Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 1575-1583.

EXTREME PRECIPITATIONS IN ARGENTINA

Mariano Re[1,2], Ramiro Saurral[1] and Vicente R. Barros[1,3] *

[1] Department of Oceanic and Atmospheric Sciences, School of Natural and Exact Sciences, University of Buenos Aires.

[2] Computational Hydraulics Program, Hydraulics Laboratory, National Institute for Water.

[3] CIMA, UBA/CONICET.

1. INTRODUCTION

Over the last few decades the South Eastern region of South America has witnessed important increases in mean and extreme precipitations, and consequently severe floods with higher frequency. Important productive zones and numerous urban centers have suffered the effects of this problem. Barros & Bejarán (2005), wonder whether the higher level of precipitations and the changes in extreme events of the last decades will continue in the coming decades or whether, on the contrary and according to an extended view among some professional circles, it is simply a humid cycle; the conclusion they arrive at is that the present change is generalized over an enormous surface area with an accumulated duration of three decades; therefore, they argue, it would be more appropriate to speak of climate change rather than of humid cycle.

Given this situation and the context of Climate Change, the classic tools to assess risk of flood and design infrastructure, based on the hypothesis of stationary climate series, are not enough. In this work we make an approach to the new methodologies that allow us to identify and analyze non-stationary series of precipitations.

In order to carry out this study, 44 years of data were used (1959-2002 period) in 45 meteorological stations throughout the Central and Eastern Argentine territory (data provided by the National Meteorological Service) (Figure 1). Once established the objective of studying extreme precipitations, the daily series were turned into precipitation series of two days with the idea of getting a better picture of extreme rainfall. Observations are made once a day, existing the possibility of occurrence of an extreme event that spreads over the two days surrounding the moment of observation. Therefore, this transformation consisted in computing for day d_i the precipitation corresponding to that very day plus that of the following day (p_i+p_{i+1}), choosing as representative, and with the aim of maintaining independence among the data, the maximum of each event.

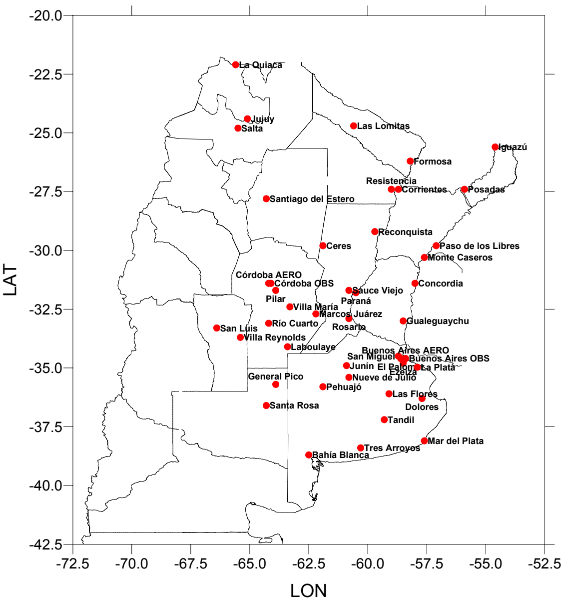
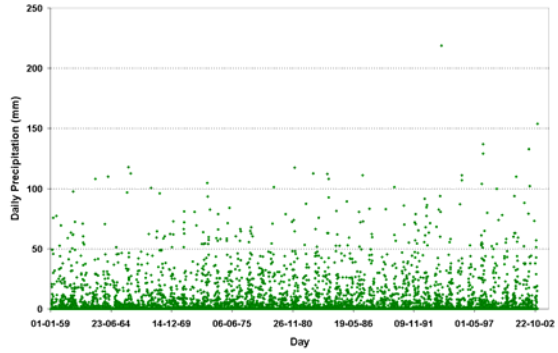


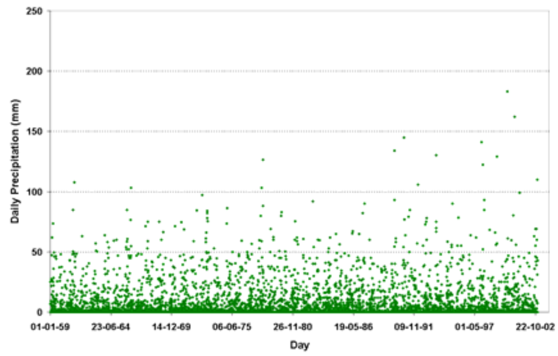
Figure 1: Meteorological stations

A preliminary analysis allows us to prove that in the period under study there have been changes in the intensity and frequency of extreme events of precipitation. Figure 2 presents the daily series of precipitation at four stations: Ceres and Sauce Viejo (province of Santa Fe), Río Cuarto (Córdoba) and Monte Caseros (Corrientes), where we can observe a more frequent occurrence of intense precipitations towards the end of the period.

