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A moving windows visual approach to analysing spatial variation in temperature trends on the Spanish mainland 1951–2010

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ABSTRACT: In this article, we approached the study of spatiotemporal variation in trends for the monthly mean values of maximum and minimum temperatures on the Spanish mainland between 1951 and 2010, in order to find out how length and selected periods affected trends. The trend and significance signals were calculated every month and for each cell individually, in a high spatial resolution grid (Mann–Kendall test) by using decreasing and increasing temporal windows (from 20 to 60 years and vice versa). Finally, the results are presented as a sequence of temporal window trend maps to show the spatiotemporal variability of trends at high resolution over the years. The results of increasing temporal window trends show that temperatures have increased overall on the Spanish mainland, but the impact is different for cold and warm months, maximum and minimum temperatures, and the area affected by significant trends varies depending on the month. The positive and significant trend affecting >20% of the total area extends in a west–east gradient during the cold months, while the reverse is true for the warmest ones. The analyses from decreasing the length of moving windows also vary greatly among months. The areas affected by significant trends are highly variable month-on-month, differ for maximum and minimum temperatures, and evolve in different ways over time. Few months show a significant trend during the last 30 years, and spatial distribution differences among trends for the maximum and minimum temperatures are detected. Spatially, a more complex gradient can be observed, but the global east–west and west–east gradient can also be generally seen in the warmest or coldest months. These findings show that a selected period determines the final trend. Furthermore, the results suggest that recent warming processes on the Spanish mainland have high spatial variability that differs among months and maximum and minimum temperatures, and has not been constant.

KEY WORDS spatial analyses; temperature; temporal analyses; trend

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1. Introduction

The significance and trend rates of any climate variable depend heavily on the selected period (Soon *et al.,* 2004; Liebmann *et al.,* 2010; Lüdecke *et al.,* 2011; Santer *et al.,* 2011; Mauget and Cordero, 2014; Anderson and Kostinski, 2016; González-Hidalgo *et al.,* 2016). This is particularly true in climate research, because natural variability and induced forcing may vary at different spatial and temporal scales, depending on global and local factors (Soon *et al.,* 2004; McKitrick, 2014; Marotzke and Forster, 2015). Thus, de Elía *et al.* (2014) suggest that the different spatiotemporal timescale at which climate change takes place would eventually have serious consequences for adaptation requirements, and they explored alternative ways of defining the timescale of climate change. All these arguments were summarized years before by Kendall *et al.* (1983), section 45.12), quoted in Mills (2006), when indicating that (speaking of trend) '… 'long'... is a relative term, and what is long for one purpose may be short for another'. Among others, Loehle (2009), Liebmann *et al.* (2010), and Santer *et al.* (2011) suggest that a minimum length of around 20 years should be used in climate trend analyses, because the signal/noise ratio is small (<1) in short timescales and becomes larger over longer periods (Santer *et al.,* 2011).

Generally speaking, trend analysis faces several problems (Mills, 2006; McKitrick, 2014). The first one is autocorrelation (i.e. the non-independence of data throughout the series), because it seriously interferes with type I errors and power of trend detection, and for which different filtering methods have been suggested to ensure trustworthy final results (Wang *et al.,* 2015). The second one is the value or magnitude of trend and significance. Although the magnitude can be calculated more easily from the linear regression slope or by nonparametric methods, this is not the same for the significance, given that

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it depends on the selected null hypothesis, which is, to a certain extent, subjective (Cohn and Lins, 2005). Last but not least, the length of the series and selected period can dramatically modify the final results, because the linear behaviour of the time series is difficult to deduce in many circumstances (Gleisner *et al.,* 2015). Recently, Fischer and Paterson (2014) described an approach to identifying the effect of both climate-related factors and observation/site-related factors on trends in meteorological data series, after noticing that trends in climate time series are often nonlinear and asymmetric in time (Cohen *et al.,* 2012, i.e. the trend is different for different seasons), while Ribes *et al.* (2016) discussed the uncertainty in linear trends, using a white noise assumption on the residuals for detecting temperature behaviour, and suggested that nonlinear estimates should be preferred to describe any climate trend.

Different approaches have been applied to solving the effect of length and selected period of temporal series on trend, such as calculating trends over a prescribed range of possible start and end years, the moving windows, the wavelet analyses for identifying optimal trend-fitting periods, or solving trend-fitting periods. Among many recent articles, Mauget and Cordero (2014) described the optimal ranking regime method to identify intra-decadal to multi-decadal regimes in US climate division temperature data from 1896 to 2012; Gil-Alana (2015) applied linear and segmented trends in sea surface temperature data analyses using fractional integration, allowing long memory behaviour in the de-trended series; Anderson and Kostinski (2016) examined the evolving variability of monthly mean temperatures and their dependence on the beginning and final year by using an index based on record-breaking statistics; Marotzke and Forster (2015) analysed simulations and observations of global mean surface temperature from 1900 to 2012, using a multiple regression approach in all possible 15- and 62-year trends, concluding that the differences between simulated and observed trends were dominated by random internal variability over the shorter timescale and by variations in the radiative forcing used to drive models over the longer timescale. Last but not least, several articles have tackled the problem of presenting all the possible temporal windows in triangular diagrams, including the significance, and the signal or rate of the trends, avoiding *a priori* selection of any period (Brunetti *et al.,* 2006; González-Hidalgo *et al.,* 2010, 2016; Liebmann *et al.,* 2010; Servain *et al.,* 2014).

Generally speaking, the variability in temperature trends in time have been approached by using global, national, or regional series. These analyses do not usually capture spatial variability, for which in some cases different statistical techniques such as principal component analyses or cluster analysis (see an example for the Spanish mainland in Brunet *et al.,* 2007) have been applied to the original data set to analyse global spatial variability, and by which homogeneous areas are defined, performing the analysis in regional or subregional, instead of global or national series. However, these results do not spatially capture the combined effect of both on trend: the length of series and the selected period (i.e. start–end year). On the other hand, the temporal window approach presented in a triangular diagram is an easy way to detect the combined effect on trend of length and selected period, but is virtually impossible to apply to each station or cell individually when a high spatial density data set or grid is analysed. In this case, an optimal solution to showing the spatial variability of trend over time is as follows: instead of a triangular diagram for each station or cell (virtually impossible), a sequence of charts (maps) is created.

In this article, we will present an analysis of the spatial variation of trends across the maximum ($T_{\max}$) and minimum ($T_{\min}$) monthly mean values on the Spanish mainland (1951–2010) using the aforementioned approach. The research completes previous work focused on the spatial variability of the 1951–2010 trend (González-Hidalgo *et al.,* 2015) and temporal variability of trends for a Spanish average series of minimum and maximum temperatures (González-Hidalgo *et al.,* 2016). In the first case, we analysed the spatial variability of trends over the complete period included in the MOTEDAS data set (1951–2010), month by month; in the second, we averaged the whole data set in a national average series and then studied the changes in trend over time. Both approaches still leave unanswered the question relating to changes in trends in the combined domain of space and time, which is the aim of the present article.

The article is organized as follows: in Section 2, we briefly present the study area and the database used and summarize the temporal windows approach and the selected sequence of temporal windows analysed. Section 3 presents the main results and is divided into two sub-items showing the analyses obtained from increasing and decreasing the length of the period for trend estimation. Finally, Sections 4 and 5 discuss the global results and conclude with a summary of the main points.

2. Data and methods

The Spanish mainland is located in the Iberian Peninsula, a place that has been cited on many occasions as a suitable area to analyse the change in climate, as it is home to various effects arising from its latitudinal position and location between two strongly contrasting bodies of water: the Atlantic Ocean and Mediterranean Sea. As a consequence, it has been suggested as an ideal place for observing seasonal changes in atmospheric circulation, meridian displacements of centres of action, pressure systems, and associated flows, and the effect of contact between land-water masses. Furthermore, the relief could cause effects to be superimposed and contribute to a varied climate response in a mini-continental area (Figure 1). Finally, during the last few decades, dramatic land use changes have occurred in mainland Spain, particularly the Mediterranean coastland and mid-southern areas (González-Hidalgo *et al.,* 2015). In this study, we analysed the high-resolution grid ($10 \times 10\,\mathrm{km}^2$, period 1951–2010) of monthly mean maximum ($T_{\max}$) and

