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# LOW FREQUENCY OSCILLATIONS IN SERIES OF REFERENCE ON DAILY MAXIMUM AND MINIMUM TEMPERATURE IN SOUTH AMERICA. INFERENCE ABOUT PERIODS, LONGITUDE AND INPUT CIRCULATIONS

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## Abstract

*In order to detect temporal changes in temperature structure, particularly trends, series of maximum and minimum daily surface temperatures were analyzed at 8 reference stations in the south east of South America during variable periods and the longest existing periods (around 100 years). To make a correct diagnosis of the secular variations, a previous analysis was made of the different inhomogeneities existing in the temporal series.*

*To study the evolution of the temperature series and reduce the number of parameters, an algorithm of nonhierarchical cluster analysis was used. This algorithm assigns each day to one of the four groups (i.e. each day is represented by one group only). These groups were classified as Warm, Wet, Cold and Dry.*

*The study shows low frequency variations in the groups which were analyzed through specific properties such as persistence changes, dynamic entropy and circulation structure. The association between the series of groups obtained in the clusters and precipitation was also studied.*

### *1. Introduction*

Long-term variability in the climatic system is one of the principal agents which affect the biosphere and the development of living beings in it. Within this system, human activities, both productive and cultural, interact with these variations so that their effective diagnosis is of strategic interest for the future.

In Argentina, in the middle of the 20th century, the interest of the people of Patagonia who attributed the reduction in pastures in this region to climate change, led the National Development Council to prepare a “study of the existence of climate change in Patagonia” (Galmarini and Raffo del Campo, 1965). In this report, the authors analyzed the thermal regime (on the basis of the secular and temporal trend) at 7 climate stations in Patagonia having records of 60 years. They concluded that the secular trend lines at all the stations were horizontal and consequently showed that the Patagonia thermal regime did not change from 1900 to 1960.

Focusing on the long term variabilities, Hoffman, 1990, studied the variations in air temperature at 8 Argentine stations from 1903 to 1989. The analysis of the stations located to the north of 45ºS did not show a significant variation in temperature as from the 1940s except for those which were affected by urbanization. At the stations in Argentine Patagonia, the author found a warming as from 1930 although he explained that this warming could be due as much to natural fluctuations as to anthropogenic effects.

*Hoffmann, et al* (1997) analyzed mean extreme decadal temperature variability and found a significant increase in maximum ($\mathbf{T_x}$) and minimum temperatures ($\mathbf{T_i}$) at stations to the south of 50ºS while at the stations to the north of 42ºS, mean extreme temperatures varied in the opposite direction: mean $\mathbf{T_x}$ had a negative trend and $\mathbf{T_i}$ had a positive one. This pattern is consistent with precipitation variation and vapor pressure.

*Barrucand* (2001) and *Rusticucci and Barrucand* (2004) analyzed the trends of mean values, deviations and extremes (percentiles 5 and 95) of maximum and minimum temperatures in Argentina from 1959 to 1998 and found that the summer minimum temperature had the greatest regional trends. The authors also showed that the rise in mean summer temperature was strongly related to the increase in number of extreme warm events.

The objective of this paper is to analyze the presence of low frequency oscillations, particularly the trends of the maximum and minimum temperatures in different features of the daily scale in series with the longest possible record in the south of South America (reference series).
In view of the length of the reference series and in order to prepare a good diagnosis of the characteristic features associated with them, it is shown that it is possible to adapt work methodology to take maximum advantage of the information available.
Consequently, an exhaustive analysis was made of the inhomogeneities produced by anthropogenic factors. A method was developed to eliminate the different systematic errors for the cases where the stations were relocated and for those where urban growth affected mean values.
A bi-varied classification was then proposed of the daily anomaly series of maximum and minimum temperatures to infer the behavior of different circulation patterns associated to these.
Finally, the results of the low frequency oscillation diagnosis were studied with reference to the temperature anomaly groups in the reference series.

### *2. Data and methodology:*

A station or a reference series is one that has a long record (as far as possible it should cover an instrumental period), its measurement quality is recognized and it must represent different or specific climatic regions. It is necessary to make the diagnosis of secular variations in a reference series since the presence of oscillations with periods comparable to the more commonly used record periods affects the results significantly.
So, on adopting the selection criterion for the reference stations, the length of the records was taken into consideration and a representative geographic distribution of the stations, trying as far as possible to take the climatic regions of the south of South America and cover an ample latitudinal selection (the transect covers from 23º to 55ºS).

Before starting the analysis, the daily maximum and minimum temperatures (**Tx** and **Ti** respectively) were checked for consistency following, among others, the recommendations of the quality control guide for surface climate data published by the WMO within the world climate data program (1984).

| Country | Station | Longitude | Latitude | start | end |
|---|---|---|---|---|---|
| *Argentina* | *Santa Rosa* | *-64.26* | *-36.54* | *1937* | *2004* |
| | *Río Gallegos* | *-69.45* | *-51.99* | *1896* | *2004* |
| | *Pergamino* | *-60.53* | *-33.90* | *1931* | *2000* |
| | *Corrientes* | *-58.74* | *-27.43* | *1894* | *2004* |
| | *Pilar* | *-63.85* | *-31.64* | *1931* | *2004* |
| | *S. M. Tucumán* | *-65.20* | *-26.80* | *1891* | *2000* |
| | *O.C. Buenos Aires* | *-58.42* | *-34.57* | *1906* | *2000* |
| *Brasil* | *Campinas* | *-47.12* | *-23.00* | *1890* | *2003* |

**Table 1** *Description, geographic location and observation period of the 8 reference stations analyzed.*

In view of the length of the periods of the series under consideration, it was necessary to make a homogeneity study to know the effect of possible systematic changes in the values measured and adopt a methodology which would minimize errors in the diagnosis of existing secular variations.
The absolute inhomogeneities in the temperature series averages may be due to natural effects, as in the case of climate jumps (Yamamoto et al. 1985). Another disturbing factor of the temperature series are the anthropogenic agents. These changes are mainly due to two factors: 1. the growth of cities which surround the meteorological station and impose an increase in the values registered and 2. the relocation of stations for operative reasons, usually urban, to the closest airports.
On this topic Vargas and Minetti (1997) studied the inhomogeneities in temperature series of northwest Argentina and found that the magnitude of the errors in the observations (either because of the relocation or changes in the estimated mean temperatures) could lead to wrong results in the study of long term climate variations. They also found that urban-industrial warming significantly affected the mean minimum temperature series, particularly in winter.
The climate time series with monthly and annual resolution count with a number of established statistical methods to determine their homogeneity. Peterson et al (1998) contains a complete review of this methodology. For the daily climate series these methods are scarce and, in general,

monthly or annual variable scales are used for the daily values to calculate the date on which a jump occurs in the mean values (*Wijngaard, et al 2003*).
Because of this, it is very important to know the documentation (metadata) with the detailed information on changes in the location of a station, in the type of instruments, etc. Starting with this reference, it is possible to infer the presence of absolute inhomogeneities, particularly useful in the series analyzed in this study as the length of the period does not allow a coherence study with stations of the same climatic region.
According to the data supplied by the databank of the National Meteorological Service, the Corrientes and Rio Gallegos stations recorded changes in the location of the measurement station.
The Corientes station, which was located in the capital was declared operative on 1.1.1873 until the end of 1969. In November 1961 a "Corrientes aero" station was installed at the airport of that city and it is still recording surface variables now. With reference to this, the present study analyzes a series composed by the records of the urban station until 1961 and as from 1962 the values of the airport station are used.
The Rio Gallegos station started operating at the town center of that city in 1986. As from 1945 it has been operating at the local airport.

### *2.1 The Corrientes Case*

Since in Corrientes the town and rural stations were operating at the same time from 1961-1969, it is possible to make a comparative analysis to determine the coherence between these two stations. Taking the **$T_x$** and **$T_i$** daily values of the Corrientes town and Corrientes airport stations, it was possible to calculate the averages for each day of the year and obtain the annual cycles for these two stations.
Then, to determine whether there was a change in the mean values of these series, the differences between the annual cycles for each extreme temperature were calculated as follows:

$$\Delta T^i = T_{town}^i - T_{aero}^i \quad \text{where } i=1,\ldots,365 \text{ days of the year}$$

Figure 2.1 shows the difference between the annual **$T_x$** and **$T_i$** cycles at both stations during the overlap period. The warming caused by urbanization can be seen clearly during the whole year in the two variables.

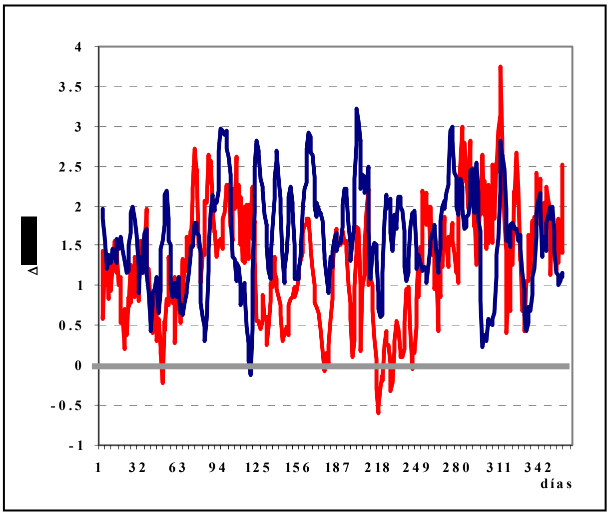



**Figure 2.1** *Differences in the annual cycles of Tx and Ti ($\Delta T = T_{town} - T_{aero}$) between the rural and the town stations during the overlap period from 1961-1969. (5 day moving averages)]. Red: Tx; Blue: Ti.*

The average difference in maximum temperature is 1.3ºC; it is bigger in autumn and spring when it reaches 2ºC on average. As to minimum temperatures, it was found that the mean annual difference between the airport and the town is 1.6ºC. This variable is more sensitive to the effect of urban warming in the winter when average differences over 2ºC are observed.

