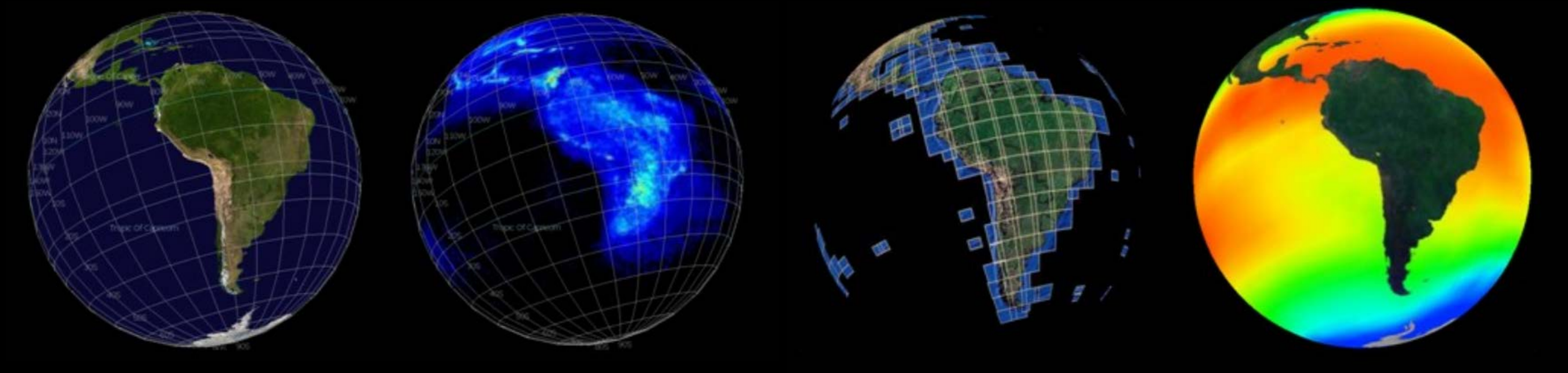
The changing South American Climate: Large-scale forcing and impacts



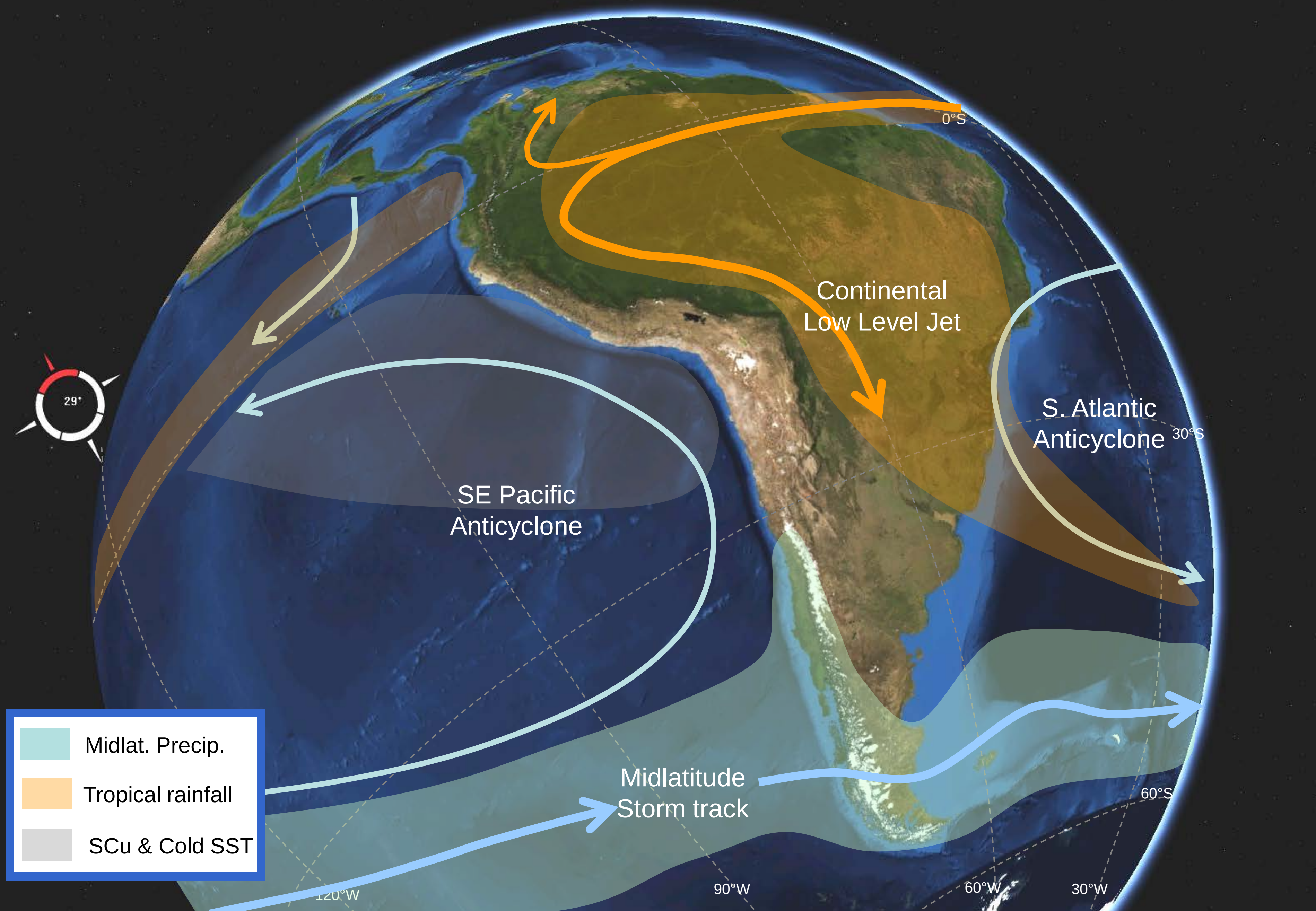
René D. Garreaud
Department of Geophysics, Universidad de Chile
Center for Climate and Resilience Research (CR2)

South American Drought Atlas meeting, May 2017

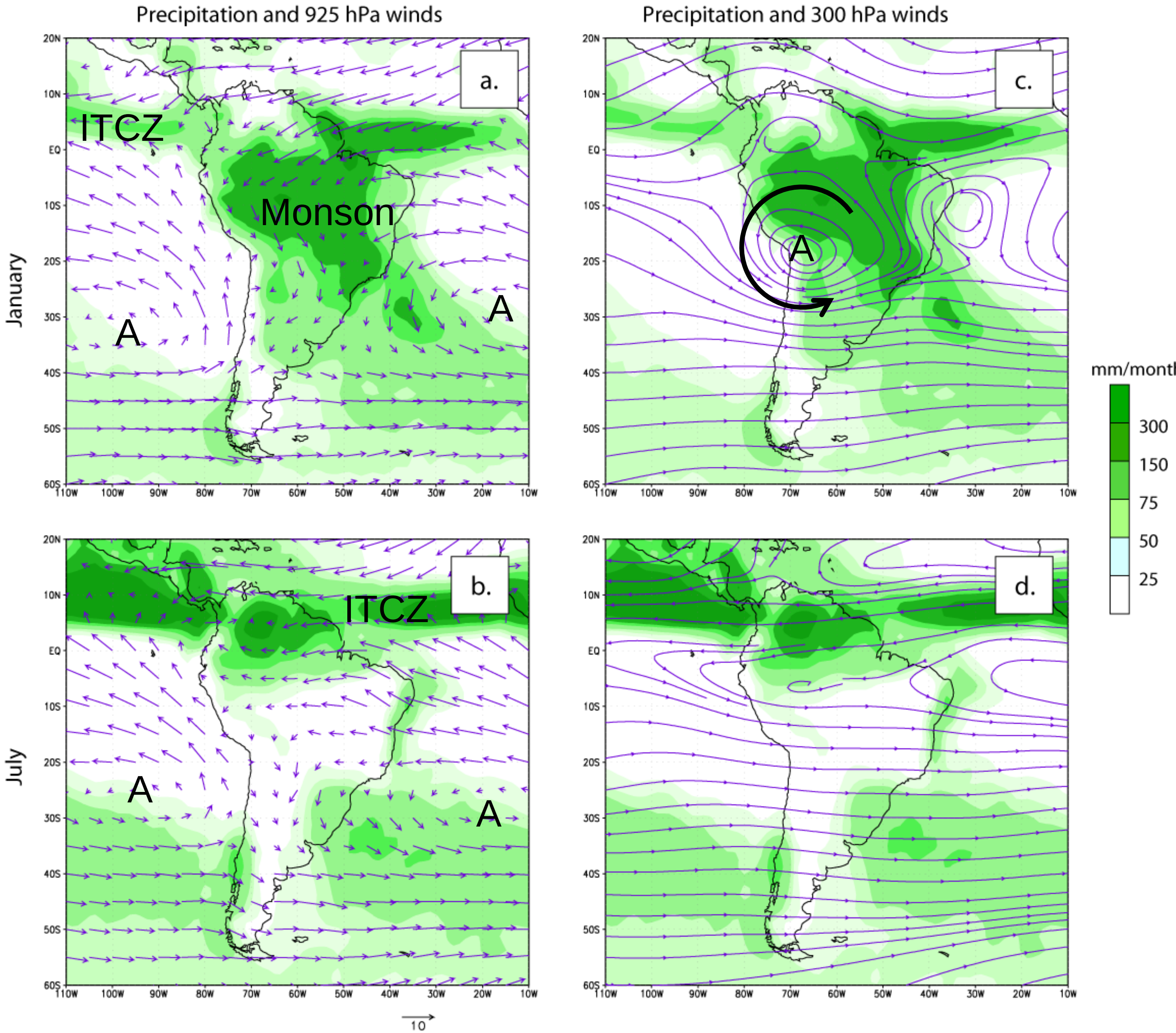
In this presentation….

- South American (Andes) Climate 101
- Leading modes of variability
- Contemporaneous climate change
- Why do we (climatologist) need SADA?

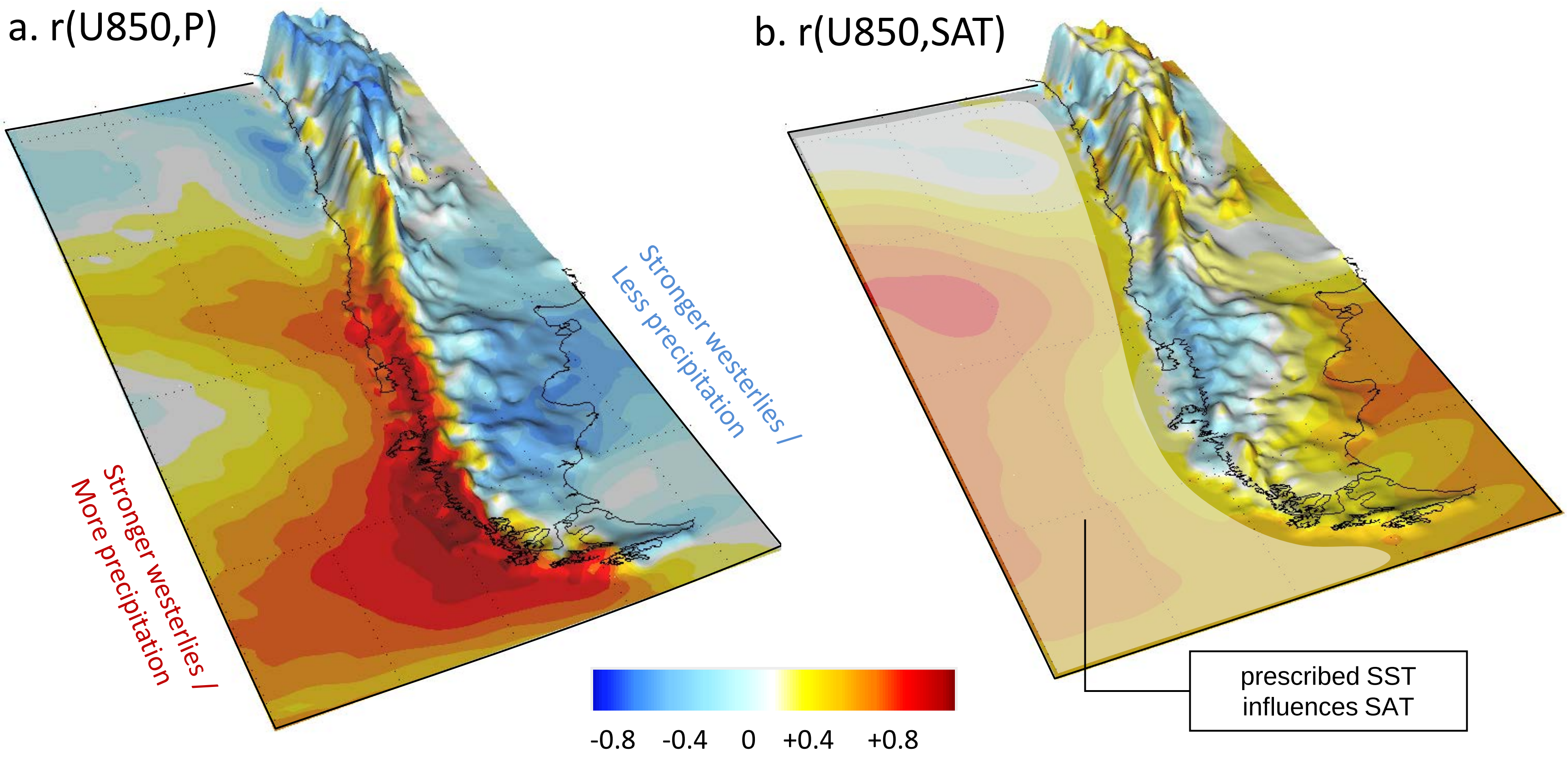
The big picture



Seasonal long term means



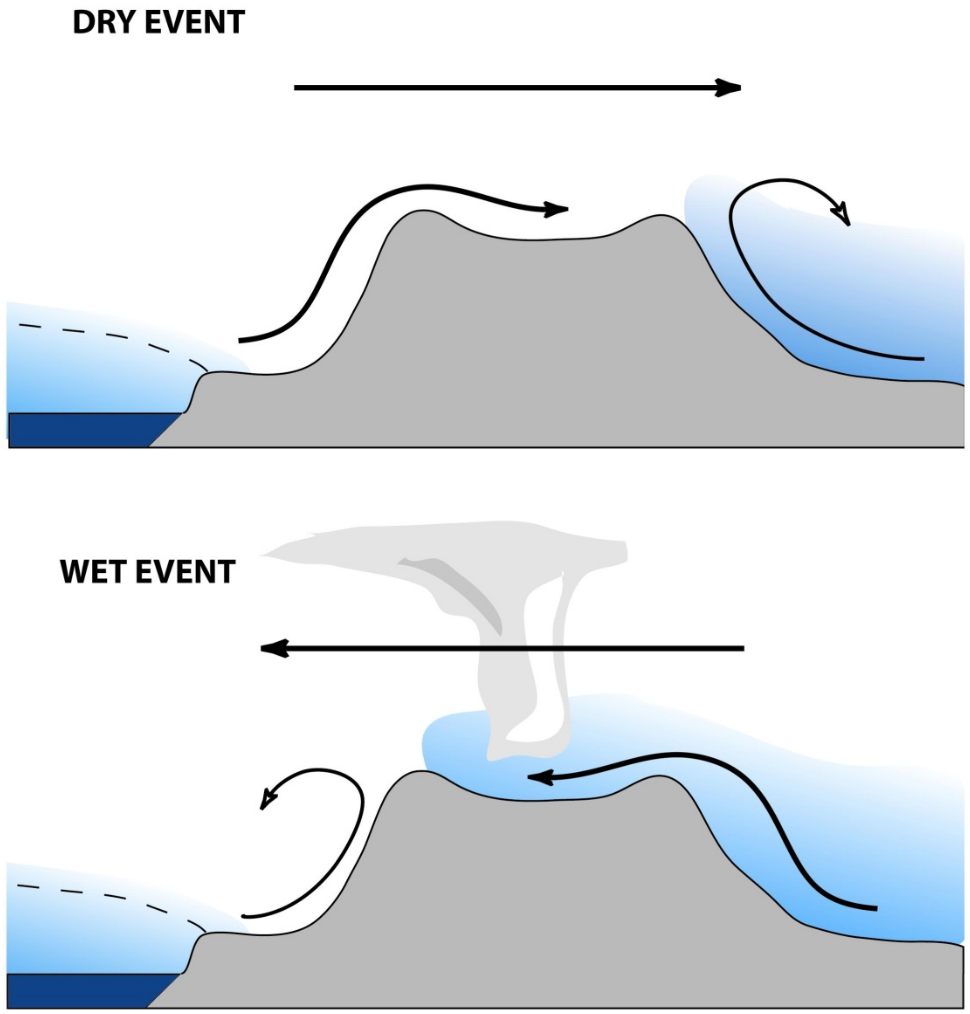
Wind-precipitation and Wind-SAT covariability at annual timescale (year-to-year)



Garreaud et al 2013

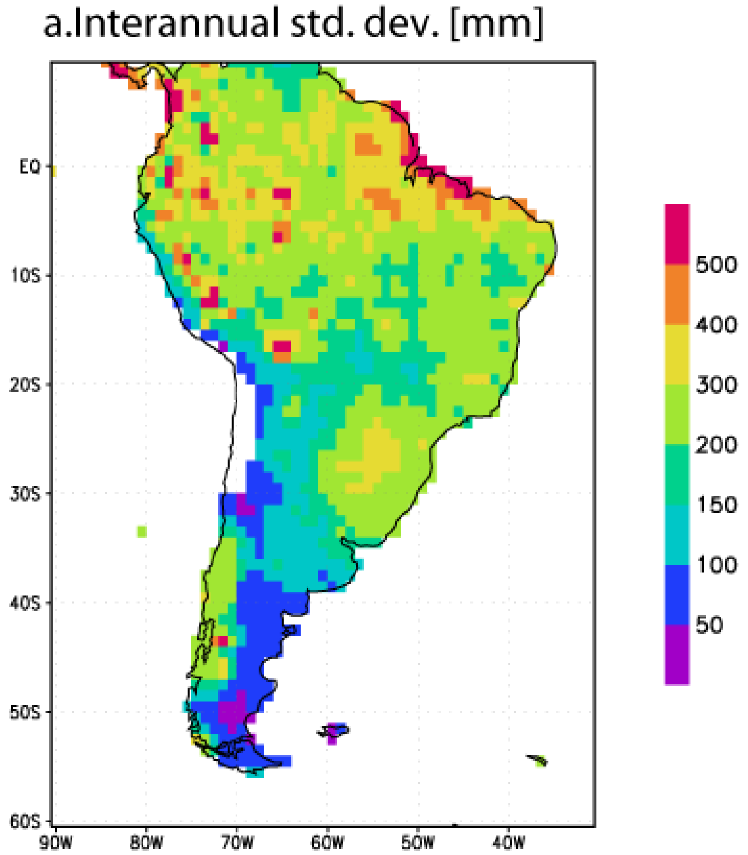
Central Andes Rainfall

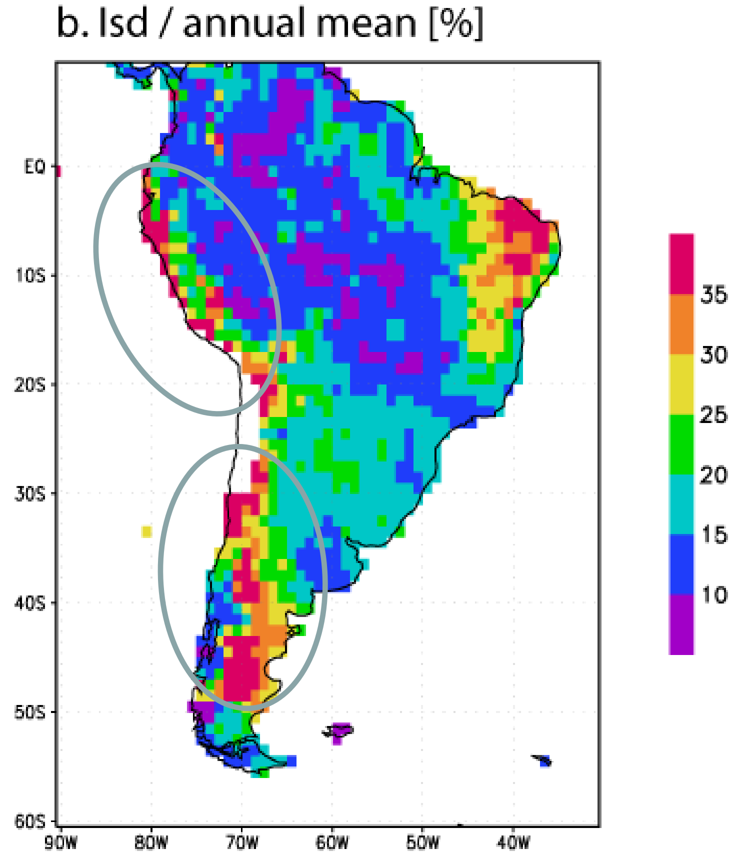
* Closely tied to moisture availability
* Wind aloft controls the transport of moisture towards the Altiplano



Falvey and Garreaud 2005

Interannual Precipitation Variability





Principales modos de variabilidad atmosférica
ENOS – PDO – AAO (SAM)

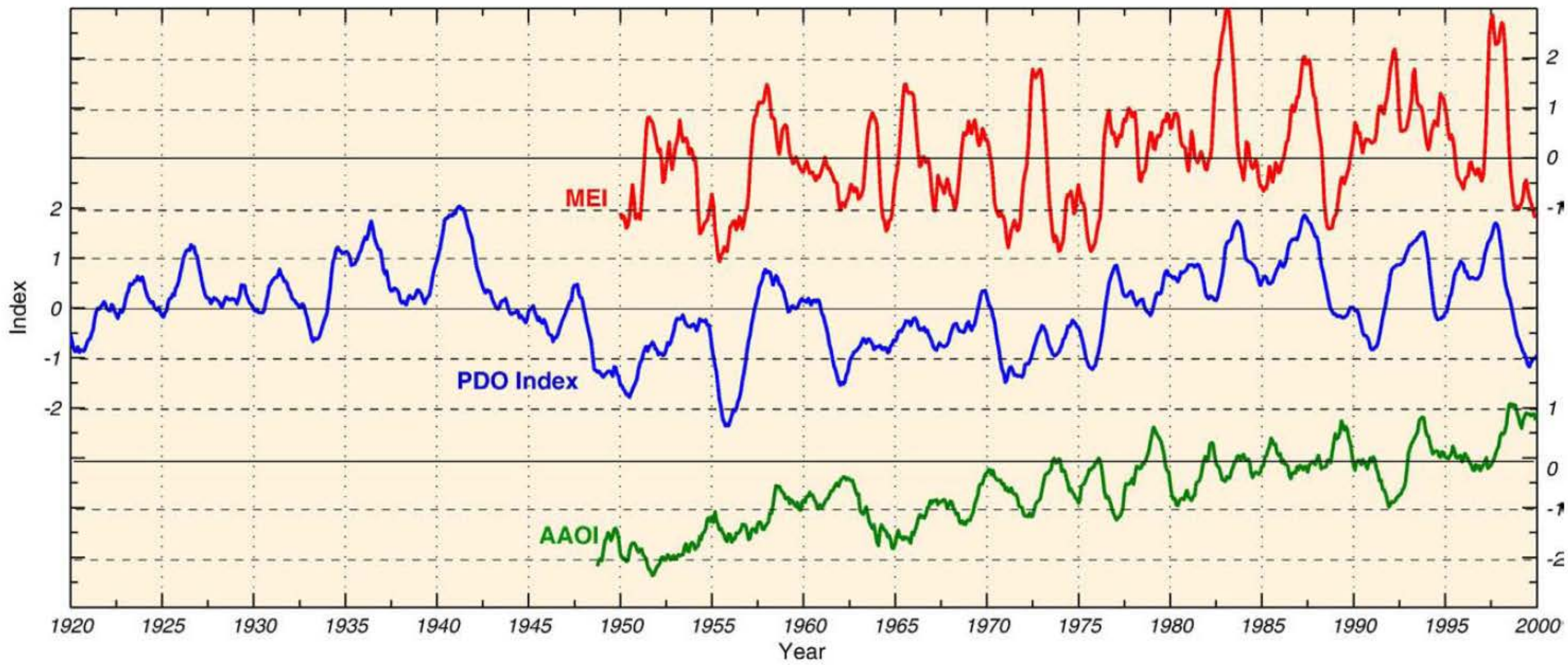
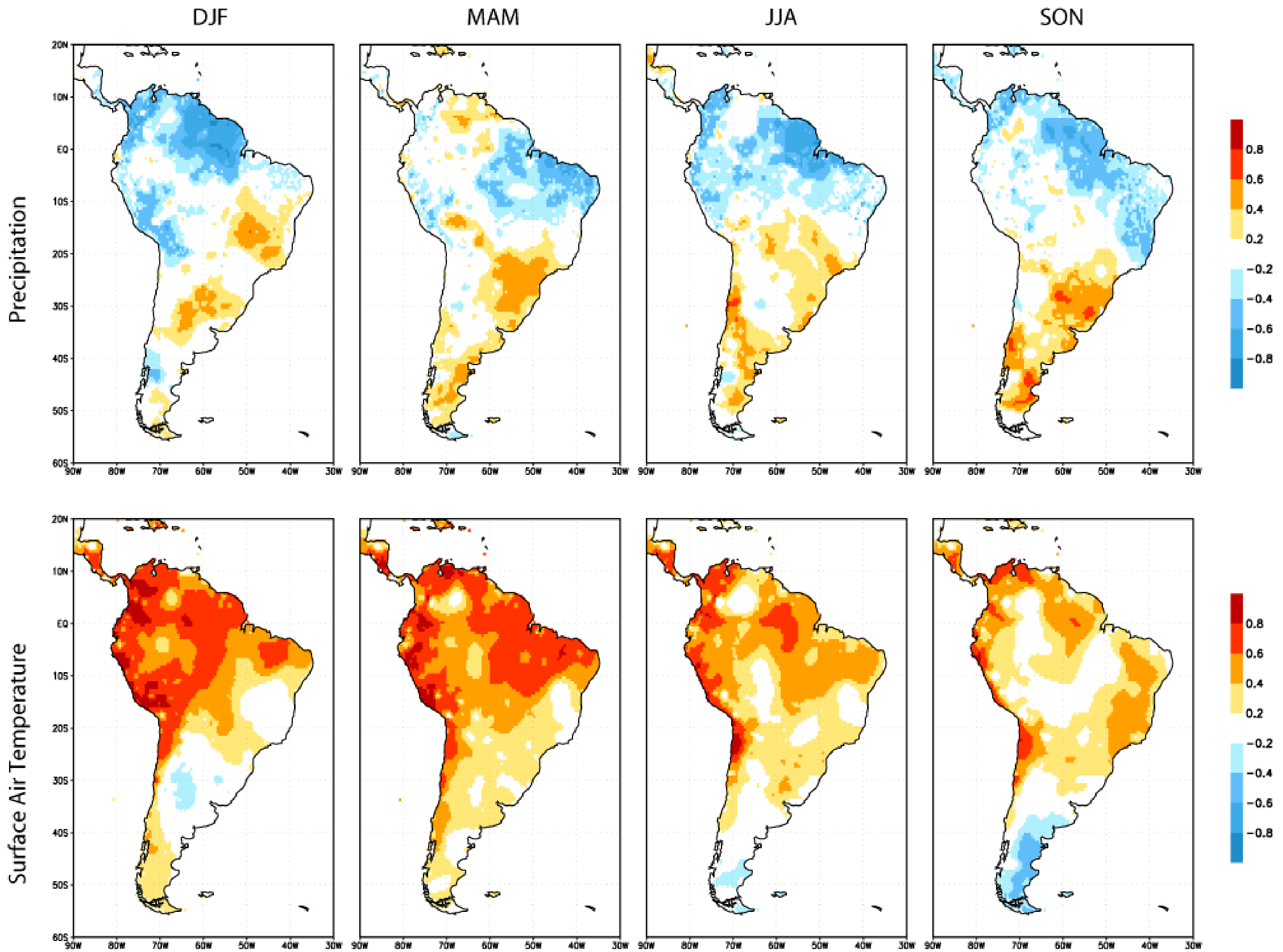


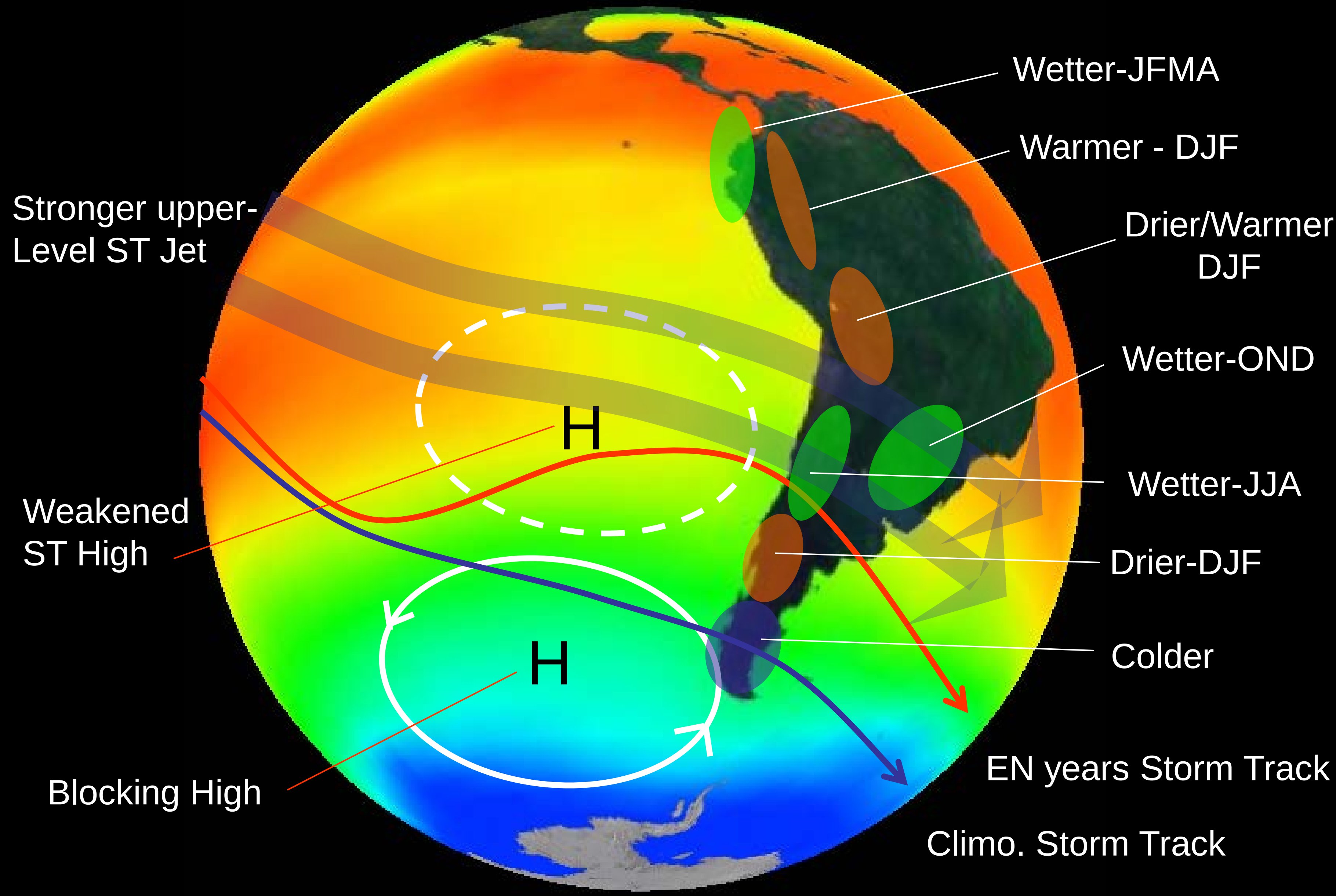
Fig. 5. Time series (1920–2000) of monthly mean Multivariate ENSO Index (MEI), PDO Index and AAO Index. All indexes were smoothed using a 5-month running mean filter. Original indices obtained from Climate Diagnostic Center (NOAA).

