Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 249-253.

ANNUAL AND MONTHLY TRENDS IN FROST DAYS IN THE WET PAMPA

María E. Fernández Long* and Gabriela V. Müller**
Faculty of Agronomy. University of Buenos Aires, Argentina
Institute of Astronomy, Geophysics and Atmospheric Sciences. University of Sao Paulo, Brazil

1. INTRODUCTION

Many critical climate impacts are controlled by extreme events rather than mean values. Systems that are particularly vulnerable are agricultural and forest ecosystems. Climate change is expected to affect extremes, since small changes in mean conditions can lead to large changes in the frequency of extremes (Kats and Brown, 1992). Nicholls *et al*. (1996) concluded that globally significant changes in extremes have occurred during the 20th century. There has been a clear trend to fewer extremes of low temperatures in several widely separated areas in the late 20th century. The IPCC (2001) review concludes that the general warming would tend to lead to an increase in extremely high temperature events and a decrease in winter days with extremely low temperatures.

Rusticucci and Barrucand (2004) studied the changes in temperature extremes over the 1959-98 period, based on daily minimum temperature in Argentina. Trend analysis was performed on seasonal means, standard deviations and extremes (5th and 95th percentiles). Particularly in winter mean minimum values present positive trends. The trends in the standard deviations, although significant in only a few cases, present different signs. Extreme trends were analyzed and no remarkable patterns were detected. Pascale and Damario (2004) also found trends in the absolute values of annual maximum and minimum temperatures in a large number of cities of Argentina, showing an important decrease at the annual extreme thermal amplitude.

Elsewhere around the globe, a few studies document changes in frost days. Frich *et al*. (2002) found evidence of fewer frost days in much of the midle and high latitudes in the Northern Hemisphere in the last 50 years. Easterling (2002) shows no changes in either the number of frost days or changes in the frost-free season in the southeast of United States, which has shown a cooling trend in annual temperatures over the 20th century. Furthermore, Heino *et al.* (1999) found decreasing frost days across northern Europe during the 20th century, and similarly, Bonsal *et al.* (2001) also found decreasing frost days in Canada. Particularly in the Wet Pampa (Argentina), Fernández Long *et al.* (2005) found a decrease in the frost period all over the region, except in the South of Buenos Aires where it increased. Pascale and Damario (1997) also found a decrease of the frost period at the Alto Valle del Río Negro (Argentina).

The purpose of this study is to evaluate the annual and monthly trends (March-October) of frost days, as defined by days when the minimum temperature is below 0ºC at the meteorological stations of the central-eastern region of Argentina, called the Wet Pampa, one of the most productive agricultural regions of South America.

2. DATA AND METHODOLOGY

Technically, the word “frost” refers to the formation of ice crystals on surfaces, either by freezing of dew or a phase change from vapor to ice (Blanc *et al*., 1963); however, the word is widely used by the public to describe a meteorological event in which crops and other plants experience freezing injury. In this paper “frost” is the occurrence of a temperature less than or equal to 0ºC measured in a shelter at a height of 1.5 m.

For examining the annual and monthly trends in frost days, daily minimum temperature data were extracted from the Servicio Meteorológico Nacional (SMN) and the Instituto Nacional de Tecnología Agropecuaria (INTA) both of Argentina. The meteorological stations have been selected following the condition that the percentage of daily minimum temperature data available should be at least 80%. The indexes were derived from data from 55 stations (Figure 1) and were analyzed over the 1964-2003 period. Inhomogeneities or discontinuities caused by site changes of meteorological stations, among others, influence the climatic data. Fernández Long *et al*. (2006) have made considerable efforts to homogenize the time series of minimum temperatures at 55 climate stations, that include those that are used in this study.

