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Assessing the capacity of large-scale hydrologic-hydrodynamic models for mapping flood hazard in southern Brazil

Avaliação da capacidade de modelos hidrológicos-hidrodinâmicos de larga escala para mapear o risco de inundação no sul do Brasil

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ABSTRACT

Mapping flood risk areas is important for disaster management at the local, regional, and national scales. The aim of this study was to evaluate the ability of large-scale models to obtain flood hazard maps. The models were compared to the estimates developed by the Brazilian Geological Survey (CPRM) for different return periods (RP). The floods were evaluated for the municipalities of Uruguaiana, Montenegro and São Sebastião do Caí in the Rio Grande do Sul state. It was shown that the flood mapping generated by MGB covers larger areas (greater than 1000 km^2; Siqueira et al. 2018), with a lower cost of obtaining for large scales. The - Hit Rate of the regional and continental MGB model versions with the CPRM maps ranged from about 40% to 90% in different cities, and the Hit Rate between the regional model and the CPRM map increased with the increased return period floods. The continental model compatibility was similar for all analyzed RPs. Our results suggest the agreement in terms of Hit Rate of current large-scale hydrological-hydrodynamic models to assess flood hazard.

Keywords: Flood mapping; Hydrodynamic modelling; Large scales.

RESUMO

Mapear áreas com risco de cheias é importante para o gerenciamento de desastres em nível local, regional e nacional. O objetivo deste estudo foi avaliar a capacidade de modelos de grande escala na obtenção de áreas inundadas com tempos de retorno específicos, em comparação com a mancha de inundação desenvolvida pelo Serviço Geológico do Brasil (CPRM). Foram avaliadas as manchas para os municípios de Uruguaiana, Montenegro e São Sebastião do Caí, no Rio Grande do Sul. Observou-se que os resultados gerados pelo MGB são mais abrangentes espacialmente (áreas maiores que 50km^2), com um custo de obtenção menor para grandes escalas. A taxa de acerto das versões do modelo MGB regional e continental com os mapas da CPRM variaram desde cerca de 40% até 90% nas diferentes cidades, sendo que a taxa de acerto, entre o modelo regional e o mapa da CPRM aumentou com o aumento do TR. Já a compatibilidade do modelo continental foi similar para todos os TRs analisados. Os resultados sugerem a capacidade, em termos de taxa de acerto, dos modelos hidrológico-hidrodinâmicos de larga escala para avaliar o risco de inundação.

Palavras-chave: Manchas de inundação; Modelagem hidrodinâmica; Grandes escalas.

INTRODUCTION

Floods are the most common type of natural disaster in world and represent substantial risks to population life (Mishra et al., 2022). Floods can impact urban populations, as many cities are located on river floodplains (Serviço Geológico do Brasil, 2017; Defesa Civil, 2018). It can also impact land used for agriculture, livestock, and industry. Thus, knowledge of the dynamics and extension of floodable areas for managers and decision makers is essential for the efficient management of these disasters (Dottori et al., 2016; Annis et al., 2020).

Mapping flooded areas, especially in urban areas or other regions where property damage can be extensive, such as agricultural areas, can serve as an important tool for territorial management and decision-making (Garcia & Souza, 2017). In this sense, knowing the region's flooding patterns is an important risk management tool. Public institutions, such as Brazilian Geological Survey (CPRM), have developed flood hazard maps for cities susceptible to these disasters, especially for urban areas. Examples are the SACE (Critical Event Alert System) and RIGEO (Institutional Repository of Geosciences) flood hazard maps (Serviço Geológico do Brasil, 2021), in which floods with specific Return Periods (RP).

Flood hazard mapping can be done locally, after the occurrence of a flood, through in situ observations or conducting interviews with local communities (Paixão et al., 2018; Luo et al. 2014; Benito & Thorndycraft, 2005; Koenig et al., 2016; Feaster & Koenig, 2017;). The difficulty with this type of approach is that technical teams are needed to carry out the activity (Paixão et al., 2018), while some locations to be mapped may be inaccessible or at risk.

Several techniques have been developed over the last decades to map flooded areas based on remotely sensed products (Teng et al., 2017). Some of these techniques are simple and only require the use of a digital elevation model (DEM) and an observed flood stage (Mengue et al., 2016, 2017; Goerl, et al., 2017; Speckhann, et al., 2018; Dantas & Canil, 2017; Milanesi et al., 2017), as is the case of the HAND (Height Above the Nearest Drainage) terrain descriptor, described by Rennó et al. (2008). This methodology has some limitations, such as the cross-sectional geometry and water level are averaged and considered uniform for each river reach. Hence, backwater effects and cross-sectional variations are not represented. In addition, the computation of water depth at a given floodplain pixel is limited as it relies only on its relative elevation to the nearest downstream drainage network pixel, independently from the hydraulic connections (Hocini et al., 2021).

The hydrodynamic simulation represents a more complex technique and apply mathematical equations for modeling the flood wave propagation and the associated flooded area (Alcrudo, 2004; Lauriano et al., 2011; Ahmad et al., 2016; Siqueira et al.; 2016; Fleischmann et al., 2021). There are several software that can be applied to estimate the flood extent. For instance, some widely used software, such as HEC-RAS (U.S. Army Corps of Engineers, 2010) and LISFLOOD-FP (Bates & Roo, 2000), are consolidated tools for mapping floods generally at local scales, due to computational effort, or in some software the need cross-sections data to represent the area (Adnan & Atkinson, 2012; Neal et al., 2012; Coutinho, 2015; Ahmad et al., 2016; Monte et al., 2016). These models can provide flood hazard maps estimate that are recognized in the literature as more precise than large scale models (Fleischmann et al., 2021). However, they are computationally heavy and need several data from cross sections that are difficult to obtain when applications are focused on large scales. Besides, Teng et al. (2017), in a review of flooded area mapping methodologies, suggest that 2D modeling is generally considered infeasible for areas larger than 1000 km^2.For application in larger areas, studies have been developed, such as the one by Hoch et al. (2019), where the authors present GLOFRIM in its version 2.0 as an applicable framework for integrated hydrologic-hydrodynamic modeling. The authors coupled the hydrological model PCR-GLOBWB (Sutanudjaja et al., 2018) to the hydrodynamic models CaMa-Flood (Yamazaki et al., 2011, 2013) and LISFLOOD-FP (Bates et al., 2010), for simulation of the Amazon and Ganges River basins. The results show that replacing the kinematic wave approximation of the hydrologic model with the local inertia equation of CaMa-Flood increases the accuracy of the high flow simulations. Also, that the inundation maps obtained with LISFLOOD-FP improved the representation of the observed inundation extent compared to the reduced products of PCR-GLOBWB and CaMa-Flood.

