Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 1491-1499.

LOOKING FOR CLIMATE SIGNALS USING WAVELET TRANSFORM: EXTREME TEMPERATURES IN ARGENTINA, ATLANTIC SEA SURFACE TEMPERATURE AND OTHER RELATED VARIABLES

[1,2] M. Barrucand – [2] M. Rusticucci – [1,2] W. Vargas

[1] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)
[2] Departamento de Ciencias de la Atmósfera y los Océanos – FCEN (UBA)

1. Introduction:[*]

Most traditional mathematical methods used to analyze time series, such as Fourier analysis, show periodicities in a frequency domain, but they don't reveal whether they are stationary in time, intermittent or whether the time series have suffered a shift in the data. Wavelets are functions that permit to transform a time series into a bi-dimensional variable (frequency and time spaces). They are useful to study non-stationary processes occurring over finite spatial and temporal domains. Torrence and Compo (1998) presented a complete guide of wavelet analysis together with a free software that has been extensively used (see reference below)

In the present study, we look for common climate signals in temperature extremes and Atlantic sea surface temperatures performing wavelet analysis In the literature, Sea surface temperature studies related with atmospheric conditions are led by ENSO events studies (Karoly, 1989, Trenberth and Carol, 2000 and reference there in). With respect to the influence in South America we can mention Garreaud and Battisti (1999), Rusticucci (2000) and Rusticucci and Vargas (2002), Vera et al (2004), among others.

In general terms, the South Atlantic Ocean has been less studied -in part because the lack of information- but it plays an important role in the climate system. Some characteristics of SST Atlantic variability can be found in Venegas et al (1997) and Tanimoto and Xie (2002). Rusticucci et al (2003) showed that the Atlantic SST has a more relevant influence in temperature extremes in Argentina than Pacific SST. In this work we continued the last mentioned study, with an improved discrimination of cold and warm events and an extension of the analysis at different scales variability. Also, the cloudiness and humidity variability are analyzed.

2. Data and methodology

Time series analyzed in this study were based on daily maximum and minimum temperatures of 22 Argentine stations from 1964 to 2003. Different indices were calculated as it is suggested in the list of indices developed by The Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI). Here, the indices are the percentage of days (in a month for each year) below the 10th percentile (cold cases) or above the 90th percentile (warm cases) for minimum (TN) and maximum (TX) temperatures. In this way, four series per meteorological station were considered in relation to the extreme temperature behavior: TN10, TN90, TX10 and TX90.

The South Atlantic Ocean was explored within 3 specific regions: SST30, SST36 and SST45.These boxes are centered at 30S 38W , 36S 50W and 45S 68W respectively with a length of 6º latitude and a width of 6º to 12º longitude (figure 1). The election of these zones was due to previous results about Atlantic SSTs - extreme temperatures relation (see Rusticucci et al, 2003) and because these can be referents of the Brazilian current (SST30), the Malvinas current (SST45) and their confluence zone (SST36). Monthly average temperatures at the different boxes were obtained from the NCEP dataset (Kalnay et al, 1996). In this work, only the SST30 and SST36 results are presented.

Dew point temperature and cloudiness were analyzed too. Due to the absence of data of humidity and cloudiness at the same time when the maximum or minimum temperature occurs, two specific hours (from the 3 o 4 available) were selected: 12 and 18 UTC (9am and 3pm local time). It is assumed that they are the closest to the real time of occurrence of extreme temperature values (minimum and maximum respectively). The dew point treatment was identical to the extreme temperature one. The percentage of days below (above) the 10th(90th) percentile per month and per year was

---

[*] Corresponding author address: Mariana Barrucand
CONICET/ Dto. Ciencias de la Atmósfera y los Océanos –
Facultad de Ciencias Exactas y Naturales. (UBA)
Buenos Aires, Argentina E-mail: barrucand@at.fcen.uba.ar

calculated: Td10 and Td90. Seasonal average were considered as it was done with the extreme temperatures. The daily cloud sky coverage (in eighth of covered sky) was classified into 3 groups following the classification of the Argentine National Weather Service: cleared (0-2 eighths), partly clouded (3-5 eighths) and clouded (6-8 eighths). Two indices were constructed with this dataset: one takes into account the percent of days (per month and per year) with clear sky and the other, percent of days with a covered sky. Once more, seasonal averages were considered.

