Física do Meio Ambiente
Aula introdutória

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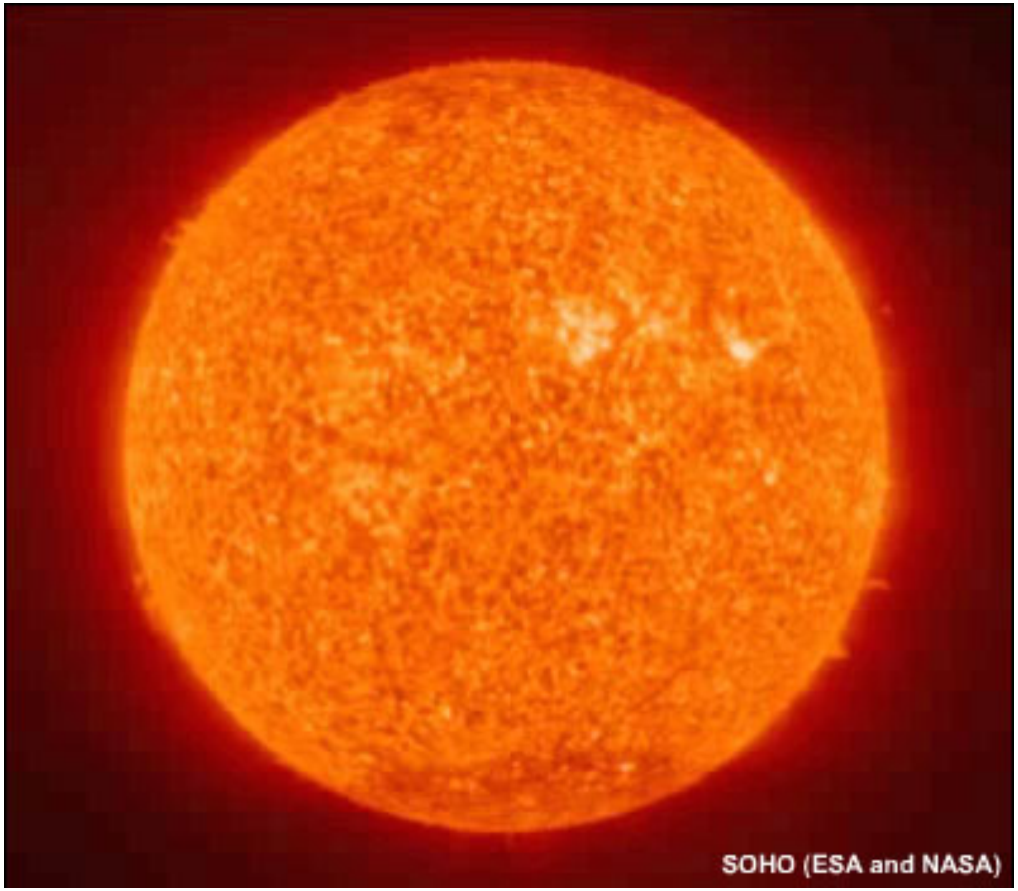
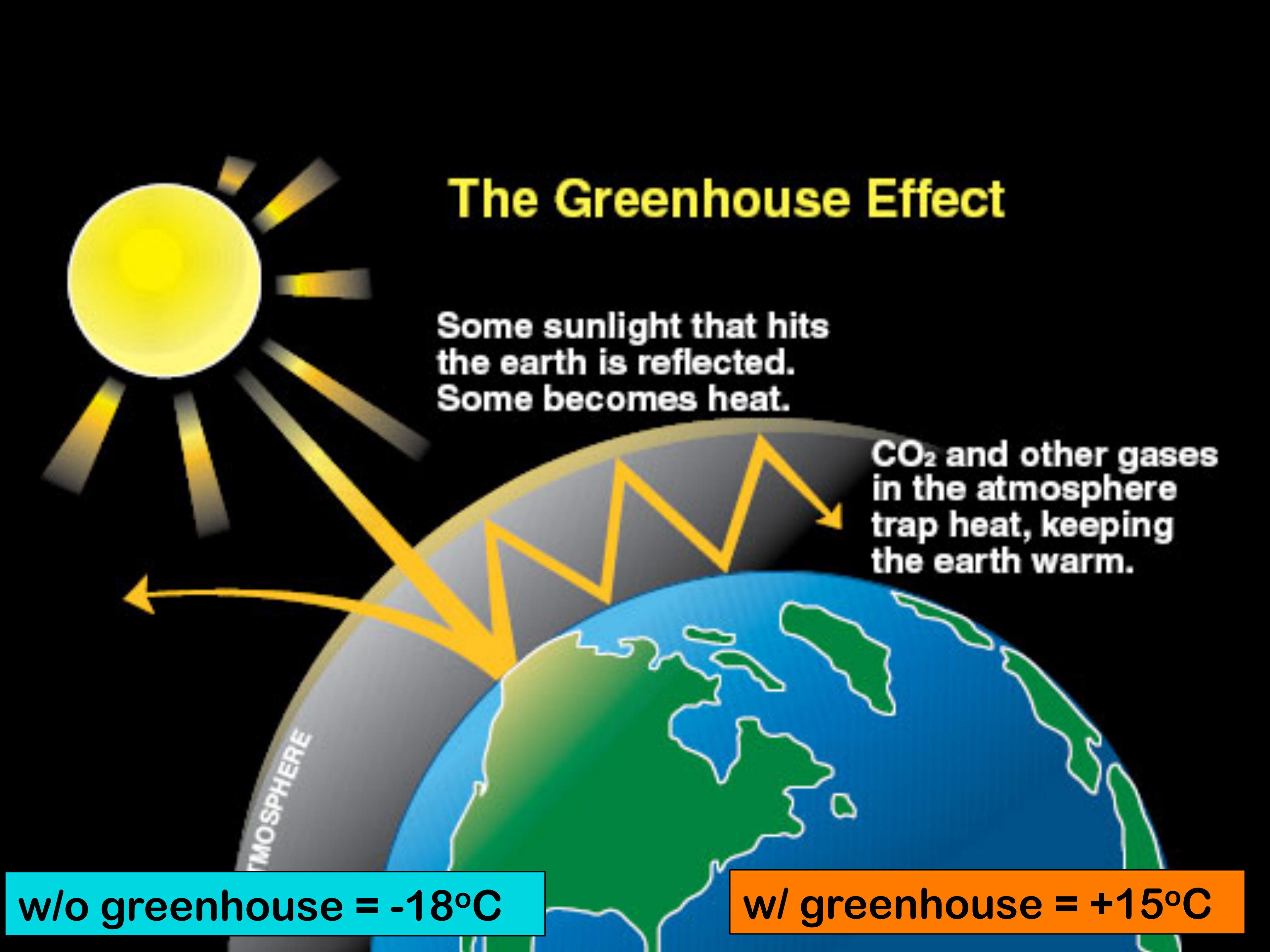
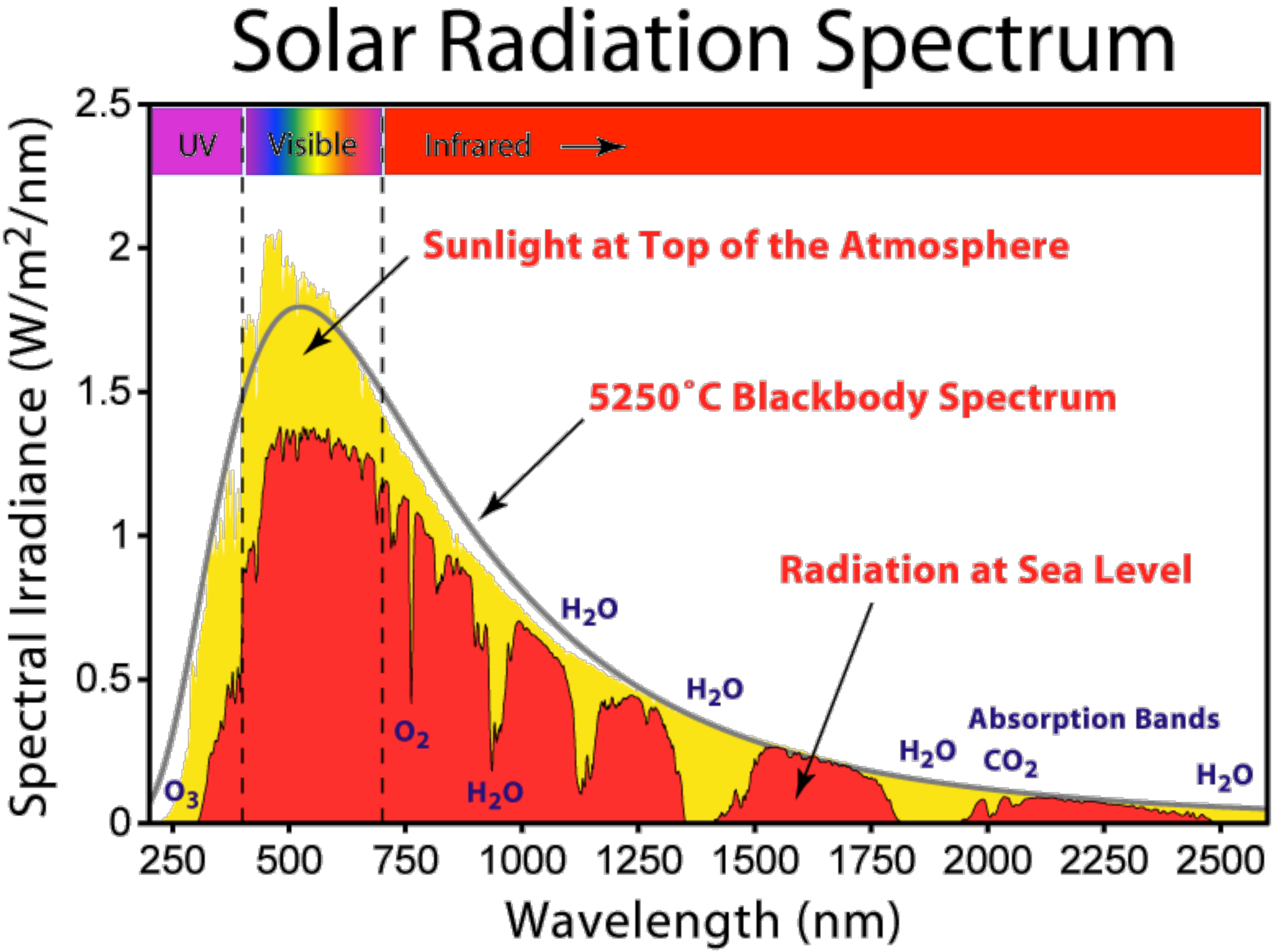
O Sol é a nossa fonte de energia

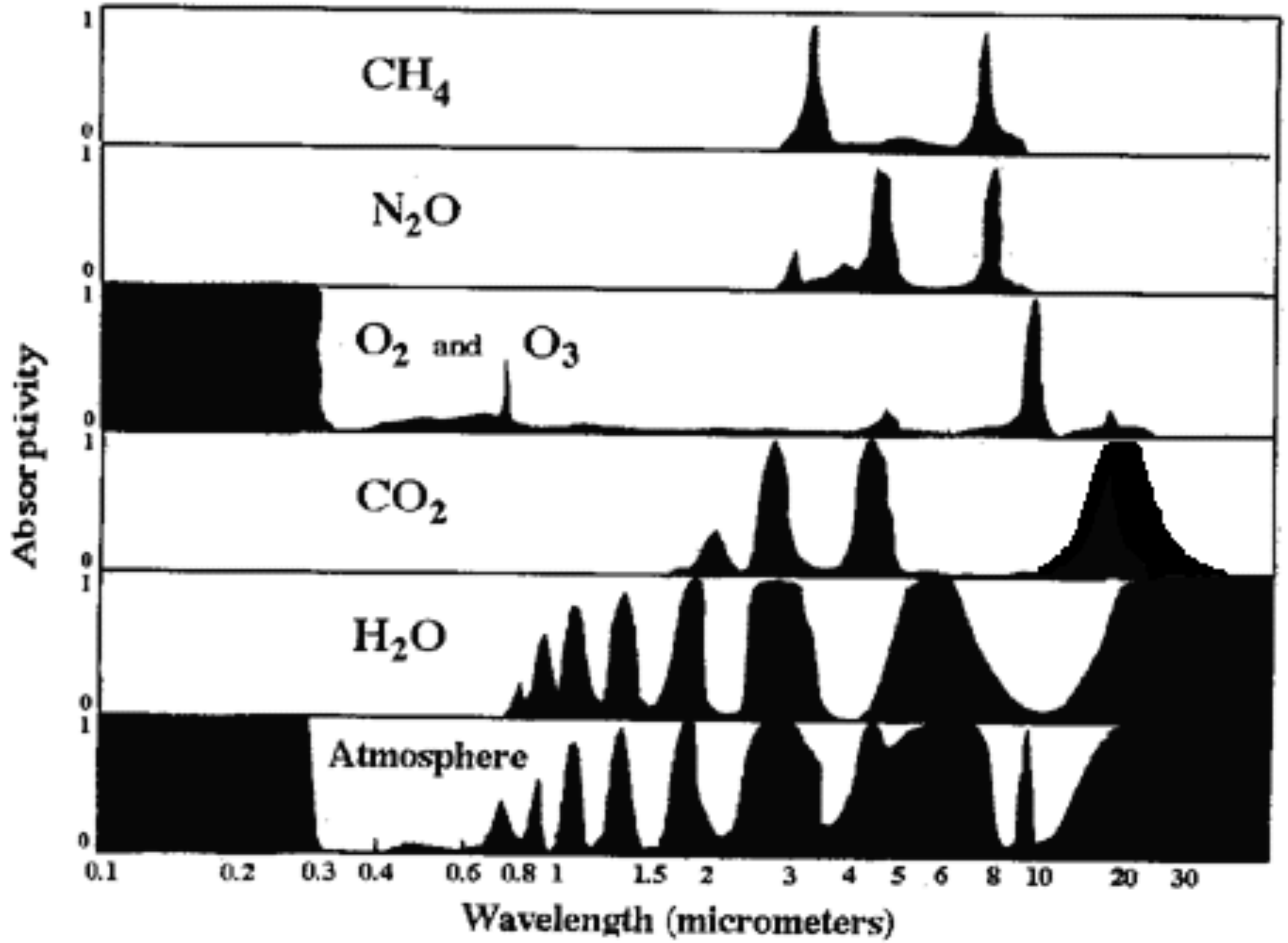


Sem o Sol, a temperatura na Terra seria -270^{o}C


The Greenhouse Effect
Some sunlight that hits the earth is reflected. Some becomes heat.
CO_2 and other gases in the atmosphere trap heat, keeping the earth warm.
TMOSPHERE
w/o greenhouse = -18^{o}C
w/ greenhouse = +15^{o}C

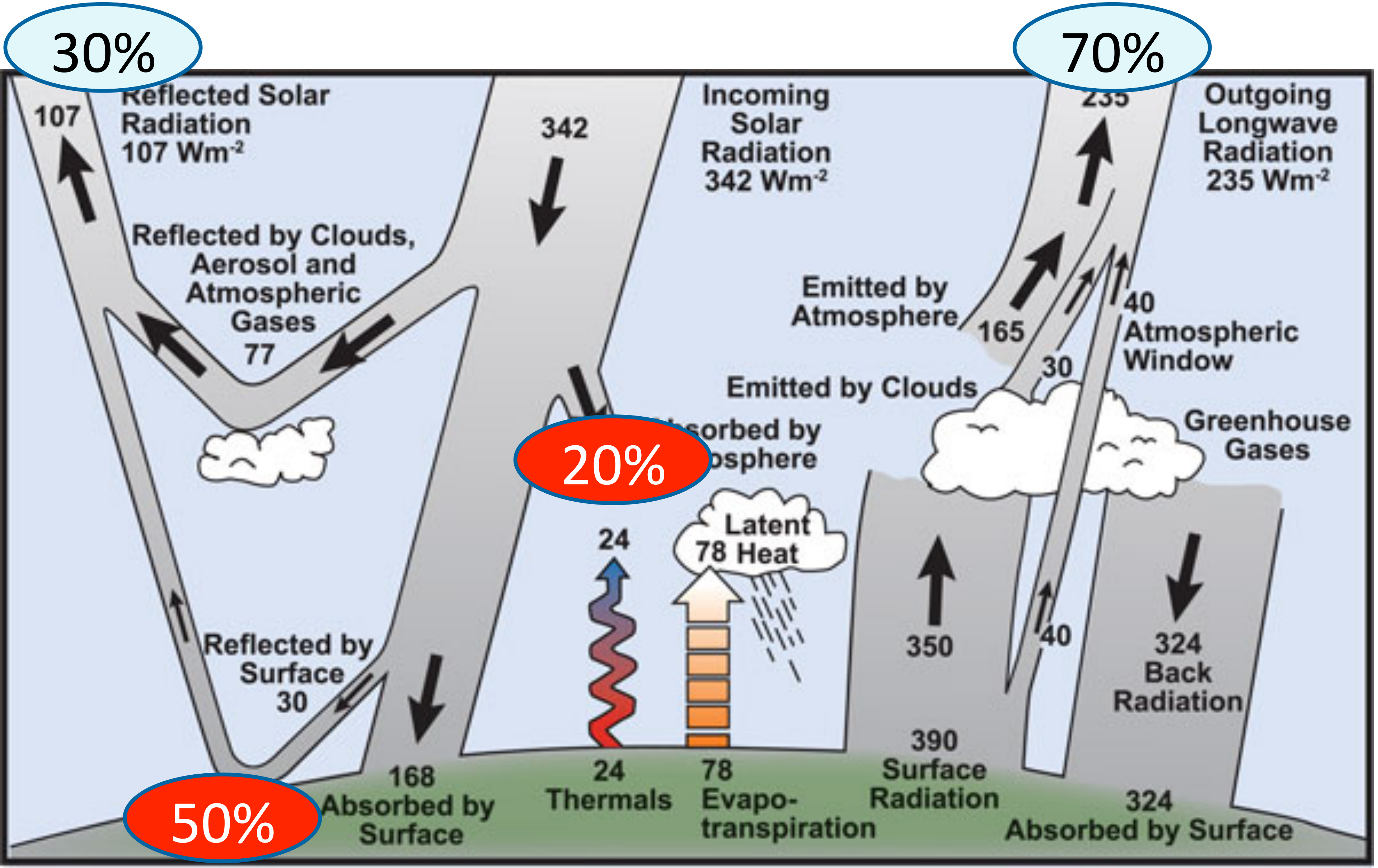


Solar Radiation Spectrum
UV
Visible
Infrared
Sunlight at Top of the Atmosphere
5250˚C Blackbody Spectrum
Radiation at Sea Level
Absorption Bands
O_3
O_2
H_2O
H_2O
H_2O
H_2O
CO_2
H_2O
Spectral Irradiance (W/m^2/nm)
0
0.5
1
1.5
2
2.5
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)



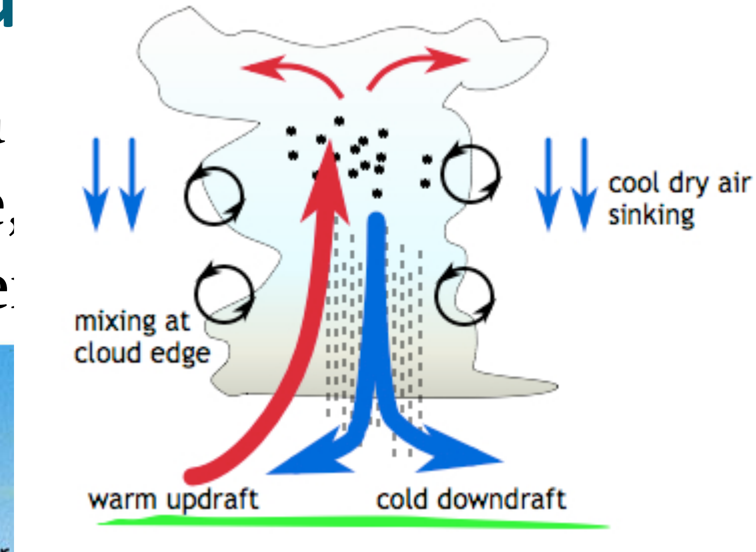
Absorptivity of various gases of the atmosphere and the atmosphere as a whole as a function of the wavelength of radiation. An absorptivity of zero means no absorption while a value of one means complete absorption. The dominant absorbers of infrared radiation are water vapor (H_2O) and carbon dioxide (CO_2). Oxygen (O_2) and ozone (O_3) absorb much of the sun's ultraviolet radiation.

Atmospheric Energy Balance

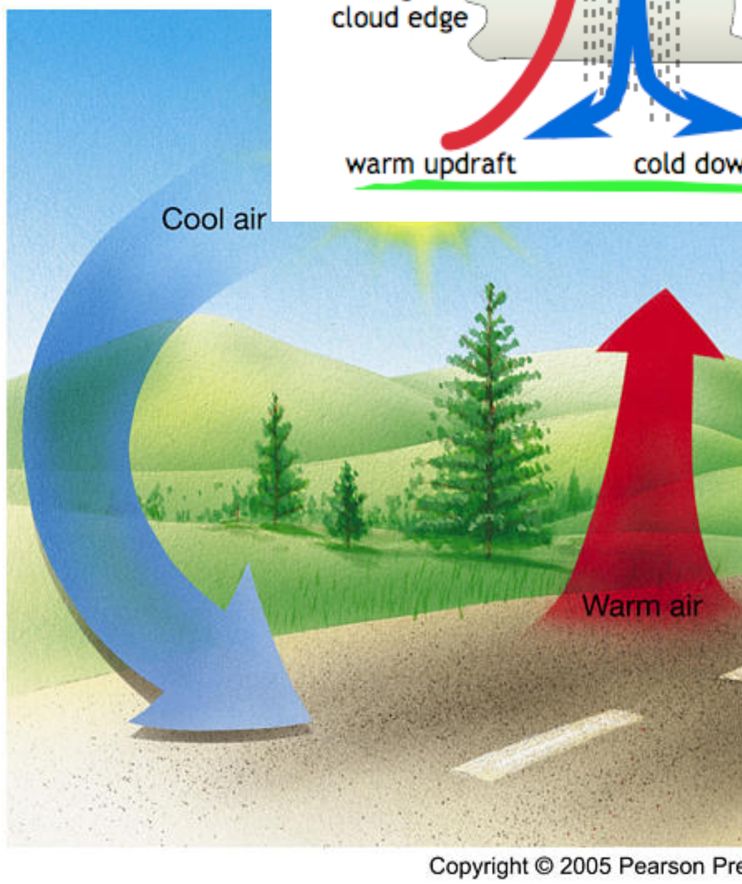


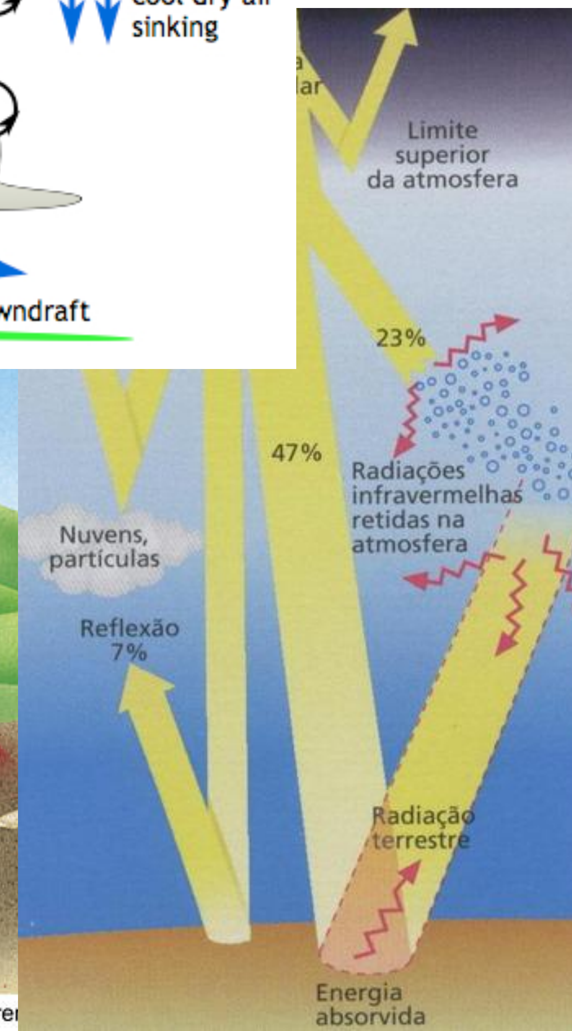
Convecção e Nu

- Como a maior parte da
absorvida na superfície,
esquentando a atmosfe



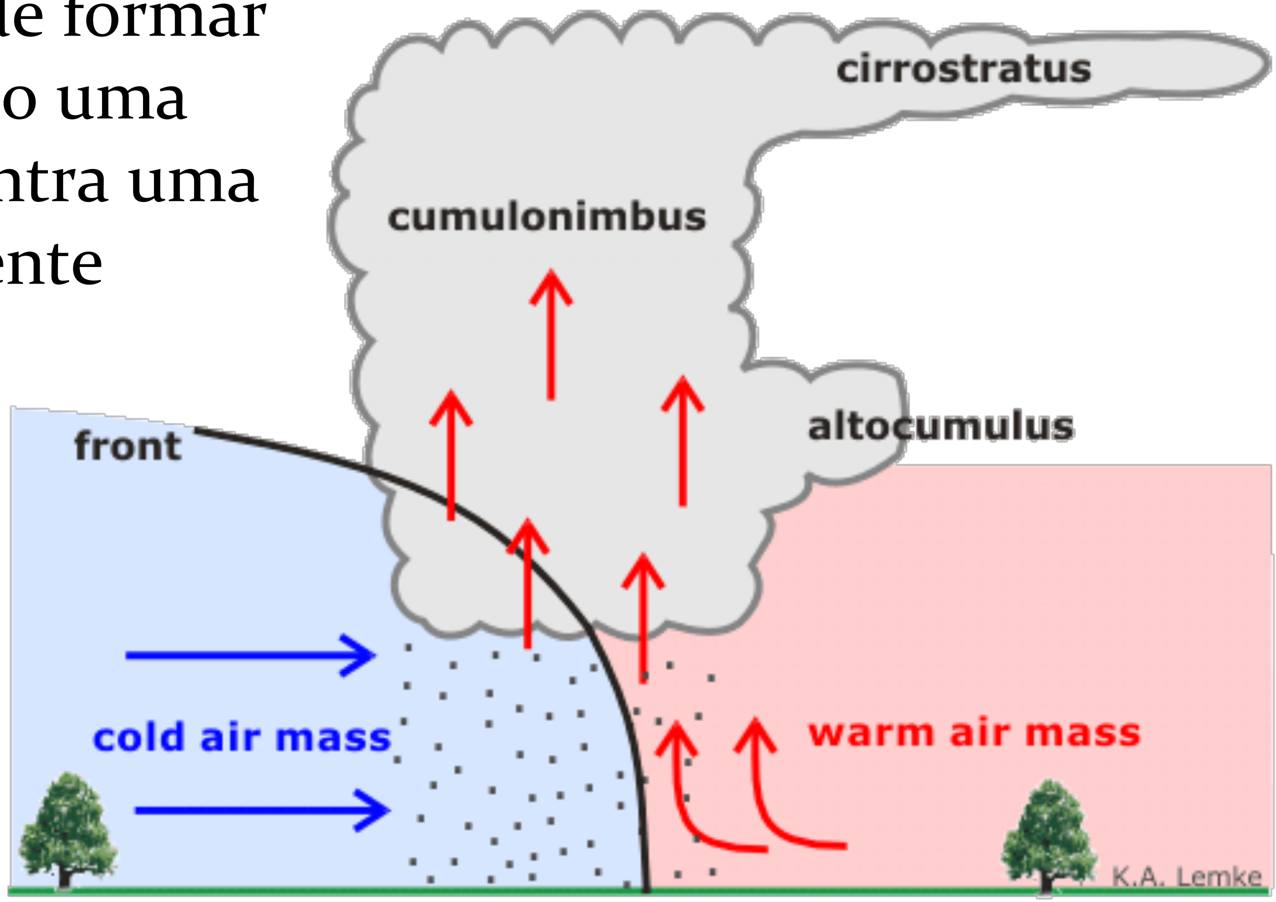
O ar quente é menos denso e sobe, pois o ar frio que está em cima é mais pesado.





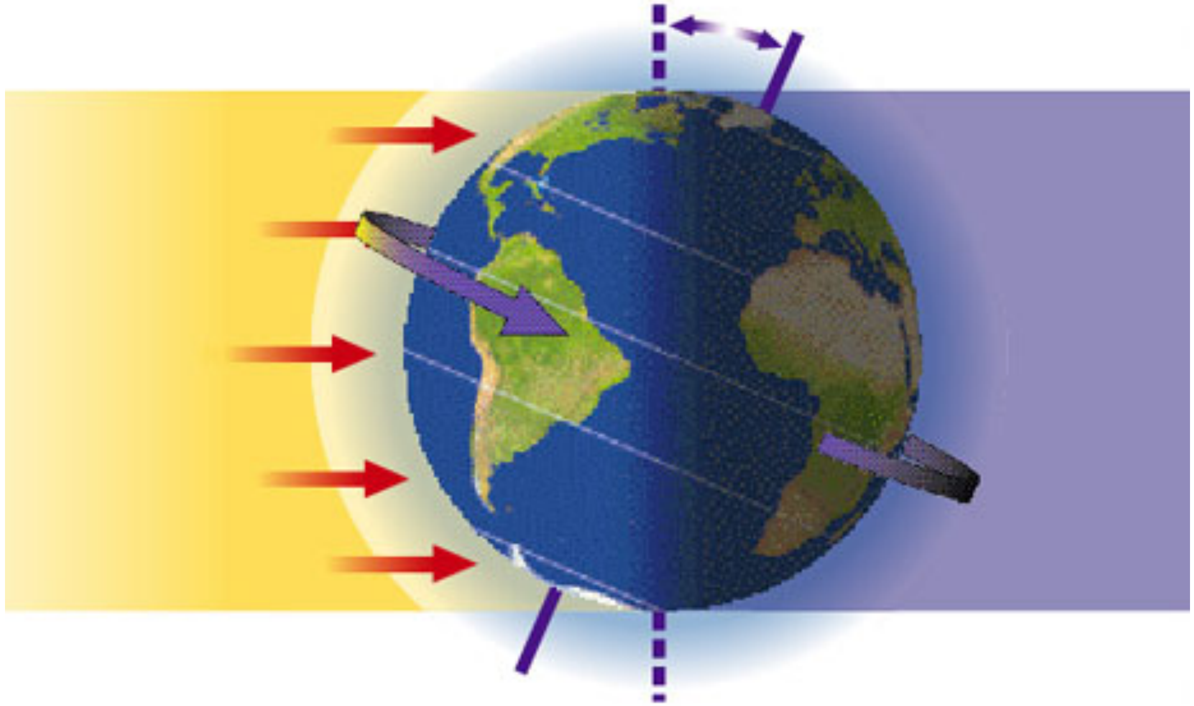
Nuvens e Frentes

- Uma outra maneira muito comum de formar nuvens é quando uma frente fria encontra uma massa de ar quente

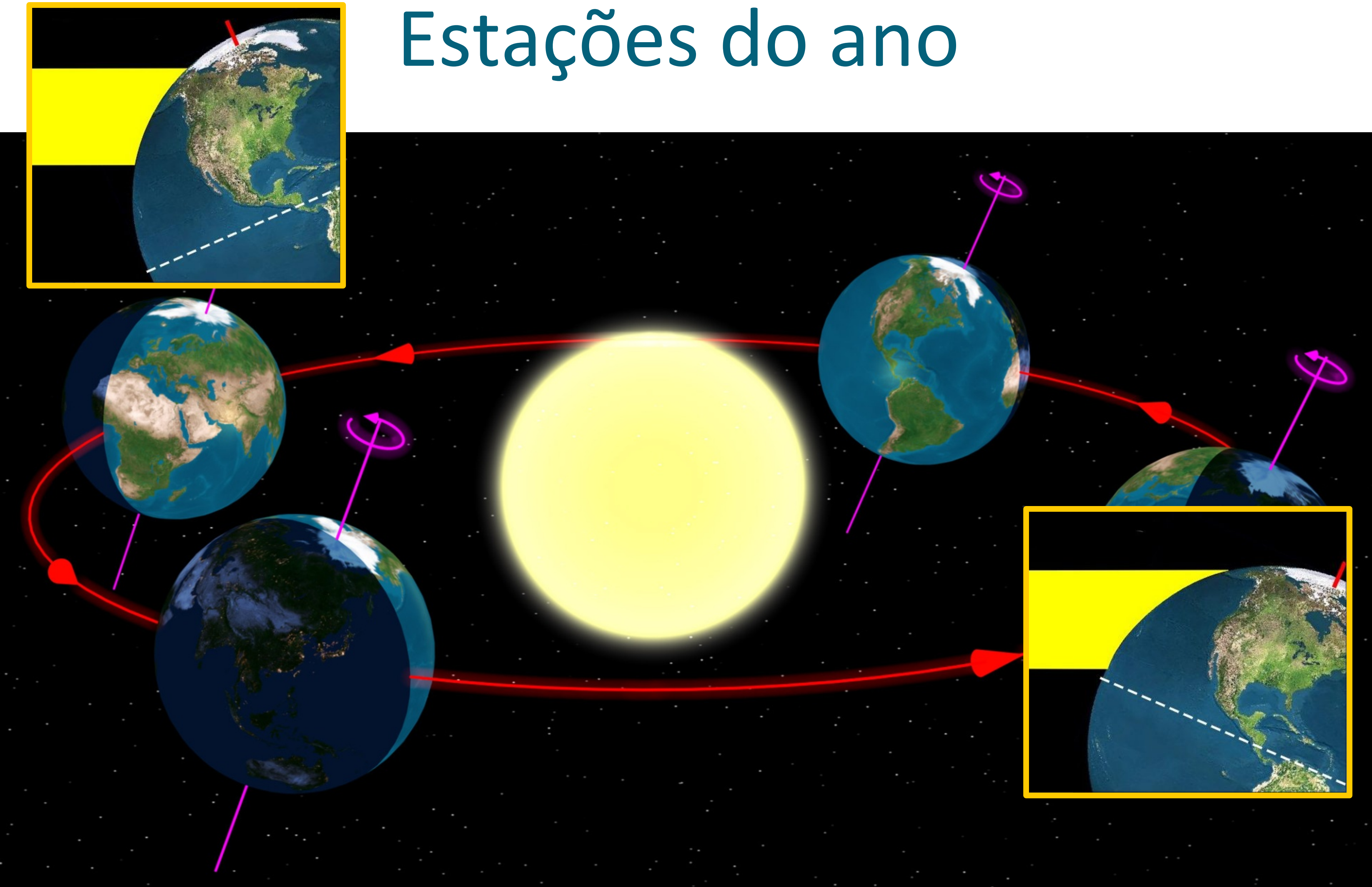


Dia e Noite

- A energia que recebemos do Sol também não é distribuída igualmente pela superfície do planeta!
  - Giro em torno do próprio eixo
  - O eixo é inclinado em relação a órbita em torno do Sol



