The link between the tropical precipitation and Hadley circulation

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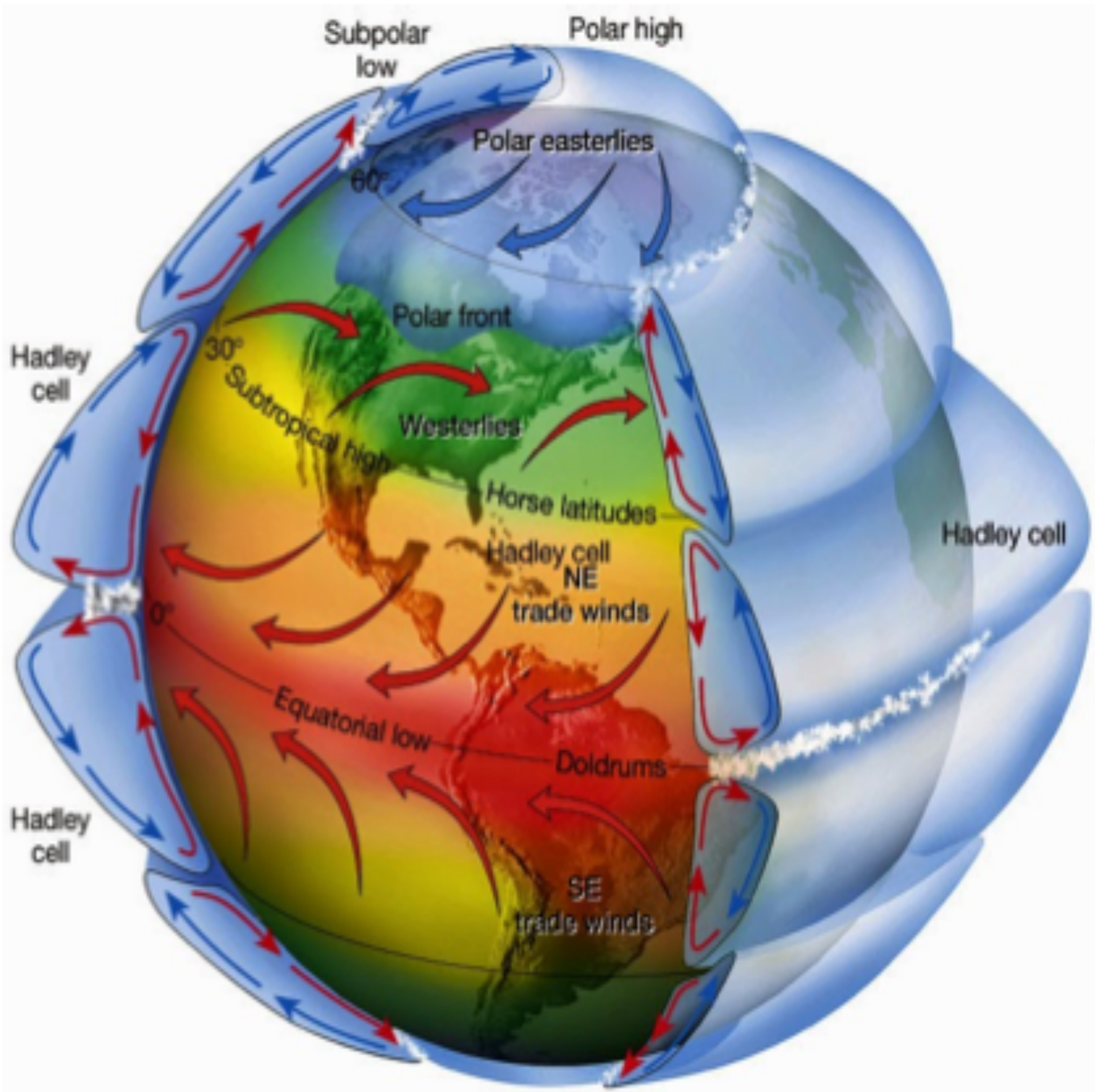
Hadley Circulation



The Hadley Circulation (HC) plays an important role in transferring energy, momentum and moisture form tropics to extratropics (*Diaz and Bradley, 2004*)

Halley (1686) was the first to describe the manner in which differential heating would result in a fluid motion but he did not explain of why there was an easterly component of the surface trade winds.

Hadley (1735) understood the relevance of the angular momentum on the HC dynamic

Its meridional extent and intensity have influences on global and regional climate. The HC spans half the area of the globe and its variability can affects the lives of billions of people (*Holton and Hakim, 2012*)

