Reconstructing Past Regional Climate Variations
in South America over the late Holocene
4-7/10/2006 Malargue-Argentina

(How) can we link local paleoclimate signals with large-scale circulations?

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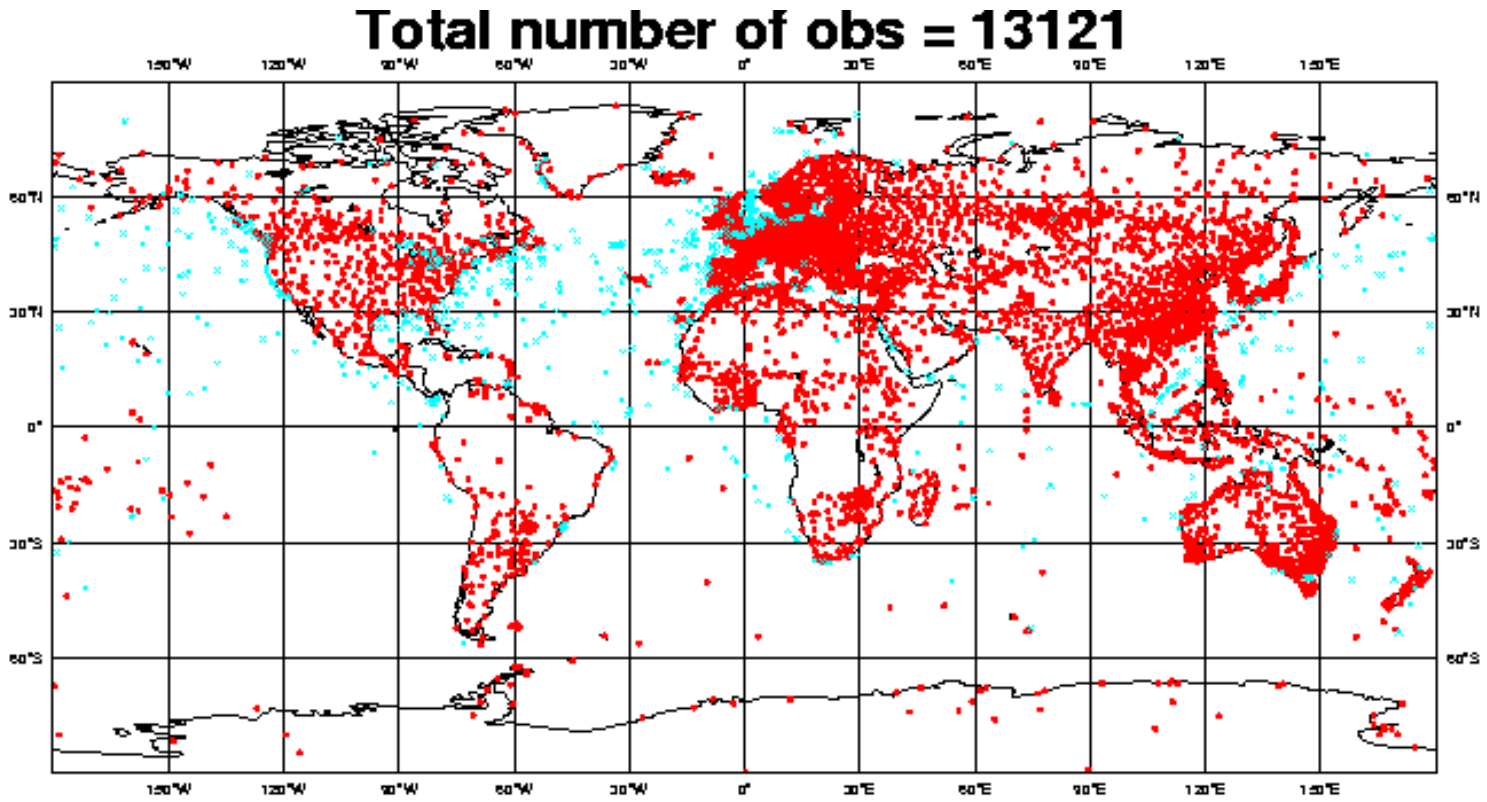
How can we link local paleoclimate signals with large-scale circulations?

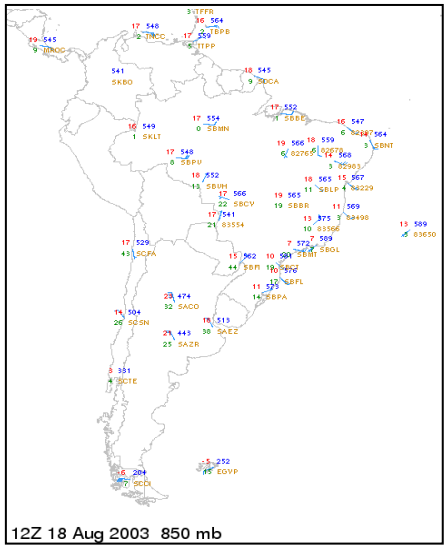
- Tools in modern climatology
- Local co-variability of precipitation and circulation
- Large scale circulation anomalies – local rainfall
- Large scale circulation modes

Surface (land/ocean) Synoptic Stations
Met. Observations (T,Td,P,V,…) @ 0, 6, 12, 18 UTC are transmitted in real-time to WMO and Analysis Centers

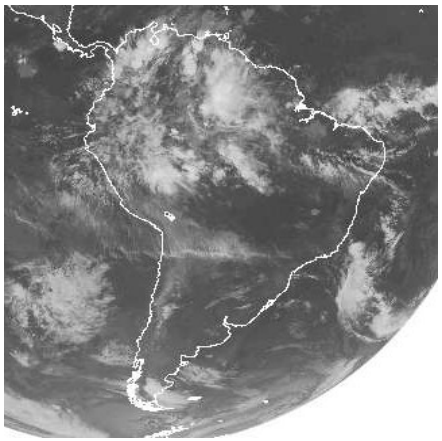


Analysis (gridded data)

Surface and Upper Air Observations

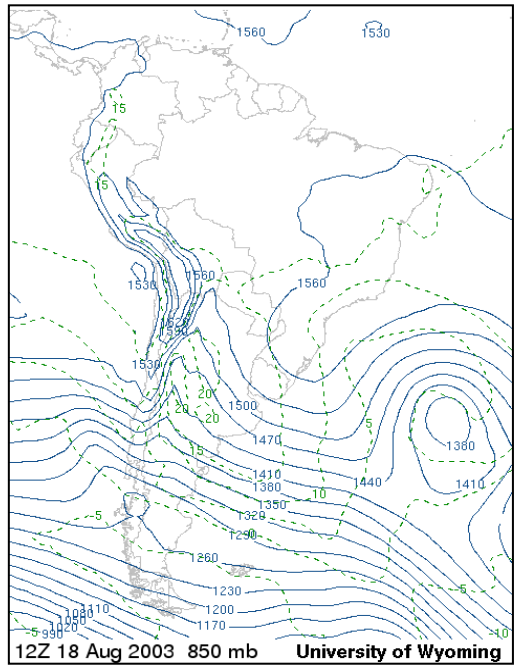


Satellite Products



Assimilation system

Gridded Analysis (displayed here using contours)



Reanalysis?!

Because analysis are produced in real-time, some data is not assimilated, but it was archived. In the 90's the NCEP-NCAR (USA) began a major project in which they re-run their assimilation system with all the available data.

The result is the widely used "Reanalysis" data, including many fields (air temperature, wind, pressure) on a regular 2.5°x2.5° lat-lon grid, from 1948 to present every 6 hours (also available daily, monthly and long-term-mean means). Fields are 2- or 3-Dimensional. Preferred data format: NetCDF. Freely available.

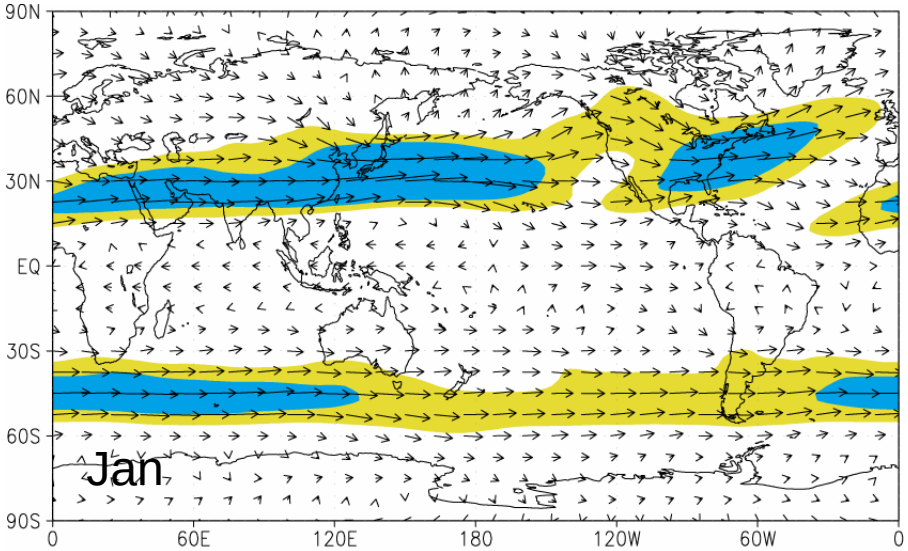
Reanalysis

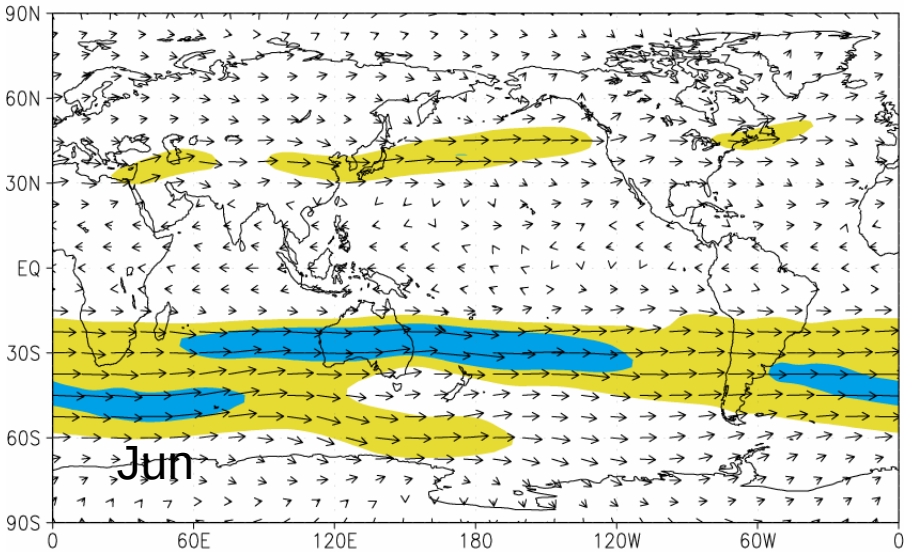
Reanalysis system also includes a meteorological model from which precipitation and other not-observed variables (e.g., vertical motion) are derived.

Reanalysis data is great for studying interannual and higher frequency variability. Interdecadal variability and trends are not so well depicted (we don't trust much before the 70's, particularly in the SH).

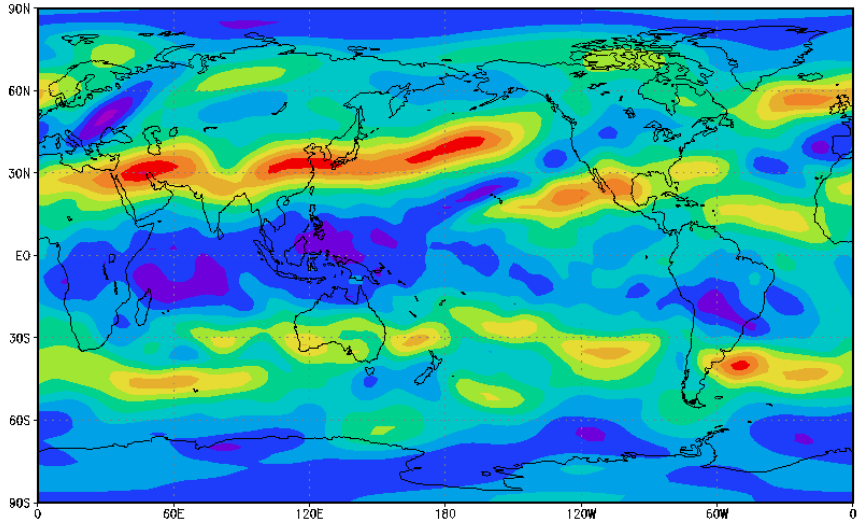
European Center (ECMWF) did a similar effort (ERA-15 and ERA-40). Higher horizontal resolution (1.25°x1.25°), but harder to get.