Other model that has been widely applied in South America is the MGB (Large Basins Model), developed by Collischonn & Tucci (2001) and improved over the last few years especially concerning flooding hydrodynamics (Paiva et al., 2013; Fan & Collischonn, 2014; Fleischmann et al., 2015; Pontes et al., 2017; Fagundes et al., 2017; Siqueira et al., 2017; Lopes et al., 2018; Siqueira et al., 2018; Brêda et al., 2020; Fagundes et al., 2021). These applications can be considered regional or continental scale because they are made for regions that comprise not only stretches of rivers, but large hydrographic basins or continents.

Given the possibilities of identifying flooded areas and the different complexities for flood hazard mapping, this study aims to assess the capacity of large-scale models to obtain flood spots for specific return periods compared to local existing studies. For this, we evaluated the capacity of the MGB model, in a regional and a continental version, to map the flood spots proposed by CPRM for the urban areas of three cities in the Rio Grande do Sul state in Brazil. The comparison is made because Regional MGB is an application that a person would do by downloading the model, creating a project, calibrating, and running the simulation. In the case of the Continental MGB, the model is already prepared for South America region and enables a quick estimation of flood hazard maps despite its coarser resolution, less detailed calibration, and larger meteorological forcing data uncertainties. Therefore, this comparison is relevant, because it can help to understand to which extent placing efforts in developing a regional 1D hydrological-hydrodynamic model would translate into improvements in flood hazard maps compared with estimations from a continental-scale model, and if such estimates would agree with those produced by local institutions that make use of high-resolution DEMs.

This paper aims to help fill this gap by comparing official local flood hazard maps produced by the Geological Survey of Brazil with estimates based on hydrologic-hydrodynamic models applied at regional and continental scales. The result can be used to guide future practices for mapping flood hazard areas and for the selection of scales to be applied in the studies.

CASE STUDIES

In the context of recent floods in the state of Rio Grande do Sul, municipalities located on the floodplains of large rivers, such as the Uruguay river and Caí river, have been frequently affected by flood episodes. This is the case of Uruguaiana, São Sebastião do Caí and Montenegro cities (Figure 1).

According to the vulnerability atlas of the National Water and Sanitation Agency (ANA), the Caí and Uruguay rivers present medium to high vulnerability to flooding along their course, as shown in the Figure 2 (Agência Nacional de Águas e Saneamento Básico, 2021). The municipalities selected for this study are located near these rivers and present local flood hazard maps developed by CPRM. For this reason, they were selected for the study.

MATERIAL AND METHODS

Two ways of applying the MGB model, at different spatial scales, were compared, one at a regional (Alves et al., 2021) and another at a continental scale (Siqueira et al., 2018), with the local flood mapping developed by CPRM as the benchmark. From MGB, flood areas were simulated for specific return periods which occurred in the Uruguay river at Uruguaiana, and in the Caí river at São Sebastião do Caí and Montenegro cities. The results were compared with the floods obtained from SACE (https://www.cprm.gov.br/sace/) and RIGEO (https://rigeo.cprm.gov.br/) platforms (CPRM). Figure 3 presents the flowchart of the activities performed.

MGB model

MGB is a semi-distributed hydrological-hydrodynamic model with a physically based flow propagation, and which simulates the river basin by subdividing it into unit-catchments (Pontes et al., 2017). The MGB model presents coupled hydrologic and hydrodynamic simulation, enabling the interaction between precipitation, evaporation, and infiltration in the flow generation and propagation (Paiva et al., 2013; Fleischmann et al., 2017).

In this study two MGB model applications (regional and continental scale) are tested in flood hazard mapping.

Regional MGB model

The regional version was calibrated manually for Rio Grande do Sul state (RS) for the period 1990-2010. The calibration period corresponds to period with old data already consolidated, published in the ANA database. The model was validated for the period 2011-2020, corresponding to more recent years.

For calibration and validation, flow data from 117 gauge stations, available in the ANA database, were used. The verified points are shown in the Figure 4 and in supplementary material the codes and names of the gauges used are presented.

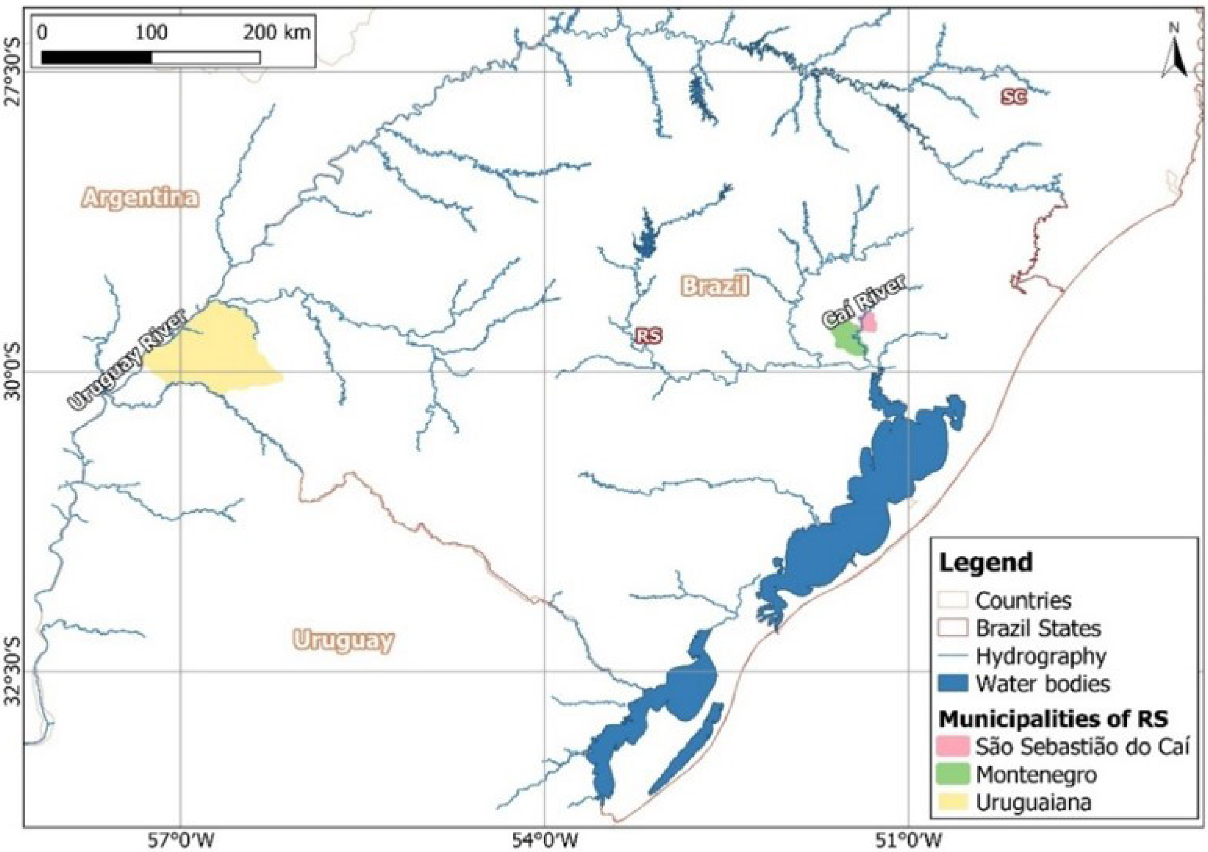

Figure 1. Study area and location of the three assessed cities in the Rio Grande do Sul state in Brazil.

