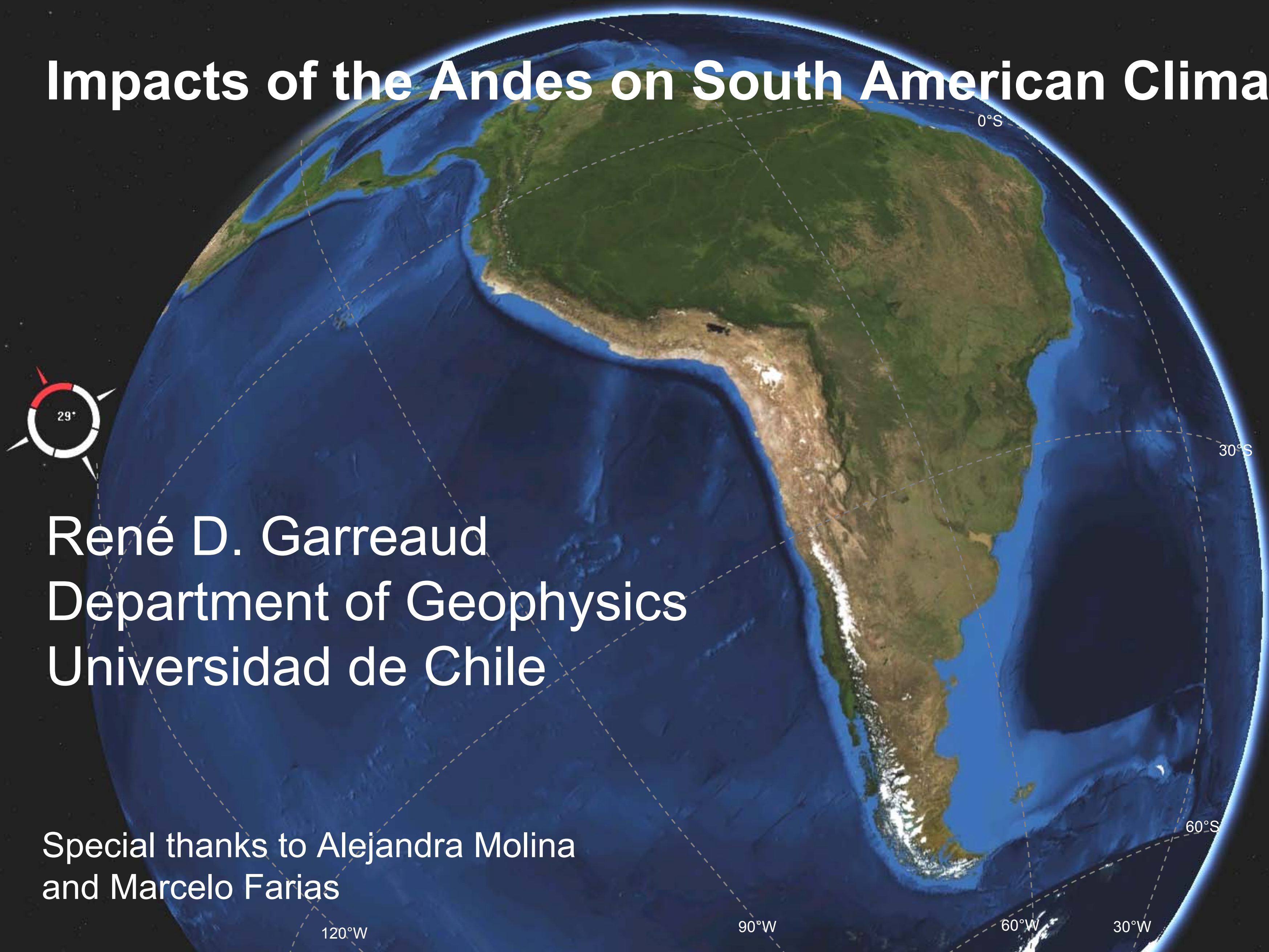
Impacts of the Andes on South American Climate



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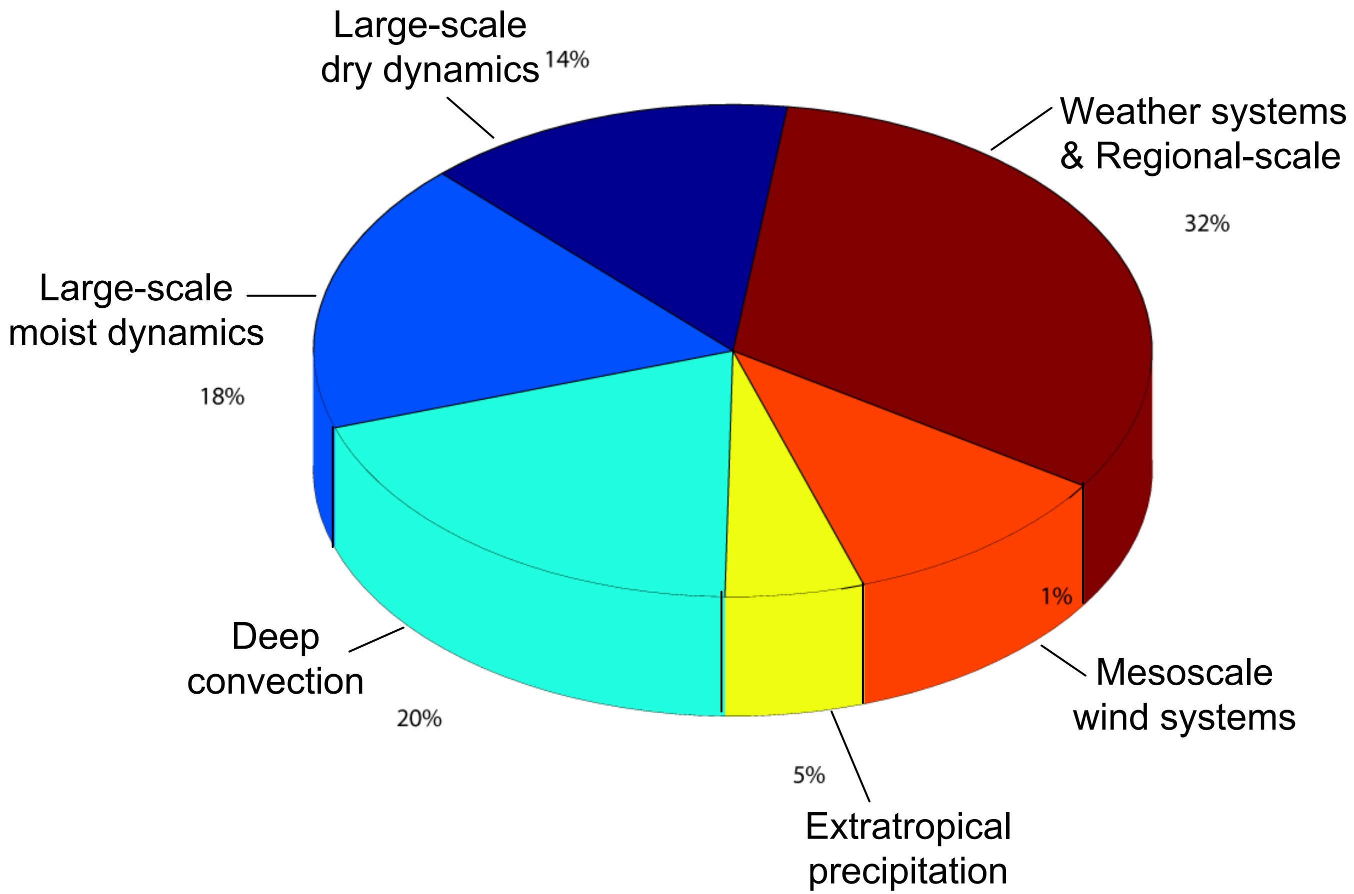
Department of Geophysics
Universidad de Chile

Special thanks to Alejandra Molina
and Marcelo Farias

Meteorology & Climate Papers on the Andes Cordillera

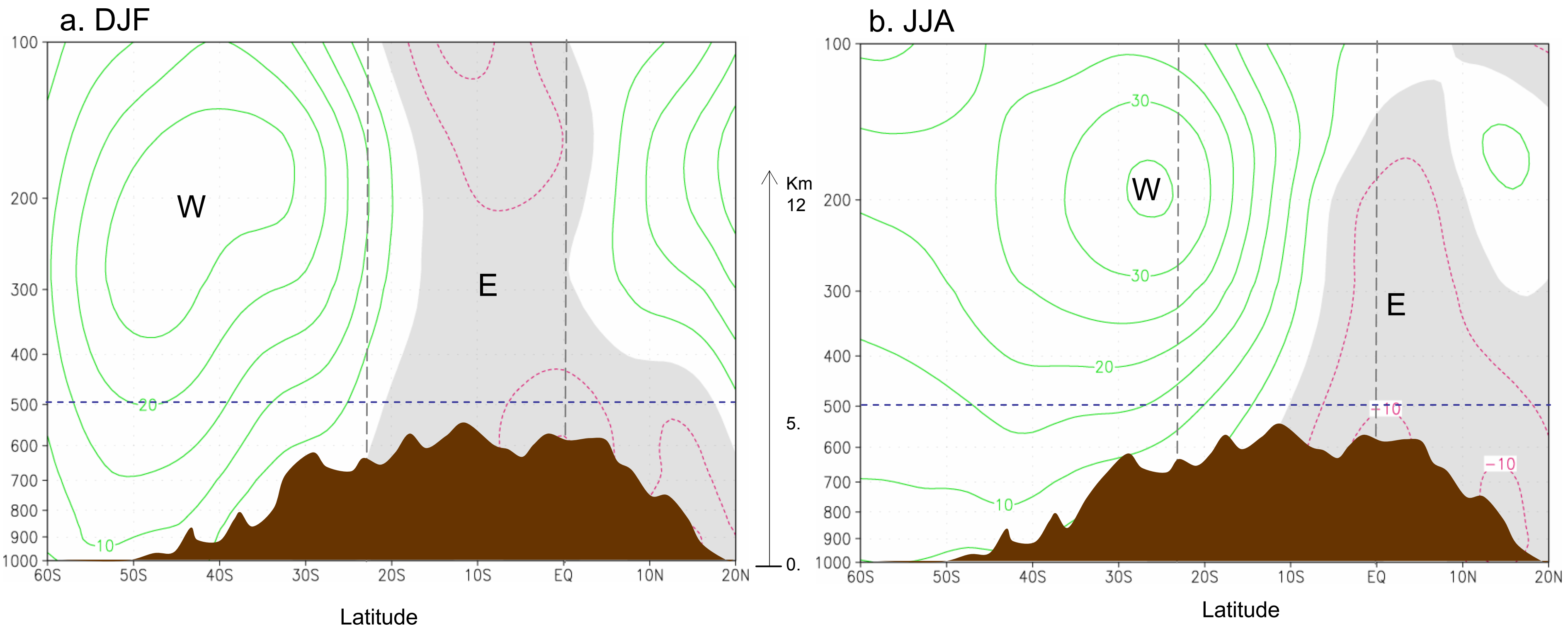
Survey of all American Meteorological Society Journals 1950-2008. “Andes” in title or abstract



