Variabilidad y cambio climático en el Altiplano Sud Américano

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Seminario Cambio Climático y Humedales Altoandinos

Temario

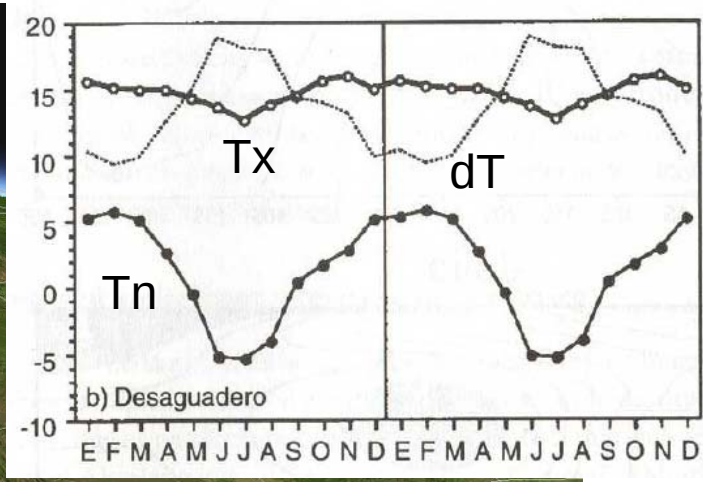
1. Clima actual del Altiplano

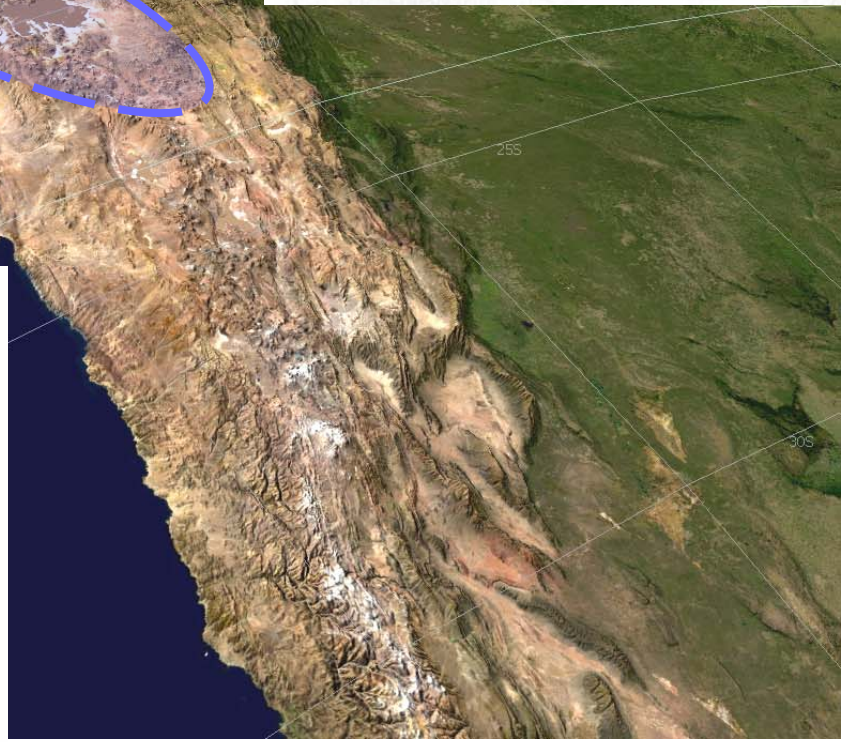
2. Tendencias climáticas observadas

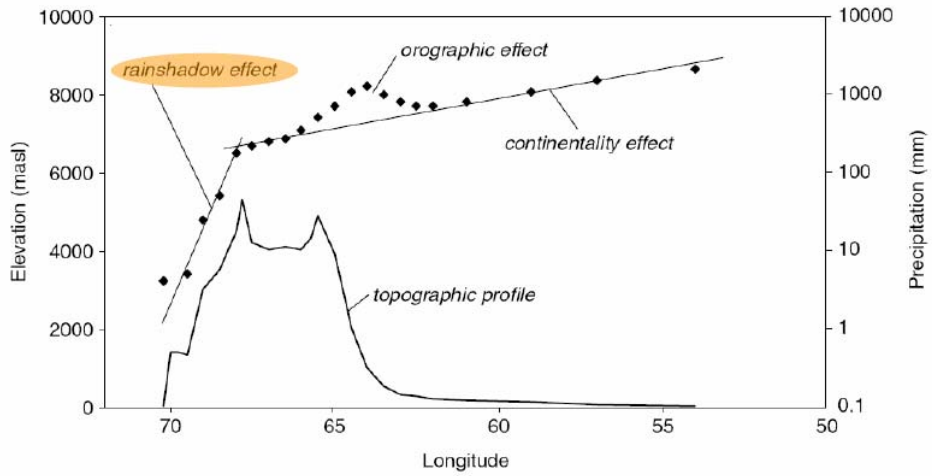
3. Proyecciones para el siglo XXI

Aspectos básicos del clima del Altiplano

* Cuenca cerrada en los Andes centrales
* Limitada por desierto costero y zona humeda de Bolivia
* Hm = 3800-4200 m, Psfc ~600 hPa
* Tsfc baja y con fuertes ciclos diarios y anuales
* HR y q muy bajas
* Condiciones aridas, PP estivales







Ciclo anual y distribución espacial de PP

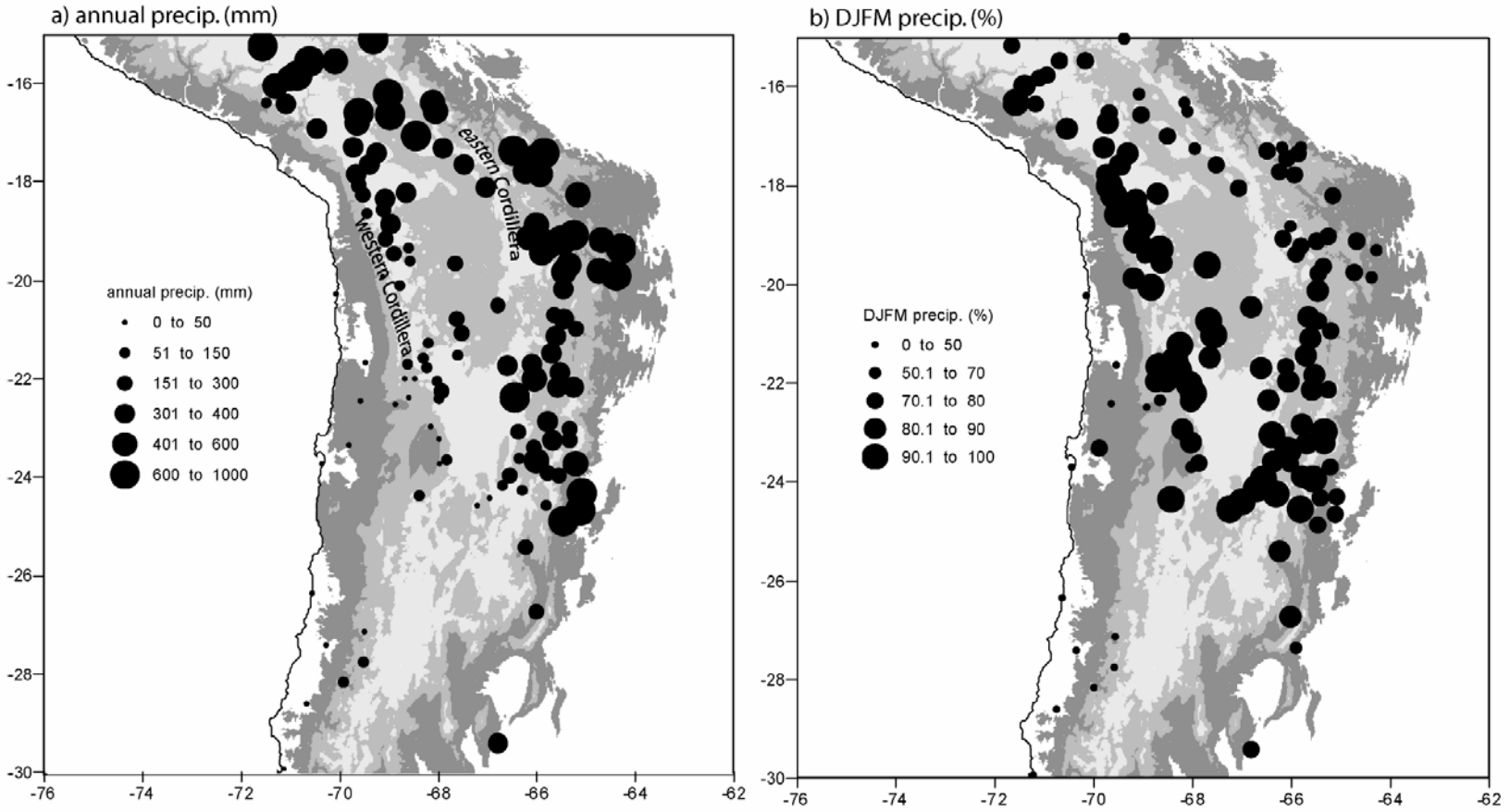
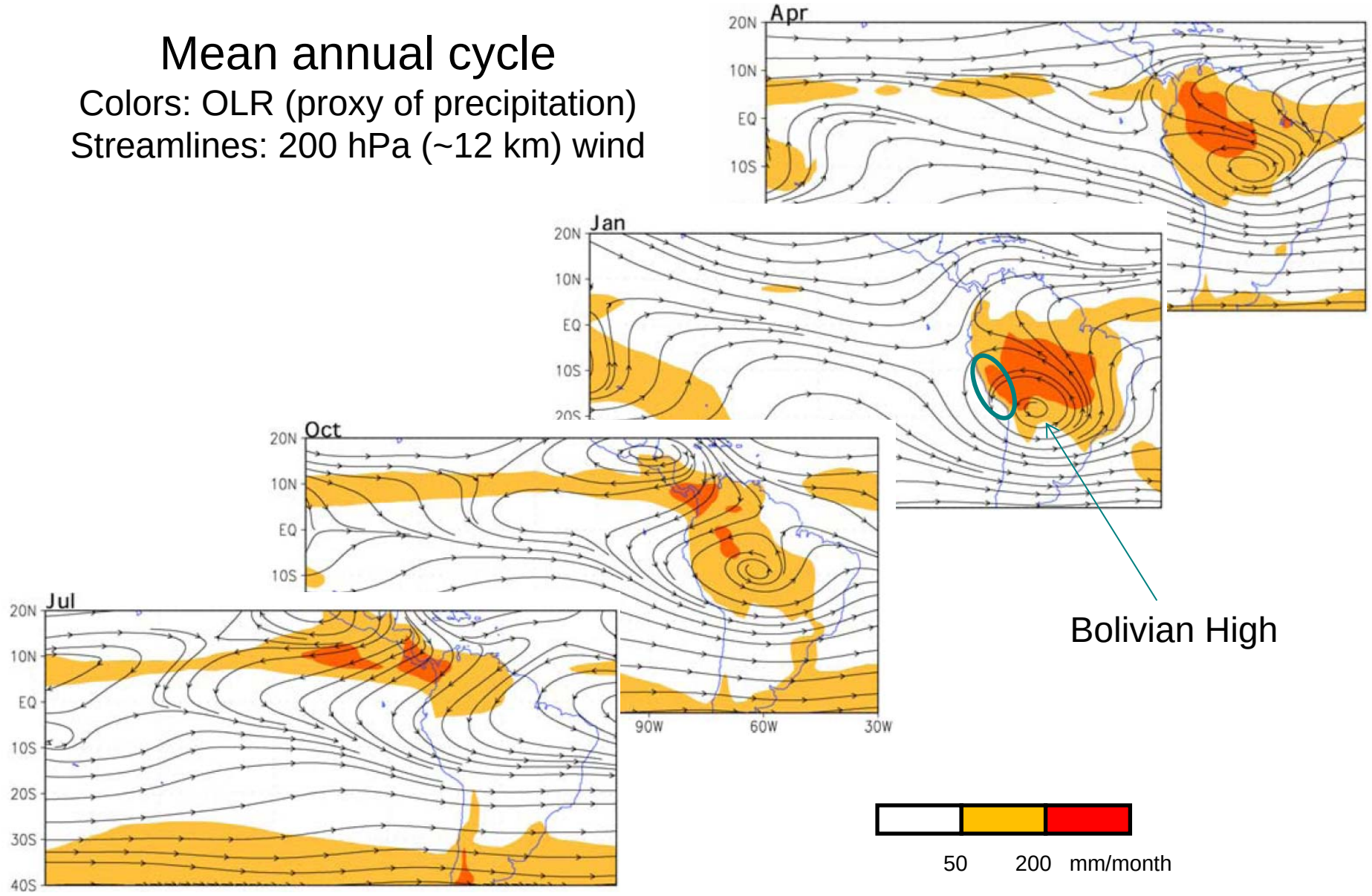


FIG. 1. (a) Long-term annual mean precipitation amount (mm) and (b) percent precipitation in DJFM of the annual total in the central Andes. To the east of the Andes only rain gauge data >1500 m are shown. Shading indicates elevation zones above 1000 m (dark gray), 2500 m (medium gray), and 4000 m (light gray). Record lengths of individual stations vary.

