The Abdus Salam International Centre for Theoretical Physics

Workshop on the Science of Climate Change: a focus on Central America and the Caribbean Islands

Climate Variability and Change: What can we predict and why.

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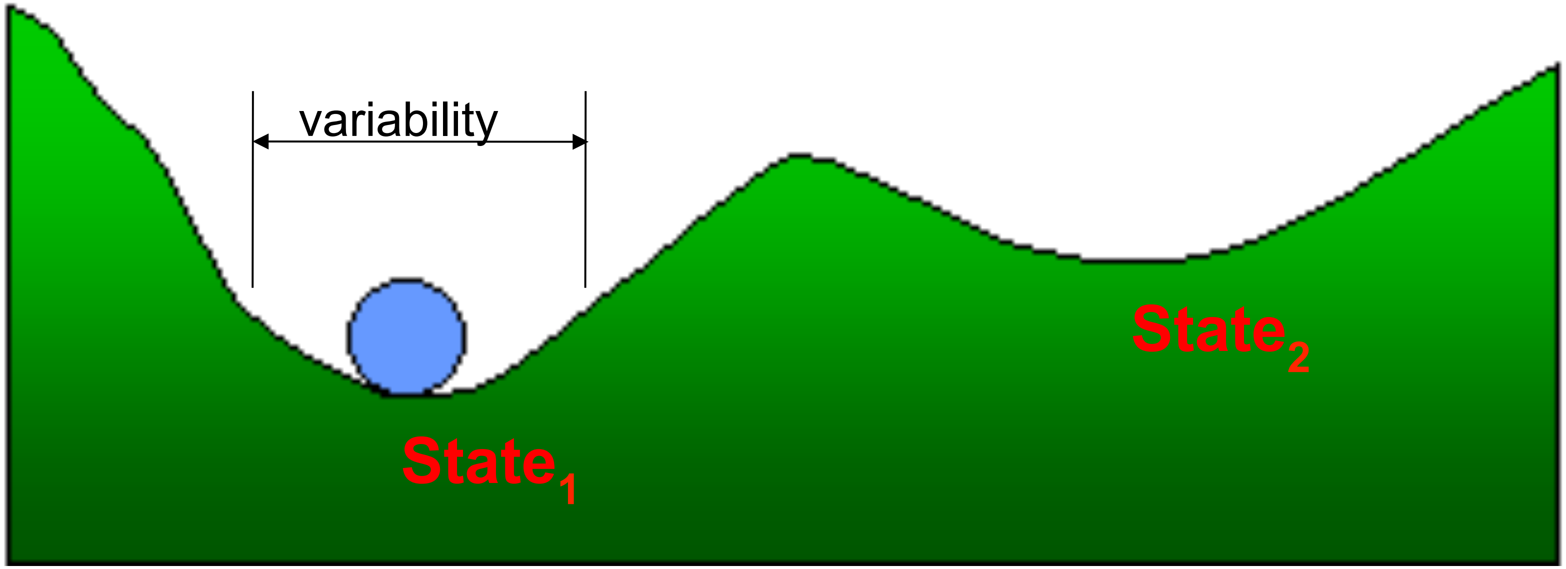
National Institute for Space Research – INPE
Brazil

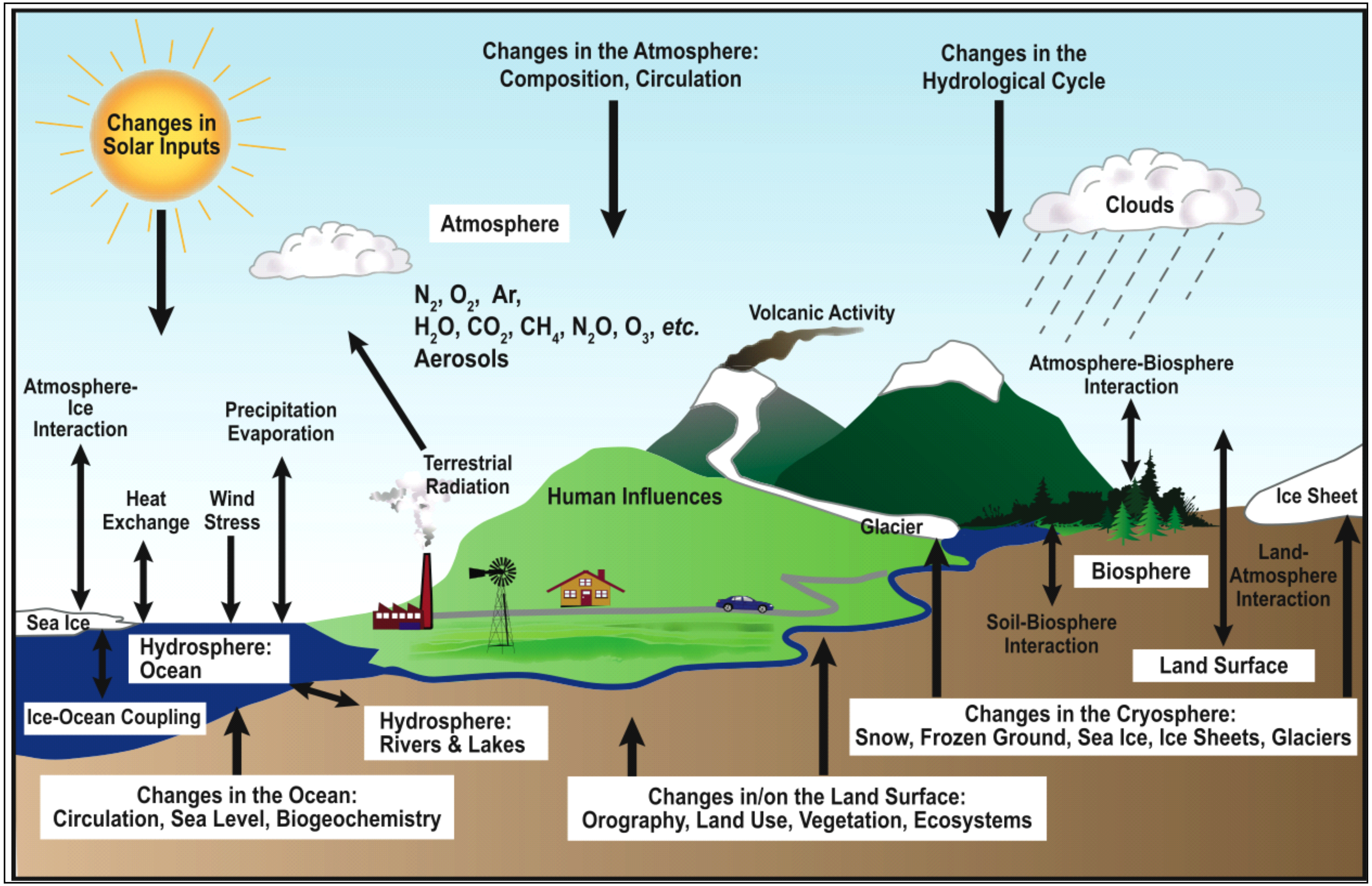
14 - 16 March 2017 Centro Cultural Tomas de Aquino
Universidad San Carlos, Antigua, Guatemala

Climate
Variability x Change



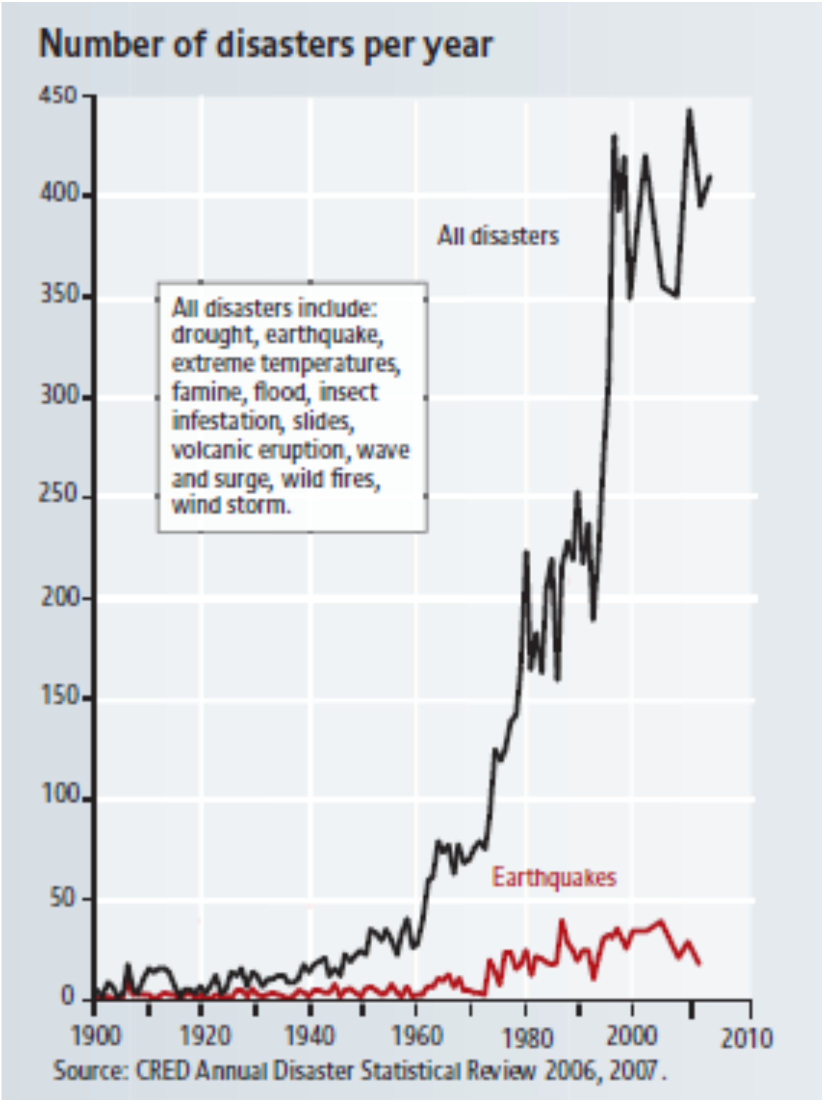
$T_1 < T_2$

The Global Climate System



Climate Variability and Change: What can we predict and why. Credit: IGBP

Climate Extremes and Trends

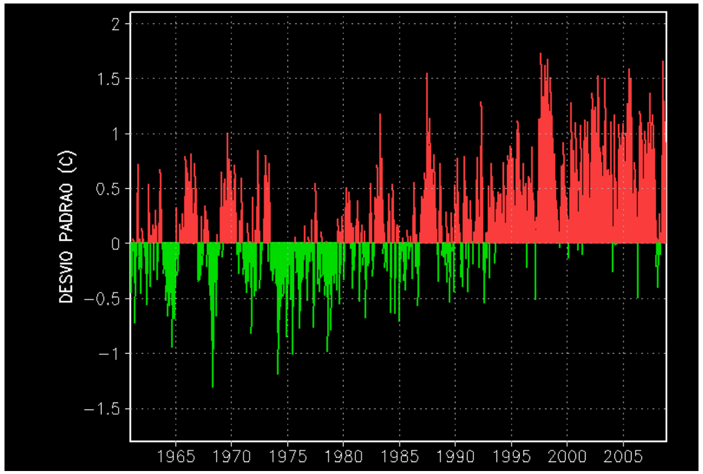


The Blue Carbon Report - UNEP

Hurricane Catarina (2004)

Hadley Centre, UK

Brazil temperature trend



Paulo Nobre (pers. Comm)

Climate Variability and Change: What can we predict and why.

2015: The Warm… ear on Rec…

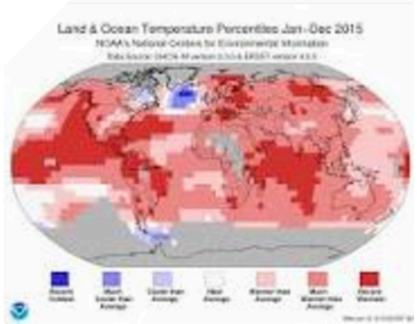
OLD NEWS

2015

Sixteen Warme…

Rank 1 = Warmest P… of Recor… 1880–…		Anomaly °C
1		0.90
2		0.74
3	…10	0.70
4	2013	0.66

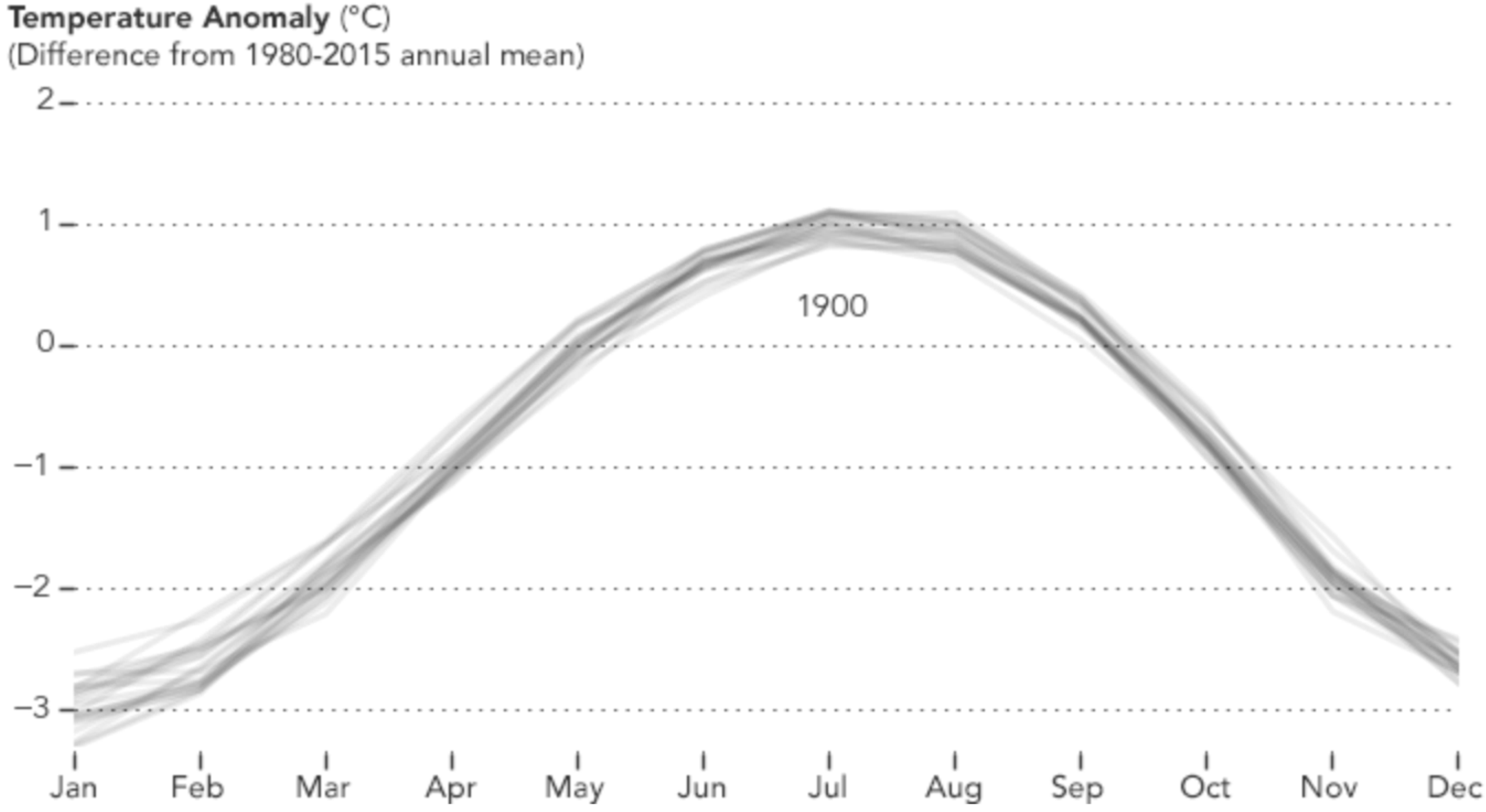
12 more rows, 1 more column



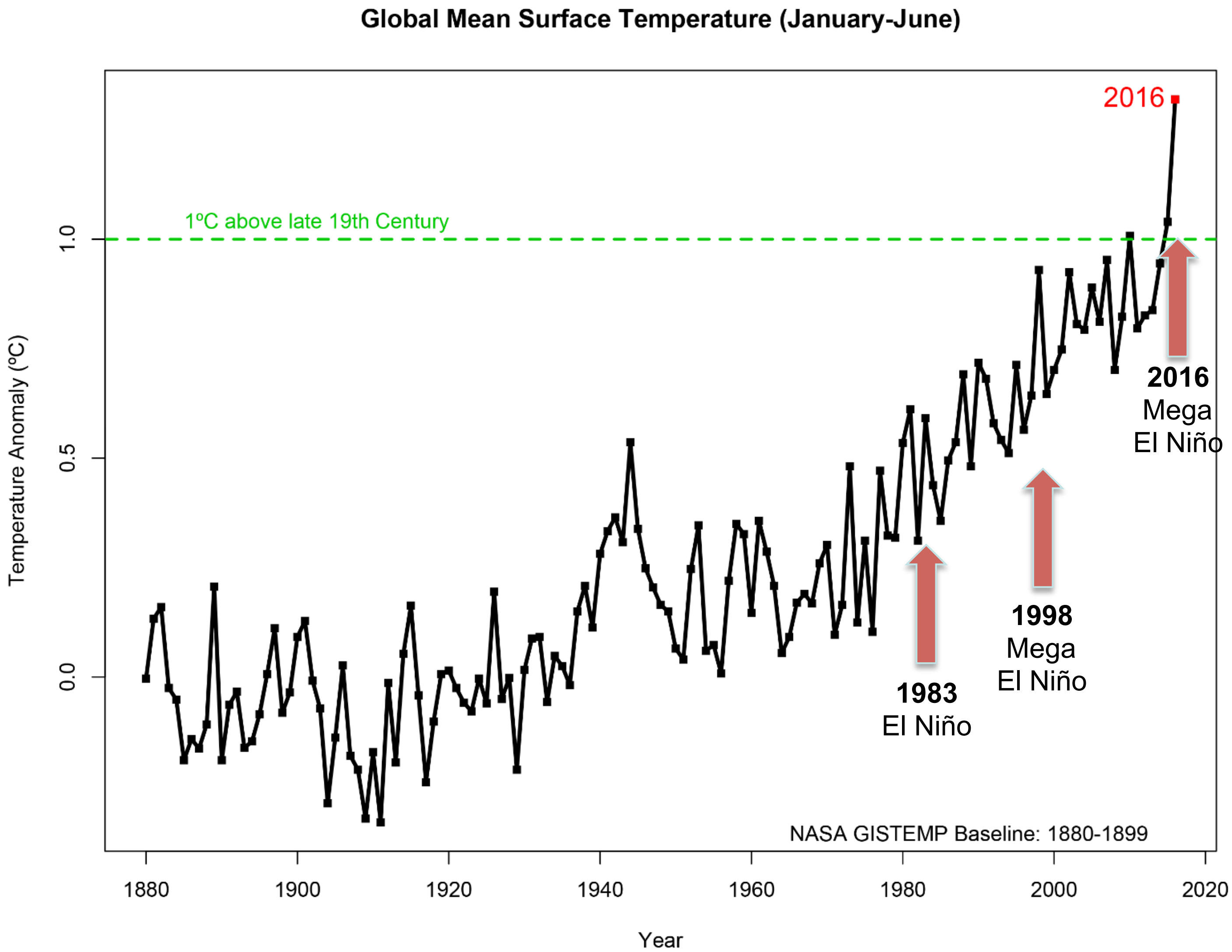
Global Analysis - Annual 2015 | National Centers for ...
https://www.ncdc.noaa.gov/sotc/global/201513

Climate Variability and Change: What can we predict and why.

