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HOMOGENEITY AND QUALITY CONTROL OF LONG TIME SERIES OF DAILY TEMPERATURE IN URUGUAY

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1. INTRODUCTION

Climate data can provide a great deal of information about the atmospheric environment that impacts almost all aspects of human life. To be accurate, the climate data used for long-term climate analyses, particularly climate change analyses, must be homogeneous. A homogeneous climate time series is defined as one where variations are caused only by variations in weather and climate. Unfortunately, most long-term climatological time series have been affected by a number of non-climatic factors that make these data unrepresentative of the actual climate variations occurring over time. Inhomogeneities in station data records are often caused by changes in observational routines, among which are station relocations, changes in measuring techniques and changes in observing practices. Few papers studying extreme temperatures in Uruguay can be found. Most of them related to ENSO, (Bidegain and Podesta (2000), Bidegain and Renom (2001, 2002). And none of them study data homogeneity.

2. DATA

This project is the first attempt to gather all the different temperature data sources together over Uruguay. Data sources included the Dirección Nacional de Meteorología (National Weather Service), and for the meteorological station of La Estanzuela, data source was the Instituto Nacional de Investigaciones Agropecuarias (National Agricultural Research Institute). Daily maximum and minimum temperature from seven surface meteorological stations from Uruguay were used for this study; note that Uruguay is a small country (around 177.000 Km^2) so we used almost the total of the data available (Fig. 1). There are three longest series, with start dates in 1930, and are located near the Uruguay river, the rest of the series start around 1950, see Table 1.
Much of the data was in paper form; with the financial support of the project PROSUR (IAI-CRN-055) we can put this information in magnetic support. Only the data from the stations of Salto, Paysandú, Mercedes, Carrasco and La Estanzuela was in magnetic support but without an exhaustive quality control. The rest of the information were in paper form and had to be digitized.
With the aim to compare some results, we introduce the Argentinean meteorological station; Observatorio Central Buenos Aires (OCBA, 34º 35' S, 58º 29' W), which is located in the city of Buenos Aires, Argentina, because it have longer time series of maximum and minimum daily temperature as the longest station from Uruguay.

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Station Name	NºWMO	Lat (ºS)	Long(ºW)	Alt	Period
Salto	86360	31º23,8'	57º57,9'	32,89m	1970-2002
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'	57º50.6'	80m	1931-2002
Carrasco	86580	34º50'	56º00,7'	32.88m	1970-2002
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

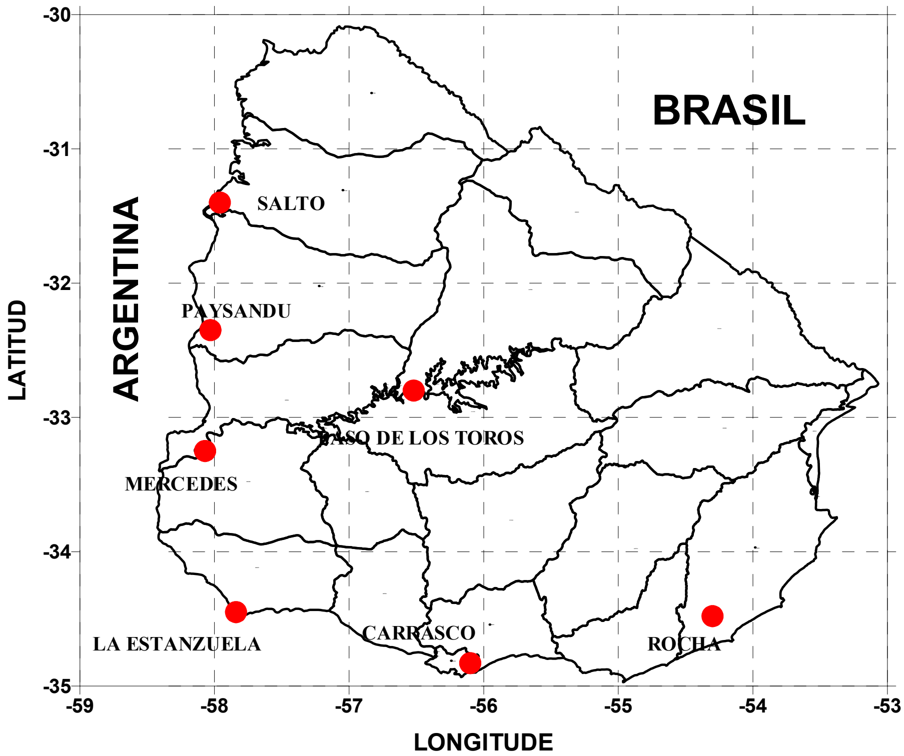


Figure 1. Location of the 7 temperature stations in this investigation.