In order to examine changes in frost days in the whole region, time series of standarized anomalies of the number of frost days were calculated for each year and month of each station. Then, the time series of each station was used to calculate a regional averaged time series. Thus. the following variables are defined:

* Facultad de Agronomía, Cátedra de Climatología y Fenología Agrícolas. Universidad de Buenos Aires. Av. San Martín 4453. 1417 Buenos Aires. Argentina. flong@agro.uba.ar
** Department of Atmospheric Sciences. Institute of Astronomy, Geophysics and Atmospheric Sciences. University of Sao Paulo, Brazil..gabriela@model.iag.usp.br

- Monthly standardized anomalies of the frequency of frost days for each meteorological station and for the regional averaged time series
- Annual standardized anomalies of the frequency of frost days for each meteorological station and for the regional averaged time series.

Which, for simplicity, will be referred to as frost frequencies.

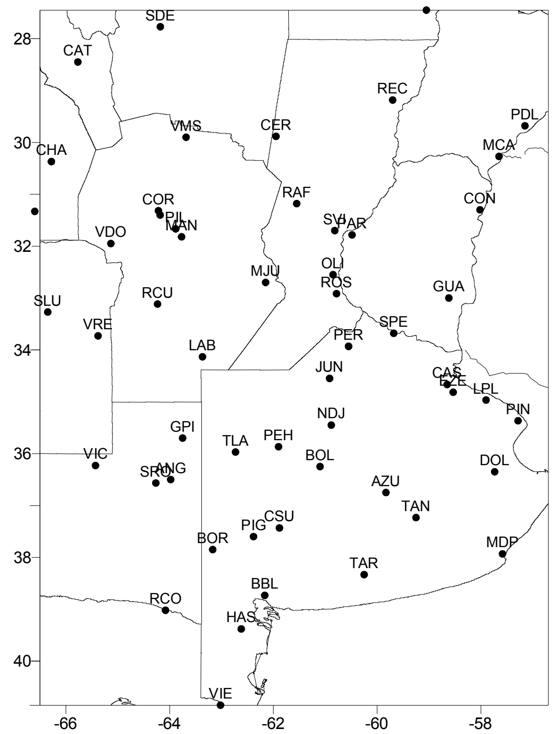

Figure 1: Map of the Wet Pampa showing all stations used (dots) and abbreviations referred in the text.

Finally, simple linear trends were calculated for each variable and the results are showed in the maps of Figures 2 to 7. In order to test the statistical significance of trends (95%), the Mann-Kendall and Spearman (WMO, 1966) test were applied. In order to confirm the results, in some cases it was also calculated the trend of the averaged minimum temperature, either monthly or annually, depending on each case.

3. RESULTS

3.1 Annual Trends

The trend in the frequency of annual frosts is negative for the regional averaged time series (Figure 2a). The analysis by regions however reveals a zonal pattern as can be observed in Figure 2b. To the north of 34ºS there are positive trends to the west and negative trends to the east, for example Sauce Viejo (SVI) and Paraná (PAR) that has a significant negative trend. On the other hand, the nearby stations of Concordia (CON) and Ceres (CER) show the opposite trend, although not significant. To the south of 34ºS two sub regions stand out with a well-defined east-west dipole. To the west, there is a core of significant negative trends (in green in the figure) comprised by the meteorological stations of Santa Rosa (SRO), Pigüé (PIG), General Pico (GPI), Bordenave (BOR) and Anguil (ANG). On the contrary, the east core shows significant positive trends (in red), for the stations of Coronel Suarez (CSU) and Tandil (TAN).

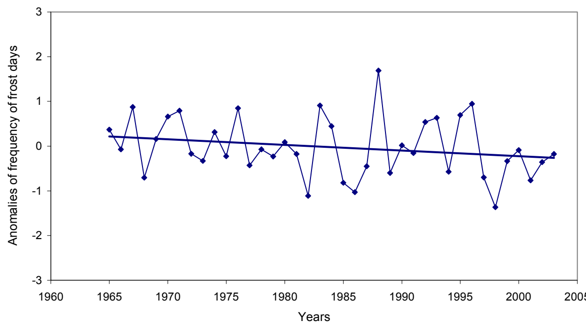

Figure 2(a): Average regional time series of the frequency of frost days over the period 1964-2003, for 55 stations. Linear trends are also shown.

