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STUDY OF THE FREQUENCY OF EXTREME DAILY PRECIPITATION ON THE SOUTH OF ANDES MOUNTAIN RANGE. TEMPORAL VARIABILITY IN THE PERIOD 1961-2003 AND RELATION WITH ANTARCTIC OSCILATION

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Abstract

For the period 1961-2003, the climatology of extreme daily precipitation intensity presents a maximum in winter (22mm/day), as well as the percentage of extreme events (9%). Winter explains 36% of the annual percentage of events greater than percentile 75th (PE>75th), however summer explains 15%. Autumn and spring explains 27% and 22%, respectively. Trends for percentage of events greater than 0,1mm (PE>0.1) and PE>75th are non significant for all seasons and also for annual terms. However, during winter season the coefficient is negative for both indices (PE>0.1 and PE>75th), indicating that the number of rainy days or extreme rainy days are only decreasing in this season. This hypothesis was confirmed through the change of PE index between two excluded periods 1961-1975 and 1980-1996. The highest percentage of changes was observed for PE>75th during winter (-36%). In spring, interdecadal variability of PE>01 and PE>75th are in opposite phase. For the period 1979-2003, the relationship between Antarctic Oscillation (AAO) index and extreme rainy days (PE>75th index) was analysed. Both monthly indices are out of phase. This negative relationship was also observed when the seasonal analysis was performed, observing the highest and significant cross-correlation during autumn and spring (-0.52 and –0.27; respectively). Finally, the phase of AAO in autumn explains significantly the occurrence of PE>75th two seasons in advance (spring, -0.24).

1. INTRODUCTION

South of the Andes mountain range, in the provinces of Chubut, Neuquén and Rio Negro, Southern Argentina, seven hydroelectric dams are located. [1]They are placed in a relatively small region compared to the surface of Argentina. These hydroelectric dams produce in annual terms 15741 Gwh, a value that represents approximately 16.7% of the total amount of energy produced during the year 2004 in Argentina (Precensio Deck et al, 2006). Water from melting of snow or glaciers of the mountain range is the main source for electrical generation. In addition, these dams are used to regulate rivers flow, irrigation and industrial activities or human consumption. Therefore, the temporal and spatial knowledge of rainfall in the region is important.

Few studies analyse this subject, mainly due to the lack of stations with long term series and good quality data in the region. Barros and Mattio (1977/1978) found positive trends in annual precipitation until the 50s in the region of study, but they suggested that trend changes in the 60s. Haylock et al (2006) observed a decrease of the annual precipitation and in daily extreme rainfall over south Chile in the period 1960-2000.

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The Antarctic Oscillation (AAO) contributes to a significant proportion of Southern Hemisphere mid-latitude circulation variability on many time scales (Hartmann and Lo, 1998; Kidson, 1999). The AAO results mainly from the internal dynamics of the atmosphere and it is an expression of storm track and jet stream variability (Hartmann and Lo, 1998; Limpasuvan and Hartmann, 2000). Silvestri and Vera (2003) found that during spring AAO positive (negative) phases are associated to the intensification of an upper-level anticyclonic (cyclonic) anomaly, to the weakeness (enhancement) of moisture convergence and to the decrease (increase) precipitation over the South East of South America (SESA).

This work attempts to provide information on rainfall trends in South Andes mountain, specially for extreme events and to look at links with the circulation. Therefore, the objectives of this research are: a) make a climatology of daily precipitation; b) study the temporal variability of daily rainfall frequency and c) explore the relationship between AAO and daily extreme rainfall in the South Andes mountain.

2. DATA AND METHODOLOGY

There are no records of snowfalls over the mountain range in this region of Argentina and only a few raingauges in Patagonia region. Therefore daily precipitation of Esquel was used (43ºS - 71ºW) (Figure 1). This station, located at the South East of The Andes mountain range was selected because it has a long record (1961-2003) without missing data.

Extreme events are infrequent meteorological phenomena and their severity will depend on the natural environment affected. This implies that the definition of an extreme event will largely depend on the activity and the region affected (Das et al, 2003).