3. QUALITY CONTROL

For the quality control we firstly used the RClimdex 1.0 (available at http://cccma.seos.uvic.ca/ETCCDMI/software.html), which detect some common errors such as maximum temperature cooler than minimum temperature and outliers. Because we found some errors that this software doesn't detect, we applied another methodology.

3.1 Missing Data

In a first reading of the data, we detect a high percentage of missing data. We try to recover it by reading the thermograph bands, when they were available. The final rate of missing value is 4 % over the total of daily data (maximum and minimum temperature). Although, this percentage is low, the major problem is that missing data are grouped in continuous days or months, which affect some homogeneity test. In many stations there are periods of lost data that they can reach to several months. Table 2, shows the final total percentage of missing data for each station, and for each variable (maximum and minimum temperature). Station La Estanzuela is complete.

Station Name	Tot. % missing values	Tmax	Tmin
Carrasco	0.05%	0.05%	0.05%
Mercedes	2.5%	2%	2.95%
Paso de los Toros	1.5%	1.55%	1.52%
Paysandú	0.2%	0.25%	0.25%
Rocha	2%	2.1%	1.86%
Salto	0.1%	0.15%	0.13%

Table 2. Percentage of missing values for each station

3.2 Impossible Values

- **Maximum temperature cooler than minimum temperature**: this is a frequent error and is easy to detect. We found that this error not always was a typing mistake, sometimes respond to an interpretation error or a not well defined period to consider the variables, for example:
  a) Observers that consider the period for maximum and minimum temperature of the day between 0 and 24 Local hours.
  b) Other criteria were the stipulated from WMO on SYNOP code. Up to year 1982, this code require to report this variables in the following way: maximum temperature at 00 UTC and minimum temperature at 12 UTC. After 1982 the code was modified, and the observer has to send the values of maximum and minimum temperature at 12 and 00 UTC. This generates confusions on data digitalization, because they have four values for each day. The most amounts of data in magnetic support follow SYNOP code criteria up to year 1982. Because of that, we adopted it.

- **Typing error:** the most common were like: 119,0 or 19..2.

3.3 Internal Consistency:

We control over differences in temperature between two consecutive days for each station and for the maximum and minimum temperature. This last analysis is based on the persistence of the atmospheric data in order to detect others errors, such as typing errors. We establish a threshold of acceptance for the variable tested, following the criteria presented in Rusticucci and Barrucand (2001). We decided to control the cases when the interdiurnal difference in two consecutive days was higher than 4 times the standard deviation, for each month. This procedure found out more erroneous data, these errors are mostly detected in maximum temperature (79%). The most common errors were: typing errors and confusion between maximum and minimum temperature. Particularly in one station we found a complete month with erroneous data in both variables, so perhaps they input another variable (see Table 3) this error was not detected by RClimdex software.
The cases detected with this methodology, which statistically had a very low probability of occurrence, not always were erroneous data. Some large interdiurnal differences could be associated to synoptic phenomena, because of that they were analyzed case by case. An example of a large interdiunal difference due to a synoptic phenomenon is the case of 25 August 1996. On that day, 3 stations had a difference in maximum temperature when compared to the previous maximum temperature, which was up to

20°C. This case was also detected in Argentina as is shown in the study of Rusticucci and Barrucand (2001). So it was not considered as erroneous. This type of test allows, in a first analysis, detections of possible cases of warm spells as well as the region affected.