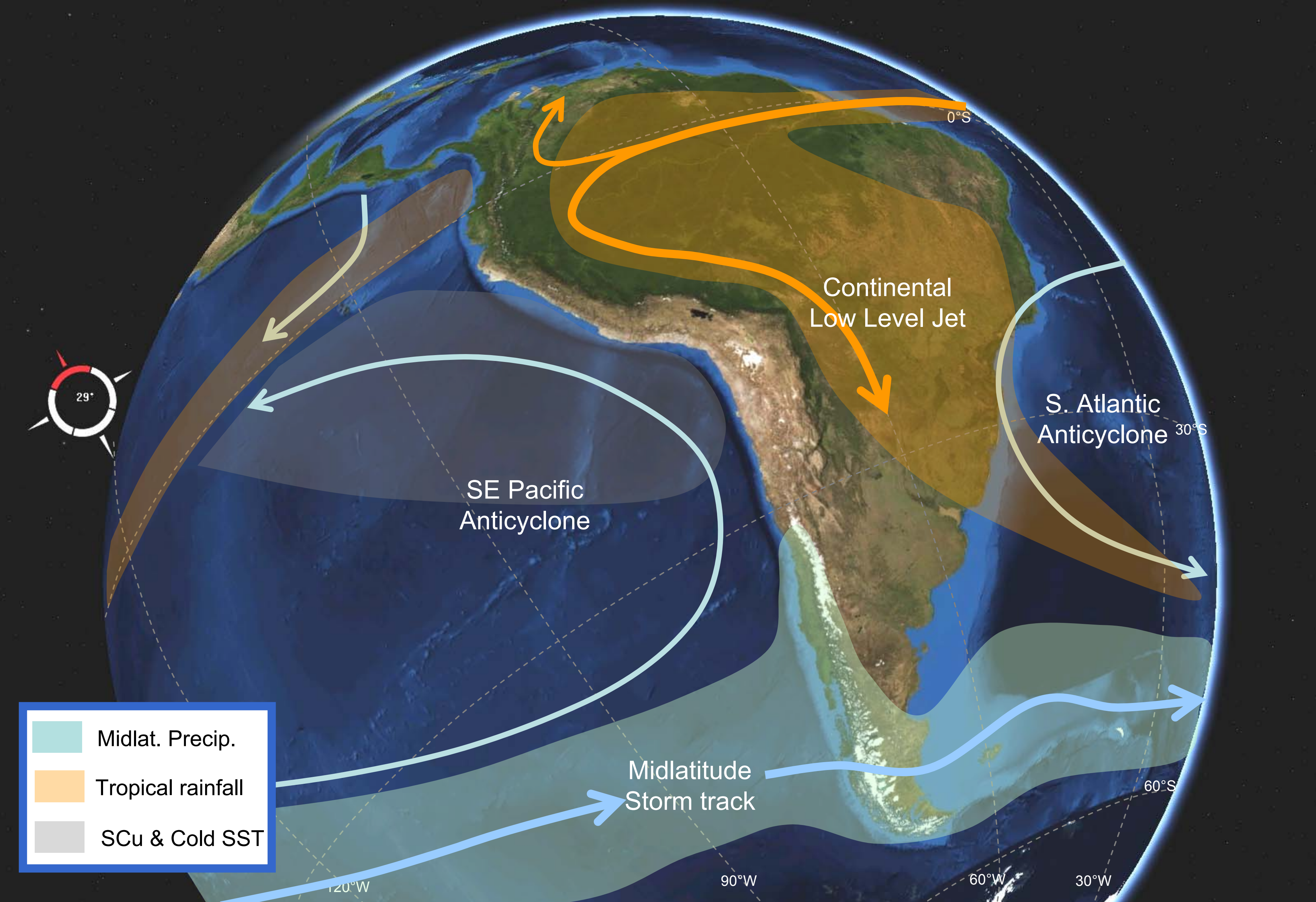
Zonal (east-west) mean flow over the Andes

Brown area: Terrain mean height

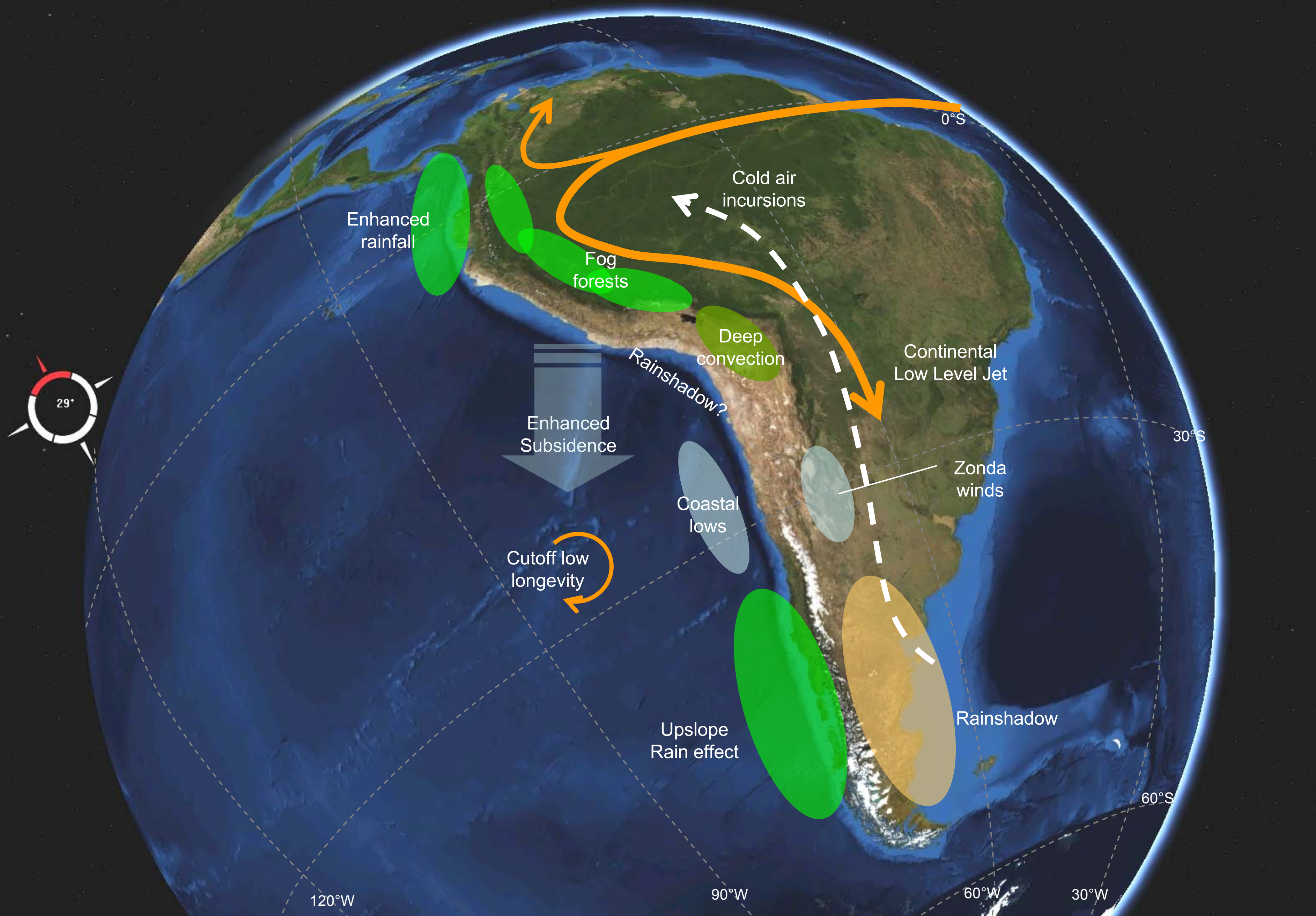
Dashed line: 500 hPa, half of the atmosphere below!



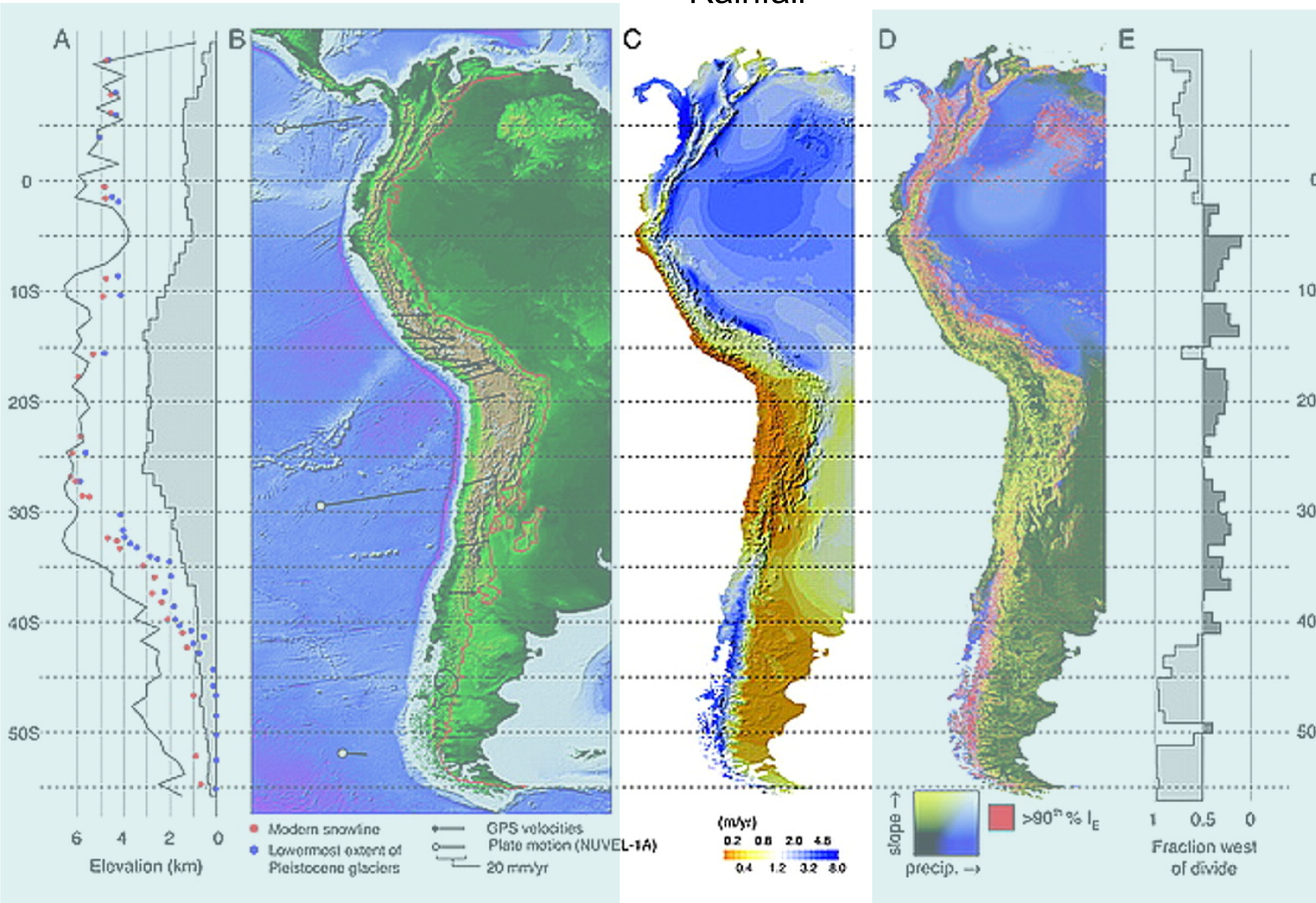
The Andes cordillera and the main low-level circulation patterns



