CPTEC
Centro de Previsão de Tempo e Estudos Climáticos

MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Extended Weather Forecast and Seasonal Climate Prediction at INPE-CPTEC

Paulo Nobre

E. Giarolla, M. Malagutti, S. Costa, J. P. Bonatti, G. Gonçalves, R. G. de Moura, C. Coelho, S. Freitas, C. Cunningham, S. Nilo

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13th ECMWF Workshop on Meteorological Operational Systems
Reading, 3 November 2011

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- **Talk Outline**

  Motivation

  The Evolution of CPTEC's AGCM

  Forecast Skill Measures-Challenges

  Model Improvements on the go

  Scientific Challenges Ahead

  Development of the Brazilian Model of the Global Climate System

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13th ECMWF Workshop on Meteorological Operational Systems
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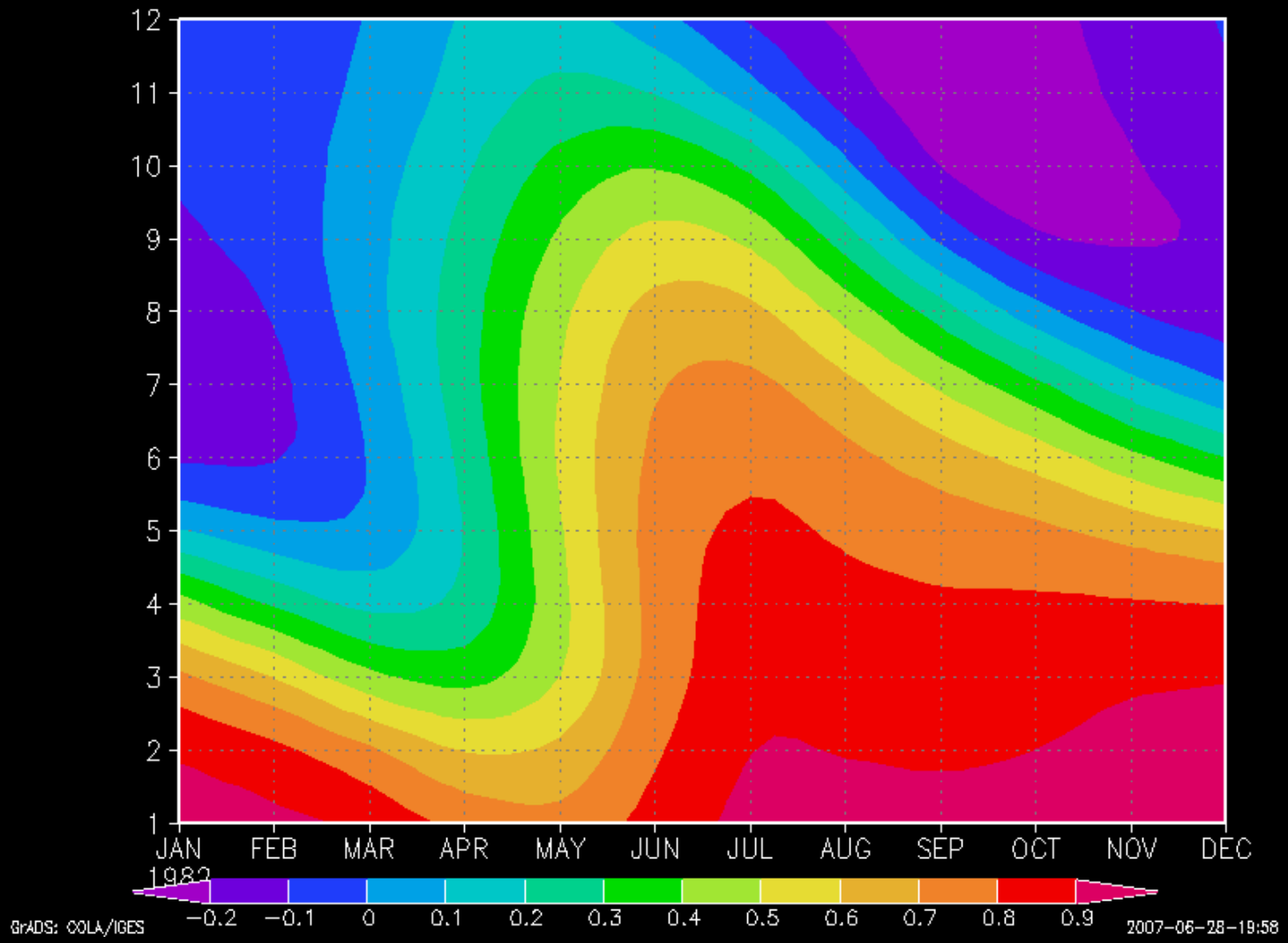
Tropical Hurricane Catarina Hits Brazil on 27 March 2004

Source: Hadley Centre, UK

Niño 3.4 SST Predictability

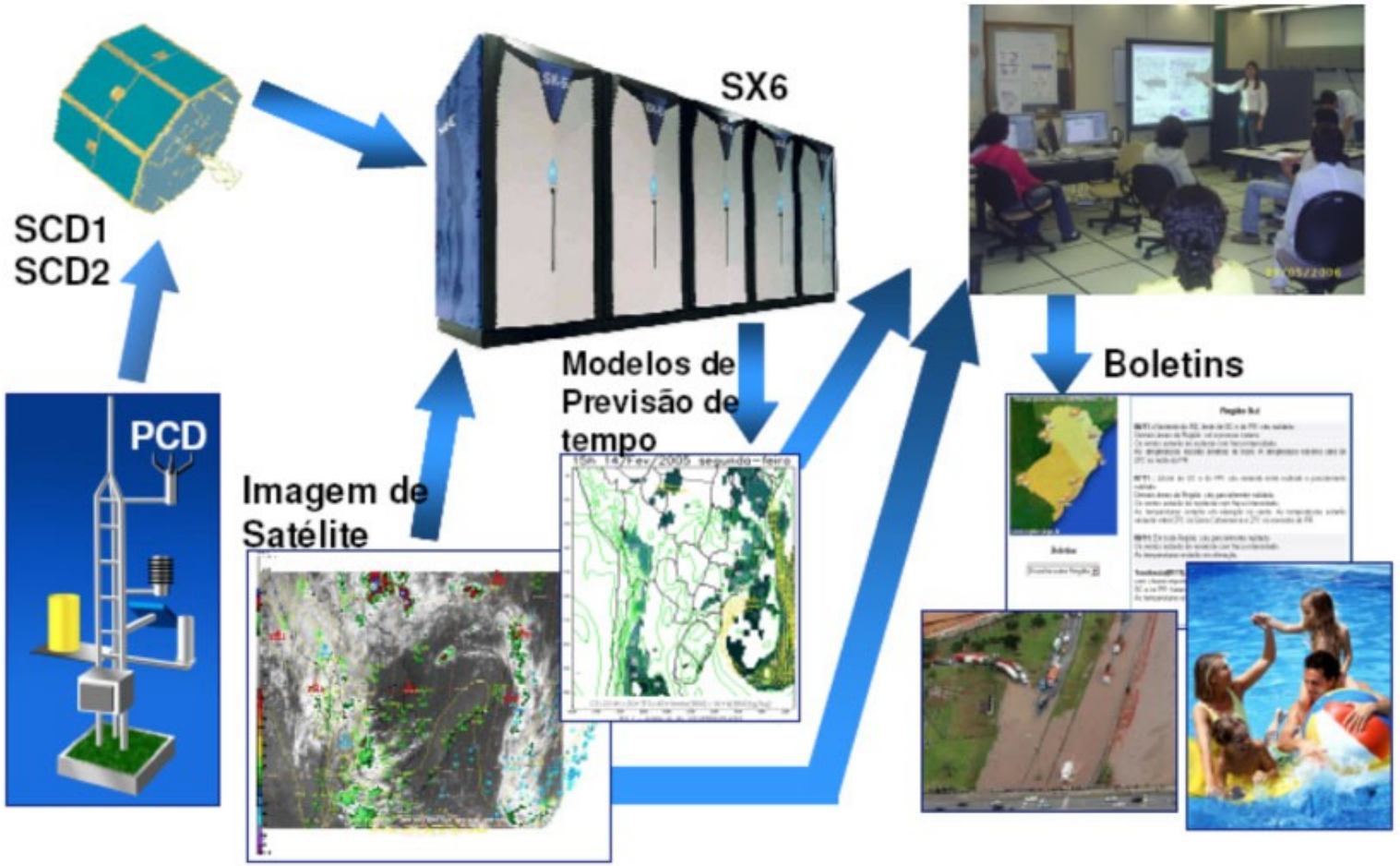
INPE-CPTEC's O-A Coupled Model V 1.0



CPTEC innovated in NWP and Climate Science in Brazil

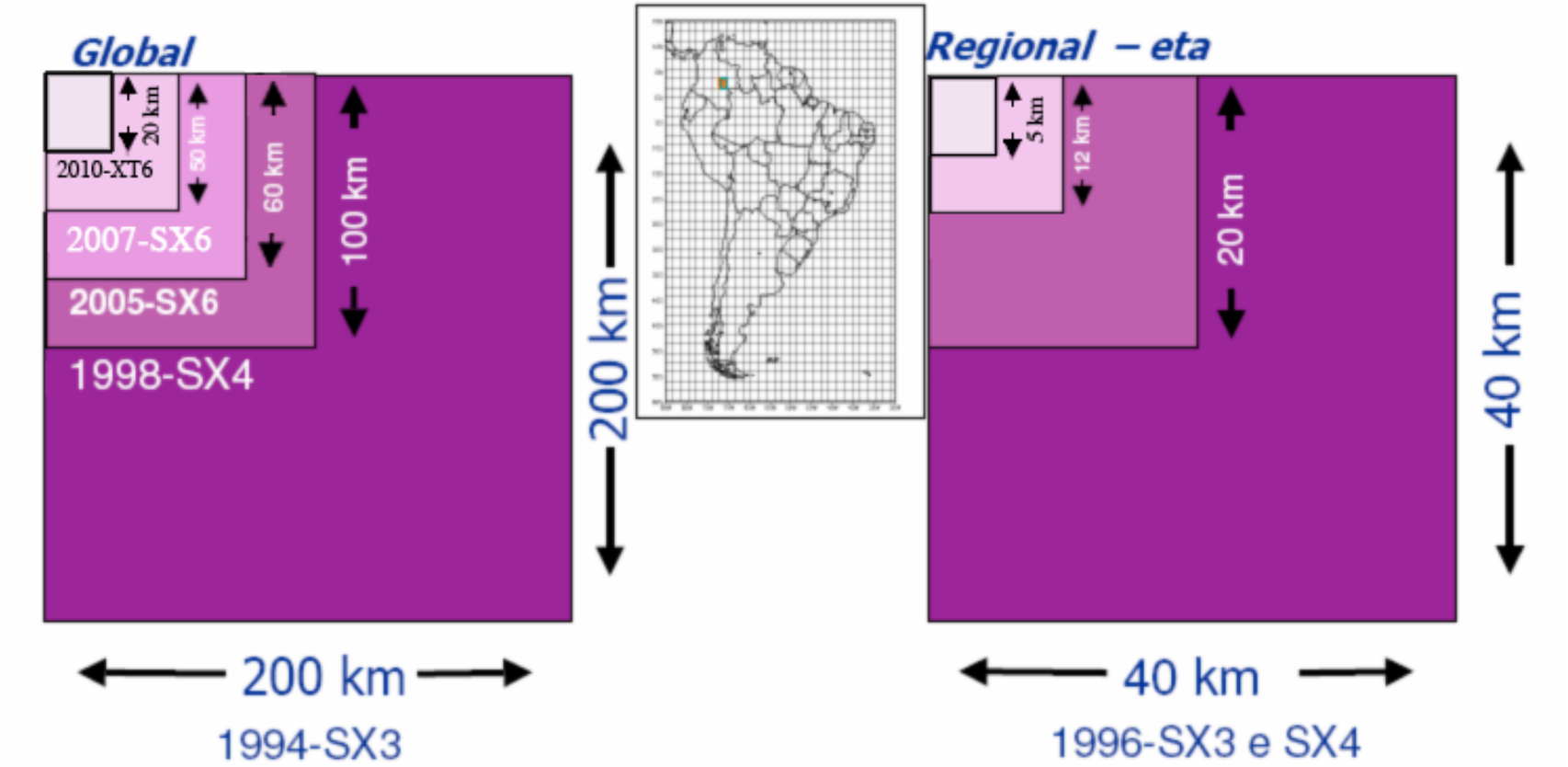
15 years of experience in developing Numerical Weather Prediction (NWP), Numerical Seasonal Climate Prediction (NSCP), Regional Climate Change Modeling, Air Quality Prediction at CPTEC, and climate modeling in general.

CPTEC's Numerical Weather Forecasting System



Coordinator: Dr. J. P. Bonatti

CPTE's Atmospheric Models: Evolution of Resolution



Vertical Levels:

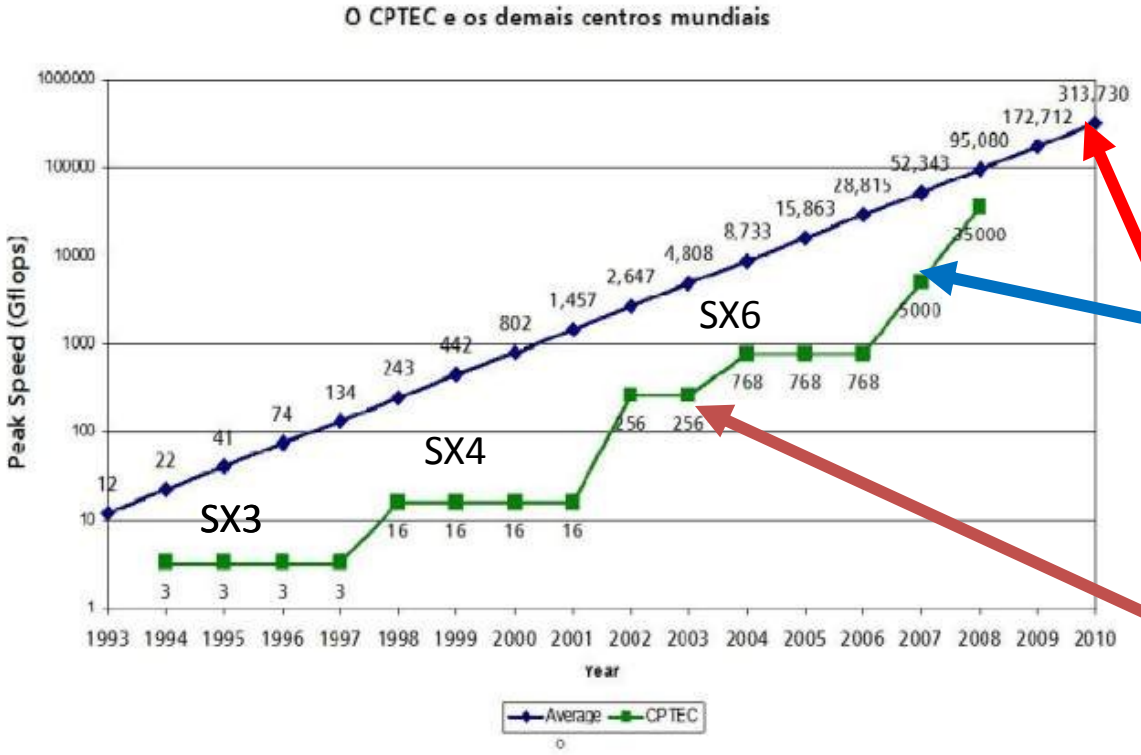
1994 – 28
2005 – 42
2006 – 64
2010 – 96

Vertical Levels:

1994 – 38
2006 – 50

Courtesy: J. P. Bonatti, INPE/CPTEC

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 Data Storage//

Courtesy: J. P. Bonatti, INPE/CPTEC

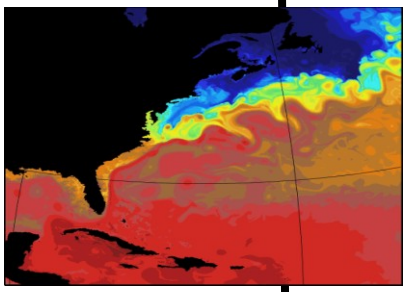
Ministério da Ciência e Tecnologia

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

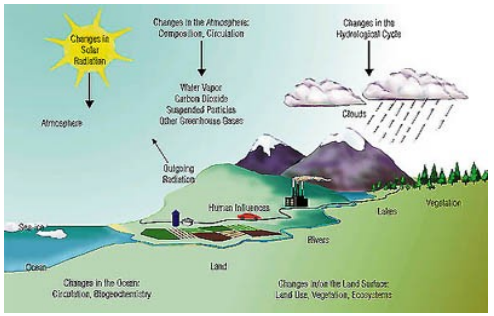
and will make it possible to run global climate model simulations at high spatial resolutions to grid sizes of 20 km !