Year	Month	Day	Tx mag. supp.	Tn mag. supp.	Tx paper form	Tn paper form
1980	4	1	9.1	6.8	28	18.8
1980	4	2	9.2	6.3	30	20
1980	4	3	9.1	6.6	28.5	20
1980	4	4	9.6	5.4	31.8	19.7
1980	4	5	9.5	6.5	28.8	21.8
1980	4	6	9.9	6.3	29.4	20.8
1980	4	7	9.8	5.9	29	20.9
1980	4	8	9.8	5.5	27.2	19.9
1980	4	9	9.8	5.6	30.5	18
1980	4	10	9.8	6.4	31.2	21.8

Table 3. Station Salto, April 1980. Example of erroneous data detected

4. STATISTICAL HOMOGENEITY

Different homogenization procedures were used together with the aim of comparison. They are based in different theories and different sensibilities in the detections of steps inside the time series. The selected test methods are: the Standard Normal Homogeneity Test (SNHT); Alexandersson (1986); Buishand Range Test Buishand (1982); and the Homogeneity test proposed by Vincent (1998) using regression models. The first two tests suppose under the null hypothesis that the annual values Y_i of the testing variable Y are independent and identically distributed. Under the alternative hypothesis, they assume that a step-wise shift in the mean is present. Although these two tests have many characteristics in common, they are also different. The SNHT detects breaks near the beginning and end of a series relatively easily, whereas the Buishand range is more sensitive to breaks in the middle of a time series, Hawkins (1977). The test proposed by Vincent, is sensible to identify undocumented changepoints. This is a very useful property of the test, because there is a poor station history reports in Uruguay. For our database there is a weakness of it related to the exigency of complete data set. The method does not calculate monthly mean if time series have more than 3 consecutive days of missing data or more than 5 days, and if a monthly mean is missing, it does not calculate the annual mean.

The three test selected are capable of locating the year where a break is likely. The first two tests are capable to detect a single step, while the other is capable to detect multiple steps.

For the SNHT and Buishand test, the selected tested variable, at first, was annual mean of the diurnal temperature range (mDTR), suggested by J.B. Wijngaard et al (2003). In some cases we applied these test to annual mean maximum and minimum temperature series. The other test uses as a tested variable the annual mean of maximum and minimum temperature separately.
We broke up the total period in two parts, to better analyze inhomogeneities. Sub periods are of no less than 30 years traiyng to maintain the statistical stability of the test.

5. RESULTS

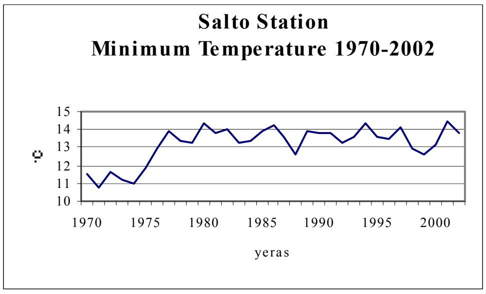
The outputs of test applied are given in the next tables for each station. Significant years of change detected by each of the tests, as well as the variable tested and their significance level, are put into the tables.
SNHT: bold, Buishand: italic, <u>Vincent et al: underlined</u>. Significance: **:1%, *:5%, ^: 10%.

Salto Station

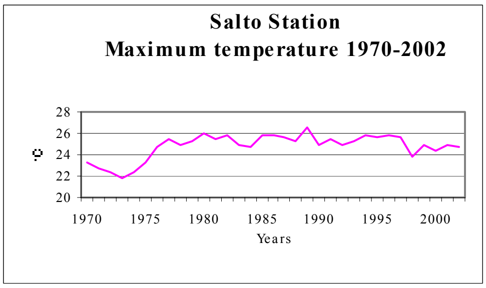
<table>
<tr><th>Period</th><th>Vble</th><th>Changepoints</th></tr>
<tr><td>1970-2002</td><td>Tx</td><td><u>1976** 1997**</u></td></tr>
<tr><td>1970-2002</td><td>Tn</td><td><u>1976**</u></td></tr>
<tr><td>1977-2002</td><td>mDTR</td><td>1998*</td></tr>
<tr><td>1977-2002</td><td>Tx</td><td><u>1998* </u>1997**</td></tr>
</table>

There was a documented relocation of the station, in year 1976. Before this change, station was inside of the city of Salto and more accurately in the backyard of the observer house. It was changed to a big park, Parque Harriague, which is an open place.
This relocation is detected for the entire test selected, when the variables tested are the annual mean of maximum and minimum temperature series. While if we use the variable mDTR, SNHT and Buishand test are not capable to detect this change. In Figure 2, we show the annual mean series for maximum and minimum temperature and diurnal temperature range. This relocation of station, clearly affect the annual mean maximum