ENOS: El Niño – Oscilación del Sur
PDO: Oscilación Decadal del Pacifico
AAO: Oscilación Antártica (SAM: Modo Anular del Sur)

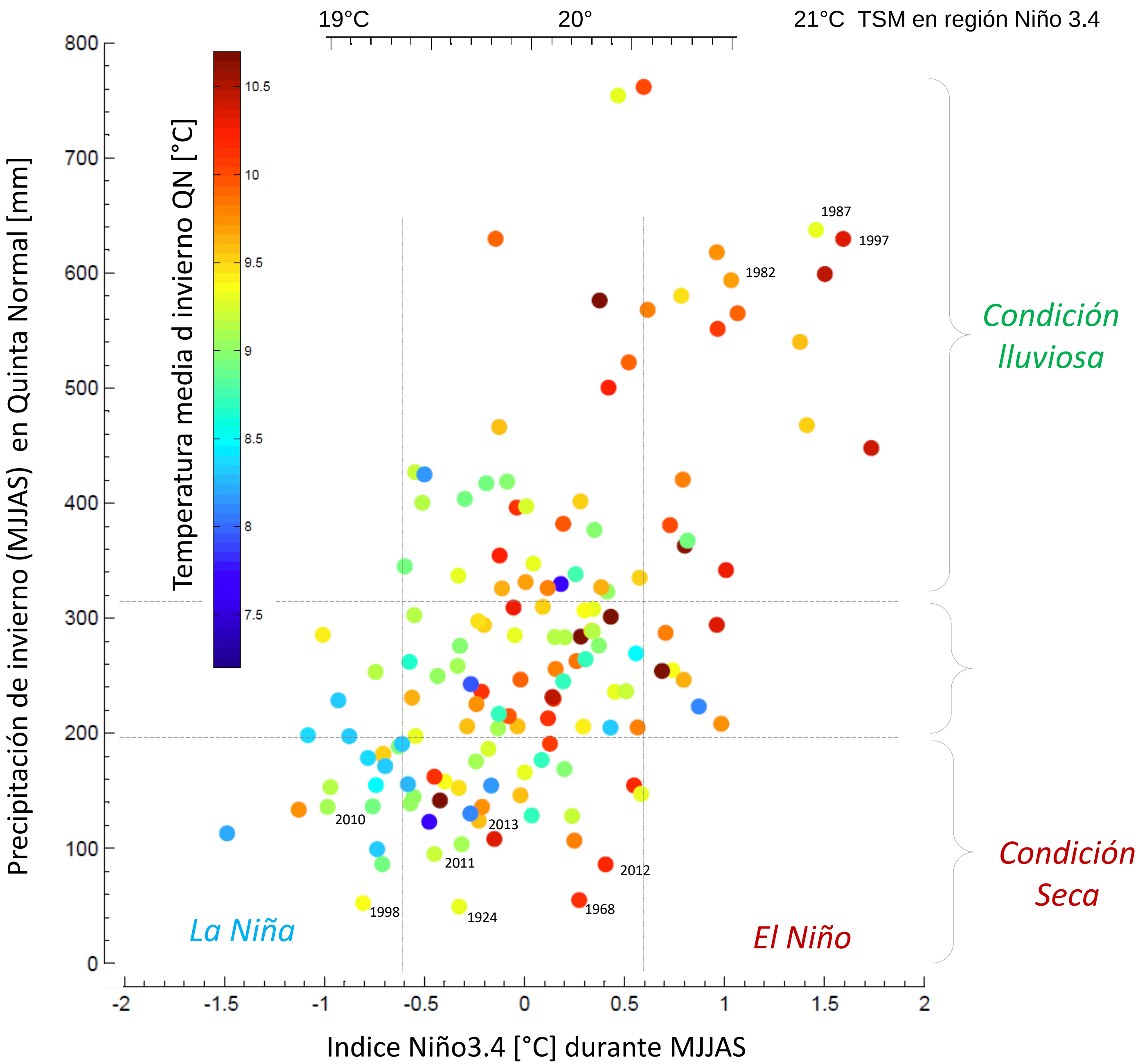
Seasonal correlation between Precip/SAT and Multivariate ENSO Index (50 years of data)



Interannual variability - Major ENSO impacts



Valores invernales del Índice Niño3.4 y Precipitación en Santiago (1876-2013)



Central Andes (Altiplano Region) Interannual rainfall variability

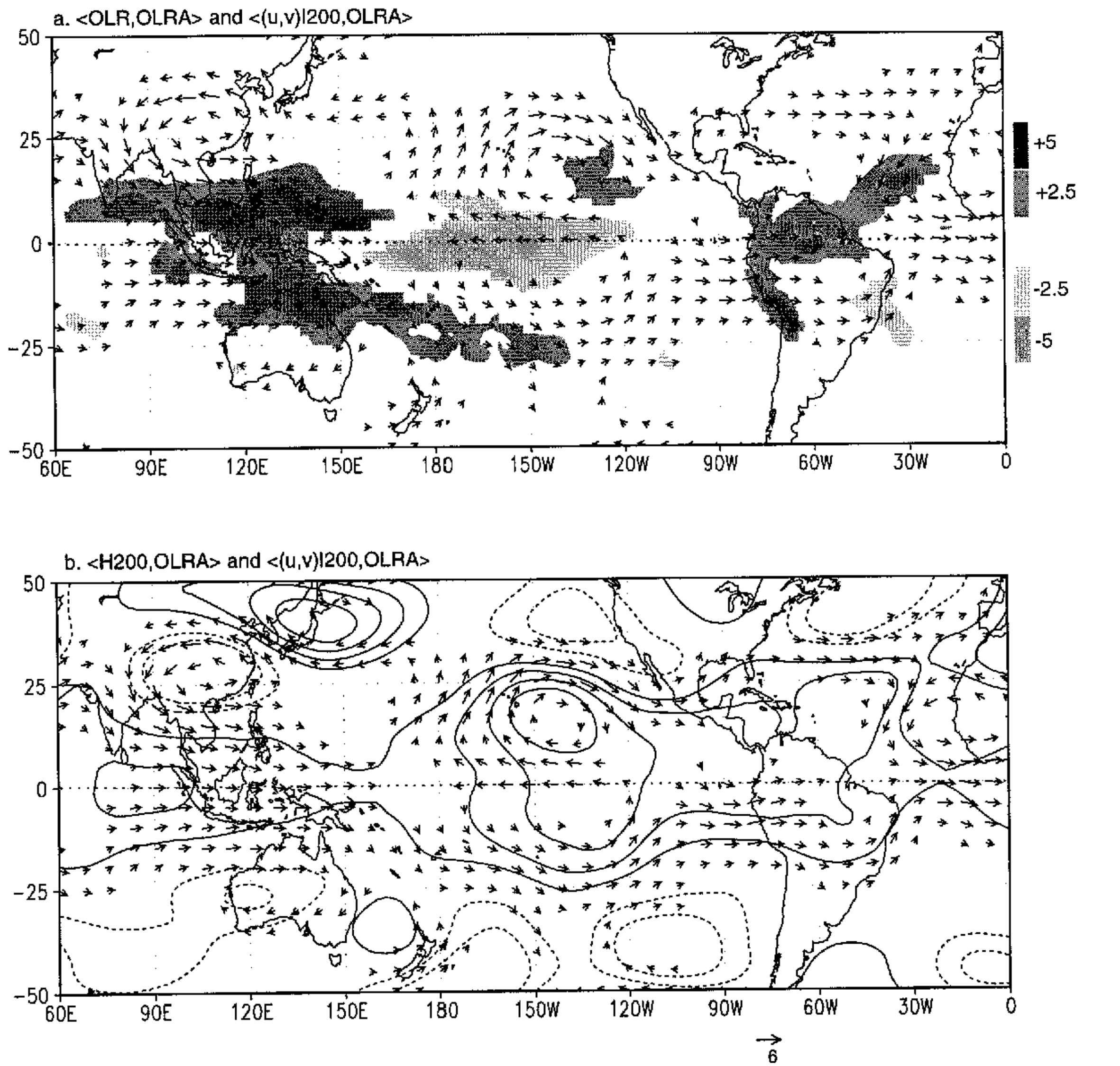
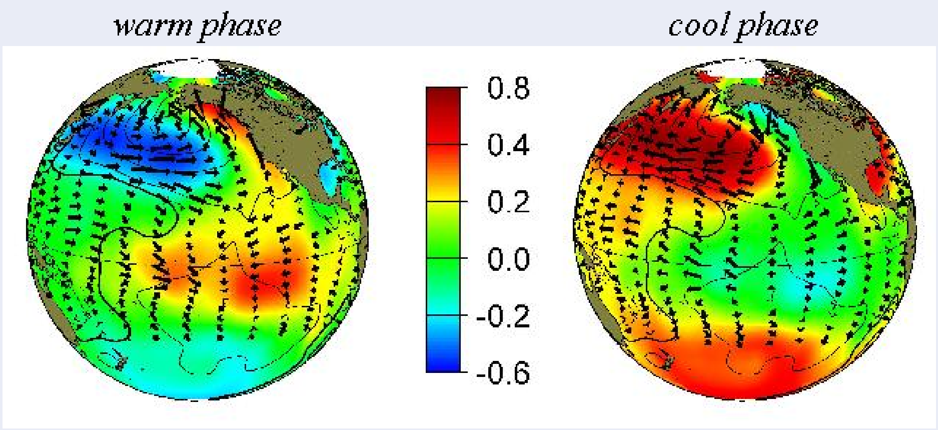
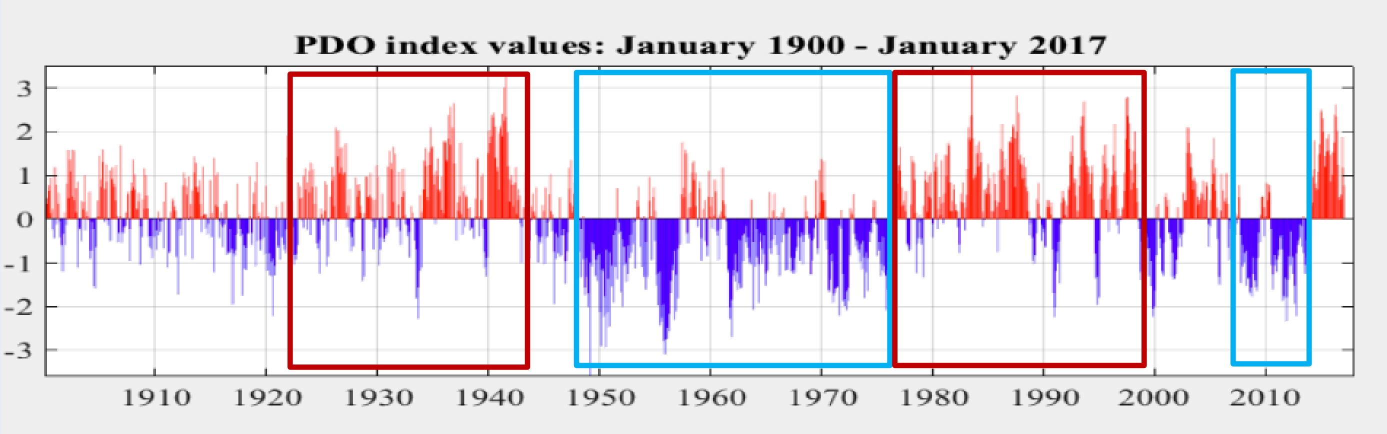


FIG. 7. Regression maps in the interannual range (see section 2 for details on calculation and statistical significance). (a) OLR (shaded, scale in units of W m^{-2} per std dev) and 200-hPa wind regressed upon CI (OLR over the Altiplano). (b) 200-hPa height and winds regressed upon CI. Contour interval 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.

The Pacific Decadal Oscillation (PDO)

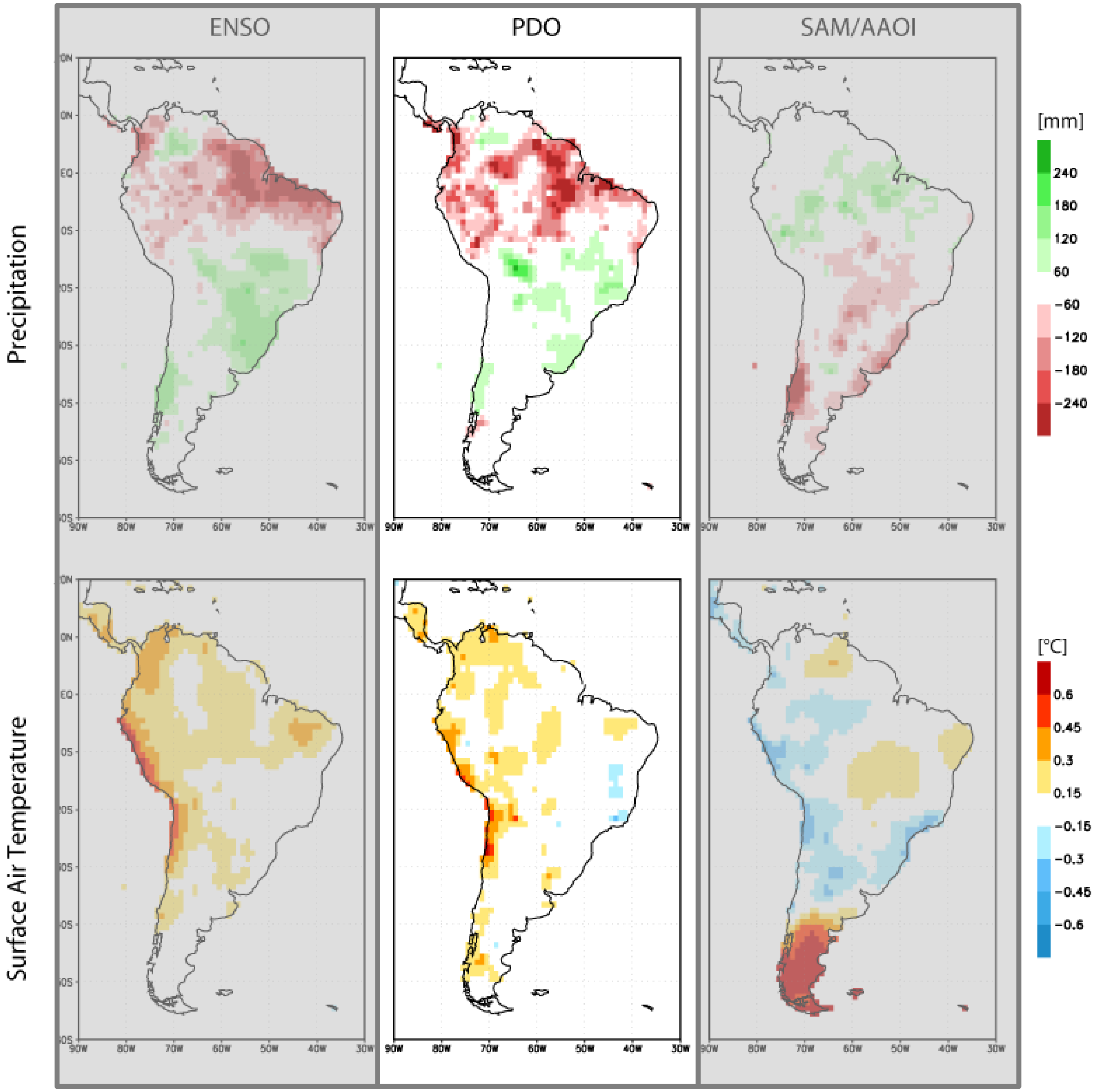
Typical wintertime Sea Surface Temperature (colors),
Sea Level Pressure (contours) and surface windstress (arrows) anomaly patterns during warm and cool phases of PDO





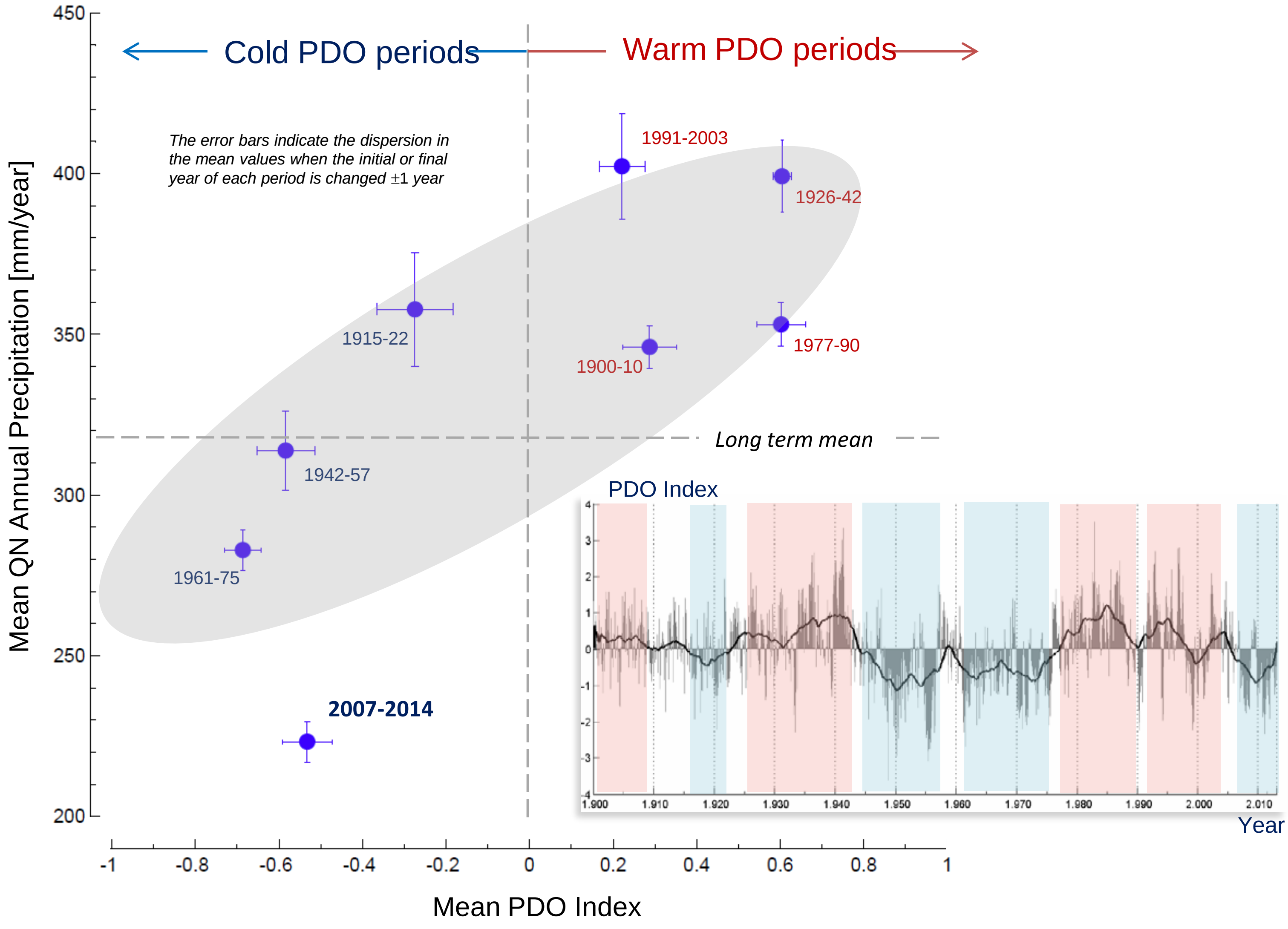
http://research.jisao.washington.edu/pdo/

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



Garreaud et al 2009

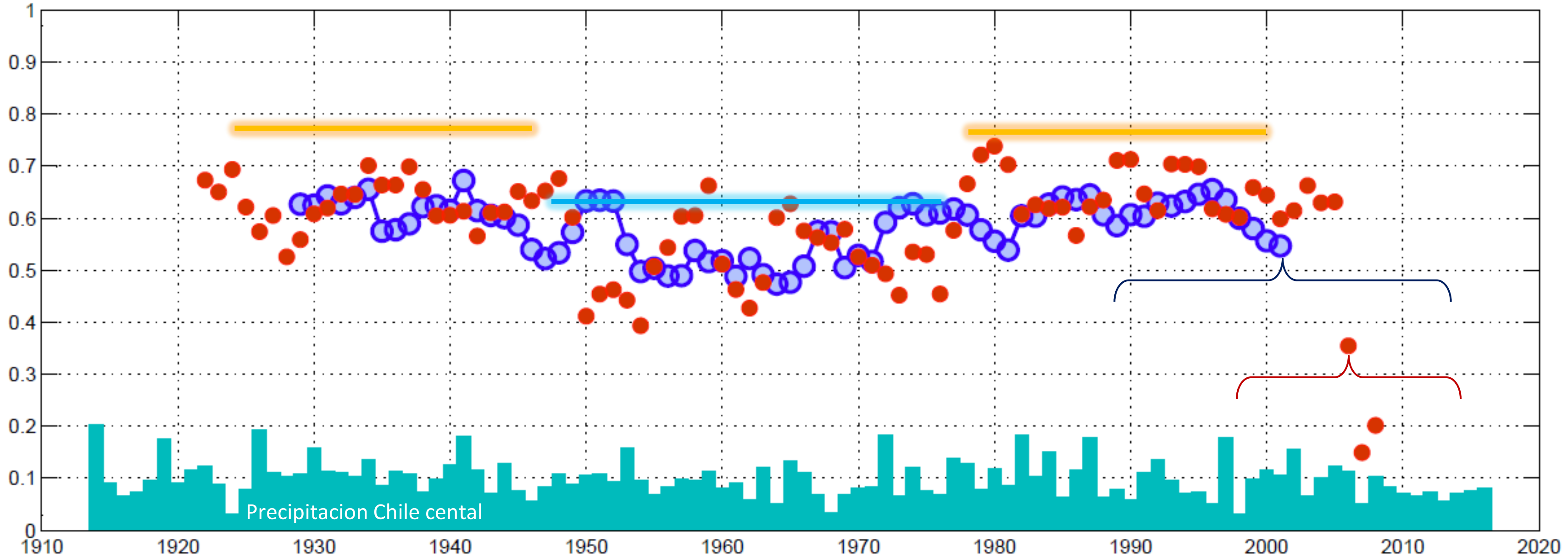
PDO and central Chile precipitation

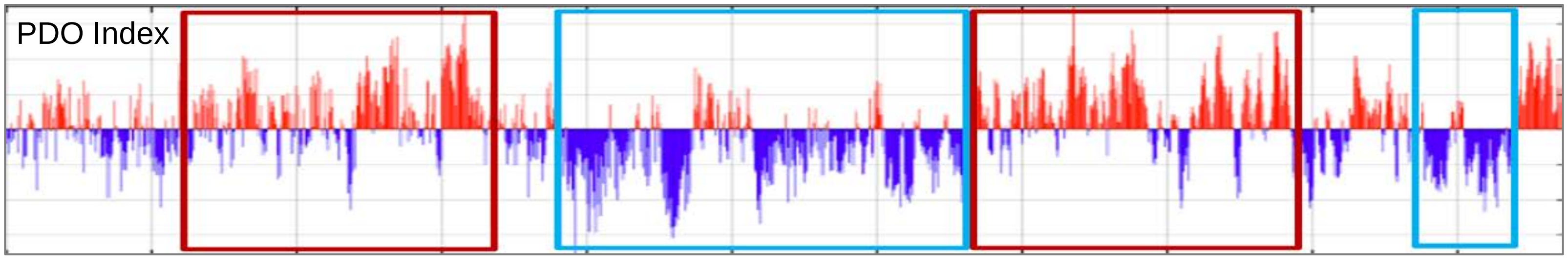


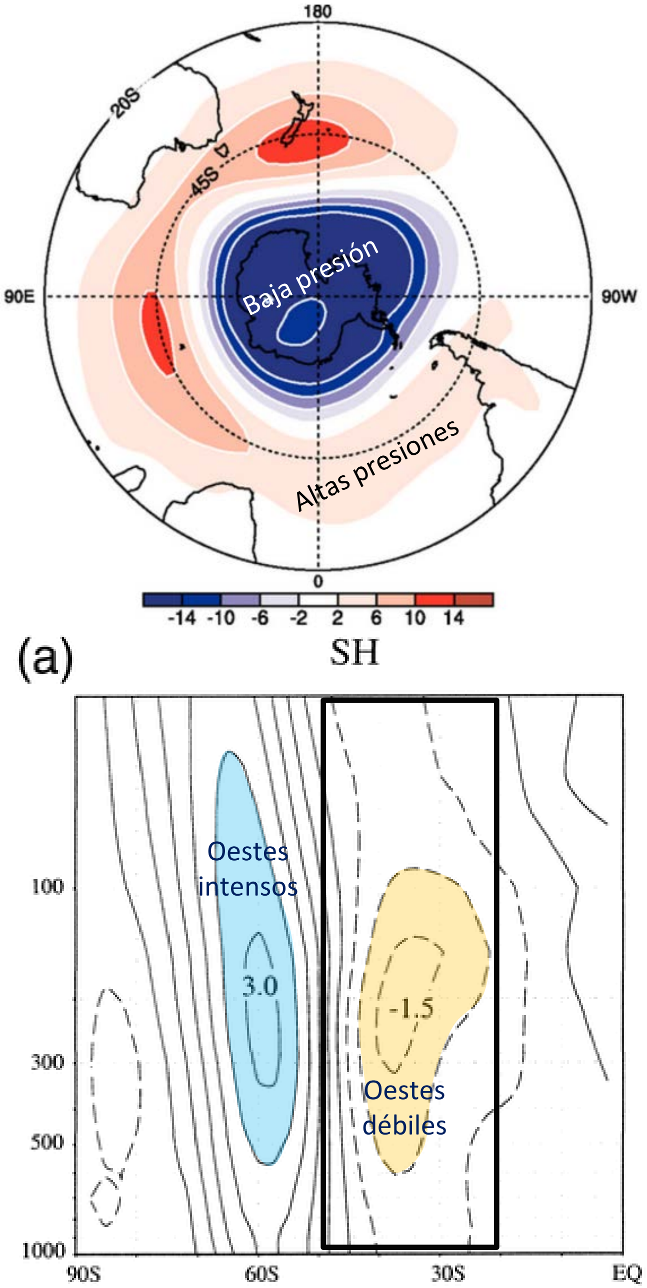
r(PP-Chile Central, Nino3.4-MJJAS)

