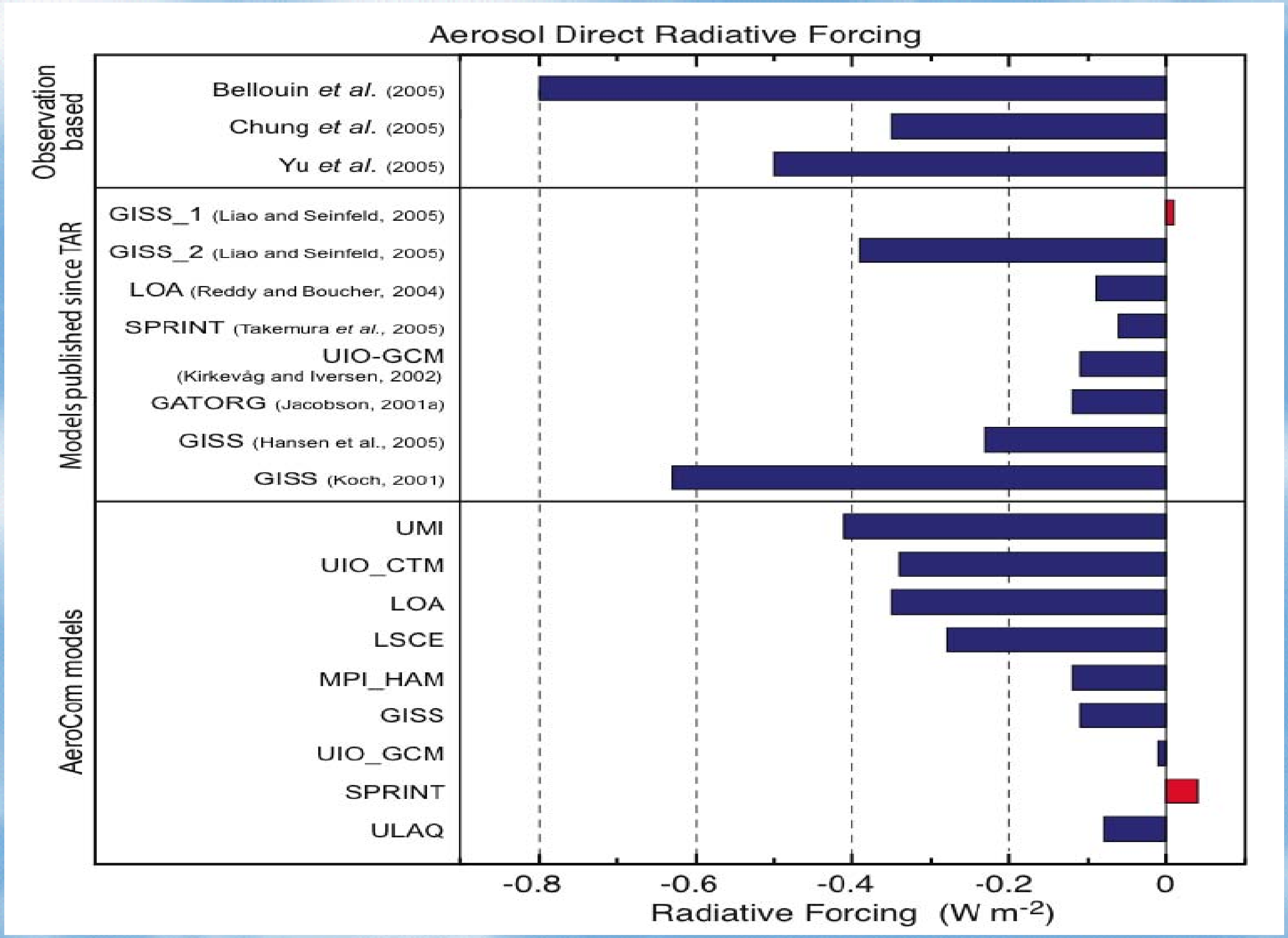




Radiative forcings of the global climate system IPCC 2007

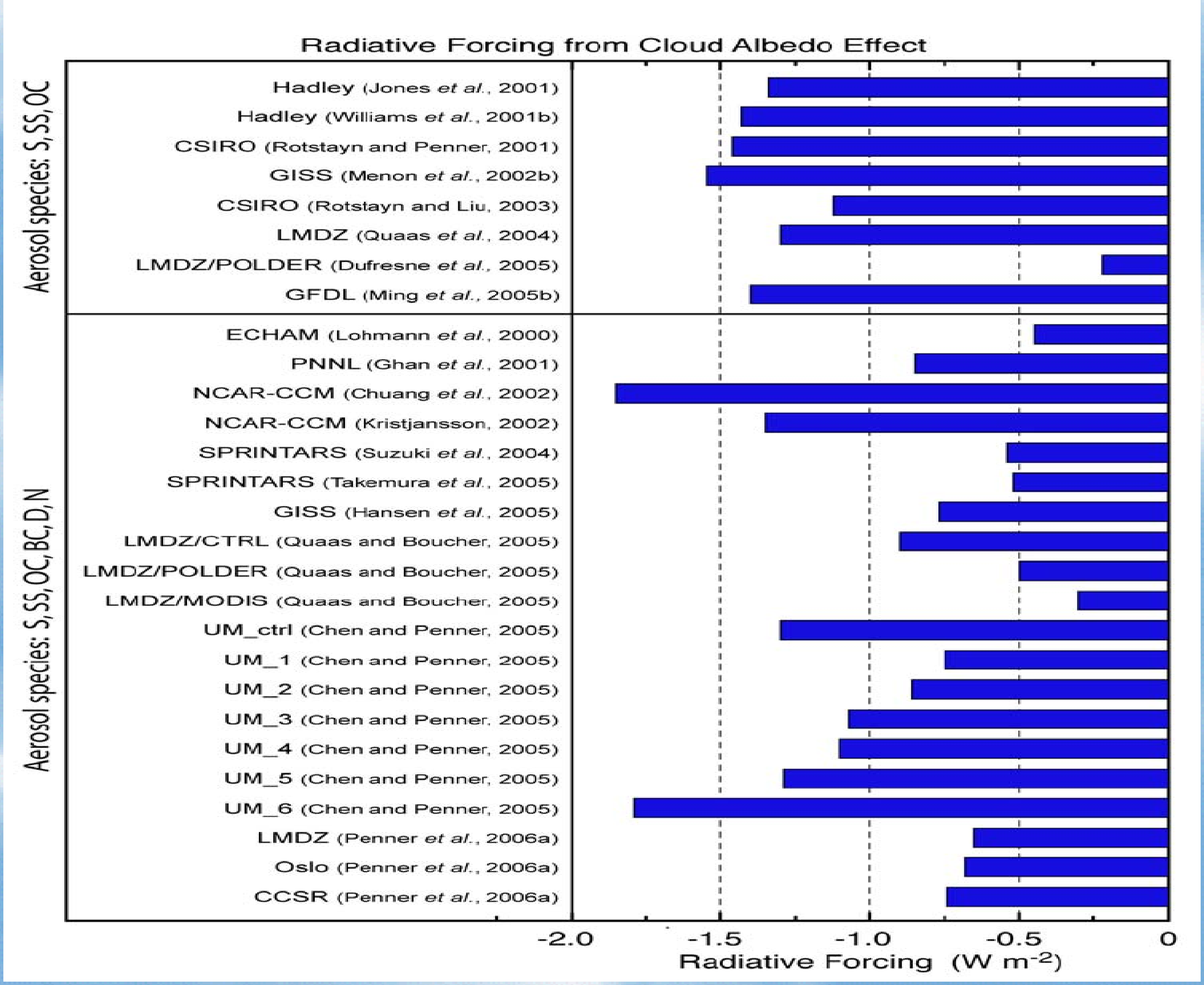


Estimates of the aerosol direct radiative forcing by different climate models



Best estimate: -0.5 W/m^2 *Range:* -0.9 to -0.1 W/m^2

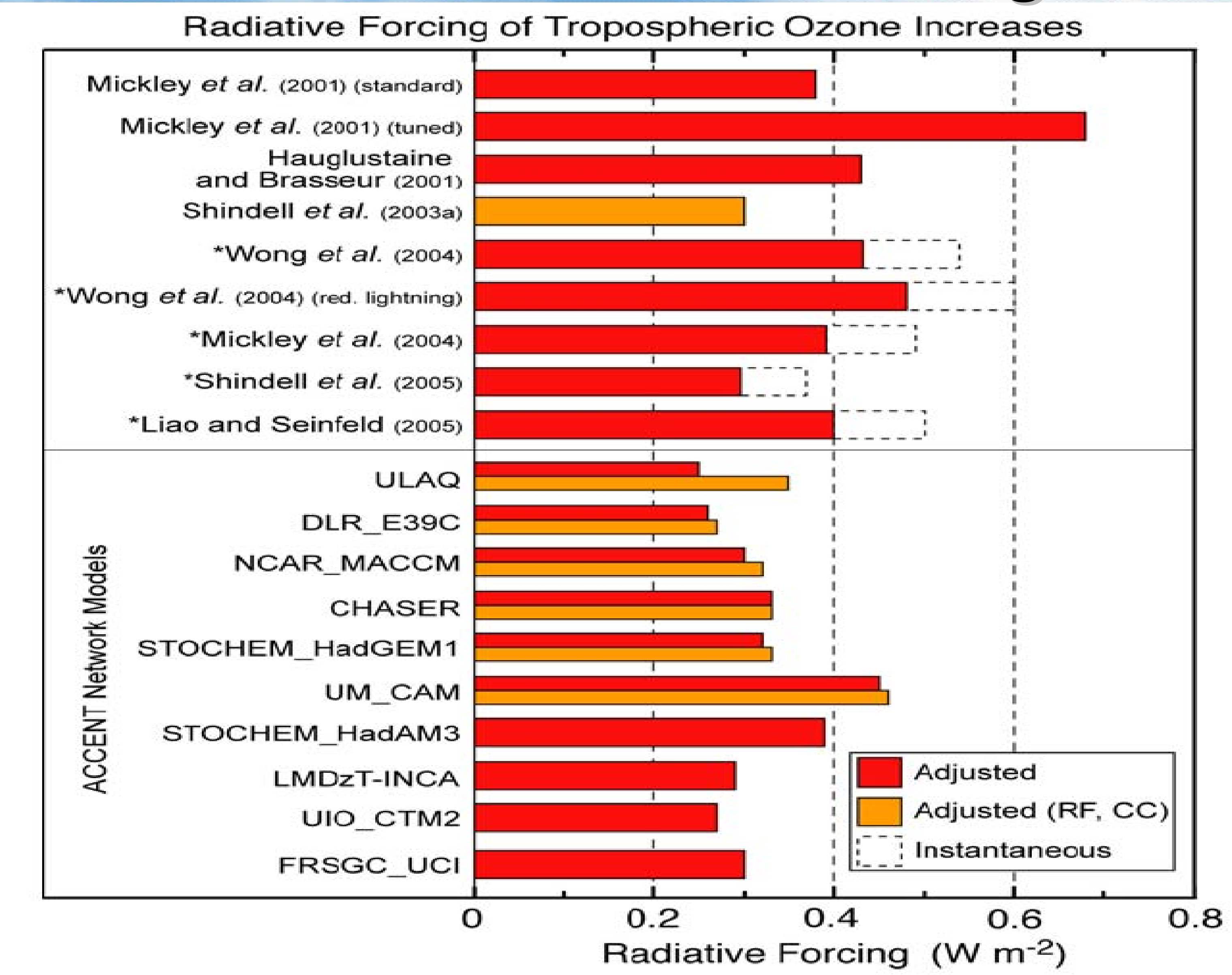
Estimates of the Cloud Albedo radiative forcing due to aerosols from different models



Best estimate:
-0.7 W/m²

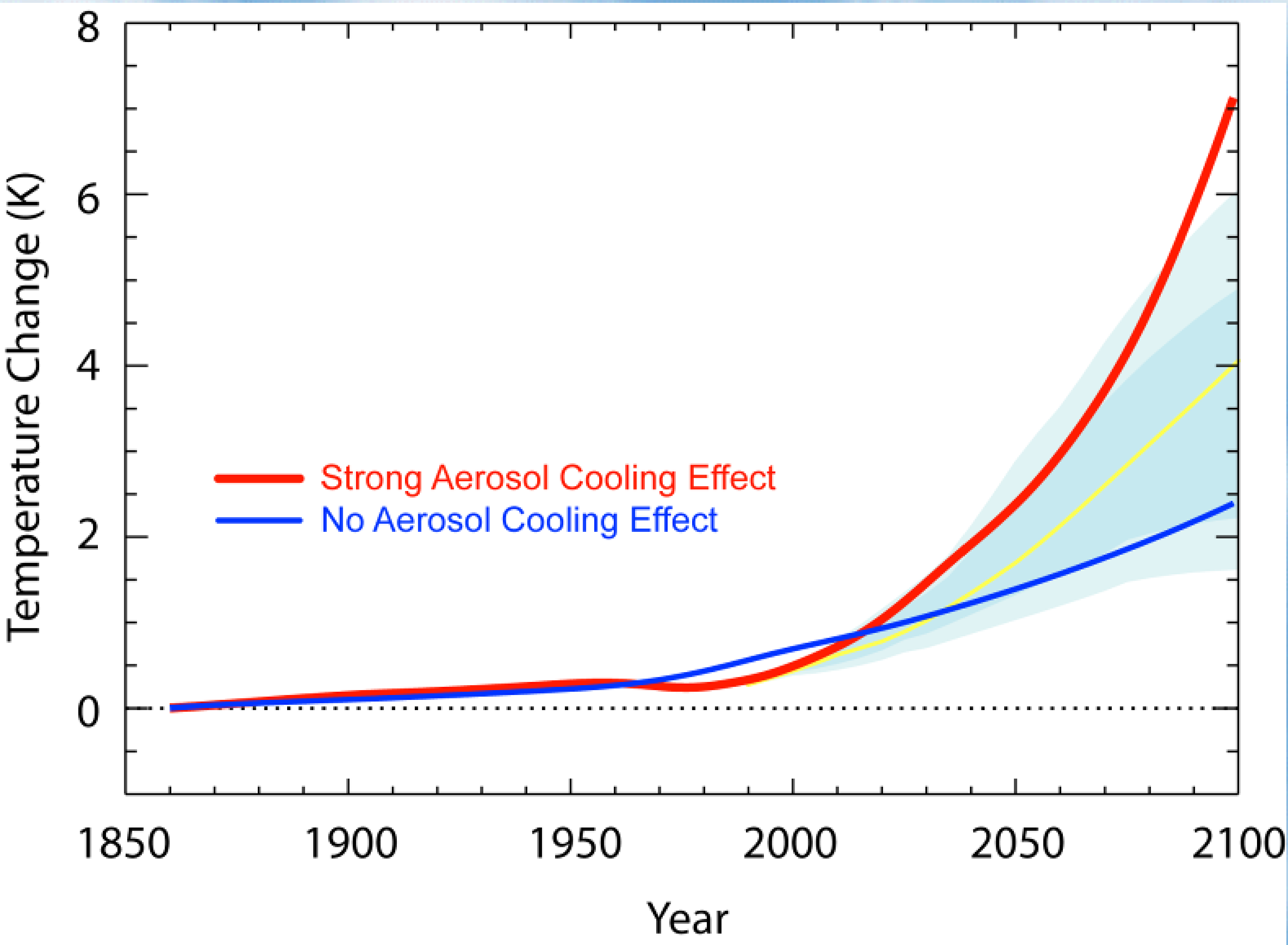
Range:
-1.8 to -0.3 W/m²

Ozone radiative forcing



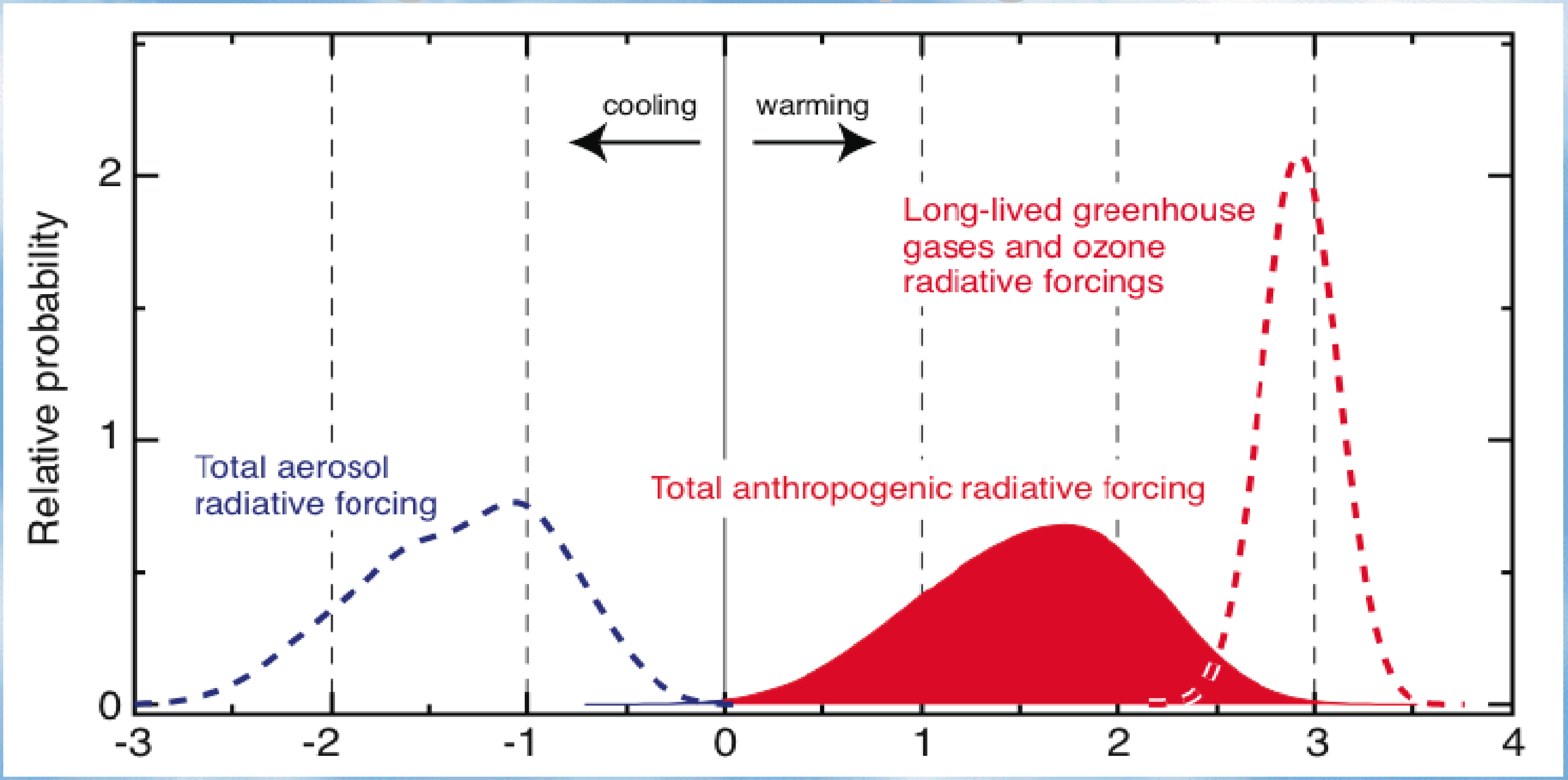
Best est.: **0.35 W/m²** *Range:* 0.25 to 0.65 W/m²

Temperature change simulated by a climate model for the period 1850–2100 with strong or weak aerosol effect



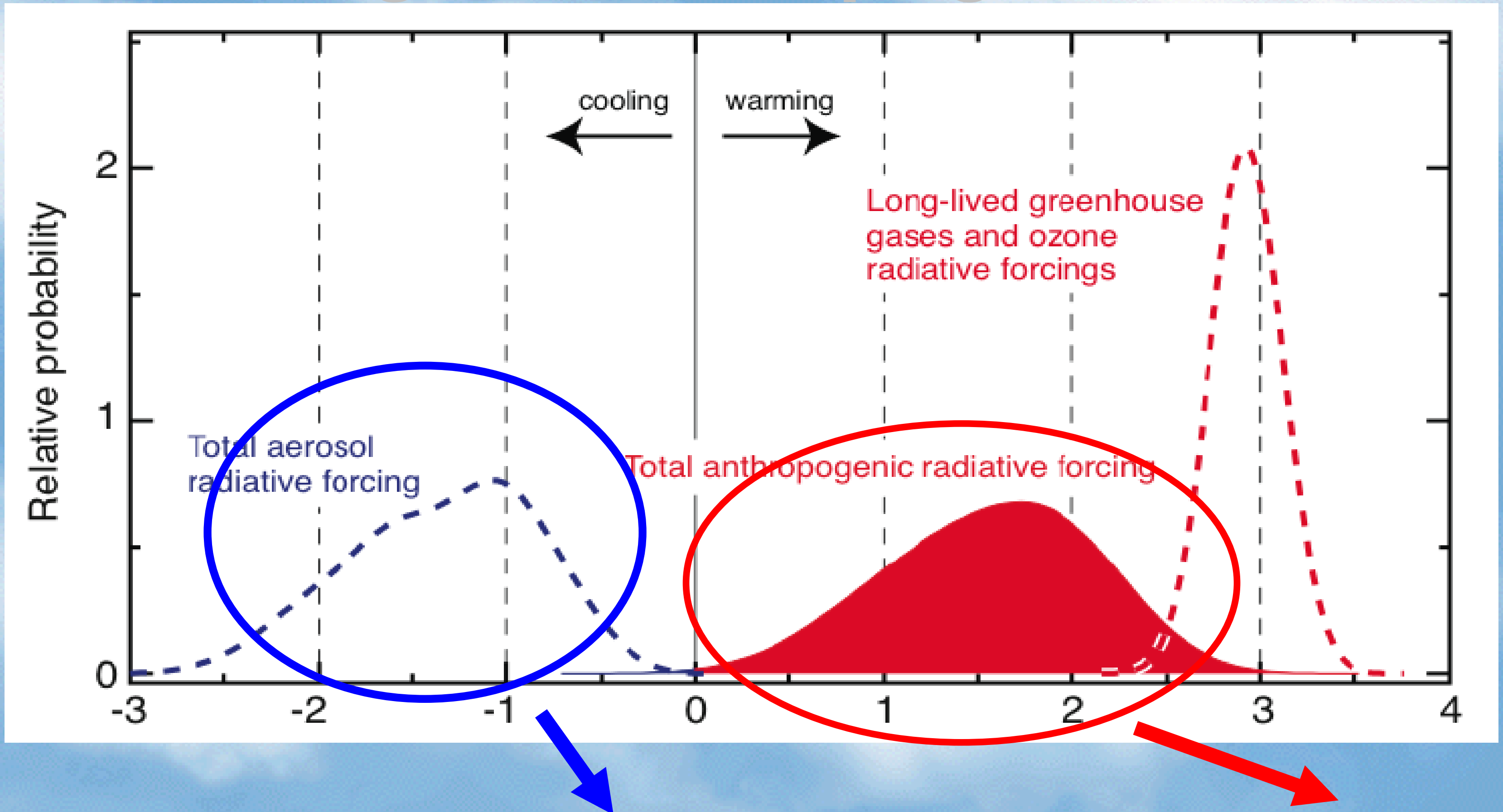
Andreae et al., Nature (2005)

