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EVIDENCE FOR INTERANNUAL AND INTERDECADAL EXTREME TEMPERATURE VARIABILITY IN URUGUAY

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1. Introduction

Climate extreme events have the most impacts on human activities. Identify natural climate extreme variability is very important to understand the interaction between this kind of variability and the anthropogenically-forced. There are fewer studies of regional variability in climatic extremes for South America. Rusticucci and Barrucand (2004) present a study of trends in daily maximum and minimum temperature for Argentina, concluding that minimum temperature presents the largest number of stations with observed positive significant trends. This result was confirmed and extended to all South America by Vincent et all (2005). They examined trends in indices of daily temperature extremes for South America. They found no consistent changes in indices based on daily maximum temperature, but significant trends were found in indices based on daily minimum temperature. Relationship between extreme temperature events and sea surface temperature were studied for Argentina. Rusticucci et all (2003) found that extreme temperature events show high correlation with the sea surface temperature of the coastal waters in South Atlantic and South Pacific, stronger than the influence of ENSO variability (Rusticucci and Vargas 2002). There are no studies at all for Uruguay, exploring temporal variability of extreme temperature events. This paper presents a study of temporal variability of extreme temperature indexes in interannual and decadal scales from a daily database of maximum and minimum temperature from five meteorological stations in Uruguay.

2. Data and Methods

Daily maximum and minimum temperature from five meteorological stations from Uruguay was used for this study. Periods of records varied by stations but all of them covered 1961-2002. The stations located near the Uruguay river are the longest ones, with start dates around 1930 (Paysandú, Mercedes and La Estanzuela); the station located over the Atlantic coast (Rocha), starts in 1950 and the station located in the center of the country (Paso de los Toros) starts around 1961, (see Table 1).
Data quality assessment is an important requirement for the daily analysis, since any erroneous outlier can have a serious impact on the results related to extremes.
An exhaustive quality control and homogeneity analysis was performed, as detailed in Rusticucci and Renom (2005).
A set of four temperature indices related to the frequency of warm days (TX90), cold days (TX10), warm nights (TN90) and cold nights (TN10) were constructed for each station and calculated on a

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monthly and/or annual basis. These temperature indices based on percentiles are calculated as percentage of days (in a month or year) above or below the 90th or the 10th percentile. The percentiles are calculated from a 5-day window centered on each calendar day from the reference period 1961-1990.
Data quality and calculation of the indices were performed using the program RClimDex 1.0 available at http://cccma.seos.uvic.ca/ETCCDMI/software.html.
Our tool for detecting significant spectral peaks in time series is the multitaper method MTM, (Percival and Walden 1993). In contrast to the classic Blackman-Tukey correlogram method where a unique spectral window or "taper" is used, MTM uses a small set of optimal window functions (tapers) to reduce the variance of the spectral estimate. A set of independent estimates of the power spectrum are computed by premultiplying the time series by orthogonal tapers, which are chosen to minimize the spectral leakage that arises due to the finite length of the time series. Averaging over this ensemble of spectra fields a better and more stable estimate than do single-taper methods. Statistical significance is determined against a red noise null hypothesis using chi-squared test. The null hypothesis spectrum is determined by fitting an analytical first-order autoregressive [AR(1)] spectrum to the smoothed MTM spectrum of the time series; the smoothing uses a median filter to remove narrowband "signals", which would otherwise distort the noise null hypothesis. The MTM was implemented using the SSA-MTM Toolkit for Spectral Analysis, available at http://www.atmos.ucla.edu/tcd/ssa/.
In this study, focus will be on variability of the detrended data. If the trends do indeed represent climate change, the detrended variability may more accurately represent the underlying natural variability. Because at a first sight, all of the annual indices series for the entire stations shows tendency, we estimate trend and evaluate its significance before applying MTM method. The best-fit linear trend is often used to describe changes in a climatological series. For this purpose we use a non parametric method used in determining the presence of slope proposed by Sen (1968).The estimator is the median of the slopes obtained from all joining pairs of the point series. The statistical significance of the trends was assessed at 5% confidence level. To look for the variability of trends over different periods, the calculations were performed for three periods: 1935-2002 (3 stations), 1950-2002 (4 stations) and 1961-2002 (all 5 stations).

