Recent precipitation variability over 67 years in mainland Portugal

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Niederschlagsvariabilität der letzten 67 Jahre in Portugal

1 Introduction

In the context of climate change and global warming, the consequences of change in air temperature concerning precipitation intensity have been discussed by, among others, ALLEN & INGRAM (2002), TRENBERTH et al. (2003), and BERG & HAERTER (2011). One issue is whether changes in precipitation distributions could have far more impact than the more often cited risk of global warming. Changes in the atmospheric circulation will affect the circulation between sources and reduce redirecting moisture: this will have an impact on the water cycle that will suffer adjustments, namely in small drainage basins. As a consequence, hydrological regimes and therefore the distribution, availability and sustainability of regional water resources are expected to be affected. Change in precipitation amounts and patterns and near surface air temperature will affect surface water, groundwater and other components of the hydrological cycle such as soil moisture and evapotranspiration.

The link between the processes of precipitation, evaporation and heating is such that it is important to deal not only with accumulated amounts, but also precipitation rates and frequency (e.g. TRENBERTH, 1999). Stronger rainfall events have been observed in many parts of the world, a behaviour that is often associated to the increased moisture content of the atmosphere as a result of global warming. However, rainfall increases might be scattered because of mismatches in the rates of rainfall versus evaporation (e.g. TRENBERTH, 1999).

The complex character of precipitation makes it difficult to model this process reliably. In many models, the relevant processes cannot be resolved by the model grid (typically

Zusammenfassung

Dieser Beitrag präsentiert die Klimatologie des Niederschlags des portugiesischen Festlands mit dem Ziel, das Verständnis für die Auswirkungen von Änderungen auf das hydrologische Regime zu vertiefen. Dabei werden Trends spezifischer Indizes von 57 Niederschlagsstationen im Gebiet über 67 Jahre analysiert. Es zeigte sich ein abnehmender Trend des Niederschlags im Frühling, ein verstärktes Auftreten von Starkniederschlagsereignissen im Herbst und eine generelle Reduktion der Dauer der Niederschlagsperioden. Die resultierenden Auswirkungen auf das hydrologische Regime mit besonderer Berücksichtigung kleiner Einzugsgebiete werden dargestellt.

Schlagworte: Niederschlag, Klimavariabilität, Trends, Klimaindizes, Trockenheit.

Summary

This study discusses the climatology of precipitation in mainland Portugal, aiming at the increased understanding of the potential implications of change for the hydrological regimes. It explores trends in selected specific indices that are computed from daily precipitation data of 57 measuring stations across the territory, recorded over 67 years. Results show that precipitation exhibits statistically significant decreasing trends in spring, while extremely heavy precipitation events have become more pronounced in autumn; moreover, results suggest a tendency for a reduction of duration of the rainy season. The expected consequences for the hydrological regimes and for the overall dryness conditions that normally affect large parts of the study area are analysed, especially concerning the hydrology of small basins.

Keywords: Precipitation, climate variability, trends, indices, droughts.

200 km) which causes the introduction of parameterizations at the sub-grid scale; point data can nevertheless give some insight into local and regional specificities, which urge to be understood. In fact, although changes in the water cycle are related to a large range of spatial and temporal scales, their local impact can differ with geographical location. Particular attention should then be given to the local variability in the hydro-climatological variables and processes and in the mean and extreme events (maximum and minimum).

In recent years several studies have already reported observed changes in the precipitation and air temperature for several regions worldwide (e.g. ALEXANDER et al., 2006), including Europe and, in particular, the Iberian Peninsula. In general, these studies discussed trends in annual, monthly and daily data, and sometimes they were conducted for restricted geographical areas and few representative sites. Studies focussing on smaller time scales are often lacking or have been conducted for short time series. For mainland Portugal, which is our area of interest, recent studies by RAMOS et al. (2011) and DE LIMA et al. (2013) reported results of trend analyses conducted on time series of several standard indices for precipitation and air temperature extremes; they contributed to clarify some features of the regional climate. In this work we continue searching for evidence of change in climate extremes in mainland Portugal, focusing on threshold, probability and duration indices for precipitation. Our main concern is on the consequences for the variability in the hydrological regimes in the area.