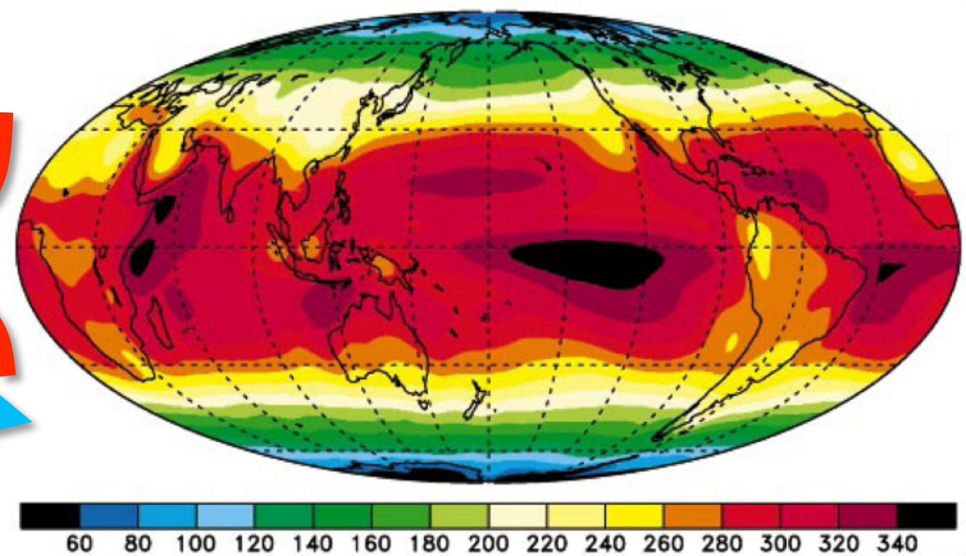
Estações do ano



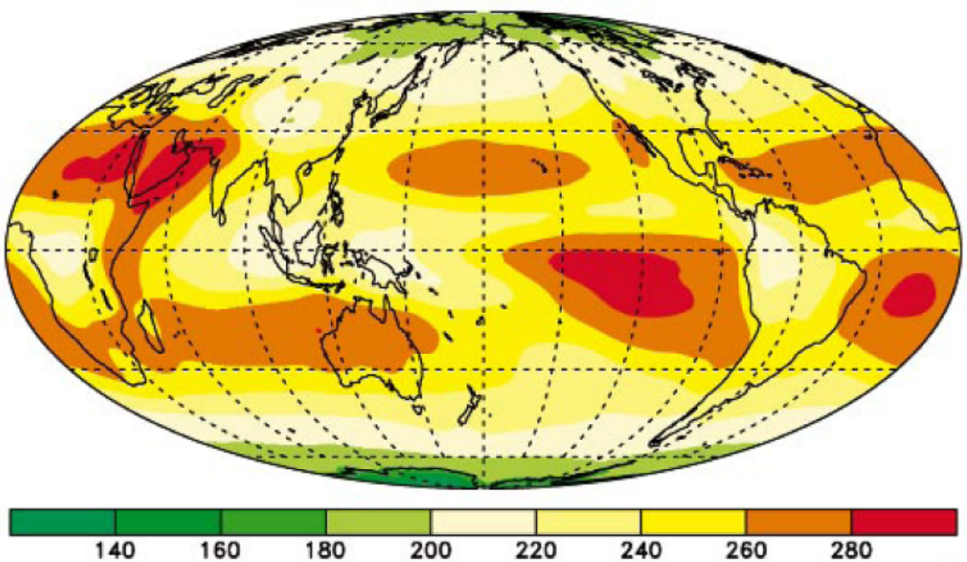
Distribution on the Earth

Hot air rises at the equator

Cold dry air decendes at high latitudes



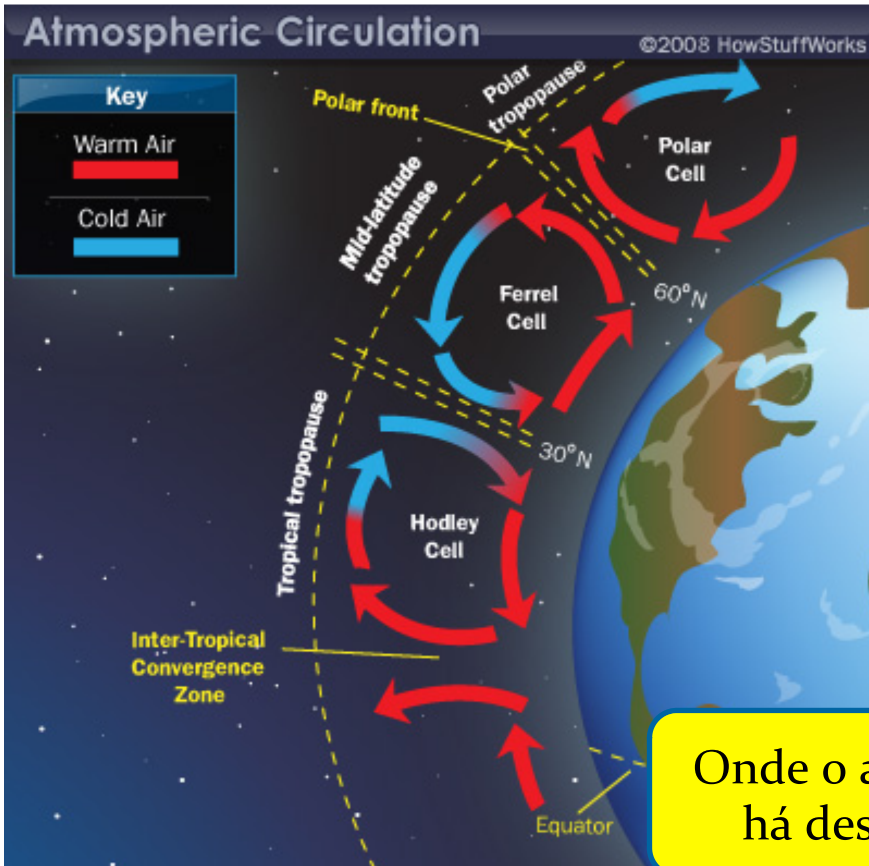
Annual mean solar radiation budget at top (W/m2)

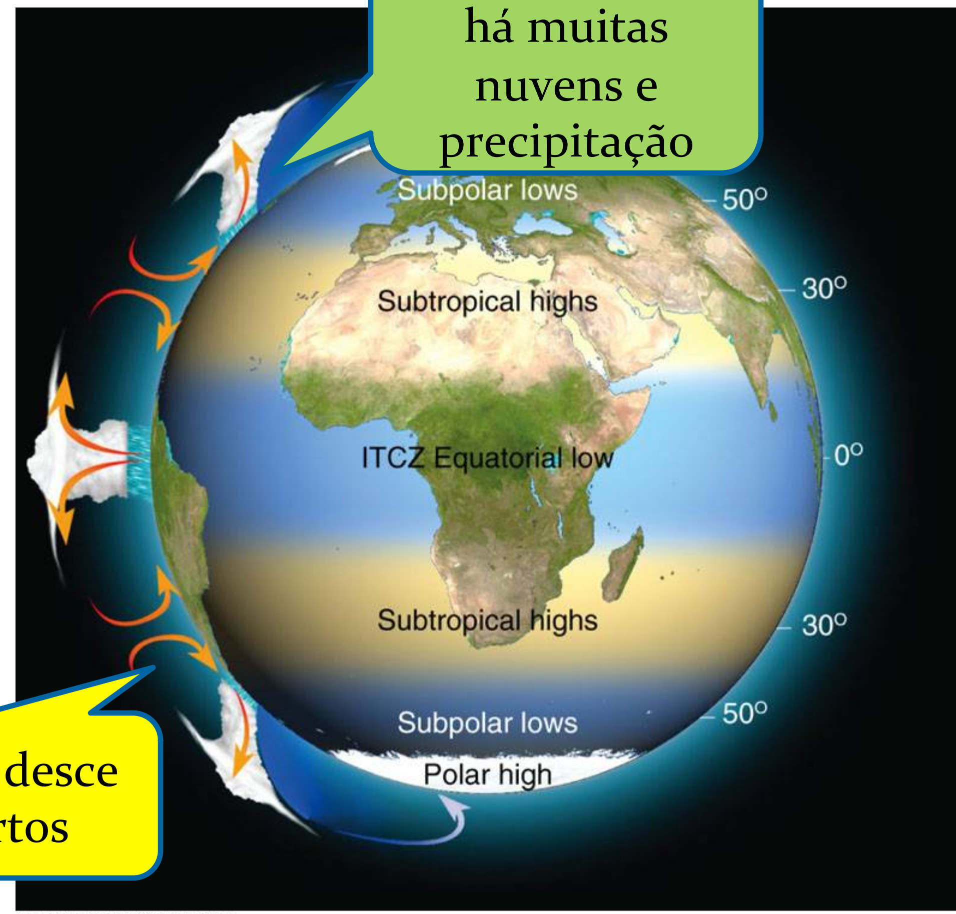


Annual mean outgoing long wave radiation at top (W/m2)

Trenberth and Stepaniak, J. Clim. (2003)

Circulação de grande escala



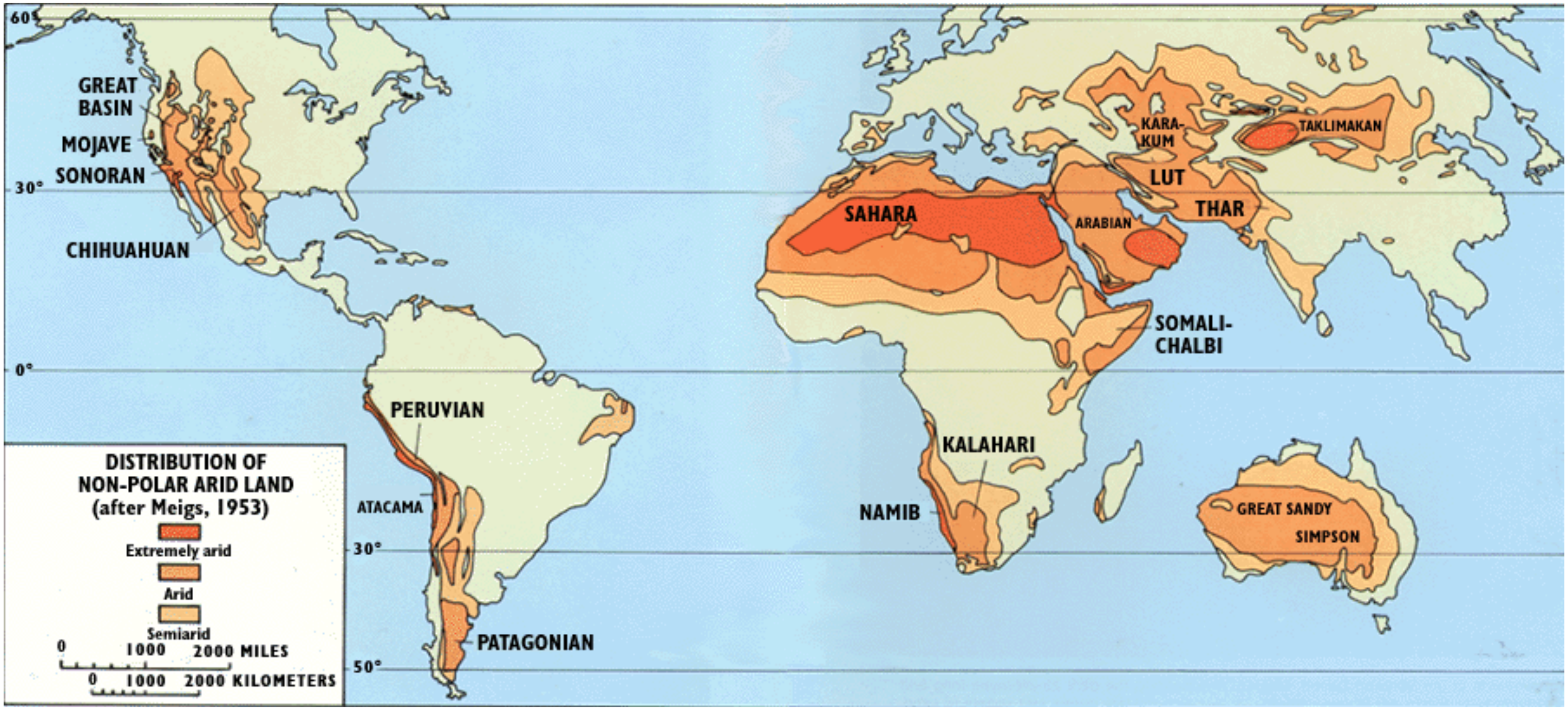


Onde o ar sobe há muitas nuvens e precipitação

Onde o ar desce há desertos

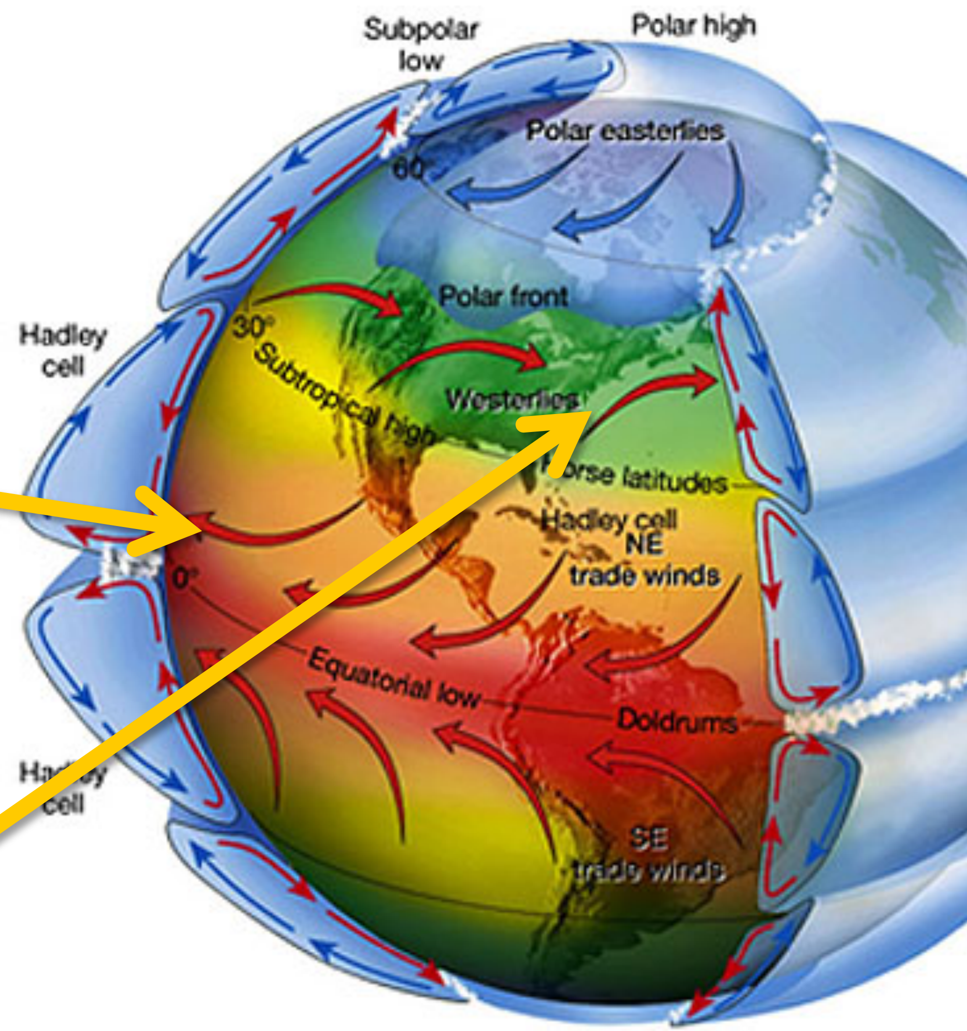
Localização dos grandes desertos

- Nas latitudes onde o ar desce seco e frio, há precipitação é pouco e as regiões são desérticas.



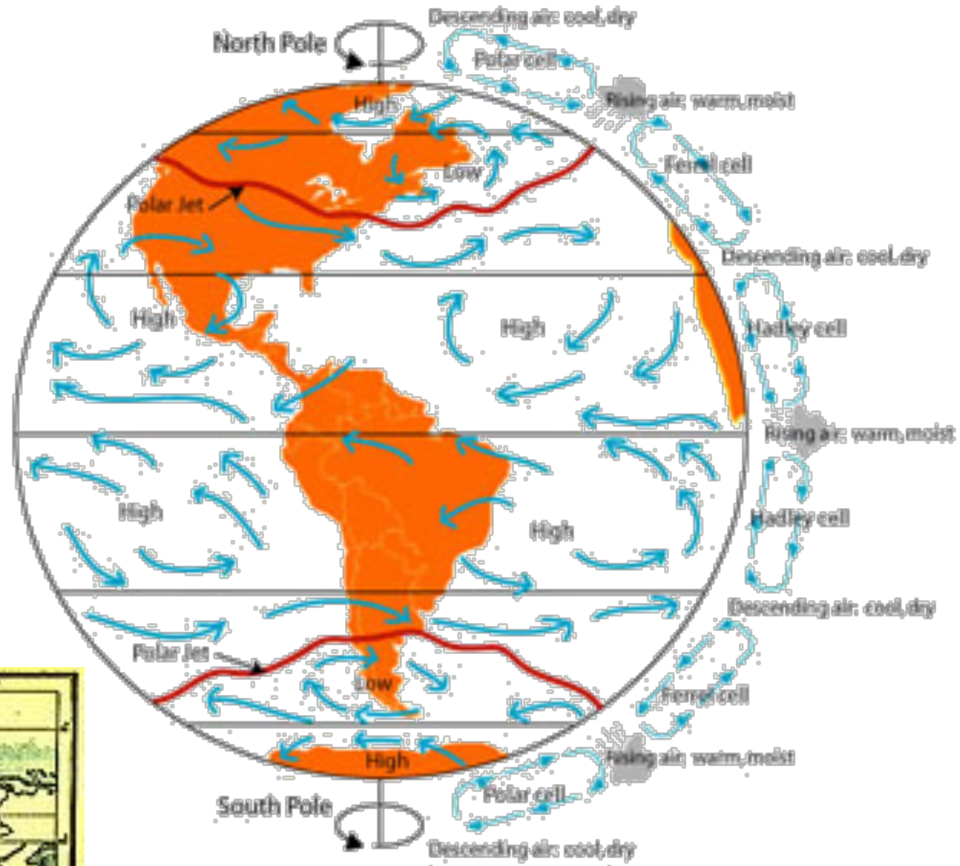
Circulação global

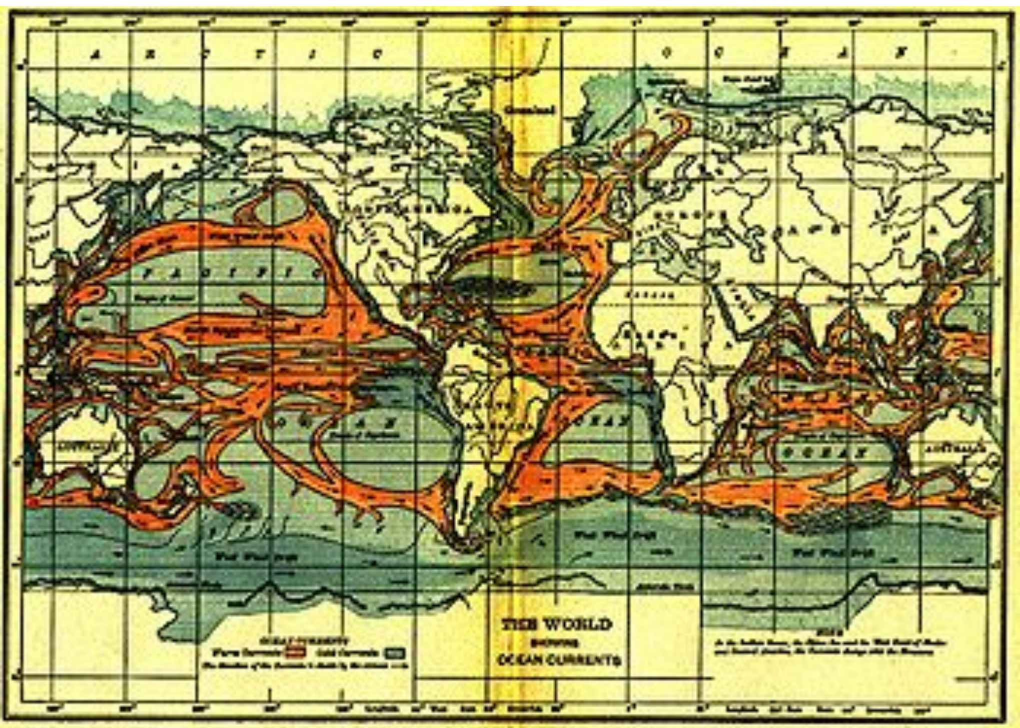
- Como a terra gira, por inércia, a atmosfera acaba ficando para traz.
  - A célula de Hadley fica inclinada no equador, formando os **Alísios**.
  - Já o ar que desce em latitudes mais altas está girando mais rápido que a chão (ele estava no EQ), e a circulação é ao contrário



Circulação Global

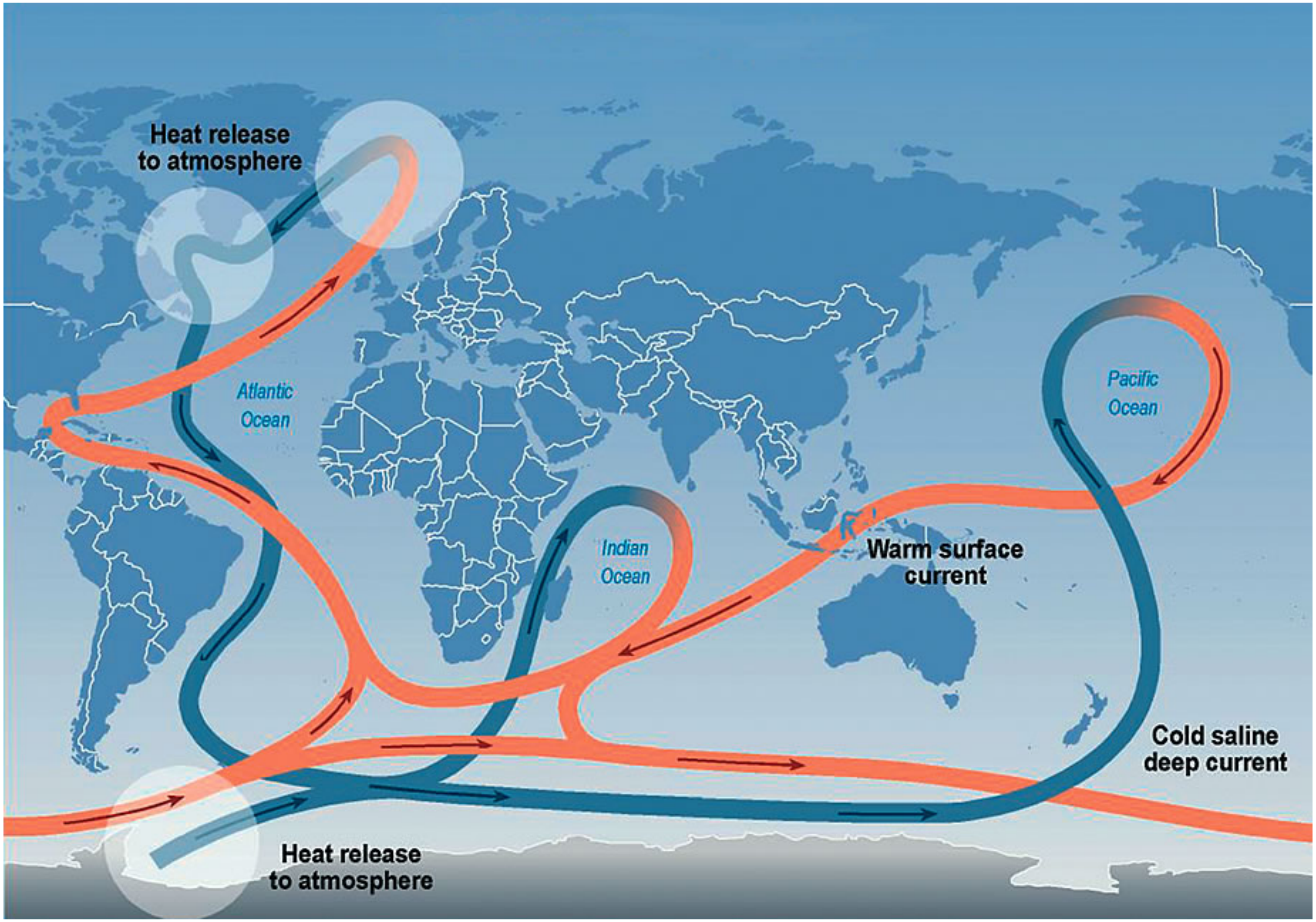
- Os ventos próximos da superfície forçam o surgimento de correntes oceânicas





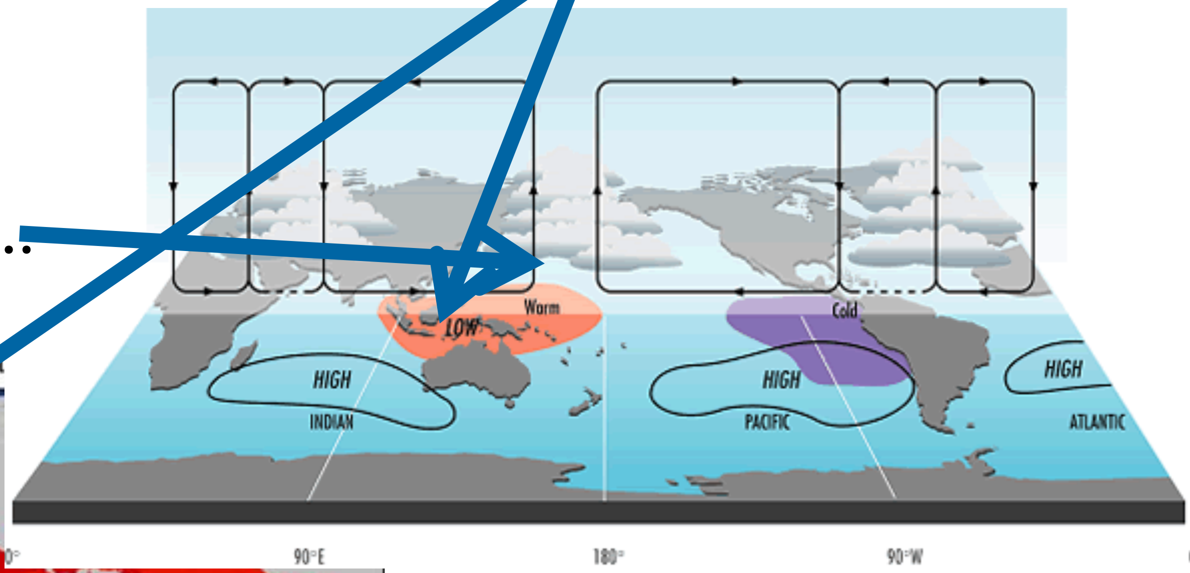
1911

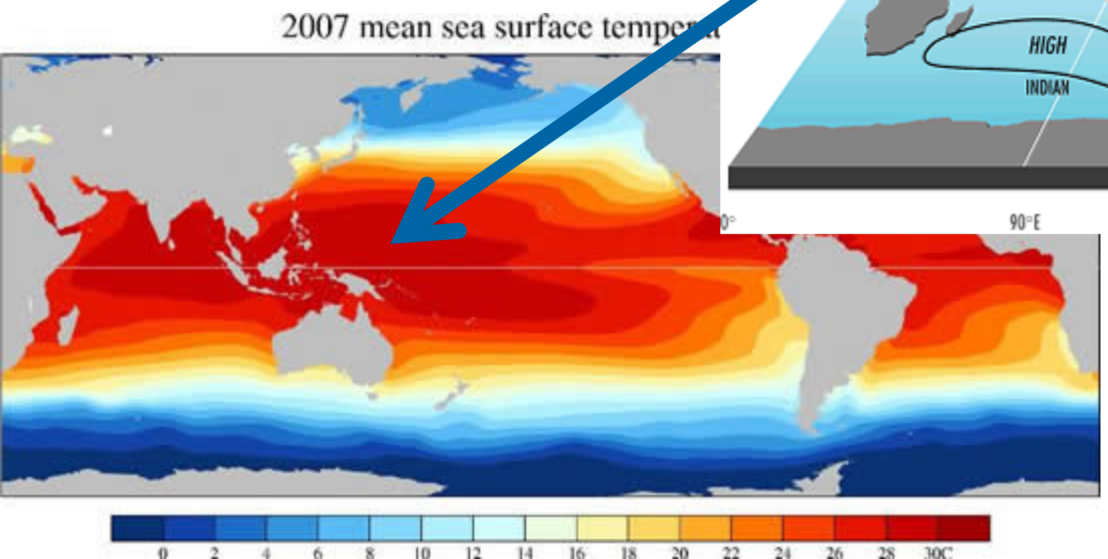
Oceanic circulation



Circulação de Walker

- Devido a presença constante dos ventos alísios, a água mais quente vai sendo empurrada para oeste.
- Esta região de águas quentes força uma convecção constante...

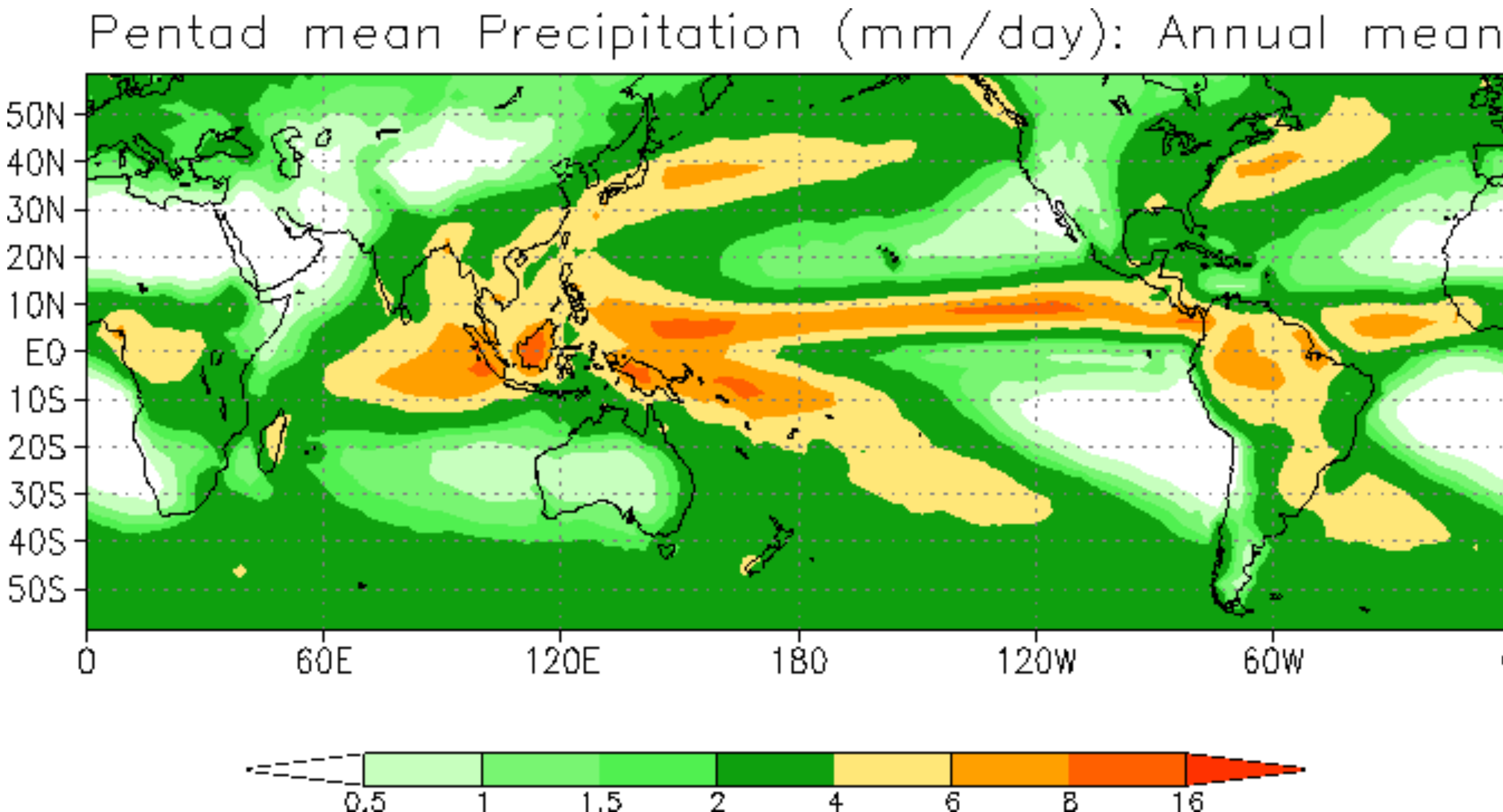




- Estas células formam a circulação de Walker.

Precipitação

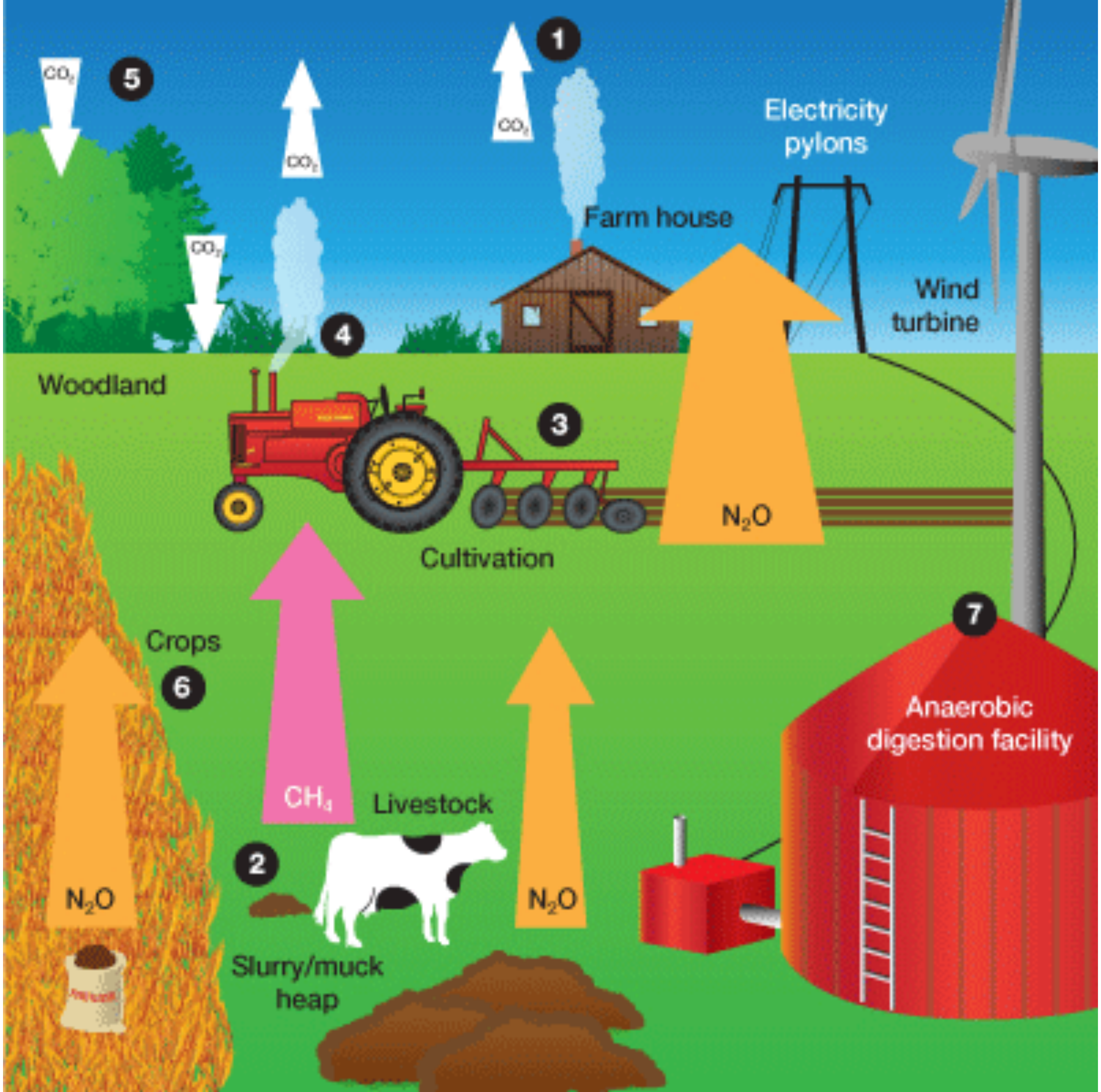
- A distribuição global dos ventos, e principalmente de onde eles sobem e descem, determinam em grande parte a distribuição da precipitação



Circulação da Atmosfera

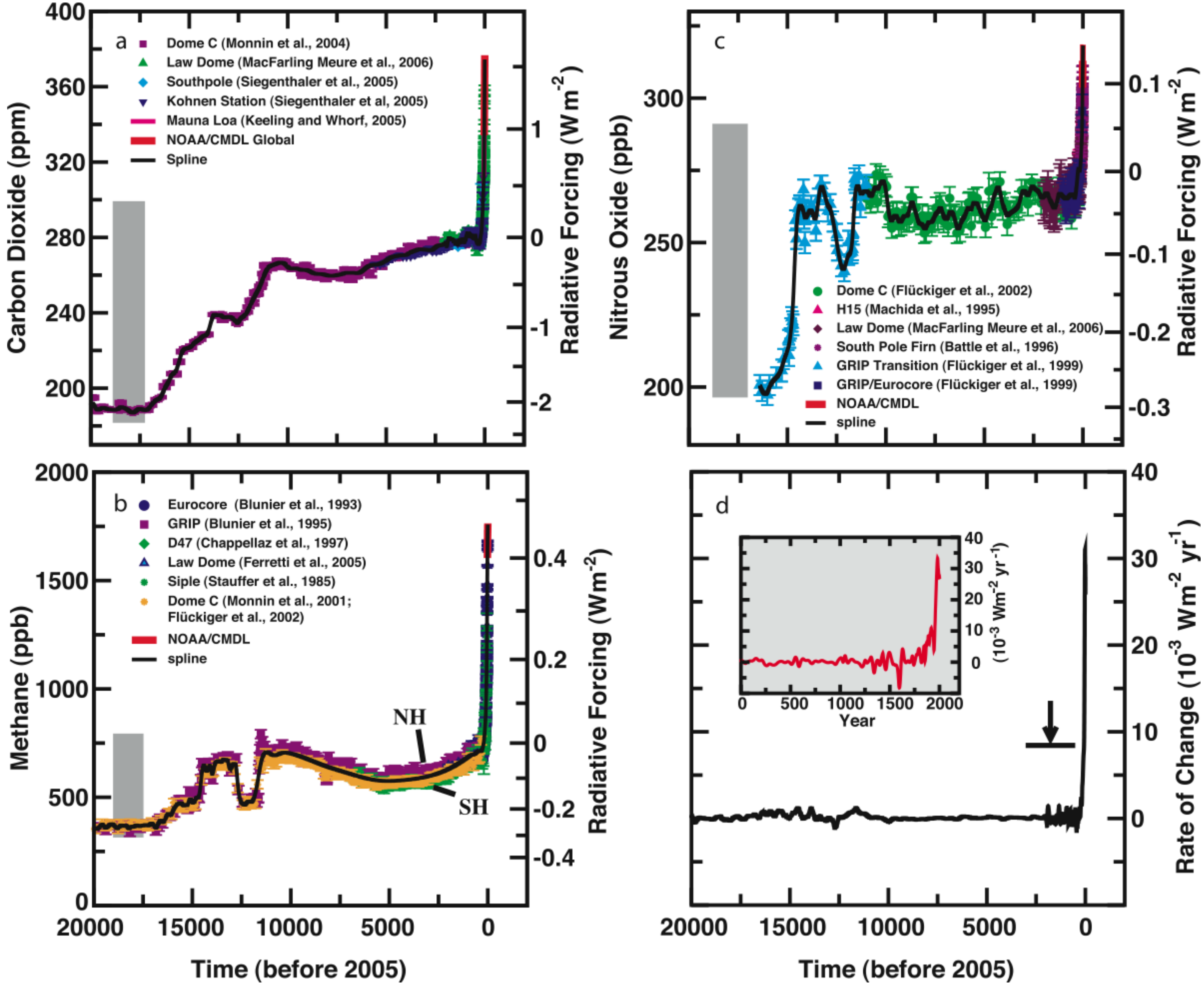
- A terra recebe energia do sol, a maior parte chega na região tropical e é absorvida na superfície.
- Esse aquecimento desigual força o surgimento de ventos na atmosfera e de correntes no oceano.
- Esta circulação redistribui a energia

A teoria que explica o movimentos dos fluídos é chamada de dinâmica dos fluídos.