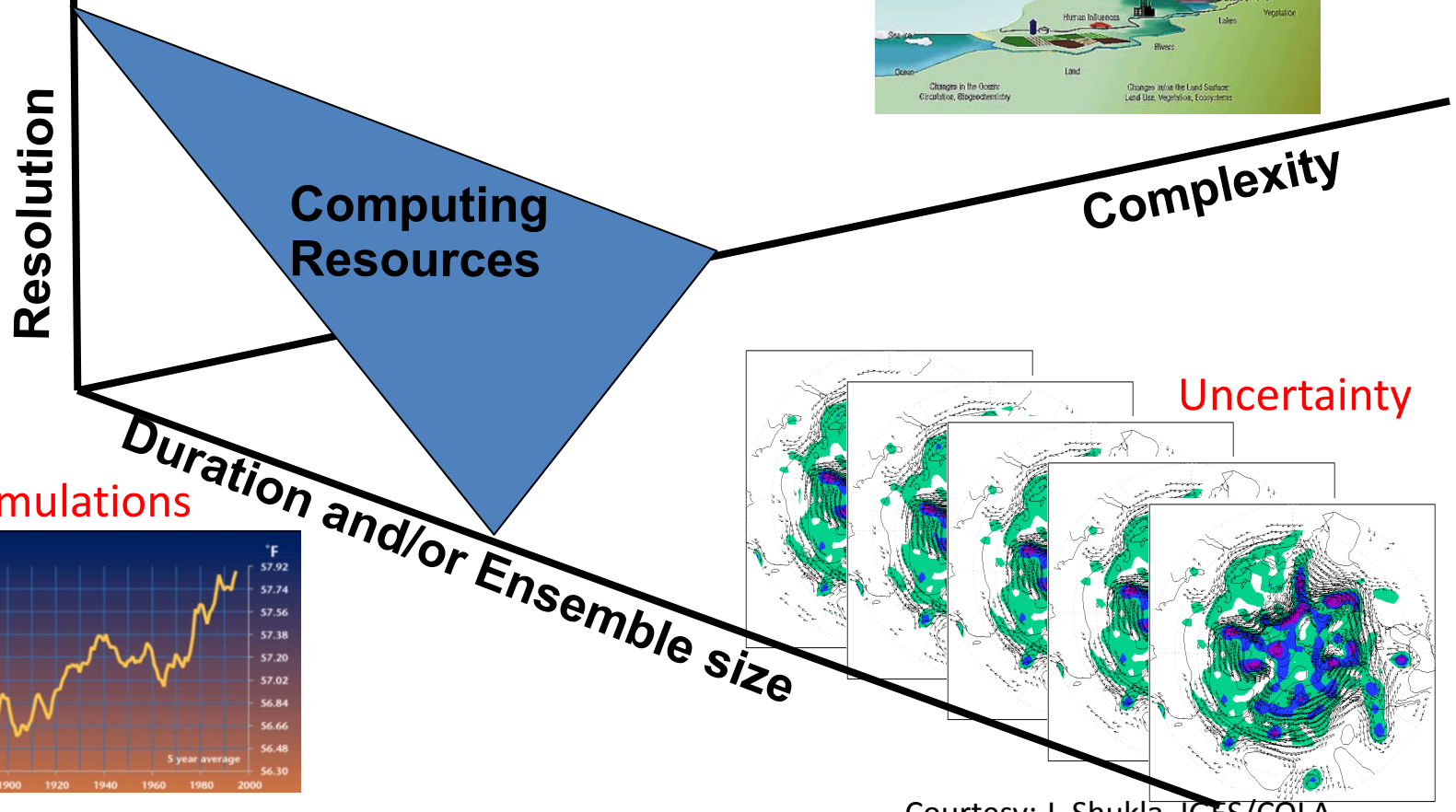
Competing demands of resolution, complexity, uncertainty, and long integrations in Climate System Modelling:



Resolution

Complexity



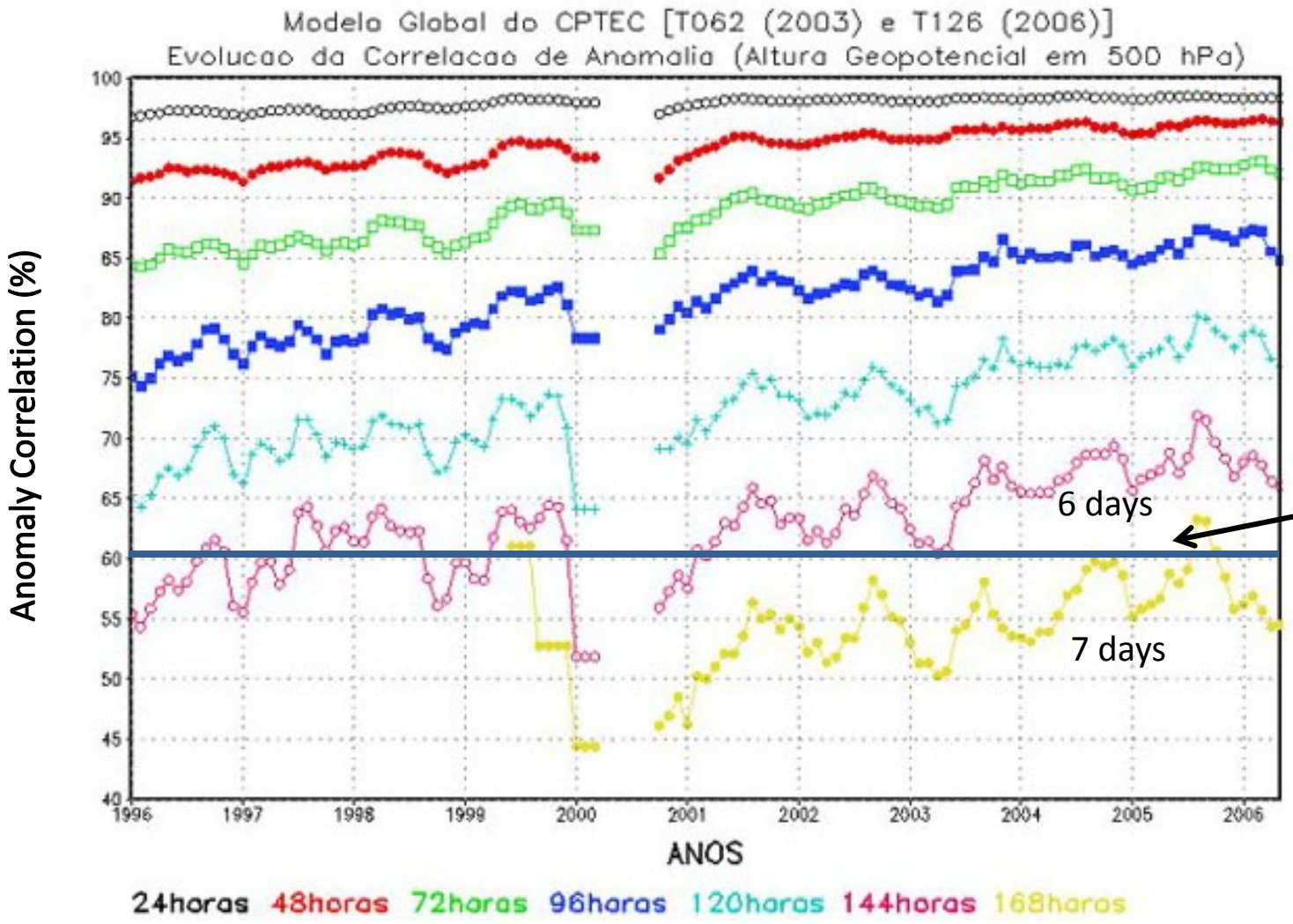


Long simulations

Uncertainty

Courtesy: J. Shukla, IGES/COLA

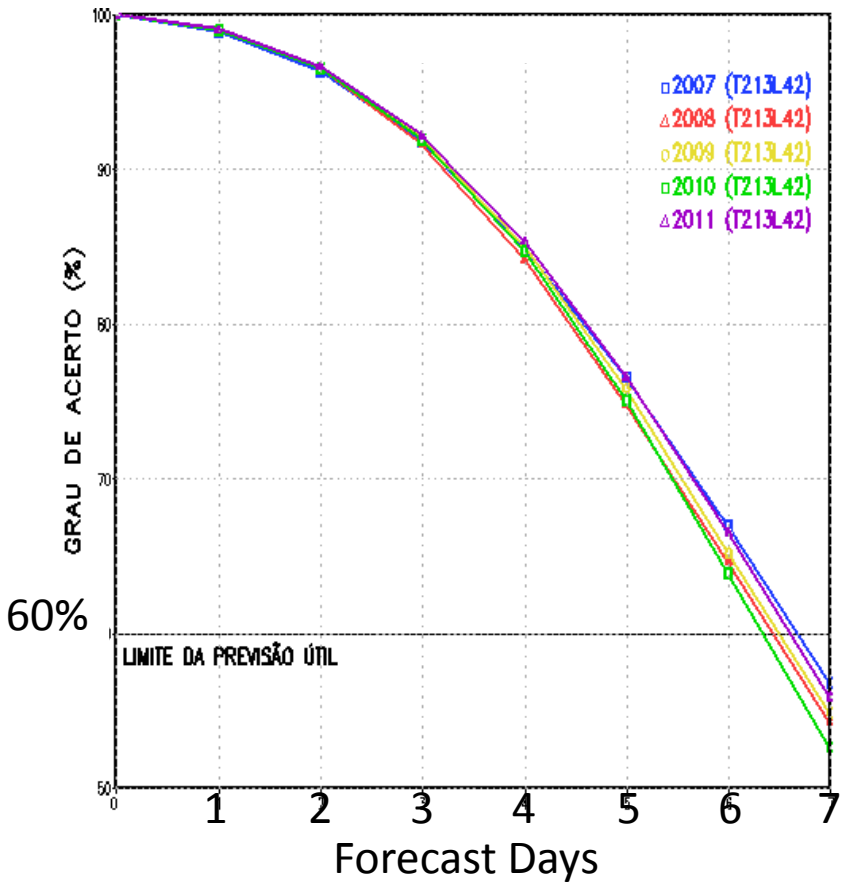
CPTEC's NWP
forecast Skill Historical Evolution



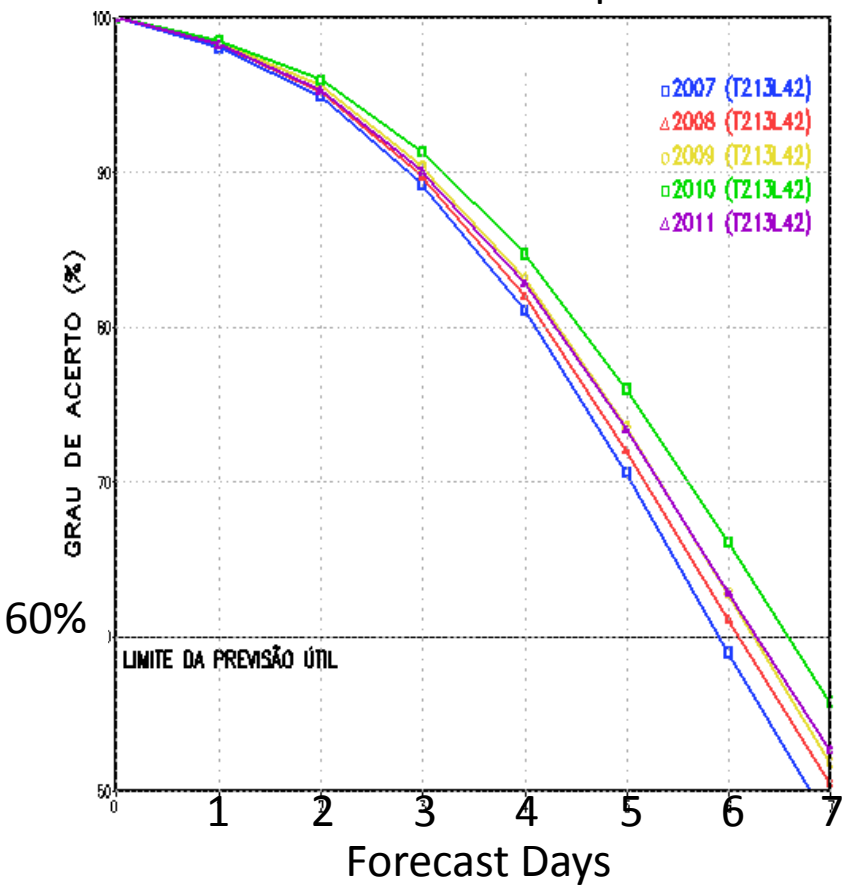
CPTEC's AGCM (T213L42)

