Current climate trends in the Southeast Pacific
Natural and anthropogenic contributions

René D. Garreaud
Professor, Geophysics Department, Universidad de Chile
Deputy Director, Center for Climate and Resilience Research

Current climate trends in the Central Chile
Natural and anthropogenic contributions
Why bothering with a study on climate change in Chile? After all, there is widespread warming (perhaps more rapid at high elevations) and, because of its substantial variability (ENSO), we can’t discern any trend in rainfall. (Garreaud, 2012)

Well, one can be wrong....
Outline

Part I
- Precipitation trends
- Current (mega) Drought
- Drought dynamics
- Attribution and projection

Part II
- Cooling ocean, Land Warming (COWL)
- Global warming hiatus and PDO
- Role of SAM (midlatitudes)
- Projections
Contemporaneous rainfall trends in central Chile (1960-2000)
Contemporaneous rainfall trends in central Chile (Updated)

- Annual precip. trend 1979-2014
- 2009-2015 (?) drought
- 65 mm (~7.1%) dec^{-1}
- 44 mm (~5.6%) dec^{-1}

Bosier et al. 2016
Central Chile Mega Drought

Return Period of driest year within MD: Norte Chico 7, Centro 15, Centro-sur >30

Recurrence of a sequence of 4+ dry years: Norte Chico 4-6, Centro 2-3, Centro-sur 1?
Dry and warm

Promedio anual de la temperatura máxima en Santiago (DMC)
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$)

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Central Chile Climate Change Projections

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

- Temperature increase 2.5-3.5°C
- Rainfall decline 25-35%

Estudio DGF/UCh-CONAMA 2007 empleando PRECIS
Central Chile Rainfall
The next decade challenge

Rainfall anomaly wrt 1970-2000

Rainfall deficit wrt 1970-2000

Climate Change Signal

Recent Past
Mega Drought
Mid Future RCP8.5
Far Future RCP8.5

1995  2005  2015  2025  2080
Large-scale context for central Chile droughts

Drought Composite

Rainfall (GCPC)  Z500 (NNR)  SST (NCEP-OI)
Large-scale context for central Chile droughts

La Niña

El Niño

$r \approx 0.6$
Large-scale context for central Chile droughts

Drought Composite

Rainfall (GCPC)  Z500 (NNR)  SST (NCEP-OI)

-60 0 +60 mm/month
-50 0 +50 m
-1 0 +1°C

Cold
Warm
Dry
Wet
Large-scale context for central Chile droughts

$Z_{500}$ difference

$r \approx -0.6$
The 2010-2015 drought in Central Chile

Rainfall

Z500

SST

Drought Composite

1967, 68, 64, 73, 76, 85, 96, 87, 03, 07

2010-2014 Average

-60 0 +60 mm/month

-50 0 +50 m

-1 0 +1°C
The 2010-2015 drought in Central Chile: ENSO

Monte Carlo Experiment: 5000 samples of 4 randomly chosen ENSO-neutral years

Central Chile winter rainfall anomaly

MJJAS Niño3.4 index [°C]
The 2010-2015 drought in Central Chile: PDO

The error bars indicate the dispersion in the mean values when the initial or final year of each period is changed ±1 year.

Warm PDO periods
Cold PDO periods

Long term mean

Mean PDO Index

Mean QN Annual Precipitation [mm/year]
The 2010-2015 drought in Central Chile

$\mathbf{r} \approx 0.6$
The 2010-2015 drought in Central Chile
Attribution of the 2010-2015 mega drought

AMIP-X simulations: Atmospheric Global Circulation Model (AGCM) forced by

- Observed SST & Sea Ice Distribution
- Observed Radiative Forcing (CO2, aerosols, O3,...)
- Special AMIP simulations with natural-historical RF (1900')

- 10-30 “runs” of several decades long with slightly different initial conditions
- Ensemble mean reveals the “natural” SST forced response
- Ensemble spread reveals impact of internal variability (weather)
- Ensemble mean with NH-RF excludes direct anthropogenic impact