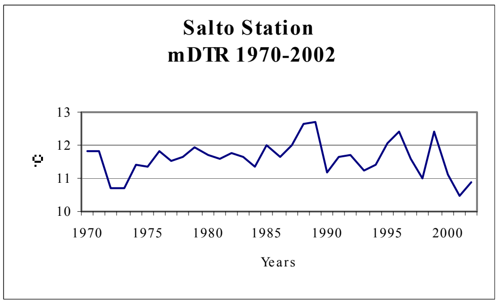
and minimum temperature series, with a step in 1976, of around 3°C, while the step in the mDTR series is not so pronounced.



a)



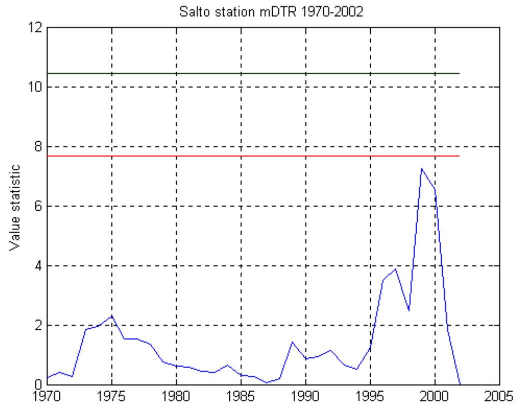
b)



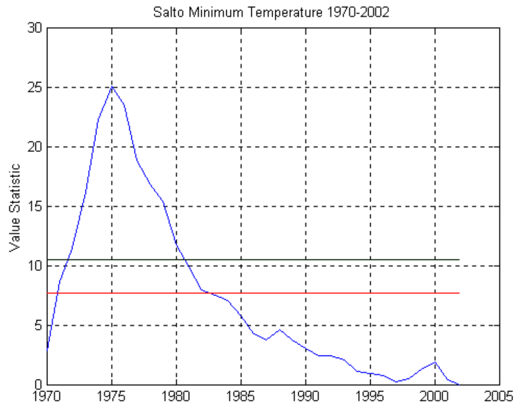
c)

Figure 2: Annual mean series of a) Minimum Temperature, b) maximum temperature and c) diurnal temperature range. For Salto station within 1970 – 2002.

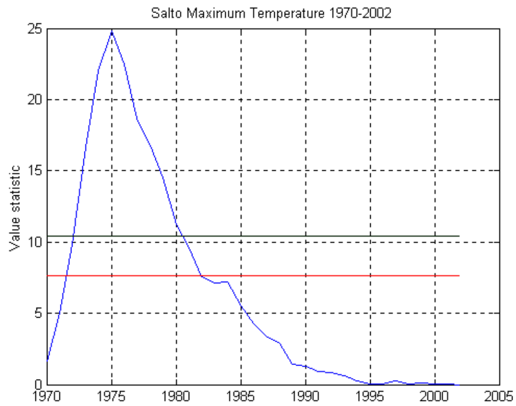
Figure 3 shows the results of SNHT test applied to the mDTR and annual mean of minimum and maximum temperature series of Salto. The results of the Buishand range test are similar. Contrary to maximum and minimum temperature series there are hardly any indications for a break around 1976 in the series of mDTR. This is of particular importance in climatic studies using this variable. We broke up the series, and study the sub-period 1977-2002, to see if the tests are capable to detect the other documented change of location around 1997. Test applied show that this relocation affects more the maximum temperature.



a)



b)



c)

Figure 3. Test results of SNHT applied to the mDTR series (a), annual mean of minimum (b) and maximum (c) temperature series of station Salto. Green line gives 1% critical values; red line 5% critical values. The results of the Buishand range test (not shown) are similar.

Paysandú Station:

Period	Vble	Changepoints
1935-2002	mDTR	**1946**** ***1957**** **1989***
1935-2002	Tn	***1957**** ***1969****
1935-2002	Tx	1946** 1977** **1945***
1935-1970	mDTR	**1945**** ***1957****
1935-1970	Tx	***1945**** ***1954****
1935-1970	Tn	***1957****
1971-2002	Tn	**1996*** **2000****

In this station is important to mention that the documented change of location in 1967 is not detected for anyone of the applied test.

