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CLIMATOLOGY OF EXTREME RAINFALL EVENTS IN EASTERN AND NORTHERN SANTA CATARINA STATE, BRAZIL: PRESENT AND FUTURE CLIMATE

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ABSTRACT. The eastern region of Santa Catarina State (Brazil) has an important history of natural disasters due to extreme rainfall events. Floods and landslides are enhancedby local features such as orography and urbanization: the replacement of natural surface coverage causing more surface runoff and, hence, flooding. Thus, studies of this type of events – which directly influence life in the towns – take on increasing importance. This work makes a quantitative analysis of occurrences of extreme rainfall events in the eastern and northern regions of Santa Catarina State in the last 60 years, through individual analysis, considering the history of floods in each selected town, as well as an estimate through to the end of century following regional climate modeling. A positive linear trend, in most of the towns studied, was observed in the results, indicating greater frequency of these events in recent decades, and the HadRM3P climate model shows a heterogeneous increase of events for all towns in the period from 2071 to 2100.

Keywords: floods, climate modeling, linear trend.

RESUMO. A região leste do Estado de Santa Catarina tem um importante histórico de desastres naturais ocasionados por eventos extremos de precipitação. Inundações e deslizamentos de terra são potencializados pelo relevo acidentado e pela urbanização das cidades da região: a vegetação nativa vem sendo removida acarretando um maior escoamento superficial e, consequentemente, em inundações. Desta forma, torna-se de suma importância os estudos acerca deste tipo de evento que influencia diretamente a sociedade em geral. Neste trabalho é realizada uma análise quantitativa do número de eventos severos de precipitação ocorridos nas regiões leste e norte de Santa Catarina dos últimos 60 anos, por meio de uma análise pontual, considerando o histórico de inundações de cada cidade selecionada, além de uma projeção para o fim do século de acordo com modelagem climática regional. Na análise dos resultados observou-se uma tendência linear positiva na maioria das cidades, indicando uma maior frequência deste tipo de evento nas últimas décadas, e o modelo climático HadRM3P mostra um aumento heterogêneo no número de eventos para todas as cidades no período de 2071 a 2100.

Palavras-chave: inundações, modelagem climática, tendência linear.

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INTRODUCTION

Disorders brought about by anomalous rainfall cause great harm to society in general, especially in towns, given the greater effects of urbanizing factors. The change in surface coverage tends to reduce the seepage of water into the soil, increasing surface runoff and consequently causing an accumulation of waters in the lower regions of urban areas, characterizing flooding. Other factors, such as river floods, also lead to urban floods, thus amounting to a spectrum of events of varying durations which may cause disorders: events of either sudden or gradual flooding. Sudden floods (also known as flash floods) are normally associated with individual convective storms, of brief duration and great intensity, and more characteristic of large cities, due to the impermeability of the soil. Gradual flooding, on the other hand, is characterized by daily rainfall rates that are not so high, but which accumulate continuously over a greater number of days, normally associated to meteorological systems of longer duration, such as stationary, seasonal or climatic systems. Therefore, flooding is always linked to extreme rainfall events. The literature contains different methodologies for determining an extreme event, such as those indicated, for example, in Doswell et al. (1996), Brooks & Stensrud (2000), Schumacher & Johnson (2005) and Teixeira & Satyamurty (2007). Here, extreme events will be determined based on the track record of flooding in each town, as in Da Silva & Nunes (2011a), considering the precipitation accumulated over 15 days, given that one of the factors that influence the occurrence of rainfall is the quantity of water accumulated in the soil.

The State of Santa Catarina displays an important history of disorders related to extreme rainfall events, particularly in the eastern region of the State, as verified by Marcelino et al. (2004 and 2006) and Herrmann (2006) among others. As a recent example, we may cite the torrential rains of November 2008, which caused climatological records of rainfall in various towns in the region in question (Pinheiro & Severo, 2010). The northern and eastern region of Santa Catarina State is home to important towns for the Brazilian economy, such as Blumenau, Joinville and Florianópolis; these two latter are the most populous in the State. Moreover, due to economic development in various sectors of the economy, the North of Santa Catarina State is one of the regions with the highest GNP in Brazil (IBGE, 2010).

Just as analyzing the trend of severe events is important to find out whether such events are becoming more frequent, analysis of a future scenario may provide scientific support for better town planning. Some studies, such as, for instance, Alexander et al. (2006), Groisman et al. (1999), Tebaldi et al. (2006) and indicate an increase in the number of severe events in overall terms, which is also being verified in the south and southeastern regions of the country (Marengo et al., 2007; Marengo, 2008; Milly et al., 2002 and 2005, Valverde & Marengo, 2010). Thus, this work will also assess the behavior of this type of event for the period from 2071 to 2100, according to the HadRM3P regional climate model (Marengo et al., 2009), thus making a climatic analysis of extreme rainfall events in the northern and eastern region of the State for the present and future climate.

METHODOLOGY

The methodology employed to obtain the variation over time (trend) of extreme events may be organized into four steps: collecting cases of flooding, associating data of rainfall observed in each case of flooding, obtaining the thresholds that identify the extreme events occurring over recent decades, and quantifying the events (Medin et al., 2010; Da Silva et al., 2010). The cases of flooding were obtained from various sources, such as the State Civil Defense, decrees of an emergency situation or state of public calamity, from scientific works such as those of Silva (2003), Herrmann (2006), Silveira (2008), Herrmann & Mendonça (2007) and Silveira & Kobiyama (2007), besides local news items published in newspapers (such as 'Diário Catarinense' and 'A Notícia'), and from the State Databank of Hydric Resources. According to this bibliographic research, 18 towns were selected, displaying a good track record of flooding, as shown in Figure 1.