Global Air Temperature



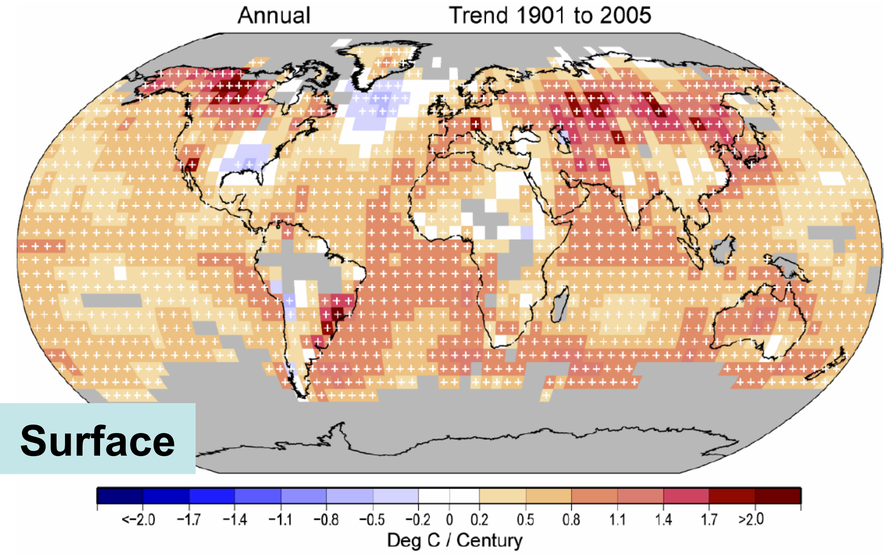
Credits: NASA/Goddard Institute for Space Studies

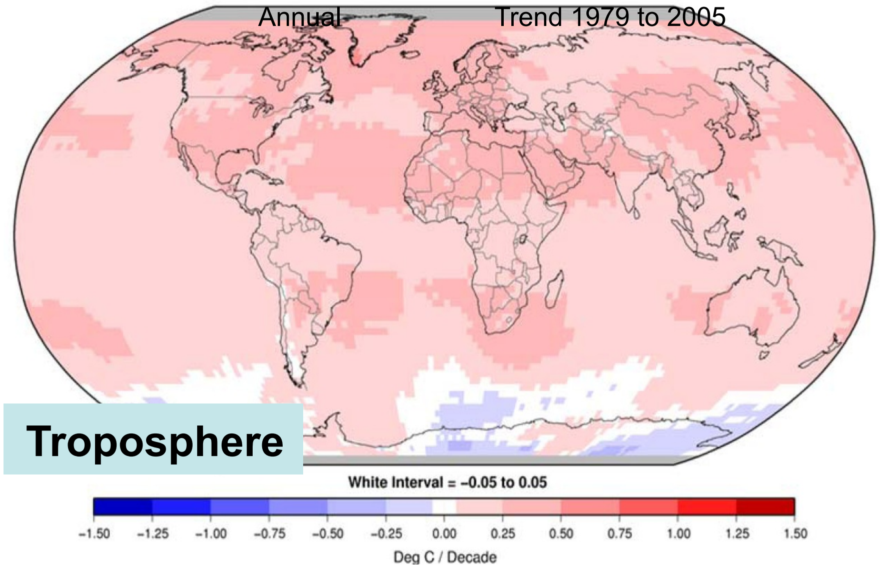


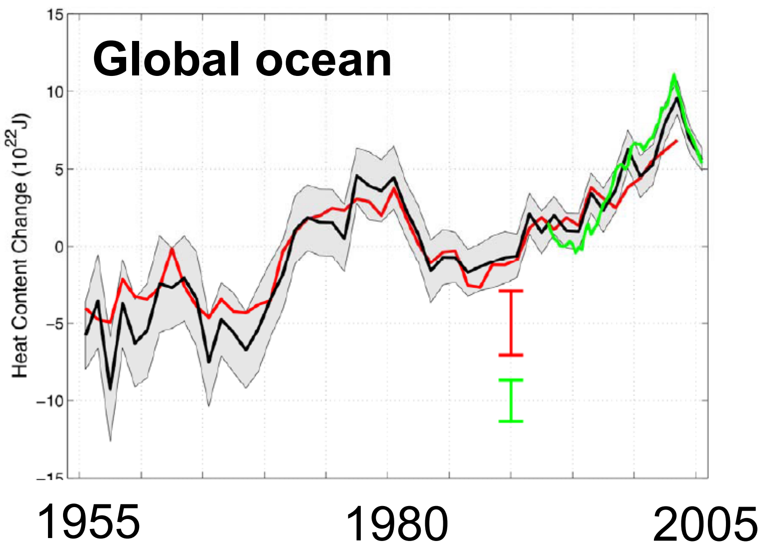
The first six months of 2016 were the warmest six-month period in NASA's modern temperature record, which dates to 1880. Credits: NASA/Goddard Institute for Space Studies

Climate Variability and Change: What can we predict and why.

Observed Global Warming







- Extremaly unlikely without an external forcing
- Very unlikely due to natural causes alone

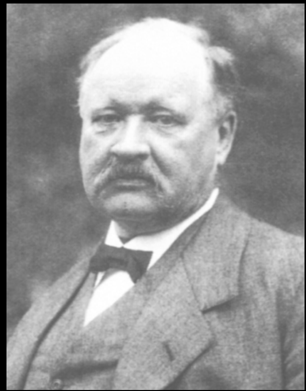
Pachauri (2007) – WG I Contribution to 4th IPCC Report

Fourier

The Grand Challenge of:
Predicting Climate Change

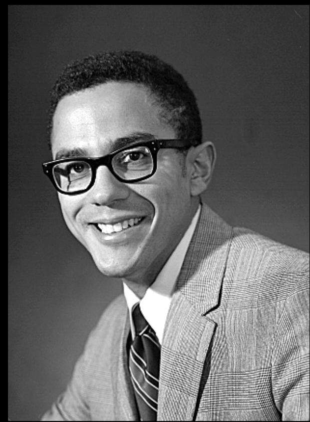
- Arrhenius quantifies in 1896 the changes in surface temperature (approx. 5 C) to be expected from a doubling in CO_2, based on the concept of ”glass bowl” effect introduced in 1824 by Joseph Fourier
- Norman Phillips develops the first global atmospheric GCM, and early climate models are being developed by many (Manabe, Mintz and Arakawa, Washington, etc.)

Arrhenius



Manabe

Arakawa



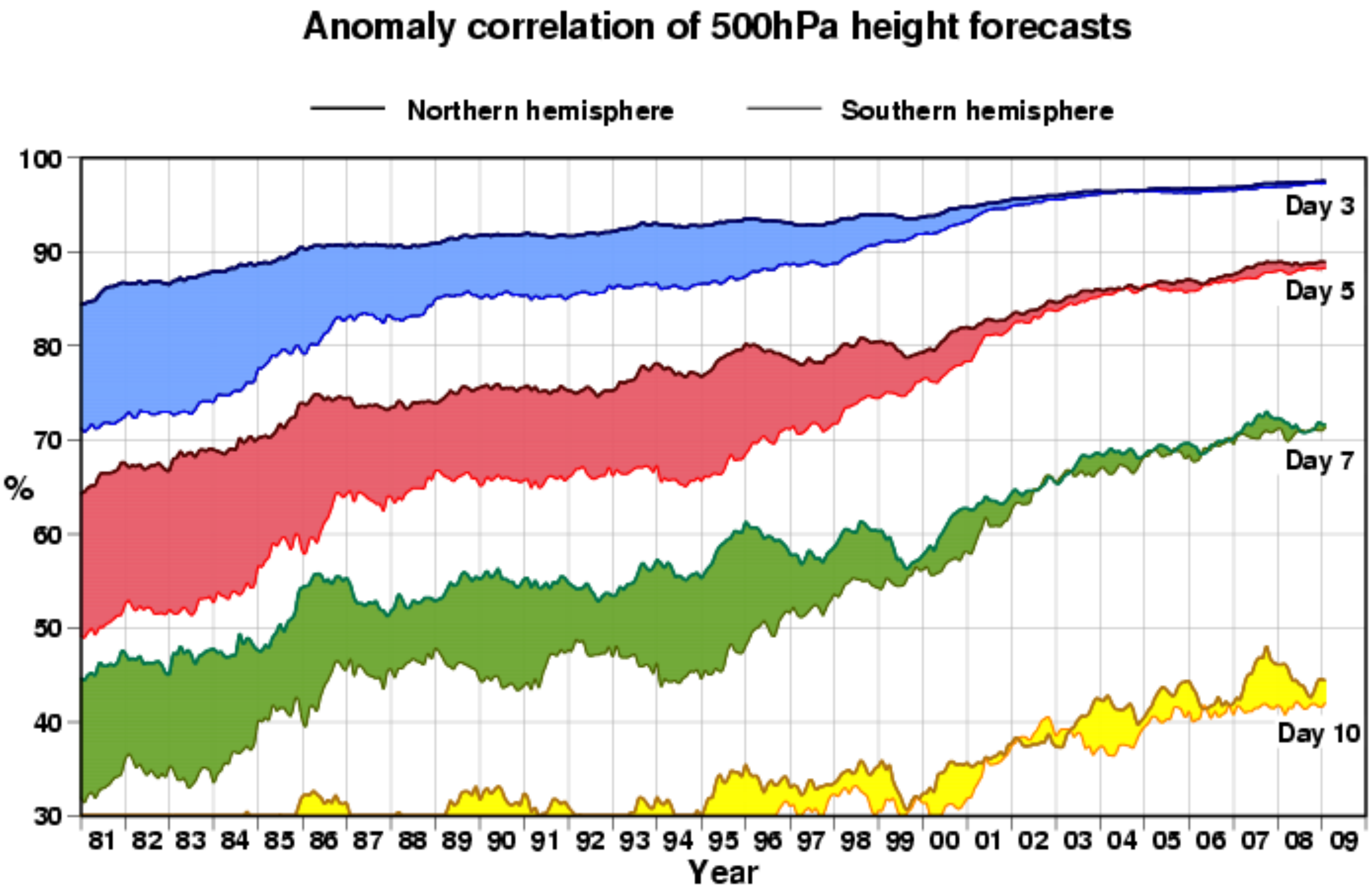
Washington

Courtesy: Prof. Guy Brasseur (2011)

The Climate Prediction Puzzle

- **Initial Condition**
  - Weather forecasting
  - Intra-seasonal prediction
- **Boundary Condition**
  - Seasonal prediction
  - Decadal to centennial prediction/scenarios
- **Internal Dynamics**
  - The whole of turbulence/chaos attractors
  - Representation of small scales processes.

Advances in Weather Forecasts

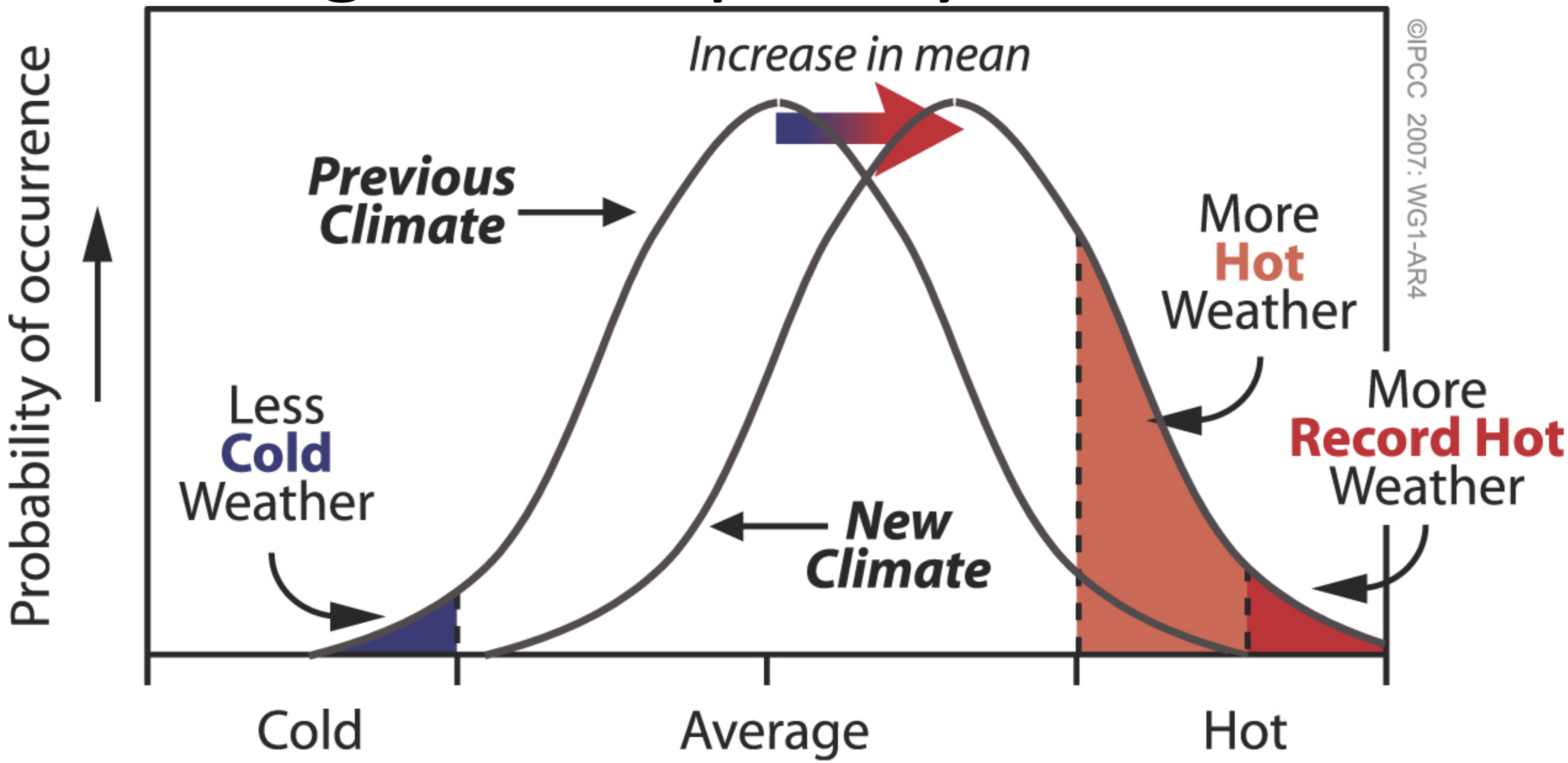


Climate Variability and Change: What can we predict and why.

Limits of predictability of a complex system

- Validity of parameterizations
– Degree of nonlinearity: $\overline{X'Y'} \neq 0$
- Seasonal cycle:
– $X(s,t) \sim \overline{X(s,t)} + X'(s,t)$
– Systematic errors:
- Degree of internal complexity:
– Individual clouds / solar radiation interactions
– Dynamical vegetation / forest fires…
– Oceanic eddies / river discharge