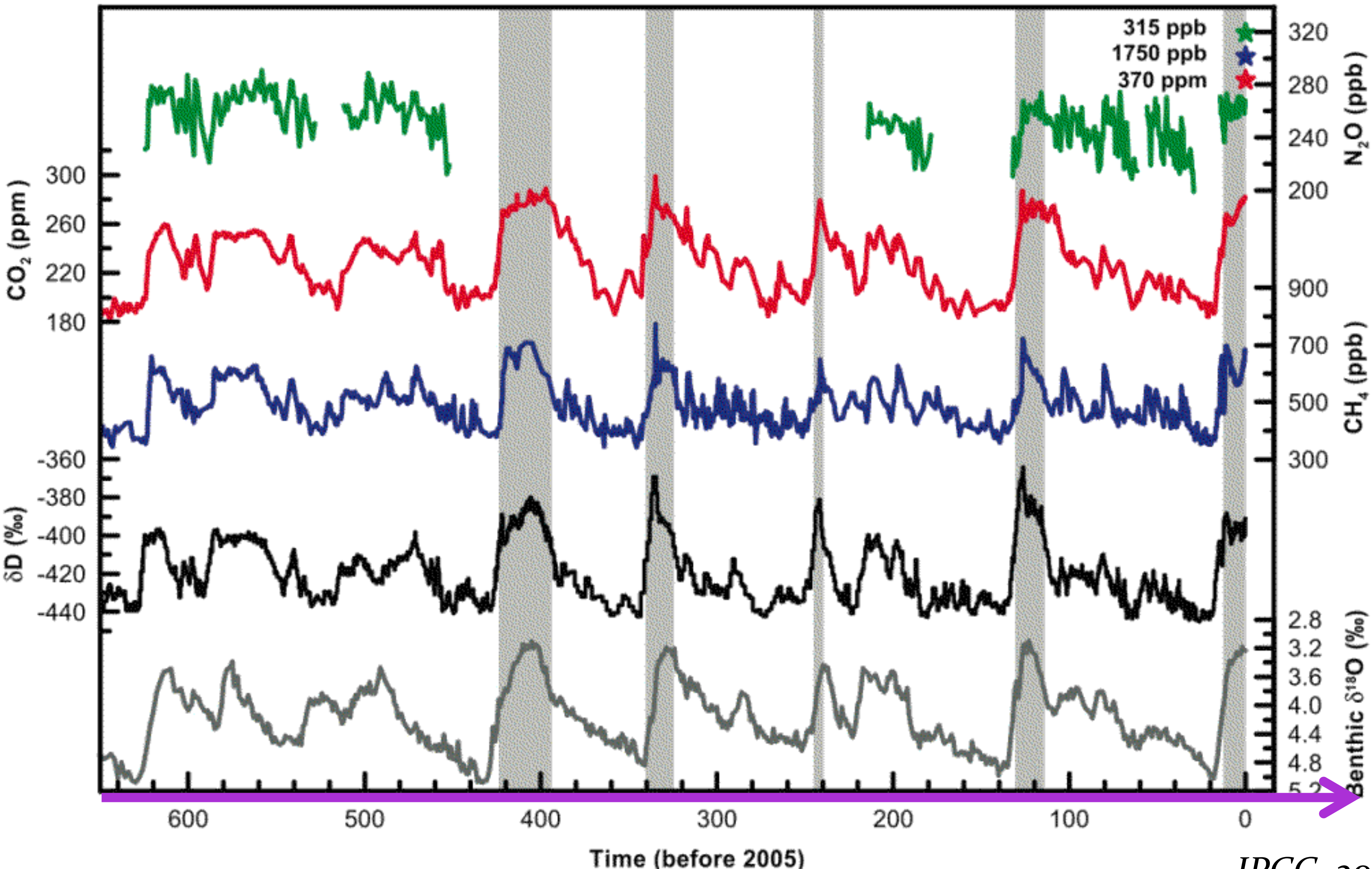
1
5
CO_2
CO_2
CO_2
CO_2
Electricity pylons
Farm house
Wind turbine
4
Woodland
3
N_2O
Cultivation
7
Crops
6
CH_4
Livestock
2
N_2O
N_2O
Anaerobic digestion facility
Slurry/muck heap

Antropogenic? Yes!



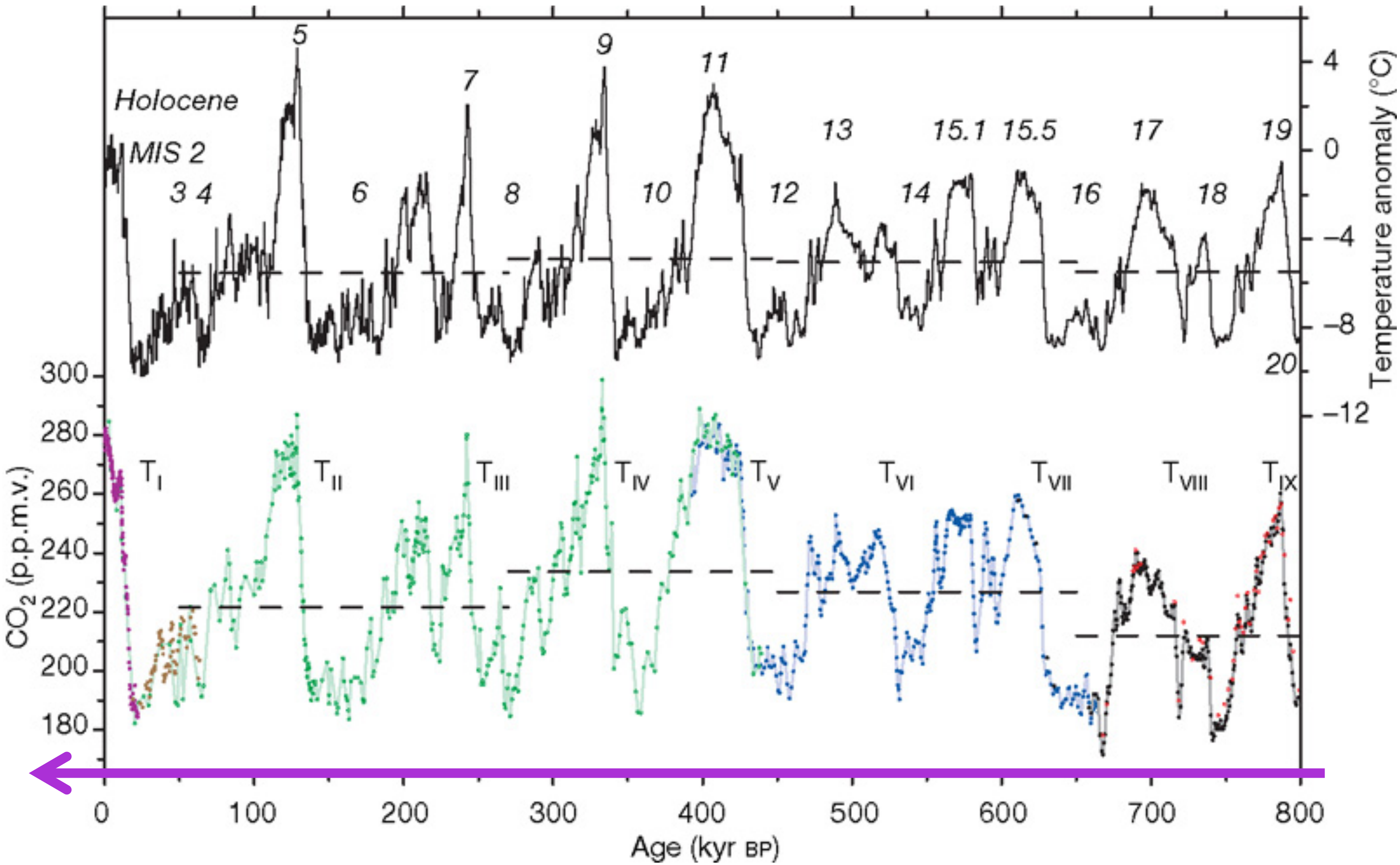
IPCC, 2007

Vostok (650ky)



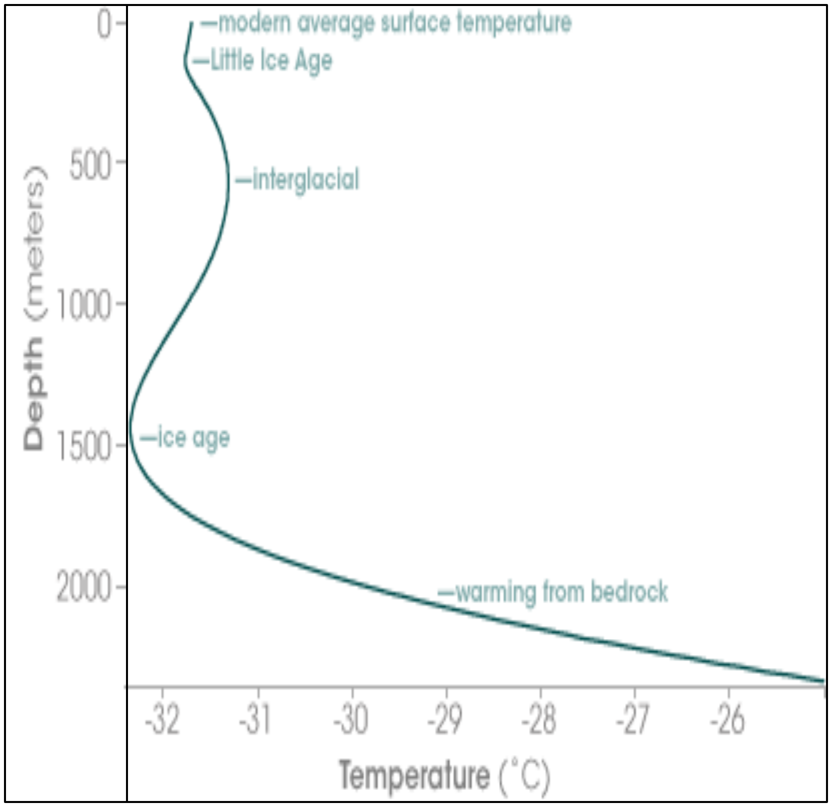
IPCC, 2007

Dome C (800ky)

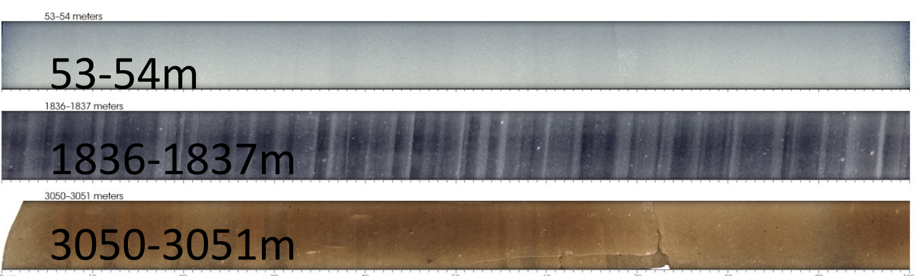


Luthi et al, Nature **2008**

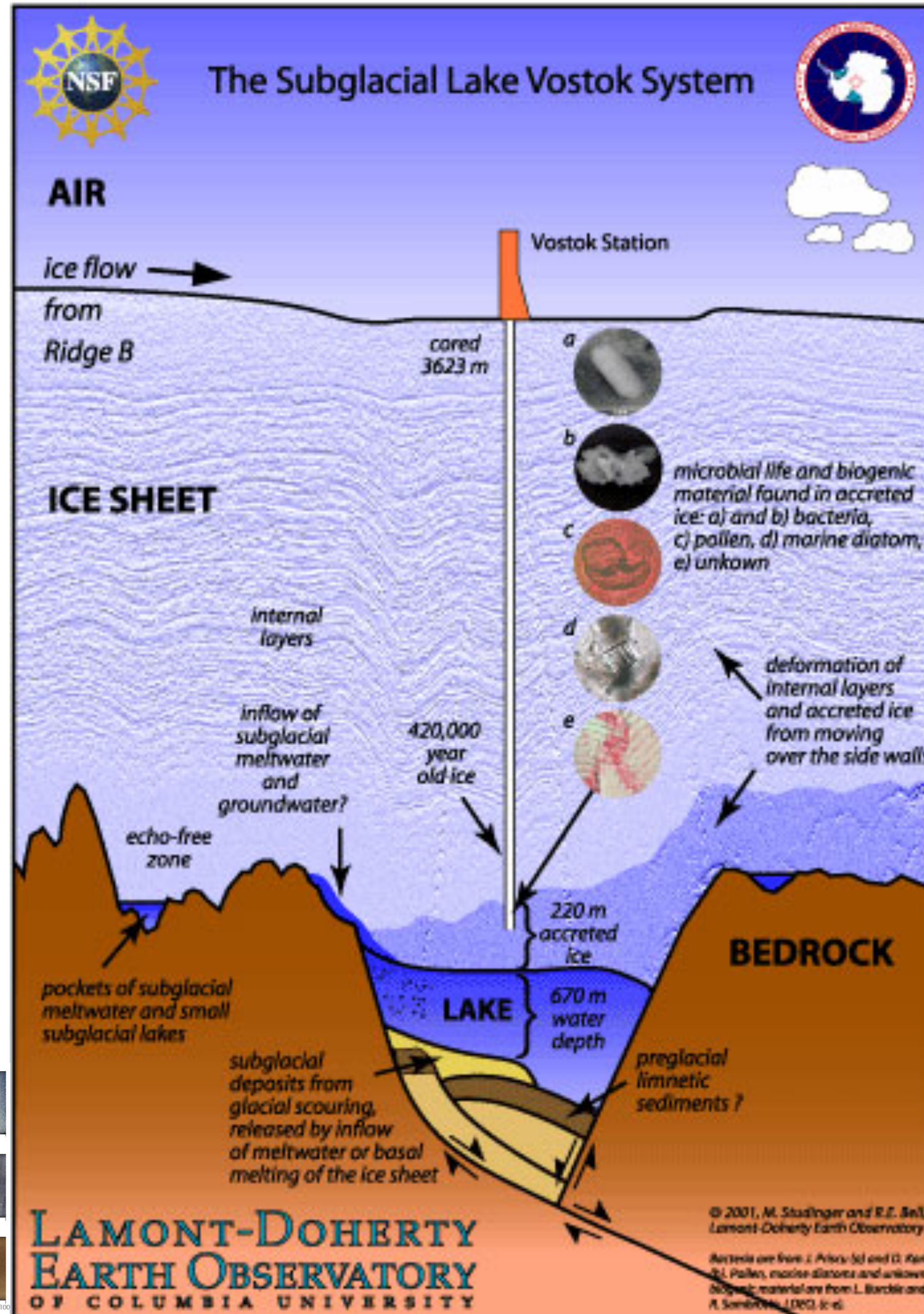
Ice Cores



0
500
1000
1500
2000
Depth (meters)
—modern average surface temperature
—Little Ice Age
—interglacial
—ice age
—warming from bedrock
-32
-31
-30
-29
-28
-27
-26
Temperature (°C)

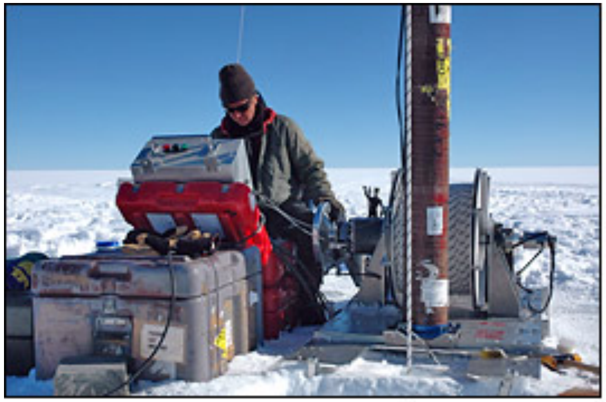
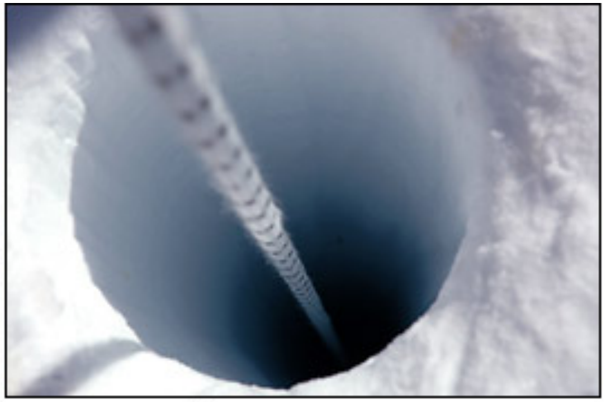


53-54 meters
53-54m
1836-1837 meters
1836-1837m
3050-3051 meters
3050-3051m



NSF
The Subglacial Lake Vostok System
AIR
Vostok Station
ice flow
from
Ridge B
cored
3623 m
a
b
c
d
e
ICE SHEET
microbial life and biogenic material found in accreted ice: a) and b) bacteria, c) pollen, d) marine diatom, e) unkown
internal layers
deformation of internal layers and accreted ice from moving over the side walls
inflow of subglacial meltwater and groundwater?
420,000 year old ice
echo-free zone
220 m accreted ice
BEDROCK
pockets of subglacial meltwater and small subglacial lakes
LAKE
670 m water depth
subglacial deposits from glacial scouring, released by inflow of meltwater or basal melting of the ice sheet
preglacial limnetic sediments ?
LAMONT-DOHERTY EARTH OBSERVATORY OF COLUMBIA UNIVERSITY
© 2001, M. Studinger and R.E. Bell, Lamont-Doherty Earth Observatory

Ice Cores

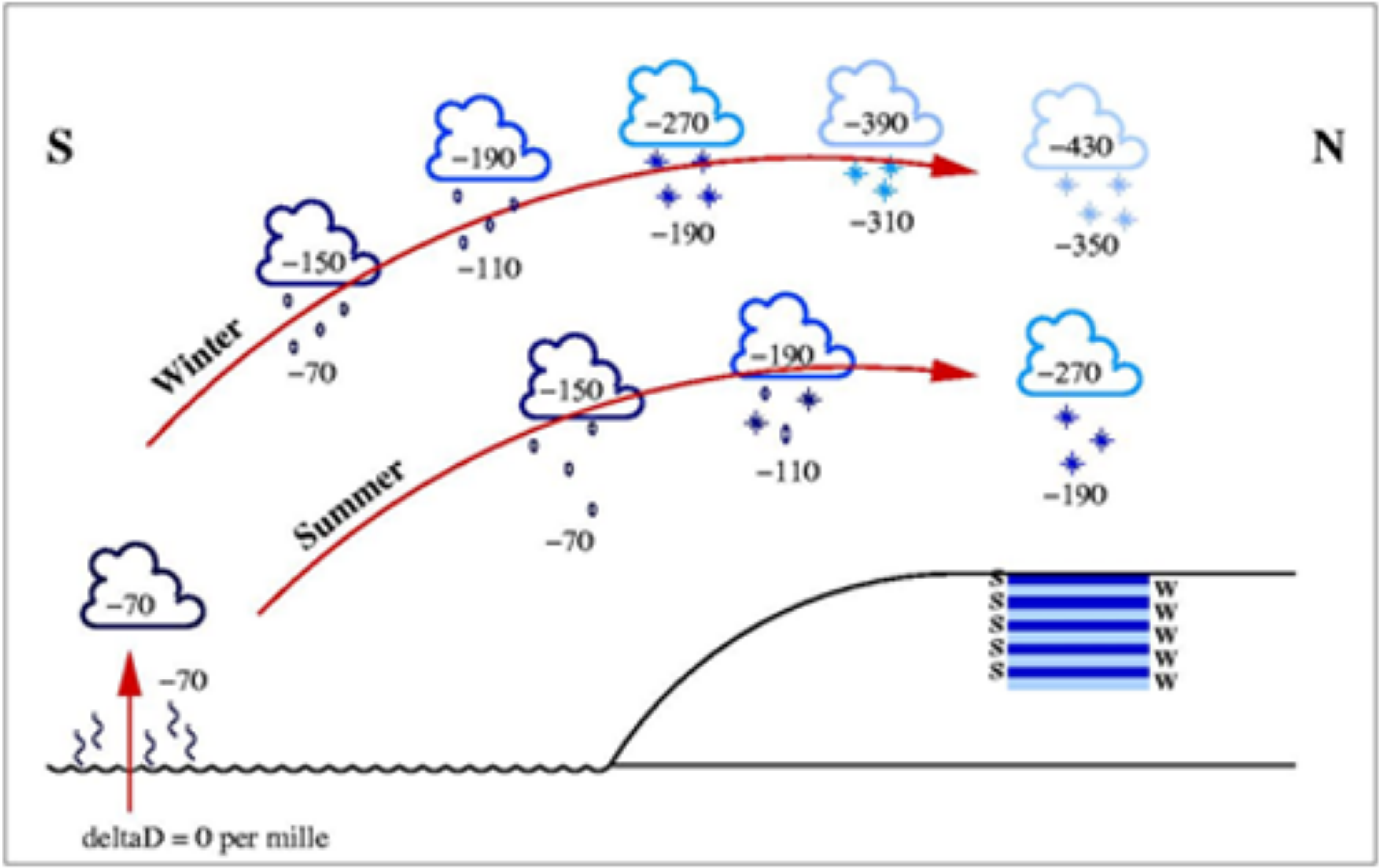






Dating ice

1. Counting layers
   - From temperature
   - From solar radiation
2. Pre dated tracers
   - Other ice cores
   - Volcanic sediments
3. Radioactive elements

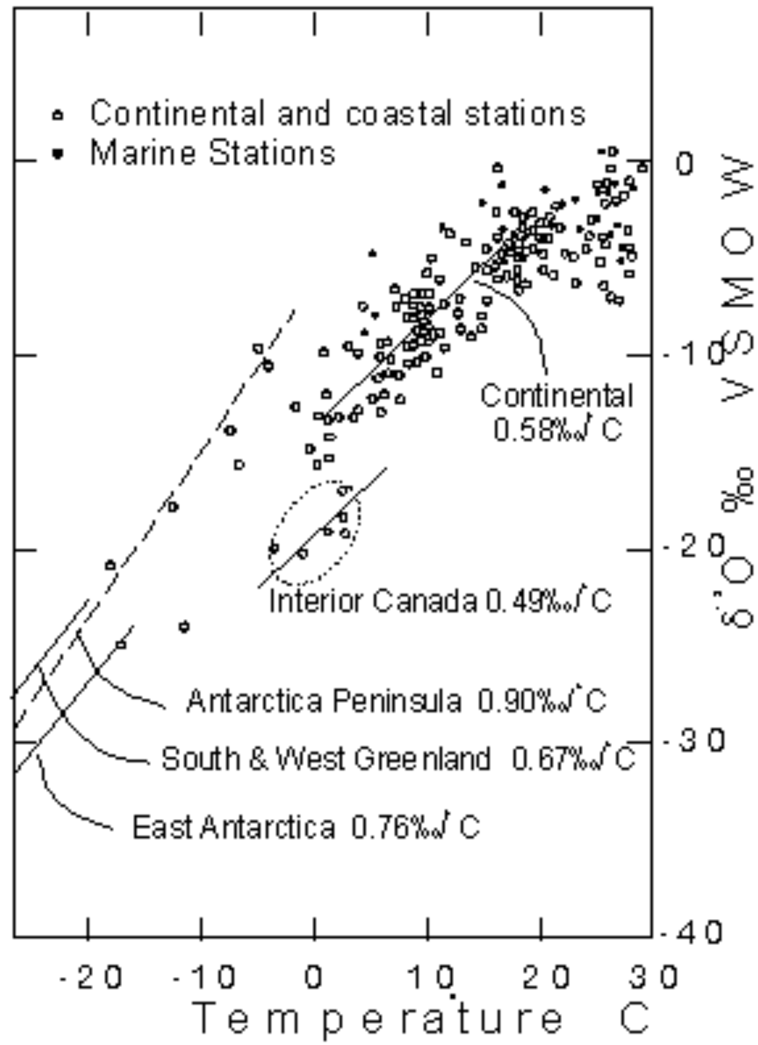
One way

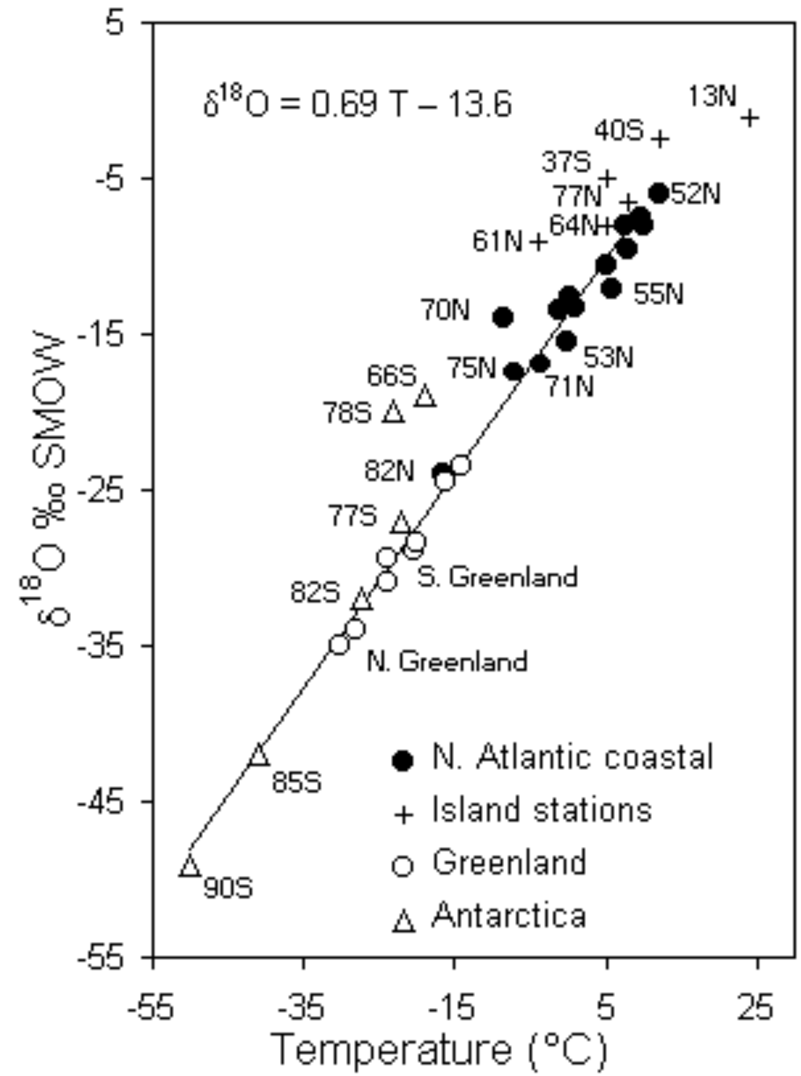


http://www.iceandclimate.nbi.ku.dk

Temperature dependency

$$\delta^{18}O = \left(\frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} - 1 \right) * 1000\ ‰$$

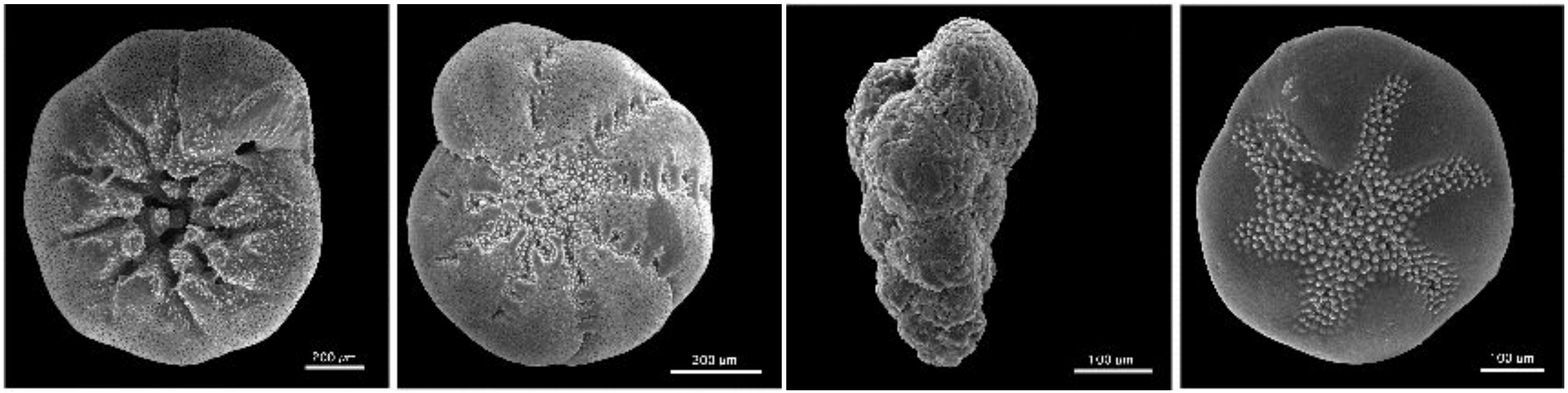


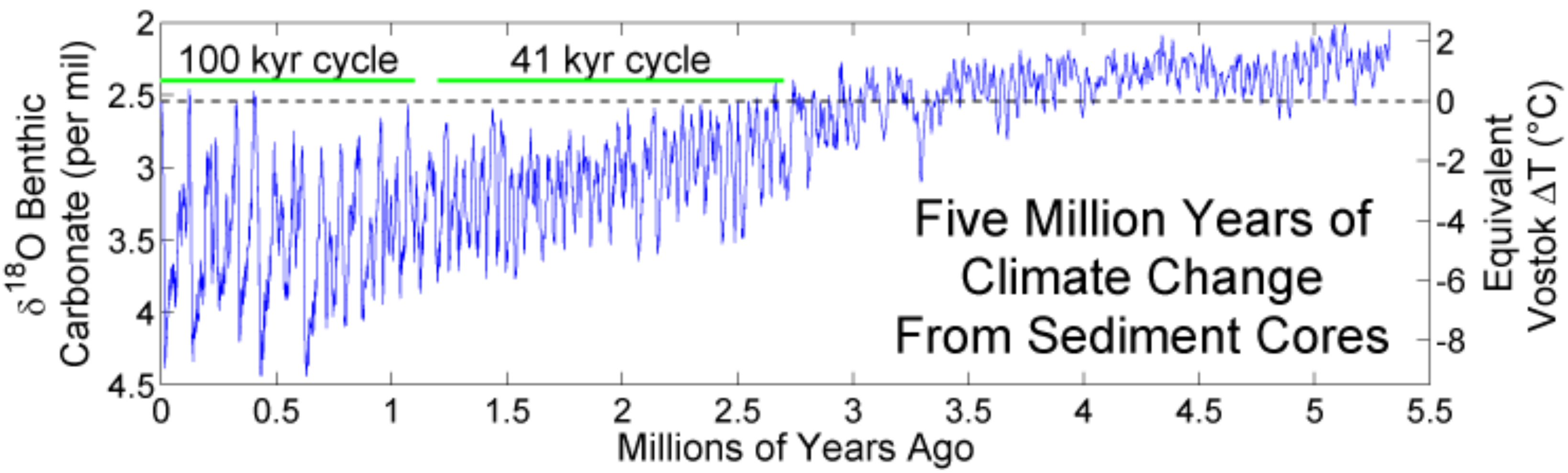


Dansgaard, 1964 e Rozanski et al., 1993

Same thing now on ocean sediments

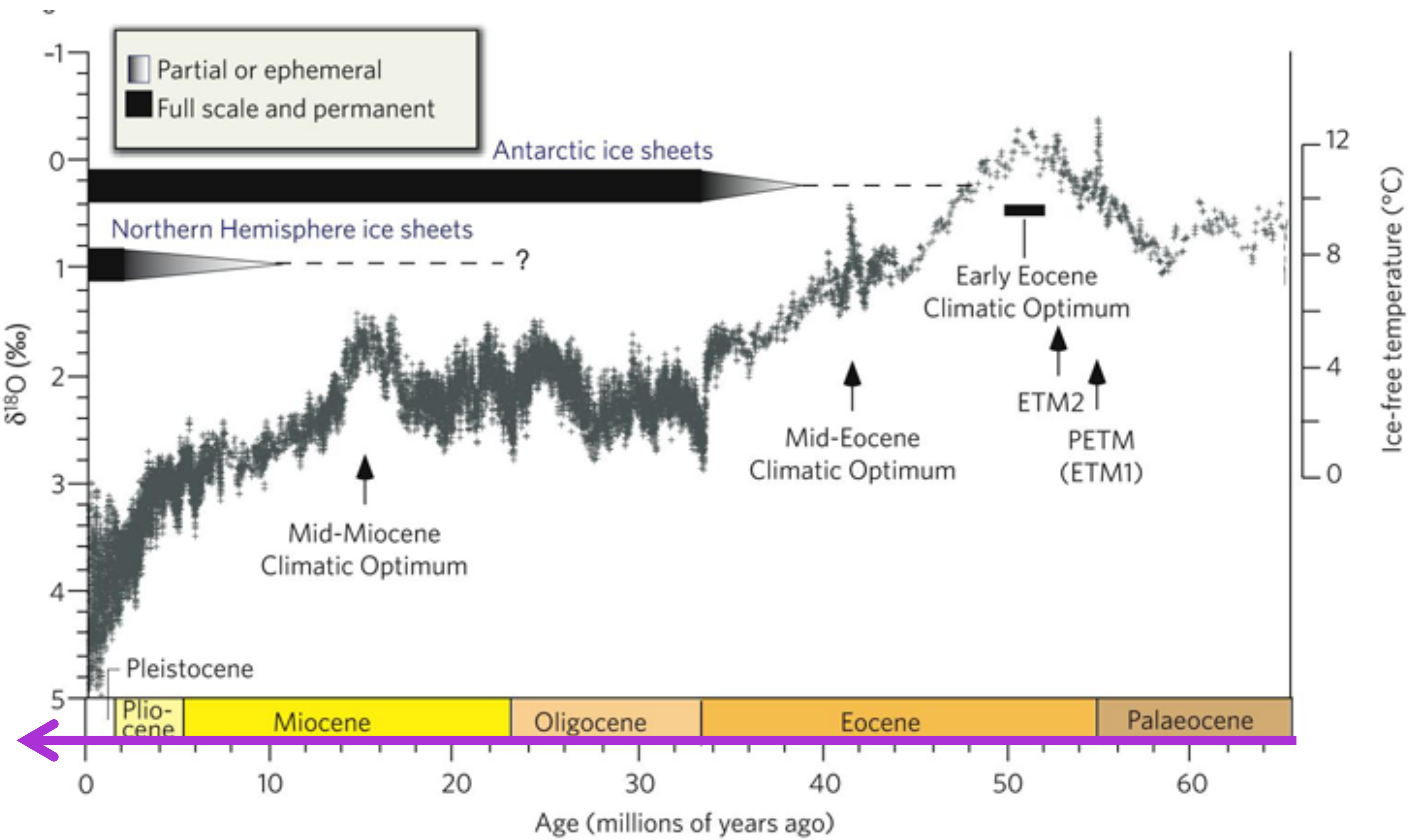
Shell of Foraminifera's is made of $CaCO_3$





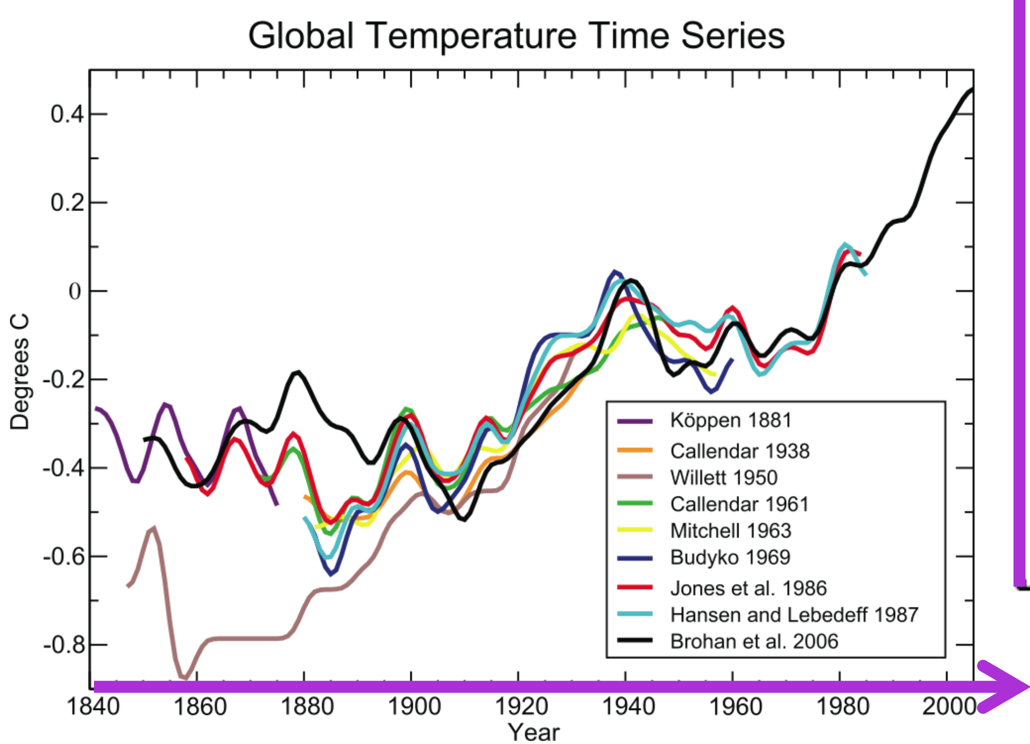
Lisiecki and Raymo (Paleoceanography, 2005).

