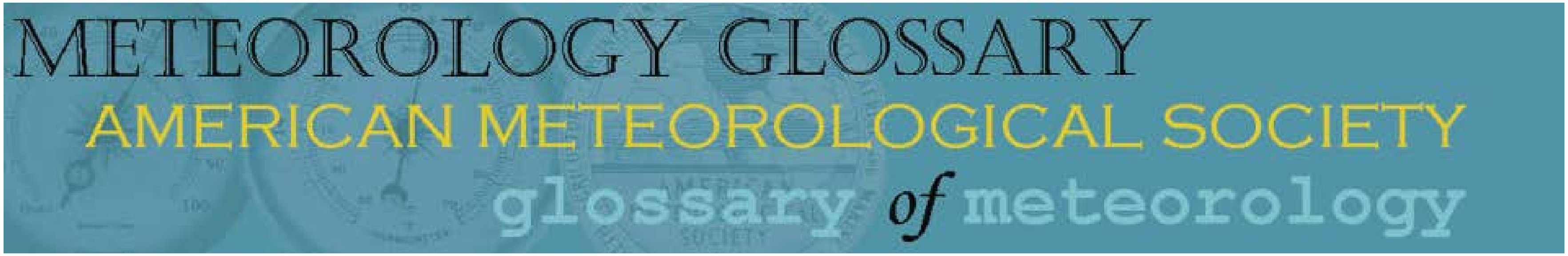
The Climate of the Amazonia
Local, regional and planetary connections

René D. Garreaud

Departamento de Geofísica y (CR)[2]
Universidad de Chile

Taller internacional sobre
MODELIZACIÓN AMBIENTAL EN AMAZONIA
Manaus, Brasil, Noviembre 2013



Teleconnection

A linkage between weather changes occurring in widely separated regions of the globe.

A significant positive or negative correlation in the fluctuations of a field at widely separated points.

Most commonly applied to variability on monthly and longer timescales, the name refers to the fact that such correlations suggest that information is propagating between the distant points through the atmosphere.

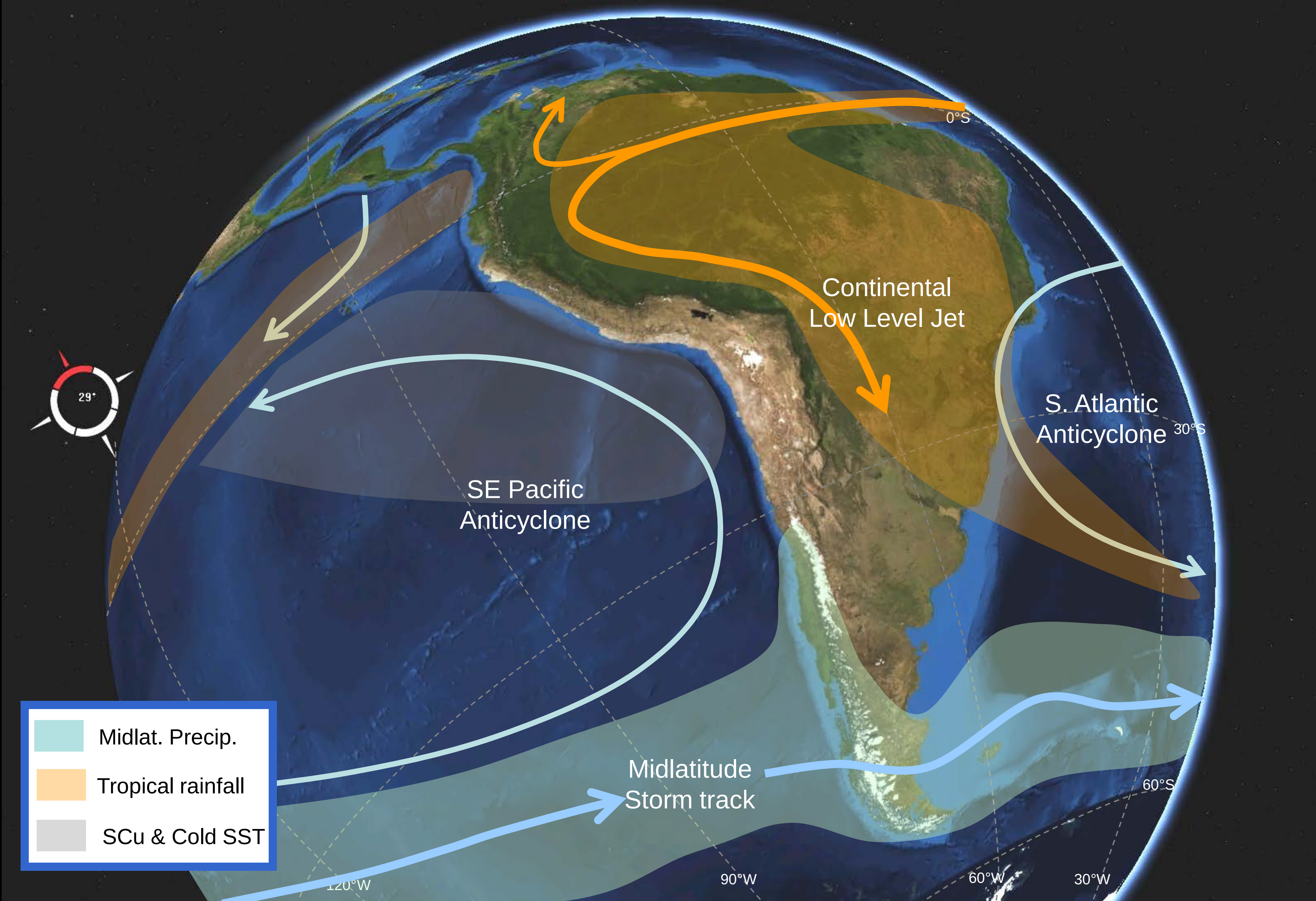
The Climate of the Amazonia
Local, regional and planetary connections

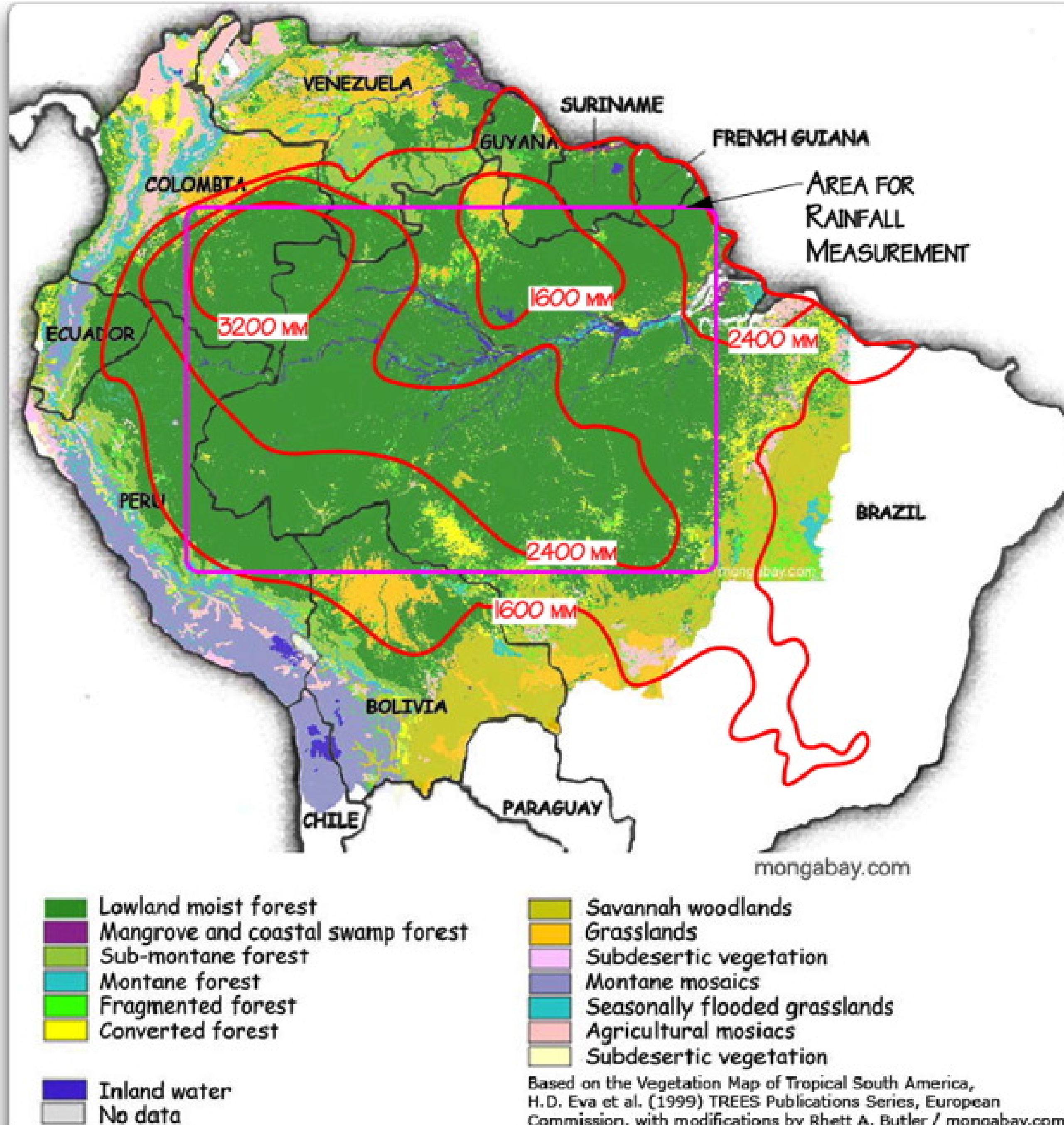
Outline

- Climatological aspects (mean annual and diurnal cycles)
- Interannual Variability (ENSO and Atlantic influences)
- Impacts of deforestation (local, regional and beyond)
- Climate Change (What is known and what is not)

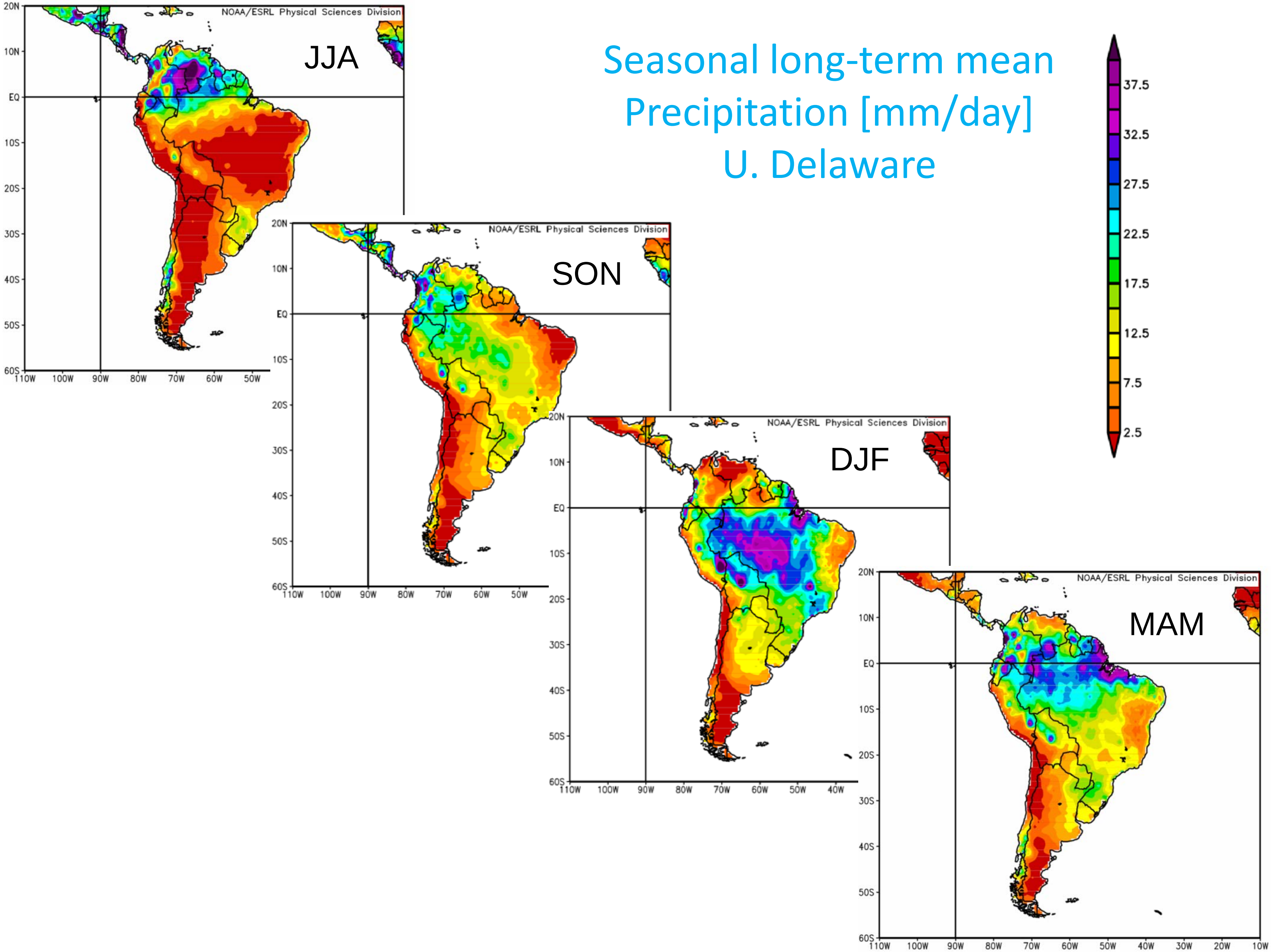
Geographical setting

The big picture



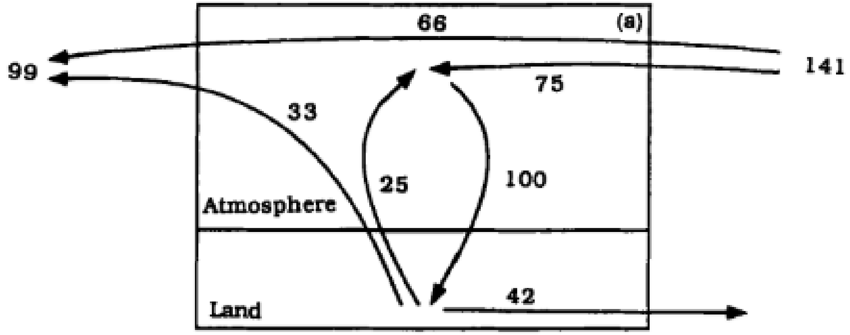

VENEZUELA
SURINAME
GUYANA
FRENCH GUIANA
COLOMBIA
AREA FOR
RAINFALL
MEASUREMENT
1600 MM
3200 MM
ECUADOR
2400 MM
PERU
BRAZIL
2400 MM
1600 MM
BOLIVIA
PARAGUAY
CHILE
mongabay.com
Lowland moist forest
Mangrove and coastal swamp forest
Sub-montane forest
Montane forest
Fragmented forest
Converted forest
Inland water
No data
Savannah woodlands
Grasslands
Subdesertic vegetation
Montane mosaics
Seasonally flooded grasslands
Agricultural mosiacs
Subdesertic vegetation
Based on the Vegetation Map of Tropical South America,
H.D. Eva et al. (1999) TREES Publications Series, European
Commission, with modifications by Rhett A. Butler / mongabay.com

