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Precipitation trends in mainland Portugal in the period 1941–2000

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Abstract The presence of a trend in hydrological parameters can result from the highly variable nature of hydrological processes or be related to climate variations. The purpose of this work is to contribute to a better understanding of the variability of precipitation by investigating recent trends in the temporal structure of this process in mainland Portugal. The study uses annual and monthly precipitation data from 107 locations scattered over the territory. The time span of the records is 60 years, from 1941 to 2000. The data are analysed using statistical methods (e.g. Mann-Kendall trend test). In order to take into account seasonality and serial correlation, the months of the year were analysed separately. The analyses of both annual and monthly data led to a characterization of changes in the distribution of precipitation over mainland Portugal and within the year.

Key words climate change; mainland Portugal; precipitation; seasonality; trend

INTRODUCTION

Due to its importance, climate change has been an active area of research in the last decades. Despite the use of complex models for exploring climatic change scenarios, analysis of field data continues to give valuable information to climate studies. Nevertheless, the characterization of the behaviour (and changes) of the climate system is often biased due to the large temporal and spatial variability of many of the relevant processes in climate studies, the lack of data of suitable resolutions, and the limited length of the records.

Precipitation is perhaps the most important component of the complex hydrological cycle because of its impact on our daily life. Therefore precipitation is often taken as a starting point towards the understanding of changes of the governing processes of climate. Point precipitation data is extensively recorded over the land surface and constitutes an important element for monitoring the hydrological cycle.

The precipitation regime in mainland Portugal is characterized by high variability in both the temporal and spatial domains (see e.g. de Lima, 1998; de Lima *et al*. 2002). The large east–west and north–south precipitation gradients, together with large seasonal and inter-annual variability, makes Portugal, and the Iberia, one of the most challenging regions of Europe to study in terms of precipitation variability and climate change scenarios. The study of precipitation variability is very relevant, mainly because of its impact on society, economic activities (e.g. agriculture), land use and water resources.

The purpose of this work is to contribute to a better understanding of the variability of precipitation by investigating recent trends in the temporal structure of this process in mainland Portugal. The Mann-Kendall trend test was applied to both annual and monthly point precipitation series.

PRECIPITATION DATA

This study uses monthly precipitation recorded at 107 locations scattered all over mainland Portugal. The time span of the records is 60 years, from 1941 to 2000. Figure 1 shows the location of the measuring sites and also the altimetry of Portugal. The area of the territory is around 88 700 km^2.

