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# CHANGES IN EXTREME TEMPERATURES RETURN PERIODS OVER ARGENTINA

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## 1. INTRODUCTION

The extreme events influence the ecosystems and the society severely. The high and low temperatures are one of the most studied extreme events, since their occurrence concerns severely the agriculture (many crops could be affected by the number of frost days per year, or by the quantity of hot days per year), the human health (the last heat wave that affected Europe caused more than 15.000 deaths), the water resources and the availability of drinkable water, the demand of energy, among others. Under a climatic change, a small variation in the average values of temperature, could cause big changes in the daily temperatures.

The study of historical values has shown that persistence and intensity of extreme values of temperature has been changing anywhere in the world (Bonsal et al. 2001, Collins et al. 2000, Frich et al. 2002, Manton et al. 2001, Vincent et al. 2005, Klein-Tank and Können 2003, Alexander et al. 2006) and also in Argentina (Barrucand and Rusticucci 2001, Rusticucci and Barrucand 2004). In general, the minimum and maximum temperatures have increased their value, although in different intensity, leading to decrease of daily temperature range. Changes of extreme temperatures, which can be present before an increase of $CO_2$ (Zwiers and Kharin 1998), can cause severe impacts especially if it is not prepared for them (Schubert and Henderson-Sellers 1997)

In this paper changes in return periods of annual extreme temperatures are studied with the aim of evaluate the observed climate change in return levels through the XXth century in Argentina.

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## 2. DATA AND METHODOLOGY

Daily maximum and minimum temperatures over the longest available periods were used to calculate the annual Highest Maximum (Minimum) Temperature called HTMx (HTMn) and the annual Lowest Maximum (Minimum) Temperature, called LTMx (LTMn).

Long term observed series starting on 1906 and 1931 were analysed. Therefore, return levels obtained by fitting a GEV distribution to the mentioned series in different periods are compared.

Goodness of fit has been analysed by the QQ plot and PP plot as well as applying the bootstrapping technique to the Kolmogorov-Smirnov test. Both the graphical and the non-parametric tests are consistent and bring a 95% confidence level of good adjustment to the GEV distribution.

Periods to be contrasted are 1906-1936, 1937-1976 y 1977-2004 –depending on records availability- in the following stations: OCBA (Buenos Aires), Pilar (Córdoba), Pergamino (Buenos Aires) and Santa Rosa (La Pampa) (see Figure 1). These periods were defined so that consequences on extreme temperatures of the climatic jump of 1976-1977 can also be analysed.

## 3. RESULTS

Time series of the stations mentioned above are shown in Figure 2. It can also be seen in this Figure the corresponding linear trend for each period, which have been substracted previous to the GEV adjustment.

### *3.1 OCBA*

In OCBA, the GEV distribution was fitted in the three mentioned periods, so that three different sets of return levels were obtained,

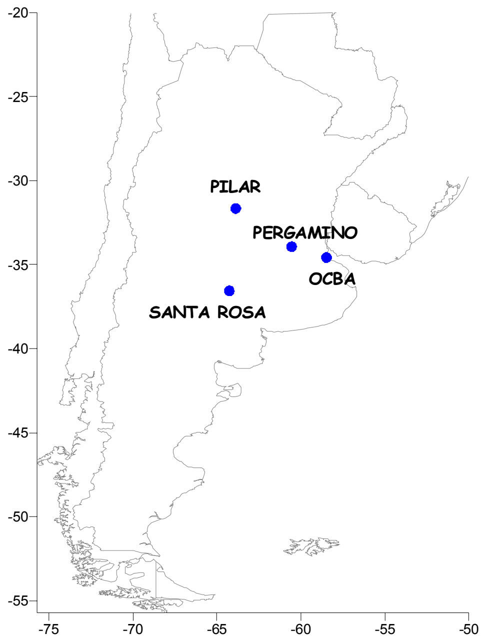


**Figure 1:** Analysed stations

which are shown in Figure 3 a), together with the difference between each other shown in Table I a). It can be seen that differences between return levels as well as uncertainty intervals are bigger as return periods increase.

For the highest and lowest MaxT, return levels obtained by fitting a GEV distribution in the period 1937-1976 are 1.4 to 3.8ºC higher than those obtained in the previous period. However, they are lower than in the more recent period, although this difference is not so important.

For the highest and lowest MinT, the sign of the difference between return levels is positive in almost all cases, showing that return levels for these extremes increase if calculations are made on more recent periods. It is important to emphasize that this enlargement is more significant in the period post-1976 than between the first two periods, when the city of Buenos Aires has increased its population. There are two aspects to be considered: firstly, the variability is principally seen in MinT; secondly, the effect of global warming observed in the last years that increased significantly the temperature trend, resulting in that 10 out of the last 11 years are the warmest of the whole record, has to be added to the effect of the city.

### *3.2 Pilar*

Due to lack of previous data, in Pilar the comparison is made only between periods 1937-1976 and 1977-2004. In Figure 3 b) and Table I b) return levels obtained for both periods and its differences are shown. It can be seen that return levels associated with summer, i.e. highest MaxT and MinT, present negative differences, meaning that return levels decrease when the GEV fit is made over a more recent period.

For the highest MaxT, differences are even greater than 5ºC for the longest return periods. This drop in return levels associated with summer extremes could be related to an increase in cloudiness and humidity due to the observed rise of precipitation.

For the lowest MaxT and MinT, the differences are positive but of less magnitude.