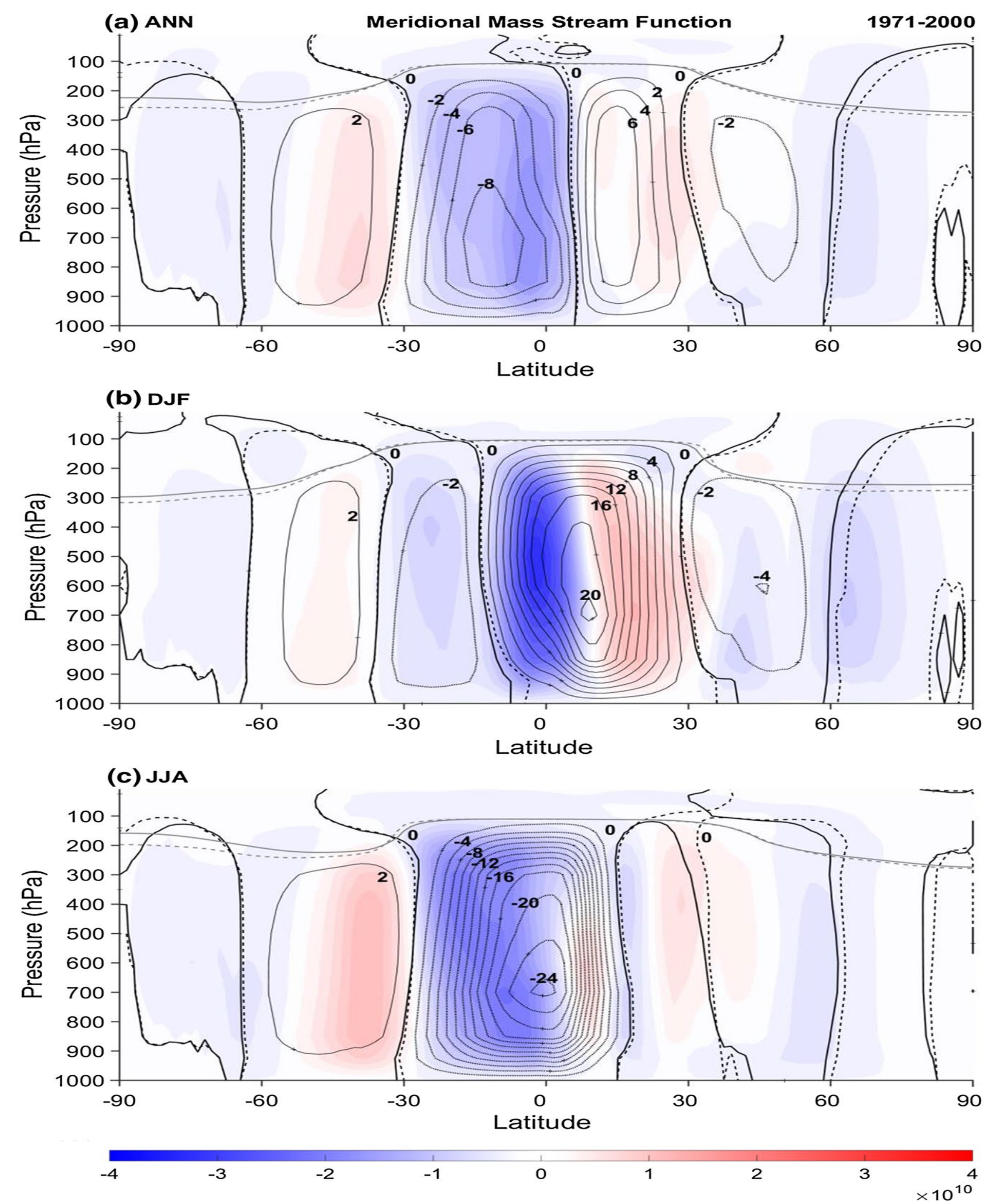
Previous studies

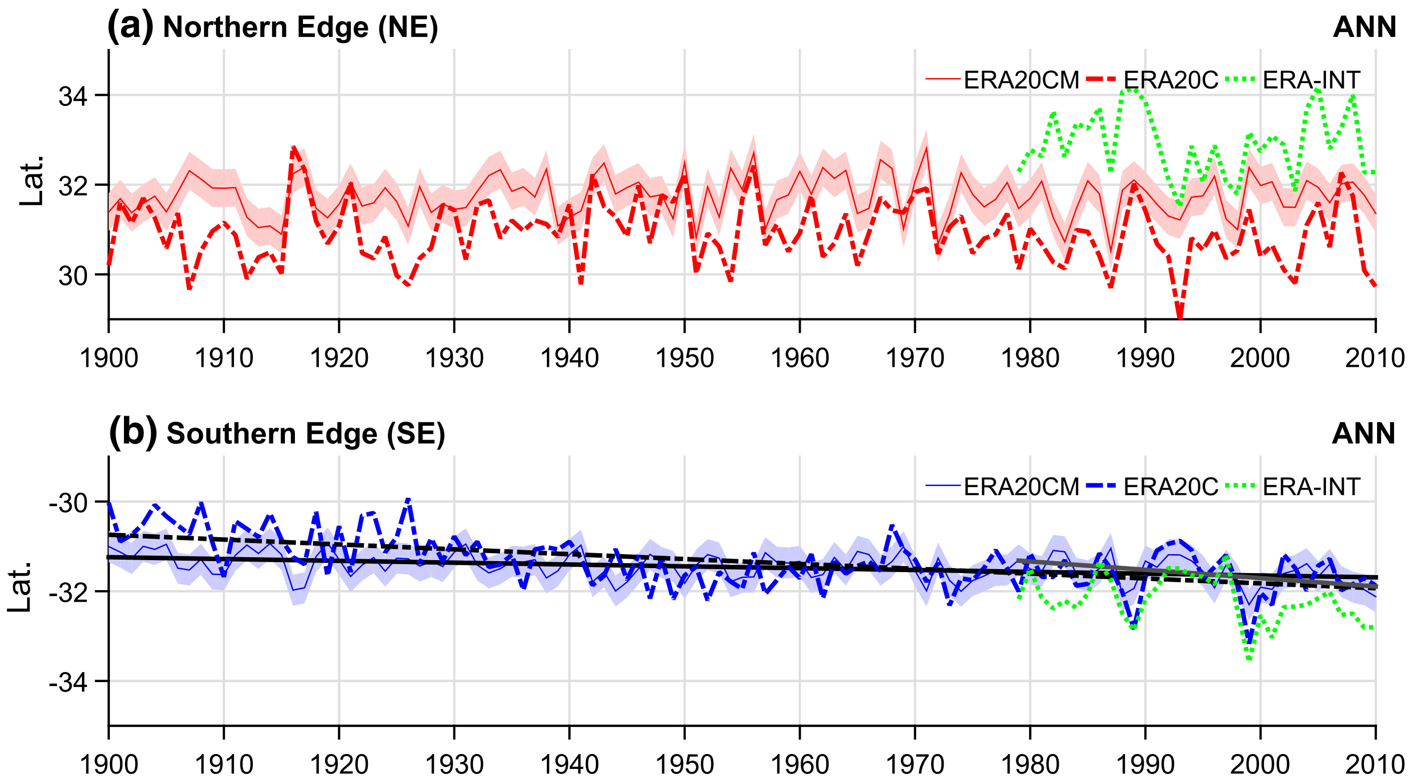
(D'Agostino and Lionello, 2016)

Monthly mean mass stream function (ψ)

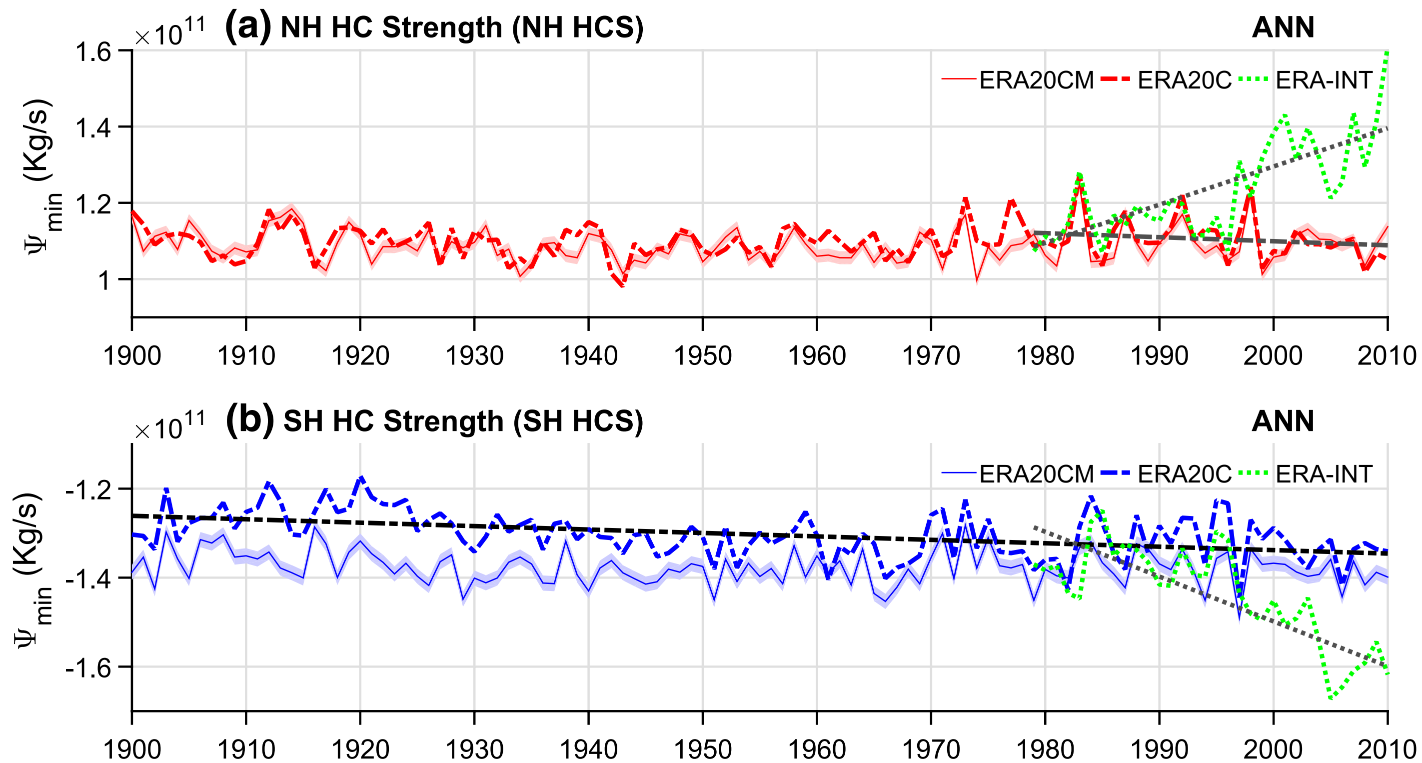
$$\psi = \frac{2\pi a \cos\phi}{g} \int_0^p [\bar{v}]dp$$

