The São Sebastião Extreme Precipitation Event: A Radar and Regional Climate Model Analysis

João Gabriel Martins Ribeiro & Michelle Simões Reboita

Federal University of Itajubá - UNIFEI

August 27, 2025

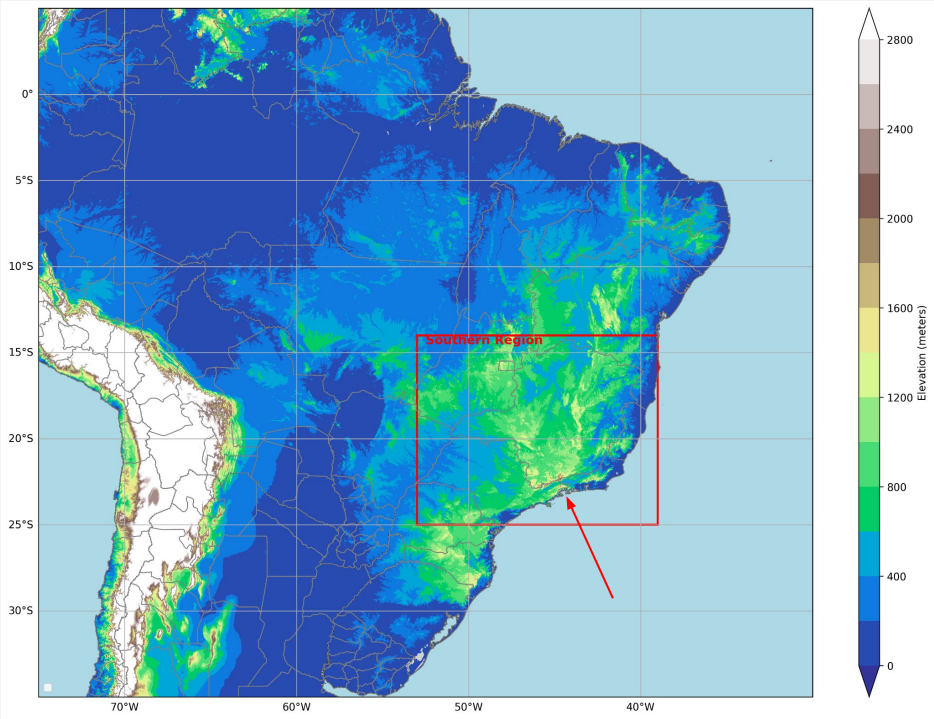
Contributions: Rosmeri P. da Rocha, Carlos Augusto Morales Rodriguez, Leidinice Silva

INTRODUCTION

The North Coast of São Paulo: A Vulnerable Coastal Environment

Geographical Context:

Located in the Southeast Region of Brazil, the north coast of São Paulo state is characterized by a narrow coastal plain bordered by the Serra do Mar mountain range. This region is a popular tourist destination known for its beaches and lush Atlantic Forest.



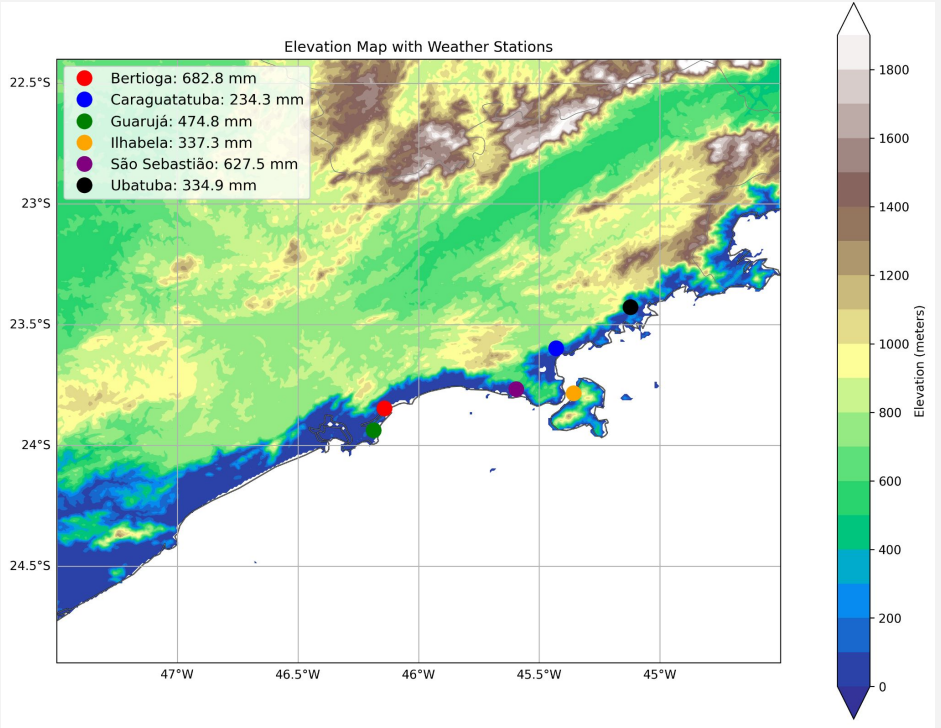
INTRODUCTION

The North Coast of São Paulo: A Vulnerable Coastal Environment

Orographic Influence:

The proximity of the Serra do Mar, a steep coastal mountain range, plays a crucial role in local weather patterns, especially in enhancing orographic precipitation.

Air masses moving inland from the Atlantic are forced upwards, leading to condensation and heavy rainfall.



INTRODUCTION

The North Coast of São Paulo: A Vulnerable Coastal Environment

Demographics and Vulnerability:

Many urban settlements, particularly in São Sebastião, are situated in high-risk areas on mountain slopes, often in precarious conditions, making them highly vulnerable to landslides and floods.

Families return home after a month of rain in São Sebastião; up to 900 properties are expected to be built

A city on the northern coast of São Paulo recorded 600 mm of rainfall in 24 hours, a volume never seen in the country in such a short period.

With CNN

03/18/23 at 07:00 | Updated 03/18/23 at 07:00

Rains: the number of deaths in the São Sebastião tragedy reaches 57

Among the people who lost their lives, 15 are children

BRUNO BOCCHINI - REPORTER FOR AGÊNCIA BRASIL

Published on 02/24/2023 - 20:13

São Paulo

CONTEXT

Devastation and Loss

Humanitarian Crisis:

- 1126 people lost their homes.
- 1090 people were displaced.
- A tragic total of 65 deaths were registered.

Infrastructure Damage: The event resulted in numerous blocked roads, collapsed barriers, and falling trees, severely disrupting transportation and emergency response efforts.

Focus on Natural Disasters: Studies, such as Marengo et al. (2023), further highlight the profound impact of this event as a natural disaster.

Civil Defense of the State of São Paulo report

CONTEXT

February 2023: An Unprecedented Rainfall Event

Event Date and Duration: From 15 UTC Feb 18 to 15 UTC Feb 19, 2023, Brazil's highest daily rainfall on record occurred on São Paulo's north coast.

Record rainfall in Brazil

The 24-hour event recorded 682 mm of rainfall, this highest precipitation was concentrated in Bertioga and São Sebastião.

ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

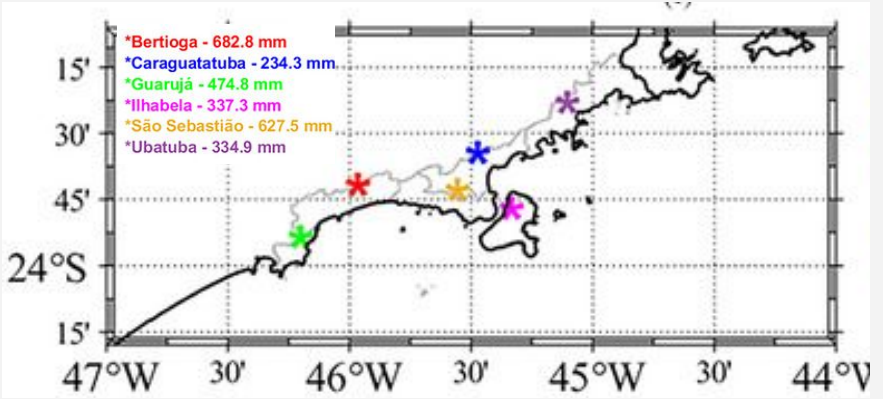
Volume 1549, Issue 1
July 2025
Pages 120-138

ORIGINAL ARTICLE | Open Access

Brazil climate highlights 2023

Luana Albertani Pampuch, Paola Gimenes Bueno, Michelle Simões Reboita, Ana Carolina Nóbile Tomaziello, Ana Maria Pereira Nunes, Andressa Andrade Cardoso, Caio A. S. Coelho, Camila Bertoletti Carpenedo, Francisco das Chagas Vasconcelos Jr, Helber Barros Gomes, Henri Rossi Pinheiro, Hugo Alves Braga, Iuri Valério Graciano Borges, Maria de Souza Custodio, Maria Leidinice da Silva, Marta Llopart, Rosmeri Porfírio da Rocha, Tércio Ambrizzi, Gyrlene Aparecida Mendes da Silva ... See fewer authors

First published: 15 June 2025 | https://doi.org/10.1111/nyas.15394



CONTEXT

February 2023: An Unprecedented Rainfall Event

Combined Factors: This event was the result of a critical combination of synoptic and small-scale processes:

A cold front, enhanced by the Serra do Mar mountains and warm ocean heat fluxes, triggered persistent, extreme rainfall.

ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

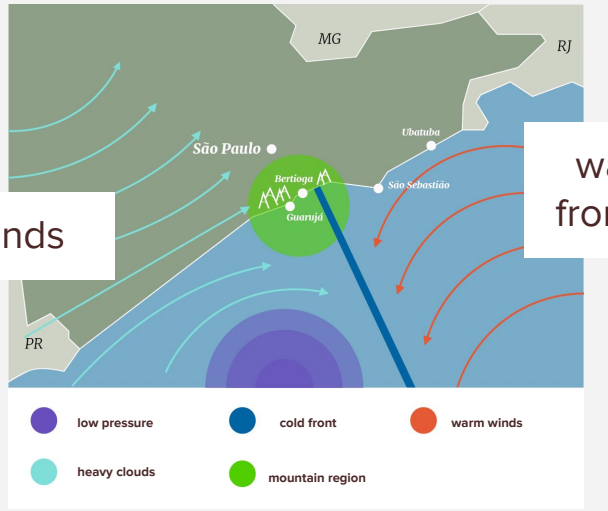
Volume 1549, Issue 1
July 2025
Pages 120-138

ORIGINAL ARTICLE | Open Access

Brazil climate highlights 2023

Luana Albertani Pampuch, Paola Gimenes Bueno, Michelle Simões Reboita, Ana Carolina Nóbile Tomaziello, Ana Maria Pereira Nunes, Andressa Andrade Cardoso, Caio A. S. Coelho, Camila Bertoletti Carpenedo, Francisco das Chagas Vasconcelos Jr, Helber Barros Gomes, Henri Rossi Pinheiro, Hugo Alves Braga, Iuri Valério Graciano Borges, Maria de Souza Custodio, Maria Leidinice da Silva, Marta Llopart, Rosmeri Porfírio da Rocha, Tércio Ambrizzi, Gyrlene Aparecida Mendes da Silva ... See fewer authors

First published: 15 June 2025 | https://doi.org/10.1111/nyas.15394



moist southerly winds

warm winds from the north

CONTEXT

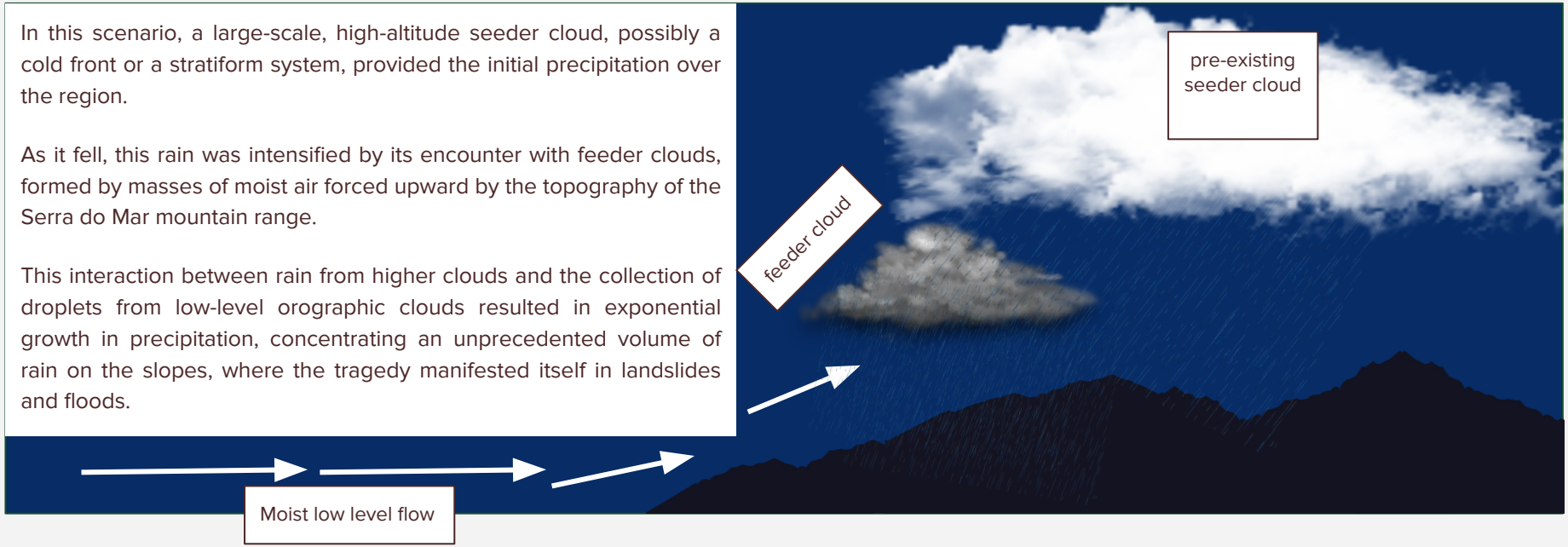
February 2023: An Unprecedented Rainfall Event

This event can be directly related to the **seeder-feeder** mechanism (Bergeron, 1935), a key process in the intensification of rainfall in mountainous areas.

In this scenario, a large-scale, high-altitude seeder cloud, possibly a cold front or a stratiform system, provided the initial precipitation over the region.

As it fell, this rain was intensified by its encounter with feeder clouds, formed by masses of moist air forced upward by the topography of the Serra do Mar mountain range.