### *3.3 Pergamino*

Differences between return levels based on periods 1937-1976 and 1977-2004 in Pergamino are shown in Figure 3 c) and Table I c). The behaviour is similar to that observed in Pilar, with negative differences in summer extremes and positive in winter. However, the greatest differences come up in winter extremes reaching up to 6.6ºC for the lowest MaxT 1000-return level.

### *3.4 Santa Rosa*

In Santa Rosa, return levels are also calculated for periods 1937-1976 and 1977-2003. The behaviour of the difference between these two sets of return levels shown in Figure 3 d) and Table I d) is similar to the previous cases: negative for summer extremes and positive for winter. However, except the highest MaxT, the annual extremes do not show important changes in their return levels.

## 4. DISCUSSION

For OCBA, the linear trend along the complete period is positive in all the extremes studied, except in the HTMx that presents slight negative tendency. In the most recent period, 1977-2004, the warm extremes tend to diminish, whereas the cold extremes increase in the big city of Buenos Aires (OCBA). It is interesting to note that LTMn displays positive trends in each one of the sub periods studied and in the complete period, with the most important values of trends of at least 3ºC every 100 years.

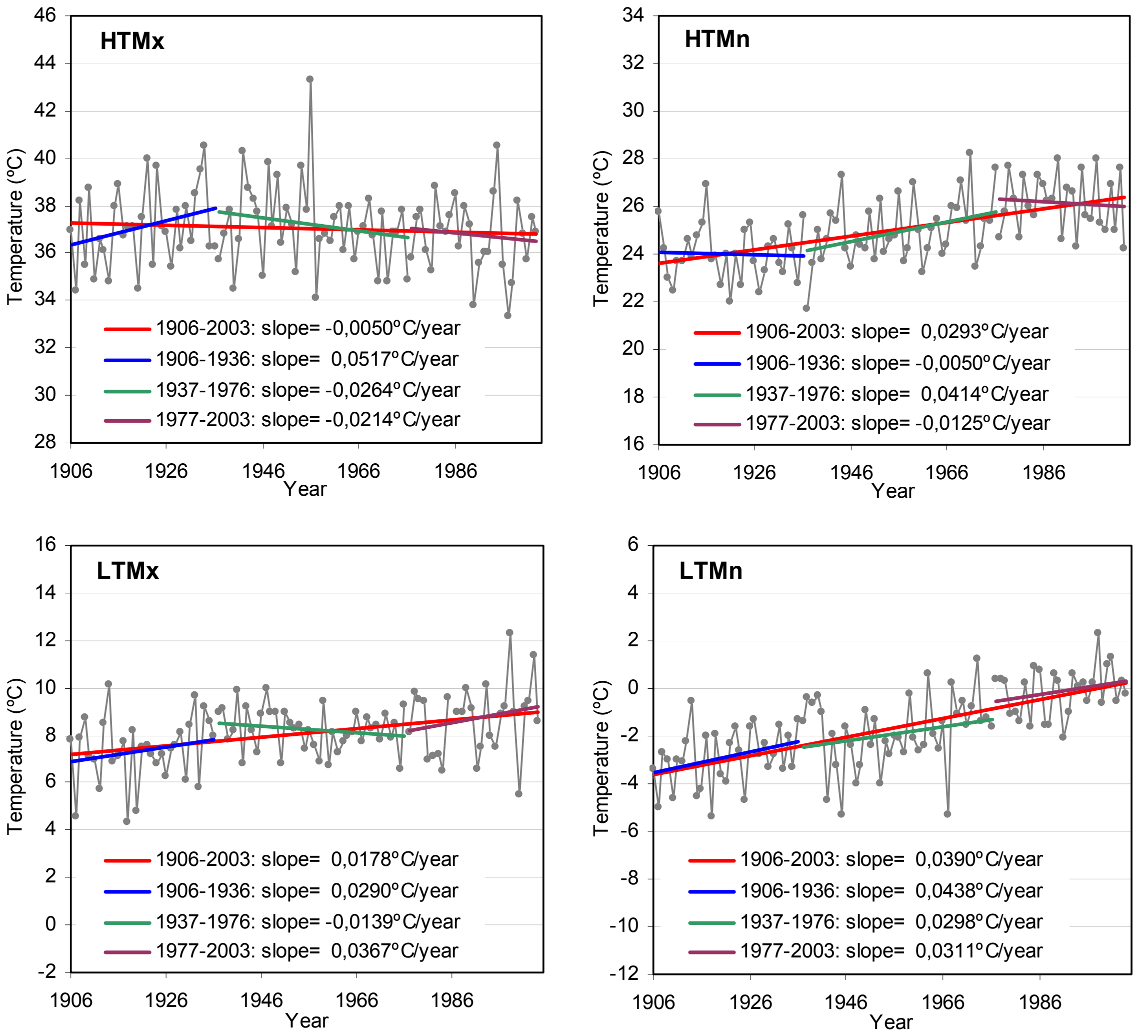


**Figure 2 a)** Time series of Highest Maximum Temperature (HTMx), Highest Minimum Temperature (HTMn), Lowest Maximum Temperature (LTMx) and Lowest Minimum Temperature (LTMn) for Observatorio Central Buenos Aires (OCBA). Superimposed are the trends for the complete period and sub periods indicated

It is possible to see that while the HTMx does not change with the basic periods, the HTMn and LTMn undergo a significant change. For example, for a return period of 10 years, the cold ends increase from -5.3 to -3.6ºC, and the warm ones from 25.1ºC to 26.6ºC. This shows that the city of Buenos Aires has increased the frequency of extreme values towards warmer values.