Ventanas de ±15 años centradas en año *j*

Ventanas de ±8 años centradas en año *j*







Thompson and Wallace 1999

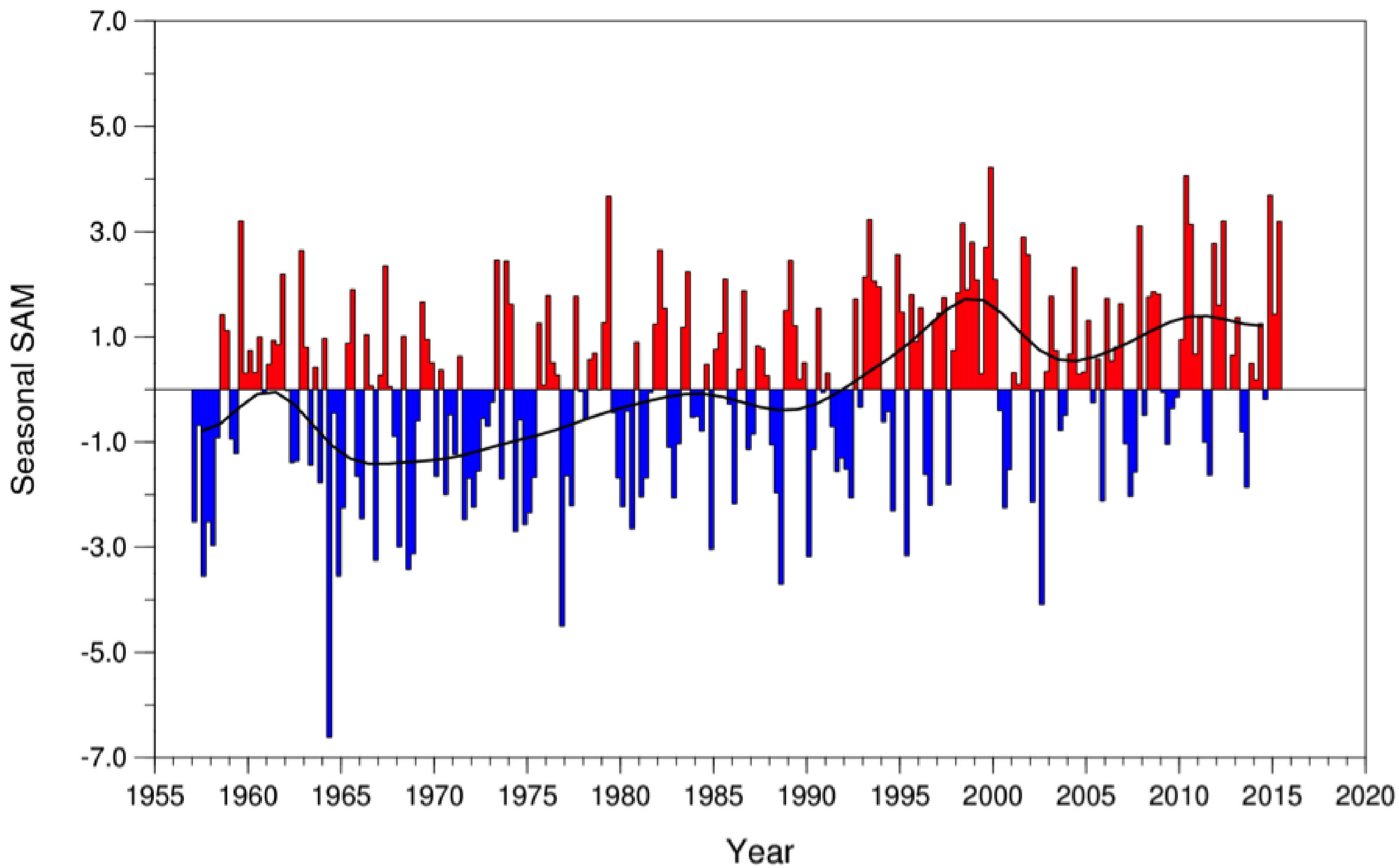
The **Southern Hemisphere Annular mode** (SAM), or **Antarctic Oscillation**, is the leading mode of monthly and longer variability of the tropospheric circulation poleward of 20ºS.

SAM is tropospheric deep, highly symmetric mode, involving mass exchange between high and mid latitudes. What causes SAM is not well known, likely eddy – mean flow interaction

The SAM has shown a trend toward decreases pressure over Antarctica (positive polarity; faster polar vortex), partially attributed to decrease in stratospheric O3.

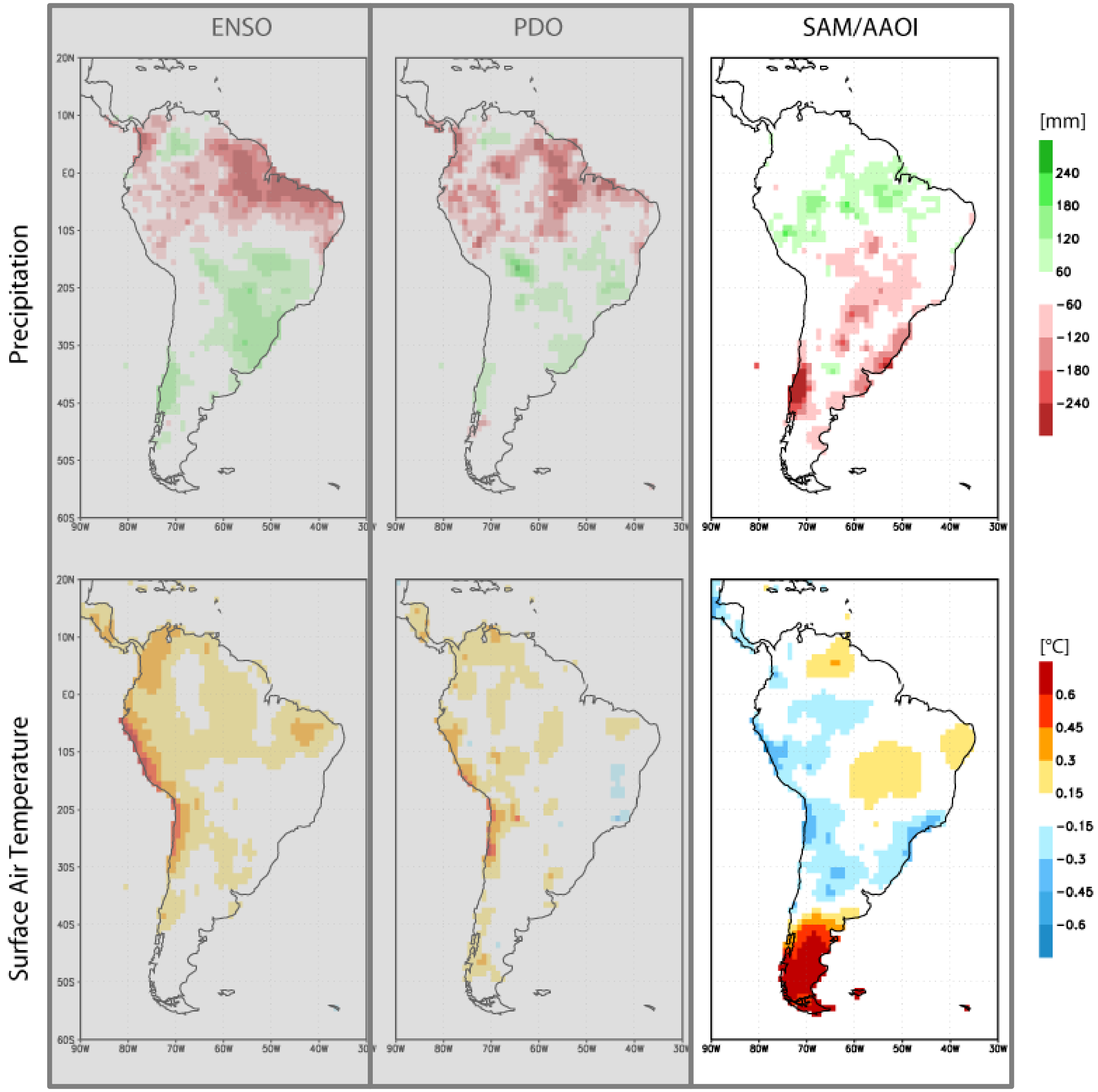
← AAOI regressed upon SLP (upper panel) and zonal average of zonal wind (lower panel)

SAMi: Diferencia de presion 60°S-40°S
SAMi mensual: Alta variabilidad + tendencia



https://climatedataguide.ucar.edu/climate-data/marshall-southern-annular-mode-sam-index-station-based

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

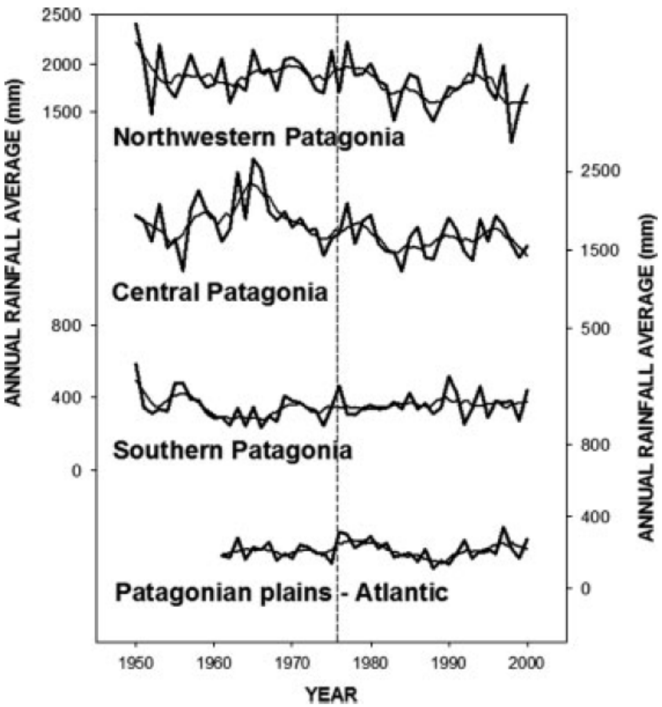


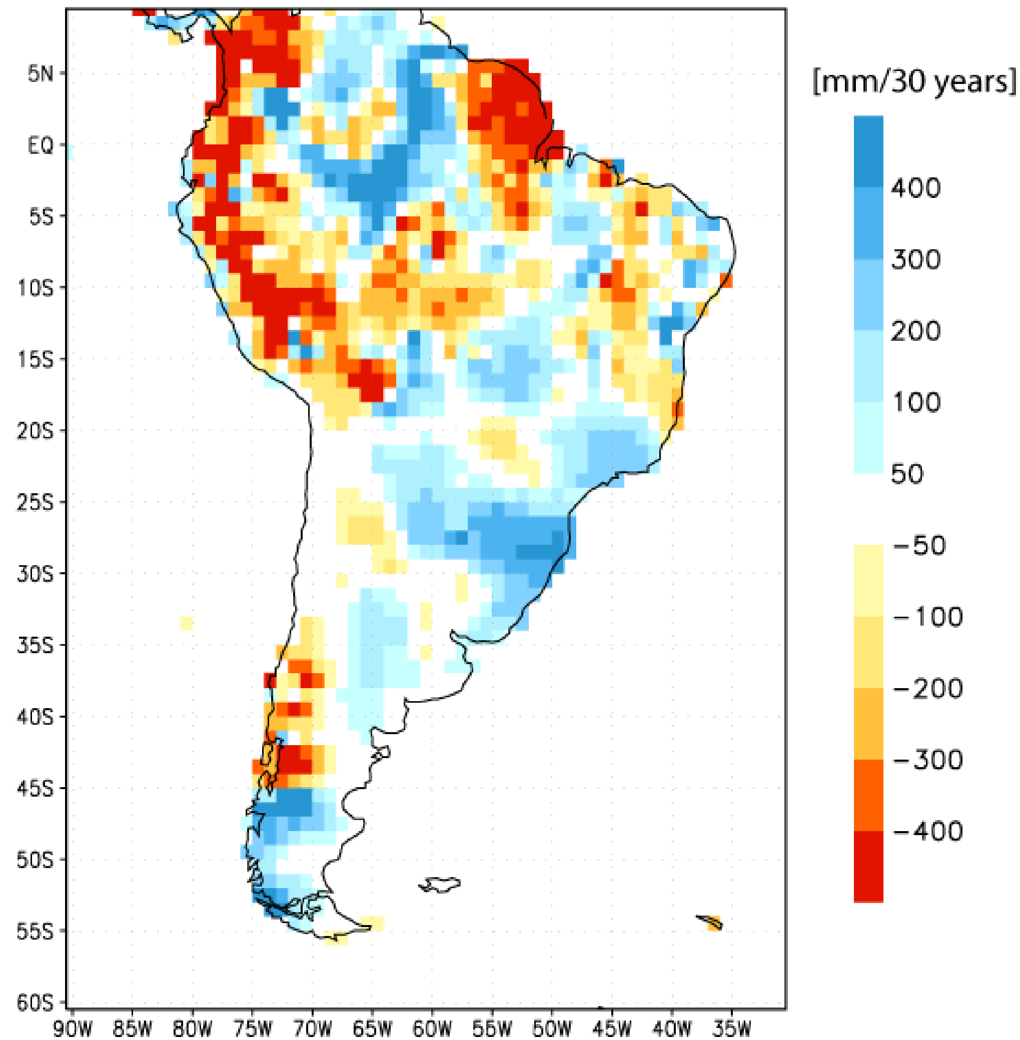
Climate Change

The recent past and the near future

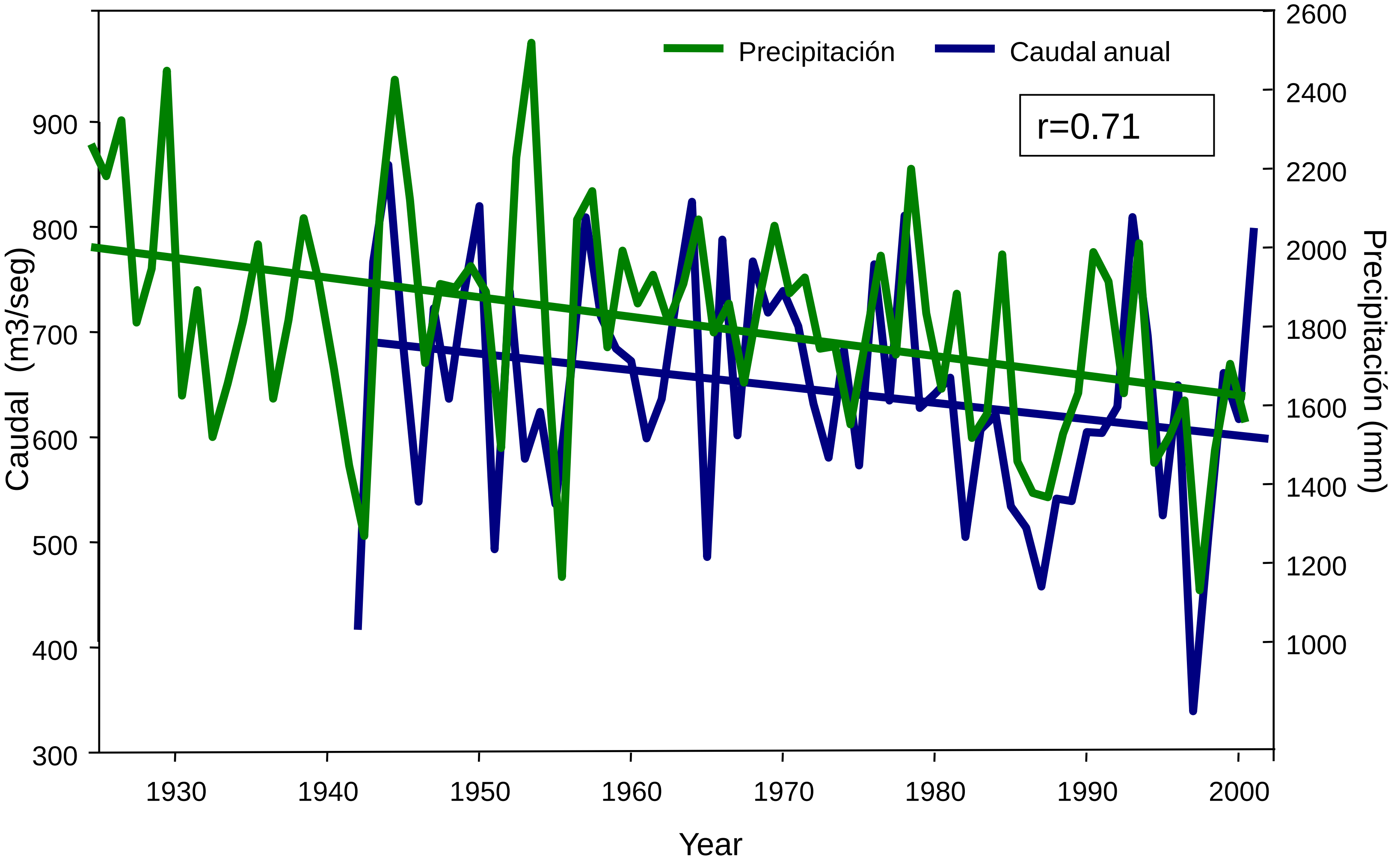
Observed (U.Delaware) Precip trend (1960-2000)

Aravena & Luckman 2010

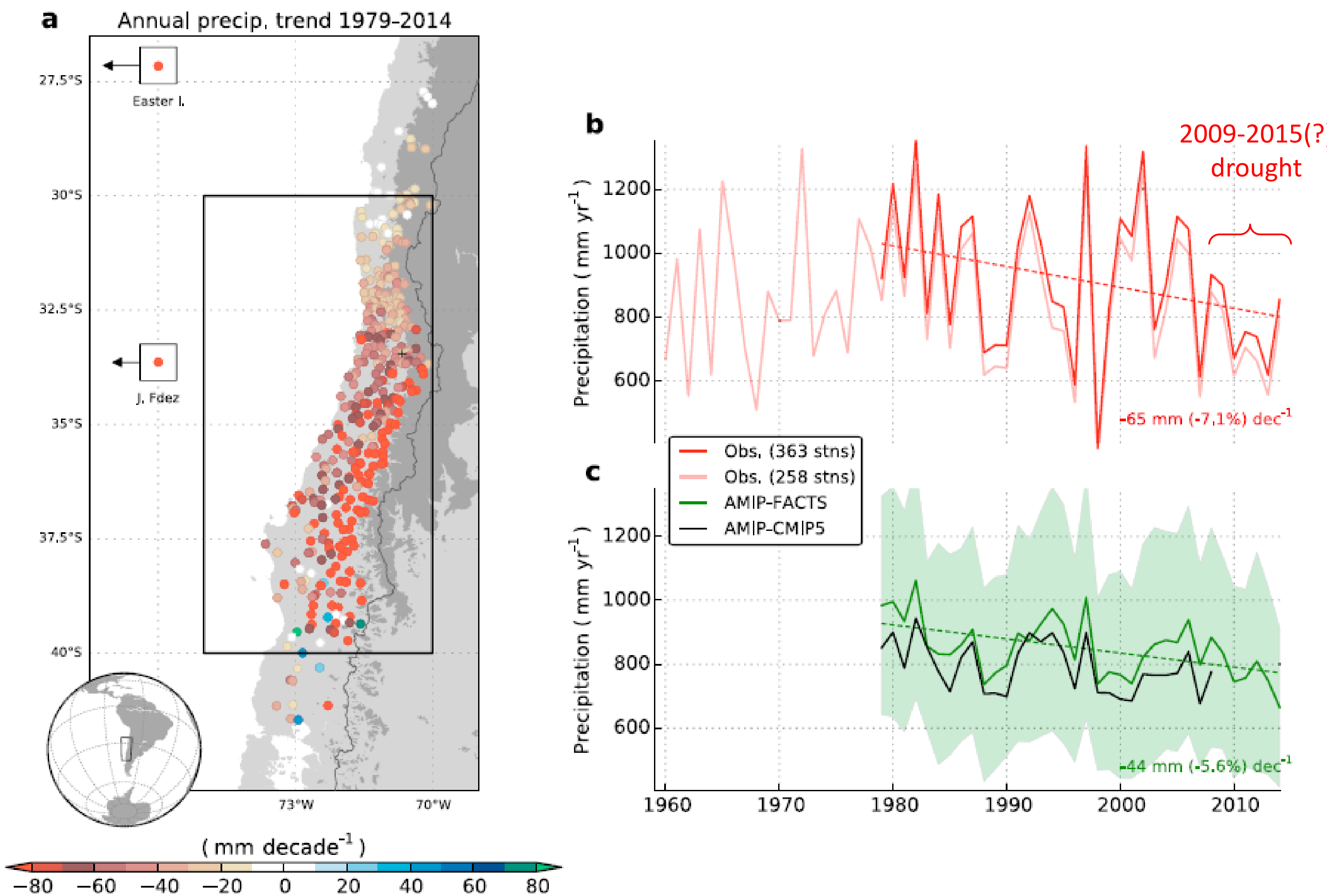




Comparación entre la precipitación de Pto. Montt y el caudal del Río Puelo (Fuente: Antonio Lara, UACH)



Contemporaneous rainfall trends in central Chile (Updated)



Boisier et al. 2016

Tendencias observadas de precipitación: ¿?

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*

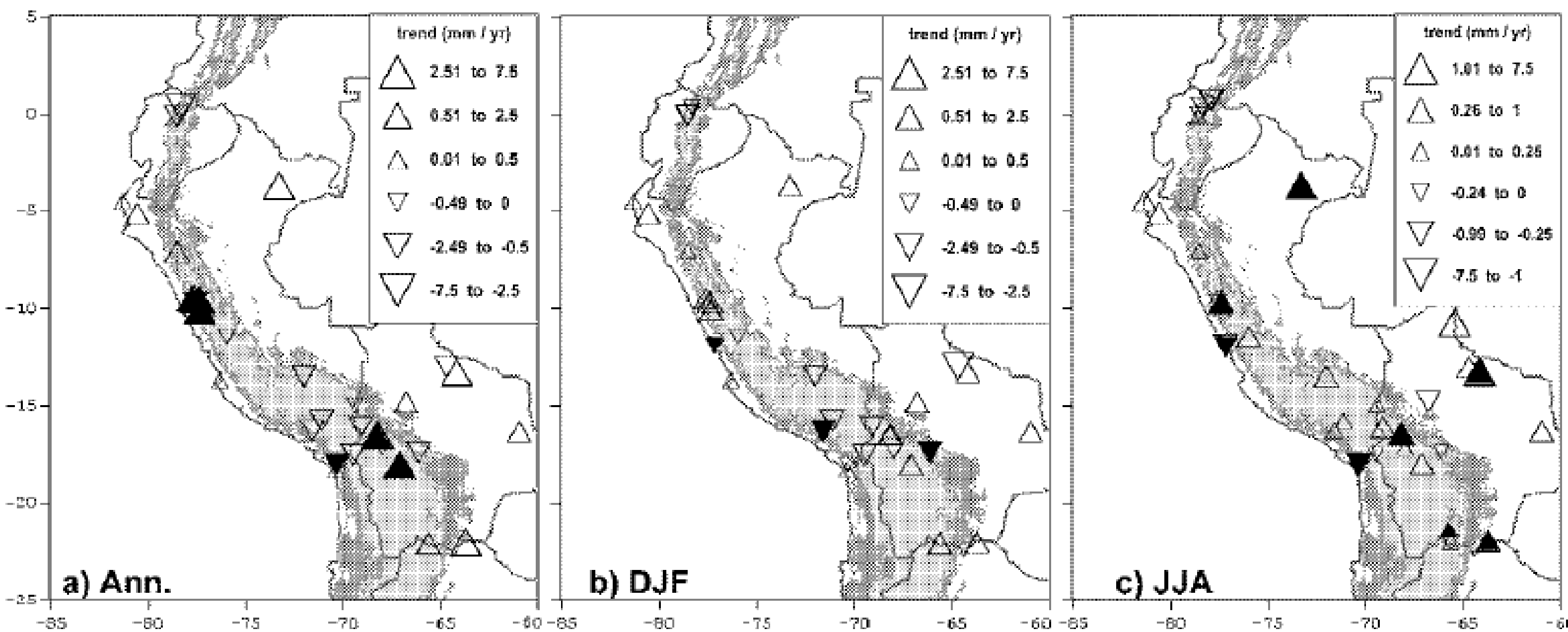


Figure 3. Trends in station precipitation (mm yr^{-1}) between 1950 and 1994 for (a) annual sum, (b) DJF, (c) JJA. Upward (downward) pointing triangles indicate an increase (decrease) in precipitation. Note different scaling in (c). Filled (open) triangles indicate that the trend is (not) significant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