Change of Frequency of Extremes

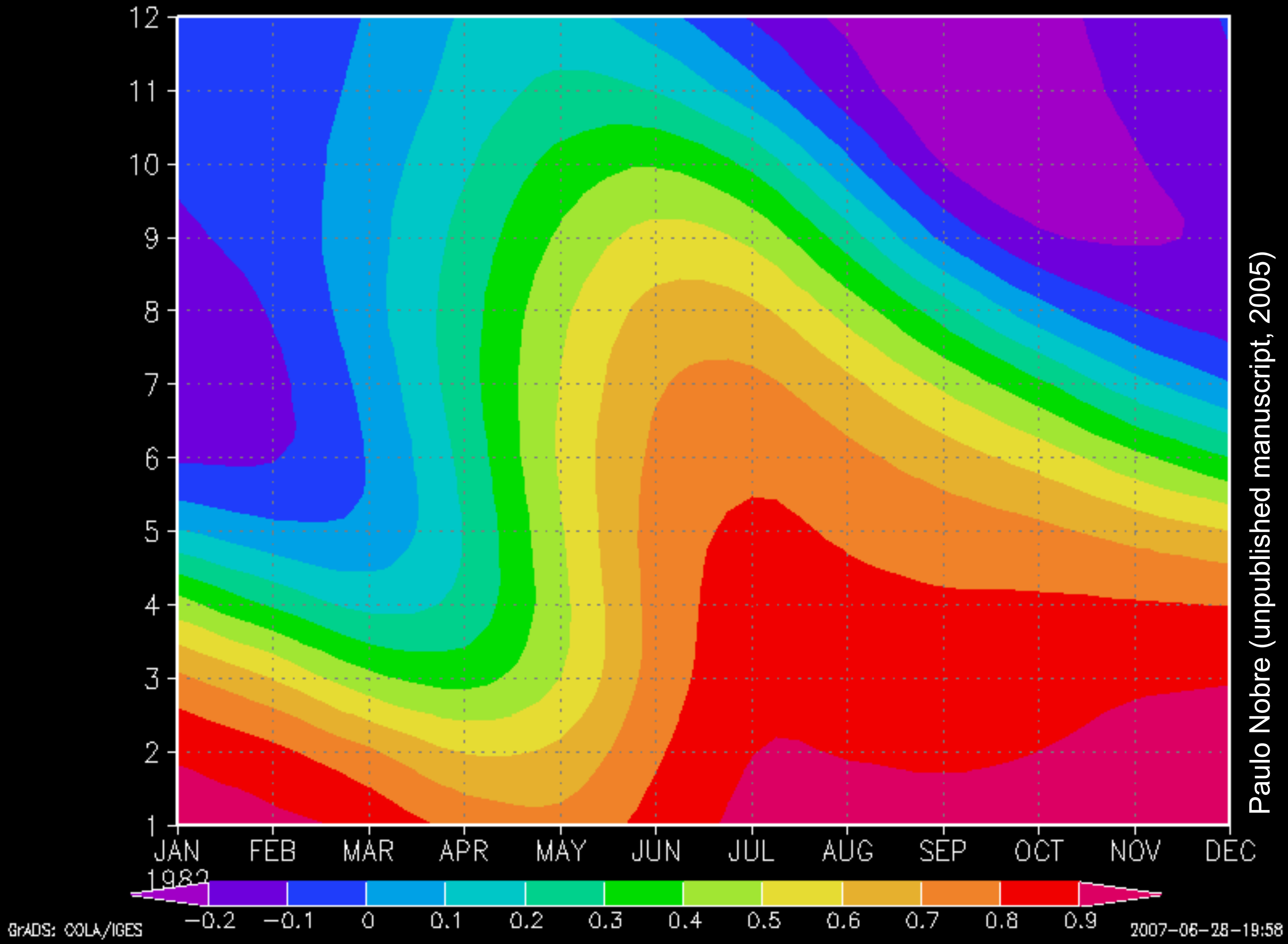


Two "one-in-a-century" Amazon Droughts within a 5 years period

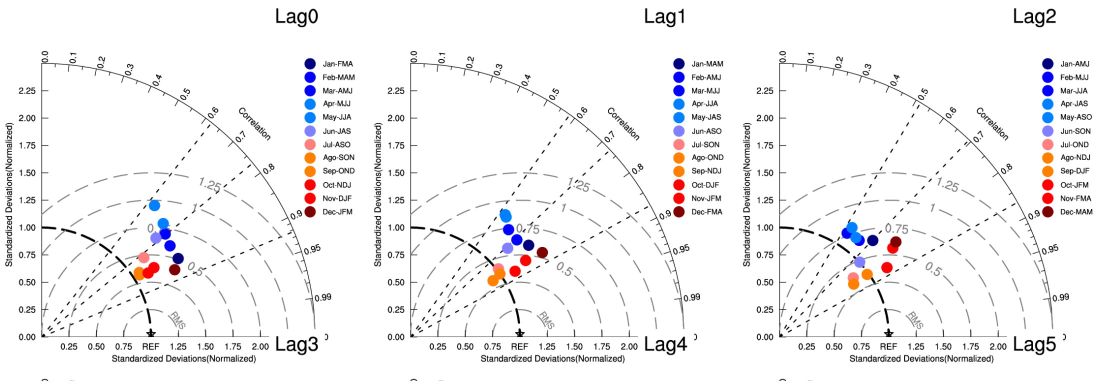
2005 and 2010 Amazon Droghts

Niño 3.4 SST Predictability

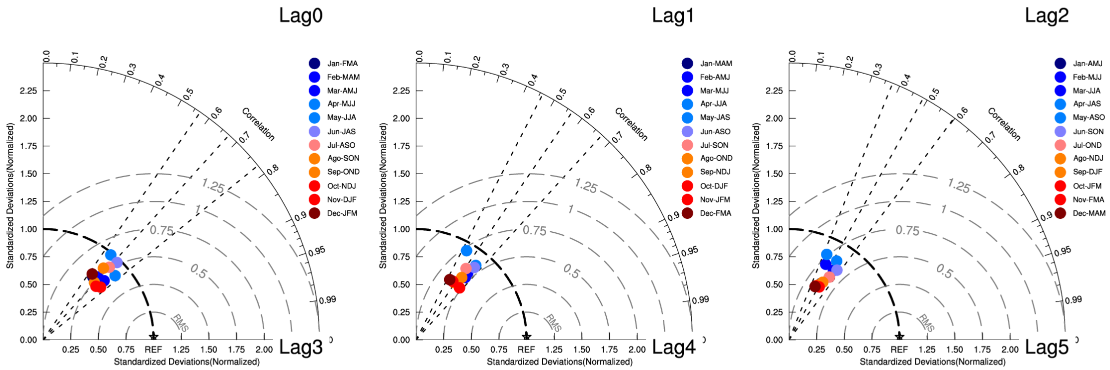
INPE-CPTEC's O-A Coupled Model



BESM Equatorial Pacific SSTA Predictability



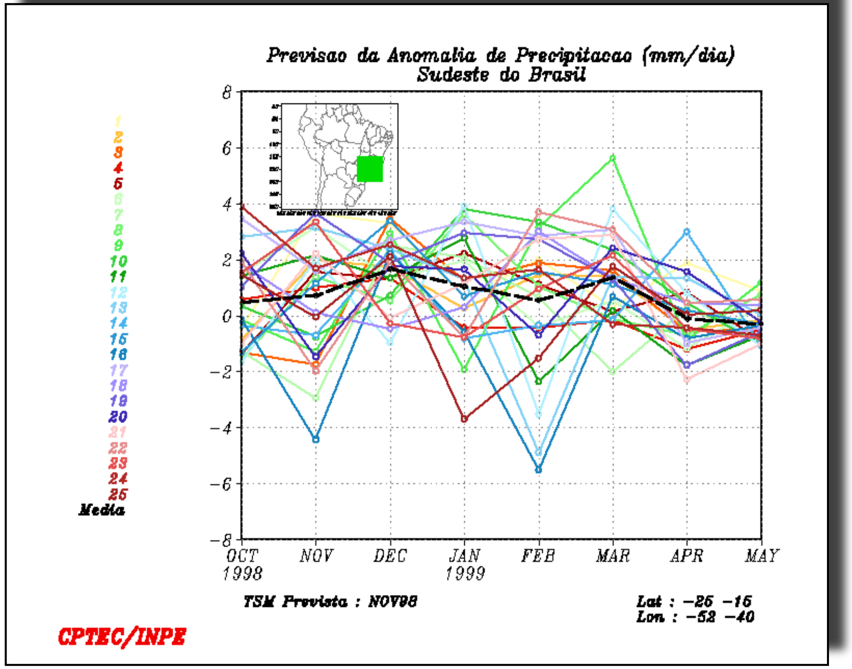
BESM North Tropical Atlantic SSTA Predictability

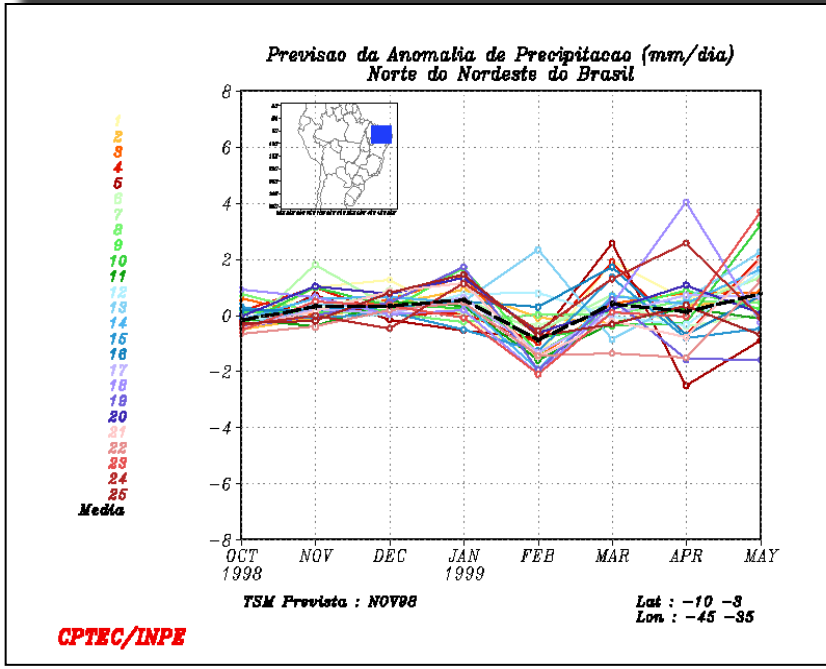


Paulo Nobre (manuscript in preparation)

Climate Variability and Change: What can we predict and why.

Centro de Previsão de Tempo e Estudos Climáticos





Higher inter-ensemble member dispersion

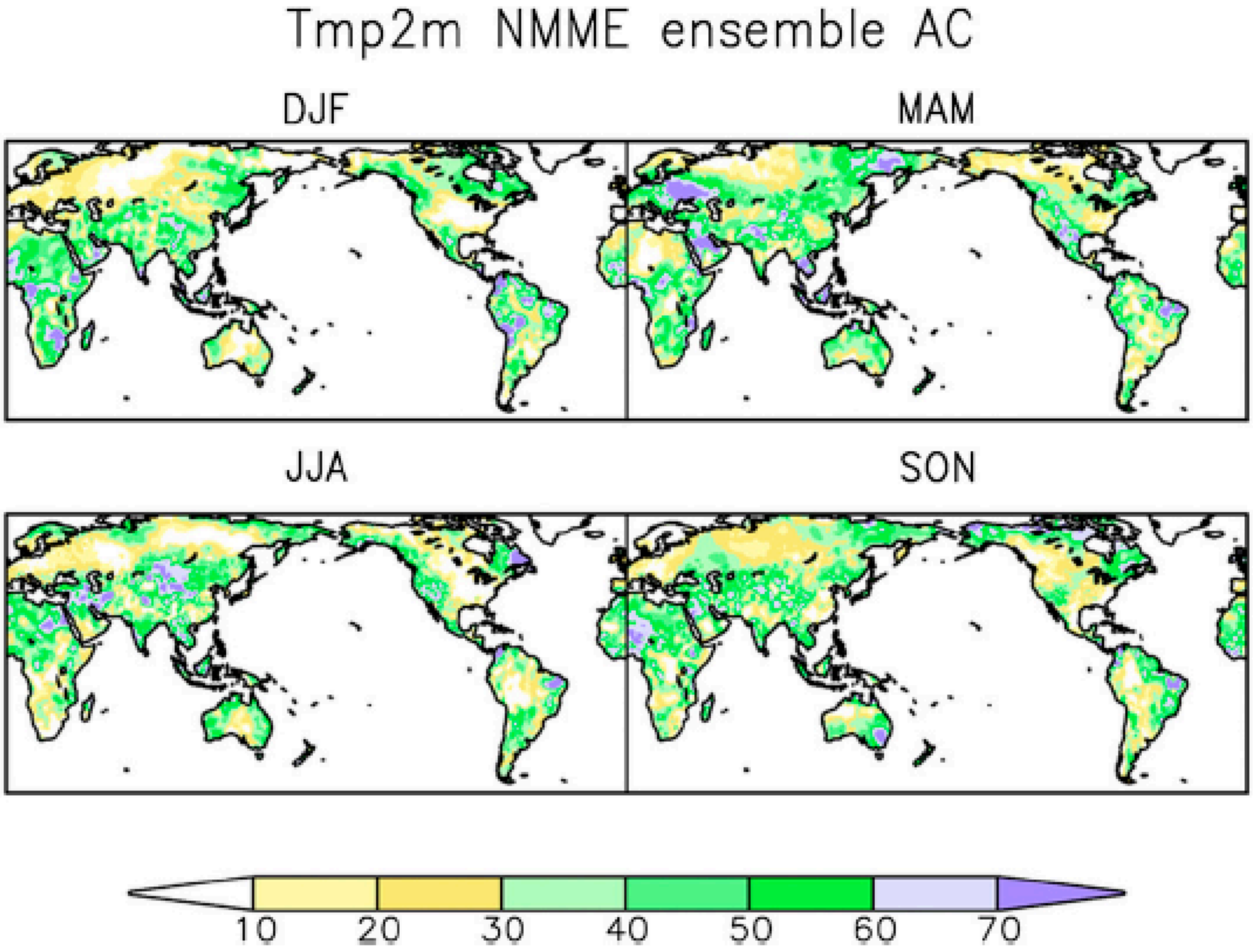
⇩

Lower predictability

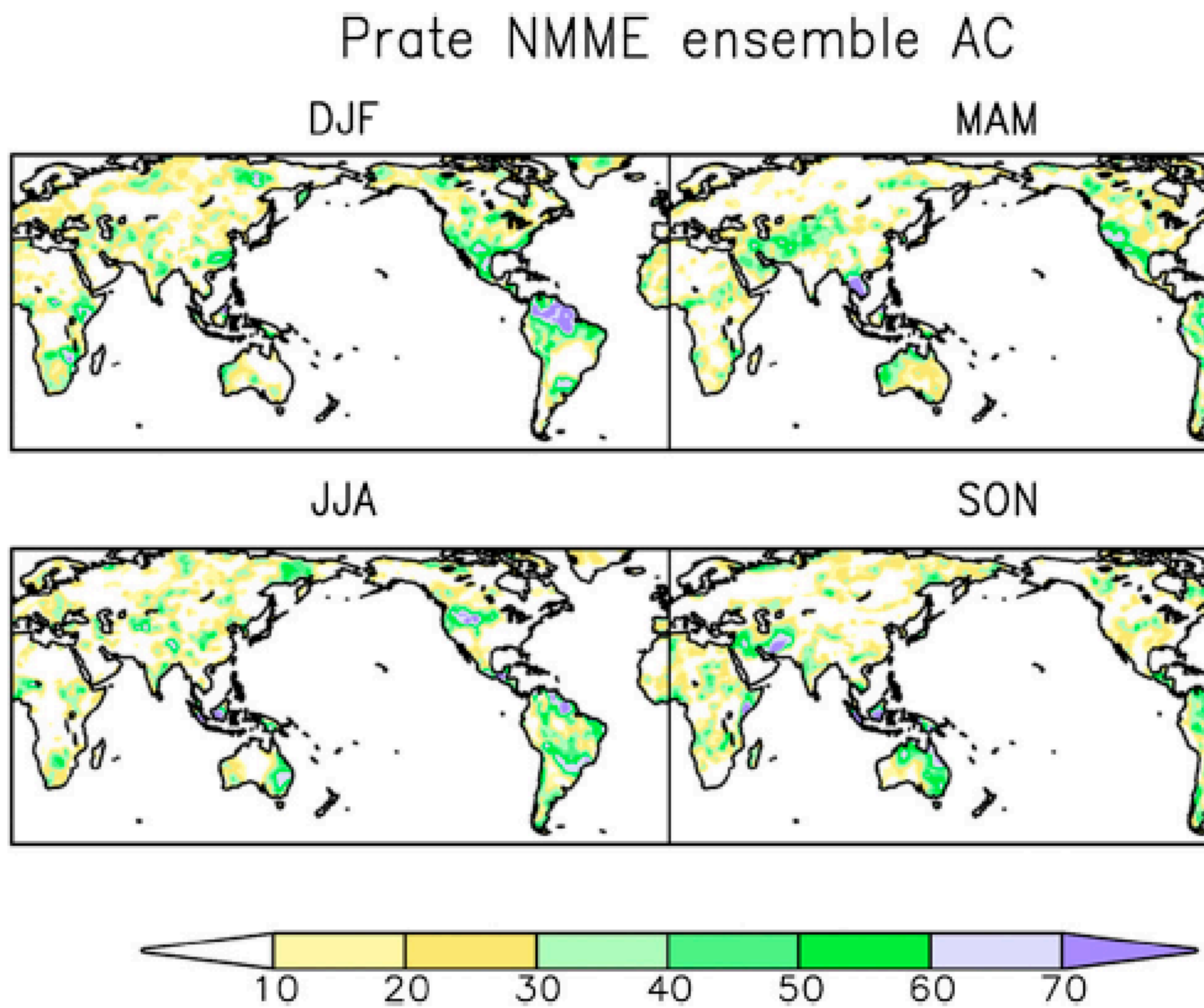
Smaller inter-ensemble member dispersion

⇩

Higher predictability

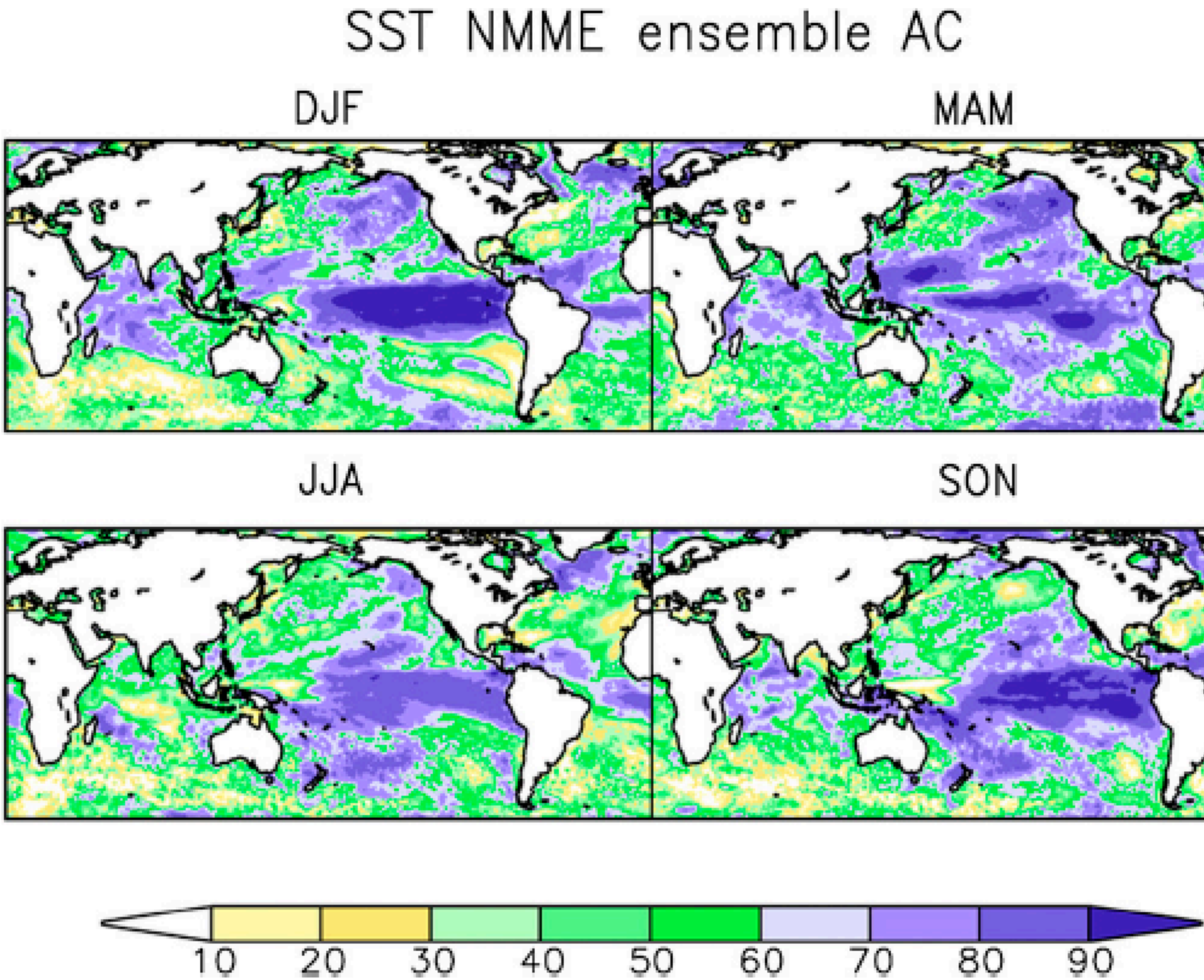


Source: Becker et al (2014)



Source: Becker et al (2014)

Climate Variability and Change: What can we predict and why.