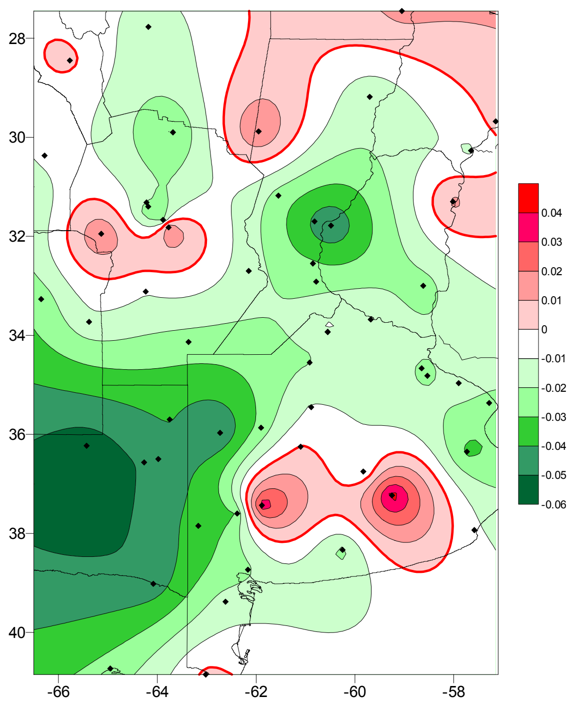

Figure 2(b): Annual trends of the frequency of frost days. Positive (negative) linear trends are in green (red). Red line indicates zero.

The trend analysis of the mean annual minimum temperature of the meteorological stations of the Wet Pampa displays an inverse relationship between the trend of the mean annual minimum temperature and the frequency of frost, i.e. a positive trend (negative) in the minimum temperatures in those places where the frost frequency trends are negative (positive).

3.2 Monthly trends

The trends in autumn (March, April, May), winter (Jun, July and August) and spring (September, October) are analyzed. Trends are negative in the average regional time series in autumn. As from April, trends have a differential behavior, which is more evident as from May, when the mentioned dipole appears with a positive trend core to the east of the center south of Buenos Aires province and a negative trend core in the west (Figure 3).

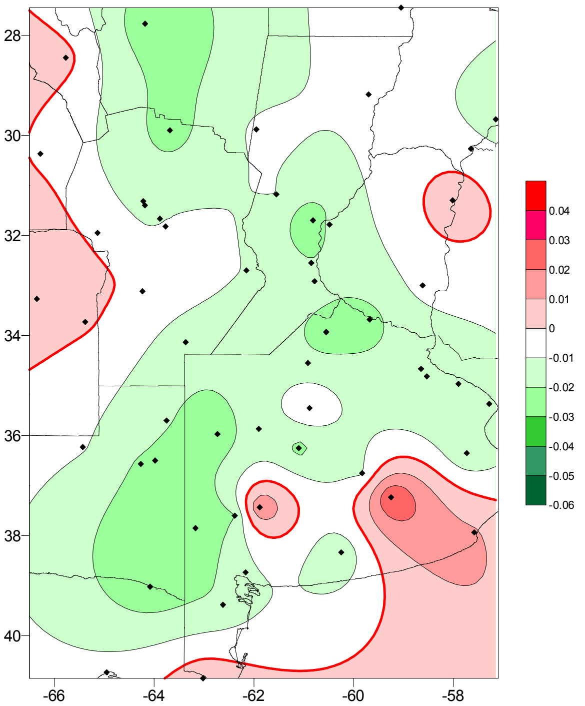

Figure 3: Monthly trends in the frequency of frost days for May. Positive (negative) linear trends are in green (red). Red line indicates zero.