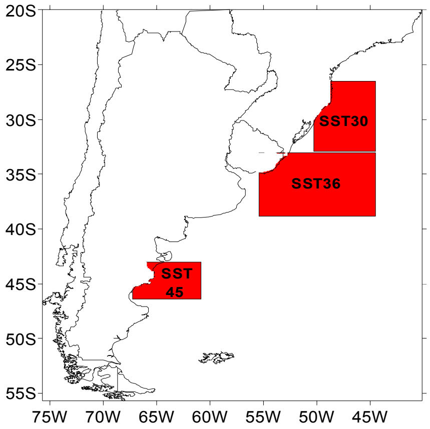


Figure 1: boxes of the Atlantic Ocean where the SSTs were averaged.

A cluster analysis of the indices was done with the “K-means” technique in order to select some reference stations at different areas of the country. This method classifies exactly k different clusters of greatest possible distinction. One station per cluster was chosen to perform a wavelet analysis.

Torrence and Compo (1998) analyzed seasonal anomalies of SSTs at Niño 3 region (4 data per year) as an example of the wavelet method. In this work a similar analysis was done with the extreme temperatures and dew point. The wavelet transform was applied to seasonal subsets too: summer (Dec-Jan-Feb), autumn (Mar-Apr-May), winter (Jun-Jul-Aug) and spring (Sep-Oct-Nov). In table I some specifications about the performed wavelet analysis are presented

Table I: inputs at the wavelet analysis

Mother Function:	Morlet
Pad with zeros:	yes
Background Spectrum:	White noise
Level	10%

3. *Spatial Homogeneity of extreme series*

The first aspect to be analyzed was the spatial homogeneity of the indices. That would permit to select some reference stations of the country. Two time scales were considered with this aim:

a) annual (considering 12 months per year) and
b) seasonal (considering only 3 months per year with the seasonal definition mentioned above).

The results of the clustering for the time scale a) are presented in figure 2. A general separation: north, center and south (Patagonia) is observed, but some differences could be appreciated between cold (TN10-TX10) and warm cases (TN90-TX90). Although the Patagonia couldn’t be represented adequately, the two stations analyzed were separated in different “single groups” (both with an unique case) when cold extremes were considered (fig. 1a and 1c). The “in-homogeneity” at Patagonia stations did not appeared at warm cases, but a west-east regional separation was found (fig. 1b and 1d). The warmest cases (TX90) could be clustered with an additional group. In this case, the five regions classified resemble the traditional classifications.

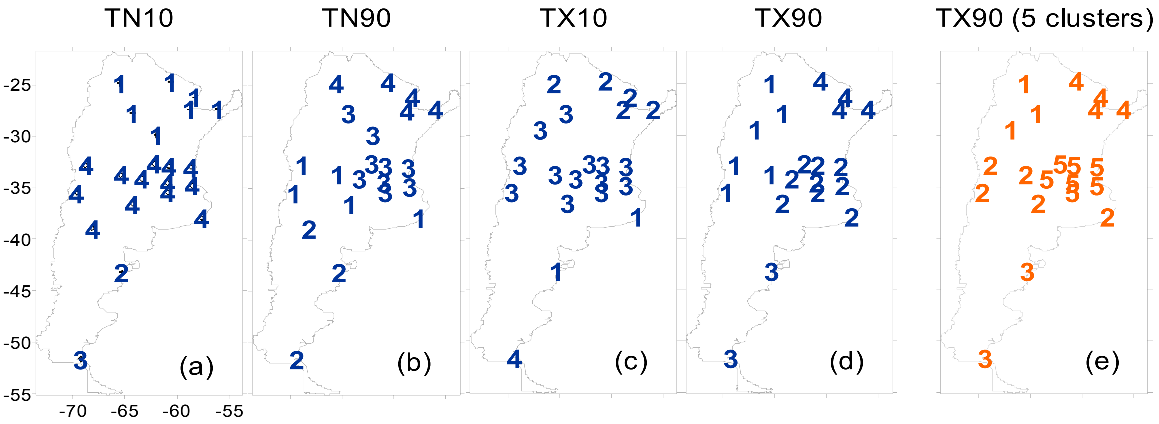


Figure 2: cluster of series: a) TN10 b) TN90 c) TX10 d) TX90 e) idem d, except for 5 groups

When K-means technique was performed to the seasonal series, some differences were observed. An example can be found in the TX90 analysis (the warmest cases). If four clusters are constructed, the Patagonia stations are classified in the same group in summer, but this do not occur in winter. In general terms TN10 and TX10 show a similar regional homogeneity (with a north-south distribution of clusters). On the other hand, TN90 and TX90 also show similar homogeneity, but with an east-west distribution of clusters. This reflects that the “tails of the distributions” have similar characteristics between variables. In other words, the coldest (warmest) cases of minimum and maximum temperature have the same spatial representativeness.