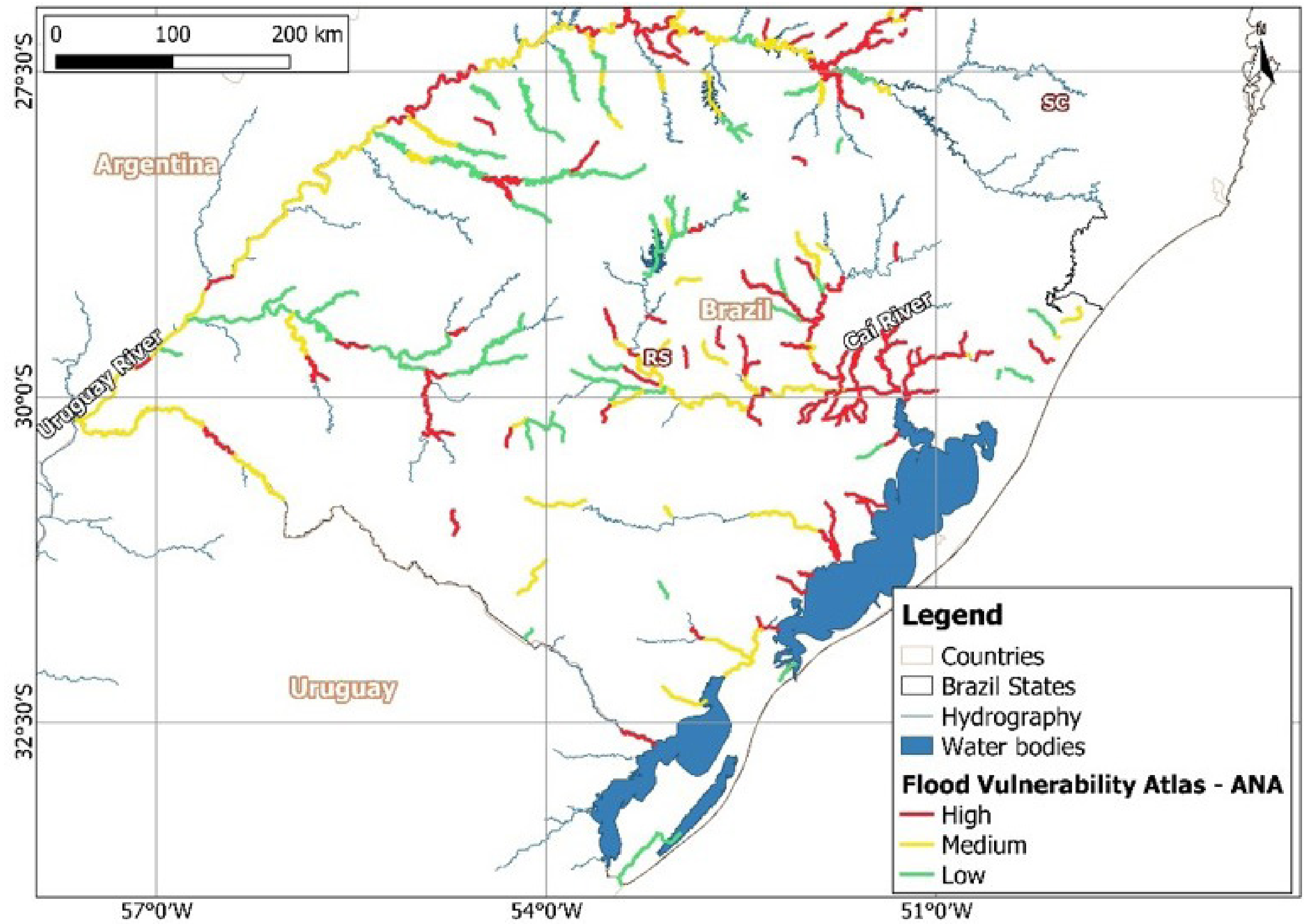

Figure 2. Flood vulnerability Atlas (ANA) in the Rio Grande do Sul state (BR).

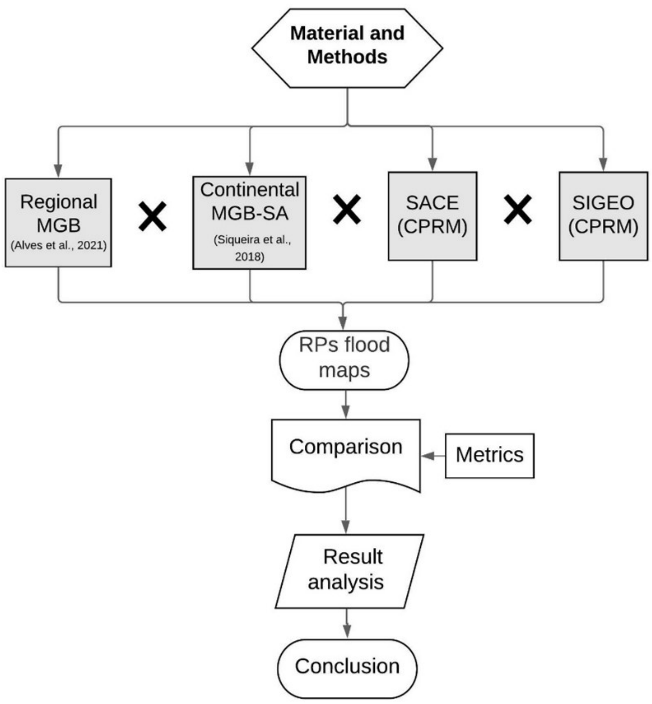

Figure 3. Flowchart of the activities performed.

