Recent variations in climate variables in mainland Portugal: daily precipitation and air temperature extremes

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Abstract — Modifications in the climate are expected to be noticeable in different climate variables including precipitation and surface air temperature. Changes in precipitation and air temperature variability and extremes can be studied by inspecting trends in specific indices defined for daily occurrences. This approach is used in this study, which explores recent modifications in the climatology of extreme events in precipitation and surface air temperature (maximum and minimum) using data from various locations in mainland Portugal. The study is conducted by analysing trends and variations in selected specific indices derived for daily observations; this is done for different time periods and different seasons. The precipitation data are from 57 measuring stations and cover the period 1941-2007. For air temperature, data are from 23 stations and the sub-periods investigated are 1945-1975 (cooling period) and 1976-2006 (warming period). The study aims mostly at understanding variations in the intensity, frequency and duration of extreme events and pays special attention to regional differences and seasonality.

Keywords — air temperature, precipitation, climate variability, trend

1 Introduction

Modifications in the climate are expected to be noticeable in different climate variables, including precipitation and surface air temperature extremes. The impact of change in climate variables on society and the environment are often not well understood; for example, health implications, particularly in vulnerable groups, and changes in the water cycle. The local impact of those changes can be affected by local conditions and regional specificities, which justifies investigating point data from different origins.

Changes in the precipitation and air temperature variability can be studied by inspecting trends in specific indices defined for daily occurrences and, in particular, for extremes. These indices are simple to compute and include threshold indices, probability indices, duration indices and other indices. They are currently being used in many studies, the advantage being that the comparison of results from different studies is facilitated (see e.g. [1]).

This study aims mostly at understanding variations in the intensity, frequency and duration of extreme events and investigates regional and seasonal patterns in the behaviour observed. Special attention is devoted to clarifying some issues such as: (i) has the warming observed in recent decades been accompanied by significant variation in extreme precipitation? (ii) is the variation observed in the number of rainy days more pronounced than the variation in the annual total? (iii) is the increase in average temperature being accompanied or not by a change in frequency of hot days and / or a decrease in the frequency of very cold days?

2 Overview of the study area and data

2.1 The study area

In mainland Portugal the climate is characterized by strong seasonality and large north-south and east-west gradients; orography and the distance to the Atlantic Ocean are dominant factors. This behaviour is particularly manifested by precipitation.

2.2 Temperature and precipitation data

For evaluating recent tendencies in precipitation and surface air temperature extremes in the mainland Portugal, daily precipitation from 57 climatological weather stations and rain-gauges (from the networks of the Institute of Meteorology, IM, and Institute for Water, INAG) and daily surface air temperature from 23 climatological weather stations (IM network) have been studied. The location of the stations is shown in Fig. 1.

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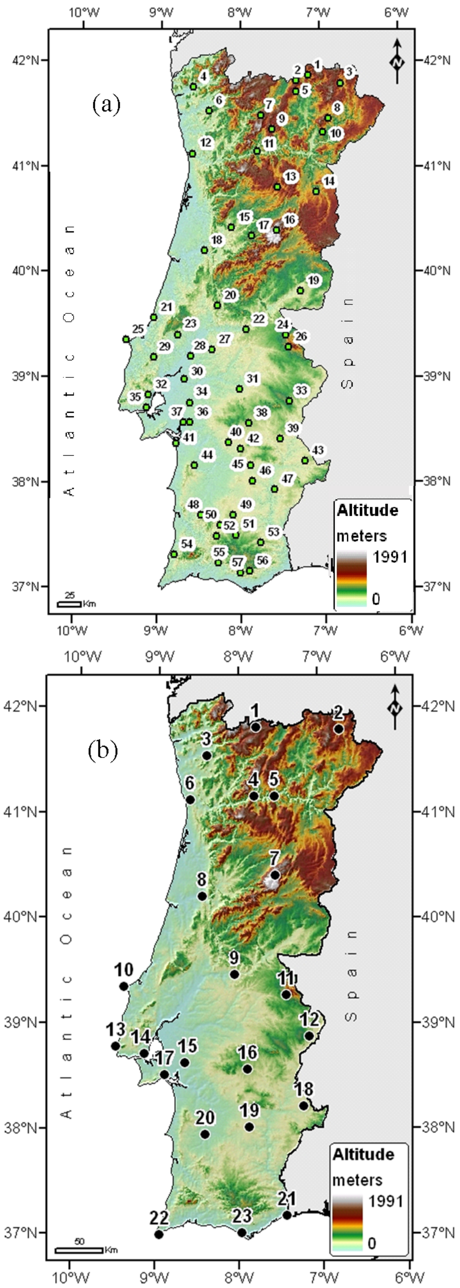