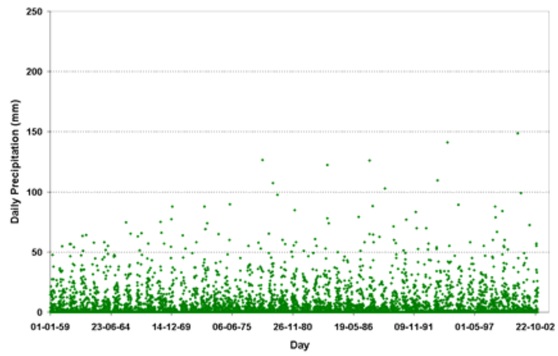
* Corresponding author address: Mariano Re, Department of Oceanic and Atmospheric Sciences, University of Buenos Aires, e-mail: mre@fi.uba.ar



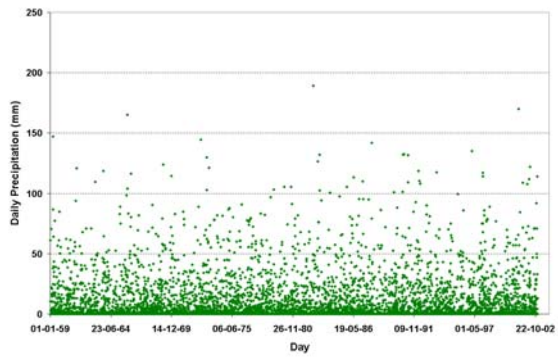
a) Ceres



b) Sauce Viejo



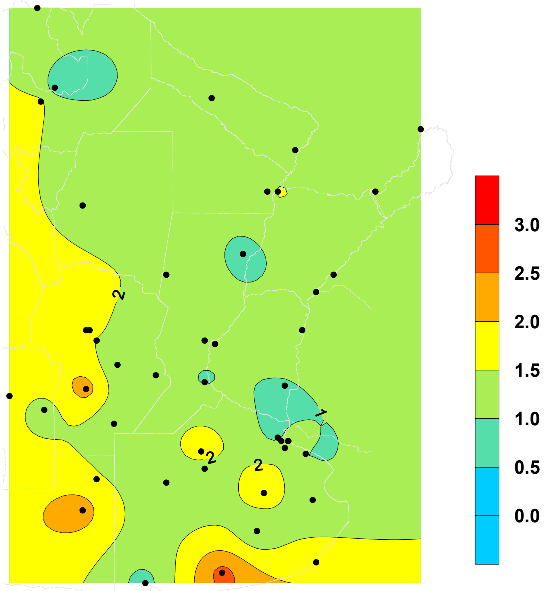
c) Río Cuarto



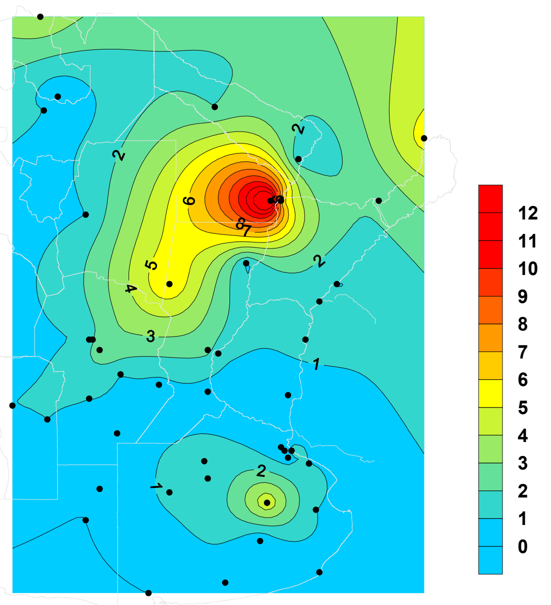
d) Monte Caseros

Figure 2: Series of daily precipitations (1959-2002)

As to the frequency of occurrence of extreme events, the study of the number of precipitations that exceed a certain threshold reveals an occurrence sensibly greater towards the end of the period as compared with the beginning. Figure 3 shows the quotient of the number of events occurred in the period 1983-2002 with reference to the period 1959-1978 that exceed the 75 and 150 mm thresholds.



a) Threshold: 75 mm



b) Thresholds: 150 mm

Figure 3: Quotient of frequencies (1983-2002 / 1959-1978).

From Figure 3 we can infer that the increase in the frequency of extreme precipitations has been general throughout the central and eastern regions of the country. In the western and southern areas of the studied region, where precipitations have lower incidence, this increase becomes evident in the events of more than 75 mm where the quotient of frequencies more than doubled in the second period with respect to the first. Towards the east, that quotient is greater than 1 and lower than 2 in vast areas of the territory showing an increase in frequency of a much lesser extent than the one that occurs with the 150 mm threshold. With this threshold there is no more increase in the west and south because in those less rainy regions, such extreme events are extremely rare.

Finally, we should calculate the significance of these trends. The objective of this study is to quantify trends in the increase of intensity and frequency of extreme precipitations in central and eastern Argentina and its significance.

