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"Rainfall extremes in the late twenty-first century in Metropolitan Area of Sao Paulo (MASP): Vulnerability to climate change"

[1]María Valverde and [2]José Marengo
[1]Urban and Environmental Engineering - Federal University of ABC (UFABC), Santo André, 09210-170, Brazil.
maria.brambila@ufabc.edu.br
[2]Center for Earth System Science – National Institute for Space Research (INPE) Av. Dos Astronautas, 1758, CEP 12227-010, Brazil

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Objetive

- ✓ The aim of this paper is to evaluate the extreme rainfall through climate extreme indices (CEI) over past and future changes in MASP.
- ✓ Furthermore, an index to empirically assess relative levels of social vulnerability to extreme rainfall in MASP was created.

Data

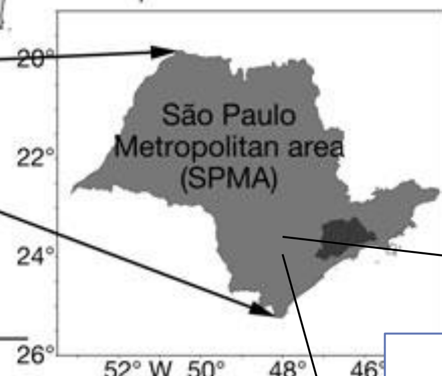
1. ETA_HadCM3

Here projections of future changes in rainfall extremes in the MASP region were derived from the ETA-HadCM3 40 km regional model nested in the HadCM3 global model, with 4 available members for the A1B emissions scenario to the end of the 21st century

2. Observed Data

We use the data from the Meteorological Station of the University of São Paulo referred as IAG-Agua Funda (23,65°S – 46,61°W, 800 m.o.s.l), with data available since 1933.

Location of the Metropolitan Area of São Paulo, MASP.



Indices of extremes and trend analysis

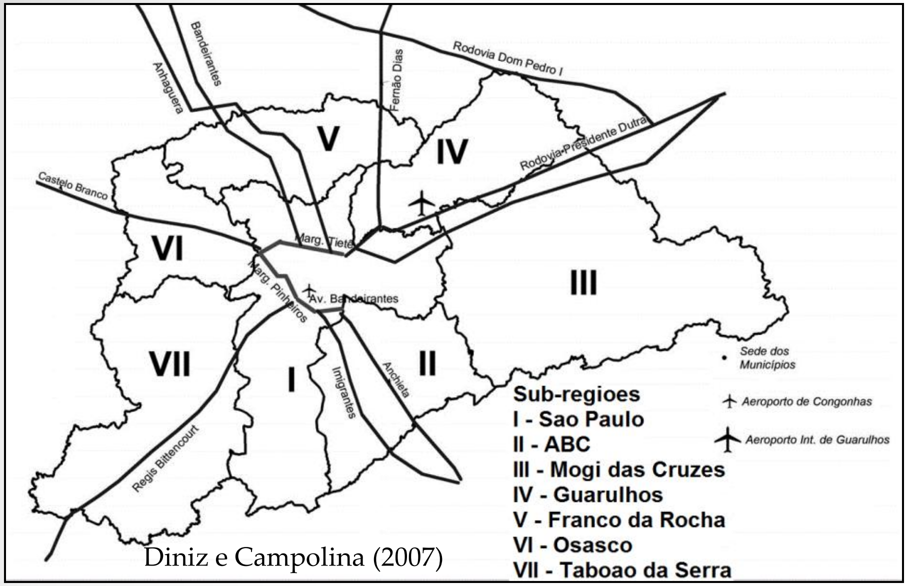
The definition of CEI follows the methodology established by the task group for the detection and attribution of changes in climate: Climatic Variability and Predictability (CCI/ CLIVAR), which developed 21 indices based on daily data of precipitation and maximum and minimum temperature.

In addition, we defined another index: *Light rain* (R5): the number of days with precipitation between 0.1 and 5 mm.