This interaction between rain from higher clouds and the collection of droplets from low-level orographic clouds resulted in exponential growth in precipitation, concentrating an unprecedented volume of rain on the slopes, where the tragedy manifested itself in landslides and floods.



WORK OBJECTIVES

Analyze the ability of the RegCM5 and WRF to simulate the extreme precipitation event in the coastal region of São Paulo in February 2023

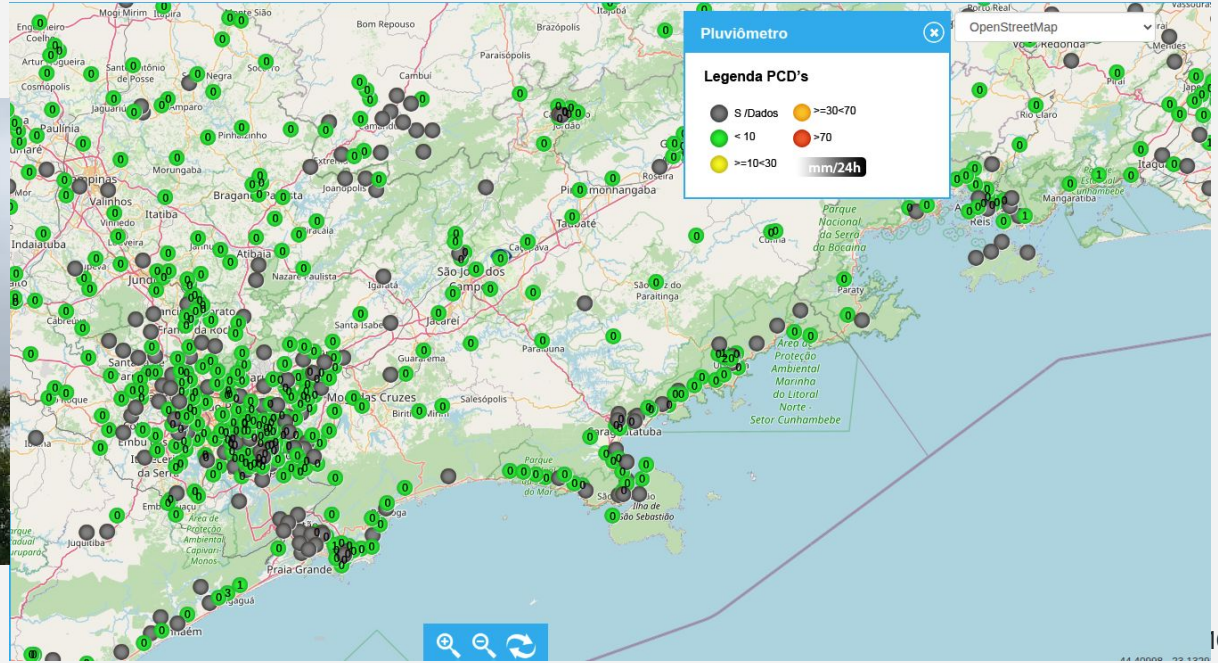
- **Analysis of observed data**
- **Analysis of radar data**
- **Comparison of model outputs with radar estimates**

DATA AND METHODS

Data Used: Precipitation data

Source: Automatic rain gauges from CEMADEN Environmental Observational Network. Hourly precipitation data.

Purpose: Evaluate the extreme precipitation that occurred during the event and compare the precipitation with model outputs and radar estimates.

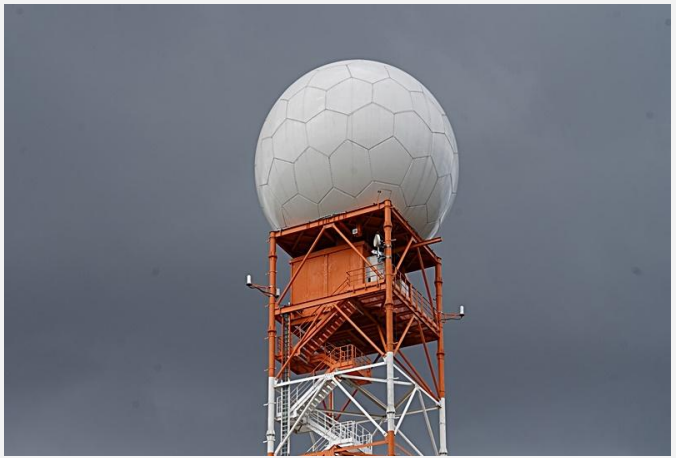


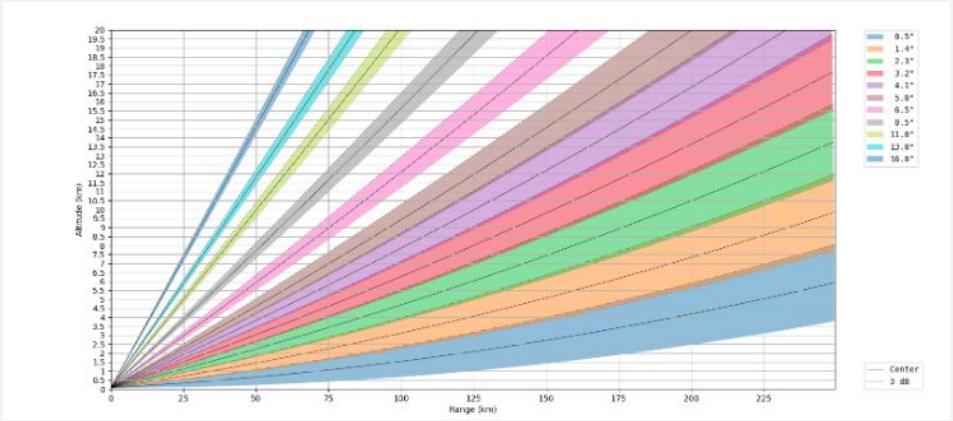
DATA AND METHODS

Data Used: FCTH Radar Data

Data from the S-band dual polarization radar of the Hydraulics Technology Center Foundation (FCTH), located in Salesópolis, was used to analyze the precipitation event.

FCTH radar with temporal resolution of **5 minutes**, horizontal resolution of **1 km** and a range of **190 km**, provides high-resolution information on rainfall intensity and distribution. The data, estimated by a specific algorithm (Ryzhkov et al., 2005), are considered reliable because they are well calibrated with on-site rain gauge measurements. These radar data will serve as an accurate basis for validating the model results.





DATA AND METHODS

Data Used: Weather Research and Forecasting Model (WRF)

Purpose: Compare the ability to predict the event with regard to RegCM5 outputs and radar estimates.

Key Parameters and Adjustments:

Double grid: 1 km grid nested within 3 km grid (ERA5)

45 vertical levels

Smaller grid of 330 longitude points x 321 latitude points

Microphysics: Thompson (8)

Radiation: RRTM

PBL: Boulac (8)

Surface scheme: NOAH

DATA AND METHODS

Data Used: Regional Climate Model (RegCM5)

Purpose: RegCM5 is a high-resolution regional climate model used to simulate atmospheric processes, including precipitation, at finer scales than global models. It allows for a deeper understanding of the mechanisms contributing to extreme events.

Key Parameters and Adjustments:

Convection Permitting (CP): This is a critical configuration where the model resolution is fine enough (typically 1-4 km horizontal resolution) to explicitly simulate convective clouds and their dynamics, rather than relying on parameterizations. This is crucial for accurately representing intense, localized rainfall events like the one in São Sebastião.