Seasonal long-term mean Precipitation [mm/day] U. Delaware

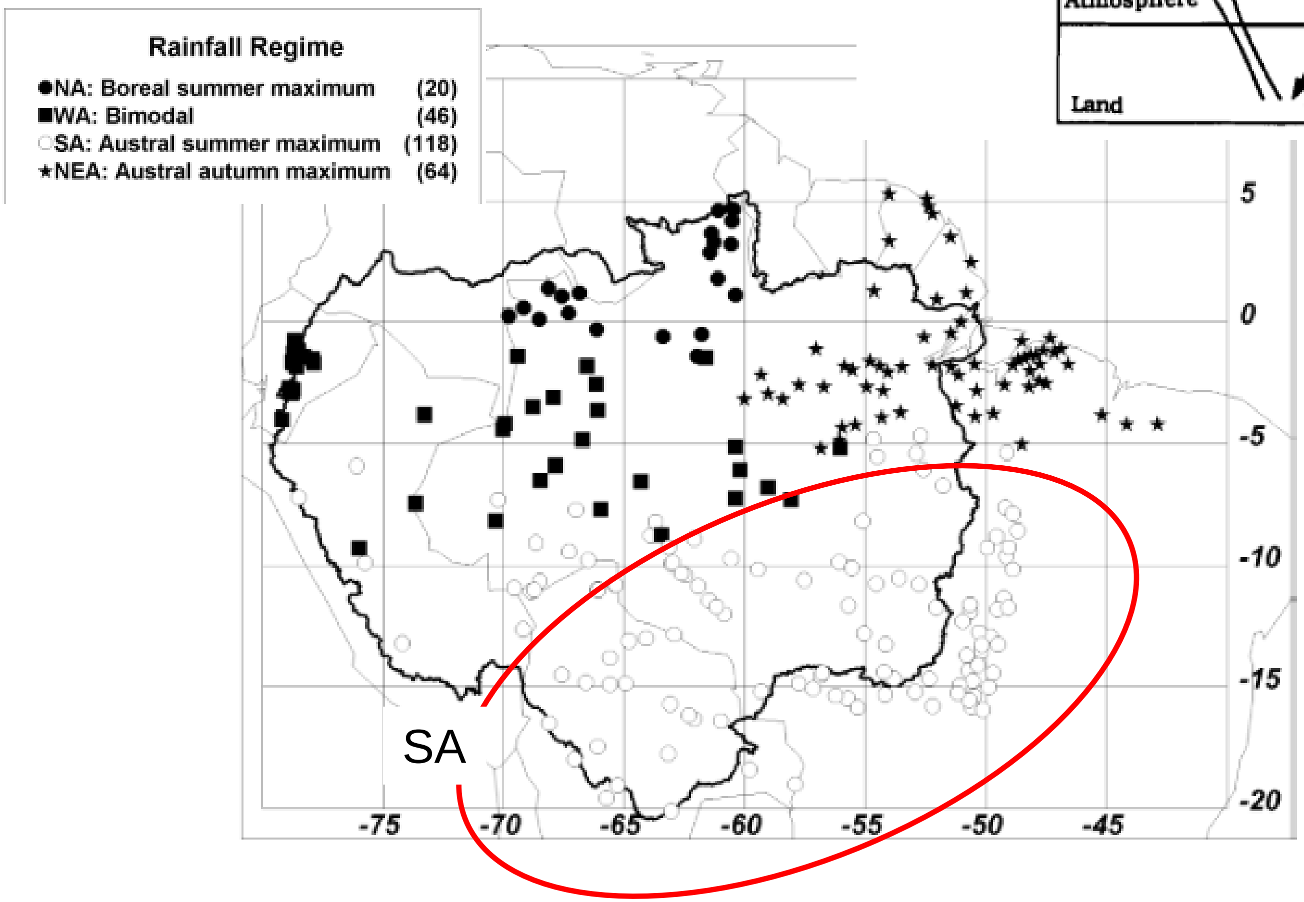


The annual cycle of precipitation in the Amazon region

Recall that 30-40% of the precipitation is recycled

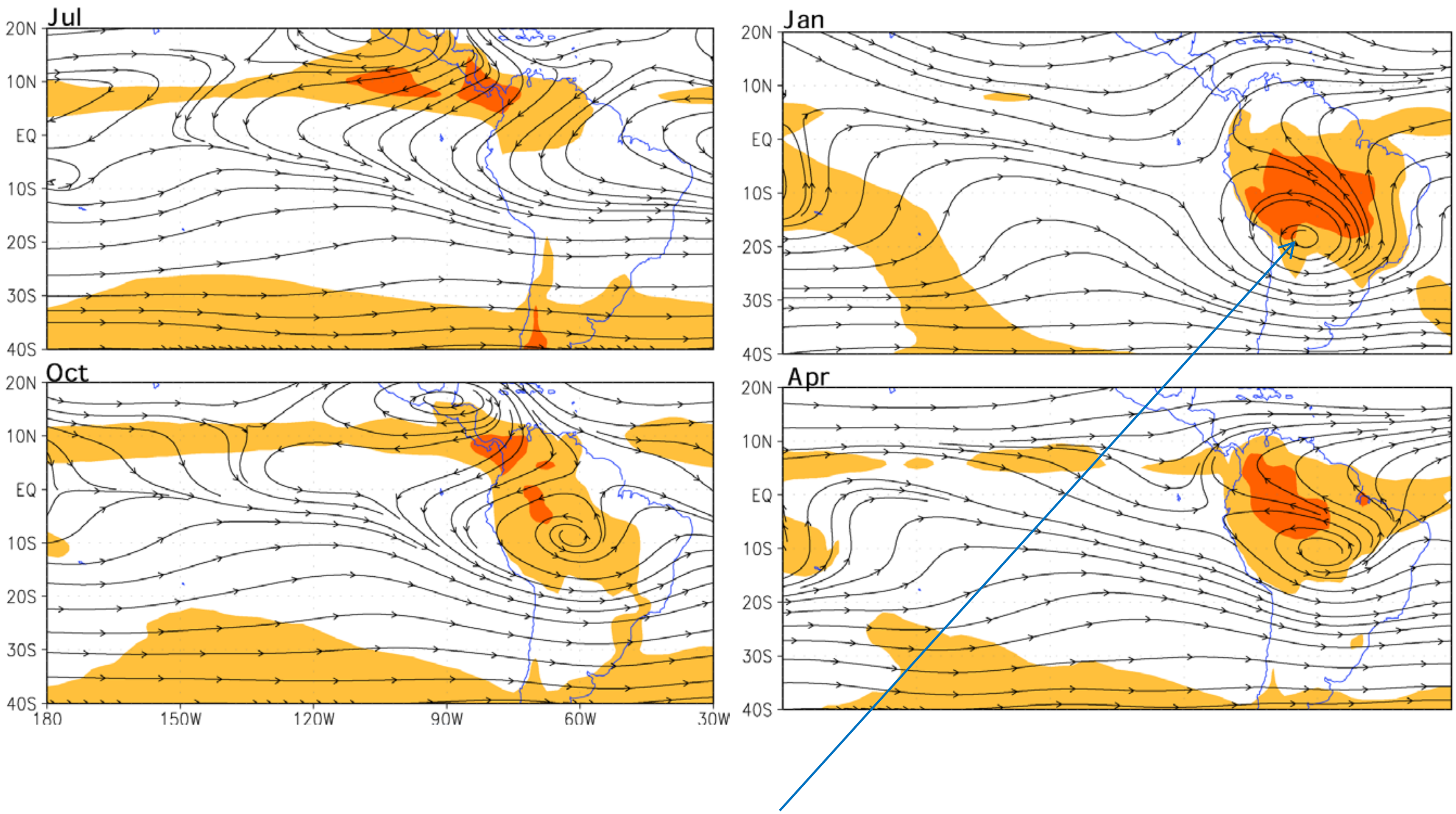


Eltahir and Brass 1995



Ronchail et al. 2002

Long-term-mean OLR (shaded; proxy of convection) and 200 hPa wind (stream lines at about 10 km ASL)



Bolivian High: Originally it was attributed to sensible heating over the Andes but then it was recognized that is largely due to diabatic heating over the Amazon basin. Very important for Altiplano precipitation during austral summer by providing moisture laden air from the interior of the continent…

Southeast South America Precipitation (SESA, warm season)

Northerly low-level jet provides much of the moisture for the southern Plains

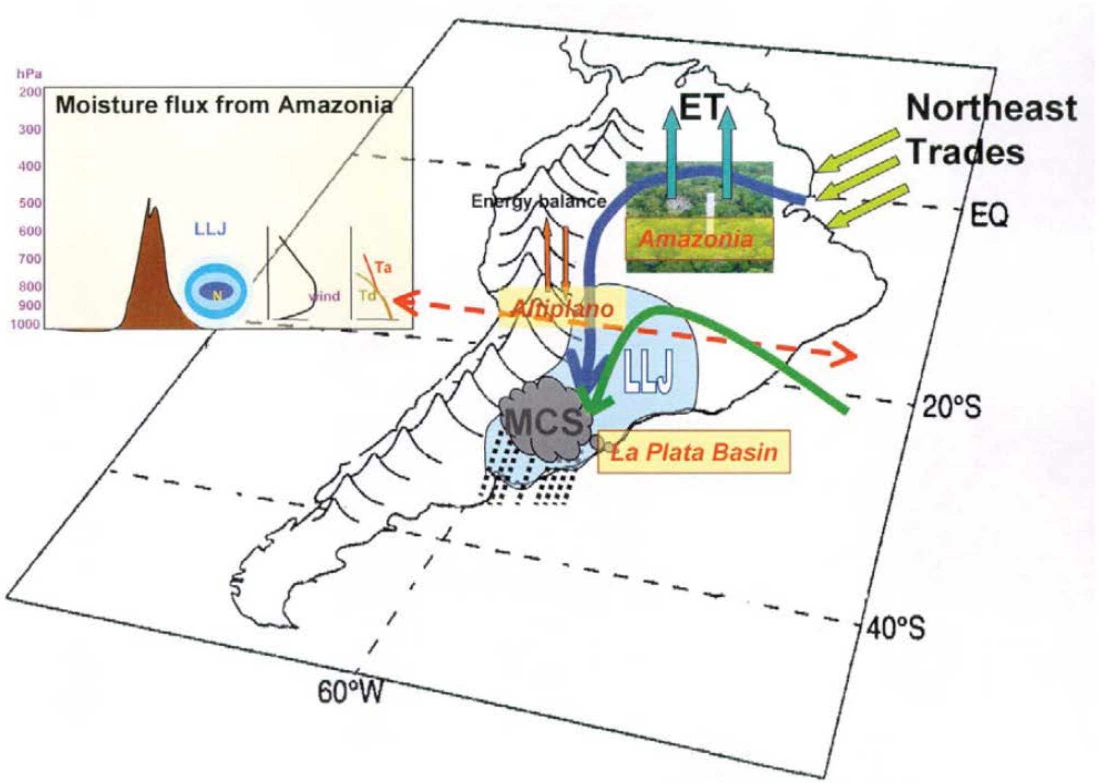
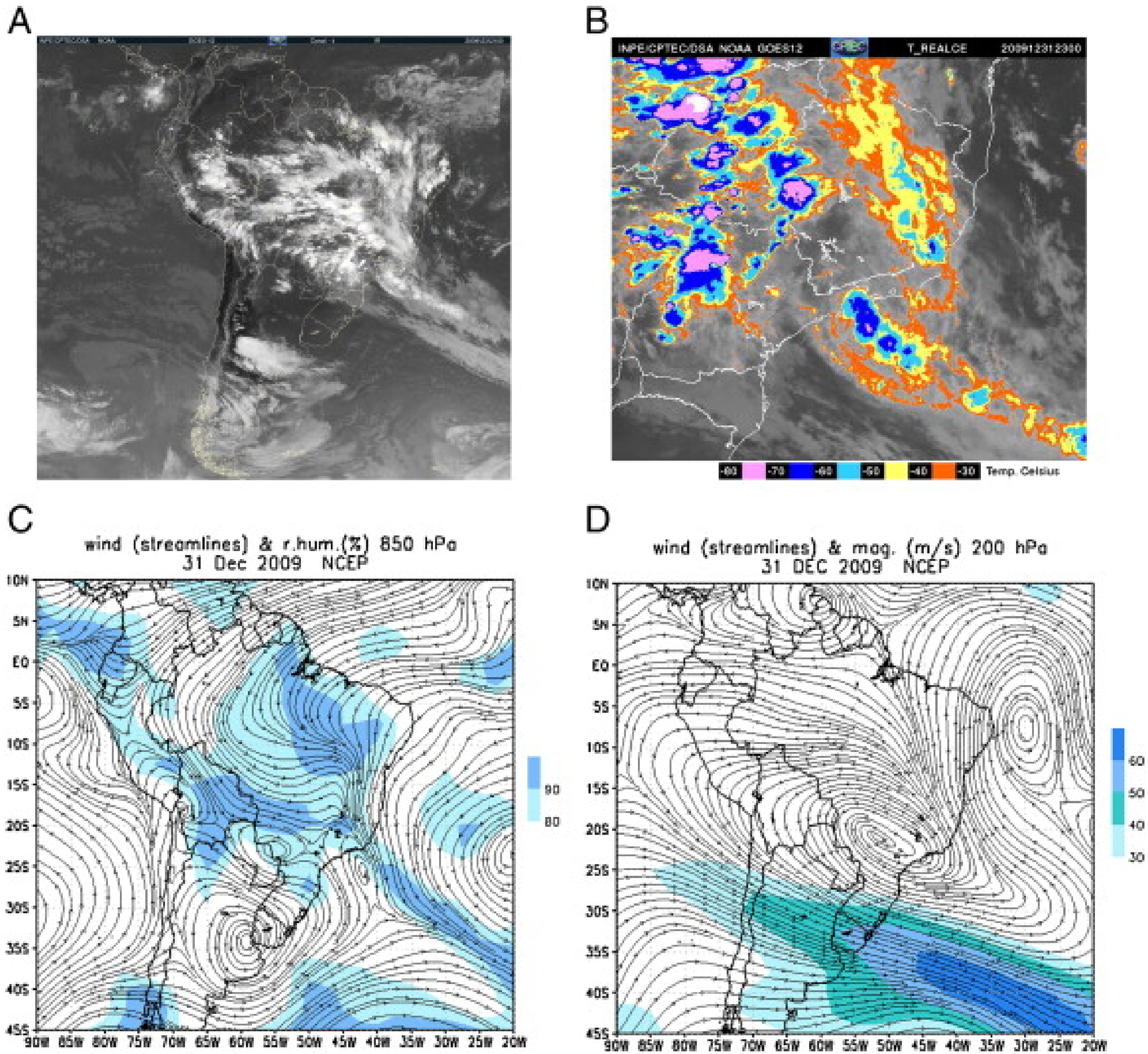


FIG. 1. Schematic diagram of elements relevant to poleward moisture transport over South America. Blue and green arrows depict the moisture transport into the continent from the tropical and South Atlantic Ocean, respectively. The inset represents a vertical cross section of the northerly flow along the red dashed line displayed in the diagram, including wind and temperature profiles representative of the LLJ core.

Vera et al. 2006 (BAMS)

Another feature influenced by the Amazon

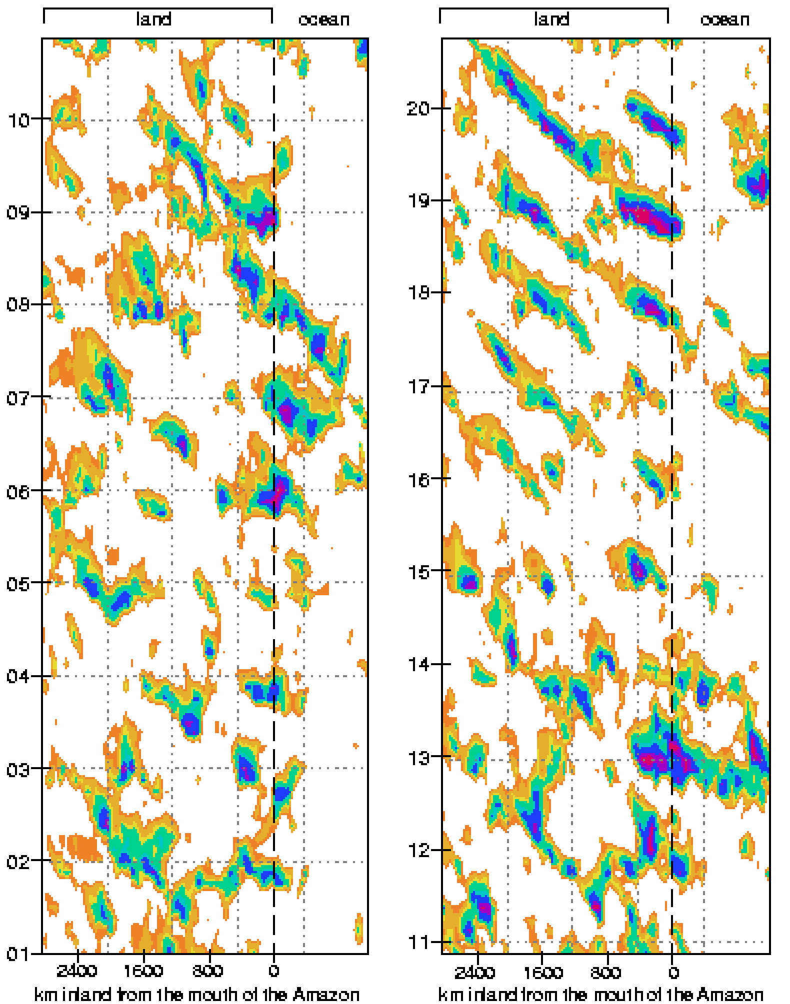
The South Atlantic Convergence Zone (SACZ)