From a total of 27 available indices, we used 5 of them:

Index	Definitions	Expression	Units
CDD	Annual maximum numbers of consecutive dry days. Let RR_{ij} be the daily precipitation amount on day i in period j. Count the largest number of consecutive days where:	$RR_{ij} < 1mm$	Days
RX1day	Annual maximum 1-day precipitation. Let RR_{ij} be the daily precipitation amount on day i in period j. Then maximum 1-day values for period j are:	$Rx1day_j = \max(RR_{ij})$	mm
RX5day	Annual maximum consecutive 5-day precipitation. Let RR_{kj} be the precipitation amount for the 5-day interval ending k, period j. Then maximum 5-day values for period j are:	$Rx5day_j = \max(RR_{kj})$	mm
R95p	Let RR_{wj} be the daily precipitation amount on a wet day $w(RR \geq 1.0mm)$ in period j and let $RR_{wn}95$ be the 95th percentile of precipitation on wet days in the 1961-1990 period. If W represents the number of wet days in the period, then:	$R95p_j = \sum_{w=1}^{W} RR_{wj}$ Where $RR_{wj} > RR_{wn}95$	mm
R20mm and R50mm	Number of days per year with precipitation amount ≥ 20mm, and ≥ 50 mm, respectively. Let RR_{ij} be the daily precipitation amount on day i in period j. Count the number of days where:	$RR_{ij} \geq 20mm$	Days
PRCPTOT	Annual total precipitation from wet days. Let RR_{ij} be the daily precipitation amount on day i in period j. If represents the number of days in , then:	$PRCPTOT_j = \sum_{i=1}^{I} RR_{ij}$	Mm

Vulnerability Index



Diniz e Campolina (2007)

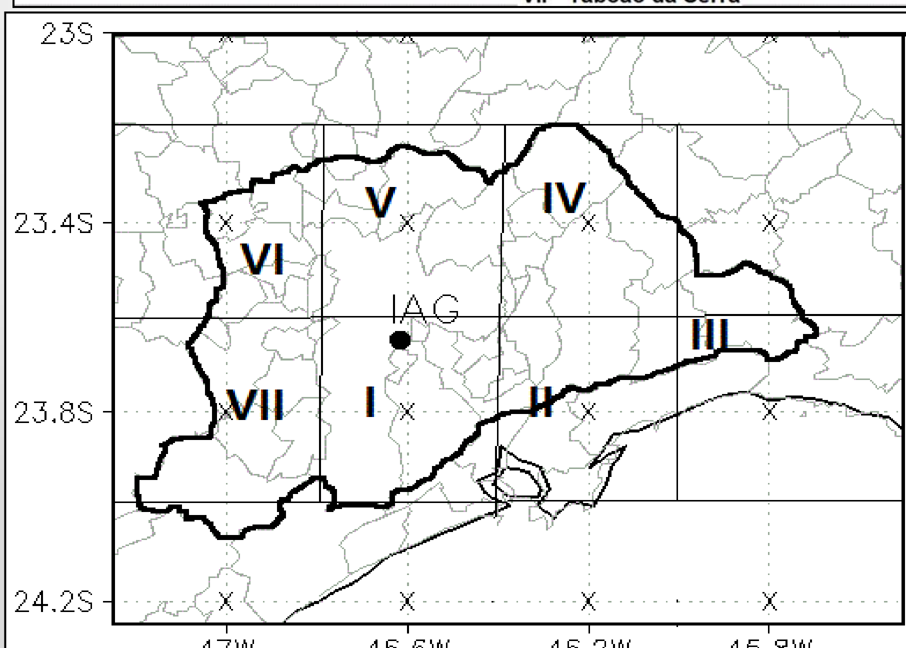


Tabla II - Municípios que compõem as sub-regiões da RMSP

Sub-region	Municípios
I - São Paulo	São Paulo
II – ABC	São Bernardo do Campo, Santo Andre, Mauá, Diadema, São Caetano do Sul, Ribeirão Pires, Rio Grande da Serra
III – Moji das Cruzes	Moji das Cruzes, Itaquaquecetuba, Suzano, Ferraz de Vasconcelos, Poá, Biritiba-Mirim, Guararema, Salesópoli
IV – Guarulhos	Guarulhos, Mairiporã, Arujá, Santa Isabel
V- Franco da Rocha	Francisco Morato, Franco da Rocha, Caieiras, Cajamar
VI – Osasco	Osasco, Carapicuíba, Barueri, Itapevi, Jandira, Santana de Parnaíba, Pirapora do Bom Jesus
VII Taboão da Serra	Embu, Taboão da Serra, Cotia, Itapecerica da Serra, Embu – Guaçu, Vargem Grande Paulista, Juquitiba, São Lourenço da Serra

Grid of ETA_HadCM3 model assigned for Sub-region of MASP.

