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RESEARCH ARTICLE

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MOPREDAS_century database and precipitation trends in mainland Spain, 1916–2020

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Abstract

Due to its geographical location in the western Mediterranean region, the Iberian Peninsula involves a challenge for current climatic conditions and future projections. In this study we analysed monthly precipitation trends over mainland Spain from 1916 to 2020 by using the new MOPREDAS_century database. This database combines information from the Spanish Meteorological Agency's archives, as well as data retrieved from Annual Summaries between 1916 and 1950. A combination of both sources produced the largest amount of original information ever collected and researched in mainland Spain between 1916 and 2020.

KEYWORDS

1916-2020 period, mainland Spain, monthly precipitation trend, Western Mediterranean basin

1 | INTRODUCTION

In western midlatitude continental coastland climate is characterized by summer droughts and winter precipitation. These are named Mediterranean climate types Cs in the Köppen classification. The most extended areas experiencing such conditions are located around the Mediterranean Sea, including areas of Europe, Asia and Africa.

From the influential atlas of European precipitation (by Schonwiese & Rapp, 1997) it has been suggested that the trends for the annual amount of precipitation in southern Europe were negative (nonsignificant) during the 20th century, mostly due to a decrease in winter precipitation (Hoerling et al., 2012; Quadrelli et al., 2001). These characteristics have been repeated, not only at a Mediterranean basin scale (Caloiero et al., 2018; Deitch et al., 2017; Philandras et al., 2011; Seager et al., 2019; Tanarhte et al., 2012), but also at more local ones (Maheras & Kolyva-Machera, 1990; Piervitali et al., 1997).

Nevertheless, precipitation trends in these environments are far from clear and do not display uniform behaviour. In the papers of Norrant and Douguedroit

(2005), Reiser and Kutiel (2010) or Gonzalez-Hidalgo et al. (2011), among others, extended compilations of references have been published detailing a high spatial variability of trends from eastern to western areas, showing trends that are usually nonstatistically significant, nonmonotonic. Over time successive dry-wet periods were also detected during the 20th century (Dünkeloh & Jacobeit, 2003; Xoplaki et al., 2004). The most recent global research covering the complete 20th century around the basin did not detect any generalized negative or significant trends (Peña-Angulo et al., 2020). Moreover, at more local scales, significant positive trends have been found in recent years, both in western (Chargui et al., 2018; Nouaceur & Murărescu, 2016) and eastern areas (Ajjur & Sami, 2021; Kafle & Bruins, 2009; Nashwan et al., 2019). These can sometimes be attributed to the increase of extreme events (Benabdelouahab et al., 2020; Hadri et al., 2021).

With spatial and temporal variability of precipitation trends being one of the main characteristics of Mediterranean climate areas (López-Moreno et al., 2009; Raymon et al., 2016; Seager et al., 2019; Zittis, 2018, among many others), a general question that has not yet been solved in climate analysis is about the comparison between different studies. This is true, not only because of the different dataset used, but also the periods analysed. As an example, Kelley et al. (2012) detected generalized negative trends in winter during the period of 1965–1994, but positive trends in the western Mediterranean basin and negative ones in the eastern part during the 1901–2007 period. Therefore, the reliability of climate research in Mediterranean environments would only be achievable if analysis were done using data of the highest quality, as well as the densest spatial and temporal information.

In this research paper we outline the new datasets from MOPREDAS_century (MOnthly PREcipitation DAtabase of Spain_century) with the aim of analysing precipitation trends in the western Mediterranean basin (Spanish mainland, Iberian Peninsula). This database combines National Climate Database archives from the Spanish Meteorological Service (AEMet), as well as data retrieved and digitalized from Annual Climate Summaries (ACS) (period 1916–1950). This extends back to the initial version of MOPREDAS (1945–2005) (Gonzalez-Hidalgo et al., 2011). The objectives were to analyse at monthly scale the significance of trend, their change over time and their temporal and spatial variations. This is done by using a moving windows approach from 1916 until present day.

2 | STUDY AREA

Mainland Spain is located in the Western Mediterranean basin and accounts for around 80% of the total Iberian Peninsula area. From a climate point of view, one of the most relevant characteristics is the location between two different and contrasting water masses: the Mediterranean Sea and the Atlantic Ocean. A second prominent geographical feature with climate effects is the global relief disposition. This consists mostly of longitudinal west–east mountain chains (from north to south: Cordillera Cantábrica, Sistema Central, Sistemas Béticos), while to the east the Sistema Ibérico develops from north to south, parallel to the coast. As a consequence, Atlantic storms from the west can affect far inland to the east, while the Mediterranean eastern perturbation only affects areas that are close to the coastline (Figure 1). Both of these factors explain why precipitations in central and western areas depend on very few synoptic configurations, mostly advection from NW-W-SW, while on the Eastern Mediterranean coastland precipitation depends on a higher variability of atmospheric conditions, which, in turn, also causes more local effects (Cortesi et al., 2014).

Much valuable research has been carried out on precipitation in the study area (see revision in Gonzalez-Hidalgo et al., 2011). Their global results suggested a negative but nonsignificant annual trend during the second part of the 20th century (del Rio et al., 2011; Gonzalez-Hidalgo et al., 2011), while at the same time detailing changes in seasonal rainfall with respective decreases/increases in the spring and autumn seasons (de Luis et al., 2010). However, these global results hide some more detailed ones because only generalized and significant trends were detected in March, June (negative) and October (positive), while scarcely any information is available from the previous decades.