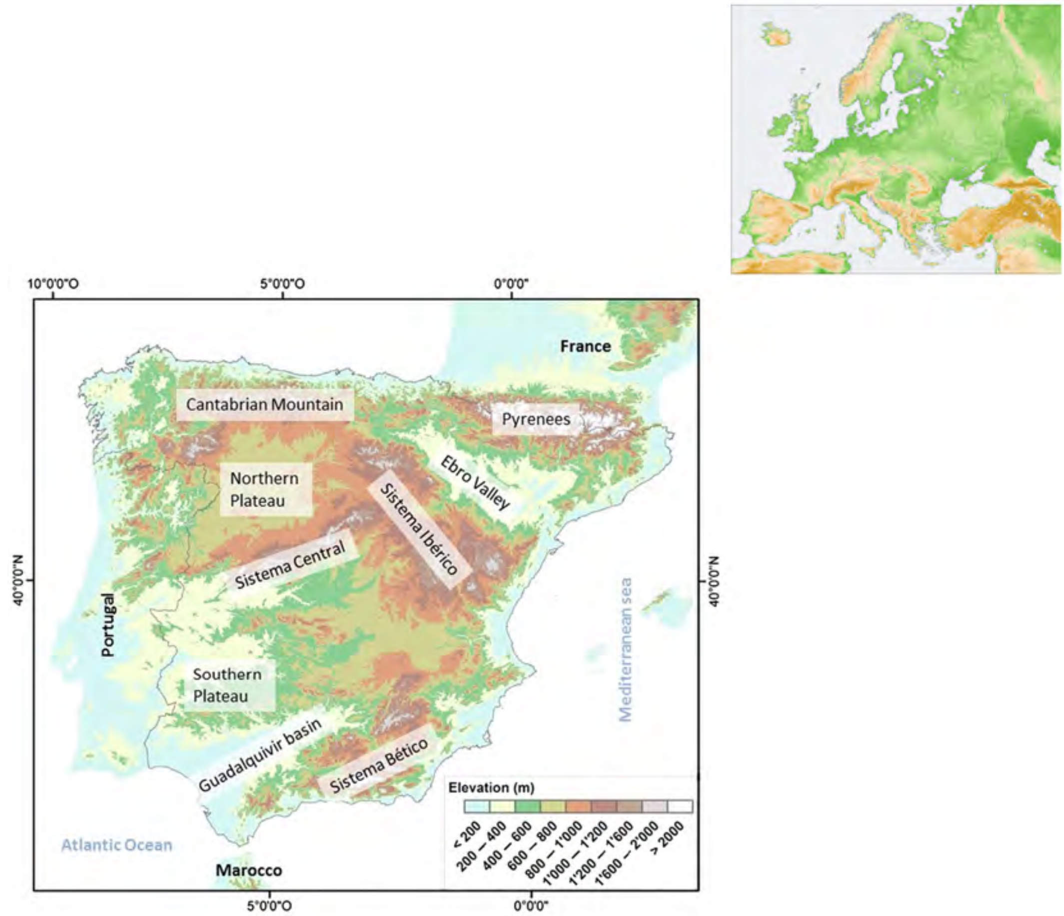

Figure 1. Location of the study area: Spanish mainland in the European continent. [Colour figure can be viewed at wileyonlinelibrary.com].

minimum (T_{min}) temperatures from the MOTEDAS data set (González-Hidalgo *et al.,* 2015).

The variations of monthly trends in time were analysed by using two types of temporal windows. The first fixed the starting year at 1951 and increased each run by 1 year up to 2010. In the second, we started by using the complete series, i.e. 1951–2010, and fixing the ending year in 2010, we decreased each run by 1 year. For each cell, month, and thermometric measurement, we calculated the signal and significance of trend by using the Mann–Kendall test. To avoid loss of power in autocorrelation (Wang *et al.,* 2015), we tested it at each temporal window using a pre-whitening method and corrected in affirmative case before trend analyses following the procedure described in González-Hidalgo *et al.* (2015). Increasing the length of temporal windows expresses the cumulative effect of data in time and is similar to the continuous updating procedure in any data series; those series correspond to a sequence from 1951–1970 to 1951–2010. The results from decreasing the length express different effects on trends, as if a station network had begun to record data in the initial year of each temporal window. In that case, the series would correspond to a sequence of temporal windows from 1951–2010 to 1991–2010.

In both cases, the complete trend series were calculated from 60 down to 20 years, bearing in mind that 20 years is the minimum length required to detect climate signals not produced by normal variability (Loehle, 2009; Liebmann *et al.,* 2010; Santer *et al.,* 2011; Servain *et al.,* 2014).

In each temporal window, the spatial distribution of trend (using two p levels $p < 0.01$ and $p < 0.05$) was mapped and the percentage of total land with significant trend ($p < 0.05$) was calculated. Given that is virtually impossible to present the complete collection of maps for showing the temporal evolution of monthly trends (Appendix S1, Supporting Information), only specific temporal windows showing the spatiotemporal warming evolution in different months were selected. Moreover, the trend magnitude is misleading without the associated uncertainty, and it is not possible to represent all these three parameters in the maps.

3. Results

The complete spatial analyses comprising the whole set of temporal windows is included in Figures S1–S4, Appendix S1 for T_{max} and T_{min}, with increasing and decreasing temporal windows, respectively), and the main text only presents a discrete sequence of maps at regular time steps of 10 years. In Appendix S1 the data of Figures 2, 4, 6, and 8 are also included (Tables S1–S4 for increasing and Tables S5–S8 for decreasing temporal windows).

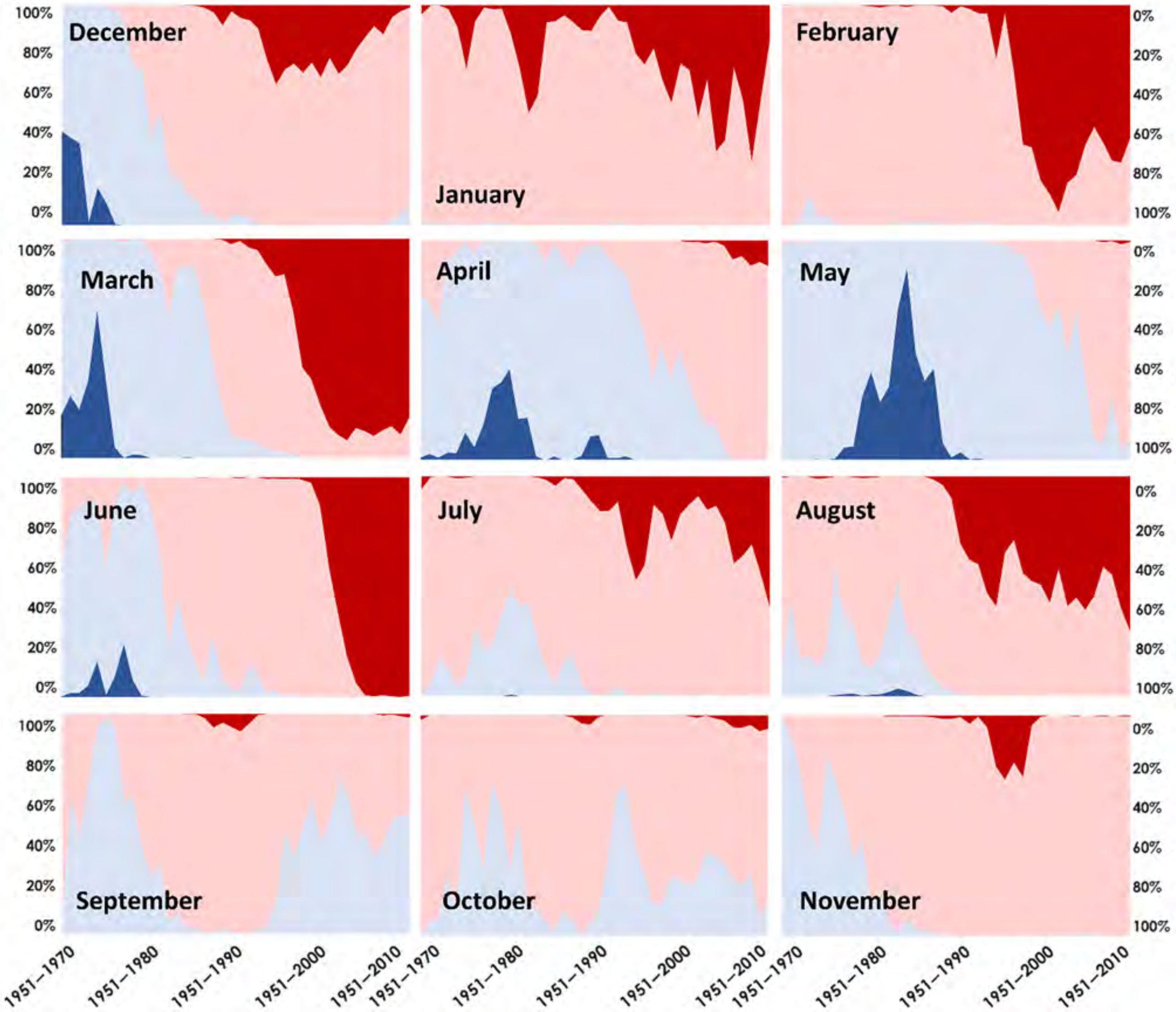

Figure 2. T_{max} monthly analyses of the percentage of total land (cumulative) under increasing temporal windows according to trend. The figure shows the area affected by positive and negative (red/blue), significant/no significant (strong/slight colour) trend ($p < 0.05$). The x-axis label indicates the temporal windows (start–end year) from 1951–1970 to 1951–2010, and the y-axis label indicates the percentage of total under specific signal and significance of trend. Tables S1–S4 in Appendix S1 for individual windows data. [Colour figure can be viewed at wileyonlinelibrary.com].

