The Climate of Patagonia: Glaciers, Flashes and Shadows

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New Haven, April 26, 2016

Outline

- Patagonia 101
- Large-scale control of the regional climate
- Synoptic, orographic and convective precipitation
- Outlook

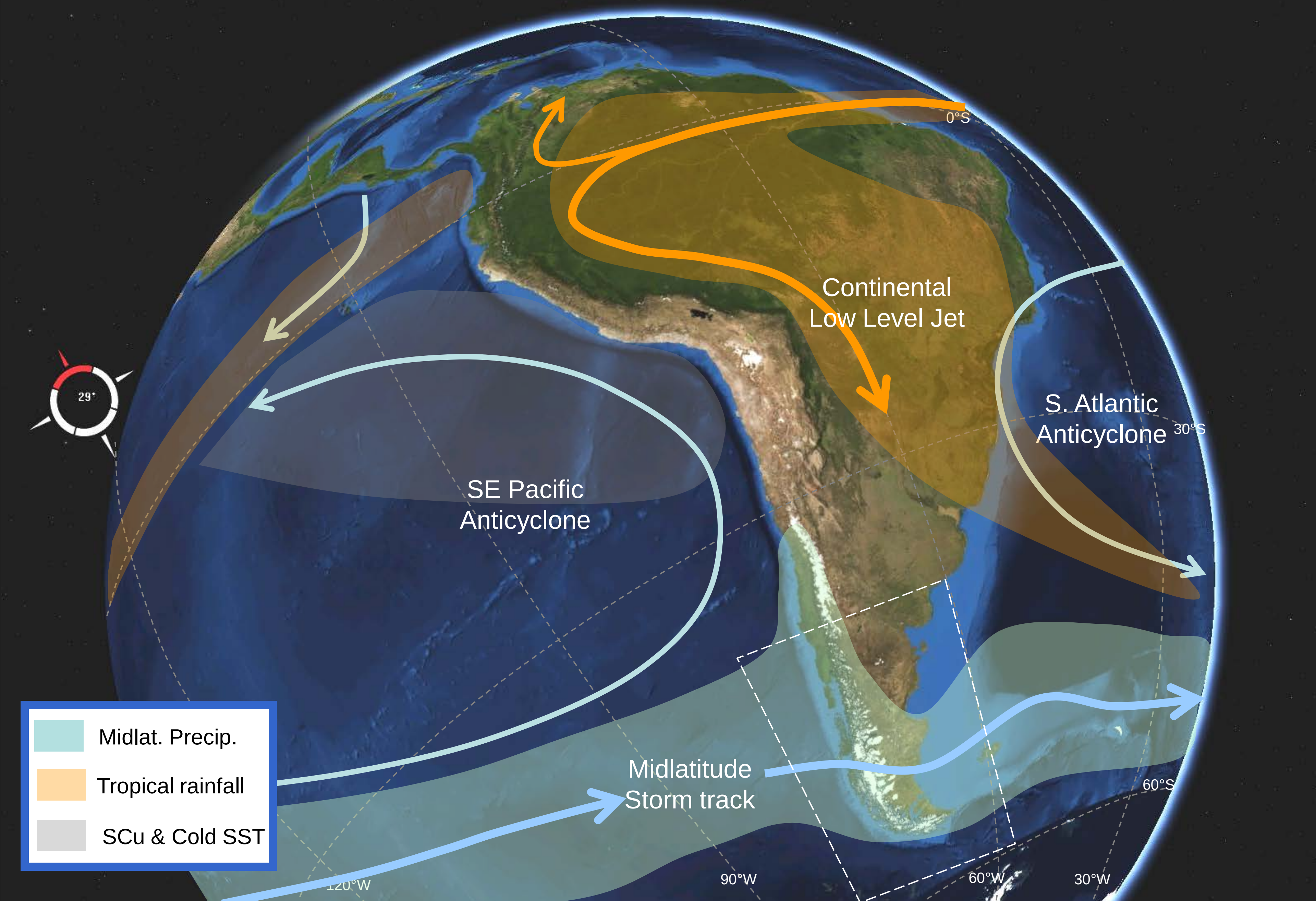
Acknowledgements

Faculty, staff and students at Yale Geology and Geophysics Department, specially Ron Smith, Mark Brandon, Larry Bonneau, Pam Buonocore and Aida Rodriguez.

We all love Patagonia.....

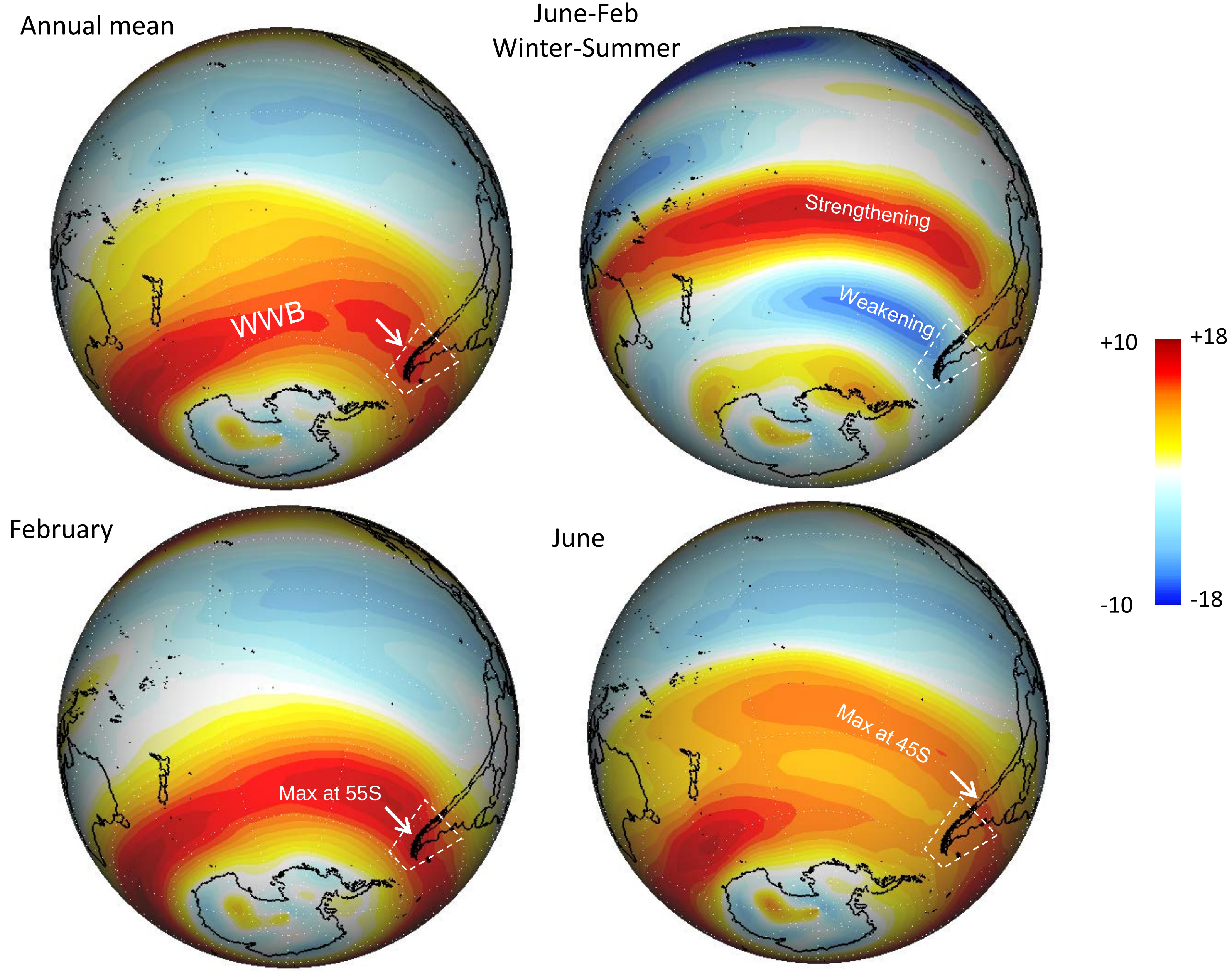
- Large area, complex terrain
- Current climate of Patagonia supports glaciers, ice fields, rain forests, and massive rivers in the western side.
- Biodiversity hotspot
- Gas, oil and dinosaurs in the eastern side
- Contemporaneous climate-driven environmental changes
- Numerous paleorecords (lakes, glaciers, tree-rings)
- Meteorological data clearly insufficient to address climate change/variability

The big picture



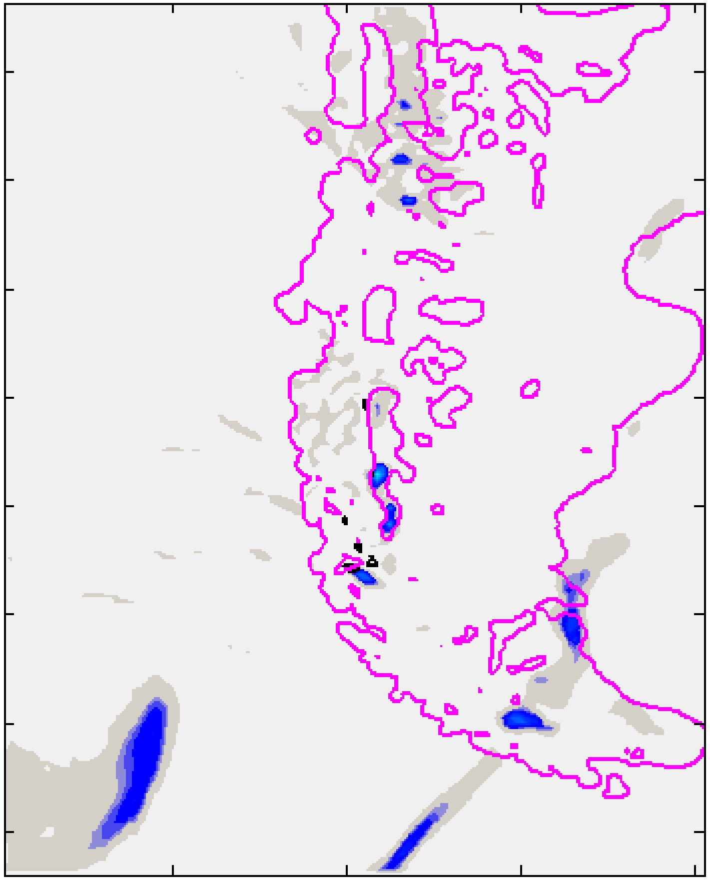
Long term mean zonal wind at 700 hPa

(best predictor of precipitation over the extratropical Andes)



One (typical) storm simulation (WRF)

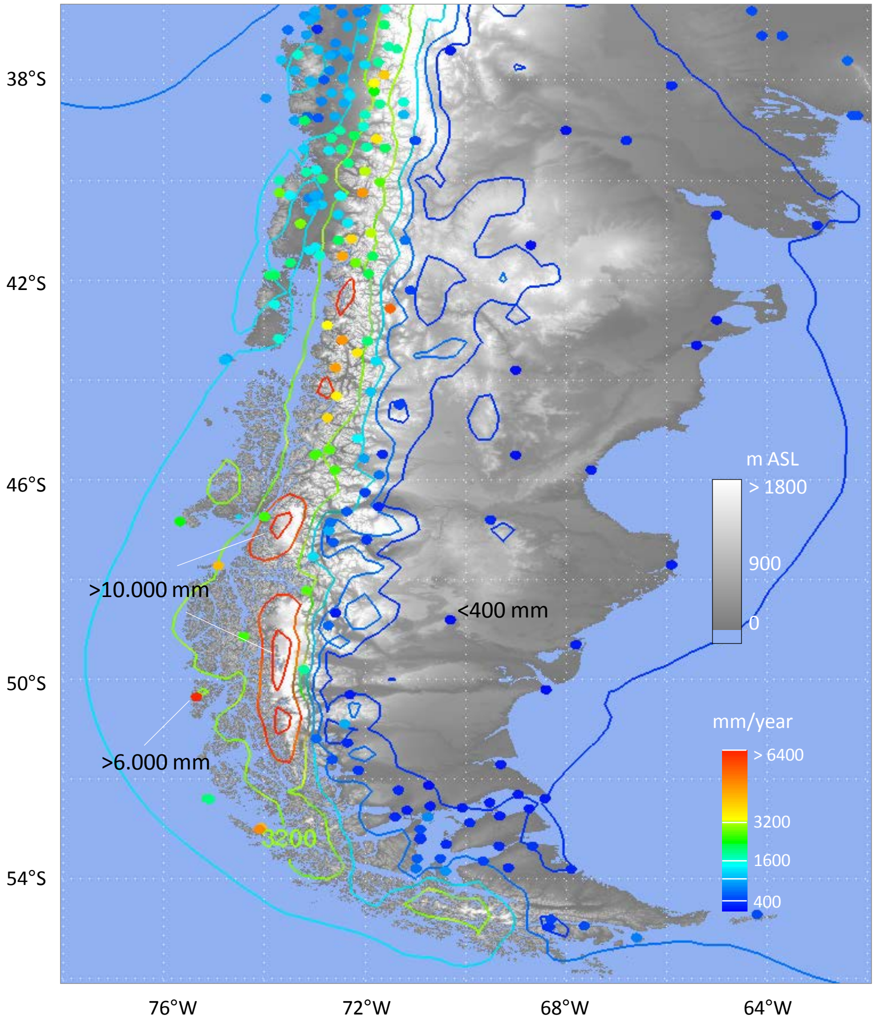
Hourly results during a 3 day period. Resolved precipitation (colors), Convective rainfall (contours) and topography



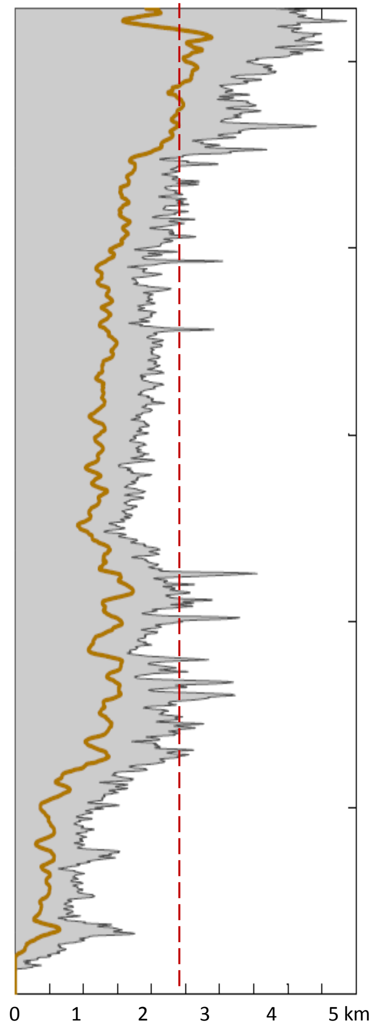
Salient features: Rainfall enhancement over the Andes windward slope, Rain shadow, Convective rainfall along the coast

Patagonia 101

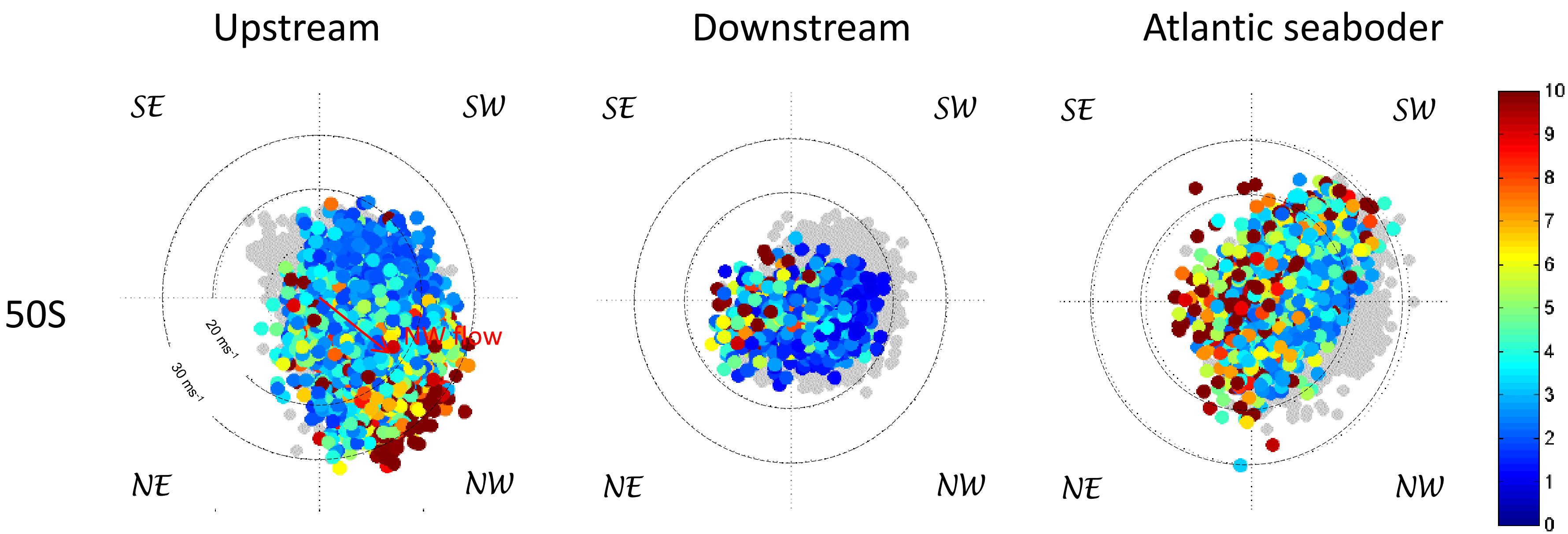
Mean Annual Rainfall (everybody guess)

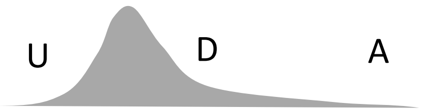


Height (max, 90%)



850 hPa (1500 m ASL) Wind roses for all days (grey) and rainy days (color) at selected locations in Patagonia





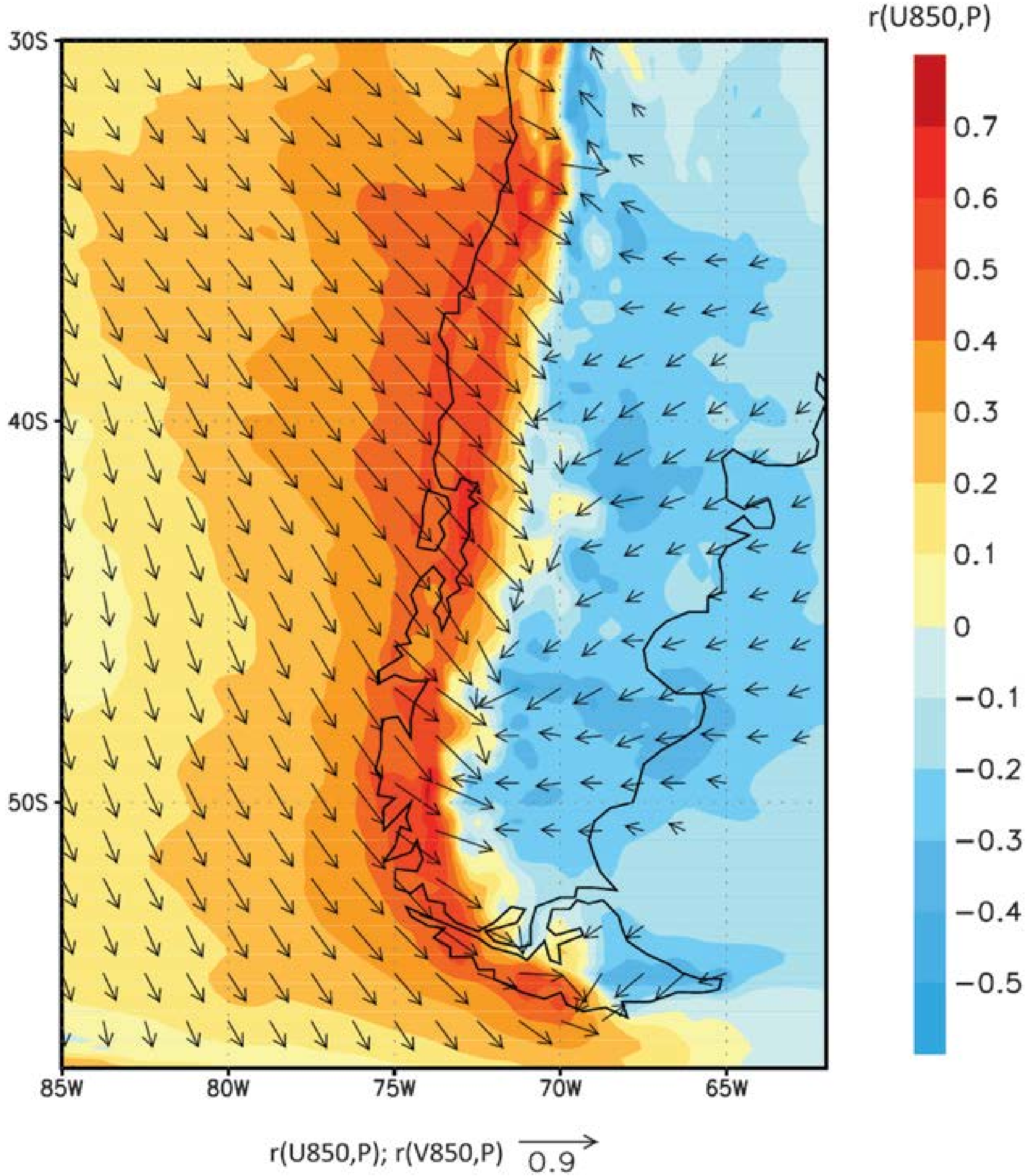


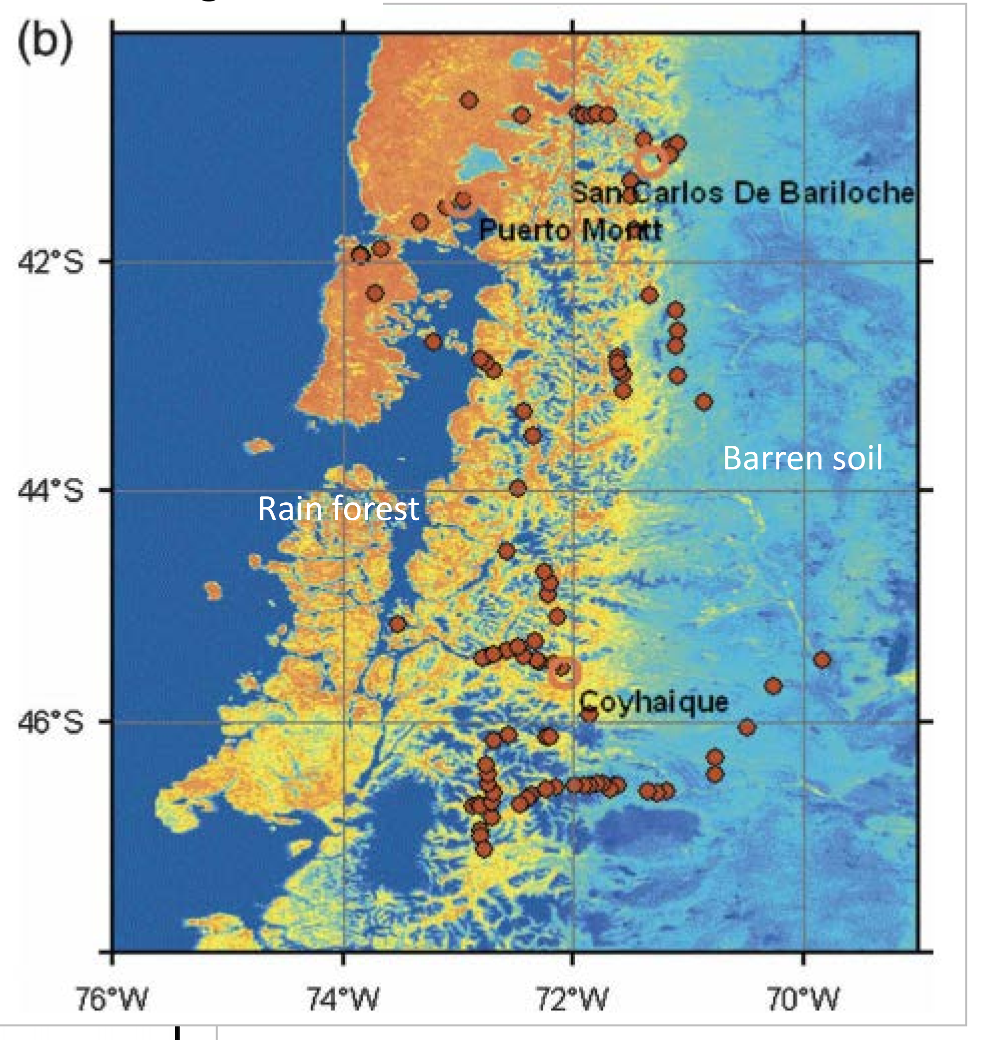
FIG. 4. Local (point-to-point) correlation map between daily precipitation (P) and 850-hPa zonal and meridional wind components (U850; V850) using PRECIS-DGF results from 1980–90. At each grid point the correlation was calculated for the sample of days with P >1 mm.