The study from Moriasi et al. (2007) suggests that simulation model can be considered satisfactory if NSE > 0.50 and volume error to ±25%. In regional MGB model, more than 70% of the verification points had Nash and Nash-log values above 0.5, and more than 75% had volume error values ranging from -25 to +25 for all gauges in the calibration period. For gauges with drainage areas greater than 10^3 km^2, more than 90% of the verification points had Nash values above 0.5. In the validation, the Nash values were above 0.5 in 80% of the verified points and in 83% of the points with drainage areas greater than 10^3 km^2. These values are shown in Table 1, for all gauges and with a drainage area greater than 10^3 km^2.

Continental MGB model

The continental version, developed for the entire South America (MGB-SA), was developed by Siqueira et al. (2018), and was also calibrated for the period from 1990 to 2010. In the Rio Grande do Sul (RS) region the continental model was calibrated with a performance of Nash around 0.55, and Nash-Log on average 0.44. In the validation period the Nash was on average 0.65 and the Nash-log at 0.48. More details can be found in Siqueira et al. (2017, 2018); Brêda et al. (2020); Fagundes et al. (2021).

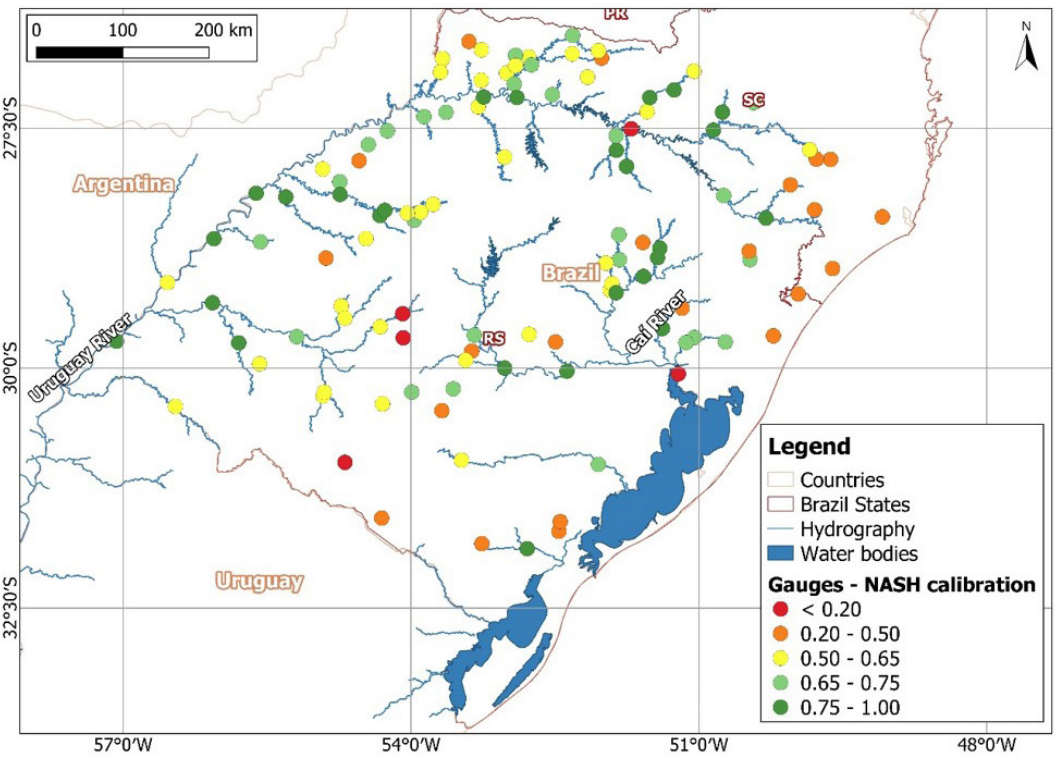

Figure 4. Gauges used for calibration and validation of regional MGB.

Table 1. Calibration and validation of the Regional MGB.

	Calibration				Validation		
	Value	All gauges	Area > 10^3 km²		Values	All gauges	Area > 10^3 km²
NASH	<0.2	4.3%	5.6%	**NASH**	<0.2	17.9%	16.7%
	0.2 to 0.5	20.5%	0.0%		0.2 to 0.5	11.1%	0.0%
	0.5 to 0.65	29.9%	11.1%		0.5 to 0.65	23.1%	5.6%
	0.65 to 0.75	22.2%	16.7%		0.65 to 0.75	22.2%	22.2%
	0.75 to 1	23.1%	66.7%		0.75 to 1	25.6%	55.6%
NASH-LOG	<0.2	5.1%	5.6%	**NASH-LOG**	<0.2	14.5%	22.2%
	0.2 to 0.5	24.8%	11.1%		0.2 to 0.5	20.5%	11.1%
	0.5 to 0.65	27.4%	11.1%		0.5 to 0.65	24.8%	11.1%
	0.65 to 0.75	22.2%	38.9%		0.65 to 0.75	19.7%	27.8%
	0.75 to 1	20.5%	33.3%		0.75 to 1	20.5%	27.8%
VOLUME ERROR	< -50	1.7%	0.0%	**VOLUME ERROR**	< -50	0.9%	0.0%
	±50 to ±25	23.1%	5.6%		±50 to ±25	24.8%	22.2%
	±25 to ±15	25.6%	33.3%		±25 to ±15	18.8%	22.2%
	±15 to ±10	18.8%	27.8%		±15 to ±10	15.4%	5.6%
	-10 to 10	30.8%	33.3%		-10 to 10	40.2%	50.0%

Flood mapping procedures with MGB models

The mapping of the flooded area with the MGB models for specific RPs was carried out as follows:

- From the series of levels modeled with the MGB (regional and continental), the level corresponding to the same RP of the flood of the reference map to be compared was calculated.
- The level was calculated with the Gumbel distribution, for the specific RPs.
- The flood map was prepared by forcing the hydrodynamic modelling with the calculated level, on regional and continental scale.

For comparison with the local flood maps, the inundation extent of both regional- and continental-scale models were generated for the following RPs:

- Uruguaiana (Uruguay River) – RP ~37 years (flood of 1983).
- Montenegro (Caí River) – RPs 5, 10, 15, 25, 50 and 100 years.

- São Sebastião do Caí (Caí River) – RPs 5, 10, 15, 25, 50 and 100 years.

Local benchmarks

Flood hazard maps from the CPRM's SACE system were used as a benchmark for the cities of São Sebastião do Caí and Montenegro (Serviço Geológico do Brasil, 2016) (https://www.cprm.gov.br/sace/conteudo/manchas_inundacao/cai_montenegro/relatorio.pdf). And the flood area of CPRM's RIGEO was used for the urban area of Uruguaiana (Serviço Geológico do Brasil, 2014) (https://rigeo.cprm.gov.br/jspui/handle/doc/20144).

