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Seasonal intensity-duration-frequency relationships for Pelotas, Rio Grande do Sul, Brazil[1]

Relações intensidade-duração-frequência obtidas sazonalmente para Pelotas, Rio Grande do Sul, Brasil

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HIGHLIGHTS:
The intensity-duration-frequency (IDF) equation obtained with summer rain can be applied to estimate the maximum rainfall of Pelotas.
The IDF curve can be obtained only during months of maximum rainfall.
A satisfactory IDF curve can be drawn in the absence of data for periods in which rainfall is less intense.

ABSTRACT: Although several studies have evaluated the intensity-duration-frequency relationships of extreme rainfall events, these relationships under different seasonal conditions remain relatively unknown. Thus, this study aimed to determine whether the intensity-duration-frequency relationships obtained seasonally from the rainfall records in the winter and summer represent the maximum rainfall events for the city of Pelotas, Rio Grande do Sul state, Brazil. Pluviographic data from 1982 to 2015 were used to create two seasonal series: one for the summer from December 21 to March 20 and the other for the winter from June 21 to September 22. These seasonal relationships were compared with the annual pluviographic data. The intensity, duration, and frequency relationships obtained from the summer rain data adequately represented the maximum rainfall in Pelotas, Rio Grande do Sul state, Brazil. The maximum intensity values of rainfall obtained from the relationship of intensity, duration, and frequency for the winter did not adequately encapsulate the occurrence of rain with greater intensities.

Key words: intense rainfall, convective, frontal

RESUMO: Embora vários estudos tenham objetivado obter as relações intensidade-duração-frequência de eventos extremos de precipitação, essas relações sobre diferentes condições sazonais ainda são relativamente desconhecidas. Desta forma, objetivou-se verificar se as relações de intensidade-duração-frequência, obtidas sazonalmente por meio de registros de precipitação do inverno e do verão, são representativas dos eventos de precipitação máxima da cidade de Pelotas, Rio Grande do Sul, Brasil. Para isso, foram utilizados dados pluviográficos de 1982 a 2015 para constituição de duas séries sazonais: uma para o período do verão composta pelo intervalo de 21 de dezembro a 20 de março; e outra para o inverno, de 21 de junho a 22 de setembro. As relações sazonais foram comparadas com os dados pluviográficos anuais. As relações de intensidade duração e frequência obtidas com os dados de chuva do verão representam adequadamente as precipitações máximas da localidade de Pelotas, Rio Grande do Sul, Brasil. Os valores de intensidades máximas de precipitação obtidos pelas relações de intensidade, duração e frequência do inverno não retratam o cenário de ocorrência de chuvas com maiores intensidades.

Palavras-chave: precipitação intensa, convectivo, frontal

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INTRODUCTION

Hydrological models of surface runoff require knowledge of the maximum rainfall events and river basin characteristics as inputs. Maximum rainfall events are characterized by mathematical functions of their intensity-duration-frequency (IDF) curves. These curves are indispensable tools for evaluating locations in which hydrological flow data are not readily available and must be obtained through rainfall-runoff transformation (Ritschel et al., 2017). Developing IDF curves is important for designing various hydraulic structures such as culverts, dams, and stormwater drainage systems (Al-Wagdany, 2020).

Several previous studies focused on obtaining IDF relationships by analyzing maximum rainfall events in different regions of the world, such as in northern England (Fadhel et al., 2017), South Korea (So et al., 2017), and Hong Kong (Xu et al., 2018). However, the influence of seasons on maximum rainfall intensities has not been widely evaluated.

One such study analyzed the interference of convective systems on rainfall in Peninsular Malaysia and showed that the pattern of rainfall intensity varied by region (Ariff et al., 2012). Tye et al. (2016) studied the correlation between seasonality and the intra-annual variations of extreme rainfall events in the United Kingdom and found that over several years, maximum rainfall occurred earlier in autumn (September-November) in the north and west parts of the country.

Understanding seasonal variations is fundamental for identifying the most intense rainfall periods. Thus, this study aimed to determine whether IDF relationships obtained seasonally from rainfall records from the winter and summer represent the maximum rainfall events for the city of Pelotas, Rio Grande do Sul state, Brazil.