Colors indicate the P–U850 correlation.

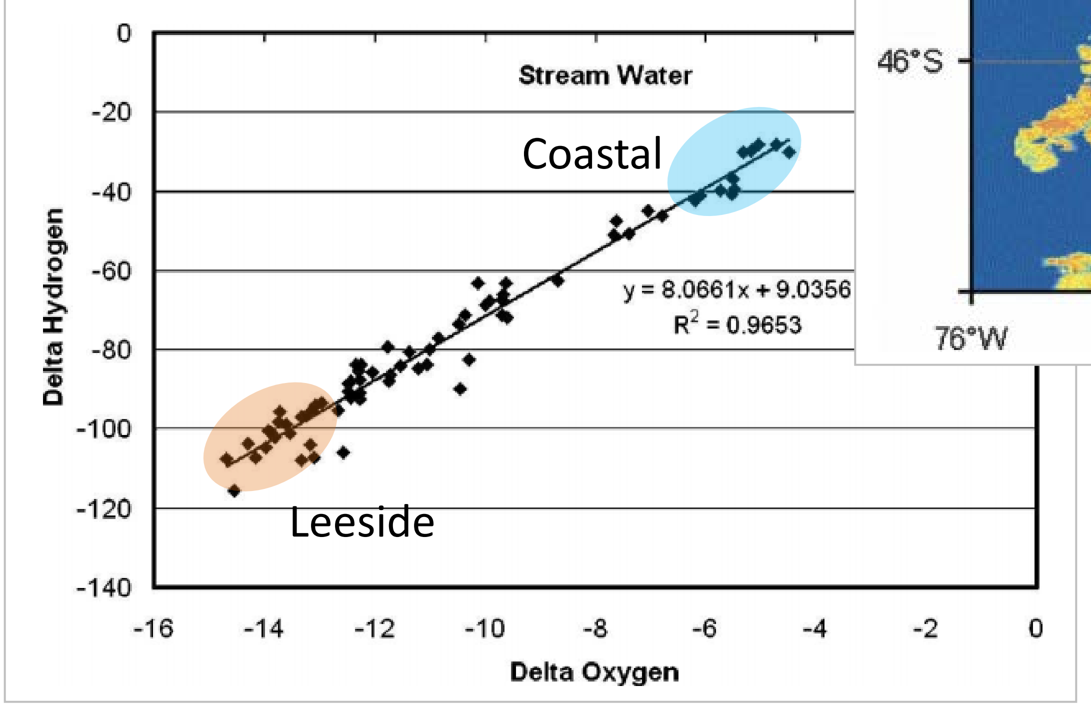
Vectors are constructed using r(P, U850) and r(P,V850) (scale at the bottom) and only shown where absolute value exceeds 0.3.

Precipitation gradient leads to other two biophysical contrasts: vegetation and isotopes

MODIS Vegetation

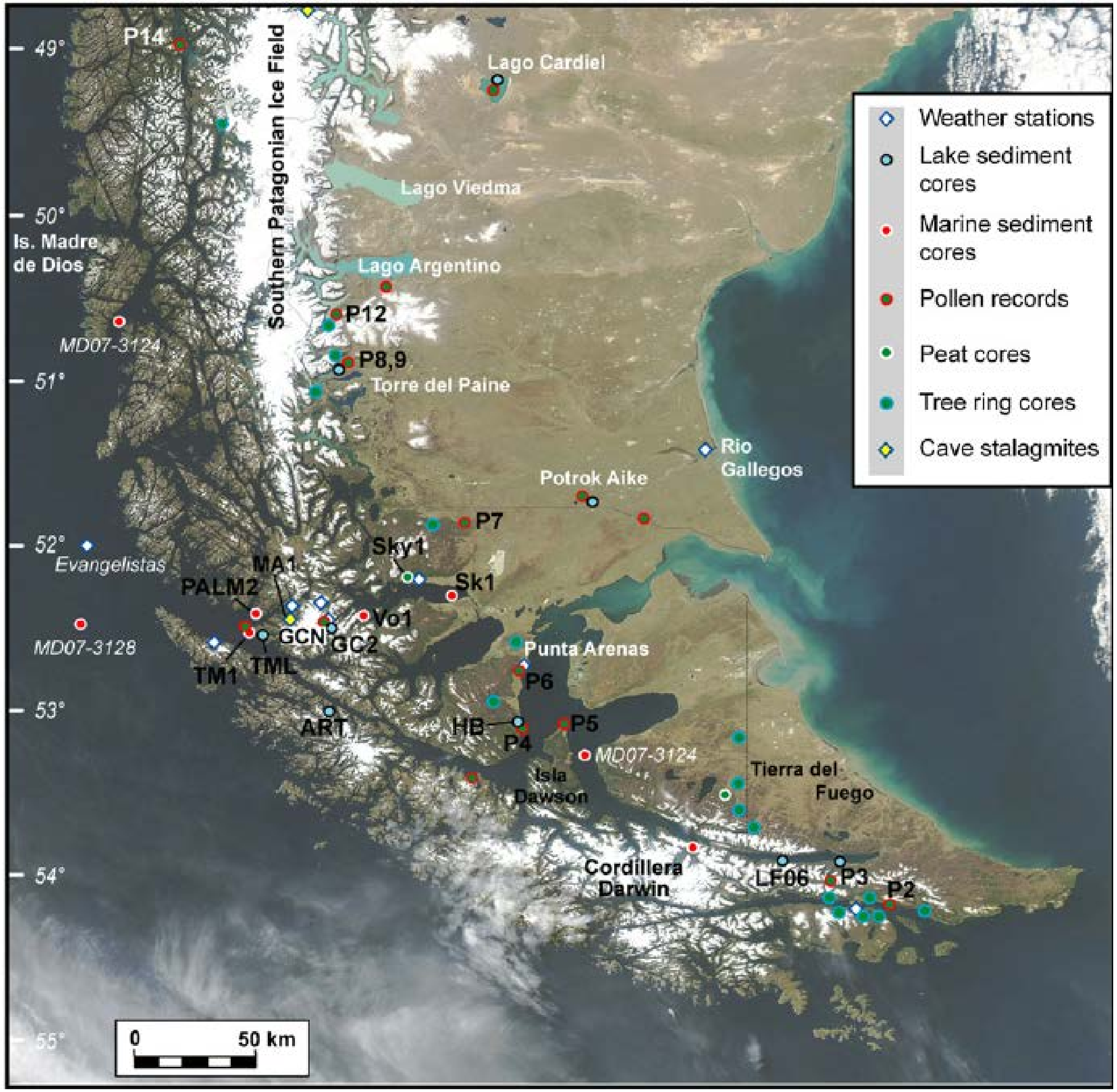


Stable isotopes



Smith and Evans 2007

Not much people or weather stations but plenty of Paleo records in the only SH land mass extending into the core of the westerly wind belt



Kilian and Lamy 2012

Large Scale Control of the Patagonia Climate

(Garreaud 2007; Garreaud et al. 2013)

The hydroclimate variability in Patagonia can hardly be described on the basis of few in-situ records so we attempt linking local climate variability (∂SAT and ∂P) with large-scale circulation anomalies (e.g., ∂U_{aloft}). That will allow:

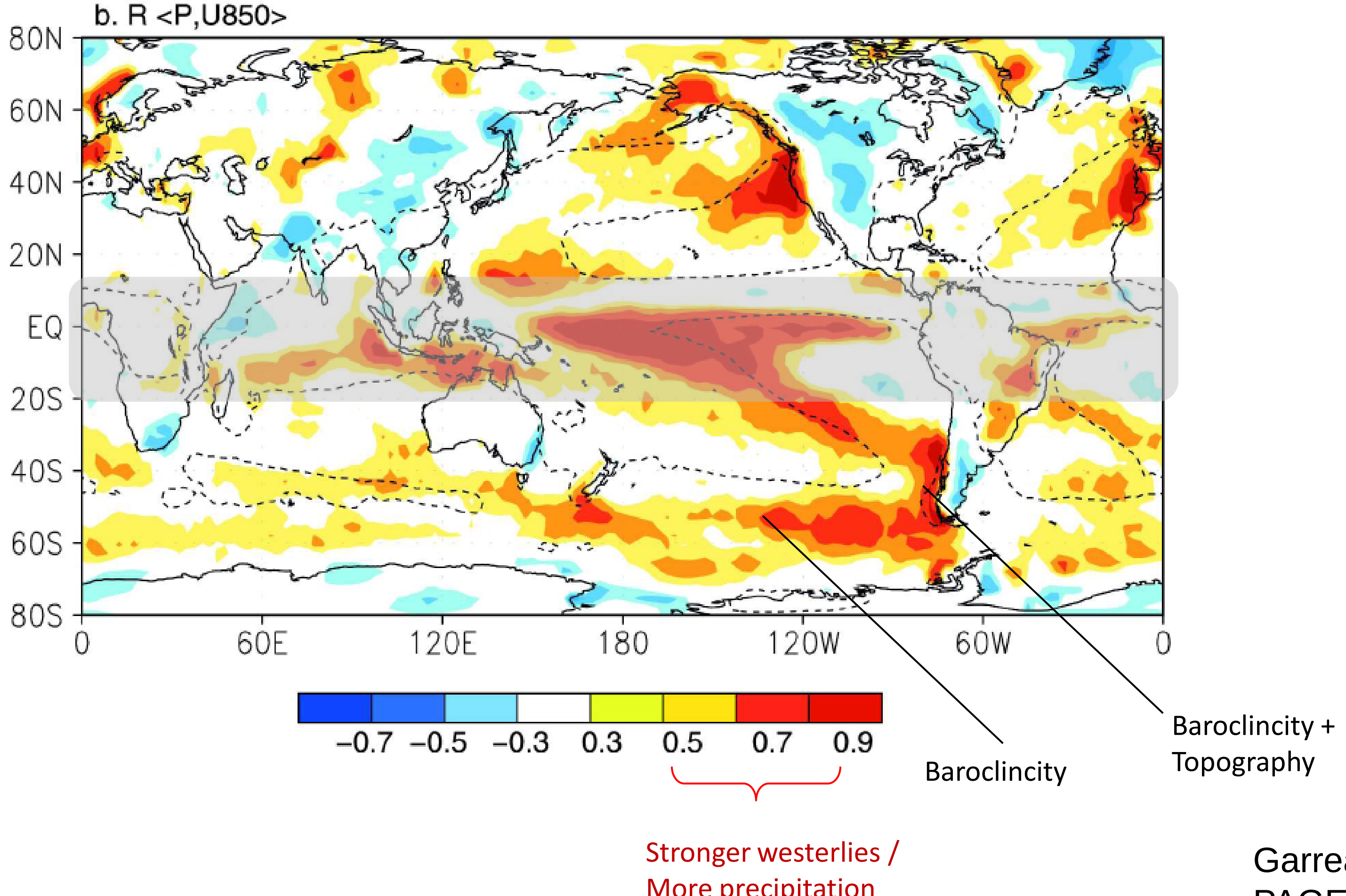
(a) downscale large-scale signals

(b) ***upscale*** local environmental changes.

Co-variability of zonal wind and precipitation

Point-to-point correlation between U850 (*NNR*) and precipitation (*CMAP*)

Both data sets 2.5º×2.5º lat-lon, annual means, 1979-2005



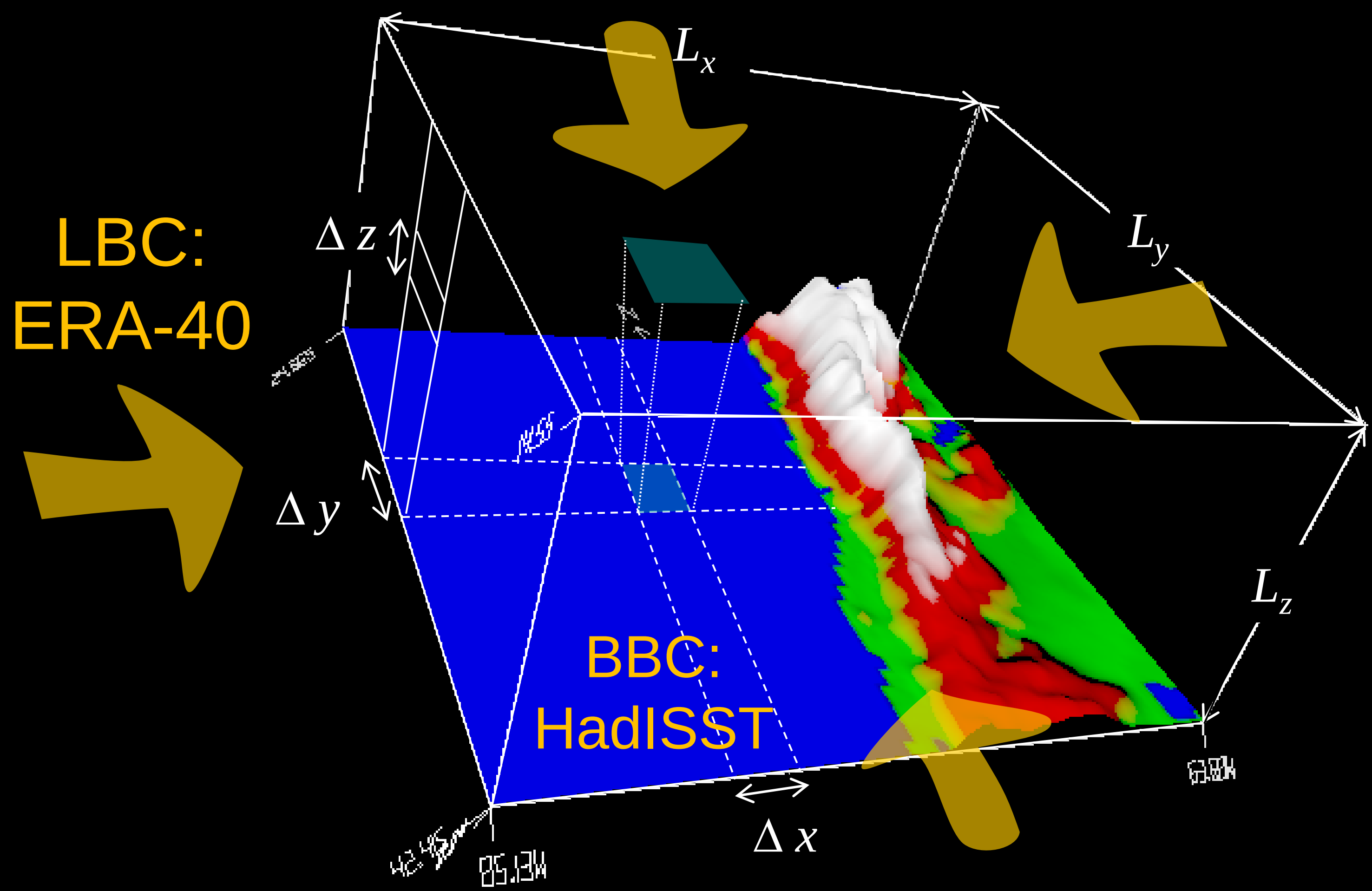
Garreaud 2007
PAGES 2006

PRECIS-DGF Simulation

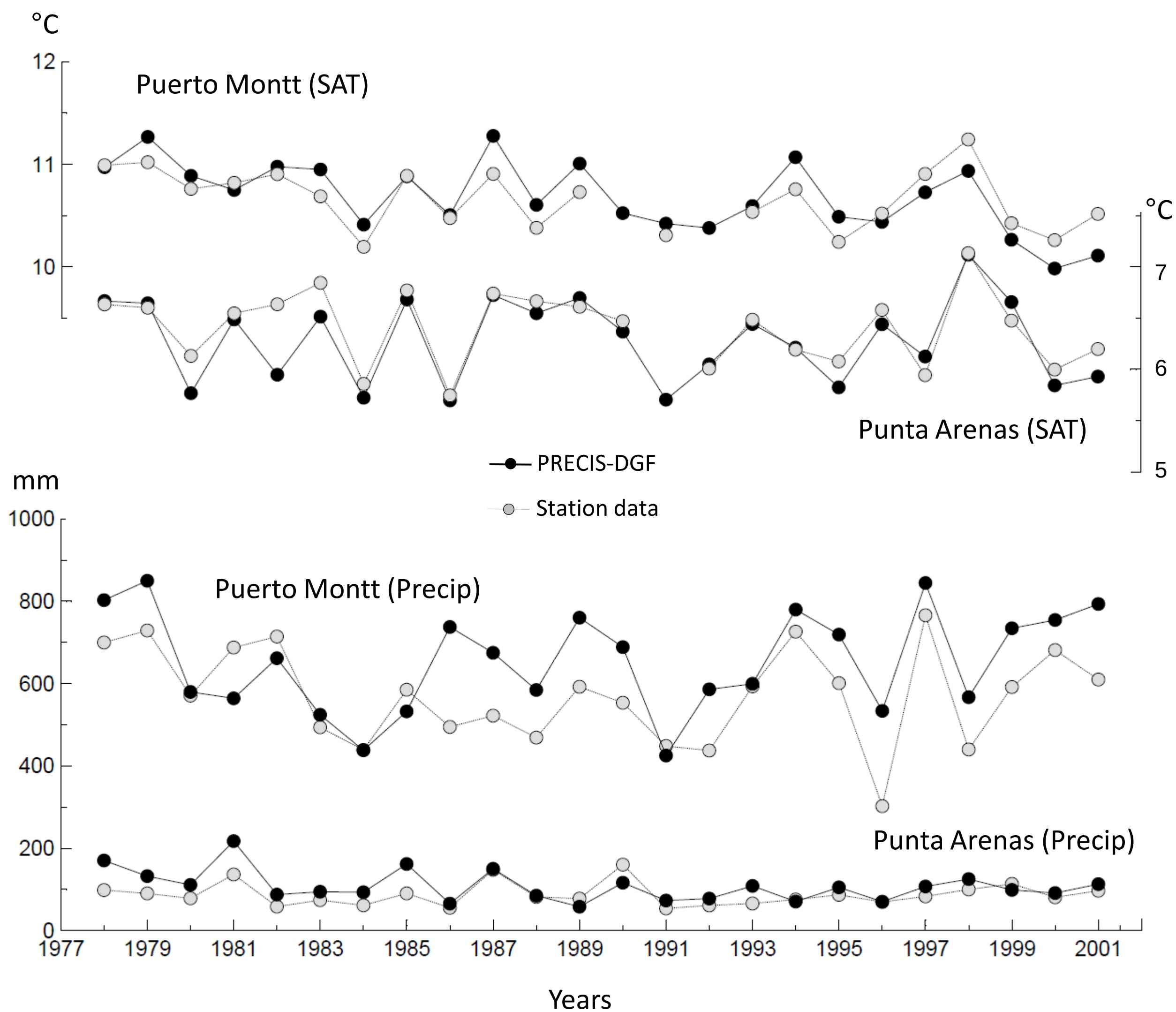
Period: 1978-2001 (avail: 1958-2001)

