

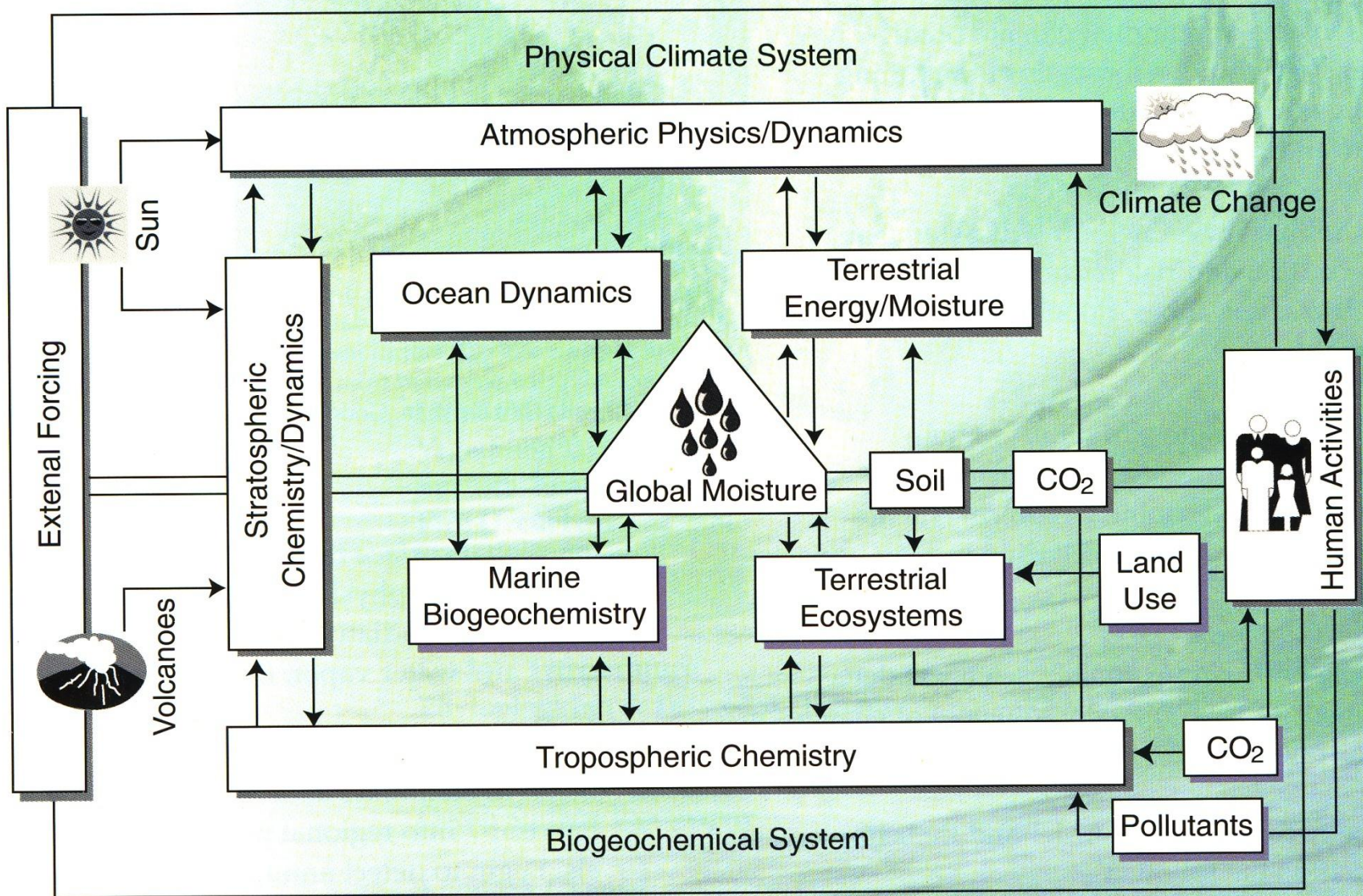
Instituto de Física da UFF – Seminário 1 de Abril de 2009

Questões de fronteira em física aplicada a questões ambientais

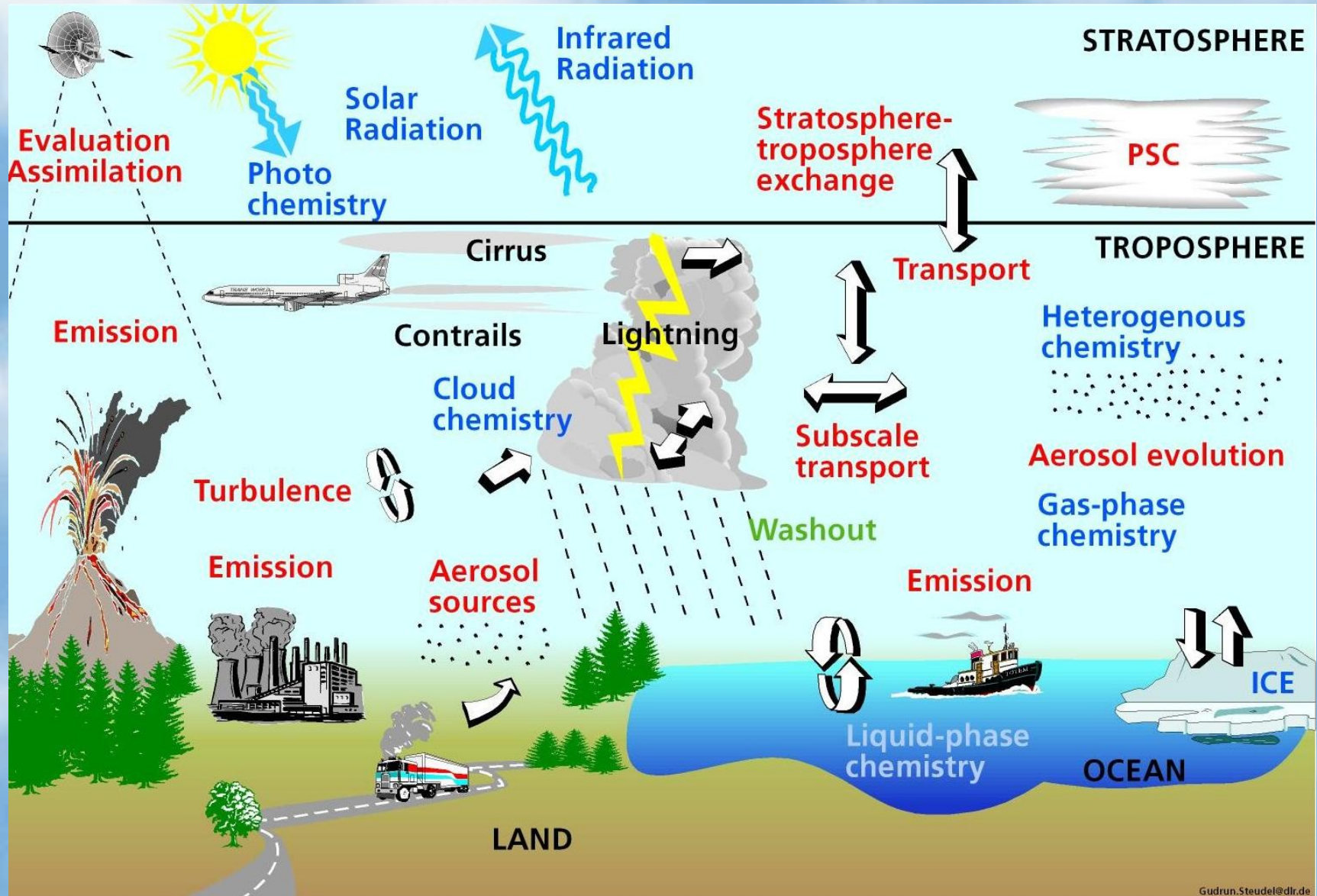
Paulo Artaxo - Instituto de Física, Universidade de São Paulo artaxo@if.usp.br



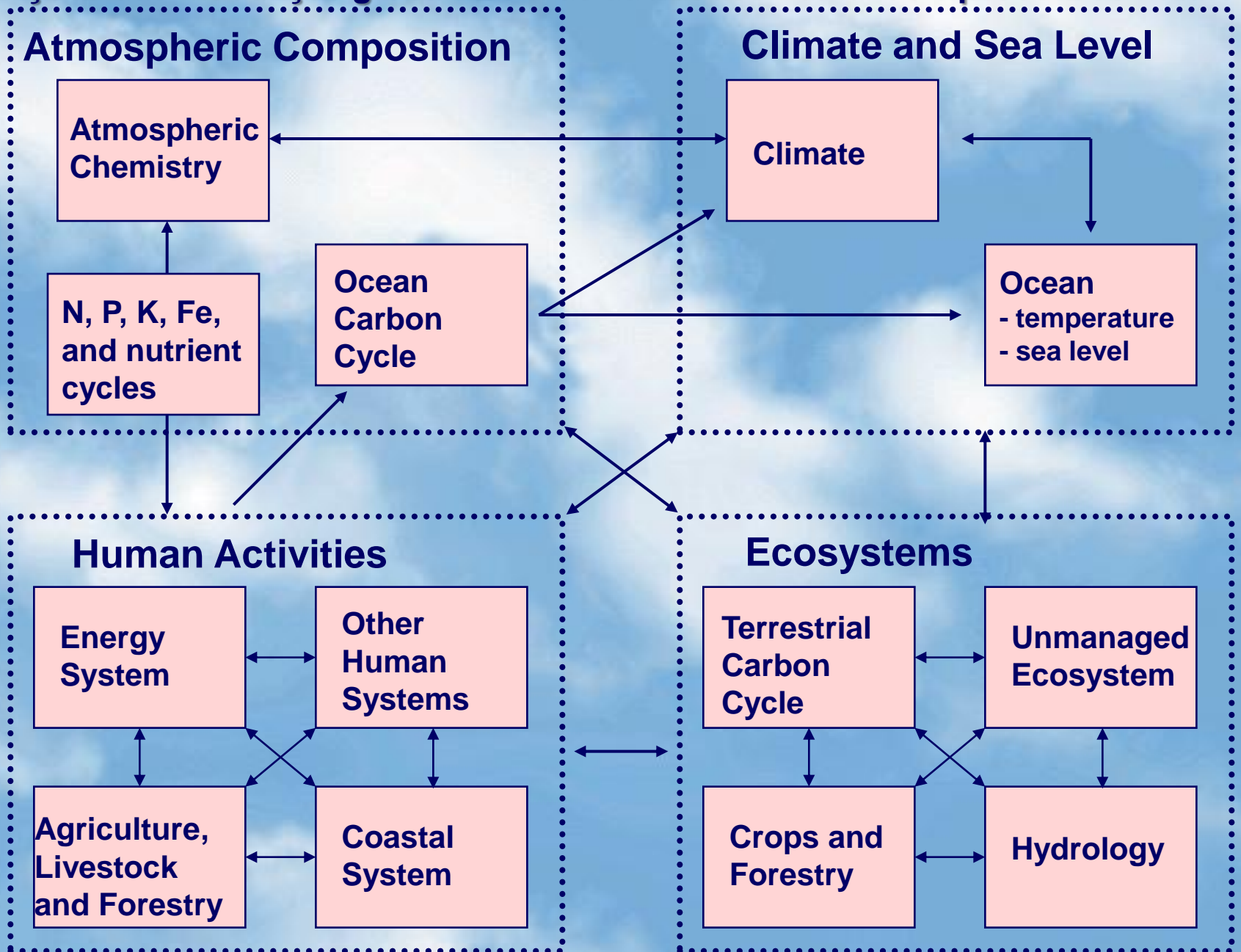
Um sistema dinâmico complexo: o sistema climático terrestre e suas interações



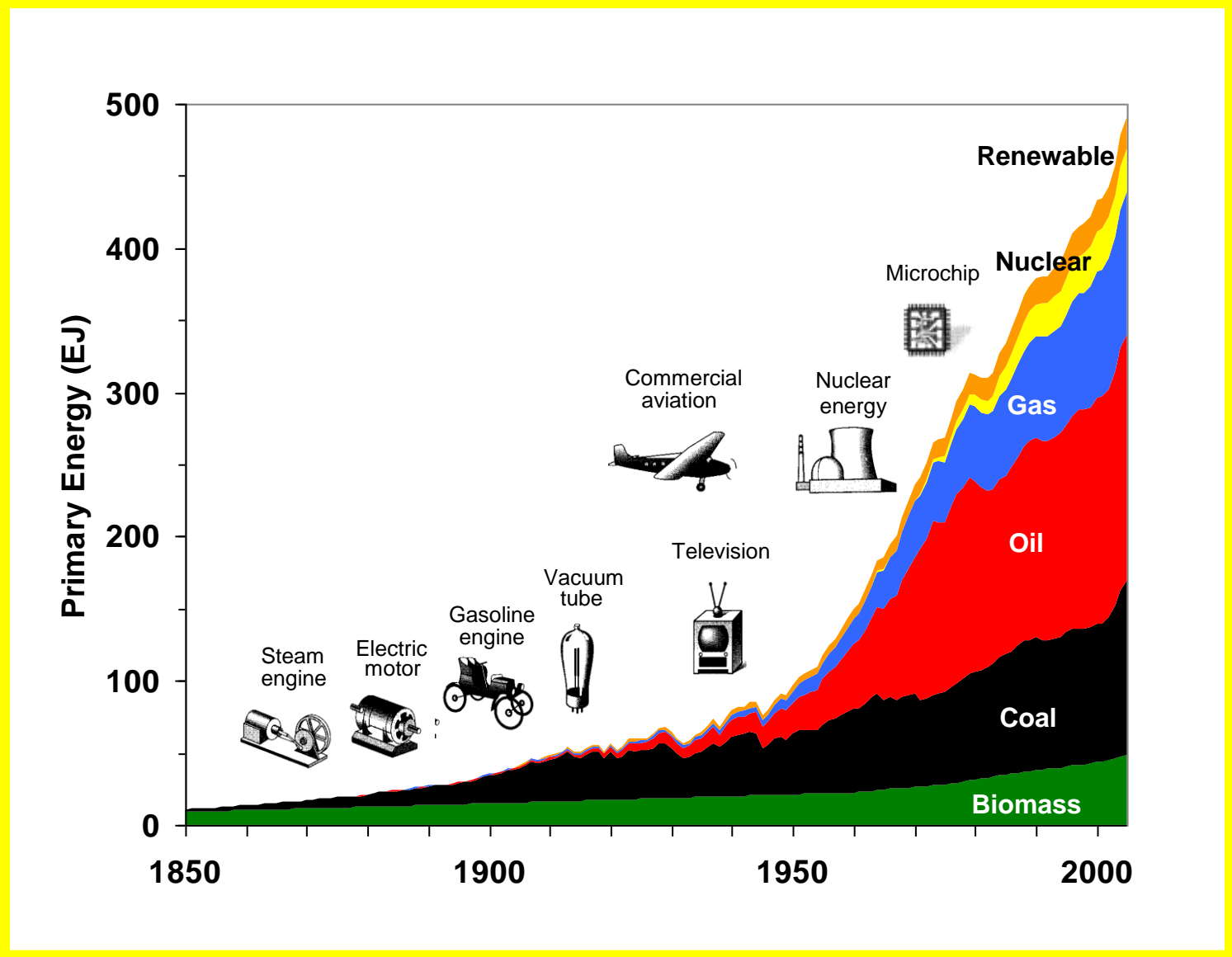
Processos físico-químicos-biológicos que afetam a composição da atmosfera



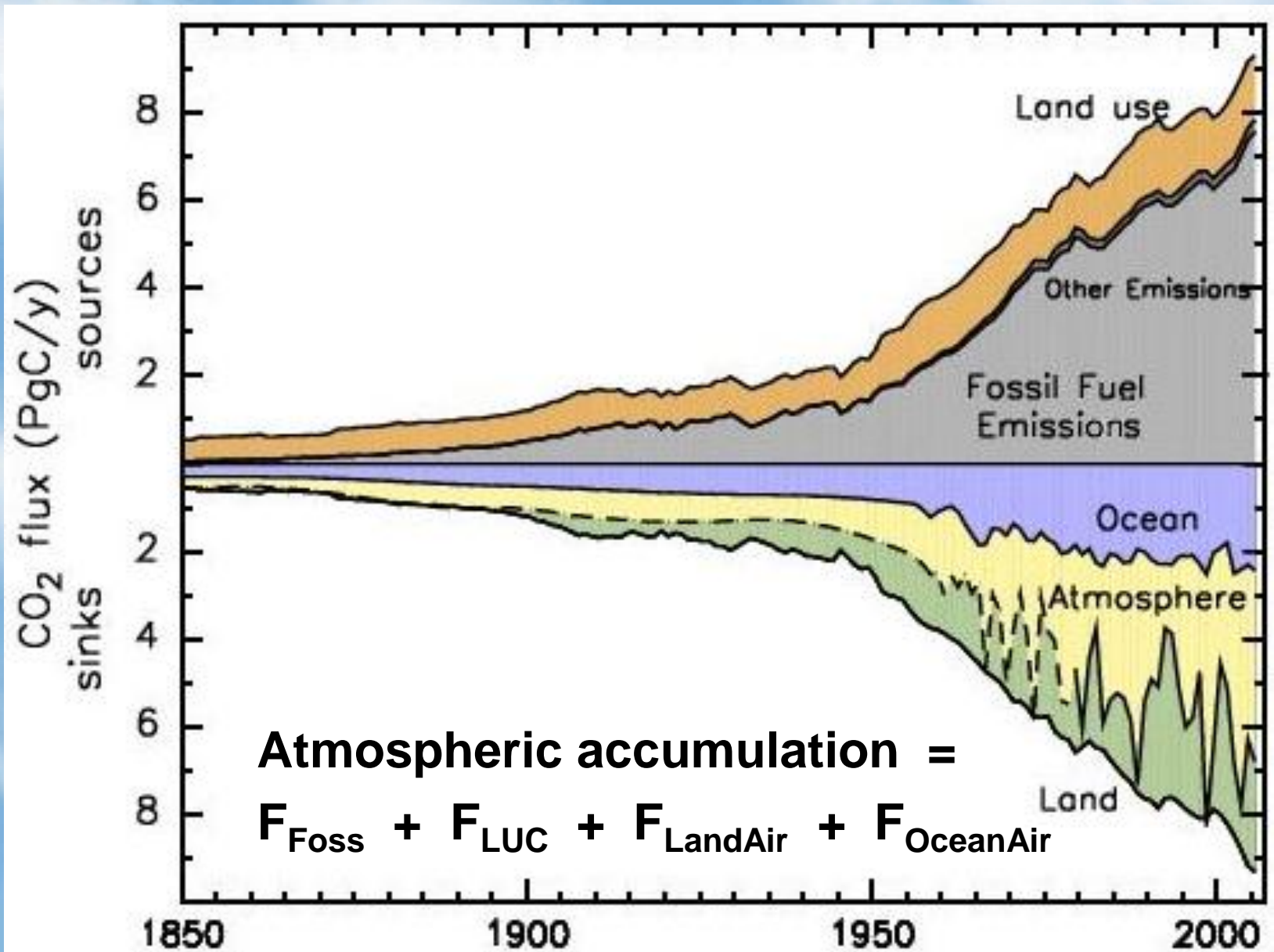
Interações das mudanças globais com as atividades humanas e processos naturais



Energia Primária Mundial



Emissões e absorção de CO₂ atmosférico

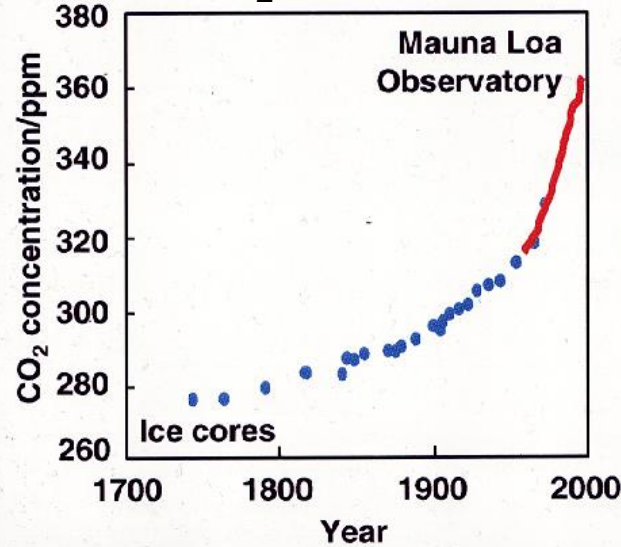


A atmosfera terrestre é MUITO fina...

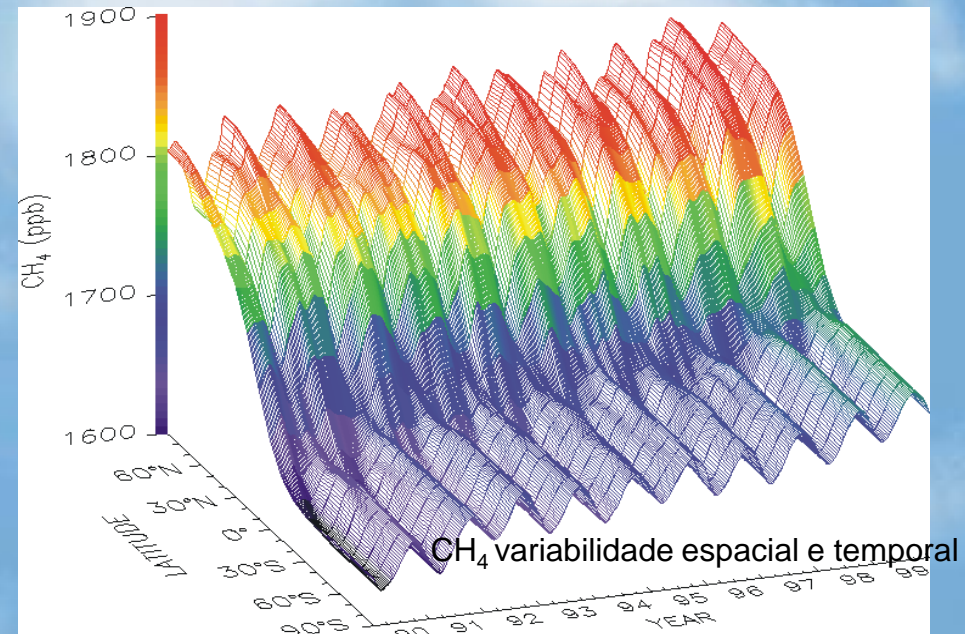
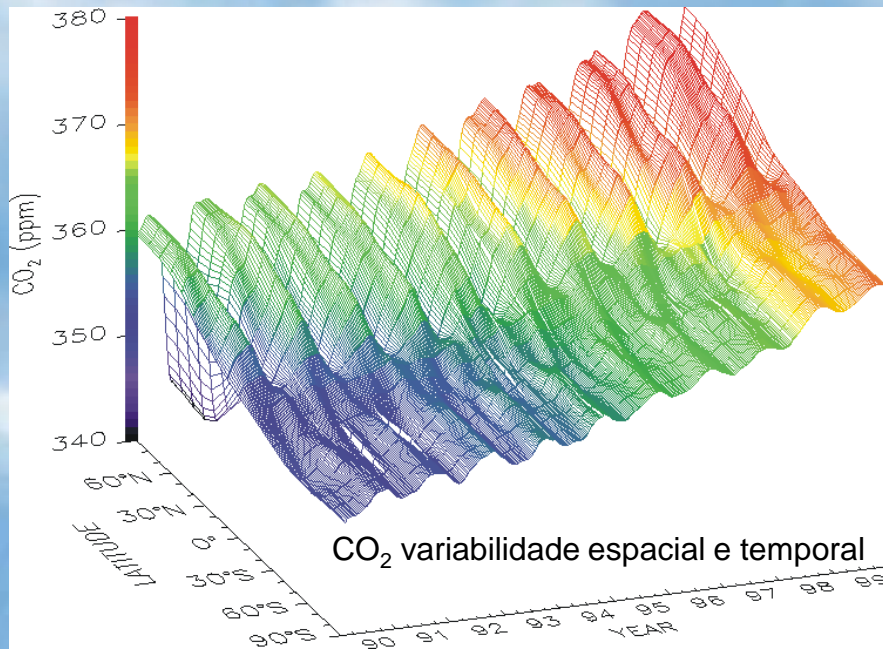
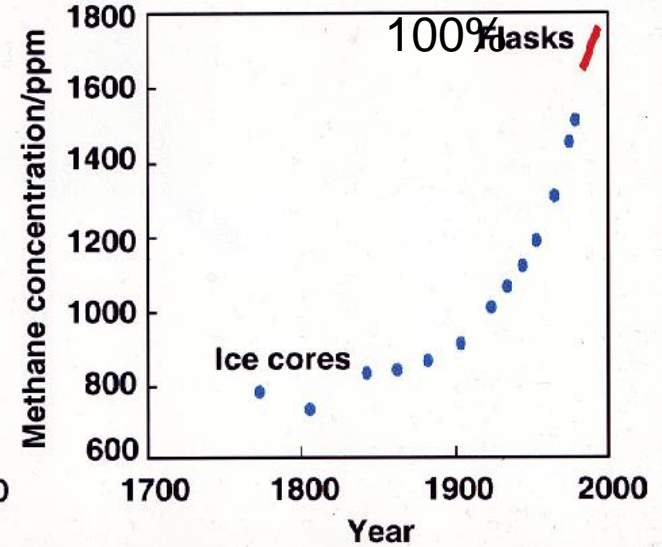


Dióxido de carbono e metano aumentaram significativamente desde a revolução industrial

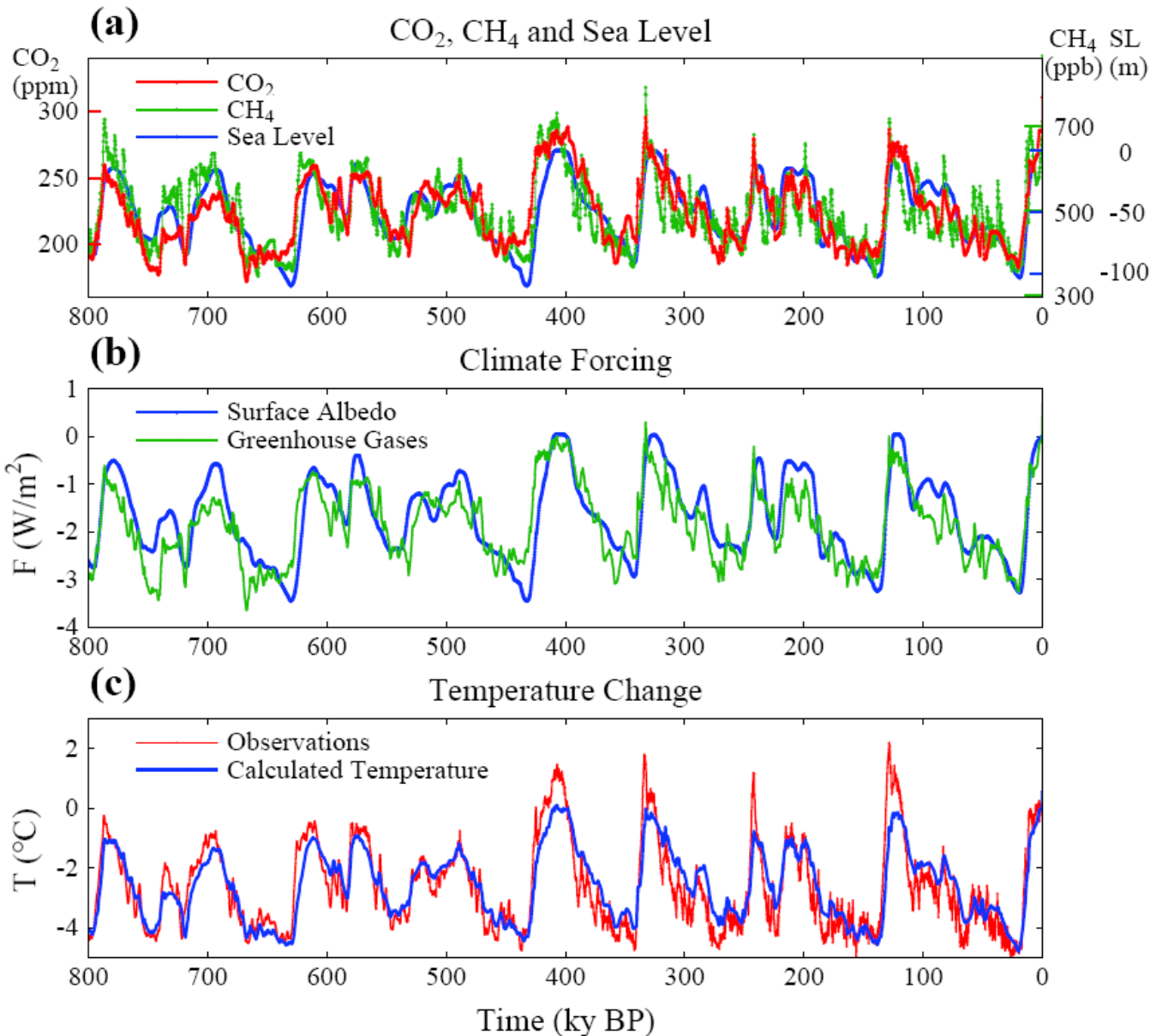
CO₂: aumento de 33%



CH₄: aumento de 100%



800.000 anos de história climática

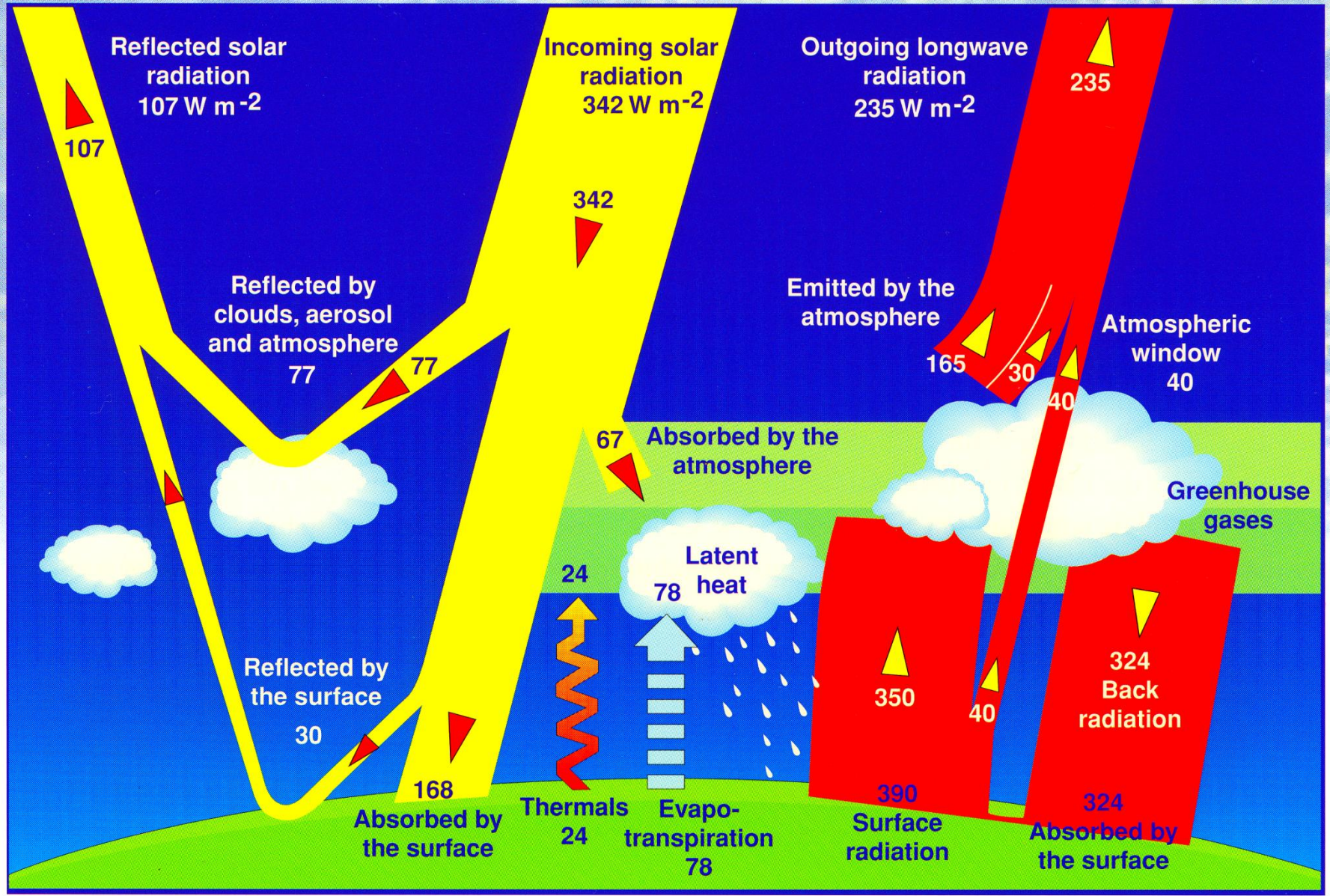


(a) CO₂, CH₄ e nível do mar nos últimos 800.000 anos

(b) Forçantes climáticas devido a mudanças nos gases de efeito estufa e áreas congeladas.

(c) Temperatura global calculada baseada nas forçantes acima e em uma sensibilidade climática de $\frac{3}{4}$ °C por W/m².