Station Name	NºWMO	Lat (ºS)	Long(ºW)	Alt	Period
Paysandú	86430	32º20,9'	58º02,2'	61m	1935-2002
Mercedes	86490	33°15,0'	58°04,1'	17m	1931-2002
La Estanzuela	86532	34º27,4'	57°50.6'	80m	1931-2002
Rocha	86565	34º29,6'	54º18,7'	18.16m	1950-2002
Paso de los Toros	86460	32º48'	56º31,6'	75,48m	1960-2002

Table 1. Number, Lat., Long., and period of the Meteorological Station analyzed

3. RESULTS

3.1 Trends

Figure 1 presents the map of trends for indices based on daily maximum temperature. Warm days (TX90) trend in La Estanzuela station, although its negative in all the periods considered, in the last period considered, lost its significance. A change in sign occurs at Paysandu station, while trend in the whole period (1935-2002) is negative, when 1950-2002 or 1961-2002 is consider change to positive, neither positive nor negative are significant. Cold days (TX10) show a negative trend in all periods considered, except in station Paso de los Toros. When study the trends in indices based in minimum temperature, we found that warm nights (TN90) show positive trends in all the periods and for all the stations. However it is significant for one station in each period. (See Figure 2) The most profound changes are observed in the percentage of days with cold nights. Almost all the stations show significant decreasing trends in the percentage of cold nights, while the last period analyzed 1961-2002 show the most decreasing trend, around -1.2 %/decade compared to the others periods studied, with trends around -0.7%/decade. This indicate a strong warming of nighttime temperature with fewer cold nights and more warm nights, in accordance with Rusticucci and Barrucand (2004) and Vincent et all (2005).
Another test for linear trends was applied. This test study the slope of the best linear fit, in general, it shows higher significance than Sen estimator for all the indices.