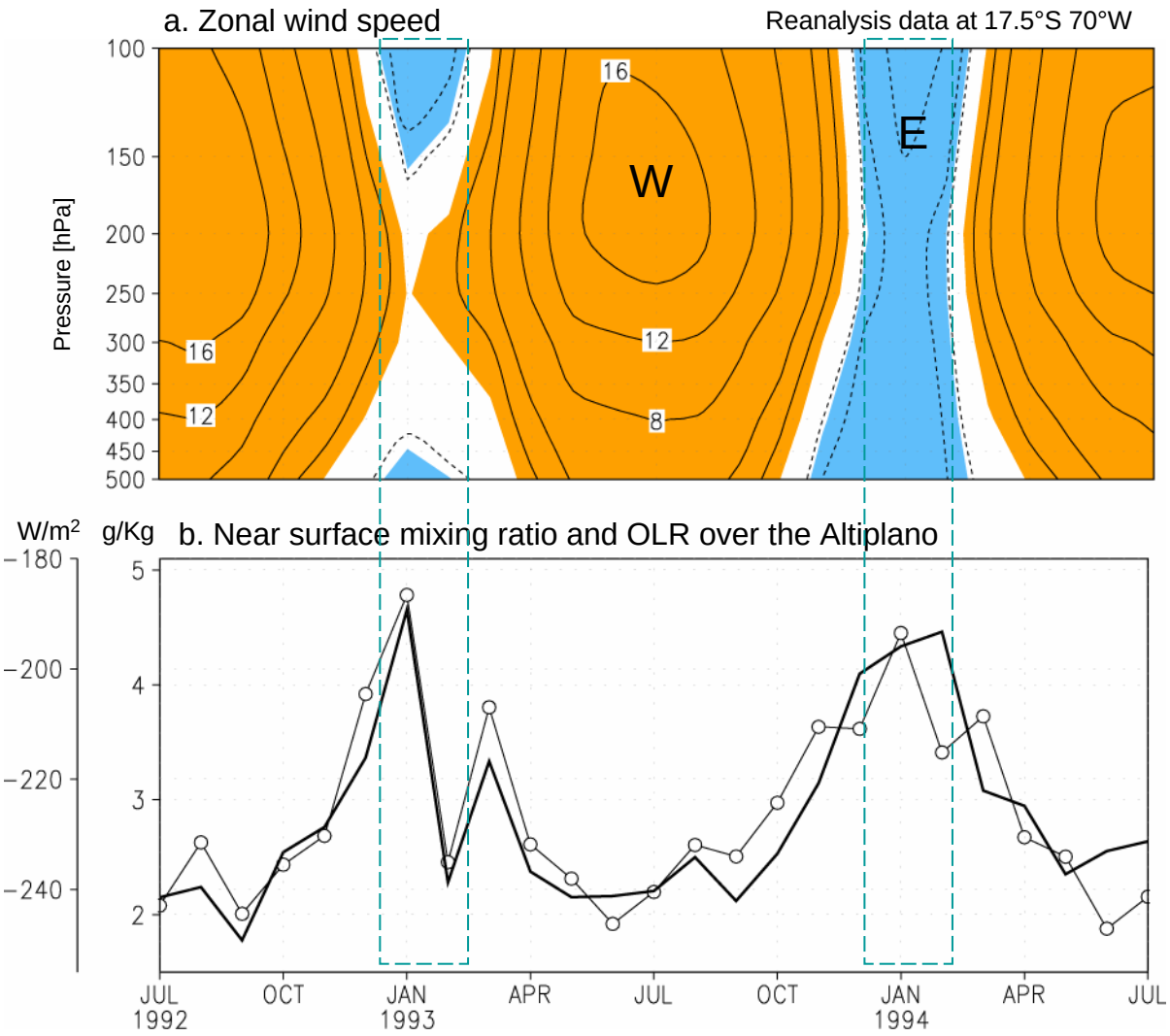
Regimen Monsonal de Precipitación y Vientos en Altura

Mean annual cycle

Colors: OLR (proxy of precipitation)
Streamlines: 200 hPa (~12 km) wind

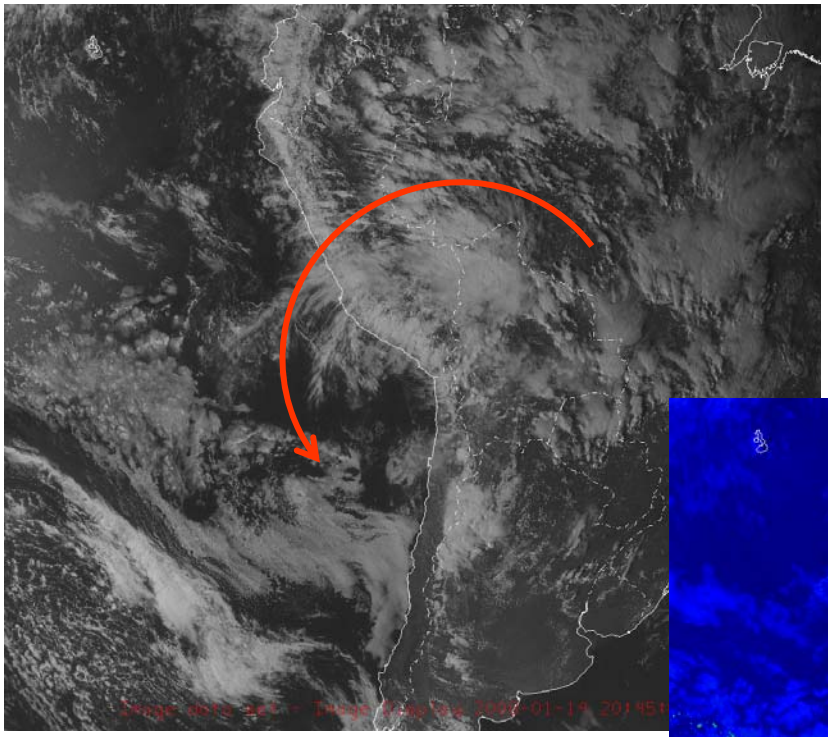


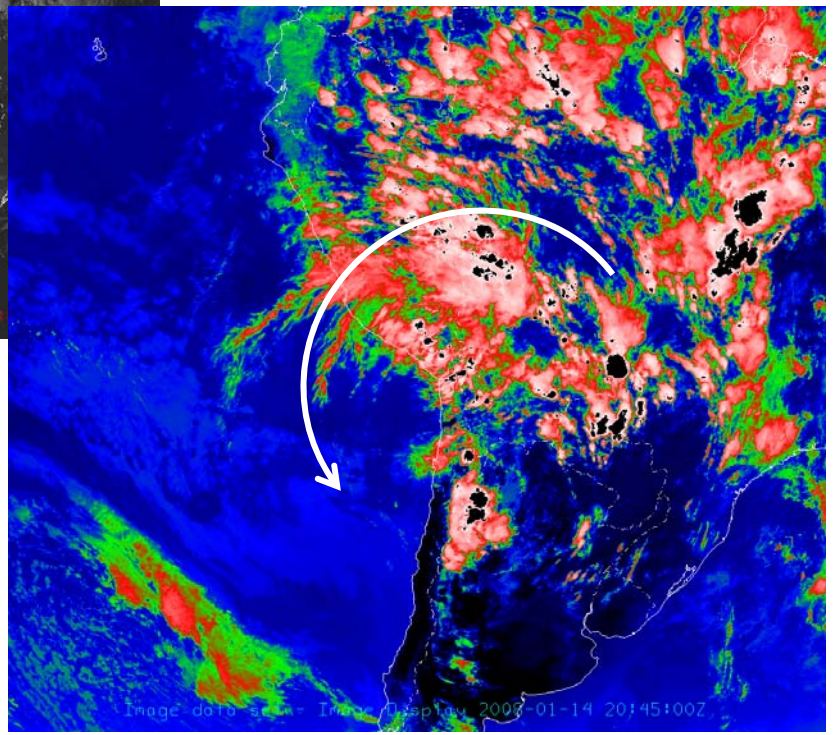
Regimen Monsonal de Precipitación y Vientos en Altura



•Precipitación

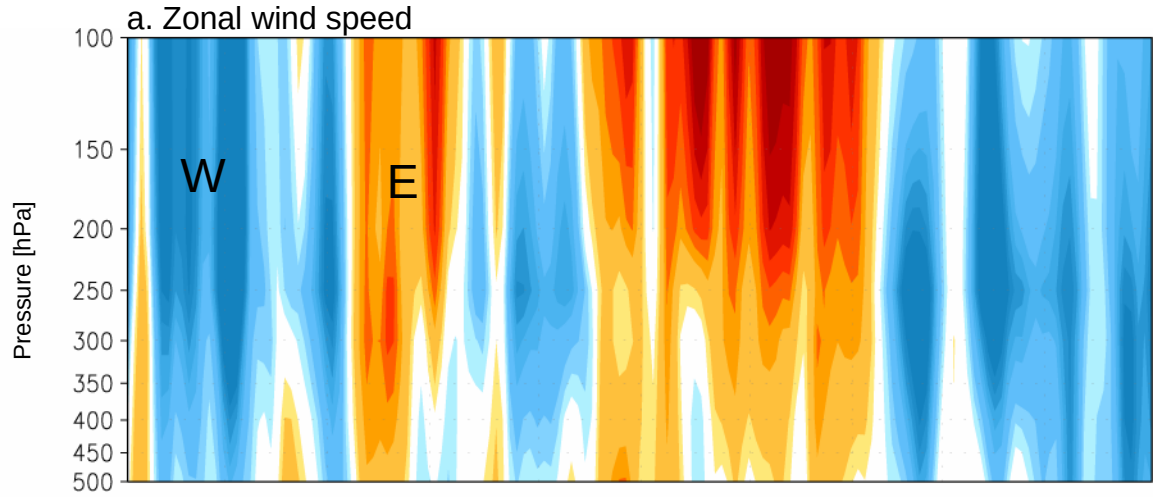
Regimen Monsonal de Precipitación y Vientos en Altura