Horizontal dimensions: 150 (number of points in latitude) and 150 (number of points in longitude)

Vertical levels: 41 (sigma levels)

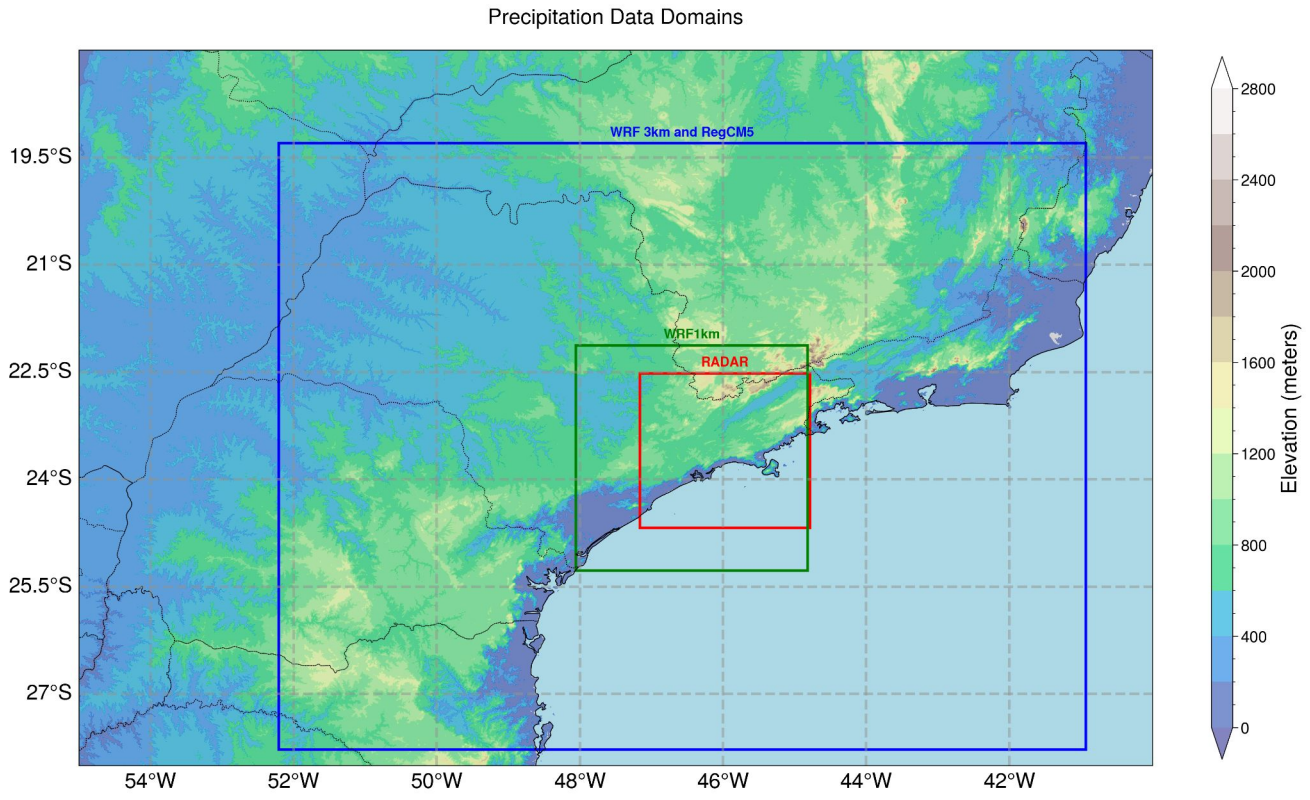
Horizontal resolution: 3.0 km

Boundary conditions: ERA5 (6 h)

Experiment	Parameter	Namelist section	Configuration	Description	
1. Control (Standard)	ibltyp	&physicsparam	1	Holtslag PBL, standard scheme for the boundary layer.	default
exp1	ipptls	&physicsparam	1	SUBEX microphysics scheme (explicit moisture).	
	irrtm	&physicsparam	0	Standard radiation scheme (CCSM).	
	iboudy	&physicsparam	5	Lateral boundary conditions scheme by exponential relaxation.	
2. PBL variation	ibltyp	&physicsparam	2	UW PBL.	physics
exp2	ipptls	&physicsparam	1	microphysics scheme (control).	
	irrtm	&physicsparam	0	radiation scheme (control).	
	iboudy	&physicsparam	5	boundary conditions (control).	
3. Variation in Microphysics	ibltyp	&physicsparam	1	Holtslag PBL scheme (control).	NOTTO + microphysics
exp3 to exp6	ipptls	&physicsparam	2	Explicit moisture Nogherotto/Tompkins	
	iautoconv	&microparam	1 to 4	changing autoconversion parameterization	
	vfqr	&microparam	4	rainfall velocity default.	
4. Radiation Variation	ibltyp	&physicsparam	1	Holtslag PBL scheme (control).	radiation
exp7 to exp9	ipptls	&physicsparam	1	microphysics scheme (control).	
	irrtm	&physicsparam	1	radiation scheme to RRTM.	
	icld	&rrtmparam	1 to 3	Changing the cloud overlap assumption for the RRTM scheme.	
5. exp2 and exp6 combined	ibltyp	&physicsparam	2	UW PBL.	PBL + NOTTO + microphysics
exp10	ipptls	&physicsparam	2	Explicit moisture Nogherotto/Tompkins	
	iautoconv	&microparam	4	autoconversion parameterization Sundqvist	