Present Climate

After collecting the cases of flooding, daily rainfall data were obtained for rainfall preceding the events of flooding, to determine an average numerical value (rate) that may identify extreme events. The data, referring to the period from 1951 through 2010, were obtained from rain gauge stations of the ANA (Agência Nacional de Águas), using the site http://hidroweb.ana.gov.br, after identifyingt the stations with data available in the region. Missing data from the stations amounted to, on average below 2% of the total (Da Silva, 2011). Two types of threshold were obtained: the first with the aim of capturing only events of sudden flooding caused by transient systems, representing the rainfall necessary to potentially produce flooding in a short period (up to 4 days before the flooding) of accumulated rainfall; the second indicates the average rainfall accumulated in the 15 days prior to the date of the flowing, and captures the short duration storms in sequence or events that may cause rainfall at rates that are not so

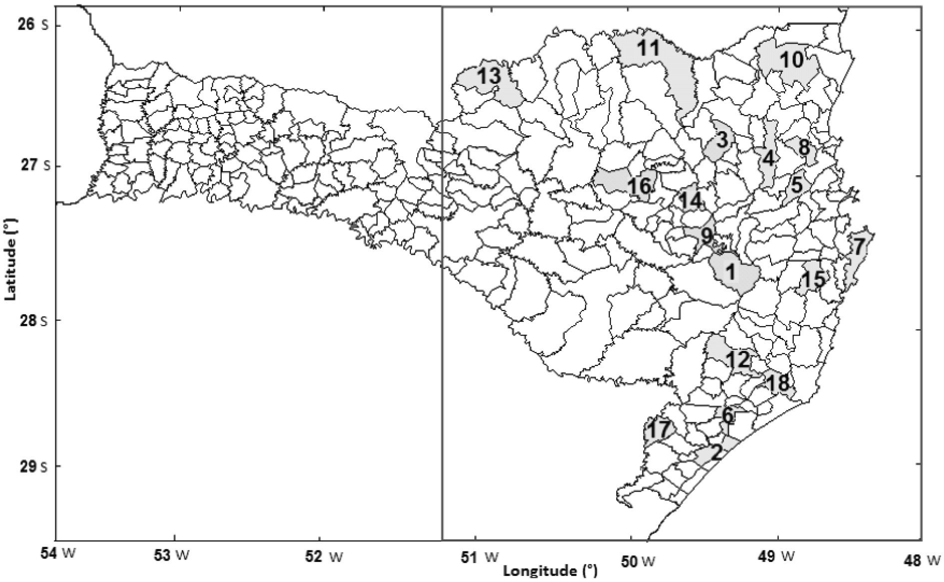

Figure 1 – Location and numbering of the towns studied (inside the rectangle): 1 – Alfredo Wagner; 2 – Araranguá; 3 – Benedito Novo; 4 – Blumenau; 5 – Brusque; 6 – Criciúma; 7 – Florianópolis; 8 – Ilhota; 9 – Ituporanga; 10 – Joinville; 11 – Mafra; 12 – Orleans; 13 – Porto União; 14 – Rio do Sul; 15 – Santo Amaro da Imperatriz; 16 – Taió; 17 – Timbé do Sul; 18 – Tubarão.

high, but with a considerable accumulated value, on the surface or inside the soil, over up to 15 days, which likewise tends to cause flooding. The first threshold is determined based on the rate (mm/day) that displays least standard deviation, that is to say, the rate of least spreading, whereas the second is determined by the average rainfall accumulated in the 15 days preceding the floods, according to Da Silva & Nunes (2001b, c). These two thresholds served to filter, from the rainfall data from 1951 through 2010, the extreme rainfall events analyzed in this work. Here, what is addressed as cases of severe events is the number of days under the influence of the severe event, to consider the fact that a large volume of rainfall continues to interfere, either on or under the surface of the soil, and thus its period of influence is considered the same as the number of days of the threshold (Da Silva, 2011).

Example of obtaining the first threshold

Figure 2 shows an example of obtaining a threshold according to the methodology described above for the town of Ilhota. The line with squares indicates the average accumulated rainfall over the 30 days preceding the flood (Day 0) – which are average daily values that preceded the 15 events of flooding observed in the town between 1980 and 2010, while the line with asterisks is the standard deviation. It is expected that the greater the interval preceding the flood, the greater the standard deviation. However, a reduction in the value of standard deviation may indicate a rate with little spreading, i.e. with good matching between the cases, serving as a threshold. In this example, the threshold is defined as being the 2nd day before the flood, as the value of the standard deviation was the smallest (with the exception of the first day), of 29 mm, and the accumulated rainfall 78 mm, with this threshold called 2d78. Thus, analysis of the floods that occurred in this town (from 1980 to 2010), indicates that events with rainfall values equal to or greater than 78 mm accumulated in two days have great potential for causing a flood situation in the town of Ilhota. Here, the term "potential" is necessary, as it means that the event was in a position to cause a flood, not necessarily entailing (due to more complex geographical factors), or that it really may have caused flooding, and this may not be recorded by the sources of information. In the Figure, we note that according to this methodology other threshold values for this town can also be defined, such as, for example, 147 mm of rain in 14 days, if we wished to analyze a longer period of accumulation. However, this feature was not easily observed in the other towns, and this methodology was chosen to determine thresholds referring to periods of a few days.

An analysis of accumulated average rainfall was made for all the 18 towns under study, while each town displays a different pattern standard of rainfall and number of floods (which range from 13 to 36) between 1980 and 2010. Thus, each town tends to present its own threshold due to the irregular distribution of rains, and peculiar geographical and town planning aspects.