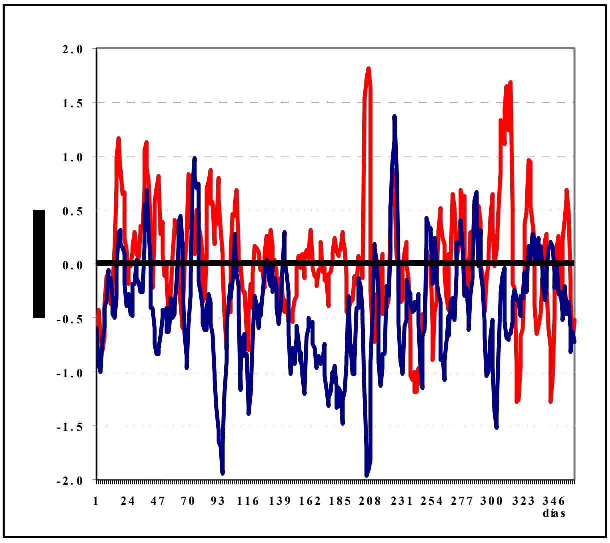



**Figure 2.2** *Differences in the annual cycles of standard deviations ($\sigma_T$) of Tx and Ti ($\Delta\sigma_T = \sigma_{T\,town} - \sigma_{T\,aero}$) between the urban and the rural stations during the 1961-1969 overlap period. [5 day moving averages].Red: $\sigma_x$ ; Blue $\sigma_i$.*

To analyze the inter-annual variation of extreme temperatures, the annual cycles of the standard deviations ($\sigma_t$) were studied. Figure 2.2 shows the differences in the $\sigma_t$ cycles at the town and airport stations. A smaller annual variation is observed here in the minimum temperature in the town, particularly during the winter when the differences are more than 0.5ºC. As to inter-annual maximum temperature

To see whether these functions represent the same process, the functions obtained were compared with those associated to a Markov process, i.e. where $r_k = r_1^k$. If it is assumed that the process has a memory, i.e. it is a red noise process, the $r_k$ standard error is:

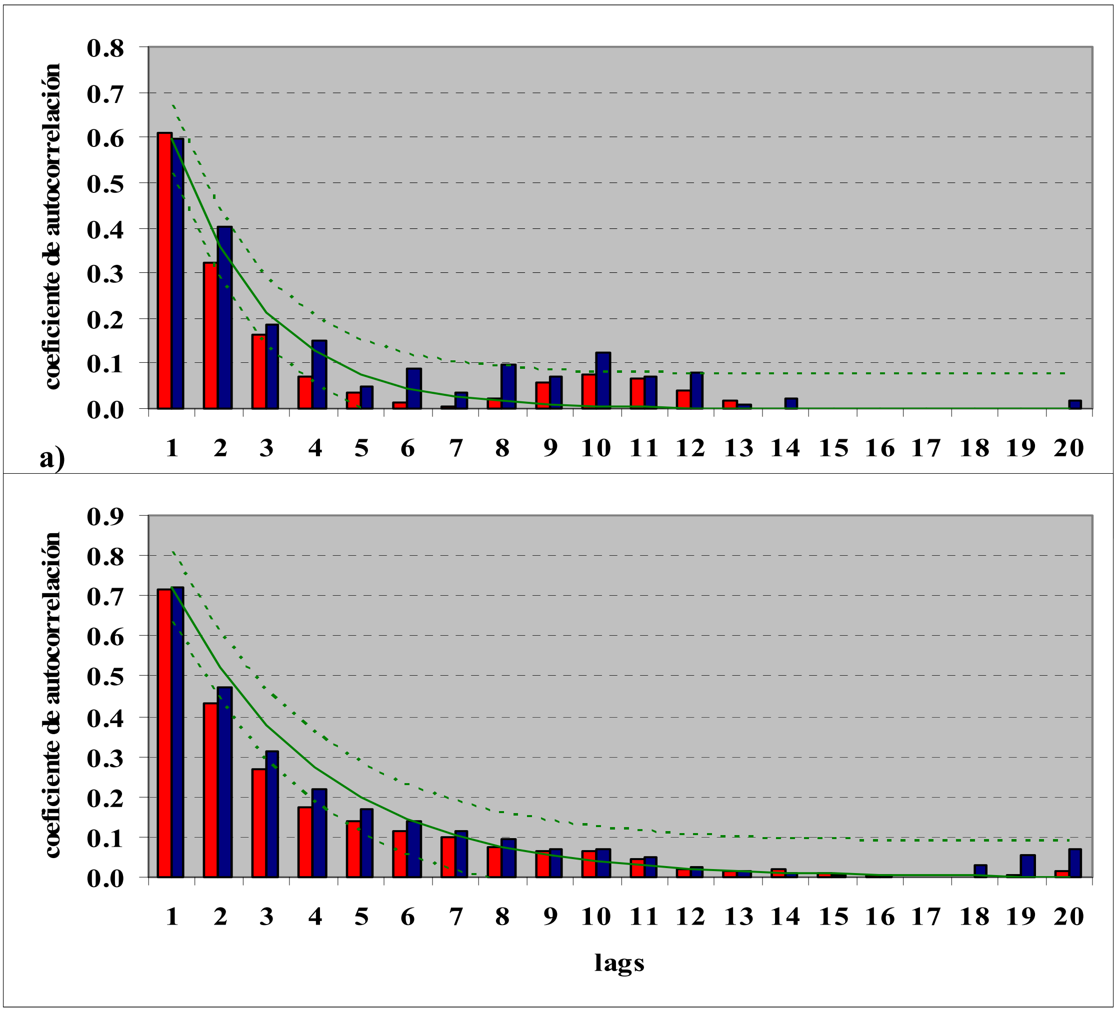



**Figure 2.3** *Daily a) Tx' and b) Ti' autocorrelation functions at the Corrientes town station (in red) and the airport station (in blue) and the Markov process associated to its confidence interval (in green) from 1961 to 1969.*

variations, no systematic shift is observed in the deviation values so that it may be inferred that $\sigma_{Tx}$ are not affected by urbanization.

In order to determine whether the synoptic scale physical processes, associated to inter-daily variation are modified by urbanization the autocorrelation function of the daily extreme temperature series at the two stations were analyzed.

$$stderror(r_k) = \sqrt{(\frac{1}{N})\left[1 + 2 * \sum (r_i)^2\right]}$$

with i=1, .. , k-1.

where k is the lag and N the number of data.

Figure 2.3 shows the autocorrelation function for the daily maximum and minimum temperature series. Analyzing the first function coefficient which characterizes the stochastic process associated to the Markov model, it can be observed that there are no differences in any of the temperatures. This result shows that the inter-daily variation for $\mathbf{T_x}$ and $\mathbf{T_i}$ is not affected by urbanization.

If the autocorrelogram associated to $\mathbf{T_x}$ is analyzed more in detail, it can be observed that at both stations the processes correspond to the same Markov model if $\mathbf{T_x}$ variations of less than 10 days are considered.

For $\mathbf{T_i}$ the variations between two and four days show a smaller relation in the town station than at the airport and the Markov process which governs these. This may be due to the minimum temperature variance being smaller than in town as was shown in the description of figure 2.2. For variations of more than five days the processes are associated to the same model.

Based on these results it is concluded that the change of site of the measurement station affects to a large extent the mean values of the temporal series and imposes a systematic shift of the measurements. These differences are observed to a smaller extent in the minimum temperature deviations, especially in winter. Finally, it is found that the stochastic processes associated to the daily temperature series are not modified. This implies that the synoptic processes which form the inter-daily to weekly scale variation are not affected by the urbanization effect.

To eliminate the shift induced on mean values and since the analysis of low frequency oscillations will be made on

$$Tx^*_{l} = \frac{1}{365}\sum_{m=1}^{365} Tx'_{jklm} \qquad Ti^*_{jk} = \frac{1}{365}\sum_{m=1}^{365} Ti'_{jklm}$$

temperature anomalies, it was decided to calculate these anomalies with respect to the town and country periods. In this case, the records for 1894 to 1961 were taken for the urban period and those for 1962 to 2004 for the rural period. Daily anomalies were thus obtained according to

$$Tx'_{jkl} = Tx_{jkl} - \overline{Tx}_{jk}$$

$$Ti'_{jkl} = Ti_{jkl} - \overline{Ti}_{jk}$$

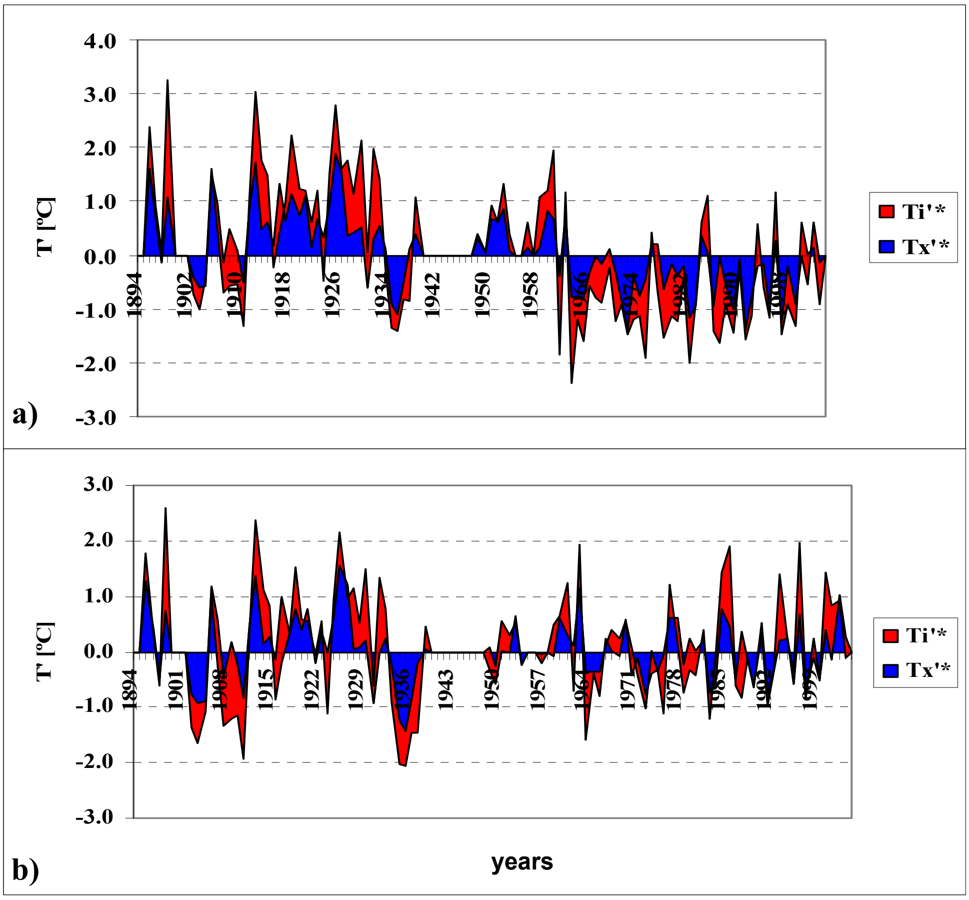



**Figure 2.4** *Annual average of maximum and minimum temperature anomalies [**Tx'*** and **Ti'***] for a) the original series and b) the homogeneous series.*

Where $\mathbf{Tx_j}$' and $\mathbf{Ti_j}$**'** are the values of the maximum and minimum temperature anomalies respectively for day **j**, month **k** and year **l**; $\mathbf{Tx_{jkl}}$ and $\mathbf{Ti_{jkl}}$ are the values of temperature on day **j**, month **k** and year **l** and

$$\overline{Tx}_{jk} = \frac{1}{n}\sum_{l=1}^{n} Tx_{jkl} \qquad \overline{Ti}_{jk} = \frac{1}{n}\sum_{l=1}^{n} Ti_{jkl}$$

are the maximum and minimum temperature climate averages on day **j** and month **k** and **n** is the number of years in the series of each sub-period.