Combining all anthropogenic effects



- ***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**

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.**
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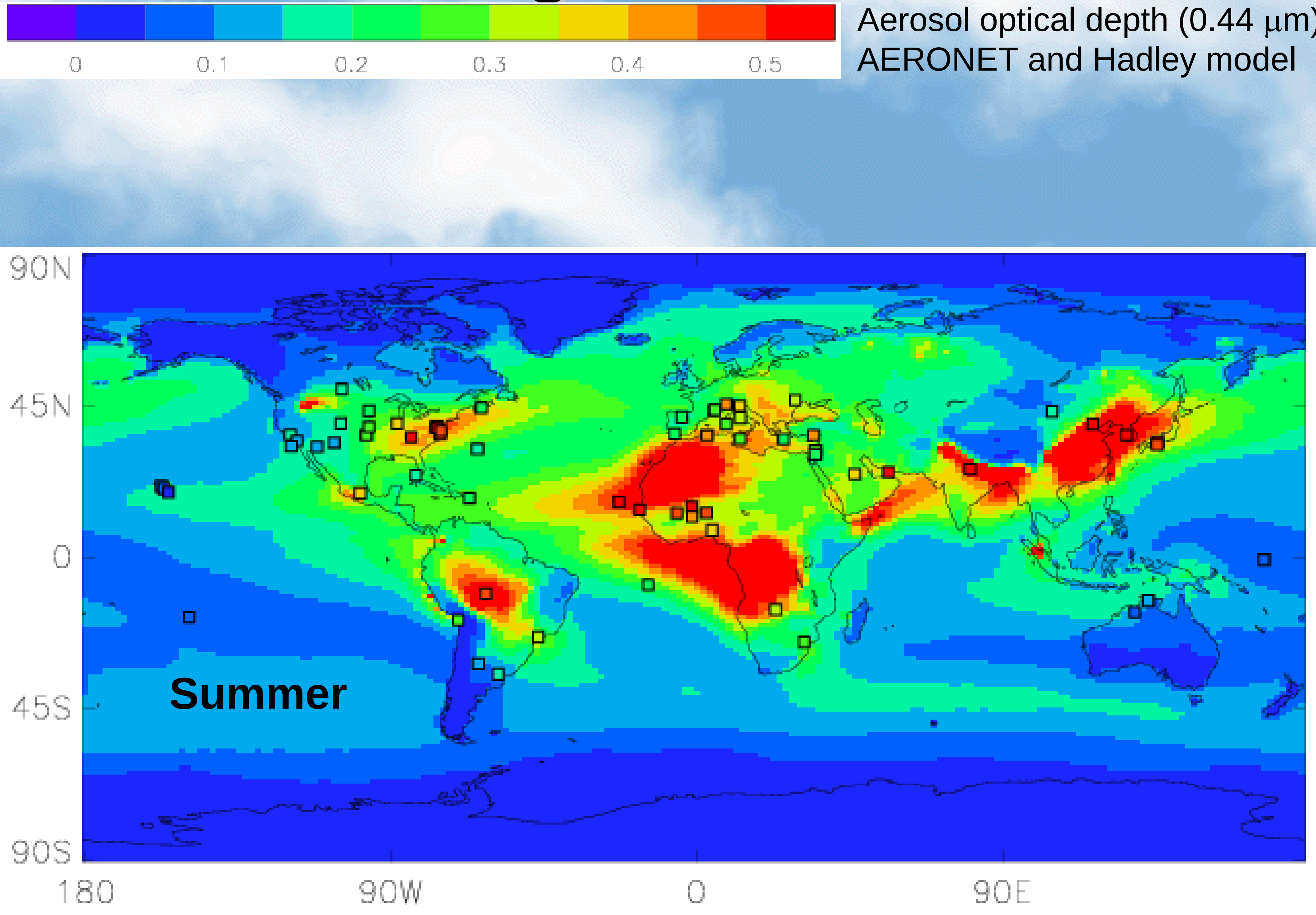
Aerosol global distribution

Aerosol optical depth (0.44 μm)
AERONET and Hadley model

Aerosol global distribution

Aerosol optical depth (0.44 μm)
AERONET and Hadley model



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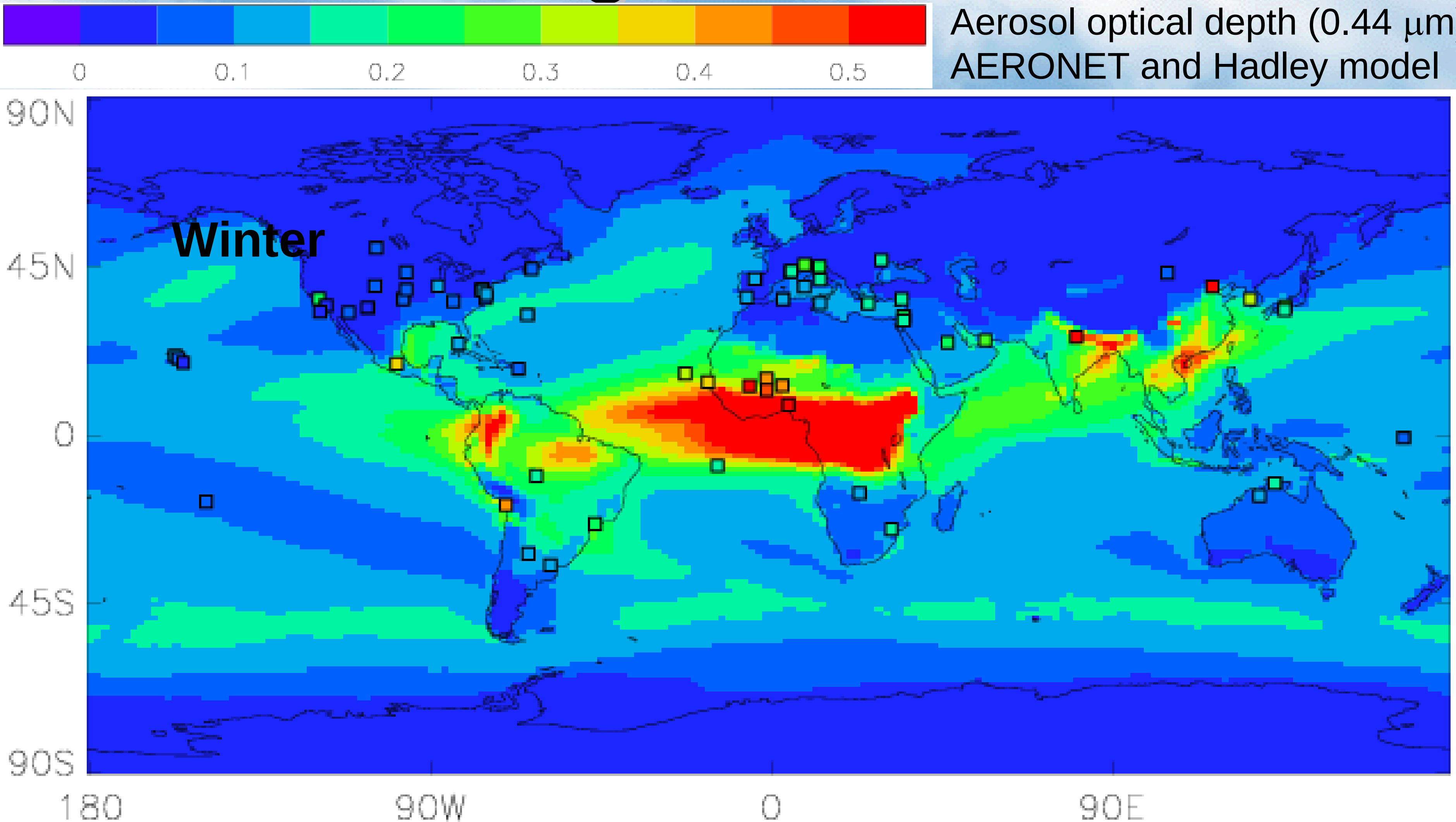
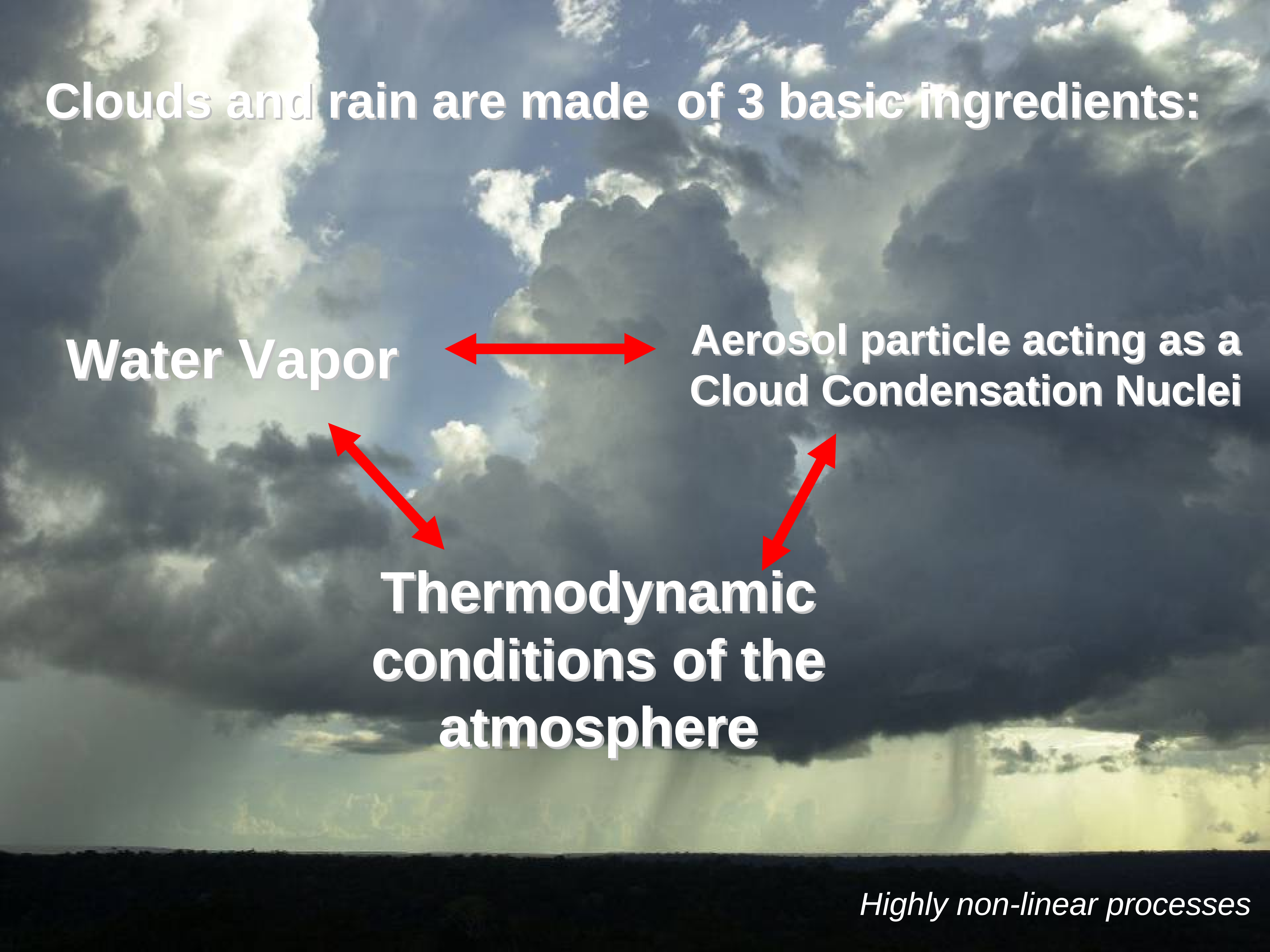




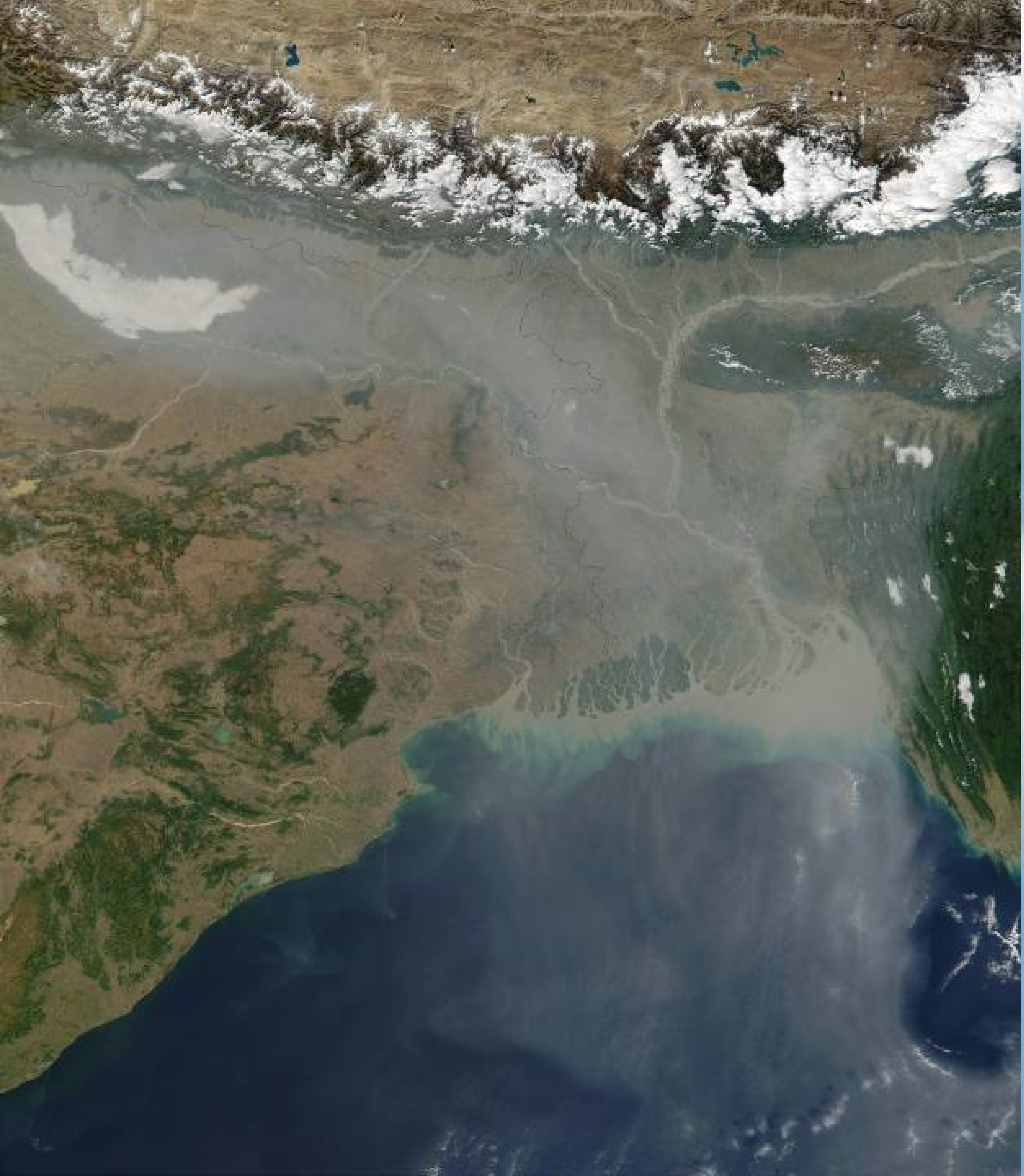
Clouds and rain are made of 3 basic ingredients:

Water Vapor

Aerosol particle acting as a Cloud Condensation Nuclei

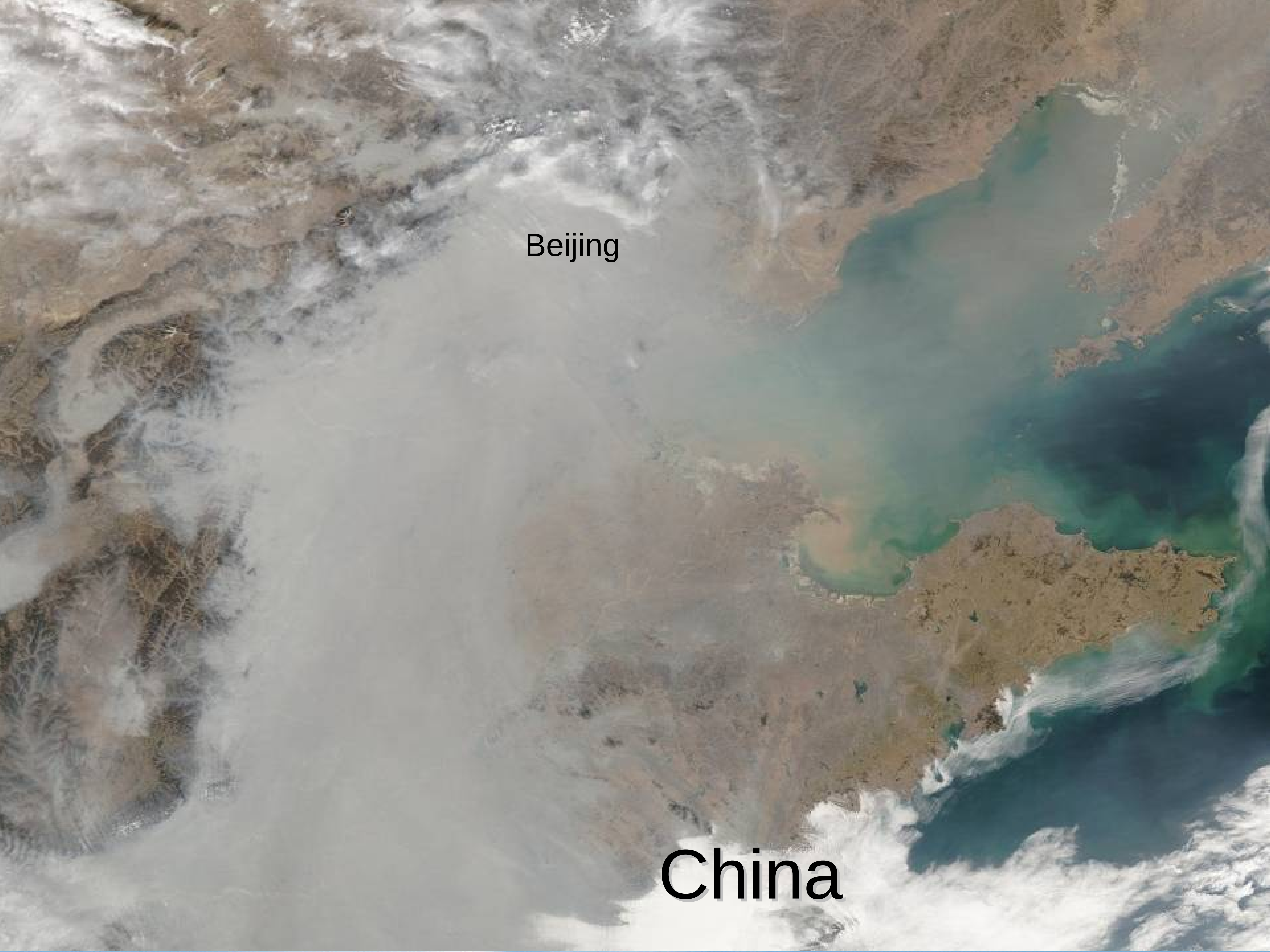
Thermodynamic conditions of the atmosphere

Highly non-linear processes

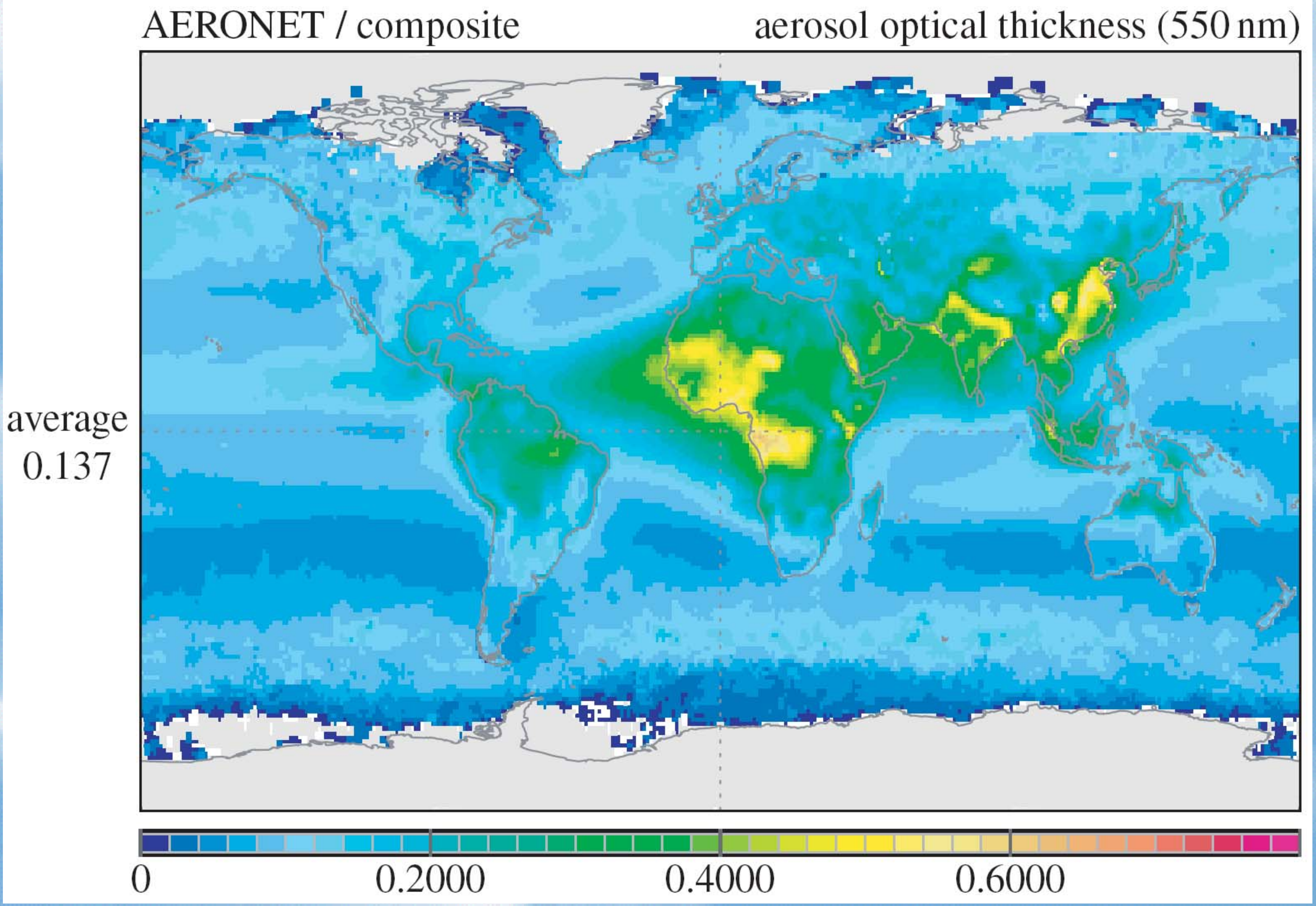


India: Haze over Ganges - Brahmaputra plain

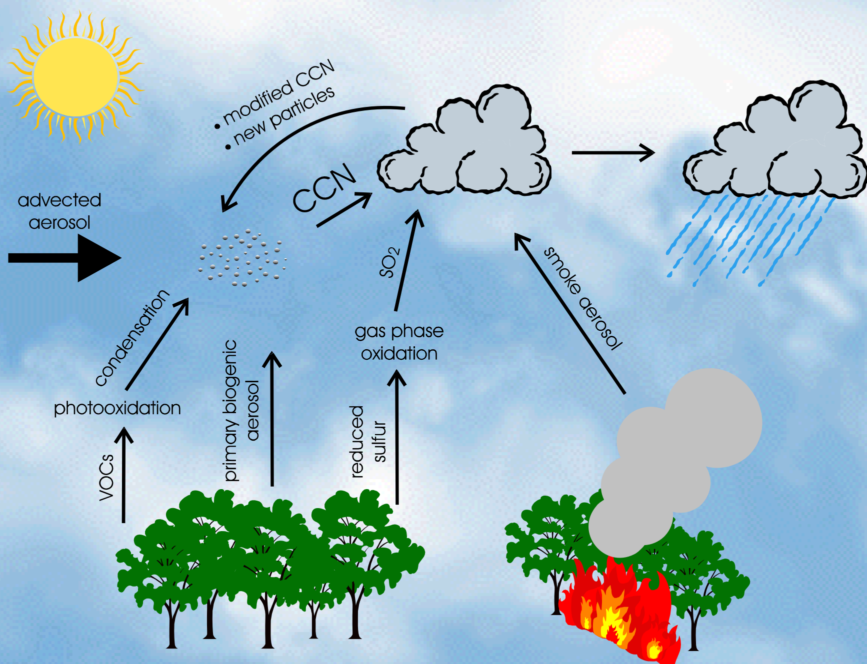
Note: Haze is <u>lighter</u> than surface almost everywhere, especially over ocean, but <u>darker</u> over the low cloud patch in the upper Ganges plain