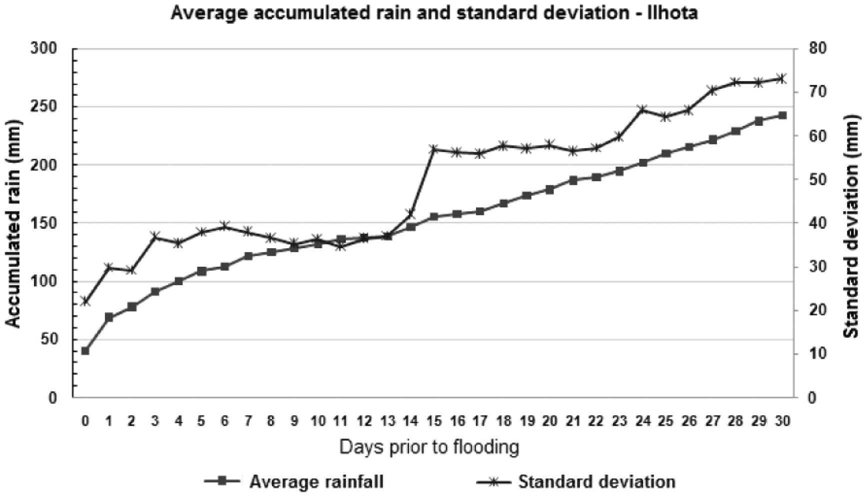

Figure 2 – Example of the rainfall threshold with potential to cause flooding, obtained for the town of Ilhota (SC). The line with asterisks represents the standard deviation (mm) and the line with squares represents the accumulated rainfall (mm).

Future Climate

To analyze the behavior of severe events in the future climate, future scenarios were used according to the HadRM3P regional climate model, from the Hadley Centre, in the United Kingdom, whose projections were made by the Centro de Ciências do Sistema Terrestre at the Instituto Nacional de Pesquisas Espaciais (CCST/INPE) (Marengo et al., 2009). The simulations made use of the PRECIS modeling system (Providing REgional Climates for Impacts Studies), which is being employed by various countries for regional climate forecasts (for example, Tadross et al., 2005; Rupa Kumar et al., 2006; Xu et al., 2006a, b; Islam & Rehman, 2006; Zhang et al., 2006). In Brazil, a system has been implemented to study the future climate (2071-2100) and impacts of climate changes, the CREAS (Regional Climate Change Scenarios for South America), which was financed by MMA/BIRD/GEF/CNPq (PROBIO Project), by the National Program of Climate Changes of the Ministry of Science, Technology and Innovation (MCTI), by the UK Global Opportunity Fund – GOF Project Using Regional Climate Change Scenarios for Studies on Vulnerability and Adaptation in Brazil and South America, and by the GOD-Dangerous Climate Change (DCC). The HadRM3P model has a spatial scale of 50 km and surrounding conditions generated by the general circulation model (global scale) HadAM3P, also from the Hadley Center, in which the principal forcing factors for the simulation of the period from 1961 to 1990 (baseline) are the surface temperature of the sea and the cover of sea ice. To simulate the future scenarios, HadAM3P adds to the baseline conditions trends generated by the coupled HadCM3 model (Gordon et al., 2000), whose atmospheric components consider, for the baseline case, observed data on emissions of greenhouse gases and, for the case of future scenarios, simulated emissions from the SRES (Special Reports for Emissions Scenarios). Validation of the model in relation to rainfall for the present (1961-1990) was performed in South America (Alves, 2007; Marengo et al., 2009; Soares and Marengo, 2008), making a comparison with observed data to ensure the skill to simulate the trend of climate extremes for the future. The CREAS generates high resolution scenarios for South America, taking into account the "GEE" (greenhouse gases) and SO_2 emitted, based on two scenarios from the United Nations (UNO) Intergovernmental Panel on Climate Changes: A2, pessimistic and B2, optimistic. The concentration of CO_2 in SRES A2 is approximately 300 ppm during the decade of 1980, and approximately 700 ppm during the decade of 2080, while concentrations of NO2 are in the order of 280 and 400 ppb, respectively (Soares, 2008). Besides the uncertainties inherent to weather numerical modelling, climate modelling, especially those which estimate projections for a long period of time, such as decades, have additional sources of uncertainties, such as the variations (and difficulties in measurements) of emissions of greenhouse gases and the methods of mitigation, both functions of the socio-economic development of nations, besides the inherent complexity of the of the climatic system dynamics (Soares, 2008).

Identification of severe events in the rainfall data of the future scenario will be done by employing the thresholds obtained from the present climate. Here, we shall consider climate change according to scenario A2 – considered in this work as more realistic than the optimistic scenario (more information on the different scenarios in Pesquero (2009)) – and will be obtained by the ratio between the data from scenario A2 (2071-2100) and the baseline (1960-1990). Finally, the number of events in the future climate will be determined according to the product between the term referring to climate change and the number of events observed in the present (Da Silva & Nunes, 2011c).

RESULTS

Thresholds for detection of extreme rainfall events

Firstly, the two thresholds were obtained for detecting extreme rainfall events, as *per* Table 1, below:

Table 1 – Rainfall thresholds determined and used to quantify the extreme events for the period from 1951 to 2010.

City	1st threshold (X days, mm)	15 days (mm)
1 – Alfredo Wagner	4d126	167
2 – Araranguá	3d101	167
3 – Benedito Novo	3d108	185
4 – Blumenau	2d96	187
5 – Brusque	2d118	219
6 – Criciúma	4d133	190
7 – Florianópolis	3d112	215
8 – Ilhota	2d78	155
9 – Ituporanga	2d78	155
10 – Joinville	3d120	204
11 – Mafra	4d116	223
12 – Orleans	3d99	184
13 – Porto União	3d127	230
14 – Rio do Sul	2d85	171
15 – Sto Amaro da Imperatriz	4d144	252
16 – Taió	4d123	199
17 – Timbé do Sul	4d131	201
18 – Tubarão	3d122	224

From Table 1 we can observe that the towns of Ilhota and Ituporanga, which have identical thresholds, display a greater propensity to flooding, not only among the towns whose first threshold uses two days, but also among all, if we consider a period of 15 days. On the other hand, considering a period of 15 days, it is the town of Santo Amaro da Imperatriz which, among those selected in this work, that requires most rainfall to bring about a flood. Based on the thresholds obtained, events were quantified, year by year, according to the rainfall data from 1951 to 2010.

