Accepted Manuscript

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PII: S0169-8095(16)30139-9
DOI: doi: 10.1016/j.atmosres.2016.05.020
Reference: ATMOS 3702

To appear in: *Atmospheric Research*

Received date: 12 February 2016
Revised date: 19 May 2016
Accepted date: 23 May 2016

FINE-SCALE ESTIMATIONS OF BIOCLIMATIC CHANGE IN THE VALENCIA REGION, SPAIN

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ABSTRACT

Recent advances in statistical downscaling have allowed the reconstruction of temperatures for the complete 1948-2011 period in a spatial resolution of 90 m and without gaps for the Valencian Community (Spain) and bordering areas. It presently enables analyses in this region, which allows the determination of recent temperature changes at subregional and local scales. The present work focuses on obtaining the thermicity index according to Rivas-Martínez, a well-known indicator of different thermotypes associated with bioclimatic horizons. The change in this index, which has happened in the region between 1948 and 2011, was calculated by generating fine-scale maps of the potential extension of different thermotypes. The results show a greater regression for the thermotypes in a finicolous position, e.g. Orotemperate, Supratemperate and Supramediterranean horizons, which herein indicate greater potential vulnerability in climate change. In the absence of, and given the need for, such fine-scale information, this work should be useful for specialized researchers to spatially limit the potentially most vulnerable biotopes to climate change.

Key words: Climate change, temperatures, bioclimatic horizons, Rivas-Martínez, regressive thermotypes, fine-scale mapping.

1.-INTRODUCTION

1.1 Background

The latest IPCC reports have indicated that the widest variability and greatest uncertainty about the impacts of climate change are on change patterns at regional and local levels (IPCC, 2013). This is especially true for Mediterranean regions given their spatial and temporal variability of climate, which render studies of climate change and impacts on those scales necessary.

Such a necessity stems from the recently proven general regression trend of the cyclonic circumpolar vortex influence, in favor of the Hadley cell, at Mediterranean latitudes (Frauenfeld and Davis, 2003; Angell, 2006; Muñoz-Díaz and Rodrigo, 2006; Graff and LaCasce, 2012, 2014), which has also led to the identification of a general trend of rising temperatures in the Iberian Peninsula (Brunet, *et al*., 2007; Del-Río *et al*., 2012). Changes in the precipitation patterns in the same area have also been identified (Esteban-Parra *el al.* 1998; Millán *et al.*, 2005; Muñoz-Díaz and Rodrigo, 2006; Estrela *et al*,. 2010; Gonzalez-Hidalgo *et al.*, 2010; Gallego *et al.*, 2011).

As to the need to research at fine-scale levels (subregional and local), we now benefit from the recent advances made in relation to temperatures in a Mediterranean region, e.g. Valencia (VC, Spain; Figure 1). This statistical downscaling (SD), from the data (daily temperatures) observed from more than 300 stations in the region, and also from the NCEP/NCAR data re-analysis, obtained a spatial interpolation (SI) of temperatures (T) at a resolution of 90 m for the entire period (no gaps) that covered 1948-2011 (Miró *et al*., 2015, 2016) (hereinafter SDSITVC). This work was carried out by taking into account local temperature patterns based on the original information obtained from the observed series, and by clustering the observatories related to site characteristics (valleys, hillsides, mountains, etc.) with their thermal attributes. The use of a hybrid artificial neural network (ANN-MLP and Hebbian) determined the relational patterns between the variables obtained from the re-analysis and the data observed in each location type, with barely any overfitting. This allows, on the one hand, to refill gaps and to reconstruct the series observed for the entire 1948-2011 period (daily, monthly and annual data). It also permits the extrapolation of temperature patterns and the estimation of temperature values on all the points covered by spatial interpolation. To this end, we made full use of ANN's capacity to filter the inhomogeneity and other errors (e.g. instrumental or accidental) of the observed series, with a very acceptable final bias (usually ±0.3°C for maximum temperatures and ±0.2°C for minimum temperatures for monthly data). Spatial interpolation was subjected to cross-validation at the points where the observed data were available, and close to 15% of the stations available in the input data were extracted to interpolate validation. Thus a measure of expected error for the temperature estimated by spatial interpolation at those points with no observed data (station) was obtained. For the yearly data of the 90 m spatial interpolation, cross-validation found an expected error of ±0.4ºC for the maximum temperatures and of ±0.8ºC for the minimum ones.

The results of the temperature trends that derived from the SDSITVC, already obtained in the works of Miró *et al*. (2015, 2016), have indicated important and distinct local patterns of temperature change over the study area in recent decades. They indicated a much more significant temperature rise in mountainous areas, especially in their apexes. These works also pointed out a further increase in the maximum temperatures, in spring and early summer, while also showing a decoupling of trends in minimum temperatures. The latter followed a clear upward trend in mountains, which was attenuated, and even reversed in certain cases, at the bottom of inland valleys. This has been related to more situations being prone to temperature inversion due to changes in the circulation patterns throughout the region. This conclusion has also been drawn for other mountainous regions in middle latitudes around the world (Daly *et al*., 2010; Pepin *et al.*, 2011; Dobrowski, 2011), while there is some evidence otherwise in high latitudes (Bourne *et al*., 2010).

Within the Iberian Peninsula context, a high variability of temperature patterns due to geographical and atmospheric factors has been defined (Peña-Angulo *et al.*, 2016). In any case, unlike some different result for other regions (Del-Rio, *et al*., 2005), there is also evidence indicating a greater warming in spring and summer linked to changes in atmospheric circulation patterns (Fernández-Montes *et al.*, 2013), especially in a neighboring region as the Ebro basin (El Kenawy, *et al.*, 2012). But are the recent studies employing suites of regional climate models (RCMs) to asses future changes those that best fit with the patterns of temperature change already detected in Miro *et al*. (2015). Therefore these indicate a greater tendency to warming at higher altitudes, specifically in the Pyrenees and the Iberian System (López-Moreno *et al*., 2008, 2014; Jerez *et al*., 2012; El Kenawy, *et al*., 2015).

The Mediterranean Basin offers extraordinary floristic wealth, which includes up to 25000 species, 50% of which are endemic (Quezel, 1985). In the study area, the presence of endangered endemic species has been reported (Laguna *et al.*, 1998; Serra *et al.*, 2004). Many of these endemic and singular species in this region are in a finicolous position; that is, they are refugees in end-point sectors of the bioclimatic horizons of middle and high elevations after their regression at the end of the last glaciation. This makes them potentially very vulnerable to climate change, which would cause greater regression, or even the disappearance, of their potential habitat (Ohlemueller, 2008). In fact, taxa and sectors in such a finicolous position have been defined in the study area (Serra *et al.*, 2004; Peñas *et al.*, 2005; Marco *et al*., 2006; Azorín and Jover, 2010). The above-mentioned vulnerability has been estimated as high, even in a mild climate change scenario (Dirnböck *et al.*, 2011).

Therefore, the results obtained in Miro *et al*. (2015) suggest that such a change is already underway given the faster warming in settlements of medium and high elevations than elsewhere in the area.

The usefulness of bioclimatic indices to study the climate change impact on biotopes has already been considered from various perspectives. Although the climate factor (applied to these indices) is not the only one to determine changes in biotopes, it can be used as a marker of potential changes (Pearson and Dawson, 2003).

When taking only temperatures into account, the thermicity index of Rivas-Martínez (Rivas-Martínez, 1987; Rivas-Martínez *et al*., 2011; www.globalbioclimatics.org) is generally considered a good indicator of different bioclimatic thermotypes, particularly in the Iberian Peninsula and the Mediterranean Basin (e.g., Gavilán, 2005; Loidi *et al*., 2007; Azorín and Jover, 2010; Costa *et al*., 2012; Monteiro-Henriques *et al*., 2015). Indeed this index has begun to be considered an indicator of bioclimatic change in some studies about climate change (e.g., Monteiro-Henriques and Espírito-Santo, 2011; Ighbareyeh *et al*., 2015).