3.1. Increasing temporal windows

The evolution of the percentage of land affected by significant trend of T_{max} in successive increasing temporal windows from 1951–1970 to 1951–2010 shows that the months highly affected by significant positive trends are January, February, March, June, and August (Figure 2 and Tables S1–S3 in Appendix S1). From the middle of the 1990s in February and March, the area affected by significant positive trends is higher than 75% of total land, while in December and January the area affected by significant positive trend is slightly smaller (<50% of total, Figure 2 and Tables S1 and S2 in Appendix S1). June is the only month in which all the Spanish mainland is affected by a significant positive trend in the last temporal windows, i.e. a warming of the overall territory between 1951 and 2010. During July and August warming seems to start early, despite the total land affected by a significant positive trend being less in the global period (between 50 and 70%, Figure 2, Table S3 in Appendix S1). Furthermore, during the coldest months, from December to March, significant positive trends expanded and increased from west to east (Figure 3 and for complete sequence Figure S1 in Appendix S1). On the other hand, during the warmest months of June, July, and August, the areas with positive significant trends increased from east to west (Figures 3 and S1 in Appendix S1). In the other months, April, May, and September–November, we did not detect large areas with significant trends in maximum temperature in the successive temporal windows (Figures 2, 3, and S1 and Tables S2 and S4 in Appendix S1).

This analysis also discovered periods with a significant decrease in monthly mean temperatures, particularly in March, April, and May, affecting north midland, and also southern areas in June and August during the first decades (Figure S1 and Tables S2 and S3 in Appendix S1).

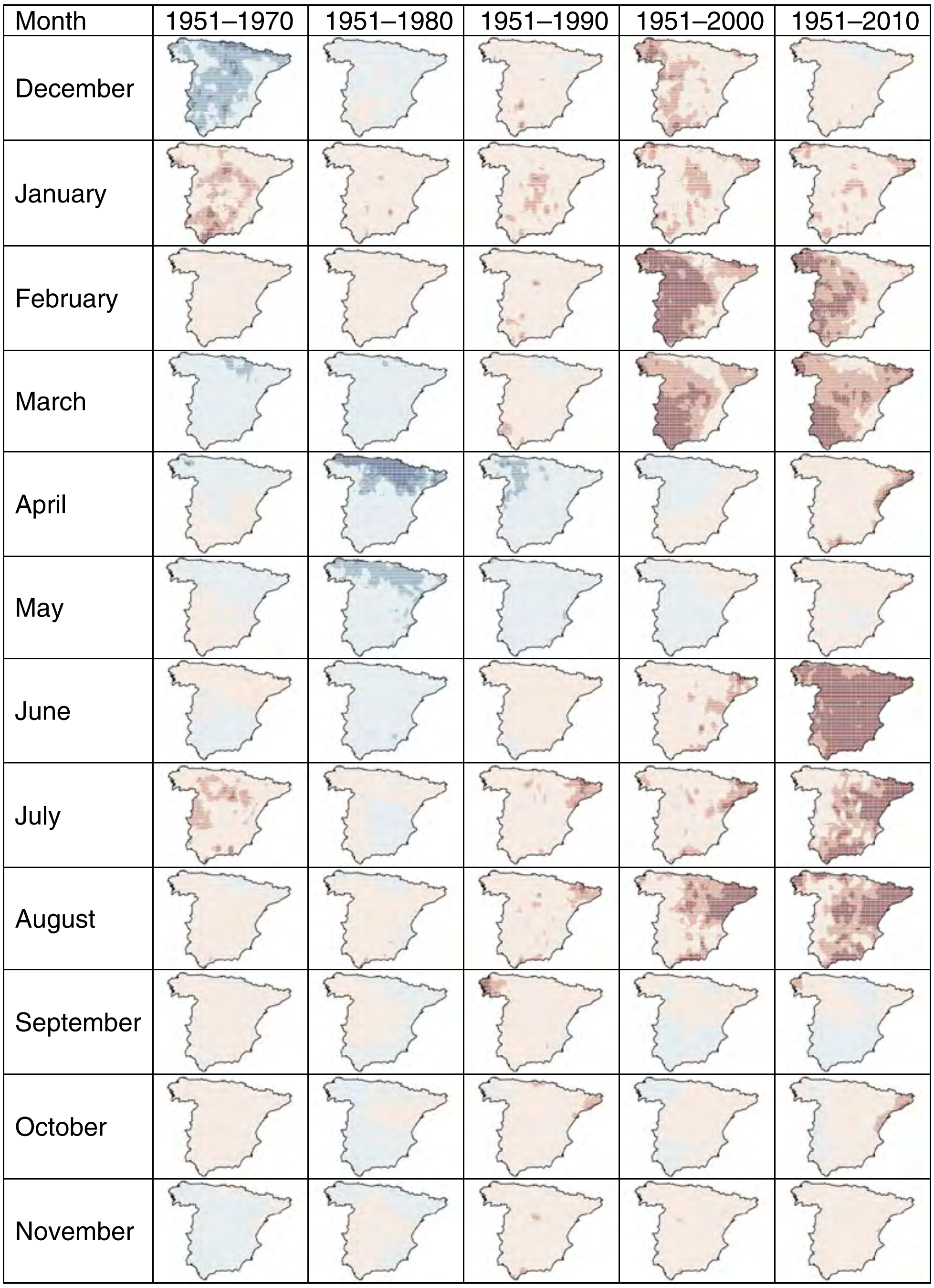

Figure 3. Monthly T_{max} spatial trend evolution under increasing temporal windows. The figure is an extract of Figure S1 in Appendix S1 (colour scale) and shows some specific temporal windows to demonstrate the west–east and east–west gradient in cold and warm months in T_{max}. Blue/red and intensity of colour (slow/high) indicate negative/positive, no significant/significant trend according to Mann–Kendall test ($p < 0.01$ and $p < 0.05$). [Colour figure can be viewed at wileyonlinelibrary.com].

As far T_{min} is concerned, the evolution of the percentage of land under positive significant trend is highly variable among months, and from the beginning of 1990s, a significant positive trend was found affecting more than 75% of total land globally, particularly in warm months from June to August (Figure 4 and Table S3 in Appendix S1). Again, the area affected by significant trends evolved in a definite pattern from east to west in the successive temporal windows (Figures 5 and S2 in Appendix S1) and seemed to start first in August, and later in July and June, with more than >25% of land affected by significant trends, respectively, from 1951–1991, 1951–1994, and 1951–2001 (Table S3 in Appendix S1). The same spatial pattern of evolution of areas affected by significant positive trends was found in March, April, and May, although except for March, the areas under a significant positive trend were lower, and for April and May the overall warming ceased decades ago, and recently is located only in the Mediterranean coastland (Figures 5 and S2 and Table S2 in Appendix S1). The same is true in September (mostly non-significant) and October, in which case the total land finally affected by significant positive trends has

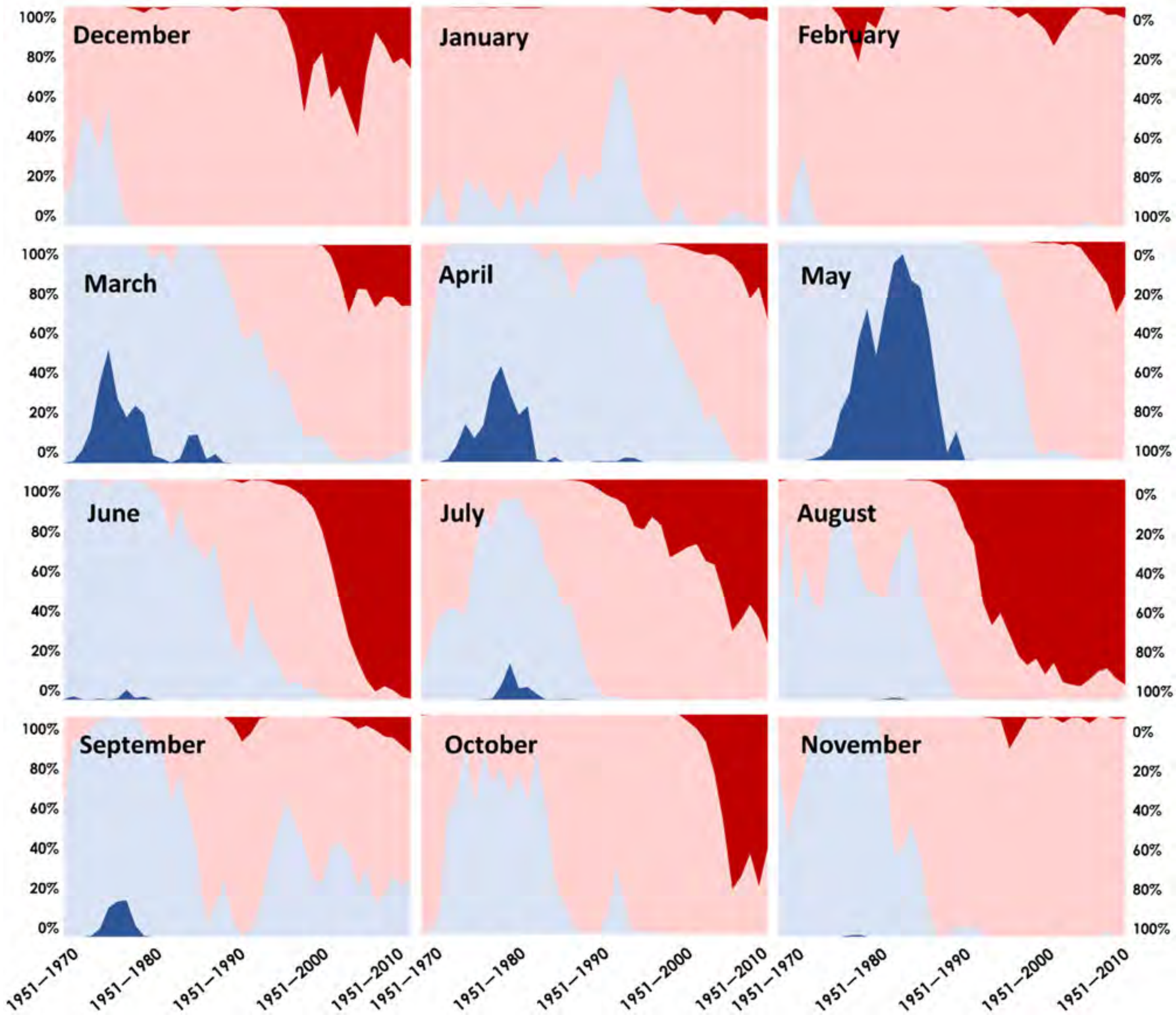

Figure 4. T_{min} monthly analyses of the percentage of total land (cumulative) under increasing temporal windows according to trend. As Figure 2. Tables S1–S4 in Appendix S1 for individual windows data. [Colour figure can be viewed at wileyonlinelibrary.com].