MATERIAL AND METHODS

Pluviograph data were obtained from the city of Pelotas (31° 46’ 34” S, 52° 21’ 34” W), which is located at an altitude of 13.20 m. According to the Köppen climate classification, the region is classified as subtropical (or warm temperate), humid, and without drought (Teixeira et al., 2011).

Hyetographic data were obtained from the conventional pluviometer at the Agroclimatological Station of the Empresa Brasileira de Pesquisa Agropecuária, Instituto Nacional de Meteorologia, together with the Universidade Federal de Pelotas.

The pluviographic series encompassed the period from 1982 to 2015, totaling 34 years without missing data. The pluviograms were digitized using a manual scanner. These rainfall records were used to create two seasonal series, with one for the summer from December 21 to March 20 and another for the winter from June 21 to September 22 across the analyzed period.

A discretization process was created in MATLAB to derive series across 5, 10, 15, 30, 60, 120, 360, 720, and 1440 min. The maximum annual rainfall intensities were estimated for all discretized durations during summer and winter. The Gumbel distribution was applied to the seasonal series of intensities to identify the maximum rainfall events that are likely to be equal to or exceed the maximum every 2, 5, 10, 20, 50, and 100 years.

The equation parameters of heavy rainfall were estimated by nonlinear multiple regression. The rainfall intensity-duration-frequency relationships are represented according to Eq. 1:

$$I = \frac{K\ T^{a}}{\left(t + b\right)^{c}} \tag{1}$$

where:

I - rainfall intensity, mm h^{-1};
T - return time, years;
t - duration of rain, min; and,
K, a, b, c - adjusted parameters based on the observed data.

The Root Mean Square Error (RMSE) was used as a criterion to adjust the IDF curve (Eq. 2):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(I_{eq} - I_{obs}\right)^{2}}{n}} \tag{2}$$

where:

I_{obs} - observed values of maximum rainfall intensity, mm h^{-1};
I_{eq} - estimated values of maximum rainfall intensity, mm h^{-1}, using the IDF relationships obtained by minimizing the RMSE coefficient; and,
n - the number of elements of the series.

The adjusted IDF relationships were compared with those obtained using conventional annual pluviographic data for the same location and period to determine the representativeness of the maximum intensities of seasonal rainfall. The following intensity equation was proposed by Dorneles et al. (2019) (Eq. 3):

$$I = \frac{1100T^{0.163}}{\left(t + 16.45\right)^{0.766}} \tag{3}$$

where:

I - rainfall intensity, mm h^{-1};
T - return time, years; and,
t - duration of rain, min.

The maximum rainfall intensities associated with a given duration and return time corresponding to the summer and winter periods, and those conventionally determined by Dorneles et al. (2019), were converted into maximum rainfall to examine the applicability of the results to engineering.

The two series were assessed using the RMSE (Eq. 2) and two quality metrics used by Bayer et al. (2012), which are the Aggregate Error Rate (evaluation of the accuracy of the results) (Eq. 4) and Nash-Sutcliffe coefficient (Eq. 5).

$$AER = \frac{\sum_{i=1}^{h} Z_i - \sum_{i=1}^{h} \hat{Z}_i}{\sum_{i=1}^{h} Z_i} \tag{4}$$

$$\mathrm{NSC} = 1 - \frac{\sum_{i=1}^{h}\left(Z_i - \hat{Z}_i\right)^2}{\sum_{i=1}^{h}\left(Z_i - \bar{Z}_i\right)^2} \qquad (5)$$

where:

AER - aggregate error rate;

NSC - Nash-Sutcliffe coefficient divided into three levels to evaluate: unsatisfactory (NSC < 0.50), satisfactory (0.50 < NSC < 0.65) and very good (0.75 < NSC < 1.00);

h - number of terms in the series;

Z_i - maximum rainfall obtained from the IDF relationships determined using the conventional pluviographic method, mm (Dorneles et al., 2019);

Z_i - maximum rainfall determined based on the adjusted IDF relationships for the summer and winter periods, mm; and,

Z_i - the arithmetic mean of the maximum rainfall obtained from the IDF relationships determined using the conventional method, mm (Dorneles et al., 2019).

