

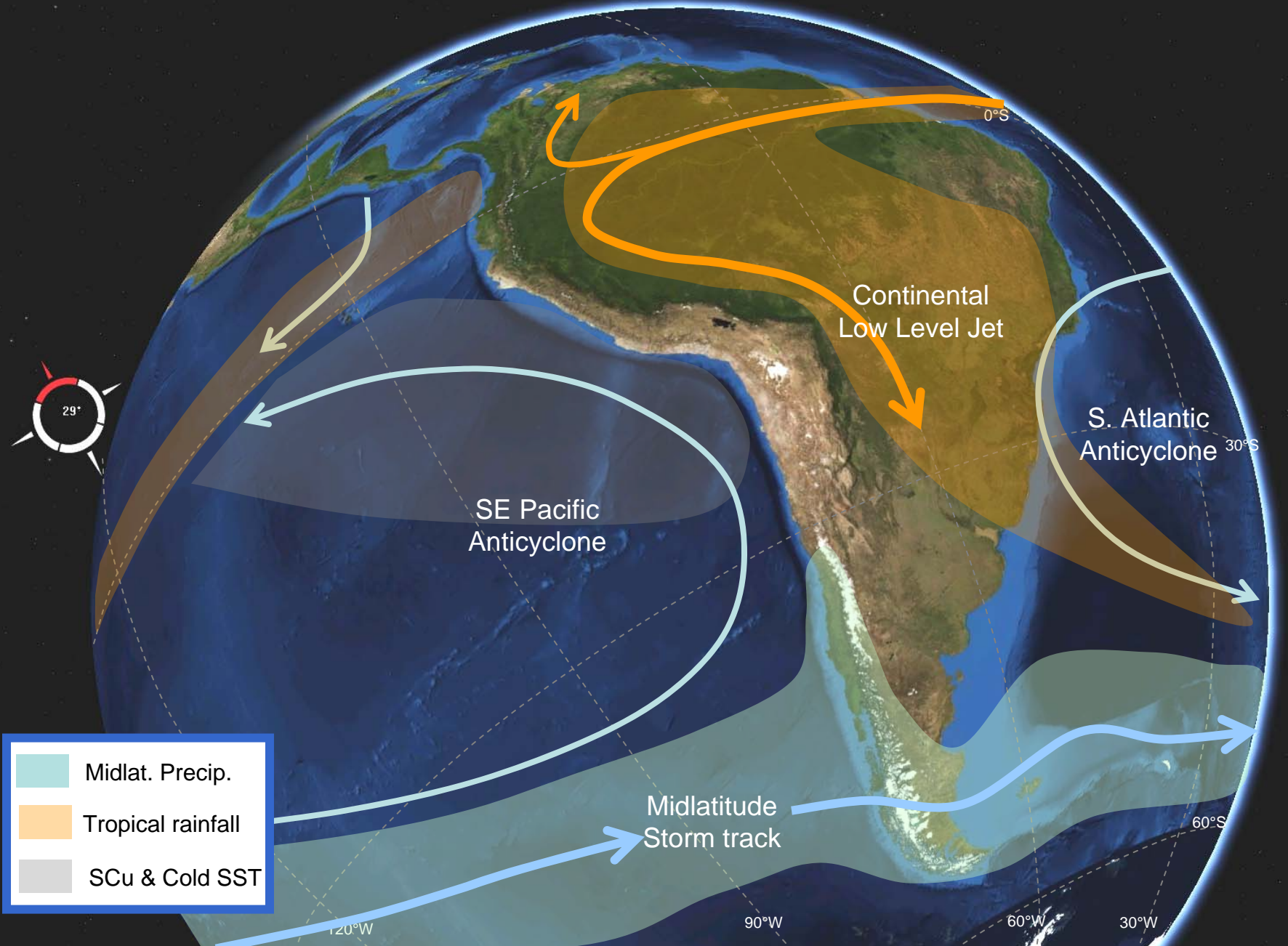
# Andean Uplift and Atacama Hyperaridity: A Climate Modeling Perspective (\*)



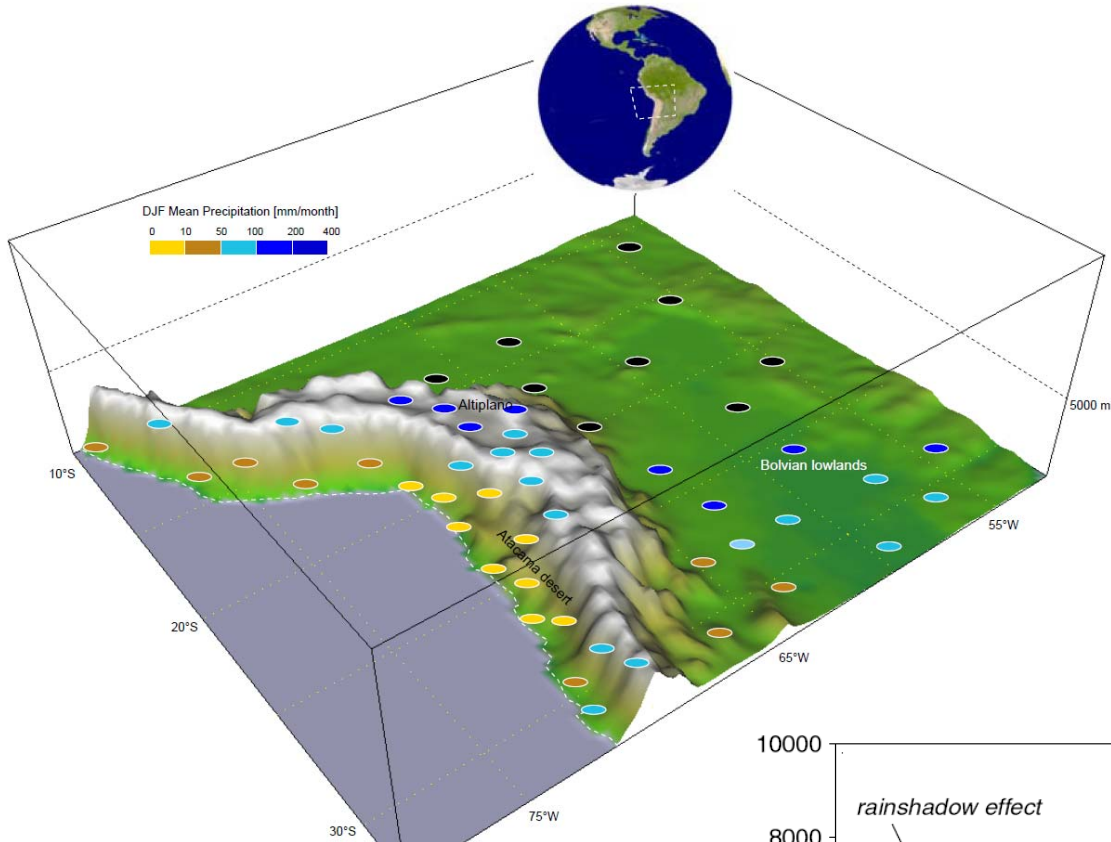
René Garreaud, Alejandra Molina, Marcelo Farias  
Department of Geophysics  
Universidad de Chile

(\*) Conditionally accepted EPSL

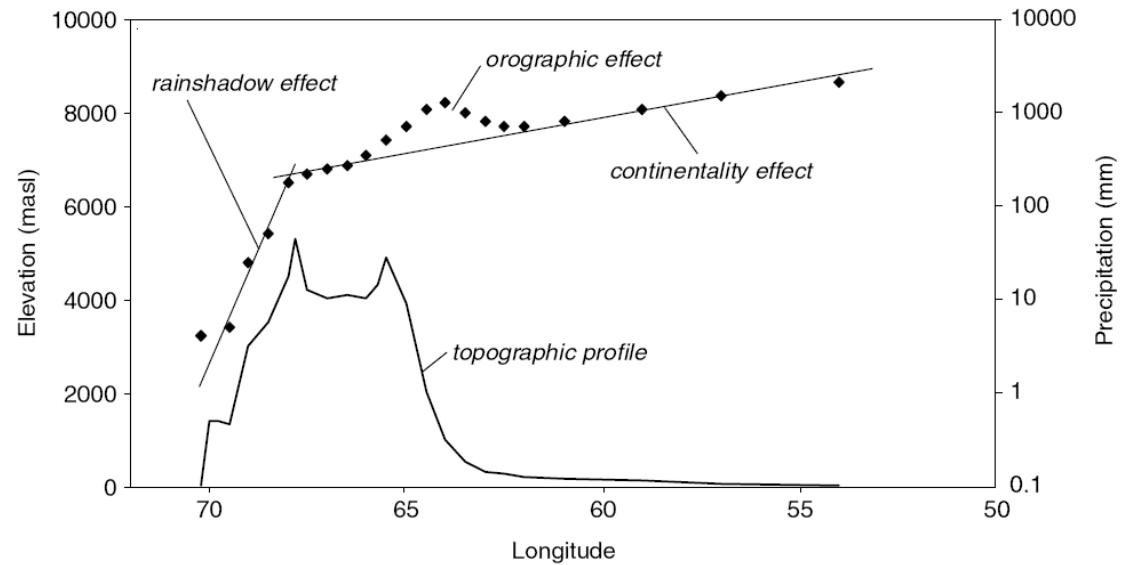
# High Andes & dry Atacama



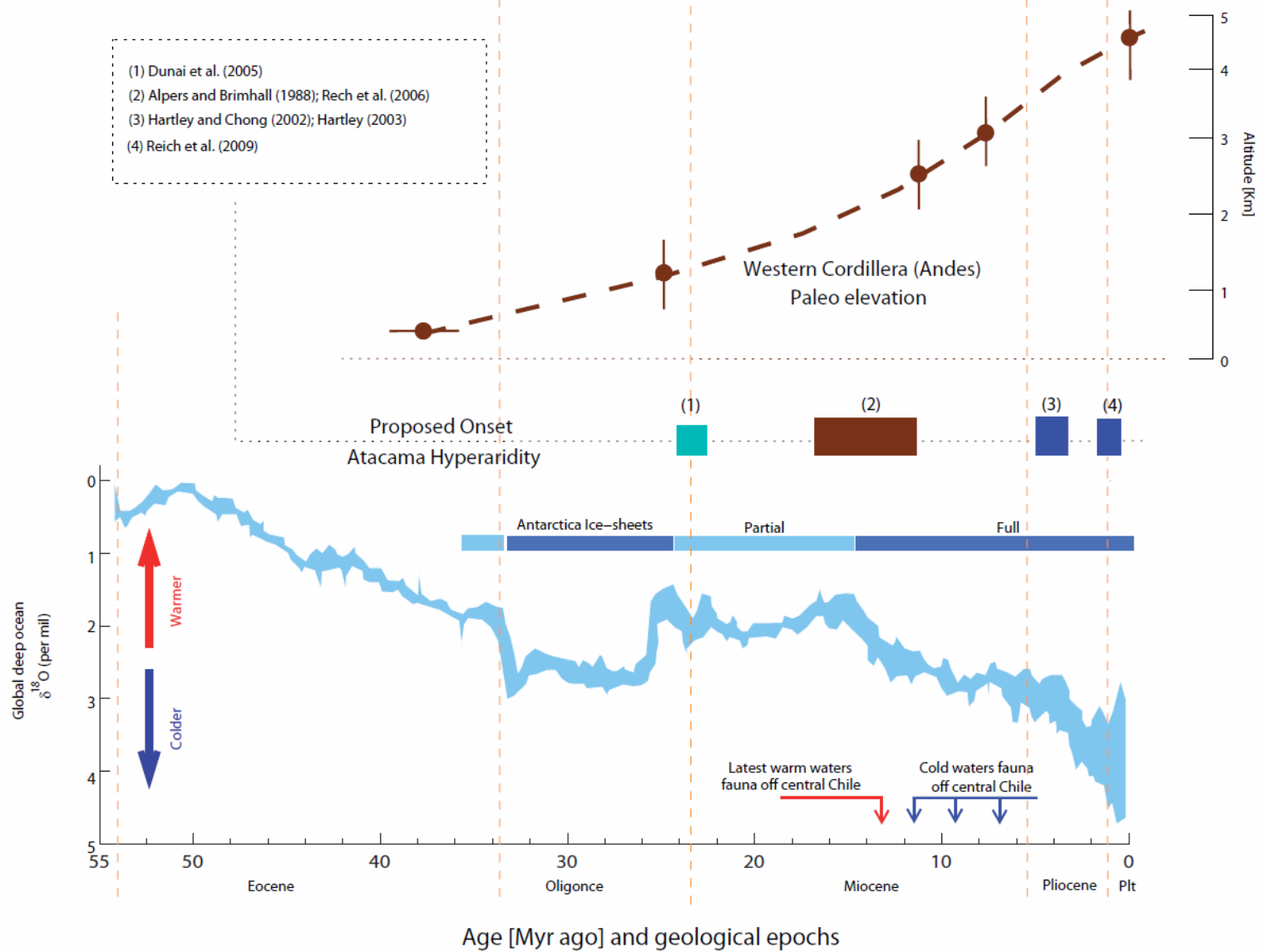
# High Andes & dry Atacama



Hartley and Houston 2003



# High Andes & dry Atacama



# Andean uplift ► Atacama hyper-aridification

INTERNATIONAL JOURNAL OF CLIMATOLOGY

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## THE CENTRAL ANDEAN WEST-SLOPE RAINSHADOW AND ITS POTENTIAL CONTRIBUTION TO THE ORIGIN OF HYPER-ARIDITY IN THE ATACAMA DESERT

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*Received 31 January 2003*

*Revised 19 May 2003*

*Accepted 22 May 2003*

### ABSTRACT

The west slope of the central Andes exhibits a pronounced rainshadow effect. Precipitation between 15° and 27°S is dominated by summer convective activity from Amazonia, and data analysis shows that the increase in precipitation with elevation due to the rainshadow effect best fits an exponential correlation. Coupling with limited data from high elevations suggests that the correlation is accurate to 4500 m above sea level (m a.s.l.) and perhaps to 5500 m a.s.l., suggesting that increased precipitation goes unrecorded over the peaks of the western Cordillera. South of 27°S the precipitation is dominated by winter frontal sources and shows no well-defined relationship with elevation. The core zone of hyper-aridity in the Atacama Desert extends from 15 to 30°S at elevations from sea level to 3500 m a.s.l. Although the Atacama Desert has existed since at least 90 Ma, it is considered that the initial onset of hyper-aridity was most likely to have developed progressively with the uplift of the Andes as they reached elevations between 1000 to 2000 m a.s.l. coupled with the intensification of a cold, upwelling Peruvian Current between 15 and 10 Ma. Also apparent in the palaeogeographic record are subsequent fluctuations between (semi-) arid to hyper-arid conditions that were probably largely controlled by changes in orbital and oceanic forcing. Copyright © 2003 Royal Meteorological Society.