increased (values around 60%; Figure S2 and Table S4 in Appendix S1).

Differences in the percentage of areas affected by significant positive trends are prominent between T_{max} and T_{min}, depending on the month; they also differ according to spatial distribution. In February and March, the areas under significant positive trends are 60.8 and 81.4% for T_{max}, while for T_{min} they are 6.4 and 27.9%, respectively, in the complete 1951–2010 period (Tables S1 and S2 in Appendix S1), while in 1951–1990 they were, respectively, 3.5 and 0% in T_{max} and 0 and 2.0% in T_{min} (Figures 3 and 5 and Tables S1 and S2 in Appendix S1). On the other hand, in July and August the area affected by significant positive trends in the windows 1951–2010 was 59.3 and 70.3% in T_{max}, and 74.5 and 93.1% in T_{min}, meanwhile in the 1951–1990 windows they were, respectively, 11.3% (July) and 9.9% (August) in T_{max}, and 1.9% (July) and 3.9% (August) in T_{min} (Table S3 in Appendix S1 and Figures 3 and 5). To a lesser extent, this asymmetry between percentage of area under significant positive trends in favour of T_{min} is also evident in April, May, and October (Figures 2 and 4 and Tables S2 and S4 in Appendix S1). Finally, June is the only month that shows generalized warming in the period 1951–2010 both in T_{max} and in T_{min} (Table S3 in Appendix S1), except the inland northwest plateau.

3.2. Decreasing temporal windows

The sequence of decreasing temporal windows from 1951–2010 to 1991–2010 shows that highest spatial variations in land affected by positive significant trends on T_{max} occurred from March to August, especially March and June, in the complete period (Figures 6 and S3 and Tables S6 and S7 in Appendix S1), and, depending on the selected windows, also April and May (between 1960s ending 1970s temporal windows; Table S6 in Appendix S1); in all these months and windows, more than 75% of land was affected by significant positive trends. The

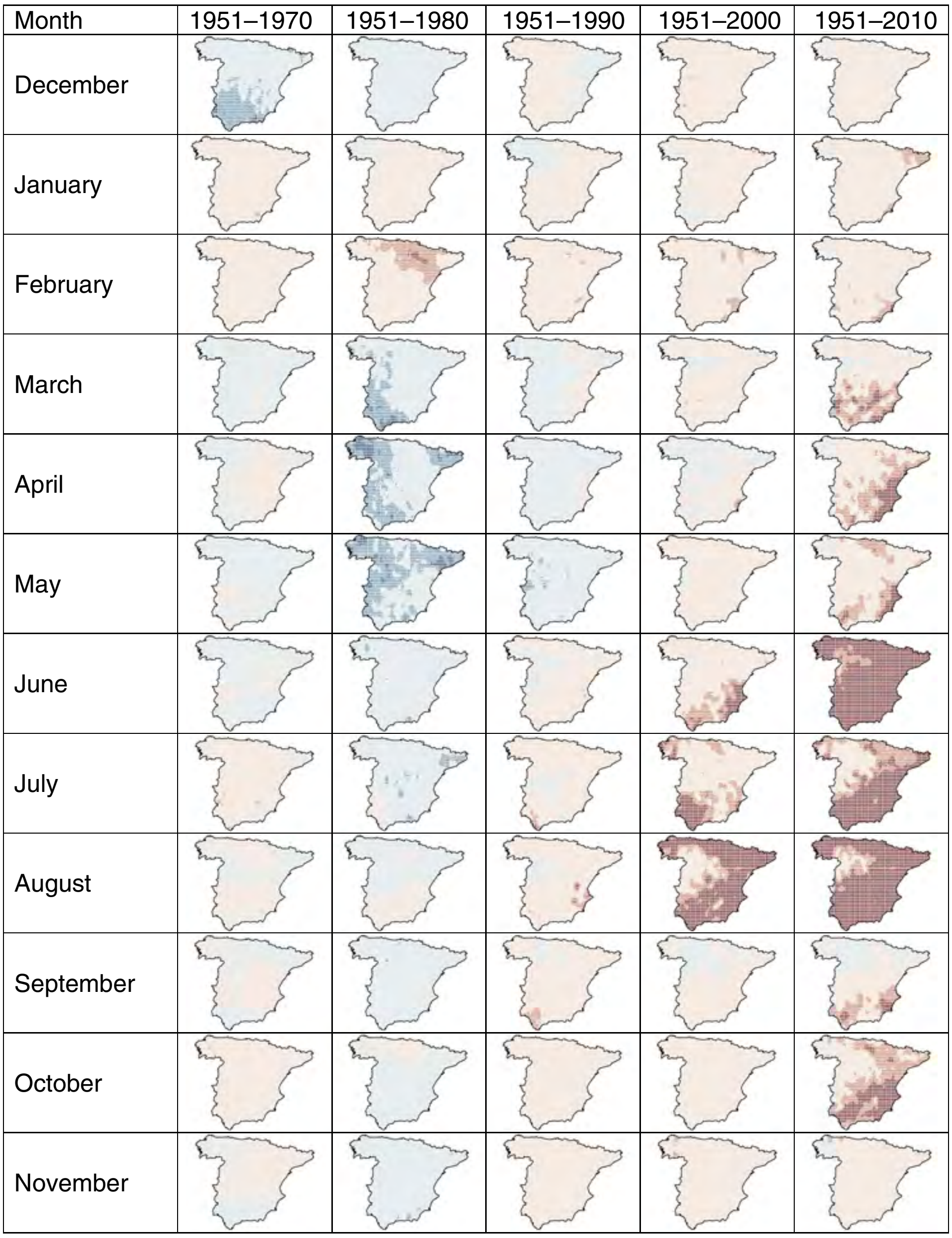

Figure 5. Monthly T_{min} spatial trend evolution. The figure is an extract of Figure S2 in Appendix S1. Legend as in Figure 3. [Colour figure can be viewed at wileyonlinelibrary.com].

significant negative trend affecting from 25 to 50% of land in the last windows for December (Figure 6 and Table S5 in Appendix S1) is a special case.

The analyses of sequential charts again detect the two spatial patterns of variation from west to east in the coldest months, and vice versa in warmest months (Figures 7 and S3 in Appendix S1). Generally, T_{max} trends are non-significant from the beginning of the 1970s, except along the Mediterranean coastland and overall in June (Figure S3 and Tables S5–S8 in Appendix S1).

The global evolution of areas affected by different trends and significances in T_{min} shows that they evolve differently from T_{max}. For example, in February we did not detect any significant trends over large areas, while between March and October there were clear differences, and sometimes the area affected by significant trends is 100%, except September (Figure 8 and Tables S5–S8 in Appendix S1). In general, decreasing temporal windows implies a spatial reduction of land affected by significant trends that are progressively reduced to the east Mediterranean coastland in the warmest months (May–September), or to the southwest in March (Figures 9 and S4 in Appendix S1).

Except for April and June, the trends of monthly minimum temperature are not significant in the Spanish mainland generally from the beginning of the 1980s (Figures 9 and S4 and Tables S5–S8 in Appendix S1).