The homogeneity study permitted the election of some reference stations in order to analyze some climatic signals using the index of observed extreme temperatures. In table II some details about the selected stations used for this purpose are presented. All of the them have the least count of missing values

Table II: selected stations at different regions of the country. The numbers at the STATION column correspond to WMO classification. Latitude (LAT), longitude (LON) and height (H) are indicated

STATION	NAME	LAT (S)	LON(W)	H (m)
87047	Salta	24º 51’	65º 29’	1221
87166	Corrientes	27º 27’	58º 46’	62
87506	Malargue	35º 30'	69º 35’	1425
87548	Junín	34º 33’	60º 55’	87
87828	Trelew	43º 12’	65º 16'	43

4 **Detecting climate signals: the wavelet approach**

The wavelet approach has been applied to the seasonal extreme temperatures indices and has been compared with the result of the Atlantic Sea Surface temperatures. Here, TN10, TN90, TX10 and TX90 must be considered as sub-annual data, with 4 data per year . When only one season is considered, the corresponding season was indicated (Ex: TN10_spring)

4.1 Temperature extremes:

a) TN10

In figure 3 it can be seen the TN10 series and the Graphic of the Wavelet Power Spectrum (GWPS). Except for the Patagonia station, a general negative trend in the number of cold days can be appreciated in the great majority of the meteorological stations studied. This is reflected by significant zones of the spectrum at scales closer and upper than sixteen years This zones are affected by the cone of influence COI (COI: zone in the wavelet spectrum where the result can be affected by borders effects) so this result must be considered with caution. However, Rusticucci and Barrucand (2004) showed that a colder extreme (5th percentile) was also affected by a negative tendency, specially in summer, so the results found in the wavelet analysis are consistent with that. Nevertheless, we are not interested in the analysis of tendencies here, but other periodic (or non periodic) signals in the data.

In general terms, two characteristics can be mentioned: stronger signals in the first 2 decades at the 2-year and less band and a signal at the 4-year scale.