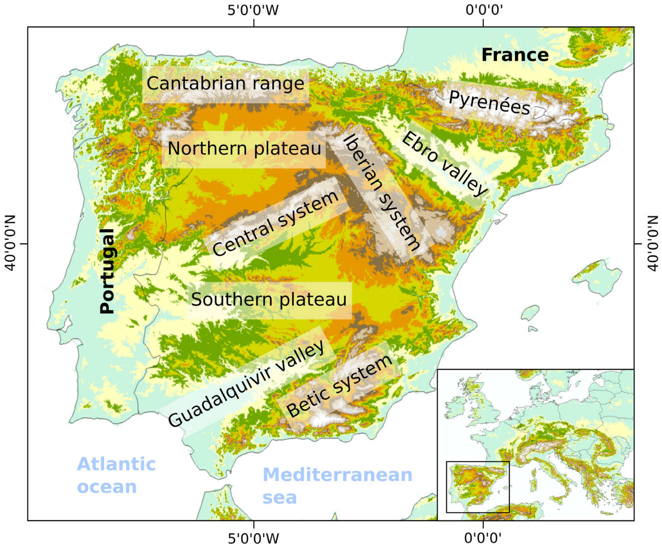

FIGURE 1 Study area and the main spatial distribution of mountain chains [Colour figure can be viewed at wileyonlinelibrary.com]

3 | DATA AND METHODS

The new MOPREDAS_century database (MOnthly PREcipitation DAtabase of Spain) has been created by combining digital data stored at the National Climate Database of the Spanish Meteorological Agency (AEMET) with new data digitized from the Annual Climate Summaries (ACS), which were published from 1916 to 1950 by the former National Meteorological Service of Spain. Dataset merging and quality control were equivalent to the ones used in the development of the MOTEDAS_century temperature dataset (Gonzalez-Hidalgo et al., 2021). We used local universal kriging to create monthly precipitation grids, following a two-stage process: first, interpolation of the probability of zero precipitation, and second estimation of the precipitation magnitude. For the latter, ratios of the observed monthly precipitation with respect to the 1961–2000 climatology were used as the dependent variable in order to rescale the data to a common scale. As independent variables we used elevation above sea level and the monthly mean climatology.

The grid was calculated to maximize the original information with the aim of achieving the highest possible spatial density. Then, instead of reconstructing individual series (i.e., data points), we adopted a monthly field reconstruction along the 1916–2020 period. At the same time, the procedure also avoids any redundancy that can be produced after reconstructing series because a monthly fields approach uses only original data. On the contrary, the main weakness has been that spatial density and spatial location changed from month to month. More information and comments about the approach can be found in Gonzalez-Hidalgo et al. (2021) and Beguería et al. (submitted). The grid resolution is 10 × 10 km.

Trend analysis was carried out by the nonparametric Mann–Kendal test on pre-whitened time series to eliminate temporal autocorrelation. The significance level selected was $\alpha = 0.10$, in accordance to previous precipitation research over the same study area (see Gonzalez-Hidalgo et al., 2011). We analysed the temporal evolution of trends by using fixed 30 and 60 years windows, and also by using increasing and decreasing temporal window lengths. Fixed intervals were used to avoid the effect of varying length in significance testing (sample size-effect). Increasing temporal windows ranged from 1916–1935 (20 years) to 1916–2020 (covering the complete study period) is similar to the process of updating a database year by year. Decreasing temporal windows ranged from 1916–2020 to 1996–2020 and simulate the outcome from the start of the records. Spatial variations in trends were analysed through map sequences covering different temporal windows, and also by calculating the percentage of grid cells with different trend sign and significance.

4 | RESULTS

4.1 | Annual precipitation in mainland Spain 1916–2020

The trend concerning the spatial evolution of annual precipitation is shown in Figure 2 with decreasing temporal windows and selected pictures at 10 years intervals. The figure shows the global time frame that covers MOPREDAS_century and indicates that there has been a mostly nonsignificant decrease in annual precipitation in the complete period (1916–2020). However, the trend varies considerably in different windows. If we consider the complete period, there are extended areas with negative and significant trends until the middle of the century which are specifically located in mountain areas to the north and south, as well as central areas where original information from the database is scarce. On the other hand, the decreasing windows covering the second half of the century (from 1951 to 2020) do not show extended areas with a significant negative trend. Moreover, this can be confirmed by checking the last window with a significant trend affecting more than 20% of the grid which was 1963–2020. These results mean that in the setup of

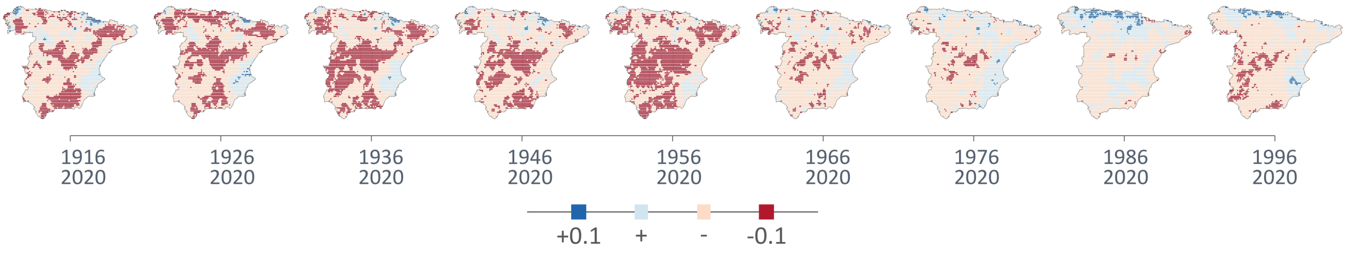

FIGURE 2 Annual precipitation trends in decreasing temporal windows from 1916–2020 (105 years) to 1996–2020 (25 years). Blue (red) colours indicate positive (negative) trends, while dark (pale) colour shades indicates significance (nonsignificance), according to Mann–Kendall test and significance level $\alpha = 0.10$ [Colour figure can be viewed at wileyonlinelibrary.com]

the meteorological observation network after the 1960s, nonsignificant negative trends were detected, and more precisely, a significant positive trend in the northern coastland areas and a nonsignificant trend in the whole land would have been identified during the most recent decades (see 1986–2020 windows in Figure 2).