500 hPa Geopotential Height Anomaly Correlation

Southern Hemisphere

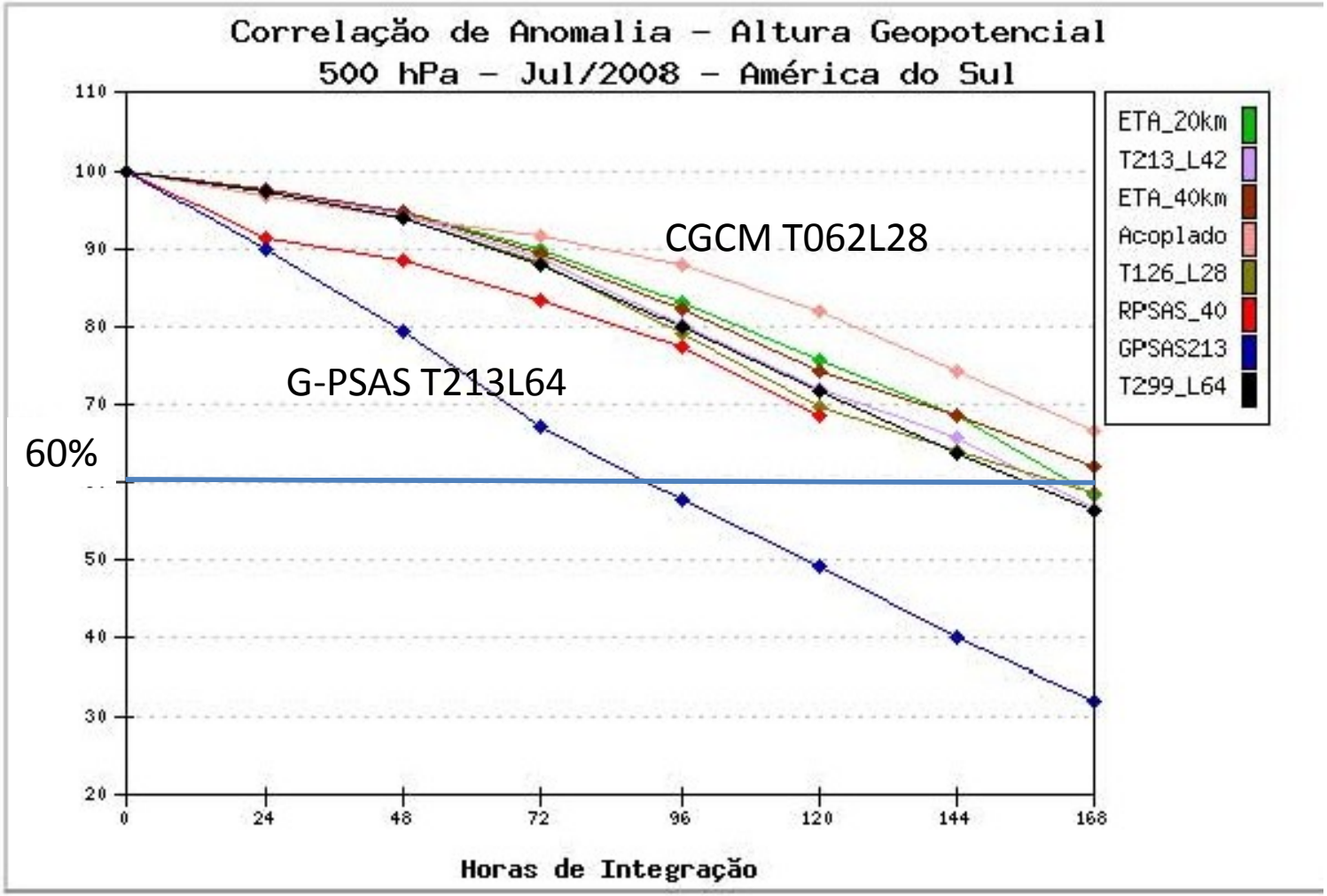


Northern Hemisphere



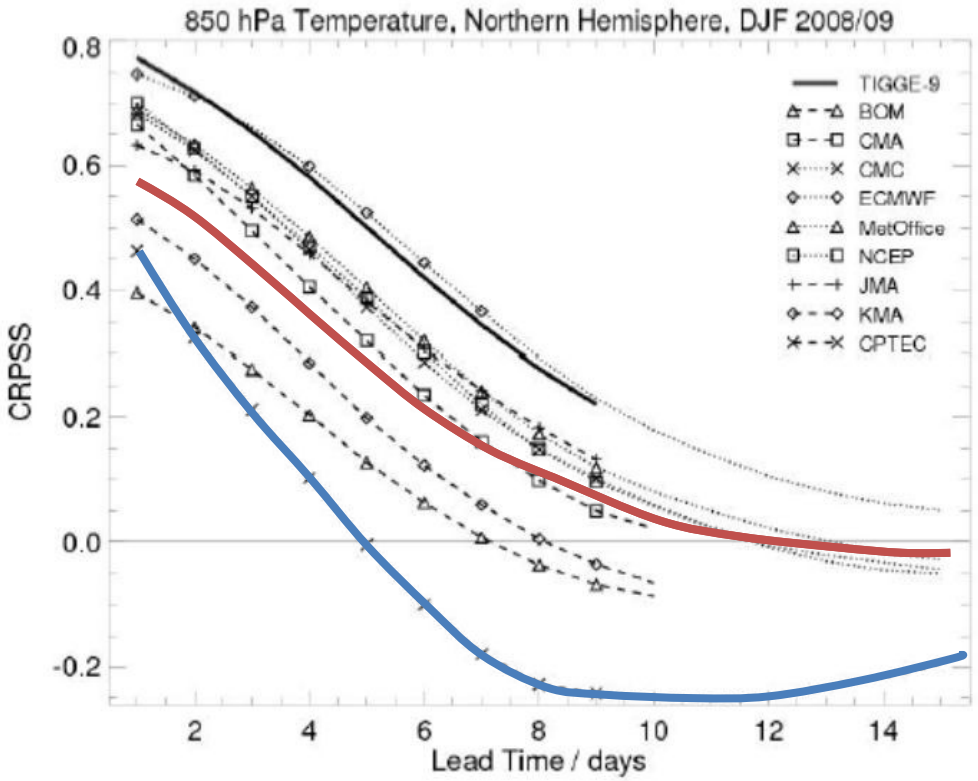
CPTEC NWP MODELS

500 hPa Anomaly Correlations
South America



CPTEC's Challenge

CRPSS: Continuous Ranked Probability Skill Score



CPTEC AGCM – in 4 years

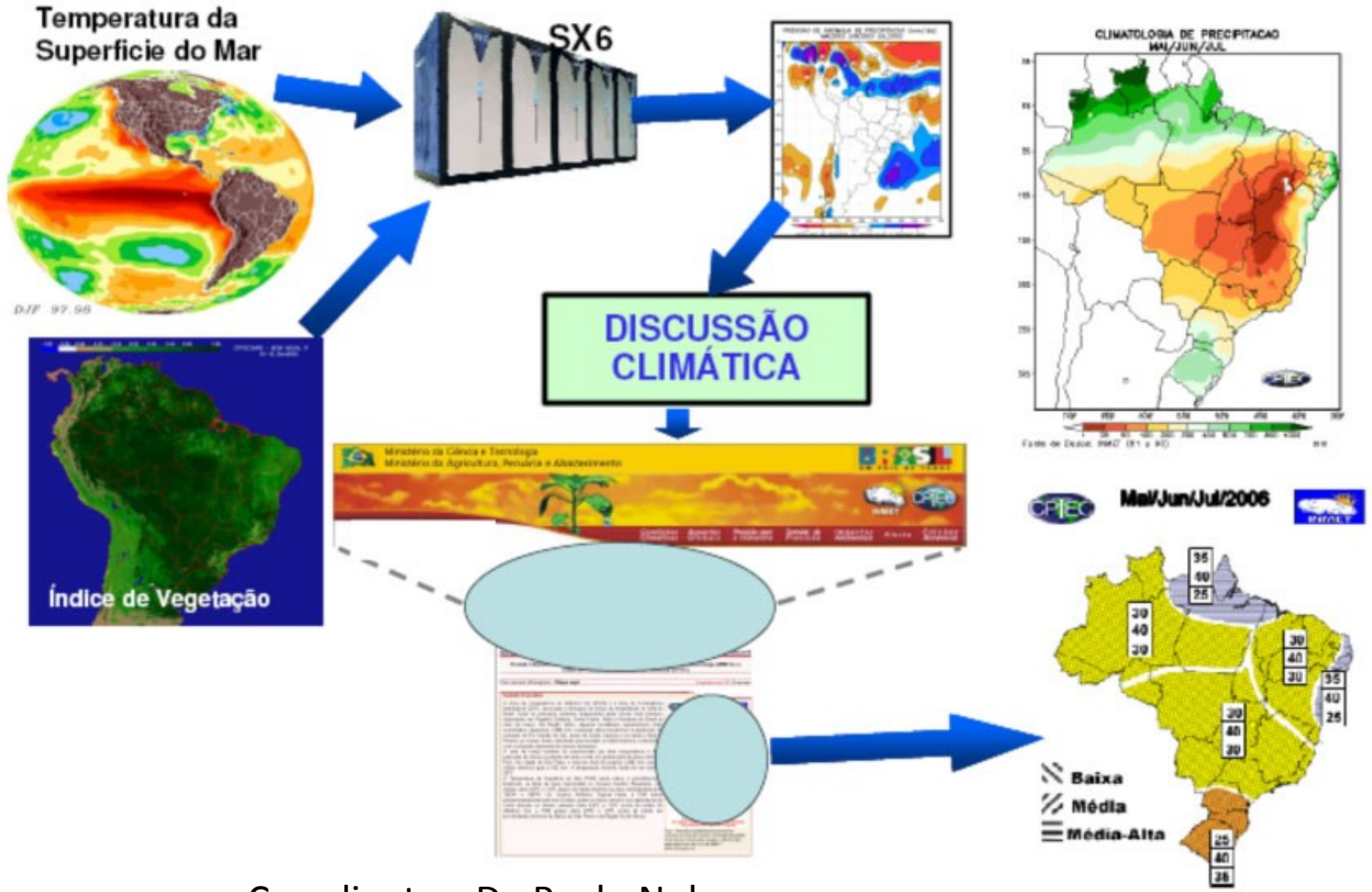
CPTEC AGCM – 2008/09

Hagedorn et al, 2010

Seasonal Climate Prediction at INPE: Timeline

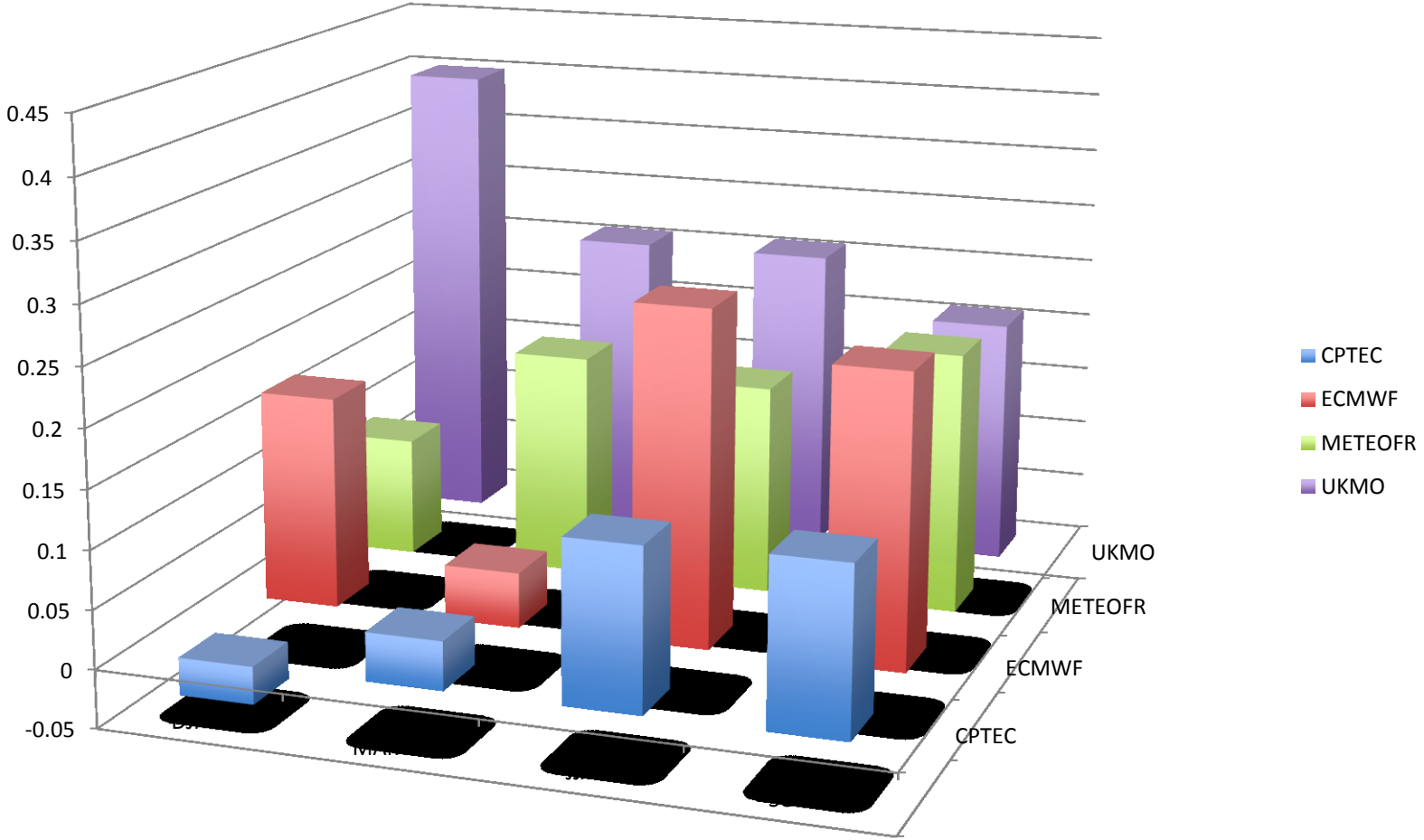
- 1987 – Conceptual Prediction of northern Nordeste MAM Precipitation Anomalies: ENSO, Atlantic Dipole, NAO…
- 1995 – CPTEC/COLA T62L28 AGCM's 5 member ensembles: additional element to the consensus prediction (persisted SSTA globally).
- 1997 – CCA statistical prediction for tropical Atlantic SSTA and 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's Seasonal Climate Prediction System



Coordinator: Dr. Paulo Nobre

COUPLED O-A SEASONAL FCST
ROC SKILL SCORES
AVERAGED OVER BRAZIL



Data Source: Eurobrisa; This figure: Paulo Nobre; 02MAR2011

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:

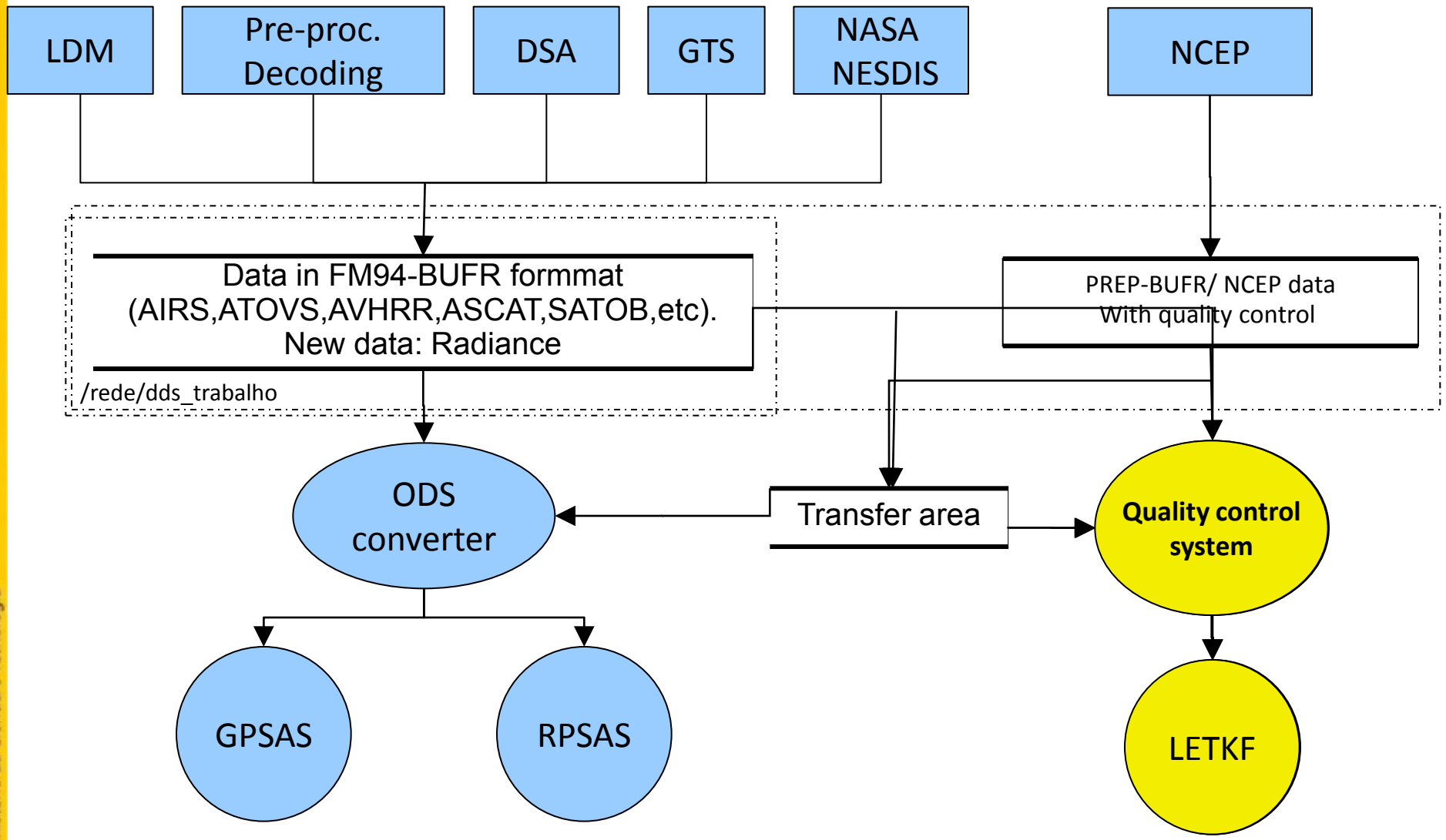
- Primitive Equations (Zonal and Meridional Winds)
- Semi-Implicit Time Integration (Semi-Lagrangean) and Asselin Filter

Courtesy: J. P. Bonatti, INPE/CPTEC

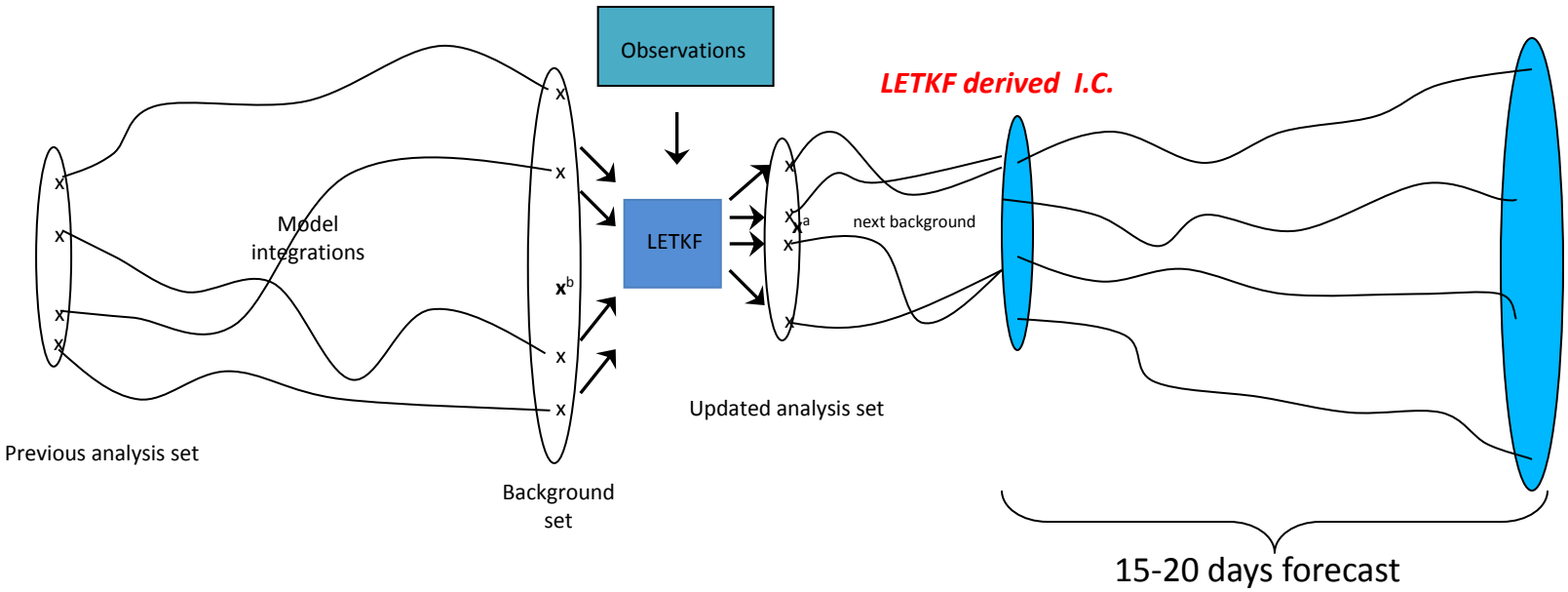
Current developments on the CPTEC's AGCM

- Atmospheric data assimilation using LETKF.
- Inclusion of gas-phase chemistry and aerosols.
- Inclusion of PBL scheme from Hostlag and Boville (1993).
- SIB2.5 and IBIS-2.6 surface schemes.
- Deep convection scheme from Zhang et al. (1995).
- Shallow convection from Hack et al., (1994).
- Cloud microphysics (Kiehl et al, 1996) porting routines from the CAM Model.

Simplified Description of the Current Data Stream



Plans for use of the LETKF at CPTEC's seasonal forecast system



"Among other applications we are working towards using the analysis uncertainty statistics provided by the LETKF system to improve the initialization of CPTEC's mid-range seasonal forecast…"

Leading Researcher: Dr. G. Gonçalves

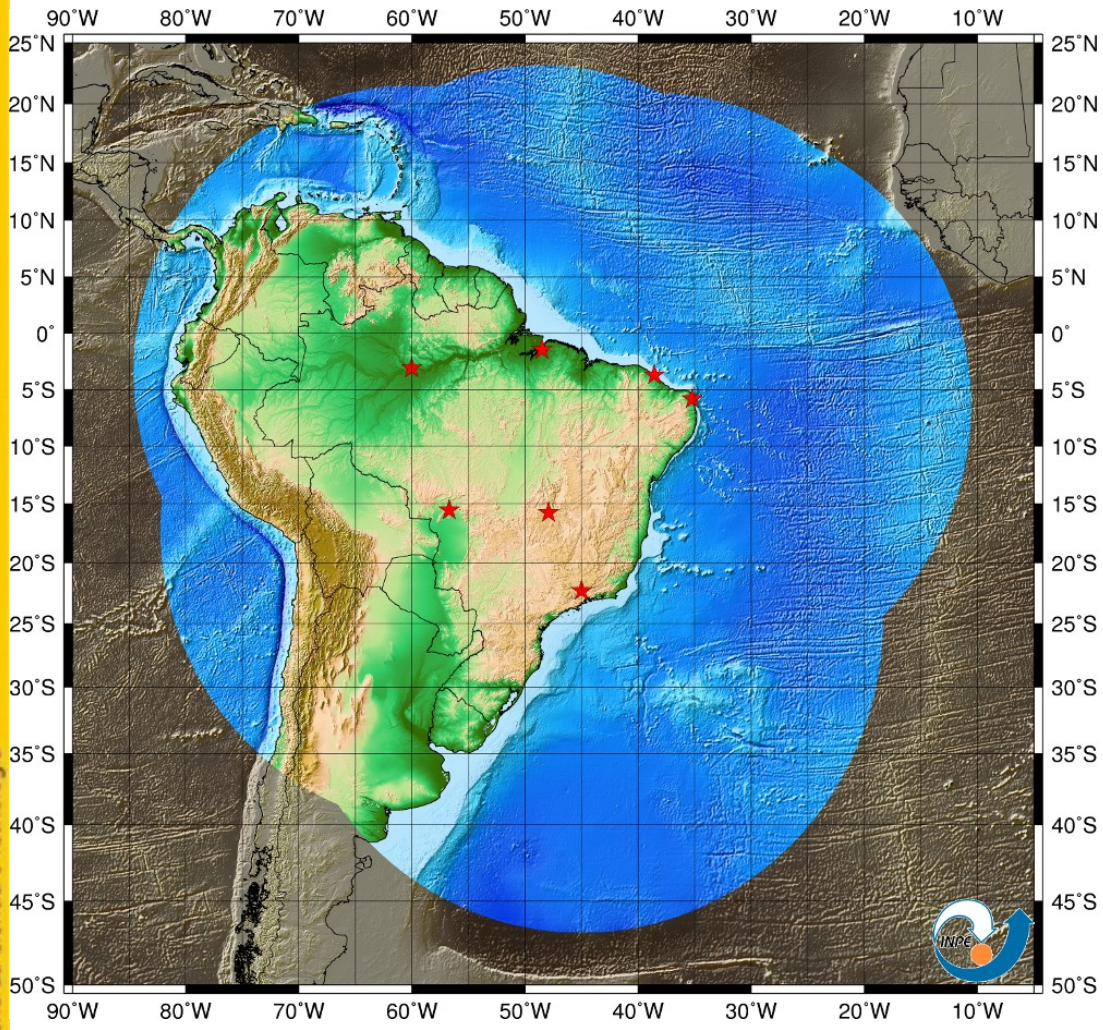
Towards a broader use of satellite to NWP in CPTEC

- CPTEC is working on the implementation of the new data assimilation system (LETKF – Local Ensemble Transform Kalman Filter). Details on LETKF: Dr. José Aravéquia (also attending the workshop).