In the cases of HTMn and LTMn, the sign of the difference between the return values based on successive periods is positive in almost all the cases, indicating that the values of these extremes increase if we based our calculations on more recent periods, as we have previously learned. It is important to enhance that this increase in return values of highest and lowest MinT of the year is more significant in period post-1976, that between both first periods, when the city increased significantly its population. There are two aspects to be considered. On the one hand, the variability is more well-known in the minimum temperature, consistent with global results. On the other, the effect of the city is added to the effect of the greater global warming observed in the last years, when the global tendency of temperature increased significantly.

In Pilar, it can be seen that the annual warm extremes (HTMx, HTMn) present negative differences on return levels calculated on consecutive sub periods, that is to say, return values diminish if the adjustment of the GEV distribution is made on a more recent period. In the case of HTMx the highest return periods show differences of more than 5ºC in the return levels. The decrease of warm temperature extremes is observed in the whole center of the country both in the average values of the maximum summer temperature and the warm extremes (percentile 95) as was studied for the period 1959-98 in Rusticucci and Barrucand (2004). This trend could be associated with changes in the use of the soil (Bonan, 2001) or with the increase in precipitation observed in the region (Camilloni 2005).

***Acknowledgement***

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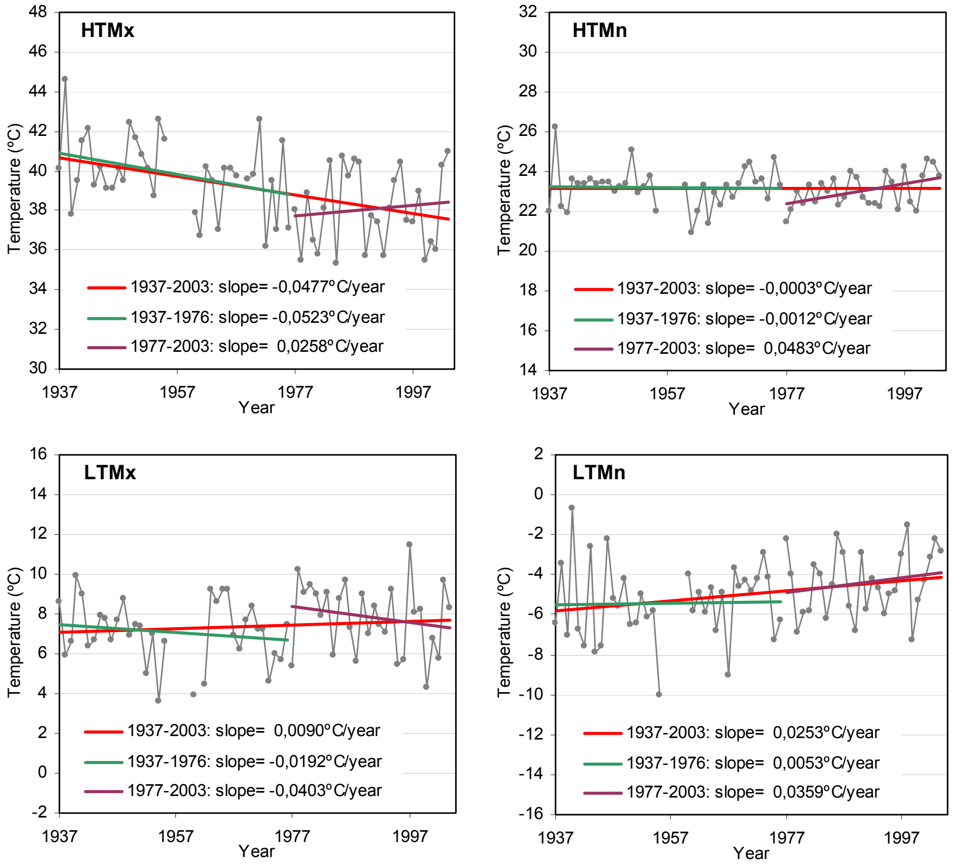