This study aimed to use SDSITVC as an available data source to assess changes in the bioclimatic horizons defined by the Thermicity Index of Rivas Martínez (It) in our study area between 1948 and 2011 (Figure 1). A spatial resolution of 90 m for SDSITVC allows this to be currently done on a fine scale.

1.2 The Setting

The Valencia Community is located on the east coast of the Iberian Peninsula, and is characterized by a very complex orography. It is placed between the south-centre of the arch formed by the Iberian System mountains, and northeastern side of the Pre-Betic System mountains (Figure 1). The littoral is occupied by a series of coastal plains.

The region is divided into three parts, which roughly coincide with the provincial administrative demarcation: *Castellón*, in the North, contains the highest mountains on its interior limit (*Gúdar* and *Javalambre*, over 2000 m), as well as the most reduced coastal plains; *Valencia*, in the centre, comprises the amplest coastal and pre-coastal plains (the *Júcar* and *Turia* rivers) and mountains of a medium elevation inland; *Alicante*, in the south, has two distinct parts: northern *Alicante*, where the Pre-betic mountains define a territory of complex terrain relief of maximum elevation, 1558 m, with the *Aitana* mountain; southern *Alicante* is a flood plain that moves deeply inland (the *Segura* river). This configuration leaves very contrasting climatic attributes between coastal plains and inland mountains, as well as complex atmospheric interactions (Millán *et al.*, 1998, 2005; Pastor *et al.*, 2015); i.e., a very bold contrast in rainfall between northern *Alicante* (subhumid) and southern *Alicante* (semiarid), and complexities in modeling (Gómez *et al.*, 2014a, 2014b, 2015a, 2015b). There are also temperature contrasts: while coastal plains clearly have a mild subtropical Mediterranean climate, the inland quickly acquires continental traits or colder traits at higher elevations.

According to the classification system of Rivas-Martínez (used in this study) the region is mainly characterized by the Mediterranean macrobioclimate. Although the upper parts of the Iberian System (North inland) become a Temperate macrobioclimate with submediterranean bioclimatic variant (e.g., Gúdar area, Javalambre peak). Thermo and Mesomediterranean thermotypes occupy most of the territory, at least half South and all littoral-prelittoral strip (Piñas et al., 2008; López et al., 2015). Supramediterranean, supratemperate and orotemperate thermotypes already usually appear in high redoubts and finicolous position for taxa. Although the oromediterranean thermotype could be potentially present in the middle South of the region, there are no elevations high enough for its presence. Meanwhile, on the South side of Javalambre supratemperate and orotemperate thermotypes are on the edge of being oromediterranean (according to data derived from the SDSITVC).

These higher elevations are the only holdouts to provide temperatures and rainfall that favor the taxa and types of forest which have disappeared from most of the region by not only the arrival of the Holocene period, but also by subsequent human pressure and fire events (Gil-Romera *et al.*, 2010).

Many of these bioclimatic mountainous holdouts are currently protected by Natural Parks or protected mountain landscapes. These depend on climatic conditions, and somewhat differ from protected coastal areas that depend more on the presence of water sheets.

According to the SDSITVC results reported in Miró *et al*. (2015, 2016), these areas and mountainous Nature Reserves are located in the areas that are more affected by climate change in the region. Therefore, apart from the present study covering a wider region, it also focuses on a selection of representative Natural Parks and mountains, namely: *Tinença de Benifassà*, *Penyagolosa* (and the nearby area of *Gúdar*), *Puebla de San Miguel*, *Serra d´Espadà*, *Mariola*, *Font Roja* and the *Aitana* Mountain.

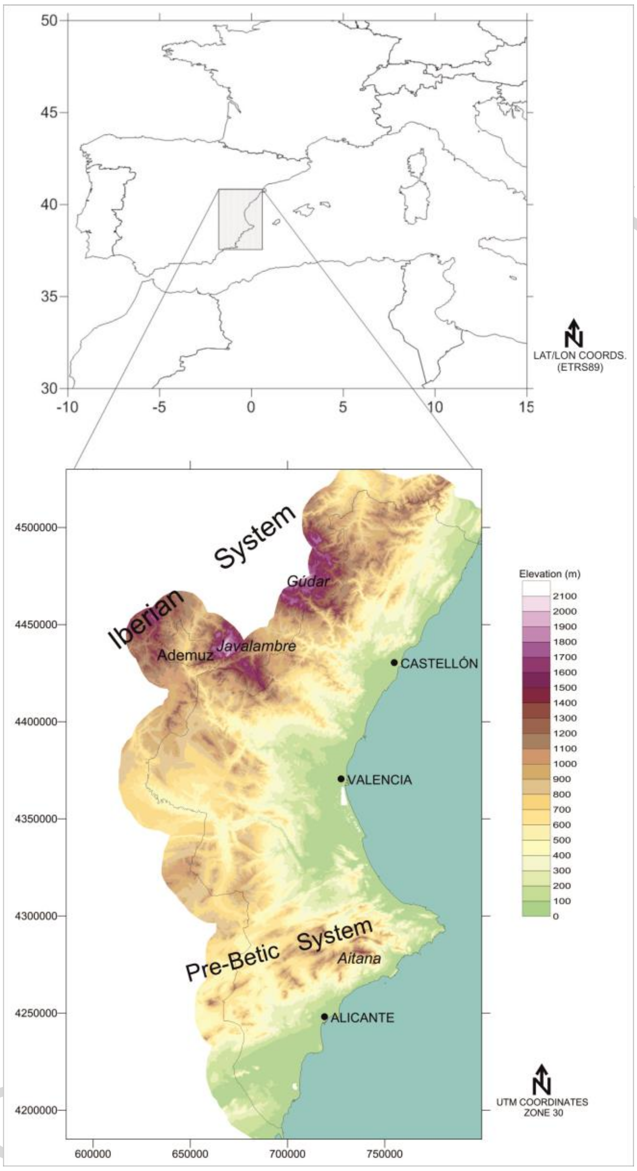


Figure 1: Study area (the Valencian Community and neighboring areas)

2.-DATA AND METHODS

According to Rivas-Martínez (1987) and Rivas-Martínez *et al*. (2011), a thermicity index (It) can be used to define spatial areas in temperature-dependent bioclimatic regions. It = (T+m+M)10, where T is the average annual temperature, m is the average of the minimum temperatures in the coldest month (January in this case) and M is the average of the maximum temperatures in the coldest month. Hence this index considers low temperatures as the limiting factor where plant taxa are present.

It should be noted that for the middle latitudes rules the Compensated Thermicity Index (Itc), that is 'It' is compensated by a continentality index. Itc = It ± C, where C is a compensation value that applies only if the average range between the temperatures of the warmest and coldest months of the year (Ic) is higher than 18 or less than 8. This is not the case in the study area, except for specific sectors at inland limits of Valencia sector, where Ic slightly exceeds a value of 18. Although there are almost no differences between the use of 'It' or 'Itc' in the study area, it has been applied the last one, according to the rule: if(18.0 < Ic <= 21.0) then C = (Ic-18.0)*5 (Rivas-Martínez *et al.*, 2011).

Additionally, when the Itc is lower than 120 then the value of the positive annual temperature (Tp) replaces the Itc in order to calculate thermotypes. Tp is the sum in tenths of degrees centigrade of the average monthly temperatures (Ti) when these are higher than 0ºC. That is, $Tp = (\sum Ti \geq 0º)\ 10$.

In order to calculate Itc´s spatial distribution, information about T, m, M and C has been used, which derived from SDSITVC. An algebraic operation that describes Itc was then applied to the different layers obtained from the spatial interpolations of T, m, M and C, which SDSITVC offers. The same applies to Tp (Itc < 120). These interpolations were obtained by ordinary Kriging (OK), and by bearing in mind that the number of points (stations) with available data, and their good presence toward the edges of the spatial interpolation, were suitable for OK (Miró *et al.*, 2015, 2016).