Vulnerability Index

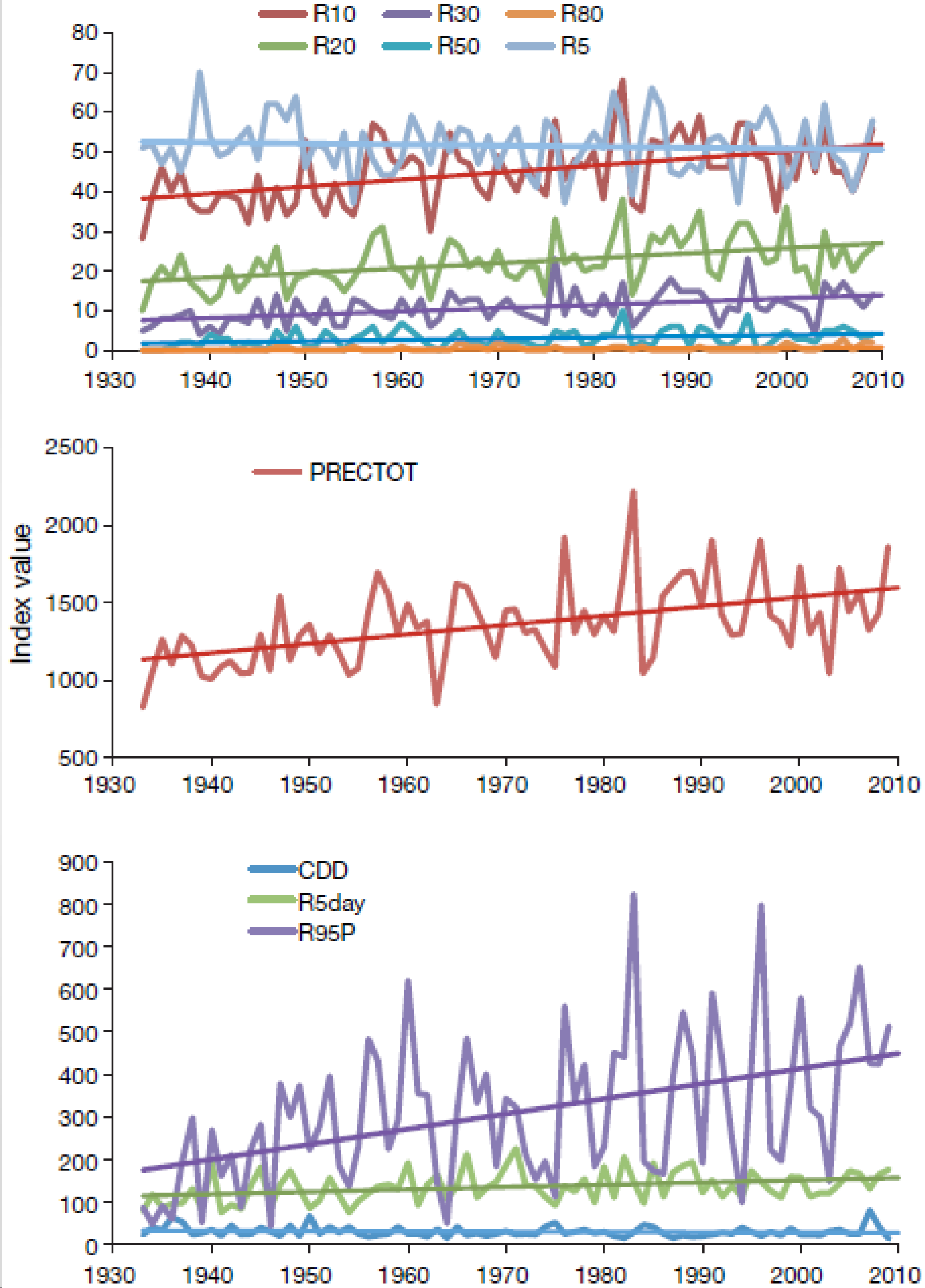
The overall equation summarizing the model employed for the VI for each sub region of MASP is thus (Vicent, 2004):

$$VI_{MASP} = \frac{1}{N}\left(w_{er} * \mathrm{I}_{\mathrm{er}} + w_{se} * I_{se} + w_{de} * I_{de}\right)$$

Ier = extreme rainfall sub-index
Ide= demographic structure sub-index
Ise = Socioeconomic sub-index
VI = Vulnerability Index

$$I_i = \frac{1}{n}\left(\mathrm{C}_{\mathrm{p1}} + C_{p2} + \ldots + C_{pn}\right)$$

