SEVENTH ICTP WORKSHOP ON
THE THEORY AND USE OF REGIONAL CLIMATE MODELS
12 - 23 May 2014 Miramare, Trieste, Italy

Interannual variability associated with ENSO: present and future climate projections of RegCM4 for South America-CORDEX domain

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Outline

- Motivation and objective
- Observed data, simulations, ENSO identification
- Present climate (1975-2005): precipitation climatology and ENSO signal
- Near- (2020-2050) and far-future (2070-2098) climates: precipitation trends and ENSO signal
- Summary and conclusions

- ## Motivation

- one of the most remarkable aspects of the climate is its variability;

- most important coupled atmospheric-oceanic phenomenon responsible for interannual variability on a global scale is the El Niño-Southern Oscillation (ENSO)

- over the South America (SA) El Niño (EN) is typically associated with below (above) normal precipitation over northern-northeastern (southeastern) SA. The opposite signal is normally observed during La Niña (LN).

- ## Objective

- In the context of Coordinated Regional Downscaling Experiment (CORDEX), the objective of this study is to investigate the simulated interannual precipitation variability associated with ENSO over SA in both present and future climates.

Observed data, RegCM4 simulations, ENSO identification

- # Observacional Data

- For validation of the simulated present climate we used the dataset from:

  <u>Precipitation</u>

- **CMAP:** (Xie and Arkin 1996); satellite+ raingauge → $\Delta x =$ 2.5º
- **CRU:** (Mitchell and Jones 2005)
- **CPC:** (Chen et al. 2008)
- **UDEL:** (Legates and Willmott 1990)

  – **CRU, CPC, UDEL**: only raingauge and $\Delta x =$ 0.5º

  EnsObs = (CRU+CPC+CMAP+UDEL)/4 → over continent and

  EnsObs = CMAP → over oceans

  <u>SST</u> (to calculate observed Oceanic Niño Index – ONI)

  mean monthly SST from ERSST.vb3 (Smith et al. 2008)

RegCM4 simulations

CORDEX-SA RegCM4 simulations (USP+ICTP) were forced by 3 GCMs

Period: 1975-2100 (continuous run)

Two combination of parameterizations:

CLM land-surface with Emanuel convection – CE

BATS land-surface with mixed convection (Grell-continent+Emanuel-ocean) - BG

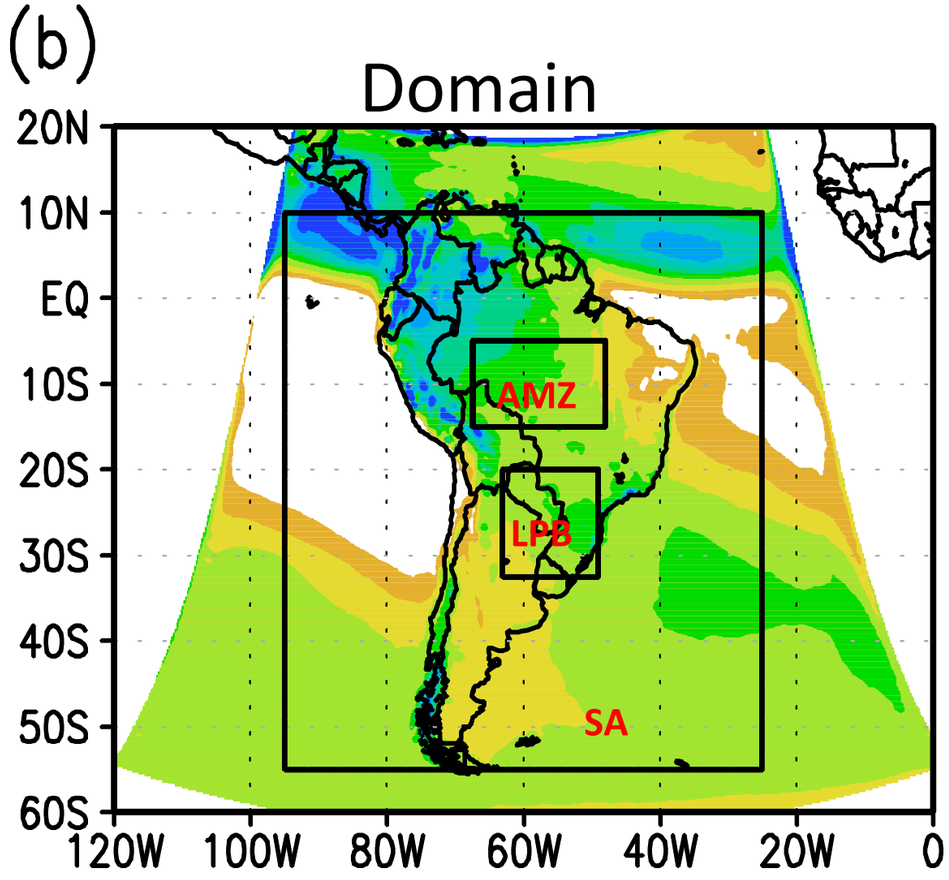
3 GCMs: HadGEM2-ES; MPI-ESM-MR; GFDL-ESM2M

2 RCPs: 4.5; 8.5

Four (two) RegCM4 simulations in the RCP8.5 (RCP4.5) - (Llopart, 2014).

Future	Present	Surface	Convection	RCP	GCM
Had85ctrl	BGRegHad	BATS	Mixed	8.5	HadGEM2
Had85CLM	CERegHad	CLM	Emanuel	8.5	HadGEM2
Had45ctrl	BG	BATS	Mixed	4.5	HadGEM2
Had45CLM		CLM	Emanuel	4.5	HadGEM2
MPI85CLM	CERegMPI	CLM	Emanuel	8.5	MPI
GFDL85CLM	CERegGFDL	CLM	Emanuel	8.5	GFDL

Simulation domain and analyzed periods



3 time-slices

Periods/ Simulations	CERegHad RCP8.5	CERegHad RCP4.5	BGRegHad RCP8.5	BGRegHad RCP4.5	CERegMPI RCP8.5	CERegGFDL RCP8.5
1975-2006	X		X		X	X
2020-2050	X	X	X	X	X	X
2070-2098	X	X	X	X	X	X

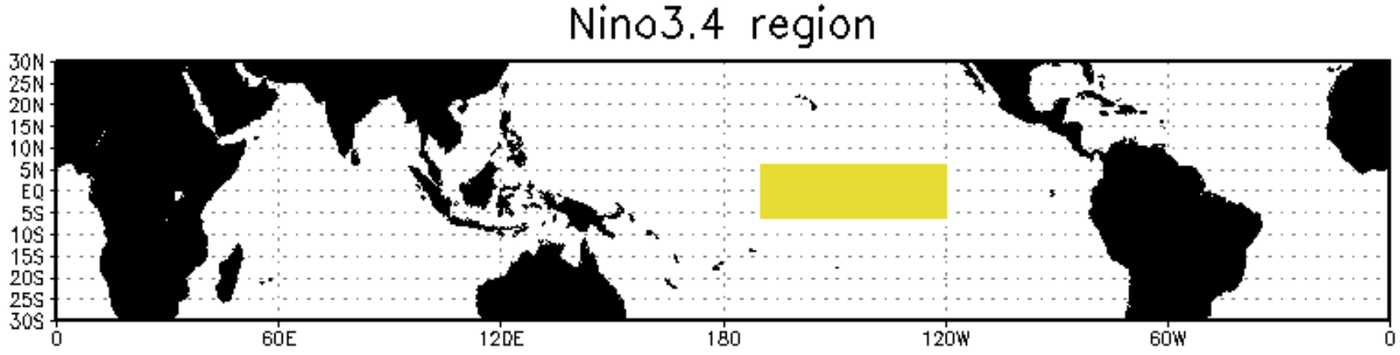
Interannual variability: Oceanic Niño Index (ONI)

- interannual variability associated with ENSO is evaluated using composites for the **austral spring** (SON: September, October and November);

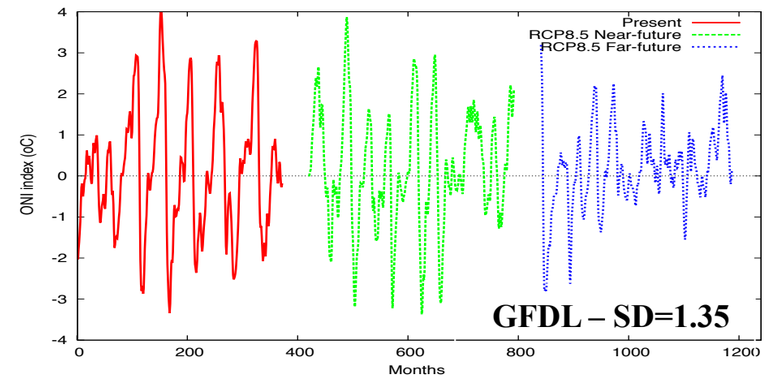
- Why SON? → ENSO signal in the precipitation is stronger over SESA than in other regions of South America (Grimm and Ambrizzi 2009);