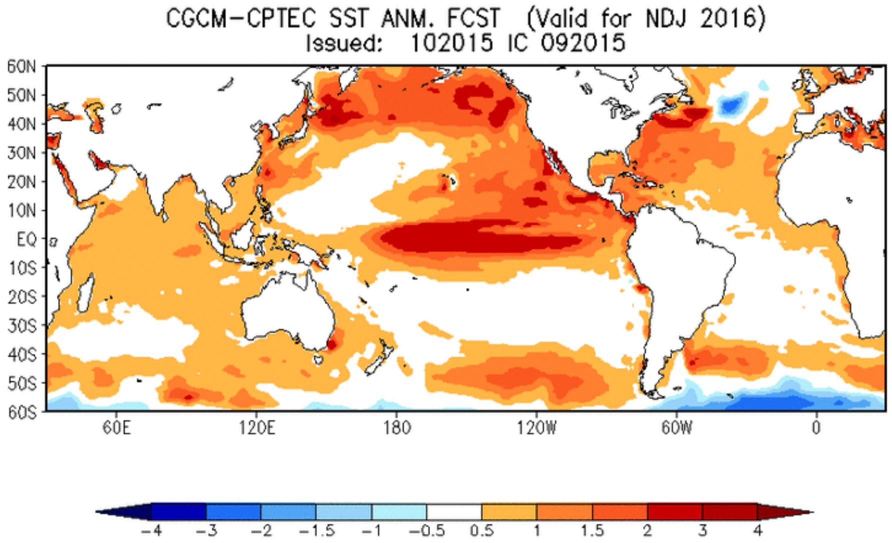
Climate Variability and Change: What can we predict and why.

Source: Becker et al (2014)

BESM/CPTEC ENSO FORECAST

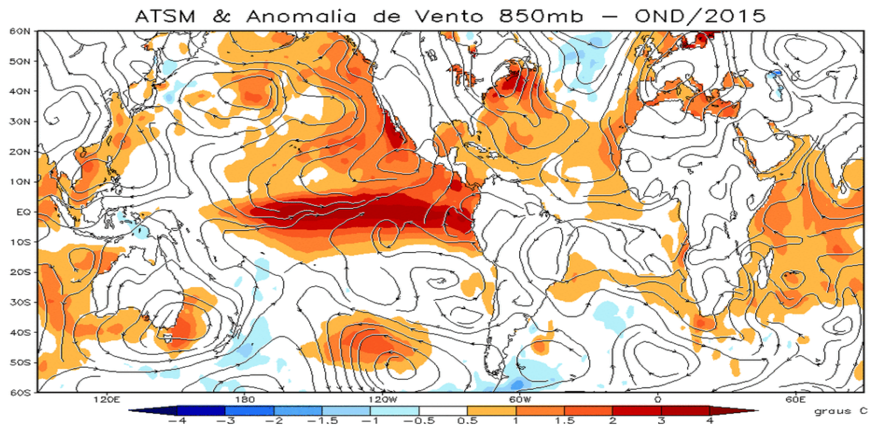
OND 2015 SST FCST

IC: Sept/2015



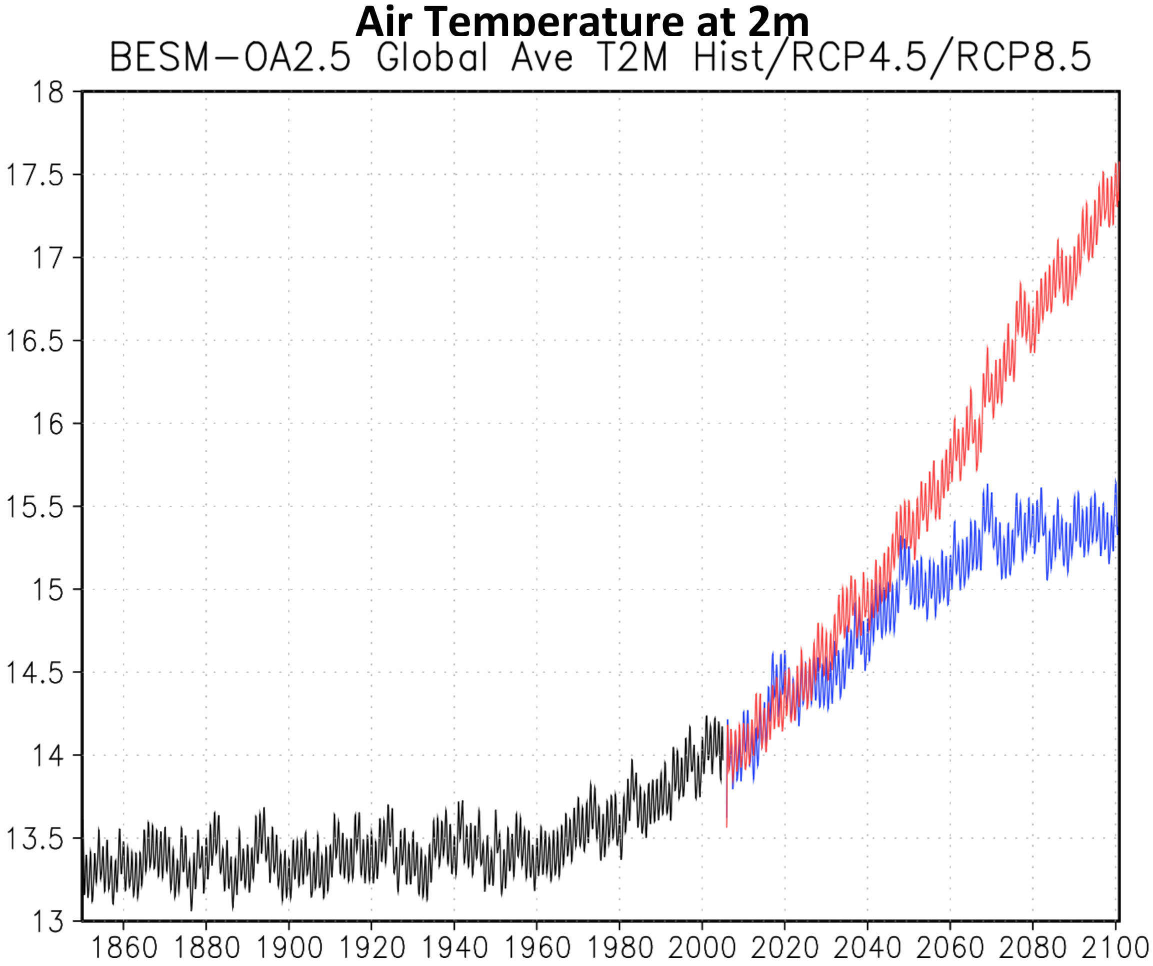
OND 2015 SST

ersst



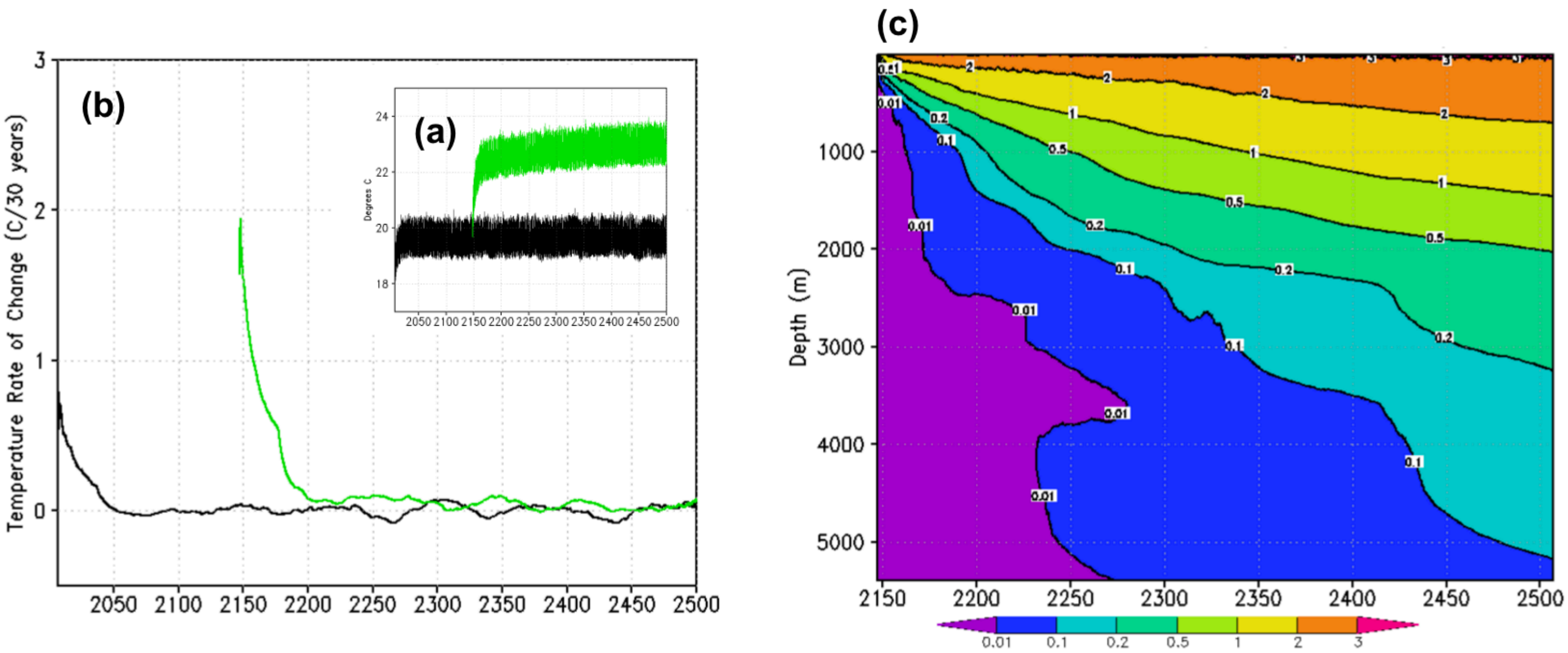
Courtesy: INPE/CPTEC

BESM2.5 CMIP5 Runs 1850-2100



Courtesy: V. Capistrano, INPE/BESM

Adjustment time scales of the coupled global ocean-atmosphere system



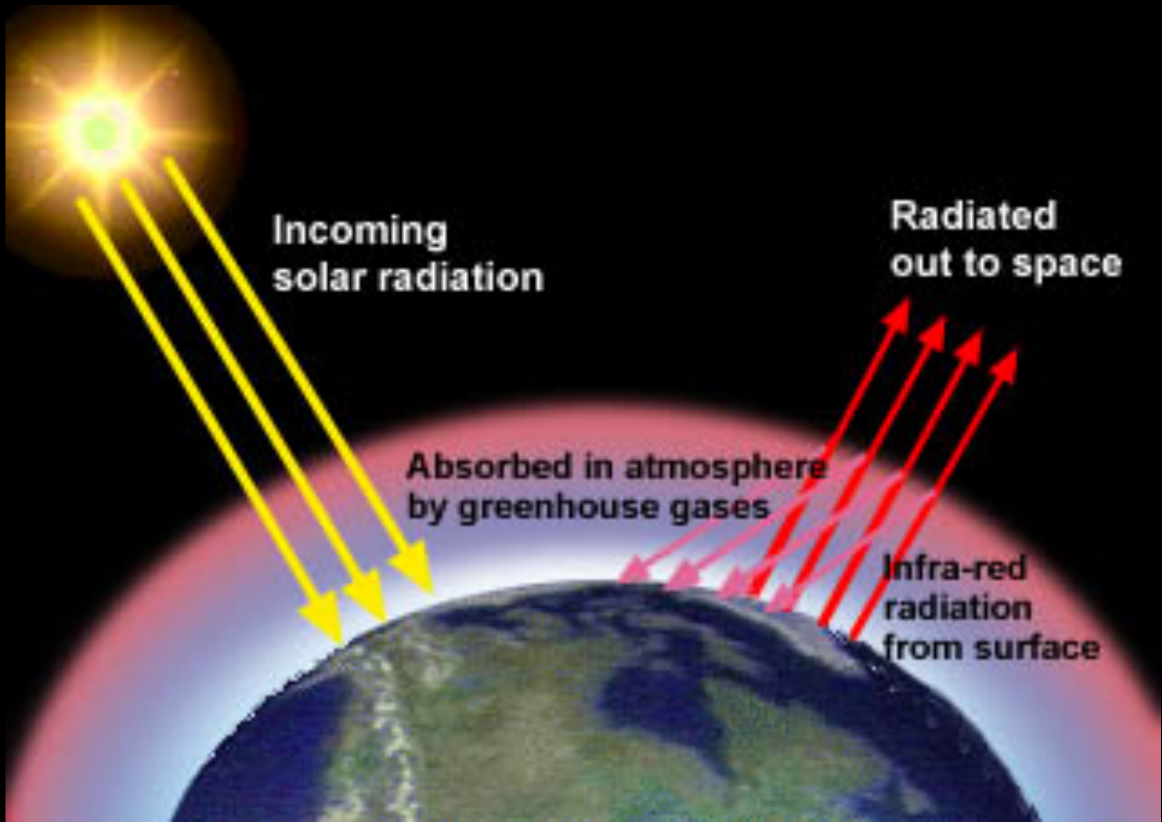
Paulo Nobre et al (manuscript in preparation)

Climate Variability and Change: What can we predict and why.

Potential Sources of Climate Predictability

- Slowly varying boundary conditions
  - Green House Gas (GHG) concentration growth
  - Tropical SST
  - Soil Moisture/ Ice extent
- Initial Conditions
  - Atmospheric Blocking
  - Ocean initialization
- Internal variability of the coupled ocean-atmosphere system
  - PDO, NAO, ENSO, trends

What is the "greenhouse effect"?



Like the sun, the Earth also emits radiation. It is much cooler than the sun, though, so it emits in the infrared. Some of that energy is absorbed by molecules in the atmosphere, affecting the global energy balance:

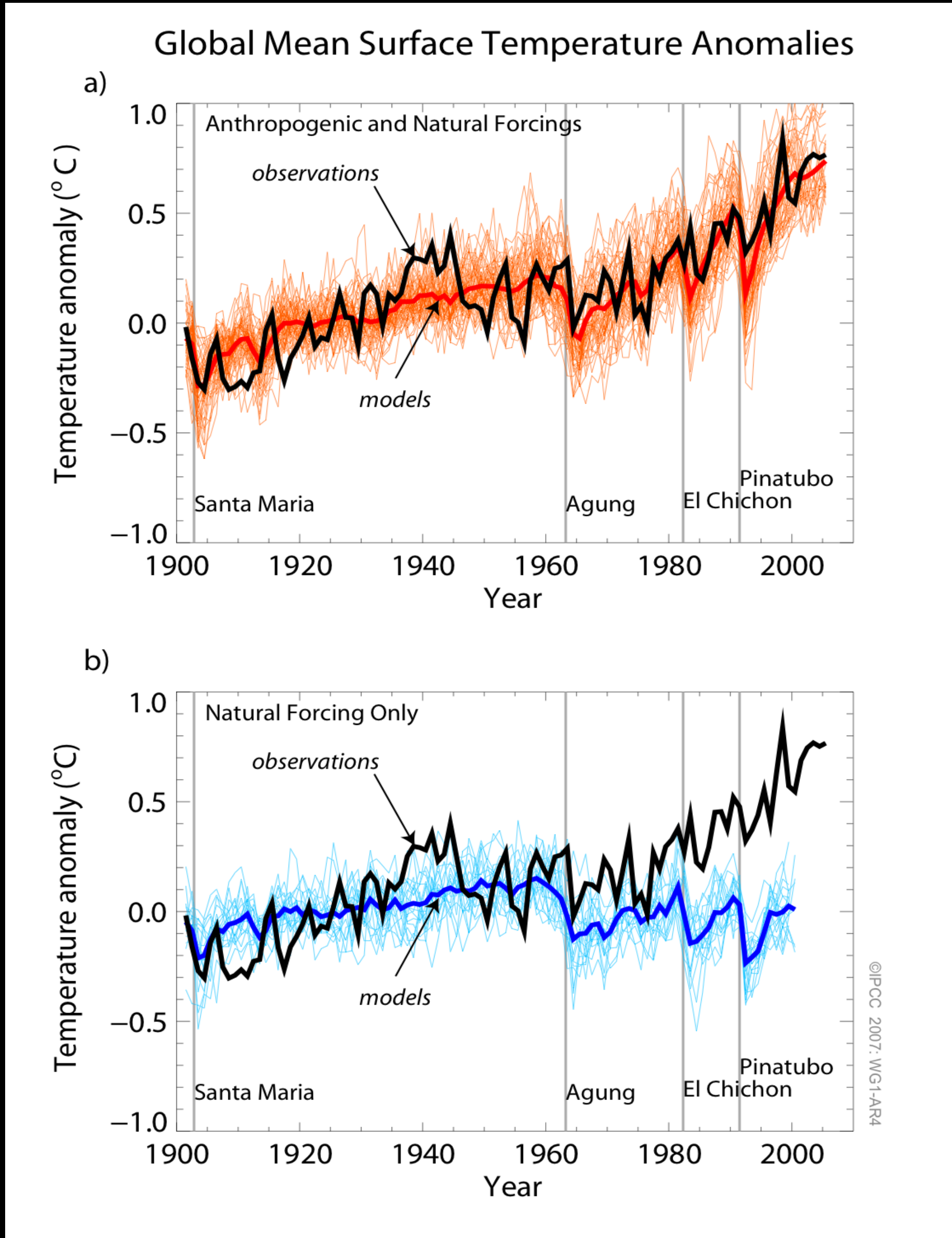
With no greenhouse effect, $T_e \approx -18°C$. We'd be frozen. The real average temperature is +15°C, due to the Earth's natural greenhouse effect.