Beijing
China

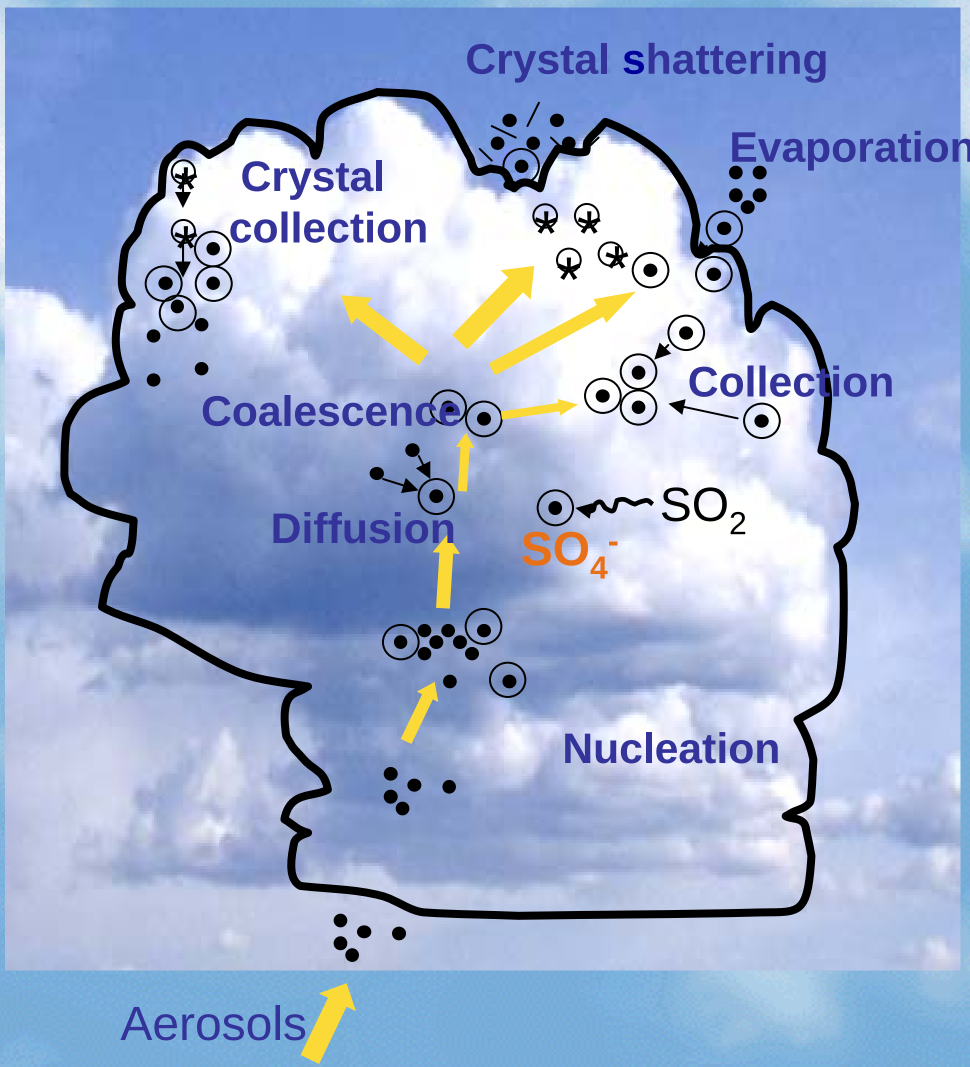
Global distribution of atmospheric aerosols represented as aerosol optical thickness, i.e. the extinction of sunlight by atmospheric aerosols.



Aerosol particles, cloud condensation nuclei and rain

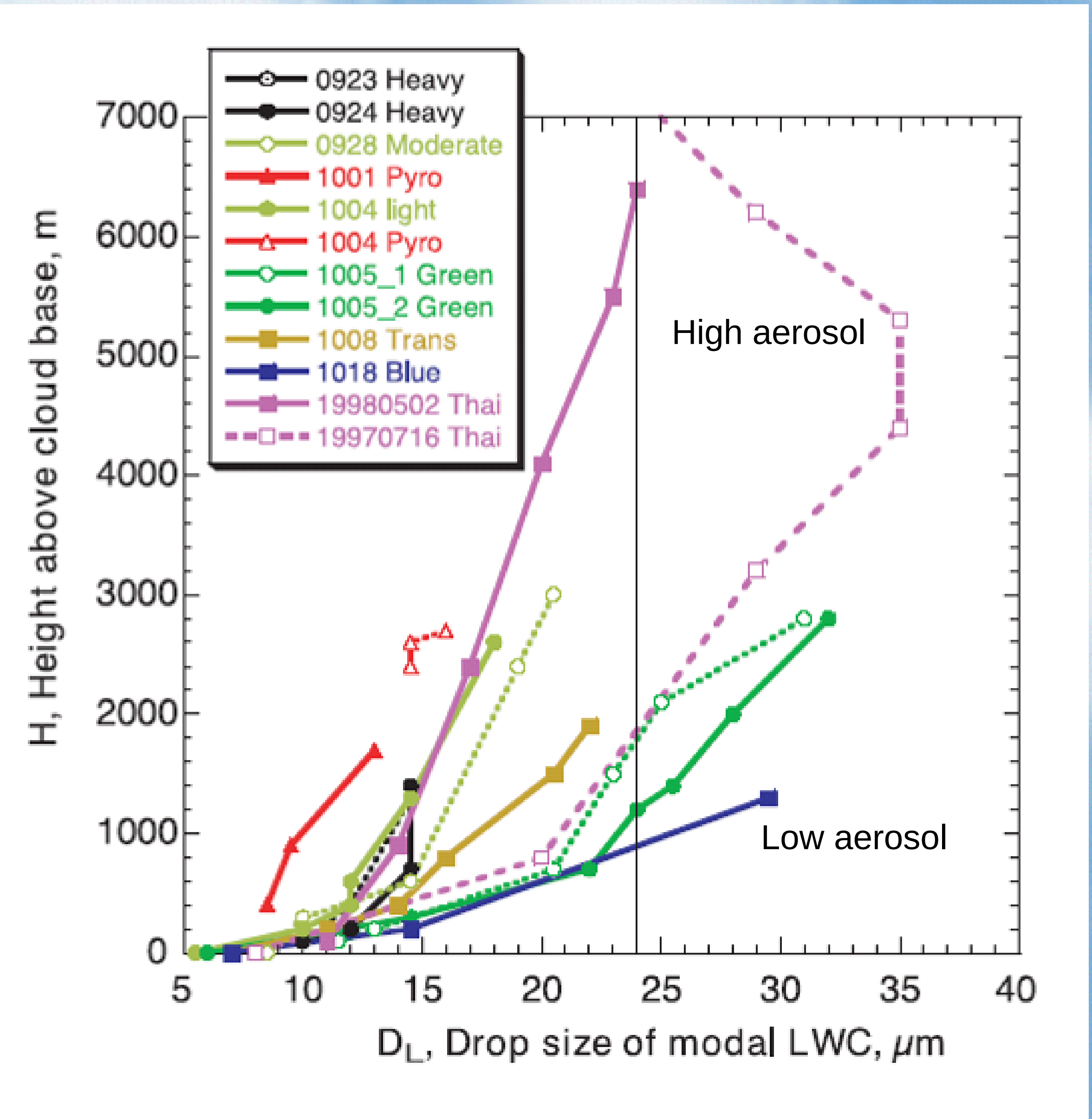


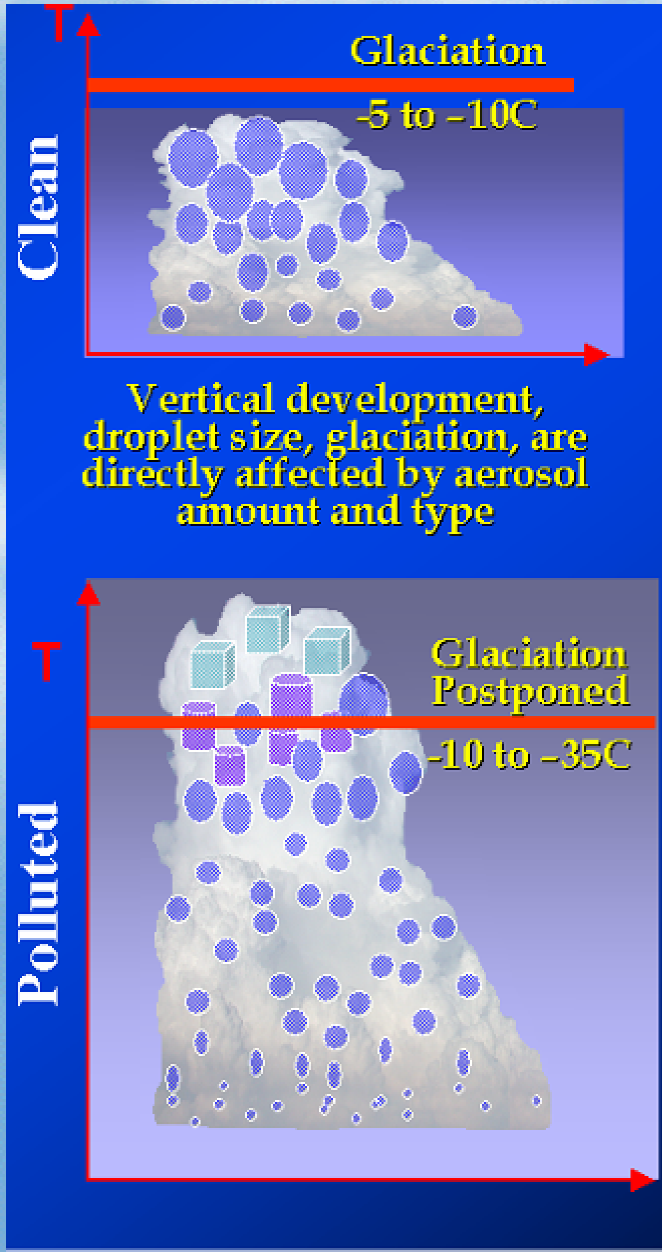
Cycle: Vegetation-Aerosols-CCN-Clouds-Rain



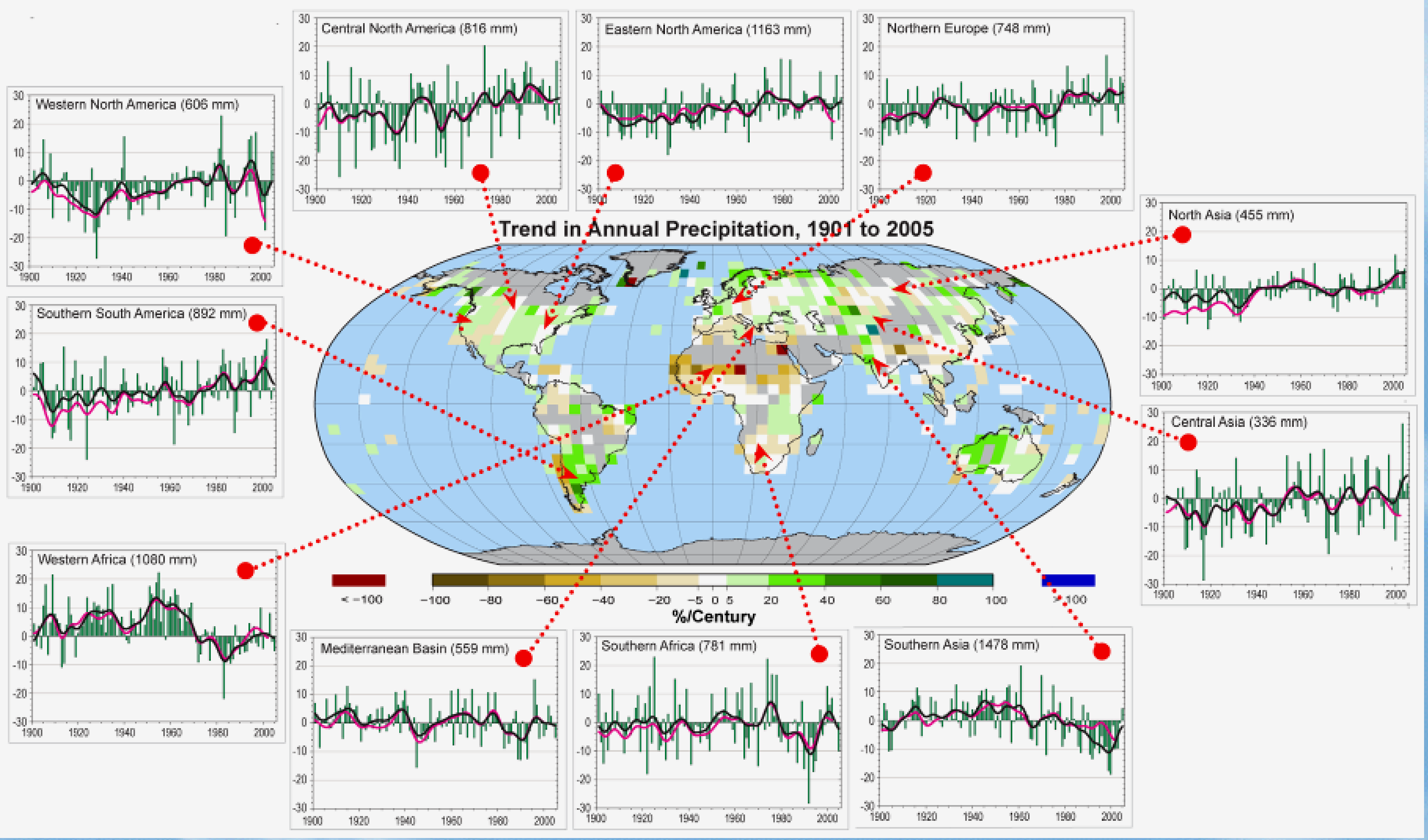
Precipitation formation

The effect of aerosol particles in the vertical profile of cloud droplets size, phase, and precipitation





Precipitation is being altered over several areas



Smoothed annual anomalies for precipitation (%) over land from 1900 to 2005; other regions are dominated by variability.

IPCC AR4

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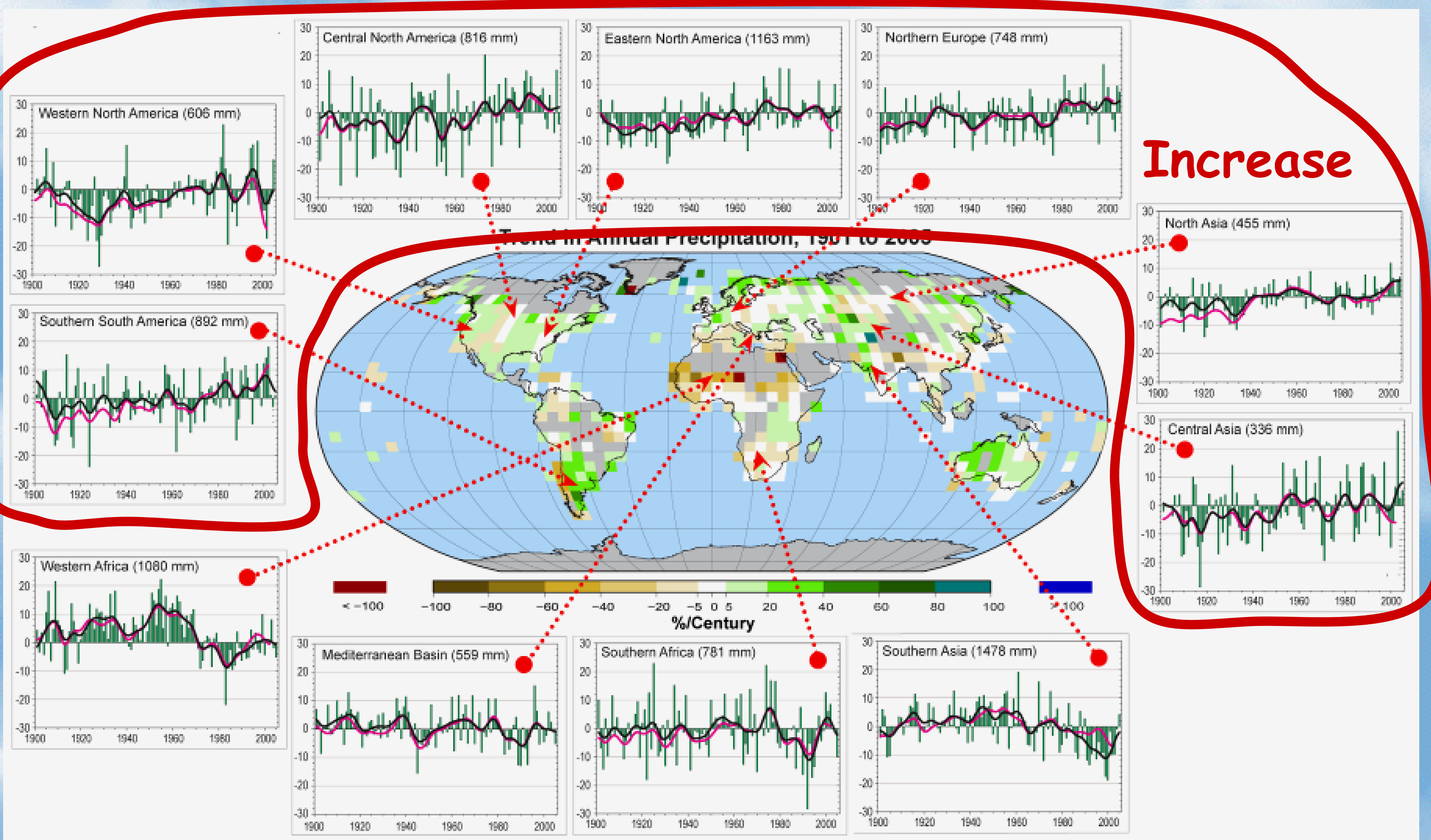

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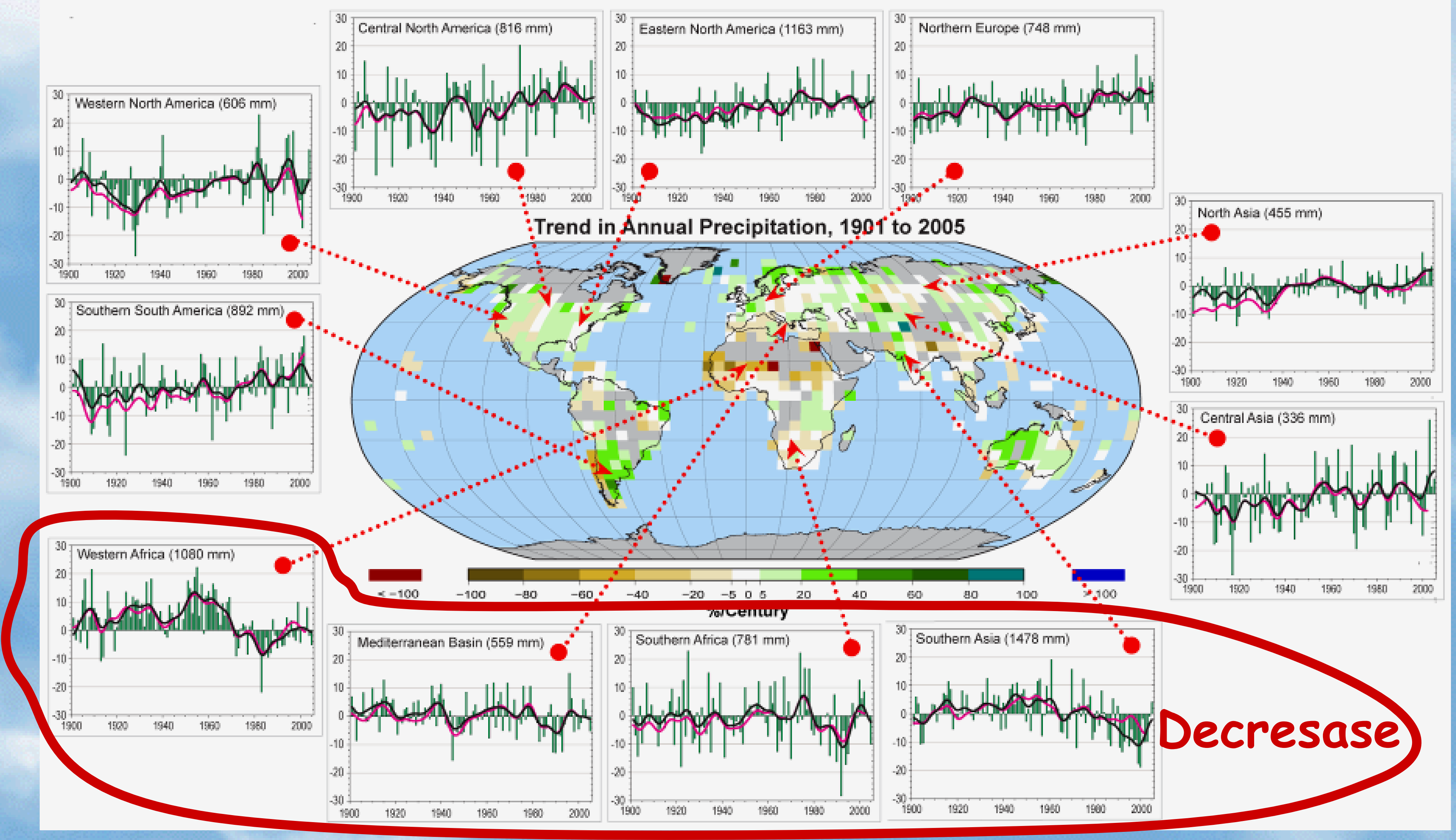
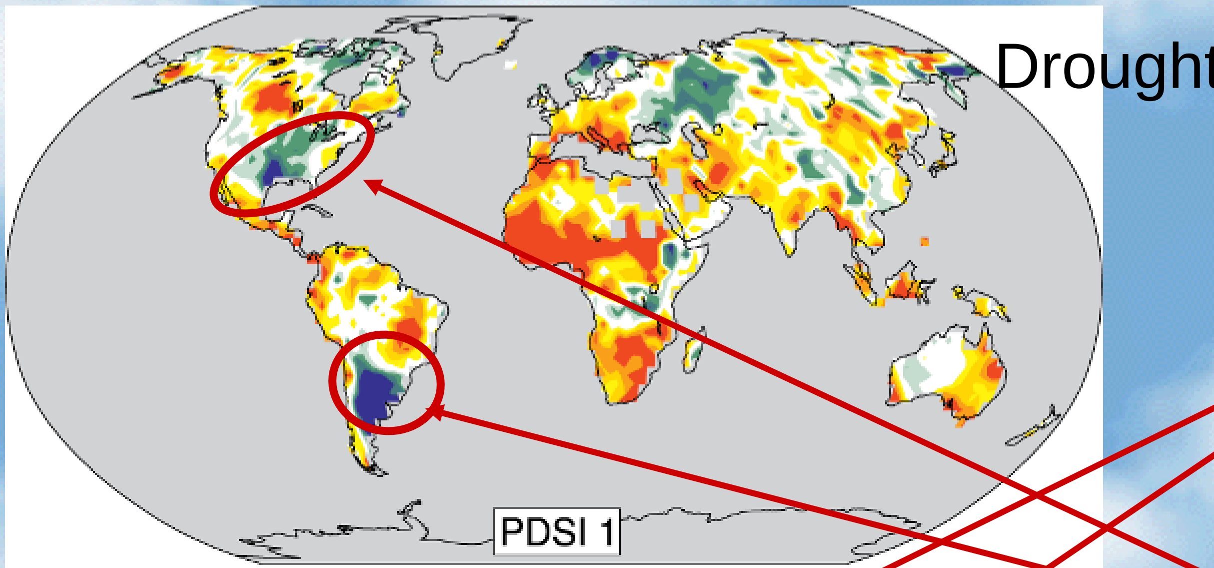
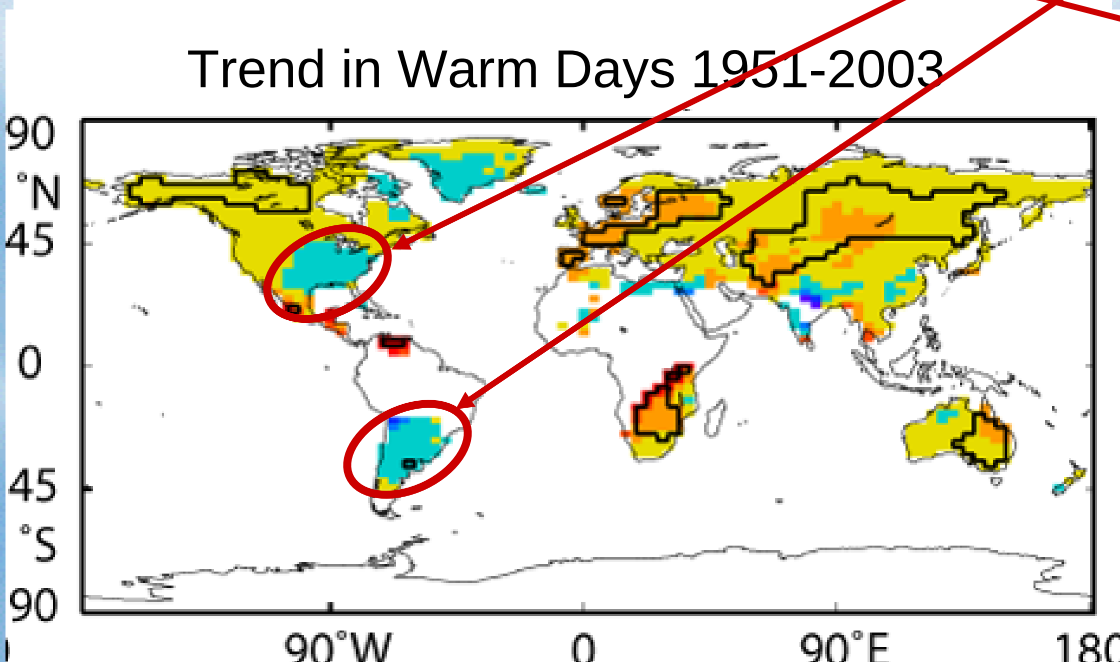


Smoothed annual anomalies for precipitation (%) over land from 1900 to 2005; other regions are dominated by variability.