4.2 | Monthly precipitation in mainland Spain 1916–2020

Annual trend analysis hides the highly variable monthly behaviour. In Figure 3, we show, month by month, the percentage of the grid accordingly signal (positive/negative) and the significance of trends using an increasing temporal windows approach, that expresses the effect of having an up-to-date database.

Increasing temporal windows trend analysis shows that no global pattern can be detected in months, and there is unambiguous evidence that changes in annual totals depend on only a few months. Then, negative trends were mostly generalized from 1916 to 2020 in March, and to a lesser extent in February, June and July. Globally speaking, October and, to a lesser extent, April and August have increased precipitation. In the rest of the months during 1916–2020 the total monthly values do not seem to change, although sometimes negative changes, both significant and generalized in November and February of the first decades, and positive ones in January and August are detected. These spatiotemporal changes suggest that, on the Spanish mainland, more than there being global changes in annual precipitation values, there has been a sequence of wet-dry periods.

Consequently, a decrease in global precipitation between 1916 and 2020 is not recent and is not generalized in all months; therefore, it seems to be linked to specific months during the 20th century.

Complementary analysis using decreasing temporal windows is shown in Figure 4. On the left side the percentage of the grid representing trend and significance is shown, and then, on the right, spatial distribution of trend at selected temporal windows. A complete sequence of charts (1 year steps) is detailed in Figure S1, Supporting Information.

In the sequence of windows from 1916 to 2020 extended areas of negative and significant trends were detected in March and June until 1970s; from the middle of the century in February and, in recent decades, in May, and also in September, October and December, albeit affecting lower percentages of the grid. In recent decades, an increase in precipitation in March and April has been observed and then, to a lesser extent, in February, June and November. Extended areas with positive and significance trends in October and September were also prominent until recent decades but these have recently changed to negative ones.

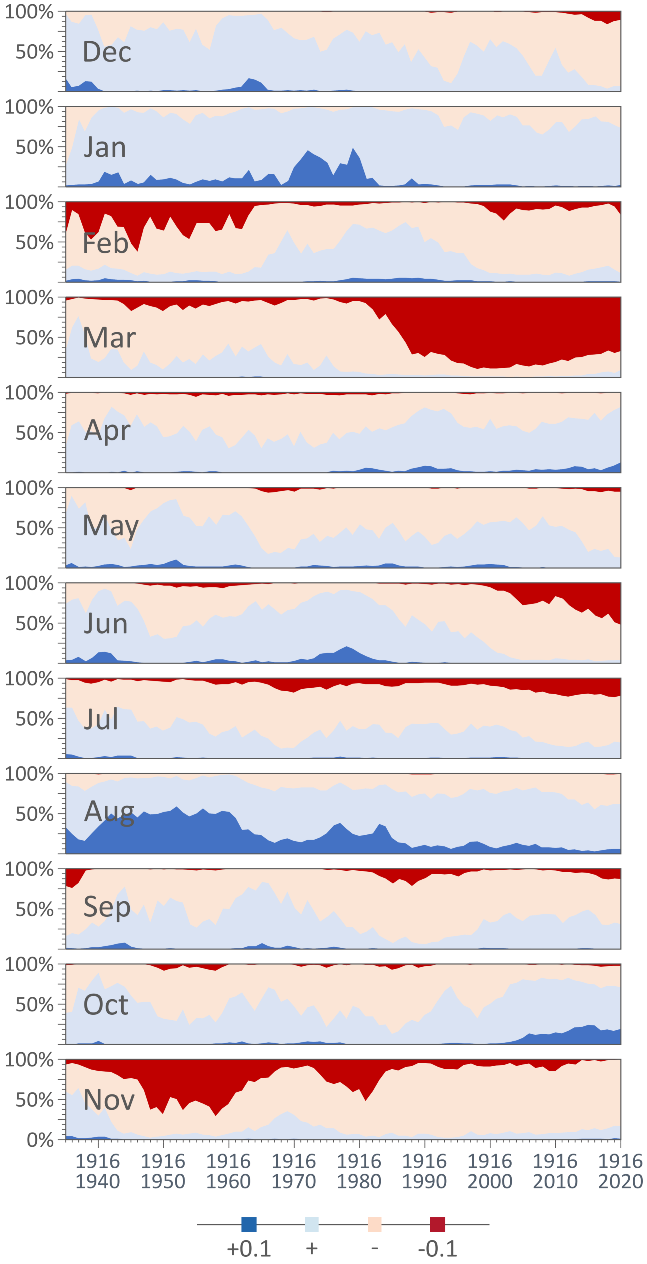

FIGURE 3 Percentage of grid cells according to their trend sign and significance under increasing temporal windows from 1916–1935 to 1916–2020, in 1-year increments. Legend as in Figure 2 [Colour figure can be viewed at wileyonlinelibrary.com]

The spatial evolution of trends is highly diverse and sometimes shows a spatial gradient along the temporal windows. One of the most prominent spatial gradients is the west–east one in March and October with opposite patterns; in March (−/+, western/eastern) and in October (+/−, western/eastern). Also, a north to south pattern can be detected in June (+/−, north/south) and September (−/+, north/south). In general, no global behaviour is found and trends vary from month to month in decreasing

