Rainfall variability pattern over time in Andalousia and its links with the North Atlantic Oscillation.

PITA, M.F., CAMARILLO, J.M., AGUILAR, M.
Department of Physical Geography
University of Seville (Spain)
C/ Maria de Padilla s.n. 41004 SEVILLA (SPAIN)
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Abstract:
The moving coefficient of variation over a 30 year period has been applied to precipitations series in seven meteorological stations in Andalousia, starting from the late 18th century until 1996. These coefficients show important variability changes in the region: periods of either strong or weak variability have been detected, describing a cyclic pattern in these time coefficient series. A 44-year cycle is predominant in the stations located in the northern part of the region, whereas an 88 year cycle is found in southern Andalousia. Rainfall variability and the North Atlantic Oscillation of the atmosphere have been compared in order to find the possible links existing between them.

Key Words: Rainfall variability, Spectral Analysis, Climate Change, Andalousia, NAO index.

Introduction.

The majority of climatic change studies try to identify significant variations of central tendency values of time series, especially for temperature and less frequently for rainfall series. These studies begin to achieve clear results in relation to temperature: increasing minimum temperature values, particularly for urban environments. On the contrary, rainfall research does not achieve such precise results, and in some cases discrepancies can even be found in different studies referring to the same spatial area; that is the case of the Mediterranean (Tabony , 1981; Djellouly et Daget, 1989; Maheras, 1988; Maheras et Vafiaris, 1990; Benito, Orellana y Zurita, 1994). However, variability pattern has rarely been under consideration in this type of studies. More often, this topic has been indirectly dealt with by use of the analysis of extreme events (Kutiel et al., 1996) and the IPCC document even uses this methodology when examining variability trends (Houghton et al., 1996).

Therefore, variability is a major descriptive parameter for observational series, like the central tendency ones and, for many spatial domains, such as the Mediterranean, variability both defines and characterises those environments having important socio-economic effects. Thus, periods of weak variability facilitate water resource management due to the fact that most years have rainfall values close to the annual average. The opposite occurs when variability increases and extreme values multiply, provoking droughts and floods, which cause negative impacts (Pita, Camarillo y Aguilar, 1998; Aguilar y Pita, 1996).

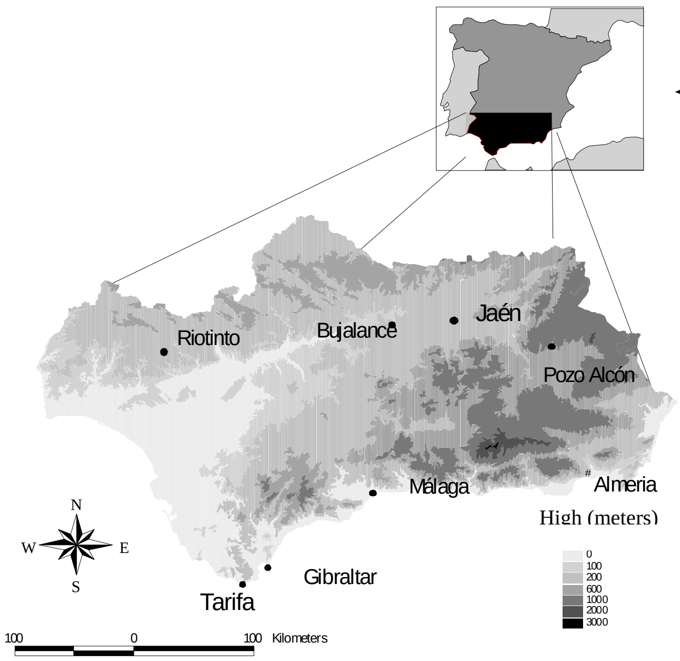
The same considerations can be made in relation to the North Atlantic Oscillation. Most research has been focused on trend analysis (Kalnicky, 1987; Makrogiannis et al., 1991; Hurrel, 1995; Karl, 1995 and Ruizdelvira and Ortizbeviá, 1997) but very little has been done to analyse its variability. So, various reasons would seem to suggest the need for this type of study in our region.

