Paleoclimatic Aspects of the South American Monsoon System

Pedro L. Silva Dias(1)
University of São Paulo, Institute of Astronomy, Geophysics and Atmospheric Sciences,
São Paulo – BRAZIL

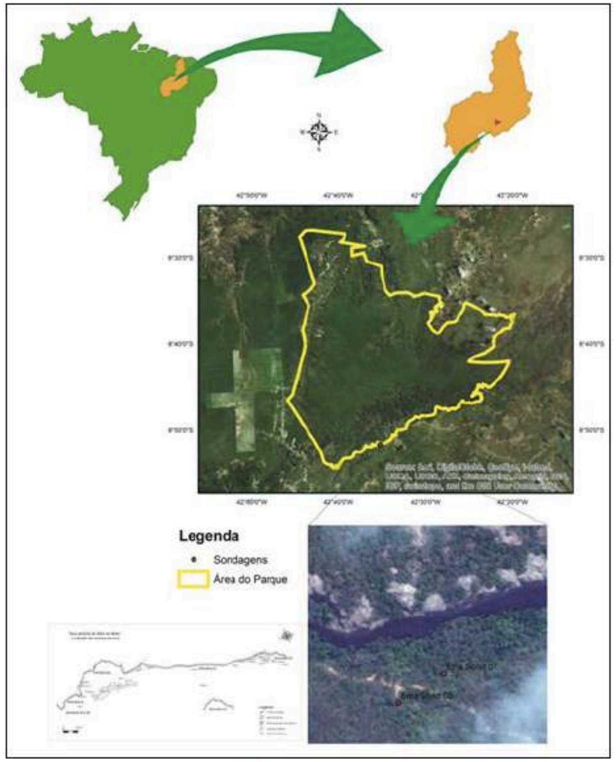
Advanced School and Workshop on American Monsoons: progress and future plans

August 19-23, 2019
ICTP-SAIFR, São Paulo, Brazil
Auditorium of IFT-UNESP

Amazon

Indications of evolved agricultural practices In the Amazon – pre- 11k BP

NE Brasil



Evidences of ruptures in the civilization in the Serra do Capivara (Piaui) between 9 ka and 6 ka BP (the driest period) – indication of migrations to Minas Gerais.

a) Porção leste do sítio Toca da Ema do Sítio do Brás I.

b) Porção oeste do sítio Toca da Ema do Sítio do Brás I.

Indicadores de alterações na paisagem decorrentes de variações climáticas durante o Pleistoceno-Holoceno no Sudeste do Piauí, Brasil:

Métodos para investigação de mobilidade e uso de recursos no território

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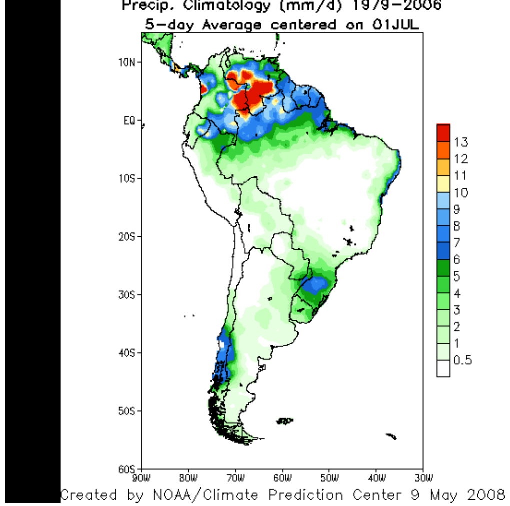
Luana Campos

Docente recém-doutora do Mestrado Profissional em Preservação do Patrimônio Cultural do Instituto do Patrimônio Histórico e Artístico Nacional – IPHAN

ENSAIOS DA PAISAGEM II

MÉTODOS E ANÁLISES DA PRÉ-HISTÓRIA

South American Monsoon System


Precip. Climatology (mm/d) 1979–2006
5–day Average centered on 01JUL

Created by NOAA/Climate Prediction Center 9 May 2008

SAMS

Strong seasonal differences.

Winter: Dry
Summer: Wet

Two systems: ITCZ and SACZ

Rainy season:
SE: early October

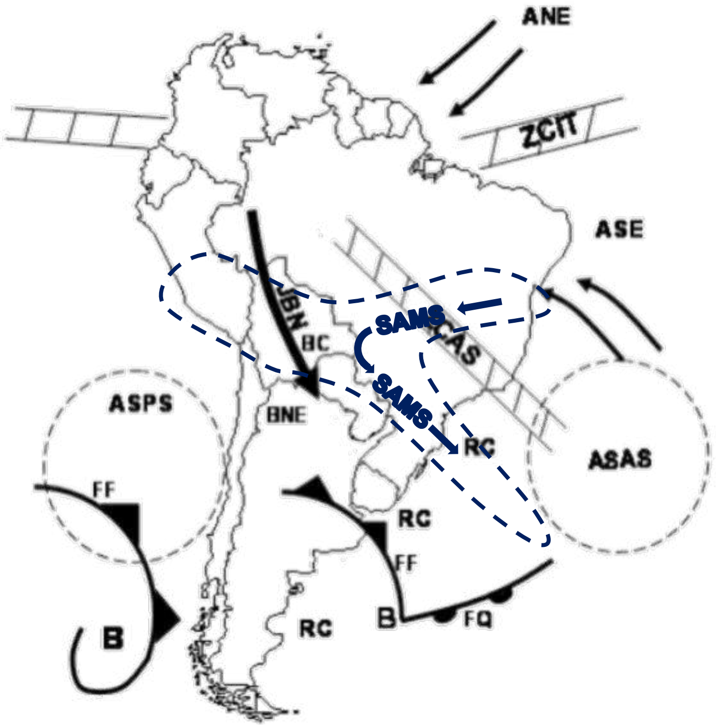
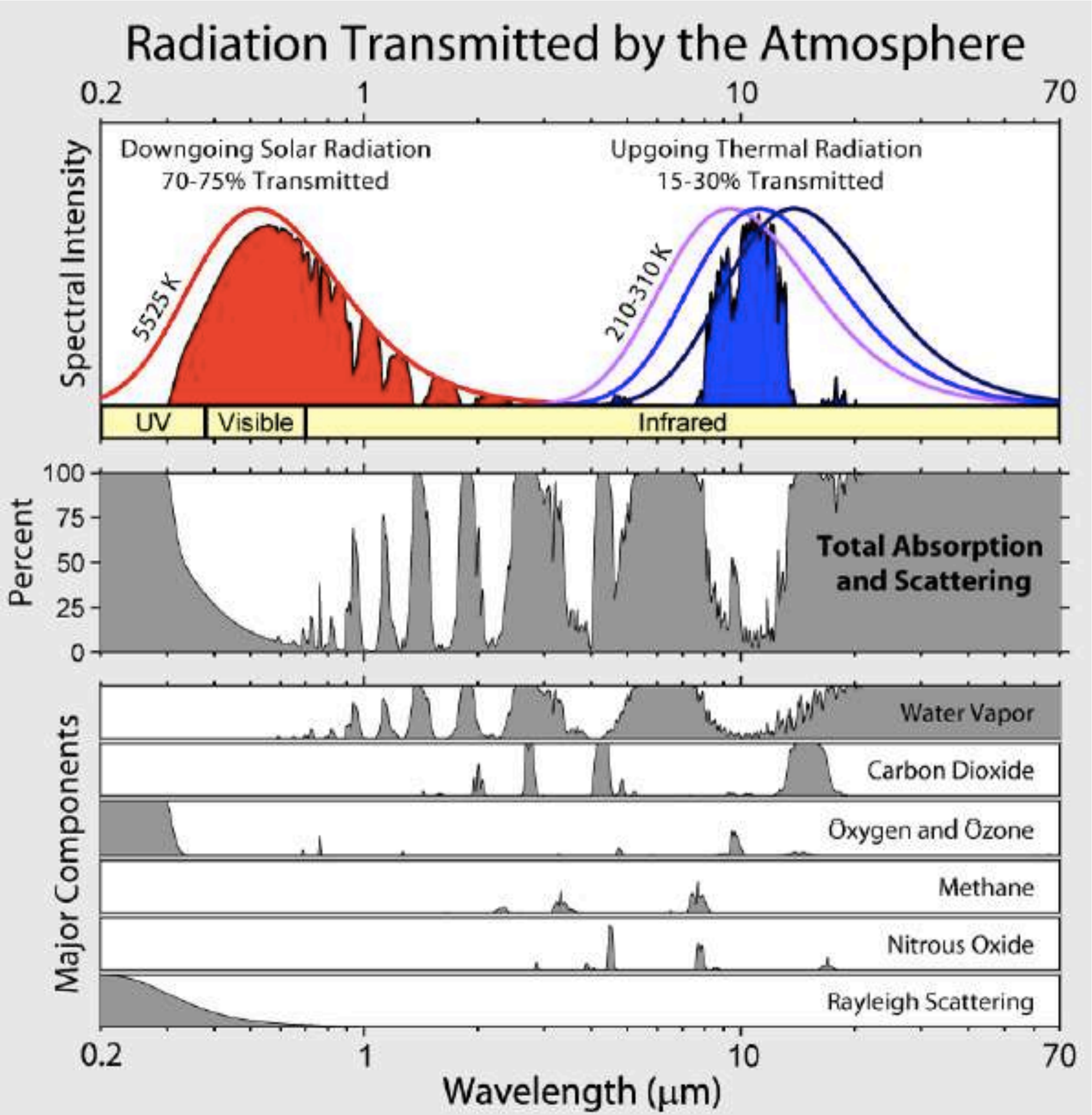


Fig. 1. Schematic representation of atmospheric systems in the lower troposphere operating in South American. Adpted from Reboita et al. (2010; pg. 199).

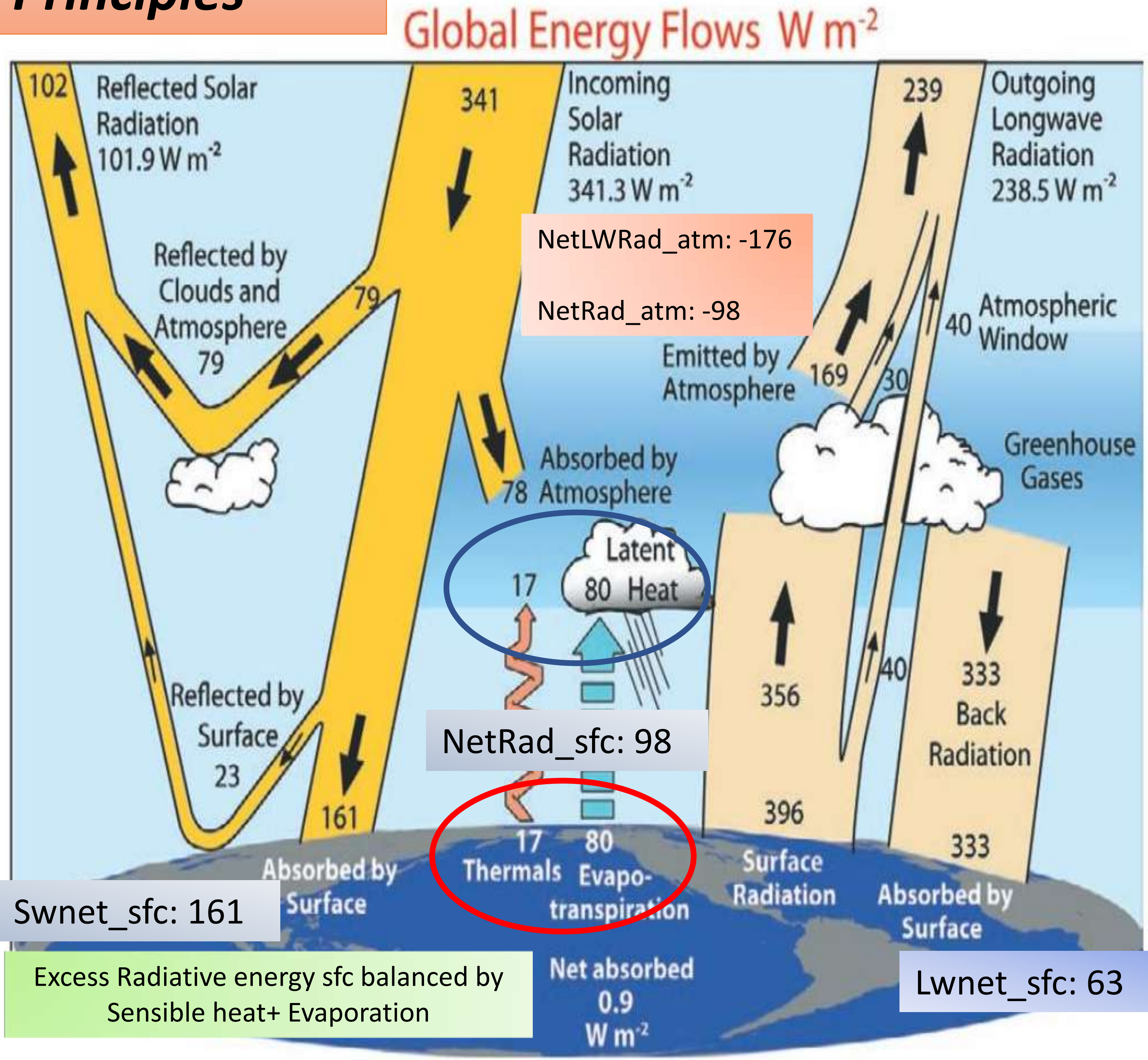
Basic Principles

1. Energy Conservation:
   - Earth receives energy from the Sun in short wave radiation and looses energy to space in long waves.



Basic Principles

1. Energy Conservation:
   - Earth receives energy from the Sun in short wave radiation and looses energy to space in long waves.
   - Radiative energy balance at the surface is positive: solar energy received > long wave loss ➔ energy surplus at the surface is transferred to the atmosphere by conduction and evaporative cooling.
   - Radiative energy balance in the atmosphere is negative ➔ receives excess energy from the surface through conduction, turbulent transfer (dry processes and clouds);



NetLWRad_atm: -176

NetRad_atm: -98

NetRad_sfc: 98

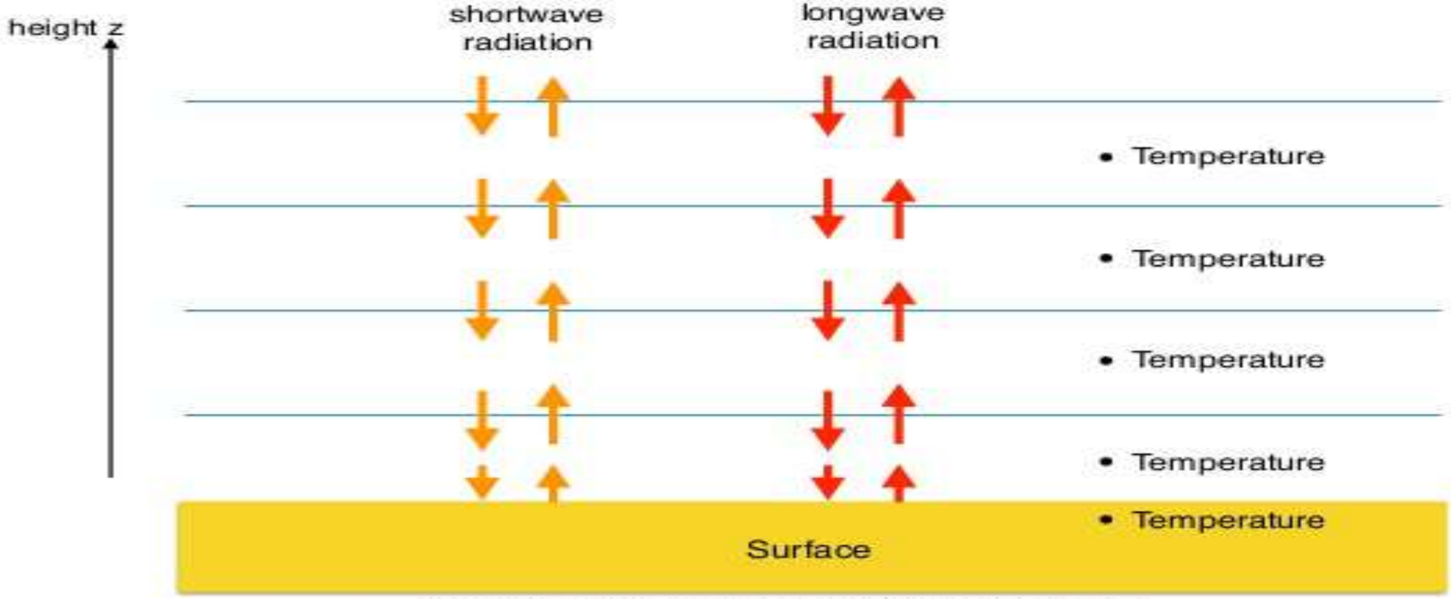
Swnet_sfc: 161

Excess Radiative energy sfc balanced by Sensible heat+ Evaporation

Lwnet_sfc: 63

1D Radiative Convective Models

$$C\partial T(z)/\partial t = F_{SW,in} - F_{SW,out} + F_{LW,in} - F_{LW,out} + \text{Convection}$$



Radiative fluxes are calculated similarly as in MOTRAN
Convection occurs if the stratification becomes unstable. In this case lapse rate is set to the moist adiabatic (6.5 K/km).

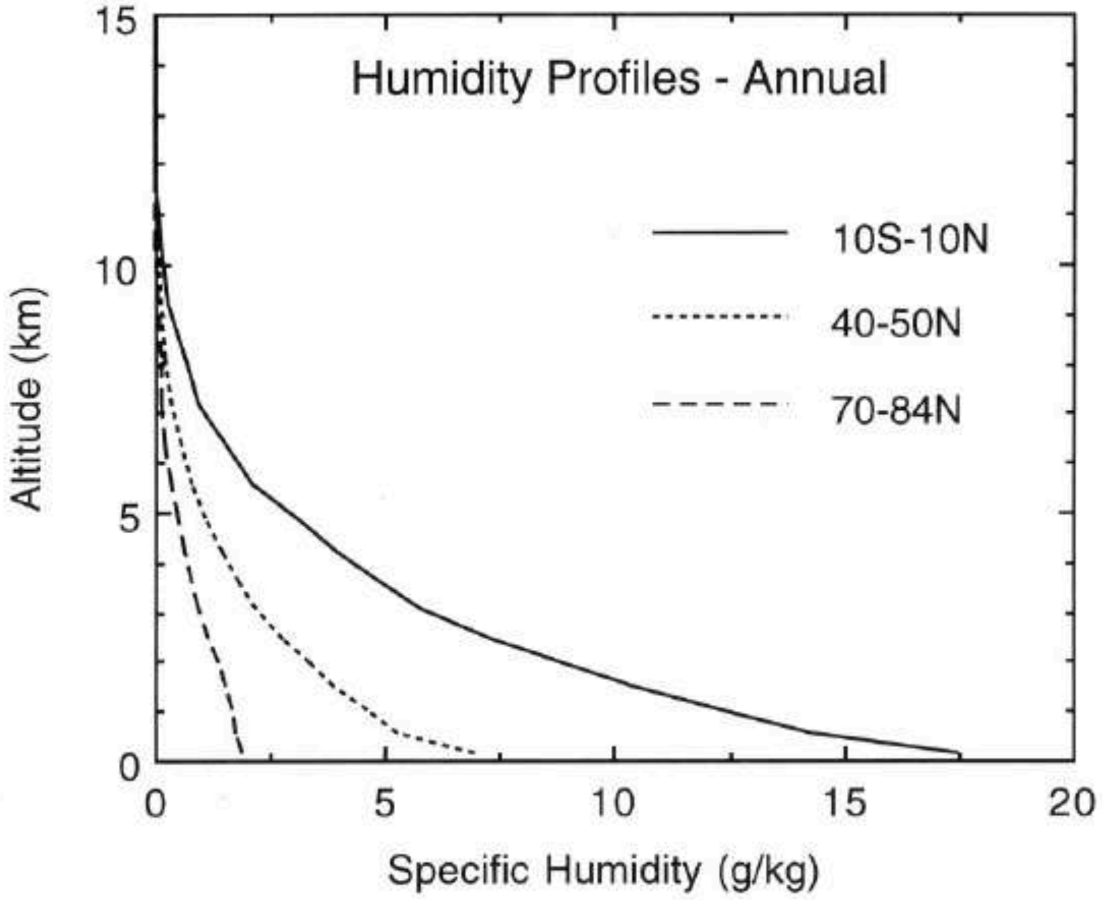
$$4\,\pi\,R^2\,h\,\rho\,c\,\frac{\mathrm{d}T}{\mathrm{d}t} = \pi\,R^2\,(1-\alpha)\,S_0 - 4\,\pi\,R^2\,\varepsilon\,\sigma\,T^4\ ,$$

$R = 6371$ km	radius of the Earth
$h = 8.3$ km	vertical extent of the air layer
$\rho = 1.2\ \mathrm{kg\ m^{-3}}$	density of air
$c = 1000\ \mathrm{J\ kg^{-1}\ K^{-1}}$	specific heat of air
T	globally averaged surface temperatu
$\alpha = 0.3$	planetary albedo (reflectivity)
$S_0 = 1367\ \mathrm{W\ m^{-2}}$	solar constant
$\varepsilon = 0.6$	planetary emissivity
$\sigma = 5.67 \cdot 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}$	Stefan-Boltzmann constant

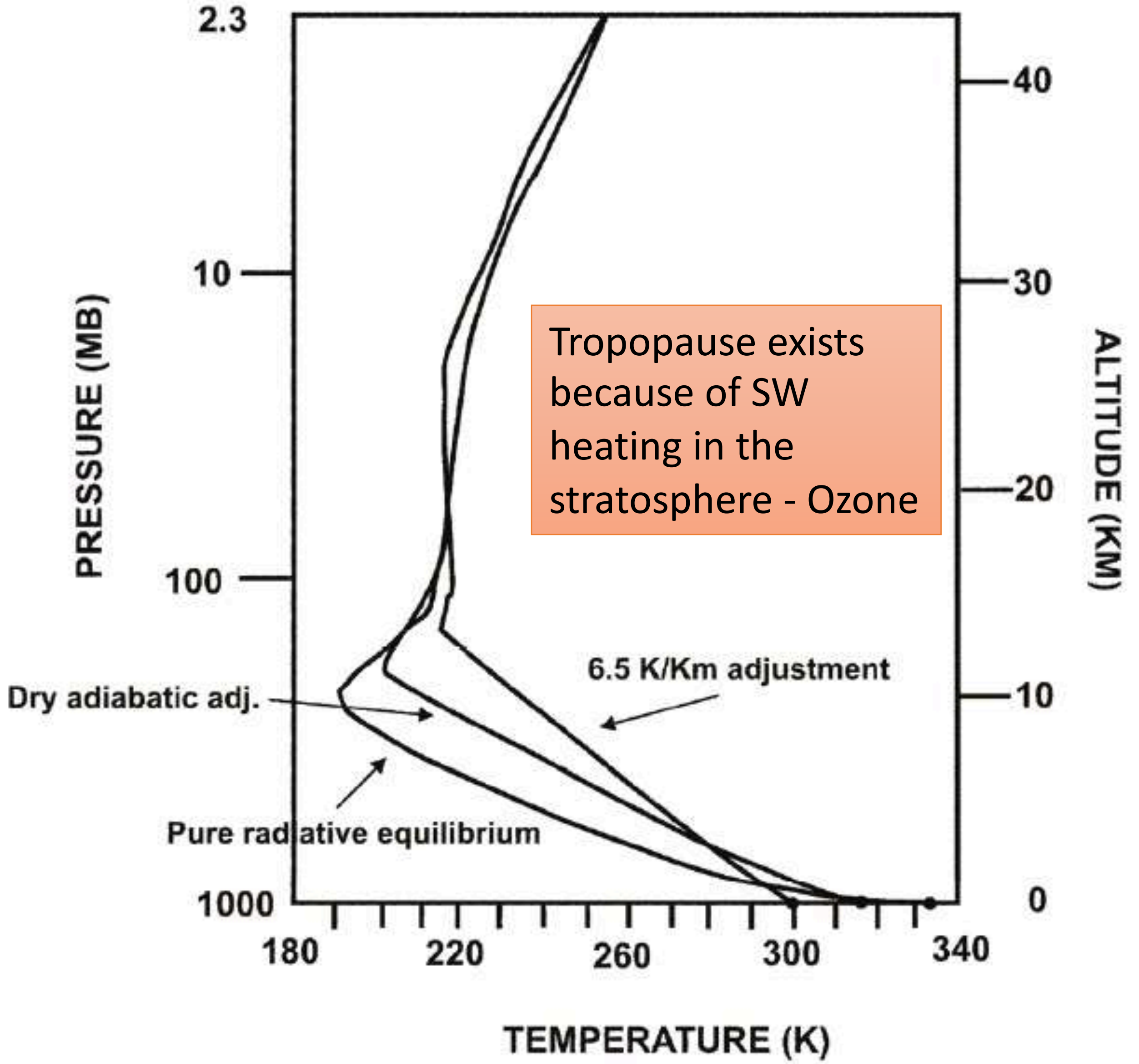
Primarily due to the Effect of CO2, H2O

See figure of "Humidity Profiles -- Annual"

In book:
Global Physical Climatology
ISBN: 0123285305
Author: Dennis L. Hartmann
Publisher: Academic Press
Number of pages: 411



Manabe and Strickler 1964 calculation:



Tropopause exists because of SW heating in the stratosphere - Ozone

CO2 concentration is uniform

Basic Principles

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   - Radiative energy balance at the surface is positive: solar energy received > long wave loss ➔ energy surplus at the surface is transferred to the atmosphere by conduction and evaporative cooling.
   - Radiative energy balance in the atmosphere is negative ➔ receives excess energy from the surface through conduction, turbulent transfer (dry processes and clouds);
   - More solar radiation is received in the equatorial region than at high latitudes. Long wave loss in the atmosphere is approximately the same in the tropical and higher latitudes ➔ need to transfer heat from the equator to the poles!!

See figure of seasonal variation of solar radiation

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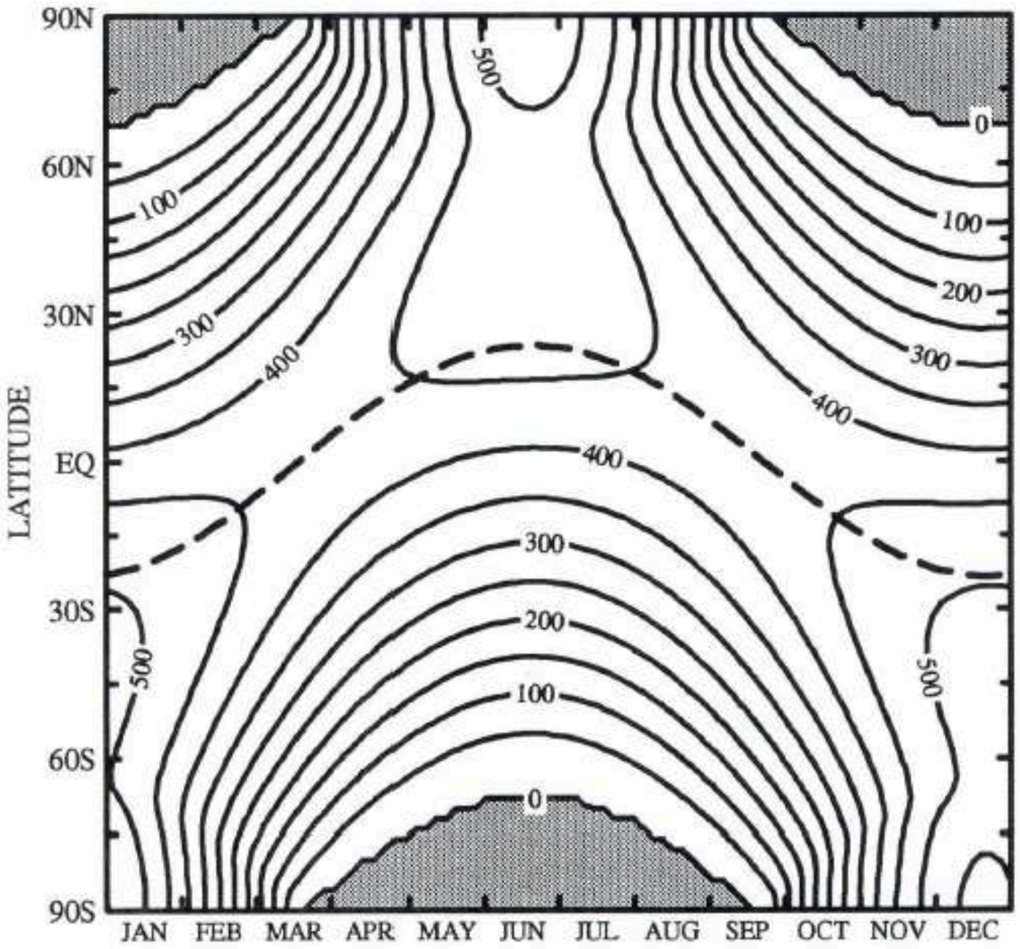
Note that Southern Hemisphere receives a little more solar radiation than the Northern Hemisphere – consequence of the fact that the Sun is not at the center of the eliptic orbit of the Earth.

This is important for understanding paleoclimate variability as well as changes in SW planetary albedo/absorptivity (e.g. volcanism) – changes in O3 (solar influence) – changes in LW emissivity (CO2, H20…)



See figure Temperature vs Latitude

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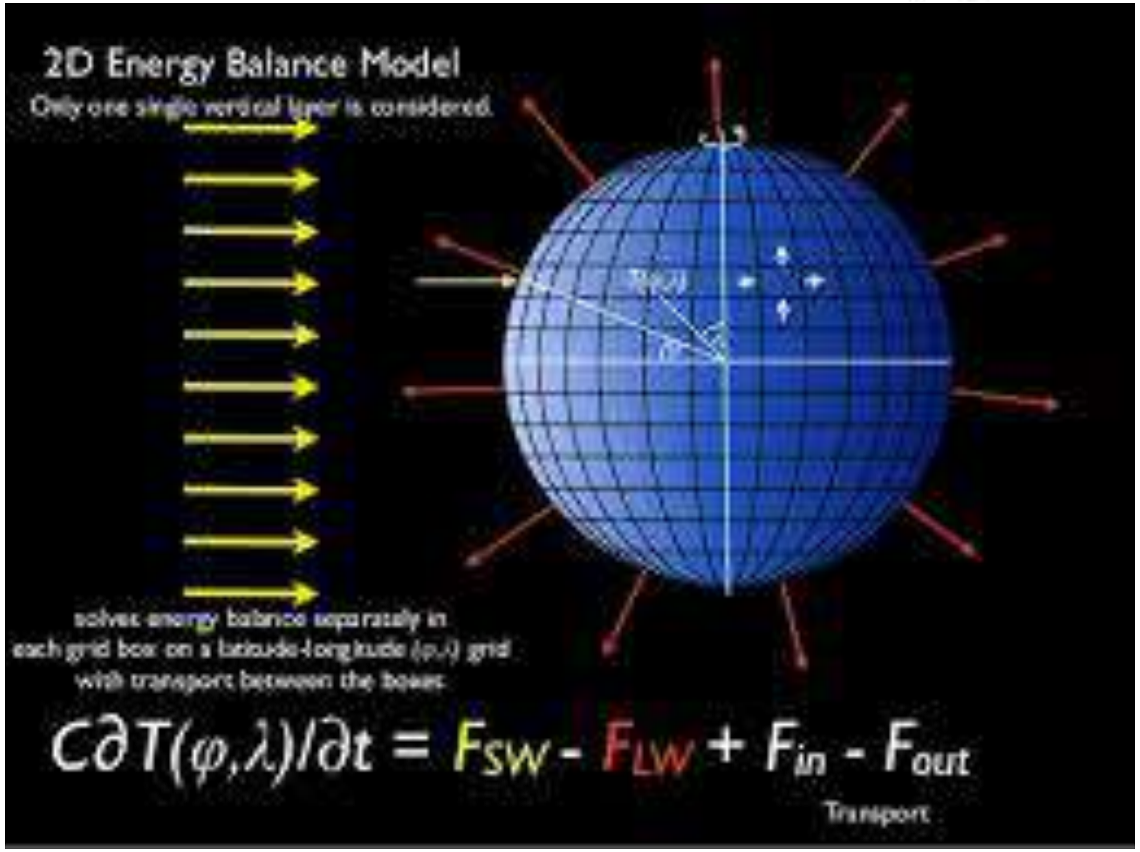


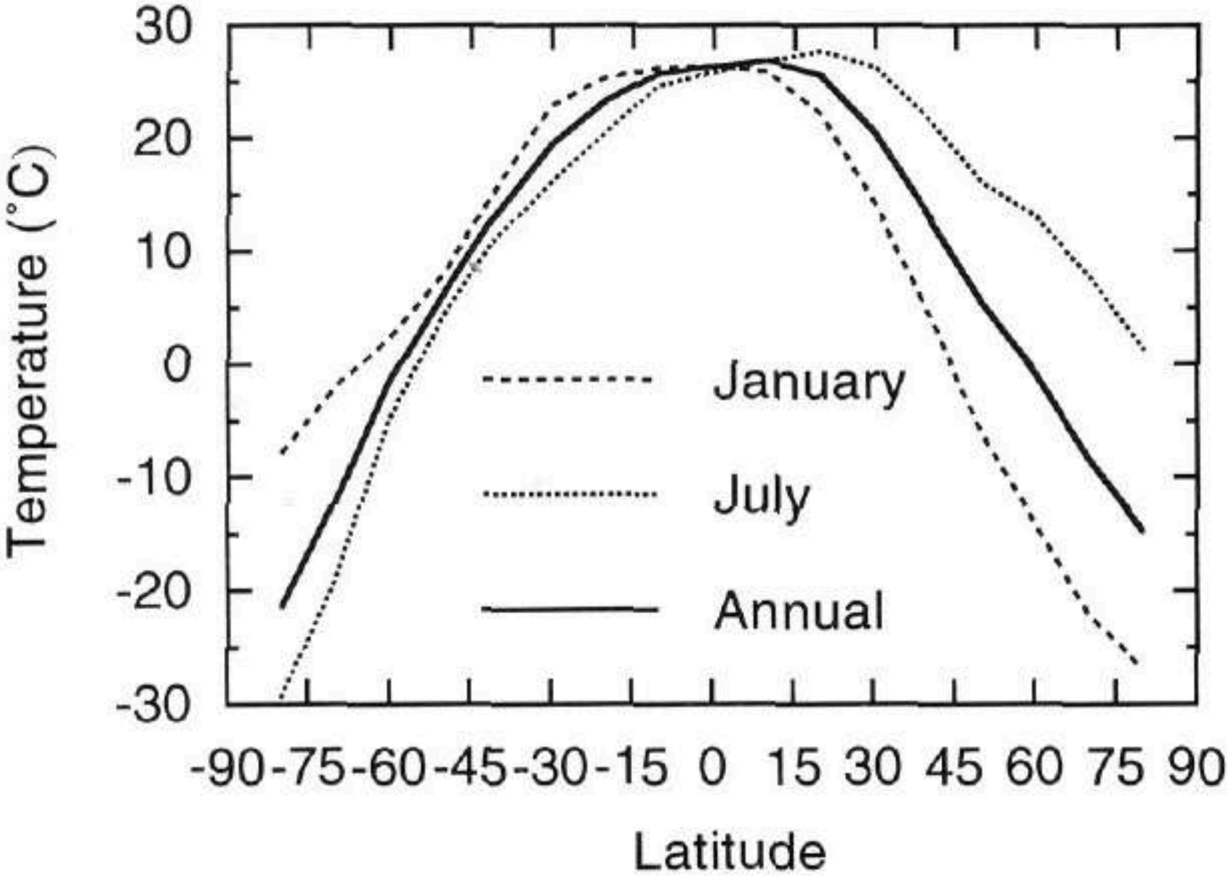
2D Energy Balance Model

Only one single vertical layer is considered.