Expansión de la Celda de Hadley

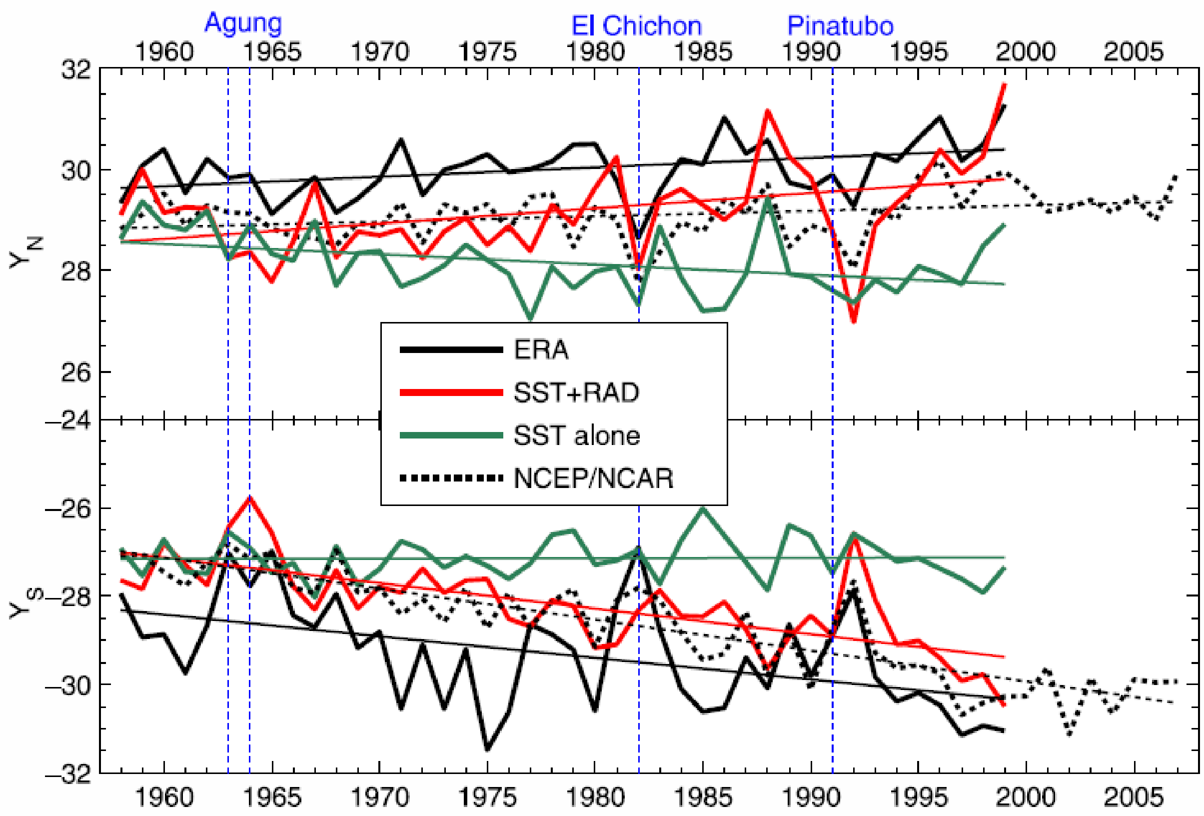
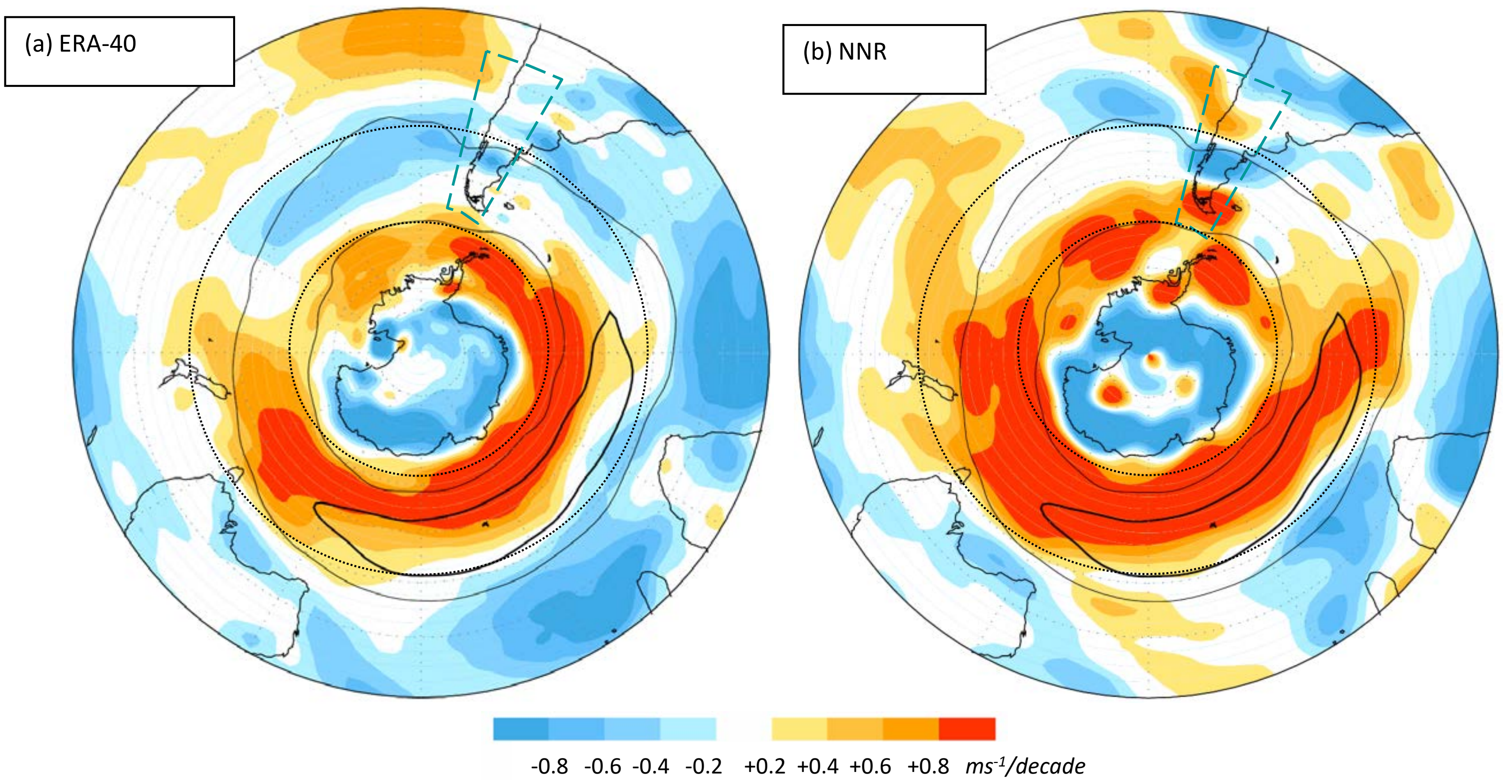


Figure 2. Annual time series of the location of the tropical edges, defined as the latitudes where days with tropopause pressures <120 hPa (heights > 15 km) exceed 200 days per year. Estimates are from ERA40 (black) and NCEP/NCAR (dashed black) reanalysis data, and from the *SST* (green) and *SST+RAD* (red) simulations. The years of major volcanic eruptions are also indicated.

Lu et al, 2009. GRL

Downscale the U-P, U-SAT relationships



Linear trends in the annual mean zonal wind at the 850 hPa level using the (a) ERA-40 and (b) NCEP-NCAR reanalysis. **Shading indicates the change between 1968 and 2001 of a linear least squares trend fit calculated at each grid-box**

Tendencia hacia polaridad positiva de SAM/AAO

Modelos sugieren un forzamiento radiativo

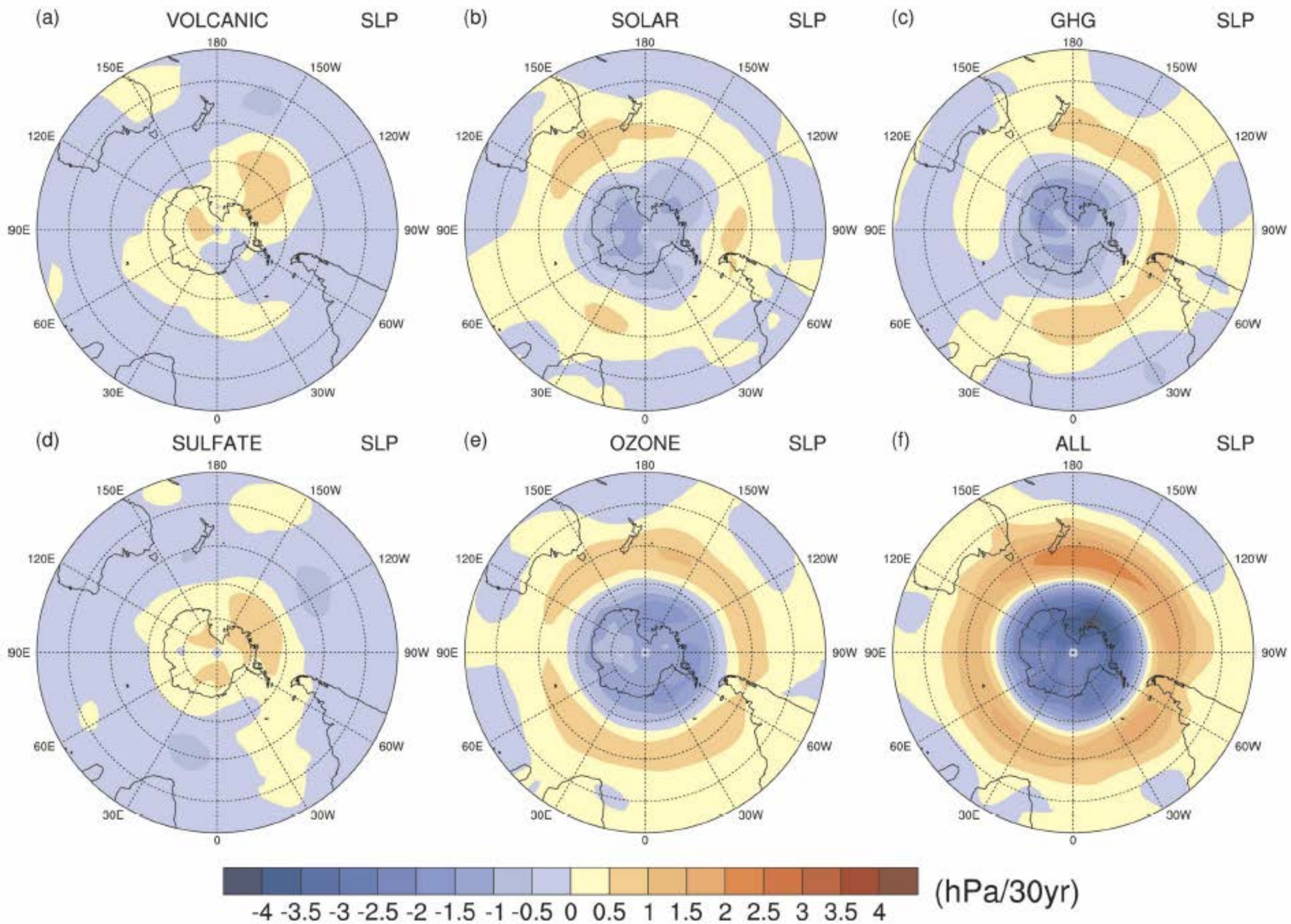
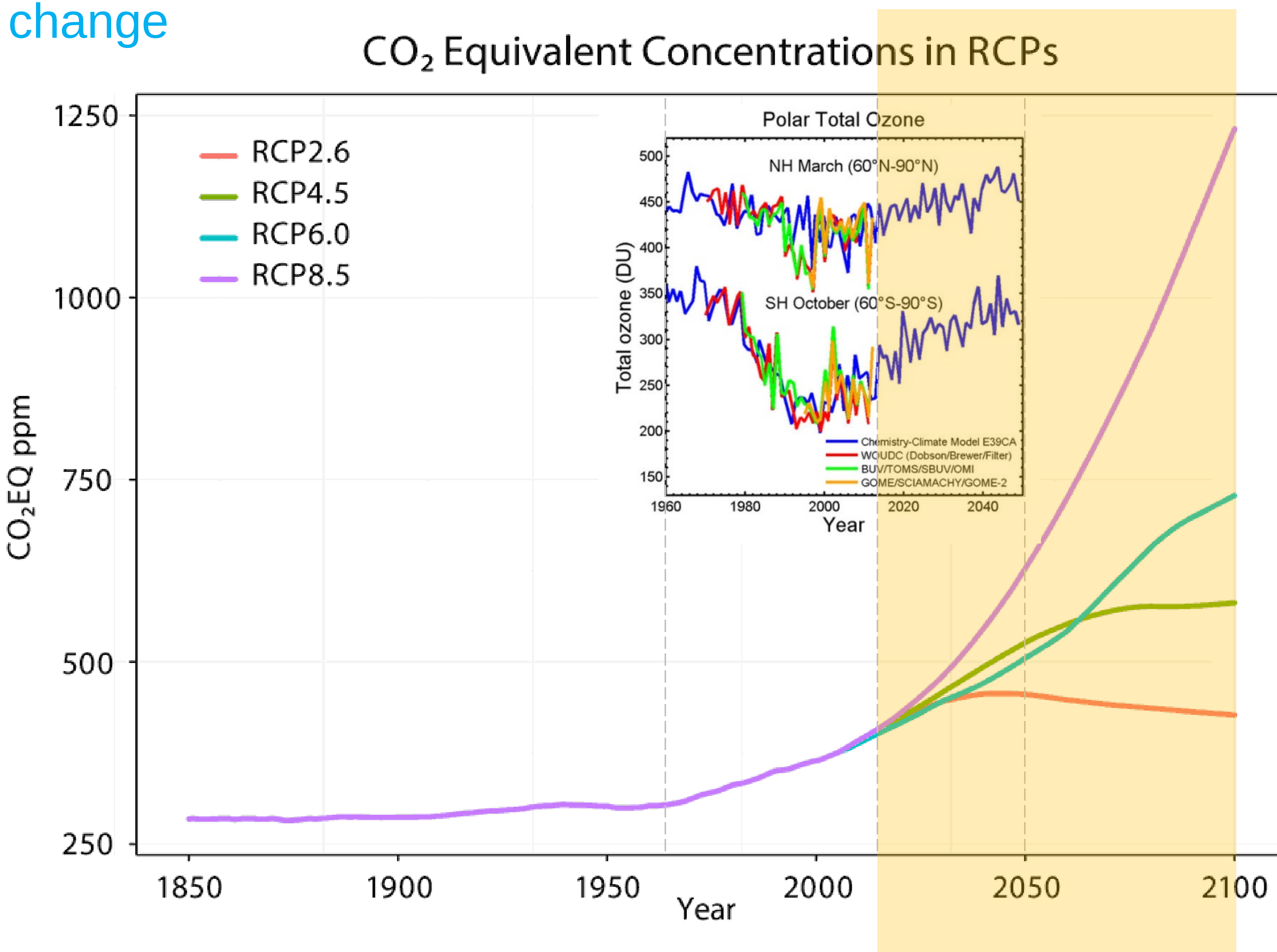


FIG. 1. Ensemble mean DJFMAM sea level pressure trends (hPa 30 yr^{-1}) for the period of 1958–99 of the (a) volcanic, (b) solar, (c) GHGs, (d) sulfate aerosols, (e) ozone, and (f) all-forcings simulations from the PCM.

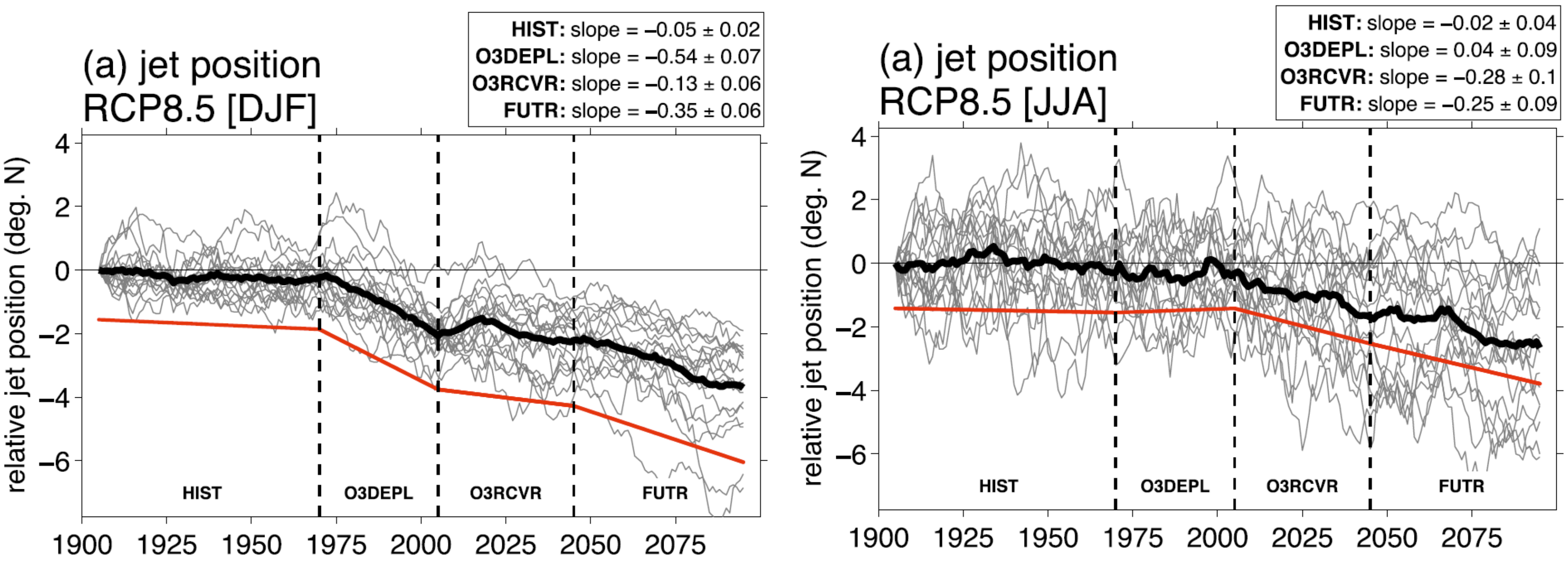
Arblaster and Meehl, 2006. J. of Climate

Greenhouse gases and Ozone: the main drivers of climate change



Projections of Jet Position

Implications for Patagonia hydro climate

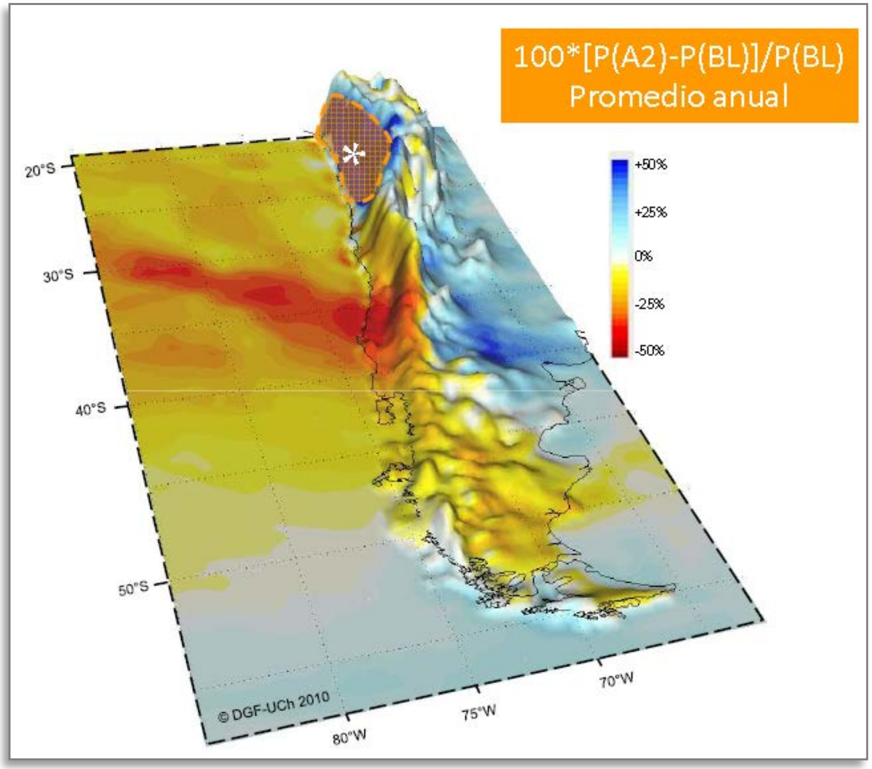


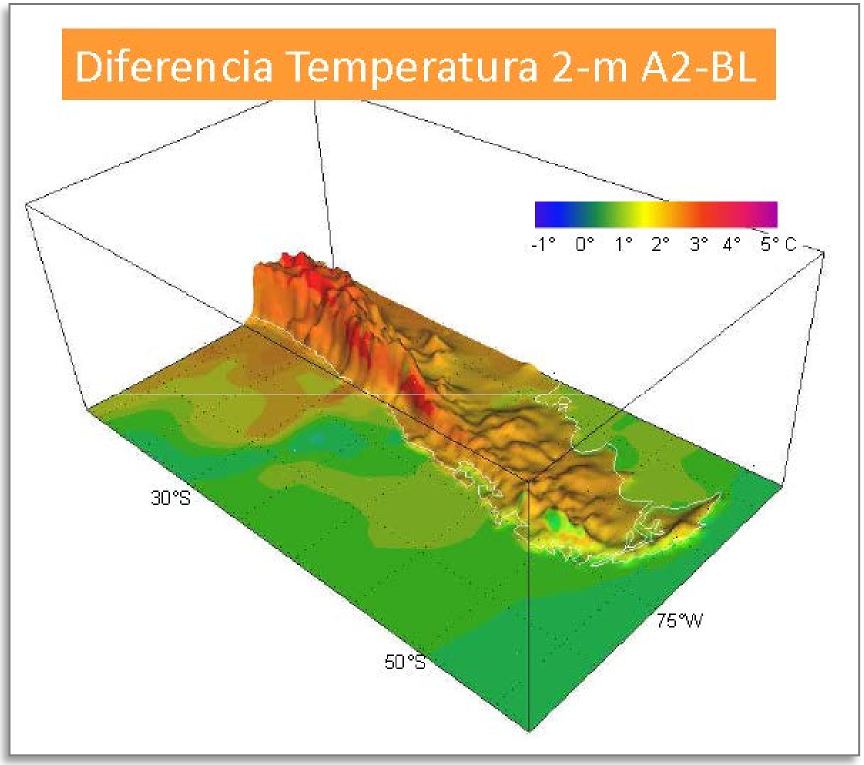
Delayed Southern Hemisphere Climate Change Induced by Stratospheric Ozone Recovery, as Projected by the CMIP5 Models

ELIZABETH A. BARNES

Southern SA Climate Change Projections

Towards the end of century under A2 (RCP8.5)

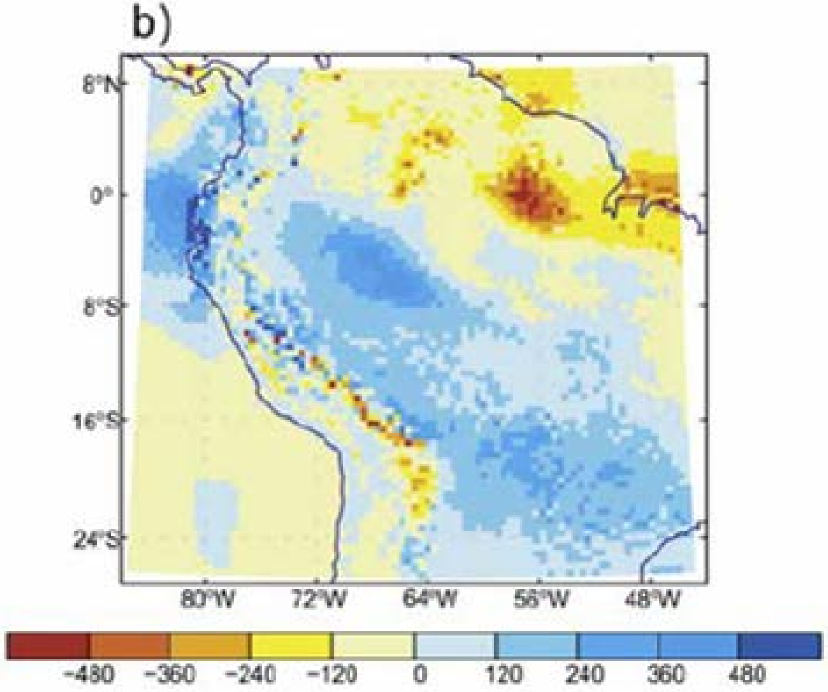




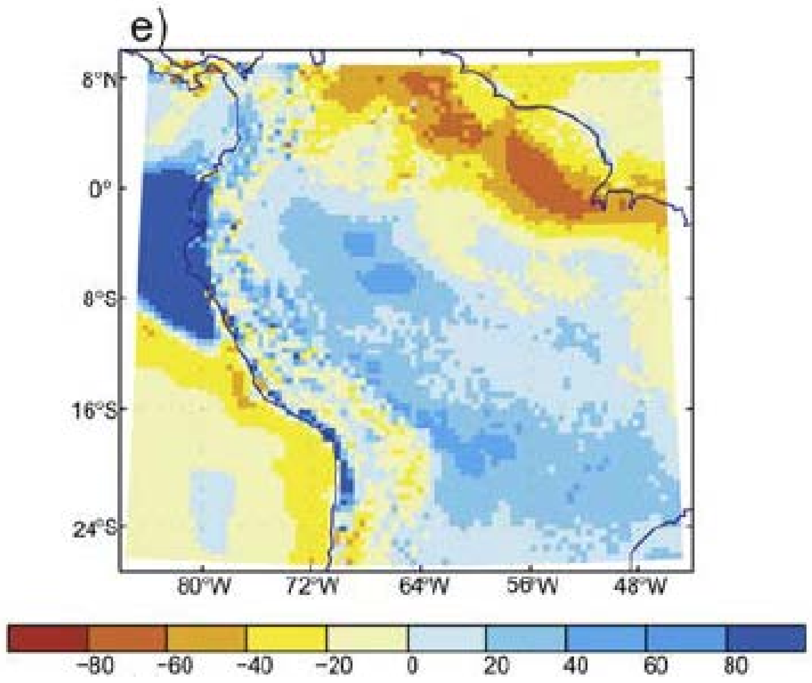
Estudio DGF/UCh-CONAMA 2007 empleando PRECIS

Diferencia Pp A2(2100-2070) – BL(1960-1990)
Obtained with a regional climate model (PRECIS) forced by Echam4 / A2

dP (mm/año)

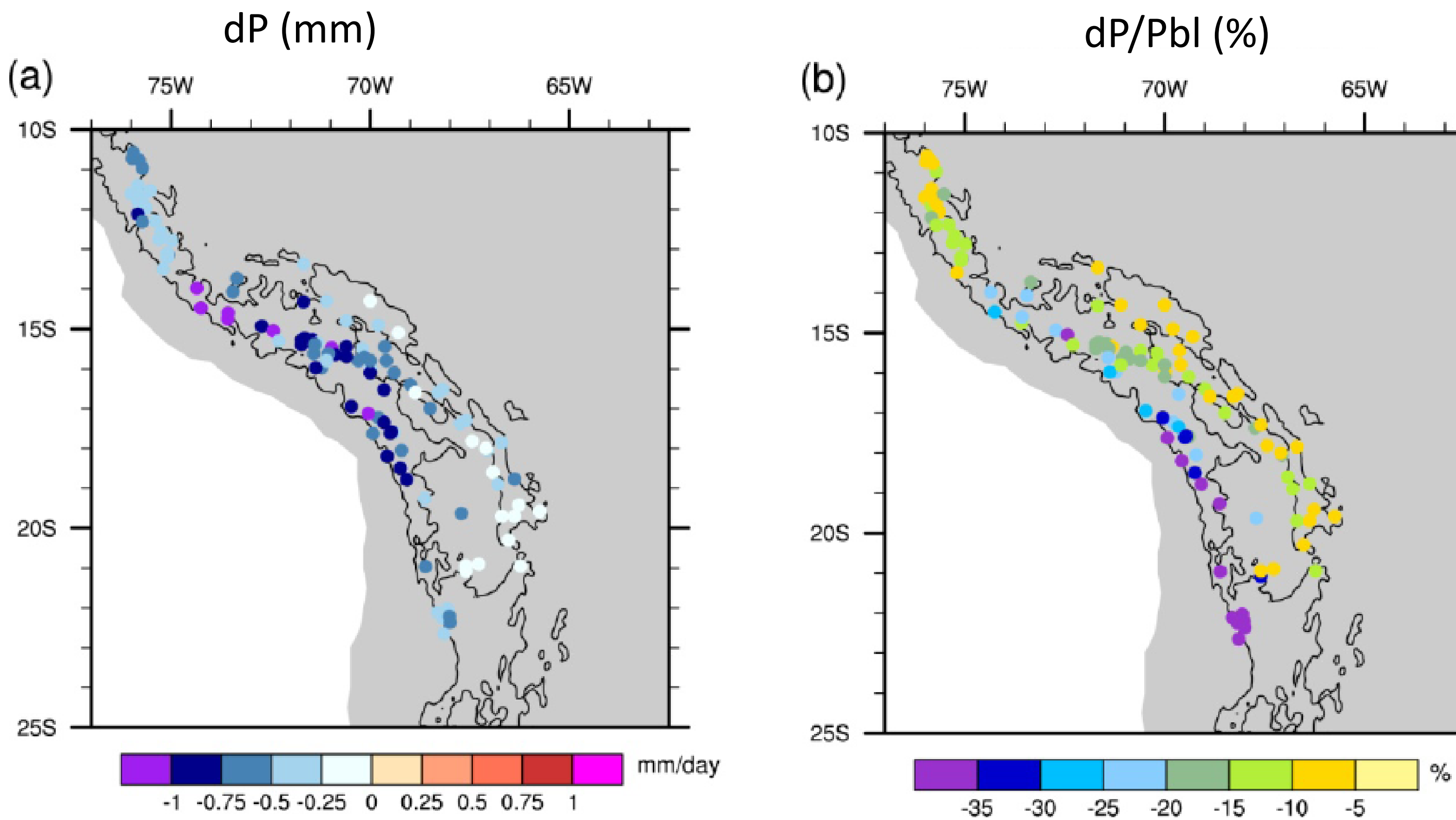


dP/Pbl (%)