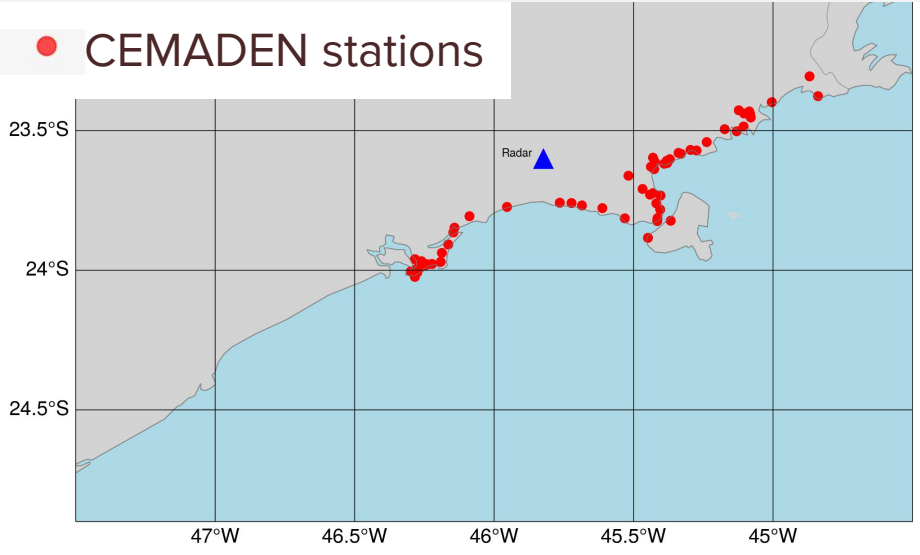
DATA AND METHODS

Data Used: Data domain

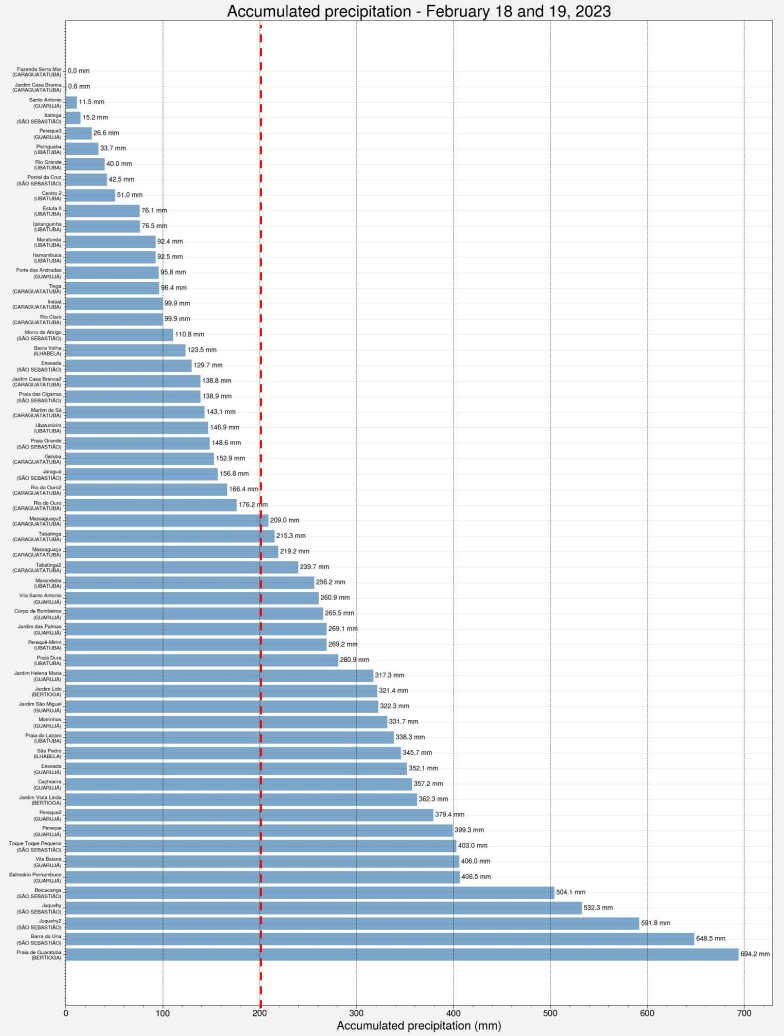


RESULTS

Observational analyses



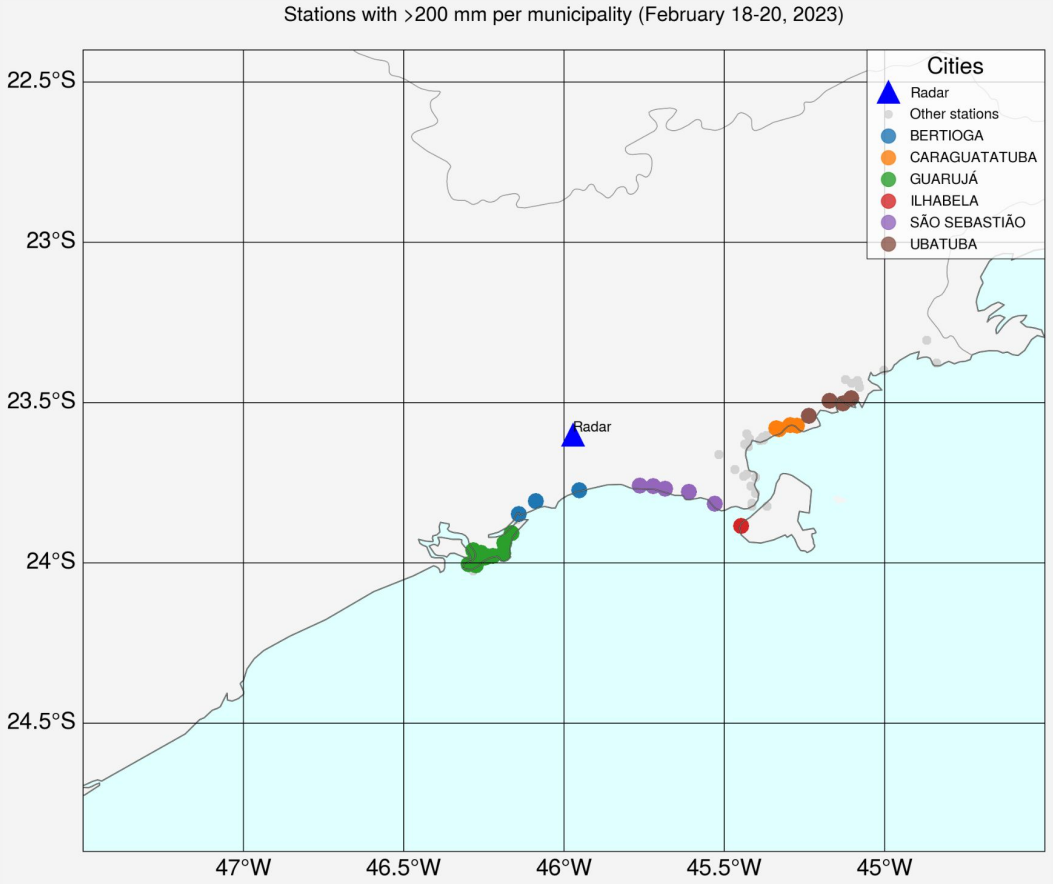
From all CEMADEN stations, we filtered only those stations with accumulated precipitation up than 200 mm.