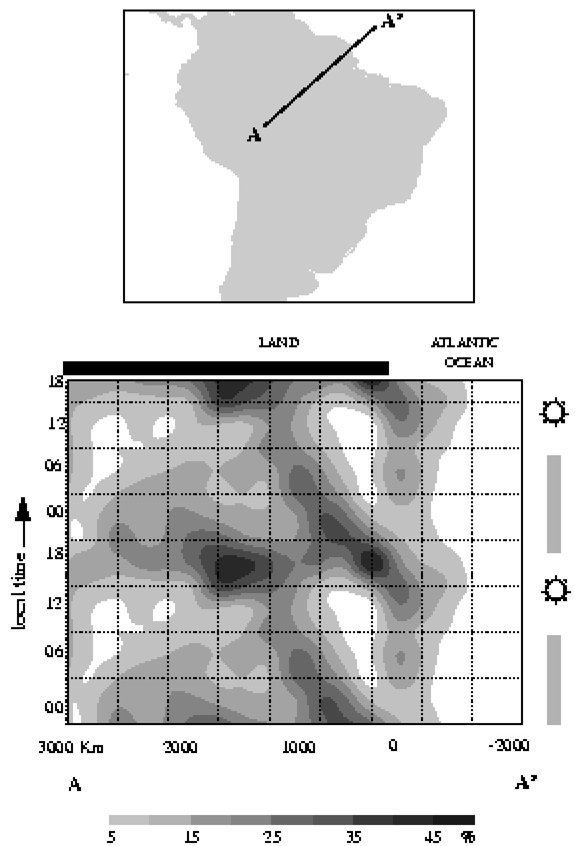


Iracema Fonseca Albuquerque Cavalcanti

The diurnal cycle of precipitation in the Amazon region

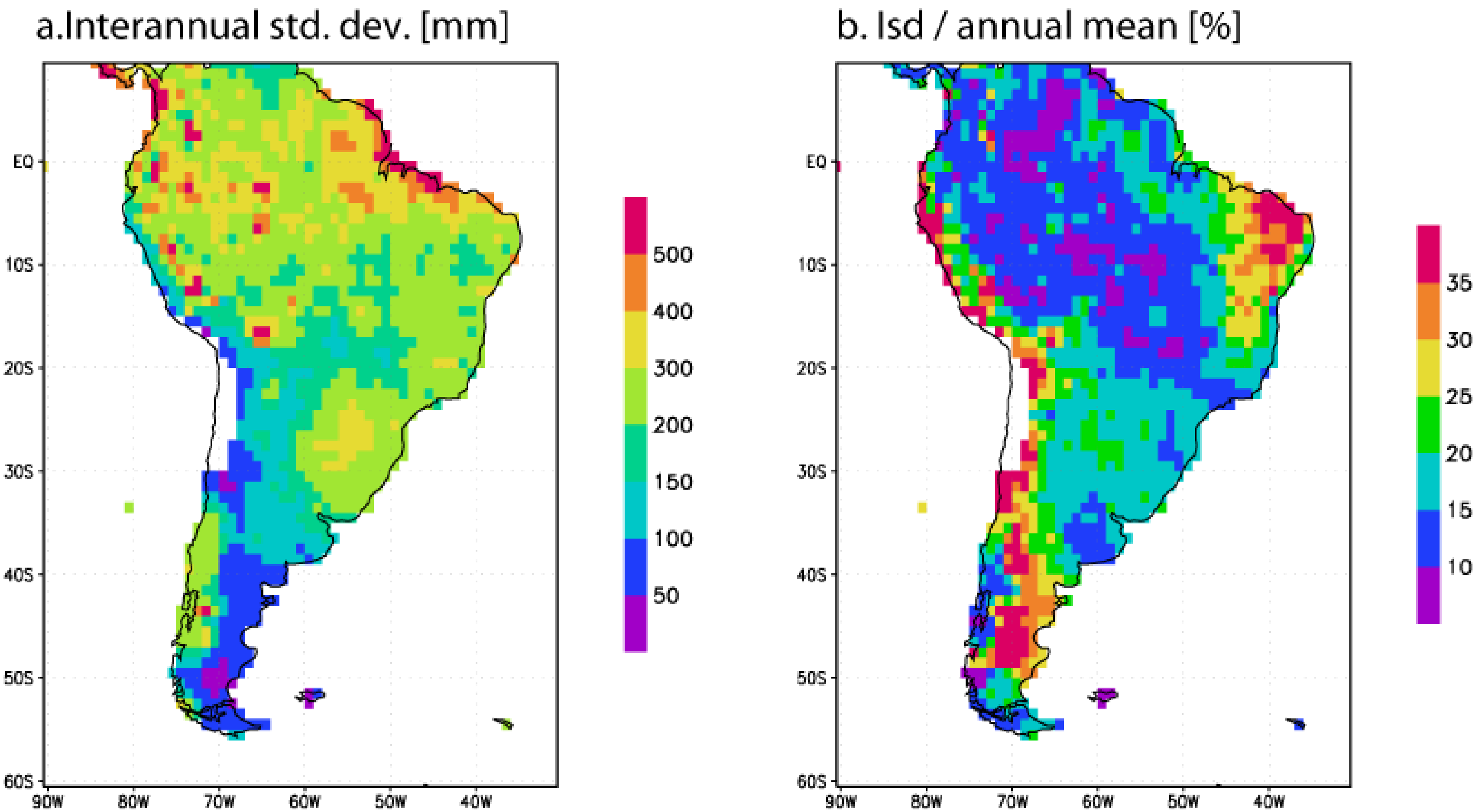
In addition to the increase in Cu Convection during afternoon, Amazon squall lines penetrate inland almost daily.



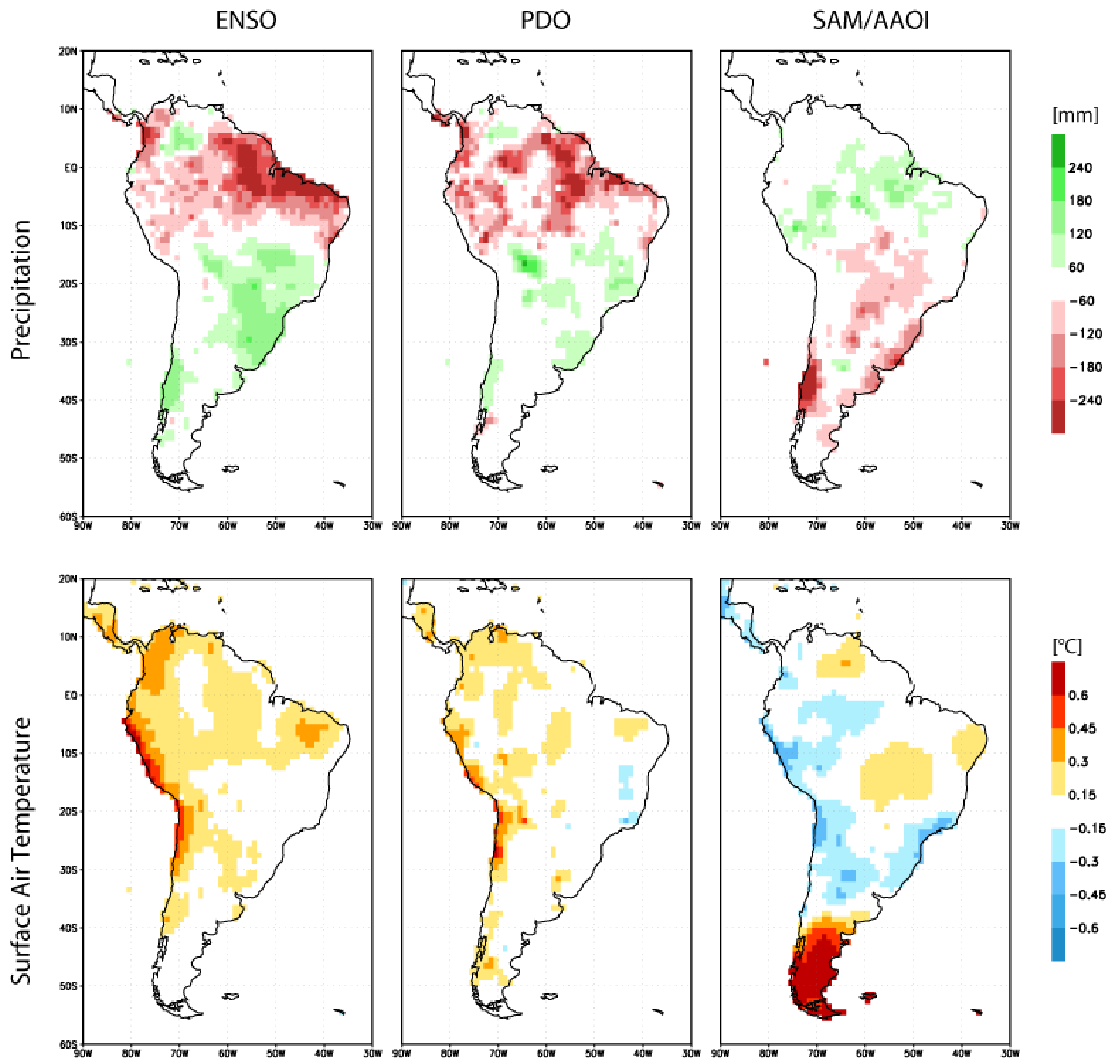


Interannual Precipitation Variability (UdW data)

Mostly externally forced, but some indications of internal variability

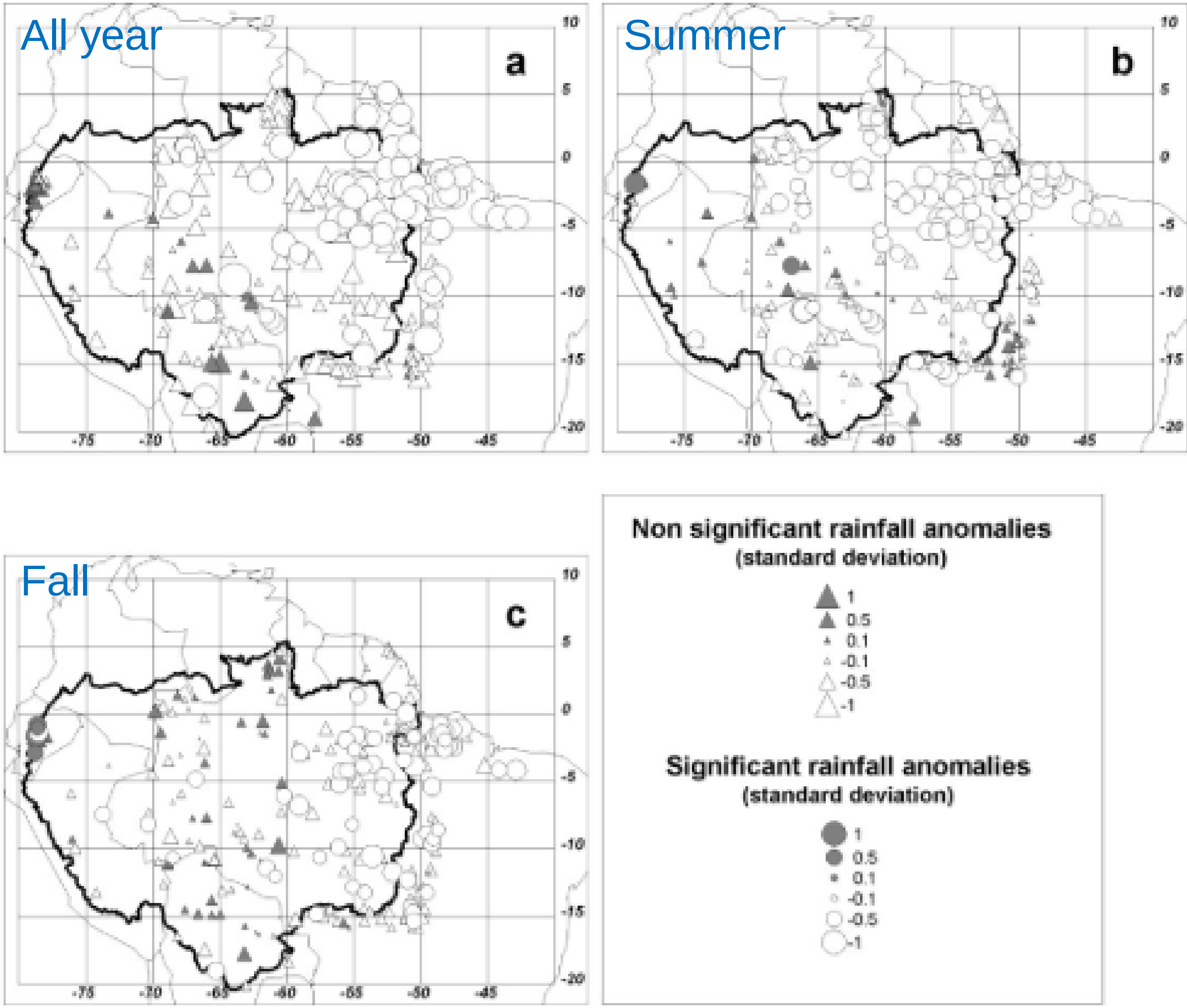


Annual mean Precipitation/SAT regressed upon index of large-scale modes (50 years of data)



Garreaud et al 2008

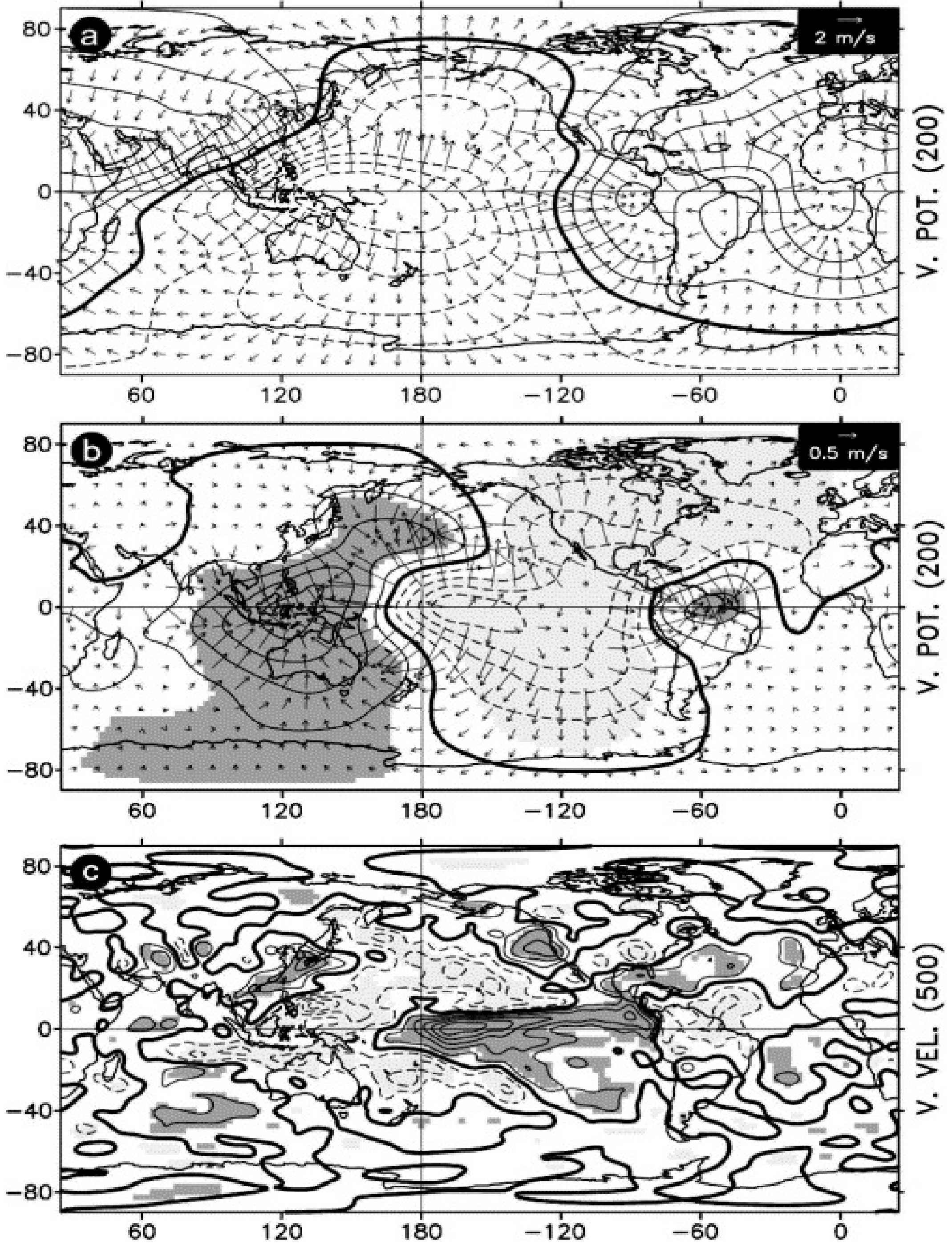
ENSO Impacts over the Amazon basin



Ronchail et al. 2002

Climo

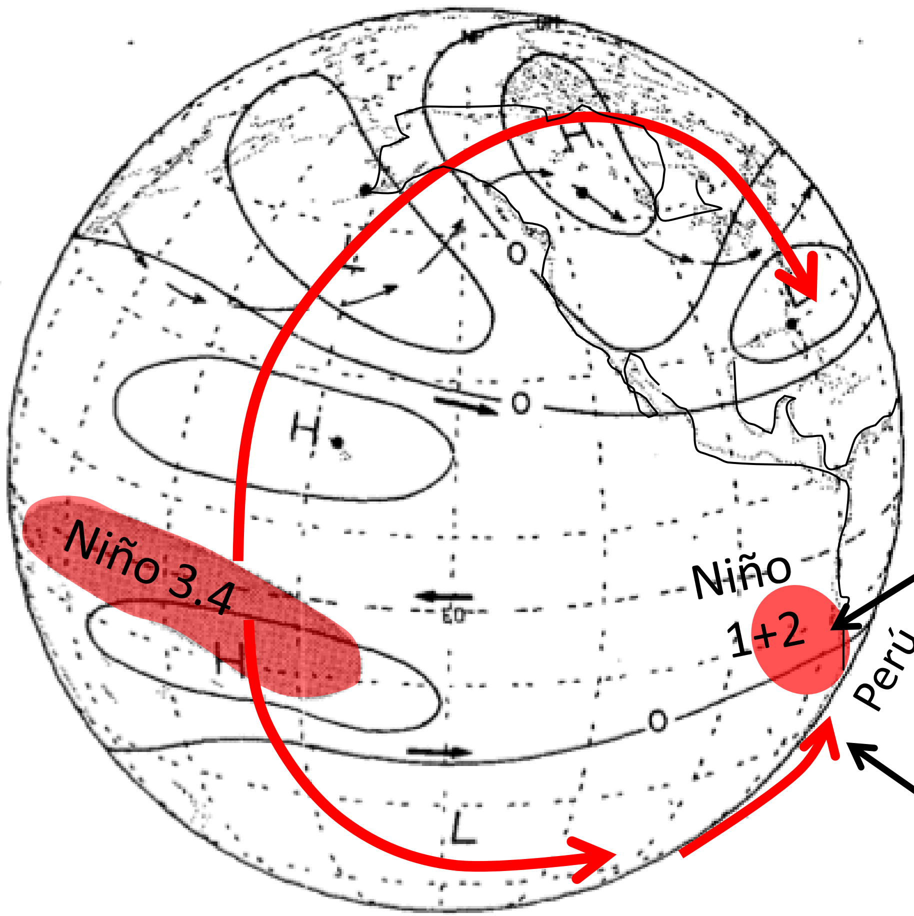
ENSO



Enfield et al. 2006

Atmospheric teleconnections

The eastward displacement of convection acts as an anomalous heat source that forces planetary scale atmospheric waves that alter the climate worldwide.



