

## SPATIOTEMPORAL VARIABILITY OF PRECIPITATION AND TEMPERATURE IN THE SOUTHEAST IBERIAN PENINSULA (1950-2007)

FERNÁNDEZ-MONTES, Sonia; RODRIGO, Fernando S.

Andalusian Centre for Evaluation and Monitoring of Global Change (CAESCG),  
Department of Chemistry and Physics, University of Almería, Spain

soniafm@ual.es, [frodrigo@ual.es](mailto:frodrigo@ual.es)

### ABSTRACT

In this work climate variability of the SE region of the Iberian Peninsula is analysed during 1950-2007, using the high-resolution dataset “Spain02”. To that end, Principal Component analysis is applied on annual and seasonal basis to anomalies in total precipitation, and in average maximum and minimum temperatures (Tmax, Tmin).

Long-term changes in temperature are more significant and widespread than in precipitation. Tmax and Tmin have increased in most of the region, especially in spring, summer and autumn, but with sub-regional differences. Tmax has risen remarkably in main mountainous areas and SE sub-region from the 1970s to 1990s and in Sierra Nevada Mountains especially in the 1990s and early 2000s. However, Tmax depicts cooling patterns in SW coastal Almeria province (El Ejido area) and in parts of the NE (Alicante-Murcia), which are probably explained by an albedo effect of greenhouses and other urban reflective surfaces, as well as to evaporative cooling through irrigation. By contrast, Tmin has risen continually since late 1950s in the NE (Alicante-Murcia), possibly linked with an intense urbanization process in that area, and in the SW/W (Alpujarras-Sierra Nevada-Guadix regions) in late-1970s onwards. Precipitation depicts high interannual and decadal fluctuations, with a clear distinction in the regimes between west and east regions, and specific patterns for small geographical areas. Decreasing precipitation patterns are observed in the northern face of Sierra Nevada Mountains from 1950s to 1990s and in the northern part of Sierra Cazorla Mountains in the 1980s onwards. An opposite pattern is observed towards the most arid E/SE region, with a slight recovery in total precipitation since the 1980s, mainly due to winter.

Results point out the vulnerability of mountainous areas to global warming and changing circulation patterns, whereas coastal regions in SE Spain seem to be also highly influenced by anthropic land use changes, such as intensive agriculture and urbanization. We discuss large-scale and regional factors driving the observed variability in the different sub-regions, as well as feedbacks between temperature and precipitation. We also discuss impacts on the environment and drawn possible strategies to mitigate global and climate change in this region.

Keywords: semiarid areas, sub-regional changes, total precipitation, maximum and minimum temperatures, decadal variability, land-use changes

### RESUMEN

En este trabajo se analiza la variabilidad en el clima de la región SE de la Península Ibérica (PI) durante el período 1950-2007, usando la base de datos de alta resolución “Spain02”. Para ello, se aplica un análisis de Componentes Principales tanto en base

anual como estacional a las anomalías de precipitación y de temperatura máxima y mínima (Tmax, Tmin).

Los cambios a largo plazo en las temperaturas son más significativos y generalizados que en la precipitación. Tmax y Tmin han aumentado remarcablemente en la mayoría del área considerada, especialmente en primavera, verano y otoño, aunque mostrando deferencias sub-regionales. Tmax ha aumentado más en las principales regiones montañosas y en el SE desde los 1970s y Sierra Nevada en los 1990s y 2000s. En cambio, Tmax sigue patrones de descenso (enfriamiento) en la zona costera del SW de Almería (área de El Ejido) y en partes del NE (Alicante y Murcia), que están probablemente ligados a un efecto albedo de los invernaderos -y otras superficies urbanas reflectantes- así como a un enfriamiento por evaporación en zonas de regadío. Por el contrario, Tmin ha aumentado continuamente desde finales de los 1950s en el área Alicante-Murcia, probablemente ligado a un intenso proceso de urbanización. Tmin también ha aumentado notablemente en la región W/SW (Alpujarras- Sierra Nevada-Guadix) desde finales de los 1970s. La precipitación muestra importantes fluctuaciones interanuales y decenales, con una clara distinción entre las regiones occidentales y orientales, y patrones específicos para pequeñas áreas geográficas. Se observan patrones de disminución en la parte norte de Sierra Nevada (desde 1950s hasta 1990s) y de la Sierra de Cazorla (desde los 1980s). Un patrón opuesto se obtiene para la zona más árida, al E/SE, con una recuperación de la precipitación total desde los 1980s, sobre todo debido al aumento en invierno.