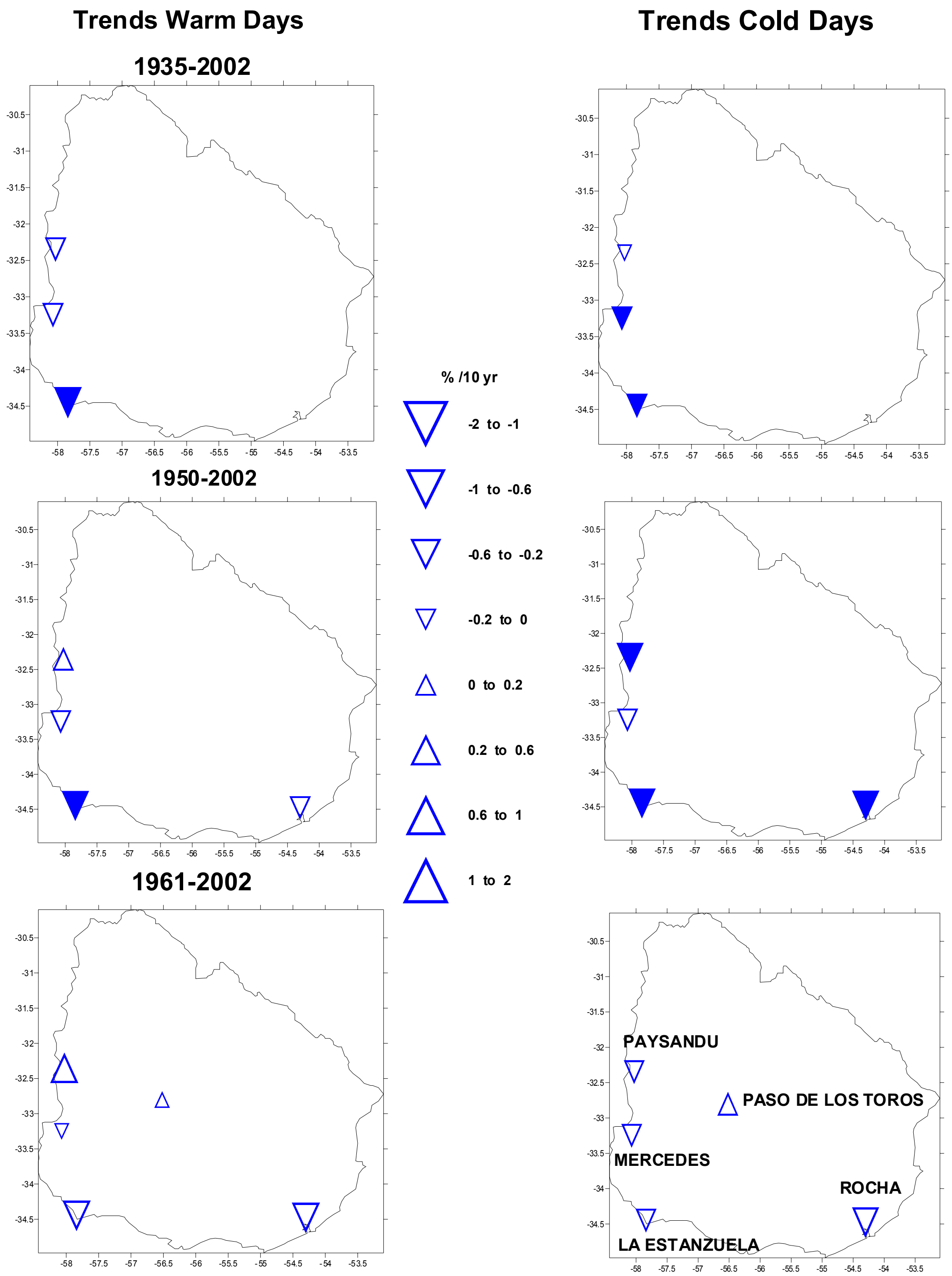


Fig. 1. Slope of the trends (in %/decade) for two indices based on daily maximum temperature over three periods: 1935-2002, 1950-2002, 1961-2002. Upward and downward pointing g triangles indicate positive and negative trends, respectively. Filled triangles correspond to trends significant at the 5% level. Size of triangle is proportional to the magnitude of the trend in % per decade.