2. ANALYSIS OF THE INTENSITY OF EXTREME PRECIPITATIONS

2.1 Methodology

The tails of probability distributions of climatic variables are of special interest because they allow us to model extreme events with low probability of occurrence; in the case of daily precipitation it is the right tail area of the probability distribution which allows this type of modeling (Morata Gasca & Almarza Mata, 2002).

The distribution most commonly used in studies of climatic extremes is GEV Type I (Gümbel), applied to a set of data made up of annual maximums (Block Maxima Approach). The great advantage of Gümbel distribution is that very few decisions are needed from the user, but its disadvantage is that it does not use all the data available on the upper tail of the probability distribution. In a theoretical approach, Koutsoyiannis (2004) shows that the GEV Type I distribution is quite unlikely to apply to hydrological extremes and its application may misjudge the risk as it underestimates seriously the largest extreme rainfall amounts. An alternative to this idea comes from hydrology, and it is a technique that uses the Peak Over Threshold (POT) approach with the idea of making better use of the existing data (Katz *et al.*, 2005). Nevertheless, with this technique the user must make more decisions to use it satisfactorily; for example, he must choose the threshold and distance of minimum separation (Palutikof *et al.*, 2004).

The asymptotic distribution most commonly used to describe the behavior of events of a magnitude higher than a certain threshold is the Generalized Pareto Distribution (GPD). This distribution has a shape parameter γ and a scale parameter σ, and its accumulated probability distribution function is the following:

$$F(x;\sigma,\gamma) = 1 - \left[1 - \frac{\gamma}{\sigma}\cdot\left(x-u\right)\right]^{-1/\gamma} \qquad (1)$$

where u is the chosen threshold, and the differences between x and u are the exceedances. The shape of *F(x)* for the case $\xi=0$ is a function of the accumulated probability of exponential distribution, that has a simpler shape than GPD distribution, since it only requires one parameter instead of two.

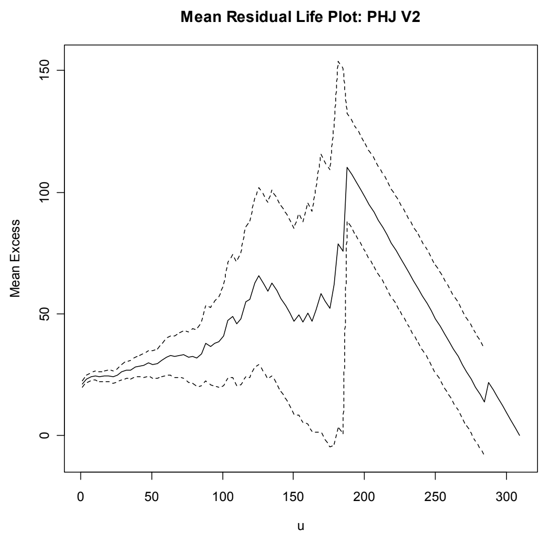
In order to make adjustments in the different precipitation series we used the ExtRemes toolkit that forms part of NCAR's (National Center for Atmospheric Research) Scientific Initiative for the Assessment of Weather and Climate Impact in the USA. ExtRemes consist of a Graphical User Interface (GUI) to model extreme values, with the object of using it to facilitate the application of the Theory of Extreme Values in problems related to climate. This tool allows us to participate in the enhancement of data in the upper tail of distribution probability, in the detection of trends by introducing co-variables and in the development of statistical models physically more realistic (Gilleland *et al.* (2004), Gilleland & Katz (2006)).

2.2 Adjustment of the series of precipitation to the Generalized Pareto Distribution

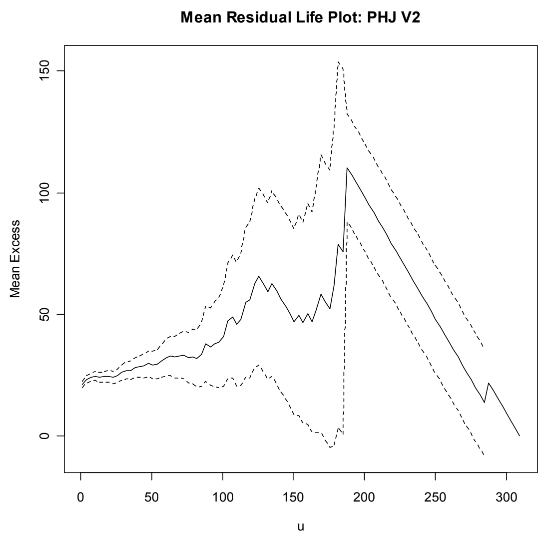
In POT methodology (Peaks Over Threshold) the choice of threshold is not a very simple task, being the result of a compromise between high and low values. A very low threshold guarantees a series with greater number of observations, but it may happen that the asymptotic theorem that fundaments the GPD may not be considered exact when it conducts a biased assessment. On the other hand, a threshold too high generates very few exceedances, something that produces a high variance in the assessment (Beguería, 2005).