Results and Discussion

The maximum rainfall values in the summer period across the durations analyzed were obtained by adjusting the Gumbel distribution to the rainfall records, considering all return periods (Table 1). The model showed a good fit to the values of the maximum rainfall intensity for the summer values when the chi-square test was applied. Maximum rainfall values based on the IDF relationships obtained using the conventional method and the respective quality measures of the RMSE, AER and NSC were also determined.

The results for each duration and return period analyzed showed that the maximum rainfall adjusted for the summer using the Gumbel distribution was similar to that obtained through the IDF, as estimated by Dorneles et al. (2019).

The maximum rainfall values for 5–15 min durations showed the smallest differences between series across all return times analyzed, with the largest discrepancy corresponding to approximately 2.44 mm. Notably, however, although the maximum rainfall divergence for a two-year return time showed a greater divergence compared to those of Dorneles et al. (2019), the maximum was 3.44 mm and lasted for 15 min.

For return times of 20–100 years and durations of 5–30 min, the maximum rainfall estimated for the summer period was generally greater than that obtained by the conventional method; however, this overestimation never exceeded ~2.40 mm. The higher values in this period can likely be explained by the presence of local, sporadic convective activity during the summer, enabling the formation of mesoscale convective systems (MCS), which are associated with high rainfall rates.

In the summer, the Rio Grande do Sul state suffers predominantly from the action of the tropical maritime mass, which is characterized as the portion of air with high temperatures and humidity on the surface (Gross & Cassol, 2015). High heat intensity related to high humidity levels is common throughout the summer in the Rio Grande do Sul state. This can cause convective rains that last for up to a few hours, mainly in the afternoon, when the temperature reaches a maximum (Britto et al., 2008).

Furthermore, the extreme events of precipitation exhibit seasonal characteristics that are well-defined in Southern Brazil, with most extreme events occurring in summer in all analyzed categories (comprehensive intense rain and non-persistence or comprehensive persistence rain and non-

Table 1. Maximum rainfall observed in the summer and by Dorneles et al. (2019) obtained from the IDF (Intensity-Duration-Frequency) relationship for the city of Pelotas, RS, Brazil, and quality metrics resulting from comparison of the series

Rainfall duration (min)	Maximum rainfall (mm)					
	Return time (years)					
	2	5	10	20	50	100
			Summer			
5	8.01	11.01	12.99	14.89	17.36	19.20
10	12.82	17.77	21.04	24.19	28.25	31.30
15	16.51	23.08	27.42	31.59	36.99	41.03
30	24.06	34.13	40.79	47.18	55.46	61.66
60	30.67	44.50	53.64	62.40	73.78	82.30
120	35.08	51.58	62.68	73.22	86.88	97.10
360	47.46	69.06	83.40	97.14	114.96	128.28
720	53.28	77.28	93.36	108.60	128.40	143.28
1440	59.52	85.92	103.20	120.00	141.60	157.68
			Dorneles et al. (2019)			
5	9.11	11.45	13.01	14.50	16.43	17.87
10	16.07	20.20	22.94	25.57	28.97	31.51
15	19.95	25.04	28.41	31.64	35.82	38.95
30	29.18	37.22	42.54	47.64	54.25	59.20
60	38.10	50.88	59.34	67.46	77.97	85.84
120	49.28	67.60	78.72	88.76	100.98	109.68
360	60.18	81.54	95.76	109.32	126.96	140.16
720	69.48	92.40	107.64	122.16	153.12	155.28
1440	56.40	91.20	109.20	124.08	142.32	153.60
RMSE	9.07	8.98	8.76	8.29	10.41	7.34
AER	0.17	0.13	0.11	0.08	0.07	0.04
NSC	0.80	0.91	0.94	0.96	0.96	0.98

RMSE - Root mean square error; AER - Aggregate error rate; NSC - Nash-Sutcliffe coefficient: unsatisfactory (NSC < 0.50), satisfactory (0.50 < NSC < 0.65) and very good (0.75 < NSC < 1.00) comprehensive), with winter showing a lower probability of extreme events (Cardoso et al., 2020).