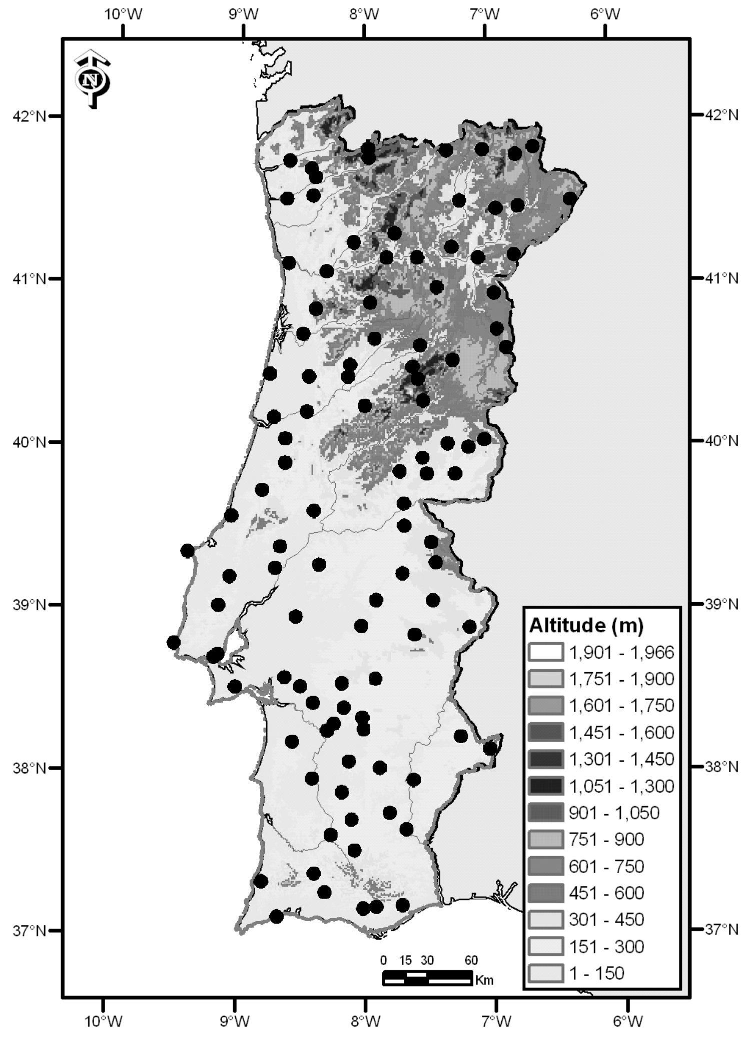

Fig. 1 Altimetry map of mainland Portugal and location of the 107 precipitation measuring sites.

The data were collected by the Portuguese Institute of Meteorology (IM) and the Portuguese Institute for Water (INAG) and are associated with different precipitation regimes across the country. The mean annual precipitation recorded in the period 1941–2000 is shown in the isohyetal map in Fig. 2 (left), which is based on the point measurements indicated in Fig. 1. The map was created using an ordinary kriging interpolation algorithm. It is an exact interpolator (i.e. at the point of the data, the estimated value is equal to the data value) and it assumes spatial correlation among data points.

Figure 2 shows that there are marked differences between the northern and southern regions, as well as between the littoral belt and the more inland regions. Among the data sets analysed in this study, the wettest location is in the north of Portugal, with an average yearly precipitation of 2386 mm, and the driest location is in the westerly point in mainland Portugal, with 491 mm per year. From 1941 to 2000, on average, the wettest and driest months were December and July, respectively. In this period, 41% of the annual precipitation fell during the months of November to January, which was the wettest trimester. The driest trimester was from June to August, with 6% of the annual precipitation.

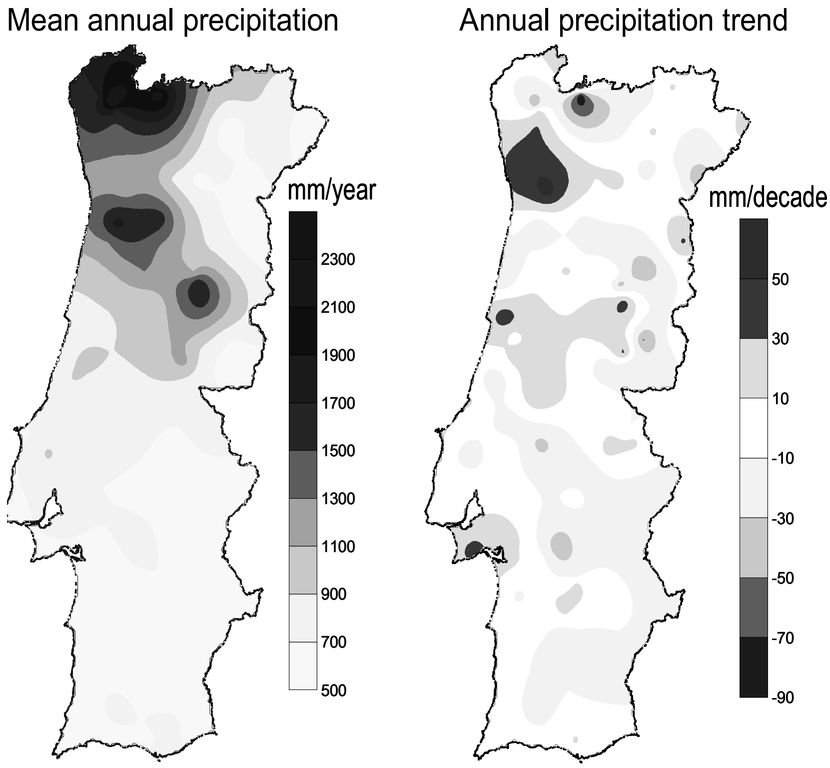

Fig. 2 Mean annual precipitation (in mm) and annual precipitation trend (in mm/decade) in mainland Portugal, from 1941 to 2000. The data are from the measuring points indicated in Fig. 1.

