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Trends in rainfall erosivity in NE Spain at annual, seasonal and daily scales, 1955–2006

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Abstract

Rainsplash – the detachment and transport of soil particles by the impact of raindrops on a bare soil – is a major mechanism of soil degradation and erosion on semiarid areas and agricultural lands. Rainfall erosivity refers to the ability of precipitation to erode soil, and depends on the characteristics of the raindrops – size and velocity – and on the rainfall intensity and duration. Despite the relevance of rainfall erosivity for soil degradation prevention very few studies addressed its spatial and temporal variability. On this study the time variation of rainfall erosivity in the Ebro valley (NE Spain) is assessed for the period 1955–2006. The results show a general decrease in annual and seasonal rainfall erosivity, which is explained by a decrease of very intense rainfall events whilst the frequency of moderate and low events increased. This trend is related to prevailing positive conditions of the main atmospheric teleconnection indices affecting the West Mediterranean, i.e. the North Atlantic Oscillation (NAO), the Mediterranean Oscillation (MO) and the Western Mediterranean Oscillation (WeMO).

1 Introduction

Rainfall erosivity can be defined as the potential of a rainfall event to erode soil, and is a consequence of the amount of energy released by raindrops when they hit the soil surface. Raindrop impacts are able to detach the soil aggregates and strike them up into the air – rainsplash –, causing a diffusive displacement of particles down the slope if the surface is not perfectly flat. Rainsplash is also able to disrupt the soil aggregates, and the redistribution of soil particles blocks the soil pores causing crusting and reduced infiltration. On addition, other processes such as sheetwash can further transport the detached particles. The efficiency of rainsplash depends on factors such as the topography and the soil characteristics, and is largely reduced by the presence of vegetation (D'Odorico et al., 2001). This makes rainsplash a major mechanism of

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soil degradation especially in semiarid and agricultural areas where the ground cover may be scarce at least during part of the year (Nearing et al., 2004).

The study of rainfall erosivity is thus highly relevant for soil degradation mitigation. Rainfall erosivity depends on the physical properties – size and velocity – of raindrops, and on rainfall intensity and duration. Despite its applied relevance, the climatology of rainfall erosivity (i.e. its interannual and seasonal variation, spatial patterns, etc) is surprisingly the topic of very few studies. In the context of climate change, a relevant question is whether or not long-term trends can be detected over the last decades that may help confirming the projections made by global climate models. The Mediterranean basin is one of the areas of the World where current climate projections suggest the highest changes in precipitation (Sauerborn et al., 1999; Kendon et al., 2010; Beaulant et al., 2011; Tramblay et al., 2012). It is expected that the annual precipitation will decrease in the Mediterranean, while higher amounts of erosive rainfall can also be expected as a consequence of changes in precipitation variability and precipitation extremes.

A number of studies found decreasing annual precipitation in the Iberian Peninsula (IP) since the mid 20th century, with seasonal and spatial differences (Rodríguez-Puebla et al., 1998; Esteban-Parra et al., 1998; Paredes et al., 2006; Lopez-Bustins et al., 2008; González-Hidalgo et al., 2009, 2010; Rodrigo, 2010; López-Moreno et al., 2010). These trends have been related to changes towards dryer conditions due to a northward displacement of the polar fronts, and are consistent with the evolution of major teleconnection patterns affecting precipitation over the IP such as the North Atlantic Oscillation (NAO), the Mediterranean Oscillation (MO) and the Western Mediterranean Oscillation (WEMO). Very few studies analysed trends in rainfall erosivity. Meusburger et al. (2012) analysed the spatio-temporal variability of rainfall erosivity in Switzerland and found an increasing trend from May to October. Focusing on the Mediterranean side of the IP, de Luis et al. (2010a) found an overall decrease in annual rainfall and increases in rainfall concentration, while changes in rainfall erosivity varied in space. Their analysis was based on the Modified Fournier Index (MFI, Arnoldus, 1977) with

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monthly precipitation data. This is an important concern, since rainfall erosivity depends largely on a few number of short but very intense rain episodes that are largely smoothed when data is aggregated at coarser time resolutions.

The USLE/RUSLE *R* factor (Wischmeier, 1959; Wischmeier and Smith, 1978; Brown and Foster, 1987; Renard et al., 1997) is probably the most widely used rainfall erosivity index. It is defined as the mean value of the annual cumulative EI_{30} index. The EI_{30} index ($MJ\,mm\,ha^{-1}\,h^{-1}$) is obtained for each rainfall event as the product of the kinetic energy of the rain (E) and the maximum intensity recorded in 30 min. Its calculation requires high frequency rainfall data – typically one data every 15 min or less –, or pluviograph records. In addition, reliable values of the *R* factor can only be obtained from long data series spanning over several decades. Such conditions are very often not met, so a number of studies have been devoted to estimating rainfall erosivity from coarser data such as highly available daily rainfall time series. (Richardson et al., 1983; Bagarello and D'Asaro, 1994; Petkovsek and Mikos, 2004; Angulo-Martínez and Beguería, 2009; Meusburger et al., 2012). Such relationships allow undertaking climatological studies of rainfall erosivity with dense and long datasets. In this article we use an estimation of the EI_{30} index based on daily rainfall intensities for assessing the temporal variation of rainfall erosivity in the NE quadrant of the IP at the annual, monthly and daily time scales.