Local effect

Warming and coastal rain

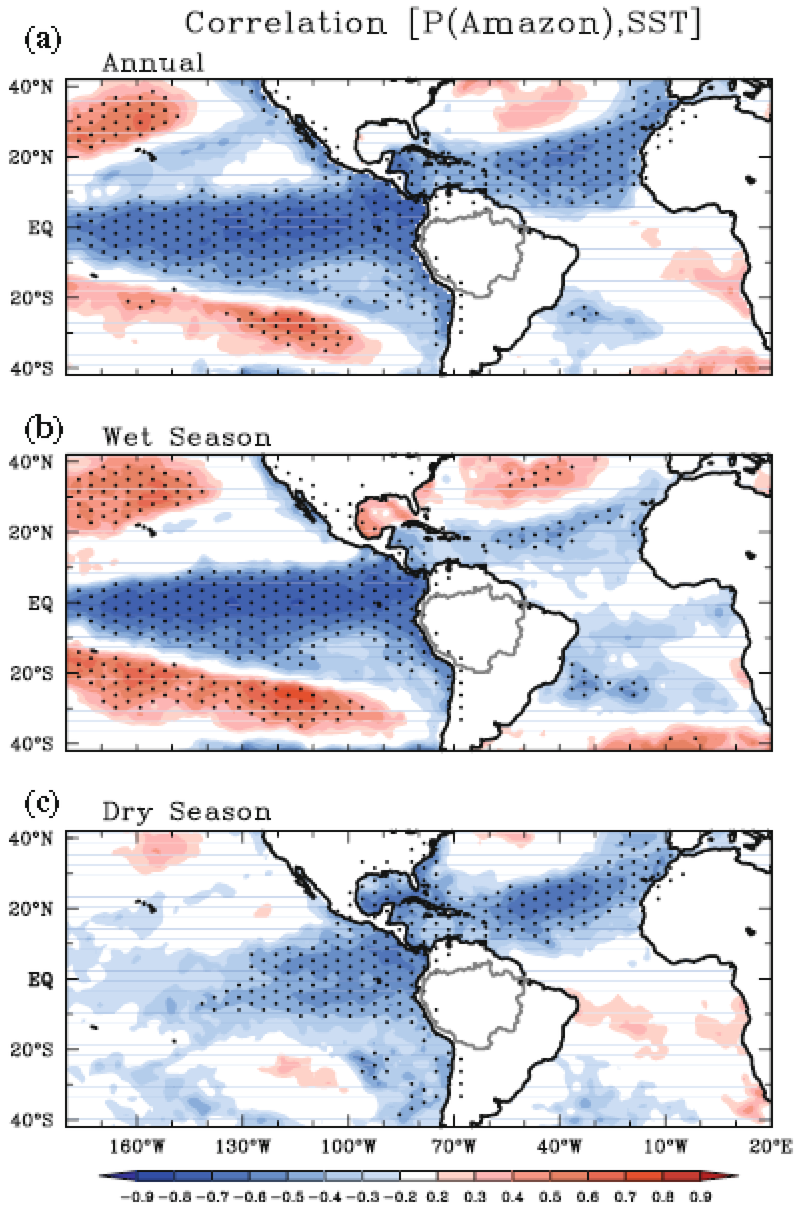
Remote effect

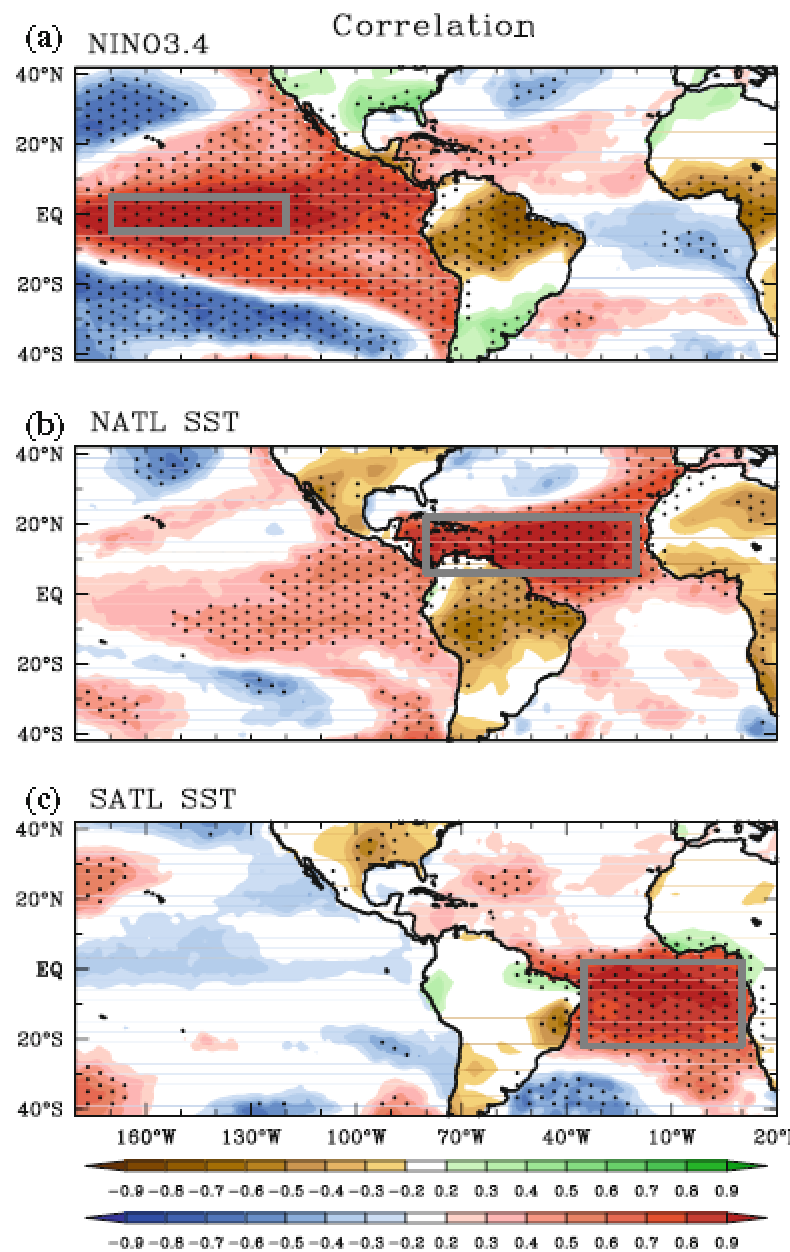
Reduction in rainfall on the Andes

FIG. 11. Schematic illustration of the hypothesized global pattern of middle and upper tropospheric geopotential height anomalies (solid lines) during a Northern Hemisphere winter which falls within an episode of warm sea surface temperatures in the equatorial Pacific. The arrows in darker type reflect the strengthening of the subtropical jets in both hemispheres along with stronger easterlies near the equator during warm episodes. The arrows in lighter type depict a mid-tropospheric streamline as distorted by the anomaly pattern, with pronounced "troughing" over the central Pacific and "ridging" over western Canada. Shading indicates regions of enhanced cirriform cloudiness and rainfall. For further details see Section 7. The locations of the stations used in Table 4 are indicated by dots.

Horel & Wallace 1981

The Pacific and Atlantic Impacts over the Amazon basin

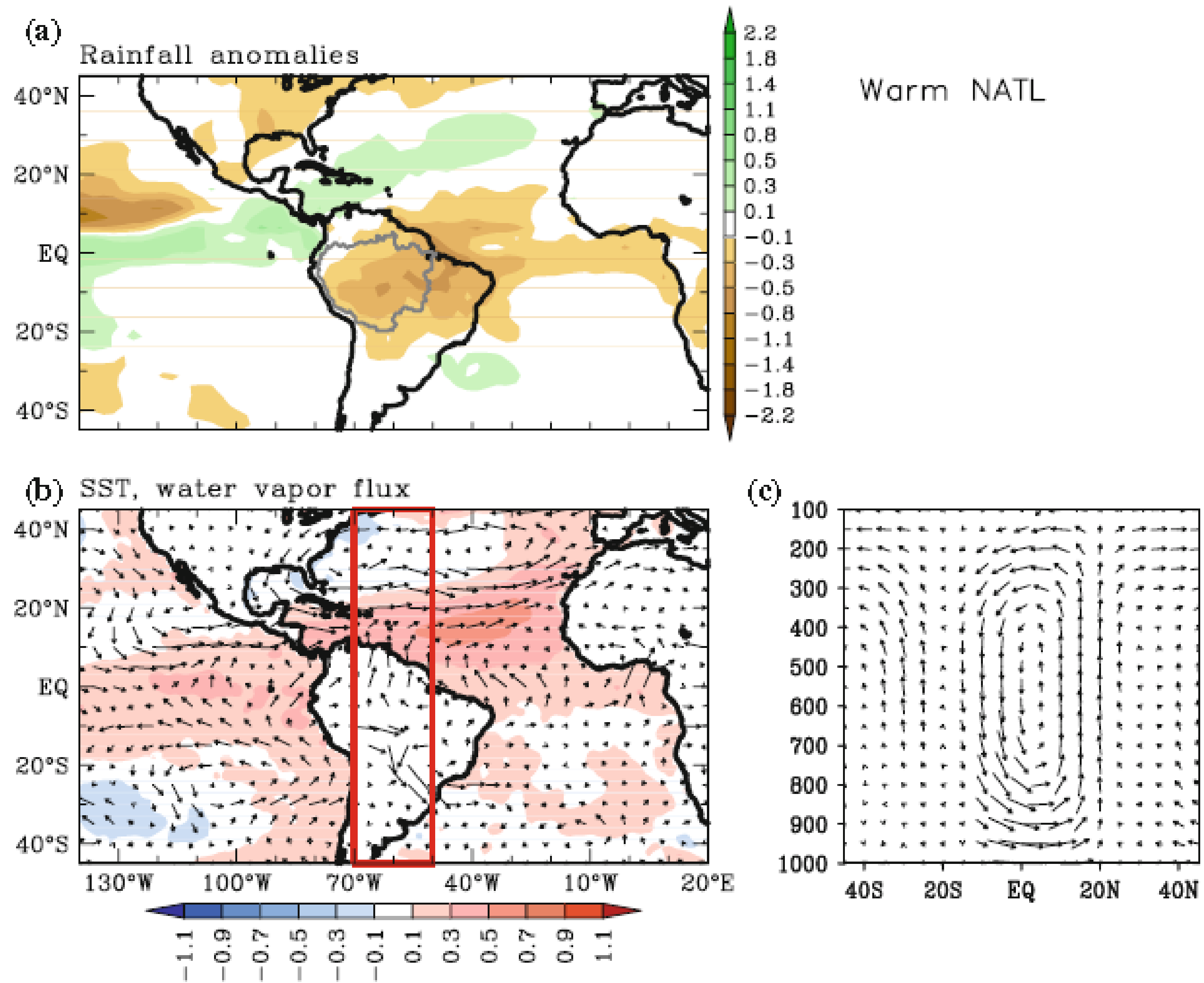


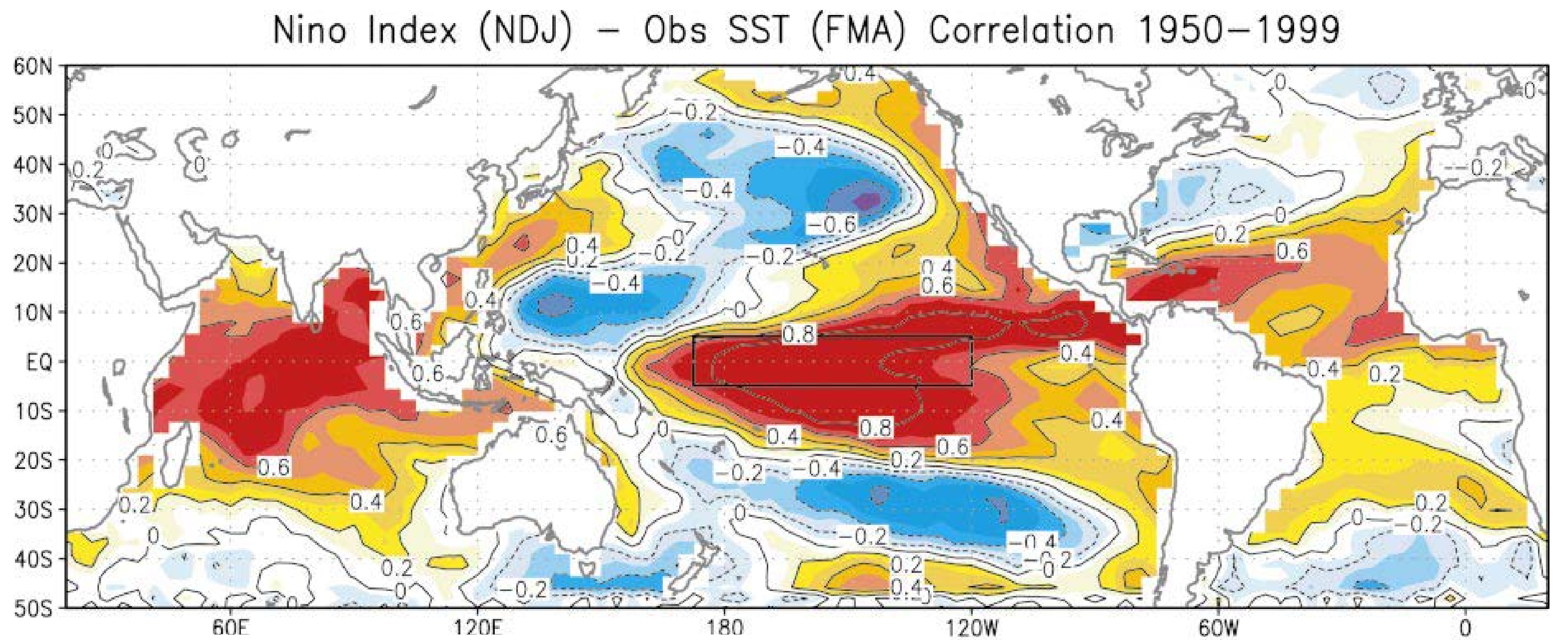


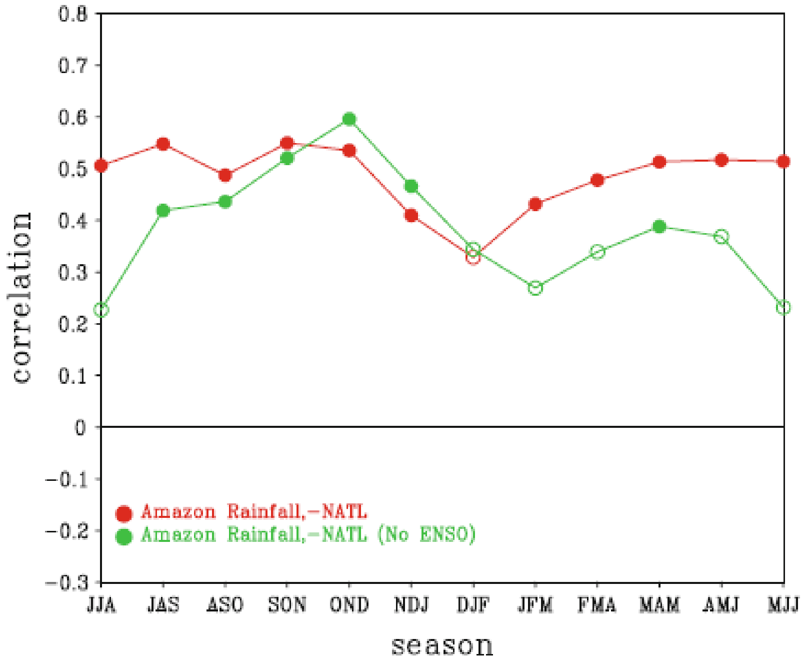
Yoon and Zeng 2010

The Pacific and Atlantic Impacts over the Amazon basin

Fig. 5 The composite patterns with the warm North Atlantic SST condition of (a) rainfall (b) SST and atmospheric water vapor flux, and (c) local north-south divergent circulation, or Atlantic Hadley Cell in Wang (2002). SST data is from the Hadley Center and atmospheric wind and water vapor flux are constructed from NCEP-R2 reanalysis. Cross-section of local north-south divergent circulation (v_D, $-\omega$) is averaged over 70–50°W (indicated by the *red box* in **b**)