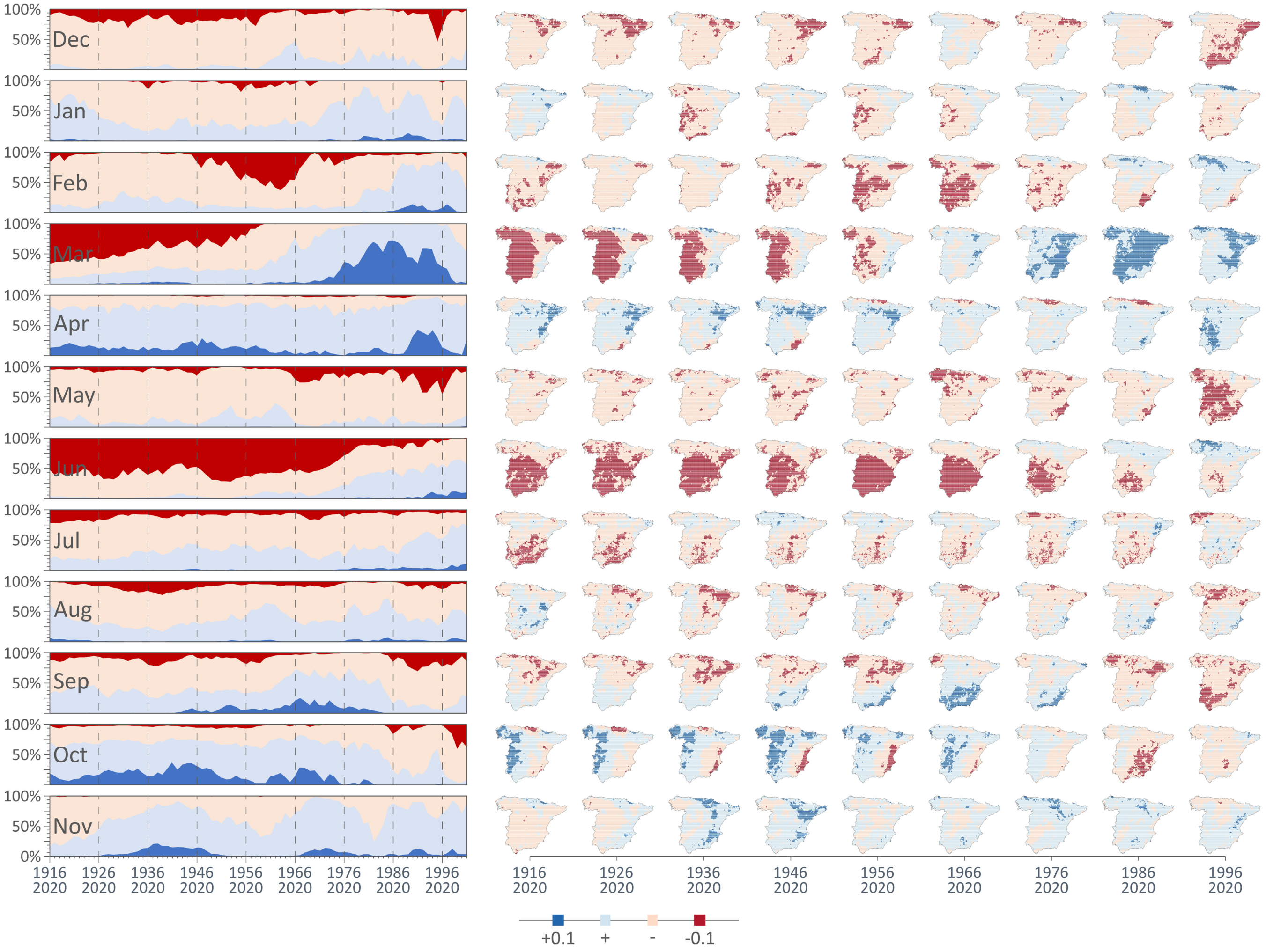

FIGURE 4 Percentage of grid cells according to their trend sign and significance under decreasing temporal windows from 1916–2020 to 1996–2020, in 1-year increments. Legend as in Figure 2. A complete sequence of charts is detailed in Figure S1 [Colour figure can be viewed at wileyonlinelibrary.com]

windows from 1916 to 2020. This suggests that the triggering factors for precipitation vary noticeably. Thus, different spatial distribution of trends can be identified in successive temporal windows: negative trends are mostly located to the south (June), to the Mediterranean fringe, on the southeast coastland (October, December), and to the west (March, February). On the contrary, positive trends can be found to the west (October), to the east (March, April, September and November), or in southern lands (September). Over time, the global pattern of monthly trends can vary (as in March) but the areas affected are not the same. Moreover, opposite trends can be found in the same area in different months such as in the north-inland Ebro basin which has a negative significant trend in December and a positive one in April and November from the 1916–2020 to 1956–2020 windows.

In brief, decreasing–increasing temporal windows show that patterns and the significance of trends on a monthly scale varied noticeably in mainland Spain during the 1916–2020 period and that current trends do not show a generalized, clear and significant pattern.

4.3 | Long-time trend analysis, 60-year temporal windows

Figure 5 shows the results of trend analysis that used fixed-length moving temporal windows (60 years). As in the previous figure, on the left-hand side we can see the percentage of the grid reflecting the signal and significance of trends, and on the right the spatial distribution of trends in selected windows. As before, the complete sequence (1-year steps) is detailed in Figure S2.

During the first part of the 20th century the most extended negative and significant trend areas were found in November, as well as in September, however, not until decades later. Meanwhile, positive trends were found at the same time in January and to a lesser extent in June,