For the purpose of this research a rainy day is one on which the rainfall is more than 0.1 mm. Rain is considered to be extreme when the daily rainfall is greater than a given threshold. Different thresholds are employed to detect their probable impact on the distribution of the variations in the number of wet spells. Rainfall thresholds chosen here are based on statistical values such as the 50th, 75th and 95th percentiles (P50, P75 and P95). The different percentiles are calculated on all the daily rainfall for each meteorological station. Daily percentiles are clarified by smoothing the data using a 7 day running average. The weights used were 0.05; 0.1; 0.2; 0.3; 0.2; 0.1 and 0.05; the symmetry of the different weights prevents any dephasing in the annual march (Hu et al, 1998).

Changes observed in monthly rainfall may be due to changes in the number of rainy days, in rainfall intensity or both. This work focuses on the first aspect: number of days with rainfall equal or greater than the thresholds above mentioned. The percentage of events (hereafter: PE> 0.1; PE > 75th and so on) was calculated for the four astronomic seasons: summer (December, January and February, DJF), autumn (March, April and May, MAM) winter (June, July and August, JJA) and spring (September, October and November, SON) and the year as a whole (December to November of the following year). The trend test applied in this study for the 1961-2003 period is the non-parametric Kendall-Tau test (confidence level = 95%, critical r = /0.22/; Siegel, 1985). This test is a rank-based procedure suitable for detecting non-linear trends in variables which do not have a Gaussian distribution which is the case of the PE index. In order to analyze if these slow timescale variations appear in the PE index, an 11 year running mean was applied. This filters the smallest variability and retains the greater variability in 10 years. The different and symmetry weights assigned are the following: 1/24; 1/24; 1/12; 1/8; 1/8; 1/6; 1/8; 1/8; 1/12; 1/24 and 1/24.

The temporal PE index study for the four seasons makes it possible to analyze the annual PE index regime variations. Finally, in order to assess this annual variability, the percentual contribution of each astronomical season to the annual component is quantified by computing a new index in two excluding periods, 1961–1975 and 1980-1996, seasonal component (SC) index: quotient between number of rain events in each astronomical season (DJF; MAM, JJA; SON) and the number of rain events for the whole year (December to November) for the two thresholds 0.1 mm (SC0.1) and percentile 75th (SC 75th), expressed in percentages.

An aspect of the atmospheric variability of Southern Hemisphere is analyzed by means of the AAO index. This index is constructed by projecting the daily (00Z) 700mb height anomalies poleward of 20°S onto the loading pattern of the AAO, obtained from the Climate Prediction Center/NOAA from data of reanalysis NCEP. The NCEP/NCAR reanalysis dataset was employed at a horizontal resolution of (lat, lon)=(2.5°X2.5°) for the period 1979 to 2003 to obtain AAO index.

3. RESULTS

3.1 CLIMATOLOGY FOR THE PERIOD 1961-2003

Firstly, the annual cycle of daily percentile is analyzed. Figure 2 shows the highest percentiles. The maximum values are observed in winter months, being 10mm/day and 25mm/day for P75th and P95th, respectively (Figure 2, orange and red line). November shows a minimum being 5mm/day and 10mm/day for P75th and P95th, respectively. Autumn months show another minimum, for P75th the minimum value is observed in March and for P95th in February. The annual cycle for P50th (blue) evidences the same annual cycle but with smaller amplitude than the other percentiles.

The annual cycle of PE>0.1mm shows a maximum in winter (33%, June) and a minimum in summer (13%, January) (Figure 3, left). The extreme event presents a similar annual cycle (PE>75th is shown in Figure 3, right).

Extreme daily precipitation intensity (Figure 4) shows a different annual cycle from the percentage of events (Figure 3), but similar to the annual cycle of percentiles (Figure 2). In June (winter), 22.2 mm/day are registered while during February (summer) the intensity is 12mm/day (Figure 4). The lowest intensity is observed in autumn months (October) with an intensity of 11mm/day (Figure 4).

The probability that it rains, when the previous day was rainy (persistence of the rainy day (P11)), also shows an annual cycle with a probability of around 0.55 (0.35) in winter (summer) months (Table 1). Spring and autumn present values between 0.40 and 0.45. Persistence of no rainy day (probability that it doesn’t rain, when the previous day was not rainy, P00), shows values greater than 0.75 over the year, with a maximum (minimum) in summer (winter) (Table1).