Courtesy: Prof. Guy Brasseur (2011)

Attribution

- Asks whether observed changes are consistent with
- ☑ expected responses to forcings
- ☒ inconsistent with alternative explanations

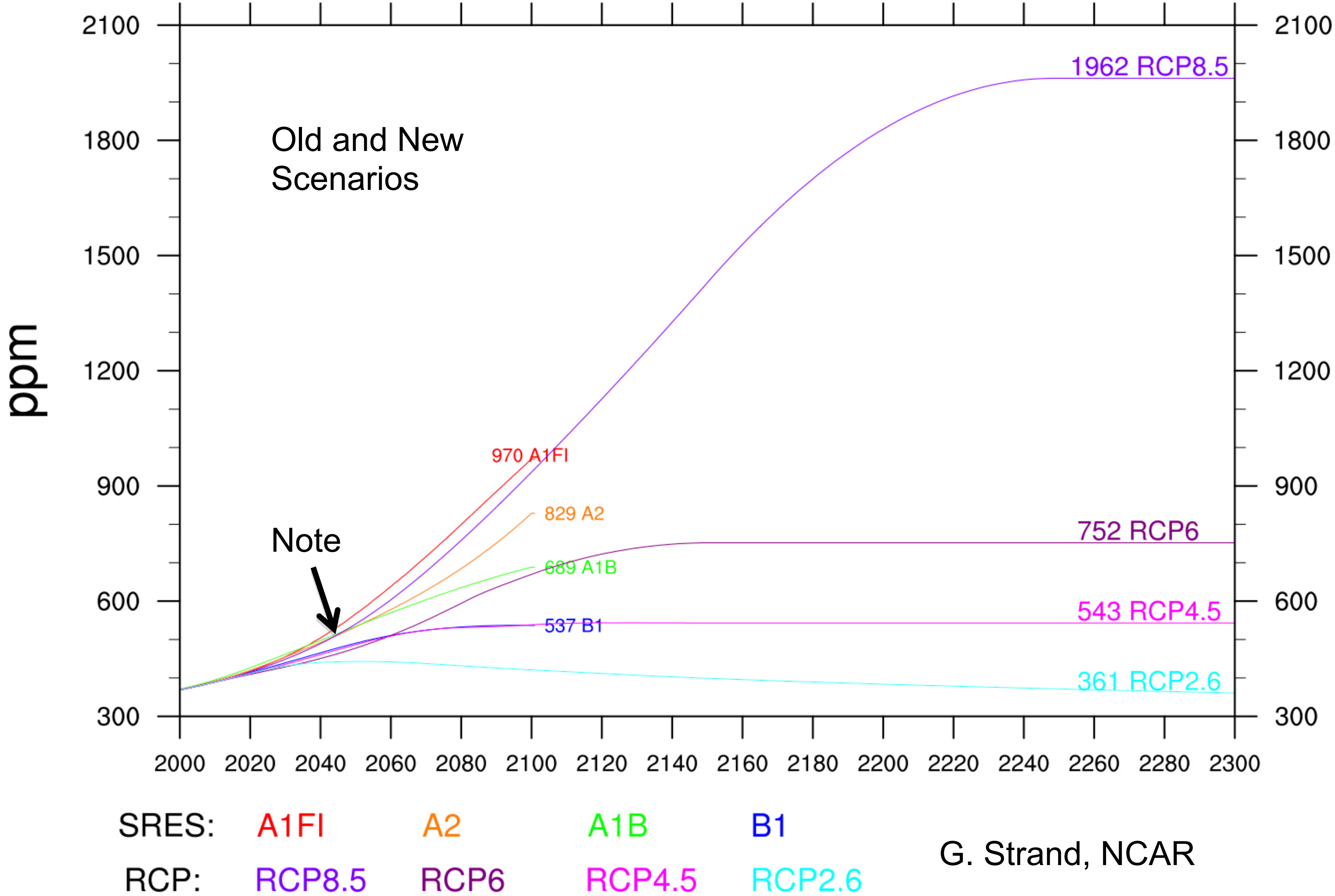
Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely (>90%) due to the observed increase in anthropogenic greenhouse gas concentrations



TS-23

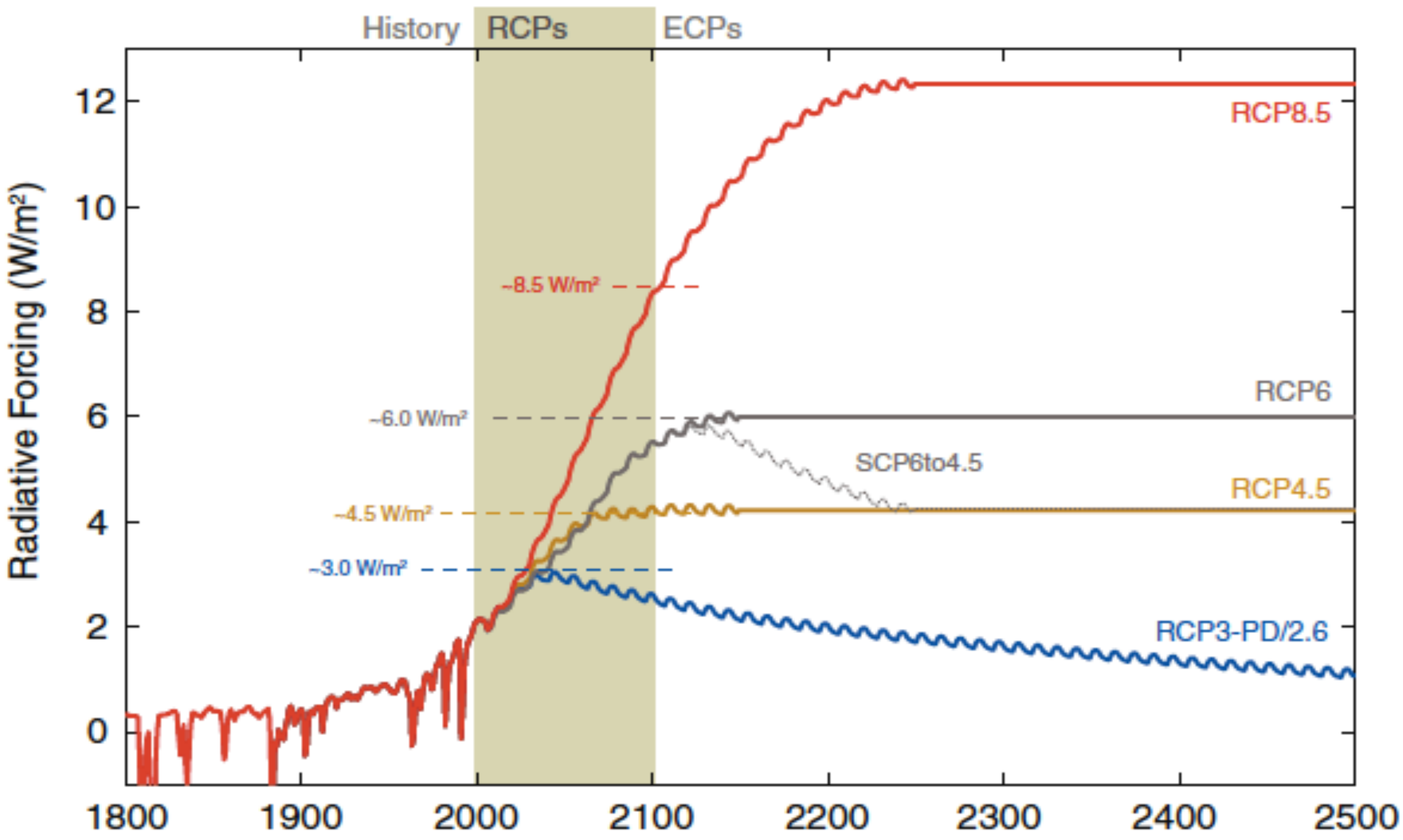
Courtesy: Prof. Guy Brasseur (2011)

CO_2 concentrations



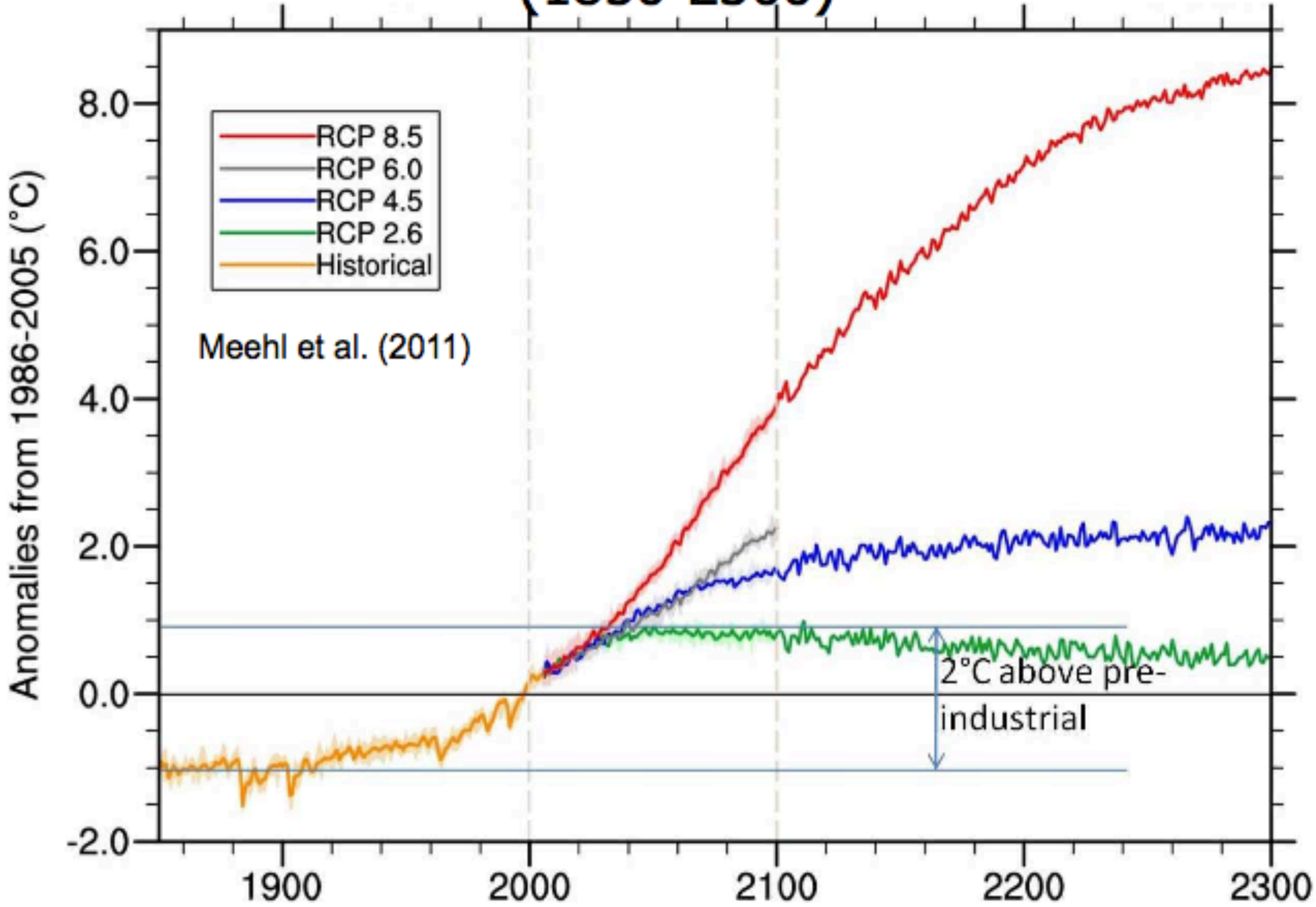
G. Strand, NCAR

RCP Climate Forcing

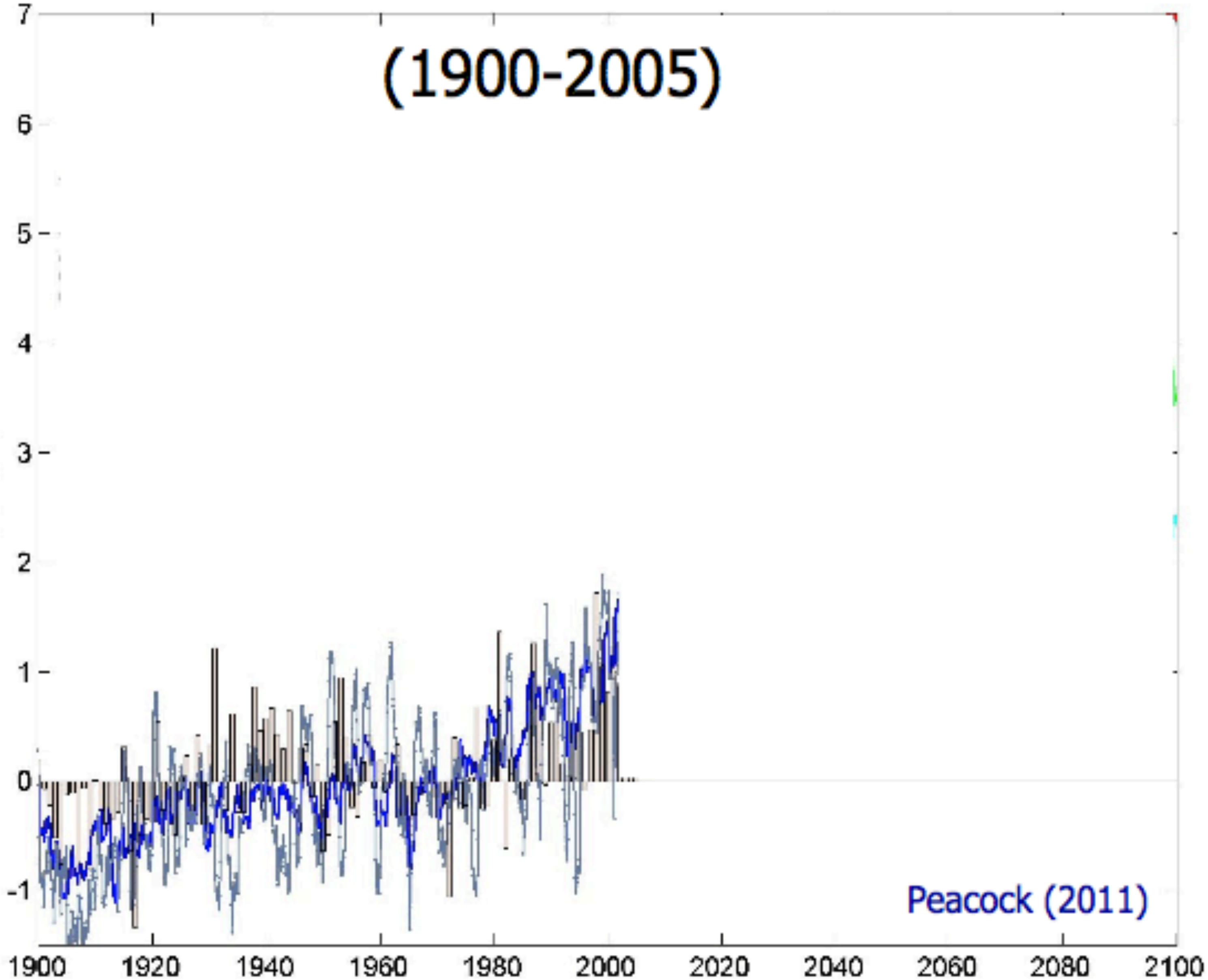


Climate Variability and Change: What can we predict and why.

Global Surface Temperature
(1850-2300)

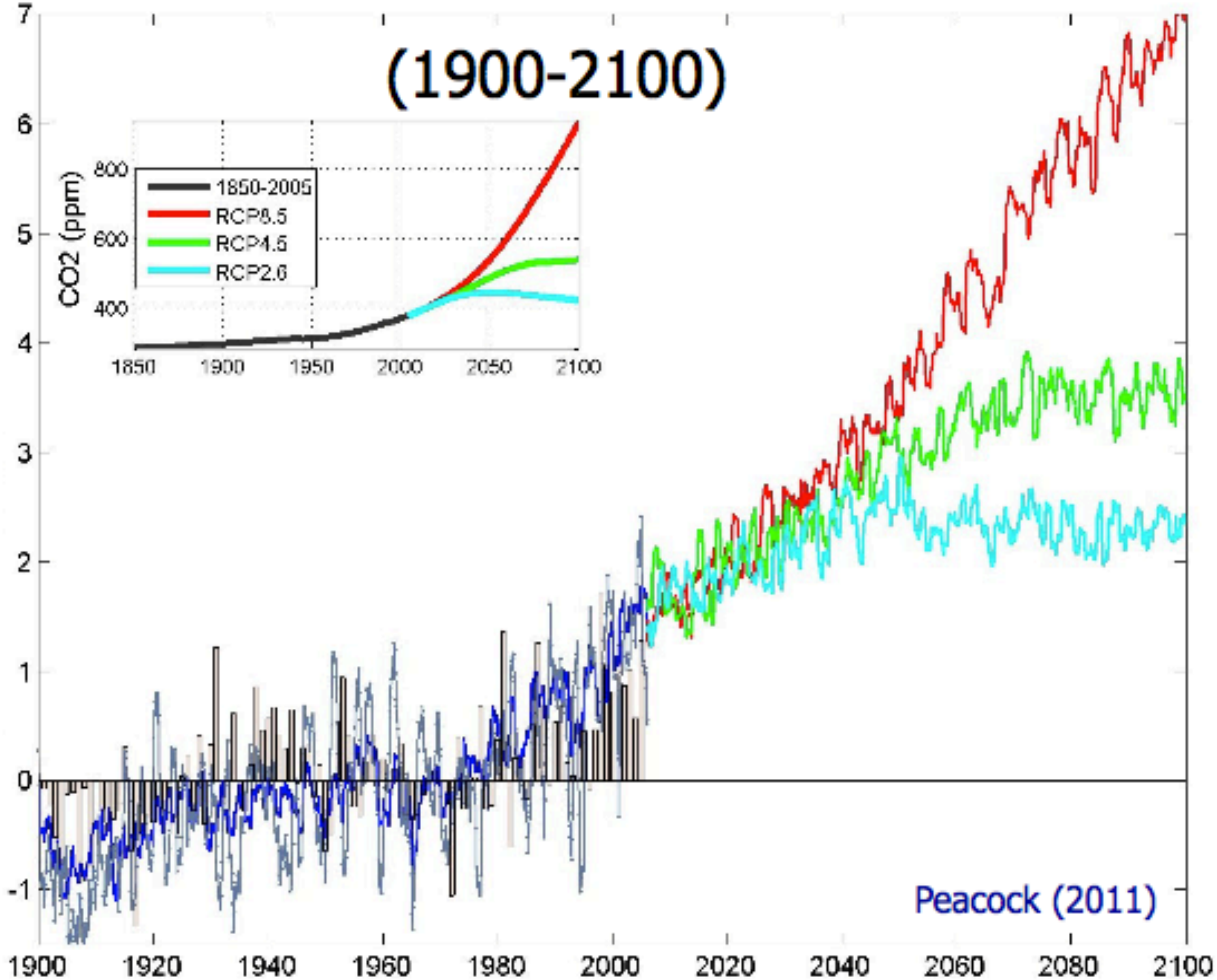


North American Annual Surface T (ºC)