Linear trend of extreme events from 1951 to 2010

The linear trend is considered to grow if the angular coefficient of the straight-line equation is positive and to fall if the angular coefficient is negative. The statistical significance of the trend is determined according to the Mann-Kendall Test (Kendall, 1975; Da Silva, 2011); positive (negative) significant values (here referred to as SIG) by at least 5% indicate a significant growing (falling) trend of annual occurrence of extreme events in the period from 1951 to 2010. On the other hand, values that are not significant (here referred to as N), indicate the absence of a significant trend), either positive or negative. Table 2 presents the results of the linear trend according to the first threshold, considering the number of events year by year.

Table 2 – Linear trend of events according to the 1st threshold. The term b column represents the angular coefficient of analysis of regression and the Mann-Kendall column indicates whether the trend is statistically significant at 5% according to such test. SIG represents the significant trends and N those not significant.

City	b	Mann-Kendall
1 – Alfredo Wagner	0,0081	N
2 – Araranguá	–0,0110	N
3 – Benedito Novo	0,0412	SIG
4 – Blumenau	0,0195	SIG
5 – Brusque	–0,0014	N
6 – Criciúma	–0,0116	N
7 – Florianópolis	0,0278	N
8 – Ilhota	0,0542	SIG
9 – Ituporanga	0,0019	N
10 – Joinville	0,0466	SIG
11 – Mafra	0,0186	N
12 – Orleans	0,0031	N
13 – Porto União	0,0139	N
14 – Rio do Sul	0,0153	N
15 – Sto A. da Imperatriz	0,0013	N
16 – Taió	–0,0011	N
17 – Timbé do Sul	0,0702	SIG
18 – Tubarão	0,0590	SIG

The results shown indicate a positive trend, or rather, an increase in the number of events, in 14 of the 18 towns studied (almost 78%). According to the Mann-Kendall Test at 5%, there was statistical significance in just 6 towns: Benedito Novo, Blumenau, Ilhota, Joinville, Timbé do Sul and Tubarão, all showing a positive trend. No negative trend with statistical significance was found. Through this analysis we do not observe any regional coherence of the sign of the trend. For example, in the south of the

State two towns were found with a growing and significant trend (Timbé do Sul and Tubarão), and two towns with a falling trend (Criciúma and Araranguá), yet not significant.

Analysis of the linear trend of events determined by the threshold of 15 days (2nd threshold) is shown in Table 3. This threshold seeks to detect longer duration extreme events, generally linked to gradual flooding, or various short events in sequence.

According to the second threshold, we observed 12 towns (67%) with a positive trend indicating an increase in the number of cases. Statistical significance was observed in 9 towns. Of these, just one displayed a negative trend: Araranguá. In the others with statistical significance, Benedito Novo, Ilhota, Joinville, Mafra, Porto União, Rio do Sul, Timbé do Sul and Tubarão, a positive trend was observed. Considering only the cases with statistically significant linear trends, we have the towns of Benedito Novo, Blumenau, Ilhota, Joinville, Mafra, Porto União, Rio do Sul, Timbé do Sul and Tubarão as those requiring greatest attention from society in relation to events of extreme rainfall. Of these, Benedito Novo, Ilhota, Joinville, Timbé do Sul and Tubarão require even more attention, as they display significant positive trends with both thresholds.

Table 3 – Same as Table 2, but according to the 2nd day threshold.

City	b	Mann-Kendall
1 – Alfredo Wagner	–0,0471	N
2 – Araranguá	–0,0846	SIG
3 – Benedito Novo	0,2378	SIG
4 – Blumenau	0,1003	N
5 – Brusque	–0,0164	N
6 – Criciúma	0,0169	N
7 – Florianópolis	0,0751	N
8 – Ilhota	0,2787	SIG
9 – Ituporanga	–0,1554	N
10 – Joinville	0,2342	SIG
11 – Mafra	0,0700	SIG
12 – Orleans	–0,0688	N
13 – Porto União	0,0716	SIG
14 – Rio do Sul	0,1540	SIG
15 – Sto A. da Imperatriz	0,0492	N
16 – Taió	–0,0047	N
17 – Timbé do Sul	0,3031	SIG
18 – Tubarão	0,0392	SIG

Seasonal climatologies

Figure 3 shows the seasonal climatologies of extreme events in the towns selected.

The first threshold, for cases of short duration, does not display seasonal homogeneity, that is to say, it does not reveal one season standing out as that with more or less cases. However, we may point summer (DJF = December, January and February), as observed in 11 of the 18 towns, as the season most propitious for this type of event. From the same standpoint, although with less clarity, we may point out winter (JJA = June, July and August), as observed in 7 of the 18 towns, as the season with least cases of events. Meanwhile, the graphs according to the 15-day threshold clearly indicate summer as most propitious for this type of event. This feature is observed in all the towns, with the exception of Porto União, in which the season with most cases is the spring (SON = September, October and November). The season with least cases, just as in relation to the 1st threshold, is winter (10 towns), followed by autumn (MAM = March, April and May), with 7 towns. This trend of a larger number of cases in summer indicates greater potential for convective storms to cause flooding than the frontal systems which, while they occur the year round, are more intense in winter.

Seasonal climatologies of the future climate

The results of the HadRM3P climate model are employed here to obtain the estimate of seasonal climatologies for the period from 2071 to 2100, according to the pessimistic scenario (A2). Figure 4 shows the average number of cases according to the first threshold for the four seasons of the year, according to scenario A2.