There are several methods to search for optimal thresholds and in this work we use the one proposed by Coles (2001), which consists of making, for each series of data, the graphics of the mean exceedances of a certain number of thresholds. For that we use the mean sample of the exceedances series over a threshold u*, as assessor of the value expected from the exceedances. Where the graphic is approximately linear, there is an interval of thresholds capable of being selected. For the assessment we used one of the functions of the extRemes set of tools. We obtained a graphic called Mean Residual Life Plot where mean exceedances are represented for 100 different thresholds taking into account a level of confidence of 95%.

Graphics for mean exceedances were drawn for all the analyzed precipitation series; in figure 4 two of them can be observed. From the observation of these results we conclude that the threshold of 50 mm is a compromise option for all the series.



a) Pehuajo (Serie 2 days)



b) Sauce Viejo (Serie 2 days)

Figure 4: Mean Residual Life Plots. Search of thresholds.

GPD was adjusted to each of the series, obtaining as a result agreements of a quality similar to the one shown in figure 5. The method of adjustment is that of Maximum Likelihood (ML), which consists of searching the parameters that maximizes the likelihood function (Clarke, 2005).

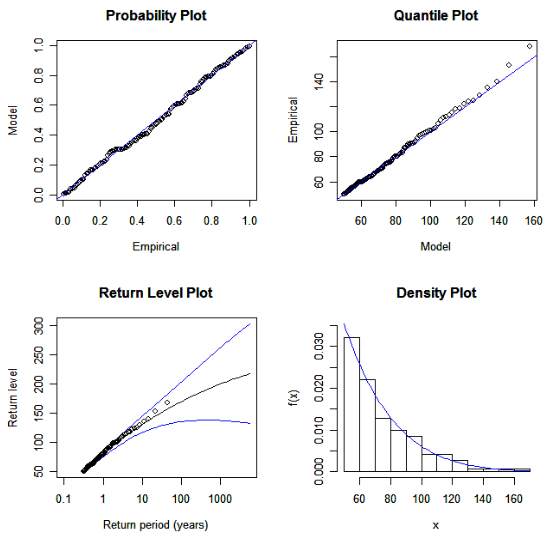


Figure 5: Fitting the GPD to the serie at Villa Maria station.

Methods based on likelihood allow us to model different situations, such as seasonal variability or long-term trends, to explain variability o non-seasonality of GPD distribution (Méndez *et al.*, 2005). It is for this reason that, in order to detect the presence of temporal trends in the values of intensity of the precipitation series analyzed, they were again adjusted to GPD, but assuming linear variation in time for the scale parameter σ ($\sigma(t)= \sigma_0+\sigma_1.t$). The scale parameter accounts for the *power* of an extreme event, and it is prone to vary with time. The shape parameter describes a physical behavior of a particular variable, and therefore in our case, can be considered constant. Figure 6 shows one case of fitting the GPD with linear trend in the scale parameter.

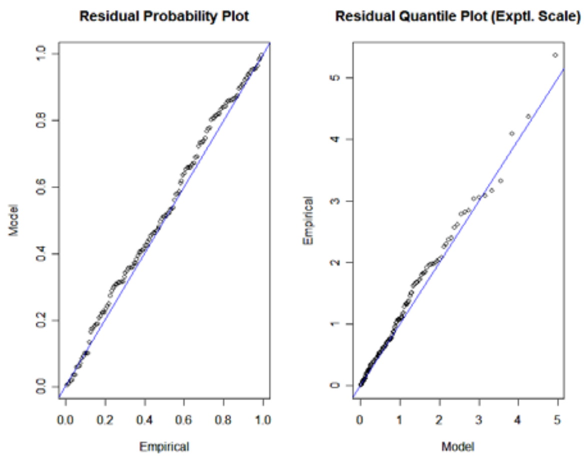
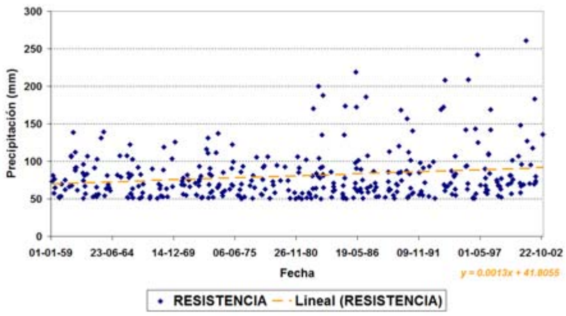


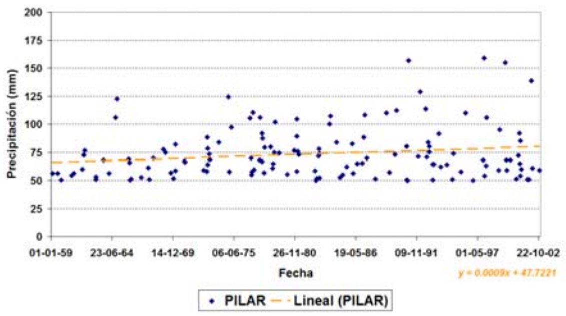
Figure 6: Fitting of GPD with linear trend to the serie at Villa Maria station.