Even deeper

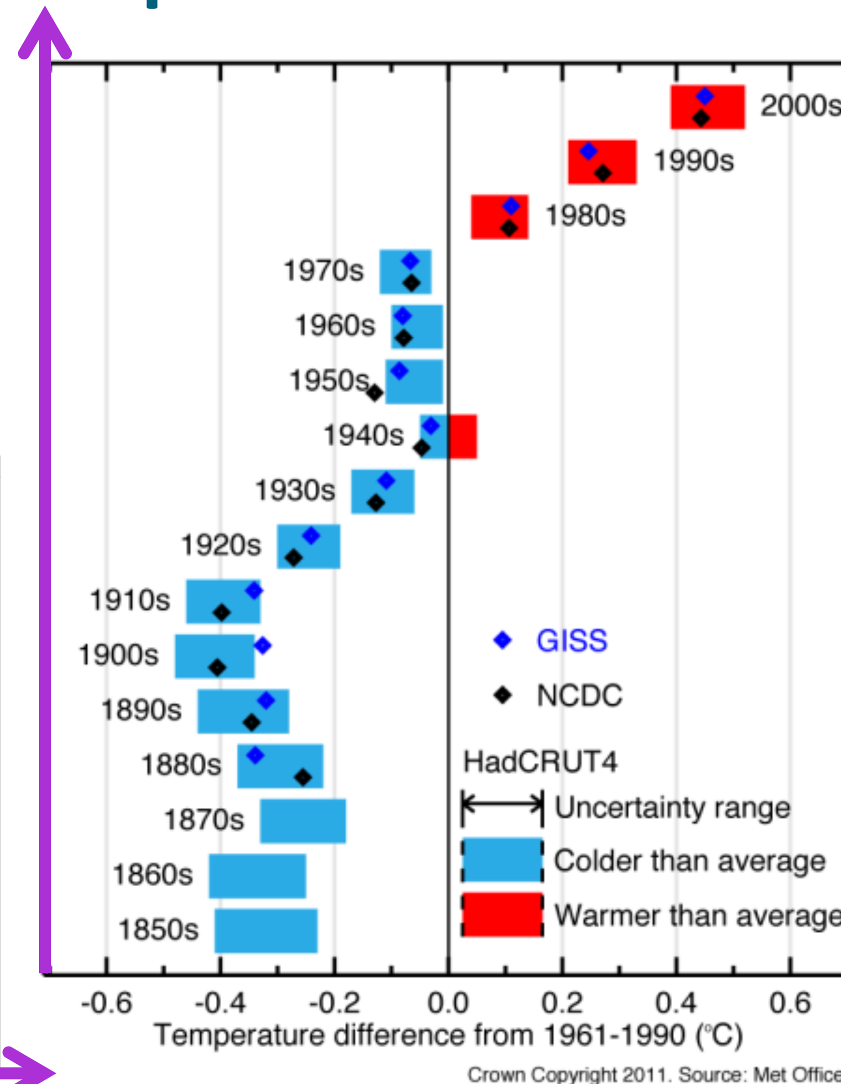


Zachos et al. (Nature, 2008)

Observation of Temperature Increase

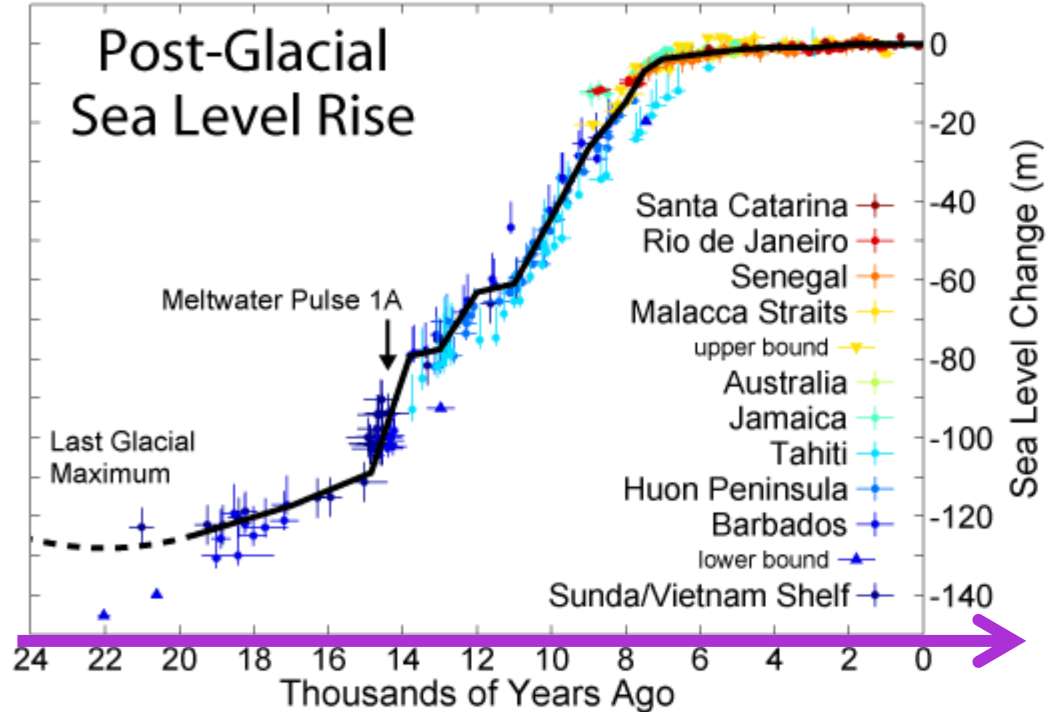


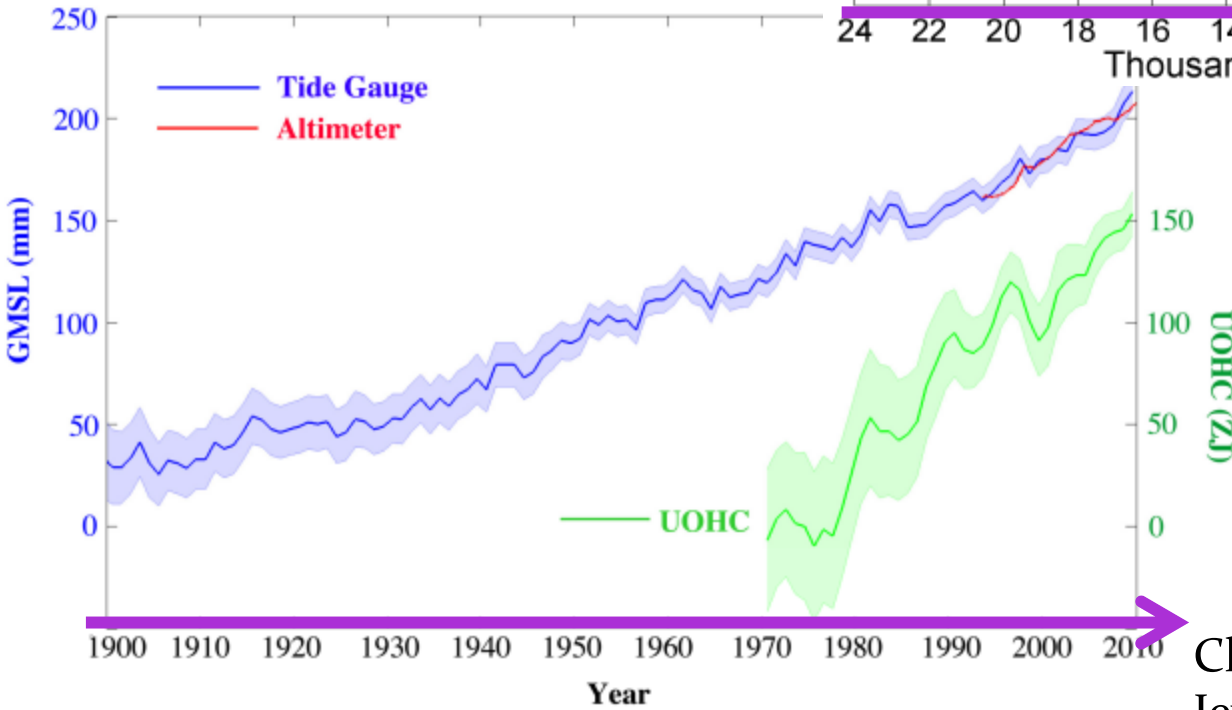
IPCC, AR4 2007



IPCC, AR5, 2013

(2) Sea level





Church and White, 2011;
Jevrejeva et al., 2008;
Nerem et al., 2010

IPCC, AR5, 2013

A bit of history

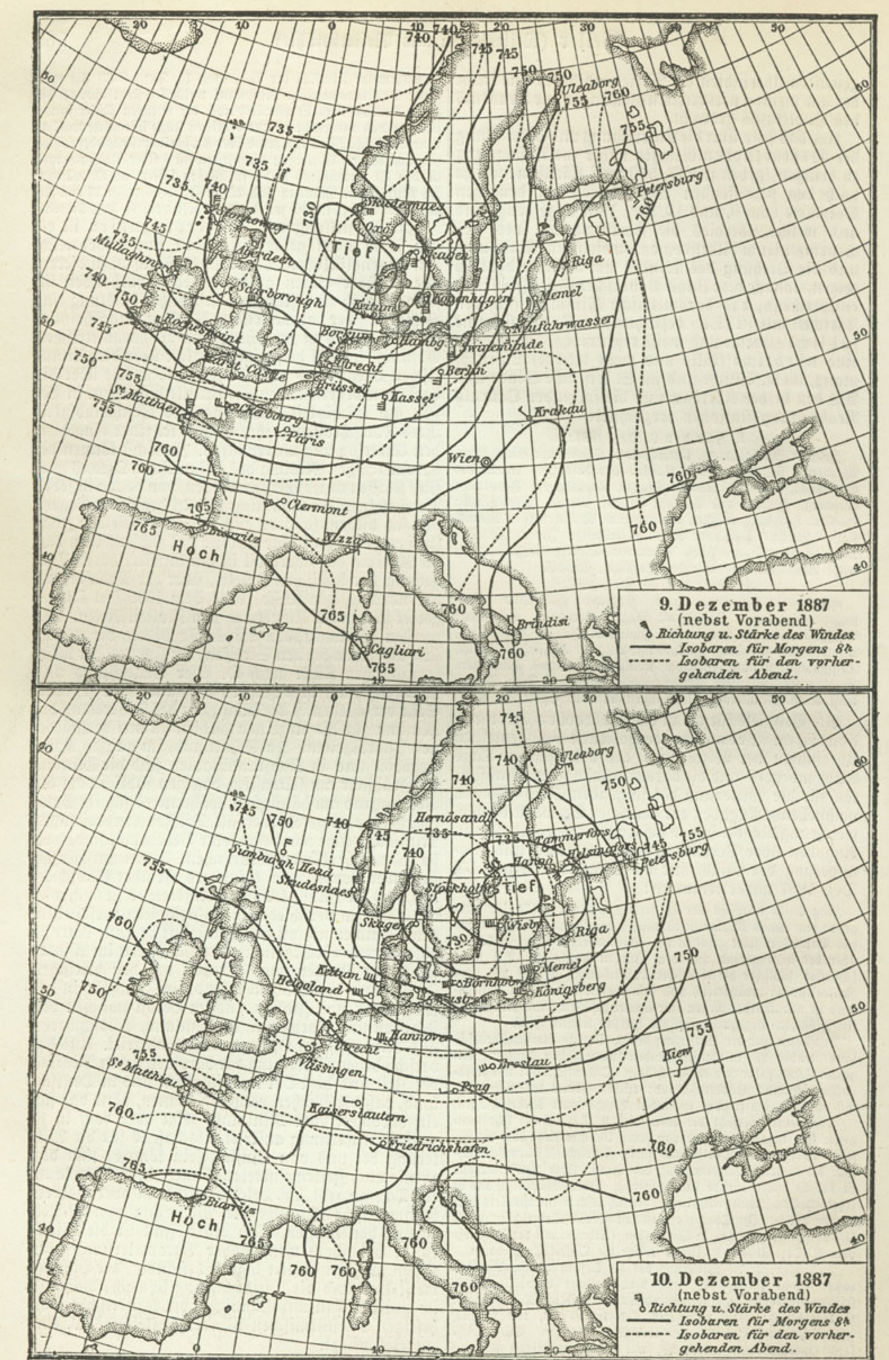
Weather forecasts began as observation of repetitive patterns

- 650 AC Babylonians made forecasts from cloud formations and position of the start
- 340 AC, Aristotle described a series of meteorological situations in a book called *Meteorológica*
- Since 300 AC Chinese made some sort of weather forecast

> Lets explain the thunder (…). There are two kinds of exhalations: dry and humid. (...). The humid condenses and forms a cloud (…). The radiated heats disperses on the top of the cloud, cooling it. A dry exhalation, that gets trapped in the process, will be eject from the the cloud with high speed. When it collides with the neighboring clouds it makes a noise. We call this noise: thunder.
> – **Aristoteles Meteorologica**

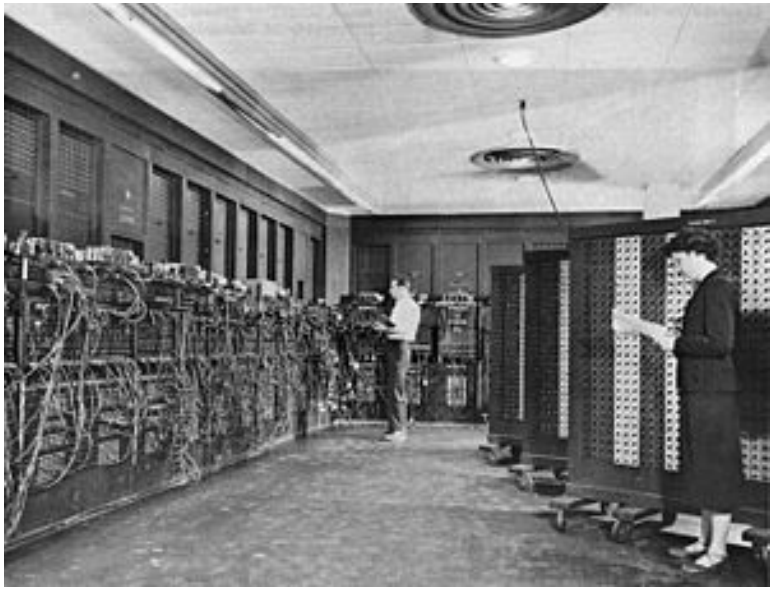
Modern History

- 1400's
  - Hygrometer - Cryfts (1450)
  - Anemometer - Alberti (1450)
- 1500's
  - Thermoscope - Galileo
- 1600's
  - Barometer - Torricelli (1643)
  - Les Meteores - Descarte (1637)
- 1700's
  - Trade winds - Hadley (1730)
- 1800's
  - Three-cell model - Ferrel (1855)
  - Weather maps of surface pressure
- 1900's
  - Weather prediction - Bjerknes (1903)
  - Polar front theory - Bjerknes (1921)

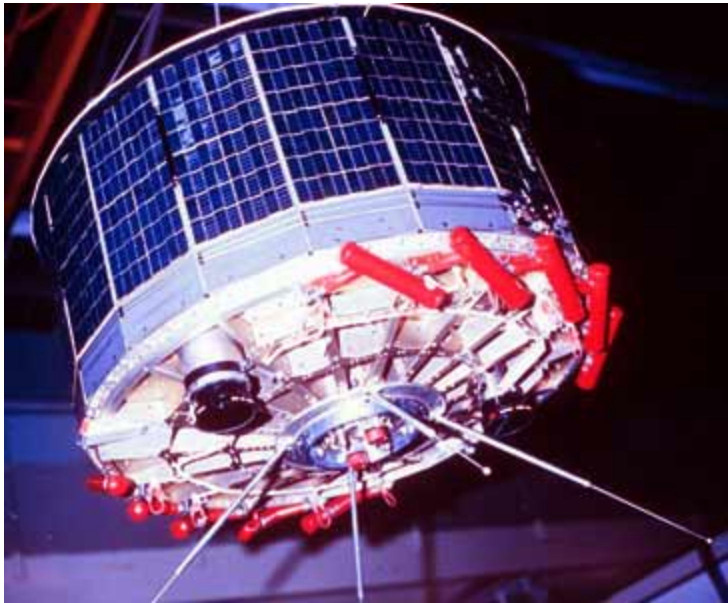


Wetterkarten vom 9 und 10. Dez. 1887 (Deutsche Seewarte).

Modern Technology



- 1900's
  - Numerical weather prediction
    - Richardson (1922)
  - Daily balloon observations (1940's)
  - First computer – ENIAC (1946)
  - First weather forecast
    - Von Neumann and Charney (1950)
  - Weather satellites (Tiros I, 1960)
  - First global model
    - Smagorinsky (1963)



Fluid dynamics

- The most important equation is Navier-Stokes. Derived from Newton's second law, states the conservation of momentum

$$\frac{\partial \mathbf{v}}{\partial t} = -\mathbf{v}\cdot\nabla\mathbf{v} + \upsilon\nabla^2\mathbf{v} - \frac{\nabla P}{\rho} + \mathbf{g}$$

- Partial
- 2^{nd} order
- 1^{st} degree
- Homogeneous
- **Non-Linear**

$$\sum_j v_j \frac{\partial v_j}{\partial x_j} \Rightarrow$$

CAOS

1^{st} law of thermodynamics

- By defining a virtual potential temperature

$$\theta_v = T_v \left(\frac{1000\,\text{hPa}}{p_a} \right)^{\kappa}$$

- That already includes pressure variation, conservation of energy gives

$$\frac{d\theta_v}{dt} = \frac{1}{c_p^d} \frac{\theta_v}{T_v} \frac{dQ}{dt}$$

Mass Conservation

- If mass is conserved, then **dρ/dt=0**, where

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = \frac{\partial \rho}{\partial t} + \mathbf{v} \cdot \nabla \rho$$

- ... Similar to conservation of momentum:

$$\frac{\partial q}{\partial t} = -\mathbf{v} \cdot \nabla q + D_q \nabla^2 q + F_q - S_q$$

$$\frac{\partial \mathbf{v}}{\partial t} = -\mathbf{v} \cdot \nabla \mathbf{v} + \nu \nabla^2 \mathbf{v} - \frac{\nabla P}{\rho} + \mathbf{g}$$

Molecular diffusion

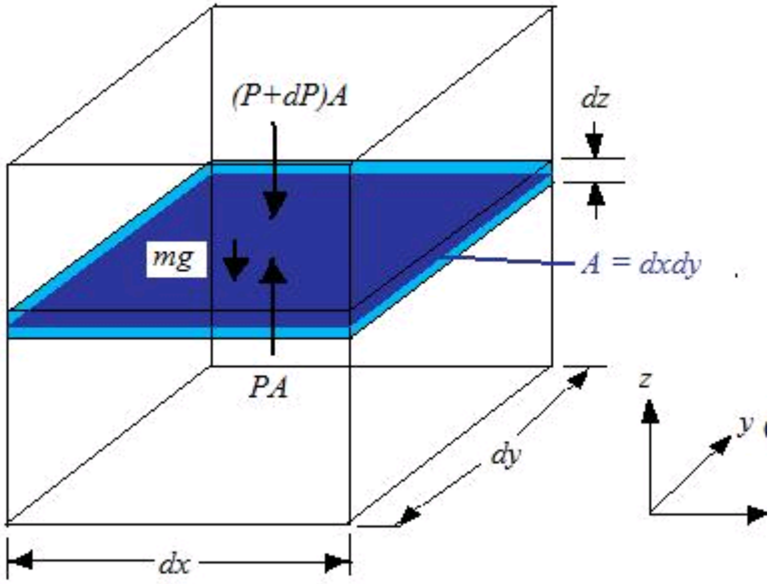
Sources and sinks of water vapor

Sources and sinks of momentum

Equação Hidrostática

- É a equação de movimento na ausência de aceleração verticais. É dada pelo equilíbrio entre a força gradiente de pressão e a gravidade

$$dp_a = -\rho_a g dz$$



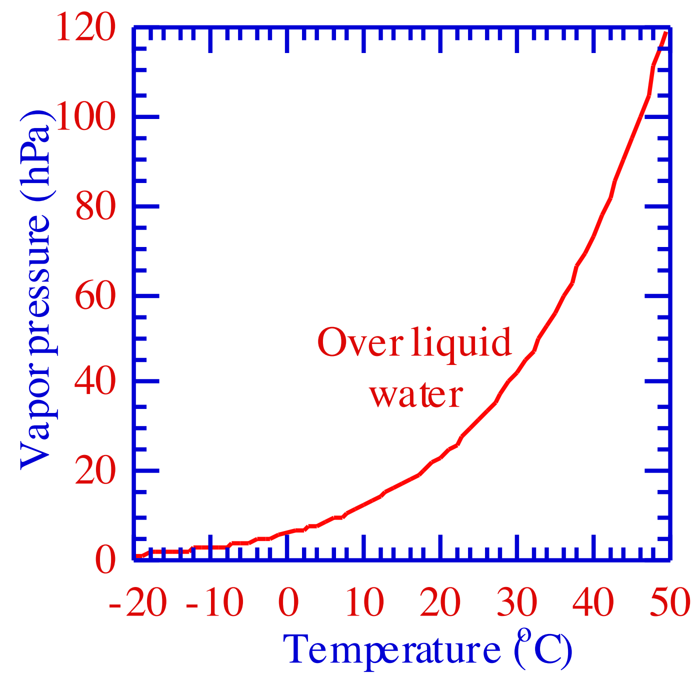
Equação de Clausius-Clapeyron

- A pressão de vapor de saturação varia com a temperatura:

$$\frac{\mathrm{d}p_{v,s}}{\mathrm{d}T} = \frac{\rho_{v,s}}{T} L_e$$

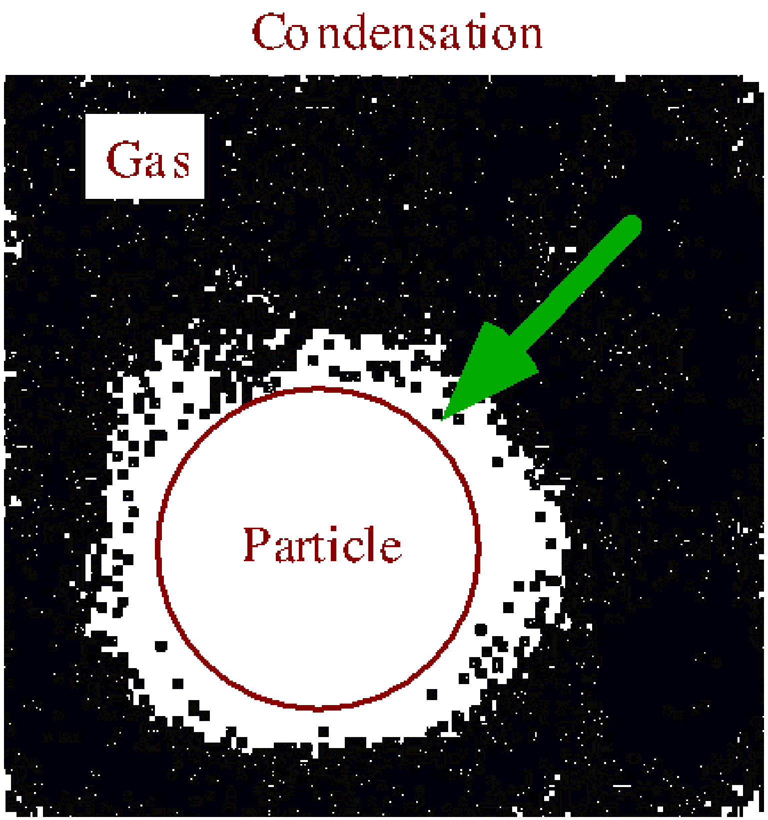
- E podemos encontrar uma expressão para ela:

$$p_{v,s} = 6.112\exp\left(\frac{17.67T_c}{T_c + 243.5}\right)$$

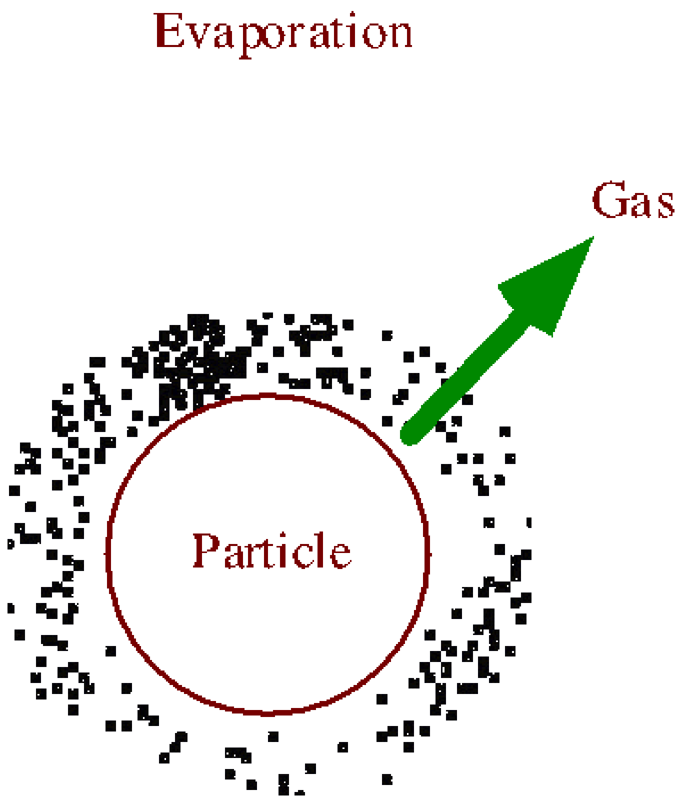


Condensação/Evaporação

Condensação para $p_v > p_{v,s}$

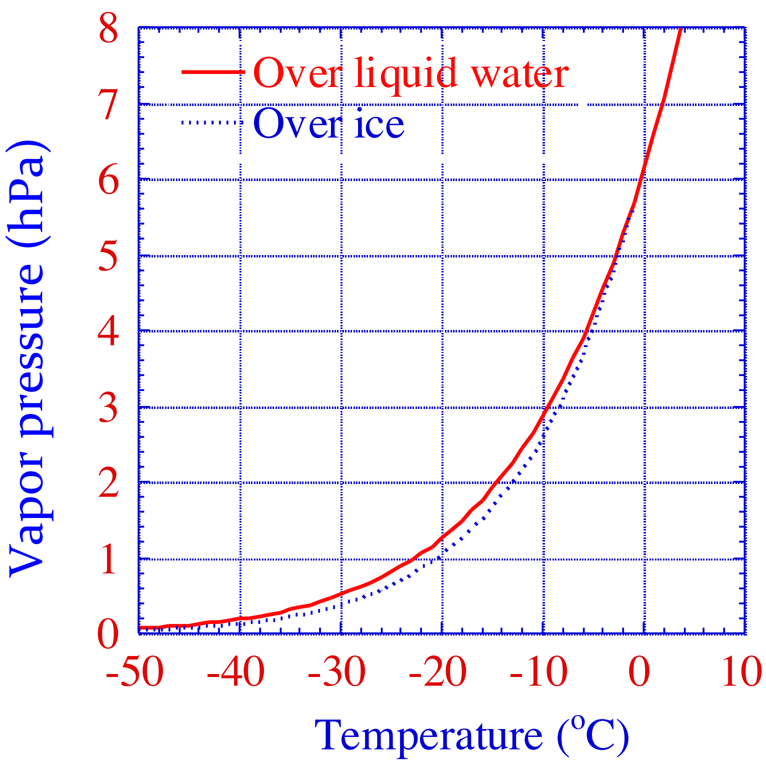


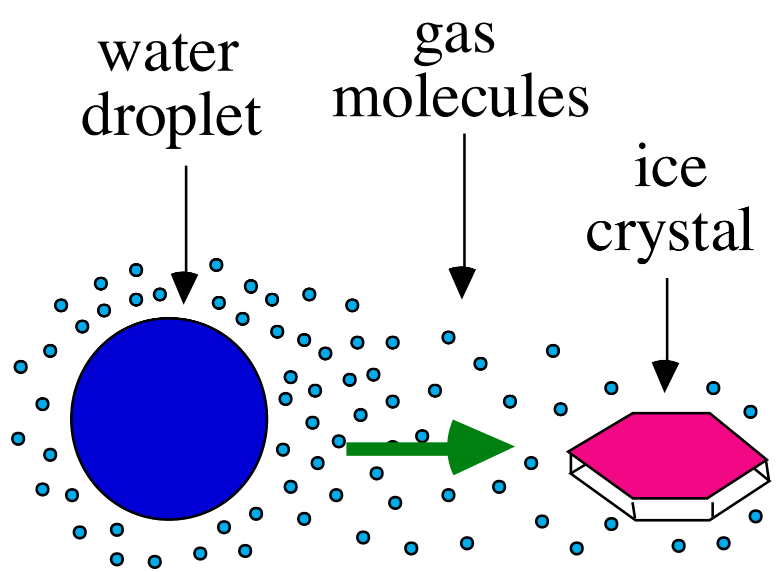
Evaporação para $p_v < p_{v,s}$



Formation of Rain in Cold Clouds

Ice Crystal (Bergeron) Process





- $p_{v,s}$ sobre gelo é menor que sobre água
- As gotas evaporam e o vapor flui para os cristais

Equations of motion

$$p_a = \rho_a R' T_v \qquad \mathrm{d}p_a = -\rho_a g \mathrm{d}z \qquad T_v = T\left(1 + 0.608\mathrm{q}_v\right)$$

$$\frac{d\theta_v}{dt} = \frac{1}{c_p^d}\frac{\theta_v}{T_v}\frac{dQ}{dt} \qquad \theta_v = T_v\left(\frac{1000\,\mathrm{hPa}}{p_a}\right)^{\kappa}$$

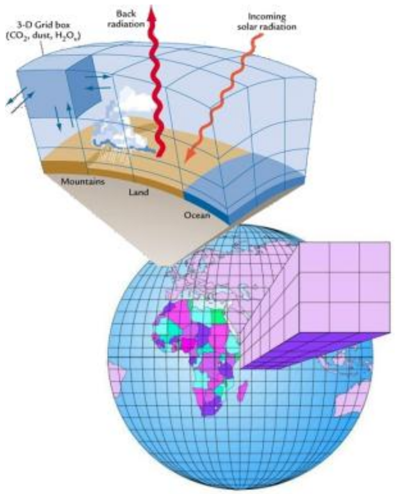
$$\frac{\partial \mathbf{V}}{\partial t} = -\mathbf{V}\cdot\nabla\mathbf{V} + \nu\nabla^2\mathbf{V} - \frac{\nabla P}{\rho} + \mathbf{g} \qquad \frac{\mathrm{d}\rho}{\mathrm{d}t} = \frac{\partial\rho}{\partial t} + \mathbf{v}\cdot\nabla\rho$$

+ chemistry (about 200 prognostic variables)
+ aerosols (about 30 prognostic variables)

Equações de Din. dos Fluídos

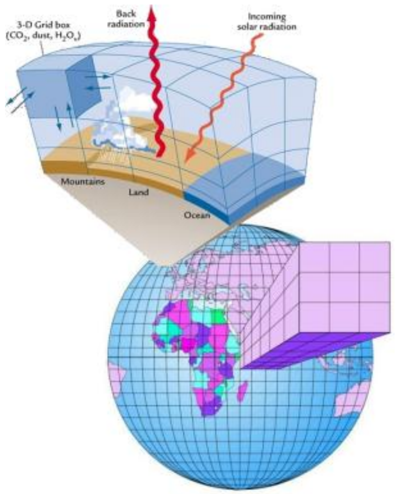
- Estas equações juntas podem descrever o movimento
  - da atmosfera,
  - das correntes oceânicas,
  - da água em um cano,
  - do ar passando sobre uma asa
  - das estrelas em uma galáxia

Do these equations solve it all?



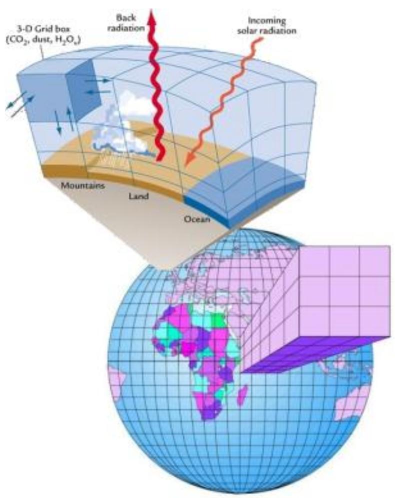
How to include subgrid processes?

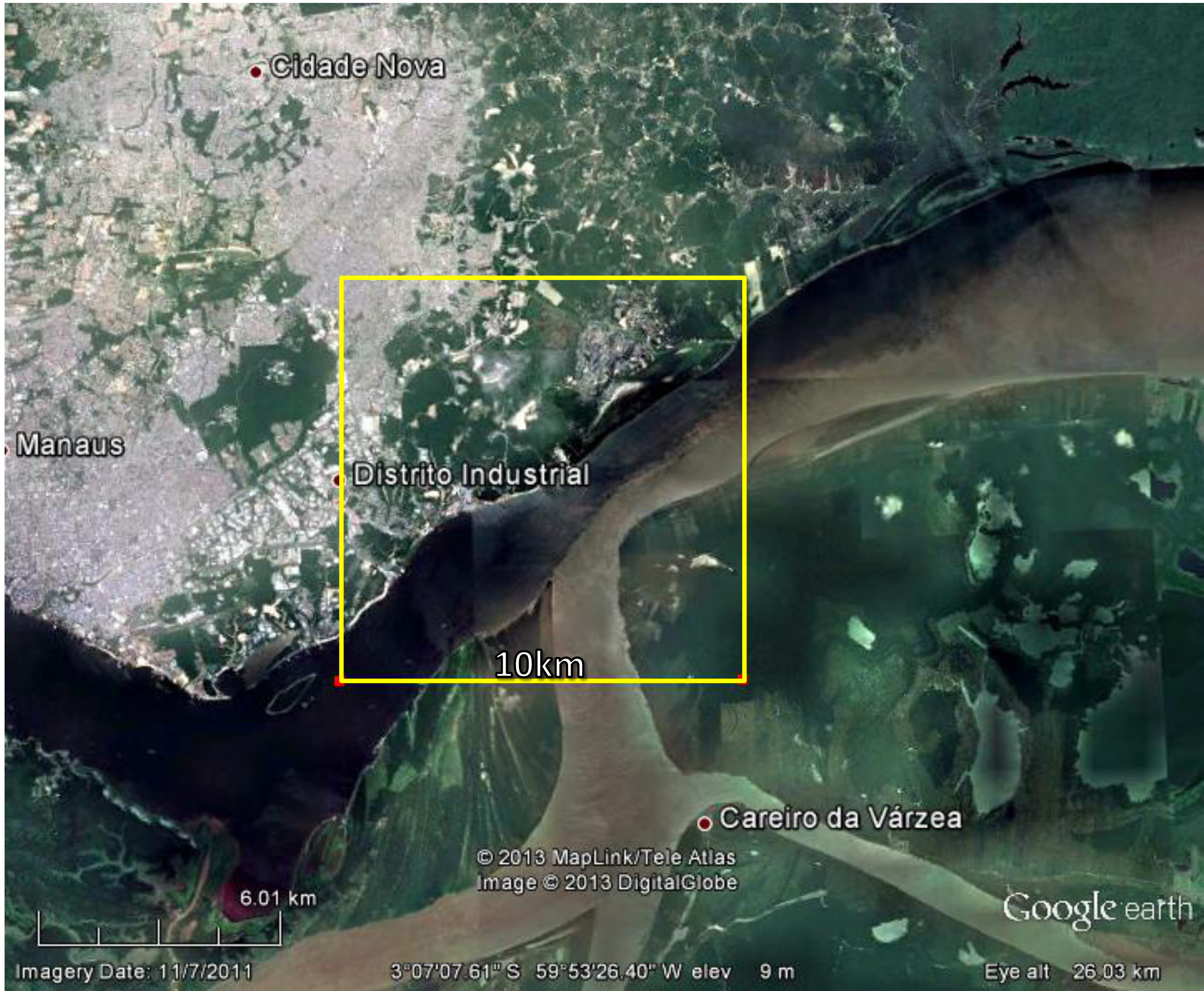
How to include the subgrid scale?



Clouds, rain, vegetation, cities, rivers, etc, etc, etc...

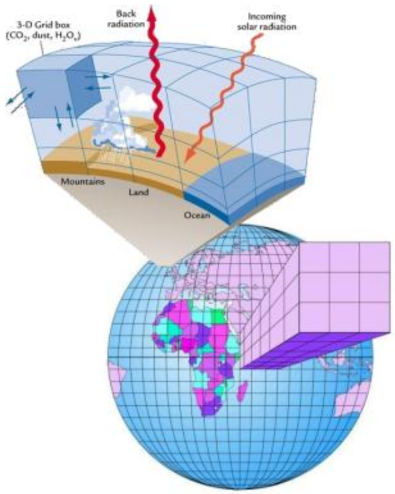
How to include the subgrid scale?





