BESM
Brazilian Earth System Model

BESM: The Experience of developing an Earth System Model in Brazil

Paulo Nobre, V. B. Capistrano, M. C. Costa, H. C. Soares, R. L. Mello, E. Giarolla, A. Lanfer, M. Baptista Jr., M. Bottino, S. N. Figueroa, D. Alvin, P. Kubota, J. P. Bonatti, E. Ramirez, B. Antunes, G. Sampaio, M. Cardoso, C. Augusto Jr, F. Casagrande, F. Odorizi, J. Pendharkar, J. Silva

National Institute for Space Research – INPE

IITM-ICTP Summer School ESM, Pune, 20 July 2016

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The Challenge:

- ***To build an Earth System Model in Brazil, from state of the art component models in the nation and abroad:***

1. **To incorporate expert knowledge** about ocean-ice-atmosphere-biosphere interactions of relevance to Brazil;
2. To provide the scientific foundations of global climate change scenarios for **mitigation and adaptation policies to climate change in Brazil**;
3. To contribute to **form a new generation of modeling-capable earth system scientists** in the nation.

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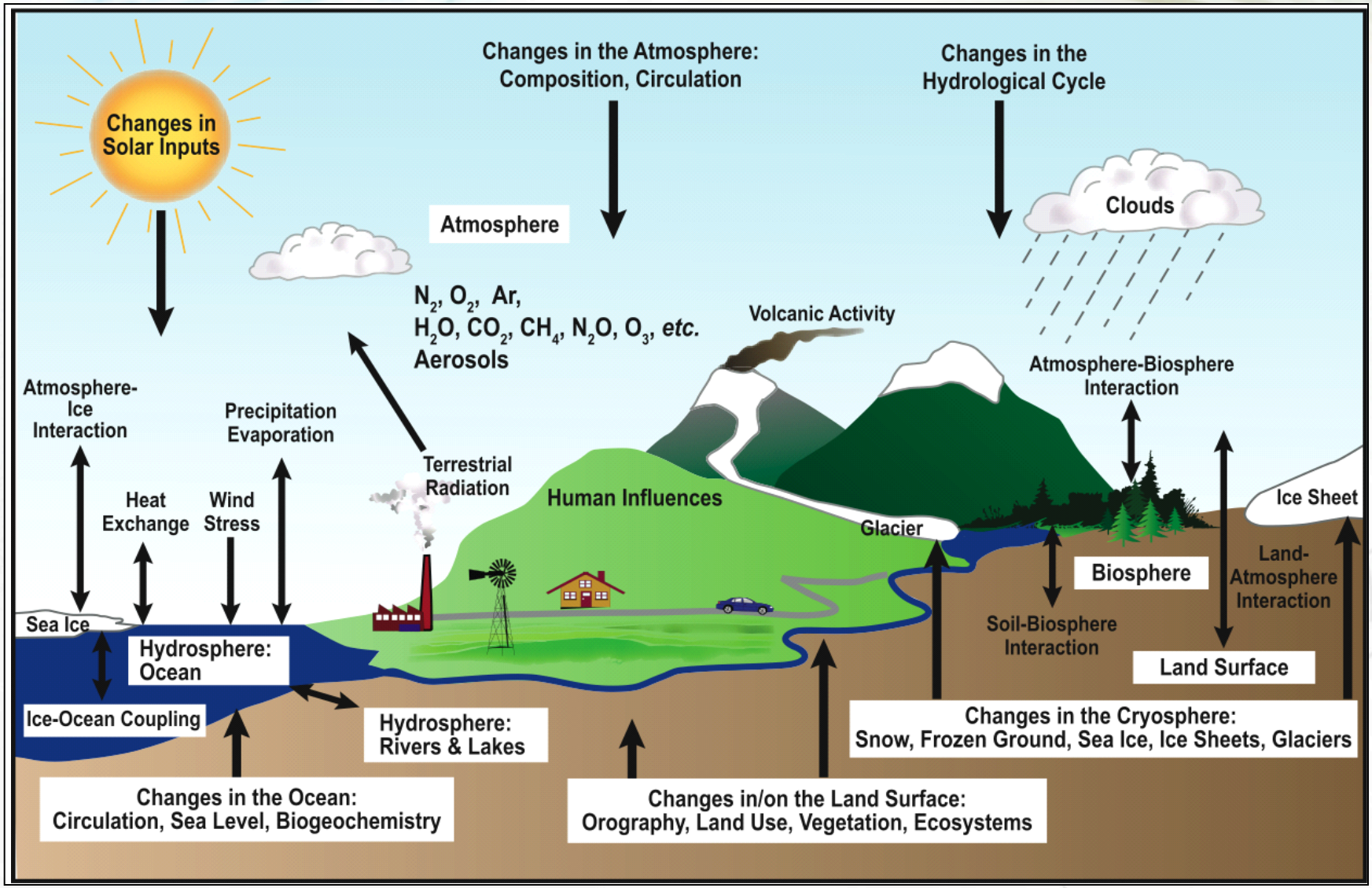
The Global Climate System



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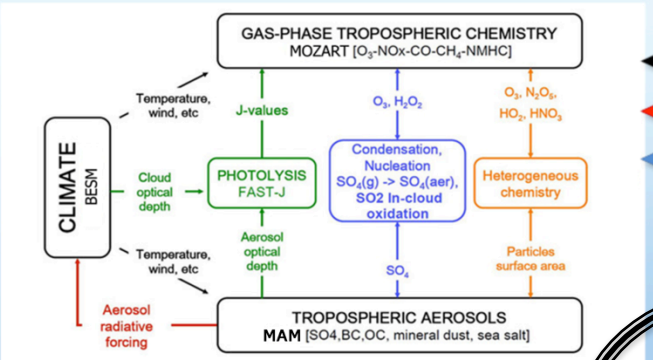
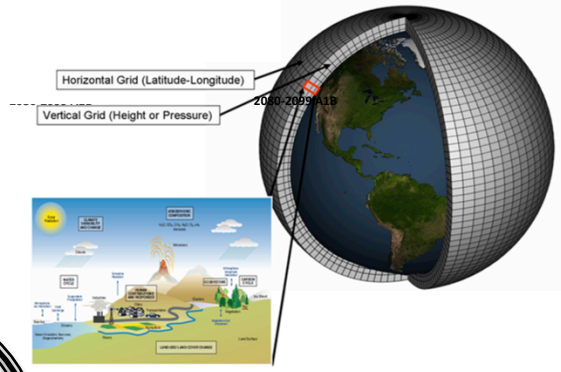
Component Models

ATMOS CHEMISTRY (MOZART- NCAR)



CO_2
Trace Gases
Particles
Heat
H_2O
CO_2

ATMOSPHERE (INPE/CPTEC)



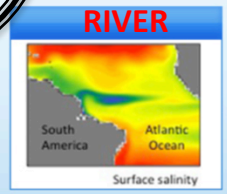
FMS COUPLER

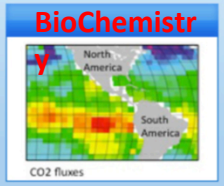
LAND (INLAND – INPE/CCST)

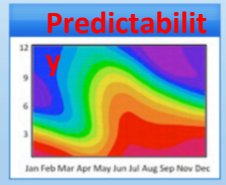
Hydrology Land Use

RIVERS

OCEAN (MOM5 – NOAA/GFDL)







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

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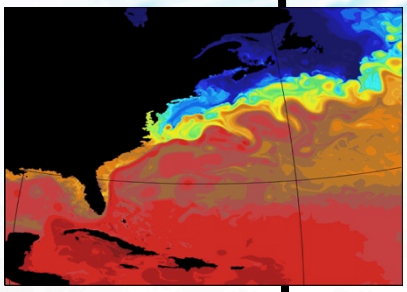
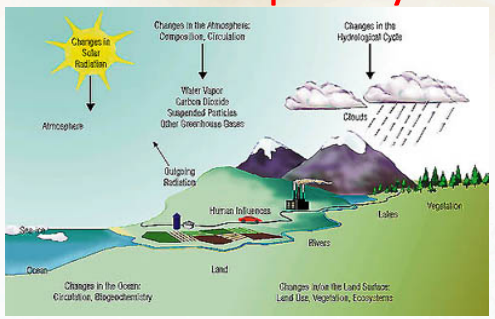


Resolution

Complexity



Human,

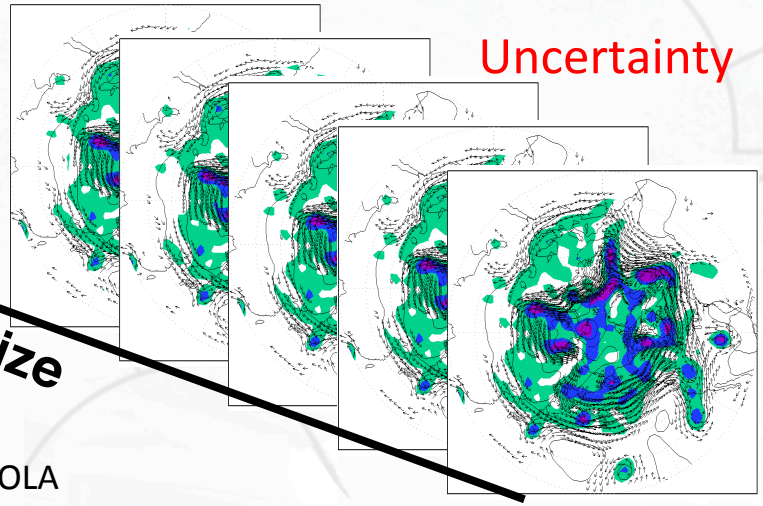
Computing Resources

Resolution

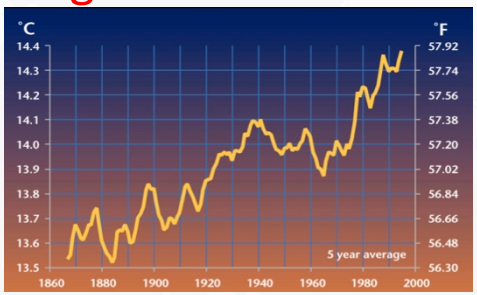
Complexity

Duration and/or Ensemble size

Uncertainty



Long simulations



Courtesy: J. Shukla, IGES/COLA

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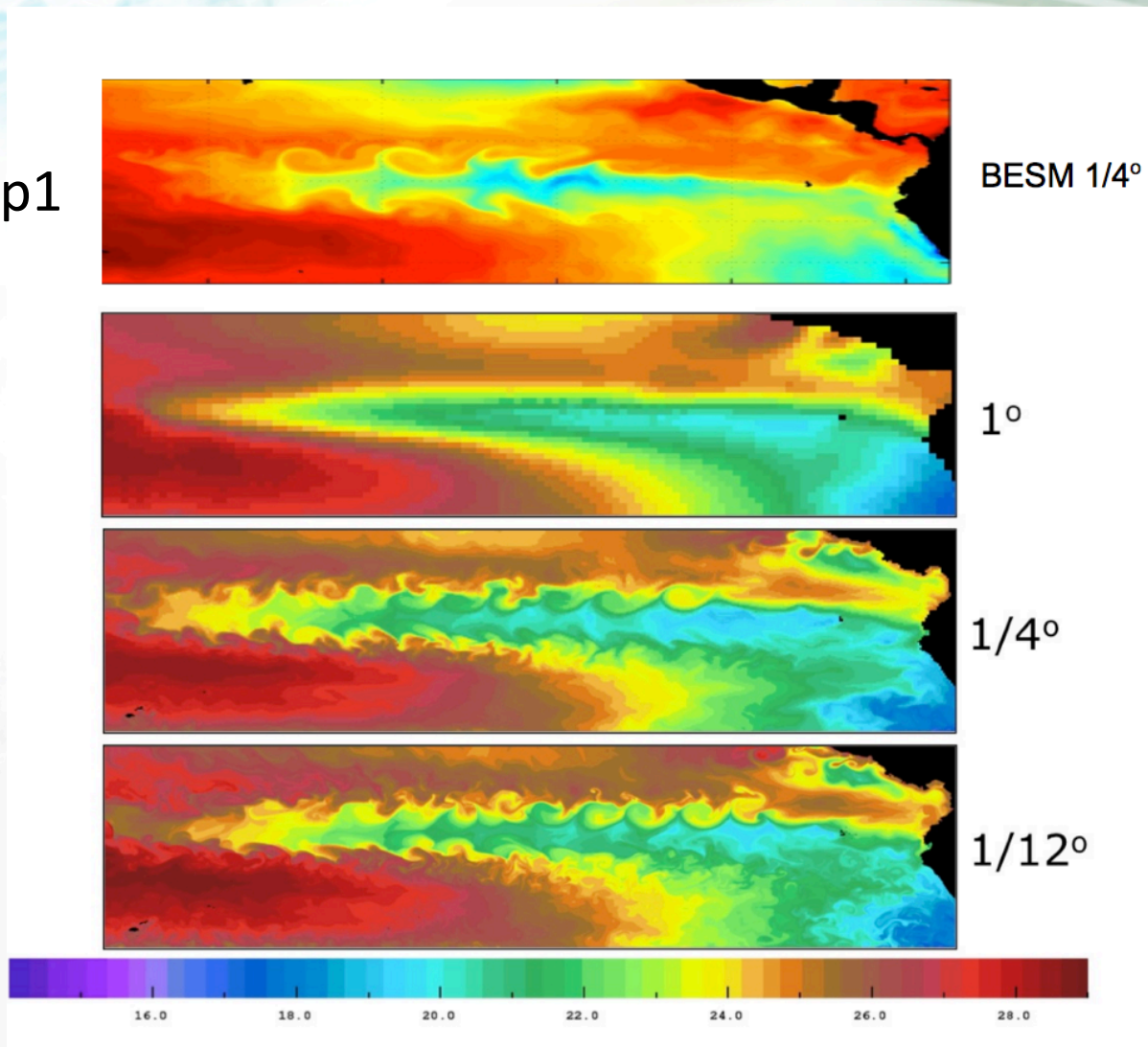
High Resolution Ocean Modeling

BESM/MOM4p1

COLA/MOM



Adapted from Prof. J. Shukla, by E. Giarolla

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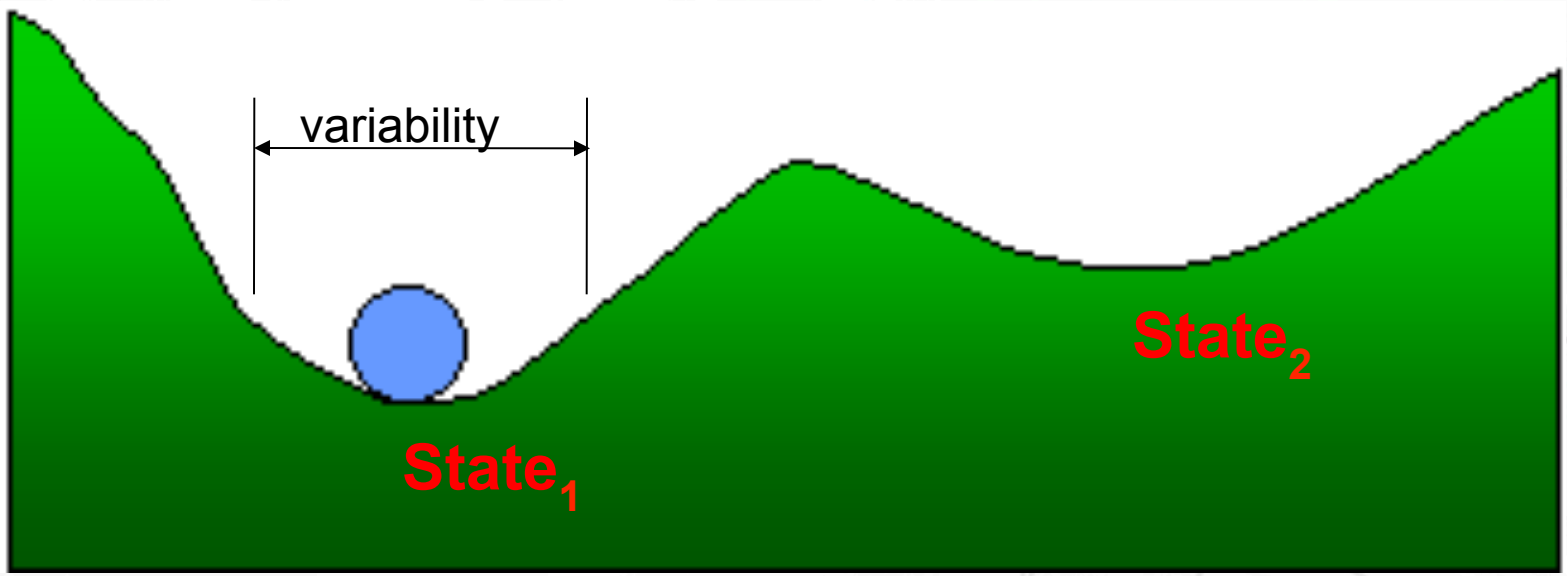
Climate
Variability x Change



$T_1 < T_2$

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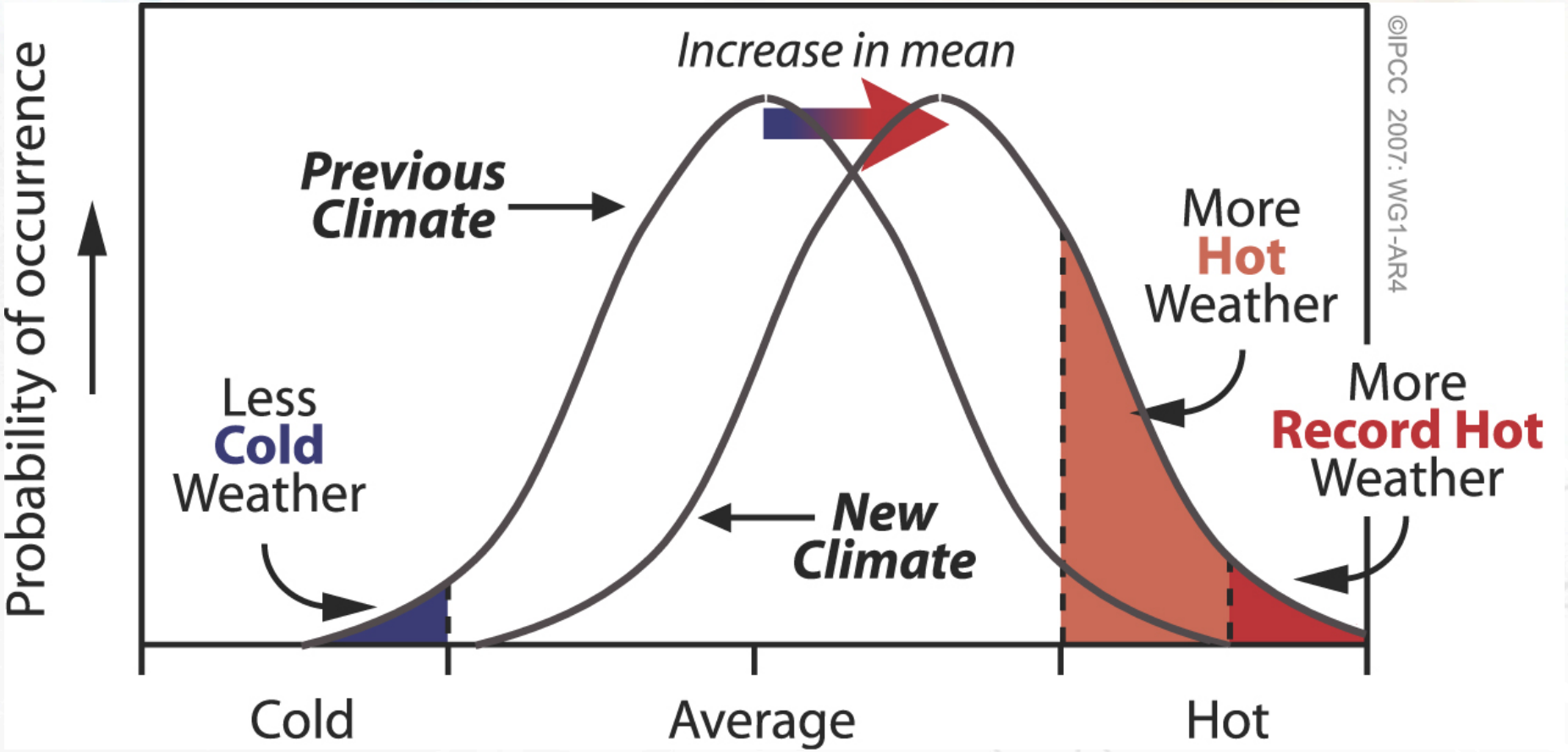
Change of Frequency of Extremes



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2015: The Warmest Year on Record

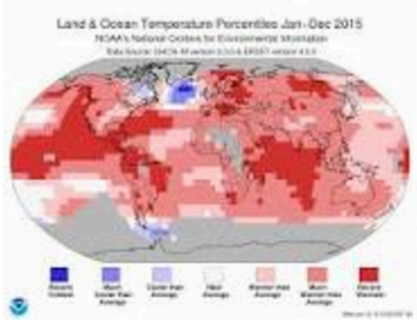
2015

Sixteen Warmest Years (1880–2015)

Rank 1 = Warmest Period of Record: 1880–2015	Year	Anomaly °C
1	2015	0.90
2	2014	0.74
3	2010	0.70
4	2013	0.66

12 more rows, 1 more column

Global Analysis - Annual 2015 | National Centers for ...
https://www.ncdc.noaa.gov/sotc/global/201513



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Hydrologic Extremes:
Impacts on Health & Economy

Courtesy: P.Nobre, INPE/CPTEC

ESTADÃO | POLÍTICA + | ECONOMIA + | INTERNACION

Maiores represas do Cantareira viram córrego

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DEVELOPMENT STRATEGY

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

(ii) collaboration with advanced climate change centers abroad: GFDL, NCAR,

- Take CPTEC Global Coupled Ocean-Atmosphere Model as the structuring building-block
- Use GFDL/FMS coupler to add components:
  - Dynamic vegetation with carbon cycle;
  - Continental hydrology-ocean coupling;
  - Ocean carbon cycle;
  - Sea ice;