Urrutia and Vuille 2009

Cambios de Precipitación esperables por cambio de viento

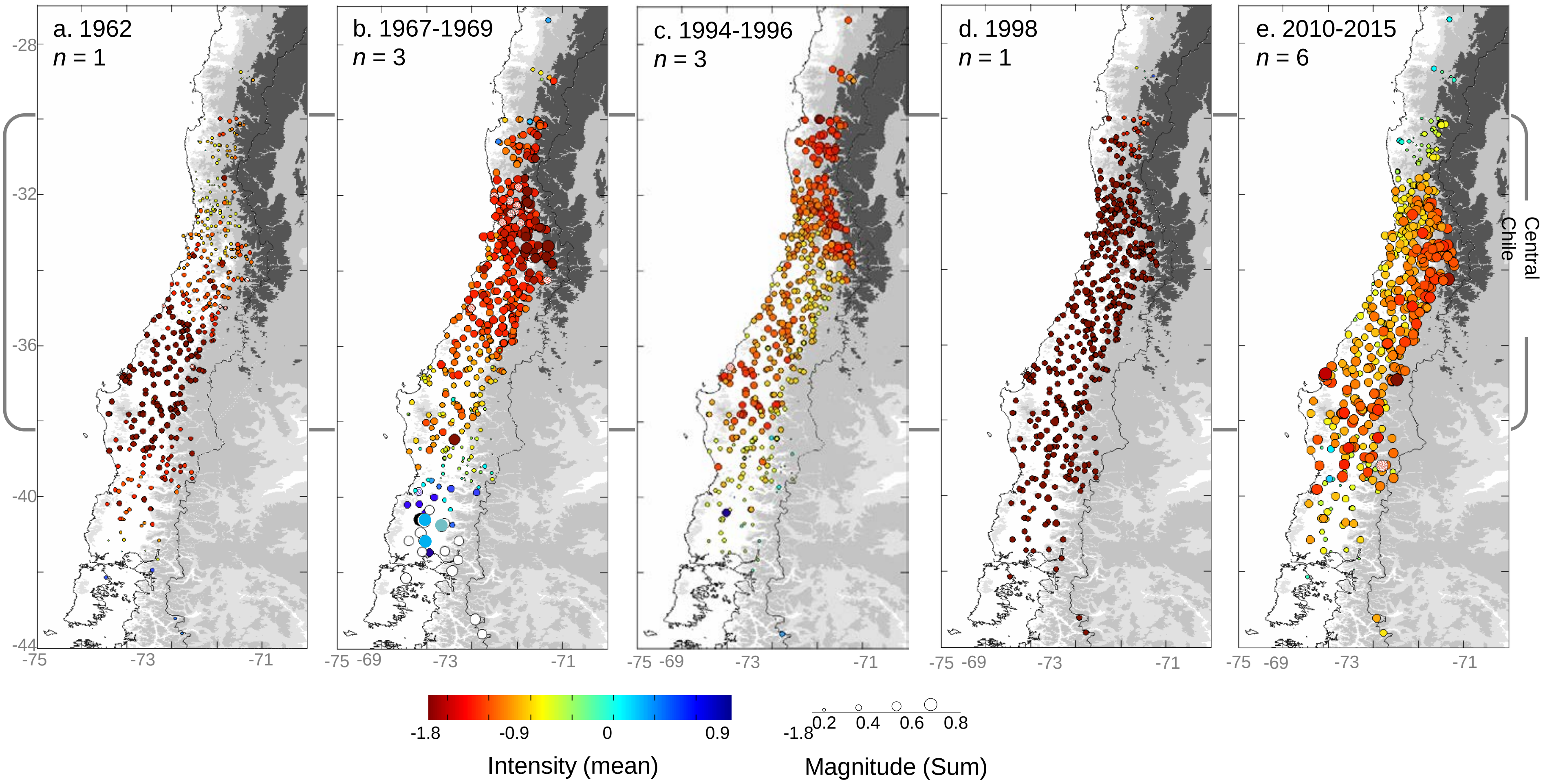


Minvielle and Garreaud 2010

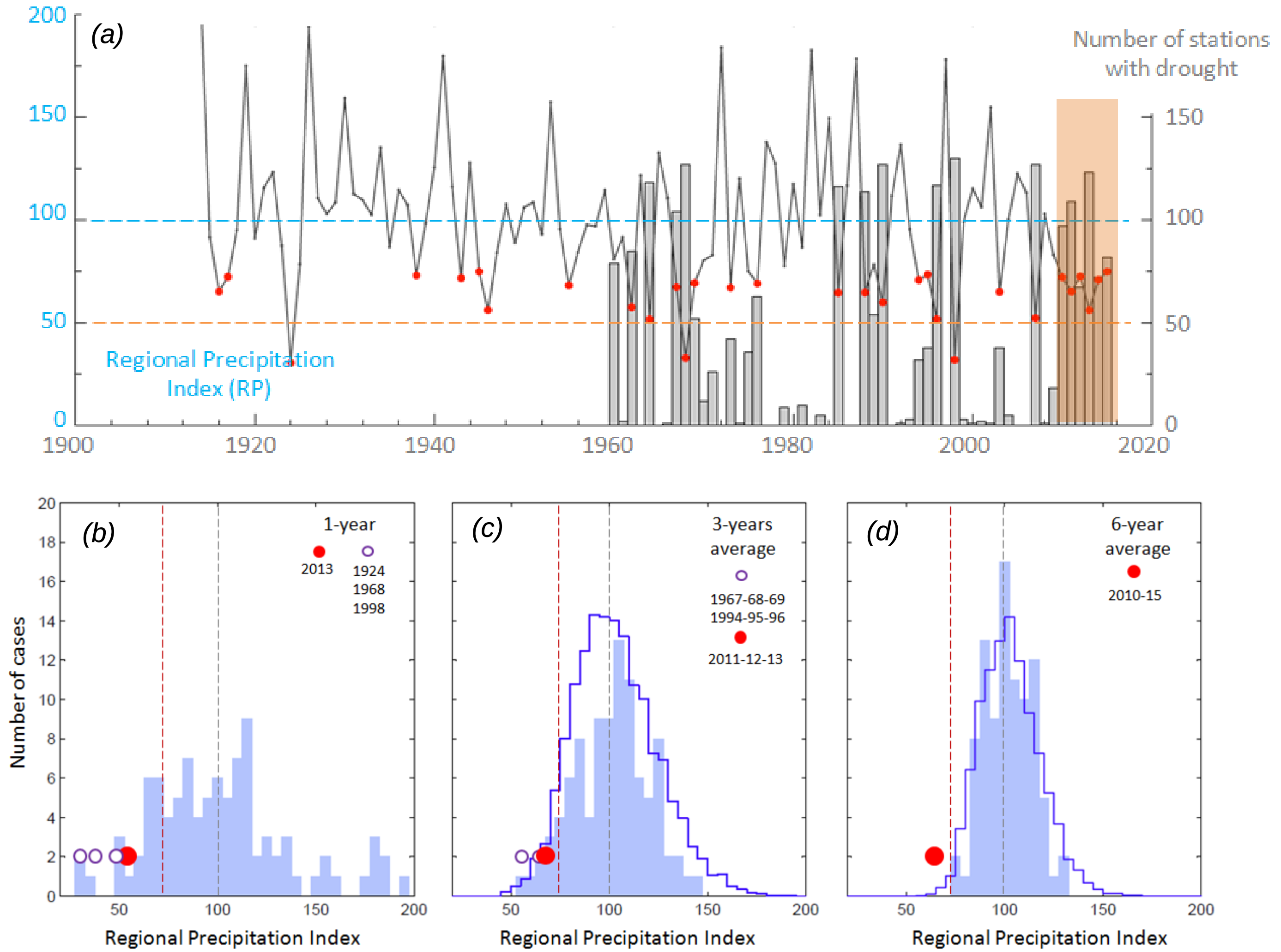
The central Chile Mega Drought…and why we need SADA?

Grandes sequía contemporaneas

Indice Estandarizado de Precipitación (SPI-12, Dic)

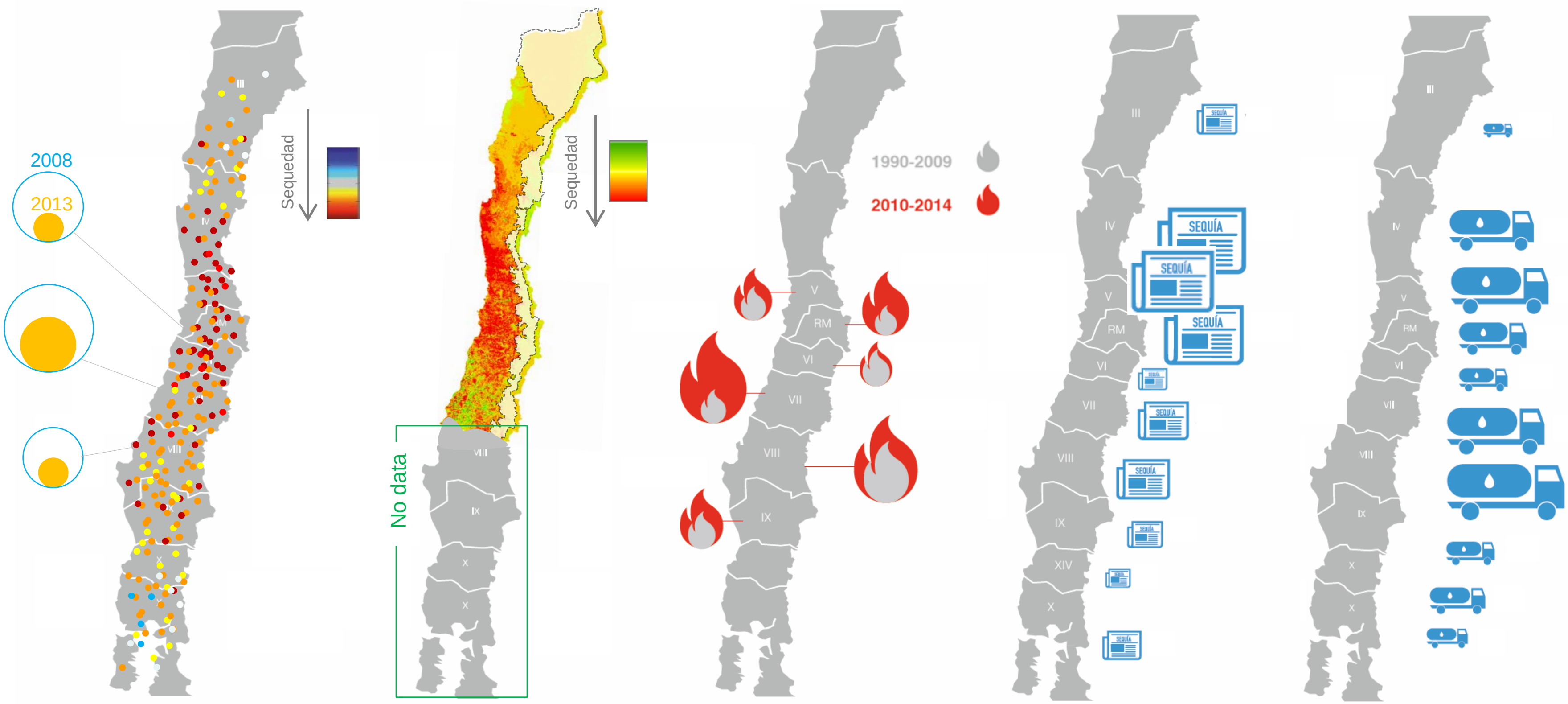


La Megasequía 2010-2015

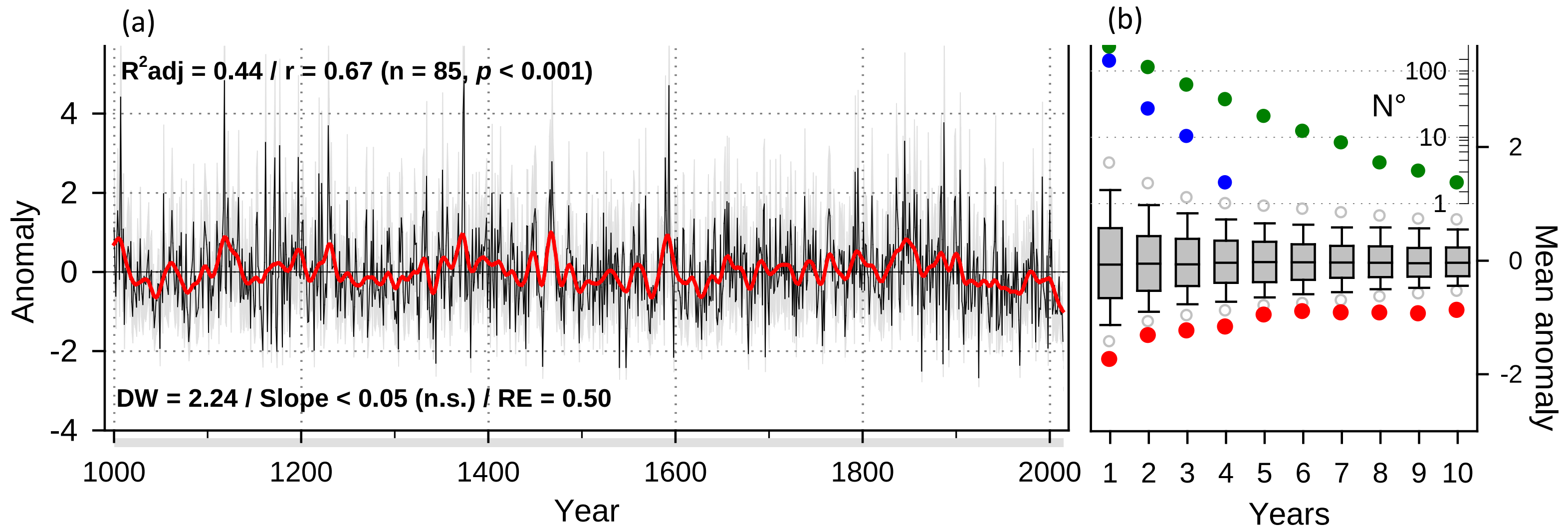


La Megasequía 2010-2015

Transporte de sedimentos en invierno	Déficit Pluviométrico (2010-2014)	Deterioro vegetación Agosto 2010-2015	Incendios forestales de magnitud	Apariciones en prensa escrita (2014)	Gastos en Camiones Aljibes (Mill$)



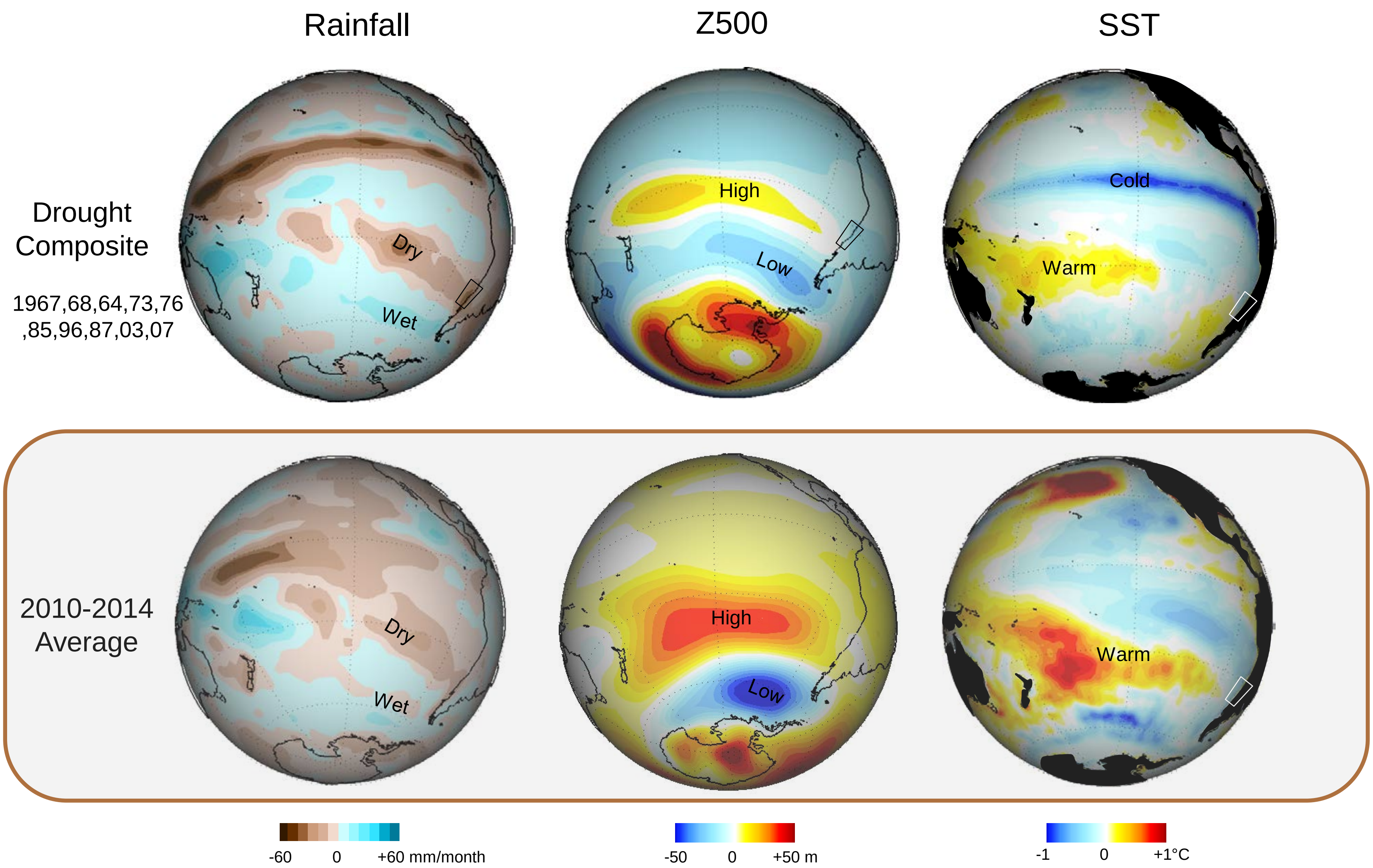
La Megasequía 2010-2015



Reconstrucción de precipitación en Chile central en base a crecimiento de anillos de arbol

Solo 2 o 3 casos como la Mega sequia (>4 años con >30% de deficit) en los últimos 1000 años

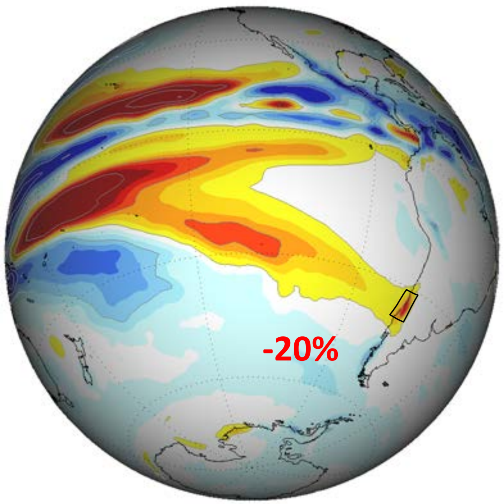
La Megasequía 2010-2015



La Megasequía 2010-2015

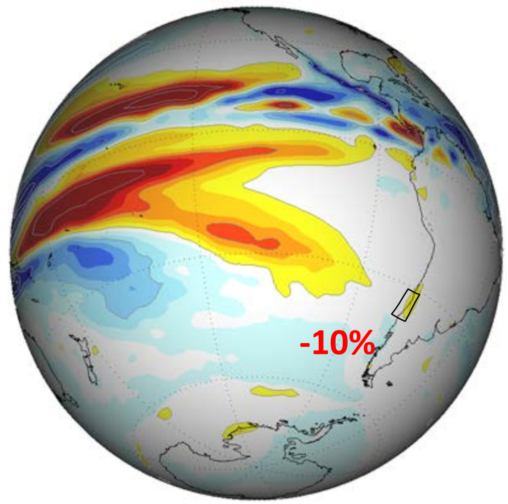
Anomalías de precipitación, MJJAS, 2010-2015
simuladas por diversos modelos. Defict observado ~**30%**

AMIP-ORF



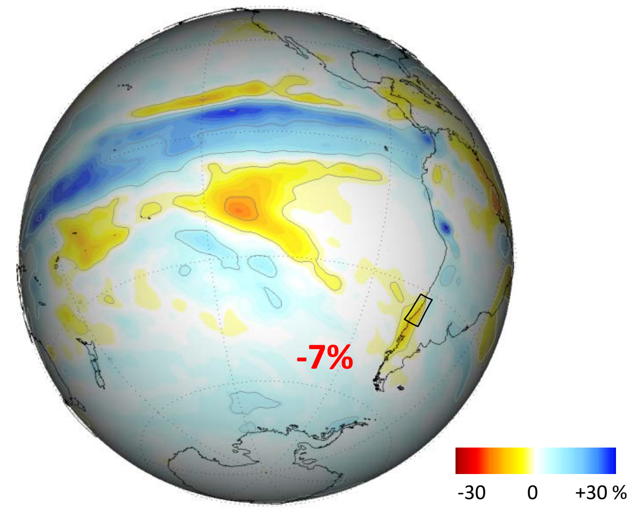
TSM prescrita
GEI actuales
Promedio muchas corridas revela forzamiento del oceano en clima
NAT+**ANTROP**

AMIP-NHF



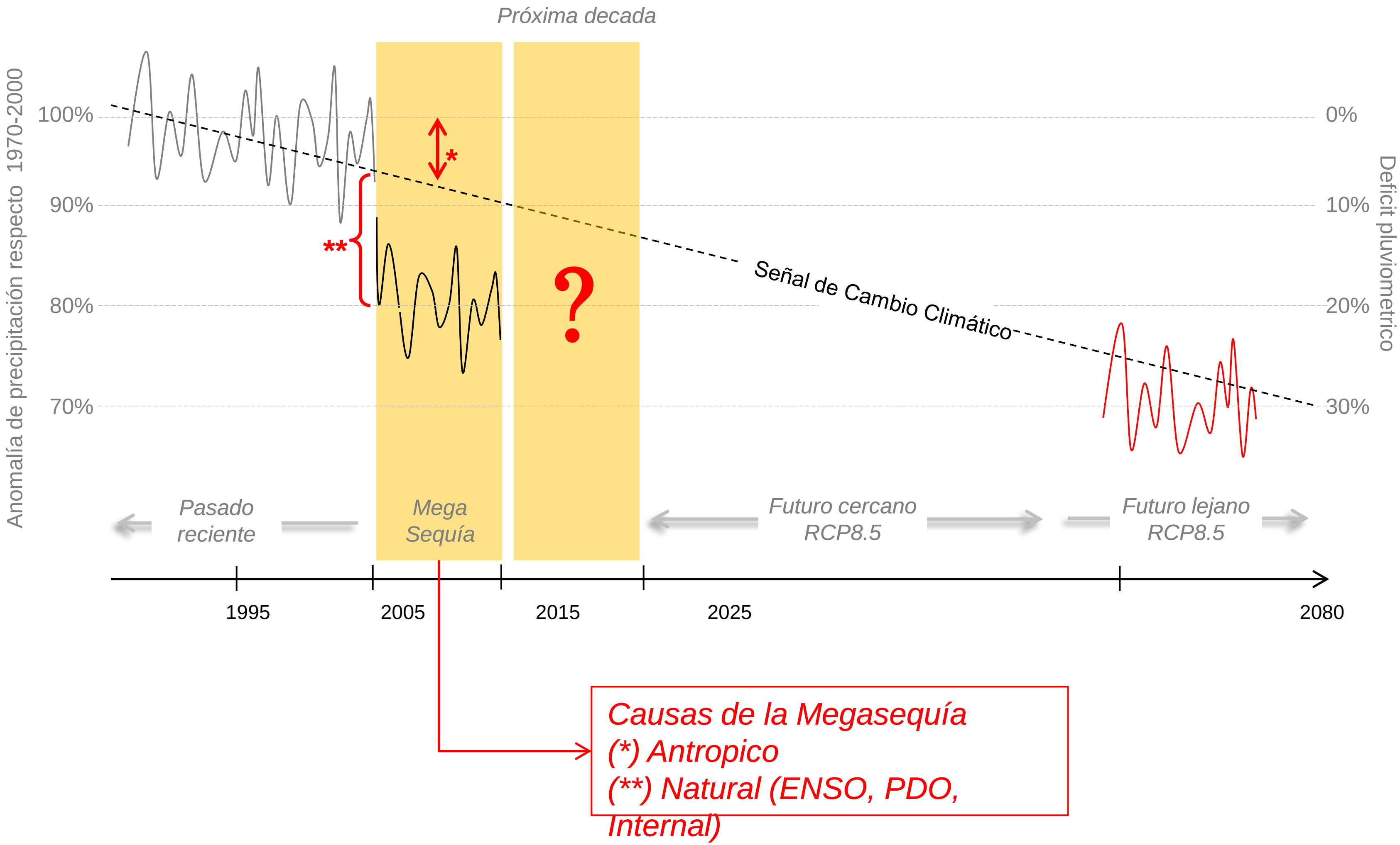
TSM prescrita
GEI historicos (1800)
Promedio muchas corridas del mismo modelo (CAM5.1)
NAT'

CMIP5/RCP8.5

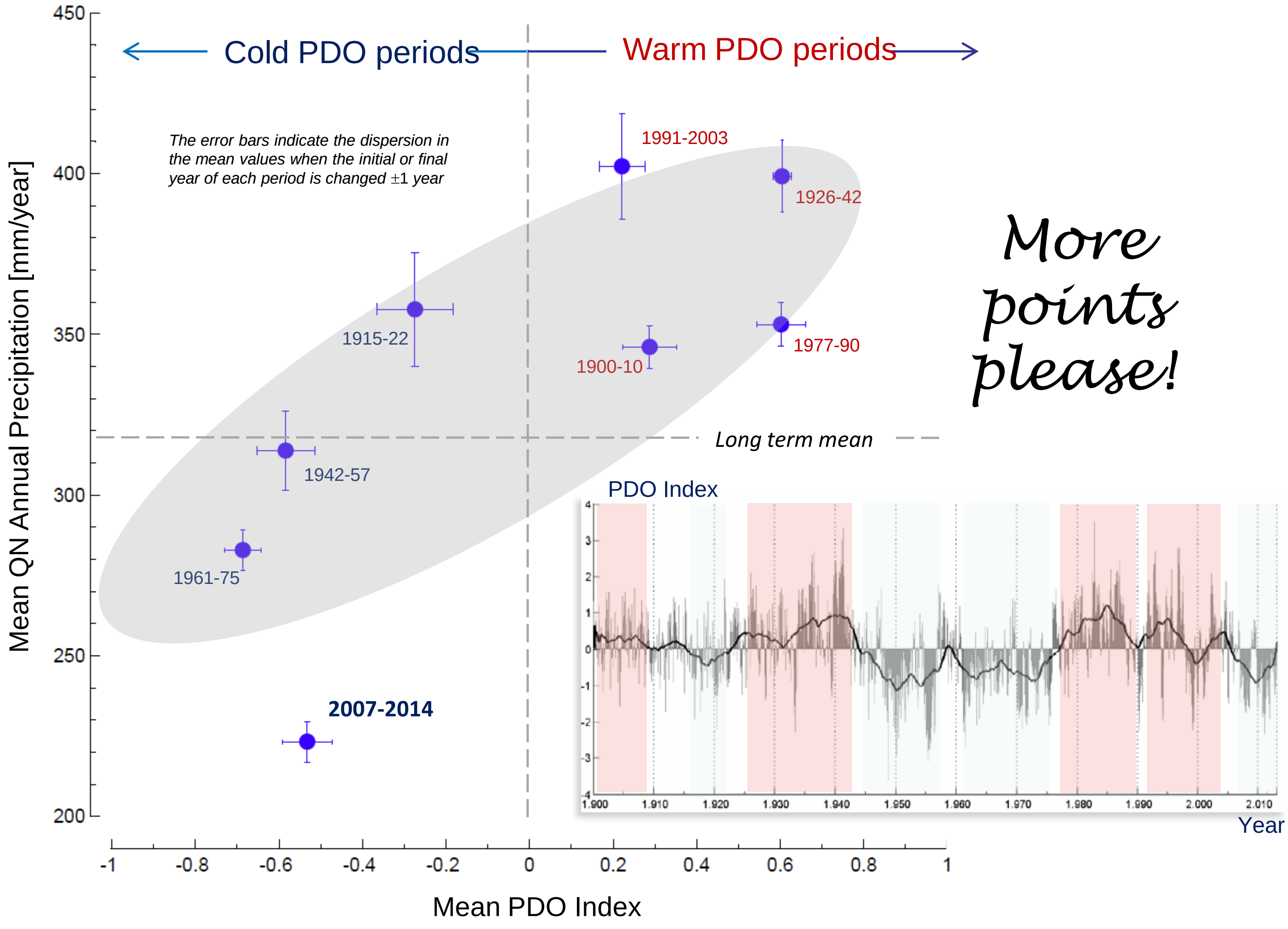


TSM calculada
GEI actuales
Promedio muchos modelos revela forzamiento radiativo
ANTROP