4. Discussion

Variation in global temperature according to fixed periods has been noticed in the last Intergovernmental Panel

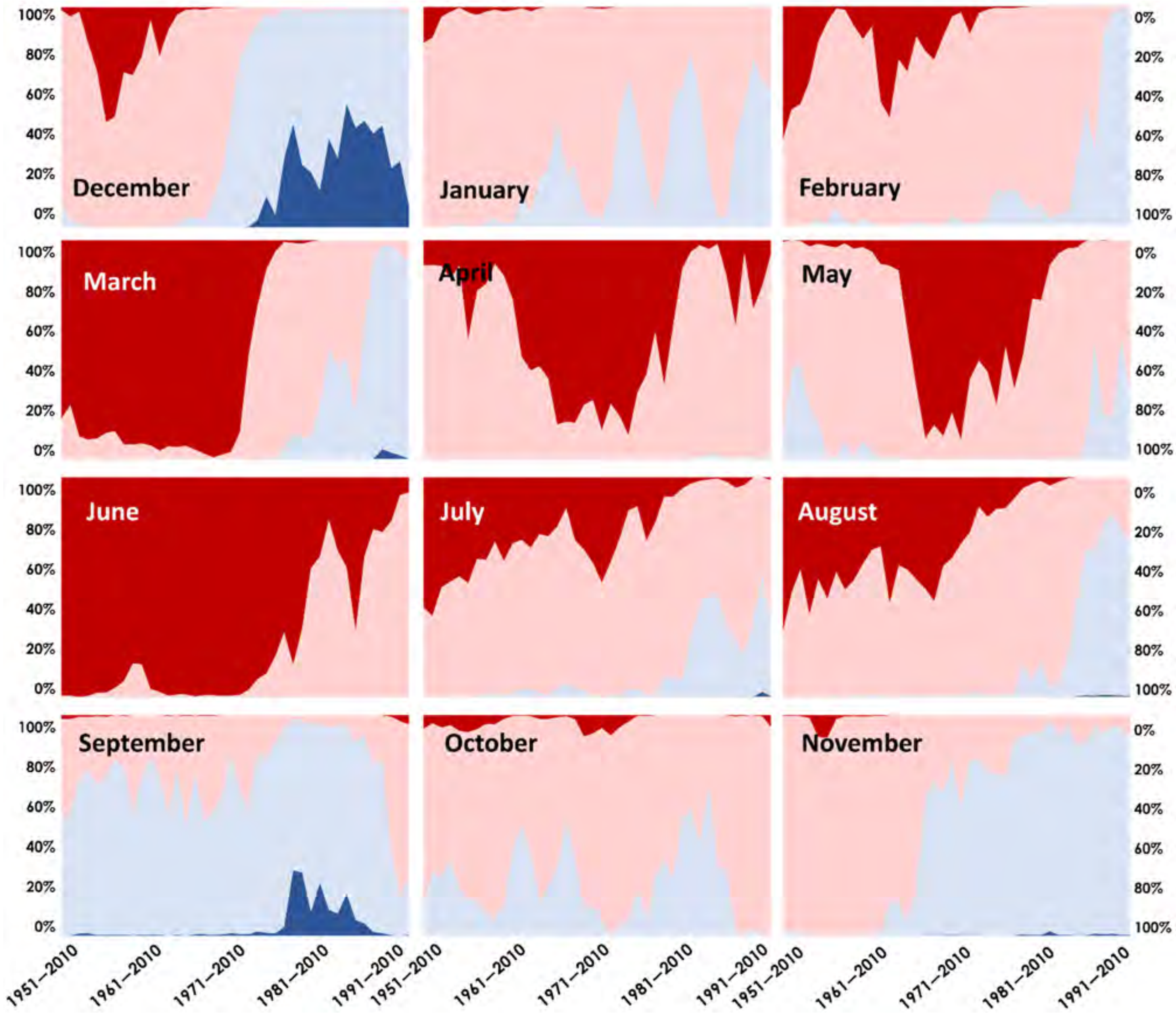

Figure 6. T_{max} monthly analyses of the percentage of total land (cumulative) under decreasing temporal windows according to trend. As Figure 2. Tables S5–S8 in Appendix S1 for individual windows data. [Colour figure can be viewed at wileyonlinelibrary.com].

on Climate Change (IPCC) report, and spatial variation in temperature trends has been also detected on a global (Lyubushin and Klyashtorin, 2012) and regional scale (Capparelli *et al.,* 2013; Gleisner *et al.,* 2015). These global results agree with temperature trends on the Spanish mainland, where asymmetric trends have been detected at seasonal and monthly scales with important inter-month spatial variations during the second half of the 20th century (González-Hidalgo *et al.,* 2015).

In the aforementioned articles, temperature trend evolution was estimated assuming constant or monotonic behaviour, and their temporal variations were hidden because of the fixed periods analysed. This problem is what has been researched in the present study, and the main results suggest that temperature trend evolution on the Spanish mainland from 1951 to 2010 has not been homogeneous, but displayed high spatial and temporal variability. Thus, the global increase in temperature in the study area has arisen over a specific time period, has been heterogeneous on a monthly scale, diverse spatially, and affected diurnal and night-time measurements differently. In the present research, the minimum temporal window used to analyse trends is 20 years, which is the minimum period over the threshold suggested by Santer *et al.* (2011) to separate year-to-year variability from long-term climate signals. Similar time periods are suggested by Loehle (2009) and Liebmann *et al.* (2010) among others. However, there is still no general consensus in the scientific community on this choice.

The analysis clearly shows that the selected period determines the results of trend, and depending on this, the conclusions could be ‘apparently’ opposite. Generally speaking, long-series trend values inform us about the global evolution context and represent a cumulative effect. This is what we found in the present study by using increasing temporal windows, in which we detected a global increase in temperature on the Spanish mainland between 1951 and 2010 in agreement with previous researchers (Brunet *et al.,* 2007; del Río *et al.,* 2012; González-Hidalgo *et al.,* 2015). But our research

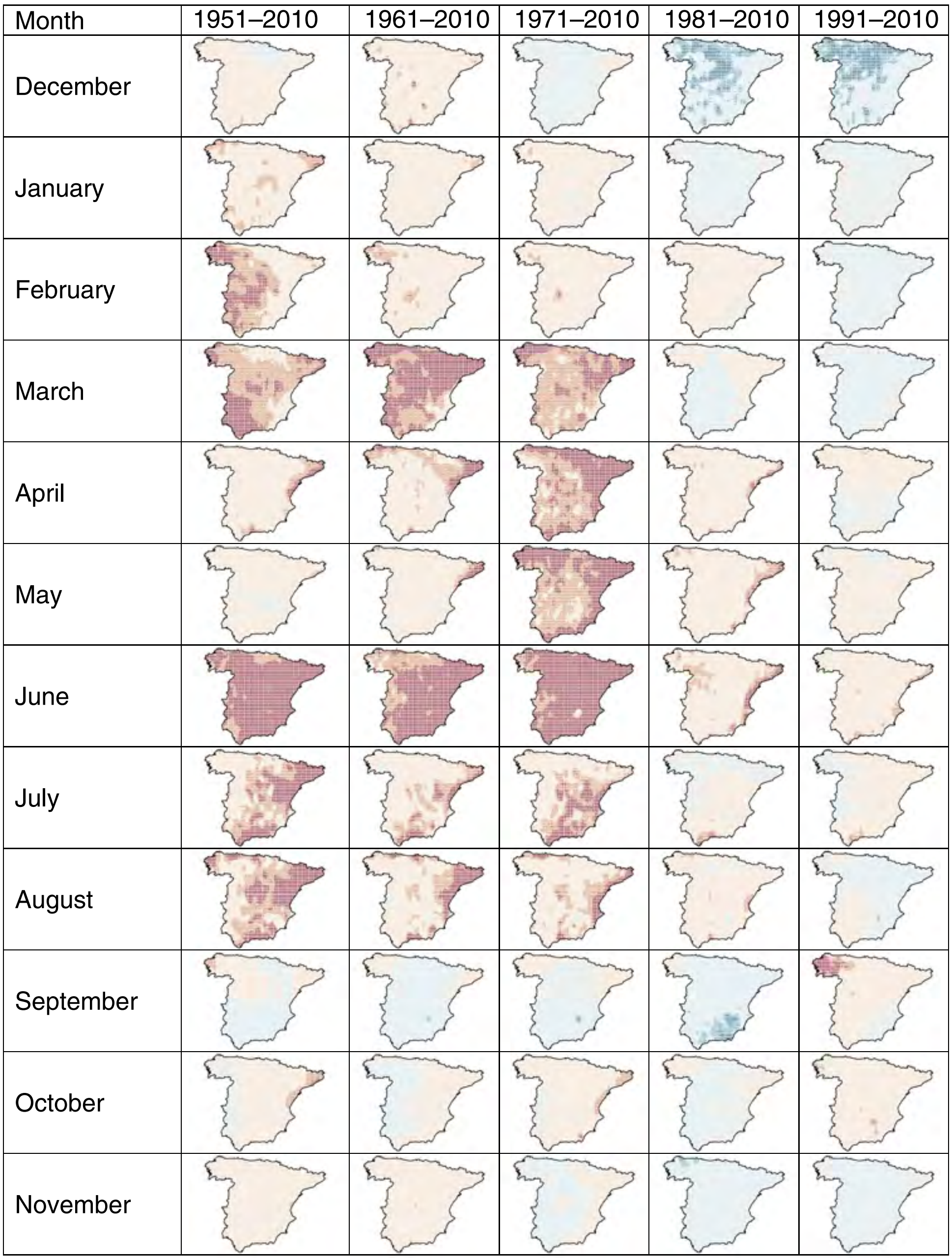

Figure 7. Monthly T_{max} spatial trend evolution under decreasing temporal windows. The figure is an extract of Figure S3 in Appendix S1. Legend as in Figure 3. [Colour figure can be viewed at wileyonlinelibrary.com].

also showed that significant warming was not uniform among months, it was heterogeneous in time, varied spatially, and affected extensive areas (i.e. more than 50% of total land) only in the last decades and in specific months. On the other hand, the decreasing temporal windows results detected a second important feature: the monthly trends in both T_{max} and T_{min} were non-significant at spatial level over the last 35 and 25 years until 2010, with the exception of T_{min} in April and June. These findings again face the question of signal-to-noise ratio not analysed in this article, but the length of these temporal windows (25–35 years) does not seem to be related to low-frequency variability drivers, and requires further explanation.