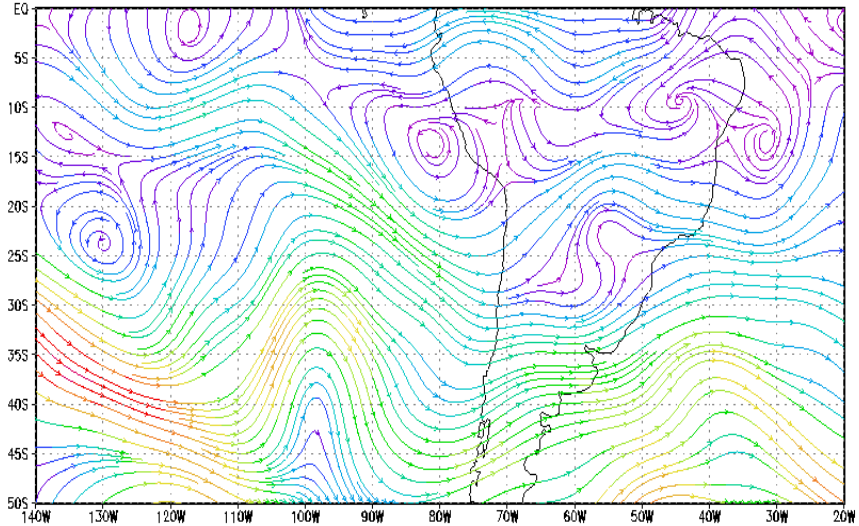
Climatology of 300 hPa winds (10-12 km) from NNR





Example of some daily fields from NNR



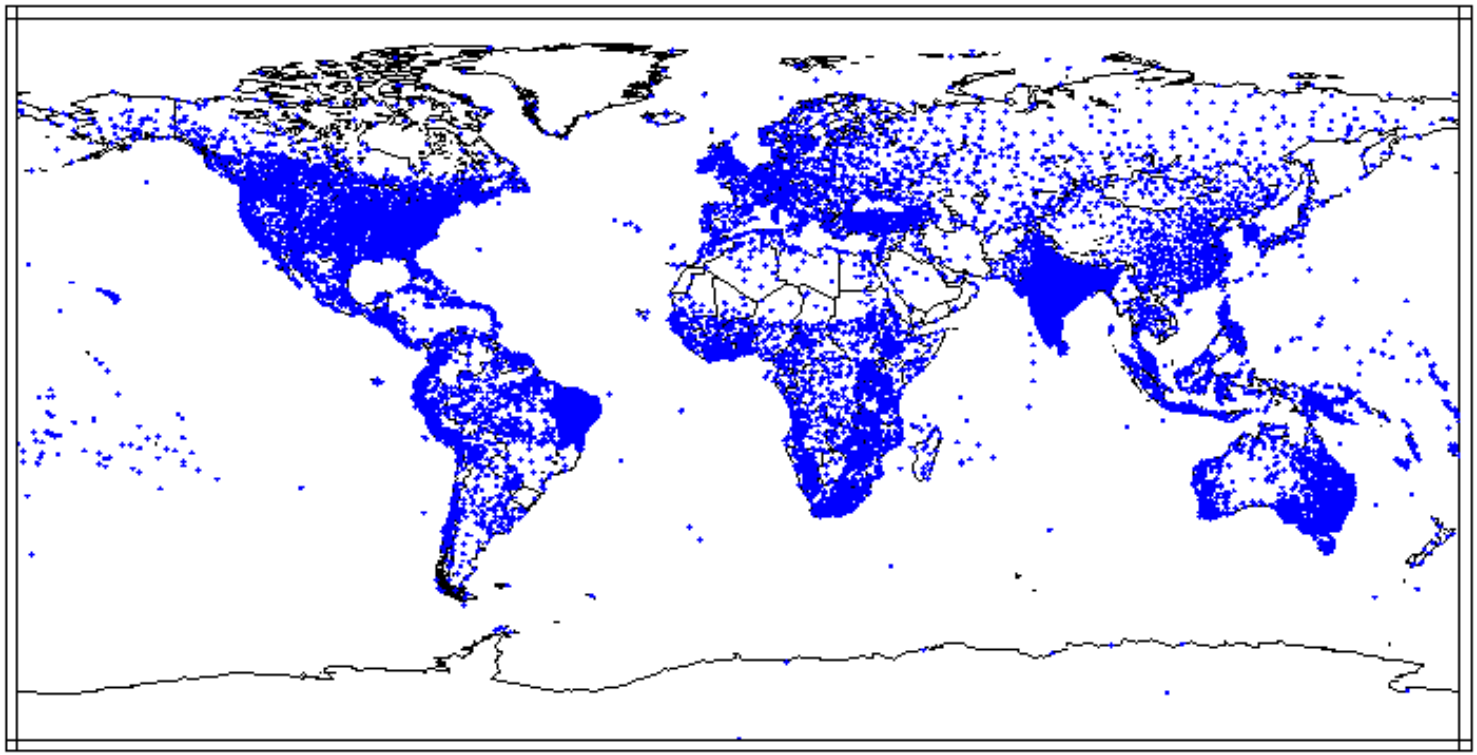


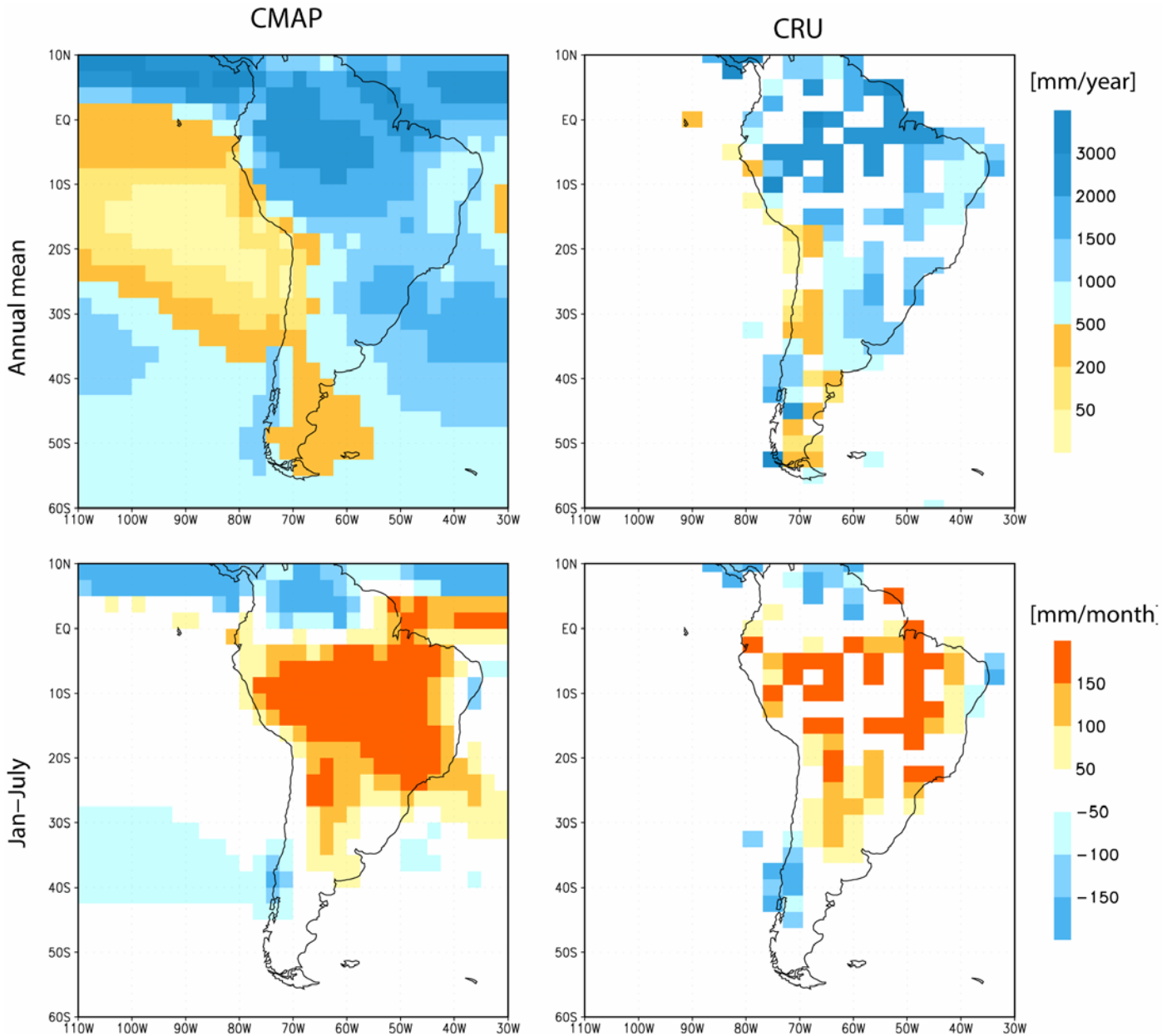
Summary of Available* Precipitation Datasets (Monthly Means)

Dataset	Type	Coverage	Resolution (lat-lon)	Period	Assimilated data
Global Historical Climatology Network (GHCN)	Station (~ 7500)	Land only	-	Variable, 1800 - today	None
Gridded GHNC	Gridded	Land Only	5.0° × 5.0°	1900 - today	GHNC stations
CRU – UEA	Gridded	Land Only	5.0° × 5.0° 2.5° × 3.75°	1900 - today	GHNC and others stations
CRU CL1 - UEA	Gridded	Land Only	0.5° × 0.5°	1961 - 1990	GHNC and others stations
GPCP (Global Precip. Climatol. Project)	Gridded	Global	2.5° × 2.5°	1979 - today	Station data, satellite estimates
CMAP (CPC Merged Analisys Precip)	Gridded	Global	2.5° × 2.5°	1979 - today	Station data, satellite estimates, NCEP-NCAR Reanalysis