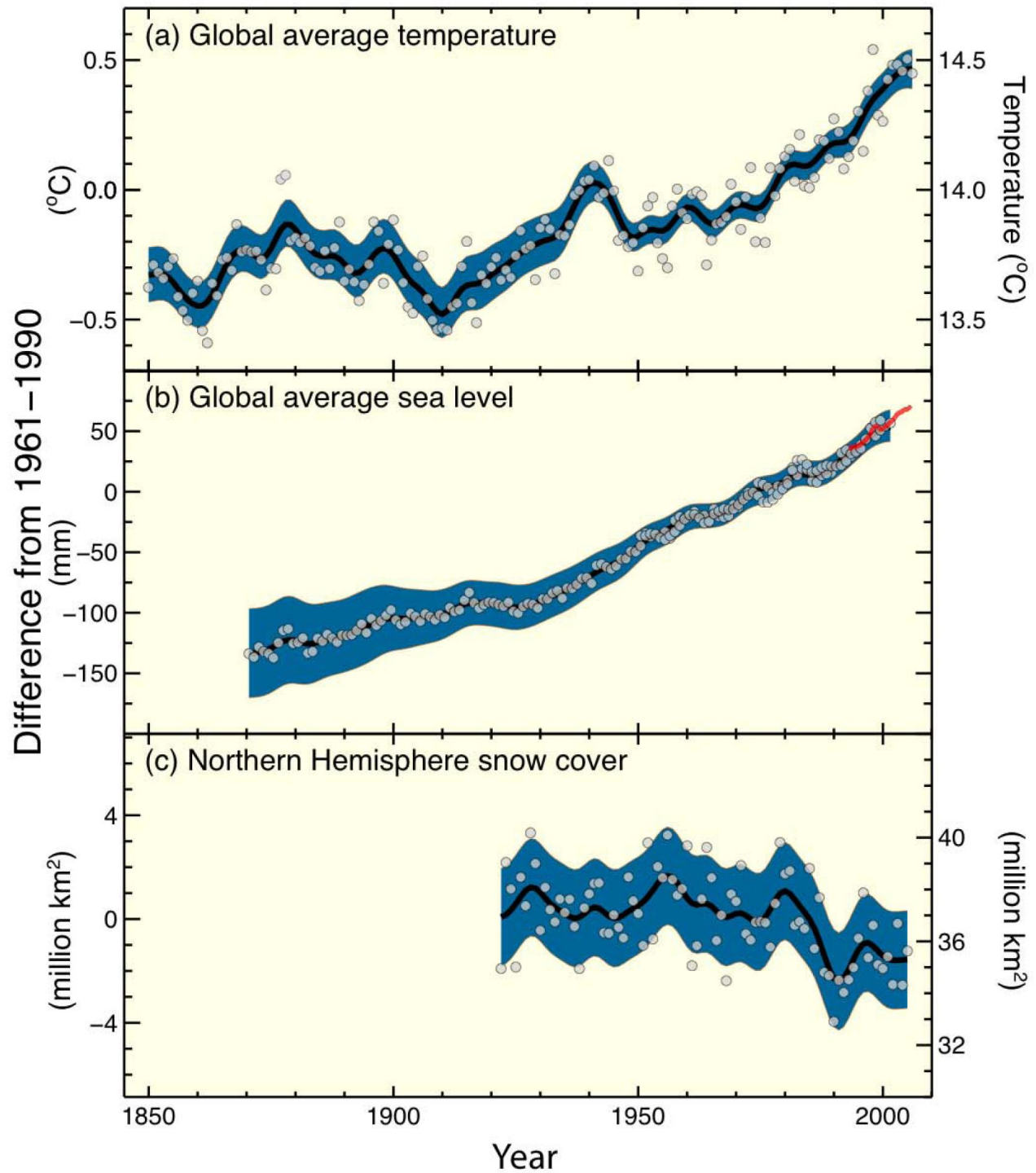
Balanco de radiação terrestre



(a) Mudanças observadas na temperatura global da superfície desde 1850;

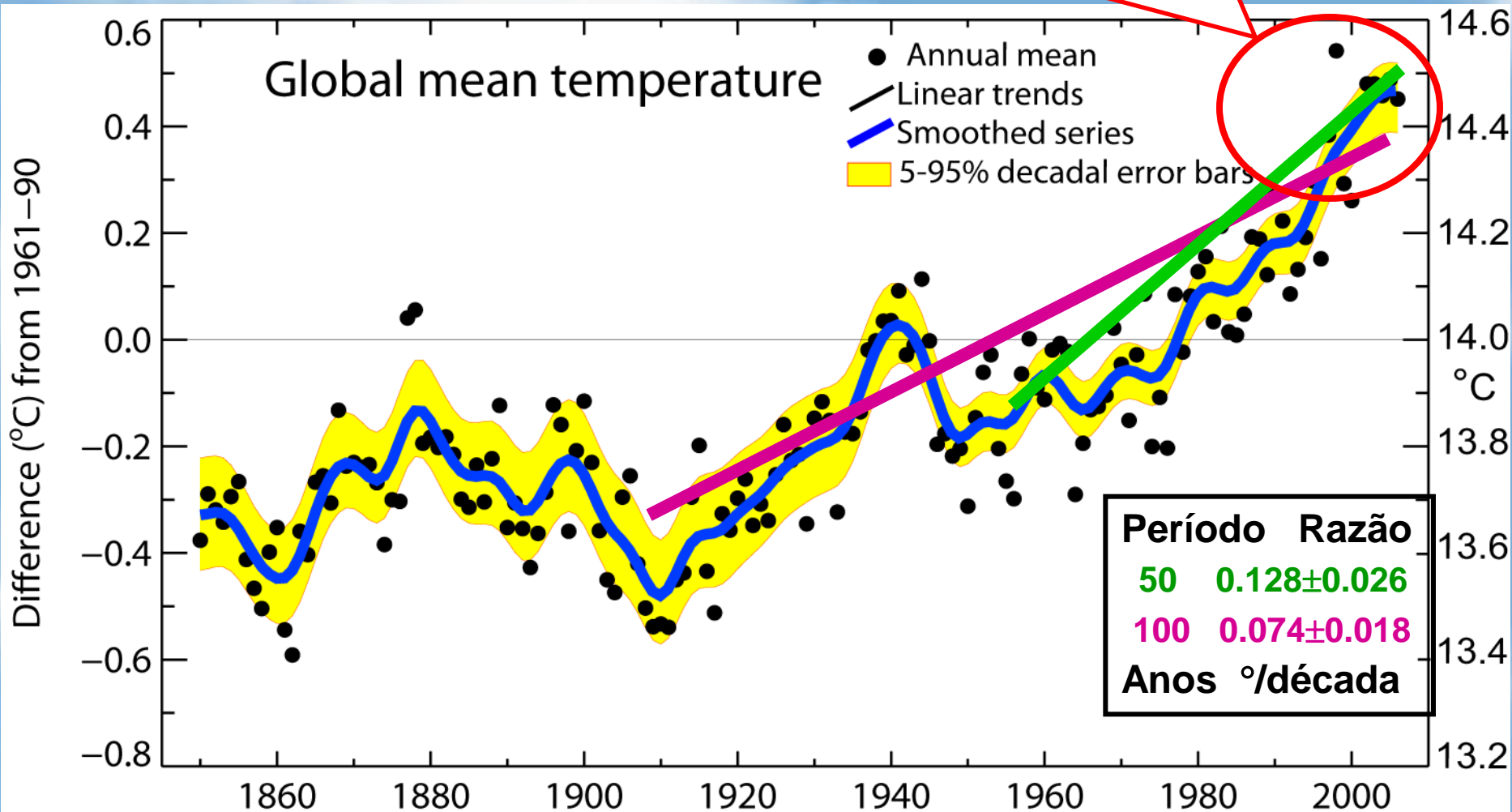
(b) Nível médio do nível do mar desde 1850

(c) Cobertura de neve no hemisfério Norte

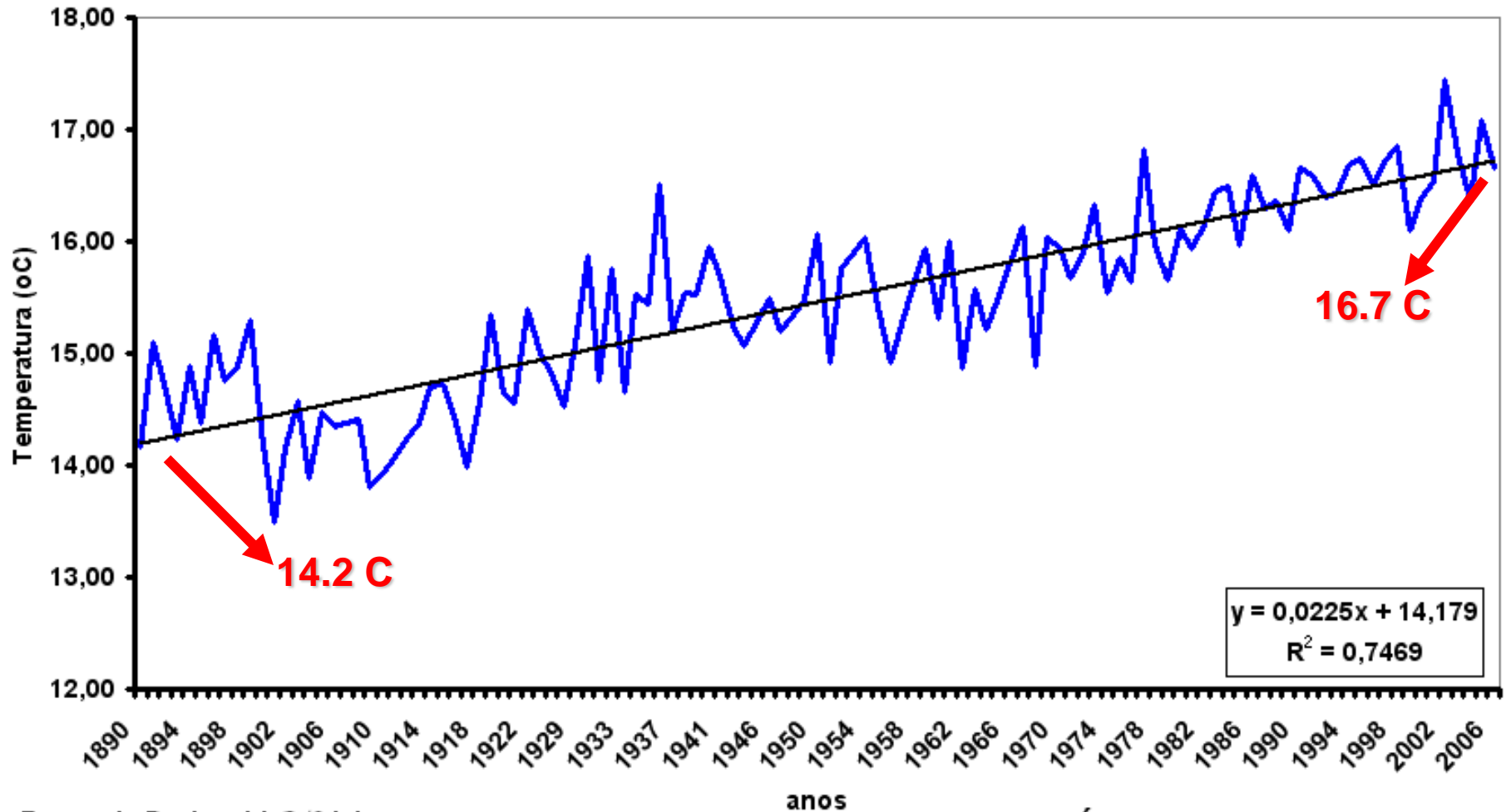


A temperatura está aumentando cada vez mais rápido

Os 12 anos mais quentes:
1998, 2005, 2003, 2002, 2004, 2006,
2001, 1997, 1995, 1999, 1990, 2000



Aumento das temperaturas mínimas em Campinas Período de 1890 a 2006

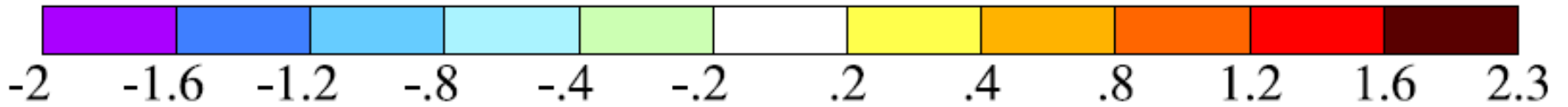
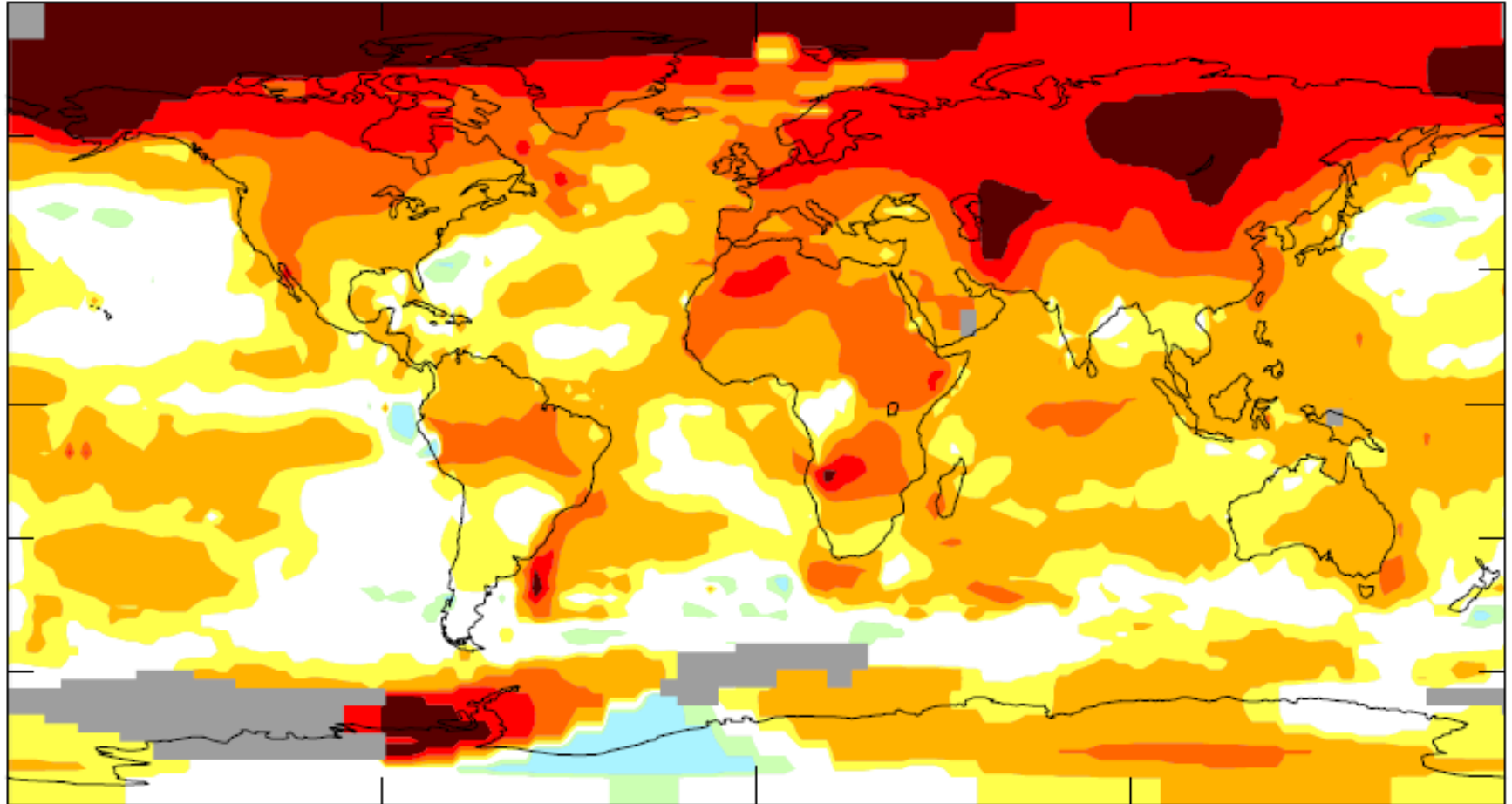


Fonte de Dados: IAC/SAA

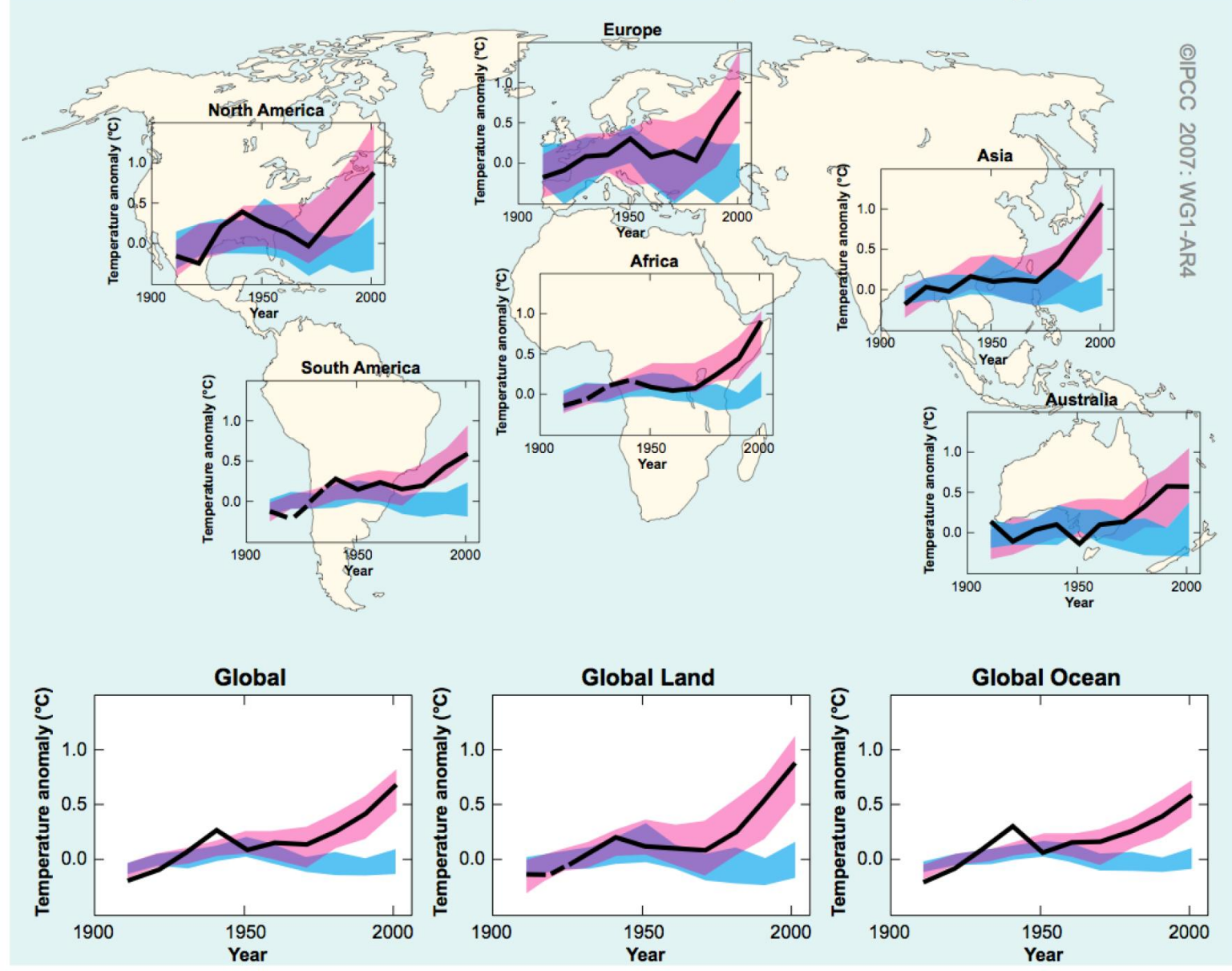
Ana Ávila/CEPAGRI-UNICAMP

Aumento da temperatura superficial 2001-2007 (°C)

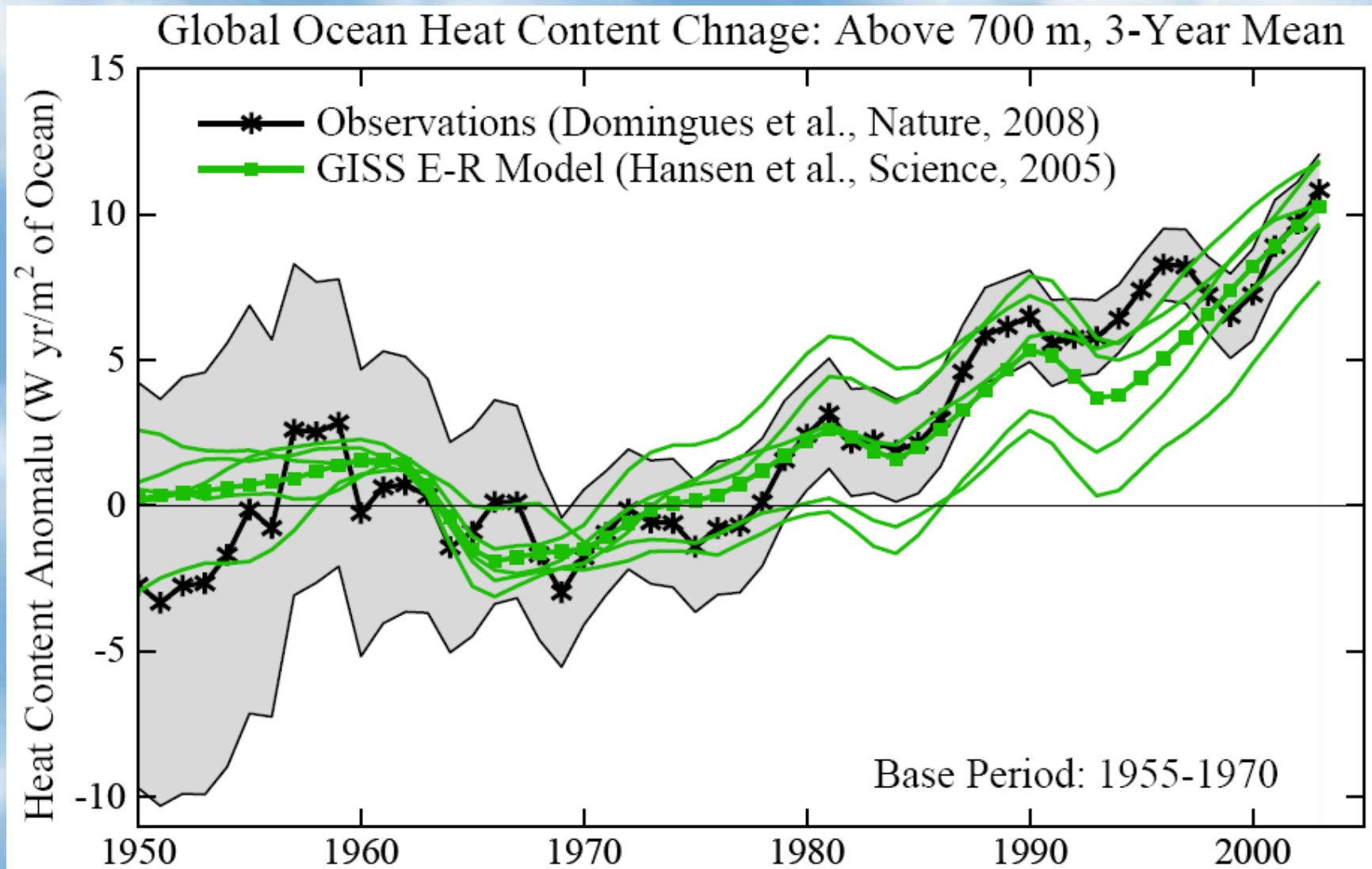
Período de referência: 1951-80



Comparação de temperaturas modeladas e observadas usando forçantes climáticas naturais e antropogênicas para cada região do planeta.



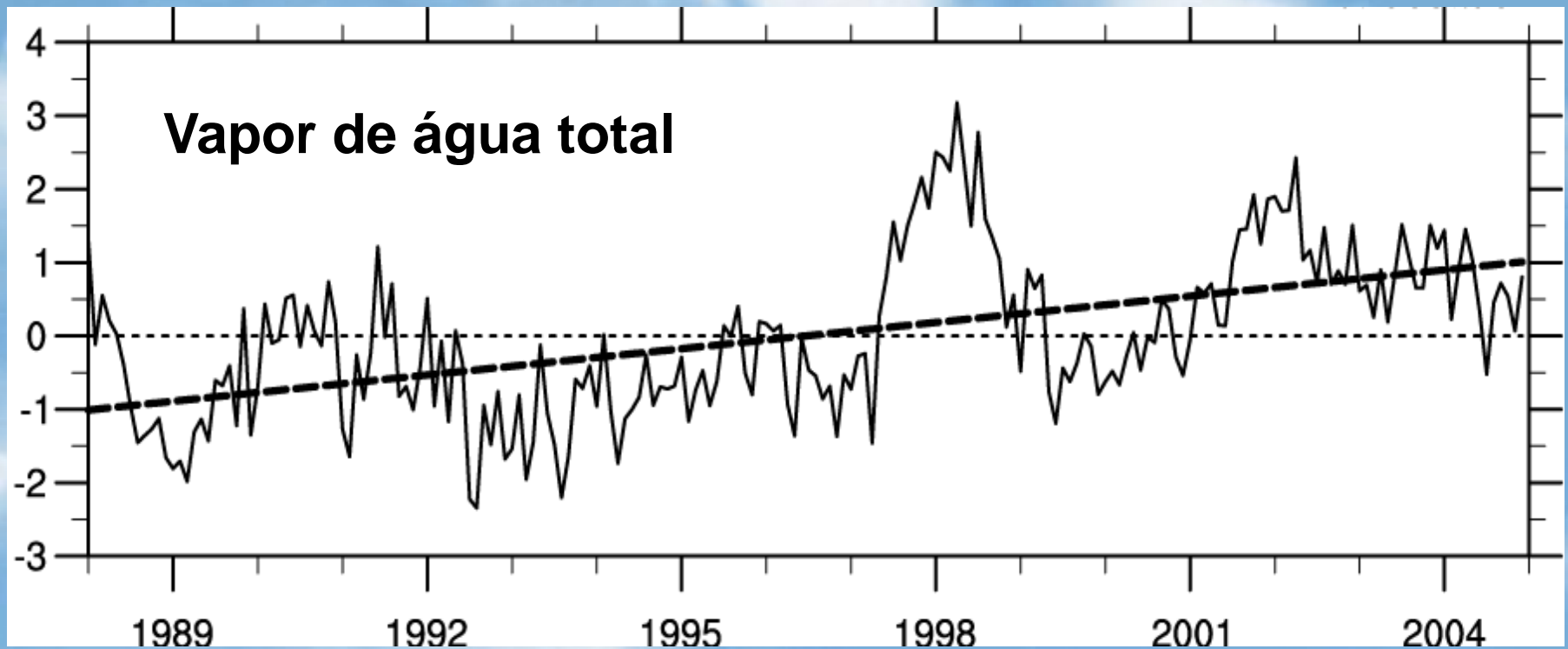
Aumento no conteúdo de calor dos oceanos



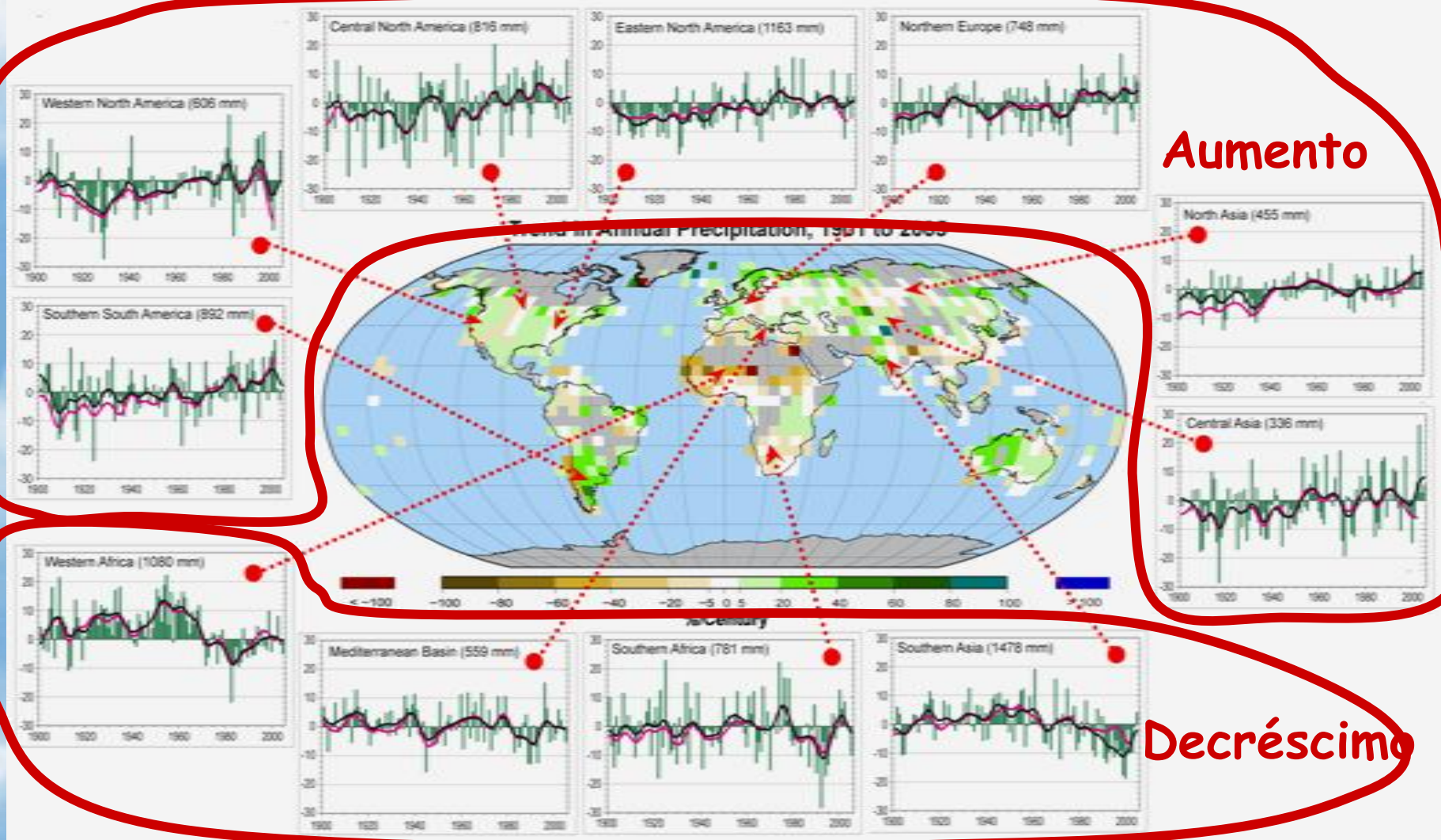
Observations: Domingues, C.M. et al., Nature 453, 1090-1093, 2008.
Model: Hansen, J. et al., Science 308, 1431-1435, 2005.

Aumento do vapor de água na atmosfera

A capacidade da atmosfera reter vapor de água aumenta 7% por aumento de 1 grau centígrado na temperatura:
Mais umidade disponível para tempestades e aumento do efeito estufa.

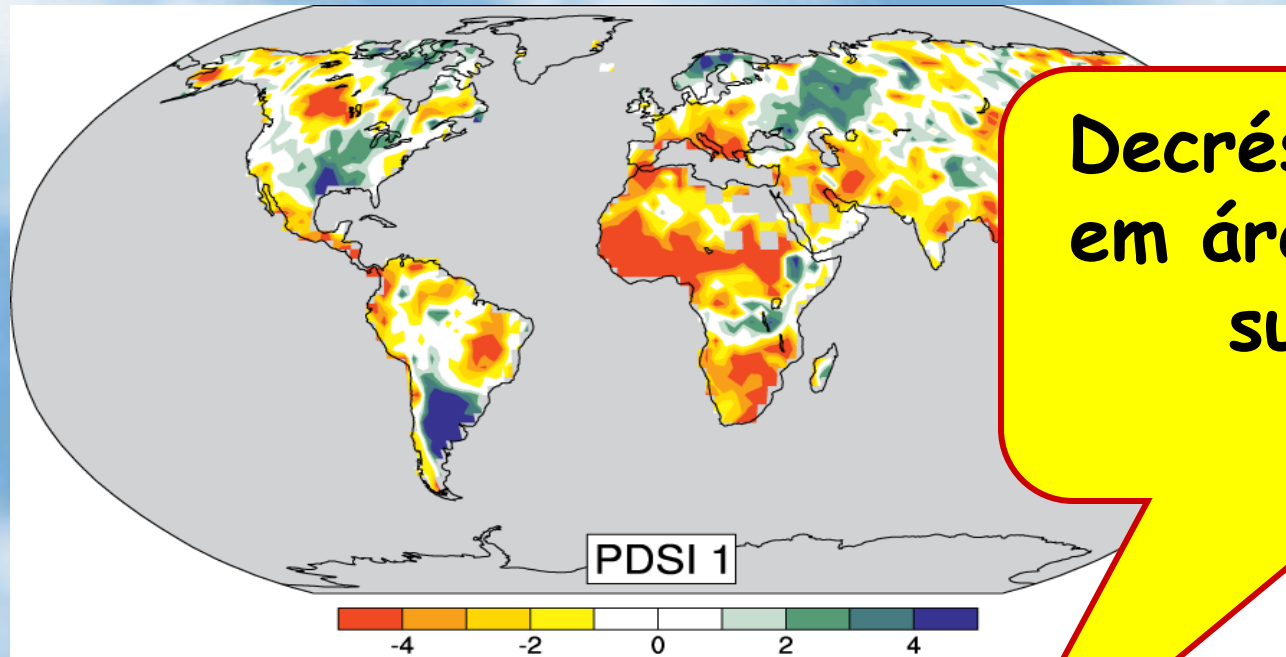


A Precipitação já está mudando significativamente em grandes áreas.

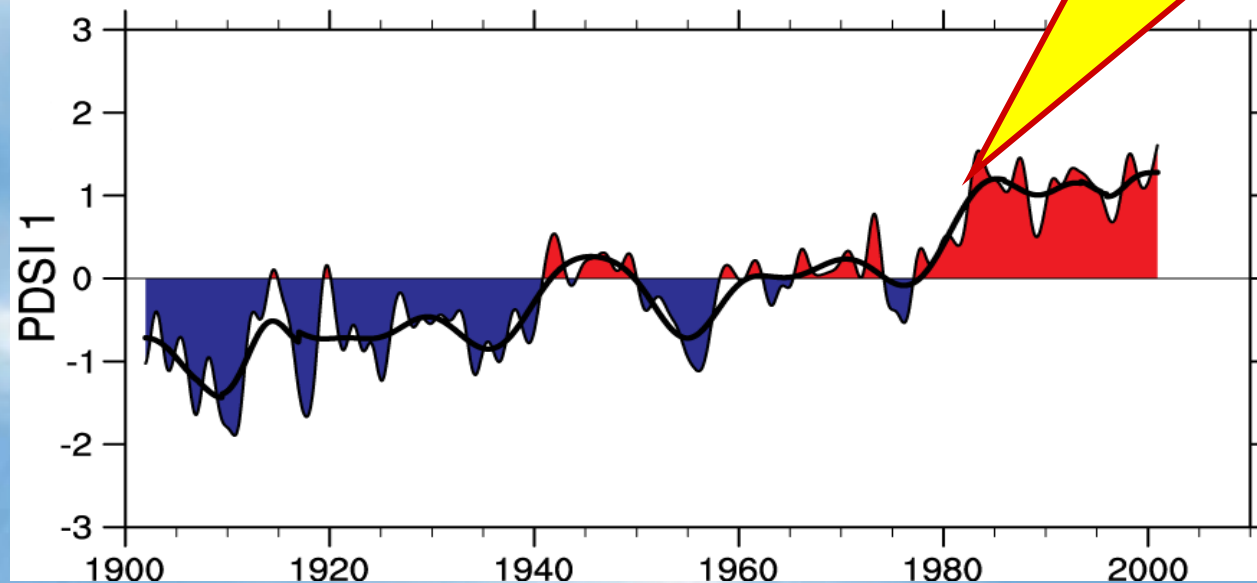


Smoothed annual anomalies for precipitation (%) over land from 1900 to 2005; other regions are dominated by variability.