As other southern European regions, Portugal is a place of mild Mediterranean climate, with a warm and dry summer period, more pronounced in the southern regions, but with well known vulnerability to climate variability. Two storm types dominate the occurrence of precipitation in mainland Portugal: convective storms and frontal storms. Convective storms are frequent during the summer season and the early and mid autumn, and are more frequent in the southern regions; frontal storms occur principally in the winter season, and affect the northern regions more.

Mainland Portugal is located in the transitional region between the sub-tropical anticyclone and the sub-polar depression zones. The spatial distribution of precipitation over mainland Portugal and its seasonal variability are the result of the characteristics of the global circulation (specifically the Atlantic origin of many synoptic disturbances; e.g. seasonal movements of the Azores high pressure system) in the context of the regional geography (e.g. latitude, orography, oceanic and continental influences). Although the variation in climate factors is rather small, it is sufficient to justify significant variations in precipitation in mainland Portugal.

METHODOLOGY

Two natural forms of persistence are the existence of trend and the presence of serial correlation. While trend is associated with long range persistence, serial correlation is associated with short range persistence (from one term to the other). Nevertheless, the existence of a serial correlation can introduce systematic error into the trend analysis (see e.g. Sneyers, 1990). The non-parametric test used for detecting serial correlation in the precipitation data was the Wald-Wolfowitz test (Wald & Wolfowitz, 1943). A typical confidence level of 95% was used to test both annual and monthly precipitation. Prior to this analysis, a method based on the determination of cumulative departures from the annual mean precipitation was used to verify the relative consistency and homogeneity of the data (see e.g. Dahmen & Hall, 1990).

In statistical terms a test for trend is a determination of whether the probability distribution from which the data arise has changed over time. The non-parametric test chosen to verify the possible existence of monotonic increasing or decreasing trends in precipitation was the Mann-Kendall test (Gilbert, 1987). Originally created by Mann (Mann, 1945) and then reformulated by Kendall (Kendall, 1948), this test does not assume any particular form for the unknown distribution function. Applications of this test to seasonal data, known as the Seasonal-Kendall test, are discussed by e.g. Hirsch *et al*. (1982), Gilbert (1987), Hirsch & Slack (1994). Both tests for the trend are based on ranks within the time series. In the absence of any assumption regarding the existence of a trend in a given direction, trend tests are correct only in their two-sided forms (e.g. Sneyers, 1990).

The slope of an existing trend (for example, expressed in mm per year), which allows for the quantification of the amount or rate of change over time, was estimated using the Sen's non-parametric method (Sen, 1968; Gilbert, 1987). This method can be used in cases where the trend can be assumed to be linear. This means that the precipitation time series $P(t)$ can be described as:

$$P(t) = Qt + B \qquad (1)$$

where Q is the slope, t is time and B is a constant.

To get the slope Q, in equation (1), we first calculate the slopes Q_i for all i pairs of data (j and k):

$$Q_i = \frac{x_j - x_k}{j - k} \qquad \text{with } j > k \tag{2}$$

For n values x_j in the time series we get $N = n(n-1)/2$ slope estimates Q_i. The Sen's estimator slope Q is the median of these N values of Q_i. This estimator is not sensitive to outliers or gross errors, and allows for gaps (i.e. missing values) in the data.

RESULTS AND DISCUSSION

Prior to the application of statistical tests for the detection of trends in the 107 point precipitation time series from mainland Portugal (Fig. 1), the data were tested for relative consistency, homogeneity and serial correlation. The trend tests were applied to both the annual and the monthly precipitation data because of the uneven seasonal distribution of precipitation in mainland Portugal. For each of the data sets, the Sen's non-parametric method was used to quantify the trend in the data: the Sen's slope was determined as an estimator for the trend in annual and monthly precipitation. The statistical significance of the result was determined at the 90, 95, 99 and 99.9% confidence level.

Annual precipitation

There was no evidence of lack of homogeneity in the precipitation time series used in this study. Results of the application to annual precipitation of the Wald-Wolfowitz test for serial correlation indicated persistence in about half of the data sets.