Just as in the present climate, we observe a greater incidence of cases in summer (Fig. 4a). In particular, the towns of Ilhota (10 cases), Alfredo Wagner (8 cases), Florianópolis and Blumenau (7 cases) stand out, indicating greater attention in this season for these towns. Alfredo Wagner is the town that displays most cases for winter and spring (Figs. 4c and 4d). However, the towns in the far north and south and the eastern sector of the State show relatively fewer cases, in the other seasons too. One exception noted was in autumn (MAM) (Fig. 4b) for the towns of Mafra and Criciúma. Figure 5 shows the seasonal climatology of the future scenario for the 15-day threshold.

The results of the thresholds with a longer period, and consequently a larger quantity of rain, show more cases, as they capture both long events and also shorter, more intense events of rainfall. Thus, it is the 1st threshold that shows the least number of cases in the quarters of the year. From Figure 5, we observe, just as in the case of the 1st threshold, a great frequency of cases in summer (Fig. 5a) and autumn (Fig. 5b), and fewer cases in winter (Fig. 5c).

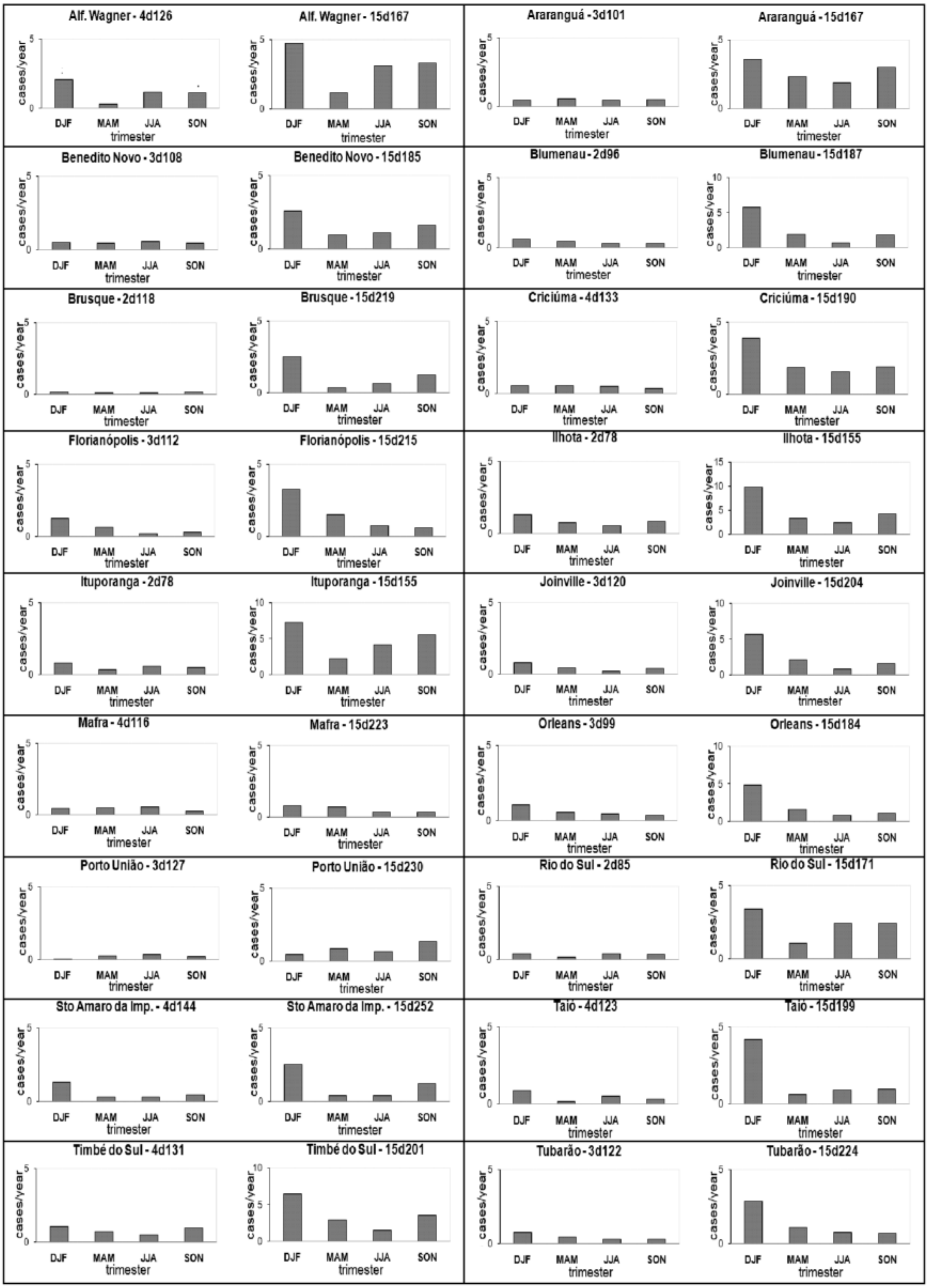

Figure 3 – Climatology of the period from 1951 to 2010 for extreme events, considering both thresholds, for the towns selected.