Los resultados resaltan la vulnerabilidad de las áreas montañosas mediterráneas al calentamiento global y cambios en la circulación atmosférica, mientras que las regiones costeras del SE de la PI se muestran además altamente influenciadas por cambios en los usos del suelo, como la agricultura intensiva y la urbanización. Discutimos los factores a gran escala y regionales que pueden estar implicados en la variabilidad observada, así como las retroalimentaciones entre temperatura y precipitación. Por último destacamos los impactos sobre el medio ambiente y perfilamos posibles estrategias de mitigación del cambio climático y cambio global en esta región.

Palabras clave: áreas semiáridas, cambios subregionales, precipitación total, temperaturas máximas y mínimas, variabilidad decenal, cambios en los usos del suelo

## 1. INTRODUCTION

The Iberian Southeast is one of the most arid regions in the Euro-Mediterranean area, although it comprises a rich variety of environments due to its climatic gradient from sea level to high mountains. This region is a major hotspot of biodiversity, with species being threatened both due to insufficient protection policies (e.g., Martínez-Hernández *et al.* 2010) and to recent climate change (Pauli *et al.* 2011). Shrubs and perennial grasses are the dominant vegetation, while forests are confined to mountainous areas (> 1500 m.a.s.l), like Sierra Nevada, S. Filabres, S. Cazorla and Segura (Fig. 1). These mountain ranges shelter SE Spain from the Atlantic cyclones and give rise to a NW-SE gradient in precipitation, from above 1000 mm/year in parts of S. Cazorla to less than 200 mm/year towards Cabo de Gata (Fig. 1). The region is characterized by few rainy days and large precipitation variability (de Luis *et al.* 2009). Temperature is moderate in the coast with mild winters and warm/hot summers, but very extreme values and strong annual temperature range can be registered in the inland mountainous regions.

Atmospheric circulation changes influence both precipitation and temperature in Mediterranean Spain, especially in winter (López-Moreno *et al.* 2011; Fernández-Montes *et al.* 2012). Some works have obtained a decreasing contribution from both Atlantic fronts and convective storms to total precipitation, together with increasing contribution from Mediterranean cyclogenesis in the cold season (Millán *et al.* 2005). Beyond large-scale forcings, regional processes and feedbacks are also of utmost importance for the climate of this region (e.g., Millán *et al.* 2005). Human activities have historically put a huge stress in the environment of SE Spain, first in mountains and recently in coastal areas (Sánchez-Picón *et al.* 2011).

Previous works analysing recent climate variability in this region have usually focussed on one or a few stations in localized areas (e.g., Lázaro *et al.*, 2001; Campra *et al.* 2008). Using high resolution datasets, trends have been assessed in seasonal precipitation (e.g., de Luis *et al.* 2009), and in maximum and minimum temperatures for Spain –including SE region- from the 1960s onwards (del Río *et al.* 2012), but without studying variability patterns. This paper aims to contribute to the knowledge about past climate change in the SE IP obtaining different sub-regional patterns which may help to understand the role of large-scale and local factors on the observed variability. The Spain02 dataset of precipitation (Precip) and maximum and minimum temperature (Tmax, Tmin) in the period 1950-2007 is considered.