Based on the results obtained for temperature trends reported in Miró *et al*. (2015, 2016), two periods were computed: a reference period and a test period. These results (Figure 2) indicated an initial period between 1948 and 1979, with no significant temperature changes, particularly because there were still no changes in the spatial patterns of temperature, but inter-decennial oscillations. Thus it was taken herein as the reference period. For the 1980-1998 period, faster temperature warming was recorded throughout the region, but still made a transition to a decoupled state of spatial temperature change patterns, which will be subsequently consolidated. Warming slowed thereafter, but in the past 15 years (1997-2011) a profound change in the spatial patterns of temperatures toward decoupling has occurred; i.e., hillsides and mountain peaks continued with a marked warming trend, which was not so marked in valleys, and with increasing differences between valleys and mountains. This is reason why the last 15 years, available for SDSITVC (1997-2011), was taken as a test period, which was also the case in Miró *et al*. (2015, 2016).

Obtained directly from SDSITVC, Figure 2 summarizes these trends, which explain subsequent grouping by decennia.

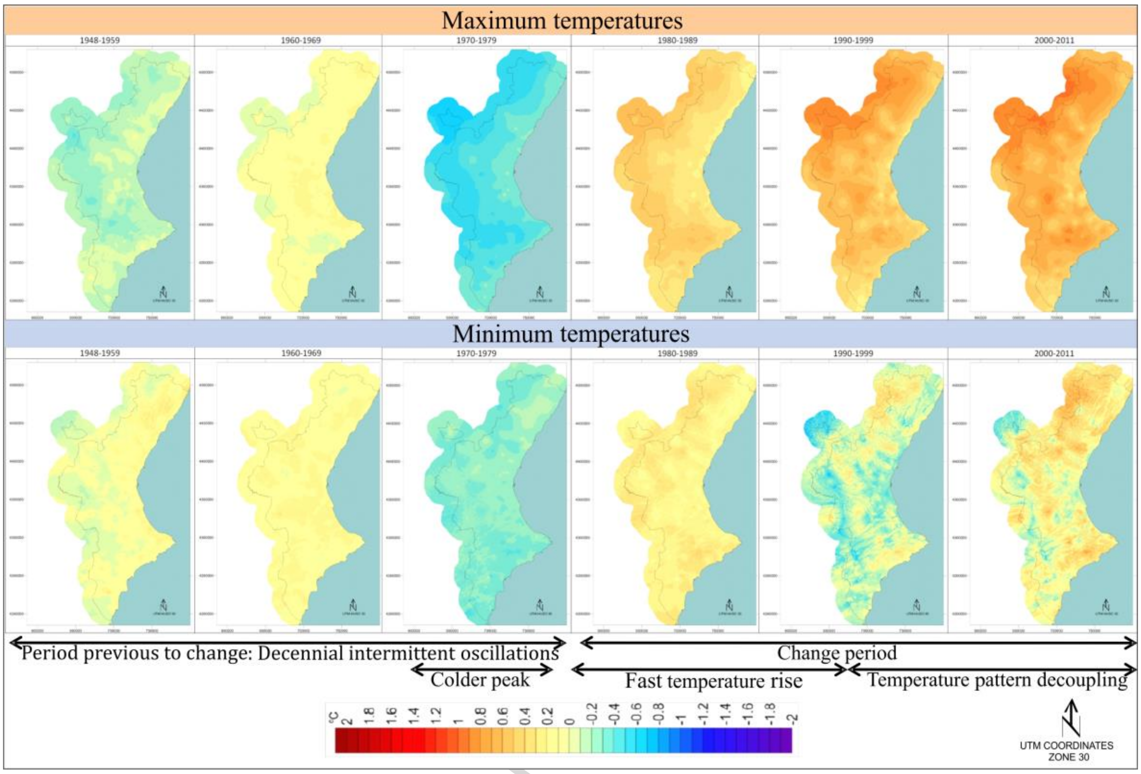


Figure 2: Temperature anomalies by decennia during the reference 1961-90 period, as calculated from SDSITVC (Miró, 2014)

After obtaining the spatial information layers of Itc for the reference and test periods, the differences in Itc units were calculated, which the test period showed on the reference period. The resulting mapping covered the VC and surrounding areas (Figure 1), but was split into several parts to properly display them: *Castellón* to the north, *Valencia* in the center and *Alicante* to the south, and focused on five mountainous areas of high natural value, which were already mentioned (Figures 3-10).

As the data that derived from SDSITVC have an error margin, we took into account the uncertainty introduced by the mean absolute error. To do this, we added the error that showed the monthly-annual data of SD (E_{sd}) and the error shown by the SI in the cross-validation (E_{si}) in order to obtain the total error (E_t) as $E_t = \pm(E_{sd}+E_{si})$. Therefore, the Itc (It) error (E_{tIt}) was obtained by averaging the total error for T (E_{tT}), m (E_{tm}) and M (E_{tM}); thus $E_{tIt}= \pm((E_{tT}+E_{tm}+E_{tM})/3)10$.

The spatial areas in which E_{tIt} was greater than the Itc change between the test and reference periods were considered doubtful changes. These areas were properly marked on the generated maps that expressed the Itc change.

The primary purpose of obtaining Itc was to limit bounded thermotypes, so that each thermotype would respond to an Itc range. According to the thermotype classification of Rivas-Martínez *et al.* (2011), the following appear in the study area (Table 1):

THERMOTYPIC HORIZONS	ABBREVIATION	It/Itc RANGE	Tp RANGE
Mediterranean macrobioclimate			
Lower Thermomediterranean	Tmei	400-450	
Upper Thermomediterranean	Tmes	350-400	
Lower Mesomediterranean	Mmei	285-350	
Upper Mesomediterranean	Mmes	220-285	
Lower Supramediterranean	Smei	150-220	
Upper Supramediterranean	Smes	120-150	
Oromediterranean	Omei	<120	675-900
Temperate macrobioclimate (submediterranean bioclimatic variant)			
Lower Mesotemperate	Mtei	240-290	
Upper Mesotemperate	Mtes	190-240	
Lower Supratemperate	Stei	120-190	
Upper Supratemperate	Stes	<120	800-1100
Lower Orotemperate	Otei		590-800

Table 1: Thermotypic horizons (Rivas-Martínez *et al.*, 2011) present in the study area

On the one hand, a cartography was generated that reflected the distribution of the thermotypic horizons expressed by Itc during the reference and test periods in order to visually locate the distribution of the horizons and their changes between the two periods. On the other hand, a cartography was produced that reflected only the change which occurred between both periods, expressed in It units, which also reflected the areas in which this change was doubtful according to the considered error margins.

It must be considered that not the complete study area is classified within the Mediterranean macrobioclimate (Table 1) since the Temperate macrobioclimate appears at North inland. This determines different thermotypes with a same Itc value. The difference between Mediterranean and Temperate macrobioclimates is characterized by a summer drought of at least two consecutive months in which P < 2T (where P is the rainfall amount and T temperature mean of each month). If this condition is not reached, thus macrobioclimate is considered Temperate instead Mediterranean (Rivas-Martínez *et al.*, 2011).

Although this study focuses on the Itc, an estimation of the area occupied by temperate macrobioclimate has been included in the cartography to better differentiate the mapped thermotypes. For this purpose, information on monthly rainfall in the area has been taken from observed series available for the periods 1948-1979 and 1997-2011 (observed period >= 15 years for 1948-1979, and observed period >= 7 years for 1997-2011). These series derive from AEMET, SIAR and CEAM stations networks, and were subjected to a quality control. However up to now, for precipitation is not available a fine-scale data source (with continuous homogeneous data without gaps) similar to SDSITVC. Thus that the available data density changes over time and are not reliable for analysis of fine-scale tendencies. Therefore its use here as a marker of bioclimatic change is uncertain and must be taken with caution.

