Global Climate Modeling: The Challenge to Create a World-Class Model in Brazil

Paulo Nobre[2,1], José P. Bonatti[2], Chou S. Chan[2,1], Marcos Costa[3], Saulo Freitas[2,1], José Marengo[1], Karla Longo[1], Gilvan Sampaio[1], Carlos A. Nobre[1,4]

[1]Center for Earth System Science
[2]Center for Weather Forecasts and Climate Studies
National Institute for Space Research – INPE, Brazil

[3]Federal University of Viçosa

[4]Presenter

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Framing the Challenge …

1. Do we have a track record of experience to embark upon the development of a world-class global climate system model?
2. Do we have a robust strategy, a road-map to reach the goal and sufficient expertise to carry it out to completion?
3. Do we have adequate infra-structure for global climate system modeling?

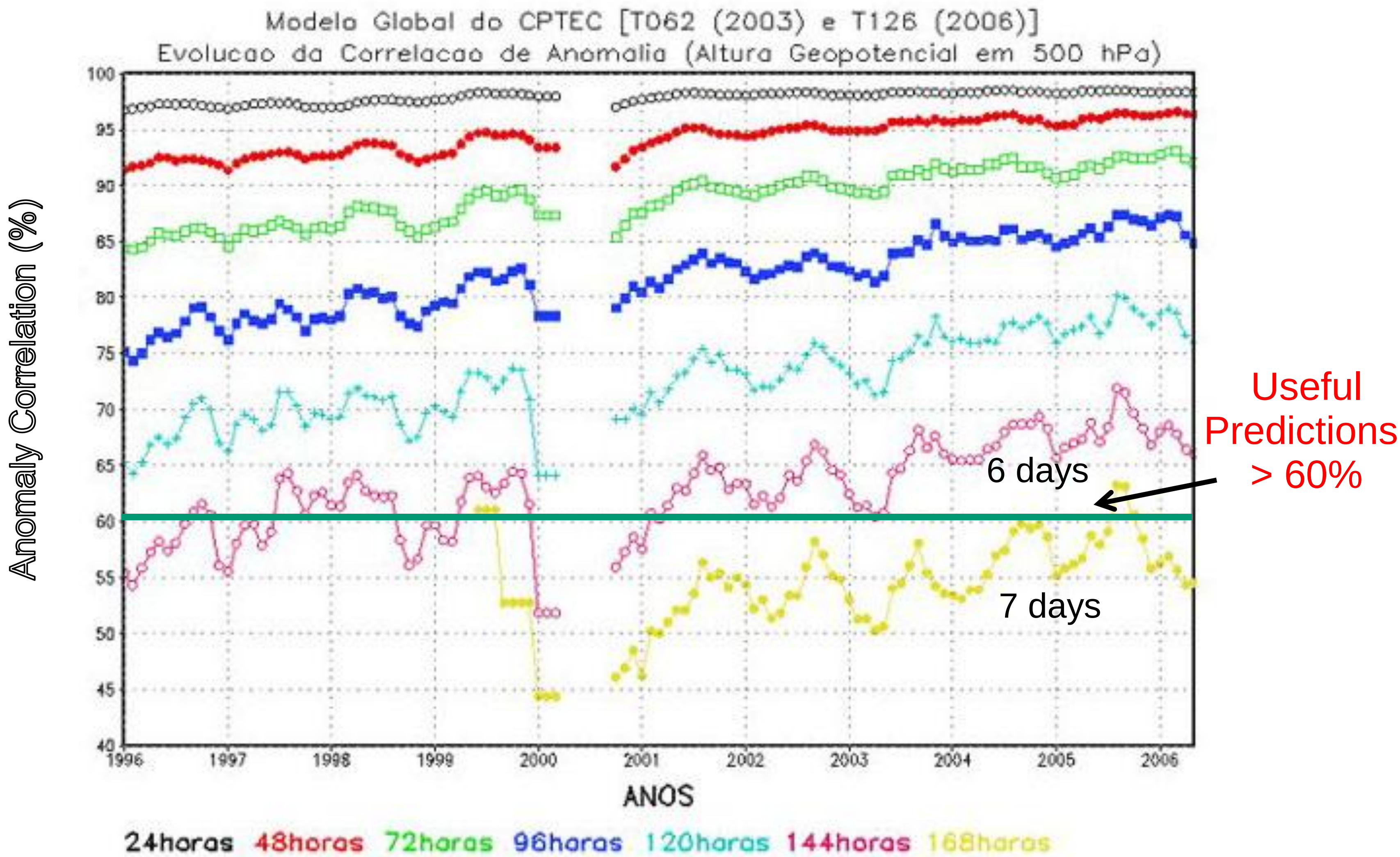
Outline …

- What we have accomplished in Numerical Weather Prediction (NWP), Numerical Seasonal Climate Prediction (NSCP), Regional Climate Change Modeling, and Air Quality Prediction at INPE
- Development of the Brazilian Model of the Global Climate System (BMGCS):
  - HadGEM: Comparison to a World-Class Model
  - What are MBSCG unique contributions in each component model
- Infra-structure and why we need big computers
- International Collaboration and South - South Cooperation: capacity building, human resources, ‘peopleware’

INPE innovated in meteorological and climate science in Brazil

15 years of experience in developing Numerical Weather Prediction (NWP), Numerical Seasonal Climate Prediction (NSCP), Regional Climate Change Modeling, Air Quality Prediction at INPE, and climate modeling in general

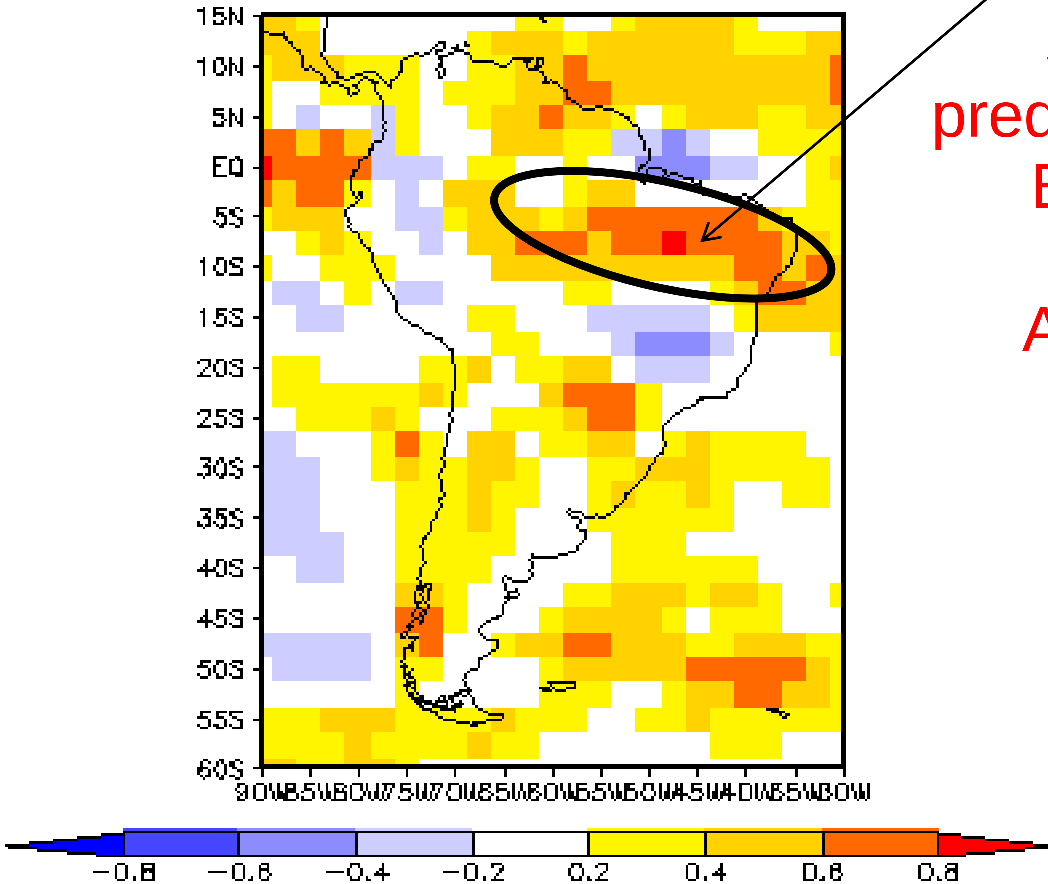
CPTEC's NWP forecast Skill Historical Evolution



Seasonal Climate Prediction at INPE: Timeline

- 1987 – Conceptual Prediction of northern Nordeste MAM Precipitation Anomalies: ENSO, Atlantic Dipole, NAO…
- 1995 – CPTEC/COLA T62L28 AGCM's 5 member ensembles: additional element to the consensus prediction (persisted SSTA globally).
- 1997 – CCA statistical prediction for tropical Atlantic SSTA and NCEP coupled prediction for the Pacific.
- 1998 – 25 members ensembles using persisted and predicted SST.
- 2000 – Use single integration of Eta regional model extended runs 3 months
- 2003 – F77 CPTEC/COLA AGCM replaced by F90 CPTEC V2.0 AGCM
- 2008 – Use of CPTEC coupled GCM to predict ENSO

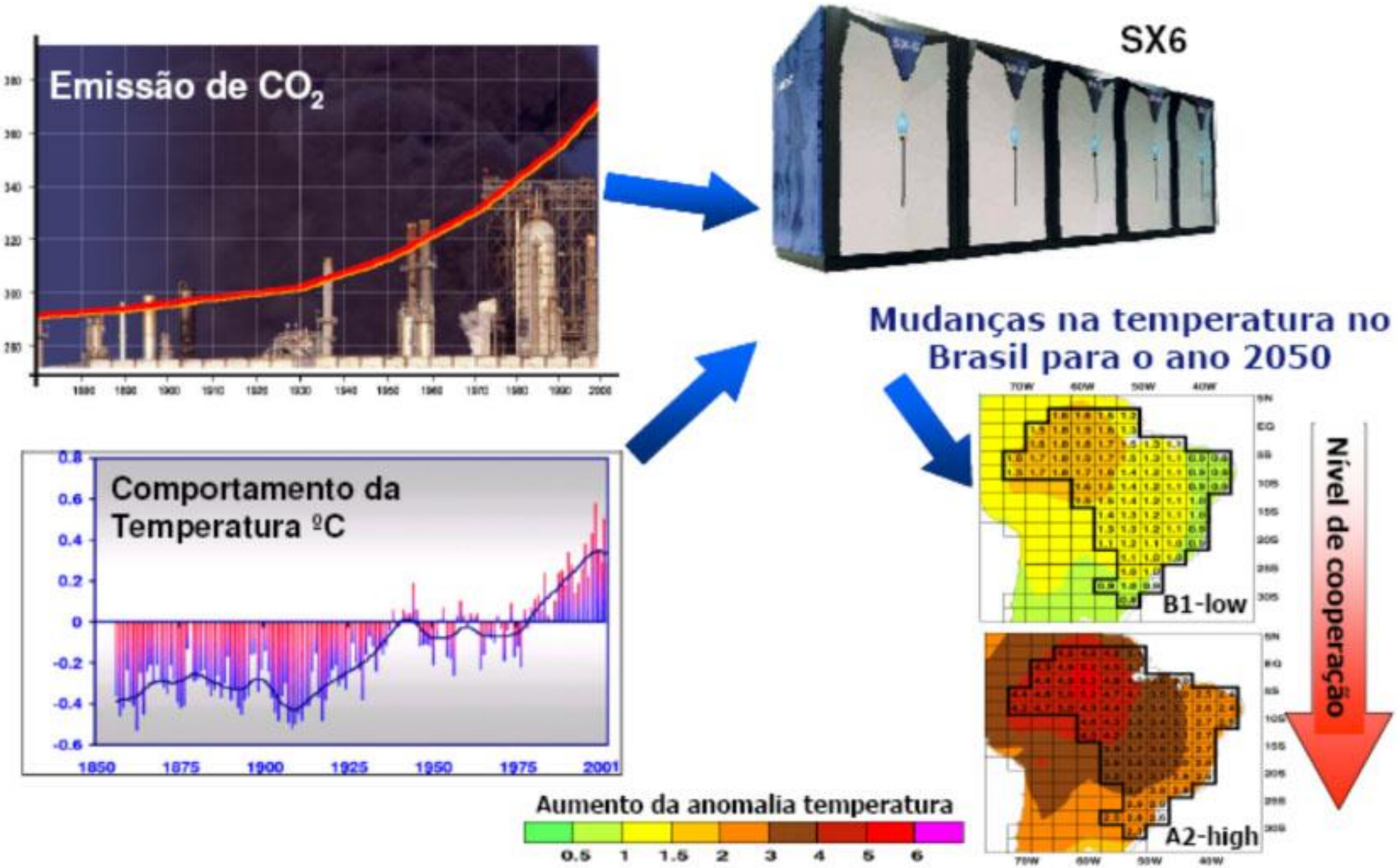
CPTEC AGCM (Kuo)
AMJ Seasonal Precipitation Forecast Skill



Very good seasonal predictions in NE Brazil and Eastern Amazonia!