After analyzing the climatology of daily rainfall, it is interesting to know how much the different seasons explain the annual cycle (Table 2). Winter season explains the highest percentage/contribution 36% of the annual daily precipitation for both threshold (0.1mm and P75th) and summer the lowest (15%) (Table 2).

3.2 TEMPORAL VARIABILITY FOR PE INDEX

Trends for PE>0.1 and PE>75th, in the period 1961-2003, are non significant for all seasons and annual terms. However, it is interesting to note that in winter the regression coefficient is negative, insinuating a decrease for both daily (PE>0.1) and extreme rainfall (PE>75th) (results not shown).

In order to complement trend analysis of daily rainfall given by the previous results, the interdecadal and interannual variations for both PE indices were analyzed. The available daily data is not long enough to determine temporal variability with more than 30 years of period. However, time series shown in Figure 5 an interesting behavior, depending on the season and the threshold. The interdecadal variation is more evident in SON for PE>75th. In winter this variation is represented by a negative “jump”, decreasing a 58% between 1972 and 1986 (Figure 5). In summer months the interannual variation prevails. In spring, it is interesting to note that interdecadal variability of PE>0.1 and PE>75th are in an opposite phase, i.e. when PE>01 presents a maximum, PE>75th evidences a minimum and vice versa.

To assess these changes, the PE index was compared in two excluded periods (1961-1975 and 1980-1996) and the percentage of change was calculated for summer, autumn, winter and spring (Table 3). Winter shows 36% less of daily precipitation events over P75th in the second period, as well as in summer and spring (19% and 14%, respectively)(Table 3). This behaviour is resembled in annual terms (18%). These results are not so clear in PE>0.1. Winter shows a 6,5% less of days of rain in the second period. However, in autumn and spring an increase of 12% is observed in average. In annual terms an increase of 4% of the days of rain in the second period is observed.

In order to analyze changes in the annual cycle of PE>0.1 and PE>75th through time, the SC index was calculated for both periods (Table 4). The decrease observed in SC 75th index during winter months is mainly due to an increase during autumn tire spring. These changes are also observed in SC 0.1 index, but it is not so clear (Table 4).

3.3 RELATIONSHIP BETWEEN THE ANTARTIC OSCILLATION AND THE DAILY RAINFALL IN THE PERIOD 1979-2003

The Antarctic Oscillation (AAO) index was used as an estimator of the circulation of Southern hemisphere in middle and high latitudes. Firstly, time series analysis was used to describe the characteristics of monthly AAO and monthly PE>75th. Figure 6 shows these time series anomalies in the period December 1979 to January 2003. A positive (negative) anomaly of amount of extreme daily precipitation is observed during the negative (positive) phase of the AAO. This out of phase characteristic is resembled by the cross-correlation coefficient for monthly AAO index and PE>75th index (-0.14; significant at or above the 95% confidence level).

The most representative characteristic of this relationship was determined by the lag-cross correlations for seasonal AAO and seasonal PE>75th indices. Table 5 and Table 6 show the seasonal cross-coefficients for lag zero and different zero, respectively. Negative cross-correlations were found in all seasons, being significant during autumn and spring (Table 5). The highest seasonal correlation was during autumn, where its variance explained is 29%.

The correlation values increase when the seasonal lag-correlations were calculated. The most relevant results are shown in Table 6, lagging up to two seasons the PE>75th index. This analysis show that the AAO index during autumn could force the occurrence of PE>75th in Esquel, two season in advance (SON).

If winter cross-correlation (lag zero) (Table 5; -0,06) is compared with seasonal one-lag cross-correlation (Table 6; autumn AAO index and winter PE>75 index; 0.17), the relationship increases. This means that the phase of AAO in autumn explains a greater amount of variance of PE>75 in the following season (winter) than in the diagnostic analysis during winter (lag zero).

4. CONCLUSIONS

For the period 1961-2003, the climatology of extreme daily precipitation intensity presents a maximum in winter (22mm/day), as well as the percentage of events great of percentile 75th (PE>75th) (9%). The minimum intensity (PE>75th) is observed in autumn (January) around 10mm/day (3%). Winter explains 36% of the annual PE>75th, however summer explains 15%. Autumn and spring explain 27% and 22%, respectively.