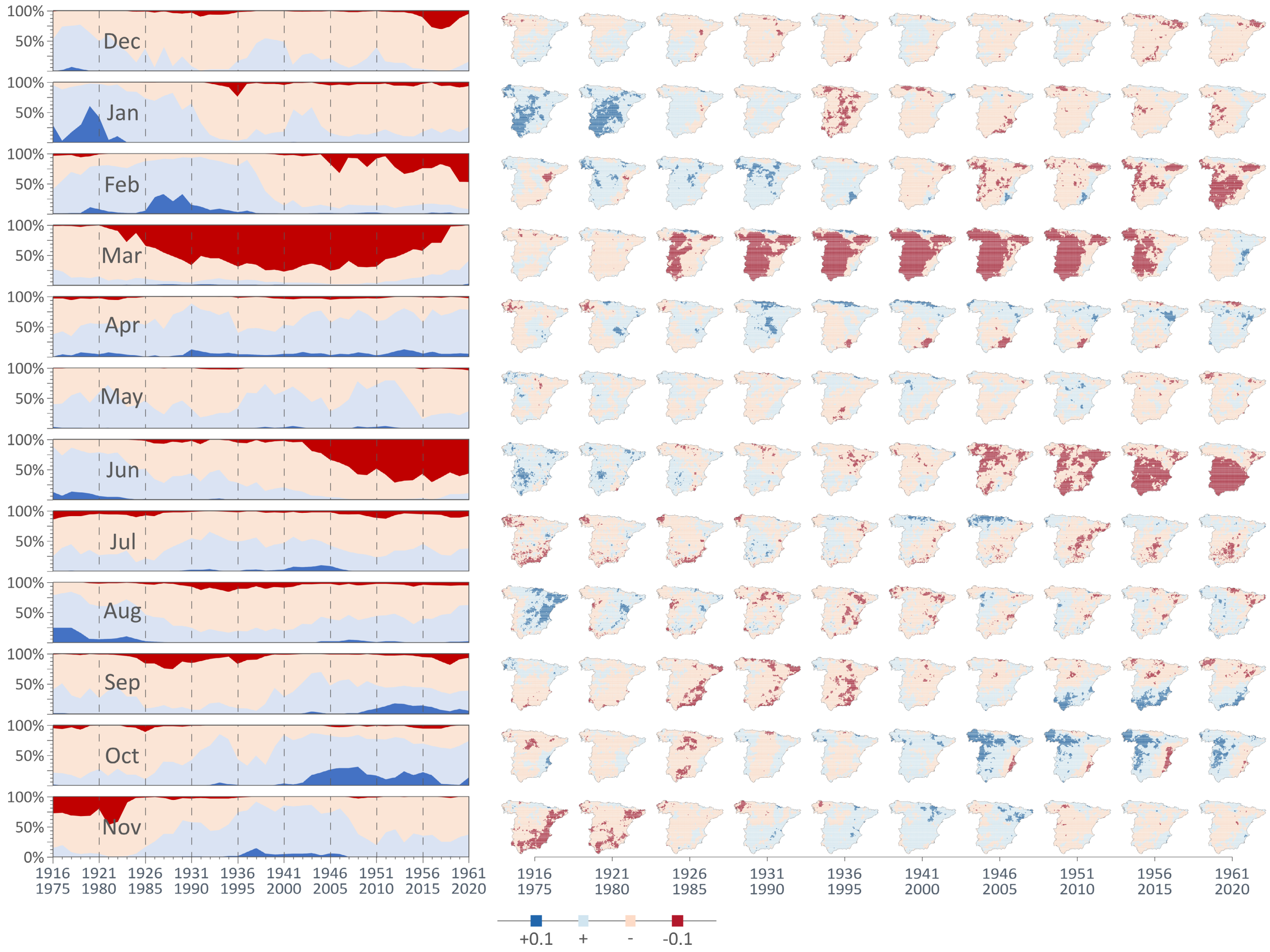

FIGURE 5 Percentage of grid cells according to their trend sign and significance under 60-year temporal windows from 1916–1970 to 1961–2020, in 1-year increments. Legend as in Figure 2. A complete sequence of charts is detailed in Figure S2 [Colour figure can be viewed at wileyonlinelibrary.com]

August, and later in February. The figure shows a significant decrease in precipitation in March from the 1930s until recent decades and also in June from the 1940 decreases are also detected in recent 60-year windows in February, although the area affected is lower than in March. Only September and October show significant positive trends in precipitation in extended areas in the recent 60-year moving windows.

The spatial distribution of trends varies between months and selected periods. In the cold season we did not find any substantial changes in December until the middle of the century when negative trends were located in eastern areas. In January, the most significant changes were located to the central south west where a positive pattern was detected at the beginning of the century which then changed to sparse negative ones recently, however, they are nonsignificant. The same is true in February, with a significant positive pattern at the beginning of the century to the northwest that changes to an extended negative one in the most recent 60 years that is mostly located to central-southern areas.

The most consistent and persistent spatial pattern is found in March, when generalized negative and significant trends were found in central-western areas from the 1920s. Nevertheless, this trend has recently changed to a significant positive one in areas located in a narrow fringe on the east coastland, whereas the significant negative pattern has disappeared from central-western areas in the most recent 60 years. The sequence of moving windows shows advancing and retreating patterns from west to east and vice versa. No generalized trend was found in April, but a significant and persistent positive pattern was detected in the northern coastland from the middle of the century while negative ones were found on the southeast coastland in different periods, which is the opposite of what occurred in the first few decades of 20th century. The same is true for May, where no generalized long-term changes seemed to take place. These results from the spring months must be taken into consideration because of their contribution to annual amounts in extended areas of mainland Spain and their relationships with agricultural farming practices.

The patterns in the summer months are highly diverse. During the first decade, precipitation increased in June mostly in the mid-southern areas and trends changed from the middle of the century to negative, significant and generalized in southern areas. The pattern in July was more variable and was similar to spatial distribution of trends in April, with significant and positive trends to the north and negative one to the south, although not in extended areas. In the first 60-year window of the century, positive and significant trends were observed in August in eastern areas that have, however, disappeared in recent periods.

Once again the autumn months show spatial variations. During September recent positive trends were located in south and south eastern coastland areas where in previous periods negative significant trends were once found. This spatial distribution is clearly different from October when a positive significant pattern had been found in northwestern inland areas, while negative trends were located in eastern coastland sectors from the middle of the century onwards. The negative pattern in November during the first decades is mostly located on the Mediterranean coastland; however, this has disappeared in recent windows.

In brief, 60-year moving windows firstly showed findings of positive and significant trends in January, June and August, and then again later in February, as well as during recent decades in September and October. On the other hand, negative trends were predominant in the first few decades during November, from the middle of the century in March, and then again more recently in June and February. Also January (1936–1995), September (1929–1988) and December (1959–2018). In Table 1 the most recent 60-year moving windows are shown in which significant trends were detected in extended areas (more than 20% of the grid). The most surprising result is that in the most recent 60-year window the trend is only statistically significant and negative in extended areas of the grid in February (central-south western areas) and June (southern). Positive significant trends in extended areas were found in previous windows (1956–2015) in September (southeastern, 14.5% of grid) and northwestern inland (October, 22.7% of grid).