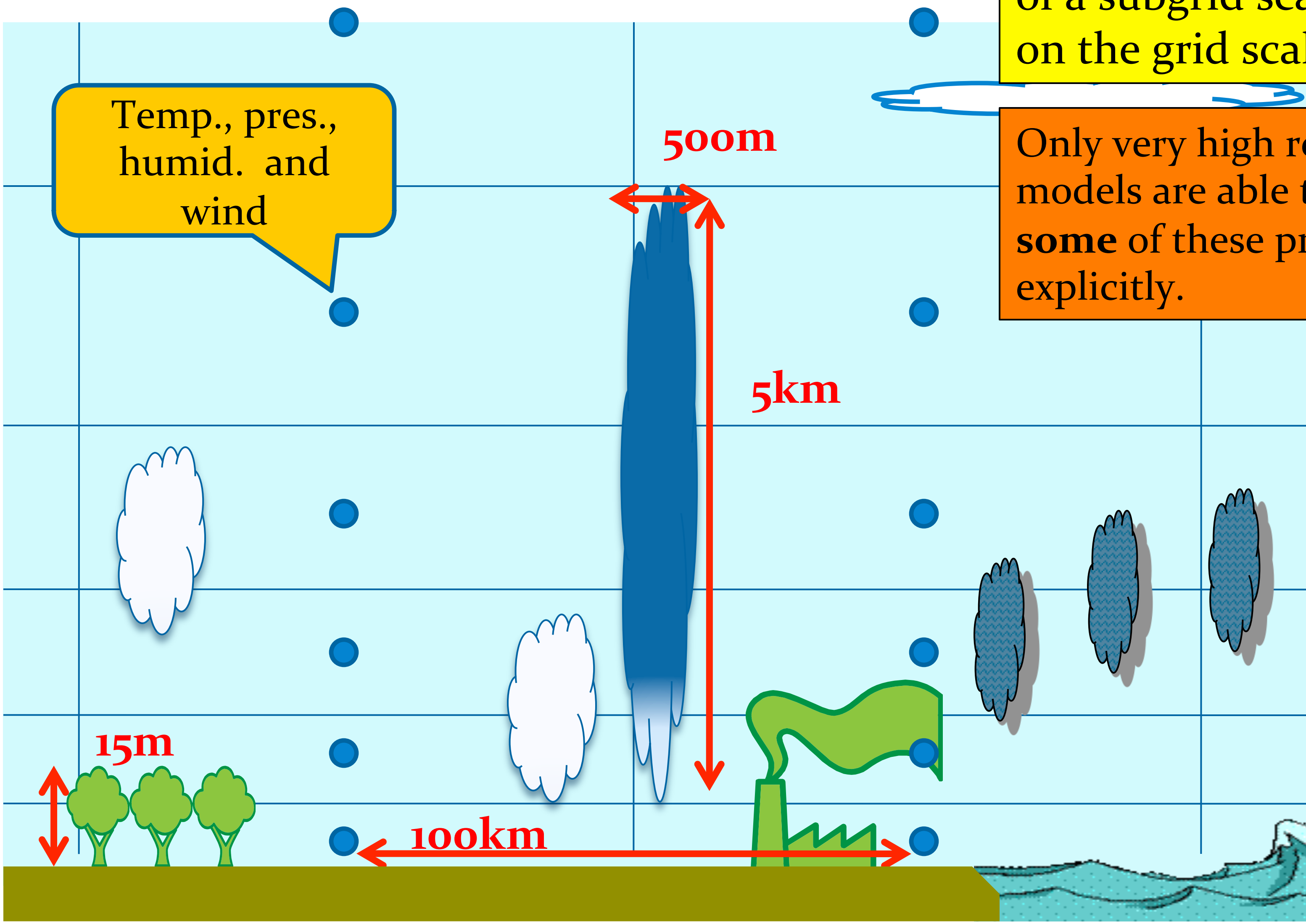
Pollution, aerosols, turbulence, etc, etc, etc...

How to include the subgrid scale?



Phisiology, human activities, etc, etc, etc...

Parametrizations



a set of **empirical** equations used to estimate the **mean effect** of a subgrid scale process on the grid scale.

Only very high resolution models are able to solve **some** of these processes explicitly.

Numerical model of the atmosphere

- Differential equations at the grid scale
- Parameterizations for representing the sub-grid scale

Source code:
Readable text written in some programming language

Binary program:
Machine language

Numerical model of the atmosphere

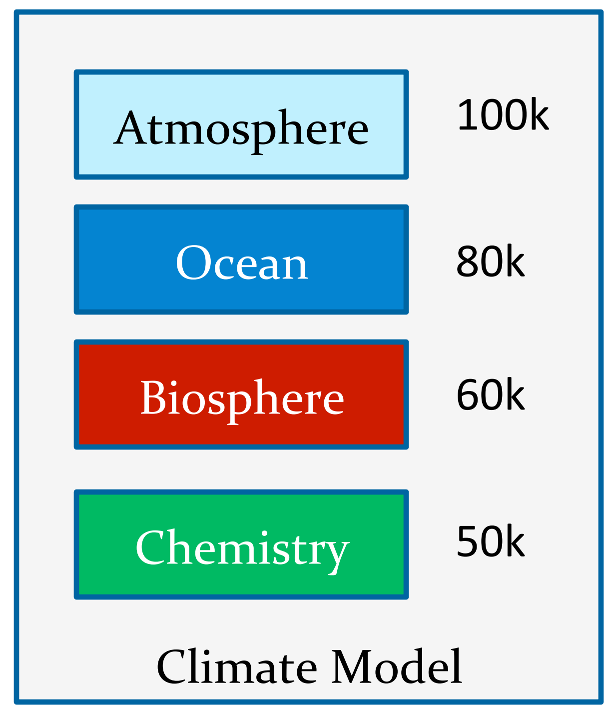
- Differential equations at the grid scale
- Parameterizations for representing the sub-grid scale

Computacional Complexity

- Many researcher, during many years.

```
PROGRAM PARES
  DO I=1,5
    PRINT I*2
  ENDDO
END PROGRAM
```

```
2
4
6
8
10
```



100-300 K lines of code

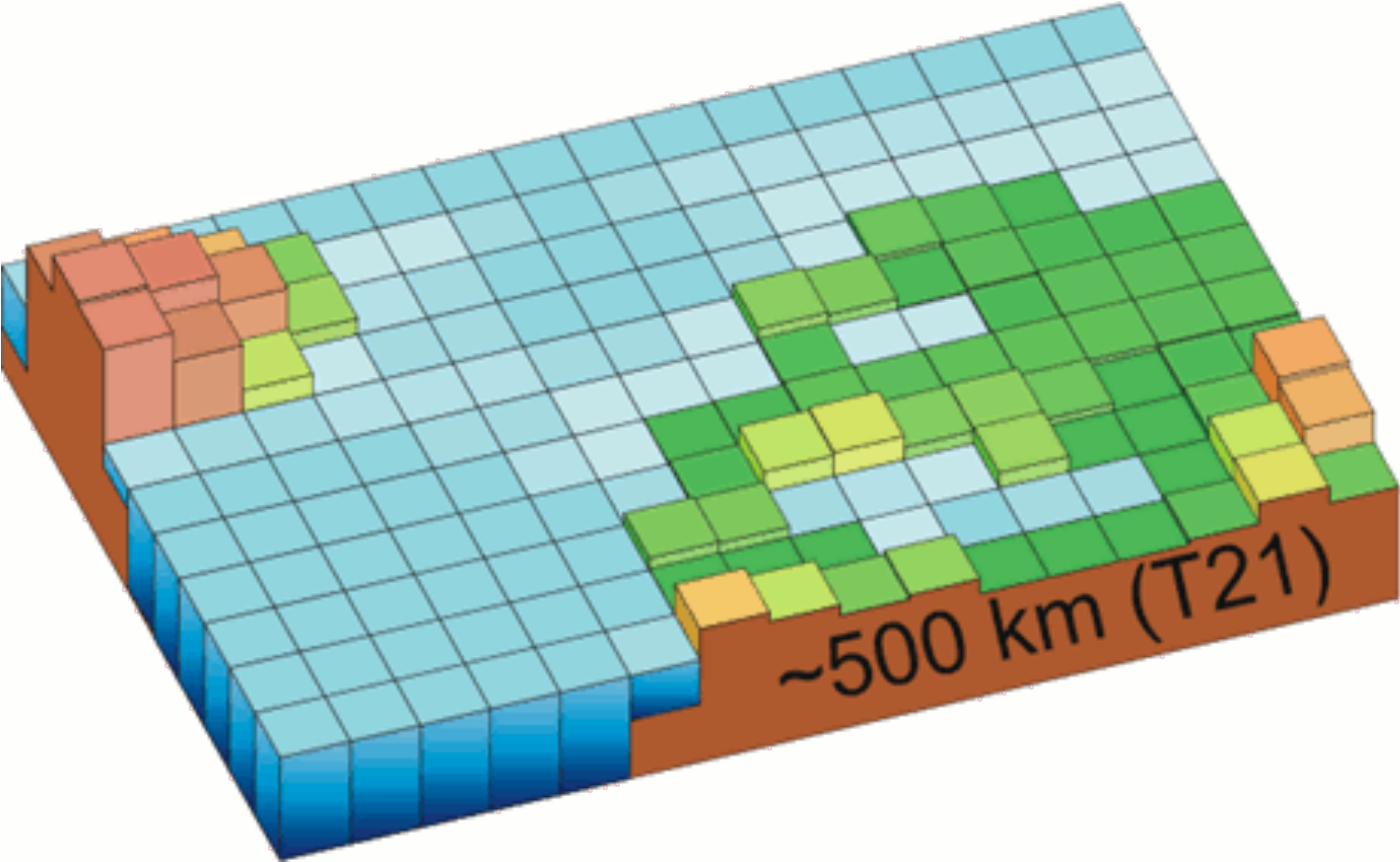
Is there gonna be bugs?

Is the weather forecast good?

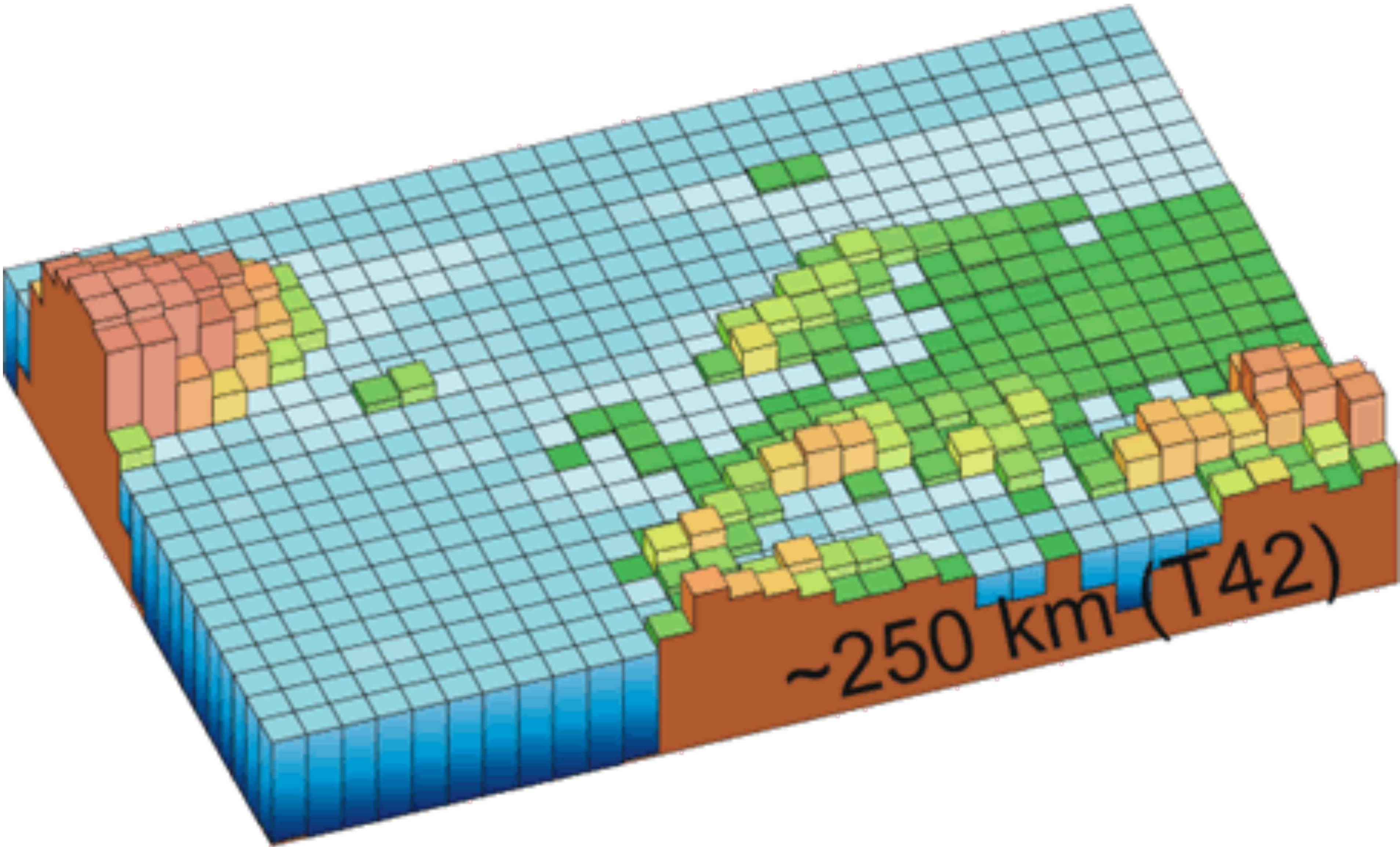
The quality of our solution (**weather forecast**) will depend on many factors:

- Adequate spatial and temporal resolutions

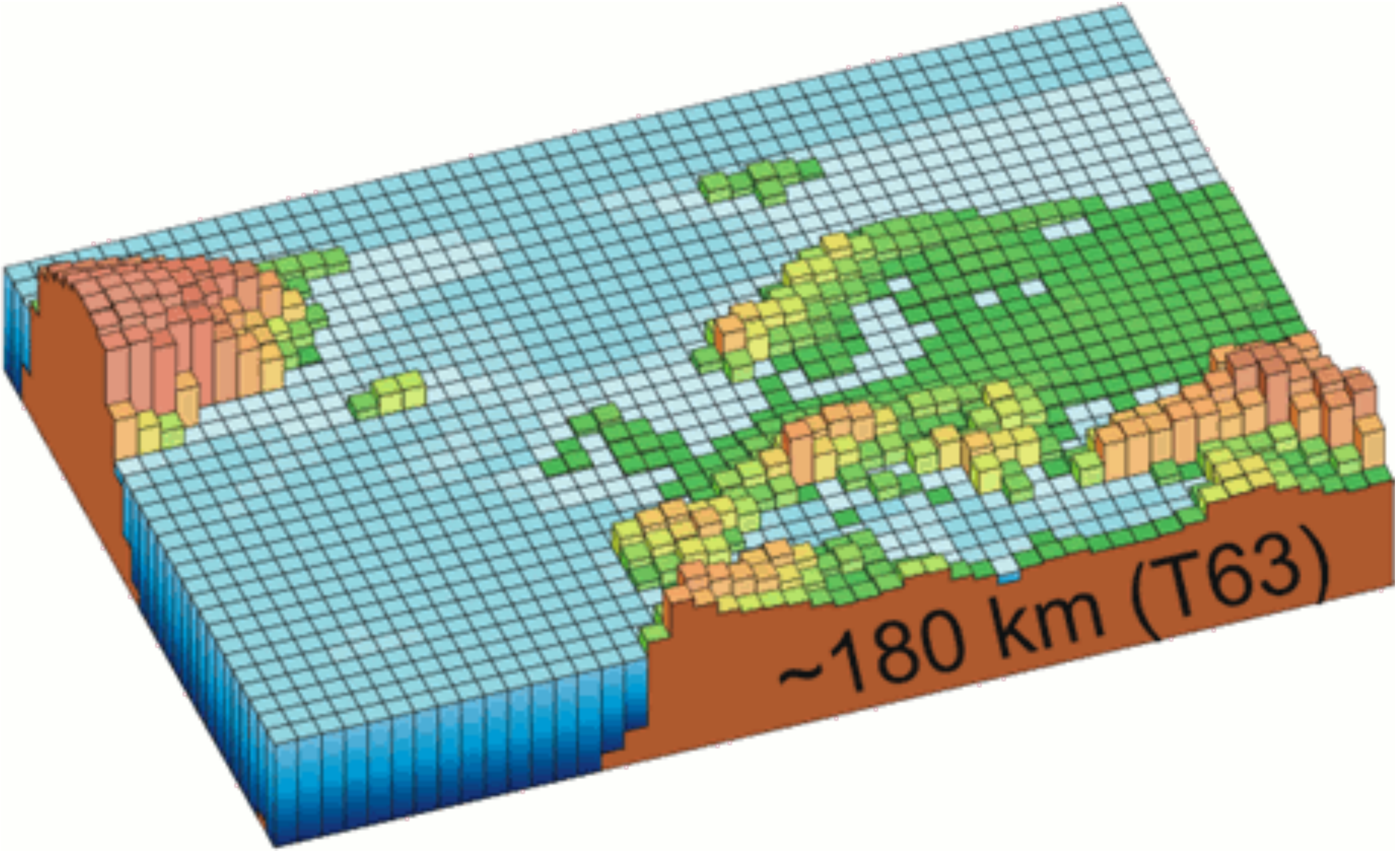
Resolution



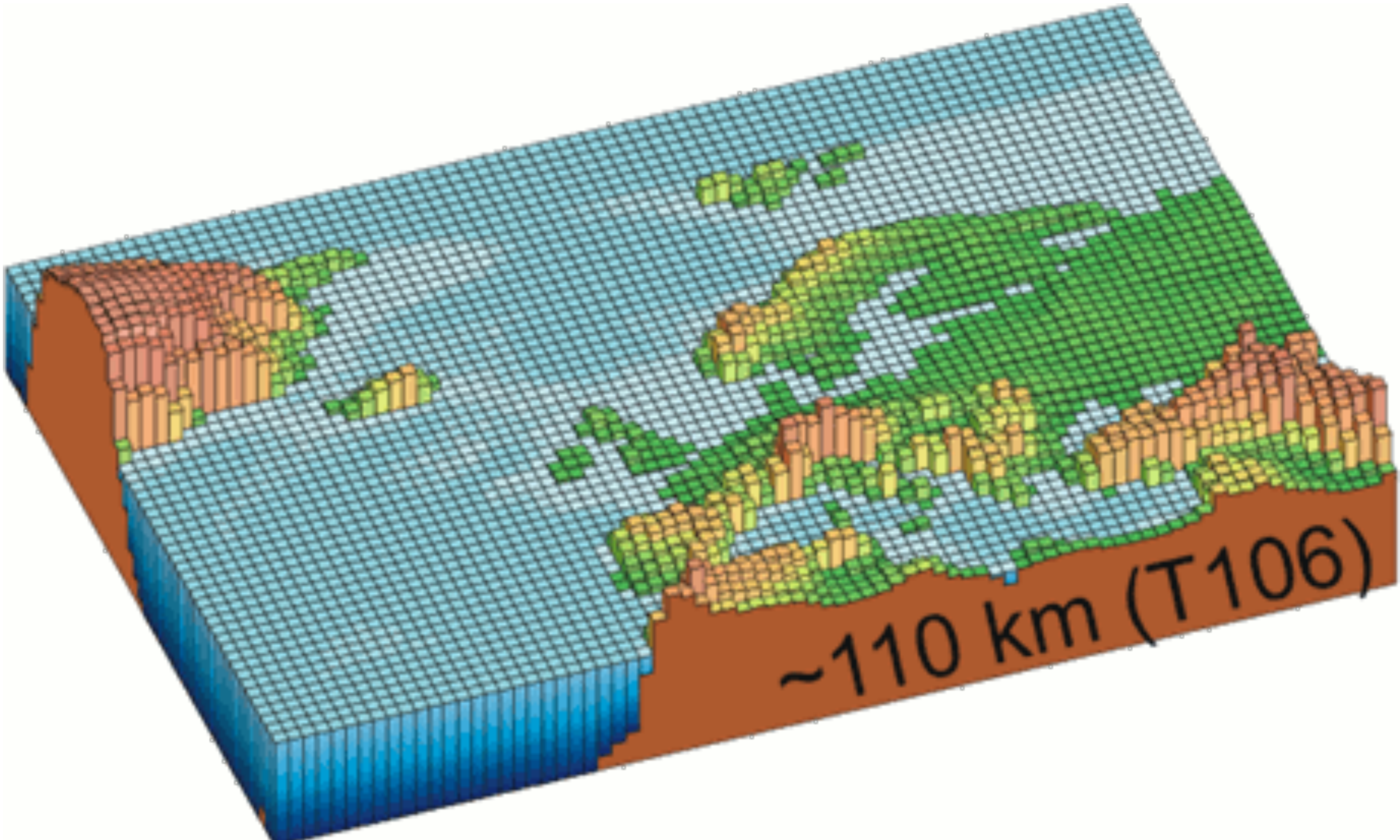
Resolution



Resolution



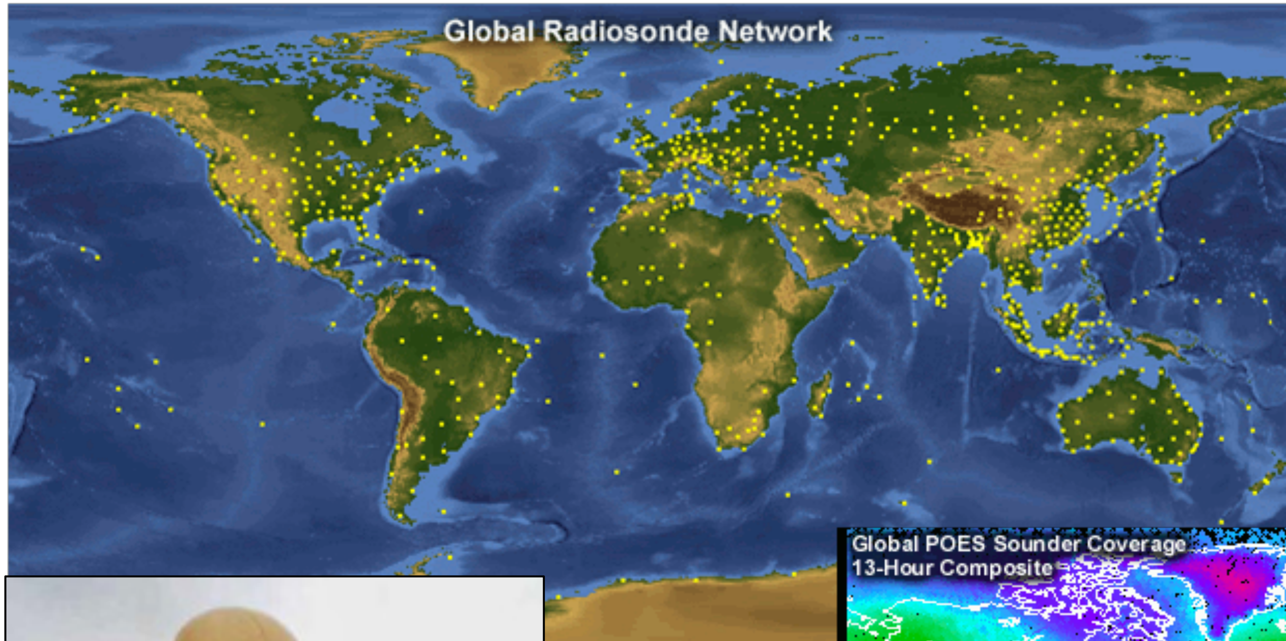
Resolution



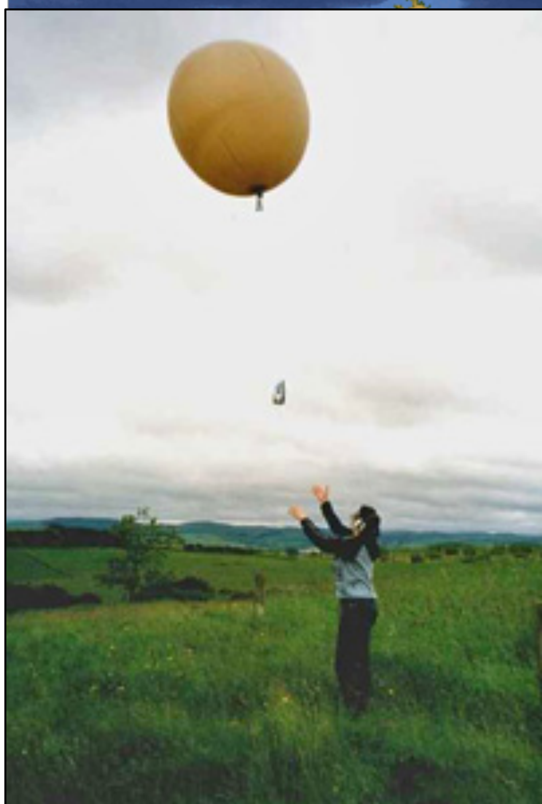
Is the weather forecast good?

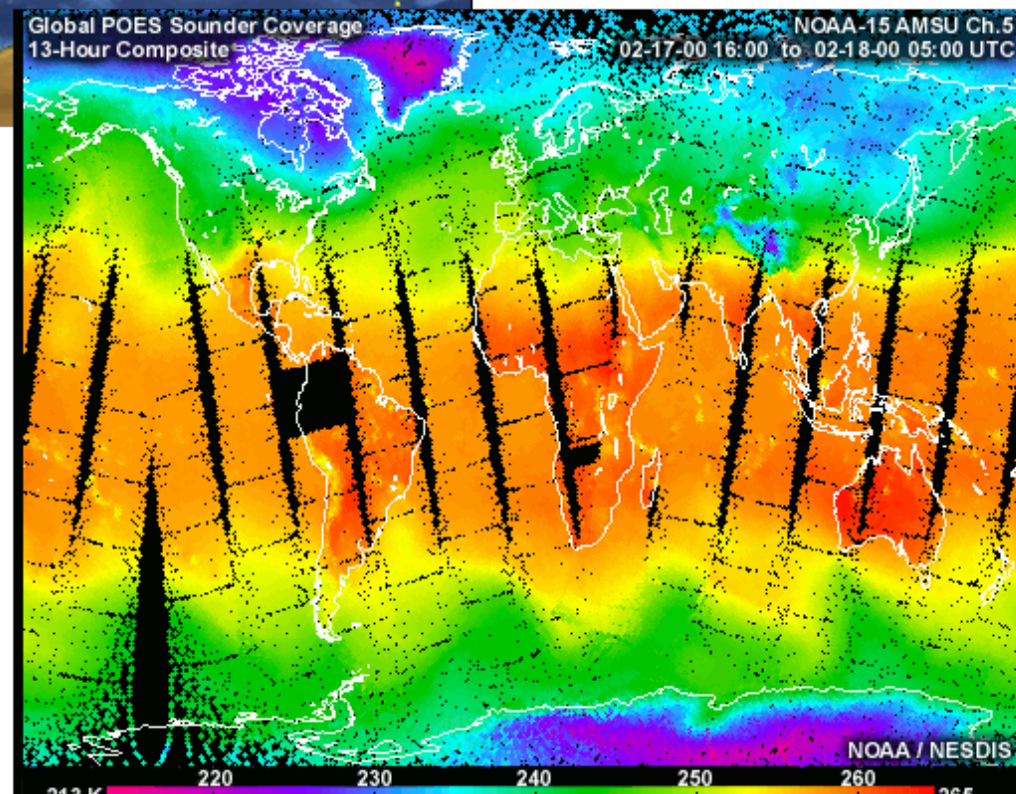
The quality of our solution (**weather forecast**) will depend on many factors:

- Adequate spatial and temporal resolutions
- Quality of initial condition
  - Great improvement with satellites in the 1970
  - Still the limiting factor today!



Radiosondes, large effort of lots of people, every day





Just 1 satellite

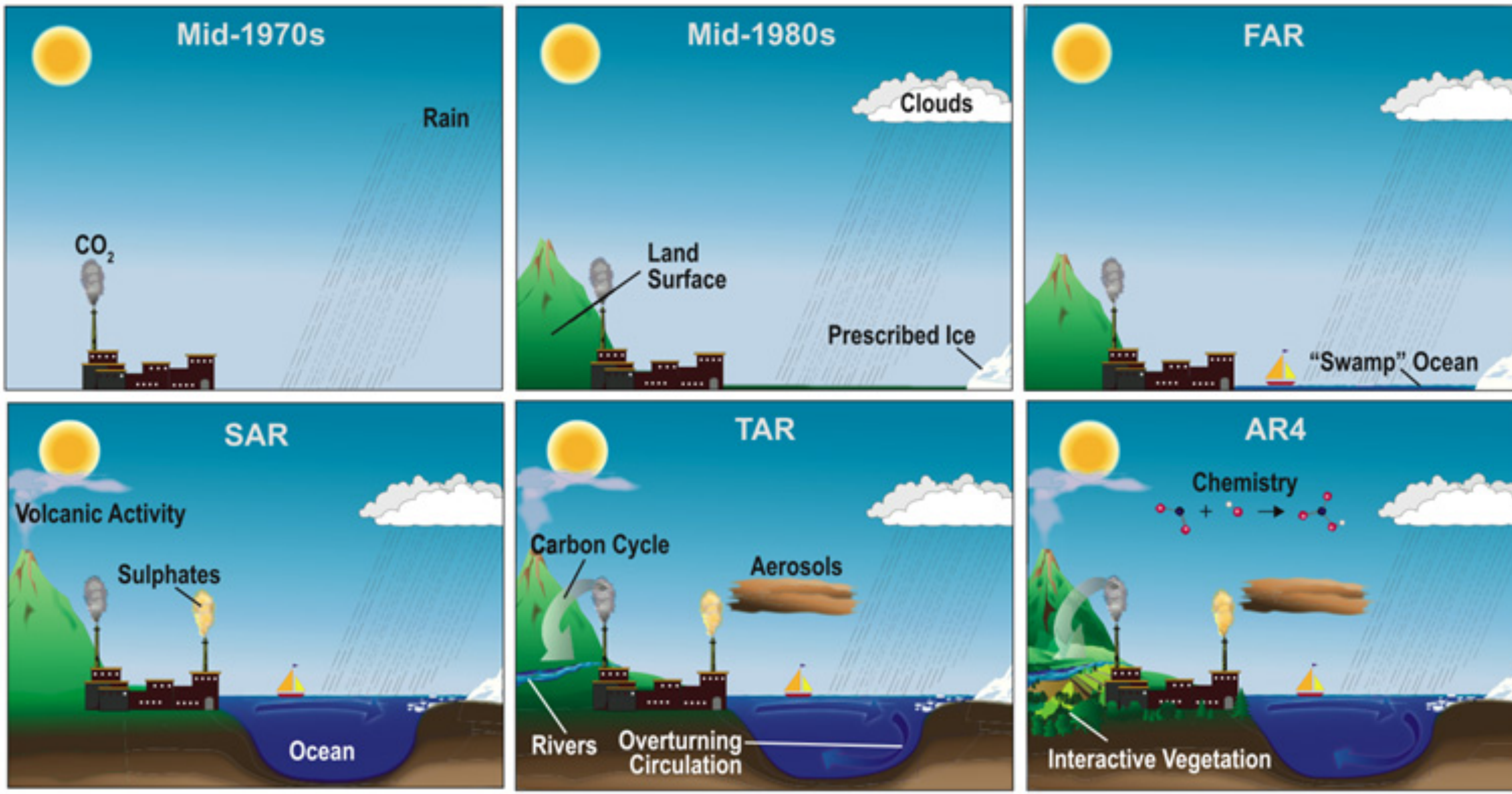
Is the weather forecast good?

The quality of our solution (**weather forecast**) will depend on many factors:

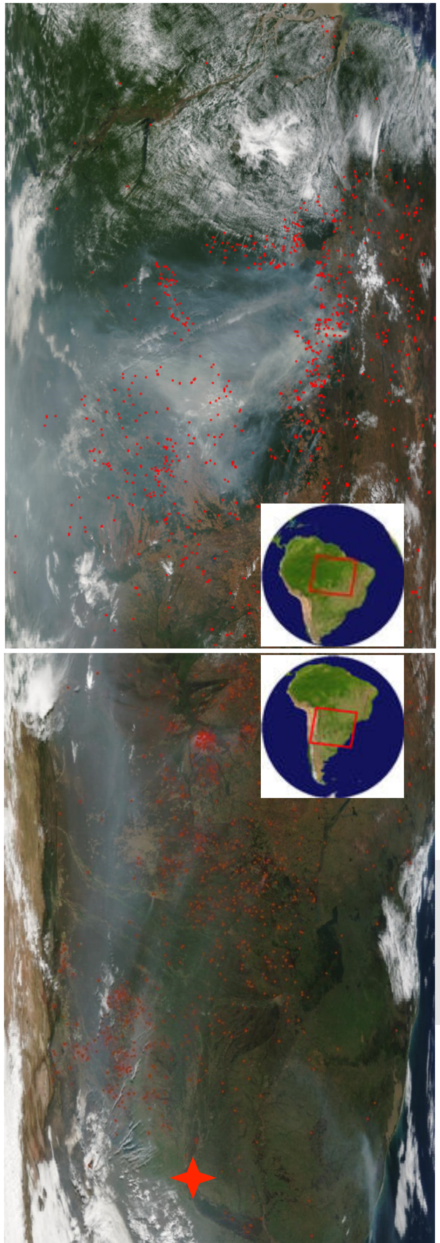
- Adequate spatial and temporal resolutions
- Quality of initial condition
  - Great improvement with satellites in the 1970
  - Still the limiting factor today (**weather**)!
- Physical processes (**limiting factor for climate**)
  - Radiation
  - Biosphere-atmosphere
  - Chemistry
  - ....

Which processes to include depend on the problem we want to takle!