Hor. Resolution: 25 km

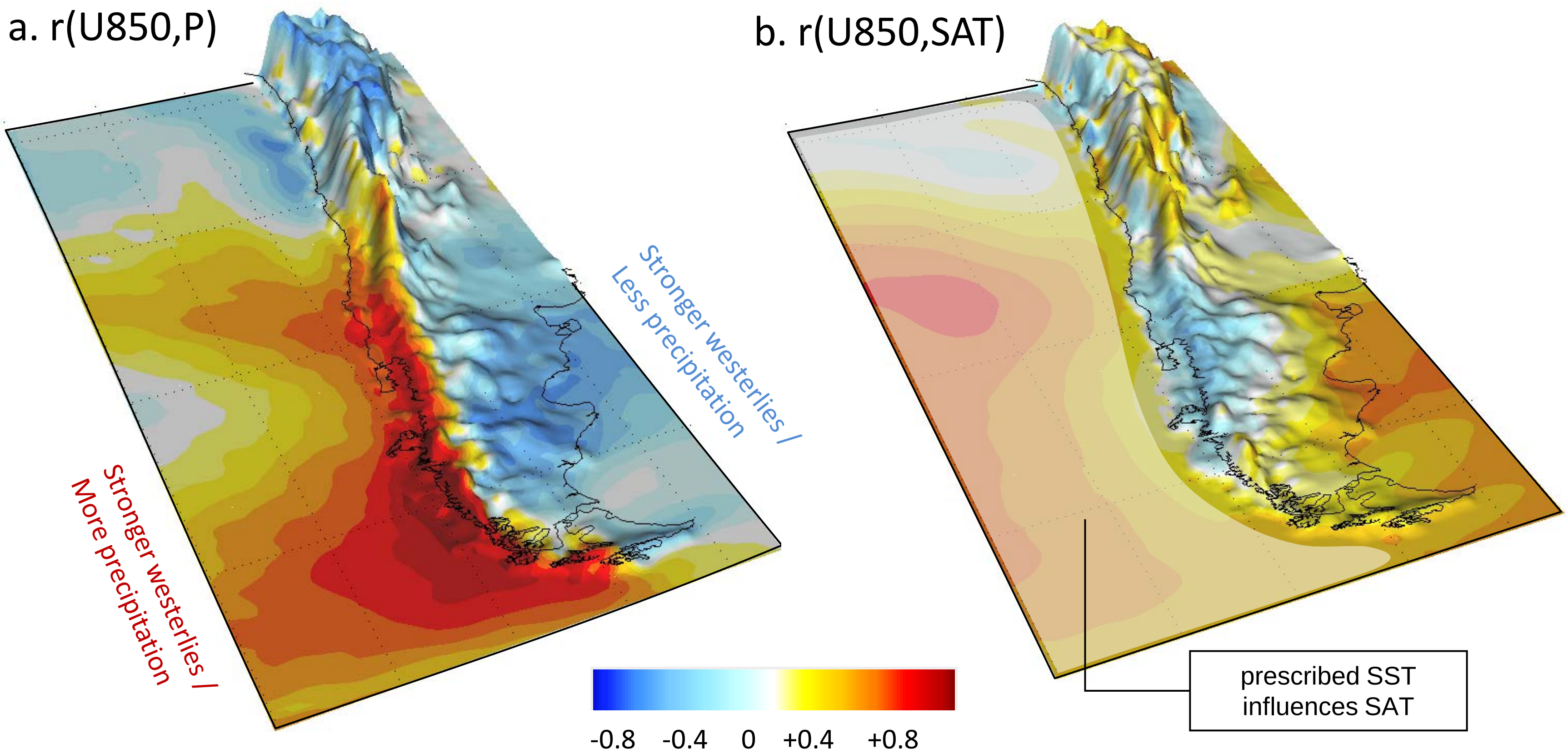
Area: Southern South America



PRECIS-DGF variability against observations…good enough



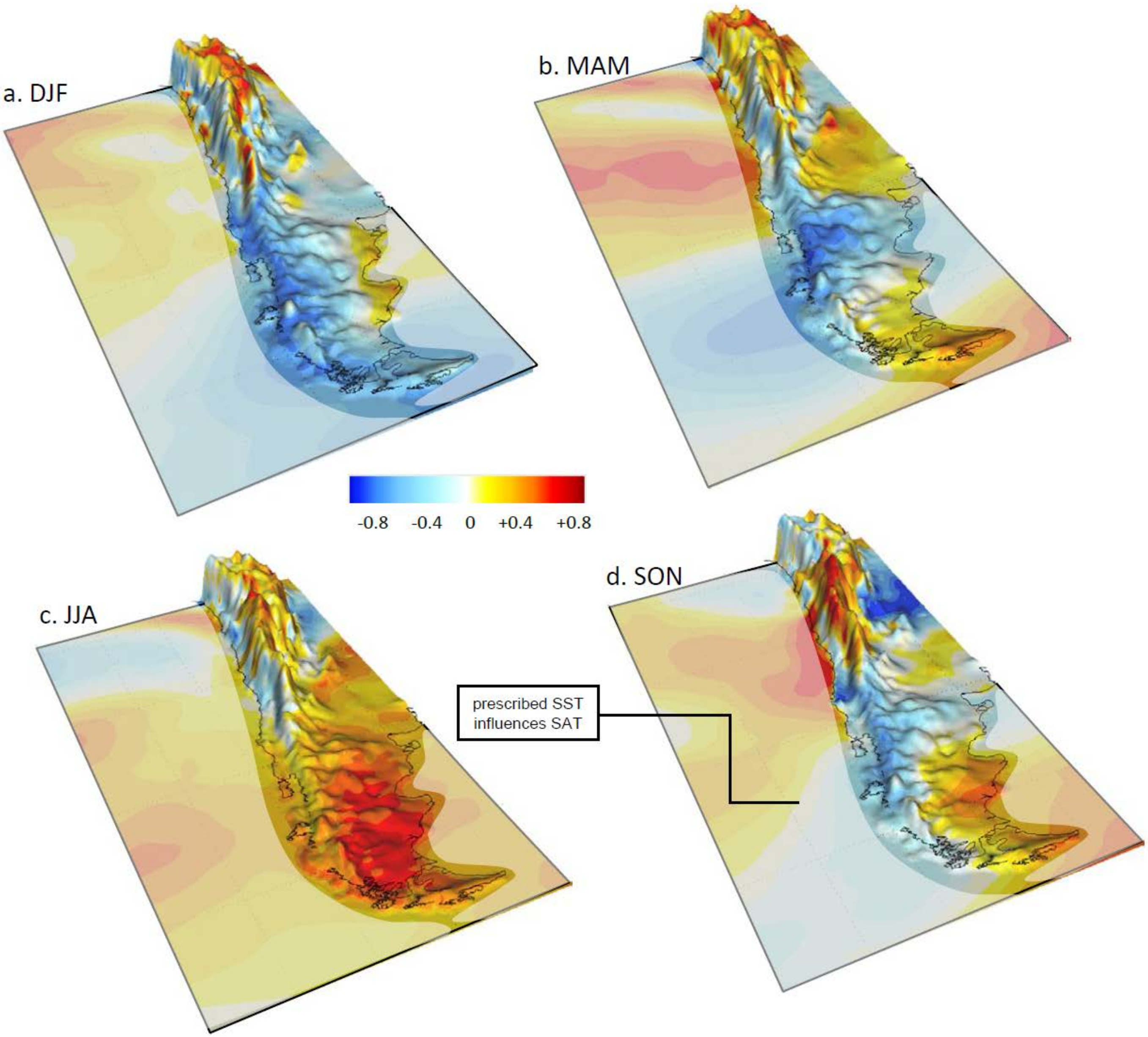
Wind-precipitation and Wind-SAT covariability at annual timescale (year-to-year)



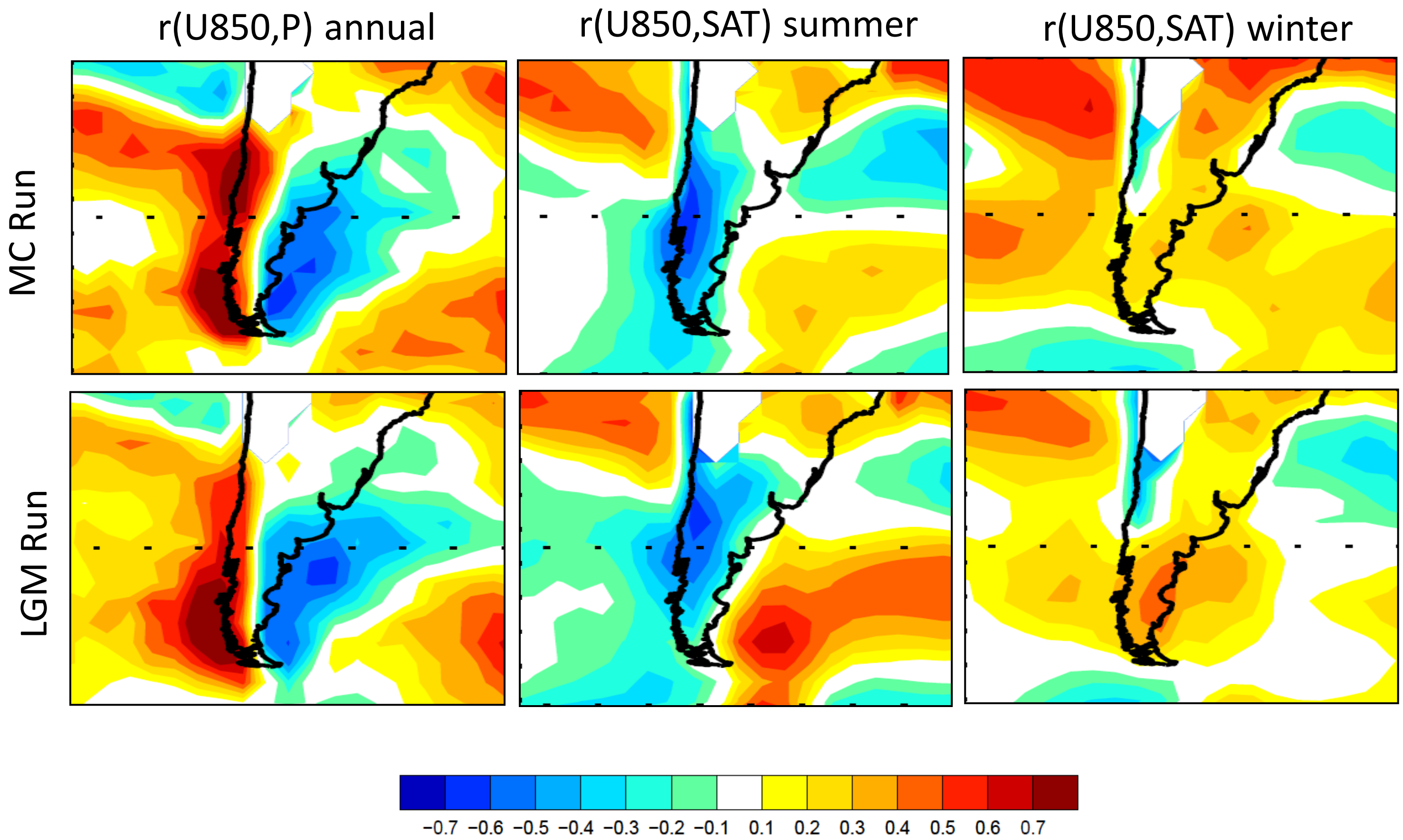
Wind-SAT covariability at annual timescale

Strong westerlies
→ cold summer

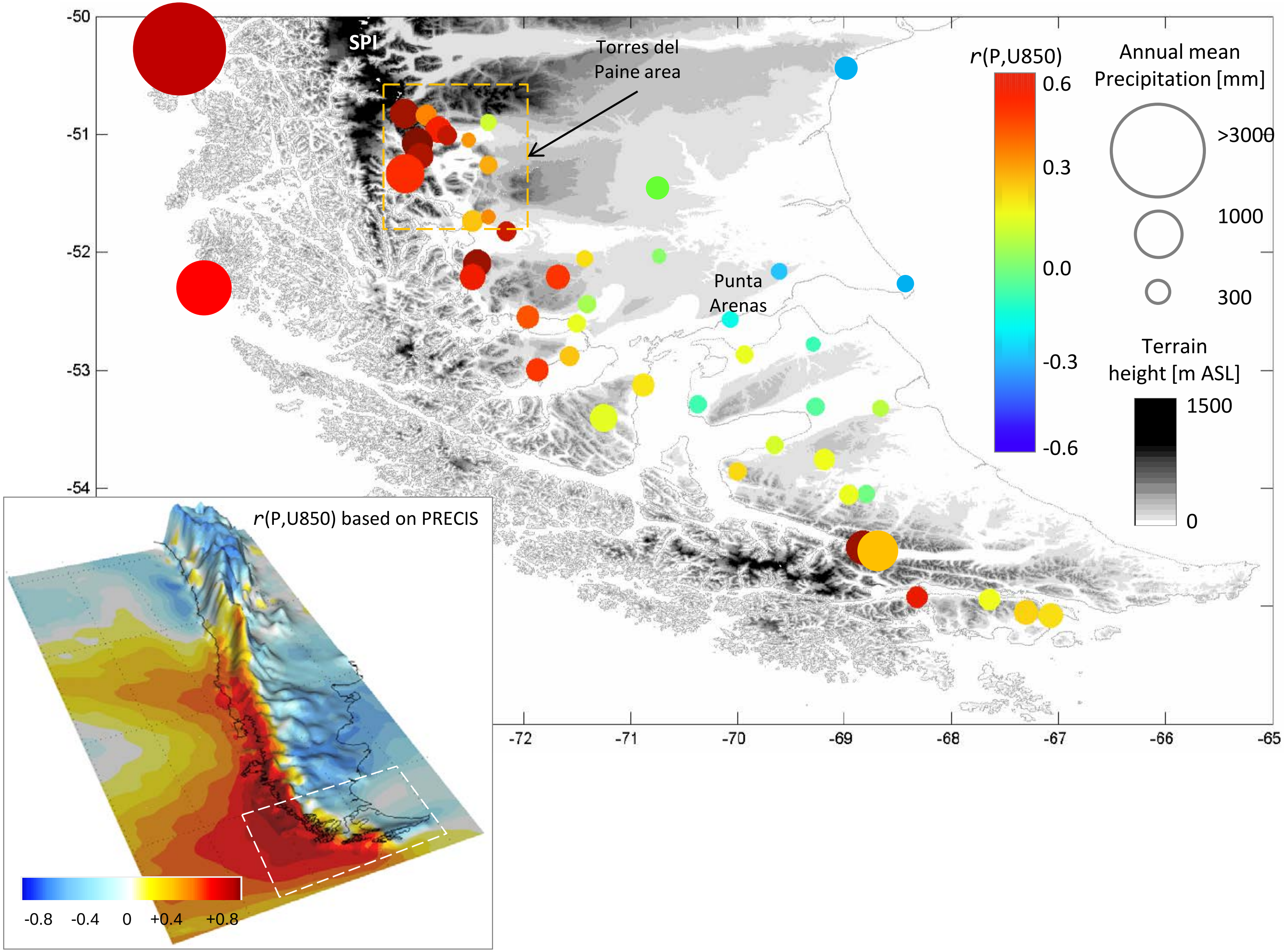
Strong westerlies
→ Warm winter



Stability of the Wind-P/SAT relationship
IPSL GCM



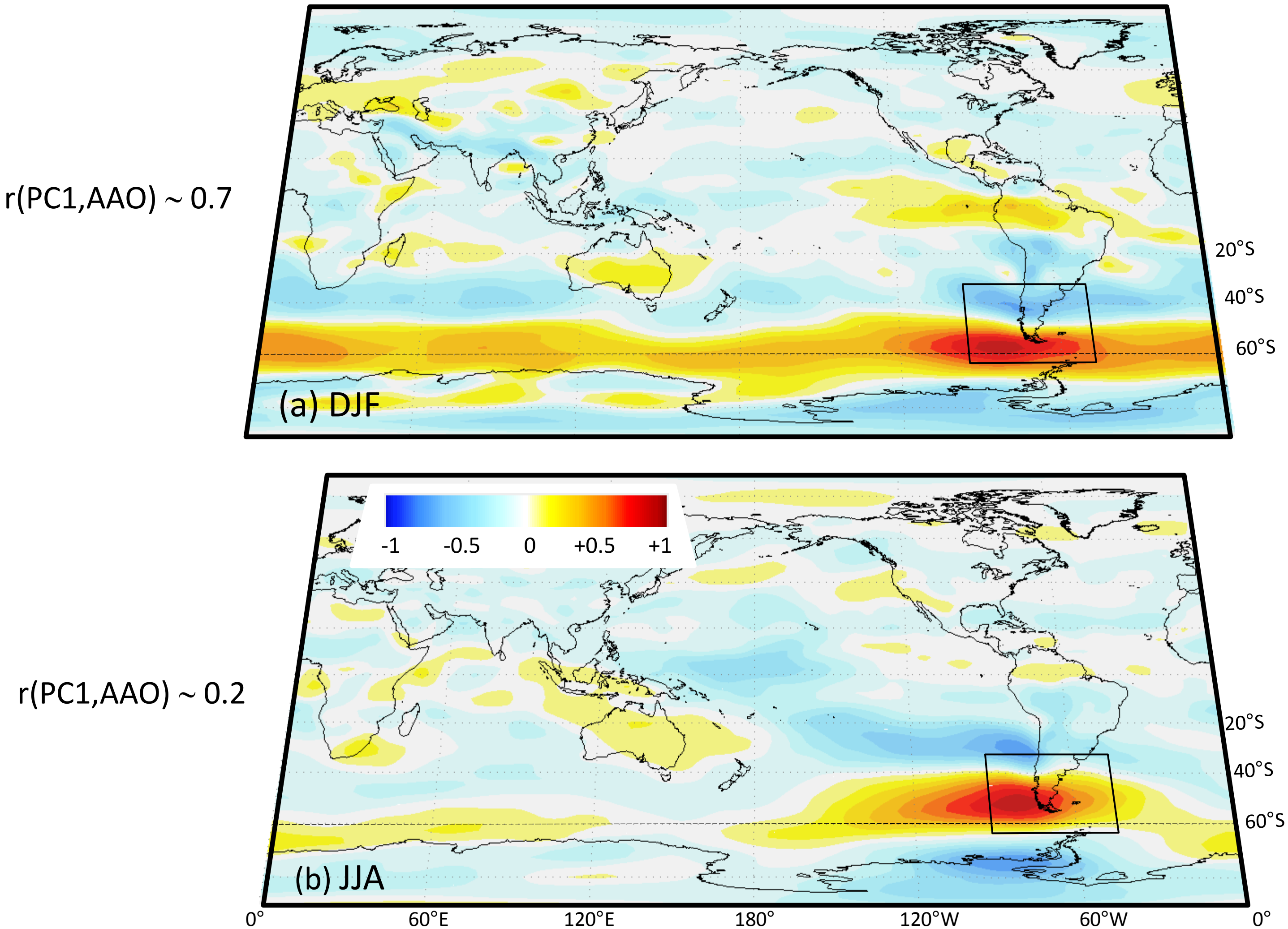
Stronger westerlies/More Precip. up to 50 km downstream of the Mnts.



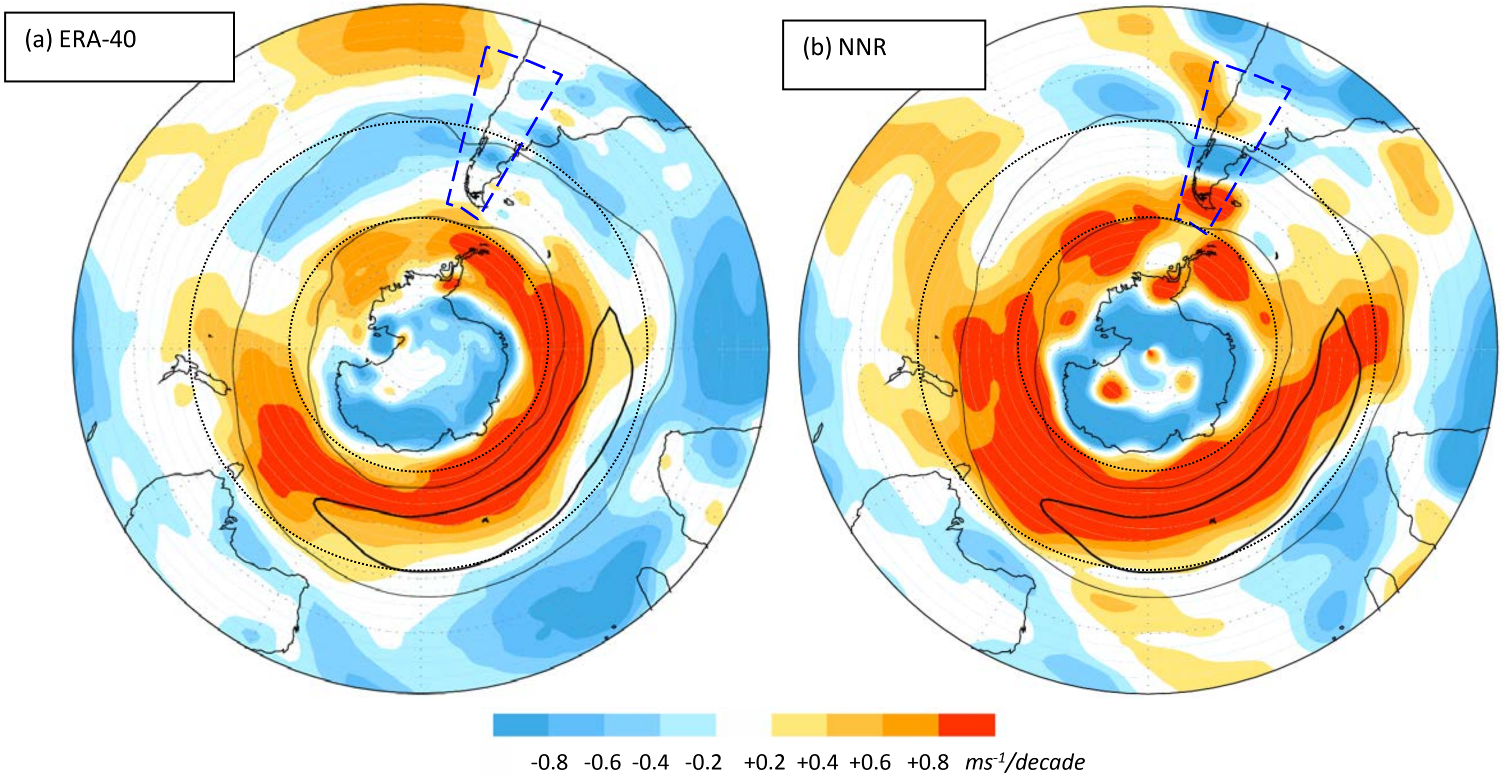
Leading modes of U850' interannual variability