Indicators (I)	Component (C)	Definitions
Extreme Rainfall	RX1day and RX5day	Annual maximum consecutive 5-day and 1 day precipitation.
	R50mm	Number of days per year with precipitation amount ≥ 50 mm.
Socioeconomic and demographic	Density demographic	Population for km^2
	Population	Number of habitant
	Annual Growth Rate	1,1% between 2000 e 2005
	Poverty	% poverty Per capita income
	education	% of population with 15 years age or over with less than 4 years of study
	Longevity (life expectancy)	Women- 74 years of age (2000) and 77 years of age (2010) Man -66 years of age (2000) and 73 years of age (2010)

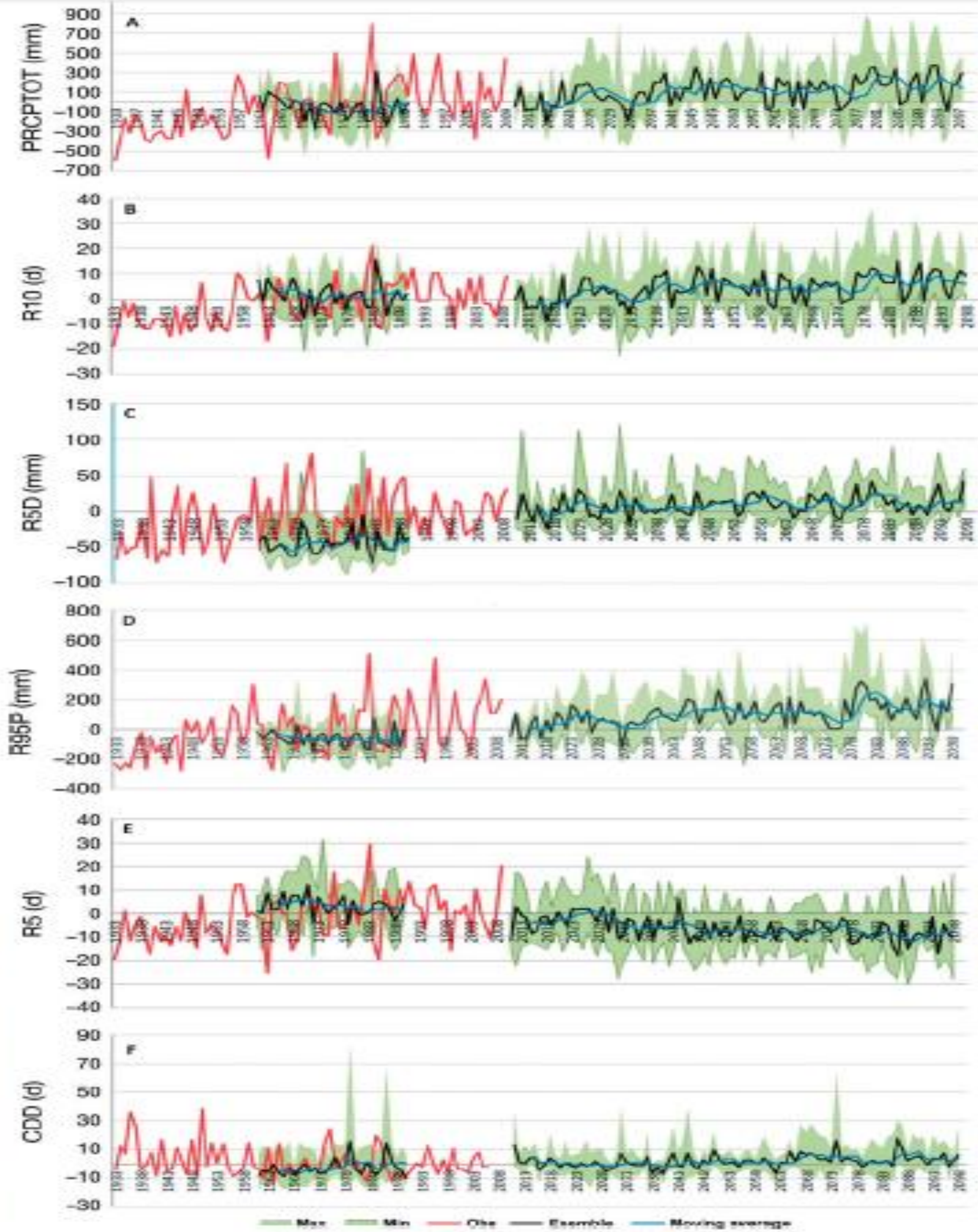


Results

Time series of indices of extremes at the IAG-USP Agua Funda meteorological station, in the MASP