The mean annual anomaly was calculated as:

Analyzing the cycle of mean annual anomalies (**Tx*** and **Ti*** in *figure 2.4*), the difference can be seen clearly between the series where daily anomalies were calculated with respect to the average for 1894 – 2004 and the series where they were calculated with respect to the averages of the different sub-periods. In series a) there is a warm period before 1960 associated to the urban warming effect while in the second part of the register for this period there are negative anomalies practically during the whole of the sub-period. This is clearly the effect induced by the moving of the station in 1961 and the analysis of this series may lead to an erroneous diagnosis of low frequency oscillations.

In series b) obtained by homogenizing the records, the anthropogenic effect does not appear. Thus, the daily anomaly series associated to this will be the one used in the following analyses.

### 2.2 The Río Gallegos Case

This station operated in the town from 1896 to 1945 when it was moved to the local airport. Unfortunately, simultaneous data at both stations are not available. That is why, to determine whether the move caused a shift in mean values, the **Tx*** and **Ti** annual anomalies were calculated in the original series and in the series where the daily anomalies were calculated with respect to the periods before and after the relocation as indicated in the section on Corrientes. Using these series, the differences between both annual **T*** cycles were calculated (*Figure 2.5*). In this case, on analyzing these differences, a discontinuity was observed in 1945, coinciding with the move of the station to the airport. The induced effect in the series corresponds to a warming of an average of 0.7ºC for $\mathbf{T_x}$ and 1.1 ºC for $\mathbf{T_i}$.
As in the Corrientes series, this systematic difference was adjusted calculating the daily anomalies in both variables in relation to the mean of the samples of the urban and suburban period.

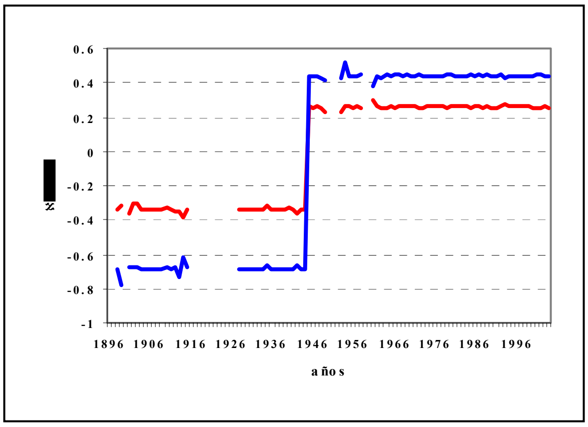



**Figure 2.5.** ***T**** *differences between the original and the homogeneous series in Rio Gallegos. Red: ΔTx; blue: ΔTi.*

### 2.3 *Effect* of urban warming

Numerous papers have been written on the thermal characteristics of urban areas (*Chandler T., 1965; Jones P, et al 1989, etc.*), which show that there is a big difference from the surrounding rural areas. In general, these thermal differences are due to the interaction of the following factors:

I- Changes in radiation balance due to the composition of the atmosphere
II- Changes in the radiation balance due to the albedo and thermal capacity
III- Heat produced by human activities.

The net effect of these thermal processes is an increase of urban temperature compared to the surrounding rural areas. Section 2.1 showed this effect on Corrientes where it was shown that the increase was more than 1ºC for the two extreme temperatures.

Although it is not possible to determine exactly whether the temperature changes are due to the growth of urban settlements and/or natural effects, it indicated that the growth of a town goes together with a rise in mean annual temperature. With reference to this, *Karl, T.* (1988) found an exponential relation between the mean annual intensity of the heat island and the population. In Argentina *Barros and Camilloni* (1994) and *Camilloni and Barros* (1994) made an extensive analysis of various stations in subtropical Argentina and particularly Buenos Aires and found that excess urban temperature depended on the population, similarly to Australia, thus validating Karl's findings.

*Figure 2.6* shows the rise in population in Buenos Aires and Greater Buenos Aires and the mean annual minimum temperature measured at the Observatorio Central Buenos Aires during the XXth century. During this period, Buenos Aires has a sustained growth until the 1950s when the population stabilizes at 3 million inhabitants. At the same time, greater Buenos Aires starts growing from 1.7 million inhabitants in the 1947 census to 8.7 million in 2001. In brief, the population of this urban conglomerate grows exponentially during the whole of the XXth century.

This effect is also recognized in Campinas, whose population was calculated at more than a million inhabitants in 2004. It must be remembered that this town is close to the San Paulo urban conglomerate of 10.8 million inhabitants in 2001.

Finally, since this recognized effect causes a trend of anthropogenic origin, it was decided to remove it from the daily series. A curve is obtained which brings this variation closest to the daily scale using minimum squares. Once this relation is known, the slope which imposes an increase in mean values is removed. Finally, the differences with the annual cycle of the new series without trends are taken as daily anomalies of the trend-less series.

It must be noted that this secular variation may be due not only to the urban factor but also to the unknown natural effects which may introduce an error in their diagnosis.

Analyzing the differences between the series of mean annual anomalies in Buenos Aires with evidence of urban warming and those series where this effect is filtered out using the method proposed. In the original series, the signal ruling urban growth dominates clearly over other natural fluctuations which may rule the behavior of the extreme temperature series.

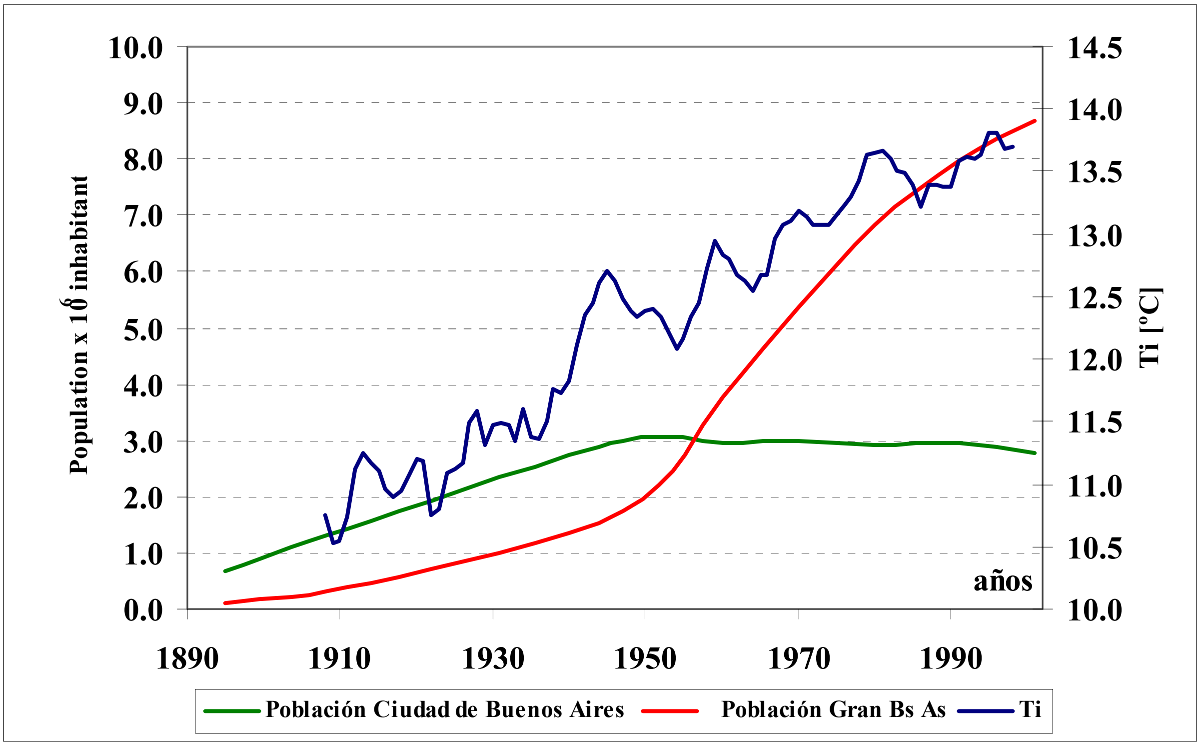



**Figure 2.6.** *Mean annual minimum temperature and demographic growth in Buenos Aires and suburbs (source INDEC 2001)*

## *3. Trends in the monthly and annual scales*

### *3.1 Trends during the second half of the XXth century*

Both in this section and in the next, the existence is discussed of trends in series where the growth of the city around the measurement station is not relevant. With reference to this phenomenon, Buenos Aires and Campinas will be referred to in section 3.3.

The first analysis was made from 1960 onwards at the 6 stations of reference. The choice of this period was conditioned by the fact that most of the meteorological records in Argentina begin in the 60s, so the results are comparable to existing bibliography.

During that period and the summer months there were significant positive trends in annual minimum temperature at the 5 stations in the north of the country. In Rio Gallegos there are no significant trends during this period at the 5% level in the minimum temperature.

A significant cooling is observed in mean annual maximum temperature in Santa Rosa, Tucuman and Pilar, also occurring mainly in the summer months. In Pergamino the behavior is similar to the other sites though no significant values were obtained.

In Corrientes and Rio Gallegos different behavior is observed. In Corrientes, though the cooling in the annual mean is not significant, it occurs in winter while in summer the behavior is not uniform. In Rio Gallegos there is a warming of the peak temperature mainly in summer, contrary to what occurs in the north, which agrees with the findings of *Hoffman, et al* (1997).

### *3.2 Trends during the first half of the XXth century*

The analysis of this period was conditioned by the availability of data (some data are missing), particularly in the early years of the Corrientes and Rio Gallegos records.

As to mean annual minimum temperature, warming occurs in Rio Gallegos, Pilar, Pergamino and Tucuman although it is significant at the 5% level at the last three. The behavior of monthly values at these places differs. In Rio Gallegos secular variations are ruled mainly by the winter months, particularly June. In Pergamino and Tucuman the summer months show the biggest change in concordance with what occurs in the second half of the century while in Pilar there is no preferential season and a rise in minimum temperature can be observed throughout the year.

Finally, in Santa Rosa a cooling of the mean annual minimum temperature was recorded and no changes occurred in Corrientes.

Maximum temperature only shows significant trends at the 5% level in San Miguel de Tucuman while the remaining stations analyzed do not show changes at this level of significance.

It is worth noting that Corrientes the maximum temperature behaves contrary to what occurs during the second stage when warming occurs, mainly in May when values are significant.

### *3.3 Trends in Buenos Aires and Campinas*

As stated in section 2.2.3, the growth of the cities causes a significant increase in temperature. Analysis of table 3.3 shows that both variables have a sustained rise during all the periods analyzed except from 1961 to 2000 in maximum temperature. Although the changes registered correspond to increases in mean $\mathbf{T_x}$ temperature values (this phenomenon can be seen in Buenos Aires and in Campinas) these are not significant at 5%.

Finally, the rise in minimum temperature is observed every month at both stations.