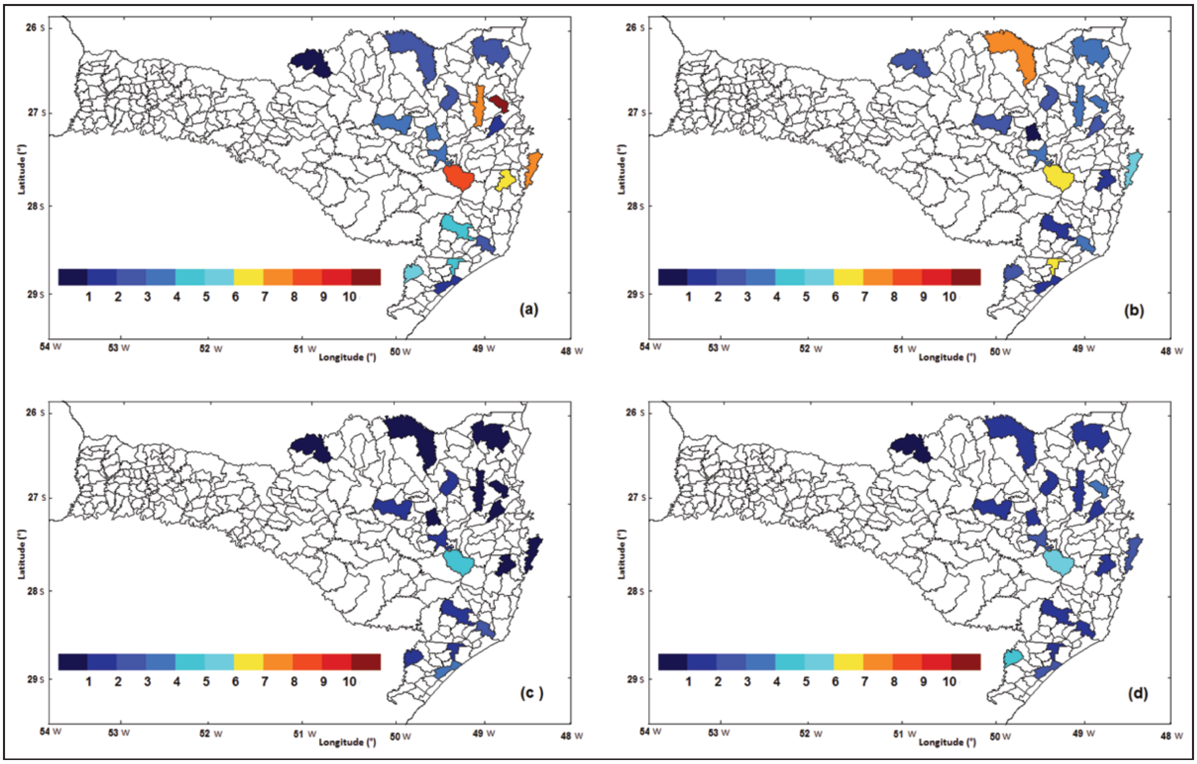

Figure 4 – Seasonal climatology of extreme events in the future (2071-2100), according to the 1st threshold. a) DJF, b) MAM, c) JJA, and d) SON. Bar of colors representing the number of cases *per* season.

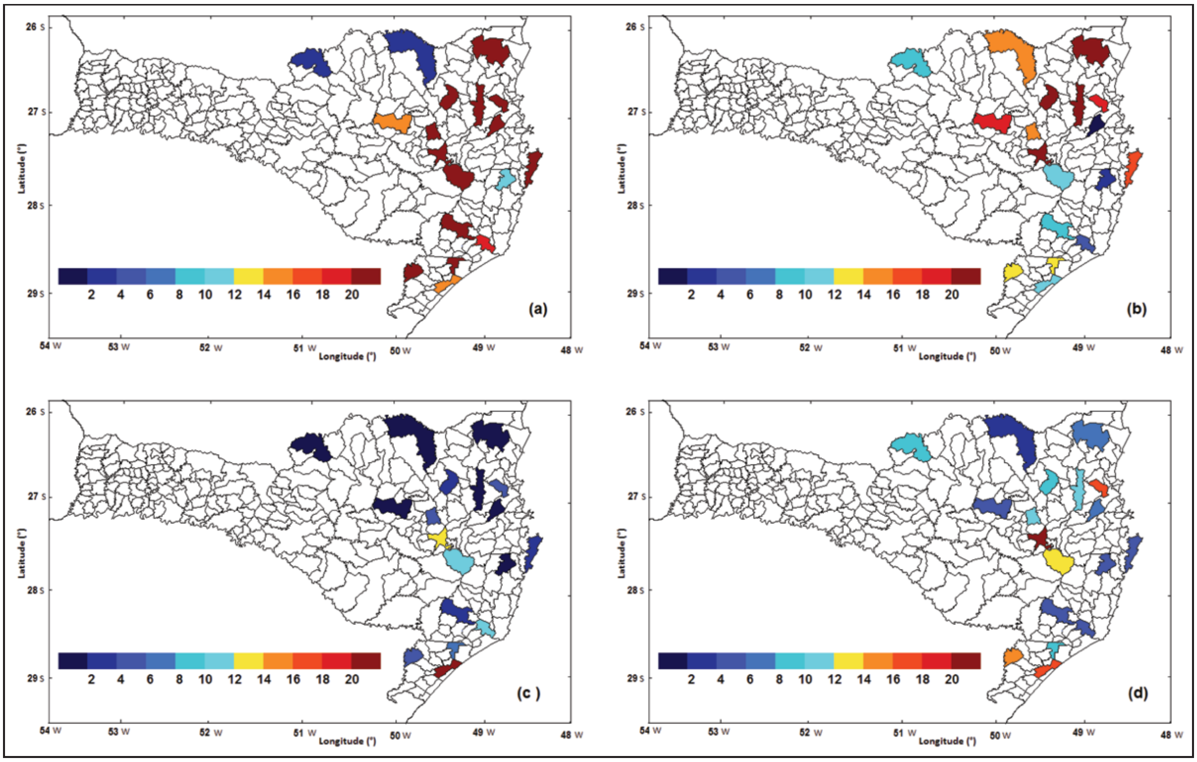

Figure 5 – Seasonal climatology of extreme events in the future (2071-2100), according to the 1st threshold. a) DJF, b) MAM, c) JJA, and d) SON. Bar of colors representing the number of cases *per* season.

Just as in the case of the 1st threshold, we do not easily identify any spatial homogeneity, that is to say, towns close to one another display different behaviors. Moreover, it must be taken into account that the numerical models display reduced trends of representation of the extreme rains simulated; which in general all numerical models do, especially in regions of irregular topography, as seen, for example, in (Guimarães et al., 2006).