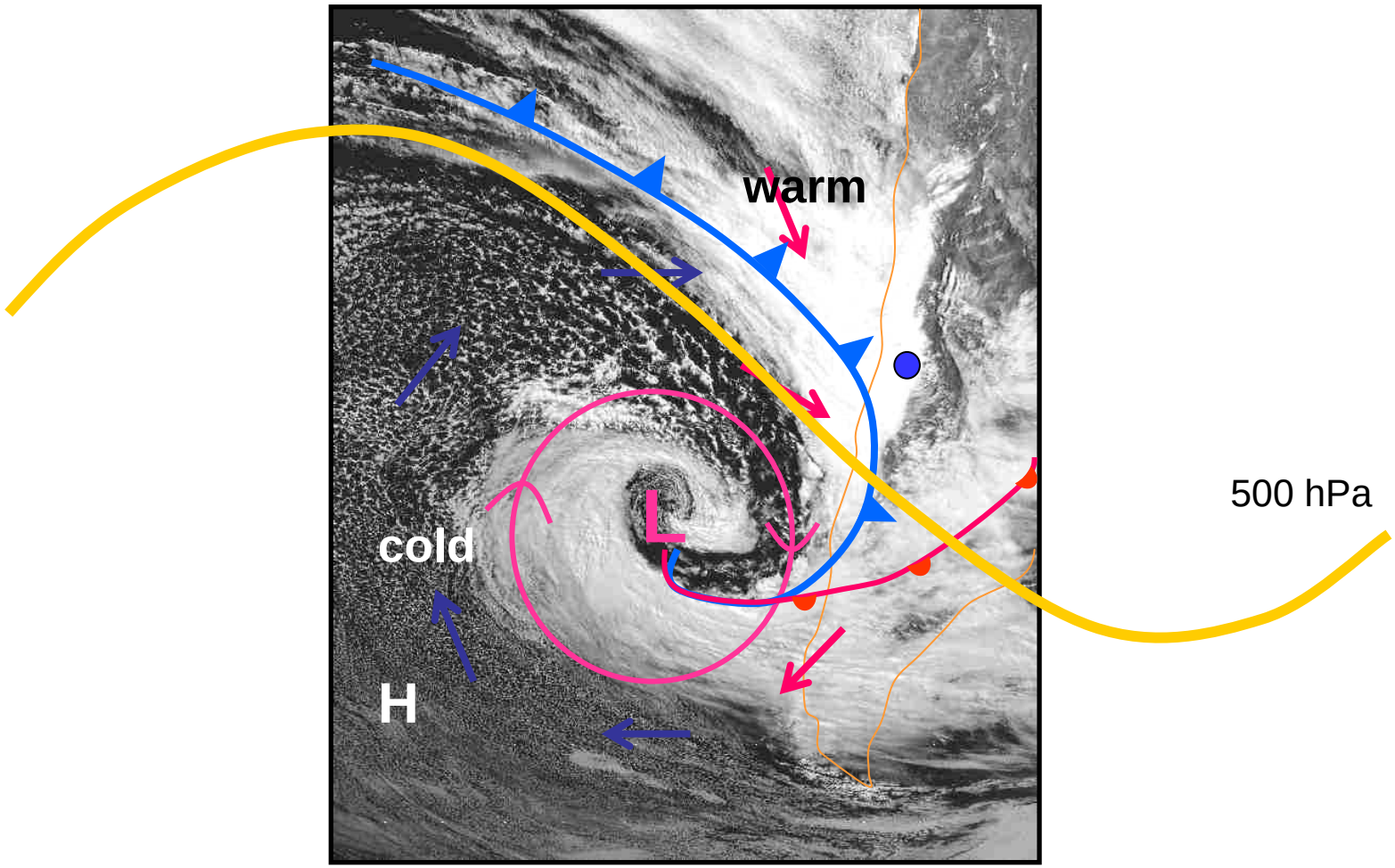
(*) Freely available from Internet in various format (ASCII, NetCDF, etc)

GHCN Version 2 Precipitation Stations



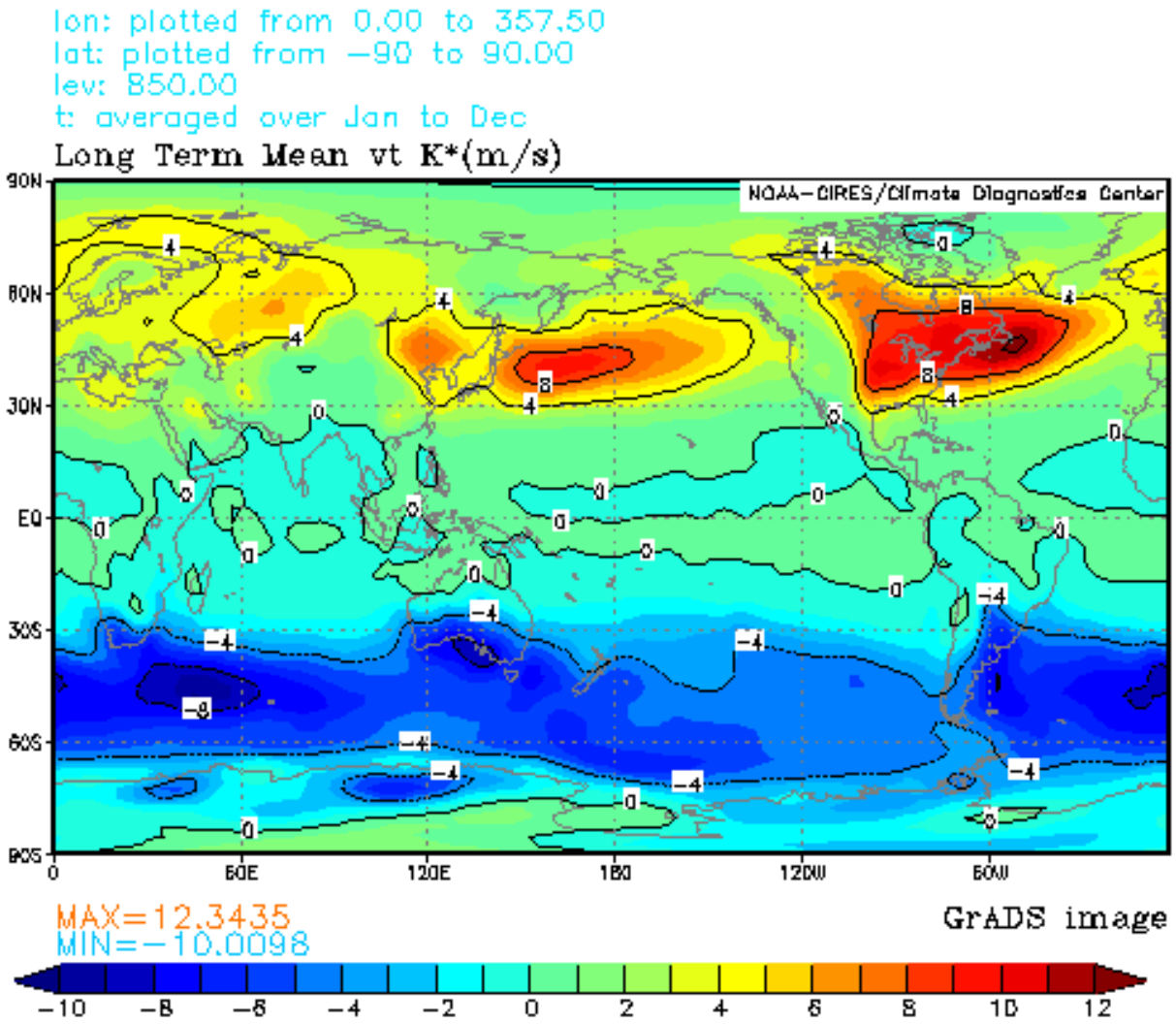

CMAP
CRU
Annual mean
Jan–July
[mm/year]
3000
2000
1500
1000
500
200
50
[mm/month]
150
100
50
−50
−100
−150
10N
EQ
10S
20S
30S
40S
50S
60S
110W
100W
90W
80W
70W
60W
50W
40W
30W

Extratropical precipitation is largely produced by deep, stratiform clouds that develop along warm and cold fronts. The frontal systems are in turn associated with surface cyclones, an integral part of the baroclinic waves that populates the midlatitudes

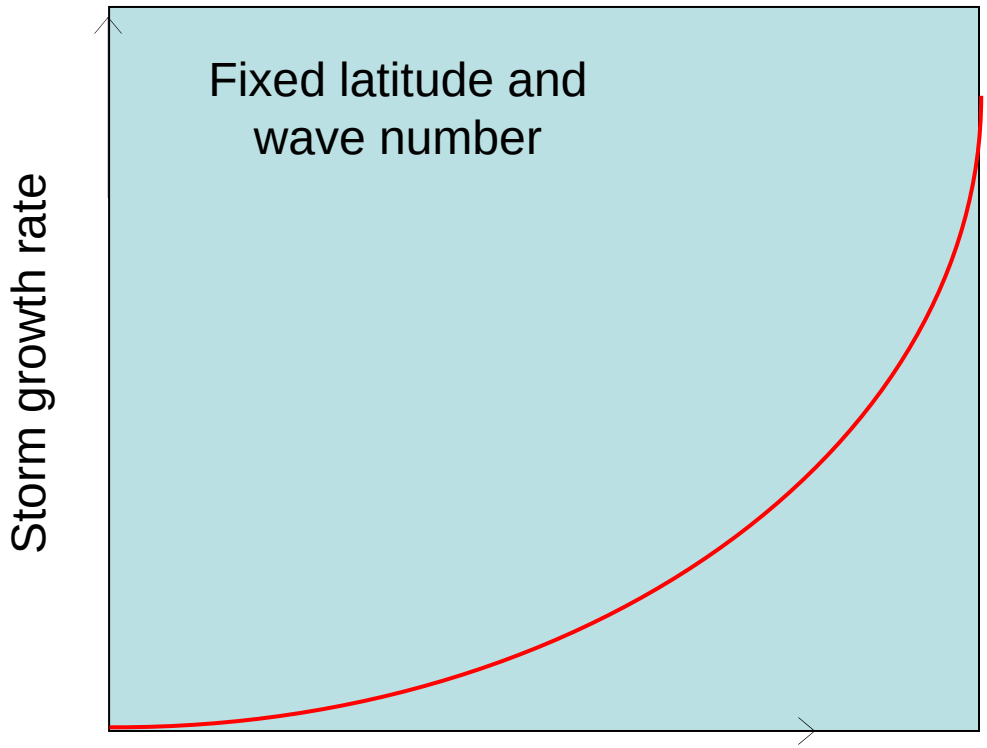


Storm Tracks: transient eddies move in preferred west-east paths

Need daily data….somewhat complex to calculate, multiple definitions.

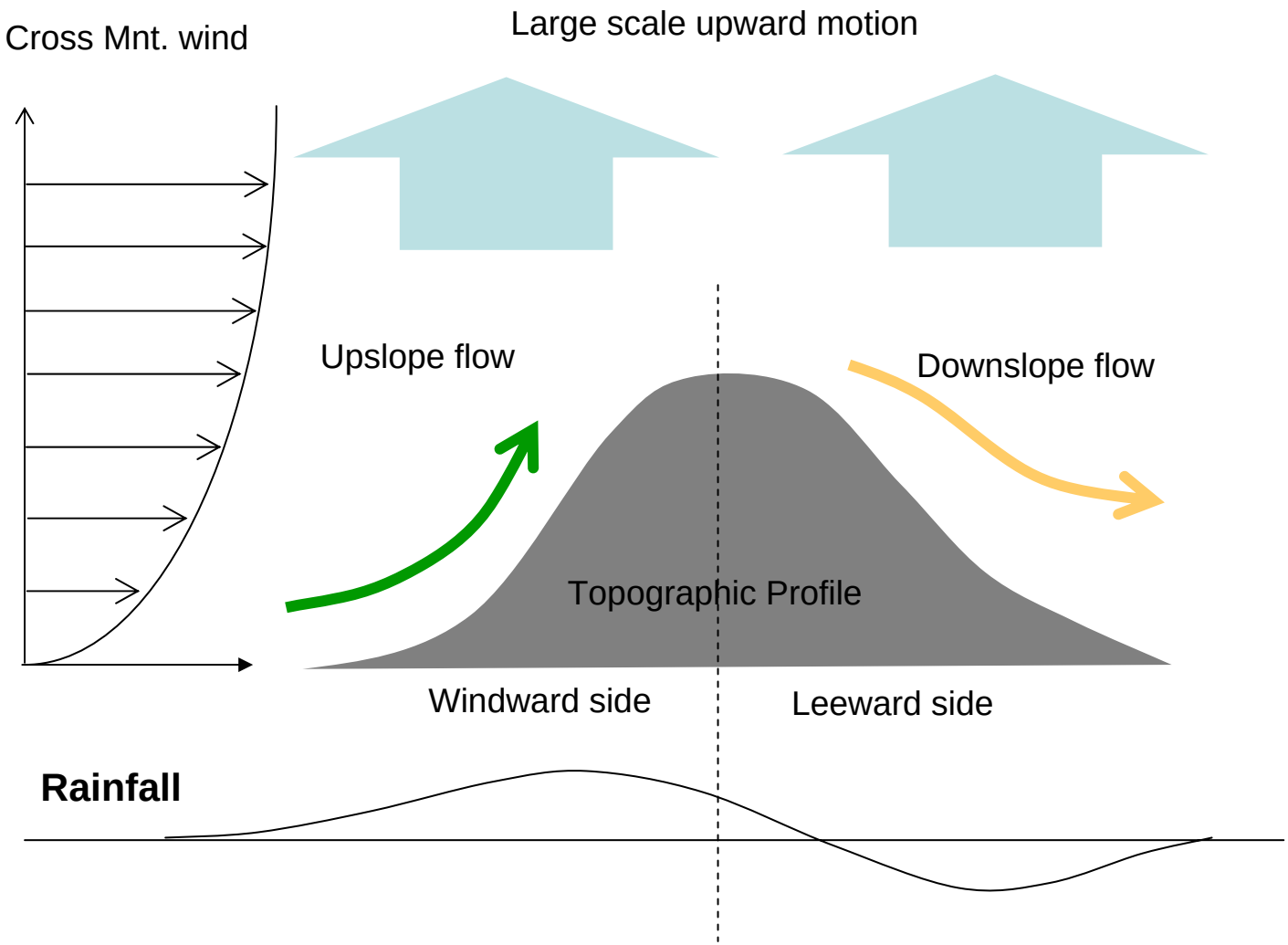


According to the linear quasi-geostrophic theory:



At monthly and longer timescales, stronger westerlies aloft are conducive of a rapid growth and fast succession of baroclinic disturbances and therefore enhanced precipitation

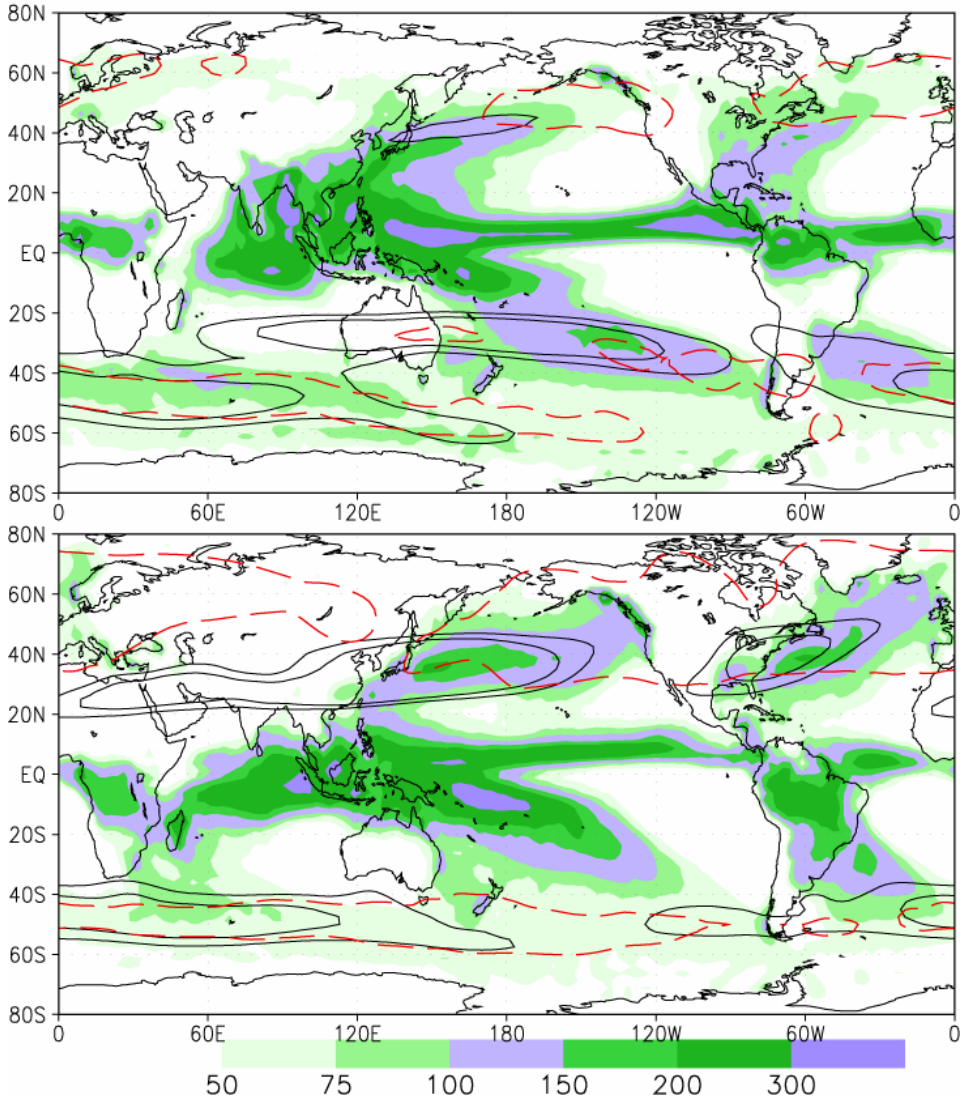
Orographic Effects



In real world the relation precipitation / storm activity / precipitation is not so simple…

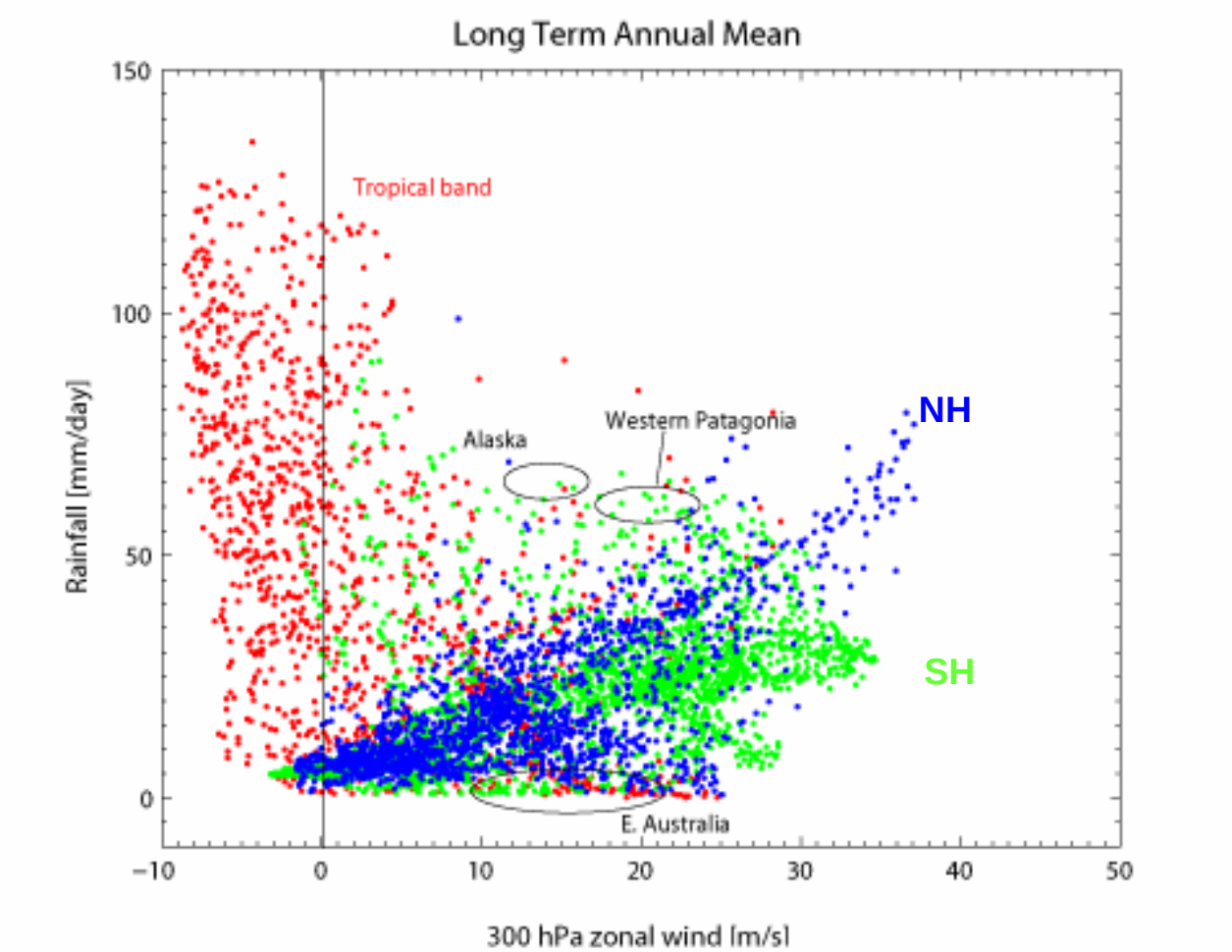
June

January

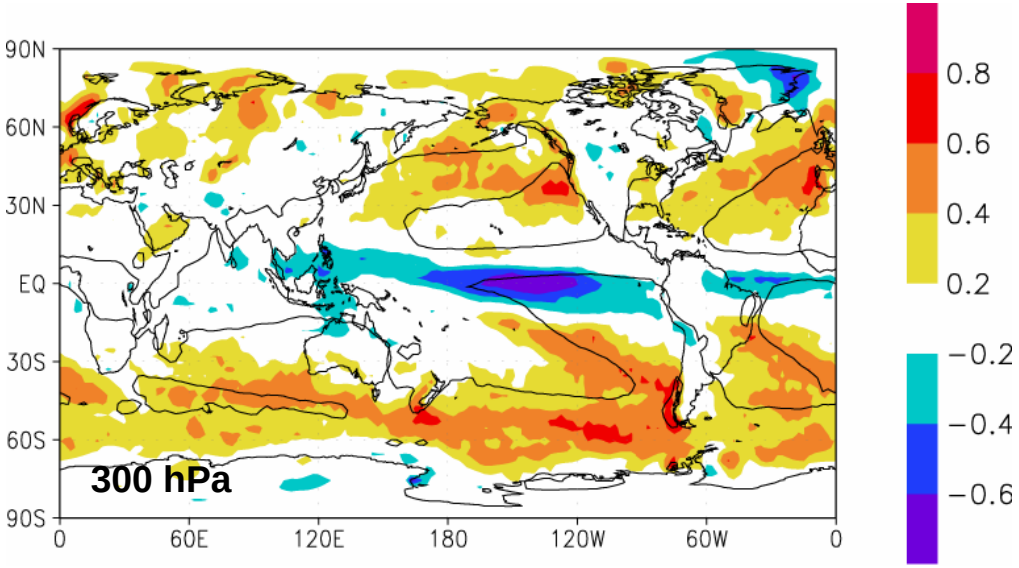


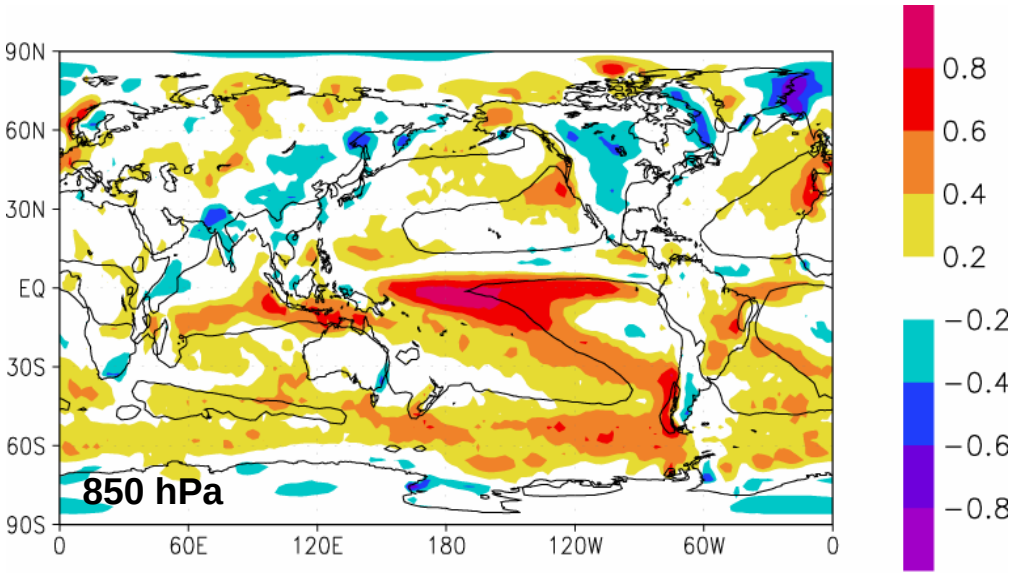
Jet streams
Storm Tracks
Rainfall

Spatial variability of the annual mean of rainfall and U300 is conveniently summarized in a scatter plot using co-located values