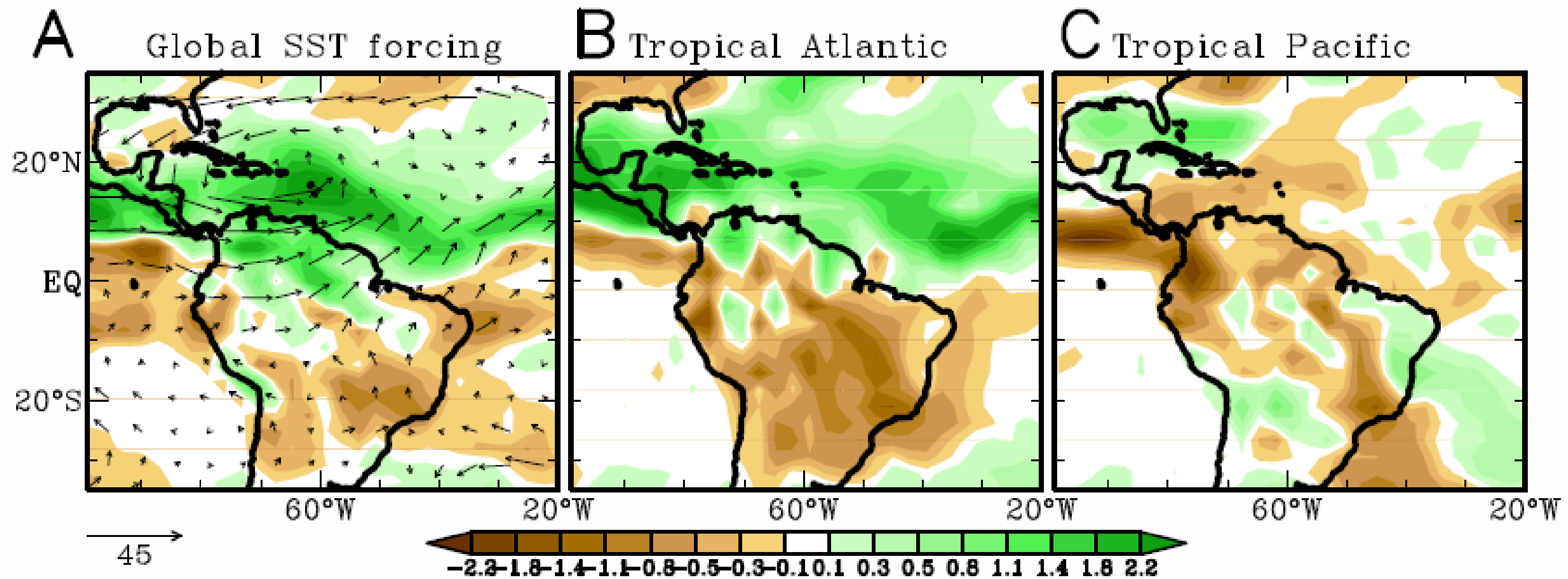


The influence of the NATL SST on Amazon rainfall stands alone only during winter, spring. In some cases, it can extends the ENSO signal from summer….

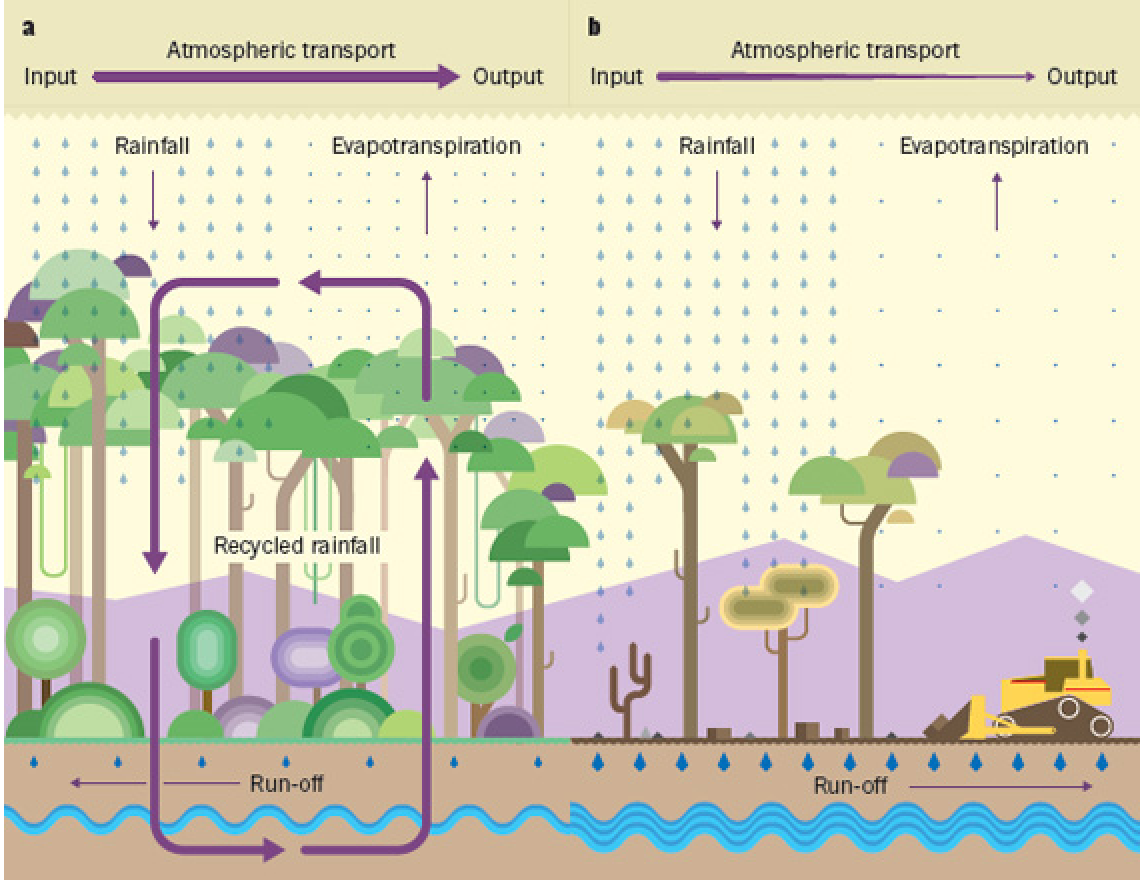
Yoon and Zeng 2010

Causes and Impact of the 2005 Amazon Drought

Ning Zeng*,[1,2], Jin-Ho Yoon[1], Jose A. Marengo[3], Ajit Subramaniam[4],
Carlos A. Nobre[3], Charon M. Birkett[2]



Amazon deforestation impacts on climate



http://news.mongabay.com/2012/0905-effects-of-deforestation-on-rainfall.html

Amazon deforestation impacts on climate

Substitution of tall, deep-rooted, evergreen trees by pasture results in local changes of a number of physical and physiological characteristics, including:

- Increased albedo (Albedo mechanism: decreased SW Radiation → Susbidence)
- Decreased surface roughness (Reduced latent heat flux → higher sfc Temp)
- Increased in stomatal resistance
- Shallower and sparse root system
- Decreased root-zone water capacity

} Reduced moisture flux into PBL

Local climate change due to deforestation has been addressed by several studies using atmospheric numerical models in which vegetation changes are prescribed. The models are integrated for several years to reach a steady state (equilibrium) the control and deforested runs are contrasted. The differences (Def-Ctr) are quite consistent among the models, including:

- Increase in near surface air temperature and soil temperature, 1-3C
- Reduced evapotranspiration (-100 to -500 mm/year)
- An even larger decrease in precipitation (-200 to -600 mm/year)

TABLE 1. Comparison of GCM simulations of Amazon deforestation. Modified from Nobre (1994, personal communication). Moisture convergence difference ΔC is calculated as the difference of ΔP and ΔE ($\Delta C = \Delta P - \Delta E$).

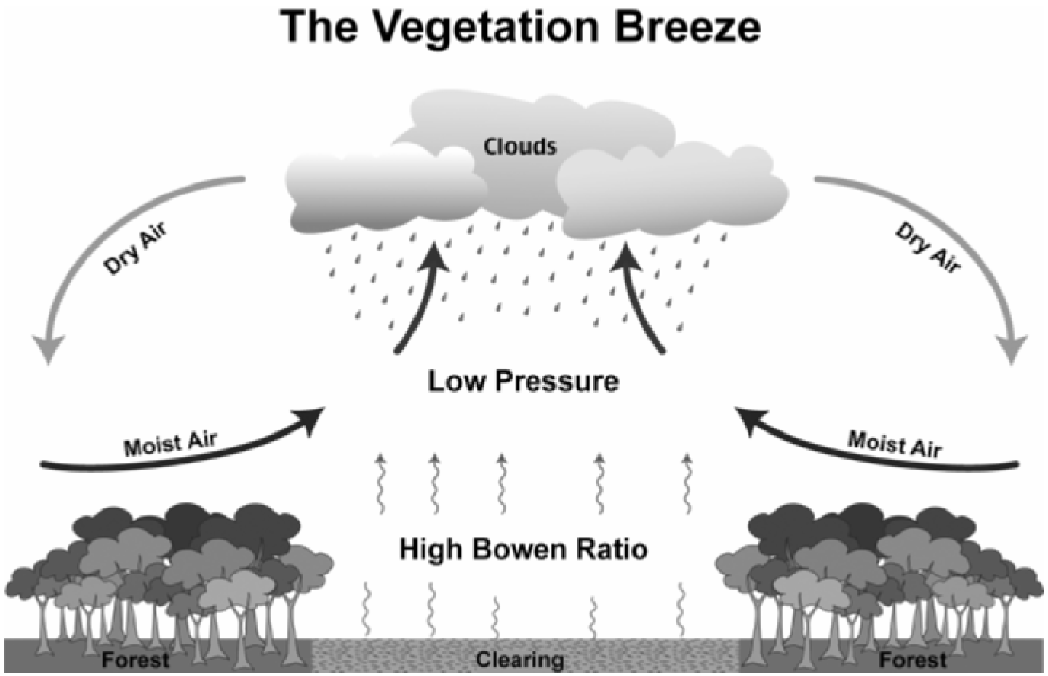
GCM Simulation of Amazonia Deforestation				
Reference[a]	ΔT (°C)	ΔP (mm day^{-1})	ΔE (mm day^{-1})	ΔC (mm day^{-1})
H.-S. & G (1984)	0	−0.6	−0.45	−0.15
DHS (1988)	+3	0	−0.56	+0.56
Lean and Warrilow (1989)	+2.4	−1.34	−0.85	−0.49
Nobre et al. (1991)	+2	−1.75	−1.37	−0.38
Dirmeyer (1992)	+1.3	+0.09	−0.4	+0.49
Dickinson and Kennedy (1992)	+0.6	−1.4	−0.7	−0.7
H.-S. et al. (1993)	+0.6	−1.61	−0.64	−0.97
Lean and Rowntree (1993)	+2.1	−0.81	−0.55	−0.26
Polcher and Laval (1993)	−0.11	−0.51	−0.35	−0.16
Sud et al. (1996)	+2.0	−1.48	−1.22	−0.26
Lean et al. (1996)	+2.3	−0.43	−0.81	+0.38
McGuffie et al. (1995)	+0.3	−1.2	−0.63	−0.56
Hahmann and Dickinson (1995)	+0.8	−0.75	−0.41	−0.37

[a] H.-S. & G: Henderson-Sellers and Gornitz; DHS: Dickinson and Henderson-Sellers.

Note that ΔP is generally larger than ΔE indicative of a reduction in large-scale moisture convergence. Such change is not trivial and signals a multiple equilibrium system.

Zeng et al. 1995

Partial deforestation may induce mesoscale circulations that tend to dry adjacent forest….



Cochrane and Laurence 2008

Regional Impacts of Future Land-Cover Changes on the Amazon Basin Wet-Season Climate

RENATO RAMOS DA SILVA, DAVID WERTH, AND RONI AVISSAR 2008

Duke University, Durham, North Carolina

Deforestation Pattern

JF precipitation anomaly

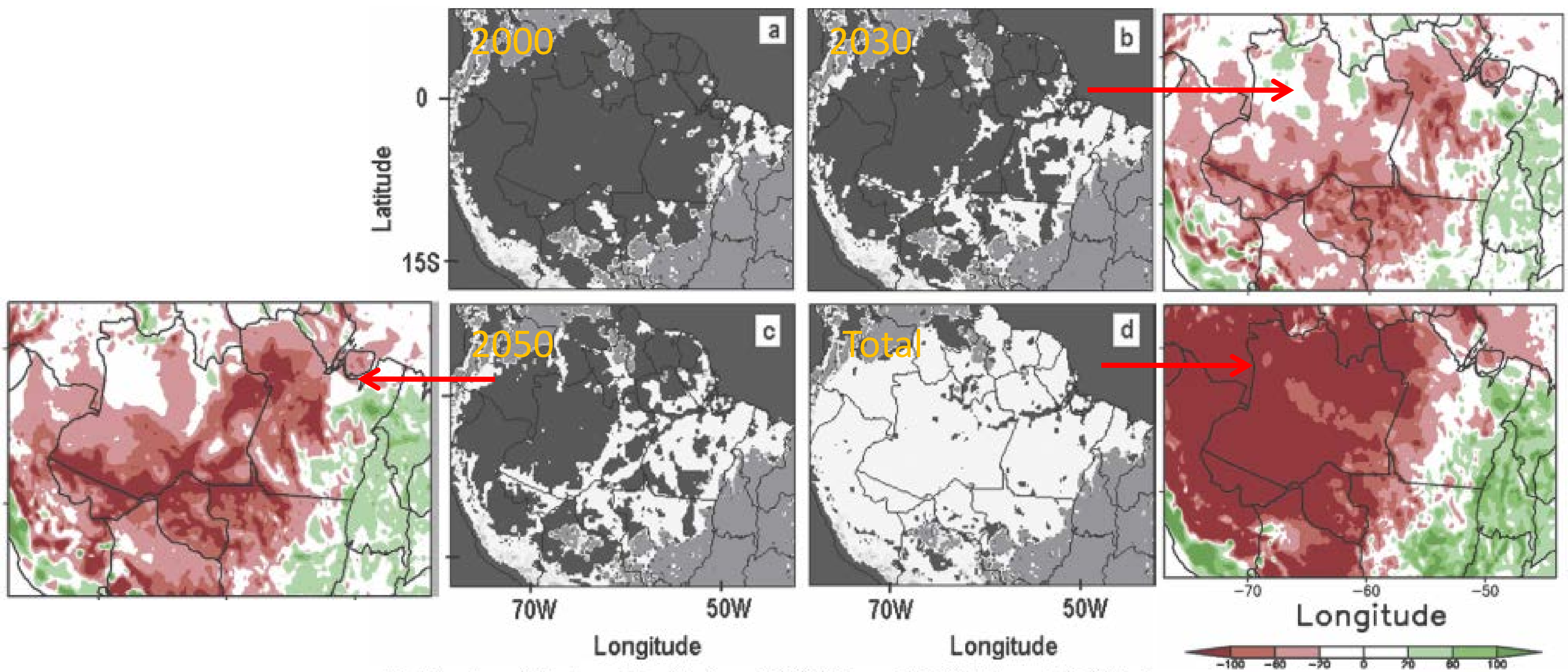
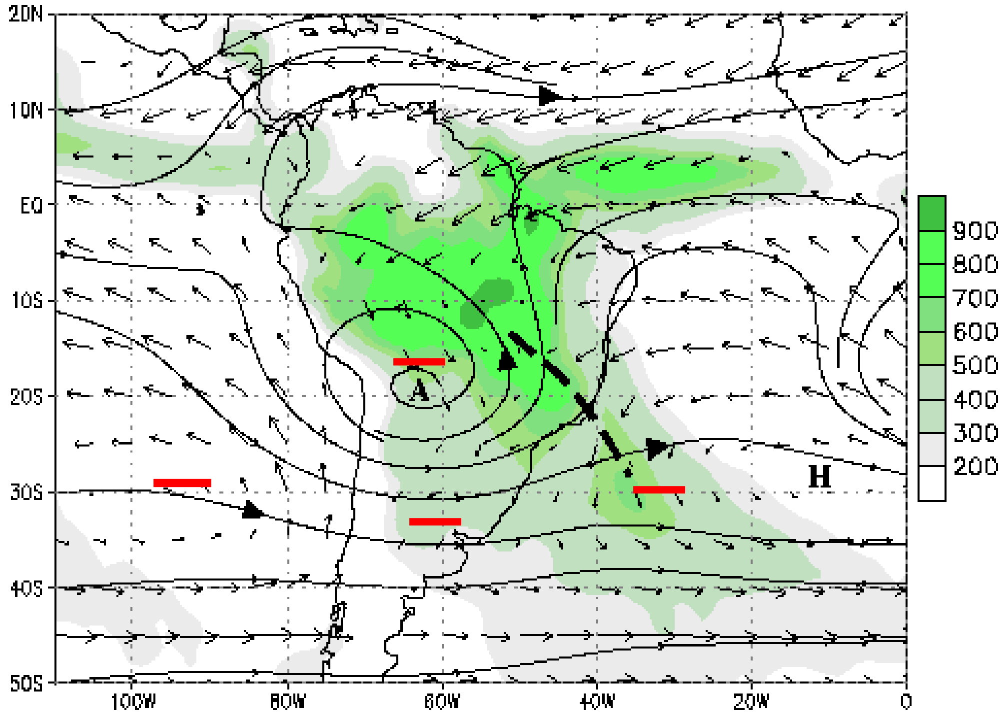