ψ is positive (negative) in the NH (SH). The strength of the HC is given by the maximum and minimum values of ψ in the NH and SH, respectively. NE and SE are defined as the zero-crossing latitudes of ψ_{bulk}, where ψ_{bulk} is the average of ψ between 150 and 700 hPa.





There is a signal of a poleward shift of the HC in the southern edge

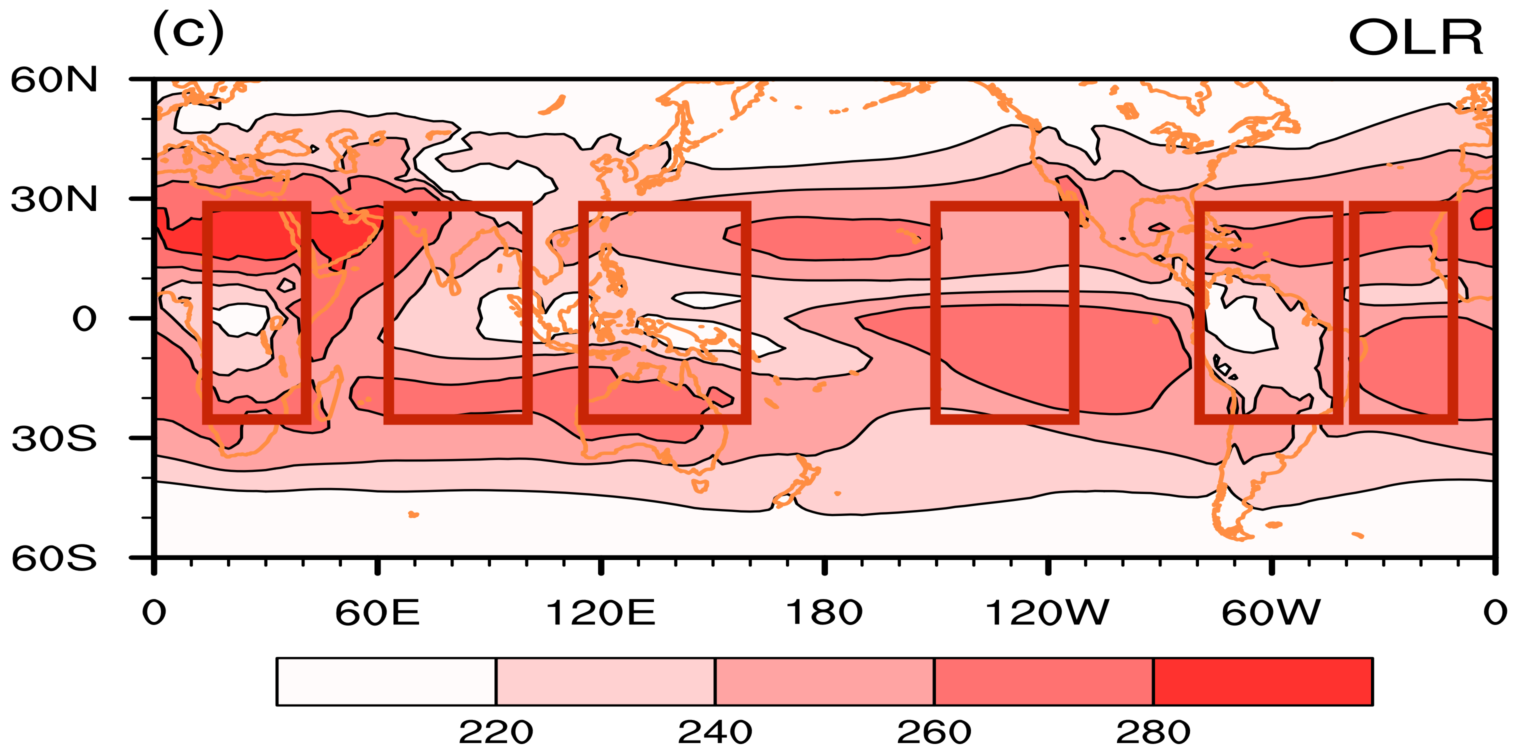


There is not an agreement about the strength of the HC; ERA-20CM and ERA-20C do not show any particular trend whereas Era-Interim show a remarkable trend