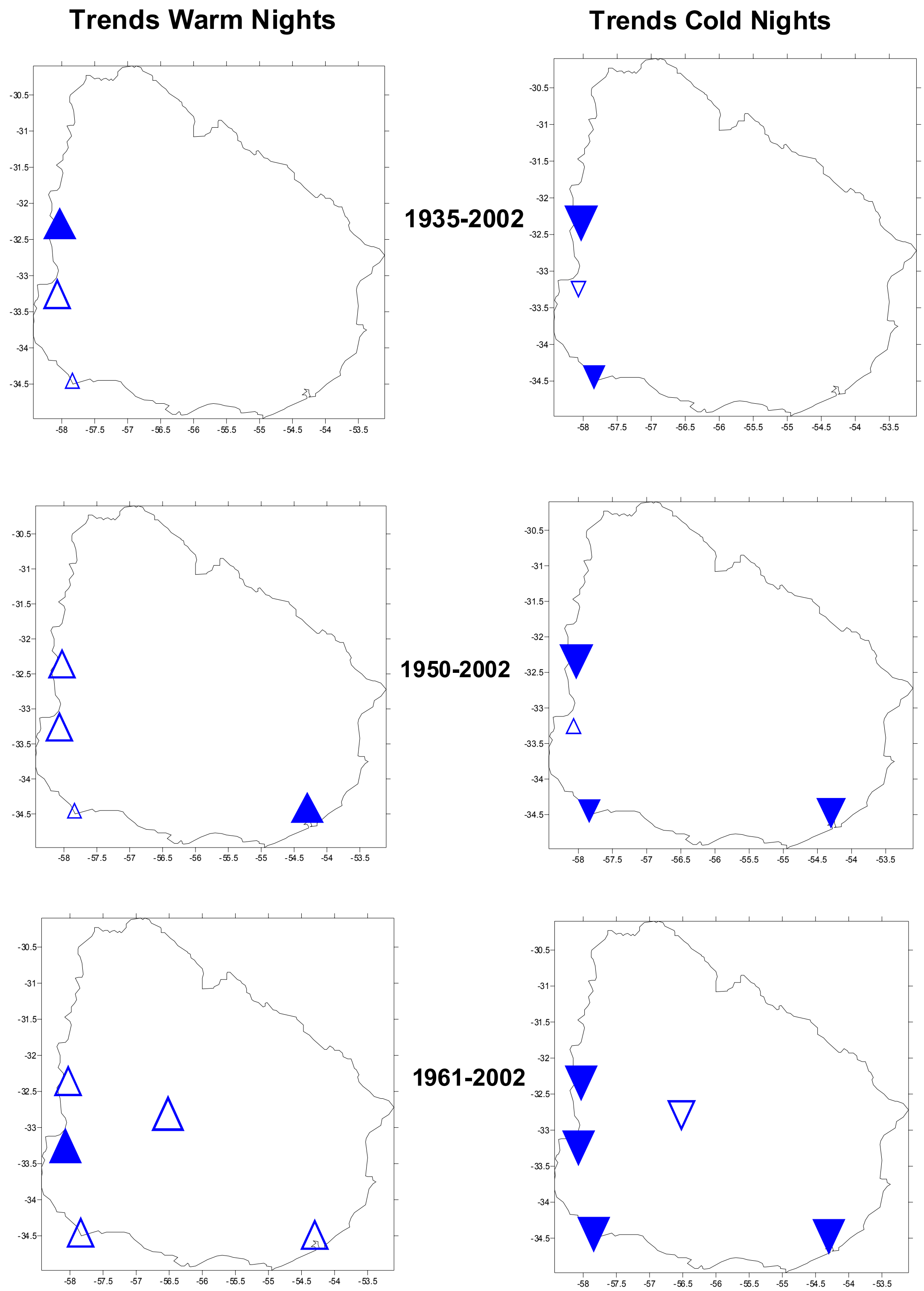


Fig. 2. Same as Fig 1 but for indices based on daily minimum temperature

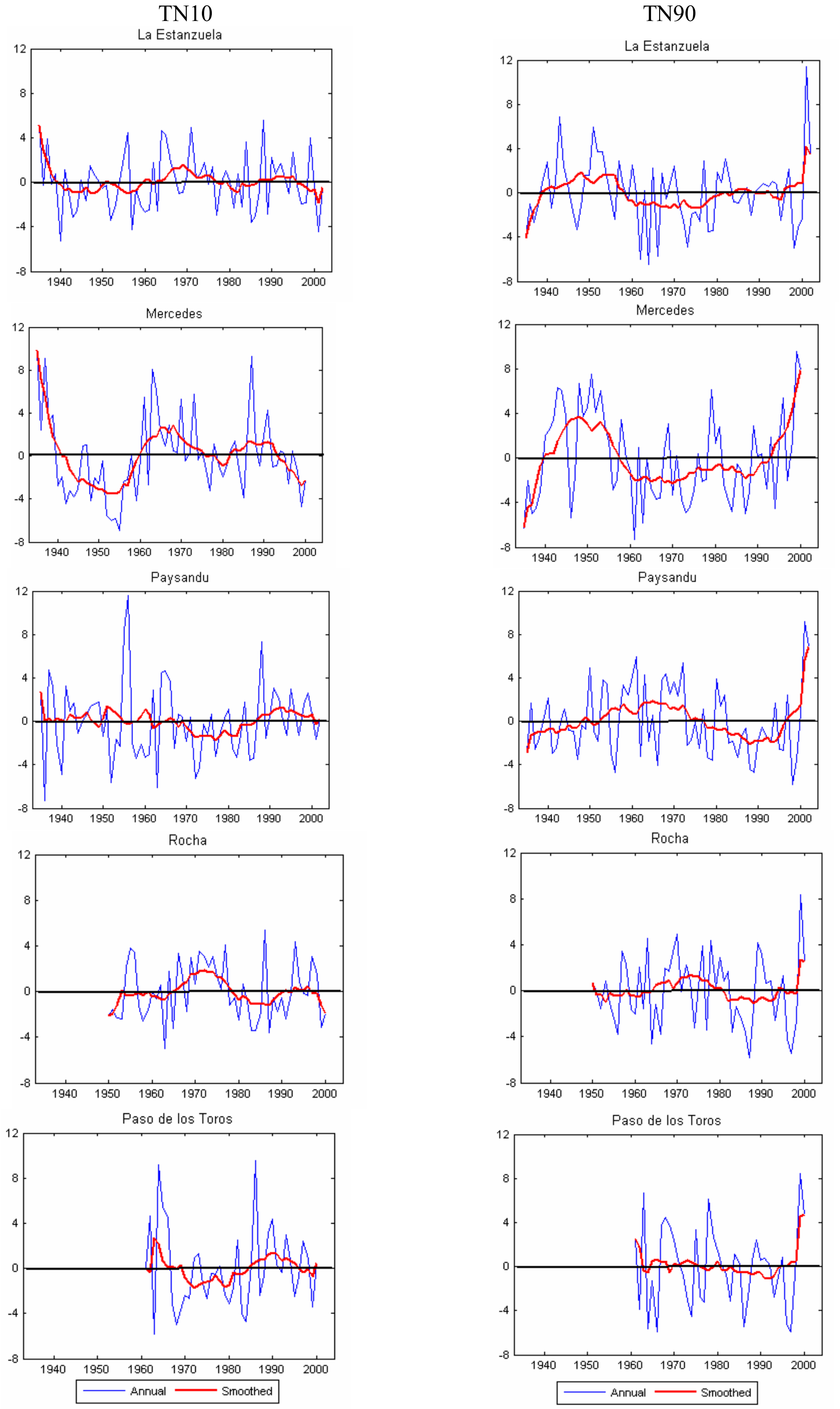


Fig. 3. Detrended annual time series (blue) and smoothed with a 10-yr running mean (red) of indices based on minimum temperature