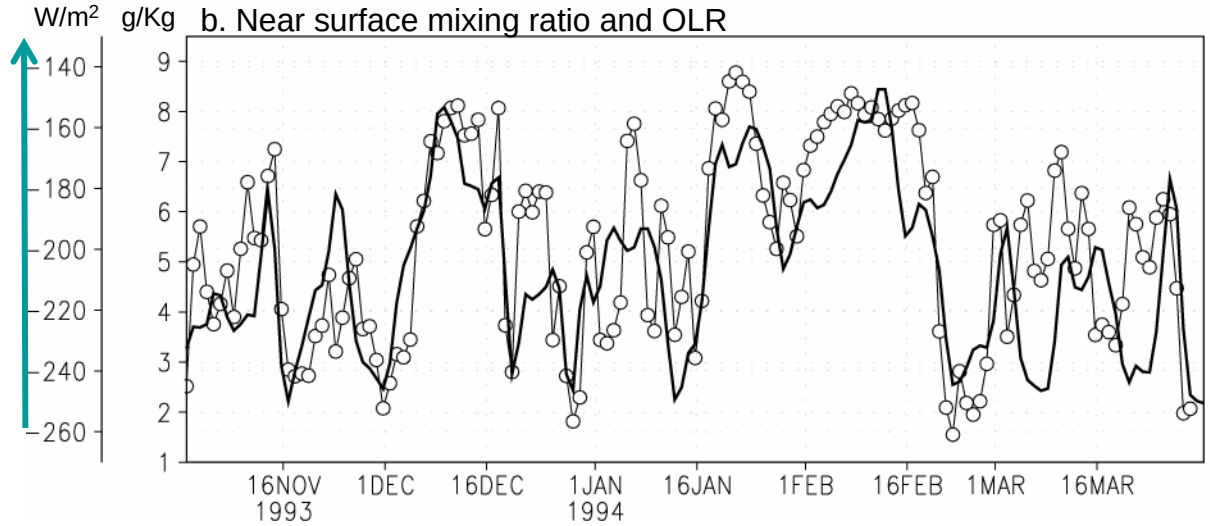




VIS and IR2 GOES images
during an active summer afternoon

Variabilidad intra-estacional del regimen de precipitación

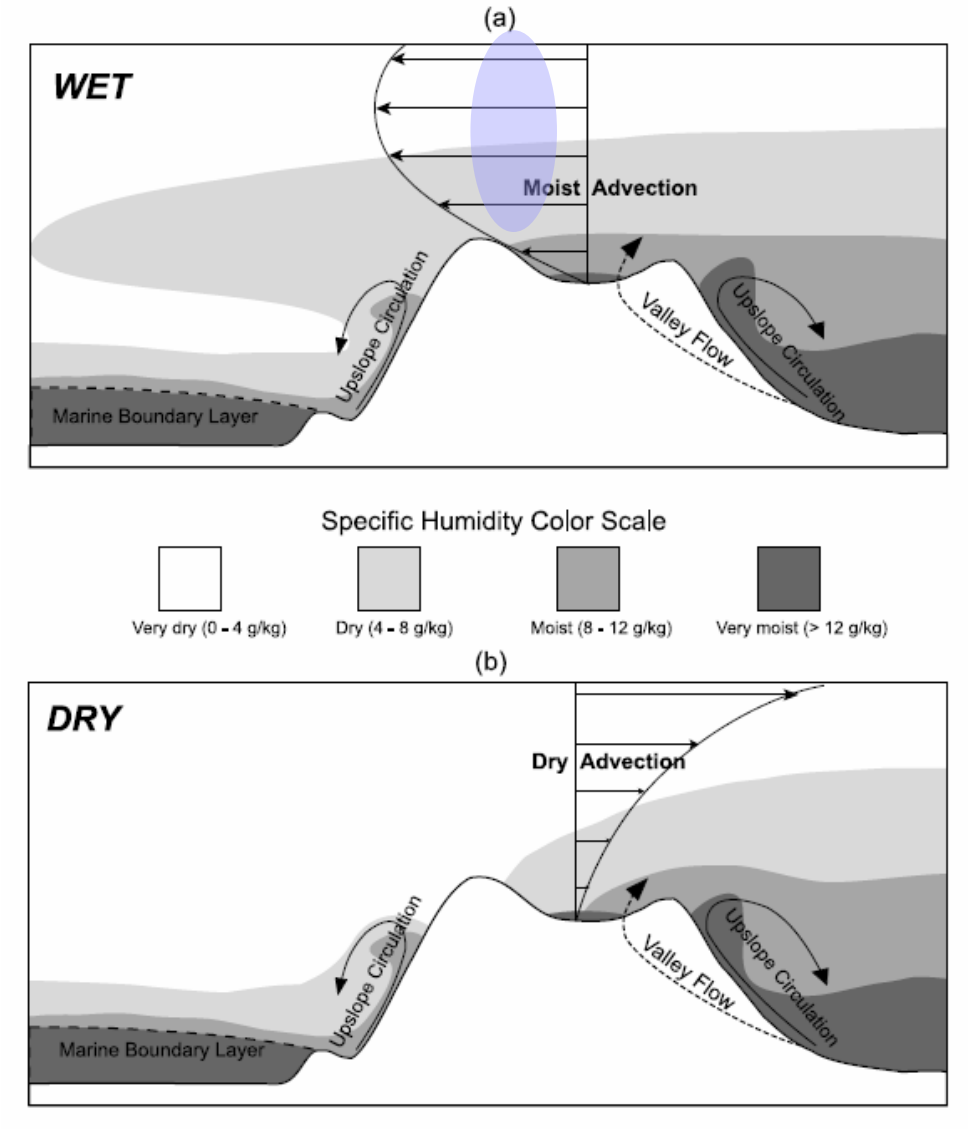




•Precipitación

Falvey and Garreaud 2005

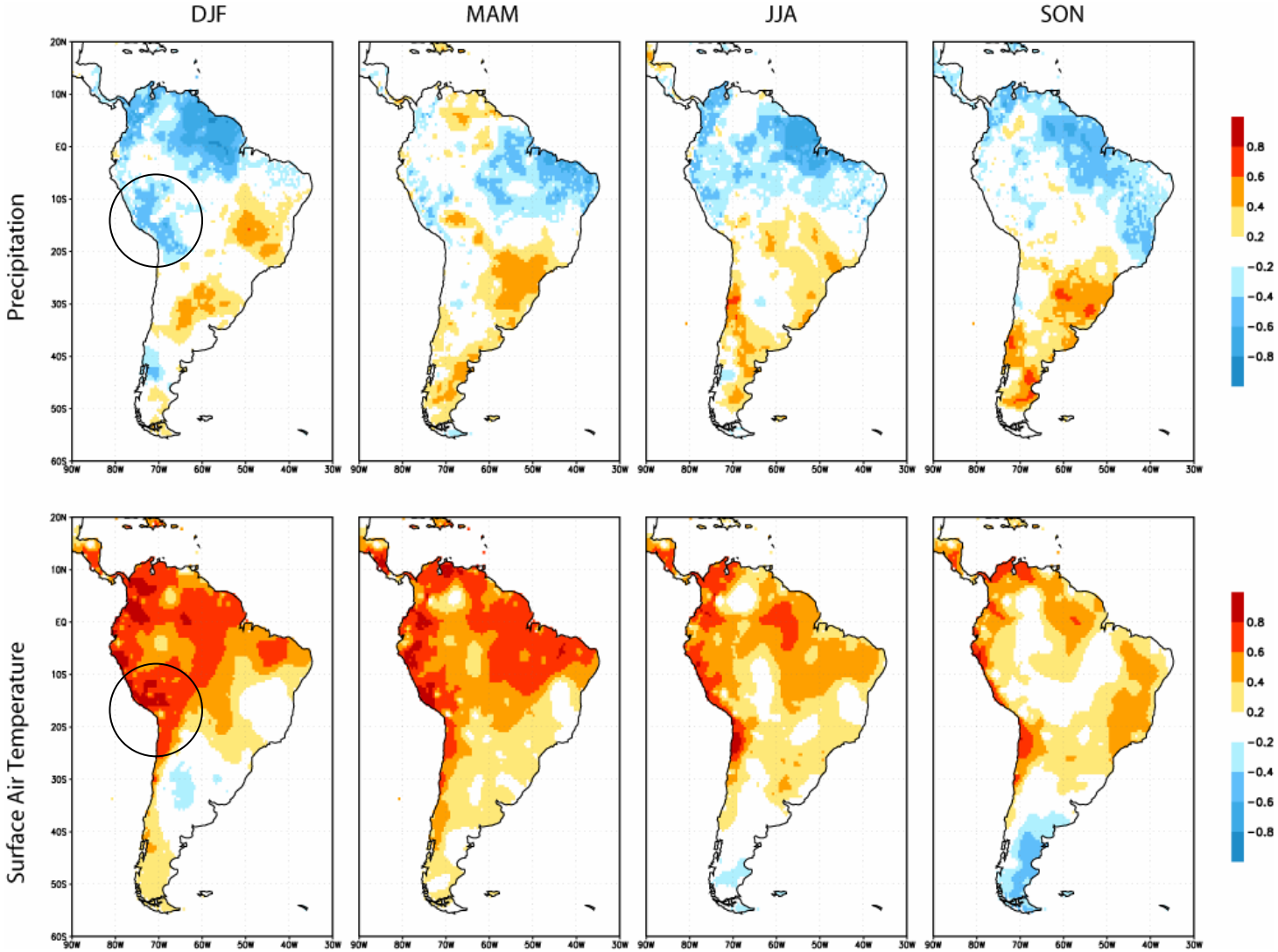
Variabilidad intra-estacional del regimen de precipitación



Falvey and Garreaud 2005

Variación interanual del precipitaciones estivales

Correlación entre indice de ENSO y precipitación / temperatura
Años El Niño más cálidos y secos que el promedio
Años La Niña más fríos y lluviosos que el promedio



Variación interanual del precipitaciones estivales

Años de El Niño aumentan flujo del oeste en altura (> 5 km), transportando aire seco hacia el Altiplano y limitando las precipitaciones

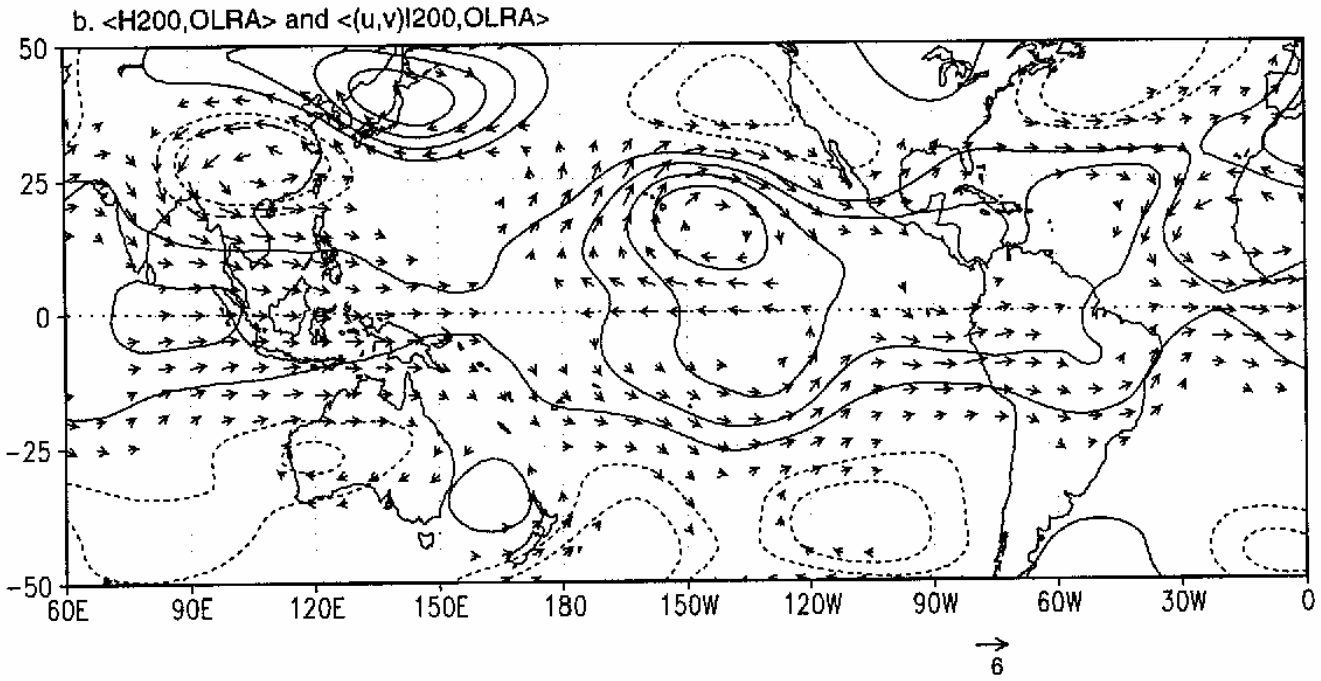


FIG. 7. Regression maps in the interannual range (see section 2 for details on calculation and statistical significance). (a) OLR (shaded, scale in units of W m^{-2} per std dev) and 200-hPa wind regressed upon CI (OLR over the Altiplano). (b) 200-hPa height and winds regressed upon CI. Contour interval is 30 m per std dev. Negative values in dashed line. The zero contour is omitted. Only values and wind vectors statistically significant at the 95% confidence level are shown. Reference wind vector (in m s^{-1}) at the bottom of the figure.

Variación interanual del precipitaciones estivales

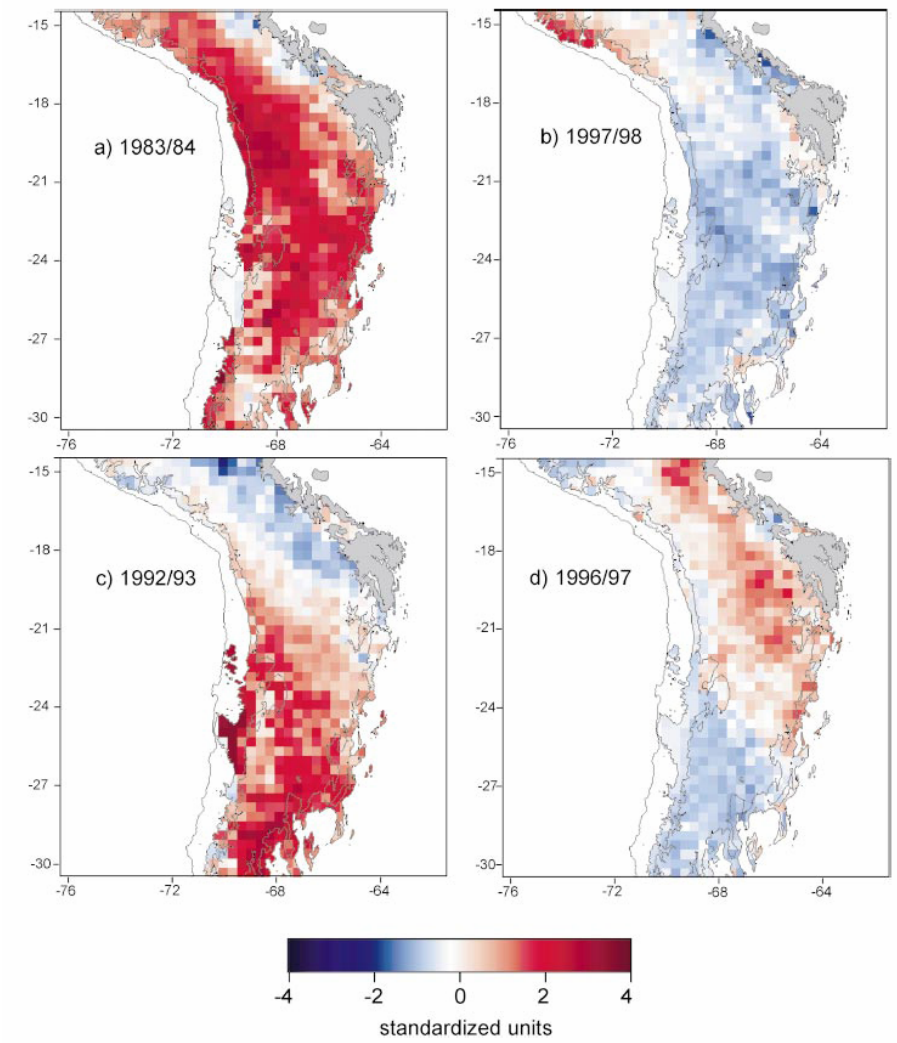
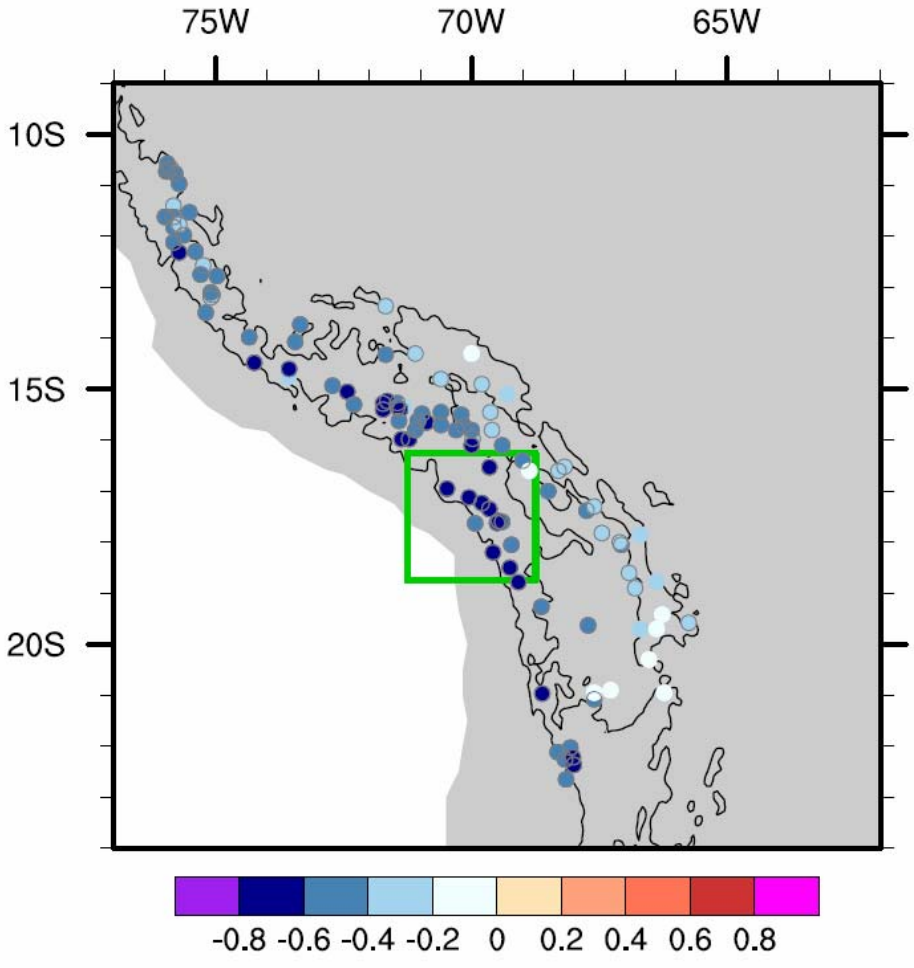


FIG. 7. Departure (standardized anomalies) of DJFM fractional cold ($T_B^* = 240$ K) cloud coverage F^* from long-term mean (1983–99) in (a) 1983/84, (b) 1997/98, (c) 1992/93, and (d) 1996/97. Only results for regions >1500 m are shown and northeast slope between 1500 and 3000 m is masked in gray. Black lines indicate 0-, 1500-, and 3000-m contour line.