As secas estão aumentando em várias regiões

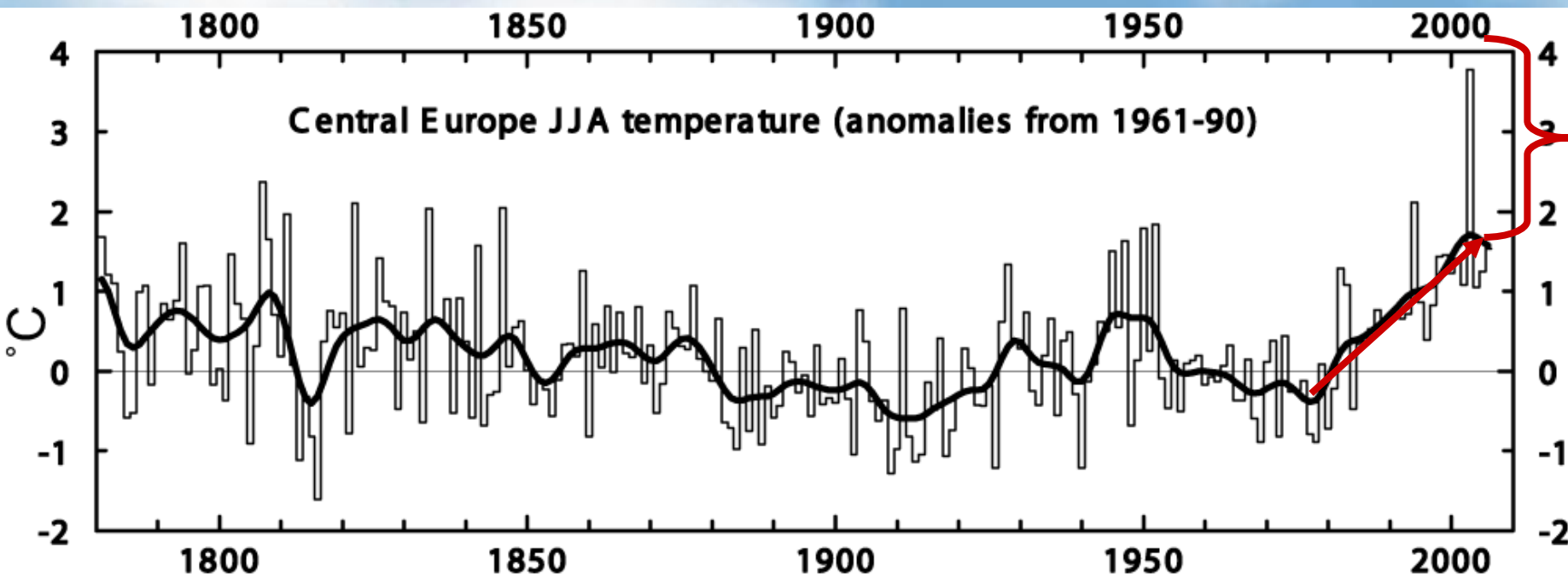


Decréscimo na chuva em áreas tropicais e subtropicais



Índice de secas (Palmer Drought Severity Index (PDSI)) para 1900 a 2002.

Aumento de ondas de calor: Exemplo da Europa



Ondas de calor extremas:
em 2003, 30.000 mortos
na Europa

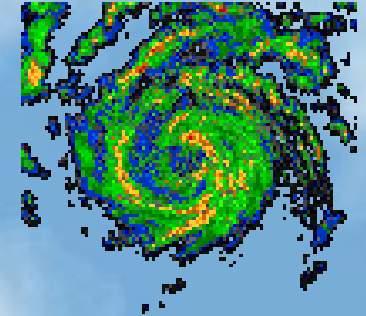
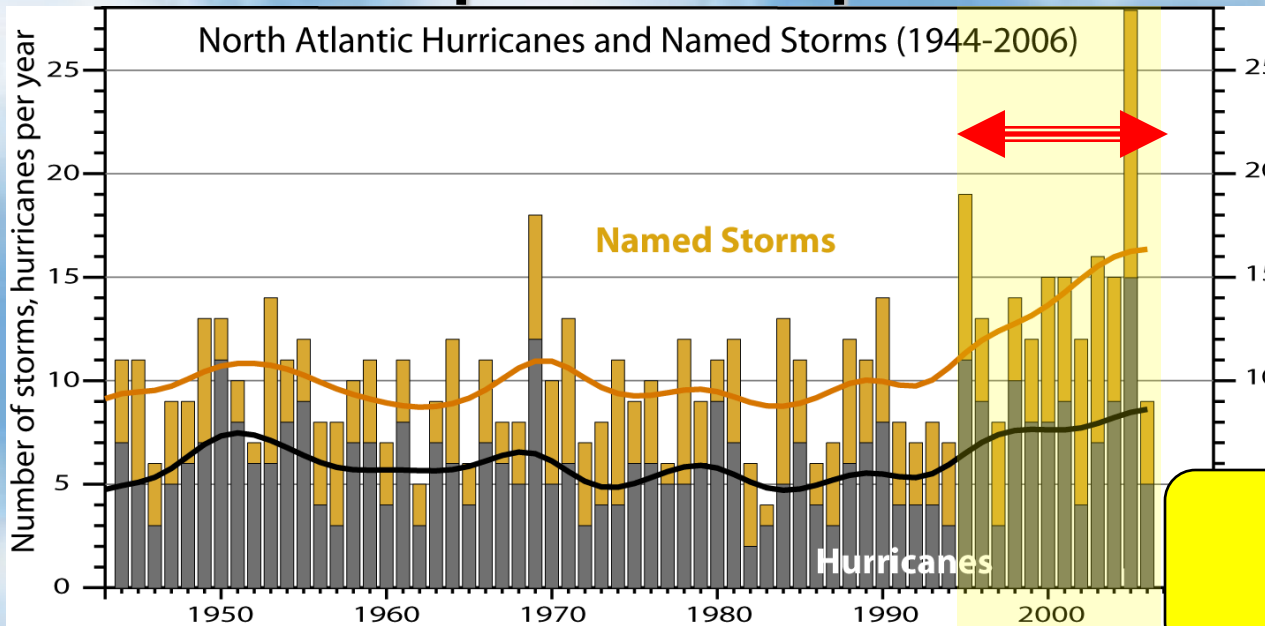
Tendência somada
à variabilidade

Mudanças na circulação atmosférica alteram temperatura e precipitação

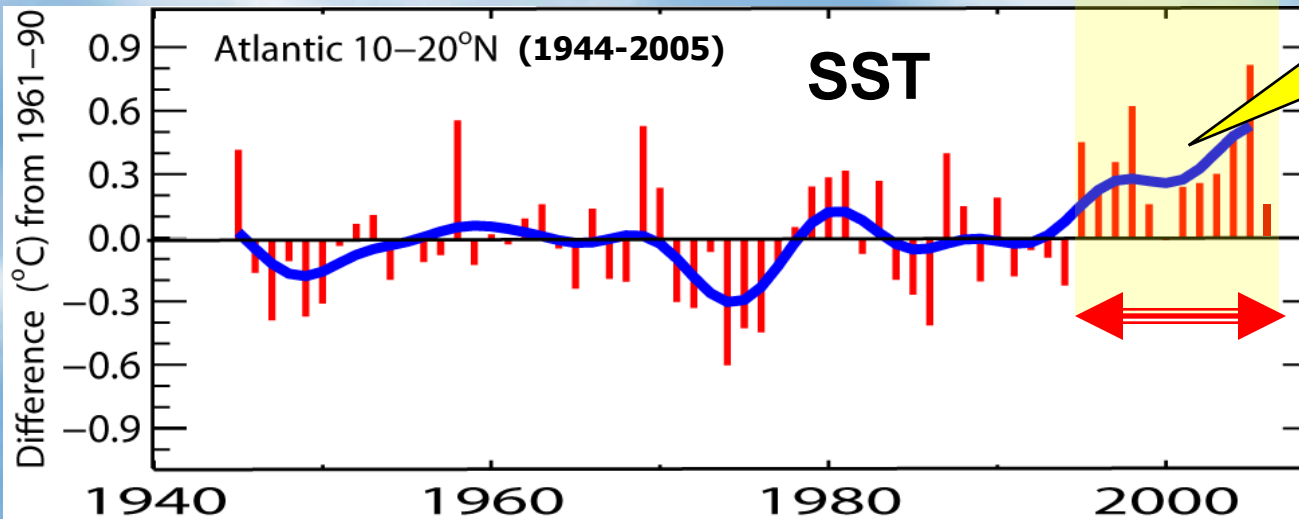
Mudanças diferenciais na temperatura, albedo e evapotranspiração estão alterando a circulação atmosférica global.



O aumento da incidência de furacões está ligada ao aumento da temperatura superficial do mar



Aumento após 1994



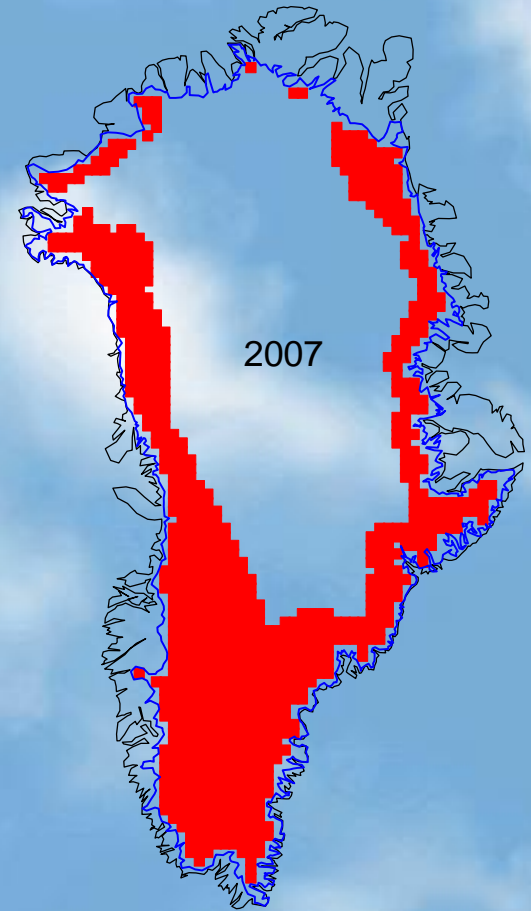
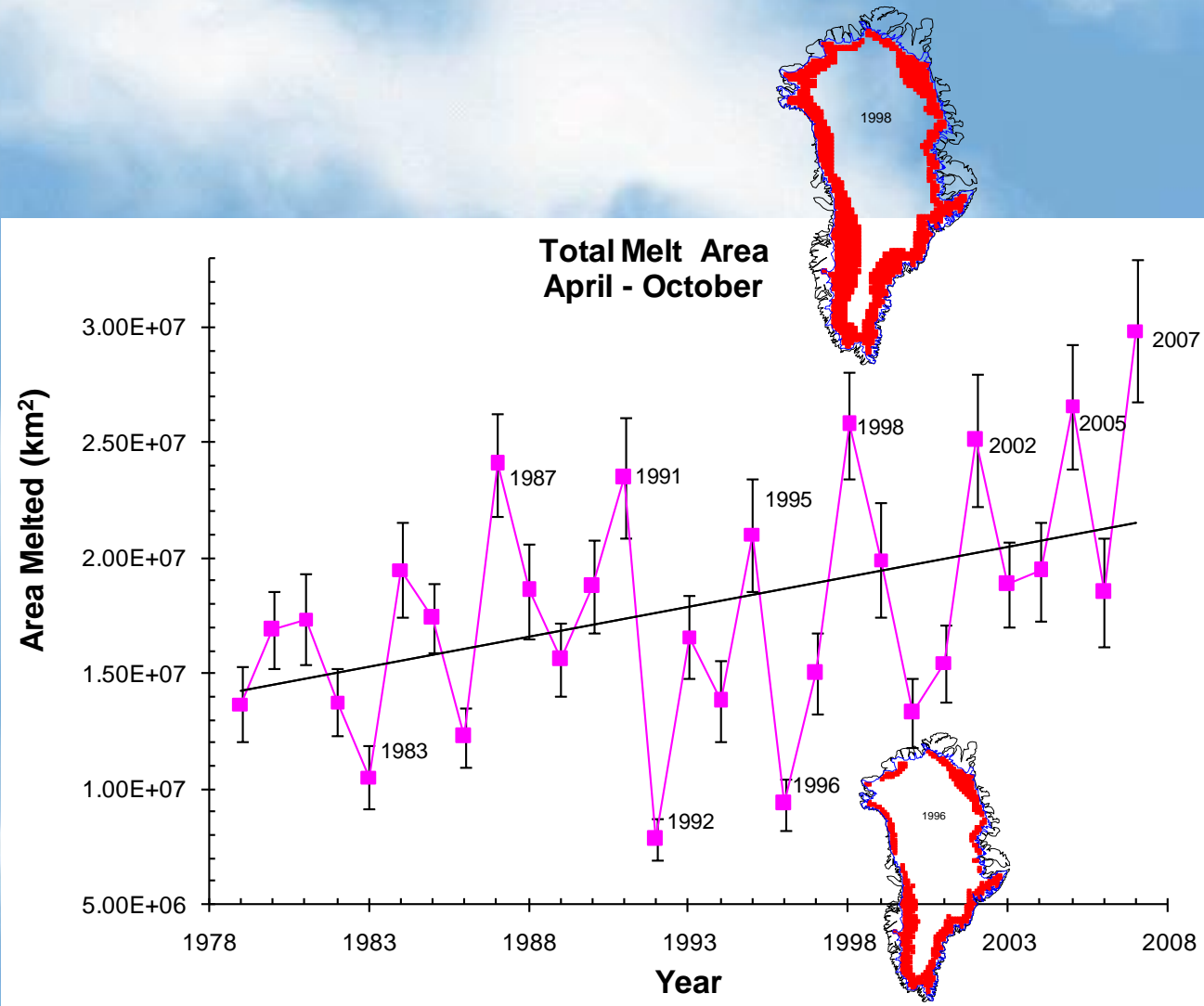
A percentagem de furacões categoria 4 e 5 está aumentando desde 1944

O clima do Ártico está mudando rapidamente

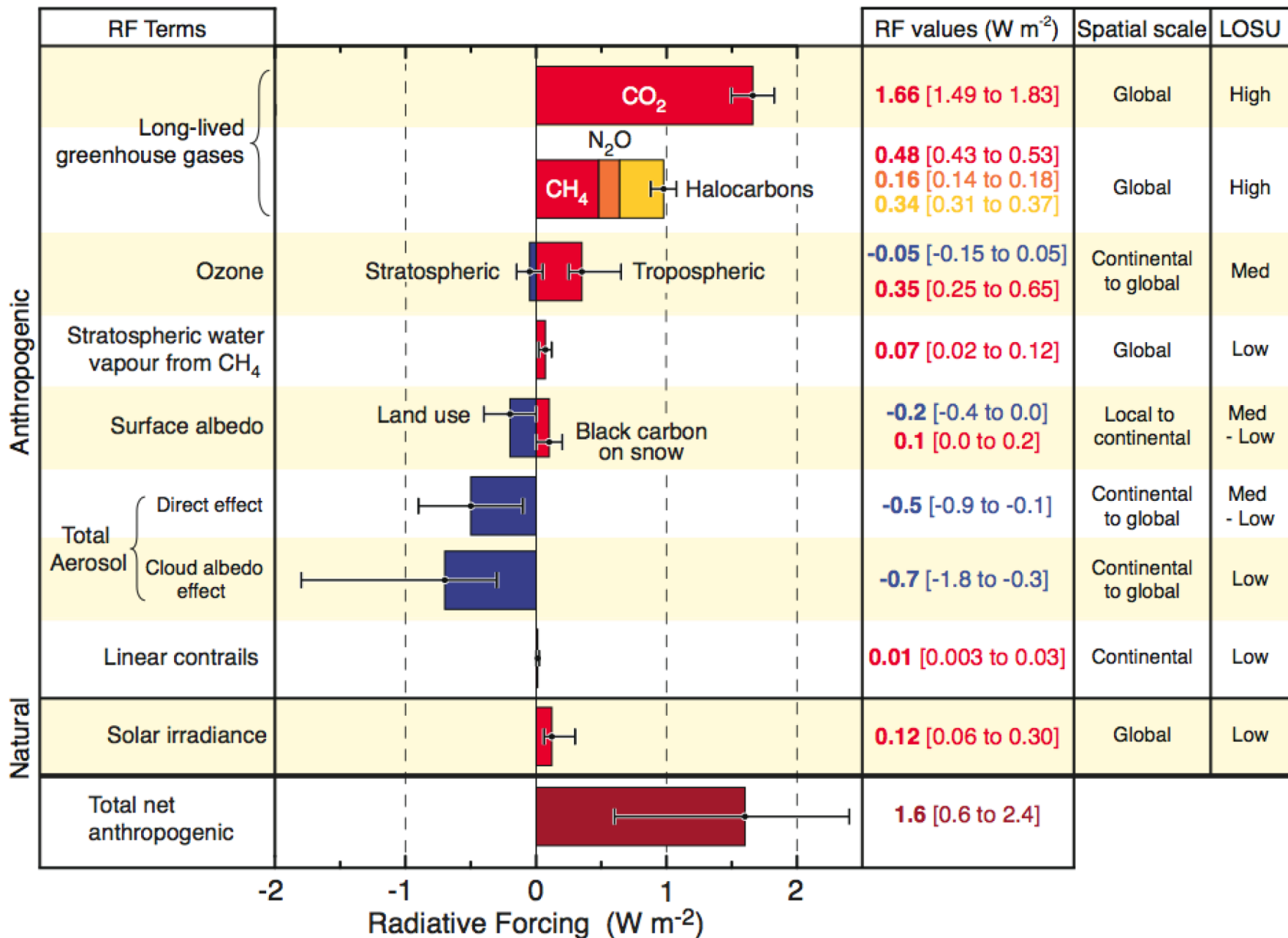


Se em 300-500 anos toda a água armazenada na Groenlândia derretesse: Aumento médio no nível do mar de 7 metros.

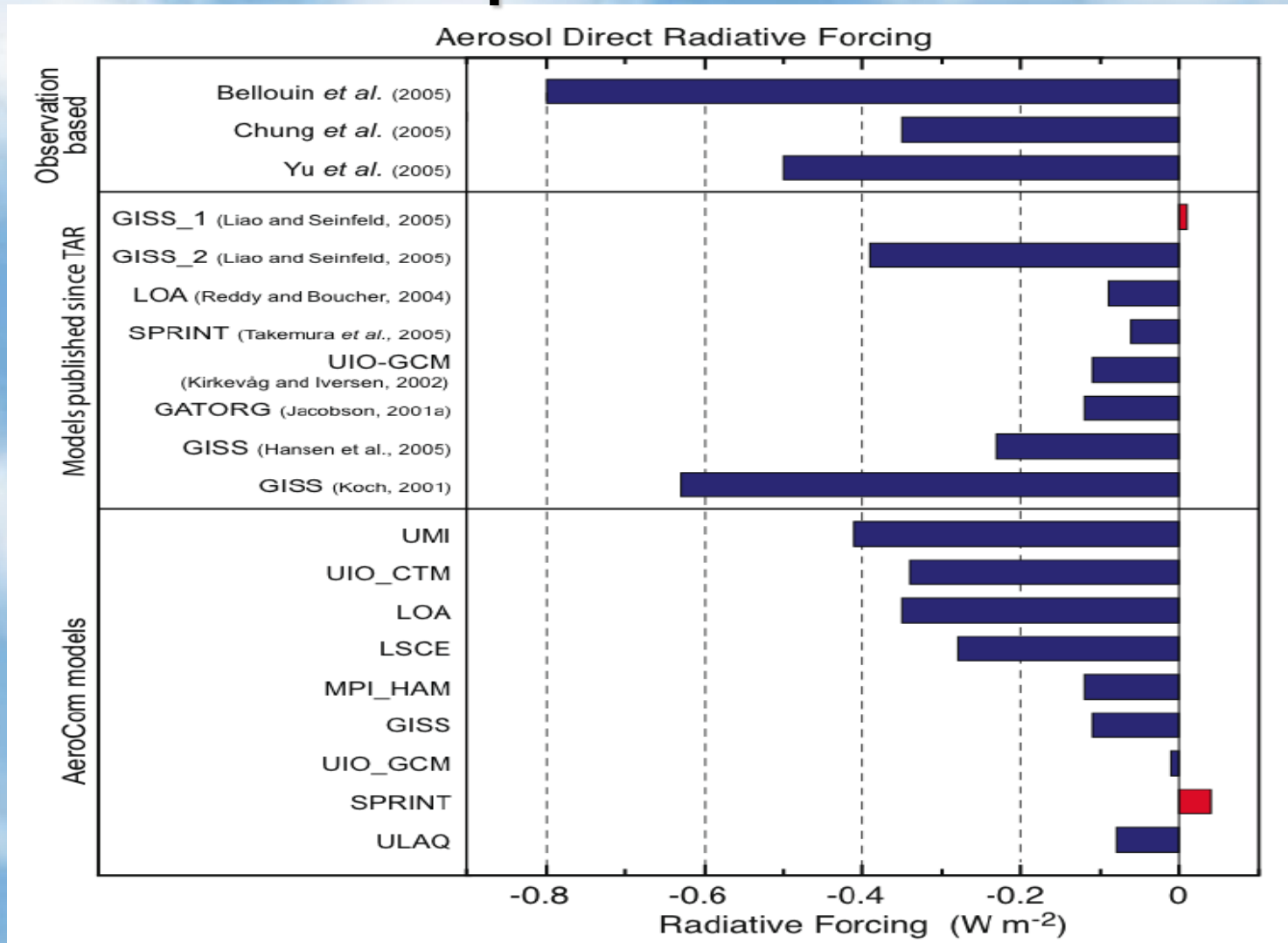
Perda de gelo na Groenlândia 1978-2007



Forçantes radiativas dos componentes do sistema climático global



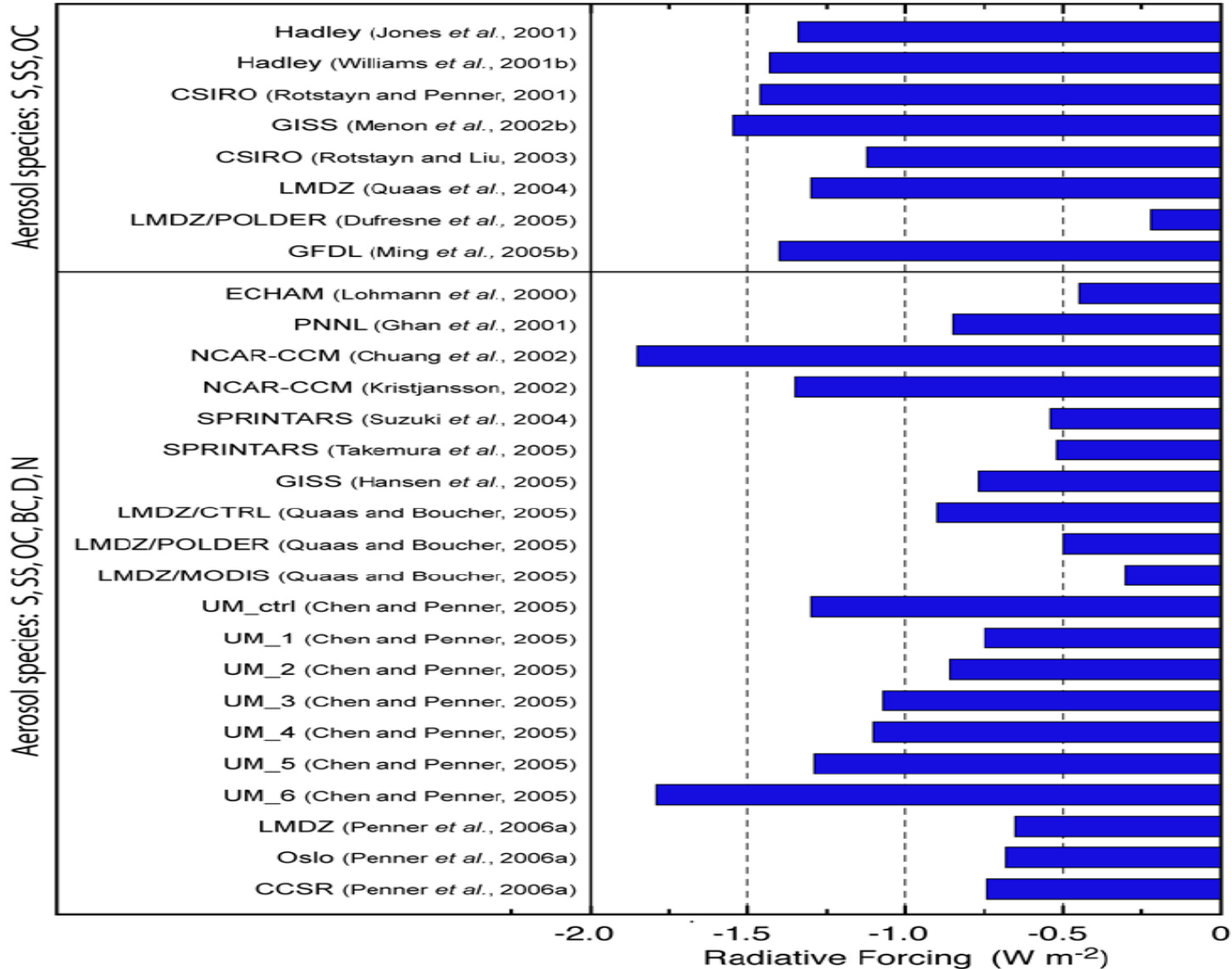
Estimativas da forçante radiativa direta dos aerossóis por diferentes modelos



Melhor estimativa: -0.5 W/m² Faixa: -0.9 to -0.1 W/m²

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

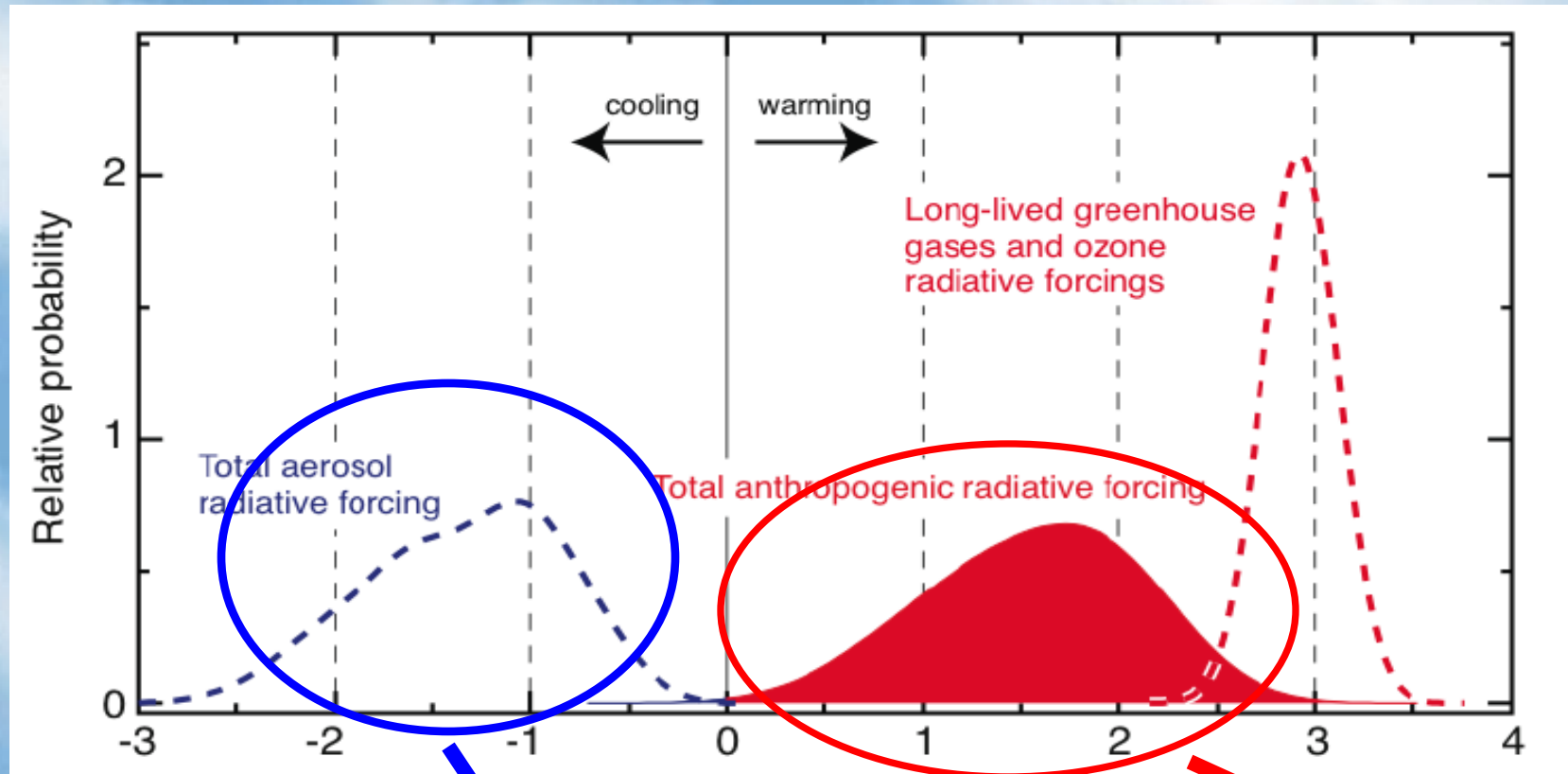
Radiative Forcing from Cloud Albedo Effect



Best estimate:
-0.7 W/m²

Range:
-1.8 to -0.3 W/m²

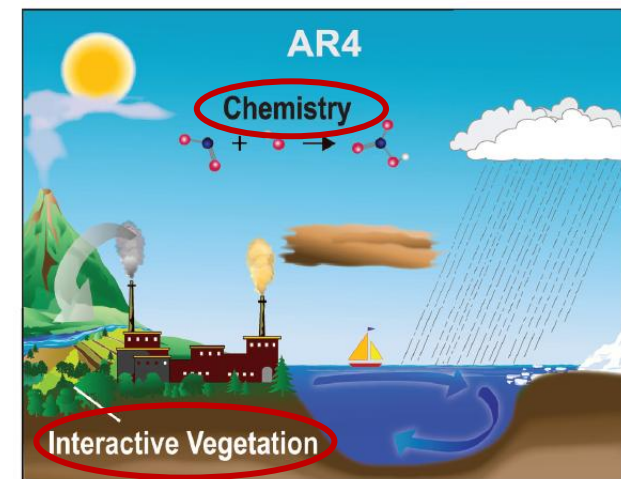
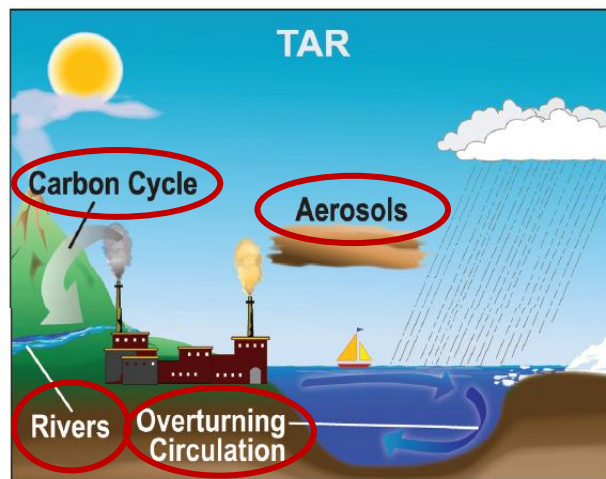
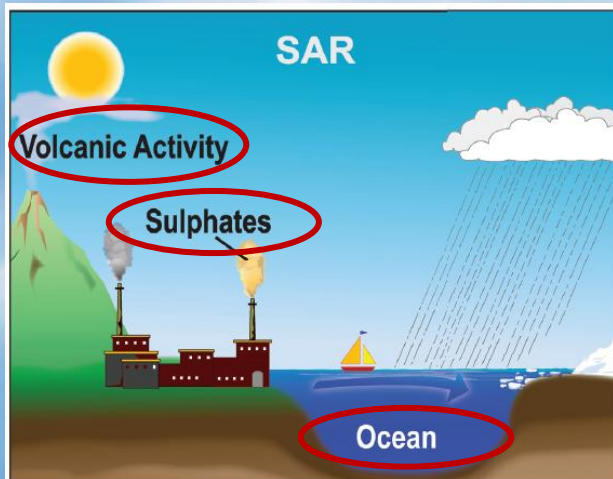
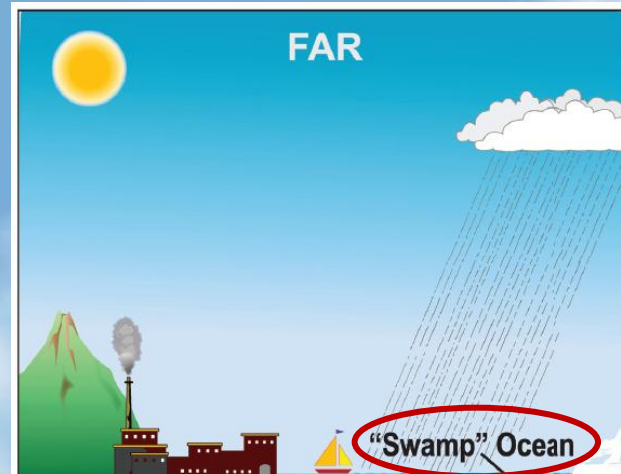
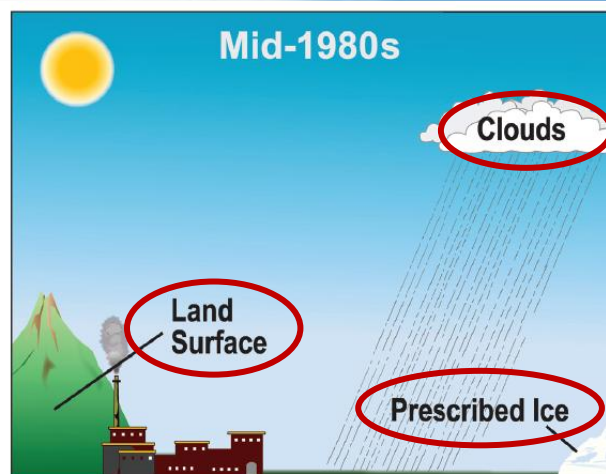
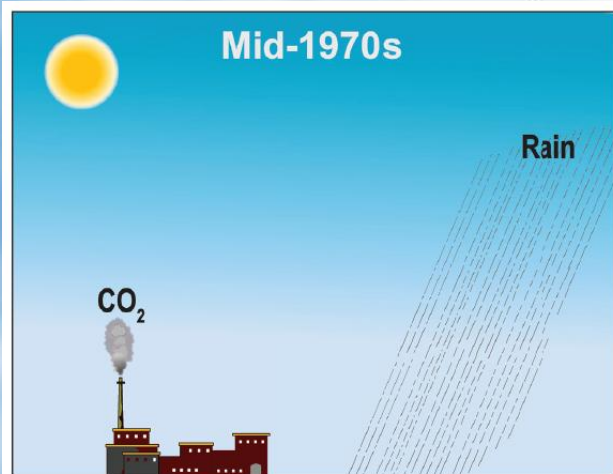
Combinando todos os efeitos antropogênicos