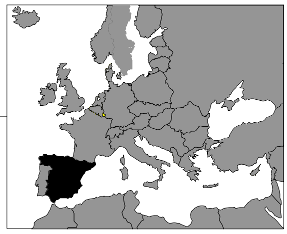
1.- Aims, data and methods.

This paper has two main objectives, first to examine rainfall variability changes over time, as well as identifying the temporal and spatial pattern of this parameter and, secondly, to assess their relationship with the North Atlantic Oscillation.

In order to study rainfall variability in Andalousia, records from eight meteorological stations were selected. All of them were well distributed over the region and had a minimum record length of 60 years, as can be seen in figure 1.

Figure 1: Study area





Meteorological stations	Record period	Record lenght
Gibraltar	1791 - 1994	203
Tarifa	1913 - 1994	81
Málaga	1878 - 1995	117
Riotinto	1882 - 1994	112
Bujalance	1903 - 1994	91
Jaen	1877 - 1994	117
Pozoalcón	1912 - 1994	82
Almeria	1911 - 1977	66

The homogeneity of the rainfall series was checked by using the double mass cumul test, thus ensuring that all series were reliable and homogeneous. Only three series presented gaps in their records and in those cases they were completed by simple linear regression analysis with the best-correlated neighbouring station.

Rainfall variability pattern was studied using moving coefficient of variation in annual totals for a 30-year period. The choice of this coefficient was based on its characteristic of being a standardised measure, which allowed for the comparison between different meteorological stations. Regarding the period length, a 30-year period was considered according to the World Meteorological Organisation and, also, due to the fact that the moving coefficient of variation starts to stabilise after a 30-year period; when reducing this period length, the coefficient of variation became too fluctuating and, consequently, the representativeness of the variability series was quite weak. When analysing time series variability pattern , spectral techniques were applied.

The North Atlantic atmospheric circulation pattern was analysed using the NAO index values obtained by Jim Hurrell, from 1865 to 1995 (Hurrell, 1995). This index is based on the difference of normalized sea level pressure between Ponta Delgada, Azores, and Stykkissholmer, Iceland.

The monthly data from the NAO index provided the basis for both annual and seasonal totals and in these, the moving averages and the moving standard deviations for a 30-year period were calculated. These new series, indicative of the general pattern of the NAO index and its variability, would later be used to check for any possible connections between rainfall variability in Andalousia and the North Atlantic Oscillation pattern.

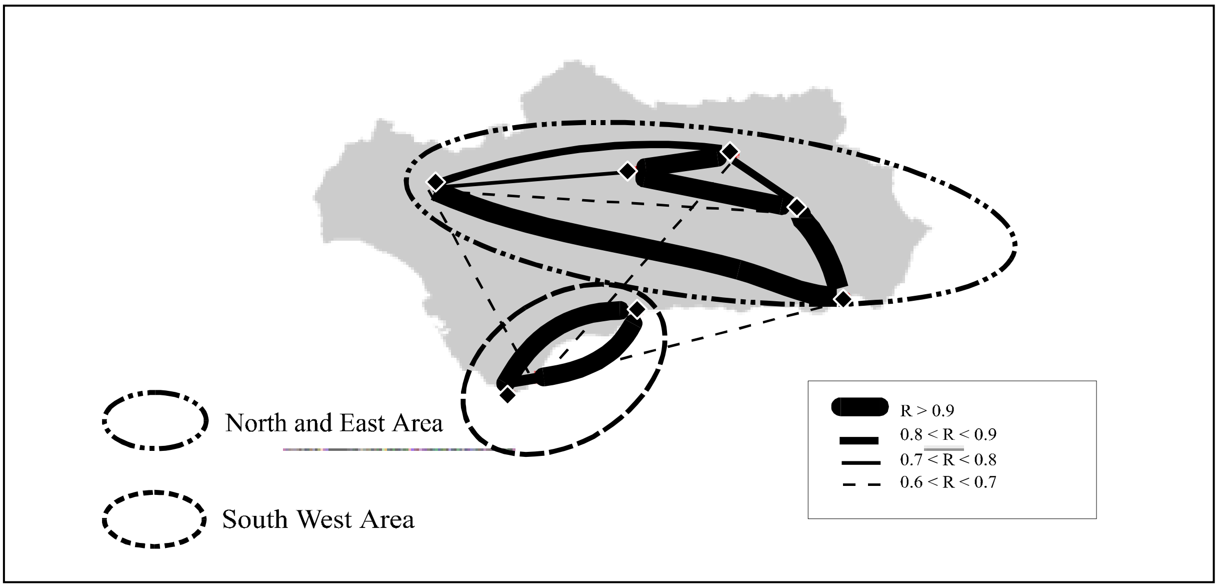
2.- Results.