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One Model: From Weather Forecasting to Global Climate Change Scenarios

Extreme Events Hit Brazil

T666L96

T213L64

T126L42

T062L28

30min 5 days — NWP — DERF — 1 month — Seasonal Climate — 1 year — Climate Change — 1 century

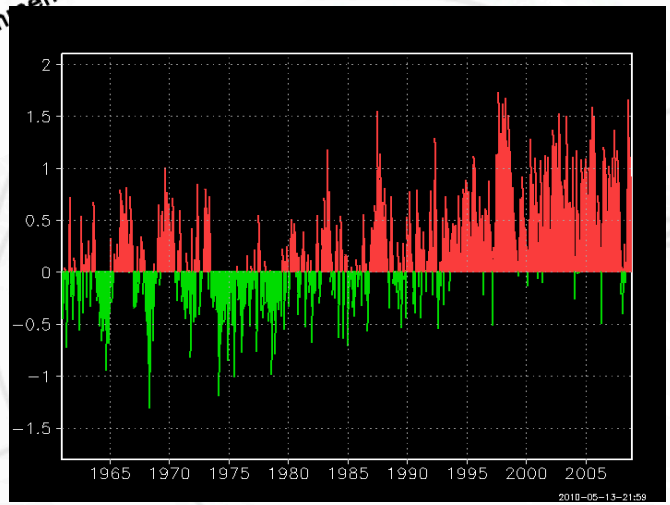
General Use

Agricuture
Planning
Water Resources
Energy

Industry (clouthing, beverages, ice creams)
Agriculture, Water Resources, Energy

Government, Public Policies, Strategic Planning

Surface Temperature Trend in Brazil



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Time Line

2011
1 IBSA
SS GCM
Brazil

2015
2 IBSA
SS GCM
Brazil

2016
IITM-ICTP
SS ESM
India

1998
Rosati
GFDL

2010
Philander
INPE

2013
Canutto
INPE

2015
Balaji
GFDL

2016
Canutto
NASA

1996
COLA
AGCM
-MOM2

1999
CCA-
MOM2

2003
COLA-
CPTEC
MOM3

2006
COLA-
CPTEC
FMS-
MOM4p0

2009
BESM2.3 –
FMS-
MOM4p1

2014
BESM2.5
FMS-
MOM4p1

2015
BESM2.6
FMS-
MOM5

1994
COLA AGCM

2002
NZK, CCA
MOM2 Paper

2009
Amazon
Paper

2012
SACZ
Paper

2013
CMIP5
Paper

2015
EUC
paper

2016
ICE
paper

1994 1996 1999 2002 2006 2008 2009 2011 2012 2013 2015 2016

Courtesy: Paulo Nobre (2016)

BESM Climate Forecast System

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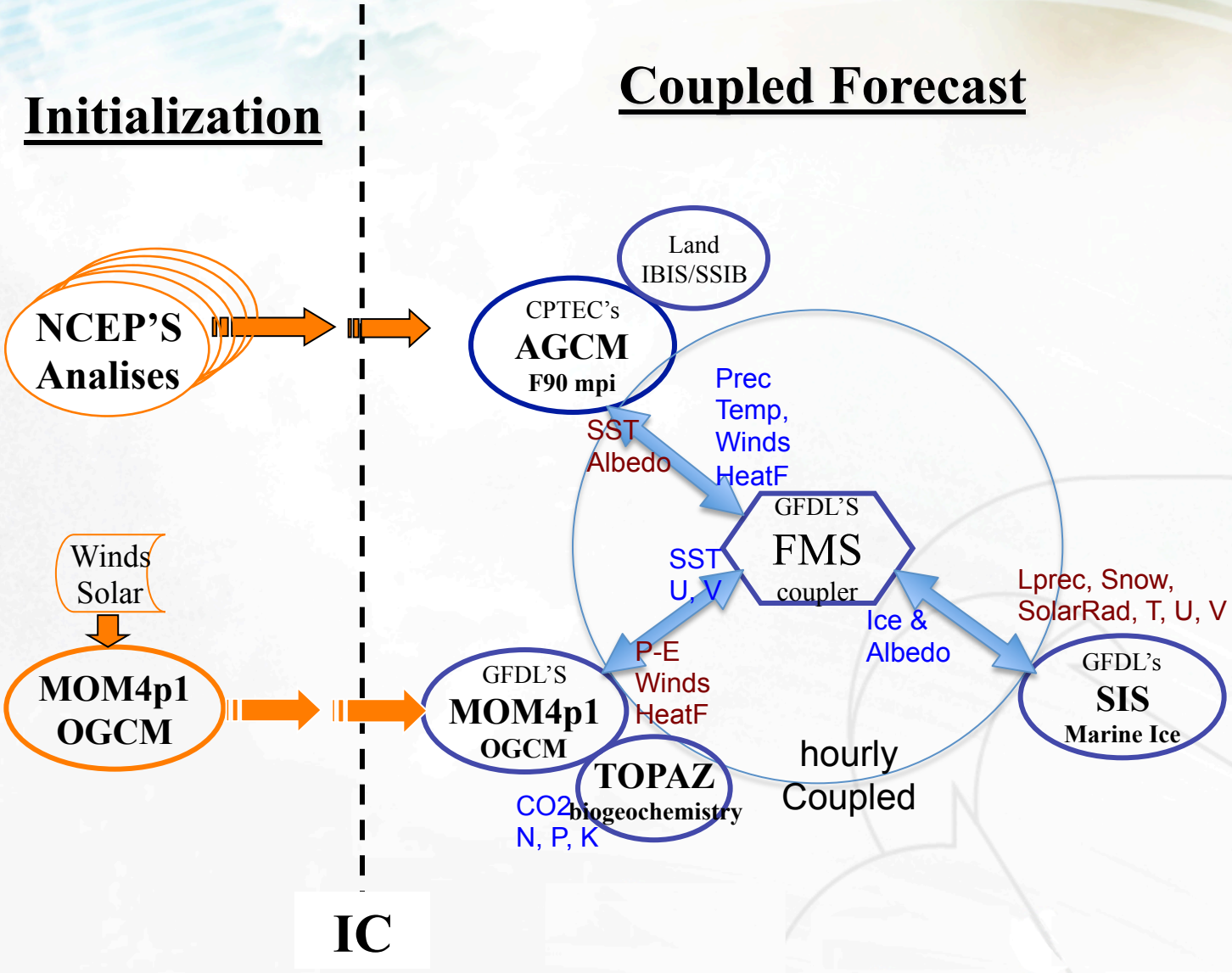
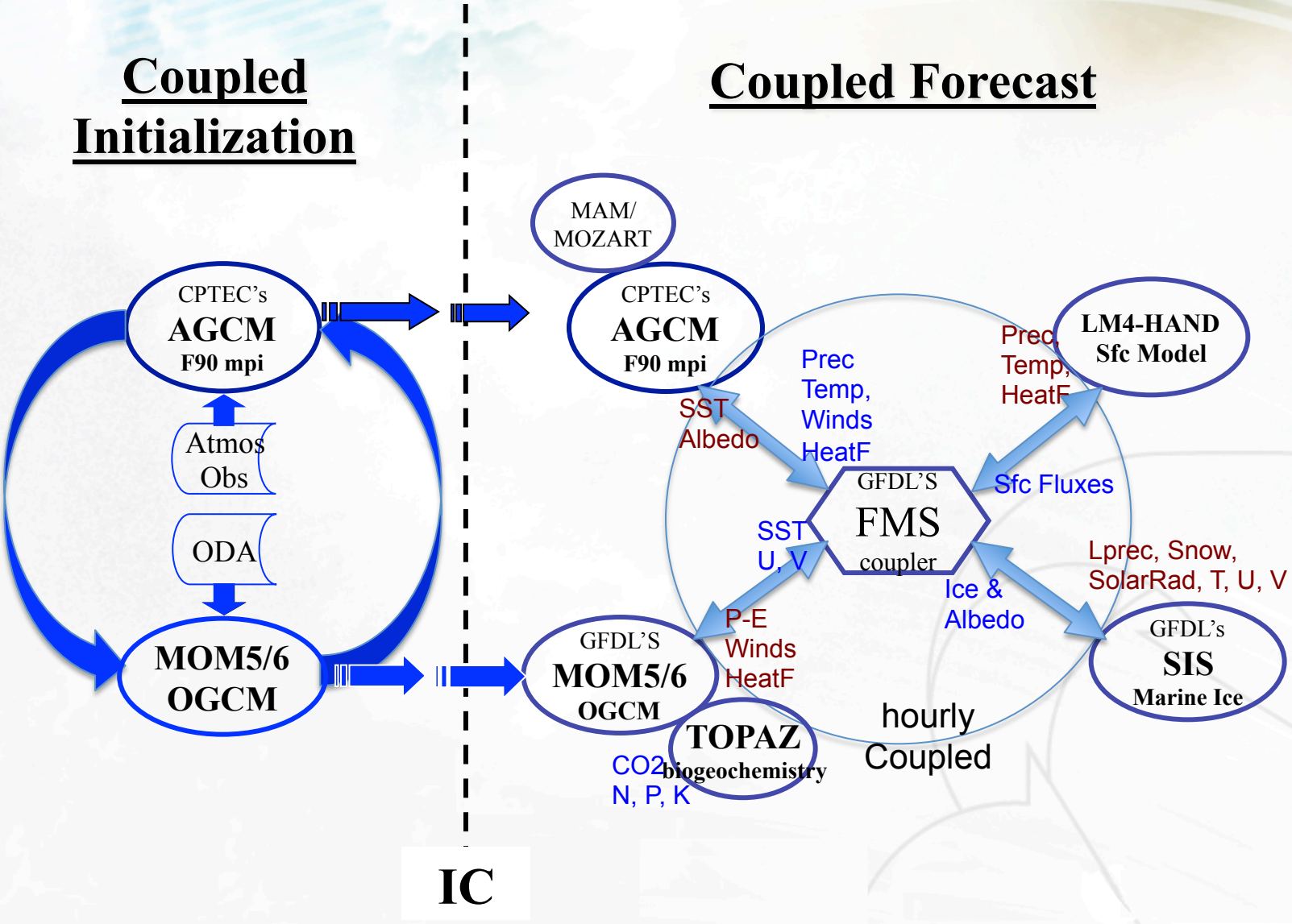


BESM Climate Forecast System goal



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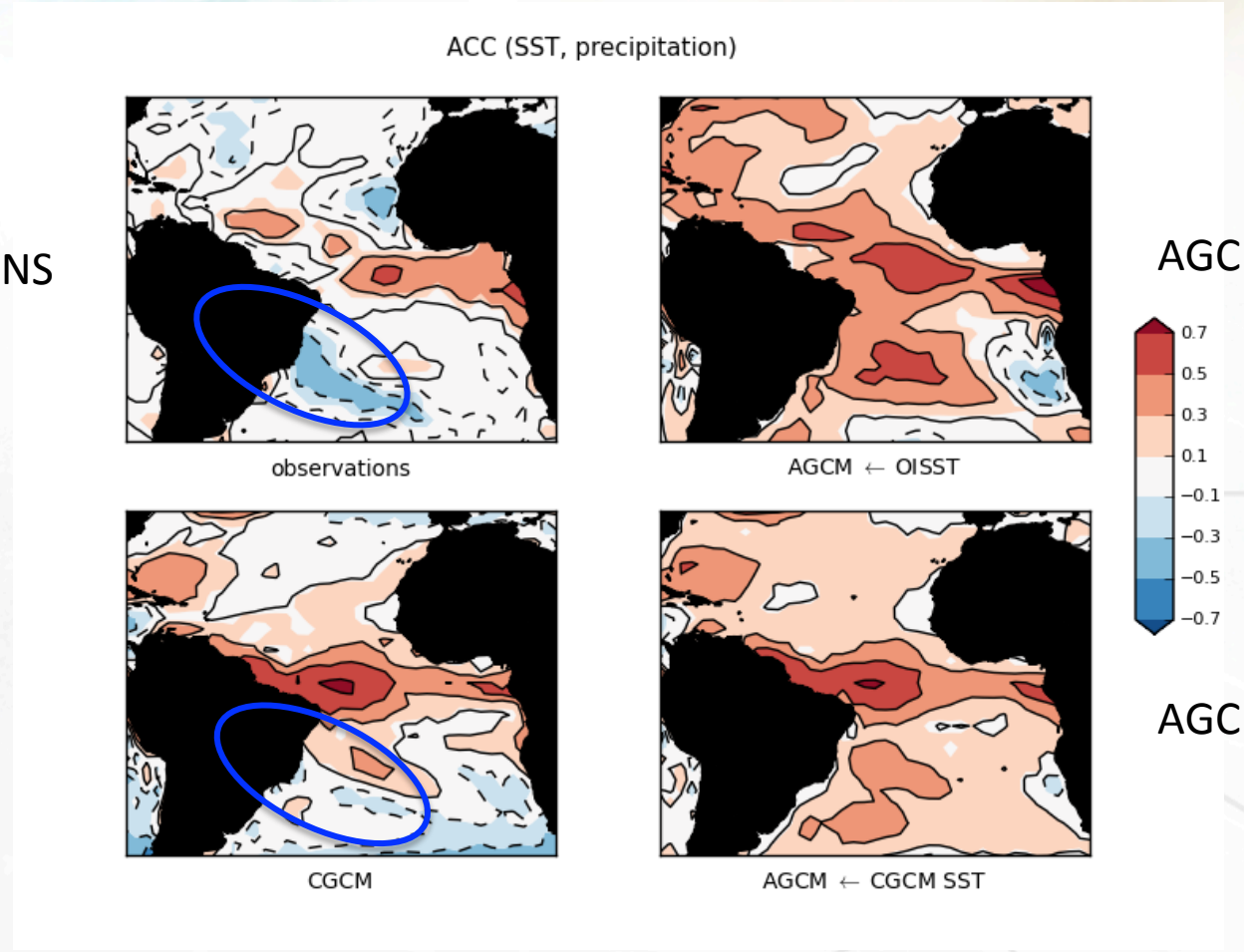
Lessons Learned

Using BESM for Hypothesis Testing

Enhanced Predictability
Rainfall over Cold Waters

OBSERVATIONS

BESM-OA2.3

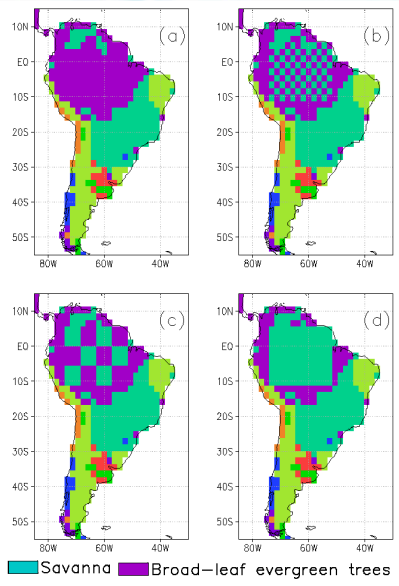


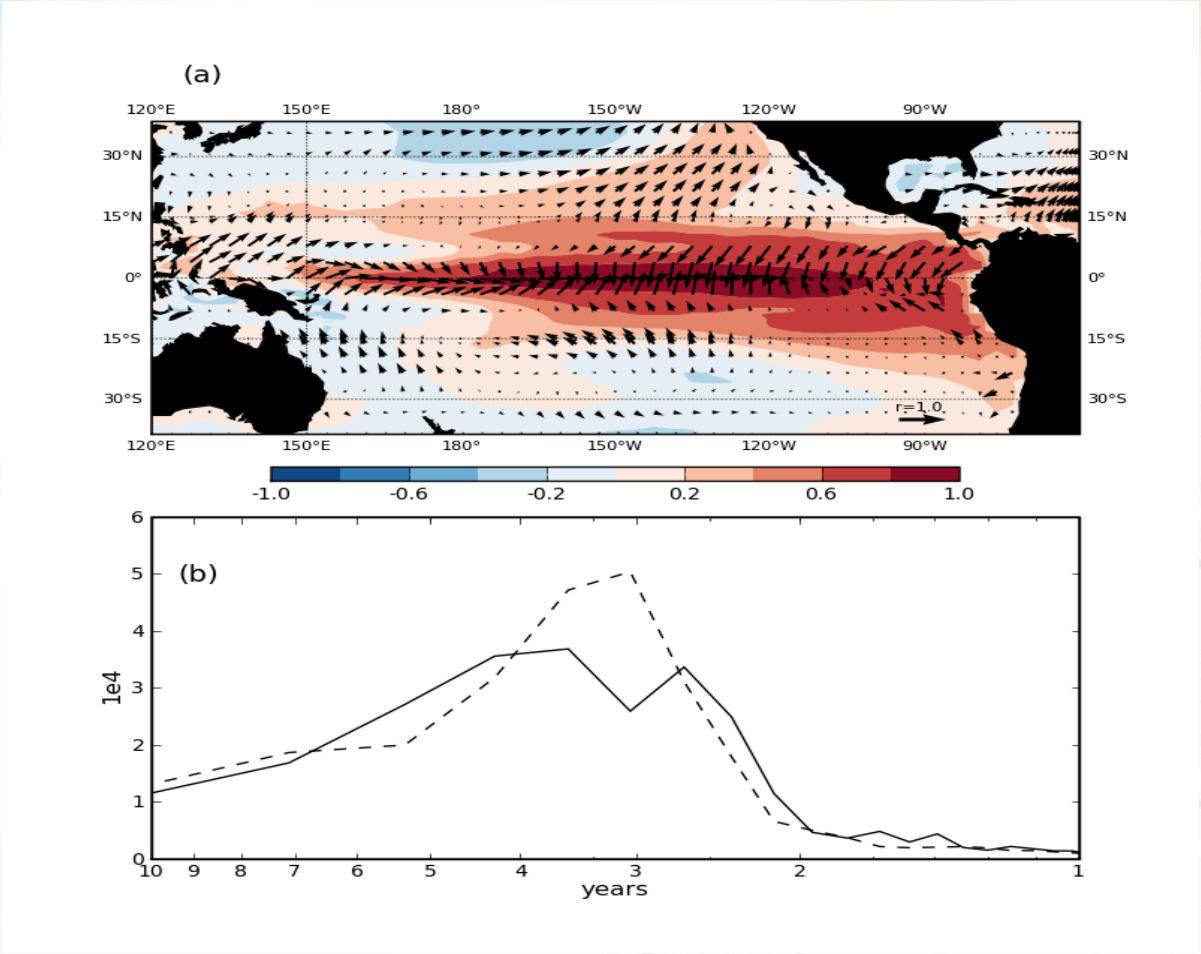
AGCM, Obs SST

AGCM, BESM SST

Source: Nobre et al. (2012)

Amazon Deforestation: Increased El Niño Conditions





Source: Nobre et al. (2009)

BESM AMAZON RAINFALL

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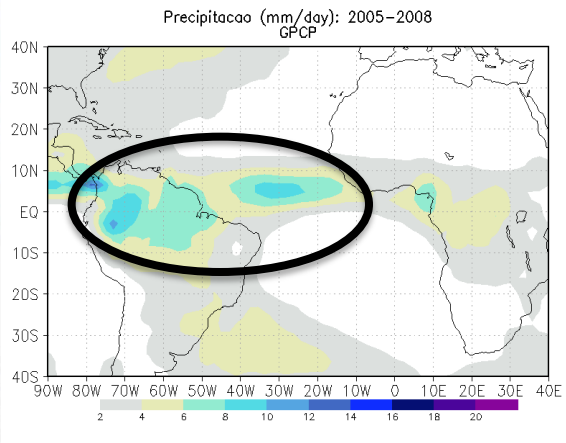
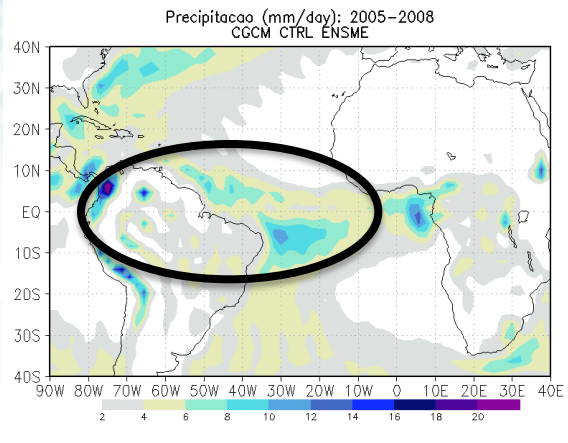
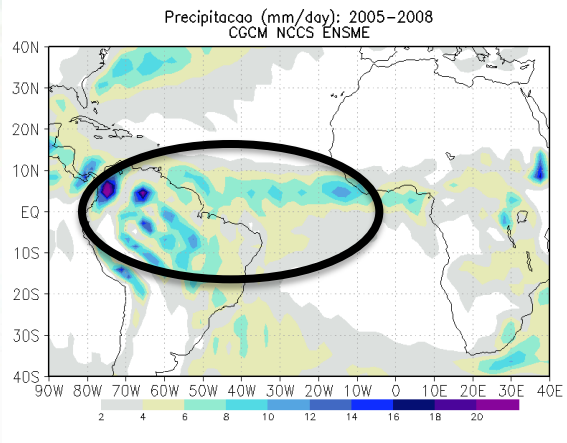
GPCP