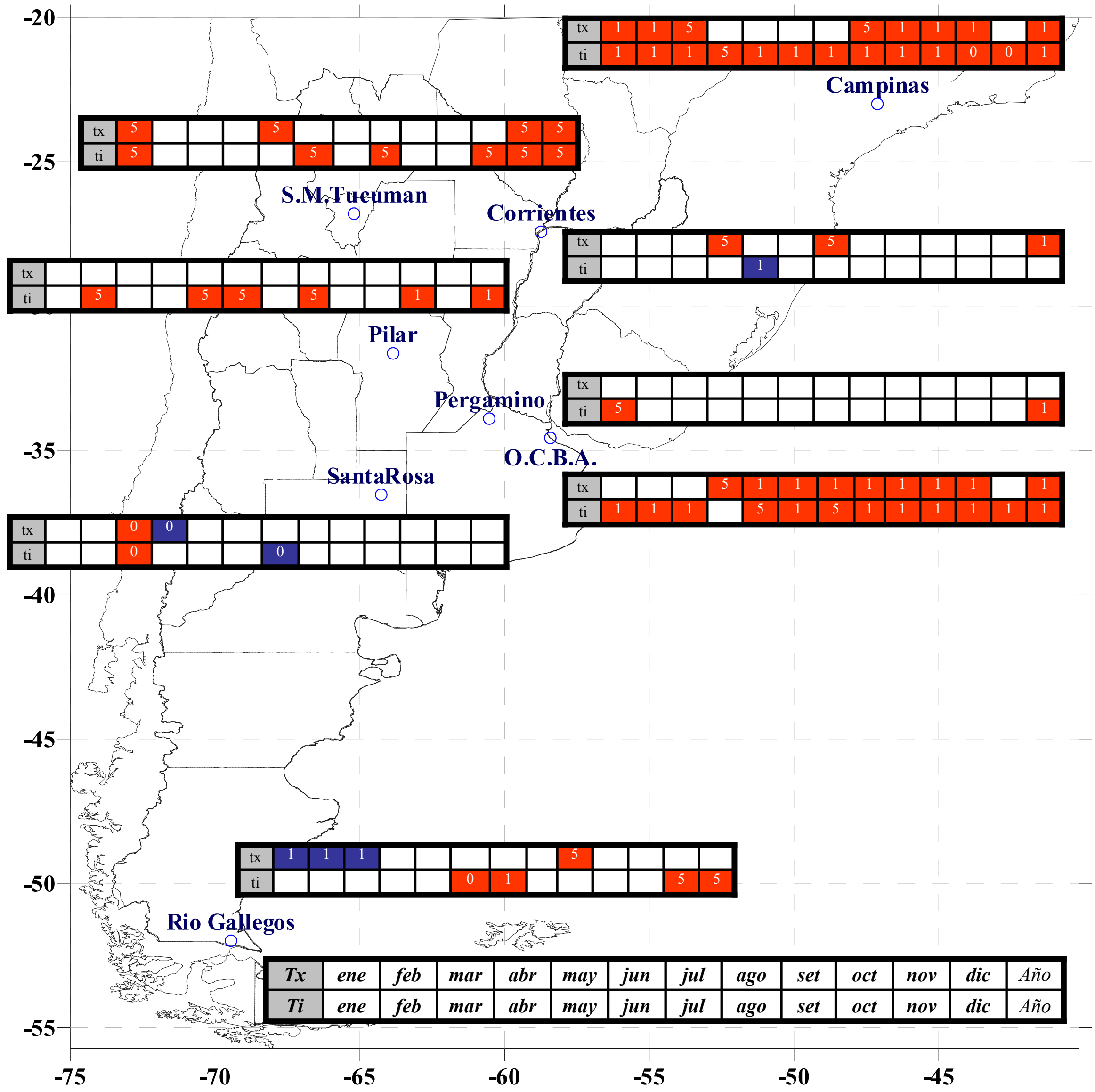



**Figure 3.1** *Monthly and annual trends at the 8 reference stations as from the beginning to 1960. Positive trends are in red and negative are in blue. The significance level is fixed at three thresholds: 10% (0), 5% (5) and 1% (1)*

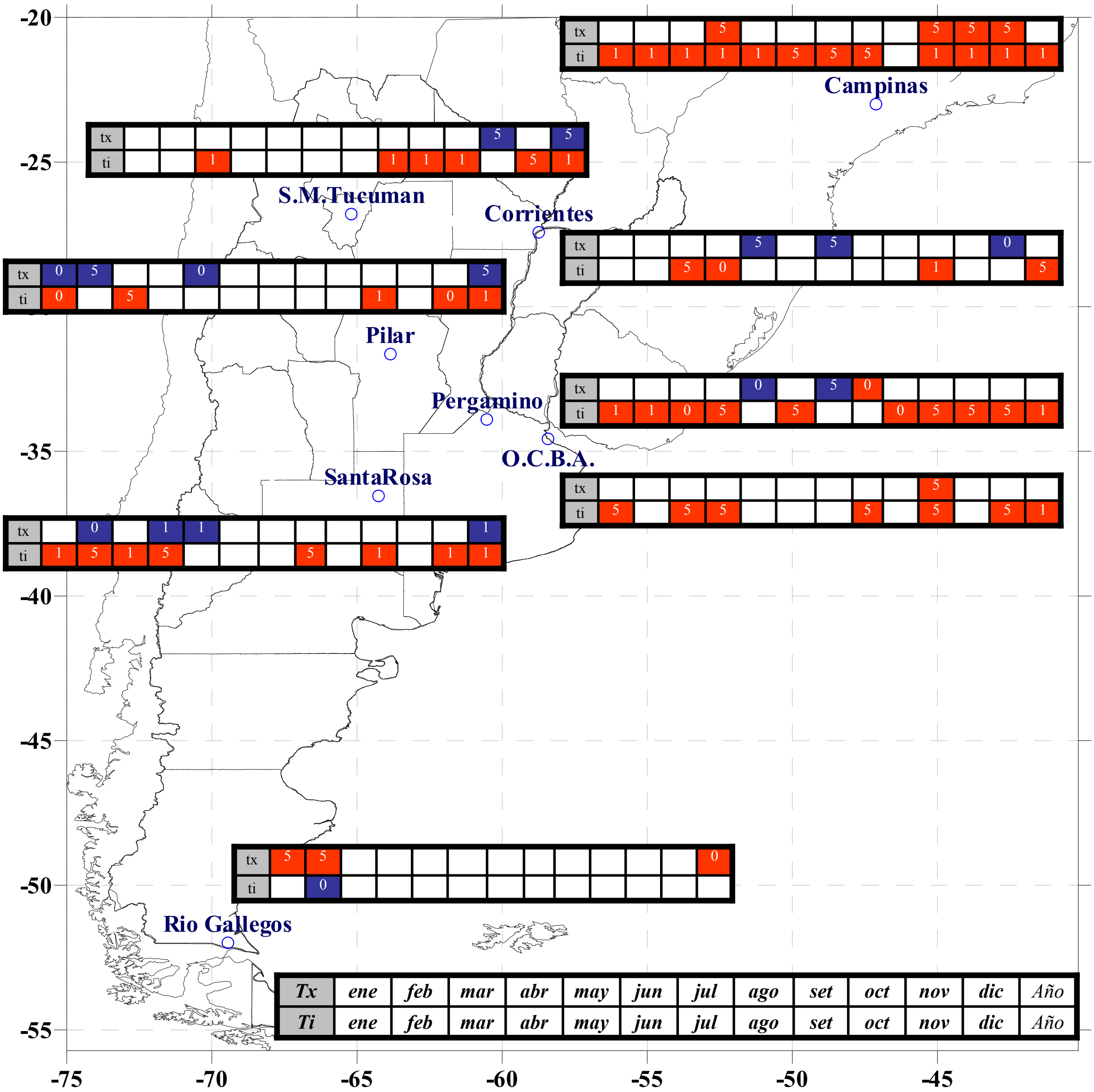



**Figure 3.2** *Monthly and annual trends at the 8 reference stations as from 1961 to the end of the records of each station. Positive trends are in red and negatives ones in blue. The significance level was fixed for thresholds: 10% (0), 5% (5) and 1% (1).*

***4. Cluster Analysis***

***4. 1 Method Description***

In this type of analysis, values of p-dimensional explicative variables X, are used for N objects, and the objective is to group them in K groups (K < N), so that the items that belong to one group resemble each other as much as possible as to these variables and differ as much as possible from the items of other groups. This approach is completely different from the usual statistical method as there are no previous hypotheses.
There are different procedures to construct the groups and different ways of determining how to measure similarity. The concept of distance between observations is introduced which, in its turn, is determined by the type of variables analyzed. Variables can be quantitative like temperature, ordinal qualitative in which the result may be assigned a number whose order makes sense but not the difference between two values or nominal qualitative which correspond to a label and where the similarity is determined as a simple coincidence of values.
For this classification it was decided to use the PAM method (Partitioning Around Medoids), *Kaufman and Rousseeuw* (1990). This algorithm is based on the search for k representative objects (medoids) in the whole dataset. These observations represent the data structure. A medoid is defined as the group object

whose mean non-similarity to all the objects of the group is minimal. After finding the group of k centers, k groups are built (clusters) on assigning each observation to the nearest center.

### *4.2 Description of the temperature series classification*

Before presenting the results on the low frequency variability of the different properties of the groups and to understand better the scope of bi-varied classification, this analysis is described in the Corrientes series. On making the classification with the PAM method, four groups are obtained which are characterized by four centroids. This results in a new series of discrete values in which each day is no longer represented by various temperature anomalies but by a symbol which refers to the belonging to the group.

| | Tx' | Ti' | N |
|---|---|---|---|
| **Goup 1** | *5.4* | *4.8* | *7691* |
| **Group 2** | *1.1* | *0.2* | *13647* |
| **Group 3** | *-4.5* | *-0.5* | *6920* |
| **Group 4** | *-4.8* | *-5.8* | *5981* |

**Table 4.1** *Centroids corresponding to the four groups obtained in Corrientes (1894 – 2004)*

*Table 4.1* shows the values of the centers and the number of cases which were classified as belonging to each group. The analysis of SC shows that for this structure the value is 0.57 which shows that the classification is mathematically consistent.

