INVESTIGATING CHANGES IN DAILY PRECIPITATION EXTREMES IN MAINLAND PORTUGAL, 1941-2007

Fátima Espírito Santo(1), M. Isabel P. de Lima(2) and Alexandre M. Ramos(3)

(1) Institute of Meteorology, Rua C ao Aeroporto, 1749-077, Lisbon, Portugal (fatima.coelho@meteo.pt)
(2) IMAR – Institute of Marine Research; ESAC/Polytechnic Institute of Coimbra, Portugal (iplima@esac.pt)
(3) Environmental Physics Laboratory, Universidad de Vigo, Spain (alexramos@uvigo.es)

Abstract

Variations in the occurrence of extreme precipitation are expected to result from changes in the climate. The potential impacts of those changes on society and the environment makes it mandatory to understand regional specificities. This work explores recent modifications in the occurrence of precipitation extremes in mainland Portugal (south-western Europe) such as the intensity, duration and frequency of those events. It investigates trends and variations in selected precipitation indices for different time periods and seasons. Data include daily precipitation from 57 climatological weather stations and rain-gauges, covering the period 1941-2007. Results show that there are regional differences in patterns of precipitation trends. Moreover, there are marked differences for trends in extremes, depending on the season, which further strengthens precipitation seasonality.

Keywords: extremes, precipitation, trend

1. Introduction

Changes in the climate are expected to affect different climate variables, namely surface air temperature and precipitation. Moreover, a number of components of the hydrological cycle and hydrological systems are expected also to be affected. Changes in the water cycle are related to a large range of spatial and temporal scales. However, significant natural variability, on interannual to decadal time-scales, in all components of the hydrological cycle, often masks long-term trends (e.g. Bates *et al*., 2008; de Lima *et al*., 2010). The uncertainty in trends of hydrological variables is furthermore enhanced by large regional differences and limitations in the spatial and temporal coverage of monitoring networks (e.g. Huntington, 2006).

The work reported herein investigates recent modifications in the climatology of precipitation extremes (maximum) in mainland Portugal. It explores daily precipitation data from 57 climatological weather stations and rain-gauges covering the period 1941-2007. The study focuses mostly on variations in the intensity, frequency and duration of extreme events. It pays special attention to regional differences and seasonality. Modifications in the precipitation regime are studied here by inspecting trends in specific indices defined for daily precipitation and, in particular, for extremes. These indices include threshold indices, probability indices, duration indices and other indices. Such approach is currently being used in many studies (e.g. Klein Tank *et al*., 2009).

2. Precipitation data

In mainland Portugal the precipitation climate is characterized by strong seasonality and large interannual variability. It also exhibits very marked north-south and east-west gradients. Across the territory mean annual precipitation varies from about 3000 mm in the north to roughly 500 mm in the southern part of the country. This behavior is highly dominated by the effect of orography and the distance to the Atlantic Ocean. Figure 1 shows a relief map of mainland Portugal; the highest altitude is roughly 2000 m.

For this study, daily precipitation from 57 climatological weather stations and rain-gauges (from the networks of the Institute of Meteorology, IM, and Institute for Water, INAG) have been used. The location of the stations in mainland Portugal is shown in Fig. 1. The selected data cover the period 1941-2007.

The selection of the data respected criteria related to the spatial distribution of the series over mainland Portugal and data length, completeness, quality and homogeneity:

a) *Completeness*: Only stations with less than 1% of missing values were used;
b) *Quality*: Basic quality controls have been undertaken for all series; outliers were identified as having

values deviating more than three standard deviations from the climatological daily average;

c) *Homogeneity*: Standard homogeneity tests (e.g. Wang *et al*.; 2007; Wang, 2008; Wang and Feng, 2010) were applied to the monthly means of the daily precipitation series; the procedure used detected change-points in the series which were checked against station metadata records (when available). Series exhibiting evidence of discontinuities of non-climatic origin in the corresponding study period were not used.