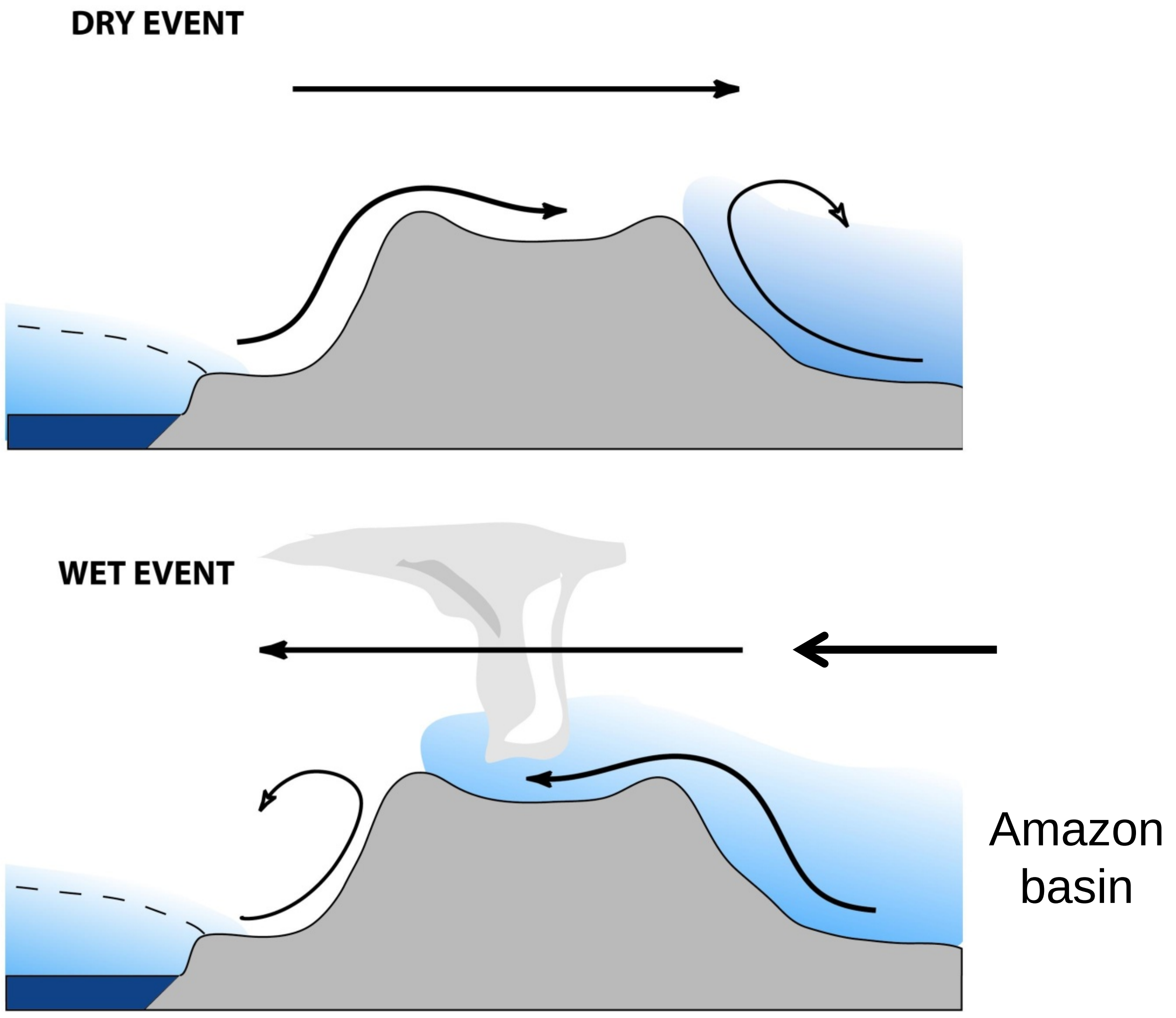
FIG. 1. Land cover in the Amazon basin: (a) observed in 2000, (b) scenario for 2030, (c) scenario for 2050, and (d) total deforestation. Dark gray represents forest, white is pasture, and light gray is mixed woodland. Scenarios for 2030 and 2050 are "business as usual," as estimated by Soares-Filho et al. (2004).

Regional-scale climate impacts induced by Amazon deforestation…during summer:

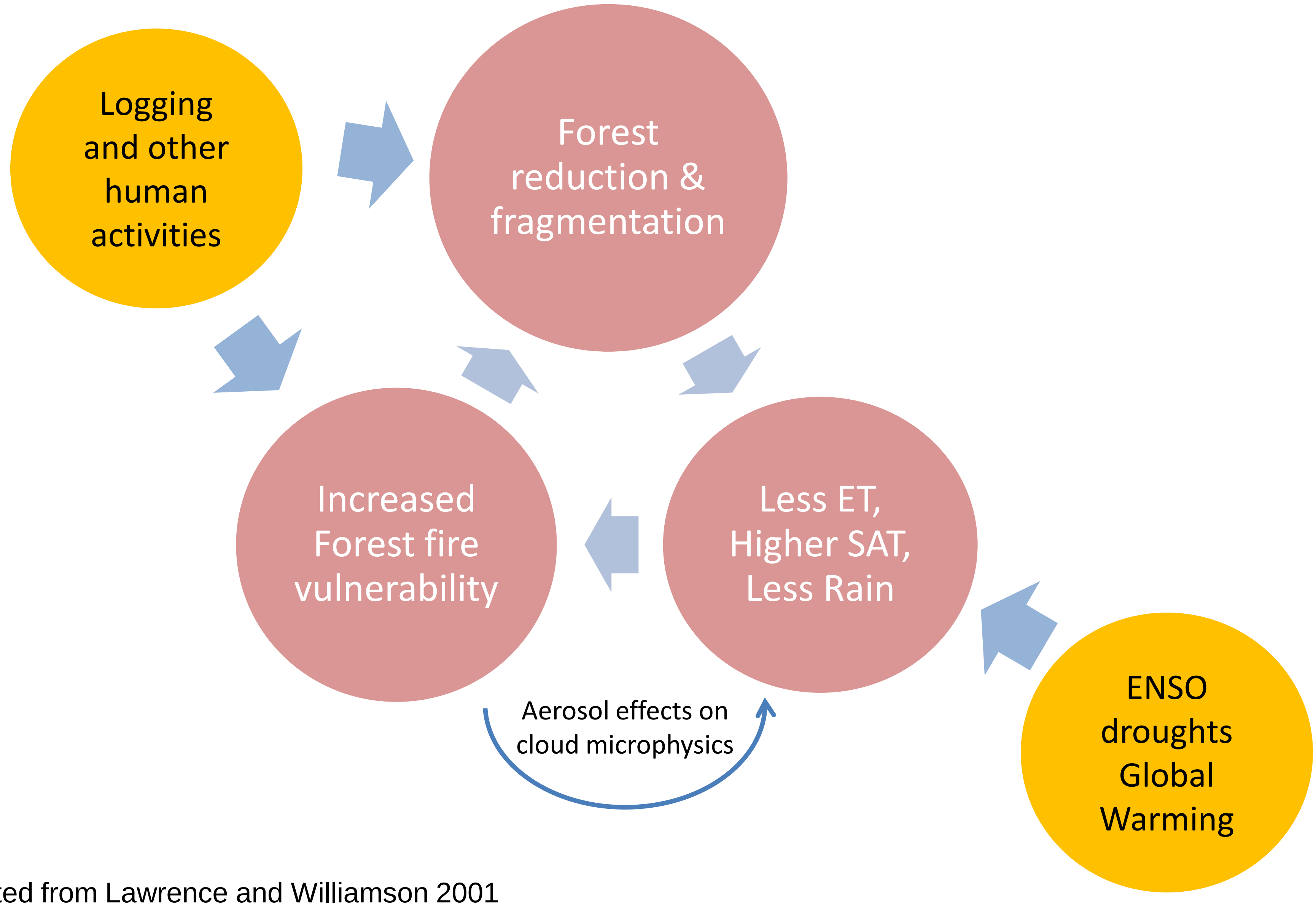
- Reduced convection → Weakening of the Bolivian high
  - Less transport of moisture toward the central Andes
  - Less precipitaion over the Altiplano
  - Reduced subsidence off Chile / Reduced SACZ
- Less moisture transport toward subtropical plains (LLJ) and precip. there



Impacts of Amazon deforestation on the Central Andes (Altiplano) climate: Reduced moisture flux



Possible feedback between deforestation and forest fires….



Adapted from Lawrence and Williamson 2001

Possible feedback between deforestation and forest fires….non local impacts via long-range trace-gases & aerosol transport.

152 SAULO R. FREITAS ET AL.

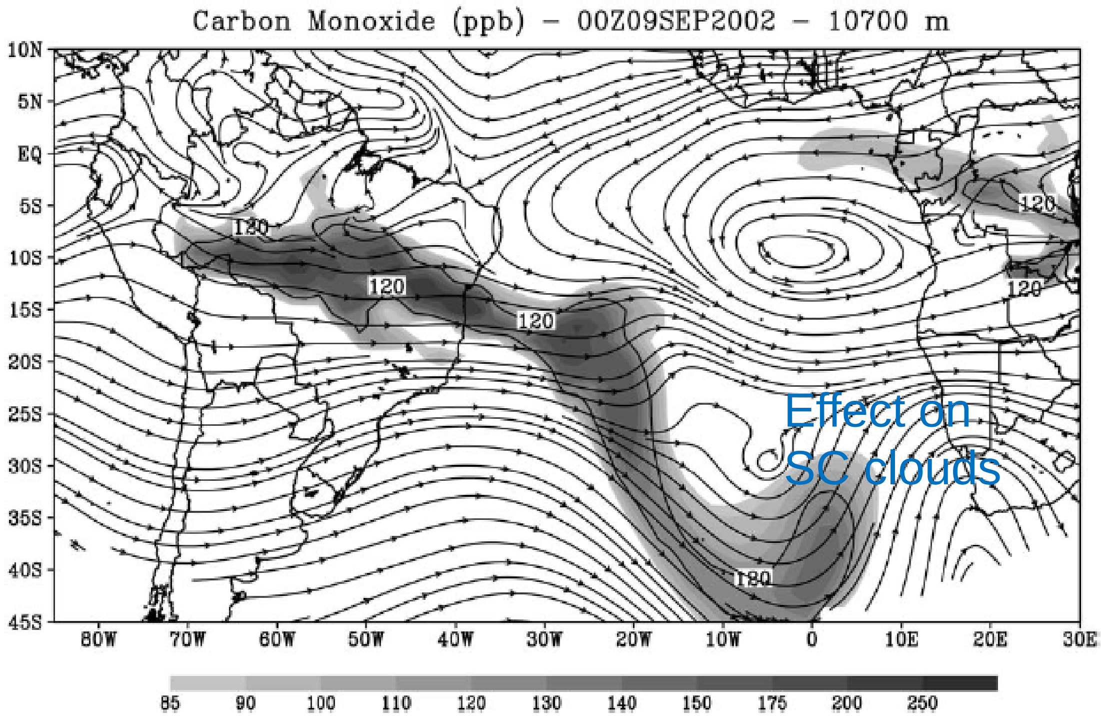


Figure 9. The long-distance transport of the CO plume at 10700 m above surface at 00Z on 9 September on the coarse resolution grid.