A few effects of the Andes on the atmospheric circulation

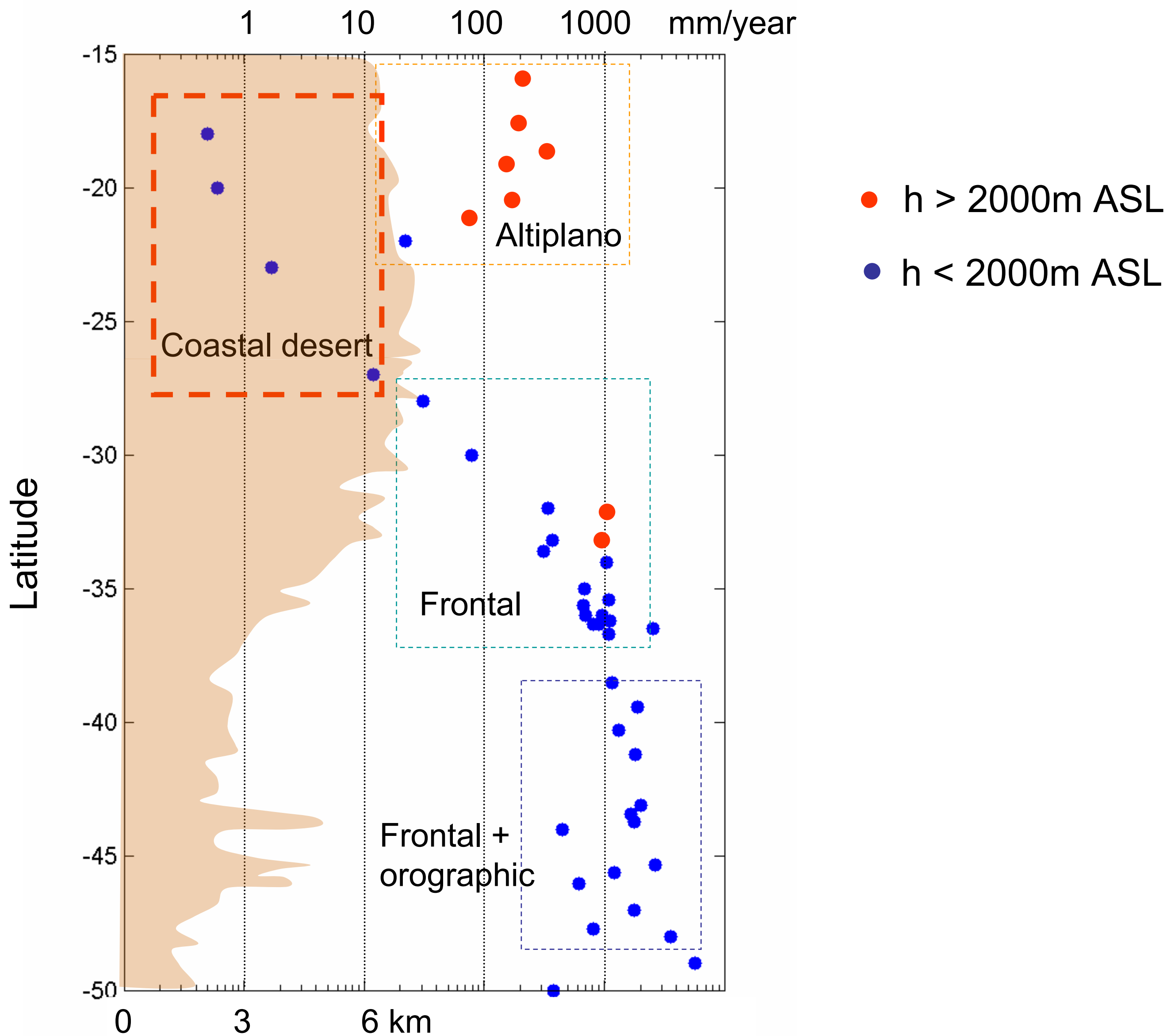


Rainfall

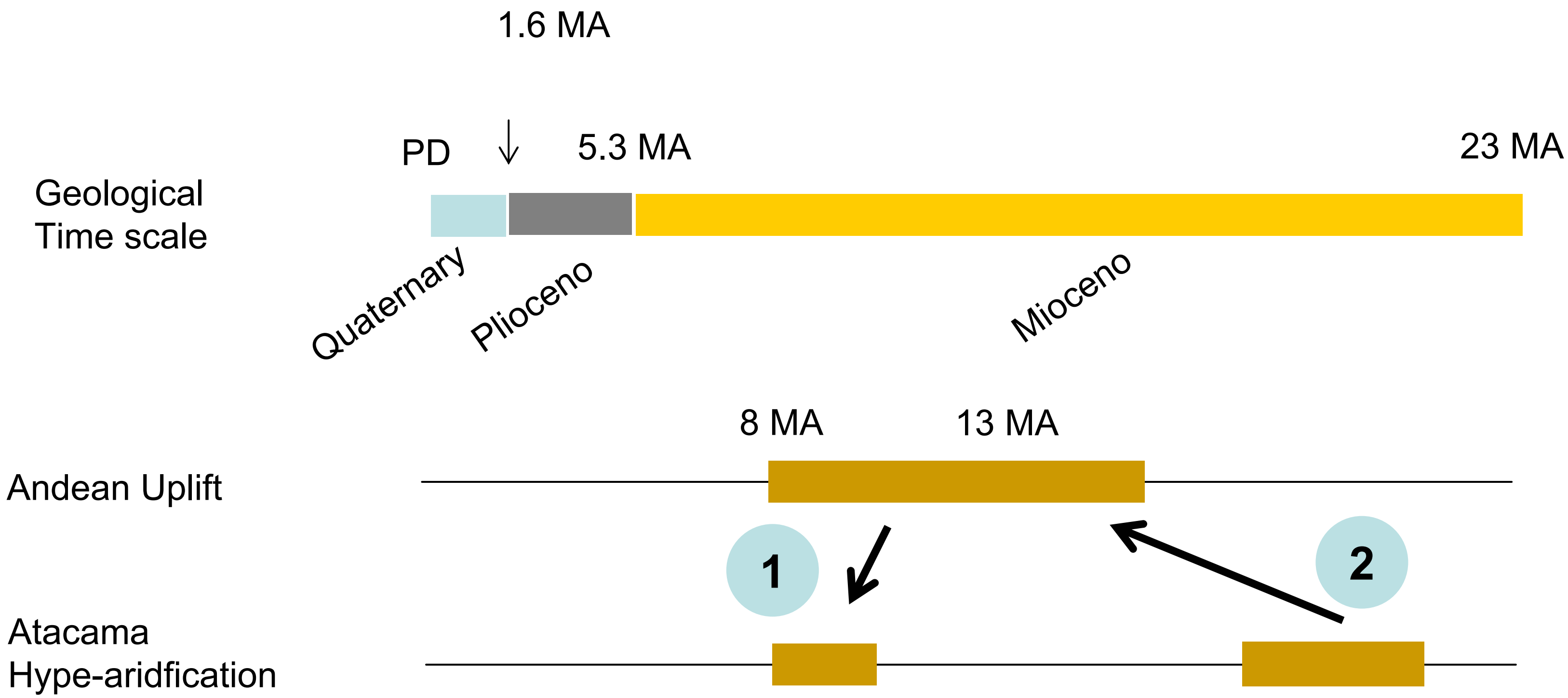


Montgomery et al. Geology 2001

Mean Annual Rainfall. Chilean stations.



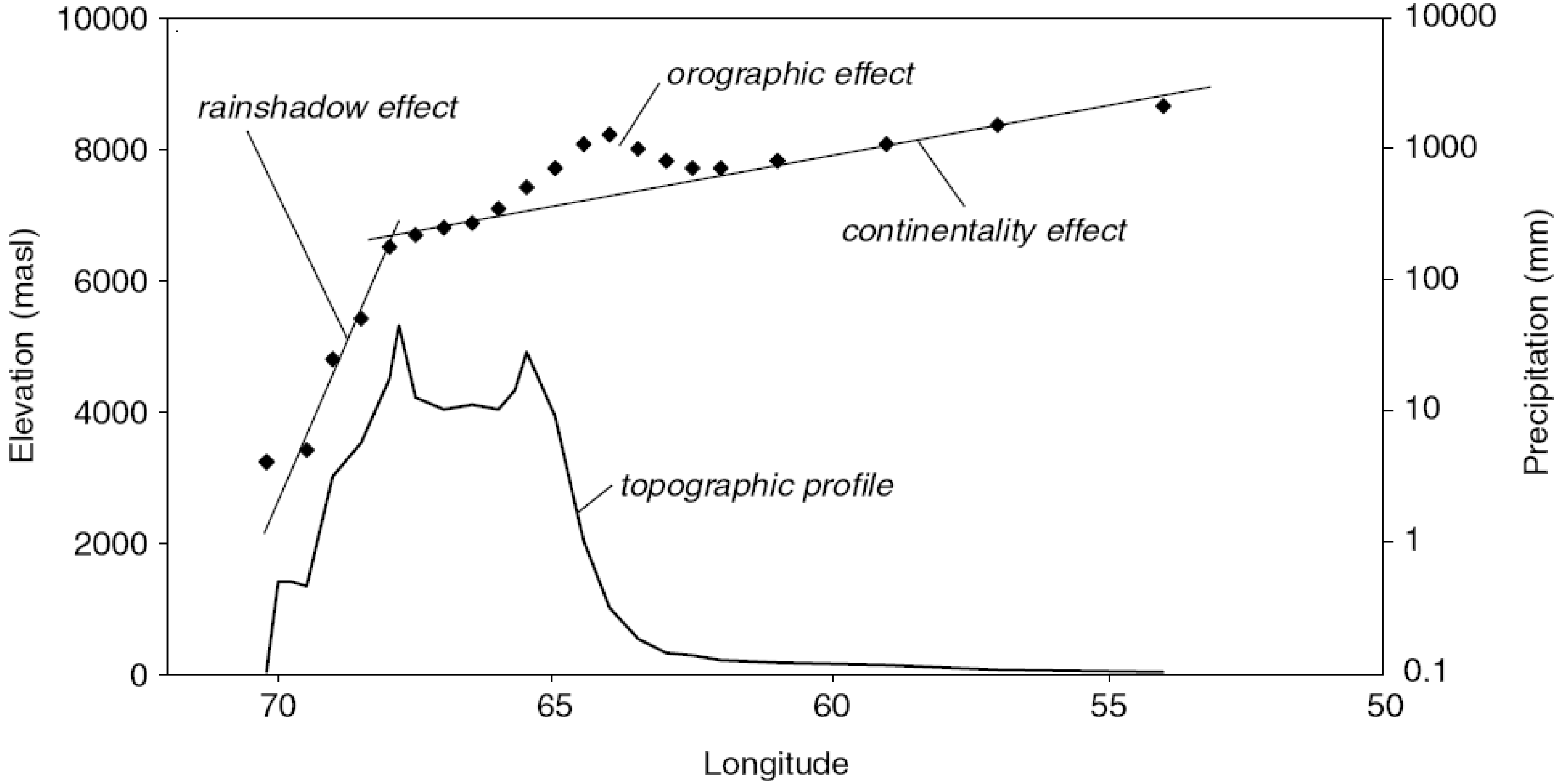
Two competing hypothesis



1. Andean uplift leads to Atacama hyper-aridity by producing a rain shadow

2. Atacama hyper-aridity contribute to Andean uplift by…see next (Lamb and Davis 2000)

Andean uplift ► Atacama hyper-aridification



Hartley and Houston 2003

Andean uplift ► Atacama hyper-aridification

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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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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.

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).

Andean uplift ► Atacama hyper-aridification

Neogene climate change and uplift in the Atacama Desert, Chile

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ABSTRACT

The relationship between Andean uplift and extreme desiccation of the west coast of South America is important for understanding the interplay between climate and tectonics in the Central Andes, yet it is poorly understood. Here we use soil morphological characteristics, salt chemistry, and mass independent fractionation anomalies ($\Delta^{17}O$ values) in dated paleosols to reconstruct a middle Miocene climatic transition from semiaridity to extreme hyperaridity in the Atacama Desert. Paleosols along the southeastern margin of the Calama Basin change from calcic Vertisols with root traces, slickensides, and gleyed horizons to an extremely mature salic Gypsisol with pedogenic nitrate. We interpret this transition, which occurred between 19 and 13 Ma, to represent a change in precipitation from >200 mm/yr to <20 mm/yr. This drastic reduction in precipitation likely resulted from uplift of the Central Andes to elevations >2 km; the uplift blocked moisture from the South American summer monsoon from entering the Atacama. The mid-Miocene Gypsisol with pedogenic nitrate is located at elevations between 2900 and 3400 m in the Calama Basin, significantly higher than modern nitrate soils, which occur below ~2500 m. Modern and Quaternary soils in this elevation zone contain soil carbonate and lack pedogenic gypsum and nitrate. We infer that >900 m of local surface uplift over the past 10 m.y. displaced these nitrate paleosols relative to modern nitrate soils and caused a return to wetter conditions in the Calama Basin by decreasing local air temperatures and creating an orographic barrier to Pacific air masses.

Keywords: Atacama Desert, Andes, paleosols, Calama Basin, soil nitrate.

INTRODUCTION

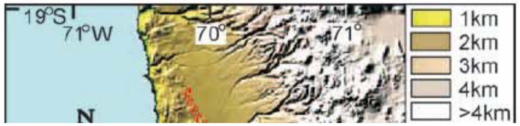
maintained through the existence of a strong

elevations above ~2800 m, but do not cause rainfall in the central Atacama.