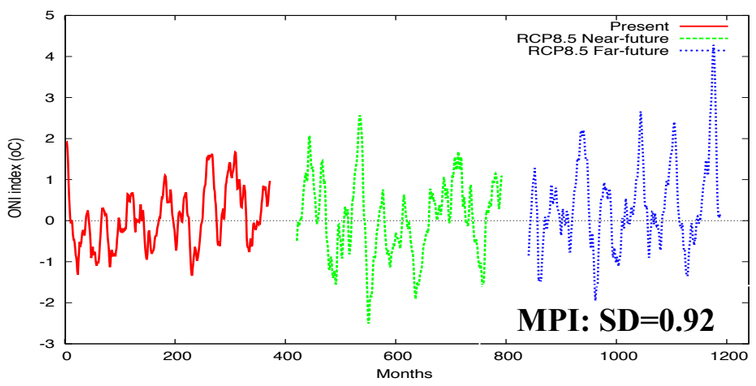
- El Niño (EN) and La Niña (LN) years are defined according to the Oceanic Niño Index (ONI)

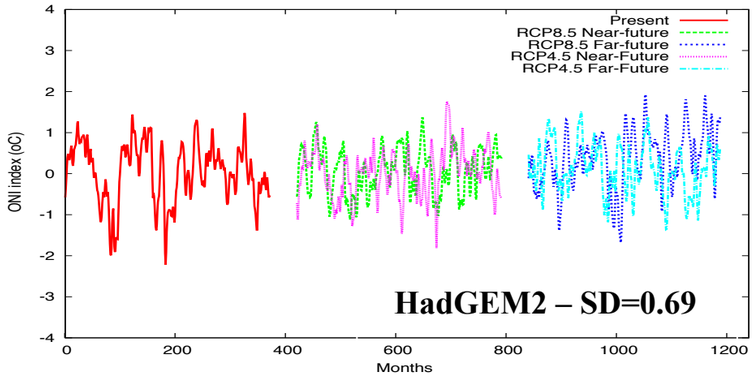
- ONI is a three-month running mean of SST anomaly in the Niño 3.4 region (5ºN-5ºS, 120ºW-170ºW)

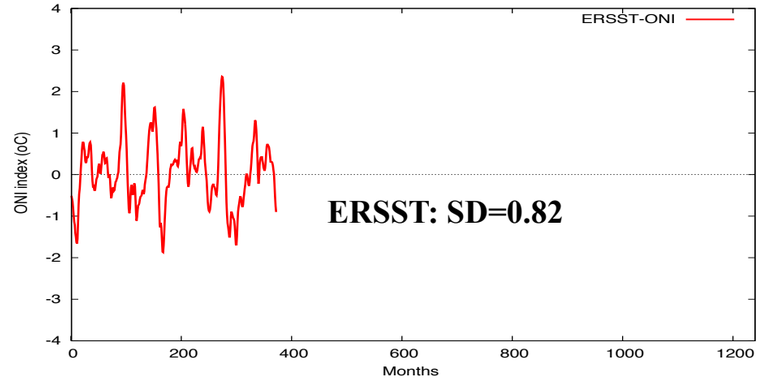


ONI - three-month running mean









Time series of ONI for GCMs (in 3 time-slices) and ERSST.vb3:

ONI thresholds are GCM dependent → 62% of ONI SD for all period resulting in:

± 0.83 ºC – **GFDL**

± 0.57 ºC – **MPI**

± 0.43 ºC – **HadGEM2**

± 0.50 ºC – **ERSST** (value normally used by CPC)

EN or LN year occurs if:

ONI is higher [EN] or lower [LN] than the positive or negative threshold for at least 5 consecutive over-lapping seasons (three-month running mean);

with these thresholds EN and LN years are identified and used for the composites of precipitation fields.

The similarities between GCM and RegCM4 ensemble means were accessed calculating:

- (1) Spatial pattern correlation (r)

- (2) “index of agreement” defined by Wilmott (1982) as:

$$d = 1 - \left[\frac{\sum_i (R_i - G_i)^2}{\sum_i (|R_i - \bar{R}| + |G_i - \bar{R}|)^2}\right]$$

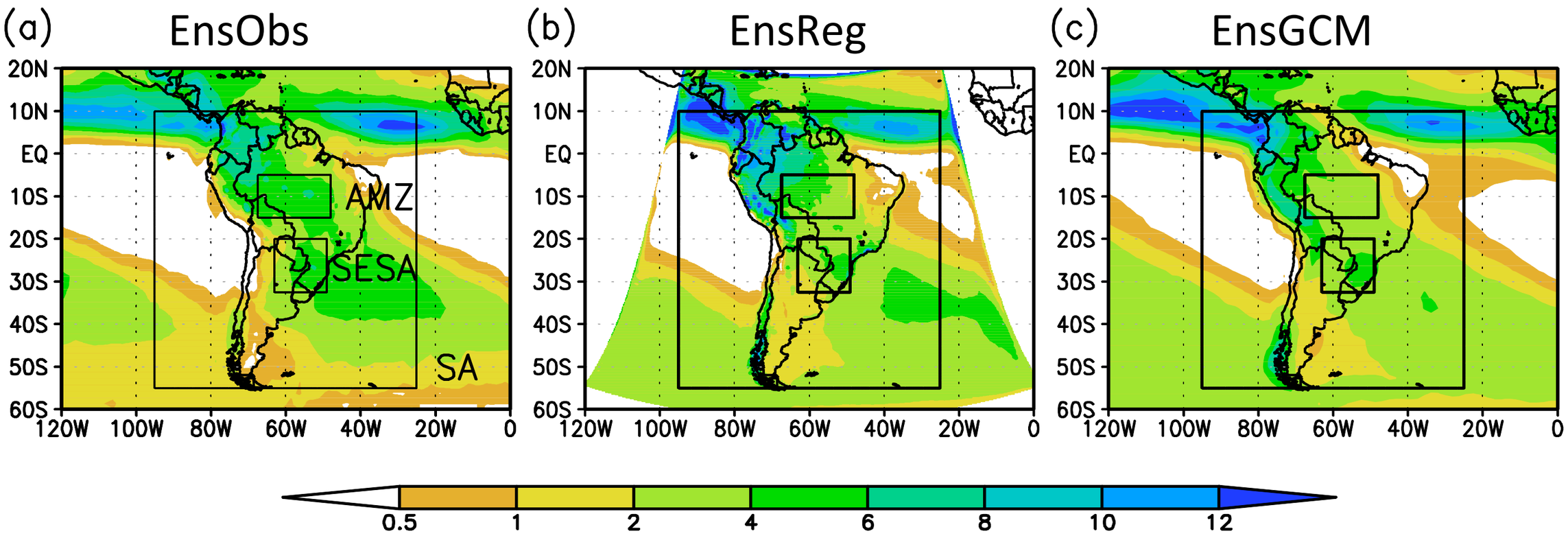
- where R_i and G_i are the ith grid point of a common subdomain of the RegCM4 and GCM, respectively;

  $0 \leq d \leq 1$ → d=1 indicates that RegCM4 reproduces exactly the GCM field.

Present climate: 1975-2005

precipitation climatology and ENSO signal

Precipitation climatology : 1975-2005



EnsReg and EnsGCM resemble the EnsObs, but there is some precipitation deficits :

Large underestimation of rainfall in the EnsGCMs over tropical SA and the subtropical South Atlantic Ocean**. In both regions, EnsReg reduces this dry bias**

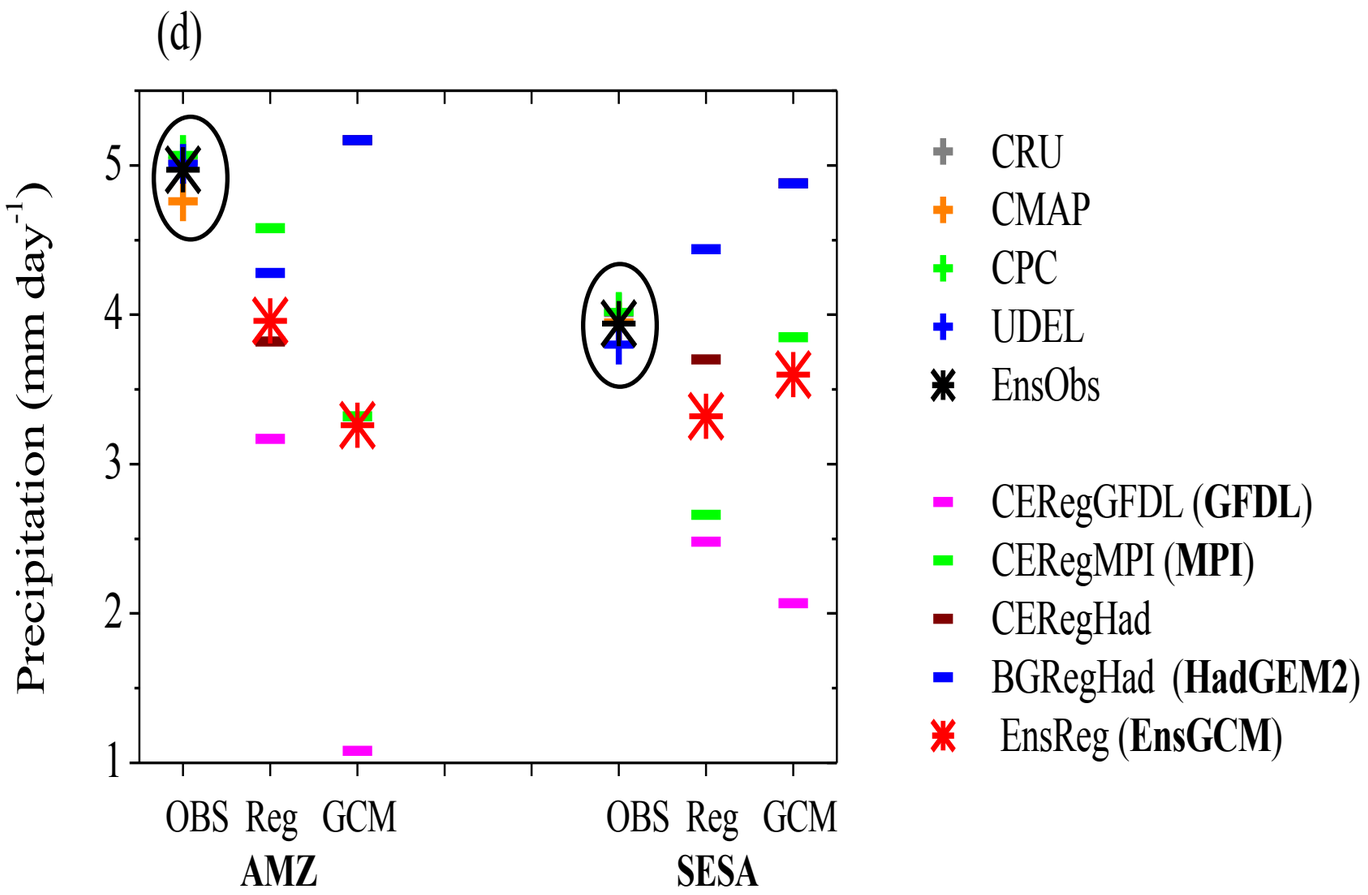
EnsReg and EnsGCM: similar underestimation of rainfall over parts of southern Brazil –
a common problem of many RCMs (Solman et al. 2013) and also of previous RegCMs (da Rocha et al. 2012);