RESULTS

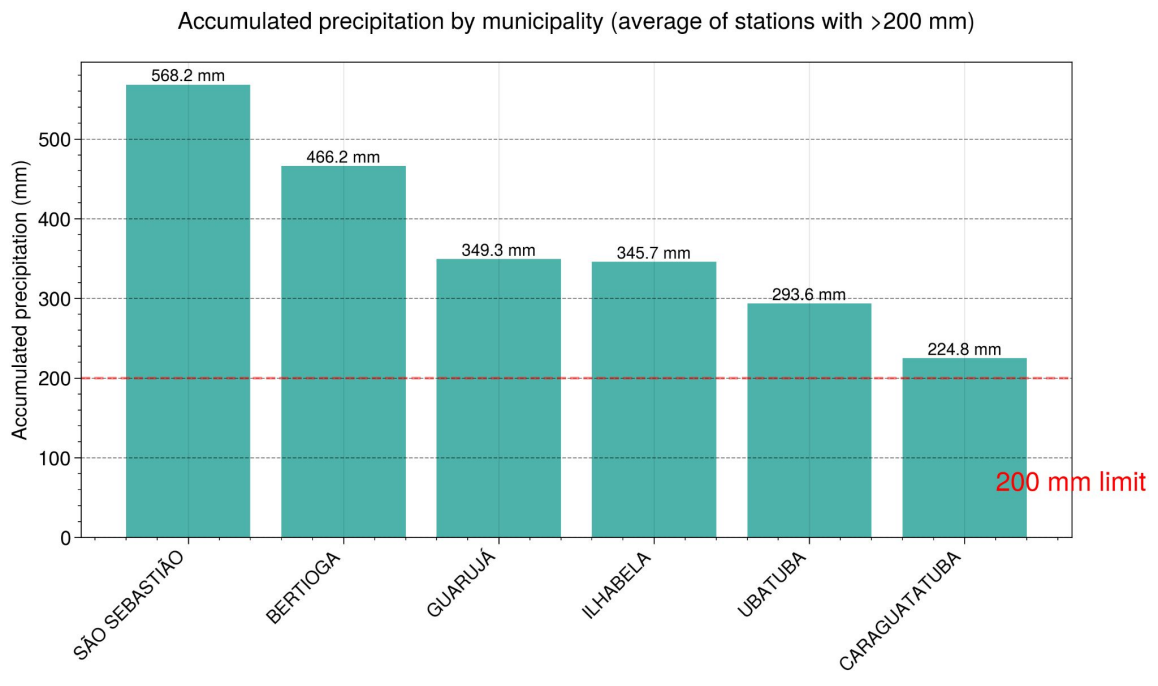
Observational analyses

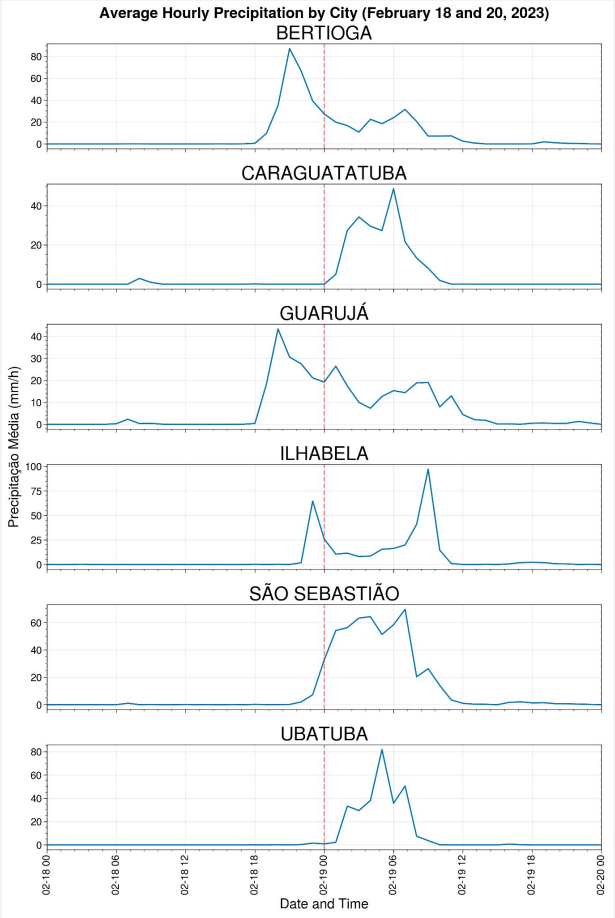
- We grouped stations with more than 200 mm per city.
- Average value per city (hourly)



RESULTS

Observational analyses



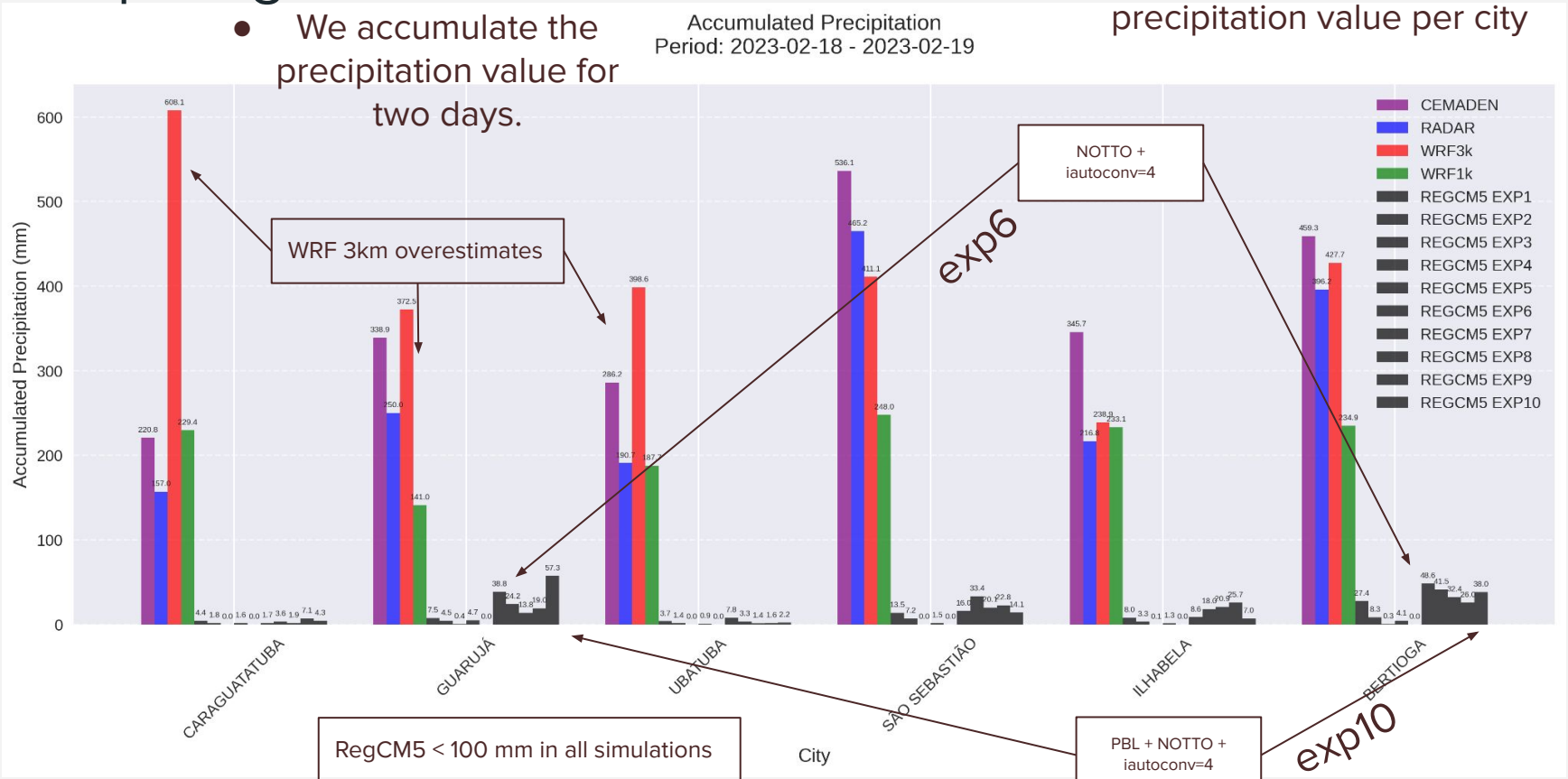


RESULTS

Comparing Simulations with Observations

- We accumulate the precipitation value for two days.