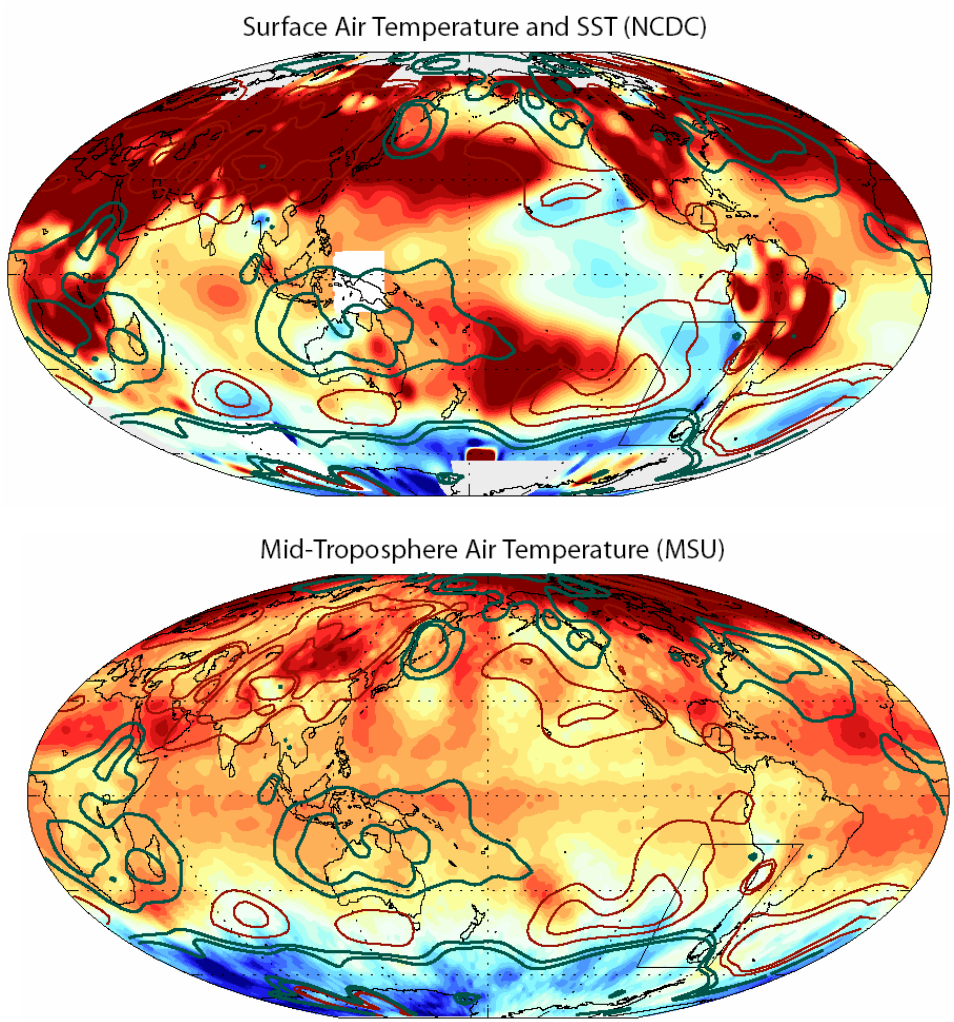
Variación interanual del precipitaciones estivales

Correlation between DJF precipitation and U200 (17°S-70°W)

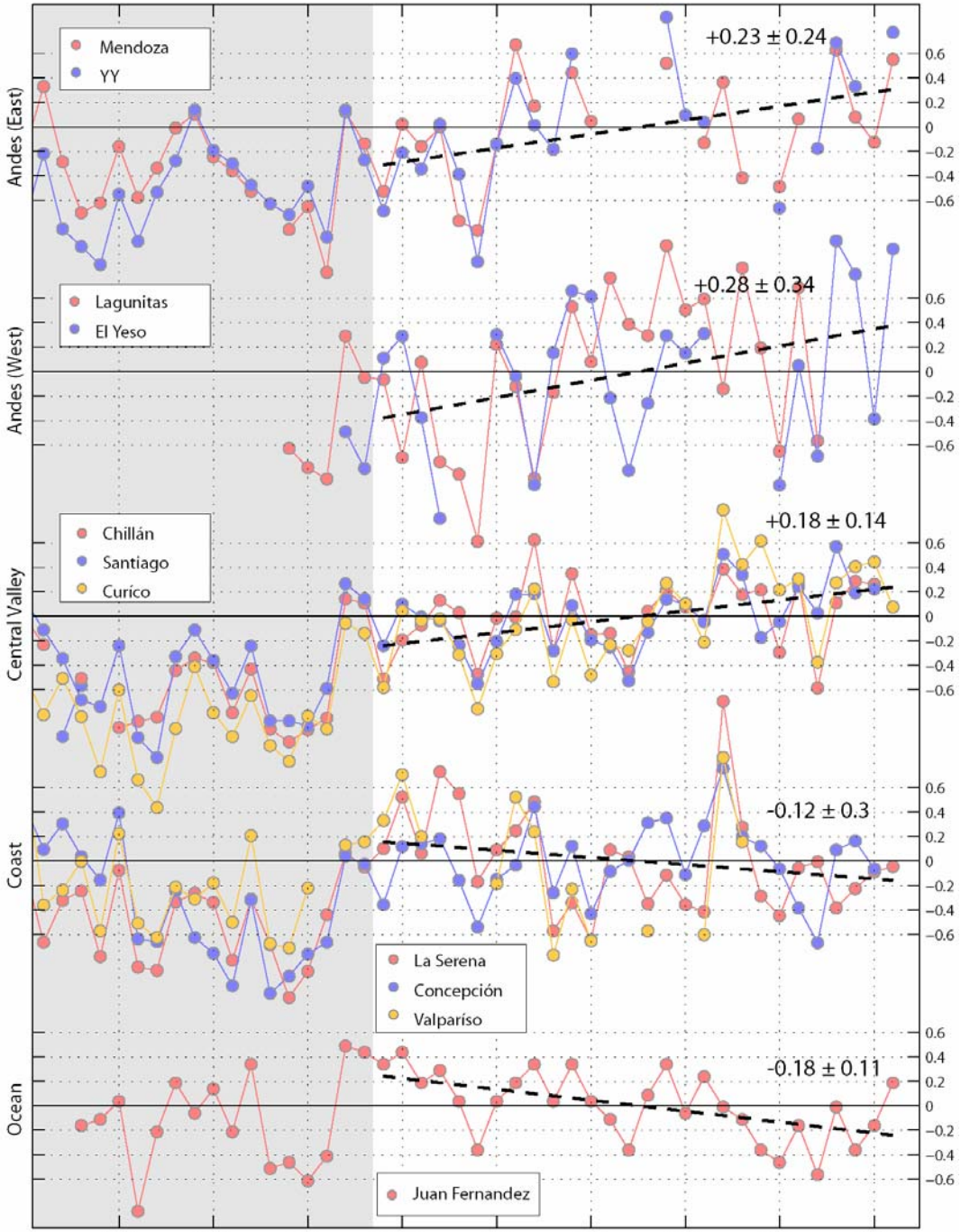


Minvielle and Garreaud 2010

Tendencias observadas (últimos 30 años): Temperatura



Observed trends (last 50 years): SAT



East Andes

West Andes

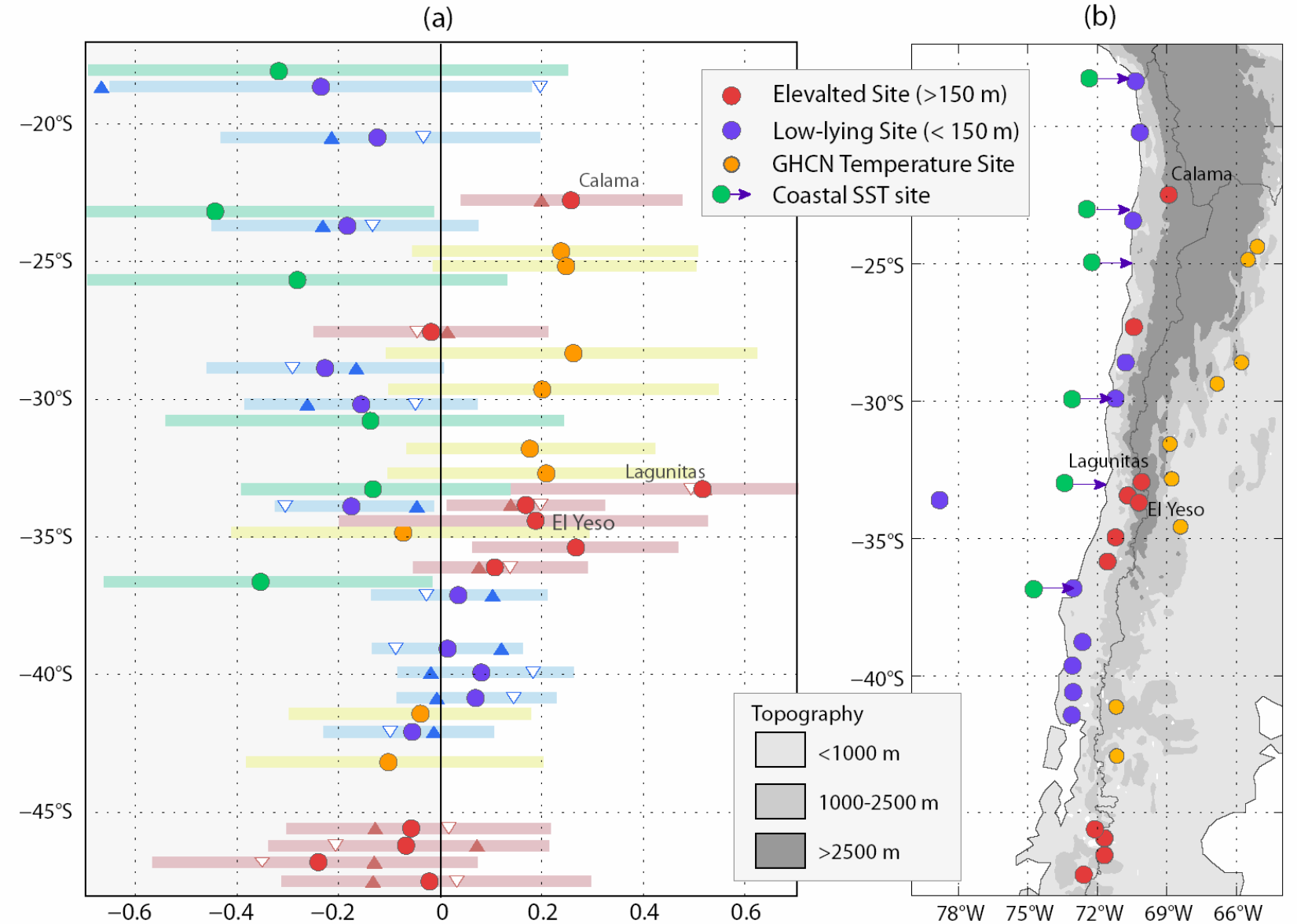
inland

coast

offshore

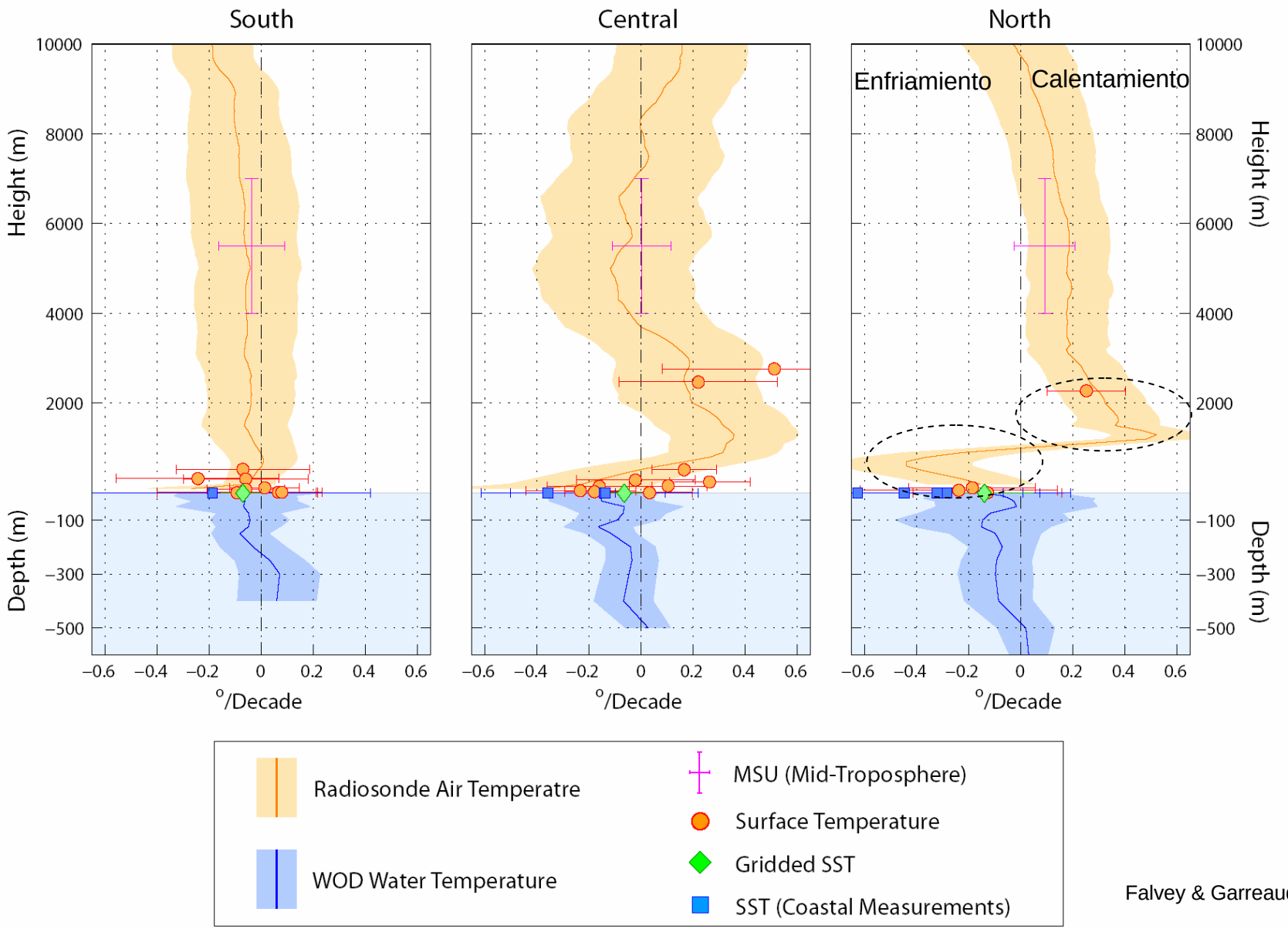
Falvey & Garreaud 2008

Ocean cooling – land warming along north-central Chile. Pattern reverses farther south



