Regional Climate Studies to South America with RegCM

Rosmeri P. da Rocha

Departamento de Ciências Atmosféricas – Universidade de São Paulo, Brazil

Colaborators: Marta Llopart, Michelle Reboita, Eduardo M. de Jesus, Cristina Arriaga, Rafael Batista, Santiago Cuadra

Objectives:

Review of the regional climate modeling (RCMs) studies evolution developed to South America (SAM) with focus on:

- Regional Climate Model – RegCM
- CORDEX-CREMA phase I
- CORDEX-CREMA phase II

RCM kind study	Reference	Grid Size	Duration	RCM used	Observation
(1) present-day simulation, parameterization testing, RCMs validation and interannual variability	Chou et al. (2000)[70]	80 km	August and November 1997	Eta	
	Menéndez et al. (2001)[99]	100 km	1979-1988	LAHM-GFDL	
	Nobre et al. (2001)[100]	80 and 20 km	January to April 1999	IRI-RCM	
	Druyan et al.(2002)[101]	50 km	March–April–May of 1985 and 1997	GISS/CCSR RCM	
	Misra et al. (2002)[82]	80 km	December to June 1997, 1998 and 1999	RSM-NCEP	Interanual variability
	Nicolini et al. (2002)[102]	125 km	January and July 1982-1993	DARLAM	
	Misra et al. (2003)[103]	80 km	January–February–March of 1997, 1998, and 1999	RSM-NCEP	
	Seth and Rojas (2003)[104]	100 and 60 km	January–May 1983 and 1985	RegCM	Domain sensitivity
	Rojas and Seth (2003)[83]	100 and 60 km	January–May 1983 and 1985	RegCM	Simulation quality Domain and changes in remote forcing sensitivity

Regional climate modeling started in 1989-1990

Firts studies to SAM appeared in 2000-years

With RegCM in 2003

First studies over SAM were dedicated to evaluate the performance of the RCMs in capturing the main features of the observed climate

4 main projects focused on the RCMs over SAM

Project	Period	Purpose	RCMs	Driving GCMs/scenarios	Reference
CREAS - Regional Climate Change Scenarios for South America	2004-2007	Intercomparison among different RCMs driven by the same boundary conditions and developing scenarios for future changes at daily time scales for extreme events	Eta/CPTEC, RegCM3, and HadRM3P	HadAM3/A 2 and B2	Marengo and Ambrizzi[85] Marengo et al.[46]
CLARIS Europe—South America Network for Climate Change Assessment and Impact Studies	2004-2007	Strengthening collaborations between Europe and SA to develop common research strategies on climate change and impact issues in the subtropical region of SA through a multi-scale integrated approach (continental-regional-local)	ETA, MM5, WRF, PROMES, RCA, LMDZ and REMO		Boulanger et al.[41] Menéndez et al.[40] https://cordis.europa.eu/project/rcn/74238_en.html
CORDEX Coordinated Regional Climate Downscaling Experiment	2009-present	Producing regional climate projections and associated uncertainties	ARPEGE, HIRHAM, RegCM3, CCLM, RACMO, REMO, RCA, PRECIS, WRF, and CRCM		Giorgi et al.[47] http://cordex.org/
CLARIS-LPB Europe—South America Network for Climate Change Assessment and Impact Studies – La Plata Basin	2008-2012	Projecting the regional climate change impacts on La Plata Basin (LPB) and designing adaptation strategies for land-use, agriculture, rural development, hydropower production, river transportation, water resources and ecological systems in wetlands.	RegCM3, RCA, MM5, REMO, PROMES, LMDZ, and ETA		Boulanger et al.[42] Solman et al.[86] Solman et al.[87] Carril et al.[45] https://cordis.europa.eu/project/rcn/89402_en.html

Brazilian project

A Europe-South America Network for Climate Change Assessment and Impact Studies (CLARIS) in La Plata Basin: CLARIS-LPB

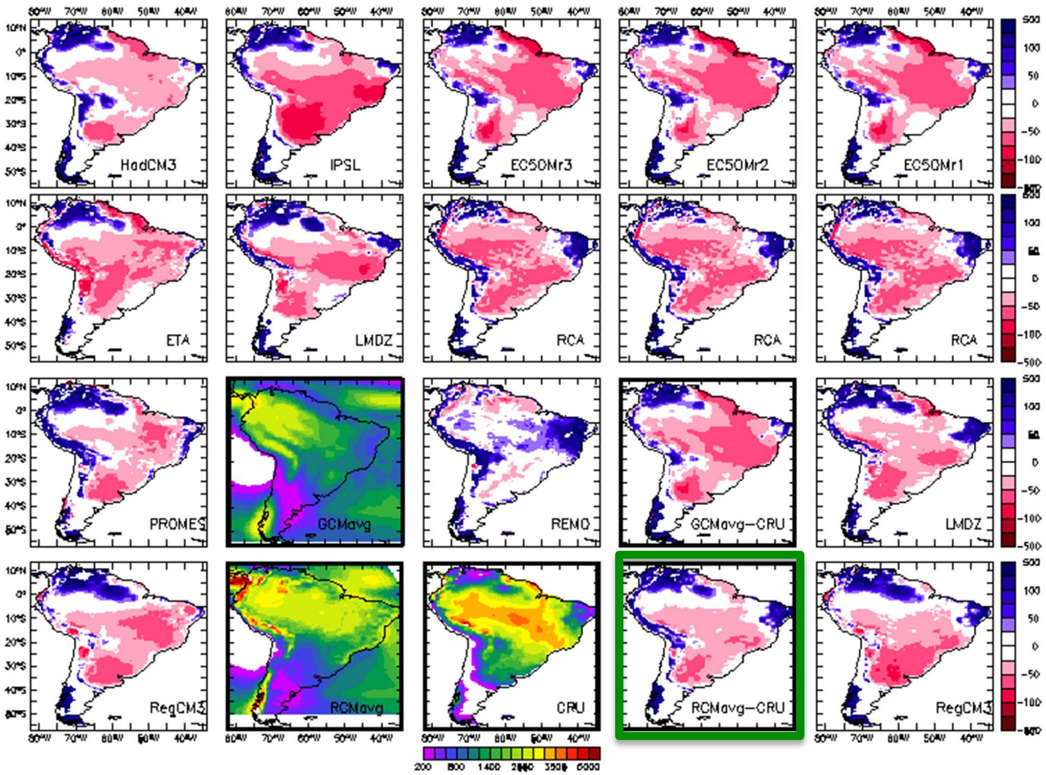
CLARIS | LPB

HYDRO-CLIMATE AND SOCIETY IN LA PLATA BASIN

It was a coordinate project to obtain regional climate projections to apply in energy, water, agriculture impact studies of climate change over La Plata Basin (Boulanger et al., 2011)

CLARIS-LPB:

7 RCMs nested in 2 CMIP3-GCMs for scenario A1B (Sanchéz et al. 2015)

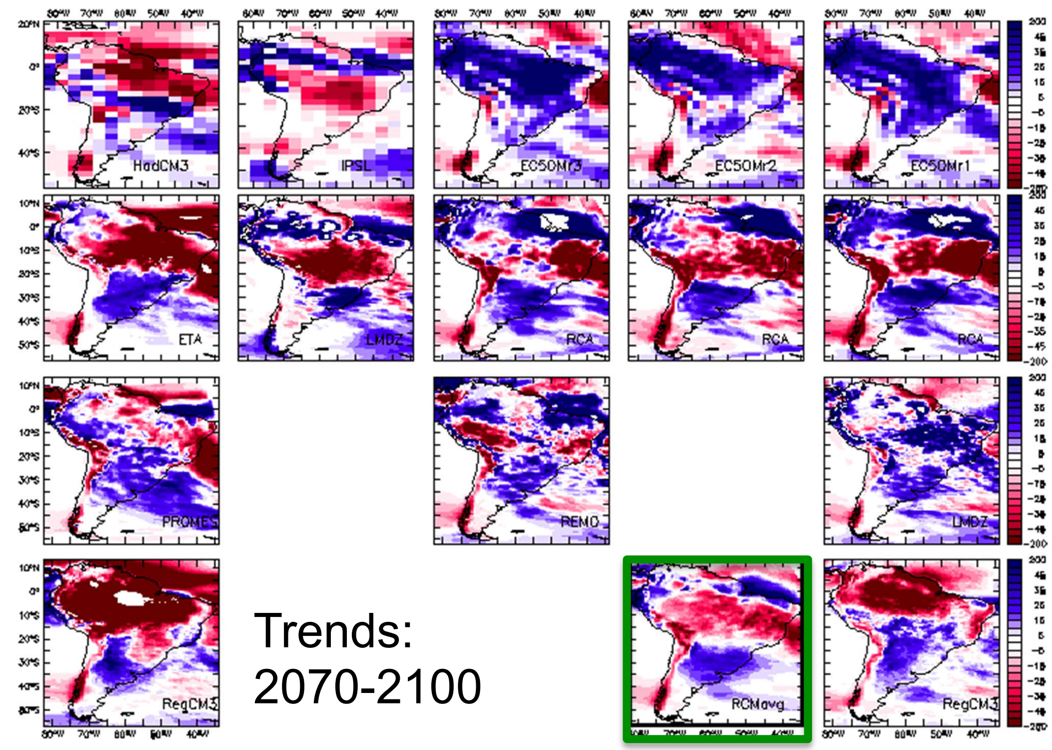


Present Climate:
Annual rainfall biases: most models underestimate rainfall over SESA ;

RCM ensemble mean → smaller biases than individual models

Future climate

RCMs ensemble:
-shows a general negative trend over central part of SAM;
- wetter conditions in SESA in future is a signal present in most simulations;



Trends:
2070-2100

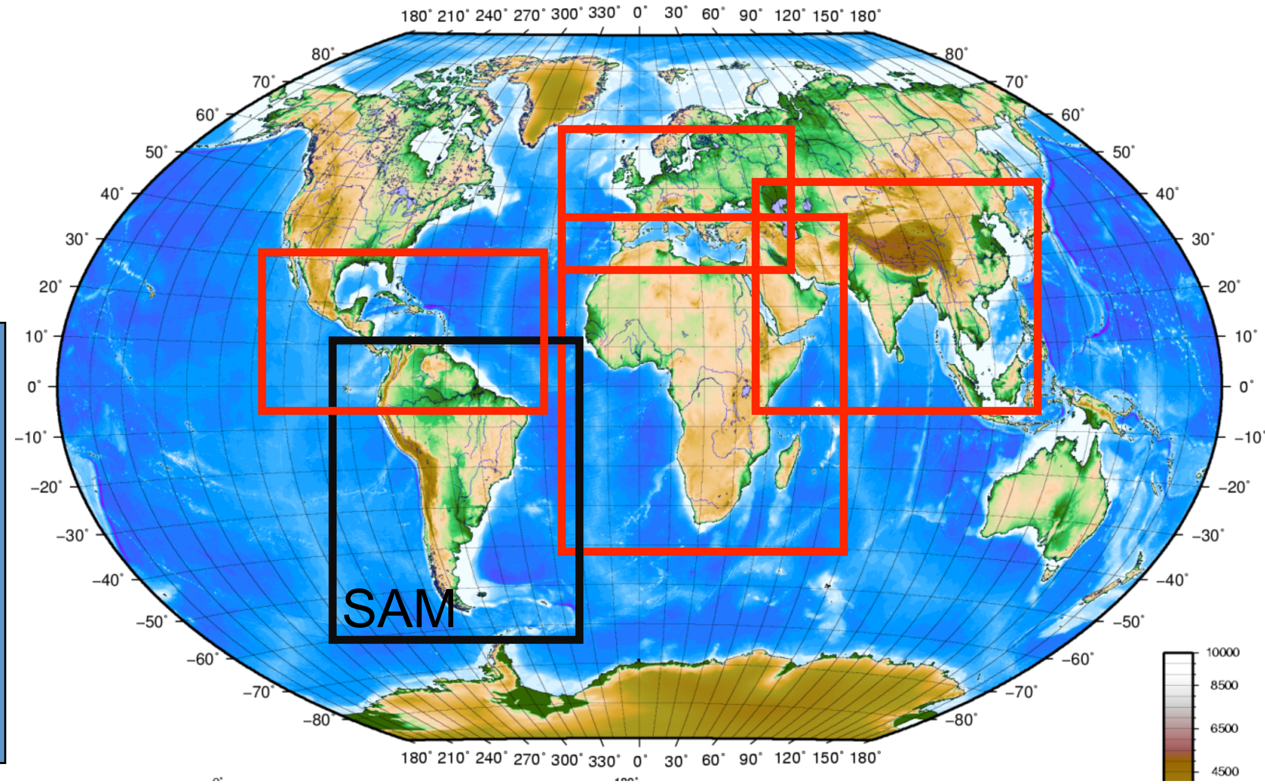
Fig. 5 As in Fig. 1, but for DJF precipitation projections absolute change from (1961–1990) to (2071–2100) period