Analysis of the conformation of the groups shows some significant differences in structure. Group 1 has higher maximum and minimum temperatures than the mean so these days are associated to warm conditions. The same occurs in group 4 in the opposite direction: the characteristic anomalies of this group are negative which indicates cold days. Group 2 represents the days with a great thermal amplitude as they have positive **Tx'**, while minimum temperatures are close to the mean values. Finally, group 3, with **Tx** values below the mean and Ti close to the mean indicates days with small thermal amplitude.
Groups 1 and 4 are associated to events which respond to a defined structure and represent warm and cold days respectively. This leads to another question. Is it possible to classify groups 2 and 3 as representing structures on a bigger scale?
To answer that question, the behavior of mean annual temperature anomalies (**Tx*** and **Ti***) on the annual scale is initially analyzed in relation to rainfall in Corrientes. Figure 4.1 shows this relation. It can be seen that the years with a higher rainfall are located in the quadrant corresponding to negative Tx and positive Ti mean anomalies, without dry events (i.e. annual rainfall under 1,200 mm, mean rainfall being 1,290 mm). Some local peak rainfalls are observed during the warm years (Tx* >0 and Ti*>0), although there are deficits in annual rainfall in this quadrant.
Dry years are best defined almost exclusively within the years with Tx* >0 and Ti* <0 conditions when annual rainfall was not higher than 1,300 mm.
It may be concluded, on the basis of the results on an annual scale, that having Tx* >0 and Ti*<0 or Tx* <0 and Ti*>0 is a sufficient condition for wet and dry years respectively. Furthermore, these events occur more frequently in these quadrants than in any other.

| Precipitation [mm] | Frecuency (%) | | | |
|---|---|---|---|---|
| | Group 1 | Group 2 | Group 3 | Group 4 |
| *0* | *76%* | *78%* | *60%* | *89%* |
| *(0,5]* | *10%* | *10%* | *19%* | *7%* |
| *(5,10]* | *3%* | *3%* | *5%* | *2%* |
| *(10,15]* | *2%* | *2%* | *3%* | *1%* |
| *(15,20]* | *2%* | *1%* | *3%* | *0%* |
| *(20,25]* | *1%* | *1%* | *2%* | *0%* |
| *(25,30]* | *1%* | *1%* | *2%* | *0%* |
| *(30,35]* | *1%* | *1%* | *1%* | *0%* |
| *(35,40]* | *1%* | *1%* | *1%* | *0%* |
| *(40,45]* | *1%* | *1%* | *1%* | *0%* |
| *(45,50]* | *0%* | *1%* | *1%* | *0%* |
| *(50,55]* | *0%* | *0%* | *0%* | *0%* |
| *(55,60]* | *0%* | *0%* | *1%* | *0%* |
| *> 60* | *1%* | *1%* | *2%* | *0%* |

**Table 4.2** *Frequencies of rainfall accumulated during 24 hours related to the classification of Tx and Ti anomalies in Corientes*

Although on the annual scale, the association between extreme temperature anomalies and rainfall is well defined, it is necessary to know what happens on the daily scale. To this end an analysis was made of the relation between daily rainfall and the occurrence of each group.

These elements make it possible to determine that the classification is not only mathematically consistent but it also determines physical structures with their own entities. This means, that four groups

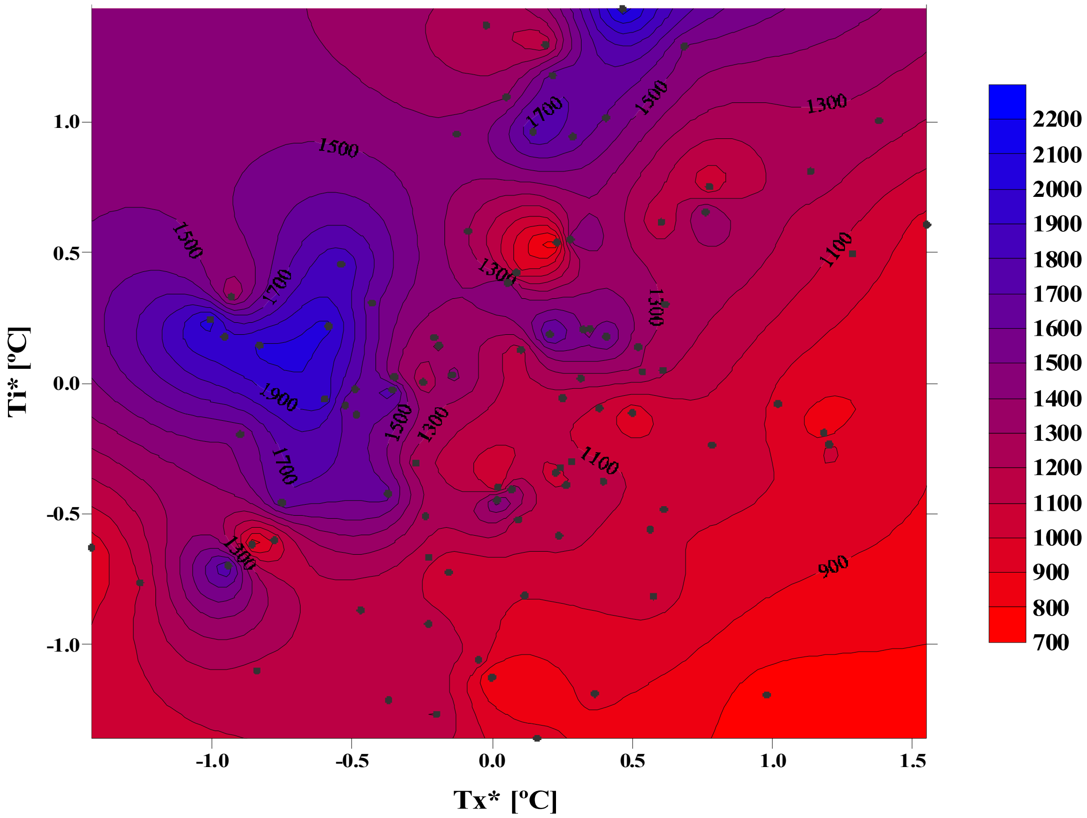



**Figure 4.1** *Relation between mean annual temperature anomalies (Tx* and Ti*) and annual rainfall in Corrientes*

are obtained objectively, which are associated with warm (*group 1*), dry (*group 2*), wet (*group 3*) and cold (*group 4*) conditions.

Table 4.2 shows the relation between daily rainfall and the events belonging to each group. Since all the groups are different in size, the relative frequencies are calculated according to the total number of cases in each cluster. As to the relation with dry days, it is considered that these preferentially occur under the conditions in groups 2 (Tx' >0 and Ti' ≈0) and group 4 (Tx' <0 and Ti' <0). The occurrence of dry days within the sample associated to group 3 (Tx' <0 and Ti' ≈0) is in general 20% smaller than in the remaining groups.
Looking at the rainfall days, group 3 is associated to the highest number of wet days. This group is also associated preferably to extreme rain events (in this case ≥ 50mm.) in 3% of cases. Wet days are also found to a lesser extent in groups 1, 2 and 4; this is associated to low intensity rainfall events.

### *4.3 Association of the classification with circulation types*

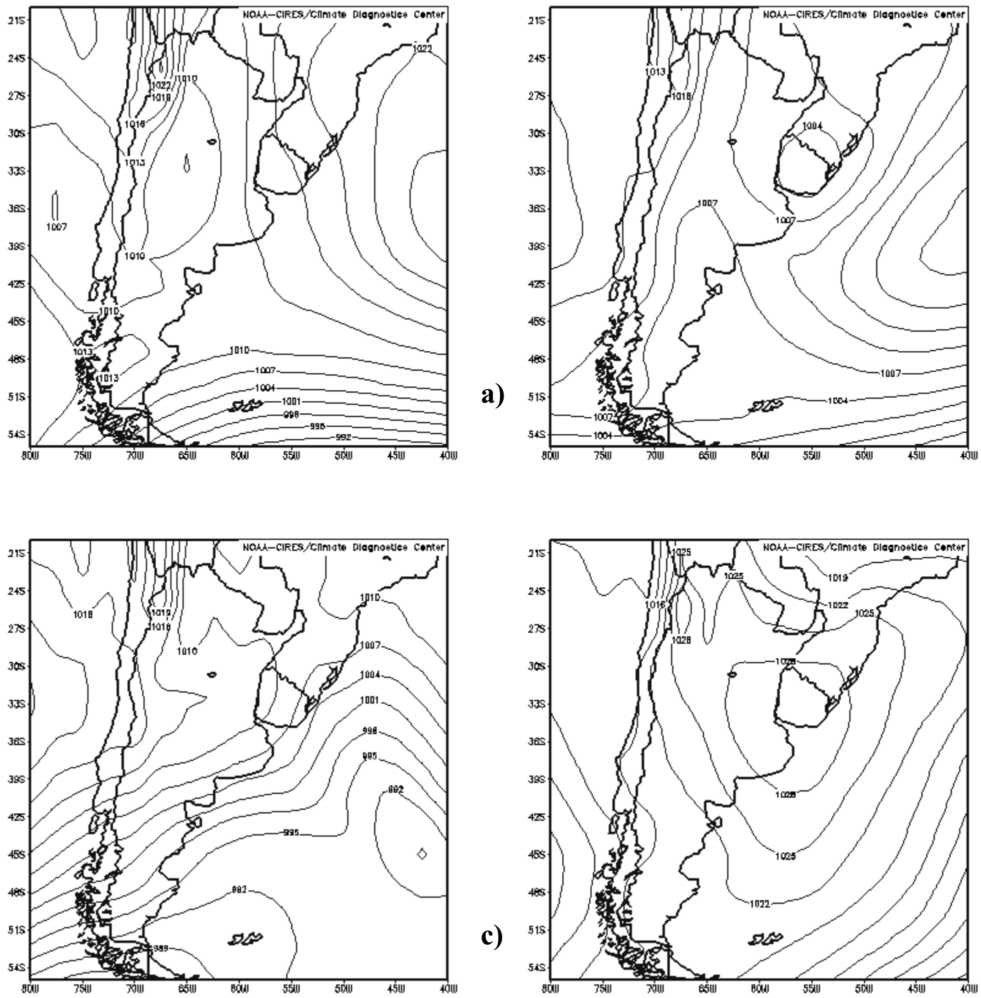
As has been shown in previous sections, the classification applied to temperature anomalies must contain information on larger scale physical processes. The groups found, in particular, are associated to different types of circulation with their own characteristics.
To validate this, the types of circulation associated to days whose Tx' and Ti' values are equal to the characteristic value of the centroid of each group in Corrientes and Rio Gallegos have been analyzed. Table 4.3 shows some dates associated to these events.

| Tipe | Corrientes | | | Río Gallegos | | |
|---|---|---|---|---|---|---|
| | Tx' | Ti' | date | Tx' | Ti' | date |
| Cálido | 5.4 | 4.8 | 16/05/1969 | 3.6 | 3.1 | 19/12/1972 |
| Seco | 1.1 | 0.2 | 27/01/1992 | 1.2 | -2.0 | 05/06/1992 |
| Húmedo | -4.5 | -0.5 | 31/03/2000 | -1.0 | 1.3 | 19/05/1997 |
| Frío | -4.8 | -5.8 | 11/06/1989 | -3.9 | -3.0 | 26/10/1996 |

**Table 4.3** *Centroids corresponding to the four groups in Corrientes and Rio Gallegos and the dates on which Tx' and Ti' coincided with these values*

The fields of sea level pressure, mean temperature anomalies and OLR (outgoing longwave radiation) were analyzed. These correspond to the *NCAR/NCEP* reanalysis and were obtained from the Climatic Diagnostic Center website.