Teleconnections induced by Amazon deforestation

Unless local effects, long-range effects are not consistent

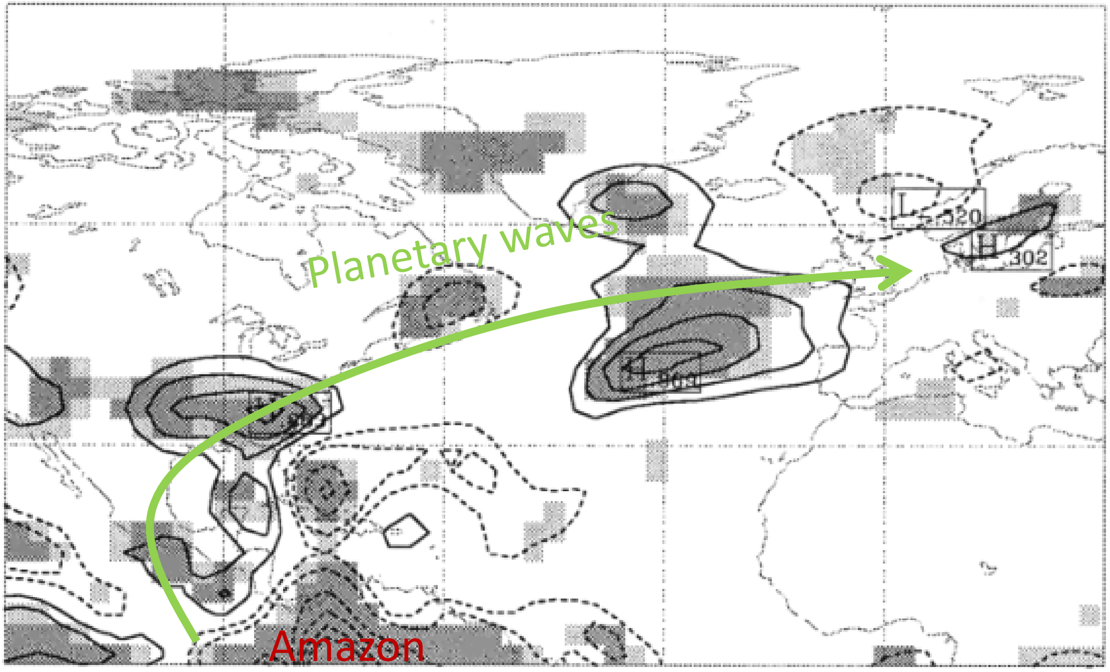
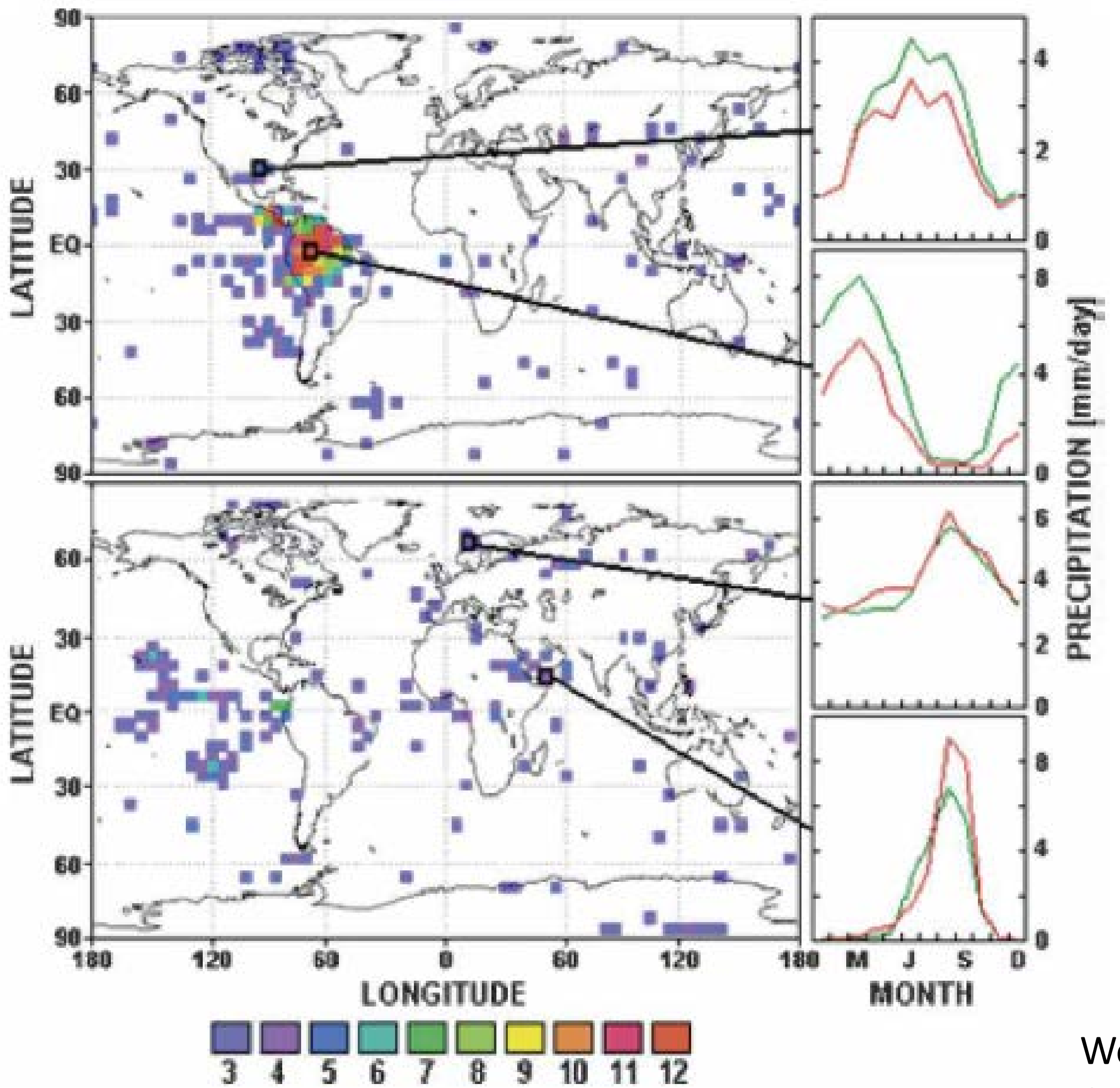


Figure 2. Spatially filtered precipitation changes in the DJF season. (Light and dark shaded areas are statistically significant at the 90 and 95% confidence levels, respectively. The contours are at -0.8 -0.6 -0.4 -0.2 0.2 0.4 0.6 0.8 mm(day)$^{-1}$).

Godney and Valdes 2000

Teleconnections induced by Amazon deforestation



Werth and Avissar 2002
Avissar and Werth 2005
Hasler, Werth and Avissar 2008

Teleconnections induced by Amazon deforestation

Weak Simulated Extratropical Responses to Complete Tropical Deforestation

KIRSTEN L. FINDELL AND THOMAS R. KNUTSON

NOAA/Geophysical Fluid Dynamics Laboratory, Princeton University, Princeton, New Jersey

P. C. D. MILLY

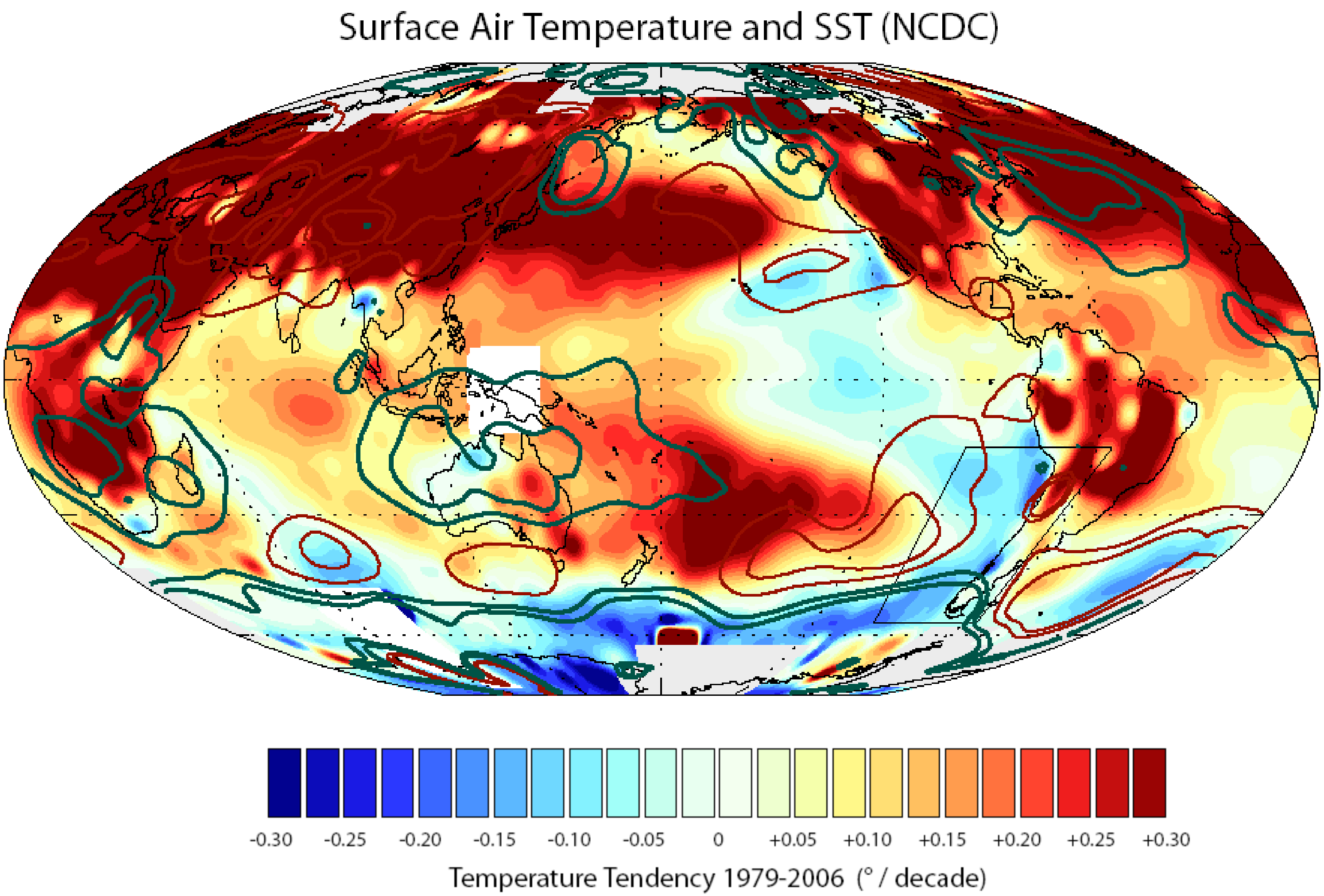
U.S. Geological Survey, NOAA/Geophysical Fluid Dynamics Laboratory, Princeton University, Princeton, New Jersey

(Manuscript received 6 May 2005, in final form 22 September 2005)

ABSTRACT

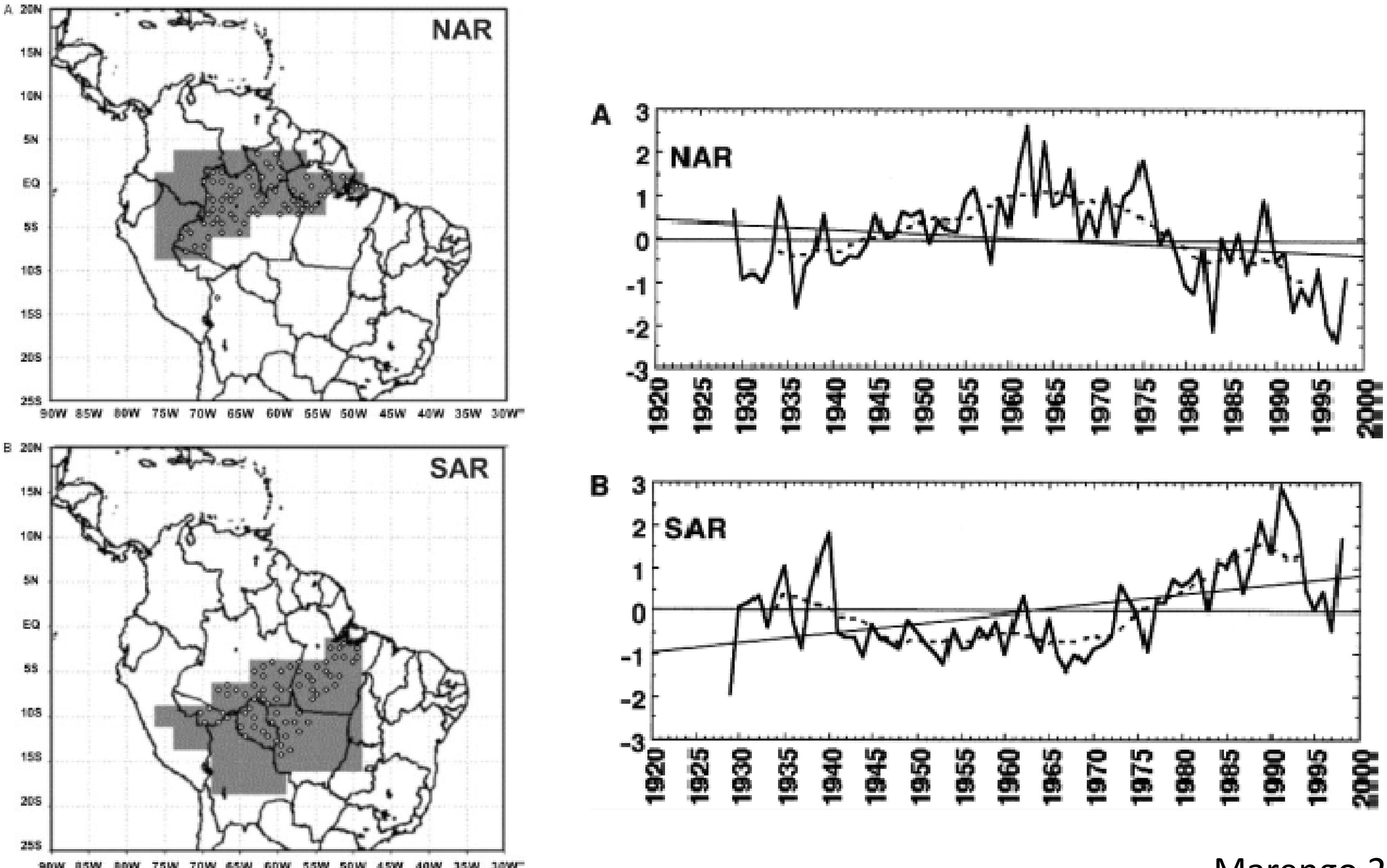
The Geophysical Fluid Dynamics Laboratory atmosphere–land model version 2 (AM2/LM2) coupled to a 50-m-thick slab ocean model has been used to investigate remote responses to tropical deforestation. Magnitudes and significance of differences between a control run and a deforested run are assessed through comparisons of 50-yr time series, accounting for autocorrelation and field significance. Complete conversion of the broadleaf evergreen forests of South America, central Africa, and the islands of Oceania to grasslands leads to highly significant local responses. In addition, a broad but mild warming is seen throughout the tropical troposphere (<0.2°C between 700 and 150 mb), significant in northern spring and summer. However, the simulation results show very little statistically significant response beyond the Tropics. There are no significant differences in any hydroclimatic variables (e.g., precipitation, soil moisture, evaporation) in either the northern or the southern extratropics. Small but statistically significant local differences in some geopotential height and wind fields are present in the southeastern Pacific Ocean. Use of the same statistical tests on two 50-yr segments of the control run show that the small but significant extratropical differences between the deforested run and the control run are similar in magnitude and area to the differences between nonoverlapping segments of the control run. These simulations suggest that extratropical responses to complete tropical deforestation are unlikely to be distinguishable from natural climate variability.

Contemporaneous climate change: SAT



Falvey & Garreaud 2007

Contemporaneous climate change: Rainfall
(Interdecadal variability + weak trends)



Marengo 2009

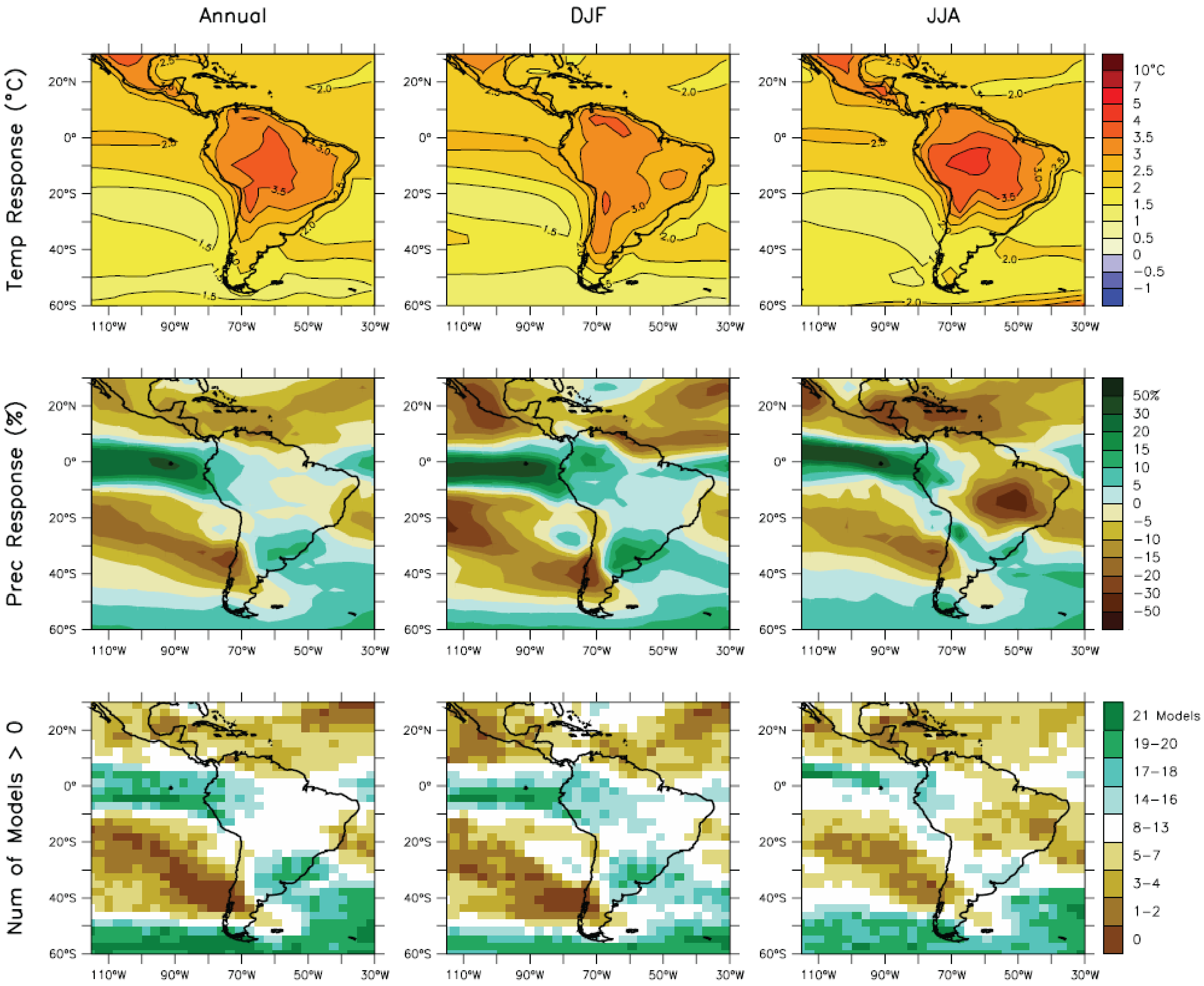


Figure 11.15. *Temperature and precipitation changes over Central and South America from the MMD-A1B simulations. Top row: Annual mean, DJF and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Middle row: same as top, but for fractional change in precipitation. Bottom row: number of models out of 21 that project increases in precipitation.*