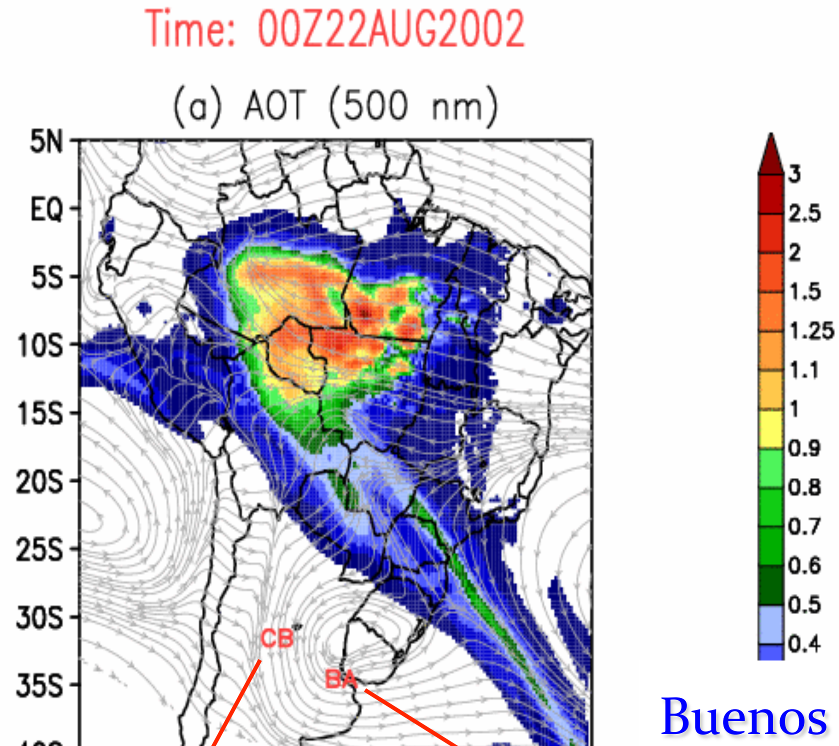
Evolution of climate models



An example of long range transport (advection) of smoke

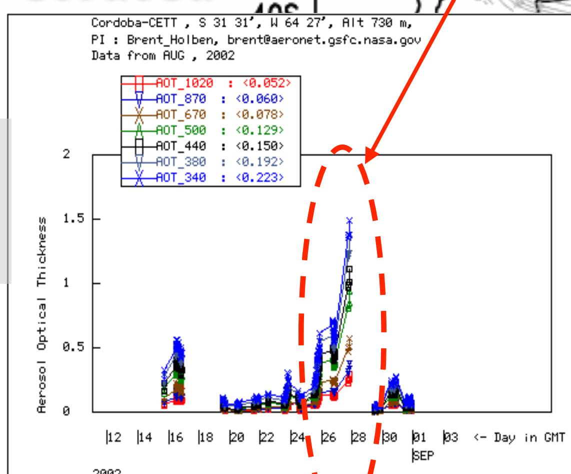


27 August 2002



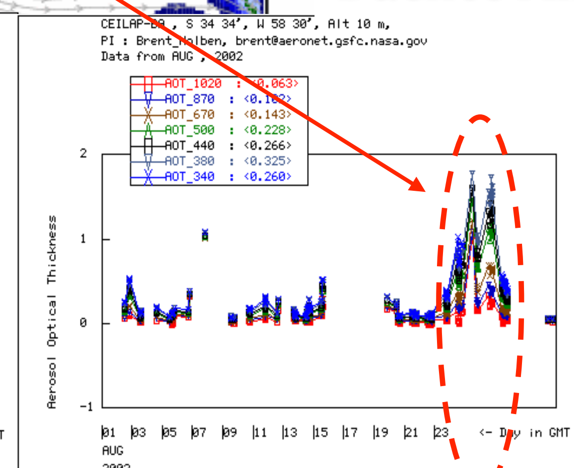
Córdoba

AOT



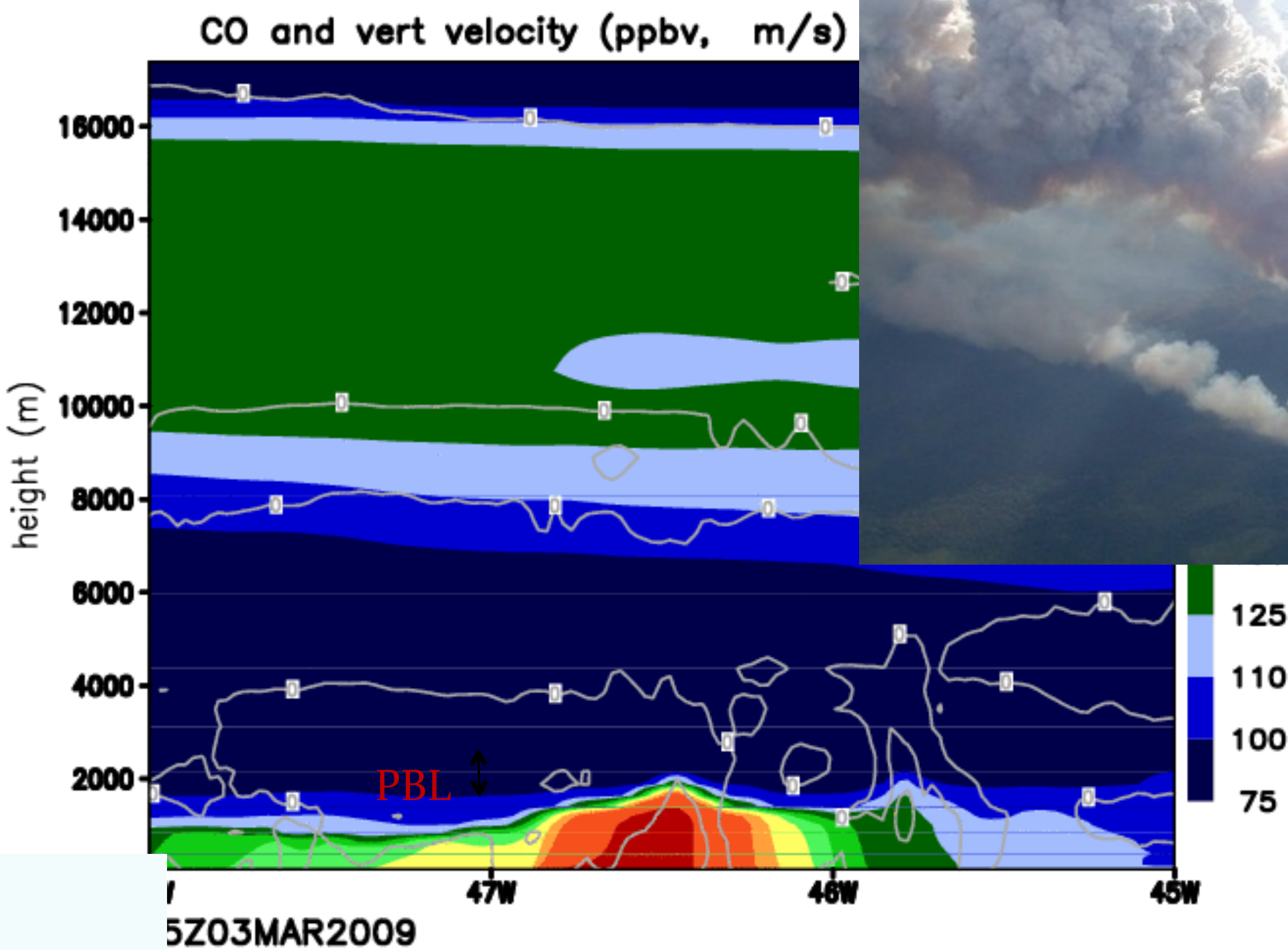
26–29 Aug 2002

Buenos Aires



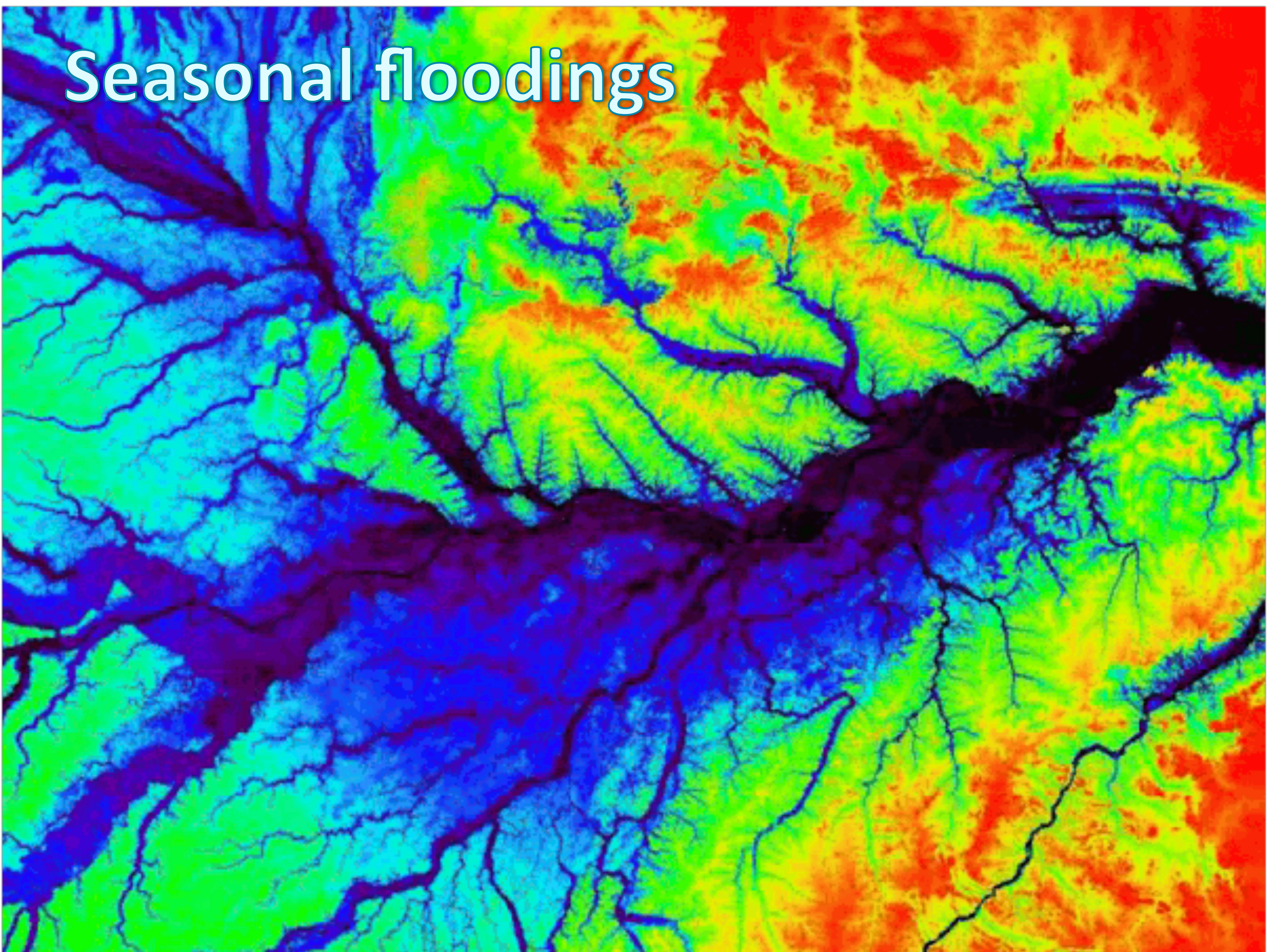
26–29 Aug 2002

Vertical cross section showing vertical velocity and the transport of CO from the PBL to the high troposphere



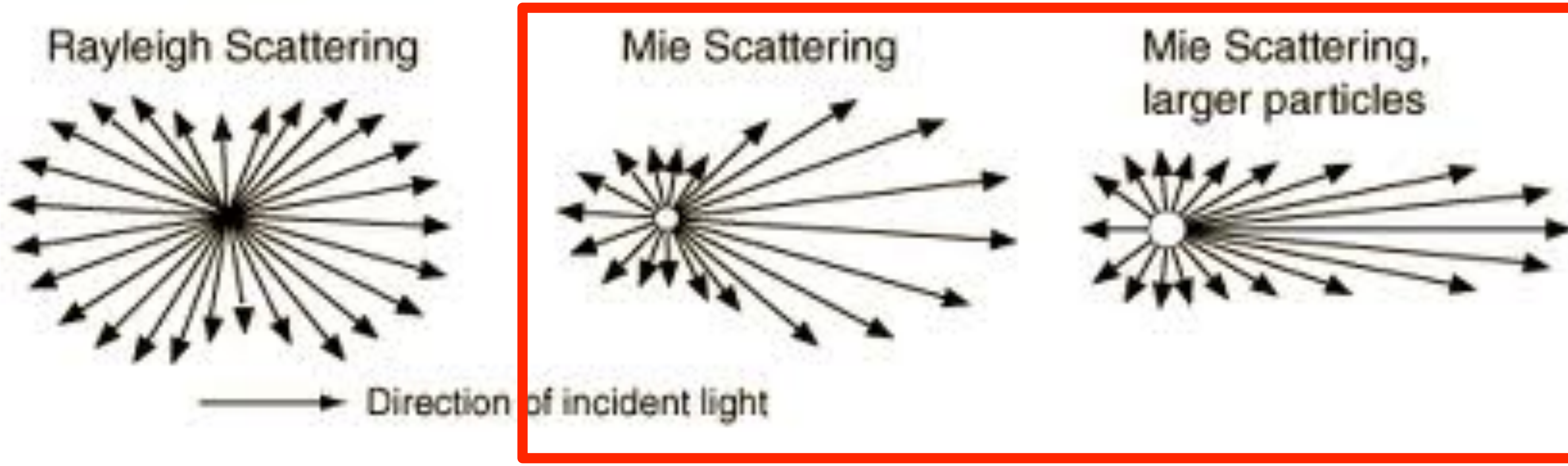
S. Freitas - INPE

Seasonal floodings



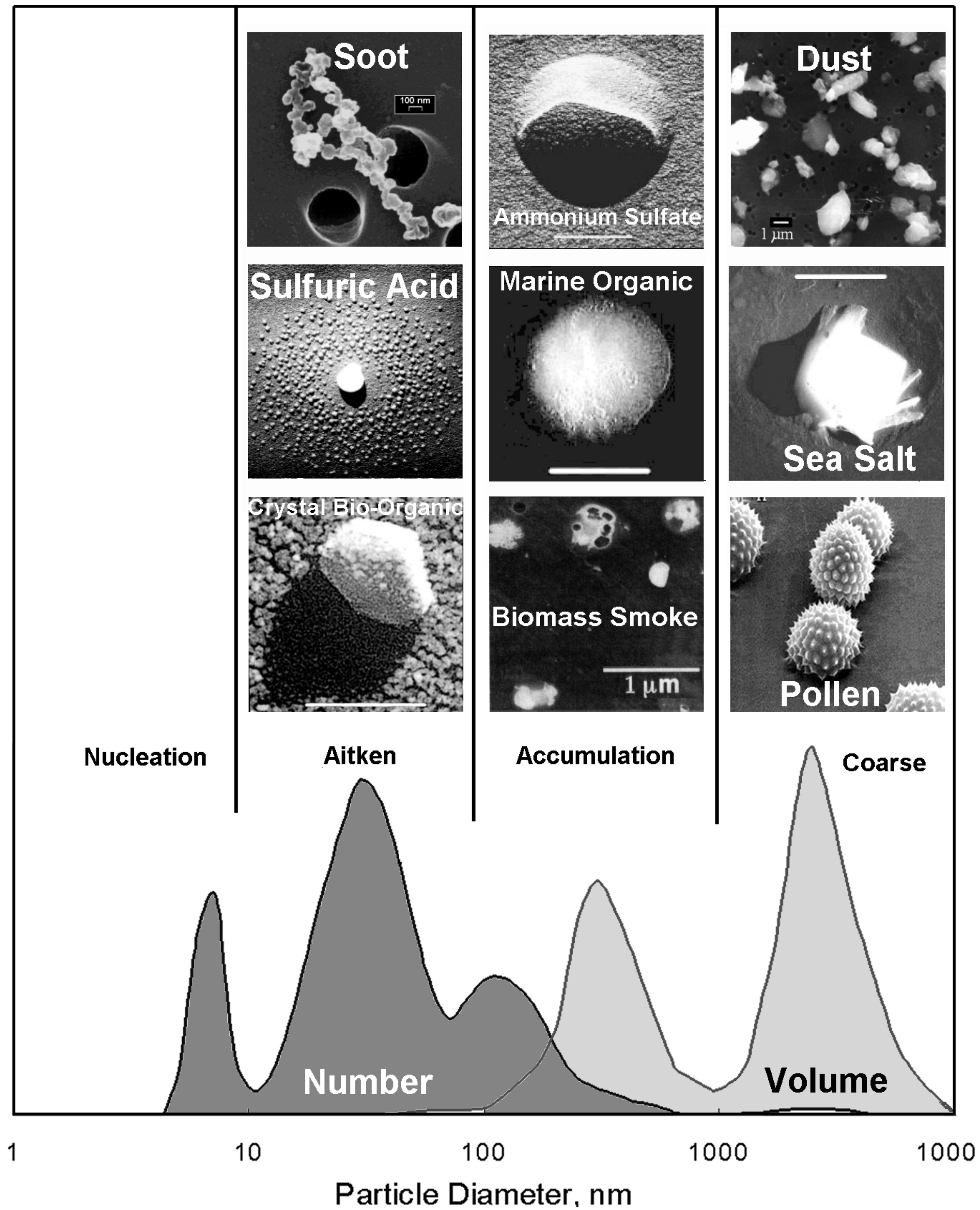
Aerosols are very complicated

- Classical electromagnetism
  - Rayleigh scattering - molecules
  - Mie scattering – aerosol and droplets

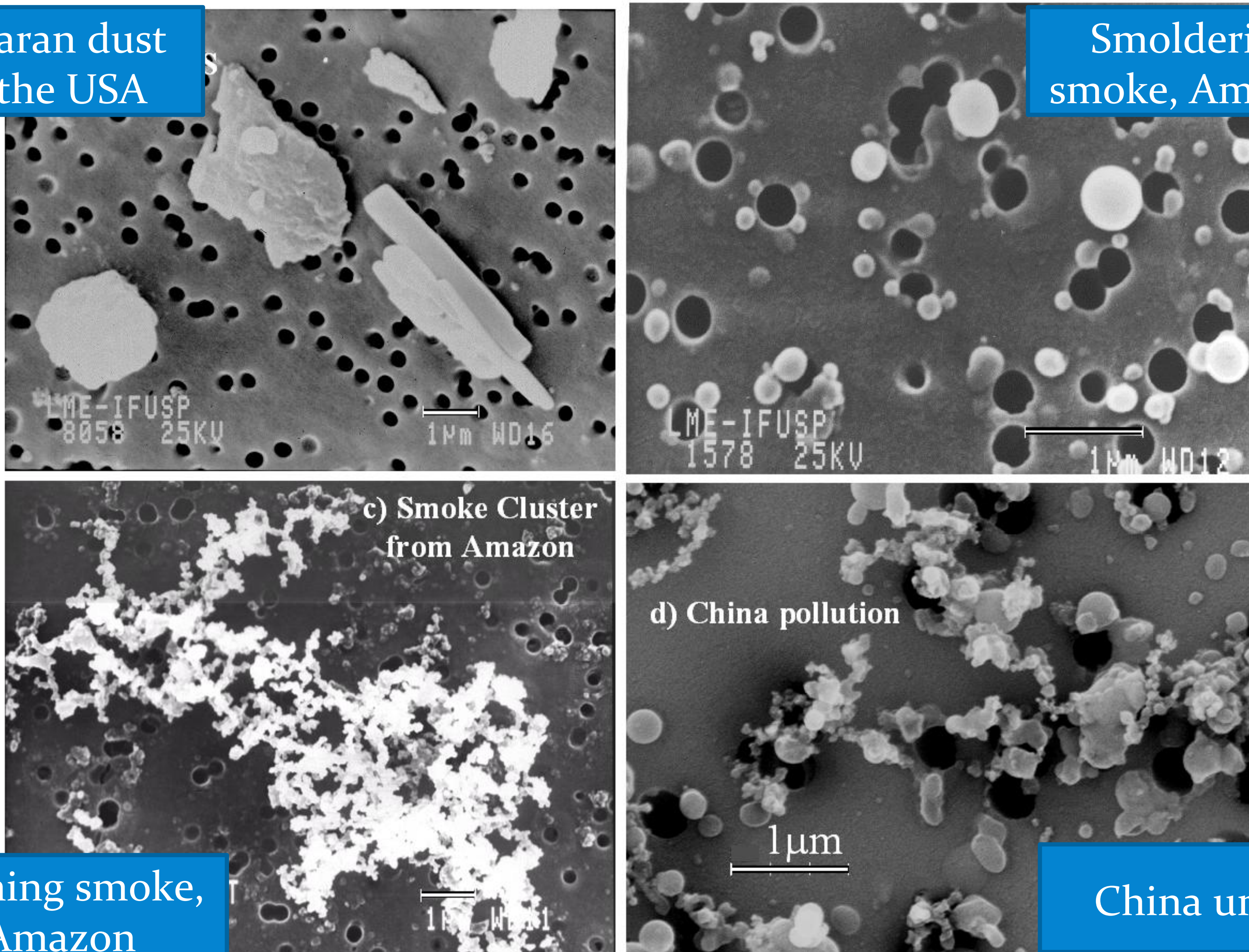


Size << λ **Size ≈ λ** **Size > λ**

- Interaction of the aerosol with the radiation field depends:
  - Size
  - Shape
  - Surface properties



... Aerosols can be very different



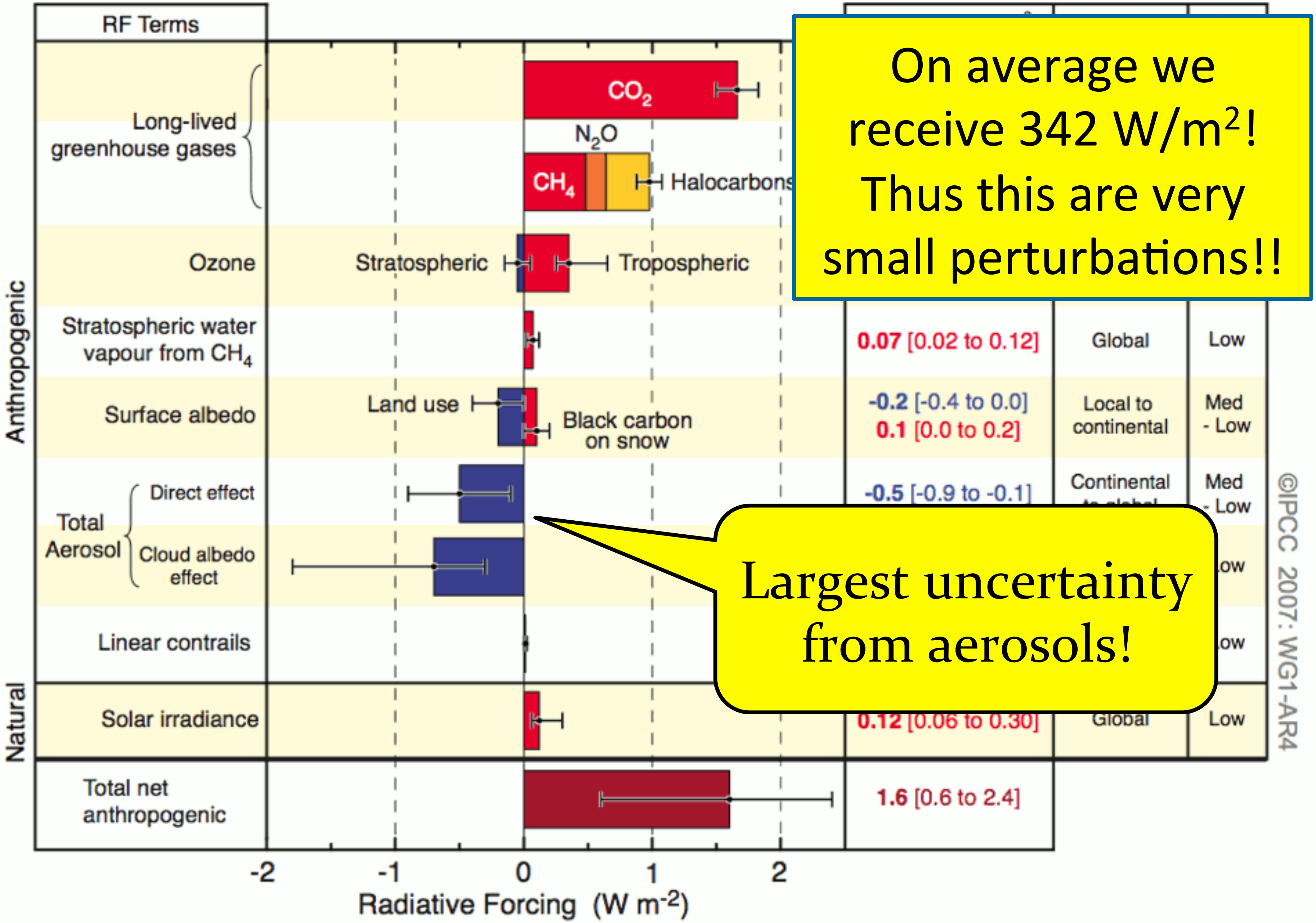
Saharan dust in the USA

Smoldering smoke, Amazon

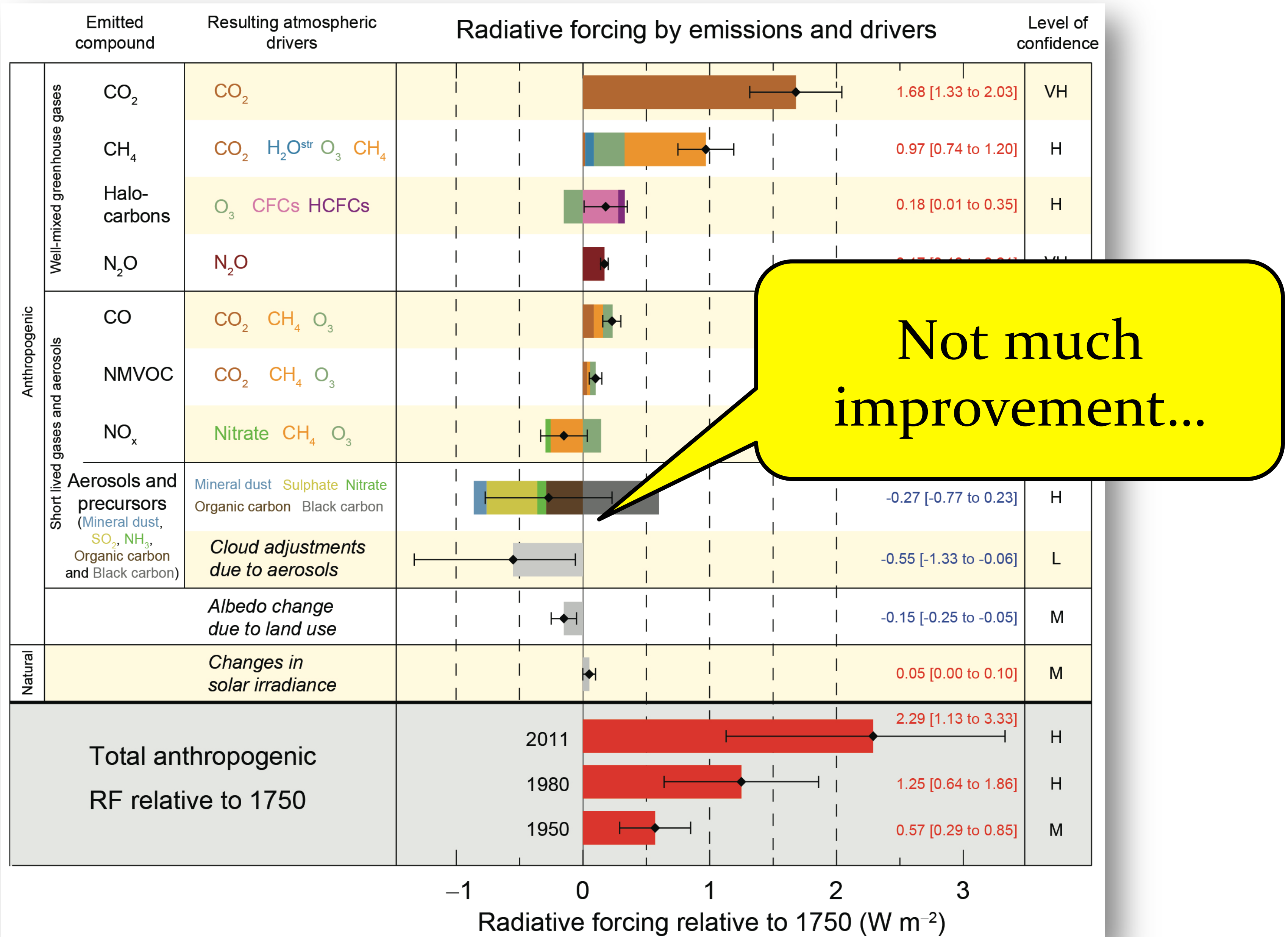
Flaming smoke, Amazon

China urban

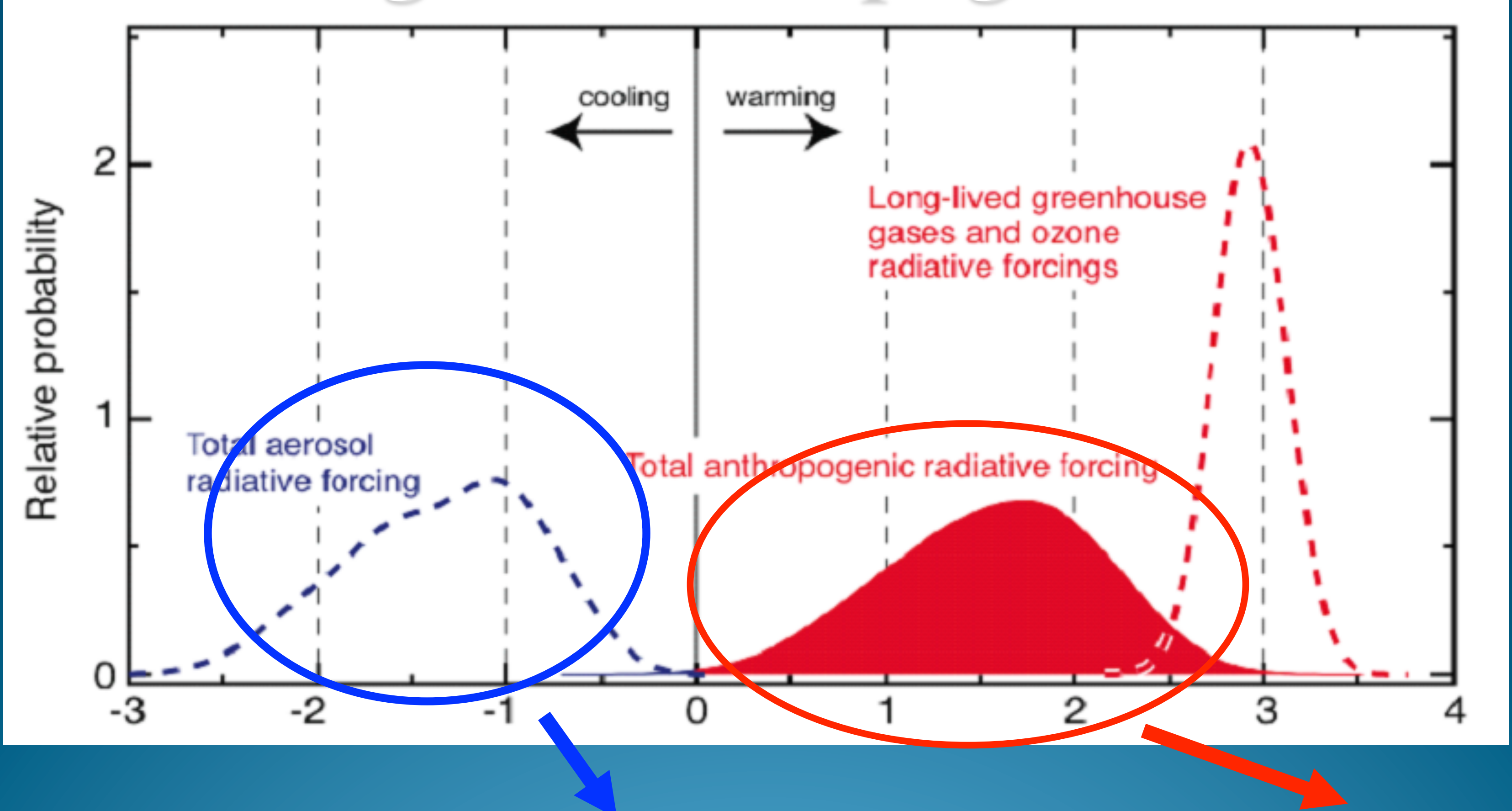
Radiative forcings of the global climate system IPCC 2007



Forçante radiativa do sistema climático global (IPCC 2013)



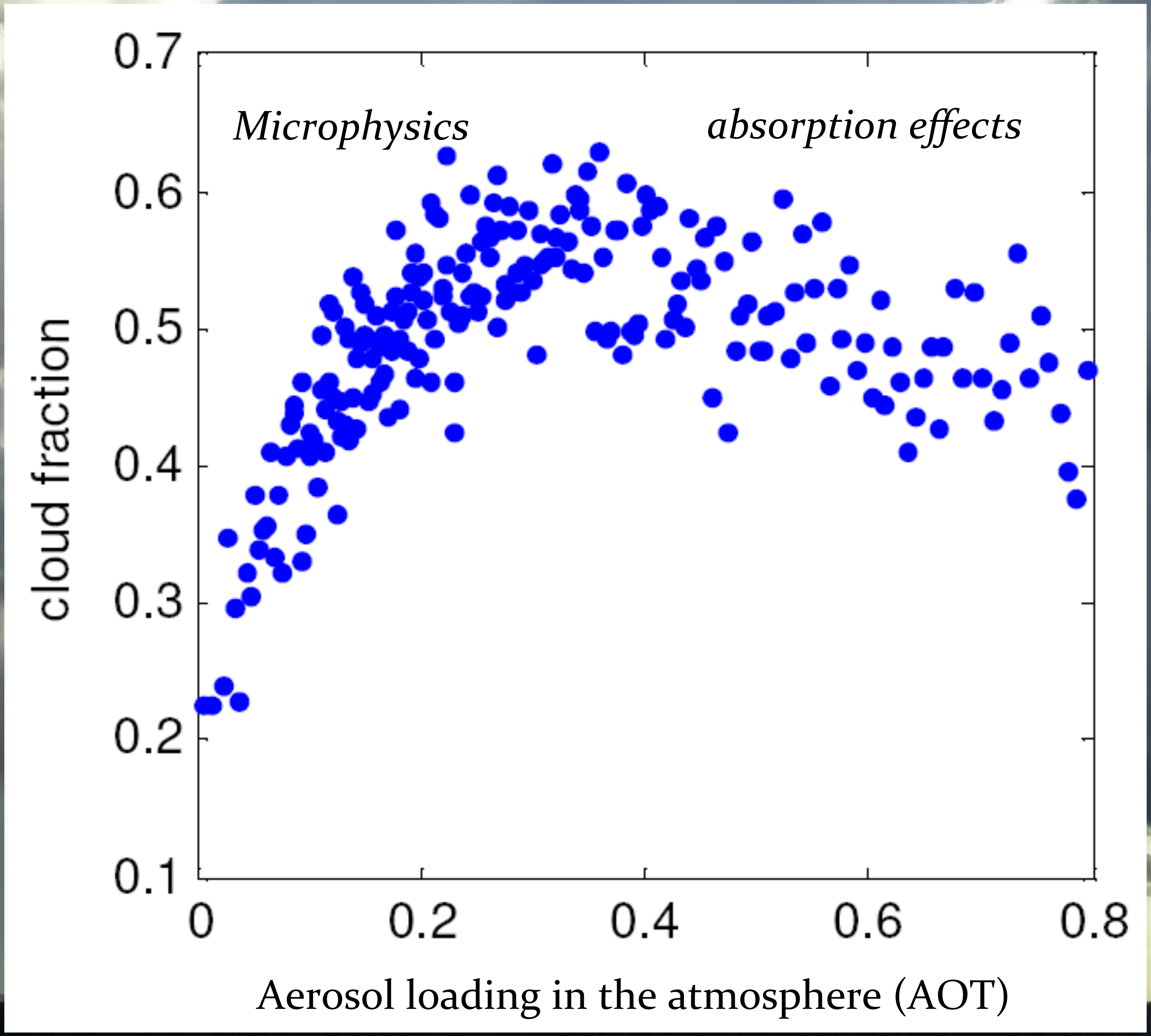
Combining all anthropogenic effects



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

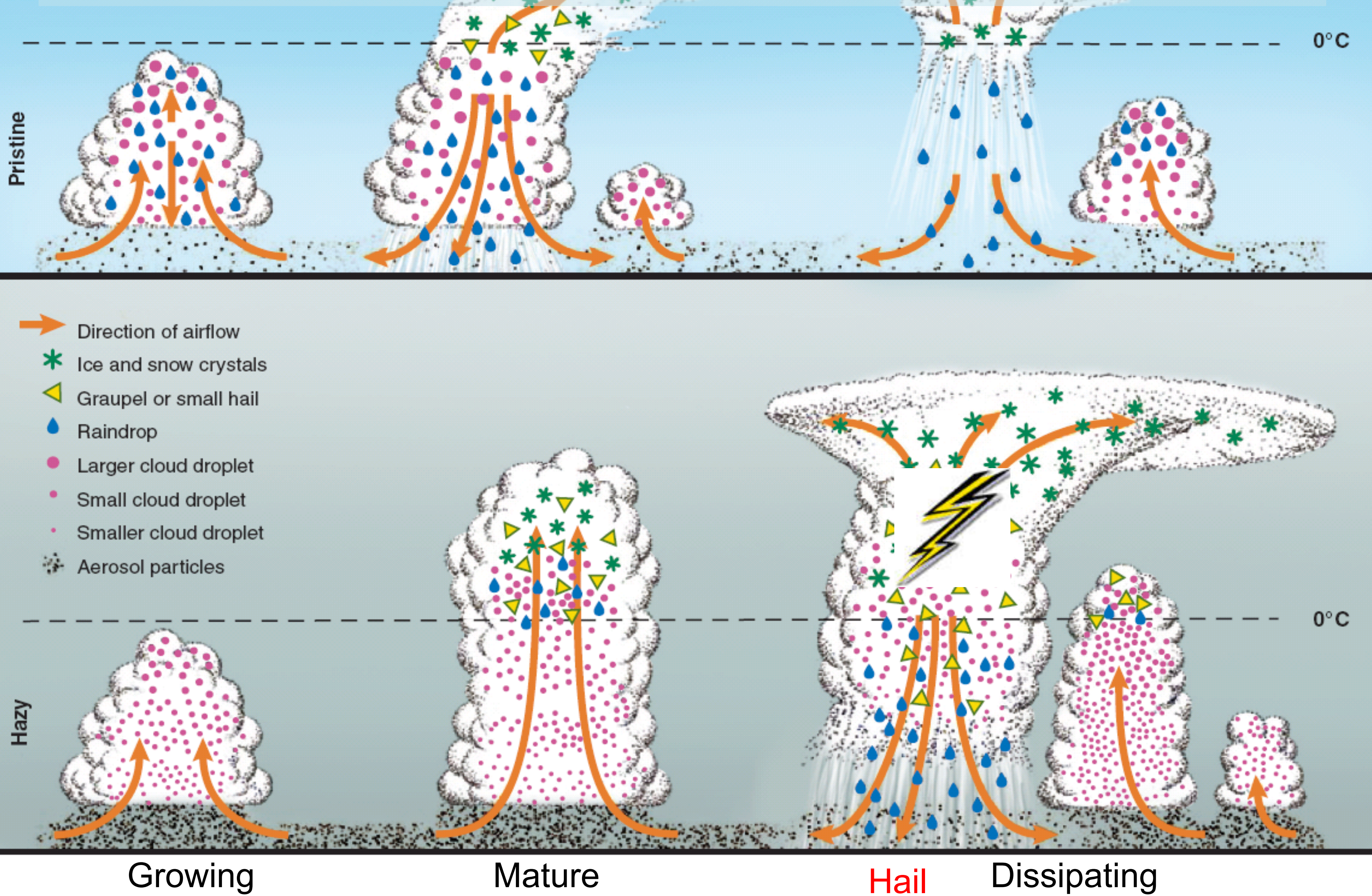
- *Combined anthropogenic forcing* is not straight sum of individual terms.
- Tropospheric ozone, cloud-albedo, contrails → asymmetric range about the central estimate
- Uncertainties for the agents represented by normal distributions except: contrail (lognormal); discrete values → trop. ozone, direct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

Relationships between cloud properties and aerosol loading in Amazonia

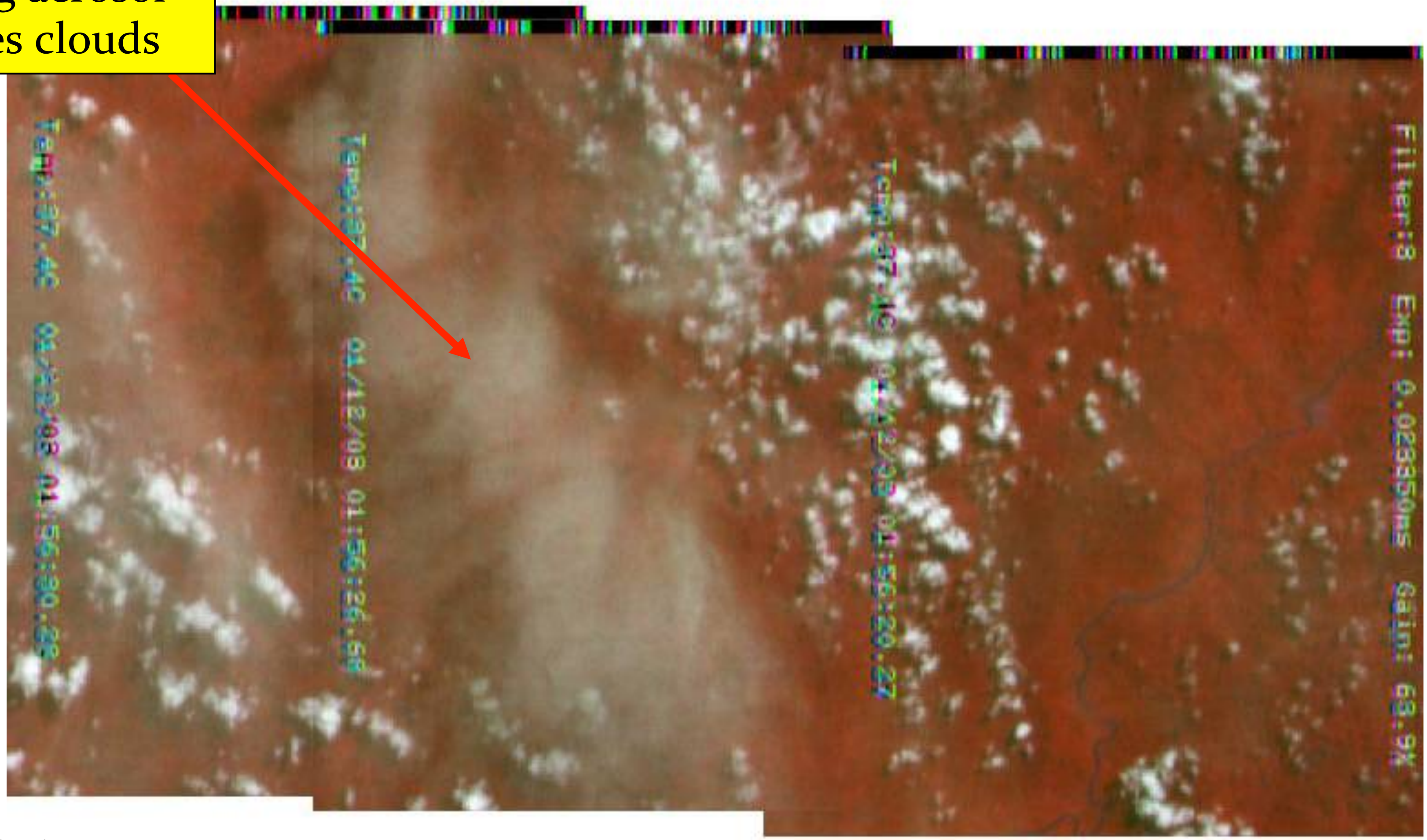


Koren et al., Science 2008

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.