During winter, June and August present negative trends in the average regional time series with higher values in August (Figure 4). The positive core however, remains in the southeast of Buenos Aires province (which reflects a tendency to the occurrence of more frost events). To the north of the study region trends become positive in Ceres (CER) and Concordia (CON) and other isolated stations. On the contrary, in July, there is a positive trend in the average regional time series (Figure 5), opposite to the annual trend observed in Figure 2. In this case the minimum temperature trend is also negative, with some meteorological stations with significant values, such as Tandil (TAN).

Müller *et al.* (2005) also found a noteworthy circulation in July, with important surface anticyclonic anomalies over the Pacific Ocean in the southwest of the continent, which favors the entrance of anticyclones from the SW during the years of maximum frost frequency. This fact explains the low level wind anomalies in July, when two pressure anomalies one in the north and the other in the south dominate the center northeast of Argentina and the south of the country, respectively.

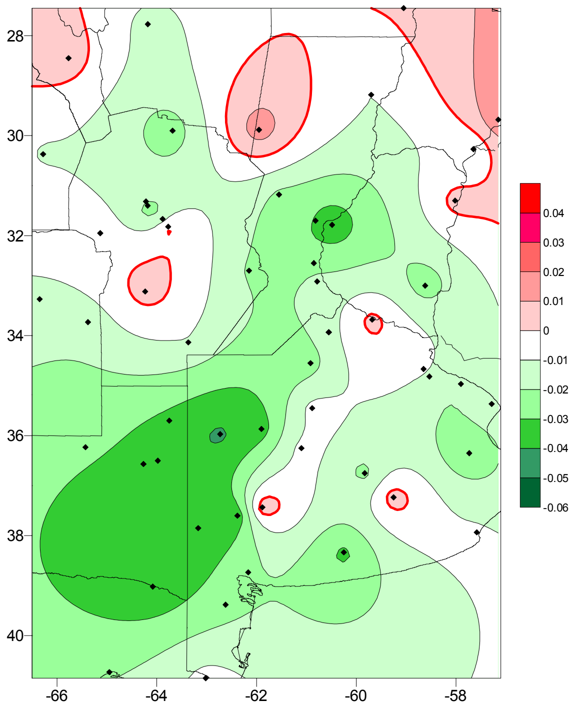

Figure 4: Idem Figure 3 for August

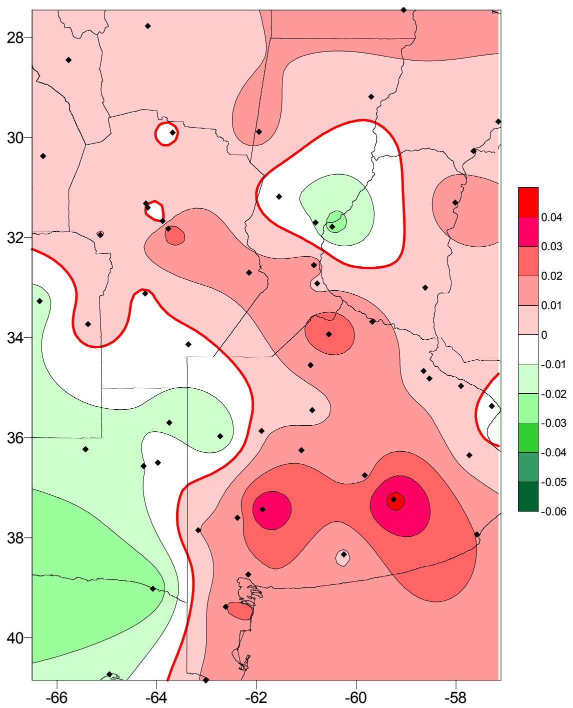

Figure 5: Idem Figure 3 for July

Although trends in the average regional time series are opposite, especially in July and August, the east-west dipole persists in the south of the Wet Pampa. An example of opposite trends is shown for July and August in Figure 6a and Figure 6b at Tandil (southeast core) and Anguil (southwest core), respectively. In the 40-year study period there is a marked rise in frost frequency in Tandil (Figure 6a). Anguil instead, shows a negative though not significant trend (Figure 6b).