Fig. 1. Relief map of mainland Portugal and location of the measuring stations used in this study for (a) precipitation and (b) surface air temperature.

The data cover the periods 1941-2006, for temperature (maximum and minimum), and 1941-2007, for precipitation.

Only stations with less than 1% (precipitation) or 5% (temperature) of missing values were used. Standard homogeneity tests (e.g. [2], [3], [4]) were applied to the monthly means of the daily precipitation and temperature series; those series that exhibited evidence of discontinuities of non-climatic origin in the corresponding study period were not used.

3 METHODOLOGY

This study was conducted by analysing trends and variations in selected specific indices derived for daily observations of precipitation and surface air temperature; this was done for different time periods and seasons.

3.1 Indices for extremes

The indices selected in this study for characterizing precipitation and temperature extremes are described in Table 1 (e.g. [5]); they are related to:

- The intensity of wet precipitation extremes;
- The frequency of days exceeding intensity levels (i.e. thresholds) in a given period;
- The duration of spells (days) which exceed a certain intensity level.
- The duration of spells (multiple-day) defined by an interrupted sequence of days all exceeding a certain intensity level.

3.2 Trend tests

Linear trends in time series of indices of precipitation and temperature were calculated by ordinary least squares fits; the statistical significance of the trends were evaluated using the student's *t* test and the non-parametric Mann–Kendall test (e.g. [6]).

Trend calculations for the temperature and precipitation data were carried out for the entire 66(7)-years period (i.e. 1941-2006(7)) and for two consecutive sub-periods: 1945-1975 and 1976-2006(7); the number between brackets identifies the corresponding period for the precipitation series. The selection of these sub-periods was based on the ("standard") breakpoints obtained by [7], for air temperature: 1945-1975 (cooling period) and 1976-2006 (warming period).

The study of the extreme events was conducted for annual and seasonal time scales. The seasons investigated were: spring (March to May, MAM), summer (June to August, JJA), autumn (September to November, SON) and winter (December to February, DJF).

4 RESULTS AND DISCUSSION

4.1 Precipitation

Results of the analyses of trends in precipitation indices calculated at the seasonal and annual scales are summarized in Table 2.

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 was identified.

Table 1. Indices of wet precipitation extremes and indices of low and high temperature extremes.

Description	**Definition** [Unit]
Precipitation indices	
RX1d, RX5d: Greatest 1 and 5 day precipitation total	Maximum precipitation sums for 1 and 5 days intervals [mm]
R20: Very heavy precipitation days	Number of days with RR≥20 mm/day [days]
R99p: Precipitation on extremely wet days	Precipitation amount above a site-specific threshold value for extremely wet days, calculated as the 99th percentile of the distribution of daily precipitation amounts on wet days in the reference period 1961-1990 [mm]
PRCPT: Total wet-day precipitation	Total precipitation in wet days (RR≥1mm) [mm]
Temperature indices	
HWDI: Heat Wave Duration Index	Number of days in intervals of at least 6 consecutive days when TX>mean+5ºC calculated for each calendar day (reference period) using running 5-day window [days]
TXHW90	Maximum number of consecutive days with TX>90th percentile calculated for each calendar day (reference period) using running 5-day window [days]
TX25: Summer days	Number of days with daily maximum temperature > 25°C [days]
TX35: Number of extremely hot days	Number of days with daily maximum temperature > 35°C [days]
TN20: Tropical nights	Number of days with daily minimum temperature > 20°C [days]
TXx: Warmest day	Maximum value of daily maximum temperature [ºC]
TNn: Coldest night	Minimum value of daily minimum temperature [ºC]
DTR: Diurnal Temperature Range	Mean difference between maximum and minimum temperature [ºC]
ETR: Extreme Temperature Range	Difference between TXx and TNn [days]