IPCC AR4

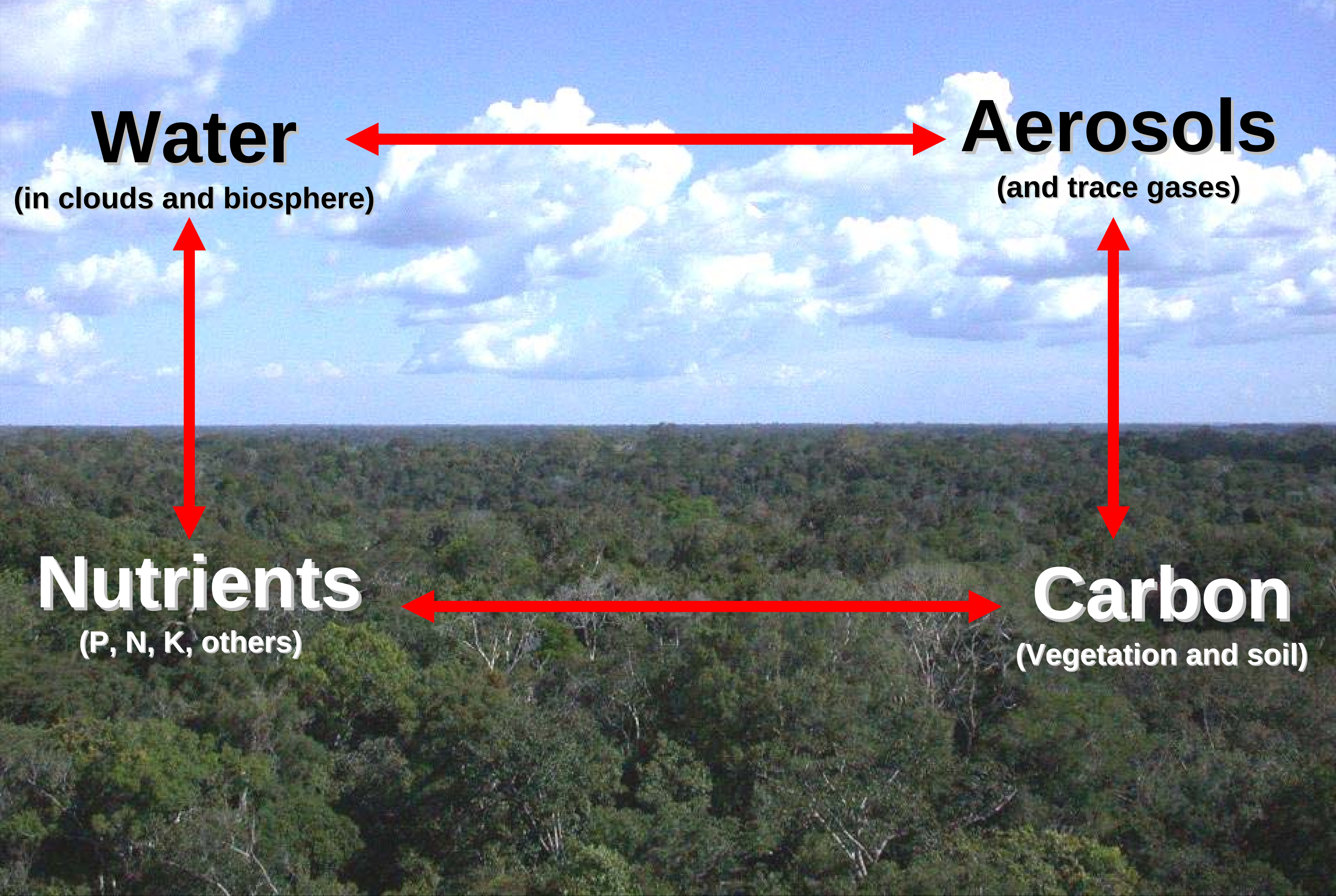
Increases in rainfall and cloud counter warming





Absence of warming by day coincides with wetter and cloudier conditions

The Large Scale Biosphere Atmosphere Experiment in Amazonia - LBA



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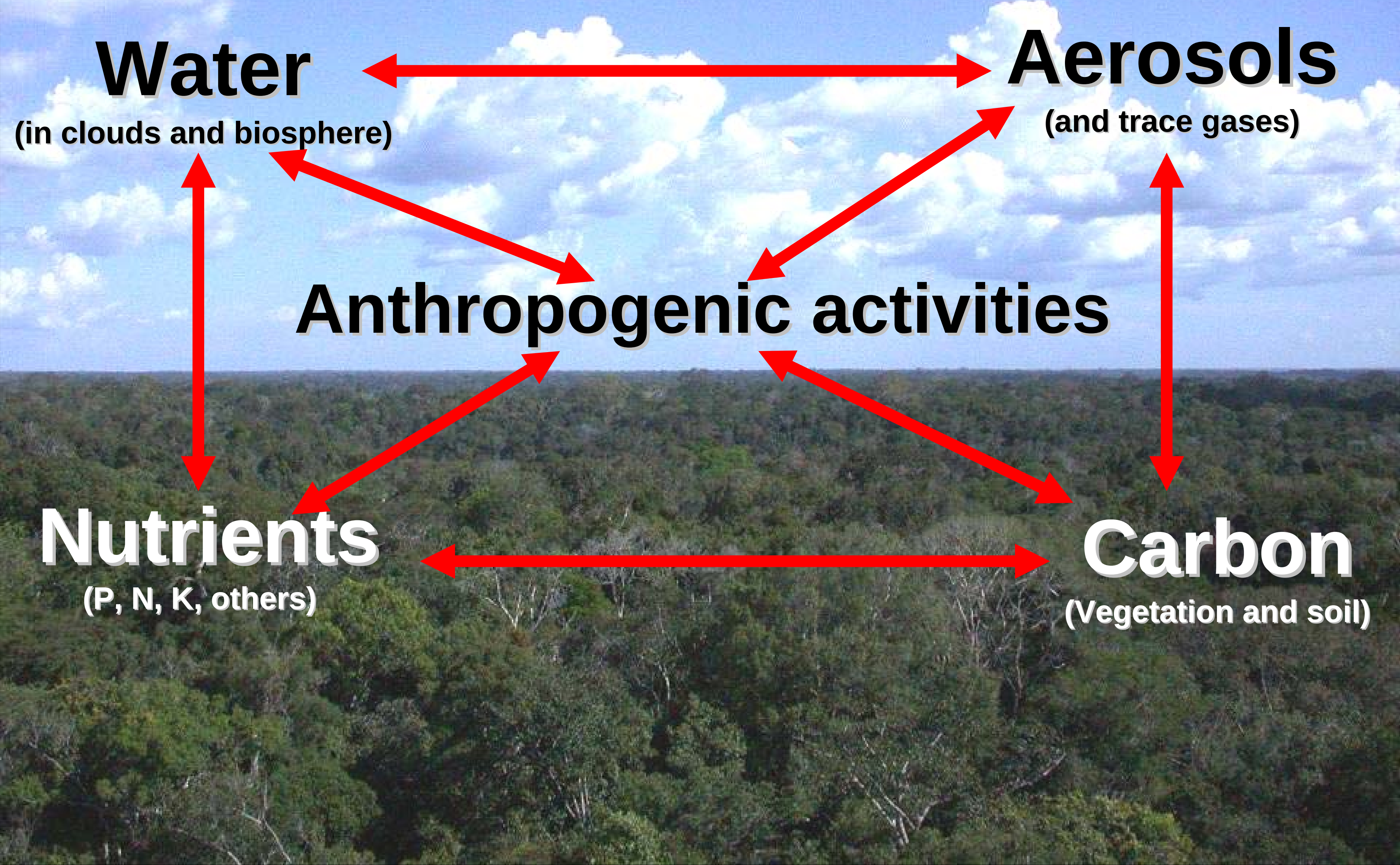
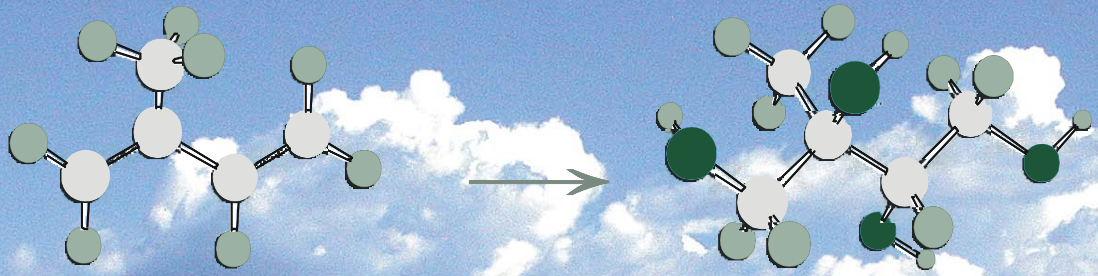


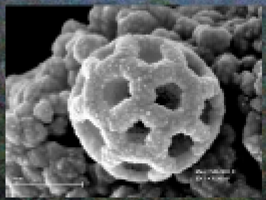
Natural production of CCN in Amazonia

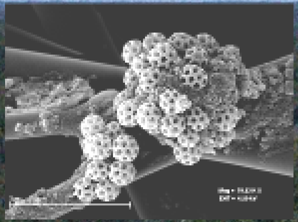


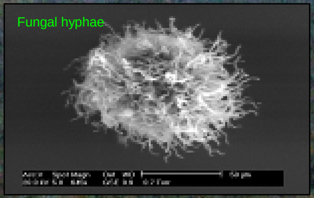
Isoprene

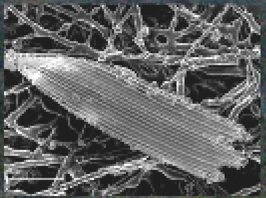
2-methilthertiol

(From Clayes et al., Science 2004)



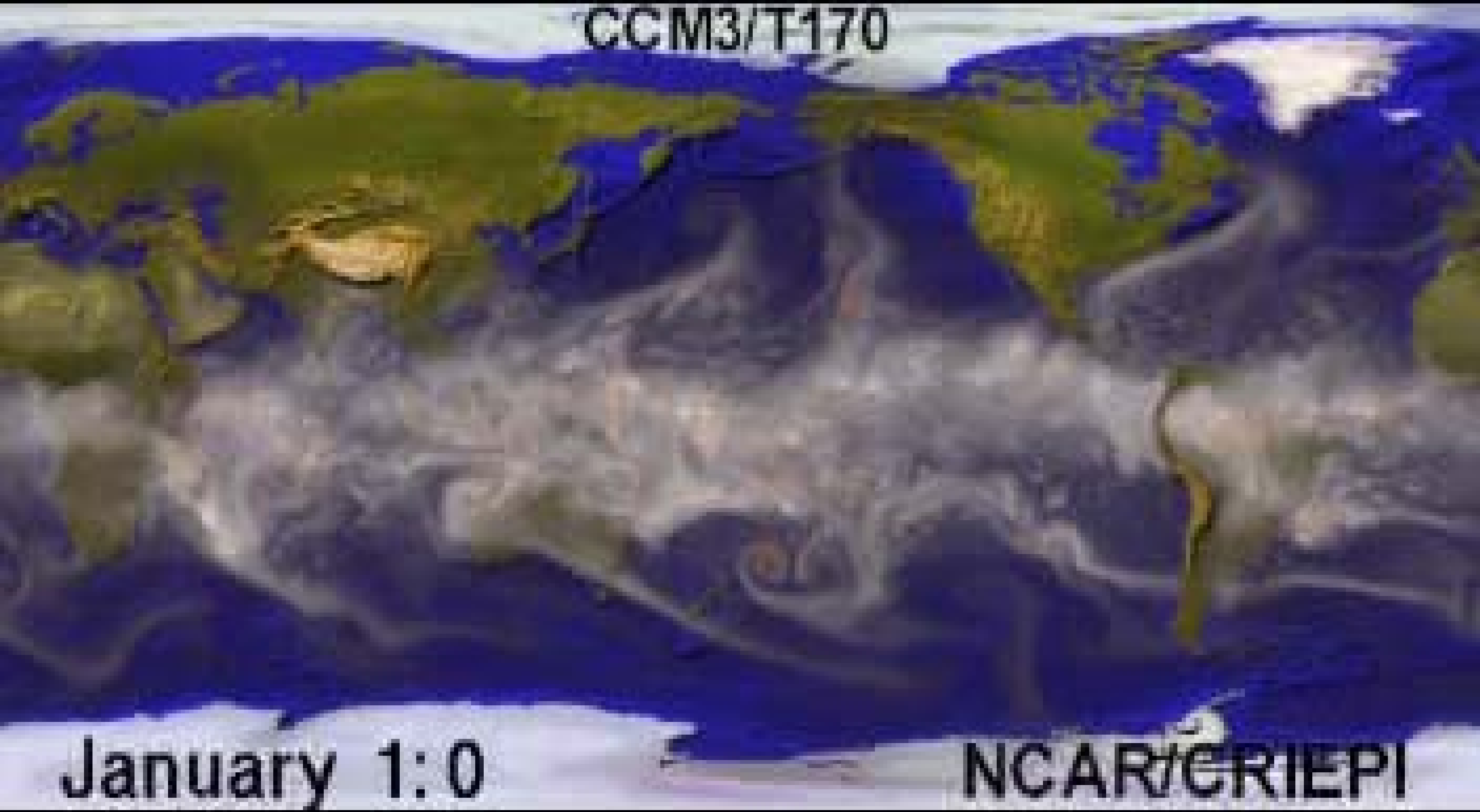




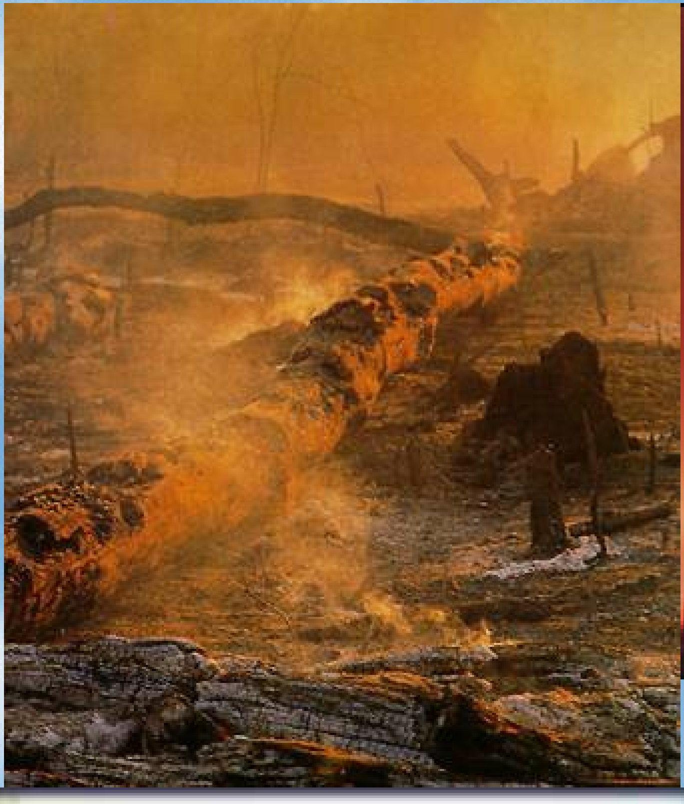


1) Primary biogenic particles acting as Giant CCN
2) Secondary organic aerosol from terpenes, isoprene, and others
3) Soil dust (very little)
4) Sulfates and nitrates (low contribution)

Global atmospheric water vapor

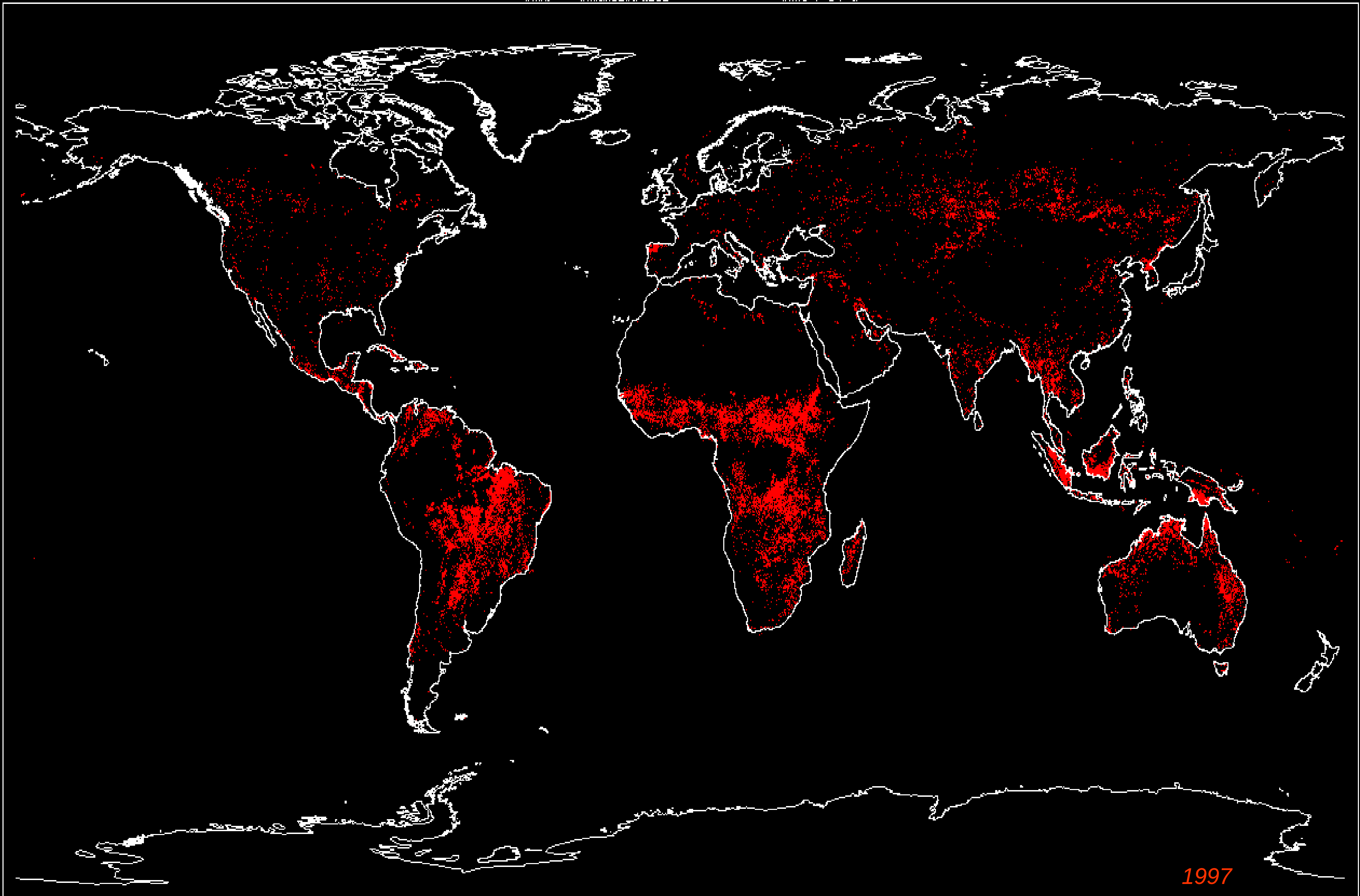


Biomass burning: a key issue...