***Figure 2 b):*** *Pilar station.*

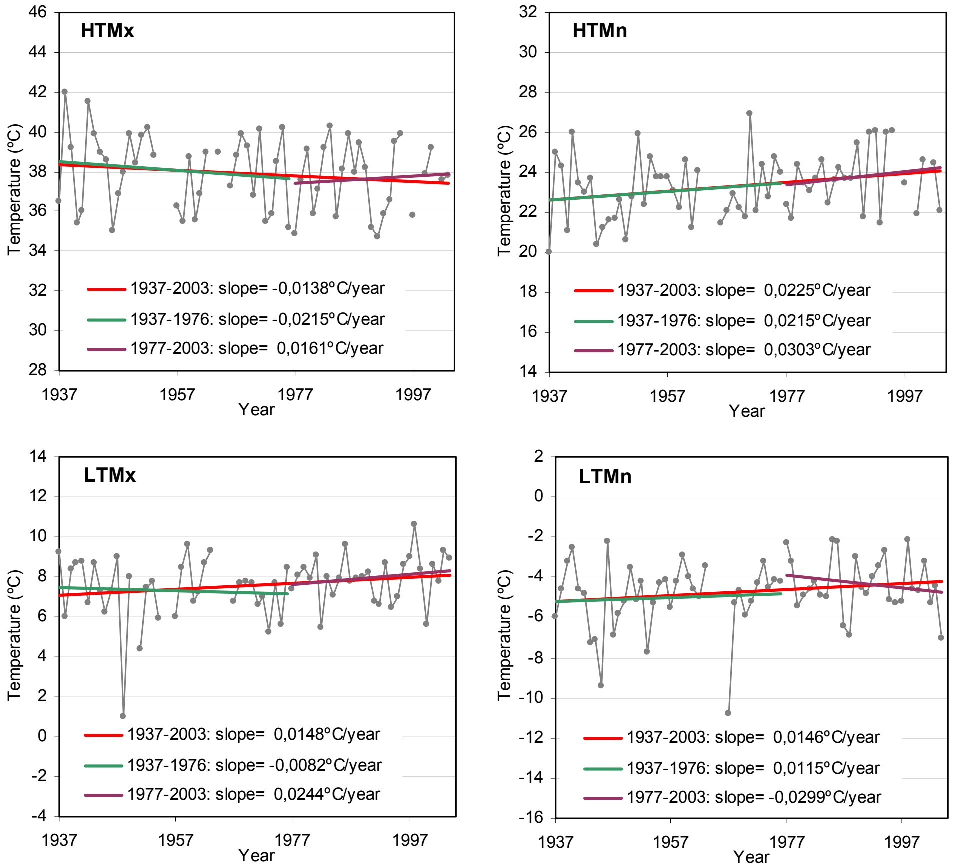
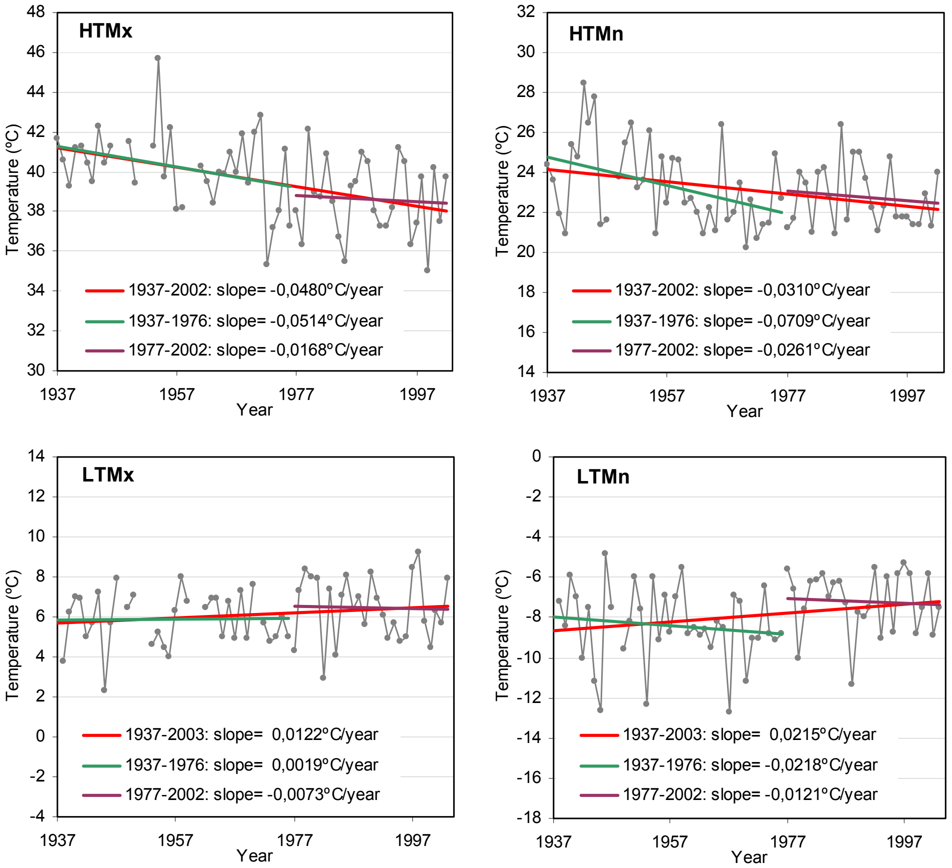



***Figure 2 c):*** *Pergamino station.*




***<u>Figure 2 d)</u>*** *Santa Rosa Station.*

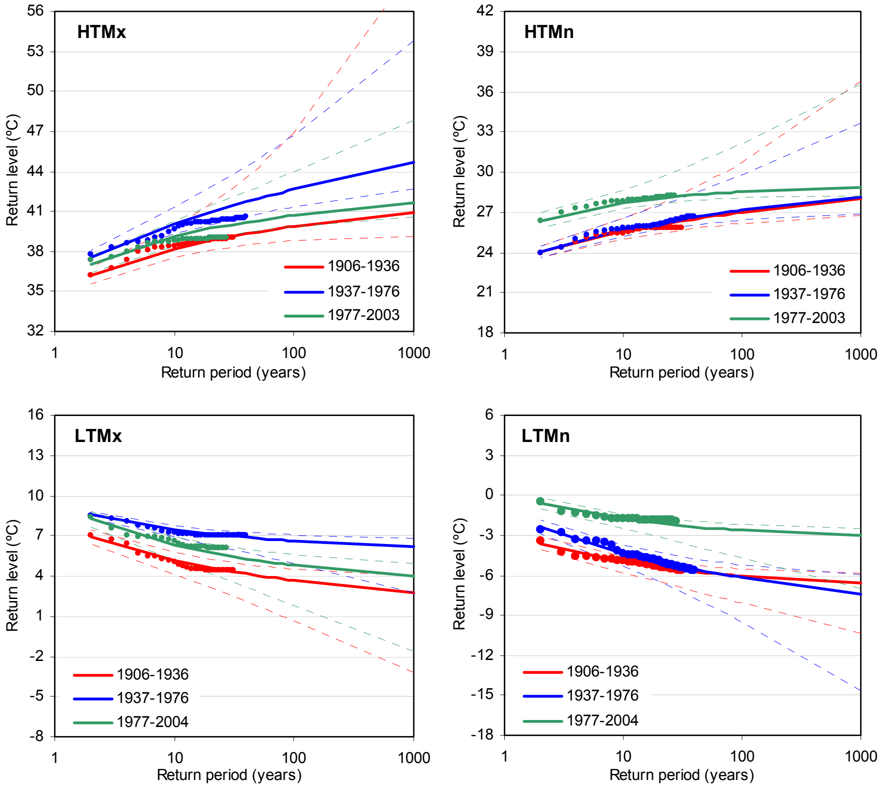



***Figure 3 a):*** *GEV distribution calculated in the periods indicated. Return levels (ºC) vs return periods (years). OCBA*.