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

Index	**Spring**				**Summer**				**Autumn**				**Winter**				**Annual**			
	+	Sig +	–	Sig –	+	Sig +	–	Sig –	+	Sig +	–	Sig –	+	Sig +	–	Sig –	+	Sig +	–	Sig –
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

Nevertheless, in general, the analyses of trends in the extreme daily precipitation indices highlight the strong seasonal variability in precipitation. Furthermore, results suggest increased seasonality: indices related to intense precipitation revealed 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. Some analyses results are shown bellow.

Trends observed for indices RX1day and RX5day, which correspond to the greatest 1-day and 5-day totals, respectively, are both positive and negative across mainland Portugal; these results indicate both increasing and decreasing tendencies in the occurrence of these events, depending on location. The results of the trend tests are significant at the 5% level for, respectively, 10 and 14% of the stations studied. The other indices of precipitation extremes show also irregular behaviour, depending on location; overall, there is no evidence of a well-defined spatial pattern of precipitation trend.

Fig. 2 compares the trend in the precipitation on extremely wet days (above the 99th percentile) for 1945-1975 (cooling period) and 1976-2007 (warming period). For 1945-1975, the decrease in precipitation amounts on extremely wet days is statistically significant at the 5% level for 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). The strongest increasing trends for precipitation data are revealed by extreme

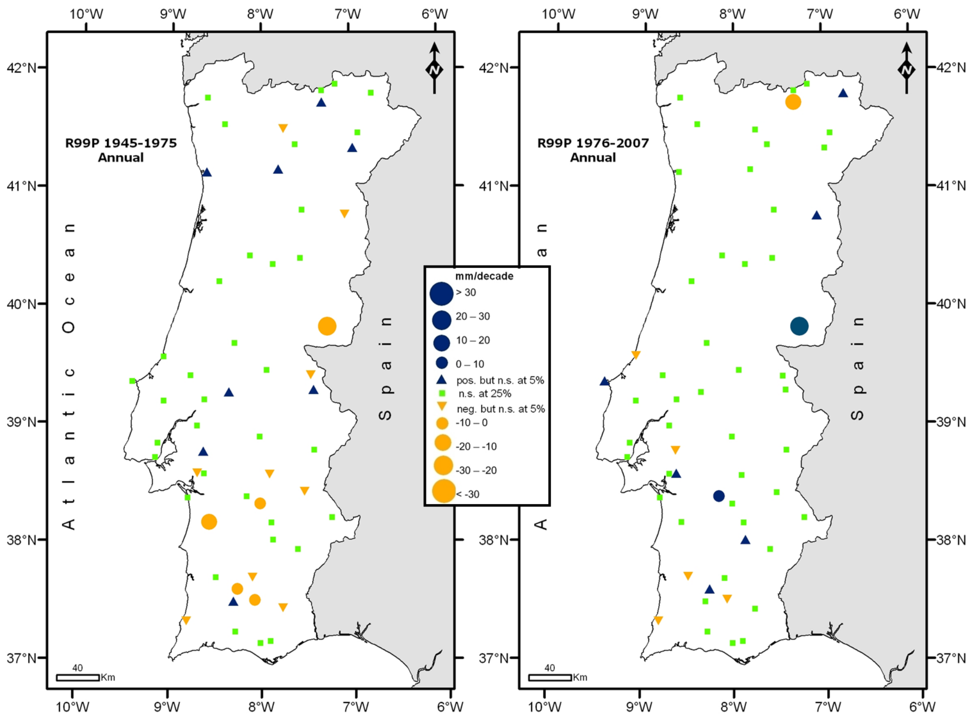

Fig. 2. Trends (in mm/decade) in the annual amount of precipitation due to extremely wet days (R99p), in the periods 1945-1975 (left) and 1976-2007 (right). The dots are scaled according to the magnitude of the trend: blue corresponds to increasing trends and yellow corresponds to decreasing trends.