### 5.3. Elevation forcing

Regional uplifts, such as the Andes, have been shown unequivocally to cause increasing aridity (Manabe and Broccoli, 1990; Ruddiman *et al.*, 1997). At elevations of 1000 m the effects of topographic forcing begin to be felt (Browning, 1980), with increasing effect by the time elevation has reached 2000 m (Hay and Wold, 1998; Otto-Bliesner, 1998), and palaeoclimate modelling of the Himalayas suggests that the impacts on climate may develop progressively and in step with increasing uplift Zhiseng *et al.* (2001).

## The Effects of Orography on Midlatitude Northern Hemisphere Dry Climates

A. J. BROCCOLI AND S. MANABE

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

(Manuscript received 18 July 1991, in final form 13 February 1992)

### ABSTRACT

The role of mountains in maintaining extensive midlatitude arid regions in the Northern Hemisphere was investigated using simulations from the GFDL Global Climate Model with and without orography. In the integration with mountains, dry climates were simulated over central Asia and the interior of North America, in good agreement with the observed climate. In contrast, moist climates were simulated in the same regions in the integration without mountains. During all seasons but summer, large amplitude stationary waves occur in response to the Tibetan Plateau and Rocky Mountains. The midlatitude dry regions are located upstream of the troughs of these waves, where general subsidence and relatively infrequent storm development occur and precipitation is thus inhibited. In summer, this mechanism contributes to the dryness of interior North America

**articles**

# **Cenozoic climate change as a possible cause for the rise of the Andes**

**Simon Lamb<sup>1</sup> & Paul Davis<sup>2</sup>**

<sup>1</sup>*Department of Earth Sciences, Parks Road, Oxford, OX1 3PR, UK*

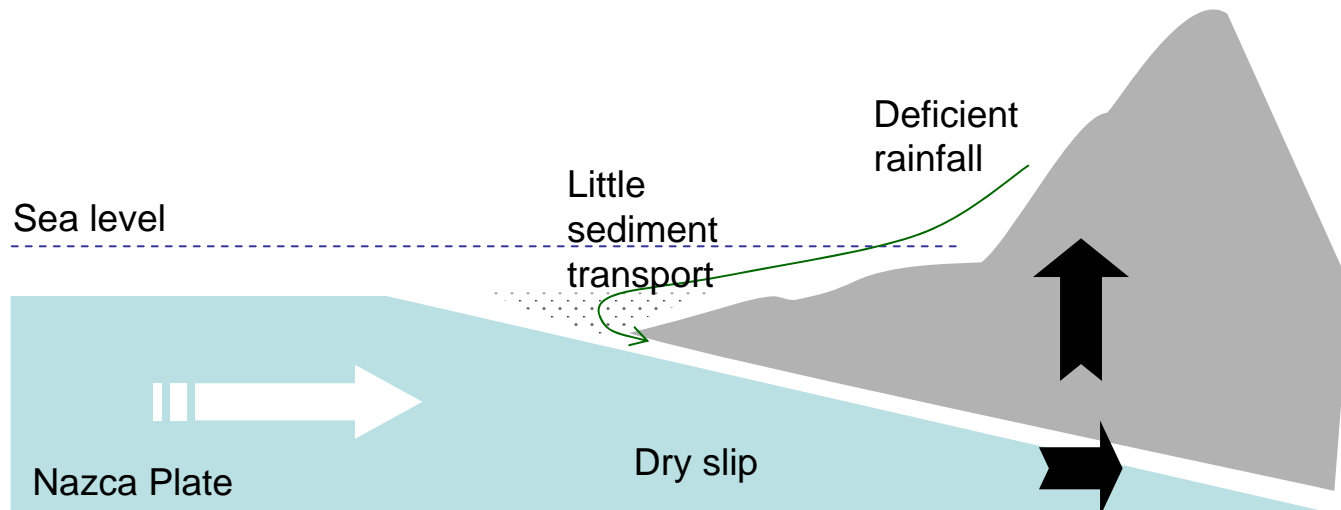
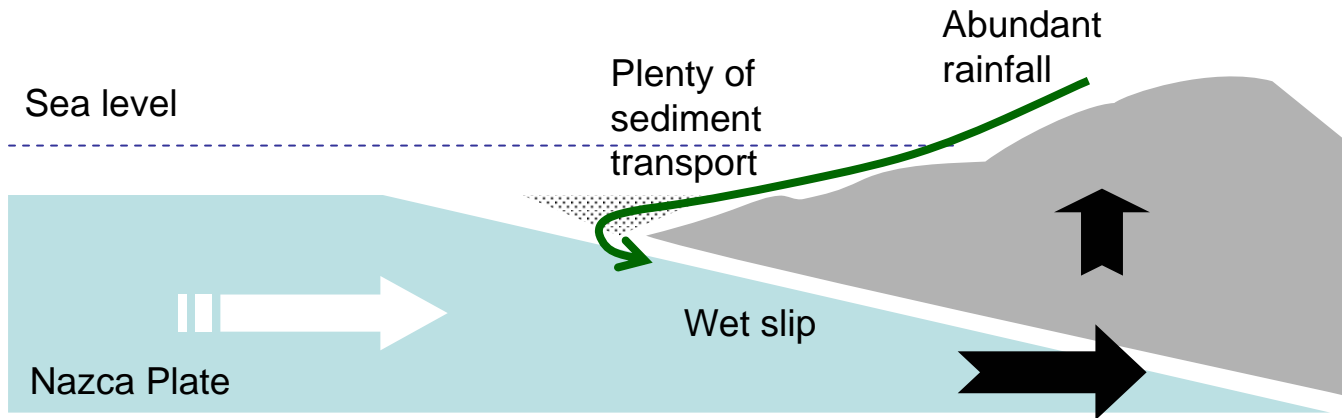
<sup>2</sup>*Department of Earth and Space Sciences, University of California, Los Angeles, California 90095, USA*

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Causal links between the rise of a large mountain range and climate have often been considered to work in one direction, with significant uplift provoking climate change. Here we propose a mechanism by which Cenozoic climate change could have caused the rise of the Andes. Based on considerations of the force balance in the South American lithosphere, we suggest that the height of, and tectonics in, the Andes are strongly controlled both by shear stresses along the plate interface in the subduction zone and by buoyancy stress contrasts between the trench and highlands, and shear stresses in the subduction zone depend on the amount of subducted sediments. We propose that the dynamics of subduction and mountain-building in this region are controlled by the processes of erosion and sediment deposition, and ultimately climate. In central South America, climate-controlled sediment starvation would then cause high shear stress, focusing the plate boundary stresses that support the high Andes.

Lamb and Davis; Nature 2003

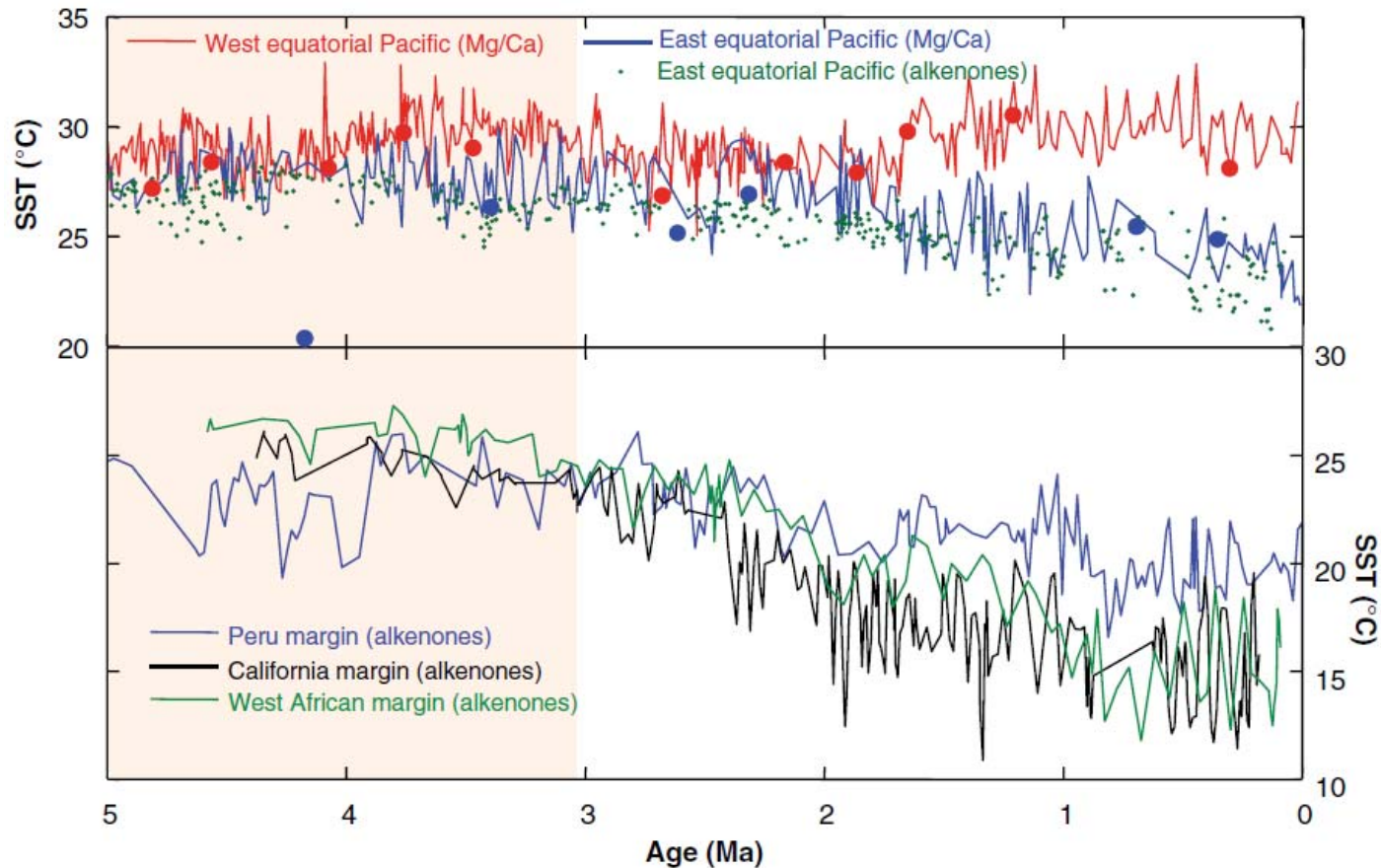
# Atacama hyper-aridification ► Andean uplift



Adapted from Lamb and Davis; Nature 2003



## Southeast Pacific Cooling ► Atacama hyper-aridification



**Fig. 3. (Top)** SST records in the western equatorial Pacific (red line, ODP site 806) and in the eastern equatorial Pacific (blue line, site 847), both based on Mg/Ca and adapted from (11), and that for the eastern Pacific based on alkenones (green dots, site 847) and adapted from (24). Larger circles are for the data based on Mg/Ca but from (44) for ODP sites 806 (red) and 847 (blue). Pink shading denotes the early Pliocene. For discussion, see (6). **(Bottom)** Alkenone-based SST records for the California margin (black, ODP site 1014) (24), the Peru margin (blue, site 1237) (24), and the West African margin (green, site 1084) (22). The locations of the ODP sites are shown in Fig. 2; for the exact geographical locations, see (47).