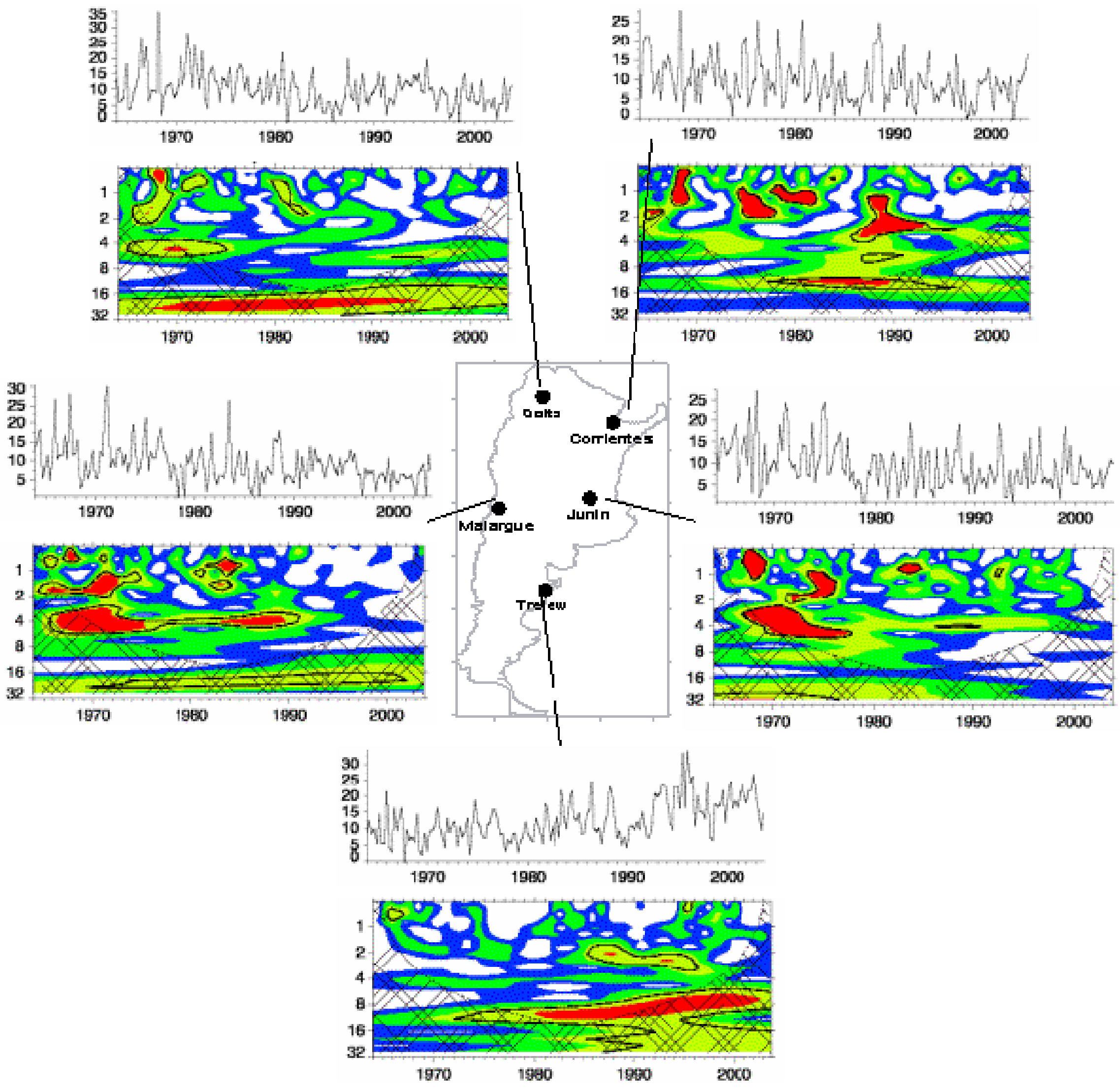


Figure 3: time index series TN10 [% days vs. time (years)] and the local Wavelet Power Spectrum [Period (years) vs. time (years)] for the selected stations. The contour levels are chosen so that the 75% (red), 50% (light green), 25%(green), 5% (blue) of wavelet power is above each level. The thick contour encloses regions of greater than 95% confidence for a white-noise process. Cross-hatched regions on either end indicate the "cone of influence" .

When separated seasons were considered, the graph of Wavelet Power Spectrum (GWSE) appeared with a large COI in relation with the total spectrum. Nevertheless, some interesting characteristics can be observed when the different GWSE were compared

Summer was the most affected season concerning the decreases of "cold days", especially in the 1964-1979 period. This characteristic appeared clearly on the wavelet results together with the 4-year signal at many stations.

Significant signals in the 2 to 4 years band are present in many stations in autumn, principally in the first years. Trelew station is the exception. This signal is observed in the last years, together with an enhance in the number of cold days in that station. A quasi-decadal significant signal (near 8 years) is present at center-east stations too. During winter, the only significant signal that can be mentioned is a 4-year one in many stations in the center and north of the country, especially during the 80's. Finally, the spring season appeared with a marked 8-year signal at all stations (fig 4). A near 4-year signal is present too as a secondary variability mode. This season will be especially analyzed later.