EOF analysis performed each month using NNR & ERA40

First mode accounts for 40-50% of the variance



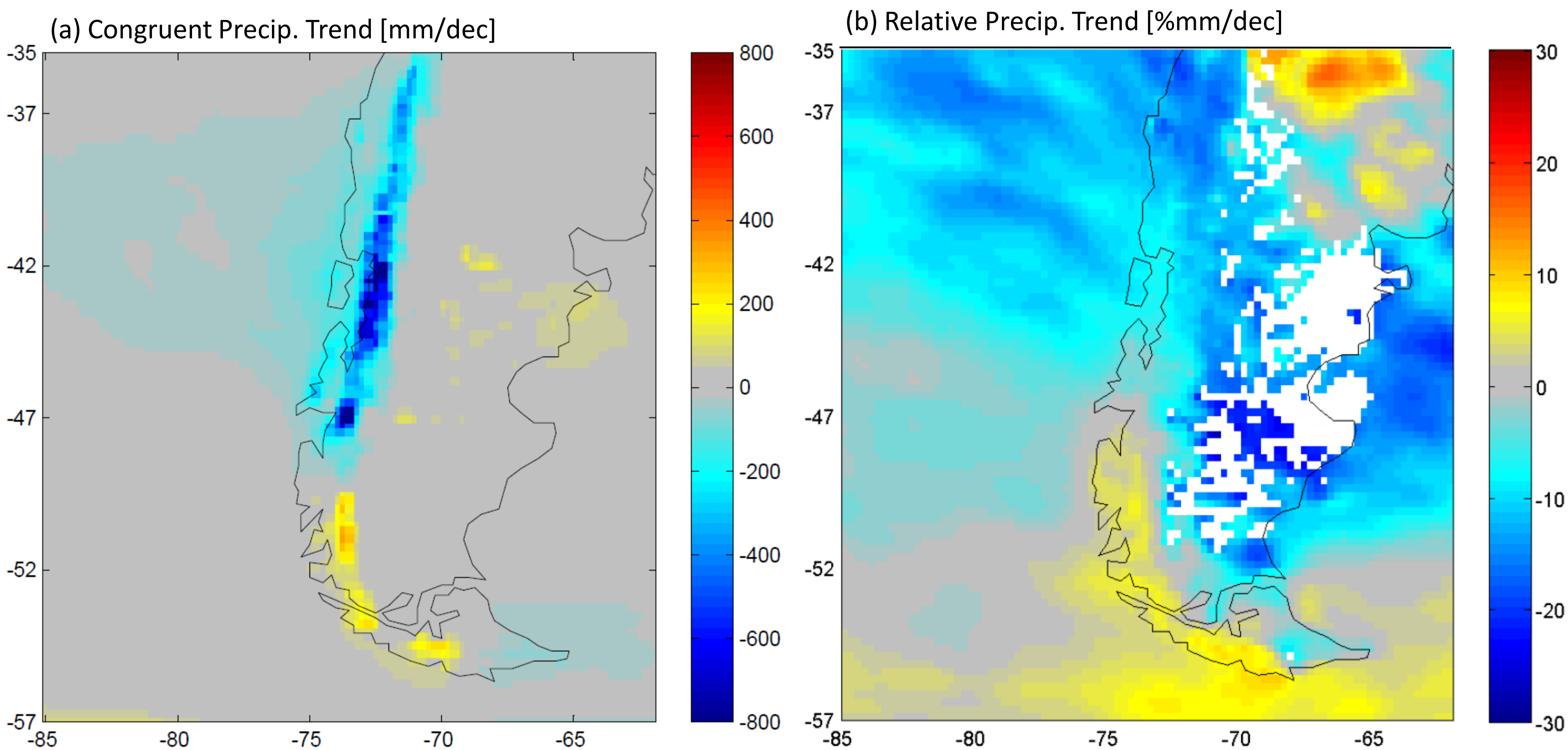
Downscale the U-P, U-SAT relationships



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

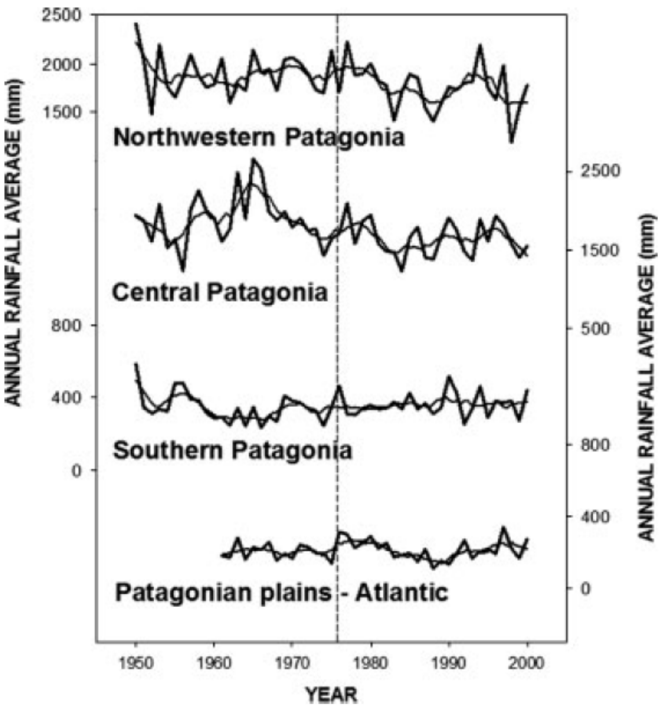
Wind-congruent precipitation trends(1968-2001)

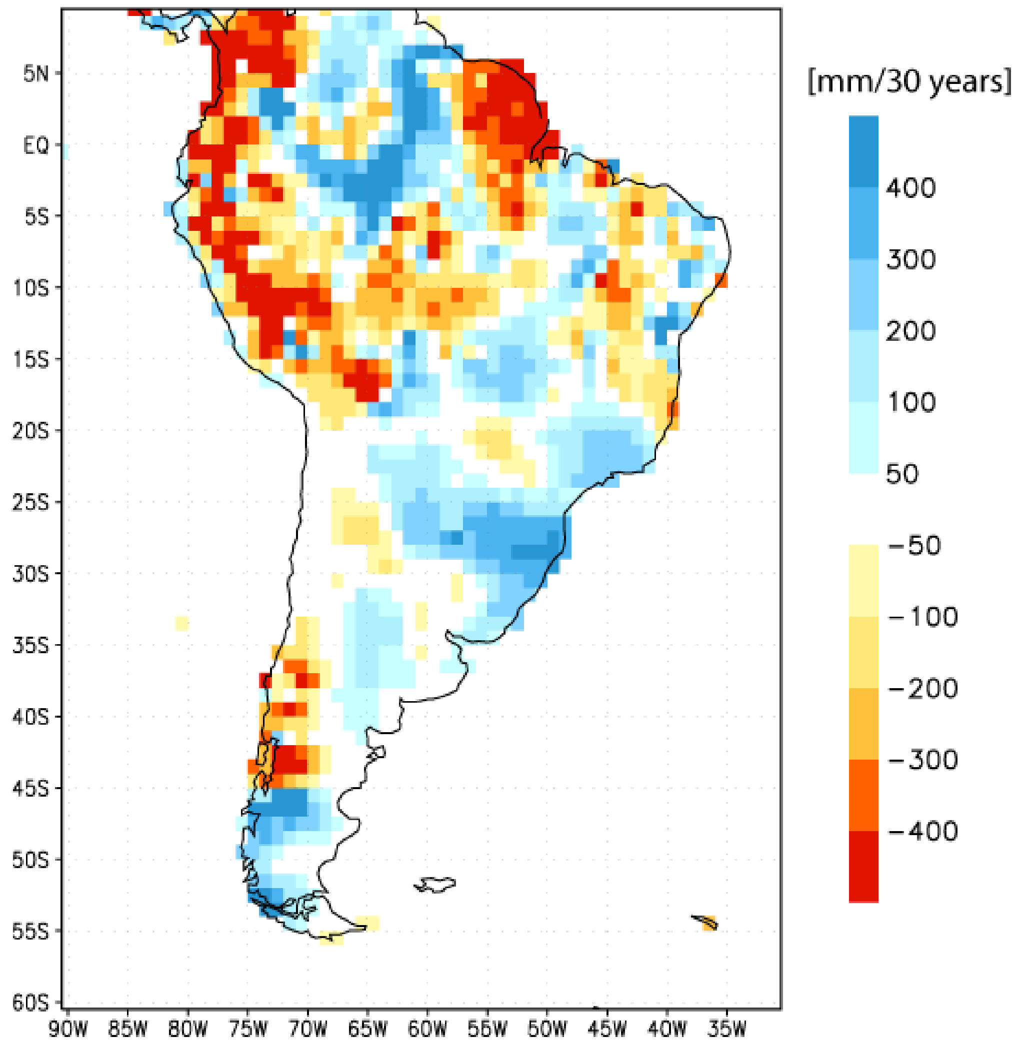
$$\Delta P^* = \beta \cdot \Delta U_{850}$$



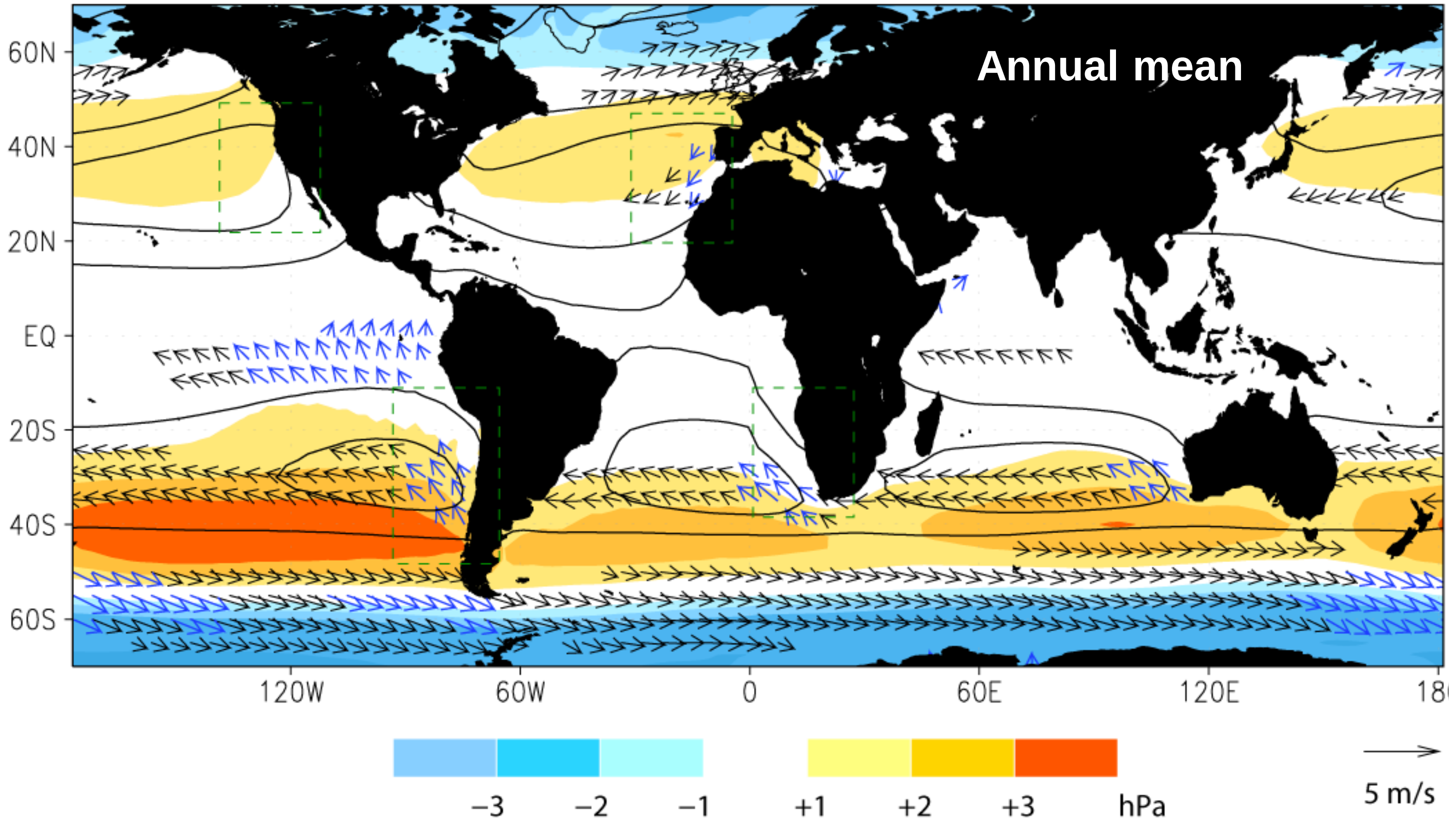
Observed (U.Delaware) Precip trend (1960-2000)

Aravena & Luckman 2010





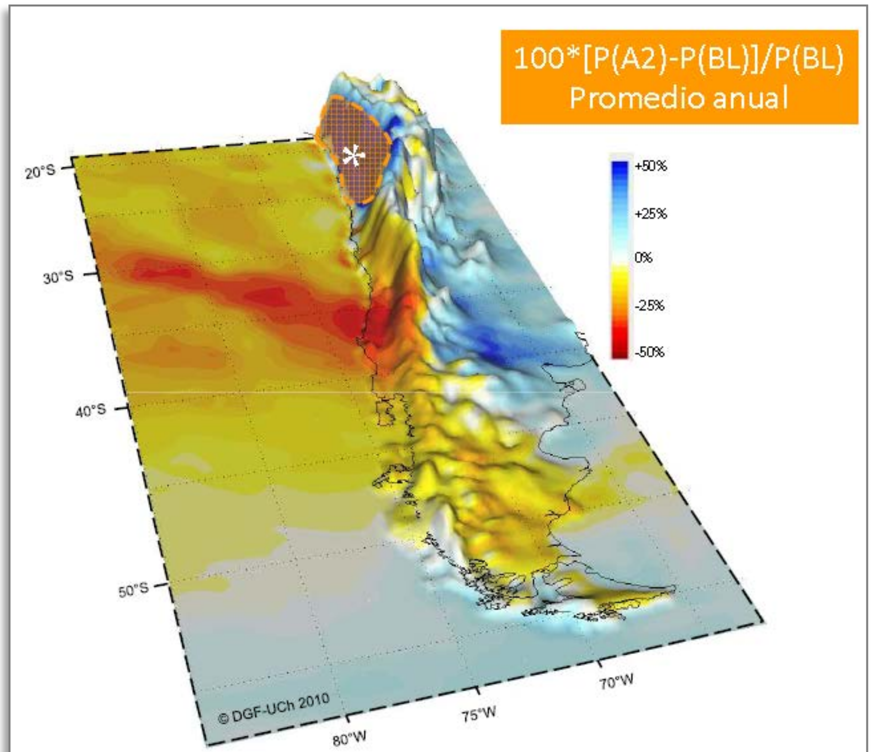
Multimodel average SLP and sfc wind difference betweenA2 (2070-2100) and BL (1970-2000)

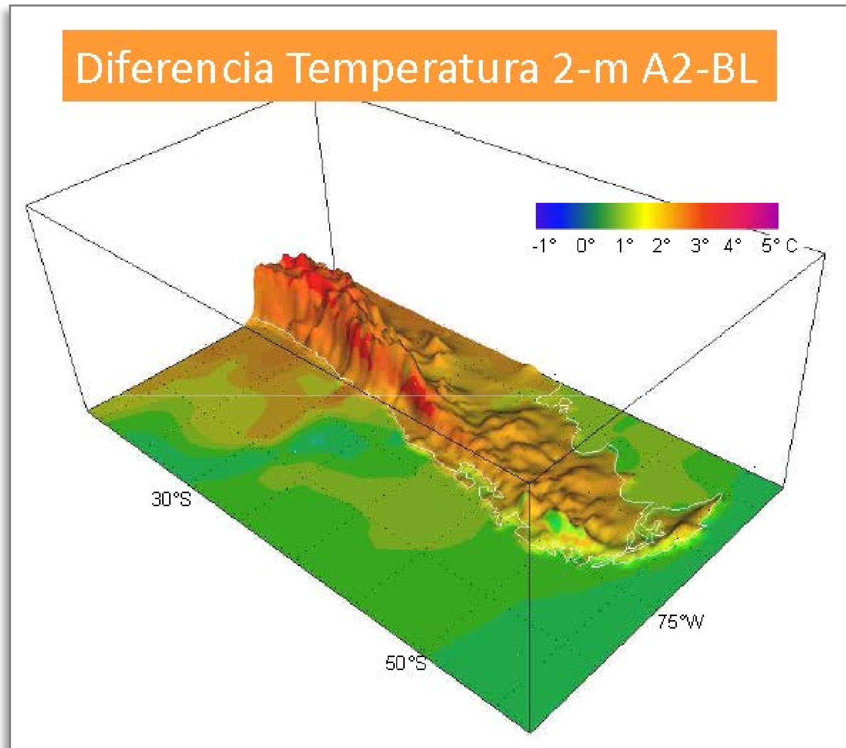


Over open ocean Δv in geostrophic balance with ΔSLP.
Near the coast Δv more controlled by along-coast ΔSLP

Southern SA Climate Change Projections

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





Estudio DGF/UCh-CONAMA 2007 empleando PRECIS

Evidencia de paleo-incendios en Patagonia Oeste sugiere ocurrencia de rayos en esta región

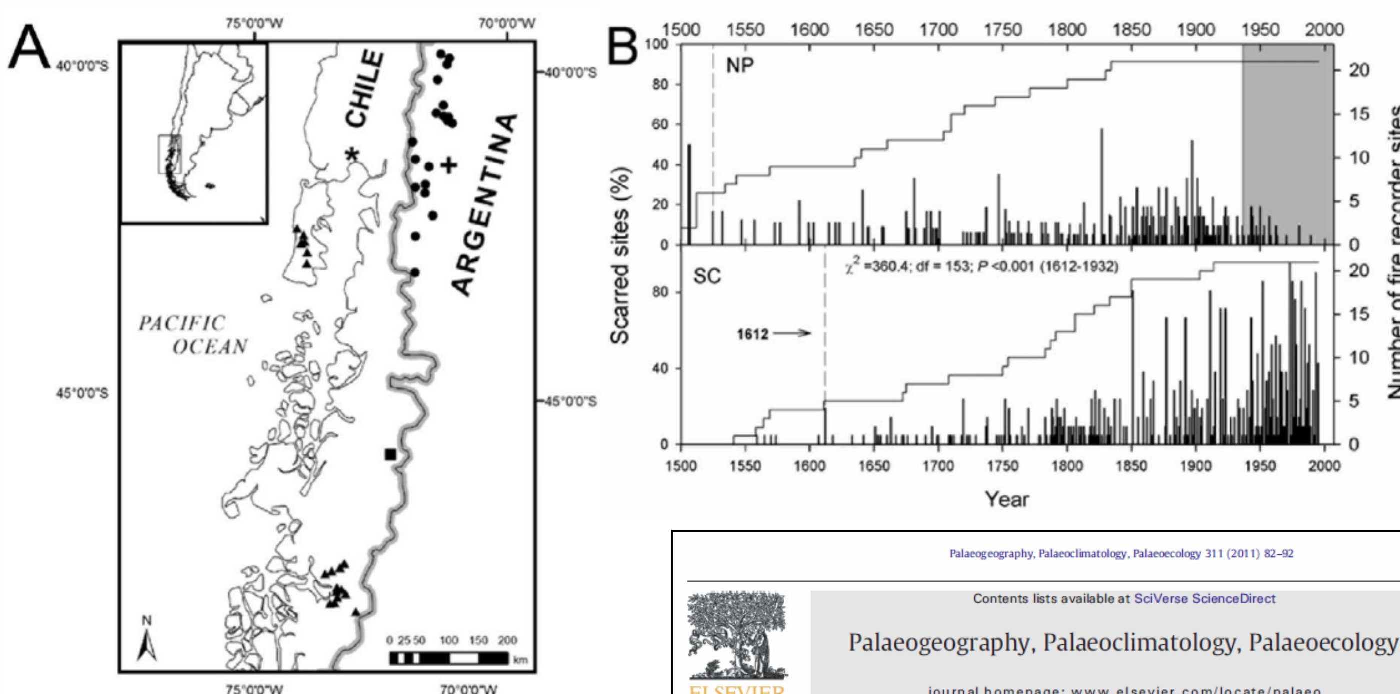


Figure 2. (a) Locations of the regional fire-chronologi
triangles), and of the Puerto Montt (asterisk), Bariloche (
(1500–2004) of all fire events and sample depth of each
period (post-1932) in the NP area). Chi-square and p-va
(≥10% of all sites in each area, with a minimum of two s
Vertical dashed-lines and “1612→” indicate the start year of the fire chronology and of analysis.

Palaeogeography, Palaeoclimatology, Palaeoecology 311 (2011) 82–92

Contents lists available at SciVerse ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

ELSEVIER

The amplifying effects of humans on fire regimes in temperate rainforests in western Patagonia

Andrés Holz *, Thomas T. Veblen
Department of Geography, University of Colorado, Boulder, CO 80309 USA

Cloud electrification 101

Cloud electrification in convective clouds due to elctrostatic induction and depends on microphysical factors ($q_{droplet}$, q_{ice} > 0 in a deep layer between 0 and -40°C) and dynamical factors (strong ($w \geq 5$ ms^{-1}) and sustained updraft in the mix-phased layer).