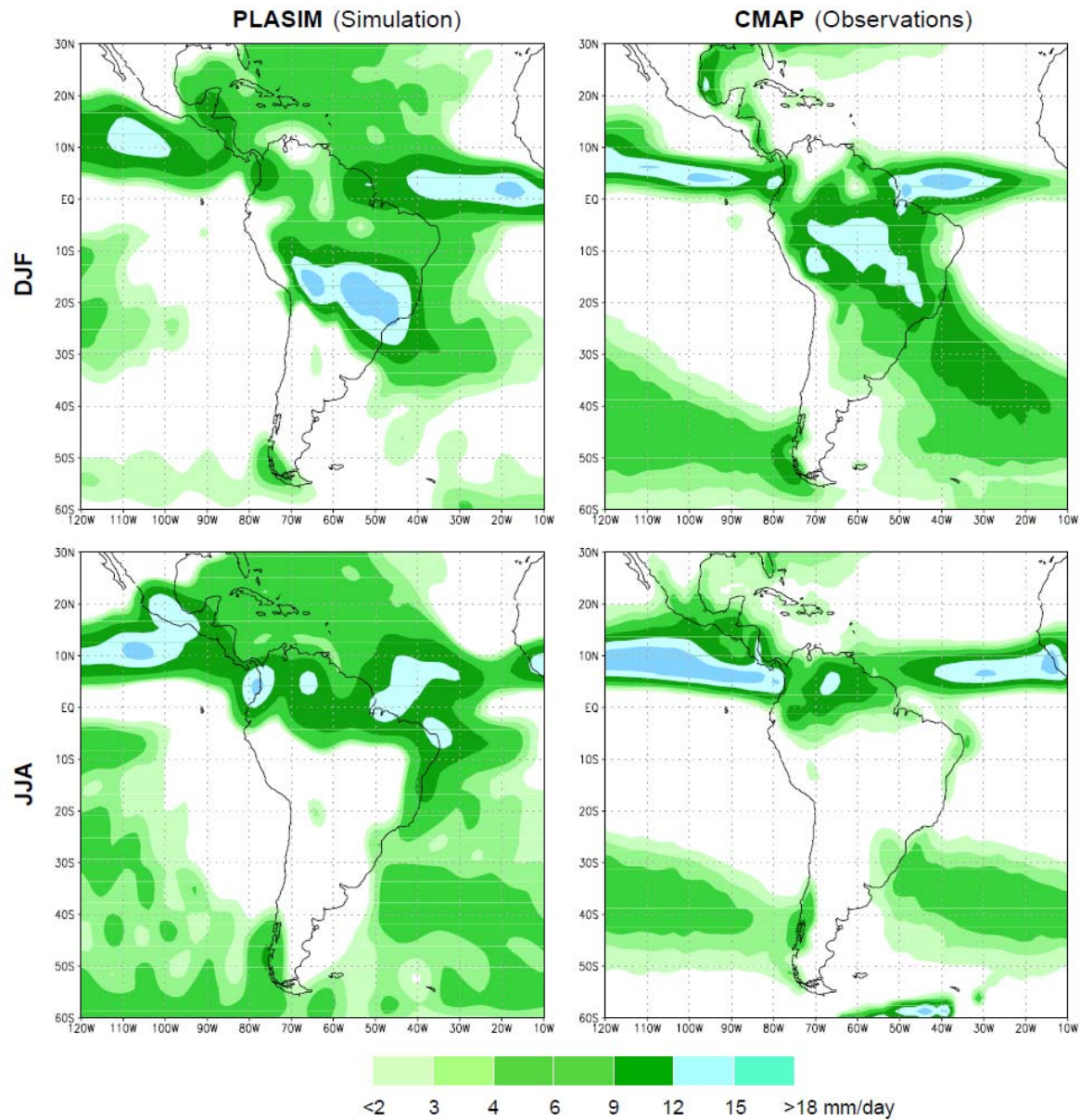
Conceptually, both Andean uplift and SEP cooling may increase dryness of the Atacama desert...it would be nice to use a “simple” climate model to study these two conditions.

We use PLASIM, an Earth System Model of Intermediate Complexity from Hamburg University:

- Atmospheric component: PUMA
- Simple slab model for SST and Sea Ice
- SIMBA for biosphere

We performed 50 year long simulations altering one Boundary condition at a time

# Model Validation

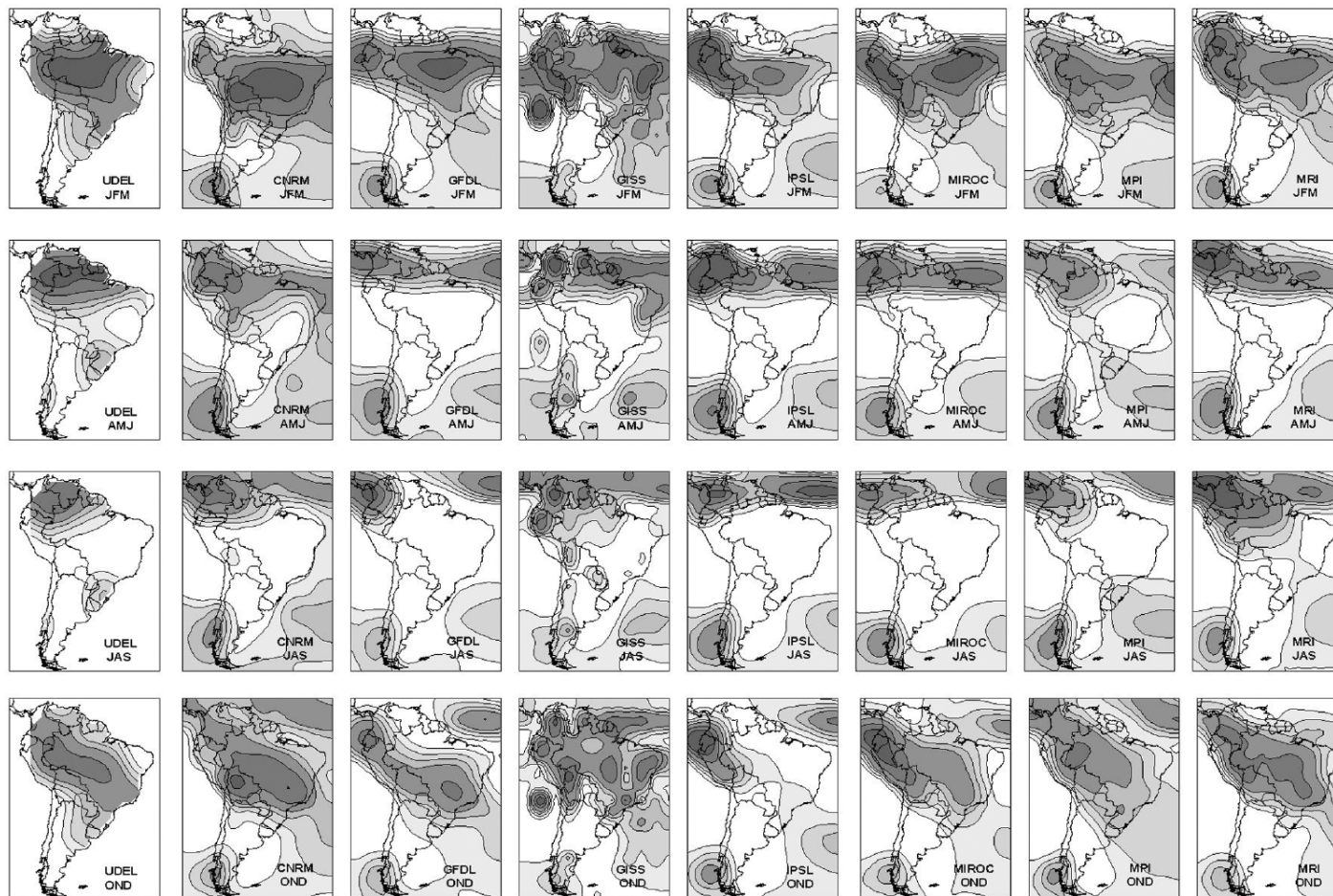


# Model Validation

L13707

VERA ET AL.: CLIMATE CHANGE IN SOUTH AMERICA

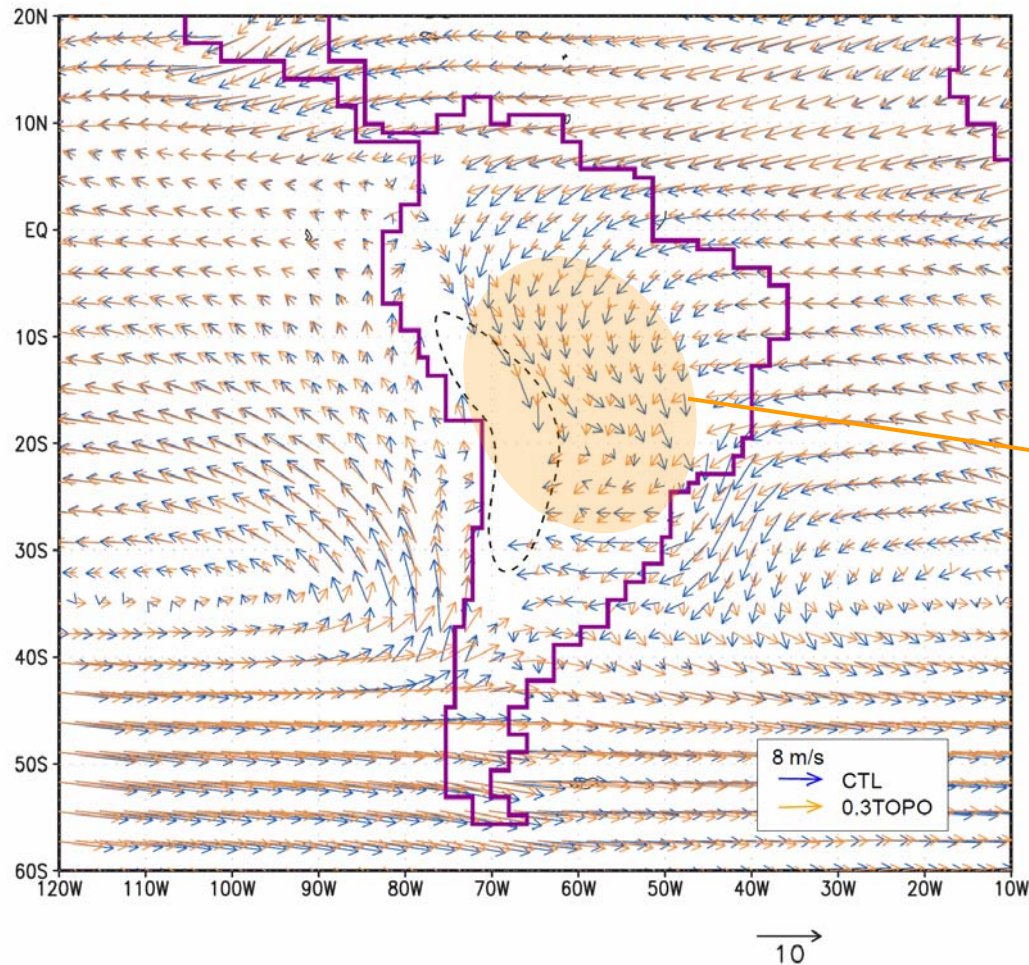
L13707



**Figure 1.** Seasonal mean precipitation computed for 1970–1999 period from observations (UDEL), and IPCC-AR4 models (see list in the text). Contour level is 1 mm day<sup>-1</sup>, values larger than 2 mm day<sup>-1</sup> are shaded.

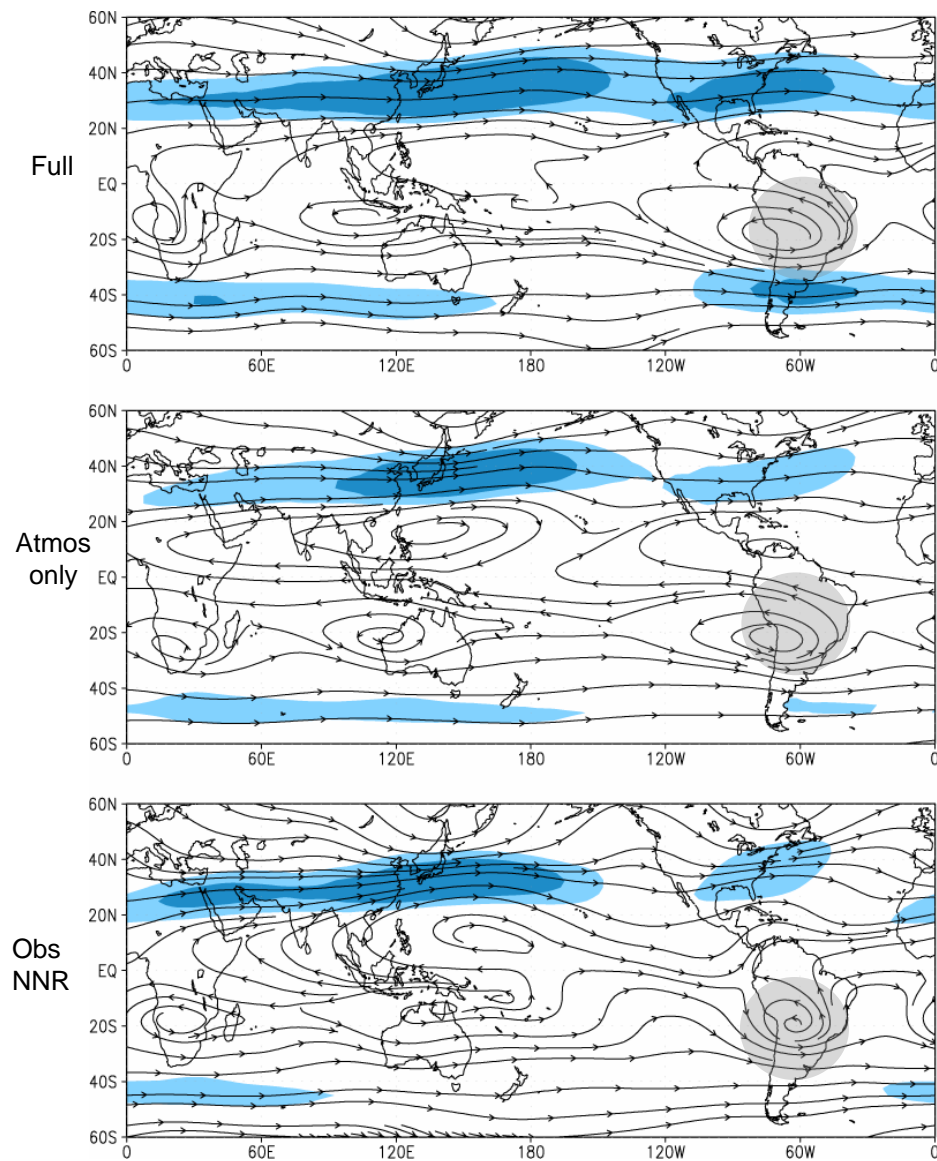
# Model Validation

Long-term mean DJF 900 hPa wind  
0.3\*Topo (red) and Control (blue)