2.1.- Rainfall variability pattern.

The application of this method shows the existence of important changes in the moving coefficient of variation for all the series under study. Minimum values of coefficient fall to 20%, whereas the maximum values vary between 35% to 45%, with the average difference of variation of 15% to 20%. Nevertheless, there are certain meteorological stations that exceed these values (see figure 2).

The weakest variability period occurs at the end of the 19^{th} century for all the studied stations. From then onwards there is a general increase in variability, with maximum values being reached at the present times for the southern observatories, and in the middle of the 20th century for the northern ones. In the case of the Gibraltar station, which has a much longer record length, second maximum and minimum variability periods are found, the former at the beginning of the 19^{th} century and the latter in the late 18^{th} century and in the early 19^{th}.

Figure 3: Pearson correlation coefficients (R) calculated between annual rainfall moving coefficients of variation (30 years) of studied stations



These results shed light on a spatial pattern in the region, where important differences between the northern and southern domains are found. Pearson`s correlation coefficient was calculated between the moving coefficient of variation of all record series, and this spatial pattern became evident, with strong links between the observatories of the same spatial domain (Pearson`s values from 0,8 to 0,9) and weak correlation coefficients between stations from different spatial domains (see figure 3).

To illustrate this phenomenon more clearly, the average moving coefficients of variation in the northern and southern stations were calculated separately. Then, the spatial pattern was particularly clear from the mid 20th century onwards, when the southern and northern domains began to show opposite trends (see figure 4a). Up to the 1950`s, both domains describe almost the same temporal pattern but, from then onwards the observatories located south experience an increase in their variability index, whereas the northern stations start to decrease.

Furthermore, the absolute differences between the coefficient values of both regions remain constant around 3% up to the 1950`s. From that date to the present time, the differences increase up to 20% in recent years (see figure 4b).

Figure 4 a): Moving coefficients of variation (30 years) for the North and South West areas

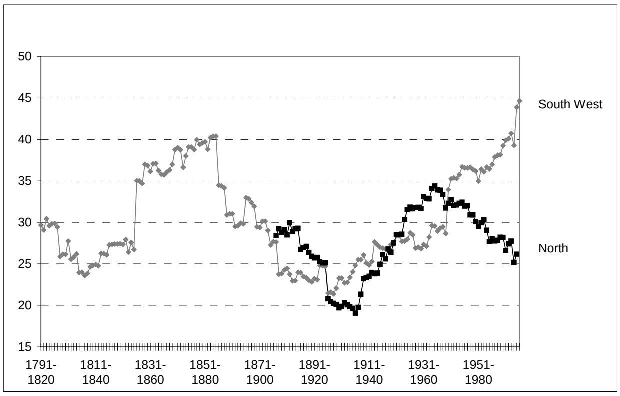
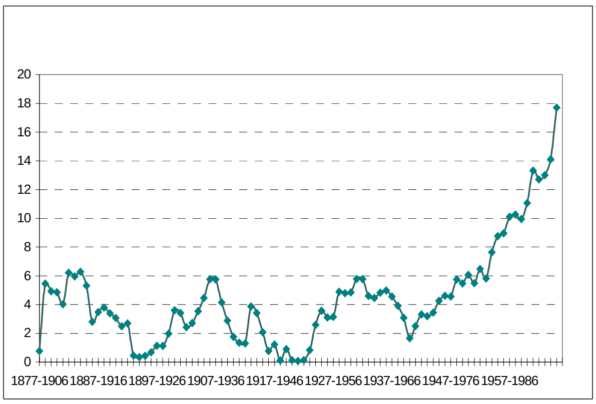