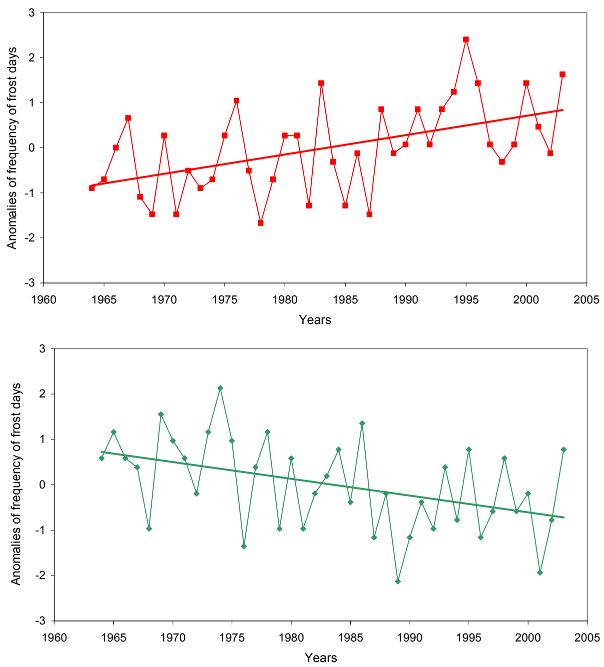

Figure 6: Frequency of frost days at the Tandil (TAN) station in July (a) and at the Anguil (ANG) station in August (b). Monthly trends are also shown (line).

The spring months did not have a homogeneous behavior. Figure 7 shows a negative trend in the average regional time series for September. The core in the SE of Buenos Aires remains positive with some isolated meteorological stations with the same trend. In October the trend in the average regional time series is also negative (not shown), although few stations in the northwest of the Wet Pampa have positive trends. Only one station (Coronel Suarez) of the two stations that form the southeast core, maintains the positive sign. Although trend values for this month are not representative due to the low number of frosts occurred in the region, the trend of mean monthly minimum temperature in October is significantly positive in numerous stations in the region. November presents few frost events and it is therefore not considered in the trend analysis.

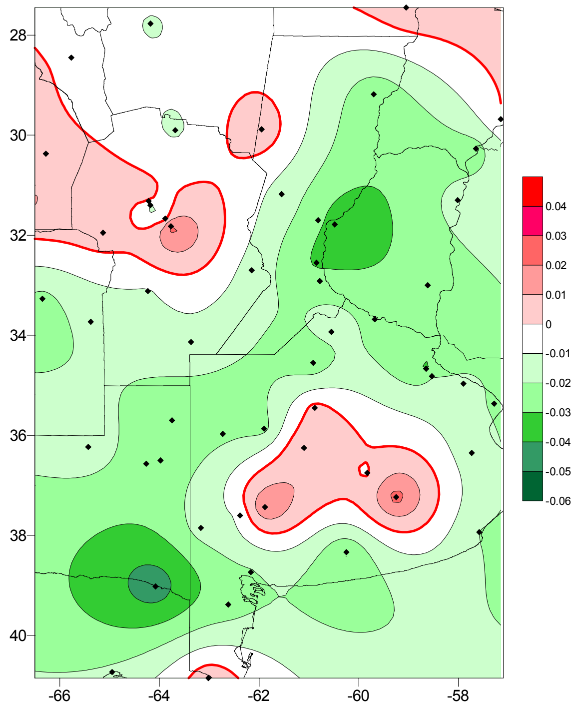

Figure 7: Idem Figure 3 for September

4. CONCLUSIONS

This paper examines annual and monthly trends in the number of days with frost recorded at the meteorological stations of the Wet Pampa from 1964 to 2003. Annual frost frequency in the region dropped, though not significantly, in the 40 years studied. Far from being uniform; annual trends at the different stations can be grouped latitudinally and longitudinally. To the south of 34ºS, there is a well defined dipole with decreased frequency of frost days in the west and increased frequency in the east in a smaller area in the south of Buenos Aires. To the north of this parallel, the inverse situation takes place, i.e., positive trends in the west and negative in the east, but with values lower than the south.