# Model Validation

## DJF mean 200 hPa winds



# Model Validation

Feature	Atmos-Only	Full
Cold tongue	Of course	weak
Warm pool	Of course	Small
ITCZ	Ok, too wide	Too strong, too zonal
South American Monsoon	Yes	Yes
SH Storm Track	Yes	Yes
Orographic precipitation	Yes	Yes
Subtropical deserts	Yes, but too small	Yes, but too small
Subtropical anticyclones	Yes, but too wide	Ok, too wide
SPCZ	Yes	No
SACZ	Ok, but too short	Yes

# PLASIM Topography Experiments

Motivated by the previous wisdoms in the paleo-climate and geological communities, we set up a numerical experiment using PLASIM. **30 years for each experiment.**

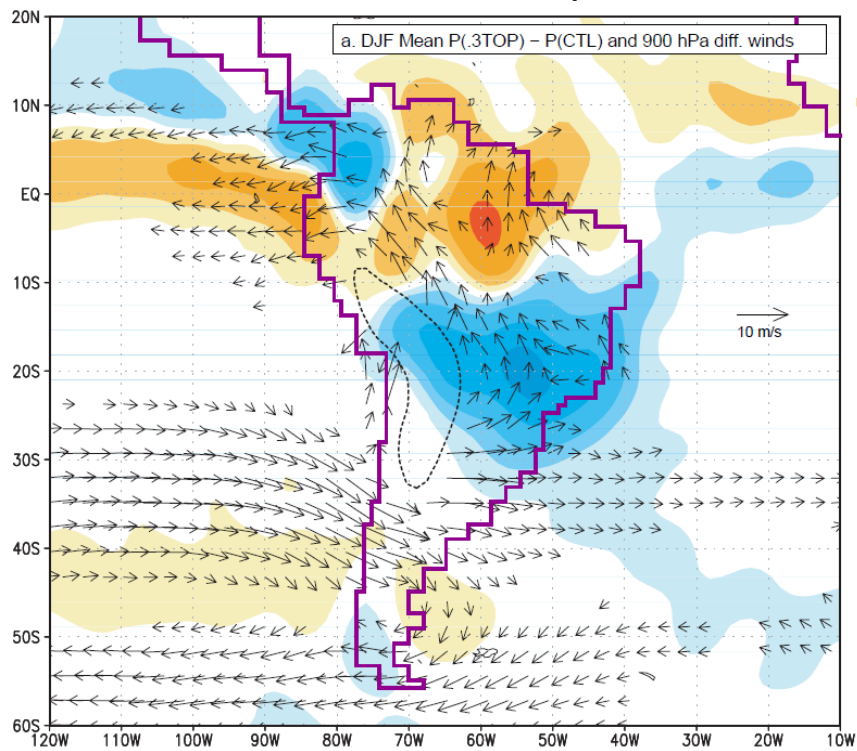
Experiment	Topography	Ocean/Ice model
Control	100%	Yes
Atmos Only	100%	No
0.1Topo-f	10% everywhere	Yes
0.3Topo-f	30% everywhere	Yes
0.5Topo-f	50% everywhere	Yes
0.7Topo-f	70% everywhere	Yes
0.9Topo-f	90% everywhere	Yes
0.3Topo-A	30% everywhere	No
0.3Andes-f	30% South America	Yes
0.3Andes-A	30% South America	No



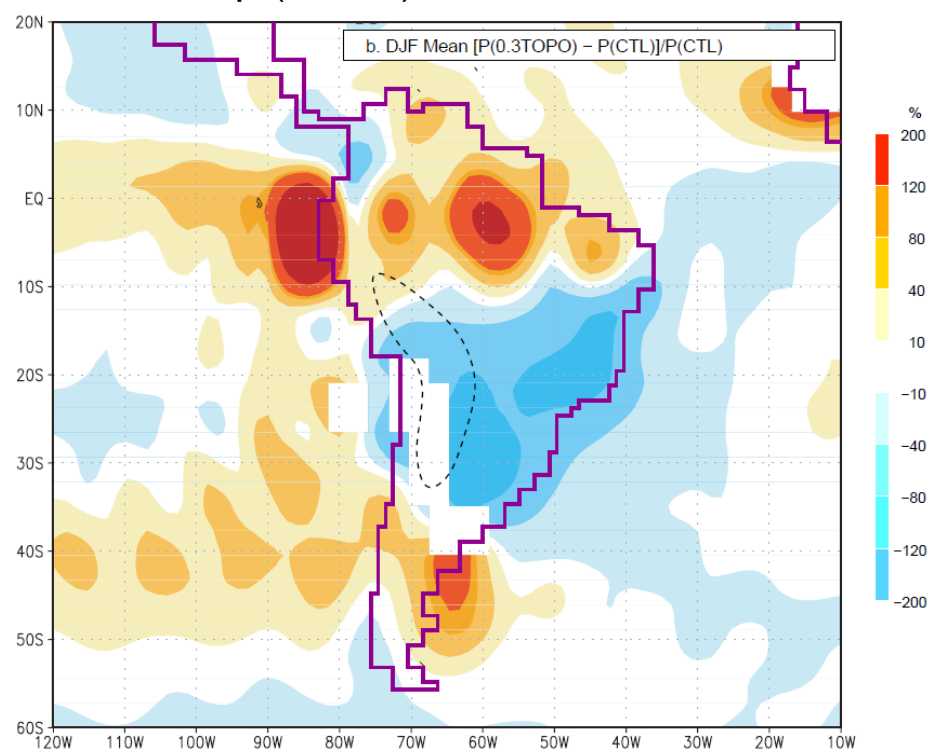
# PLASIM Topography Experiments

## 0.3\*Topo minus Control (DJF)

### 900 hPa winds and Precip

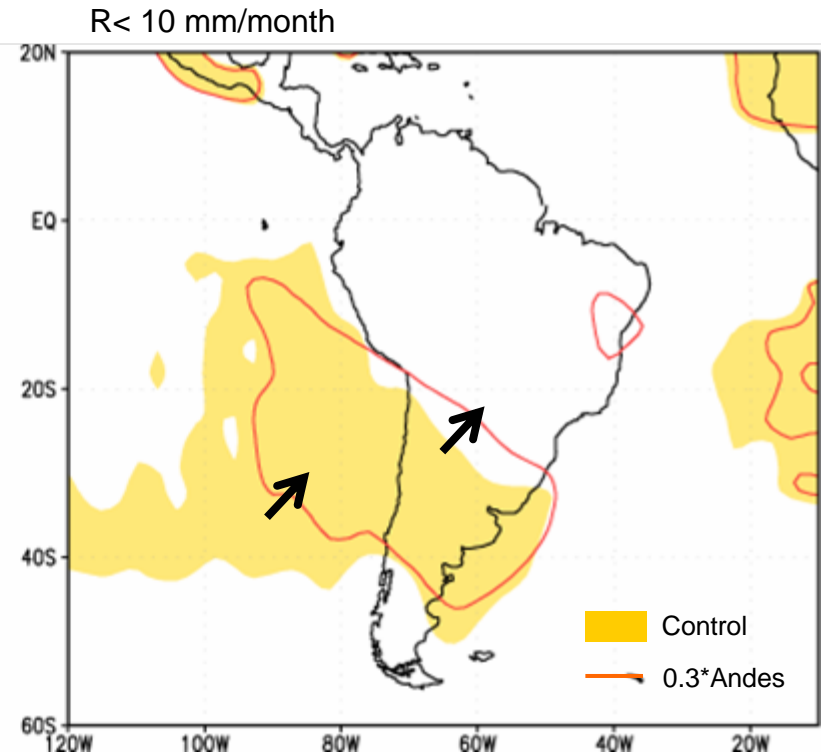
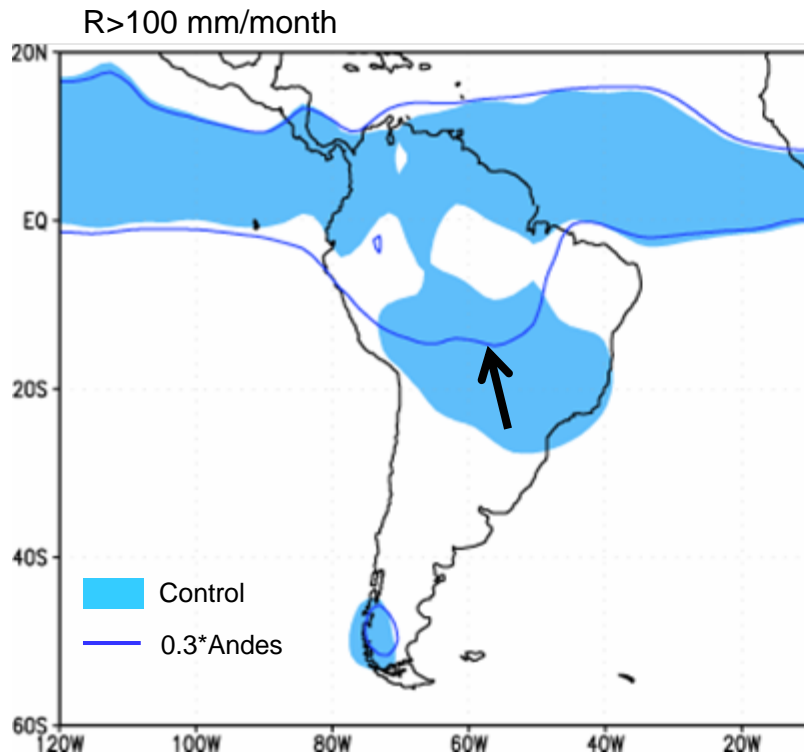