3.-RESULTS

In general, the results showed (Figures 3, 4 and 5) a predominance of upward trends for the Itc-dependent thermotypic horizons. However, this upward trend was more marked in hilly areas, especially in mountain peaks and hillsides with greater slopes. As a whole, the temperature increase was more pronounced in the Iberian System part; that is in the area of *Gúdar* and its surroundings (Figure 3), and also in the Pre-betic System, around *Aitana* (Figure 5). Thus a rise of up to 23 Itc units in the higher parts of *Gúdar* and *Aitana* was obtained. As a result, a strong regression was observed for the Orotemperate (Otei), Supratemperate (Stes, Stei) and Supramediterranean (Smes, Smei) thermotypic horizons.

Lower lands, flat areas and coastal sectors generally showed a weaker upward trend in the thermotypic horizons. Although increases still dominated in most of these areas, the uncertainty introduced by the error involved considering a doubtful change (an Itc change $< \pm 8$ as a rule).

The areas around river beds, and lowest parts of valleys and flat lands (especially those inland) even showed negative trends. These are areas in which cold conditions were linked to the frequency of temperature inversions subject to stable weather. However, these trends were doubtful so can not be inferred that there has been a significant change. We can thus consider that these areas may act as potential refuge areas for some taxa to face climate change, which is in line with Dobrowski (2011).

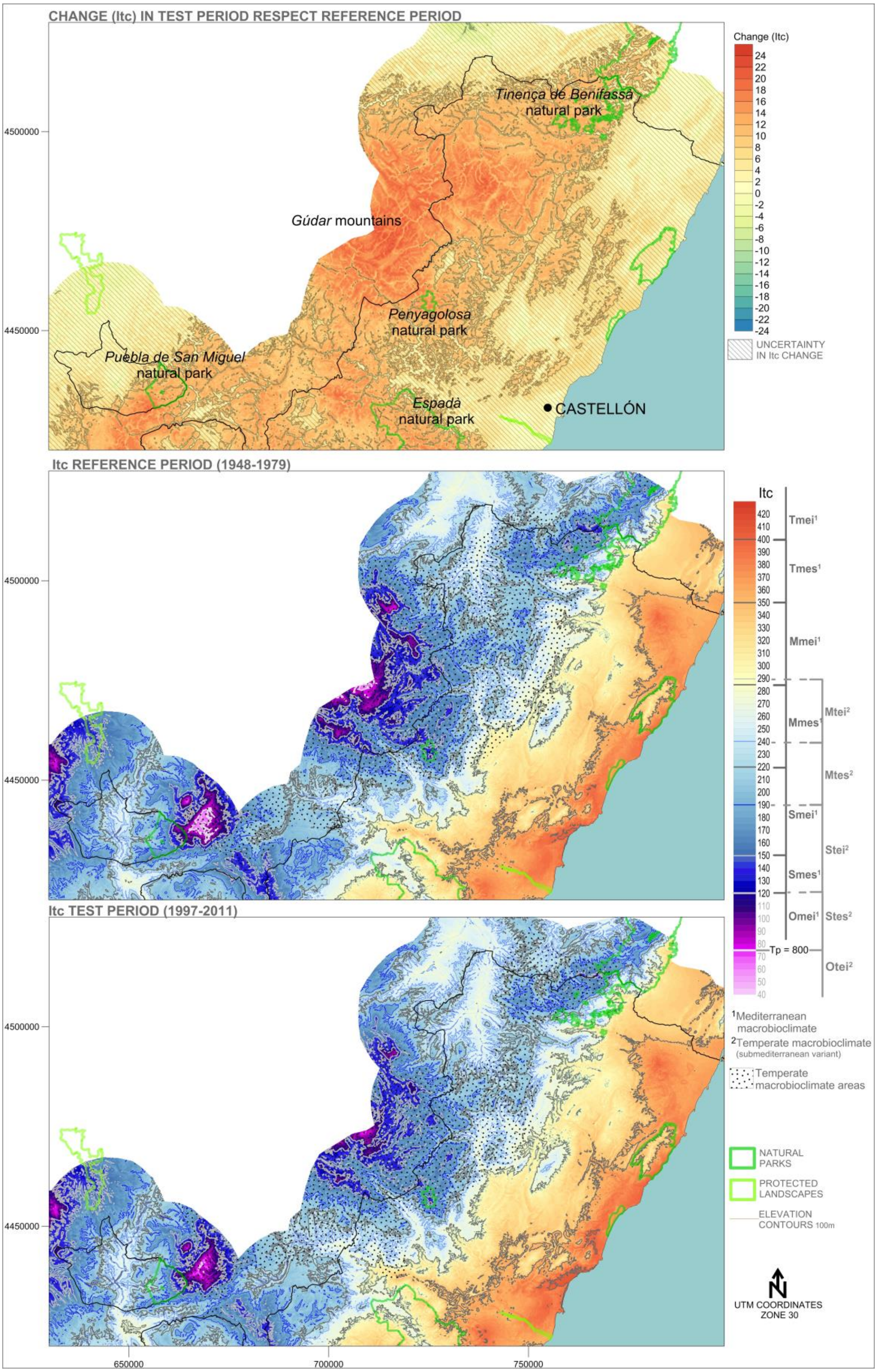


Figure 3: The Itc change during the test period compared with the reference period (up). The Itc of the reference and test periods is shown (center and bottom). North region (the areas of *Castellón* and *Ademuz*).