indices indicating very intense precipitation in autumn; the same indices reveal a significant decrease in spring. Fig. 3 illustrates the trend in the number of very heavy rain days in Spring and Autumn, for the period 1941-2007.

4.2 Temperature

Selected indices describing high and low temperature extremes were studied on a seasonal and annual basis. Some of these indices are based on fixed thresholds (e.g. number of extremely hot days); other indices are computed involving both daily maximum and minimum temperatures, which provide a measure for the variability in extreme temperature.

Table 3 summarizes the findings for different indices by showing the number of stations exhibiting positive/negative trends and the corresponding number of significant trends at the 5% level for three periods (1941-2006, 1945-1975 and 1975-2006). Results show that the warming tendencies are dominant. Below this is discussed in more detail.

Trends in temperature indices reflect an increase in both maximum and minimum temperatures. Results reveal different behaviours for the two sub-periods already defined above. The sub-period 1945-1975 is dominated by negative trends in high temperature related indices and positive trends in low temperature related indices; during the subsequent sub-period 1976-2006 there is a widespread inversion of this pattern which results in positive trends in warm related indices and negative trends in cold related indices. These results were also reported by [8].

The more significant trends were found for the period 1976-2006. After 1976 we can observe an increase in the number of daily warm extremes and a reduction in the number of daily cold extremes. The plus or minor sign of the trend does not directly indicate a warming or cooling tendency; for example, positive trends in the number of heat waves, summer days or extremely hot days, and negative trends in the number of cold days, both indicate warming climate.

In the period 1976-2006, the diurnal temperature range (DTR) has increased (0,1-0,7 °C/decade) at 13 locations and decreased (0,1–0,8 °C/decade) at 10 locations. However, none of the stations investigated in this work show significant decreasing trends in the extreme temperature range (ETR); this indicates that it is not necessarily the highest or lowest values that have changed. Results also reveal a warming trend in the night time temperature.

For the heat wave duration index (HWDI), all the stations reveal negative trends in the period 1945-1975 period and positive trends in the period 1976-2006. Among these positive trends eleven are statistically significant; a high and significant increasing trend greater than 6 days/decade was