Different factors have been suggested to understand temperature trends in the second half of the 20th century on the Spanish mainland. Perhaps the most detailed arguments month by month are those presented by del Río *et al.* (2012), and references therein) for 1961–2006, in which they considered a predominant role of the North Atlantic Oscillation (NAO) atmospheric pattern for both T_{max} and T_{min}, taking into account the relationship between radiation, cloudiness, and aerosols from the results of Sanchez-Lorenzo *et al.* (2007), Sanchez-Lorenzo *et al.,* 2009). Years earlier, Esteban Parra *et al.* (2003) had also related the temperatures with the NAO atmospheric pattern, considering that the anomalous anticyclone circulation could be one of the main drivers of cloud cover

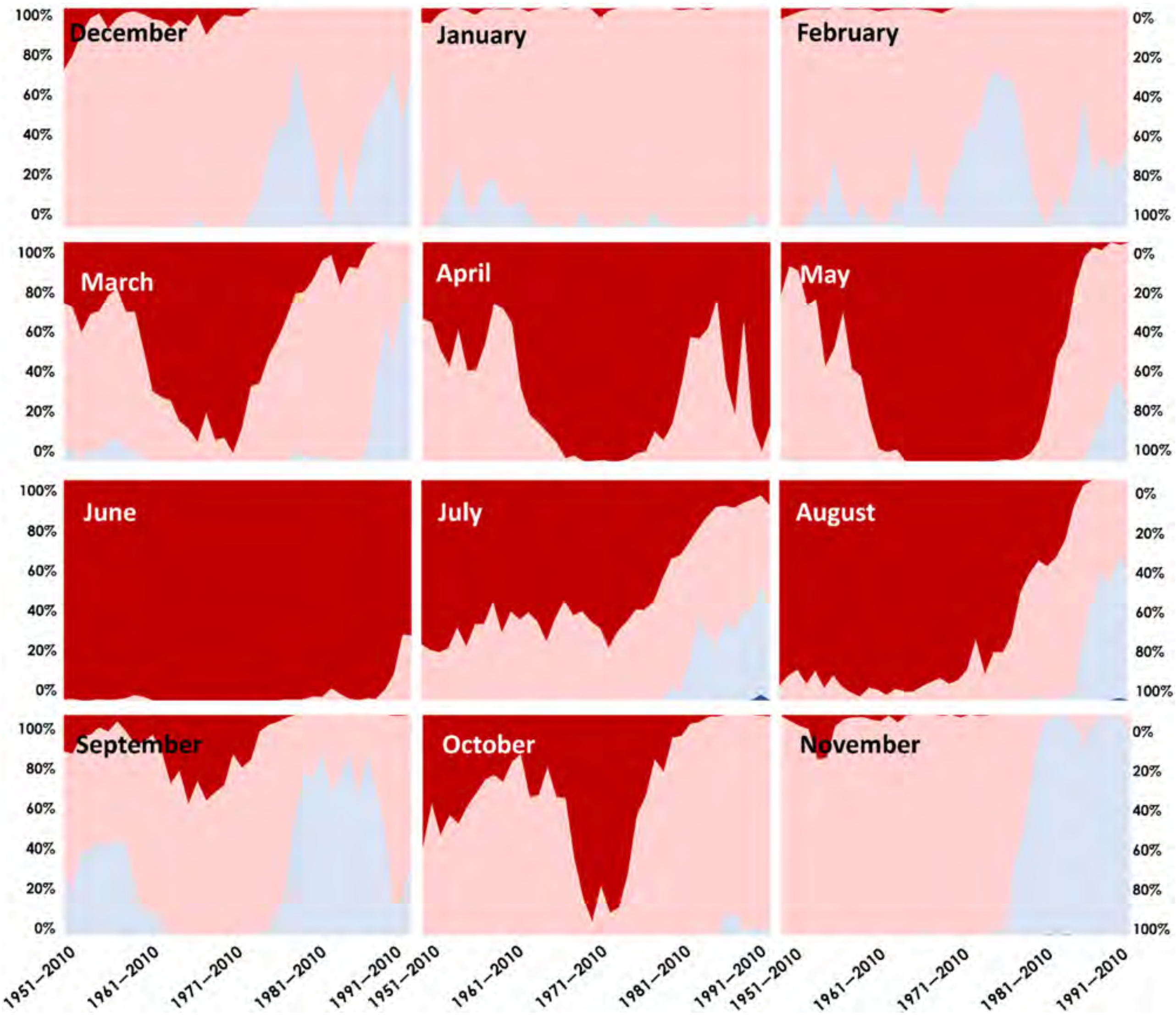

Figure 8. T_{min} monthly analyses of the percentage of total land (cumulative) under increasing temporal windows according to trend. As Figure 2. Tables S5–S8 in Appendix S1 for individual windows data. [Colour figure can be viewed at wileyonlinelibrary.com].

and radiation. Finally, more recently we have discussed the global explanation of hiatus by using the national series of MOTEDAS, and introducing the effects of variation on the water vapour transfer from the Atlantic Ocean and its relationship with clouds, solar radiation, and eventually also local factors (González-Hidalgo *et al.,* 2016). However, all these articles approached understanding trends through a fixed period and avoiding spatial variations in the time of trends, as described in this article.

These issues are not the main objective of the present research which focuses on the effect of selected periods on trends and their spatial variability, but in any case, our results suggest that no single or simple cause should be applied to understanding the recent warning on the Spanish mainland, and no single factor can be attributed at present, because we detected clear evidence of its complexity on both spatial and temporal scales. The clearest example is the double gradient of warming evolution in time between the coldest and warmest months.

As we have presented previously, the spatial distribution of areas with significant trend changes in time in a twofold spatial gradient: from west to east (cold months) or from east to west (warm months). Both patterns initially could be related to the effects of both water masses – the Atlantic Ocean and the Mediterranean Sea, and it could be suggested that they affect different months over the years according to global migration of pressure fields and winds systems, i.e. this hypothesis would suggest that winter temperature evolution, mostly maximum, should be driven by Atlantic Ocean, while Mediterranean Sea could be related to summer trends. Following this argument, and particularly for winter, NAO trend analyses may be able to help explain the west–east gradient in T_{max} trend. In Figure 10, we show the trend evolution of the NAO index for winter months from the Climate Research Unit (CRU) data set under increasing and decreasing temporal windows (tau from Mann–Kendall test, such as those presented in previous analyses). The figure shows that with increasing period