Falvey & Garreaud 2008

Tendencias observadas (últimos 30 años): Temperatura



Falvey & Garreaud 2008

Tendencias observadas en Temperatura

20TH CENTURY CLIMATE CHANGE IN THE TROPICAL ANDES: OBSERVATIONS AND MODEL RESULTS

MATHIAS VUILLE [1], RAYMOND S. BRADLEY [1], MARTIN WERNER [2] and FRANK KEIMIG [1]

[1] *Climate System Research Center, Dept. of Geosciences, Morrill Science Center, Univ. of Massachusetts, 611 North Pleasant Street, Amherst, MA 01003-9297, U.S.A.*
E-mail: mathias@geo.umass.edu
[2] *Max Planck Institute for Biogeochemistry, Jena, Germany*

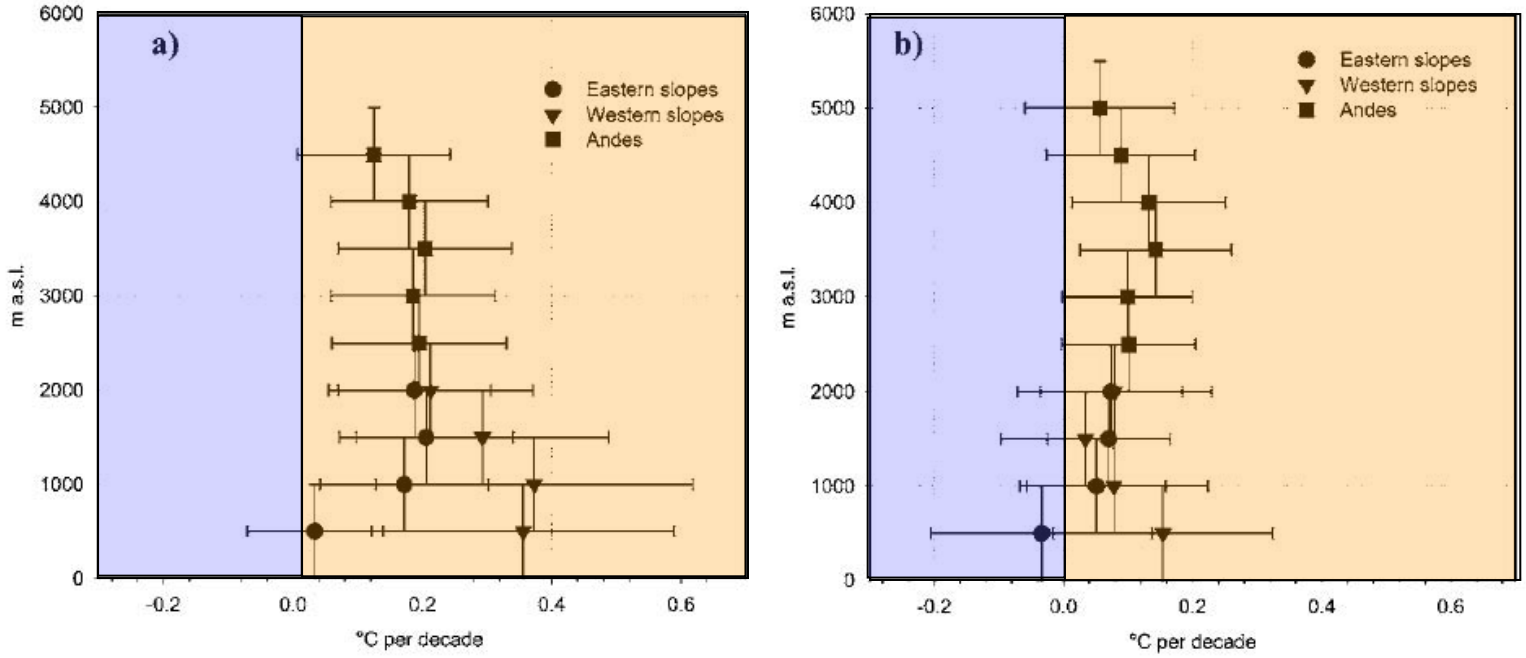
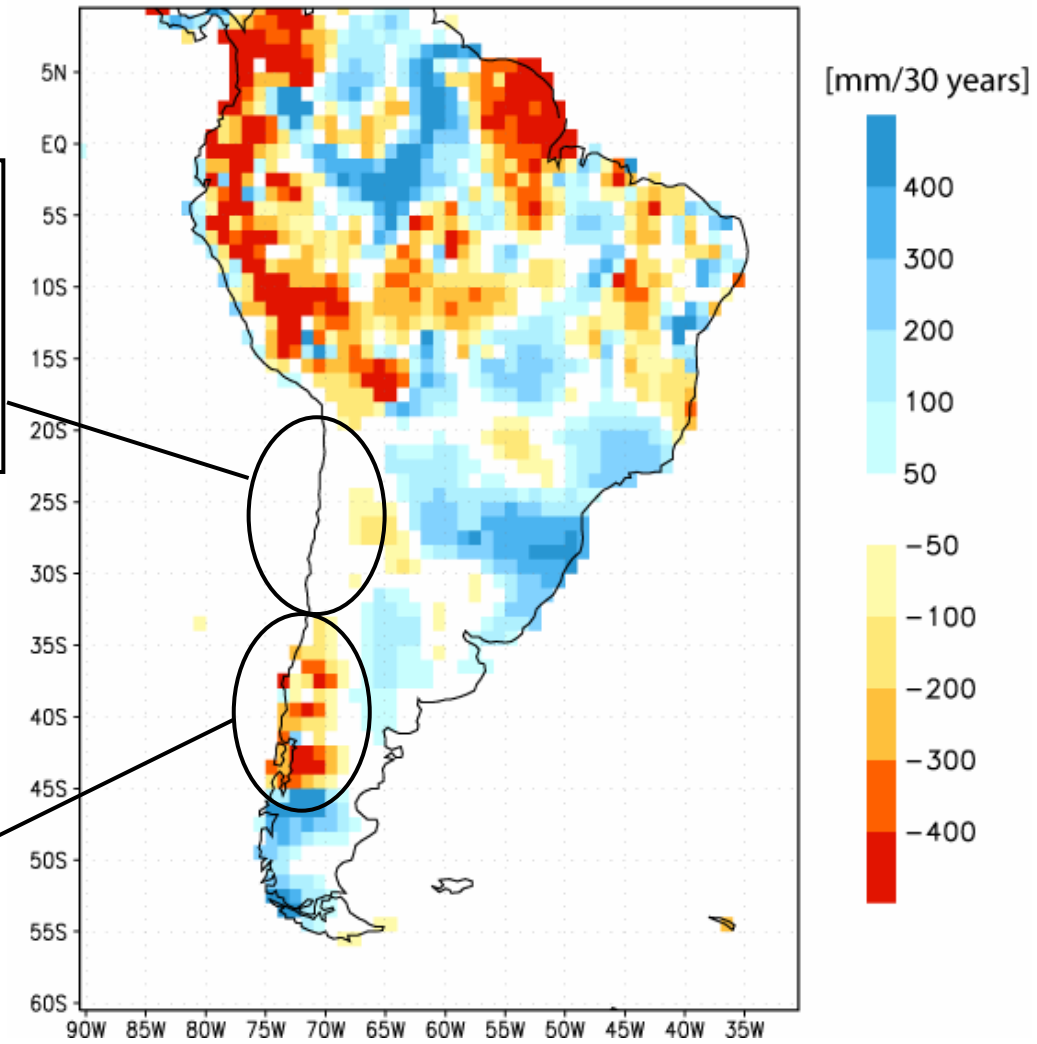


Figure 5. Mean annual temperature trend (°C decade^{-1}) as a function of elevation (m a.s.l.) based on (a) observations (1959–1994, modified from Vuille and Bradley, 2000), (b) CRU05 (1959–1994). Vertical bars indicate elevation range (1000 m) for which trend is valid. Horizontal bars are 95% confidence limits for the trend (i.e., all trends whose error bars do not intersect with the 0 °C decade^{-1} abscissa are significant at the 95% confidence level). Results in (b) are based on sub-sampling to match station coverage in (a), that is only grid cells which contain station data in (a) are considered.

Tendencias observadas de precipitación 1970-2000

- Semiarid climate
- MAP ~ 30-500 mm
- σ(IA)/MAP ~ 0.3 – 0.5
- Strong ENSO Impact
- No significant trend

- Rainy climate
- MAP ~ 1000-3000 mm
- σ(IA)/MAP ~ 0.1
- Weak ENSO Impact
- Significant drying trend



Tendencias observadas de precipitación: ¿?

20TH CENTURY CLIMATE CHANGE IN THE TROPICAL ANDES: OBSERVATIONS AND MODEL RESULTS

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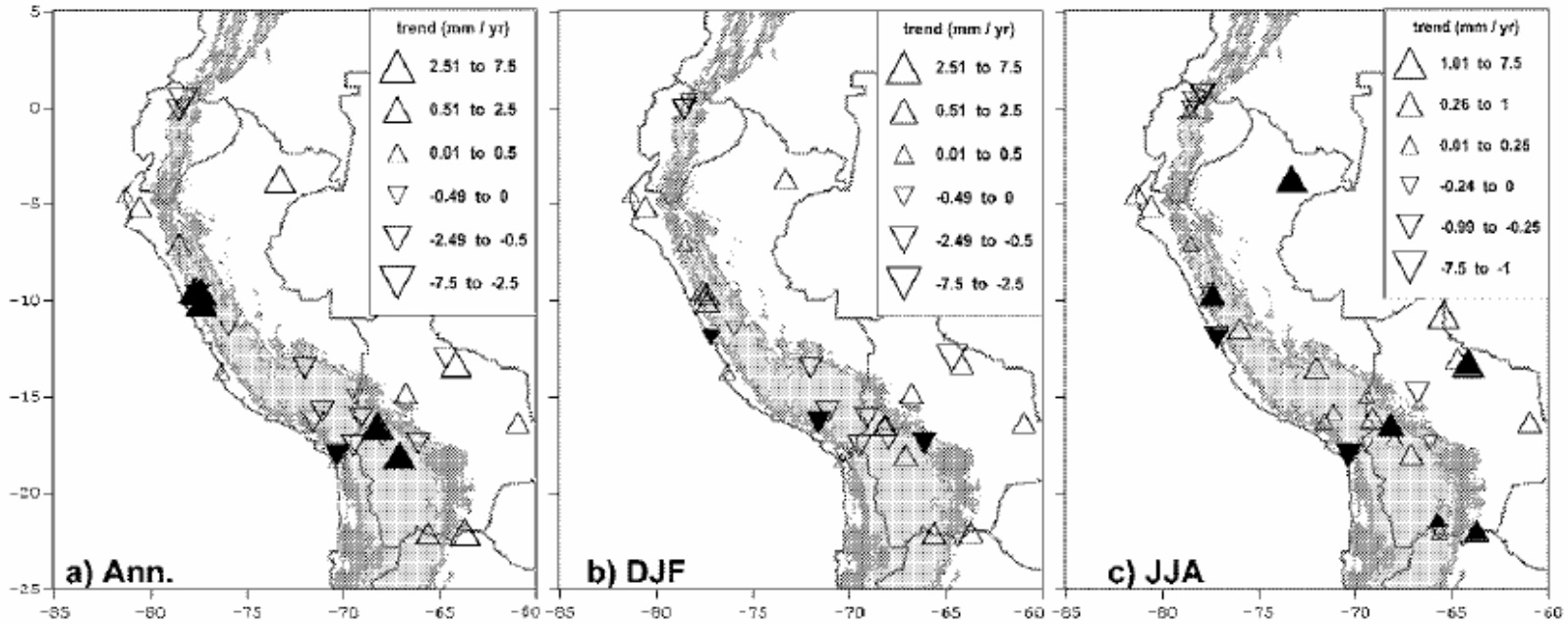
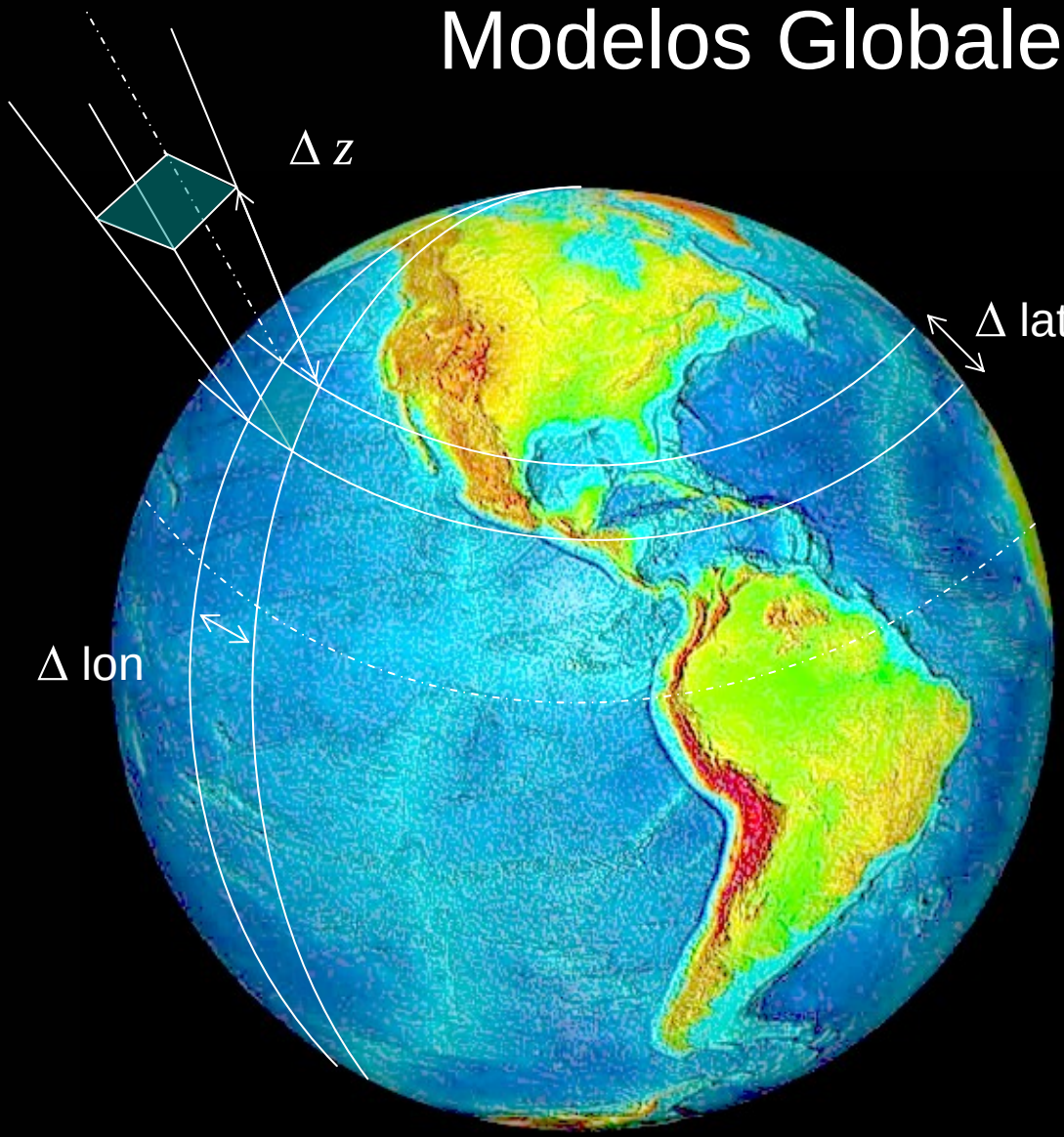