The monthly analysis presents a negative trend in the regional frequency from March to October, except July which has a positive though not significant trend. However, the trends at 39 stations (out of a total of 55) have a positive sign for this month which evidences the importance of the result. In July the east-west dipole (positive-negative trend) in the south of the Wet Pampa is still present. The dipole begins to develop in March and is still found in October, with a positive trend at only one station (Coronel Suárez). Although this feature persists during all the months studied, in general it is observed that the monthly trend behavior is not homogeneous.

6. REFERENCES

Blanc ML, Geslin H, Holzberg IA and Mason B. 1963. Protection against frost damage. WMO, *Techical Note*, No. 51. Geneva, Switzerland. 62p.

Bonsal, B. R.; X. Zhang; L. A. Vincent and W. D. Hogg. 2001. Characteristics of daily and extreme temperatures over Canada. *Journal of Climate*, **14**, 1959-1976.

Easterling, D. R. 2002. Recent changes in frost days and the frost-free season in the United States. *Bull. Amer. Meteor. Soc.*, **83,** 1327-1332.

Fenández Long ME, Barnatán IE, Spescha L, Hurtado R and Murphy G. 2005. Caracterización de las heladas en la Región Pampeana y su variabilidad en los últimos 10 años. *Rev. Fac. de Agronomía* **25**(3):247-257.

Fenández Long ME, Barnatán IE, Faroni A, Hurtado R. and Murphy G. 2006. Probabilidad de ocurrencia de heladas primaverales críticas para la siembra de cultivos estivales en la Región Pampeana. Presentado a la *Rev. Fac. de Agronomía*.

Frich, P.; L. V. Alexander; P. Della Marta; B. Gleason; M. Haylock; A. Klein Tank And T. Peterson. 2002. Global changes in climatic extremes during the 2^{nd} half on the 20^{th} century. *Climate Res.*, **19,** 193-212.

Heino R, Brazdil R, Forland E, Tuomenvirta H, Alexandersson H, Beniston M, Pfister C, Rebetez M, Rosenhagen G, Rosner S, Wibig J. 1999. Progress in the study of climate extremes in northern and central Europe. *Climatic Change*, **42**, 151-181.

IPCC. 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P. van der Linden, X. Dai, and K. Maskell, eds. Cambridge University Press, Cambridge, UK.

Kats RW, and Brown BG. 1992. Extreme events in a changing climate: Variability is more important than averages. *Climate Change*, **21**, 289-302.

Müller GV, Ambrizzi T y Núñez MN (2005). Mean atmospheric circulation leading to generalized frosts in Central Southern South America. *Theoretical and Applied Climatology*, **82:** 95-112.

Nicholls N, Gruza G, Jouzel J, Karl TR, Ogallo LA, Parker DE. 1996. Observed climate variability and change. In Climate Change 1995. *The Science of Climate Change: Contribution of Working Group I to the second Assessment Report of the Intergovernmental Panel on Climate Change*. Cambreidge University Press: 133-192.

Pascale AJ, Damario EA and Bustos C. 1997. Aumento de las temperaturas mínimas inverno-primaverales en el Alto Valle del Río Negro en los últimos 90 años. *Rev. Facultad de Agronomía*, **17**(1): 127-131.

Pascale AJ, Damario EA. 2004. Bioclimatología Agrícola y agroclimatología. Editorial Facultad de Agronomía – UBA. 550 pp.

Rusticucci M and Barrucand M. 2004. Observed trends and changes in temperature extremes over Argentina. *Journal of Climate*, **17**:4099-4107.

WORLD METEOROLOGICAL ORGANIZATION. 1996. Climatic Change. *Technical Note* N° 79.Geneva. Switzerland. 80 pp.