2 Study area and methods

2.1 Study area

The study area corresponds to the Ebro River basin in the the NE of the IP, with an area of about 85 000 km^2 (Fig. 1). The area limits to the north with the Cantabric Sea (Atlantic Ocean), the Cantabrian Range and the Pyrenees. Maximum elevations are above 3000 m a.s.l. The Iberian Range closes the Ebro basin to the S and SE, with highest elevations in the range of 2000–2300 m a.s.l. The Catalan Prelitoral Range, with maximum elevations of 1000–1900 m a.s.l., closes the valley to the E. It is a topographical complex area where the mountain areas represent approximately 20 % of the surface.

The climatology is also complex as a consequence of being a border region between the temperate and tropical zones. The climate is influenced by the Atlantic Ocean and by the Mediterranean Sea, determining a NW–SE climatic gradient. The central area – the Ebro valley – has continental climate with semi-arid conditions as a consequence of the topographic isolation by the surrounding mountain ranges (Lana and Burgueño, 1998). Precipitation variability is the main characteristic, both inter and intra annually. Thus, a dry period may be followed by torrential rainfall events. These properties are increased towards the SE (Mediterranean seaside), where the highest precipitation events have been recorded (Romero et al., 1998; Peñarrocha et al., 2002).

The spatial distribution of rainfall erosivity allows distinguishing three main areas (Fig. 2): (i) the NW area with high annual and monthly precipitation amounts but low rainfall erosivity peaking in late spring; (ii) the central area with lower precipitation totals but higher erosivity peaking in May–June and August–September; (iii) and the SE area with the highest erosivity and a typical Mediterranean regime with peaks in spring and autumn.

The land use is dominated by agriculture, covering 46 % of the area especially along the Ebro valley and in a broader area close to the Mediterranean. Agricultural soils remain largely uncovered during autumn and winter, so rainsplash erosion is a major cause of soil erosion in the region.

2.2 Daily rainfall erosivity database

For this study two databases were used (Fig. 1): (i) 110 precipitation series from the Ebro river basin authority's hydrologic information system (SAIH Ebro), with a time resolution of 15 min since 1997 (P_{SAIH}); and (ii) 156 series from the Spanish meteorological agency (AEMET), with daily (06:00 to 06:00 h) precipitation since 1955 (P_{AEMET}). Precipitation time series were pre-processed including reconstruction, gap filling, quality control and homogeneity testing following the methodology of Vicente-Serrano et al. (2009). The SAIH dataset had the adequate time resolution for computing rainfall erosivity, but only covered eleven years. The AEMET dataset had the adequate length for undertaking climatological studies, but its coarser time resolution did not allow direct computation of the EI_{30} index. Therefore, we used a statistical procedure between the two datasets for obtaining series of daily rainfall erosivity for the period 1955–2006. The process is explained at length in Angulo-Martínez and Beguería (2009), and a summary is provided as online Supplement to this article.

2.3 Trend analysis

Daily rainfall erosivity series were summarized at the monthly and annual scales for the period 1955–2006. All the events corresponding to a given season or year were summed to create seasonal and annual time series; in the case of daily events they were separated according to the season. Temporal evolution of rainfall erosivity was analysed by linear regression between rainfall erosivity and time, and the variation is expressed as per-decade change in rainfall erosivity. In the case of daily rainfall erosivity the time variation in the number of days with rainfall erosivity values corresponding to the quintiles at the annual and seasonal scales was analysed. To help visualising spatial differences in the per decade change maps were generated by means of local first grade polynomial interpolation. Variations significant at the $\alpha = 0.05$ confidence level were evaluated by the Mann-Kendall test.

Trends in rainfall erosivity were finally compared to the evolution of three teleconnection indices (NAO, MO and WEMO) in search for an atmospheric explanation. Details on the construction of time series of teleconnection indices are given in the supplementary material.

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3 Results

Annual and seasonal rainfall erosivity

The annual rainfall erosivity experienced decreasing trends in most of the study area (Fig. 3). Per decade change reached $-200\,\mathrm{MJ\,mm\,ha^{-1}\,h^{-1}\,yr^{-1}}$ in some areas such as in the NE (eastern Pyrenees), but in most of the area it was lower than $-30\,\mathrm{MJ\,mm\,ha^{-1}\,h^{-1}\,yr^{-1}}$. When compared to the mean annual rainfall erosivity (Fig. 2), the highest relative changes occurred at the NE of the study area were they represented 60–80 % of the average over the whole study period (five decades).