CMIP-X simulations: AO coupled Global Circulation Model (AOGCM) forced by

- Observed or projected RF (CO2, aerosols, O3,...)
- Multi-model, multi-run mean reveals the RF forced response
SST variability + Obs. Rad. Forcing during 2010-2014 accounts about half of the observed Z and P anomalies. Remaining anomaly can due to “bad luck”
Winter (MJJAS) rainfall anomaly 2010-2014
LBNL CAM 5.1 AMIP simulations (50 runs)

(a) Nat-Hist forcing / Obs SST

(b) Obs. Rad. Forcing / Obs. SST
Central Chile (33-36°S) winter (MJJAS) rainfall anomalies during mega drought (2010-2014)
Conclusions for part I
(The Next Decade Challenge)

Rainfall anomaly w.r.t. 1970-2000

Next Decade

Unlikely
Likely
Very unlikely

Climate Change Signal

MD Forcing
(*) Anthropogenic
(**) Natural (ENSO, PDO, Internal)
Surface Temperature Change

Falvey and Garreaud 2007
\( \partial T / \partial t \) along the western slope of the subtropical Andes

**Figure 5.** Temperature trends versus altitude along western tropical Andean slopes (2°N–18°S) for 1961–1990 (blue circle) and 1981–2010 (orange circle). The horizontal bars represent 95% confidence limits.
Figure 9. Mean annual surface temperature differences from GISS for 1999–2012 and 1976–1998 in °C, with zonal means at right for ocean (blue), land (red), and zonal mean (black).

Trenberth and Fasullo 2013.
Warmest decade on record but temperature increase has slowed down (Global warming Hiatus) in spite on monotonic rise in GEI and TAO radiative imbalance...
Main Suspect: Pacific Decadal Oscillation (PDO)

Figure 3 | Schematic of the trends in temperature and ocean-atmosphere circulation in the Pacific over the past two decades. Colour shading shows...
Over the SE Pacific, PDO-congruent trend explains less than 50% of the observed cooling...something else is going on.

\[ \times: [\delta \text{SST congruent with PDO}] / [\delta \text{SST observed}] \geq 0.5 \]
Observed SLP trends 1979-2005

(a) ERA Interim

Zonally symmetric component:
increase centered at 40ºS and decrease at higher latitudes...SAM-like pattern
Observed SLP trends 1979-2005

(a) ERA Interim

Correlation coefficients AI-OISST (colors) and AI-SLP (contours).
Observed & CMIP-5 Simulated SLP trends 1979-2005

SAM-like trend in CMIP-5 models (RF response) projects in the observed trends, but over the SE Pacific account for about ½ of the observations.
Hadley cell expansion / SAM positive trend
Forced by GEI increase and O3 depletion.
Simulated in the recent past and near future

denote poleward shift in westerly jet and poleward expansion of the Hadley cell. The linear trends are computed for the time period of 1960–1999 in the 20C3M integrations (circles) and for the time period of 2000–2049 in the A1B scenario integrations (squares), and separately shown for models with (red, blue) and without time-varying stratospheric ozone (green).

Son et al, 2009. GRL
and many others...
Observed and CMIP-simulated trends (1979-2005) in midlatitude ridging and SE Pacific cooling

In average, models don’t get SEP cooling but...
So, what’s next?
Multi model mean change in SLP between end of the century and current climate
Ridging over the south Pacific increases in a warmer world

\[ \Delta = \text{Ave}(2080-2100) - \text{Ave}(1980-2000) \]
SE Pacific “less-warming” (regional cooling) continues to the end of the century

\[ \Delta = \text{Ave}(2080-2100) - \text{Ave}(1980-2000) \]
Conclusions Part II

Current cooling trend in the SE Pacific (and west coast of South America) caused by increased equatorward flow (upwelling + evaporation), which in turn results from the superposition of PDO cold phase (transient) and radiative forcing (permanent).
El golpe final...
En simulación POGA-H se prescribe SST en Pac. Central ecuatorial (8% del planeta) + forzamiento radiativo (GEI)
Hiatos en los modelos de clima futuro

Future climate model simulation: Look for Hiatus decade...

Large-scale context for central Chile droughts

Drought composite
Mean Z500 anomalies (contours)
Std Z500 anomalies (colors)

Reduced variability downstream of anomalous ridge
Enhanced variability downstream of anomalous trough