CORDEX and CREMA

CORDEX - Coordinated Regional Climate Downscaling Experiment organized by WCRP (Word Climate Research Program) – Giorgi et al. (2009)

CREMA (CORDEX RegCM4 hyper-Matrix experiment) project was a collaborative experiment designed to provide mini-ensemble downscaling using **different physical configurations** of the RegCM4 nested in different CMIP5 CGMs and scenarios (Giorgi 2014)

The CREMA Phase I Experiment



Contribution to the CORDEX by the RegCM community

Collaboration across
ICTP
U. São Paolo (Brazil)
CICESE (Mexico)
Indian Institute of technology
U. Dakar (Senegal
DHMZ (Croatia)

Special Issue of Climatic Change (2014)

34 Scenario simulations (1970-2100) over 5 CORDEX domains with RegCM4 driven by 3 GCMs, 2 GHG scenarios (RCP4.5/8.5) and different physics schemes

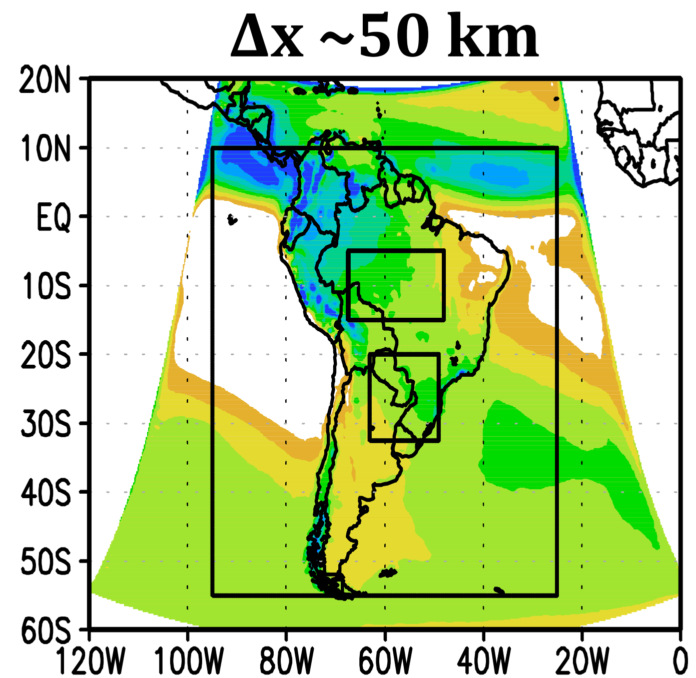
3 months dedicated time on ~700 CPUs at the ARCTUR HPC
~200 Tbytes of data produced

CREMA – SAM

Period: 1970-2100

Two combinations of physical parameterizations:

CLM land-surface with Emanuel convection – **CE**
BATS land-surface with mixed convection (Grell-land+ Emanuel-sea) – **BG**



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

RegCM	Surface	Convection	RCP	GCM forcing
BGRegHad	BATS	Mixed	8.5	HadGEM2-ES
CERegHad	CLM	Emanuel	8.5	HadGEM2-ES
BGRegHad	BATS	Mixed	4.5	HadGEM2-ES
CERegHad	CLM	Emanuel	4.5	HadGEM2-ES
CERegMPI	CLM	Emanuel	8.5	MPI-ESM-MR
CERegGFDL	CLM	Emanuel	8.5	GFDL-ESM2M

CREMA-SAM projections were used to access:

(a) interannual variability of rainfall associated with ENSO in both present and future climates (da Rocha et al. 2014);

(b) Climate change impact on precipitation for the Amazon and La Plata basins (Llopart et al., 2014);

(c) Frost events over Peruvian Andes (Arriaga, 2016);

(d) Cyclones climatology in present and future projections (Reboita et al. 2018);

(e) Residential buildings' thermal performance and comfort for the elderly under climate changes context in the city of São Paulo, Brazil (Alves et al. 2015);

(f) Projections of the thermal comfort index for the metropolitan region of São Paulo, Brazil (Batista et al., 2016);

(g) Climate change over Peruvian Andes (Bazo, 2014)

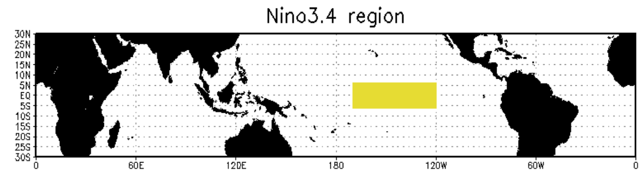
(h) Cold fronts over south Brazil (de Jesus et al., 2014)

CREMA-SAM projections of interannual variability associated with ENSO (da Rocha et al. 2014)

ENSO identification and frequency

ENSO was identified using Oceanic Niño Index (ONI):

3-month running mean of SST anomaly in the Niño 3.4



Austral spring (SON):

ENSO signal in the rainfall is stronger over SESA (Grimm and Ambrizzi 2009);

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

HadGEM2 → EN and LN similar to observation

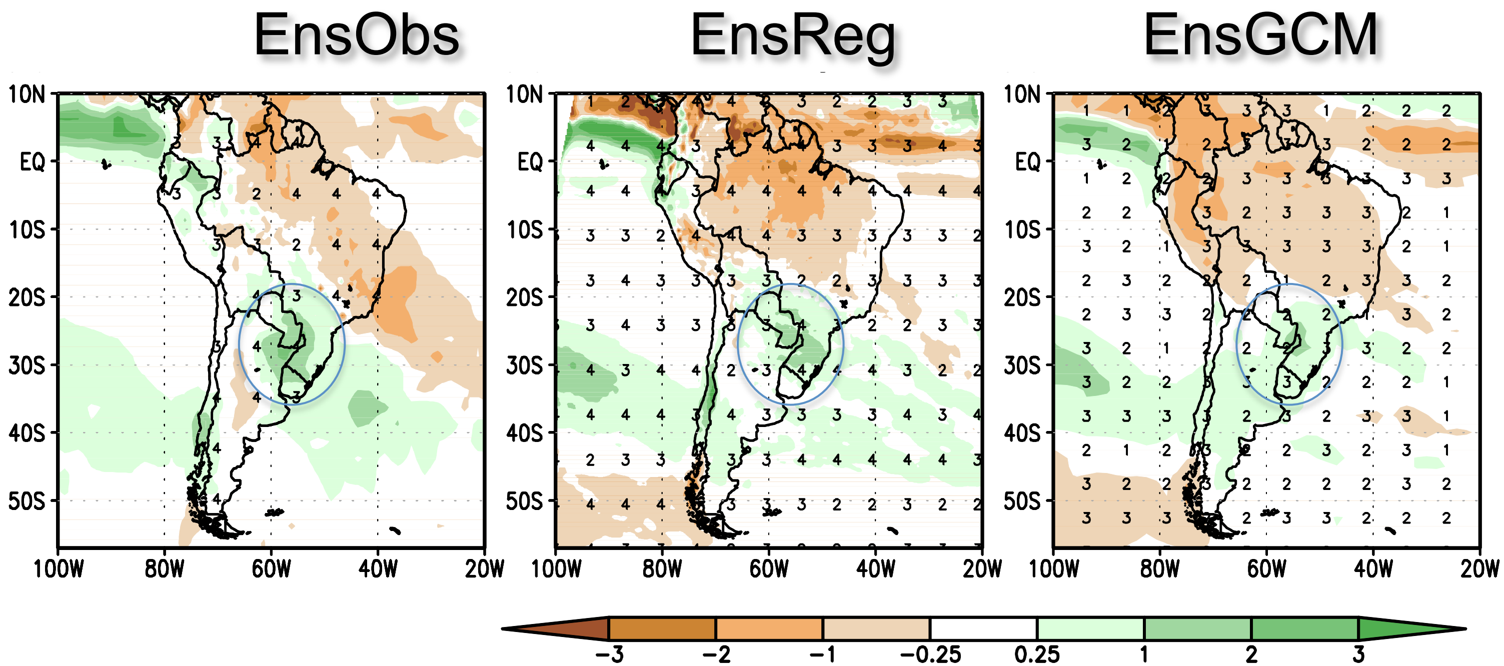
MPI/GFDL → underestimate the frequency of EN years; (GFDL → LN >EN)

Far future

Increase/decrease the frequency of EN/LN

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 (Obs)	10	-	-	7	-	-

Validation of SON present climate (1975-2005): EN-LN differences of rainfall



Ensemble means

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

EnsOBS:

EN years → less rainfall over the north-central Brazil;

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

EnsReg and EnsGCM:

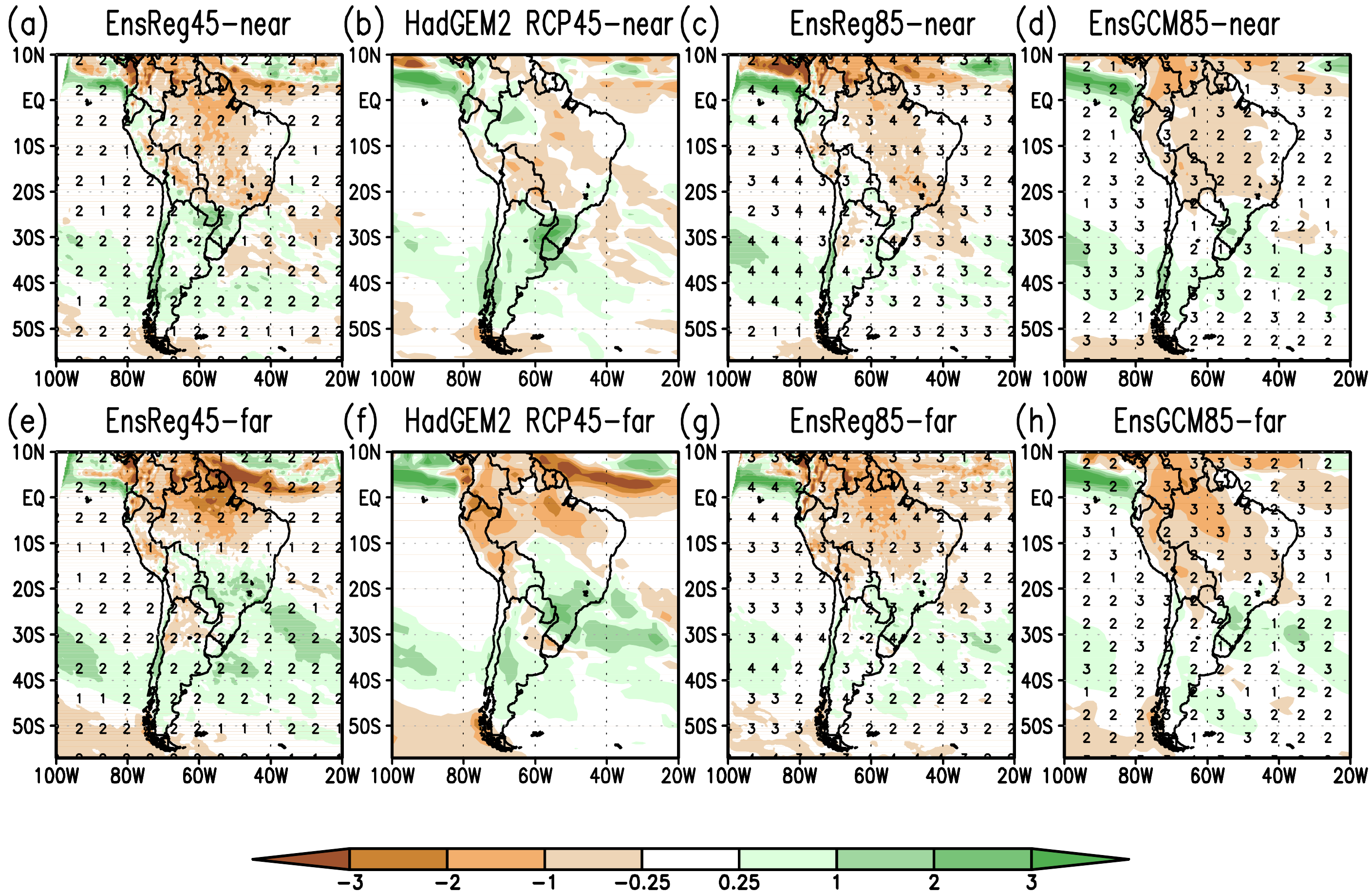
capture the observed pattern: + rainfall over SESA and - over central-north SA.

EnsReg: spatial pattern/intensity of anomaly closer to the observations → “added value”

Near- and far-future climates: ENSO signal in rainfall

Near
(2020-2050)

Far
(2070-2098)



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

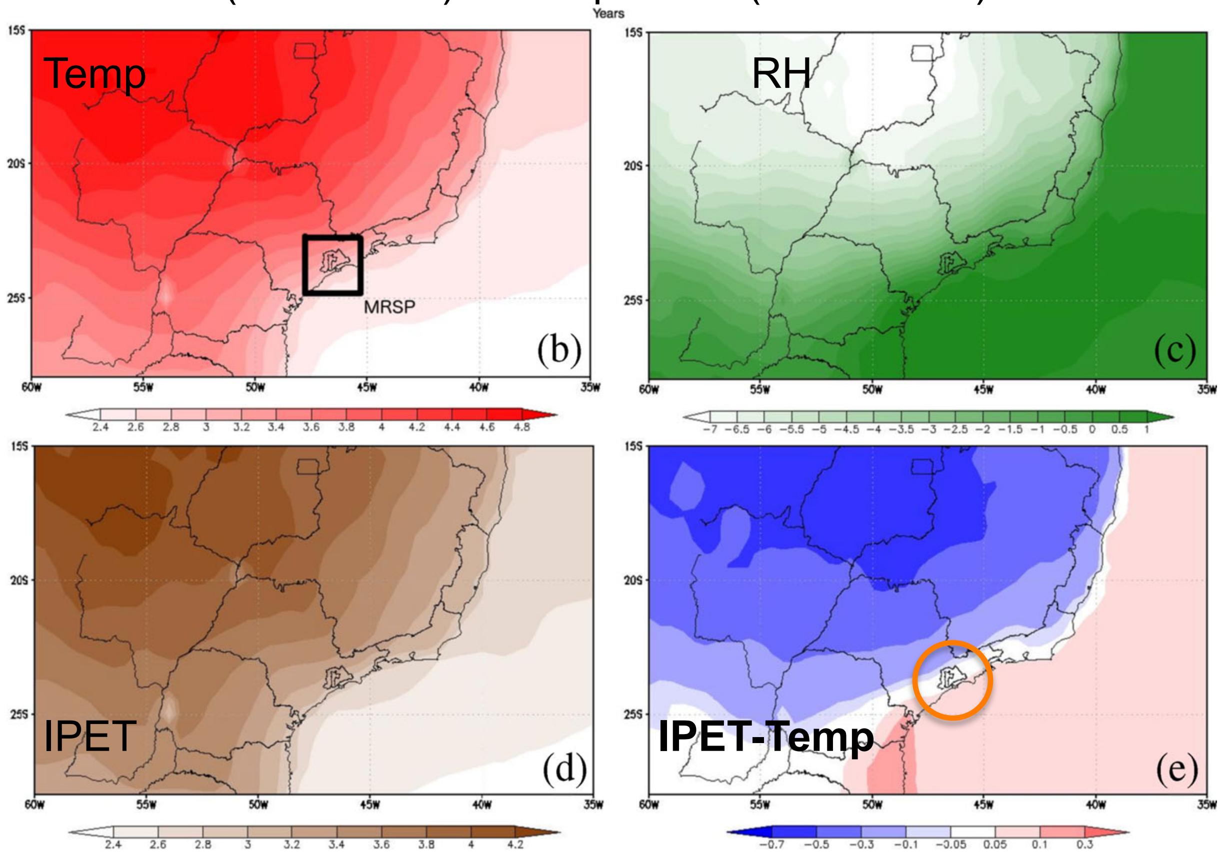
Spatial patterns od EN-LN rainfall are similar to the present climate;

Weakening of the wetter conditions during EN over SESA in the future. This is likely connected with the GCMs' projection of the ENSO signal displaced to the central basin of Pacific Ocean (EN/LN Modoki)

CREMA-SAM projections of thermal comfort index for the metropolitan area of São Paulo, Brazil (Batista et al., 2016)

Application studies: thermal comfort in São Paulo megacity under climate change RCP8.5 scenario using CREMA-SAM (grid spacing of ˜50 km)

Future (2065-2099) minus present (1975–2005) climate



Increase of air temperature is compensated by decrease of relative humidity;

IPET-Temp: São Paulo is in a transicion region of positive/ negative values;

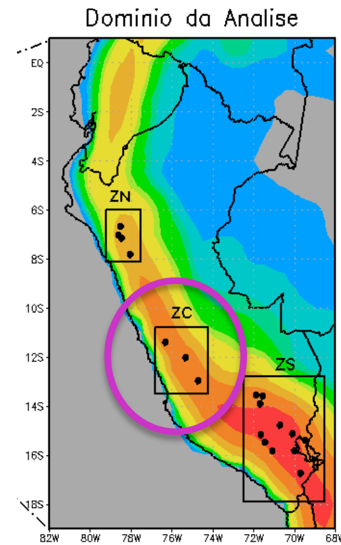
This study has shown the needing of fine resolution projections to better understand the climate change impacts

(Batista et al., 2016)

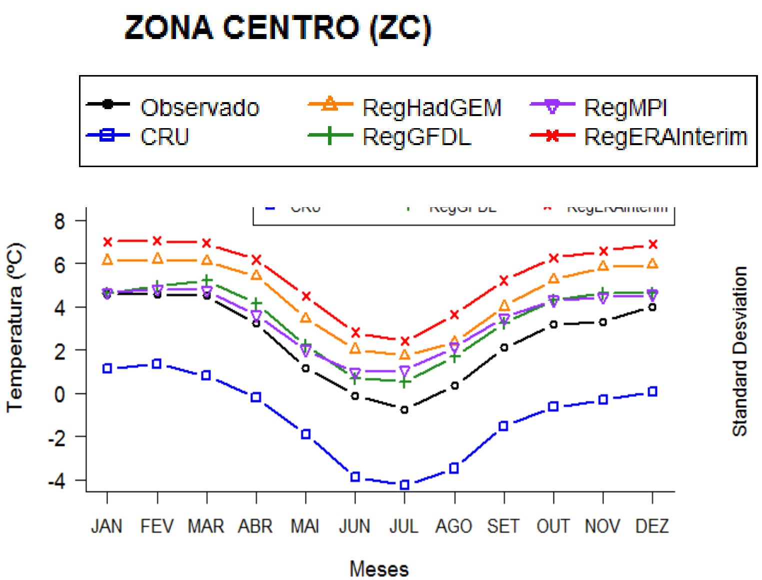
CREMA-SAM projections of frequency of frost days over Peruvian Andes (Arriaga, 2017)

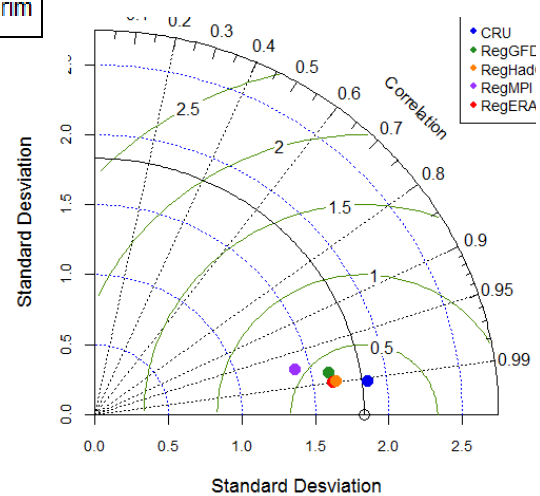
Frost days over Peruvian Andes were obtained from JJA-Tmin

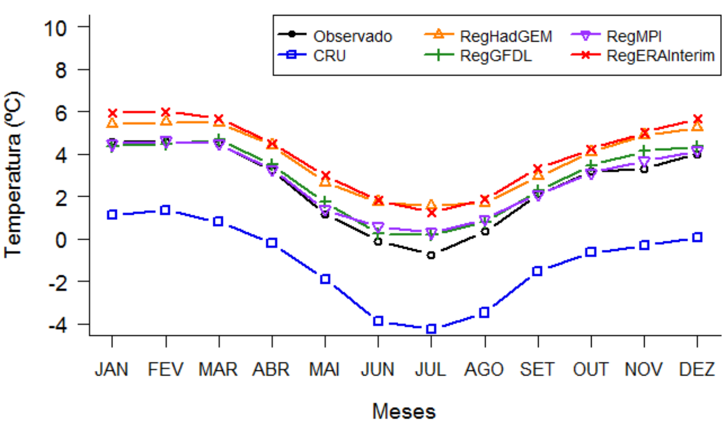
Perfect prog (PP) was used to “correct” the Tmin before to search for frost days. PP– multiple linear regression using Era-Interim as “predictor” provided the equations that were used in the simulations.