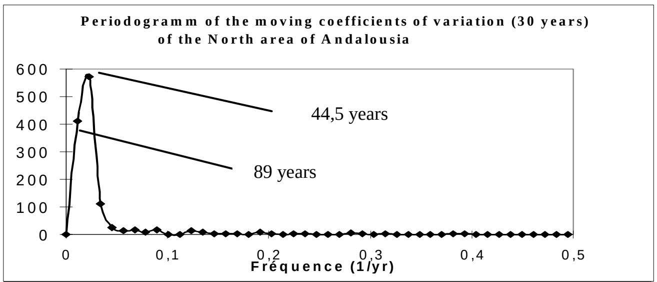
Figure 4 b): Absolute differences between the moving coefficients of variation of the North and South West areas

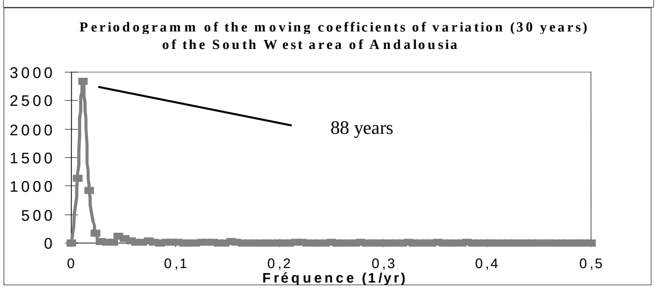


Both spatial domains have experienced a cyclic pattern in their variability, but with different wavelength and amplitude. In the southern domain amplitude is high, with differences between maximum and minimum coefficient of variation values over 20%. On the contrary, in the northern domain the wave amplitude falls to 15%.

With respect to the wavelength, its characteristics are shown in the periodogramms of each domain (see figure 5). For the southern one the periodogramm shows an 88 year harmonic which explains 50% of the series variance. In the northern part of the region a similar 89-year harmonic can be found, coinciding with the total number of the series values and explaining 33% of the variance, but this harmonic is not the main one ; there is a 44,5 year harmonic which explains 46% of the series variance.

Figure 5: Periodogramms of the moving coefficients of variation of the North and South areas of Andalousia





We should emphasise the presence in both domains of an 80 to 90 year cycle, matching the Gleisberg cycle, which has been largely documented and verified for solar activity (Burroughs, 1992; Landscheidt, 1993; Rind et Overpeck, 1993**)** and which has clear repercussions on certain climatic features like temperature (Stelmacher, 1995). Trying to connect such different phenomena could be too risky, but it might be worth doing more research in this direction.

2.2.- Rainfall variability and its links with the North Atlantic Oscillation index.

In order to analyse the possible relation between the NAO index and rainfall variability, the correlation matrices were calculated. First, a calculation was made between the moving coefficient of variation (MCV) series and the mean NAO index series and, secondly, between MCV and the standard deviation of the NAO index, both at annual and seasonal time scale.