### % Precip ( $\Delta P/P_c$ )



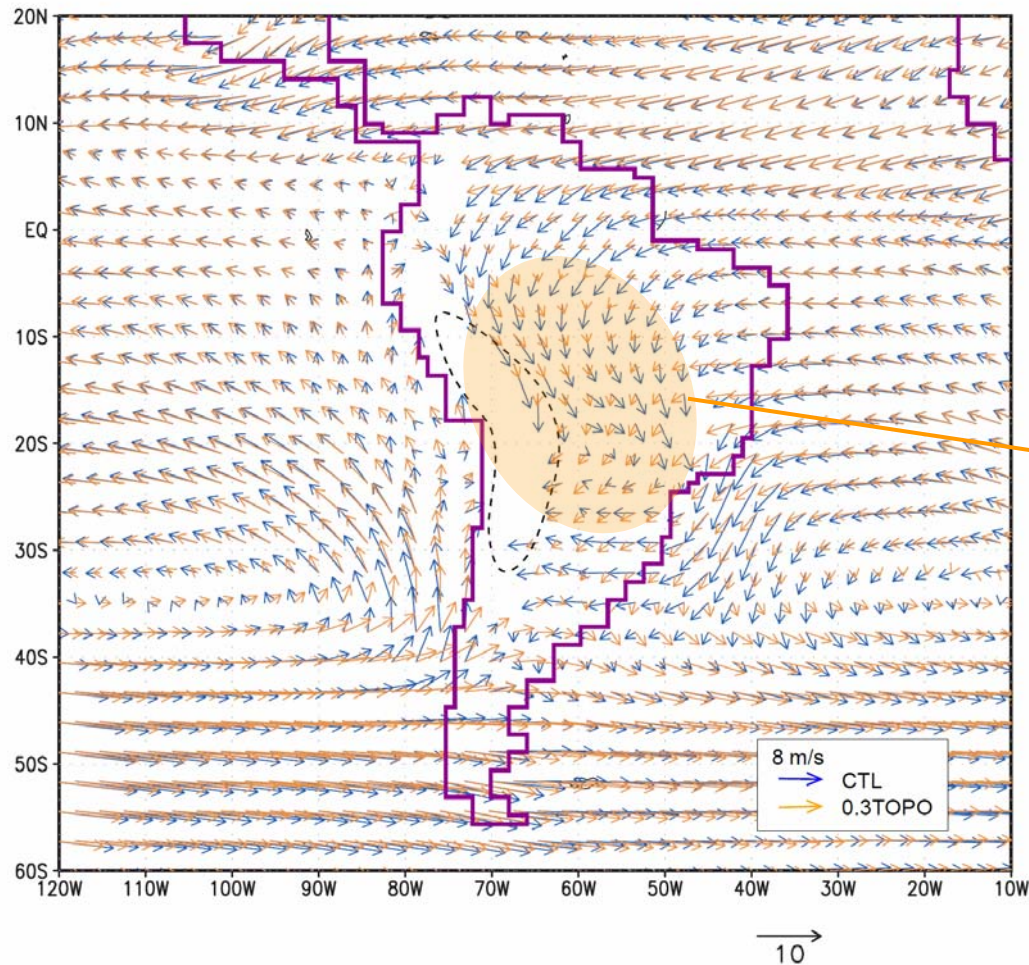
# PLASIM Topography Experiments

## DJF Precipitation



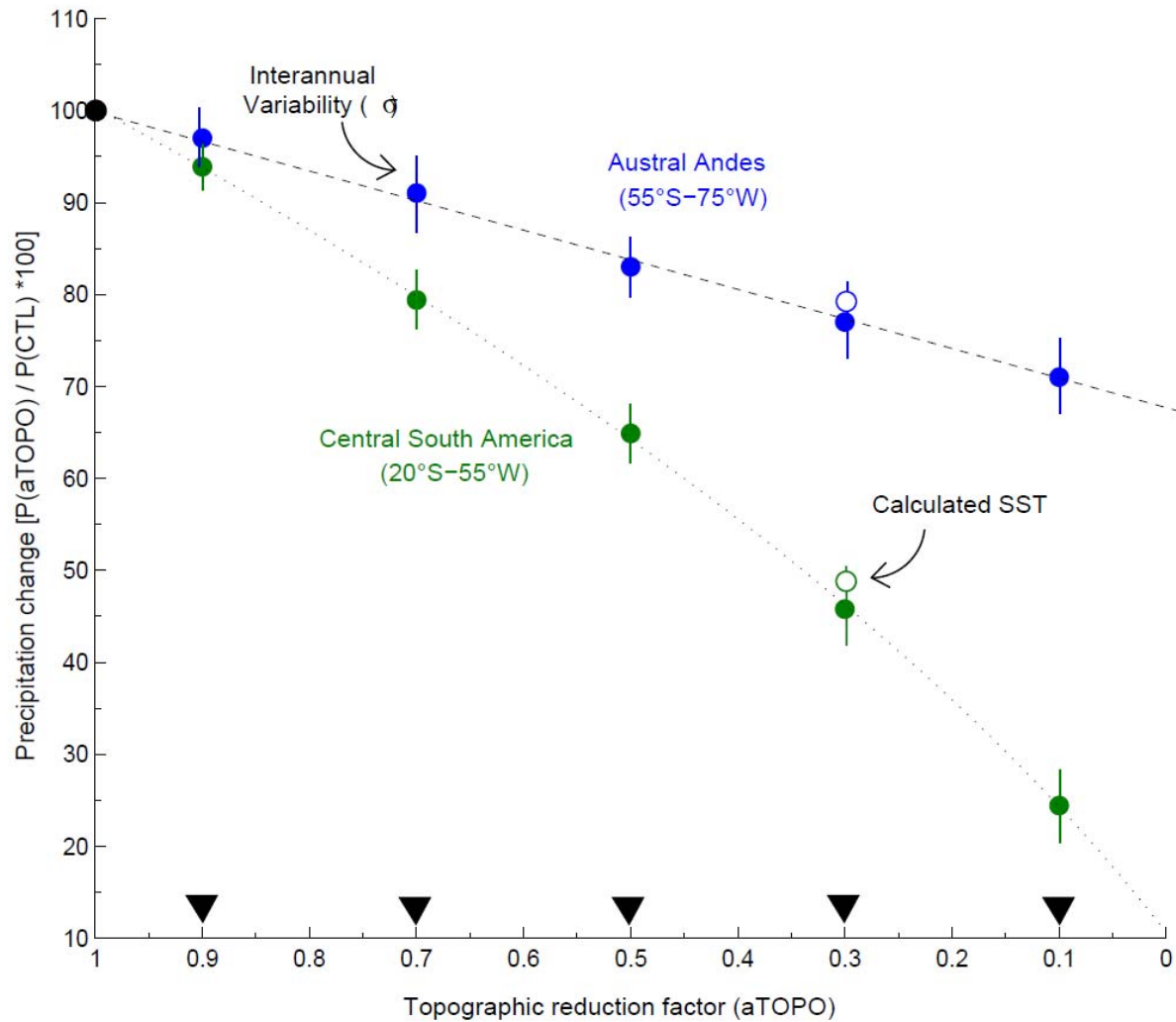
# PLASIM Topography Experiments

Long-term mean DJF 900 hPa wind  
0.3\*Topo (red) and Control (blue)

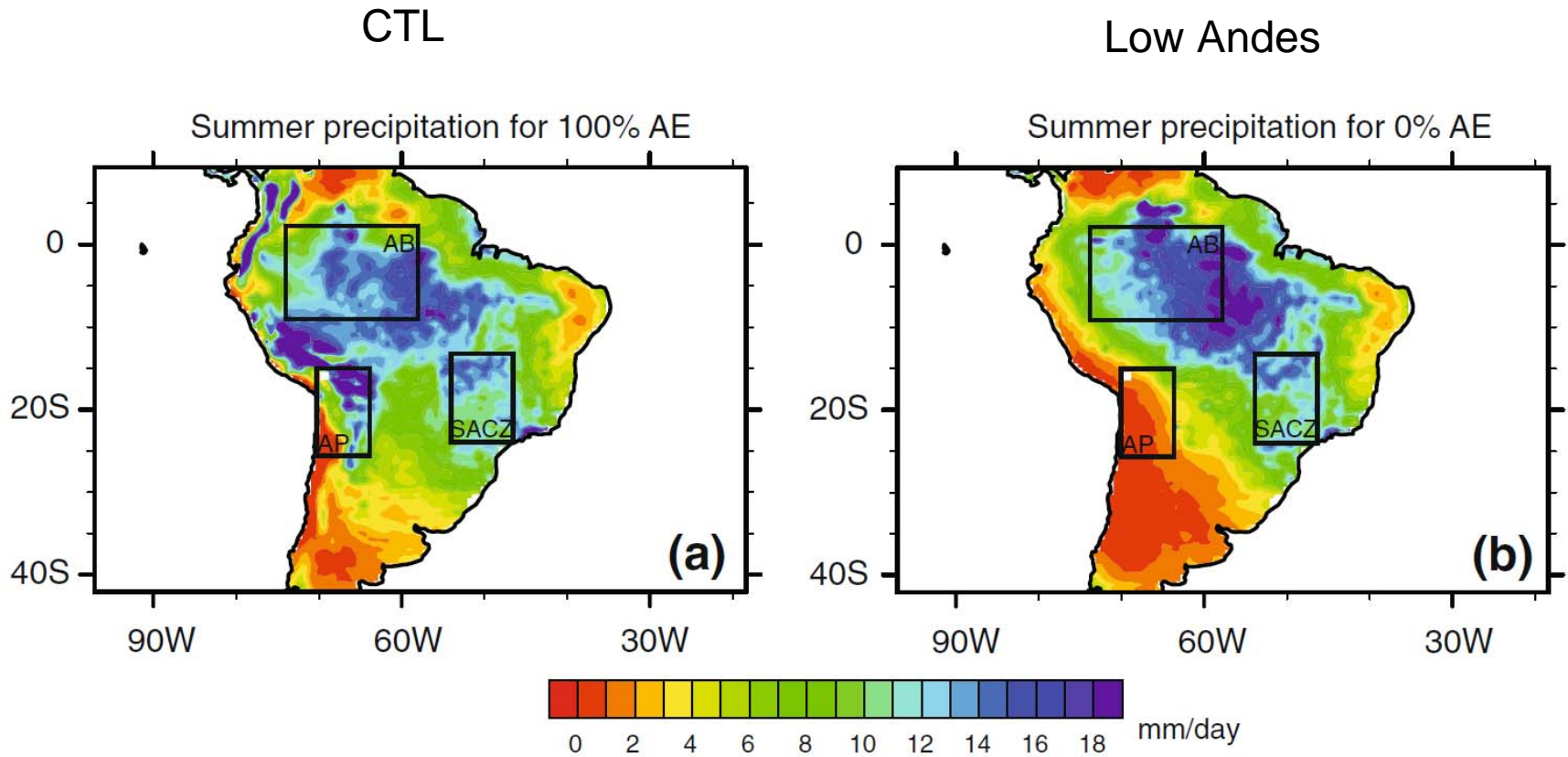


LLJ

# PLASIM Topography Experiments

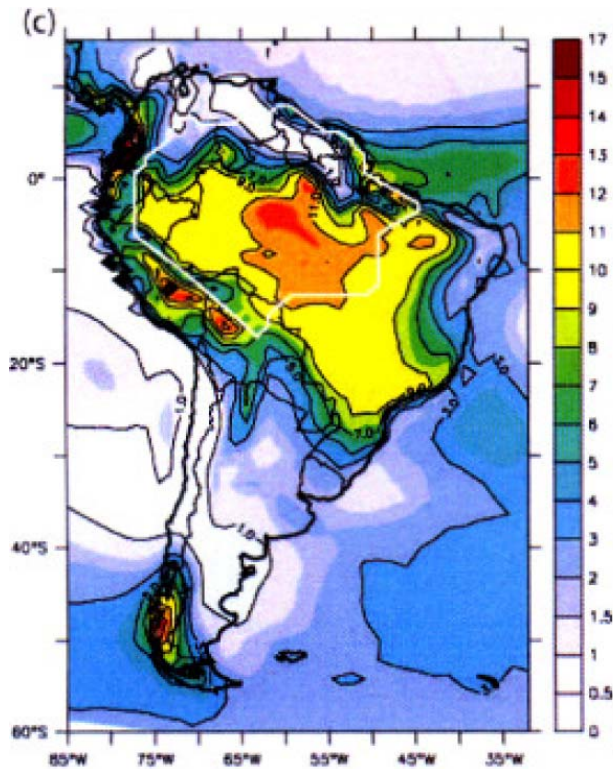


# REGCM Topography Experiments

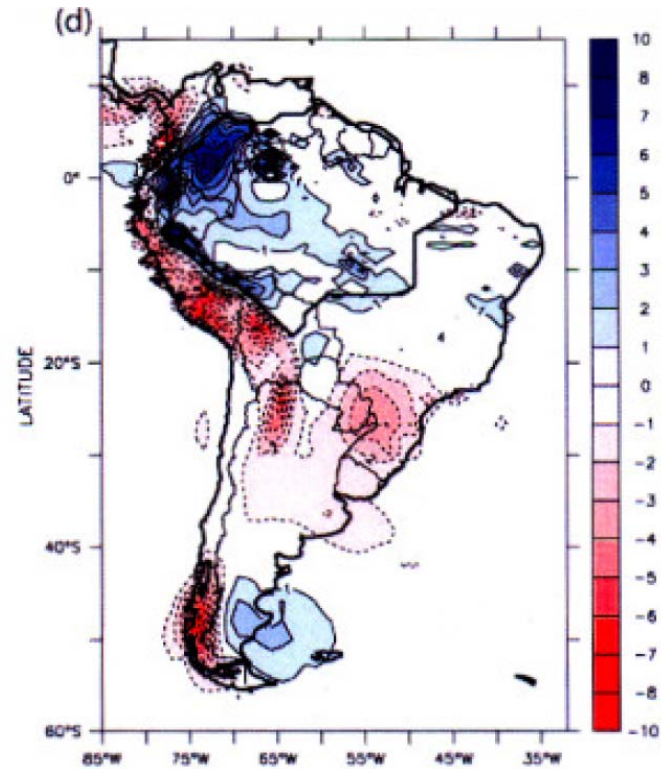


# IPSL Model Topography Experiments

CTL

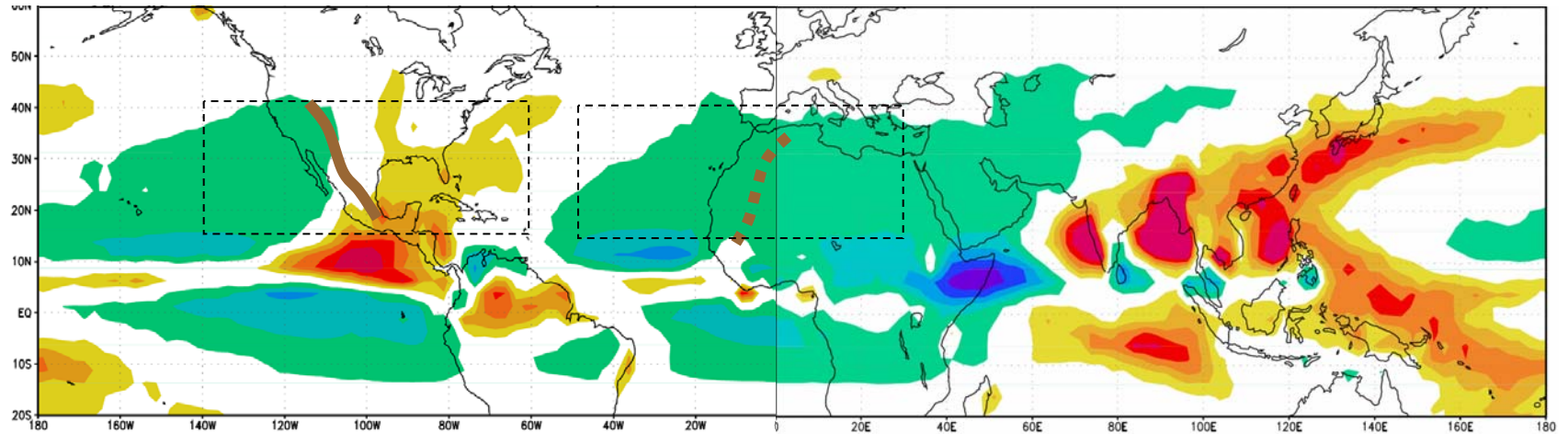


Low Andes – CTL

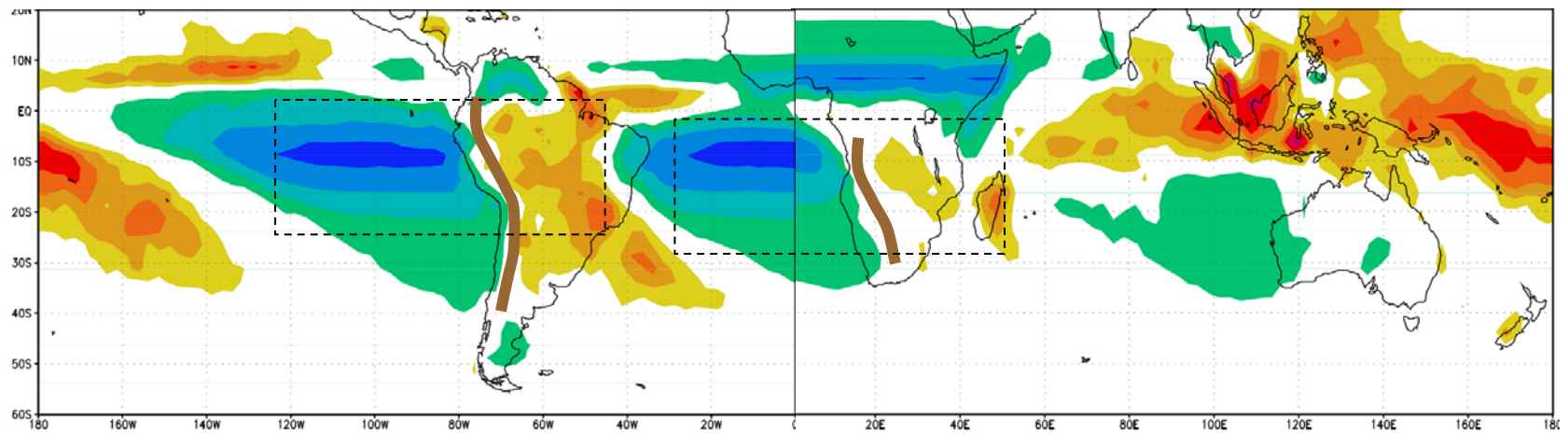


# Real World Topography Experiments

JJA (Boreal Summer)