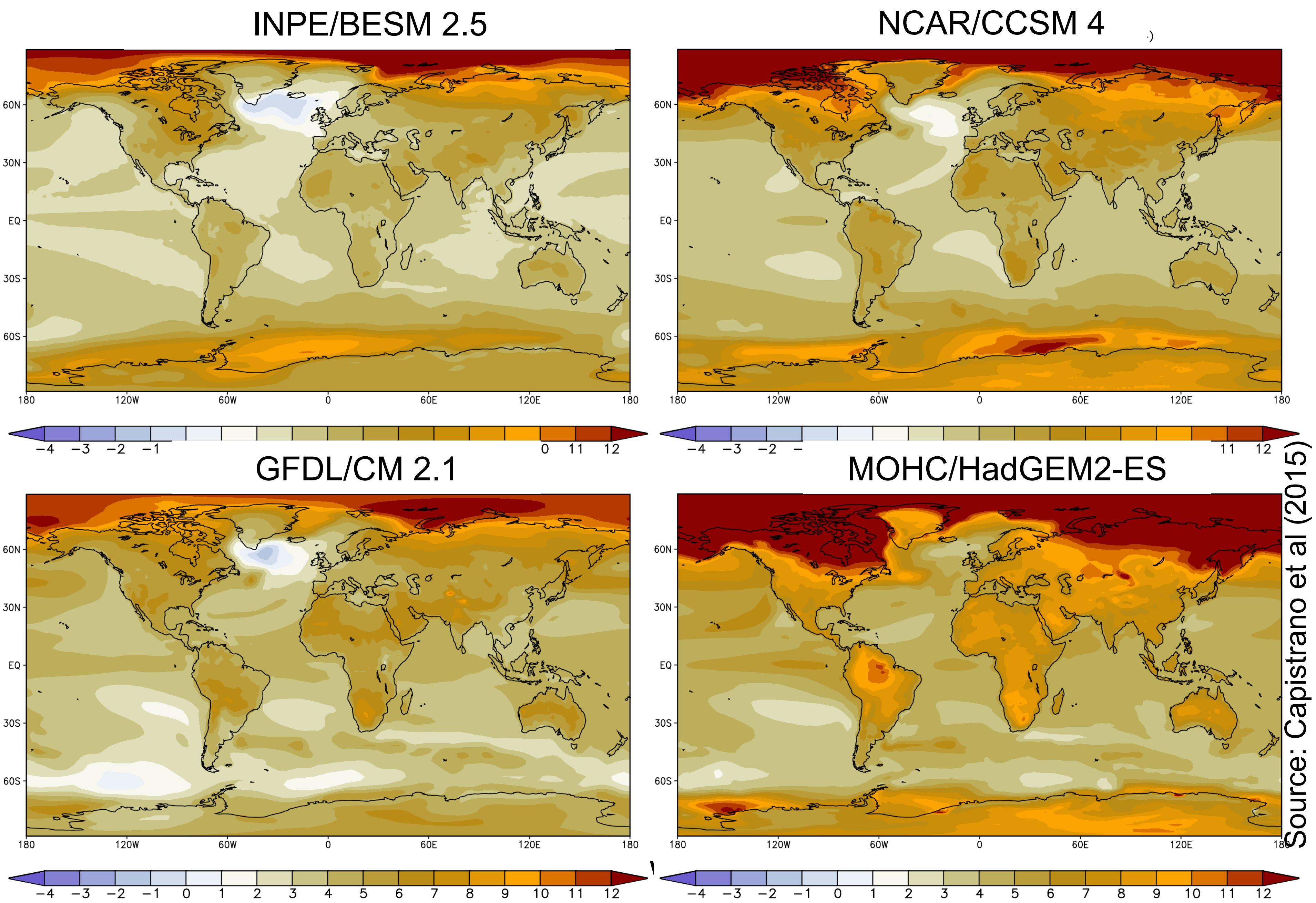
Climate Variability and Change: What can we predict and why.

North American Annual Surface T (ºC)



Climate Variability and Change: What can we predict and why.

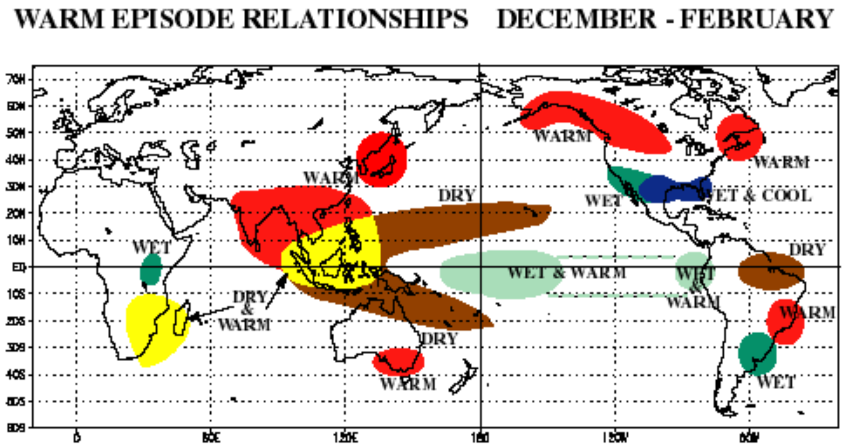
Abrupt4xCO2 - piControl

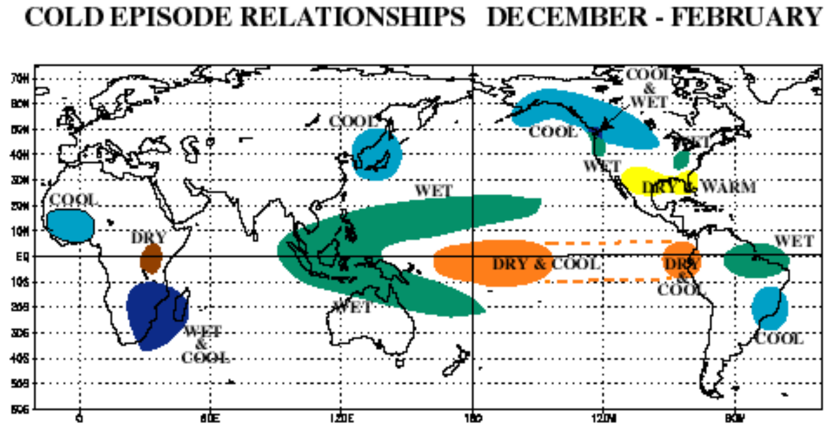


Phenomena-related Seasonal Predictability

- ENSO – El Niño-Southern Oscillation:
  - Equatorial Pacific air-sea interactions modulate large-scale atmospheric circulation, temperature and precipitation patterns;
- NAO – North Atlantic Oscillation:
  - Influences North America temperature and precipitation storm tracks
- Atlantic Meridional mode:
  - North-south SSTA gradient modulates ITCZ position, affecting rainfall distribution over northern South America
- Low Level Jet
  - Transport moisture into SESA, modulating severe weather over southern Brazil, Paraguay, Uruguay, and northern Argentina.

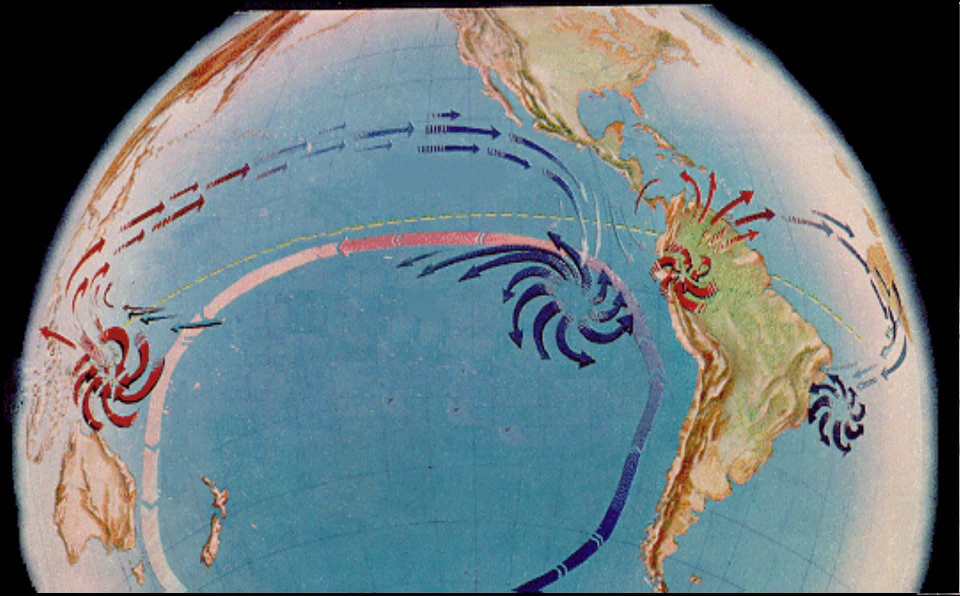
The ENSO effects



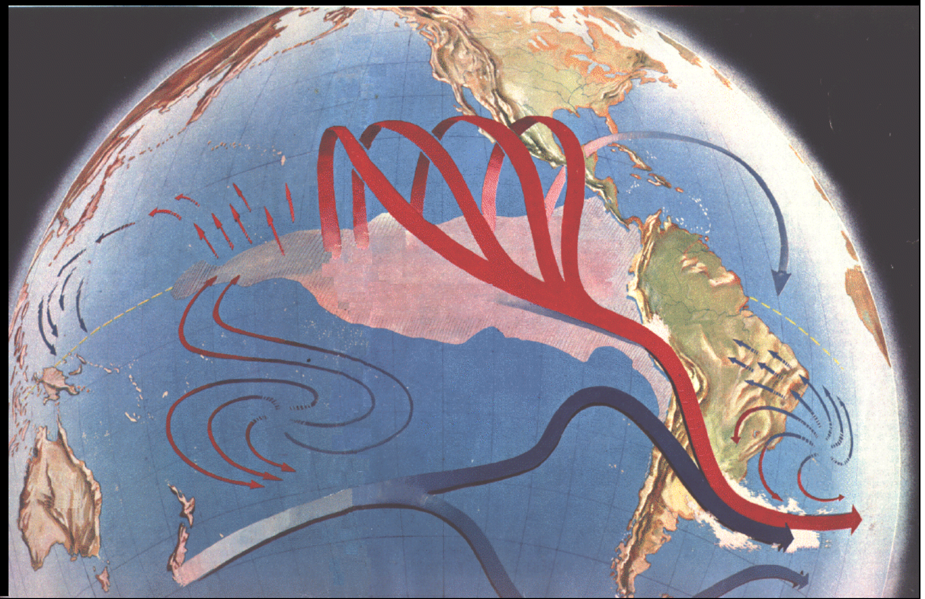


The Equatorial Pacific Influence

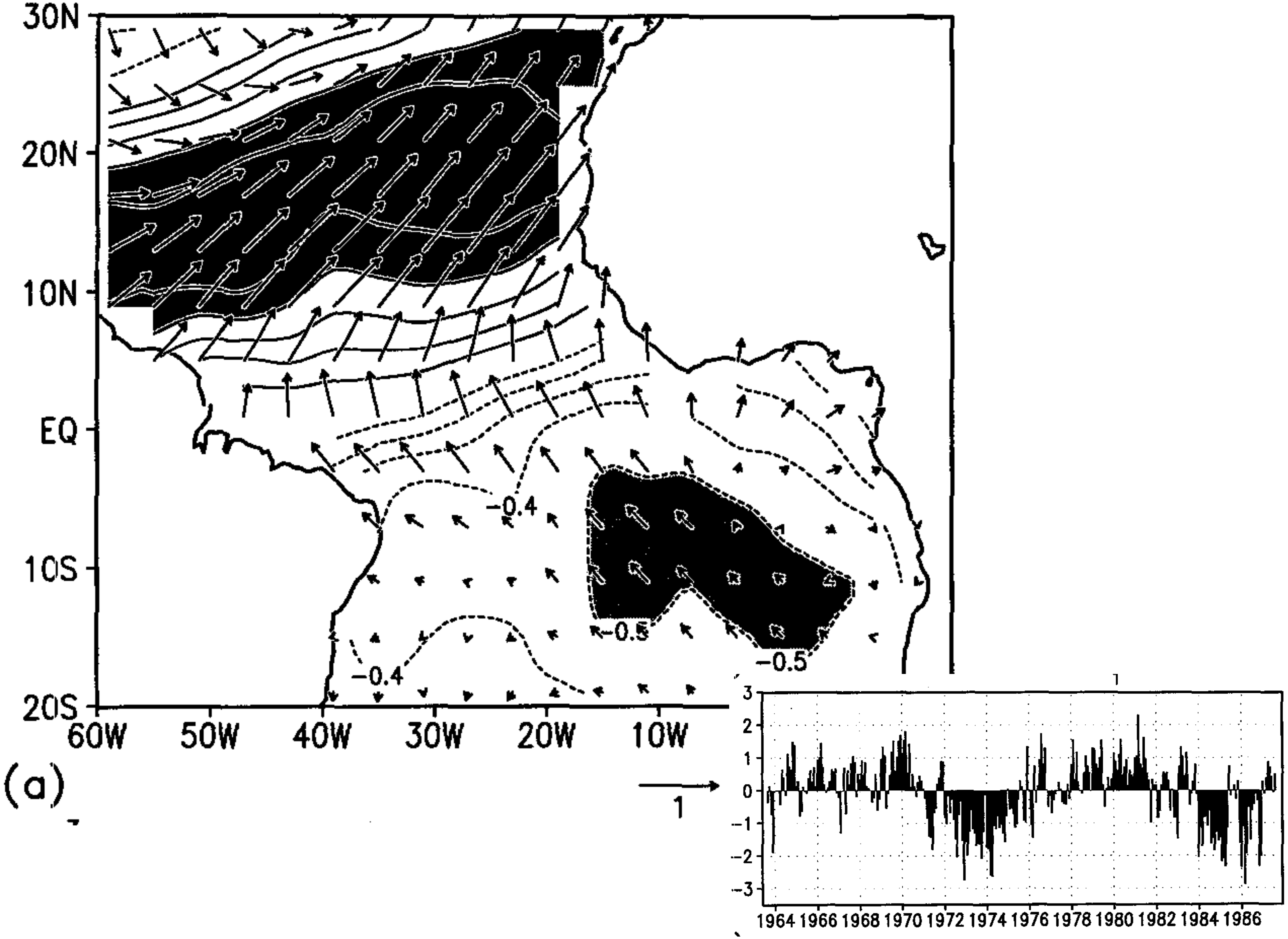
ENSO Cold



ENSO Warm



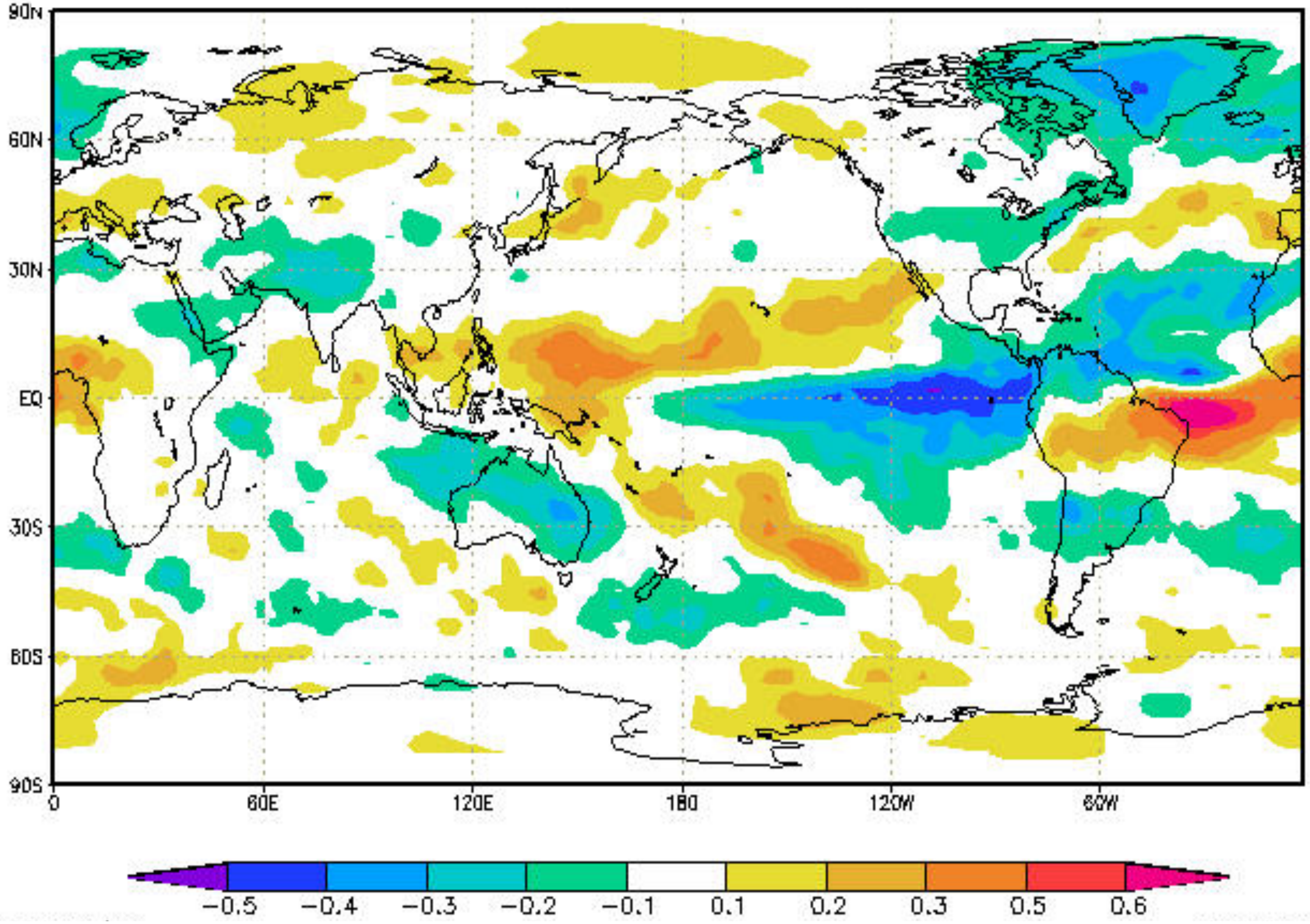
The Meridional Mode of SSTA and Wind Stress



Climate Variability and Change: What can we predict and why.