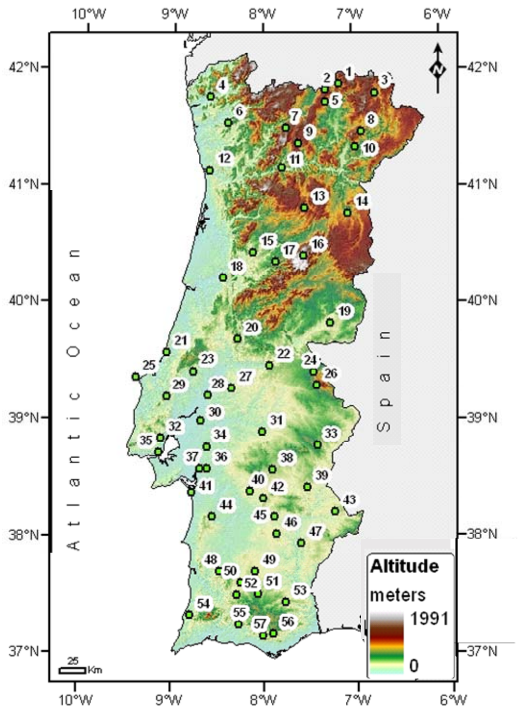

Fig. 1. Relief map of mainland Portugal and location of the measuring stations used in this study.

3. Methodology

This study is conducted by analyzing trends and variations in selected specific indices for extremes derived for daily precipitation; this is done for different time periods and for the annual and seasonal time scales. The seasons investigated are: spring (March to May, MAM), summer (June to August, JJA), autumn (September to November, SON) and winter (December to February, DJF). Trends were investigated for individual stations and also for the study region (i.e. mainland Portugal) as a whole.

The indices selected for the characterization of precipitation extremes are described in Table 1 (Peterson *et al*., 2001). They are related to:

i) The intensity of wet precipitation extremes in different periods; in some cases comparisons are made with calendar day-dependent thresholds based on percentiles of daily precipitation distribution over the 1961-1990 reference period;

ii) The frequency of days exceeding certain intensity levels (i.e. thresholds) in a given period.

Time series of indices of precipitation extremes were tested for linear trends. These trends were calculated by ordinary least squares fit; the statistical significance of the trend was evaluated using the student's *t* test and the non-parametric Mann–Kendall test (Gilbert, 1987).

The analyses were carried out for the entire 67-years period (i.e. 1941-2007) and for two consecutive sub-periods: 1945-1975 and 1976-2007. The selection of these sub-periods was based on the ("standard") breakpoints obtained by Karl *et al*., 2000, for air temperature: 1945-1975 (cooling period) and 1976-2006 (warming period). Our justification to use these sub-periods is not that the change-point is confirmed for precipitation in mainland Portugal (see e.g. de Lima *et al*., 2010); rather we are interested to exploring if the warming is linked with changes in the precipitation regime in the territory. Theoretical and climate model studies suggest that, in a climate that is warming due to anthropogenic influence, a greater increase is expected in extreme precipitation, as compared to the mean (e.g. Bates *et al*., 2008).

Table 1. Indices of precipitation extremes.

Indices	Definition	Unit
R10, R20	Heavy and very heavy precipitation days – number of days with precipitation amount ≥10mm and ≥20mm	days
RX1day, RX5day	Highest precipitation amount in one-day period and in five consecutive days	mm
R99p	Precipitation due to extremely wet days (>99th percentile)	mm
PRCPT	Total wet-day precipitation (≥1mm)	mm

4. Results and discussion

Results of the analyses of trends in annual and seasonal precipitation indices are summarized in Table 2, for the period 1941-2007. This table shows the number of precipitation series with positive and negative trends and the corresponding number of significant trends at the 5% level.

Table 2. Trends in seasonal and annual precipitation indices in the period 1941-2007: number of precipitation series with positive (+) and negative (-) trends and the corresponding number of significant trends at the 5% level. The indices are described in Table 1.

