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SYNTHETIC STORM GENERATION IN A FLATLAND REGION, SANTA FE, ARGENTINA

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The critical floods on flatland areas are generally a result of successive rainfall events. The object of this paper consists of synthetic construction of storm series with similar characteristics to measured events. Data were analyzed by means of five variables: duration of the rain, time between events, an average and maximum intensity of the rain, and storm advance coefficient. The variables were classified as independent and dependent and probability distribution functions were fitted for the independent variables. Multiplicative relationships were proposed for dependent variables and their coefficients were adjusted previously. A methodology was proposed to generate a synthetic series of storms of twenty years duration. Finally, the statistical characteristics of the synthetic series were calculated and compared with the data series. A good agreement between calculated and measured series was obtained.

INTRODUCTION

Hydrological systems in flatland areas present typical responses to rainfall which are different from other systems. These systems are very vulnerable to widespread persistent precipitation, which can generate more critical floods than localized short rainstorms with high intensity. Therefore, it is necessary to study the behavior of persistent regional rainstorms in order to find their particular characteristics that allow their synthetic reproduction, where necessary. In a previous phase, studies were carried out to characterize storms of the region by mean of histogram frequency analysis of the main variables that define the events (Navarro et al., 1996).

DATA

The rain recorder station used in this work, named 'Sapucay', is located close to Alcorta City, Province of Santa Fe, Argentina (Figure 1). Data on storm intensity and time (date and hour) of events were organized in a data base. The rain record is of five years duration (1979-1985) and hyetographs were constructed on a half-hour interval. A single rainstorm was considered one for which hyetographs were represented by one hour elapsed time with no rain or, in other words, two one hour intervals without rainfall. Rainstorms lower than 1 mm and those with duration less than one hour were excluded. After this data filtering, the number of events totaled 301 storms, divided among seasons as follows: 106 summer , 47 fall, 38 winter and 100 spring.

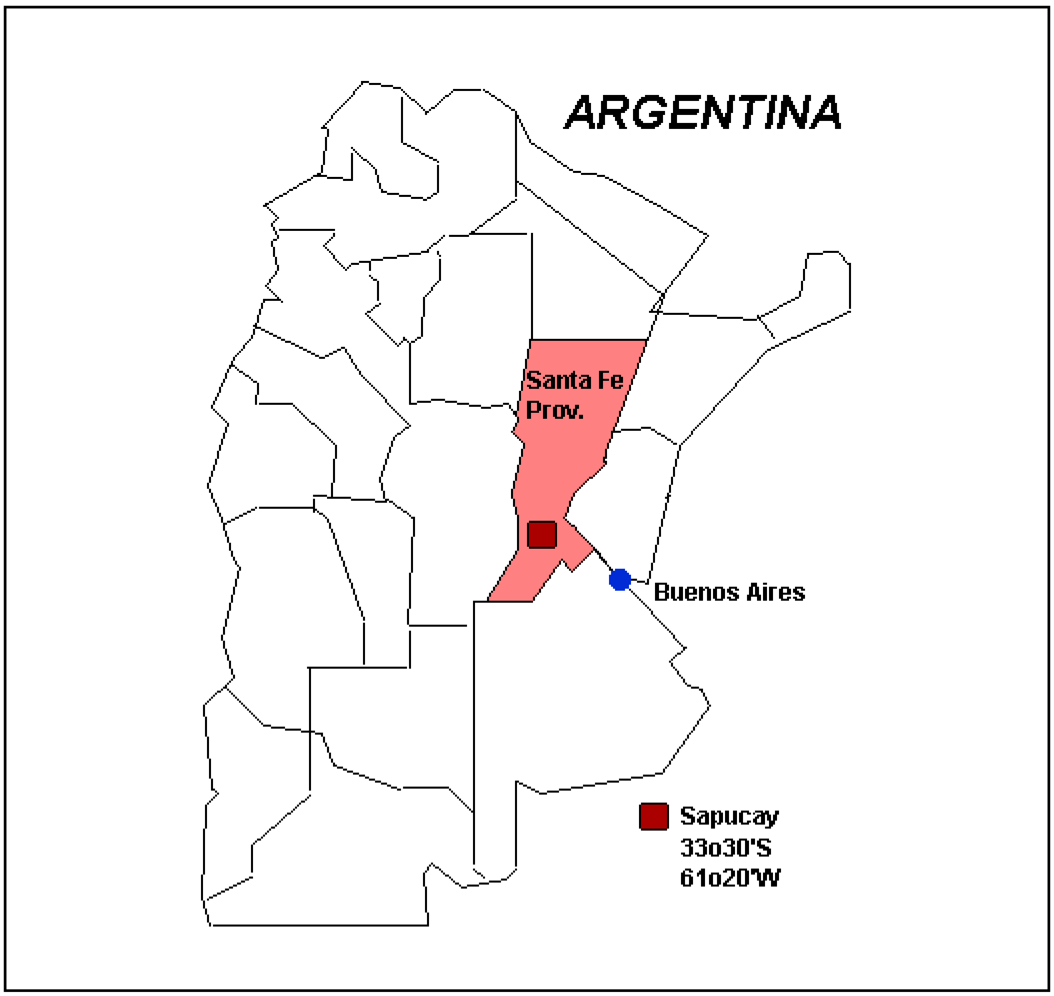

Figure 1. Location of the Sapucay rain recorder station.