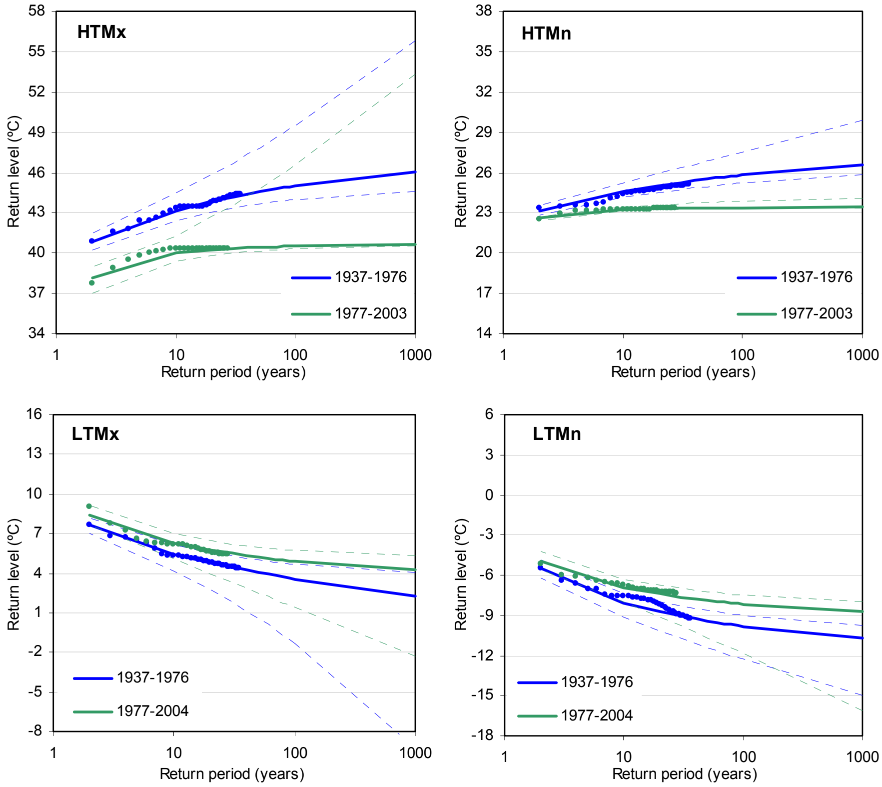



***Figure 3 b)*** *PILAR*

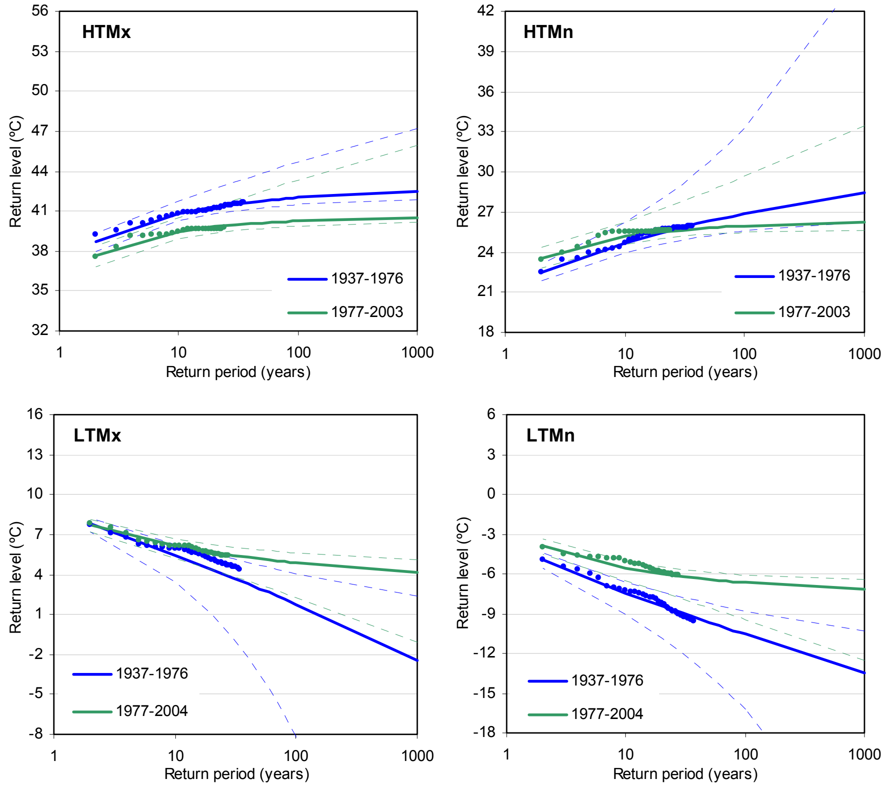



***Figure 3 c)*** *PERGAMINO*

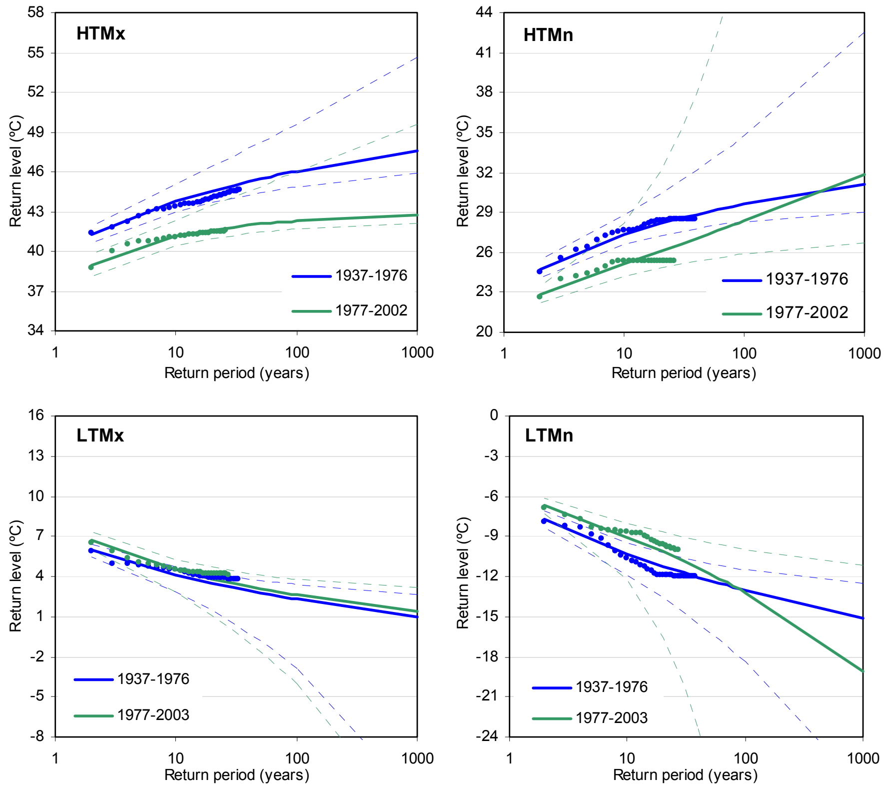



***Figure 3 d)*** *SANTA ROSA*

| HTMx | | | | | | HTMn | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Return period | Return level | | | Difference | | Return period | Return level | | | Difference | |
| | A | B | C | B-A | C-B | | A | B | C | B-A | C-B |
| 1000 | 40,9 | 44,7 | 41,6 | 3,8 | -3,1 | 1000 | 28,0 | 28,1 | 28,8 | 0,1 | 0,7 |
| 100 | 39,9 | 42,6 | 40,7 | 2,8 | -1,9 | 100 | 27,0 | 27,2 | 28,5 | 0,2 | 1,3 |
| 90 | 39,8 | 42,5 | 40,7 | 2,7 | -1,9 | 90 | 26,9 | 27,1 | 28,5 | 0,2 | 1,4 |