- Direct assimilation of satellite radiance data in numerical weather prediction (NWP) assimilation systems has proved to be an essential component for improving forecast skill, particularly for global models (e.g., McNally et al., 2000).

- In this context, satellite data receiving and satellite data monitoring are essential.

Satellite data receiving, pre-processing and disseminating



- INPE operates ground receiving stations for polar-orbiting satellite (ATOVS sounding acquisitions for Brazilian RARS network).

- INPE reception antennas:
  - Cachoeira Paulista
  - Cuiabá
  - Natal (since beginning 2011)
  - Belém (planned 2012)
  - Boa Vista (planned 2012)

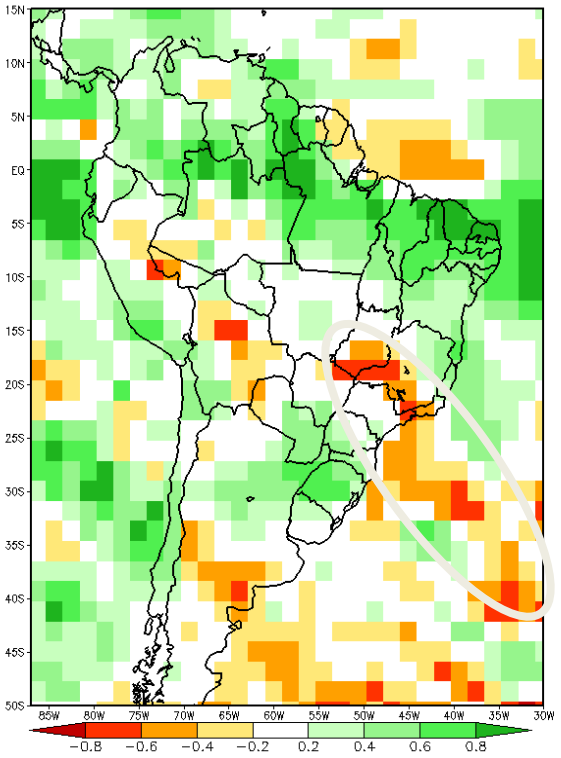
- INPE also pre-process data from
  - Brasilia (INMET)
  - Fortaleza (Funceme)

Scientific Challenges Ahead

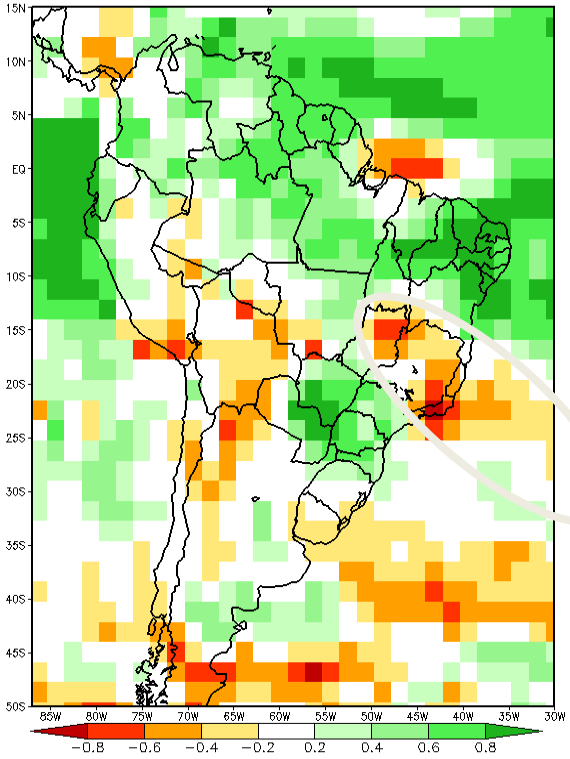
- Summer rainfall over Southeastern South America – The South Atlantic Convergence Zone
- Systematic errors of Coupled Ocean-Atmosphere GCMs over the equatorial Atlantic
- The role of the Amazon Forest hydrology on global climate

SACZ low predictability
Using AGCM 2-tier approach

DJF



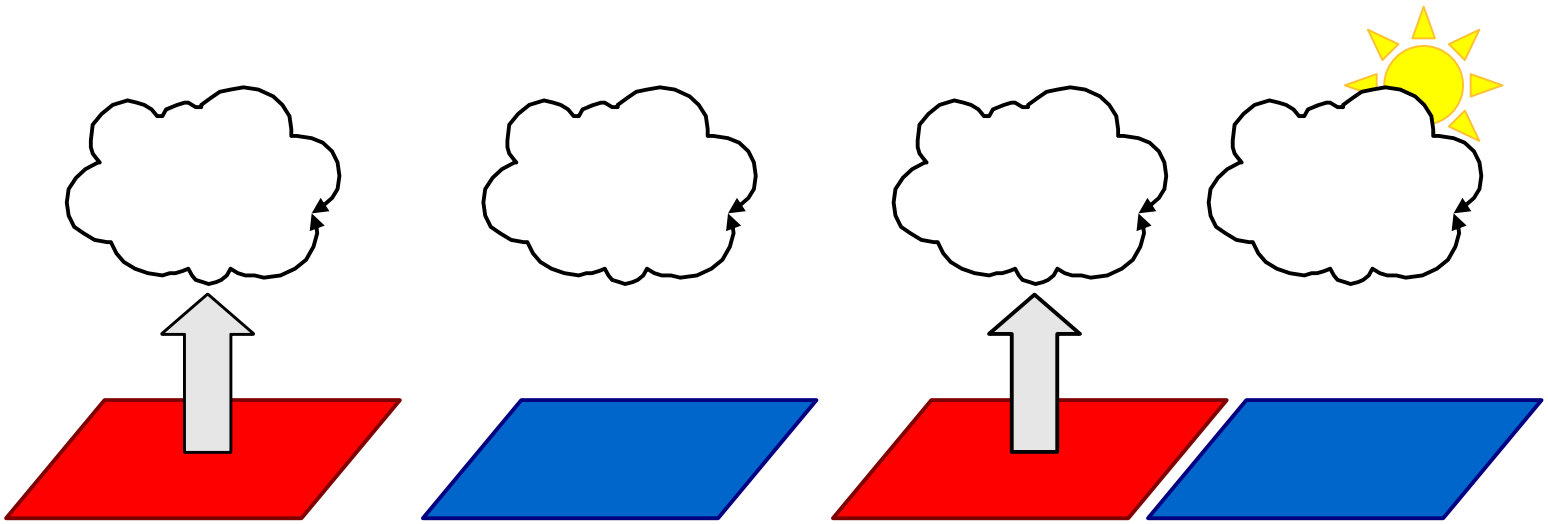
MAM



CPTEC AGCM, 50 years, 10 Member Ensemble, Kuo, T062L28, Obs SST

Marengo et al. (2002)

The dynamics of the SACZ



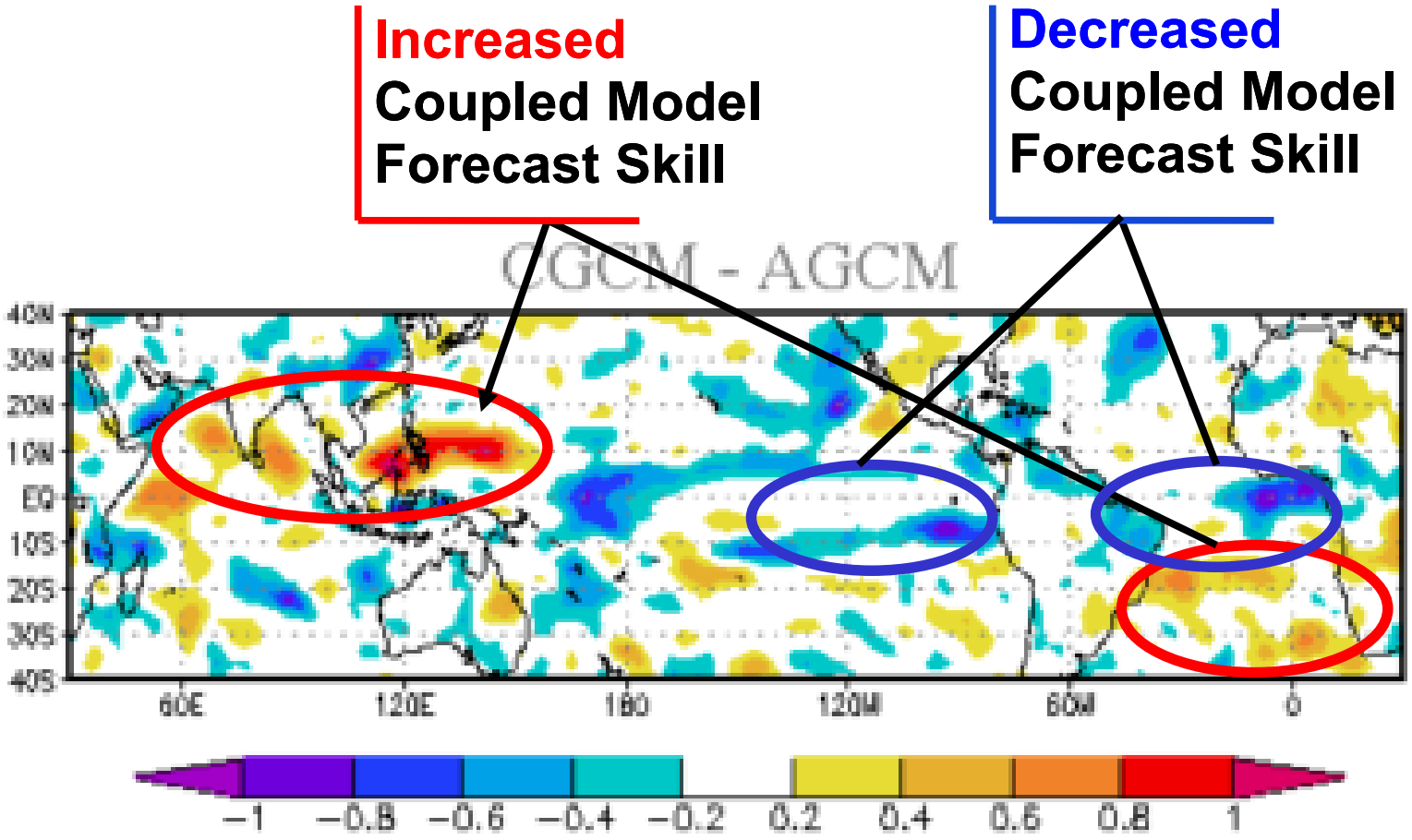
Hidrostatic

Robertson & Mechoso (2000)

Chaves and Nobre (2004)
De Almeida & al (2007)
Nobre et al. (2011)

Coupled Ocean-Atmosphere processes at play

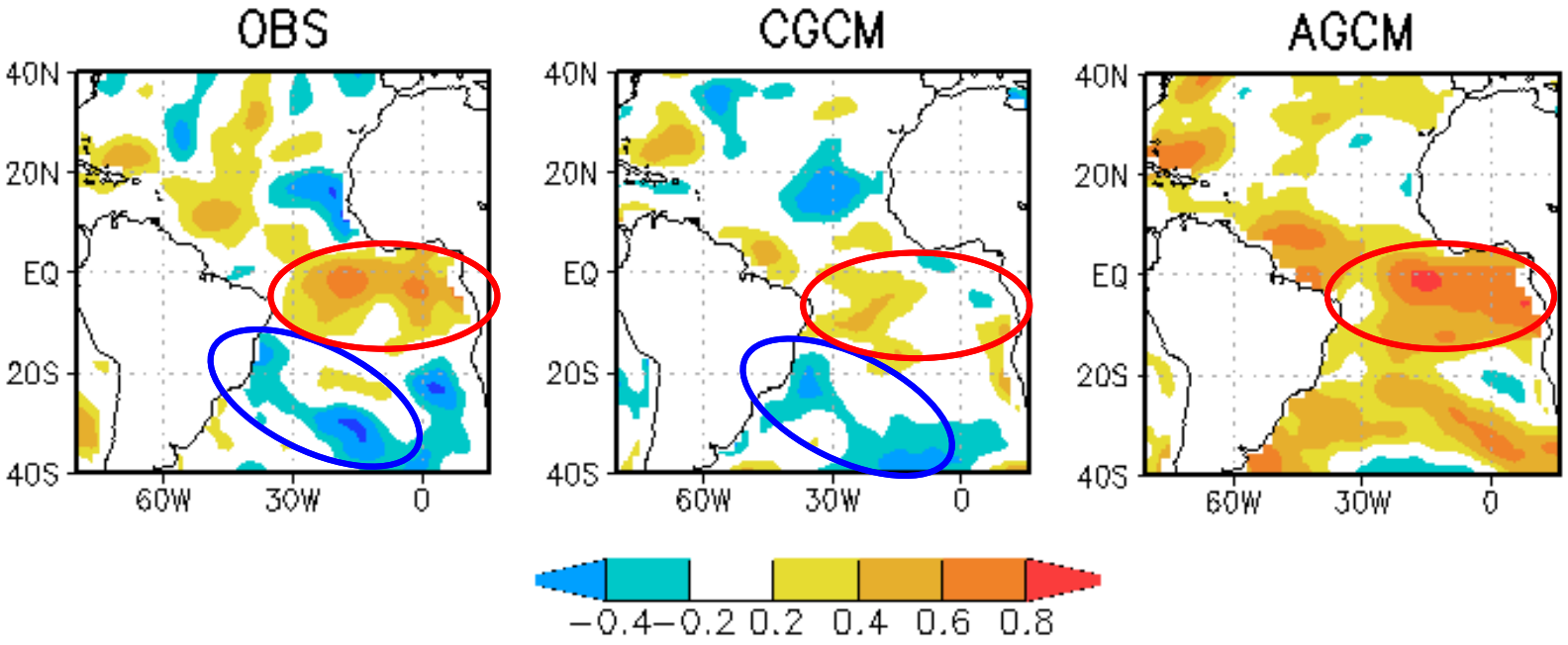
DJF Precipitation Forecasts anomaly correlations



20 years, 10 member ensemble CGCM & tween AGCM runs

Nobre et al. (2005)

Rainfall – SST
Anomaly Correlations

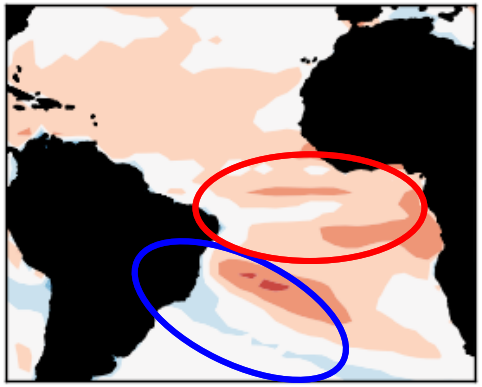


20 years, 10 member ensemble CGCM & tween AGCM runs

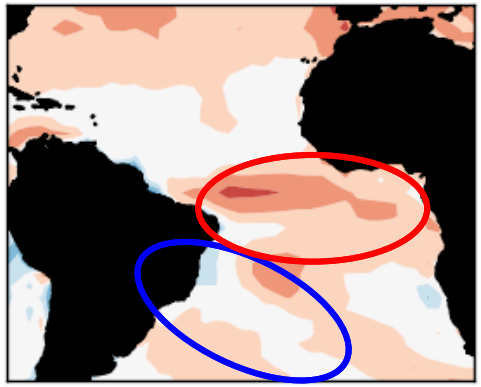
Nobre et al. (2011, revision)

Ensembles Coupled Forecasts SST-Rainfall Anomaly Correlations

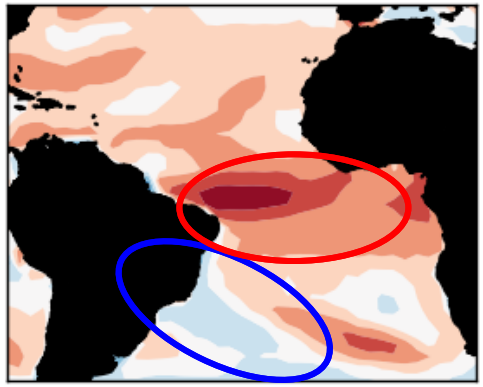
IFS/HOPE



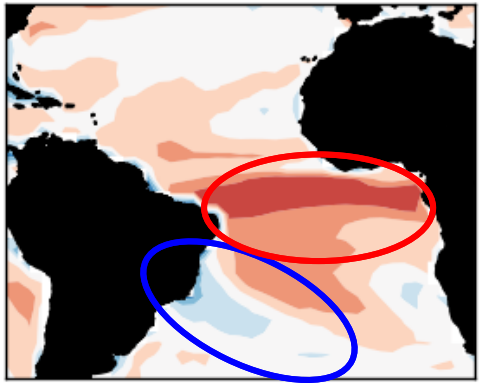
ARPEGE4/OPA



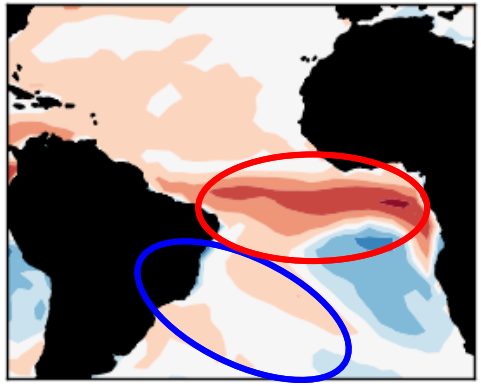
HadGEM2



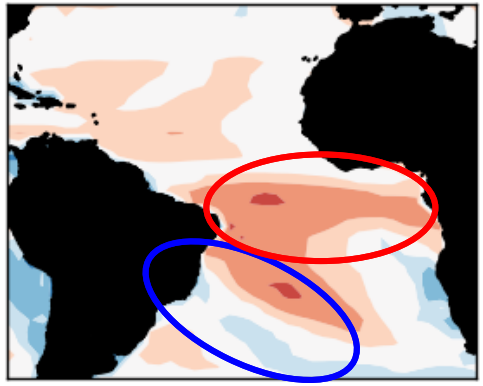
ECHAM5/OPA8.2



ECHAM5/OM1

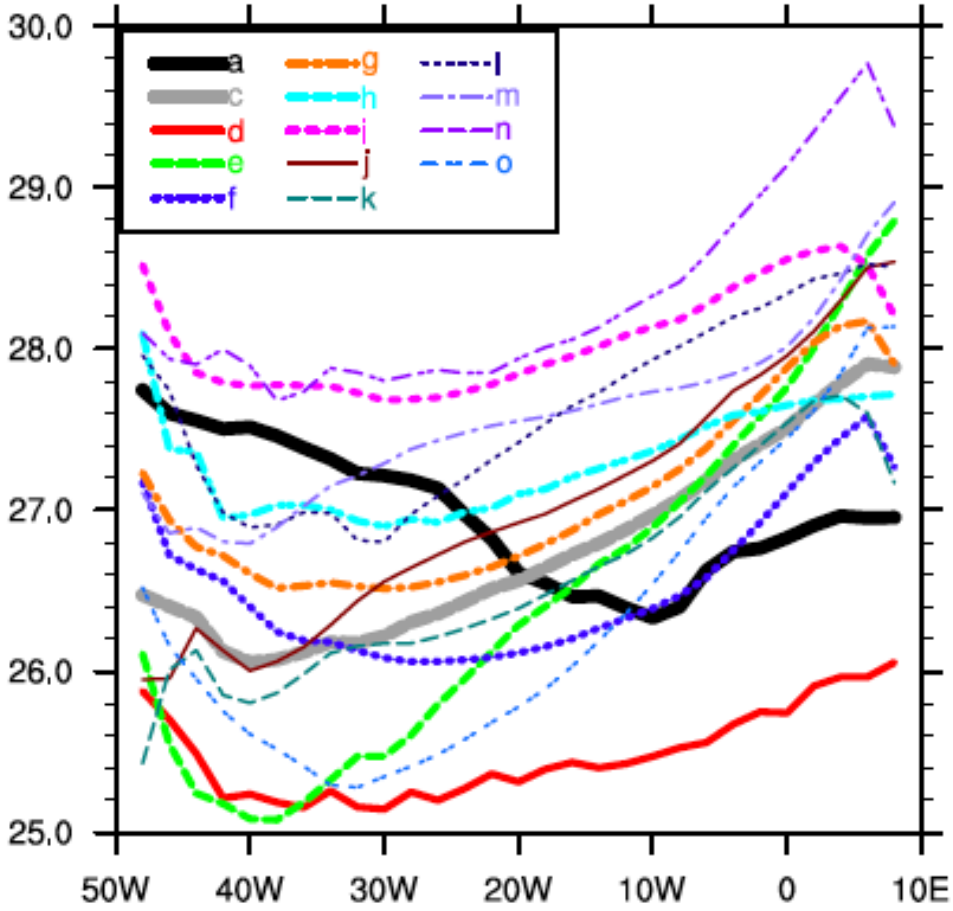


DePreSys



Nobre et al. (2011, revision)