Using isolines, Fig. 2 (right) shows the estimate of the trend (assumed to be linear and monotonic) in annual precipitation for the period 1941–2000, expressed in mm per decade. Positive values indicate an increase in annual precipitation over time, whereas negative values indicate a decrease in precipitation amounts. For the classes between –20 and 20 mm per decade, the trend has no statistical significance. Significant trends (positive and negative) were observed in the annual precipitation in 14% of the data set for the 90% confidence level, and in 8% of the data sets for the 95% confidence level. For the 95% confidence level, three annual precipitation series exhibited positive trend and six series negative trend. The largest statistically significant positive and negative trends (at the 95% confidence level) in these data correspond to an increase and decrease in annual precipitation, per decade, of around 5 and 7%, respectively, of the corresponding mean annual precipitation in the period 1941–2000.

Although, overall, there is no statistical evidence of trend in the annual precipitation in mainland Portugal, there are signs of decreasing annual precipitation (mainly in the southern and easterly regions, which are characterized by low rainfall) and increasing annual precipitation (mostly in the northern and westerly sectors) over time, in the period 1941–2000 (see Fig. 2, right). Although not very regular, the spatial pattern of behaviour seems to be influenced by regional geography.

It is not possible to determine whether these observations result from intrinsic precipitation variability, namely interdecadal variability (see e.g. Hurrel, 1995), coupled with the relatively small length of the time series that are being analysed, or if they result from modification of local conditions, either related to data acquisition (which were not possible to identify) or eventually to micro-climatic changes introduced by human-related activities. The inter-annual variability observed in mainland Portugal can not be easily explained (see e.g. Trigo & Palutikof, 2001; Trigo *et al.*, 2002): some studies have shown that this variability is mainly the result of the inter-annual variability and the main large-scale atmospheric circulation modes affecting this region of Europe, which are accompanied by important shifts of the associated storm tracks. Such changes can affect precipitation in different European regions.

Monthly precipitation

In order to take into account seasonality and serial correlation, the different months of the year were analysed separately. Analysis of the monthly series showed always no persistence. Each series contains only data corresponding to one month of the year; therefore there is a time lag of eleven months between consecutive data, which is a long enough step to have independent data.

With respect to seasonal trends in precipitation distribution over the year (see Fig. 3), results of this study show that from 1941 to 2000 there was a significant strong decrease in precipitation in the beginning of spring (March). This was observed from the north to the south of mainland Portugal. The analysis confirms the presence of a statistically significant decrease of precipitation in the month of March in 99% of the locations studied in mainland Portugal (see Fig. 1); the level of confidence is 95%. Changes over time in March precipitation amounts have been reported in several studies: some studies have reported an increase of March precipitation in northern European regions (e.g. Kiely, 1999) and others have reported a decrease in southern European regions (e.g. Serrano *et al.*, 1999; Miranda *et al.*, 2002).

The precipitation decrease in some parts of the year (Fig. 3) is somewhat compensated by an increase of precipitation in the end of spring (May) and middle autumn. The positive trend in May (see Fig. 3) is only statistically significant in 6% of the data sets analysed, at the 90% confidence level. During the autumn, a clear increase in the October precipitation is observed throughout the country. However, this trend is only statistically significant (at the 90% confidence level) for 12% of the data sets that were studied.

On average there is a positive trend of precipitation in the month of September to December, a negative trend in the months from January to March, and a positive trend in April and May. Attempts have been made by several authors to establish quantitative relationships between the monthly precipitation and the North Atlantic Oscillation or the Southern Oscillation (e.g. Ulbrich *et al.*, 1999; Rodríguez-Puebla *et al.*, 2001; Trigo & Palutikof, 2001; Knippertz *et al.*, 2003). Nevertheless, other features at the synoptic and smaller scales play an important role in terms of daily local precipitation regimes.