Spatial differences were most noticeable when analysed at a seasonal basis (Fig. 4). While negative trends were found in most of the study area in winter and spring, especially in the NE corner, larger spatial differences existed in summer and autumn. Summer yielded the most heterogeneous results, since in some interior areas slightly positive trends were registered while the NE quadrant and some smaller areas in the N and NW experienced strong negative trends. In autumn negative trends predominated overall and were especially strong in the SE and NW corners, but positive trends were also found in the N along the Pyrenean range. Although negative trends predominated overall at both annual and seasonal basis, these results should be taken with care since significance was achieved only in a small fraction of the stations (Table 1).

Variation in the number of events grouped by quintiles allowed assessing trends in the occurrence of rainfall erosivity events across the range of erosivity values (Fig. 5). Since the range of the quintiles were calculated considering the whole study period (1955–2006), negative values indicate a diminishing number of events, while positive values indicate an increasing number of events. The results show that the number of very low and low erosivity events (Q1, below 20 %, and Q2, between 20 and 40 %) increased in a large number of stations, while the number of medium, high and very high erosivity events (Q3 to Q5) decreased. Spatially, the number of events in the first quintile increased between one and four events per year in most of the study area, and only in the NE corner (eastern Pyrenees) a negative trend was found (Fig. 6).

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Trends were significant in the majority of stations (58.4 %). The number of events in the fifth quintile, on the other hand, decreased between 0.25 and one event per year, with significant trends in 29.5 % of the stations.

The same pattern (increasing number of Q1 events and decreasing number of Q5 events) was found at the seasonal basis (Figs. 7 and 8), with a few exceptions: (i) the number of Q1 events decreased in winter in the NE corner; and (ii) the number of Q5 events increased in autumn in a small area to the N (central and Western Pyrenees). The number and proportion of stations with significant trends is shown in Tables 2 and 3.

4 Discussion

Planning of soil conservation measurements, especially concerning agriculture practices, requires a good knowledge of all factors affecting soil erosion. Among them, rainfall erosivity is one of the least studied, although its spatial and temporal dynamics can be of paramount importance when they are related to other factors such as land use and cropping practices. The development of long time series of daily rainfall erosivity, even subject to uncertainty, can be of great value in assessing the spatial and temporal dynamics of rainfall erosivity. Compared to these, data at coarser temporal resolution such as monthly precipitation may miss the importance of a few, very intense events that account for a large fraction of the annual or seasonal rainfall erosivity amounts.

Our results show decreasing rainfall erosivities at the annual and seasonal scales over most of the area. This could be explained in part by negative trends in precipitation over the IP especially during the wet season from October to May (Rodríguez-Puebla et al., 1998; Esteban-Parra et al., 1998; Paredes et al., 2006; Lopez-Bustins et al., 2008; González-Hidalgo et al., 2009, 2010; Rodrigo, 2010; López-Moreno et al., 2010). However, deeper inspection revealed that this trend in the annual erosivity was related to changes in the frequency distribution of erosivity events, since the number of events of low erosivity increased while the number of highly erosive events decreased. Due

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to the exponential distribution of rainfall erosivity the higher events account for a large part of the total cumulative erosivity, so even a small reduction in the frequency of high events is able to produce a large reduction of the annual or seasonal erosivity.

These results are in agreement with previous studies. In their analysis of daily precipitation in the NE of Iberia López-Moreno et al. (2010) found decreasing trends in the number of heavy precipitation events and in the relative contribution of heavy events to the annual rainfall, while the number and relative importance of light and moderate events increased. Recent results based on the non-stationary peaks-over-threshold approach to extreme events analysis found evidences of decreasing frequency and magnitude of extreme rainfall events over most of the IP and in particular in its NE quadrant (Beguería et al., 2011; Acero et al., 2012).

Based on monthly precipitation data covering the Mediterranean basins of the IP, de Luis et al. (2010a) reported a generalized decrease in the annual precipitation. In the Ebro basin, coinciding with the study area of this study, they found that decreasing trends of the MFI predominated in general, except at the N of the study area (Pyrenees). They did not perform seasonal analysis, but in another studies the same authors found that annual and monthly precipitation generally decreased in the Ebro basin except in February and October were a slightly increase was found along the Pyrenees (González-Hidalgo et al., 2009, 2010; de Luis et al., 2010b). This coincides with our findings, since the frequency of high erosivity events (Q5) only increased in autumn in the Pyrenees.

As other authors pointed out, strong precipitation events in the study area are significantly related to negative phases of the NAO, the MO and the WEMO (González-Hidalgo et al., 2009). The generalized decreasing precipitation along the Mediterranean basin of the IP has been related to prevailing positive conditions of NAO and MO (Fig. 9). Angulo-Martínez and Beguería (2011, 2012) found a significant relationship between rainfall erosivity and three teleconnection indices, which was largest for MO and WEMO. The time evolution of the WEMO during the study period was much more stationary than the MO evolution, so it has probably contributed to a lesser extent to the evolution of rainfall erosivity.