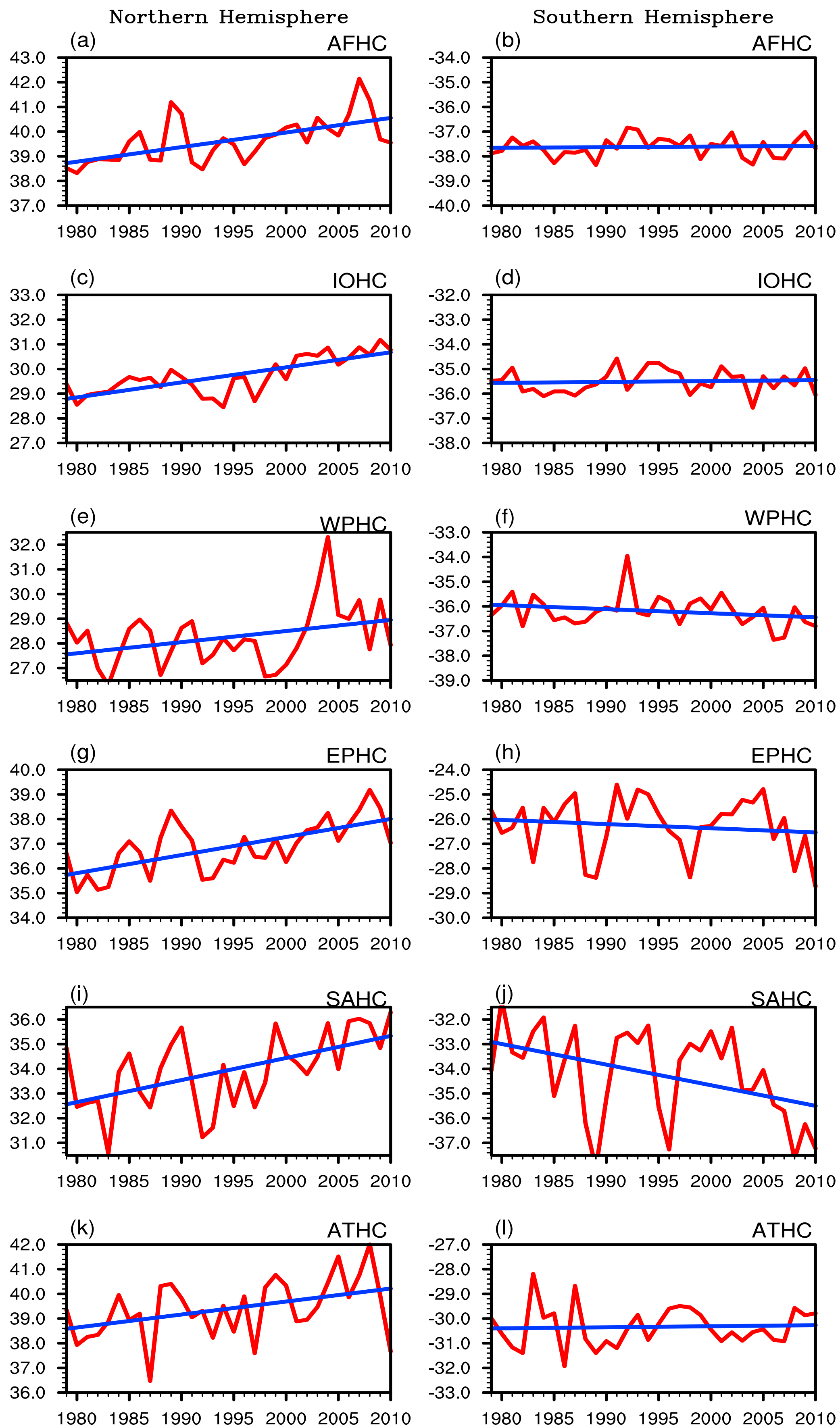
Previous studies

(Chen et al. 2014)

In this study six different regions are selected



The latitude where OLR=250 Wm^-2 is defined as the poleward edge of the HC.



- In the NH the poleward movement of that HC is displayed in all regions considered.

- In the SH only the South America sector shows a poleward displacement; the other regions do not show significative poleward shift

Previous studies

- Other recent studies (based on reanalyses) agree on a poleward expansion of HC subtropical edges during the 20th century (Hu and Fu, 2007; Seidel et al., 2008; Lu et al.2009, Birner, 2010; Davis and Rosenlof , 2012; Nguyen et al., 2013; Adam et al., 2014; D'Agostino and Lionello, 2017), but present contrasting conclusions on its strength (Mitas and Clement 2005; Liu et al. 2012; Nguyen et al. 2013)

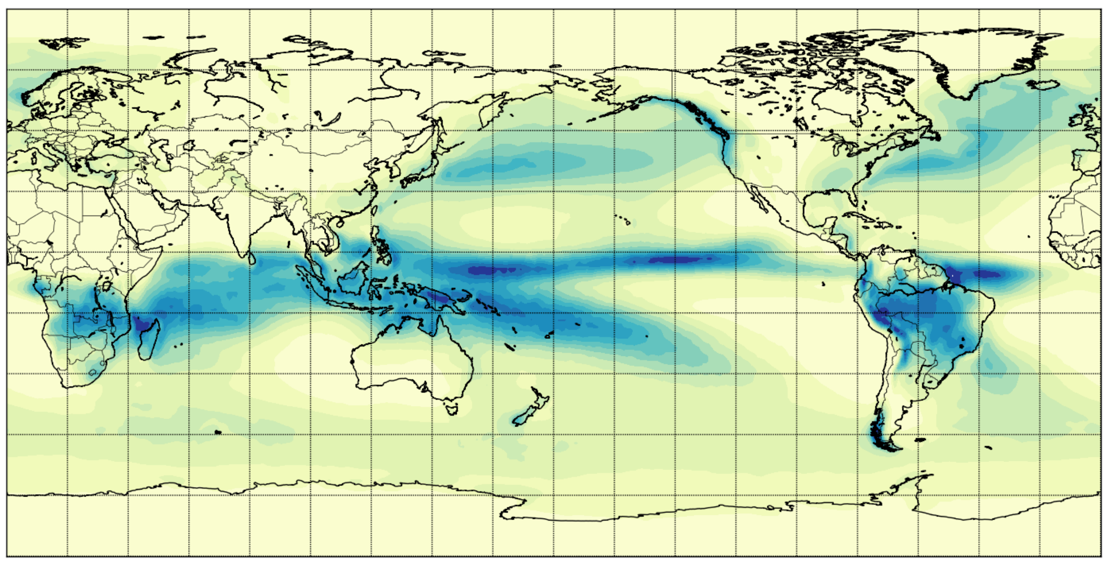
- Climate model projections consistently suggest expansion and weakening with global warming (Lu et al.2009, D'Agostino and Lionello, 2017)

- Most of these analysis are based on the meridional stream function and are unable to identify any zonal feature of the HC variations (trends).

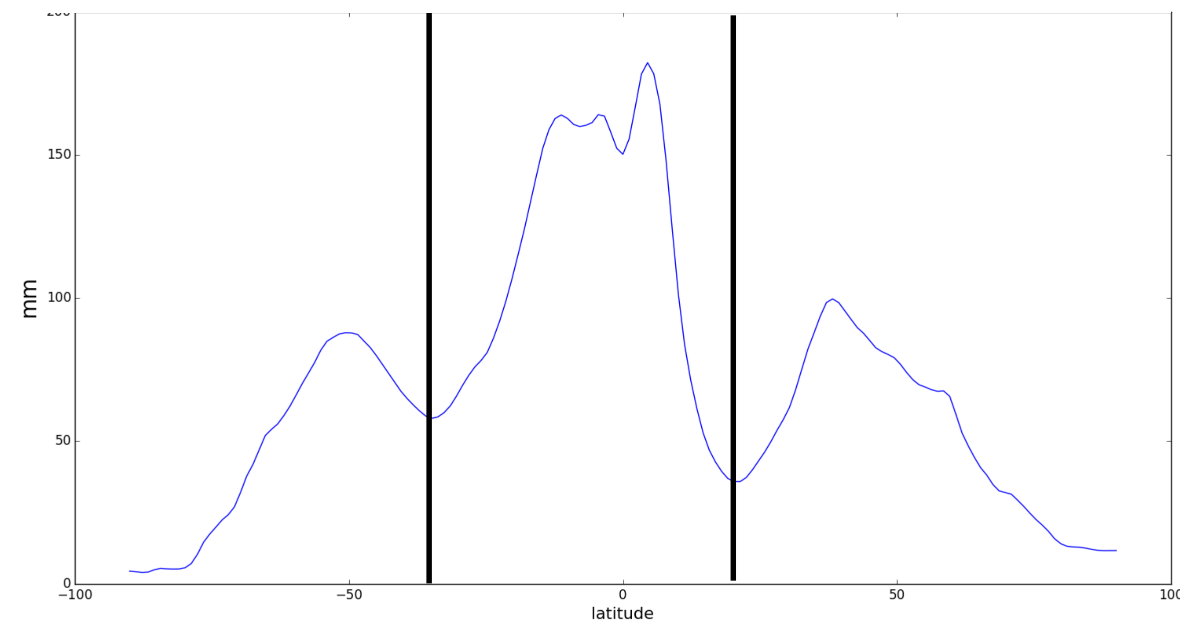
- Further analyses demonstrate that variations in regional HC poleward edges could have a significant impact in precipitation field.