Index	Observed trend	Significance (5 %)
R5	-0.12 d yr^{-1}	NS
PRCPTOT	$+5.2$ mm yr^{-1}	S
R95P	$+3.5$ mm yr^{-1}	S
R5D	$+0.6$ mm yr^{-1}	NS
R10	$+0.20$ d yr^{-1}	NS
R20	$+0.22$ d yr^{-1}	NS
R30	$+0.65$ d yr^{-1}	NS
R50	$+0.29$ d yr^{-1}	NS
CDD	-0.01 d yr^{-1}	NS

- ✓ PRCPTOT and R95P, have been increasing steadily, albeit with pronounced interannual variability. A similar tendency was observed in R10–R80.
- ✓ Light precipitation (R5) shows a slightly negative trend to 2010.

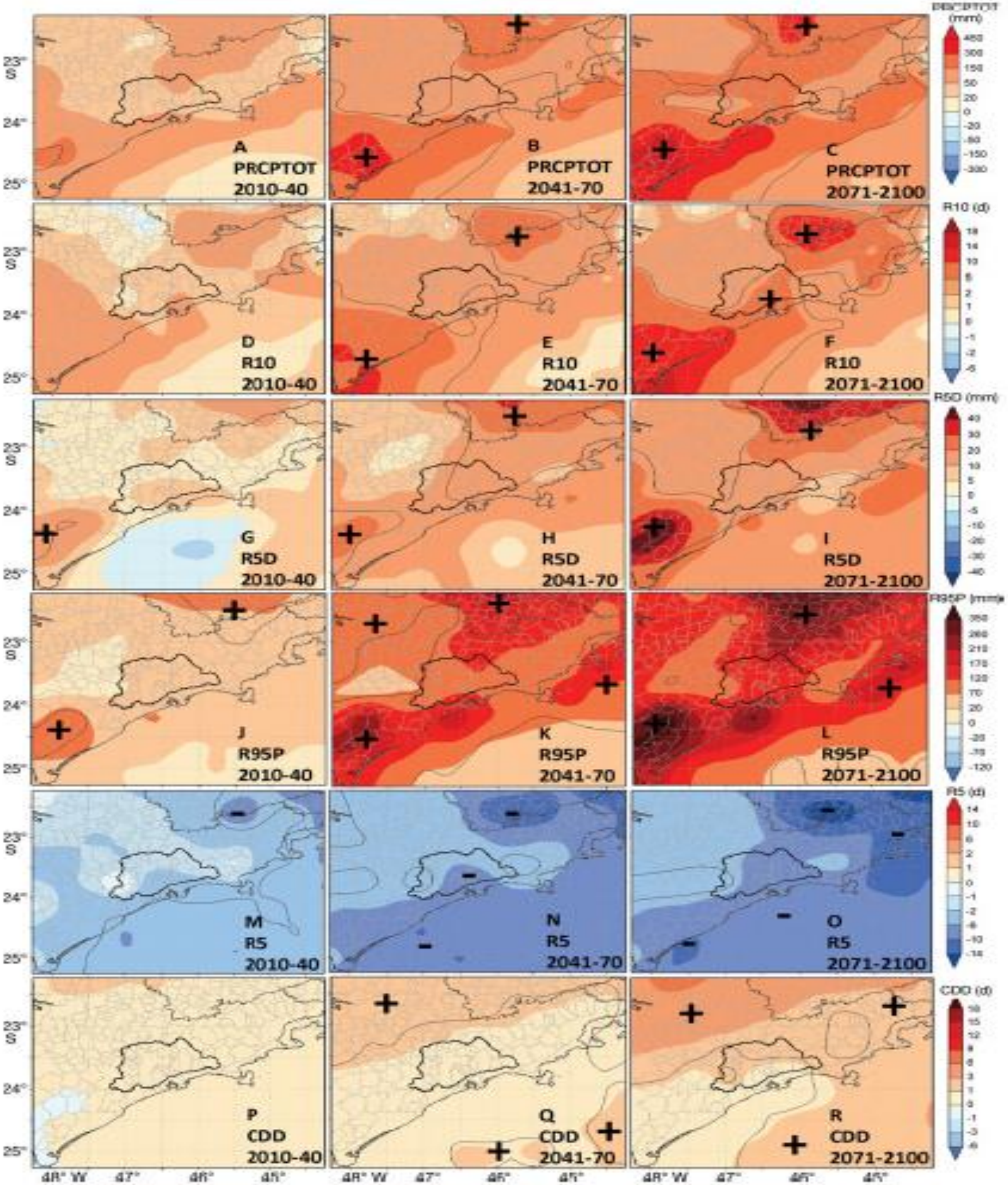


The future

Table 2. Qualitative summary of observed changes in the MASP region and projected changes in rainfall extremes generated by the Eta CPTEC-HadCM3 40 km in a grid box near the IAG USP Agua Funda station, for the A1B emission scenario and for the ensemble of 4 available members. Confidence was defined based on the results of the Mann-Kendal