Many of the correlation coefficients calculated were statistically significant, but some facts in particular should be highlighted. Firstly, the correlations between rainfall variability and the average values of the NAO index are much stronger than the correlations with its standard deviations, i.e., its variability. The reason behind this apparently surprising fact could be that periods of intense rainfall variability in the Mediterranean area are usually linked to the existence of some extremely wet years. Such years are generally associated with meridian positions of the jet stream, which, in their turn, generate very low values in the NAO index. As a consequence of this, high values of rainfall variability usually coincide with low values in the NAO index, and this is how the strong negative correlation existing between both magnitudes appears. This correlation in particularly acute in the northern part of the region, where it reaches an average value of –0,83, with an almost perfect covariation between both magnitudes, and it is somewhat weaker in the south, where this value falls to –0,45 (see figures 6 and 7). For their part, the correlation coefficients between rainfall variability and the variability of the NAO itself are positive and much weaker than the previous ones, only showing any statistical relevance on very few occasions (see figure 6).

Figure 6: Correlation coefficients between annual NAO index moving average (left) / moving standard deviation (right) (30 years) and the moving C.V.

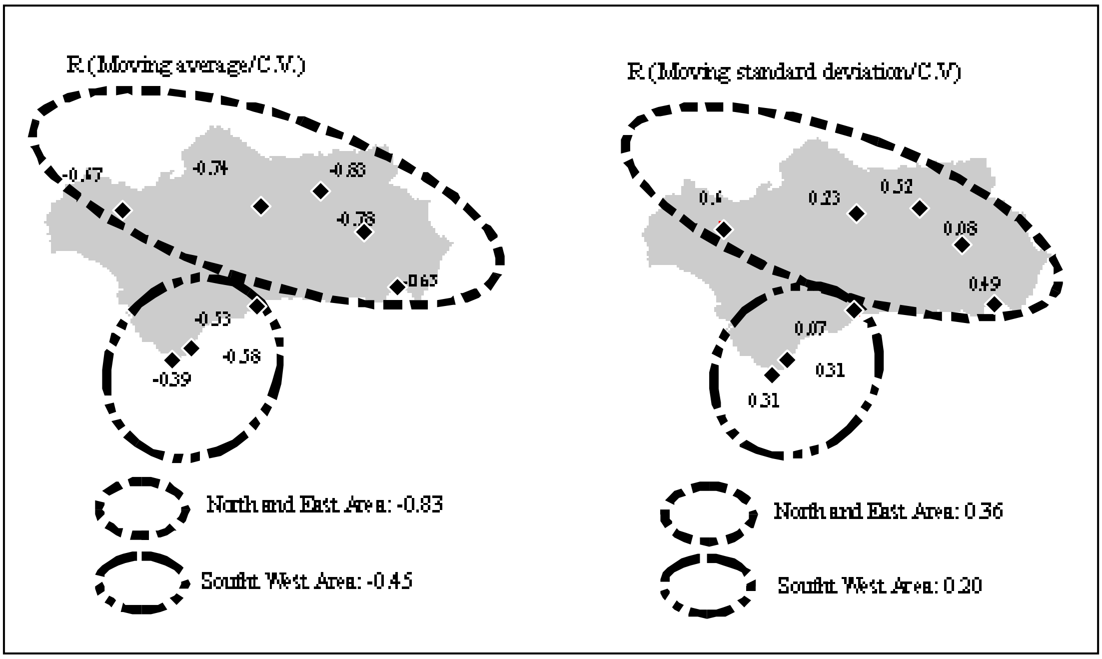
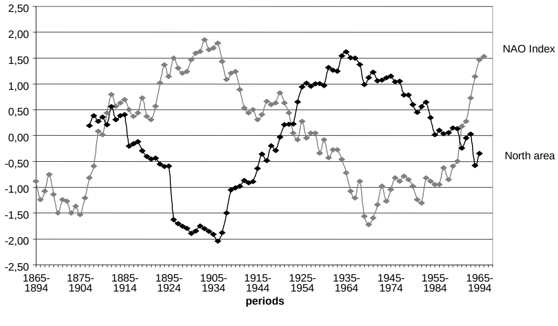
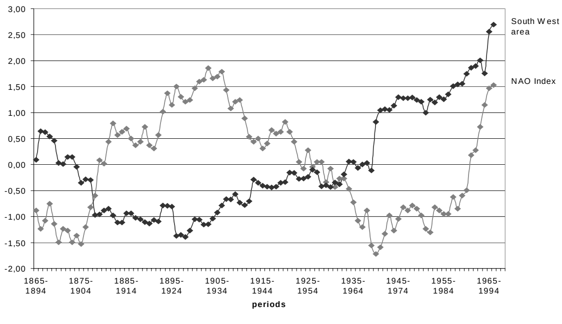