We took the grid points closest to the station
We calculated the average precipitation value per city

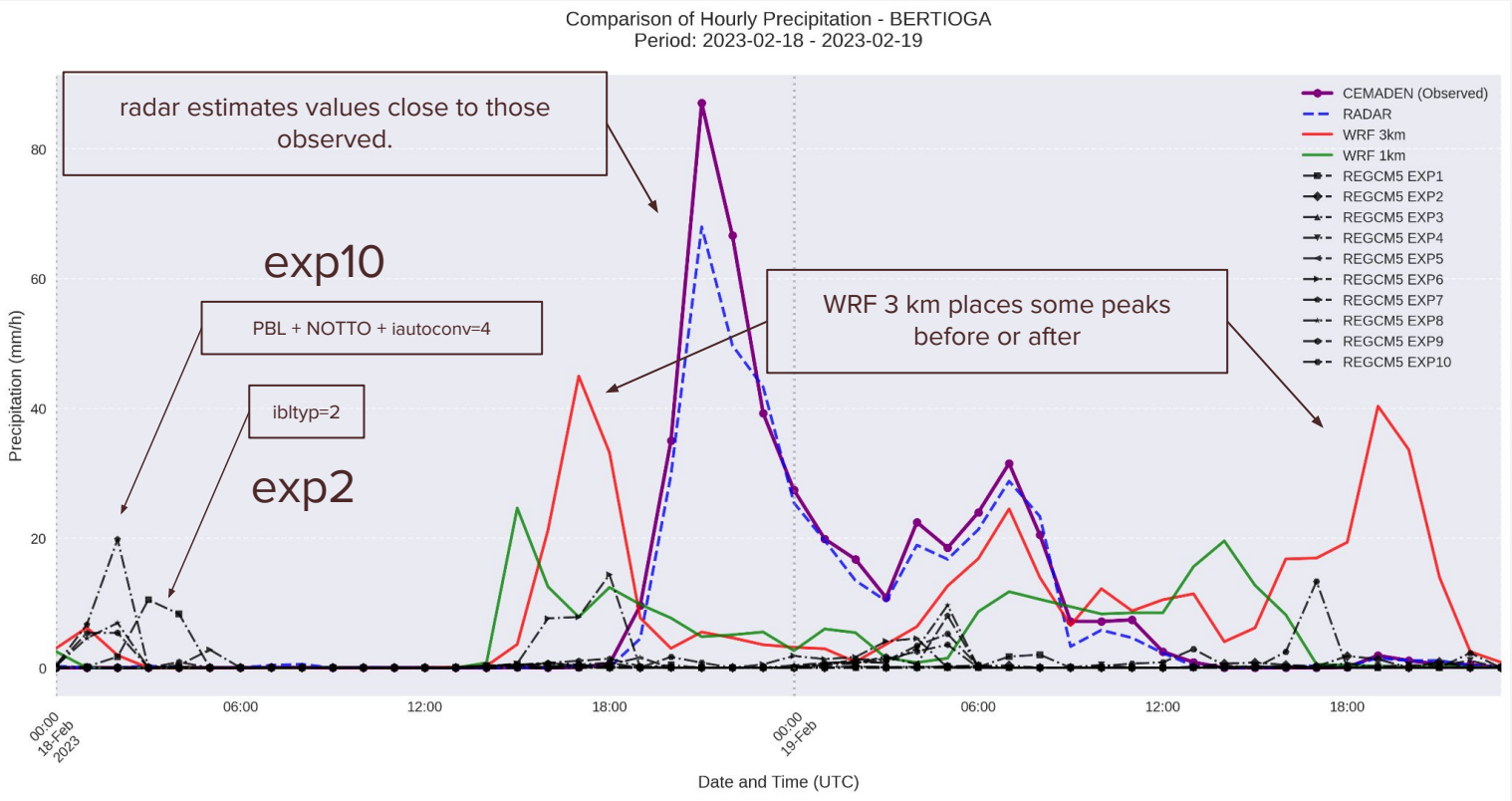


RESULTS

Comparing Simulations with Observations

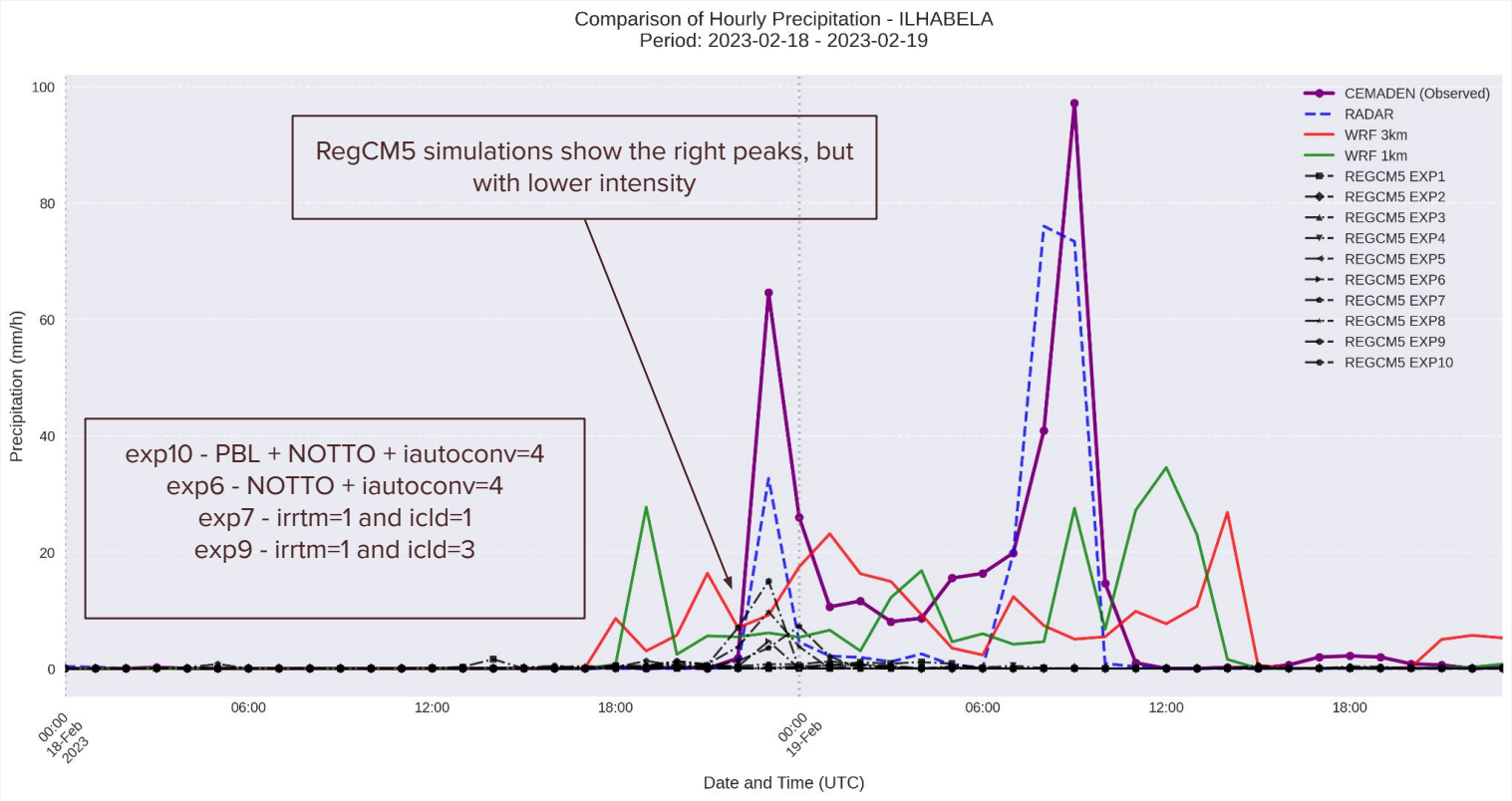
Hourly:

- We took the grid points closest to the station
- We calculated the average precipitation value per city