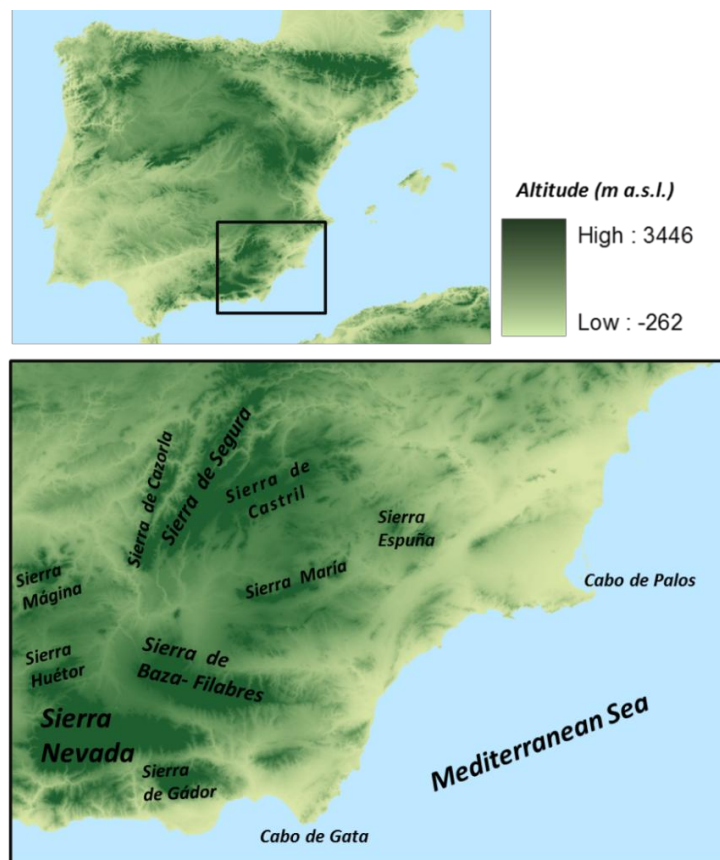


Figure 1. Study area in the SE Iberian Peninsula, showing main mountain ranges.

## 2. DATA AND METHODS

We use data from the recently developed Spain02 (Herrera *et al.* 2012), which are regular  $0.2^\circ \times 0.2^\circ$  gridded data. The dataset of monthly Tmax, Tmin and Precip is considered in the whole period 1950-2007. The area selected in SE Spain contains 113 grid points; it encompasses not only dry regions (southern and easternmost areas) but also wetter areas like Sierra Cazorla to the NW (Fig. 1). In semiarid regions water from mountains contributes in 50–90% to total runoff (López-Moreno *et al.* 2011), thus they are crucial for the study area. To validate Spain02 data we made use of 6 Tmax and Tmin and 10 Precip station series from the AEMET ([www.aemet.com](http://www.aemet.com)) and the Junta de Andalucía (<http://www.juntadeandalucia.es/medioambiente/site/rediam>). We assessed correlation between them and the corresponding gridded data, on seasonal level. In general high correlations were found ( $\rho > 0.7$ ). Lower correlations were obtained in mountainous areas for temperature data ( $\rho \sim 0.6$ ), given the very high variability of temperature in altitude gradients (one station only may not be representative for the grid point). The highest correlations ( $\rho > 0.9$ ) were achieved for the main stations of Alicante, Murcia and Almería.

To discover homogeneous regions with similar temporal behaviour in the period 1950-2007, Principal Component Analysis (PCA) in s-mode (Preisendofer, 1988) is applied to the standardized anomalies of the 3 variables (Tmax, Tmin, Precip) in each year. We apply PCA using the correlation matrix and Varimax rotation. By regression of the loadings for each rotated EOF, the PC time series (scores) that characterize the EOF time behaviour are obtained. For sake of brevity we only display results for the annual basis, although we also briefly comment on seasonal results. The existence of trends in the time-series of the PC scores is tested by means of the Rho Spearman's correlation test (Lanzante 1996). Correlation coefficients among Tmax and Precip scores series are also tested; the most significant results will be comment in next section.