From the comparison between the two adjustments (with and without linear trend) the best of all was identified by implementing the Likelihood-ratio Test (Gilleland *et al.*, 2004). This is a statistical proof of the accuracy of the fitting between both models, where one model relatively more sophisticated than the other is compared to see if that particular adjustment is significantly better. This methodology is valid when analyzing nested models, which means that the more sophisticated model differs from the previous one only in the addition of one or more parameters (in our case the more sophisticated model is the one with variable scale parameter in time, $\sigma(t)=\sigma_0+\sigma_1.t$). Likelihood-ratio Test's statistics follows approximately a chi-squared distribution, therefore in order to determine if the difference between models is statistically significant we consider the degrees of freedom that represent the number of parameters that are added to the more sophisticated model.

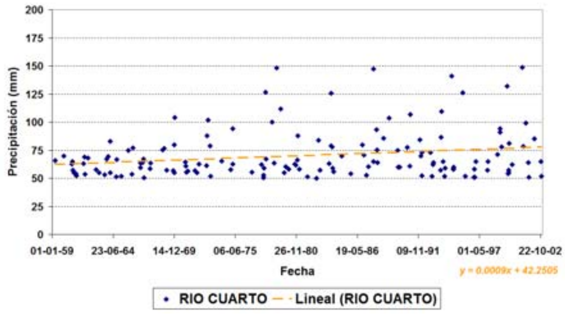
We made the Likelihood-ratio Test for each pair of adjustments to each series being analyzed (45 stations). The two adjustments were referred to the GPD with a threshold of 50 mm. Results showed that only three stations present a better adjustment to the GPD model with trend and a level of significance of 95%; those figures are shown in figure 7.



a) Resistencia



b) Pilar



c) Río Cuarto

Figure 7: Series with significant linear trend in the scale parameter (the orange line represents a least-square fitting)

3. ANALYSIS OF THE FREQUENCY OF OCCURRENCE OF EXTREME PRECIPITATIONS

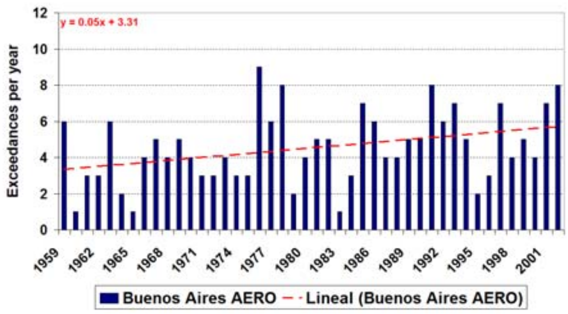
In order to detect trends in the frequency of occurrence of precipitations in the studied region, we registered the events occurred in all the stations of observation that exceeded different threshold levels.

To the study of the frequency of occurrence of extremes precipitations, we make an approach analyzing each station (not in a regional aspect), assuming that the frequencies of extremes are Poisson distributed. The Poisson distribution is fundamental as a model for the occurrence of randomly occurring events in time (Coles, 2001):

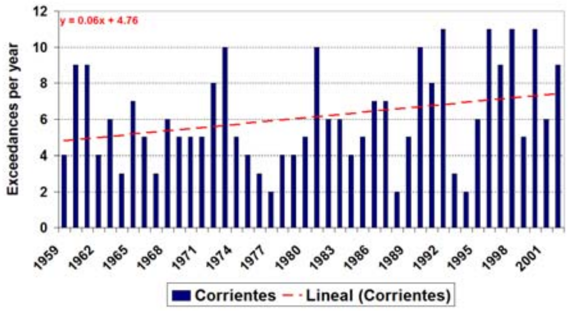
$$f(x)=\frac{e^{\lambda}\cdot\lambda^{x}}{x!} \qquad (2)$$

A property of the Poisson distribution is that the mean and variance are the same and are equal to the rate parameter, λ. The Poisson ssumption implies that the occurrences are independent (Beguería, 2005). The χ^2 statistic of each series of frequency indicates the significance of the difference in the mean and variance.

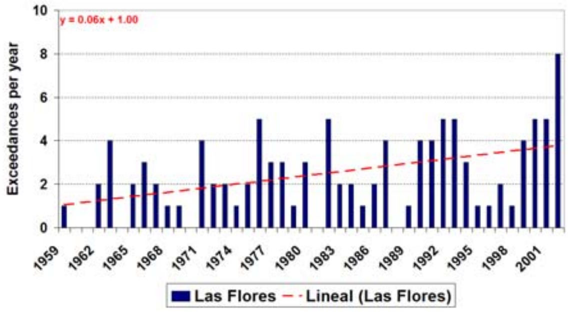
In this case we choose the threshold of 50mm and studied the frequency of occurrence of series like those from figure 8.