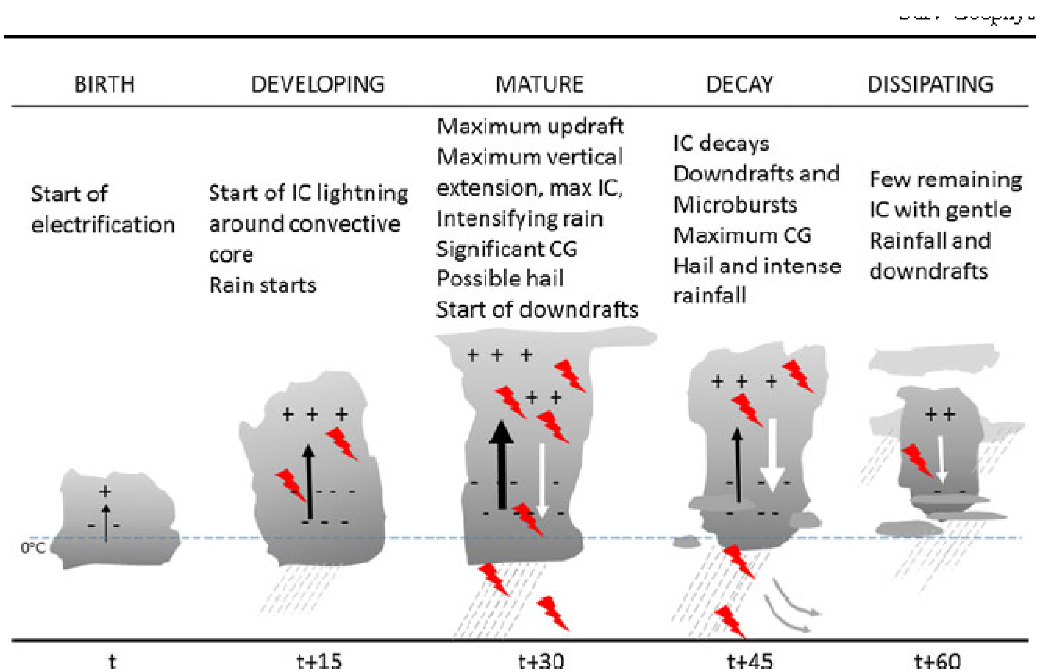
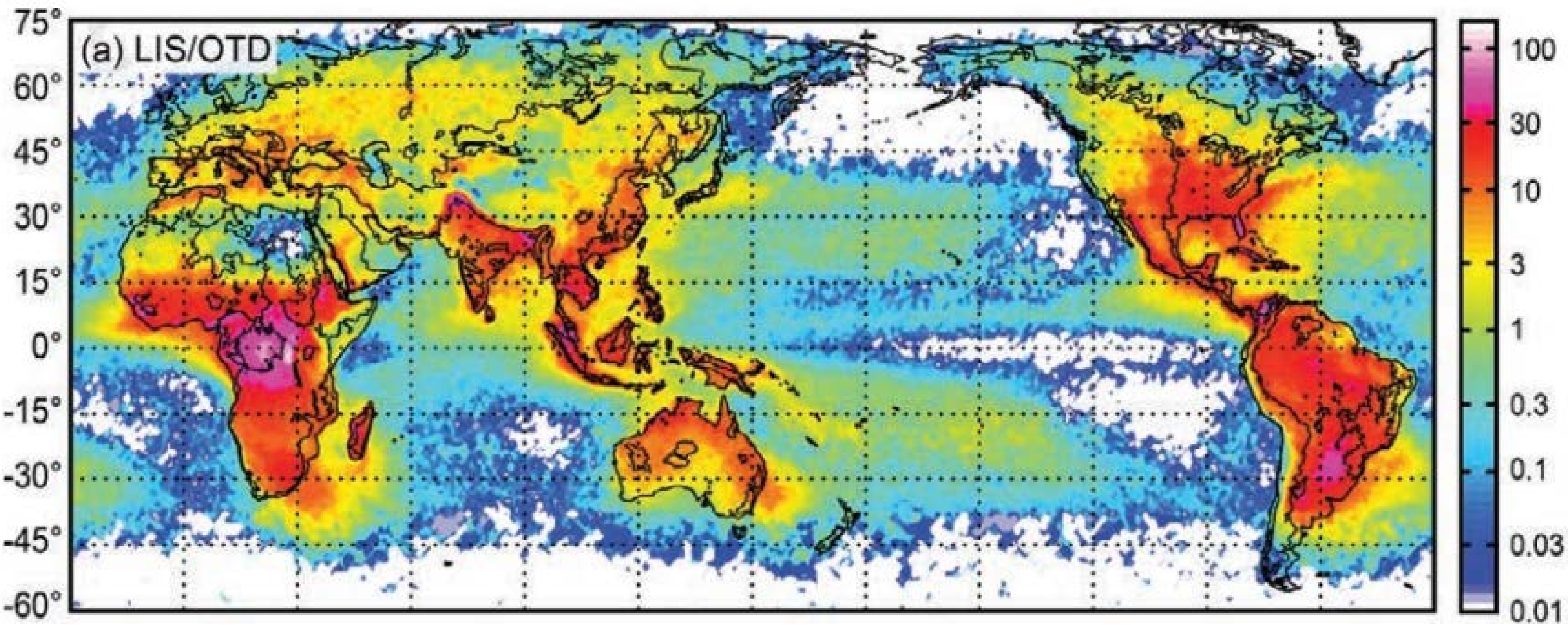


Fig. 1 The various stages of development and decay of a thunderstorm cell and the associated lightning and possible severe weather associated with each stage. Updrafts (*black arrows*) and downdrafts (*white arrows*) are shown relative to their intensity. IC and CG lightning are show in *red* either in cloud or below cloud base. The approximate time (minutes) between each stage is shown below

C. Price 2012

The Lightning Imaging Sensor (LIS)

LIS is on board of the Tropical Rainfall Measuring Mission (TRMM) detecting the discrete optical pulses associated with changes in cloud brightness at each pixel.



World Wide Lightning Location Network (WWLLN)

It monitors the VLF radio waves (sferics) emitted by lightning and uses a time of group arrival technique to locate lightning strokes within ~5 km and <10 μs. Online data available at: http://wwlln.net/

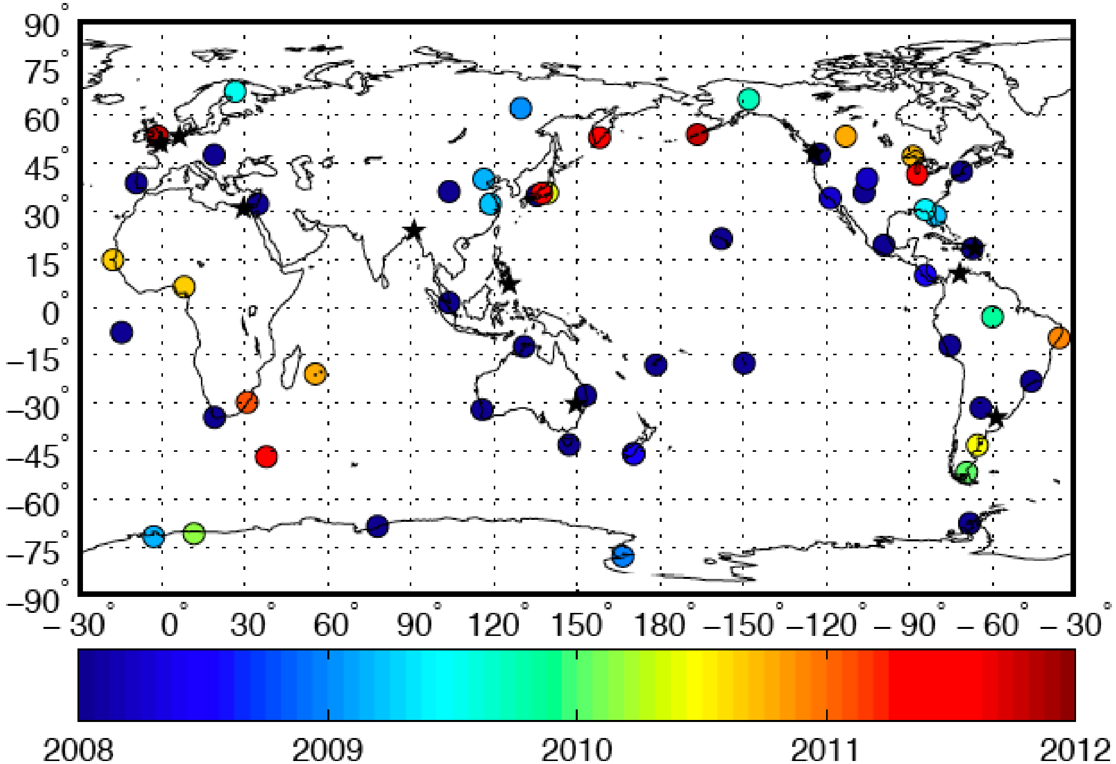
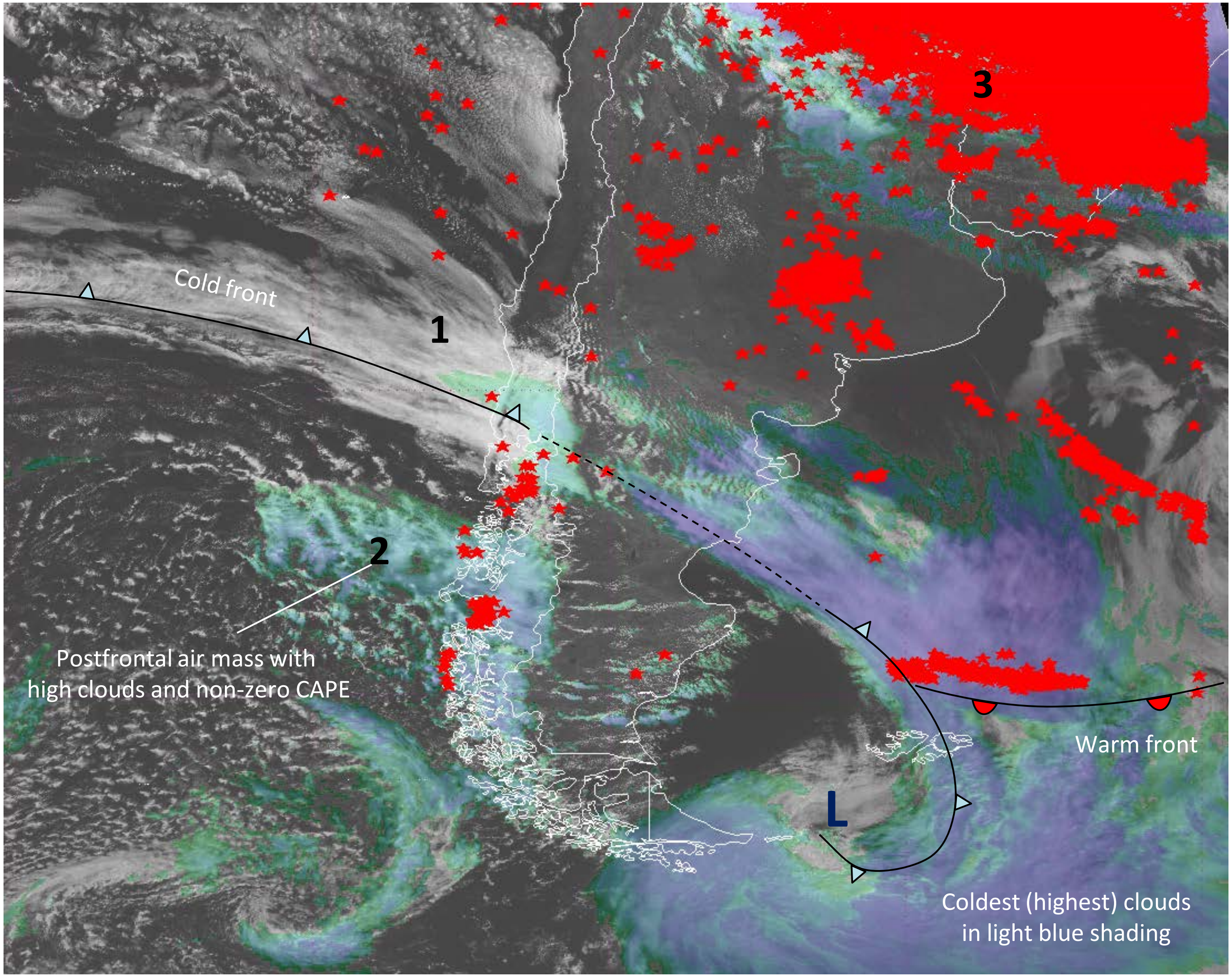


Figure 1. Location of WWLLN sensors, color-coded according to the date each was established. Stations established prior to 2008 are shown in dark blue; black stars indicate stations established 2012-present.

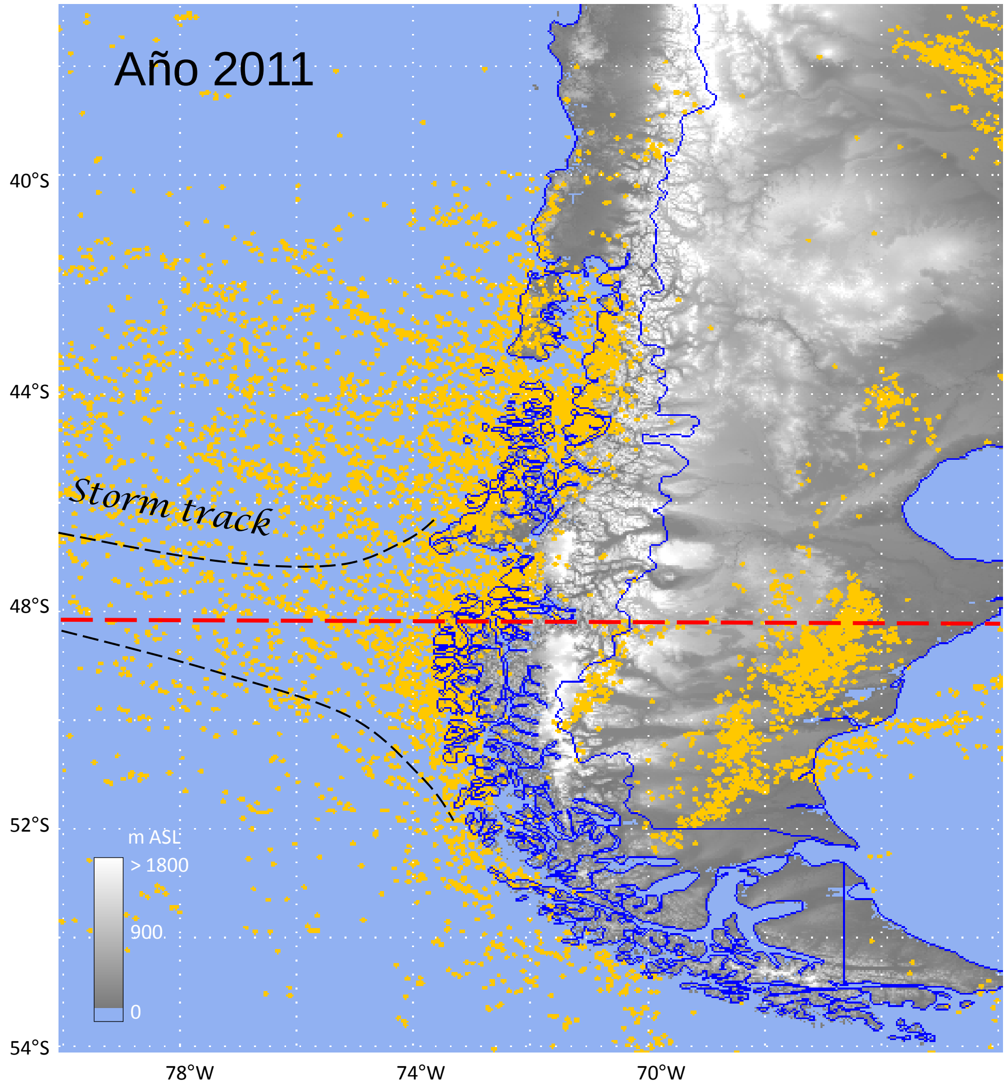
Virts et al. 2013

January 6, 2013 – 1800 UTC

GOES-13 Visible (BW) and IR4 (light shading) + WWLLN Lighting (stars)

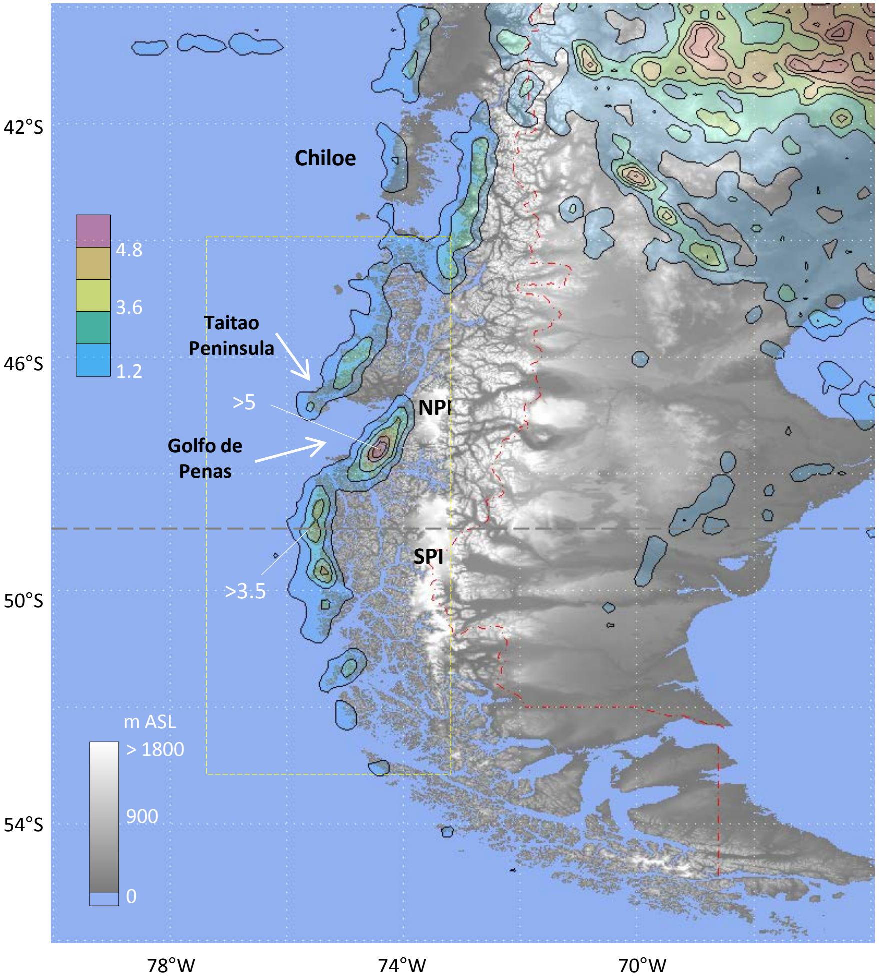


Spatial Distribution (2008-2012)

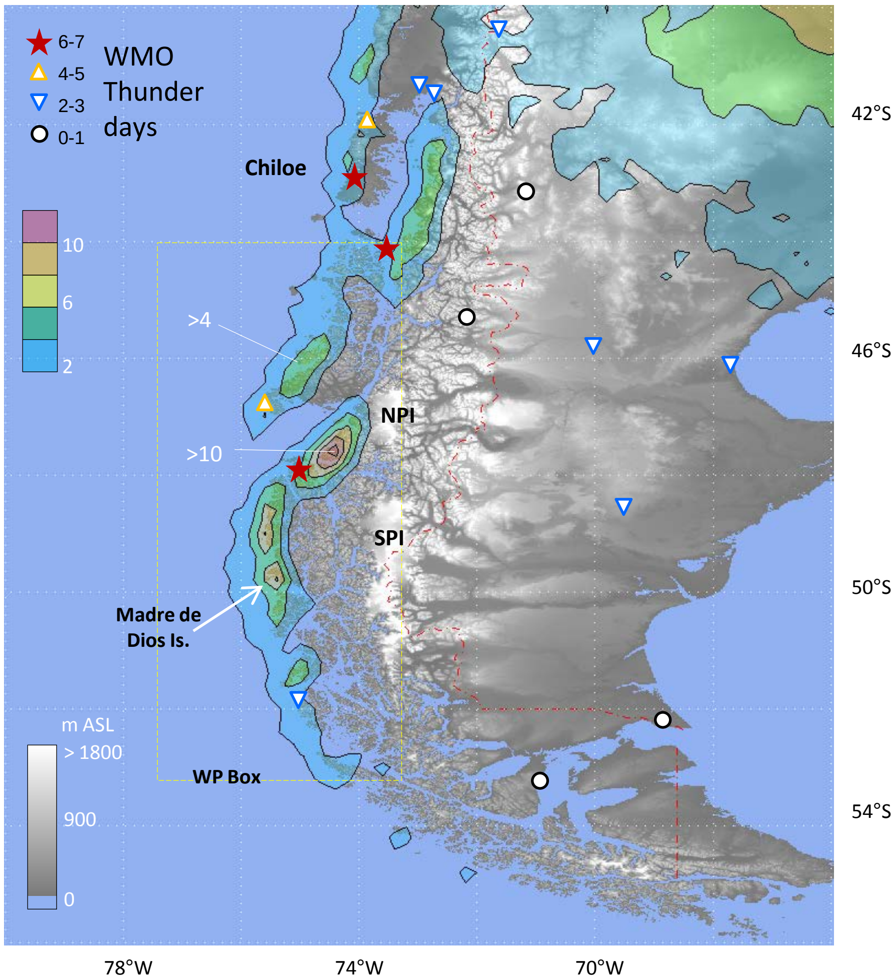


Spatial Distribution (2008-2012)

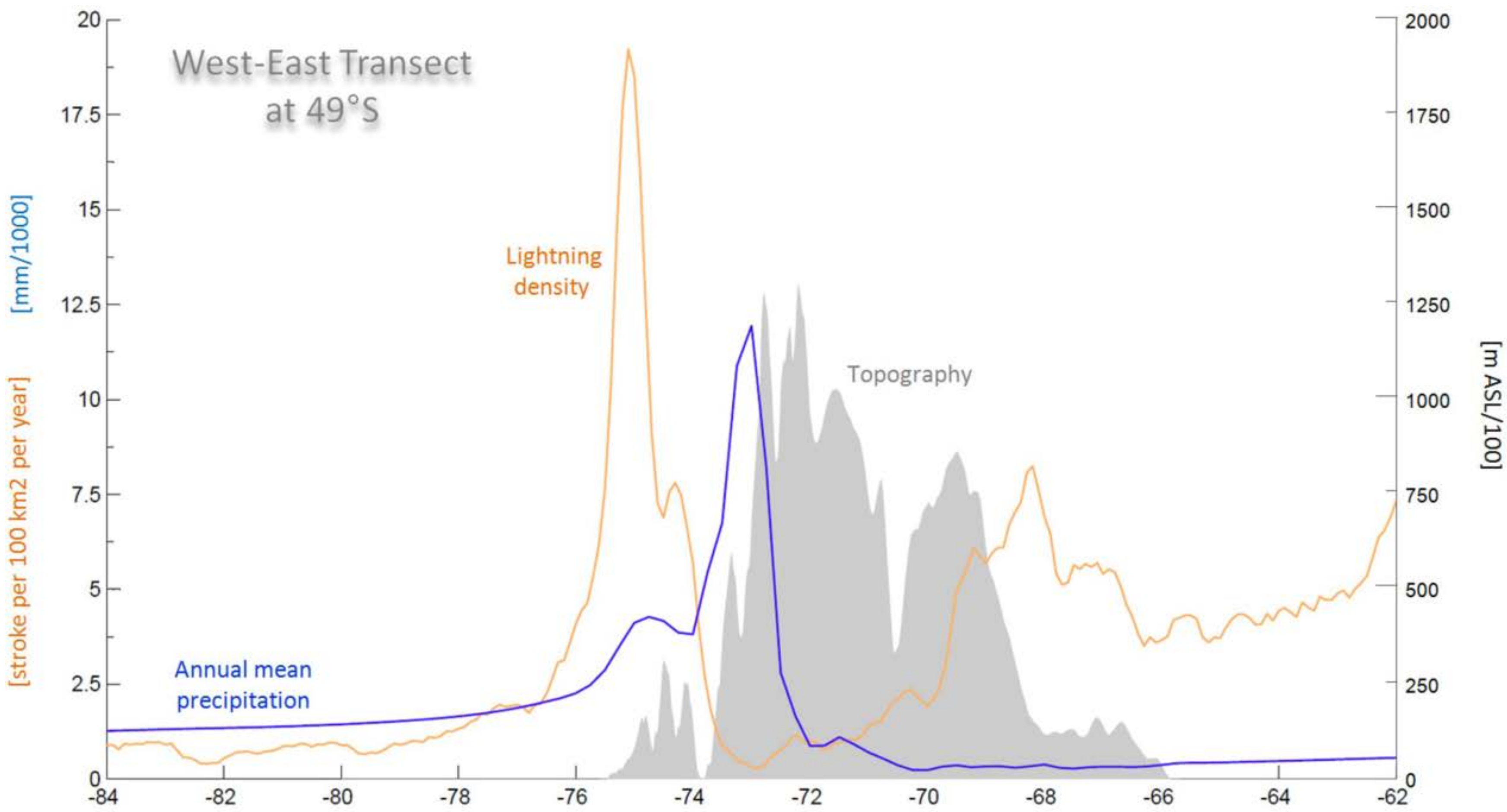
Lightning density, 0.1×0.1 lat-lon boxes