Similarities between the EnsGCM and EnsReg are confirmed by the high values of:

r = 0.84 (SA)

d = 0.89 (SA)

AMZ and LPB: precipitation climatology



There is good agreement between the observations for rainfall amounts for the SESA and AMZ areas.

Simulated rainfall amounts exhibit large spread; Spread is large in GCMs:
 # AMZ: from 1 (GFDL) to 5.4 (HadGEM2) mm/day
#SESA: from 2.1 (GFDL) to 4.8 (HadGEM2) mm/day

In both regions RegCM4 reduces the GCMs spread

SON biases	EnsReg	EnsGCM
AMZ	**-20%**	-34%
SESA	**-16%**	-9%

Although the underestimation of precipitation by the GCM in SESA is smaller than in RegCM4, **only RegCM4 provides seasonal precipitation biases smaller than ± 20% in SESA and AMZ (add value)**

ENSO events: 1975-2005

Number of EN and LN years identified by the ONI in the GCMs and Obs

GCMs and Obs	EN			LN		
	Present	Near	Far	Present	Near	Far
HadGEM2	10	8 (5)	12 (9)	7	6 (5)	3 (5)
GFDL	7	9	6	10	7	5
MPI	6	8	8	7	7	3
ERSST.vb3	10	-	-	7	-	-

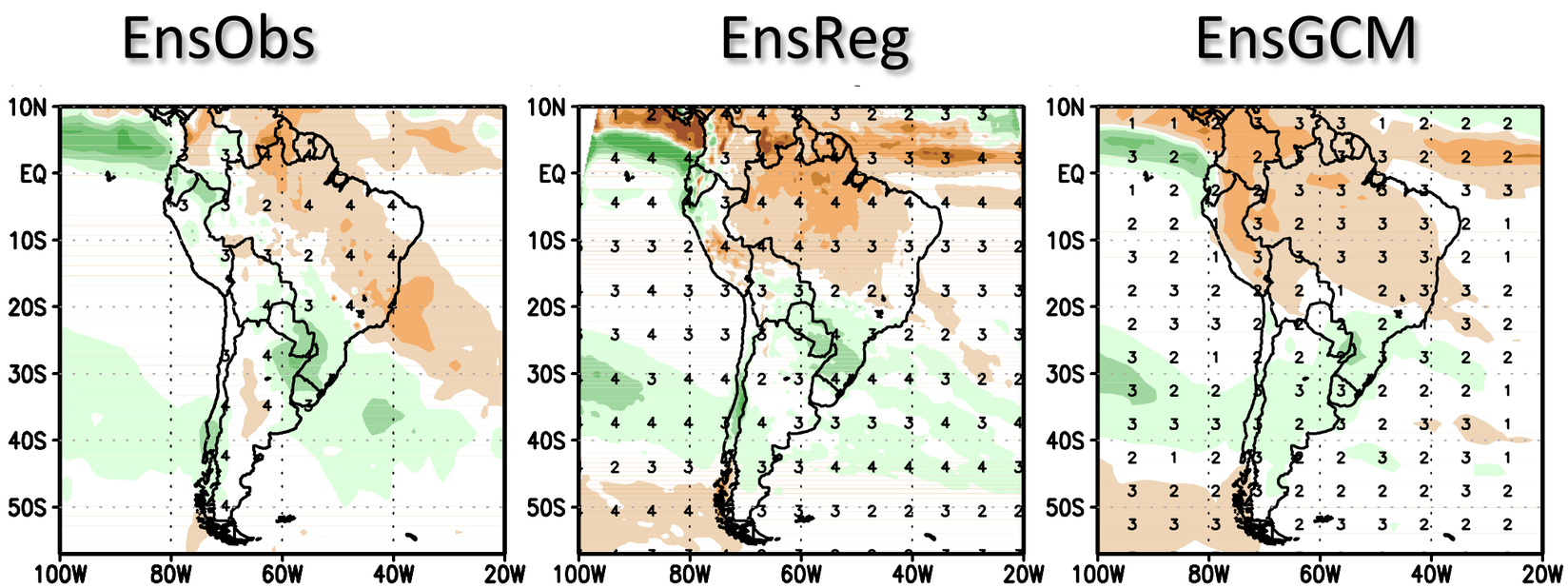
Frequency of EN and LN years - present climate (1975-2005)

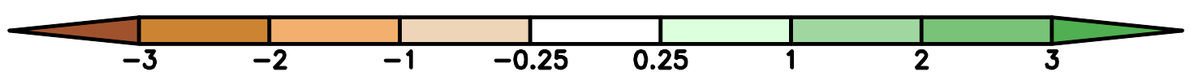
HadGEM2 → same number of EN and LN years as ERSST.vb3

MPI and GFDL → underestimate the frequency of EN years;

GFDL simulates more EN than LN in disagreement with the observation

Composites of EN-LN differences of SON precipitation: 1975-2005

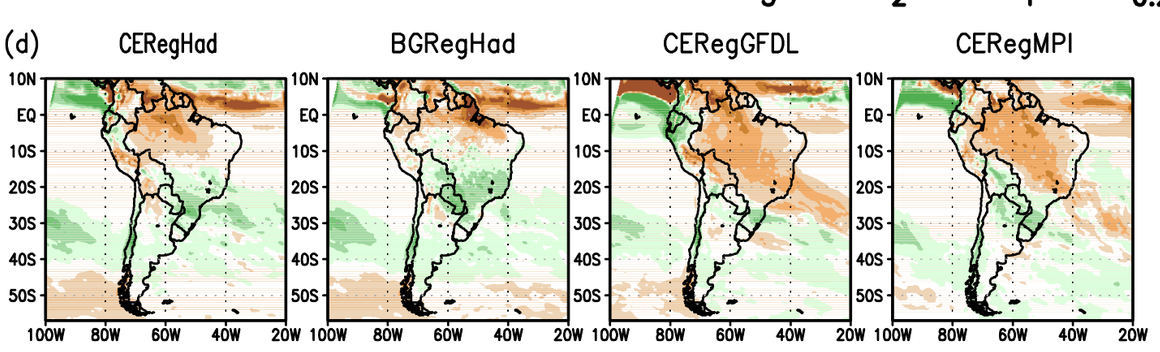




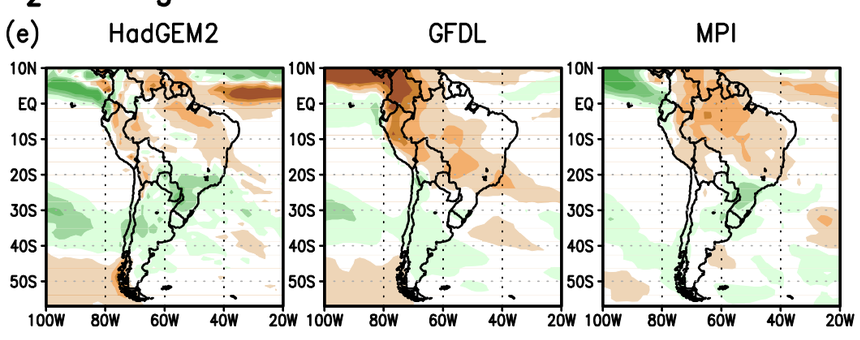
Ensemble means

Numbers indicate how many members have the same sign (+ or -) as the ensemble mean

large similarity between EnReg and EnsGCM: d=0.81 and r=0.74



Each simulation member



EnsOBS:

EN years → reduction of rainfall over the north-central Brazil;