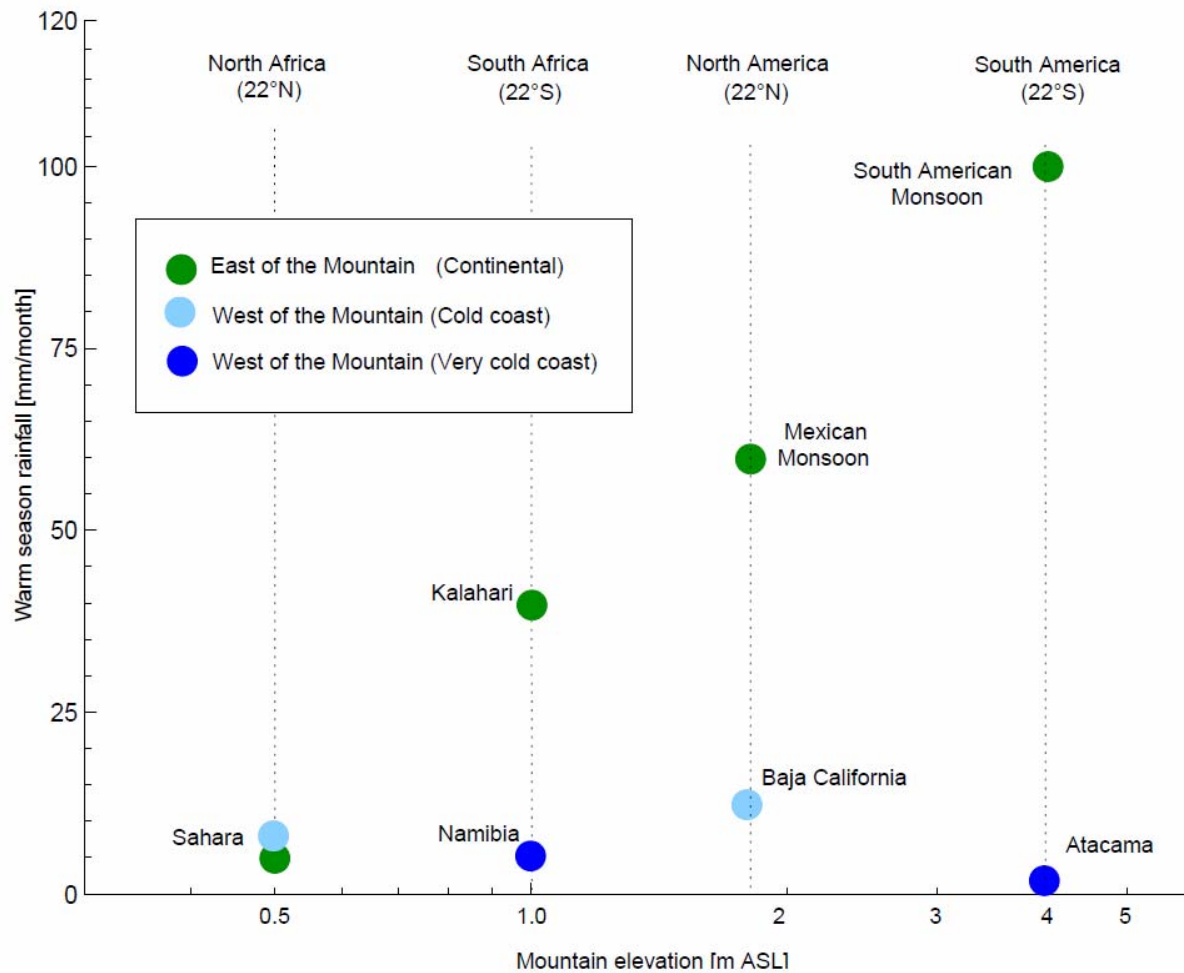


DJF (Austral Summer)



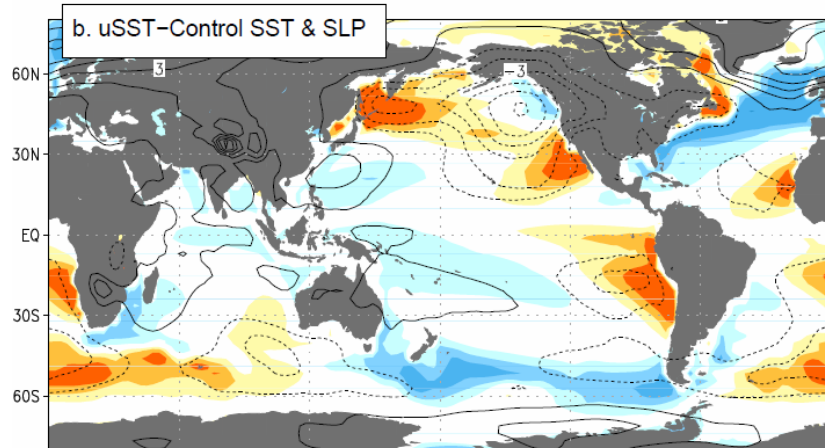
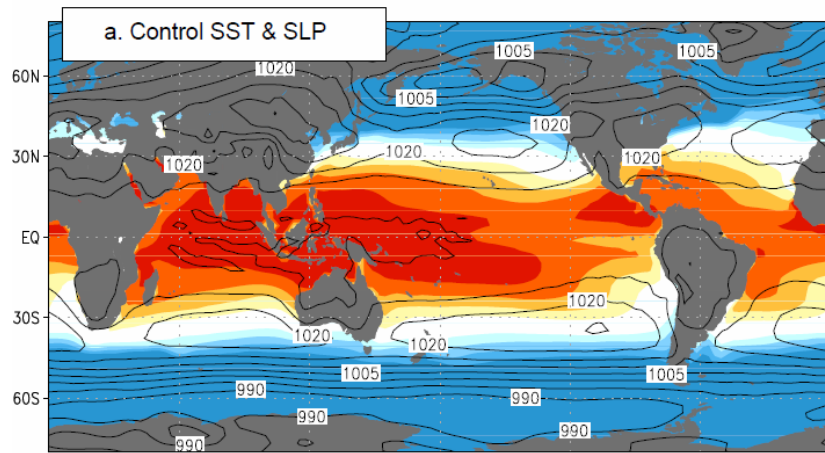
# Real World Topography Experiments

Mountain height does control continental precipitation (via LLJ) but hardly coastal precipitation

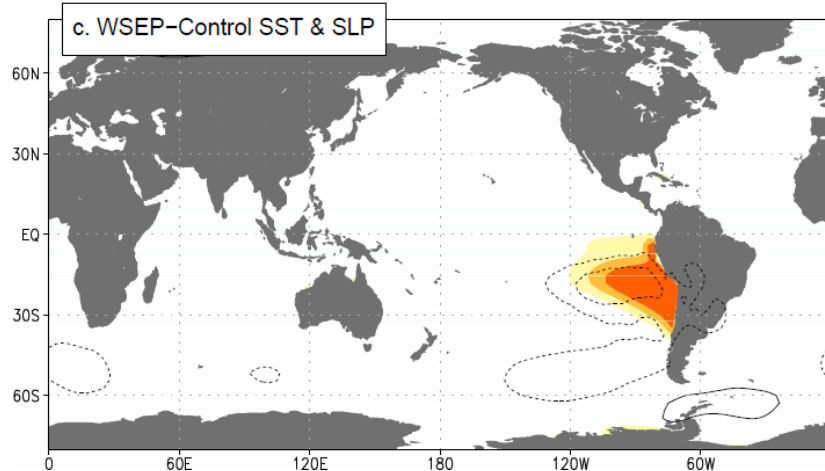




# PLASIM “Humboldt” Experiments



uSST: SST( $\phi$ ) only

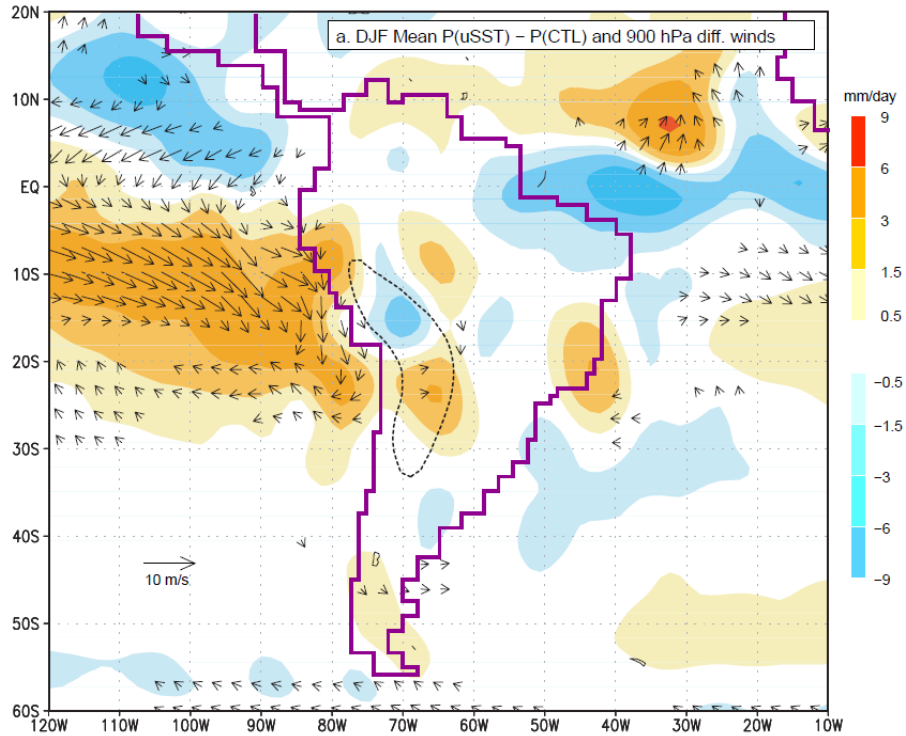


wSEP: warmer  
Southeast Pacific

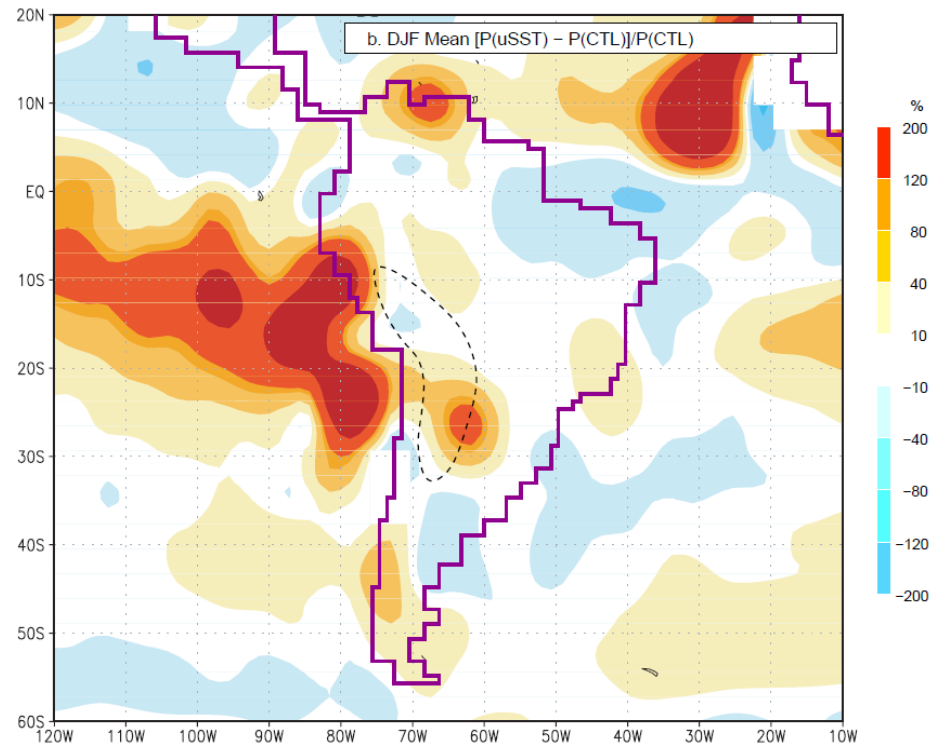
# PLASIM “Humboldt” Experiments

## uSST minus Control (DJF)

### 900 hPa winds and Precip



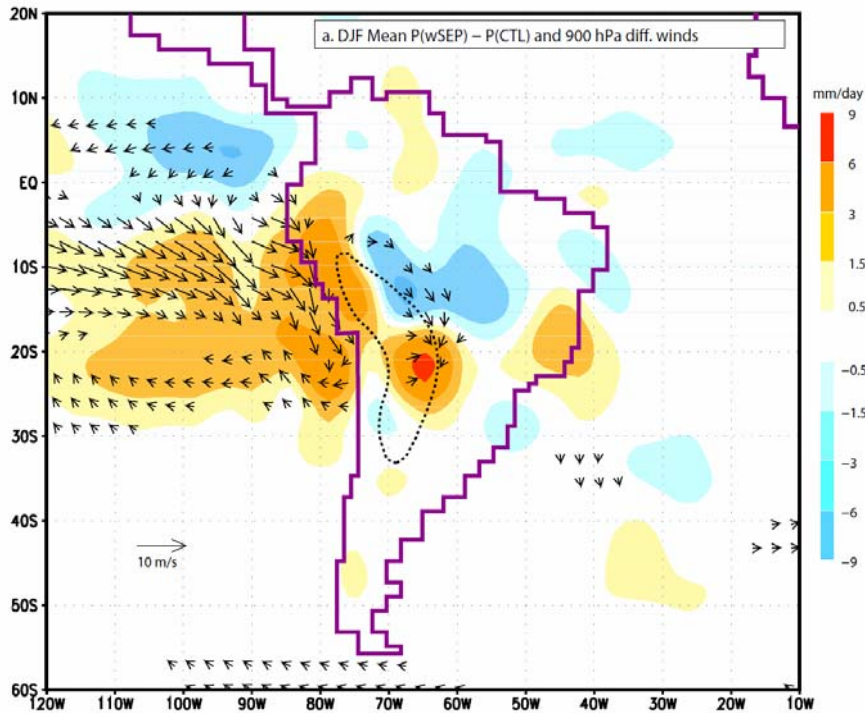
### % Precip ( $\Delta P/P_c$ )