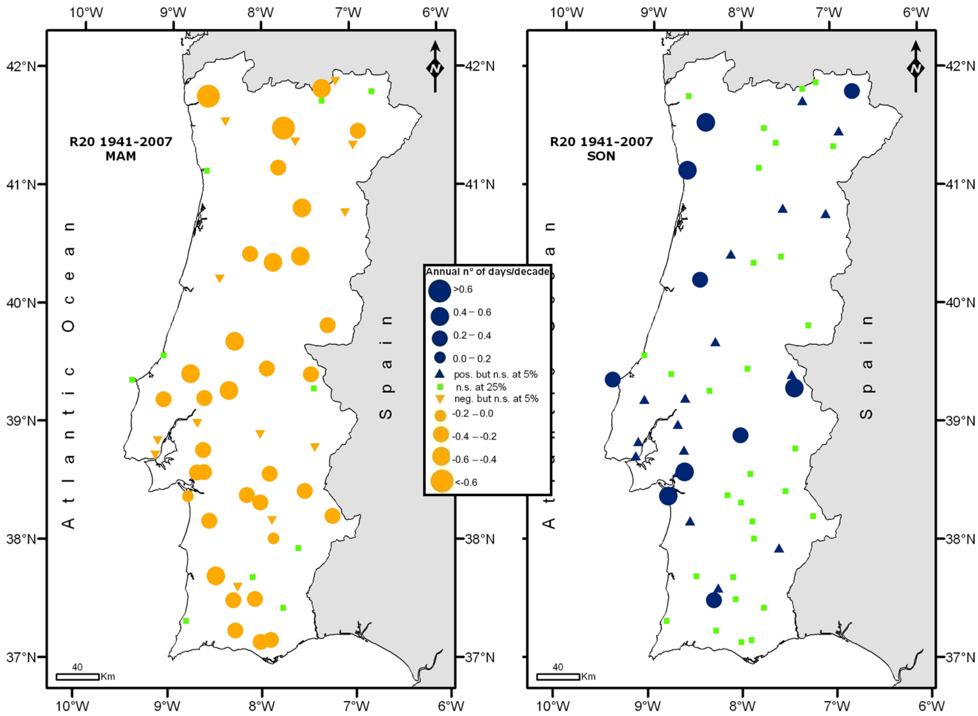

Fig. 3. Trends in the seasonal number of very heavy precipitation days, for the period 1941-2007. Left: for March, April and May (spring); right: for September, October and November (autumn). The dots are scaled according to the magnitude of the trend: blue corresponds to increasing trends and yellow corresponds to decreasing trends. The trend is expressed in number of days per decade.

Table 3. Number of temperature stations manifesting positive (+) and negative (-) trends in annual temperature indices and the corresponding number of statistically significant trends at the 5% level. The indices are described in Table 1.

Index	1941-2006				1945-1975				1976-2006			
	+	Sig +	–	Sig –	+	Sig +	–	Sig –	+	Sig +	–	Sig –
HWDI	16	9	7	0	0	0	21	9	23	11	0	0
TXHW90	19	7	4	0	0	0	21	10	23	6	0	0
TX25	15	6	8	1	3	1	18	11	21	15	2	0
TX35	16	7	7	0	3	0	18	7	23	13	0	0
TN20	23	13	0	0	5	0	16	5	23	11	0	0
TXx	15	4	8	1	2	0	19	11	22	11	1	0
TNn	22	13	1	1	15	1	6	0	18	6	5	1
DTR	9	6	14	10	6	3	15	5	13	7	10	7
ETR	4	1	19	8	2	0	19	10	19	2	4	0

found at six of these locations. In the more recent sub-period another duration index, TXHW90, show an increasing trend in all 23 stations; this index corresponds to the maximum number of consecutive days with TX>90th percentile (in heat wave). These results suggest changes over time that lead to more intense and longer heat waves.

The trends that are manifested by other three selected threshold-based indices are shown in Fig. 4, for the period 1976-2006; these indices are TN20 (tropical nights), TX25 (summer days) and TX35 (extremely hot days).

The annual lowest minimum and highest maximum temperature indices (TNn and TXx) show trends that also correspond to the warming reported globally. For 1976-2006, the trend for the warmest day index is positive for 22 series (11 results are statistically significant at the 5% level); in this period 80% of the stations show positive trends for the coldest night.

Thus, overall, the results obtained for different indices that are defined in Table1 indicate a warming trend during the entire 66-years period covered by the data (1941-2006). The cooling trend that is observed until the middle of the 1970's is followed, after 1976, by a warming trend which is confirmed by the positive trend result in relevant indices obtained for all 23 stations.