significance test (see Fig. 4). S: significant; NS: non-significant. The arrows are used to define the direction of the trends and not their magnitude

	1961–1990	2010–2040	Significance	2041–2070	Significance	2071–2100	Significance
R5	↘	↘	NS	↘	S	↘	S
PRCPTOT	↗	↗	NS	↗	NS	↗	S
R95P	↗	↗	NS	↗	S	↗	S
R5D	↗	↗	NS	↗	S	↗	S
R10	↗	↗	NS	↗	NS	↗	S
CDD	↘	↘	NS	↗	NS	↗	NS

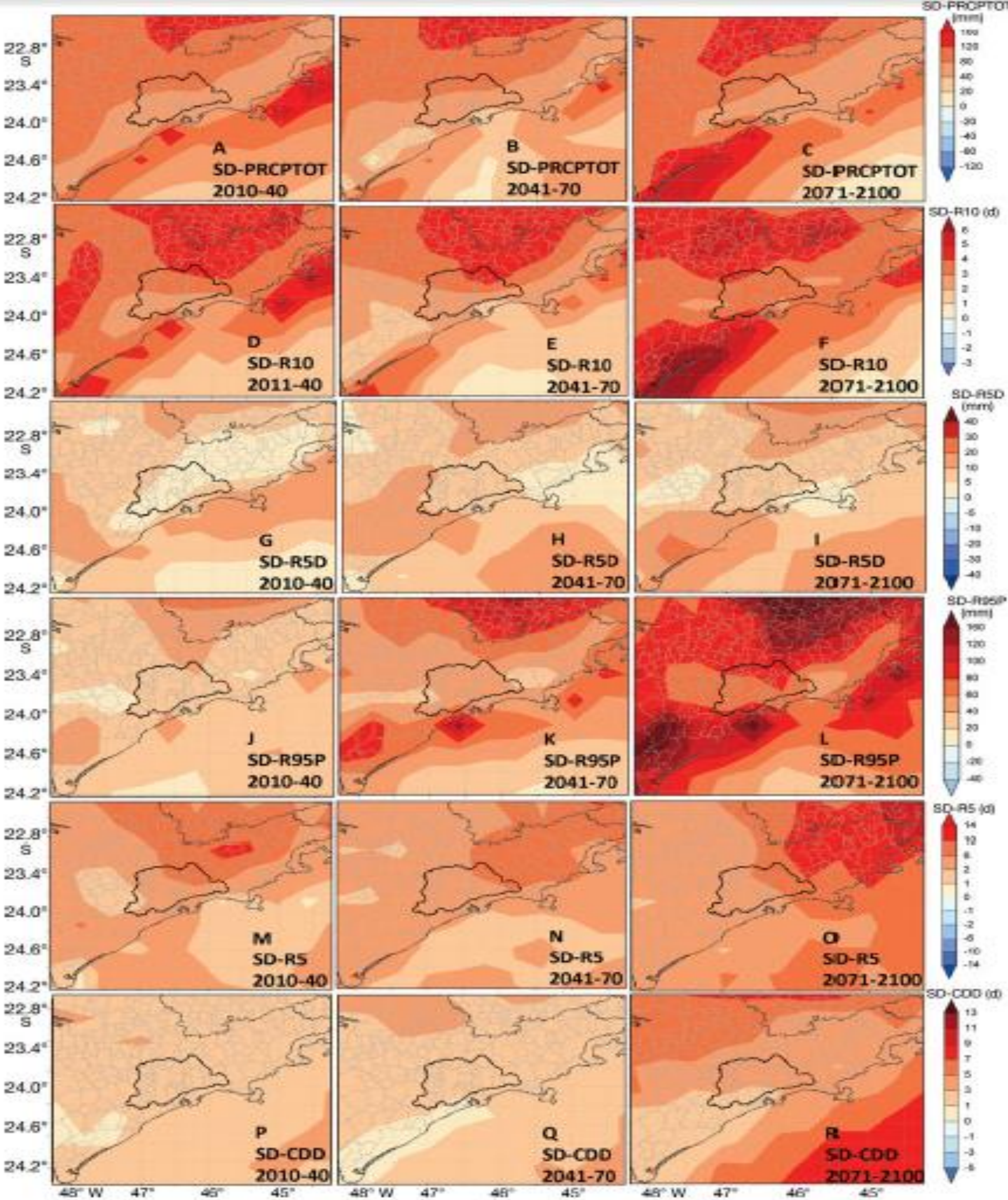
Fig. 3. Time series of anomalies of the indices: (A) PRCPTOT, (B) R10, (C) R5D, (D) R95P, (E) R5, and (F) CDD—abbreviations in Fig. 2. Red: observations at the IAG USP station (1933– 2010); black: ensemble of the 4 members from the Eta CPTEC-HadCM3 model for simulations (1961–1990) and projections (2071–2100); blue: 20 yr moving average; green shading: individual runs. Ano - malies are relative to the respective long-term mean for 1961– 1990 for observed and projected indices.