The data also indicated that for the duration of 60–1440 min, the maximum rainfall in the summer was almost always lower than that obtained by the conventional method, with the largest observed difference of ~25.00 mm (Table 1). These patterns were also observed to be shorter for durations of 5–30 min at return times of 2–10 years.

Underestimation of the maximum summer rainfall for some durations and return times may reflect the fact that transition seasons exhibit high convective system activity. Grimm (2009) described that mesoscale convective complexes (MCC), which are more intense than MCS, are more frequent and account for a large part of the total rainfall in the southern part of the country, particularly during transition seasons. The subtropical jet tends to occupy the latitudinal band during these seasons and is associated with the low-level jet, which also feeds the MCC.

The CHUVA Project developed by Machado et al. (2014) showed that in the municipality of Santa Maria (290 km from Pelotas), a greater level of convective cloudiness was observed compared to at other project sites (Belém, PA; Vale do Paraíba, SP; Alcântara, MA, and Fortaleza, CE) because of baroclinicity (a thermodynamic characteristic of mid-latitudes) favoring MCCs and cold fronts.

This likely explains the underestimated values of maximum rainfall found in the summer, as MCCs, which cause the highest rainfall rates, are more frequent in the fall and spring.

This effect was corroborated by the results of Zipser et al. (2006), who defined four types of intense rainfall events using seven years of satellite data from the Tropical Rainfall Measuring Mission. The results showed that the southern region of Brazil had events in all seasons but with a greater prevalence in spring.

Salio et al. (2007) related MCS to low-level jet in South America for the city of Pelotas, verifying that MCS centers are more frequent in autumn and spring. Rasmussen et al. (2016) similarly used 15 years of Tropical Rainfall Measuring Mission data to examine the contribution of intense convective events to total rainfall in South America. In the region in which Pelotas is located, a greater contribution was observed in spring than in summer.

Cecil & Blankenship (2012) used eight years of data from the Advanced Microwave Scanning Radiometer for the Earth Observing System and observed that hailstorms, events that are associated with high rainfall rates, were most likely to occur from September to April in southern Brazil.

Thus, the summer did not show the highest maximum intensities across all situations (duration and time of return), as the transition seasons, particularly the spring, also have elevated convective system activity associated or not with frontal systems.

The results of the performance indices showed that the maximum summer rainfall series was similar to that obtained using the conventional method of Dorneles et al. (2019). The RMSE values were $7.34 < x < 10.41$, with the lowest RMSE value obtained for a 100-year return time. For all analyzed return times, the results of the AER were $0.04 < x < 0.17$. However, the highest performance index was the NSC, for which nearly all return times were close to 1.00 (very good) (Table 1).

This analysis verified that rainfall data in the summer period evaluated using the method used in this research and those determined by the conventional methodology were strongly correlated, particularly for shorter durations and longer return times.

Thus, in the absence of an annual data series with no missing information, the maximum rainfall intensities of the summer period can be used to determine the IDF for return times of 5–100 years and durations of 5–15 min. These data have numerous important applications, such as city planning projects, for which the engineering of urban drainage networks relies on knowledge of the maximum rainfall return times.

The maximum rainfall values for the winter period and those resulting from the transformation of the IDF obtained by the conventional methodology, as well as all quality metrics, are presented in Table 2.

The series of maximum rainfall exhibited a greater level of divergence compared to the summer period. The adjusted maximum rainfall for the winter period was underestimated compared to that determined by the conventional methodology for every duration and return time analyzed, with the differences showing amplification over longer return times.

The values of maximum rainfall in the winter period showed the lowest divergence observed for durations of 5–15 min across all return times. Although they displayed only minor differences, these values were underestimated by 4.71 and 17.57 mm, respectively, for 5- and 15-min durations for a return time of 100 years.

For durations of 60–1440 min, the largest discrepancies corresponded to a return time of 100 years, with values ranging from 26.281–24.08 mm. Comparison of seasonal rainfall showed that the greatest divergence between the data was ~25.00 mm for the summer period and 124.08 mm for the winter period.