Figure 7: Standardized NAO index moving average (30 years) and moving coefficients of variation (30 years) of the North and South-West areas

North

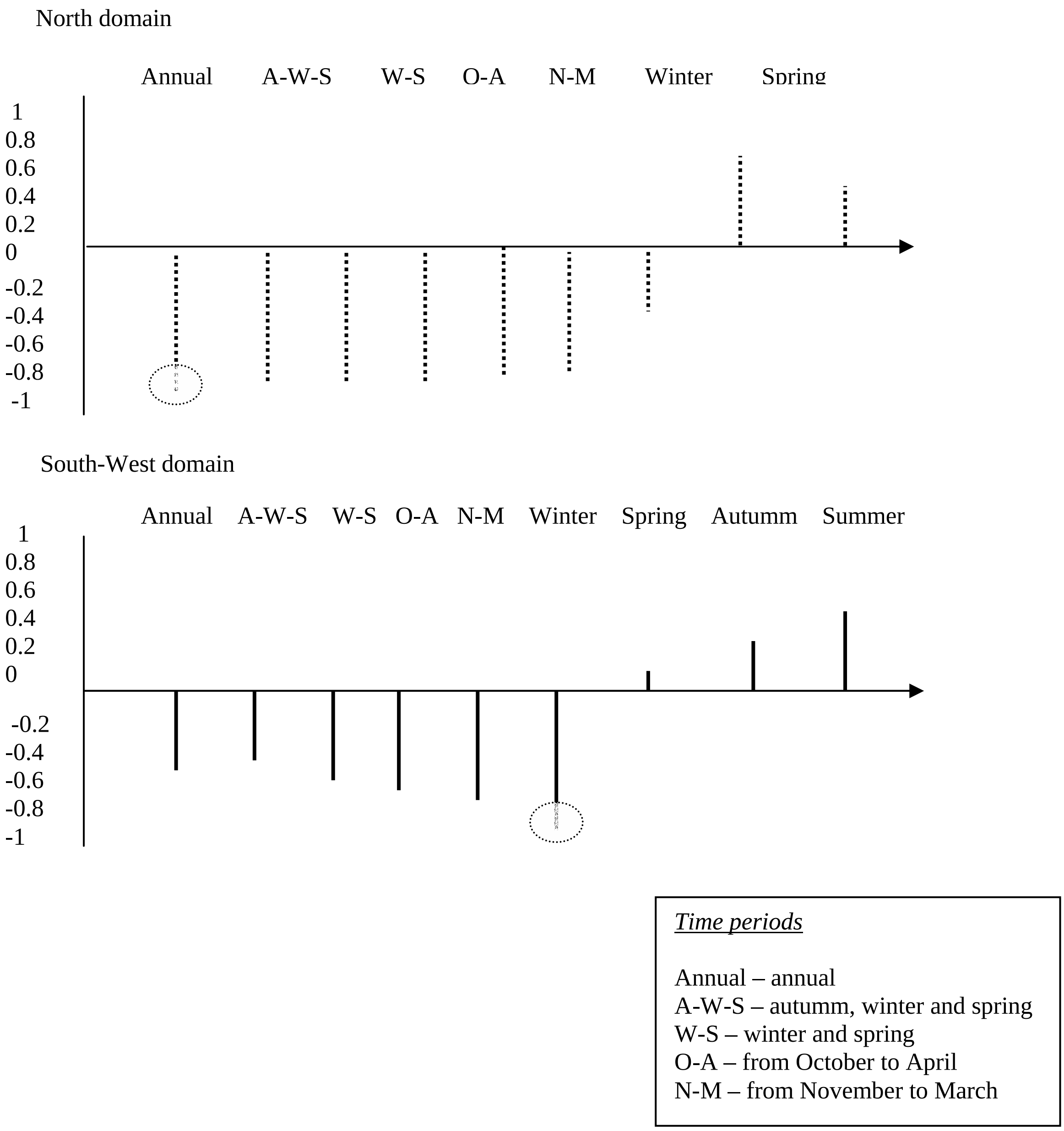


South-West



To go further in this research, different mean NAO indexes were calculated on a seasonal time scale and correlation coefficients between rainfall variability and each of these new NAO indexes were calculated (see figure 8). Some aspects should be emphasised: First of all, the fact that correlation coefficients are always negative and statistically significant, except for the summer and autumn, when correlation is positive. The autumn high correlation value in the northern domain also stands out

Figure 8: Correlation coefficients obtained between mean seasonal NAO index and annual rainfall moving coefficients of variation



Secondly, the role of winter in differentiating between the northern and the southern domains in the region. In the southern domain the winter NAO index is the one that better correlates with rainfall variability (-0,81). If we extend the NAO index period, the correlation value decreases as we enlarge the index to include more months; when considering the annual average, the correlation coefficient drops to -0,45. In the rest of the region, there is a good correlation with the winter NAO values (-0,71), but it does increase as we lengthen the period, reaching its maximum value for the mean annual index (-0,83). It seems that rainfall variability for the southern domain is determined or caused by the winter NAO performances, whereas in the northern domain all seasons have a part to play in this phenomenon.

In order to explain this occurrence, it is not enough to simply refer to rainfall regime pattern since, both in the north and the south of the region, winter is the wettest season of the year. The reasons have to be found within the seasonal pattern for rainfall variability; undoubtedly, in the south, as can be seen in these results, rainfall variability is essentially linked to the atmospheric circulation pattern in winter, while, in the north, circulation registered throughout the year constitutes rainfall variability. The concrete mechanisms through which this connection develops are, as yet, unknown to us, but we hope to examine them in forthcoming investigations.