HC is a thermally driven circulation, it varies seasonally with a season shift of the insolation. In the season migration around the Equator determines the precipitation pattern in the tropics

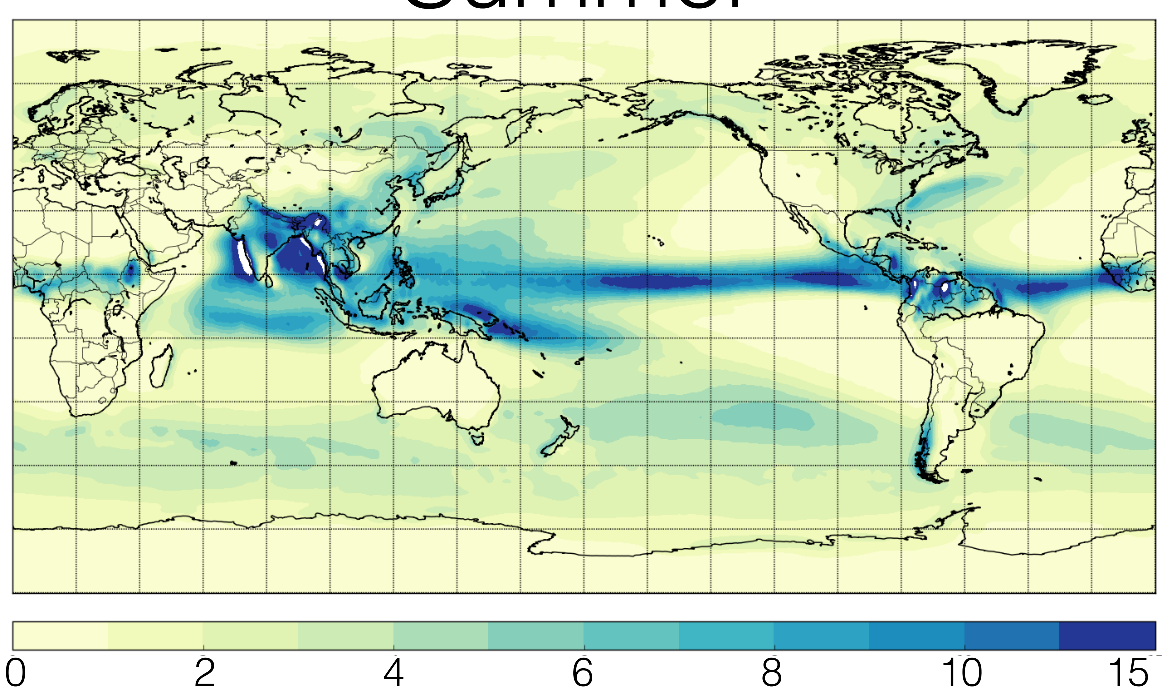
Winter



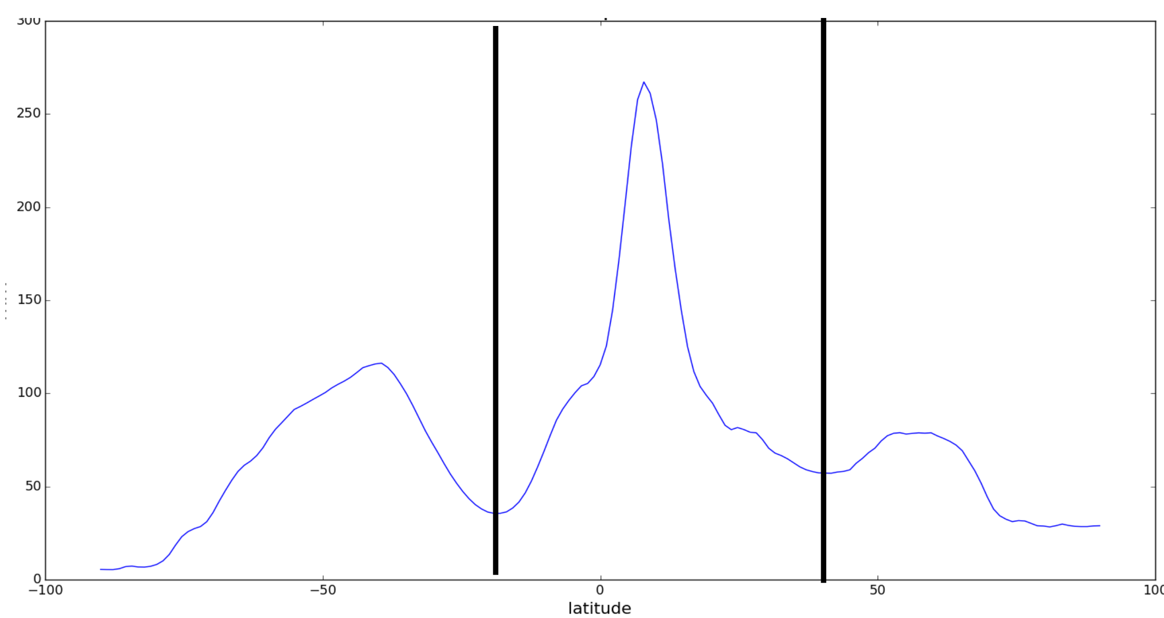
Winter



Summer



Summer



		ERA-20CM		ERA-20C		ERA-Interim	
Streamfunction	Precipitation	DJF	JJA	DJF	JJA	DJF	JJA
NE	NE	0.598	0.229	0.468	0.035	0.411	0.148
SE	SE	0.781	0.444	0.562	0.086	0.506	0.138
CE	CE	0.743	0.549	0.670	0.270	0.460	0.388
NE	TP	-0.668	-0.522	-0.336	-0.109	-0.224	-0.026
SE	TP	0.632	0.565	0.141	0.089	0.444	0.076
ψ(north)	NE	-0.804	-0.271	-0.448	-0.233	-0.243	-0.141
ψ(north)	TP	0.844	-0.156	0.669	-0.200	0.686	-0.290
ψ(south)	SE	-0.411	-0.425	-0.043	-0.194	0.084	-0.194
ψ(south)	TP	-0.422	-0.030	-0.318	-0.004	-0.037	-0.129