From Figures 3, 4 and 5 we note that the estimate of the future climate may also generate a seasonal change of behavior of intense rains in some towns, such as, for instance, in Joinville, where the maximum migrates from summer (Fig. 3) to autumn (Fig. 4b). In Rio do Sul, the winter season will cease to be one of the most active and will become that of least frequency. In the town of Tubarão the winter, which has the least frequency, becomes just like the summer, one of the most active, with the exception of the cases of the 1st threshold. Similarly the town of Taió shows a change in the pattern of intense rains; autumn will have the greatest occurrence, instead of summer, mainly in relation to more prolonged events of rain. This seasonal change will probably be a consequence of seasonal changes in the behavior of atmospheric phenomena that generate this type of event, such as convective systems and/or frontal systems. This may be verified in Valverde and Marengo (2010), where changes were identified in the pattern of general circulation of the atmosphere for the period of 2071 to 2100, according to global climatic modelling.

In general, the results of the climatic model accompany the trend observed in the present climate: the greatest incidence of cases of extreme rainfall is still foreseen for the summer. In addition, a complementary fact, and no less important, is how much the frequency of cases should increase according to the future scenario. In this regard, Figure 6 displays the intensity of seasonal climate variation (or change) of the number of cases according to the 1st threshold. Here, the intensity of the variation is shown in the following way: 0 for values close to zero (without considerable importance); 50 for a variation of up to 50%; 100 for variations of up to 100%, and 100+ for variations greater than 100%. We note, thus, than in no towns was there a reduction (at least considerable) in the number of cases, in any season of the year.

From Figure 6 we note that the season with the greatest change, or rather, the greatest increase in the number of cases of short duration (1st threshold) will be autumn (Fig. 6b), while the season with least variation in relation to the present climate will be winter (Fig. 6c). One regional characteristic worthy of note is the northern part of the study area, where no considerable climate change was found during winter. In general, we observe that the changes foreseen will be intense, varying around 10%, that is to say, the number of cases of events of short duration with potential for flooding in the future tends to double in most towns. Figure 7 sets out the results of climate change using the 15-day threshold.

In general, the results of the 15-day threshold match those obtained by means of a threshold of a few days, that is to say, autumn (Fig. 7b) was the season of most intense climate change, and winter (Fig. 7c) with the least intense change. This time, we note that situations with no considerable change are concentrated in just one: winter in the town of Porto União. Just as in Figure 6, here too we observe that, in general, the number of cases tends to double; see the example of Florianópolis, where the number of cases foreseen will have an increase of up to 100% in winter, and greater than 100% in the other seasons. The results that employed the 15-day threshold bear out what was found for the first threshold: in all the towns we see an increase in the frequency of extreme events foreseen in the future vis-à-vis the present, agreeing with various studies (IPCC, 2007; Marengo et el., 2007, 2009; Silva Dias et al., 2009). The season of the year that will have the greatest increase in the number of events is autumn (MAM), although the summer quarter (DJF) displays similar variations. In these seasons, the greater part of the towns have an addition of over 100% in relation to the period from 1951 to 2010. According to Soares & Marengo (2008), IPCC scenario A2, according to the regional HadRM3P simulated for a future period (2080-2089), showed a trend of low-level jet intensification in the region, which would favor the greater occurrence of intense rainfall systems in the south of Brazil.

CONCLUSION

The results presented in this work may be summarized in the following points:

- A positive linear trend was identified, that is to say, an increase in the frequency of extreme rainfall events in the greater part of the towns studied in the eastern and northern region of the State of Santa Catarina.
- According to Tables 2 and 3, of the 36 situations analyzed (18 towns, 2 thresholds), we observe 26 with a positive trend and 10 with a negative trend of extreme events during the period from 1951 to 2010. However, on performing the Mann-Kendall test to analyze statistical significance at 5%, we note that, from these results, only 15 are statistically significant, and of these, just one is associated to a negative trend.