METHODOLOGY

Analysis of data

First it was necessary to analyze the temporal sequence between rains in order to generate a series of events (Silber, 1995). Then characteristics of each individual event were determined. The sequence was evaluated for the intervals of time between storms. This variable, t_{ll}, was derived by subtracting the beginning times between storms. Rain characteristics like duration (d_{ll}) maximum intensity (i_{mx}), average intensity (i_{av}) and time position of maximum and duration ratio (advance coefficient, (c_{av}) were analyzed by means of frequency histograms. The main conclusions (Navarro et al., 1996) were:

• The advance coefficients have shown a normal statistical distribution with light asymmetry toward the left and remainder variables have shown an exponential statistical behavior;

• Some irregularities for d_{ll} in winter (bimodal behavior) were observed, while in fall and winter major deviations appear;

• A combined analysis of frequencies pointed out an inverse correlation between advance coefficient and duration of the rainstorm. Therefore, simple correlations were carried out between variables under several formulations (linear, multiplicative, exponential and reciprocal). The coefficients of higher correlation were obtained for multiplicative regressions between i_{mx} - i_{av} ($0.616<r<0.886$) and d_{ll} - c_{av} ($0.560<r<0.612$).

Proposed Model

Generation of the storm model consisted of the proposal of a methodology to determine the value of five storm model variables. Based on the results of the previous studies, three independent variables (t_{ll}, d_{ll} and i_{av}) and two dependent variables (i_{mx} (i_{av}) and c_{av}(d_{ll})) were selected. The formulation of the model consists of determining the independent variables by means of aleatory numbers generated with statistically adjusted distributions together with two dependent variables generated from the regression equations. Four probability distribution functions on the three independent variables for each season were proven. The applied laws were exponential, gamma (2-parameters), lognormal and Weibull distributions. The gamma function was adopted for t_{ll} in the summer, winter and spring; for d_{ll} in the spring and for i_{av} in the summer. The lognormal function was selected for t_{ll} in the fall, for d_{ll} in the summer, fall and winter and i_{av} in the fall and winter. Finally, the Weibull distribution better represented i_{av} in the spring. A prevalence of gamma and lognormal laws was observed.

Multiplicative regression, of the type $\boldsymbol{Y=a\,X^{b}}$, showed the best correlation and, therefore, was adopted to calculate the dependent variables (Table 1). A statistical analysis was carried out of the residuals, and variances were determined. The residuals were considered as *white noise*, with normal distribution and null average. Synthetic series of errors, with the same statistical properties, were generated and were added to the values of the dependent variables obtained by correlation (Zimmermann et al., 1997).

RESULTS AND DISCUSSION

Twenty years of precipitation were generated using this methodology and were separated by seasons. Generation of external variables, such as intervals between storms, allowed simulation of the sequences of rains and the generation of internal variables, such as intensities, duration and advance coefficients, permitted hyetograph simulation. To do this, a triangular time distribution with steps of time was adopted. The sequences of rains were classified in four 5-year series of storms. This

Table 1. Coefficients, Exponents and Correlations of Multiplicative Relationships

	i_{mx} summer	i_{mx} autumn	i_{mx} winter	i_{mx} spring	c_{av} summer	c_{av} autumn	c_{av} winter	c_{av} spring
Coefficient a	2.01363	2.01215	1.85127	2.18306	0.53504	0.61701	0.63716	0.55233
Exponent b	1.06464	1.01204	1.0793	0.9805	-0.19363	-0.46471	-0.25871	-0.2717
Correlation Coefficient	0.9196	0.9300	0.9043	0.9035	-0.2043	-0.4235	-0.2138	-0.2766
Variance of residuals	0.41594	0.41353	0.42280	0.42497	0.63156	0.68942	0.77682	0.62678

Table 2. Means and Standard Deviations for Annual Series

Mean & Deviations	t_{ll} **(hs)**	d_{ll} **(hs)**	i_{av} **(mm/h)**	i_{mx} **(mm/h)**	c_{av} **(adim)**
Annual Data	120.10±188.93	3.80±2.69	3.81±3.66	8.86±9.19	0.44±0.24
1st Quarter	149.10±266.84	3.49±2.69	4.18±4.10	9.01±9.21	0.46±0.39
2nd Quarter	137.60±195.49	3.63±2.49	3.54±3.60	7.66±7.86	0.42±0.40
3rd Quarter	123.39±178.62	3.67±2.79	3.79±3.68	8.22±8.11	0.46±0.39
4th Quarter	129.33±282.86	3.67±2.72	4.00±4.19	8.66±9.25	0.46±0.40

series were statistically analyzed in order to compare with the data series (Table 2). The following was observed:

1. The intervals between rains for the annual series demonstrate that the number of storms per year oscillates between 60 and 70. A very good correlation with the general frequencies of rains was observed. Also, the synthetic module annual total (1021 mm) was very near to the regional one observed (1000 mm.).