2 Study area and data

Mainland Portugal is situated between latitudes 36º 56′ and 42º 09′ N and longitudes 6º 10′ and 9º 34′ W. The highest altitude above mean sea level is roughly 2000 m. The region is characterized by asymmetric climatic conditions, despite its small area, resulting in large north-south and east-west precipitation gradients: mean annual precipitation varies from about 3000 mm in the north to roughly 500 mm in the south; annual average temperature varies between about 7 °C in the highlands of northern and central interior and about 18 °C in the south coast. Latitude, orography and the effect of the Atlantic Ocean are the factors that most dominate the climate. Although overall the climate in mainland Portugal is typically Mediterranean, the southern part of the country is identified as semi-arid. Seasonality is very marked across the area. On average, the contributions of seasonal precipitation to annual precipitation are: 24 % in spring; 6 % in summer; 28 % in autumn; and 42 % in winter.

The complexity of the relief in mainland Portugal, particularly in the northern part of the country, leads to a complex drainage network where the natural flow regimes are highly influenced by the temporal distribution of precipitation. Moreover, in general, the drainage basins in the territory have little natural storage (e.g. no large lakes). Thus the irregular hydrologic conditions and water availability (i.e. natural conditions), together with the land use and demands of societal development, have motivated the construction of many major and minor hydraulic structures and surface water reservoirs, in the context of water supply to population, agriculture and industry, and for flood control and river regularization purposes.

In this study we have inspected daily precipitation data taken from 57 climatologic weather stations and rain-gauges from the networks of the Institute of Meteorology (presently named The Portuguese Sea and Atmosphere Institute) and Institute for Water (INAG) of Portugal, covering the period 1941–2007. The measuring sites are scattered across mainland Portugal. Details about this data set can be found in DE LIMA et al. (2013).

3 Methods

This work focuses on investigating recent trends in annual and seasonal time series of specific climate indices defined for daily data (e.g. PETERSON et al., 2001). We have selected threshold, probability and duration indices from the list of climate indices that the World Meteorological Organization and the Intergovernmental Panel on Climate Change (e.g. IPCC, 2007) have been using to test trends in climate variables at many locations.

In this study we have decided to examine the changes in the R25 index, which is by definition associated with extremely heavy precipitation days: this index is computed as the number of days with precipitation greater or equal to 25 mm. We have also looked into the percentile R95p index, for precipitation due to very wet days (> 95th percentile), expressed in mm; the mean return period for these events is 20 years. Percentile indices are expressions of anomalies relative to the local climate. As they sample the same part of the probability distribution at each station, such indices are convenient for spatial comparisons (e.g. KLEIN TANK & KÖNNEN, 2003). In this study, the values of the percentiles were determined empirically from the observed station series in the climatological standard-normal period 1961–1990; the percentiles were calculated from 5-day windows centred on each calendar day to account for the mean annual/seasonal cycle (e.g. KLEIN TANK & KÖNNEN, 2003).

We have also concentrated on exploring trends in the number of consecutive dry days (CDD index) and in the number of consecutive wet days (CWD index). The CDD index is taken as the maximum length of dry spells (i.e. including days when precipitation is less than 1 mm), expressed in days, and can assess the region's vulnerability to drought. The CWD index is defined as the maximum length of wet spells (i.e. including days when precipitation is greater or equal 1 mm), in days.

The precipitation indices were computed at the annual and seasonal scales. Regional averages (i.e. for mainland Portugal) of these indices were also calculated based on the data from the 57 stations.

Linear trends in the time series of the precipitation indices were calculated by ordinary least squares fitting. The statistical significance of the trends was evaluated using Student's *t* test and the non-parametric Mann-Kendall test (e.g. KENDALL et al., 1983).

4 Results

Overall, the behaviour observed in the data indicates an increase in the already existing asymmetries in the climate in mainland Portugal, including regional differences. But the trends in the data are not always statistically significant at the 5 % level, although they might have hydrological relevancy.

The trends in the annual CDD and CWD indices that evaluate the number of consecutive dry and wet days are shown in Figure 1 for the period 1941–2007. The results illustrate that there is a decreasing trend in the CWD index, which is observed in 77 % of the stations, but only 10 % of the stations have statistically significant trends. Figure 1 shows that this behaviour affects more regions located in the centre and southern part of the study area. The negative trend might indicate a drying tendency, potentially leading to an increase of water scarcity and drought situations (minimum extremes). But it is worth noting that, also for mainland Portugal, other studies found increases in heavy precipitation at the expenses of more moderate precipitation (e.g. DE LIMA et al., 2013); it might be expected that constraints in the surface energy budget could also affect the frequency of precipitation, as discussed by e.g. TRENBERTH (1999). This behaviour, on the other hand is likely to result in increased runoff and risk of flooding.