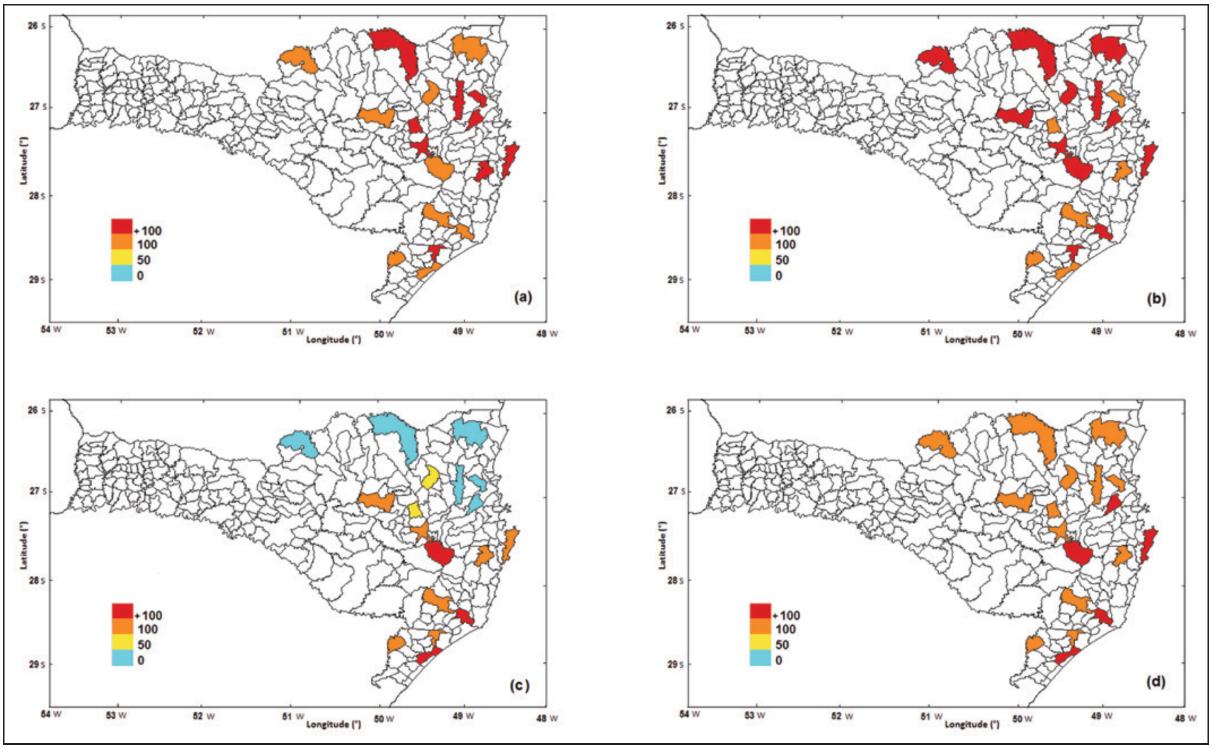

Figure 6 – Climatic variation of extreme events in the towns studied, simulated by the HadRM3P model for the future in relation to the present, according to the 1st threshold, in (a) DJF, (b) MAM, (c) JJA, and (d) SON. The measurement of variation is in % with relation to the number of present cases.

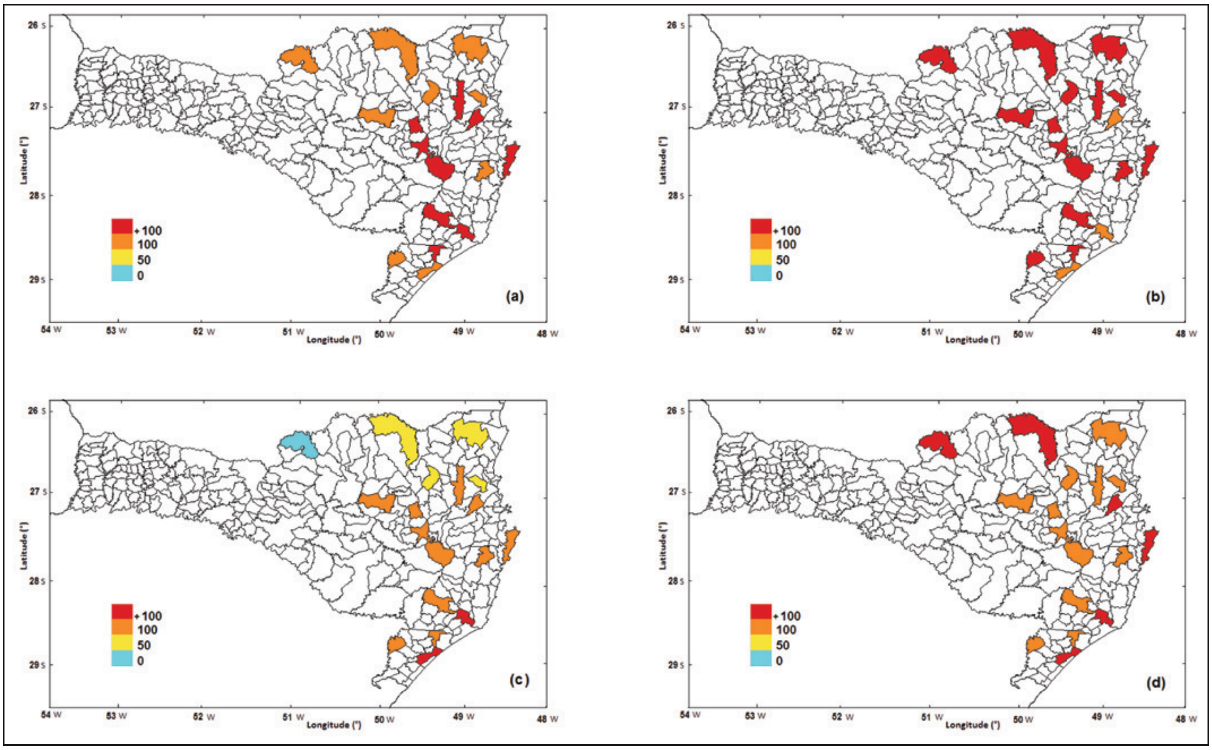

Figure 7 – Climatic variation of extreme events in the towns studied, simulated by the HadRM3P model for the future in relation to the present, according to the 2nd threshold, in (a) DJF, (b) MAM, (c) JJA, and (d) SON. The measurement of variation is in % with relation to the number of present cases.

- That is to say, by means of a careful evaluation, we have 14 situations (Blumenau with the 1st threshold; Mafra, Porto União and Rio Sul with the 2nd threshold; Benedito Novo, Ilhota, Joinville, Timbé do Sul and Tubarão with both thresholds), indicating that extreme rainfall events are more frequent, as against just one (Araranguá, with the 2nd threshold), indicating a reduction in the frequency of such events.

- In the greater part of the towns the seasonal climatologies, considering the two thresholds, for both the present and future scenario, indicate summer (winter) as the season most (least) likely to have the occurrence of extreme events. However, in some cases there may be a change in this pattern, such as Joinville, for instance, where the most active season in relation to the events will cease to be summer, to be autumn in future.

- Considering specifically climate change, that is, the difference between the results of the future and the present, the results indicate that in the greater part of towns the number of extreme event tends to increase around 100%. Autumn is the season where the greatest change will occur, and winter the season where the change will be least noticeable, to the point that, in relation to cases of short duration (1st threshold), the towns in the northern part of the region will not display considerable changes. Such results show that the atmospheric phenomena associated with severe rainfall events in the future will display a behavior different from the present, not only in relation to seasonality, but also with respect to the regions of activity.

In this way, we conclude that this work presents results that tend to stimulate, scientifically, society in general with relation to extreme rainfall events in the present and future climate in the eastern and northern region of Santa Catarina State; indicating that preventive measures addressing flooding must be part of the short and long-term planning of the towns in the areas under study.

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