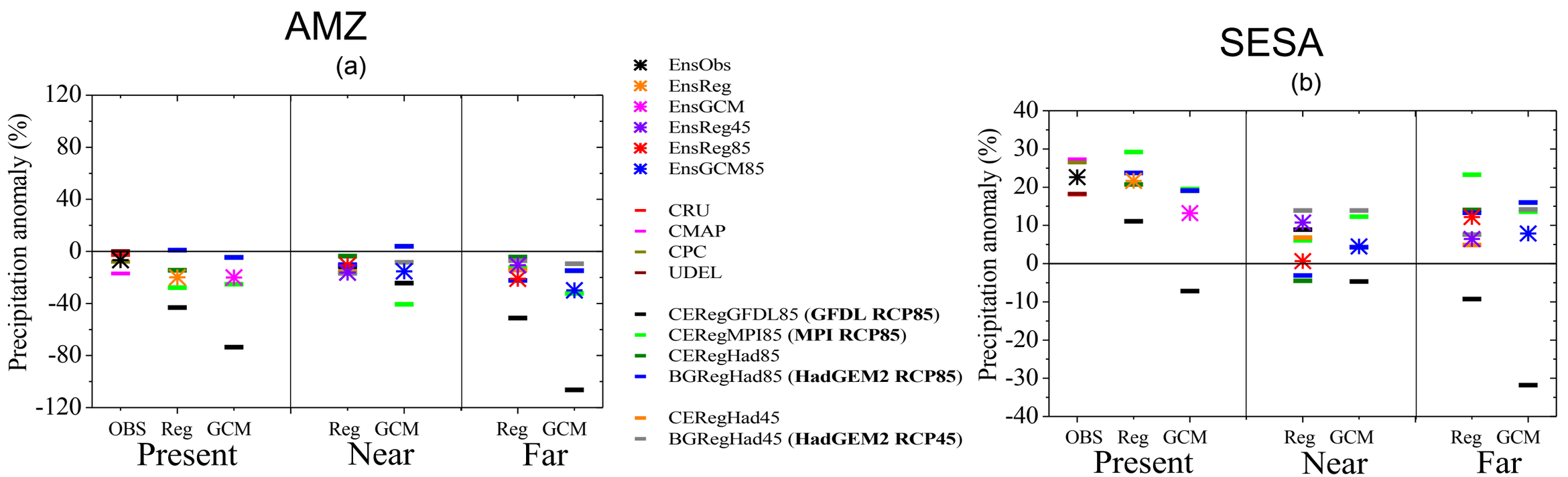
rainfall increases over SESA, north-central Peru, Ecuador, and south-central Chile.

EnsReg and EnsGCM:

capture the observed: positive EN-LN differences of rainfall over SESA and negative over central-north SA.

However, GFDL and MPI simulate negative rainfall anomalies over a larger area of SA than HadGEM2.

EN-LN precipitation differences/climatology (%) : 1975-2005



Present climate:

AMZ: large spread between the observations related to the ENSO signal: from 0% in UDEL to -17% in CMAP; simulations also indicate large uncertainty : GFDL and MPI family show greater negative signal than HadGEM2 family

Despite of the large amplitude of the anomalous signal → EnsReg and EnsGCM are closer to the EnsObs

SESA: the spread between observation and simulation members is smaller than in AMZ
EnsObs, EnsReg, (EnsGCM) provide a positive pcp anomaly of ~+22% (~+13%) in EN compared with LN

Summarizing:

(a) at regional scale the EnsReg ENSO signal has greater agreement with the obs in SESA than in AMZ.
(b) In AMZ both EnsReg and EnsGCM strengthen the relationship between ENSO and rainfall.

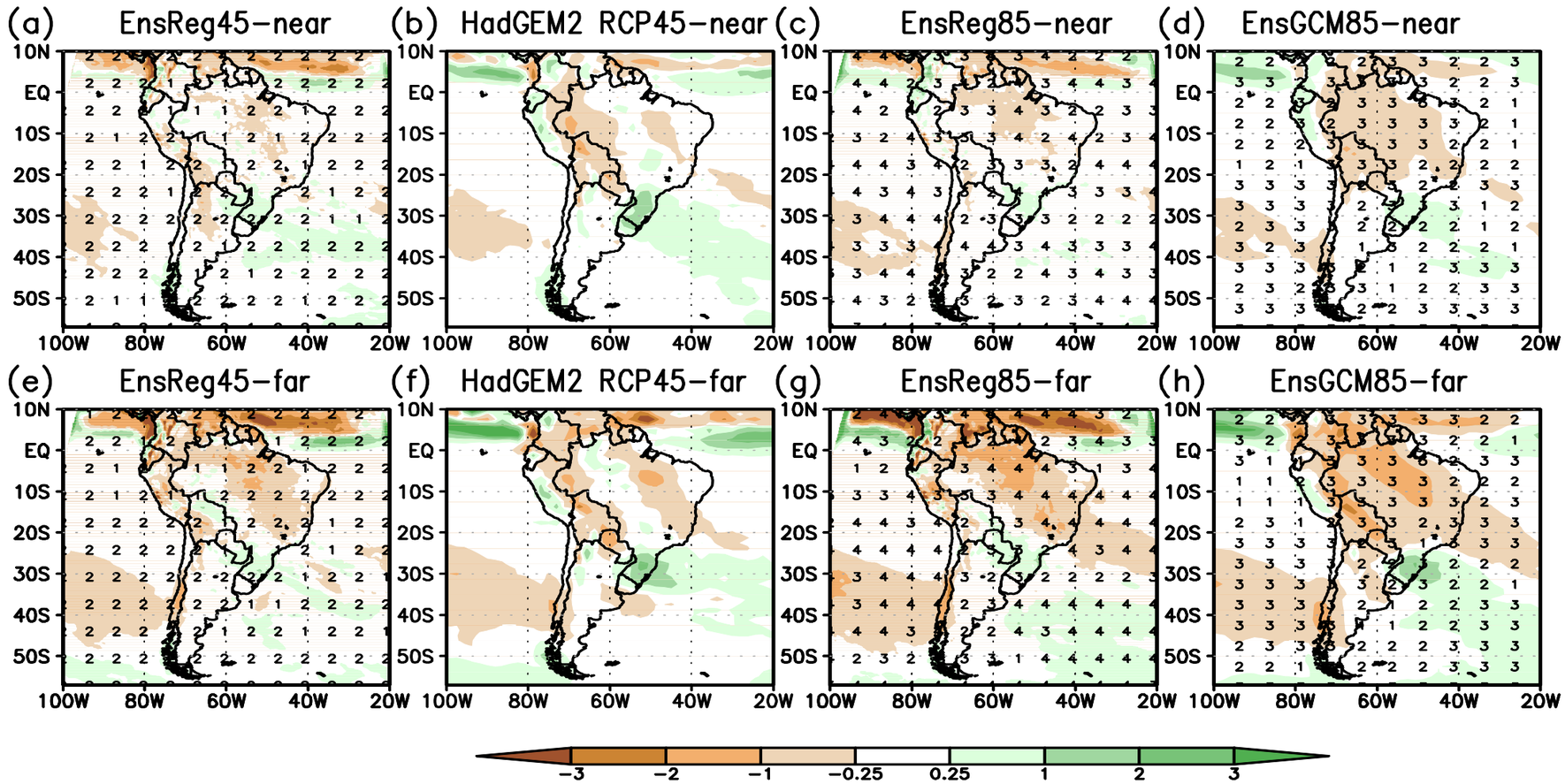
Near- (2020-2050) and far-future (2070-2098) climates:

precipitation trends and ENSO signal

Precipitation trends (mm/day): future - present

Near

Far



Numbers indicate how many members have the same sign (+ or -) as the ensemble mean

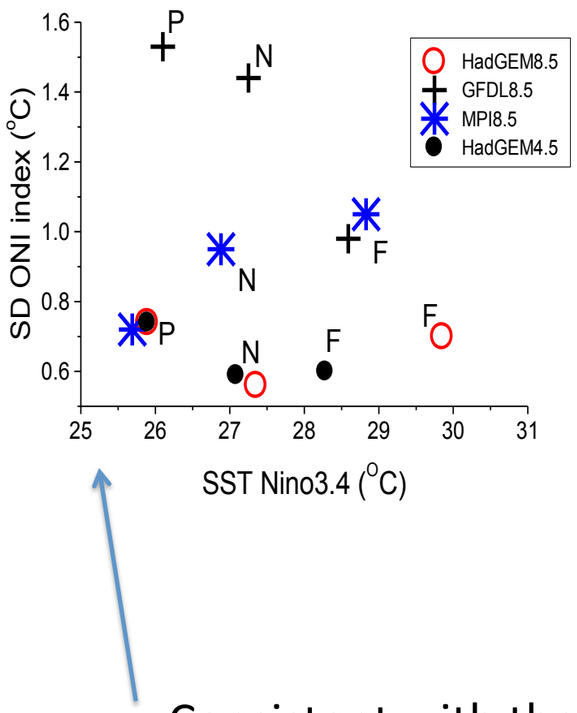
In general, all simulations and RCPs project an increase of pcp over SESA and a decrease in northern-northeastern SA. (similar to the RCMs-CMIP3 - Marengo et al., 2010; Krüger et al., 2012).