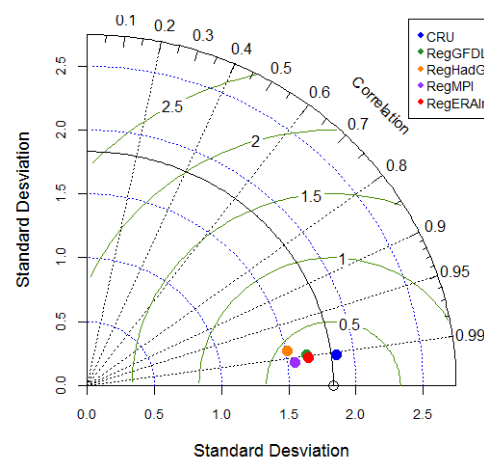


1970-2005









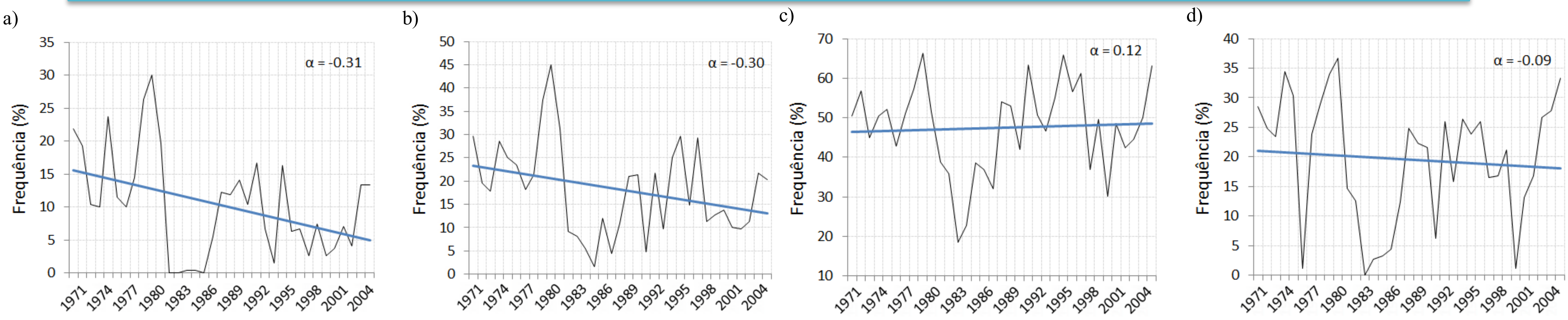
Perfect Prog:

- reduces the warm biases of the simulations;
- improves the amplitude of annual cycle (SD)

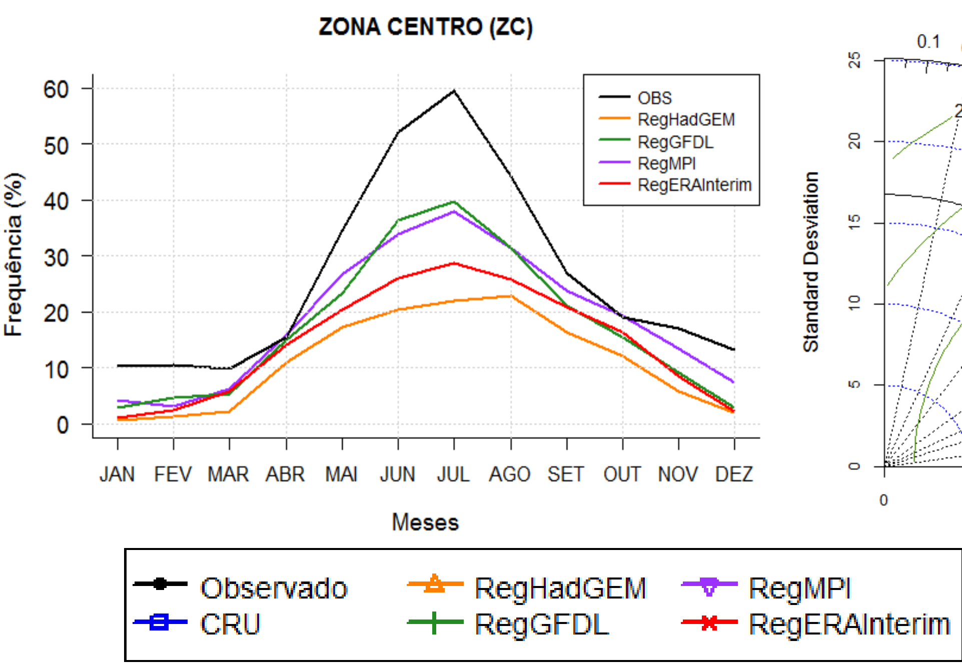
Before PP - RegCM4 is closer to local observations than of CRU → **importance of to use local observation to validate RCM simulations**

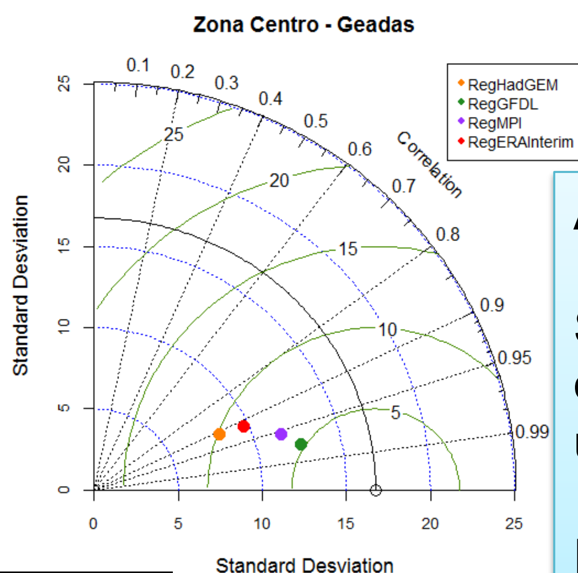
Frost days: Tmin <= 0 (applied after PP)

Observerd trends: decrease of frost days in summer/autumn; increase in winter



Summer Autumn Winter Spring





Annual cycle: obs X simulations

Simulations reproduce the shape of annual cycle, but underestimate the frequency;

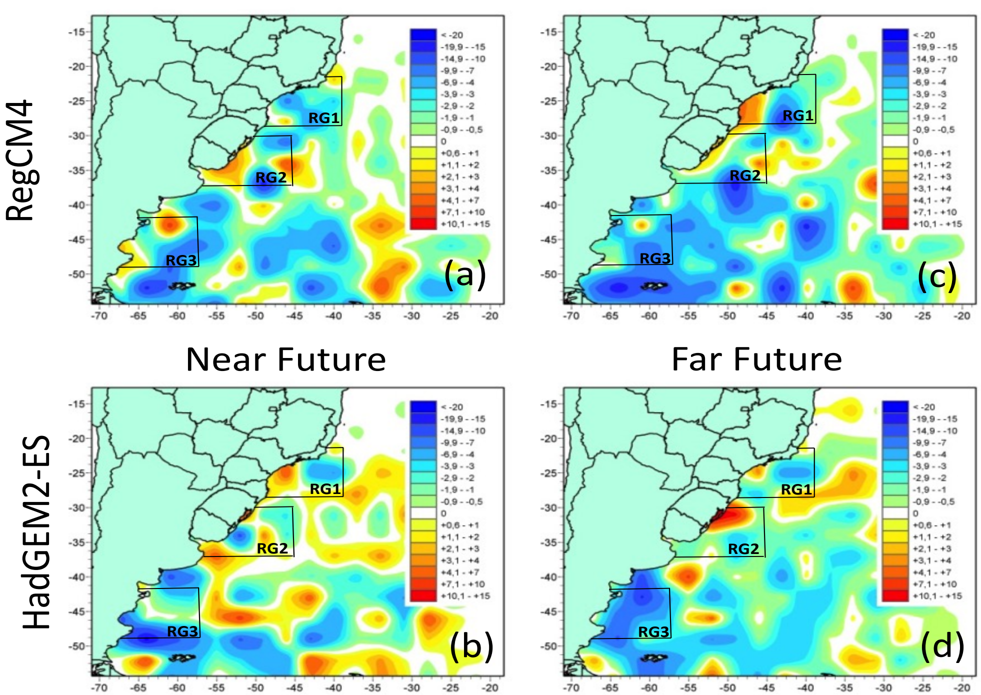
RegMPI and RegGFDL → overperform RegHadGEM

CREMA-SAM projections of cyclogenesis climatology over South Atlantic Ocean (Reboita et al.,2018)

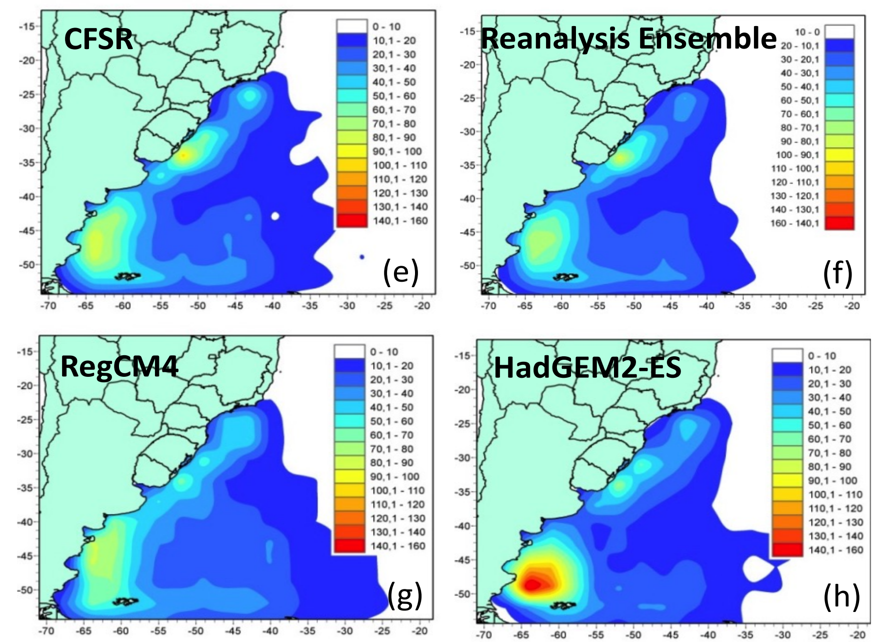
RCMs to study synoptic systems over SAM:

Reboita et al. (2018) – cyclones climatology in RCP8.5 – RegCM4 nested in HadGEM2-ES **(CMIP5) – CREMA**

Near Future Far Future



Present Climate – 1979-2005



Present: spatial pattern of cyclogenesis density simulated by RegCM4 is closer to observations;

Future: decreases of cyclogenetic activity;
Larger decrease southward 35°S
in far future (2070-2098)

What we learned with CREMA-SAM simulations?

Interannual variability:

- EnsReg: captures the ENSO signal in austral spring rainfall over SAM
  provides spatial pattern/intensity of rainfall anomaly closer to the observations;
  weakining of ENSO signal in rainfall in future (EN Modoki).

Cyclones projections:

- added value → better position of the cyclogenetic regions in RegCM than global model

Projections of thermal comfort:

- Sao Paulo city is in between (+/-) → it necessary fine resolution projections to better understand the climate change impacts;

Frost events over the Peruvian Andes:

- biases in RegCM4-Tmin are smaller when compared **with local observations** than with CRU;
- perfect-prog → enable RegCM to reproduce the observed annual cycle of frost days;

* Fine resolution simulations and local observation to validate observed features of climate

CREMA-SAM and CORDEX2 plans

Gutowski et al. (2017) → general view of the CORDEX2 (CORDEX phase 2) pointing out two main components:

a) CORDEX-CORE framework → RCM downscalings with dx~10–20 km using a set of GCMs;

b) development of targeted Flagship Pilot Studies (FPS) to address specific scientific questions of methodological and regional relevance.