BESM 2.3

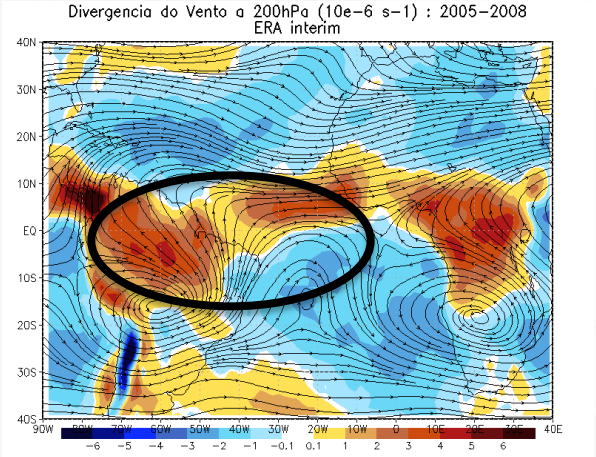


BESM 2.3.1

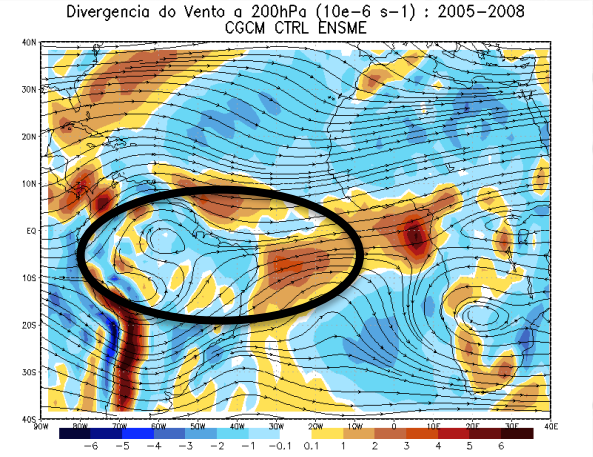


BESM UPPER LEVEL FLOW

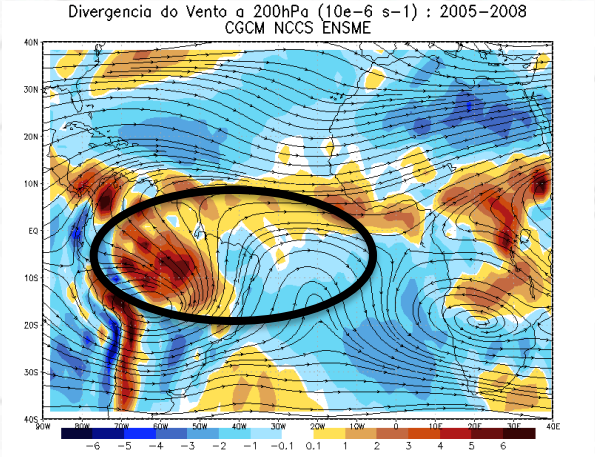
ERA interim REANALISYS



BESM 2.3



BESM 2.3.1



Bottino and Nobre (2016) to be Submitted

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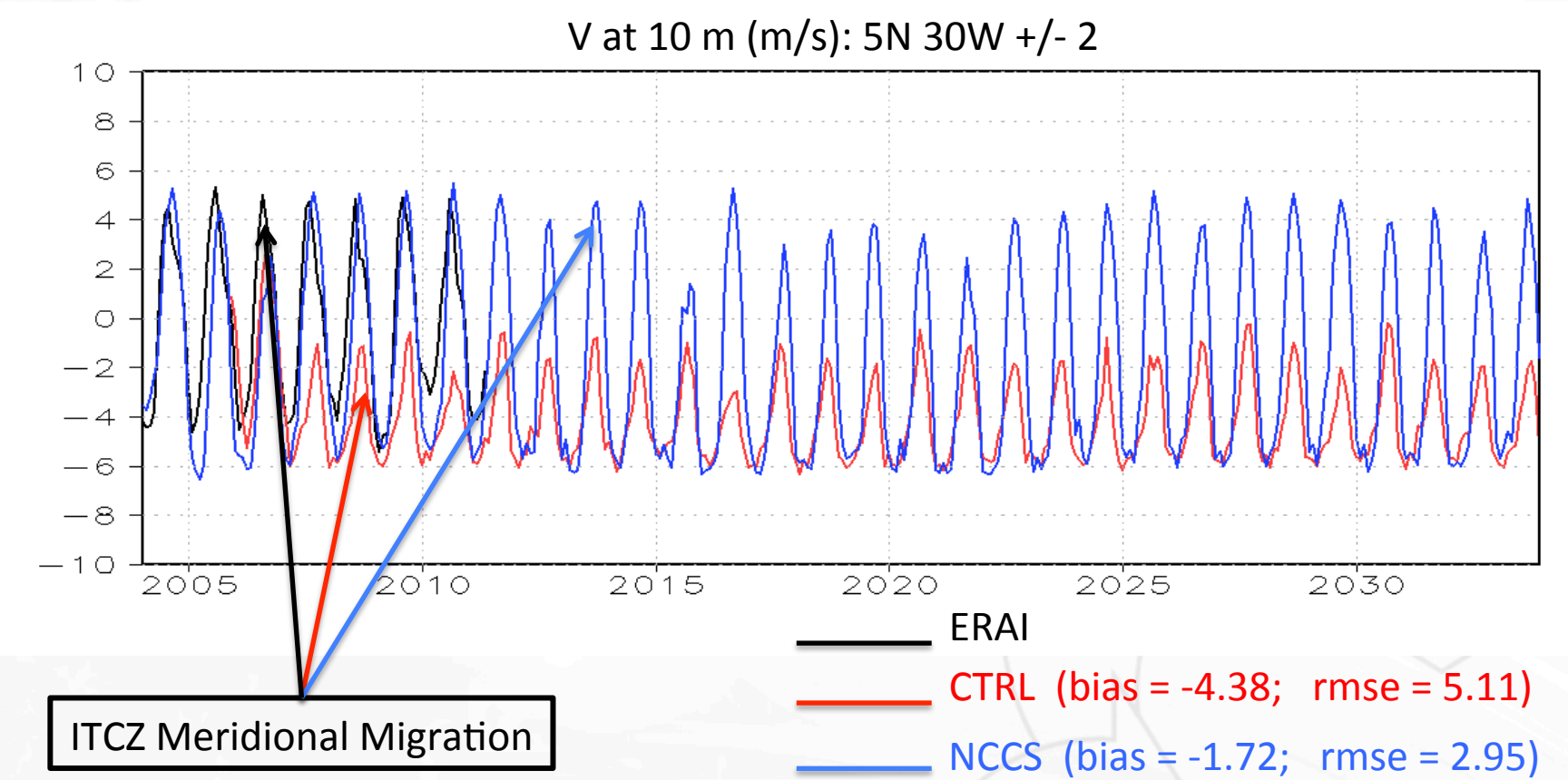
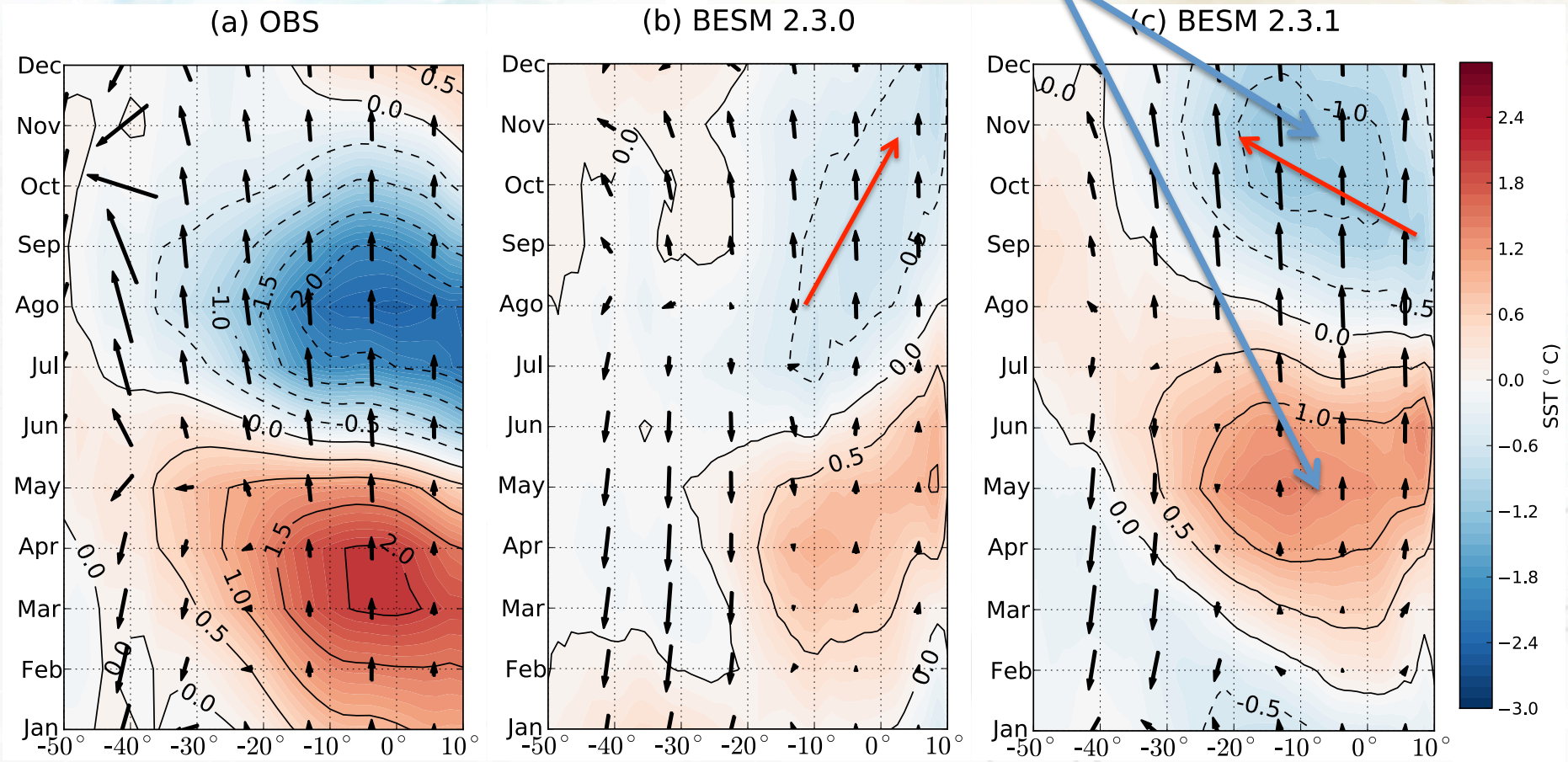
Atlantic ITCZ simulations



Bottino and Nobre (2016) to be Submitted

Tropical ATL SST-tau hovmoller

Increased wind stress, sst warming and cooling



Wrong cooling/warming propagation

Better sst annual cycle
Still has a phase shift

Siqueira et al (in preparation)

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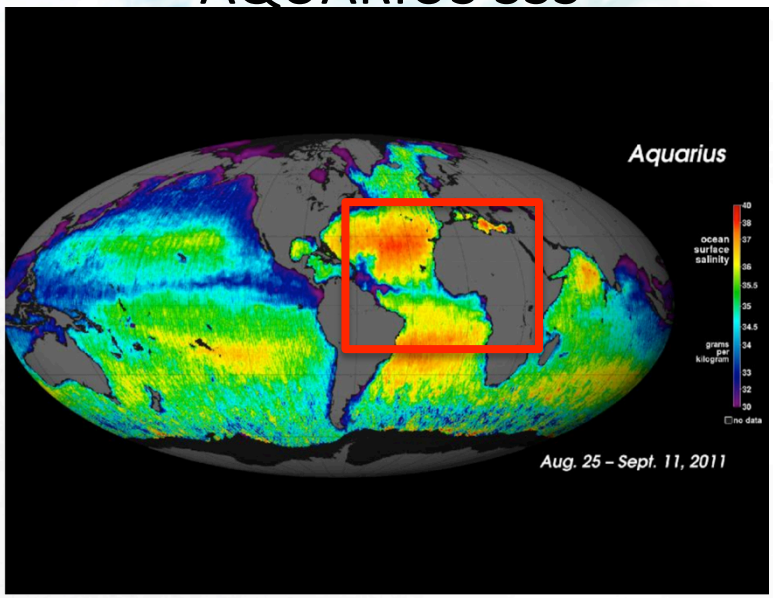
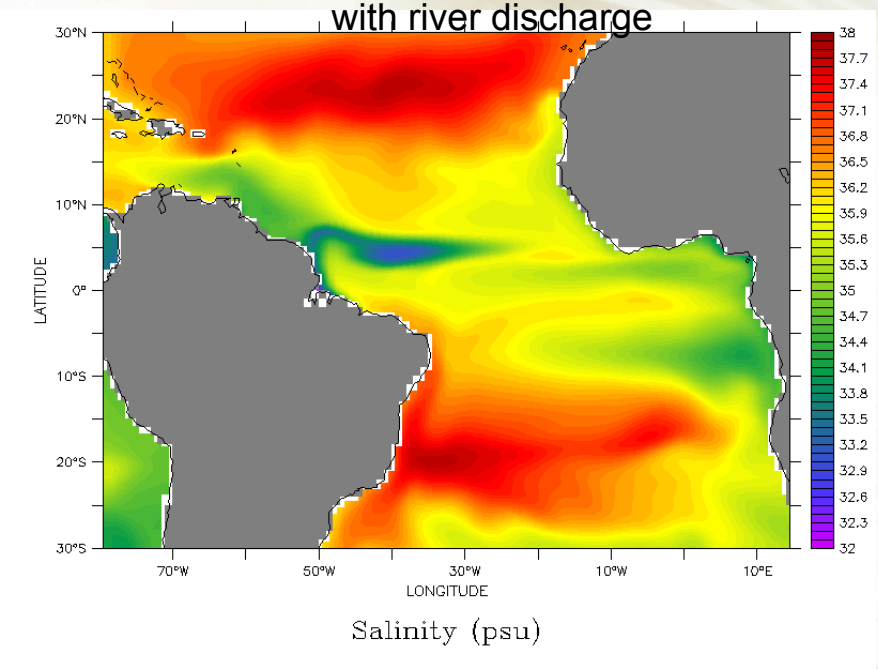
River discharge effects on Salinity

AQUARIUS SSS

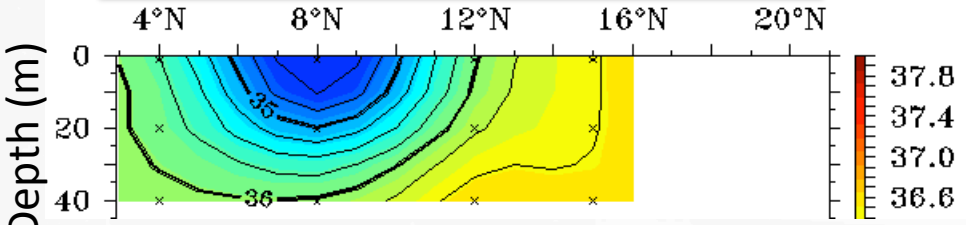


MOM4p1

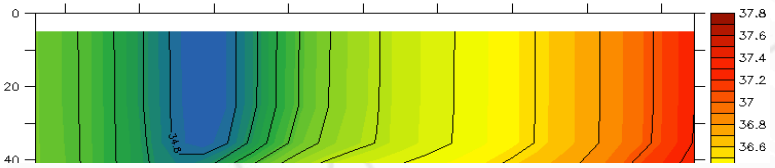
with river discharge



PIRATA DATASET



MOM4p1 SIMULATION



Source: P. Nobre (personal comm.)

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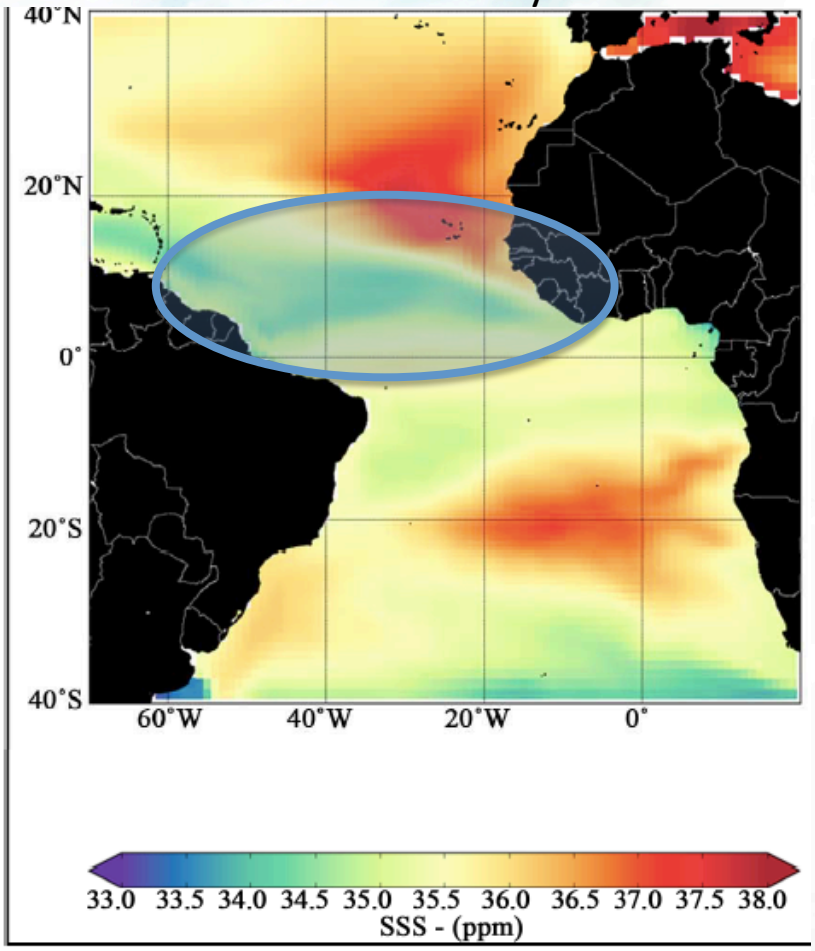
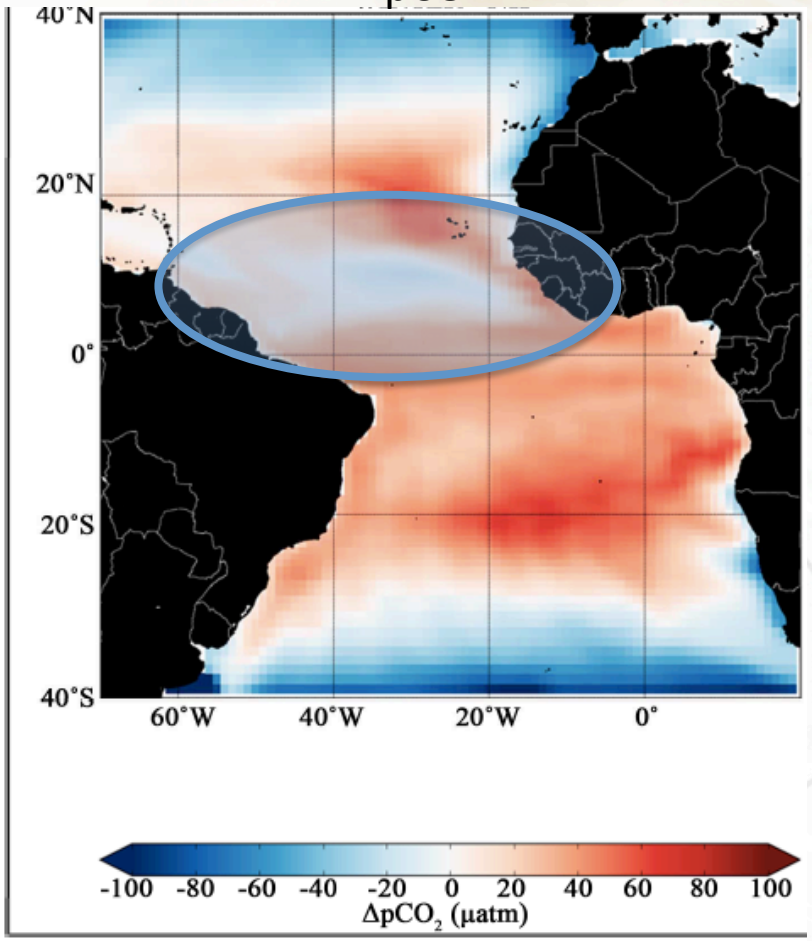
Ocean Carbon Cycle

Salinity



pCO2



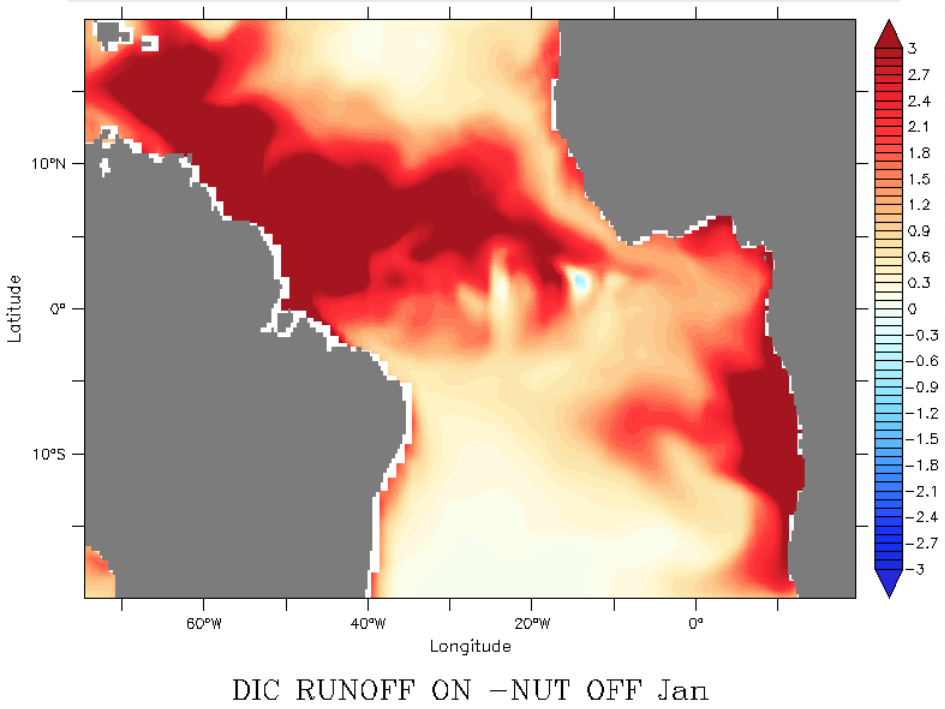
Source: De Farias et al (2012)

THE MARINE BIOGEOCHEMICAL COMPONENT IN THE BRAZILIAN EARTH SYSTEM MODEL (BESM)

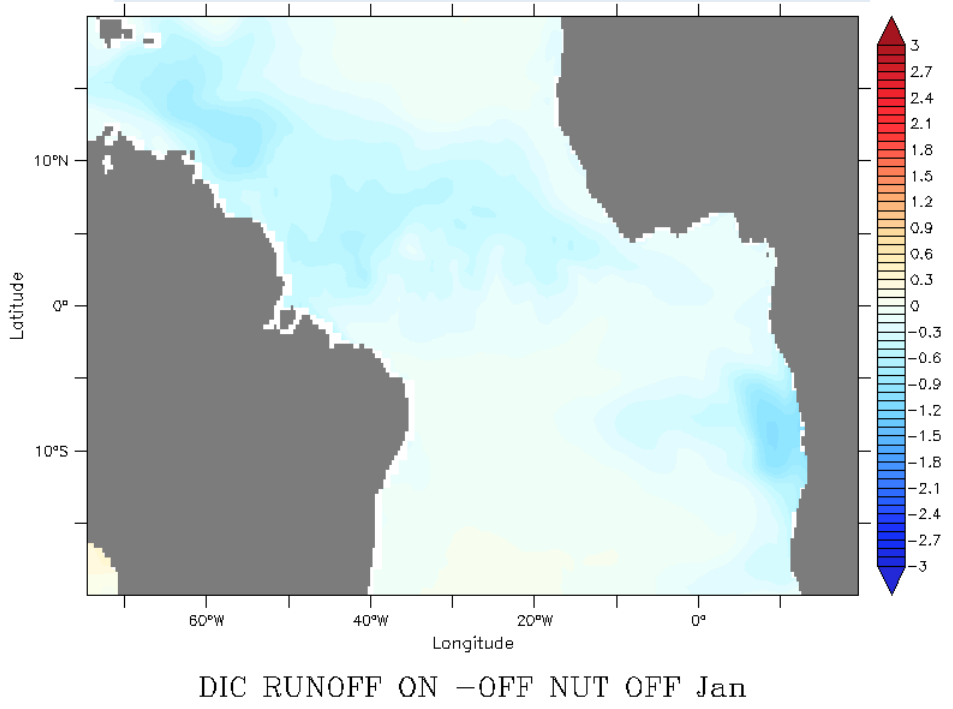
BESM Brazilian Earth System Model

Tracers of Ocean Phytoplankton with Allometric Zooplankton (TOPAZ)

The effect of removal of the nutrients transported by the rivers on DIC



The effect of the river discharges and nutrients removal on DIC



The nutrients carried by the river discharges have a impact on the Dissolved Inorganic Carbon (DIC) concentration, with the removal of the nutrients are a decrease of DIC. However with the removal of the river discharge and nutrients there is an increase of DIC due to the increase of alkalinity, as a consequence of the increase of salinity. This has consequences on the carbon flux between ocean and atmosphere.