Mean daily sea level pressure fields were analyzed (Figure 4.2) and different types of circulation were observed for each of these events. The map associated with the warm centroid shows the influence of the semi-permanent anticyclone of the Atlantic over the Mesopotamian region. Positive thermal advection prevails in that region. It is the principal cause of extreme temperature anomalies. Looking at the conditions classified as dry, a low pressure system over Uruguay excludes the influence of the semi-permanent anticyclone on the Atlantic. For the wet days, there is a minimum pressure axis associated to a frontal



a) b) c) d)

**Figure 4.2** *Sea level pressure on four days when extreme temperature anomalies coincided with the centroid values obtained for Corrientes. a. warm; b. dry; c. wet; d. cold.*

system. This system, linked to a cloud cover and possibly rainfall is found on this day near Corrientes. After analyzing what happens on the day classified as cold, a dynamic high pressure system associated to an intense cold outbreak dominates the Mesopotamian region.

analyzed. In addition to the passage of a frontal system, there is a moderating effect on maximum temperature due to the clouds associated to it. A contrary effect occurs for minimum temperature as the cloud cover prevents cooling of the same proportions and as a result it reaches values close to

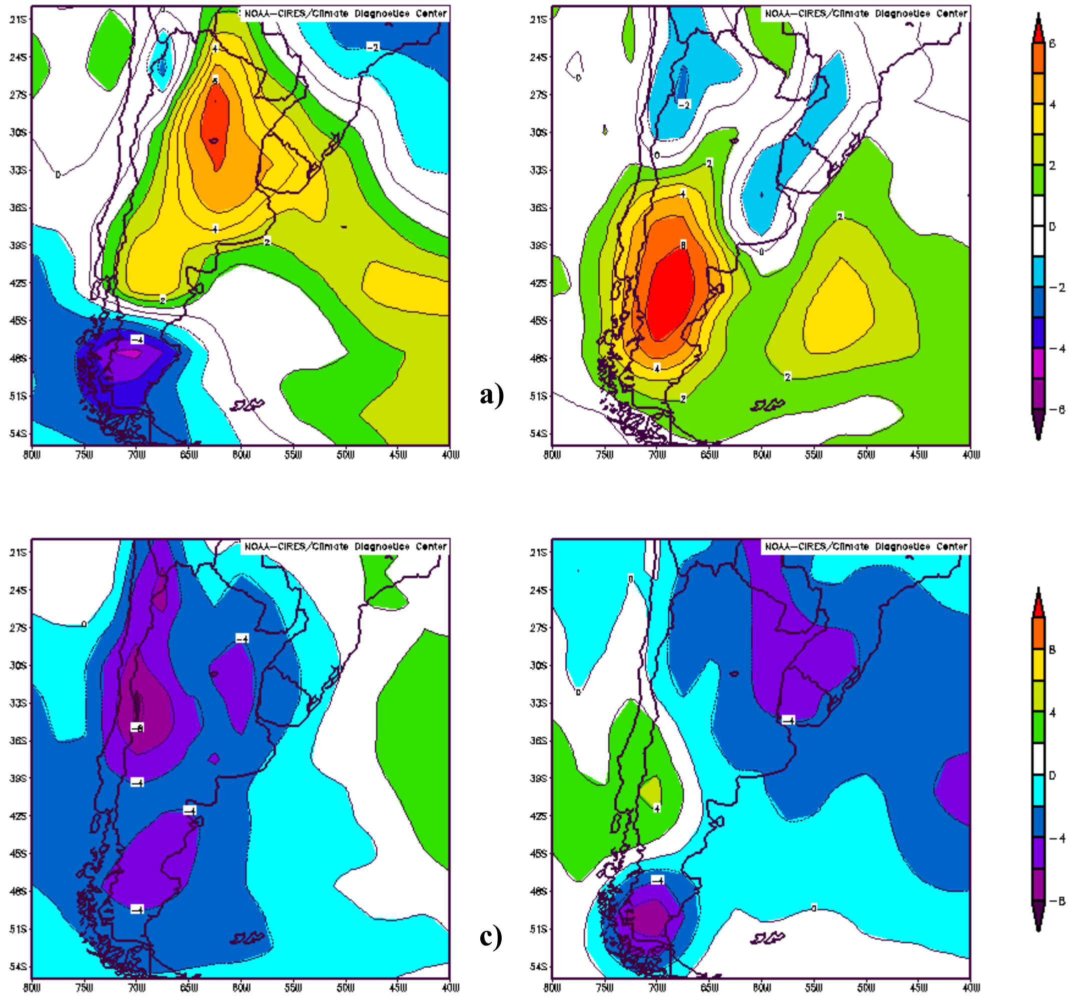



**Figure 4.3** *Mean daily temperature anomalies for four days classified as a. warm, b. dry, c. wet and d. cold in Corrientes*

Figure 4.3 maps the temperature anomalies associated to each centroid. Analyzing the warm day, positive temperature anomalies can be observed in practically the whole country although the highest values appear in the central region. On the dry day, slightly negative values or close to zero are found in the Mesopotamian region while in Patagonia there is a positive maximum with anomalies of more than 5 °C.

The presence of a cold air mass dominates practically the whole country if wet days are normal. Figure 4.3 (d) shows a cold air mass in the north of the country produced by the high pressure system which dominates the region.

The information on the long wave length coming from the earth (OLR), registered by remote sensors is an important tool to infer the presence of clouds in a given region. Thus, the greatest OLR values correspond to regions with little or no clouds while the lowest represent cloud systems of different significance.

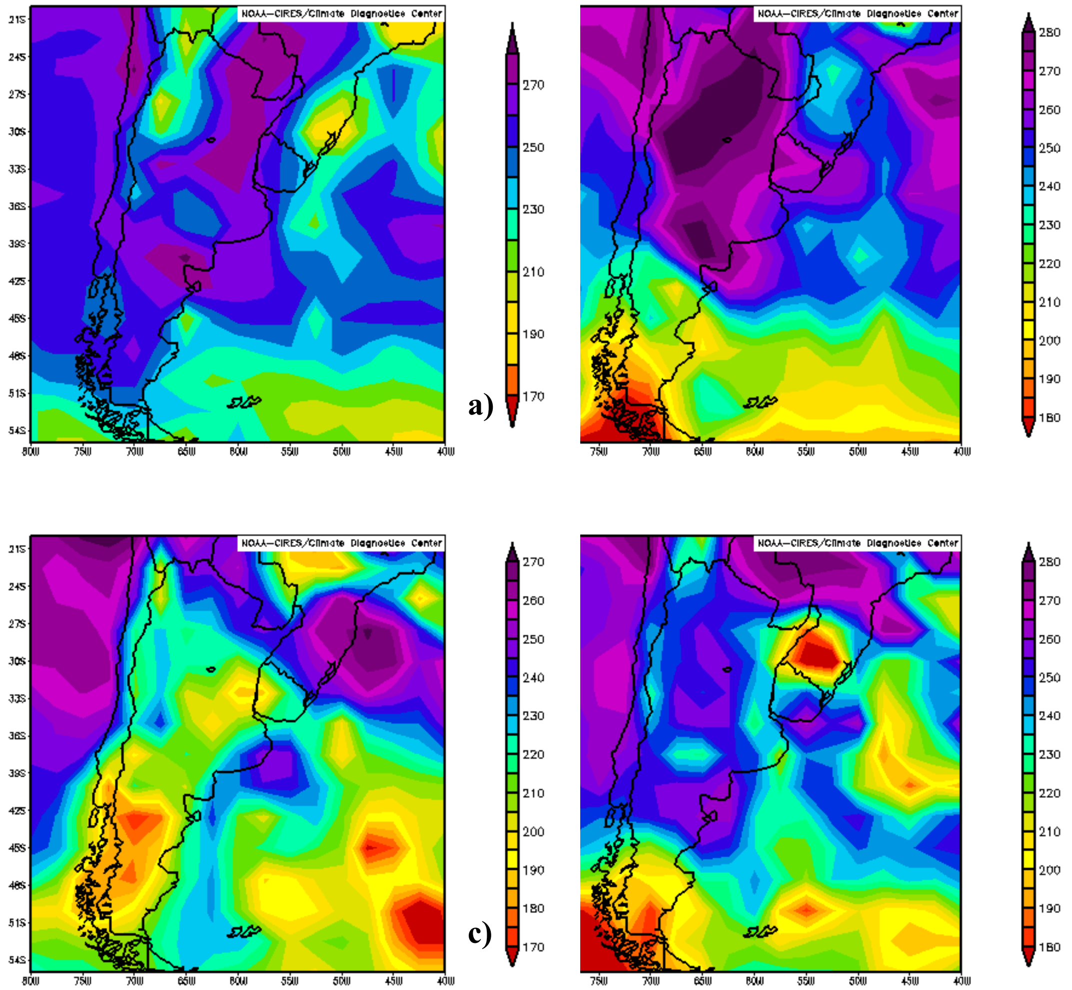



**Figure 4.4** *OLR [W/m$^2$] for 2 dry days (a) 27/01/1992, (b) 10/04/1983 and 2 days classified as wet (c) 30/04/1992, (d) 31/03/2000 coinciding with each centroid*

Figure 4.4 shows the behavior of this variable for 2 days coinciding with the dry centroid and two with the wet one. During the dry days (4.4 a and b) the absolute peaks occur in the north of the country indicating the presence of clear skies in Corrientes on those days. Finally, the wet days, on 30.4.1992 a region is observed with minimum OLR values in the center of Mesopotamia associated with the frontal system while on 31.3.2000 the minimum values appear in the west of the province of Corrientes and south of Brazil. In both cases, although with different intensity, there are clouds over the city of Corrientes.

The behavior of these types of temperature anomalies in Corrientes has been well defined. Is it possible, however, to obtain a similar coherence between the groups in Rio Gallegos on latitude 52ºS, more than 3,000 km to the south of Corrientes?

To answer this question the sea level pressure fields were analyzed for the four days coinciding with the mean values of each group (see table 4.3). Figure 4.5 shows those fields which have four different types of circulation. On the warm day, there is an anticyclone over the Atlantic, facing the coast of Buenos Aires, which is responsible for the warm advection which dominates the center of the country. An intense upper-level ridge (not shown) appears over Patagonia, the main cause of the warming of the lower atmospheric levels over this region. For the dry day, a local pressure maximum is observed close to Rio Gallegos which leads to a reduction of the baroclinicity characteristic of the region.

On analyzing the pressure field behavior on the wet day, a low pressure system appears over the Atlantic, close to the Province of Santa Cruz. This system generates intense winds from the east in Rio Gallegos with the consequent advection of humidity. Finally, Figure 4.5 d shows the cold advection in the extreme south of the continent, associated to a strong warm advection to the north of 45ºS.

The description of the regional thermal behavior is shown in Figure 4.6. In Rio Gallegos, the warm day has an important center of positive temperature anomalies over practically the whole of Patagonia, due mainly to the subsidence of an upper-level ridge in this region. Then for dry and wet days, there is a daily temperature near Rio Gallegos close to mean values. However, on the wet day, cold nuclei can be observed both to the north and to the south of Rio Gallegos. This phenomenon is due to the presence of clouds in the region which moderates extreme temperatures.