Figure 3. Trends in station precipitation (mm yr^{-1}) between 1950 and 1994 for (a) annual sum, (b) DJF, (c) JJA. Upward (downward) pointing triangles indicate an increase (decrease) in precipitation. Note different scaling in (c). Filled (open) triangles indicate that the trend is (not) significant at the 95%-confidence level. (d) As in (a) but trend in annual precipitation (in % yr^{-1}) versus elevation.

Modelos Globales (GCM)



$$\frac{d\vec{V}}{dt} + f\hat{k} \times \vec{V} = -\frac{1}{\rho}\nabla p - \vec{F}_R + g$$

$$(\frac{\partial}{\partial t} + \vec{V} \cdot \nabla)T - S_p \omega = Q_{RAD} + Q_{Conv} + Q_{Sfc}$$

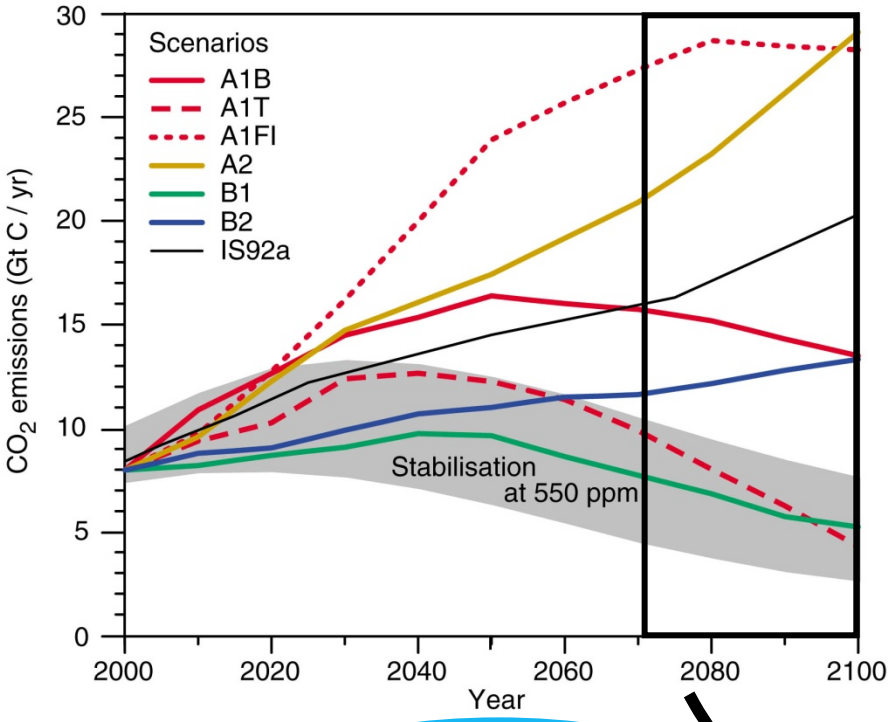
$$\nabla \cdot \vec{V} + \frac{\partial \omega}{\partial p} = 0$$

$$\frac{\partial (gz)}{\partial p} = -\frac{RT}{p}$$

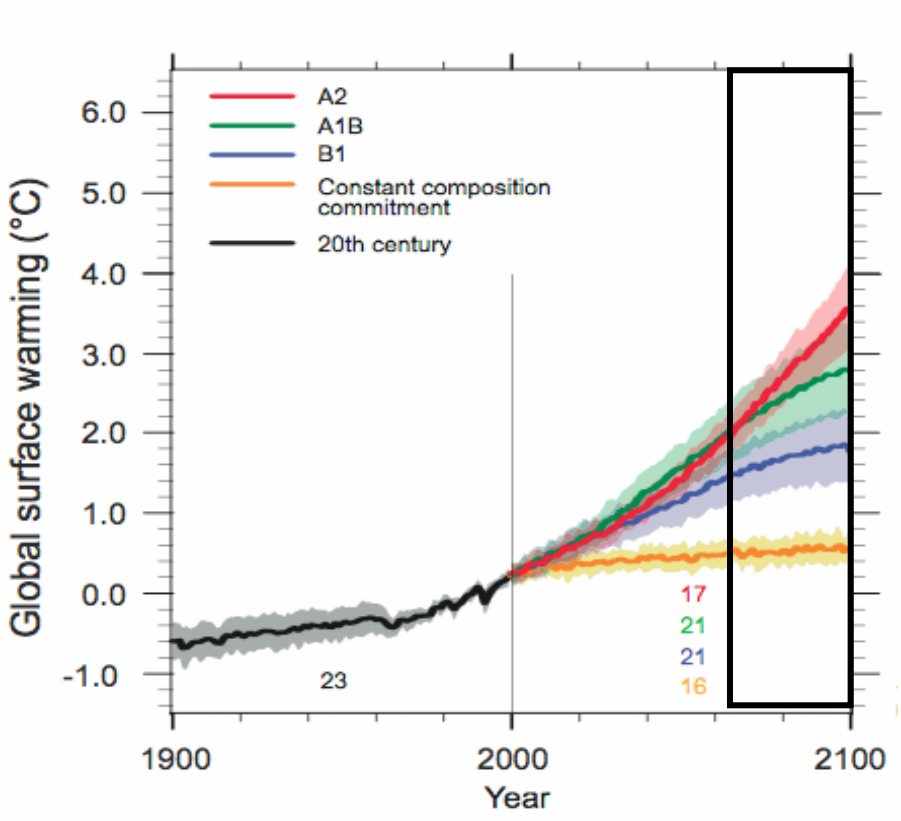
Δlat ~ Δ lon ~ 1° - 3° Δz ~ 1 km Δt ~ minutes-hours

Top of atmosphere: 15-50 km

Future Climate Scenarios
GHG (CO2,…) emissions projections + GCMs



20+ GCMs
CMIP3/IPCC AR4



Multimodel precipitation and surface temperature Changes (A2-BL)

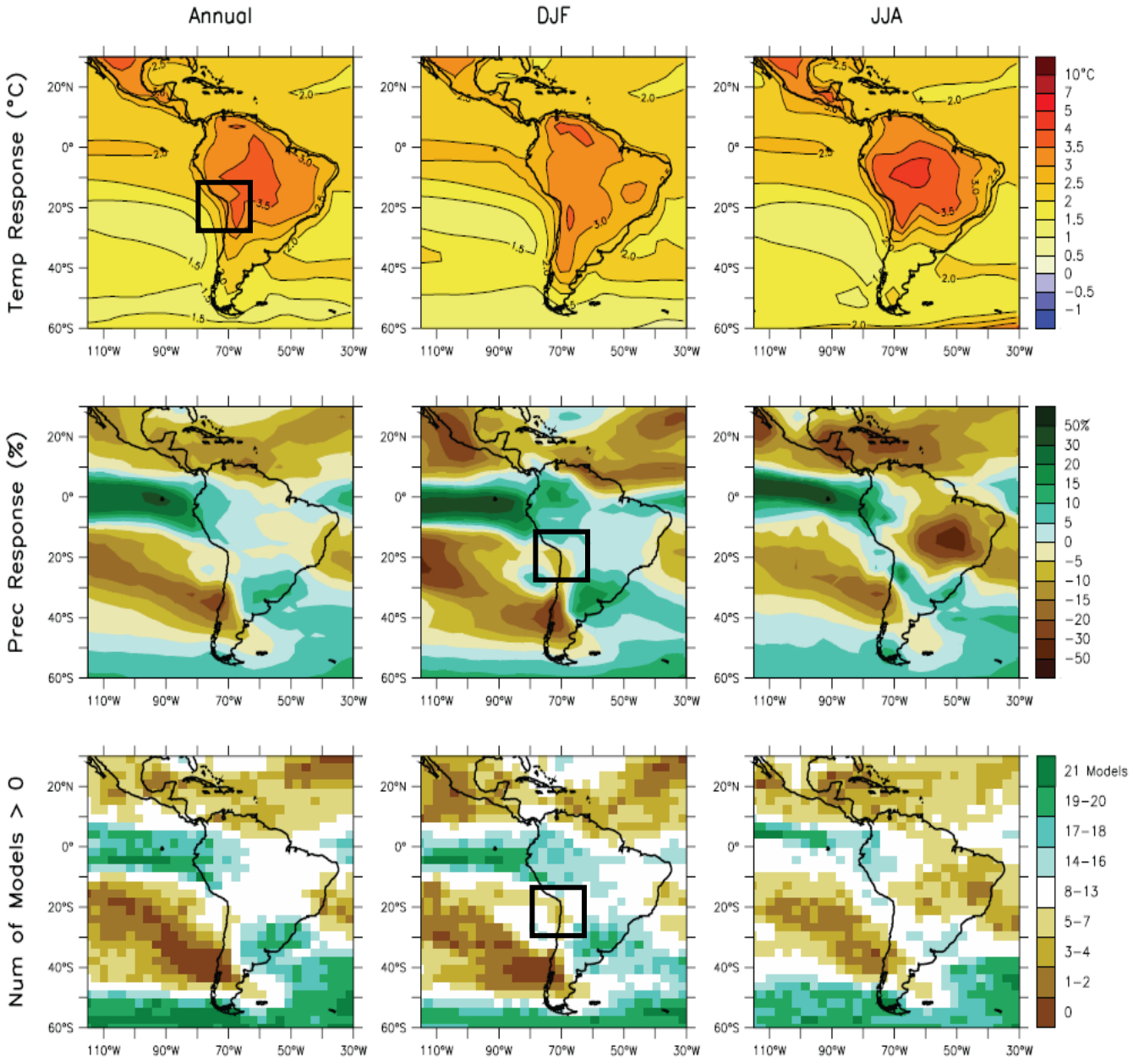
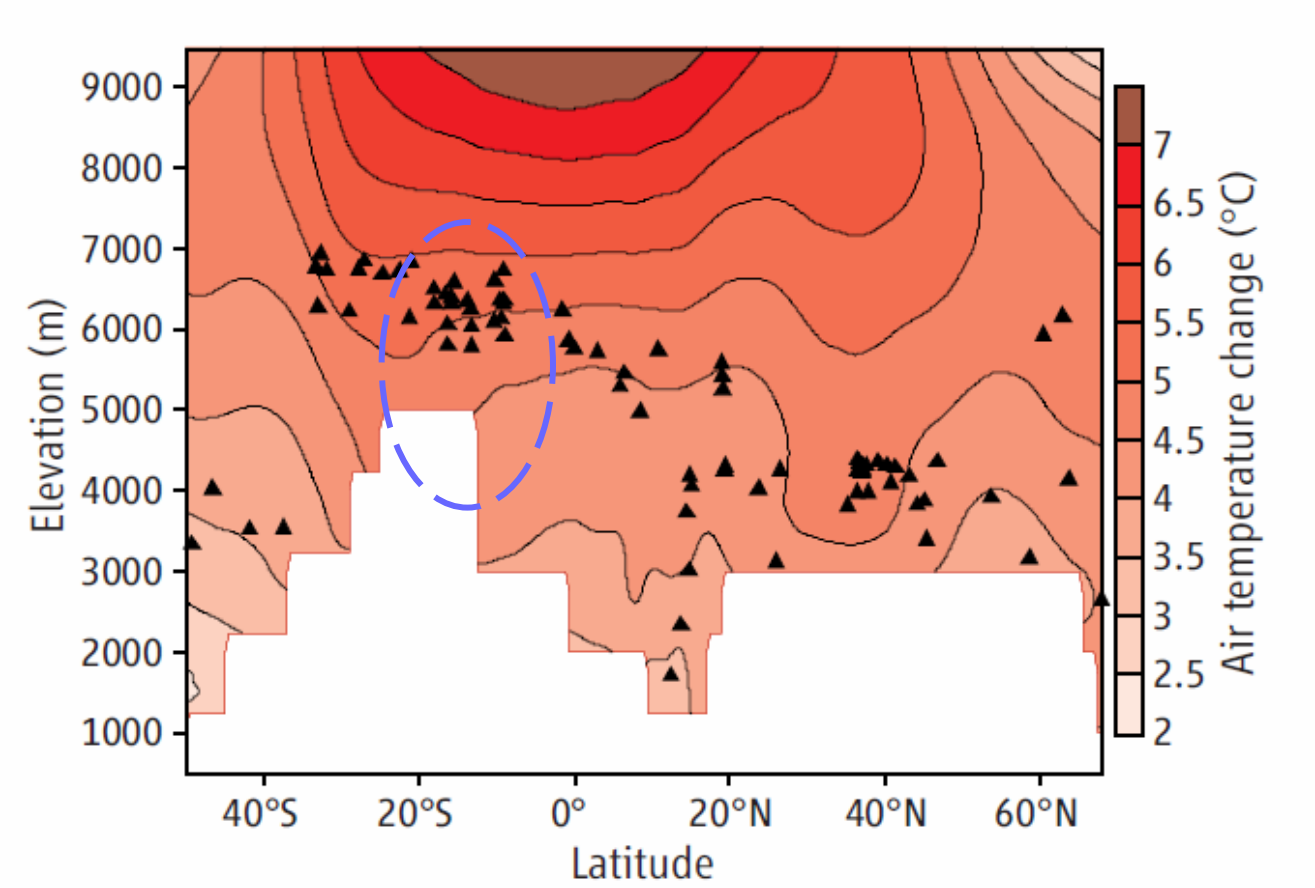