solves energy balance separately in each grid box on a latitude-longitude (φ,λ) grid with transport between the boxes

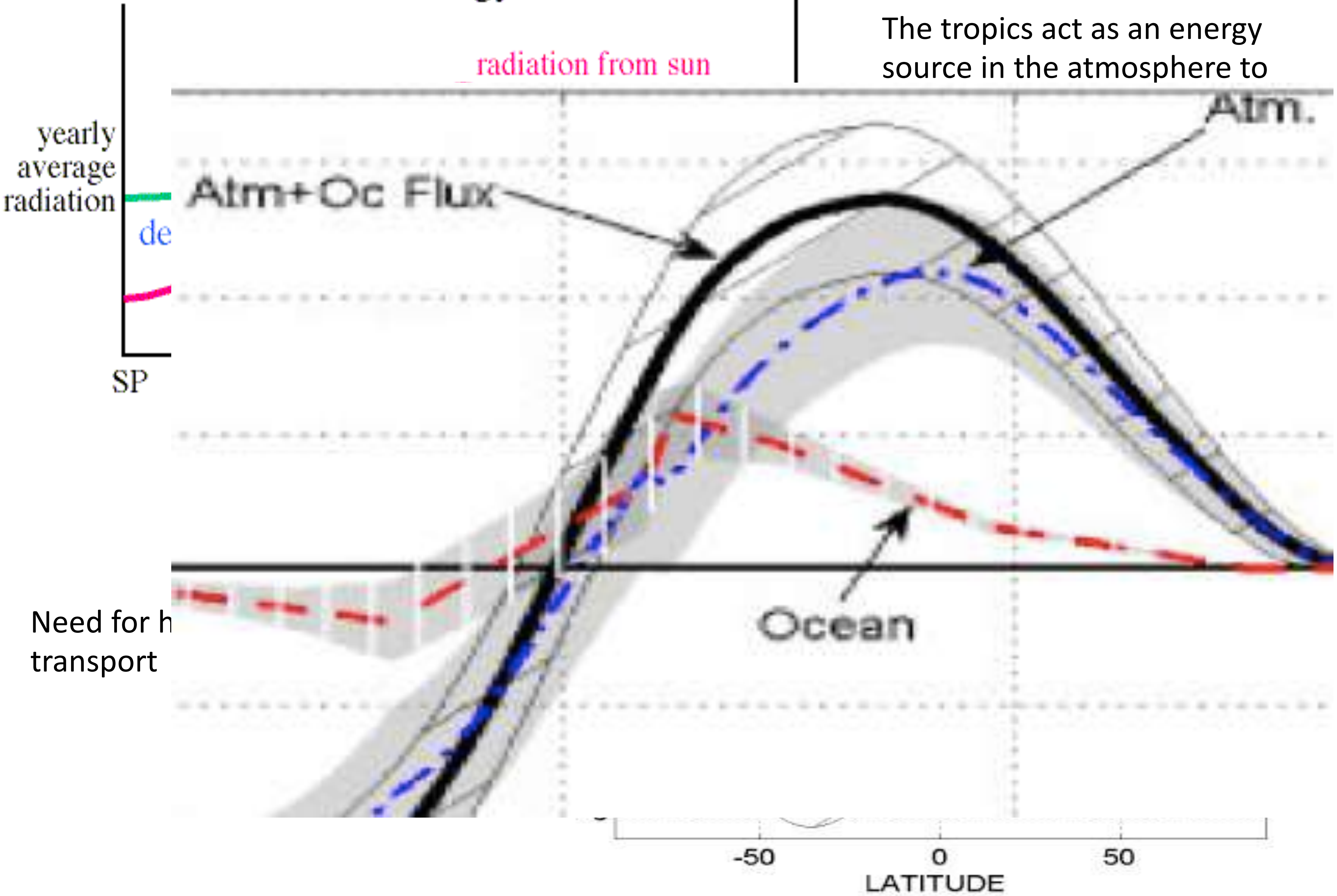
$$C\partial T(\varphi,\lambda)/\partial t = F_{SW} - F_{LW} + F_{in} - F_{out}$$

Transport

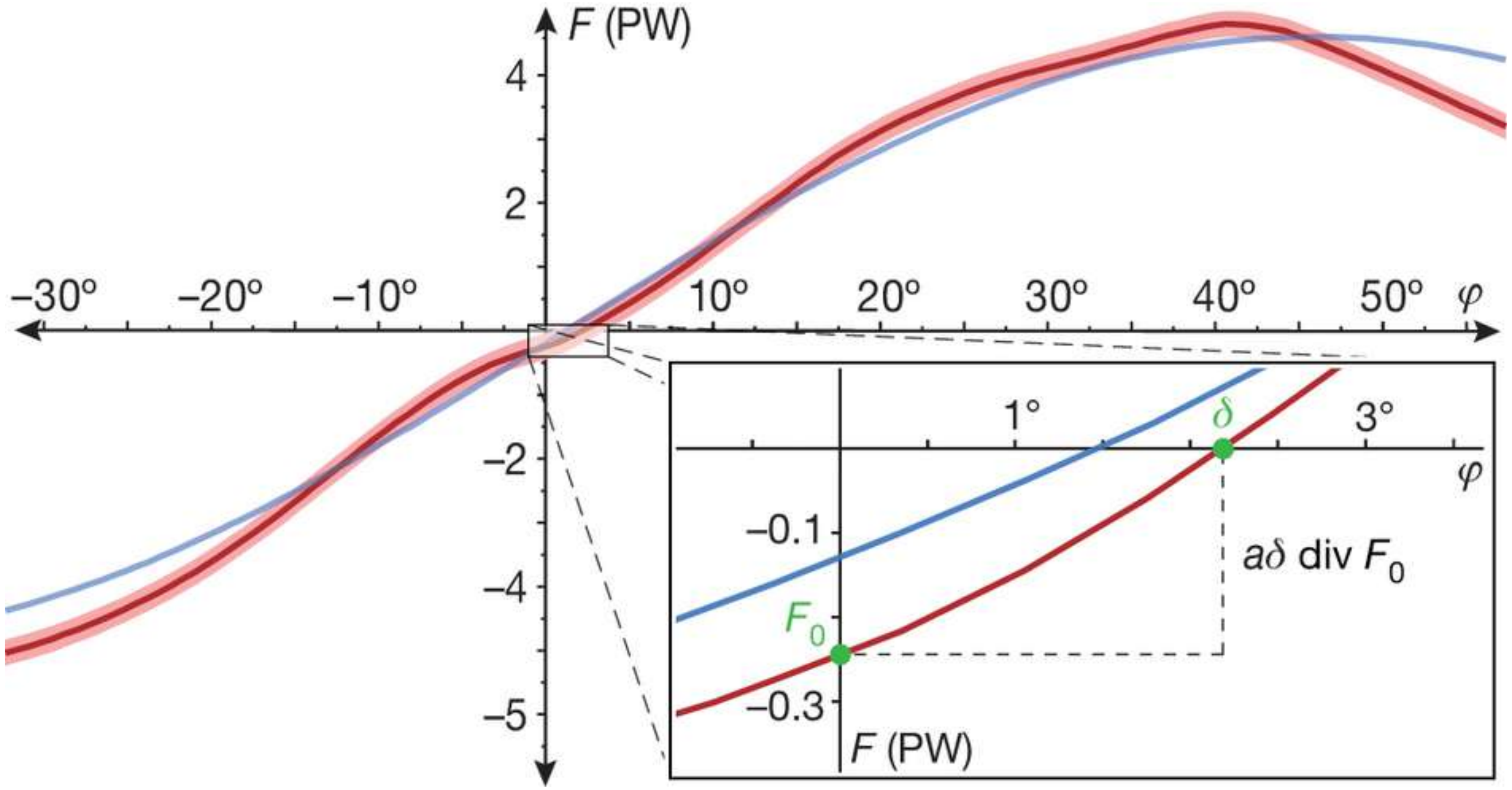


Earth’s energy balance

The tropics act as an energy source in the atmosphere to



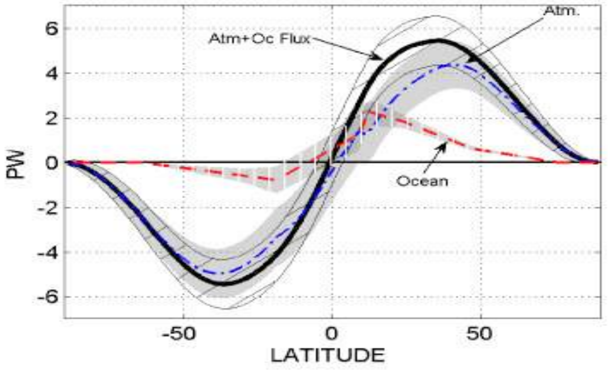
Need for h
transport

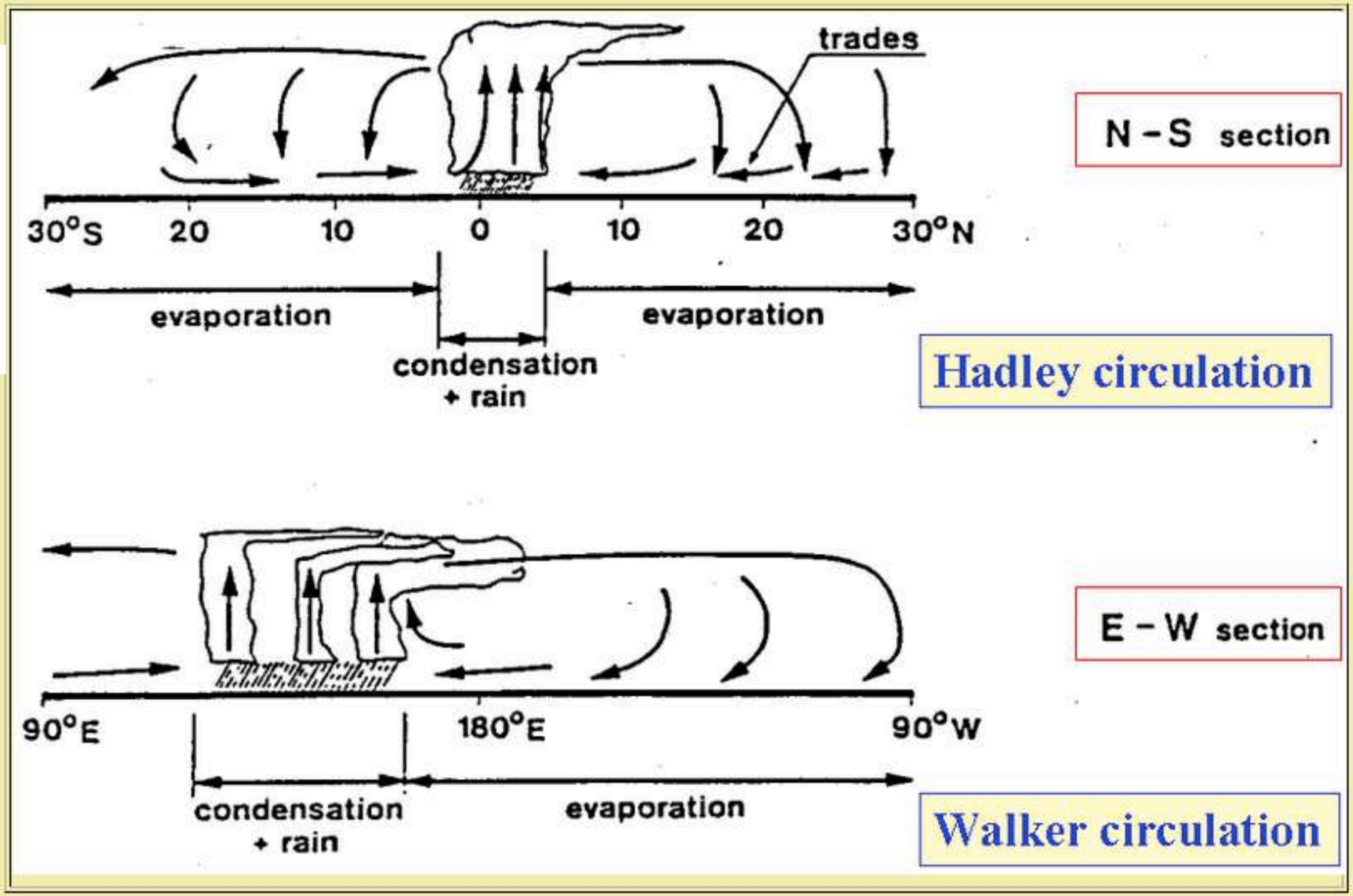


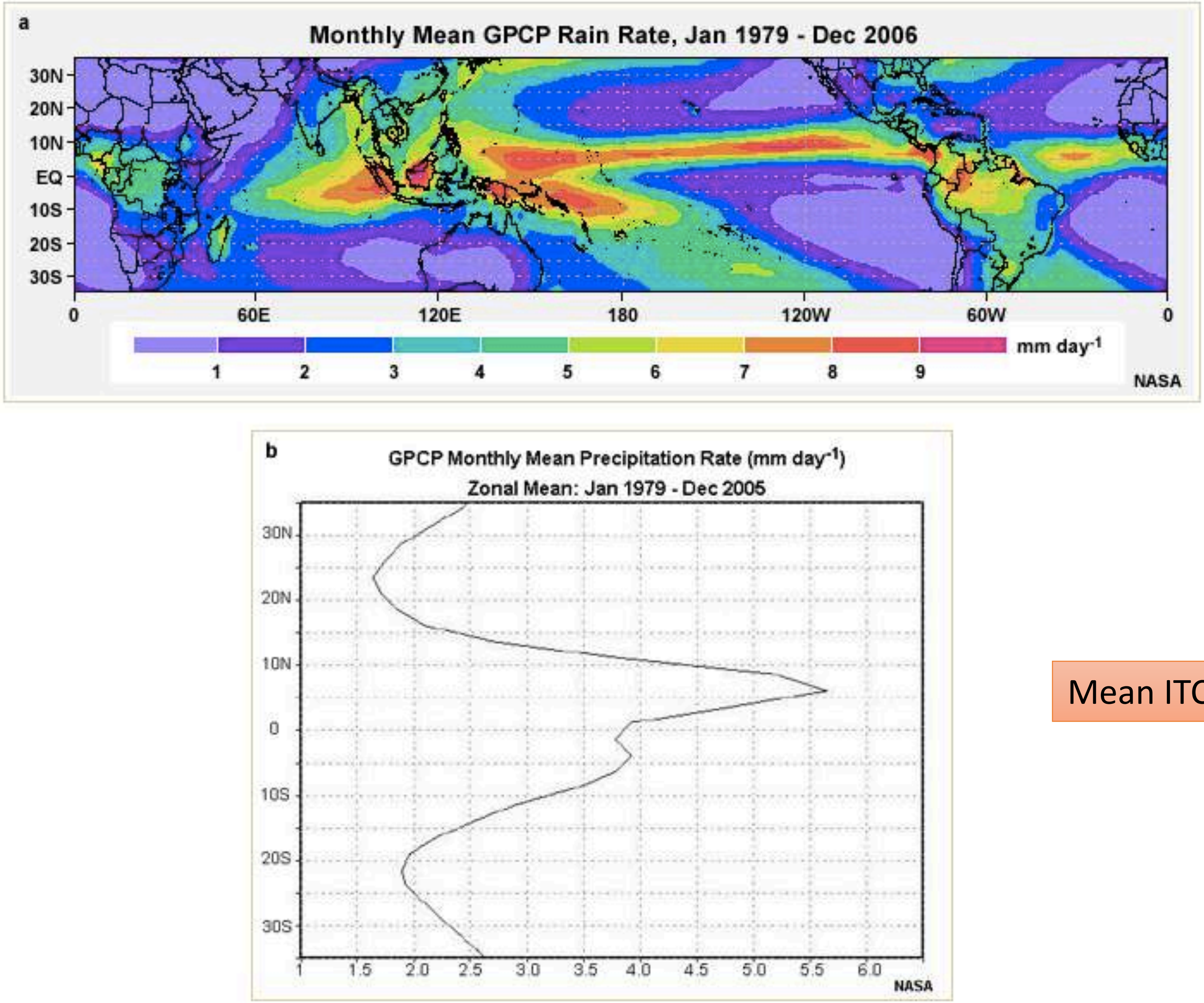
Atmospheric meridional energy flux and energy flux equator ...www.nature.com946 × 494

Atmospheric meridional energy flux and energy flux equator.

Heat Transport in the Atmosphere - Intertropical Convergence Zone ITCZ



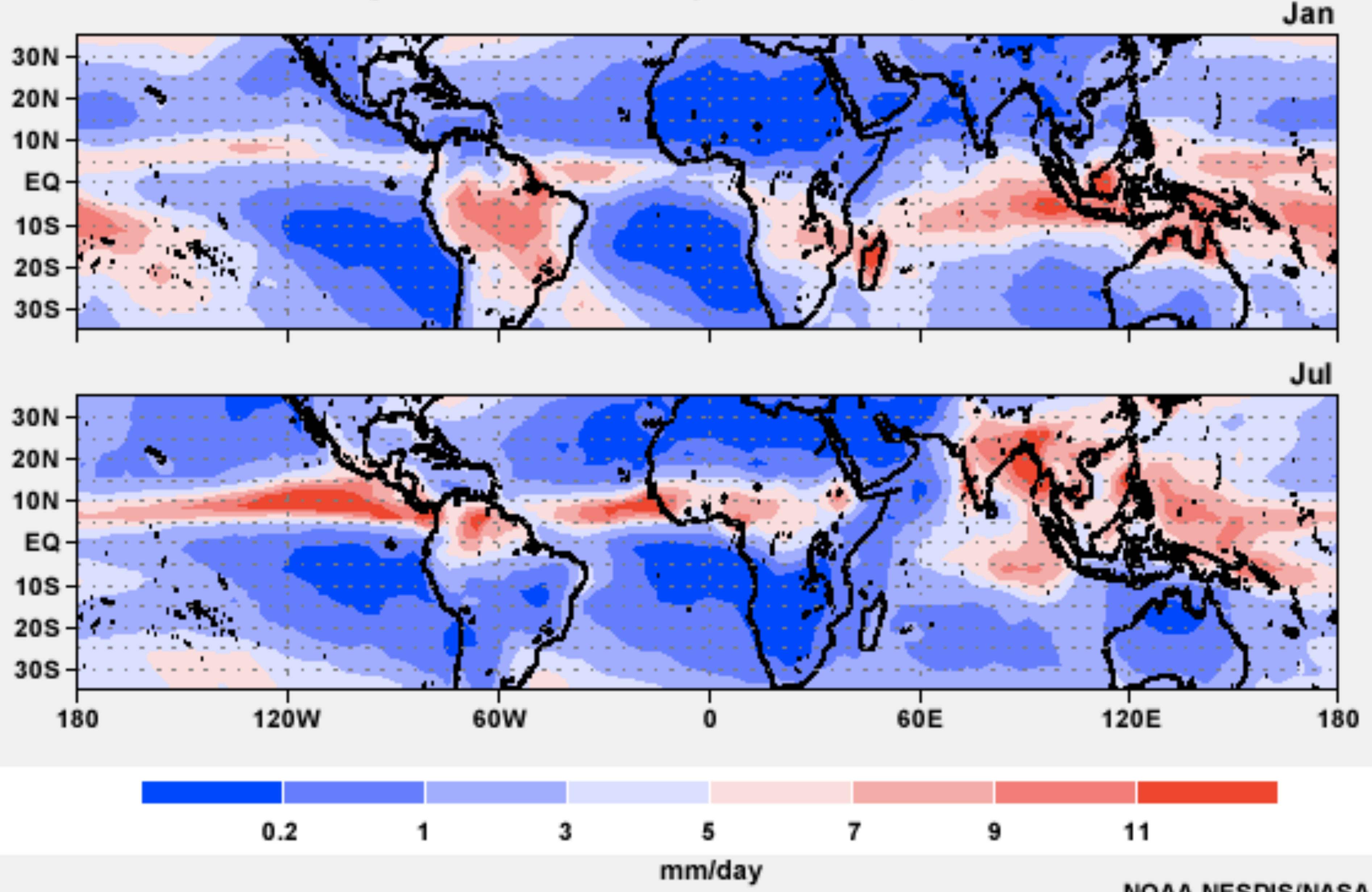




Mean ITCZ position: 6^{o}N

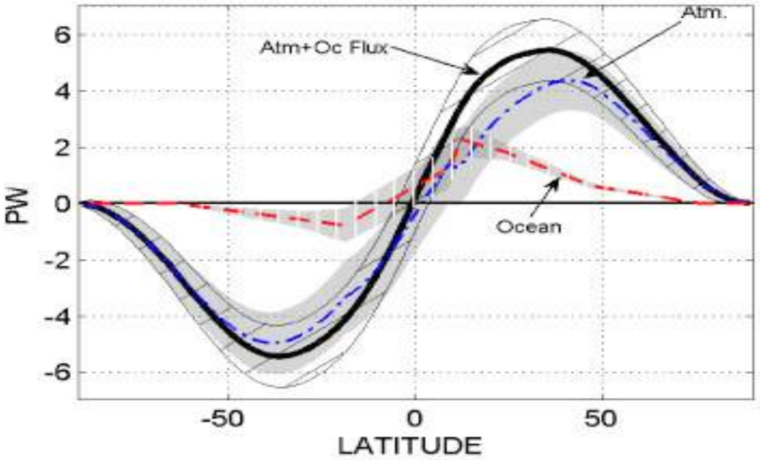
Fig. 5.29. (a, upper) GPCP monthly mean precipitation rate (mm day^{-1}) for 1979-2006 and (b, lower) the latitudinally-averaged mean for 1979-2005.

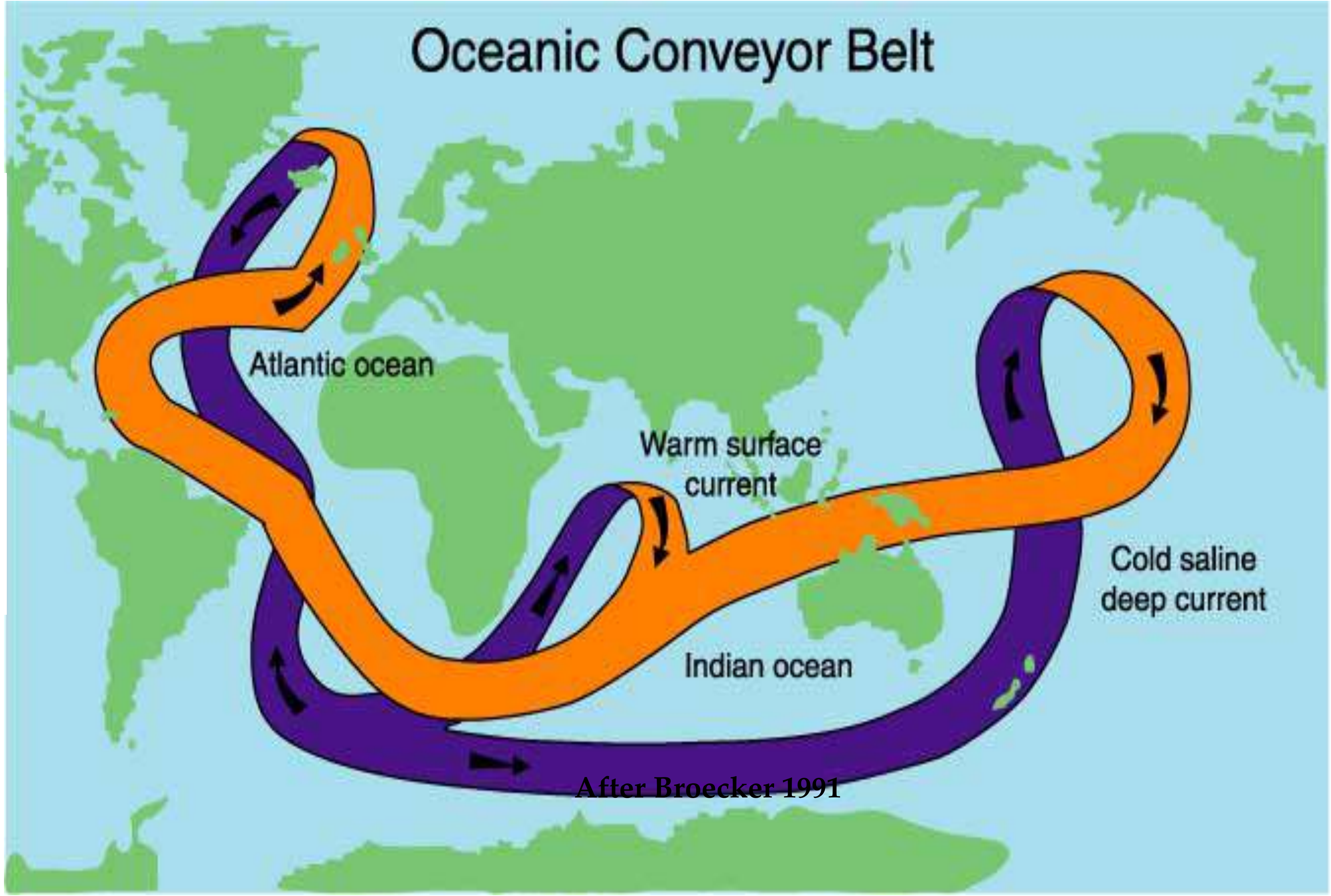
Monthly Mean GPCP Precipitation Rate, 1979 - 2006



NOAA NESDIS/NASA

Heat transport in the oceans -- ocean currents





After Broecker 1991

WHAT IS THERMOHALINE CIRCULATION (THC)?

It is that part of the ocean circulation which is driven by density differences (as opposed to wind and tides).

Because the ocean density is a function of temperature (thermo) and salinity (haline), this circulation is referred to as the themohaline circulation and indicates a driving mechanism.

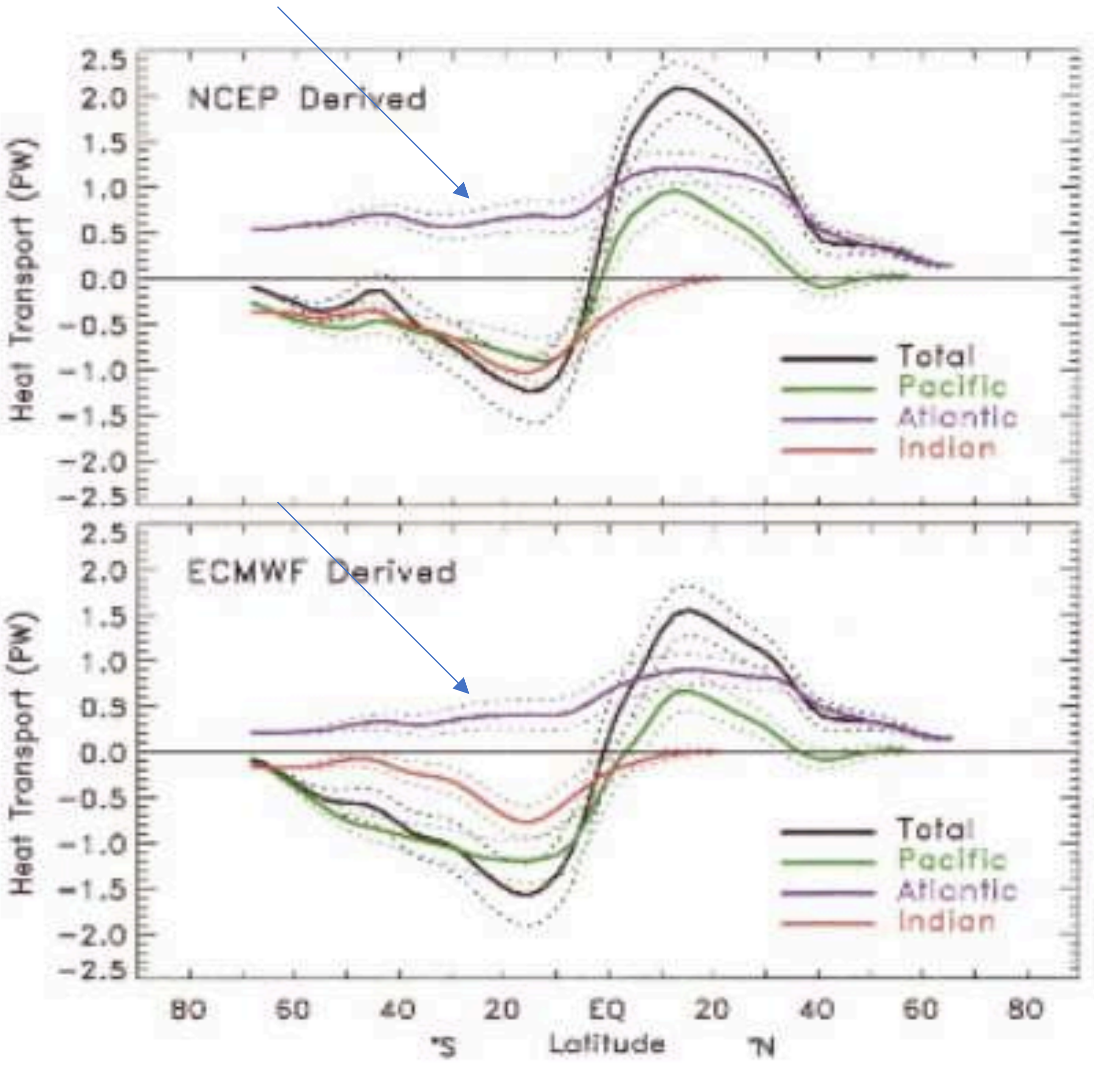
These density differences are primarily caused by surface fluxes of heat and freshwater and subsequent interior mixing.

The oceanic density distribution is itself affected by the currents and associated mixing. Thermohaline and wind driven currents interact with each other, and therefore cannot be truly separated.

THC IS NOT AN OBSERVATIONALLY MEASURABLE QUANTITY!

OCEANIC NORTHWARD HEAT TRANSPORT

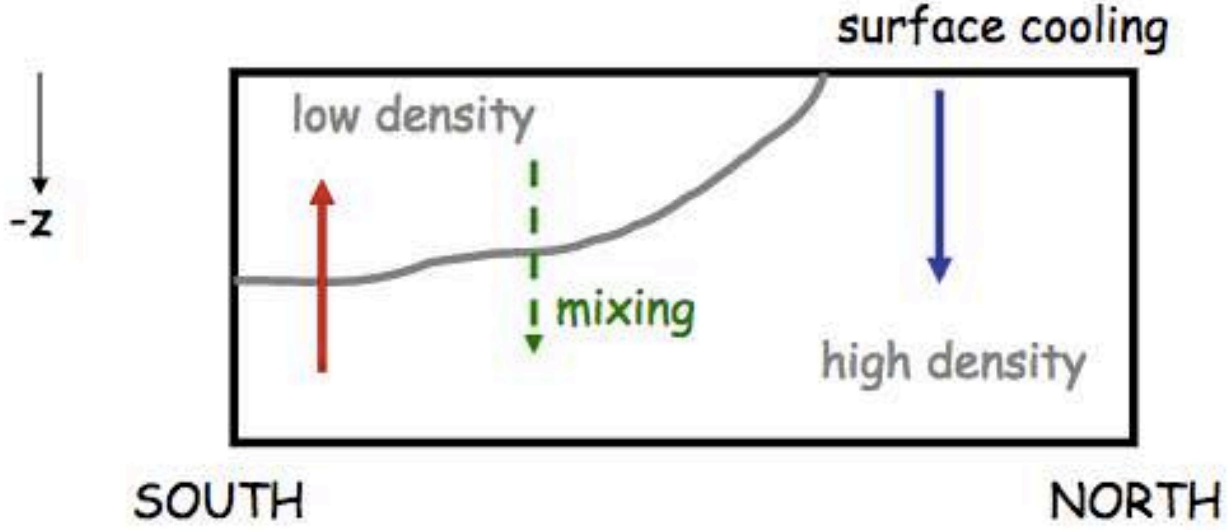
Note peculiar behavior of the Atlantic: northward heat transport all the way from the southern to the northern extreme.



Trenberth and Caron (2001)

WHAT DRIVES THC / MOC?

MECHANISM I: Cooling at high latitudes. For steady state, downward penetration of heat by mixing is necessary.