The Calama Basin is located on the eastern margin of the Atacama, ~150 km from the Pacific Coast at elevations between 2200 and 3500 m (Fig. 1). Precipitation in the center of the basin (2200 m) is ~4 mm/yr, whereas along the eastern margin (3350 m) precipitation is ~50 mm/yr.

PALEOSOLS IN THE CALAMA BASIN

We examined Miocene strata and Quaternary landforms along the southeastern margin of the Calama Basin for evidence of pedogenesis. Miocene gypcretes were first reported in this region by Hartley and May (1998). We identified Miocene and Quaternary paleosols developed on substrates of alluvial fan and flood-plain deposits, and basement bedrock.



Atacama hyper-aridification ► Andean uplift

articles

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

Simon Lamb[1] & Paul Davis[2]

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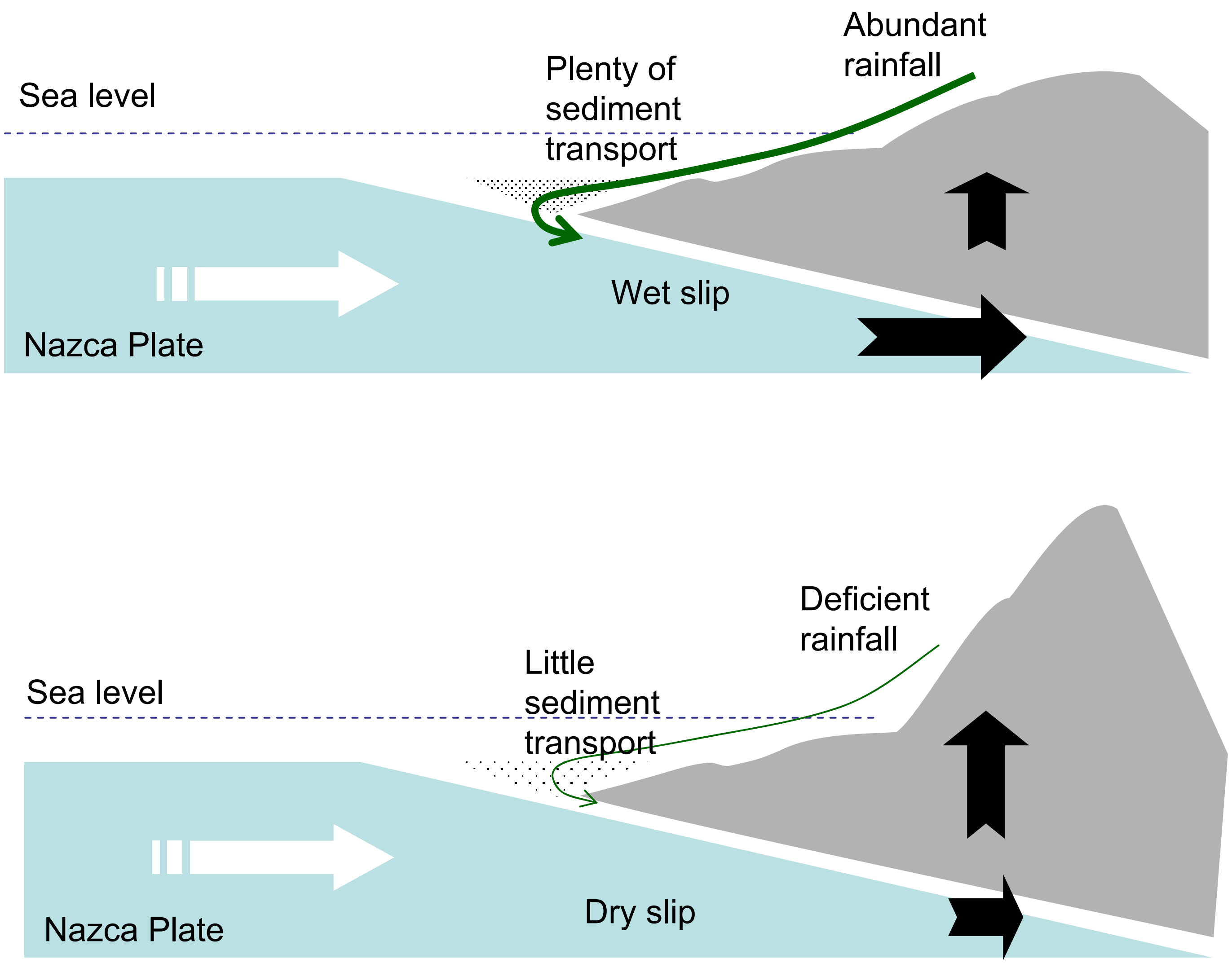
[2]*Department of Earth and Space Sciences, University of California, Los Angeles, California 90095, USA*

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

If Atacama hyper-aridification leads to Andean uplift, what caused the increase in dryness over Atacama during the Miocene?

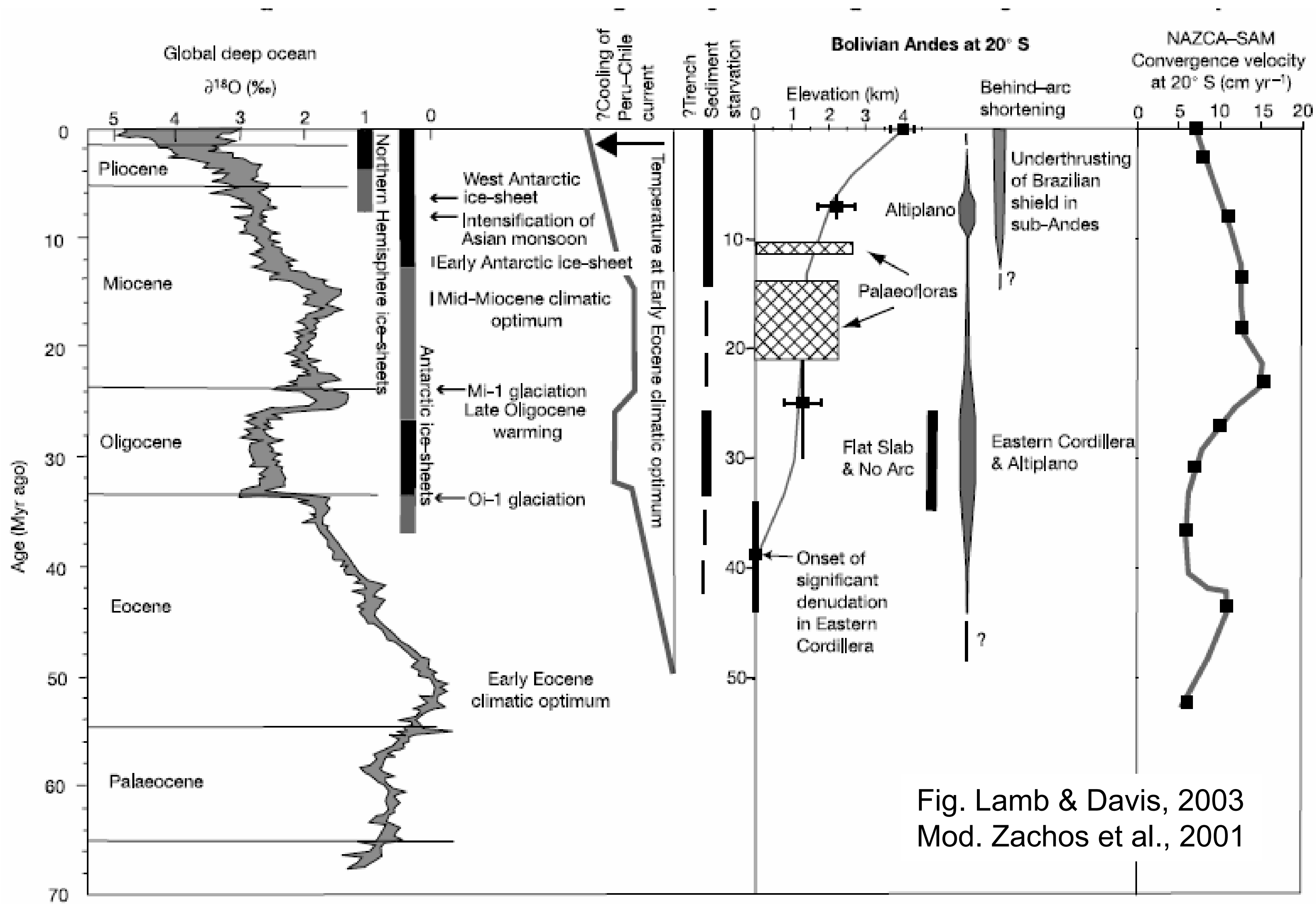


Fig. Lamb & Davis, 2003
Mod. Zachos et al., 2001

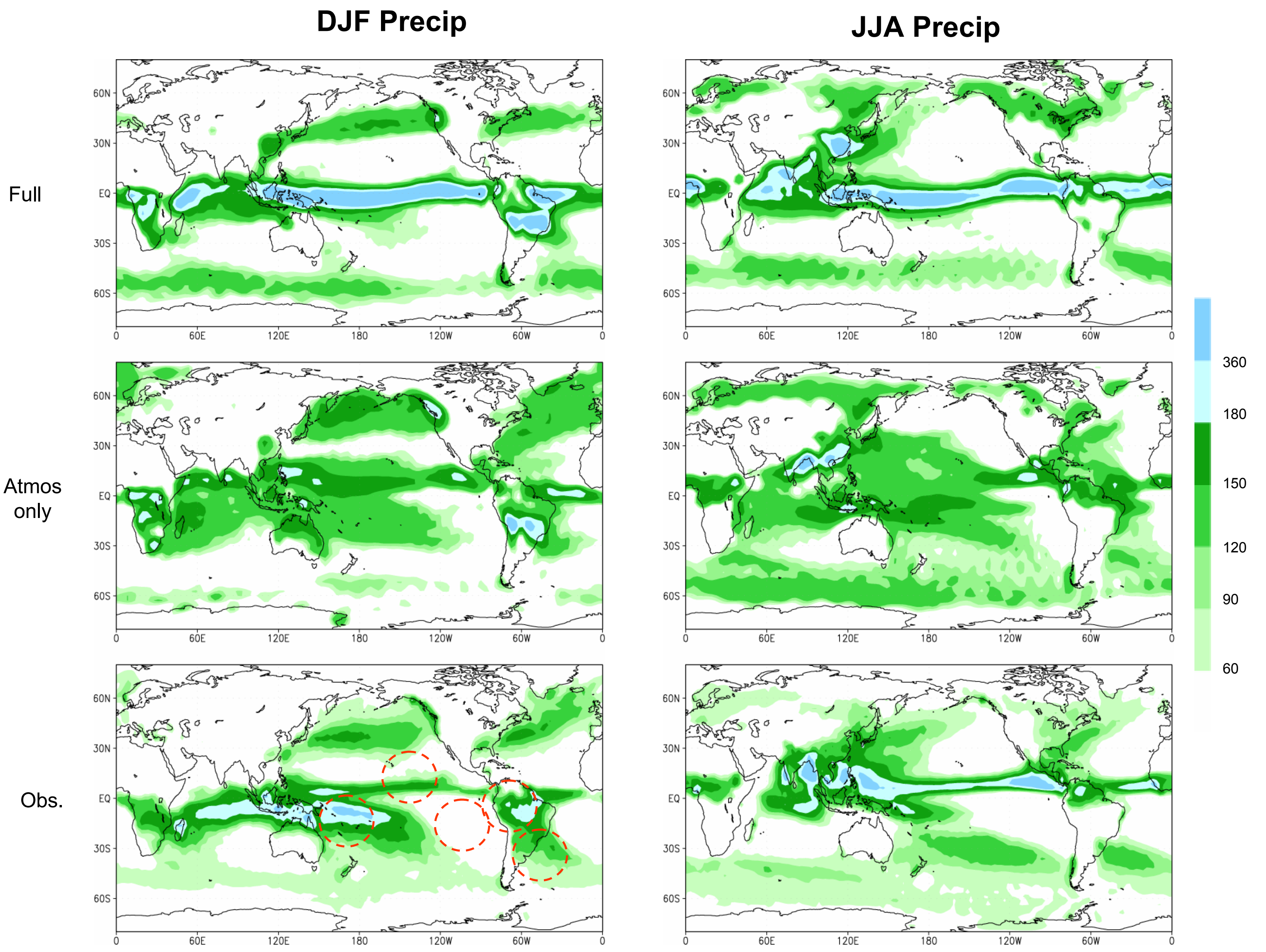
Conceptually, both Andean uplift and SEP cooling may increase dryness of the Atacama desert…it would be nice to use a “simple” climate model to study these two conditions.