Courtesy: C. Coelho, INPE/CPTEC

CCST's Regional Climate Change Modeling and Scenarios



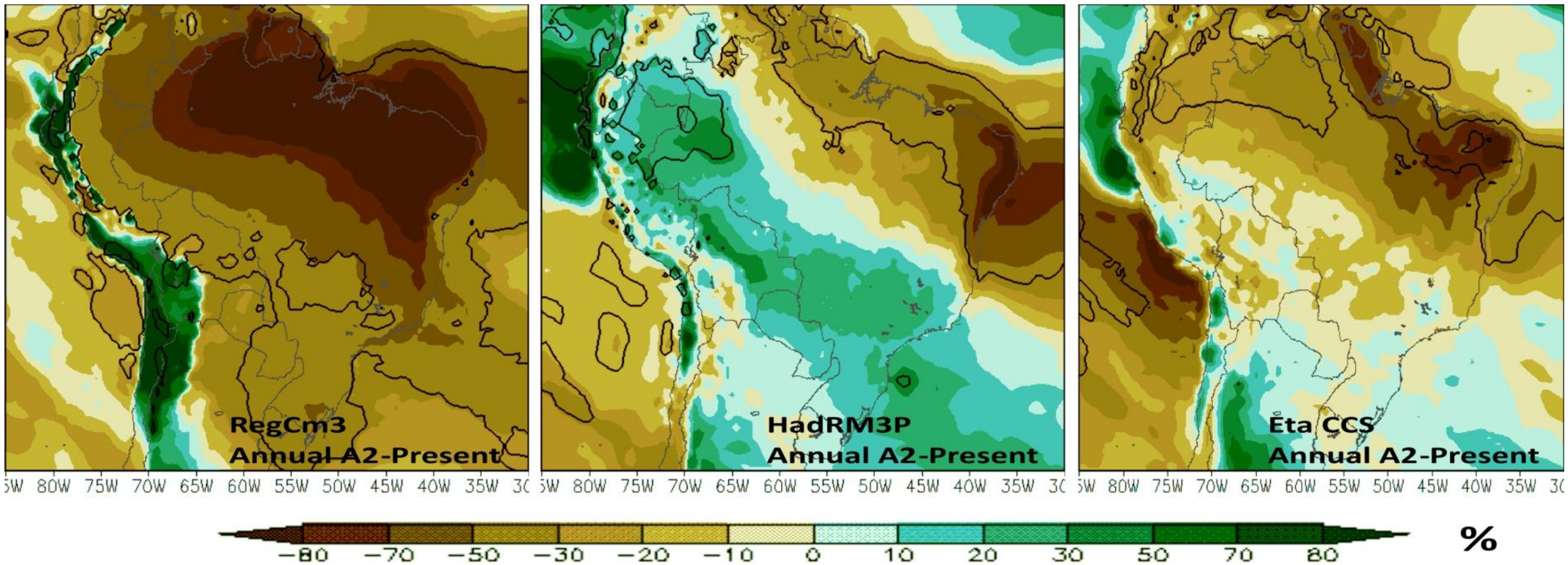
Coordinator: Dr. J. Marengo

MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

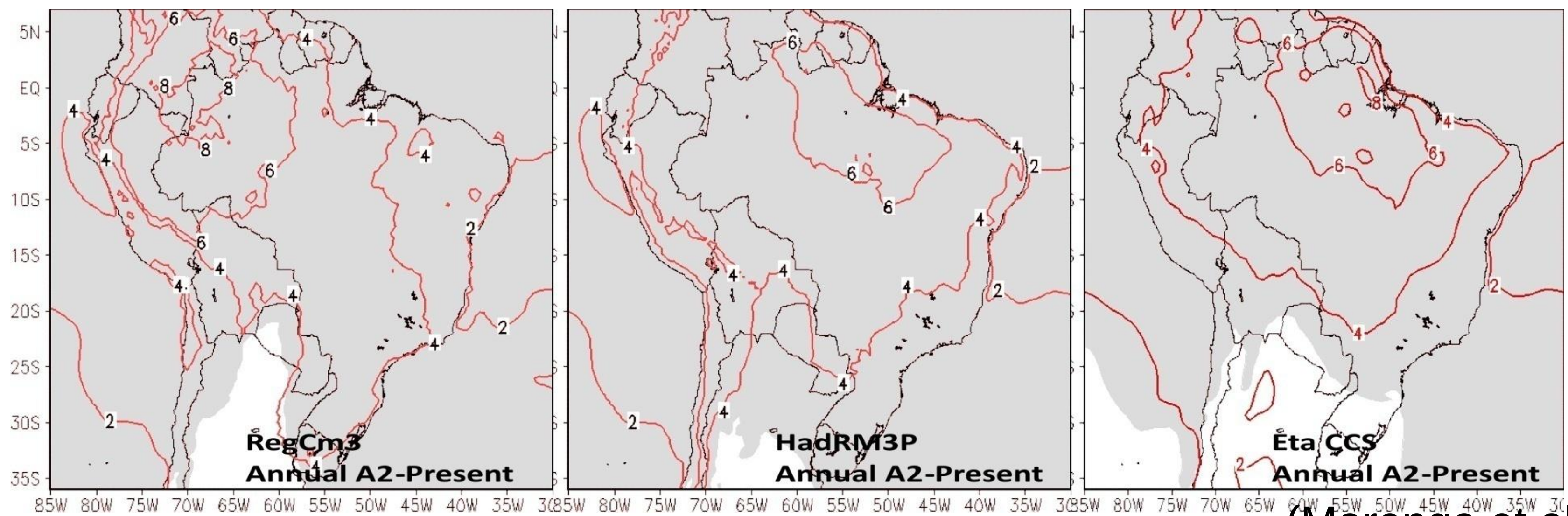
Ministério da Ciência e Tecnologia

BRASIL UM PAÍS DE TODOS GOVERNO FEDERAL

Rainfall changes (%) 2071-2100 relative to 1961-90, A2

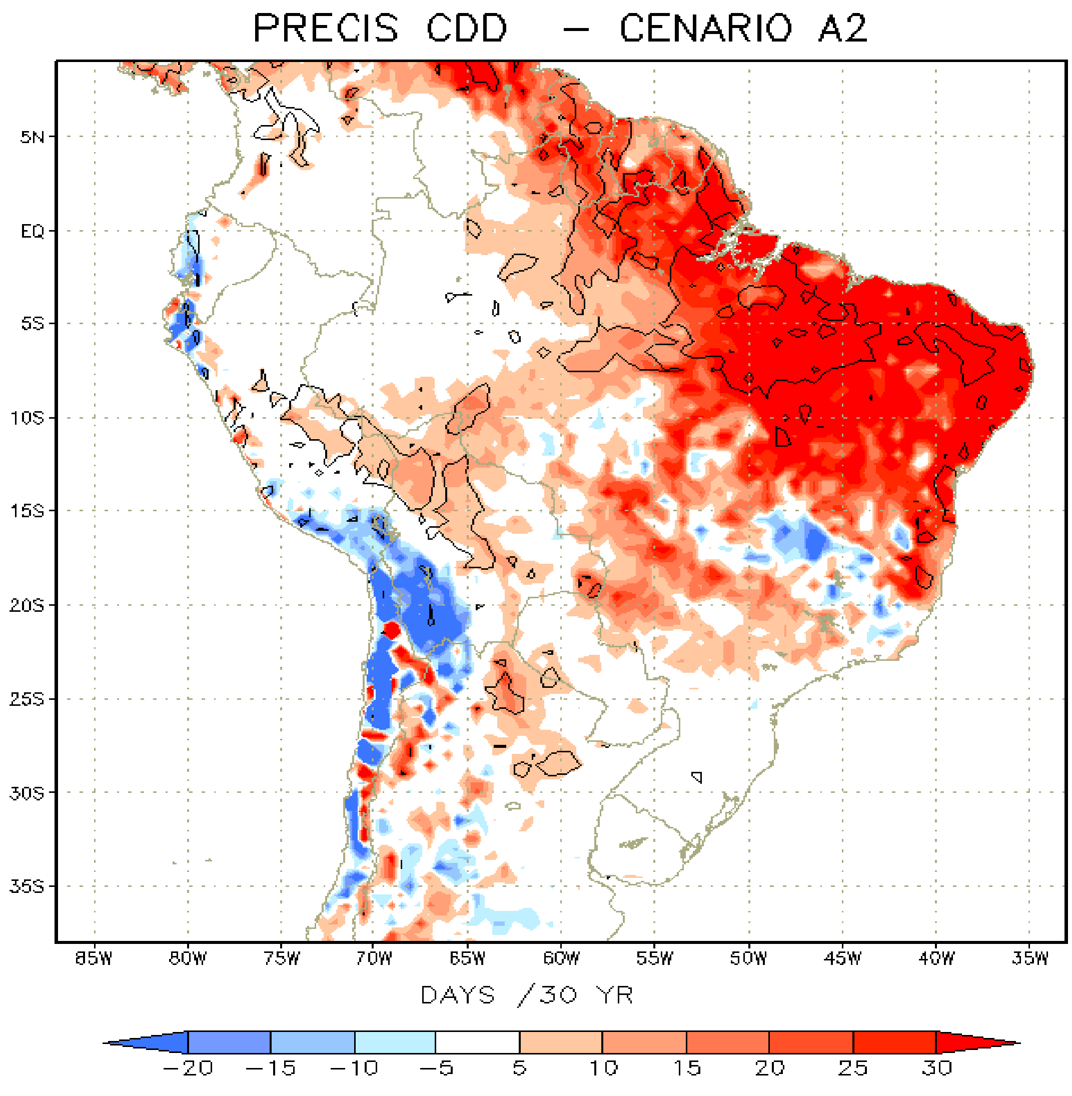


Temperature changes © 2071-2100 relative to 1961-90, A2



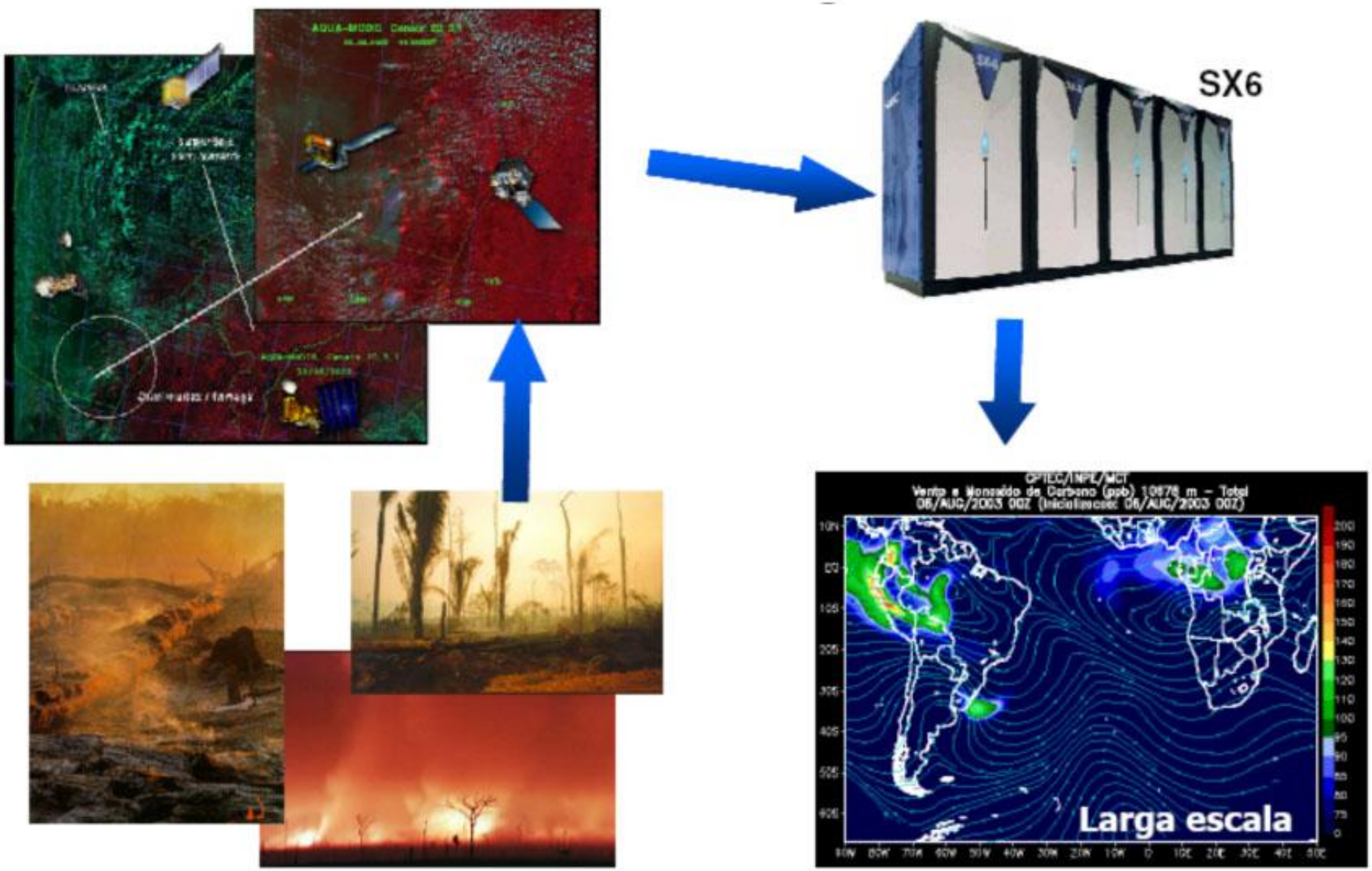
(Marengo et al 2009)

Projections of Consecutive Dry Days (CDD) simulated by the Regional Model (2071-2100)



(Marengo et al 2007)

INPE's Vegetation Fire Monitoring and Air Quality Prediction

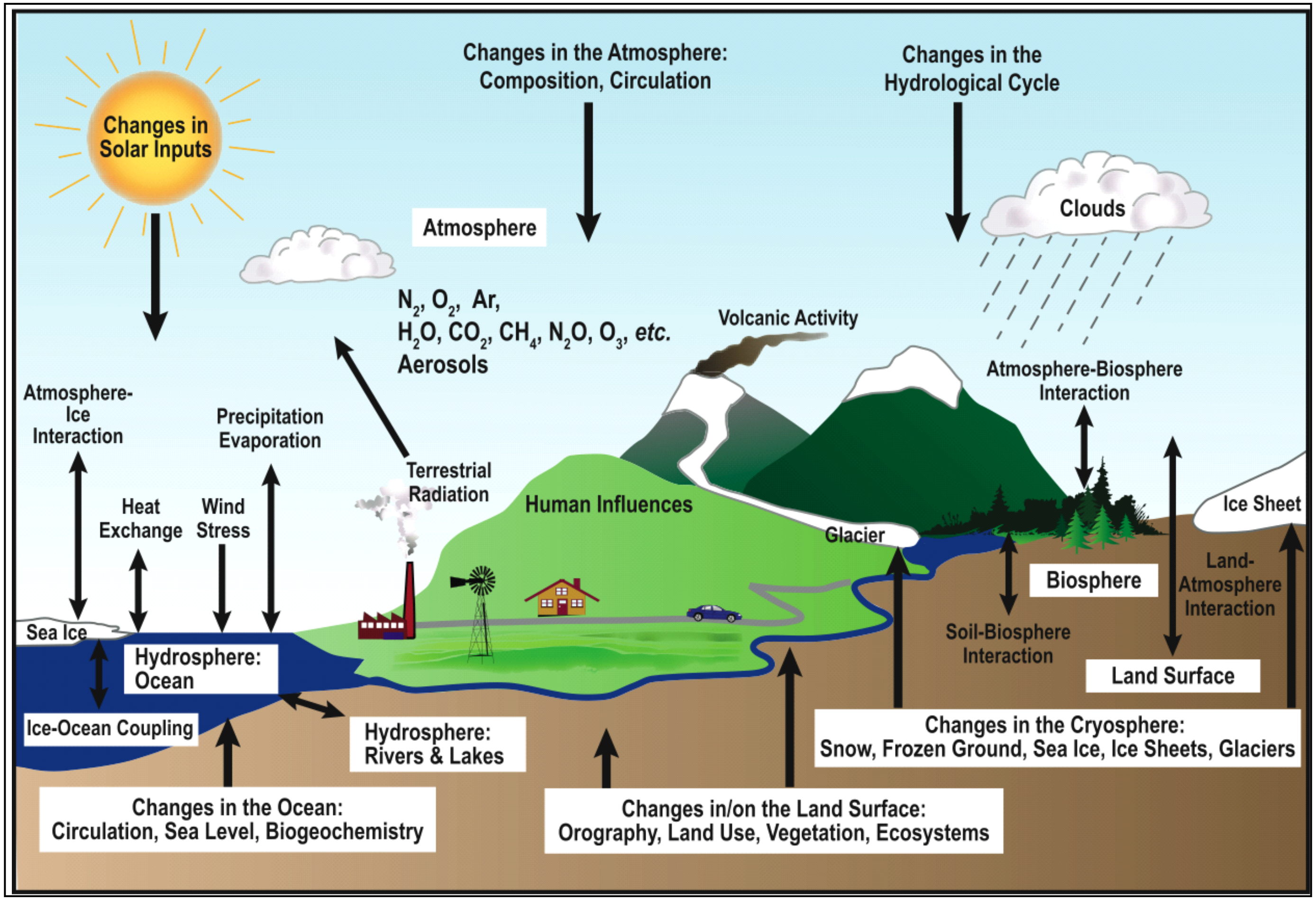


Coordinators: Dr Karla Longo and Dr. Saulo Freitas

INPE moves into climate change research

Road-map to the development of the Brazilian Model of the Global Climate System (BMGCS)