Trends for PE>0.1 and PE>75th are non significant for all seasons and also for annual terms. However, during winter season the coefficient is negative for both indices (PE>0.1 and PE>75th), indicating that the number of rainy days or extreme rainy days are only decreasing in this season. This hypothesis was confirmed through the change of PE index between two excluded periods 1961-1975 and 1980-1996. The highest percentage of changes was observed for PE>75th during winter (-36%). In annual terms, percentage of change of PE>75th evidences a decrease of 18.2%.

Interannual and interdecadal variations of PE are observed in spring and autumn for both thresholds (PE>75th and PE>01mm). In spring, interdecadal variability of PE>01 and PE>75th are in opposite phase, i.e. when PE>01 present a maximum PE>75th evidence a minimum, and vice versa. SC 75th index shows that the decrease in winter (JJA) is due to an increase in autumn.

For the period 1979-2003, the relationship between Antarctic Oscillation (AAO) index and extreme rainy days (PE>75th index) was analysed. Both monthly indices are out of phase. This negative relationship was also observed when the seasonal analysis was performed, observing the highest and significant cross-correlation during autumn and spring (-0.52 and –0.27; respectively). Finally, the phase of AAO in autumn explains significantly the occurrence of PE>75th two seasons in advance (spring, -0.24).

Acknowledgements
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FIGURES AND TABLES

Figure 1. *Esquel station localization (43º S - 71ºW, white point) in the province of Chubut, South West Argentina, South America.*

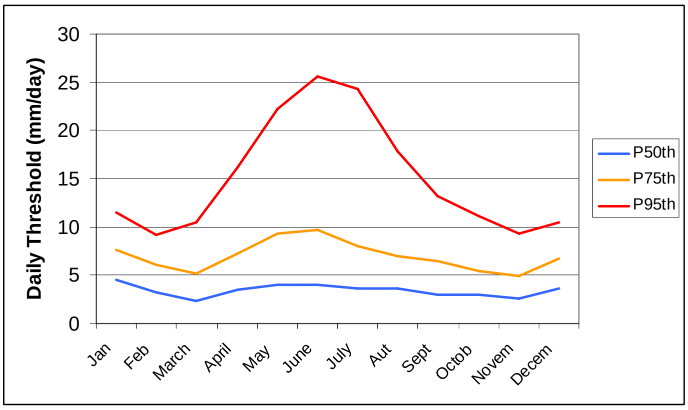

Figure 2. *Annual cycle of percentiles 50th, 75th, and 95th for the climatological period 1961-2003. (mm/day), for Esquel.*

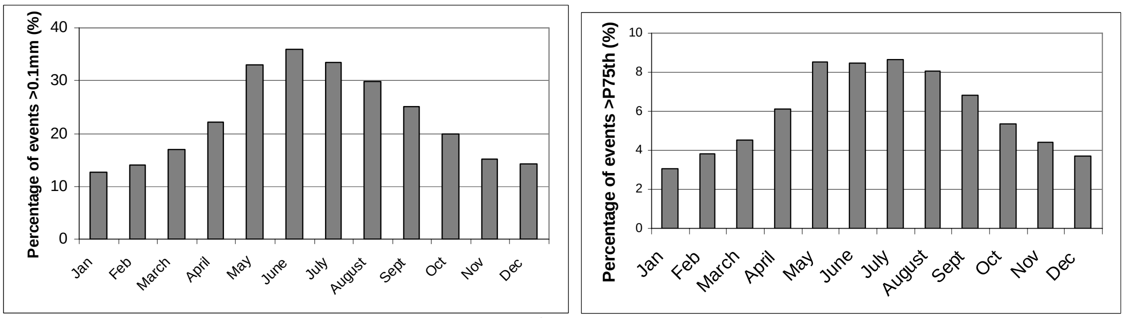

Figure 3. *Annual cycle of PE>0.1 (left) and PE>75th (right) index for climatological period (1961-2003).*