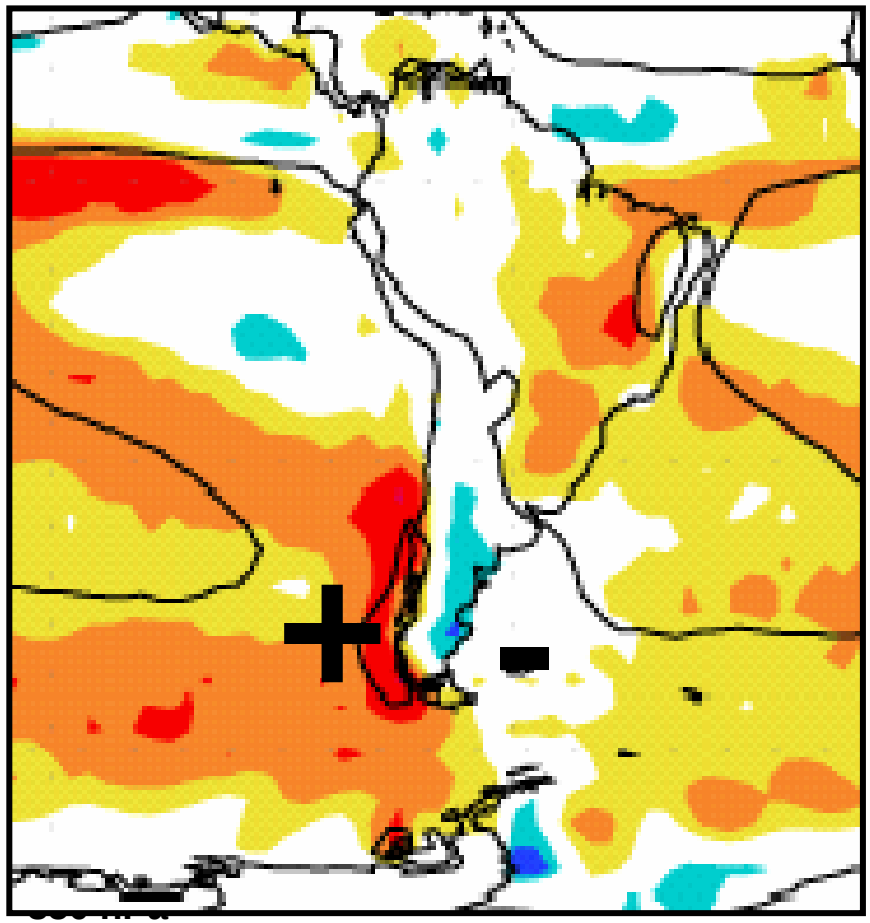


Local Correlation Uwind – CMAP Precipitation using monthly anomalies (1979-2005)





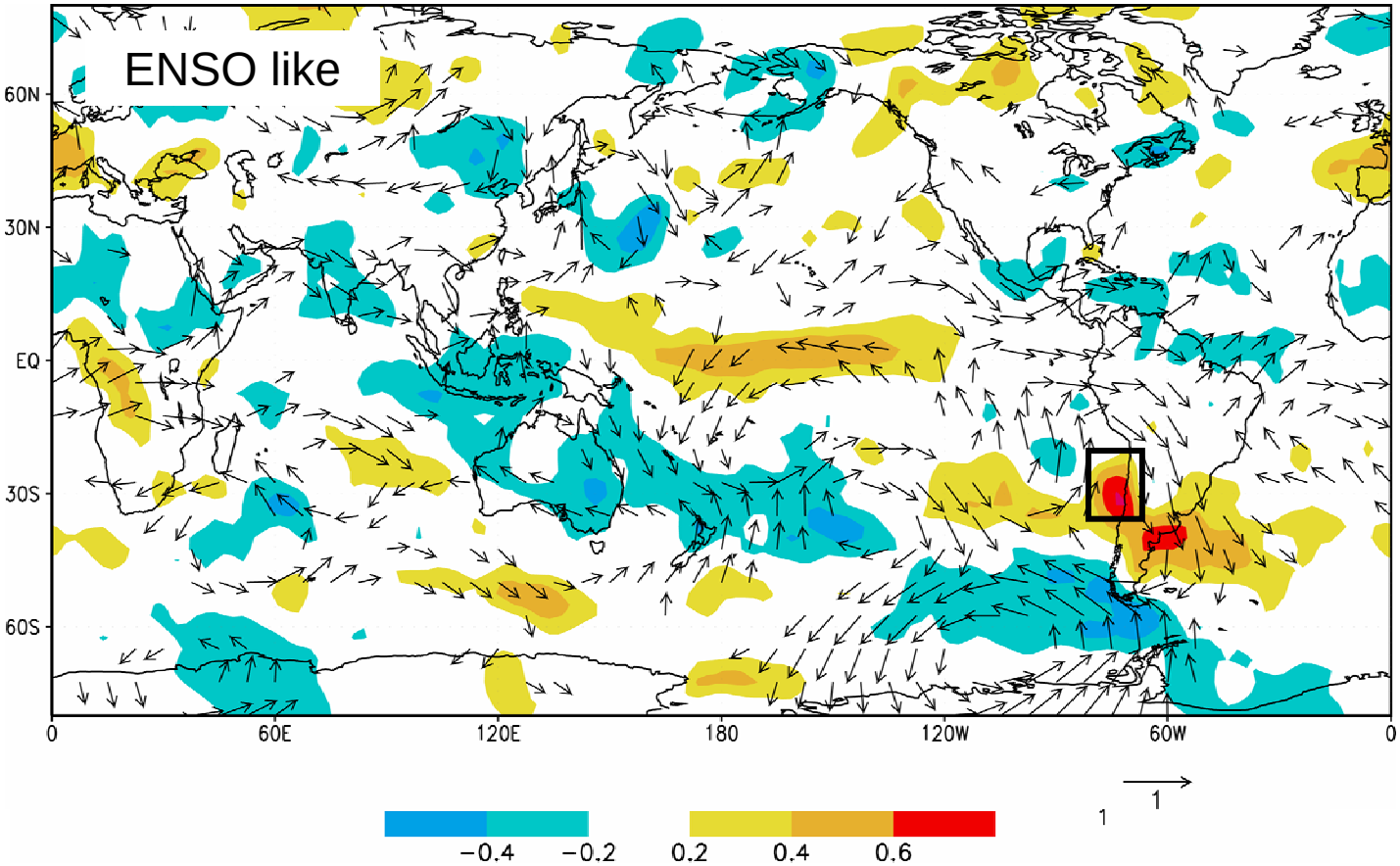
Local Correlation U850 – CMAP Precipitation using monthly anomalies (1979-2005)



Stronger than normal westerlies leads to rainy conditions over western Patagonia BUT drier conditions over eastern Patagonia….orographic effects: enhanced upslope rain / leeside rain shadow effect

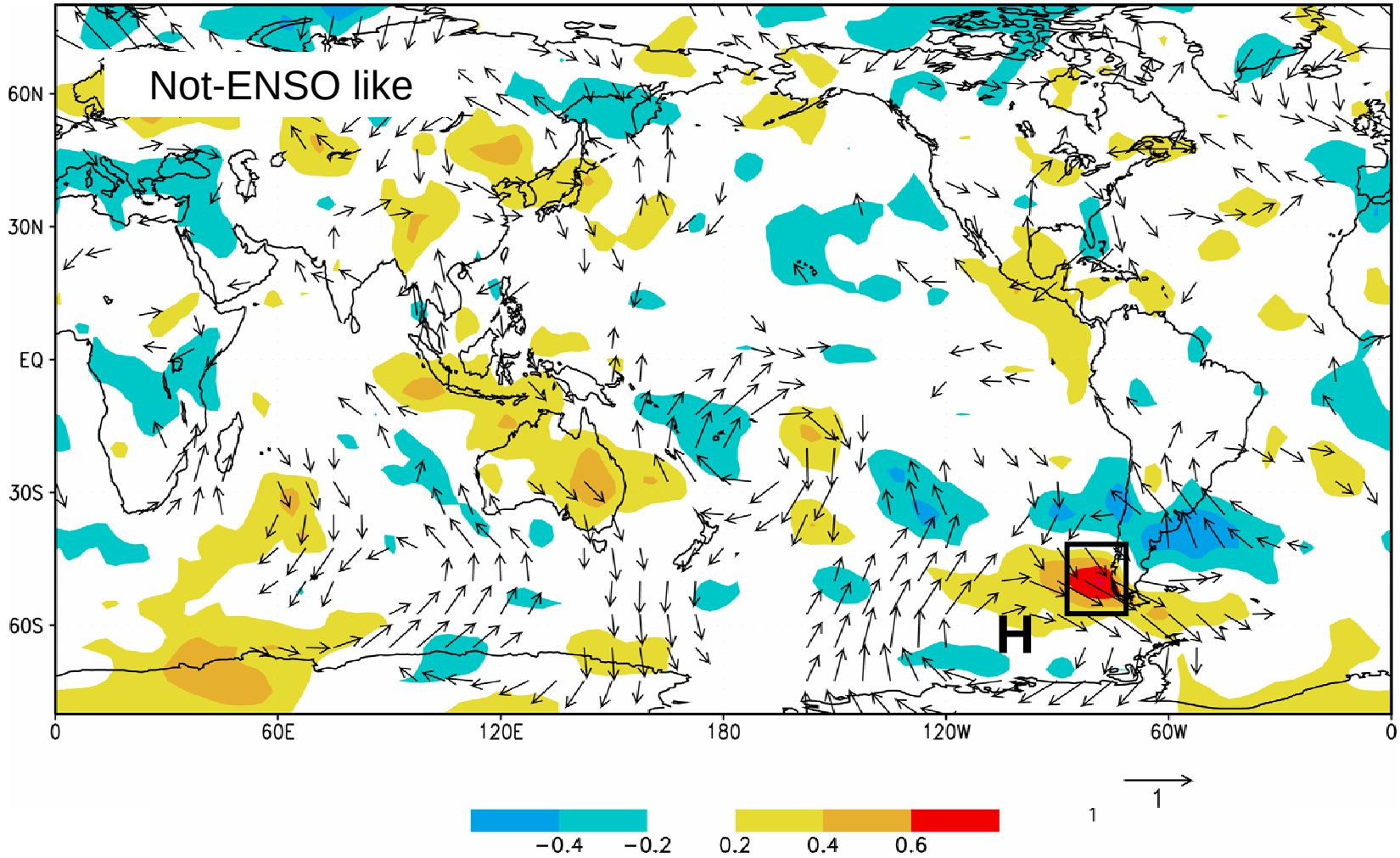
Previous maps of local correlation U-P tell don't tell us what large-scale might cause rainfall anomalies. This can be documented using 1-Point correlation maps.

Here we use seasonal means, so the maps indicate preferred mode of interannual variability.



Colores: r<P(local),P(global)> Vectors: r<P(local),V(global)>

Colores: r<P(local),P(global)> Vectors: r<P(local),V(global)>



Patterns / modes of large-scale circulation…be aware

1. Introduction

The climate dynamics literature abounds with patterns of variability; some labeled as teleconnection patterns, oscillations, clusters, seesaws, or modes; many others known only by mode number. The documentation of structures in sea level pressure (SLP) and upper-tropospheric geopotential height fields has proceeded largely independently, each yielding its own set of patterns.

The different analysis techniques used in climate dynamics research also yield different patterns, and even the same technique can yield quite different results, depending upon whether it is applied to a total field or to the zonally symmetric or asymmetric components of that field. The patterns that have emerged in various studies have also been conditioned by the spatial domain of the analysis, the manner in which seasonality is treated, and the time interval over which the data are averaged before the analysis is performed.

Quadreli and Wallace, J. Climate, 2002

How to make a circulation mode?

- Choose a variable/level from reanalysis
- You may want to pre-filter the data and select a sub-domain
- Use your favorite stat-software (Matlab, Maple, etc)
- Select a complicated tool (e.g., complex-rotated-extended-multidimensional EOF)
- Get your spatial pattern and loading factors (time series)

Unfortunately, it is very likely that you get a mode that is very similar to something already known.