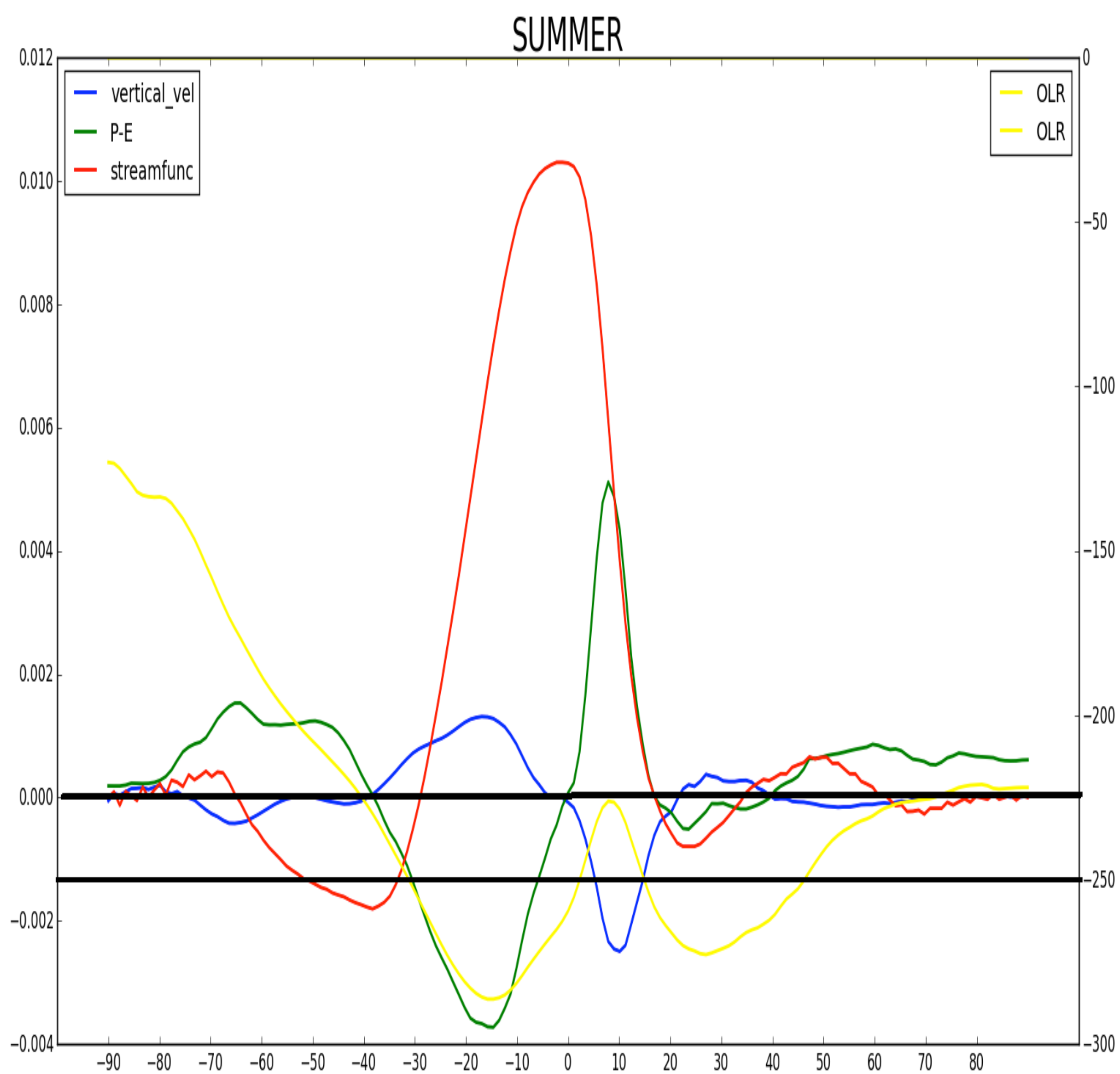
TP (Total Precipitation in the belt 30°S-30°N)

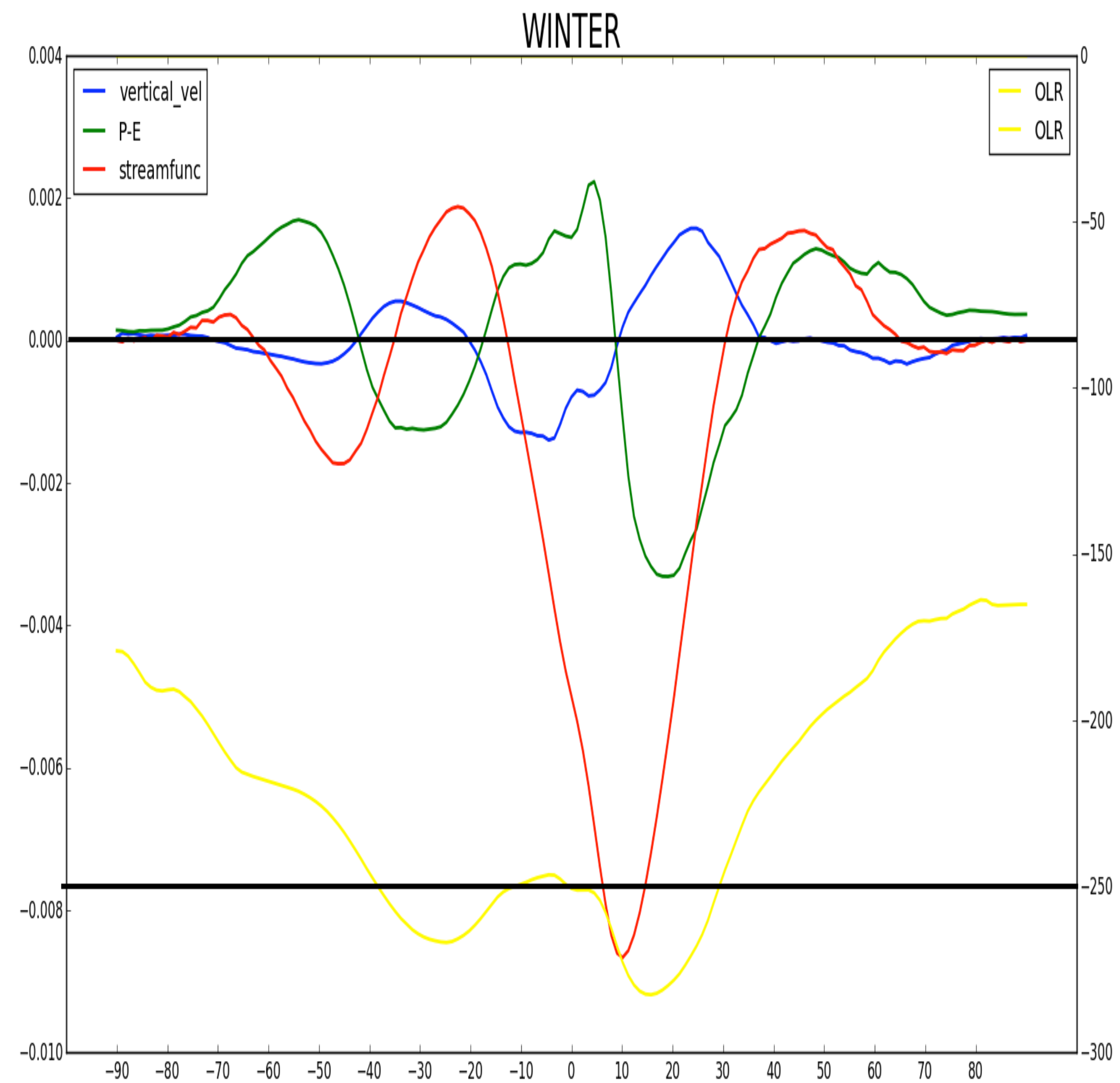
Greater the precipitation in the tropics is, stronger the stream function and less extended the HC are

There is not a zonally uniform variation of the HC and there is also a significative differences between the hemisphere and seasons

Consider other parameters to describe the Hadley circulation:

- Vertical Velocity (VV)
- Precipitation-Evaporation (PE)
- OLR
- Advantages of OLR and P-E is that they are directly based on environmental variables affected by the HC.