The range of values for the RMSE was 21.61–46.77, indicating a greater difference between the data. The results of AER were close to 0.50 for all return periods. An NSC value of 1.00 indicates that the data evaluated are very good; however, the coefficient was $0.00 < x < 0.16$, indicating a large divergence between the results and leading to their classification as unsatisfactory.

In the Rio Grande do Sul state, the frontal systems are the driving force behind rainfall events in autumn, which show an even greater frequency in the winter. These systems are characterized by long-term rainy events. Moreover, some cities are more affected than others, with greater total maximum values of rainfall in the winter, as observed in this study in Pelotas in the southern part of the state (Forgiarini et al., 2013).

Conceptual models developed by Browning (1986) showed that, generally, in frontal systems, convective rainfall is expected (which can have higher rainfall rates), followed by light rainfall closer to the cold mass. Thus, rainfall associated with frontal systems has a lower rate than that associated only with convective systems.

Britto & Saraiva (2001) used 11 years of observed data for the city of Rio Grande, RS, Brazil (60 km from Pelotas) and showed that during nearly all of winter, rainfall originated from fronts, with low accumulated values. Reboita et al. (2010) suggested that

Table 2. Maximum rainfall observed in the winter and those by Dorneles et al. (2019) obtained through the IDF (Intensity-Duration-Frequency) relationships for the city of Pelotas, RS, Brazil, and quality metrics resulting from comparison of the series

Rainfall duration (min)	Maximum rainfall (mm)					
	Return time (years)					
	2	5	10	20	50	100
			Winter			
5	4.90	7.11	8.58	9.98	11.80	13.16
10	6.95	9.56	11.28	12.94	15.08	16.69
15	8.63	12.04	14.30	16.47	19.28	21.38
30	11.20	15.24	17.91	20.48	23.80	26.28
60	14.58	19.27	22.38	25.37	29.23	32.12
120	19.96	26.88	31.46	35.86	41.56	45.82
360	32.28	43.50	51.00	58.20	67.26	74.16
720	31.44	44.04	52.44	60.48	70.80	78.72
1440	52.80	72.00	84.24	96.48	112.32	124.08
			Dorneles et al. (2019)			
5	9.11	11.45	13.01	14.50	16.43	17.87
10	16.07	20.20	22.94	25.57	28.97	31.51
15	19.95	25.04	28.41	31.64	35.82	38.95
30	29.18	37.22	42.54	47.64	54.25	59.20
60	38.10	50.88	59.34	67.46	77.97	85.84
120	49.28	67.60	78.72	88.76	100.98	109.68
360	60.18	81.54	95.76	109.32	126.96	140.16
720	69.48	92.40	107.64	122.16	153.12	155.28
1440	56.40	91.20	109.20	124.08	142.32	153.60
RMSE	46.77	45.41	37.85	33.72	29.05	21.61
AER	0.47	0.48	0.47	0.47	0.47	0.45
NSC	0.00	0.04	0.03	0.12	0.12	0.16

RMSE - Root mean square error; AER - Aggregate error rate; NSC - Nash-Sutcliffe coefficient

in winter, there are at least four passages or formations of frontal systems per month, whereas Andrade et al. (2012) suggested six to eight systems per month based on reanalysis data.

This may explain the discrepancies observed in the comparison of maximum rainfall obtained by the conventional method, as winter rainfall is less intense and does not represent the maximum rainfall for the city of Pelotas. These frontal systems have a longer duration and provide a greater rain volume over time but at a lower intensity for each instance. Thus, maximum winter rainfall is inadequate for determining the IDF relationship for Pelotas, as underestimation of maximum rainfall would provide inadequate sizing for urban drainage networks to handle the flow of the actual water volume.

The IDF adjusted equations using rainfall records for the summer and winter, respectively, are represented in Eqs. 6 and 7.

$$I = \frac{1011T^{0.242}}{\left(t+15.45\right)^{0.230}} \tag{6}$$

$$I = \frac{175T^{0.218}}{\left(t+0.801\right)^{0.627}} \tag{7}$$

The parameters adjusted for summer rainfall records were similar to the conventional IDF equation proposed by Dorneles et al. (2019) (Eq. 3). This is corroborated by the similar values of maximum intensities of summer rainfall that were representative of the intense rains in the city of Pelotas. The Eq. 7 contains parameters that differ from those of the conventional IDF (Eq. 3), and the summer equation (Eq. 4), which was expected because the winter rainfall was less intense, as shown by the results.