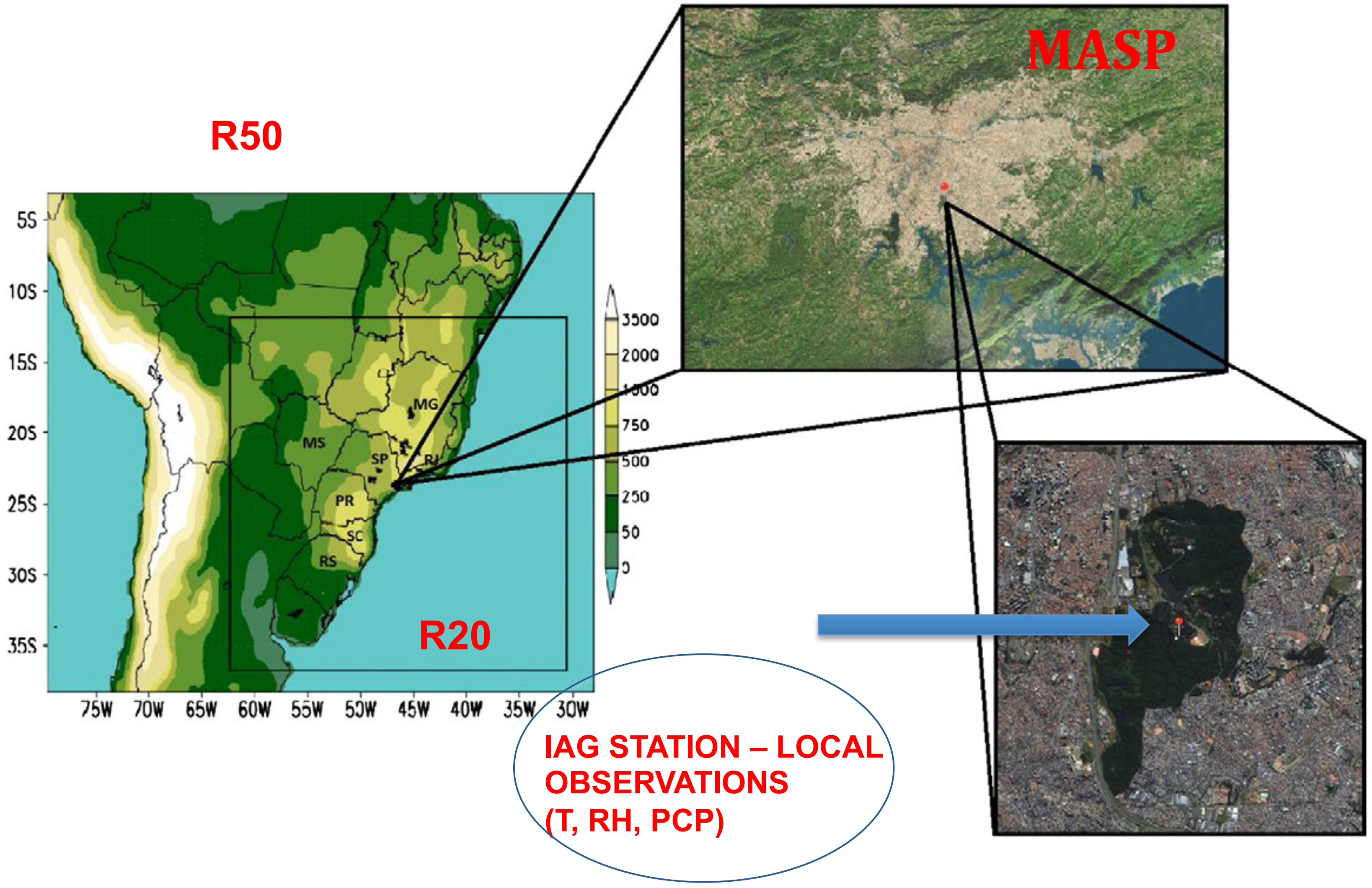
Relevance of CORDEX to interact with the CMIP6 **V**ulnerability, **I**mpacts, **A**daptation and **C**limate **S**ervices (VIACS) Advisory Board in order to identify and communicate the value, limitations and uncertainties of the information provided through the CORDEX downscaling experiments.

Grid resolution impacts on simulated local features of climate

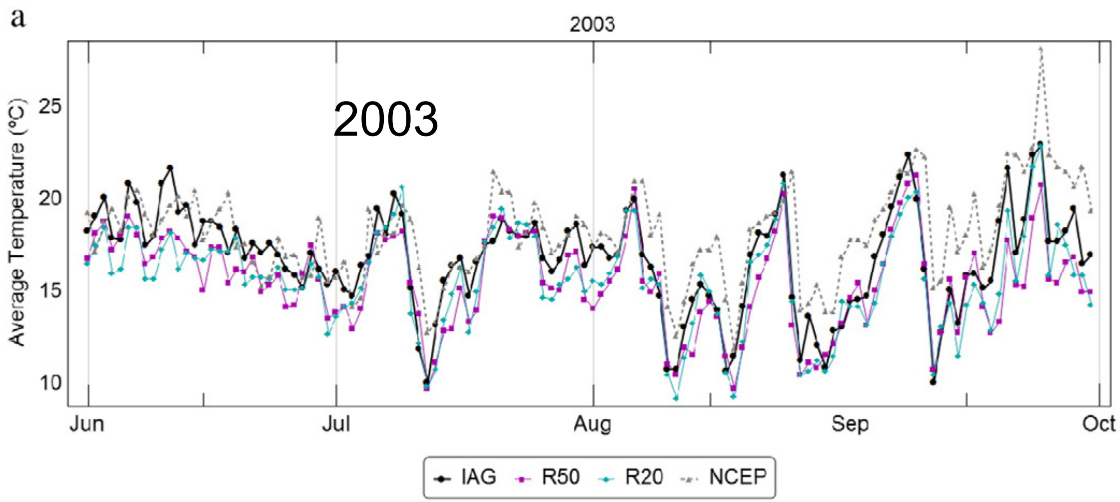
Fog events and local atmospheric features simulated by RegCM3 for the São Paulo city, Brazil (da Rocha et al., 2015)

RegCM3 simulations:

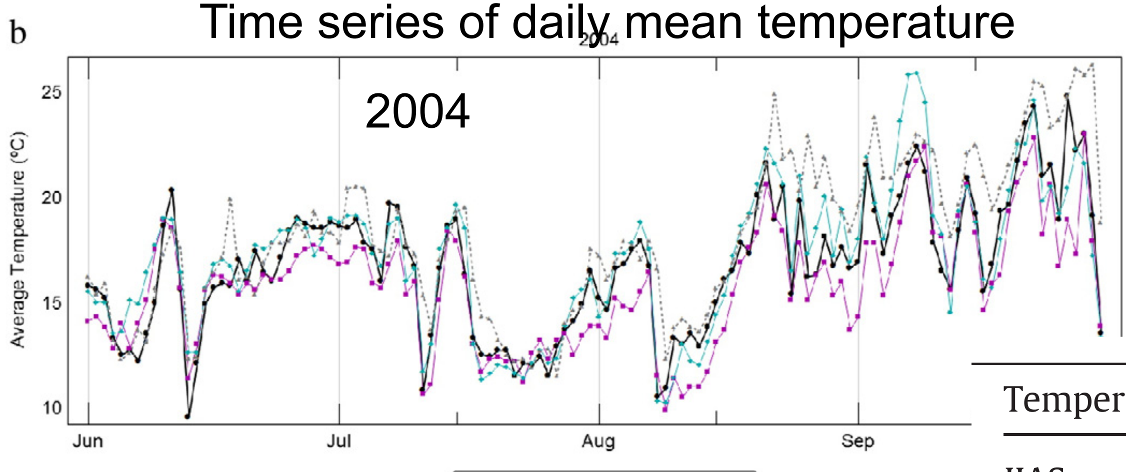
- two domains using 50 (**G50**) and 20 (**R20**) km of horizontal grid spacing;
- two (2003 and 2004) winter seasons (JJAS)
- Initial and boundary conditions from NCEP2 reanalysis



Air temperature and fogs over SP city



Time series of daily mean temperature



RegCM reproduces the observed high frequency temporal variability of air temperature;

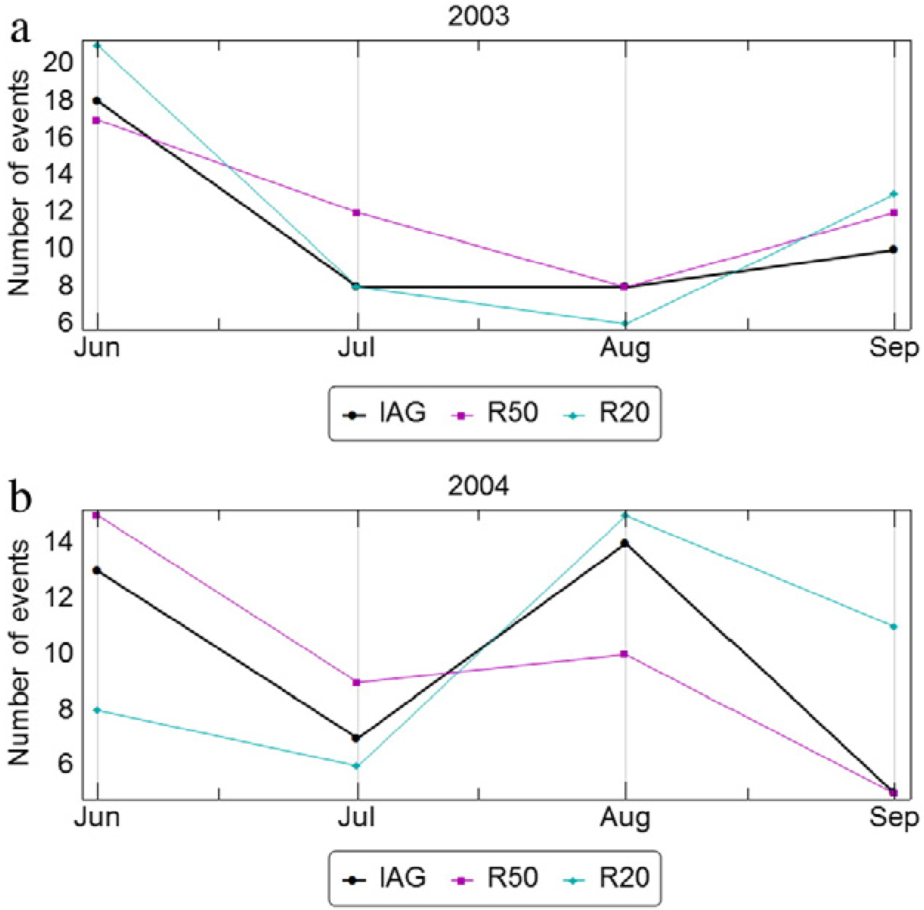
"Added value": RegCM simulations are closer to the local observations than NCEP

Temperature	Mean (°C)	
JJAS	2003	2004
IAG (A ± SD)	16.8 ± 2.7	16.8 ± 3.2
R50 (A ± SD)	15.6 ± 2.5	15.9 ± 2.8
r (RMSE)	0.89 (1.7)	0.90 (1.6)
R20 (A ± SD)	15.7 ± 2.7	15.9 ± 3.3
r (RMSE)	0.92 (1.6)	0.93 (1.5)
NCEP (A ± SD)	18.2 ± 2.6	18.2 ± 3.6
r (RMSE)	0.74 (2.37)	0.86 (2.30)