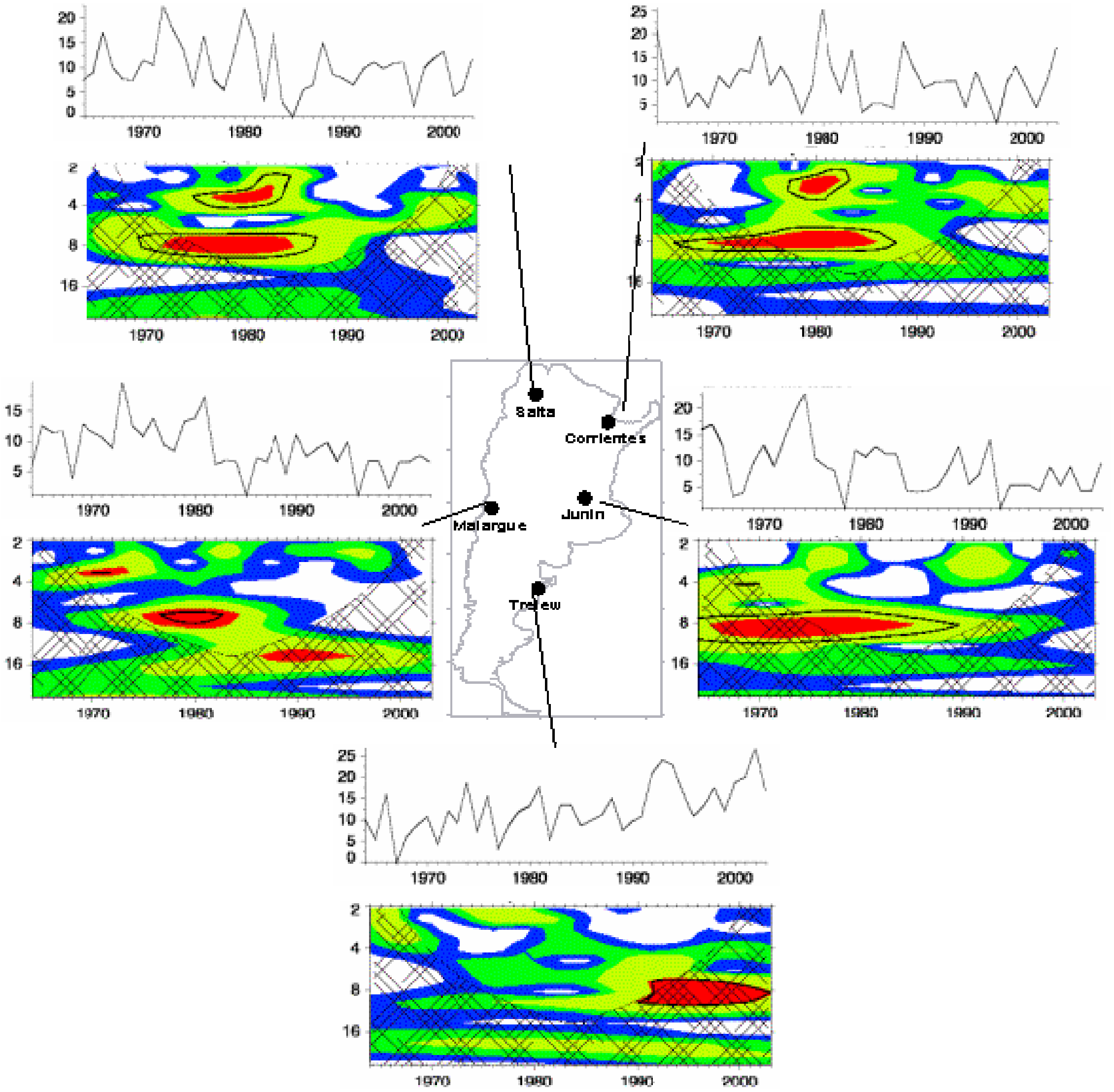


Figure 4: idem fig. 3, except for TN10_spring

b) TX10

Two signals can be observed at all the studied stations with no preferred occurrence period They are centered at 10 years and 2 to 4 years. The last one is clearly observed during summer. During autumn this signal is present at the north stations while the center stations are affected by temporal waves longer than 4 years. The other seasons (winter and spring) are principally affected by a decadal signal.

c) TN90

Two to four-year signals are present at all the studied stations. The center and north ones were affected by a positive trend during the last years. On the other hand, Trelew had a negative trend. No pattern can be found in the summer and autumn series. Winter resembles the annual features and the spring was affected by signals of 4 to 8 years. The last one is not as strong as the 8 year signal found at TN10 series, but it is present at many stations (e.g Corrientes Aero, fig 5)