Finally, a dipole is observed in the high temperature region in the northeast of Argentina and south of Brazil and low temperatures in the province of Santa Cruz. This cold nucleus is responsible for the low

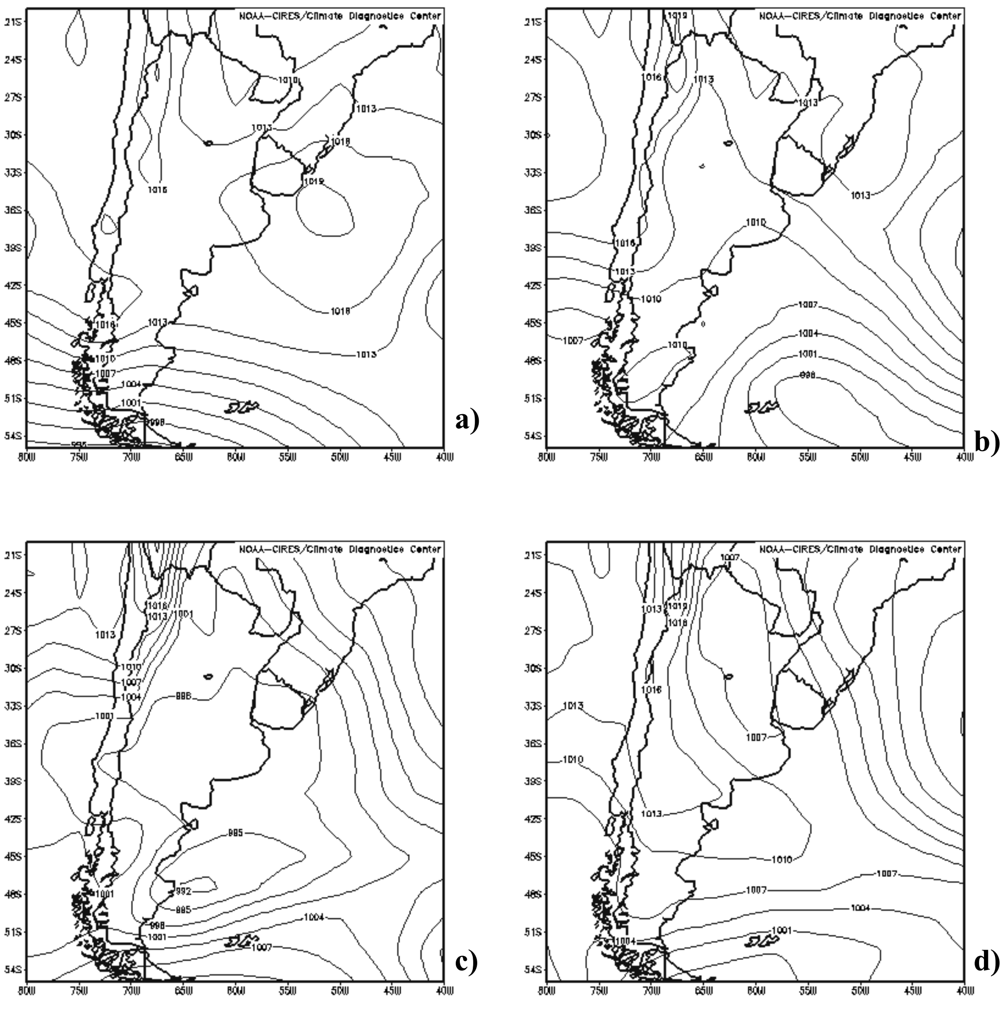



**Figure 4.5** *Sea level pressure during 4 days when the extreme temperature anomalies coincide with the values of the centroids obtained for Rio Gallegos. a. warm; b. dry; c. wet; d. cold*

temperatures in Rio Gallegos on the cold day.
Figure 4.7 shows the behavior of OLR for two days coinciding with the dry centroid and the two days coinciding with wet centroid. On the two dry days (Figure 4.7 a and b) there is a maximum in this variable in the extreme south of Argentina, so this is a local phenomenon. The same occurs on the wet days but in the opposite sense. Here the local OLR minimum is associated to the clouds in that place.

In view of the results presented in this section, inferences are made on the relation of different types of circulation and the bi-varied classification of temperature anomalies. In fact, it can be concluded that although there is a greater number of circulation types than the four groups obtained, these may be considered as traces of various circulation patterns defined by them, i.e. within each group there could be a family of subsidiary patterns forming a bigger group.

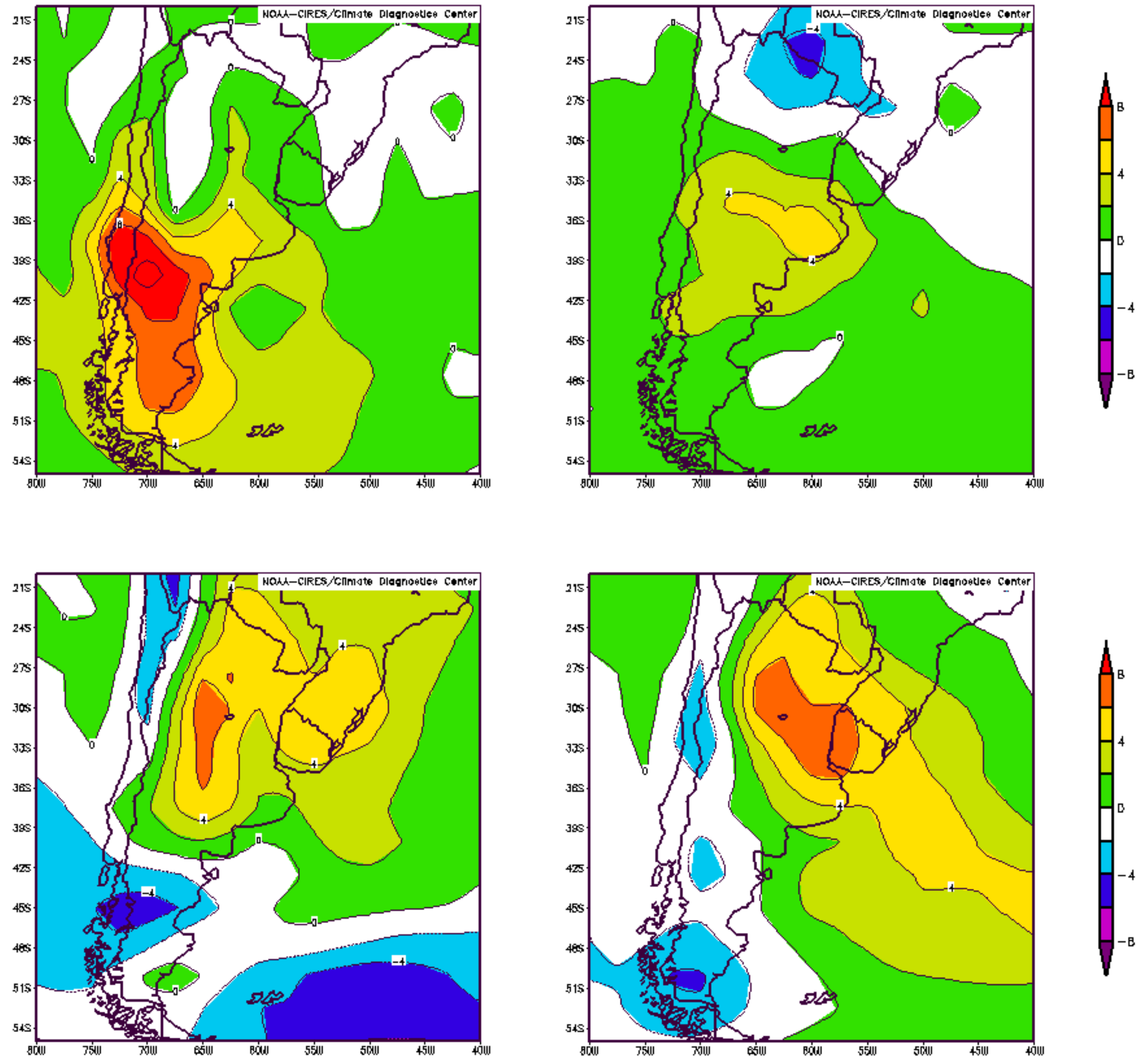



**Figure 4.6** *Mean daily temperature anomalies for four days classified as a. warm; b. dry; c. wet;. d. cold in Rio Gallegos*

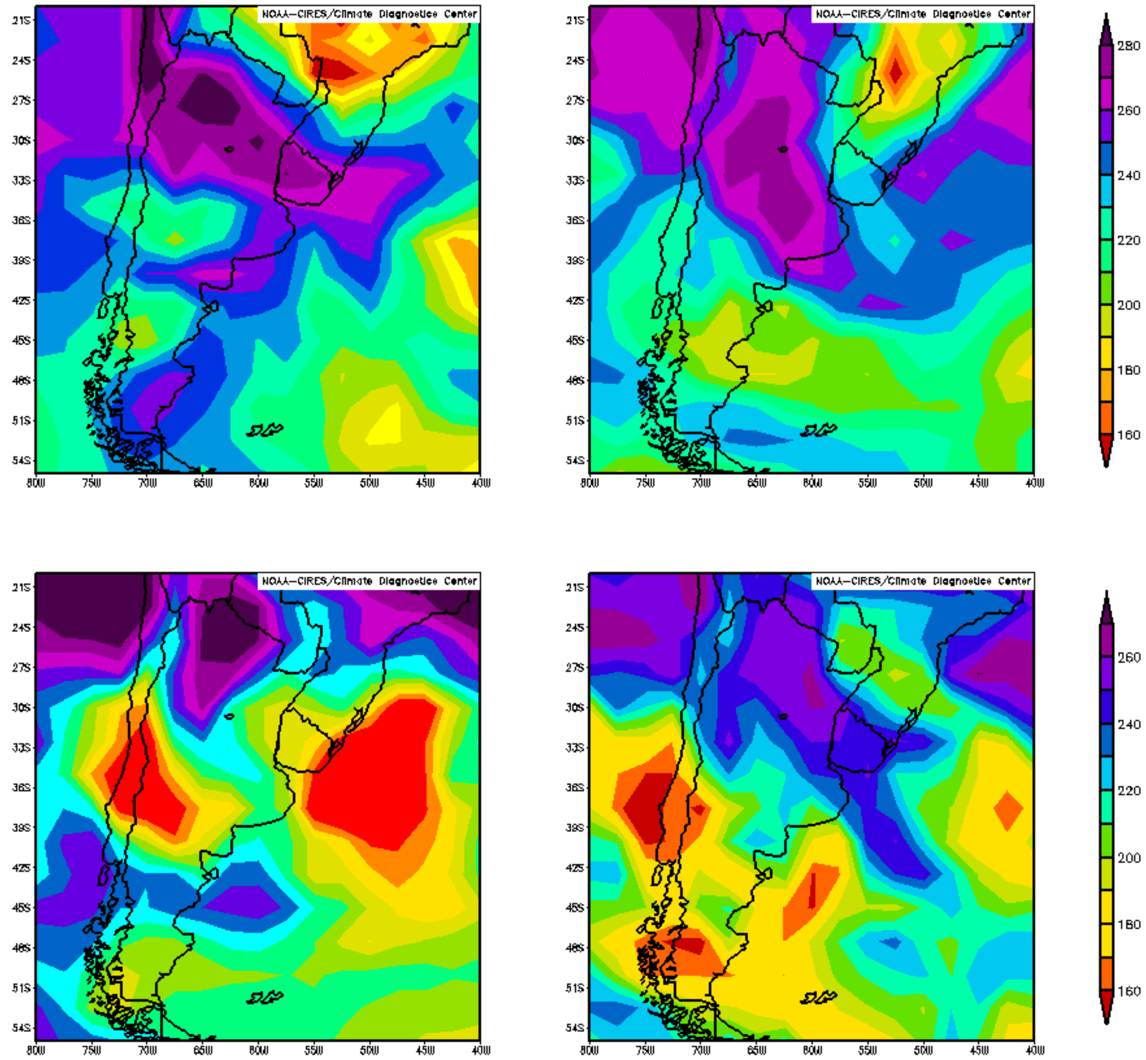



**Figure 4.7** *OLR [W/m$^2$]for 2 dry days (a) 26/10/1996, (b) 14/05/1997and 2 days classified as wet (c) 05/06/1992, (d) 11/06/2000 coinciding with each centroid in Río Gallegos*

### *5.3* Secular variations at regional level and summary

Since there are significant similarities between most of the reference stations, in this section the spatial coherence of the results will be discussed and the conclusions of this chapter presented.