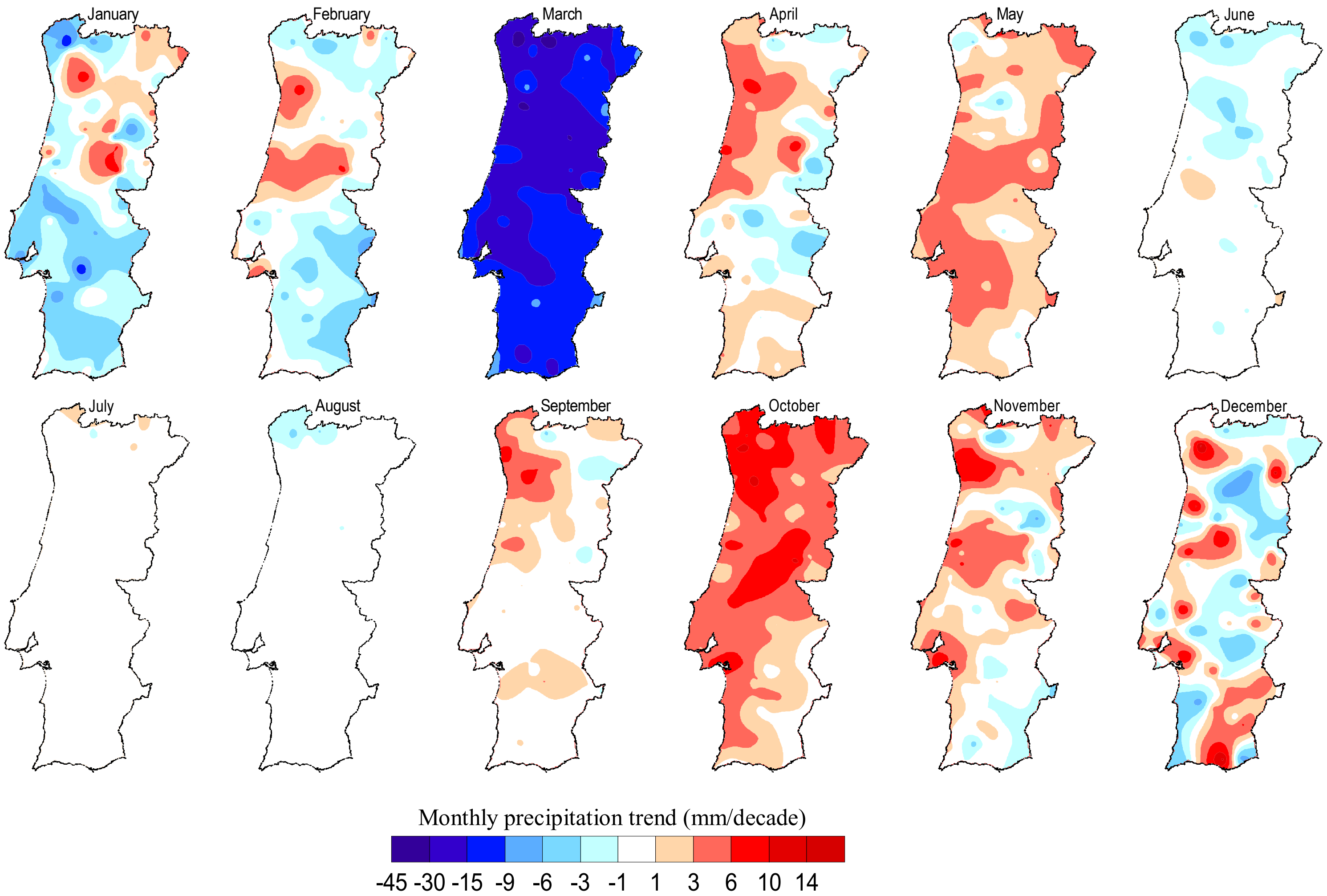

Fig. 3 Monthly precipitation trend (in mm/decade) in mainland Portugal, from 1941 to 2000. The data are from the measuring points indicated in Fig. 1.

CONCLUDING REMARKS

Overall, the annual precipitation in mainland Portugal shows no signs of statistically significant trends (i.e. at least at the 90% confidence level) during the period from 1941 to 2000. These trends in annual precipitation are limited to a few locations. There is, however, consistency in the behaviour (increase or decrease of annual precipitation over time) observed in the various regions of mainland Portugal. Results show a spatial pattern of changes in the precipitation distribution over time, from 1941 to 2000, which indicates a systematic decrease of annual precipitation in the southern sector of mainland Portugal (especially inland), although not statistically significant at the 90% confidence level.

With respect to the seasonal distribution of precipitation during the year over mainland Portugal, results show that there is a trend, from 1941 to 2000, towards the following: middle autumn has become wetter; winter has become drier; the beginning of spring has become drier whereas late spring is wetter. However, this trend is not always statistically significant.