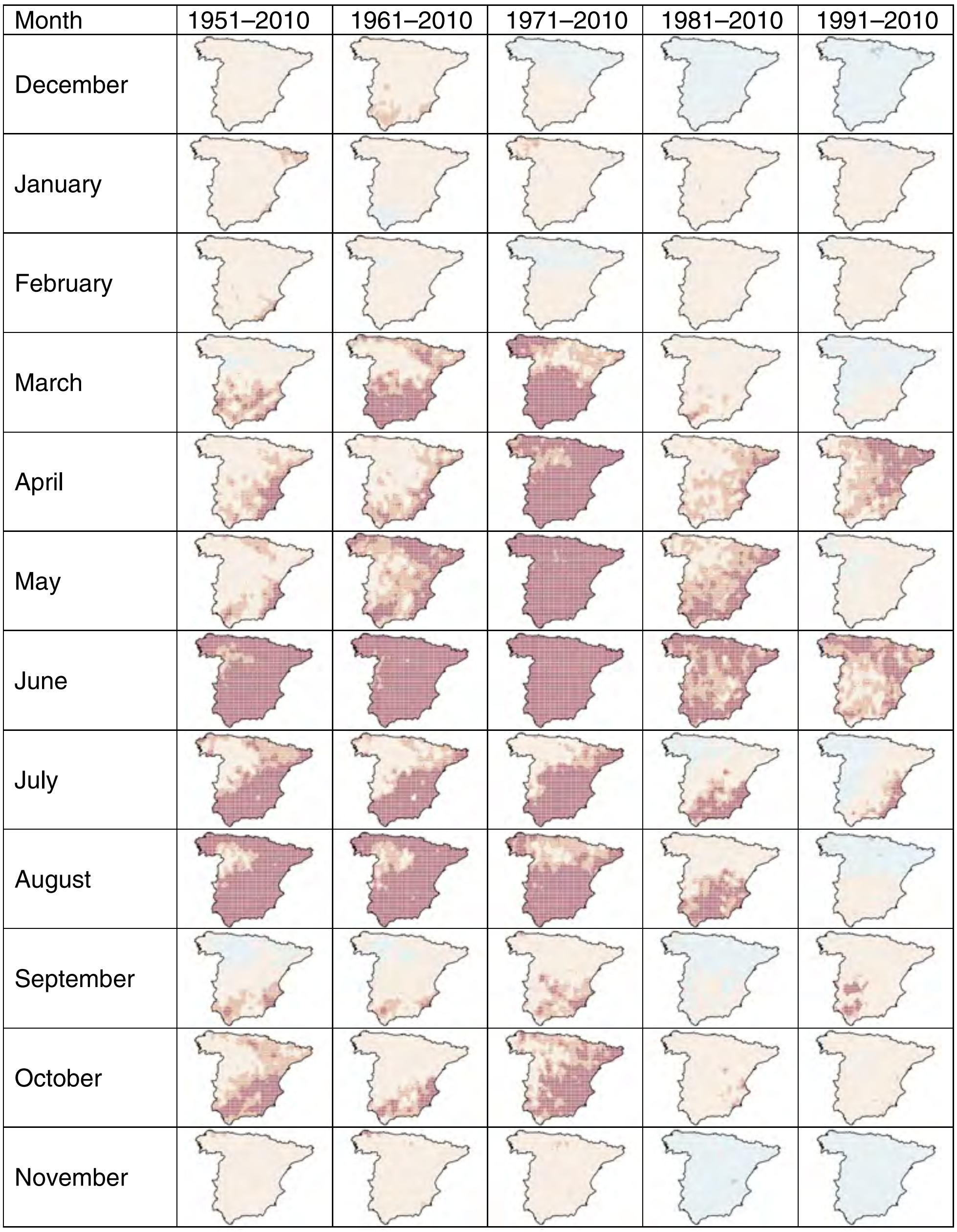

Figure 9. Monthly T_{min} spatial trend evolution under decreasing temporal windows. The figure is an extract of Figure S4 in Appendix S1. Legend as in Figure 3. [Colour figure can be viewed at wileyonlinelibrary.com].

length, the index is mostly positive except in December, while under decreasing temporal windows from 1970 it is negative; both cases agree with the global results of T_{max} trends presented above.

The east–west gradient of the warmest months seems to pose more problems, because in summer the temperature of the Mediterranean has been increasing since 1985 (Nykjaer, 2009), whereas on the Spanish mainland, we found the trend to have been mostly non-significant both in maximums and minimums during the last few decades, except along the Mediterranean coastland and mid-southern areas, where dramatic land use changes have taken place over the last 30 years from irrigation (Moliní and Salgado, 2010) and infrastructures and urbanization (Zúñiga *et al.,* 2012), which agrees with regional studies in the area that demonstrated the increase in T_{min} (global results in González-Hidalgo *et al.,* 2015, and references therein).

In conclusion, our results show that factors controlling temperature trends of any kind (global/local, natural/man-made-induced) seem to be spatiotemporally selective on the Spanish mainland. This is far from being clearly explained, while the combined results of increased–decreased temporal windows analyses indicate that warming has arisen in a specific period (from the late 1960s to the beginning of 1990s), varies from month to month, between T_{max} and T_{min} and differs at spatial levels, and consequently a single trend value for a long period hides internal variations. Furthermore, the variability in trends among months depending on different time

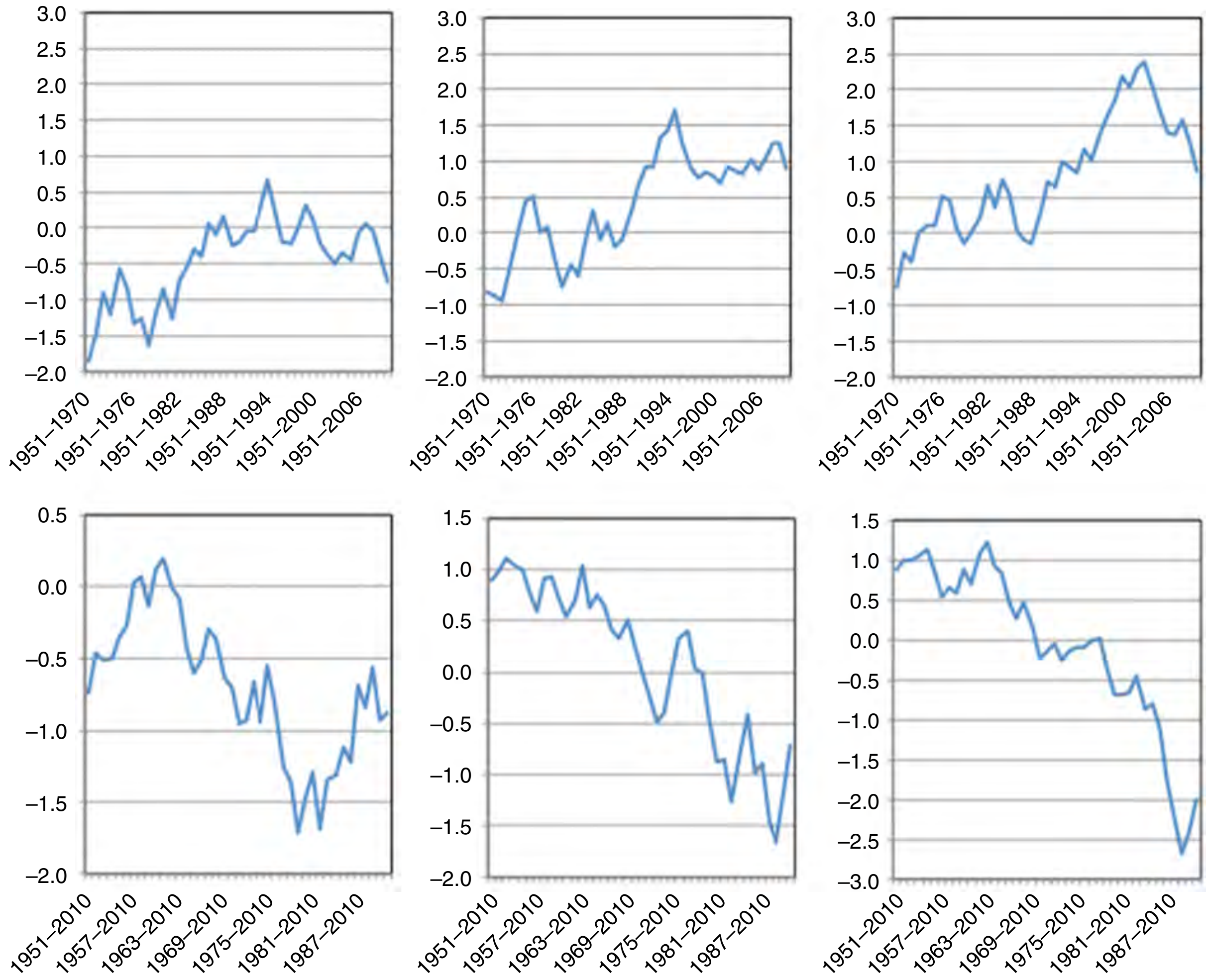

Figure 10. Mann–Kendal test in increasing (upper) and decreasing (lower) temporal windows for NAO index in December, January, and February (left–right) months. Monthly NAO data from CRU web site. [Colour figure can be viewed at wileyonlinelibrary.com].

intervals indicates that seasonal or annual values do not properly describe temperature evolution in time.

Finally, the differences between T_{max} and T_{min} have been attributed to global and local factors, but the results from the present research suggest that this global attribution needs more refinement before being able to understand the heterogeneous behaviour of trends, particularly in T_{max} temperatures.

Consequently, these findings presuppose a challenge to attributing one exclusive factor to warming processes on the Spanish mainland, because in such a case, it should be able to explain the selective action between months, areas, or thermometric measurements. All of these features are important key points that should be considered in future scenario evaluations, need further research, and offer new challenges for climate research.

5. Conclusions

In the present research we have confirmed that the choice of time period on monthly temperature trends on the Spanish mainland is crucial and a key factor in describing the behaviour of this climate variable during the last 60 years. Furthermore, given the heterogeneity found between monthly trends, and spatially in the same month in time, the annual or seasonal trend values do not properly describe temperature evolution from 1951 to 2010 on the Spanish mainland, because an increase in temperature has clearly taken place in some months, between the end of the 1960s and beginning of the 1990s, as shown by different measurements (maximum and minimum) and affecting different areas.

The increase in temperature has not been spatially homogeneous, and we discovered twofold spatial gradients depending on the coldest and warmest months that are far from being explained at present. The coldest month west–east warming gradient could be partly related to the NAO, but the warmest month gradient (east–west) is opposite to the temperature evolution of Mediterranean Sea and could be reflecting effects of dramatic change in land use.

Finally, we used high spatial resolution to detect spatial differences between maximum and minimum temperature trend evolution on the Spanish mainland. Overall, both maximum and minimum temperature trends are not significant at a monthly scale for the last 35–25 years, respectively, except along the Mediterranean coastland in

April and June. Finally, the monthly temperature evolution on the Spanish mainland is not properly described by monotonic trends and demands further research before it can be understood.

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Supporting information

The following supporting information is available as part of the online article:

Table S1. Increasing temporal windows for winter months (December, January, and February).

Table S2. Increasing temporal windows for spring months (March, April, and May).

Table S3. Increasing temporal windows for summer months (June, July, and August).

Table S4. Increasing temporal windows for autumn months (September, October, and November).

Table S5. Decreasing temporal windows for winter months (December, January, and February).

Table S6. Decreasing temporal windows for spring months (March, April, and May).