3.- Conclusions.

From the several conclusions that we can point out we have chosen the following ones. Concerning rainfall variability in Andalousia three facts can be highlighted:

Firstly, rainfall variability in Andalousia significantly changes over time. There are periods of low variability (late 19th century and early 20th) and others of extreme variability (second half of the 19th and 20th century) separated by periods of transition.

Secondly, rainfall variability distinguishes two spatial domains: the southern one, where it is weaker and more regular, and the northern domain, with high and much more irregular variability. Both spatial domains present cyclic variability pattern but with different wavelength: in the north there is a dominating 44-year cycle but a second 89-year one also exists. In the southern spatial domain the 88-year cycle predominates, thus explaining most of the variance of the series.

Thirdly, in recent years there is a maximum difference between the northern and southern domains; whereas the moving coefficients of variation start to decrease in the northern domain, the southern one registers the maximum values of the whole observational period. The time coincidence between this phenomenon and global warming registered from the 1940s onwards could allow us to consider it as one more element in the spectrum of climate change. Nevertheless, we think that the most likely hypothesis is the one which attributes it merely to the way in which the dominant cycles in each domain, which are not coincidental, are seen to overlap. In any case, the patterns of these waves will have to be followed closely over the next few years.

With regard to the links between rainfall variability and the NAO index, the most outstanding fact is the strong negative correlation existing between them. It also should be mentioned that the spatial differences previously found reappear at a seasonal level; winter NAO indexes explain rainfall variability in the southern domain, whereas the NAO index value throughout the year determines rainfall variability in the northern domain.

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