On a regional scale, some small differences between the GCM and RegCM4 are noted:

- RCP4.5: in thr near- and far-future HadGEM2 projects larger wetter area than EnsReg ➔ small values of d=0.58 and r=0.35-0.38

- RCP8.5: over SESA the positive anomaly in EnsGCM is displaced eastward compared to EnsRegCM4
- RCP.8.5: near-future EnsReg projects weaker positive/negative pcp changes than in the far-future

ENSO events: present versus future climates



Number of EN and LN years identified by the ONI

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ERSST.vb3	10	-	-	7	-	-

Near-future: in GFDL and MPI there are more EN than LN years;
HadGEM2 projects decrease of both EN and LN

Consistent with the SST warming in Niño3.4 → GCMs project less LN events in the near- and far- future compared to the present (reduction of ~50% in all GCMs)

Far-future there is a large spread related with the number of EN (LN): from 6 in GFDL (5 in GFDL) to 12 in HadGEM2 (3 in HadGEM2 and MPI) → as in CMIP3 GCMs (Meehl et al., 2006)

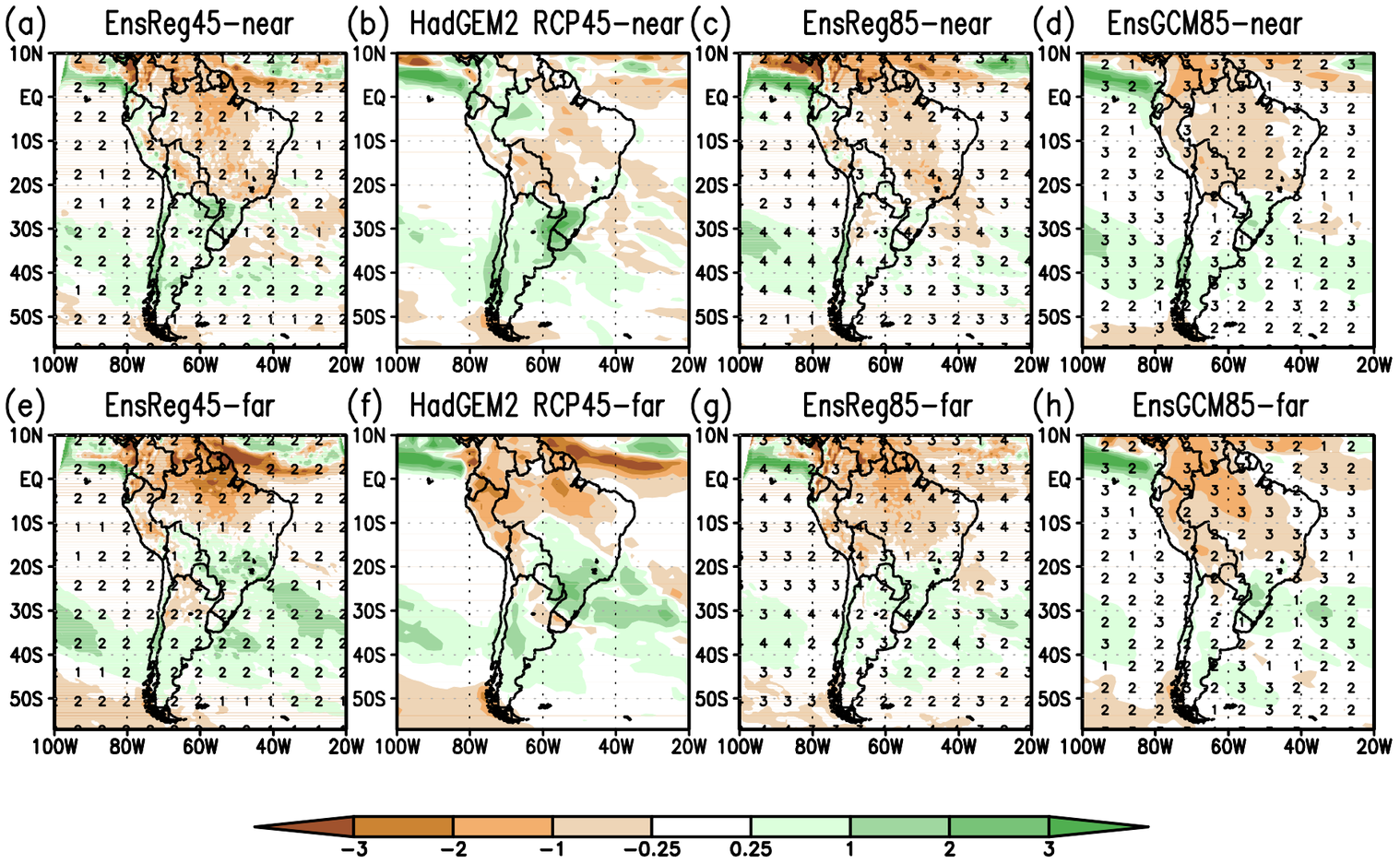
RCP8.5 far-future climates:

GCMs are indicating an increase (decrease) of EN (LN) years

EN-LN differences of the precipitation in the future climates

Near

Far



Numbers indicate how many members have the same sign (+ or -) as the ensemble mean

Spatial patterns are similar to the present climate: + precipitation during EN years over SESA

\- precipitation during EN covering north-central SA

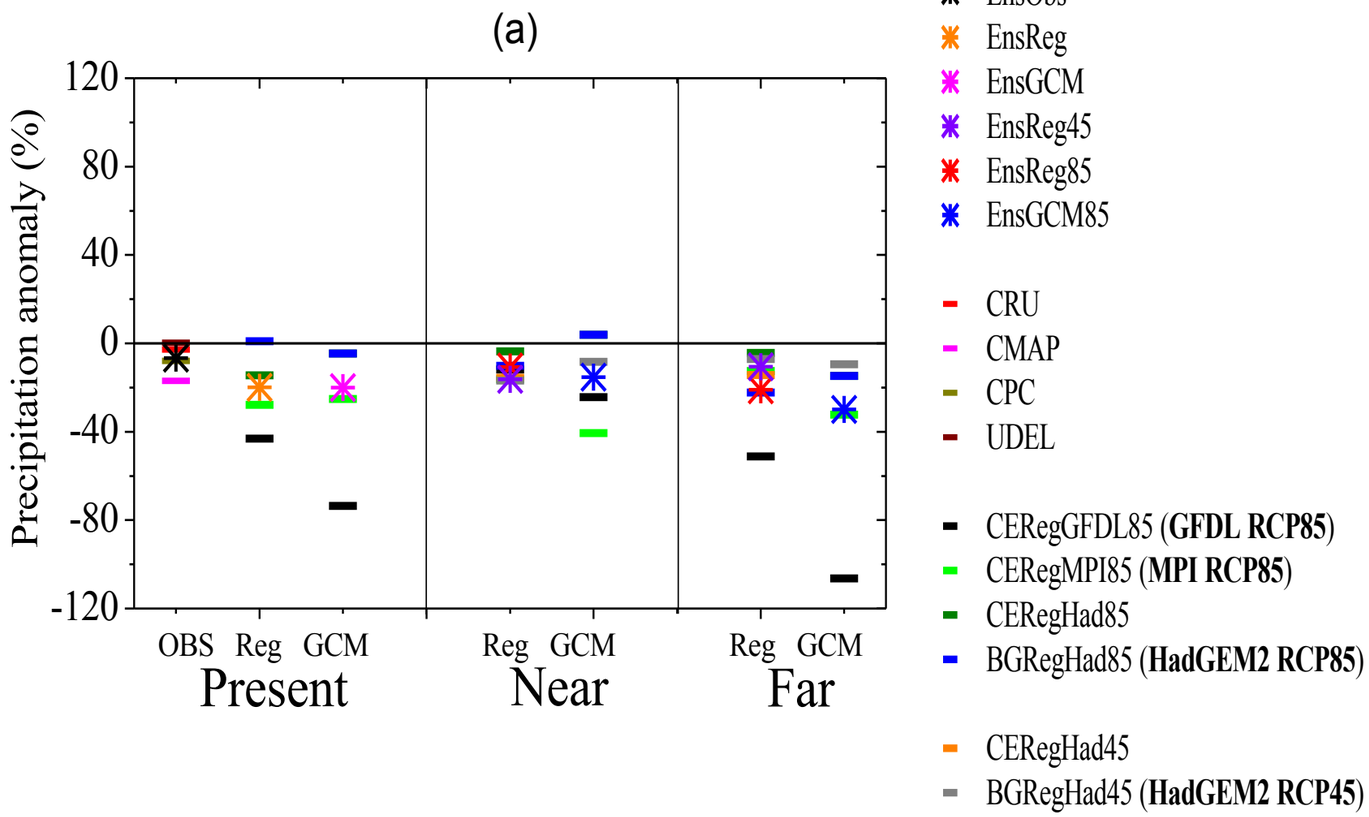
Some small differences are noted in the near- and far-future climates:

- RCP4.5 and RCP8.5: ENSO dry signal occupies larger area of continental SA in the near- than in the far-future;

- two GCM and RegCCM4 members disagree about the wetter conditions of the ensemble mean in some parts of SESA