The climate system

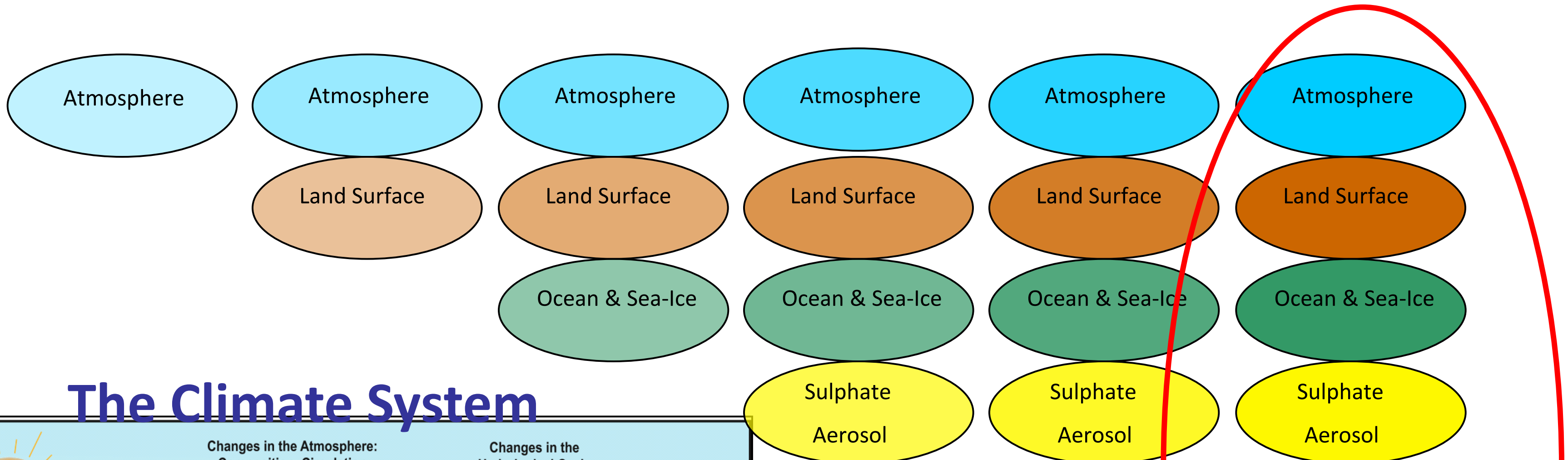


IPCC (2007)

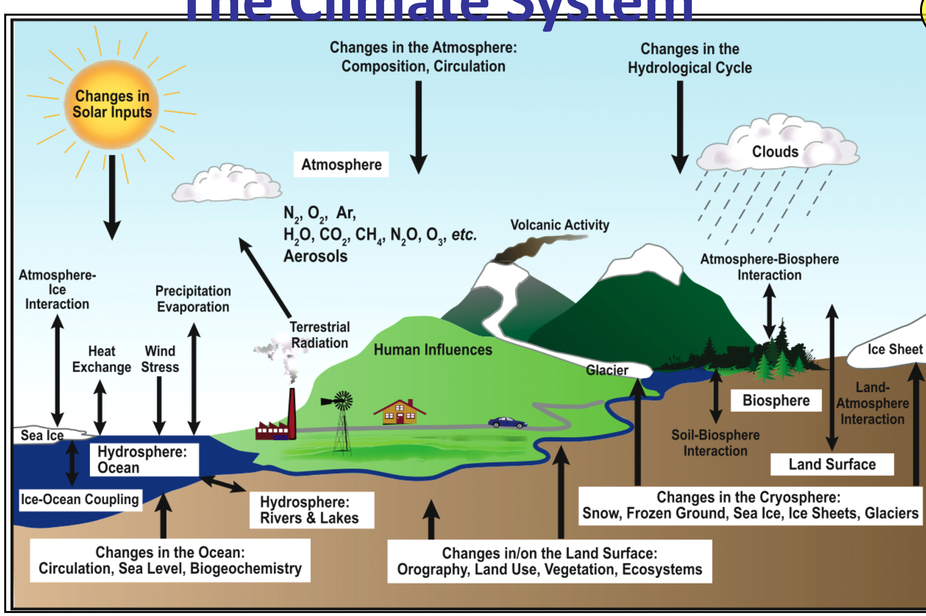
Schematic view of the components of the climate system, their processes and interactions.

Brazilian Model of the Global Climate System

Mid-1970s | Mid-1980s | Early 1990s | Late 1990s | Around 2000 | Mid 2000s



The Climate System



IPCC (2007)

Our needs –
Why do we need our own model?

- Develop in-country capacity to generate future environmental change scenarios
- Represent processes that are important to us and may be considered secondary in other models
- Benefit from and integrate with multiple large research programs in Brazil, like LBA, PRODES, GEOMA, etc.
- Form a new generation of land surface, ocean, atmosphere, chemistry… climate modelers
- Advance climate science
- Collaborate with countries with similar interests

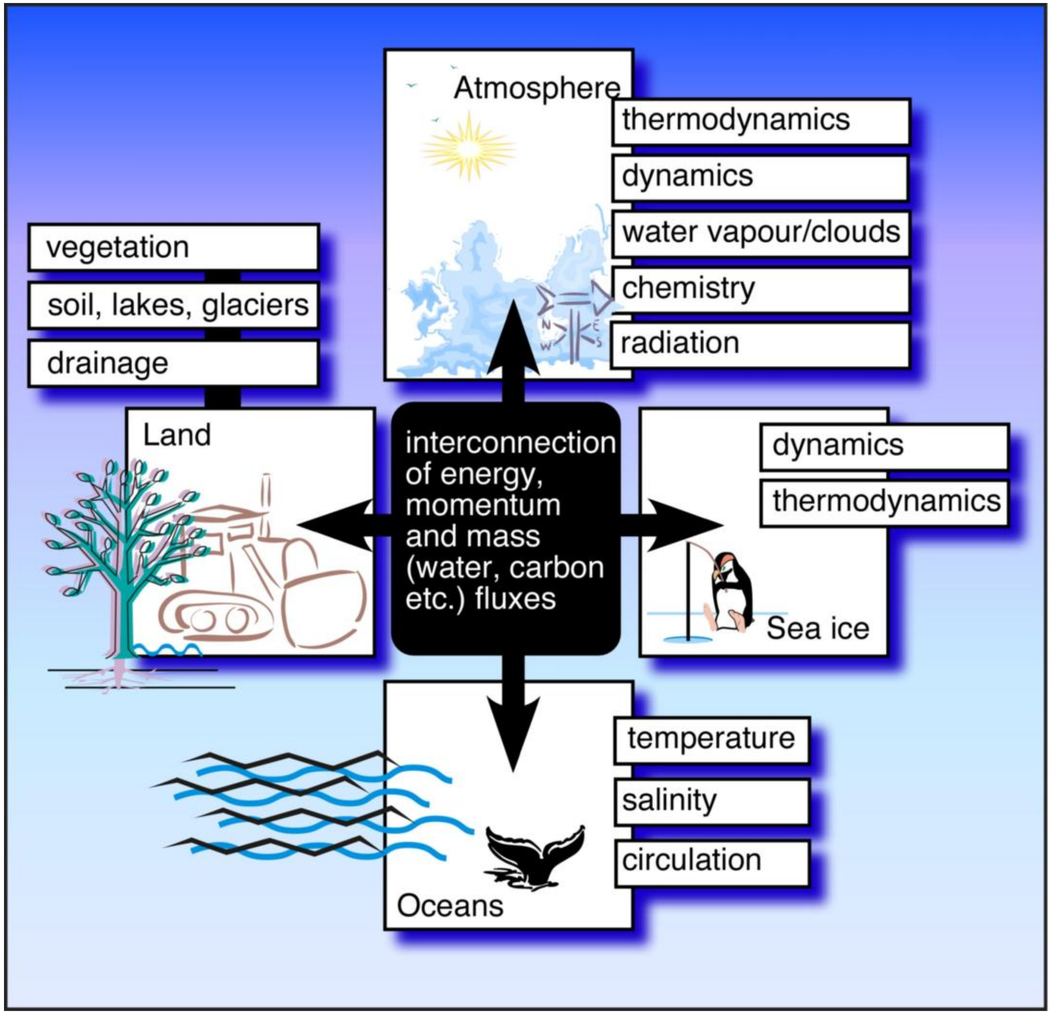
Development of INPE's Global Climate System Model

(i) full use of CPTEC's experience and sub-models

(ii) collaboration with advanced climate change centers abroad

- Take CPTEC Global Coupled Ocean-Atmosphere Model as the structuring building-block
- Use GFDL/FMS coupler to add components:
  - dynamic vegetation with carbon cycle;
  - ocean carbon cycle;
  - enhanced sea ice and pack ice;
  - GHG and aerosols;
  - atmospheric chemistry, etc.

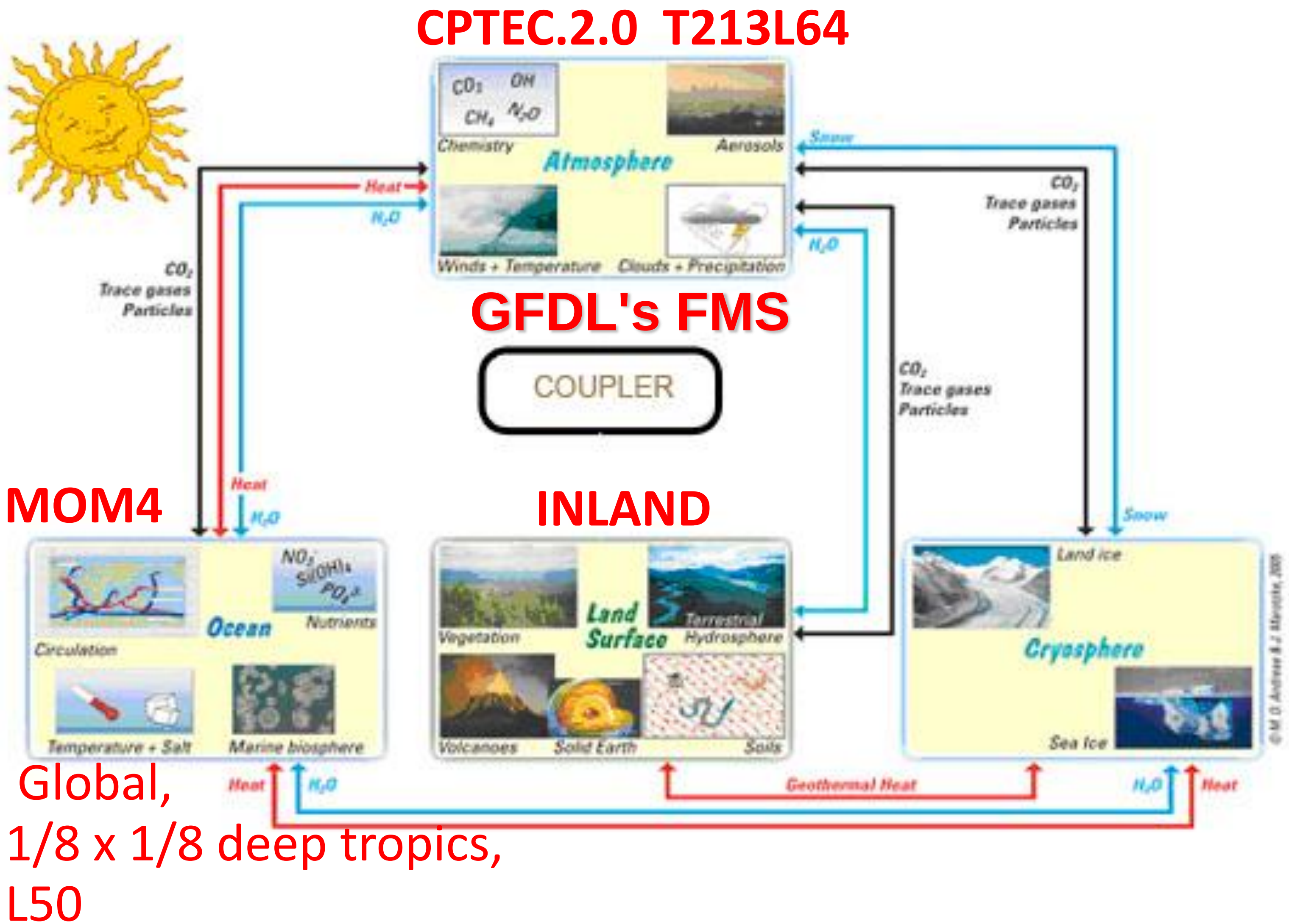
ESM component models & coupler



McGuffie & Henderson-Sellers (2005)

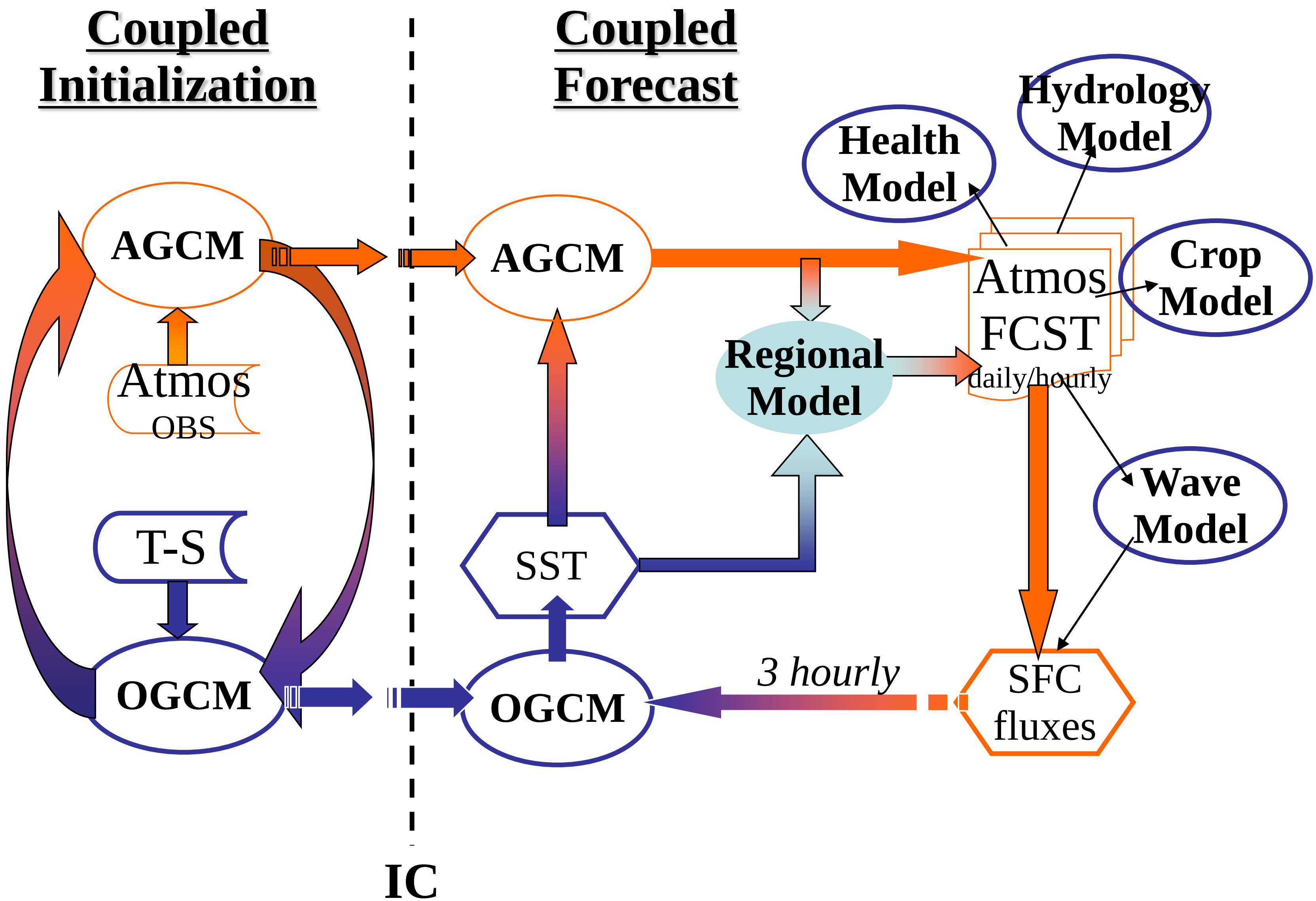
Constructed as modular components connected by a coupler (black): a program that transfers fluxes between the model components.