Index	Spring				Summer				Autumn				Winter				Annual			
	+	Sig +	–	Sig –	+	Sig +	–	Sig –	+	Sig +	–	Sig –	+	Sig +	–	Sig –	+	Sig +	–	Sig –
R10	0	0	57	39	19	1	38	0	56	7	1	0	6	0	51	0	9	0	48	9
R20	0	0	57	34	22	0	35	1	54	10	3	0	13	0	44	3	16	0	41	9
RX1d	3	0	54	20	17	0	40	2	40	8	17	0	13	0	44	8	30	3	27	3
RX5d	1	0	56	22	13	0	44	1	48	5	9	0	3	0	54	12	19	0	38	8
R99p	13	0	44	9	22	0	35	0	35	5	22	0	19	0	38	1	29	2	28	0
PRCPT	0	0	57	43	22	0	35	0	57	17	0	0	9	0	48	1	12	0	45	9

Overall, results of this study indicate that the statistical significance of changes in annual precipitation extremes for 1941–2007 is low. No consistent pattern for trend is identified. For example, for this period, indices RX1day and RX5day have mixed positive and negative trend signs across the territory, indicating both increasing and decreasing tendencies in the occurrence of these events, depending on location; for these indices the results of the trend tests are significant at the 5% level for, respectively, 10% and 14% of the stations studied.

Figure 2 compares the trend in the precipitation on extremely wet days (above the 99th percentile) for the sub-periods 1945-1975 (cooling period) and 1976-2007 (warming period). For 1945-1975, the decrease in the precipitation amount on extremely wet days is statistically significant at the 5% level at 8% of the stations; in the period 1976-2007, the mean trend over the territory is +1,2 mm/decade (result not significant at the 5% level). Overall, the analyses of the indices selected in this work do not reveal clearly possible effects of the climate warming on the precipitation regime in mainland Portugal.

In general, the analyses of seasonal trends in extreme daily precipitation indices (Table 2) confirm strong seasonal variability in precipitation. Indices related to intense precipitation reveal an increasing trend in autumn and a significant decreasing trend in spring. In summer and winter, the indices showed a decreasing trend, but not as markedly as in the spring.

For the 5-day maximum precipitation, 40% of the stations reveal a strong decrease of this index in spring, significant at the 5% level; in autumn, more than 80% of the stations reveal positive trends, which are accompanied by an increase in the number of heavy and very heavy rainy days (respectively, R10 and R20) for more than 95% of the stations. The increasing trends in these extreme precipitation indices indicate very intense precipitation in autumn; in contrast, the same indices reveal a significant decrease in spring.