In fact the drying tendency eventually resulting from the reduction in the number of consecutive wet days is not highlighted by the results obtained for the annual CDD index. Negative trends are found in 80 % of the stations, which indicate a tendency towards less dry conditions. Notably there are only two data sets indicating an increase in the number of consecutive dry days: they were recorded in the interior of Southern Alentejo, in the south of Portugal. 18 % of the stations even show a statistically significant decreasing trend between 1941–2007, which points out to the presence of less dry conditions; these stations are mainly located in the vicinity of the Atlantic Ocean where the conditions are nevertheless more humid than inland. So there are local specificities that increase the climate variability over the study area, which deserves further attention.

Focusing now on extreme precipitation events, we have explored the R25 and R95p indices at the seasonal scale for the 1941–2007 period. The regional average for the trend in the R95p index is -5.16 mm decade^{-1} (–8.71 to –1.62) in spring and is 3.66 mm decade^{-1} (–0.73 to 8.06) in autumn; in spring the statistical significance of the result is 5 % and in autumn 25 %. The regional average for the trend in the R25 index is –0.17 days decade^{-1} (–0.27 to –0.07) in spring and 0.13 days decade^{-1} (–0.02 to 0.29) in autumn; in spring 47 % of the stations revealed statistically significant negative trends for this index while in autumn the percentage of positive trends observed was 18 %.

Figure 2 shows the trends in the R95p index computed for the 57 stations, for spring as well as autumn (1941–2007). Results indicate a significant decrease in the precipitation due to very wet days in spring and an increase in autumn, although not as significant as in spring. The decreasing trend in the R95p spring index was statistically significant at the 5 % level in 40 % of the stations, whereas in autumn the increasing trend was significant in 18 % of the stations.

In autumn, the increase in the R25 and R95p indices is manifested principally in the southern part of mainland Portugal (Figure 2) where average annual precipitation is much lower than in the northern part of the country, and where precipitation is even more unevenly distributed throughout the year; typically the dry season can last several months there in the warm season. The beginning of the rainy season around the end of September or early October has always constituted a major problem in this region in relation to soil water erosion. At many places the crop rota-