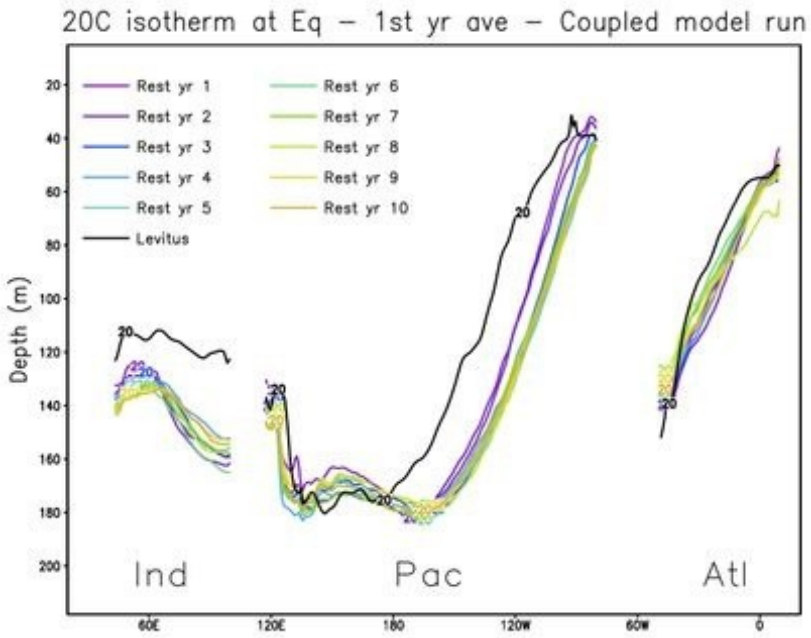
Coupled O-A Models inability to simulate Eq. Atlantic SST zonal gradient



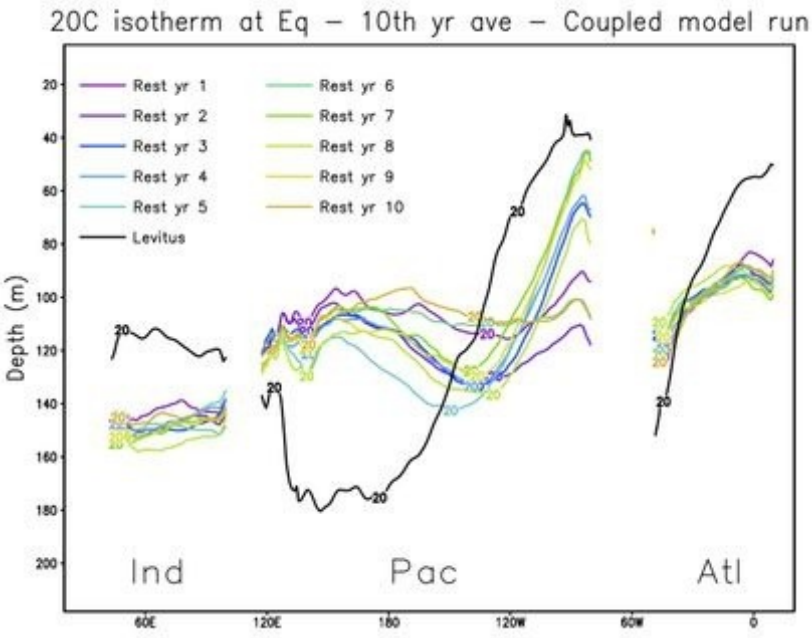
Richter and Xie, 2008

CPTEC's CGCM 2.1 Z20 multi-year runs

1st Year Several IC

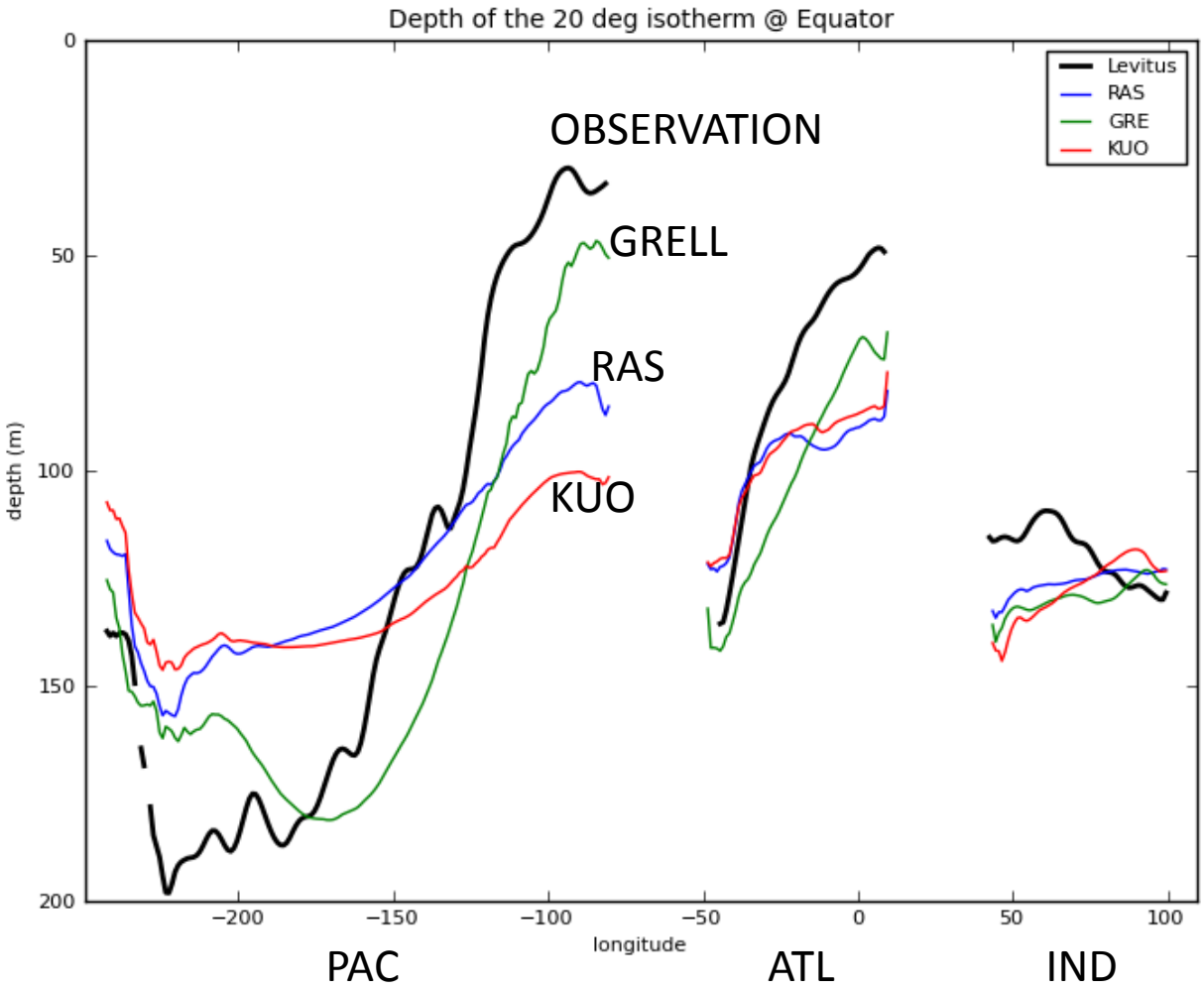


10th Year Several IC



Nobre et al (2011, in prep.)

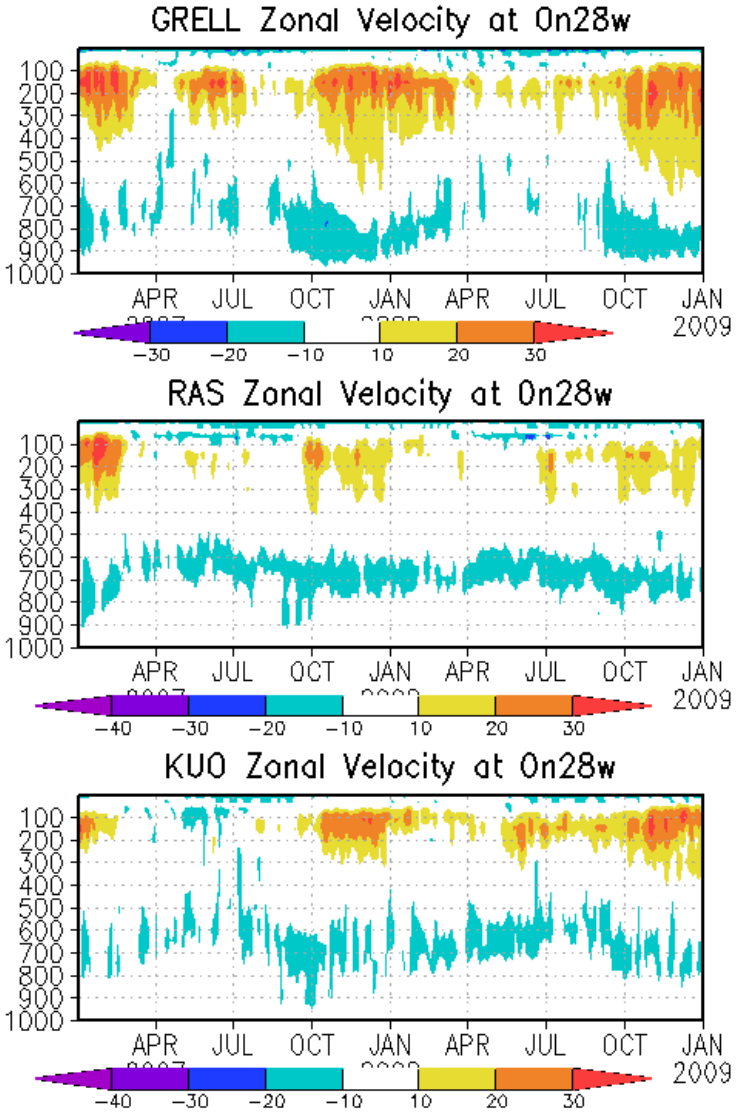
CPTEC CGCM 2.1 Z20



Nobre et al (2011, in prep.)

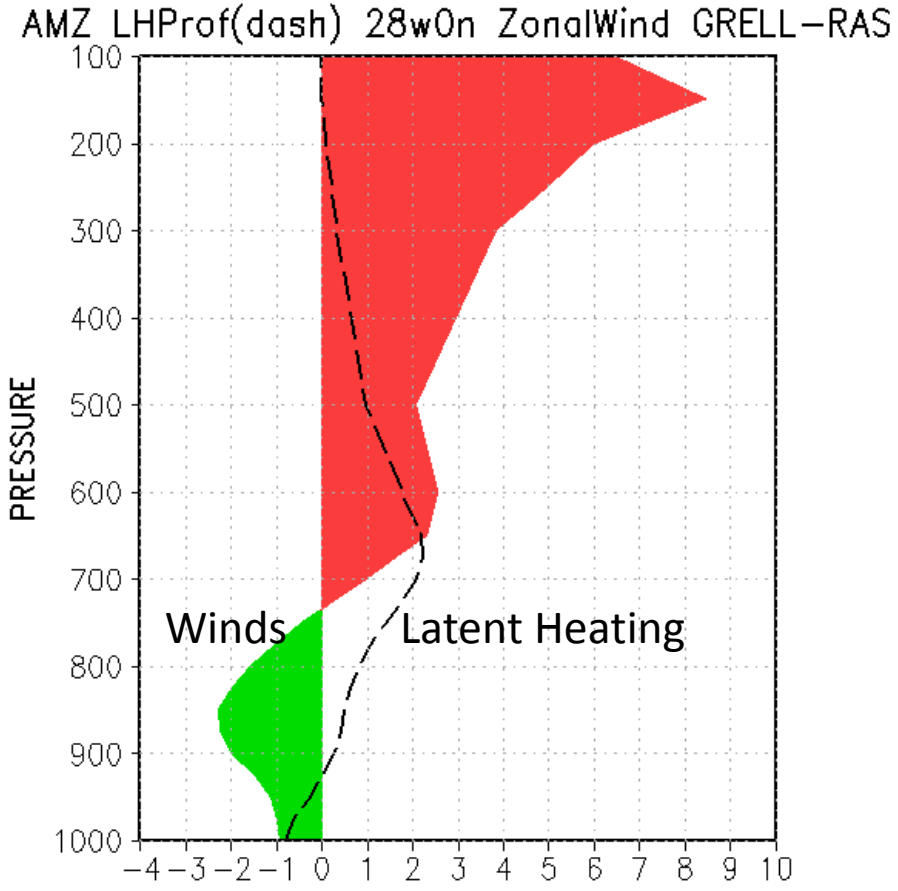
CPTEC CGCM V 2.1

Eq. Atlantic Zonal Wind Vertical Profile



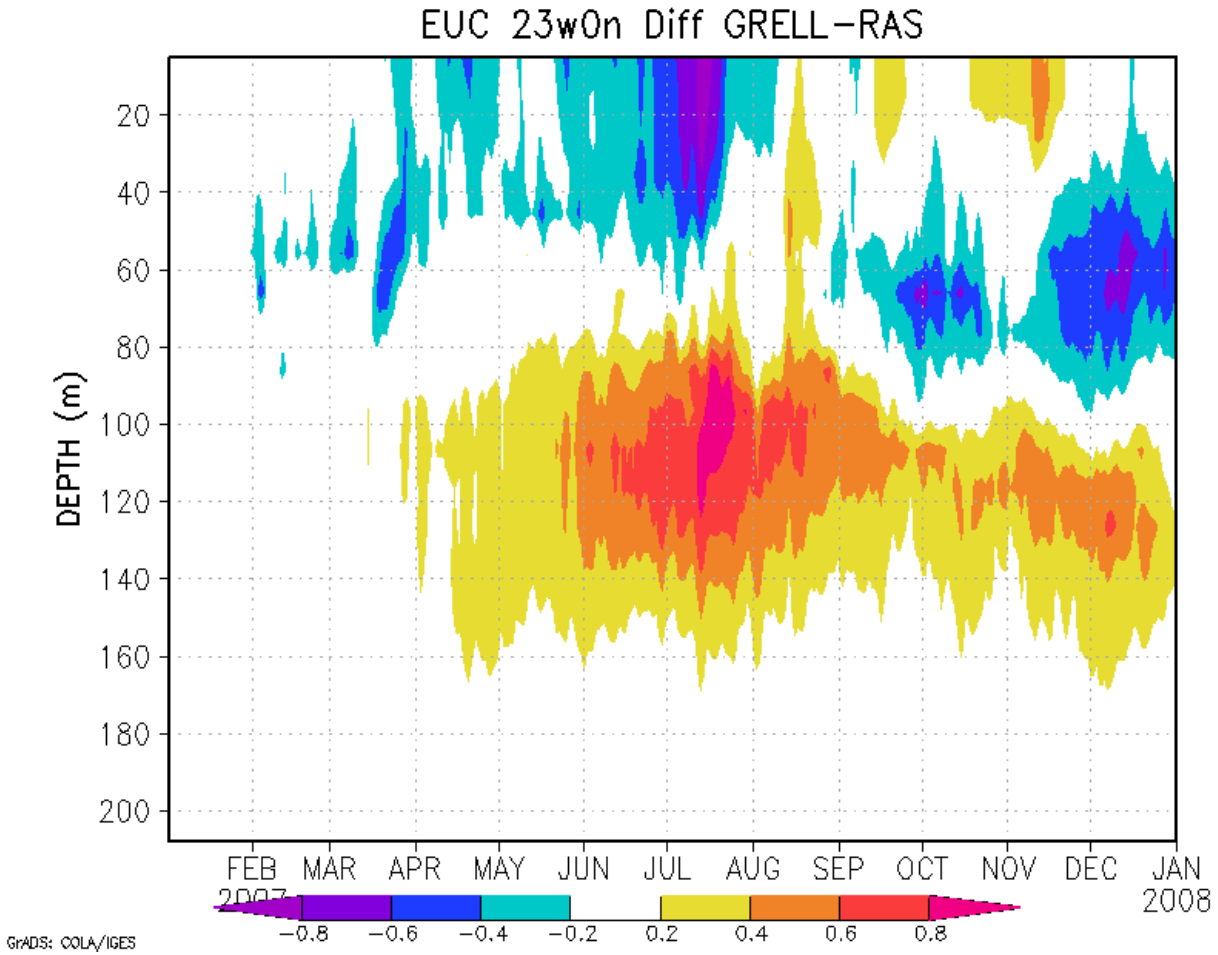
Nobre et al (2011, in prep.)