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

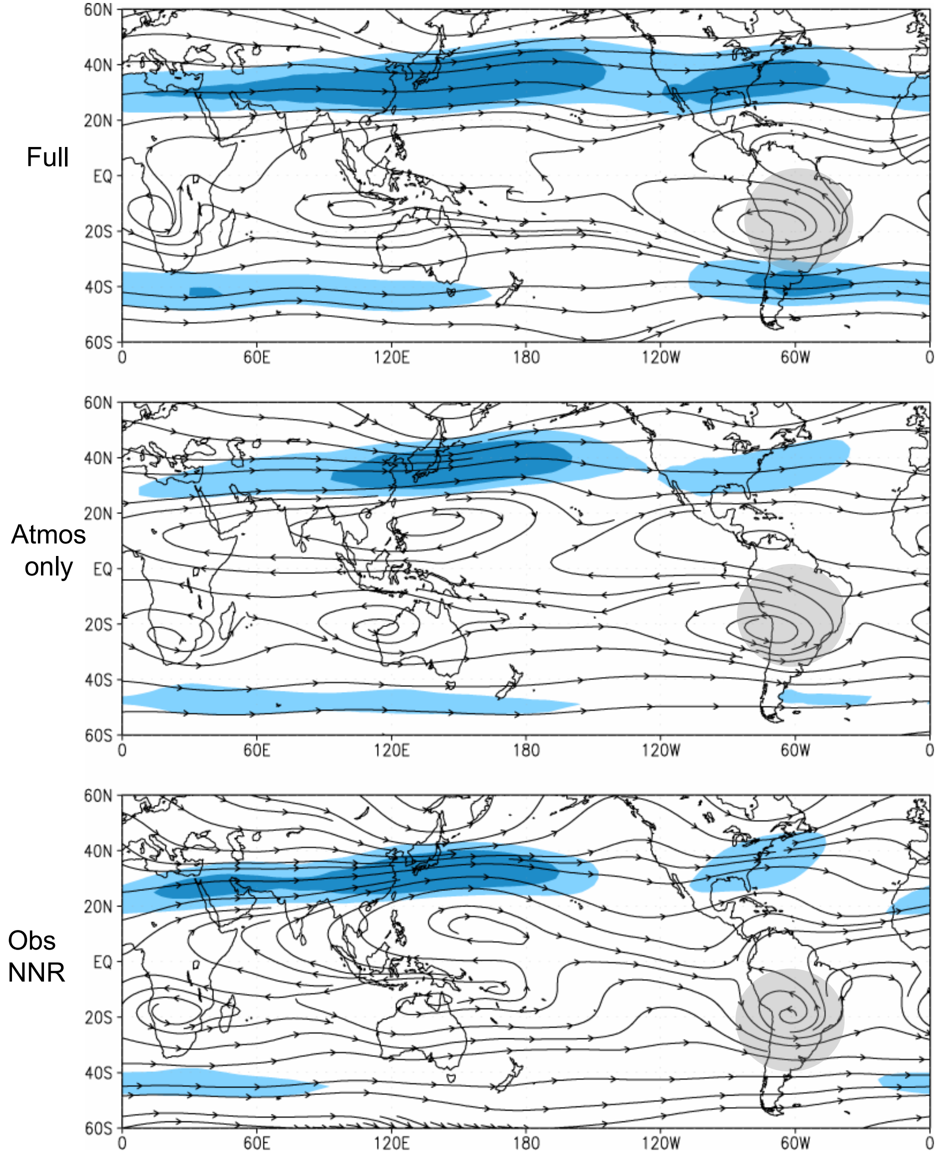
We performed 30 year long simulations altering one Boundary condition at a time

Model Validation



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 anticylones	Yes, but too wide	Ok, too wide
SPCZ	Yes	No
SACZ	Ok, but too short	Yes

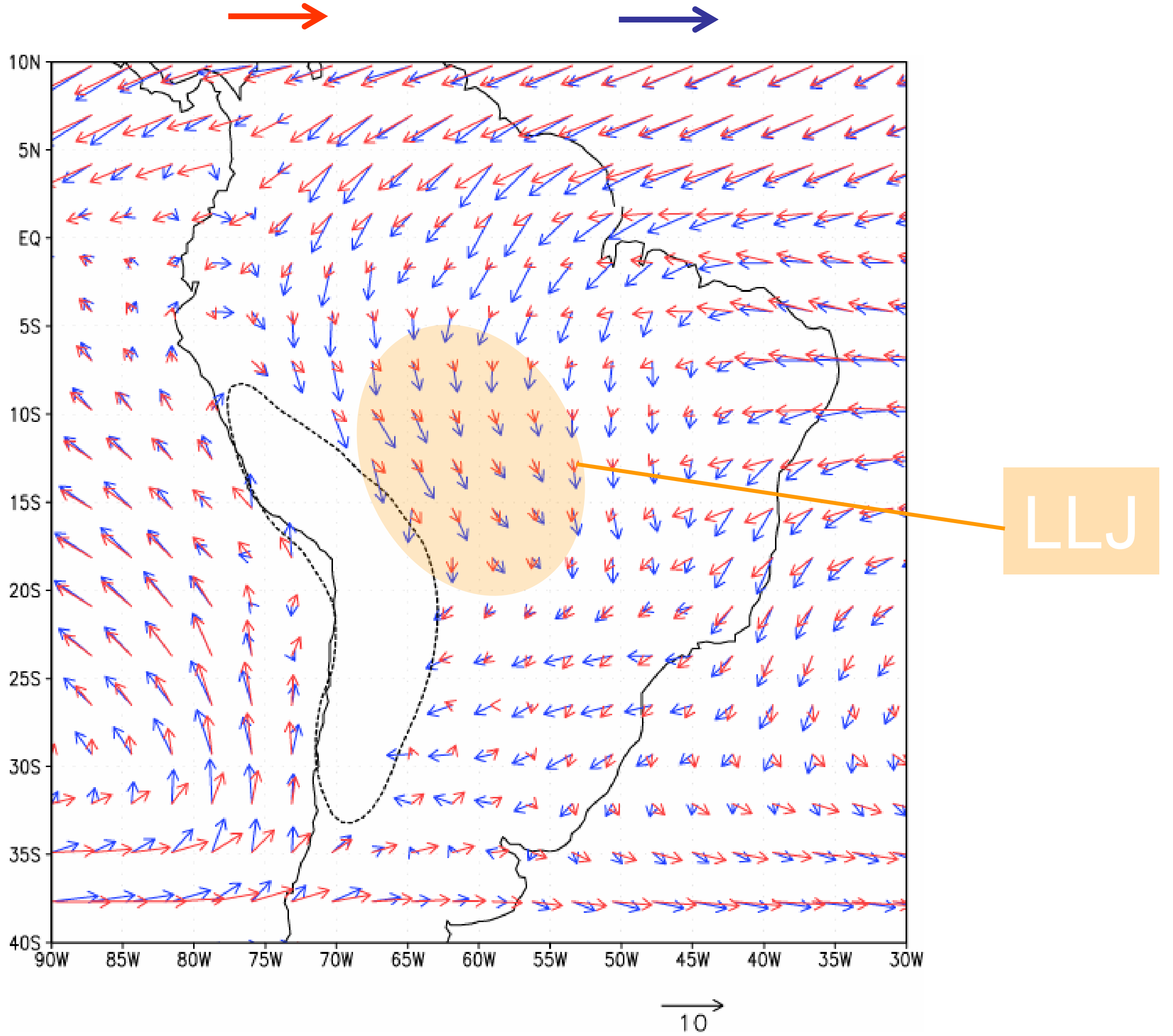
Topography Experiments

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

Topography Experiments

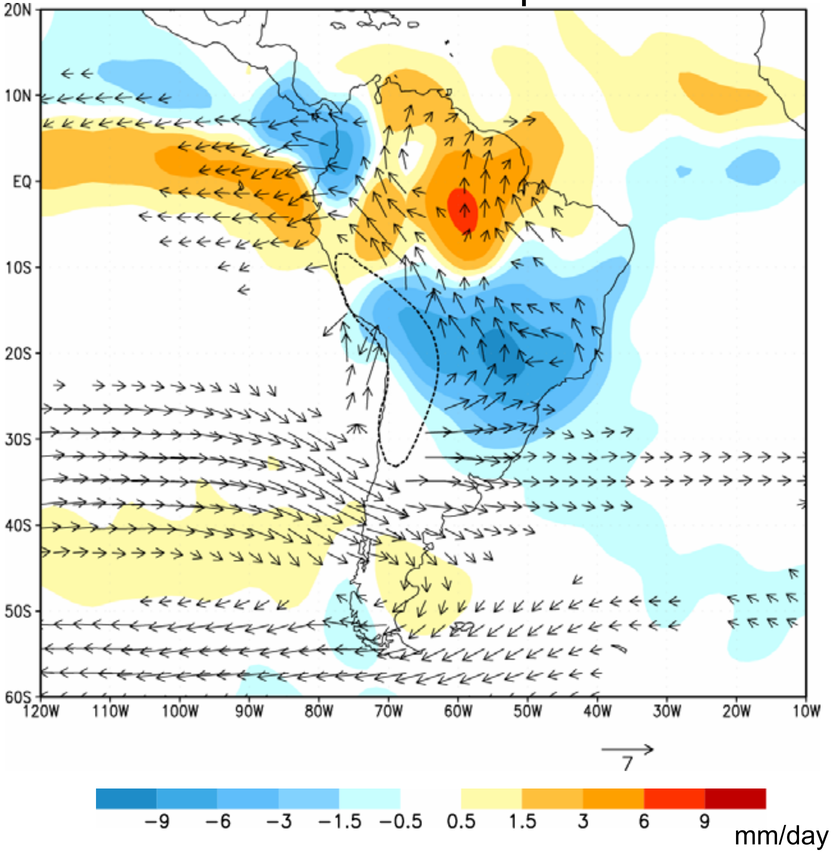
Long-term meanDJF **900 hPa wind**
0.3*Topo (red) and Control (blue)



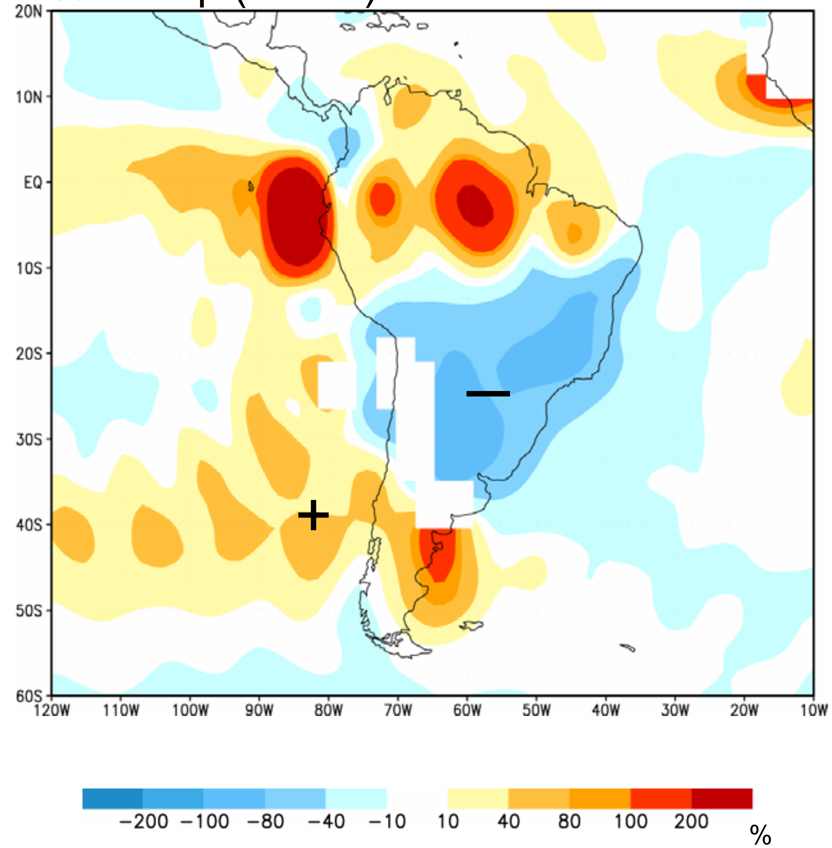
Topography Experiments

0.3*Topo minus Control (DJF)