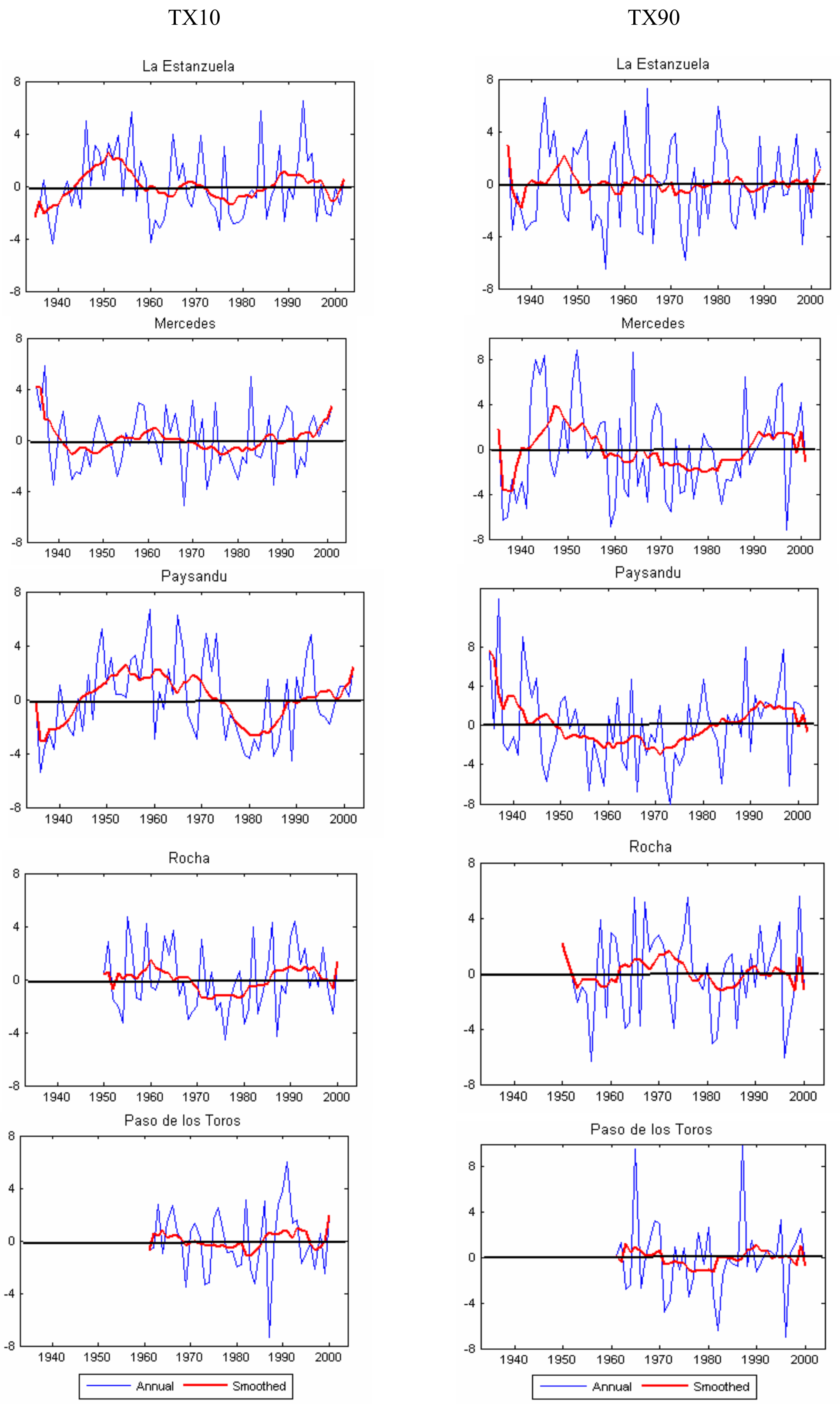


Fig. 4 . Same as Fig 3 but for indices base on maximum temperature

3.2 Interannual Variability

We apply MTM methods to the detrended annual time series of TN10, TN90, TX10 and TX90. Figures 3 and 4 present these time series. All of them were smoothed in time by ten-year running mean. The smoothed time series are also presented. We have to notice that for TN90 the absolute maximum in all the stations analyzed, occur in year 2001, meaning that was a year with the highest percentage of days with warm nights that were previously showed by Rusticucci and Renom (2005) who detect an inhomogeneity in minimum daily temperature of Uruguay. The multitaper spectrum of Mercedes station for TN90 index is shown in Figure 5, using *p* =2 tapers, as an example. For the 70-point time series, this choice of tapers allows a half-bandwidth spectral resolution of pf_R = 0.028 cy/yr (where f_R is the Rayleight frequency). In this case, spectral peaks, significant at the 95% level against a red noise null hypothesis, occur at periods of 3.4 and 2.4 yr, other 90 % significant peak occurs at 4.7 yr. The spectra of all indices exhibit peaks significant at 95 % at periods between 3 to 5 years; they may be associated with El Niño Southern Oscillations. A quasibiennal oscillation is found at periods of 2 to 2.5 years significant at 99 % . For TN90 peaks between 8 -10 years appear as 90% of significance for all the stations studied. The same was found for TX90, but not appear as significant for Mercedes and Paso de los Toros stations. These different periods of oscillation detected in extreme temperature indices were almost detected in the annual runoff in eastern South America of the Negro, Paraguay, Paraná, and Uruguay Rivers as it mentioned by Robertson and Mechoso (1998). In La Estanzuela a low frequency peak (period of 33 years) in TX10 with significance of 90% was identified; the same happens in Mercedes but for TN10. We also study the variability of Summer (DJF) and Winter (JJA) time series. The biennial variability detected is more important for summer, with significance at 99% level, rather than winter. The same was found by Rusticucci and Vargas (2001) for Argentina stations. A peak between 3 to 6 years, appears in summer as well as in winter, but is more significant in winter season. Low-frequency variability (periods of 22-30 years), appear in summer for TN10 in Mercedes and La Estanzuela.

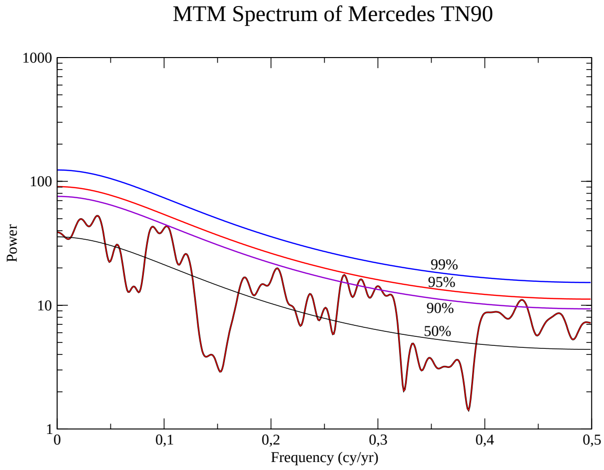


Fig. 5 Multitaper spectrum of Mercedes TN90 detrended annual time series. Two tapers were used. Thin black line give the median, 90% (violet), 95% (red) and 99% (blue) significance levels against a red noise null hypothesis.