In the SACE studies, flood hazard maps associated with different return periods were developed. These maps were developed for the municipalities of Montenegro and São Sebastião do Caí (RS), where flooding related to the Caí River was assessed. The delineation of flooded areas was performed over a topographic map with 1-m contour intervals, which was developed by the State Foundation for Metropolitan and Regional Planning – Metroplan.

The flooded areas for the cities of Montenegro and São Sebastião do Caí were obtained through GIS software, by reclassifying all DEM pixels with values below a given water surface elevation. In another words, the flood hazard map was derived from a simple reclassification procedure of the DEM (Silva, 2016). The water surface elevation was computed for different return periods (estimated from the Gumbel distribution), for the gauge stations of São Sebastião do Caí (87170000) and Montenegro (87270000). For each of the two cities, six maps were evaluated, with floods of 5, 10, 15, 25, 50 and 100 years return period (RP). These RP were defined as representative by CPRM and were adopted in this work because they are data available for comparison (Silva, 2016). In the CPRM RIGEO study, the flood maps were developed from known floods. For the city of Uruguaiana, the evaluated flood extent corresponds to that which occurred in 1983. The flood map was produced by CPRM based on topographic data and field evidence of the water level of the 1983 flood, on the Uruguay River (Hoelzel & Lamberty, 2014). The 1983 flood has a return period of approximately 37 years, based on the empirical distribution of maximum annual flows using the available discharge data. The data (Uruguaiana gauge station, code 77150000) can be obtained from ANA's Hidroweb system (https://www.snirh.gov.br/hidroweb).

Comparison metric

To compare the flooded areas produced by the different MGB configurations, different performance metrics were used. Flood extent was validated through the hit rate H (Hoch & Trigg, 2019), as shown by Equation 1.

$$H = \frac{N_{sim} \cap N_{obs}}{N_{obs}} \quad (1)$$

Where $Nobs$ e $Nsim$ indicate the number of flooded DEM pixels according to observation and simulation, respectively.

Regarding the comparison between flood hazard maps obtained from MGB model versions and CPRM, we chose not to calculate other commonly applied metrics for this purpose such as the critical successful index (CSI) and the false alarm ratio (FAR), because the CPRM map is spatially limited to the urban area.

The metric H (hit rate) is an indicator of how much the CPRM map is "filled in" by the MGB results. Thus, the H index was determined for each inundation map resulting from the MGB models in relation to the inundation extent mapped by CPRM (benchmark). For the computation of the H metric, we first converted the spatial resolution of the MGB-SA flood hazard map from 500 m to 90 m and then transformed the local flood map (polygon) into a raster with 90 m resolution. Thus, the comparison was performed at the same resolution of the Regional MGB flood hazard map (90 m).

RESULTS AND DISCUSSIONS

Results for flood mapping with specific RPs are presented following. We compared results obtained from the MGB model (in regional and continental application) with the local flood maps estimated for the extreme 1983 flood (Uruguaiana) and for specific RPs (Montenegro and São Sebastião do Caí locations).

Uruguay River at Uruguaiana

Figure 5 shows the simulated flooded areas using the regional and continental MGB model, in comparison with the 1983 flood extent delimited by the CPRM (feature line).

In both cases the areas mapped using the MGB model versions are wider than the areas delimited by CPRM. This is mainly because the focus of the CPRM map was to delimit the urban area, while the inundation extent simulated by MGB encompasses all DEM cells flooded by the river within each unit-catchment.

When comparing the regional and continental MGB, the MGB-SA resulted in more flooded areas in the upper portion of the map. This may be due to the MGB-SA model input MDE having less altitude differences in the region due to the larger pixel size (500m) compared to the MGB regional model pixel size (90m). Table 2 presents the results of the hit ratio metric (H) calculated for this case.

The results of both regional (H = 0.482) and continental (H = 0.465) models were similar (Table 2), in the same order of magnitude, suggesting that the simulated flood extent from MGB models, specifically for the urban area of Uruguaiana, are about 46% and 48% compatible with the flooded area delineated by CPRM.

Caí River at Montenegro

Figures 6 and 7 show, respectively, the simulated flood by the regional and continental MGB models in comparison with CRPM flood hazard maps, for different RPs.

The flood hazard maps produced by CPRM are focused on the urban area and have limited extent, as their upper and lower boundaries are characterized by horizontal straight lines.

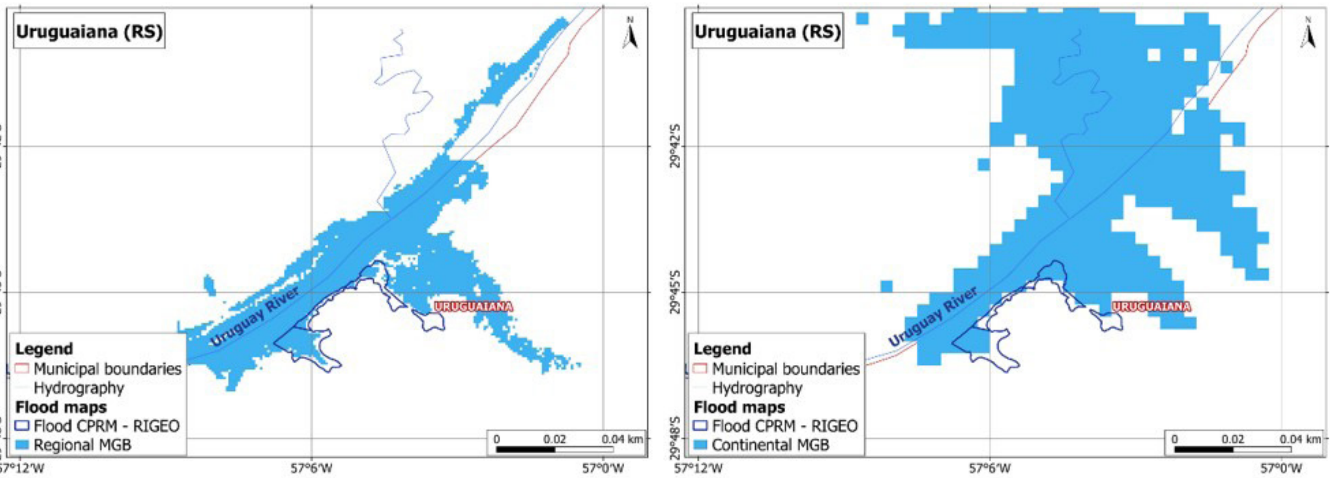

Figure 5. Flood mapping for the 1983 flood for the city of Uruguaiana obtained with the Regional and Continental MGB models.