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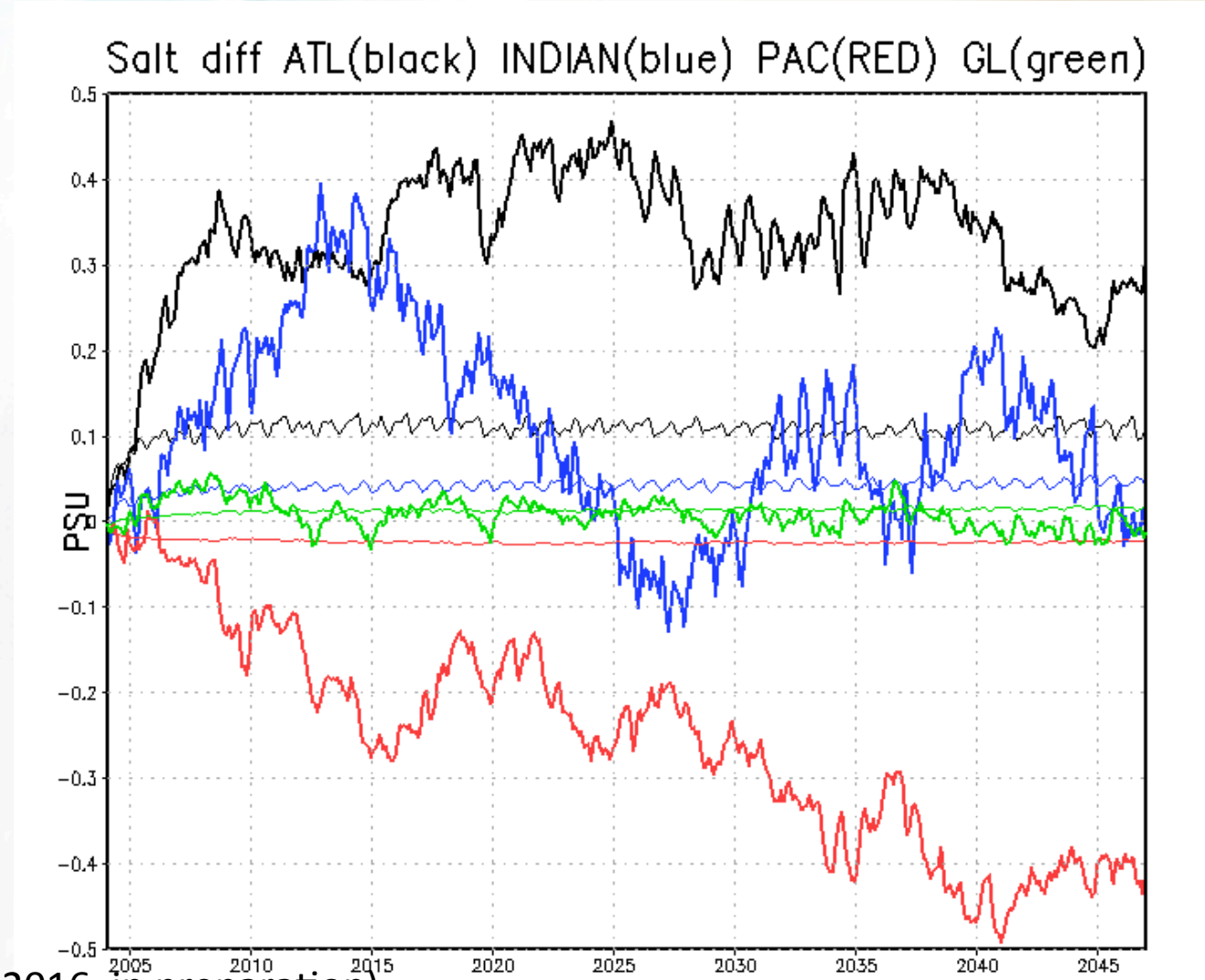
River Discharge Induced Coupled Oscilations



(Nobre et al, 2016, in preparation)

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Climate Change Results

The efforts to get into CMIP5

BESM
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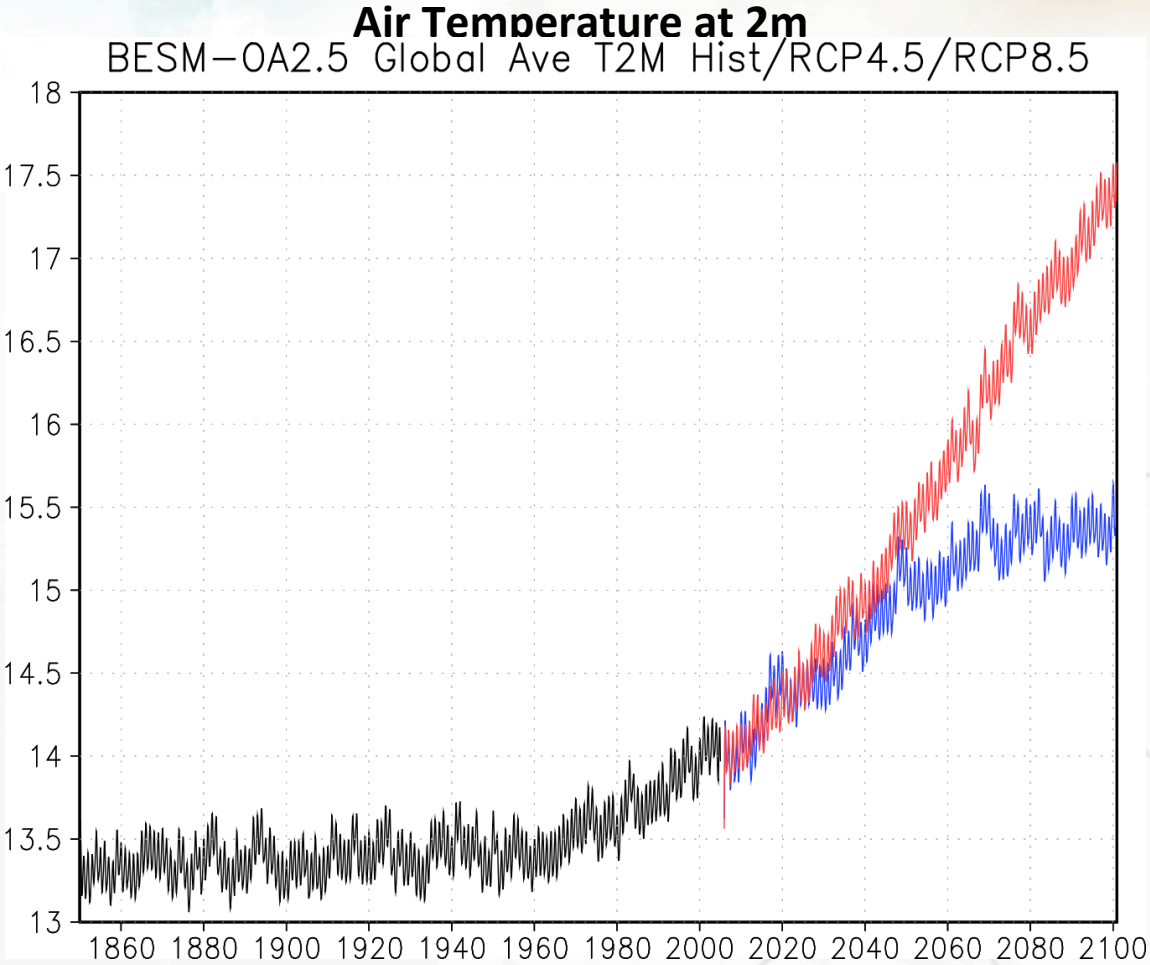
BESM2.5 CMIP5 Runs 1850-2100



Courtesy: V. Capistrano, INPE/BESM

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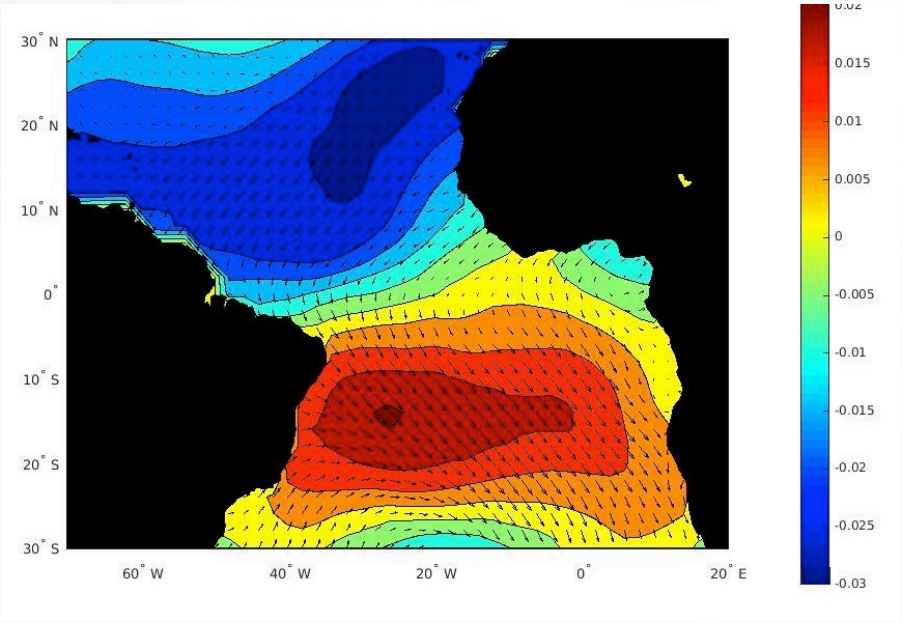
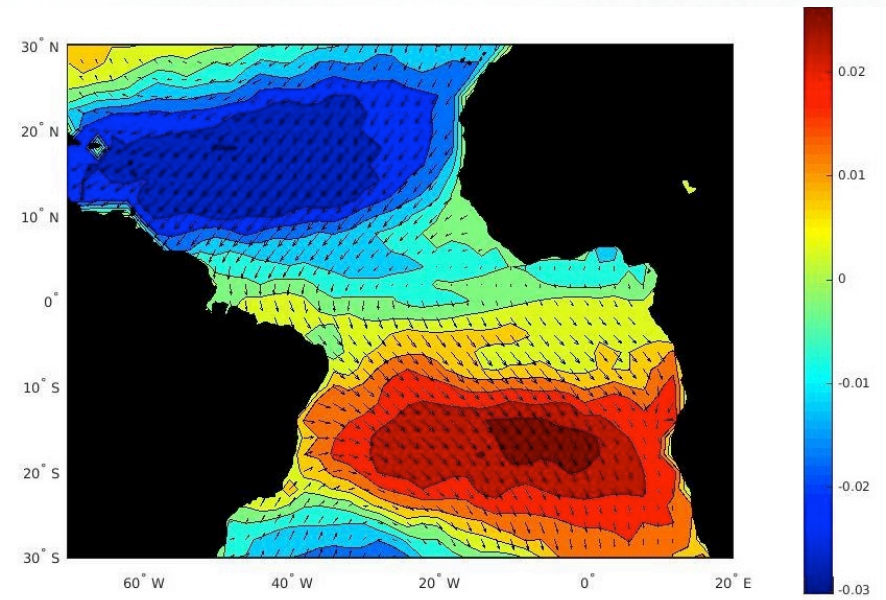
Atlantic Meridional Mode

SST, Taux, Tauy Joint EOF1

ERSSTv4 (9.3%)



BESM2.5 historical run (11.4%)



Courtesy: S. Veiga, INPE/PGMET

Air Temperature Change

Abrupt4xCO2 - piControl

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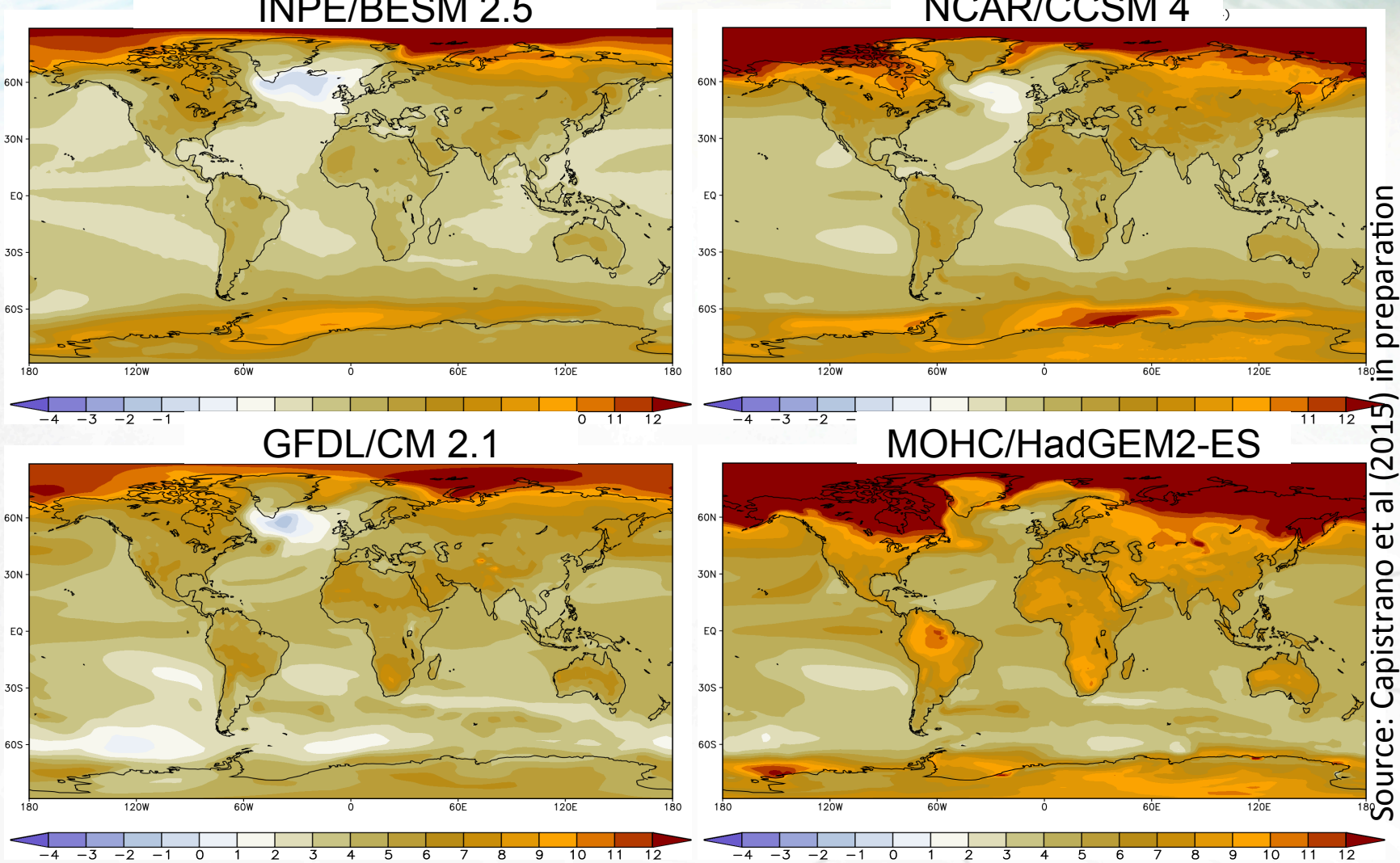

Source: Capistrano et al (2015) in preparation

Courtesy: V. Capistrano, INPE/BESM

BESM – CMIP5 Cloud Feedback

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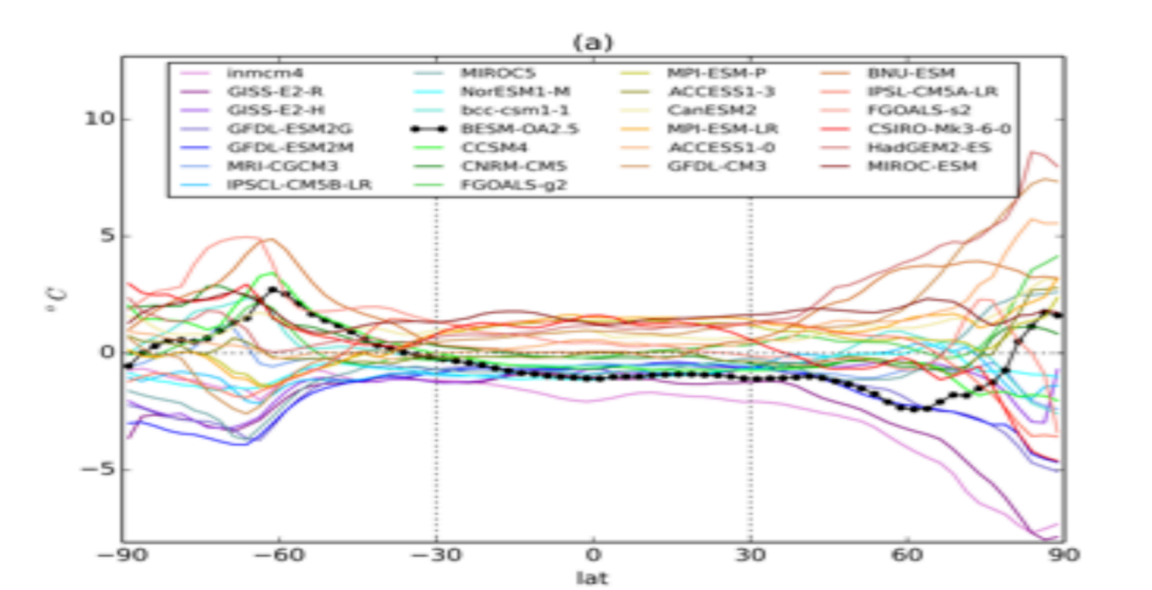
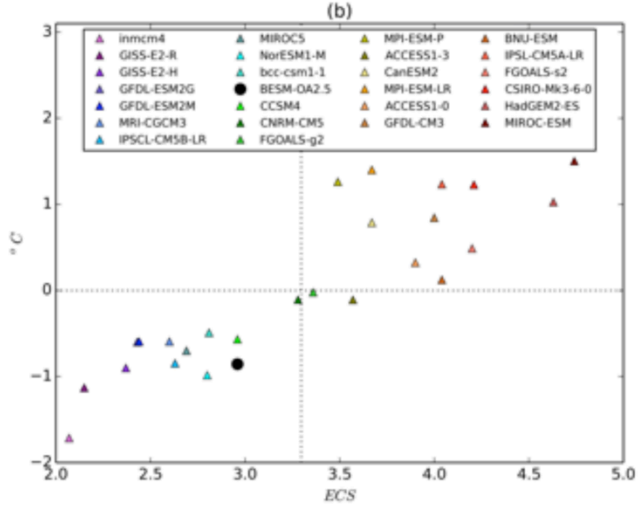
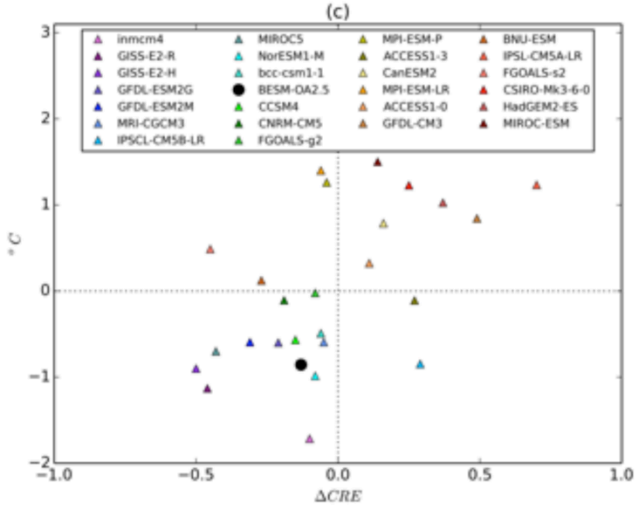