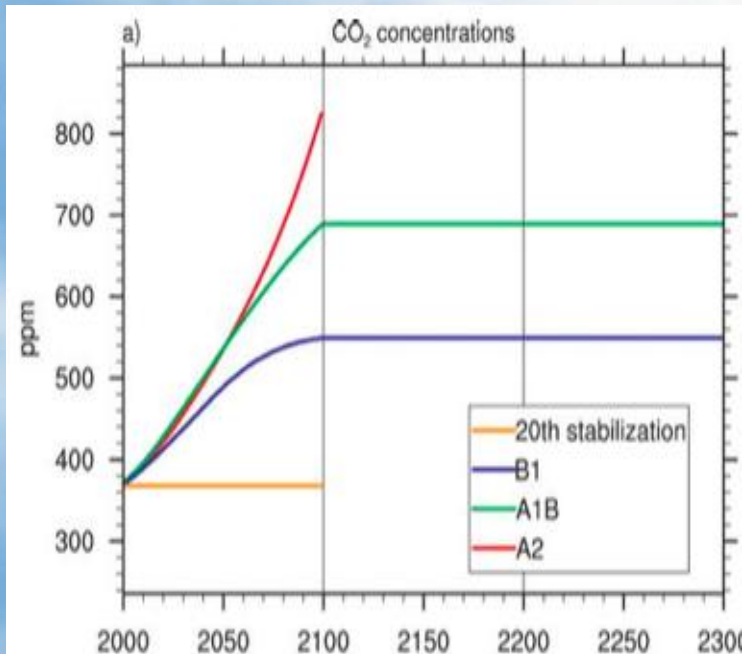
O que é feito **nesta componente** é crítico para a **forçante final**

- **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**

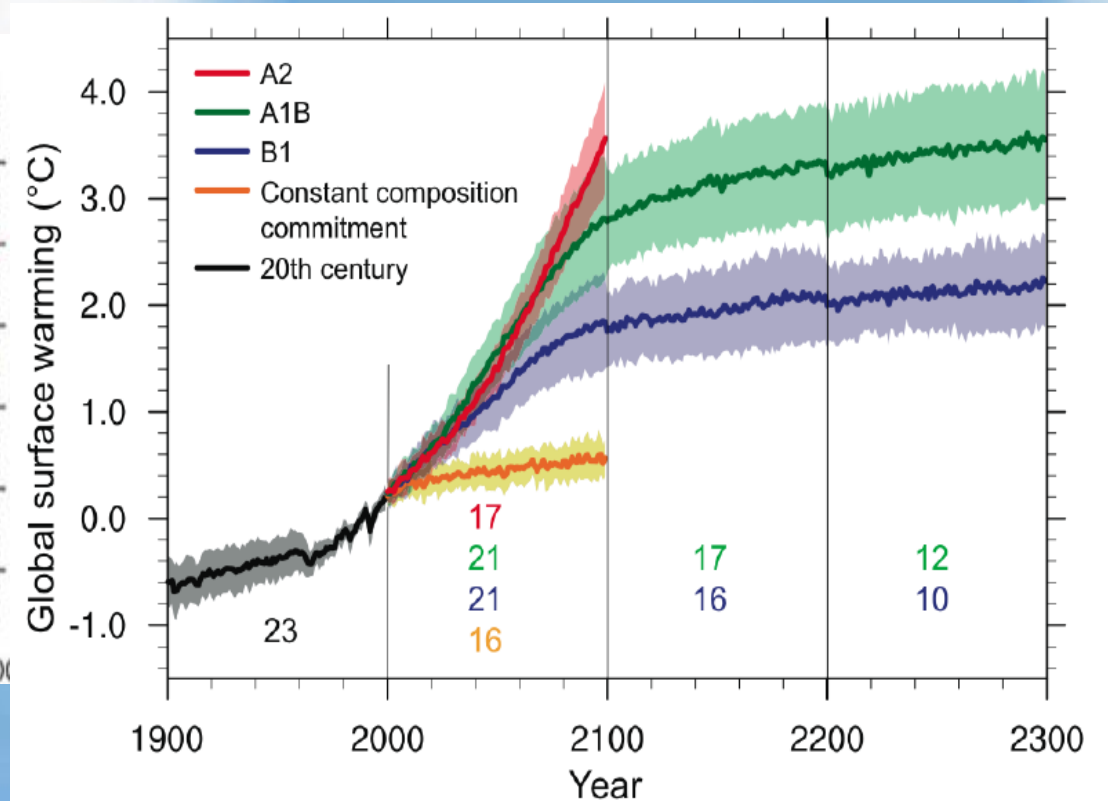
Física adicional incorporada nos sucessivos modelos climáticos globais



Previsão de aquecimento ao longo dos próximos 100 anos

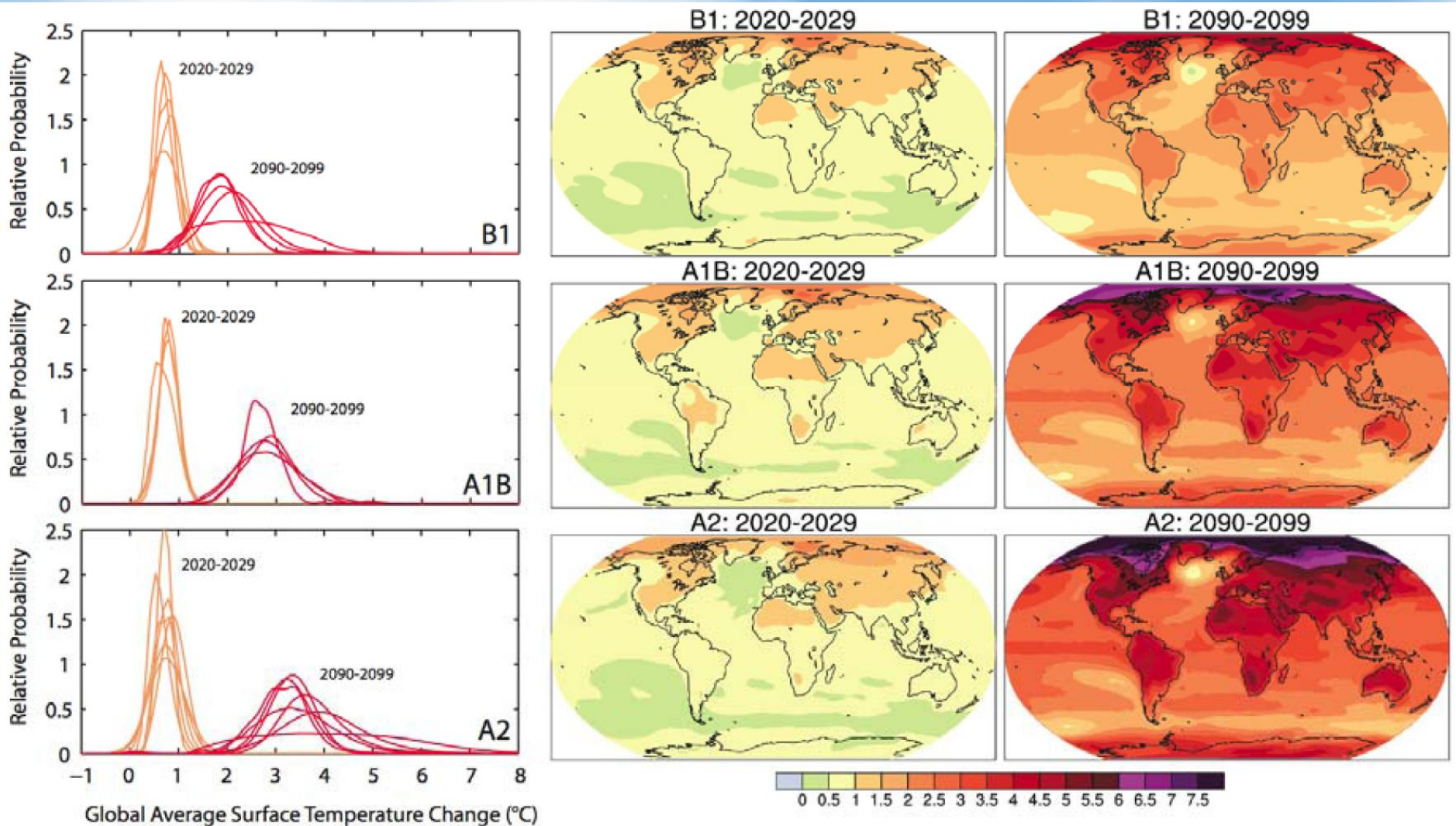


Cenários possíveis de aumento nas concentrações de CO₂



Aumento na temperatura média global: de 2 a 4 graus centígrados

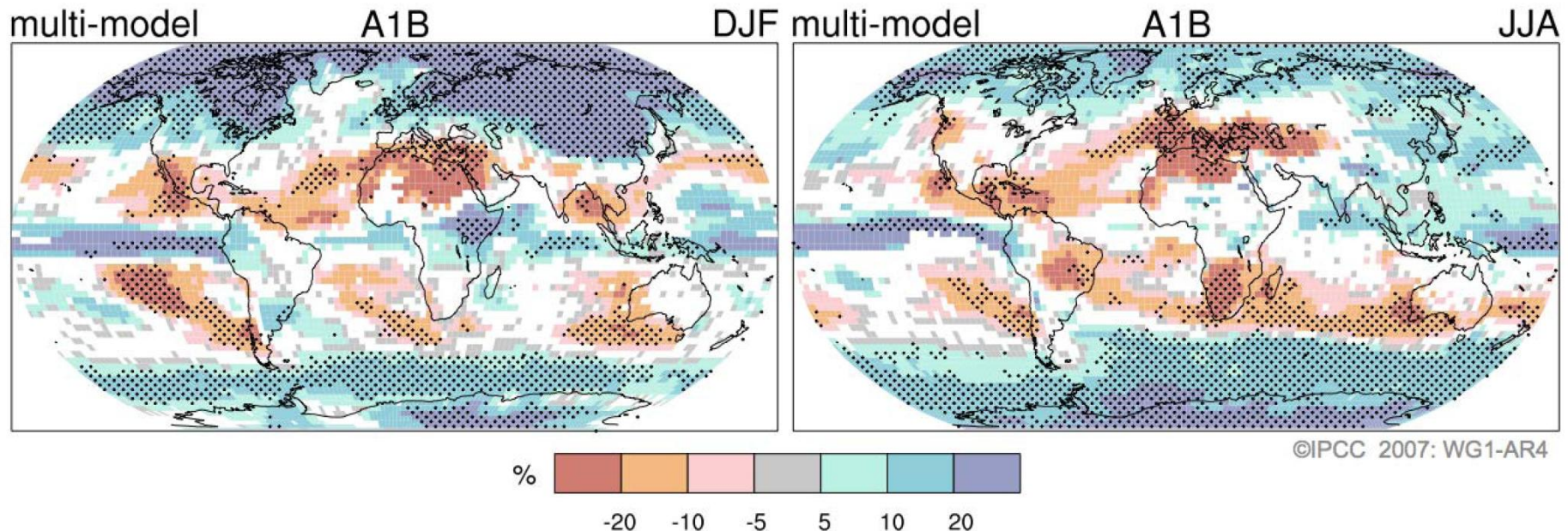
Estimativas de aumentos regionais de temperatura para 2029 e 2099 de acordo com 3 cenários de emissões



Mudanças regionais no padrão de precipitação para o final do século, relativo a 2000 (em %)

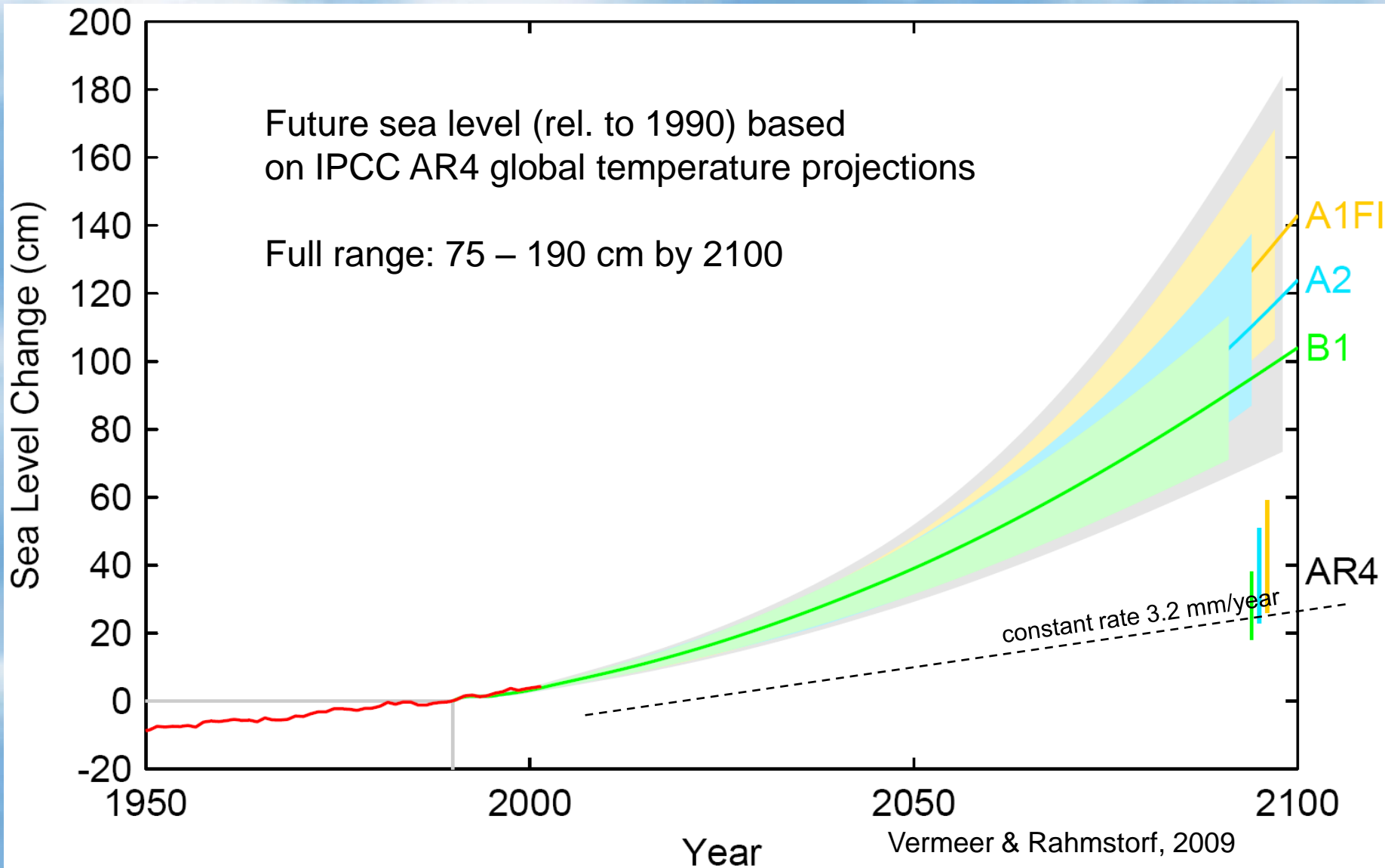
Dezembro-Fevereiro

Junho-Agosto

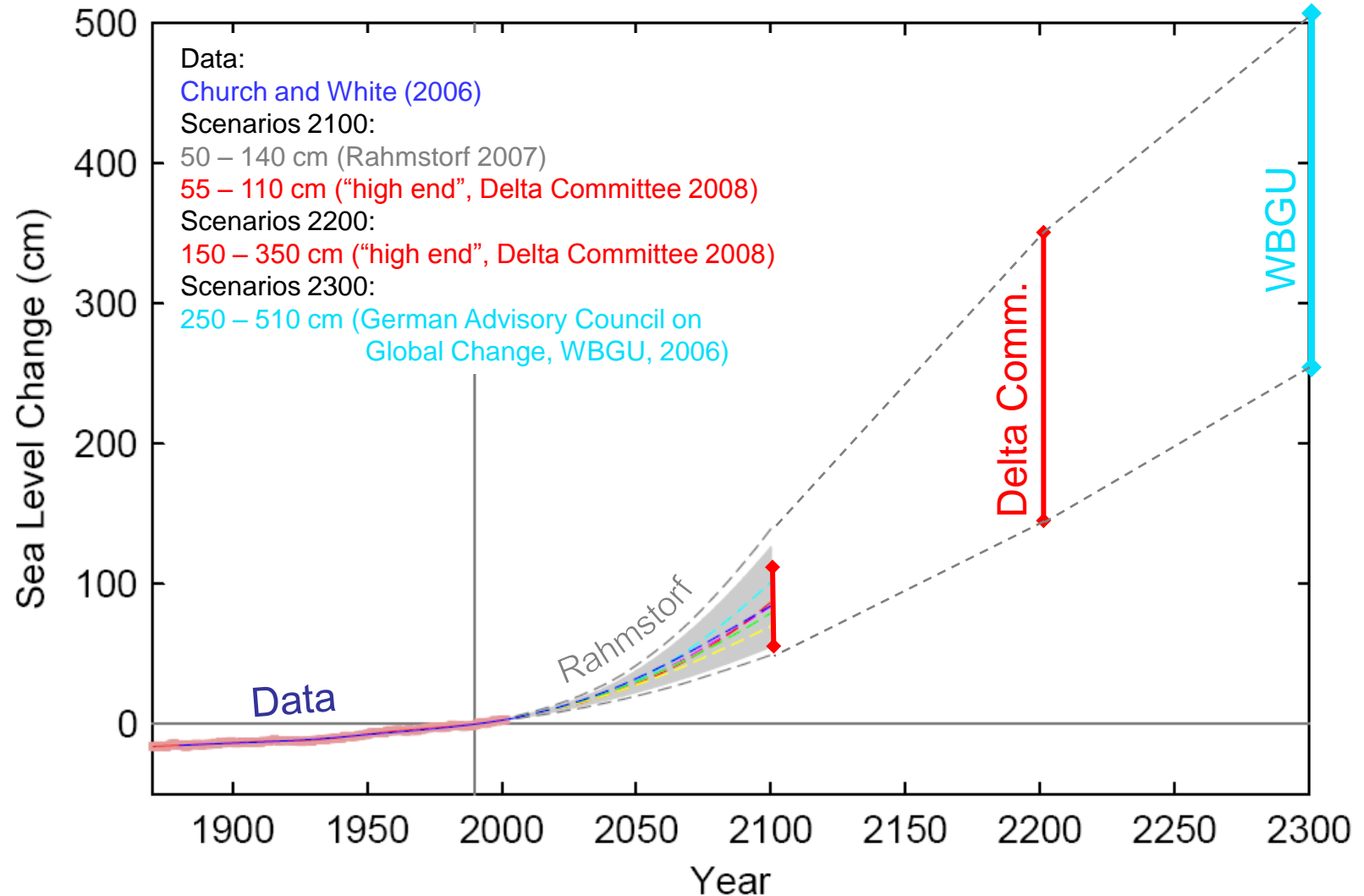


Deverá haver aumento de precipitação em algumas áreas e outras sofrerão redução na taxa de precipitação

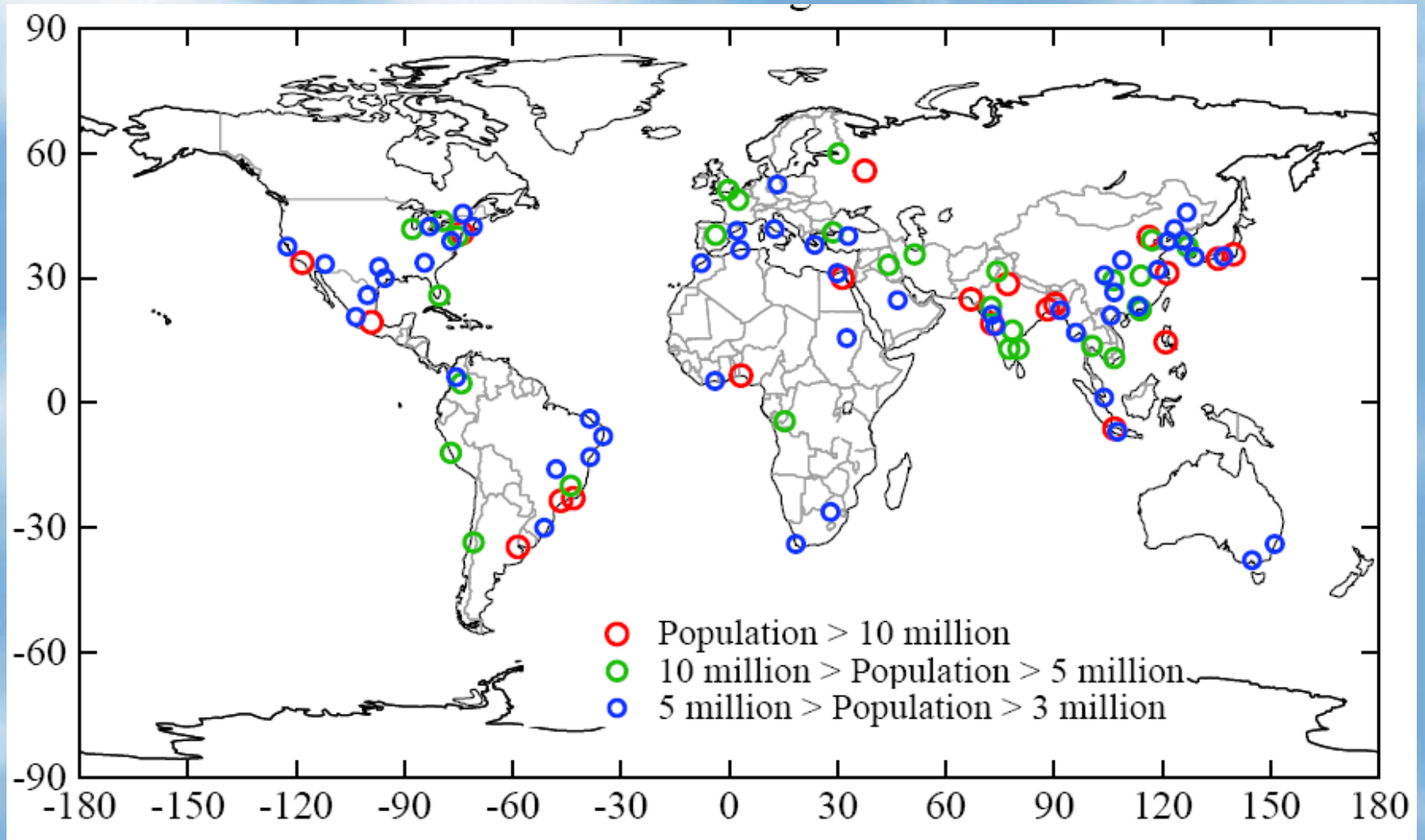
Sea Level Future Projections



Other recent sea level projections



As 100 maiores cidades do nosso planeta



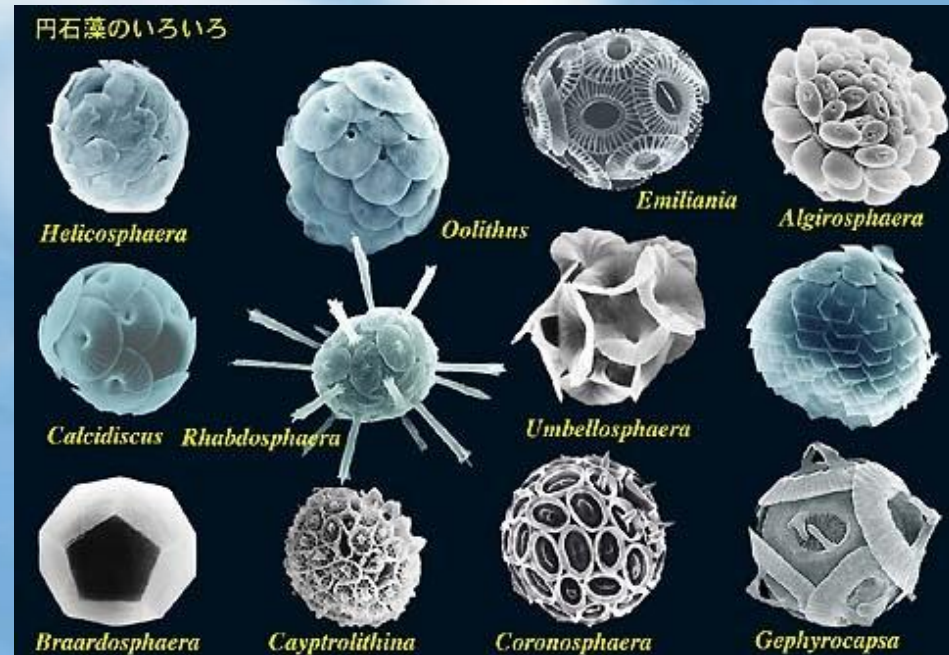
Acidificação dos oceanos

CO₂ é corrosivo ao esqueleto de muitos organismos marinhos

Corais

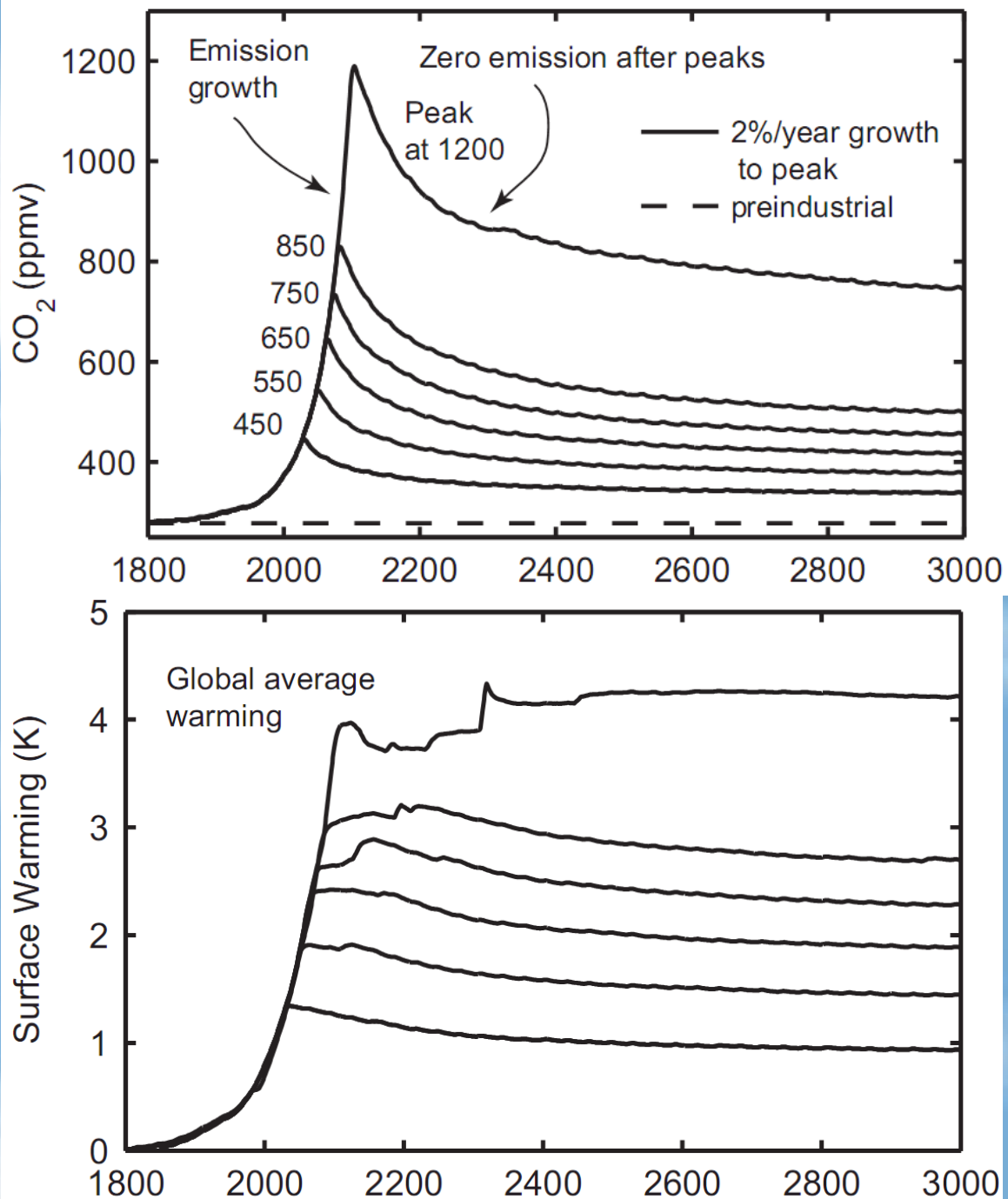


Plâncton Calcário



Quanto tempo durarão os efeitos da injeção de CO₂ na atmosfera?

Susan Salomon PNAS Fev 2009



Tipping Point Definitions

1. Tipping Level

- Climate forcing (greenhouse gas amount) reaches a point such that no additional forcing is required for large climate change and impacts

2. Point of No Return

- Climate system reaches a point with unstoppable irreversible climate impacts (irreversible on a practical time scale)
Example: disintegration of large ice sheet

Métricas para mudanças climáticas que poderiam ser consideradas “perigosas”

Exterminação de animais e espécies de plantas

1. Extinção de espécies polares e alpinas
2. Migrações não sustentáveis

Desintegração das grandes geleiras: Aumento do nível do mar

1. Mudanças regionais do nível do mar são difíceis
2. Tempo de resposta de derretimento

Alterações no clima regional

1. Aumento de eventos extremos
2. Alteração no padrão de chuva

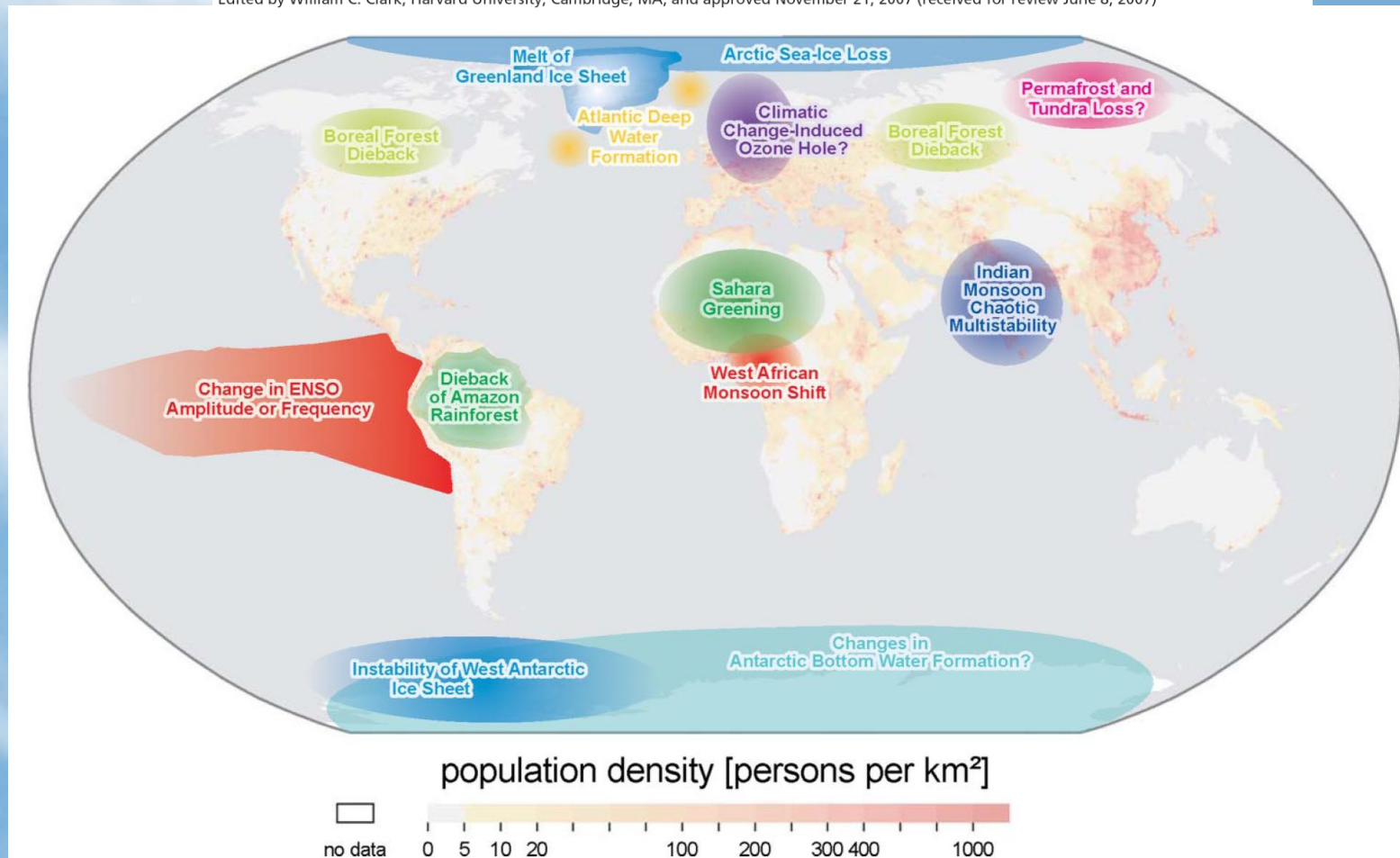
Tipping elements in the Earth's climate system

Timothy M. Lenton^{*†}, Hermann Held[‡], Elmar Kriegler[§], Jim W. Hall[¶], Wolfgang Lucht[‡], Stefan Rahmstorf[‡], and Hans Joachim Schellnhuber^{†‡||**}

^{*}School of Environmental Sciences, University of East Anglia, and Tyndall Centre for Climate Change Research, Norwich NR4 7TJ, United Kingdom; [†]Potsdam Institute for Climate Impact Research, P.O. Box 60 12 03, 14412 Potsdam, Germany; [‡]Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA 15213-3890; [§]School of Civil Engineering and Geosciences, Newcastle University, and Tyndall Centre for Climate Change Research, Newcastle NE1 7RU, United Kingdom; and [¶]Environmental Change Institute, Oxford University, and Tyndall Centre for Climate Change Research, Oxford OX1 3QY, United Kingdom

**This contribution is part of the special series of Inaugural Articles by members of the National Academy of Sciences elected on May 3, 2005.