Although the analyses of both annual and monthly data led to a characterization of changes in the distribution of precipitation over mainland Portugal and within the year, the period analysed and the selection of stations may have influenced the regional pattern.

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REFERENCES

Dahmen, E. R. & Hall, M. J. (1990) Screening of hydrological data: tests for stationarity and relative consistency. Int. Inst. for Land Reclam. and Improvement, Public. 49. Wageningen, The Netherlands.

de Lima, M. I. P. (1998) Multifractals and the temporal structure of rainfall. PhD Thesis, Wageningen Agricultural University, Wageningen, The Netherlands.

de Lima, M. I. P., Schertzer, D., Lovejoy, S. & de Lima, J. L. M. P. (2002) Multifractals and the study of extreme precipitation events: a case study from semi-arid and humid regions in Portugal. In: *Surface Water Hydrology* (ed. by V. P. Singh, M. Al-Rashid & M. M. Sherif), 195–211. A. A. Balkema Publishers, Swets & Zeitlinger B.V., Lisse, The Netherlands,.

Gilbert, R. O. (1987) *Statistical methods for environmental pollution monitoring*. Van Nostrand Reinhold , New York, USA.

Hirsch, R. M. & Slack, J. R. (1984) A nonparametric trend test for seasonal data with serial dependence. *Water Resour. Res.* **20**(6), 727–732.

Hirsch, R. M., Slack, J. R. & Smith, R. A. (1982) Techniques of trend analysis for monthly water quality data. *Water Resour. Res.* **18**(1), 107–121.

Hurrel, J. W. (1995) Decadal trends in the North Atlantic Oscillations: regional temperatures and precipitation. *Science* **269**, 676–679.

Kendall, M. G. (1948) *Rank Correlation Methods*. Hafner, New York, USA.

Kiely, G. (1999) Climate change in Ireland from precipitation and streamflow observations. *Adv. Water Resour.* **23**, 141–151.

Knippertz, P., Christoph, M. & Speth, P. (2003) Long-term precipitation variability in Morocco and the link to the large-scale circulation in recent and future climates. *Meteorol. Atmos. Phys*. **83**, 67–88.

Mann, H. B. (1945) Non-parametric test against trend. *Econometrika* **13**, 245–259.

Miranda, P., Coelho, F. E. S., Tomé, A. R., Valente, M. A., Carvalho, A., Pires, C., Pires, H. O., Pires, V. C. &. Ramalho, C. (2002) 20th Century Portuguese Climate and Climate Scenarios. In: *Climate Change in Portugal: Scenarios, Impacts and Adaptation Measures* (ed. by F. D. Santos, K. Forbes & R. Moita), 27–83. Gradiva, Lisbon, Portugal.

Rodríguez-Puebla, C., Encinas, A. H. & Sáenz, J. (2001) Winter precipitation over the Iberian peninsula and its relationship to circulation indices. *Hydrol. Earth System Sci.* **5**(2), 233-244.

Sen, P. K. (1968) Estimates of the regression coefficient based on Kendall's tau. *J. Am. Statistical Assoc.* **63**, 1379–1389.

Serrano, A., Mateos, V. L. & García, J. A. (1999) Trend analysis of monthly precipitation over the Iberian Peninsula for the period 1921-1995. *Phys. Chem. Earth* (B) **24**(1–2), 85–90.

Sneyers, R. (1990) On the statistical analysis of series of observations. Technical Note no. 143, WMO no. 145, World Meteorological Organization, Geneva, Switzerland.

Trigo, R. M. & Palutikof, J. P. (2001) Precipitation scenarios over Iberia: a comparison between direct GCM output and different downscaling techniques. *J. Climate* **14**, 4422–4446.

Trigo, R. M., Osborn, T. J. & Corte-Real, J. M. (2002) The North Atlantic Oscillation influence on Europe: climate impacts and associated physical mechanisms. *Climate Res*. **20**, 9–17.

Ulbrich, U., Christoph, M., Pinto, J. G. & Corte-Real, J. (1999) Dependence of winter precipitation over Portugal on NAO and baroclinic wave activity. *Int. J. Climatol.* **19**(4), 379–390.

Wald, A. & Wolfowitz, J. (1943) An exact test for randomness in the non-parametric case based on serial correlation. *Annals Math. Statistics* **14**, 378–388.