TROPICS



GLOBAL



Capistrano et al (TBS)

BESM Extreme Events in a Changed Climate

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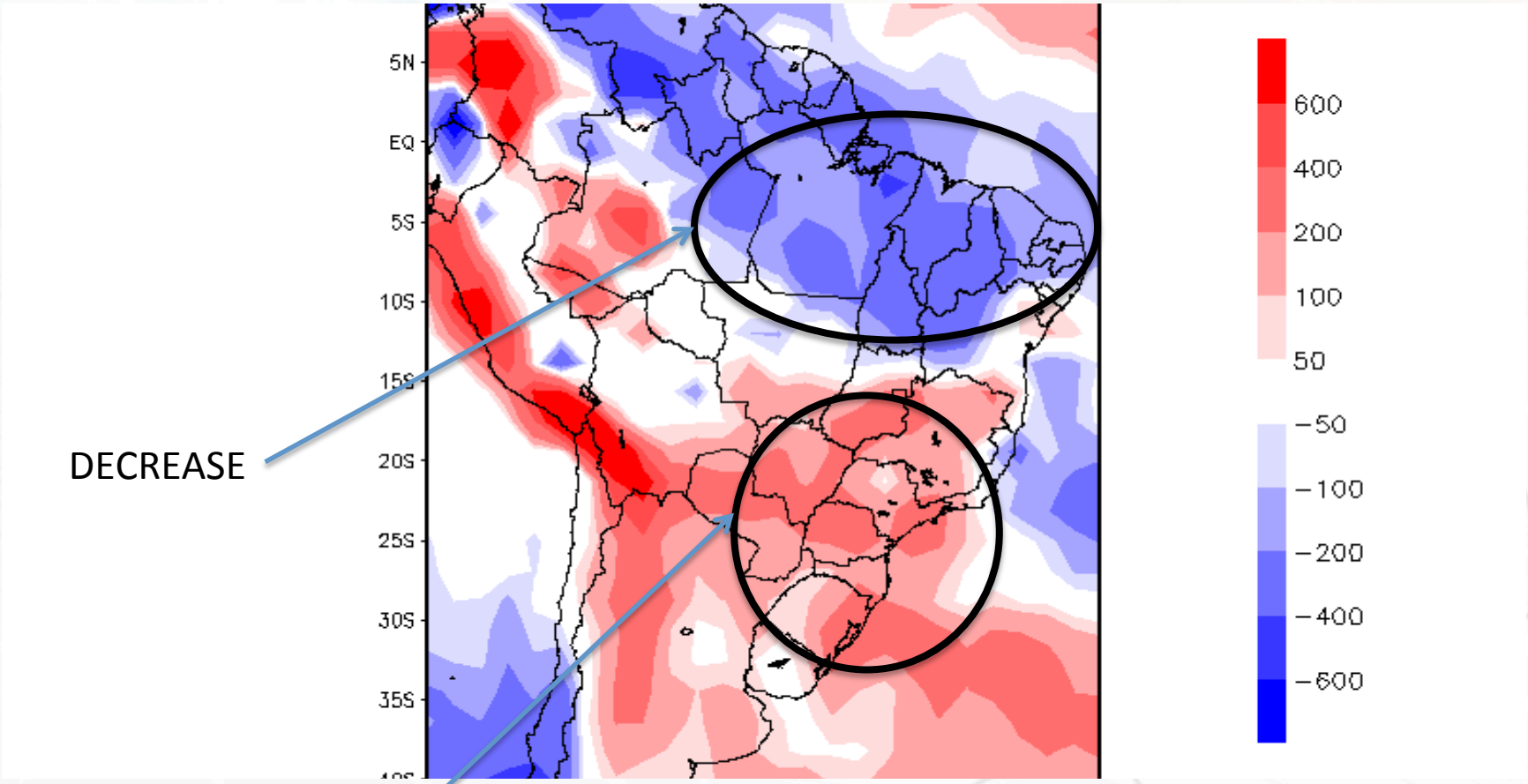
Annual Mean Precipitation Variation

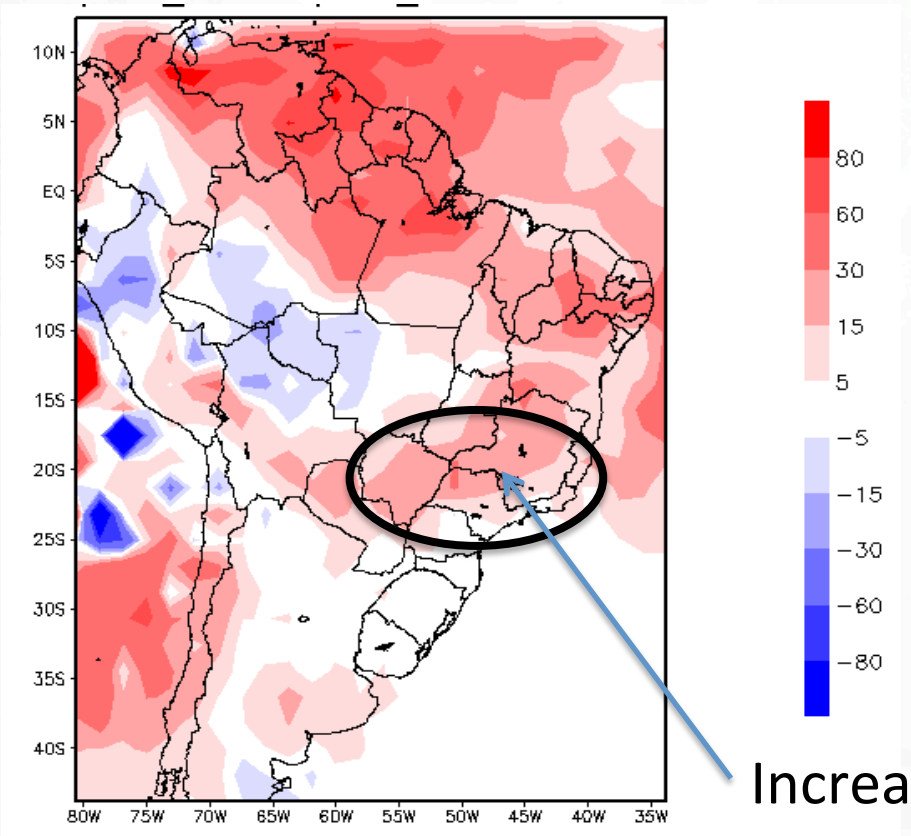


Source: Pesquero, Nobre et al (TBS)

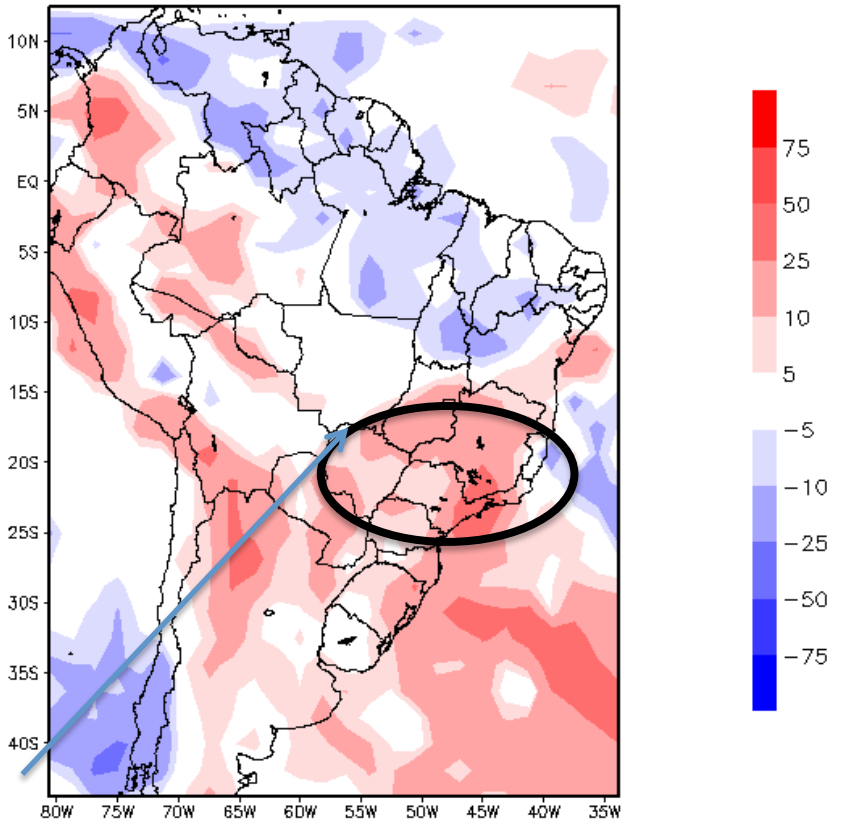
BESM Extreme Events in a Changed Climate

BESM
Brazilian Earth System Model

Consecutive Dry Days



Extreme Precipitation Days

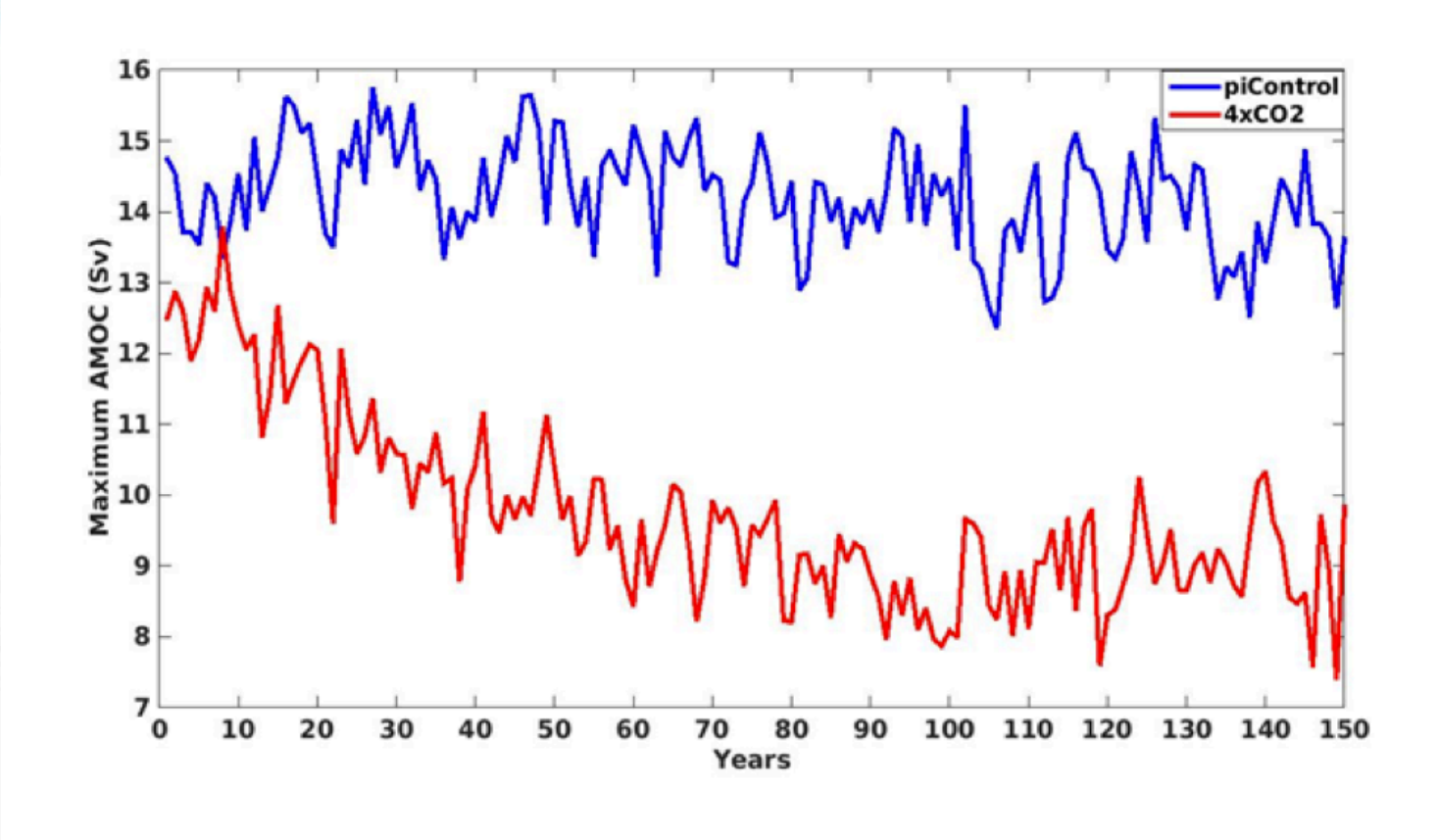


Increase

Source: Pesquero, Nobre et al (TBS)

BESM
Brazilian Earth System Model

BESM's AMOC Strength 4xCO2 Simulation

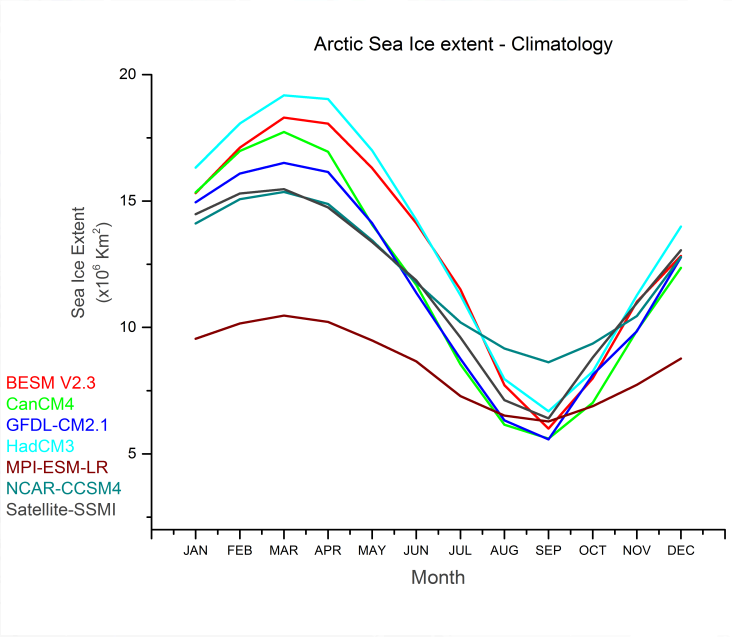


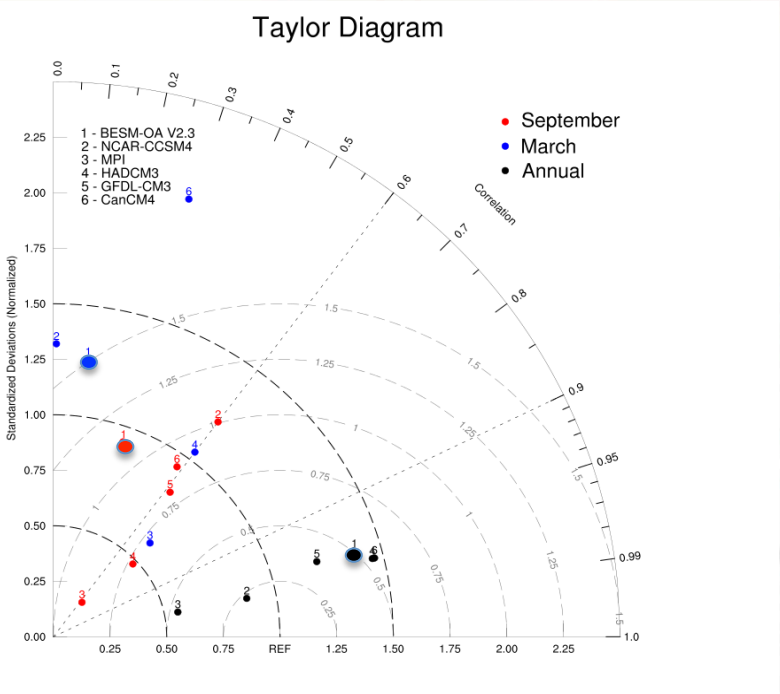
Courtesy: Sandro Veiga, PGCCST/INPE

BESM
Brazilian Earth System Model

Arctic Ice

in CMIP5 Models





Courtesy: Fernanda Casagrande, INPE/PGCCST

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Seasonal Climate Predictions

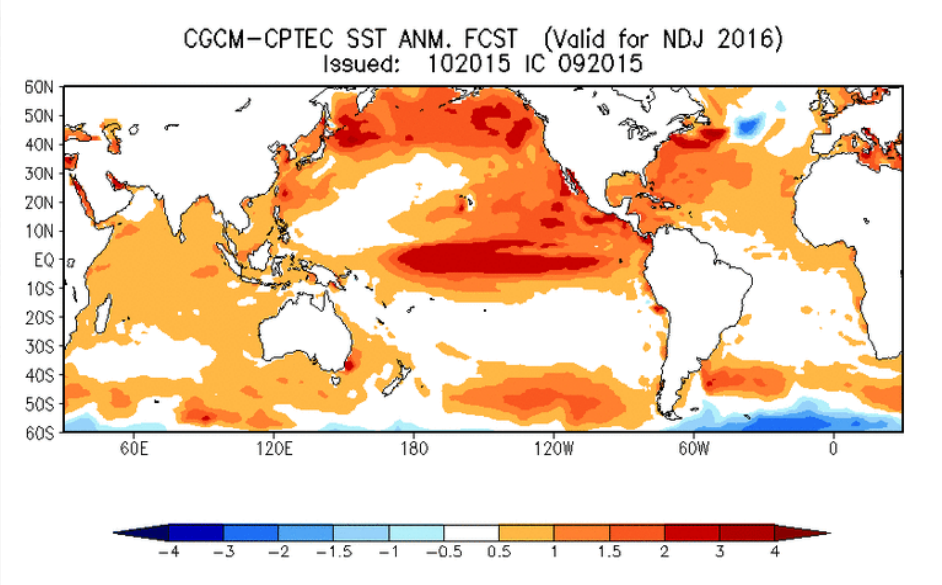
BESM as part of operational seasonal forecasting

BESM
Brazilian Earth System Model

BESM/CPTEC ENSO FORECAST

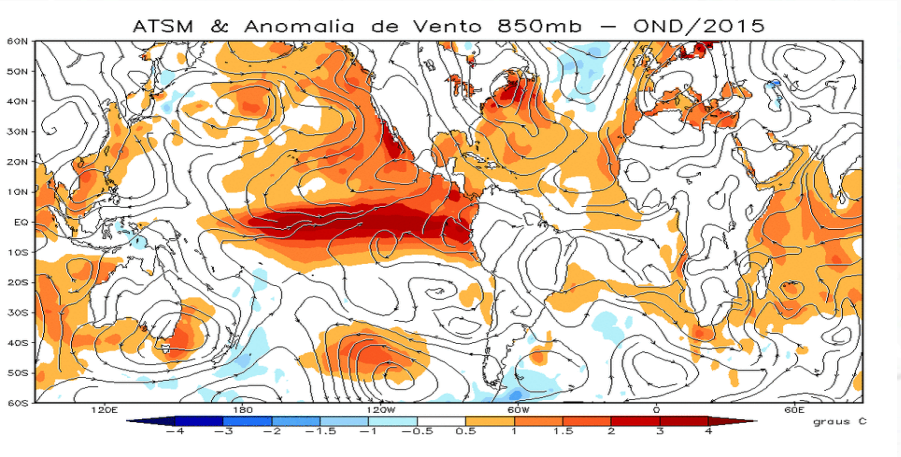
OND 2015 SST FCST

IC: Sept/2015



OND 2015 SST

ersst



Courtesy: Carlos R. de Sousa, Rede CLIMA

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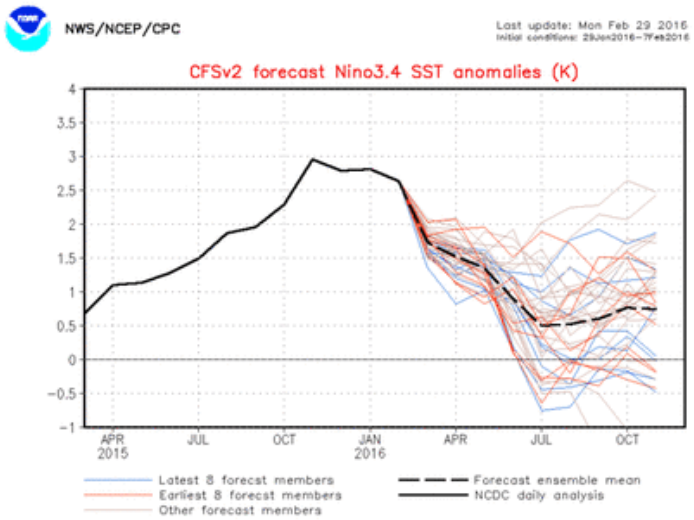
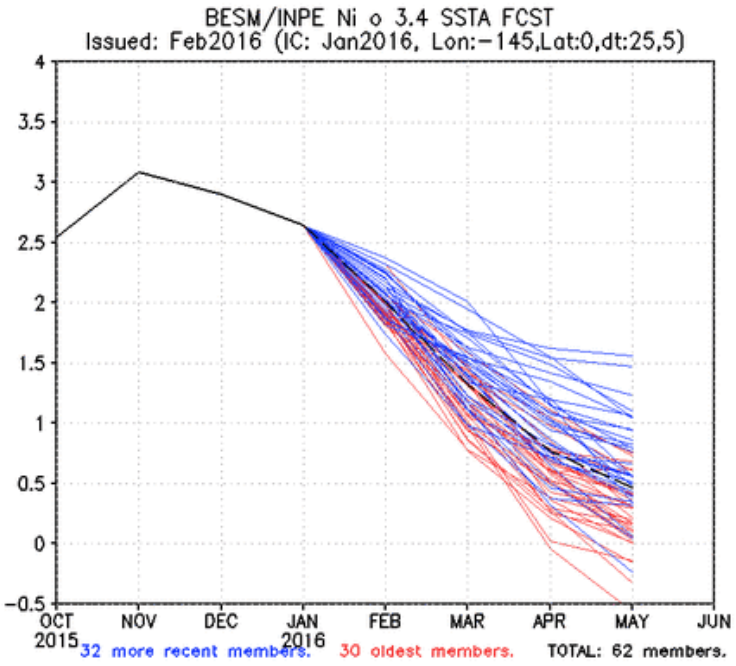
ENSO SST Outlook:

Issued: February 2016

NCEP CFSv2



INPE BESM v2.3



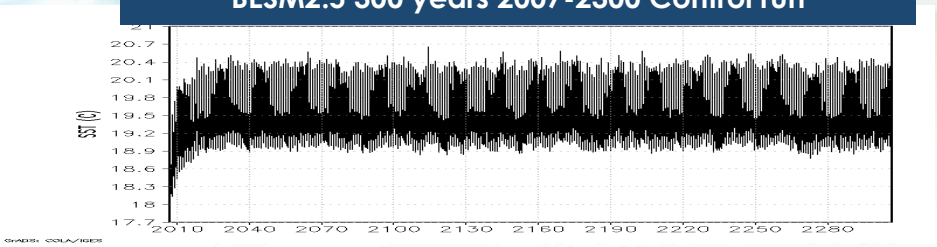
Issued: 02 October 2014

Courtesy: Carlos R. de Sousa, Rede CLIMA

BESM Runtime Environmet

BESM
Brazilian Earth System Model

BESM2.5 300 years 2007-2300 Control run



Tupã

softwares

Fortran

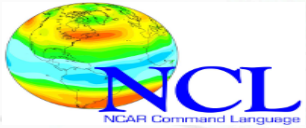
mercurial

Doxygen

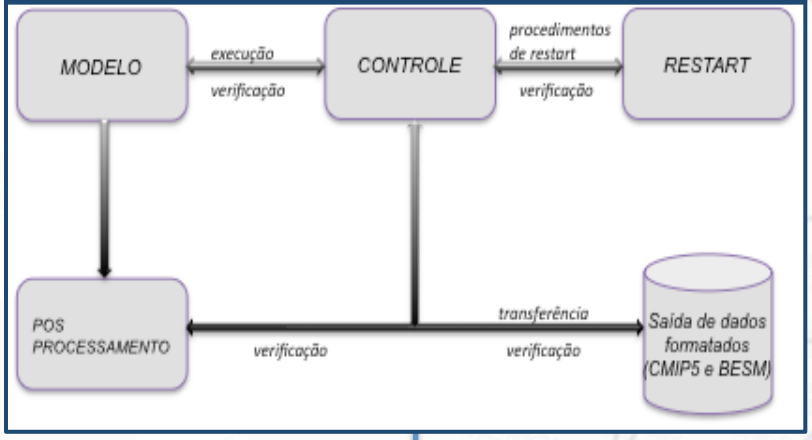
python

GrADS

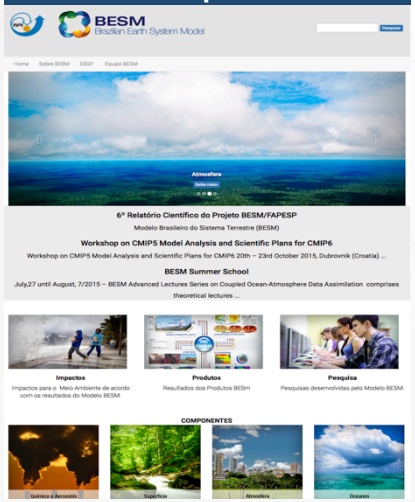
Ferret
NOAA PMEL



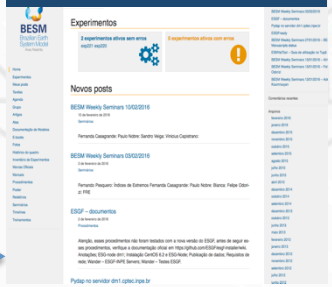
BESM Automated Run Suite



besm.ccst.inpe.br



restrito.ccst.inpe.br



Courtesy: B. Antunes, M. Baptista, F. Odorize

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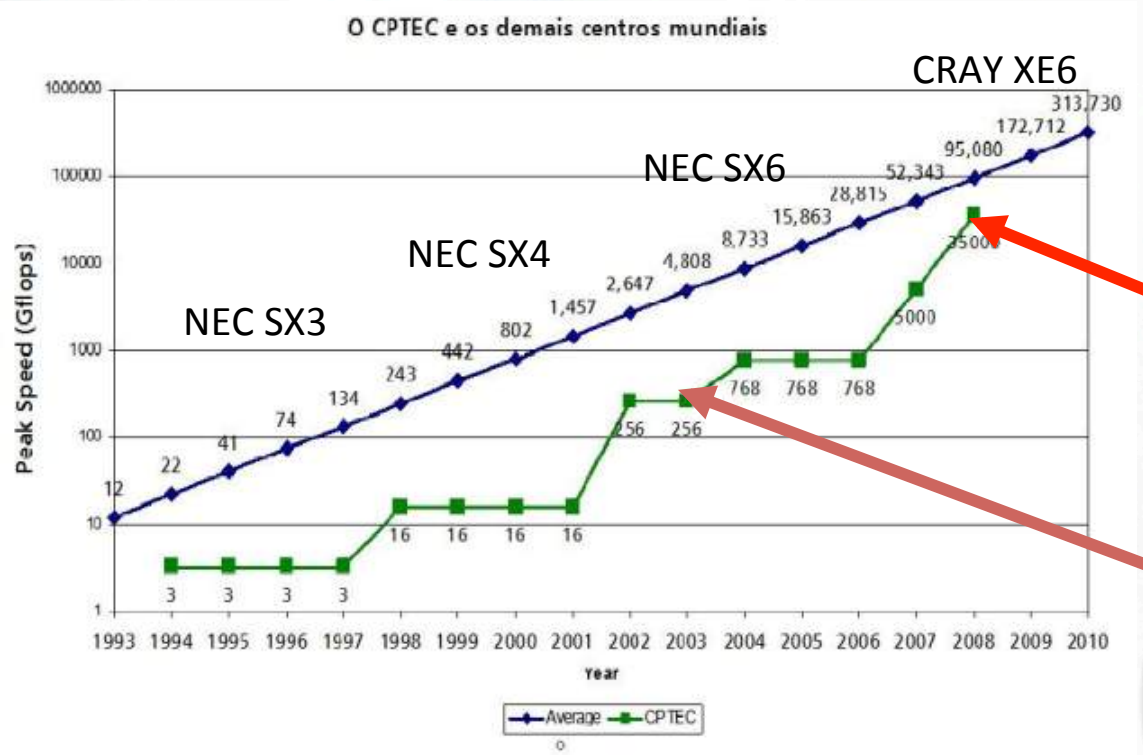
MCTI/INPE-REDE CLIMA-FAPESP
Supercomputer for Climate Change Research



15 TFlops sustained

100 Pbytes disk/tape storage

Courtesy: J. P. Bonatti, INPE/CPTEC

Brazil Participation on the Earth System Grid Federation - ESGF

BESM
Brazilian Earth System Model

Courtesy: Wander Mendes, INPE/BESM

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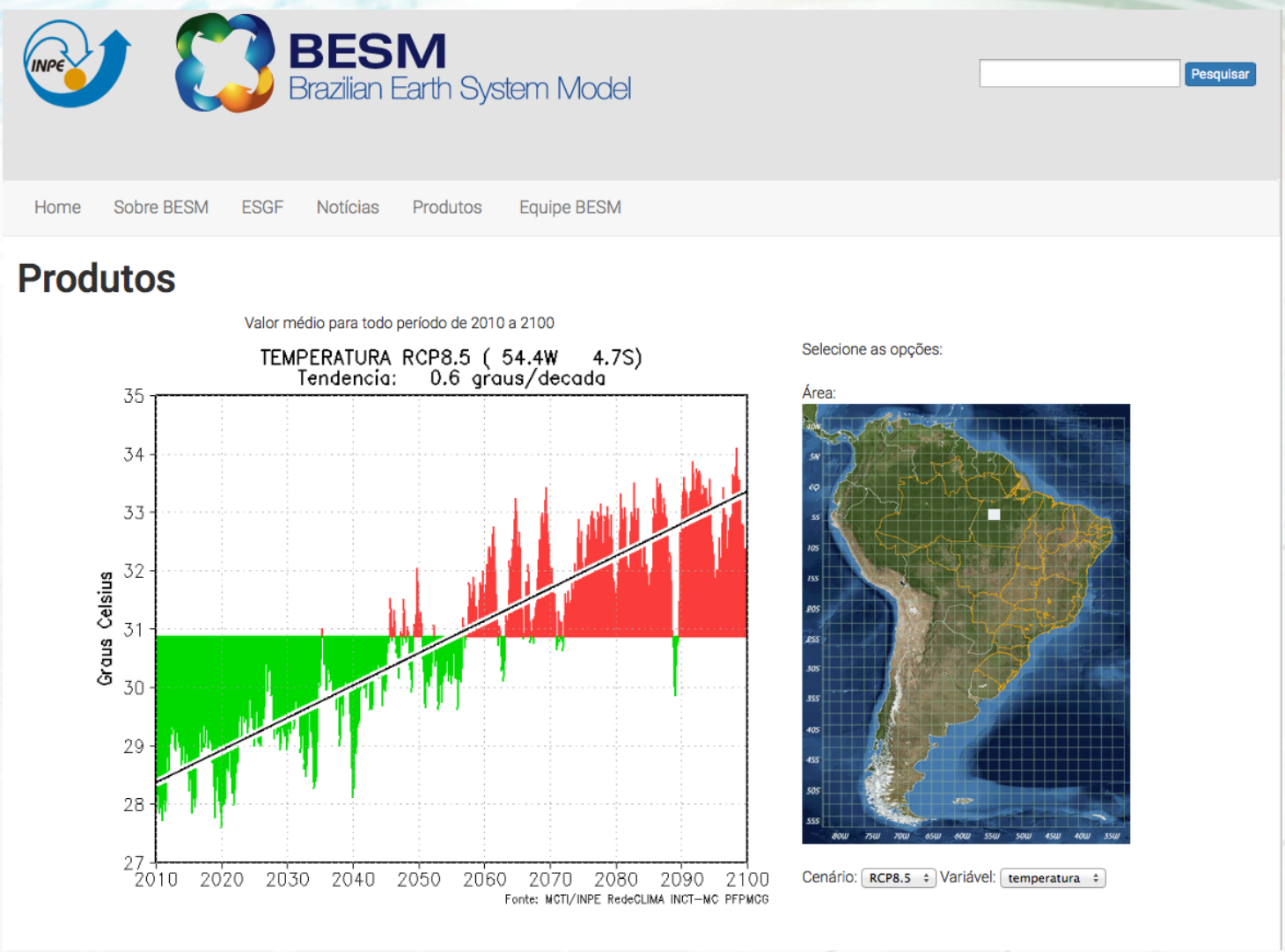
http://besm.ccst.inpe.br/produtos/



Courtesy: B. Antunes, INPE/BESM

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Brazilian Earth System Model

http://besm.ccst.inpe.br/esgf/

Hosted by INPE — MINISTÉRIO DA CIÊNCIA E TECNOLOGIA — INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS — CPTEC

Powered by ESGF and CoG

The Earth System Grid Federation is currently in the process of redeployment. Although individual sites such as this one have been brought online you should consider the system at risk until integration testing between sites is completed. An update to this notice will be made once this is the case.

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ESGF@INPE/CPTEC

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esgf-inpe
Home

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Welcome to the ESGF Node @ INPE/CPTEC

The Earth System Grid Federation (ESGF) maintains a global system of federated data centers that allow access to the largest archive of climate data world-wide. The ESGF Node at INPE/CPTEC is focused on supporting the access to the Brazilian Earth System Model (BESM) output. You can use this node as starting point for searching and downloading model output that are stored thoughout the federation. You can also start from any of the other Nodes to download climate model output, reanalysis fields, as well as gridded and satellite data.

Search & Download Data
Simple Text Search — Go
Search with options

Browse Projects
This | All | My | Tags
Parent projects (0)
Peer projects (0)
Child projects (1)
besm
Enter Tag
Reset — Go
Start typing, or use the 'Delete' key to show all available tags.

esgf-inpe Tags: *None*

Last Update: April 21, 2016, 11:58 a.m. by Admin User

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No Comments

Courtesy: F. Odorizze, INPE/BESM

BESM
Brazilian Earth System Model

Model Improvement

There will be always Much to be done

BESM
Brazilian Earth System Model

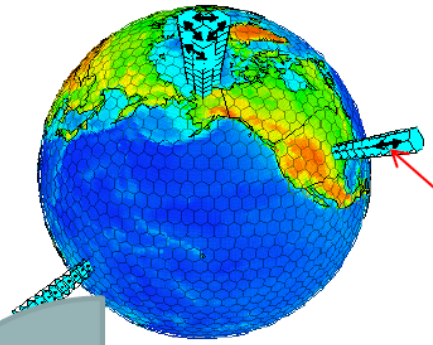
CPTEC AGCM
TQ299L64 (~44 Km)

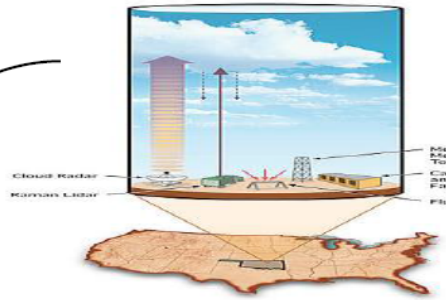
Components	BESM2.3	BESM 2.5
Dynamics	Eulerian Reduced Grid	Semi-Lagrangian Reduced Grid
Short Wave	CLIRAD (Tarasova et al. 2007)	CLIRAD (Tarasova et al 2007)
Long Wave	HASHVARDHAN (1987)	HASHVARDHAN (1987)
PBL	MELLOR YAMADA 2.0 (1982)	HOSTLAG BOVILLE (1992)
Surface	SSiB (1991)	IBIS 2.6 (1996), Kubota(2012)
Deep Convection	RAS	GRELL & DEVENYI (2002)
Shallow Convection	TIEDKE (1983)	TIEDKE (1983)
Large Scale Precip	Large Scale condensation	Ferrier (Ferrier *et al.*, 2002)
Gravity Wave	ALPERT (1988)	ALPERT (1988)

BESM
Brazilian Earth System Model

Physical Parameterization	BESM-OA2.5	BAM
Shortwave radiation	Clirad (Tarasova *et al.*, 2006; Chou and Suarez, 1999)	RRTMG (Rapid radiative transfer model for GCMs, Iacono *et al.*, 2008)
long-wave radiation	Harshvardhan (Harshvardhan and Corsetti, 1984; Harshvardhan *et al.*, 1987)	RRTMG (Iacono *et al.*, 2008)
Cloud microphysics	Ferrier (Ferrier *et al.*, 2002)	Morrison (Morrison *et al.*, 2005)
Land surface model	SSib (Xue *et al.*, 1991)	Ibis (Foley *et al.*, 1996)

What are we doing at CPTEC?

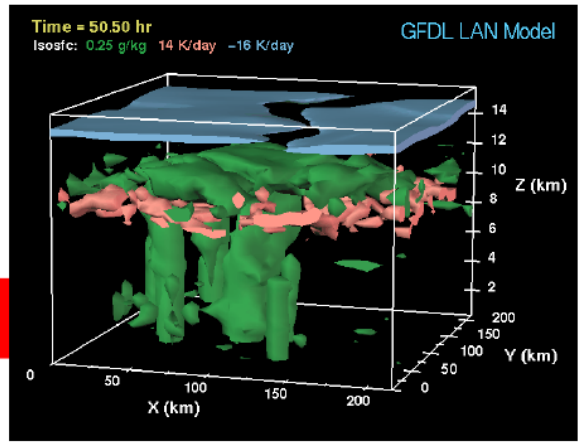


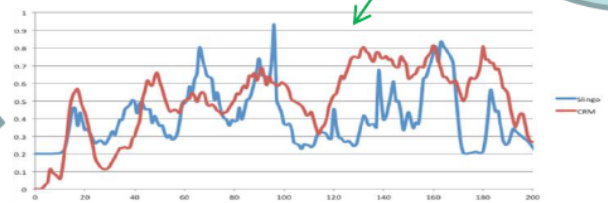


OBSERVATIONS FROM BOMEX,TOGA, LBA, ...CHUVA

Single Column Model (SCM), AGCM-1D. With new or modified SCHEME Running for 12h-48h

New/or modified Cumulus using LES or CRM





COMPARISON AGCM-CRM

Cloud Resolving Model (CRM), HResolution 10-500m, running for 12h-48 h.

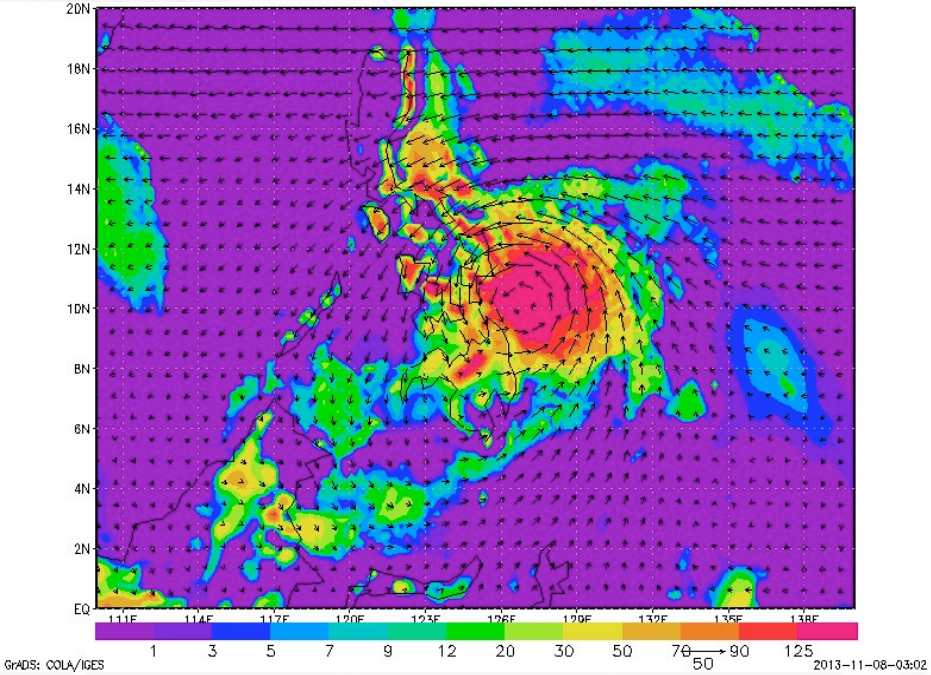
Silvio N. Figueroa (pers. Comm.)