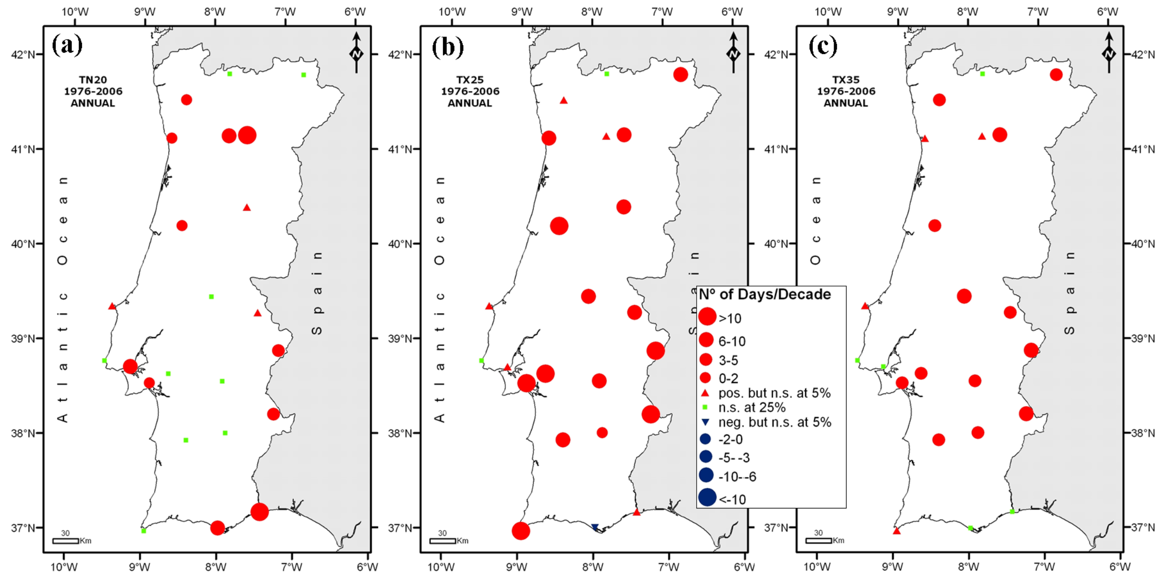

Fig. 4. Trends for the period 1976-2006: (a) Tropical nights, (b) Summer days, (c) Extremely hot days. The dots are scaled according to the magnitude of the trend, which is expressed in number of days per decade. Colour-coding is applied: red corresponds to warming trends and blue to cooling trends.

5 Concluding Remarks

The analyses reported in this work, which were conducted using empirical daily data, could not detect any consistent pattern of change in annual wet precipitation extremes over mainland Portugal in the period 1941-2007. At seasonal scale, results suggest a decrease of precipitation in the spring: for example, the decreasing trend manifested by the total wet-day precipitation index, which is the precipitation due to very wet days, and the simple daily intensity index (not shown) are significant at the 5% level. Similar results of decreasing trends in spring precipitation in mainland Portugal were also reported by other studies (see e.g. [9] and [10]). Our study show that the extreme heavy precipitation has become more pronounced in autumn in recent years, both in terms of magnitude and frequency; for the other seasons, results suggest that the extremes have not suffered any significant aggravation.

Also changes in temperature extremes were observed for mainland Portugal in the period 1941-2006, at both annual and seasonal scales. It was noticed an increase in extreme high temperatures and a reduction in extreme low temperatures. The increasing trend of the extreme daily maximum temperature is accompanied by an increasing trend in heat wave duration, for all seasons and for the majority of the stations. Increasingly intense and longer heat waves are manifested by the data, which also reveal an increasing number of warm extremes, summer days, very hot days and tropical nights.

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References

[1] A.M.G. Klein Tank, F.W. Zwiers, and X. Zhang, "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, 2009.

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

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

[4] X.L. Wang, and Y. Feng, RHtestsV3 User Manual, 2010, http://cccma.seos.uvic.ca/ETCCDMI/software.shtml

[5] T.C. Peterson, C. Folland, G. Gruza, W. Hogg, A. Mokssit, and N. Plummer, 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, 2001.

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

[7] T.R. Karl, R.W. Knight, and B.Baker, "The record breaking global temperature of 1997 and 1998: evidence for an

increase in rate of global warming?," *Geophys Res Lett*, vol. 27, no 5, pp. 719-722, 2000.

[8] A.M. Ramos, R.M. Trigo, and F.E. Santo, "Evolution of extreme temperatures over Portugal: recent changes and future scenarios," *Climate Research* (in press), doi:10.3354/cr00934, 2011.

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

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