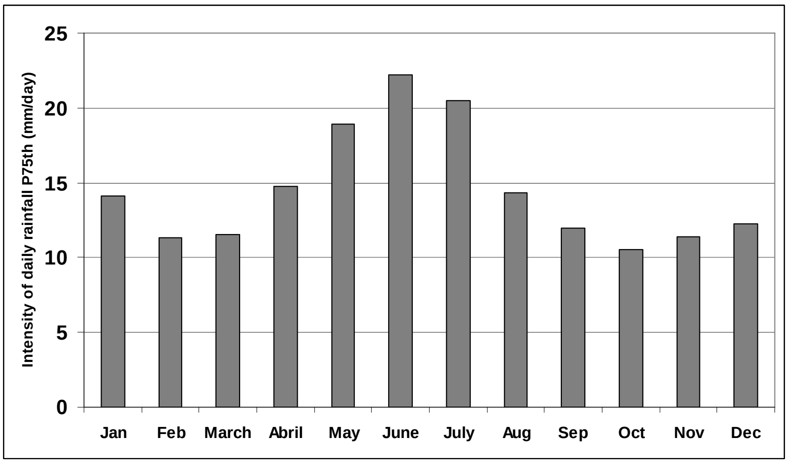

Figure 4. *Annual cycle of intensity of daily rainfall over percentile 75th threshold for the climatological period (1961-2003) for Esquel*

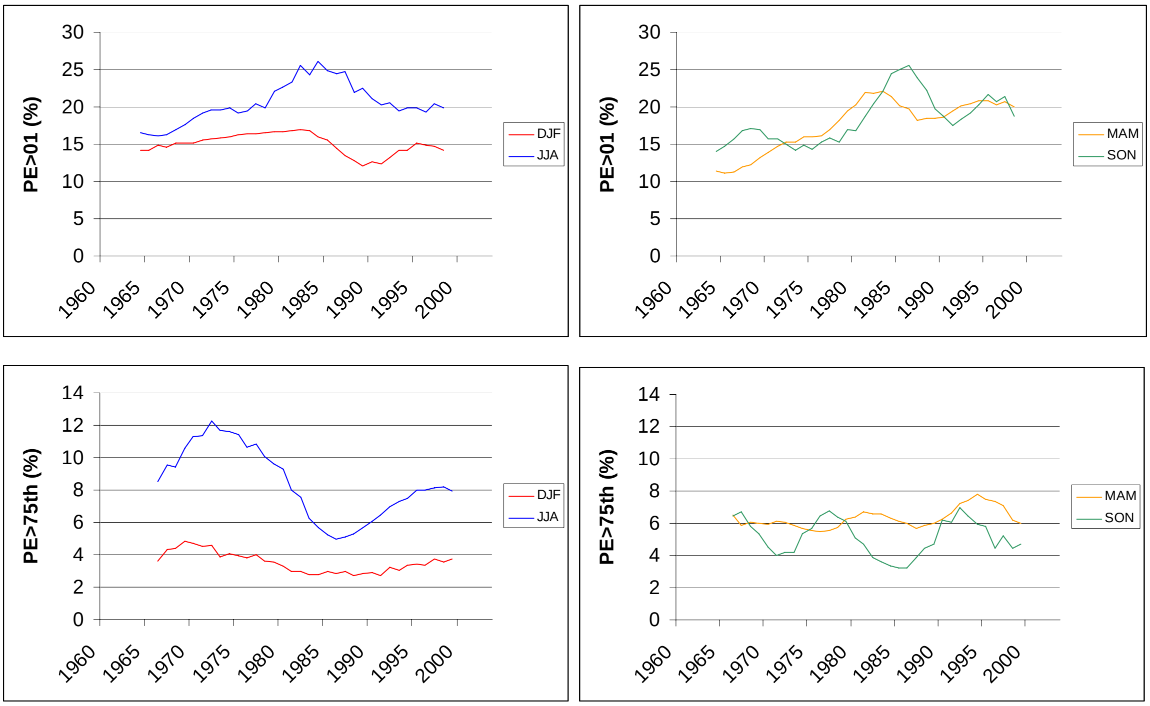

Figure 5. *Time series of PE>0.1 (upper) and PE>75*th*(bottom) indices for Esquel. Left: red summer (DJF); blue: winter (JJA). Right: orange: autumn (MAM); green: spring (SON). 11 year weight running mean was applied.*