Rainfall changes and future EN-LN differences(%) at regional scale: AMZ and LPB

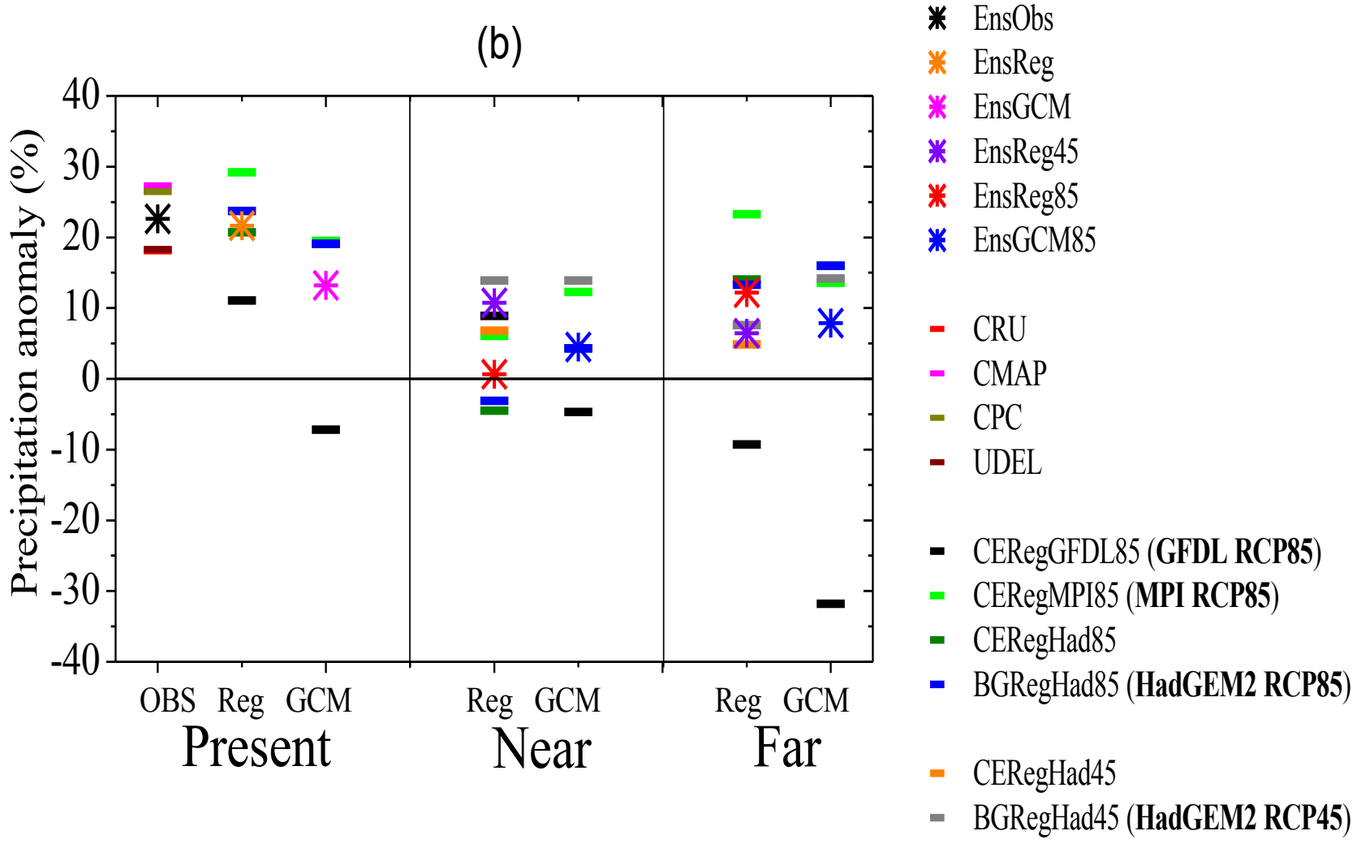
AMZ : rainfall trends (%) and ENSO signal (EN-LN, %)



Time Slice	trends (%)	EN-LN pcp (%)	
	AMZ	AMZ	
	EnsReg (EnsGCM)	EnsOBS	EnsReg (EnsGCM)
Present	-	**-7**	**-20 (-20)**
Near RCP4.5	-2 (-7)	-	-16 (-8)
Near RCP8.5	-5 (-16)	-	-11 (-15)
Far RCP4.5	-8 (-8)	-	-11 (-10)
Far RCP8.5	-15 (-33)	-	-22 (-30)

- Negative changes in precipitation over AMZ in the near- and far-future climates.
- In general, the relationship between ENSO and rainfall in most of RegCM4 and GCM members is weaker in the future than in the present climate
- Only in the far-future RCP8.5 there is a similar (EnsReg) or stronger (EnsGCM) signal of ENSO on rainfall

SESA : rainfall trends (%) and ENSO signal (EN-LN, %)



Time Slice	Trends (%)	EN-LN pcp (%)	
	SESA	SESA	
	EnsReg (EnsGCM)	EnsOBS	EnsReg (EnsGCM)
Present	-	**23**	**22 (13)**
Near RCP4.5	6 (6)	-	11 (14)
Near RCP8.5	4 (3)	-	1 (5)
Far RCP4.5	4 (6)	-	7 (14)
Far RCP8.5	10 (2)	-	12 (8)

- Positive changes in pcp over SESA in the near- and far-future climates.
- Also in SESA it is noted a weaker relationship between ENSO and rainfall in most of RegCM4 and GCM members in the future compared with present
- Likely the weakening of ENSO signal in both AMZ and LPB is connected with the GCMs' projection of the more intense ENSO signal displaced to the central basin of Pacific Ocean (EN Modoki)

Summary and Conclusions

Present climate (1975-2005):

(1) EnsReg and EnsGCM reproduced the main features of the springtime rainfall over SA (high d and r);

(2) at the regional scale, only EnsReg provides pcp biases are smaller than ±20% in both AMZ and SESA

(3) EnsReg and EnsGCM capture the + (-) pcp differences between EN-LN years over the SESA (northern SA)

EnsReg shows larger agreement with the observations than EnsGCM in SESA.

Near- and far-future (RCP4.5 and RCP8.5):

Projections indicates an increase (decrease) of pcp over southeastern (north-northeastern) SA.

ENSO:

(1) most GCMs project an increase (decrease) of EN (LN) events in the RCP8.5 far-future climate;

(2) for the near-future there is a large spread among GCMs regarding to the increase /decrease of EN/LN.

(3) ENSO relationship with the SON rainfall in most of simulation members is weaker in the near- and far-future climate than in the present-day climate

→ likely connected with the GCMs' projection of the more intense ENSO signal displaced to the central basin of Pacific Ocean in the far future compared to present climate.

Next ...

- present analysis focused on the ENSO precipitation signal during the austral spring;

- Grimm (2011) → ENSO impacts different areas of SA during the year;

- For example, the ENSO signal is stronger during March-April-May in northeast Brazil (Kayano and Andreoli 2006).

- **it would be important to perform a similar analysis for other seasons of the year to verify whether the present results are season/region dependent.**

- **Thank you!!!**

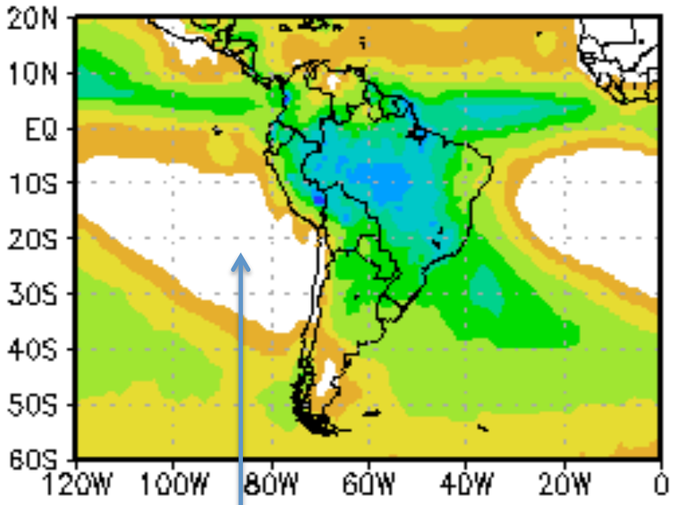
- **More details in:**
- da Rocha RP, MS Reboita, LMM Dutra, MP Llopart, E Coppola(2014) Interannual variability associated with ENSO: present and future climate projections of RegCM4 for South America-CORDEX domain. Climatic Change. Online: http://link.springer.com/article/10.1007/s10584-014-1119-y

- **Acknowledgments:** The authors thank CNPq (307202/2011-9), CAPES/PROCAD-179/2007, INCLINE-USP and CMIP5. This work has been partially funded by the Project NextData of the Italian Ministry for Education, University and Research, and the Italian Ministry of Environment, Land and Sea.

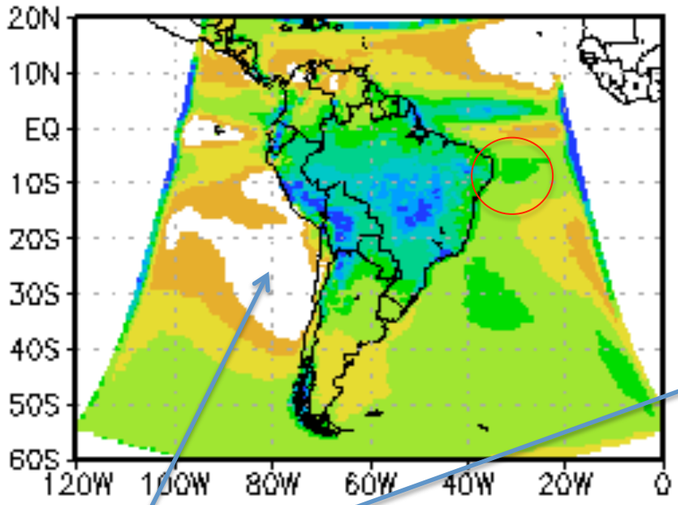
Precipitation climatology – present climate (1975-2005)