Winds and Latent Heating



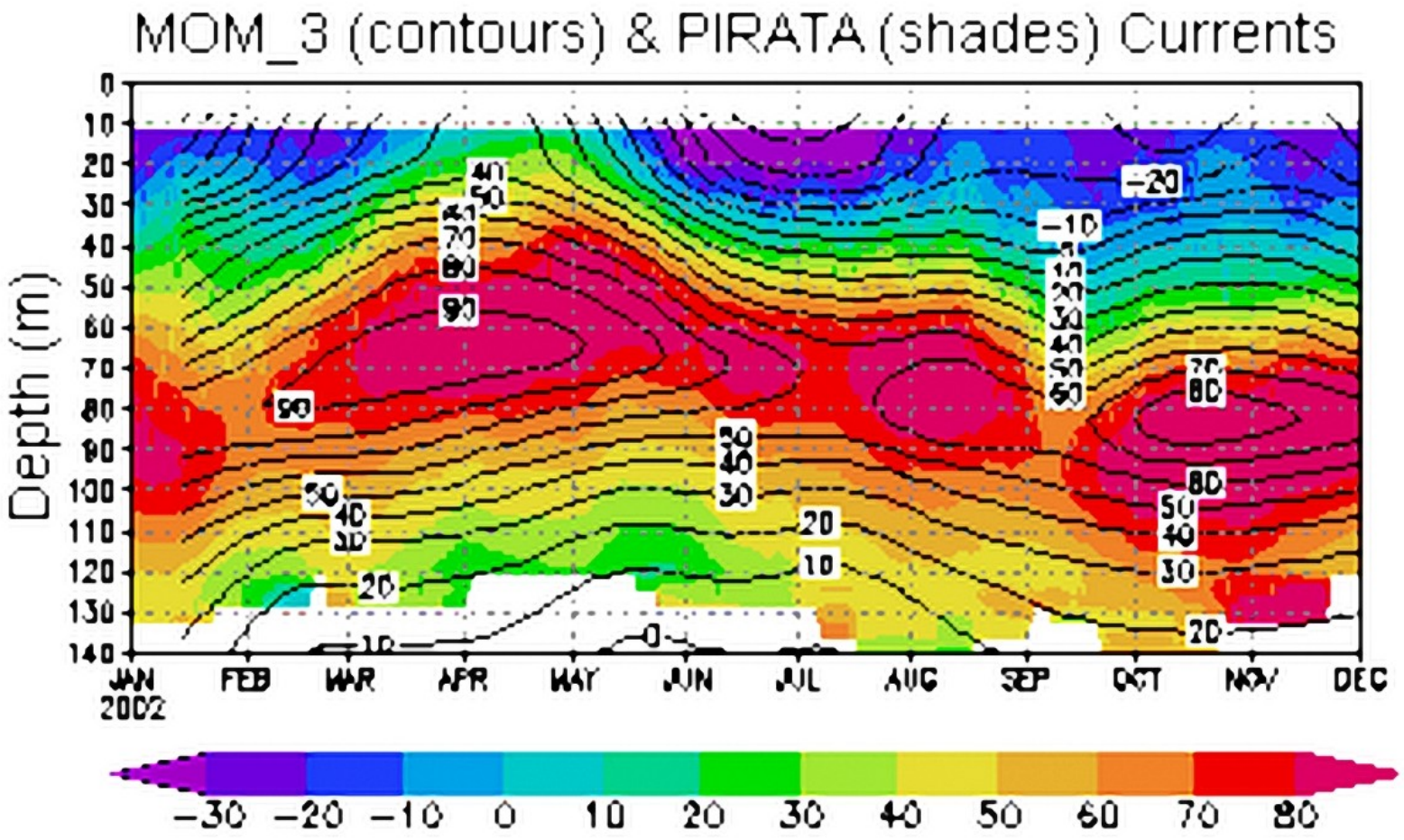
Nobre et al (2011, in prep.)

… reflecting in the Shallowing of the Atlantic EUC



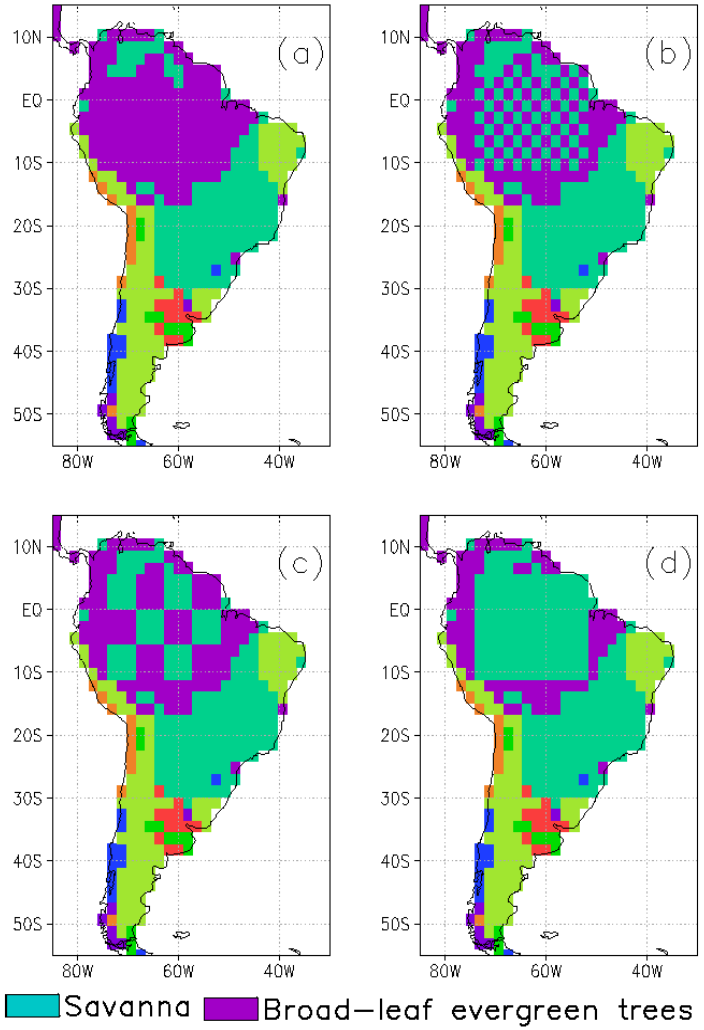
Nobre et al (2011, in prep.)

Atlantic EUC Obs & Forced Simulation at 23W



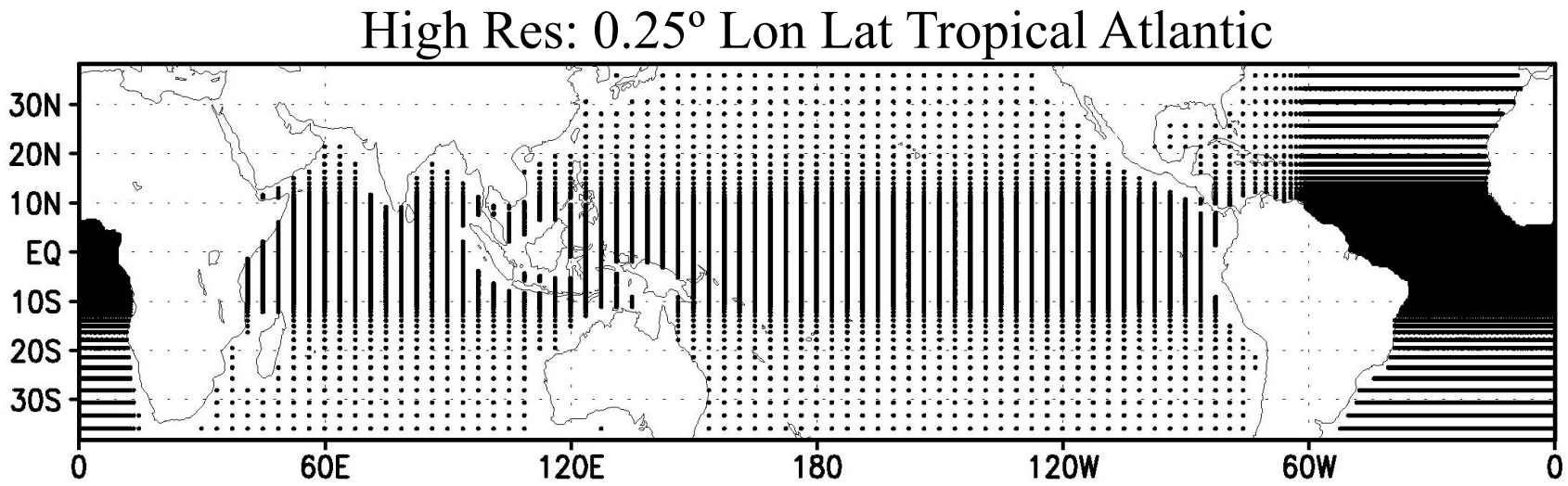
Giarola et al. (2005) GRL

Vegetation Scenarios



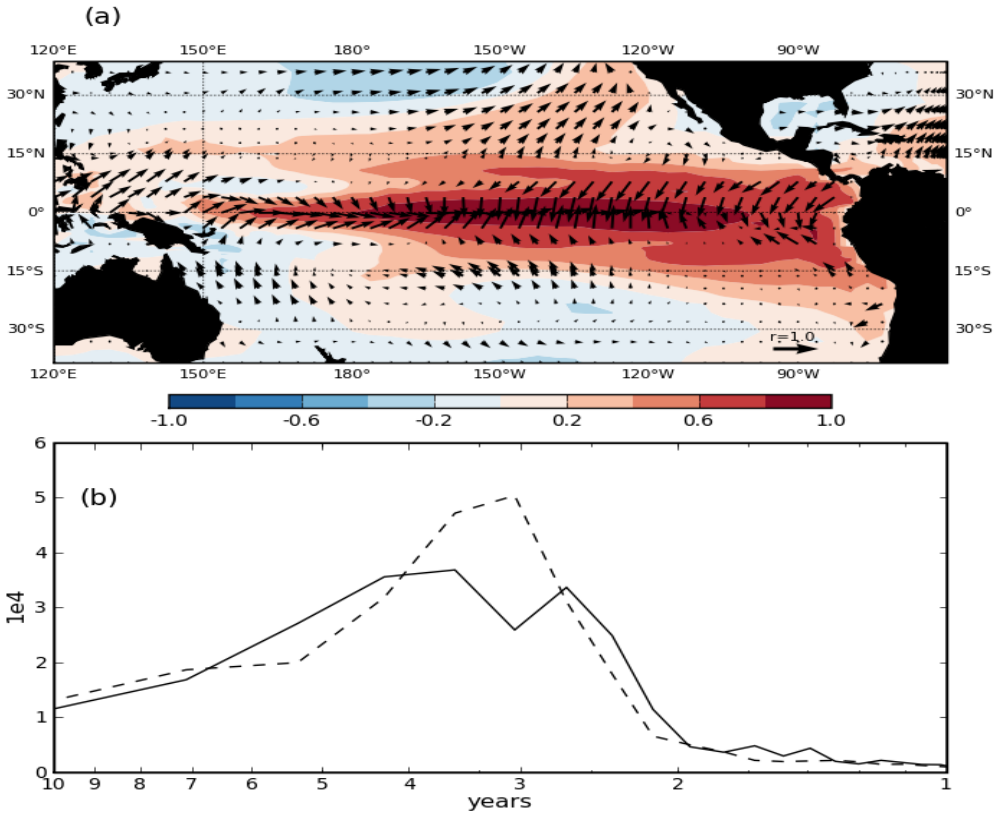
Nobre et al. (2009) J. Climate

CGCM1.0 Ocean Grid



Nobre et al. (2009) J. Climate

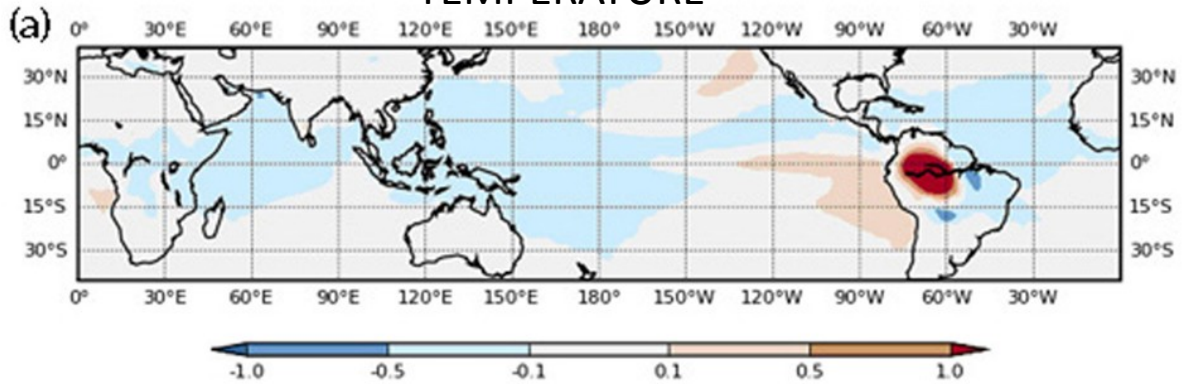
1st EOF SST-Wind Stress



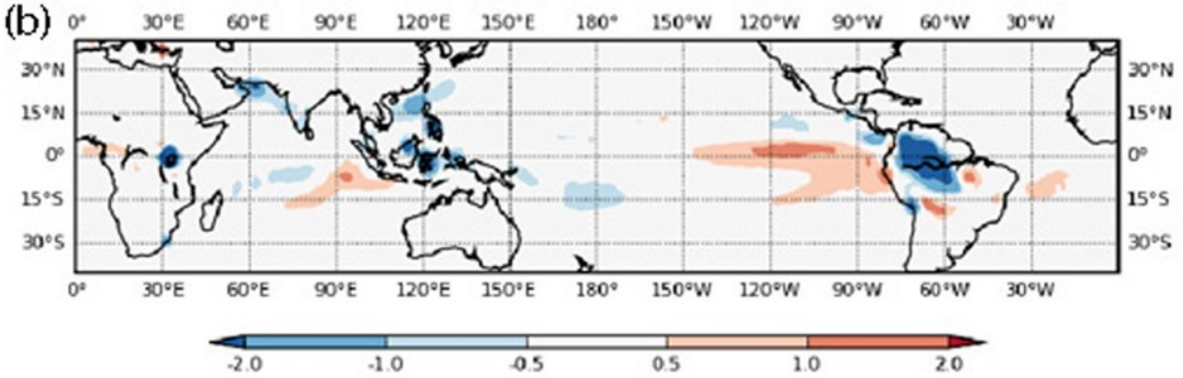
Nobre et al. (2009) J. Climate

Amazon Deforestation Experiment: Increased El Niño Conditions

TEMPERATURE



PRECIPITATION

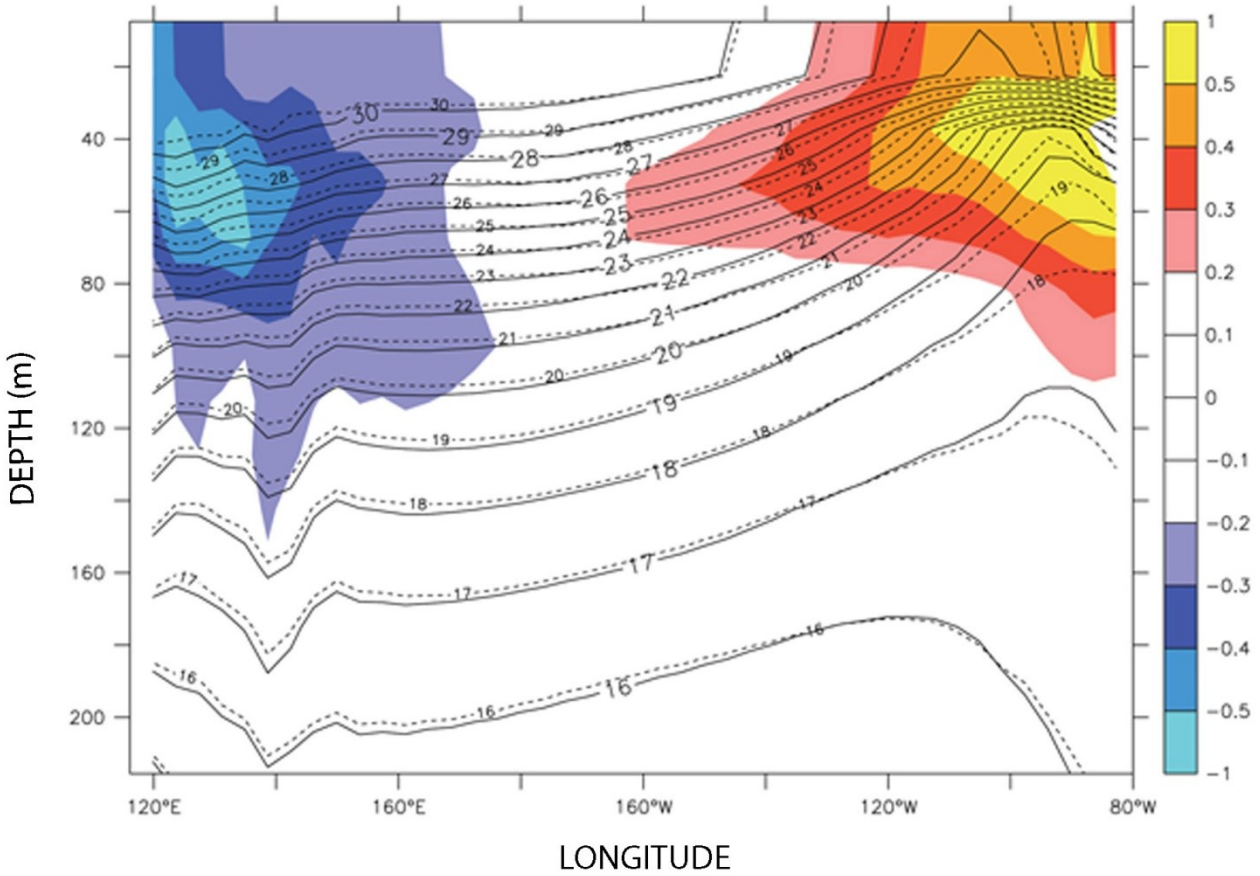


Statistically significant departures are shaded

Nobre et al. (2009) J. Climate

Pacific Thermocline Depth

Deforest – Ctrl (shades)



Nobre et al. (2009) J. Climate

Why do we need our own coupled Ocean-Land-Atmosphere model?