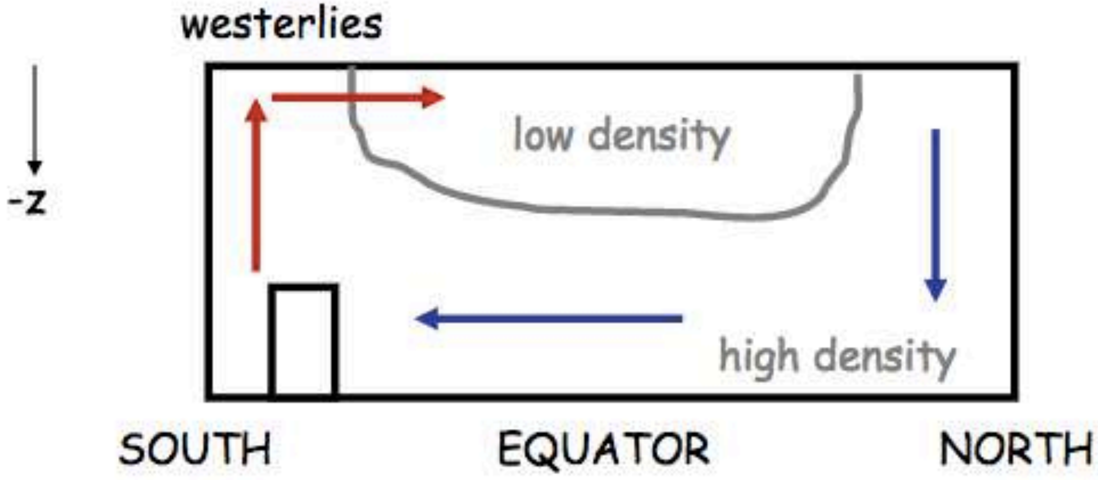


Turbulent mixing supplies energy.

WHAT DRIVES THC / MOC?

MECHANISM II: Westerly winds over the Southern Ocean. No meridional flow can be supported at intermediate depths at the latitude band of the Drake Passage due to lack of topographic barriers that can support east-west pressure gradients.

$$-f\,V = -\frac{1}{\rho}\frac{\partial p}{\partial x}$$

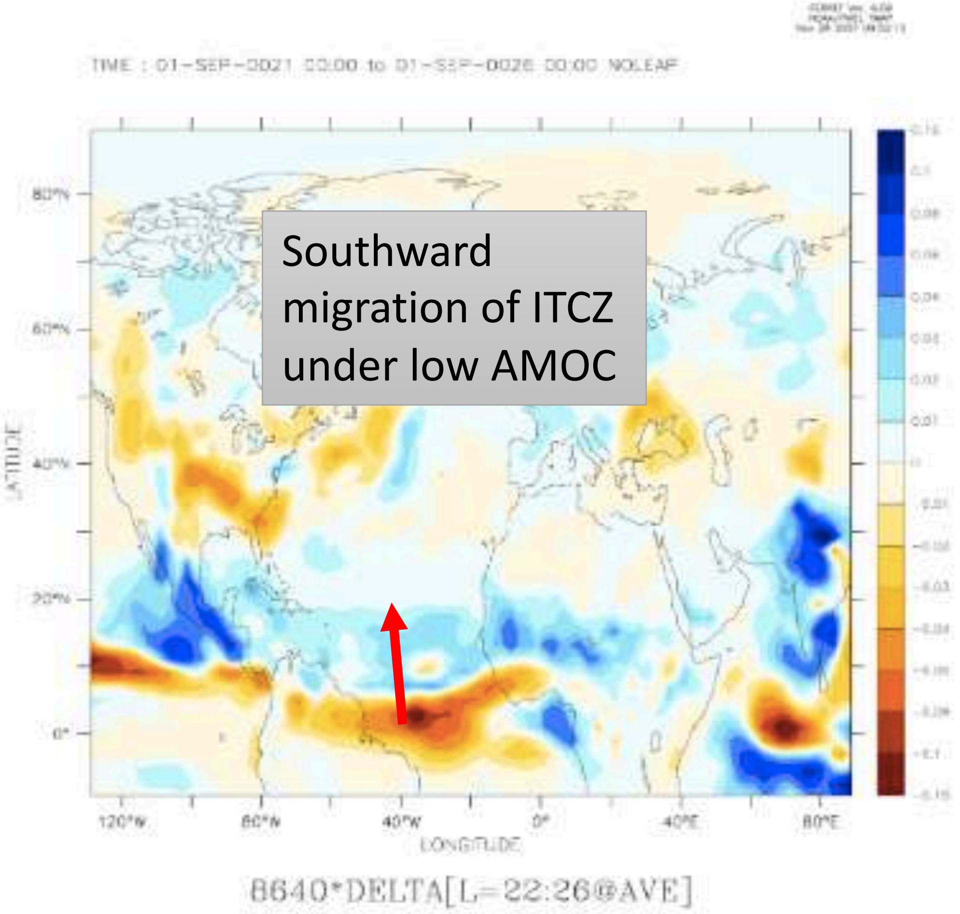


Winds directly supply energy.

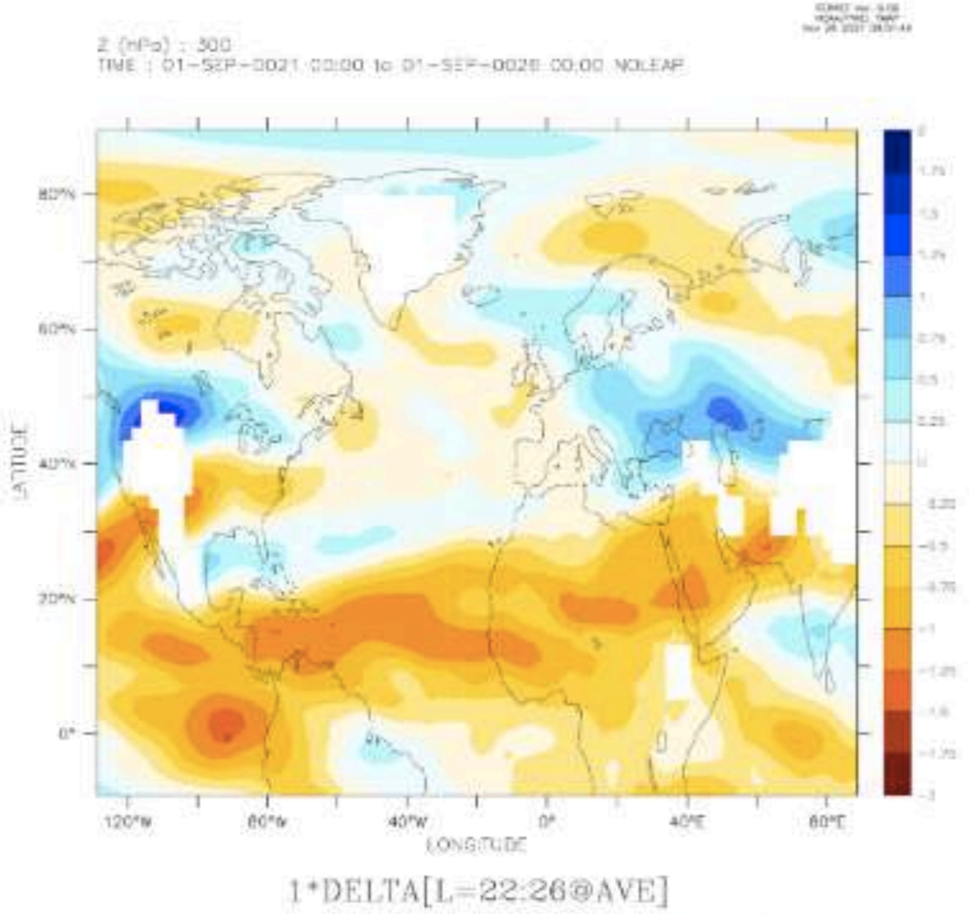
CHANGE IN SOME FIELDS BETWEEN HIGH AND LOW AMOC PERIODS IN THE GFDL CM2.1 CONTROL SIMULATION

Atmospheric Impact of Atlantic Thermohaline Circulation

Rainfall (cm day^{-1})

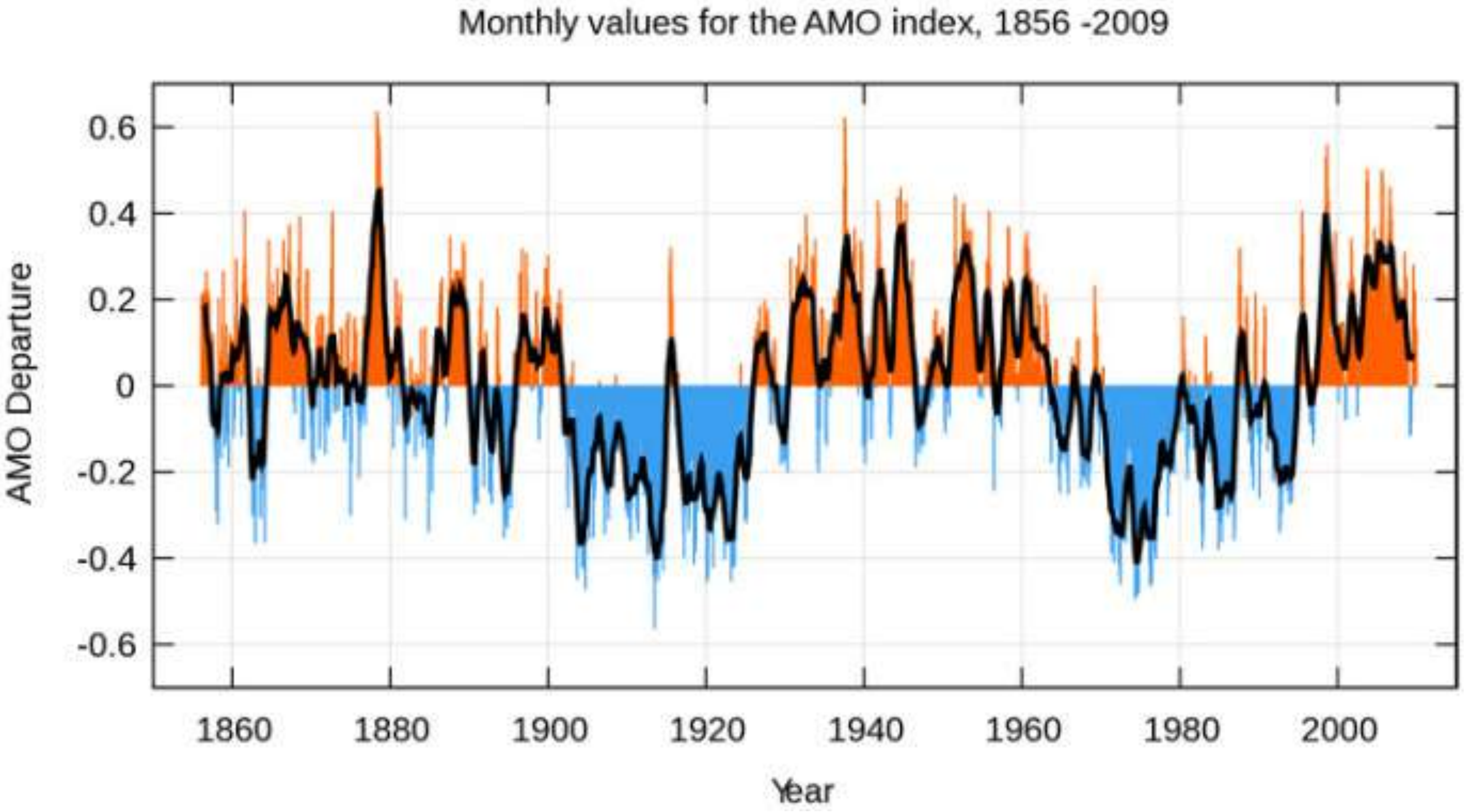

Southward migration of ITCZ under low AMOC

Vertical shear of zonal wind (m s^{-1})

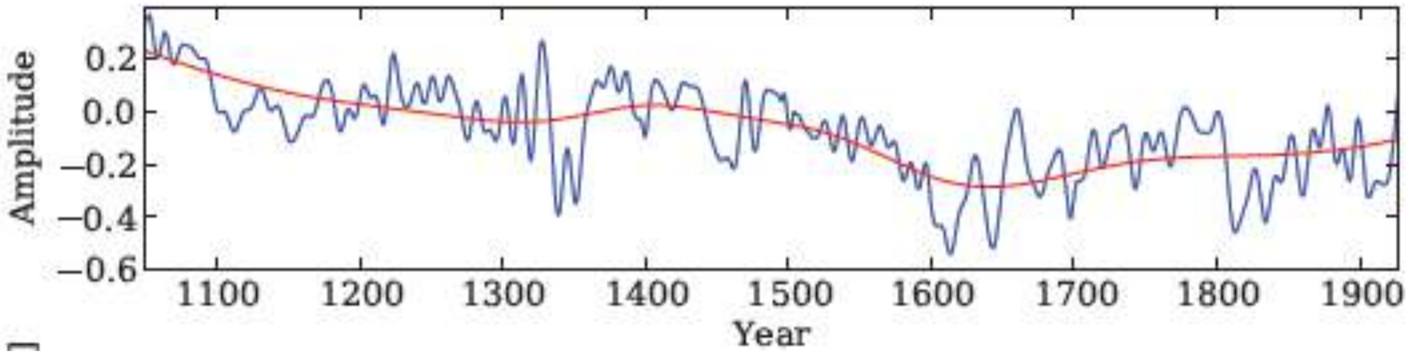


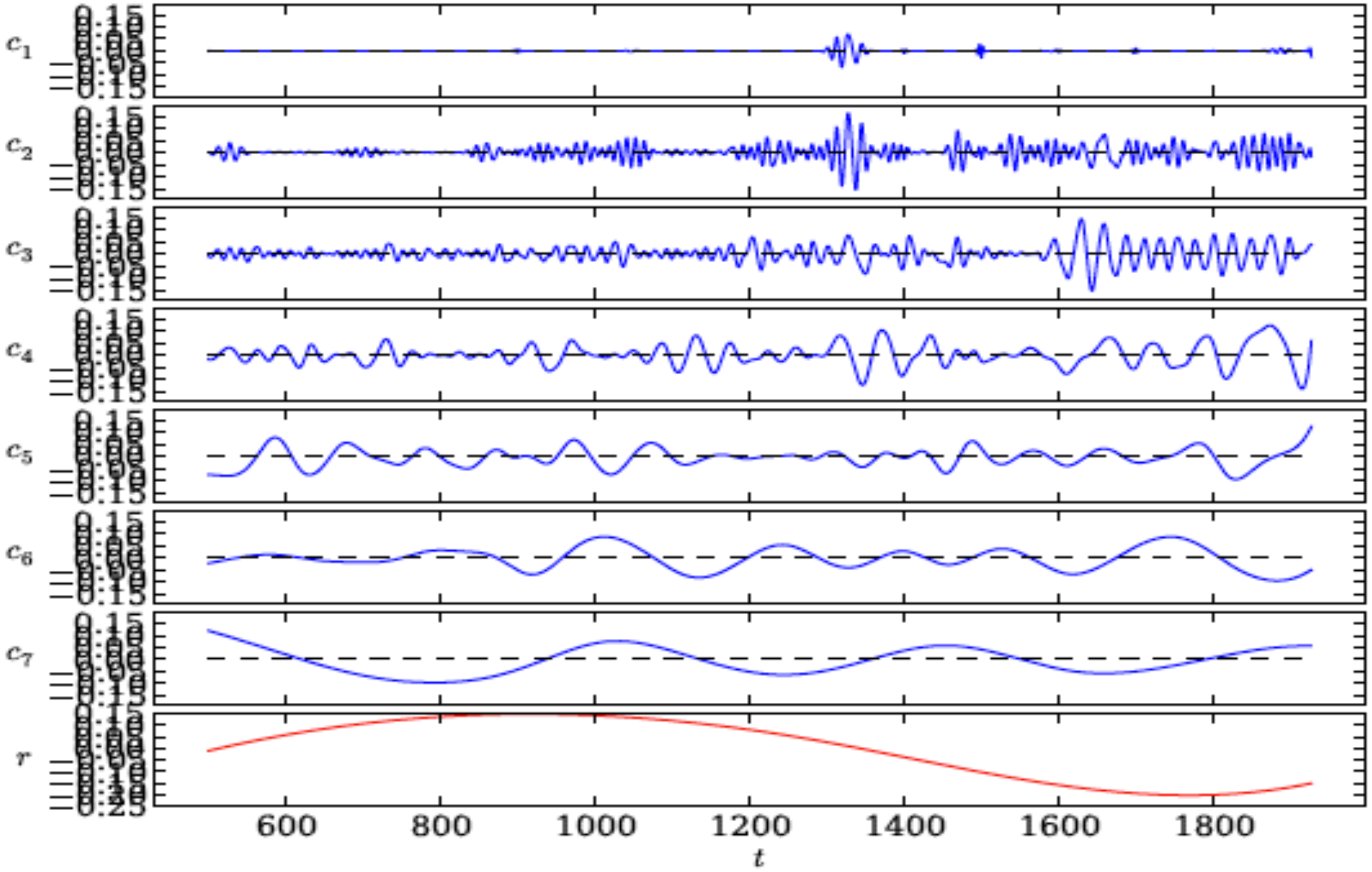
Vertical shear computed for 300 hPa – 850 hPa.

Tom Delworth

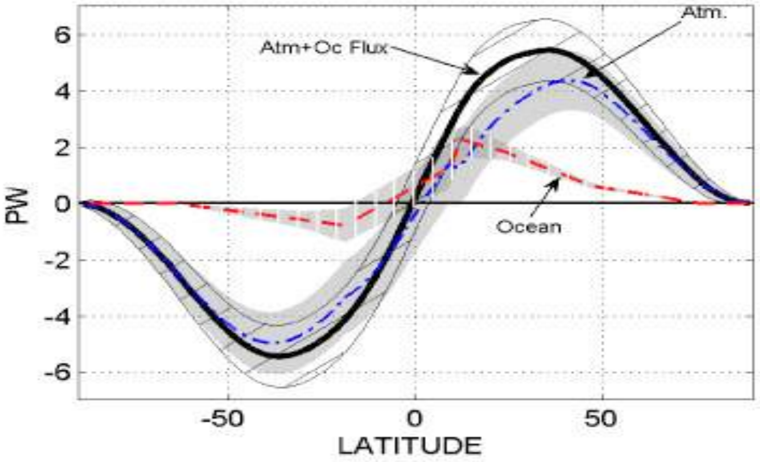

Monthly values for the AMO index, 1856 -2009

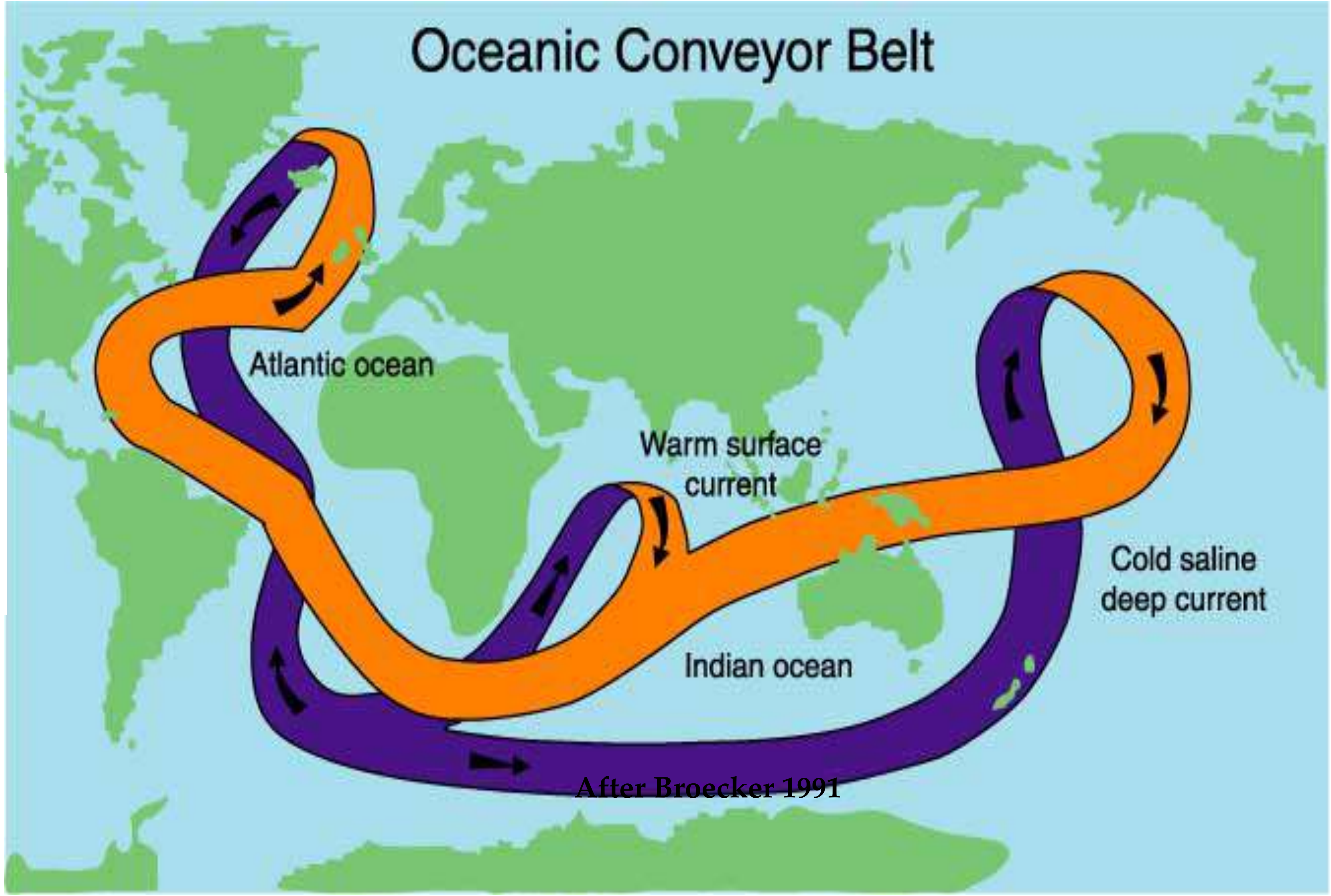
AMO, Mann (2009)



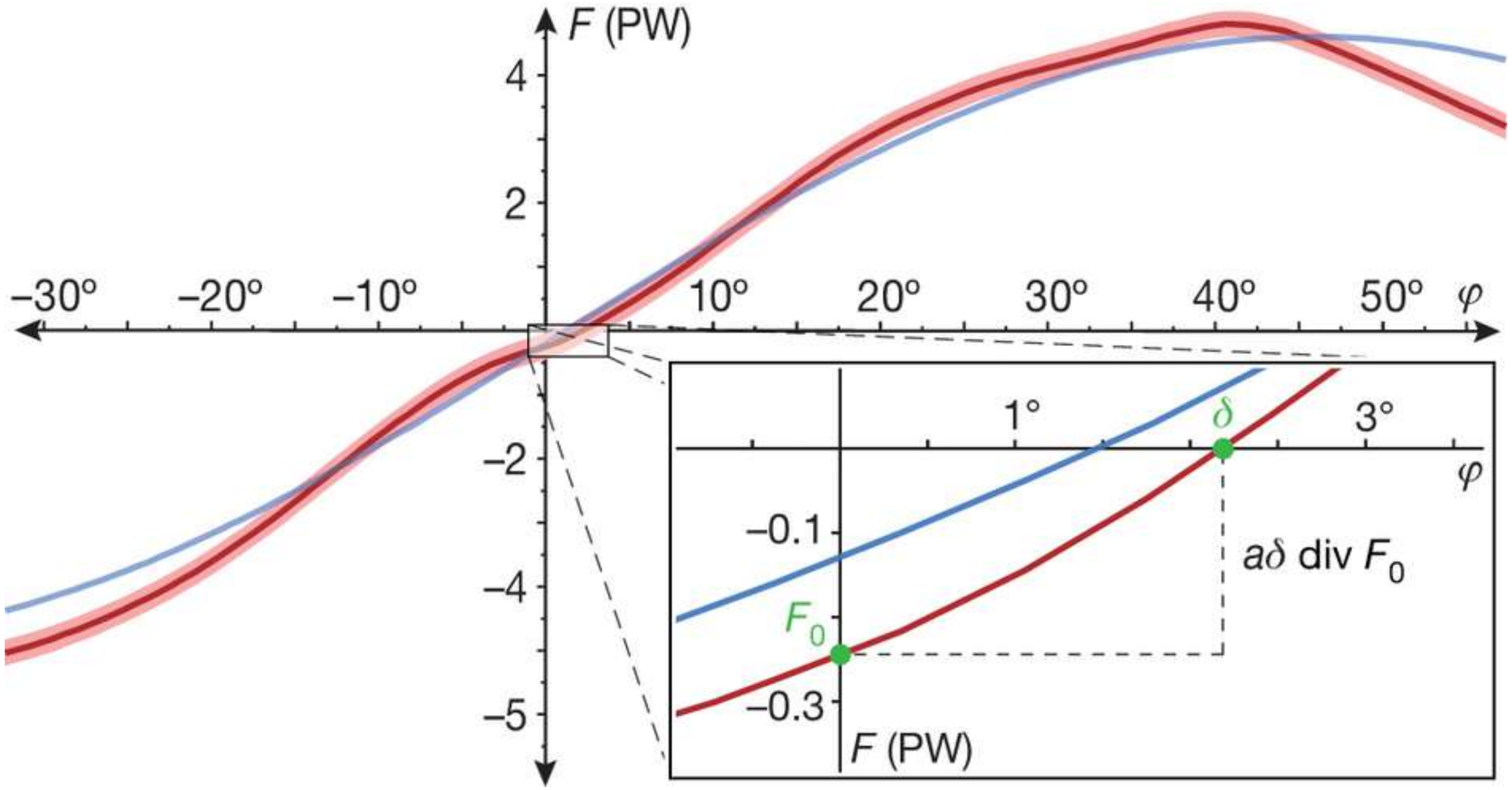


Back to the heat transport in the oceans:





After Broecker 1991



[Atmospheric meridional energy flux and energy flux equator ...www.nature.com946 × 494]

Atmospheric meridional energy flux and energy flux equator.

What are the consequences of the non-zero heat transport at the equator??

doi:10.1038/nature13636

Migrations and dynamics of the intertropical convergence zone

Tapio Schneider[1,2], Tobias Bischoff[1,2] & Gerald H. Haug[2]

Rainfall on Earth is most intense in the intertropical convergence zone (ITCZ), a narrow belt of clouds centred on average around six degrees north of the Equator. The mean position of the ITCZ north of the Equator arises primarily because the Atlantic Ocean transports energy northward across the Equator, rendering the Northern Hemisphere warmer than the Southern Hemisphere. On seasonal and longer timescales, the ITCZ migrates, typically towards a warming hemisphere but with exceptions, such as during El Niño events. An emerging framework links the ITCZ to the atmospheric energy balance and may account for ITCZ variations on timescales from years to geological epochs.

Clim Dyn
DOI 10.1007/s00382-013-1767-z

The ocean's role in setting the mean position of the Inter-Tropical Convergence Zone

J. Marshall · A. Donohoe · D. Ferreira ·
D. McGee

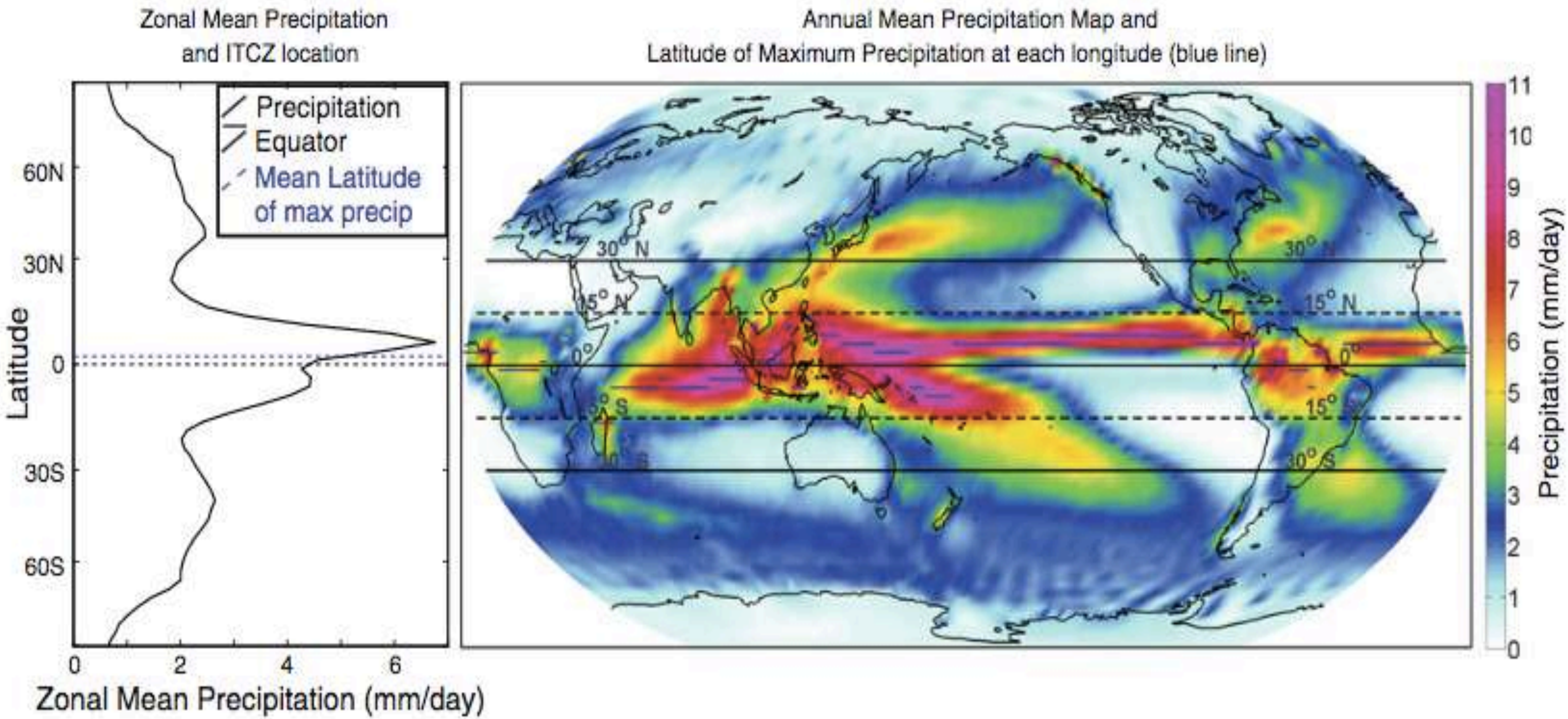


Fig. 1 The annual mean precipitation from the National Oceanographic and Atmospheric Administration's Climate Prediction Center's (NOAACPC) merged analysis (Xie and Arkin 1996). *Blue lines* indicate the meridional location of the maximum in the Tropics at each longitude. The zonal mean is shown on the left and is co-plotted with the zonal mean of the local maximum (*blue lines*) and the precipitation centroid (*dashed black lines*)

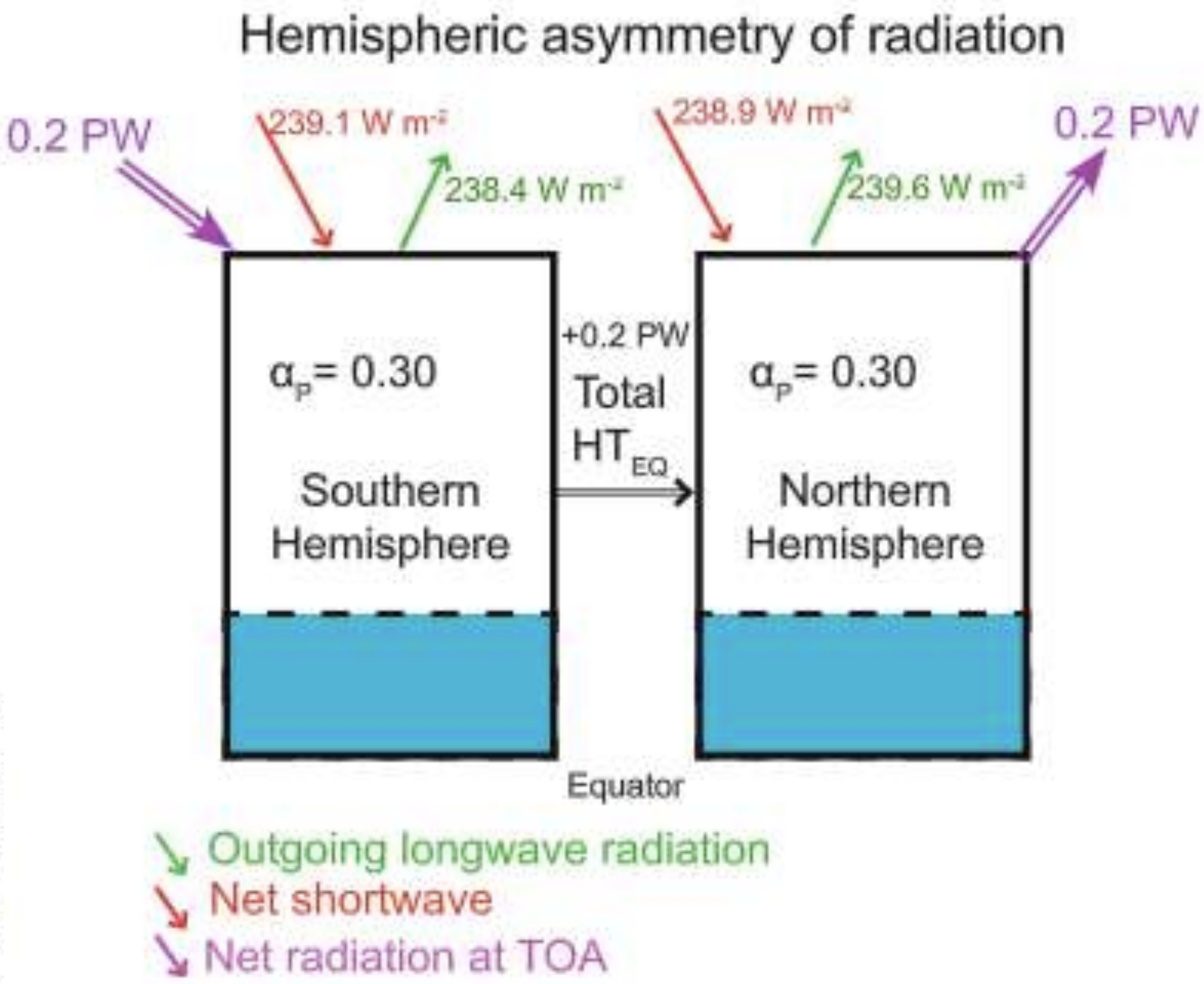
- **Previous work:**

- Implicit in the work of Zhang and Delworth (2005) who noted the shift of the ITCZ on to the equator following the collapse of the ocean's MOC (Meridional Overturning Circulation) in a coupled climate model.
- Broccoli et al. (2006) carry out perturbation (slab) experiments with cooling of the Northern Hemisphere/warming of Southern Hemisphere (implicitly imposing a southward OHT- Ocean [illegible] d atmospheric heat transport across the equator (in compensation), and a southward displacement of the ITCZ.
- Fuckar et al. (2013), using an idealized sector coupled general circulation model (GCM), observe that symmetry breaking of the ocean's MOC, with deep convection in one hemisphere and upwelling in the other, leads to a cross equatorial OHT (toward the convective hemisphere), a partial compensating atmospheric energy transport and a small displacement of the ITCZ from the equator.
- Frierson et al. (2013) make the connection between the hemispheric energy flow and ITCZ more explicit; they argue that the ITCZ's location north of the equator requires that the atmosphere be heated more strongly in the northern hemisphere (NH) than in the southern hemisphere (SH). They find that, as argued here, the hemispheric asymmetry of atmospheric heating in the observed climate system is primarily due to OHT across the equator as opposed to radiation at the TOA.