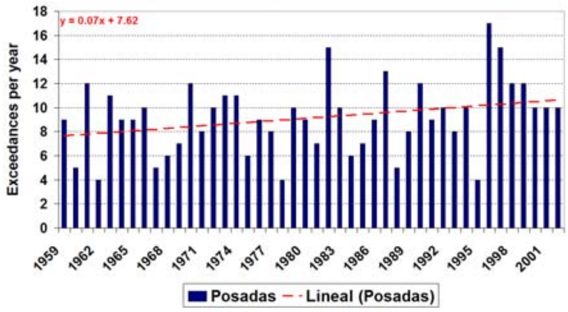
a) Buenos Aires AERO



b) Corrientes



c) Las Flores



d) Posadas

Figure 8: Frequency of occurrence of precipitations that exceed a threshold of 50 mm (the red line represents a least-square fitting)

In all cases (45 stations) the χ^2 statistic shows that there are no significant difference between the mean and variance, indicating as appropriate the Poisson model.

To detect evidence of trends in frequency, we take time-varying arrival rates in a non-stationary Poisson process. The fitted values for the Poisson rate parameter model are:

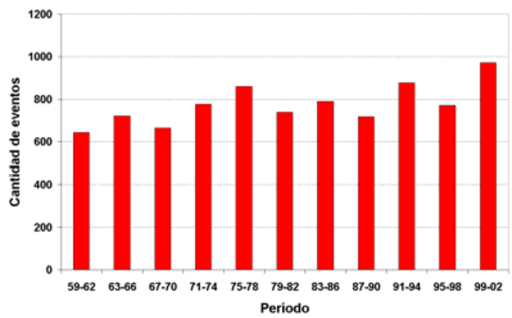
$$\log \lambda(t) = \lambda_0 + \lambda_1 . t \quad \textit{(with } t = 1, \ldots, 44\textit{)} \qquad (3)$$

To compare the stationary fitting versus the non-stationary one, a Likelihood-Ratio Test was made where the ratio is the null model (of no trend in the data) to the model with a trend. In 24 stations, the addition of time as a covariate shows some significance, indicating an evidence of trend in the frequency in more than fifty percent of the series.

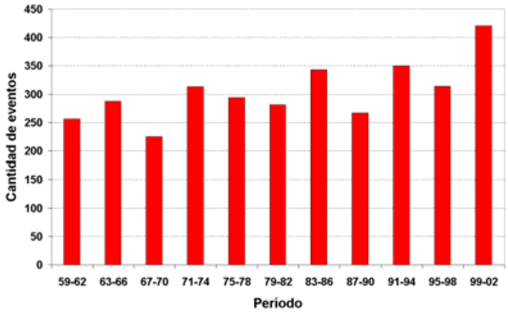
The evidence is not overwhelming in this case (when individual sites are analyzed separately), but becomes stronger when either relatively long records are available or when regional analyses are performed.

In order to make more regional our analysis, we added all the occurrences of events over a threshold of each station of each year. To test the significance, or lack of it, of the trends we used the Mann-Kendall Test, a non-parametric test that makes no assumptions about the distribution of probabilities of the variable analyzed (Clarke, 2005). With this test we want to accept the null hypothesis, which claims that observations are ordained at random and identically distributed versus the alternative hypothesis of a monotonous trend in time.

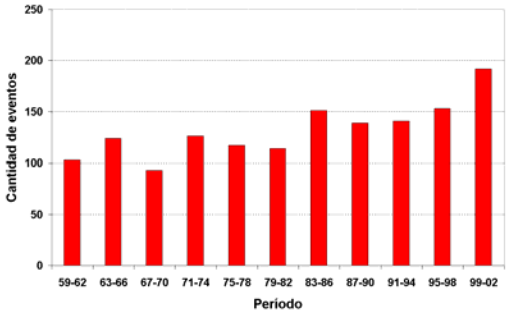
To achieve greater independence, we included the events occurred in periods of four years from 1959-1962 to 1999-2002 obtaining as a result new series of extremes (Figure 9). A priori, we observe a greater variation in the occurrence of precipitations of thresholds greater than 100 mm. Furthermore, the positive trend appears as from the 1980's.