| 80 | 39,8 | 42,4 | 40,6 | 2,7 | -1,8 | 80 | 26,9 | 27,1 | 28,5 | 0,2 | 1,4 |
| 70 | 39,7 | 42,3 | 40,5 | 2,6 | -1,8 | 70 | 26,8 | 27,0 | 28,4 | 0,2 | 1,4 |
| 60 | 39,6 | 42,1 | 40,4 | 2,5 | -1,7 | 60 | 26,7 | 26,9 | 28,4 | 0,2 | 1,5 |
| 50 | 39,5 | 41,9 | 40,3 | 2,5 | -1,6 | 50 | 26,6 | 26,8 | 28,4 | 0,2 | 1,5 |
| 40 | 39,3 | 41,7 | 40,2 | 2,4 | -1,5 | 40 | 26,5 | 26,7 | 28,3 | 0,2 | 1,6 |
| 30 | 39,1 | 41,4 | 40,0 | 2,3 | -1,4 | 30 | 26,3 | 26,5 | 28,2 | 0,2 | 1,7 |
| 20 | 38,8 | 40,9 | 39,7 | 2,1 | -1,2 | 20 | 26,1 | 26,3 | 28,1 | 0,2 | 1,8 |
| 10 | 38,2 | 40,1 | 39,1 | 1,8 | -0,9 | 10 | 25,6 | 25,7 | 27,8 | 0,2 | 2,0 |
| 2 | 36,2 | 37,5 | 37,0 | 1,4 | -0,5 | 2 | 24,0 | 24,1 | 26,4 | 0,1 | 2,3 |