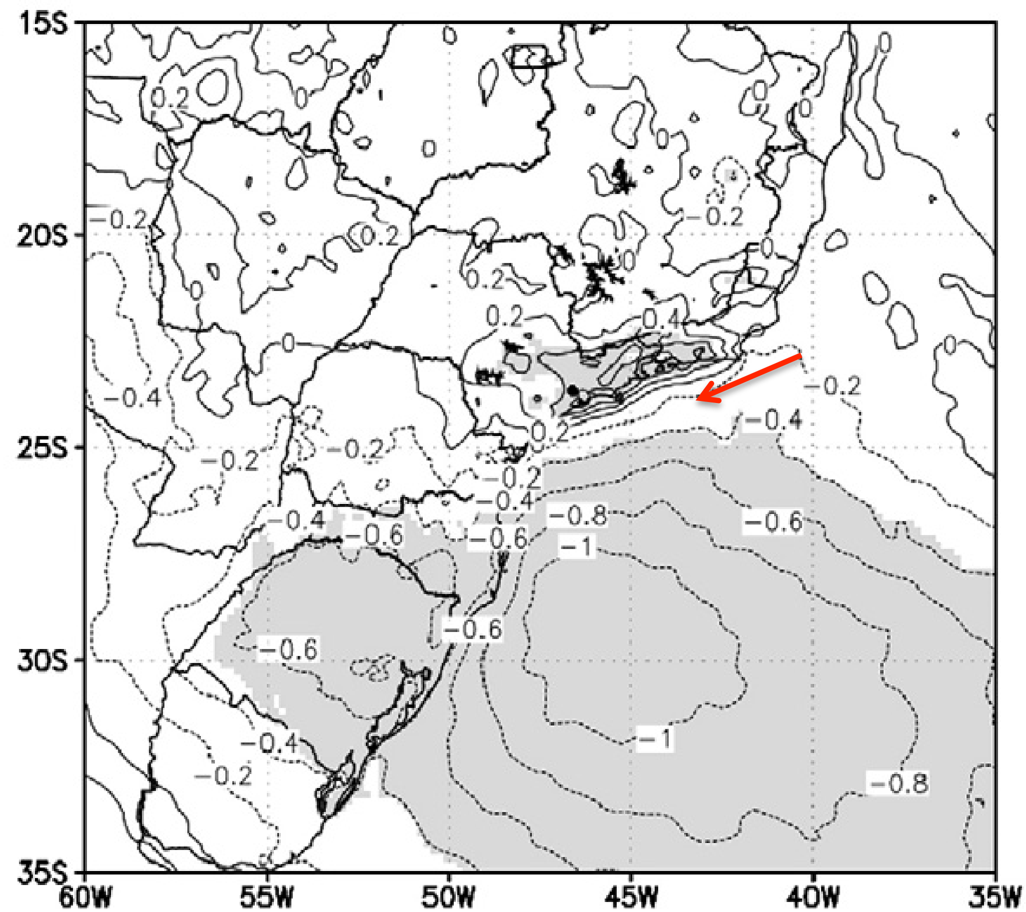
Positive impact of fine resolution: greater correlation, smaller rmse, closer SD

Fog events over SP city

RegcM3 reproduces the observed cycle



G20 → fogs occur under positive anomaly of specific humidity over SP city and negative southward (anomalous anticyclone)



- fine resolution captures well the occurrence of fog events;

- realistic synoptic pattern associated with fogs is simulated by G20.

Grid resolution impacts on simulated local features of climate

Assesement of fine resolution RegCM simulations over south-southeast Brazil (da Rocha et al., 2018)

Model version: RegCM4.6.1

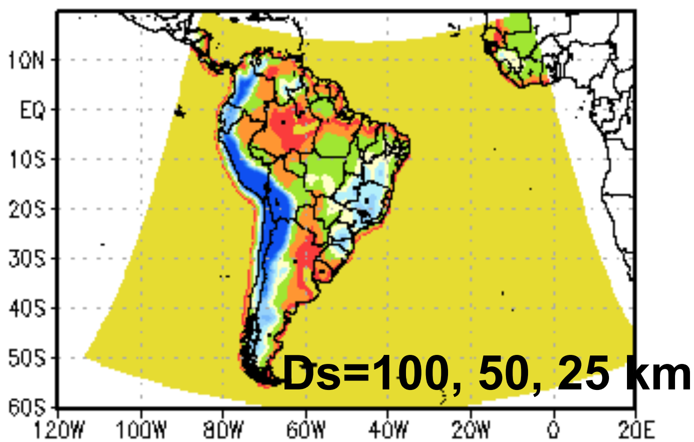
→ **Simulation period: December/2009 – December/2010 (analysis – 2010)**

→Initial and boundary conditions: ERA-Interim (~ 75km) – Dee et al. (2011)

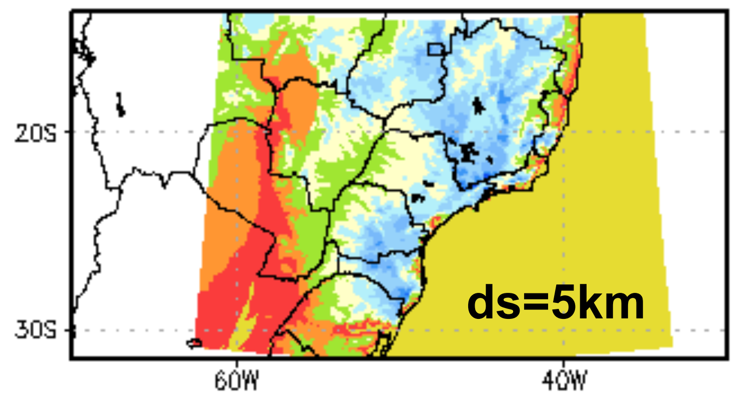
→Convective scheme: Emanuel over all domain; Large scale precipitation: SUBEX

→Surface schemes: **BATS and CLM4.5**

Hydrostatic

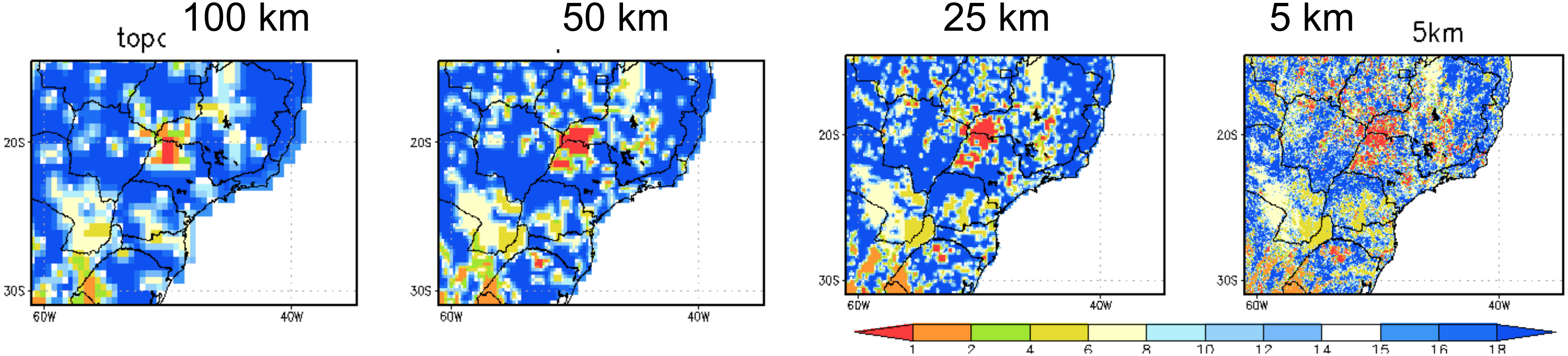


non-Hydrostatic

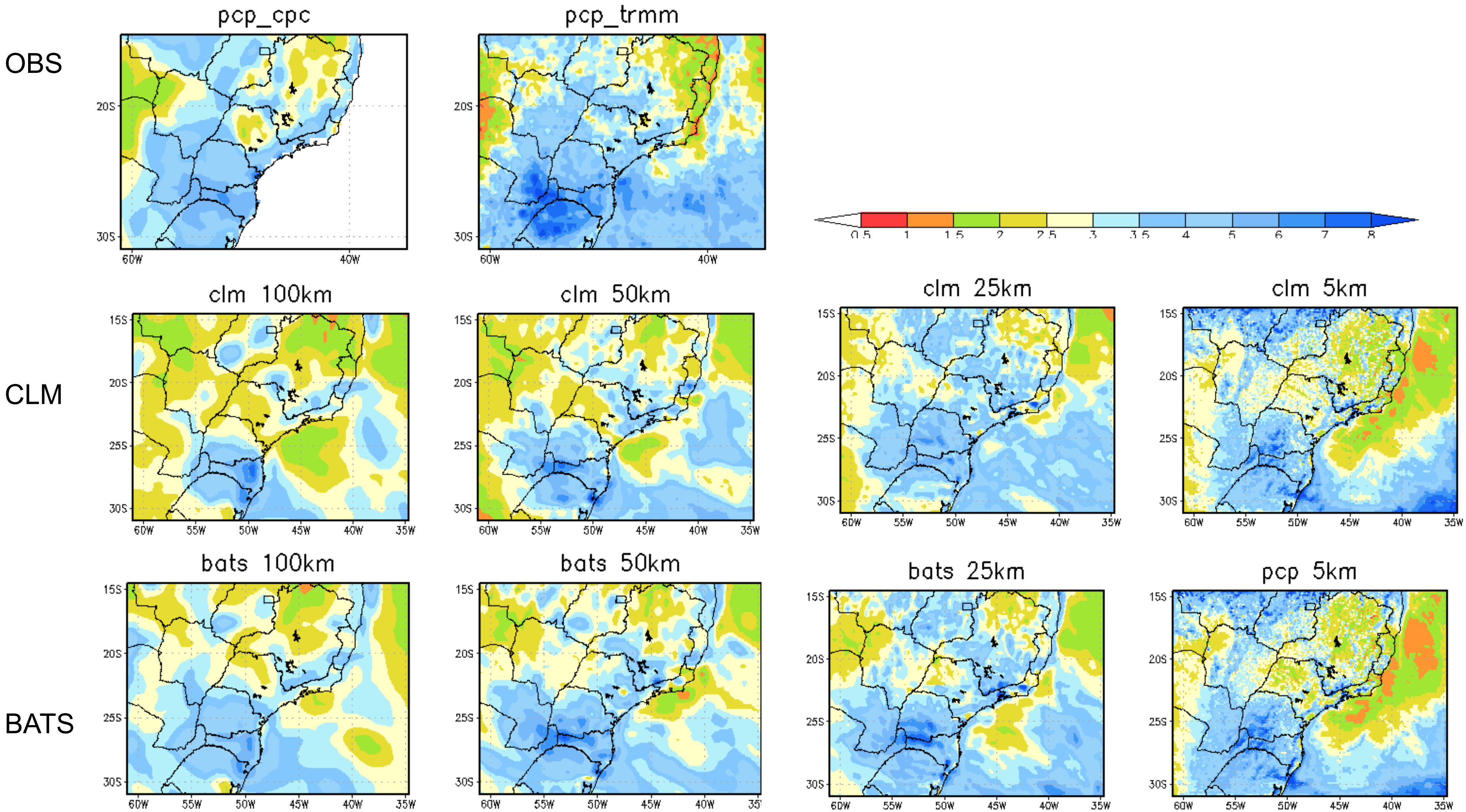


Landuse: zoom over south-southeast Brazil

100 km 50 km 25 km 5 km



Annual mean rainfall – 2010



→Location of more intense rainfall over south Brasil/Paraguay: BATS has greater agreement with observations;