## 3. RESULTS AND DISCUSSION

### 3.1. Precipitation

Results of applying a PCA to annual precipitation (anomalies) for the period 1950-2007 are presented in Fig. 2. The first five PCs represent nearly 80% of total variability. Among them, two main patterns are identified, jointly explaining more than 50% of the total variability: the first one (PC1) is weighted towards E-NE region and presents high annual and decadal variations with peaks in the early 1970s and late 1980s. The Rho-Spearman correlation test detected a positive trend in this PC at 10% s.l. ( $p$ -value=0.058). PC2 is weighted towards western regions (mainly to the NW and SW of the area) (Fig 2a). It also shows positive trend at 10% s.l. in the whole period, probably because the 1950s were notably dry (Fig 2b). Its temporal variability seems fairly opposite to the previous one (i.e., PC2 maximums are coincident with PC1 minimums). This behaviour is meaningful, given the different origins of precipitation, i.e., primarily due to easterly vs westerly fronts and cyclones. PC3 encompasses the northern face of Sierra Nevada Mountains and inter-ranges region of Guadix-Baza. It depicts a declining in precipitation from the 1950s to 1990s, with slight increase since then but negative trend (at 1% s.l.) in 1950-2007. PC4 is weighted towards the eastern mountains of S. Alhamilla and Filabres and shows peaks of precipitation in the mid-1950s and early 1990s, high inter-annual variability, and no long-term trends.