Also Barrero lecture yesterday !

- **Marshall et al. paper extend the observational calculations of the hemispheric asymmetry of energy input into the atmosphere to include additional data sets, explore the uncertainties in these calculations and the processes controlling the hemispheric differences in energy budgets and cross-equatorial heat exchange.**
- **They also demonstrate the role of OHT in setting the ITCZ location in an idealized, coupled system that resolves the key dynamical processes at work, rather than an atmosphere coupled to a slab ocean with prescribed OHT.**

- There is a slight deficit of net radiation in the NH relative to the SH because the NH emits more longwave radiation than the SH by virtue of it being slightly warmer (Kang and Seager 2013).



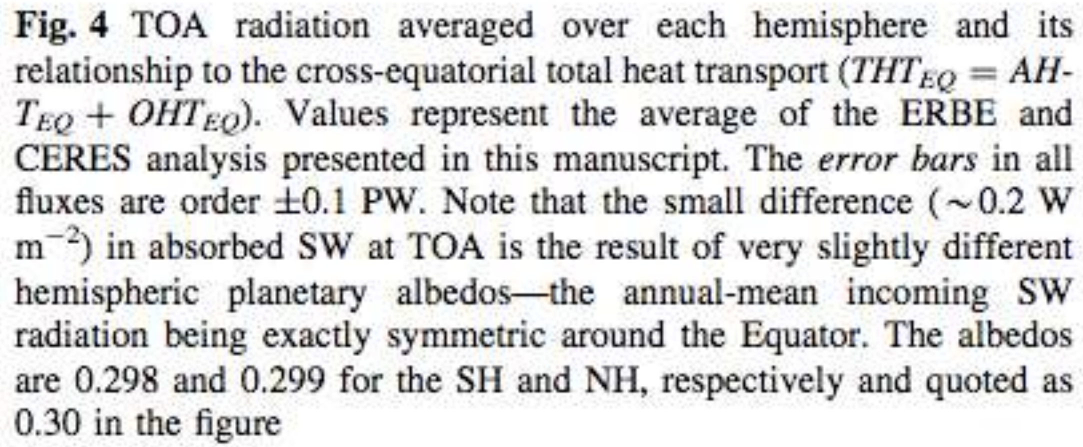


Fig. 4 TOA radiation averaged over each hemisphere and its relationship to the cross-equatorial total heat transport ($THT_{EQ} = AHT_{EQ} + OHT_{EQ}$). Values represent the average of the ERBE and CERES analysis presented in this manuscript. The *error bars* in all fluxes are order ±0.1 PW. Note that the small difference (~0.2 W m^{-2}) in absorbed SW at TOA is the result of very slightly different hemispheric planetary albedos—the annual-mean incoming SW radiation being exactly symmetric around the Equator. The albedos are 0.298 and 0.299 for the SH and NH, respectively and quoted as 0.30 in the figure

Annual Solar Energy: SH > NH

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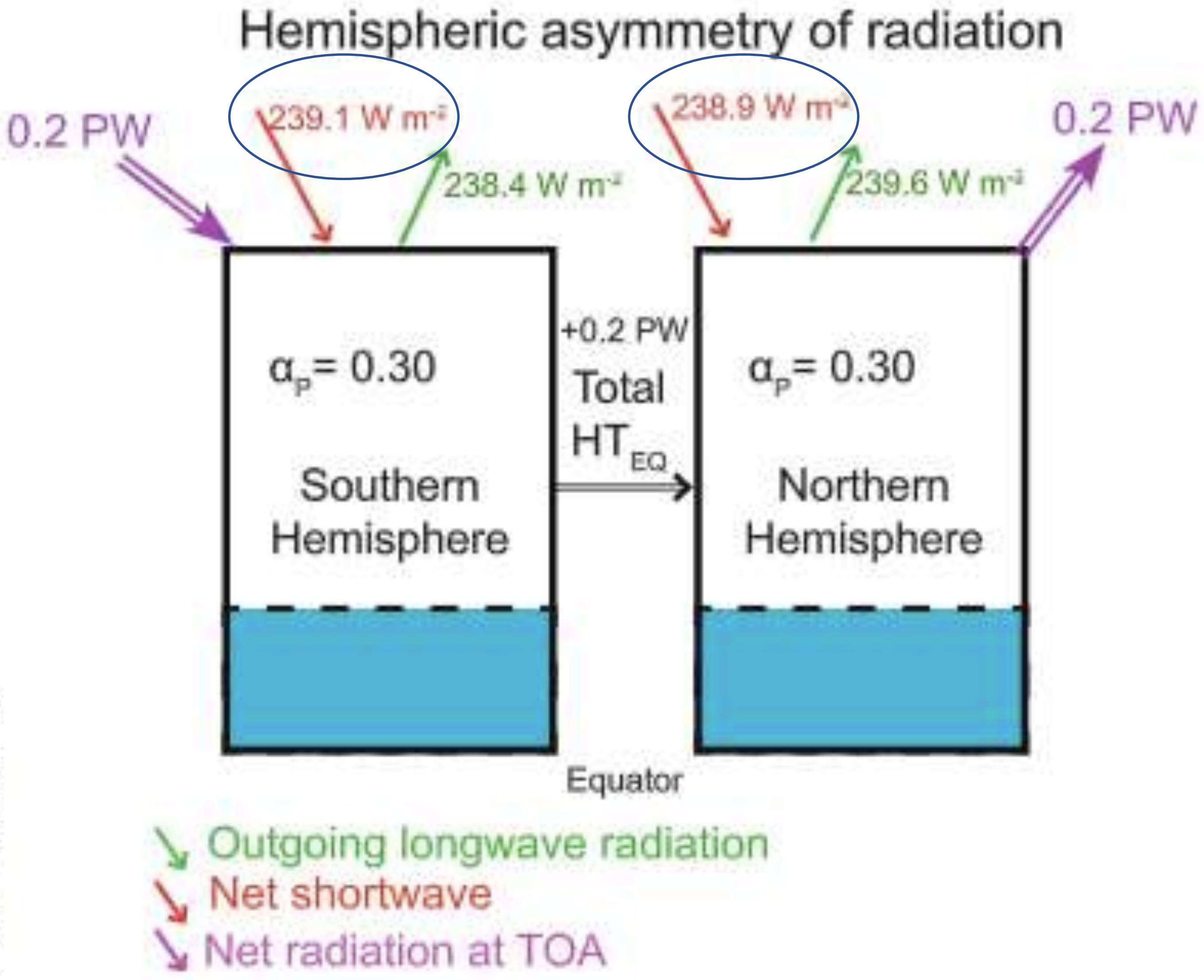

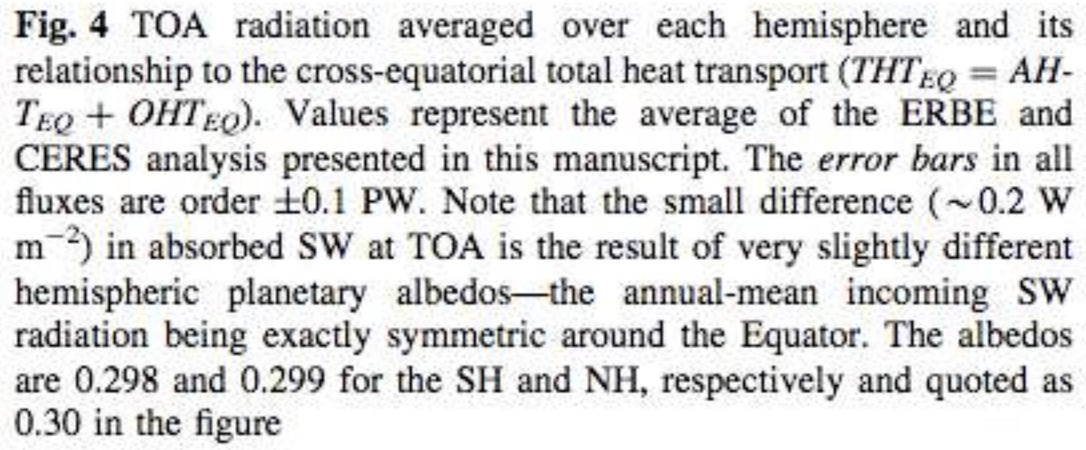
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Mean hemispheric albedo: SH = NH

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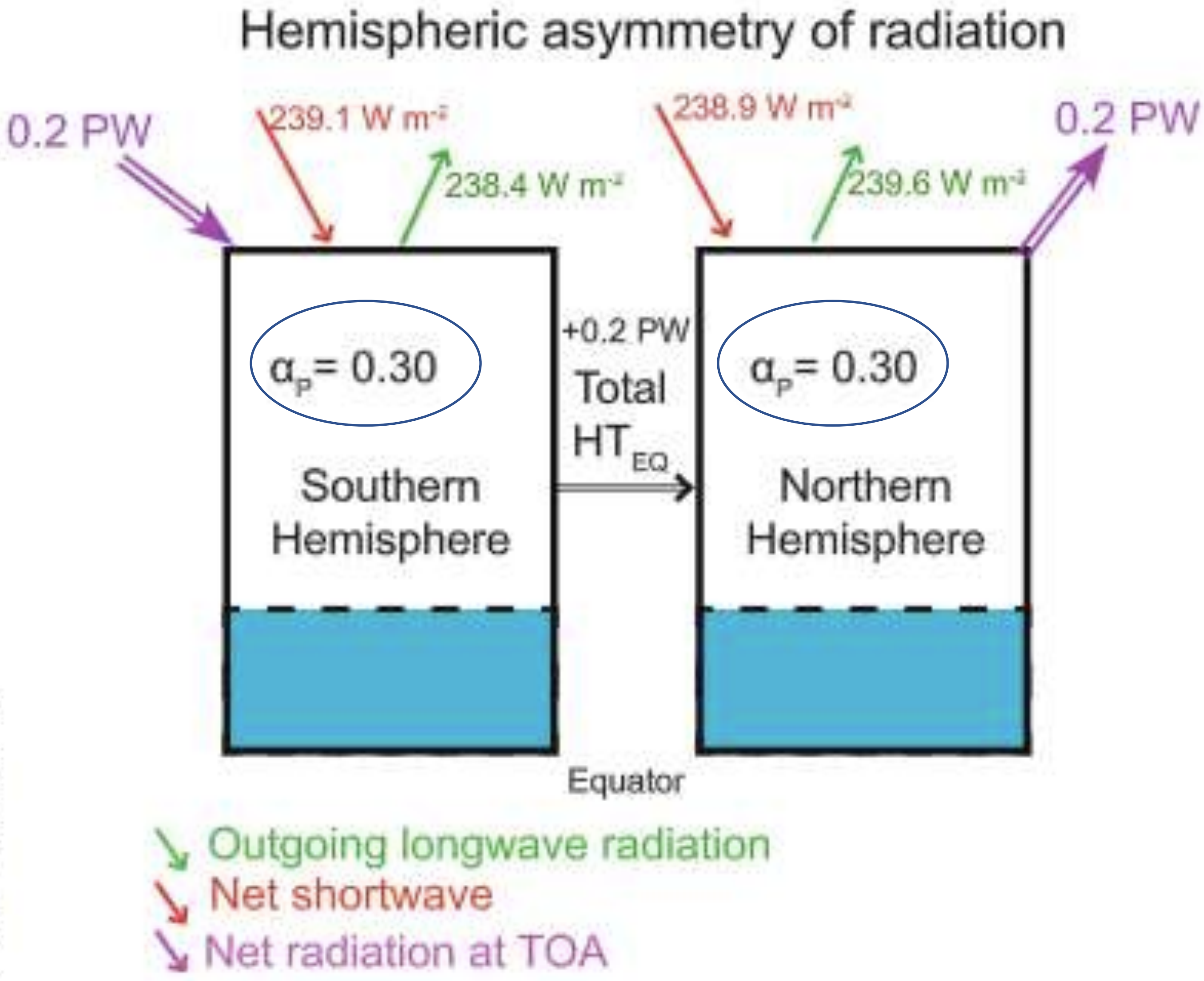

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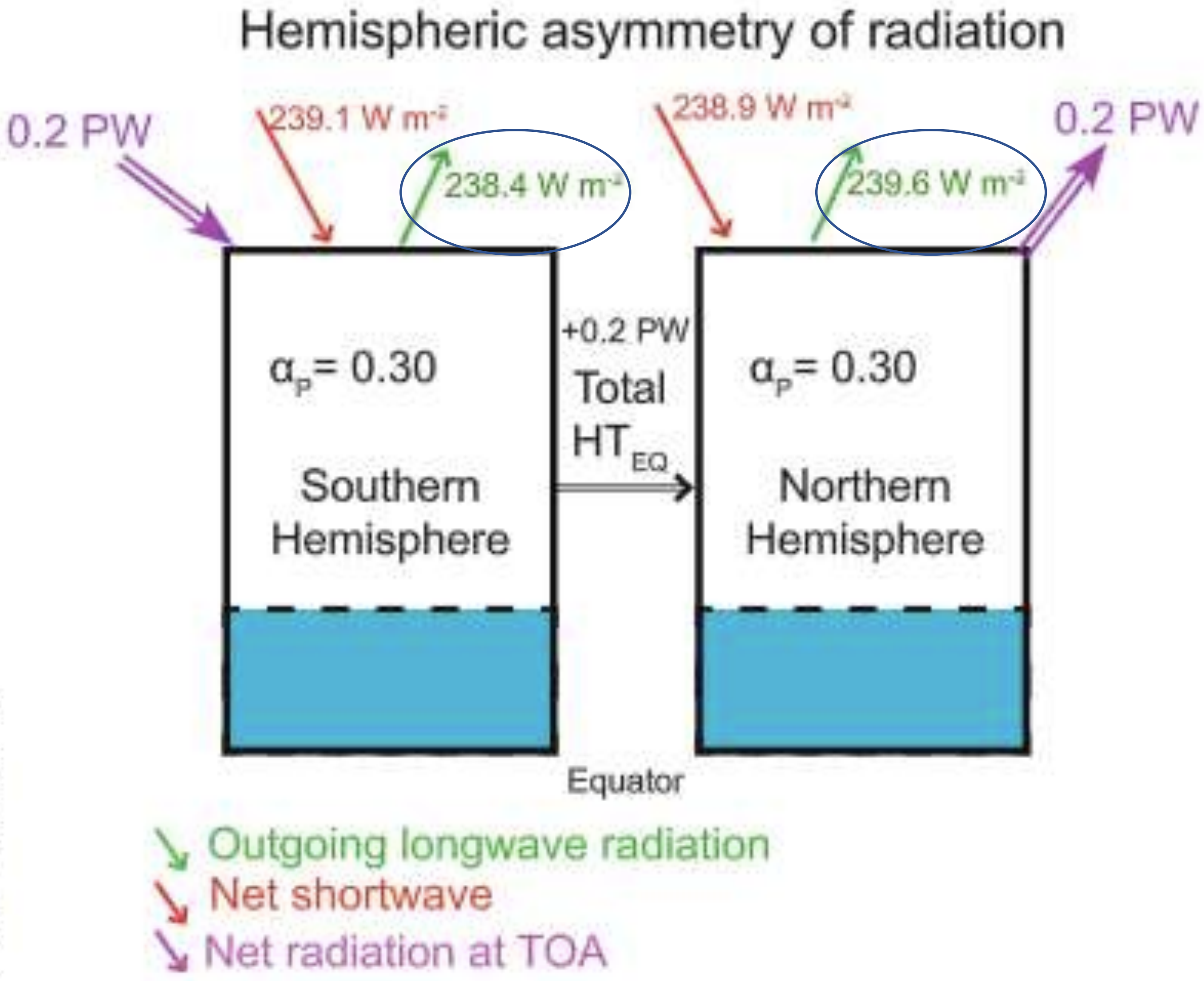
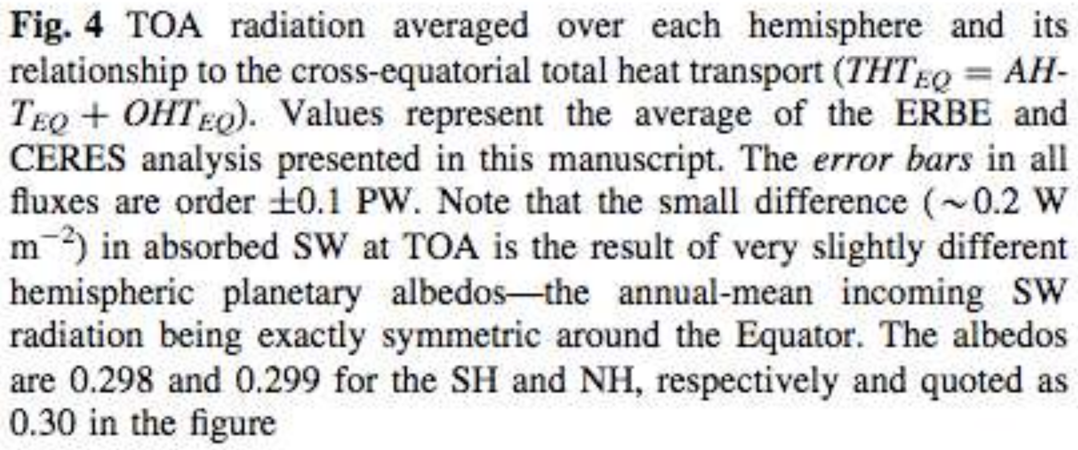
Mean hemispheric longwave emission: NH > SH

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Atmospheric/ocean heat transport across the equator

- The observations suggest that there is a net radiative loss at the TOA (Top of the Atmosphere) in the NH and gain in the SH.
- Therefore, in the absence of other processes, the atmospheric heat transport would have to be directed northward across the equator.
- Given that the **atmospheric energy transport** in the deep tropics is dominated by the meridional overturning circulation (MOC) – Hadley Cell , the **ITCZ would have to be located south of the equator** to achieve the necessary transport.
- **This is contrary to observations.**

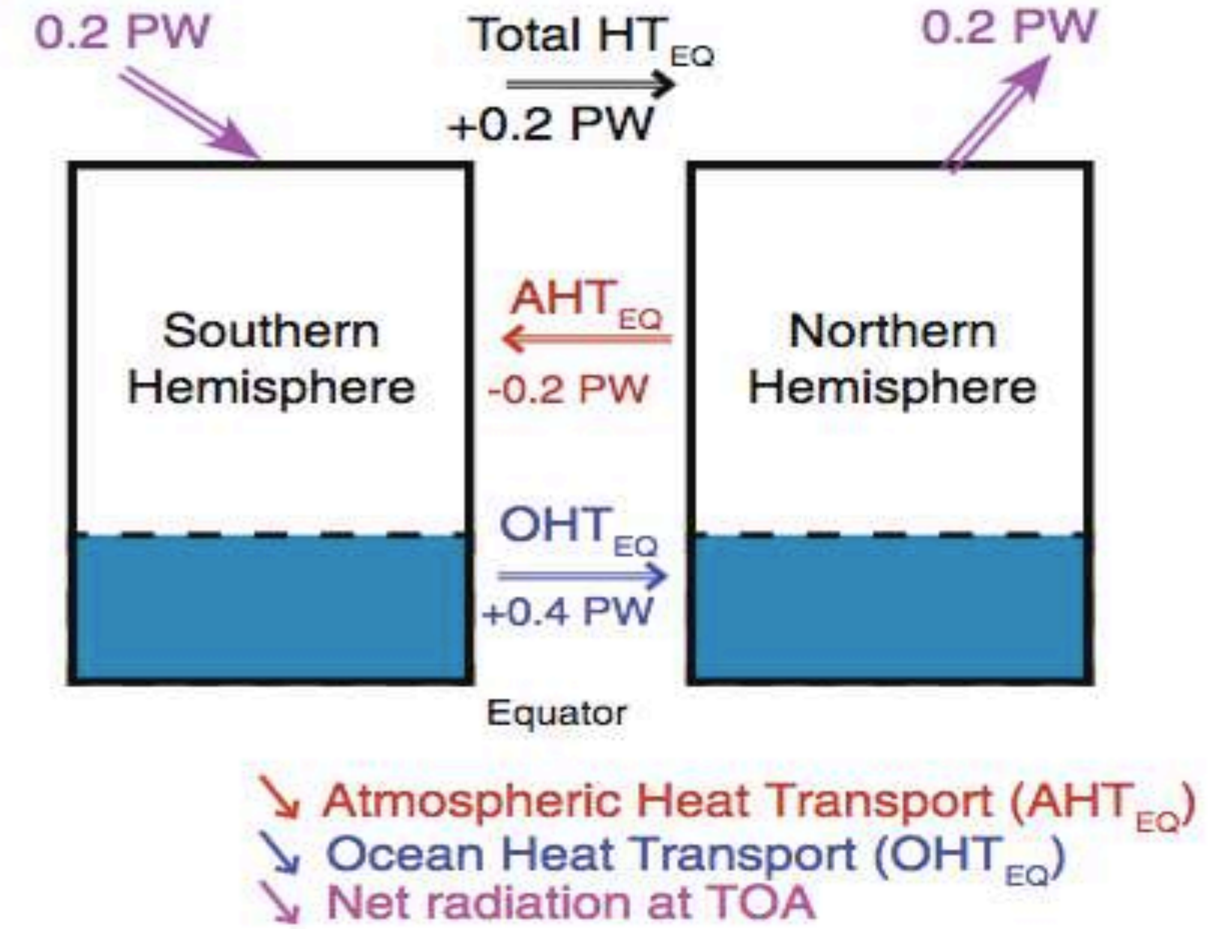


Fig. 2 Energy input at the TOA and its relationship to energy flux across the equator. AHT_{EQ} and OHT_{EQ} are the atmospheric and oceanic heat transport across the equator respectively. The *numbers* are estimates obtained in this study using observational reanalysis and satellite data. The *error bars* in all fluxes are order ±0.1 PW. OHT transport is estimated as a residual

- The annual mean meridional atmospheric overturning streamfunction is calculated from the zonal and time mean velocities in the ECMWF reanalysis (ERA) for the period 1979–2006, and is co-plotted with the precipitation in Fig.3.
- The tropical precipitation maximum is collocated with the ascending branch of the Hadley cell and is north of the Equator.
- As a consequence, there is northward mass transport at the surface and southward mass transport aloft.
- Given that moist static energy (MSE)[1] generally increases with height, one might therefore expect, and indeed one observes (see next Section), a net southward atmospheric energy transport across the equator associated with the Hadley Circulation.

(1) MSE = CpT+Lq+gz

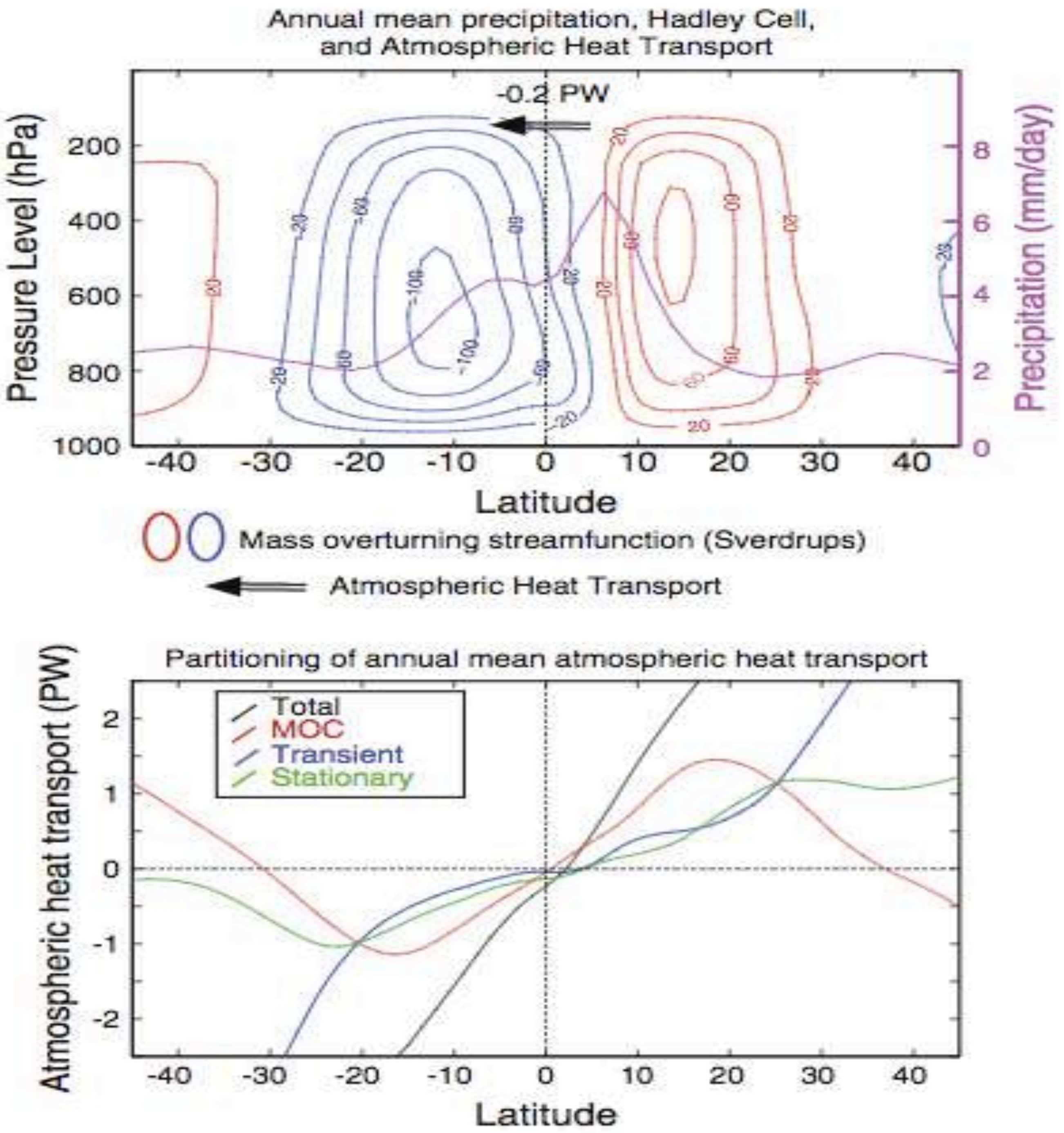


Fig. 3 The *red* (*clockwise*) and *blue* (*anticlockwise*) streamfunction of annual-mean overturning circulation derived from the ERA reanalysis. The contour interval is 20 Sverdrup (Sv) where 1 Sv = 10^9 kg s^{-1} as in Czaja and Marshall (2006). The *purple line* is the annual and zonal mean precipitation in mm day^{-1} with values given by the *purple axis* to the right. The *black arrow* indicates the atmospheric heat transport derived from the ERA re-analysis in this study (see Table 2). (*Bottom*) The partitioning of annual-mean atmospheric heat transport between MOC, transient and stationary eddies

- Hemispheric net TOA radiative forcing of the climate is almost perfectly symmetric about the equator, the total (atmosphere plus ocean) heat transport across the equator is small (order 0.2 PW).

- ***However, due to the ocean's (and in fact the Atlantic's) MOC, the ocean carries a significant amount of heat across the equator (order 0.4 PW).***

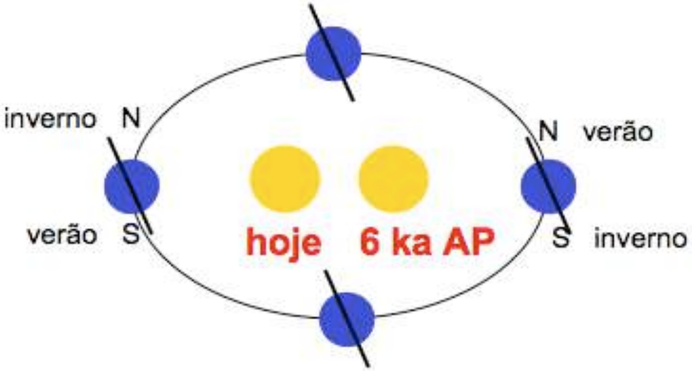
    - First AHT-Atmospheric Heat Transport is southwards across the equator to compensate (0.2 PW southwards), resulting in the ITCZ being displaced north of the equator.

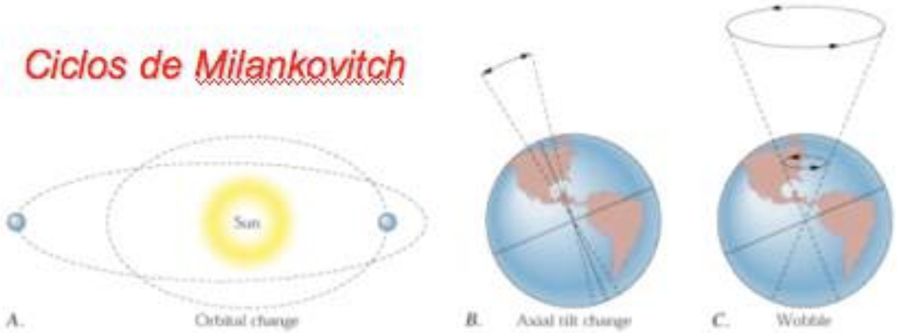
    - Secondly, the atmosphere, and indeed the ocean, is slightly warmer (by perhaps 2C) in the NH than in the SH.
        - This leads to the NH emitting slightly more OLR radiation than the SH by virtue of its relative warmth (Kang and Seager 2013) supporting the small northward heat transport by the coupled system across the equator.

Marshall et al. paper refers to the present climate:

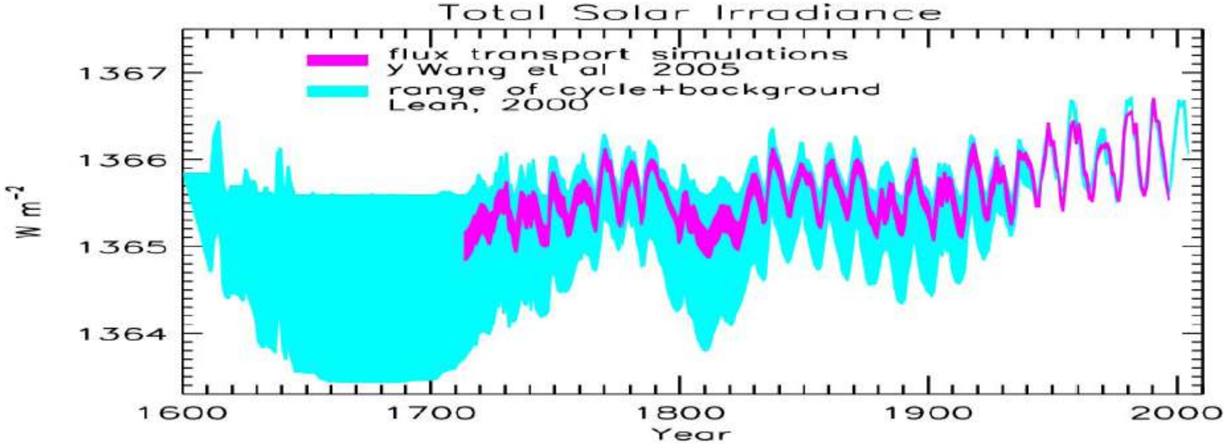
- how about past climates?