5 Conclusions

Analysis of the temporal evolution of rainfall erosivity revealed generalized decreasing trends at the annual and monthly scales during the period 1955–2006, coinciding with a decrease in the number of highly daily erosive events and increasing number of daily low erosivity events. These trends could be explained by the displacement of the polar fronts northwards revealed by the positive trend of the NAO and MO, whereas increasing trends found along the Mediterranean coast during January and February could be a consequence of the slightly negative WEMO trend.

This study reveals that rainfall erosivity is characterized by complex patterns in time and space, but their study can be undertaken based on relatively common data (long time series of daily precipitation and shorter time series of high frequency precipitation). This encourages the climatological study of this rainfall property, given the implications for soil erosion and the hydrological behaviour on natural and managed landscapes.

Supplementary material related to this article is available online at: http://www.hydrol-earth-syst-sci-discuss.net/9/6285/2012/ hessd-9-6285-2012-supplement.pdf.

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Table 1. Number and proportion of series with significant trends at the 95 % confidence level.

Time period	°N positive trends (%)	°N negative trends (%)
Annual	1 (0.6 %)	21 (13.5 %)
Spring	1 (0.6 %)	13 (8.3 %)
Summer	2 (1.3 %)	6 (3.9 %)
Autumn	1 (0.6 %)	11 (7.1 %)
Winter	0	18 (11.5 %)

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Table 2. Number and proportion of series with trends in the number of events in the first quintile (Q1) significant at the 95 % confidence level.

Time period	°N positive trends (%)	°N negative trends (%)
Annual	70 (44.9 %)	21 (13.5 %)
Spring	64 (41.0 %)	15 (9.2 %)
Summer	59 (37.8 %)	14 (9.0 %)
Autumn	82 (52.6 %)	11 (7.1 %)
Winter	63 (40.4 %)	20 (12.8 %)

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Table 3. Number and proportion of series with trends in the number of events in the fifth quintile (Q5) significant at the 95 % confidence level.

Time period	°N positive trends (%)	°N negative trends (%)
Annual	0	46 (29.5 %)
Spring	0	6 (3.8 %)
Summer	0	26 (16.6 %)
Autumn	0	13 (8.3 %)
Winter	0	32 (20.5 %)

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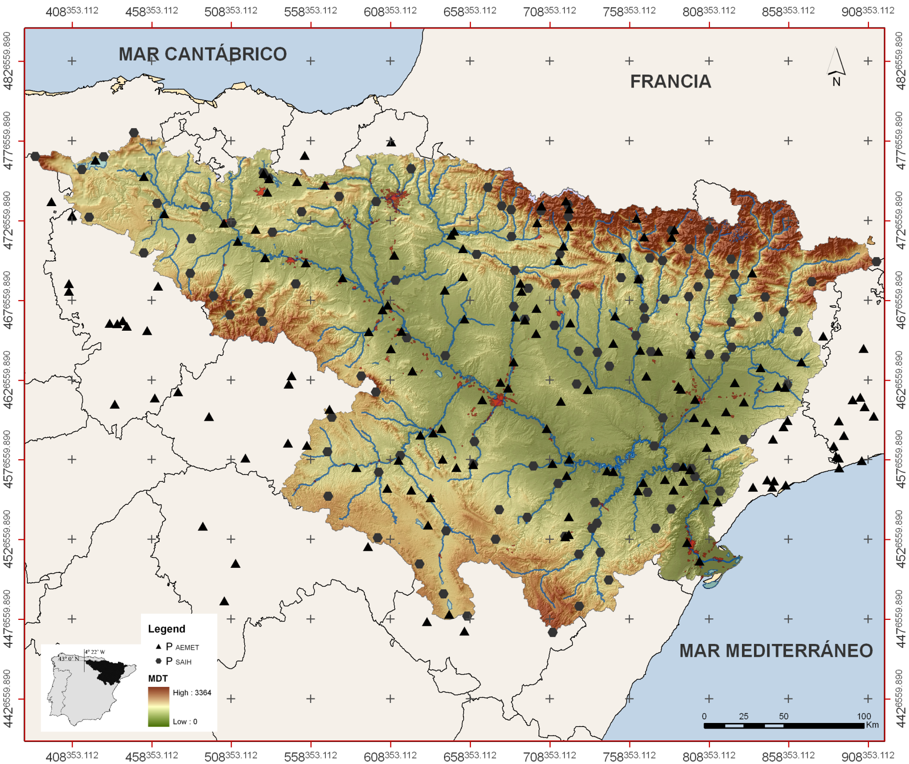

Fig. 1. Digital Terrain Model of the study area showing the spatial distribution of the rainfall gauges used in the study (UTM coordinates). P_{AEMET} indicates daily rainfall data series for period 1955–2006 provided by the Spanish Meteorological Agency. P_{SAIH} indicates the 15′ rainfall data series for period 1997–2006 provided by the Automatic Hydrologic Information System of the Ebro river basin.