Ensemble of the projections

- ✓ Projections showed positive tendencies PRCPTOT and R10, as well as weak positive trends in CDD, and negative trends in R5. This suggested a possible increase in total precipitation and in the contribution to total precipitation from more intense rainfall events, with the possibility of longer dry periods in between days with intense rain in the MASP, as well as a decrease in the number of days with light precipitation.

Fig. 4. Maps of changes of the indices PRCPTOT, R10, R5D, R95P, R5, and CDD for the northeastern part of the state of São Paulo, based on the ensemble mean of the 4 runs. Thick black line: MASP region. Changes are for the 2010–2040, 2041–2070, and 2071–2100 time slices relative to 1961–1990. Statistical significance at the 5% level was assessed by the Mann-Kendall test; dashed lines (with signs): areas where significance was reached



Maps of standard deviations

The spread among members as measured by the standard deviation (SD) of the ensemble mean can be considered an indicator of uncertainty. Fig. 5 shows the ensemble for PRCPTOT, the magnitude of the spread as shown by the SD was larger to the northeast and to the southwest of the MASP region, where the increase in rainfall was more intense and significant. This pattern was also detected in projections for rainfall extremes, days with intense and light rain, and consecutive dry days.

Fig. 5. Maps of standard deviations (SD) of changes of the indices PRCPTOT, R10, R5D, R95P, R5, and CDD for the northeastern part of the state of São Paulo, based on the ensemble mean of the 4 runs. Thick black lines: MASP region. Changes are for the 2010–2040, 2041–2070, and 2071–2100 time slices relative to 1961–1990