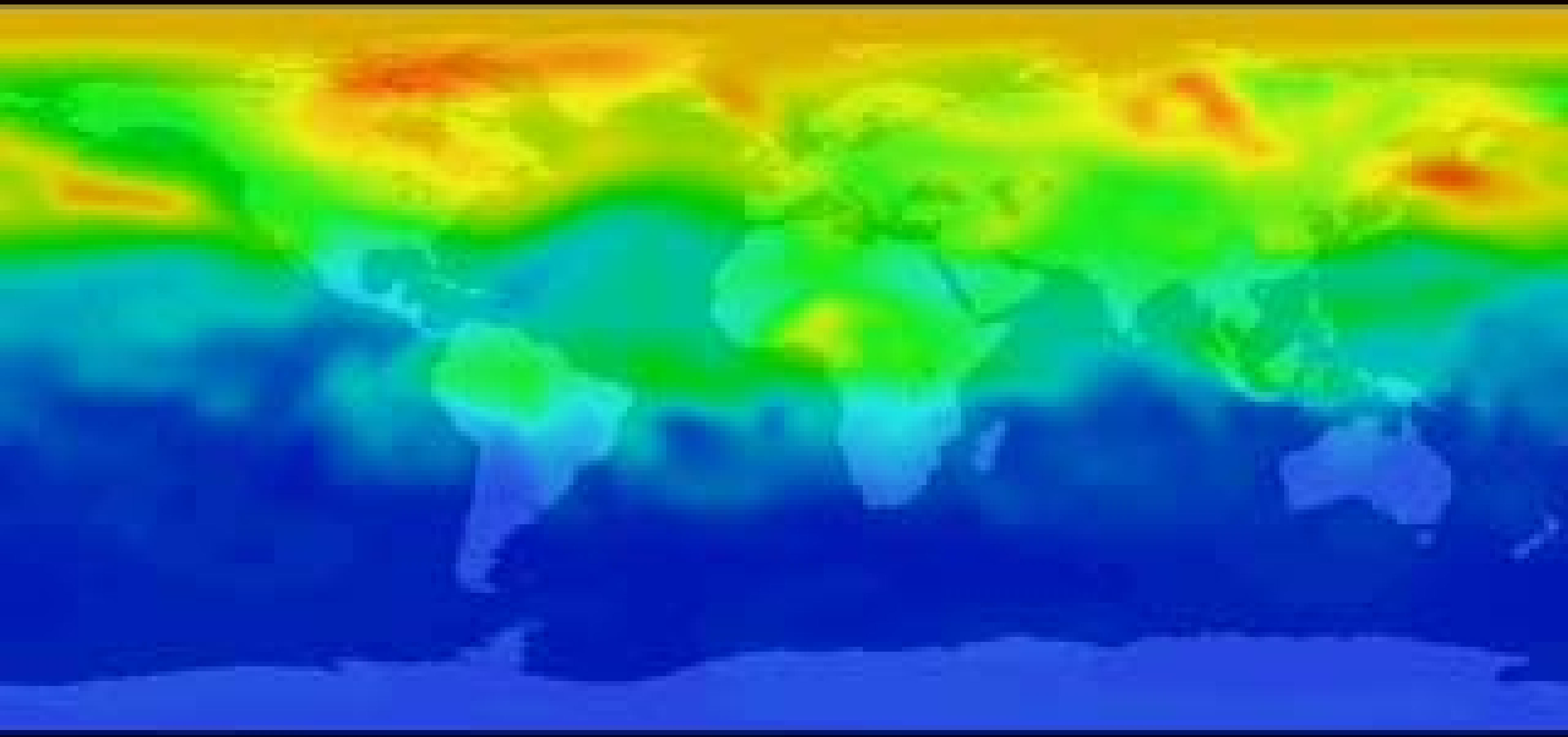


Reasons for deforestation

Global Biomass Burning

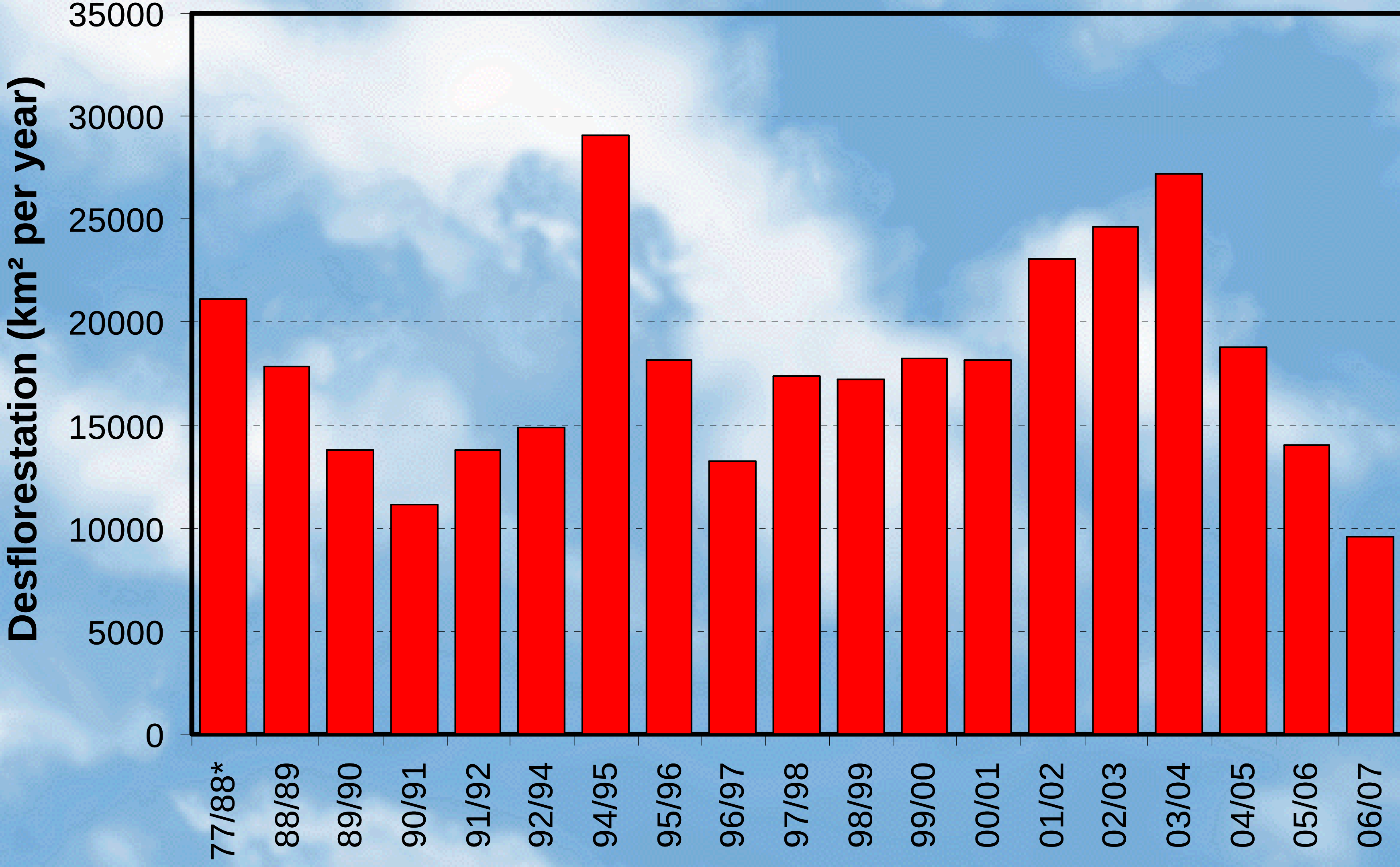


Global distribution of Carbon Monoxide (CO)



1 Mar 2000

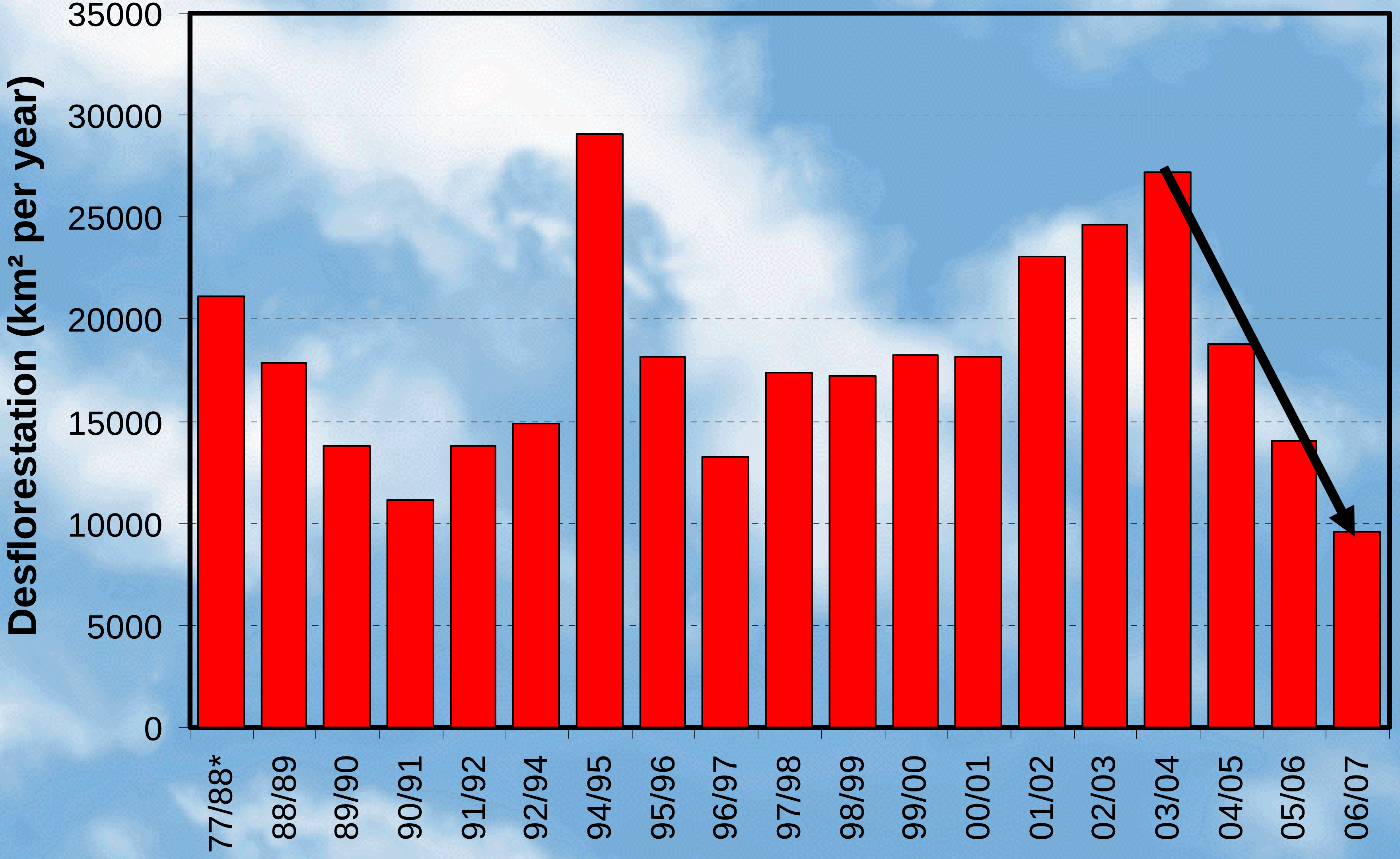
Deforestation in Amazonia 1977-2007 in km² per year



* average for the decade

INPE data, 2007

Deforestation in Amazonia 1977-2007 in km² per year



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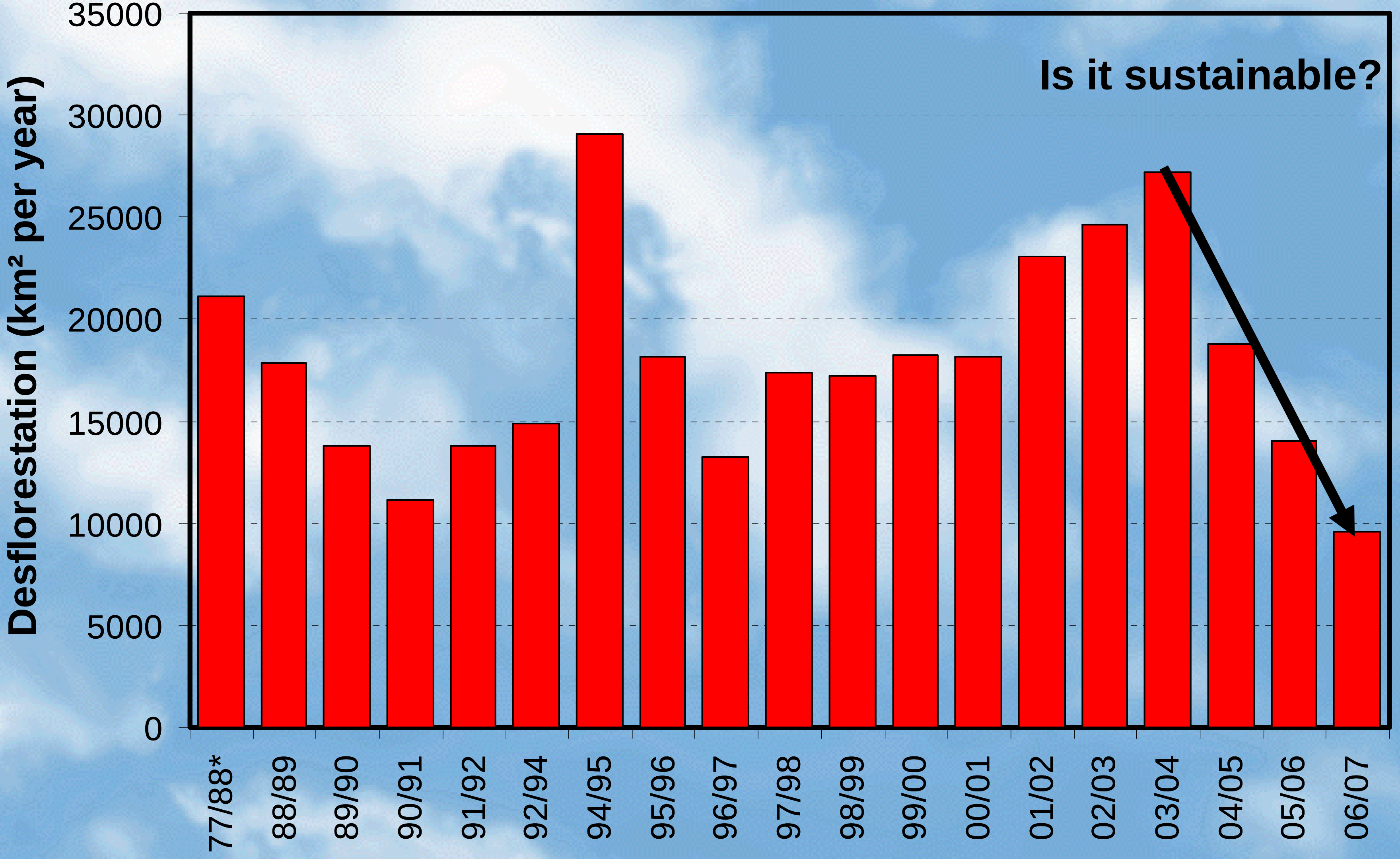
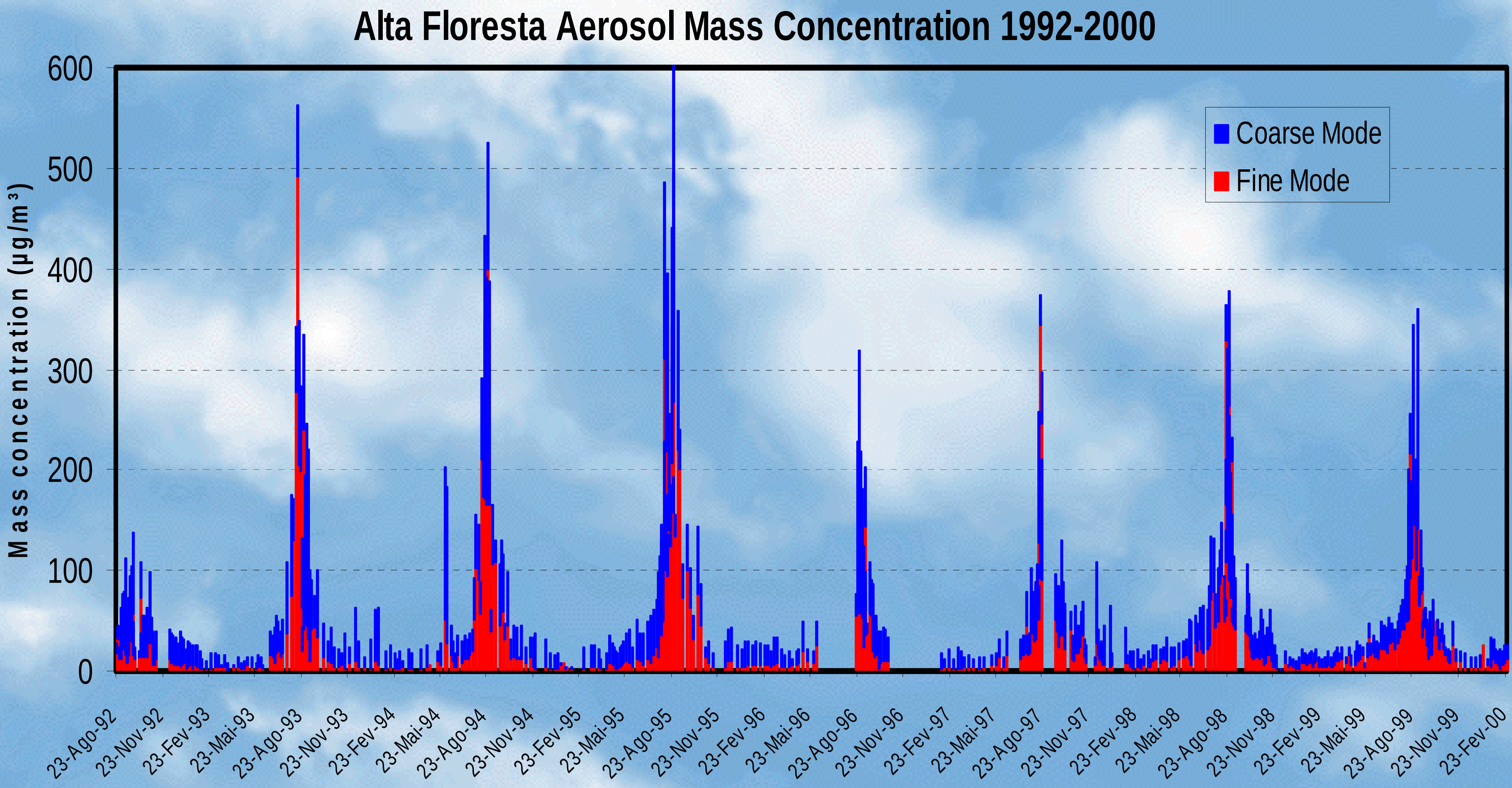


* average for the decade

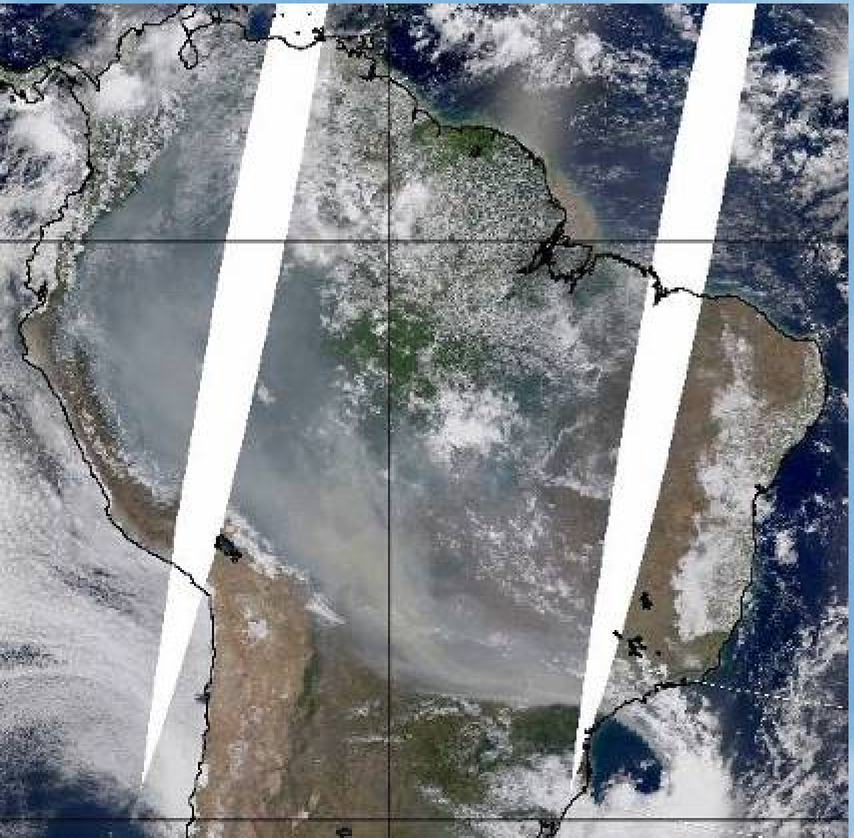
INPE data, 2007

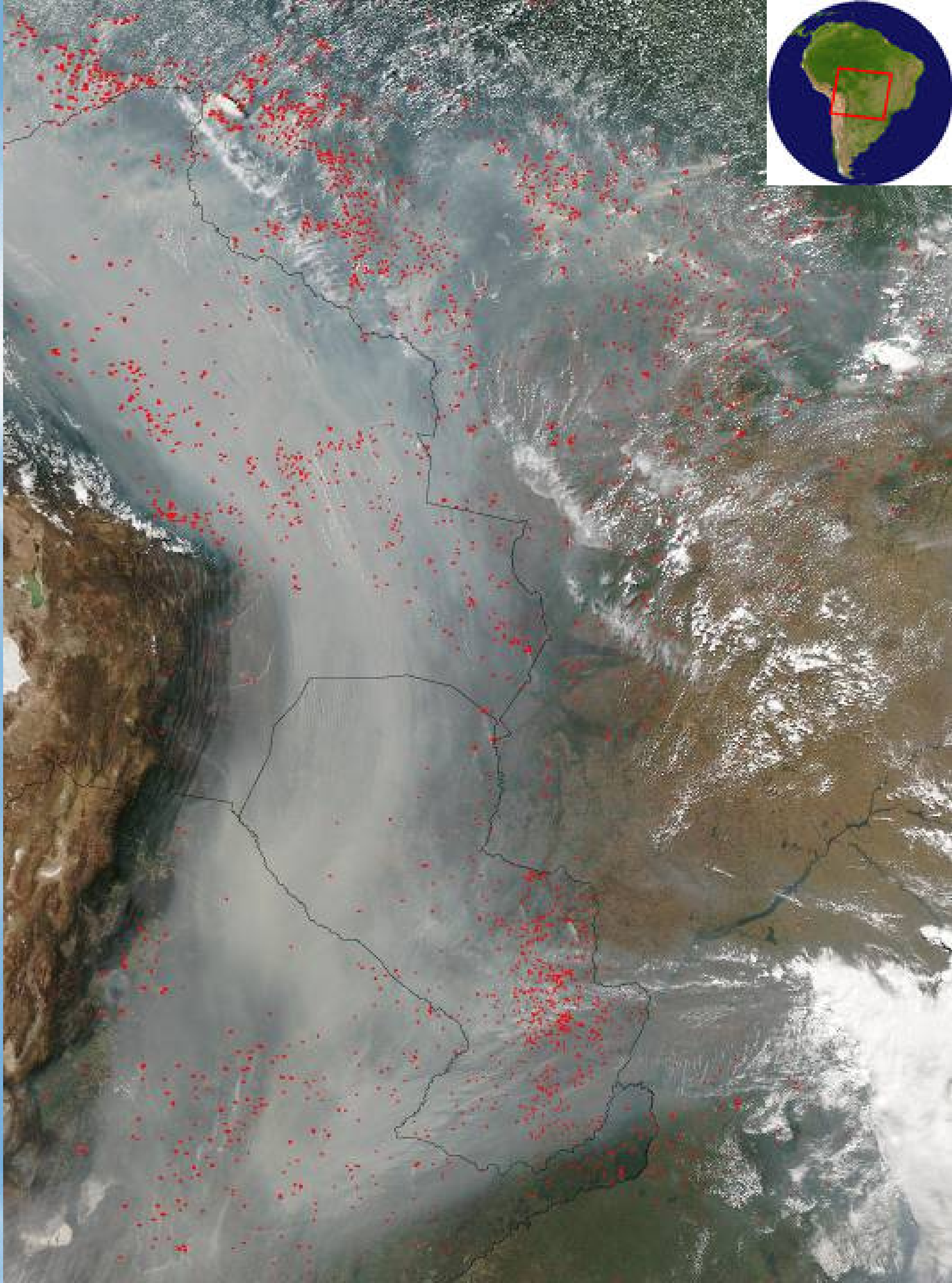
PM$_{10}$ aerosol concentrations in Alta Floresta, Amazônia, 1992-2000