The main feature found in this diagnosis is the significant increase in days classified as wet, i.e. with little thermal amplitude at all the stations between 25º and 45º S. In Campinas too an increase is observed in the occurrence of this group although the significance level is lower (10%). Only in Rio Gallegos ($\varphi$ = 52ºS) no variations are observed in the wet group. As to the intensity associated to this set of days, an increase in this variable is observed at the stations where the annual frequency varied in the same direction.

The dry day group only presents changes in Santa Rosa, Pergamino and Buenos Aires, all in the central area. These days are less frequent in recent years in Santa Rosa and Pergamino while in Buenos Aires there have been no changes in this variable. At the three stations there is a reduction in the intensity of this variable.

The warm days occur less frequently and less intensely at the stations in the north of Argentina (Corrientes and Tucuman). So, the drop in mean Tx values at these stations is mainly due to a greater occurrence of wet days, accompanied by a

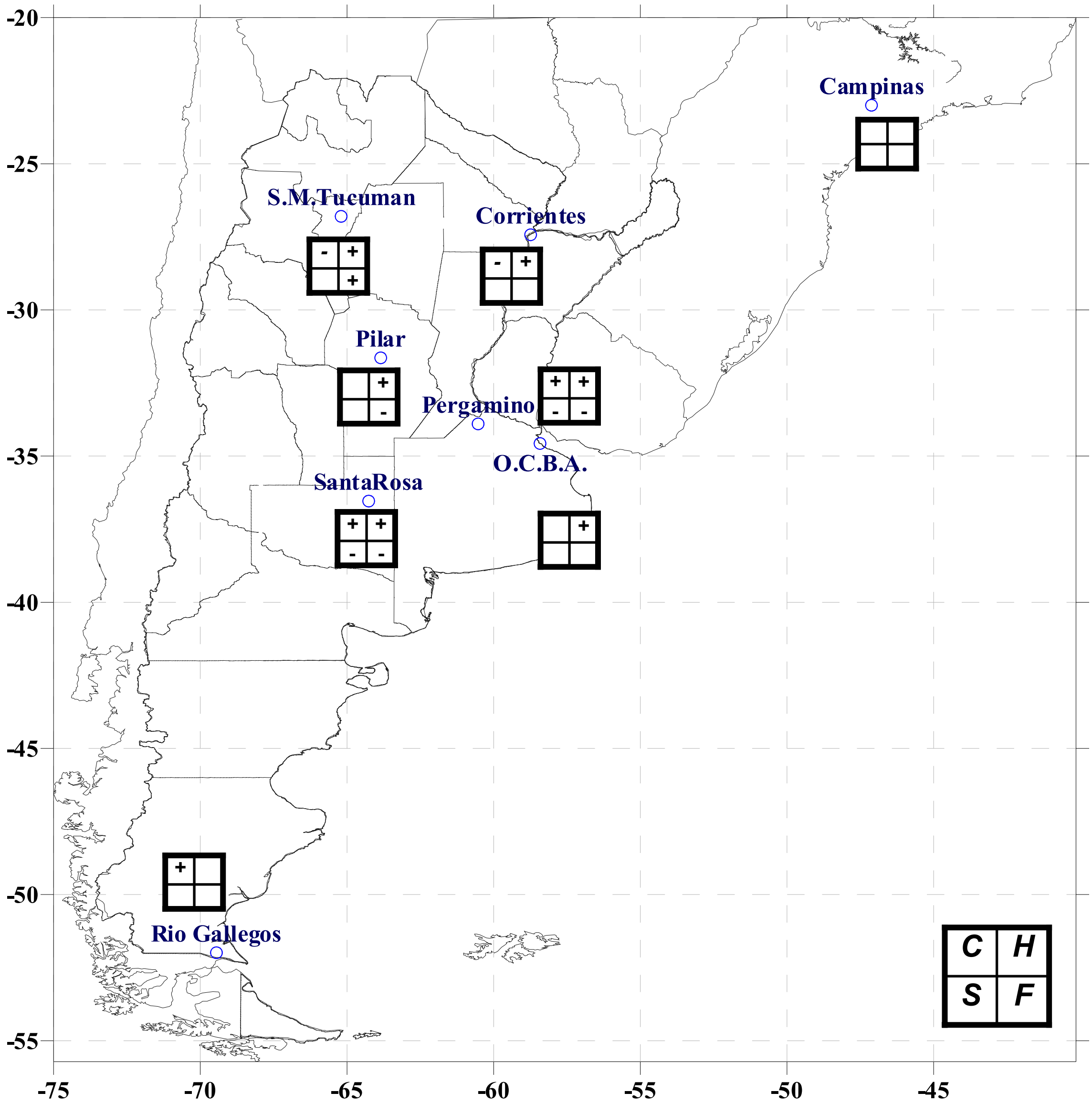



**Figure 5.1** *Trends of days per year in each group. Each box represents a group called C (warm), H (wet), S (dry) and F (cold). Positive trends are marked (+),and negative (-).*

smaller number of warm days and lower intensity events.

The contrary effect is observed in Pergamino, Santa Rosa and Rio Gallegos where there are more warm days whose intensity increased during the period under study.

Once again, the behavior of the cold group is coherent in the central region of Argentina. There is a decrease in the annual occurrence of days of this group and these events are less intense during the last part of the period analyzed.

To end, it may be concluded that the days in the wet group are one of the main causes of the secular variations in the mean values of the region under analysis. Their greater intensity implies they acquire a greater identity with reference to normal values, i.e. they have less thermal amplitude.

It is also observed that the behavior of the characteristic features of the groups is homogeneous in the central region where in general the intensity and frequency of the warm days increase and the same properties decrease on the days classified as cold or dry. Finally, both Corrientes and Tucuman have a similar behavior in the secular changes analyzed particularly for the warm day group.

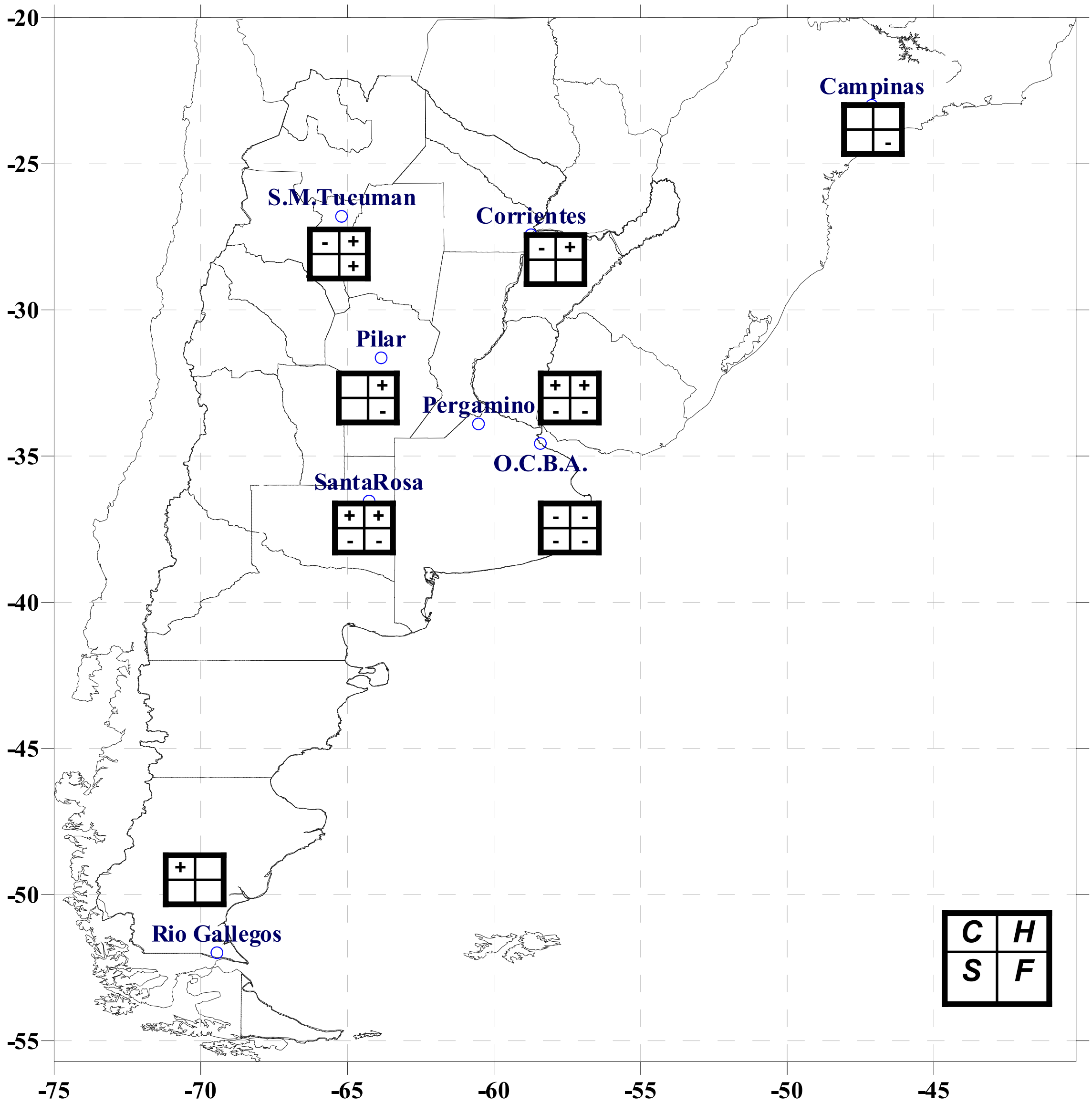



**Figure 5.2** *Intensity trends for each group. Each box represents a group called C (warm), H (wet), S (dry) y F (cold).*

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