3.3 Decadal Variability

Applying MTM methods to detrended and smoothed time series of all the indices, we found in the MTM spectra a statistically significant (at the 99% level) peak at 15-25 years in four of the stations analyzed in all indices. Paso de los Toros, presents a statistically significant peak at 12.5 years, this could be due to the shortness of the time series for this station (40 years). The summer spectra of TX90, TX10 and TN10 indices exhibit a statistically significant peak (at the 95% level) at the same period (15 to 25 yr), while for TN90 this peak is significant for La Estanzuela, Mercedes and Paysandú. Rocha and Paso de los Toros do not have significant peaks in the MTM spectra for TN90. The winter spectrum of TN90, TN10, TX90 and TX10 show a statistically significant peak (at the 99% level) in the interdecadal time scale, with periods around 20 years. Ecept in Paso de los Toros

4. Pacific relation with extreme temperatures in Uruguay

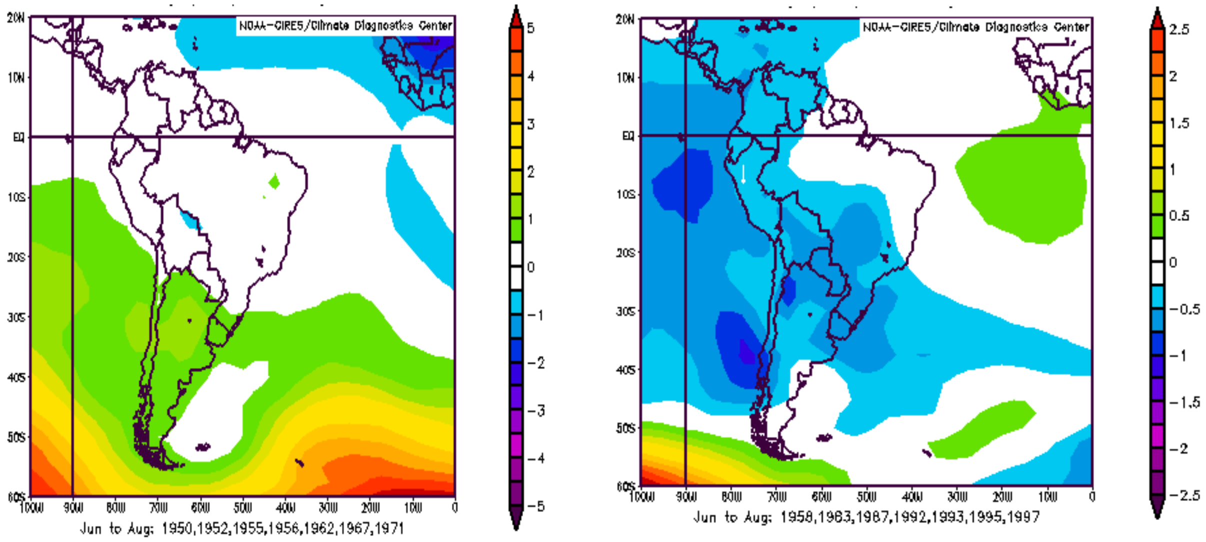
Relationship between detrended and smoothed annual, summer (DJF) and winter (JJA) seasonal series of temperature indices and Pacific Decadal Oscillation (PDO) were studied. The period analyzed was from 1950 to 2002, so we have results from four stations The temperature indices and PDO have same periods of oscillations of 15 to 25 years. Rocha present the highest correlation in smoothed annual series for TX90 and TN10 indices (-0.81 and -0.72 respectively). We compare the number of days per year of TN10 during the negative phase of PDO (1950-1976) with the number of days per year of TN10 in positive phase of PDO (1977-2002). We found that during negative phase of PDO the mean of days per year with extreme cold nights was of 41 days, while for the positive PDO was of 31 days. Studying the seasonal time series, the most relevant result, showed a significant negative correlation with PDO phases. A positive (negative) PDO index is correlated with cold (warm) winters and warm (cold) summers, and is accompanied by negative (positive) SLP winter and annual anomalies. (See Figure 6).

In Table 2, we present the correlations (statistically significant at the 95% level).

In the case of TX10 only Paysandú station present significant correlation with PDO in annual and the summer series. Rocha does not present correlation at all in any of the temporal series analyzed for this index. Higher correlations appear for summer season. While no significant correlation appear in annual series for Mercedes and La Estanzuela; high correlations appear for summer time series, and for la Estanzuela a positive winter correlations is detected. For TX90 we can see that in annual series, Paysandu have positive correlation with PDO, but not present correlation with summer or winter season, while La Estazuela have only in winter a significant correlation. Rocha is the one that present highest correlation in annual as well as in seasonal series. All of the stations present correlation in winter for TN90, Rocha have the highest value (-0.90) .For TN10, Paysandu have in summer negative correlation, while in winter present positive correlation, that could influence , the result when the annual series is considered. The correlation coefficient for TN10 annual series, increase from north–west to south-east. From Fig.3 and 4, an out of phase behavior of TN10 and TX90 10-yr runnig mean indexes is detectable between Paysandu and Rocha stations. For TX90, Rocha have a significant negative correlation with PDO, while Paysandu have positive correlation. For TN10, while Rocha have negative correlation; Paysandu does not present significant correlation with PDO. This could explain the out of phase behavior between these stations. Correlation between PDO and fall (MAM) and spring (SON) seasons time series will be study, to complete the seasonal correlations.