Table 2. Hit ratio metric (H) of inundation maps obtained as the MGB model with reference to the CPRM map.

Flood of 1983	Model	H
Uruguaiana	MGB REG	0.482
	MGB AS	0.465

Once again, for all RPs the inundation extent simulated by both MGB model versions are wider than those delimited by the CPRM. This is mainly because the focus of the CPRM map was to delimit the urban area, and it was made within a predefined polygon.

For the case of Montenegro, the MGB-SA model tended to map more flooded areas than the regional MGB model, while the latter showed more non-flooded areas. This likely occurs because the spatial and vertical resolution of the MGB-SA model input MDE is lower, with less altitude differences in the region due to the larger pixel size (500m). Even for the different return periods, the continental model showed similar flooded areas, even with the increase in RP, always compatible with the CPRM map.

In the regional MGB model, it was observed the increase in flooded areas with the increase in RP, which is naturally expected. However, there is a progressive increase in agreement between the flood maps estimated by the regional MGB model and CPRM. In other words, the higher the RP, the higher is the agreement between flood maps from the regional MGB model and CPRM. This happens due to valley-filing, because as the flood occurs, the water is already "fitted" in the floodplain. Therefore, only the water depths increase, without a substantial increase in the flooded areas. Table 3 presents the results of the hit ratio (H) metric calculated for this case.

As can be seen in Table 3, the results of the regional MGB model ranged from 69% to 86% (H = 0.689 for RP 3 years to H = 0.860 for RP 100 years). The continental model compatibility was similar for all RPs (H =0.920 ~ 0.947), indicating compatibility between the MGB-SA and CPRM methods over 90%.

Caí River at São Sebastião do Caí

Figure 8 shows the maps for the different RPs simulated by the MGB Regional model compared to the CPRM map and Figure 9 for the MGB SA compared to the CPRM delineation. It is observed that the flooded area mapped by CPRM for São Sebastião do Caí also had as its focus the urban area and was limited in the extremes.

For the case of São Sebastião do Caí, the comparison between the regional and continental MGB presented opposite results in relation to the Montenegro case study. Note that MGB-SA tended to map less flooded areas in general, while the regional model showed more flooded areas.

However, once again, for the different return periods, the continental model showed similar flooded areas even with the increase in RP. This can be attributed to the fact that the spatial and vertical resolution of the MGB-SA model input MDE is lower, with less altitude differences in the region due to the larger pixel size (500m). In the regional MGB model, the results were visually closer compared to the CPRM maps than the continental model, for all RPs analyzed. Table 4 presents the results of the calculated hit ratio (H) metric.

Results of the regional model were in general more suitable with the CPRM map (Table 4), compared to the MGB-SA. It is also noted that the results of the regional model are progressively more compatible with the CPRM map with the increase in RP (H = 0.723 for RP 3 years to H = 0.868 for RP 100 years). In other words, the method compatibility ranged from 72% to 86%.

The continental model compatibility was similar for all RPs (H =0.607 ~ 0.635), indicating that the compatibility of the MGB-SA and CPRM methods was between 60% and 63%.

DISCUSSIONS

Observing the results, the agreement in terms of the Hit Rate of the regional and continental MGB models with the CPRM maps ranged from around 40% for Uruguaiana to values

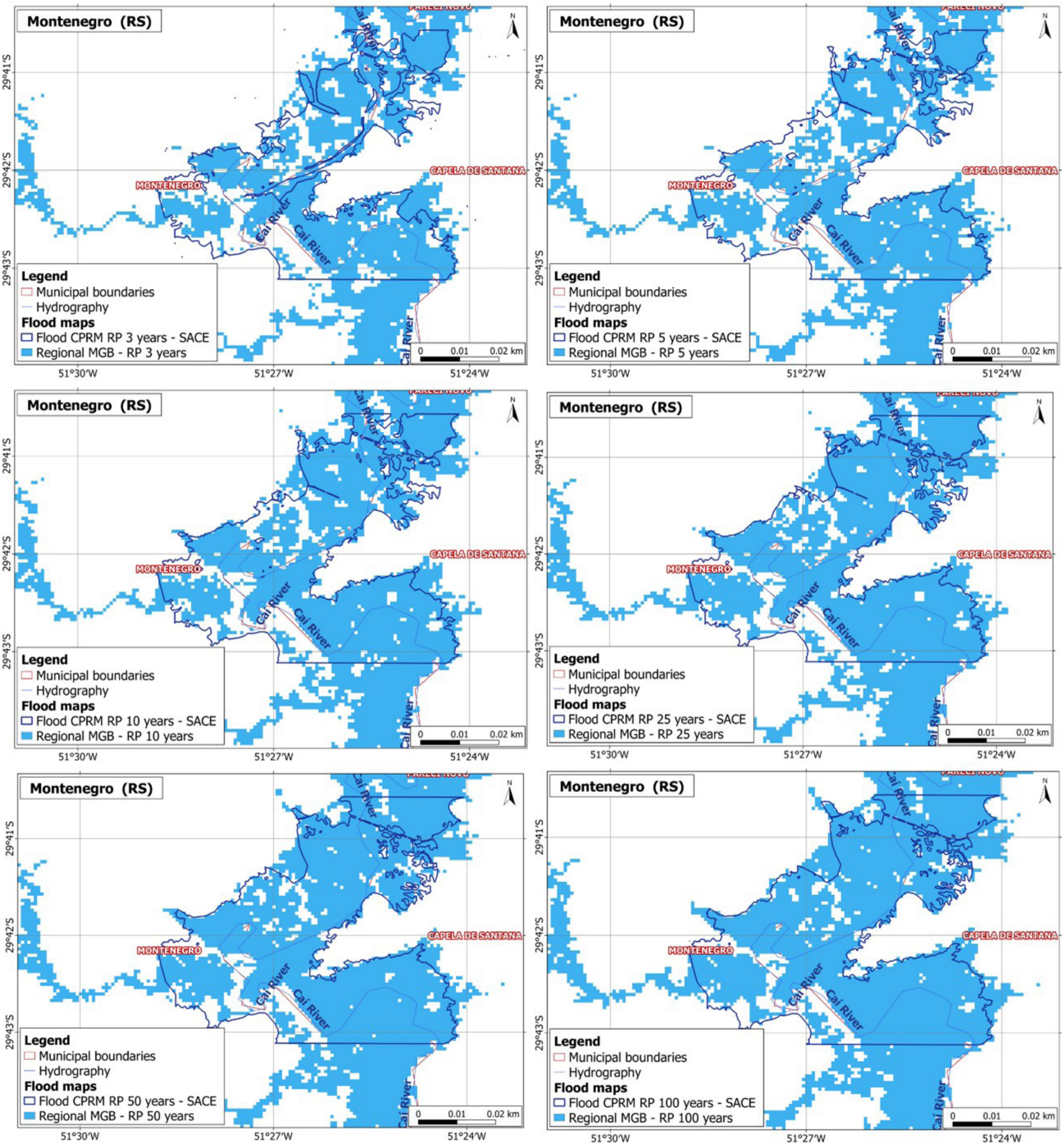

Figure 6. Flood map obtained with the regional MGB model compared to the flood map delineated by CPRM in Montenegro (Caí River) for the analyzed RPs (3, 5, 10, 25, 50 and 100 years).

in the order of 60% to 90% in the cities on the banks of the Caí river. We believe that the main differences between regional and continental models probably correspond to the DEM resolution, where the Regional MGB DEM has a higher resolution.