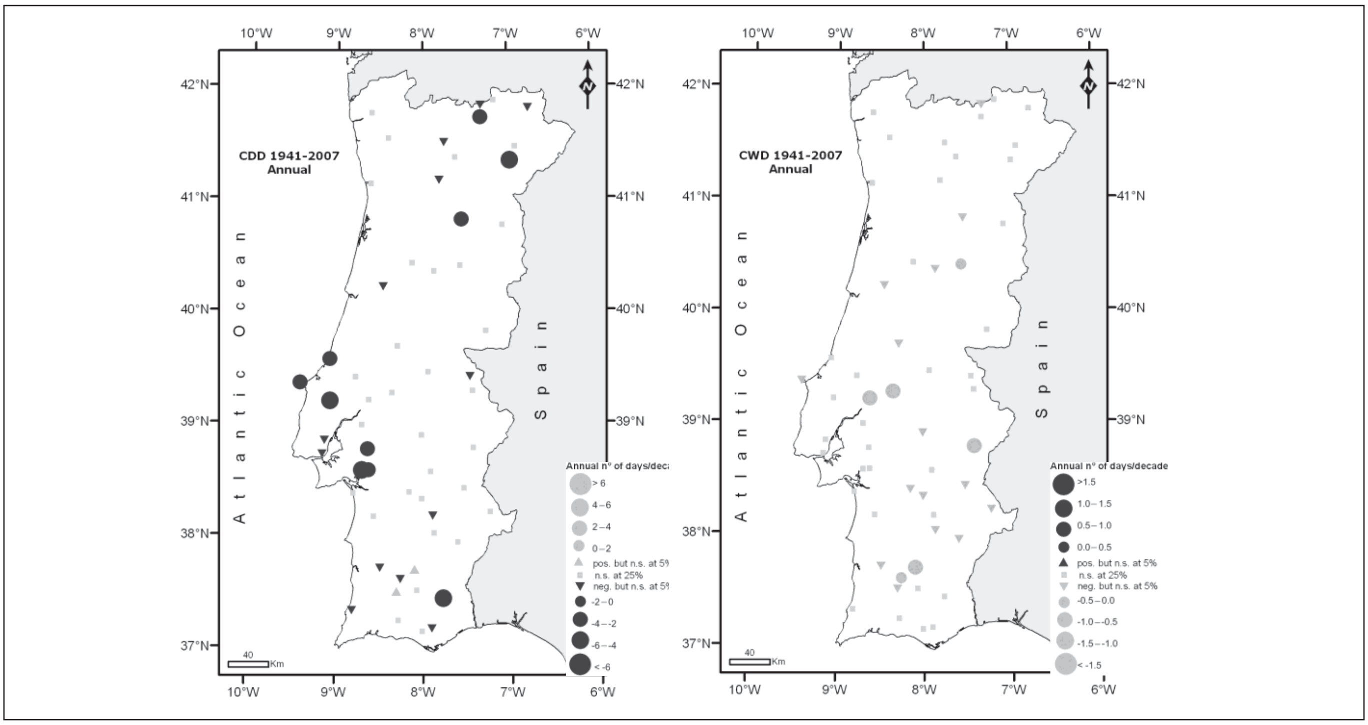

Figure 1: Trends in the CDD index (left) and CWD index (right) for the period 1941–2007. The dots are scaled according to the magnitude of the trend, which is expressed in days decade^{-1} and statistically significant at the 5 % level. Colour coding: CDD index – grey is for positive trends, black is for negative trends; CWD index: black is for positive trends and grey is for negative trends

Abbildung 1: Trends des CDD-Index (links) und CWD-Index (rechts) für den Zeitraum 1941–2007. Punktgröße in Relation zu Trendkoeffizient (Tag/Dekade). Farbcodierung: CDD-Index: Positiver Trend in grau, negativer Trend in schwarz. CWD-Index: Positiver Trend in schwarz, negativer Trend in grau

tion is such that the soils are usually bare in the beginning of the rainy season and highly susceptible to water erosion. Over large areas the soil is already very shallow, with very low water storage capacity, resulting in large runoff rates. The increase in the intensity and frequency of heavy rains in autumn tends to intensify these problems.

5 Discussion

Intensification of the climate signal across mainland Portugal, particularly in the more vulnerable regions, might contribute to endanger already fragile soil and water resources and ecosystems as well as the local environmental and economic sustainability. In particular, it is likely that small basins will be more affected. Changes in heavy precipitation events, namely the increased number of events and its erosivity, may have severe implications and impact on the flood risk and soil erosion, resulting in increased soil degradation. On the other hand, aggravation of drought episodes is also expected to have negative impact, particularly at the seasonal scale. This contrasting behaviour should be considered in local climate change assessment and for correctly defining adaptation and mitigation measures and their implementation criteria.

The trends observed in the annual indices of precipitation discussed in this study for mainland Portugal are not always statistically significant in the period of 1941–2007. But partial trends in the annual data and trends in several indices computed at seasonal scale are in many cases statistically significant (see e.g. DE LIMA et al., 2010; SANTO et al., 2011; DE LIMA et al., 2013). On the one hand, this means that intense changes are occurring at the intra-annual scale and also that the results might be affected by the record period. In particular, there are studies reporting multidecadal variations in the temporal structure of precipitation (e.g. DE LIMA et al., 2010). On the other hand, trends in spring and autumn precipitation have opposite signals: in spring, we found statistically significant drying trends and a reduction in extremes; in autumn, wetting trends are observed, although overall they are not statistically significant at the 5 % level. These results suggest a reduction tendency in the duration of the rainy season; this behaviour is consistent with some climate change scenarios