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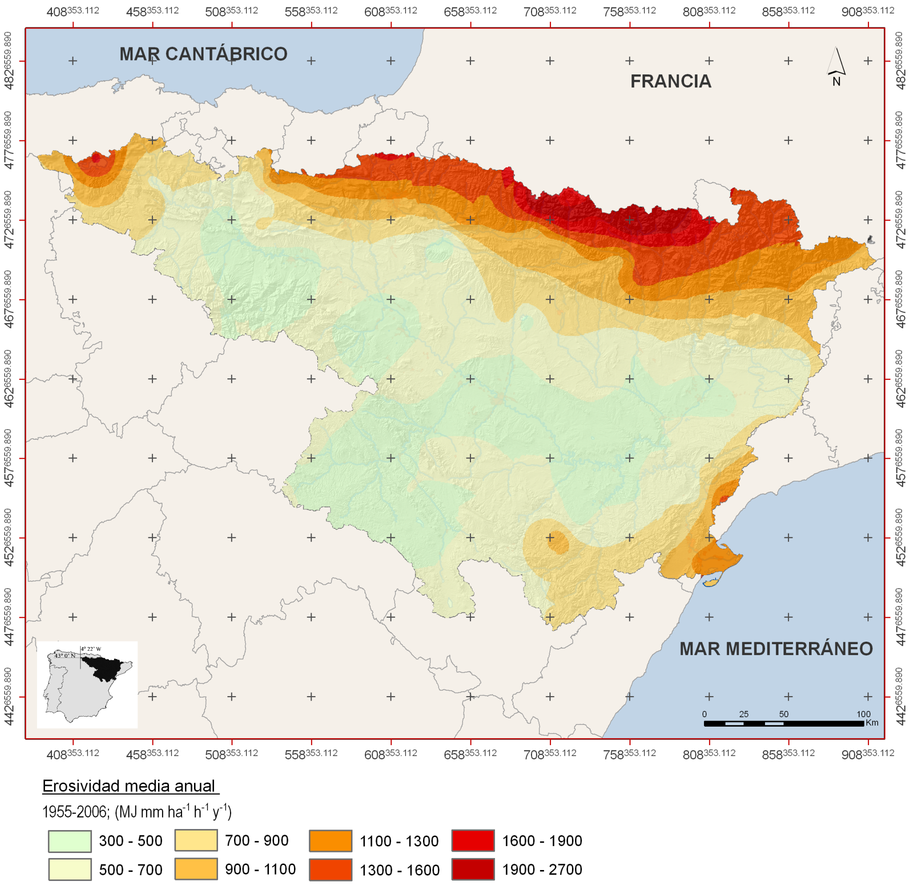

Fig. 2. Mean annual rainfall erosivity during the period 1955–2006 (MJ mm ha^{-1} h^{-1} yr^{-1}).

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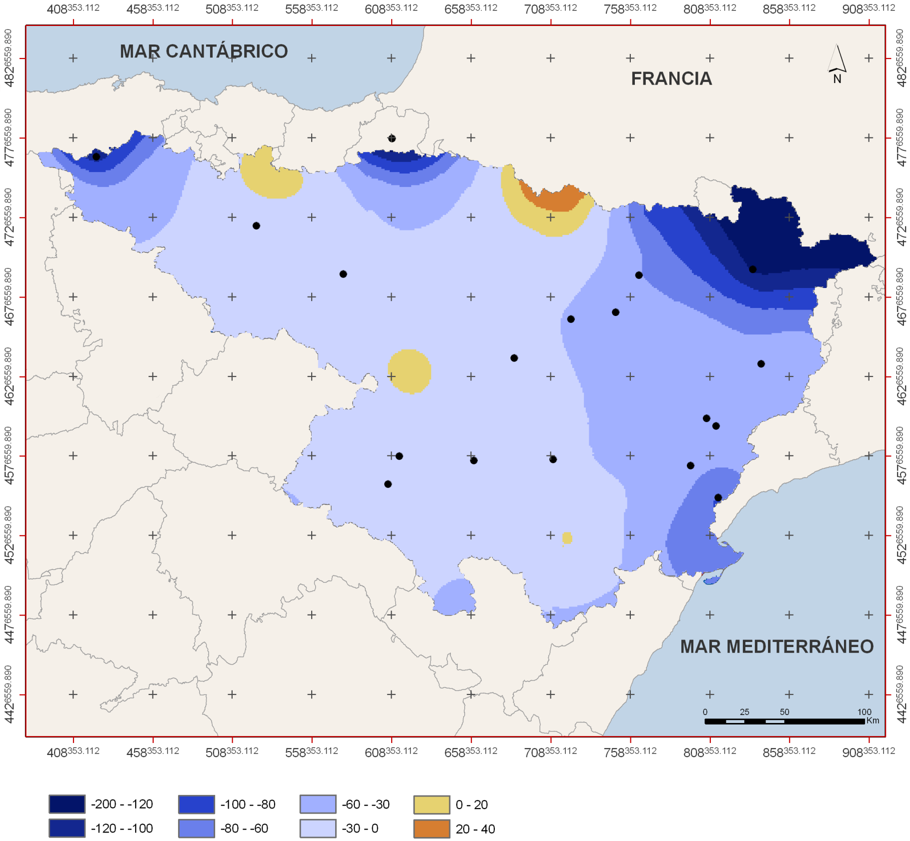