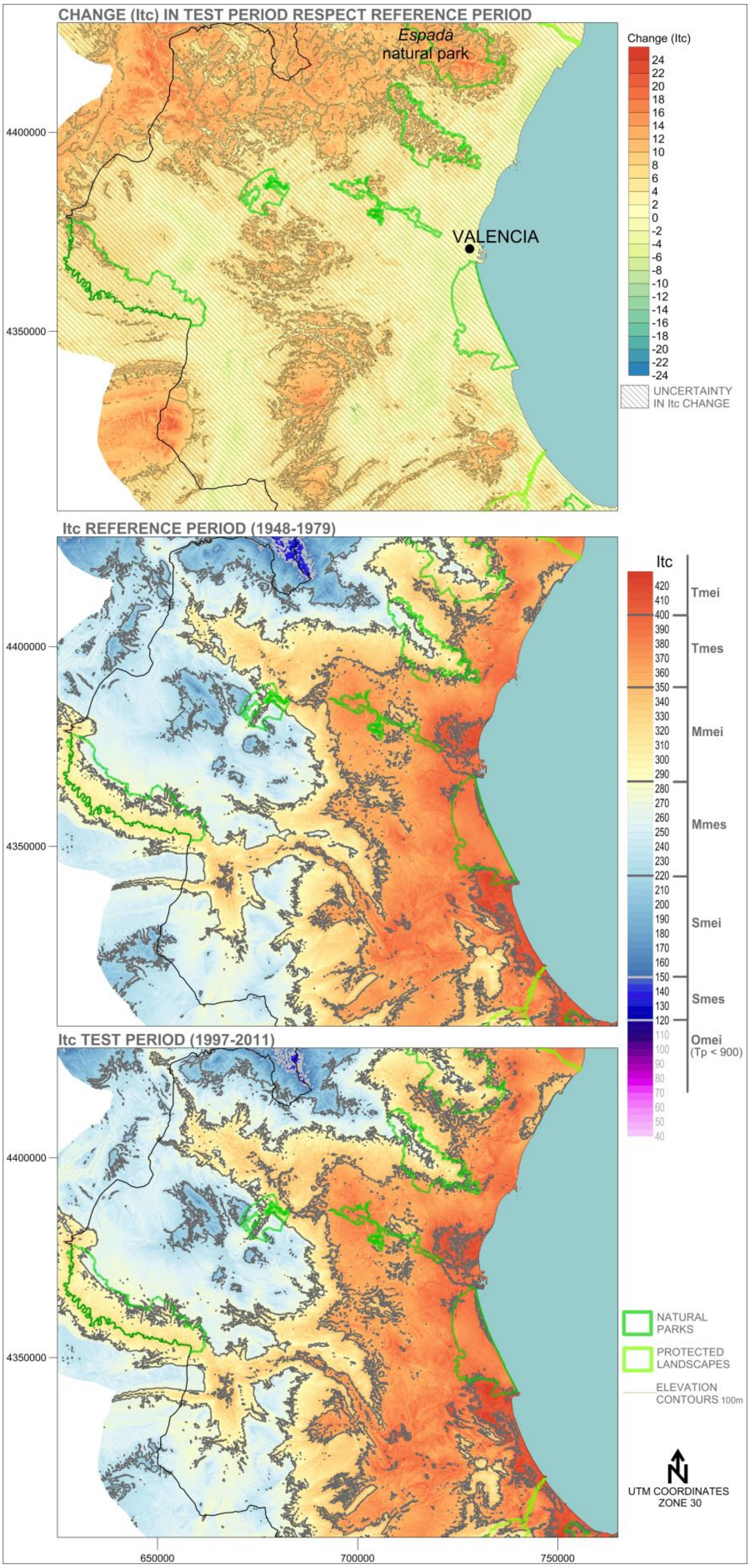


Figure 4: The Itc change during the test period compared with the reference period (up). The Itc of the reference and test periods is shown (center and bottom). Central region (the area of *Valencia*).

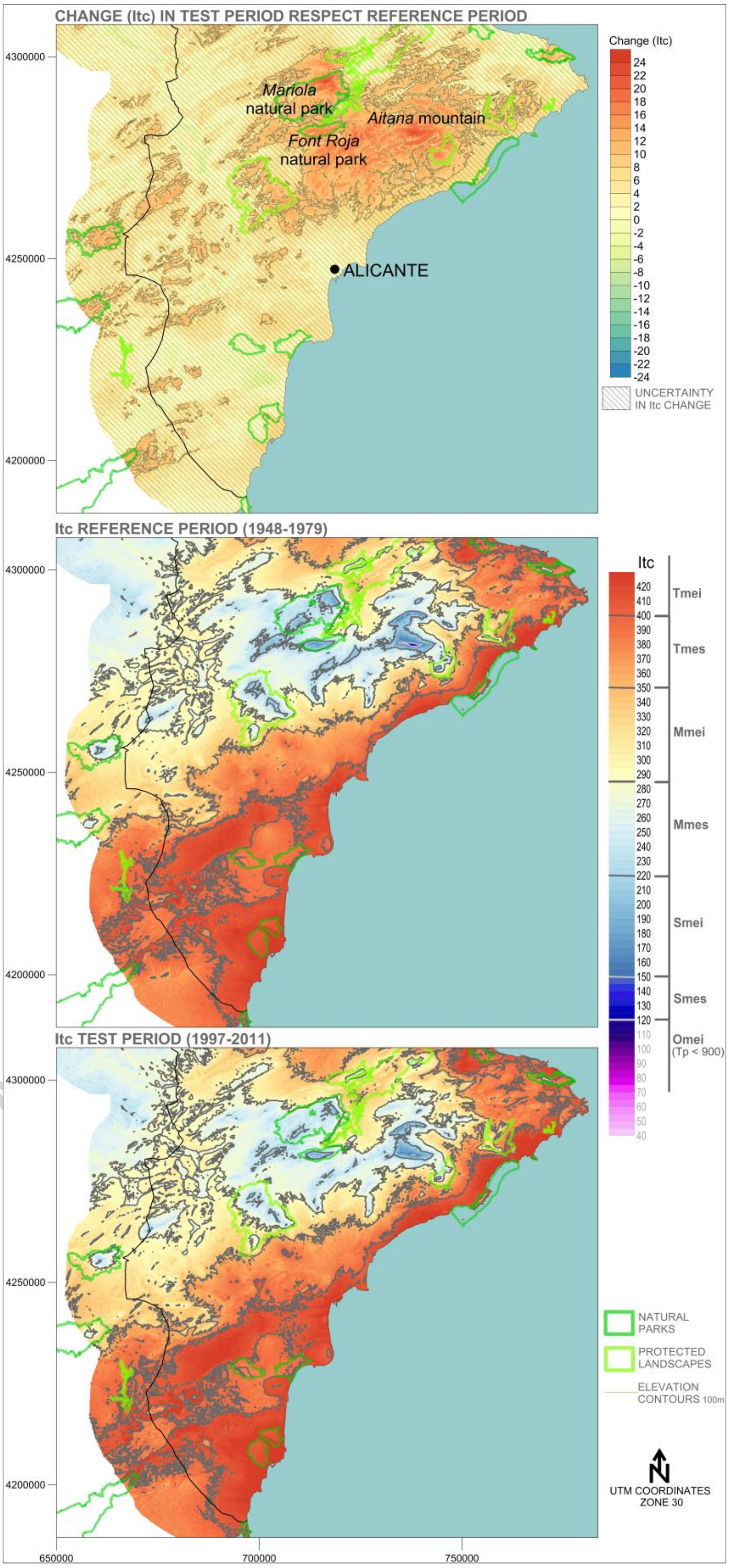


Figure 5: The Itc change during the test period compared with the reference period (up). The Itc of the reference and test periods is shown (center and bottom). South region (the area of *Alicante*).

Figure 6 shows a zoom in on the *Tinença de Benifassà* Natural Park sector (the northern end of the region). Here a major regression of the thermotypic horizon Stei, and Mediterranean equivalent Smes, stands out, which occurred between the reference and test periods. This means that they tend to disappear from the area if this trend continues in future, especially if the macrobioclimate changes to be mostly Mediterranean (maximum elevation of 1235 m). Therefore, the results confirm a potential risk for taxa in a finicolous position.

The results are more pronounced in Figure 7, which focuses on the *Penyagolosa* Natural Park and the area of *Gúdar* (entire area within Temperate macrobioclimate). In this case, a strong regression of the Otei and Stes horizons was observed. Otei have already disappeared in the Gúdar section that has been mapped (up to 1900 m) between the reference and test periods. While in Penyagolosa (maximum elevation of 1813 m) Stei diminished by 60% and Stes almost disappeared (75%) during the test period. The regression for the Mtes horizon was also quite remarkable.

Figure 8 focuses on the *Puebla de San Miguel* Natural Park sector, to the east of *Ademuz*. Once again, a clear regression of the Otei-Stes (≈ Ome) and Smes (≈ Stei) horizons was noted inside the park (maximum elevation of 1836 m in the park, and 2020 m further northeast of the park in *Javalambre*) which gave way to Smei and Mmes in lower park sections. Very remarkable is that Otei horizon has dropped more than 90% in the highest area of Javalambre. In contrast, a different manner was observed in the lower valley section, which lies further west of the park, where the *Turia* River crosses the area of *Ademuz*. In this continentalized setting, and very close to the river bed, some sectors even showed a negative Itc change, although not significant.

Once again similar results were found for Figure 9, which focused on the *Serra d´Espadà* Natural Park. In this case the Smei horizon appeared in higher park sections, and do not appear upper horizons (as the higher elevations there do not go beyond 1106 m). However, the regression of this horizon (Smei) was very clear, while the Mmei horizon extended to lower park sections.

Finally, Figure 10 focuses on the main Natural Parks (*Mariola* and *Font Roja*) and the higher elevation (*Aitana* – 1558 m) in the Pre-betic sector, located to the south of the study area. According to the results, the clear presence of the Smes horizon in the upper sections and peak of Aitana mountain (reference period) almost disappeared during the test period. In this case, the presence of taxa in a finicolous position has been well reported (Marco *et al*. 2006).