Summer

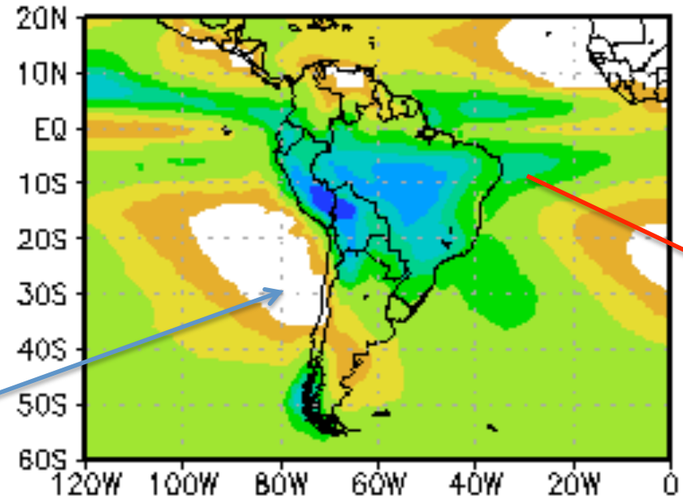
EnsObs

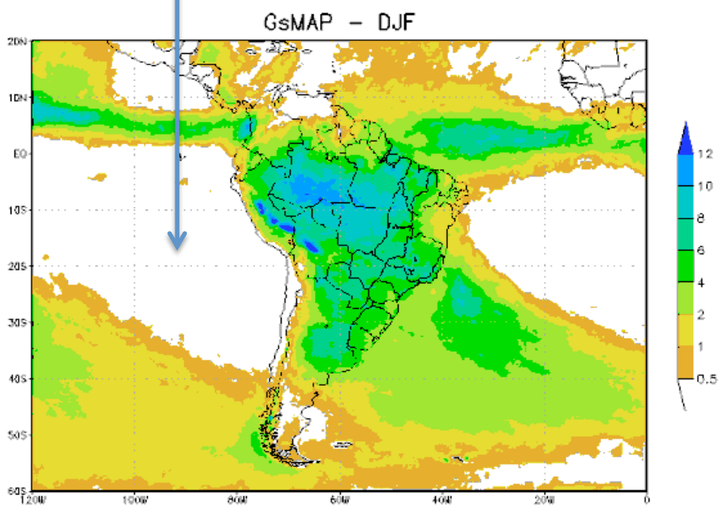


EnsRegCM4



EnsGCMs





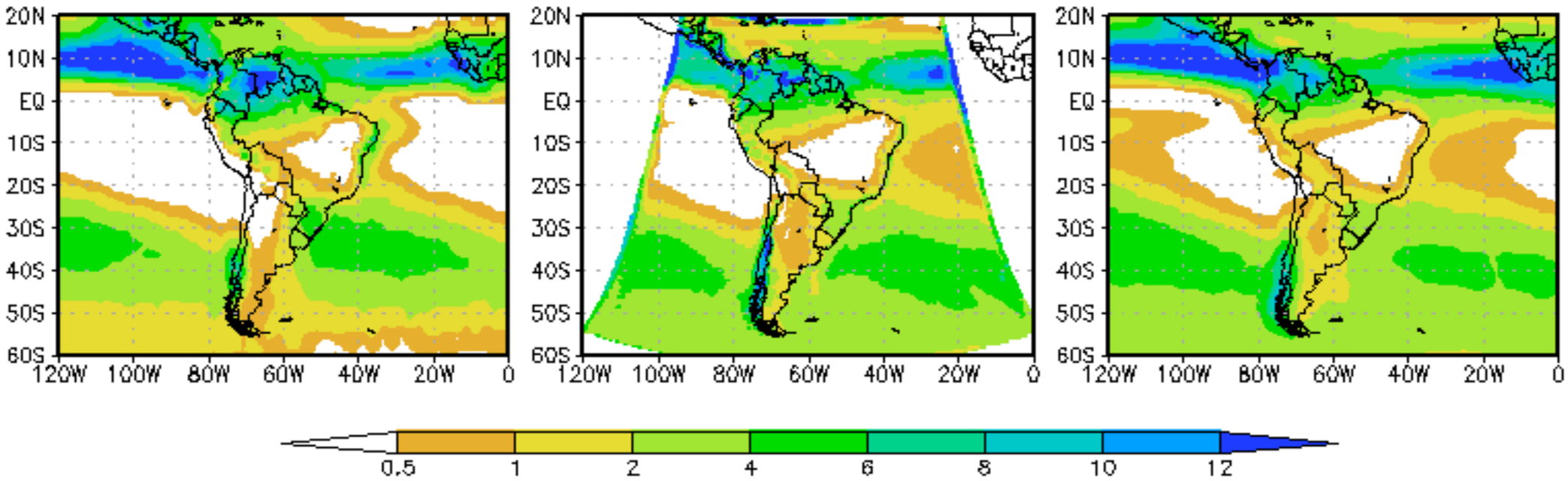
Simulations reproduce the more intense rainfall in SACZ in agreement with obs.

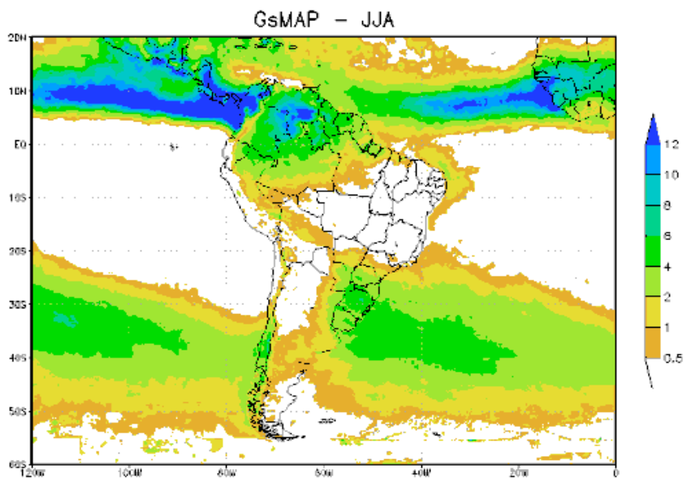
Problems: (1) excessive rainfall in eastern NE Brazil in the EnsGCMs (due the MPI model) that is only partially improved in EnsRegCM4; (2) too much rainfall in the subtropical anticyclonic areas (Pacific and Atlantic);

Precipitation climatology – present climate (1975-2005)

Winter

EnsObs EnsReg EnsGCMs





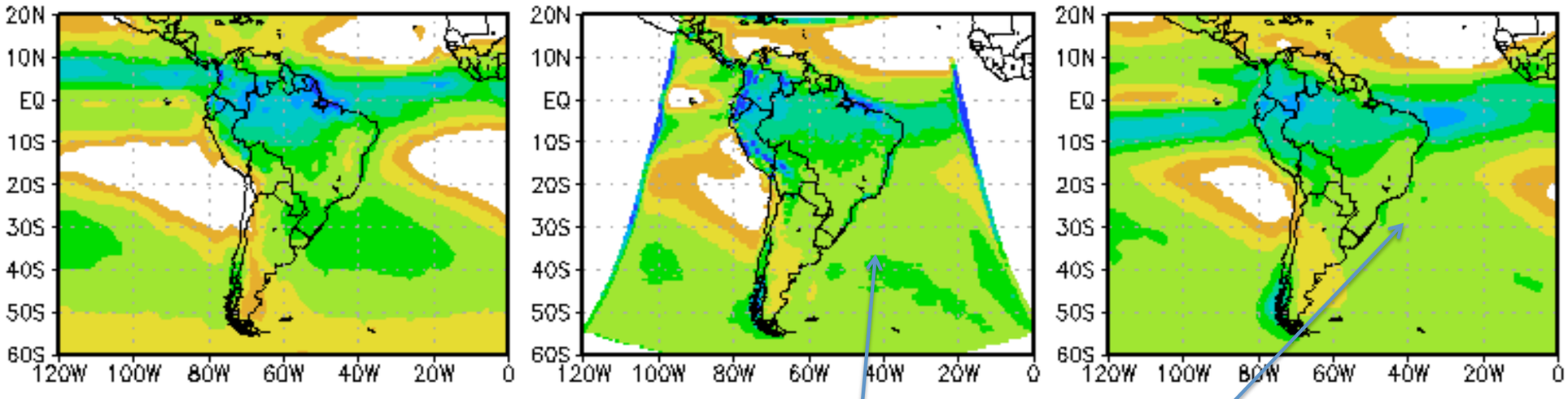
Main rainfall centers are simulated by both RegCM4 and GCM

Small differences in north (ITCZ) and southeastern (storm tracks) of SA

Precipitation climatology – present climate (1975-2005)

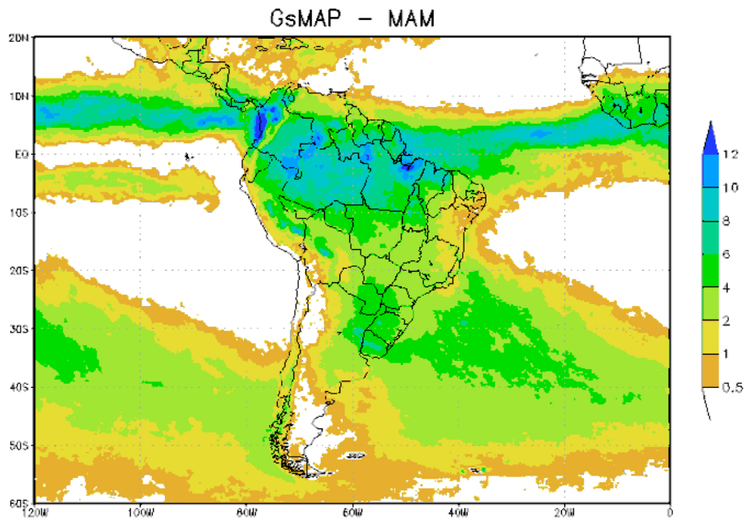
Autunm

EnsObs EnsReg EnsGCMs



General observed patterns is present in simulations;