| LTMx | | | | | | LTMn | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Return period | Return level | | | Difference | | Return period | Return level | | | Difference | |
| | A | B | C | B-A | C-B | | A | B | C | B-A | C-B |
| 1000 | 2,8 | 6,1 | 4,0 | 3,4 | -2,2 | 1000 | -6,6 | -7,4 | -3,0 | -0,8 | 4,4 |
| 100 | 3,7 | 6,6 | 4,8 | 2,9 | -1,8 | 100 | -6,1 | -6,2 | -2,6 | -0,1 | 3,5 |
| 90 | 3,7 | 6,6 | 4,8 | 2,9 | -1,8 | 90 | -6,0 | -6,1 | -2,6 | -0,1 | 3,5 |
| 80 | 3,8 | 6,7 | 4,9 | 2,9 | -1,8 | 80 | -6,0 | -6,0 | -2,6 | 0,0 | 3,4 |
| 70 | 3,9 | 6,7 | 5,0 | 2,9 | -1,7 | 70 | -5,9 | -5,9 | -2,5 | 0,0 | 3,4 |
| 60 | 3,9 | 6,8 | 5,1 | 2,8 | -1,7 | 60 | -5,9 | -5,8 | -2,5 | 0,1 | 3,3 |
| 50 | 4,0 | 6,8 | 5,1 | 2,8 | -1,7 | 50 | -5,8 | -5,7 | -2,4 | 0,1 | 3,2 |
| 40 | 4,2 | 6,9 | 5,3 | 2,7 | -1,6 | 40 | -5,7 | -5,5 | -2,4 | 0,2 | 3,2 |
| 30 | 4,3 | 7,0 | 5,5 | 2,6 | -1,5 | 30 | -5,6 | -5,3 | -2,3 | 0,3 | 3,0 |
| 20 | 4,6 | 7,1 | 5,7 | 2,5 | -1,4 | 20 | -5,4 | -5,0 | -2,1 | 0,5 | 2,9 |
| 10 | 5,1 | 7,4 | 6,3 | 2,3 | -1,2 | 10 | -5,1 | -4,4 | -1,8 | 0,7 | 2,6 |
| 2 | 7,0 | 8,6 | 8,2 | 1,6 | -0,3 | 2 | -3,6 | -2,4 | -0,6 | 1,2 | 1,8 |

***Table I a)*** *Return levels for some return periods, resulting from the GEV adjustment to different periods: A: 1906-1936, B: 1937-1976, C: 1977-2004. The last two columns indicate the differences in return levels between the two periods indicated. OCBA Station.*

| HTMx | | | | HTMn | | | |
|---|---|---|---|---|---|---|---|
| Return period | Return level | | Difference | Return period | Return level | | Difference |
| | B | C | B-C | | B | C | B-C |
| 1000 | 46,1 | 40,6 | -5,5 | 1000 | 26,6 | 23,4 | -3,2 |
| 100 | 45,0 | 40,5 | -4,5 | 100 | 25,8 | 23,4 | -2,4 |
| 90 | 45,0 | 40,5 | -4,4 | 90 | 25,8 | 23,4 | -2,4 |
| 80 | 44,9 | 40,5 | -4,4 | 80 | 25,7 | 23,4 | -2,3 |
| 70 | 44,8 | 40,5 | -4,3 | 70 | 25,7 | 23,4 | -2,3 |
| 60 | 44,7 | 40,5 | -4,2 | 60 | 25,6 | 23,4 | -2,2 |
| 50 | 44,6 | 40,4 | -4,1 | 50 | 25,5 | 23,4 | -2,1 |
| 40 | 44,4 | 40,4 | -4,0 | 40 | 25,4 | 23,4 | -2,0 |
| 30 | 44,2 | 40,4 | -3,8 | 30 | 25,2 | 23,4 | -1,9 |
| 20 | 43,8 | 40,3 | -3,6 | 20 | 25,0 | 23,3 | -1,7 |
| 10 | 43,2 | 40,0 | -3,2 | 10 | 24,6 | 23,2 | -1,3 |
| 2 | 40,8 | 38,2 | -2,7 | 2 | 23,1 | 22,6 | -0,6 |

| LTMx | | | | LTMn | | | |
|---|---|---|---|---|---|---|---|
| Return period | Return level | | Difference | Return period | Return level | | Difference |
| | B | C | B-C | | B | C | B-C |
| 1000 | 2,3 | 4,2 | 2,0 | 1000 | -10,7 | -8,7 | 2,0 |
| 100 | 3,6 | 4,9 | 1,3 | 100 | -9,8 | -8,2 | 1,7 |
| 90 | 3,6 | 4,9 | 1,3 | 90 | -9,8 | -8,1 | 1,6 |
| 80 | 3,7 | 5,0 | 1,3 | 80 | -9,7 | -8,1 | 1,6 |
| 70 | 3,8 | 5,0 | 1,2 | 70 | -9,6 | -8,0 | 1,6 |
| 60 | 3,9 | 5,1 | 1,2 | 60 | -9,5 | -8,0 | 1,6 |
| 50 | 4,1 | 5,2 | 1,1 | 50 | -9,4 | -7,9 | 1,5 |
| 40 | 4,2 | 5,3 | 1,1 | 40 | -9,3 | -7,8 | 1,5 |
| 30 | 4,5 | 5,5 | 1,0 | 30 | -9,1 | -7,6 | 1,4 |
| 20 | 4,8 | 5,7 | 0,9 | 20 | -8,7 | -7,4 | 1,3 |
| 10 | 5,5 | 6,3 | 0,8 | 10 | -8,1 | -6,9 | 1,2 |
| 2 | 7,6 | 8,4 | 0,8 | 2 | -5,5 | -4,9 | 0,6 |

***Table I b)*** *PILAR*

| HTMx | | | | HTMn | | | |
|---|---|---|---|---|---|---|---|
| Return | Return level | | Difference | Return | Return level | | Difference |
| period | B | C | B-C | period | B | C | B-C |
| 1000 | 42,4 | 40,5 | -2,0 | 1000 | 28,5 | 26,3 | -2,2 |
| 100 | 42,0 | 40,2 | -1,8 | 100 | 26,9 | 26,0 | -0,9 |
| 90 | 42,0 | 40,2 | -1,8 | 90 | 26,8 | 25,9 | -0,9 |
| 80 | 41,9 | 40,2 | -1,7 | 80 | 26,7 | 25,9 | -0,8 |
| 70 | 41,9 | 40,2 | -1,7 | 70 | 26,6 | 25,9 | -0,7 |
| 60 | 41,8 | 40,1 | -1,7 | 60 | 26,5 | 25,9 | -0,6 |
| 50 | 41,8 | 40,1 | -1,7 | 50 | 26,3 | 25,8 | -0,5 |
| 40 | 41,7 | 40,0 | -1,6 | 40 | 26,1 | 25,7 | -0,4 |
| 30 | 41,6 | 40,0 | -1,6 | 30 | 25,8 | 25,7 | -0,2 |
| 20 | 41,3 | 39,8 | -1,5 | 20 | 25,5 | 25,5 | 0,0 |
| 10 | 40,9 | 39,5 | -1,4 | 10 | 24,7 | 25,2 | 0,4 |
| 2 | 38,7 | 37,7 | -1,0 | 2 | 22,5 | 23,5 | 1,1 |