- *Climate changes due to natural causes:*
  - *Solar Forcing :*
    - *Orbital Changes: Milancovitch Cycles.*

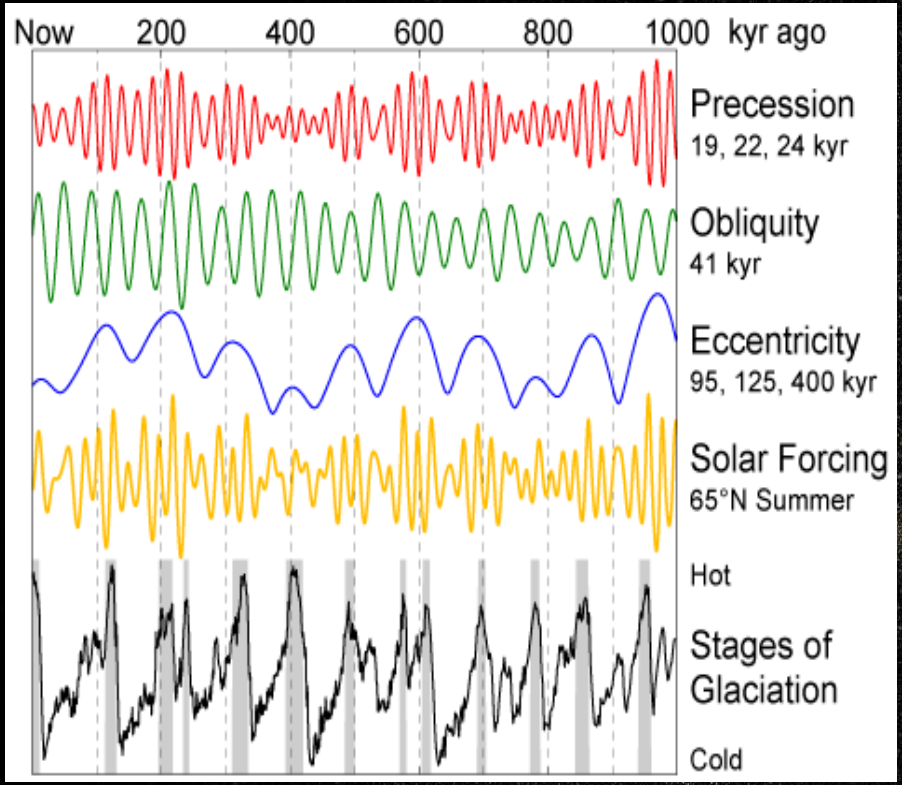


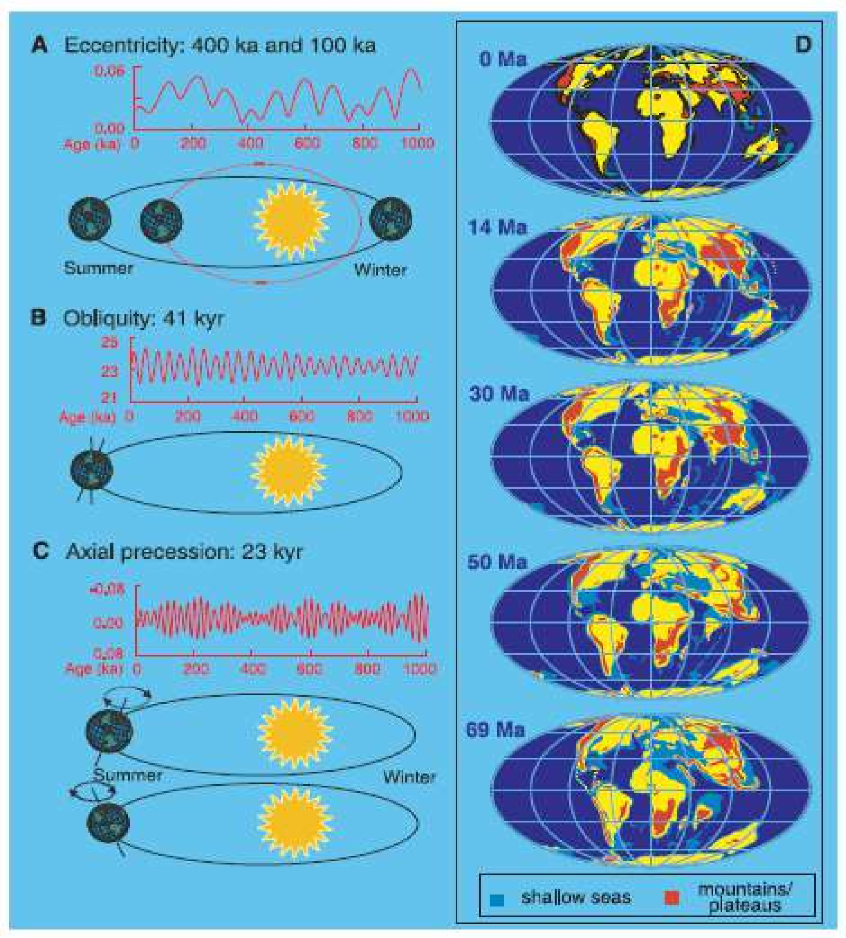


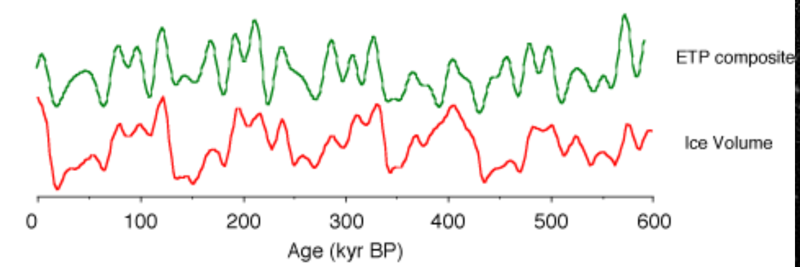
And changes in the solar energy output (spectrally dependent – UV in particular -- > Ozone



Croll-Milankovitch cycles and glacial periods





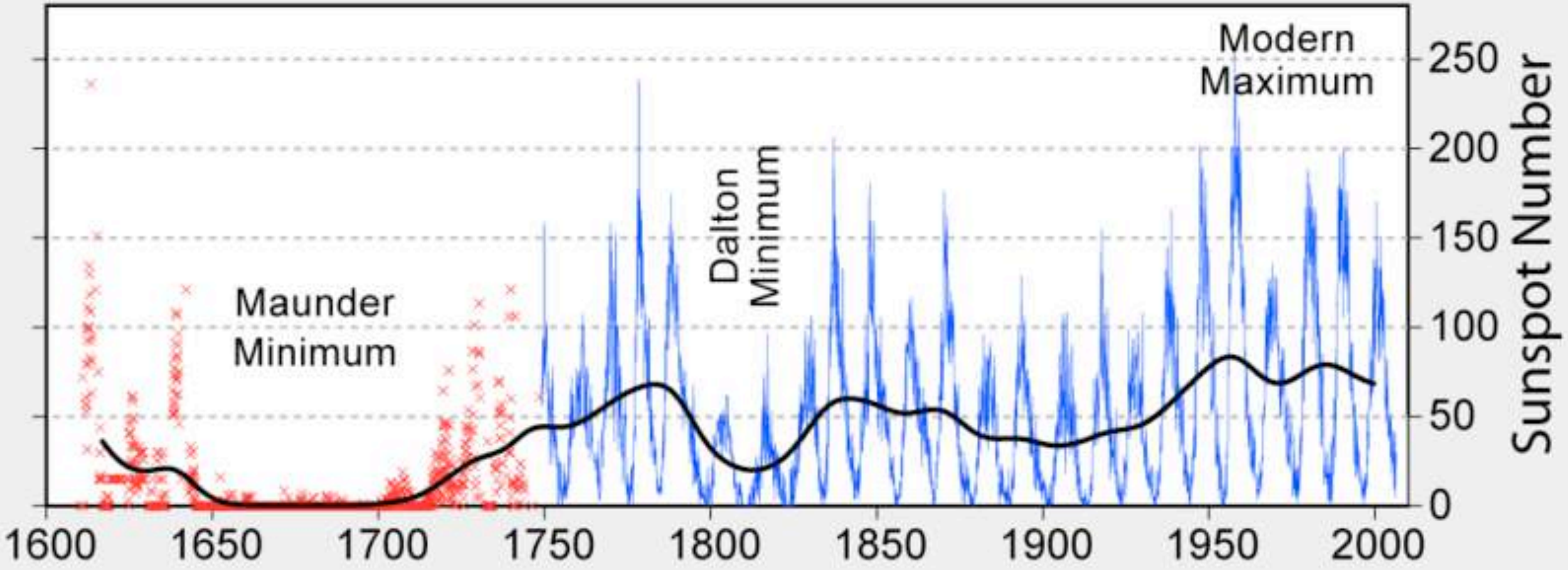


Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present

James Zachos,[1*] Mark Pagani,[1] Lisa Sloan,[1] Ellen Thomas,[2,3] Katharina Billups[4]

27 APRIL 2001 VOL 292 SCIENCE

400 Years of Sunspot Observations

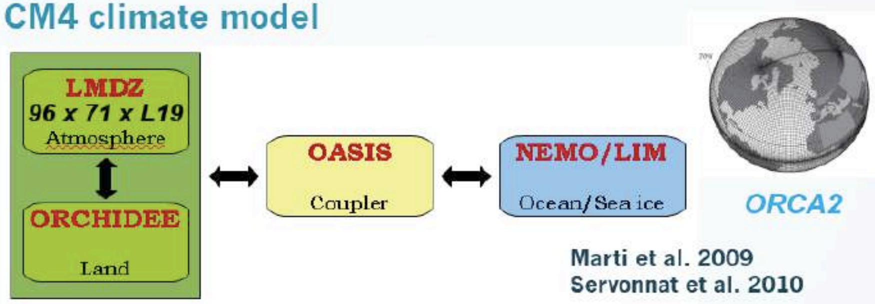


Volcanic impact on the Atlantic ocean over the last millennium

Juliette Mignot
Myriam Khodri, Jérome Servonnat,
Claude Frankignoul

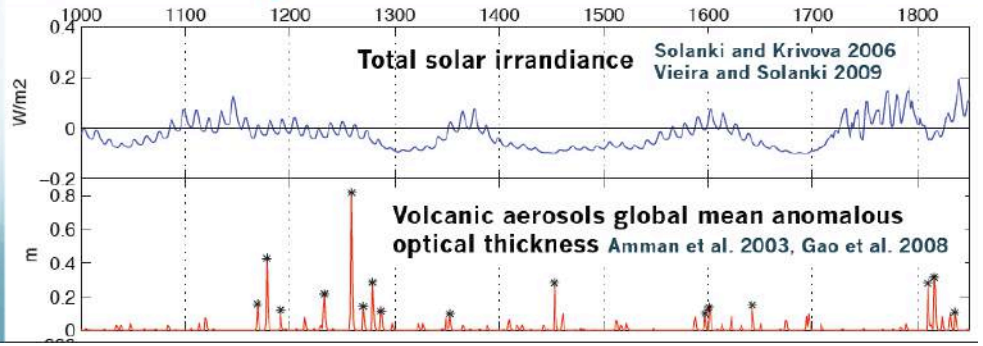
Réunion des 1000 ans
Bondy Novembre 2010

IPSL CM4 climate model

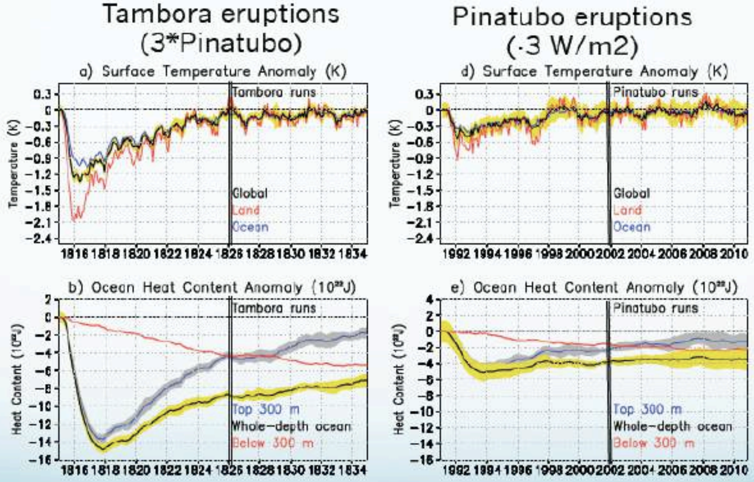


Marti et al. 2009
Servonnat et al. 2010

External forcings over the last millennium



Oceanic temperature response to volcanic eruptions



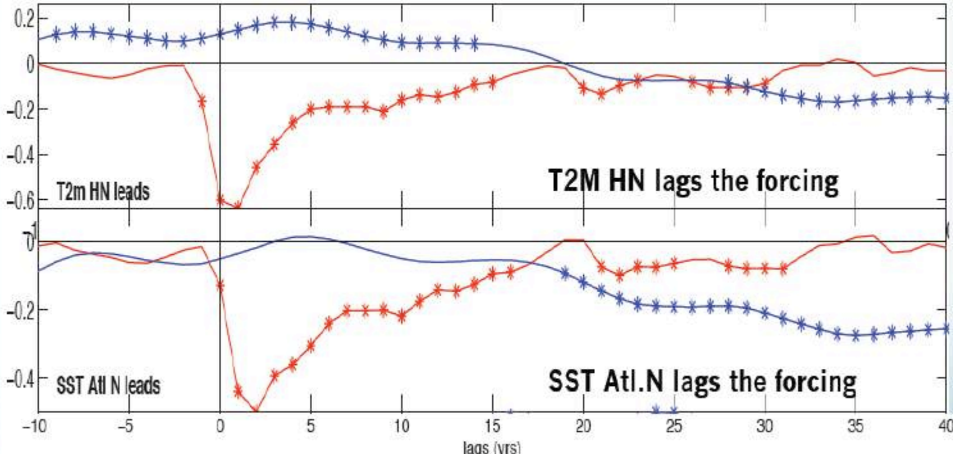
GFDL CM2.1
10 20-yr ensemble runs

Stenchikov et al 2009

Correlations with the forcing time series

Correlation with the **solar** forcing
Correlation with the **volcanic** forcing

(5% significativity tested against a block bootstrap procedure with 500 permutations of theforcing time serie)



Solar cycles (boxed quote is excerpted from http://en.wikipedia.org/wiki/Solar_variation)
Solar cycles are cyclic changes in behavior of the Sun. Many possible patterns have been noticed.

11 years: Most obvious is a gradual increase and decrease of the number of sunspots over a period of about 11 years, called the Schwabe cycle. The Babcock Model explains this as being due to a shedding of entangled magnetic fields. The Sun's surface is also the most active when there are more sunspots, although the luminosity does not change much due to an increase in bright spots.

22 years: Hale cycle. The magnetic field of the Sun reverses during each Schwabe cycle, so the magnetic poles return to the same state after two reversals.

88 years: Gleissberg cycle (70-100 years) is thought to be an amplitude modulation of the 11-year Schwabe Cycle (Sonnett and Finney, 1990).

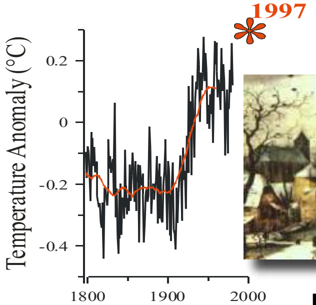
200 years: Suess cycle.

2,300 years: Hallstatt cycle.

Other patterns have been detected:
    In carbon-14: 105, 131, 232, 385, 504, 805, 2,241 years (Damon and Sonnett, 1991).

During the Upper Permian 240 million years ago, mineral layers created in the Castile Formation (West Texas/Southern New Mexico) show cycles of 2,500 years.

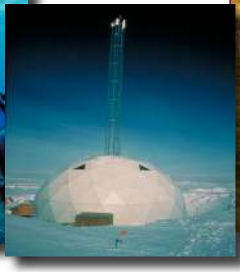
Paleoclimate Reconstruction of S. American Monsoon



Instrumental data

Historical data

Corals



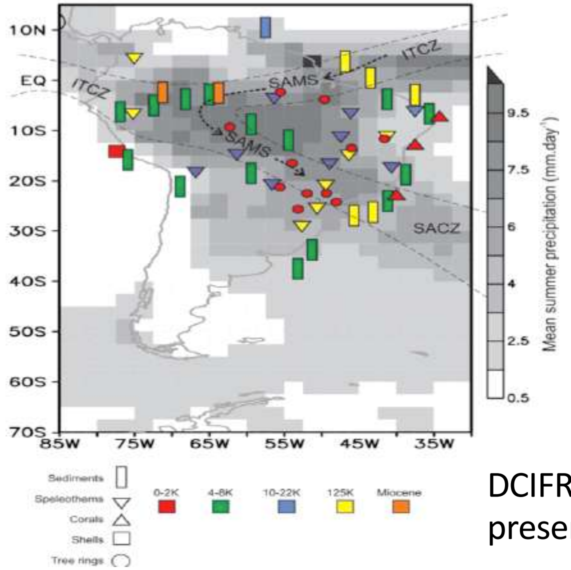
Ice cores

Lake sed.

Tree rings

Marine sed.

speleothems

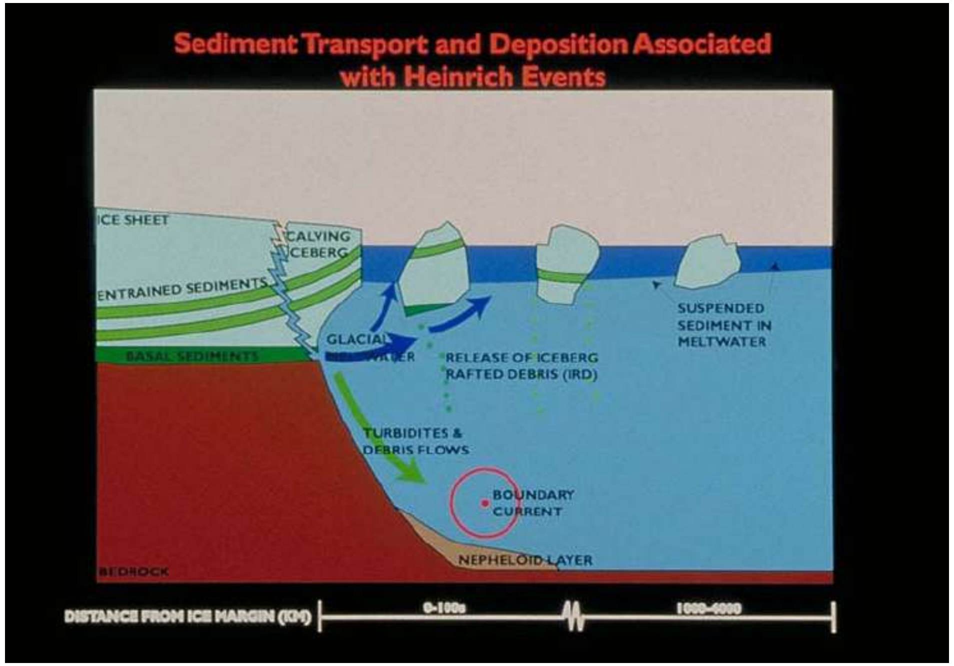


DCIFRAR - program – Abdel presentation tomorrow

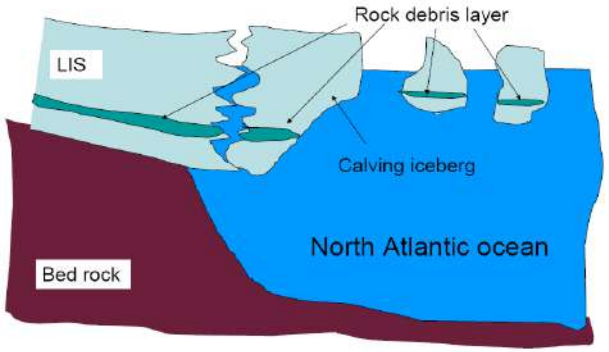
Number of reconstructions are increasing !!!

Fresh water inflow

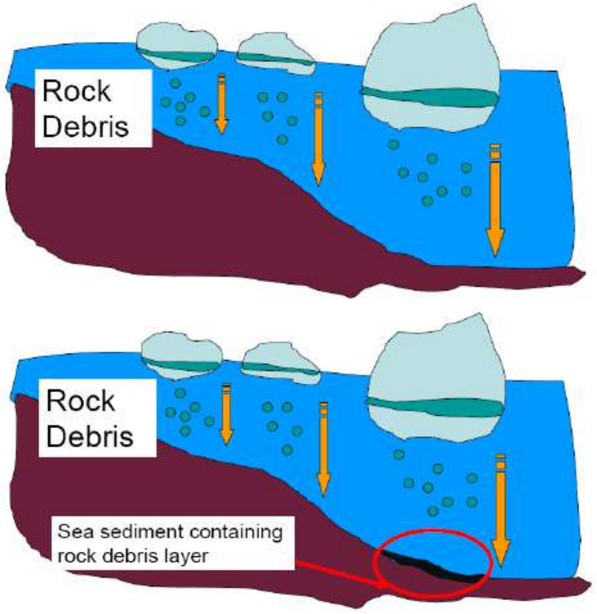
Heinrich episodes - melting



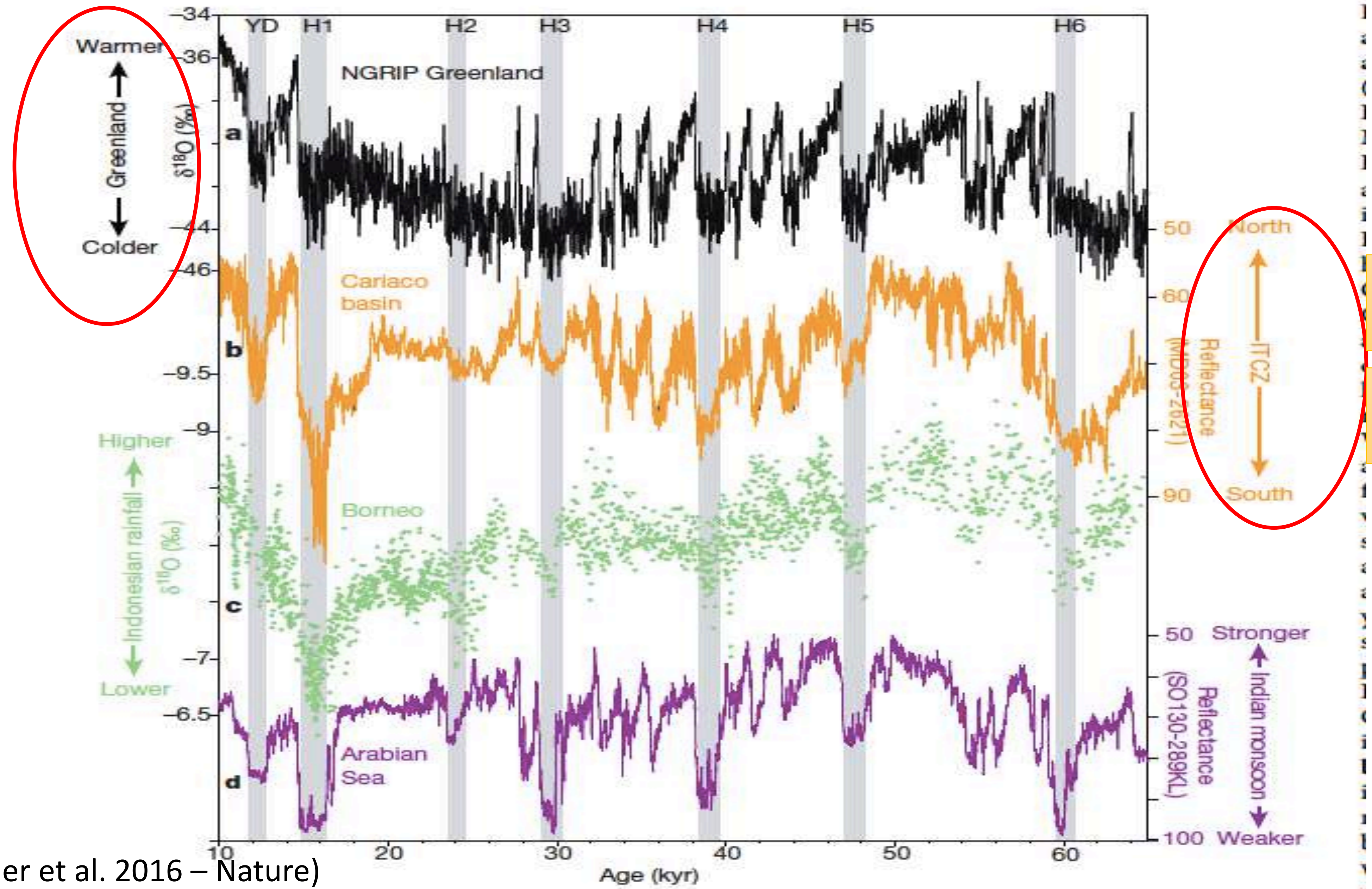
Huge armadas of ice bergs were launched from Canada into the North Atlantic



As they melted , they released rock debris that was dropped into the fine grained sediments on the ocean floor.



Differences between the southern and northern hemisphere climatology and ITCZ position: Cariaco Basin - Venezulela

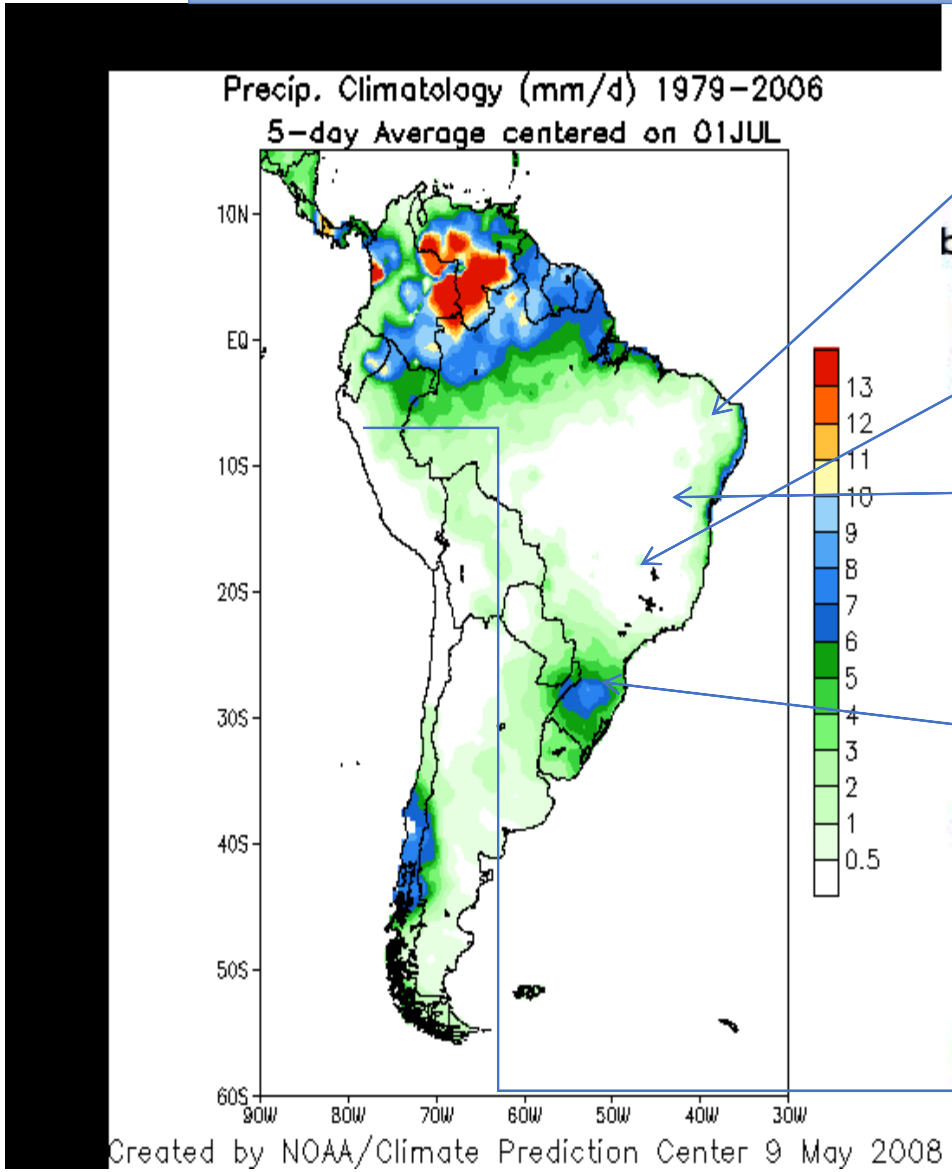


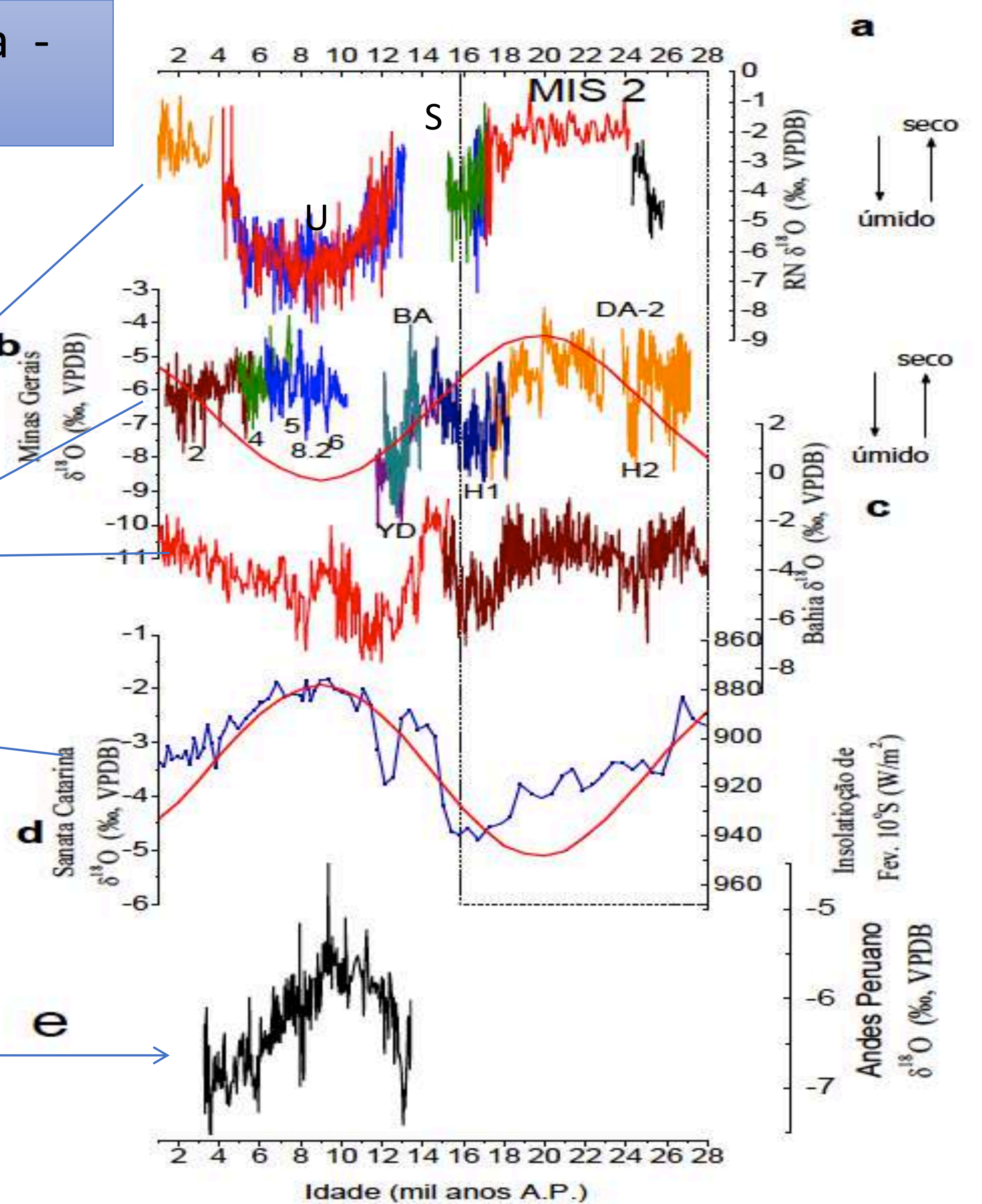
Scheneider et al. 2016 – Nature)

Warmer => Northward ITCZ

Colder => Southward ITCZ

Speleothems in S. America - caves -


Precip. Climatology (mm/d) 1979-2006
5-day Average centered on 01JUL
Created by NOAA/Climate Prediction Center 9 May 2008



NE – Seco antes do YD passando para úmido depois

Cruz et al. 2009

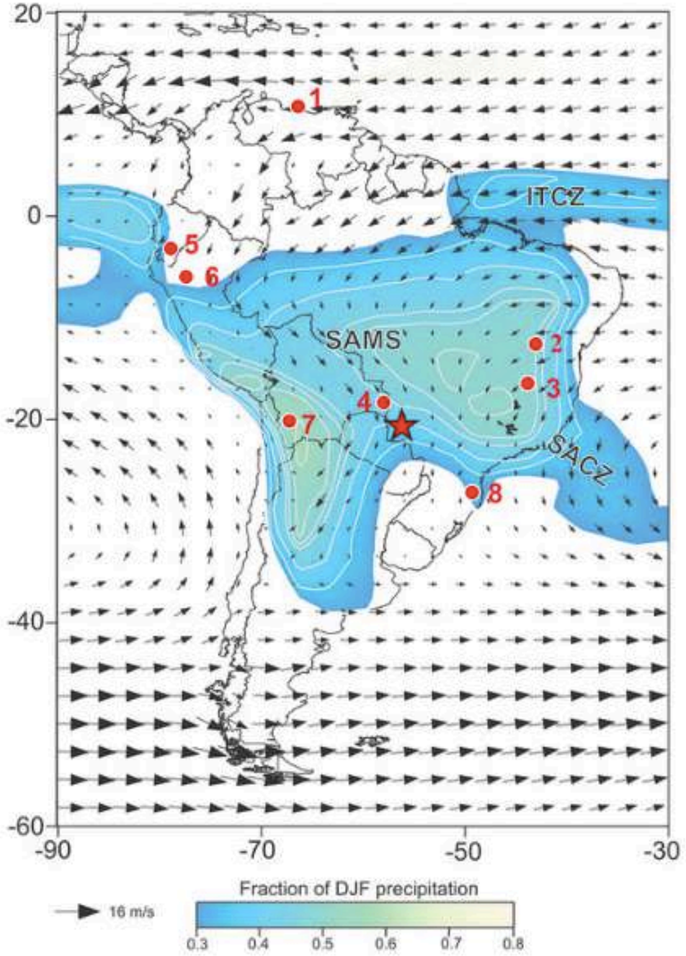
A high-resolution history of the South American Monsoon from Last Glacial Maximum to the Holocene

Valdir F. Novello ✉, Francisco W. Cruz, Mathias Vuille, Nicolás M. Stríkis, R. Lawrence Edwards, Hai Cheng, Suellyn Emerick, Marcos S. de Paula, Xianglei Li, Eline de S. Barreto, Ivo Karmann & Roberto V. Santos

Scientific Reports **7**, Article number: 44267 (2017)
doi:10.1038/srep44267

Received: 15 July 2016
Accepted: 07 February 2017
Published online: 10 March 2017

Figure 1: Map of South America with the locations of the records discussed in text.