CONCLUSIONS

1. The intensity, duration, and frequency relationships obtained using the summer rain data adequately represented the maximum rainfall in Pelotas, Rio Grande do Sul state, Brazil.

2. The maximum intensity values of rainfall obtained from the relationship of intensity, duration, and frequency for the winter did not adequately encapsulate the occurrence of rain with greater intensities.

LITERATURE CITED

Al-Wagdany, A. S. Intensity-duration-frequency curve derivation from different rain gauge records. Journal of King Saud University–Science, v.32, p.3421-3431, 2020. https://doi.org/10.1016/j.jksus.2020.09.028

Andrade, K. M.; Müller, G. V.; Cavalcanti, I. F. de A.; Long, M. E. F.; Bidegain, M.; Berri, G. Avaliação das mudanças na frequência de sistemas frontais sobre o sul da América do Sul em projeções no clima futuro. Atmospheric Sciences, v.37, p.15-26, 2012.

Ariff, N. M.; Jemain, A. A.; Ibrahim, K.; Wan Zin, W. Z. IDF relationships using bivariate copula for storm events in Peninsular Malaysia. Journal of Hydrology, v.470-471, p.158-171, 2012. https://doi.org/10.1016/j.jhydrol.2012.08.045

Bayer, D. M.; Castro, N. M. dos R.; Bayer, F. M. Modelagem e previsão de vazões médias mensais do rio Potiribu utilizando modelos de séries temporais. Revista Brasileira de Recursos Hídricos, v.17, p.229-239, 2012. https://doi.org/10.21168/rbrh.v17n2.p229-239

Britto, F. P.; Barletta, R.; Mendonça, M. Regionalização sazonal e mensal da precipitação pluvial máxima no estado do Rio Grande do Sul. Revista Brasileira de Climatologia, v.2, p.83-89, 2008.

Britto, F. P.; Saraiva, J. M. B. Estudo da precipitação associada aos sistemas frontais na cidade do Rio Grande na estação de inverno. Geografia em Atos, v.1, p.107-122, 2001.

Browning, K. A. Conceptual models of precipitation systems. Weather and Forecasting, v.1, p.23-41, 1986. https://doi.org/10.1175/1520-0434(1986)001%3C0023:CMOPS%3E2.0.CO;2

Cardoso, C. de S.; Quadro, M. F. L. de; Bonetti, C. Persistência e abrangência dos eventos extremos de precipitação no sul do Brasil: variabilidade especial e padrões atmosféricos. Revista Brasileira de Meteorologia, v.35, p.219-231, 2020. https://doi.org/10.1590/0102-7786352031

Cecil, D. J.; Blankenship, C. B. Toward a global climatology of severe hailstorms as estimated by satellite passive microwave imagers. Journal of Climate, v.25, p.697-703, 2012. https://doi.org/10.1175/JCLI-D-11-00130.1

Dorneles, V. R.; Damé, R. de C. F.; Teixeira-Gandra, C. F. A.; Veber, P. M.; Klumb, G. B.; Ramirez, M. A. A. Modeling of probability in obtaining intensity-duration-frequency relationships of rainfall occurrence for Pelotas, RS, Brazil. Revista Brasileira de Engenharia Agrícola e Ambiental, v.23, p.499-505, 2019. https://doi.org/10.1590/1807-1929/agriambi.v23n7p499-505

Fadhel, S.; Rico-Ramirez, M. A.; Han, D. Uncertainty of Intensity-Duration-Frequency (IDF) curves due to varied climate baseline periods. Journal of Hydrology, v.547, p.600-612, 2017. https://doi.org/10.1016/j.jhydrol.2017.02.013

Forgiarini, F. R.; Vendruscolo, D. S.; Rizzi, E. S. Análise de chuvas orográficas no centro do estado do Rio Grande do Sul. Revista Brasileira de Climatologia, v.13, p.107-119, 2013. https://doi.org/10.5380/abclima.v13i0.33431

Grimm, A. M. Clima da região sul do Brasil. 1.ed. São Paulo: Oficina de Textos, 2009, 464p.