Edited by William C. Clark, Harvard University, Cambridge, MA, and approved November 21, 2007 (received for review June 8, 2007)



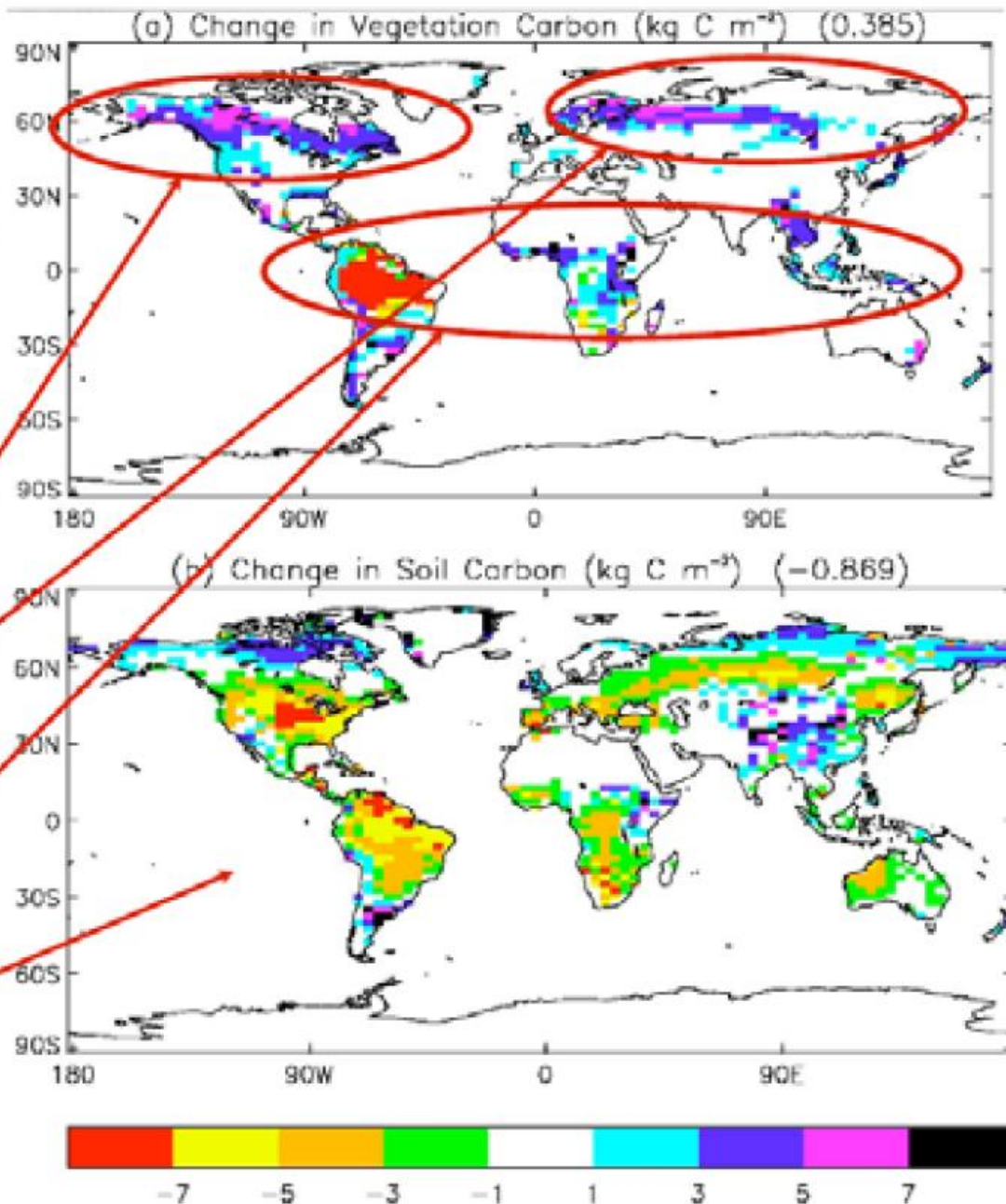
Simulated Changes in Carbon Storage Hadley Center Model 1860-2100

Carbon Cycle “Hotspots”:

Boreal Forests, Tundra
(Permafrost)

Tropical Ecosystems

Soils



(Heimann, NEESPI, 2008)

United Nations Framework Convention on Climate Change

O objetivo da Convenção do Clima é estabilizar as concentrações de gases de efeito estufa...

“...em um nível que possa prevenir interferências perigosas com o sistema climático terrestre”

Não é muito tarde, mas também não temos muito tempo...

Temperature stabilization scenarios

| Global mean temp. increase (°C) | Stabilization level (ppm CO ₂ -eq) | Year CO ₂ needs to peak |
|---------------------------------|---|------------------------------------|
| 2.0 – 2.4 | 445 – 490 | 2000 – 2015 |
| 2.4 – 2.8 | 490 – 535 | 2000 – 2020 |
| 2.8 – 3.2 | 535 – 590 | 2010 – 2030 |
| 3.2 – 4.0 | 590 – 710 | 2020 – 2060 |

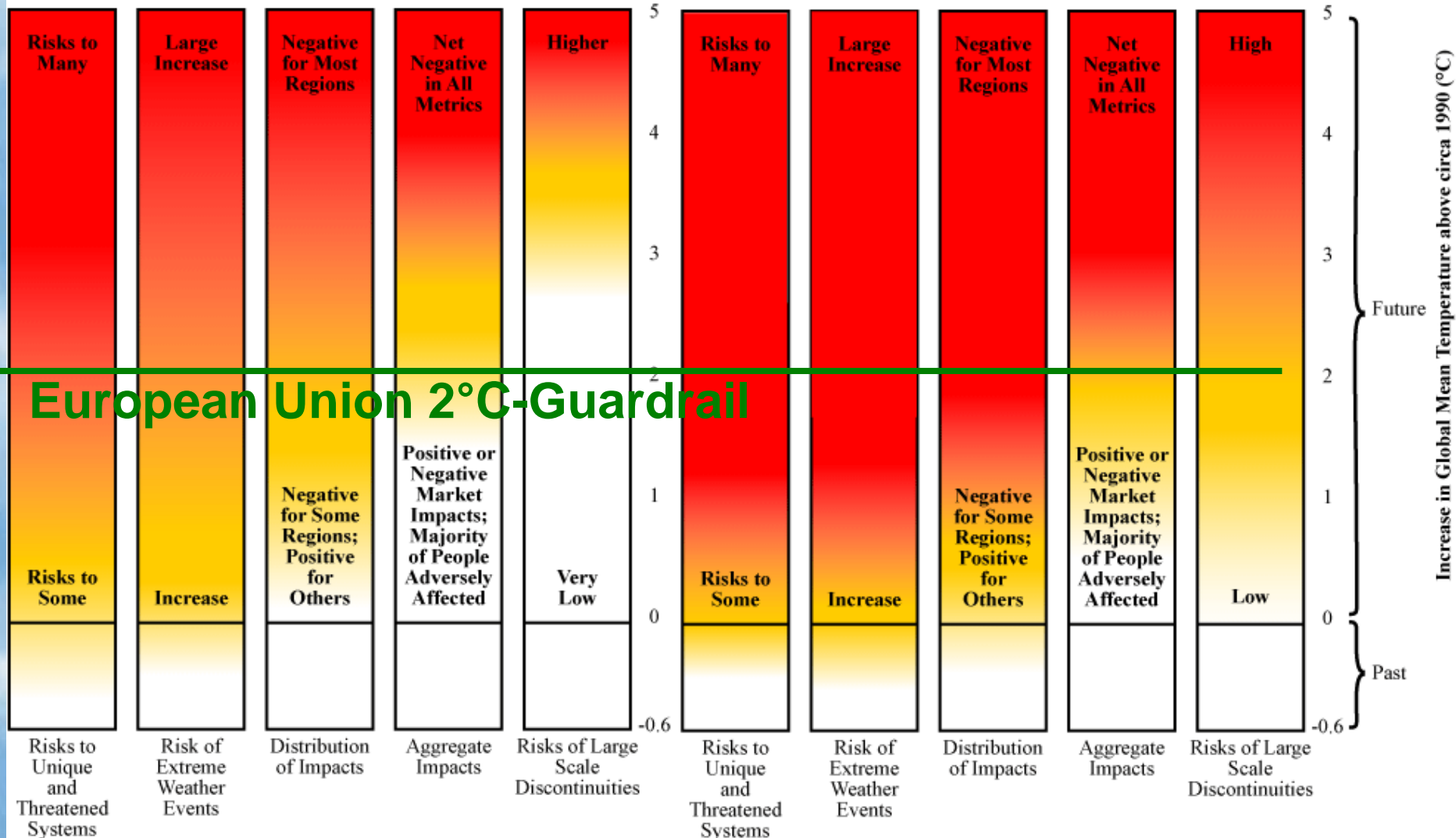
Updated Risks and reasons for concern

IPCC 2001

IPCC 2007

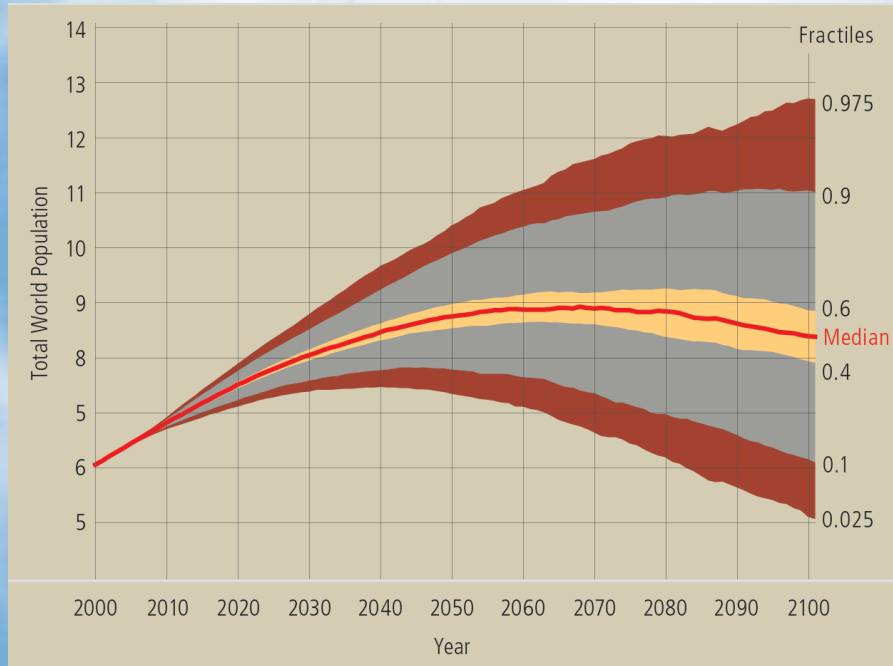
TAR (2001) Reasons For Concern

Proposed AR4 (2007) Reasons For Concern



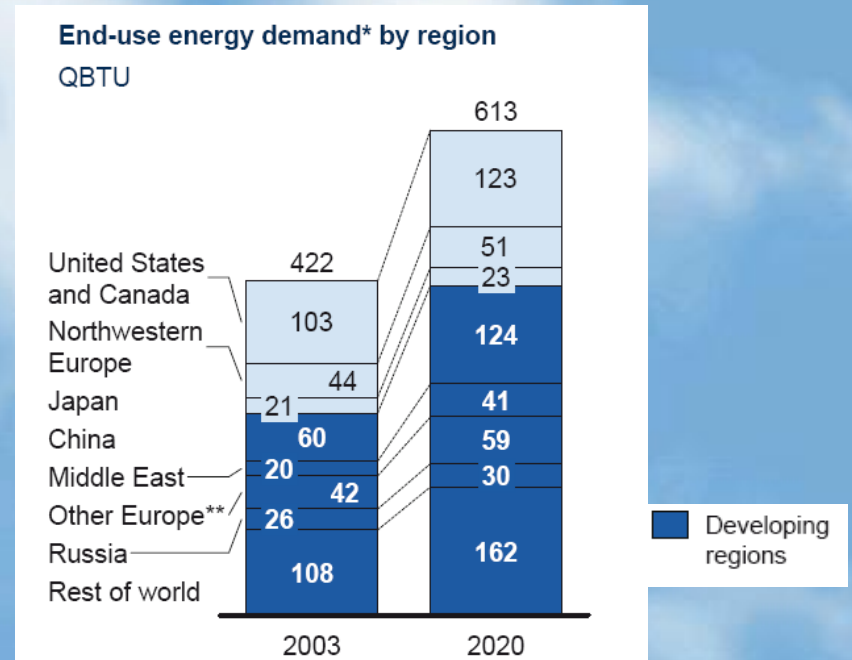
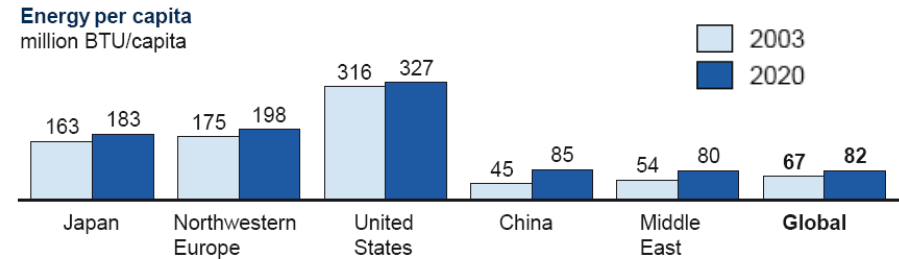
(Smith et al. 2009 PNAS)

Population Growth/Energy Demand Projections



Uncertainty distribution of total world population in 2100, in billions

(Lutz et al. IIASA 2007)



(MGI Global Energy Demand Model 2007)

Assessment of Target CO₂

Phenomenon

Target CO₂ (ppm)

- | | |
|------------------------------|---------|
| 1. Arctic Sea Ice | 300-325 |
| 2. Ice Sheets/Sea Level | 300-350 |
| 3. Shifting Climatic Zones | 300-350 |
| 4. Alpine Water Supplies | 300-350 |
| 5. Avoid Ocean Acidification | 300-350 |

→ Initial Target CO₂ = 350* ppm

*assumes CH₄, O₃, Black Soot decrease

“Free Will” Alternative

1. Phase Out Coal CO₂ Emissions

- by 2025/2030 developed/developing countries

2. Rising Carbon Price

- discourages unconventional fossil fuels & extraction of every last drop of oil (Arctic, etc.)

3. Soil & Biosphere CO₂ Sequestration

- improved farming & forestry practices

4. Reduce non-CO₂ Forcings

- reduce CH₄, O₃, trace gases, black soot

Food for a Week, Darfur Refugees, Chad

Pour les crises
enfants, O'ne
relève mission de
partage au malin.
Est-ce tant sa ferme
et
Soutien et
30



TCHAD 230 000 réfugiés de guerre soudanais vivent dans les camps de l'Onu. Chacun a droit à 2100 Cal par jour: céréales, sucre, sel, huile, légumes secs et farine vitaminée.

Food for a Week, Germany

Les plats préférés des Allemands : nouilles, frites, pizza, pudding.



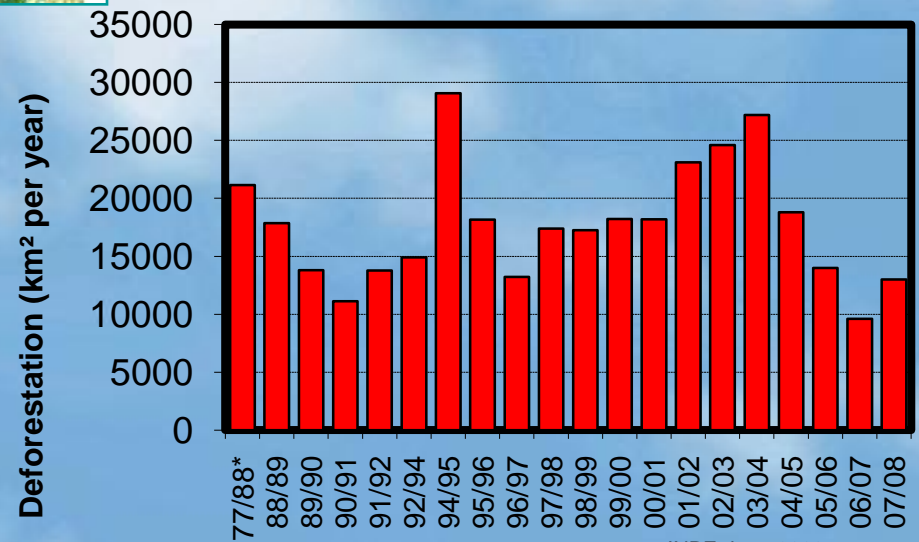
ALLEMAGNE 1500 sortes de saucisses, 1200 restaurants McDonald's, 750 millions de kebabs avalés chaque année... Plus de la moitié des Allemands sont en surpoids ou obèses.



As of 2008, 17% of the forest was deforested. By 2050, if current trends continue, about 40% of the forest could be cleared.

Vegetation change is not a slow uniform process. It happens abruptly, possibly long after it becomes inevitable—mediated by a proximate agent, in this case, fire and deforestation (which promotes fire and drying).

Deforestation in Amazonia 1977-2007 in km² per year

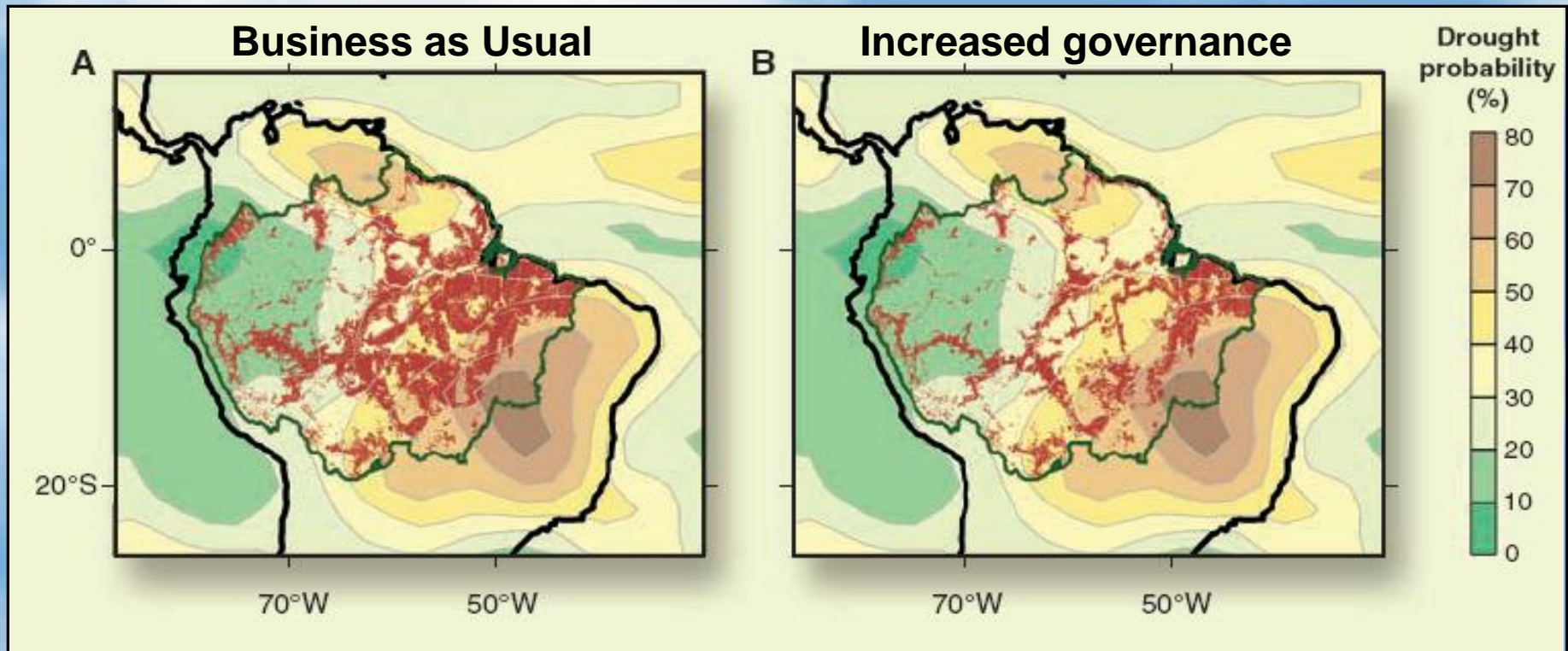


* Average for the decade

INPE data, 2008

Efeitos combinados na Amazonia de desmatamento e mudanças climáticas globais

Deforestation to 2050 (brown)



Underlying map: “probability” of substantial drought (>20% reduction in dry-season rainfall)

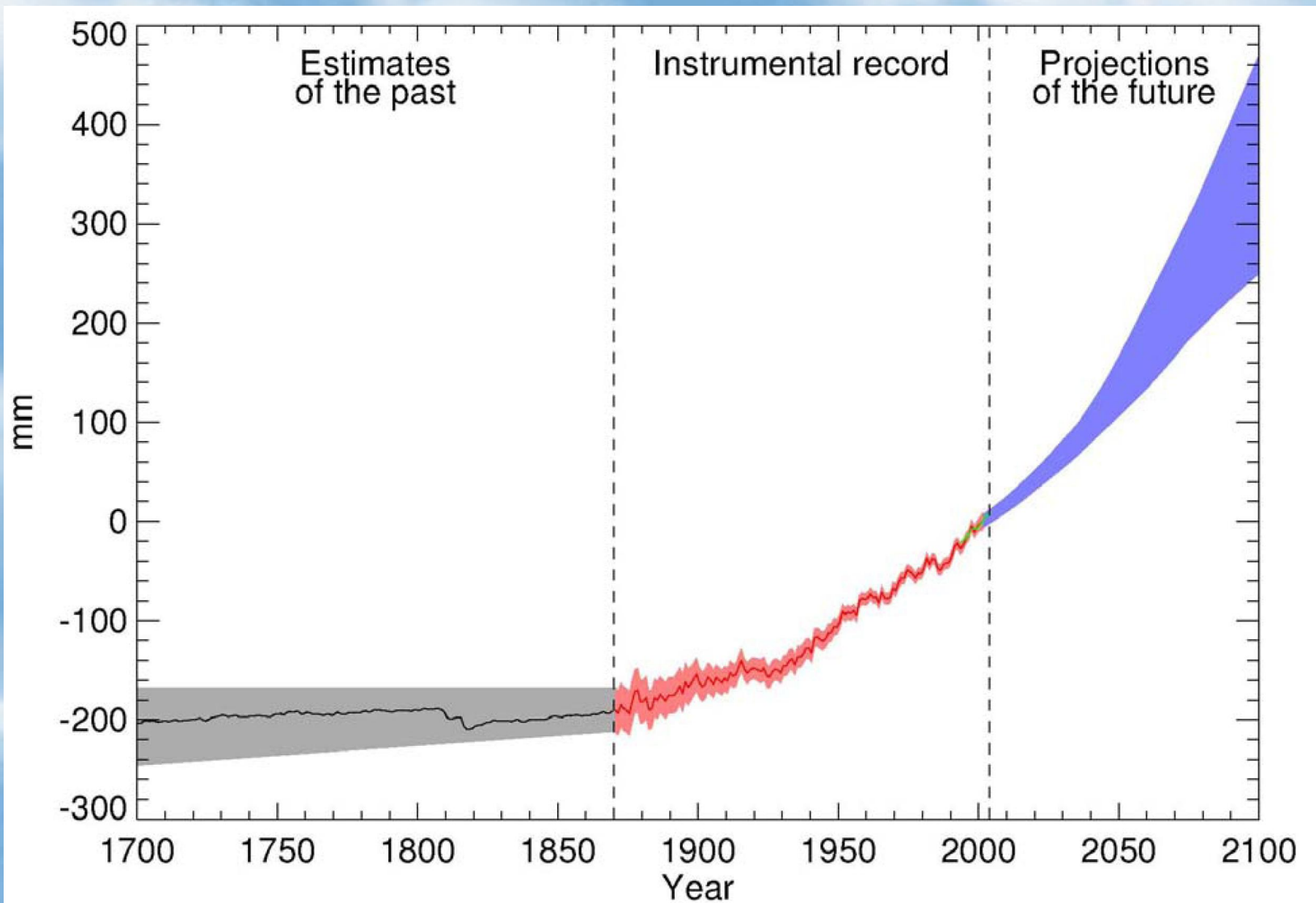
“probability” = proportion of 23 GCMs that showed rainfall decline (2080-2099 vs. 1980-1999) for IPCC AR4 mid-range emissions scenario (A1B)

Malhi et al. (2008)

Obrigado pela atenção !!!

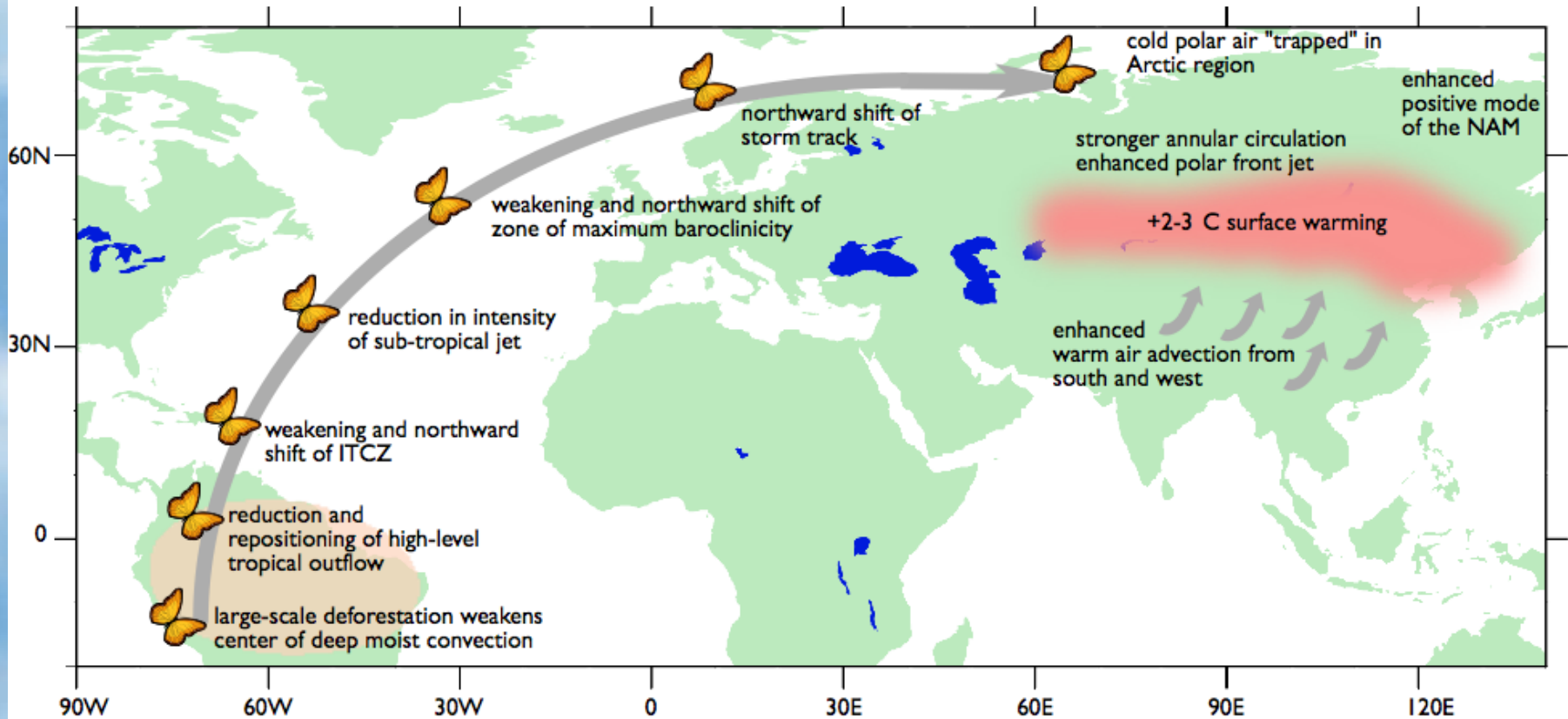


Aumento do nível do mar nos últimos e nos próximos 100 anos



Links entre Amazonia e o Tibet

Tropical-Extratropical Teleconnection Mechanism



O que cada individuo faz em cada canto do planeta afeta a todos...

Snyder, ea. J. Climate, 2005

Intergenerational Conflict

Intergenerational inequity and injustice is the result, affecting the young and unborn.

'Did not know' defense of prior generations no longer viable.

Ethical and legal liability questions raised by actions that deceived the public.

Continued failure of political process (not even available to young and unborn) may cause increasing public protests.