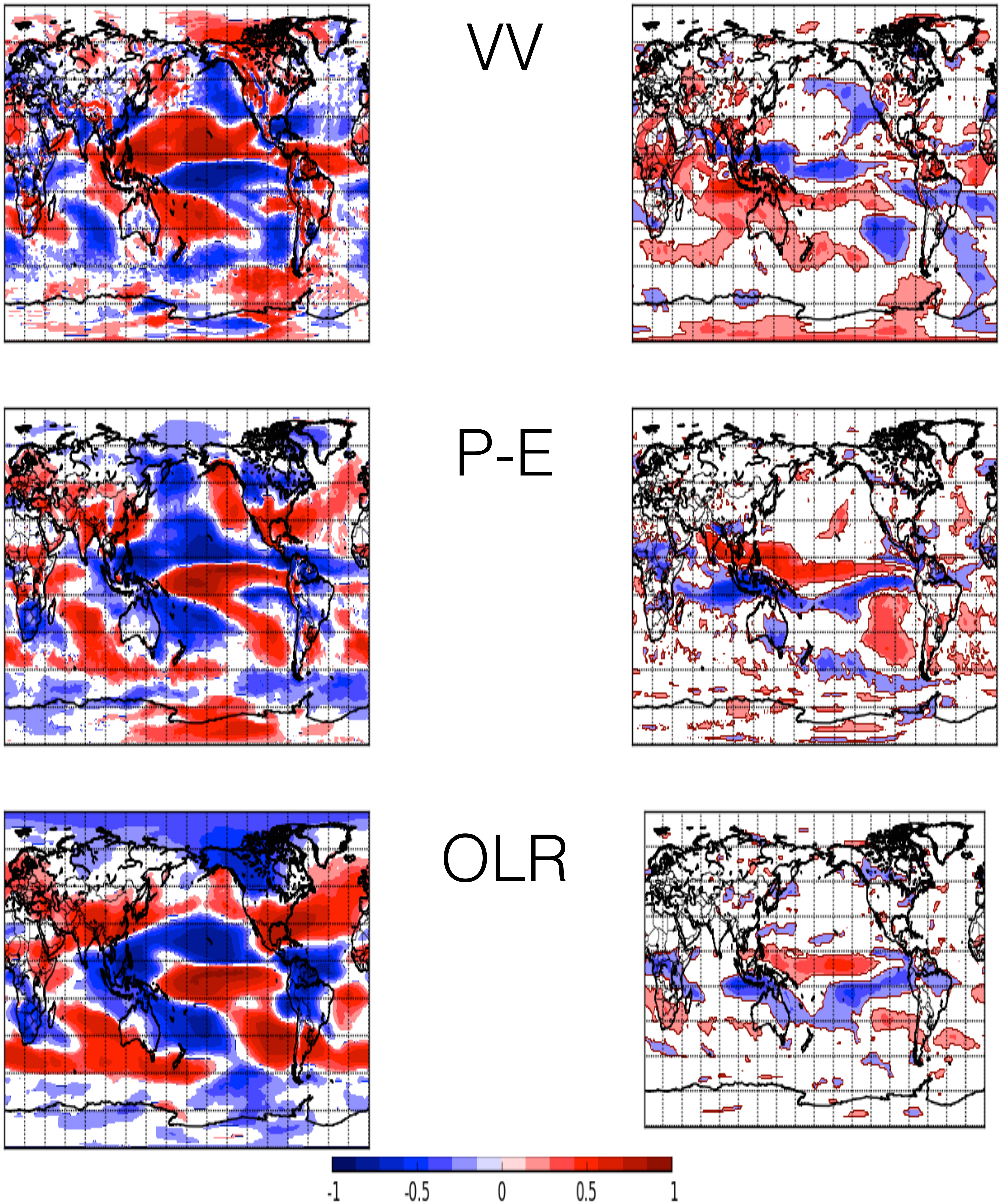




	ψ(north)		NE		ψ(south)		SE	
	DJF	JJA	DJF	JJA	DJF	JJA	DJF	JJA
VV	-0.19	0.01	0.18	0.54	-0.34	0.05	0.61	-0.31
PE	-0.74	0.09	0.51	0.03	0.53	-0.33	0.78	0.41
PE (0)	-0.67	0.03	0.66	0.52	-0.25	-0.24	0.83	0.61
OLR	-0.66	0.0	0.40	0.61	-0.53	-0.14	0.49	0.21
OLR (min)	-0.62	-0.27	0.48	-0.12	-0.20	0.0	0.70	0.31

Even considering other parameters to describe the HC, a significative differences between the hemisphere and seasons appears.

The lack of correlation is due to the different zonal patterns of the considered variables, which are completely ignored when considering zonal averages.