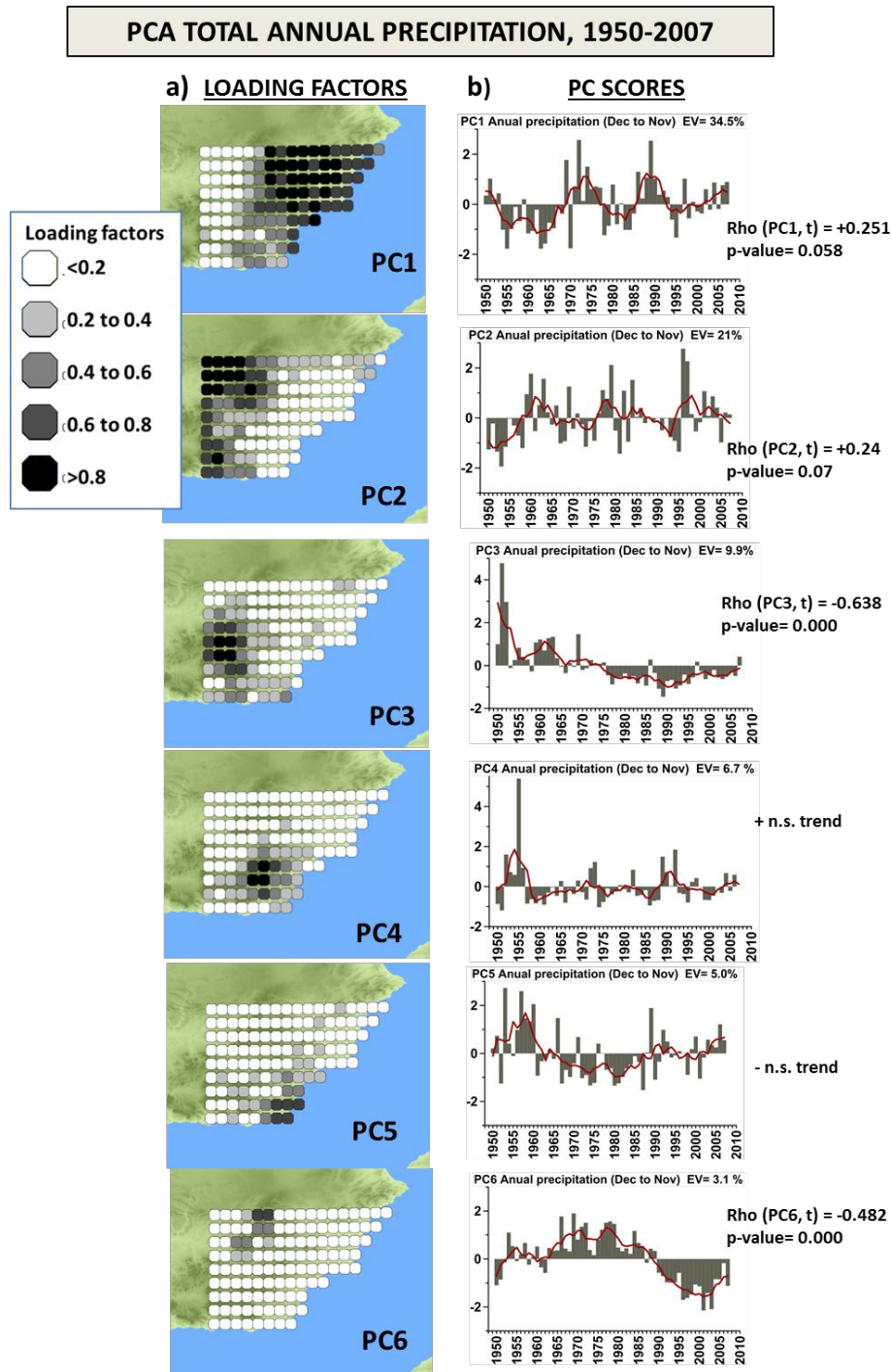


Figure 2. Results of applying a Principal Component Analysis (PCA) in s-mode to total annual (December y-1 to November y) precipitation for the period 1950-2007. a) Loading factors and b) PCs scores (bars) together with a low-pass filter of 5 yr (red line). Percentage of explained variance (EV) by each PC is given, as well as results of Rho-Spearman correlation test to identify trends in the period 1950-2007.

The SE (Cabo de Gata) region (PC5) is characterized by large decadal variability with positive rainfall anomalies in the 1950s and negative in the 1970s-1980s, slightly increasing afterward. By contrast, the northernmost region of Segura Mountains (PC6) shows decreased precipitation in the 1990s and 2000s after wetter decades from 1960s to 1980s, with significant (1% s.l.) negative trend in the period.

PCA applied to the seasonal anomalies of precipitation (winter, spring and autumn seasons) yield spatial patterns of regionalization very similar to those for annual values (not shown). The Northern Sierra Nevada-Guadix-Baza region depicts decreasing precipitation in spring and autumn in the 1950s to 1990s (similar as on annual basis, Fig.2, PC3). These evolutions concur with decreasing frequency of moderately extreme precipitation days in the SE IP in autumn (Fernández-Montes *et al.* 2014). Additionally, a major decrease in precipitation in Cazorla Mountain is observed in winter and spring seasons since the 1980s (as in annual basis). Given its location exposed to westerly circulation, it seems connected to a positive trend in the NAO index and less frequent Atlantic cyclones crossing the south IP in late winter and early spring (e.g., López-Moreno *et al.* 2011). By contrast, positive anomalies in the last 2 decades are observed over the SE area (Cabo de Gata-Níjar) in winter (larger than on annual basis). These results are likely related to increasing frequency of easterly circulations and associated back-door cold fronts -responsible for intense precipitation events in coastal areas- in the cold season since the 1950s (Millán *et al.* 2005; Fernández-Montes *et al.* 2012).

### 3.2. Maximum and minimum temperatures

Tmax (Fig. 3) shows patterns of large warming in the 1990s-early 2000s with respect to previous decades, especially to the west (PC1), and remarkably in Sierra Nevada-Guadix (PC5). In the region west-central to north (PC2, average altitude of the grid points ~1000 m.a.s.l) an increase in Tmax is notable from 1950s to 1990s, with significant trend in the whole period. This Tmax PC2 scores series correlates negatively with Precipitation PC3 series ( $\text{Rho} = -0.57$ ). This could be indicative of circulation changes affecting both Tmax and precipitation series, i.e., increasing anticyclonic conditions. A positive feedback loop between soil moisture deficit and increasing Tmax is also likely in these inner regions of the IP (Jerez *et al.* 2010). By contrast, in the SE (PC3) a cool period took place around the 1970s, Tmax increasing since then.