Precipitación en Chile Central
El desafío de la próxima década



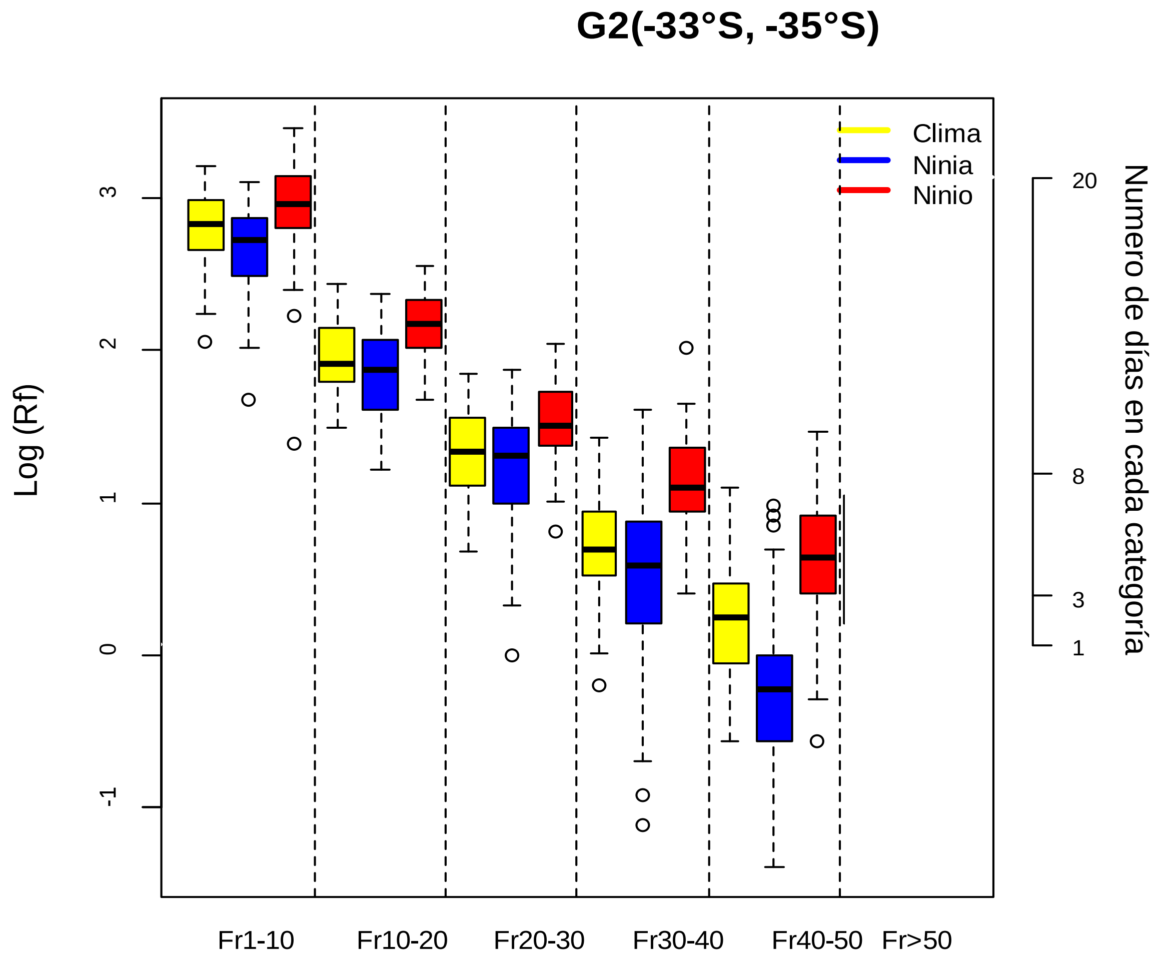
PDO and central Chile precipitation

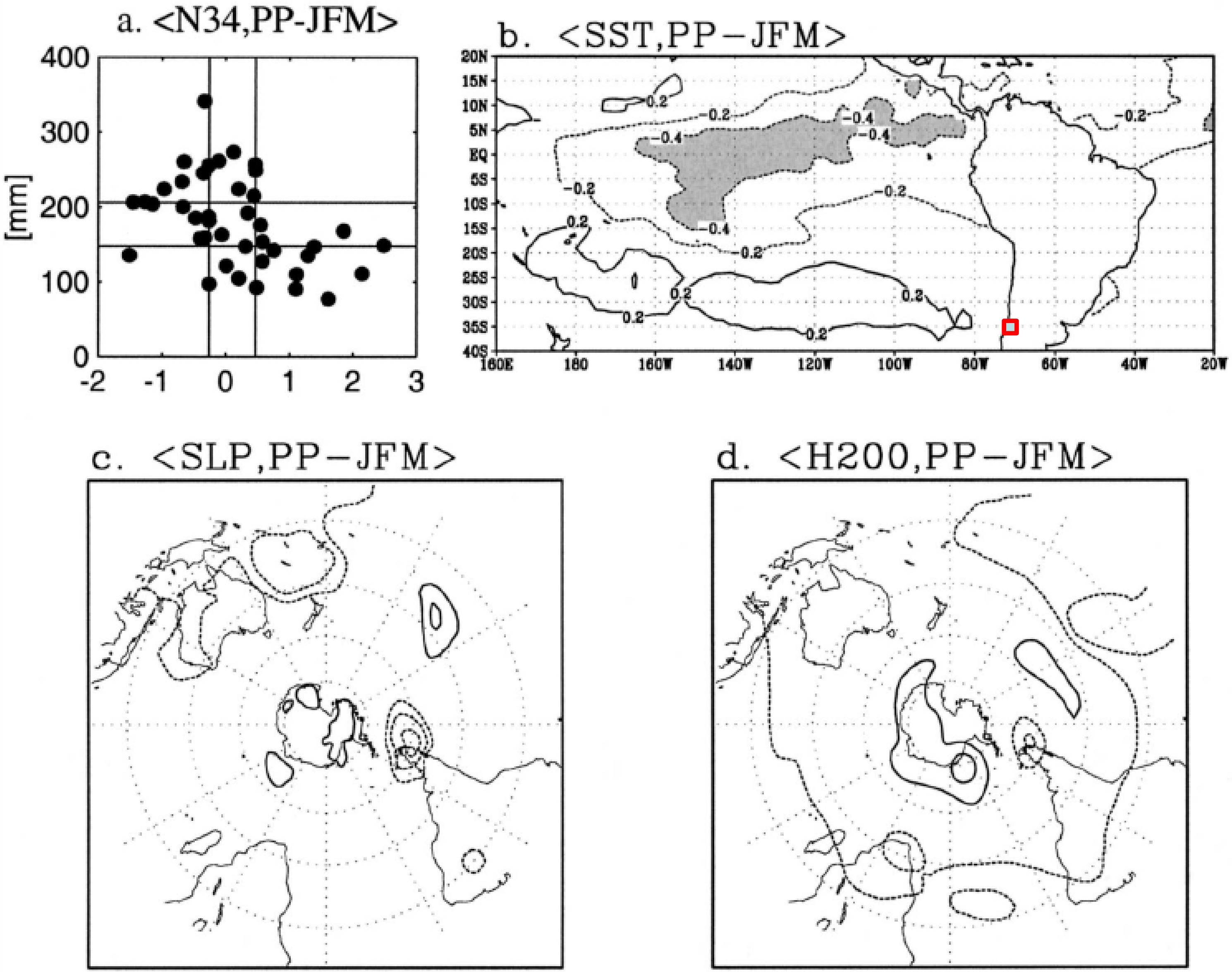


More points please!

Supplementary Material

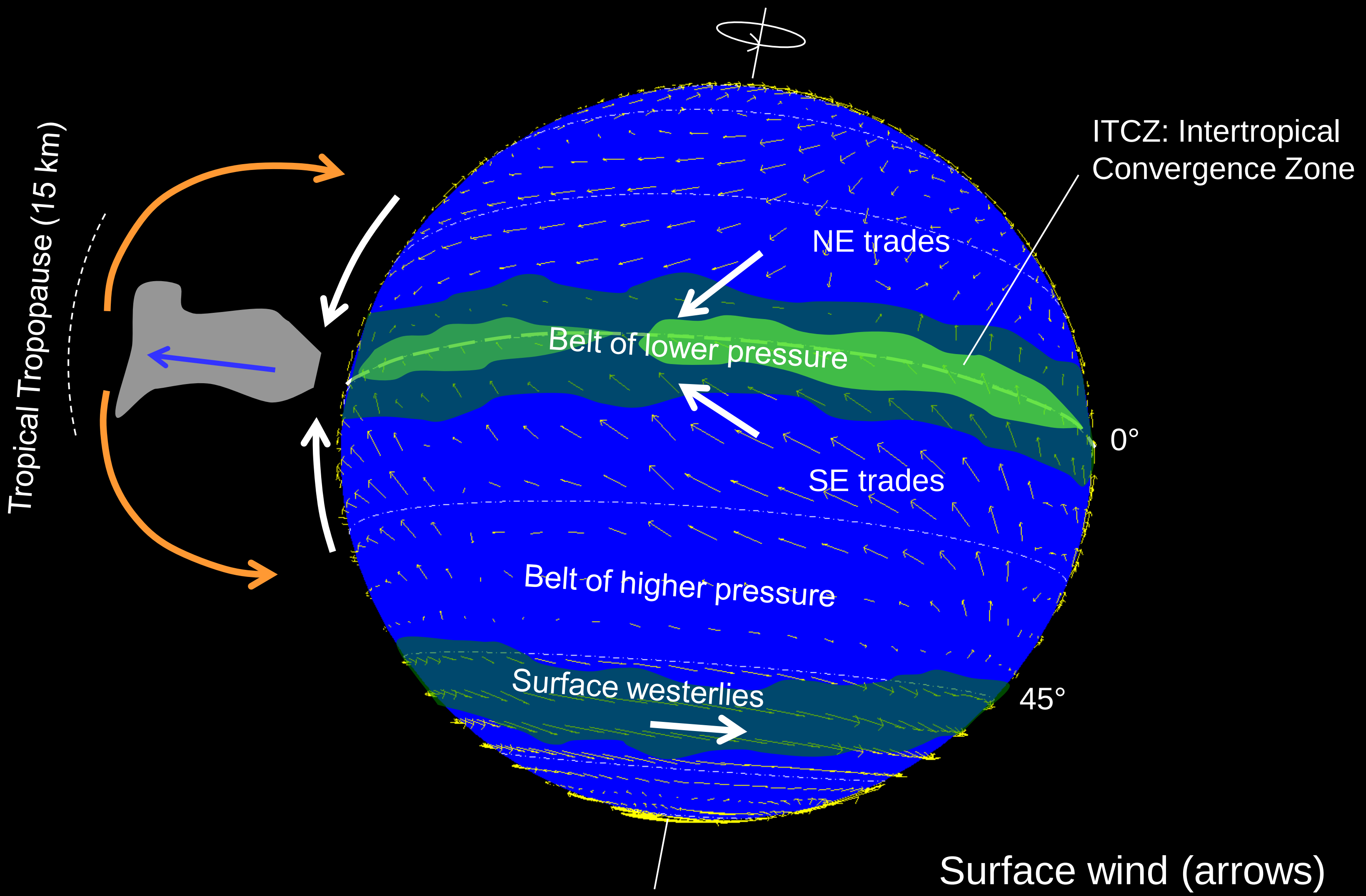
IMPACTO DE ENSO SOBRE LA LLUVIA EN CHILE CENTRAL





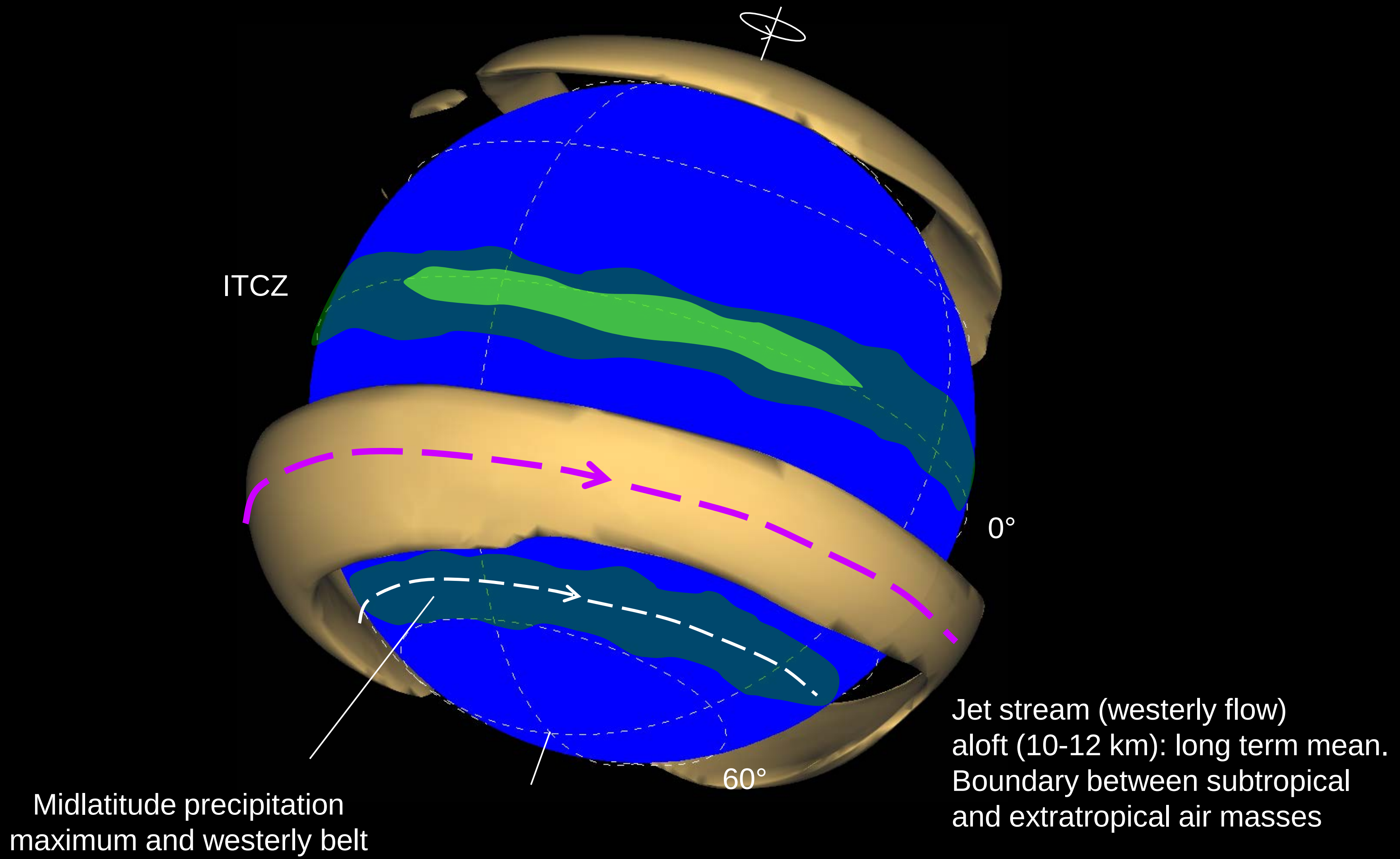
a. <N34,PP-JFM>
[mm]
400
300
200
100
0
-2
-1
0
1
2
3
b. <SST,PP−JFM>
20N
15N
10N
5N
EQ
5S
10S
15S
20S
25S
30S
35S
40S
160E
180
160W
140W
120W
100W
80W
60W
40W
20W
-0.2
-0.4
0.2
c. <SLP,PP−JFM>
d. <H200,PP−JFM>

General circulation in an aqua-planet
Perpetual Equinox

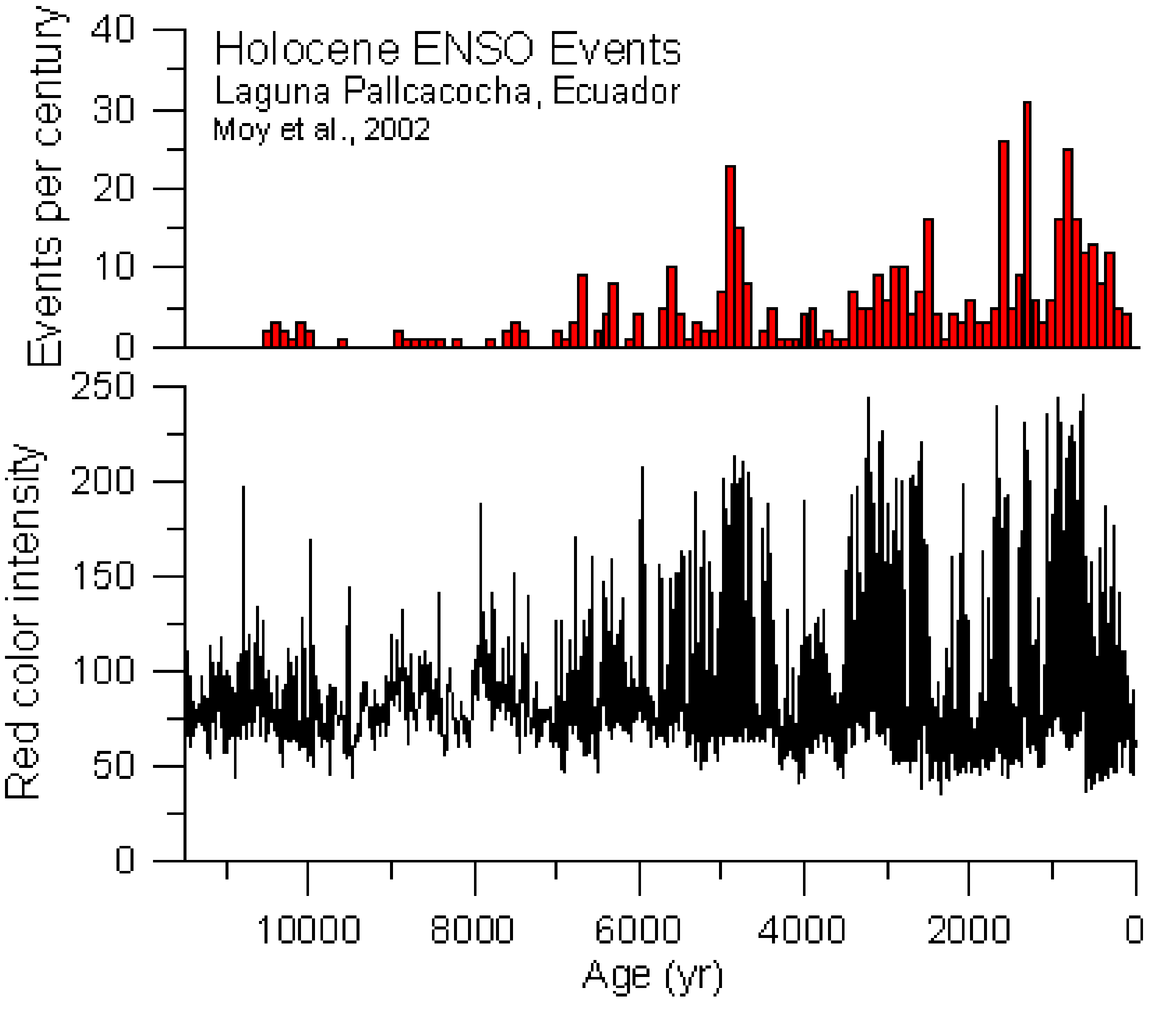


Surface wind (arrows)
Precipitation (green shadow)

General circulation in an aqua-planet
Perpetual Equinox

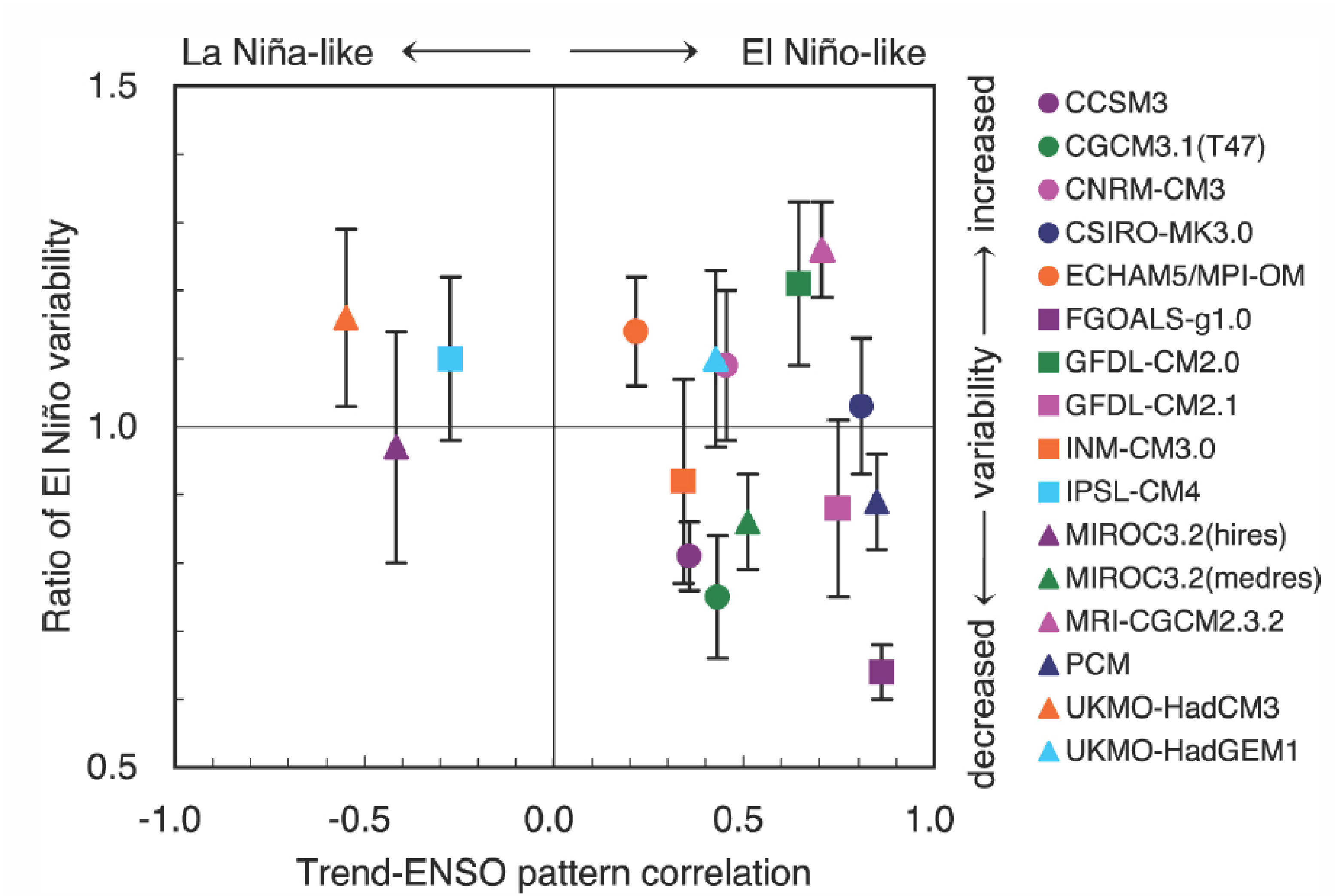


ENSO en el pasado

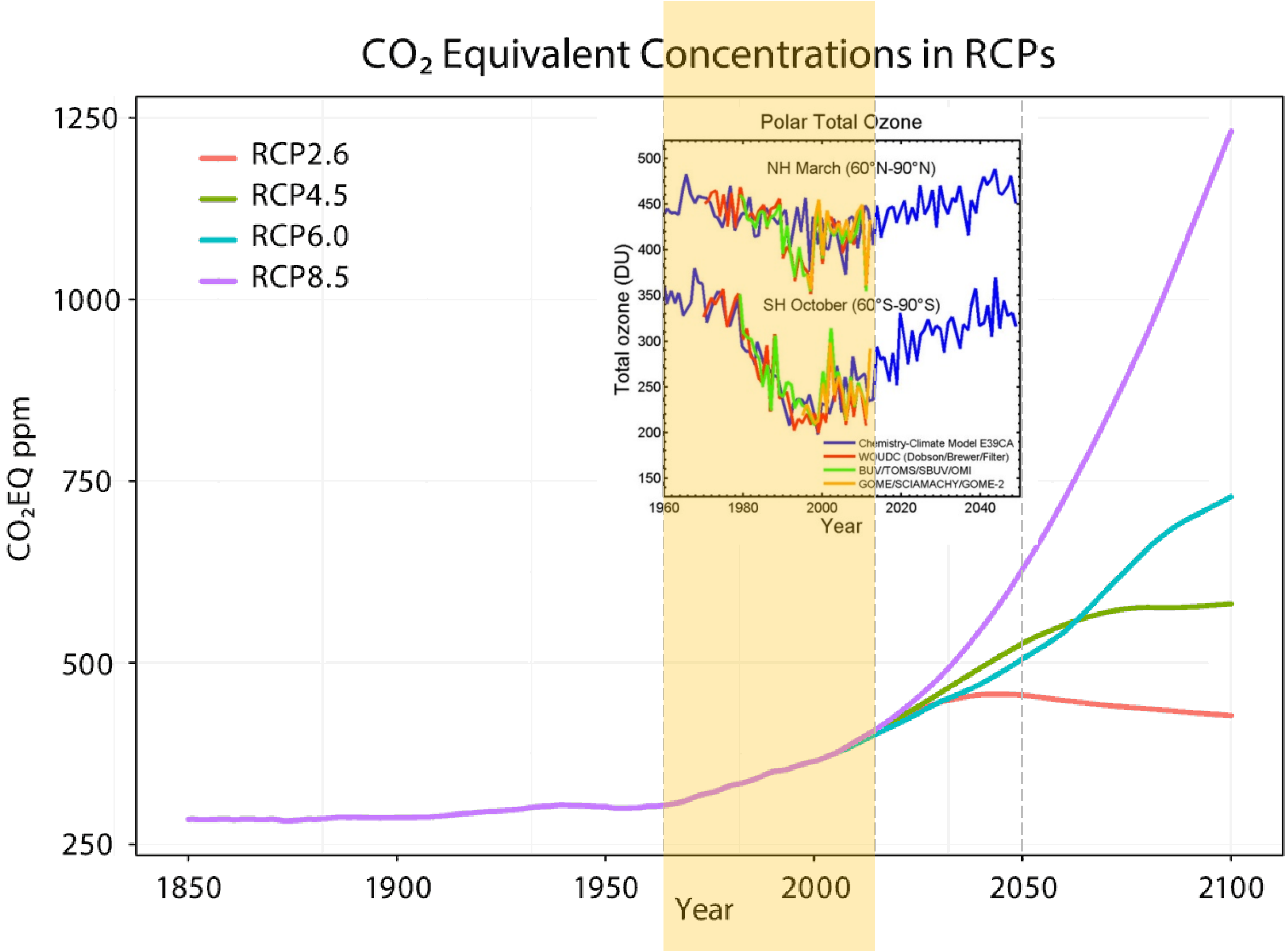


Variability of El Niño/Southern Oscillation activity at millennial timescales during the Holocene epoch
Nature, 420, 162 - 165 (2002); doi:10.1038/nature01194
Christopher M. Moy[1,4], Geoffrey O. Seltzer[1], Donald T. Rodbell[2], and David M. Anderson[3]