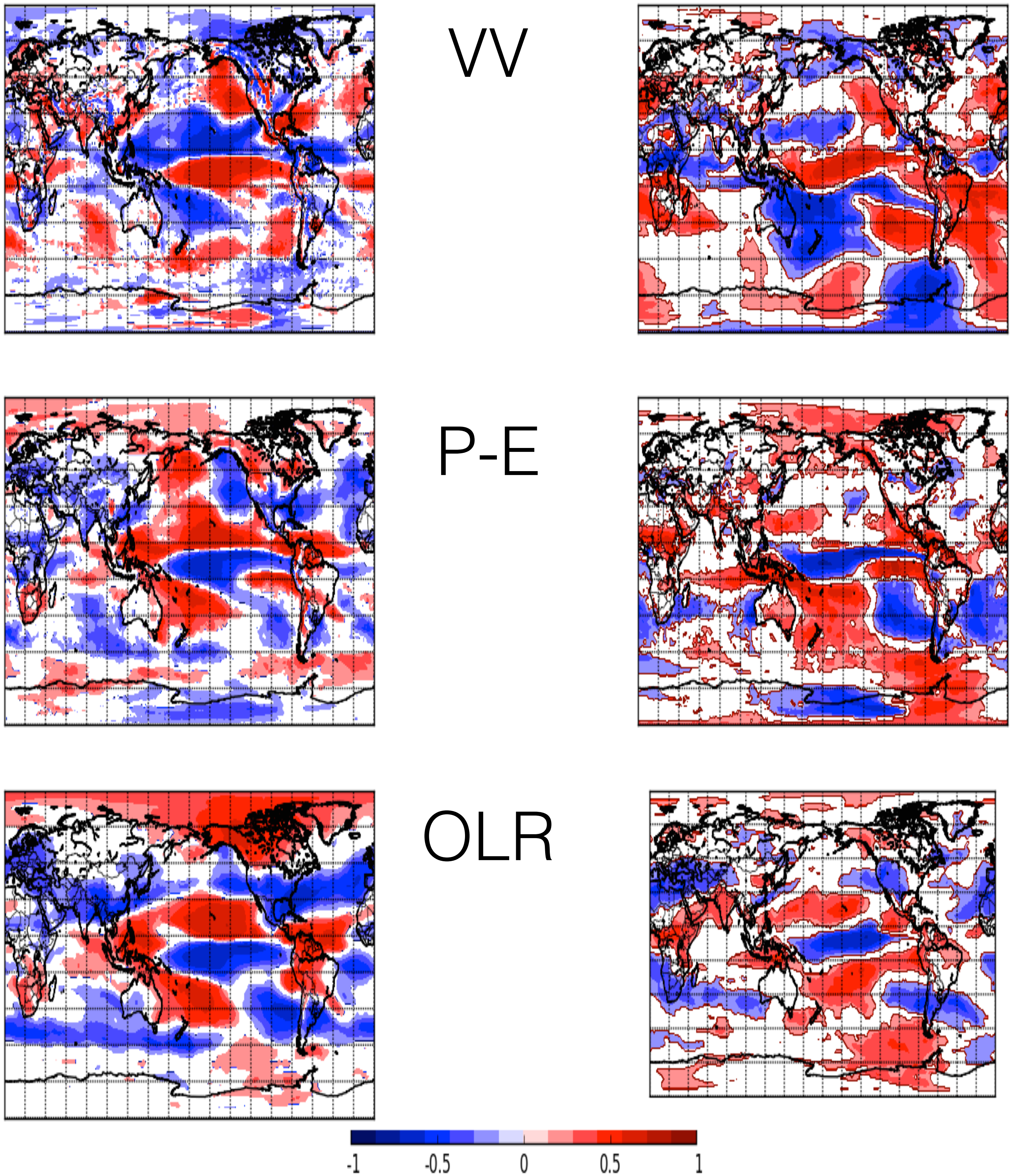


Stronger the ψ is, less extended the HC is.

The ITCZ is narrower

Boreal winter the signal is dominated by the Pacific region

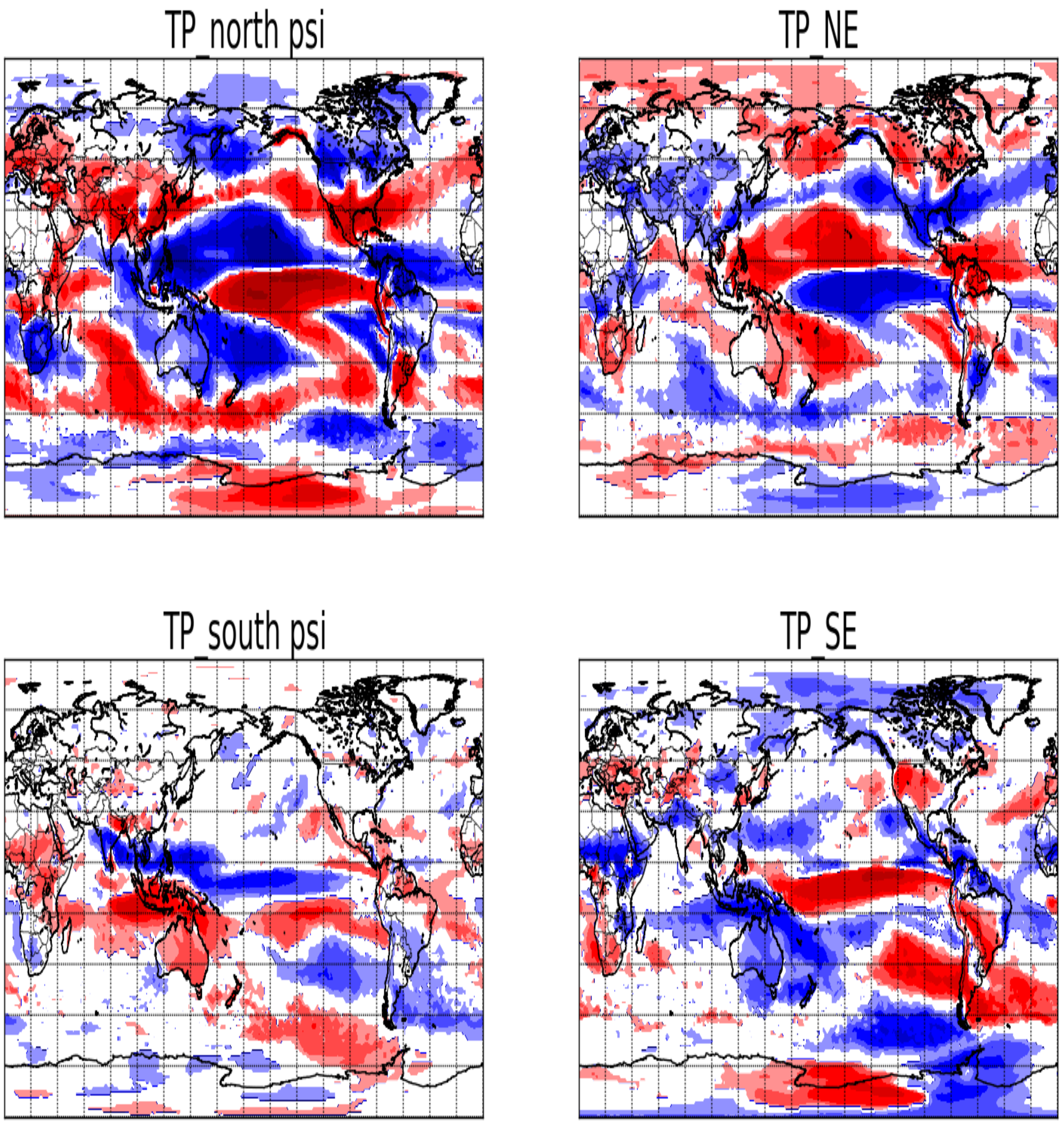
During austral winter the signal is in general weaker and even in this case is dominated by the Pacific/ Maritime continent.



More extend the HC is less precipitation in the ITCZ area and a poleward movement of the sub-tropical dry regions.

Even in this case the circulation is dominated by the Pacific region

Many zonal features appears that may lead to a confused interpretation of zonal mean values.



Even considering the precipitation there is that same signal: HC is dominated by the Pacific and it is not a zonally uniform circulation

Summary

- HC is expanding at a rate of 0.35°lat/K warming even though there is a disagreement among models.
- This expansion is not zonally uniform and shows differences between the two hemispheres: the response of NH to tropical heating is much stronger than in the SH.
- There is a strong signal in the Pacific region that dominates the HC.
- Monsoon circulation related features can perturb the HC variability?
- There are “hot spots” (Maritime Continent and Central America) of high correlation that are possibly suitable for studying the HC behaviour.