With too much aerosols: Cloud supression

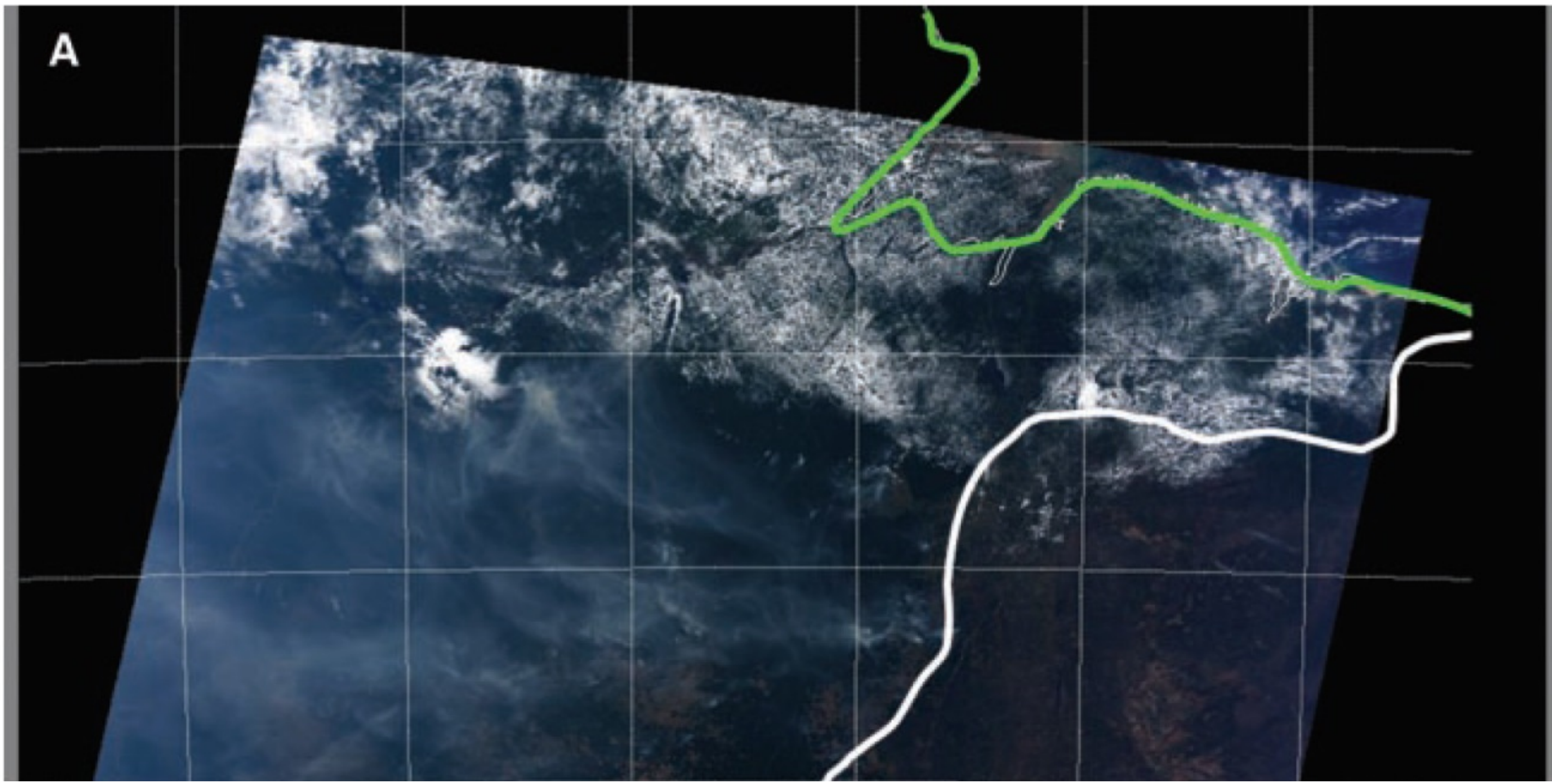


- Stabilization
- Suppression of surface fluxes
- Microphysical influences on droplets

Columbia Shuttle January 2003

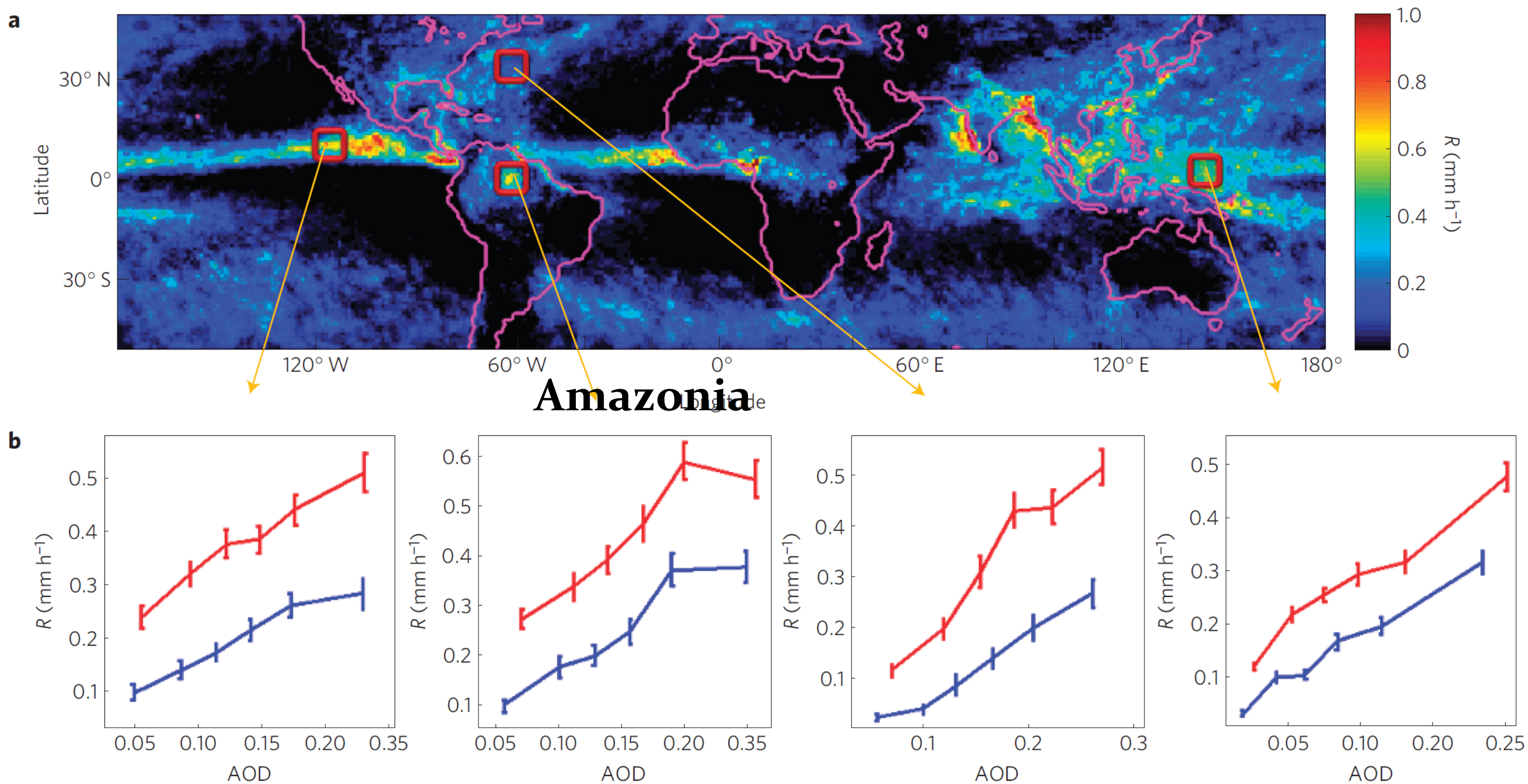
Terra and Aqua satellite images of the east Amazon basin, 11 August 2002. *(From Koren et al., 2004)*

Large scale low cloud suppression



Rain rate (TRMM) versus Optical Depth (MODIS)

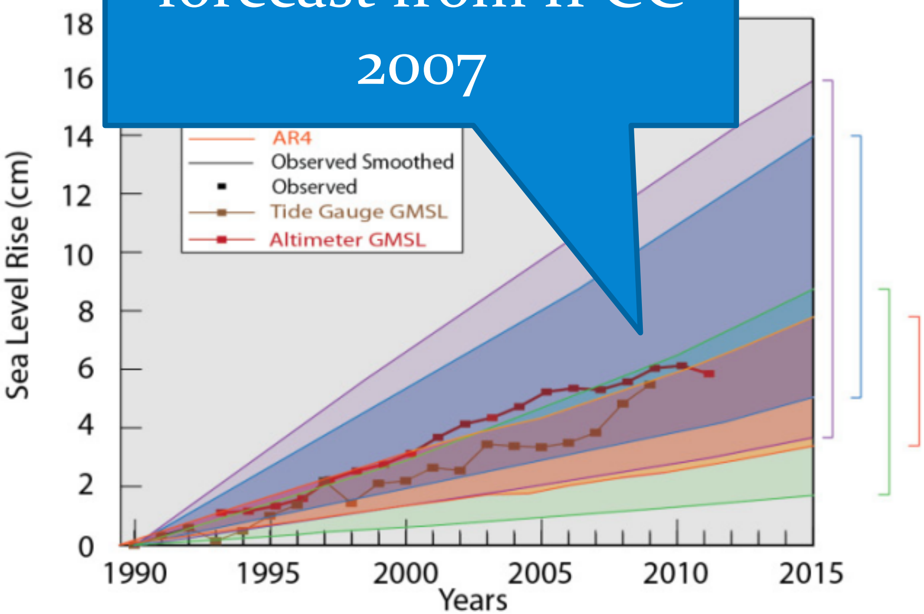
NATURE GEOSCIENCE DOI: 10.1038/NGEO1364 LETTERS

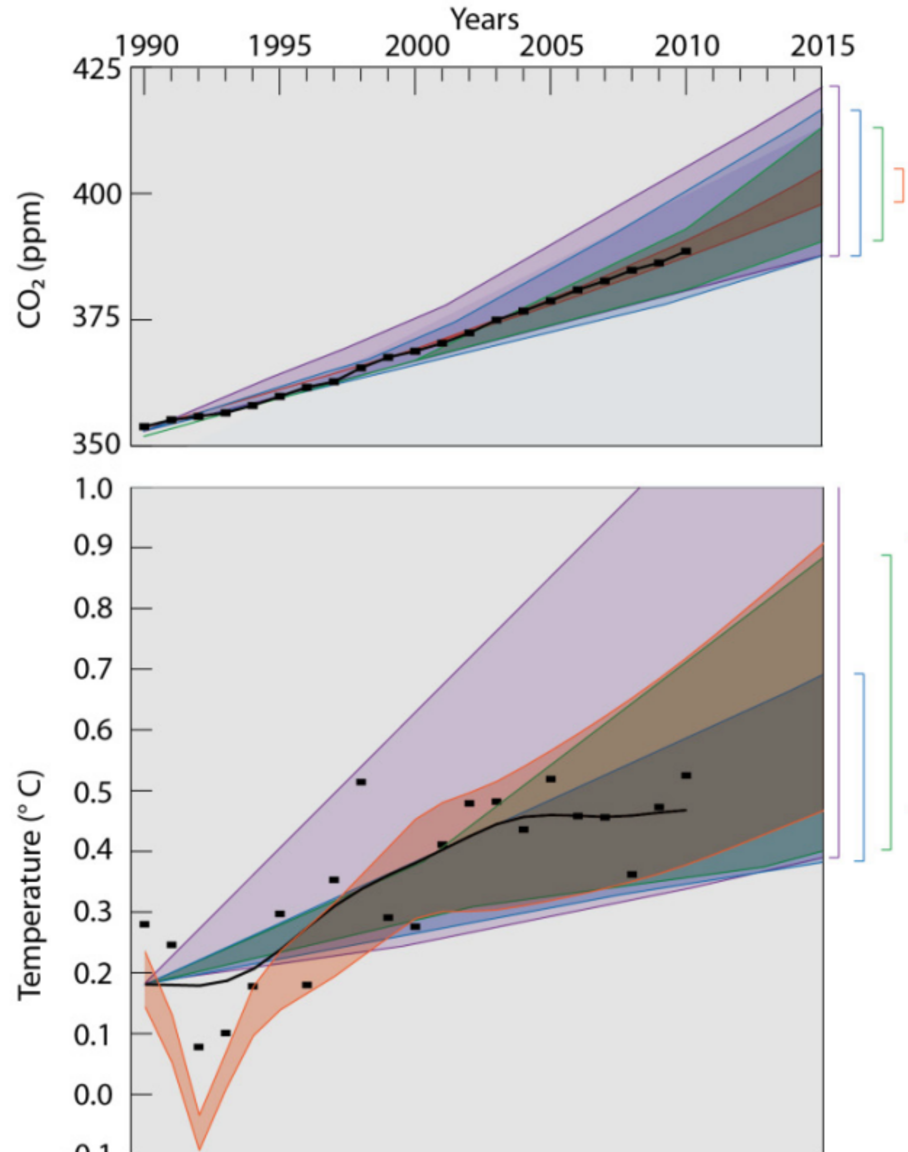


13:30 local-time map of rain rate (R) and the observed trend with aerosol loading in four selected regions. Period: July and August 2007. **b**, The average R values are plotted for six aerosol-loading sets (blue, including zero R grid squares; red, without zero R grid squares). Note the R intensification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

Despite it all...

Current increase larger than worse forecast from IPCC 2007

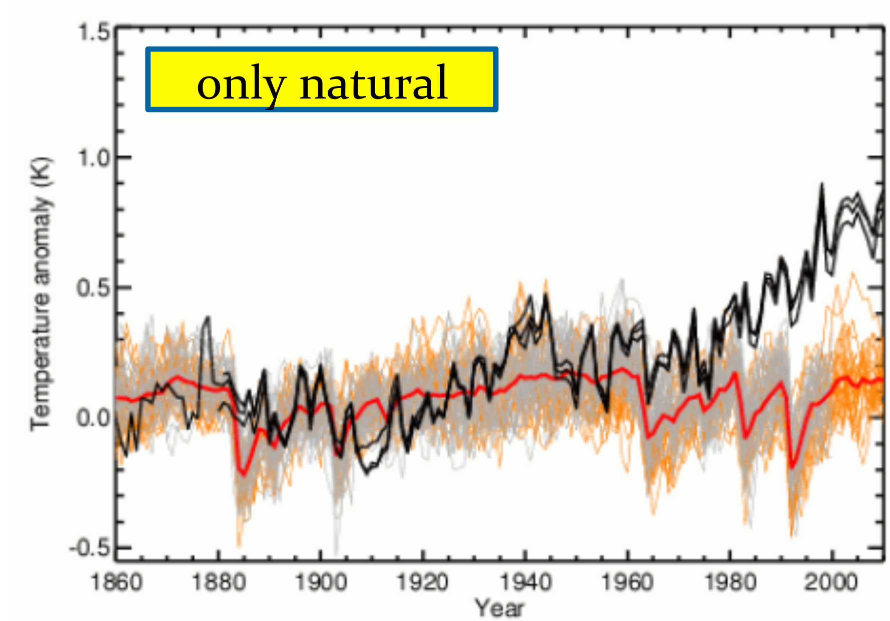


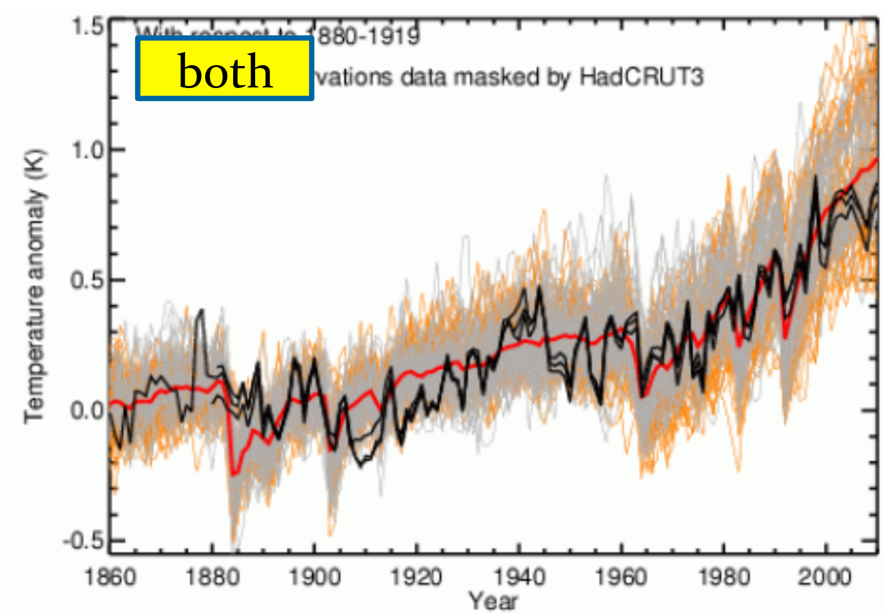


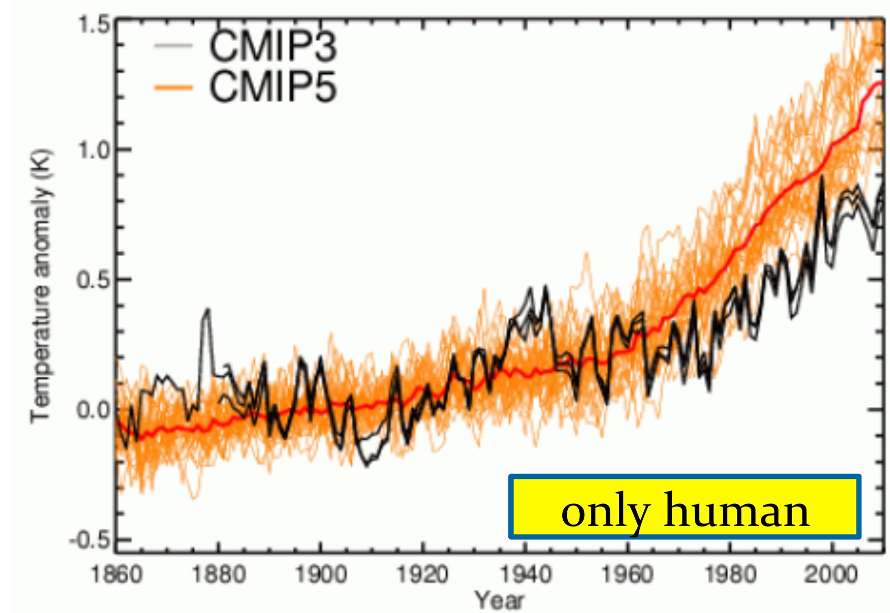
IPCC, AR5, Unpublished

Only explained by

- natural+antropogenic



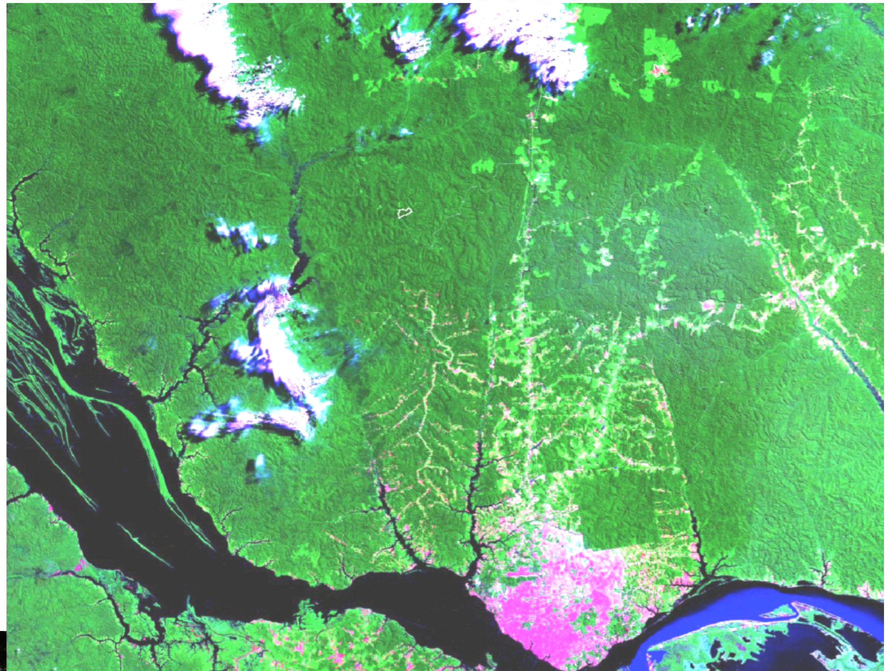


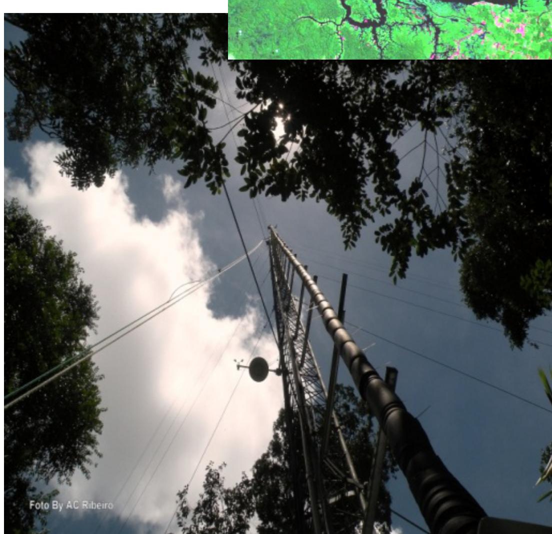


IPCC, AR5, Unpublished


Manaus

The ZF2 measurement site in Central Amazonia



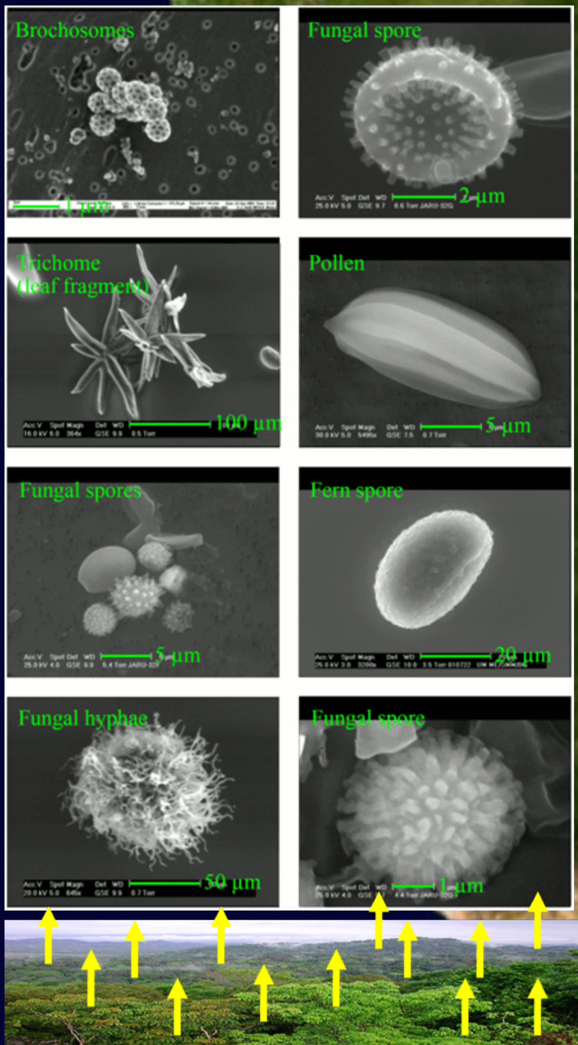


Dry aerosol (RH<40%)
Site continuously operational since Feb 2008.

Manaus ZF2 site: Instruments, dryer and ACSM

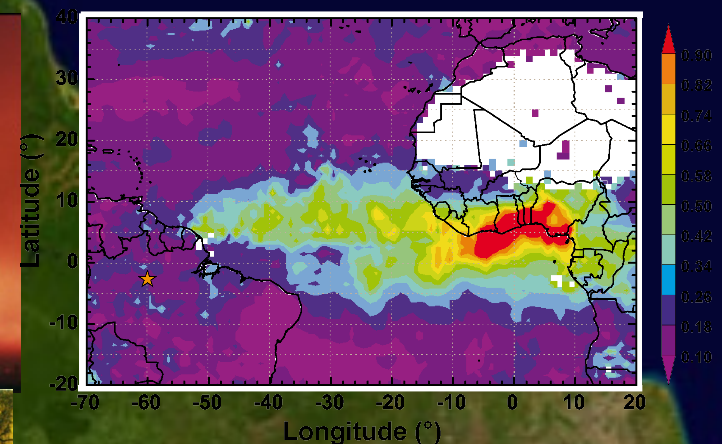
Amazonia: 3 different types of aerosols

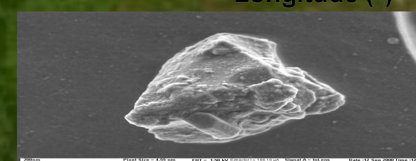
Biogenic (primary and SOA)

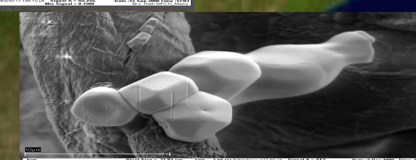


Biomass Burning

Dust from Sahara



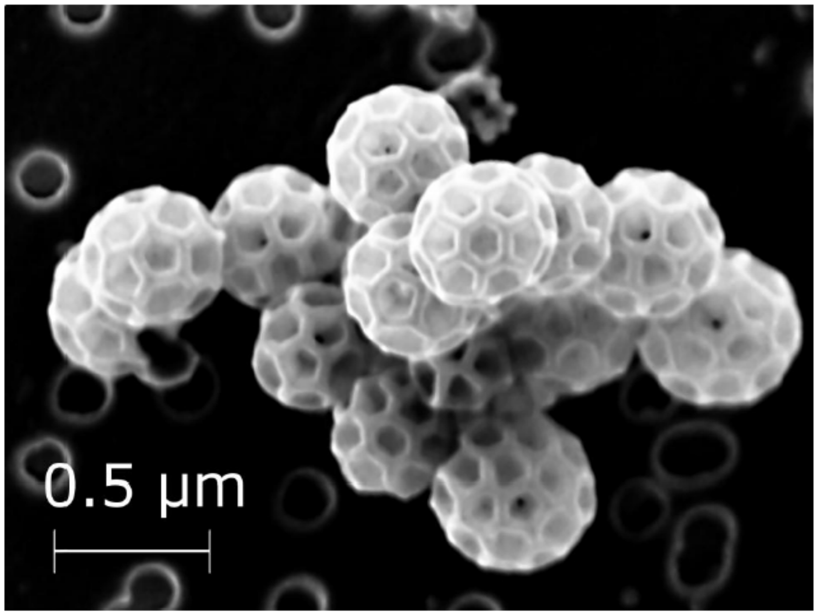


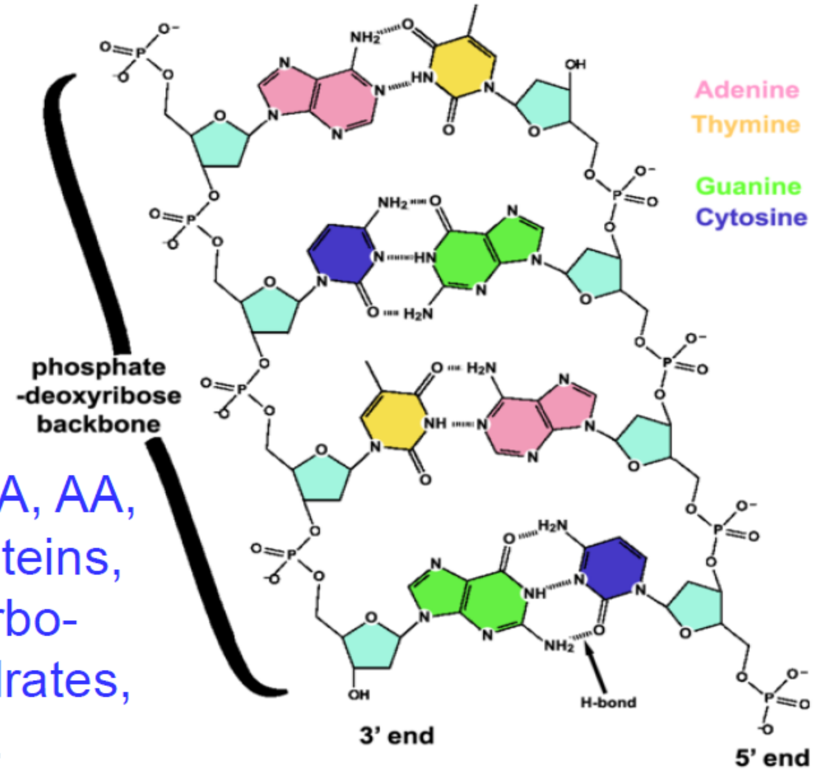


Each with VERY different properties and impacts

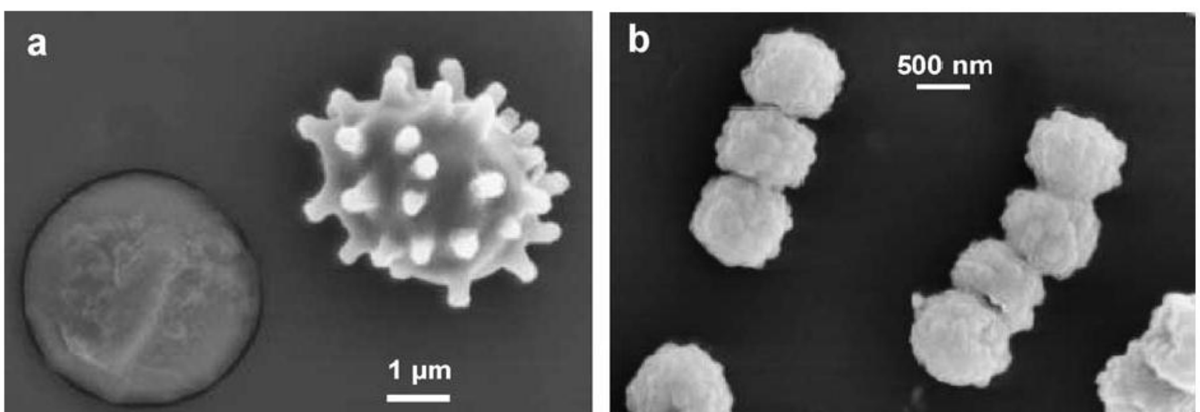
Biological Particles & Molecules

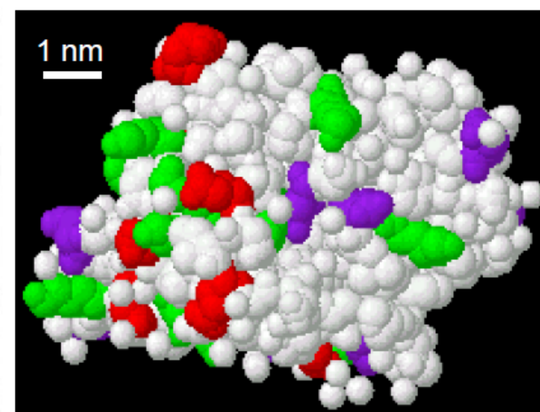
Bacteria, Brochosomes, Spores, Pollen, Plant Debris, etc.

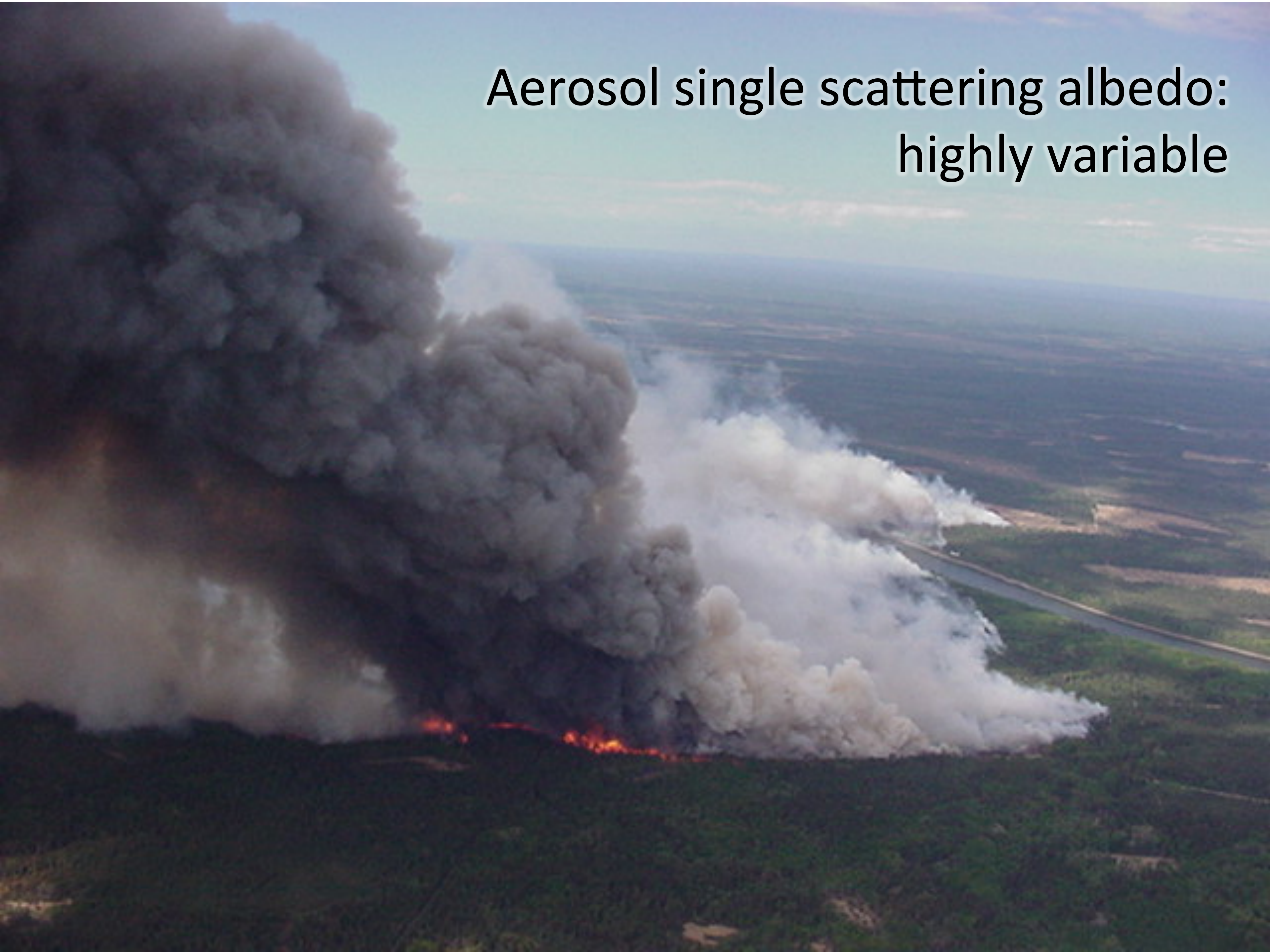




DNA, AA, Proteins, Carbo-hydrates, etc.