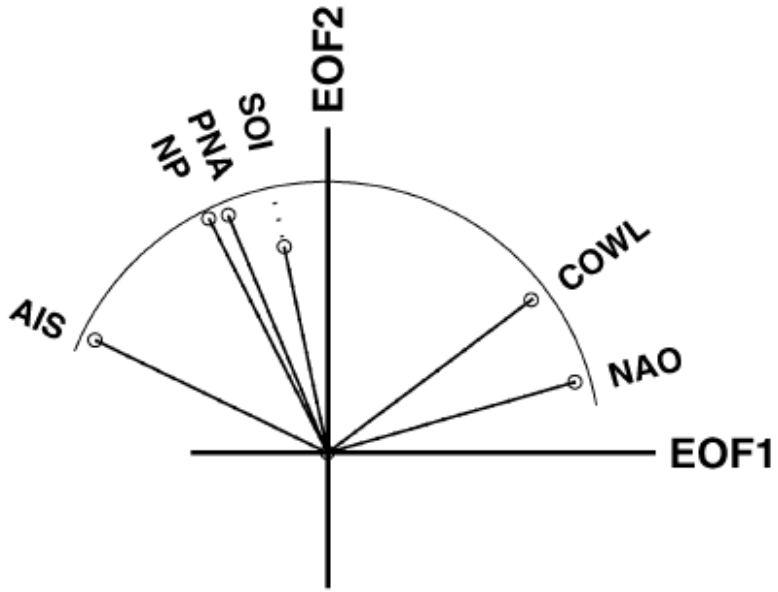
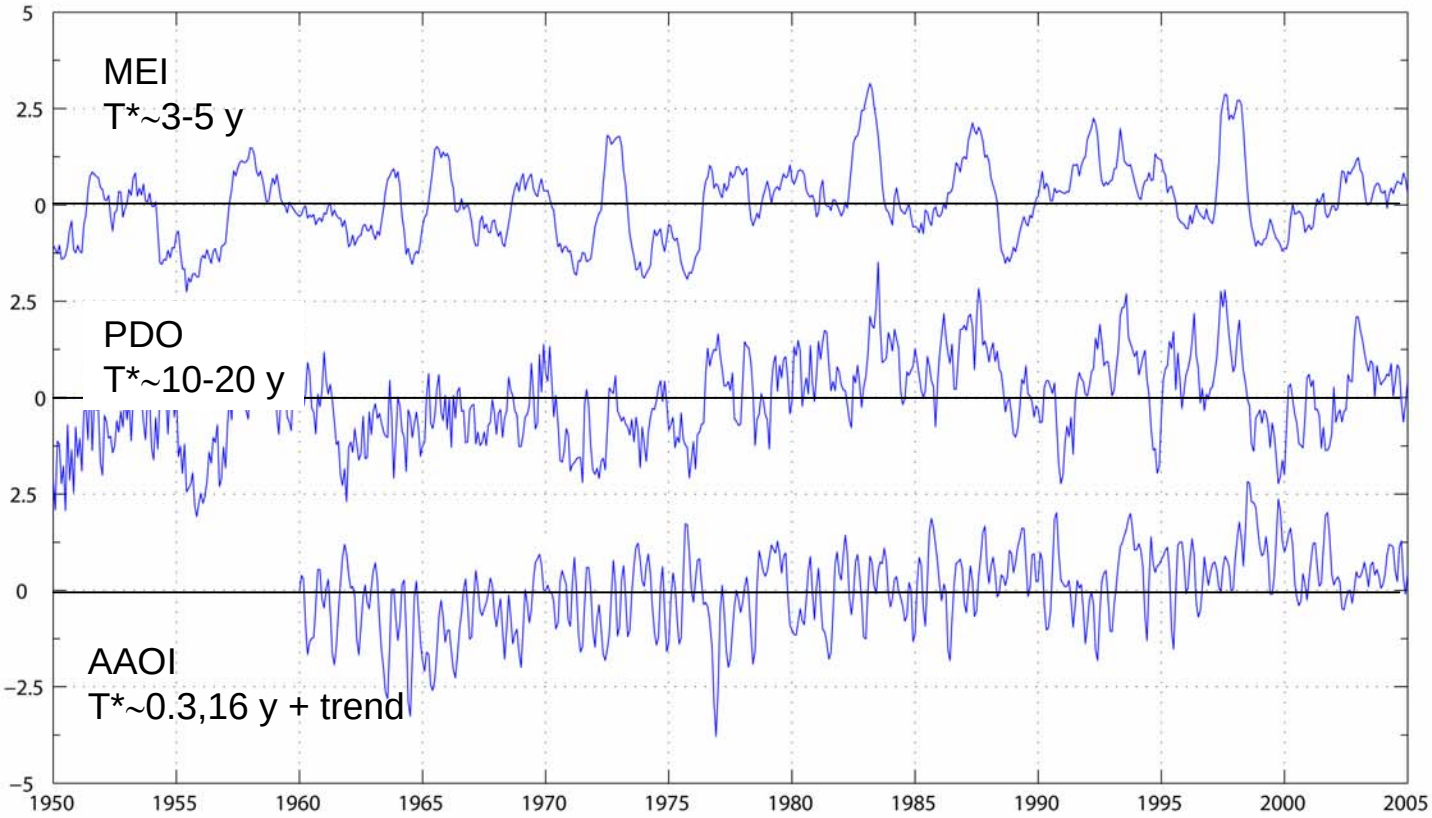
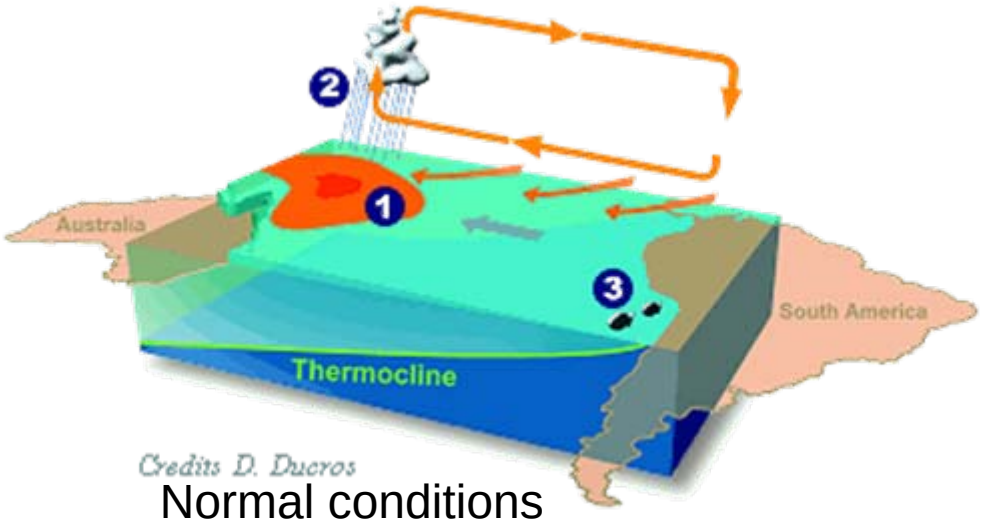


FIG. 4. Projections (area-weighted spatial correlations) of patterns associated with various indices on the phase space defined by the two leading EOFs of monthly DJFM NH SLP anomalies, north of 20°N. For reference, a circle of unit radius is shown in the plots. Positive values of the EOFs denote polarities indicated in Fig. 1.

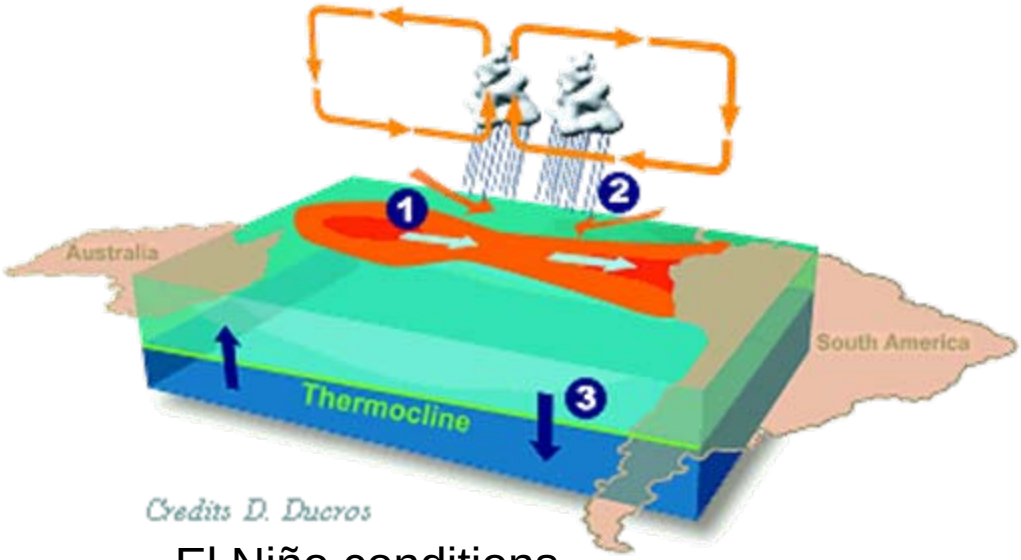
Quadreli and Wallace
J. Climate, 2002

Leading large-scale circulation modes: time-domain





Normal conditions



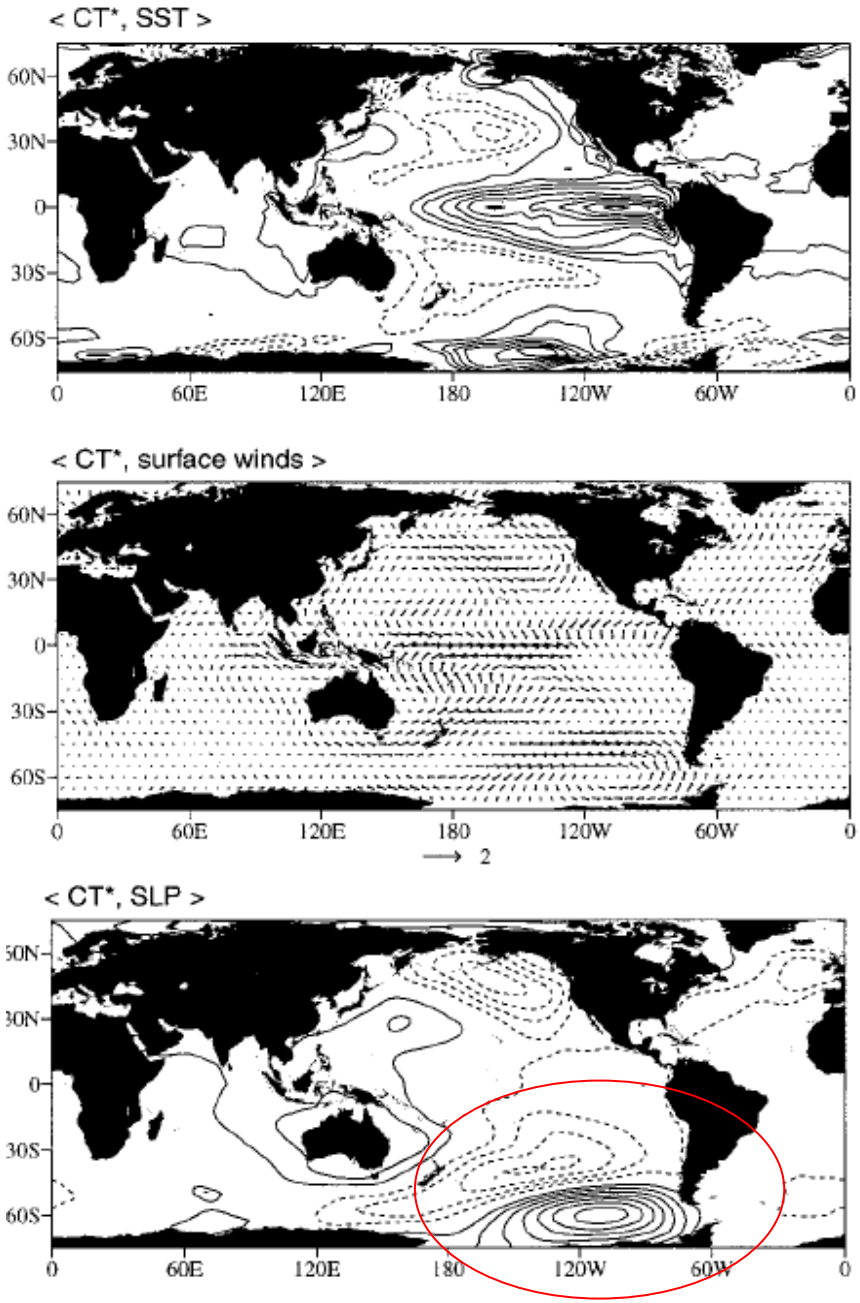
El Niño conditions

El Niño – Southern Oscillation (ENSO) is the leading mode of tropical variability, caused by the instability of the air-sea interaction over the equatorial Pacific.

