Climate change in Patagonia
What we should expect in the next 50 years?

René D. Garreaud

Departamento de Geofísica Universidad de Chile
Centro del Clima y Resiliencia

Global change at basin and fjord scale and future water management challenges in Patagonia

Coyhaique, 7-9 Nov 2018
Outline

• Patagonia 101: Basic aspect
• Large scale control of regional climate (U-P, U-T)
• Climate variability and change
• The awful 2016
We all love Patagonia.....

- Large, complex territory, high biodiversity
- Ice fields, glaciers, major rivers in the west
- Hydrocarbons, wind and dinosaurs to the east
- Climate and environmental changes
- Multiple paleo-records but few climate stations
The big picture

- SE Pacific Anticyclone
- S. Atlantic Anticyclone
- Continental Low Level Jet
- Midlatitude Storm track
- Midlat. Precip.
- Tropical rainfall
- SCu & Cold SST
Long term mean zonal wind at 700 hPa
(best predictor of precipitation over the extratropical Andes)
One (typical) storm simulation (WRF)

Hourly results during a 3 day period. Resolved precipitation (colors), Convective rainfall (contours) and topography

Salient features: Rainfall enhancement over the Andes windward slope, Rain shadow, Convective rainfall along the coast
Patagonia 101: Precipitation

Mean Annual Rainfall (everybody guess)

Height (max, 90%)
Atmospheric Rivers landfalling on Patagonia

Clouds and upper level winds

Precipitable water
Atmospheric Rivers landfalling on Patagonia
Atmospheric Rivers landfalling on Patagonia
Landfalling AR – Global Survey
15 year landfalling AR climatology

Viale et al. 2018

![Map showing the frequency of landfalling ARs on Western South America with contours indicating the number of AR days and MeanIVT for JJA and DJF.]
15 year landfalling AR climatology
Viale et al. 2018

AR contribution to annual rainfall

Fraction of AR-related EPEs (top 25%)

Viale et al. 2018
Large scale control of regional climate
(Garreaud 2007; Garreaud et al. 2013)

Linking U with P/SAT we can:
* Downscale large-scale signals
* Upscale local-scale records
Local (point-to-point) correlation map between daily precipitation (P) and 850-hPa zonal and meridional wind components (U850; V850) using PRECIS-DGF results from 1980–90. At each grid point the correlation was calculated for the sample of days with P > 1 mm.

Colors indicate the P–U850 correlation.

Vectors are constructed using r(P, U850) and r(P, V850) (scale at the bottom) and only shown where absolute value exceeds 0.3.

Garreauad et al. 2013
Wind-precipitation covariability at annual timescales (year-to-year)

Stronger westerlies / More Precip. up to 50 km downstream of the Mnts.
Trend and Variability

![Graph showing trend and variability in precipitation and streamflow](image)
ENSO impacts on Patagonia

El Niño Composite JFM

Colors: SST anomalies
Contours: Z300 anomalies

← Correlación estacional
ONI-PP

Garreaud et al. 2009
SAM impacts on Patagonia

SAM+ Composite

Colors: SST anomalies
Contours: Z300 anomalies

→ Regresión annual
SAMI-PP,T

Garreaud et al. 2009
Contemporaneous climate change
Recent past and near future
Weak temperature trends
Heterogeneous precipitation trends

Annual rainfall trends (1960-2016)

Central Chile

Southern Chile

Boisier et al. 2018, Elementa
Precipitation trends 1960-2005: Attribution
Both O3 depletion and GHG increase, but O3 effect dominates in summer

Boisier et al. 2018, *Elementa*
Greenhouse gases and Ozone: the main drivers of climate change

Both contribute to SAM trend to +phase
How much CO2 will be emitted in the future?

Socio-economic development pathways

Climate Scenarios

Balance De Masa

GCMs (more than 40)
Projected climate change

(a) RCP2.6
Change in average surface temperature (1986–2005 to 2081–2100)

(b) RCP8.5
Change in average precipitation (1986–2005 to 2081–2100)

© IPCC 2015: WG1-AR5
Southern SA Climate Change Projections
Towards the end of century under A2 (RCP8.5)

Estudio DGF/UCh-COMANMA 2007 empleando PRECIS
Programa de Capacitación

Simulaciones Climáticas Regionales y Plataformas de Visualización
Servicios Climáticos CR2

¿Qué pasó?
→ Explorador Climático
Datos históricos diarios, mensuales y anuales en estaciones en Sud América
http://explorador.cr2.cl/

¿Qué pasó?
→ Camels CL
Explorador hidrológico en cuencas de Chile
http://camels.cr2.cl/

¿Qué esta pasando?
→ VisMet
Registros horarios en tiempo real en estaciones en Chile
http://vismet.cr2.cl/

¿Qué pasará?
→ Plataforma Simulaciones
Resultados de modelos climáticos globales y regionales para el siglo XXI
http://simulaciones.cr2.cl/
Projected Changes for Chaiten – Summer (DJF)
Explorador Climatico CR2
The Glass Half-Empty: Climate Change Drives Shortage in Freshwater Inputs from a Trans-Andean Basin to the Coastal System of Chilean Northern Patagonia

Rodrigo Aguayo\textsuperscript{1}, Jorge León-Muñoz\textsuperscript{2,3*}, José Vargas-Baecheler\textsuperscript{1}, Aldo Montecinos\textsuperscript{4,5}, René Garreaud\textsuperscript{6,7}, Mauricio Urbina\textsuperscript{8,9}, Doris Soto\textsuperscript{3}, José Luis Iriarte\textsuperscript{10,11}
SST and Salinity changes under RCP8.5
CO₂ Equivalent Concentrations in RCPs

Contrasting effects on SAM & Precip
What about Extreme Events?
The awful 2016
Ocean state variables
- Temperature
- Stratification ($\rho(z)$)
- Vertical velocity
- Currents
- pH

Atmosphere/Land Boundary Conditions
- Solar Radiation
- Fresh Water

Atmospheric Fluxes
- Nutrients (P,N)

Physical processes
- Turbulence
- Upwelling

Biological processes
- Bloom

© RGarreaud / DGF-UCh + CR2
Climate Control of HABs in Patagonia
Garreaud, Massoti et al. 2019?
The awful 2016

(a) Precipitation anomalies

(b) Enhanced Vegetation Index anomalies

(a) Streamflow anomalies

Chiloe Island
Puerto Montt
NW Patagonia
Aysen River
Coyhaique

Argentina
Chile

Drying
No change
Greening
El Niño!
Natural....

\[ r = -0.2 \]

SAM!
Antrophogenic

Large scale conditions JFMA 2016
Conclusions

* Climate anomalies (wet/dry) accounted by changes in westerly wind impinging the austral Andes. Drivers of Temperature?

* Large scale circulation anomalies modulated by ENSO (Natural) and SAM (anthropogenic: GHG+O3)

* Robust changes in precipitation, not so clear in temperature. Local scale? Hydrological response?

* Climate projections: drying in central Patagonia + warming, superimposed on natural variability. Uncertainty? Extreme events (ARs, severe droughts)? Other drivers?
Environmental extremes and change → Social tensions

Local activities

Climate variability
Climate change