900 hPa winds and Precip

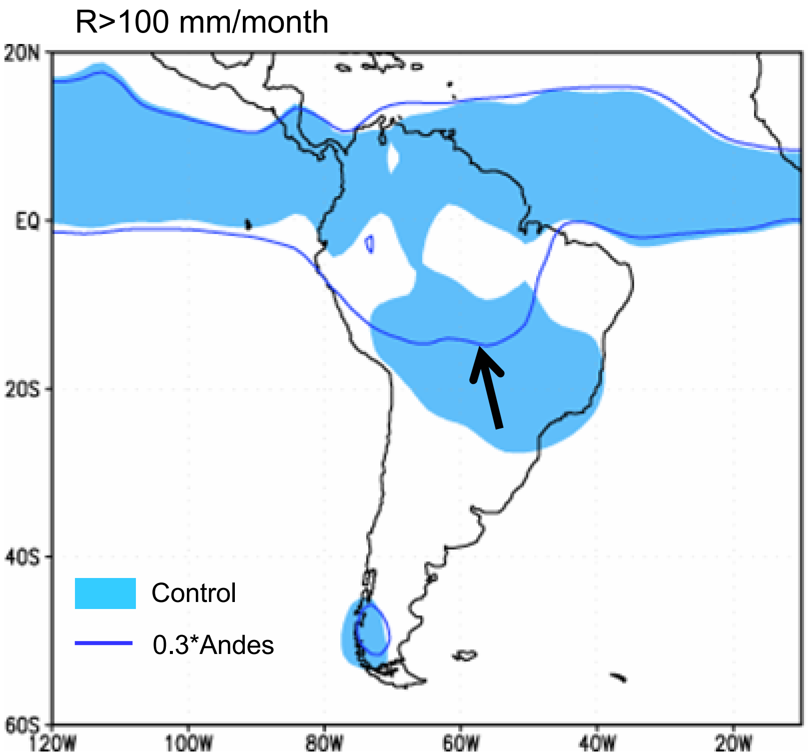


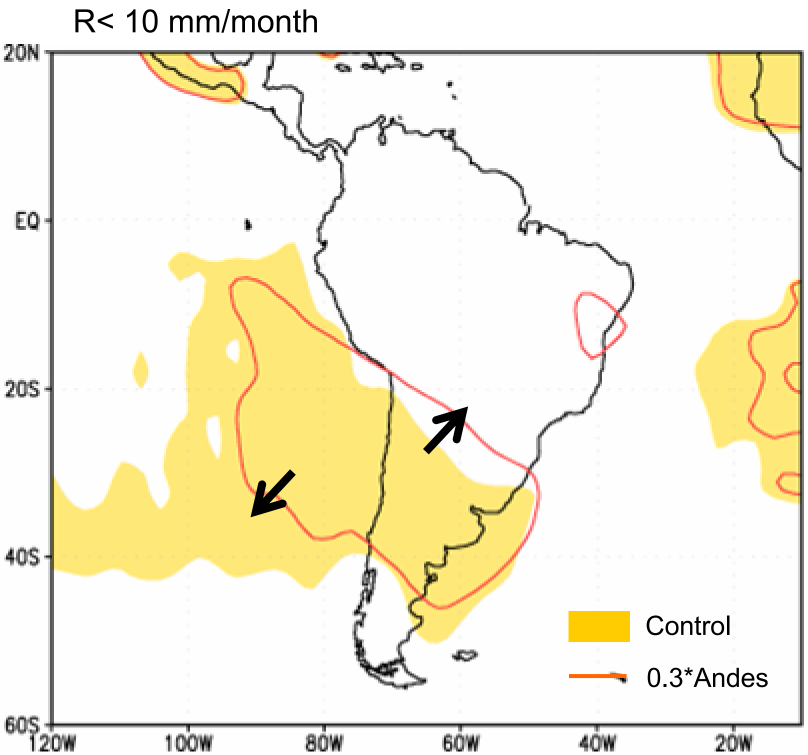
% Precip (ΔP/Pc)