Changes in the SST/wind pattern in the tropical Pacific alters the distribution of deep convective clouds.

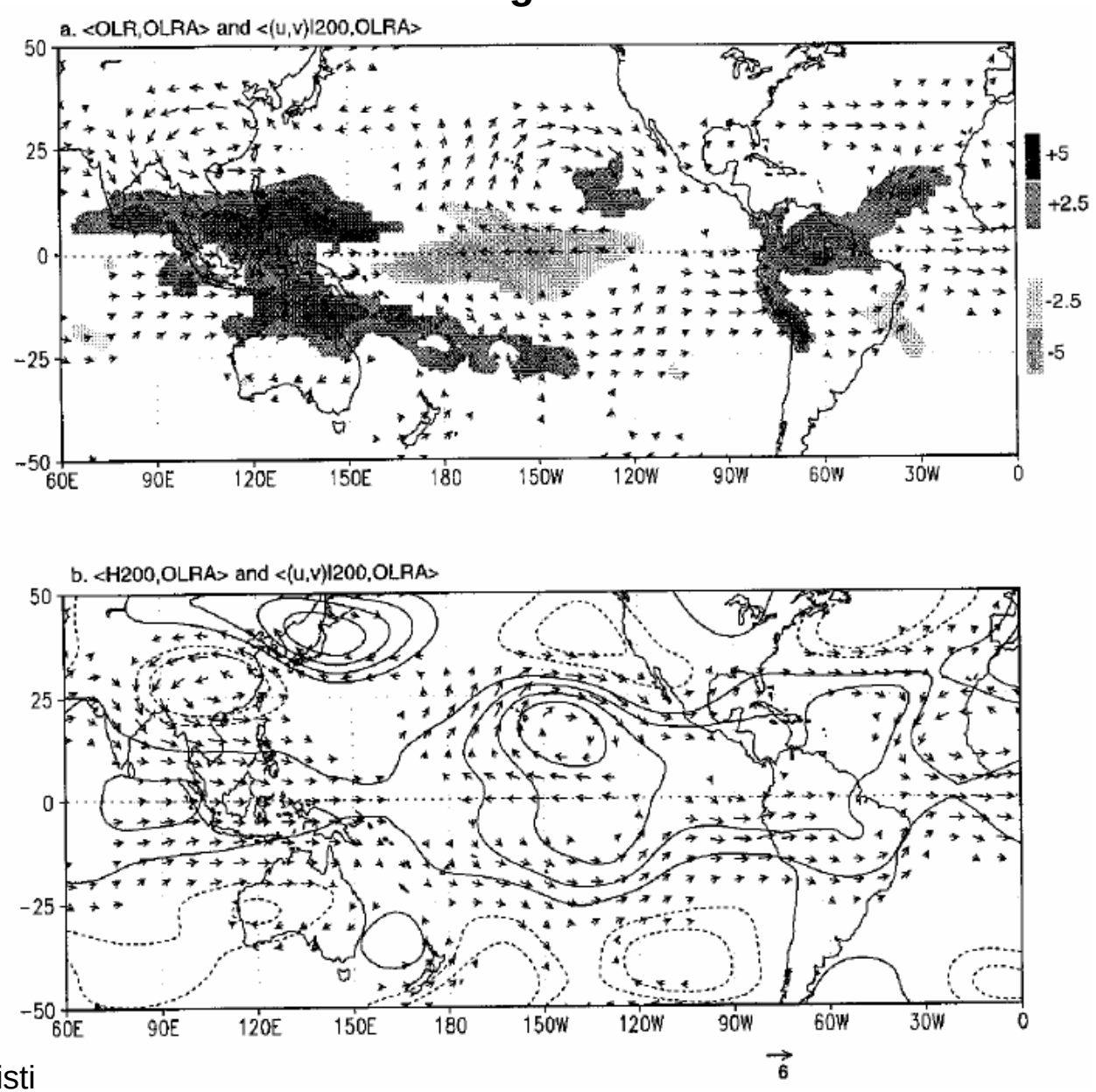
In turn, the anomalous outflow from convective clouds have a significant effect on the atmospheric circulation elsewhere, including the excitation of Rossby wave trains in the SH extratropics.

ENSO signatures

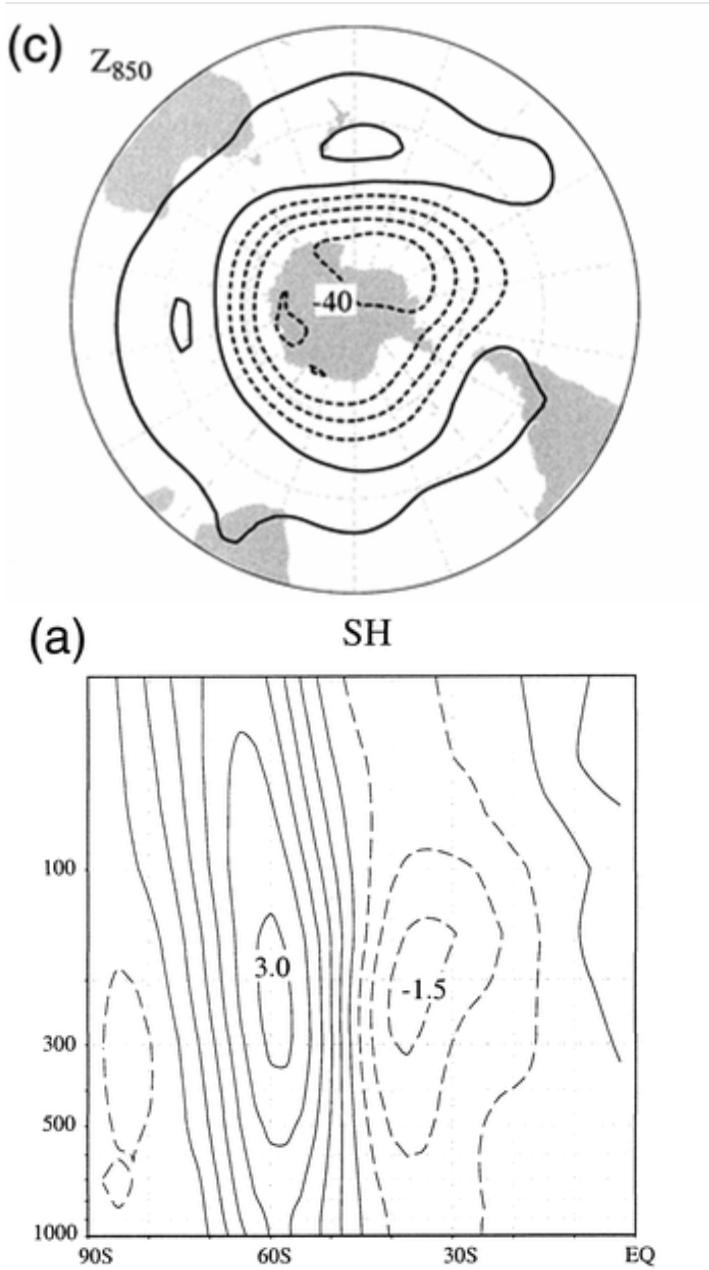


Garreaud and Batisti
J. Climate, 1999

ENSO signatures



Garreaud and Batisti
J. Climate, 1999



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)

The "Pacific Decadal Oscillation" (PDO) is a long-lived El Niño-like pattern of Pacific climate variability. While the two climate oscillations have similar spatial climate fingerprints, they have very different behavior in time. Causes for the PDO are not currently known.

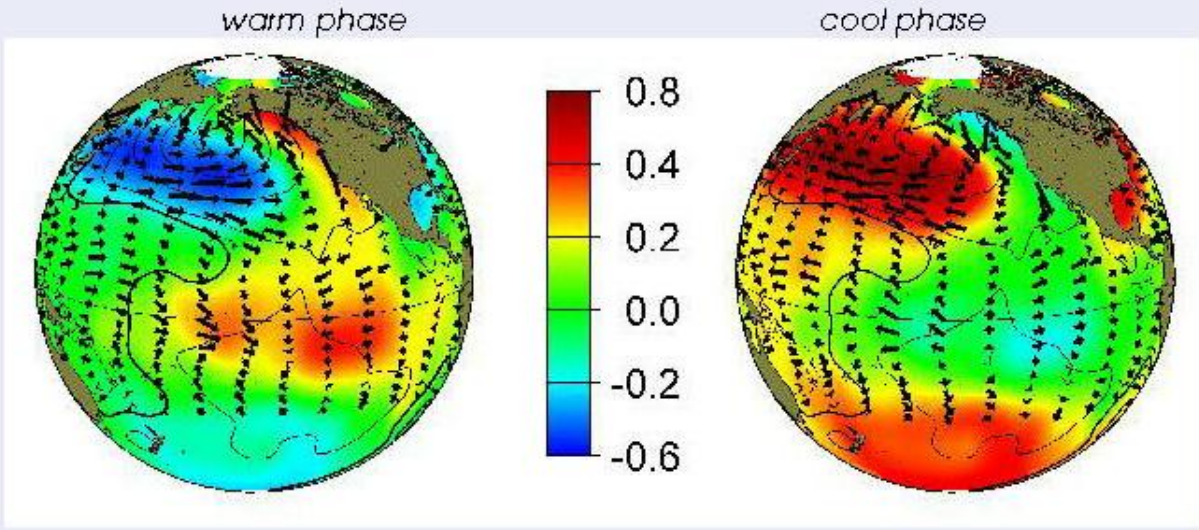
Two main characteristics distinguish PDO from ENSO:

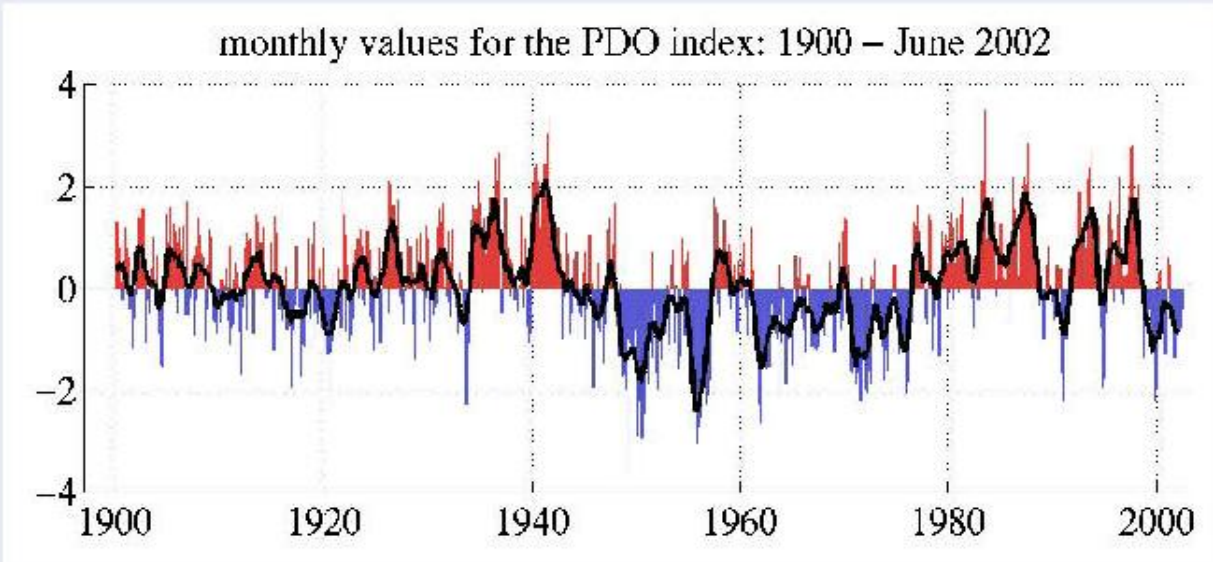
1. 20th century PDO "events" persisted for 20-to-30 years, while typical ENSO events persisted for 6 to 18 months

2. The climatic fingerprints of the PDO are most visible in the North Pacific/North American sector, while secondary signatures exist in the tropics and the SH - the opposite is true for ENSO.