| LTMx | | | | LTMn | | | |
|---|---|---|---|---|---|---|---|
| Return | Return level | | Difference | Return | Return level | | Difference |
| period | B | C | B-C | period | B | C | B-C |
| 1000 | -2,5 | 4,1 | 6,6 | 1000 | -13,4 | -7,1 | 6,3 |
| 100 | 1,8 | 4,9 | 3,1 | 100 | -10,5 | -6,7 | 3,9 |
| 90 | 2,0 | 4,9 | 3,0 | 90 | -10,4 | -6,6 | 3,8 |
| 80 | 2,2 | 5,0 | 2,8 | 80 | -10,3 | -6,6 | 3,7 |
| 70 | 2,4 | 5,0 | 2,6 | 70 | -10,1 | -6,5 | 3,5 |
| 60 | 2,6 | 5,1 | 2,5 | 60 | -9,9 | -6,5 | 3,4 |
| 50 | 2,9 | 5,2 | 2,3 | 50 | -9,7 | -6,4 | 3,2 |
| 40 | 3,3 | 5,3 | 2,0 | 40 | -9,4 | -6,3 | 3,0 |
| 30 | 3,7 | 5,5 | 1,7 | 30 | -9,0 | -6,2 | 2,8 |
| 20 | 4,4 | 5,7 | 1,3 | 20 | -8,5 | -6,0 | 2,4 |
| 10 | 5,4 | 6,1 | 0,8 | 10 | -7,5 | -5,6 | 1,9 |
| 2 | 7,8 | 7,7 | -0,1 | 2 | -5,0 | -3,9 | 1,0 |

***Table I c)*** *PERGAMINO*

| HTMx | | | | HTMn | | | |
|---|---|---|---|---|---|---|---|
| Return | Return level | | Difference | Return | Return level | | Difference |
| period | B | C | B-C | period | B | C | B-C |
| 1000 | 47,6 | 42,7 | -4,8 | 1000 | 31,1 | 31,8 | 0,7 |
| 100 | 46,0 | 42,3 | -3,7 | 100 | 29,6 | 28,3 | -1,3 |
| 90 | 46,0 | 42,3 | -3,7 | 90 | 29,5 | 28,2 | -1,3 |
| 80 | 45,9 | 42,2 | -3,6 | 80 | 29,4 | 28,0 | -1,4 |
| 70 | 45,7 | 42,2 | -3,6 | 70 | 29,3 | 27,8 | -1,5 |
| 60 | 45,6 | 42,1 | -3,5 | 60 | 29,2 | 27,6 | -1,6 |
| 50 | 45,4 | 42,1 | -3,4 | 50 | 29,0 | 27,4 | -1,7 |
| 40 | 45,2 | 42,0 | -3,3 | 40 | 28,8 | 27,0 | -1,8 |
| 30 | 45,0 | 41,8 | -3,1 | 30 | 28,6 | 26,6 | -1,9 |
| 20 | 44,6 | 41,6 | -2,9 | 20 | 28,2 | 26,1 | -2,1 |
| 10 | 43,8 | 41,1 | -2,6 | 10 | 27,4 | 25,1 | -2,2 |
| 2 | 41,2 | 39,0 | -2,2 | 2 | 24,7 | 22,8 | -1,9 |

| LTMx | | | | LTMn | | | |
|---|---|---|---|---|---|---|---|
| Return | Return level | | Difference | Return | Return level | | Difference |
| period | B | C | B-C | period | B | C | B-C |
| 1000 | 0,9 | 1,4 | 0,5 | 1000 | -15,1 | -19,1 | -4,0 |
| 100 | 2,3 | 2,6 | 0,3 | 100 | -13,0 | -13,2 | -0,2 |
| 90 | 2,4 | 2,7 | 0,3 | 90 | -12,9 | -13,0 | -0,1 |
| 80 | 2,5 | 2,8 | 0,3 | 80 | -12,8 | -12,7 | 0,1 |
| 70 | 2,6 | 2,9 | 0,3 | 70 | -12,7 | -12,5 | 0,2 |
| 60 | 2,7 | 3,0 | 0,3 | 60 | -12,5 | -12,2 | 0,3 |
| 50 | 2,8 | 3,1 | 0,3 | 50 | -12,3 | -11,8 | 0,5 |
| 40 | 3,0 | 3,3 | 0,3 | 40 | -12,1 | -11,4 | 0,7 |
| 30 | 3,2 | 3,5 | 0,3 | 30 | -11,7 | -10,9 | 0,9 |
| 20 | 3,5 | 3,8 | 0,3 | 20 | -11,3 | -10,2 | 1,1 |
| 10 | 4,1 | 4,5 | 0,4 | 10 | -10,4 | -9,0 | 1,3 |
| 2 | 6,0 | 6,7 | 0,7 | 2 | -7,7 | -6,6 | 1,1 |

***Table I d)*** *SANTA ROSA*