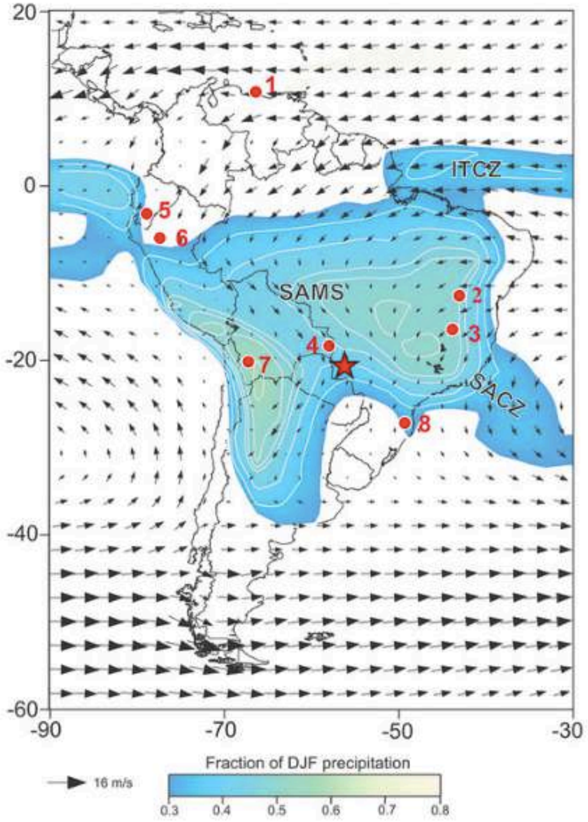
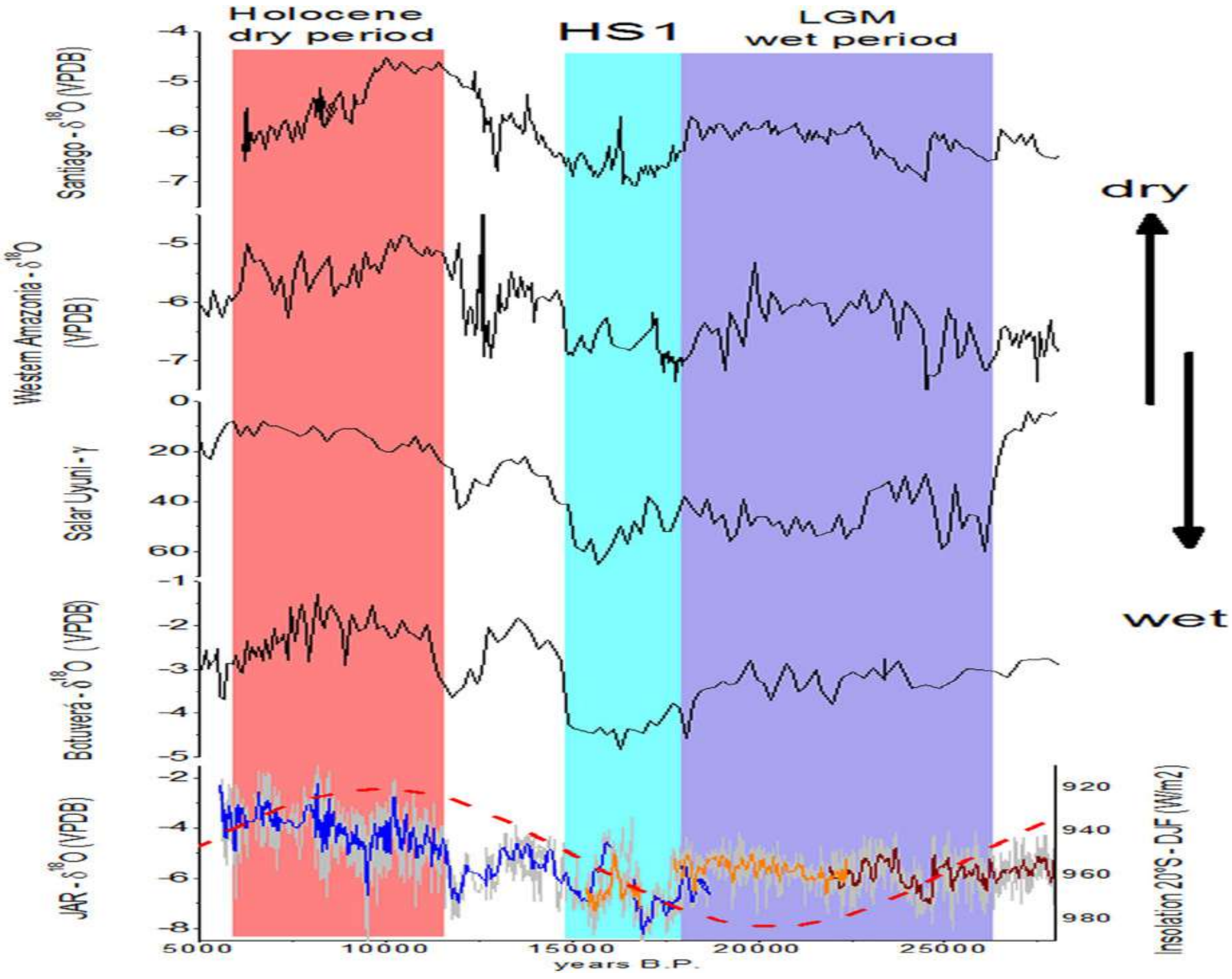
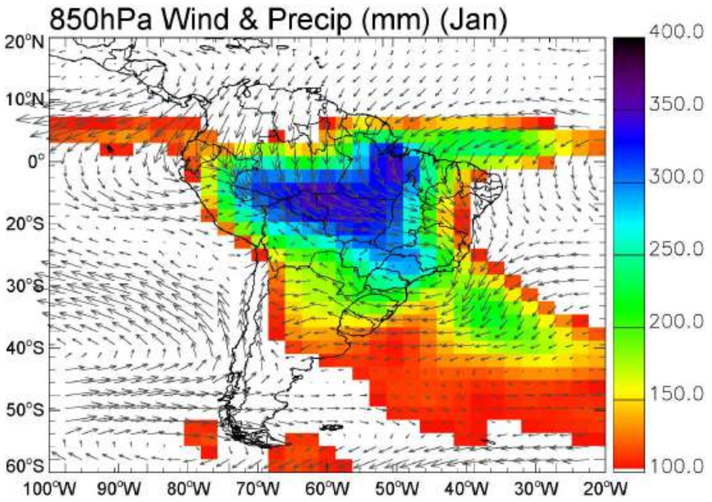
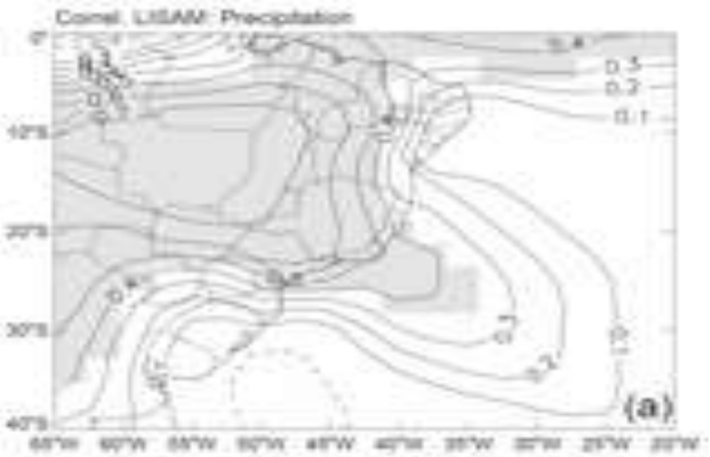


Figure 1: Map of South America with the locations of the records discussed in text.

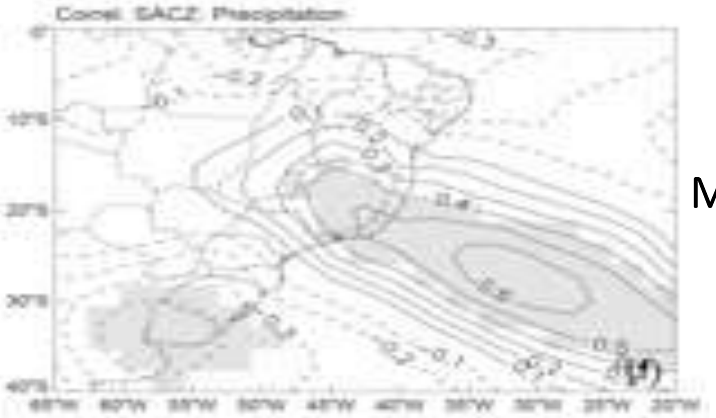


Large Scale Index for South America Monsoon (LISAM index) (Silva and Carvalho 2007)





Mode 1
LISAM



Mode 2
SACZ

SAMS is characterized by seasonal changes in:

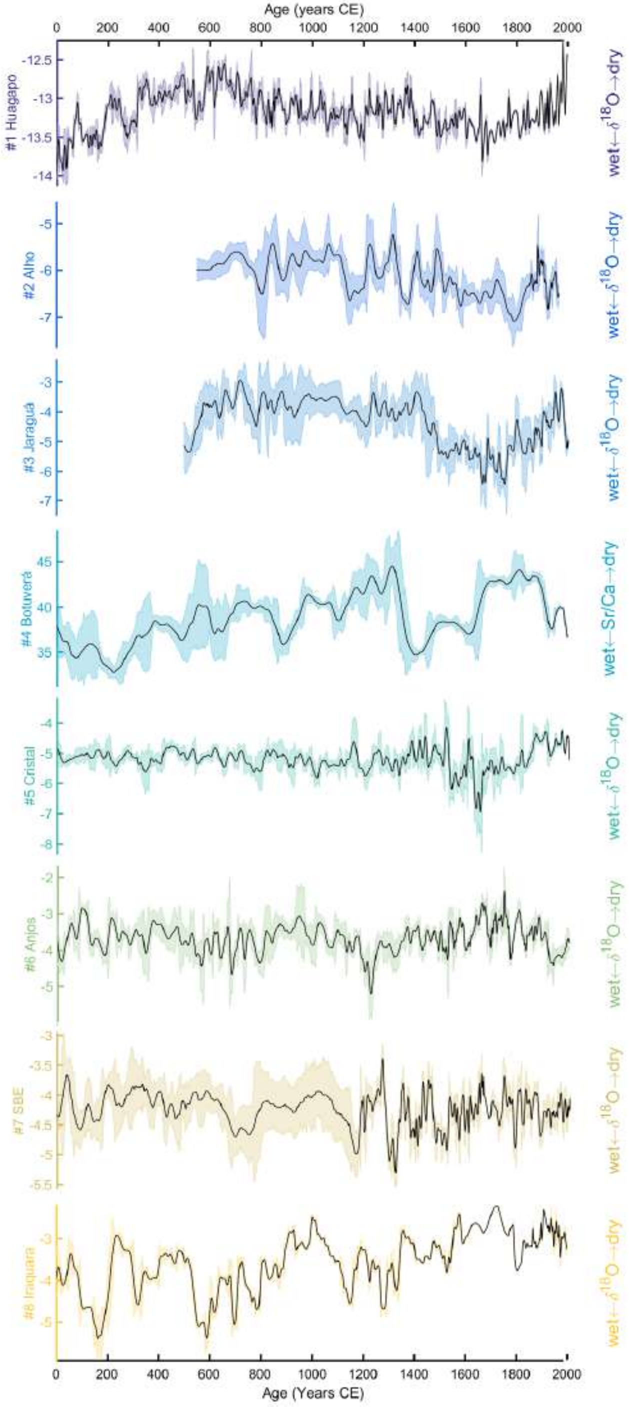
☐ Circulation anomalies
☐Precipitation
☐Moisture
☐ Temperature

LISAM index was designed to characterize the ONSET, DEMISE, DURATION, AMPLITUDE, BREAKS AND ACTIVE PHASES of SAMS based in all variables above.

Based on grid point data

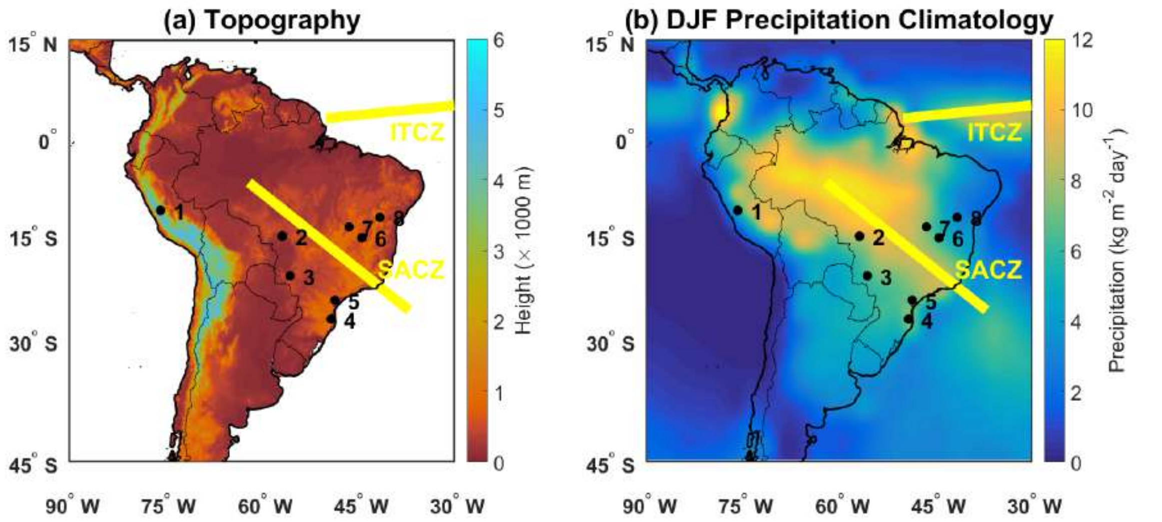
Speleothems Time Series Last Millenium - *search for the LISAM/SACZ patterns in proxies*

Jose Leandro Campos PhD Thesis – IAG/USP)

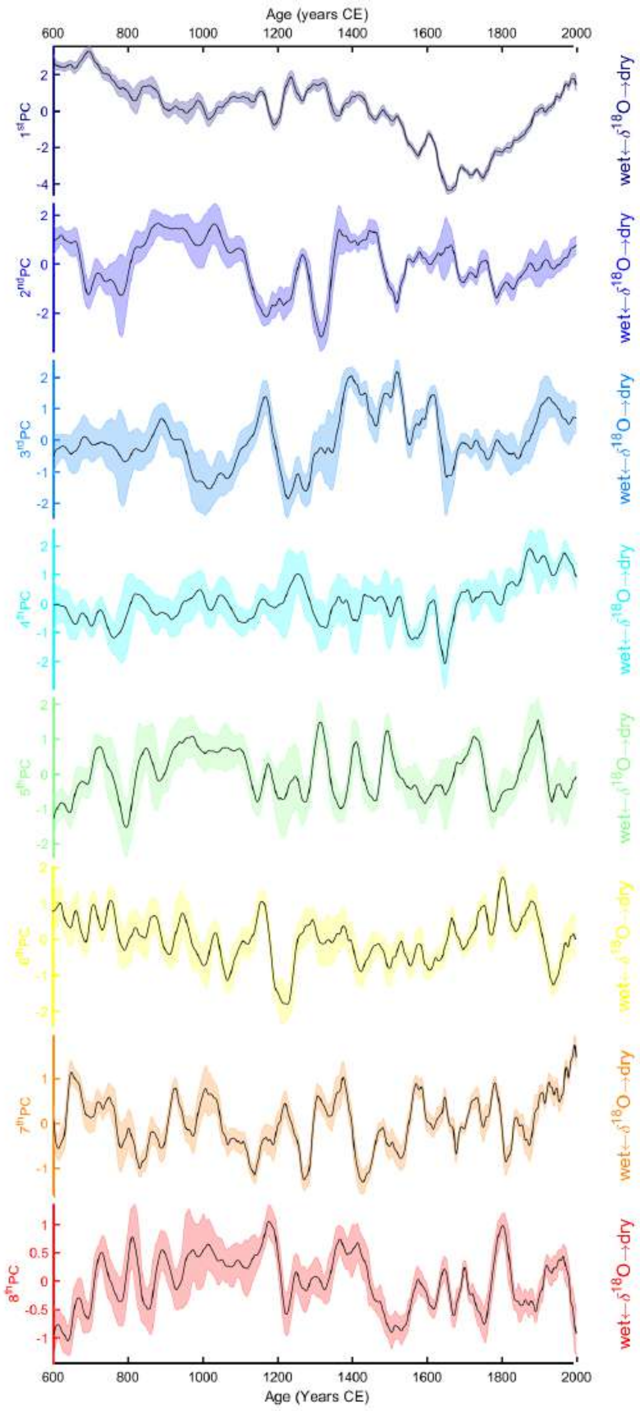


Speleothems Info

Proxies	ID	Proxy	Lat	Lon	Reference
Huagapo	1	$\delta^{18}O$	11.27°S	284.21°E	Kanner et al.2013
Pau d'alho	2	$\delta^{18}O_l$	15.20°S	303.20°E	Novello et al.2016
Jaraguá	3	$\delta^{18}O$	21.08°S	304.42°E	Novello et al.2018*
Cristal	4	$\delta^{18}O_l$	24.58°S	311.42°E	Taylor et al. 2010
Botuverá	5	Sr/Ca	27.22°S	310.85°E	Bernal et al. 2016
Anjos	6	$\delta^{18}O$	15.44°S	315.60°E	Unpublished
SBE 3	7	$\delta^{18}O$	13.81°S	313.65°E	Unpublished
Iraquara	8	$\delta^{18}O$	12.36°S	318.43°E	Novello et al.2013

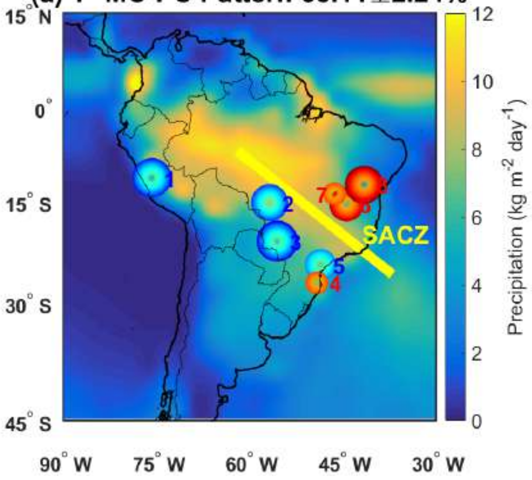


Jose Leandro Campos PhD Thesis – IAG/USP)

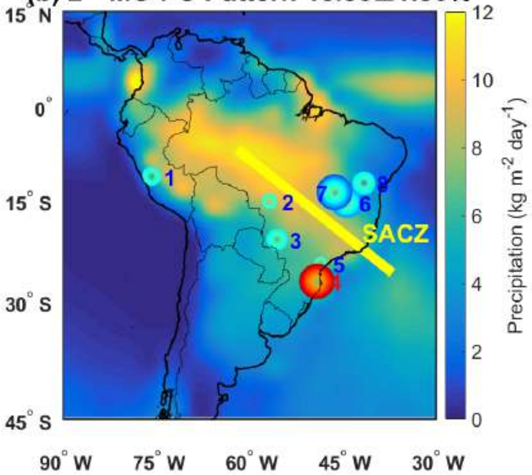


Monte-Carlo Principal Components - Scores

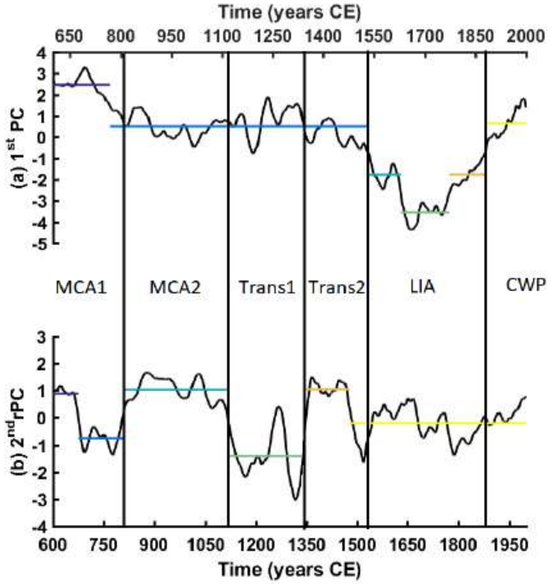
(a) 1stMC-PC Pattern 38.11±2.24%



(b) 2ndMC-PC Pattern 15.36±1.56%



Rodionov Test for Means

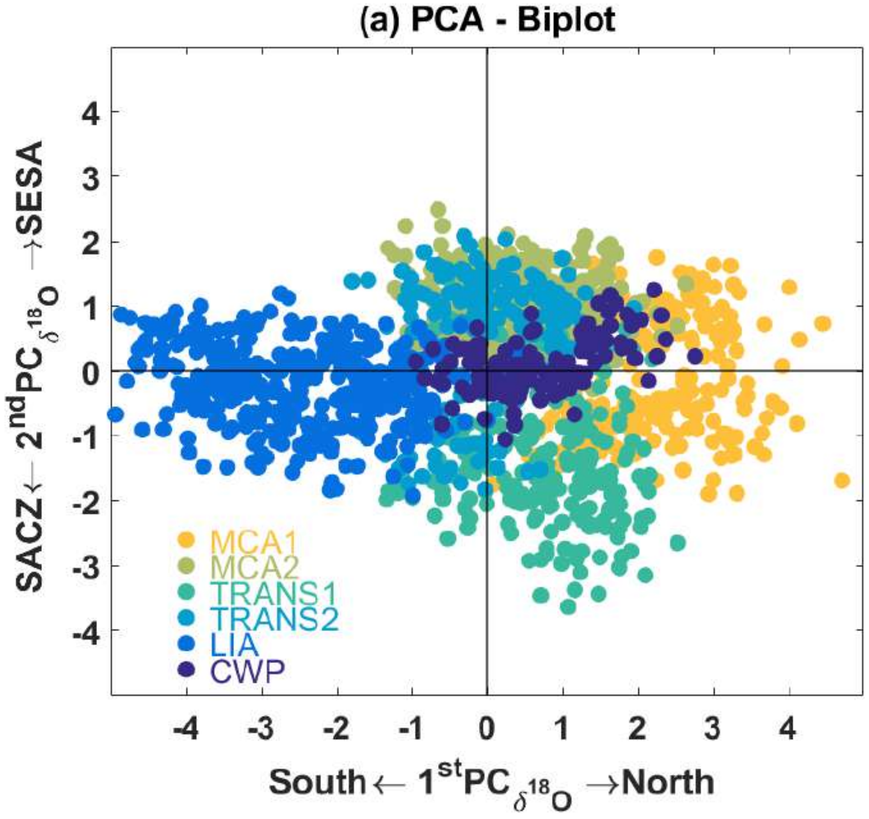


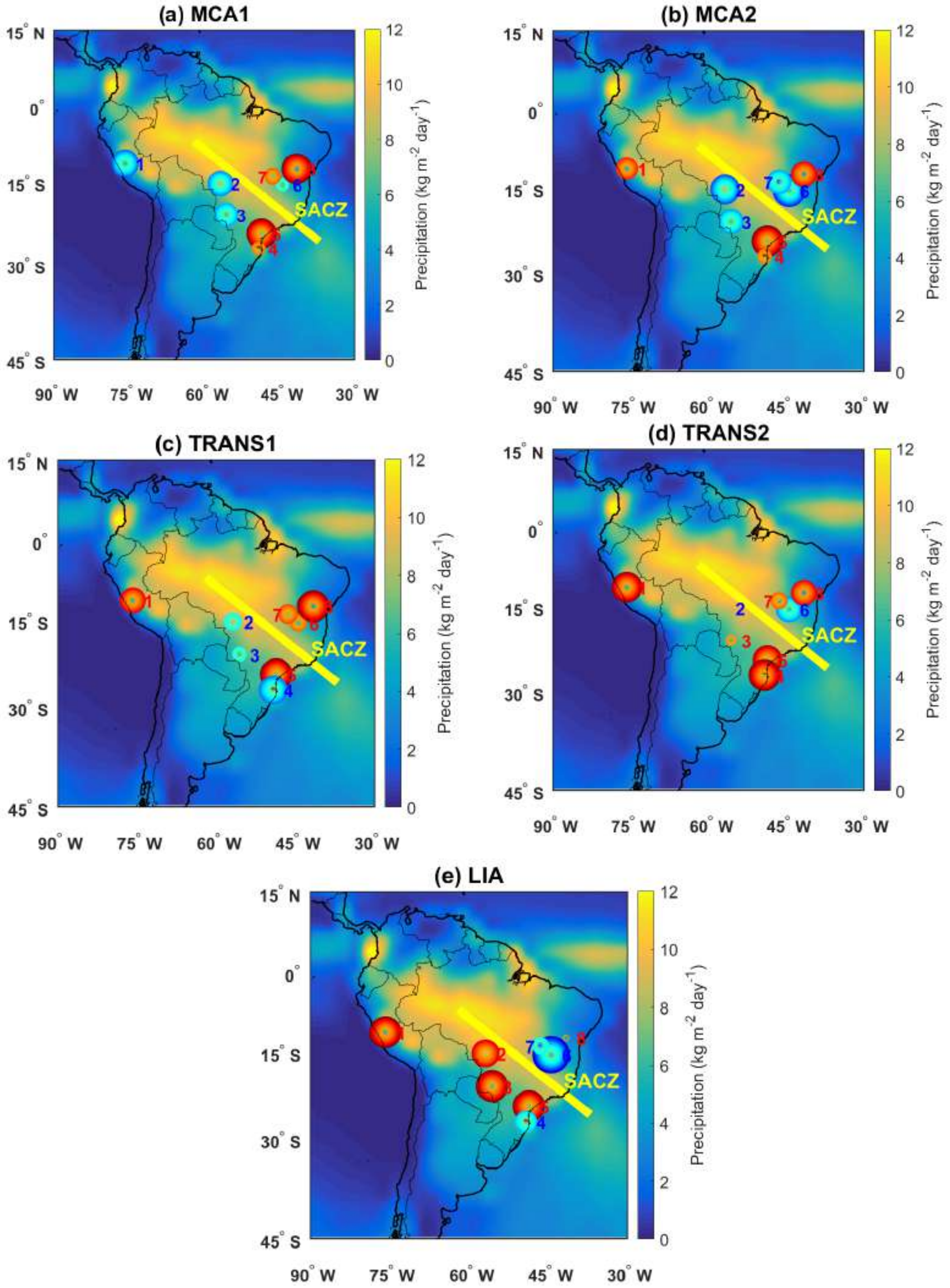
- 6 regime shift periods are found!
- Significance test evaluated through the Paired t-test

Biplot

Principal Components & δ^{18}O Composites

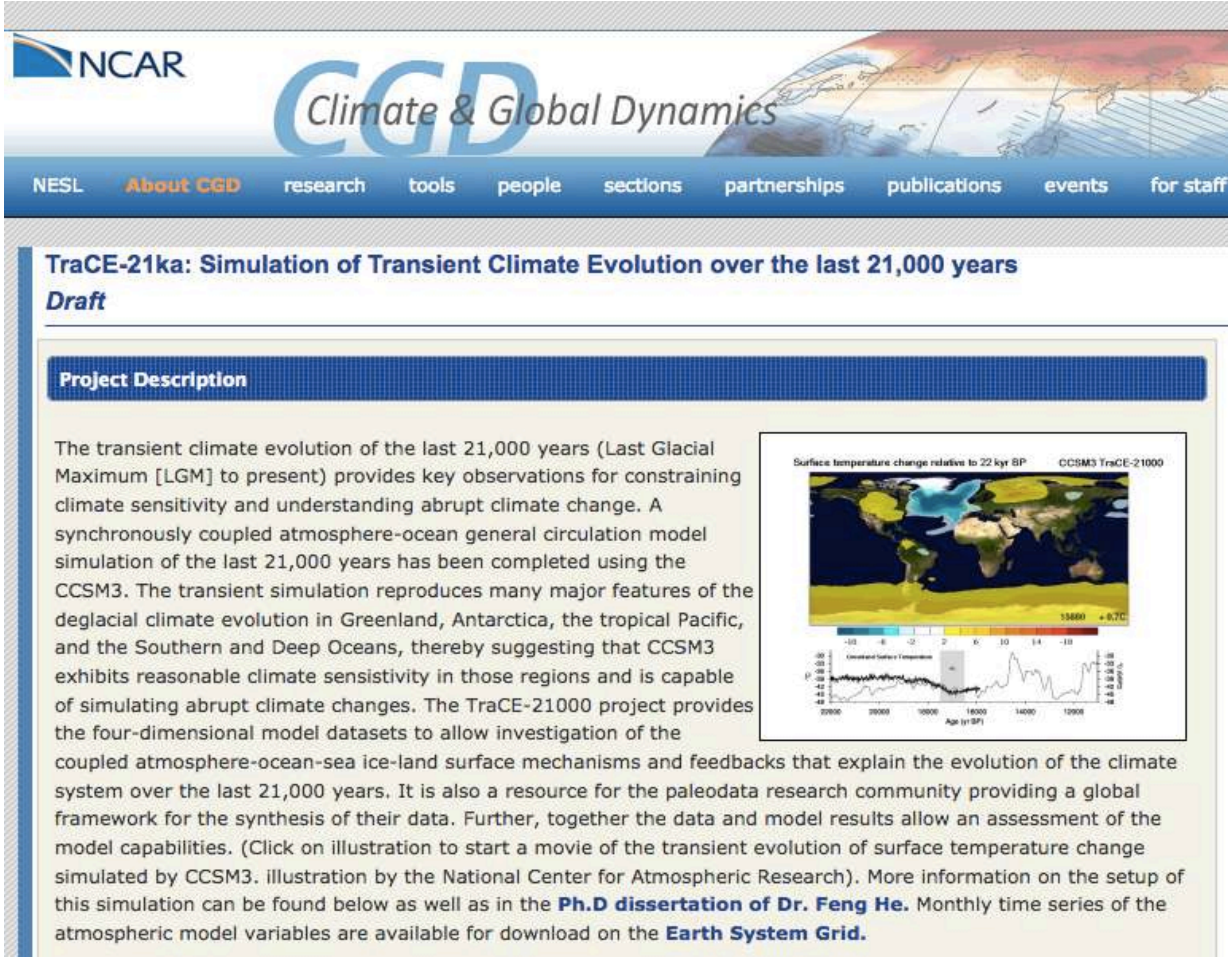
Jose Leandro Campos PhD Thesis – IAG/USP)





Trace21k Experiments

http://www.cgd.ucar.edu/ccr/TraCE/



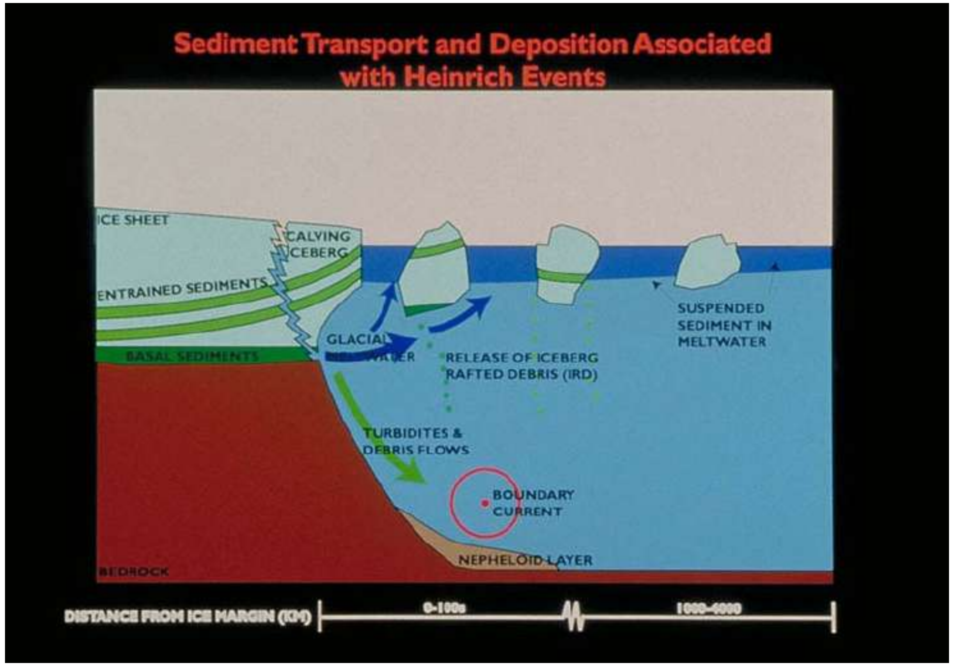
TraCE-21ka: Simulation of Transient Climate Evolution over the last 21,000 years

Draft

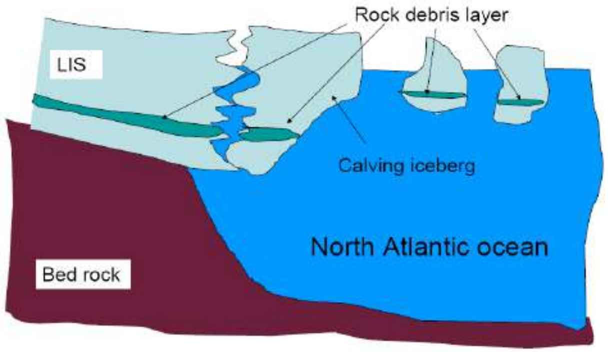
Project Description

The transient climate evolution of the last 21,000 years (Last Glacial Maximum [LGM] to present) provides key observations for constraining climate sensitivity and understanding abrupt climate change. A synchronously coupled atmosphere-ocean general circulation model simulation of the last 21,000 years has been completed using the CCSM3. The transient simulation reproduces many major features of the deglacial climate evolution in Greenland, Antarctica, the tropical Pacific, and the Southern and Deep Oceans, thereby suggesting that CCSM3 exhibits reasonable climate sensistivity in those regions and is capable of simulating abrupt climate changes. The TraCE-21000 project provides the four-dimensional model datasets to allow investigation of the coupled atmosphere-ocean-sea ice-land surface mechanisms and feedbacks that explain the evolution of the climate system over the last 21,000 years. It is also a resource for the paleodata research community providing a global framework for the synthesis of their data. Further, together the data and model results allow an assessment of the model capabilities. (Click on illustration to start a movie of the transient evolution of surface temperature change simulated by CCSM3. illustration by the National Center for Atmospheric Research). More information on the setup of this simulation can be found below as well as in the **Ph.D dissertation of Dr. Feng He.** Monthly time series of the atmospheric model variables are available for download on the **Earth System Grid.**

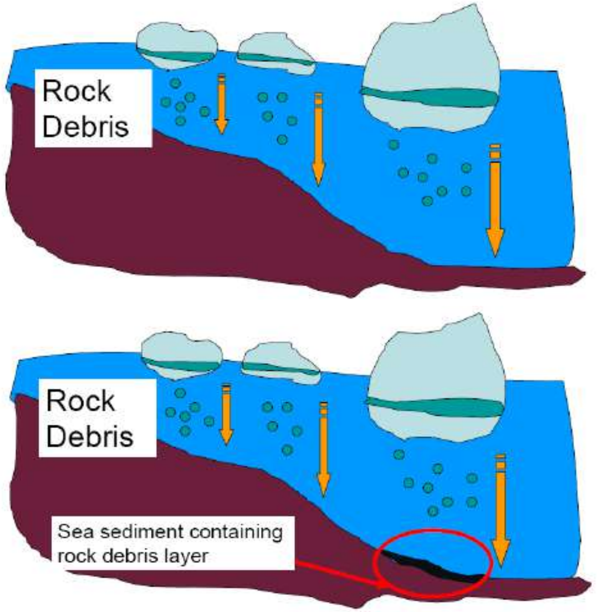
Fresh water inflow



Huge armadas of ice bergs were launched from Canada into the North Atlantic

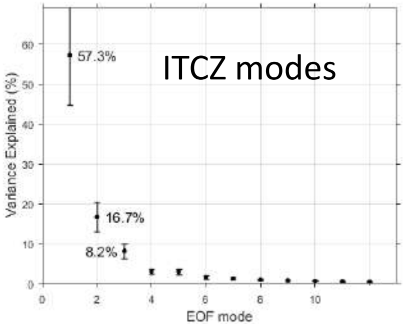


As they melted , they released rock debris that was dropped into the fine grained sediments on the ocean floor.