Gross, J. A.; Cassol, R. Ocorrências de índices de anomalia de chuva negativos no estado do Rio Grande do Sul. Revista Geográfica Acadêmica, v.9, p.21-33, 2015. https://doi.org/10.18227/1678-7226rga.v9i2.3012

Machado, L. A. T.; Silva Dias, M. A. F.; Morales, C.; Fisch, G.; Vila, D.; Albrecht, R.; Goodman, S. J.; Calheiros, A. J. P.; Biscaro, T.; Kummerow, C.; Cohen, J.; Fitzjarrald, D.; Nascimento, E. L.; Sakamoto, M. S.; Cunningham, C.; Chaboureau, J.; Petersen, W. A.; Adams, D. K.; Baldini, L.; Angelis, C. F.; Sapucci, L. F.; Salio, P.; Barbosa, H. M. J.; Landulfo, E.; Souza, R. A. F.; Blakeslee, R. J.; Bailey, J.; Freitas, S.; Lima, W. F. A.; Tokay, A. The Chuva Project: how does convection vary across Brazil? Bulletin of the American Meteorological Society, v.95, p.1365-1380, 2014. https://doi.org/10.1175/BAMS-D-13-00084.1

Rasmussen, K. L.; Chaplin, M. M.; Zuluaga, M. D.; Houze Junior, R. A. Contribution of extreme convective storms to rainfall in South America. Journal of Hydrology, v.17, p.353-367, 2016. https://doi.org/10.1175/JHM-D-15-0067.1

Reboita, M. S.; Gan, M. A.; Rocha, R. P. da; Ambrizzi, T. Regimes de precipitação na América do Sul: uma revisão bibliográfica. Revista Brasileira de Meteorologia, v.25, p.185-204, 2010. https://doi.org/10.1590/S0102-77862010000200004

Ritschel, C.; Rust, H. W.; Ulbrich, U. Rainfall extremes on multiple time scales-Bartlett-Lewis rectangular pulse model and intensity-duration-frequency curves. Hydrology and Earth System Sciences, v.21, p.6501-6517, 2017. https://doi.org/10.5194/hess-21-6501-2017

Salio, P.; Nicolini, M.; Zipser, E. J. Mesoscale convective systems over South America and their relationship with the South American low-level jet. Monthly Weather Review, v.135, p.1290-1309, 2007. https://doi.org/10.1175/MWR3305.1

So, B.; Kim, J.; Kwon, H.; Lima, C. H. R. Stochastic extreme downscaling model for an assessment of changes in rainfall intensity-duration-frequency curves over South Korea using multiple regional climate models. Journal of Hydrology, v.553, p.321-337, 2017. https://doi.org/10.1016/j.jhydrol.2017.07.061

Teixeira, C. F. A.; Damé, R. de C. F.; Rosskoff, J. L. C. Intensity-duration-frequency ratios obtained from annual records and partial duration records in the locality of Pelotas-RS, Brazil. Engenharia Agrícola, v.31, p.687-694, 2011. https://doi.org/10.1590/S0100-69162011000400007

Tye, M. R.; Blenkinsop, S.; Fowler, H. J.; Stephenson, D. B.; Kilsby, C. G. Simulating multimodal seasonality in extreme daily precipitation occurrence. Journal of Hydrology, v.537, p.117-129, 2016. https://doi.org/10.1016/j.jhydrol.2016.03.038

Xu, Q.; Chen, J.; Peart, M. R.; Ng, C.; Hau, B. C. H.; Law, W. W. Y. Exploration of severities of rainfall and runoff extremes in ungauged catchments: a case study of Lai Chi Wo in Hong Kong, China. Science of the Total Environment, v.634, p.640-649, 2018. https://doi.org/10.1016/j.scitotenv.2018.04.024

Zipser, E. J.; Cecil, D. J.; Liu, C.; Nesbitt, S. W.; Yorty, D. P. Where are the most intense thunderstorms on Earth? Bulletin of American Meteorological Society, v.87, p.1057-1072, 2006. https://doi.org/10.1175/BAMS-87-8-1057