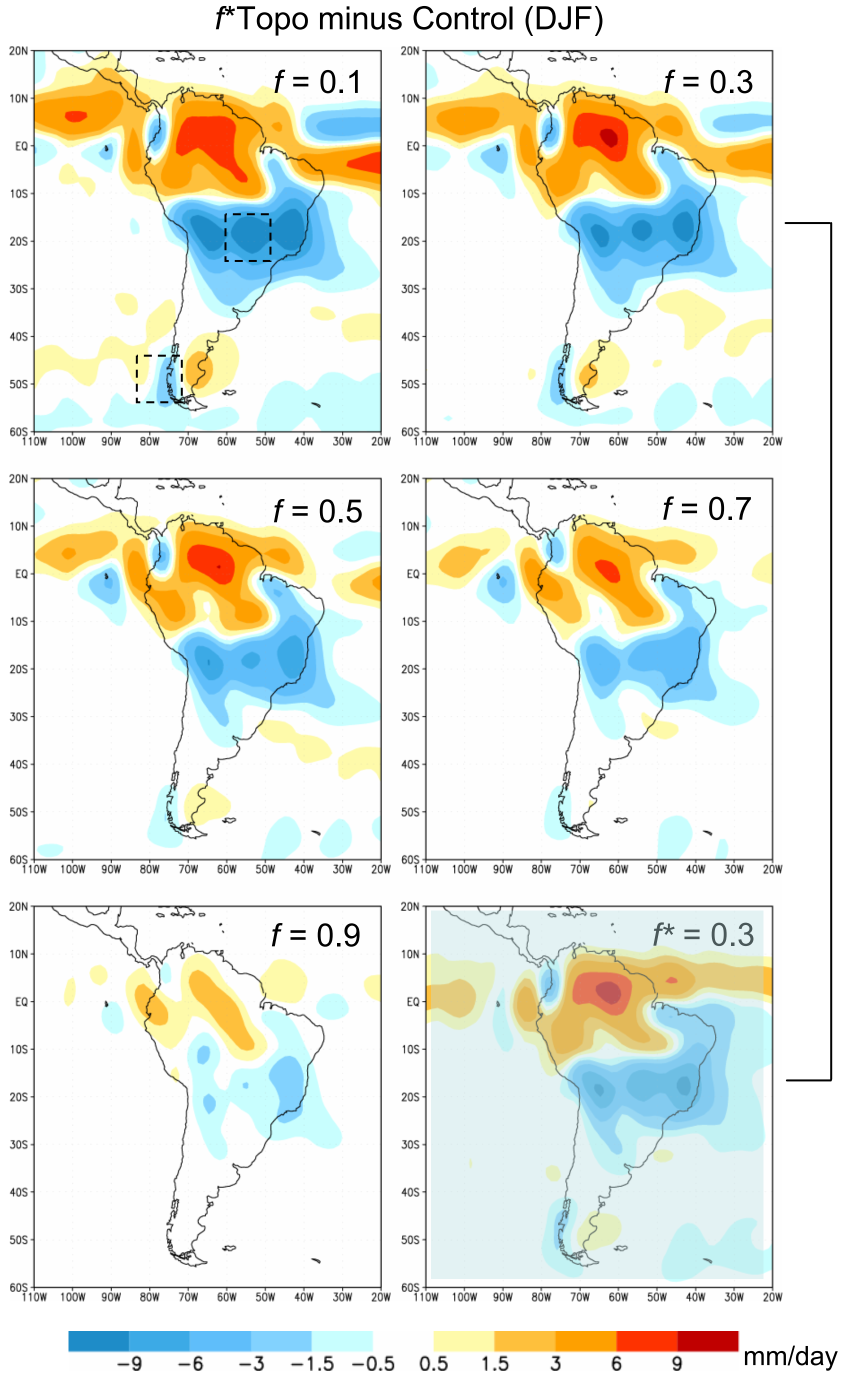
Topography Experiments

DJF Precipitation

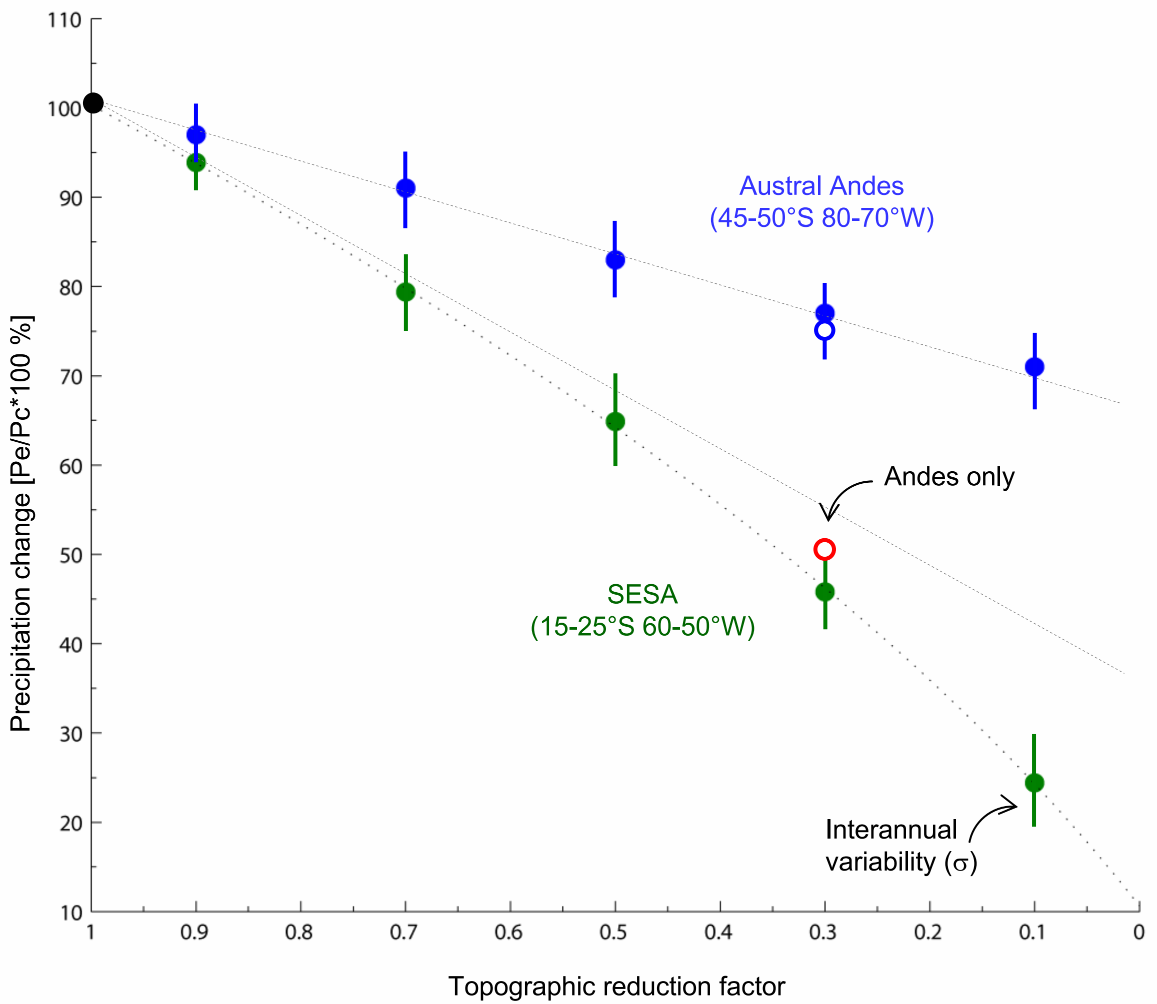




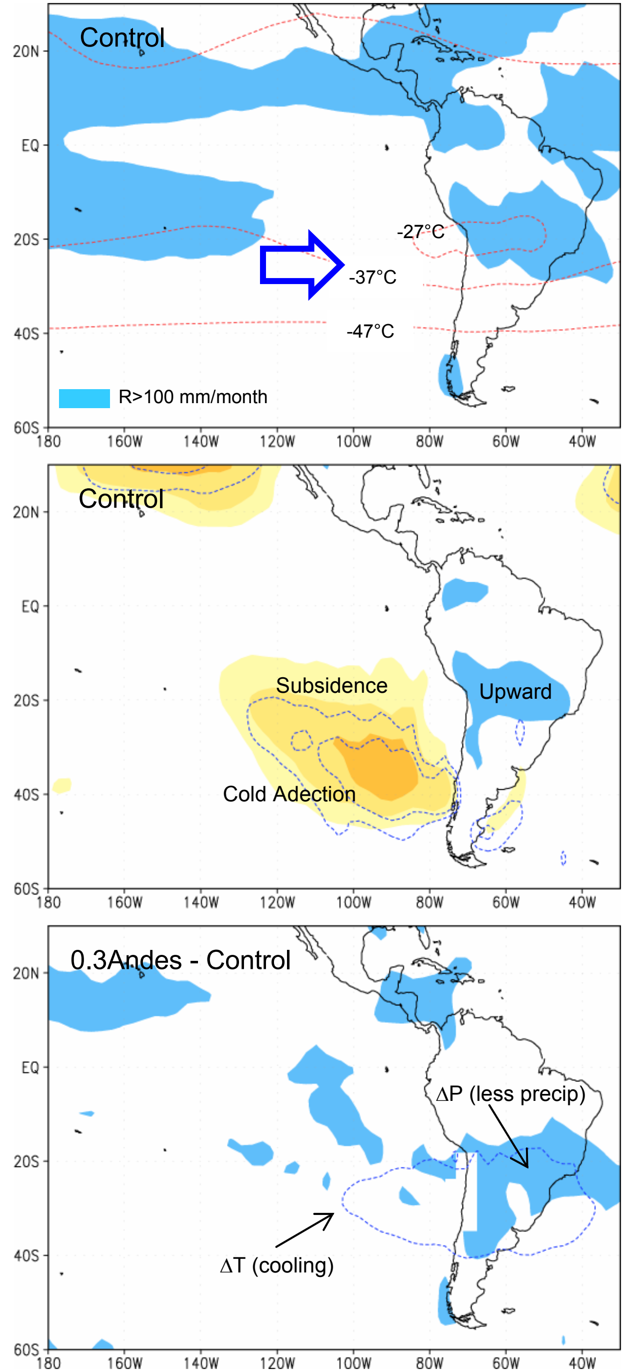
Topography Experiments



Topography Experiments



Topography Experiments



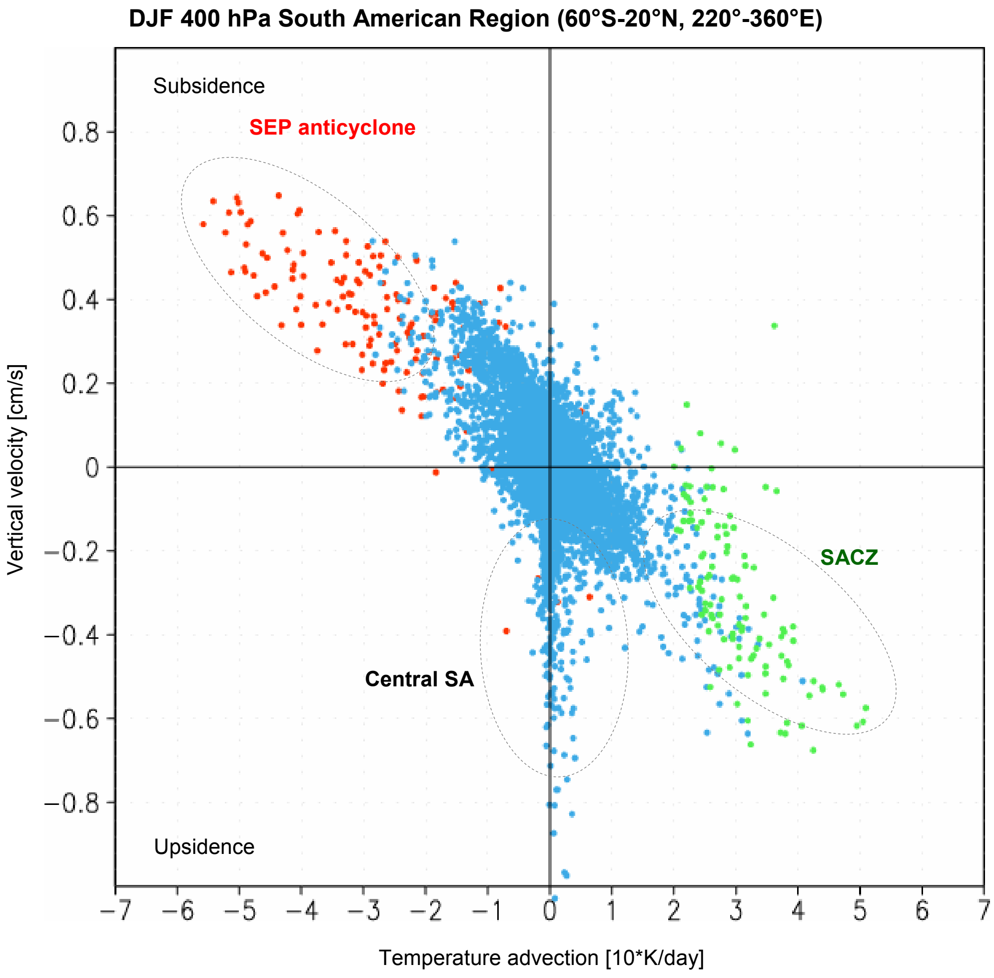
Deep convections warms the tropical / subtropical tropospher, producing a warm-core upper-level anticyclone

Rodwell-Hoskins Mechanism

Strong cold advection occurs where the westerly flow "encounters" the upper-level warm region. Thermal balance requires enhanced susbidence, strengthening the SEP subtropical anticyclone

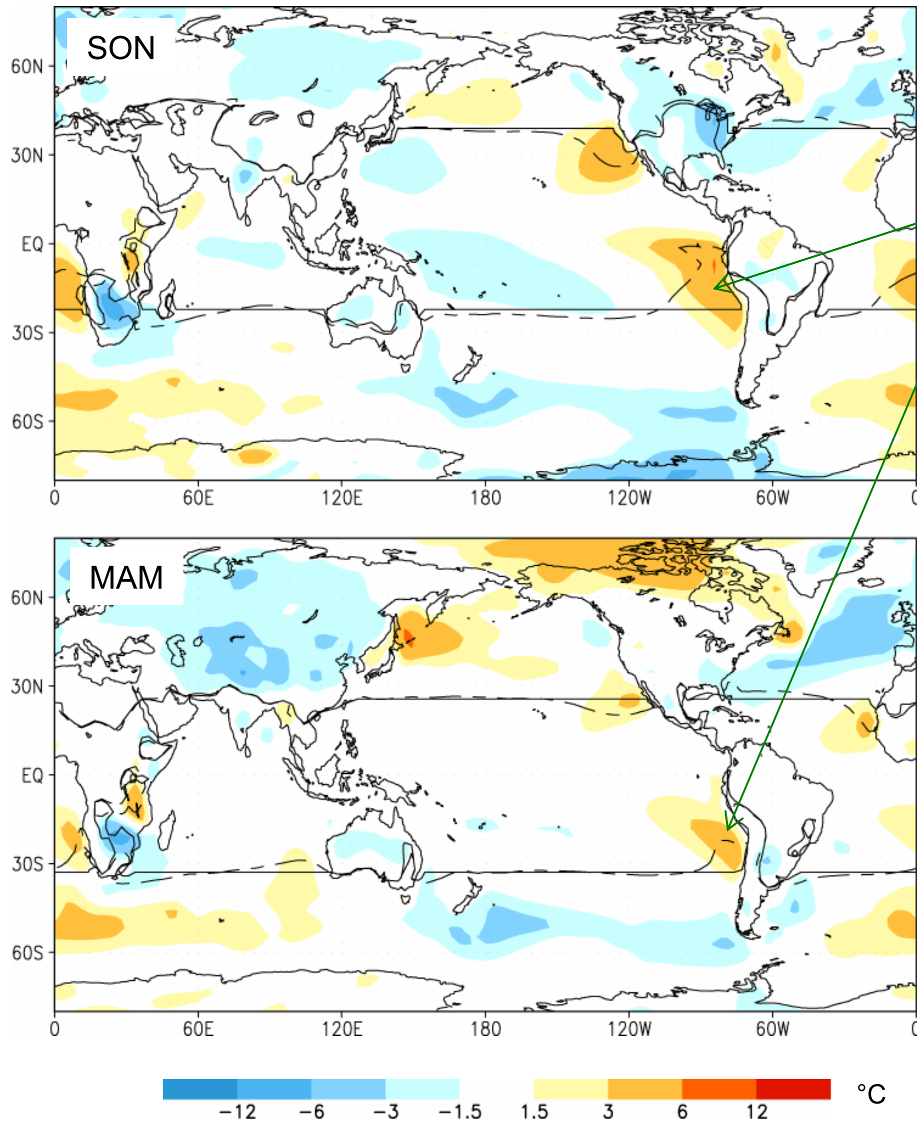
Smaller Andes reduce rainfall over the interior of the continent and thus reduce the warming of the upper-troposphere…
less thermal gradient…
less cold advection….
less subsidence?