BESM
Brazilian Earth System Model

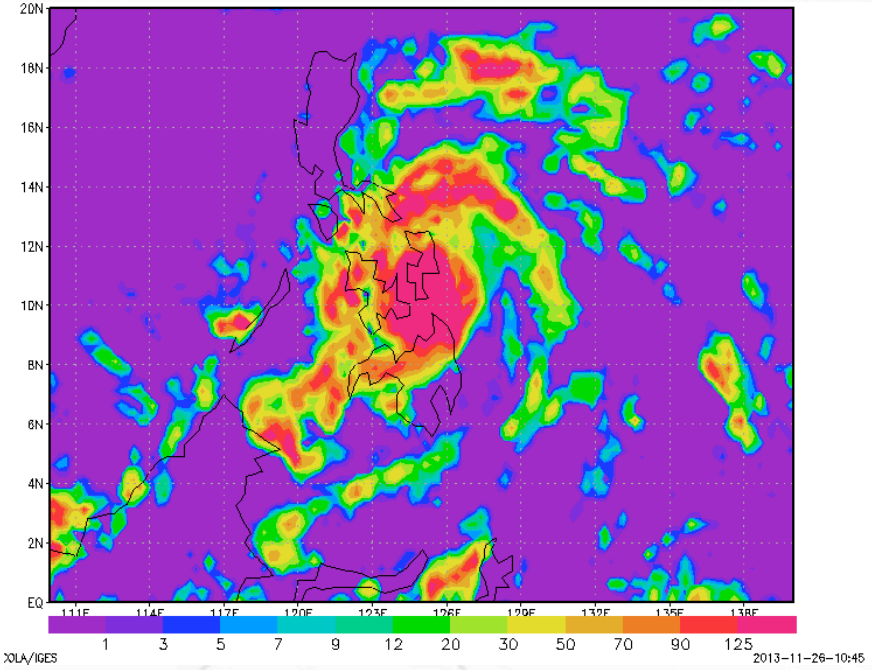
Super Typhoon Haiyan 2014

24 h FCST CPTEC-AGCM (T666L64)

CPTEC T666L64 24h FCST



TRMM RAINFALL OBS



Courtesy: Silvio N. Figueroa, INPE/CPTEC

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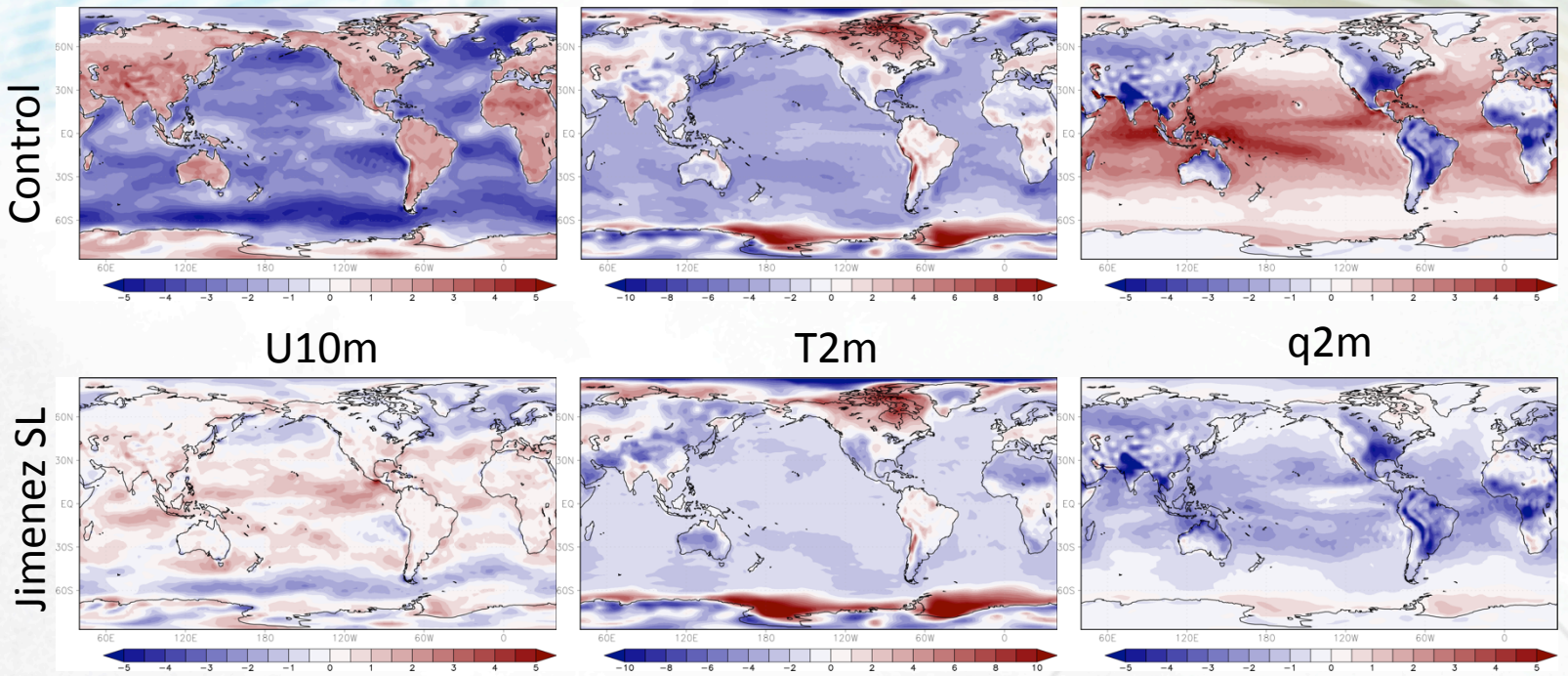
PBL PARAMETERIZATION



Normalized root-mean-square-error (NRMSE).

	u10m	T2m	q2m
Control	7.90	0.30	2.88
Jimenez SL	1.19	0.17	4.30

NRMSE over the ocean.

	u10m	T2m	q2m
Control	15.57	0.40	6.45
Jimenez SL	1.22	0.17	3.79

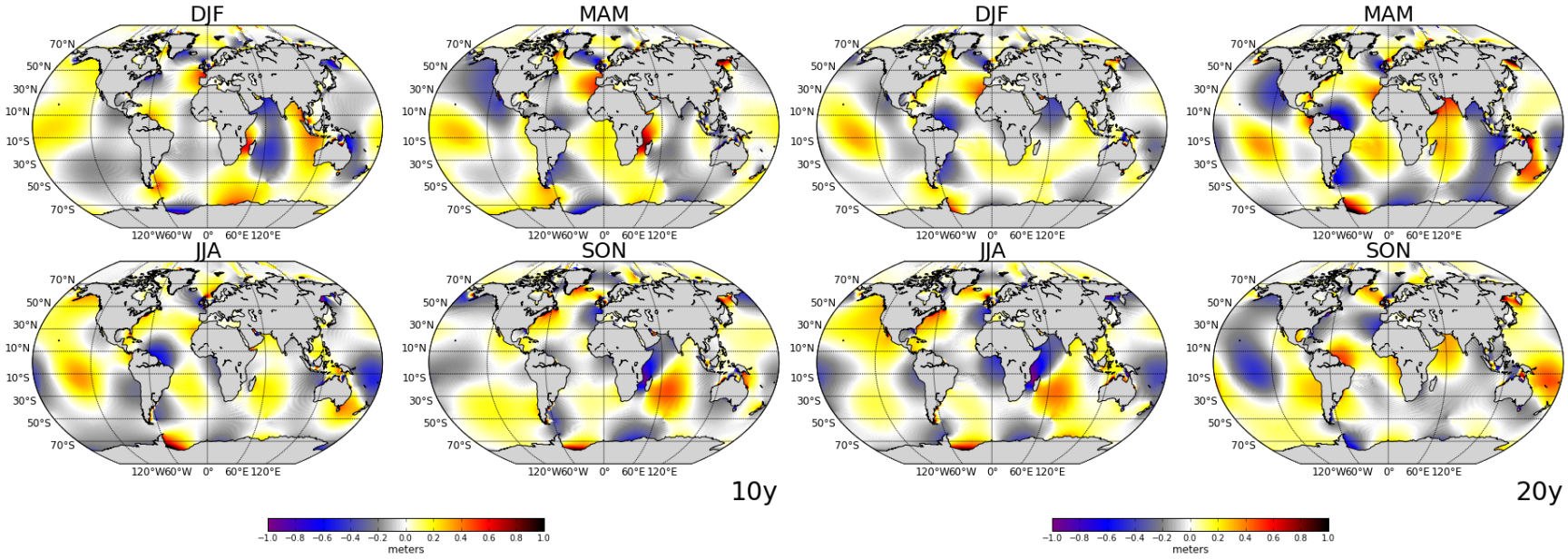
Courtesy V. Capistrano, INPE/BESM

BESM
Brazilian Earth System Model

MOM5 Tidal Phase Impact

10 Years

20 Years

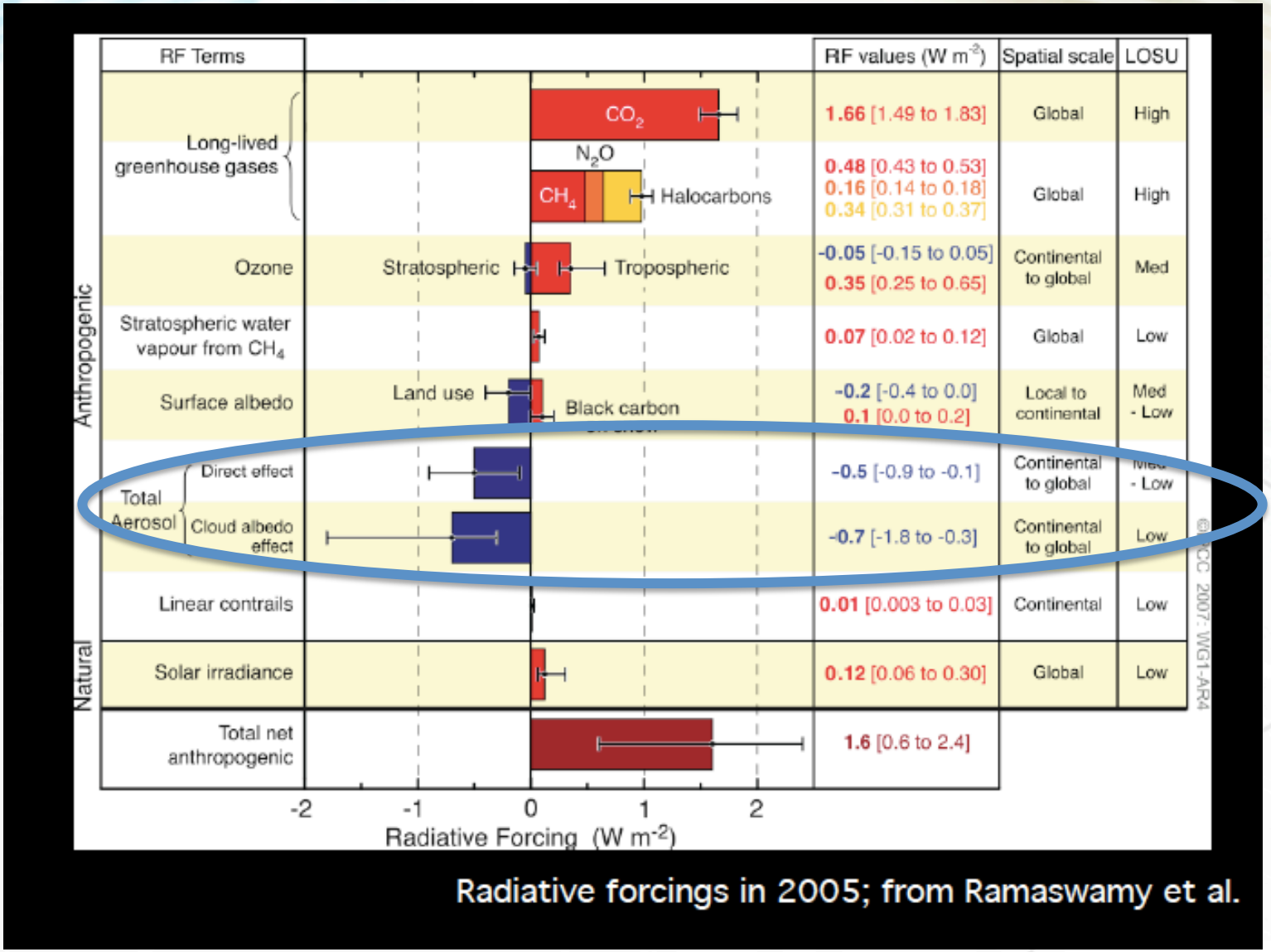


Sea level seasonal differences between default configuration , DFT (just amplitudes) and T8 (amplitude plus phase) after 10 and 20 years of simulation

Courtesy: M. C. Costa, INPE/PGCST

BESM
Brazilian Earth System Model

Radiative Forcing



Radiative forcings in 2005; from Ramaswamy et al.

BESM
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Using the superficial drainage as topographical reference

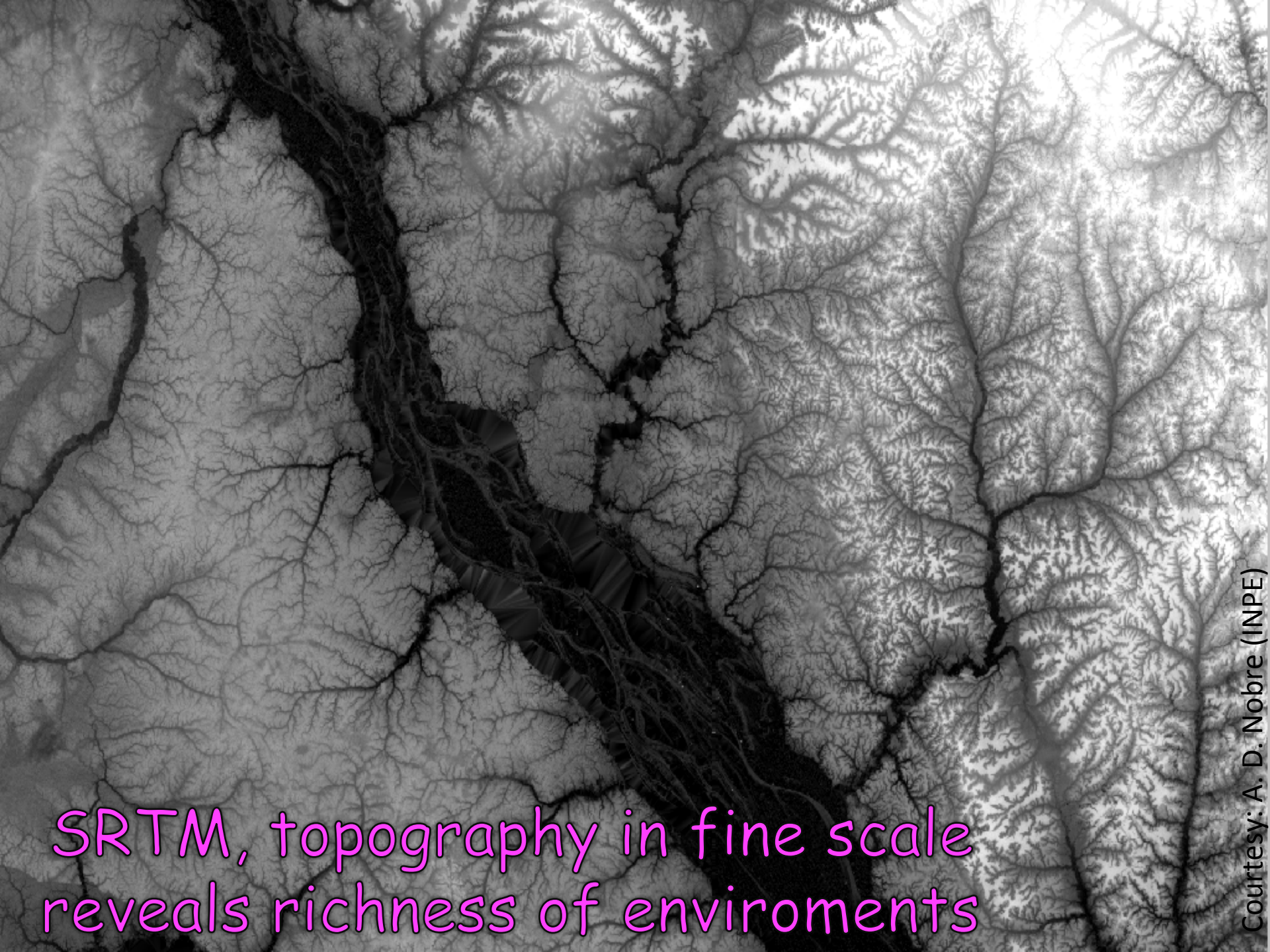
The HAND Algorithm

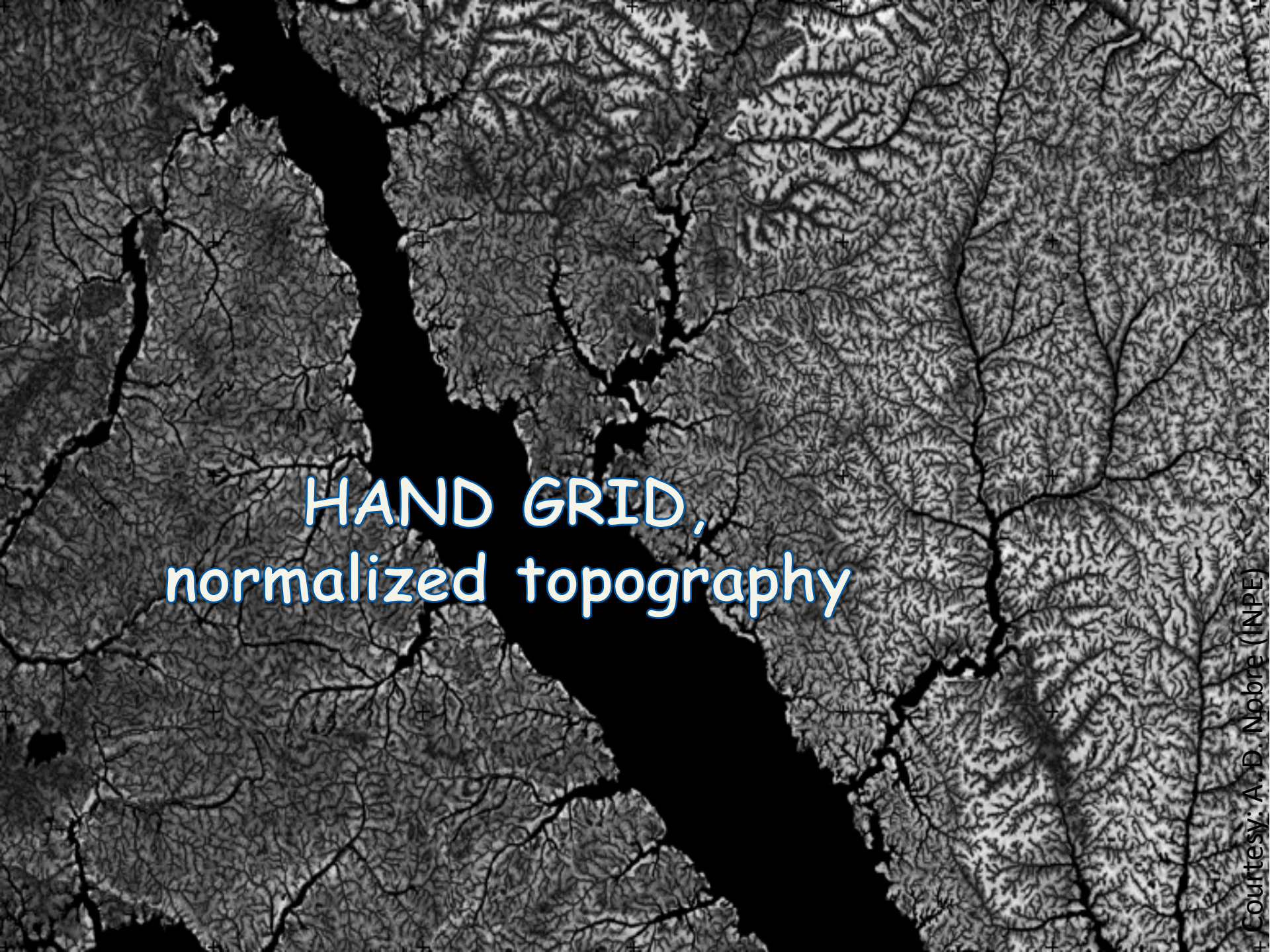
HAND, a new terrain descriptor using SRTM-DEM: Mapping terra-firme rainforest environments in Amazonia

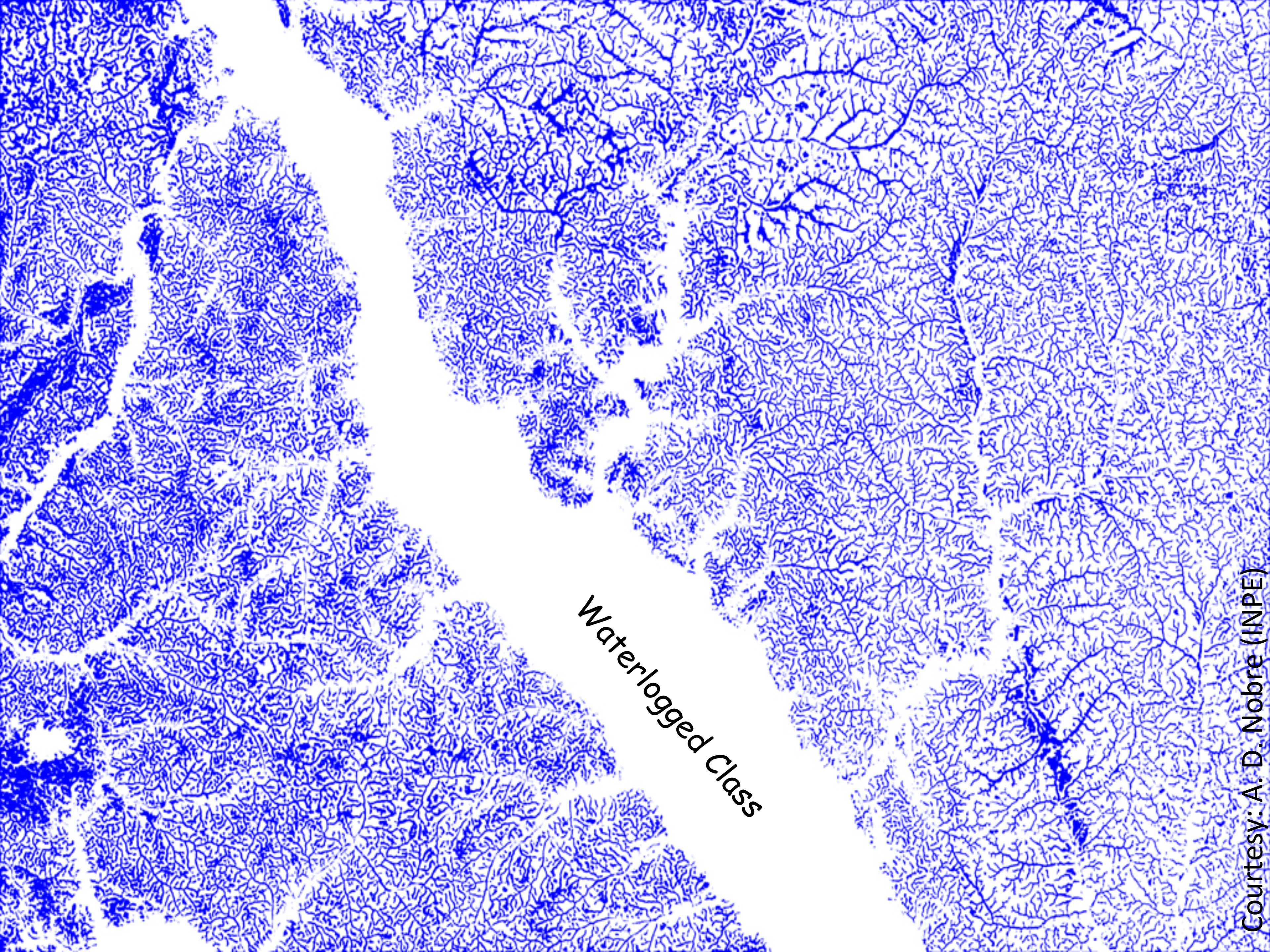
Camilo Daleles Rennó [a,*], Antonio Donato Nobre [b], Luz Adriana Cuartas [a], João Vianei Soares [a], Martin G. Hodnett [c], Javier Tomasella [a,b], Maarten J. Waterloo [c]