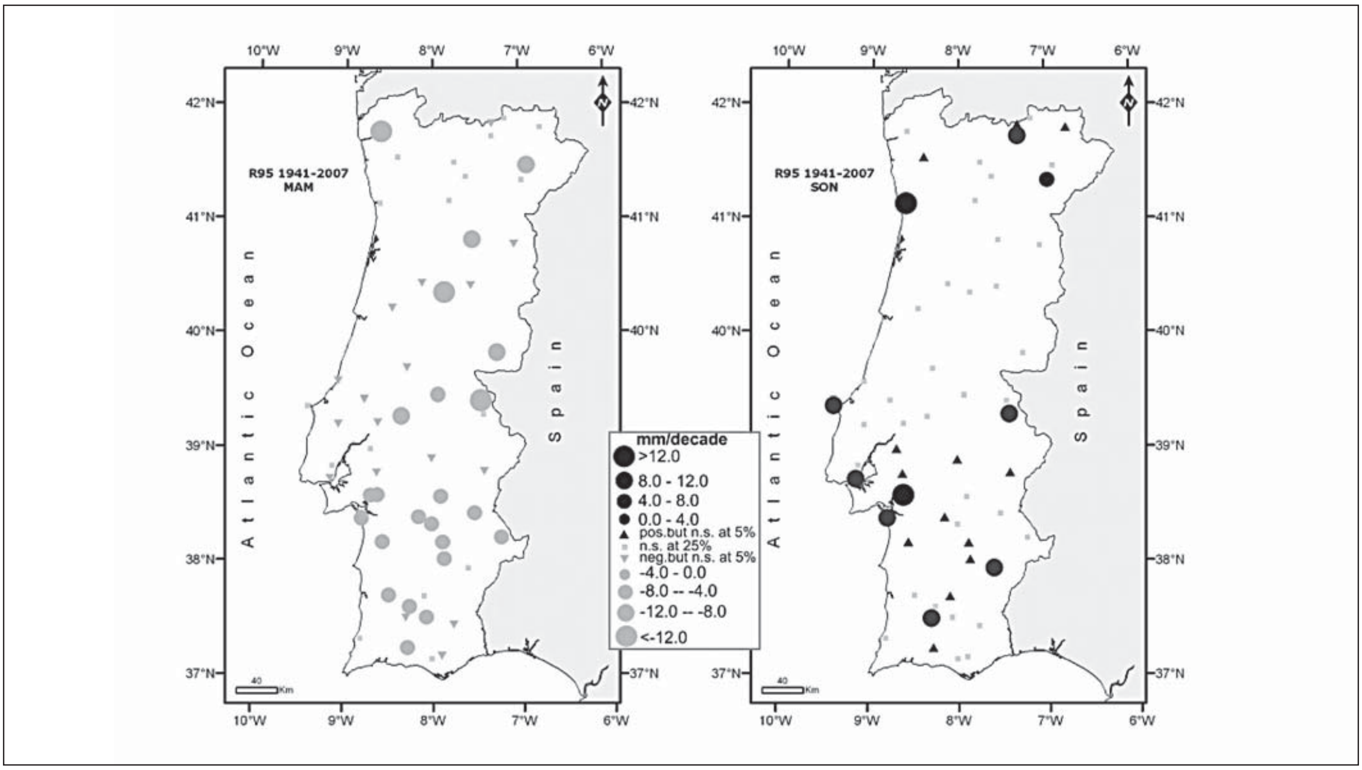

Figure 2: Trends in the spring (left) and autumn (right) for the R95p index, for the 1941–2007 period. The dots are scaled according to the magnitude of the trend, which is expressed in mm decade-1; dots indicate statistical significance at the 5 % level. Colour coding: black is for positive trends and grey is for negative trends

Abbildung 2: Trends des R95p-Index für Frühling (links) und Herbst (rechts) im Zeitraum 1941–2007. Punktgröße in Relation zu Trendkoeffizient (mm/Dekade). Farbcodierung: Positiver Trend in schwarz, negativer Trend in grau

predicted by climate models. In addition, despite the non-statistical significance (at the 5 % level) of the regional trends, at the local scale there are statistically significant trends that suggest spatial trends in the behaviour of precipitation. Thus we should carefully keep in mind the changes in the precipitation climate that are taking place over mainland Portugal.

6 Conclusion

Results show that precipitation exhibits statistically significant decreasing trends in spring, while extreme heavy precipitation events have become more pronounced in autumn; moreover, results suggest a tendency for a reduction in the duration of the rainy season. These changes in rainfall patterns, including the wet and dry extremes, are expected to affect the hydrological regimes and to aggravate the overall dryness conditions that normally affect large parts of mainland Portugal. Moreover, these changes could have greater impact on the hydrology of small basins because of the local climatic and specific physiographic conditions.

The basic insight into changes and challenges in water-related issues in mainland Portugal given by this study needs to be complemented with the examination of a larger data set, including other hydrologic variables; for example, it is pertinent to model water balances in catchments that would help to relate trends in the inputs (e.g. precipitation) to trends in the outputs (e.g. streamflow, evapotranspiration). In this context, the scientific role of research focussing on small basins (such as the research conducted in the framework of Experimental Representative Basins) is very relevant to increase our understanding of the consequences of climate change and to investigate adaptation and mitigation strategies.

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