The agreement in terms of Hit Rate between the regional model and the CPRM map increased with the increase of the RP. The continental model compatibility was similar for all analyzed RPs, probably due to the DEM pixel size and to its more generalized representation of elevations.

Analyzing the results of comparing floods mapped with RP and extreme flood levels, it was observed that both mapping approaches have technical limitations. The CPRM results were

Figure 7. Flood map obtained with the MGB-SA model compared to the flood map delineated by CPRM in Montenegro (Caí River) for the analyzed RPs (3, 5, 10, 25, 50 and 100 years).

obtained using more local information, such as field inferences and a more detailed DEM. The main negative points of the CPRM maps were the limited spatial coverage and the DEM's "slicing" approach to flood mapping. This does not consider the water surface slope. Table 5 present the strengths and weaknesses of the methodologies used in this work.

The results do not necessarily indicate a performance analysis, as the CPRM map is spatially limited and is also an estimate. It cannot be interpreted as an observation of the true flood extent, but it is useful as a comparative reference of the expected results from other studies that will use the MGB for this purpose.

Table 3. Hit ratio (H) of the flood maps obtained with the MGB model using the CPRM map for Montenegro in Caí River as a reference.

RP	Model	H	RP	Model	H
3 years	MGB REG	0.689	**25 years**	MGB REG	0.812
	MGB AS	0.920		MGB AS	0.947
5 years	MGB REG	0.715	**50 years**	MGB REG	0.832
	MGB AS	0.937		MGB AS	0.937
10 years	MGB REG	0.771	**100 years**	MGB REG	0.860
	MGB AS	0.928		MGB AS	0.941

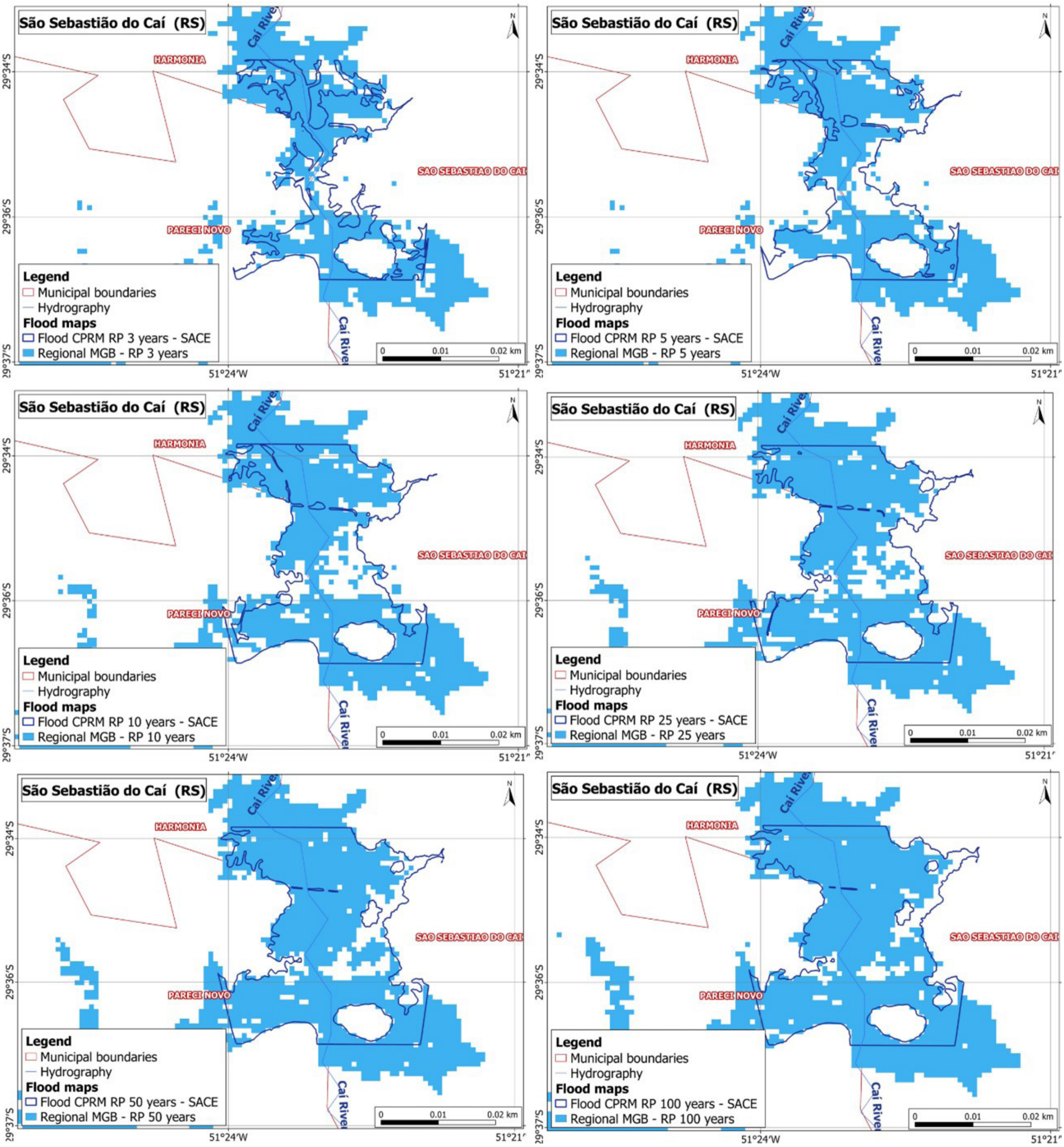

Figure 8. Flood map obtained with the regional MGB model compared to the flood map delineated by CPRM in São Sebastião do Caí (Rio Caí) for the analyzed RPs.