Number of lightning-days, 0.2×0.2 lat-lon boxes



Spatial Distribution (2008-2012)



Lightning distribution

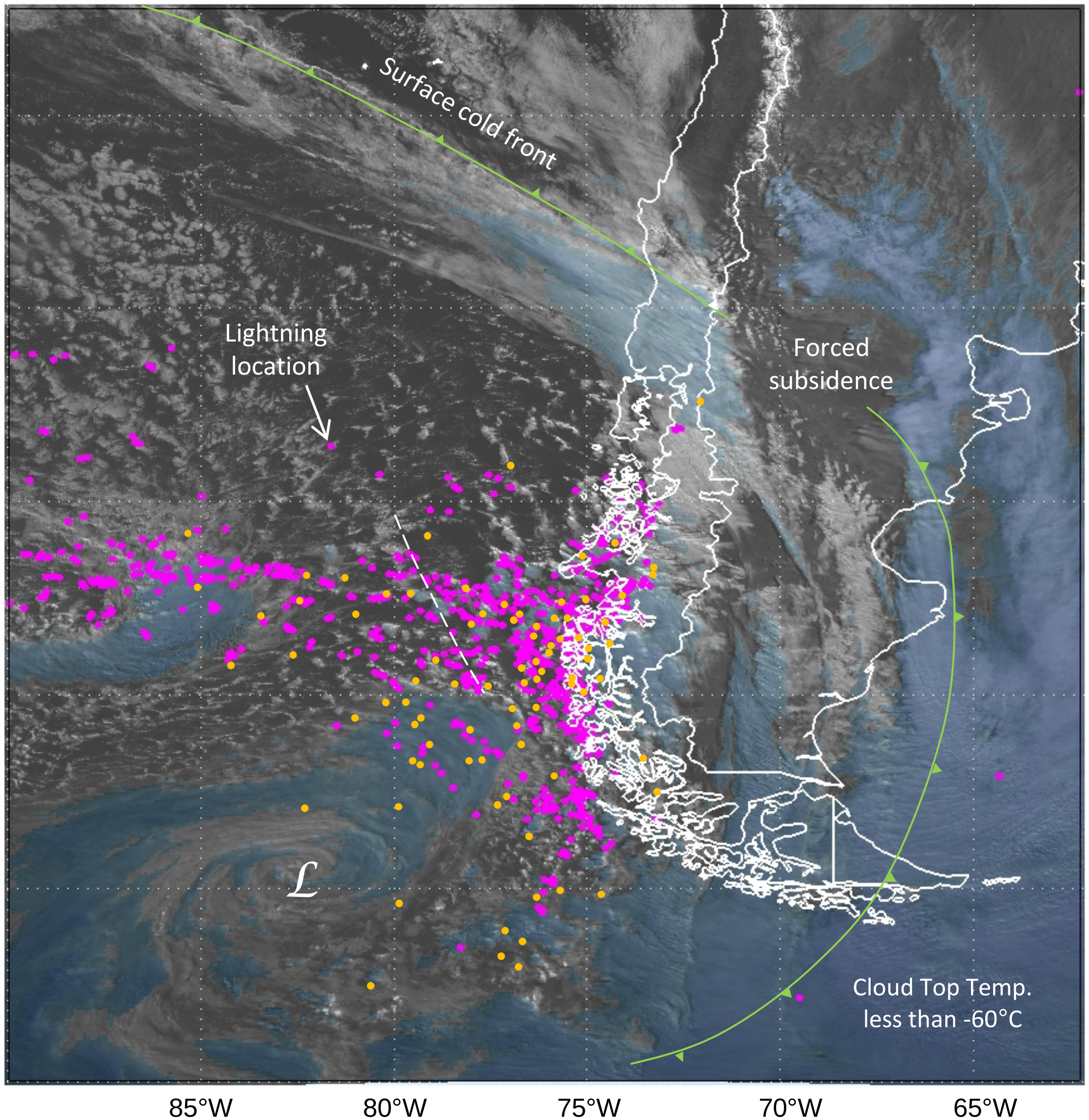
- Spatial distribution of lightning density and number of days with lightning: clustering at the coastline but some flashed offshore as well. No flashes inland!
- Small annual/diurnal cycle. Little interannual variability (may be affected by network efficiency)
- Lightning days cluster in 1-4 day events. Many storms (rainfall events) without lightning.

A case of study (30-04-2012)

- Let’s consider the event 30-Apr 03-May 2012. The first day has the highest number of flashes over WP on record.
- A slow moving, mature midlatitude cyclone over the south Pacific. Cold front intersect the Chilean coast at about 40°S. Highest precip. over the Andes.
- Cold advection at low and mid levels over relatively warm waters create weakly unstable environment off WP (CAPE>50).
- Shallow convective clouds evident in GOES-VIS and CloudSAT collocated with area with flashes.

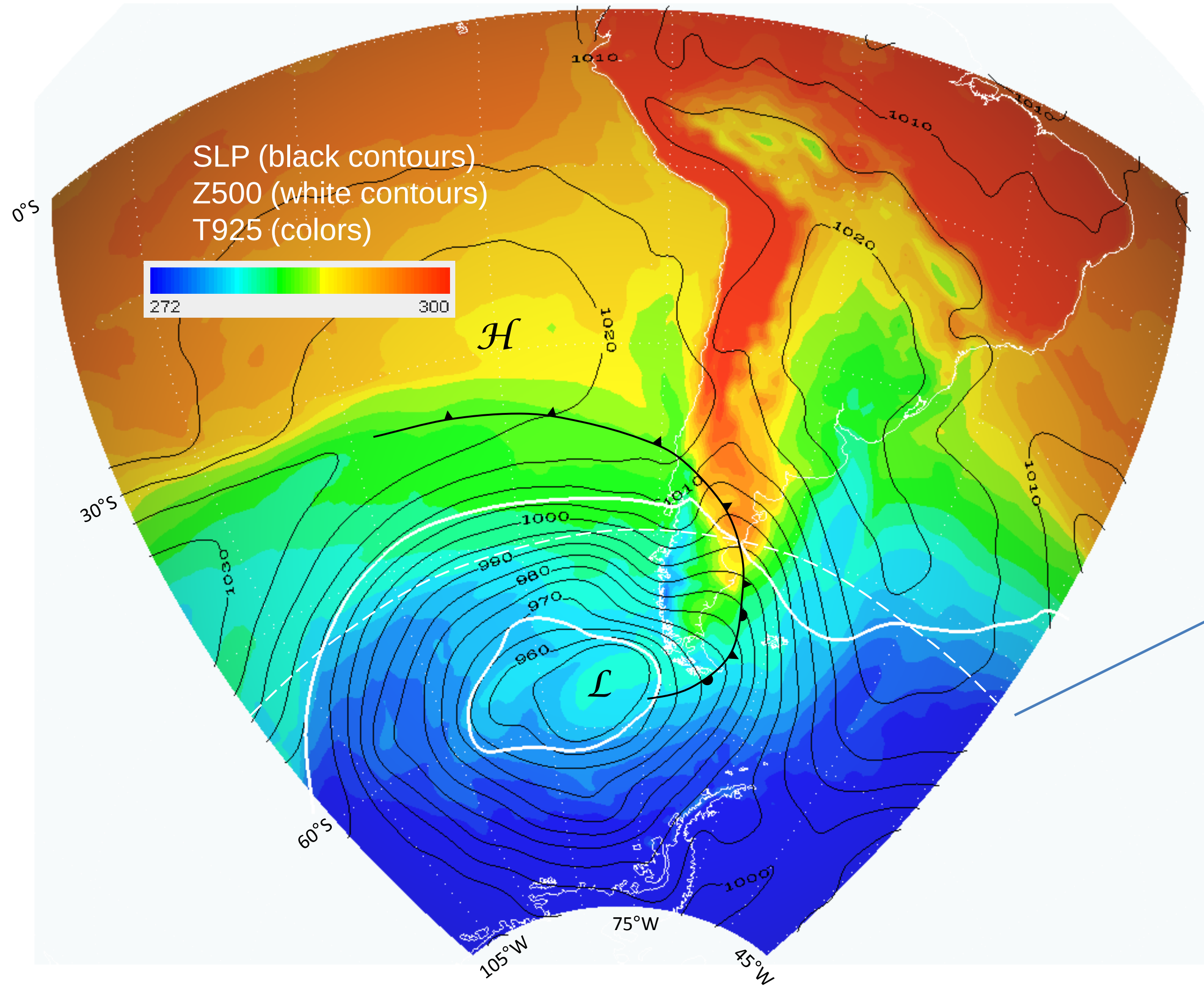
April 30, 2012 – 1800 UTC

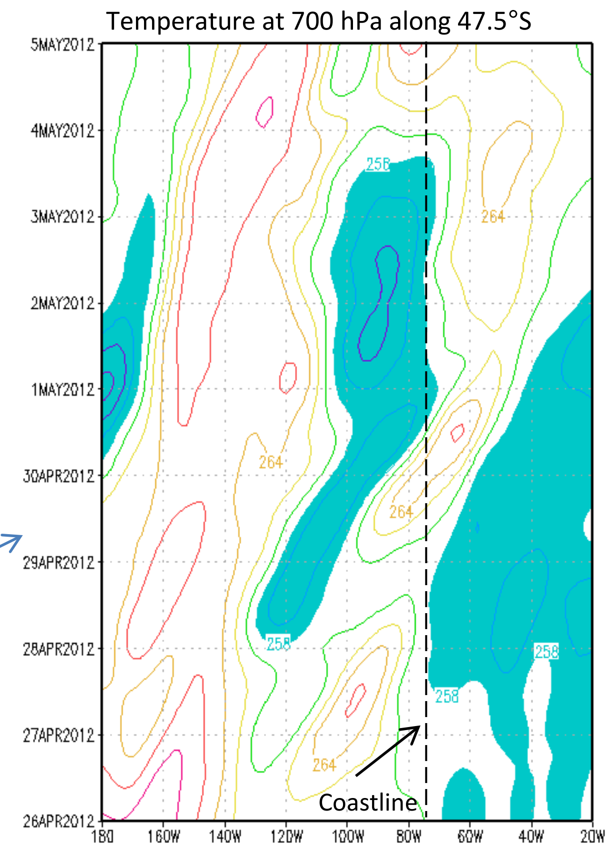
GOES-13 Visible (BW) and IR4 (light shading) + WWLLN Lighting (dots) + Starnet



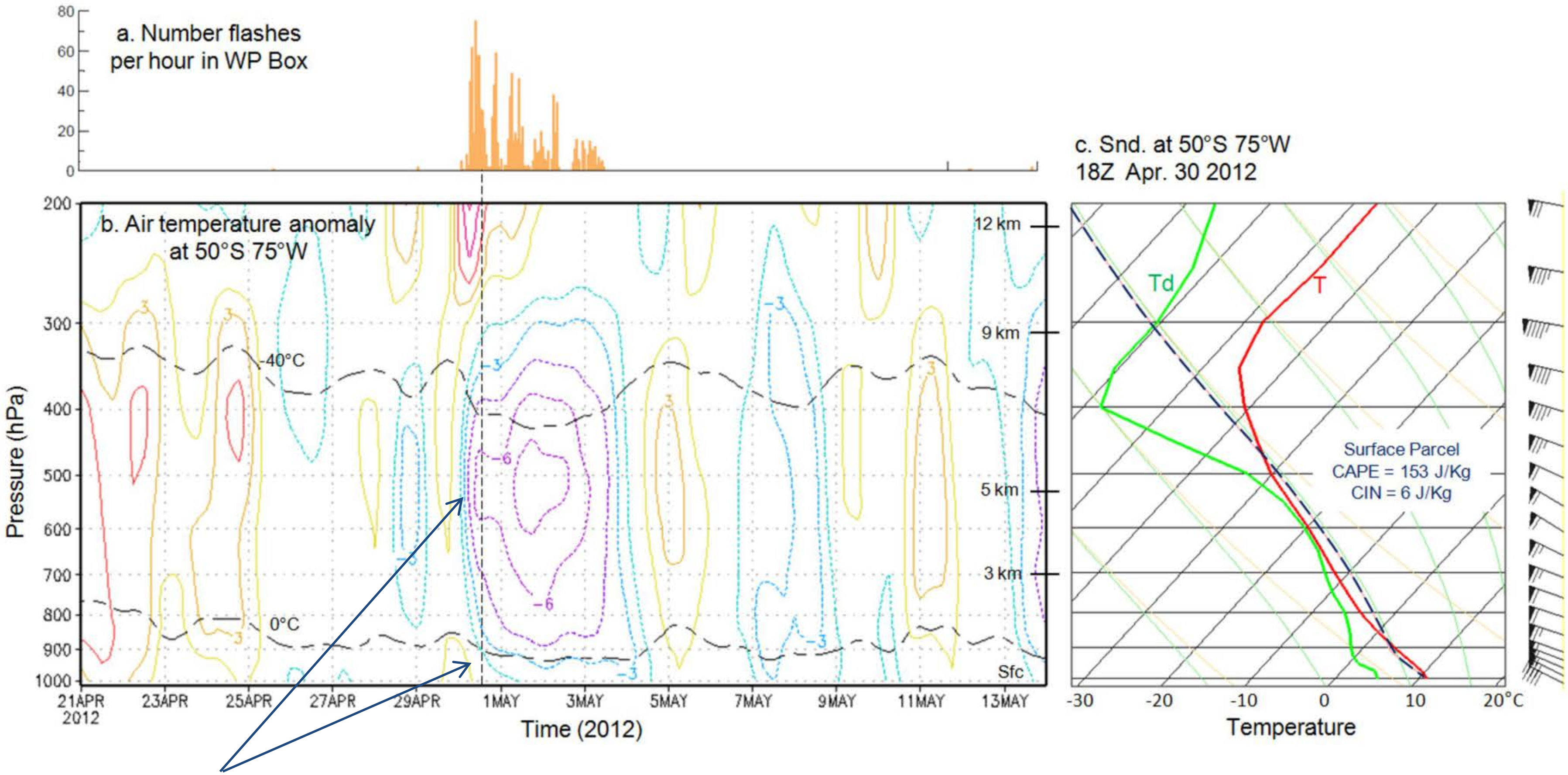
April 30, 2012 – 1800 UTC

Análisis sinóptico (CFSR)





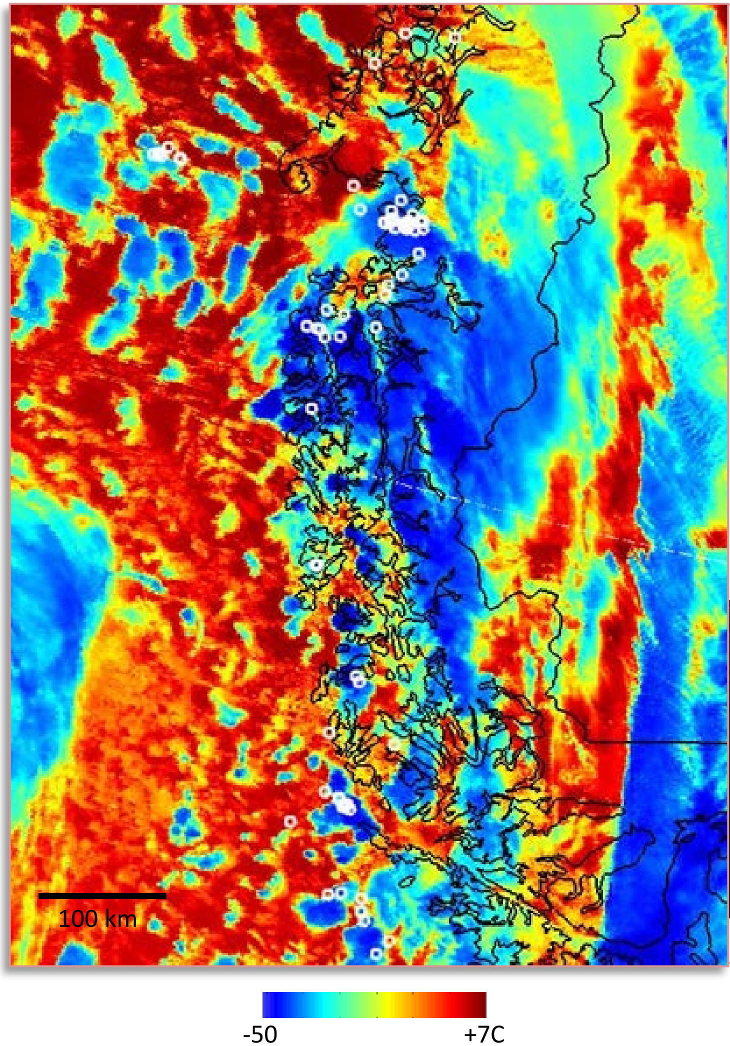
Electric activity in a slightly unstable environment and strong Westerly flow

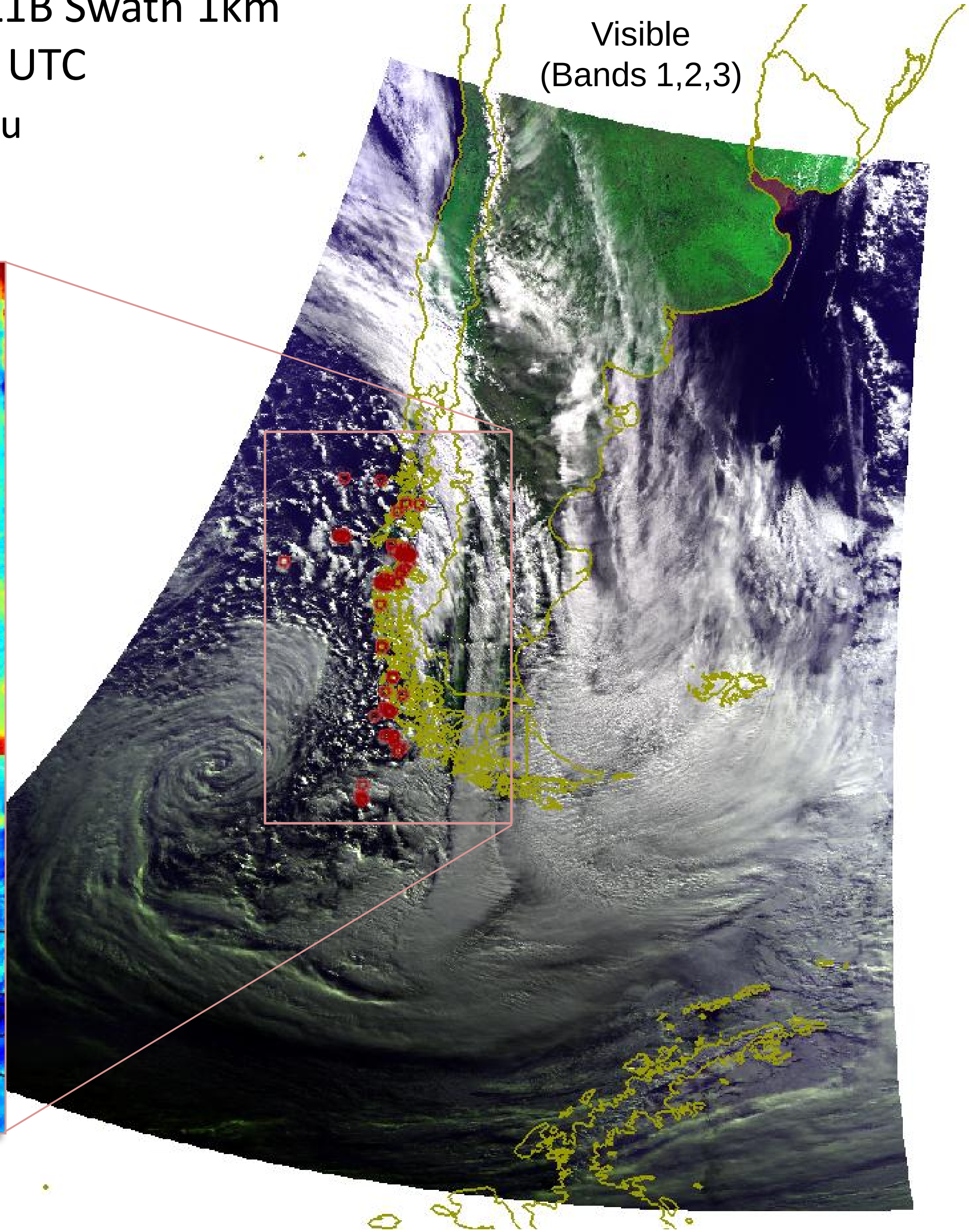


Mid level cooling stronger and before than at surface

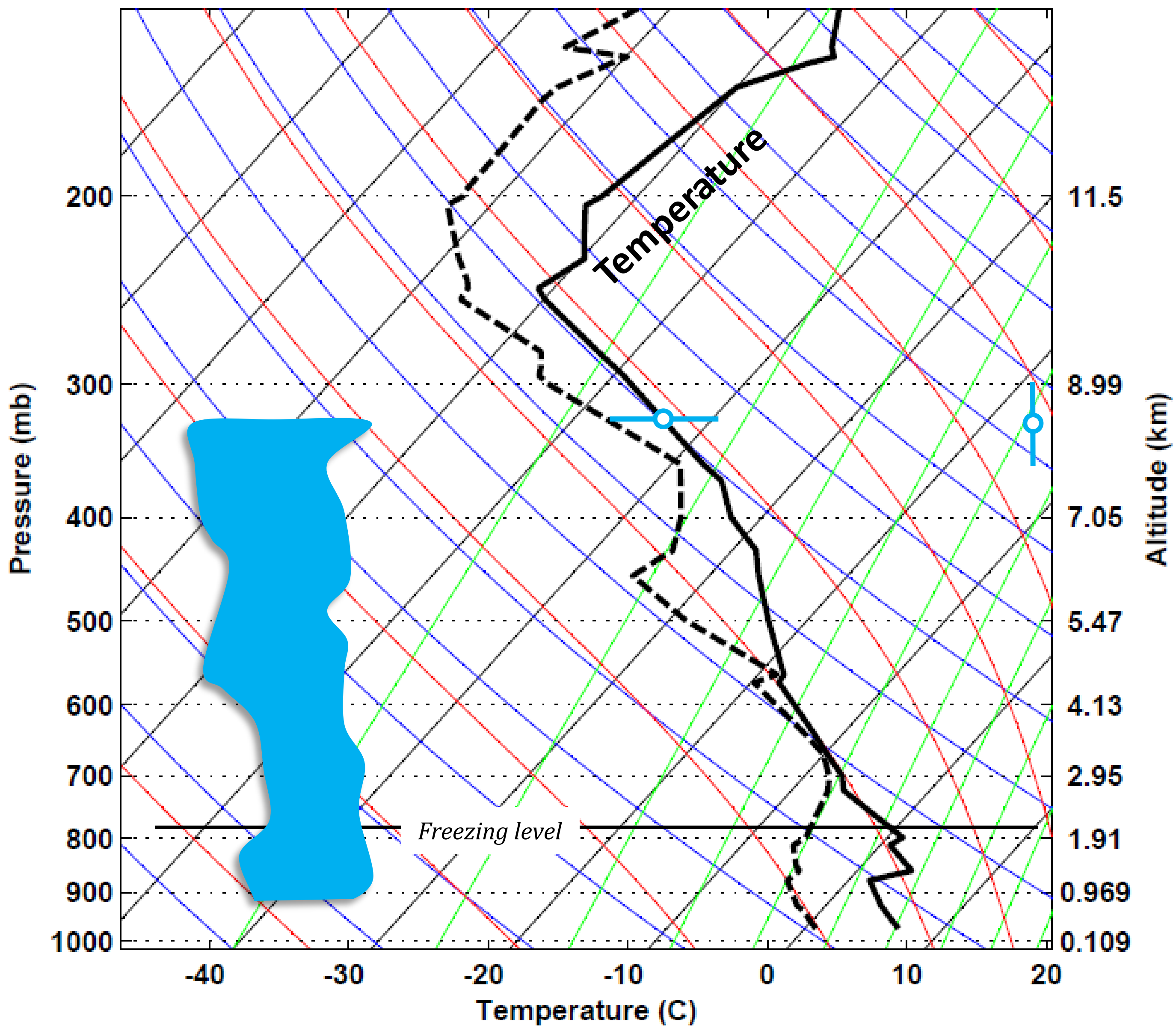
MODIS/Terra Calibrated Radiances L1B Swath 1km
April 30, 2012. 1420-1425 UTC
Courtesy of Larry Bonneau