2. The advance coefficients of the storms do not present a high seasonal or annual variability. The winter series are those that show great dispersion of results, which agrees with data. Taking an interval of 10% around the average values of data, it could be affirmed that spring and winter showed eight cases outside of this interval, fall six cases, and summer four cases. Generally, the standard deviations in both simulated series and actual data were similar.

3. Seasonal and annual relationships between i_{mx} and i_{av} were studied. A triangular shape for a hyetograph implies that the named distribution coefficient $c_{di} = i_{av} / i_{mx}$ equals 0.5, since $i_{mx} * d_{ll} /2 = i_{av} * d_{ll}$. This relationship between intensities was shown by the regression coefficients (Table 1). It can be seen that the exponent $\boldsymbol{b}$ is near unity (linear relationship), and that $\boldsymbol{a = c_{di}^{-1}}$ is near to 2. The distribution of frequencies of c_{di} was analyzed in the annual and seasonal series of the data. Figure 2 shows the relative frequencies of c_{di} for annual data. A strong tendency of the storms to be distributed in triangular shape (c_{di} =0.5) can be seen, although a minor portion spreads to the hyperbolic shape (c_{di} = 0.3), similar to the Chicago hyetograph. Despite the fact that deviations exist, a triangular distribution constitutes a simple and representative tool.

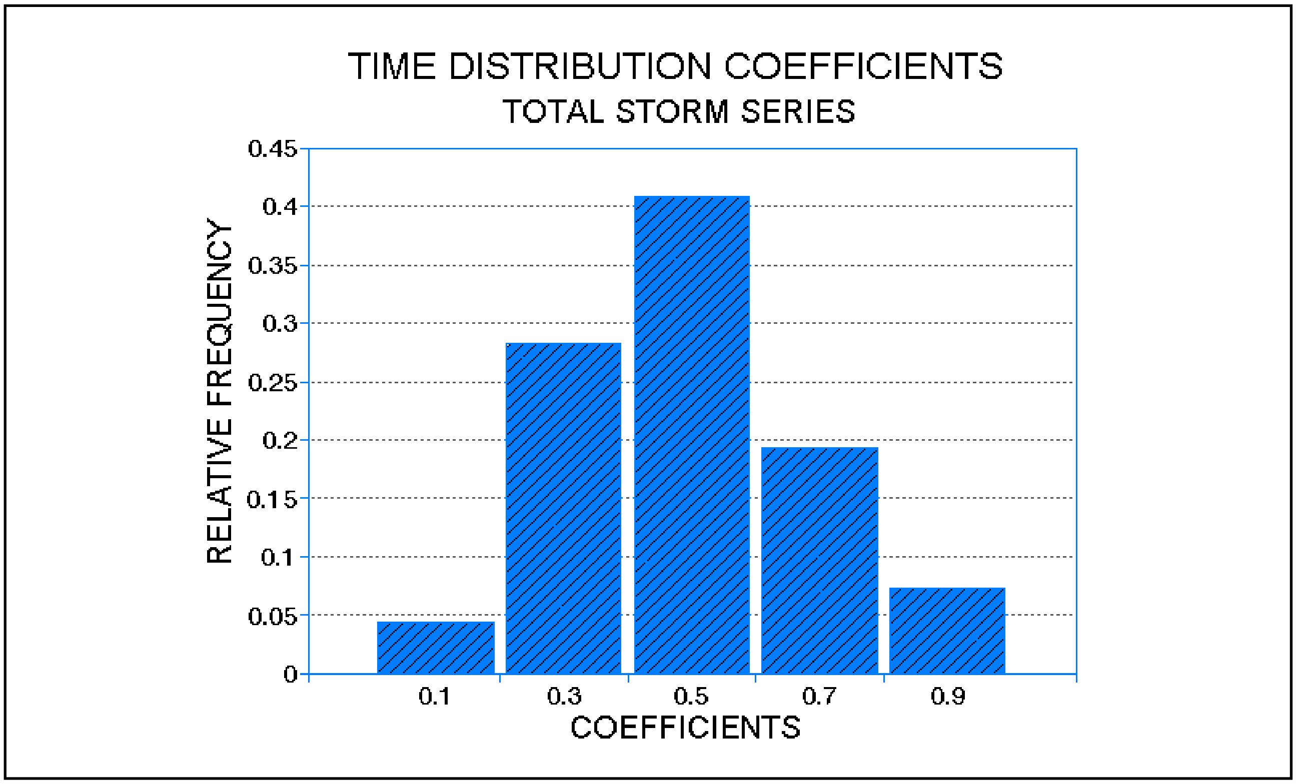

Figure 2. Relative frequencies of c_{di} for annual data.

CONCLUSION

The synthetic series of storms obtained present the same statistical pattern as the observed series. The same behavior is observed for the seasonal series except for the winter. In this case, the great deviation in the results is probably due to the small number of events during winter, which is the driest season. The methodology proposed to generate sequences of synthetic storms is believed to be reliable and can be used to analyze the vulnerability of hydrological systems in flatlands by means of the operation of rainfall-runoff models.

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