From: Nobre and Shukla (1996)

ATLANTIC ITCZ POSITION AND OLR ANOMALY CORRELATION



Source: Paulo Nobre (unpublished manuscript)

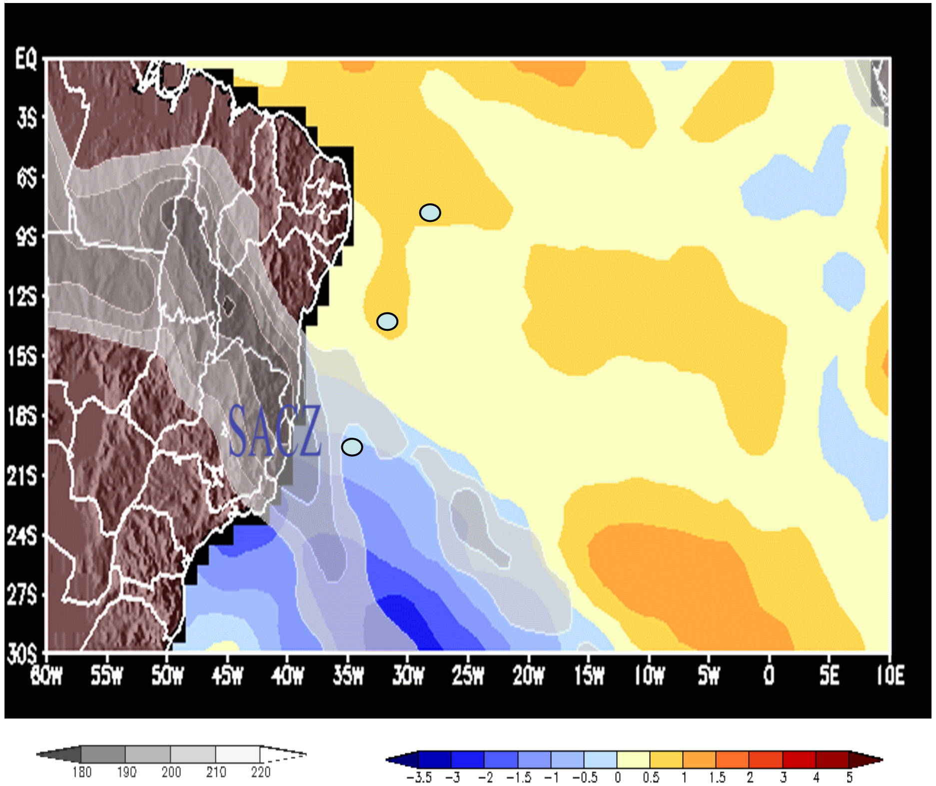
One x Two Tier

- "Perfect" SST-forced Atmospheric GCM
  - Assumes that atmosphere is completely forced by sfc temperature/humidity distribution
  - Generally a good assumption in thermally direct driven cases like ENSO and Atlantic ITCZ.
  - However, prescribe incorrect sfc fluxes in the cases of convection over cooler waters, e.g. SACZ.
- Coupled O-A GCM:
  - Correct surface fluxes over cold/warm waters
  - Systematic errors growth hinders further predictability!

The South Atlantic Convergence Zone (SACZ)

- SACZ formation over cold waters => Atmospheric forcing of underlying SST?

- Robertson and Mechoso (2002)
- Chaves and Nobre (2004)
- De Almeida et al (2007)
- Nobre et al (2009)

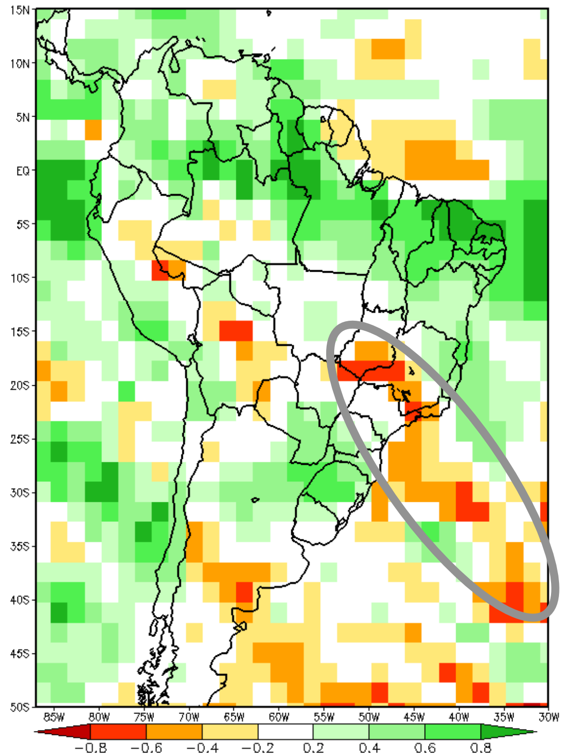


OLR SSTA

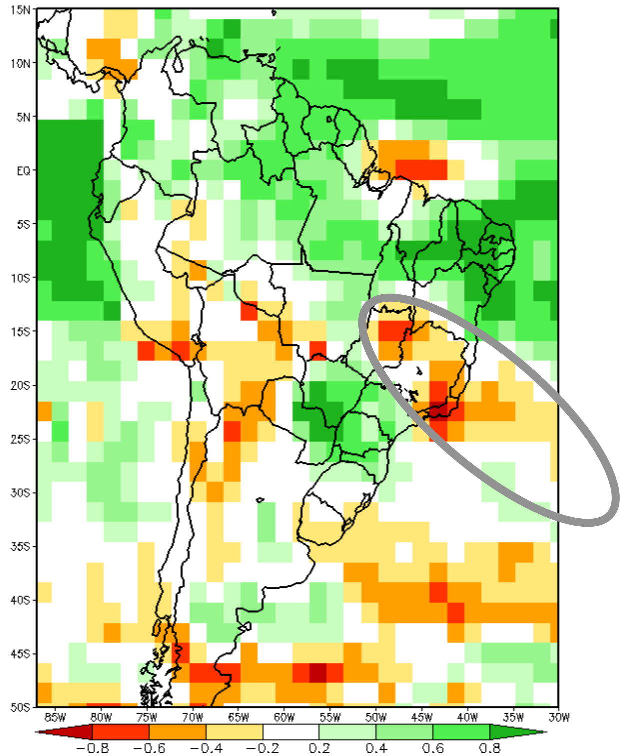
OBS: 17-25 NOVEMBER 1999

SACZ low predictability

DJF



MAM



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

Marengo et al. (2002)

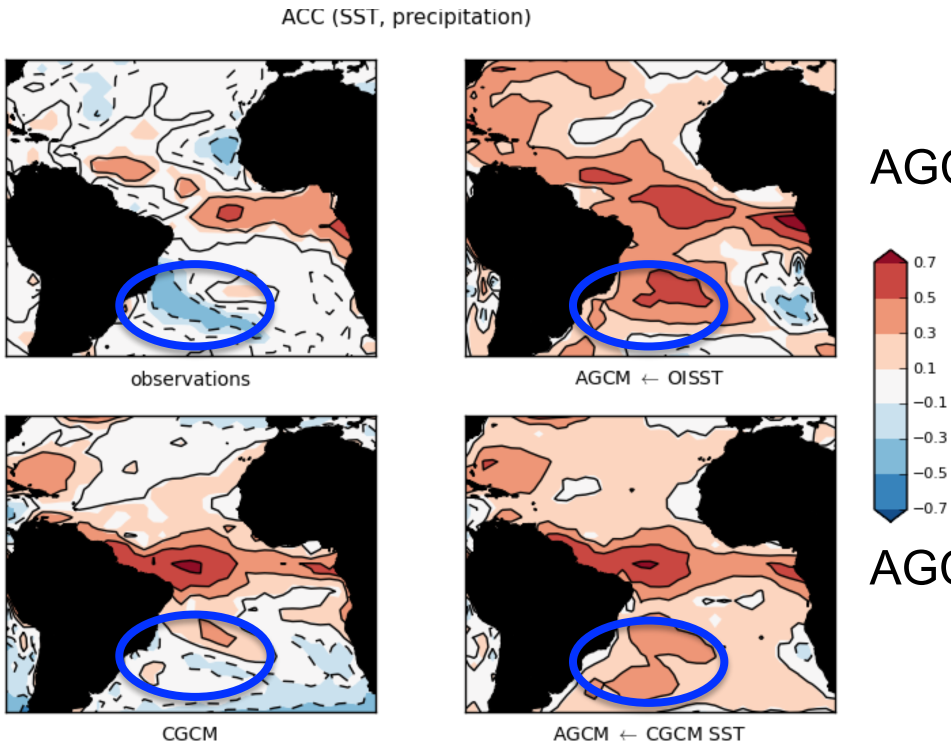
Climate Variability and Change: What can we predict and why.

BESM Predicts SACZ over colder Waters

SST-RAINFAL ANOMALY CORRELATIONS

OBSERVATIONS

AGCM/$SST_{observations}$



MBSCG

AGCM/SST_{cgcm}

Nobre et al. (2012, JClimate)

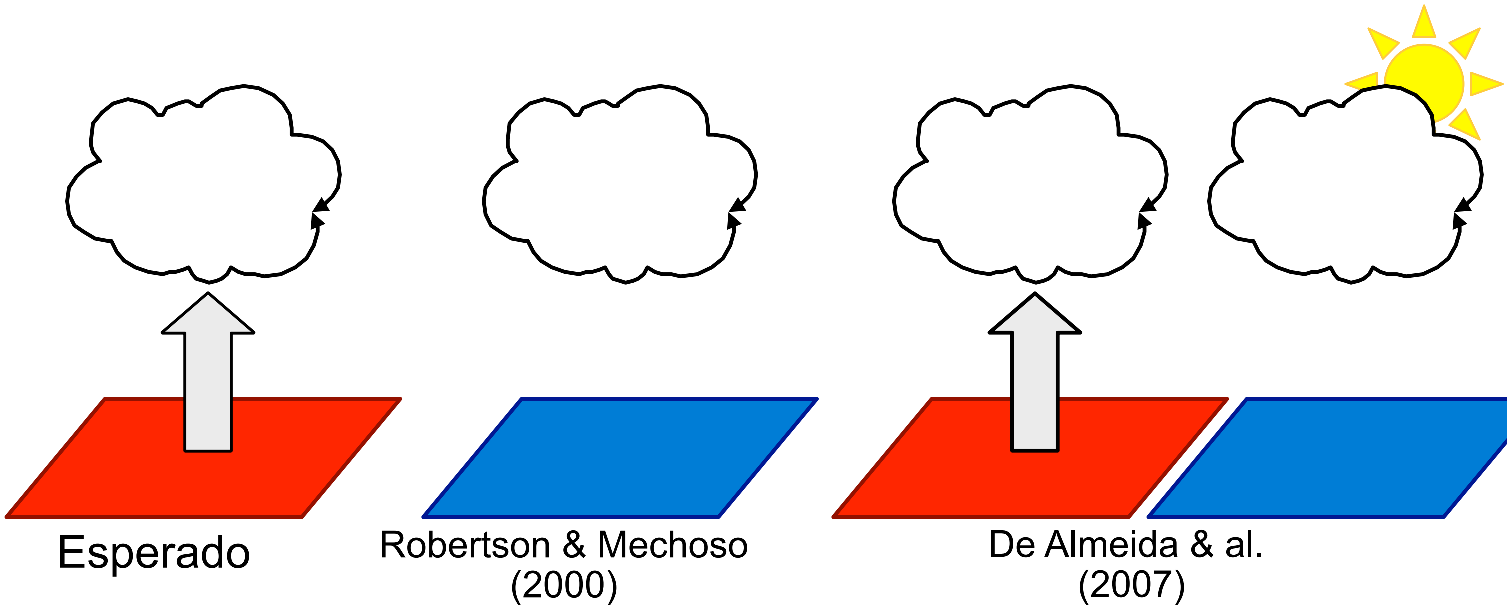
Climate Variability and Change: What can we predict and why.

TABLE 1. ACCs between surface air temperature (SAT), sea surface temperature (SST), rainfall (PREC), and downward shortwave radiation (SWR) for the PIRATA buoys at 8°S, 30°W and 19°S, 34°W. Daily values smoothed with a 30-day-running-mean filter for the DJF periods of 2005–10, totaling 450 pairs of data for each time series. Cross-correlation values greater than 0.35 (italic) [0.6 (boldface)] are statistically significant at the 90% (99%) level according to a one-sided Student's *t* test with 15 degrees of freedom.

Cross correlation	Buoy at 8°S, 30°W	Buoy at 19°S, 34°W
SAT–SST	**0.91**	**0.94**
SWR–PREC	**−0.64**	**−0.74**
SAT–SWR	*−0.38*	*0.49*
SST–SWR	−0.18	*0.41*
SAT–PREC	*0.56*	−0.32
SST–PREC	0.33	−0.19

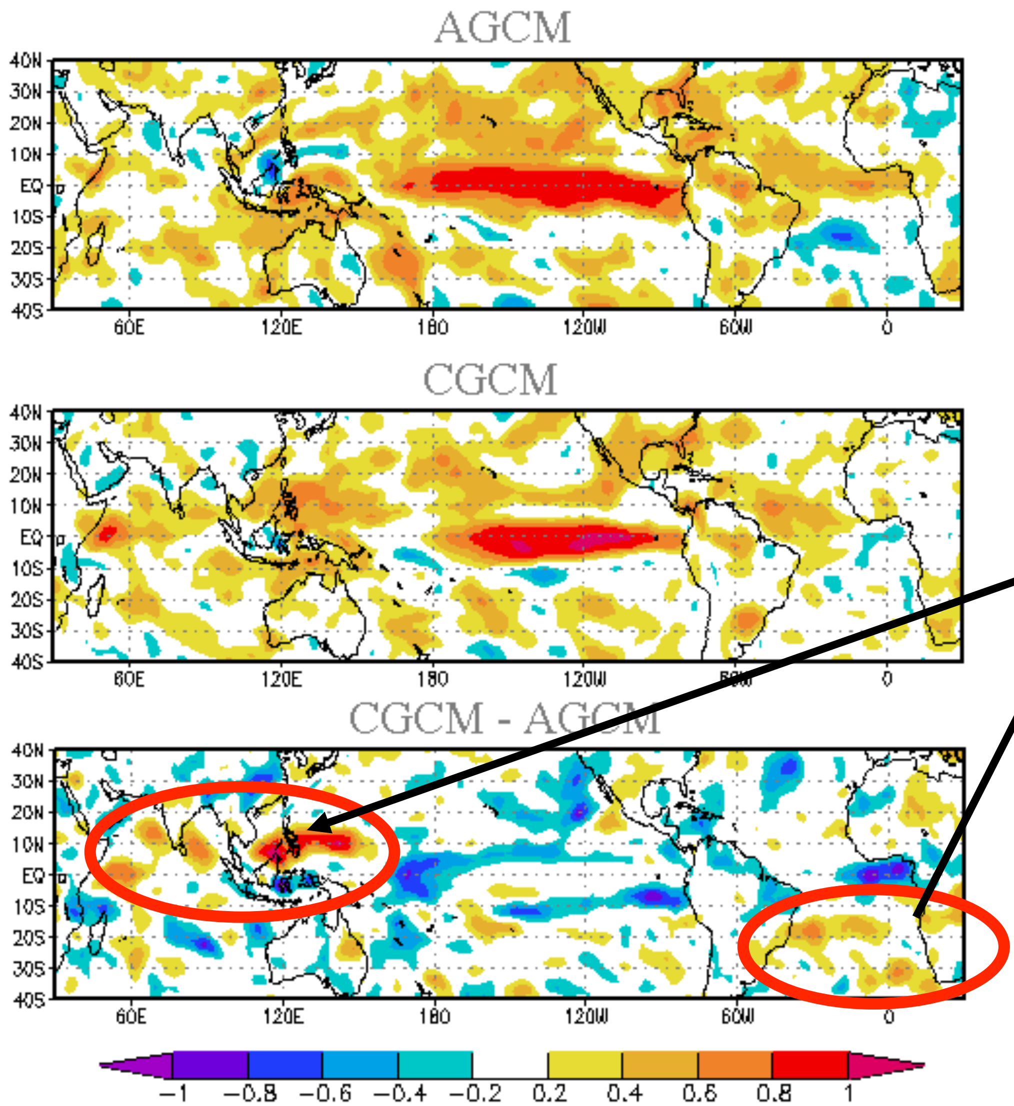
the AGCMs, the results are only marginally statistically significant over the area of the SACZ. Yet, one could expect that the more physically sound representation of the SACZ dynamics and thermodynamics by the CGCM can leave its imprint on rainfall predictability over the southwestern Atlantic. Figure 5 shows DJF rainfall hindcast skill as measured by ACC between observed and simulated rainfall. The AGCM runs forced by OISST (Fig. 5a) depict the same robust correlation pattern of positive correlations along the equatorial area and negative correlations over the SACZ area, reproducing previous results that used AGCMs forced by observed SSTs to simulate the SACZ (Nobre et al. 2006; Robertson et al. 2003). It is noteworthy, however, that the strong negative ACC shown for the AGCM runs forced by observed SST is drastically reduced on the

Nobre et al. (2012, JClimate)


Esperado
Robertson & Mechoso
(2000)
De Almeida & al.
(2007)

Coupled Ocean-Atmosphere processes at play

DJF Precipitation Forecasts anomaly correlations



Increased Coupled Model Forecast Skill

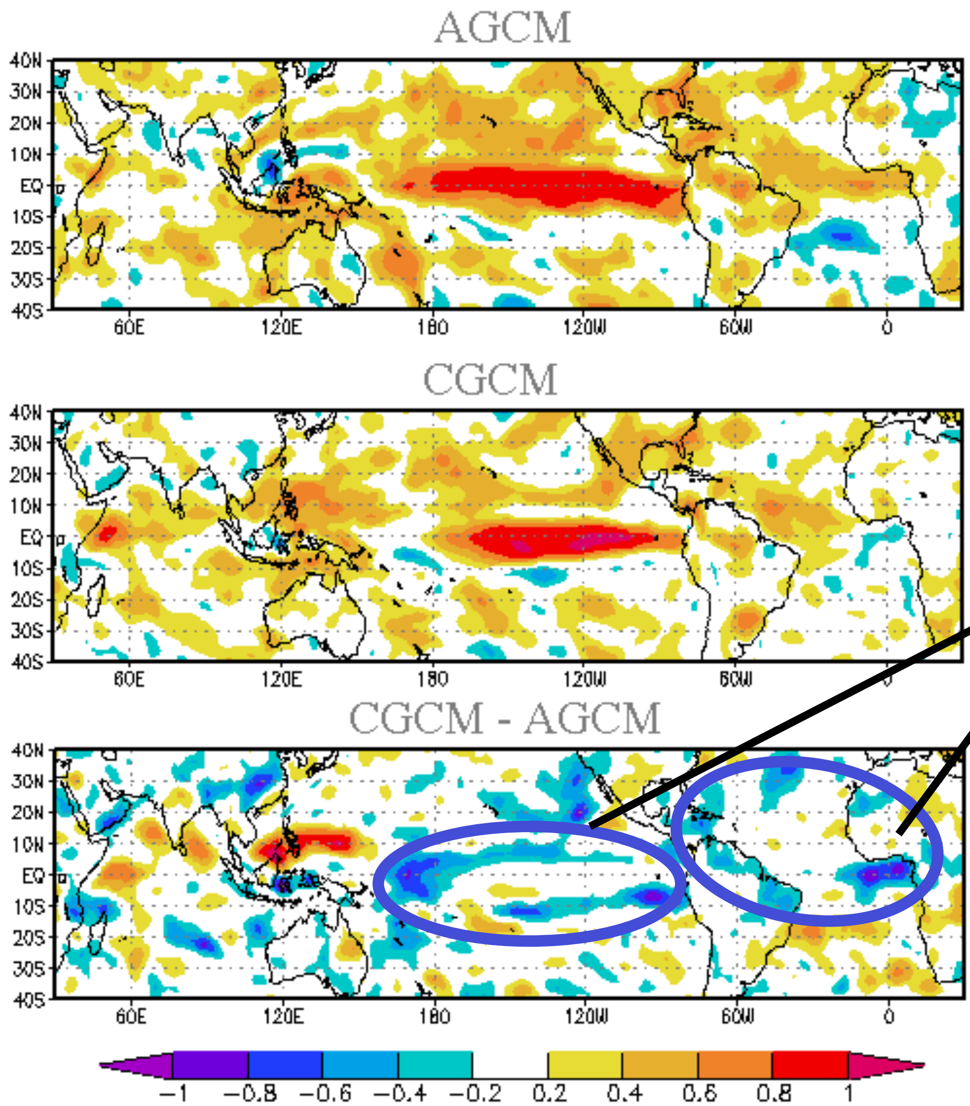
Nobre et al. (2009)

Clima

y.