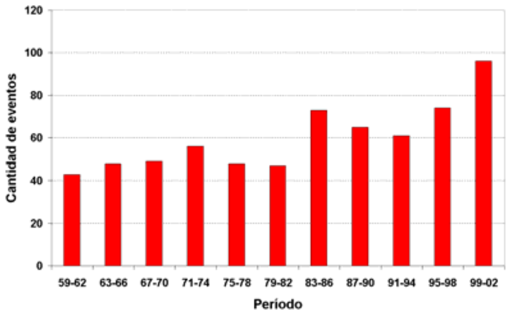
a) Threshold 50 mm



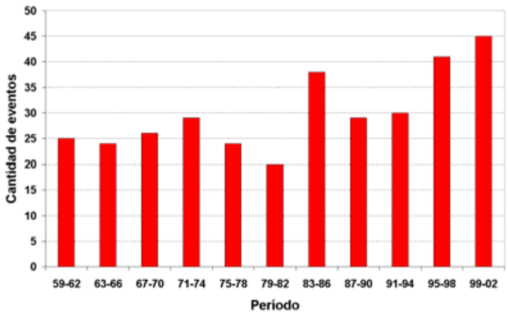
b) Threshold 75 mm



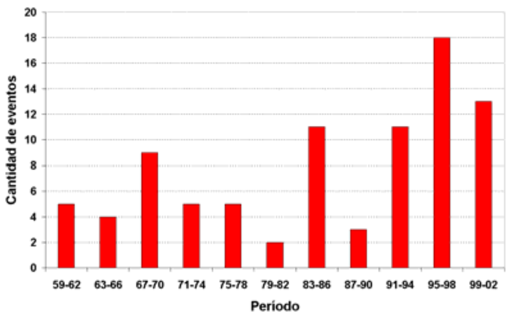
c) Threshold 100 mm



d) Threshold 125 mm



e) Threshold 150 mm



f) Threshold 200 mm

Figure 9: Frequency of occurrence of precipitations that exceed different thresholds

The results of the Mann-Kendall Test for the 6 series of frequency of occurrence of extreme precipitations show a rejection of the null hypothesis for 5 of them (thresholds 50 mm, 75 mm, 100 mm, 125 mm and 150 mm). This means that these series are not homogeneous, and present growing trends with a level of significance of 95%.
With the purpose of study these trends with a greater degree of detail, we divided the area into three regions taking into account the different characteristics of precipitation in each one of them (Figure 10).

Region 1: Buenos Aires, La Pampa, San Luis and Córdoba.

Region 2: Entre Ríos, Santa Fe, Santiago del Estero, Tucumán, Salta and Jujuy.

Region 3: Misiones, Corrientes, Chaco and Formosa.

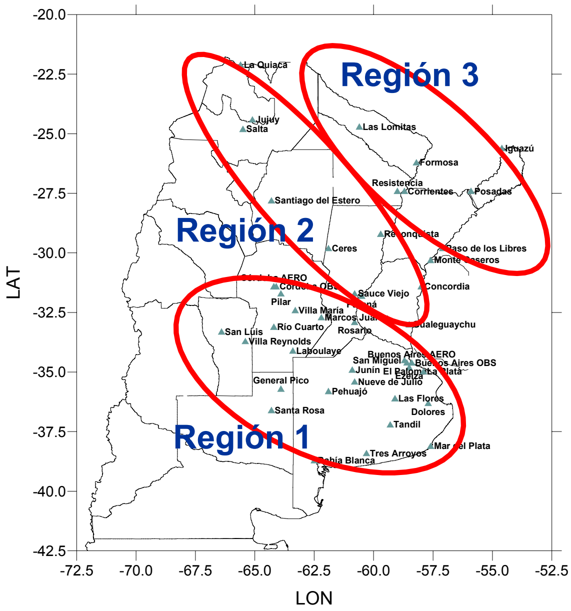
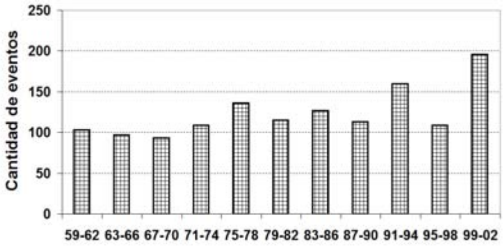
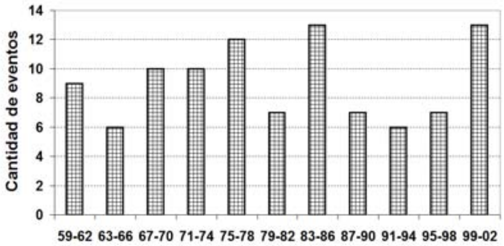


Figure 10: Regions for frequency of occurrence analysis of extreme events.

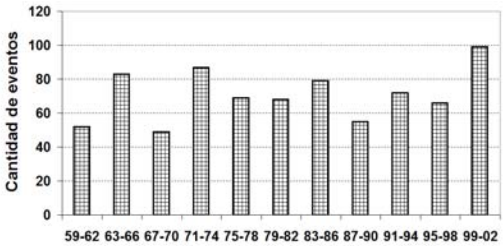
For this regional analysis only thresholds of 75 mm and 150 mm were taken into account. The series made for each region and for each threshold, also obtained from 4-year periods, are shown in figure 10.