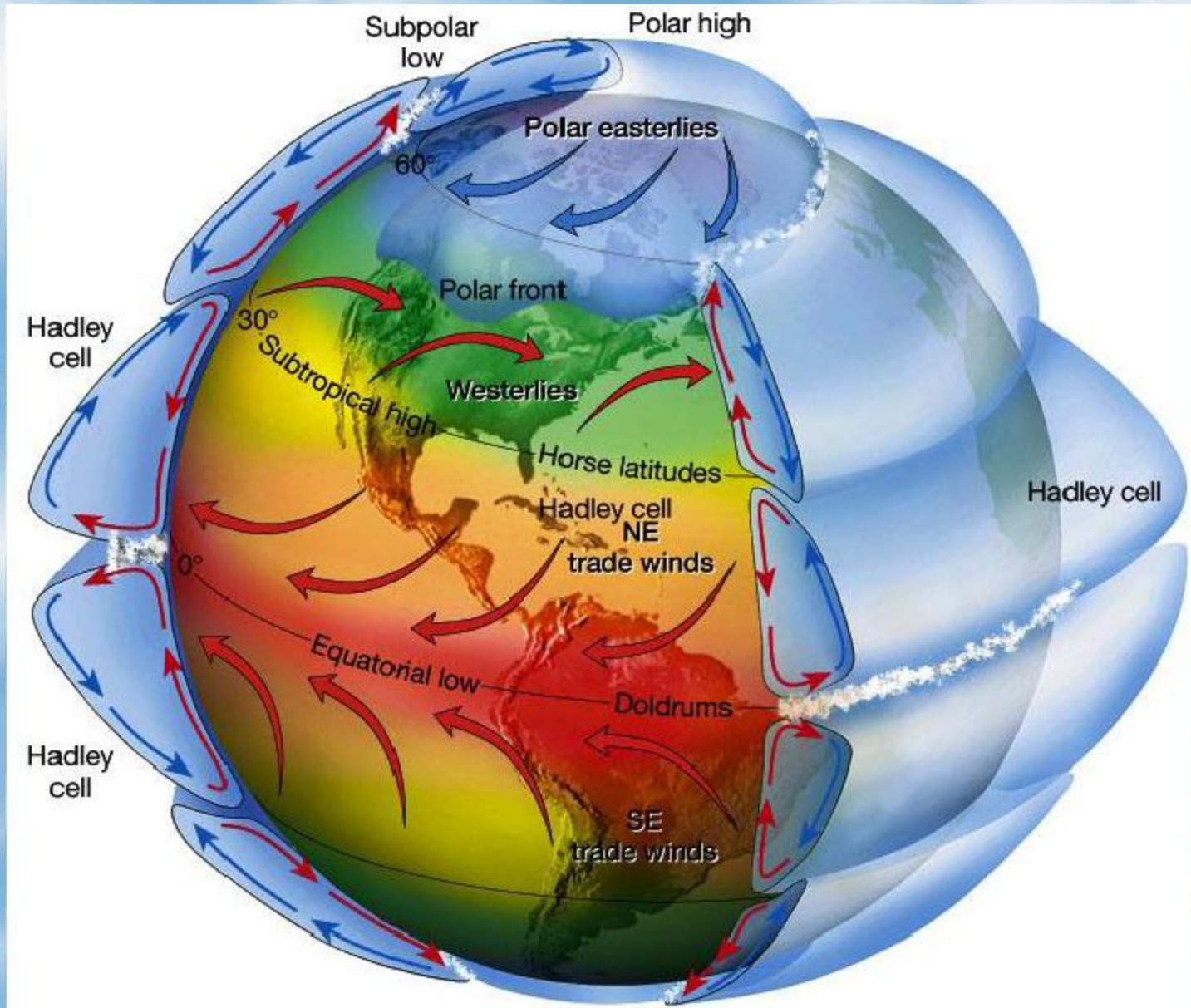
Alvo para CO₂:

< 350 ppm

Para que a civilização como a conhecemos seja preservada

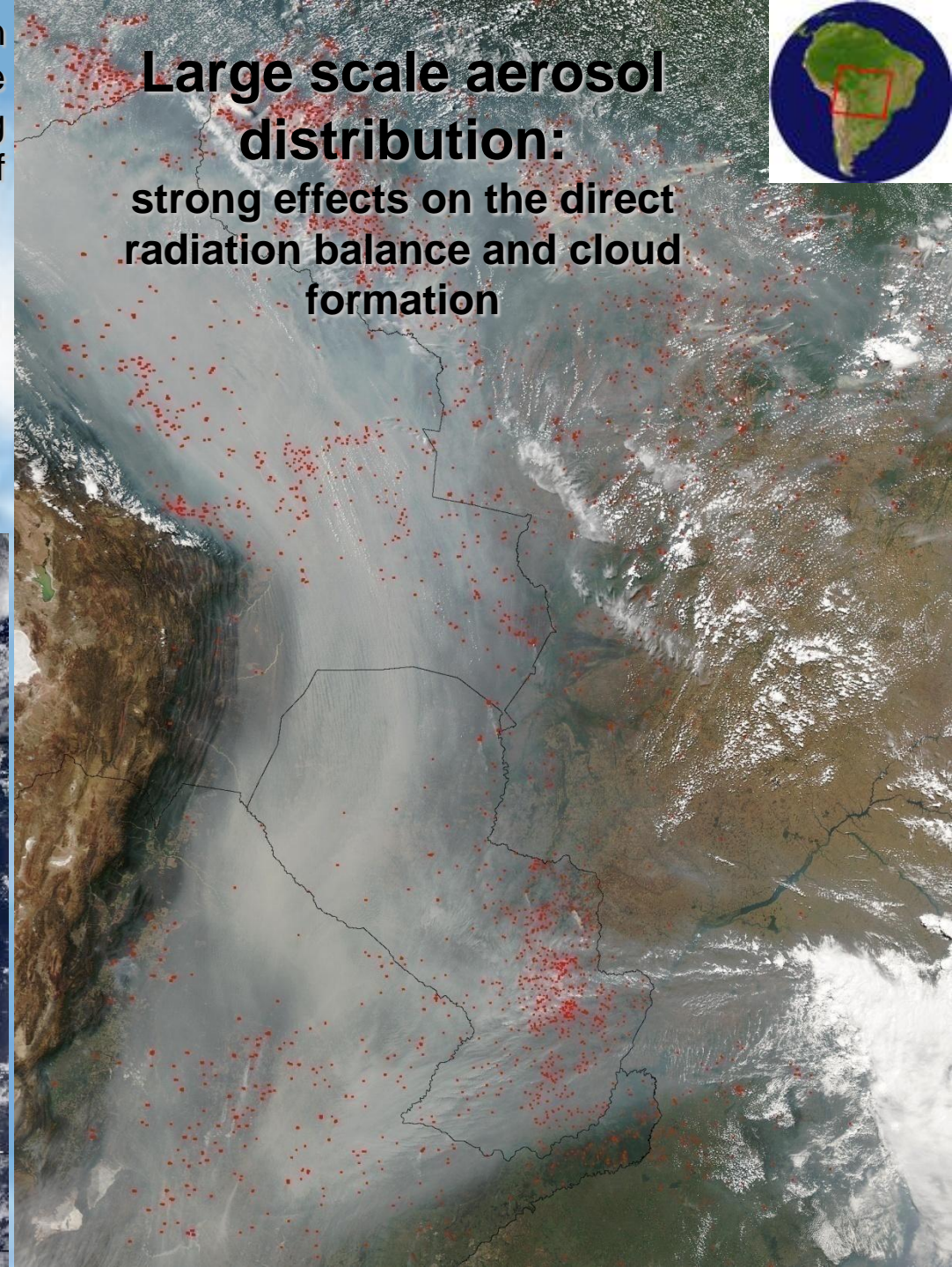
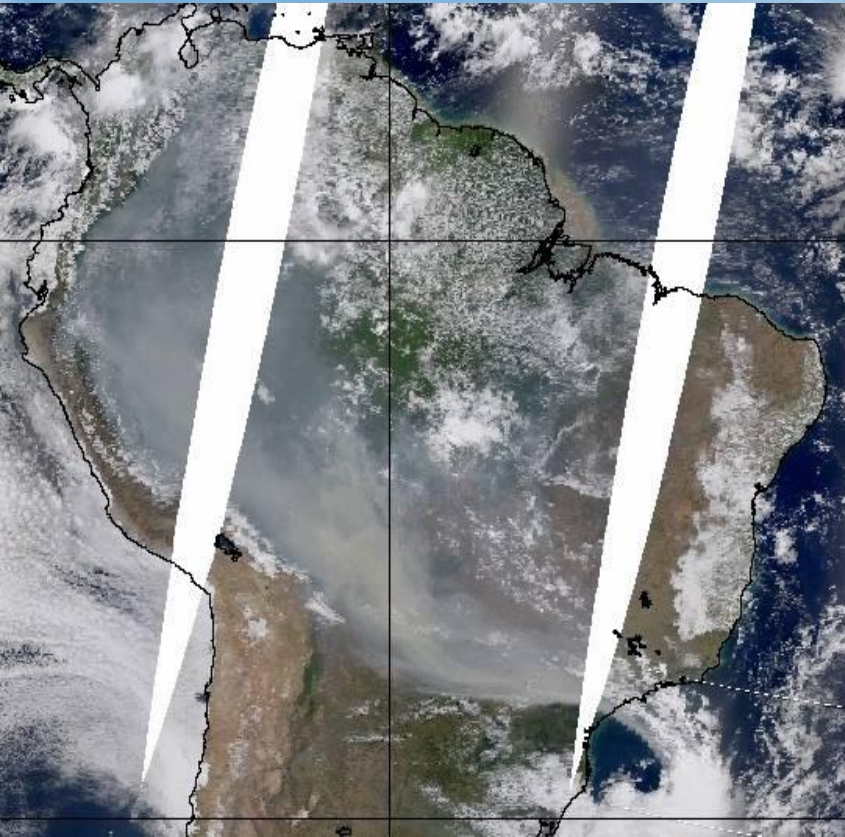
PS: Estamos agora em 385 ppm e crescendo cerca de 17 ppm por década...

A Amazônia é crítica na manutenção do vapor de água global



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 ...

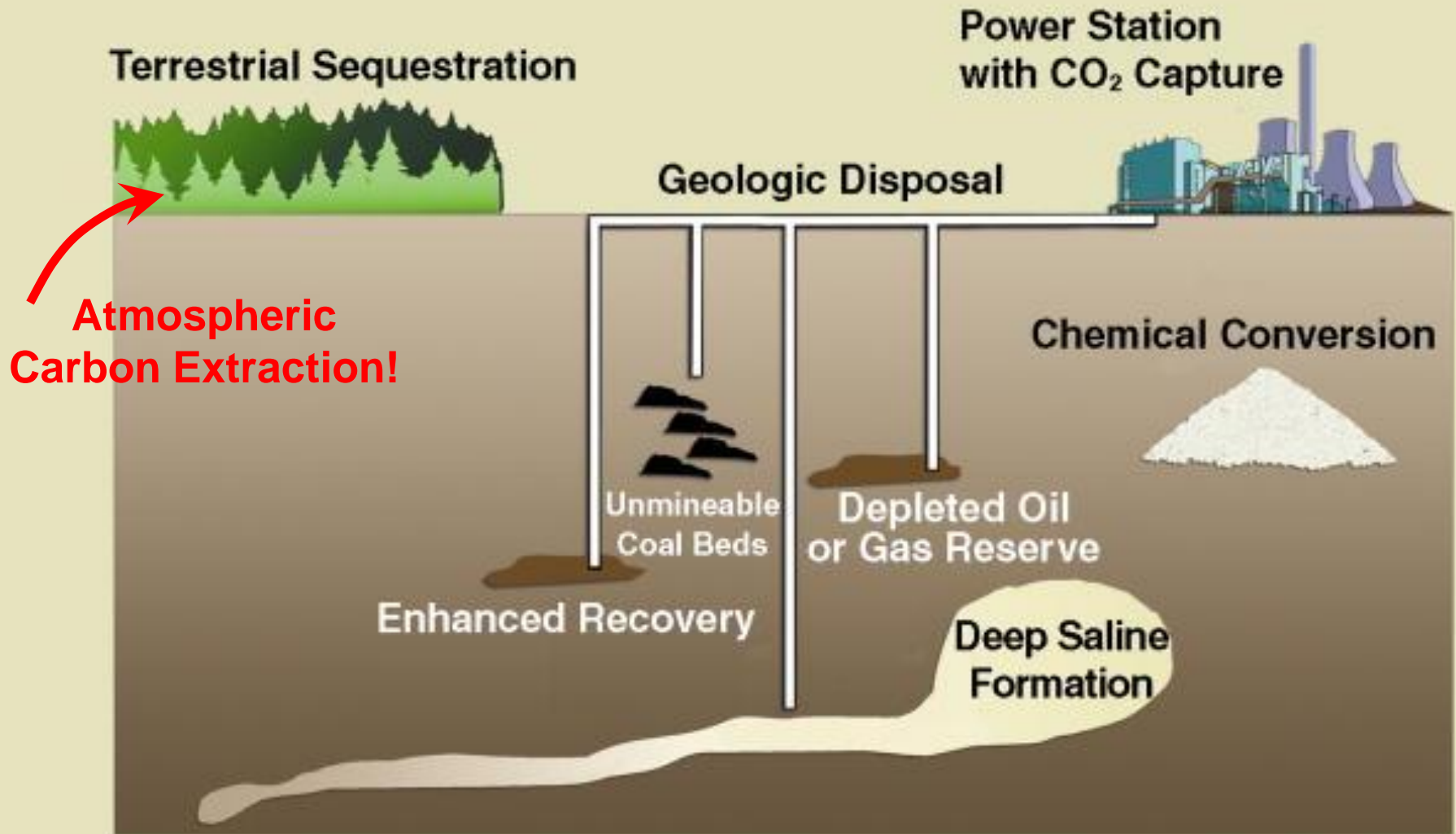
- Severe health effects on the population
- Climate effects
- Weather effects



Large scale aerosol distribution:
strong effects on the direct radiation balance and cloud formation

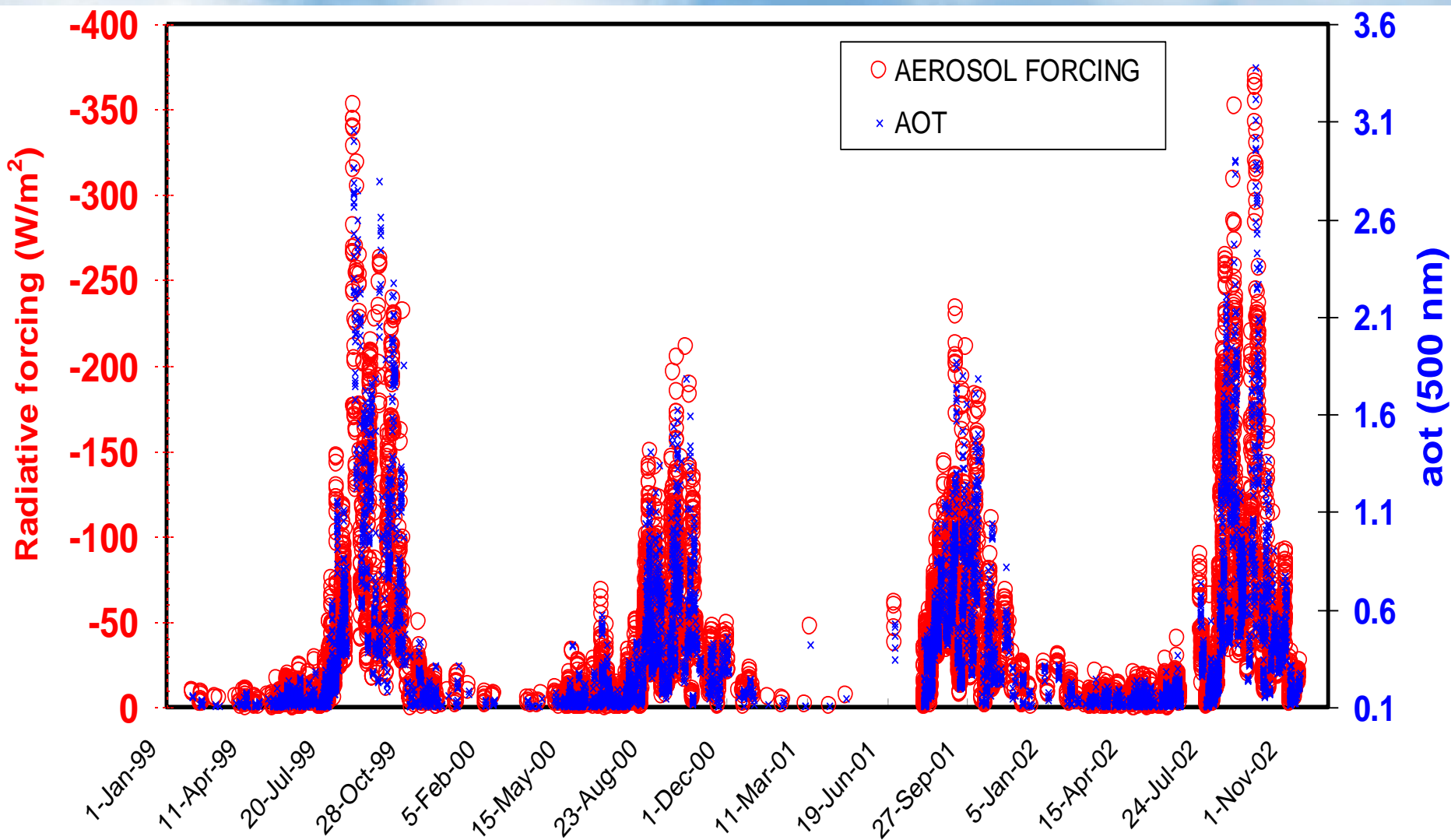


Carbon Sequestration Options





Aerosol surface forcing in Rondonia 1999-2002





Amazonia

Average aerosol forcing clear sky

Top: - 10 w/m²



Atmosphere: + 28 w/m²

Surface: - 38 w/m²

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

Procópio et al. (2004)

INDOEX

average aerosol forcing clear sky

Top: - 7±1 w/m²



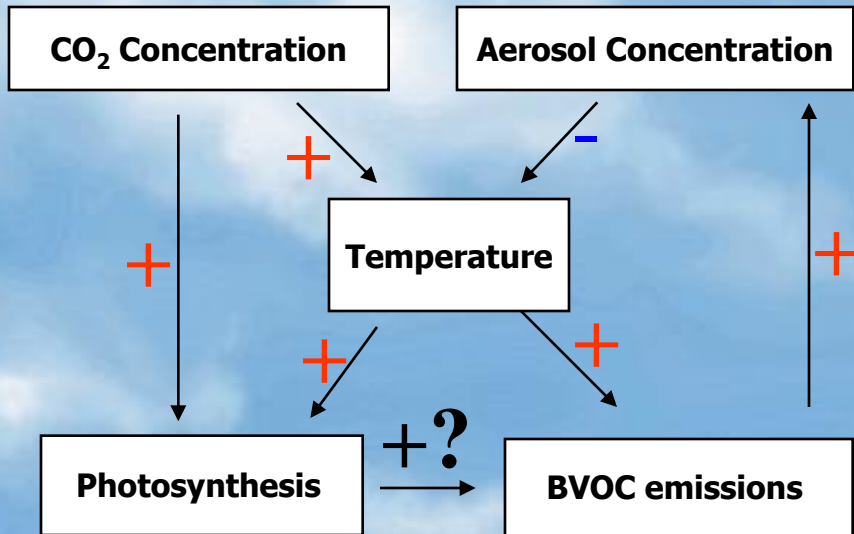
Atmosphere: + 16±2 w/m²

Surface: - 23±2 w/m²

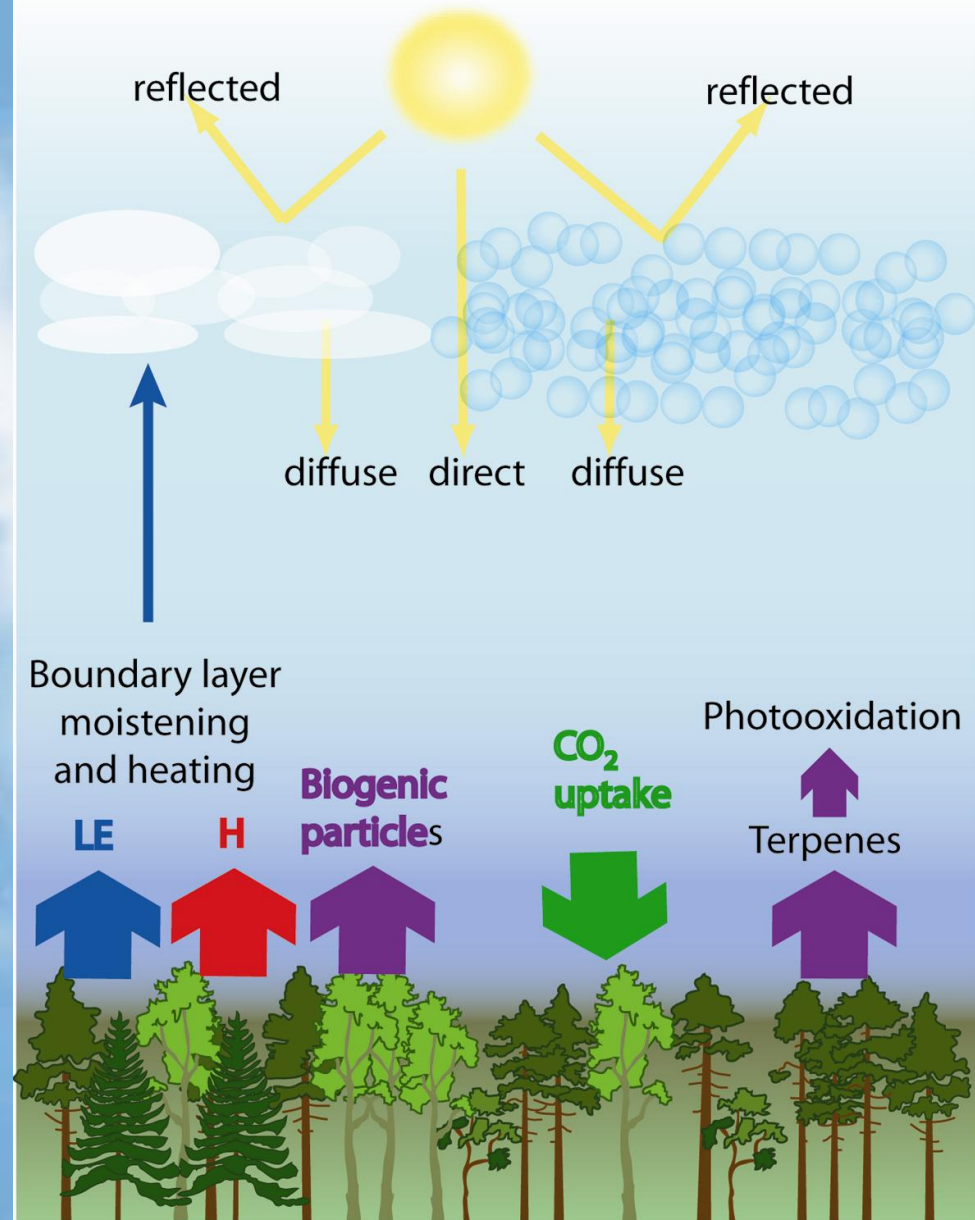
*Conditions: surface: ocean
AOT ($\tau=0.3$ at 630 nm); 24 hour average
Jan-Mar 99*



Aerosol effects on the Net Plant Productivity



Kulmala et al., 2004

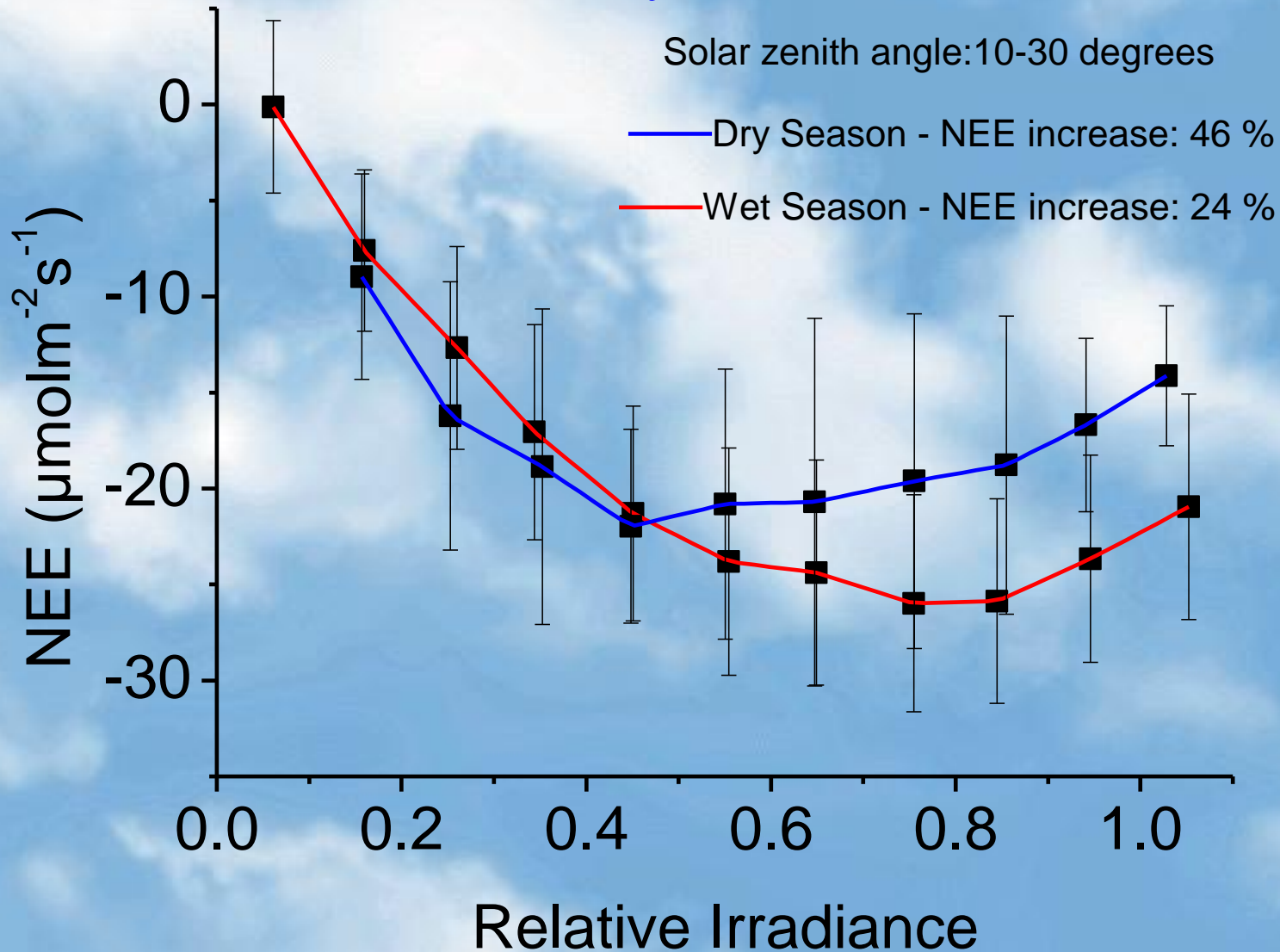


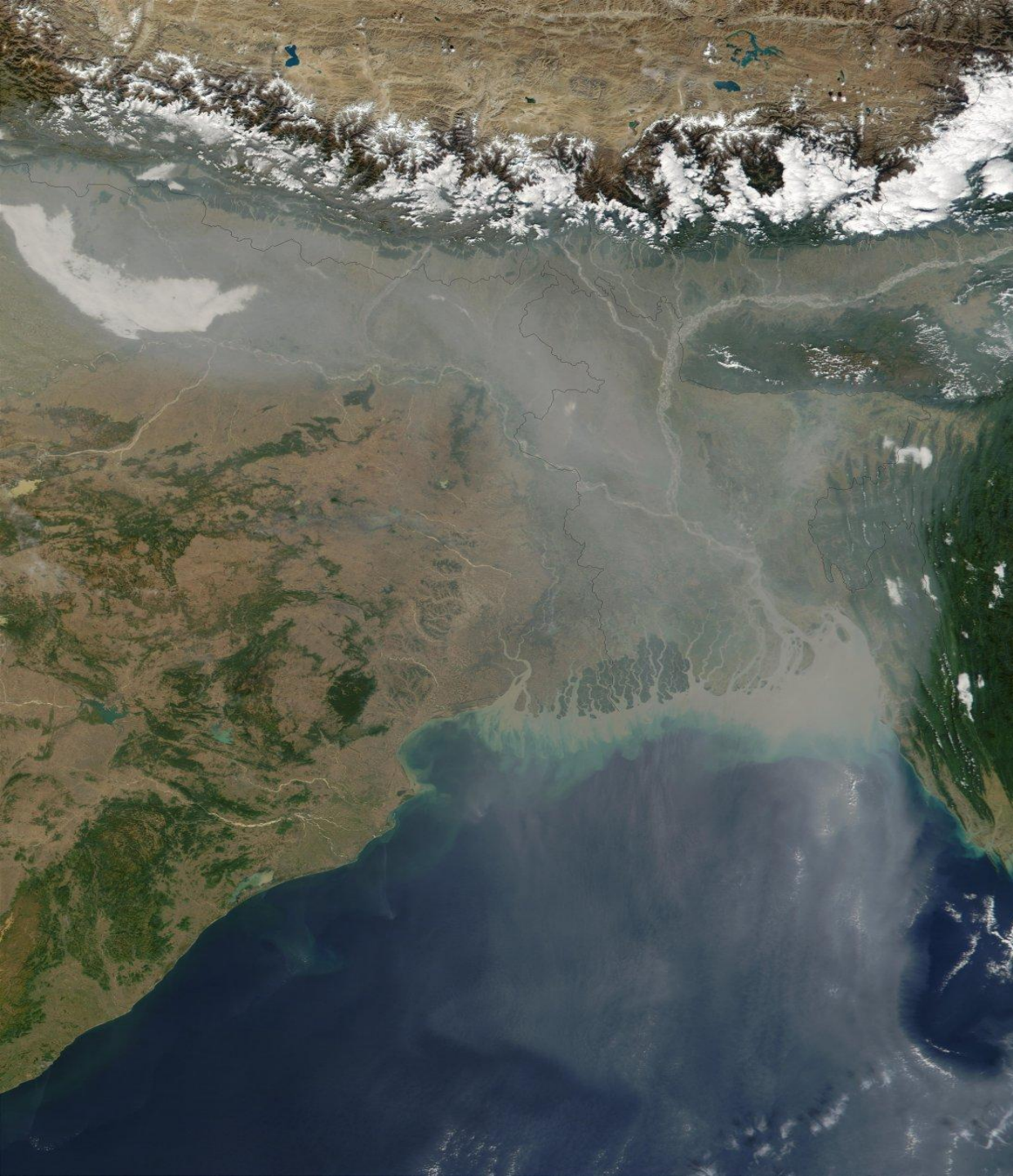


Significant effects of aerosols on net primary productivity in Amazonia



Forest site, year: 2000-2001

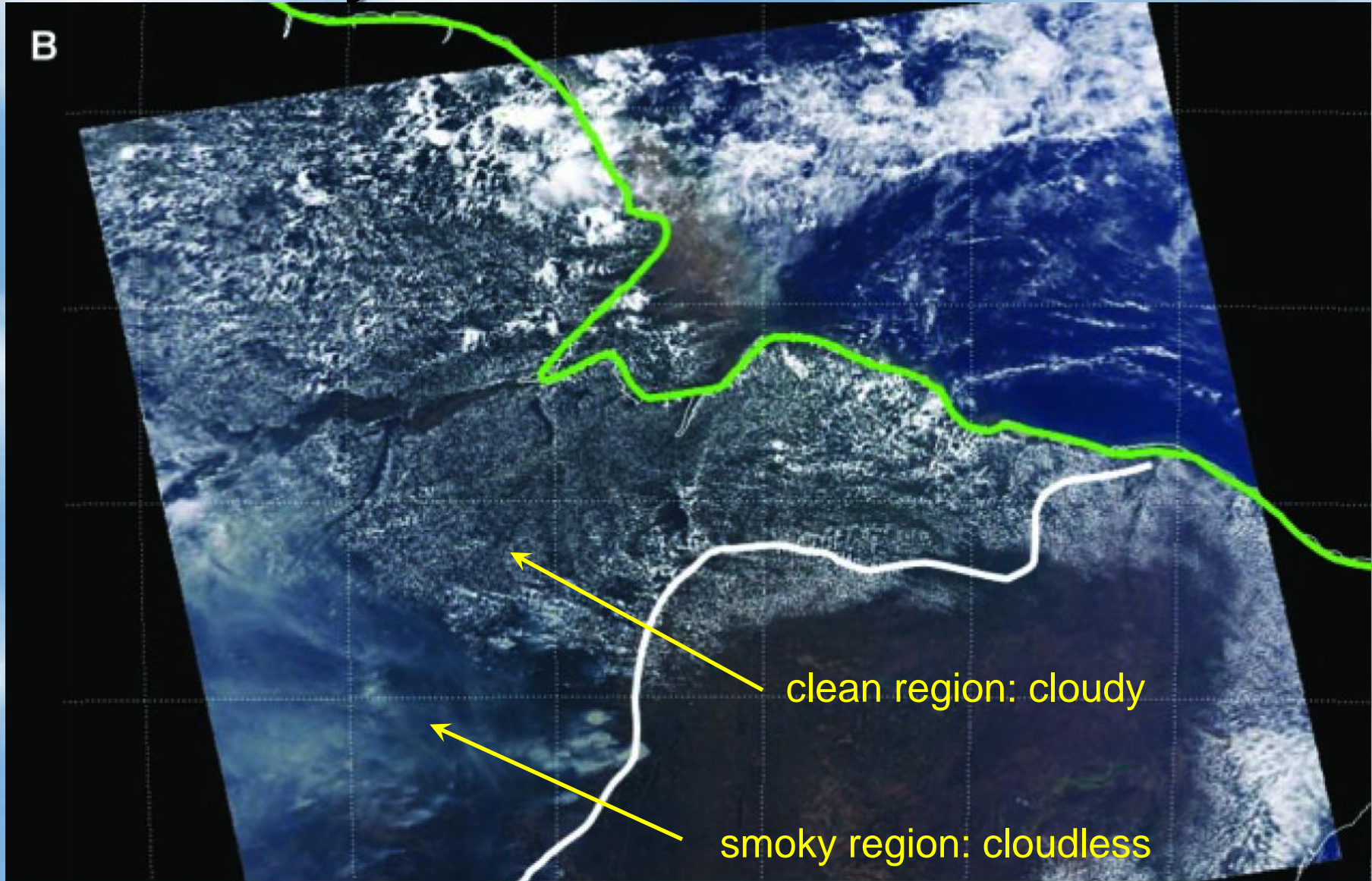




“Aerosol direct climate effects”

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

Indirect aerosol effects: Cloud suppression by smoke in the Amazon





Fires and Smoke in West Africa

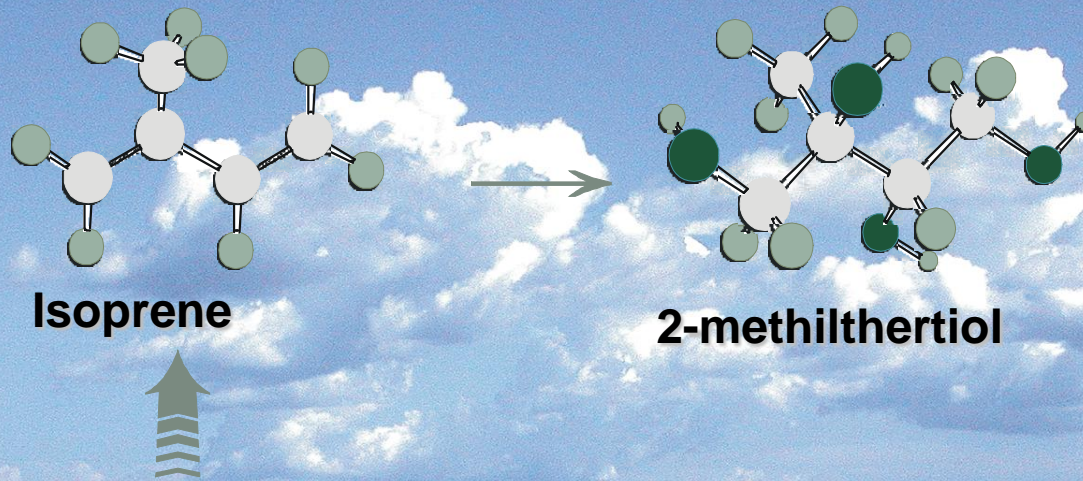
A satellite image of China showing a significant grey haze covering the landmass. The word "Beijing" is labeled in the center of the haze. The surrounding oceans are visible in shades of blue and green, and some white clouds are scattered around the edges of the continent.

Beijing

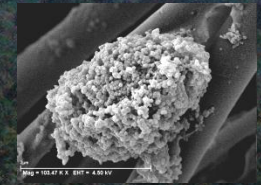
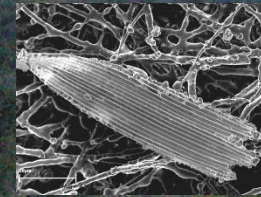
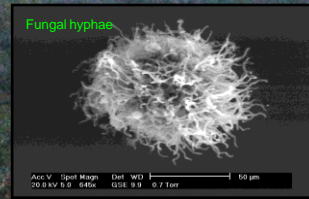
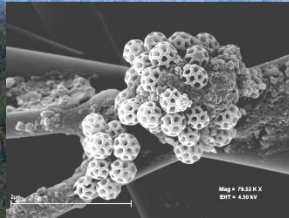
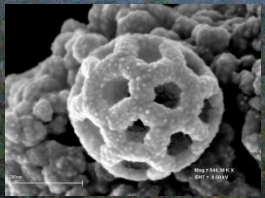
At risk from semidirect effect? Does grey haze over China reduce rainfall?