The strong regression of the Smei horizon, which occupied the upper *Font Roja* and *Mariola* Natural Park parts (maximum elevation of 1356 m and 1390 m, respectively) was noteworthy. In the latter (*Mariola*), Smei diminished by 60% between the reference and test periods.

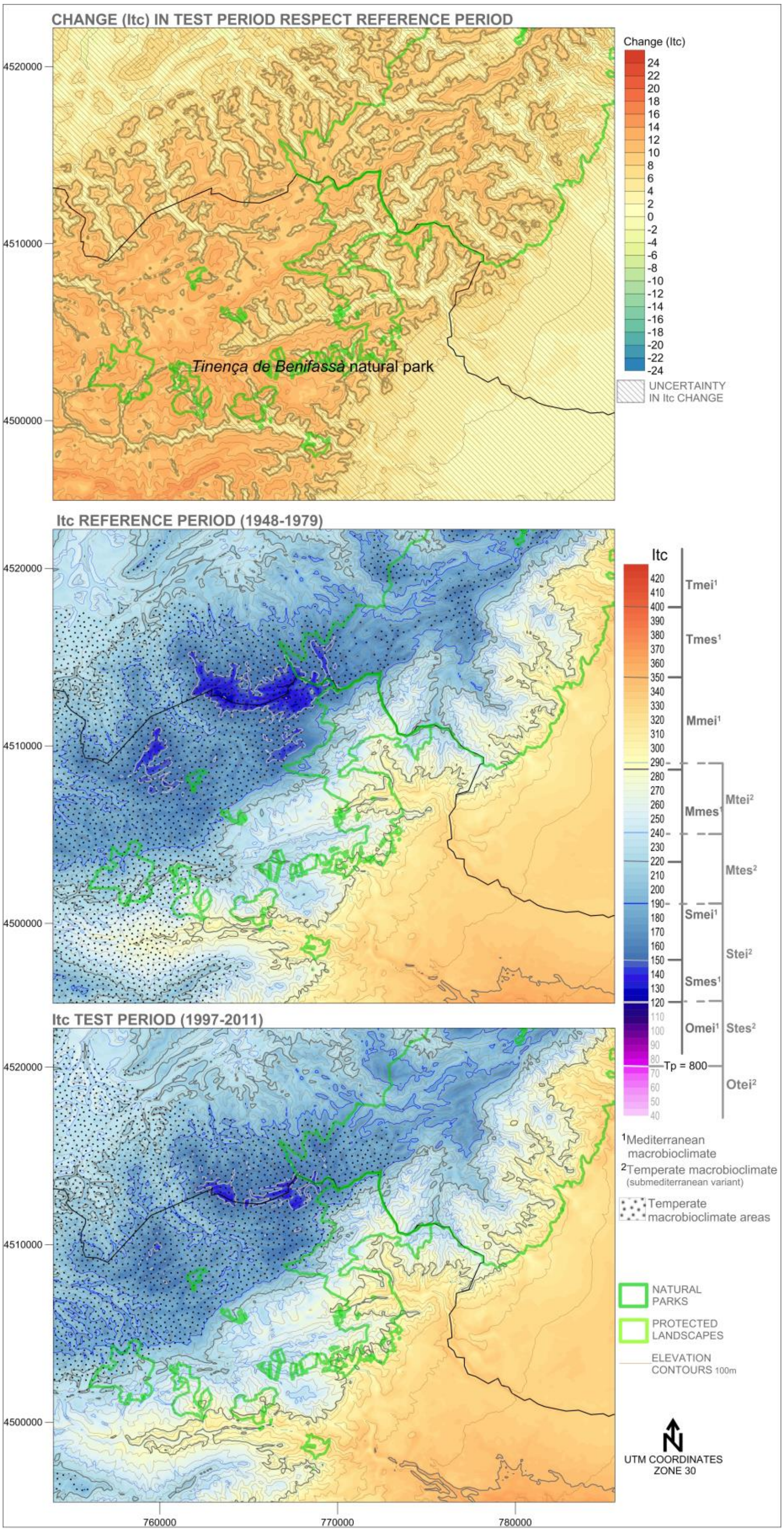


Figure 6: The Itc change during the test period compared with the reference period (up). The Itc of the reference and test periods is shown (center and bottom). It focuses on the *Tinença de Benifassà* Natural Park.

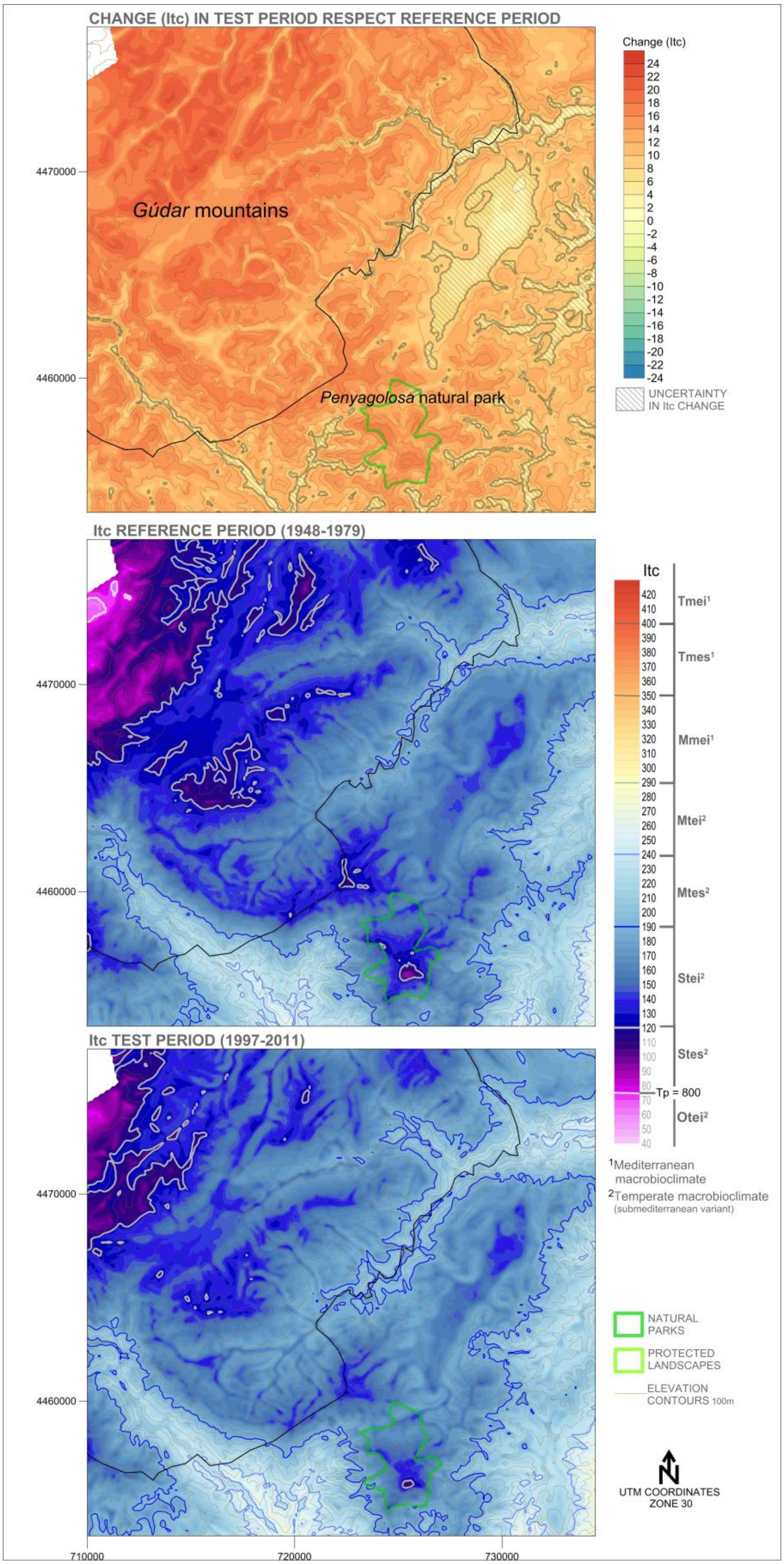


Figure 7: The Itc change during the test period compared with the reference period (up). The Itc of the reference and test periods is shown (center and bottom). It focuses on the *Penyagolosa* Natural Park and the *Gúdar* mountains.