4.4 | Short-time trend analysis, 30-year temporal windows

A complementary short-term analysis has been done by using moving windows of 30 years in length. This short-term approach offers a more detailed set of results about the present situation from which other variations emerge that remain hidden in a longer 60-year moving window. This is the case if we consider that many of the atmospheric patterns that can affect precipitation trends in Iberian Peninsula (such as North Atlantic Oscillation, Western Mediterranean Oscillation, etc.) currently vary in cycles lasting a few decades. In Figure 6, as in the previous figures, the evolution of the grid percentage under different signal of trend (+/−), their significance (left), and spatial distribution of trends at selected periods (right) are detailed. As before, the complete sequence (1-year steps) is shown in Figure S3.

TABLE 1 Most recent 60-year temporal window in which significant trends were found in more than 20% of the grid, for each month

	Trend (+)	Trend (−)
January	1921–1980	1936–1995
February	1930–1989	1961–2020
March		1958–2017
April		
May		
June		1961–2020
July		
August	1918–1977	
September		1929–1988
October	1956–2015	
November		1923–1982
December		1959–2018

Negative significant trends in more than 20% of the grid surface are only achieved in February, March and June during the second half of the 20th century and more or less simultaneously. Moreover, extended negative trends were found in November during the first decades.

Significant positive and negative trends were synchronously detected in different areas in the first half of the century in January, May and August. In the mid-century windows, significant positive trend were found in January, February, June and November. In the recent decades in September, October, February and March.

The spatial distribution of trends over 30 years is shown in selected temporal windows in the right-hand panel of Figure 6. Generally speaking (see Figure S3 for complete sequence), the positive pattern is located in the southeast in January and December during the first decades, whereas a negative trend is found in the middle of the century. In February, the positive trend moved from western areas, where it was found prior to the middle of the century, to the north which had had a generalized negative pattern for some decades. For more than

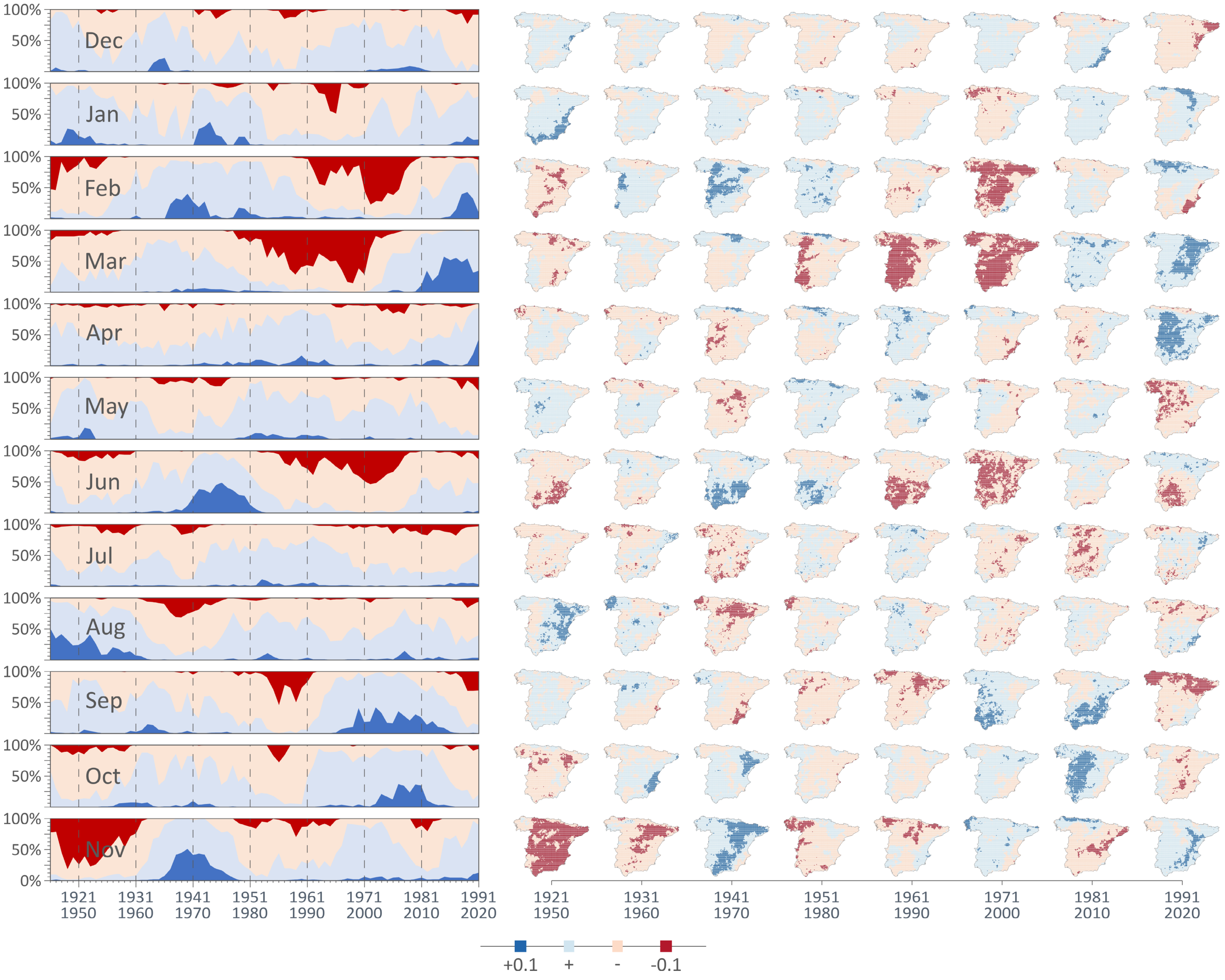

FIGURE 6 Percentage of grid cells according to their trend sign and significance under 30-year temporal windows from 1916–1945 to 1991–2020, in 1-year increments. Legend as in Figure 2 [Colour figure can be viewed at wileyonlinelibrary.com]

30 years the winter months did not show trends of any significance in more than 20% of the grid's surface. Moreover, positive trends seemed to be located to the north, while negative ones on eastern coastland.