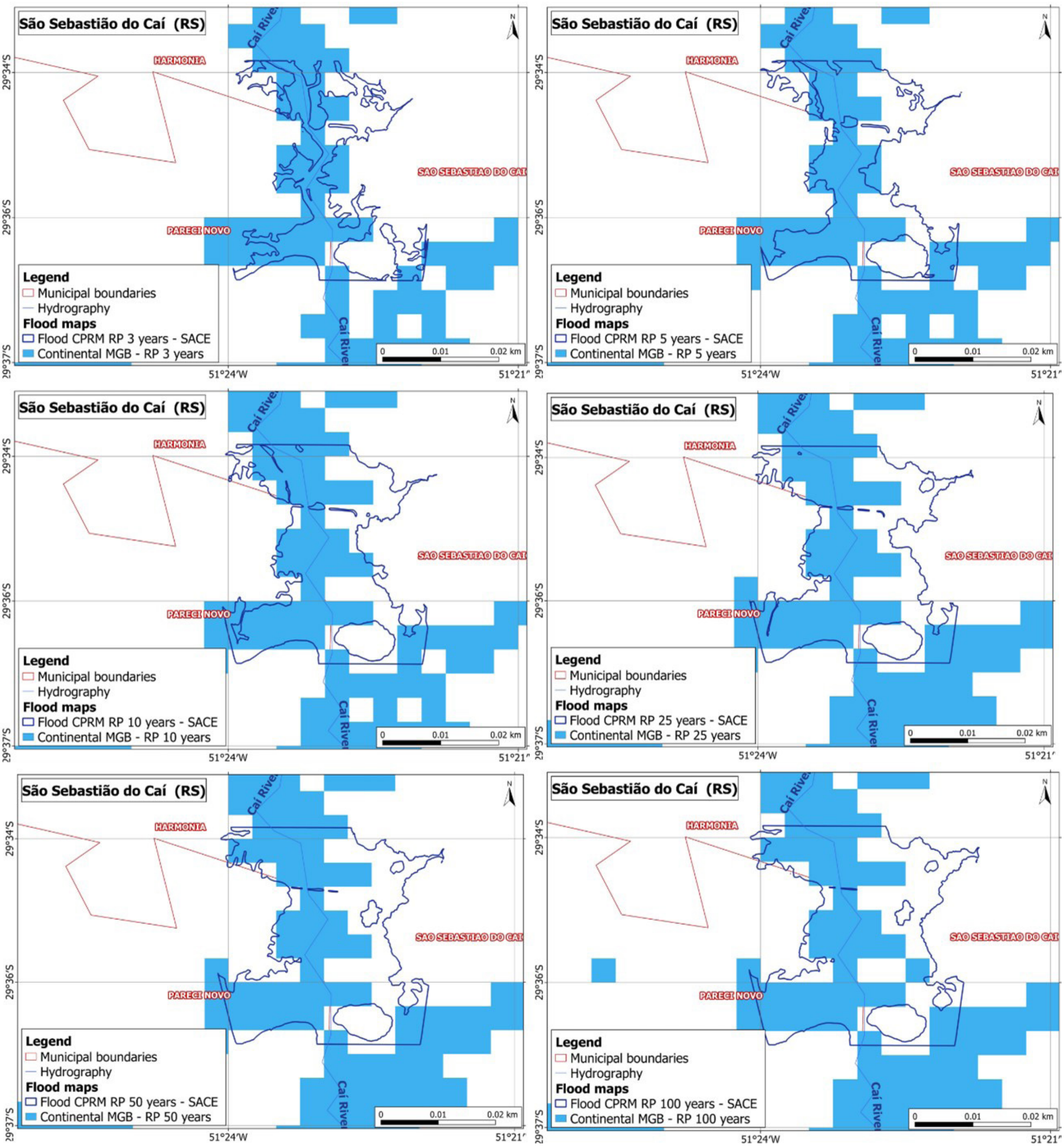

Figure 9. Flood map obtained with the MGB-SA model compared to the flood map delineated by CPRM in São Sebastião do Caí (Caí river) for the analyzed RPs.

Table 4. Hit ratio (H) of the flood maps obtained with the MGB model using the CPRM map for São Sebastião do Caí at Caí River as a reference.

RP	Model	H	RP	Model	H
3 years	MGB REG	0.723	**25 years**	MGB REG	0.784
	MGB AS	0.635		MGB AS	0.619
5 years	MGB REG	0.733	**50 years**	MGB REG	0.833
	MGB AS	0.633		MGB AS	0.608
10 years	MGB REG	0.753	**100 years**	MGB REG	0.868
	MGB AS	0.663		MGB AS	0.607

Table 5. Strengths and weaknesses of the methodologies used in this work.

Methodology	Strengths	Weaknesses
Local benchmark - CPRM	-Ease application.	-It does not consider the water surface slope.
	-Depends only on DEM and observed water level data.	-The conservation of flood volume is not ensured.
		-The flood hazard map is limited to urban areas.
Regional MGB	-Conservative mass balance approach;	-Coarser DEM resolution compared to that used in the CPRM study.
	-Hydrological-hydrodynamic simulation, with more variables represented.	- Regional MGB model calibration is necessary.
	-Model is calibrated for the area of interest.	-Limited representation of floodplain flows (only storage).
	- The flood hazard map covers a larger area, with a relatively lower local surveying effort.	
Continental MGB	-Flood hazard maps are easily extracted since the model is already prepared and calibrated.	-Coarser DEM resolution than that of the Regional MGB model.
	-Conservative mass balance approach;	-Coarser model spatial discretization.
	-Hydrological-hydrodynamic simulation, with more variables represented.	-Less detailed model calibration (water balance and river geometry parameters).
	- The flood hazard map covers a larger area, with a lower local surveying effort.	-Larger uncertainty in meteorological forcing data (e.g., satellite, reanalysis).

CONCLUSIONS

After comparisons and analyses carried out between the MGB regional and continental versions, and local flood maps produced by CPRM, and after calculation of performance metrics, it was concluded that:

- By using a continental or regional model we can have compatible results in terms of Hit Rate with the CPRM, regardless of the MGB model version. Improving the result as RP increases, probably due to the valley-filling effect.
- Both mappings have methodological uncertainties. There is an influence on the result due to the difference in scale of the topographic base map (DEM) that may be the origin of the differences found by the Hit Rate metric adopted.

The results generated by the MGB are for larger areas, with less effort to survey local information for flood area simulation, compared to the local maps generated by the references tested. This is the first work that compares this standard CPRM methodology with large scale modeling (MGB model) approaches. Future works should address the capacity of the hydrological-hydrodynamic model to map specific observed floods, to further assess the understanding of the model's usefulness.

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