Schematic Diagram of the Sub-Models of the Brazilian Global Climate System Model



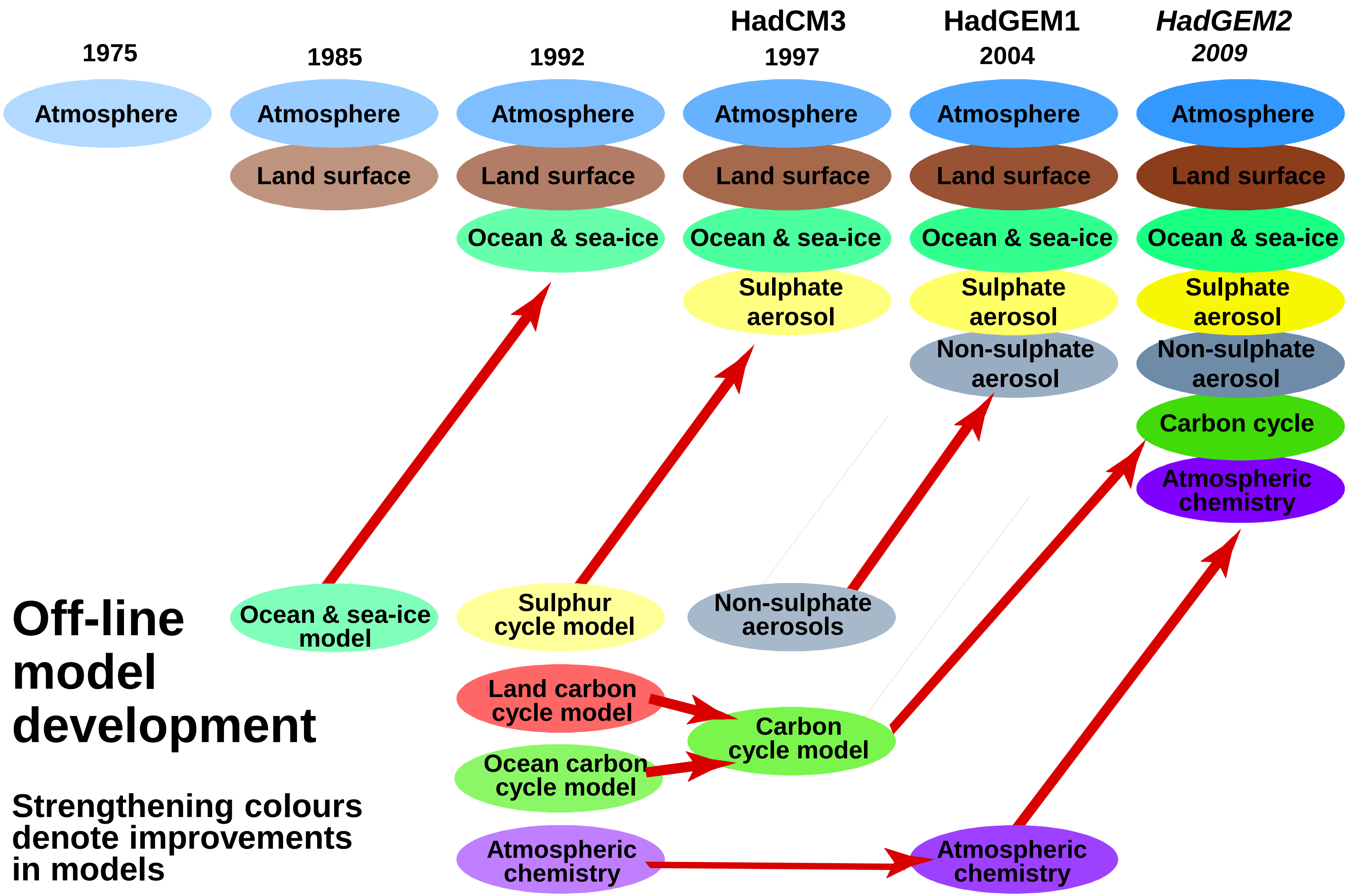
(Adapted from Brasseur, NCAR)

INPE's Climate Forecast Coupled Suite Goal



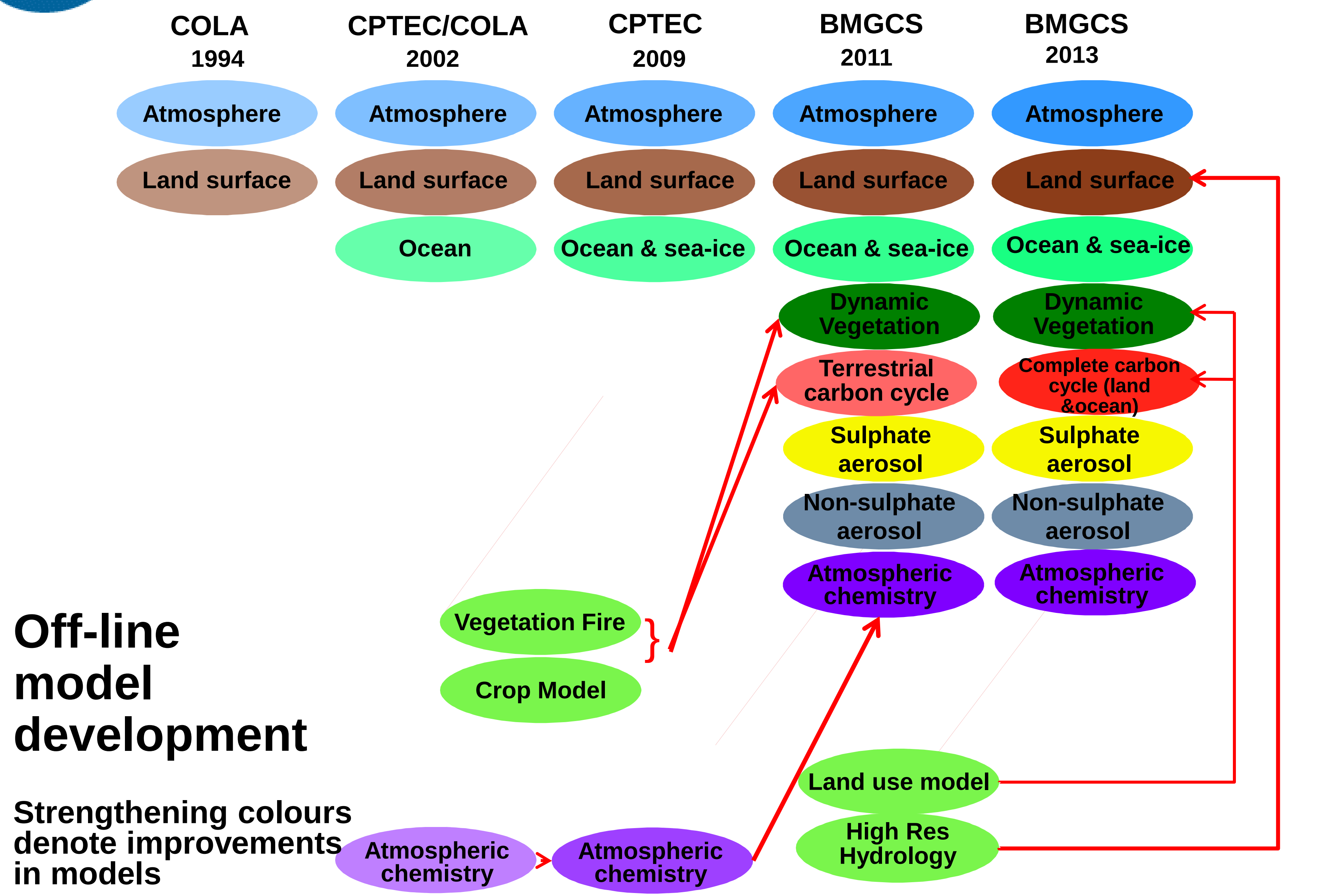
Courtesy: P. Nobre, INPE/CPTEC

Development of the Hadley Centre models



Hadley Centre / Met Office

Development of INPE Climate Models



Courtesy: G. Sampaio, INPE/CCST

Earth System Components in HadGEM2

Hadley Centre Global Environment Model 2

Fully coupled Earth System Model

- Atmosphere, ocean, sea-ice, land surface
- Land ecosystems: dynamic vegetation, soil carbon
  - TRIFFID, RothC Surface Models
- Ocean ecosystems: NPZD, diatoms, non-diatoms, DMS
  - Diat-HadOCC Biogeochemical Model
- Aerosols: Sulphate, BC, OC, dust, sea salt
- Tropospheric chemistry: ozone, methane, oxidants
  - UKCA (UK Chemistry and Aerosols Model)

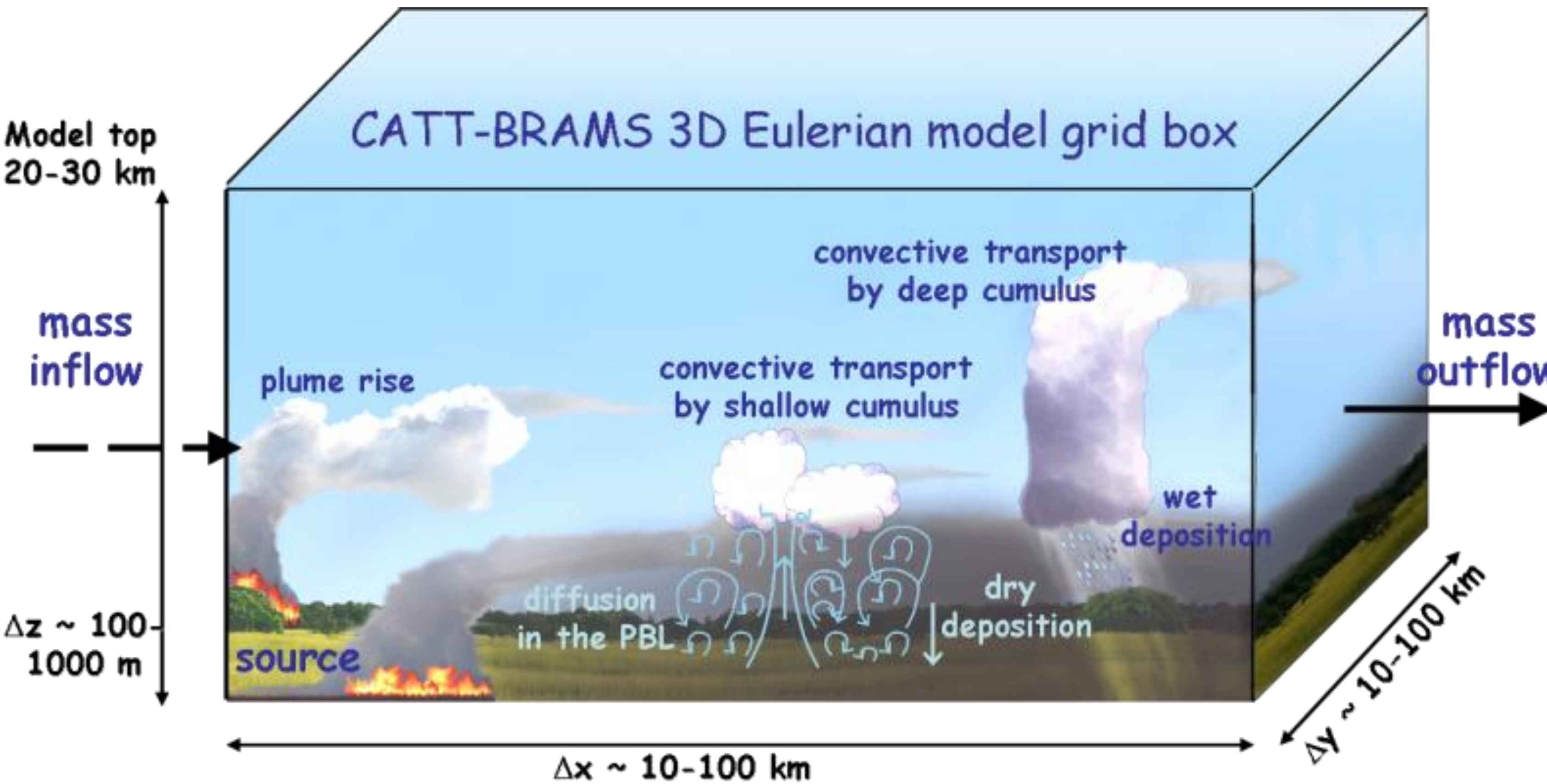
Earth System Components in BMGCS

- **Fully coupled Earth System Model**
- Atmosphere, ocean, sea-ice, land surface
- Land surface: all relevant land surface processes: exchange of mass and energy, photosynthesis, vegetation dynamics, terrestrial carbon cycle, other terrestrial biogeochemical cycles, fire, agricultural land use, surface hydrology and groundwater, ice sheets, etc.
- INLAND (IBIS) Surface Dynamic Vegetation Model
- Ocean ecosystems: NPZD, diatoms, N_2 fixation, zooplankton, $CaCO_3$
- IGBC, BLING, TOPAZ biogeochemical models
- Aerosols: Sulphate, BC, OC, dust, sea salt
- Tropospheric chemistry: ozone, methane, oxidants
- CATT (INPE's Chemical and aerosol model)