ENOS en el futuro



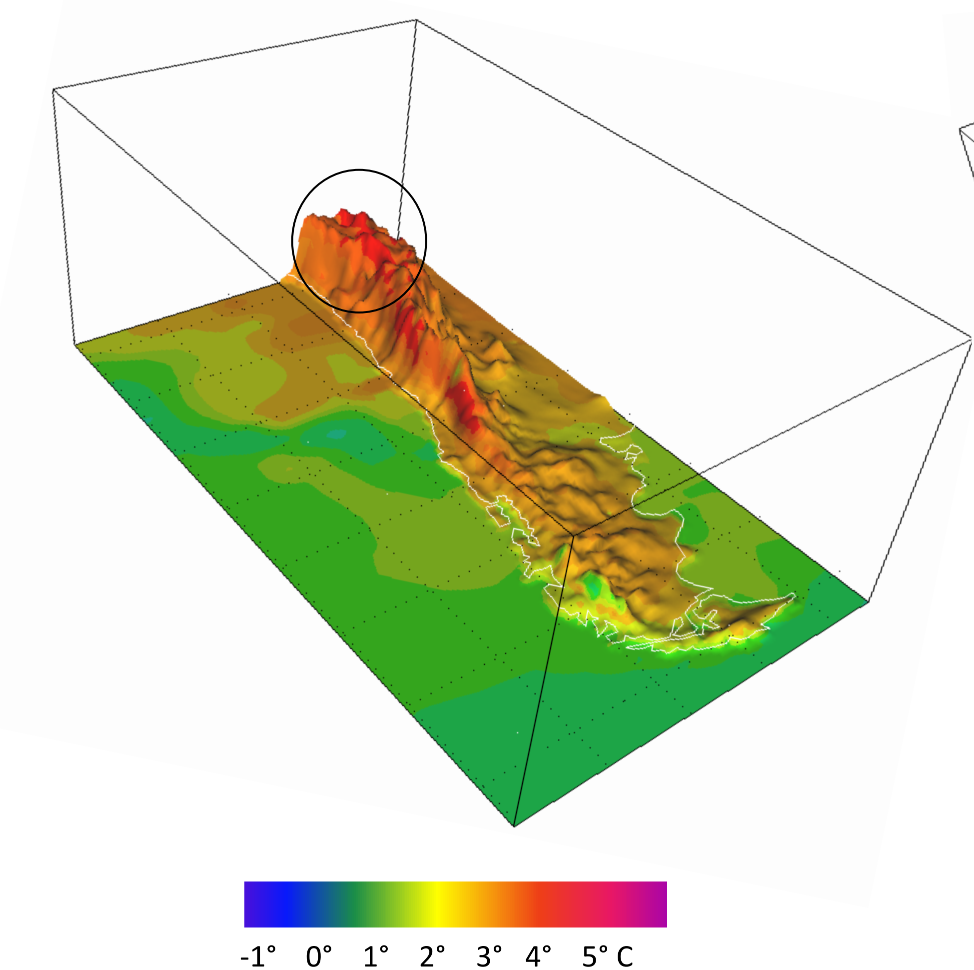
Greenhouse gases and Ozone: the main drivers of climate change



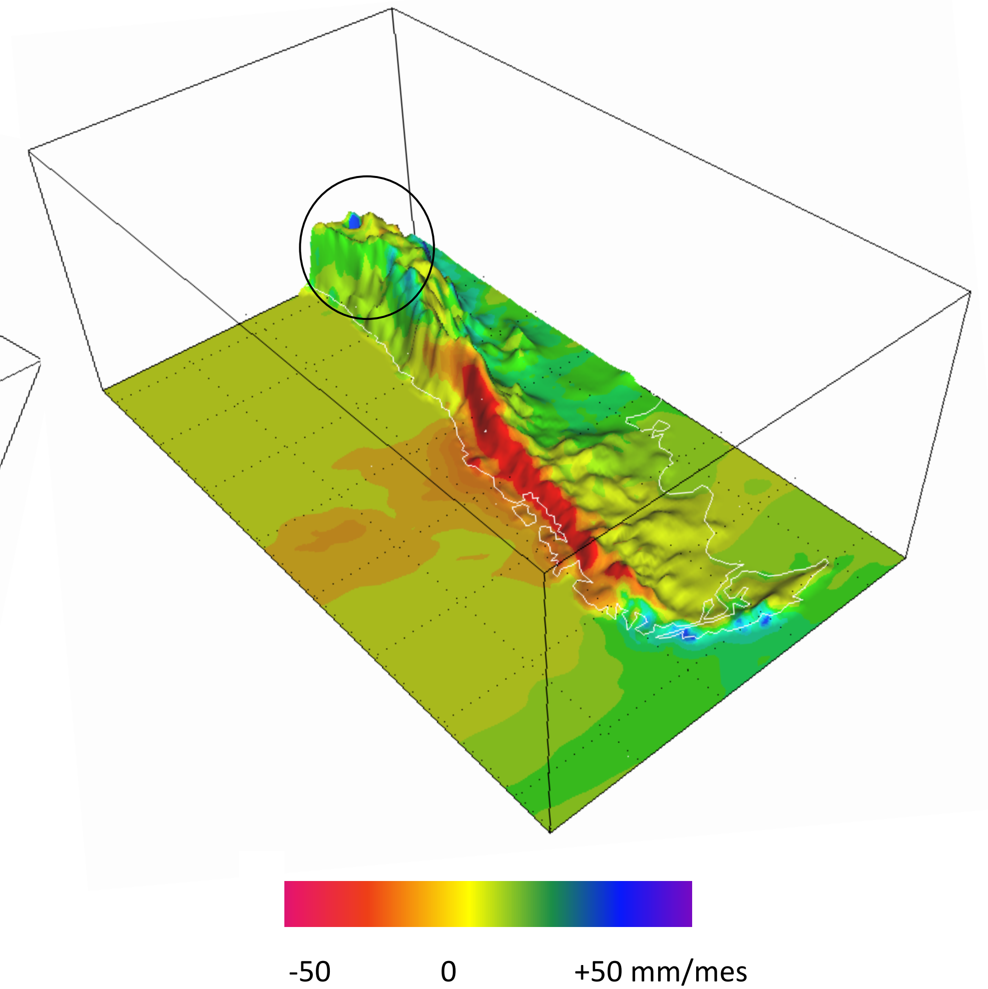
Differences A2(2100-2070) – BL(1960-1990)

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

Temperatura Superficial (SAT)



Precipitación (P)



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

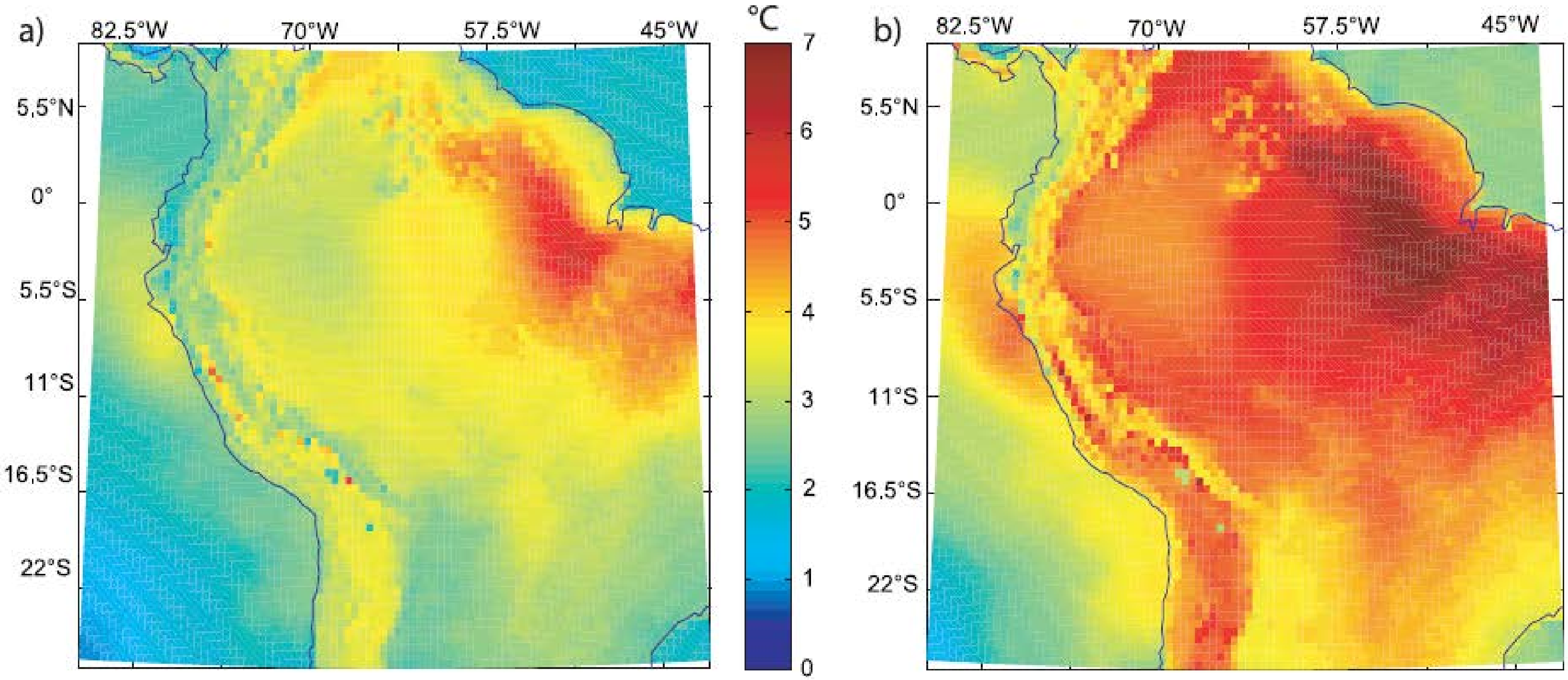
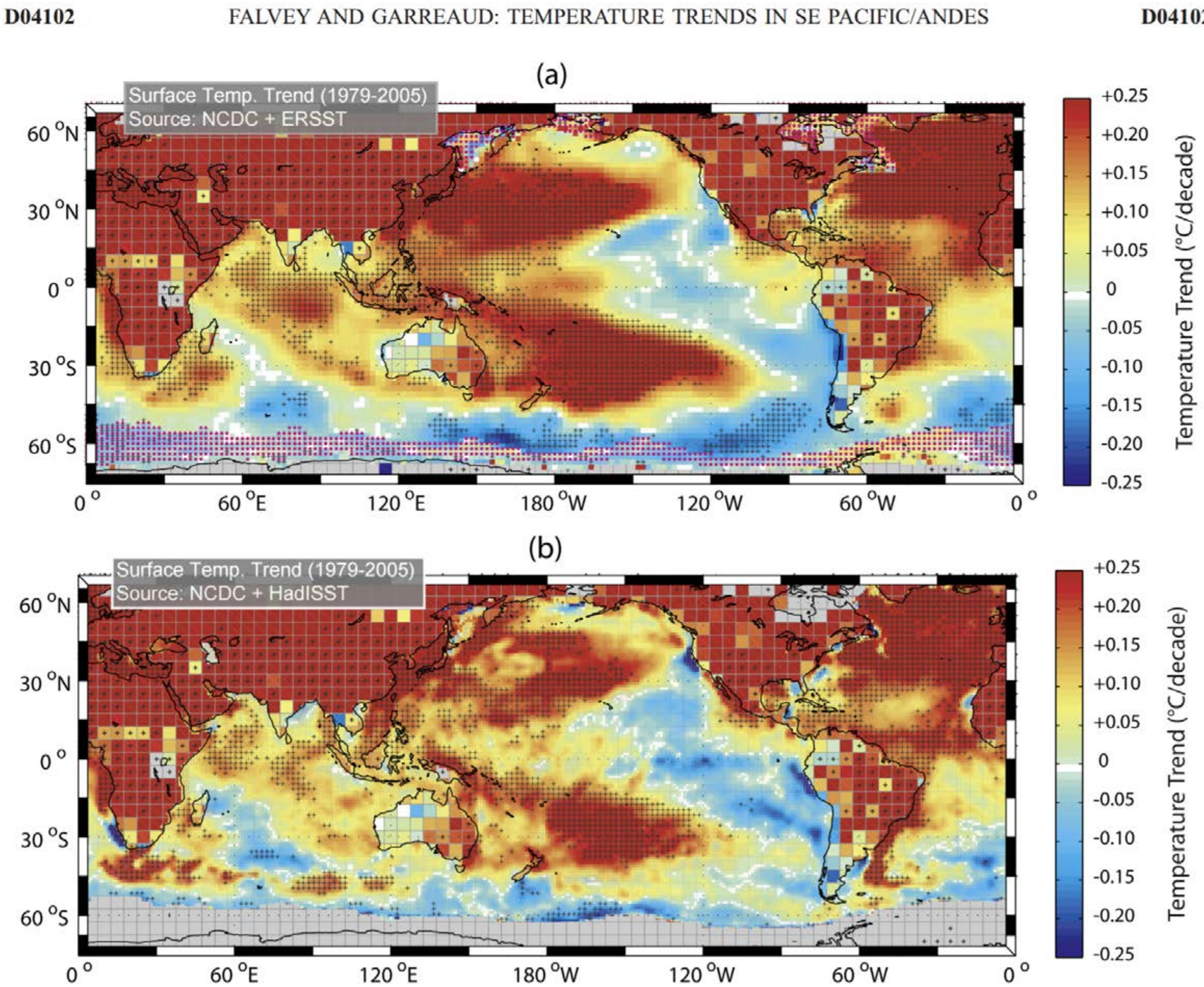
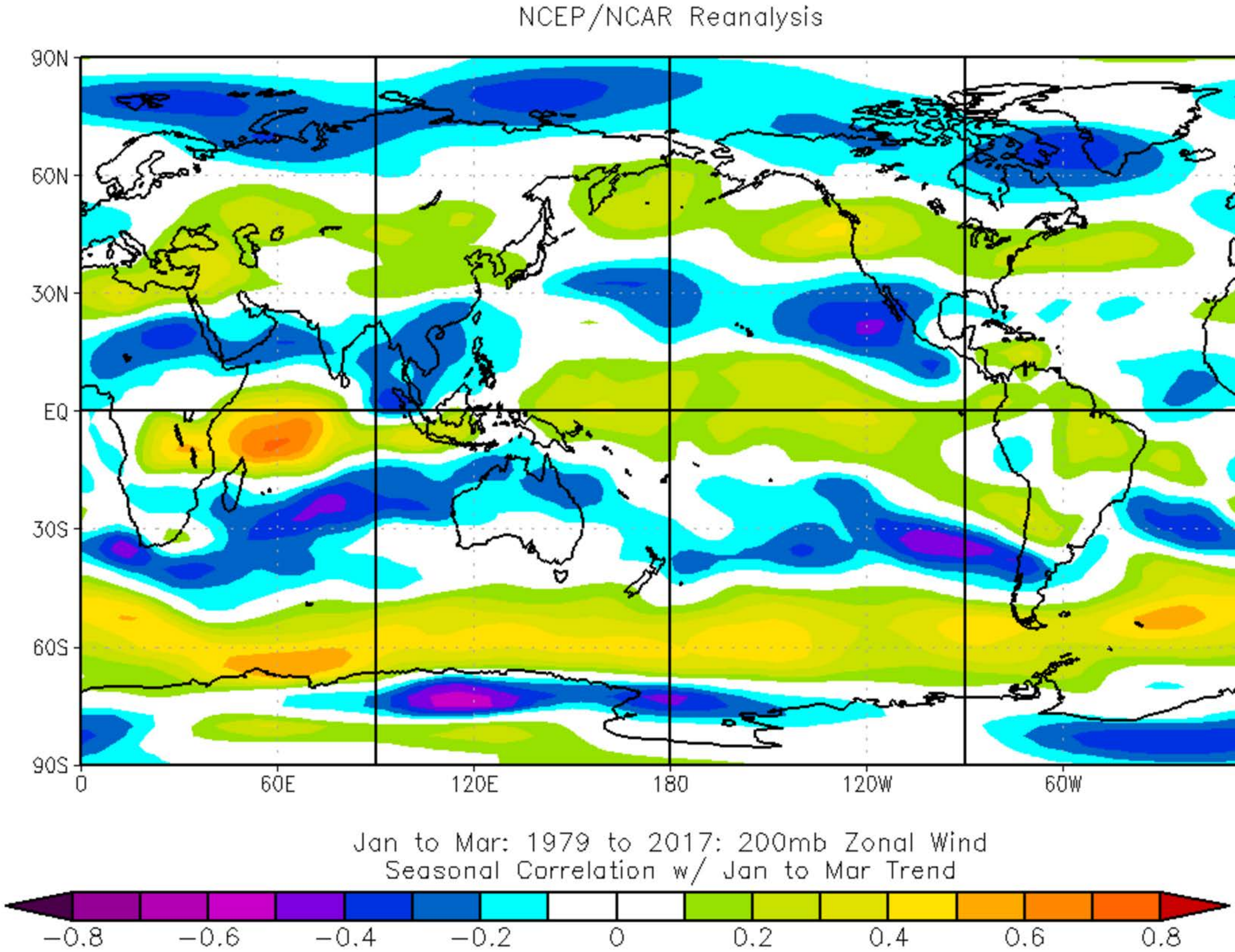


Figure 5. (a) Difference in mean annual surface temperature (in °C) between RCM-B2 and RCM-20C. (b) Same as in Figure 5a but for RCM-A2. Differences are statistically significant at the 95% level everywhere.

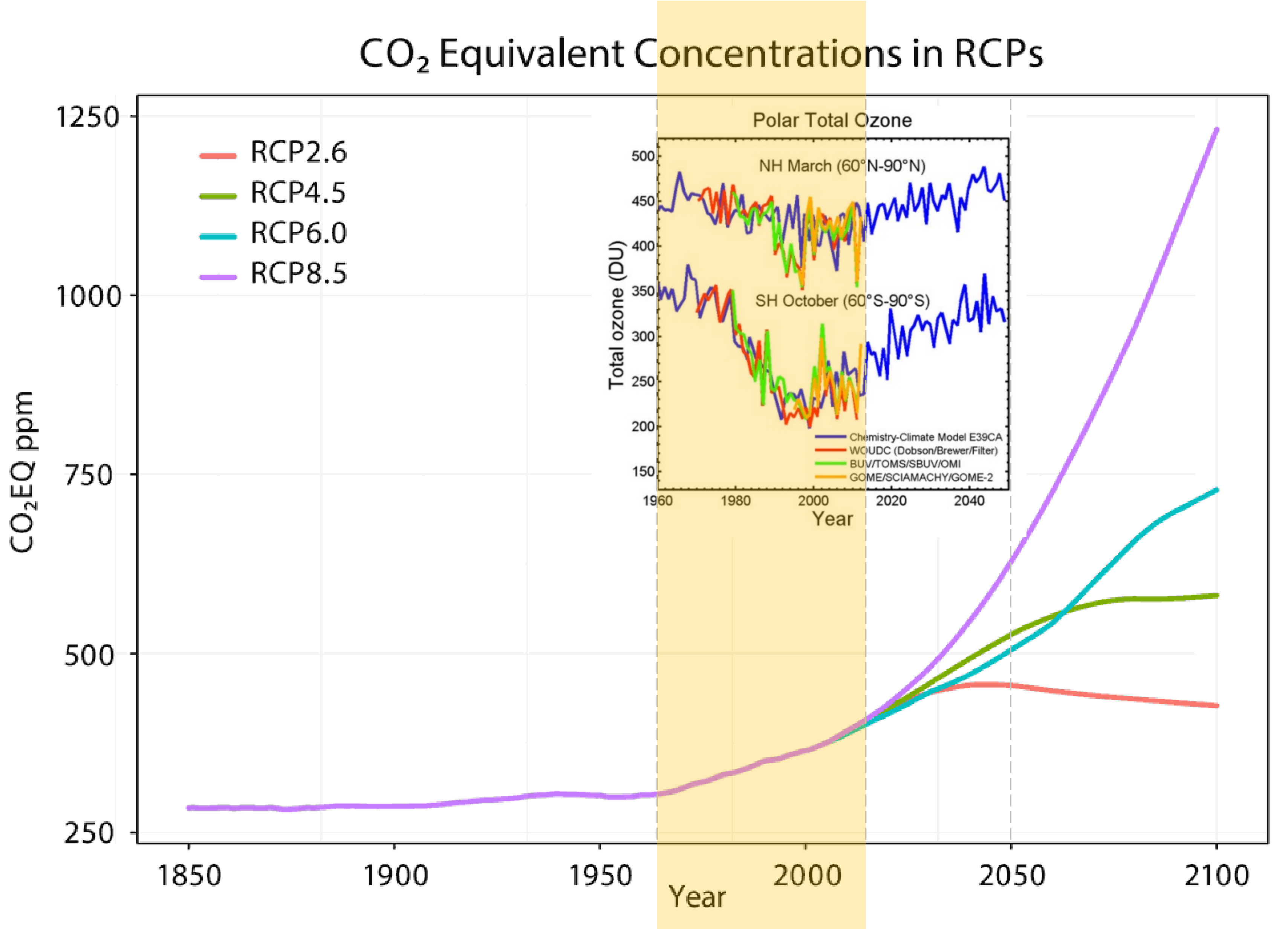
Urrutia and Vuille 2009

Tendencias recientes de temperatura...débiles.

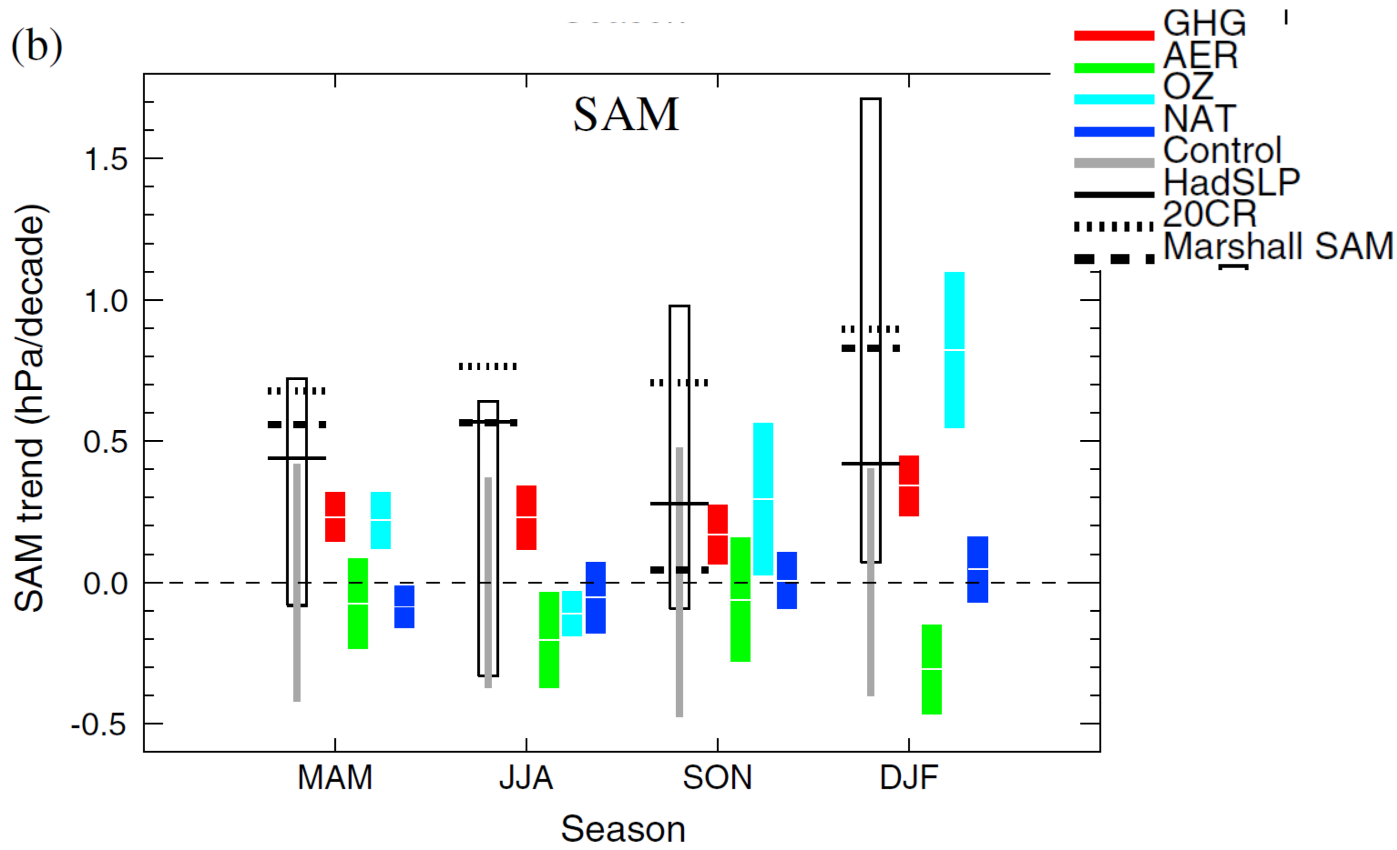



NCEP/NCAR Reanalysis
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
Jan to Mar: 1979 to 2017: 200mb Zonal Wind
Seasonal Correlation w/ Jan to Mar Trend
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8

Greenhouse gases and Ozone: the main drivers of climate change



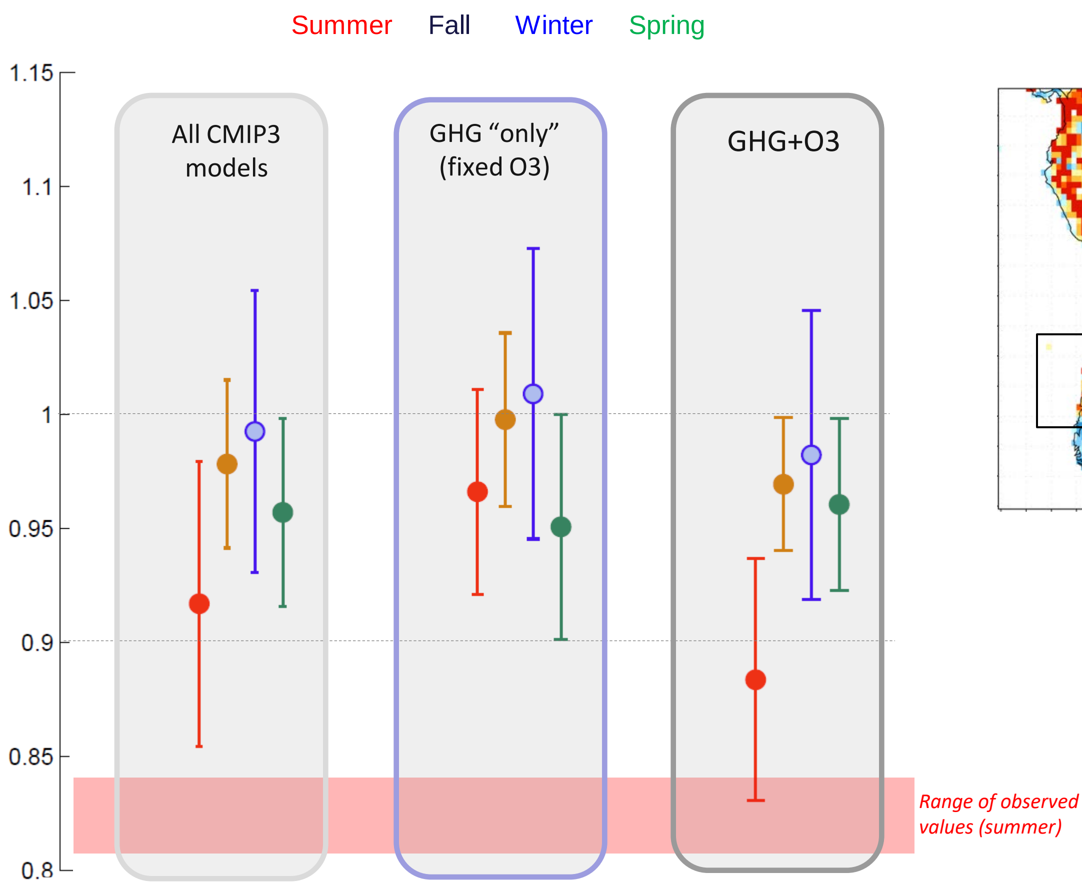
SAM trends 1950-2011: Observations and attribution

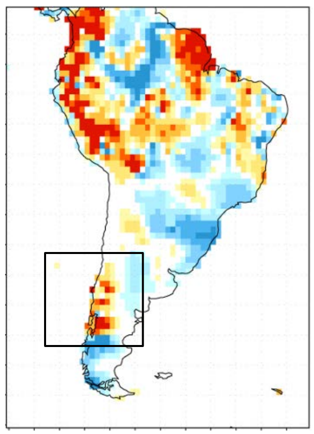


Attribution of observed sea level pressure trends to greenhouse gas, aerosol, and ozone changes