SW Almeria province (PC4) and parts of the NE region in Alicante-Murcia (PC6) show two cooling patterns since the 1960s and especially 1980s onwards, both with long-term significant negative trends (Fig 3b). These cooling signals are present throughout all seasons (not shown) and confined to the most populated areas to the NE and SW coastal regions (Sánchez-Picón *et al.* 2011). Although modulated by natural climate variability (e.g., relatively cool period in the 1970s), these patterns seem indeed affected by anthropic land-use changes (Kalnay and Cai, 2003). PC4 pattern might well be influenced by increasing albedo due to greenhouses development, as pointed by previous research in Almeria (Campra *et al.* 2008). Other urban reflective surfaces might have also increased the albedo and led to lower Tmax to the NE, as well as evaporative cooling effect due to irrigation in agricultural areas (Kalnay and Cai 2003).

The most remarkable changes in Tmin (Fig. 4) are found for PC1, towards NE region (Murcia-Alicante), with continuous increase from early 1960s to 2000s and highly

significant trend ( $Rho = 0.79$ ). This is congruent with positive trends found by del Río *et al.* (2012) for this area. The intense urbanization process undertaken since the 1960s (Gozálvez Pérez *et al.* 1993) might partially explain it.

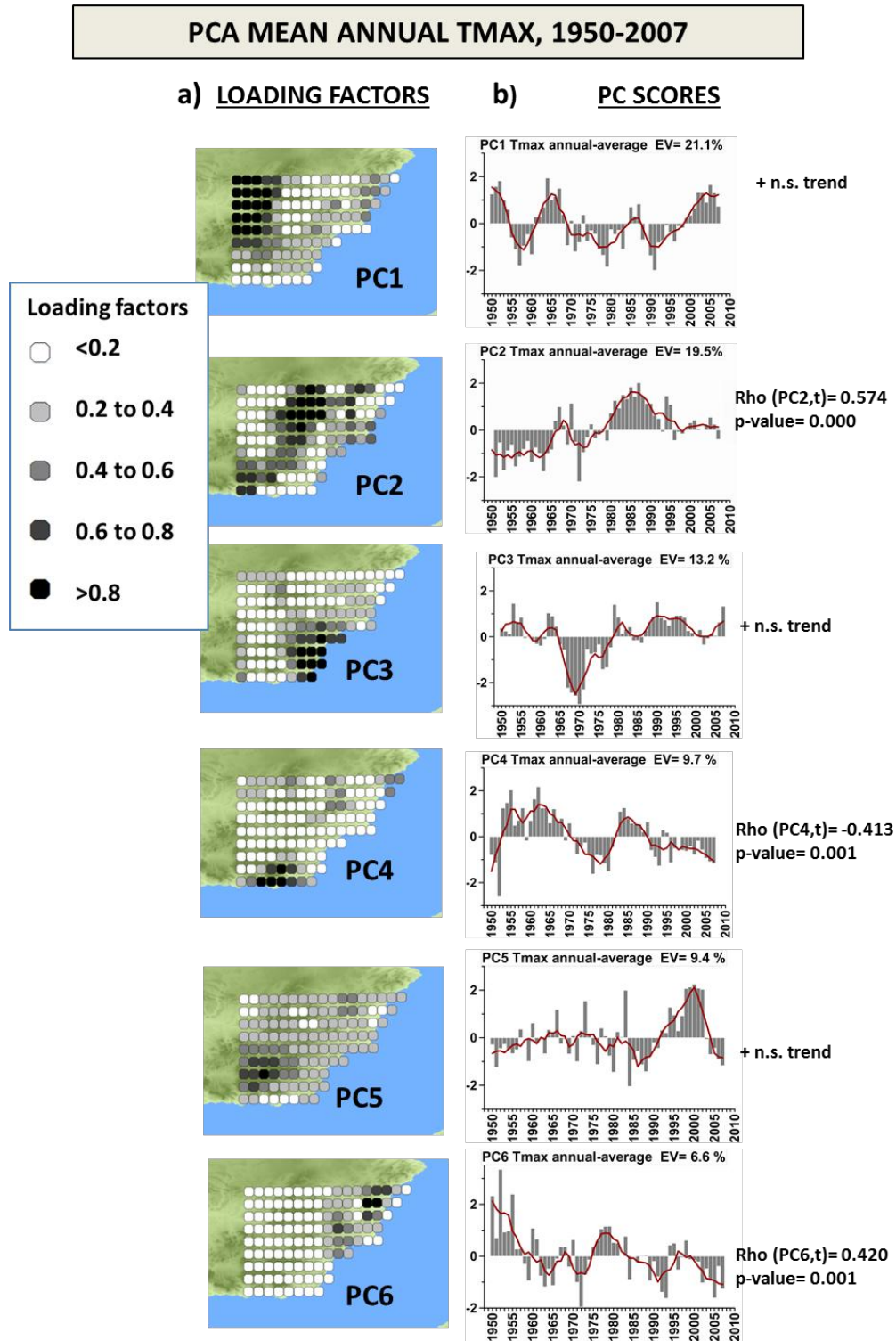


Figure 3. As in Fig. 2, but for annual (January to December) mean Tmax.