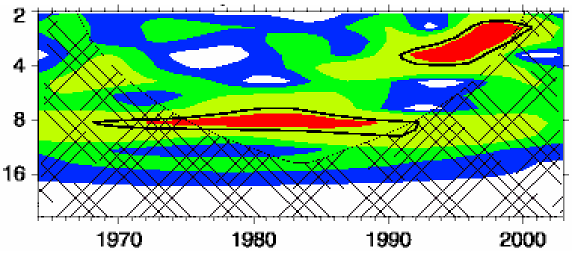


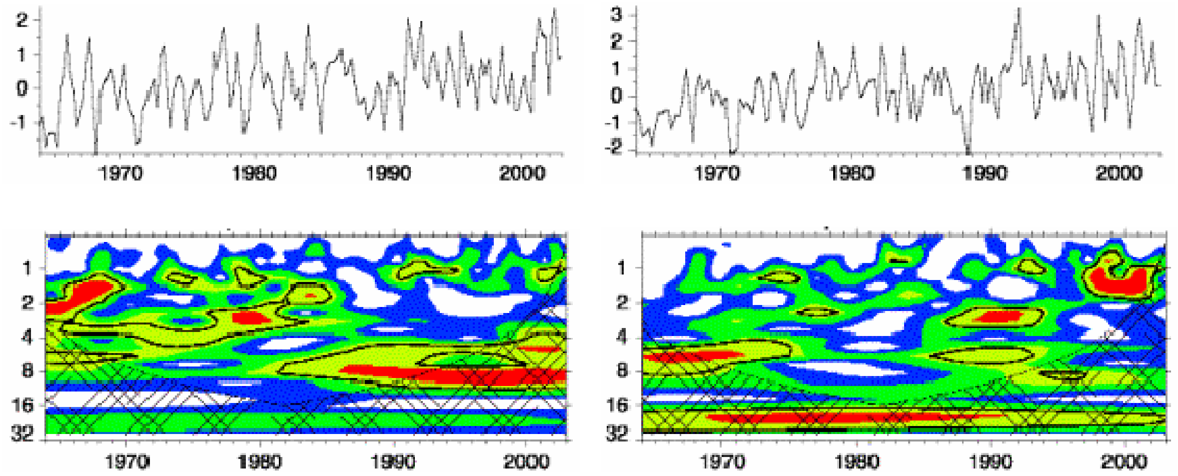
Figure 5: Wavelet Power Spectrum for TN90_spring at Corrientes station [Period(years).vs. Time (years)]. The contour levels are defined as fig. 3

d) Tx90

Two signals are present: a 2 to 4-year signal, and the other around 8-year . Summer, autumn and spring reflect a similar pattern. During winter, the 8-year signal is the most important feature during the second half of the series .

4.2 Sea surface temperature

The SST Atlantic index exhibits significant signals in a large band of scales, with a predominance of the lower ones (figure 6). The seasons showed differences among them. but in some cases, with common characteristics with the observed temperatures in the continent. During summer, 2- to 4-year signals are significant at SST30 and SST36, but not simultaneously. In Autumn these signals are only significant in the beginning of the period . A decadal signal is present in winter, only at SST30, but this result can be affected by border effects.



SST30

SST36

Figure 6: idem fig 4, except for Sea surface temperatures

Doubtlessly, the most interesting aspect of this analysis is related to the spring features. A strong 8 year signal is present during 3 decades (and a little more in the SST30 case). This coincides with a clear 8-year signal in the TN10 index during spring too(fig 7).

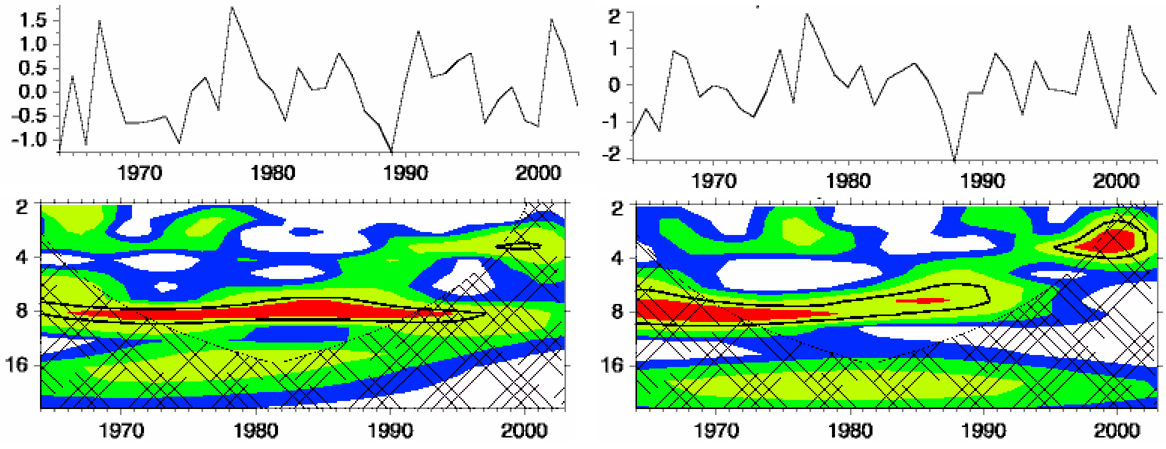
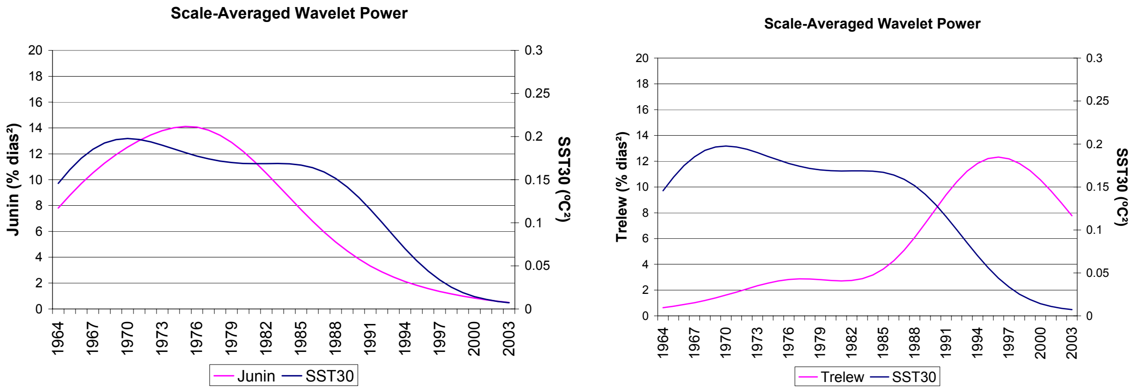