Topography Experiments



SST Experiments: SST(φ) only

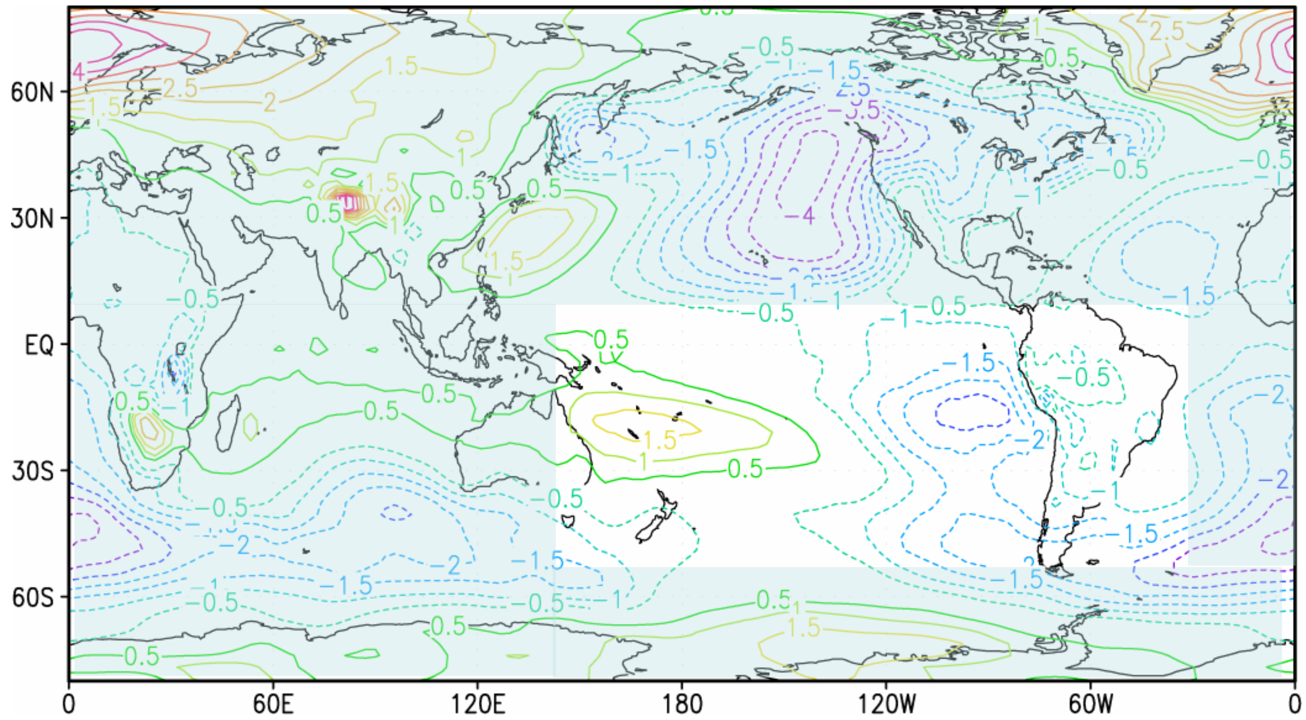
Uniform SST minus Control SST/SAT



Equivalent to shut down coastal upwelling

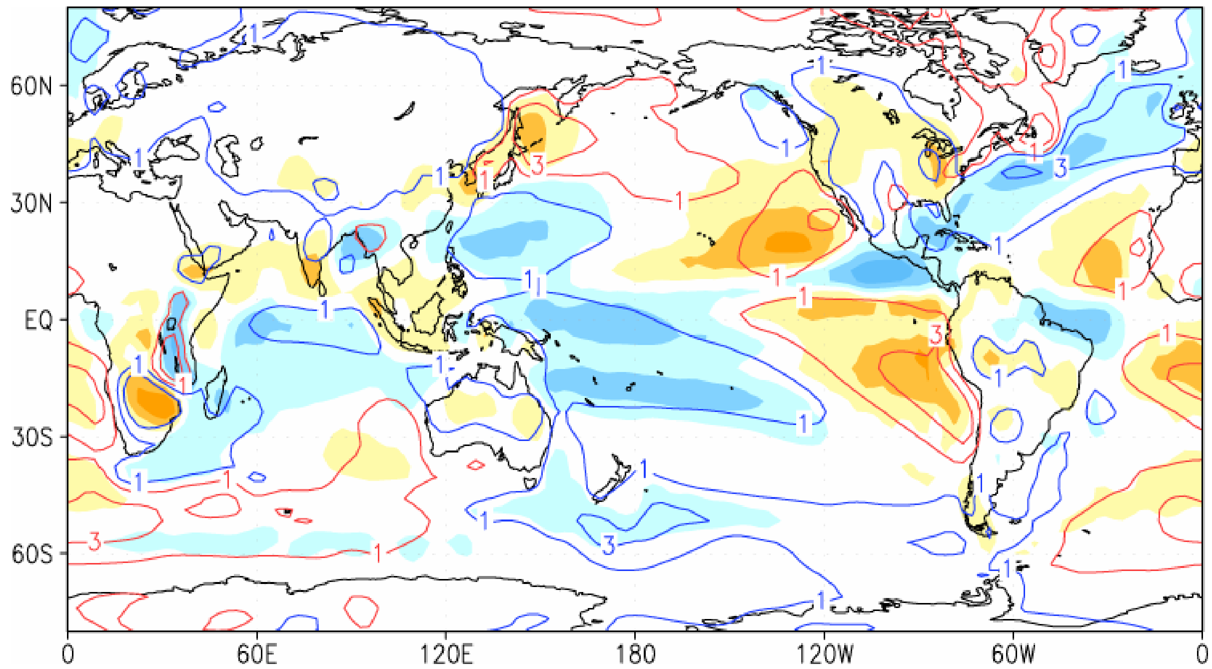
SST Experiments: SST(φ) only

Sea Level Pressure: Uniform SST minus Control



SST Experiments: SST(φ) only

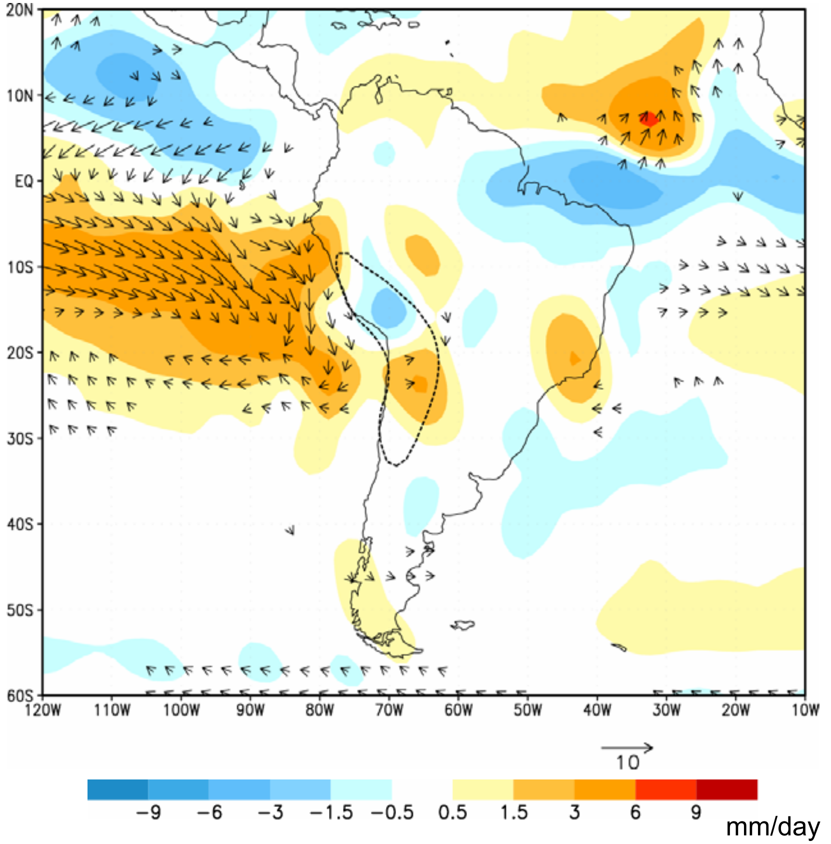
Rainfall: Uniform SST minus Control



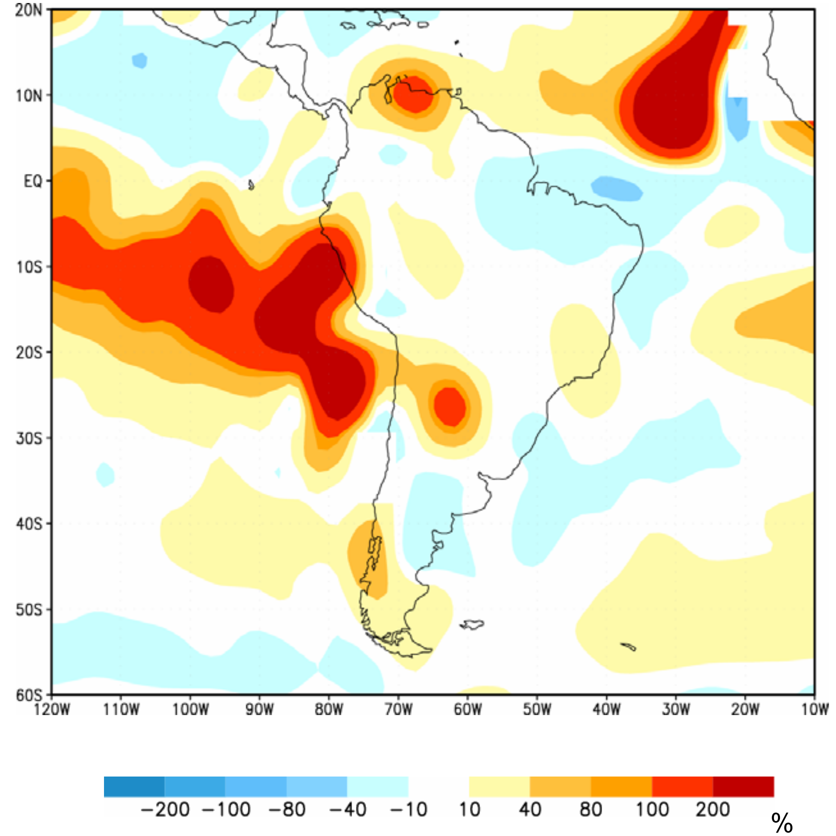
SST Experiments: SST(φ) only

U-SST minus Control (DJF)

900 hPa winds and Precip



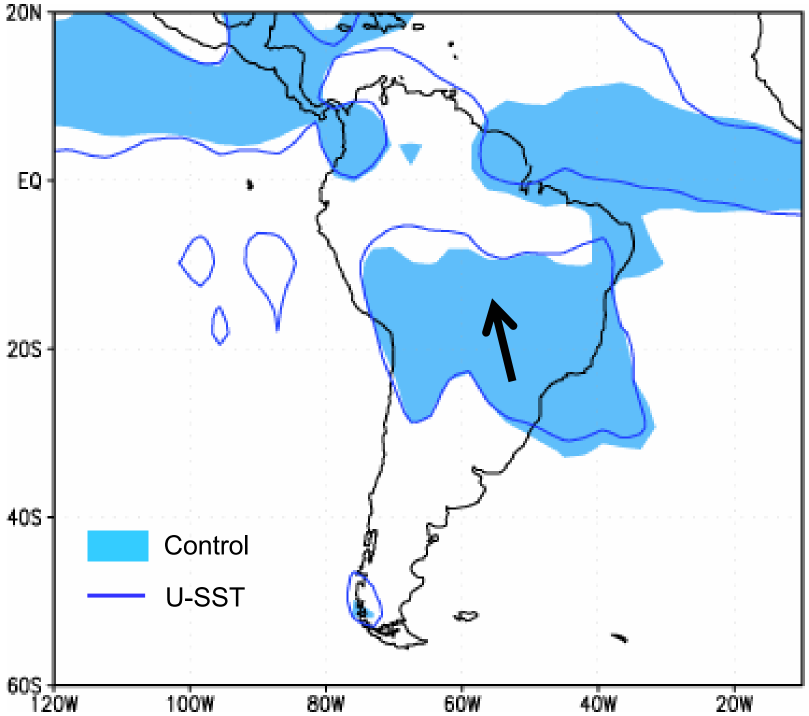
% Precip (ΔP/Pc)



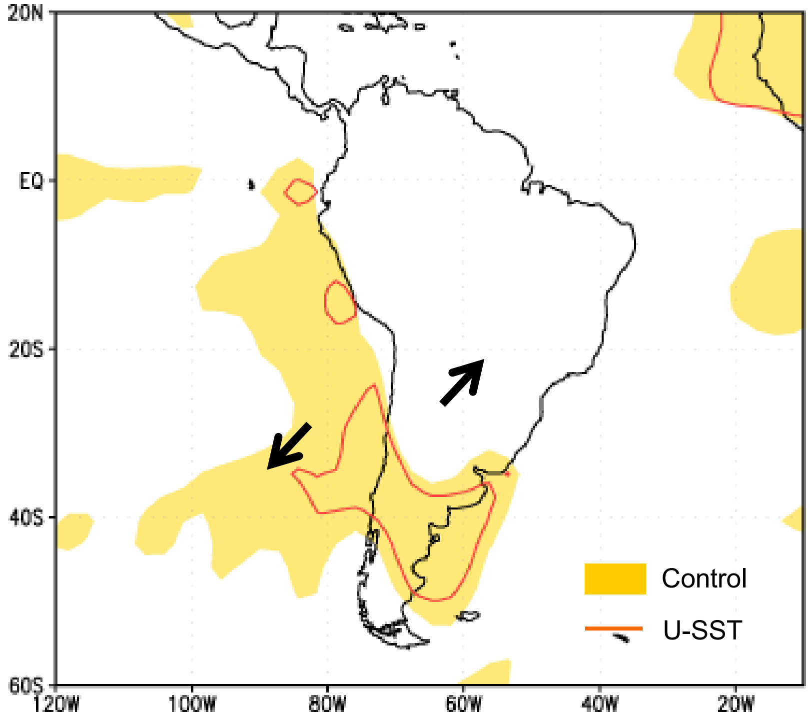
SST Experiments: SST(φ) only

U-SST minus Control (DJF)

R>100 mm/month



R< 10 mm/month



Summary

* The Andes impacts the atmospheric circulation in a wide range of temporal and spatial scales, both at tropical and extratropical latitudes

* Despite its importance, there are too many gaps in our understanding (and hence relatively few papers on these subjects), in part because the dramatic lack of in-situ data

* 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

* Preliminary experiments show that “removal” of the Andes doesn’t increase rainfall over the Atacama desert. Hyper-aridity there is much likely produced by the cold SST along the coast.