General Vulnerability Index

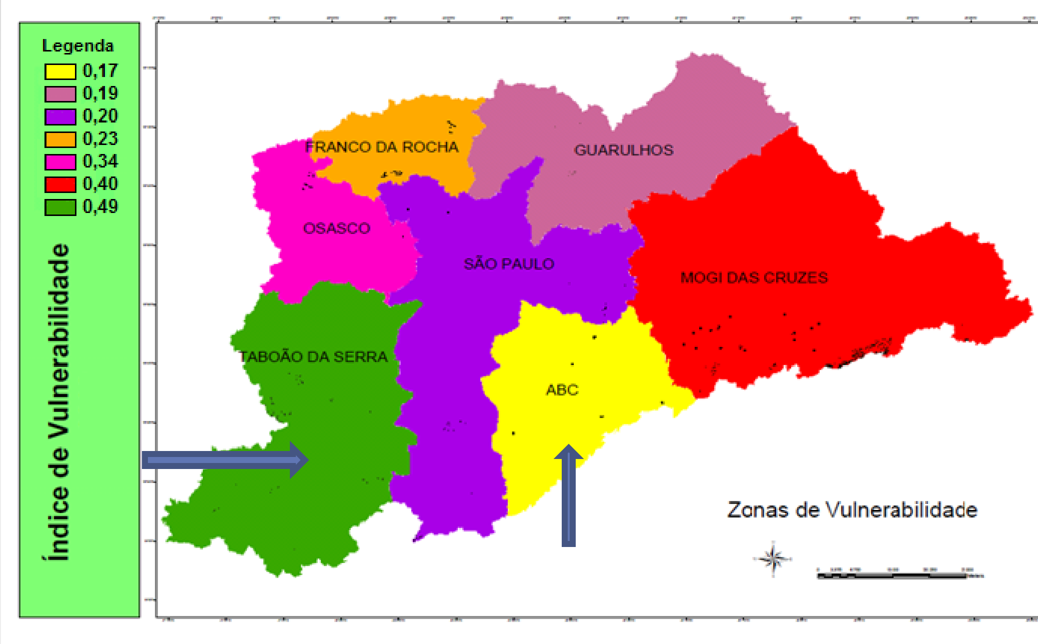
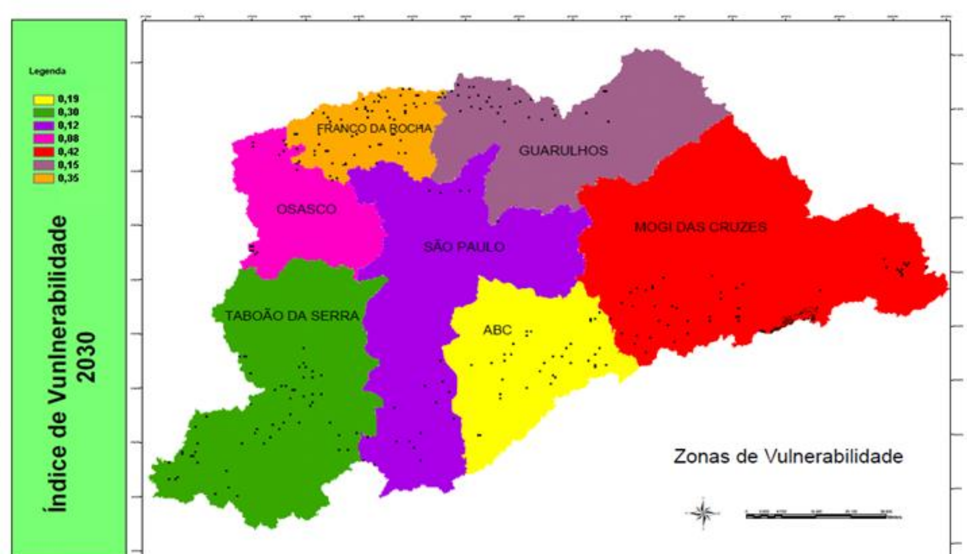


Table - Vulnerability indices for the subregions of MASP

Sub-regiões da RMSP	IV Socioeconômico e demográfico (IV_{sed})	IV de chuva extrema (IV_{pe})	IV do meio físico (risco de deslizamento) (IV_{mf})		$IV_{R\ MSP}$
			2008	2030	
Setor I – São Paulo	0,45	0,09	0,05	0,12	0,20
Setor II - ABC	0.34	0,16	0,01	0,19	0,17
Setor III – Mogi das Cruzes	0,58	0,22	0,41	0,42	0,40
Setor IV - Guarulhos	0,50	0,06	0,01	0,15	0,19
Setor V – Franco da Rocha	0,57	0,08	0,03	0,35	0,23
Setor VI - Osasco	0,38	0,63	0,01	0,08	0,34
Setor VII – Taboão da Serra	0,39	1	0,08	0,30	0,49



Final Considerations

- ✓ Observations since the mid-1930s in the MASP region have shown significant increases in total and heavy rainfall and decreases in light rain. This was probably due to natural climate variability, but with some signals of the urbanization effect, especially during the last 40 yr.
- ✓ Projections, based on percentiles and on the number of days with rainfall above a certain limit, suggested: (a) an increase in total precipitation, (b) an increase in heavy precipitation and in the contribution to total precipitation from more intense rainfall events, and (c) the possibility of longer dry periods separating days with intense rain in the MASP region.
- ✓ The trends were stronger and more significant in the second half of the 21st century.
- ✓ We are aware that dynamical downscaling may not provide information at the weather station level and that climate modeling does not resolve all uncertainties. However, we believe that this exercise enables climate assessments that, in time, can be used for general public information.
- ✓ Furthermore, this study quantified the vulnerability in the MASP linking socioeconomic indicators, climate and environment based on extreme rainfall events for the present climate.
- ✓ The outcome, which shows current vulnerability to climate change-induced extremes rainfalls, puts Taboão da Serra and Mogi das Cruzes subregions of MASP, whilst ABC and Osasco subregions are the least vulnerable, although it is important to remember that this is a relative scale and should not imply that the latter the subregions are entirely resilient.

Thanks