Figure 7: idem fig. 3, except for sea surface temperature (spring)

The "scale-averaged wavelet power" (SAWP) is the weighted sum of the wavelet power spectrum over scales S_1 to S_2. This is an useful tool to examine power fluctuations over a range of scales and modulation of one time series by another. A scale-average wavelet power (SAWP) was done for those bands in which the principal signals were found. A band of 6.5 to 10.5 year was considered, because a noticeable 8_year signal was observed in the former analysis. Figure 8 shows the results for two selected stations, where different characteristics were observed.



a b

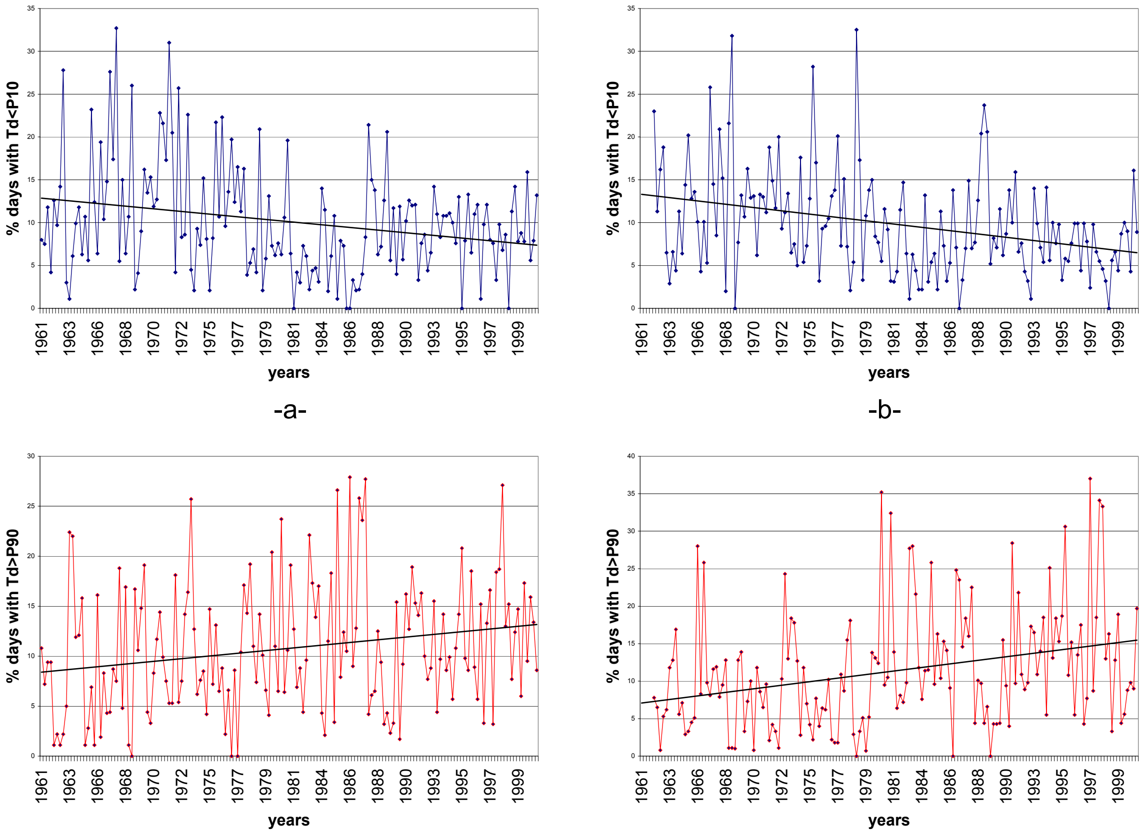
Figure 8: Scale average wavelet power over the 6.5 -10.5 years band for a) TN10_spring Junin and SST30_spring b) TN10_spring Trelew and SST30_spring. The correlations between TN10 series and the SST30 ones: r=0.9 (Junin) and r=-0.88 (Trelew)