Several independent studies find evidence for just two full PDO cycles in the past century: "cool" PDO regimes prevailed from 1890-1924 and again from 1947-1976, while "warm" PDO regimes dominated from 1925-1946 and from 1977 through (at least) the mid-1990's.

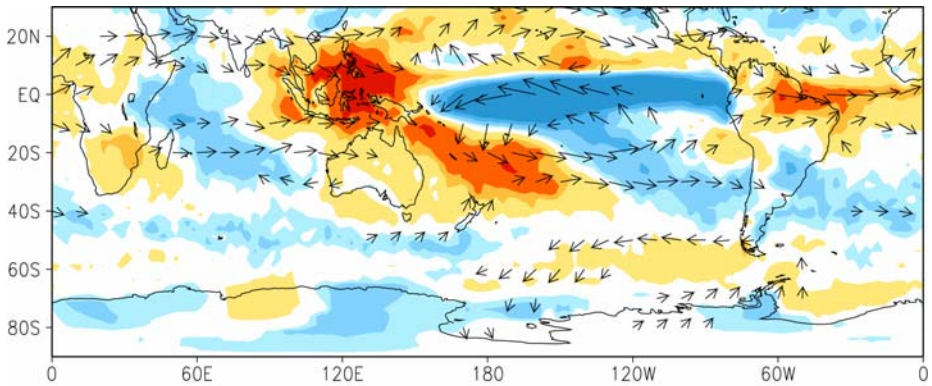
PDO Basics


warm phase
cool phase
0.8
0.4
0.2
0.0
-0.2
-0.6

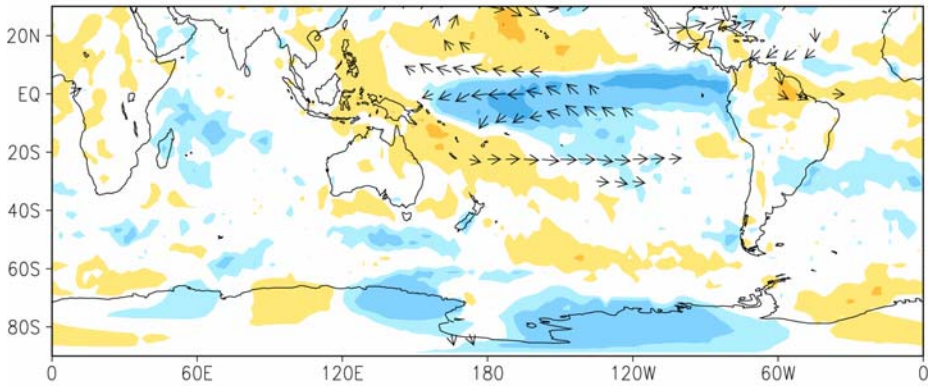

monthly values for the PDO index: 1900 – June 2002
4
2
0
−2
−4
1900
1920
1940
1960
1980
2000

$\Re$<Index, Precipitation> and $\Re$ <Index, V_{300}>
Based on monthly anomalies, 1979-2005

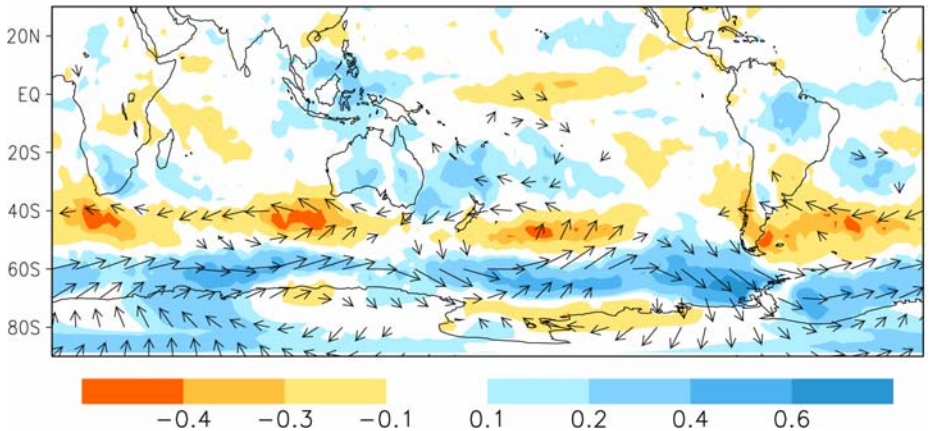
Multivariate ENSO Index



PDO Index



SAM Index (AAOI)



ENSO-Rainfall correlation shows significant seasonal variability

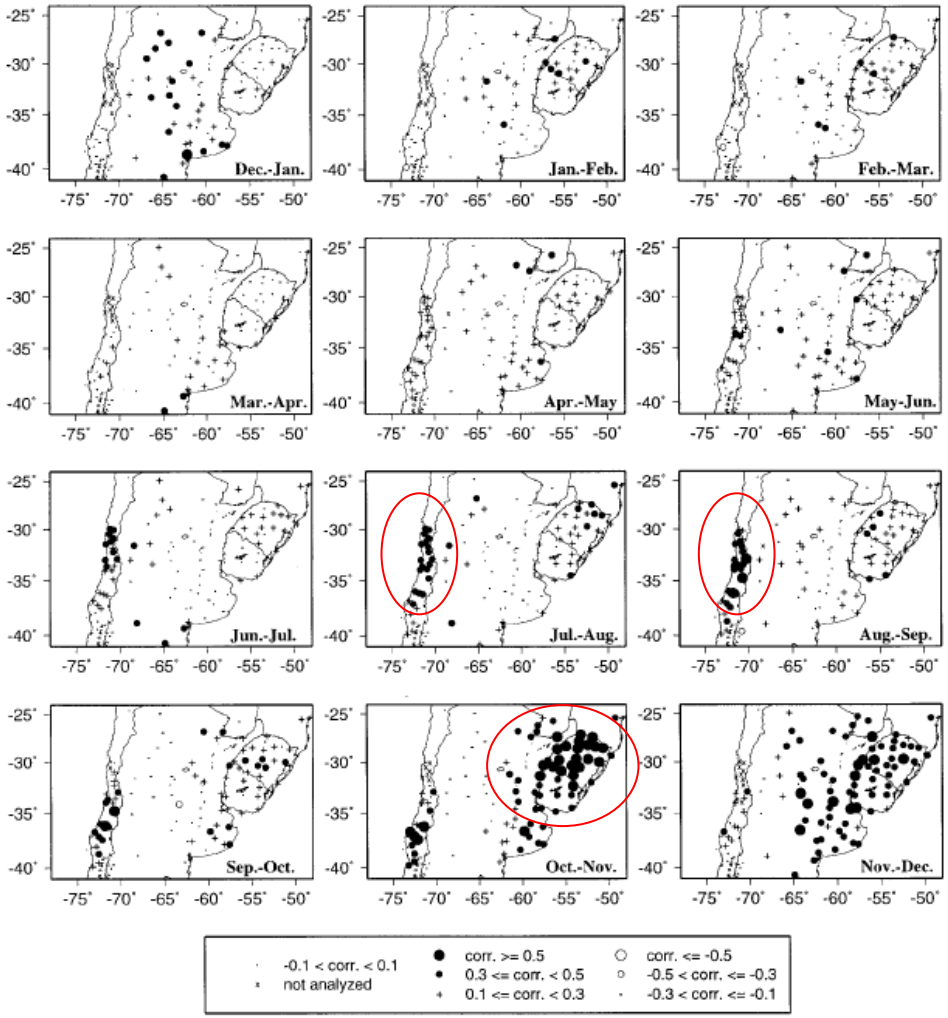


FIG. 3. Pattern of correlation between SST PC1 and rainfall for each of the 12 sliding bimonthly intervals: Dec–Jan, Jan–Feb, Feb–Mar, up to Nov–Dec. Symbols indicate magnitude and sign of correlation (see code in the figure). A magnitude larger than 0.30 is significant at the 6% level.

SAM-Rainfall correlation, seasonality ? Likely, but harder to find

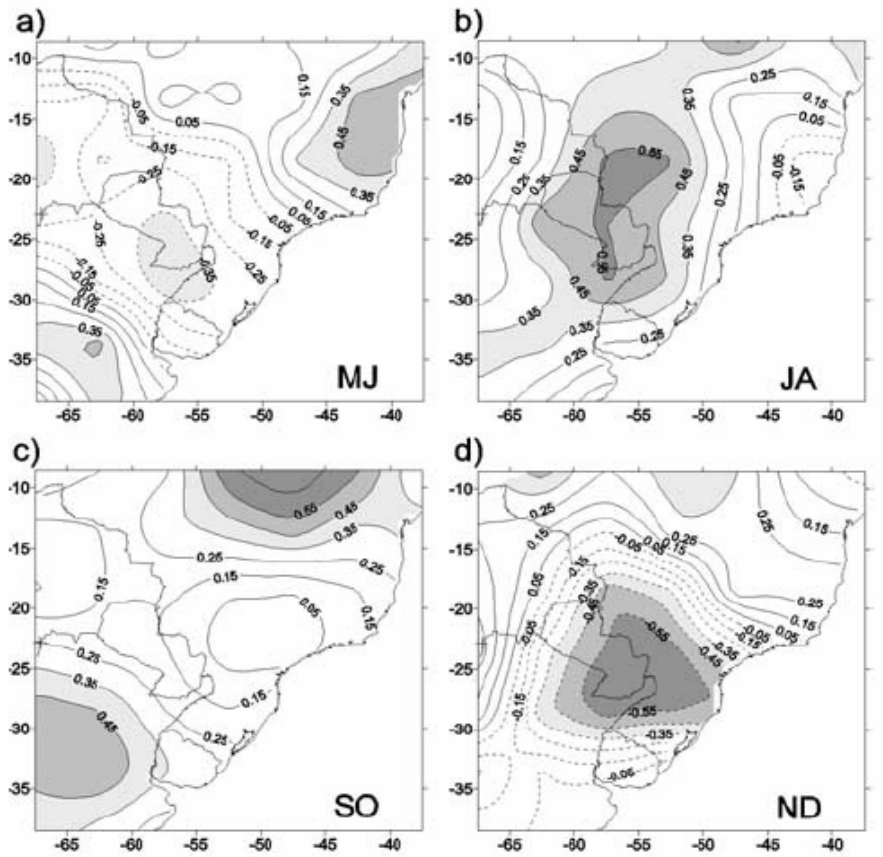


Figure 1. Correlation maps between AAO index and bi-monthly precipitation anomalies over SESA (ENSO signal removed) for a) May–Jun, b) Jul–Aug, c) Sept–Oct and d) Nov–Dec. Areas where values are statistically significant at the 90, 95 and 99% are respectively shaded.

Conclusions

- Rainfall anomalies in southern South America are strongly related with zonal flow: positive correlation to the west and negative correlation to the east of the Andes.
- We also found a dipole in rainfall anomalies along the west coast of the continent between midlatitudes and the subtropics.
- Rainfall anomalies in western Patagonia are weakly related to ENSO, moderately related to SAM, and highly related with blocking activity just west of the Antarctic peninsula.
- Please recall…all previous results based on monthly anomalies, and thus applicable to interannual variability.
- Future work: analyze signals on longer time scales