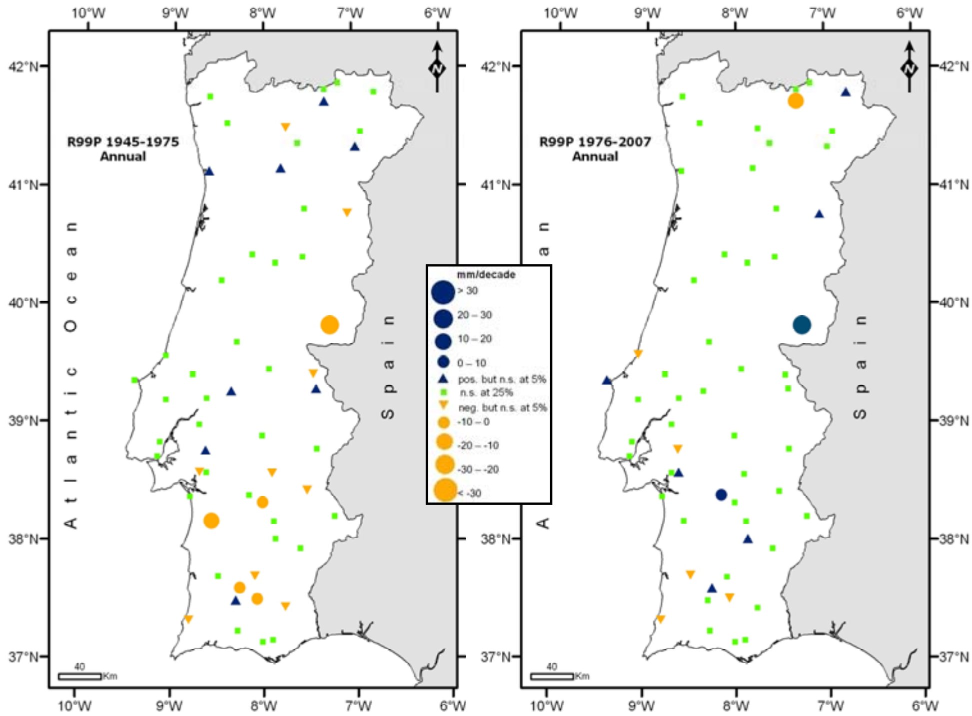

Fig. 2. Trends (mm/decade) in the annual amount of precipitation due to extremely wet days (R99p), in the periods 1945-1975 (left) and 1976-2007 (right). The dots are scaled according to the magnitude of the trend: blue corresponds to increasing trends and yellow corresponds to decreasing trends.

Figure 3 illustrates the trend in the number of very heavy rain days (R20) in spring and autumn, for the period 1941-2007. Overall, the behavior revealed by the results is similar to the previous case. The density of stations that was used in this study does not reveal the role of the altitude in the precipitation patterns of extreme heavy precipitation occurrences observed in mainland Portugal.

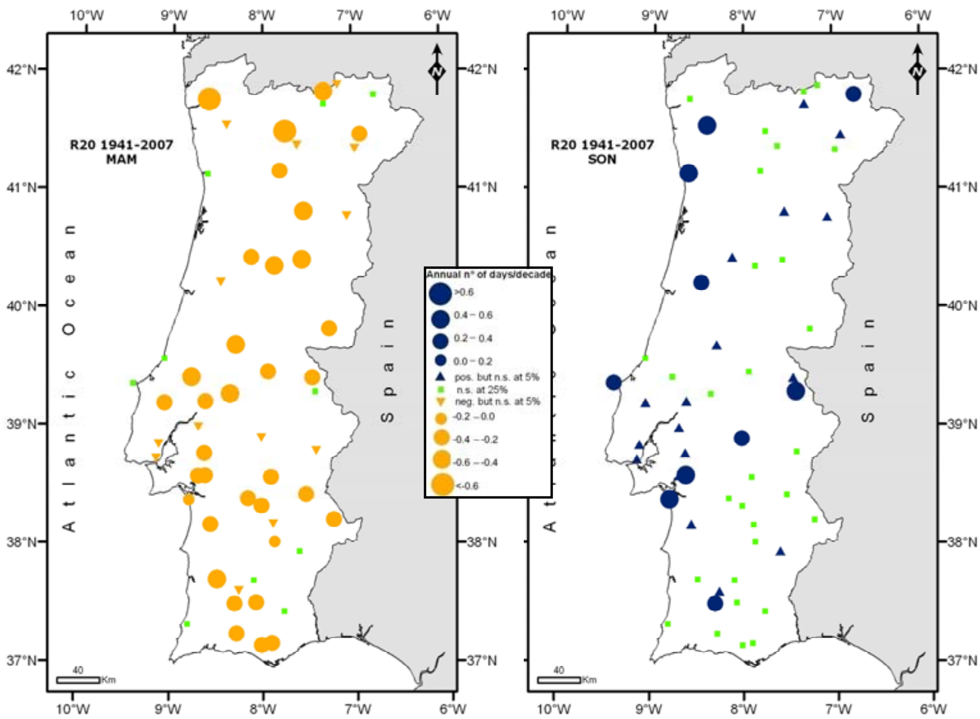

Fig. 4. Trends (days/decade) in the number of very heavy precipitation days (R20), for the period 1941-2007, in spring (left) and autumn (right).

5. Concluding remarks

The analyses reported in this work were conducted for precipitation indices calculated from empirical daily data from mainland Portugal recorded over 67-years (1941-2007) in 57 measuring stations. This investigation complements previous studies for mainland Portugal which have reported high variability in the precipitation regime and discussed recent patterns of change (de Lima *et al*., 2007; Rodrigo and Trigo, 2007; Costa and Soares, 2009; de Lima *et al*., 2010).