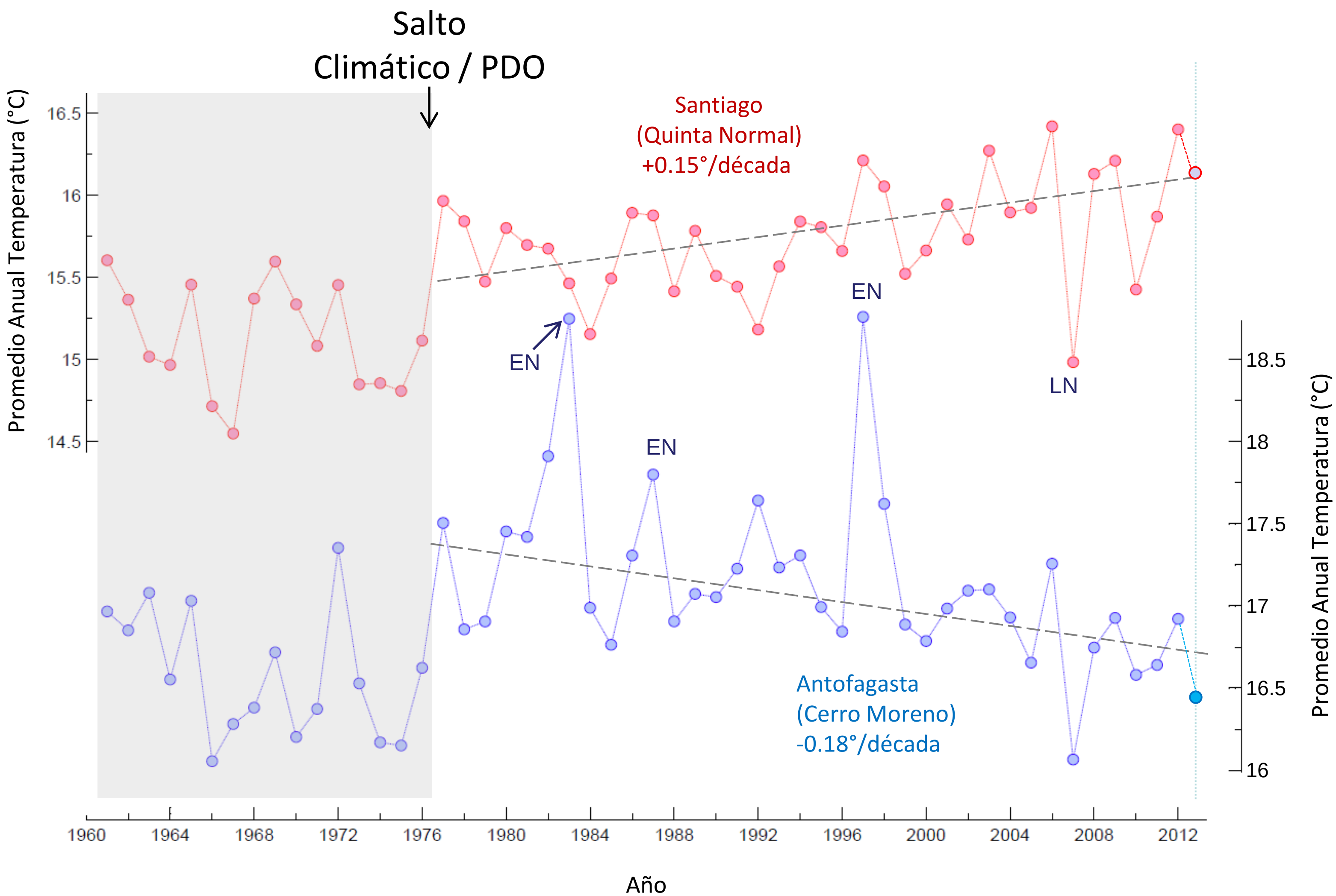
Nathan P. Gillett,[1] John C. Fyfe,[1] and David E. Parker[2]

Seasonal anomalies (P[1990-2005]/P[1960-1980])

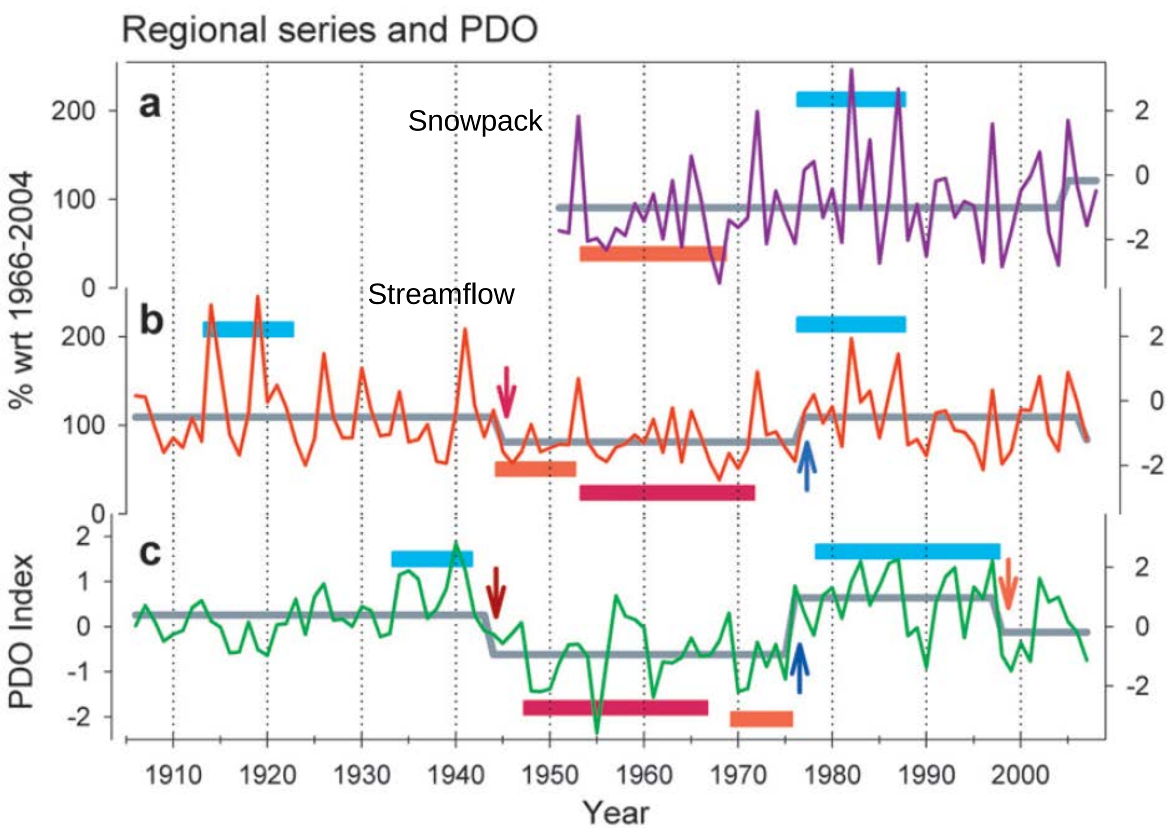


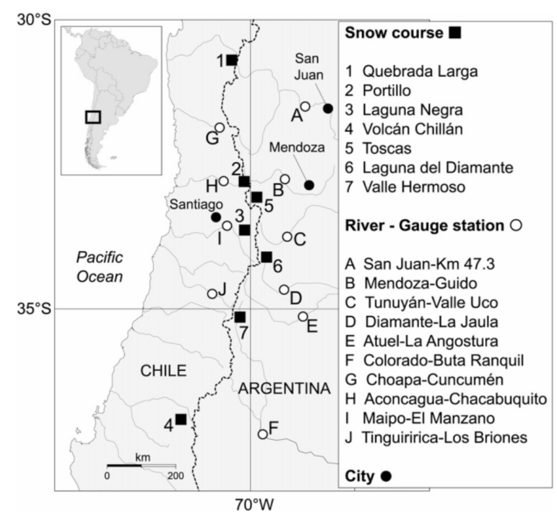


La PDO y temperatura…



La PDO y precipitación…



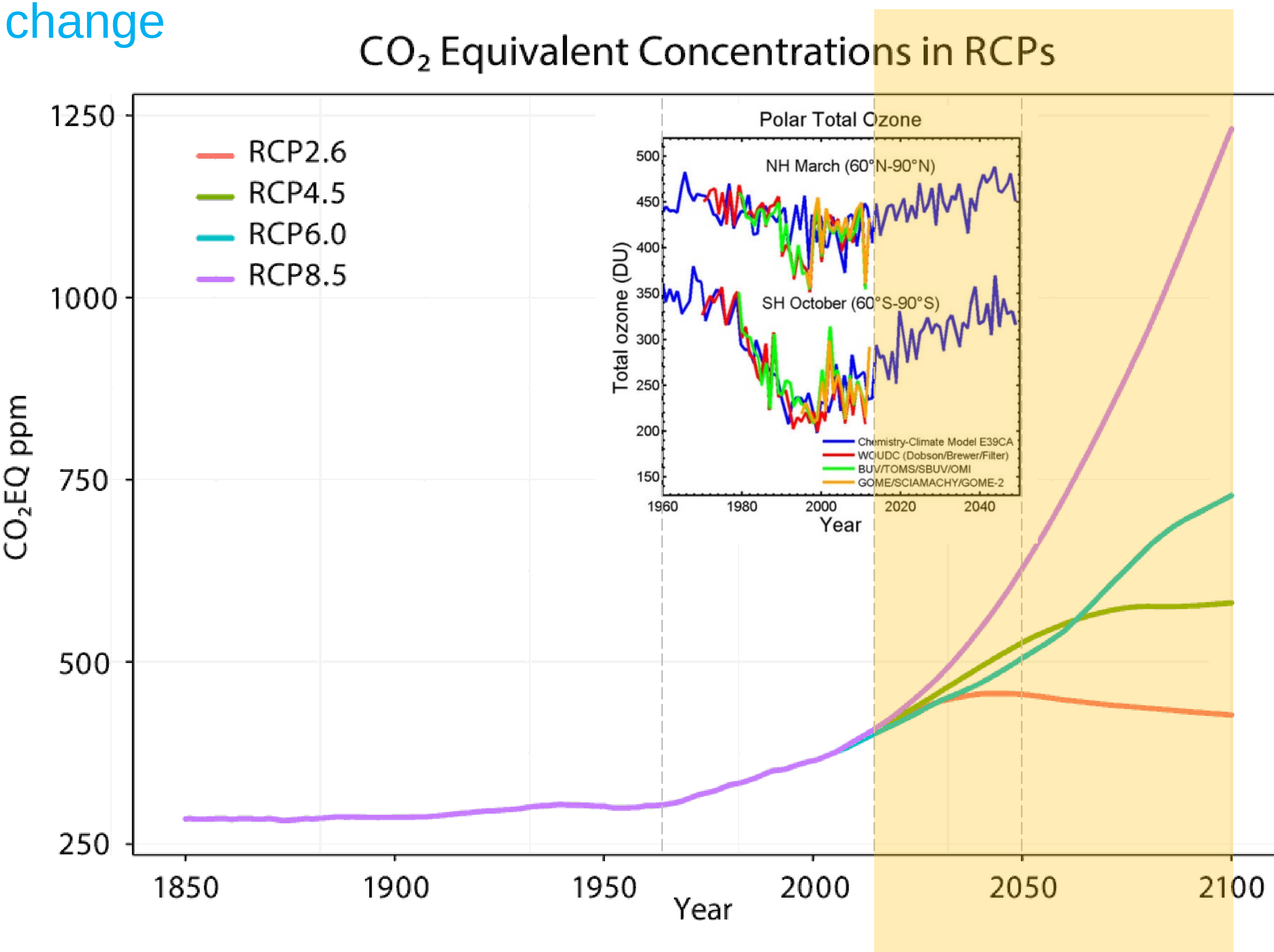


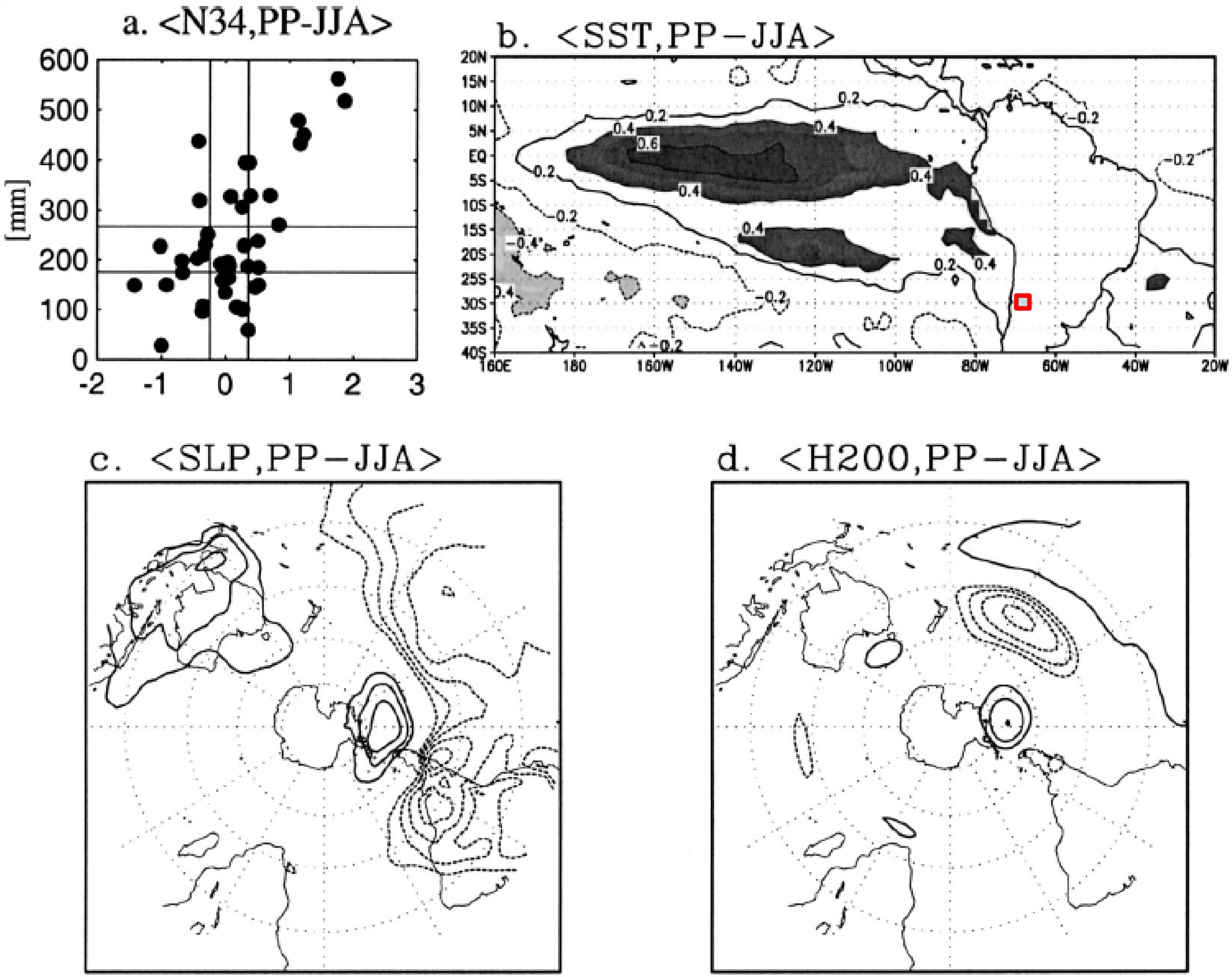
JOURNAL OF HYDROMETEOROLOGY

Intra- to Multidecadal Variations of Snowpack and Streamflow Records in the Andes of Chile and Argentina between 30° and 37°S

MARIANO H. MASIOKAS AND RICARDO VILLALBA

Greenhouse gases and Ozone: the main drivers of climate change




a. <N34,PP-JJA>
[mm]
600
500
400
300
200
100
0
-2
-1
0
1
2
3
b. <SST,PP−JJA>
20N
15N
10N
5N
EQ
5S
10S
15S
20S
25S
30S
35S
40S
160E
180
160W
140W
120W
100W
80W
60W
40W
20W
0.2
0.4
0.6
-0.2
-0.4
c. <SLP,PP−JJA>
d. <H200,PP−JJA>

Tendencias observadas de precipitación: ¿?

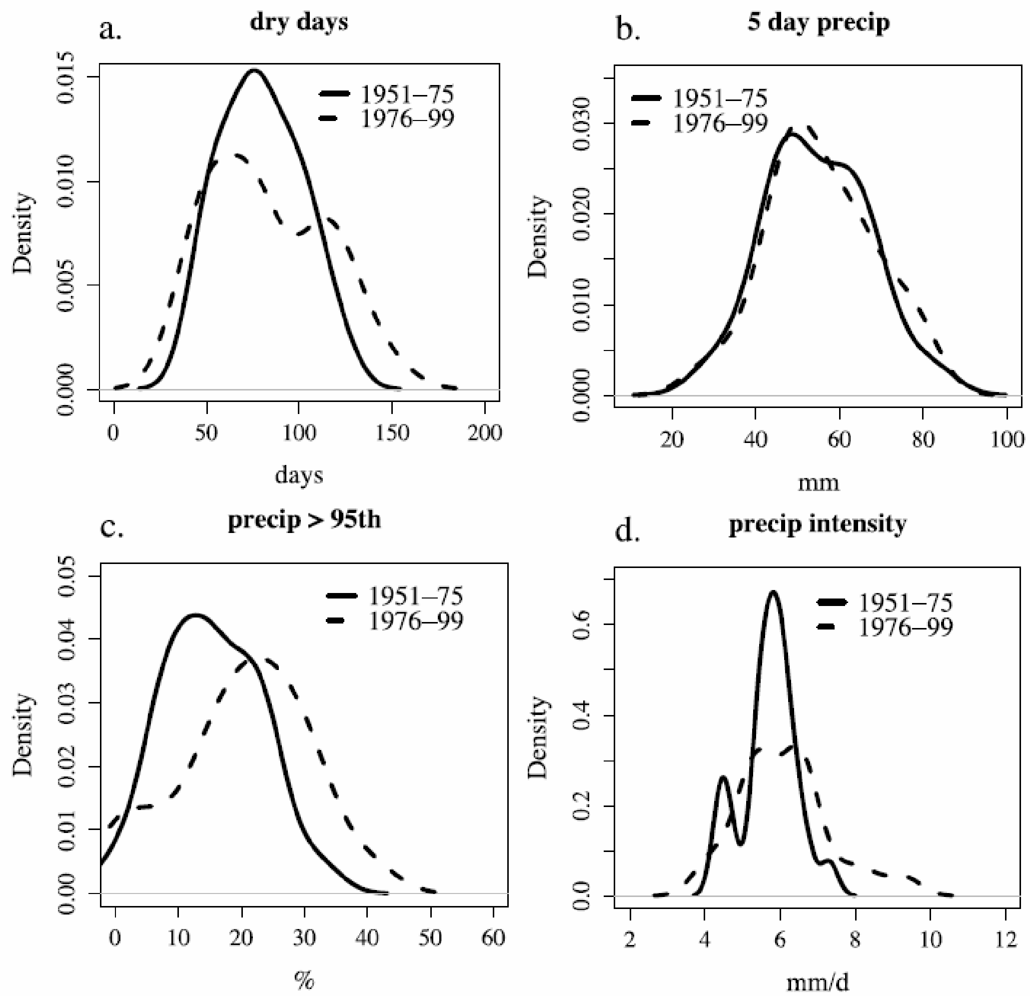
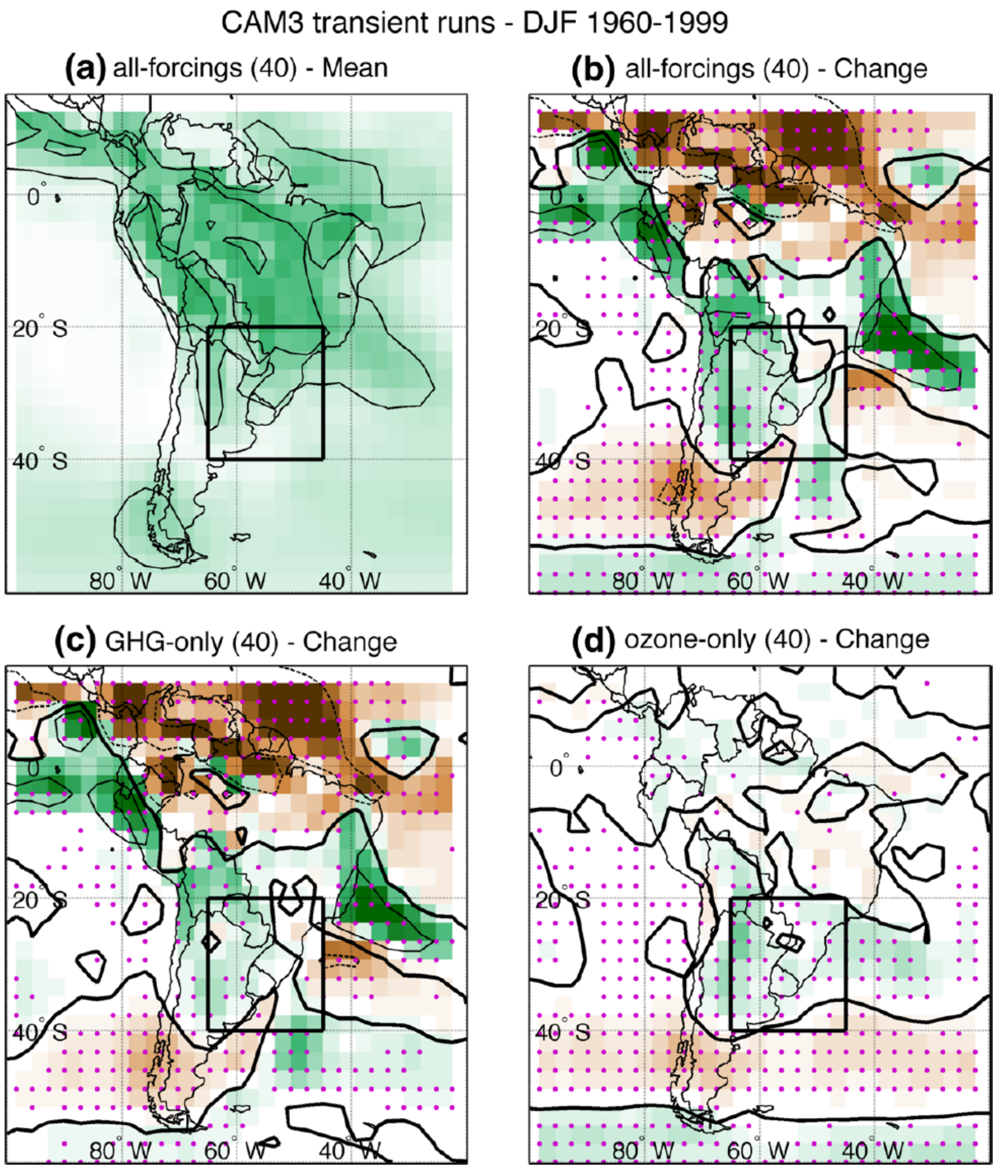


Figure 2. PDFs of precipitation extreme indices for Patacamaya, Bolivia. Two periods are shown for the 20th century: 1951–1975 (solid line) and 1976–1999 (dashed line). Data are from the ETCCDI Climate Extreme Indices data set available at http://cccma.seos.uvic.ca/ETCCDMI/data.shtml.

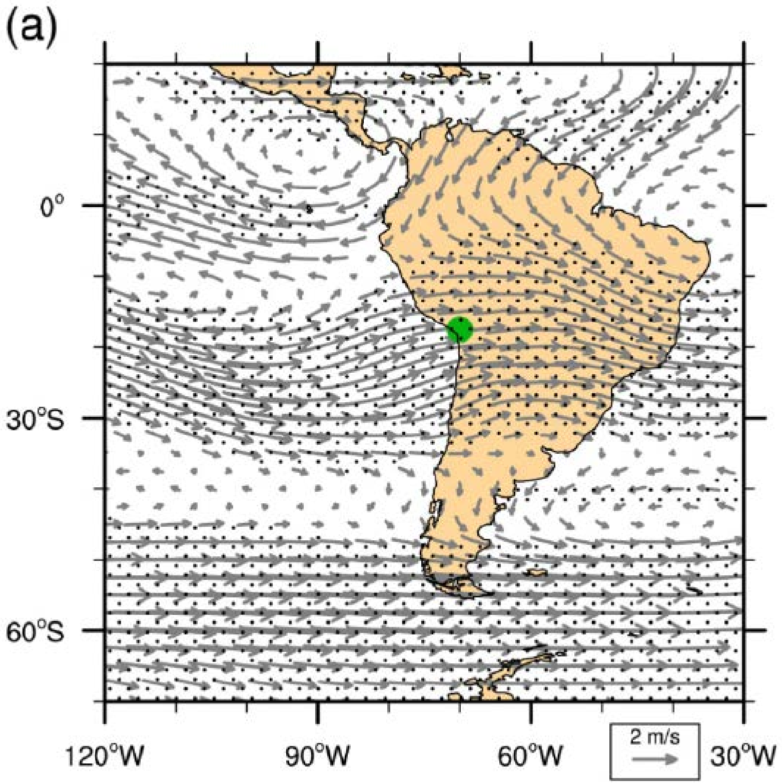
THIBEAULT ET AL.: ALTIPLANO CLIMATE EXTREMES



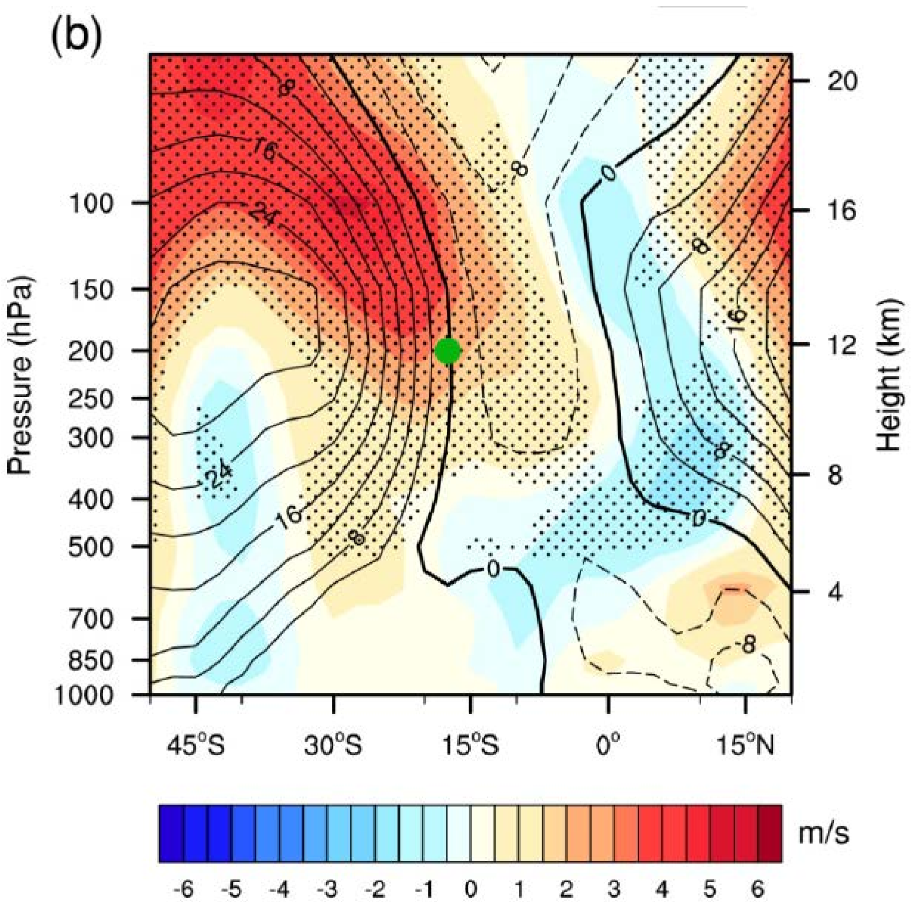
Stratospheric ozone depletion: a key driver of recent precipitation trends in South Eastern South America

Paula L. M. Gonzalez · Lorenzo M. Polvani ·
Richard Seager · Gustavo J. P. Correa

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

Impactos en Hidrología