→ positive impact of high resolution in both CLM and BATS

→ Fine resolution: deficit of rainfall over part of southeast Brazil

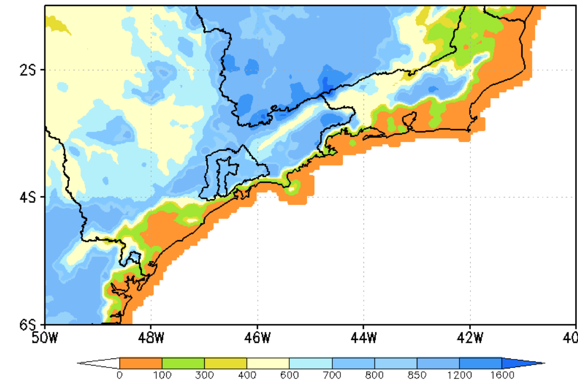
Some improvemments of the annual cycle of rainfall and spatial pattern of simulated variables in fine resolution experiments (CLM and BATS) → "Added Value"

Next → Local features of climate in the 5 km simulations

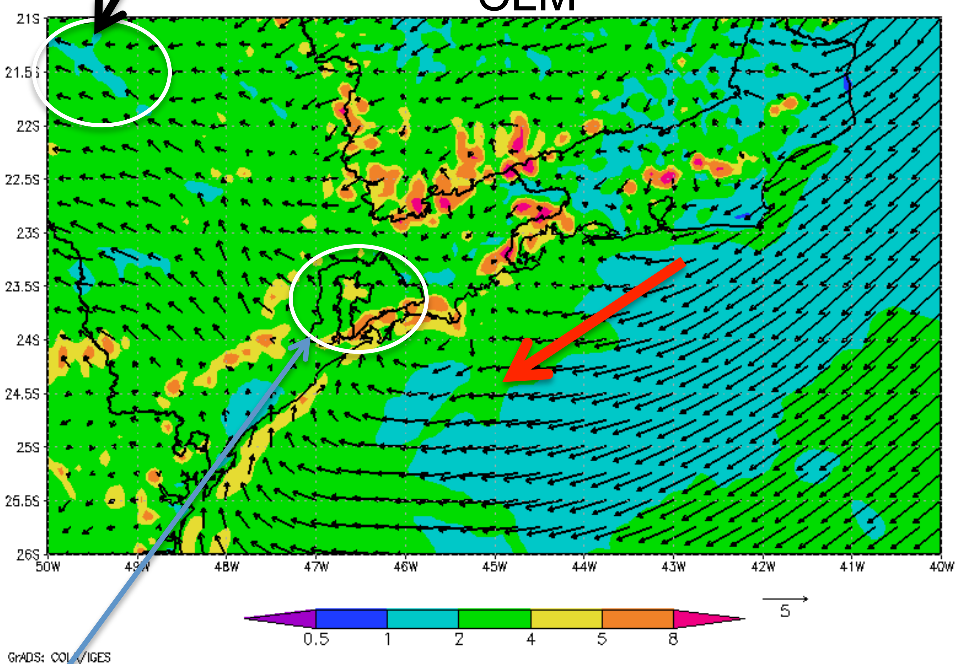
Mesoscale circulations over eastern southest Brazil: 5 km

Tiete river basin

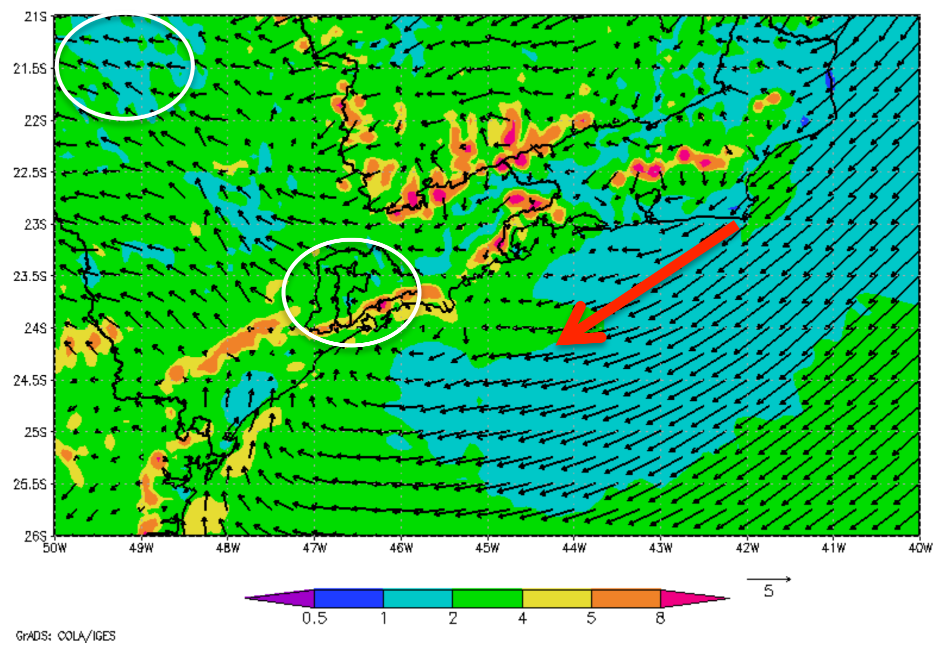
Annual mean (2010): 10-m wind and rainfall



CLM



BATS

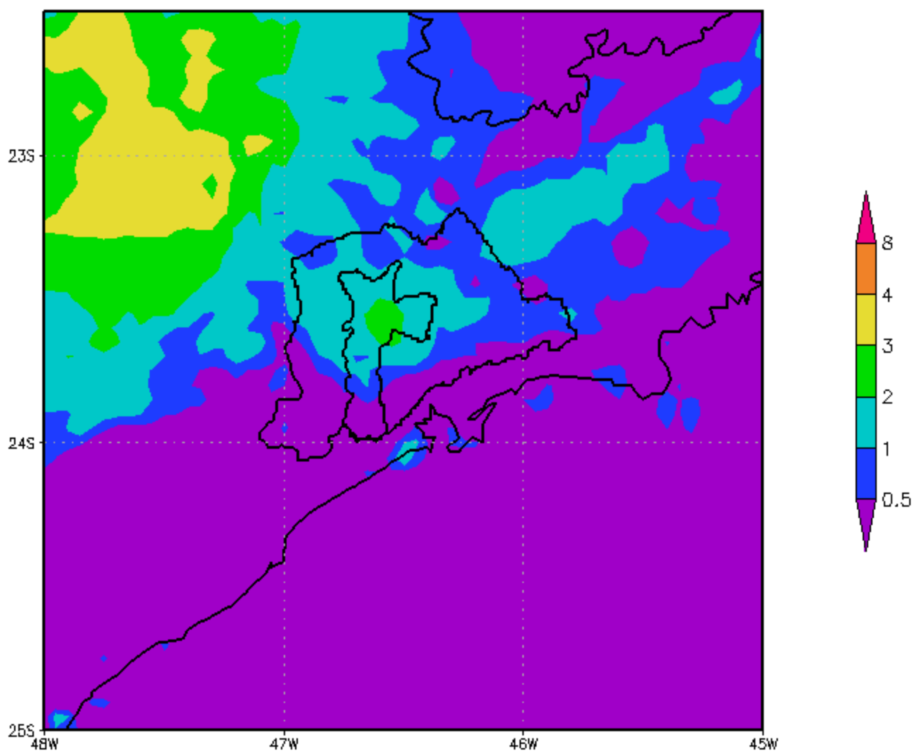


Main patterns of mean circulation/rainfall are similar in CLM and BATS;
Local features → CLM simulates less rainfall in the main SP river basin (Tiete) and more rainfall over Sao Paulo city.

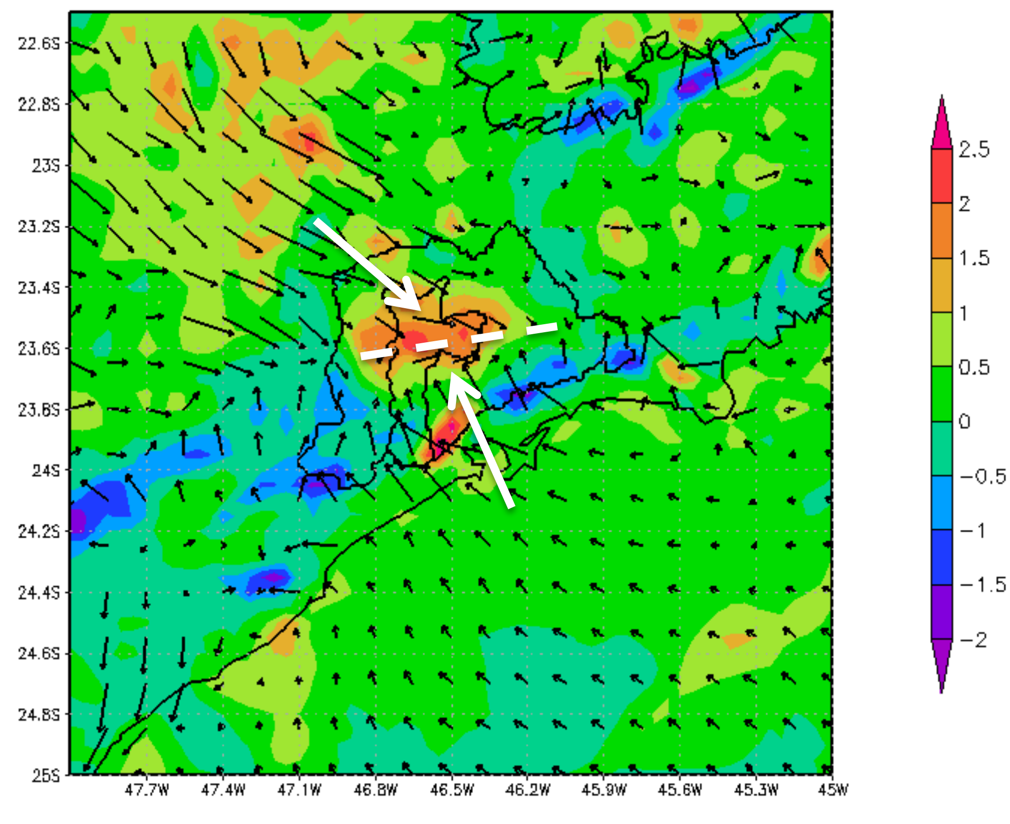
São Paulo city

Annual mean differences: CLM minus BATS

2-m air temperature



10-m wind/rainfall



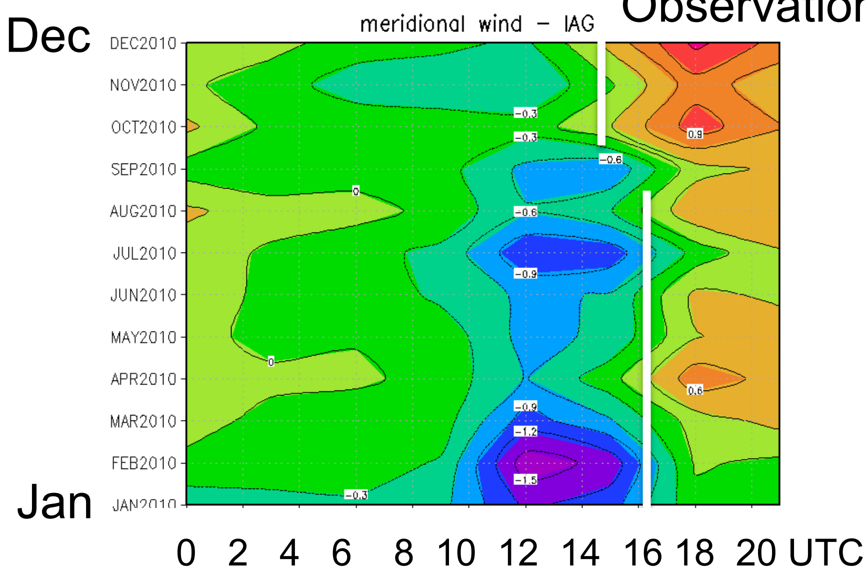
CLM simulates higher temperatures over São Paulo (urban effect?) and along the valey