Courtesy: P. Nobre, INPE/CPTEC

INPE developments on the atmospheric chemistry modeling

Coupled Chemistry-Aerosol-Tracer Transport model

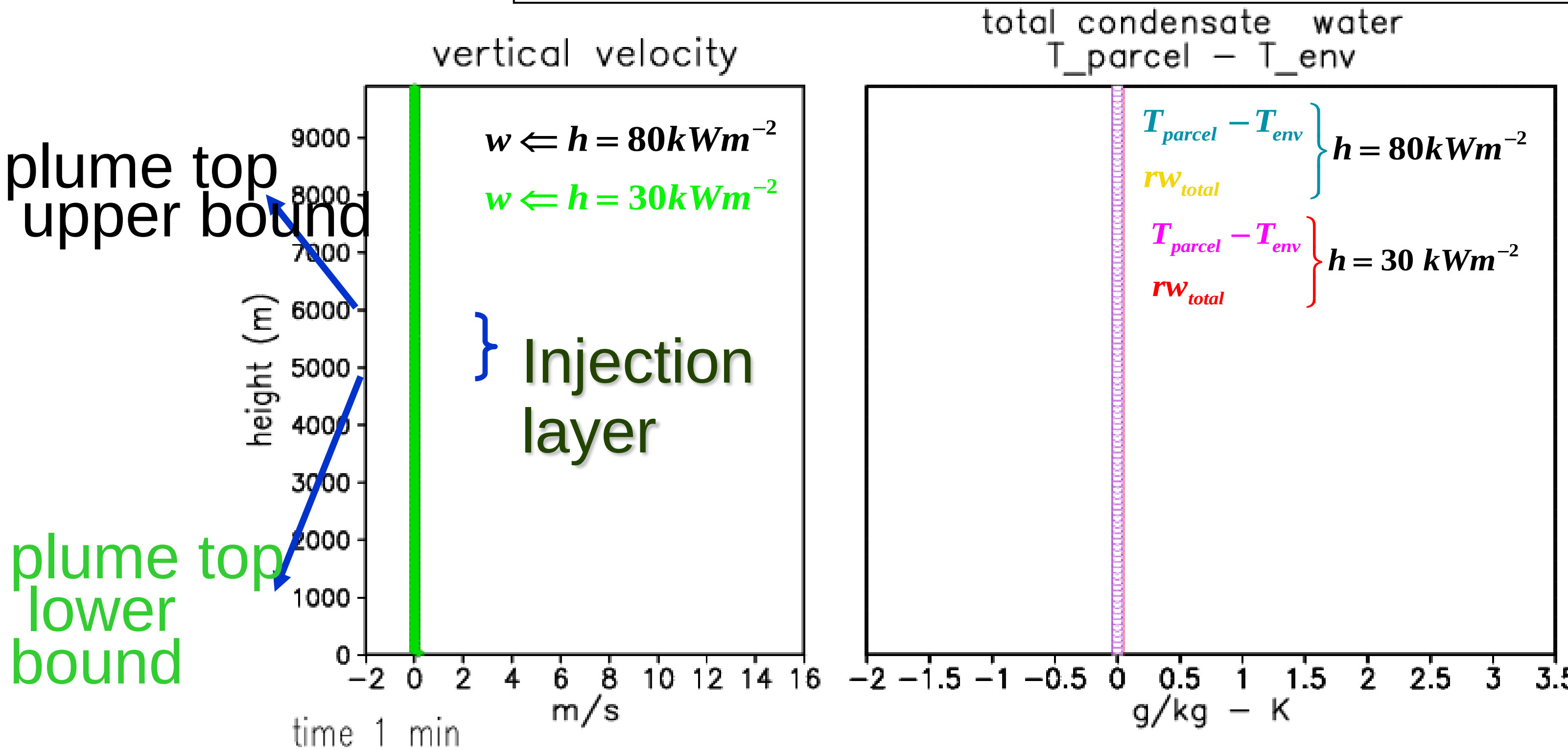


Freitas et al., 2009. Atmos. Chem. Phys., 9, 2843-2861

Including plume rise mechanism trough "*super-parameterization*" concept

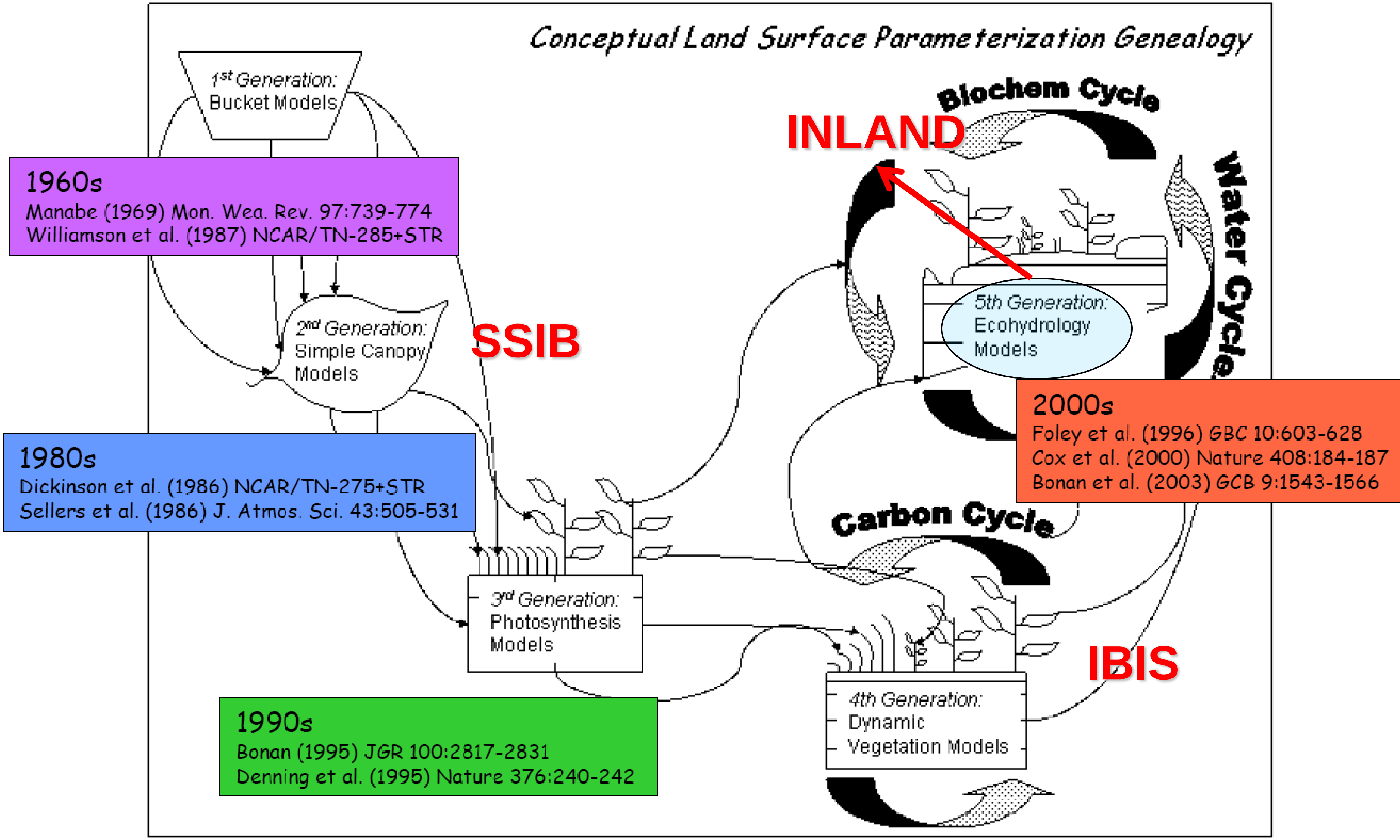
1D plume-rise model for vegetation fires
Biome: Forest
Time duration: 50 mn
Fire size: 20 ha
Heat flux: 80 kWm^{-2} / 30 kWm^{-2}

heat flux:



Freitas et al., 2006. Geophys. Res. Lett.,

Genealogy of Land Surface Parameterizations



Gochis et al., 2004

Courtesy: G. Sampaio, INPE/CCST

Trends in land surface modeling

- Models
  - 5th generation models currently tend to integrate all relevant land surface processes
    - Exchange of mass and energy
    - Photosynthesis
    - Vegetation dynamics
    - Terrestrial carbon cycle
    - Other terrestrial biogeochemical cycles (N, etc.)
    - Agricultural land use
    - Urban areas
    - Emissions of trace gases, VOCs, dust and aerosols
    - Ice sheets
    - Surface hydrology and groundwater
    - Etc.

Courtesy: G. Sampaio, INPE/CCST

BMGCS - Land Surface Model
Processes to be represented

Fluxes of radiation, energy and mass

Complete terrestrial carbon cycle

Phenology and vegetation dynamics

Recovery of abandoned lands

Urban areas

Crops

River discharge and seasonally flooded areas

Specific representation of South American ecosystems

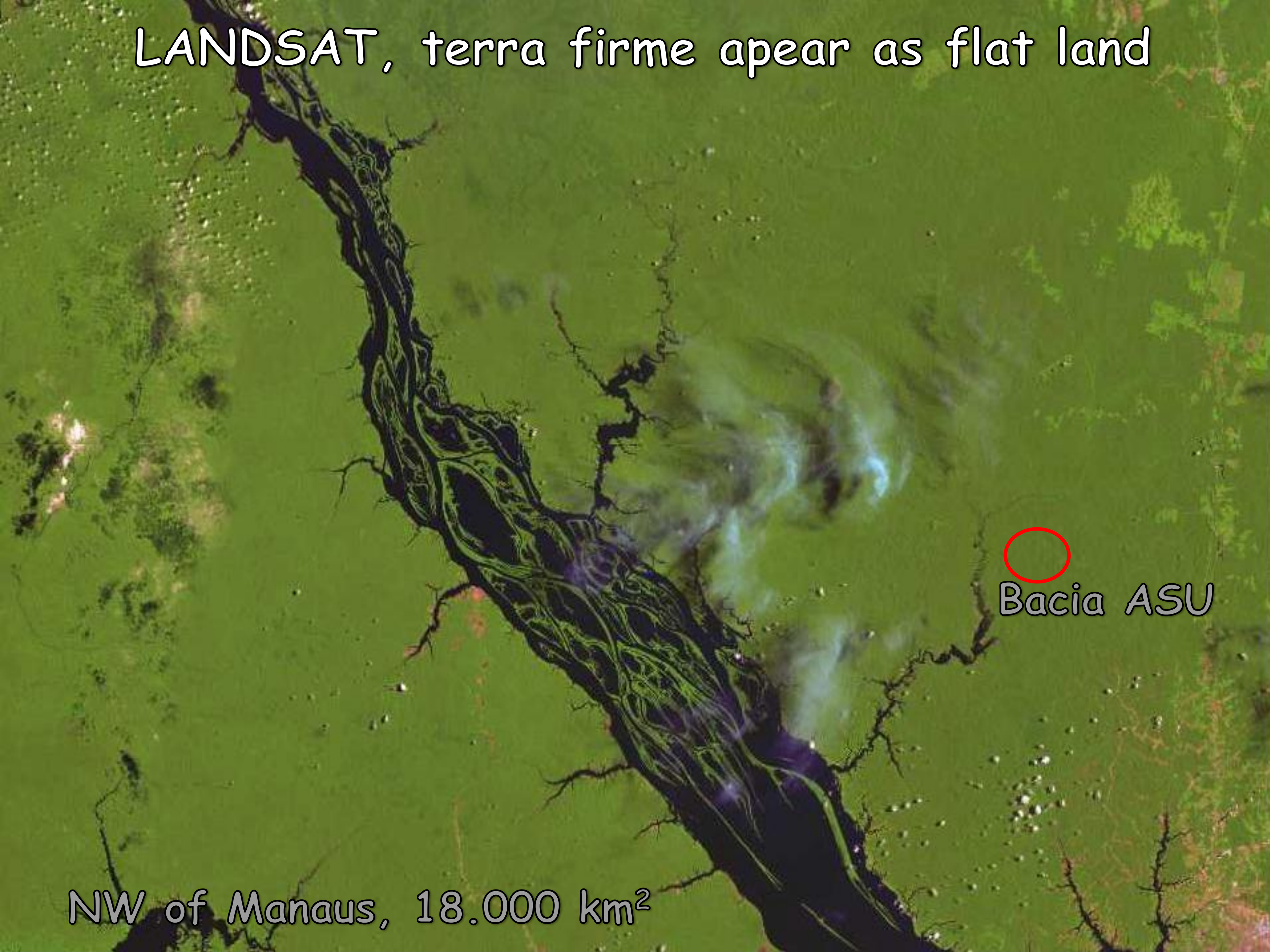
Fires (ignition, combustion, spreading, emissions)

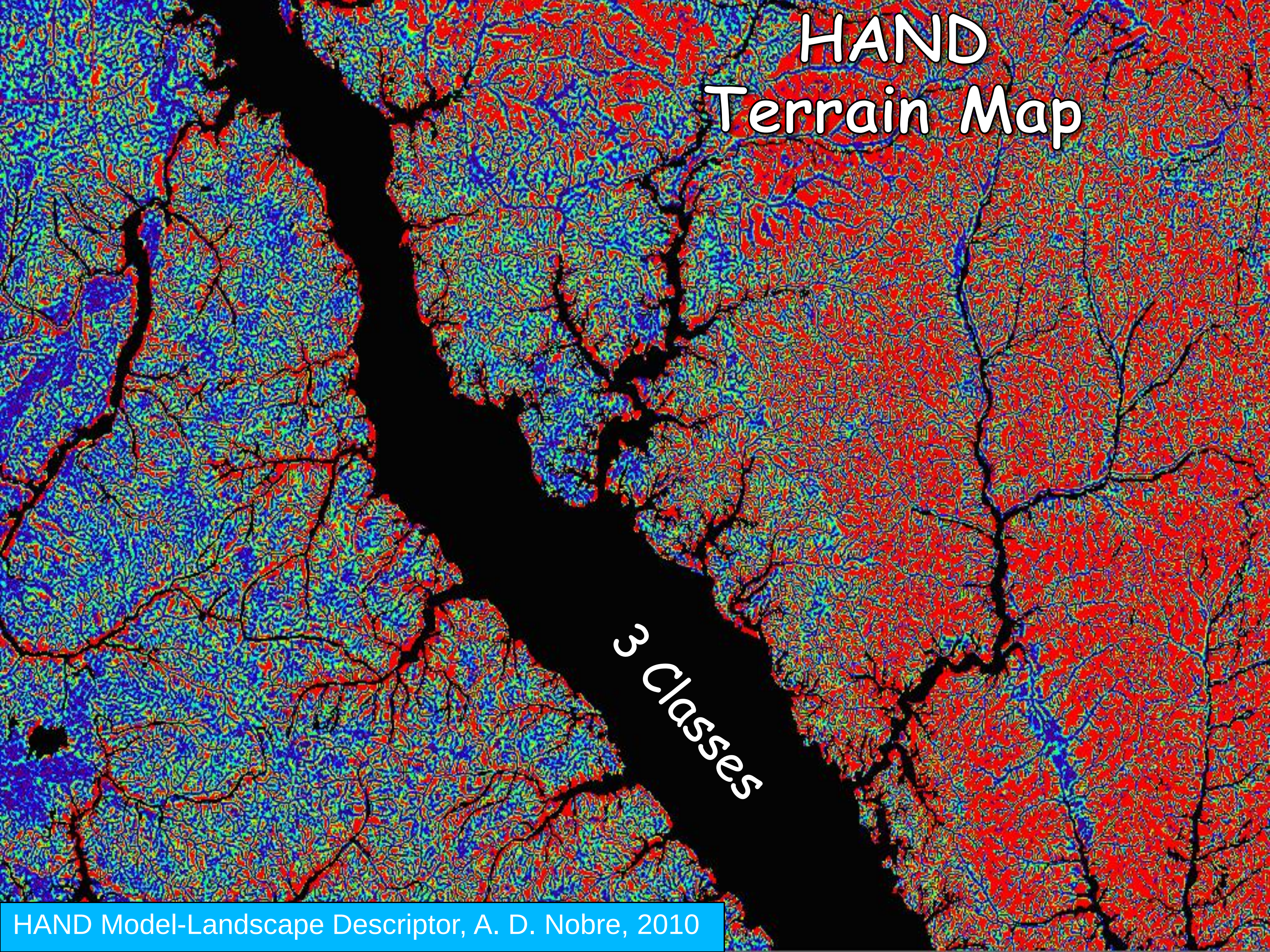
Anthropogenic land use (deforestation)