Brightness Temp. (11.03 μm) + WWLLN

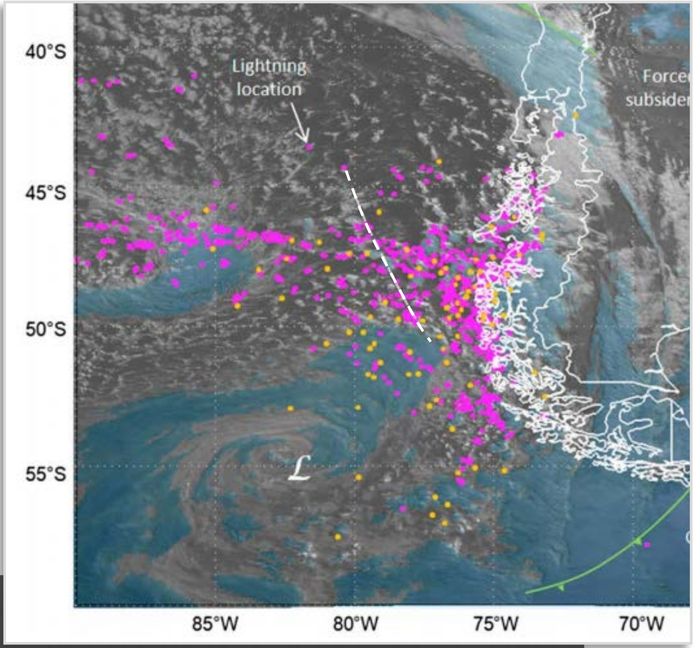


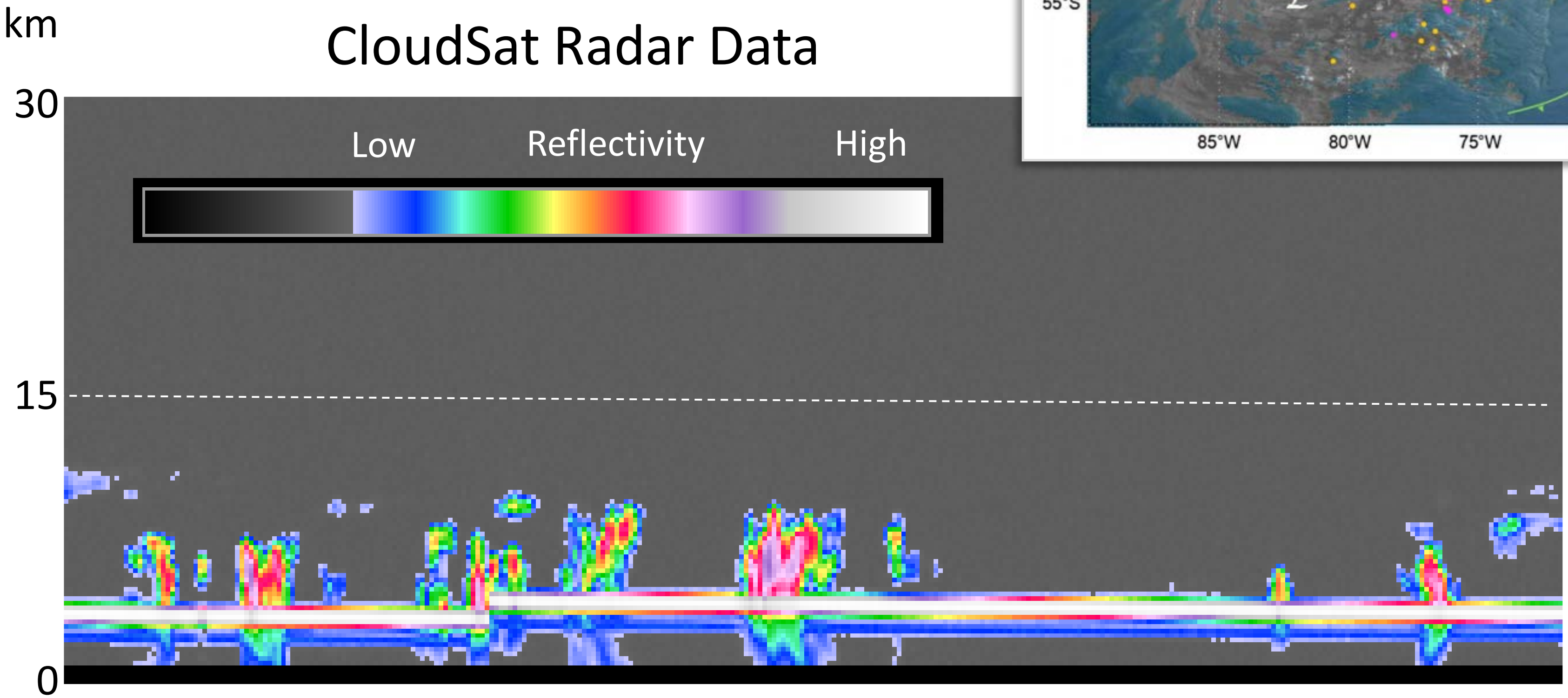


Punta Arenas Observations at 12Z 30 Apr 2012

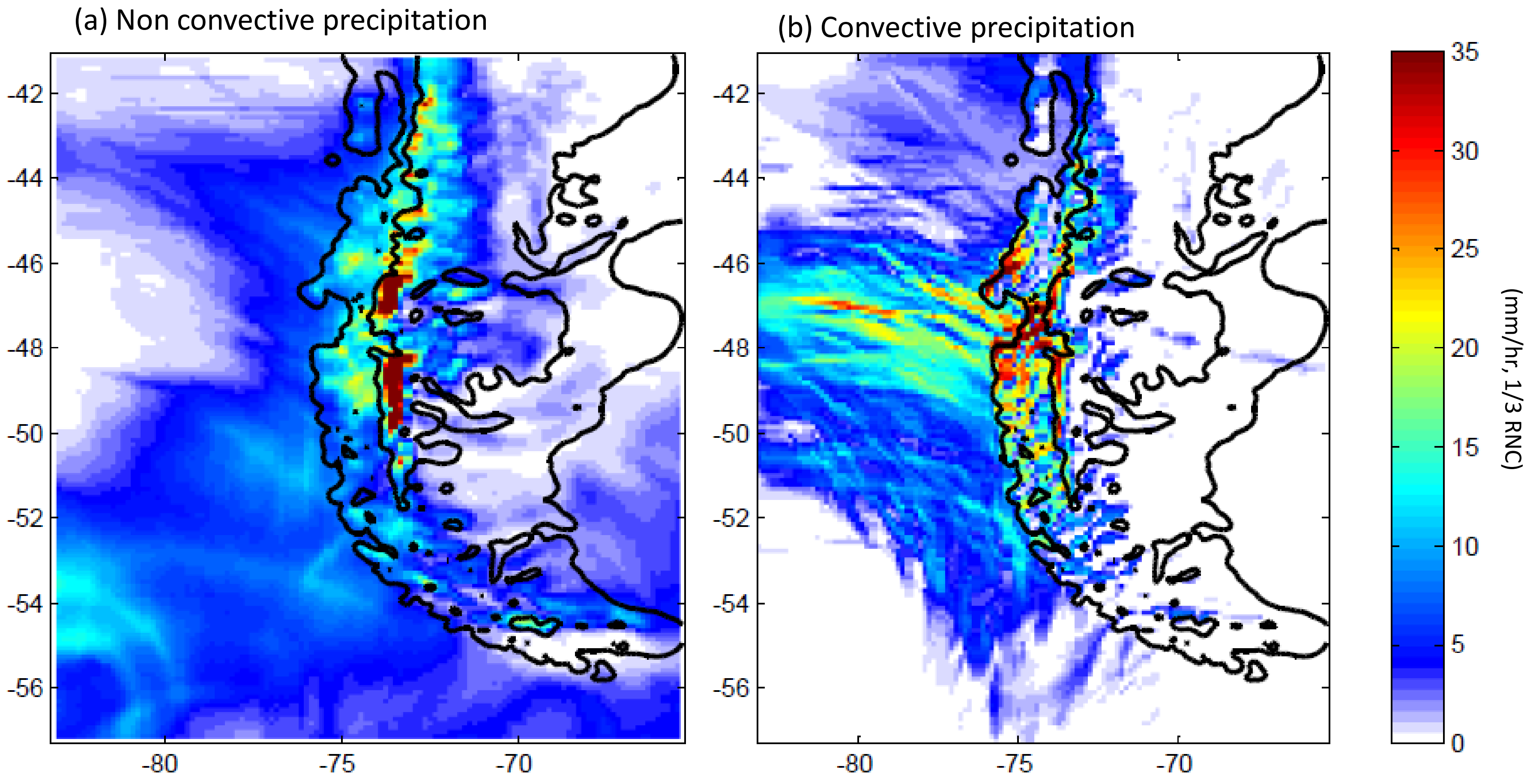


Cloud top heights derived from MODIS Tb agree well with CloudSat data and suggest horizontally small (~10 kms) but deep (~8 km) convective cores producing lightning....



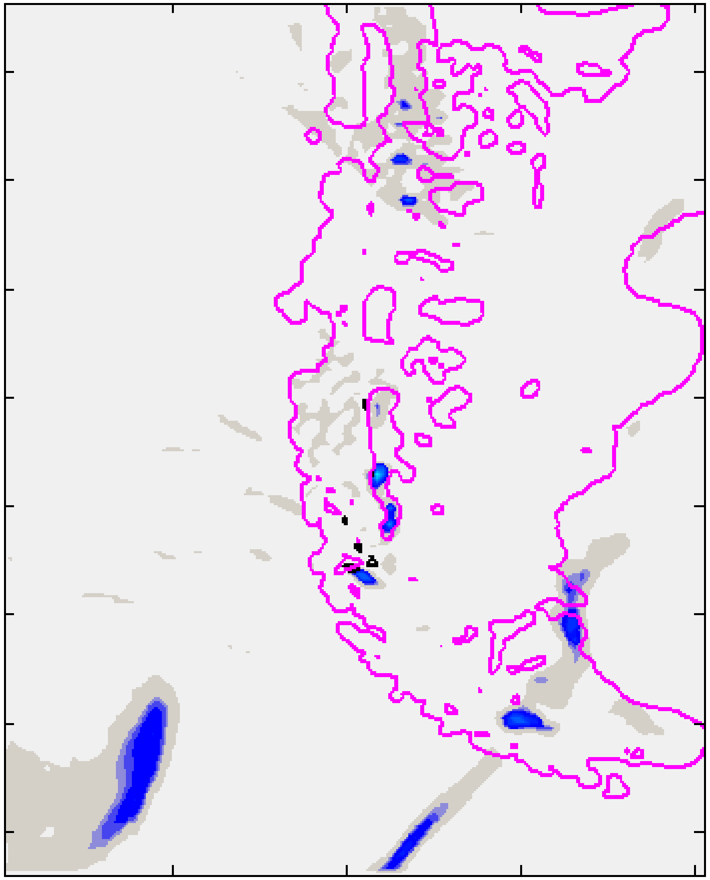


Accumulated precipitation (08 UTC, 29 April – 23 UTC, 30 April, 2012) simulated by WRF (12 km inner domain, KF-Cu Scheme)



One (typical) storm simulation (WRF)

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

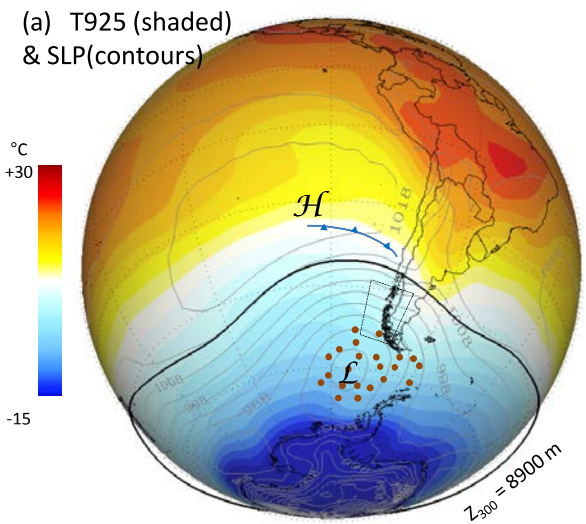


Salient features: Rainfall enhancement over the Andes windward slope, Rain shadow, Convective rainfall along the coast

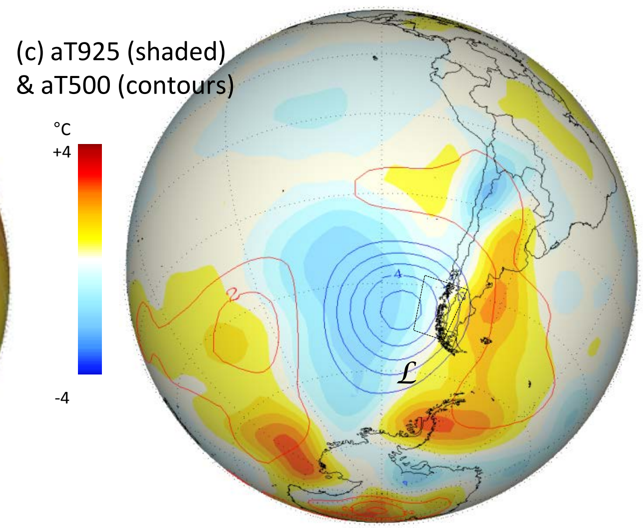
Climatology

- We inspected several episodes and found synoptic conditions similar to the case study. This is synthesized using a compositing analysis of the days with more than 50 flashes…
- Strong winds and weakly unstable conditions are *necessary conditions* for lightning events.
- Weak temporal relationship between CAPE and number of flashes…
- Area of high frequency of non-zero CAPE off WP (collocated with maximum of flash density) linked to warm SST anomaly there. Coastal topography provides the strong updrafts…

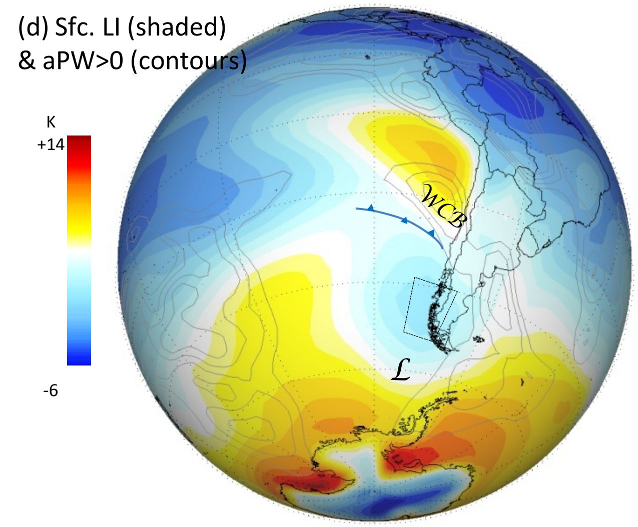
Compositing analysis for days with more than 50 flashed in WP Box (89 days)



1. Depresión Extratropical en etapa madura. PO en masa postfrontal

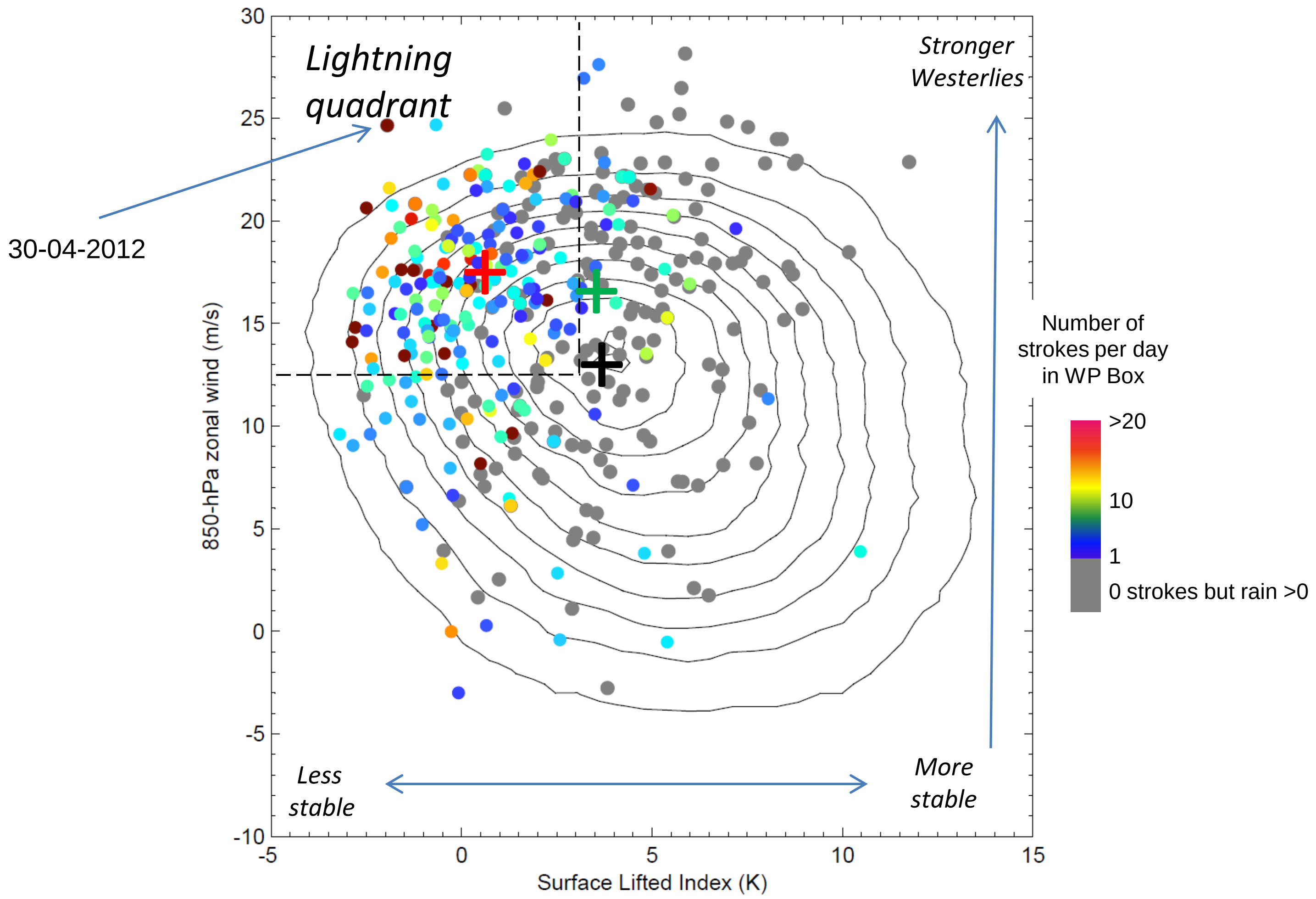


2. Enfriamiento más pronunciado en troposfera media



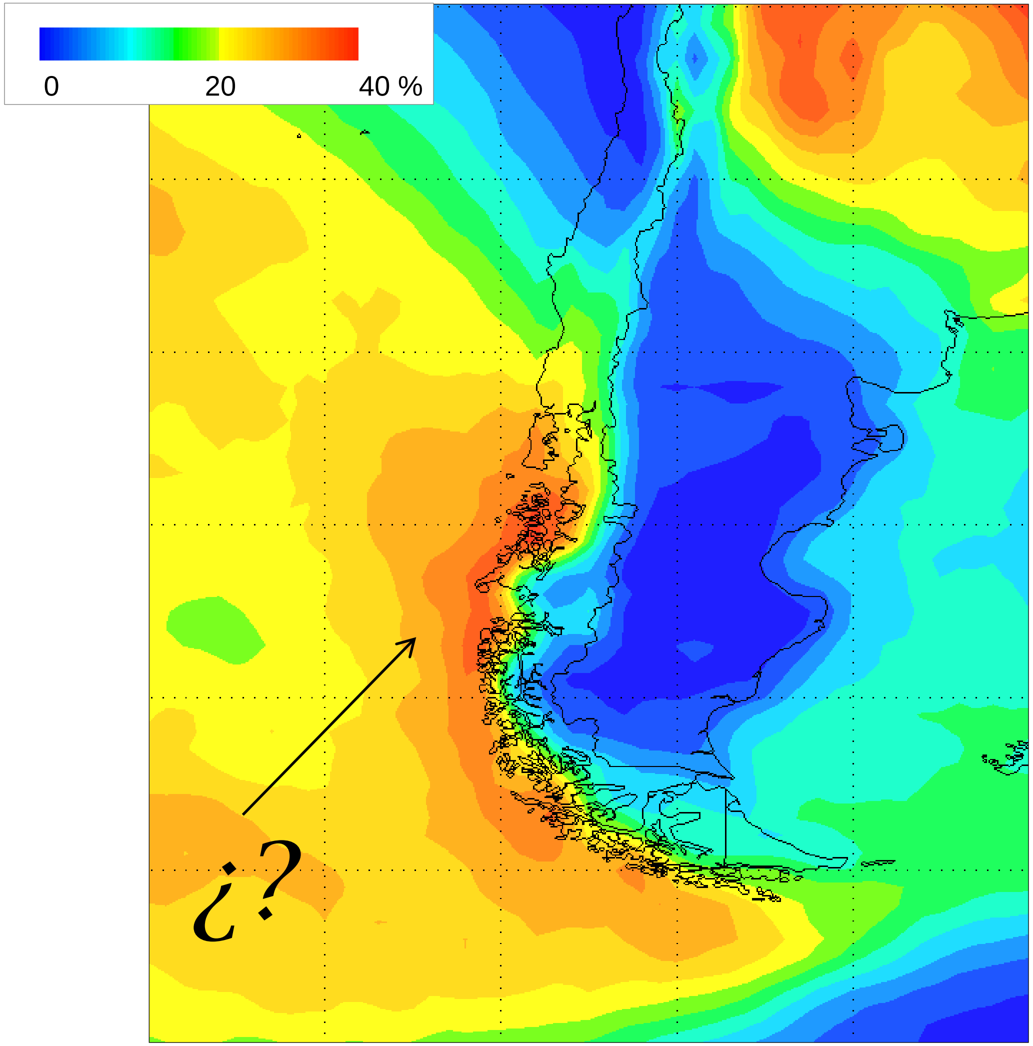
3. Ambiente ligeramente inestable sobre WP