- Represent processes that are important to South America 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 modellers
- Advance climate science
- Collaborate with countries with similar interests

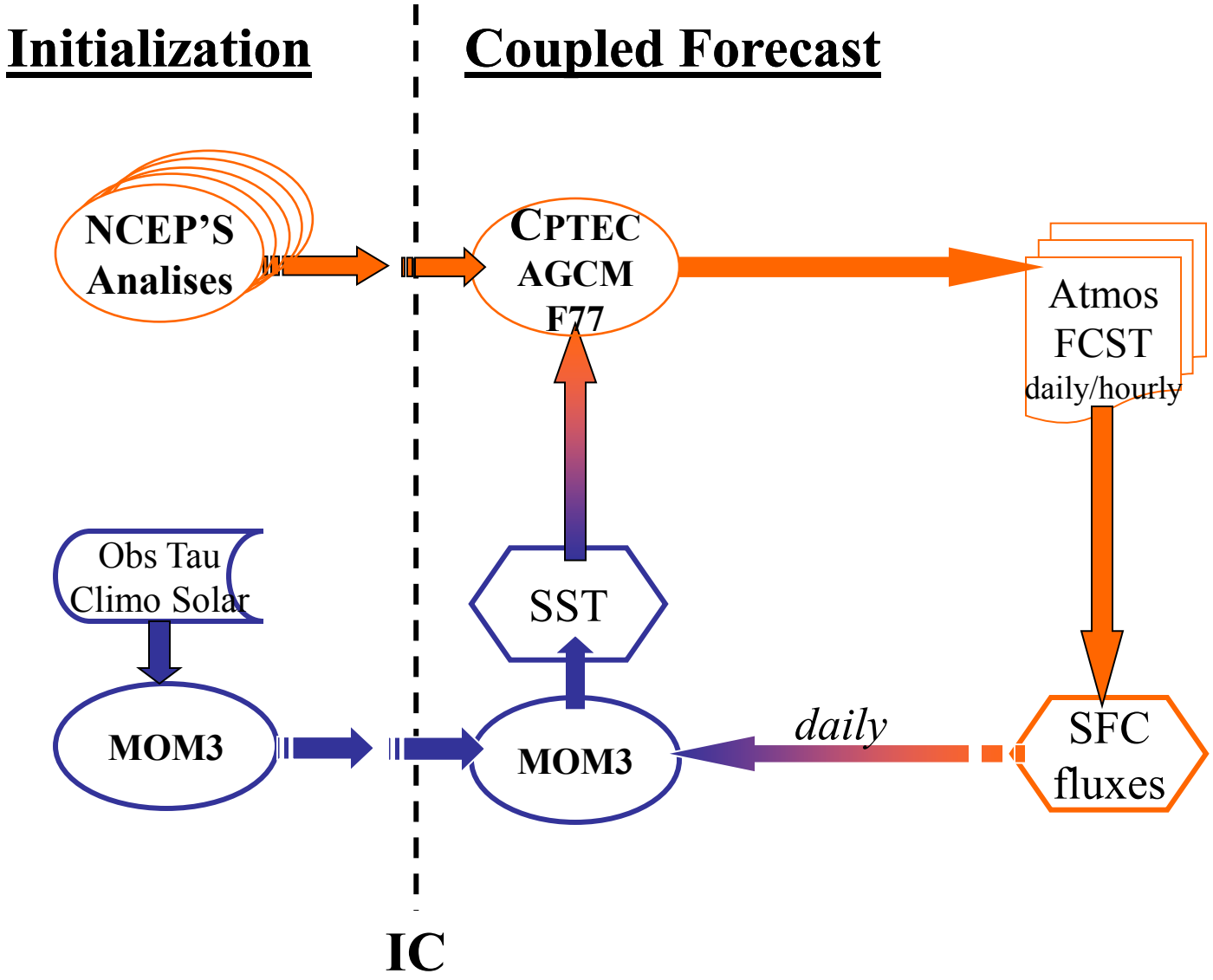
Development of INPE's Global Climate System Model

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

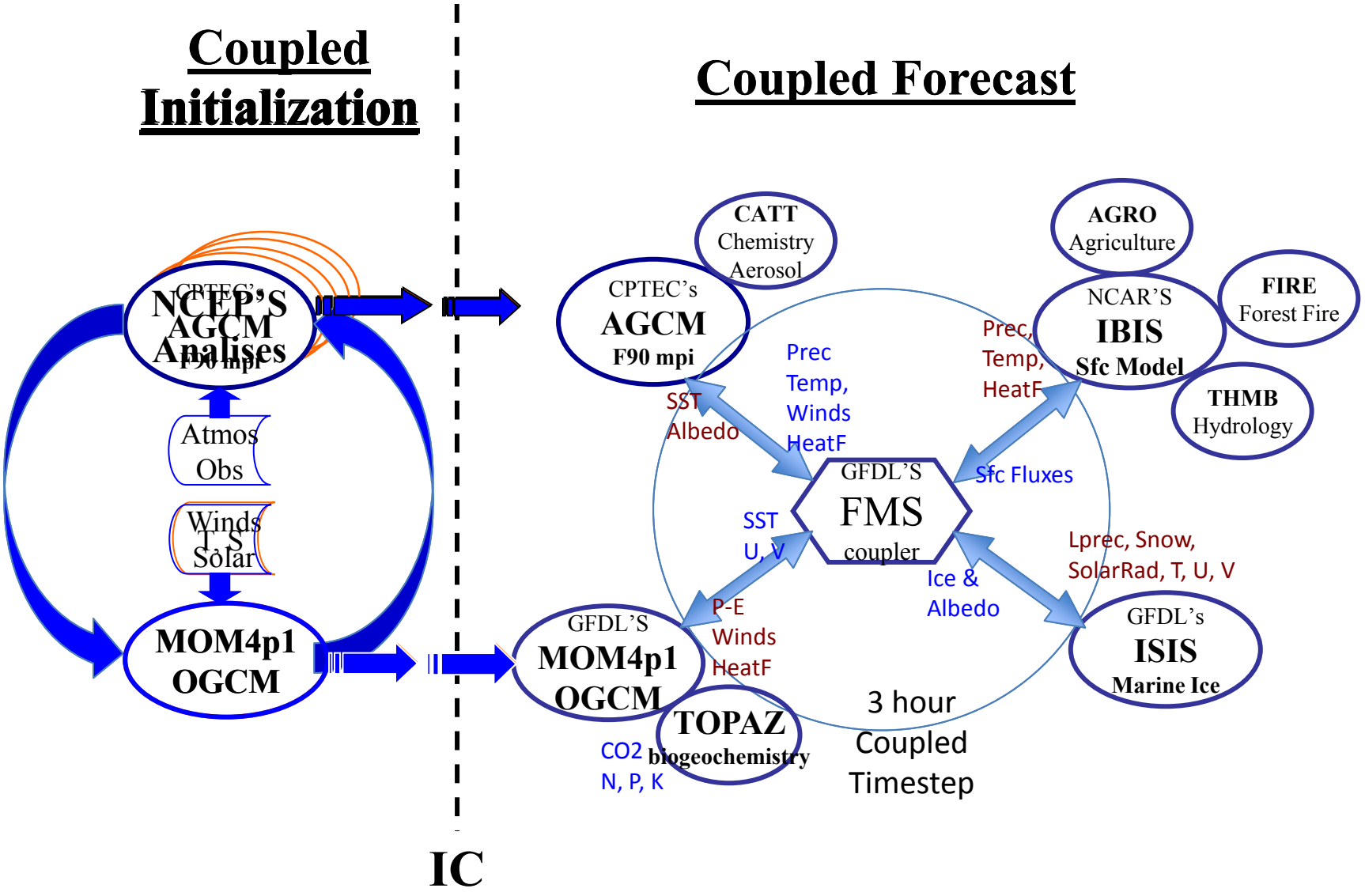
(ii) collaboration with advanced climate change centers abroad

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

CPTEC's Coupled Ocean-Atmos Seasonal Climate Forecast Suite V 1.0

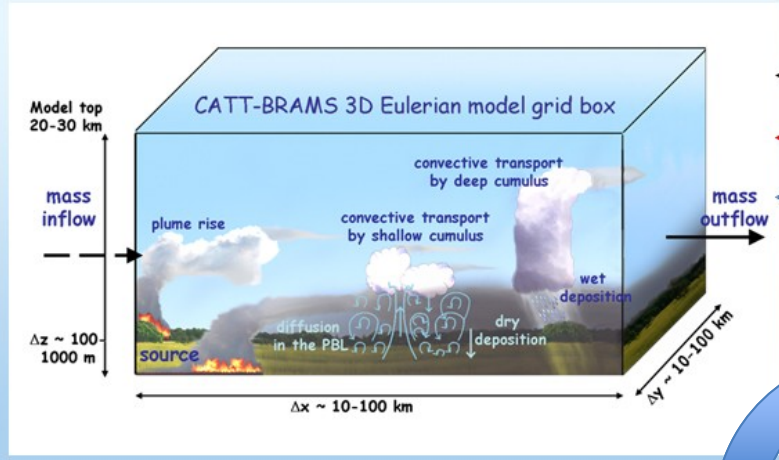


INPE's Coupled Ocean-Land-Atmos Climate Forecast System



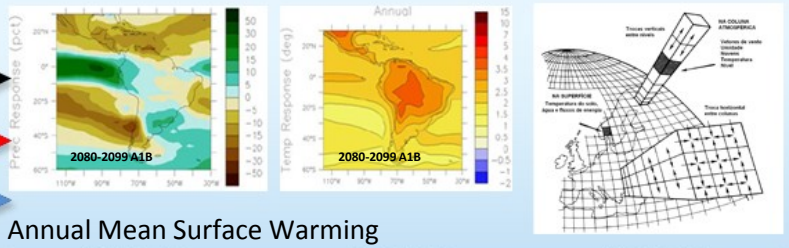
BRAZILIAN MODEL OF THE GLOBAL CLIMATE

ATMOS CHEMISTRY (CATT)

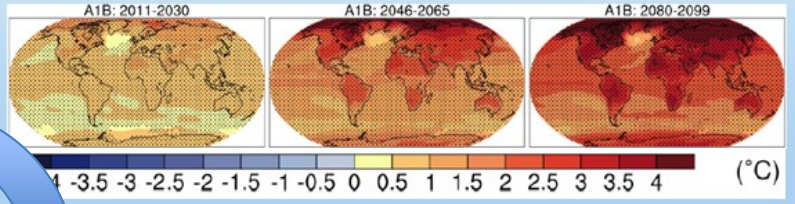


CO_2
Trace Gases
Particles
Heat
H_2O

ATMOSPHERE (CPTEC/INPE)



Annual Mean Surface Warming



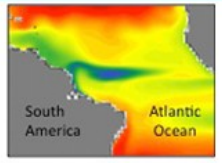
FMS COUPLER

LAND (IBIS)

RIVERS

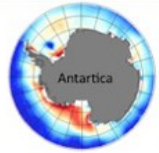
OCEAN (MOM4)

RIVER



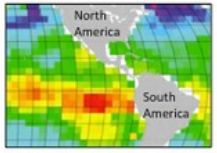
Surface salinity

ICE



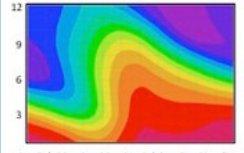
Ice thickness

BioChemistry

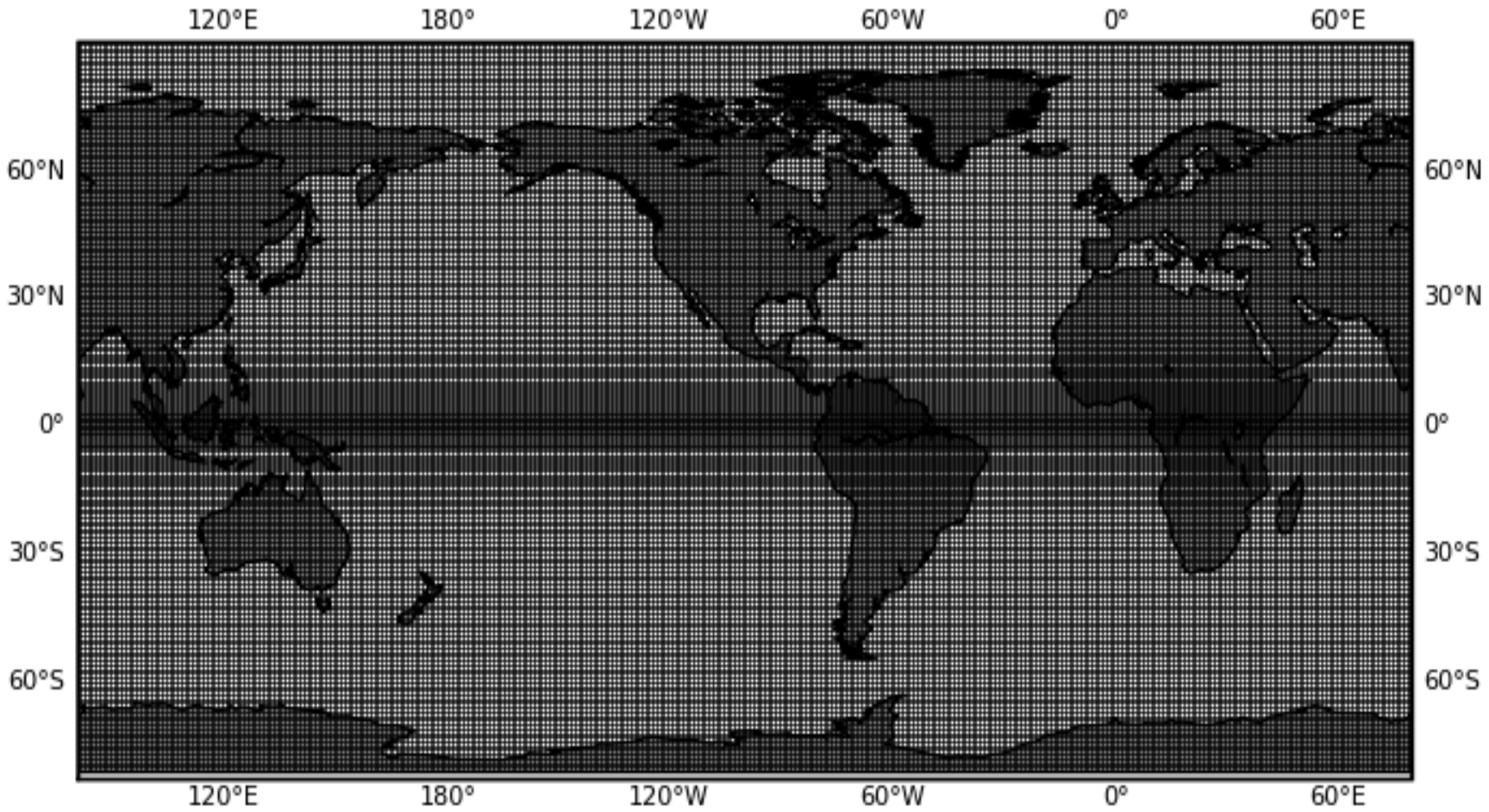


CO2 fluxes

Predictability



CGCM 2.1 Ocean Grid



BMGCS Component models…

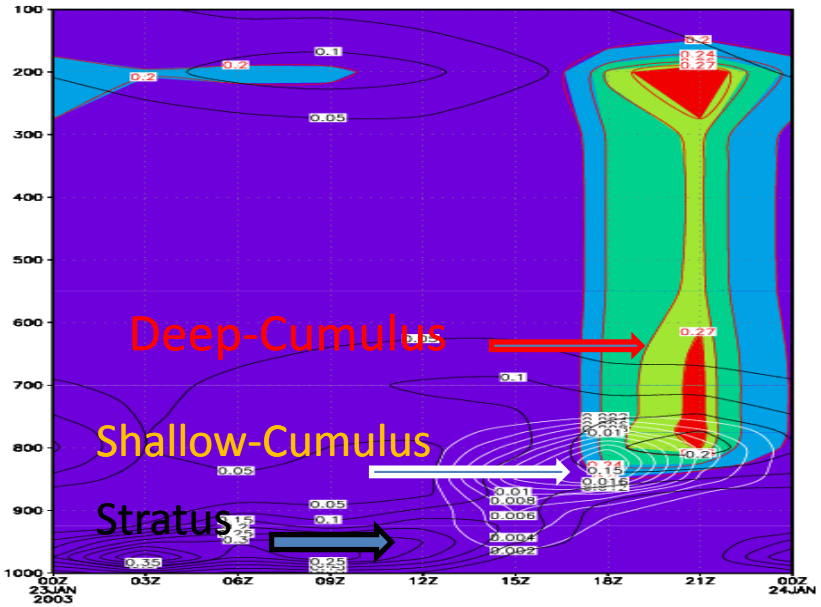
- Atmos GCM:
  - CPTEC.2.0 mpi/open_mp,
  - Semi-Lagrangian,
  - Resolution T62L64; T126L64; T213L64
    - Increased PBL and Stratosphere vertical resolution
  - RAS/Grell deep cumulus convection
    - Improved stratus parameterization scheme
  - atmospheric chemistry & aerosols
- Land Surface Model: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

BMGCS Component models…

- OGCM:
  - MOM4p1,
  - 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 (ISIS)
  - Biogeochemistry model (Topaz)
- GFDLs FMS (Flexible Modeling System) coupler
  - Up to 3-hourly coupling interval (limited by atmospheric radiation sub-routine)

Developments in Atmospheric Convection on AGCM

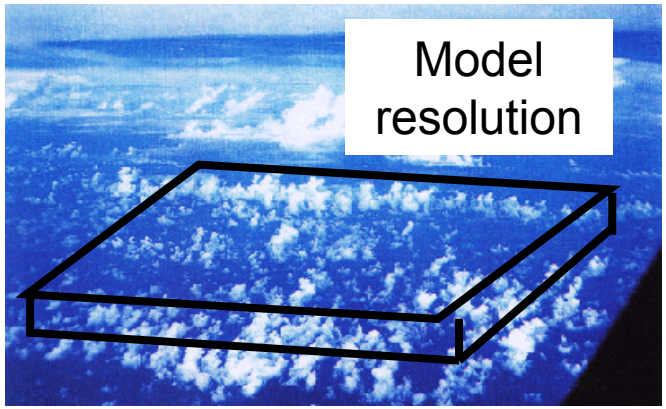
SHALLOW AND DEEP CONVECTION



Transition from stratus to shallow clouds and deep convection

SUPERPARAMETERIZATION

Cloud Resolving Model in columns of the AGCM.
Improve results by introducing features of Individual clouds.