Table S7. Decreasing temporal windows for summer months (June, July, and August).

Table S8. Decreasing temporal windows for autumn months (September, October, and November).

Figure S1. Spatial evolution of T_{max} trends under increasing temporal windows from 1951–2010 and 1991–2010. The number represents the percentage of land affected by significant trend ($p < 0.05$).

Figure S2. Spatial evolution of T_{min} trends under increasing temporal windows from 1951–2010 and 1991–2010. The number represents the percentage of land affected by significant trend ($p < 0.05$).

Figure S3. Spatial evolution of T_{max} trends under decreasing temporal windows from 1951–2010 and 1991–2010. The number represents the percentage of land affected by significant trend ($p < 0.05$).

Figure S4. Spatial evolution of T_{min} trends under decreasing temporal windows from 1951–2010 and 1991–2010. The number represents the percentage of land affected by significant trend ($p < 0.05$).

References

Anderson A, Kostinski A. 2016. Temperature variability and early clustering of record-breaking events. *Theor. Appl. Climatol.* **124**: 825–833. https://doi.org/10.1007/s00704-015-1455-5.

Brunet M, Jones P, Sigro J, Saladie O, Aguilar E, Moberg A, Della-Marta PM, Lister D, Walther A, Lopez D. 2007. Temporal and spatial temperature variability and change over Spain during 1850-2005. *J. Geophys. Res.* **112**: D12117.

Brunetti M, Nanni T, Maugeri M, Auer I, Böhm R, Schöner W. 2006. Precipitation variability and changes in the Greater Alpine region over the 1800–2003 period. *J. Geophys. Res.* **111**: D11107. https://doi.org/10.1029/2005JD006674.

Capparelli V, Franzke C, Vecchio A, Freeman MP, Watkins NW, Carbone V. 2013. A spatio-temporal analysis of US station temperature trends over the last century. *J. Geophys. Res. Atmos.* **118**: 7427–7434. https://doi.org/10.1002/jgrd.50551.

Cohen JL, Furtado JC, Barlow M, Alexeev VA, Cherry JE. 2012. Asymmetric seasonal temperature trends. *Geophys. Res. Lett.* **39**: L04705. https://doi.org/10.1029/2011GL050582.

Cohn TA, Lins HF. 2005. Nature's style: naturally trendy. *Geophys. Res. Lett.* **32**: L23402. https://doi.org/10.1029/2005GL024476.

de Elía R, Biner S, Frigon A, Cote H. 2014. Timescales associated with climate change and their relevance in adaptation strategies. *Clim. Change* **126**: 93–106. https://doi.org/10.1007/s10584-014-1209-x.

Esteban-Parra MJ, Pozo-Vázquez D, Rodrigo FS, Castro-Díez Y. 2003. Temperature and precipitation variability and trends in northern Spain in the context of the Iberian Peninsula climate. In *Mediterranean Climate*, Bolle HJ (ed). Regional Climate Studies. Springer: Berlin, Heidelberg, 259–276. https://doi.org/10.1007/978-3-642-55657-9_15.

Fischer MJ, Paterson AW. 2014. Detecting trends that are nonlinear and asymmetric on diurnal and seasonal time scales. *Clim. Dyn.* **43**: 361–374. https://doi.org/10.1007/s00382-014-2086-8.

Gil-Alana LA. 2015. Linear and segmented trends in sea surface temperature data. *J. Appl. Stat.* **42**: 1531–1546. https://doi.org/10.1080/02664763.2014.1001328.

Gleisner H, Thejll P, Christiansen B, Nielsen JK. 2015. Recent global warming hiatus dominated by low-latitude temperature trends in surface and troposphere data. *Geophys. Res. Lett.* **42**: 510–517. https://doi.org/10.1002/2014GL062596.

González-Hidalgo JC, Brunetti M, de Luis M. 2010. Precipitation trends in Spanish water planning divisions (Cuencas Hidrográficas) between 1946–2005. *Clim. Res.* **3**: 215–228.

González-Hidalgo JC, Pena-Angulo D, Brunetti M, Cortesi N. 2015. MOTEDAS: a new monthly temperature database for mainland Spain and the trend in temperature (1951-2010). *Int. J. Climatol.* **31**: 715–731 https://doi.org/10.1002/joc.4298.

González-Hidalgo JC, Peña-Angulo D, Brunetti M, Cortesi C. 2016. Recent trend in temperature evolution in Spanish mainland (1951-2010): from warming to hiatus. *Int. J. Climatol.* **36**: 2405–2416. https://doi.org/10.1002/joc.4519.

Kendall M, Stuart A, Ord JK. 1983. Design and analysis, and time series. In *The Advanced Theory of Statistics*, Vol. **3**, 4th edn. Oxford University Press: New York, NY, 780.

Liebmann B, Dole RM, Jones C, Bladé I, Allured D. 2010. Influence of choice of time on global surface temperature trend estimated. *Bull. Am. Meteorol. Soc.* **91**: 1485–1491. https://doi.org/10.1175/2010BAMS3030.1.

Loehle C. 2009. Trend analysis of satellite global temperature data. *Energy Environ.* **20**: 1087–1098.

Lüdecke HJ, Link R, Ewert FK. 2011. How natural is the recent centennial warming? An analysis of 2249 surface temperature records. *J. Modern Phys.* **22**: 1139 https://doi.org/10.1142/S0129183111016798.

Lyubushin AA, Klyashtorin LB. 2012. Short term global DT prediction using (60-70)-years periodicity. *Energy Environ.* **23**: 75–85.

Marotzke J, Forster PM. 2015. Forcing, feedback and internal variability in global temperature trends. *Nature* **517**: 565–570. https://doi.org/10.1038/nature14117.

Mauget SA, Cordero EC. 2014. Optimal ranking regime analysis of intra-to multidecadal U.S. climate variability. Part I: temperature. *J. Clim.* **27**: 9006–9026. https://doi.org/10.1175/JCLI-D-14-00040.1.

McKitrick RR. 2014. HAC-robust measurement of the duration of a trendless subsample in a global climate time series. *Open J. Stat.* **4**: 527–535 https://doi.org/10.4236/ojs.2014.47050.

Mills TC. 2006. Modelling current trends in Northern Hemisphere temperatures. *Int. J. Climatol.* **26**: 867–884. https://doi.org/10.1002/joc.1286.

Moliní F, Salgado M. 2010. Superficie artifcial y viviendas unifamiliares en España, dentro del debate entre ciudad compacta y dispersa. *Bol. Asoc. Geógr. Esp.* **54**: 125–147.

Nykjaer L. 2009. Mediterranean Sea surface warming 1985-2006. *Clim. Res.* **39**: 11–17. https://doi.org/10.3354/cr00794.

Ribes A, Corre L, Gibelin AL, Dubuisson B. 2016. Issues in estimating observed change at the local scale – a case study: the recent warming over France. *Int. J. Climatol.* **36**: 3794–3806. https://doi.org/10.1002/joc.4593.

del Río S, Cano-Ortiz A, Herrero L, Penas A. 2012. Recent trends in mean maximum and minimum air temperatures over Spain (1961–2006). *Theor. Appl. Climatol.* **109**: 605–626.

Sanchez-Lorenzo A, Brunetti M, Calbó J, Martín-Vide J. 2007. Recent spatial and temporal variability and trends of sunshine duration over the Iberian Peninsula from a homogenized dataset. *J. Geophys. Res.* **112**: D20115. https://doi.org/10.1029/2007JD008677.

Sanchez-Lorenzo A, Calbó J, Brunetti M, Deser C. 2009. Dimming/brightening over the Iberian Peninsula: trends in sunshine duration and cloud cover and their relations with atmospheric circulation. *J. Geophys. Res. Atmos.* **114**: D00D09. https://doi.org/10.1029/2008JD011394.

Santer BD, Mears C, Doutriaux C, Caldwell P, Gleckler PJ, Wigley TML, Solomon S, Gillett NP, Ivanova D, Karl TR, Lanzante JR, Meehl GA, Stott PA, Taylor KE, Thorne PW, Wehner MF, Wentz FJ. 2011. Separating signal and noise in atmospheric temperature changes: the importance of timescales. *J. Geophys. Res.* **116**: D22105 https://doi.org/10.1029/2011JDO16263.

Servain J, Caniaux G, Kouadio YK, McPhaden MJ, Araujo M. 2014. Recent climatic trends in the tropical Atlantic. *Clim. Dyn.* **43**: 3071–3089. https://doi.org/10.1007/s00382-014-2168-7.

Soon WH, Legates DR, Baliunas SL. 2004. Estimation and representation of long-term (>40 year) trends of Northern-Hemisphere-gridded surface temperature: a note of caution. *Geophys. Res. Lett.* **31**: L03209. https://doi.org/10.1029/2003GL019141.

Wang WP, Chen YF, Becker S, Liu B. 2015. Variance correction prewhitening method for trend detection in autocorrelated data. *J. Hydrol. Eng.* **20**: 04015033. https://doi.org/10.1061/(ASCE)HE.1943-5584.0001234.

Zúñiga M, Pueyo A, Calvo JL. 2012. The Spanish population during the 20th century and beyond. *J. Maps* **8**: 1–6. https://doi.org/10.1080/17445647.2012.744364.