Fig. 3. Per decade change of annual rainfall erosivity during the period 1955–2006 (MJ mm ha^{-1} h^{-1} yr^{-1}). Black circles indicate data series for which the trend was significant at the $\alpha = 0.05$ confidence level.

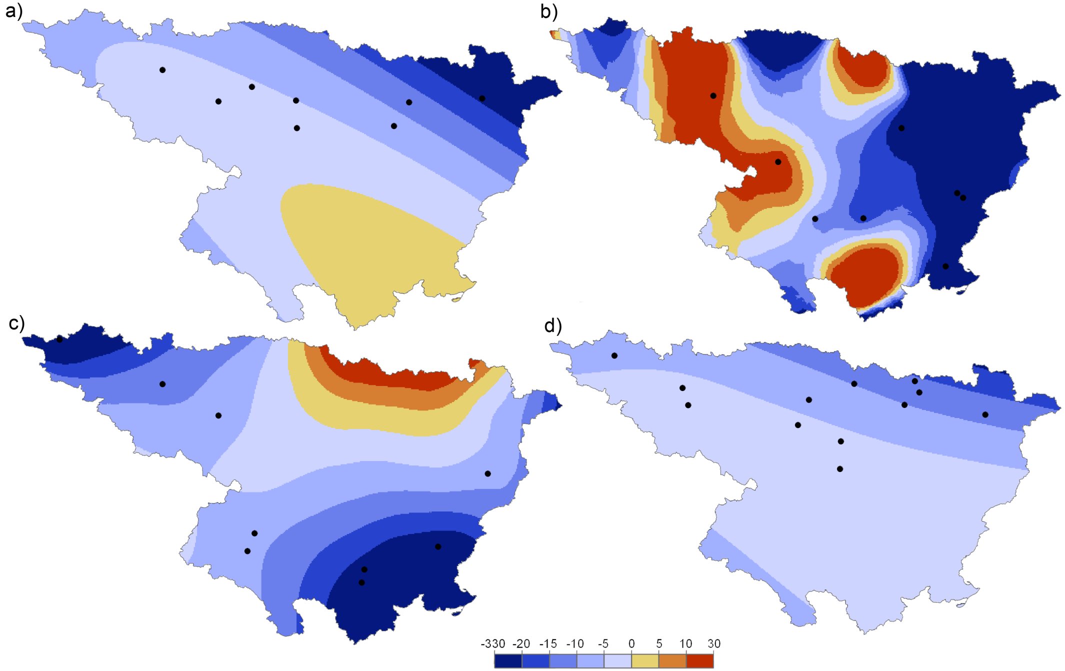

Fig. 4. Per decade change of seasonal rainfall erosivity during the period 1955–2006 ($MJ\,mm\,ha^{-1}\,h^{-1}\,yr^{-1}$): **(a)** DEF, **(b)** MAM, **(c)** JJA, **(d)** SON. Black circles indicate data series for which the trend was significant at the $\alpha = 0.05$ confidence level.

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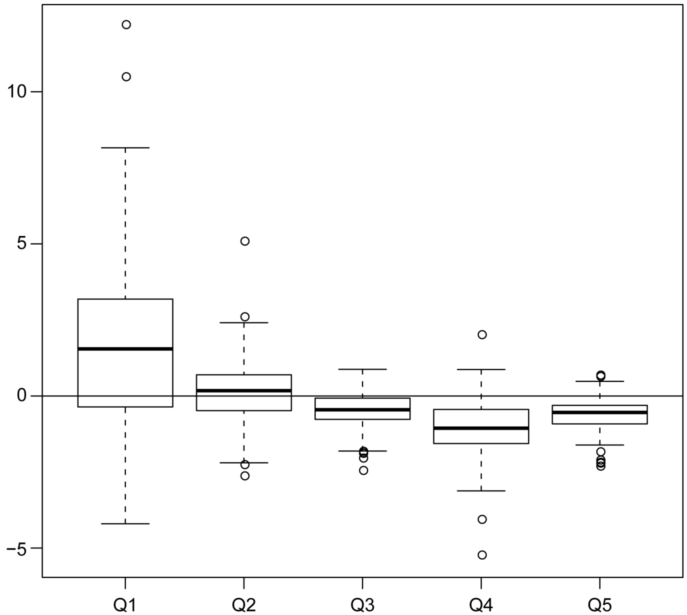

Fig. 5. Boxplots of trends with the number of daily rainfall erosivity events classified by quintiles of daily erosivity over the whole period 1955–2006.