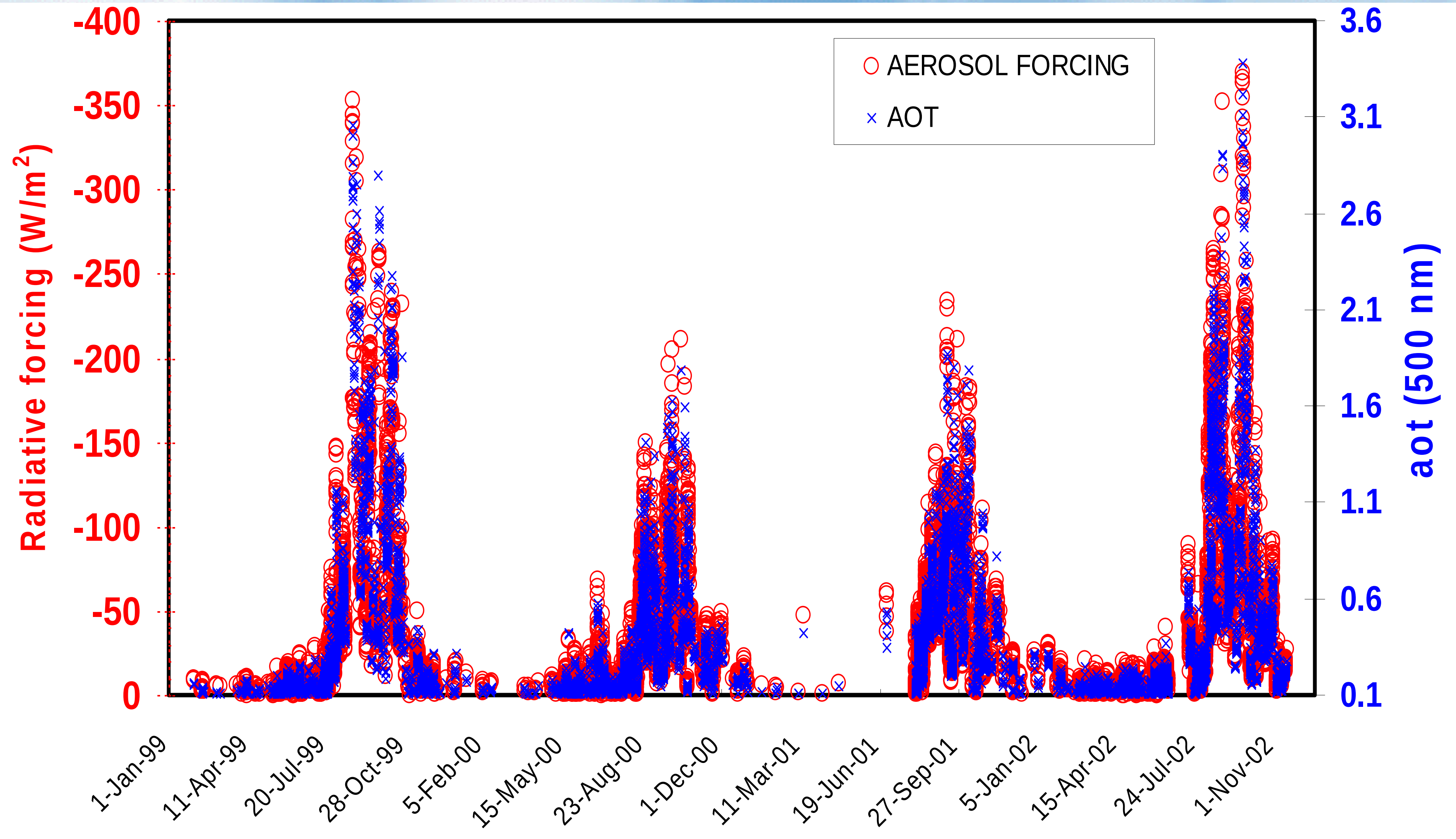
The most important air pollution issue in South America is associated to the continental scale biomass burning during the dry season. With several hundred of thousands of fires each year …

- Severe health effects on the population
- Climate effects
- Weather effects





Aerosol surface forcing in Rondonia 1999-2002



Aline Procópio, GRL 2006

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

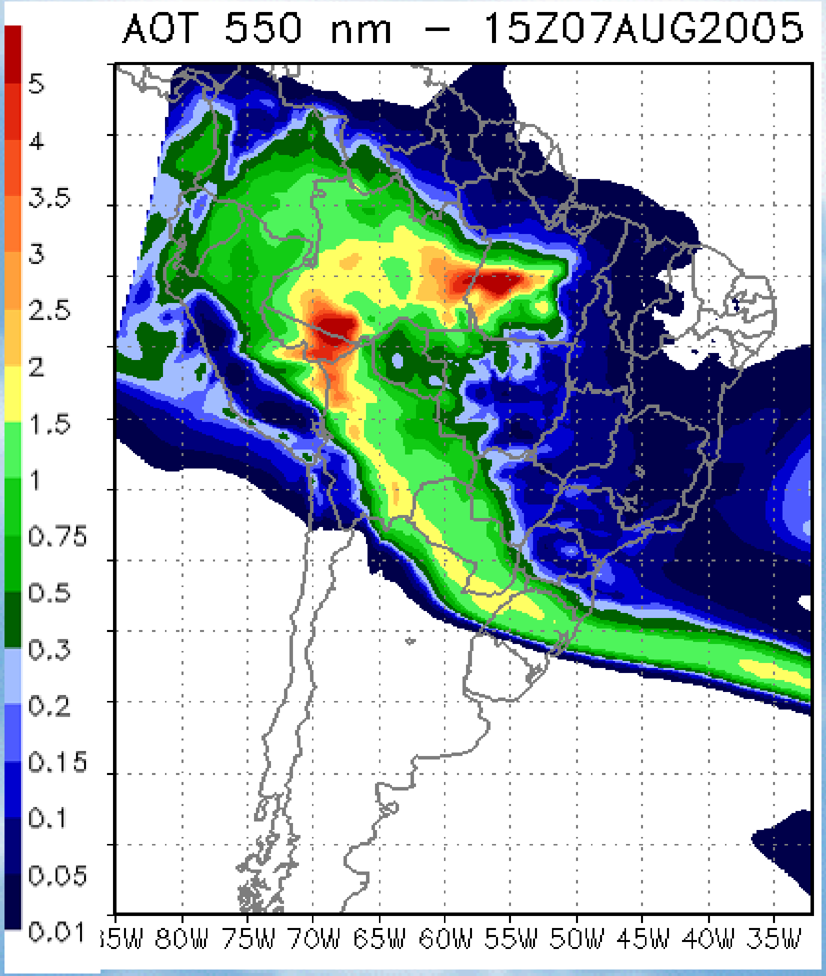
Surface: - 23±2 w/m^2

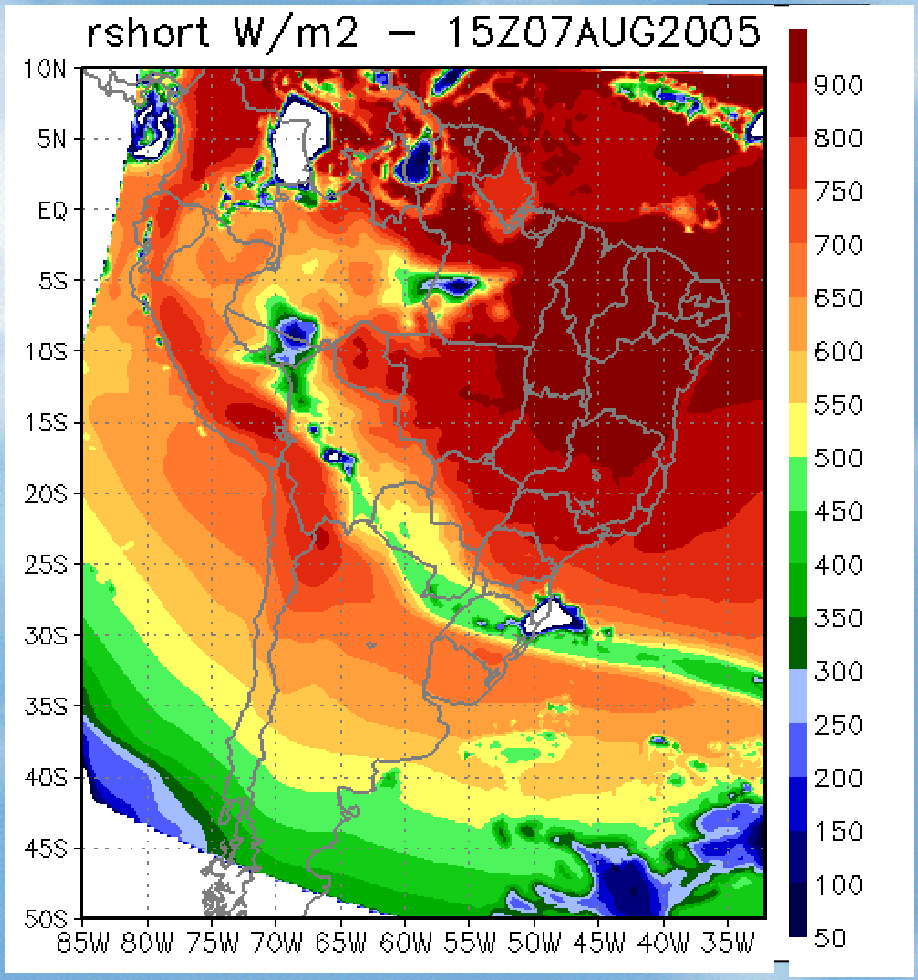
Conditions: surface: ocean
AOT (τ=0.3 at 630 nm); 24 hour average
Jan-Mar 99

Procópio et al. (2004)

Aerosol Optical Thickness 550 nm

Solar Radiation at surface (W m^{-2})

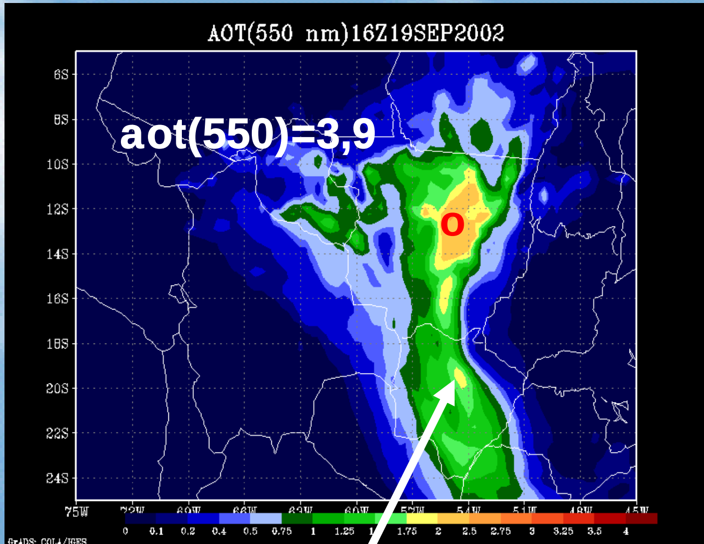


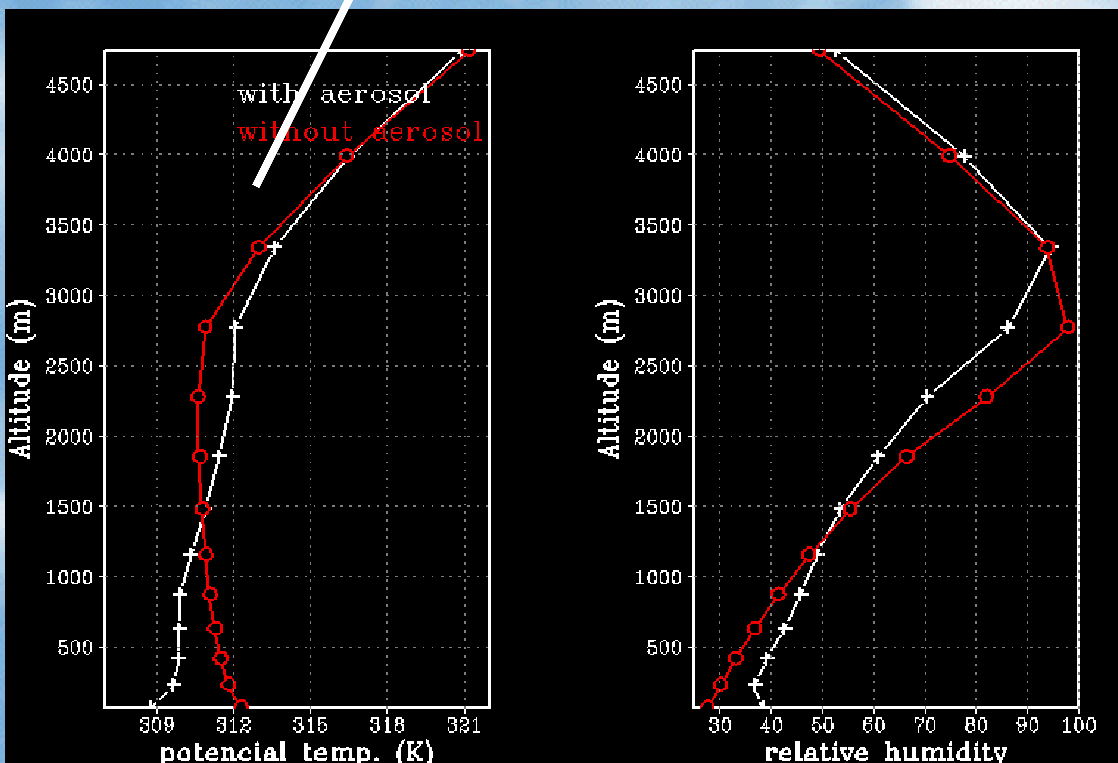


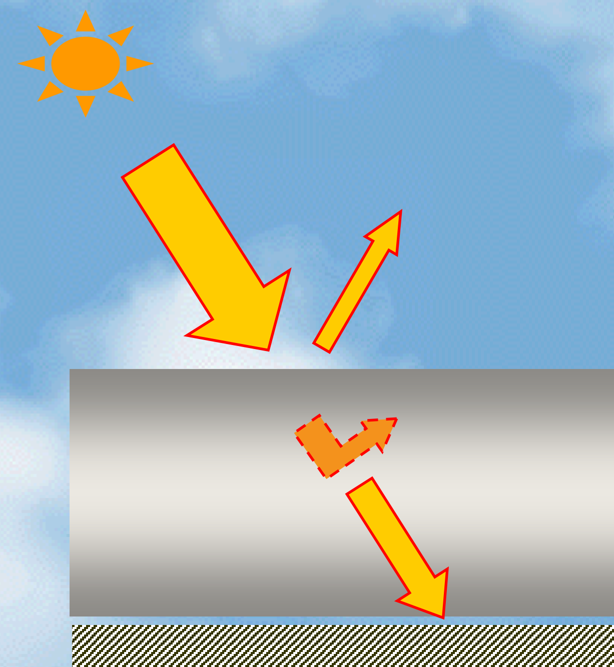
Continental scale effects

Karla Longo and Saulo Freitas, INPE/CPTEC

Impacto do efeito radiativo direto do aerossol de queimadas na estrutura termodinâmica da atmosfera







Efeitos:

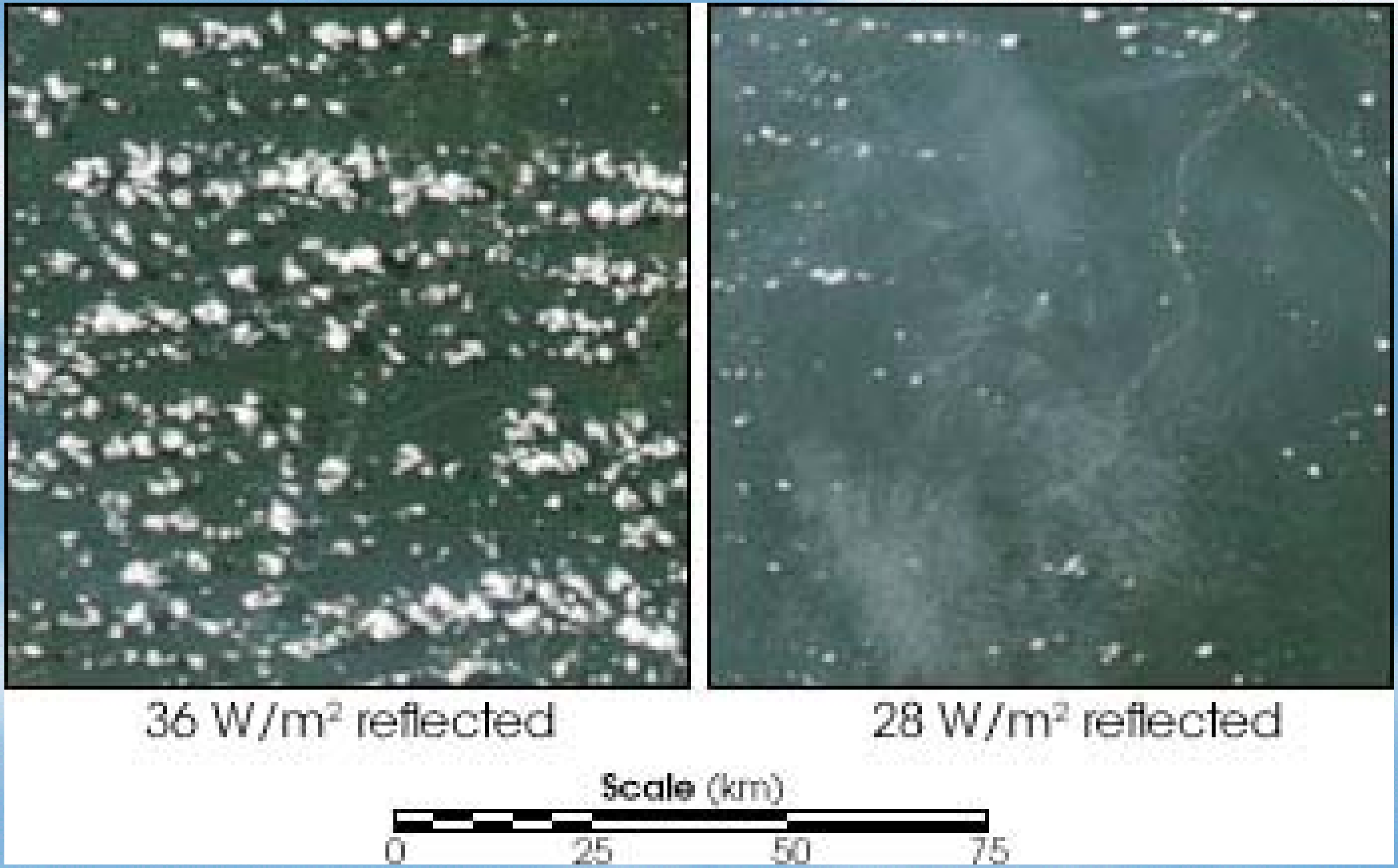
- Estabiliza a atmosfera
- Reduz a energia disponível para processos de superfícies

Karla Longo and Saulo Freitas, INPE/CPTEC

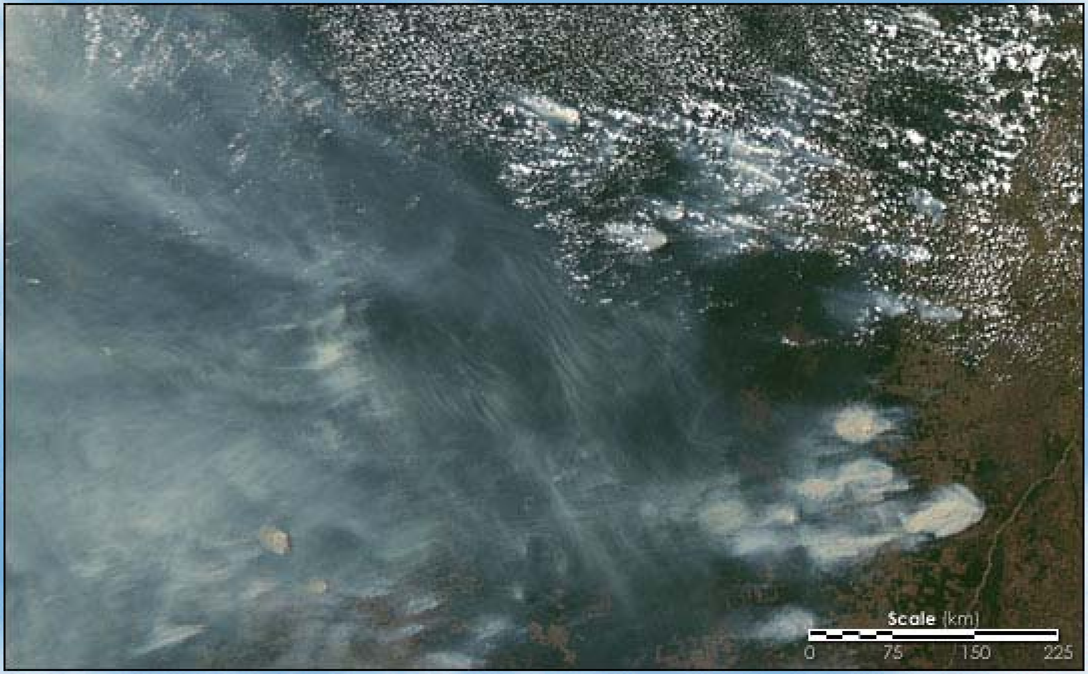
Hydrological cycle critical for Amazonia. Variety of cloud structure caused by different CCN amounts and other cloud dynamic issues

Pyrocumulus Clouds

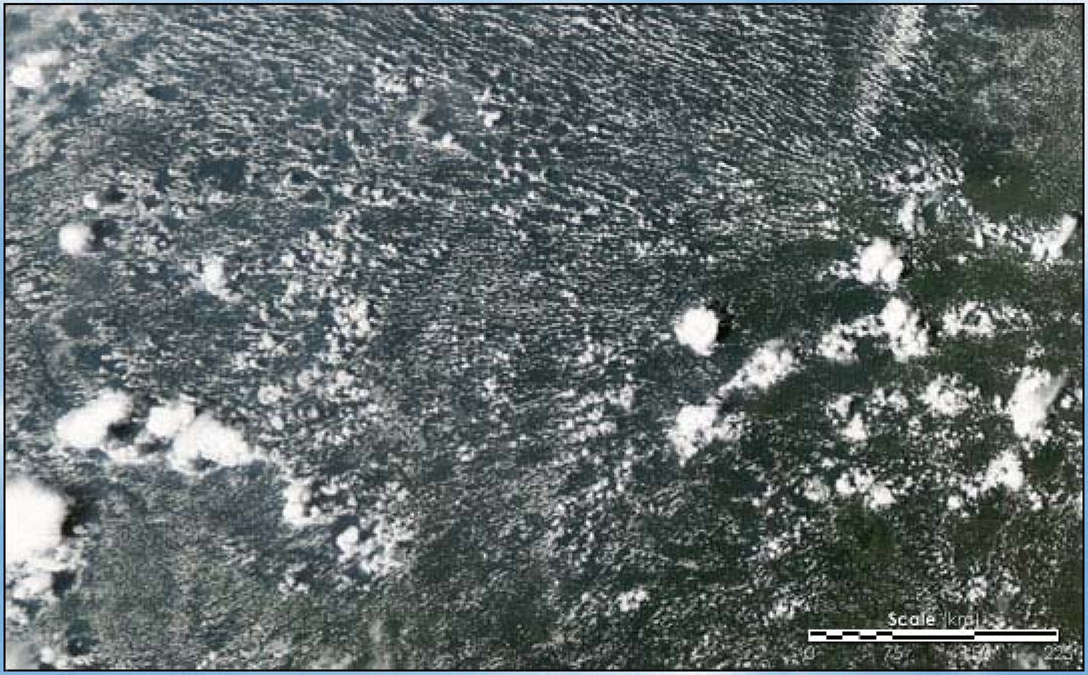
“Green Ocean Clouds“



The reduction of clouds due to smoke leads to less sunlight being reflected and more sunlight being absorbed by the Earth, resulting in warming. Areas with normal conditions of 40 percent cloud cover reflect 36 Watts per meter squared, compared to 28 Watts per meter squared for smoke-covered areas without clouds.