Natural production of CCN in Amazonia



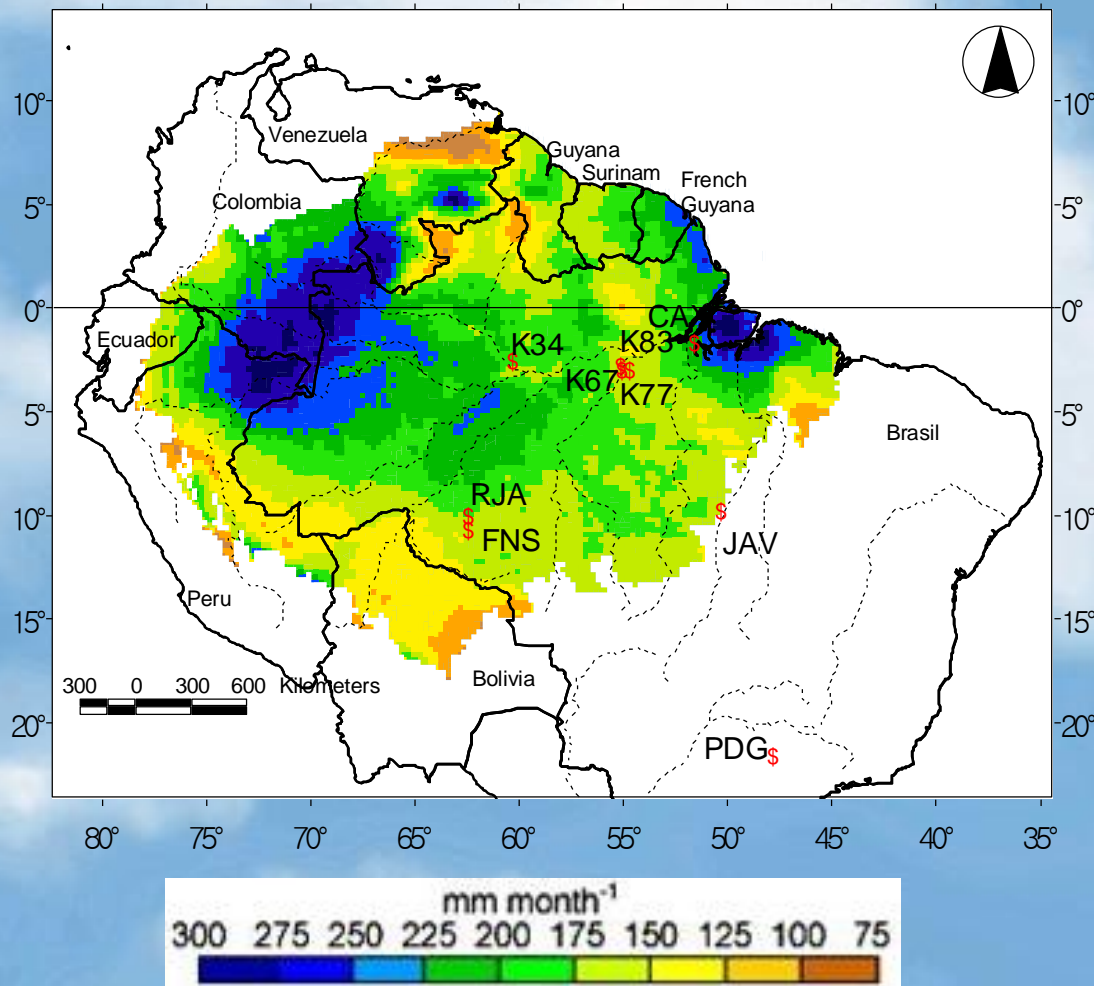
(From Clayes et al., Science)



- 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)

Amazon forest

Amazon mean annual precipitation regime



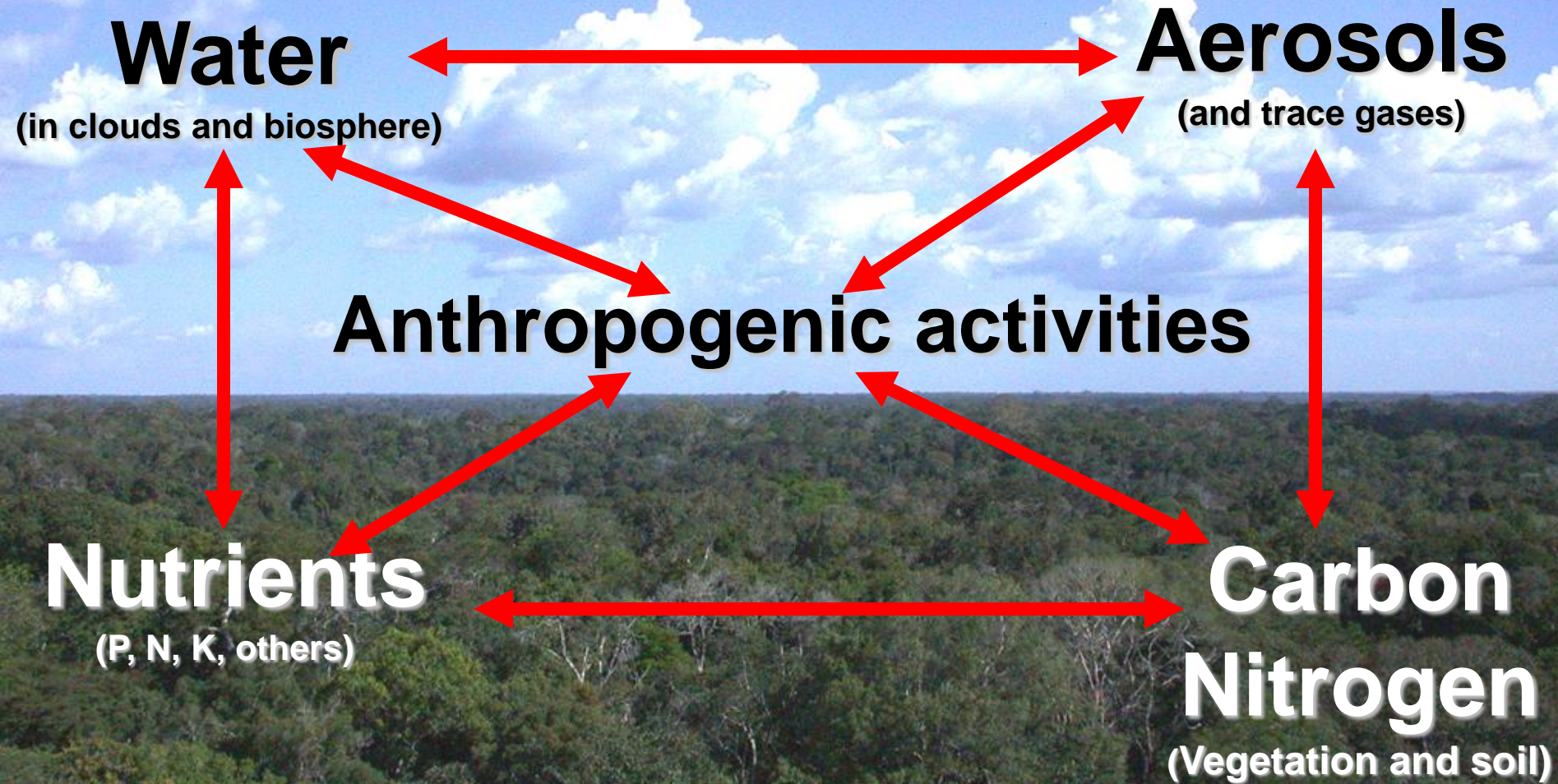
Source: TRMM satellite observations, 1998-2006

- 6 million km² (largest extant tropical forest in the world). Largest hydrological basin.
- 120 ± 30 Pg C stored in the biomass (15 years of fossil fuel emissions)
- Intact forests reportedly a sink of ≈ 0.6 Pg C yr⁻¹ (Phillips et al, 1998) (but see Clark, 2002 vs. Phillips et al., 2002; Chambers et al., 2002; Saleska et al., 2003)

- Forest metabolism provides



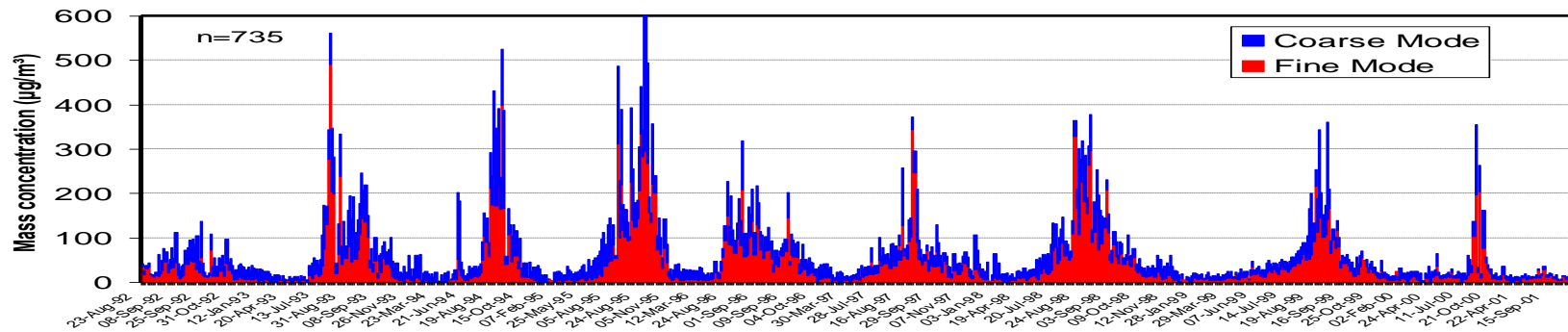
The Large Scale Biosphere Atmosphere Experiment in Amazonia - LBA



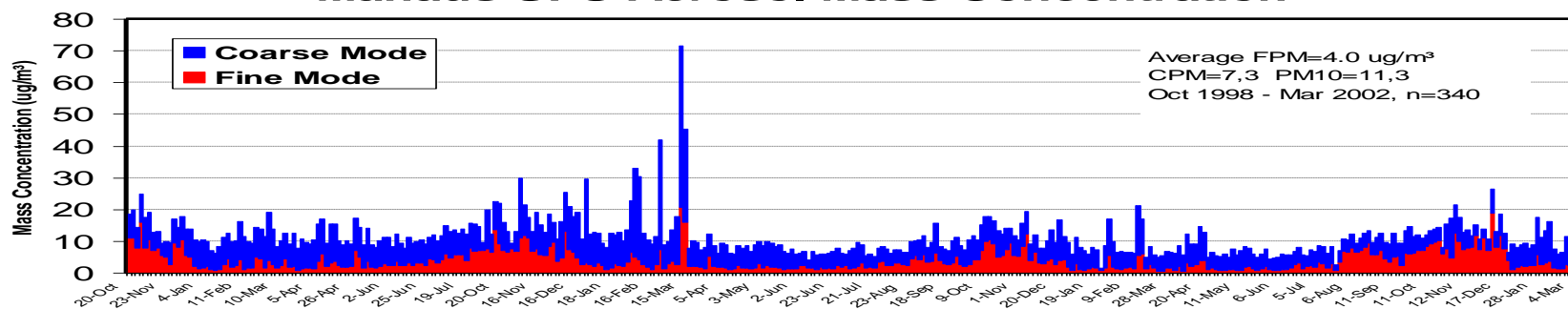


Aerosol concentration in several sites in Amazonia

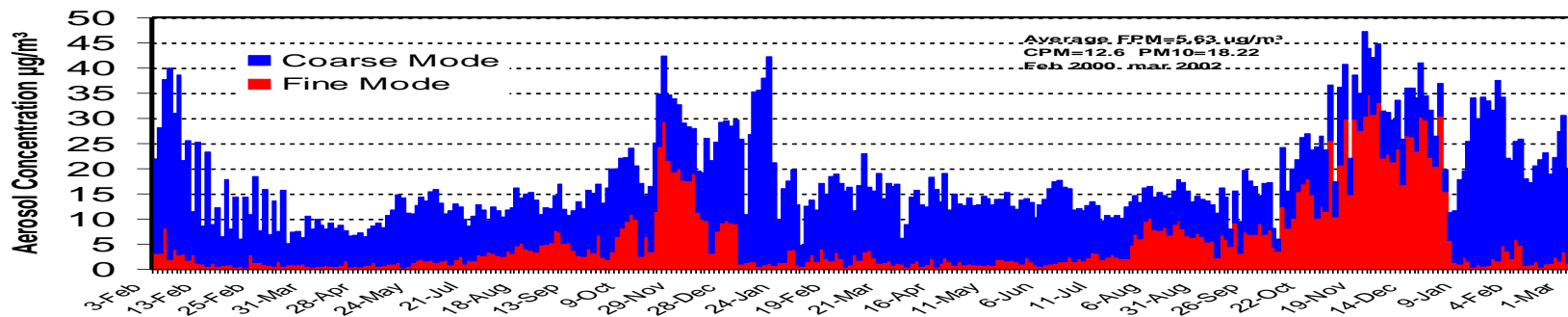
Alta Floresta Aerosol Mass Concentration 1992-2001



Manaus SFU Aerosol Mass Concentration



Santarem Aerosol Mass Concentration Feb 2000 - Mar 2002



Fire and biomass burning

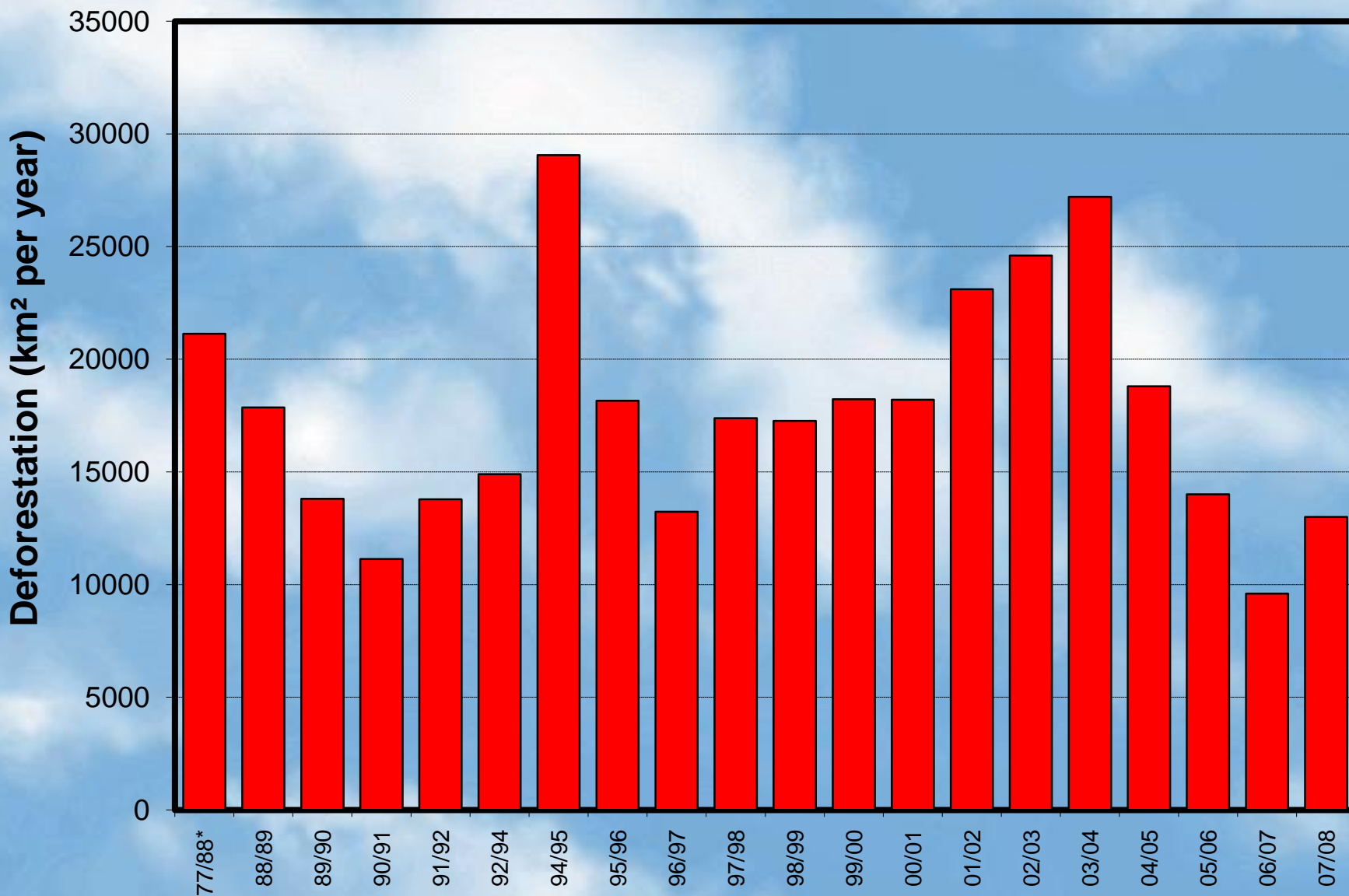


Reasons for the deforestation

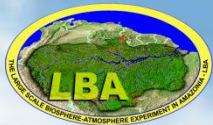




Deforestation in Amazonia 1977-2007 in km² per year

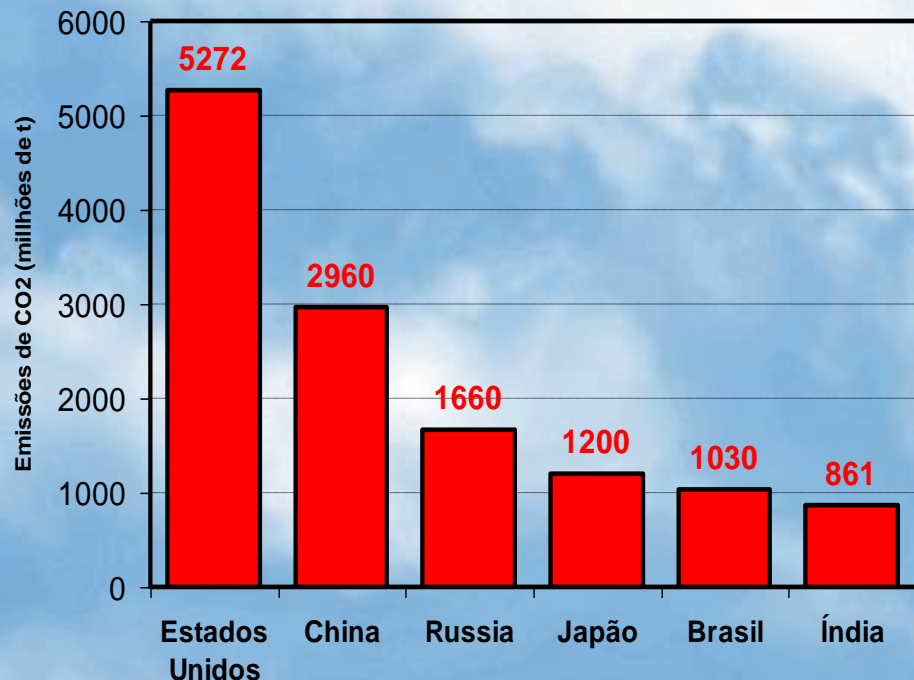


* Average for the decade



Brazil CO₂ emission inventory

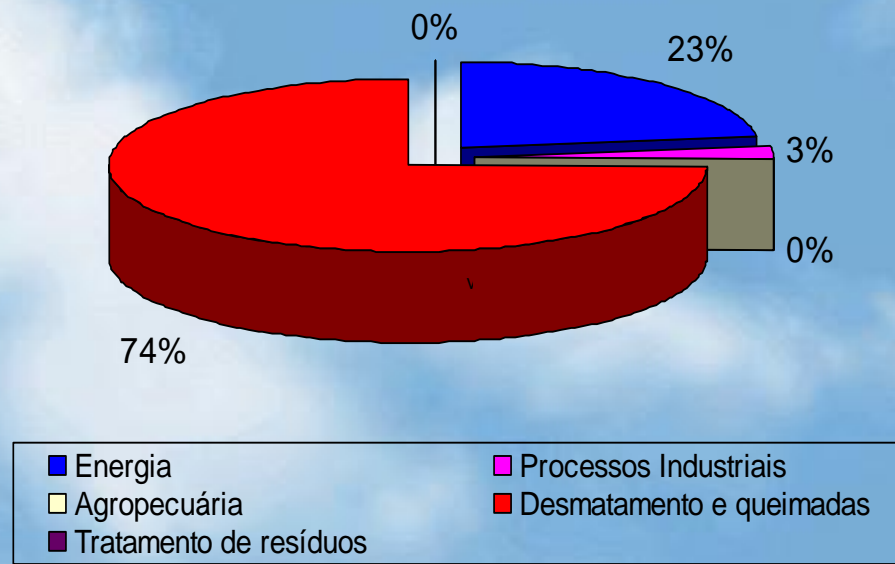
Maiores emissores globais de CO₂ em 1994



O Brasil é o quinto maior emissor mundial de CO₂ em 1994, valor que é maior em 2007.

Sem as emissões de queimadas seria o 16º

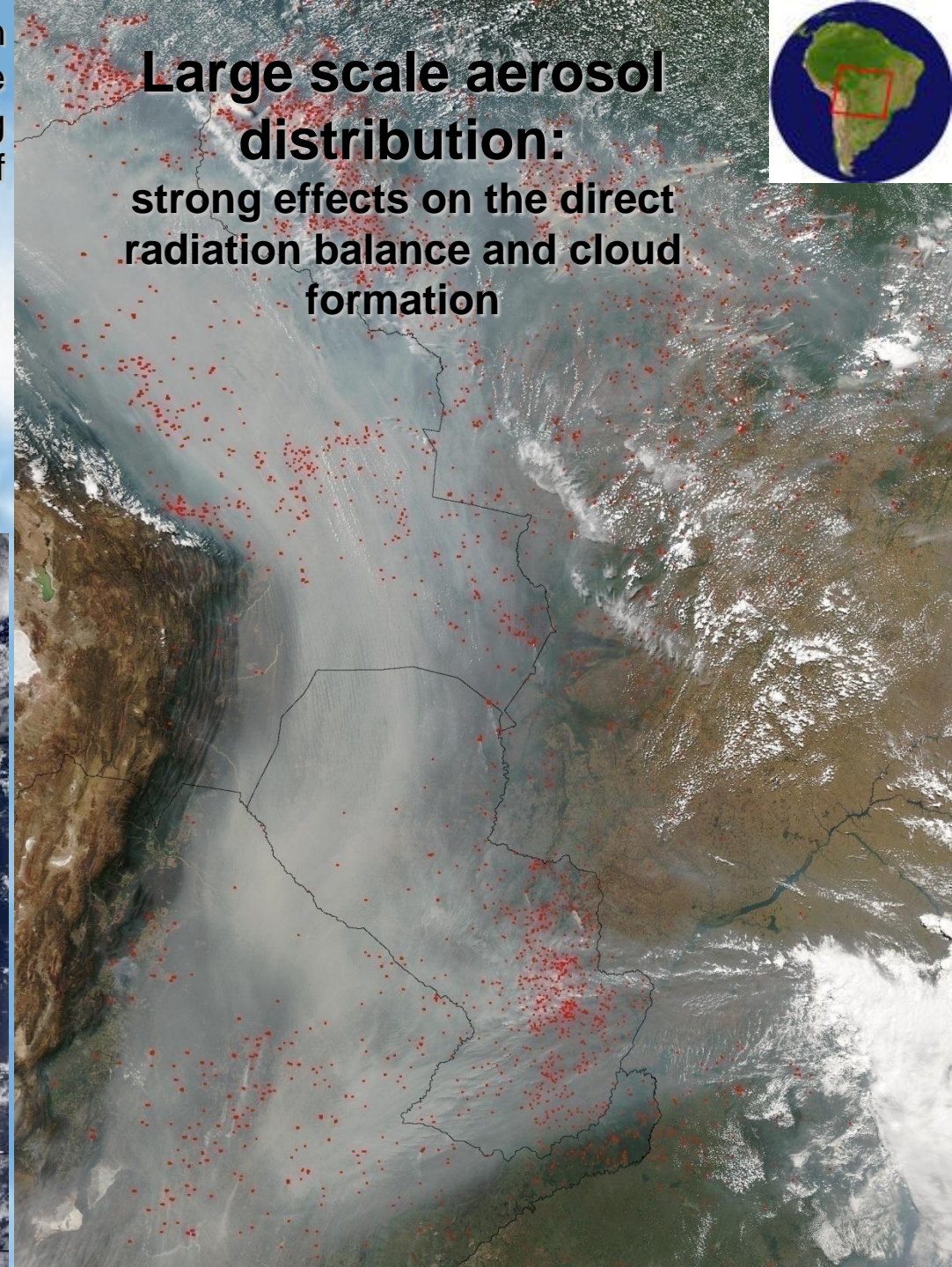
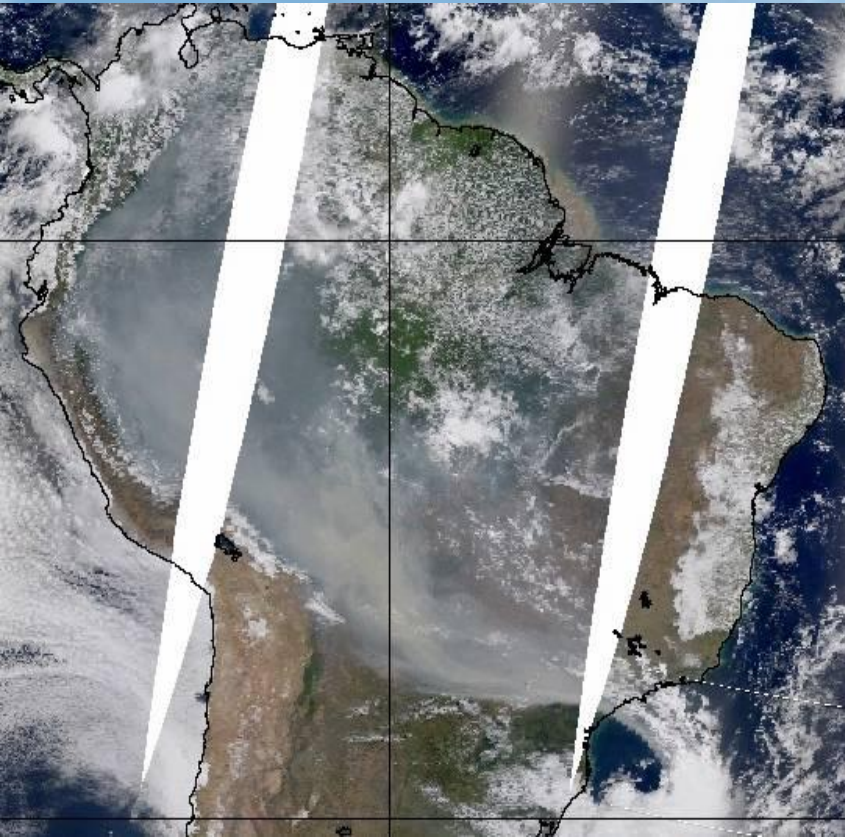
Emissão brasileira de CO₂ em 1994 por setor



A maior parte (74%) das emissões brasileiras está relacionada ao desmatamento e queimadas.

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 ...

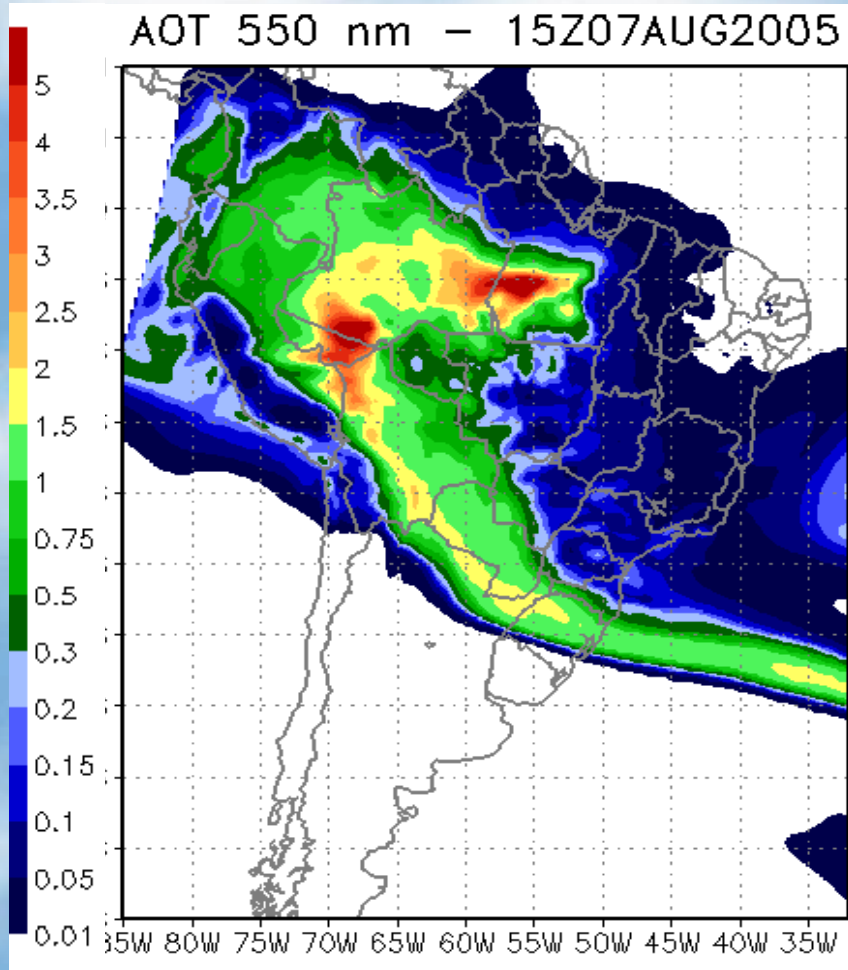
- Severe health effects on the population
- Climate effects
- Weather effects



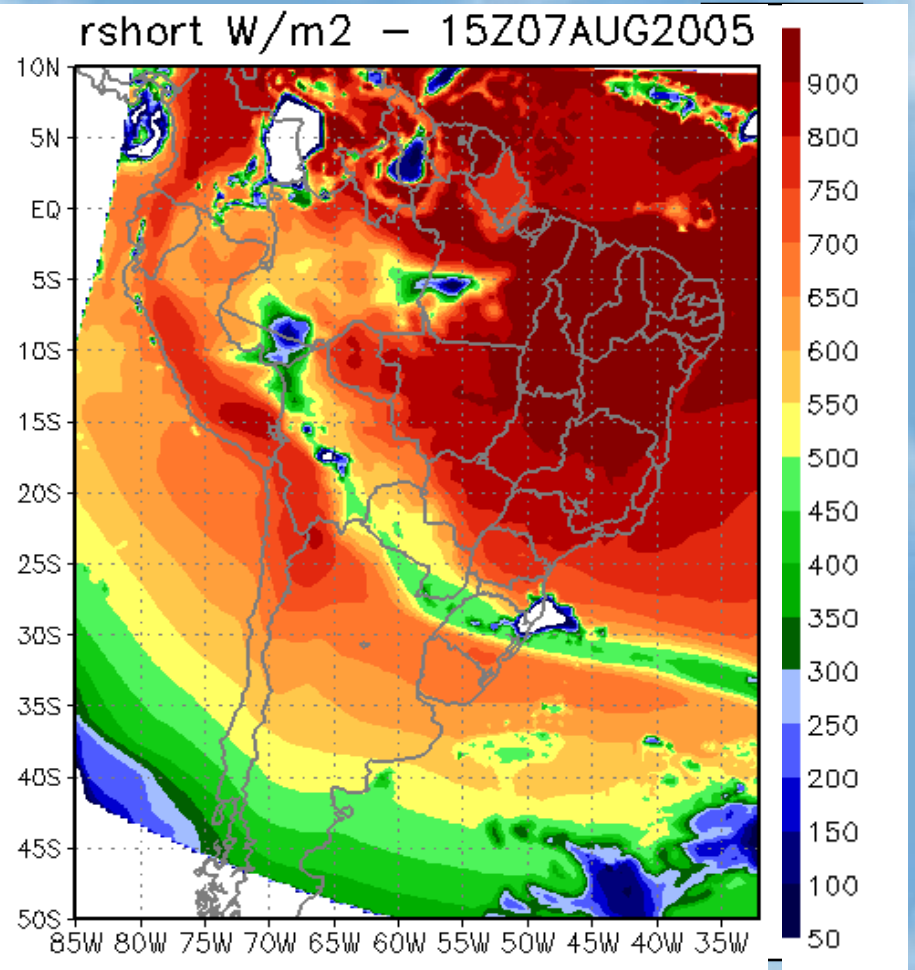
Large scale aerosol distribution:
strong effects on the direct radiation balance and cloud formation



Aerosol Optical Thickness 550 nm



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



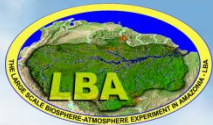
Clouds and rain are made of 3 basic ingredients:

Water Vapor

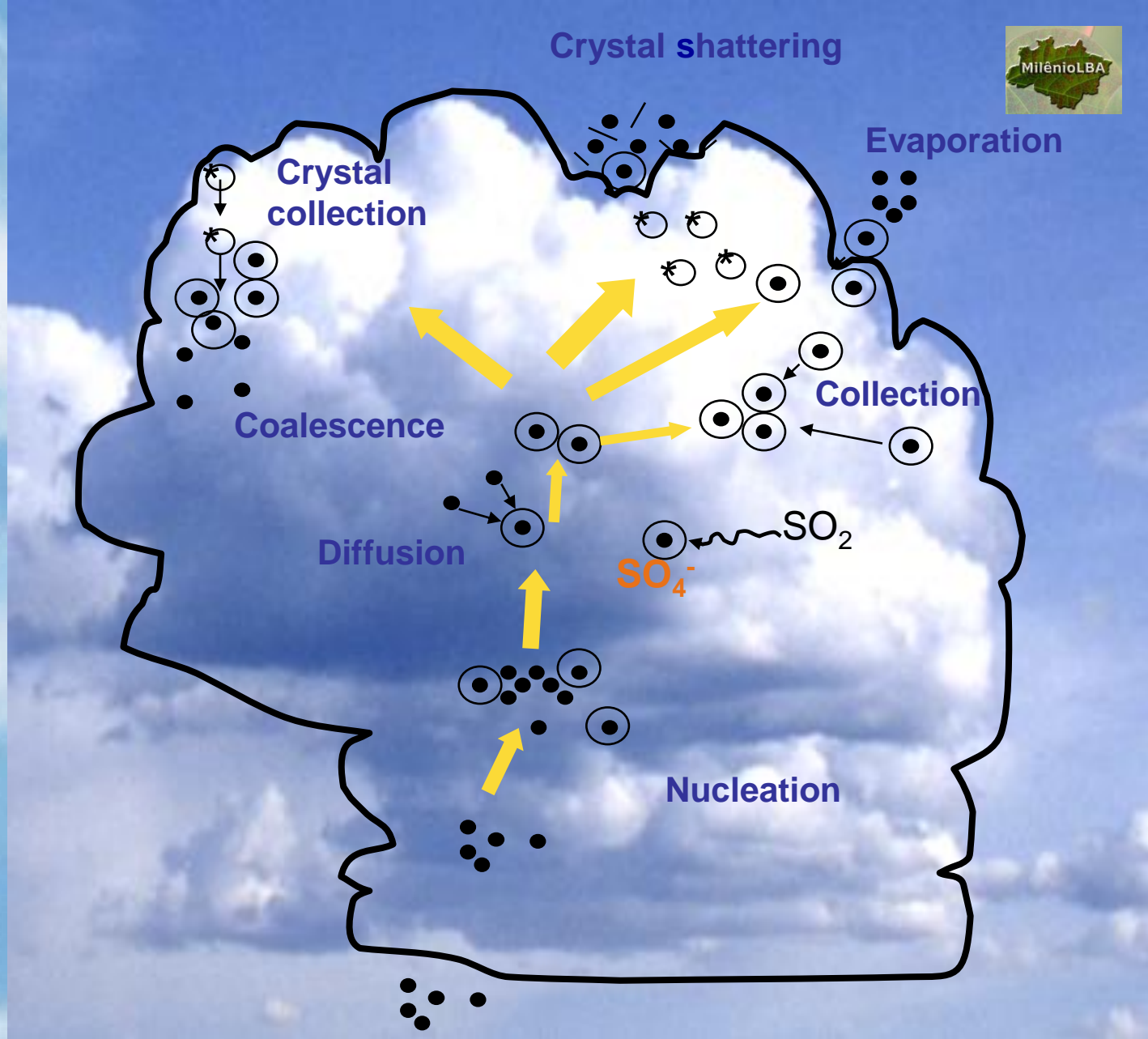
**Aerosol particle acting as a
Cloud Condensation Nuclei**