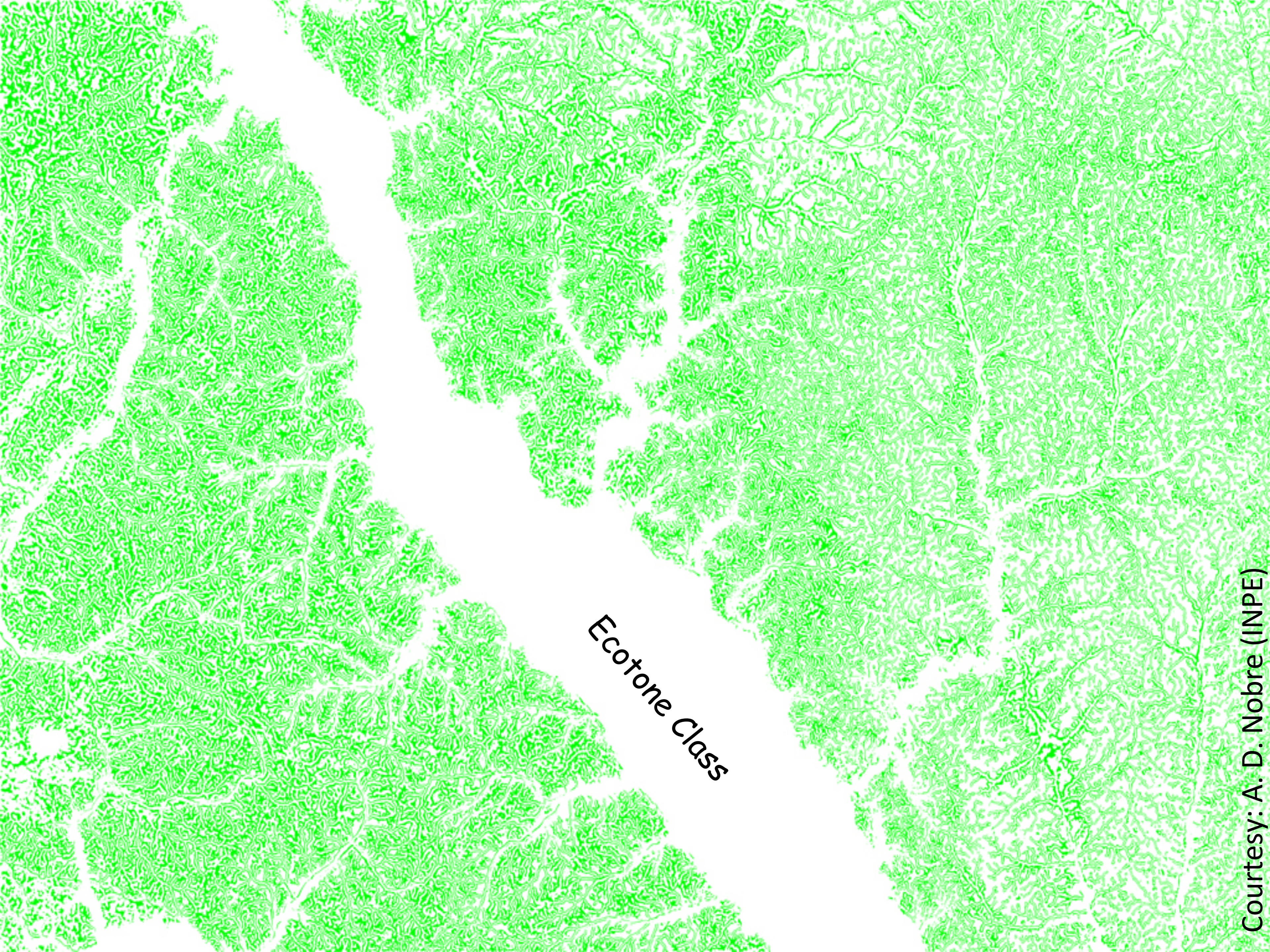
[a] Instituto Nacional de Pesquisas Espaciais, Av. Astronautas, 1758, São José dos Campos, SP, 12227-010, Brazil
[b] Instituto Nacional de Pesquisas da Amazonia, Escritório Regional do INPA, INPE Sigma, Av. dos Astronautas, 1758, São José dos Campos, SP, 12227-010, Brazil
[c] Vrije Universiteit Amsterdam, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands

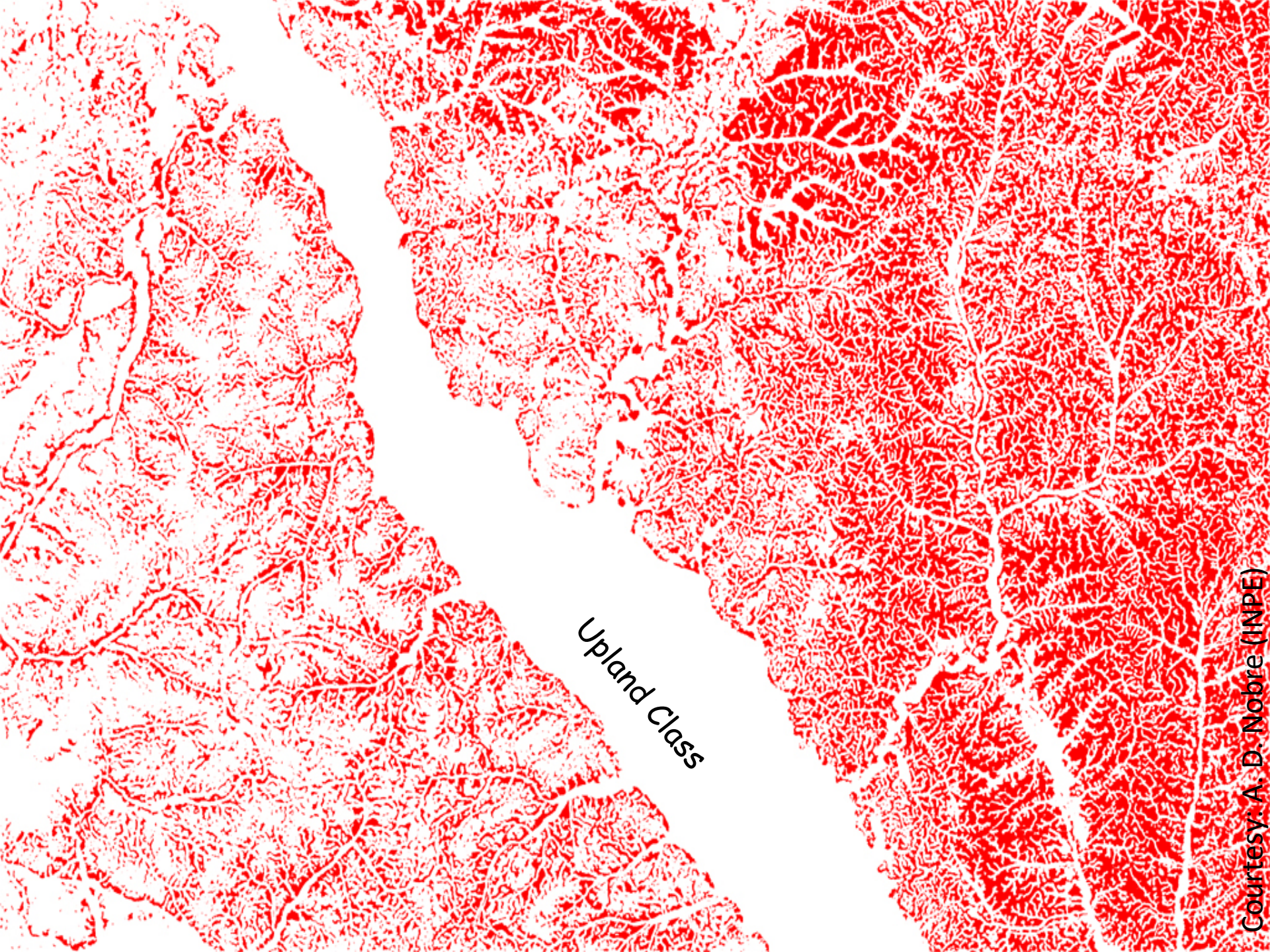

LANDSAT, terra firme apears as flat uniform land
Bacia ASU
NW of Manaus, 18.000 km²
Courtesy: A. D. Nobre (INPE)

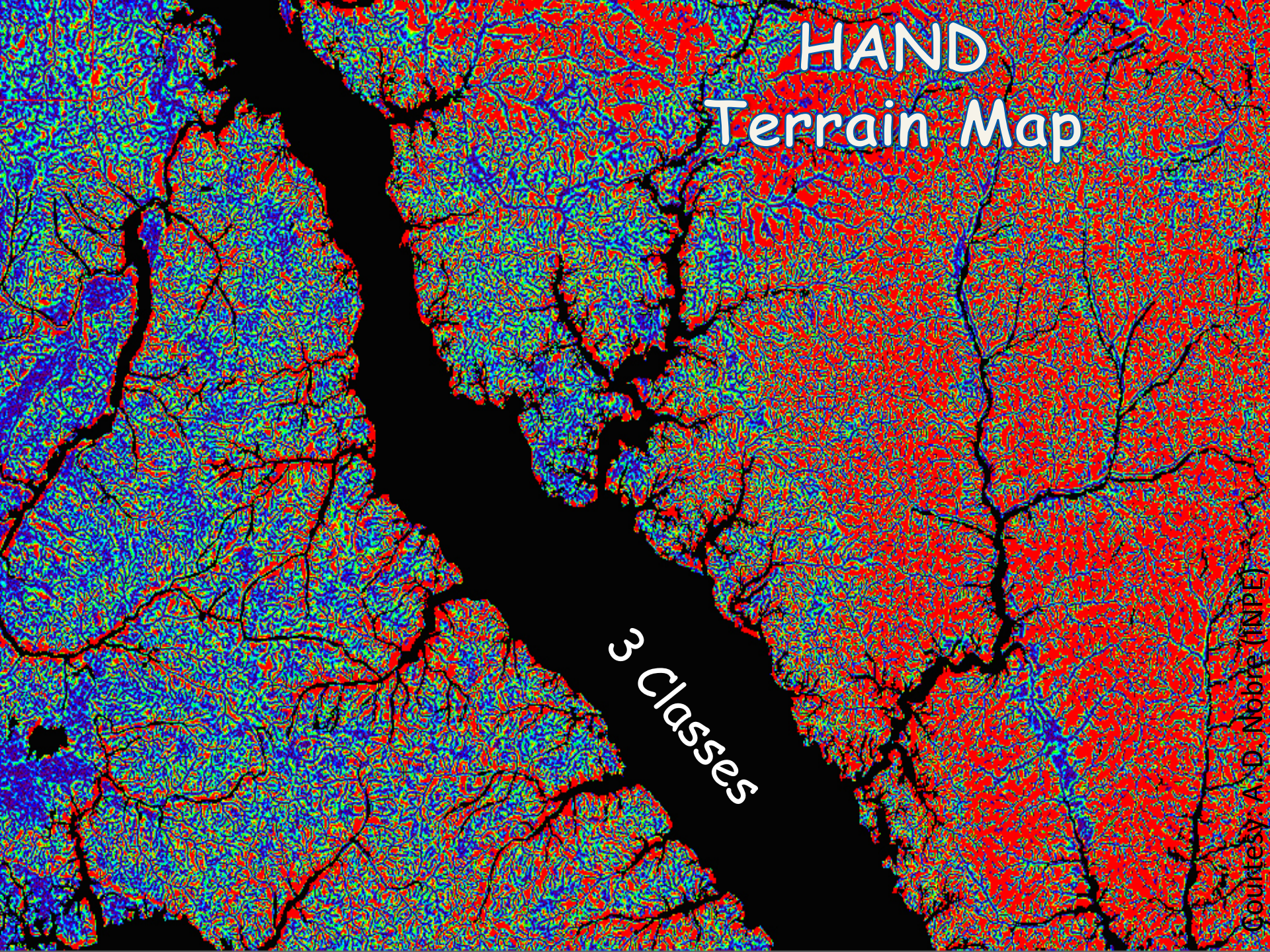

SRTM, topography in fine scale
reveals richness of enviroments
Courtesy: A. D. Nobre (INPE)

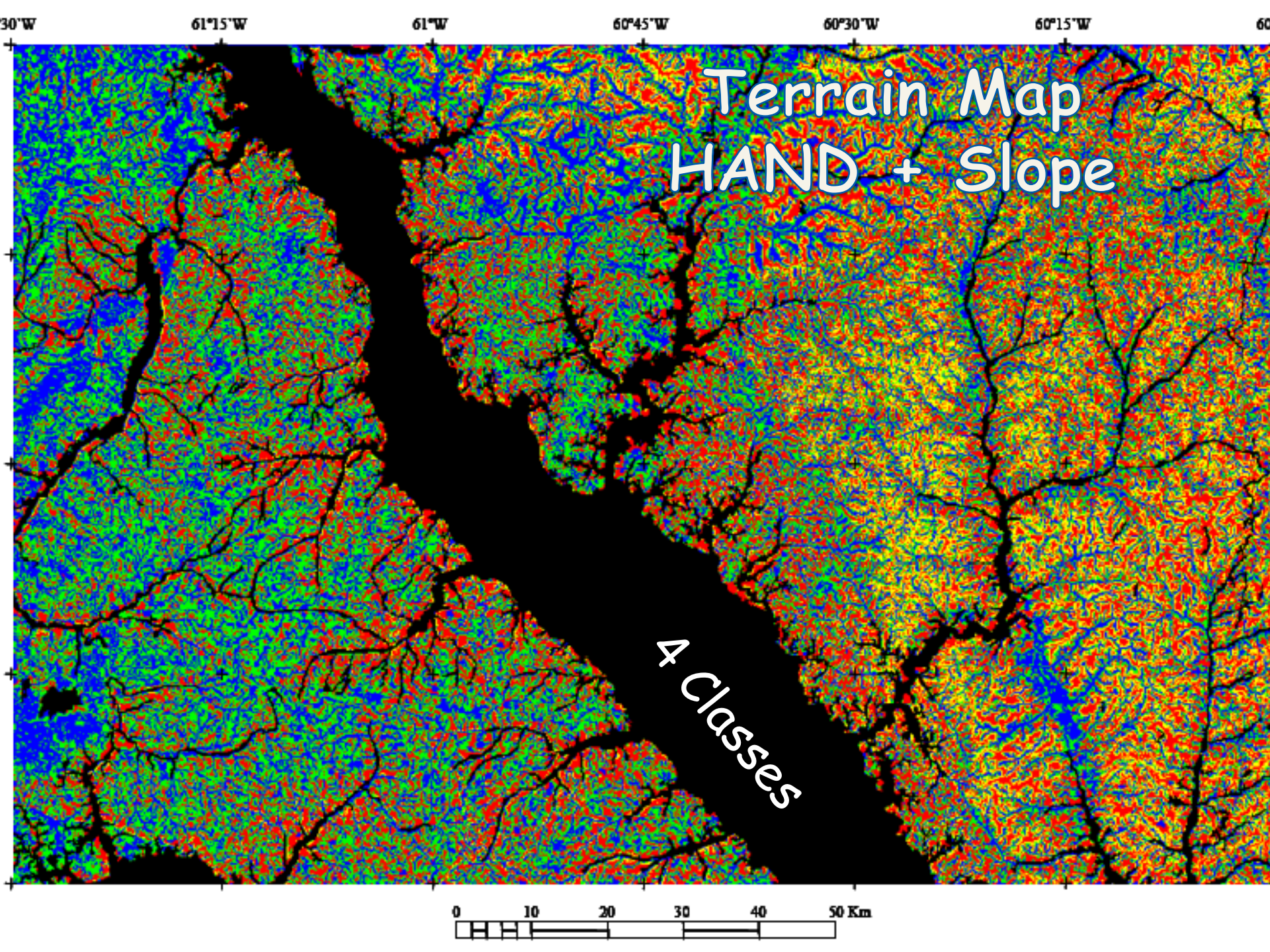

HAND GRID,
normalized topography
Courtesy: A. D. Nobre (INPE)


Waterlogged Class
Courtesy: A. D. Nobre (INPE)


Ecotone Class
Courtesy: A. D. Nobre (INPE)


Upland Class
Courtesy: A. D. Nobre (INPE)


HAND
Terrain Map
3 Classes
Courtesy A.D. Nobre (INPE)


Terrain Map
HAND + Slope
4 Classes
61°15'W
61°W
60°45'W
60°30'W
60°15'W
0
10
20
30
40
50 Km

BESM
Brazilian Earth System Model

The HAND allows the remote quantification of areas in each type terrain, with unprecedented precision

Table 1. Breakdown of areas for the four-class HAND (Terra-firme = Total area – floodland)

Class	Area km^2	% of Area	% Area Terra-Firme	% Area Terra-Firme, grouped
Floodland (mask)	3386.4	18.3		
Waterlogged	3886.2	20.9	25.6	Lowland
Ecotone	4986.8	26.9	32.9	58.5
Slope	1689.0	9.1	11.1	Upland
Plateau	4605.1	24.8	30.4	41.5
TOTAL	18553.3	100	100	100

Courtesy: A. D. Nobre (INPE)

BESM
Brazilian Earth System Model

BESM PROJECT
Production

Published Papers on Journals	**26**
Manuscripts in Preparation	**8**
Ph.D. Dissertations Completed	**3**
M.Sc. Thesis underway	**1**
Ph.D. Dissertations underway	**6**
Lectures and Conferences	**19**
Inteviews and Divulgation Articles	**19**
Seminars	**50**
Summer Schools	**5**
Global Climate Change Scenarios (years)	**10.000+**

BESM
Brazilian Earth System Model

Summer Schools

FAPESP School on Global Climate Modeling

October 2011, Ubatuba/SP.

Professors: Dr. C. A. Nobre, MCTI; Dr. P. Nobre, INPE; Dr. G. Brasseur, Max Plank Institute – Alemanha; Dr. A. D. Nobre, INPE; Dr. J. Carton, University of Maryland – EUA; Dr. L. Drude, UFC; Dr. M. Coe, Woods Hole Research Center – EUA; Dr. A. V. Krusche,-USP; Dr. P. N. Vinaychandran, IISc–India; Dr. C. Gnanaseelan, IITM – India.

2011 - Ubatuba/SP

FAPESP Advanced Lectures on the Physical Processes in the Brazilian Earth System Model (BESM): Cloud Microphysics

February 2014, Cachoeira Paulista, SP.

Professors: Dr. H. Morrison – NCAR, USA; Dr. S. N. Figueroa – INPE; Dra. R. I. Albrecht – INPE; Dr. G. P. Almeida –UFC.

FAPESP Advanced Lectures on the Physical Processes in the Brazilian Earth System Model (BESM): Planetary Boundary layer and Turbulence Parameterization

March 2014, Cachoeira Paulista, SP.

Professors: Dr. S. Park, NCAR- USA; Dr. S. N. Figueroa - INPE; Dr. O. Moraes – MCTI; Dr. O. Acevedo – UFSM; Dr. F. Denardim – UFRS.

FAPESP School on Global Climate Modeling Coupled Data Assimilation

27 July 2015, Cachoeira Paulista, SP.

Professor Dr. S. LAKSHMIVARAHAN - School of Computer Science University of Oklahoma.

2015 - Cachoeira Paulista/ SP

FAPESP School of cloud resolving models for development and improvement of moist physical parameterizations

November 2015, Cachoeira Paulista, SP.

Professor: Marat Khairoutdinov - at the School of Marine and Atmospheric Sciences, Stony Brook University.

BESM
Brazilian Earth System Model

Participating Institutions

- **Coordination**: INPE
- **Atmosphere**:
  - INPE/CPTEC, USP, UFSM, UFCG, NCAR
- **Ocean**:
  - INPE/CPTEC, NOAA/GFDL, NASA/GISS
- **Surface**:
  - INPE/CCST, USP, UFV, UFSM, WHRC, EMBRAPA
- **Chemistry**:
  - INPE, IITM, NCAR

BESM
Brazilian Earth System Model

What is the Brazilian contribution to the knowledge of global climate change and especially climate change in Brazil?

- A good representation of precipitation/convection in the Amazonia and SACZ regions is important to a good global climate representation. They are sources of humidity (Amazonia) and Rossby waves (SACZ).
- The majority of global models, although representing the general features of South America, presents deficiencies in this representation.

BESM
Brazilian Earth System Model

Concluding Remarks

- BESM-OA fully coupled global model has been completed, allowing Brazil to inaugurate its participation in the **CMIP5** global climate change model intercomparison project.
- Next steps: Developing BESM into a **Full ESM**, with dynamical vegetation, continental hydrology and atmospheric chemistry, **toward CMIP6**:
  - High Resolution Earth System Scenarios
  - Climate variability and extreme events research
  - Paleoclimate Studies

Science & Development Team

BESM
Brazilian Earth System Model

ATMOSPHERE

Silvio N. Figueroa
José P. Bonatti
Paulo Kubota
Enver Ramirez
Julio C. Chagas
Josiane Silva

OCEAN

Paulo Nobre (PI)
Vinícius B. Capistrano
Emanuel Giarolla
Andre Lanfer
Helena Soares
Raquel Leite Mello
Mabel C. Costa

SURFACE

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BESM
Brazilian Earth System Model

How to:

- BESM Global Climate Change Scenarios via ESGF:
  - http://besm.ccst.inpe.br/esgf/
- BESM Time Series over South America:
  - http://besm.ccst.inpe.br/produtos/
- Contact BESM Development Team:
  - besm@inpe.br

Foto: cortesia de Antonio Nobre