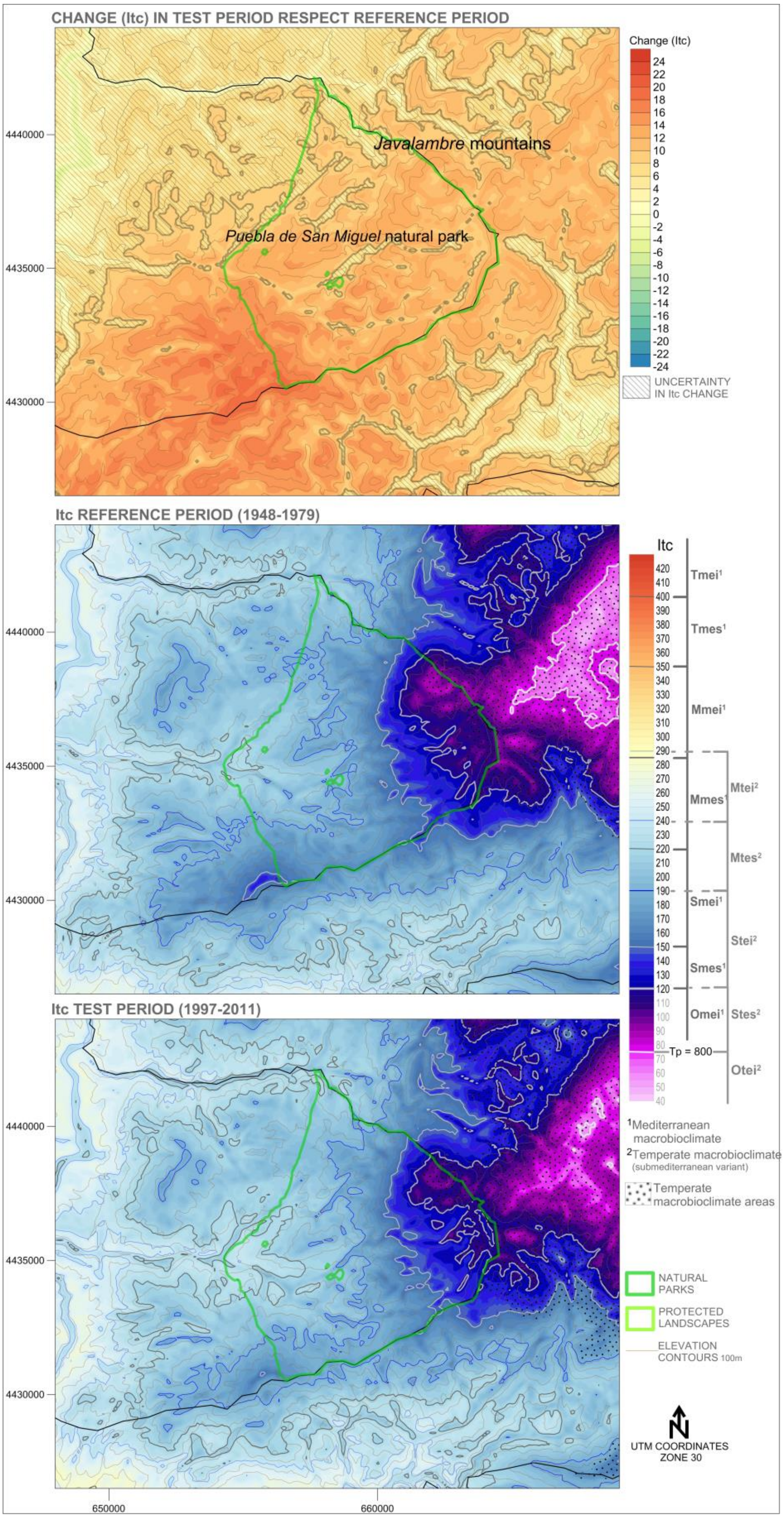


Figure 8: The Itc change during the test period compared with the reference period (up). The Itc of the reference and test periods is shown (center and bottom). It focuses on the *Puebla de San Miguel* natural park.

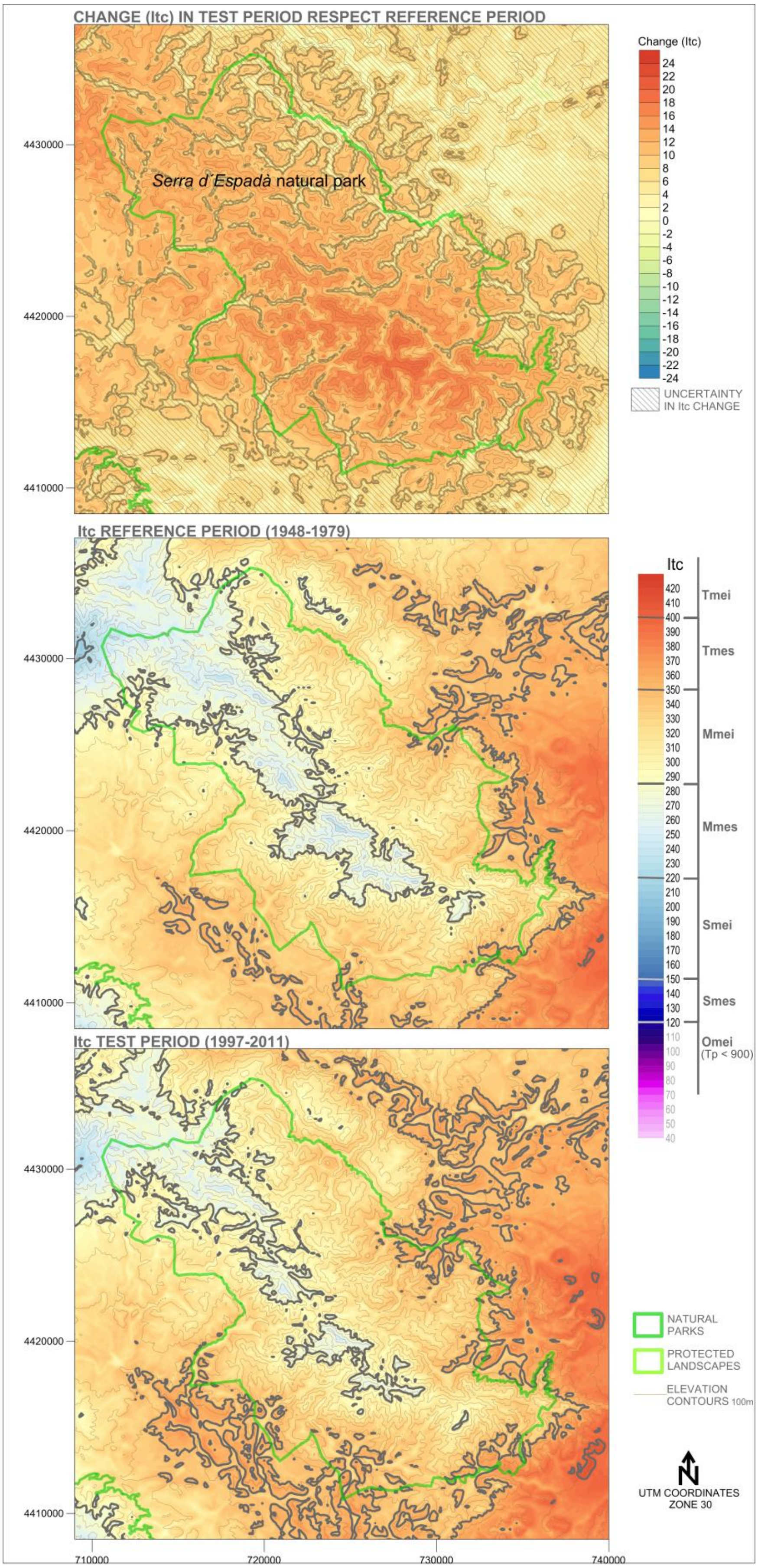


Figure 9: The Itc change during the test period compared with the reference period (up). The Itc of the reference and test periods is shown (center and bottom). It focuses on the *Serra d´Espadà* Natural Park.