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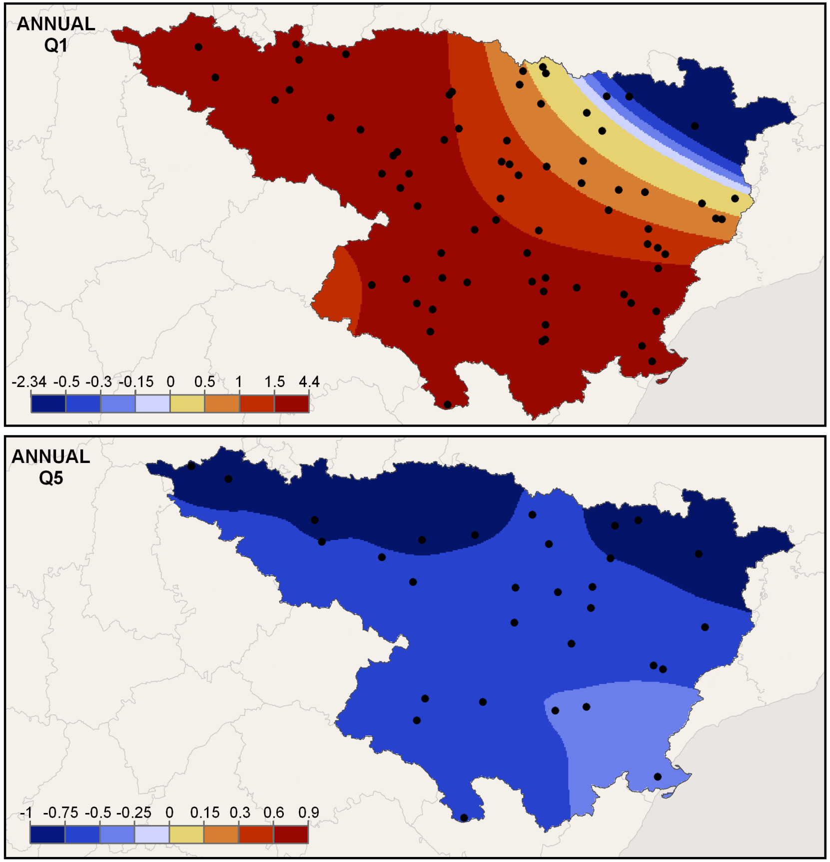

Fig. 6. Per decade change in the number of daily rainfall erosivity events corresponding to the first (Q1) and fifth (Q5) quintiles at the annual scale for the period 1955–2006. Black circles indicate significant trends at the $\alpha = 0.05$ confidence level.

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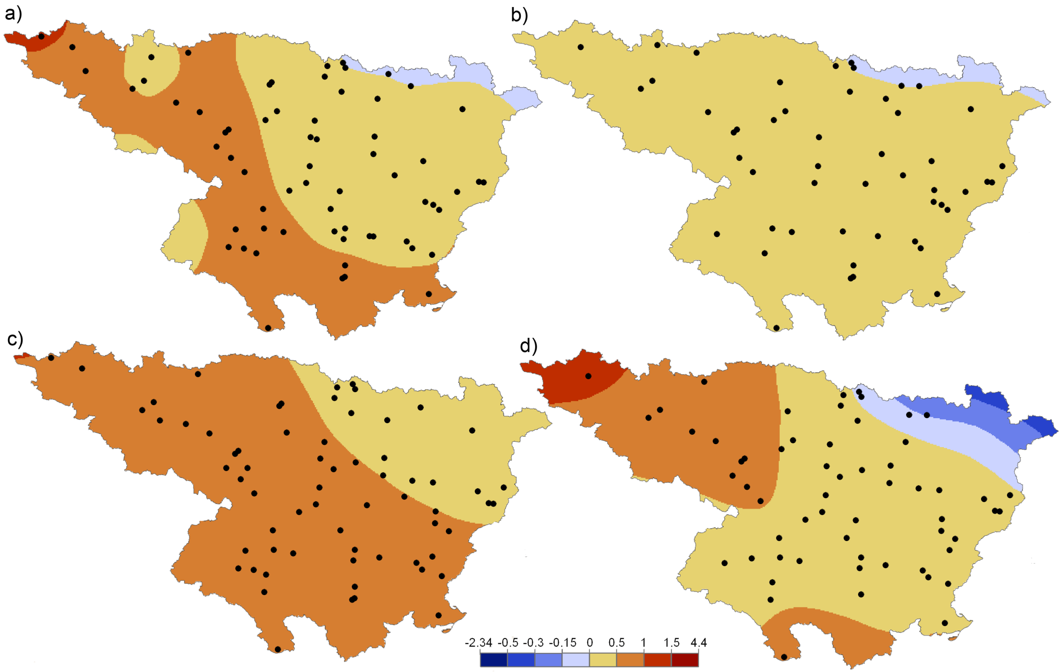

Fig. 7. Per decade change in the number of daily rainfall erosivity events corresponding to the first (Q1) quintile at the seasonal scale for the period 1955–2006: **(a)** DEF, **(b)** MAM, **(c)** JJA, **(d)** SON. Black circles indicate significant trends at the $\alpha = 0.05$ confidence level.