Mercedes Station:

Period	Vble	Changepoints
1931-2002	mDTR	**1997***
1931-2002	Tn	**1940**** **1997***
1931-2002	Tx	1942*
1931-1970	Tn	***1939****
1971-2002	mDTR	**1996*** **2000***
1971-2002	Tn	1983^ **1997****1985***

As in the previous station, the documented change of location in 1977, is not detected for anyone of the test applied.

La Estanzuela Station:

Period	Vble	Changepoints
1931-2002	mDTR	**1935****1982*** *1945**
1931-2002	Tn	**1937****1939^ 1962***1943***
1931-2002	Tx	**1935*** **1945***
1931-1970	mDTR	**1935**** *1945**
1931-1970	Tn	**1938******1935***1939* 1962^
1971-2002	mDTR	**1982***
1971-2002	Tn	**2000***

Carrasco Station:

Period	Vble	Changepoints
1970-2002	mDTR	***1976****
1970-2002	Tx	***1976****
1970-2002	Tn	**2000***

Paso de los Toros Station:

Period	Vble	Changepoints
1960-2002	Tn	**1967****

Rocha Station:

Period	Vble	Changepoints
1950-2002	mDTR	***1978**** **1990***
1950-2002	Tn	***1979**** **1990*** **2000***

OCBA Station (Argentina)

Period	Vble	Changepoints
1909-2004	mDTR	***1941****1957****
1909-2004	Tn	***1941**** ***1957****
1909-2004	Tx	**1925*****1941**1973**
1931-2004	mDTR	***1972**** **1941***
1931-2004	Tn	1940^**1941*****1966****
1931-2004	Tx	**1940*****1959****1959**
1931-1970	mDTR	**1935*****1938*****1956****
1931-1970	Tn	***1941****1956****
1931-1970	Tx	**1941****
1971-2004	Tn	**1976****

5.1 Years of changepoints detected in more than one station:

1938-1939: A significant step is detected around 1939 in the longest series of Mercedes and La Estanzuela stations. To verify a possible climatic origin of this step, we work with daily series of maximum and minimum temperature series from OCBA station, Buenos Aires, Argentine. The OCBA series are longer as the longest stations in Uruguay. The test applied detect a step around 1939 in this series, as well as in a preliminary study of Prado station (Montevideo, Uruguay) during the period 1921-1969. This step seems to be significant for the minimum temperature and is detected considering the hold period as when we broke up the series.
Figure 4. shows the annual mean minimum temperature series for the four stations where test detect the step.

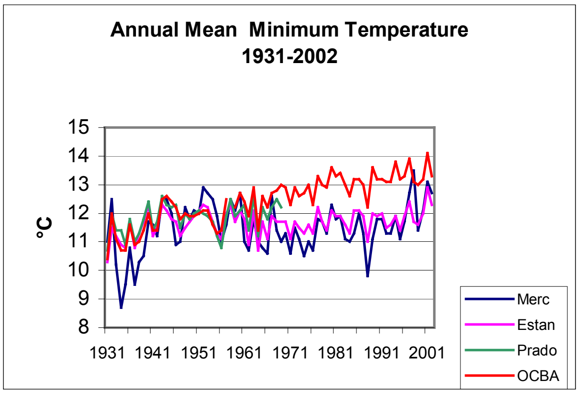


Figure 4 annual mean minimum temperatures for Mercedes, La Estanzuela, OCBA and Prado stations, where a step around 1939 is detected.

As we can see the minimum series for all the station present a step of around 1ªC compared with the following decades. We concluded that this step is a real change.

2000-2001: SNHT test applied to annual mean minimum temperature to sub-period 1971-2002, detect a step around year 2000 in Paysandú, Mercedes, La Estanzuela, Carrasco and Rocha stations with significance of 1%. Figure 5 show the annual mean of minimum temperature within 1971-2002, as we can see from the graph, year 2001 presents highest minimum temperature. When we graph the deviation from the period 1971-2002 in Figure 6, the maximum deviation is located in year 2001, with values around 1.5°C, for all the stations.