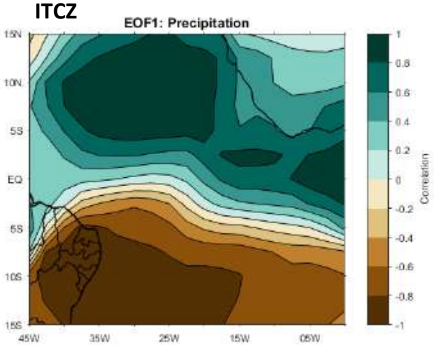


DJF

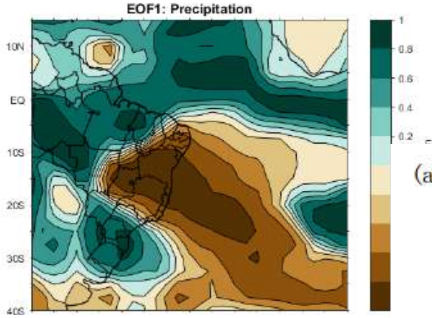
SAMS x ITCZ

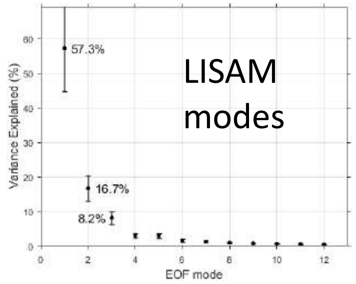


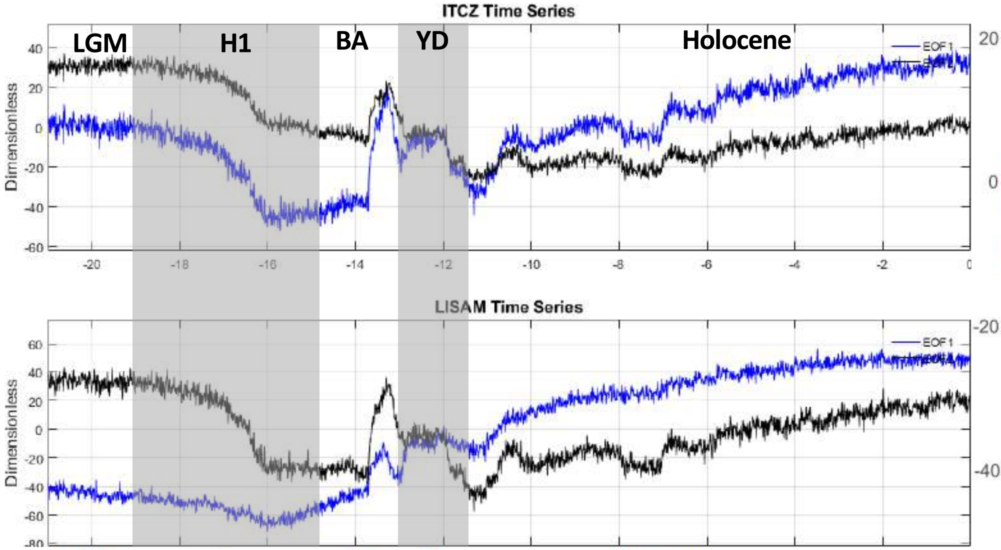
ITCZ

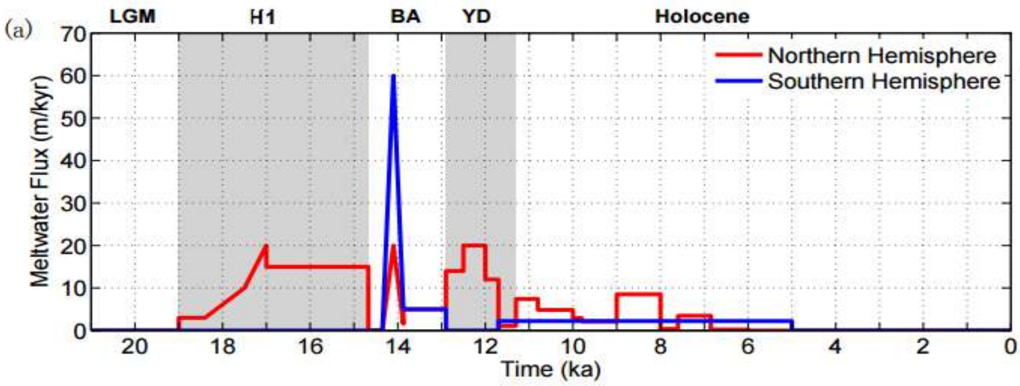


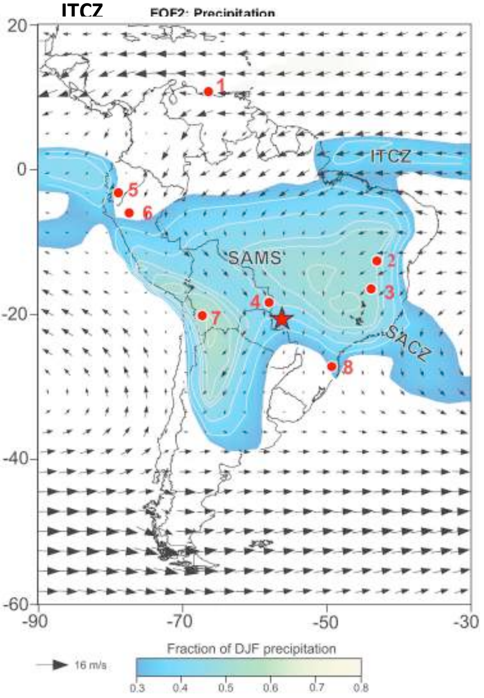
LISAM







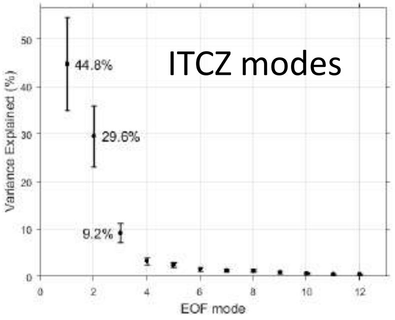




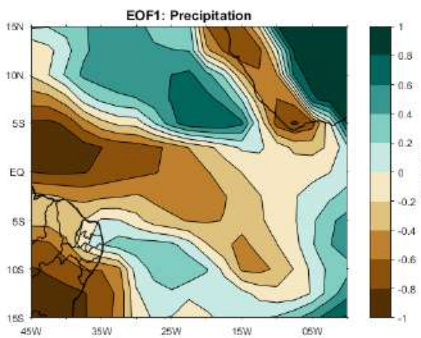
8 – Boruverá Cave (Cruz et al., 2005)

JJA

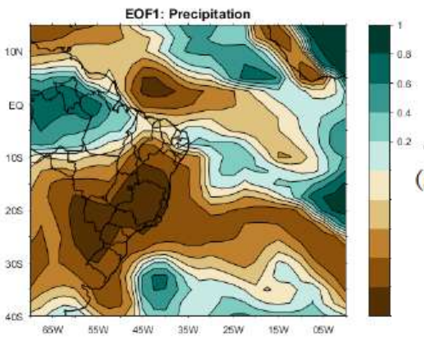
SAMS x ITCZ

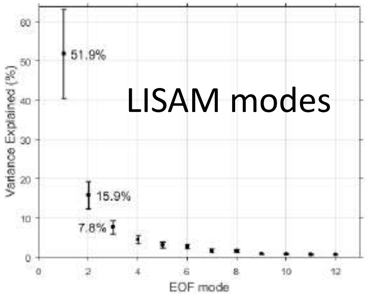


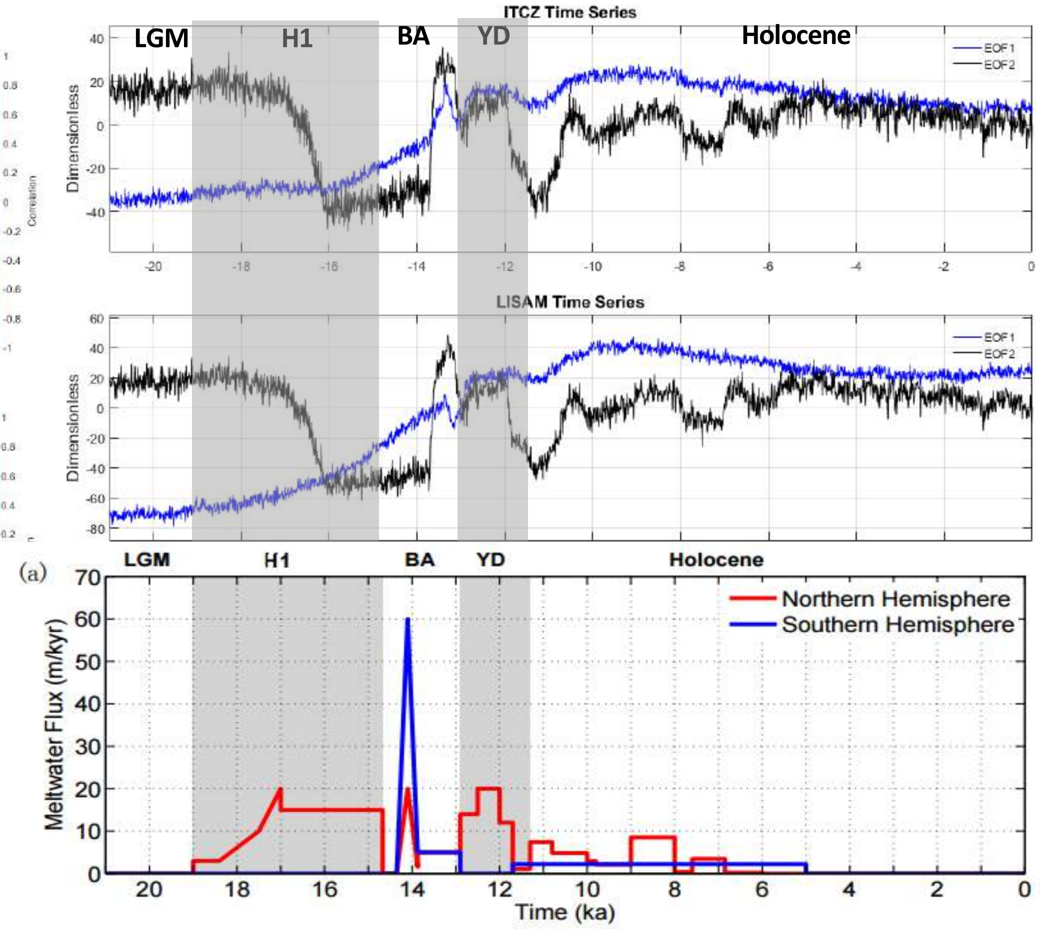
ITCZ



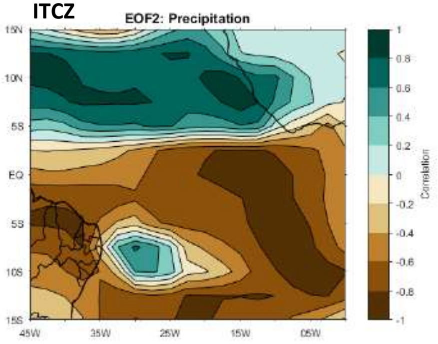
LISAM



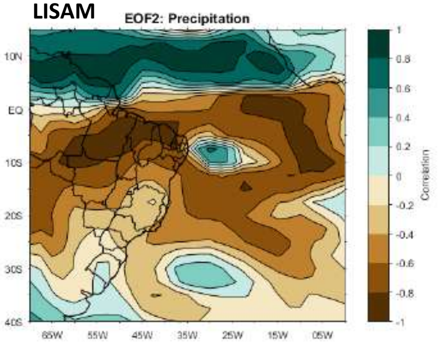


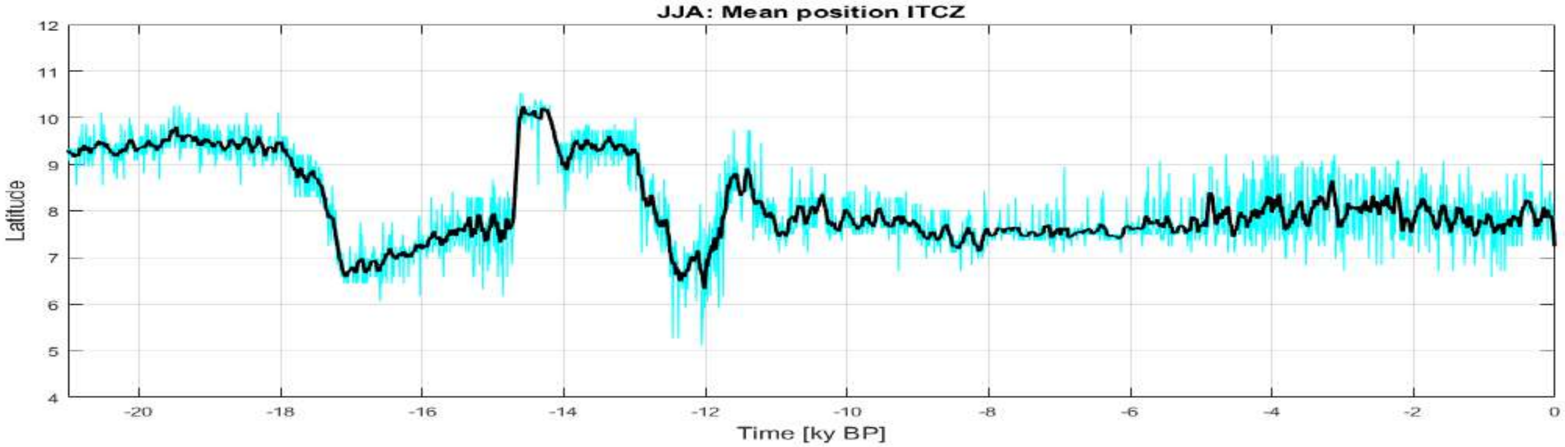


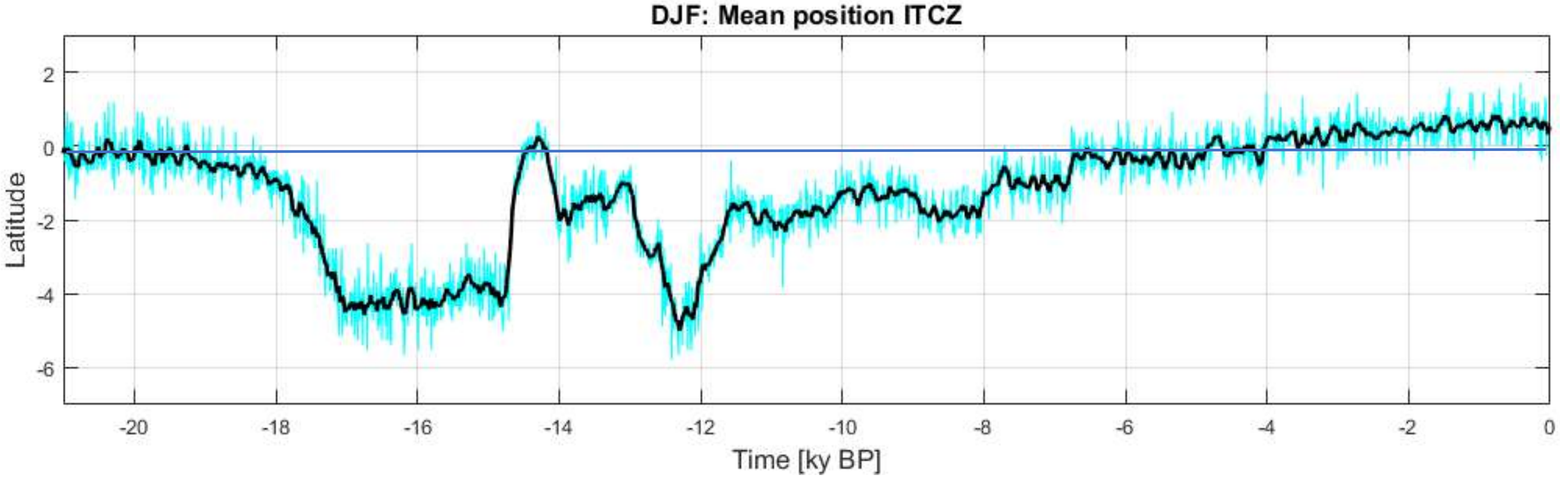
ITCZ



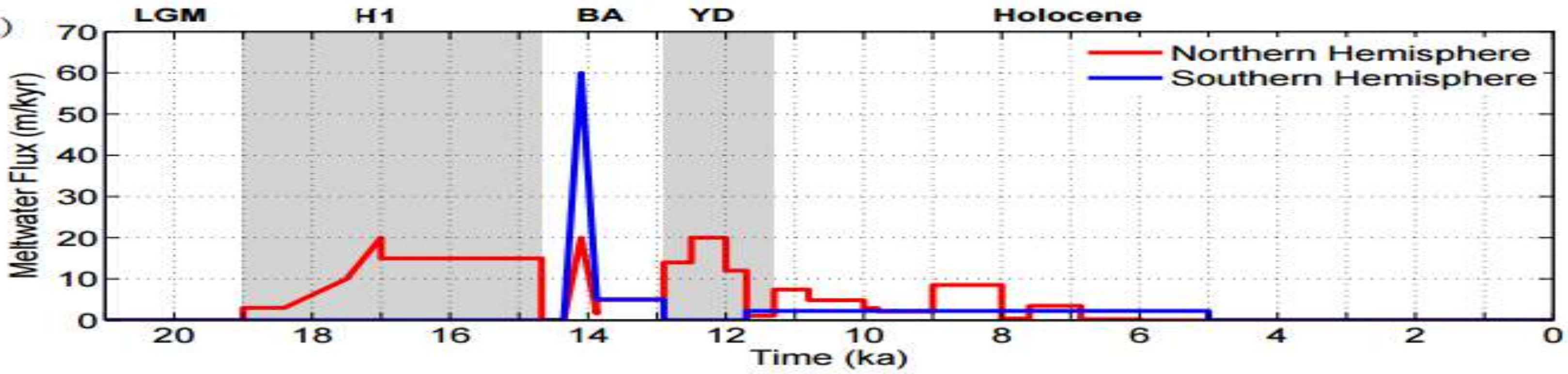
LISAM



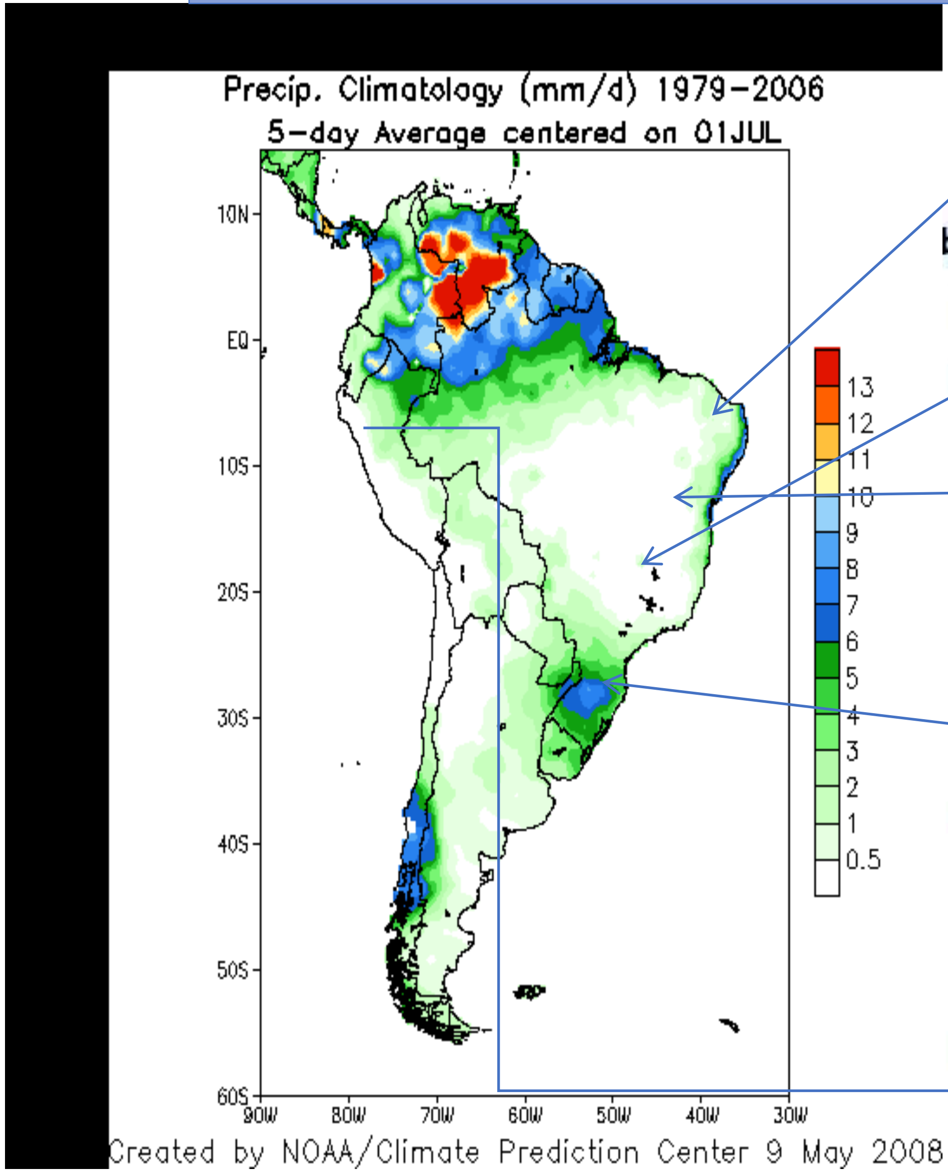

JJA: Mean position ITCZ
Latitude
12
11
10
9
8
7
6
5
4
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
Time [ky BP]

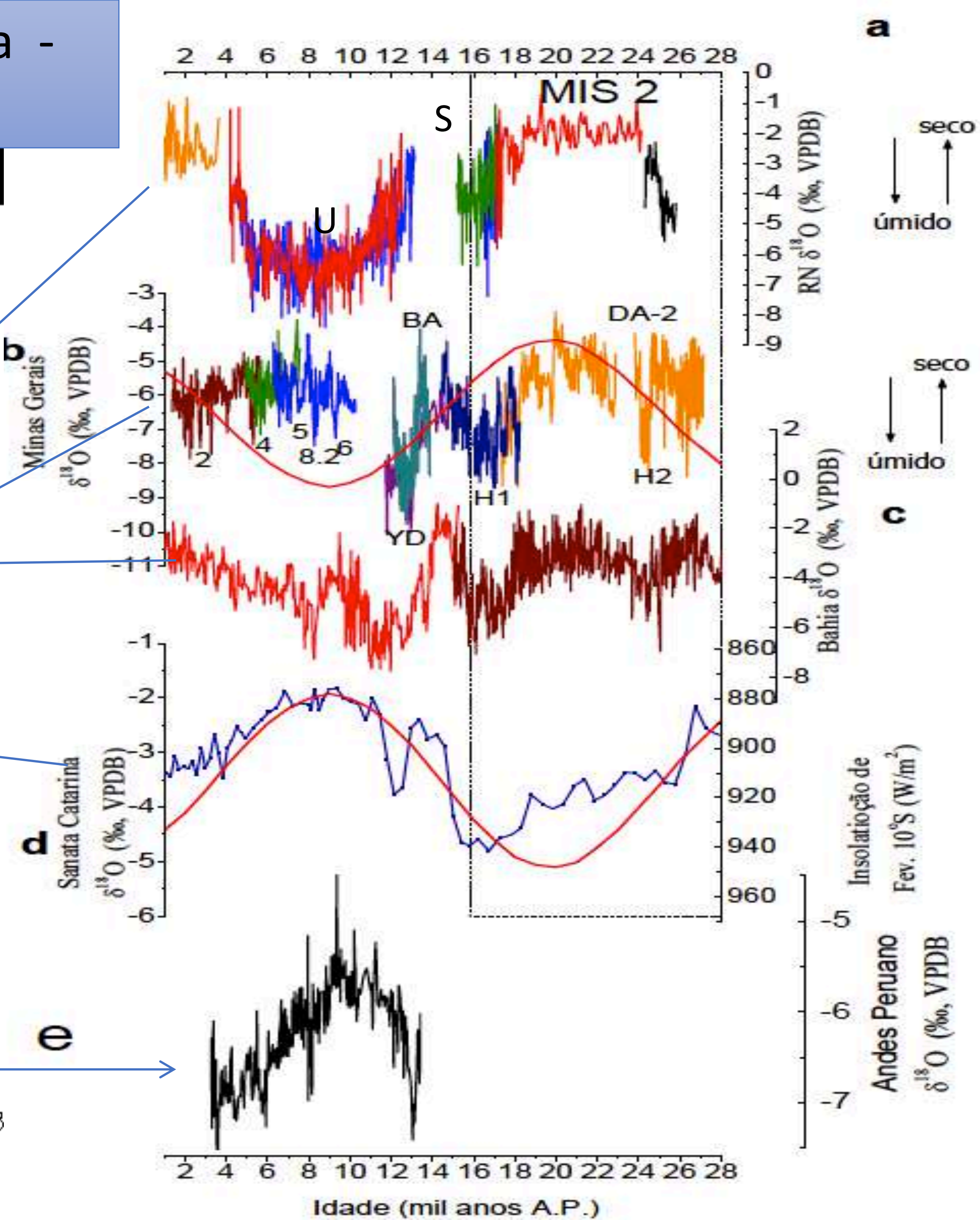

DJF: Mean position ITCZ
Latitude
2
0
-2
-4
-6
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
Time [ky BP]

(a)


LGM
H1
BA
YD
Holocene
Northern Hemisphere
Southern Hemisphere
Meltwater Flux (m/kyr)
70
60
50
40
30
20
10
0
20
18
16
14
12
10
8
6
4
2
0
Time (ka)

Speleothems in S. America - caves -





NE – Seco antes do YD passando para úmido depois

Cruz et al. 2009

Preliminary Conclusions based on Proxies

- The South America Speleothem Principal Components are representative of the SACZ displacement and intensity.

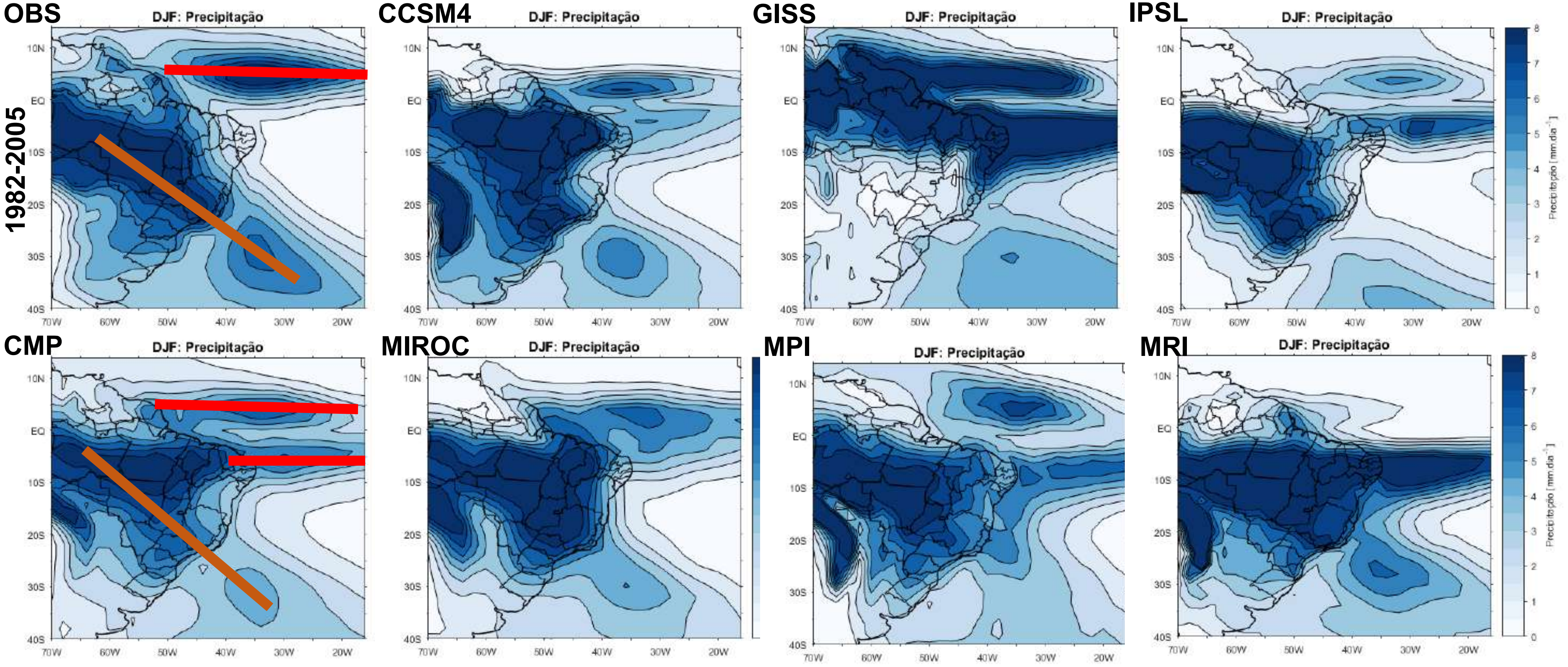
- In the last millennium the SACZ systematically migrates southward from the MCA to the 2nd half of the transition periods, migrating northward afterwards.

- However the most intense or enhanced SACZ occurred during the LIA, and the weaker SACZ occurred during the MCA2 period, in relation to the CWP.