Joint distribution of LI-U850 over WP for all days (contours), rainy days (gray dots) and lightning days (colors dots)

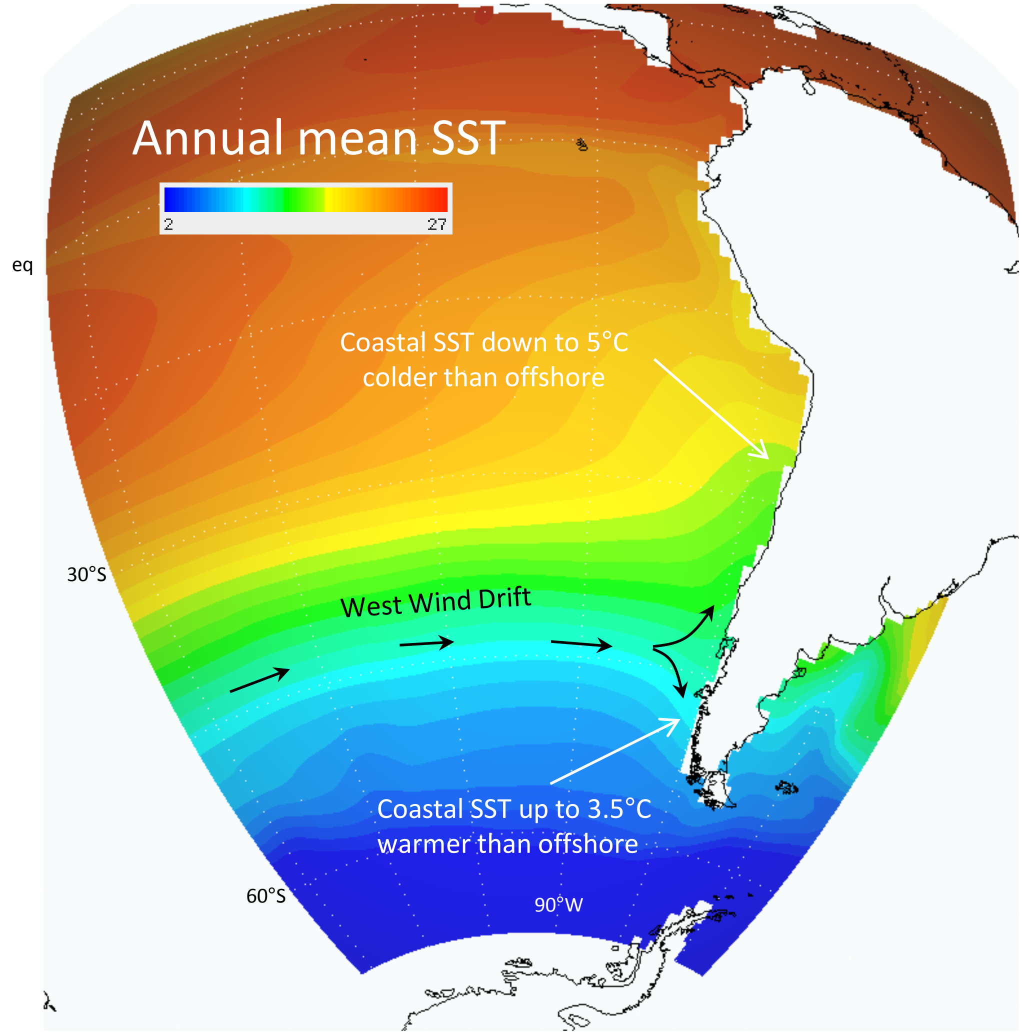


Coastal topography forces updraft under strong westerlies.
What about unstable conditions?

Frequency of days with CAPE > 0 (unstable conditions)

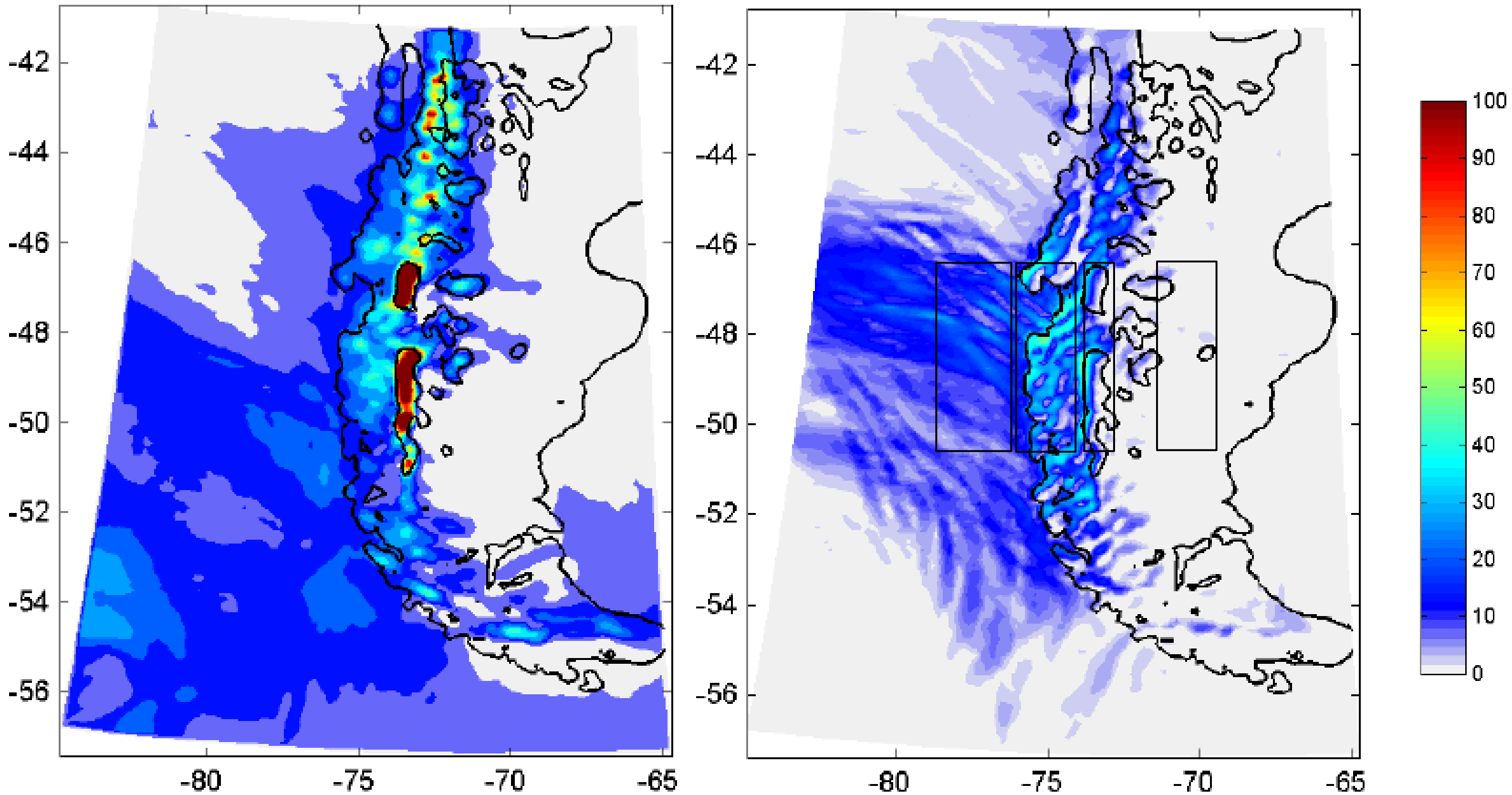


The higher frequency of unstable conditions near Patagonia maybe associated with its warmer coastal waters.



Back to Topographic Control

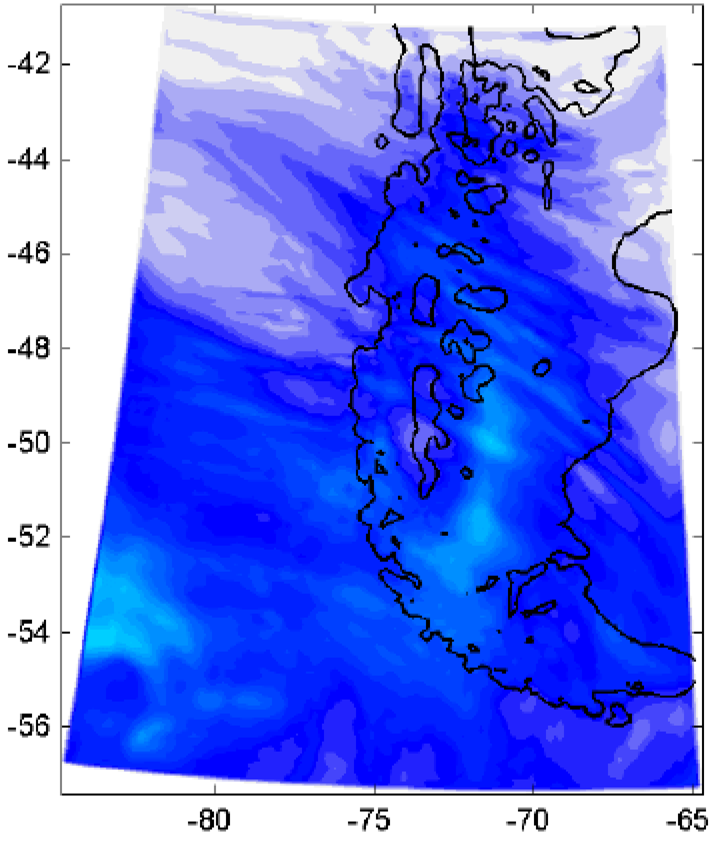
48 hr Accumulated Precip - Control Simulation



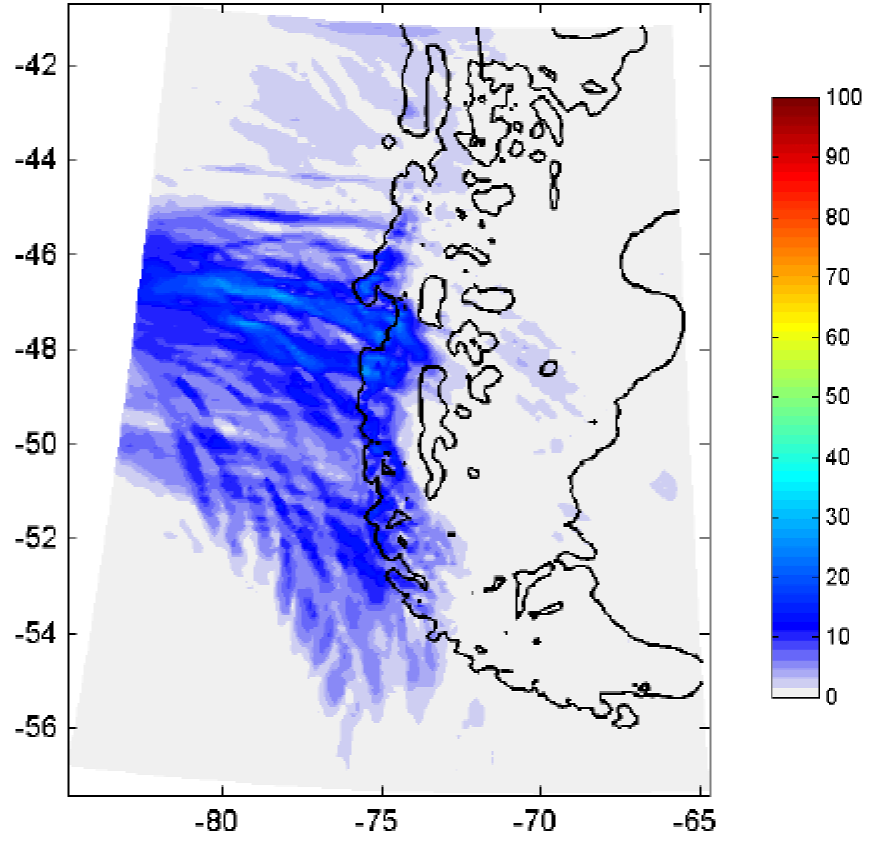
Resolved

Convective

48 hr Accumulated Precip – No Topo Simulation

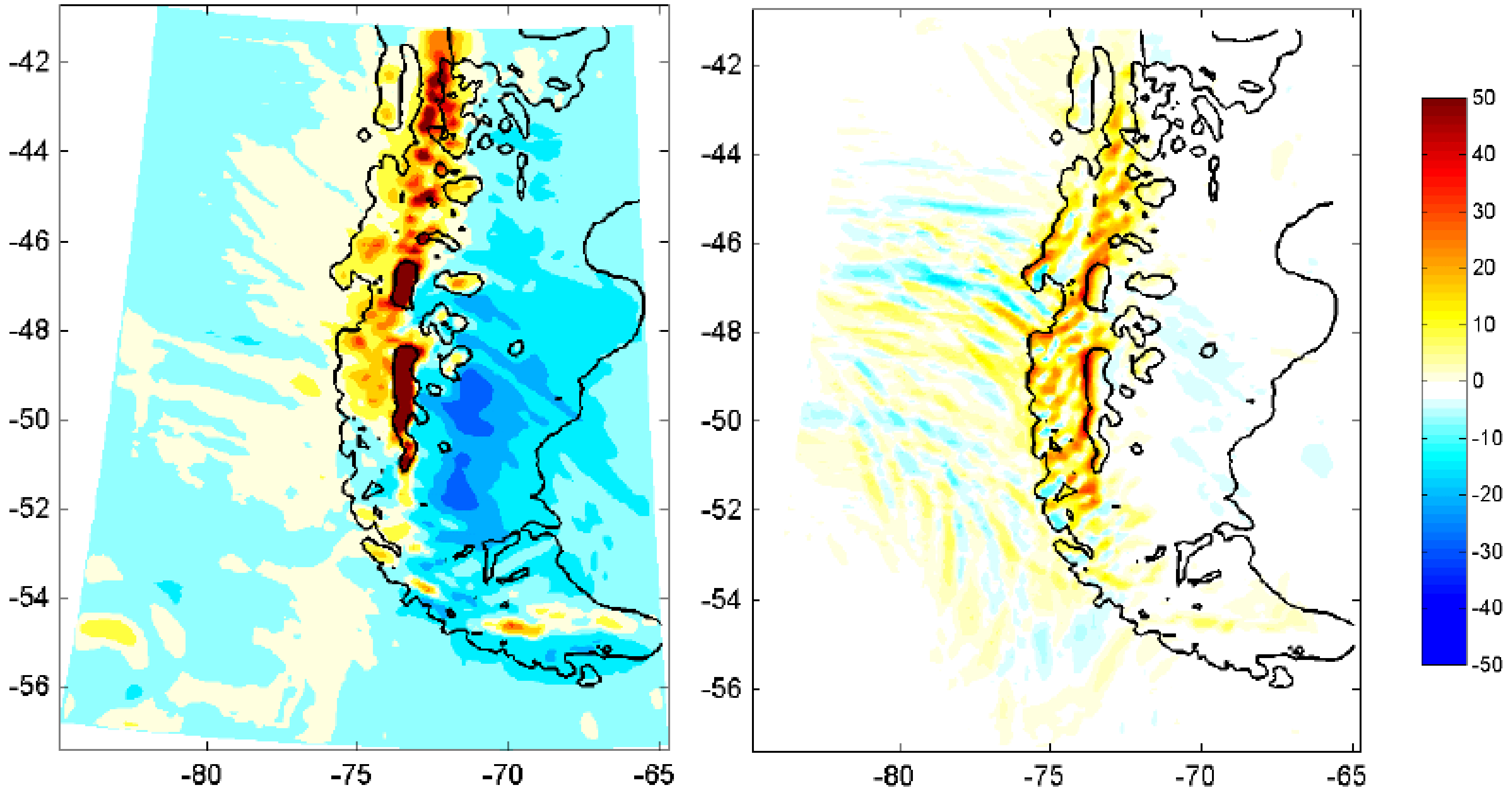


Resolved



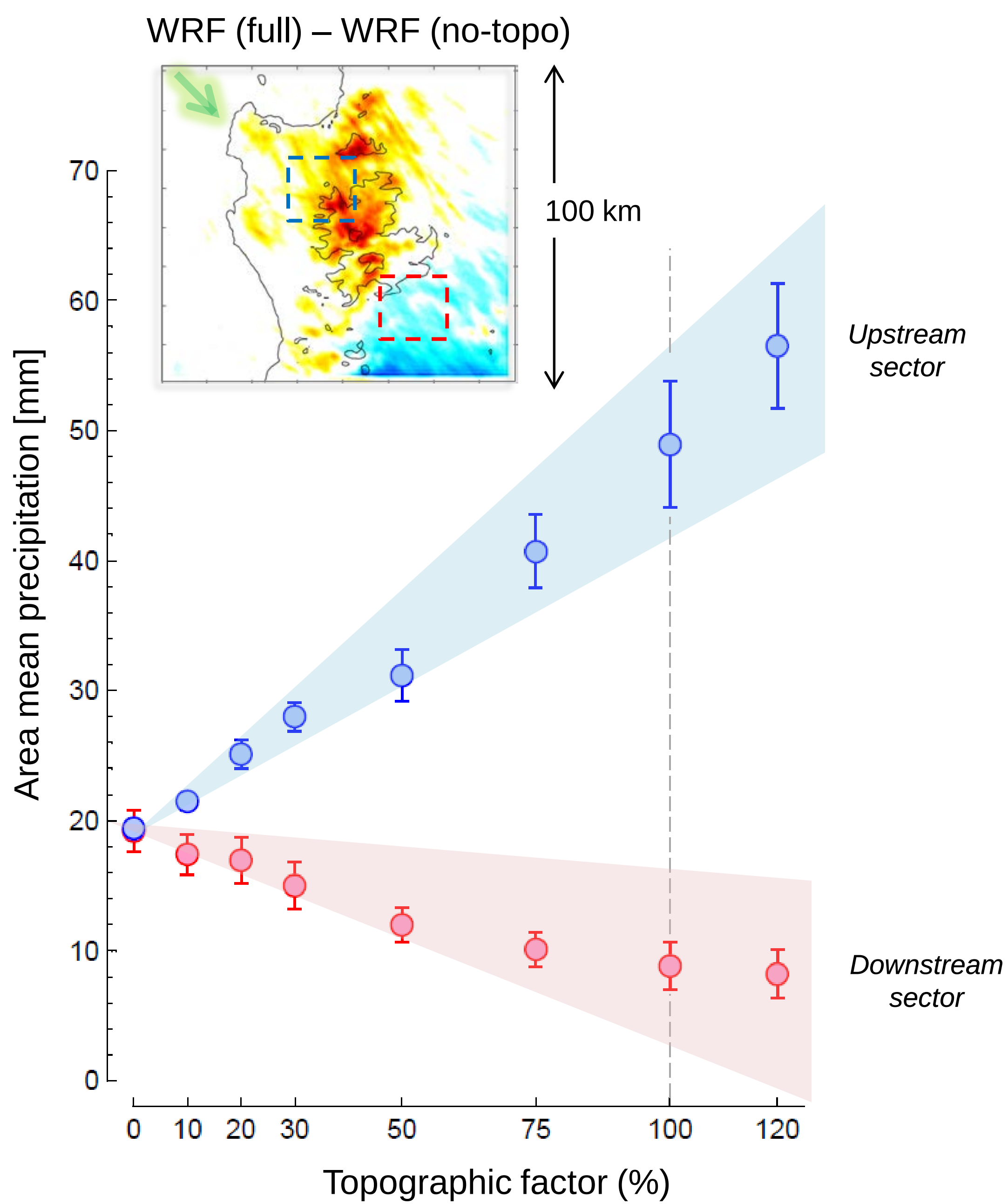
Convective

48 hr Accumulated Diff Precip (CTR-Ntopo)



Resolved

Convective



WRF (full) – WRF (no-topo)
100 km
Area mean precipitation [mm]
0
10
20
30
40
50
60
70
0
10
20
30
50
75
100
120
Topographic factor (%)
Upstream sector
Downstream sector

Outstanding questions

* How do the upwind enhancement / leeside rain shadow scale with Andes' height (implications for isotope derived paleo-elevations)? Linear or non-linear?

* What is the differential role of the coastal mountains and Andes cordillera on both stratiform and convective precipitation distribution?

* What is the role of warm coastal zone in producing convective precipitation? Long term changes?