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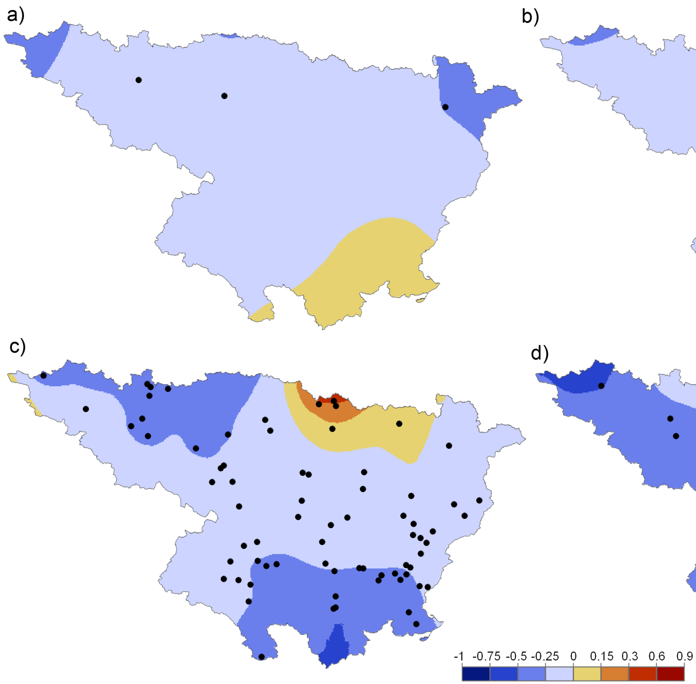

Fig. 8. Per decade change in the number of daily rainfall erosivity events corresponding to the fifth (Q5) quintile at the seasonal scale for the period 1955–2006: **(a)** DEF, **(b)** MAM, **(c)** JJA, **(d)** SON. Black circles indicate significant trends at the $\alpha = 0.05$ confidence level.

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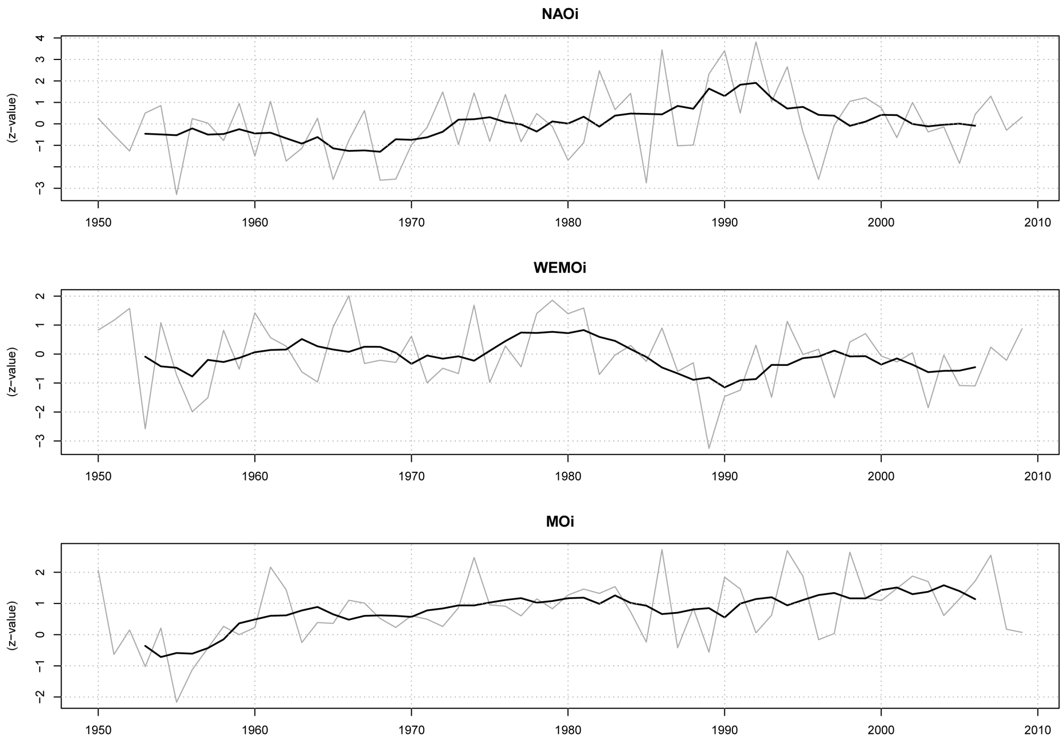

Fig. 9. Temporal evolution of October to March NAO, WeMO and MO indices obtained from average daily indices.

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