Coupled Ocean-Atmosphere processes at play

DJF Precipitation Forecasts anomaly correlations

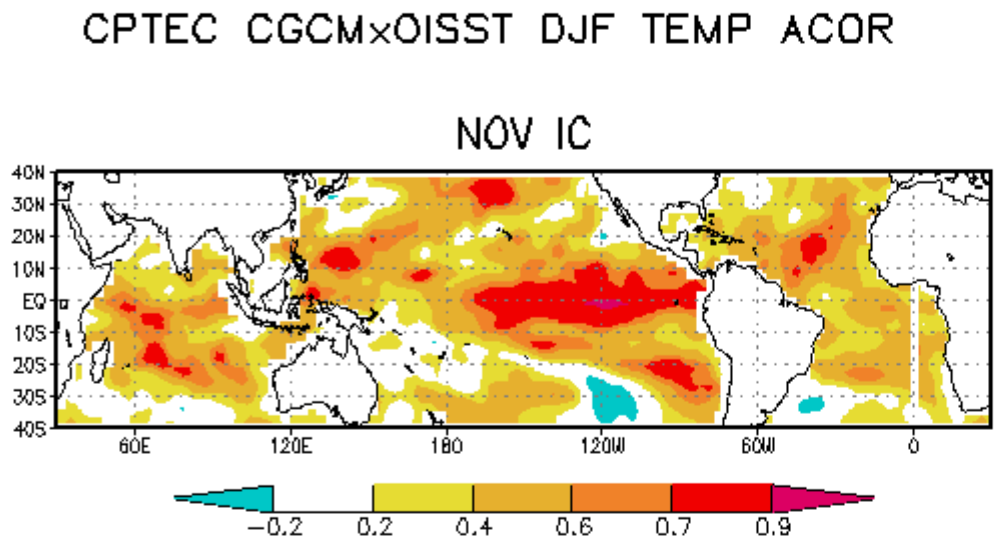


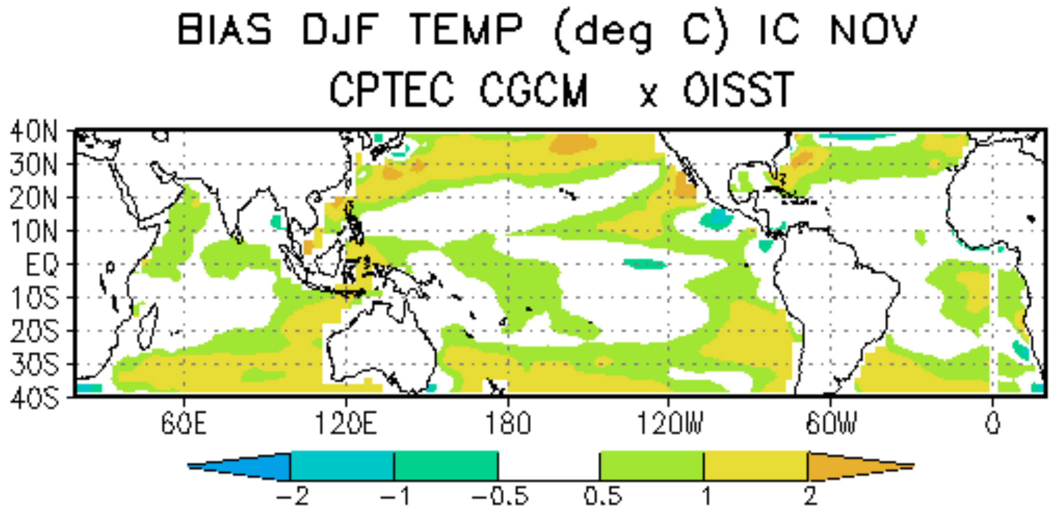
Decreased Coupled Model Forecast Skill

Nobre et al. (2009)

Clima

y.





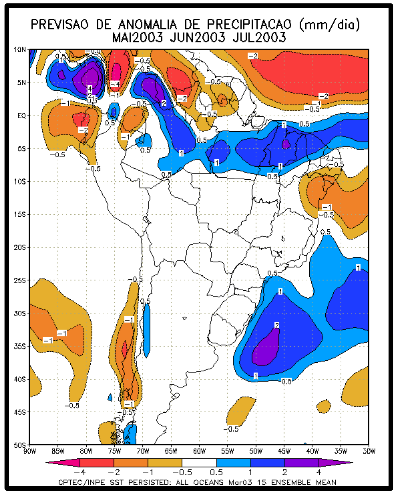
Climate Variability and Change: What can we predict and why.

Paulo Nobre (manuscript in preparation)

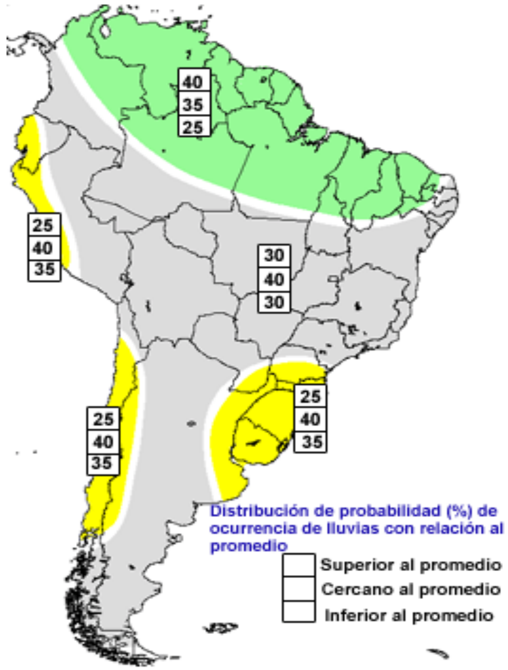
Seasonal Climate Prediction at CPTEC

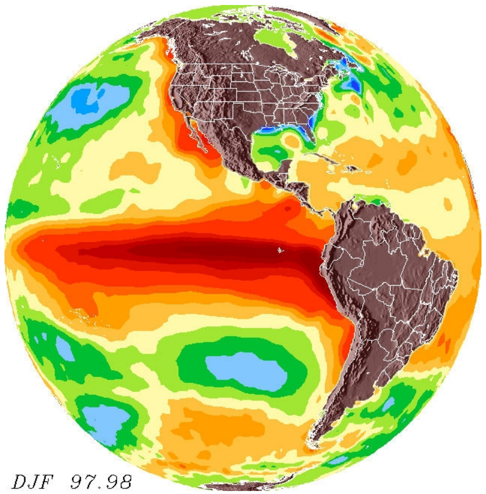
Models Suite

OBJECTIVE ENSEMBLE FORECAST



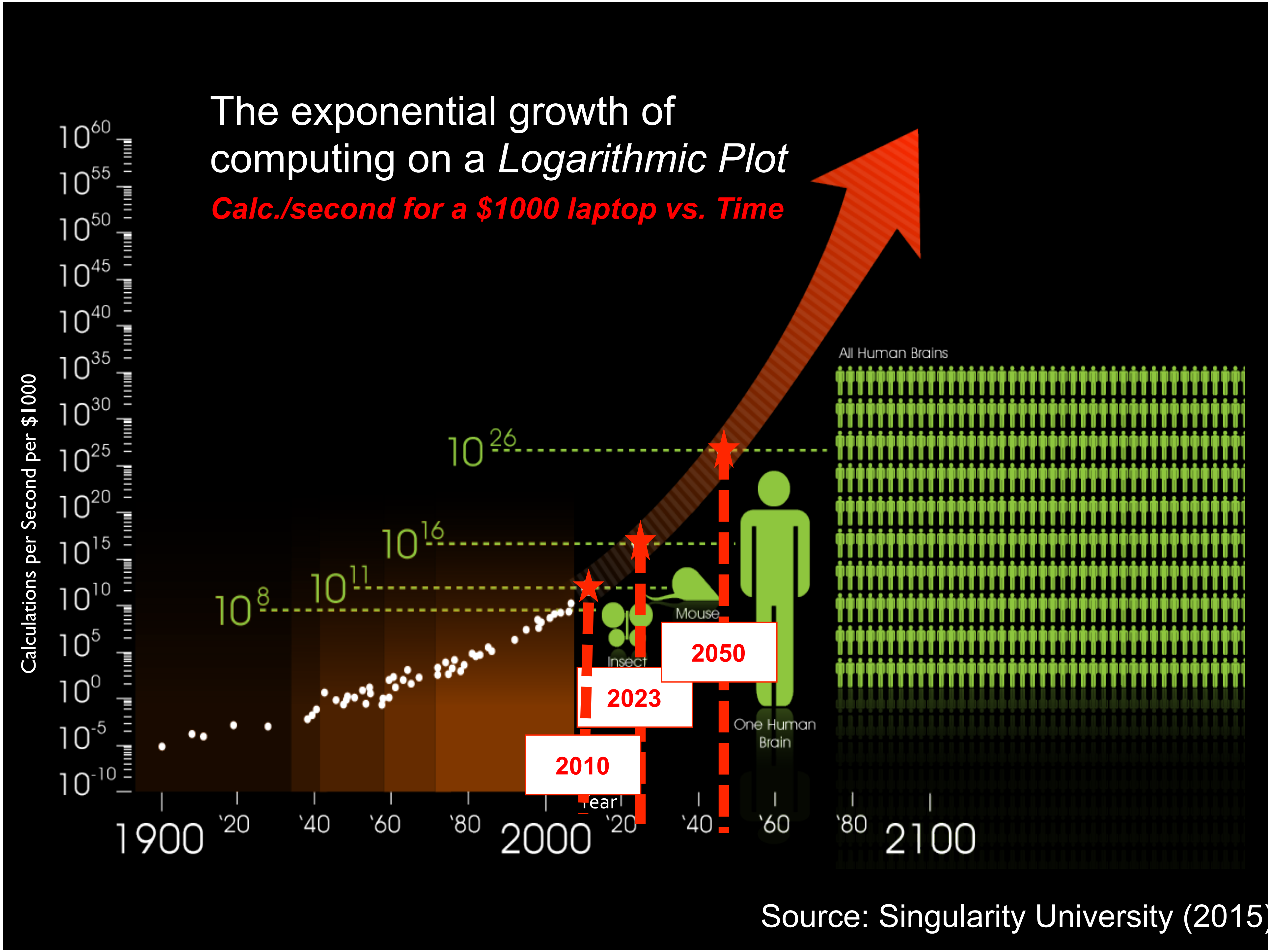
Consensus Forecast



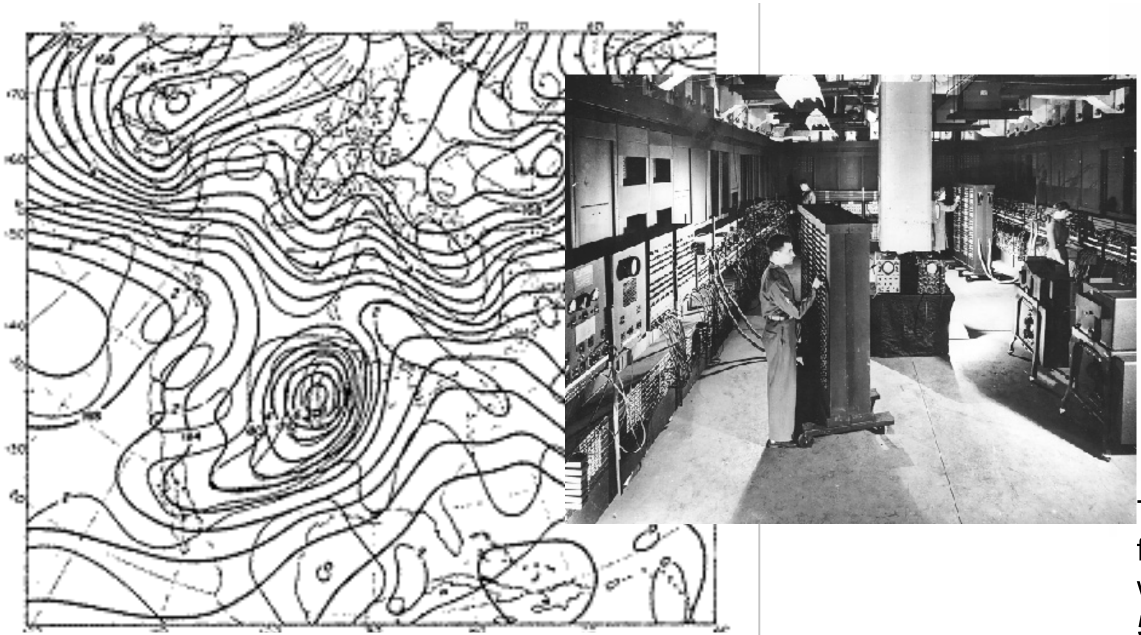


SST FORECASTS

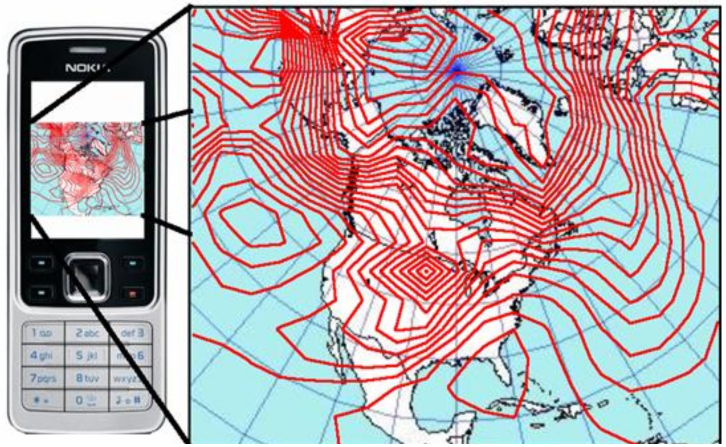
Climate Variability and Change: What can we predict and why.



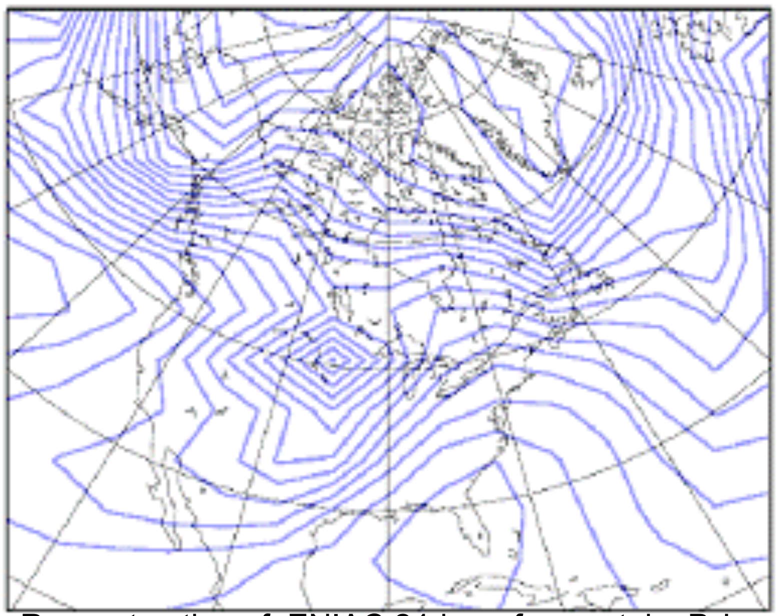
The exponential growth of computing on a *Logarithmic Plot*
Calc./second for a $1000 laptop vs. Time
Calculations per Second per $1000
10^60
10^55
10^50
10^45
10^40
10^35
10^30
10^25
10^20
10^15
10^10
10^5
10^0
10^-5
10^-10
10^26
10^16
10^11
10^8
All Human Brains
Mouse
Insect
One Human Brain
2050
2023
2010
Year
1900
'20
'40
'60
'80
2000
'20
'40
'60
'80
2100
Source: Singularity University (2015)



The ENIAC 24 h 500 hPa forecast starting at 0300 UTC, January 5, 1949. (Charney, et al., 1950).



The Nokia 6300, dubbed PHONIAC (left) and the forecast for 0300 UTC, January 6, 1949 (right) made with the program phoniac.jar. The contour interval is 50m. (by P.Lynch)



Reconstruction of ENIAC 24-hour forecast by P. Lynch

http://mathsci.ucd.ie/~plynch/Publications/PHONIAC.html

Climate Variability and Change: What can we predict and why.

Concluding remarks

- Tropical Oceans play a central role to predicting seasonal climate over the Americas
  - ENSO, NAO, AMM, ITCZ
- SACZ, however, still a challenge for both, 2-tier and 1-tier methods
- Systematic errors in 1-tier Coupled CGMs a major stone block to be studied, process resolved, models improved.