SE winds (sea breeze) and continental NW winds are stronger in CLM than in BATS → contributing to wind convergence over São Paulo → higher amount of rainfall over center-north of the city in CLM

Local validation: diurnal cycle of **meridional wind** over São Paulo

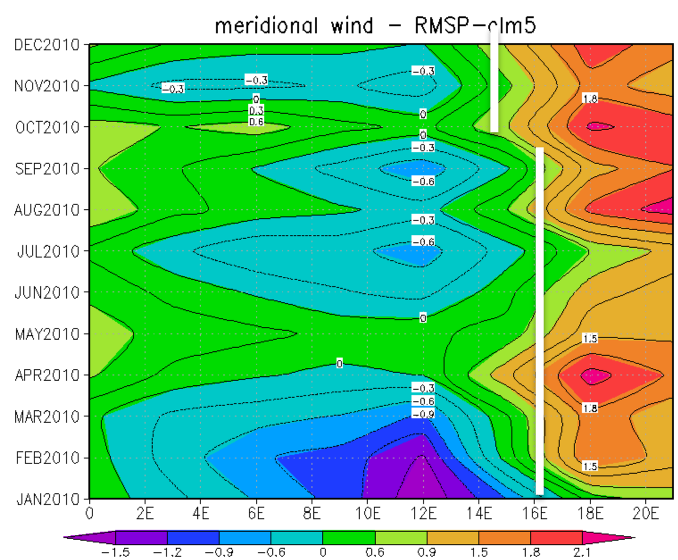
Montlhy mean diurnal cycle

Observation

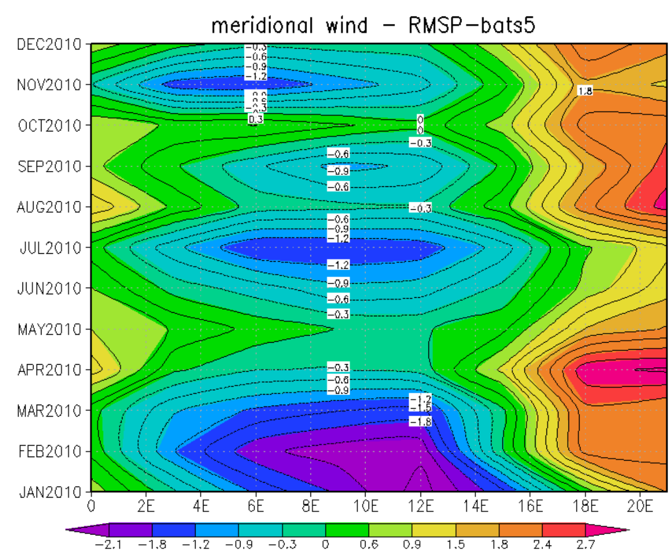


Observation: wind changes from north to south in the early afternoon (13-14 LT → 16-17 UTC; OND 11-12 LT); More intense N winds JF/ 2010

CLM



BATS



CLM has large hability to reproduce the observation (weaker winds and time of change from N to S) than BATS

Final comments

- Some progress in RegCM studies over SAM;

- **CREMA-SAM simulations**:
  - were used to access climate variability, synopitc systems climatology/trends, thermal comfort over SP, frost events over Peruvian Andes.
  - pointed the need of fine resolution simulations to access impacts;
  - relavant point: we need to use local/mesoscale observations to evaluate physical processes in the high resolution simulations.

Next

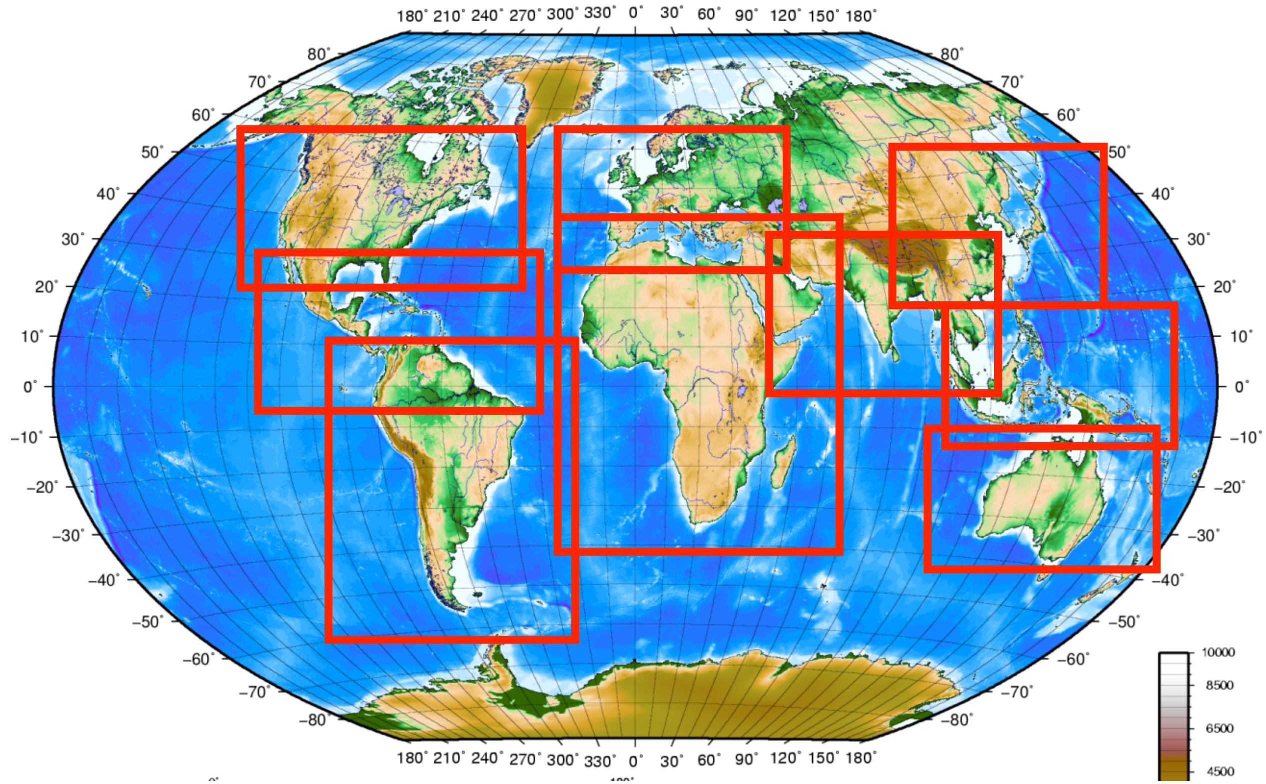
- **SESA-FPS – RegCM4 fine resolution over SESA to understand extreme precipitation events**

- **CREMA-Phase 2 is being planned/executed by ICTP: it will provided 25 km downscaling with RegCM4.7.0 nested in 3-4 CMIP5/GCMs in various CORDEX subdomains, including SAM**

Thanks!
Obrigada!

The CREMA Phase II Experiment

Contribution to the CORDEX-CORE program by the RegCM community



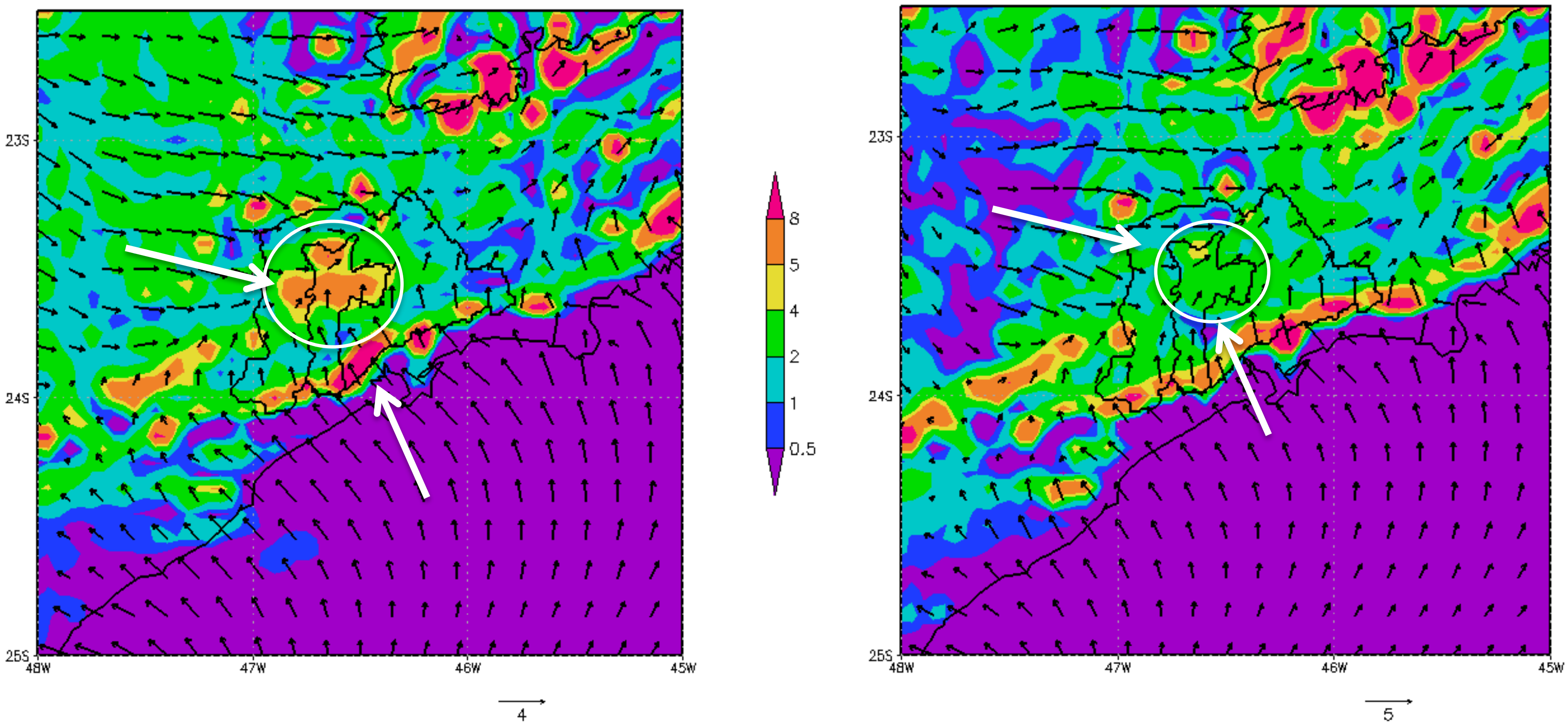
Simulations done by
ICTP
Gao-IAP
Ashfaq-ORNL
Others?

6 Scenario simulations (1970-2100)
9 CORDEX domains
RegCM4 at dx=25 km
3 driving CMIP5 GCMs
(MPI,HADGEM, NorESM)
2 GHG scenarios (RCP2.6/8.5)
CORE set of variables stored

Most simulations completed at the
CINECA supercomputing centre
~1 Pbytes of data produced ?

Day (15-21 LT) minus nigth (03-09 LT) – zoom

CLM BATS



During the day SE winds and along shore rainfall → sea breeze

CLM → greater amount of rainfall over São Paulo during the day (urban effect?)