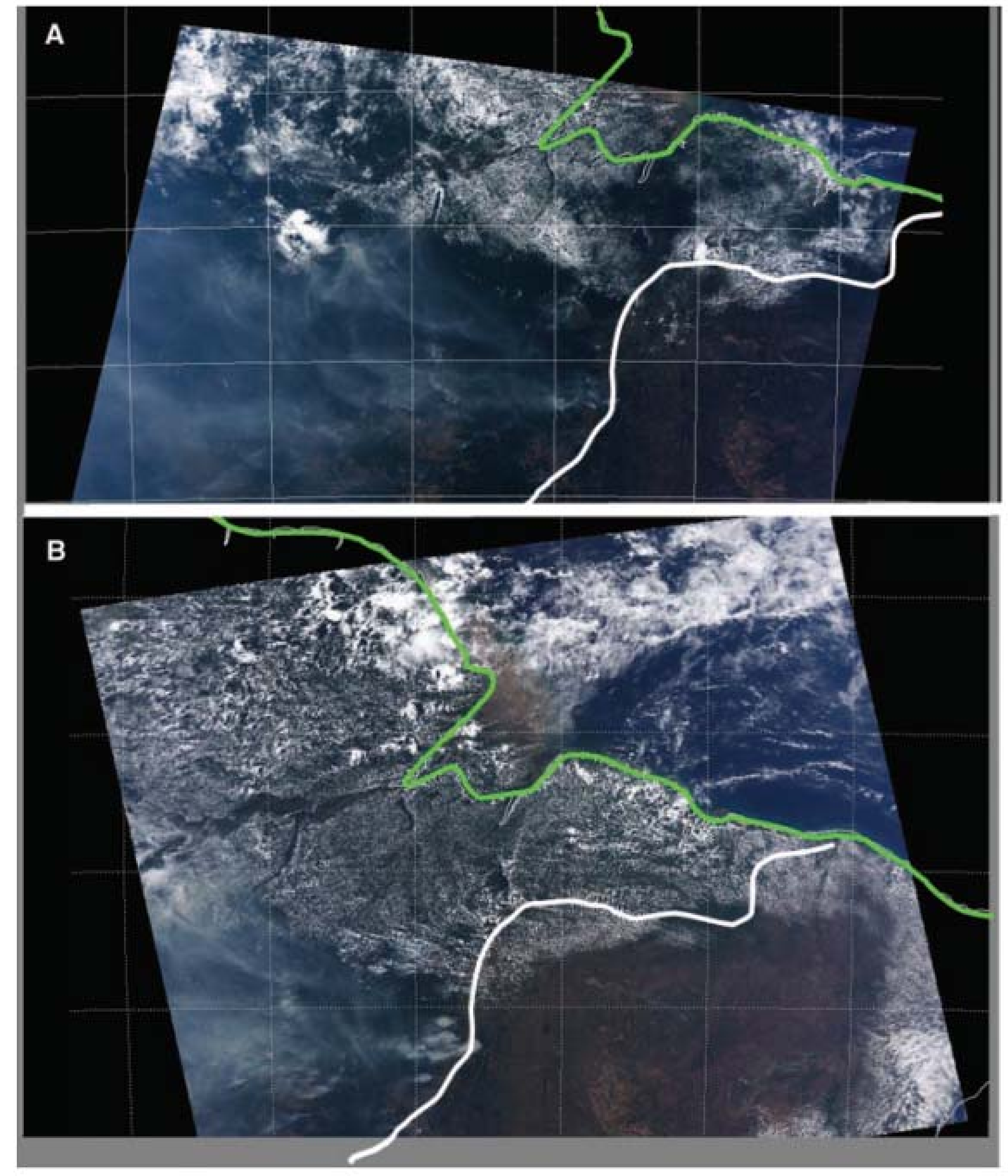


Satellite images of the Amazon rainforest rarely show smoke and cumulus clouds together.



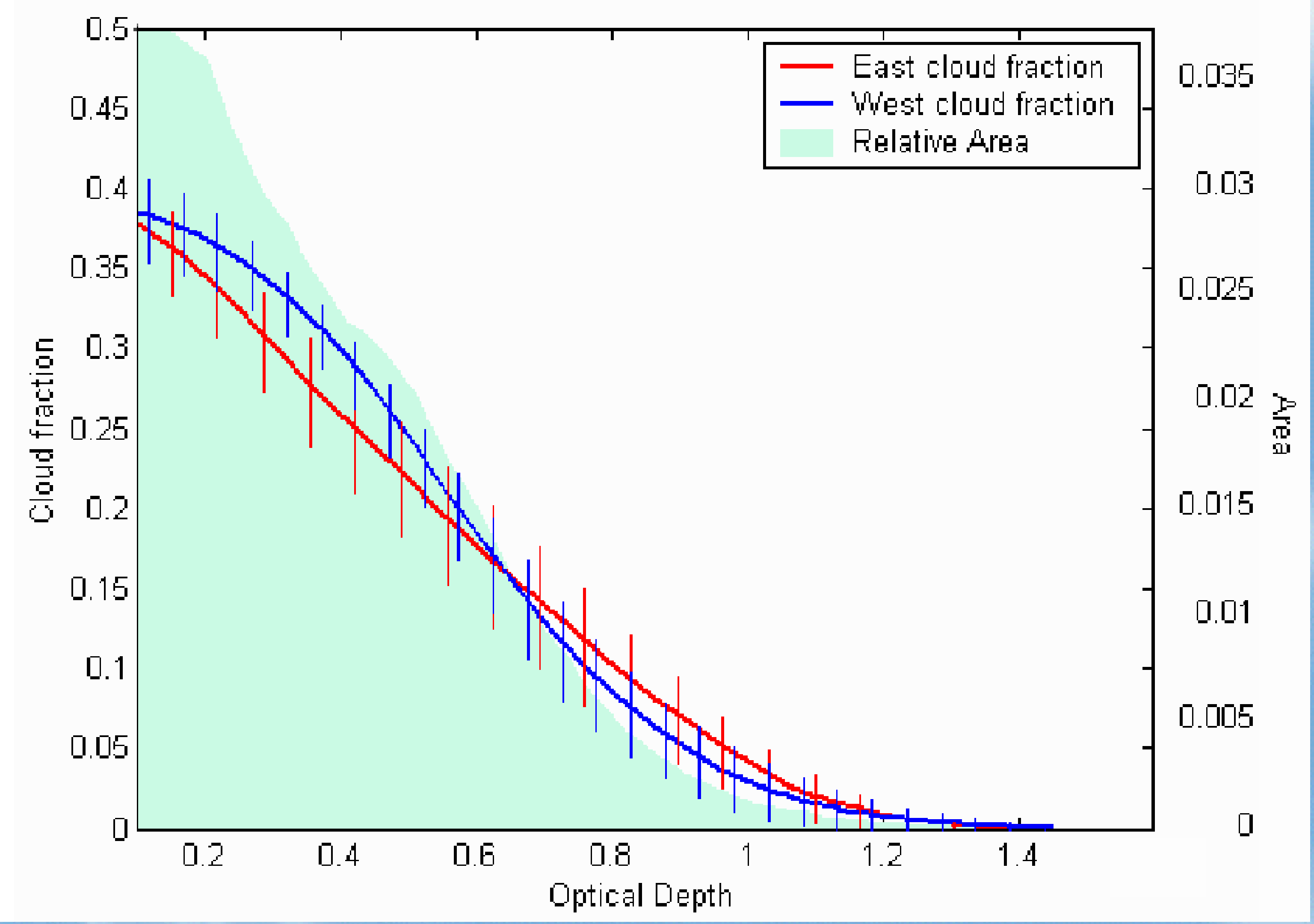
A uniform layer of scattered cumulus clouds is typically present, along with some thunderstorms, over the Amazon rainforest. Compare this image of a day with little smoke, with the image above. Both images were acquired by the Moderate Resolution Imaging Spectroradiometer aboard NASA's Aqua satellite, on August 11 (top) and November 15 (bottom), 2002.

Large scale low cloud suppression



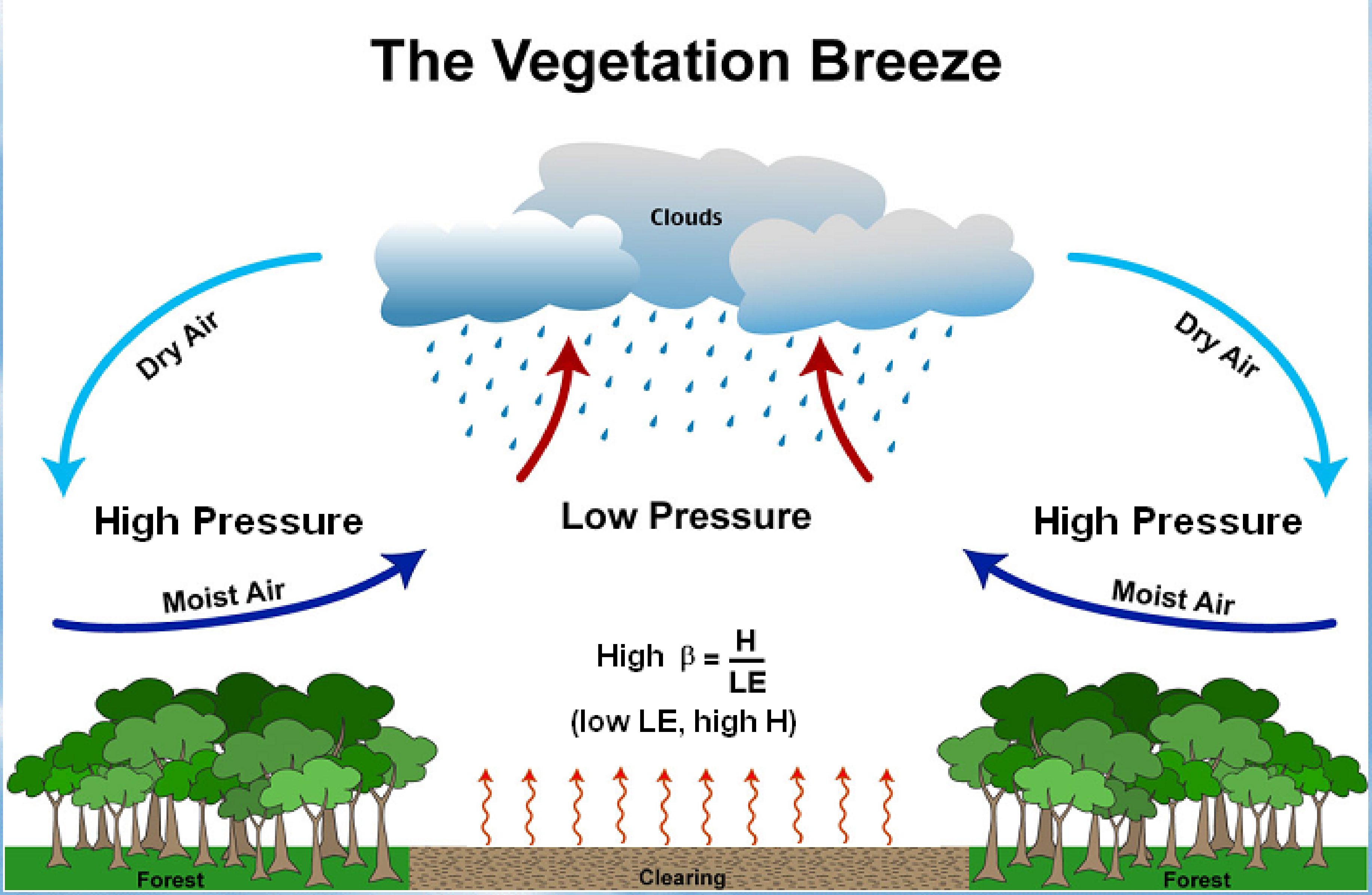
Terra and Aqua satellite images of the east Amazon basin, 11 August 2002. (**A**) The clouds (Terra, 10:00 local time) are beginning to form. (**B**) The clouds (Aqua, 13:00 local time) are fully developed and cover the whole Amazon forest except for the smoke area. The boundary between forest and Cerrado region is marked in white on both images, and the seashore is marked in green. *(From Koren et al., 2004)*

Suppression of low cloud formation by aerosols in Amazonia

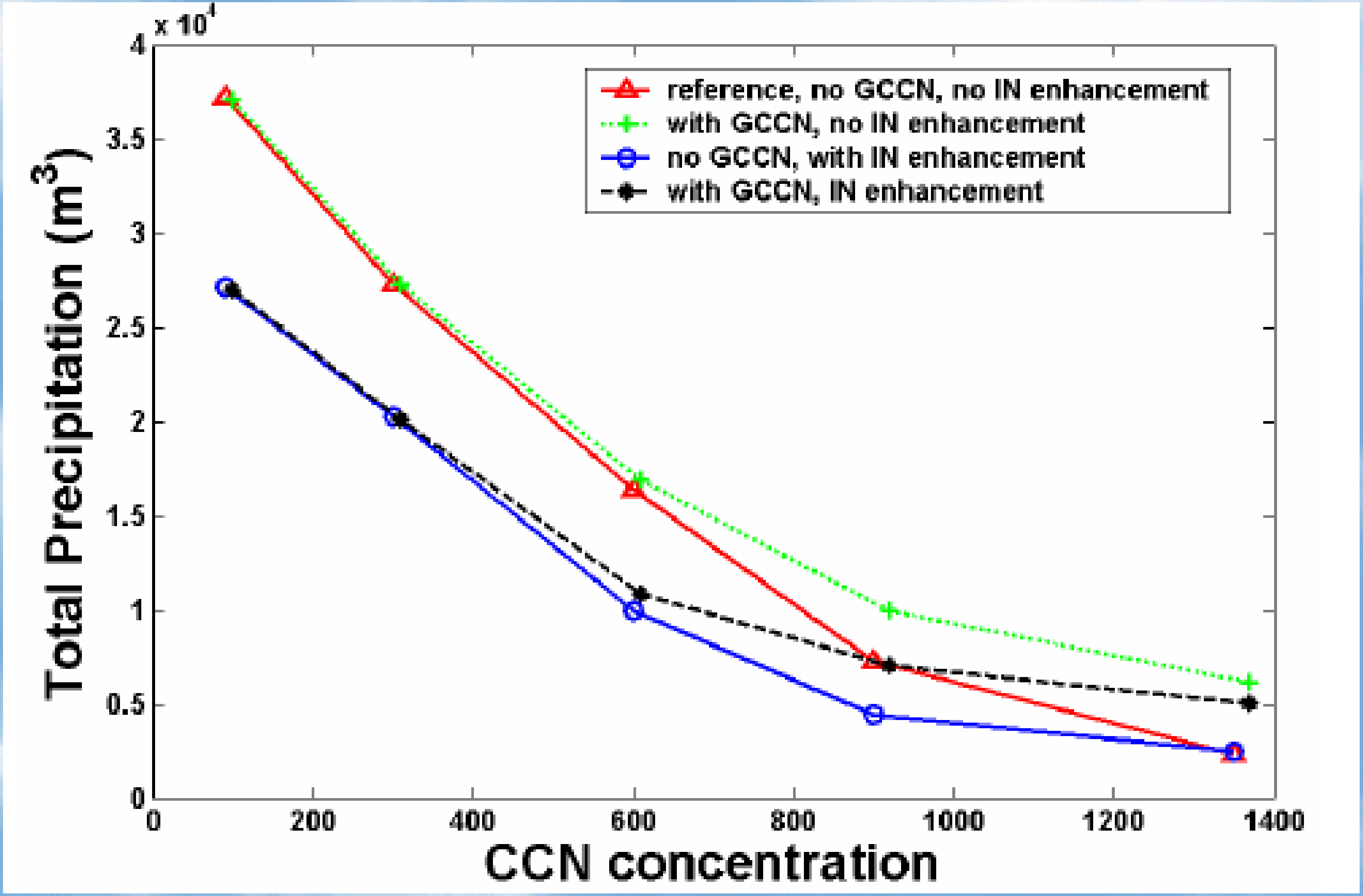


Cloud fraction as function of aerosol optical depth (OD). The cloud fraction decreases almost linearly with increasing OD. The red and blue curves denote the average of east and west areas, respectively. On average, the cloud fraction decreases to less than 1/8 of the cloud fraction in clean conditions when OD = 1. The shaded area represents the relative area covered by the respective OD, with the integral of this curve equal to one, representing the total Amazon basin. (from Ilan and Kaufman, 2003)

Deforestation increase or decrease precipitation? It depends on the scale.



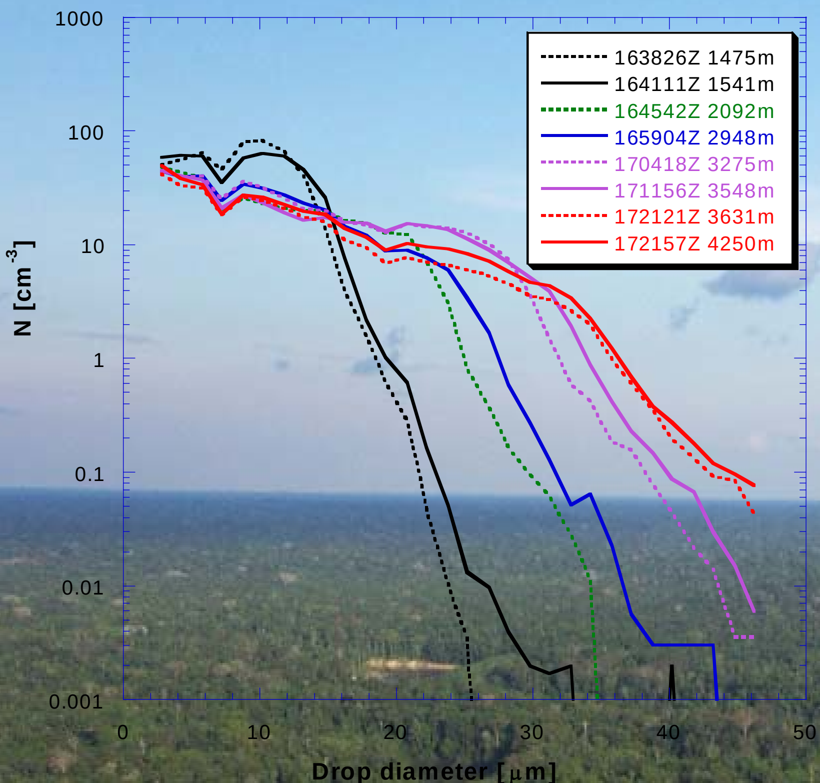
Modeling the effects of aerosol on precipitation



Teller and Zev Levin, 2006

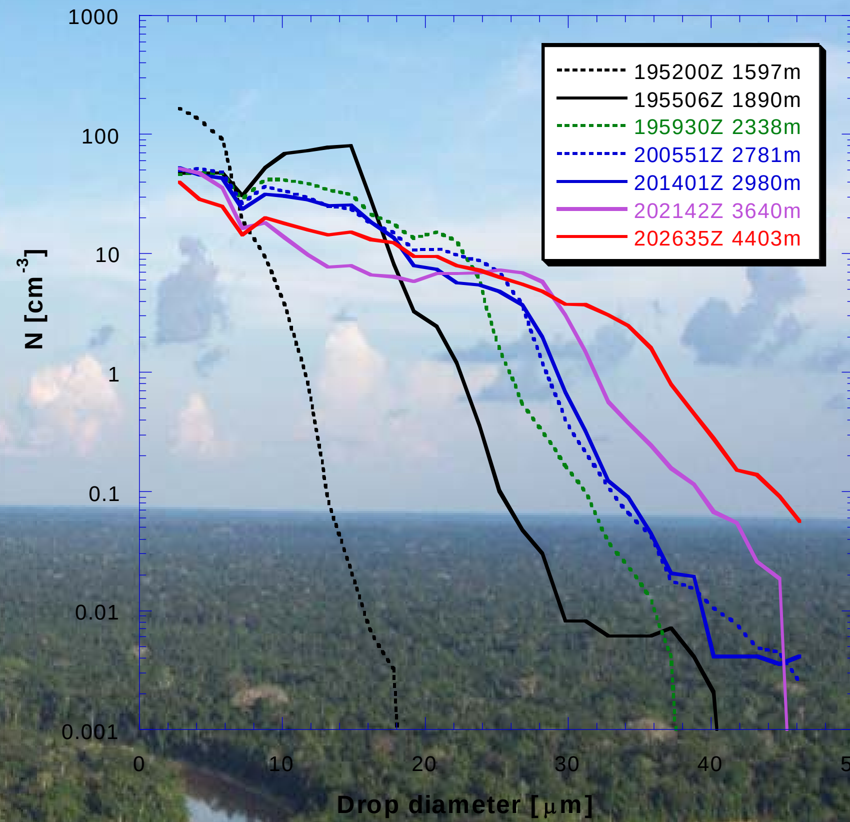
Warm rain evolution over the western tip of the Amazon, Noon.

DSD20021005_1



Warm rain evolution over the western tip of the Amazon, afternoon.