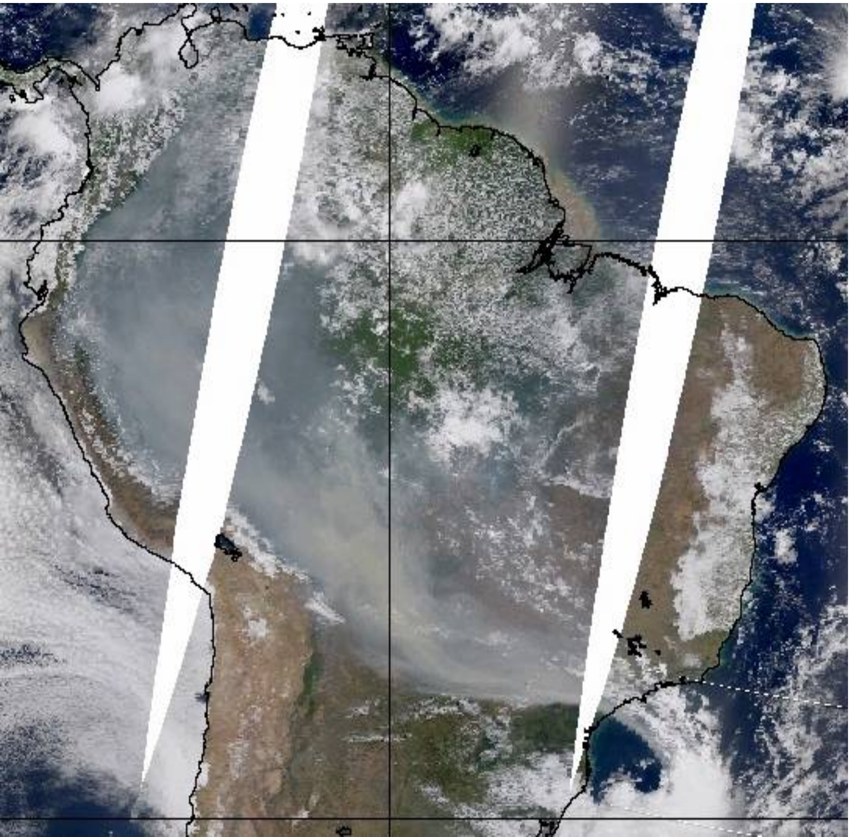


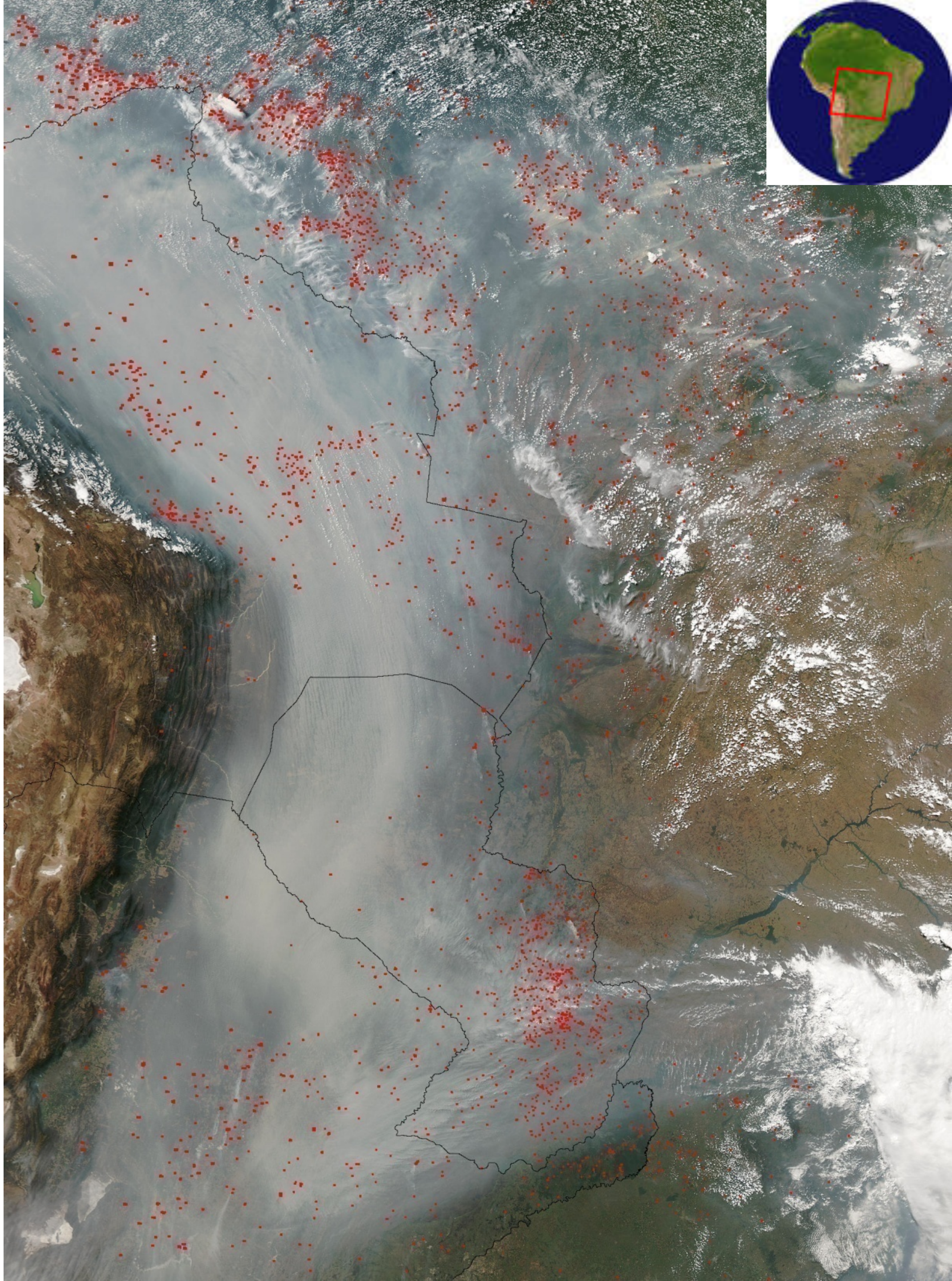



Aerosol single scattering albedo:
highly variable

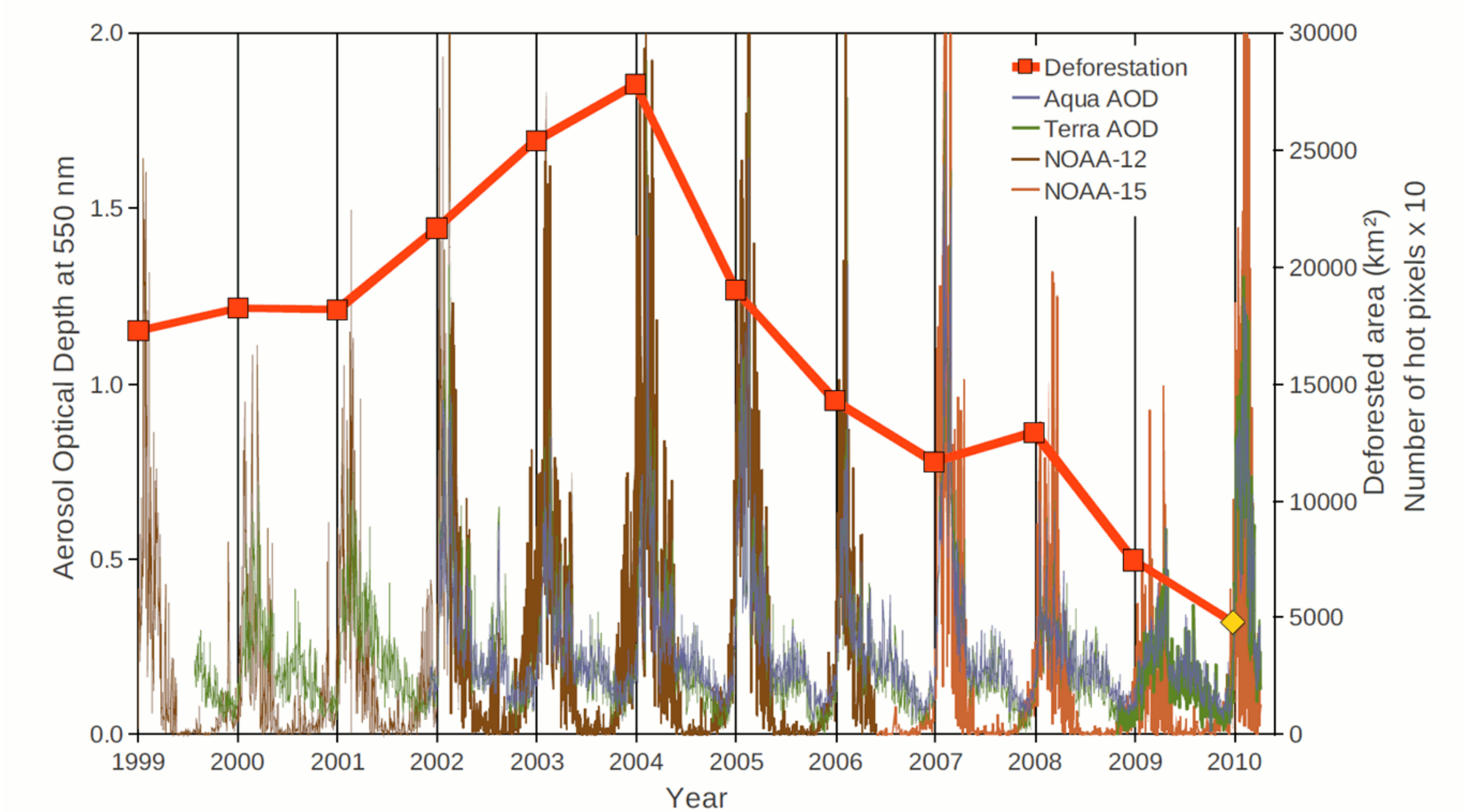
Large scale aerosol distribution in Amazonia

- 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

INDOEX

average aerosol forcing clear sky

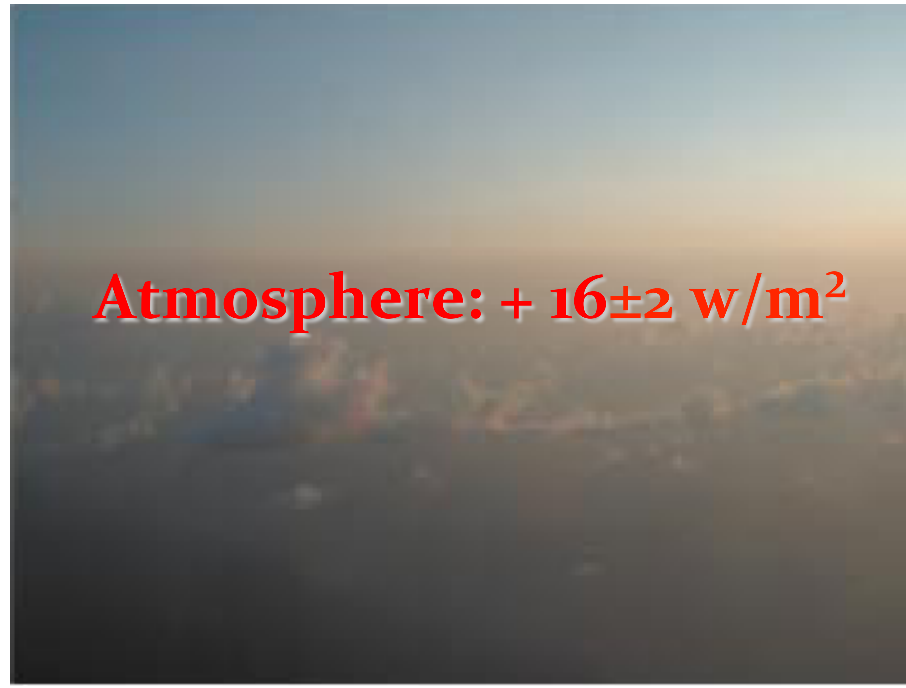
Top: - 10 w/m²

Atmosphere: + 28 w/m²

Surface: - 38 w/m²

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

Top: - 7±1 w/m²



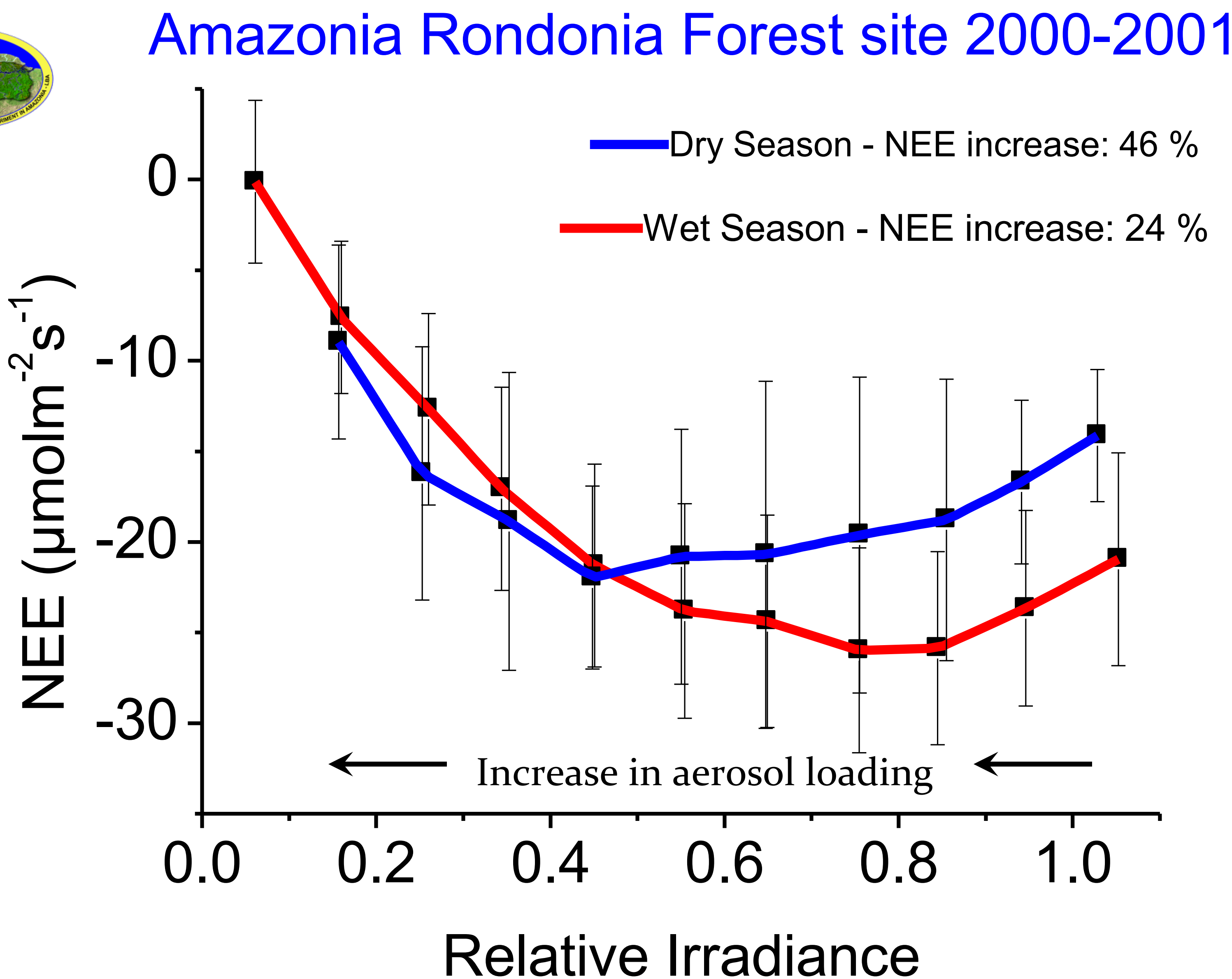
Atmosphere: + 16±2 w/m²

Surface: - 23±2 w/m²

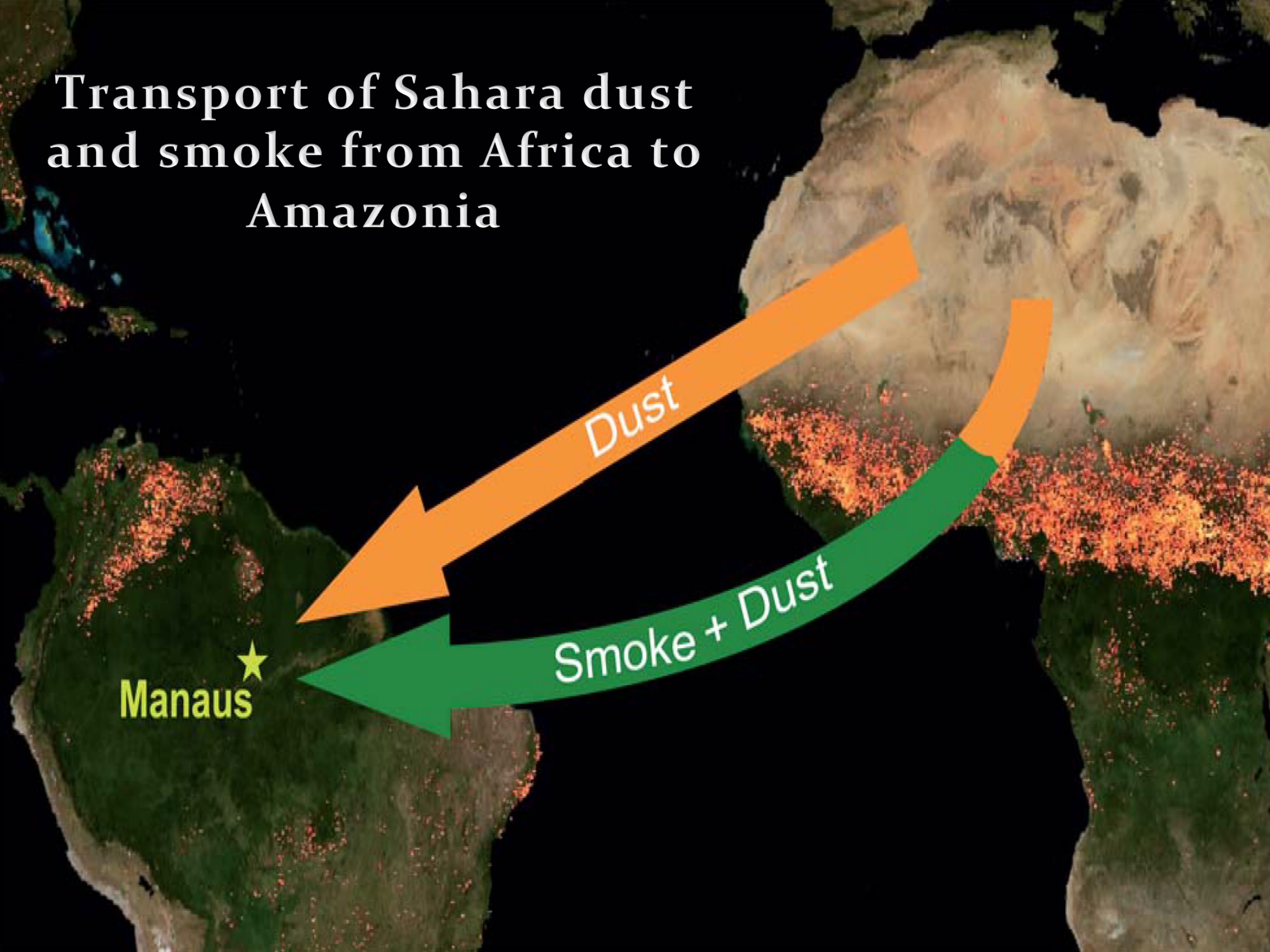
Conditions: surface: ocean
AOT (τ=0.3 at 630 nm); 24 hour average
Jan-Mar 99

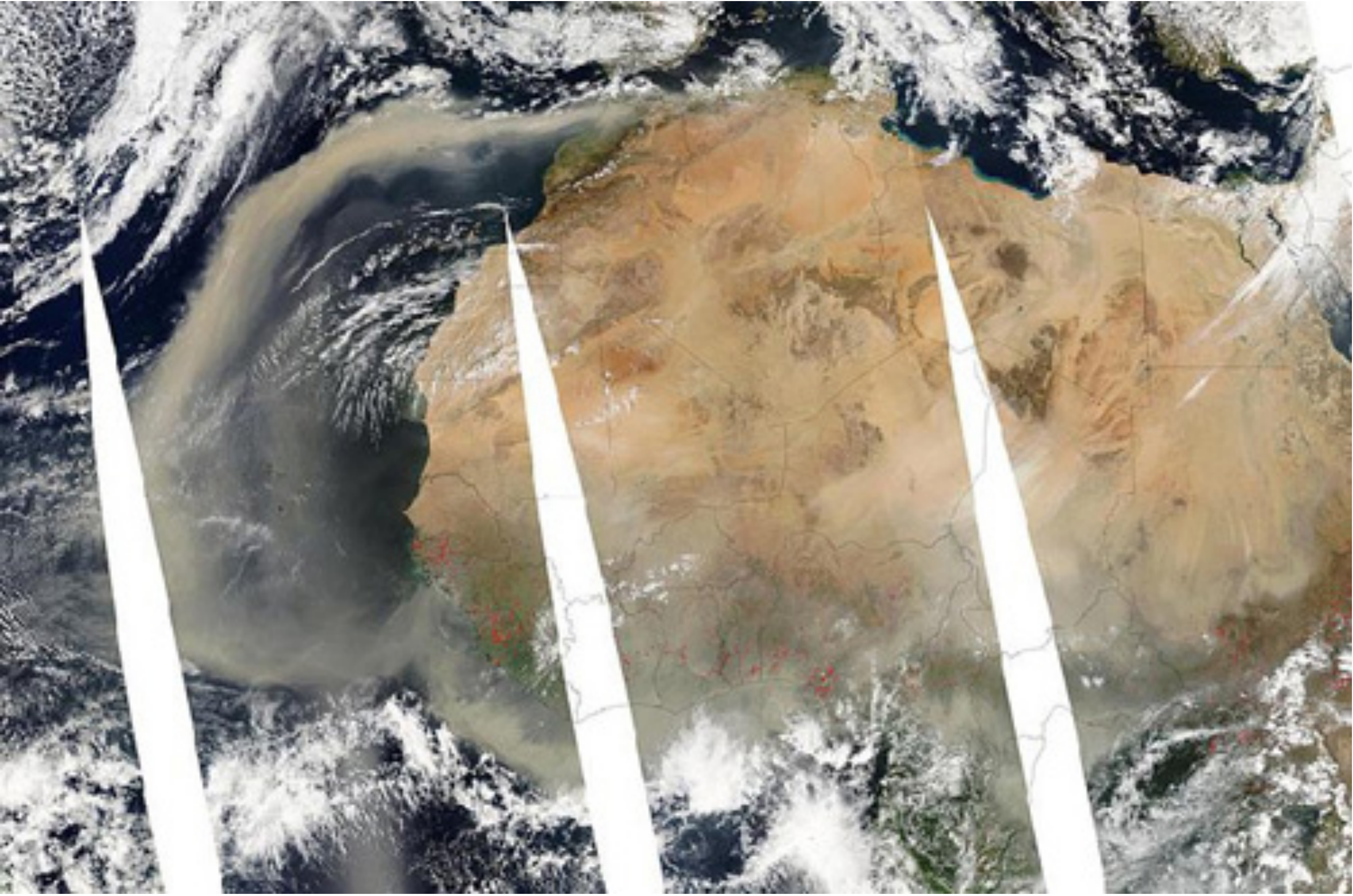
Procópio et al. (2004)

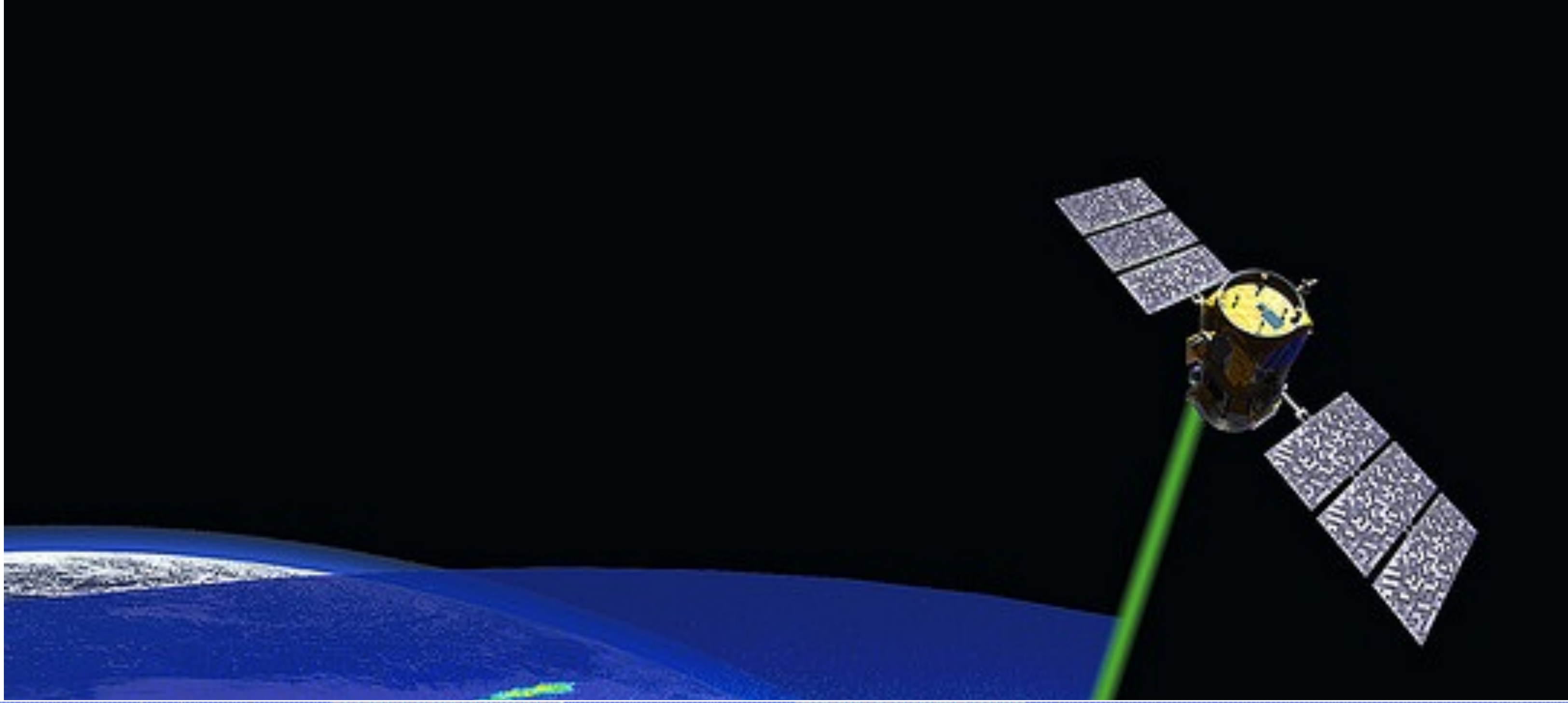
Strong aerosol effect on forest photosynthesis diffuse radiation have a large effect on CO_2 fluxes

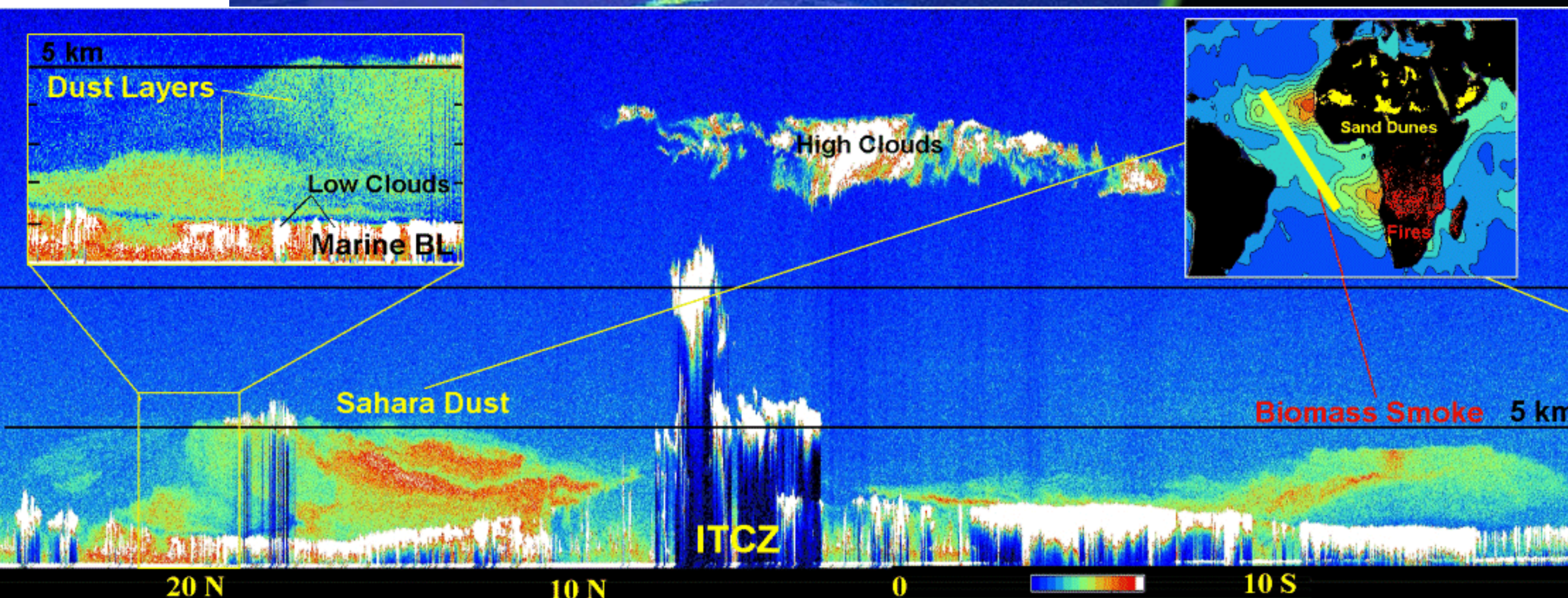


Transport of Sahara dust and smoke from Africa to Amazonia

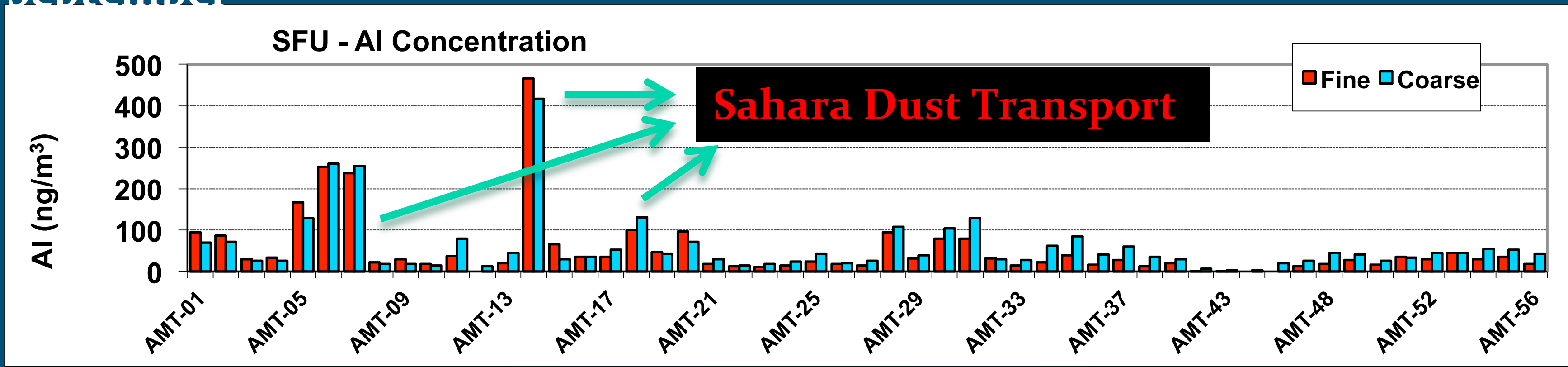


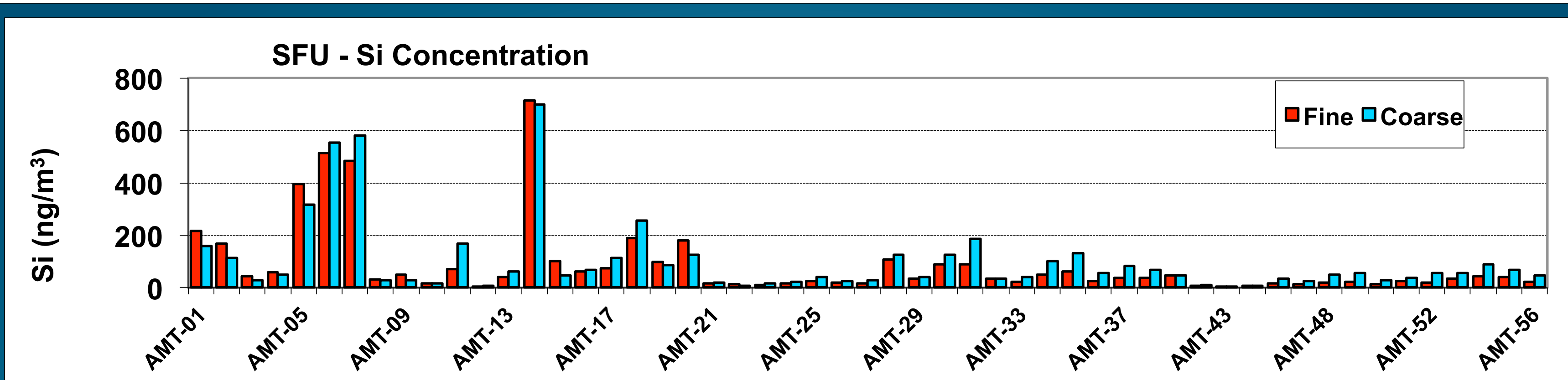


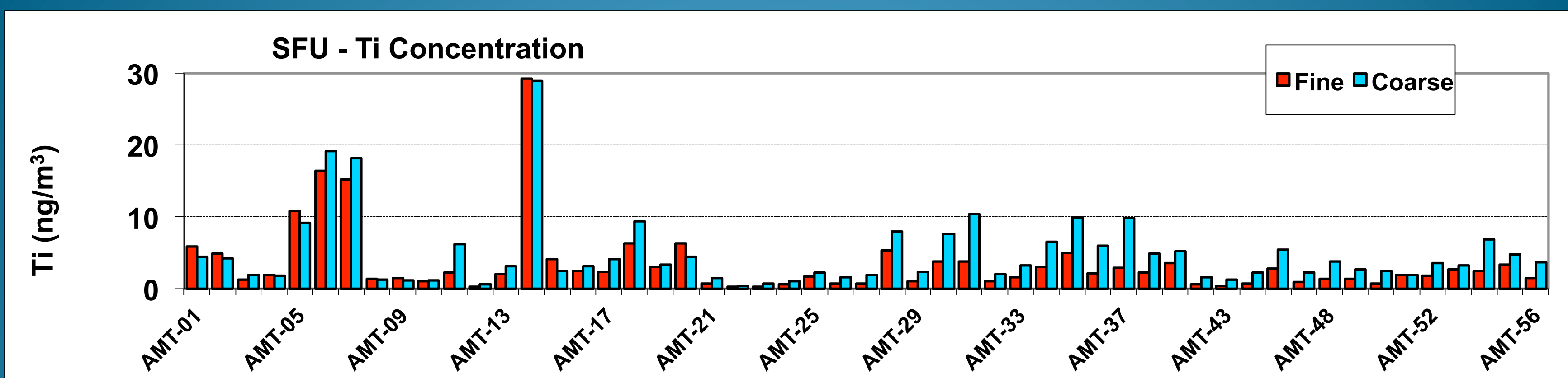


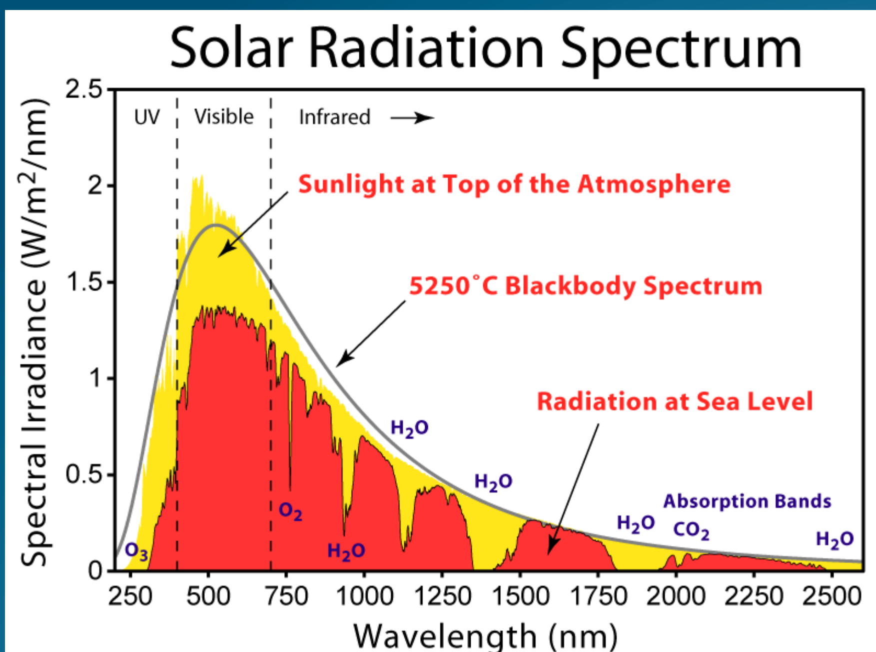

5 km
Dust Layers
Low Clouds
Marine BL
High Clouds
Sand Dunes
Fires
Sahara Dust
Biomass Smoke
5 km
ITCZ
20 N
10 N
0
10 S

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









Thanks!

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