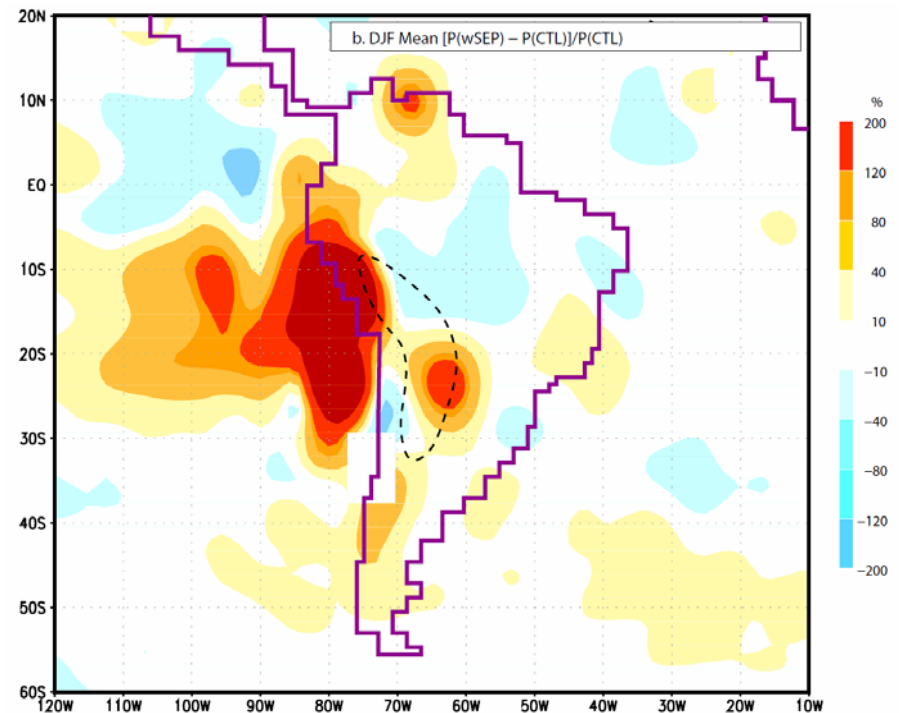
# PLASIM “Humboldt” Experiments

wSEP minus Control (DJF)

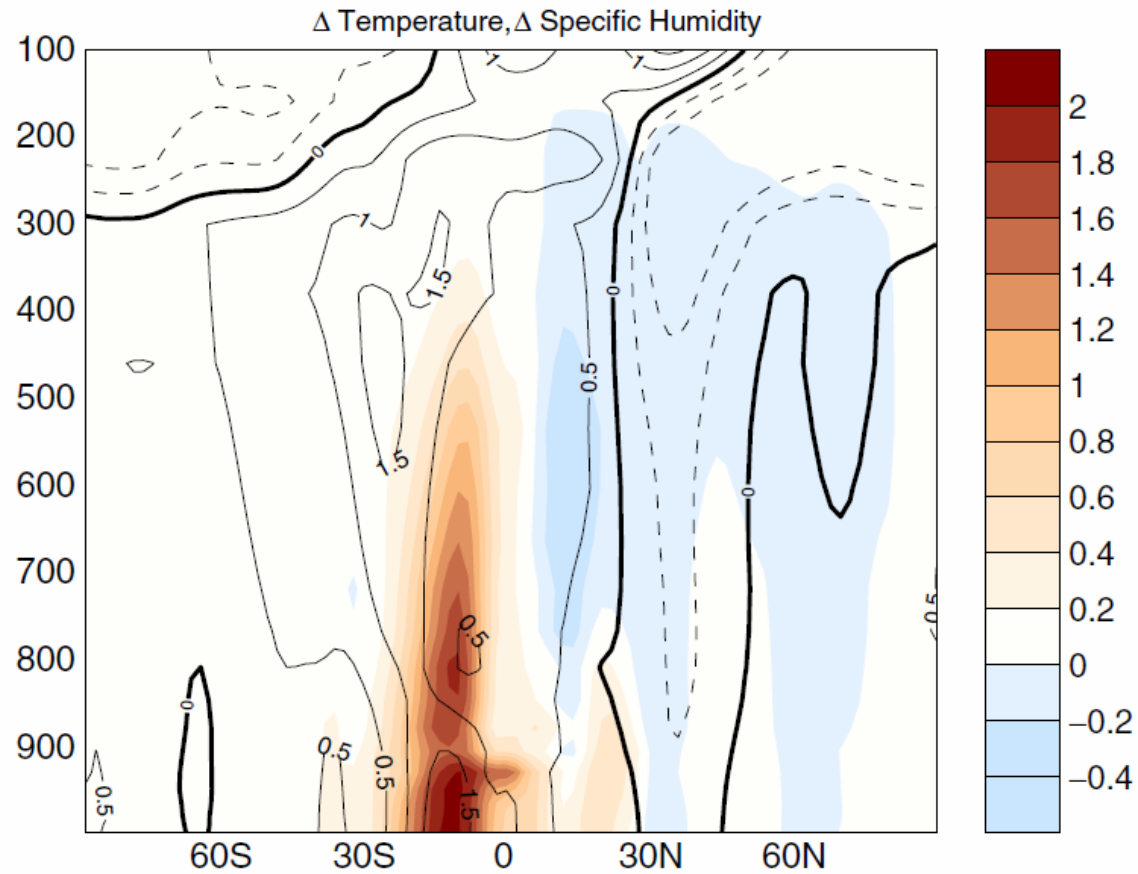
900 hPa winds and Precip



% Precip ( $\Delta P/P_c$ )



# GFDL GCM “Humboldt” Experiments



**Fig. 10** Zonal annual mean difference of temperature and specific humidity ( $10\text{e-}3$  g/kg, *color shading*) between TPLIO and Control

# GFDL GCM "Humboldt" Experiments

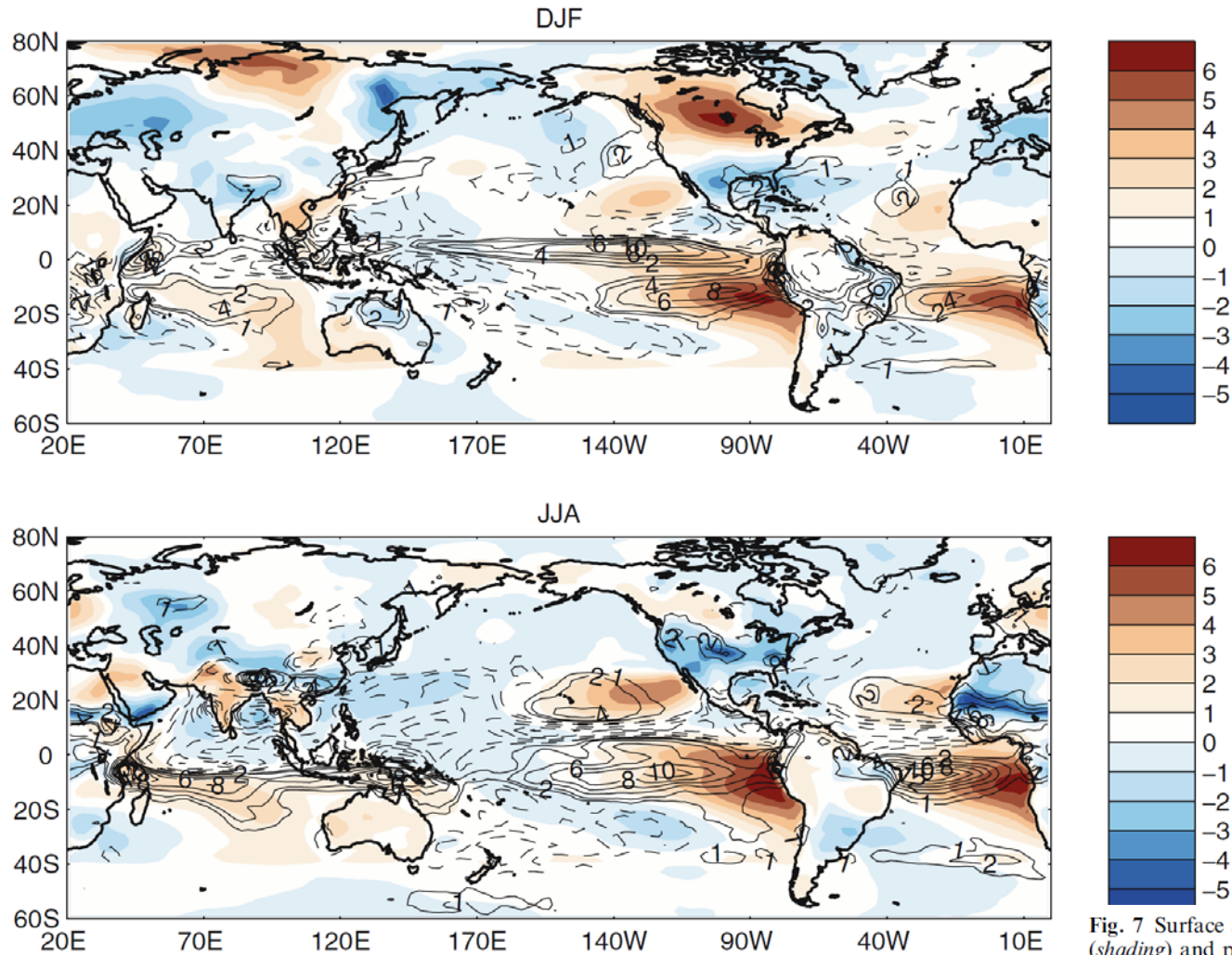


Fig. 7 Surface air temperature (shading) and precipitation (contours) differences between TPLIO and Control for December–February (upper panel) and June–August (lower panel). Precipitation in mm/day and temperature in degrees C

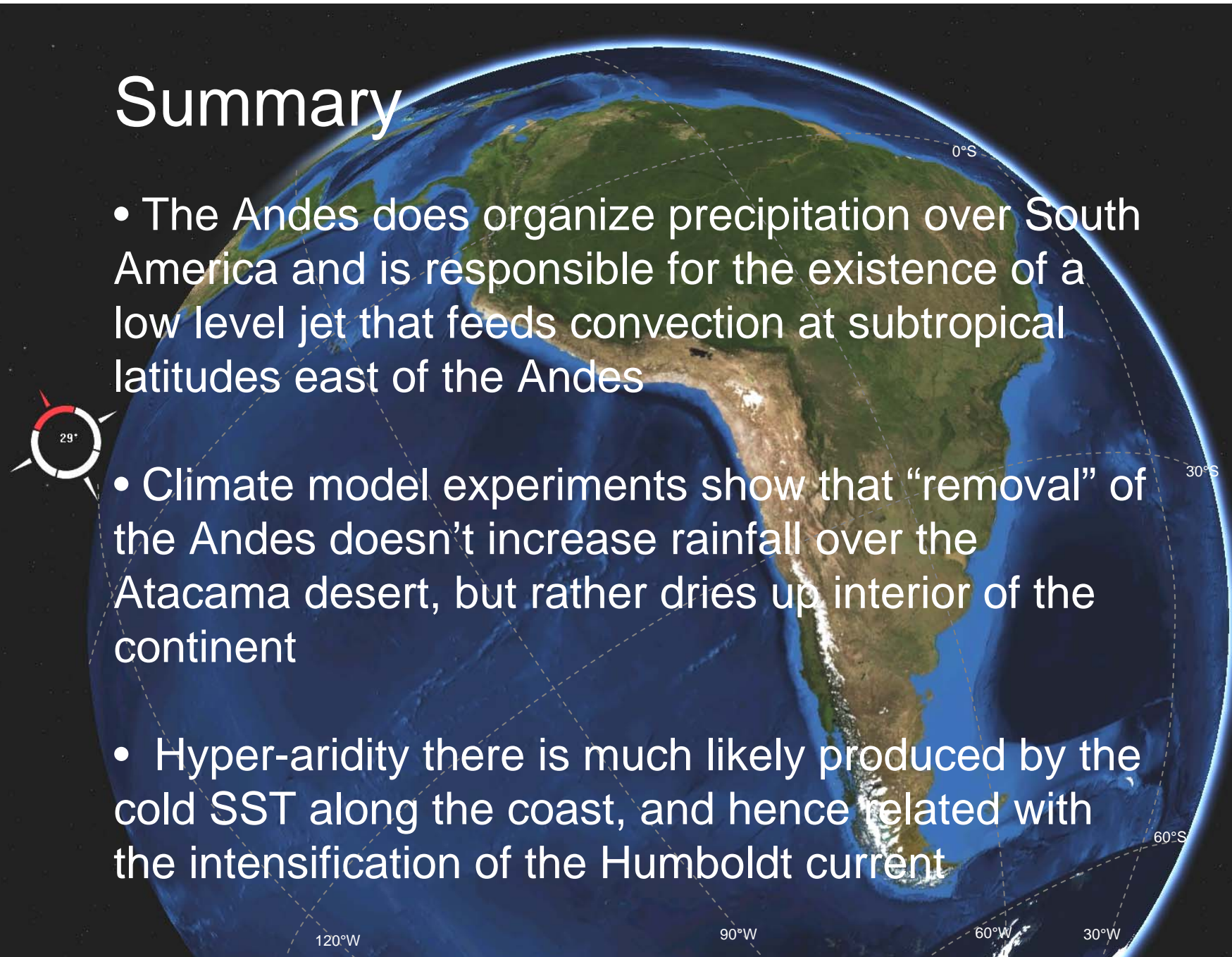
# Summary

- The Andes does organize precipitation over South America and is responsible for the existence of a low level jet that feeds convection at subtropical latitudes east of the Andes