Soil fertility, enhanced ecophysiology

Continental ice sheets

Courtesy: G. Sampaio, INPE/CCST


LANDSAT, terra firme apear as flat land
Bacia ASU
NW of Manaus, 18.000 km²

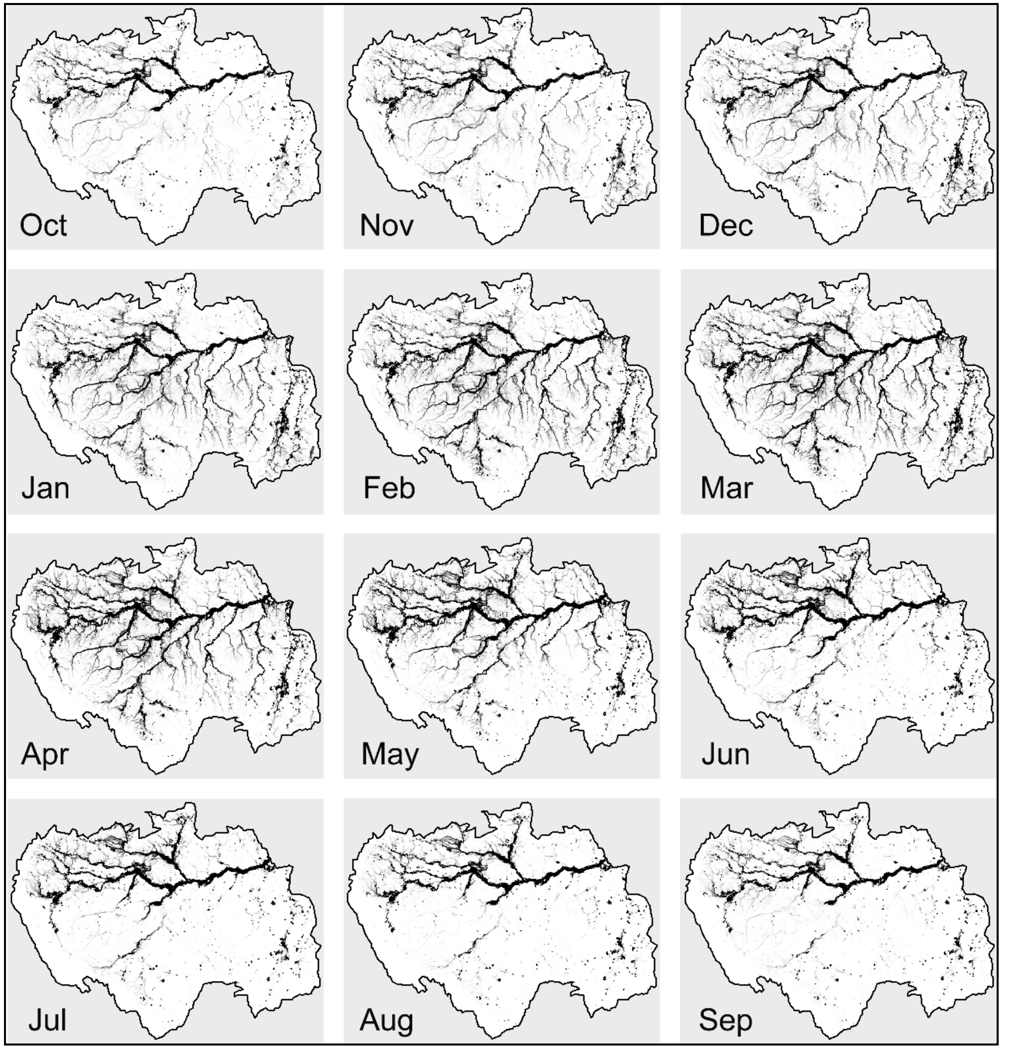


HAND Model-Landscape Descriptor, A. D. Nobre, 2010

River flow and flooded areas

- Aplications over:
  - Amazônia
  - Pantanal
  - Araguaia

- Implications:
  - Flux exchanges between surface and atmosphere
  - Hydrology
  - Carbon cycle

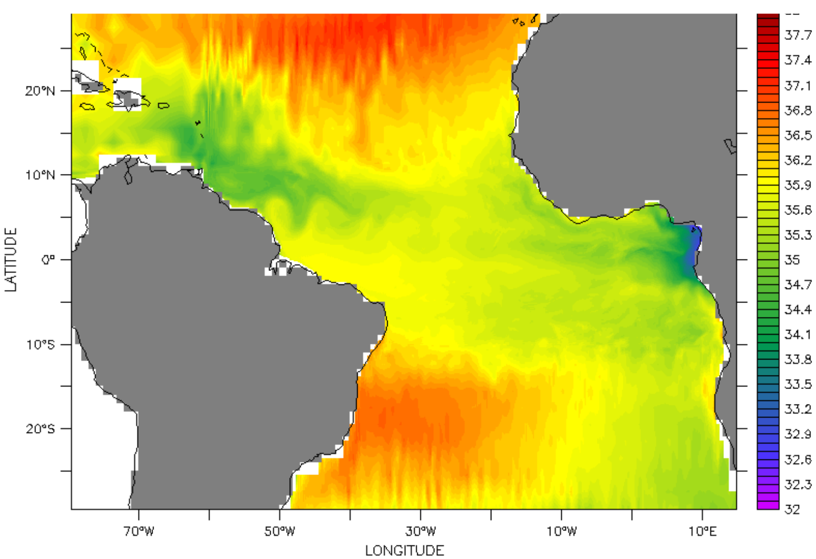


Courtesy: G. Sampaio, INPE/CCST

Land-Ocean coupling: River inflow effects on ocean circulation and salinity

MOM3

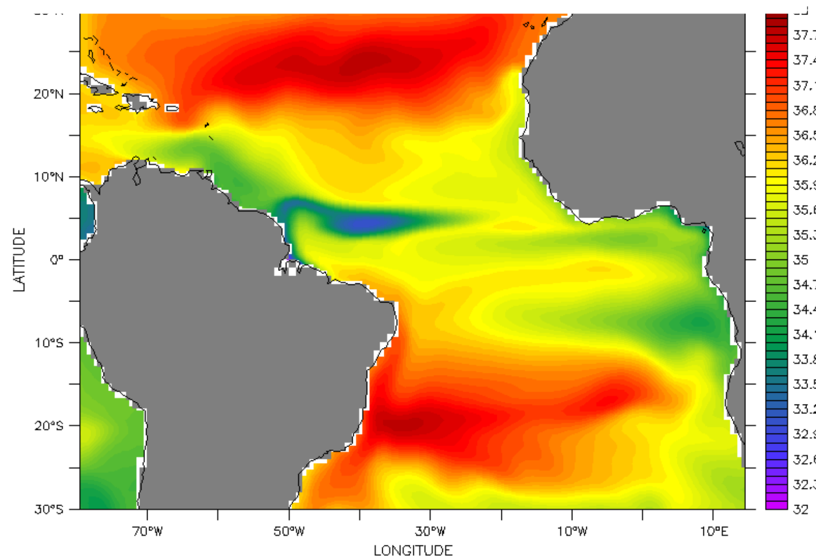
w/o river discharge



Salinity (ppm)

MOM4

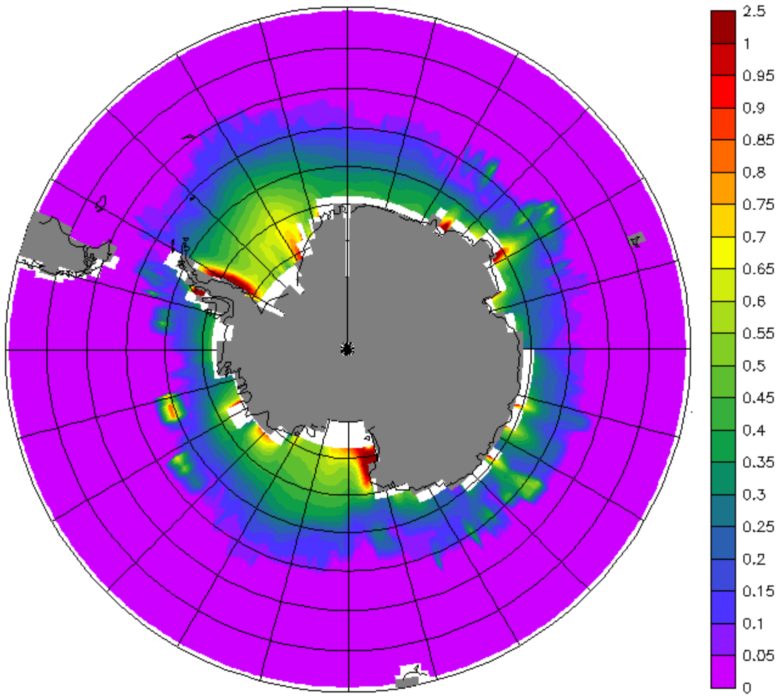
with river discharge



Salinity (psu)

Source: P. Nobre (personal comm.)

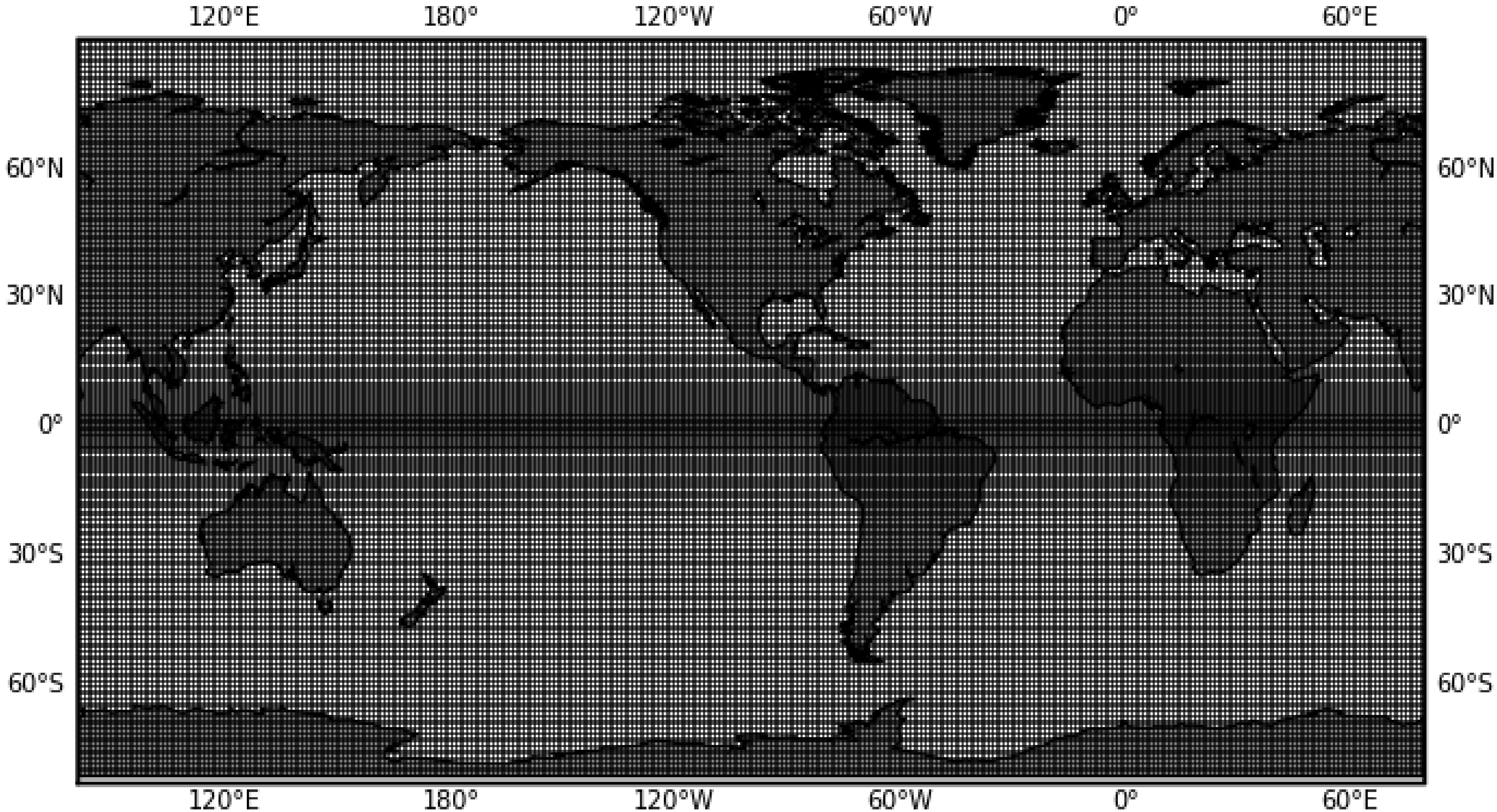
Ice Cover Simulation
INPE COUPLED O-A GCM



Ice Thickness (m) – MOM4p0/SX6
26–JUN–2007 (2Mo A–O coupled)

Source: P. Nobre (personal comm.)

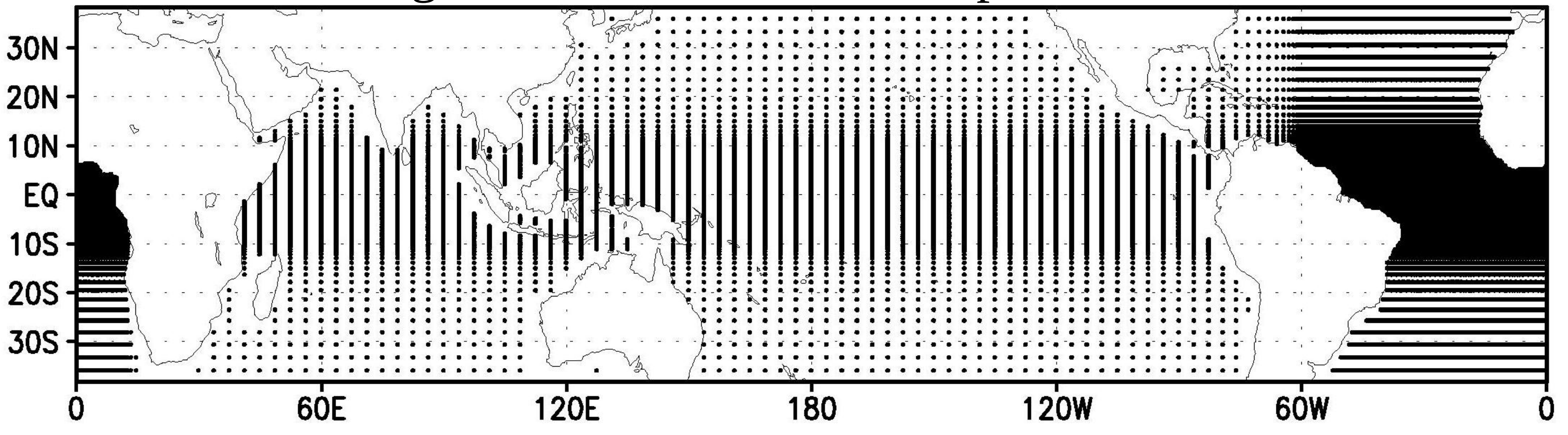
Ocean Model Grid



Source: P. Nobre (personal comm.)