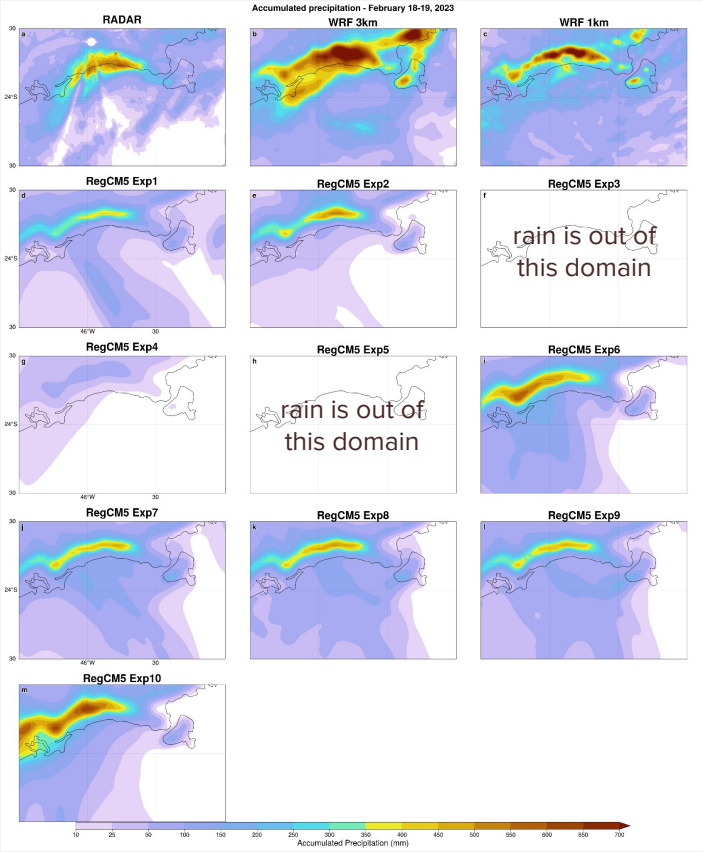
RESULTS

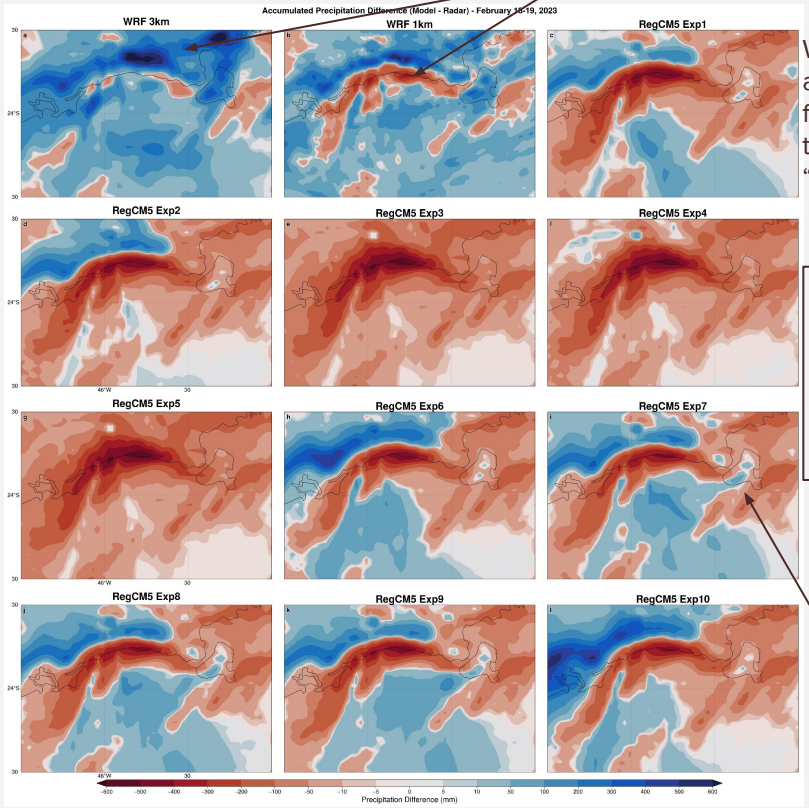
Comparing Simulations with Observations



RESULTS

Quantifying Accuracy: Spatial Patterns





WRF 3km overestimates accumulated precipitation

WRF 1km underestimates near the coast

We compared the accumulated precipitati from the event, assumir the radar field to be "true."

RegCM exp6 (NOTTO+iautoconv=4) ad exp10 (NOTTO+iautoconv=4) shows the best performance

about Ilhabela: signs closer to what was observed

RESULTS

Summary of the Extreme Precipitation Event

The event was an extreme precipitation episode, with observed rainfall totals exceeding 500 mm in São Sebastião.

WRF 1 km overestimated rainfall in some cities that received more than 300 mm.

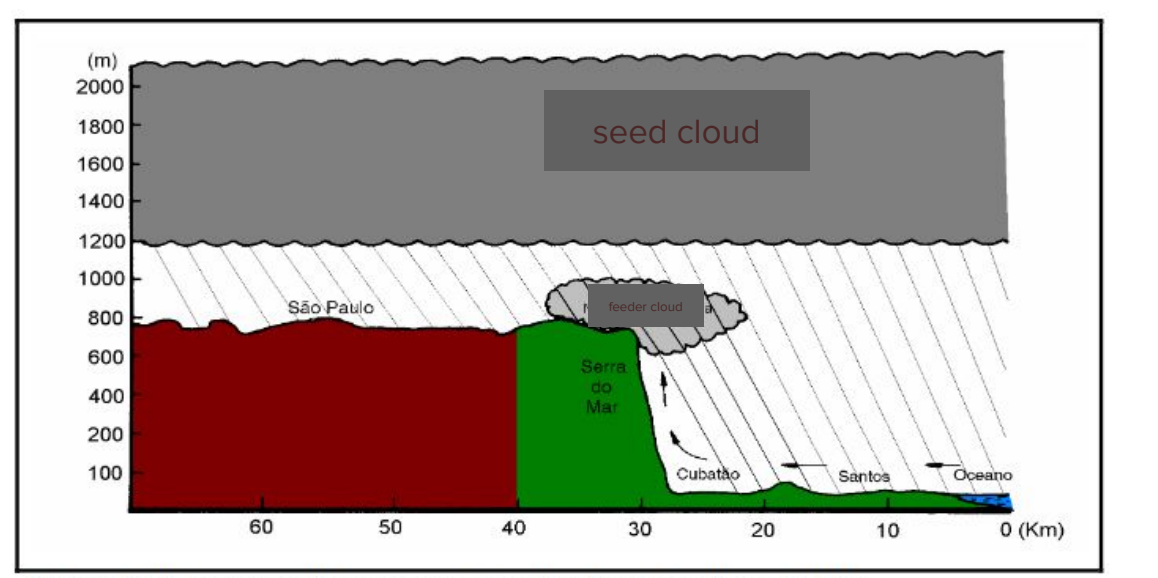
The WRF 3 km model showed mixed results, overestimating precipitation in some areas while underestimating it in others.

The RegCM5 simulations consistently fell short of the observed values, with exp6 (NOTTO + iautoconv=4), and exp10 (PBL + NOTTO + iautoconv=4) showing better performance.

This study highlights the existing gaps in modeling extreme events. To better simulate these events, it is essential to improve and adjust key input parameters within the models.

RESULTS
Next steps

- Analyze the vertical profiles of simulations
- Verify that the seeder-feeder mechanism is well simulated by the models



Thanks for your attention!

Q&A

Contact: gabrielmr472@unifei.edu.br