Main problem is the deficit of rainfall in southwestern Atlantic and south Brazil (cyclogenetic area)



Seasonal precipitation (mm/day)

LPB – DJF smaller bias in EnsReg than EnsGCM
JJA EnsReg similar EnsGCM

LPB	DJF	JJA
EnsObs	4.7 [**5.0**] 5.1	2.1 [**2.2**] 2.3
EnsRegCM4	4.2 [**5.2**] 5.8	1.5 [**1.8**] 2.3
EnsGCM	4.5 [**5.5**] 6.4	0.6 [**1.8**] 2.9

Min Mean Max

Min Mean Max

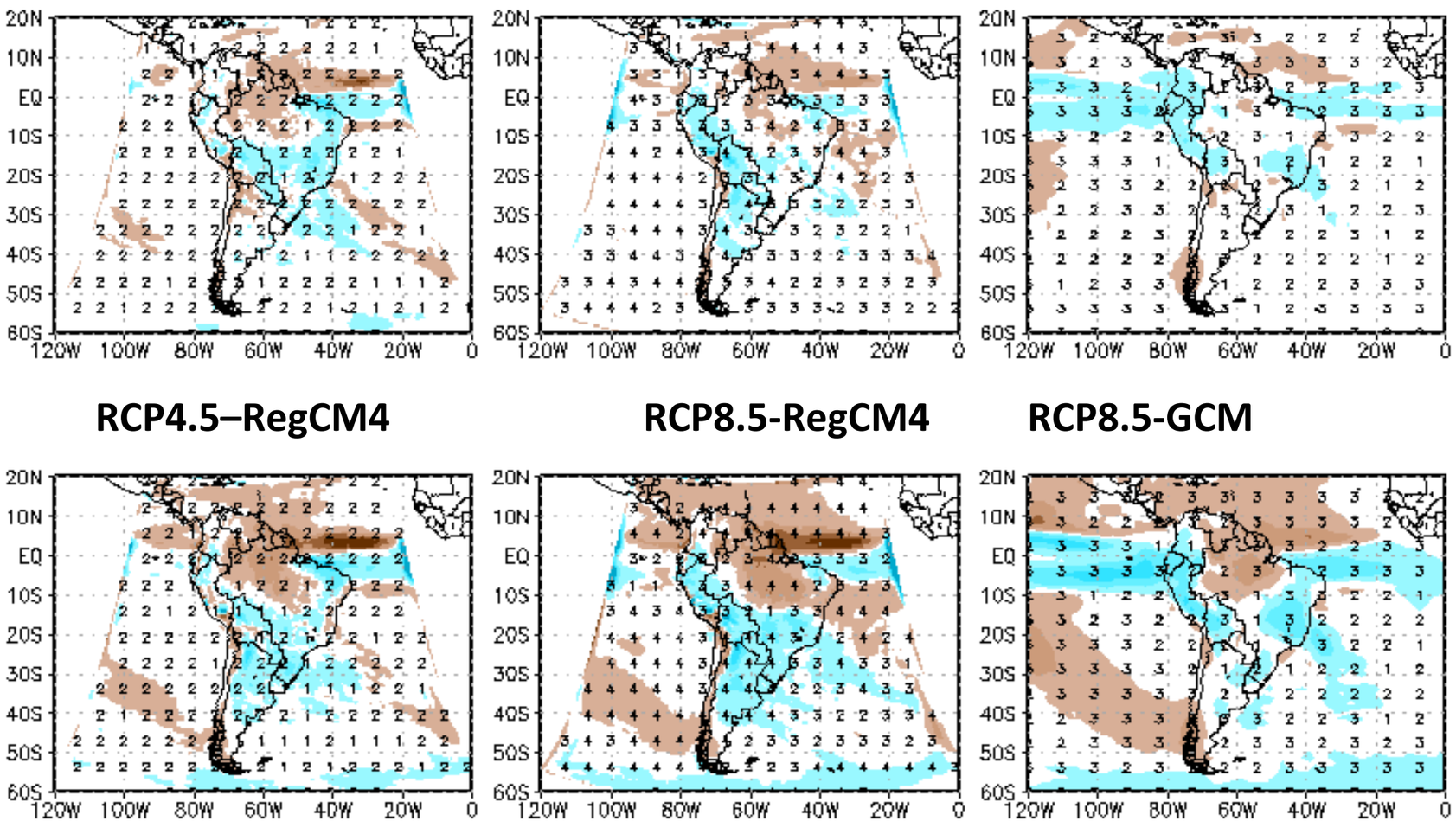
AMZ: DJF biases are low (<10%)
Large relative biases occurs in winter due mainly one dry simulation

AMZ	DJF	JJA
EnsObs	8.9 [**9.4**] 9.7	0.82 [**0.92**] 0.95
EnsRegCM4	6.8 [**8.7**] 10.9	0.30 [**0.60**] 0.94
EnsGCM	8.8 [**9.8**] 10.7	0.10 [**0.50**] 1.30

Trends: austral summer

Ensemble of the change in precipitation (mm/day): future minus present climate.

Large agreement between simulation about positive (negative) trends over southeastern (northern) South America, **which is more intense over large areas in far future/rcp8.5**

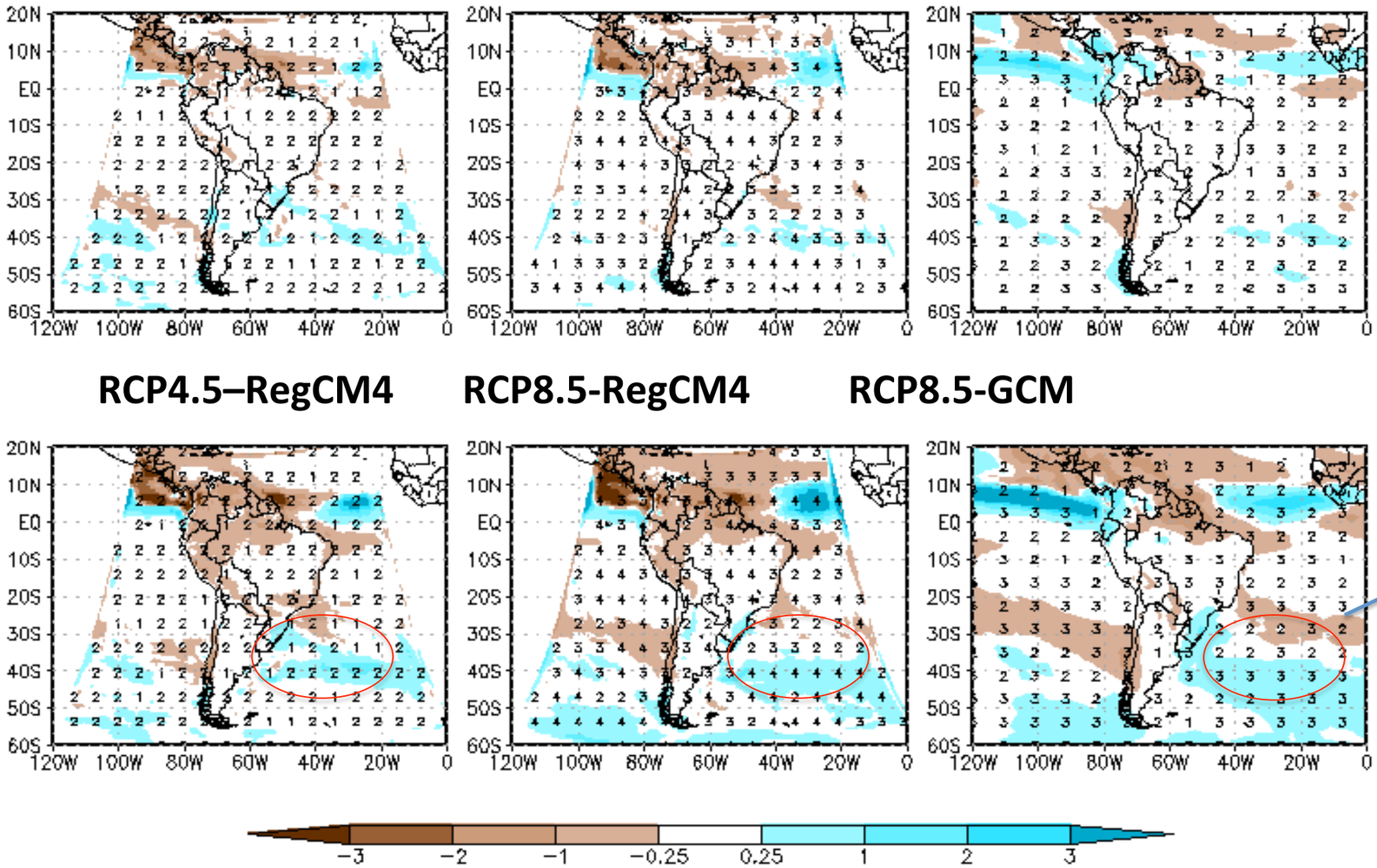


numbers indicate how many members have the same signal (+ or -) of the ensemble mean

Trends: austral winter

Ensemble of the change in precipitation (mm/day): future minus present climate.

Large agreement in simulating no changes in pcp over continental SA in near future;
North/northwest SA → negative trends in pcp in far future



Near future (2020-2050)-present (1975-2005)

Increase/decrease of pcp may be associated with southward displacement of storm tracks

Far future (2070-2098)-present (1975-2005)

numbers indicate how many members have the same signal (+ or -) of the ensemble mean.