OGCM Grid

High Res: 0.25º Lon Lat Tropical Atlantic



Source: P. Nobre (personal comm.)

CPTEC AGCM In-House DEVELOPMENTS:

NEW VERSION:

- Triangular 3.0 CPTEC AGCM
- Use of Fortran 90/95 Features (Dynamical Allocation, Modules, etc)
- New Optimizations: Vectorization and OpenMP and MPI Paralelism
- Reduced Linear Gaussian Grid
- Main Resolutions: T_L199L42, T_L256L42, T_L511L64, T_L639L96

BOUNDARY CONDITIONS:

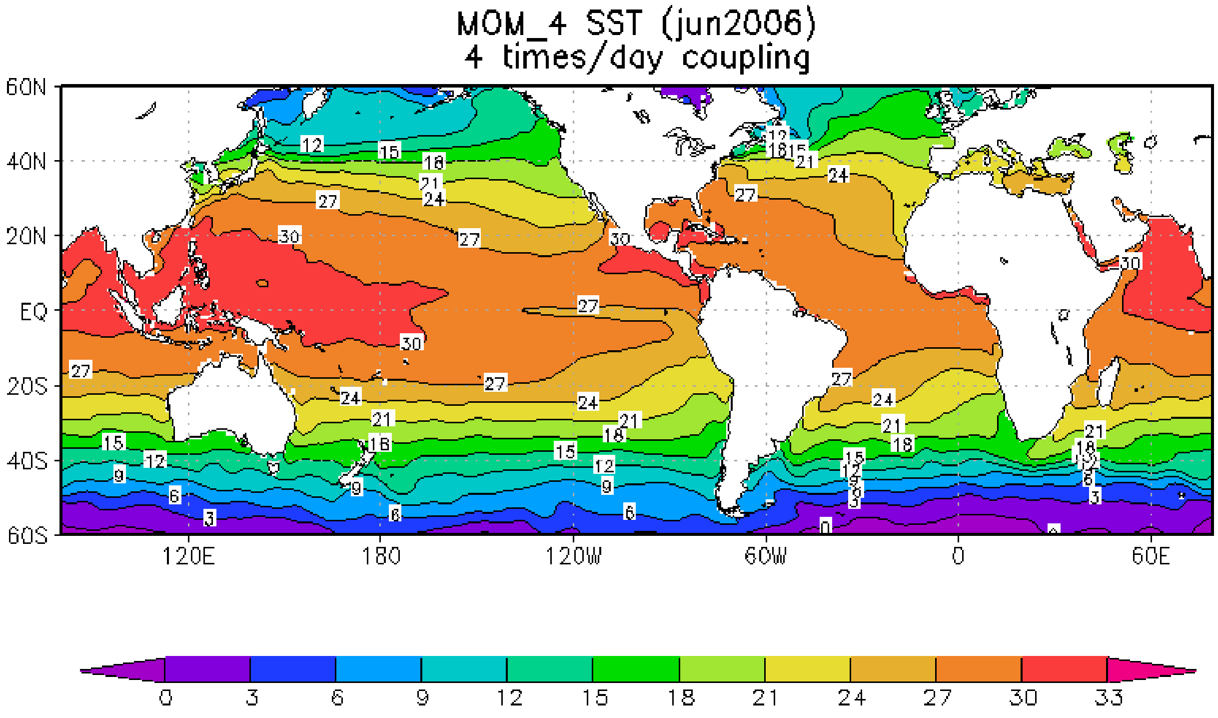
- Three-Dimensional Ozone Fields
- Variable Values for Atmospheric CO_2 Amount
- Observed Soil Moisture and Snow.

SPECTRAL DYNAMIC:

- Primitive Equations (Zonal and Meridional Winds)
- Semi-Implicit Time Integration (Semi-Lagrangean) and Asselin Filter

Courtesy: J. P. Bonatti, INPE/CPTEC

INPE-CPTEC CGCM V.2.0
T213 L64, Kuo, 4 x daily coupling
30 days avrg spinup SST



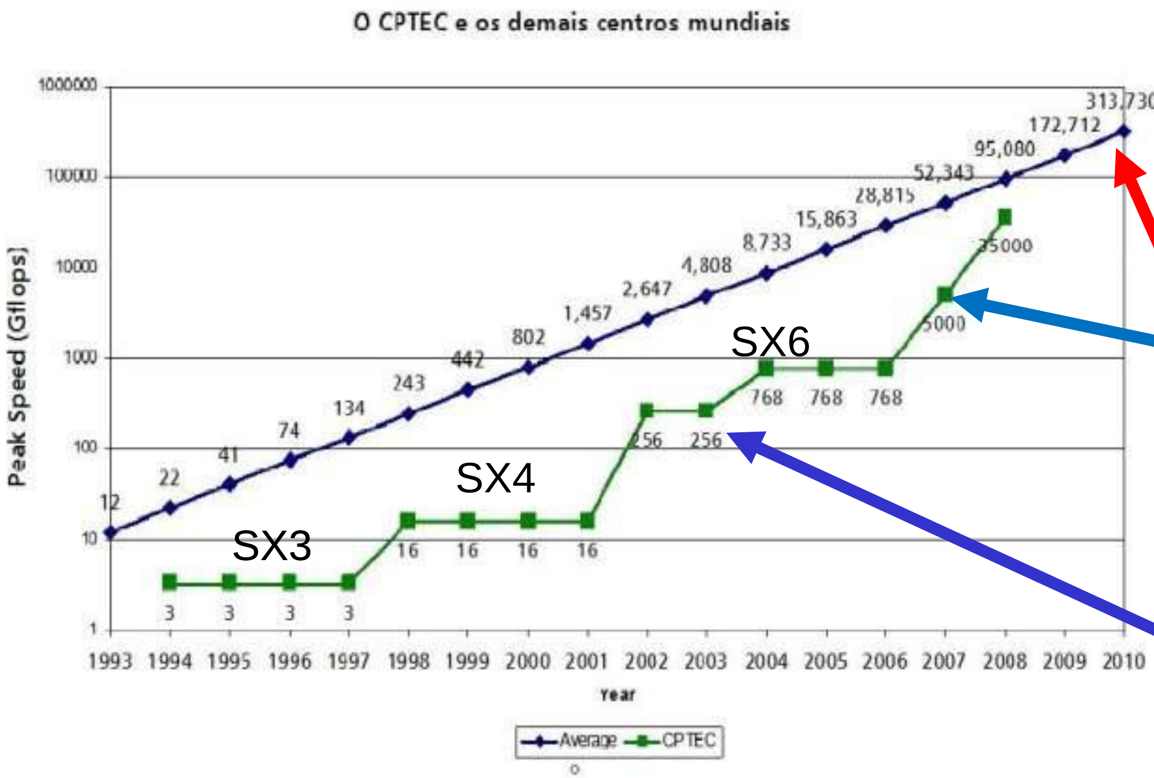
Source: P. Nobre (personal comm.)

INPE initiated operating a supercomputer back in 1994

Global climate system models require big supercomputers

The Earth Simulator in Japan

INPE's supercomputing facility



	SX3	SX4	SX6
NUMERO DE NÓS	1	1	12
NUMERO DE PROCESSADORES	1	8	96
DESEMPENHO MÁXIMO	3,2 Gflops	16 GFlops	768 GFlops
MEMÓRIA	0,5 GBytes	8 GBytes	768 GBytes
DISCO	60 GBytes	220 GBytes	1PByte

15 TFlops sustained

100 Pbytes armazena//

Courtesy: J. P. Bonatti, INPE/CPTEC

MCT/INPE-REDE CLIMA-FAPESP
Supercomputer for Climate Change Research

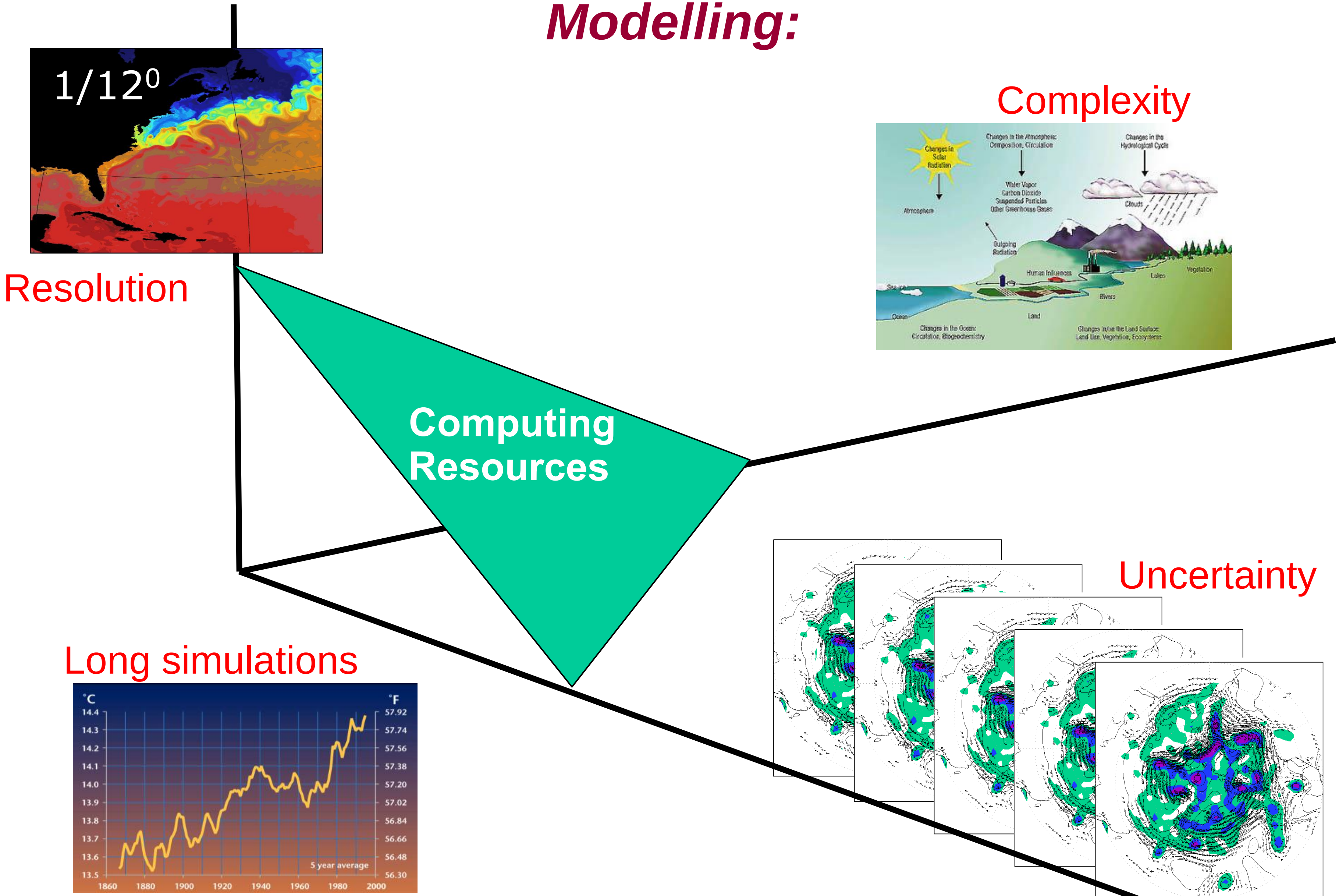
Sustained Throughput	15 Tflops
Main Memory	20 TBytes
Primary Storage	3 PBytes
Aquisition Installation	Late 2010
Total budget	US$ 25 M

and will make it possible to run global climate model simulations at high spatial resolutions to grid sizes of 20 km !

Why do we need super and ultra-computing capabilities?

Dealing with the question of very high resolution model runs to resolve climate variability and change…

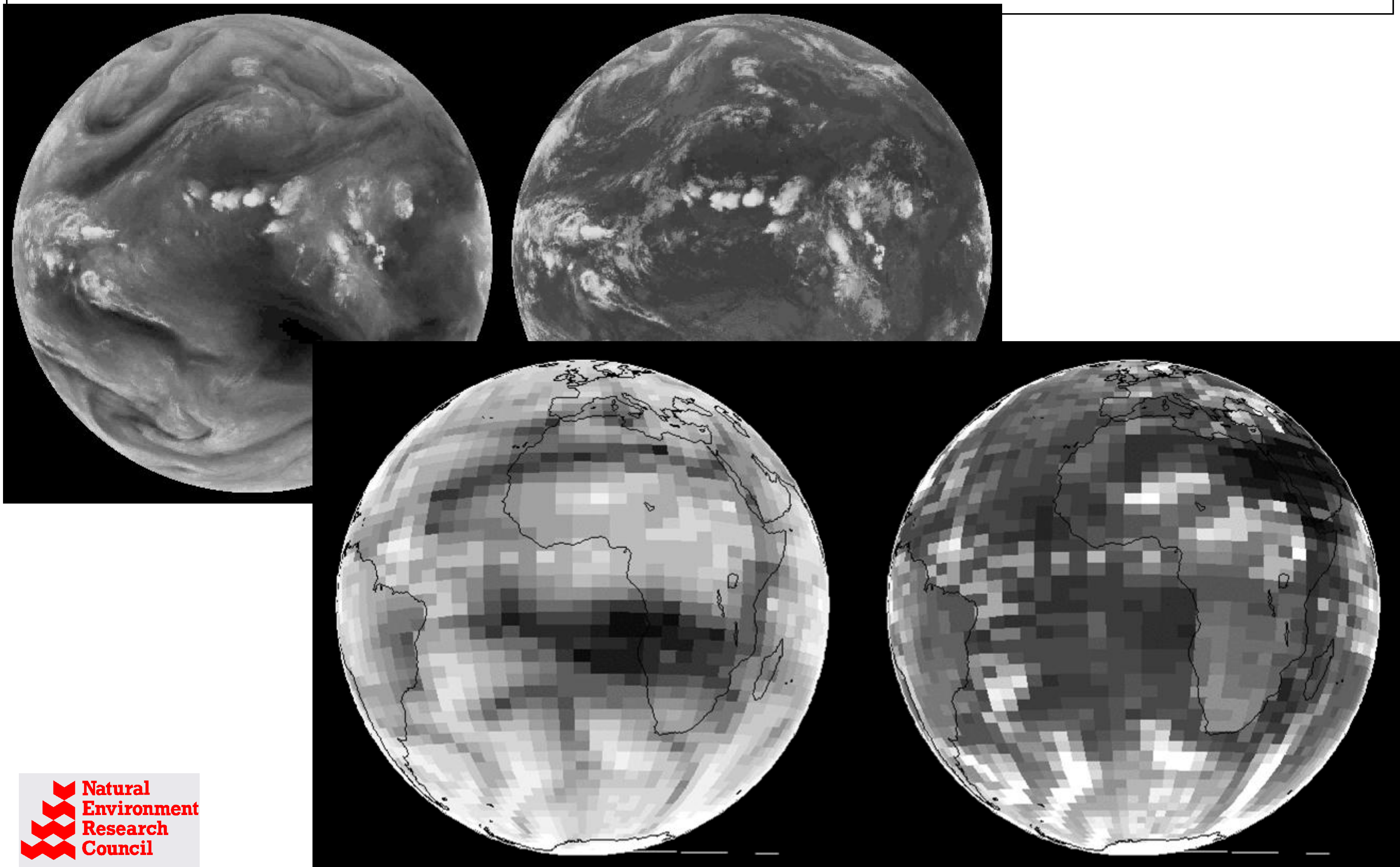
Competing demands of resolution, complexity, uncertainty, and long integrations in Climate System Modelling:



Courtesy: J. Shukla, IGES/COLA

Why a move to higher resolution is necessary

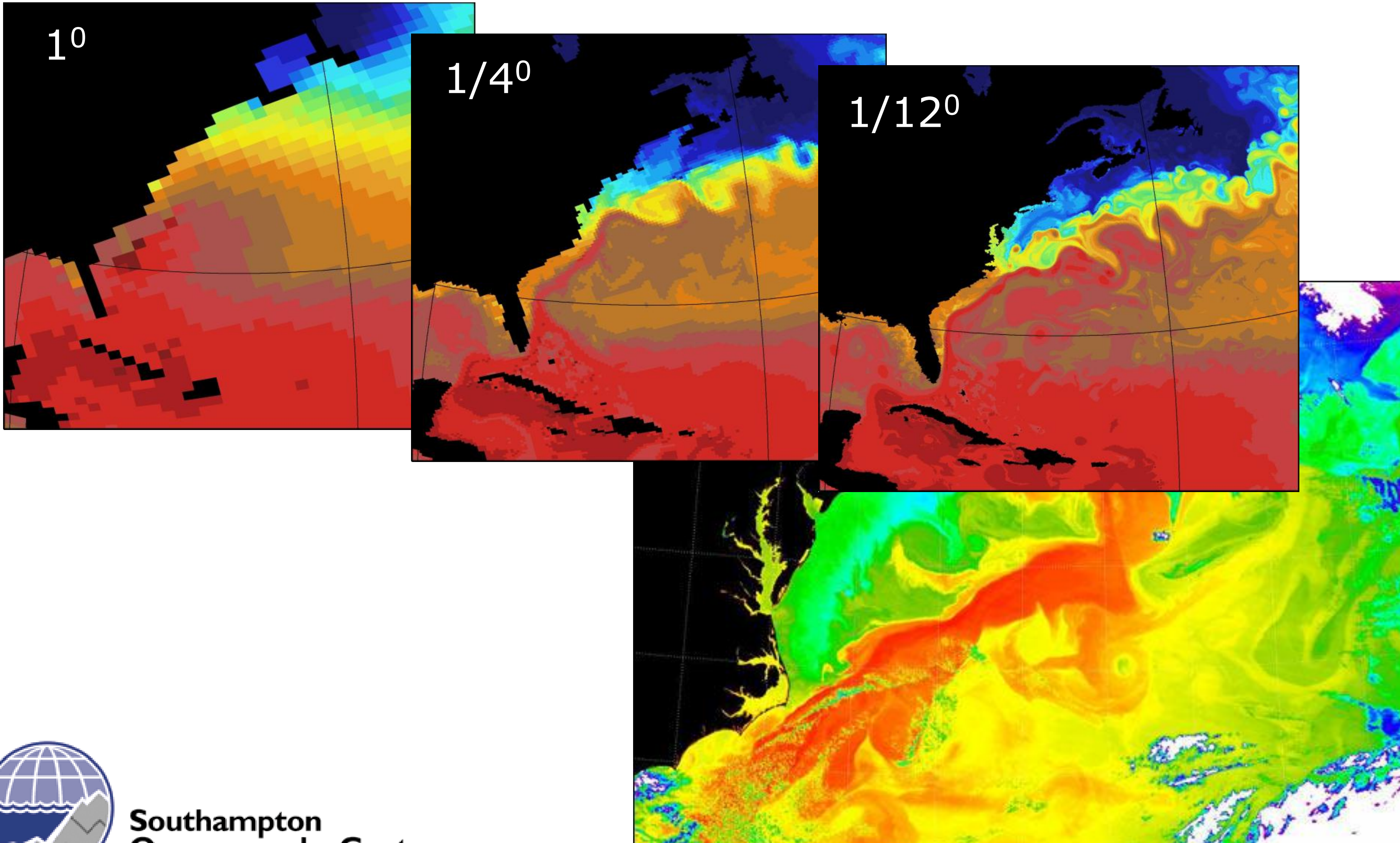
I: Complexity in the atmosphere



Natural Environment Research Council
ESSC

Courtesy: J. Shukla, IGES/COLA

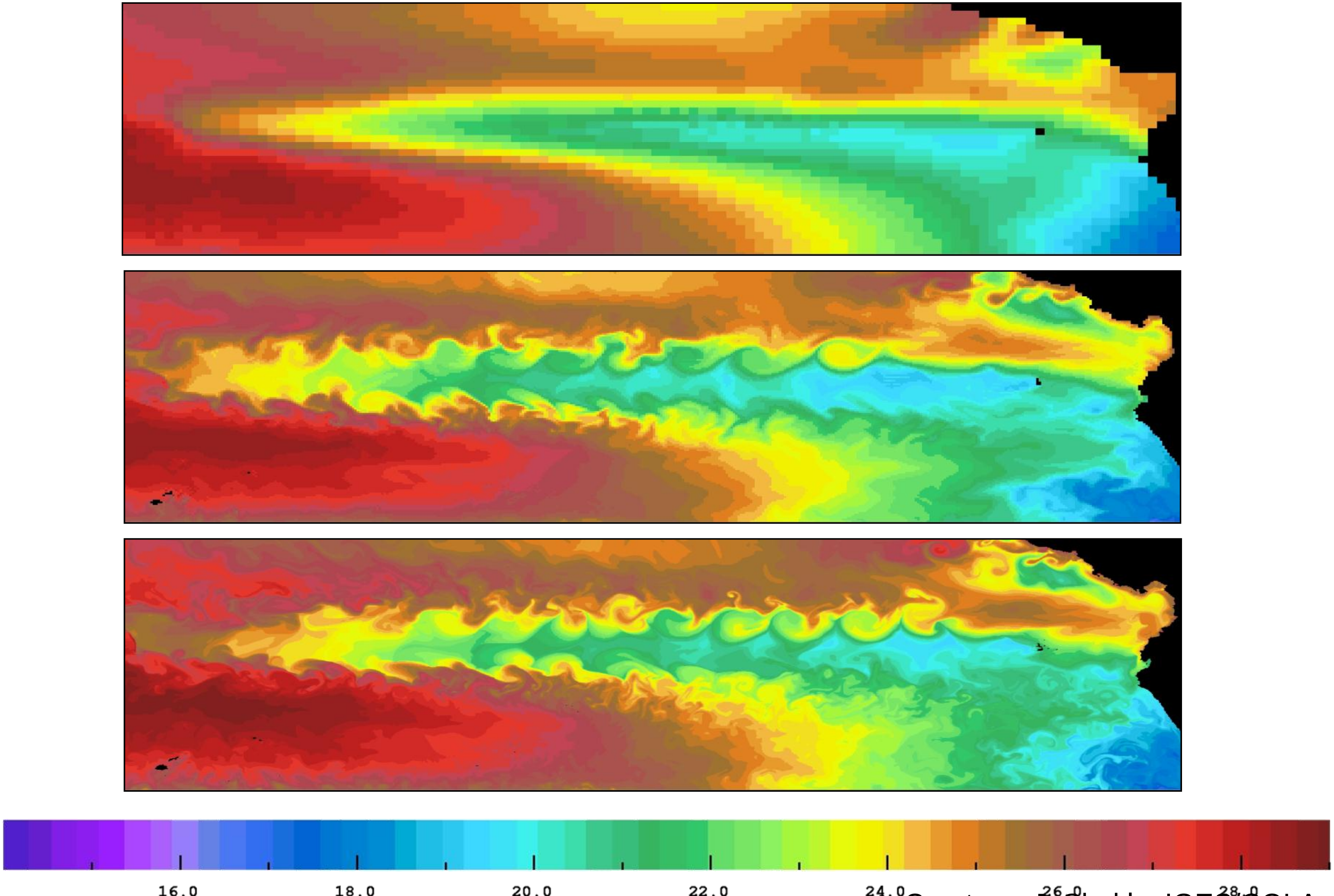
II: Complexity in the ocean



Courtesy: J. Shukla, IGES/COLA

Southampton
Oceanography Centre

Equatorial Pacific sea surface temperatures (^{0}C) from UK Ocean Model



Courtesy: J. Shukla, IGES/COLA

Weather Prediction Model of ~2020

Coupled Ocean-Land-Atmosphere Model

~1 km x ~1 km
100 levels
Unstructured, adaptive grids

Landscape-resolving
(~100 m)

~1 km x ~1 km
50 levels
Unstructured, adaptive grids

Assumption: Computing power enhancement by a factor of 10^3-10^4

Courtesy: J. Shukla, IGES/COLA

Tropical Hurricane Catarina Hits Brazil on 27 March 2004

Source: Hadley Centre, UK

Do we have sufficient human resources for the task ahead?

The greatest challenge of all: human resources, international collaboration and South - South cooperation: capacity building

The greatest Challenge:‘Peopleware’

Model Component	Present*	In 5 years*	In 10 years*
Atmosphere	15 + 10	30 + 15	45 + 30
Land	20 + 25	30 + 50	50 + 70
Chemistry	7 + 5	15 + 20	25 + 30
Ocean	10 + 5	20 + 40	30 + 80
TOTAL	52 + 45	95 + 125	150 + 210

* Researchers + Students/Collaborators

- Long term research programs: FAPESP Research Program on Global Climate Change; Rede CLIMA; INCT for Climate Change

- 10 Doctoral programs supporting capacity building in Earth System Modeling

- Annual “International Summer Schools” will engage some 40 doctoral students/post-docs from S. America, S. Africa and India fellows per year.

Interactions with the international community

- Established partnership with other Research Institutions
  - University of Wisconsin
  - University of Minnesota
  - Woods Hole Research Center
  - MIT, CNRS, University of Toronto, University of British Columbia
- "South-South" Climate Model Development
  - South Africa: CSIR, UCT
  - India: IITM, IISc
  - South America: Chile, Argentina, Uruguay…
- Joint development, parameterization and testing
- Code sharing
- Conferences, etc.

Conclusions …

1. **We do have in Brazil a track record of work with the type of models one needs for the development of a world-class global climate system model.**
2. **We do have a road-map to reach the goal and have completed already several steps.**
3. **We are modernizing supercomputer infra-structure with a state-of-the-art computer.**
4. **We have minimum "critical mass" and this is perhaps the great challenge for the success of this project.**


Thank you!
Foto: cortesia de Antonio Nobre

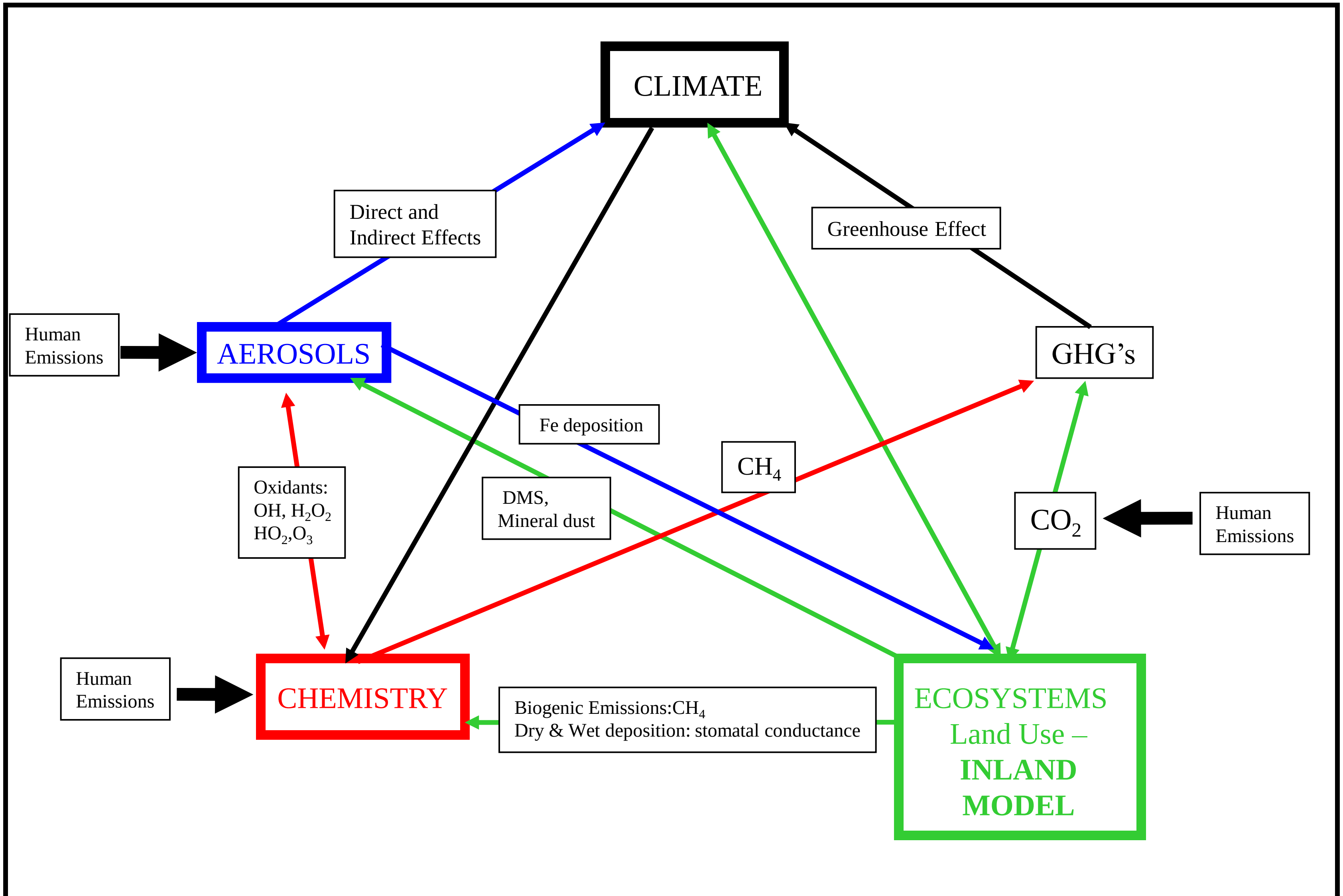
BMGCS Component models…

- Atmos GCM:
  - CPTEC.2.0 mpi/open_mp,
  - Semi-Lagrangian,
  - Resolution T62L64; T126L64; T213L64
    - Increased PBL and Stratosphere vertical resolution
  - RAS/Grell deep cumulus convection
    - Improved stratus parameterization scheme
  - atmospheric chemistry & aerosols
- Land Surface Model: INLAND
  - Dynamic vegetation
  - Carbon Cycle
  - Fire Model
  - Improved hires land surface hidrology

BMGCS Component models…

- OGCM:
  - MOM4,
  - Global, 1/4 x 1/4 deep tropics,
  - L50, 10m spacing upper 250 m,
  - Philander and Pakanowski vertical mixing
  - free surface,
  - fresh water flux,
  - river inflow;
  - Dynamical ice model (SIS)
  - Biogeochemistry model (Topaz, Bling)
- GFDLs FMS (Flexible Modeling System) coupler
  - Up to 3-hourly coupling interval (limited by atmospheric radiation sub-routine)

The climate system – Brazilian Model



Adapted from UKMET Office

The climate system – HadGEM2