Figure 11.15. *Temperature and precipitation changes over Central and South America from the MMD-A1B simulations. Top row: Annual mean, DJF and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Middle row: same as top, but for fractional change in precipitation. Bottom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

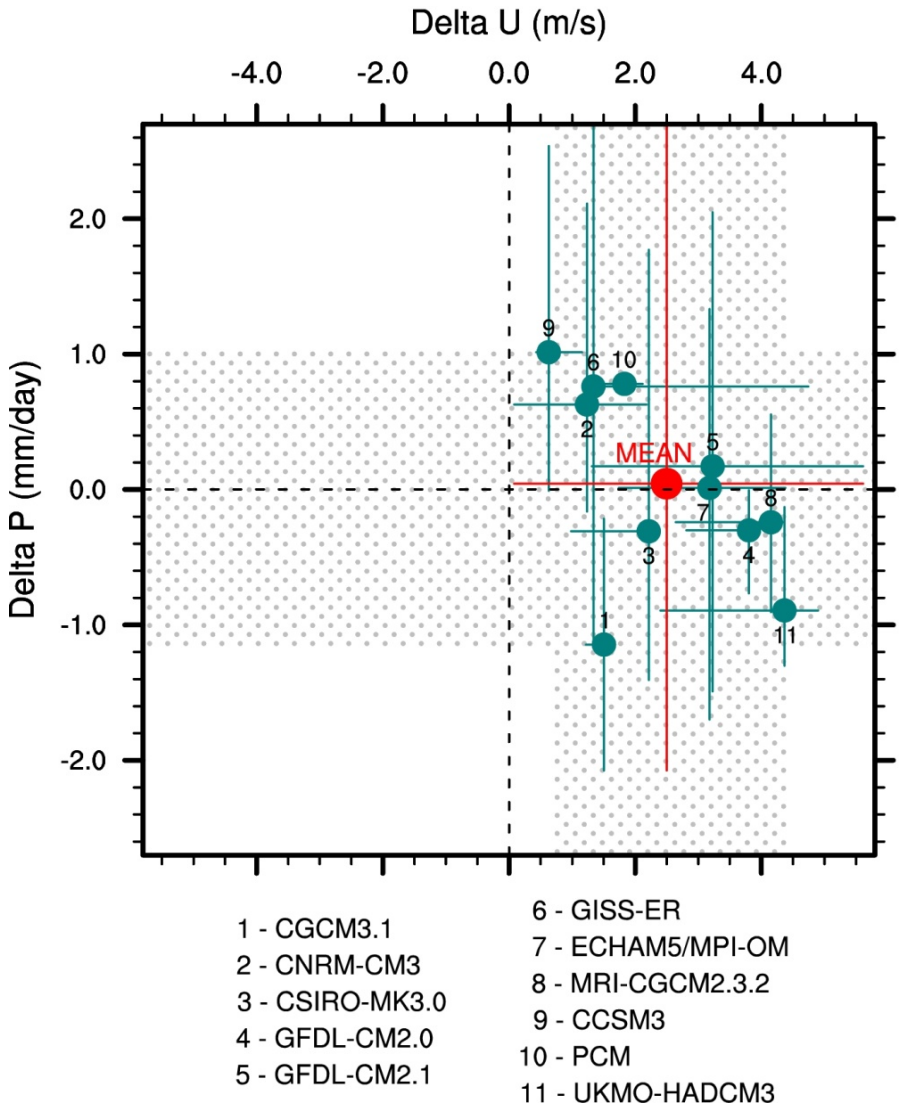
Cambio de temperatura A2 (2090-99) menos LB (1990-99)



Global warming in the American Cordillera. Projected changes in mean annual free-air temperatures between (1990 to 1999) and (2090 to 2099) along a transect from Alaska (68°N) to southern Chile (50°S), following the axis of the American Cordillera mountain chain. Results are the mean of eight different general circulation models used in the 4th assessment of the Intergovernmental Panel on Climate Change (IPCC) (*15*), using CO_2 levels from scenario A2 in (*16*). Black triangles denote the highest mountains at each latitude; areas blocked in white have no data (surface or below in the models). Data from (*15*).

Bradley et al. 2003

Cambio de precipitación A2 (2090-99) menos LB (1990-99)



Mas PP

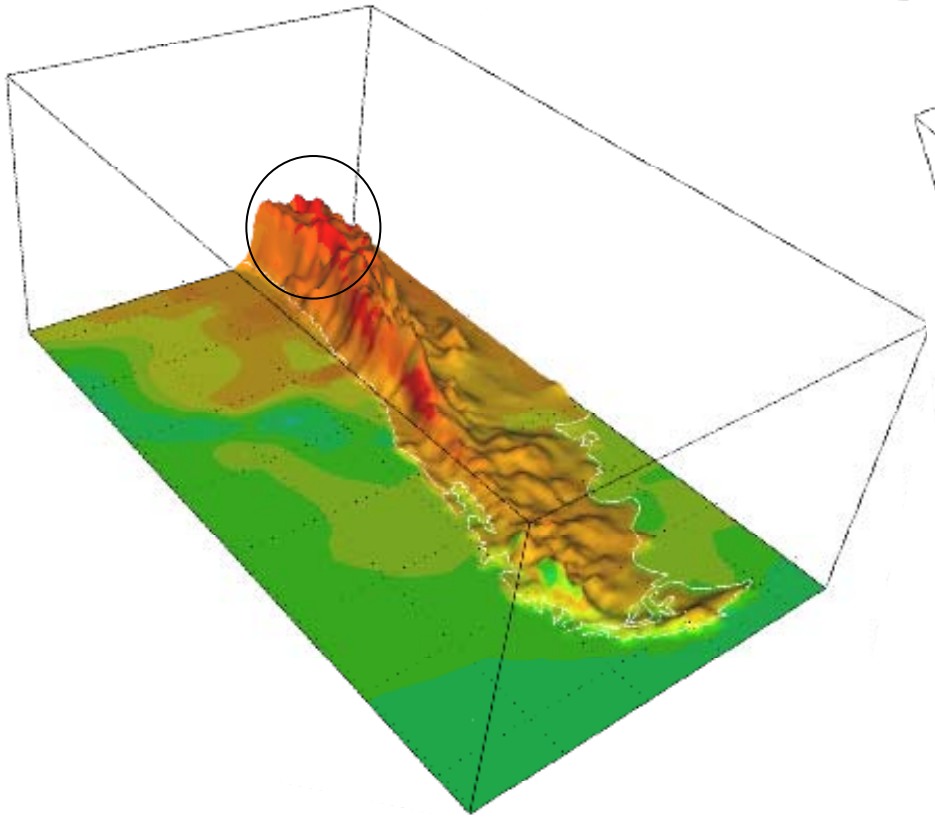
Menos PP

Minvielle and Garreaud 2010

Differences A2(2100-2070) – BL(1960-1990)

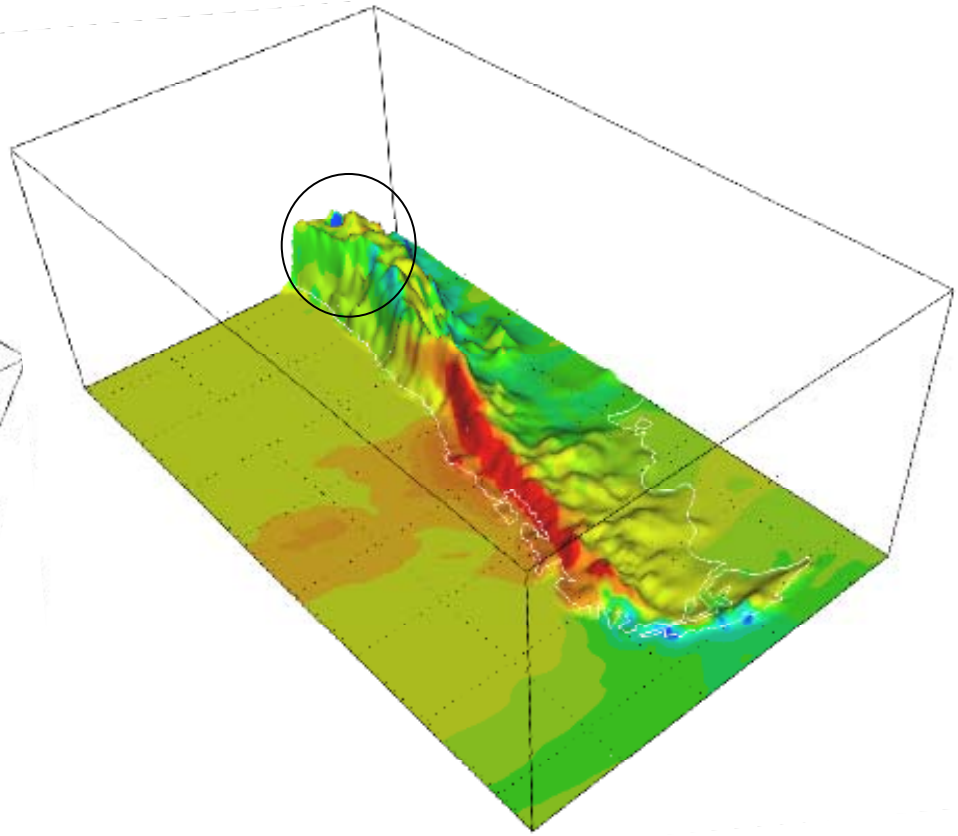
Obtained with a regional climate model (PRECIS) forced by HadCM3 / A2

Temperatura Superficial (SAT)



-1° 0° 1° 2° 3° 4° 5° C

Precipitación (P)



-50 0 +50 mm/mes

PRECIS-DGF-UCH

Diferencia T_{2m} (2100-2070) – (1960-1990)