DSD20021005_2



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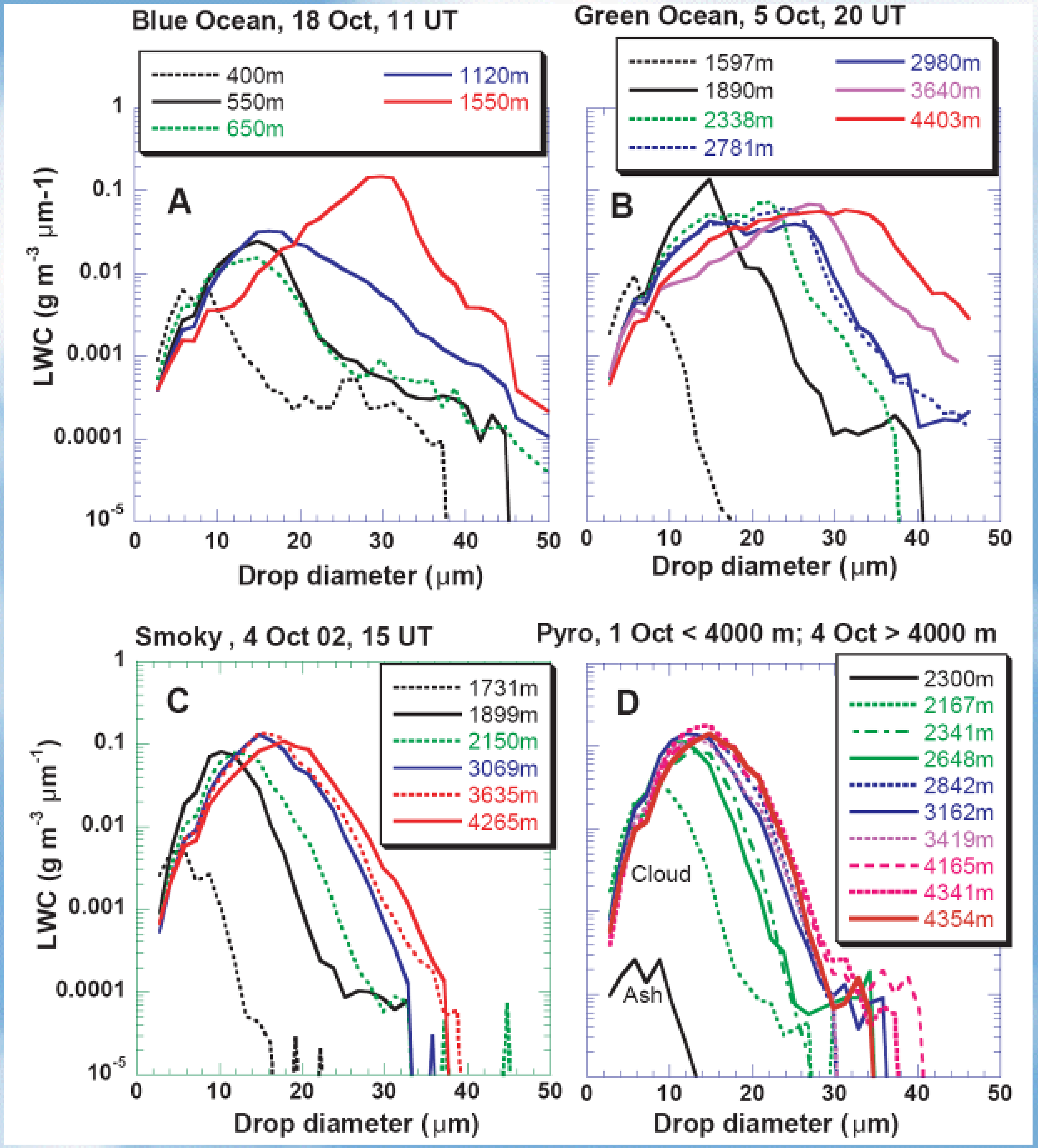
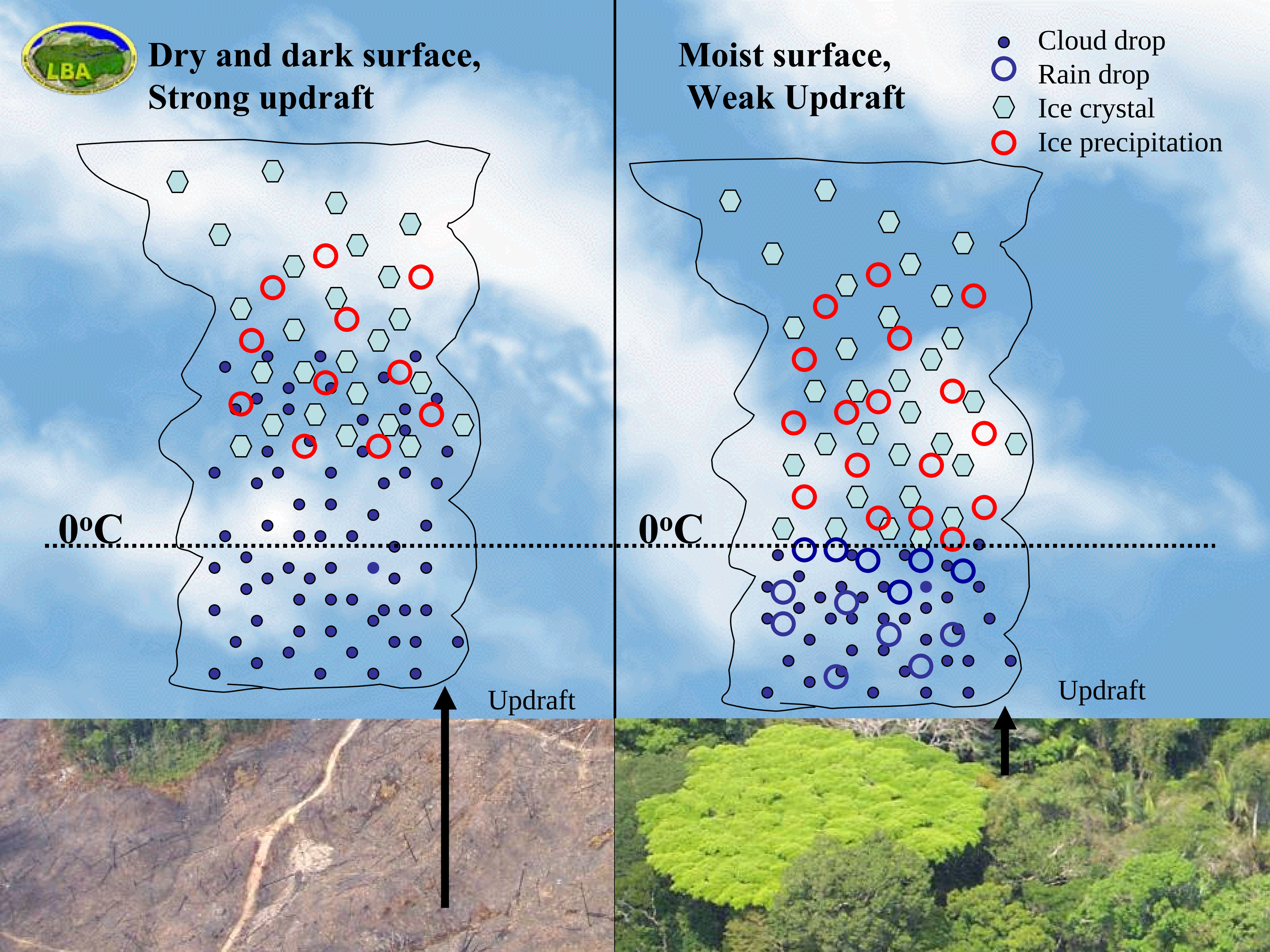
Addition of pyrogenic CCN has pronounced impact on cloud droplet size spectra



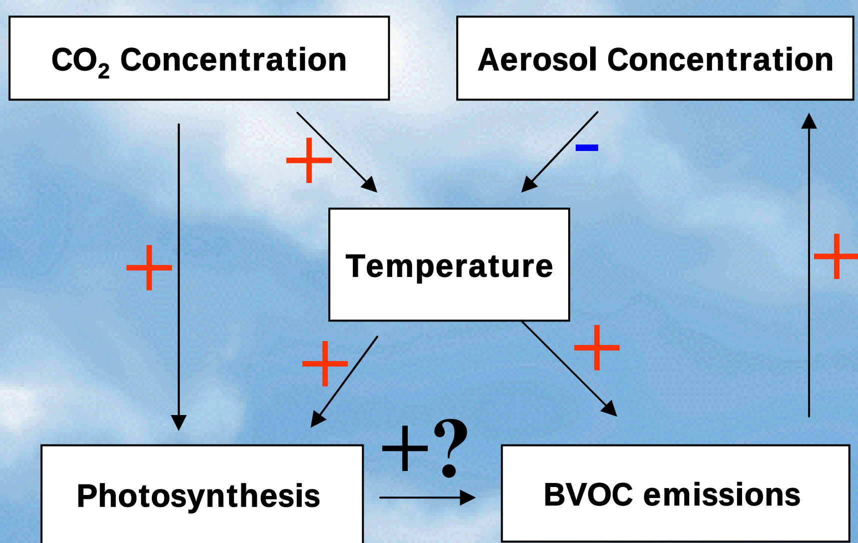
Four aerosol regimes of:
(A) *Blue Ocean*,(B) *Green Ocean*,
(C) *Smoky clouds,* (D) *Pyro-clouds*

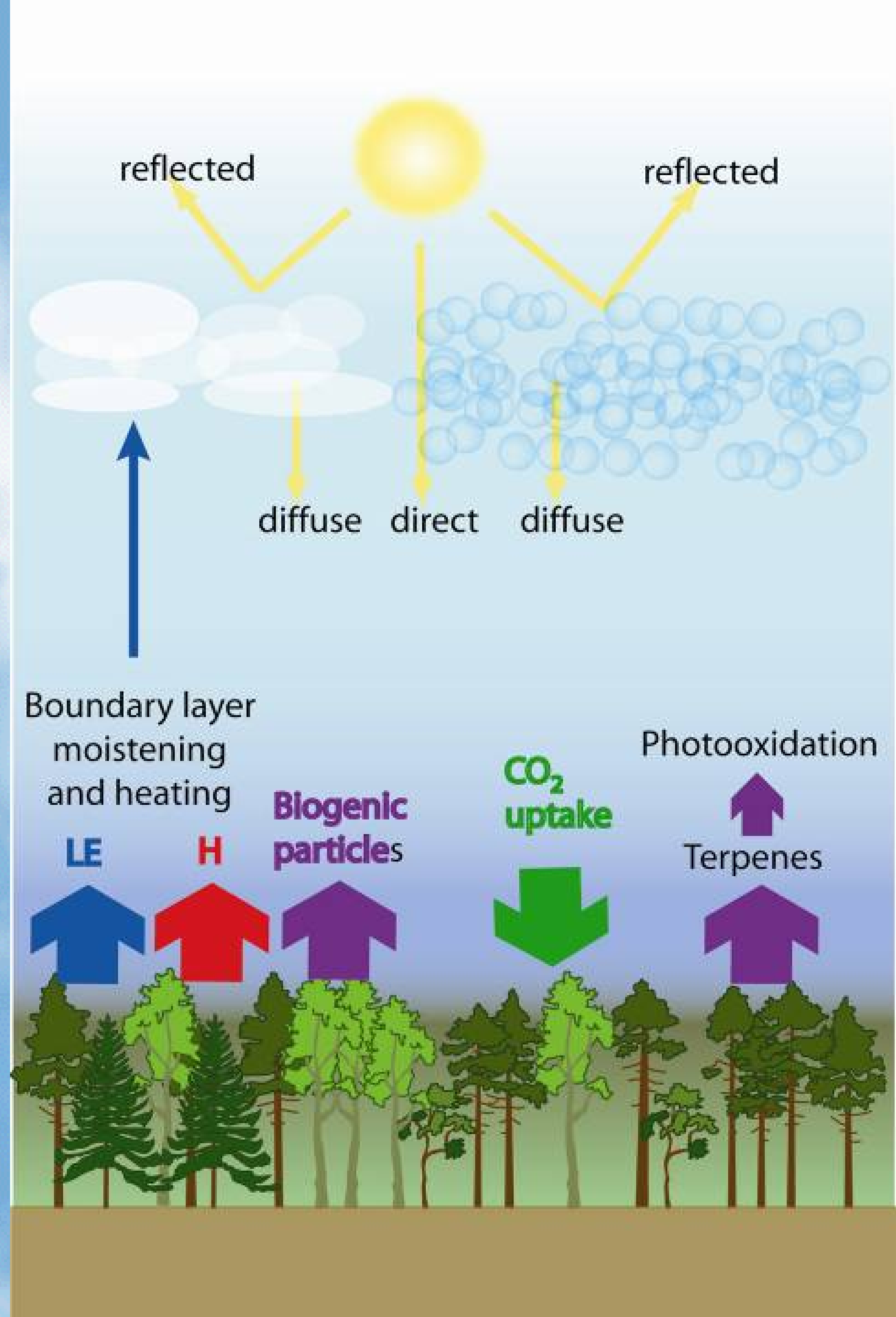
Note that the narrowing of CDSD and the slowing of its rate of broadening with height for the progressively more aerosol rich regimes from A to D.

D. Rosenfeld, 2004


LBA
Dry and dark surface,
Strong updraft
Moist surface,
Weak Updraft
Cloud drop
Rain drop
Ice crystal
Ice precipitation
0ºC
0ºC
Updraft
Updraft

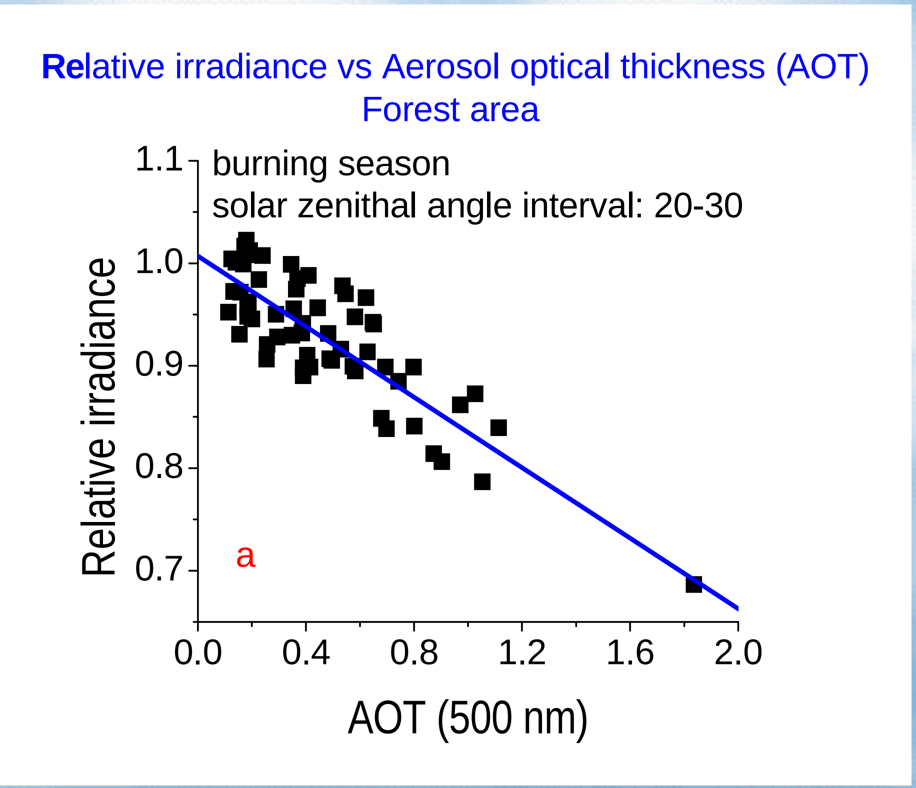
Effect of aerosol particles on forest photosynthesis



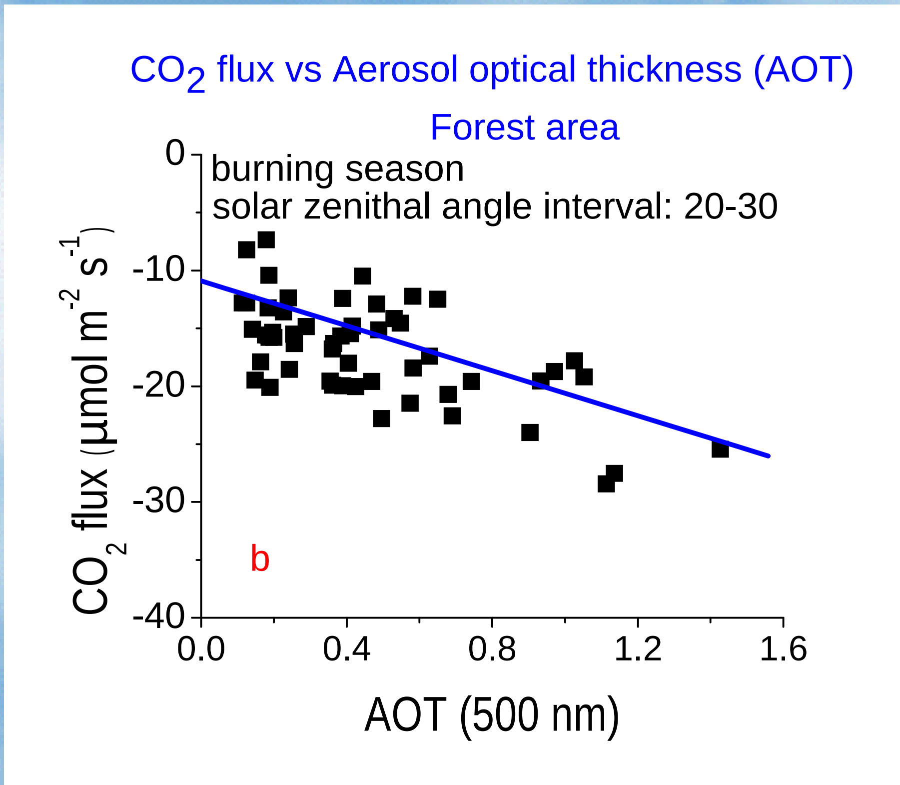


Kulmala et al., 2004

Relative irradiance versus AOT



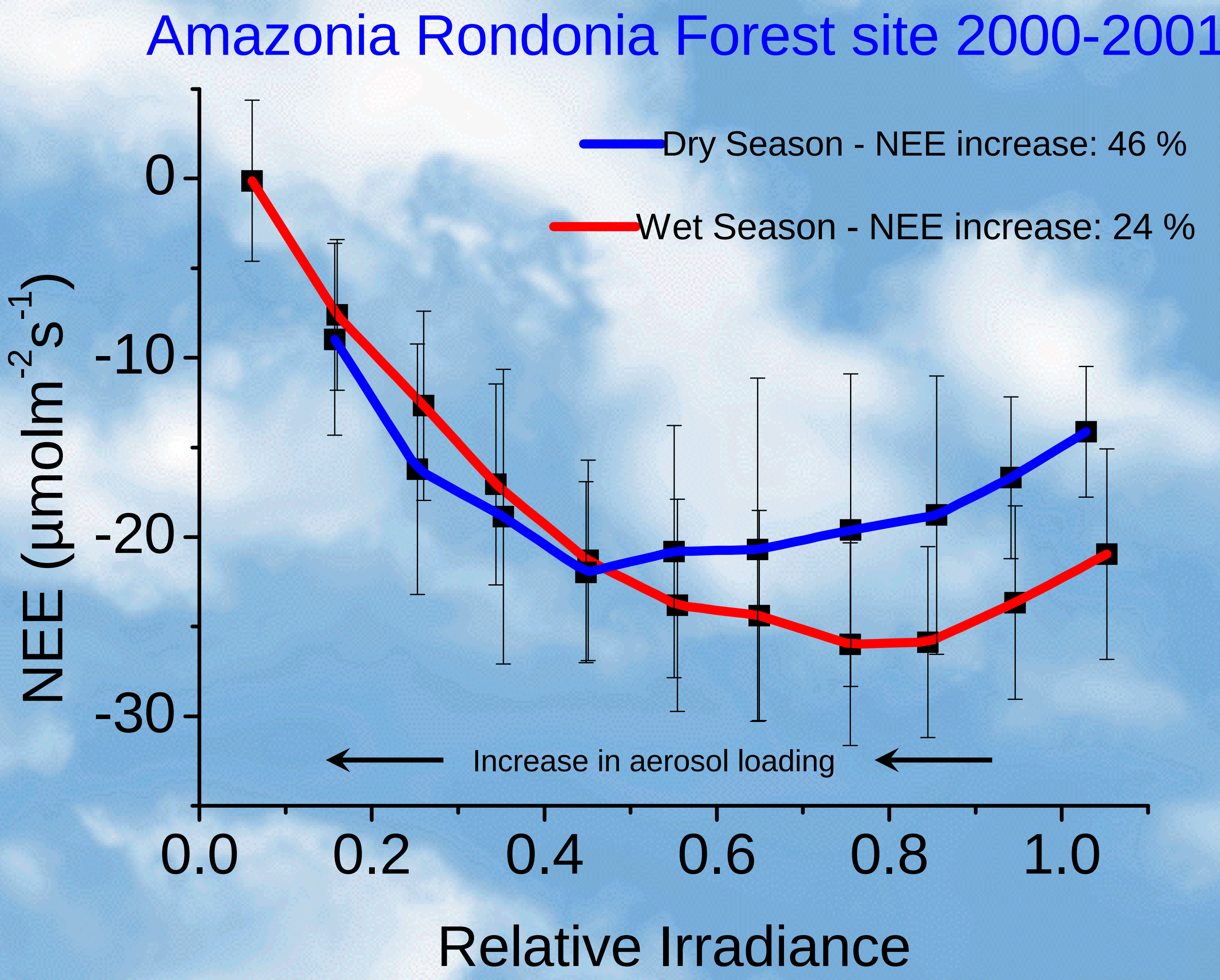
CO_2 flux versus AOT

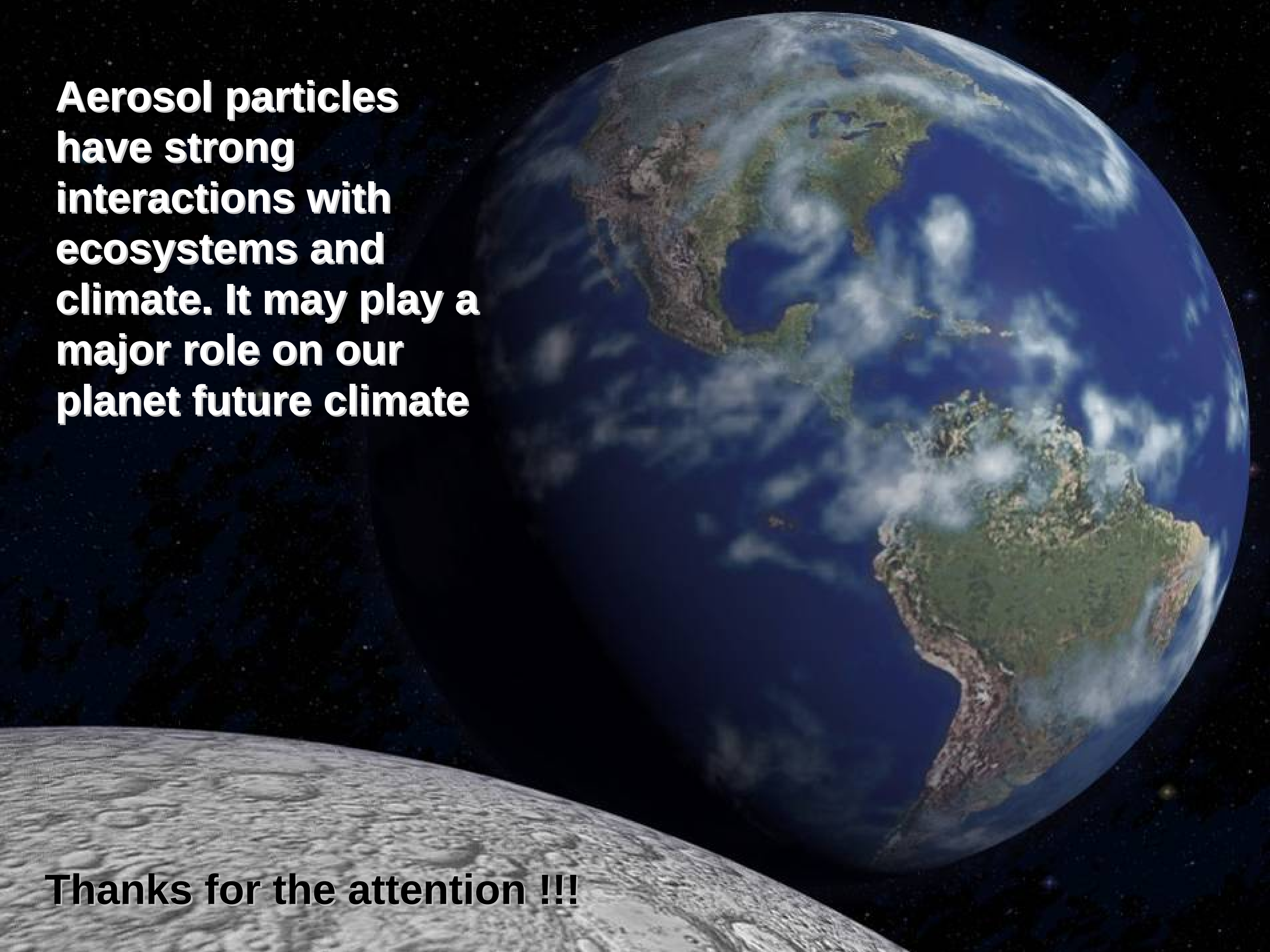


ΔAOT: 0.1 to 1.2 → Δ f_B: - 20 % → Δ NEE: + 50 %

After doing cloud screening to get only the aerosol effect, the result is shown in (a). The irradiance is reduced up to 20 % for AOT varying from 0.1 to 1.2. The relationship between CO_2 fluxes measurements (NEE, storage corrected) and aerosols (b), expressed as AOT. The CO_2 flux increases up to 50 % for AOT varying from 0.1 to 1.2. The increase in the diffuse fraction of the solar irradiance is the factor that explain this behavior.

Strong aerosol effect on forest photosynthesis





Aerosol particles have strong interactions with ecosystems and climate. It may play a major role on our planet future climate

Thanks for the attention !!!