The trend tests applied to the selected time series could not detect any consistent pattern of change in annual wet precipitation extremes for the majority of the indices used in this work. At seasonal scale, the decreasing trend manifested by the total wet-day precipitation index, which is the precipitation due to very wet days, is significant at the 5% level and suggest a reduction of the precipitation in the spring. Similar results of decreasing trends in spring precipitation in mainland Portugal were also reported by other studies (e.g. de Lima *et al*., 2007, 2010). The present study reveals further that extreme precipitation indices (e.g. number of heavy and very heavy precipitation days, highest 1 and 5-days precipitation) manifested strong negative trends in the spring over the period investigated. In contrast, the extreme heavy precipitation has become more pronounced in autumn, both in terms of magnitude and frequency. For the other seasons (summer and winter) results suggest that the extremes have not suffered any significant aggravation.

Acknowledgment

This work was supported in part by research projects PTDC/GEO/73114/2006 and HSR-Risk (MIT-Portugal Program). The authors wish to thank Álvaro Silva and Sofia Cunha (Institute of Meteorology, Portugal), for their help in processing the maps in Figures 1 to 4.

References

Bates, B. C., Z. W. Kundzewicz, S. Wu, and J. P. Palutikof, Eds., 2008. *Climate Change and Water*. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

Costa, A. C., and A. Soares, 2009. Trends in extreme precipitation indices derived from a daily rainfall database for the South of Portugal, *Int. J. Climatol*., 29 (13), 1956–1975.

de Lima, M. I. P., A. C. P. Marques, J. L. M. P de Lima, and M. F. E. S. Coelho, 2007. Precipitation trends in Mainland Portugal in the period 1941–2000, IAHS Publ. 310, International Association of Hydrological Sciences, 94–102.

de Lima, M. I. P., S. C. P. Carvalho, and J. L. M. P. de Lima, 2010. Investigating annual and monthly trends in precipitation structure: an overview across Portugal, *Nat. Hazards Earth Syst. Sci.*, 10, 2429-2440, doi:10.5194/nhess-10-2429-2010.

Gilbert, R. O., 1987. *Statistical methods for environmental pollution monitoring*, John Wiley & Sons, New York, USA.

Huntington, T. G., 2006. Evidence for intensification of the global water cycle: review and synthesis, *J. Hydrol*., 319, 83–95.

Karl, T. R., R. W. Knight, and B. Baker, 2000. The record breaking global temperature of 1997 and 1998: evidence for an increase in rate of global warming?, *Geophys. Res. Lett.*, 27 (5), 719-722.

Klein Tank, A. M. G., F. W. Zwiers, and X. Zhang, 2009. Guideline on analysis of extremes in a changing climate in support of informed decisions for adaptation, Climate Data and Monitoring WCDMP-No. 72, WMO-TD No. 1500, Geneve, Switzerland.

Peterson, T. C., C. Folland, G. Gruza, W. Hogg, A. Mokssit, and N. Plummer, 2001. Report on the Activities of the Working Group on Climate Change Detection and Related Rapporteurs 1998-2001. Report WCDMP-47, WMO-TD 1071, World Meteorological Organisation, Geneva, Switzerland.WMO-TD No. 1071.

Rodrigo, F. S., and R. M. Trigo, 2007. Trends in daily rainfall in the Iberian Peninsula from 1951 to 2002, *Int. J. Climatol*., 27, 513– 529.

Wang, X. L., 2008. Accounting for autocorrelation in detecting mean-shifts in climate data series using the penalized maximal t or F test, *J. Appl. Meteorol. Climatol.*, 47, 2423-2444. DOI:10.1175/2008JAMC1741.1.

Wang, X. L., and Y. Feng, 2010. RHtestsV3 UserManual, (http://cccma.seos.uvic.ca/ETCCDMI/software.shtml)

Wang, X. L., Q. H. Wen, and Y. Wu, 2007. Penalized Maximal t-test for Detecting Undocumented Mean Change in Climate Data Series, *J. App. Meteor. Climatol*., 46, 916–931.