Obtained with a regional climate model (PRECIS) forced by Echam4 / A2

B2-LB

A2-LB

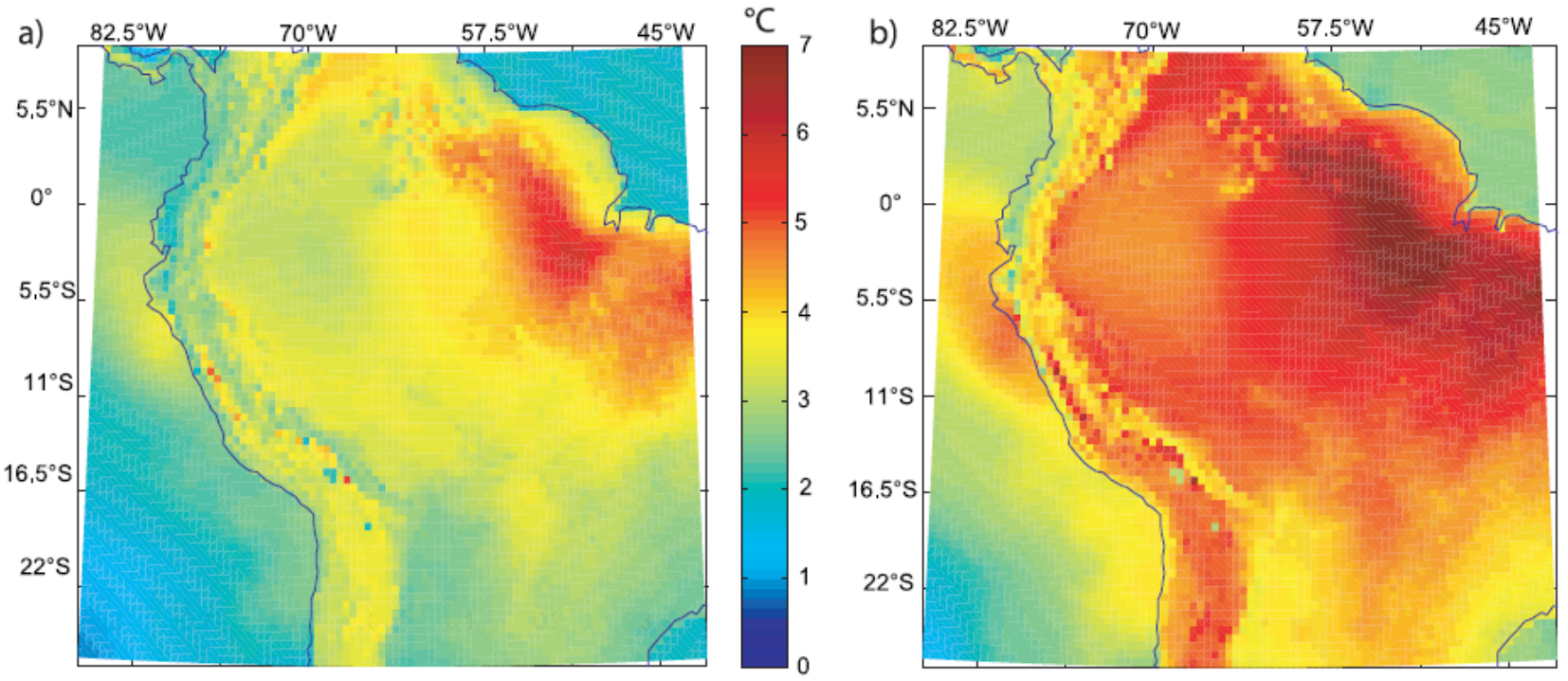


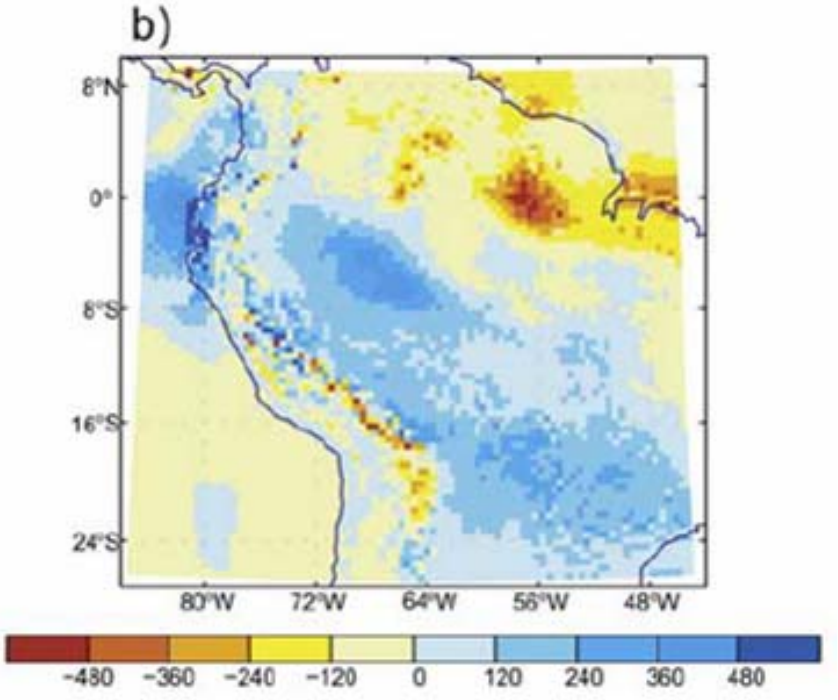
Figure 5. (a) Difference in mean annual surface temperature (in °C) between RCM-B2 and RCM-20C. (b) Same as in Figure 5a but for RCM-A2. Differences are statistically significant at the 95% level everywhere.

Urrutia and Vuille 2009

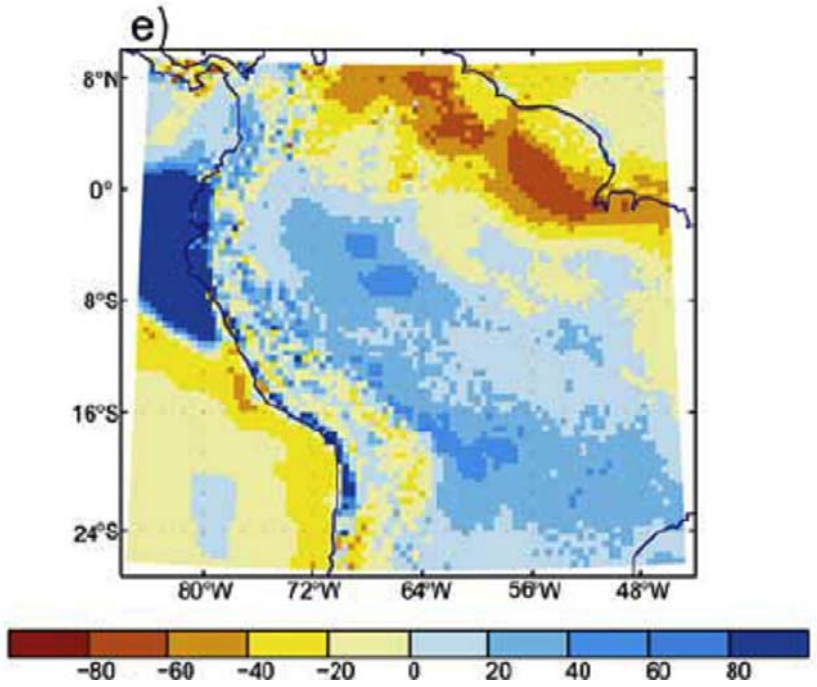
Diferencia Pp A2(2100-2070) – BL(1960-1990)

Obtained with a regional climate model (PRECIS) forced by Echam4 / A2

dP (mm/año)

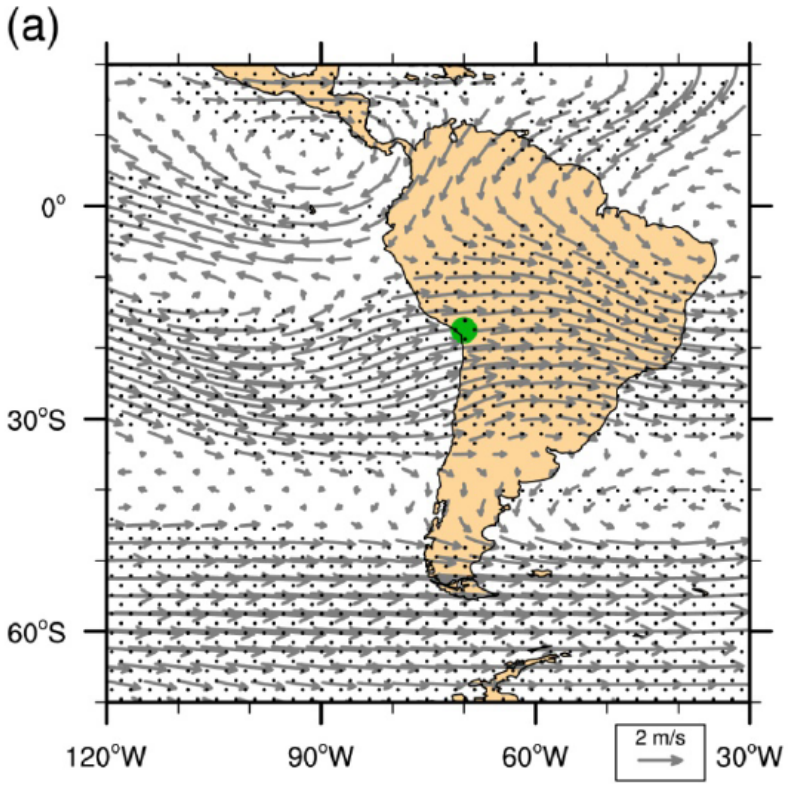


dP/Pbl (%)

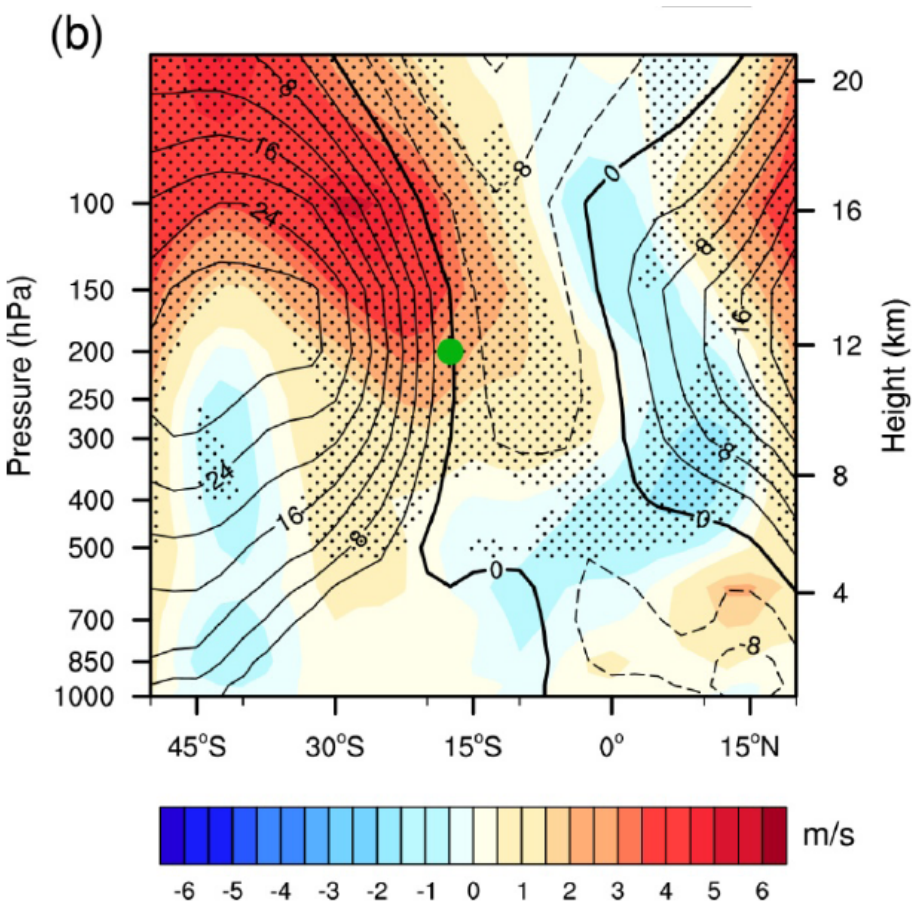


Urrutia and Vuille 2009

Cambios de Circulación A2- BL



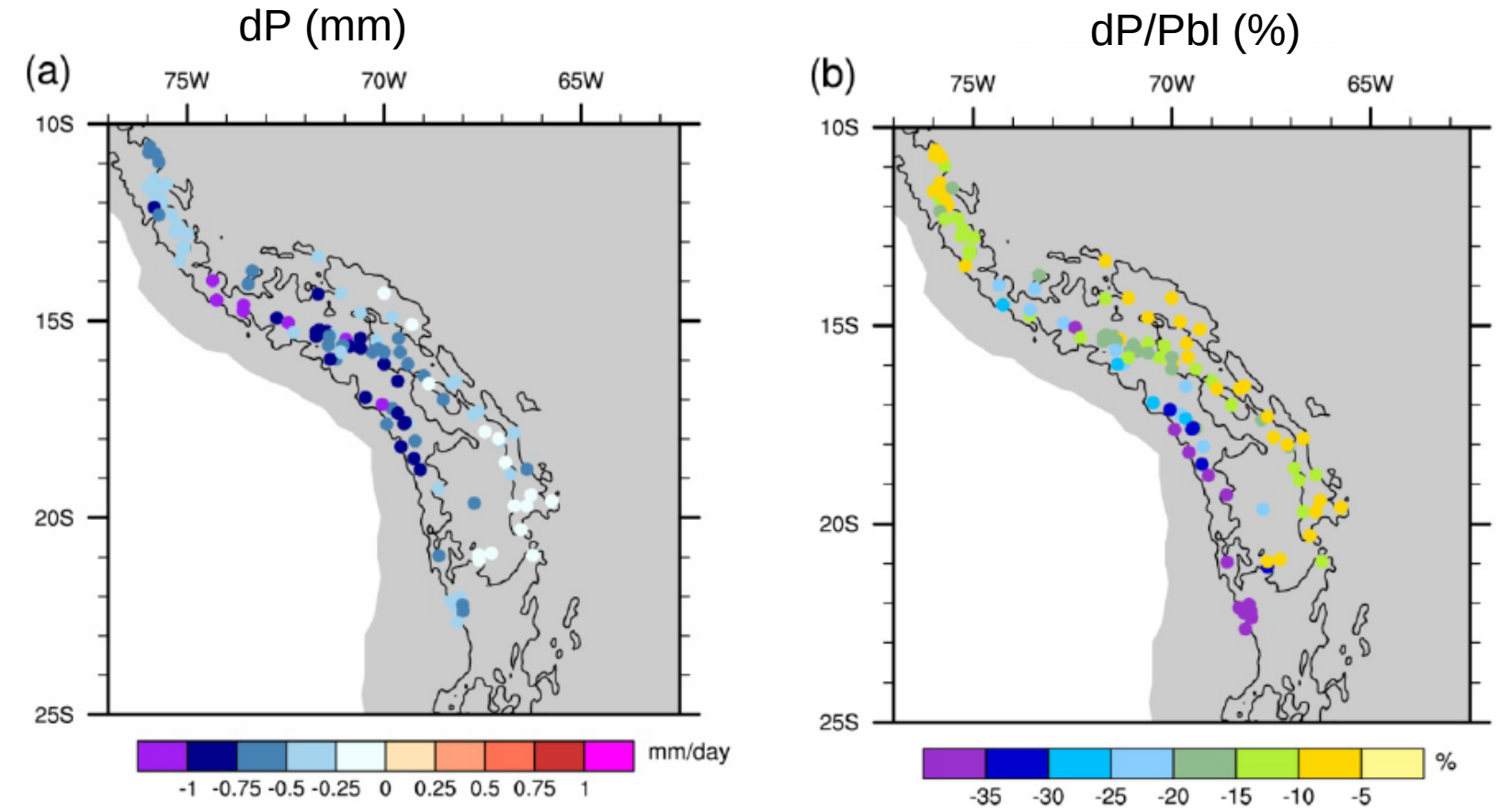
Multimodel mean diff. A2-BL in 200 hPa wind, summer



Multimodel mean diff. A2-BL in zonal wind along 70°W summer

Minvielle and Garreaud 2010

Cambios de Precipitación esperables por cambio de viento



Minvielle and Garreaud 2010

Conclusiones

* Clima del Altiplánico altamente estacional y con marcada variabilidad interanual (Niños secos & cálidos / Niñas lluviosas & frías; señal espacial no homogénea).

* Tendencia al calentamiento superficial en últimas décadas (0.2º/dec) bastante robusto y espacialmente coherente. Red de estaciones marginalmente apropiadas para detectar cambios.

* Tendencias de precipitación difícil de detectar y espacialmente variable. Red de estaciones (P, Q, Asub) insuficiente.

* Proyecciones para resto de siglo XXI: continua el calentamiento en altura ($\rightarrow$ 4ºC) y probablemente reducción de precipitaciones ($\rightarrow$ 10-30%)