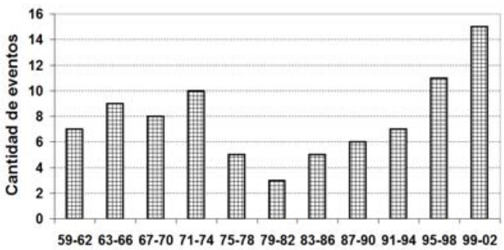
a) Region 1 - Threshold 75 mm



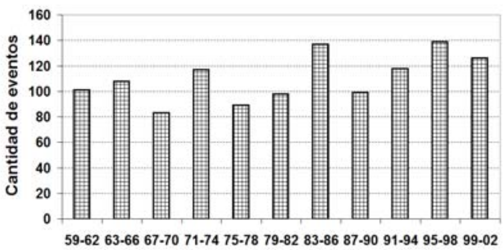
b) Region 1 - Threshold 150 mm



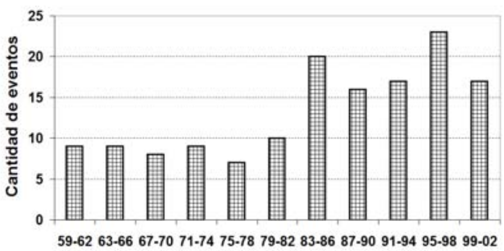
c) Region 2 - Threshold 75 mm



d) Region 2 - Threshold 150 mm



e) Region 3 - Threshold 75 mm



f) Region 3 - Threshold 150 mm

Figure 10: Frequency of occurrence of precipitations that exceeds different thresholds by region.

From the Mann-Kendall Test for these series, we conclude that those that present a positive trend are the one in Region 1 above a threshold of 75 mm and the two of Region 3. The level of significance of these tests is of 90%. These results relate to the different characteristics, in intensity, of the extreme events in the different zones of Central and Eastern Argentina.

4. CONCLUSIONS

The aim of the paper lies in the identification of significant linear trends in the intensity and frequency of extreme precipitations in Central and Eastern Argentina. We have conducted an extreme value analysis of daily rainfall for 45 locations.

In the last few decades in the Center and East of Argentina it was registered a higher frequency of extreme events, but not in the extreme values of precipitation. The IPCC in its third report (IPCC, 2001) points out that this behavior is expected in a context of global warming and it has already been observed in many regions of mean latitude in the Northern Hemisphere during the second half of the last century. In our case, this suggests a greater occurrence of events of extreme characteristics, which translates into a greater vulnerability of the people and infrastructure potentially affected.

5. REFERENCES

Barros, V.R., Bejarán, R., 2005, Adaptación al cambio climático en Argentina ¿Dónde estamos?, Working Paper, Departamento de Ciencias de la Atmósfera y los Océanos, FCEyN - UBA.

Beguería, S., 2005, Uncertainties in partial duration series modelling of extremes related to the choice of the threshold value, Journal of Hydrology, 303, 215–230.

Clarke, R., 2005, Chapter 16: statistical analysis of extreme events in a non-stationary context. From the book in press: Cambio climático en el Río de la Plata: Nuevas herramientas para las proyecciones climáticas e hidrológicas.Eds. V. Barros, R Clarke y P. Silva Días.

Coles, S., 2001, An introduction to statistical modeling of extreme values, Springer-Verlag, London, UK.

Gilleland, E., Katz, R.W., Young, G., 2004, Extremes toolkit (extRemes): weather and climate applications of extreme value statistics, NCAR.

Gilleland, E., Katz, R.W., 2006, Analyzing seasonal to interannual extreme weather and climate variability with the extremes toolkit (extRemes), 18th Conference on Climate Variability and Change, 86th American Meteorological Society (AMS) Annual Meeting, 29 January - 2 February, Atlanta, Georgia. P2.15.

IPCC, 2001. Climate Change 2001: The Scientific Basis. Cambridge University Press, USA, 881 pp.

Katz, R.W., Parlange, M. B., Naveau, P., 2002, Statistics of extremes in hydrology, Advances in Water Resources, 25, pp. 1287–1304.

Katz, R.W., Brush, G.S., Parlange, M.B., 2005, Statistics of extremes: modeling ecological disturbances, Ecology, 86(5), pp. 1124–1134.

Koutsoyiannis, D., 2004, Statistics of extremes and estimation of extreme rainfall: 1, Theoretical investigation, Hydrological Sciences Journal, 49(4), 575-590.

Méndez, F.J., Menéndez, M., Luceño, A., Losada, I.J., 2005, A model for the analysis of trends of extreme value wave climate, Ocean Waves Measurement and Analysis, Fifth International Symposium WAVES 2005, 3-7 de Julio, 2005, Madrid, Spain.

Morata Gasca, A., Almarza Mata, C., 2002, Ajuste de la distribución de probabilidad de máxima precipitación diaria en Santa Cruz de Tenerife a la Distribución Generalizada de Pareto, III Congreso de la Asociación Española de Climatología, 16-19 de junio, Palma de Mallorca, España.

Palutikof, J.P., Holt, T., Brabson, B.B., Lister, D.H., 2004, Methods to calculate extremes in climate change studies, Climate Research Unit, University of East Anglia, *http://www.cru.uea.ac.uk/projects/mice/extremes_description.pdf*.