- Climate model experiments show that “removal” of the Andes doesn’t increase rainfall over the Atacama desert, but rather dries up interior of the continent

- Hyper-aridity there is much likely produced by the cold SST along the coast, and hence related with the intensification of the Humboldt current



# Age, distribution, tectonics, and eustatic controls of the Paranense and Caribbean marine transgressions in southern Bolivia and Argentina

R.M. Hernández et al. / Journal of South American Earth Sciences 19 (2005) 495–512

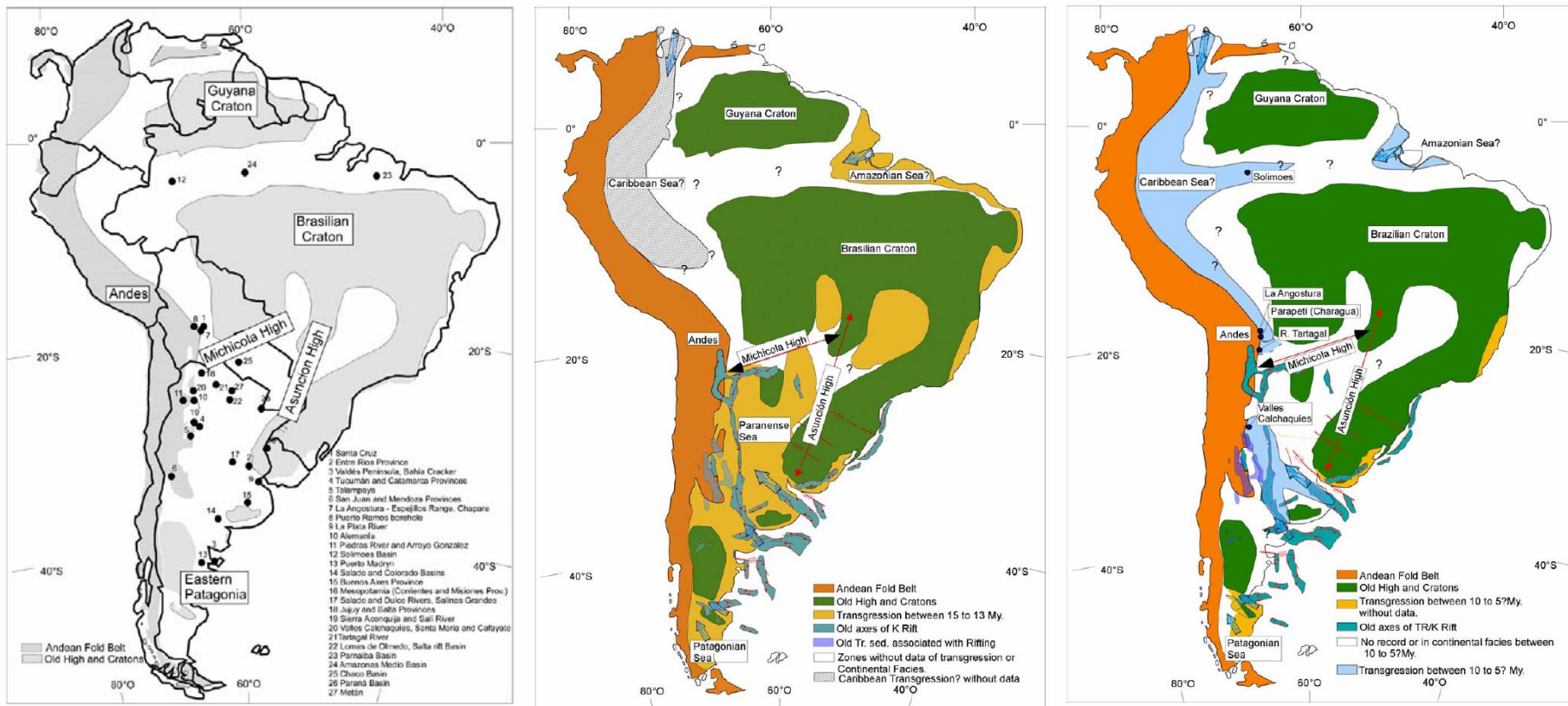


Fig. 1. Generalized location map of South America.

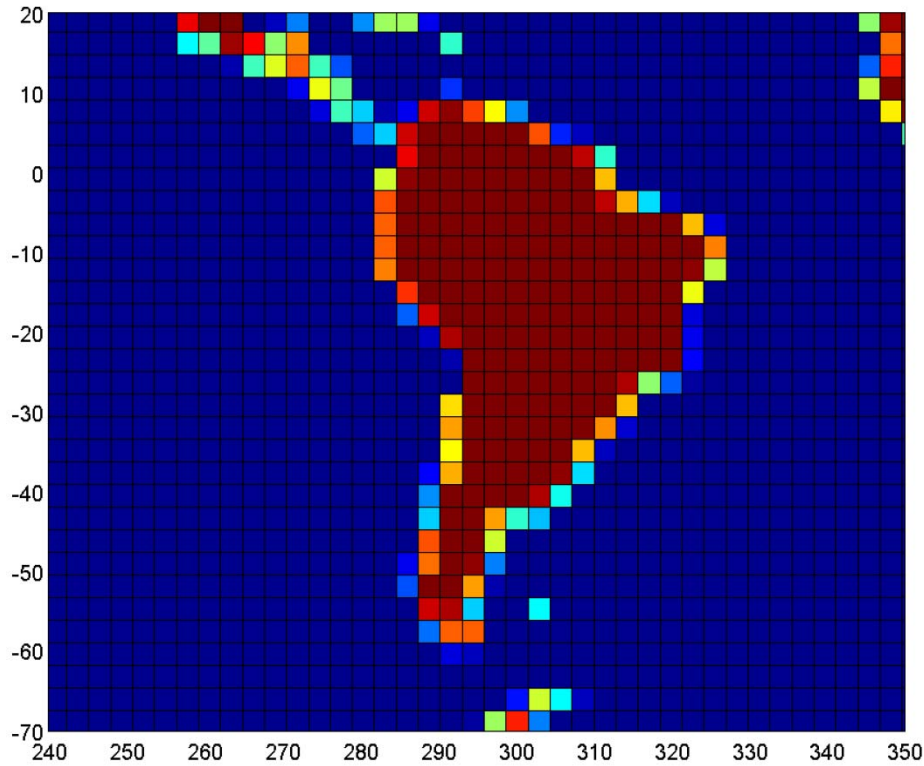
General Map

Marine Transgression 15-13 Ma

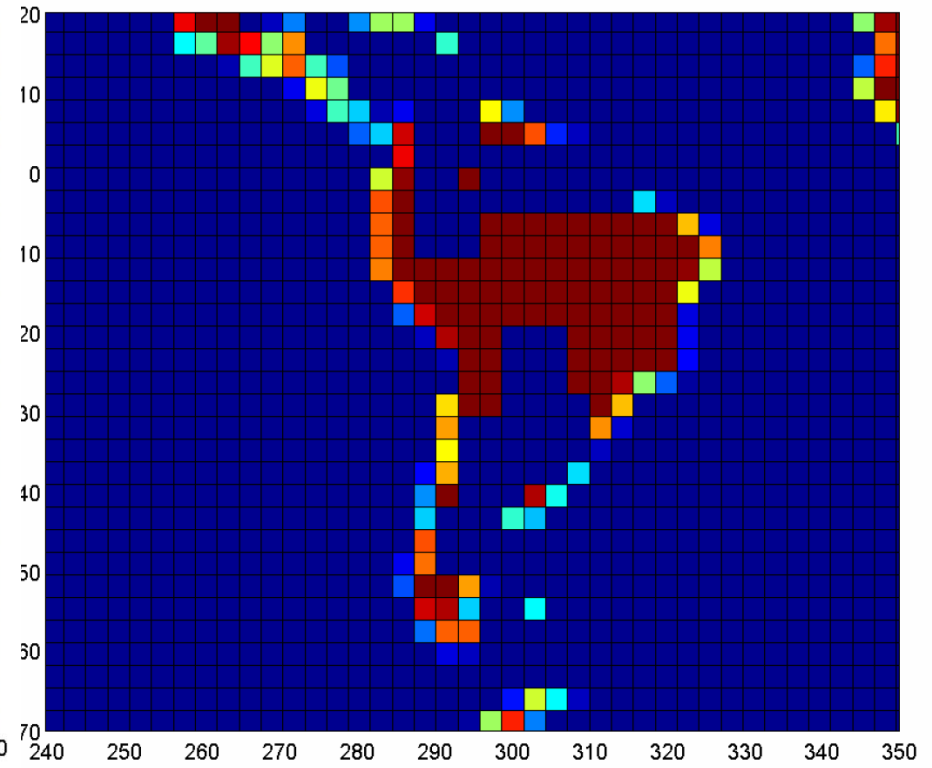
Marine Transgression 10-5? Ma

# PLASIM land-sea mask

Original (Control)

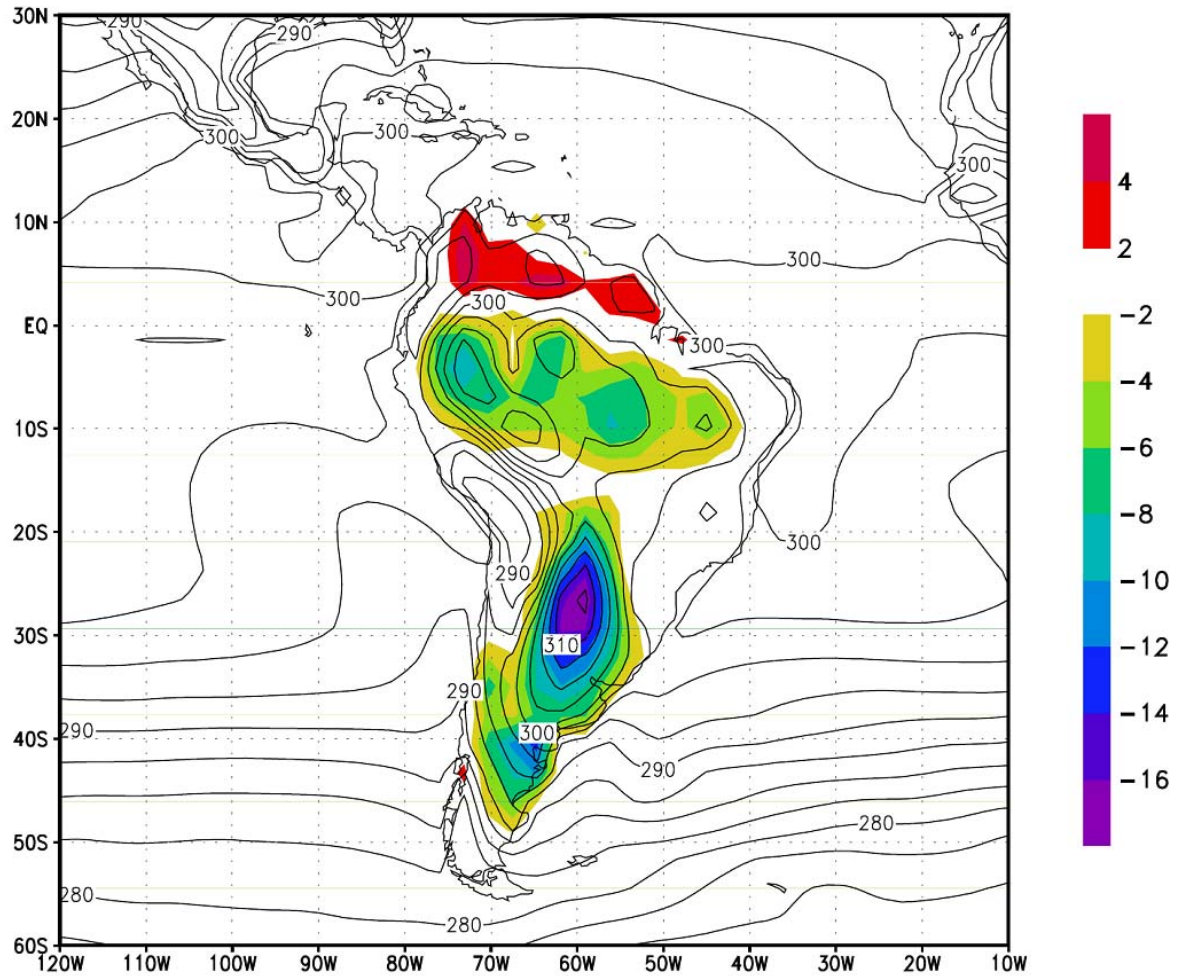


Modified (Transgression)





# DJF Control Tsfc / SST (contours) TRANS-CTL Tsfc / SST (shaded)



# DJF TRANS-CTL Precipitation (shaded)