Correlations generally above 0.80 were found in spring, when a 8-year band was selected. This is the case of Junin station (r=0.90), where a clear association was found. The opposite situation was observed in Trelew, where the 8_year signal is out of phase with the SST one. Unfortunately, we need longer series to compute adequately a correlation coefficient, because an important subset of SAWP at the beginning and at the end of the series could be affected by border effects. Nevertheless, the "8-year signal" detected in the frequency of cold event series during spring (TN10_spring) and in the Atlantic SSTs series are sufficiently noticeable to be investigated with detail

5 Analyzing other related variables

Noticeable changes in Td indices were found in the stations of the north, specially in the morning. A diminution in the Td10 index and an increase in the Td90 one at the two reference stations can be seen in figure 9. These characteristics reflect more wet air masses in the region. However, the cloud cover presents differences in the two cases. In one case (Salta) the increase in the humidity is accompanied by more days with a covered sky, something that is expectable, but it is not observed in the other station (Corrientes).

The wavelet analysis performed on the Td index showed significant signals at different scale-bands. A 4-year signal was the most frequent at the different stations analyzed, with a shift to longer scales in the second half of many series. As it was observed with extreme temperature indices, significant signals at scales closer and upper than sixteen years were observed when the index series has a trend. All this features need to be closely studied in order to understand climatic aspects of temperature extremes variability.



-a-

-b-

- c -

- d -

Figure 9: Td10 and Td90 index for a Salta (a and c) and Corrientes (b and d) (9 A.M. local time)

Acknowledgement This work was partly funded by Grants UBAX135 and UBAX234. The authors would like to thank Dr. Silvia Venegas.

References

Garreaud René, D. David & S. Battisti. 1999: Interannual (ENSO) and Interdecadal (ENSO-like) Variability in the Southern Hemisphere Tropospheric Circulation***.** *Journal of Climate*: Vol. 12, No. 7, pp. 2113–2123.

Karoly, D. J., 1989: Southern Hemisphere circulation features associated with El Niño-Southern Oscillation events. *J. Climat*e, 2, 1239-1252

Kalnay, E. M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, A. Leetmaa, B. Reynolds, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, Mo K.C., C. Ropelewski, J. Wang, R Jenne &D Joseph. 1996: The NCEP/NCAR 40-Year Reanalysis Project**.** *Bulletin of the American Meteorological Society*: Vol. 77, No. 3, pp. 437–471.

Rusticucci, M. 2000, "Potential ENSO-Related Predictability of Temperature Extreme Situations in Argentina" Actas Sixth International Conference on Southern Hemisphere Meteorology and Oceanography, Santiago, Chile, 3-7 April 2000., 108-109.

Rusticucci, M, Vargas, W, 2002: Cold and warm events over Argentina and their relationship with the ENSO phases: Risk evaluation analysis. Int. J. of Climatology. Vol. 22, pags 467-483..

Rusticucci, M, Venegas S & Vargas W, 2003: Warm and cold events in Argentina and their relationship with South Atlantic and South Pacific Sea surface temperatures. Journal of Geophysical Research, VOL. 108, NO. C11, 3356, doi:10.1029/2003JC001793

Rusticucci M, M. Barrucand, 2004: Observed Trends and Changes in Temperature Extremes over Argentina**.** *Journal of Climate*: Vol. 17, No. 20, pp. 4099–4107.

Tanimoto, Y & S. Xie, 2002: Inter-hemispheric Decadal Variations in SST, Surface Wind, Heat Flux and Cloud Cover over the Atlantic Ocean Journal of the Meteorological Society of Japan, Vol. 80, No. 5, pp. 1199--1219, 2002

Torrence, C. Compo, G. P.1998: A practical guide to wavelet analysis. Bull. Am. Meteorol. Soc., 79, 61–78, 1998.

Trenberth K, Caron, J, 2000: The Southern Oscillation revisited: Sea level pressures, surface temperatures, and precipitation. *J. Climate*,13pp.4358-4365

Vera C., Silvestri G., Barros V. &Carril A.. 2004: Differences in El Niño Response over the Southern Hemisphere. *Journal of Climate*: Vol. 17, No. 9, pp. 1741–1753.

Venegas, S.A., L.A. Mysak & D.N. Straub, 1997: Atmosphere-ocean coupled variability in the South Atlantic. J. Climate, 10, 2904–2920.