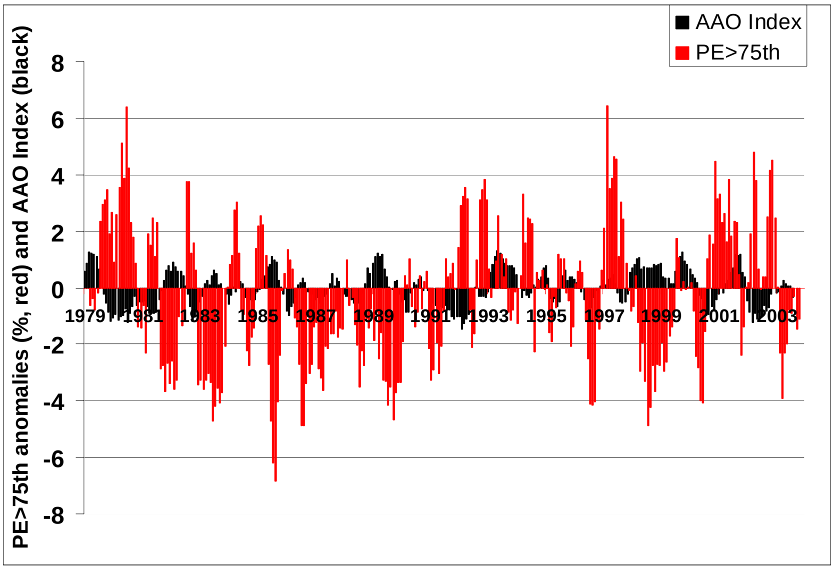

Figure 6. *Monthly times series anomalies of AAO index (black) and PE>75th for Esquel (Red) between 1979-2003. Five months weight running mean was applied.*

	DJF (Summer)	MAM (Autumn)	JJA (winter)	SON (spring)
P00	0,89	0,82	0,76	0,85
P11	0,35	0,43	0,5	0,41

Table 1. *Seasonal persistence of rainy day (P11) and not rainy day (P00) for the climatological period (1961-2003) for Esquel.*

	DJF (Summer)	MAM (Autumn)	JJA (winter)	SON (spring)
SC 01	15	27	36	22
SC P75	15	27	35	23

Table 2. *Seasonal component (SC) index for PE>0.1 (SC 0.1, upper) and PE>75th (SC P75th, bottom) calculated for the climatic period (1961-2003) for Esquel.*

(1961-1975/ 1980-1996)	DJF (Summer)	MAM (Autum)	JJA (winter)	SON (spring)	Annual
Percentage of change of PE>01	-0.3	15.8	-6.5	11.2	4.3
Percentage of change of PE>75th	-19.5	4.9	-36	-14.1	-18.2

Table 3. *Percentage change for PE>0.1(upper) and PE>75th (bottom) for summer, autumn, winter, spring and annual values, between the two periods: 1961-1975 and 1980-1996, for Esquel.*

	DJF	MAM	JJA	SON
SC 01 1961-1975	15	27	38	20
SC 01 1980-1996	14	28	36	22

	DJF	MAM	JJA	SON
SC 75th 1961-1975	14	27	38	21
SC 75th 1980-1996	13	33	31	22

Table 4. *Seasonal Component (SC) index for each astronomical season (DJF; MAM, JJA; SON) for the two thresholds 0.1 mm (SC0.1, upper) and percentile 75th (SC 75th, bottom), for two periods: 1961-1975 and 1980-1996. It is expressed in percentages.*

	DJF (Summer)	MAM (Autumn)	JJA (Winter)	SON (Spring)
Corralation between AAO and PE>75th	-0.14	-0.52 **	-0.06	-0.27 *

Table 5. *Cross-correlation (lag zero) between seasonal AAO index and seasonal PE>75th. Significant values at 95% (**) and at 90% (*).*

	PE>75th		
	MAM	**JJA**	**SON**
AAO MAM (Autumn)	-0.52 **	0.17	-0.24 *

Table 6. *Lagged cross-correlation between seasonal AAO index and seasonal PE>75th. Significant values at 95% (**) and at 90% (*)*