In March, in the middle of the century, statistical significant trends (negative) are located in central-western areas after 30-year windows with positive one having been to the west. The negative pattern has changed in recent 30-year windows to positive but the location of this trend is found to the east. There is no clear distribution of patterns in April and May until recent 30-year windows; significant positive trends are detected in extended areas in central-western locations in April in some recent windows, while in May, in recent decades, negative trends are detected to the west.

Summer months are highly variable and spatial patterns probably reflect the effect that convective processes have on precipitation genesis. Negative trends in June at the beginning of the period were found to the southeast, but later changed to positive ones. These subsequently changed to negative again in the second half of the century. In the most recent 30-year windows, significant negative trends are located to the southwest. In July, there are negative trends during the first decades in the north, and no clear spatial distribution is found in recent decades. Finally, in August, significant positive trends were detected at the beginning in the eastern peninsula, and negative ones in northern lands in the middle of the century. In the summer months during the last 30-year window no significant trends have been detected in more than 20% of the grid surface.

In autumn, the spatial variability of trends along the windows is high. In September, according to the windows selected, significant positive trends were identified inland to the north west during the first decades; negative trends

TABLE 2 Most recent 30-year temporal window in which significant trends were found in more than 20% of the grid, for each month

	Trend (+)		Trend (−)	
January	1944–1973	37.7%	1966–1995	49.6%
February	1990–2019	32.0%	1978–2007	23.9%
March	1991–2020	34.1%	1972–2001	30.4%
April	1991–2020	42.7%		
May			1991–2020	22.7%
June	1950–1979	27.1%	1977–2006	24.1%
July				
August	1927–1956	20.3%	1941–1970	22.3%
September	1981–2010	25.5%	1991–2020	30.8%
October	1981–2010	34.3%	1956–1985	28.4%
November	1944–1973	23.9%	1982–2011	21.3%
December	1936–1965	21.8%	1989–2018	23.4%

were found in different areas from south east to north east during the middle of the century and then to the north in the last 30 years. Also, in October, noticeable changes occurred. In recent decades positive trends have been located inland to the northwest, while during the first decades they were in the south east on the Mediterranean coast and in the northeastern areas. Lastly, significant negative trends were found in November in central-eastern areas (at the beginning) and then changed to positive ones by the middle of the century. Changes from negative to positive were also observed in eastern parts of the land. In recent decades, no significant generalized trends have been detected during the autumn months in more than 20% of the grid except in September (northern coastland). Other prominent changes were identified in November along the eastern side, although they were positive (affecting less than 20% of the grid).

The most recent moving windows in which trends were statistically significant in extended areas (>20% of the grid) are shown in Table 2.

Apart from September to the north, and May to the northwest (Table 2 and Figure 6) no other month shows significant generalized negative trends in the most recent 30-year window (1991–2020). On the contrary, during the same period the trends are statistically significant and positive in an extended area in March to the east (34.1% of the grid), April to the west (42.7% of the grid), also in February to the north in 1990–2019 (32% of the grid). In November, a clear significant positive trend is located in eastern areas nevertheless the significance of trend affects less than 20% of grid. The well-known positive pattern which existed in previous periods in September (south east) and October (west) until 1981–2010 changed to negative in northern areas in September (Table 2). The same is true for negative trend in March.

5 | DISCUSSION

5.1 | No clear pattern

The Mediterranean region is considered a climate ecotone given its latitudinal position, and models suggest that climate change could have been detected first in this area (Giorgi & Lionello, 2008; Tuel et al., 2021; Tuel & Eltahir, 2020). One of the reasons frequently cited to have caused this occurrence is the movement of high subtropical pressure to the north and the expansion of Hadley's cell (Nojarov, 2017; Oroud, 2018). In these environments, water resources are coming under increasing pressure due to high population density, as well as the demands arising from agricultural and tourist activity.

On the other hand, the spatial density of meteorological stations and their spatial distribution have been recognized as some of the most crucial factors that explain the differences between climate datasets (Isotta et al., 2015; Sun et al., 2018). These effects also stand out more in areas where spatial and temporal variability of climate elements are high. This is the case with Mediterranean climate precipitation, and at least, partially explains the different results achieved with regards to several datasets around the Mediterranean basin (Gampe et al., 2019; Zittis, 2018). It also explains the discrepancies between model and observatory trends, particularly in regional and subregional detailed scales (Barcikowska et al., 2020; Barkhordarian et al., 2013; Tuel et al., 2021).

The aforementioned paragraphs explain the abundant research that has been carried out on precipitation around the Mediterranean basin and reinforce the value of the present study, which has been done using a new database that offers the highest spatial density from the original information available, after a complete retrieval processes from original sources combined with official databases from the AEMet. The global conclusion is that, in mainland Spain, annual precipitation mostly decreased at an unsignificant rate from 1916 to 2020. Nevertheless, this global trend hides a high spatial and temporal variability found at monthly scales. It also shows that trends are not statistically significant for the most recent decades. Furthermore, significant negative trends seem to be located, in preference, in areas where spatial density of information is low and the values of the grid were interpolated.

Another important result is that the moving windows approach applied at a fixed length identified that the trends regarding the annual amount of precipitation depended on the behaviour of specific months, the length of the period, and the selected period. In particular, in 60-year moving windows we detected a decrease in precipitation in February, March and June from the middle of the century but the areas affected varied, as well as the specific periods. While the areas affected in February and March were predominantly located to the west, in June they were southerly. Over time, the decrease in March changed to February and then, more recently, to June. In the meantime, increments in precipitation levels are also clear in the second part of the 20th century during October and September; nevertheless, they affected lower extensions and were spatially located to the west in October, and on eastern coastland in September. The analysis of sequential charts indicates that trends changed over time, and no clear spatial pattern emerges except for in March (west–east and vice versa) and in June (south–north).