**PCA MEAN ANNUAL TMIN, 1950-2007**

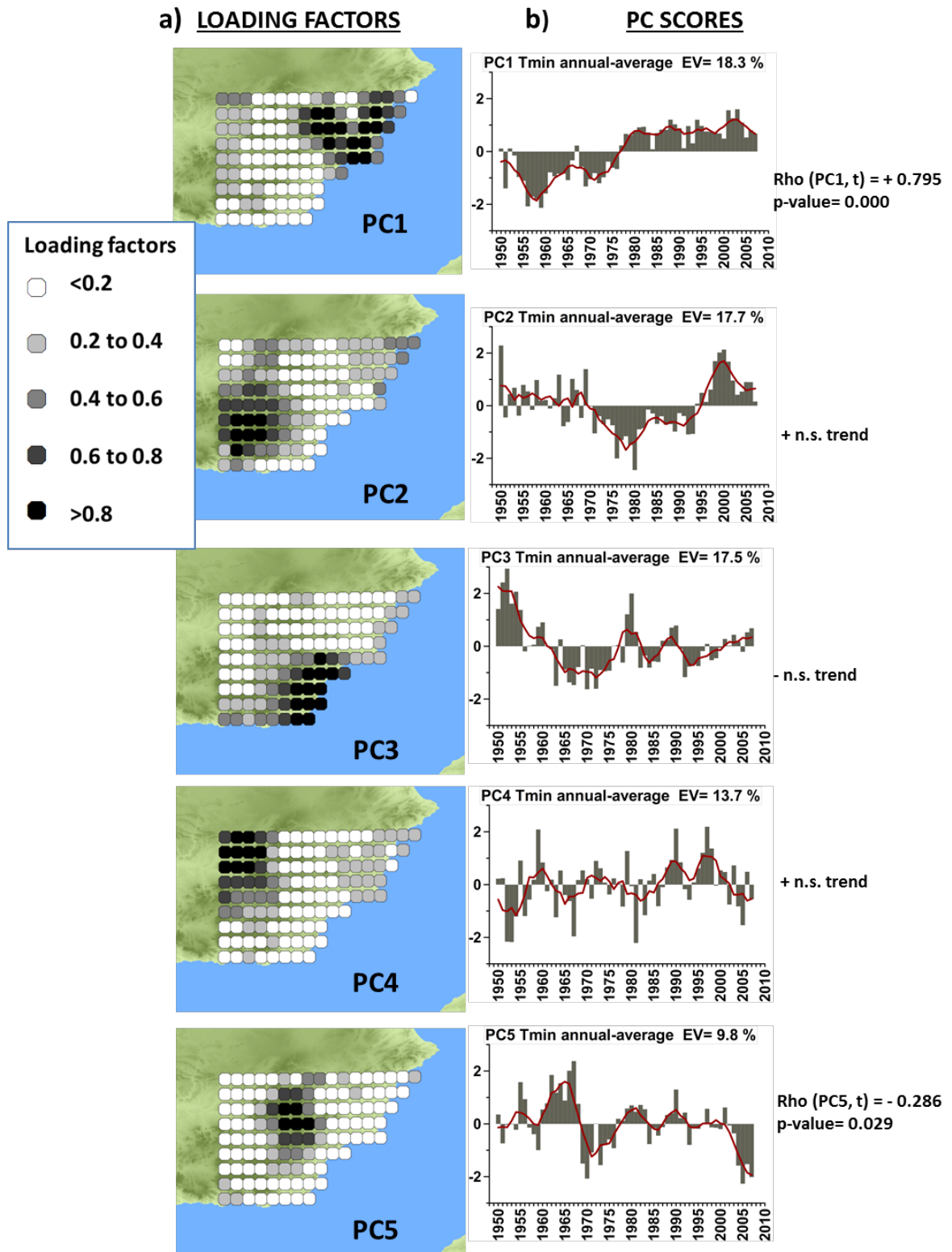


Figure 4. As in Fig 3 but for annual (January to December) mean Tmin.



For the second PC (SW region), an increase in T<sub>min</sub> is remarkable in the 1990s and 2000s. This period is concurrent with global and hemispheric warming and positive Atlantic SST anomalies (Ting et al. 2009). In the SE-most area, highest T<sub>min</sub> values were achieved in the 1950s followed by a cooler period in the 1960s- 1970s and slightly increasing pattern in last decades. This evolution seems also well related to decadal changes in SST (Ting et al. 2009). Towards the NW (PC4), high annual and decadal variability and a recent decrease in T<sub>min</sub> are observed. Finally, PC5 depicts a significant (5% s.l.) negative trend in the time-pattern, weighted towards northern Almeria and Granada provinces (PC5).

As a consequence of different evolutions in T<sub>min</sub> and T<sub>max</sub>, the diurnal temperature range has decreased to the NE and SW (most urbanized areas and eastern S.Nevada-Alpujarras), while increased in S. Cazorla and S. María mountains and east Almeria province in the 1970s onwards (not shown). Regionalization of seasonal T<sub>max</sub> and T<sub>min</sub> provides some additional information. For example, winter T<sub>min</sub> increased remarkably in S.Nevada in the 2000s after a cooling period in 1980s-1990s. This could be related to atmospheric circulation fluctuations: dominant positive NAO in the 1980s-1990s means strengthened anticyclone, with clear skies and northerly winds which damp T<sub>min</sub> (López-Moreno *et al.* 2011; Fernández-Montes *et al.* 2012). Conversely, the period of larger T<sub>max</sub> increase in most regions (especially in summer) is 1980s onwards, congruently with increasing solar radiation (Sánchez-Lorenzo *et al.* 2013).