A major question: ENSO in the future

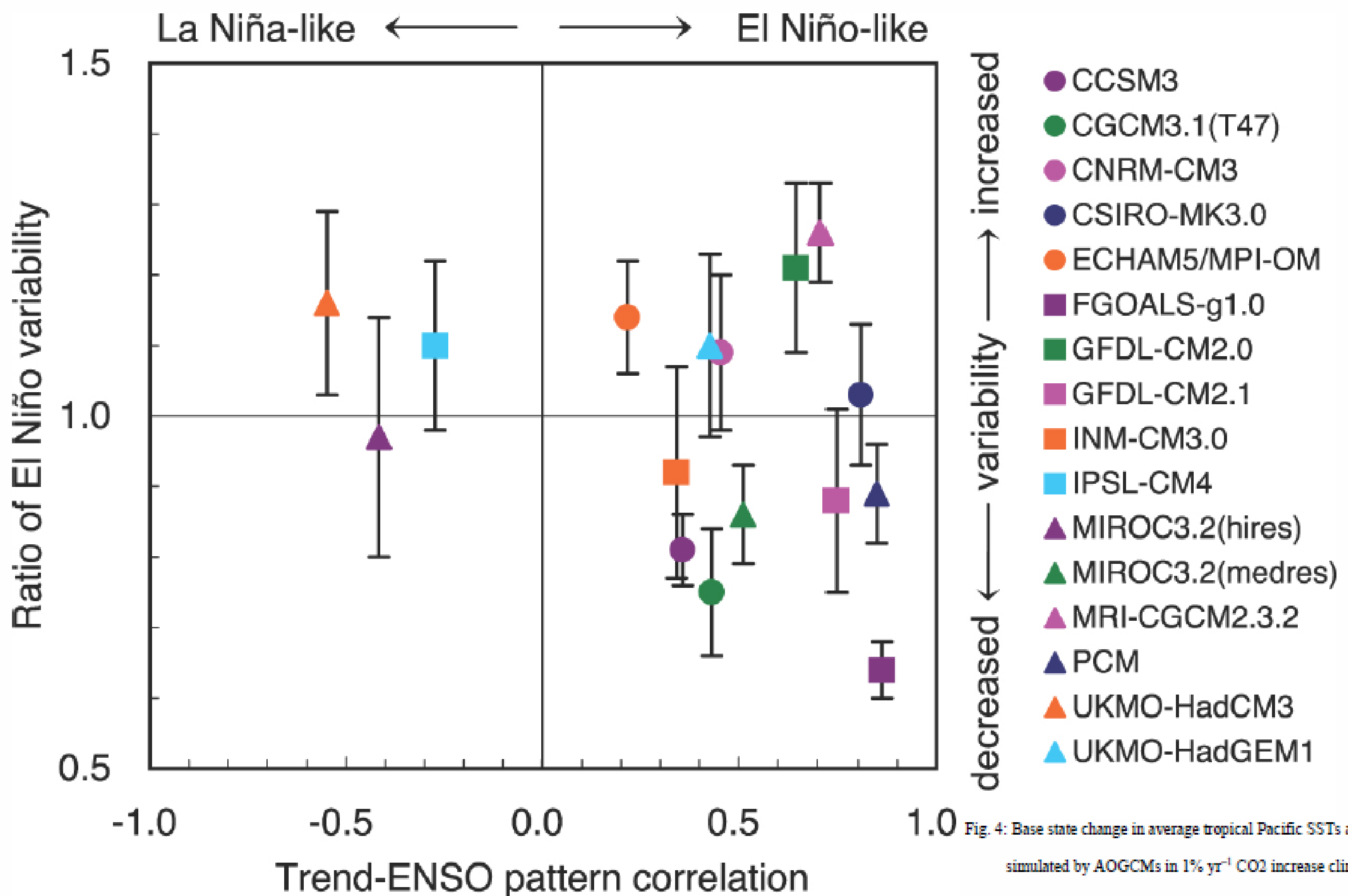


Fig. 4: Base state change in average tropical Pacific SSTs and change in El Niño variability simulated by AOGCMs in 1% yr^{-1} CO2 increase climate change experiment. Positive correlation values (horizontal axis) indicate that the mean climate change has an El Niño-like pattern, and negative values are La Niña-like. Note that tropical Pacific base state climate changes with either El Niño-like or La Niña-like patterns are not permanent El Niño or La Niña events, and all still have ENSO interannual variability superimposed on that new average climate state in a future warmer climate (reproduced from Meehl et al., 2007 (Figure 10.16), with permission from the Intergovernmental Panel on Climate Change).

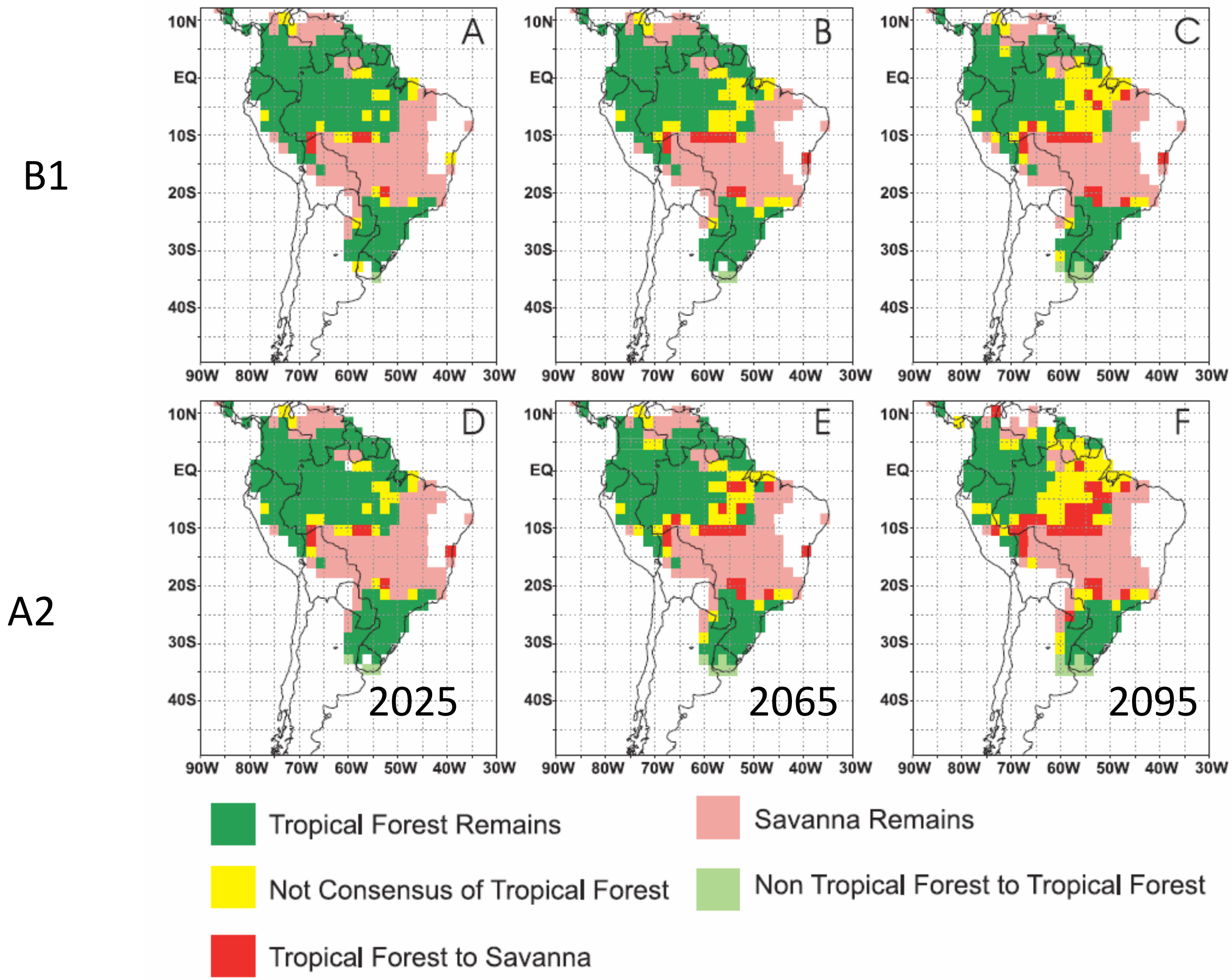
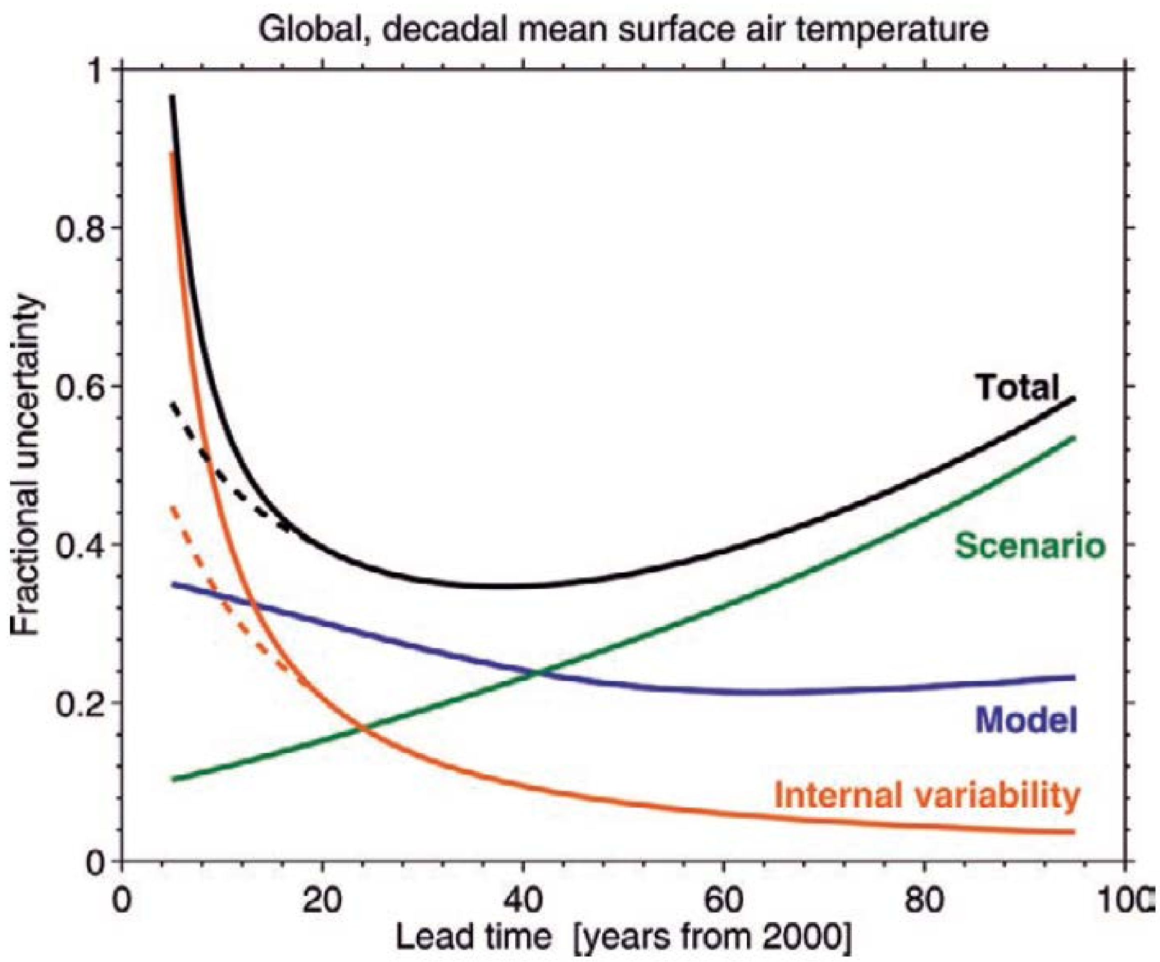


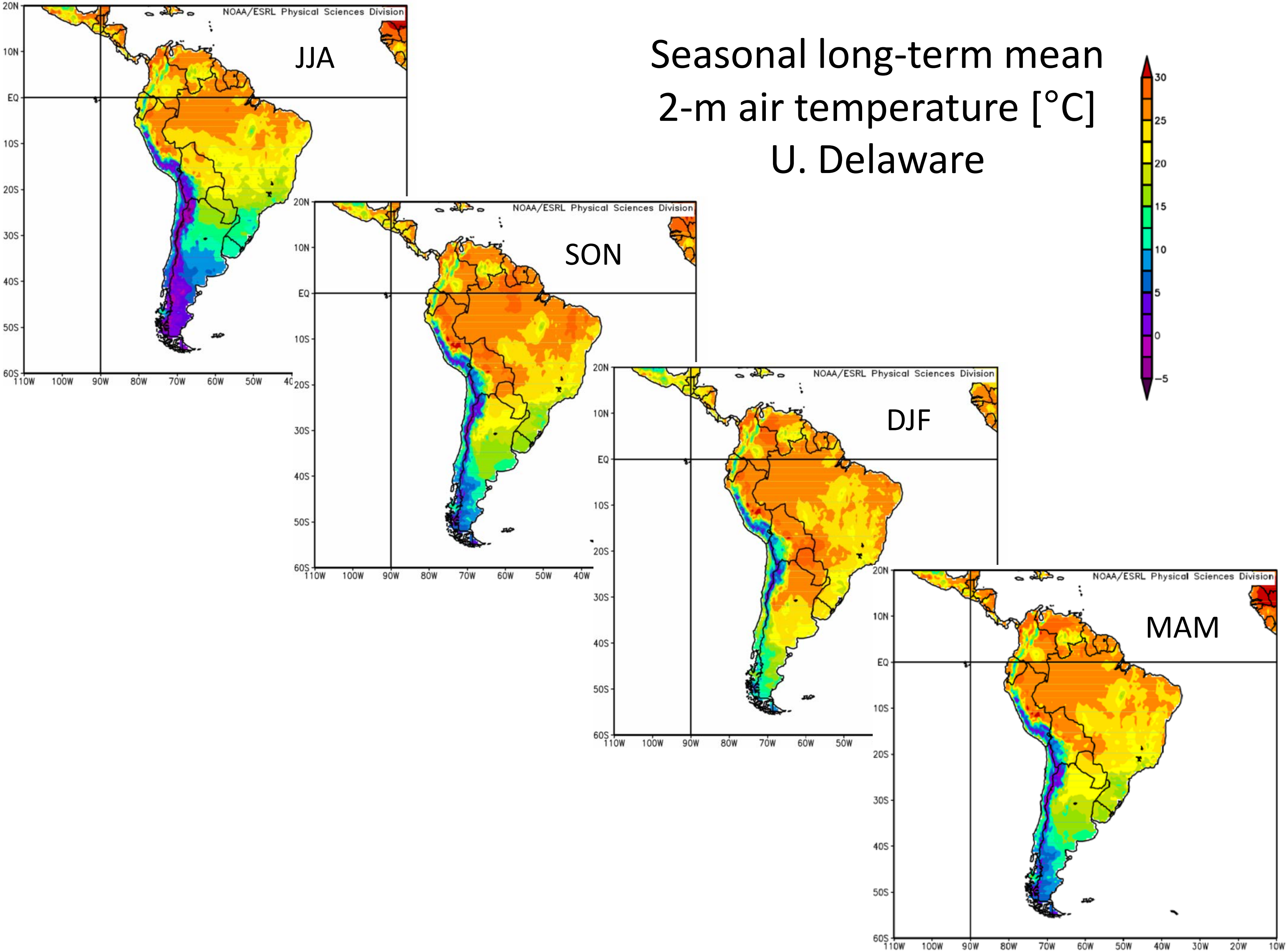
Figure 2. Grid points where more than 75% of the models used (>11 models) coincide as projecting the future condition of the tropical forest and the savanna in relation with the current potential vegetation, resulting in the following possibilities: tropical forest remains; savanna remains; tropical forest to savanna shift; non tropical forest to tropical forest shift. The figure also shows the grid points where a consensus amongst the models of the future condition of the tropical forest was not found for the periods (a) 2020–2029, (b) 2050–2059 and (c) 2090–2099 for B1 GHG emissions scenario and (d, e and f) similarly for A2 GHG emissions scenario.

Please recall the high level of uncertainty in the near and far future…
…so we still have much work to do both at the global and regional scales



Hawkins and Sutton 2009

Seasonal long-term mean
2-m air temperature [°C]
U. Delaware



Climatic Impact of Amazon Deforestation—A Mechanistic Model Study

NING ZENG, ROBERT E. DICKINSON, AND XUBIN ZENG

Institute of Atmospheric Physics, The University of Arizona, Tucson, Arizona

(Manuscript received 22 May 1995, in final form 11 October 1995)