	TX90			**TX10**			**TN90**			**TN10**		
	Ann	Sum	Win	Ann	Sum	Win	Ann	Sum	Win	Ann	Sum	Win
Paysandu	0.30			-0.64	-0.77		-0.69	-0.40	-0.61		-0.52	0.68
Mercedes	-0.32		-0.34		-0.59				-0.31	-0.33	-0.54	
La Estanzuela			-0.45		-0.69	0.32	0.49		-0.58	-0.67		-0.34
Rocha	-0.81	-0.62	-0.67				-0.44		-0.90	-0.72	-0.47	

Table 2. Correlations between detrended and smoothed annual, summer and winter seasonal time series with PDO index, significant at 95% level.



a) b)

Fig. 6. SLP composites anomalies in winter for negative PDO (a) and positive PDO (b) phase.

5. Conclusions

From a high quality database of daily maximum and minimum temperature series from five meteorological stations from Uruguay, a set of four temperature indices were constructed for each stations. The indices are related to the frequency of warm days (TX90), cold days (TX10), warm nights (TN90) and cold nights (TN10), calculated on a monthly and/or annual basis. To better recognize natural variability, we analyze trends in the time series, to see if the extreme temperature indices have statistically significant trends. The most profound change were detected in the percentage of days with cold nights (TN10), were the last period analyzed 1961-2002 show the most decreasing trend, respect to the other periods considered. The only index that presents a positive trend was TN90. These results are indicating a strong warming of nighttime temperature, with fewer cold nights and more warm nights. This change is more significant in the last period (1961-2002) analyzed, than changes during other periods considered. For indices based in daily maximum temperature we found that cold days present negative trend in all periods considered, except for Paso de los Toros stations. The period 1950-2002 is the one where this trend is significant at 95 % level Because of the result obtained by trends analysis, and trying to identify natural variability, the multitaper method was apply to detrended annual, summer (DJF) and winter (JJA) seasonal series of the four indices. In interannual time scale we found peaks between 3 to 5 years statistically significant at 95% level may be associated with El Niño Southern Oscillations. A quasibiennal oscillation at periods of 2 to 2.5 years was found and is more significant (at 99% level) than the oscillation mentioned above. A peak near decadal scales, was found for the warm tails of the indices studied (TX90 and TN90) in almost all the stations, significant at 90% level. Low frequency peaks were found in La Estanzuela and Mercedes for TX10 and TN10 respectively. Analyzing seasonal time series, we found in that the biennial oscillation is more important for summer than winter season, while oscillations between 3 to 6 years are more significant for winter rather then summer season. For cold days for summer a low frequency variability were detect for two of the longest series analyzed. To identify variability in longer time scale, the detended time series were smoothed in time by ten-year running mean. Significant peak in interdecadal time scales (15-25 years) were found in all of the indices. Only Paso de los Toros stations do not present a significant peak in this scale, may be due to the shortness of the time series (40 years). The TX90, TX10 and TN10 summer time series, present oscillations in interdecadal scales, while TN90 only the longer series present this peak as significant. No significant peaks at all appear for Rocha and Paso de los Toros summer time series. In the of winter spectrum an oscillations with periods around 20 years, significant at 99 % level were detected for all the indices and almost all the stations analyzed .

Correlations between extreme temperature indices and the Pacific Decadal Oscillation were explored during the 1950-2002 period. For annual time series Rocha is the station that present highest negative correlation, but only for warm days and cold nights, while Paysandu present highest negative correlation with cold days and warm nights. Analyzing seasonal time series, a correlation between PDO phases and warm temperature indices (TX90 and TN90) is found for winter, while in summer this correlation is significant for cold temperature indices (TX10 and TN10).

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