#### 4. CONCLUSIONS

This study analyses precipitation and temperature (T<sub>max</sub> and T<sub>min</sub>) in the SE Iberian Peninsula in 1950-2007. Large inter-annual to decadal variability characterizes precipitation patterns, whereas temperature depicts more multidecadal and long-term changes. Several physical factors seem evolved in the different sub-regional patterns, but a rigorous evaluation goes beyond the scope of this paper. Nonetheless, the intense urban and agriculture development in the Alicante-Murcia region and in SW coastal Almería has very likely lowered T<sub>max</sub> and increased T<sub>min</sub> in those areas.

In the region with the most arid conditions (Cabo de Gata-Níjar) precipitation slightly increased since the 1980s and temperature has moderately risen since mid-1970s. By contrast, the region around Sierra Nevada Mountains has experienced an important shift towards drier conditions in the 1980s and 1990s, accompanied by recent large increases in T<sub>min</sub> and T<sub>max</sub>. In most of the area, increases in temperature together with non-significant changes in precipitation have likely driven this region to an intensification of droughts during the last five decades (Vicente-Serrano *et al.* 2014). The observed climatic –and land use- changes have surely had several environmental impacts. As increasing temperature is expected in coming decades, local policy-makers should start mitigation and adaptation plans. These should include improvements in water resources management, e.g., by means of more sustainable and spread agriculture systems (including policies for re-using abandoned rural inland areas). Similarly, important effort should be put in monitoring droughts and in forest fires early-warning systems.

## 6. ACKNOWLEDGEMENTS

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