**Thermodynamic
conditions of the
atmosphere**

Highly non-linear processes



Aerosol particles, cloud condensation nuclei and precipitation

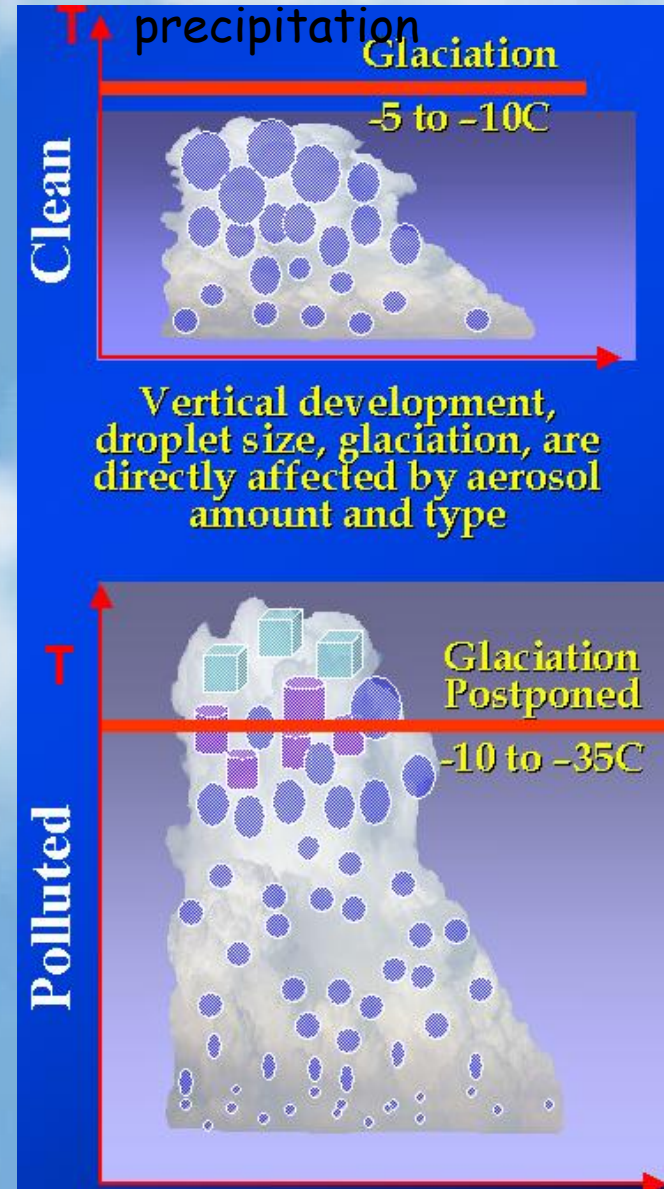
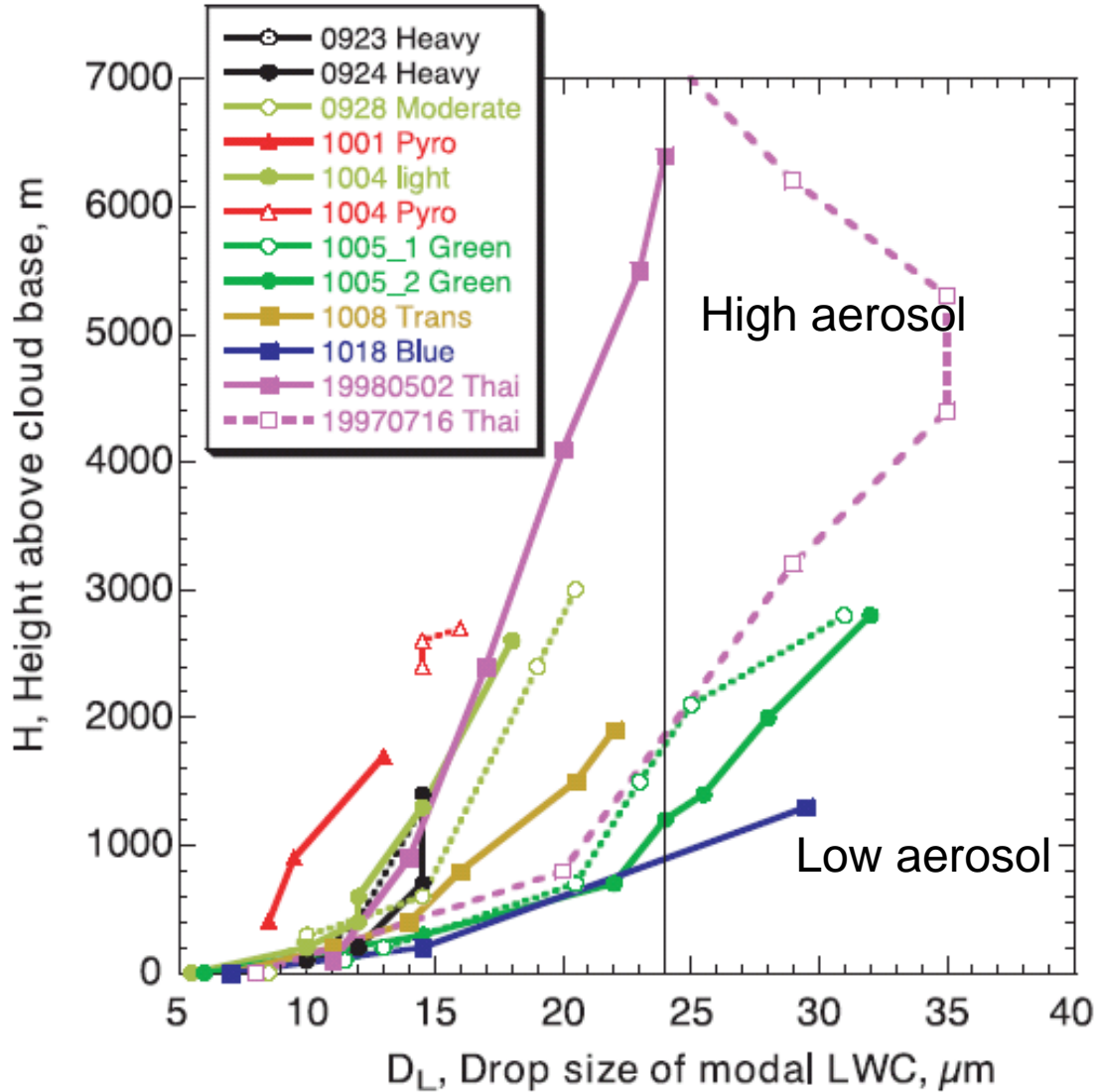


Aerosols → **Soluble: Nitrates, DON, NH_3 , NH_4^+ , etc...**



Precipitation formation

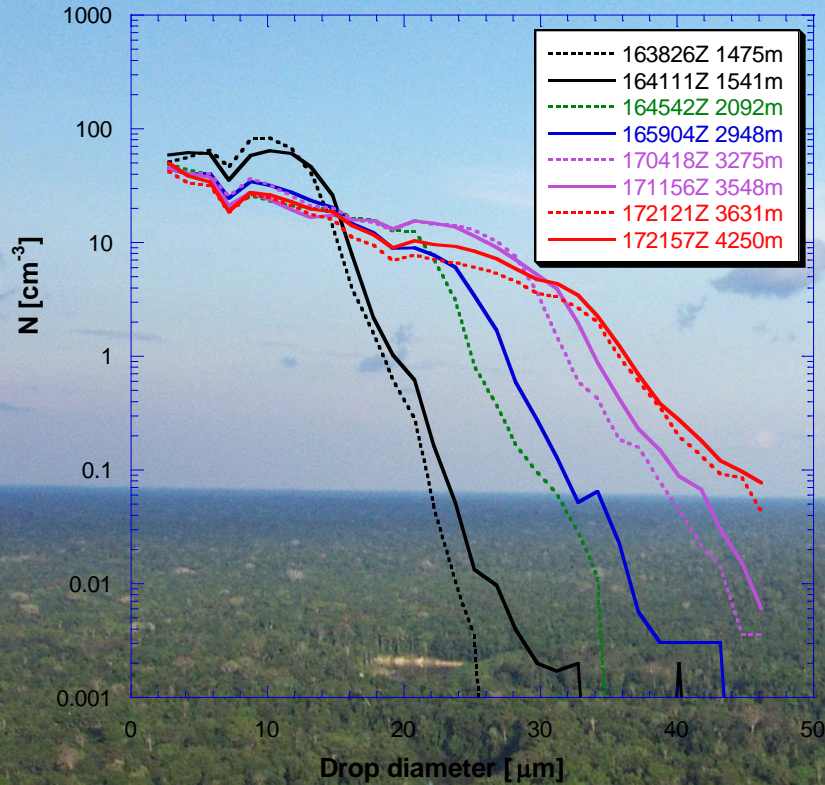
The effect of aerosol particles in the vertical profile of cloud droplets size, phase, and





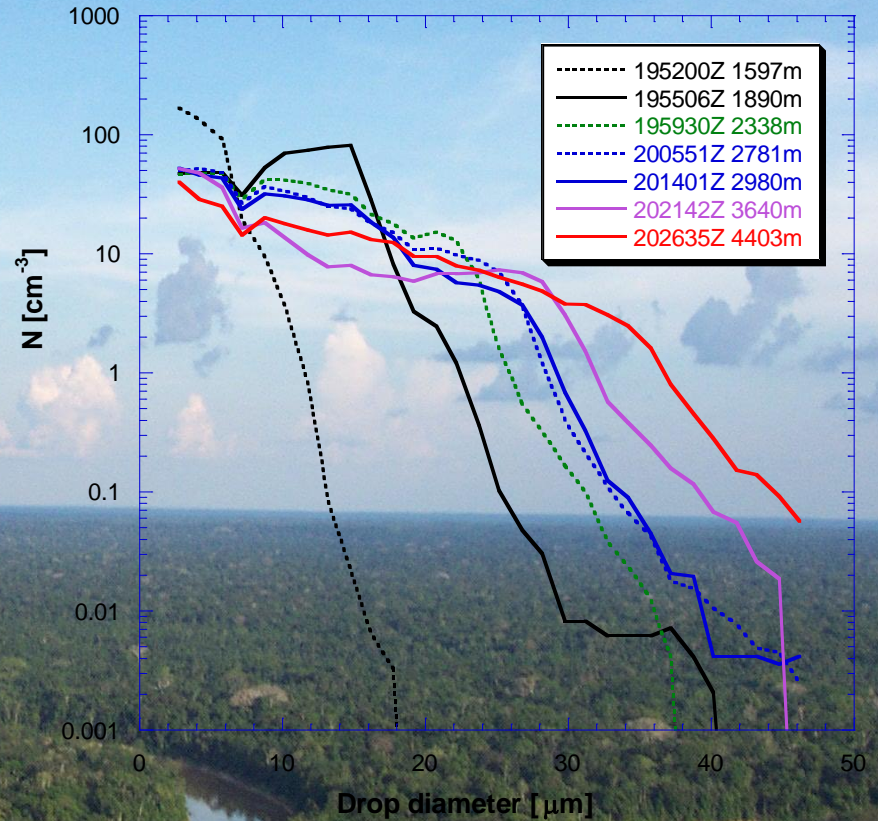
Warm rain evolution over the western tip of the Amazon, Noon.

DSD20021005_1



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

DSD20021005_2



05 10 2002 21:35

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

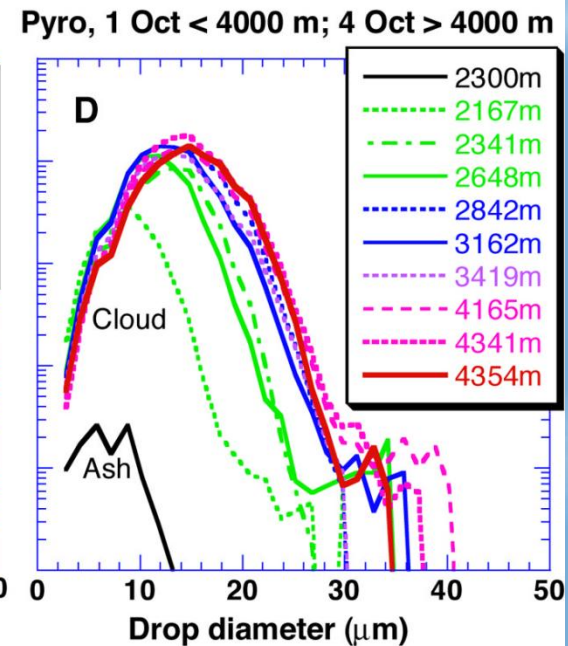
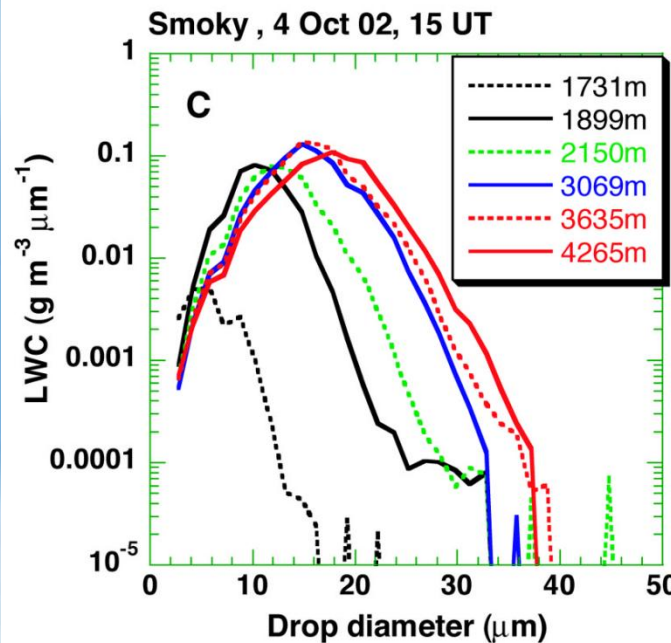
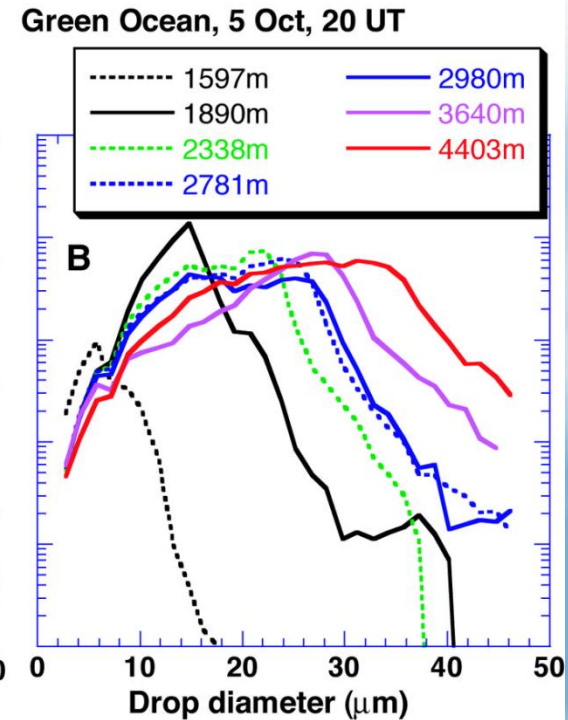
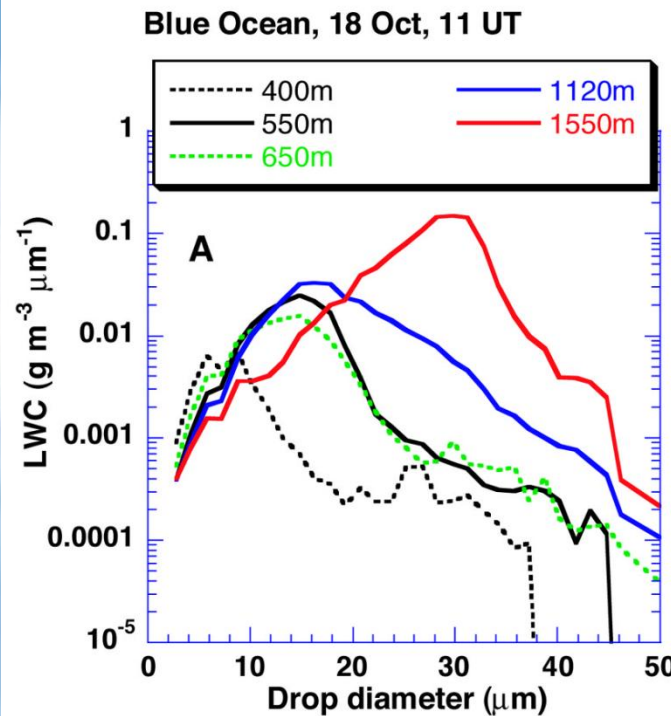


Pyrocumulus Clouds



“Green Ocean Clouds”

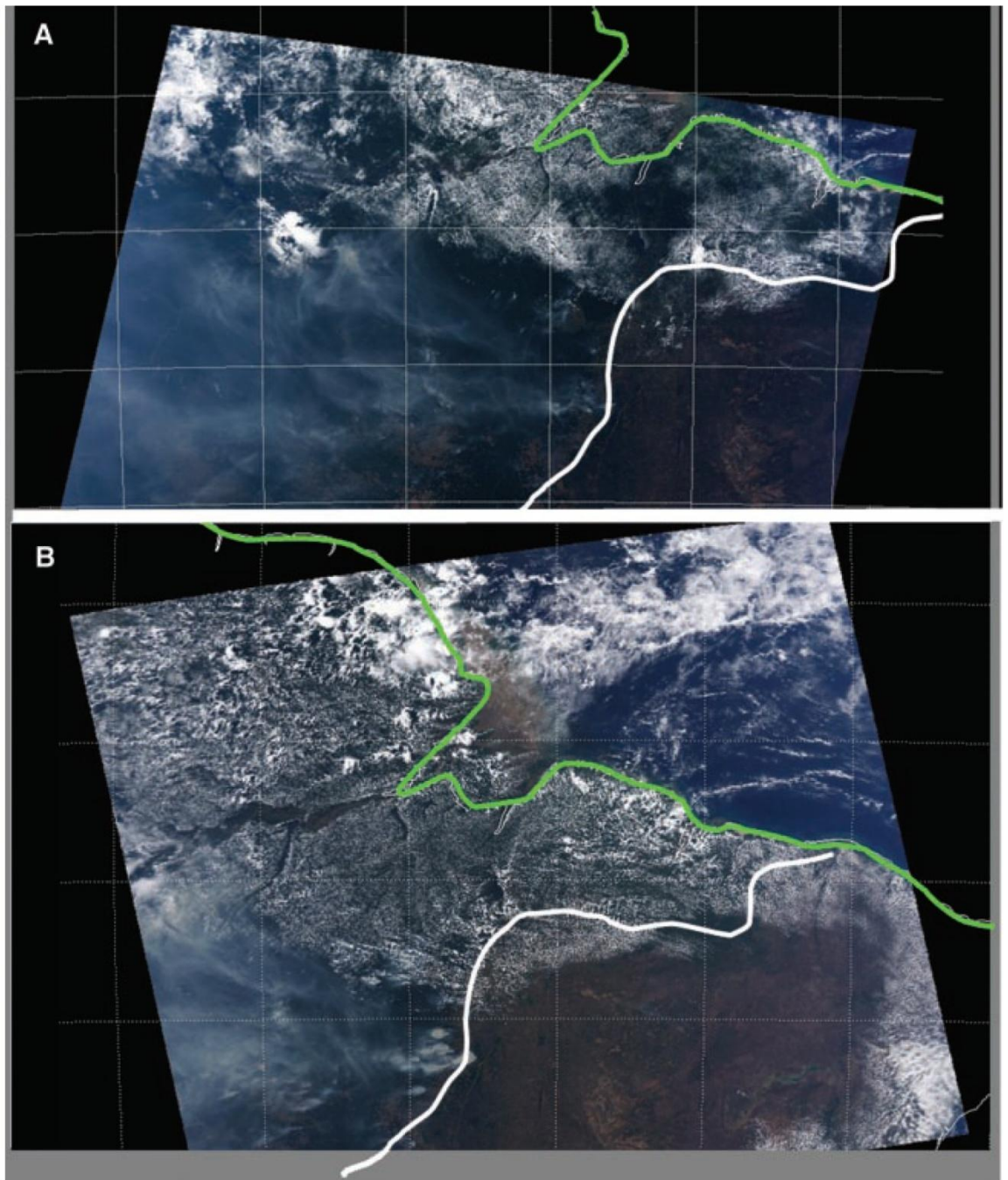
**Addition of
pyrogenic
CCN has
pronounced
impact on
cloud
droplet size
spectra!**

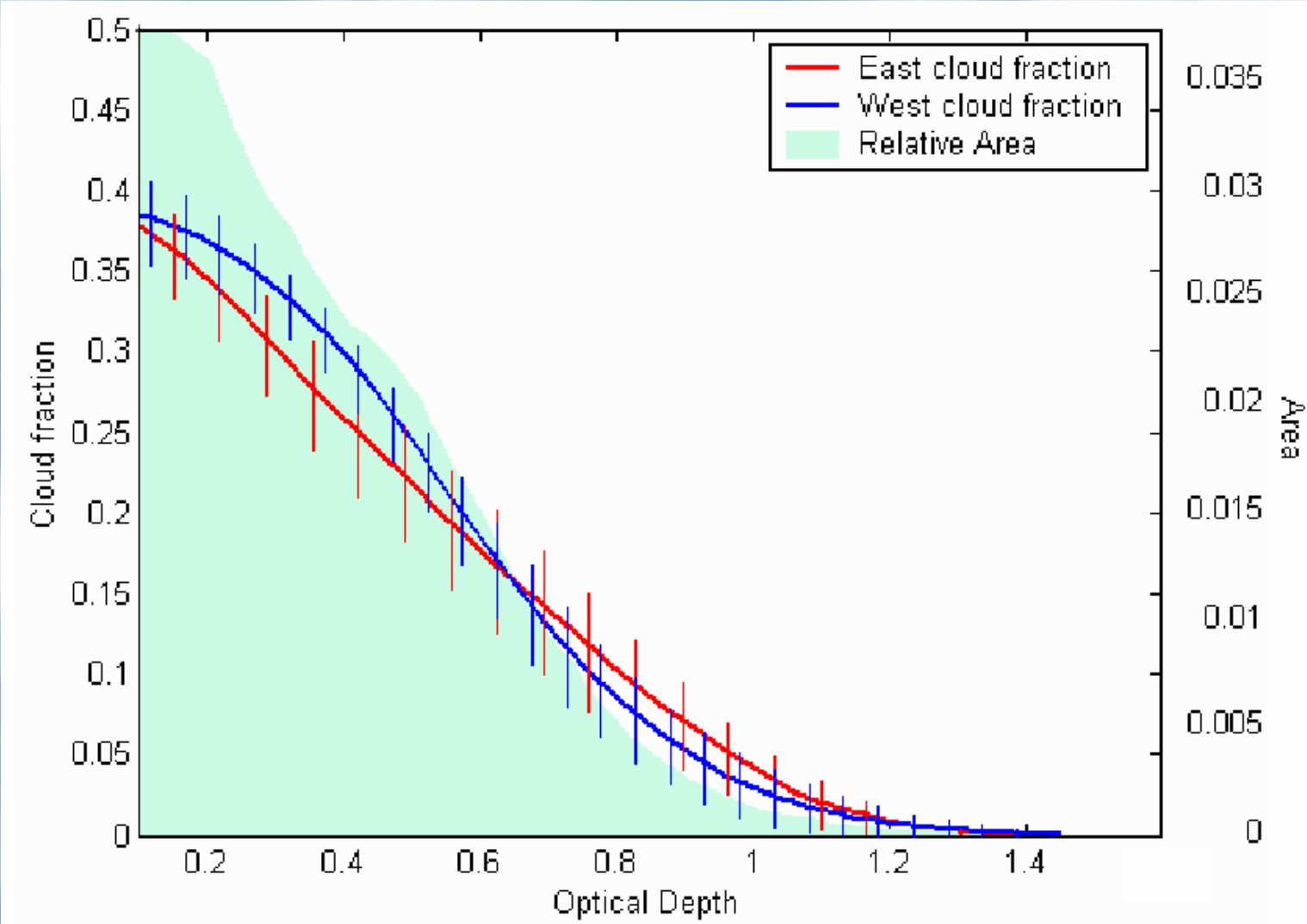




Large scale low cloud suppression by biomass burning aerosols

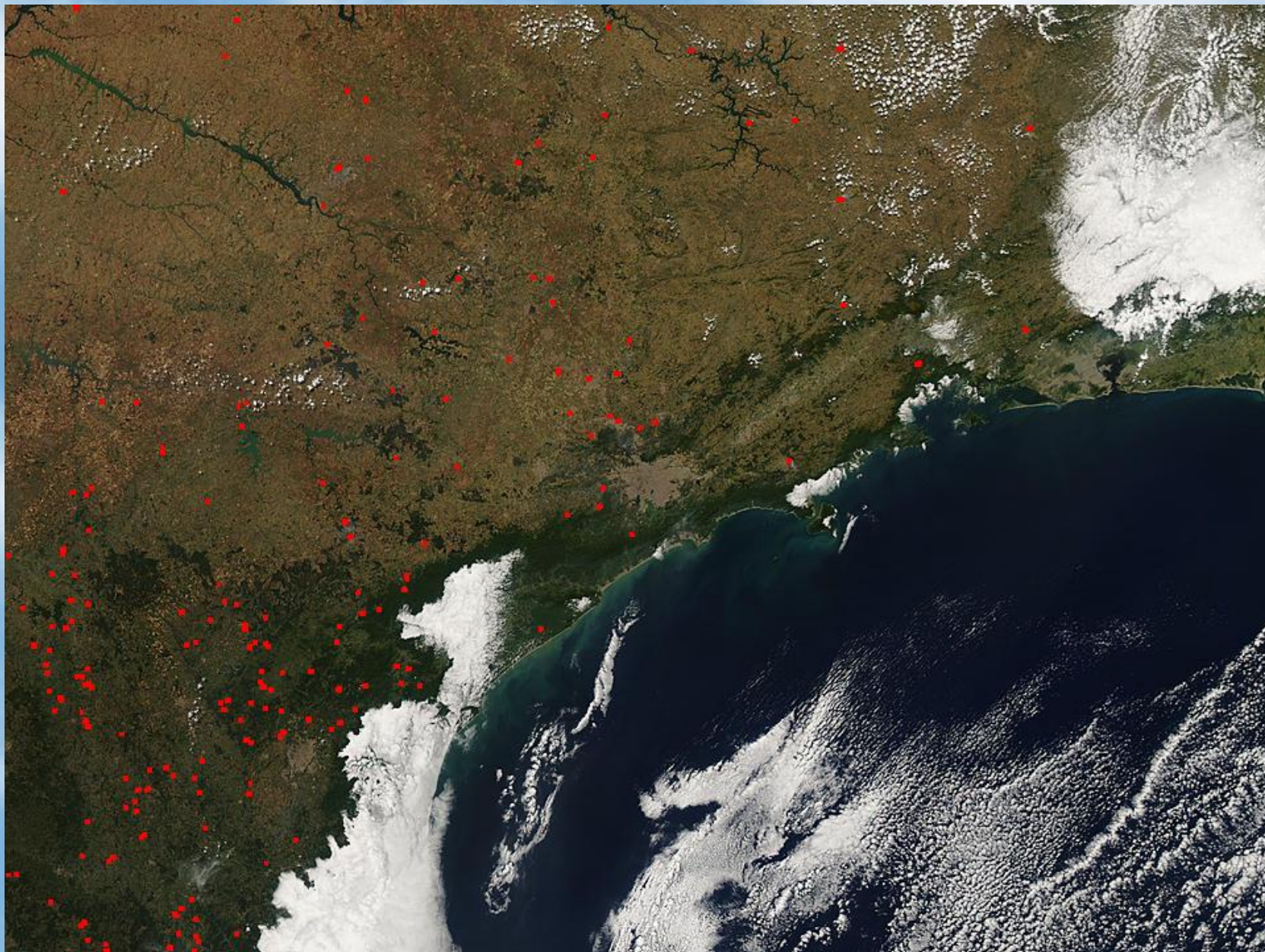
Terra and Aqua satellite images of the east Amazon basin, 11 August 2002. **(A)** The clouds (Terra, 10:00 local time) are beginning to form. **(B)** The clouds (Aqua, 13:00 local time) are fully developed and cover the whole Amazon forest except for the smoke area. The boundary between forest and Cerrado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



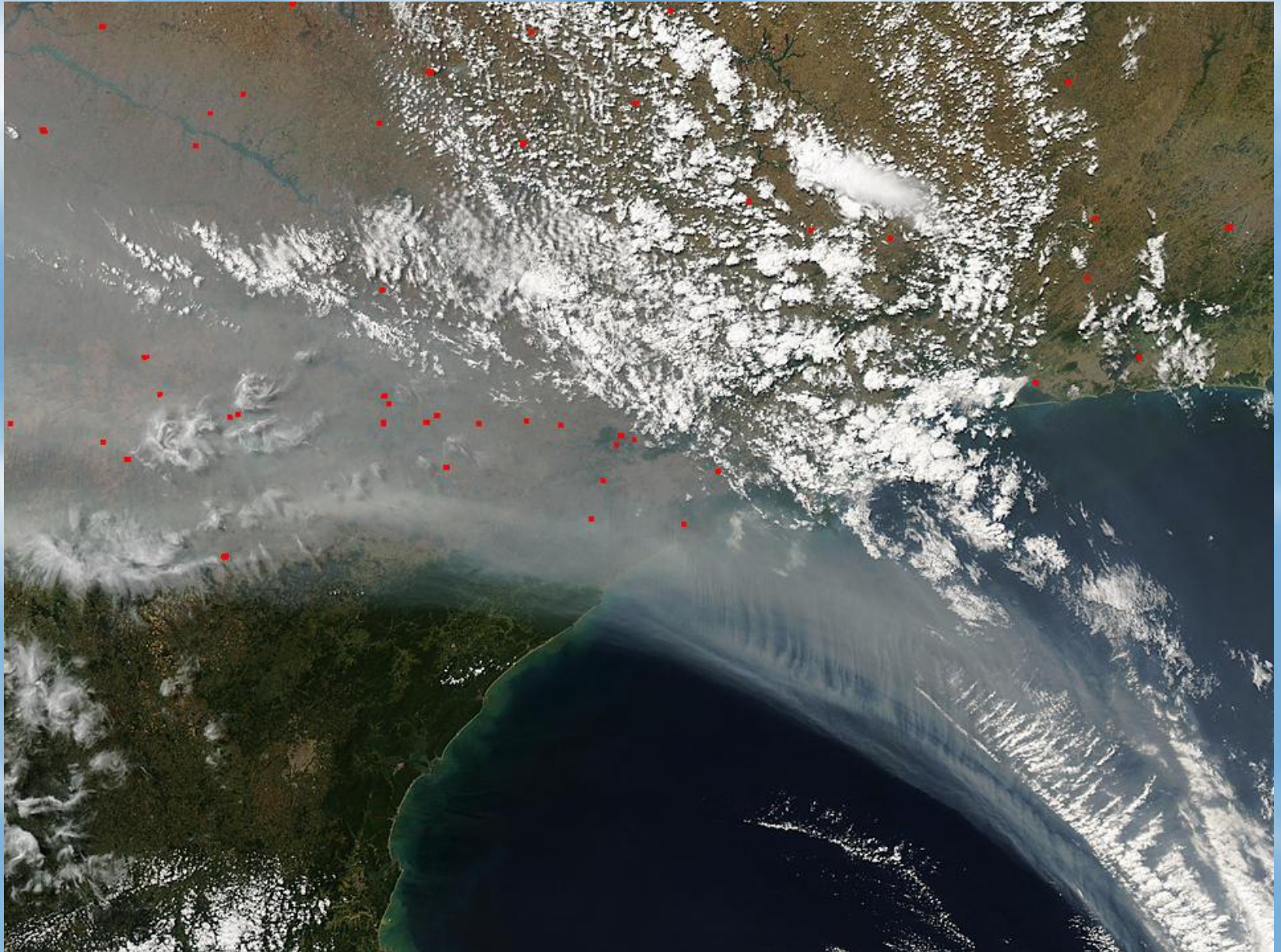


Cloud fraction as function of aerosol optical depth (OD). The cloud fraction decreases almost linearly with increasing OD. The red and blue curves denote the average of east and west areas, respectively. On average, the cloud fraction decreases to less than 1/8 of the cloud fraction in clean conditions 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)

São Paulo – 06 de setembro de 2004



São Paulo – 15 de setembro de 2004





Mudanças no albedo de superfície e fluxos influenciam a dinâmica de nuvens



30 09 2002 17:33