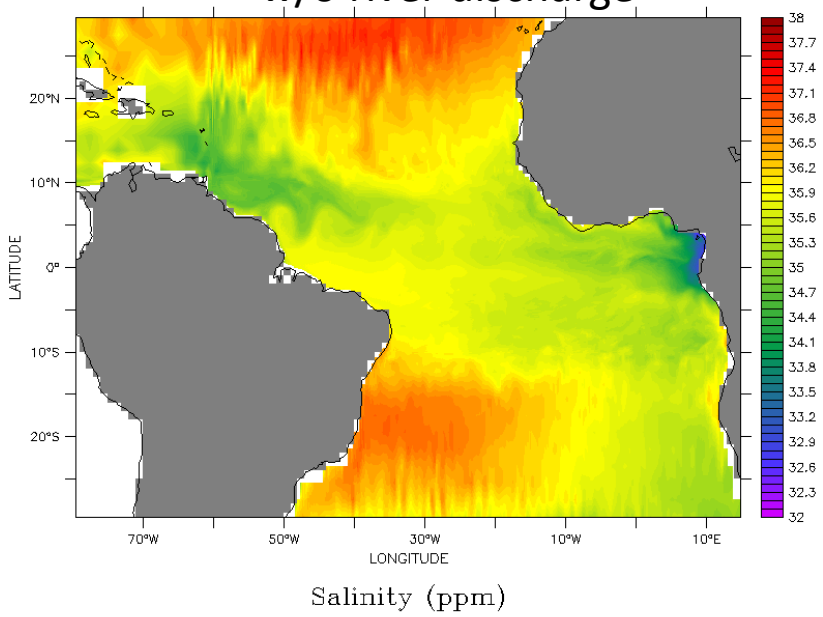


Courtesy: I.F.A. Cavalcanti, INPE/CPTEC

Processes Resolved:
River inflow effects on salinity

MOM3

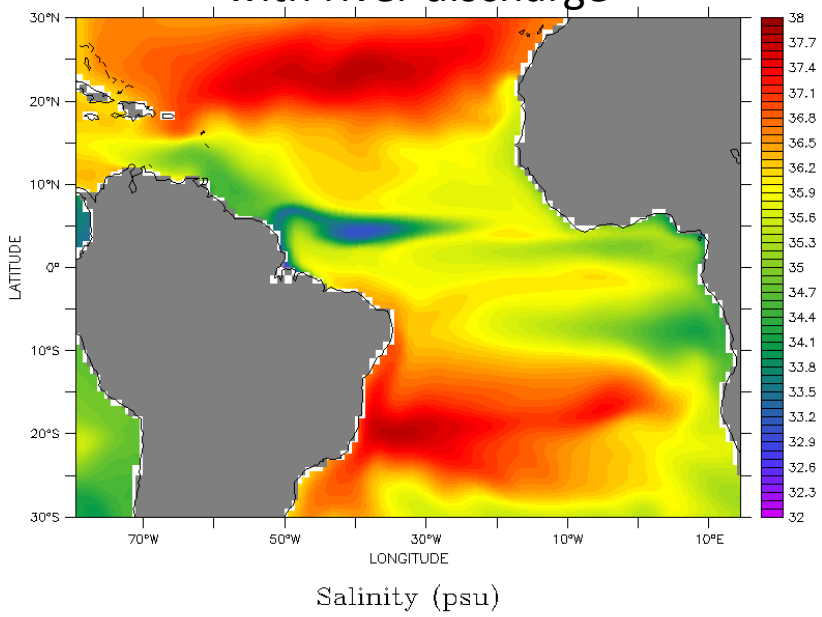
w/o river discharge



Salinity (ppm)

MOM4

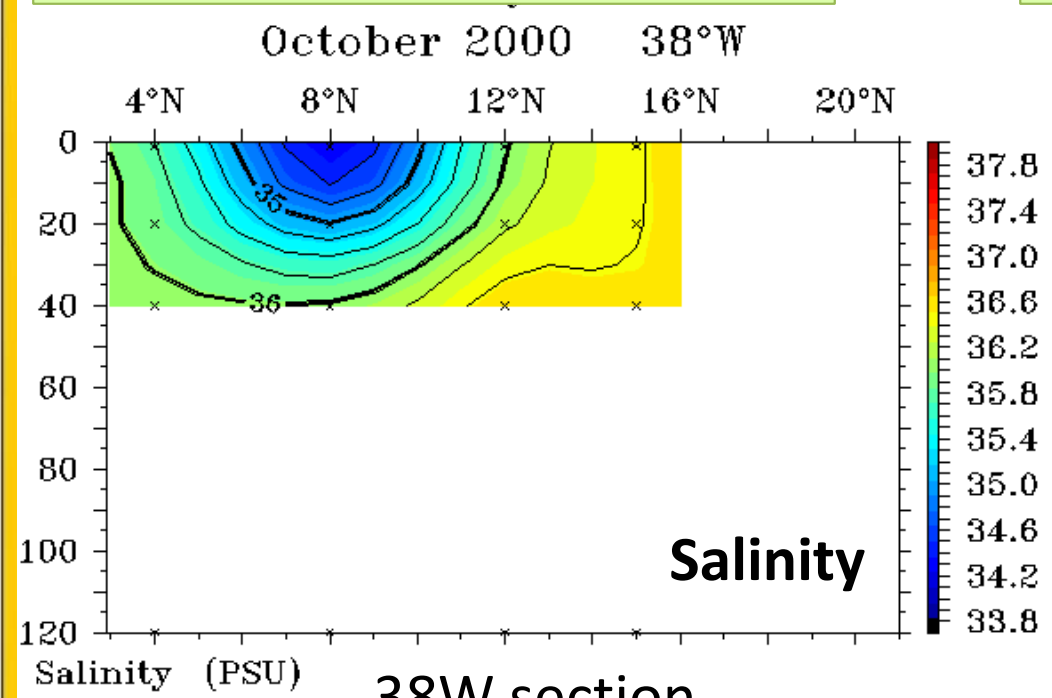
with river discharge

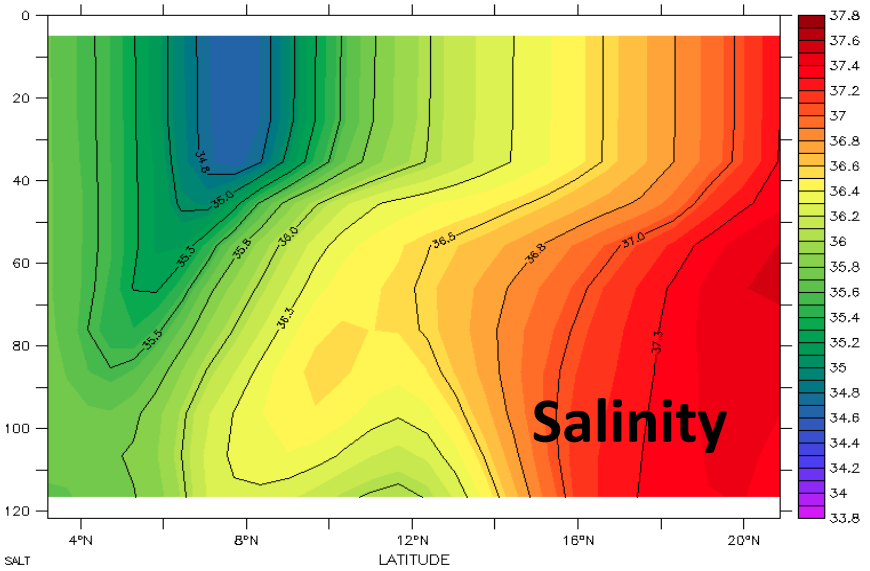


Salinity (psu)

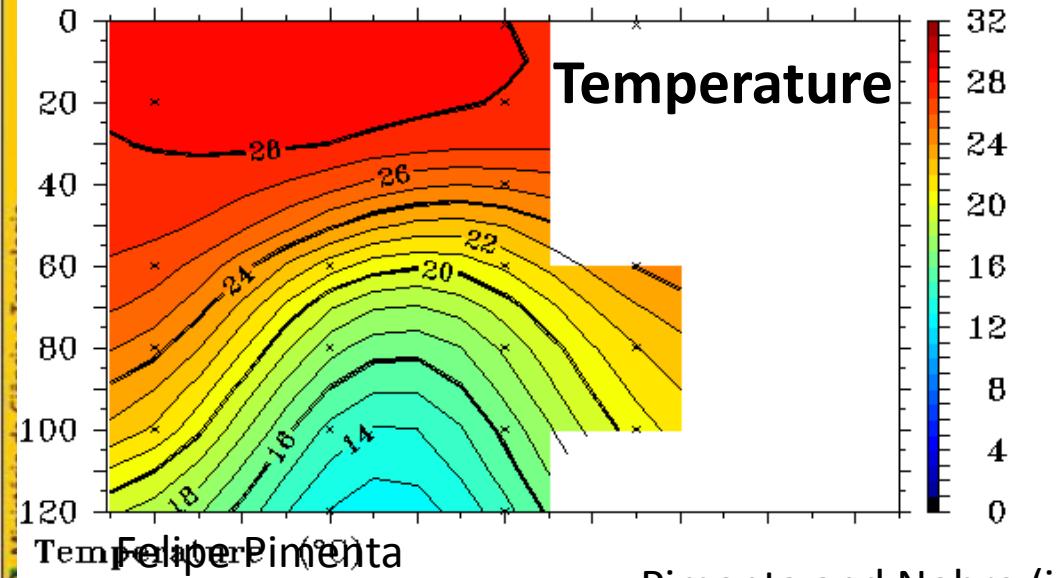
PIRATA DATASET

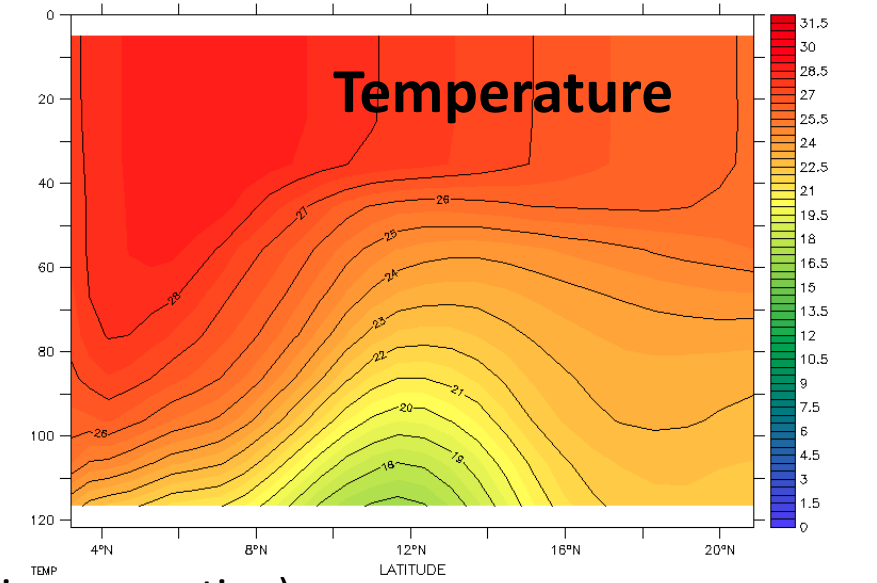
MOM4p1 SIMULATION





38W section

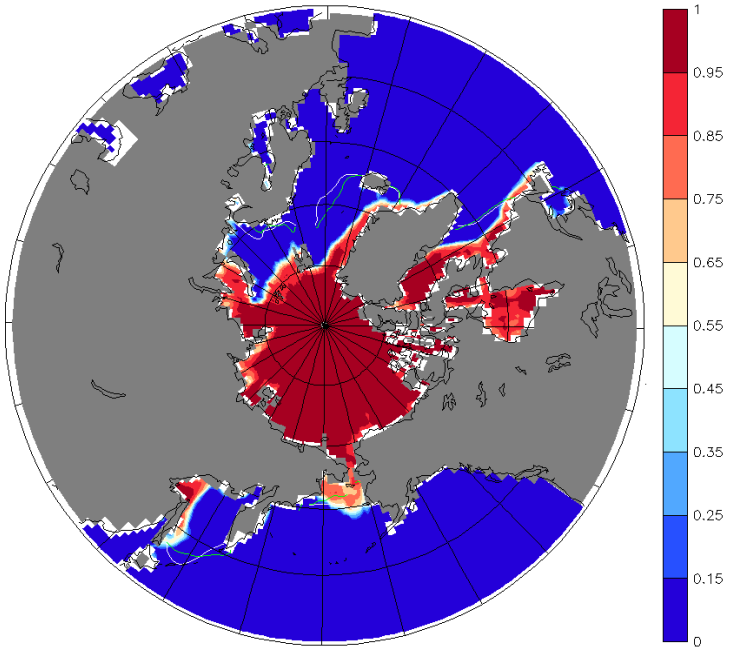




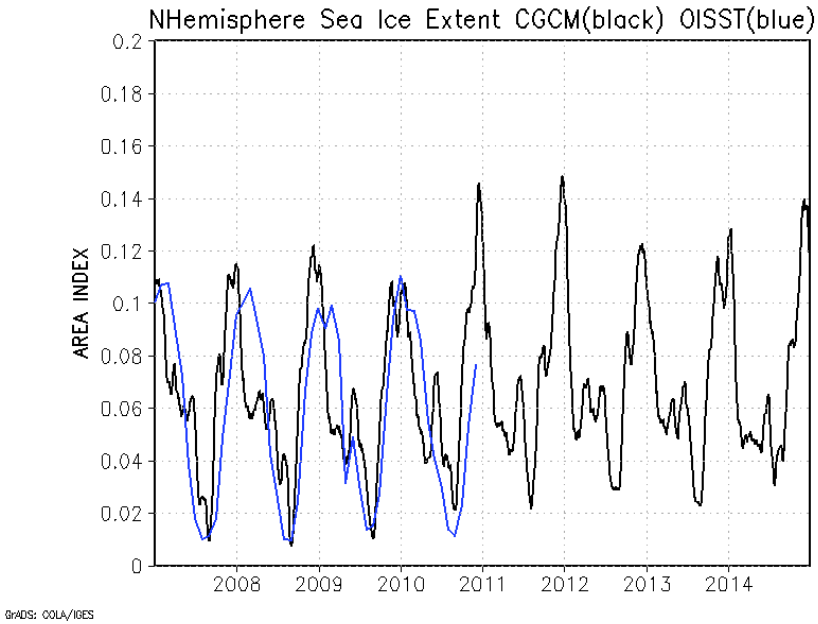
Felipe Pimenta

Pimenta and Nobre (in preparation)

Northern Hemisphere Ice Fraction

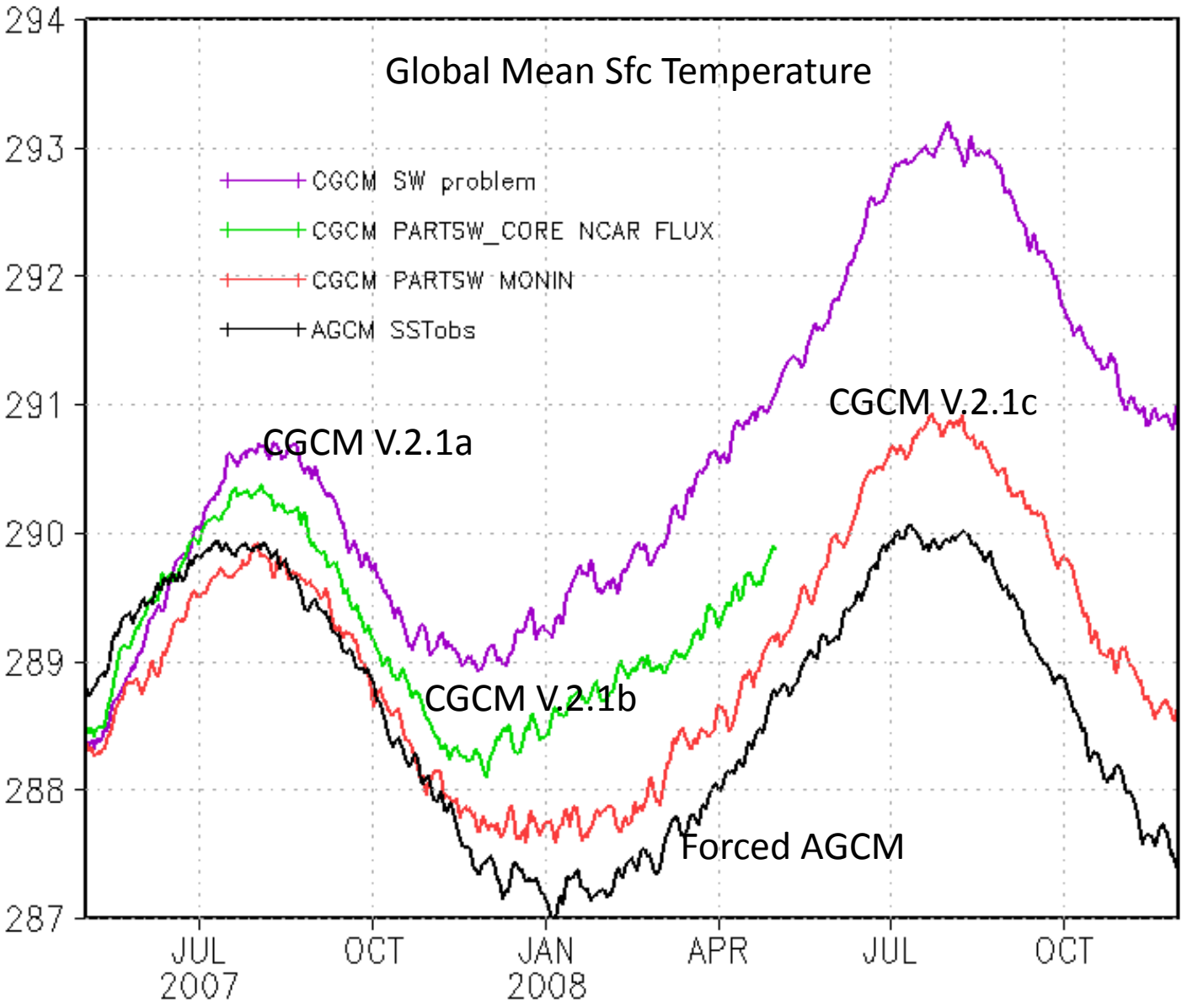


Ice Fraction (percent) – CGCM2.1(lines) vs OBS(colors)
APR 2007



M. Malagutti and P. Nobre

CGCM Development Evolution Index



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.

CPTEC
Centro de Previsão de Tempo e Estudos Climáticos

MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Thank you.

WWW.CPTEC.INPE.BR

13th ECMWF Workshop on Meteorological Operational Systems
Reading, 3 November 2011

Ministério da Ciência e Tecnologia