ITCZ in the CMIP models

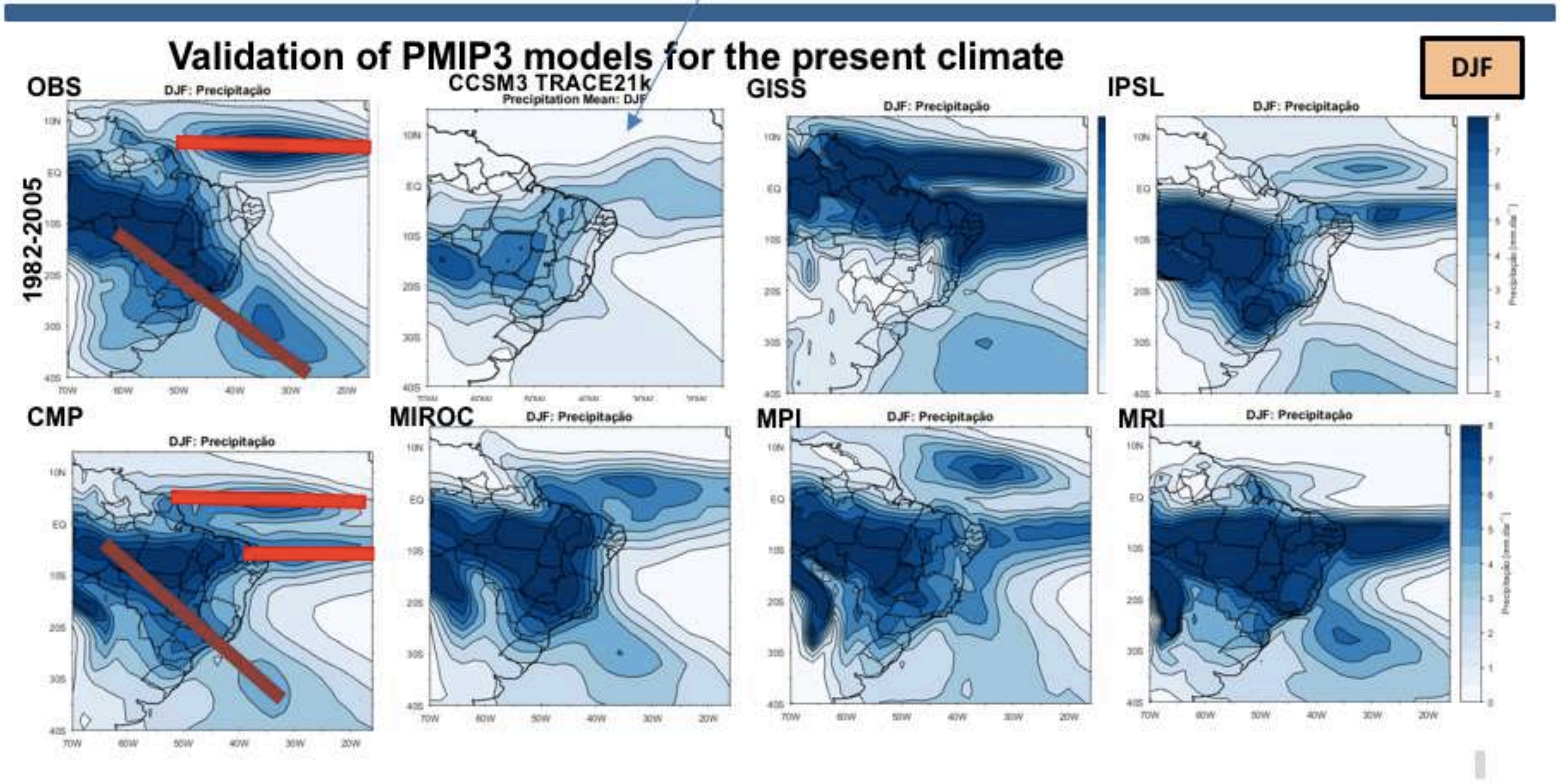
Validation of PMIP3 models for the present climate

DJF



Custodio, Jorgetti, Silva Dias and Wainer – in preparation

Last 1k



Validation of PMIP3 models for the present climate

Custodio, Jorgetti, Silva Dias and Wainer – in preparation

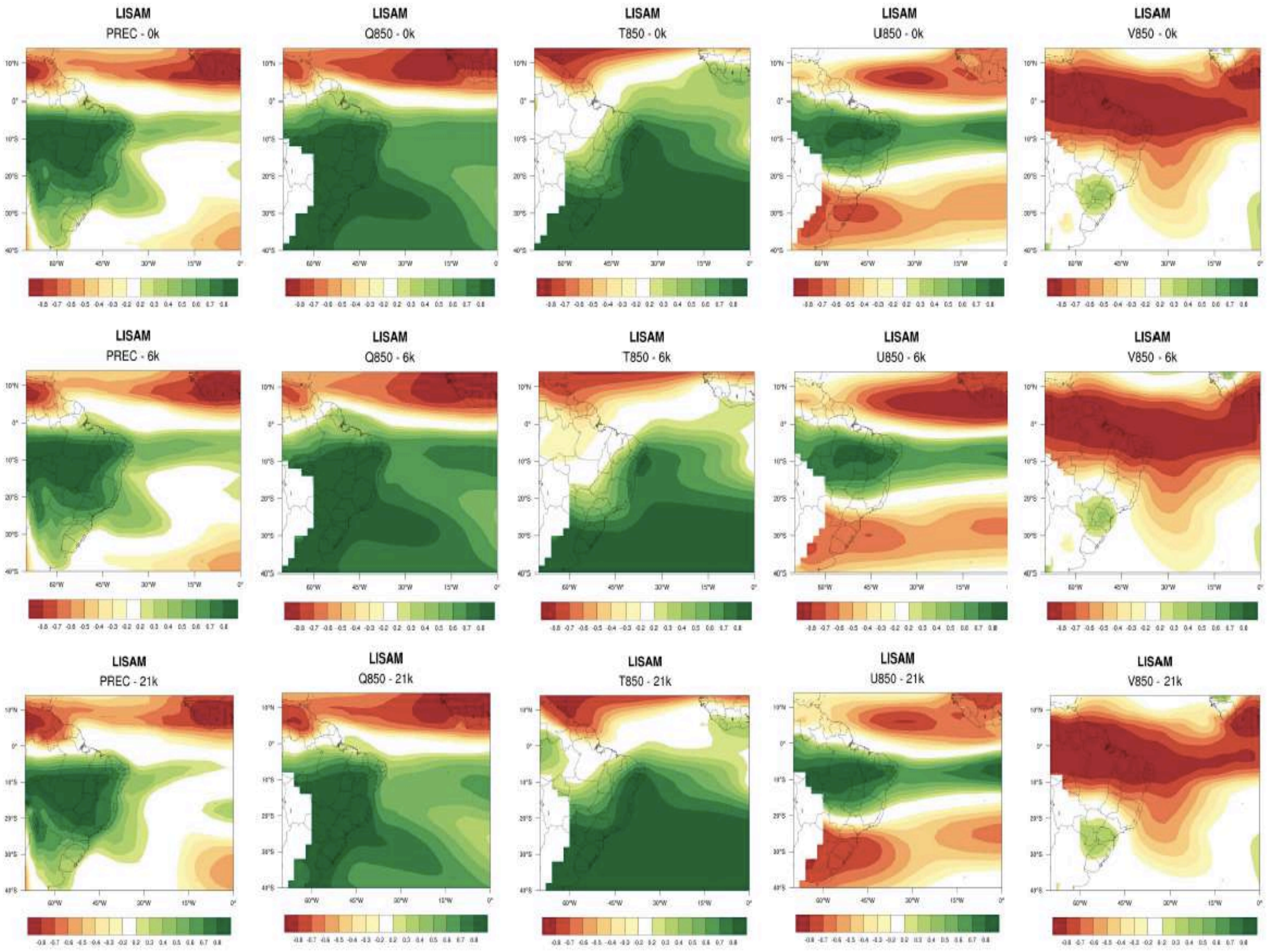
LISAM for the LGM - PMIP3

Changes in the S.A. Monsoon structure – LISAM – 1st mode

Present

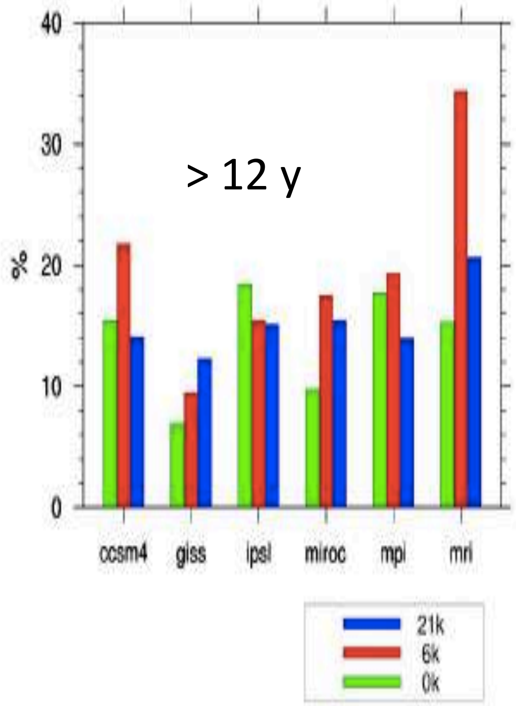
6k

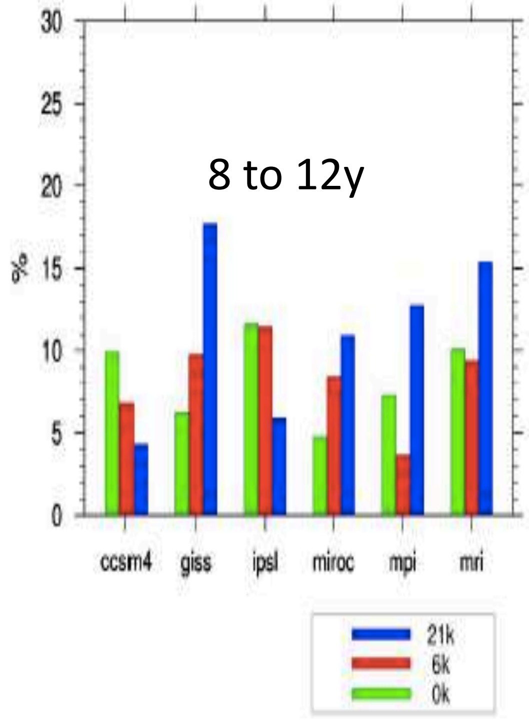
21k

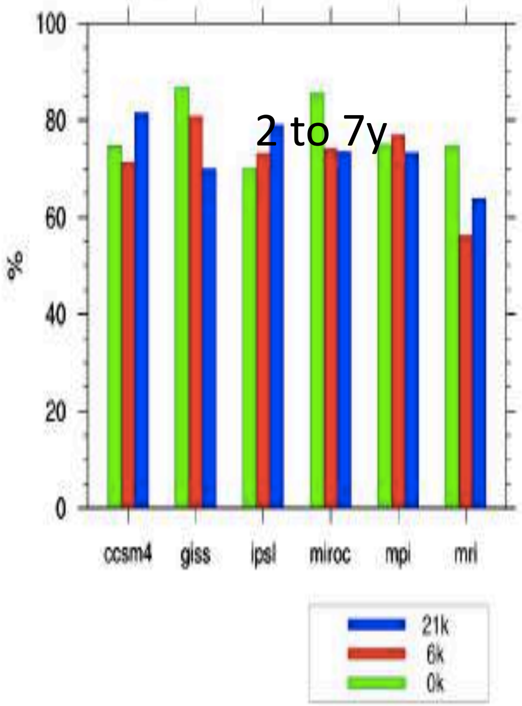


Jorgetti,et al. – paper in preparation

Variance Percentage in the interanual (2-7 years), decadal (8-12 years) and multidecadal (> 12 years) for the CCM4, GISS, IPSL, MIROC, MPI and MRI models (PMIP3) SAMS - 1st EOF





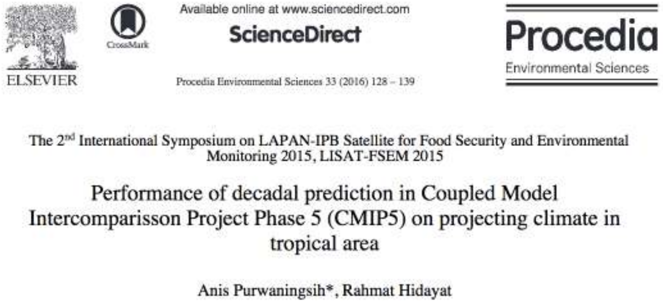


LISAM %

	0k	6k	21k
CCSM4	44,1	44,8	47,1
GISS	43,1	39,5	41,7
IPSL	45,6	44,1	43,6
MIROC	49,9	48,2	51,4
MPI	46,2	45,9	46,3
MRI	43,6	43,4	44,7

Jorgetti, Custodio, Silva Dias and Carvalho, 2018 – in preparation

Models have a southward bias of the ITCZ in the current climate or more intense



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Procedia Environmental Sciences 33 (2016) 128 – 139

Procedia Environmental Sciences

The 2nd International Symposium on LAPAN-IPB Satellite for Food Security and Environmental Monitoring 2015, LISAT-FSEM 2015

Performance of decadal prediction in Coupled Model Intercomparisson Project Phase 5 (CMIP5) on projecting climate in tropical area

Anis Purwaningsih*, Rahmat Hidayat

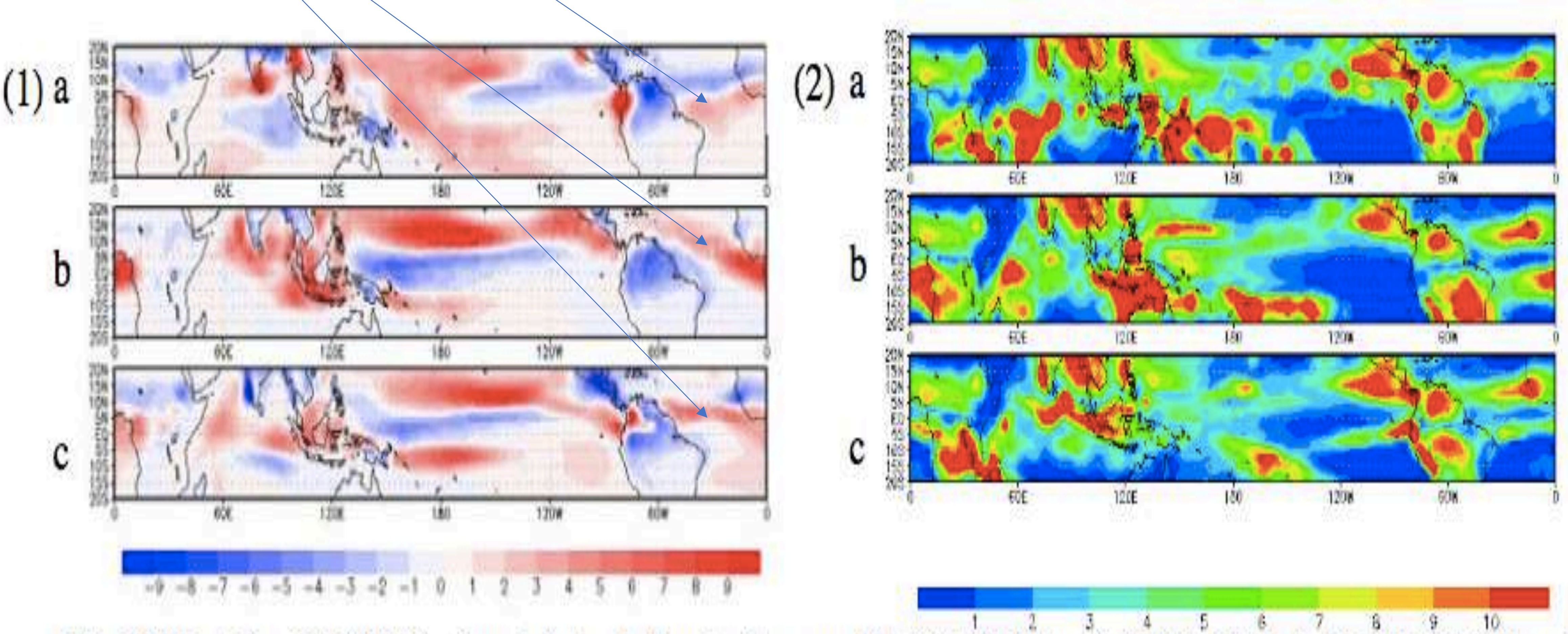


Fig. 12. Bias (1) and RMSE (2) of precipitation in Tropical Area on JJA 1981-2010 from (a) BCC_CSM1.1, (b) MPI-ESM-LR and (c) IPSL-CM5A-LR

Clim Dyn (2015) 45:1169–1180
DOI 10.1007/s00382-014-2366-3

The Atlantic ITCZ bias in CMIP5 models

Angela Cheska Siongco · Cathy Hohenegger ·
Bjorn Stevens

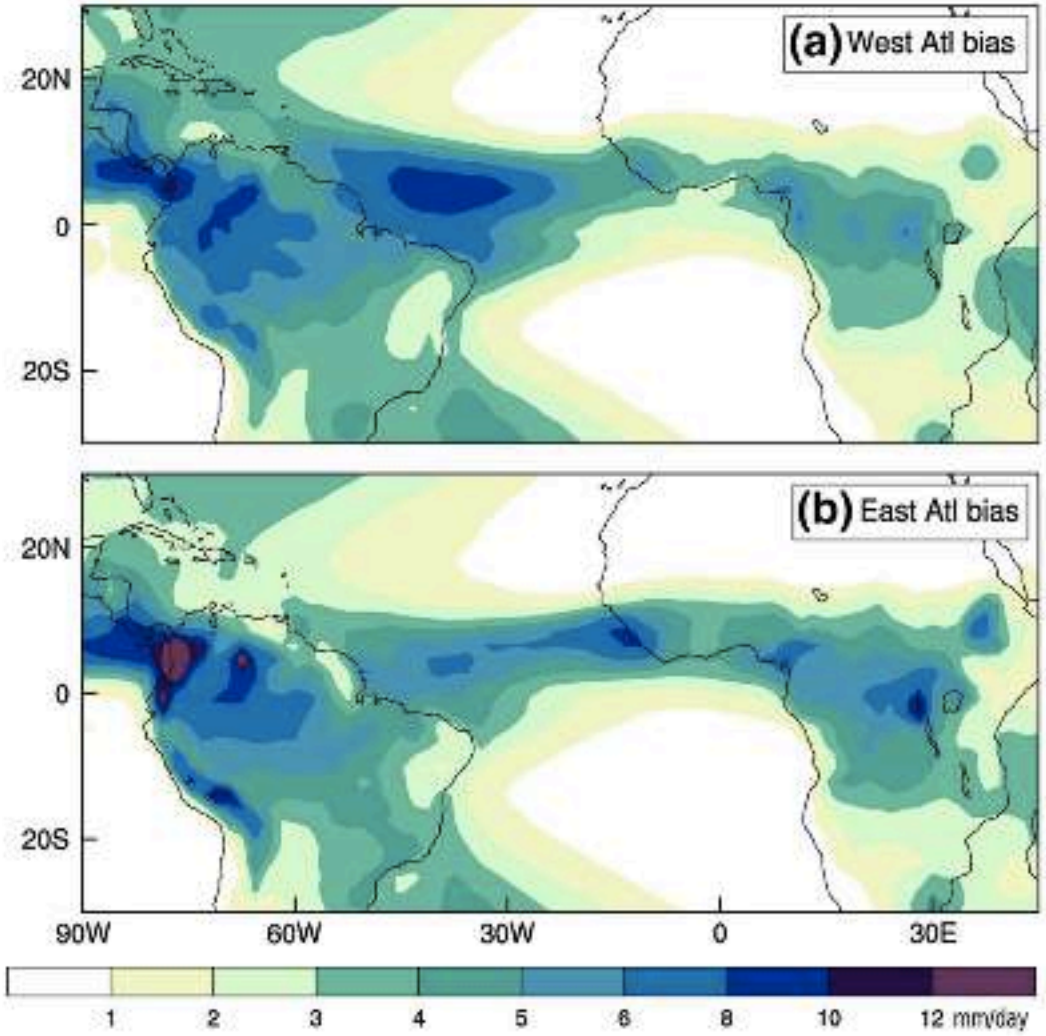
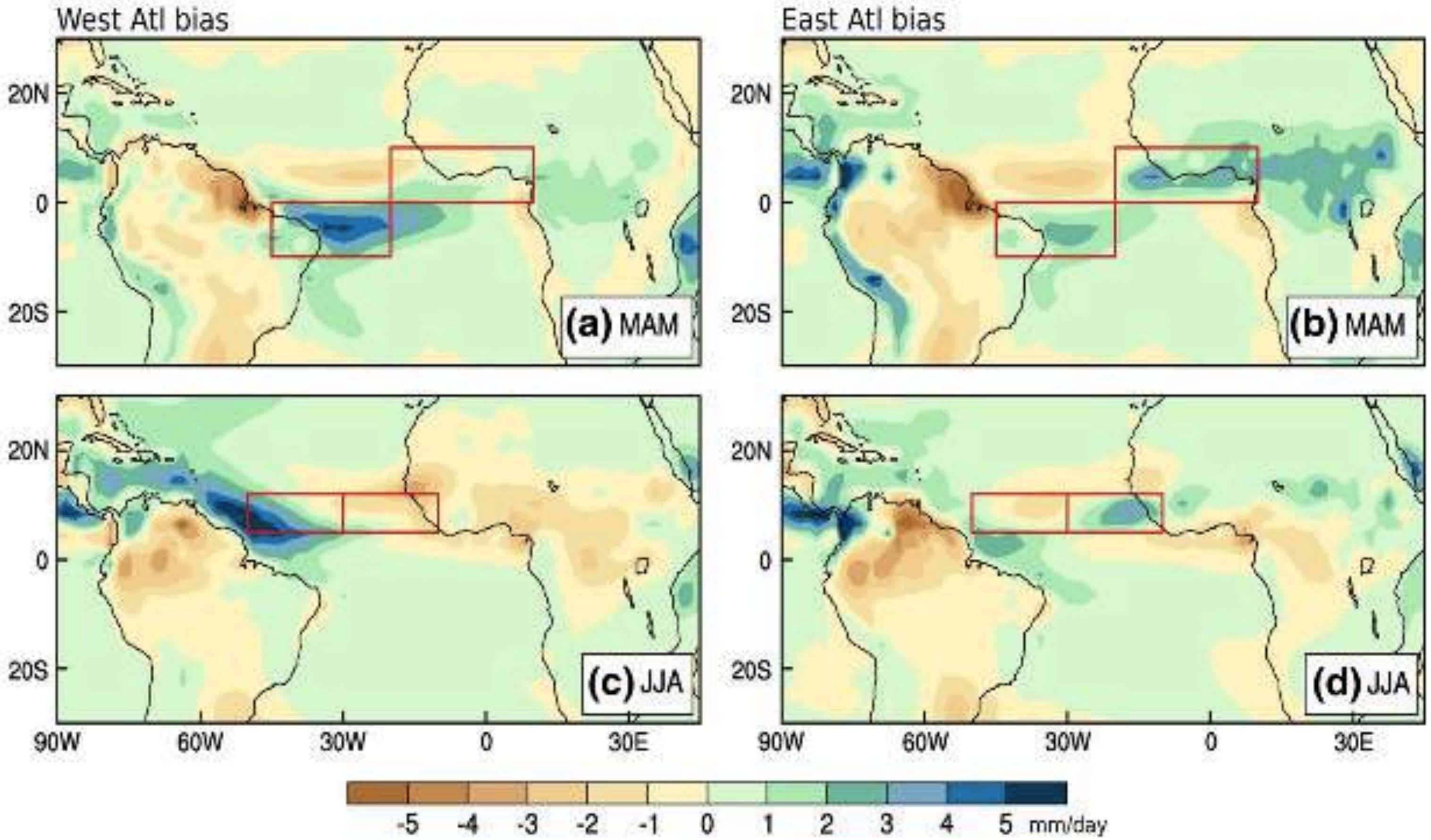


Fig. 4 Mean state of precipitation over the tropical Atlantic for models with **a** West Atlantic bias and **b** East Atlantic bias

Fig. 6 Precipitation anomaly (model minus GPCP observation) in MAM (**a**, **b**) and JJA (**c**, **d**) for models with the West Atlantic bias (**a**, **c**) and with the East Atlantic bias (**b**, **d**). *Red boxes* are used for the conceptual diagram in Fig. 9



CMIP models have a a southward bias of the ITCZ

Clim. Past, 12, 1681–1691, 2016
www.clim-past.net/12/1681/2016/
doi:10.5194/cp-12-1681-2016

Climate of the Past
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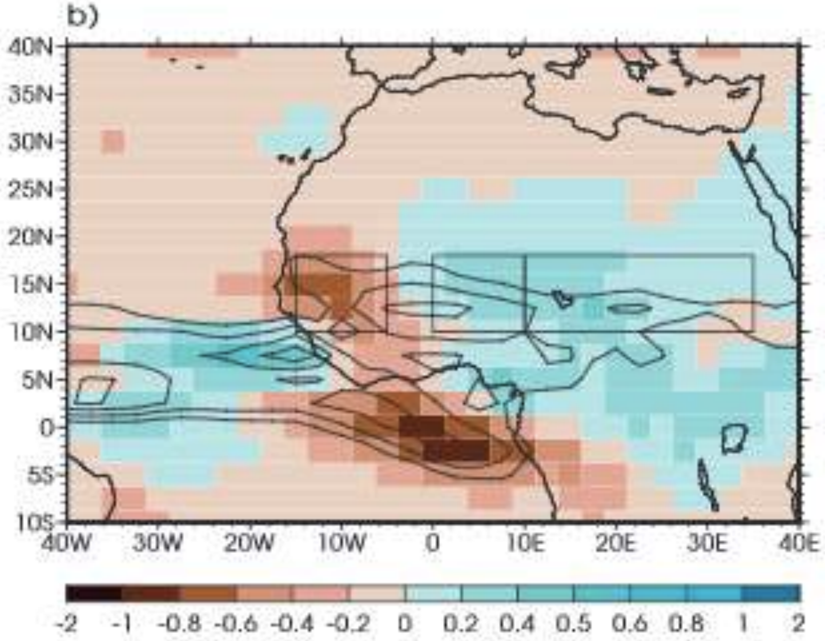
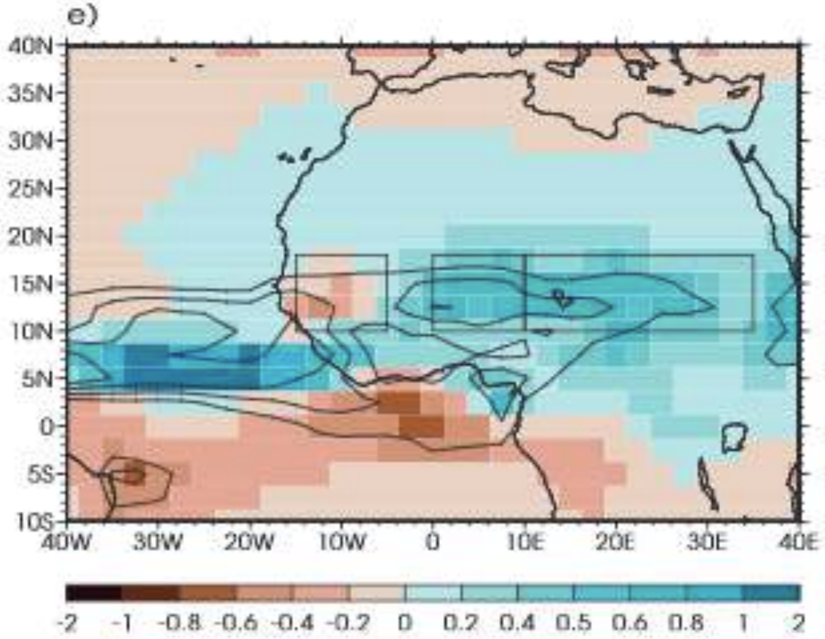
The South American monsoon variability over the last millennium in climate models

Maisa Rojas[1,2], Paola A. Arias[1,3], Valentina Flores-Aqueveque[2], Anji Seth[4], and Mathias Vuille[5]

[1]Department of Geophysics, University of Chile, Santiago, Chile
[2]Millennium Nucleus PaleoClimate, Santiago, Chile
[3]Grupo de Ingeniería Gestión Ambiental (GIGA), Escuela Ambiental, Facultad de Ingeniería,
Universidad de Antioquia, Medellín, Colombia
[4]Department of Geography, University of Connecticut, Storrs, CT, USA
[5]Department of Atmospheric and Environmental Sciences, University at Albany, State University of New York,
Albany, NY, USA





The Present and Future of the West African Monsoon: A Process-Oriented Assessment of CMIP5 Simulations along the AMMA Transect

ROMAIN ROEHRIG, DOMINIQUE BOUNIOL, AND FRANCOISE GUICHARD
CNRM-GAME, Toulouse, France

FRÉDÉRIC HOURDIN
LMD, IPSL, Paris, France

JEAN-LUC REDELSPERGER
LPO, Brest, France

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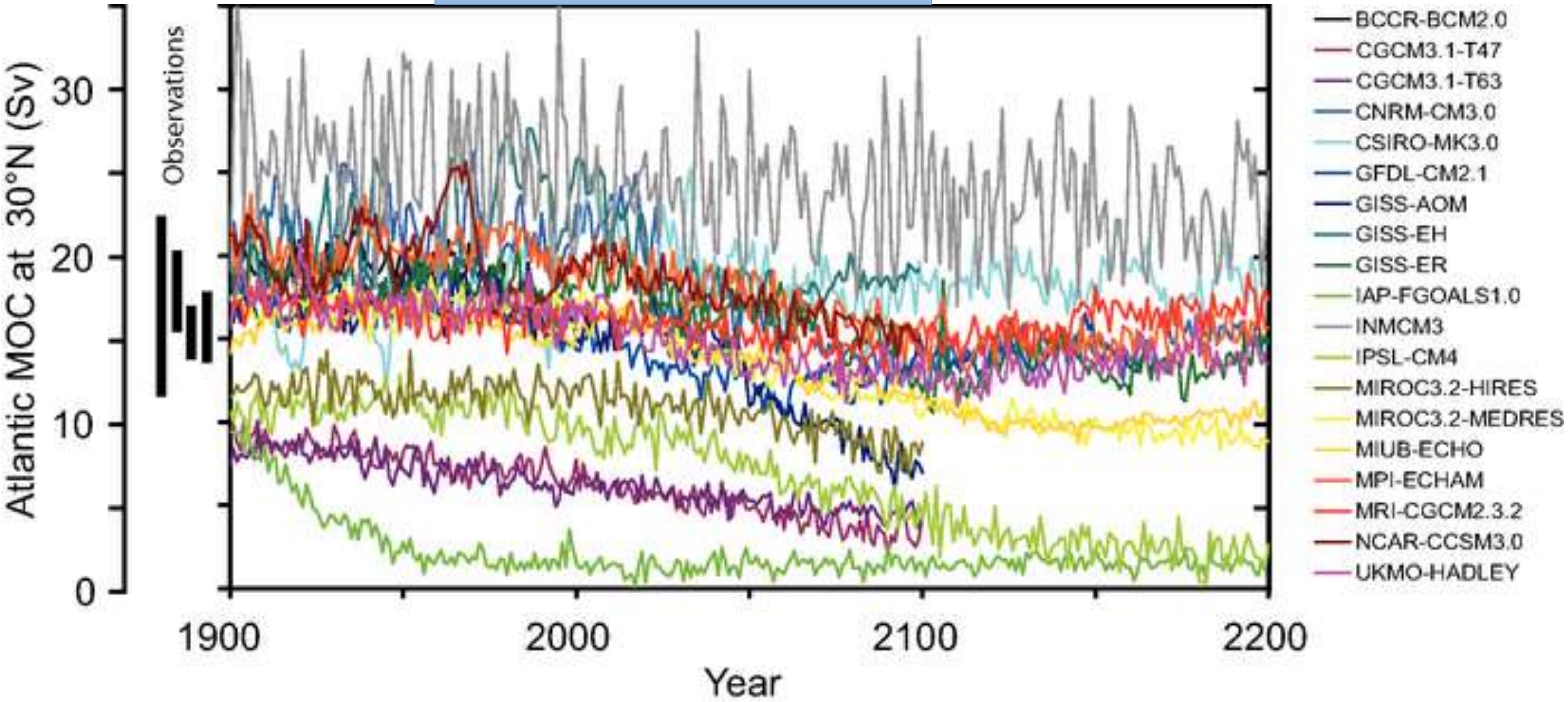
difference between the periods 2071–2100 and 1971–2000 for the JAS season for the CMIP3

contour every 0.3 mm day^{-1}, beginning at 1.0 mm day^{-1}

Future climate -> northward shift of the Atlantic ITCZ

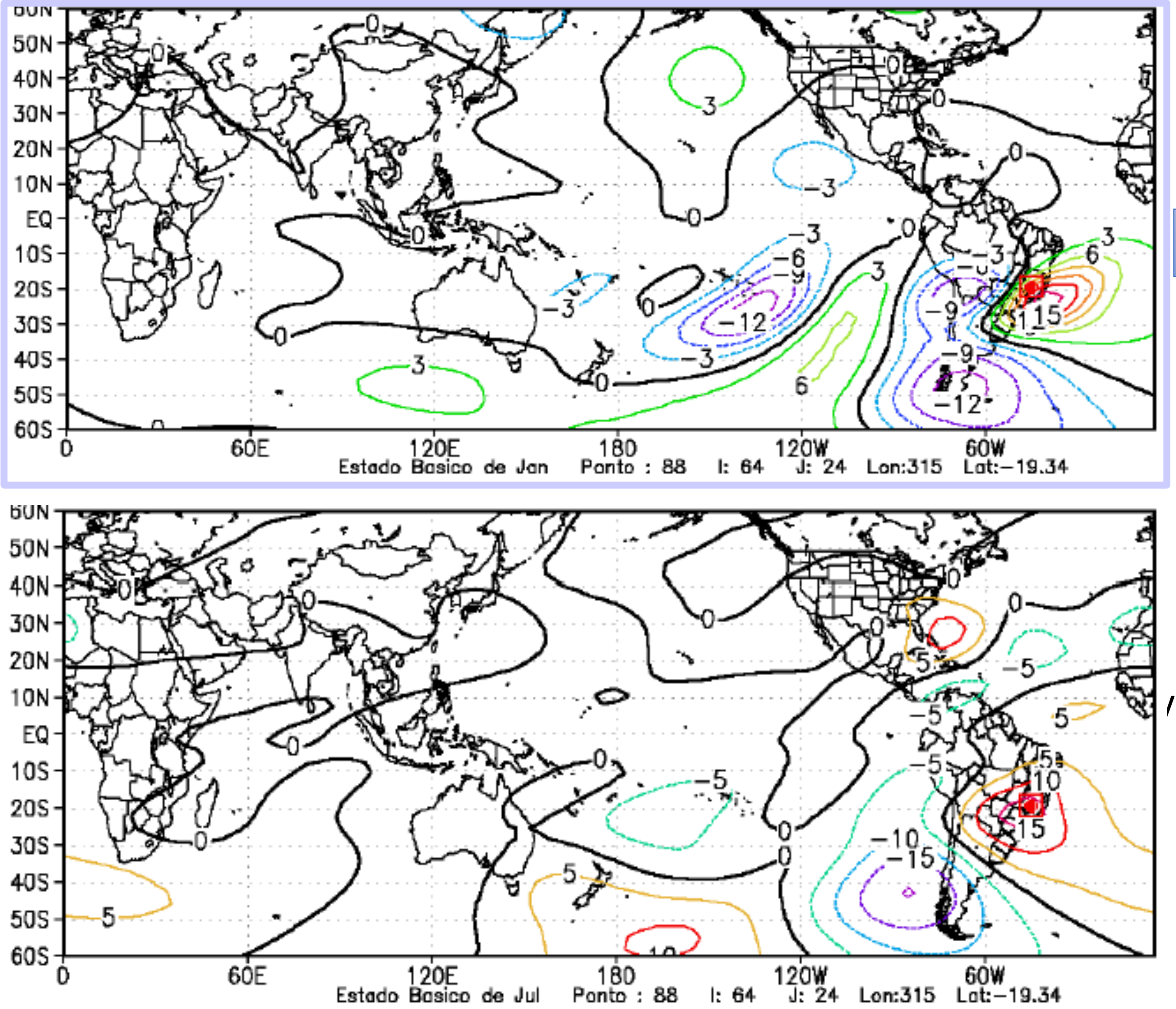
IPCC – 2007 AMOC intensity



A decrease of AMOC intensity might, at first sight, to be be interpreted as a tendency for a southward shift of the ITCZ - but this is not observed (on the contrary)

Global warming tends to heat more the northern hemisphere => NH has to get rid of the excessive heating transferring more energy to the SH!!! One way is to intensify the ITCZ and keep it in a northernmost position!!!

However, the Pacific Ocean ITCZ and SPCZ also influence the SAMS.



JANUARY

JULY

Influence Function for a target point in SE Brazil - Grimm and Silva Dias (1995) – Aravequia (2004)

Conclusion

- Classical view of the ITCZ position: based on the continental distribution and associated temperature gradientes.

- Current view on the ITCZ positioning: energy balance -> SH> NH -> oceans (primarily Atlantic) exagerates on northward transport across equator.
  - Atmosphere sends back energy to the H -> ITCZ to the north of the equator!

- ITCZ variability – Paleoclimate scale: observations and TRACE21K - analysis of atmosphere/ocean transport -> role of AMOC and fresh water inflow at higher latitudes.

- CMIP - ITCZ bias => connected to ocean transport – Atlantic...
- Future climate: conflict between the fresh water inflow (melting polar caps) and atmospheric heating more intense in the HN => smaller change in the ITCZ position than expected due to AMOC slow down.

- Paleoclimate SAMS: significant changes since the last Glacial Period -> Holocene (8K) and last millenium significant changes : models tend to underestimate – AMOC problem...

Thanks

Pedro L. Silva Dias

pedro.dias@iag.usp.br

OUTLINE

1. Climate System: Basic principles
    a. Intertropical Convergence Zone (ITCZ) as a complex network (ocean/atmosphere)
    b. Variability induced by external forcing
    c. Internal Variability

2. Current Views of Controlling Processes on the Mean Position of the ITCZ;

4. Long Term Variability
    a. Last 20 k - Trace21k and Observations
    b. Last Milenia
    c. Future
5. Conclusions