A more restricted moving window using a 30-year time span suggests that between 1916 and 2020 there existed a sequence of wet and dry periods that varied between months and years. To conclude, in most parts of the Spanish mainland precipitation has not decreased significantly over recent decades, and in some months it has even increased significantly (as in March and April).

These facts indicate that it is necessary to combine analysis from different periods (i.e., temporal windows and length) to be able to give correct context to the different modes of variability that can be inserted. In brief, the results of the monthly trend analysis once again found a high spatiotemporal variability of precipitation in the western Mediterranean basin.

5.2 | Four months in question: February and March versus September and October

In extended areas of mainland Spain the seasonal precipitation regime changes from a pure winter maximum (south west and northern areas) to a bimodal one in which spring (mostly inland) and autumn (mostly on the eastern coastland) predominate. This spatial distribution was affected by dramatic changes during the 1945–2005 window because of negative trends in March and positive ones in October with the results of the increase at their maximum in autumn inland (de Luis et al., 2010; Gonzalez-Hidalgo et al., 2011), and then as a result spatial distribution of bioclimatic conditions have changed (see López et al., 2017). Current research has also found negative trends during the second part of the 20th century in February, although this only affects a small area and begins later than those from March. In both cases we detected an expansion-contraction spatial gradient from west (−) to east (+), and recent decades have shown extended areas with significant positive trends; however, these are located in the eastern areas of the Iberian Peninsula.

This negative trend in February and March was identified around the Mediterranean western basin (López-Moreno et al., 2009), Tunisia (Snoussi et al., 2018) and Italy (Cannarozzo et al., 2006; D'Oria et al., 2017; Gentilucci et al., 2018). Sometimes, it is only in February, as in Algeria (Bouklikha et al., 2021) while many papers reported it in the eastern basin. Finally, negative trends in March have been reported in Morocco (Ouatiki et al., 2019), Algeria (Achite & Ouillon, 2016; Bougara et al., 2020), Italy (Boi, 2018; Caloiero et al., 2019, 2020), France (Folton et al., 2019), Spain (Gonzalez-Hidalgo et al., 2011; Paredes et al., 2006) and Portugal (Paulo et al., 2012). Generally speaking, the decrease from the middle of the century in both months was attributed to a NAO positive phase which was more effective in the western basin than in eastern areas. These results are in line with the evolution of radiation and clouds in the Iberian Peninsula by Sánchez-Lorenzo et al. (2007), as well as with the west–east spatial pattern and the negative/positive trend of precipitation in the Iberian Peninsula set out in this paper.

Recent changes in trends towards positive values in March and February detected in MOPREDAS_century dataset have also been detected in Algeria (Achite et al. 2016), Italy (Caloiero et al., 2020), and particularly, in the Moroccan Atlas in March (Diani et al., 2019). These changes in trends could be a response to changes in NAO conditions. Kalimeris and Kolios (2019) suggested a connection between the positive trend in February during the 1998–2017 period in central areas of the Mediterranean basin, and the regulation of low variability of the atmospheric NAO and Scandinavian (SCAND) patterns. In brief, the most current trends found in the Iberian Peninsula are coherent with the results from adjacent areas and seems to respond to a generalized spatial pattern.

On the other hand, positive trends of precipitation at the end of summer in September and October, previously identified for decades inland in northwestern areas, coincide with results from the Moroccan Atlas (Diani et al., 2019), Algeria (Achite & Ouillon, 2016; Bougara et al., 2020; Bouklikha et al., 2021), Italy (Bartolini et al., 2018) and the western basin (López-Moreno et al., 2009). This also coincides with papers that only detect positive trends in October; such as in France (Folton et al., 2019), Spain (del Rio et al., 2011; Gonzalez-Hidalgo et al., 2011; Nieto & Rodríguez-Puebla, 2006) and Portugal (Paulo et al., 2012). A more complex behavioural pattern with a combination of positive trends in September and negative in October was detected in Italy (Gentilucci et al., 2018) and Tunisia (Snoussi et al., 2018).

The positive trends in September during 1950–2014 has been related to the effect of aerosols; thus Nojarov (2017) suggested that the decrease of aerosols weakens the high subtropical pressure and increase tropical cyclones frequency and intensity and cloudiness in the Mediterranean. On the contrary, Tang et al. (2018) has indicated that the relationship between aerosols and clouds (assumed by certain models) does not seem to exist in the Mediterranean basin. Finally, Tuel et al. (2021) suggested that, according to different models, precipitation will continue to decrease in winter and spring as a consequence of human emissions and aerosols.

The aforementioned results show that the most important contributions to annual totals precipitation (spring and autumn precipitation) have suffered dramatic changes on the Spanish mainland and more recently these changes are in line with the review of the most recent papers on monthly trends of precipitation in the western Mediterranean basin. However, the reasons are far from clearly understood. Accordingly, it has recently been suggested by Peña-Angulo et al. (2020) that different CMIP (3, 5 and 6) experiments in the western Mediterranean basin can largely overestimate the real evolution of precipitation during the last century. These results show that precipitation in the study area does not follow the pattern of human emissions in the atmosphere. Furthermore, spatial variability of trends observed in sequential moving windows suggests that this variability does not depend on global factors.

6 | CONCLUSIONS

Monthly precipitation trend analysis in mainland Spain during the 1916–2020 period does not detect any global significant trend. Observed changes are highly variable at spatial and temporal scales and no generalized pattern has been found between months.

The moving windows approach detected different wet-humid periods; thus trends are not monotonic. The most prominent changes affect February–March, as well as September–October. These changes were produced under a spatially defined pattern and they are important due to their percentage contribution to annual totals. These trends are coherent with those observed in western Mediterranean basin.

Monthly precipitation trends have been mostly non-significant over recent decades.

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