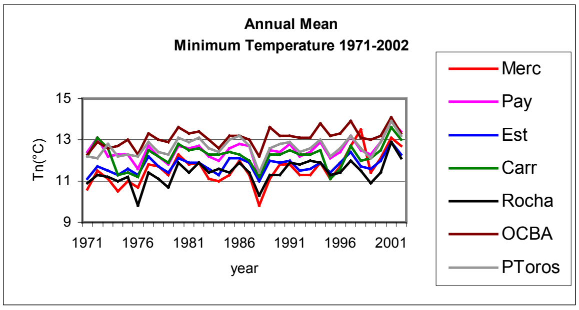


Figure 5. Annual mean minimum temperature within 1971-2002 for Mercedes, Paysandú, La Estanzuela, Carrasco, Rocha, OCBA and Paso de los Toros stations, where a step around 2000 is detected when we applied SNHT test.

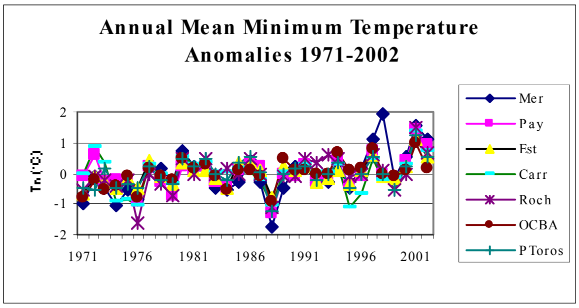


Figure 6. Annual mean minimum temperature anomalies within 1971-2002 for the same stations as figure 5. A maximum anomaly of 1.5 °C is detected for all the stations.

We have to mention, in the case of Mercedes station, that maximum anomaly in 1998, may be because we have a lot of winter missing data in this year.

Because series end in 2002, the change detected could be the result of being in one extreme, but it should be considered in longest series.

6. CONCLUSIONS

A reliable daily database of maximum and minimum temperature for 7 Uruguayan stations was generated with this work. Although in the future we pretend have data from more stations as well as longer period from the station studied here, we give here a first guide to do this.

The most frequently encountered causes for the breaks detected in the temperatures series were station relocations or changing in observing practices. Historic metadata support is essential for evaluating the breaks detected as well as for future attempt to correct series from artificial steps. Unfortunately, these metadata are very poor in Uruguay, not all the relocations of stations are documented, and changes in instrumentation locations, measuring techniques are more poorly documented.

Selection of testing variable is very important to study inhomogeneities, as we can see from test results from Salto station, the annual mean diurnal temperature range (mDTR) used as a testing variable, is not always sensible to changes, specially when they affect in the same way maximum and minimum temperature. This could be, because of the construction of mDTR, were difference between daily maximum and minimum temperature still remain the same.

This is very important for future climate studies based on this variable.

With respect to homogeneity test applied, we have to mention that not always the documented relocation of stations were detected, meaning that relocation does not make a step in the series, such are the cases of Mercedes, Paysandú and Paso de los Toros stations. In contrary, Salto and Carrasco stations, show the artificial step generated in maximum and/or minimum temperature series because of the relocation. Other steps found by SNHT and Buishand test, as the cases of Rocha and Mercedes stations, could be because of missing data.

Making adjustments to inhomogeneous series could be a method of improving the series in this dataset. However, we did not try to adjust the series for the inhomogeneities detected. Different homogeneity adjustment techniques were developed to eliminate artificial steps in series, Peterson et al (1998), present a review of them. Adjusting on a daily basis is not so easy, and needs a carefully study. However, in future studies it has to be discuss which is the best methodology to apply with such purpose.

A change around year 1939 was detected in the longest stations of Uruguay, Mercedes and La Estanzuela, and it seems to be because of the minimum temperature. To eliminate possible breaks due to changes in instrumentations, observing practices and measurement techniques, we study the OCBA and Prado (within 1921-1969) temperature series. We obtained similar results, concluding that it was a real change.

As the SNHT in sub-period 1971-2002, detect a step in 2000 annual mean minimum temperature series from five stations. Analyzing annual 1971-2002 anomalies all stations (except Salto), show a strong warming in 2001. This case could be a case study for future research.

Acknowledgements

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