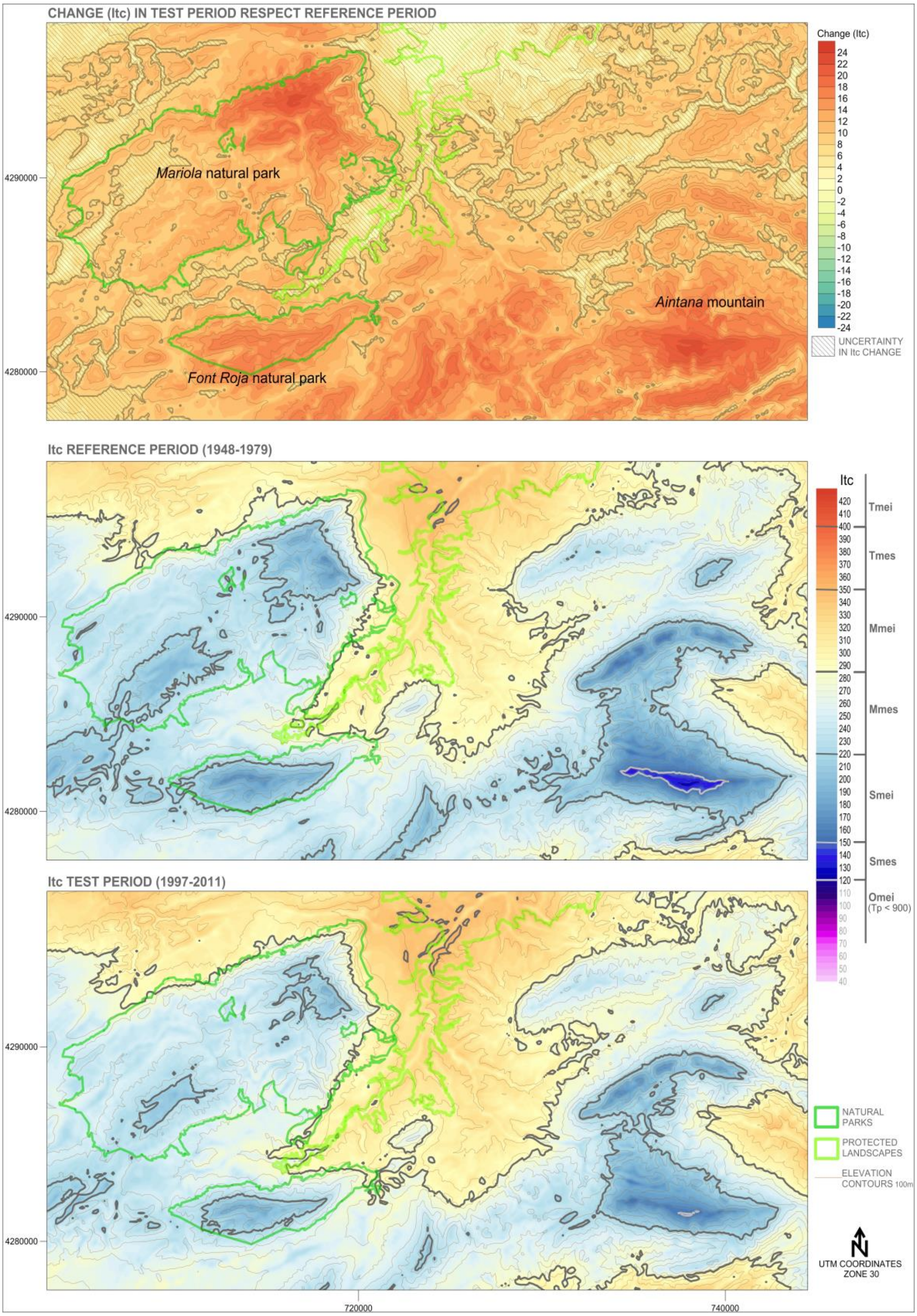


Figure 10: The Itc change during the test period compared with the reference period (up). The Itc of the reference and test periods is shown (center and bottom). It focuses on the *Mariola* and *Font Roja* Natural Parks, and the *Aitana* mountain.

4.-DISCUSSION AND CONCLUSIONS

The availability of SDSITVC, based on a complete homogeneous period (1948-2011), allowed the fine-scale mapping of changes in Itc (and the associated bioclimatic horizons) between a reference period (1948-1979) and a recent testing period (1997-2011). This, therefore, provides an account of a non estimated change in the future, but one that has already happened, which may now have potential consequences on biotopes, particularly those in a finicolous position.

The present results revealed a greater regression for the thermotypic horizons that occupy the middle and upper parts of mountain reliefs, as well as mountainous Natural Parks, and between both periods. This regression became more pronounced for the Otei-Stes, Stei and Smes horizons, but also for Smei in mountains with a lower elevation or latitude. In some cases, horizons were present and exhibited finicolous characteristics that could completely disappear (*Gúdar*, *Javalambre*, *Penyagolosa*, *Aitana*). In other cases their space reduced significantly (*Tinença de Benifassà*, *Serra d´Espadà*, *Mariola*, etc.). Conversely valleys, flat lands and low elevation areas showed less marked changes, which were doubtful when considering the uncertainty range of SDSITVC.

In any case, the translocation of thermotypic horizons to higher parts of terrain relief dominated in most parts of the study area. Yet certain locations could also act as a potential 'refuge' against change, which coincided with the bottom of valleys and river beds, which are in a more continental position; that is, where more proneness was shown to cold conditions linked to the presence of temperature inversions associated with stable anticyclonic weather and calm winds. These trends fall in line with those observed in other mountainous parts of the world at mid latitudes (Daly *et al.*, 2010; Pepin *et al.*, 2011; Dobrowski, 2011), which has also been justified by circumpolar vortex migration to higher latitudes (Frauenfeld and Davis, 2003; Angell, 2006), and the increased frequency of episodes with calm winds on the Iberian Peninsula and in the study area (Azorín-Molina *et. al.*, 2014; Miró *et al.* 2015).

A genuine rising trend of bioclimatic horizons in specific cases has already reported for the Iberian Peninsula (Sanz-Elorza *et al.* 2003), which thus reinforces the hypothesis of a potential change in bioclimatic horizons in our study area. In addition, the climate estimations made in different climate change scenarios contemplated by the IPCC have been applied to the bioclimatic classifications of Rivas-Martínez (Monteiro-Henriques and Espírito-Santo, 2011), with results that matched the basic results obtained herein.

In any case, the results obtained in this study are no real proof of changes in biotopes linked to the aforementioned horizons, but rather act as an indicator of potential change. This could be a useful tool for the scientific community that specializes in ecology and biogeography to help locate real changes that have occurred or are underway in the taxa distribution in the region.

Although this study addresses only Rivas-Martínez’s Itc (in order to constitute a bioclimatic marker as such), its overweighting at winter temperatures must be considered. In fact, more pronounced warming trends beyond winter for the region have been reported (Miró *et al*., 2006), which have been better established in the SDSITVC results shown in Miró *et al.* (2015). These warming trends are especially strong in the second half of spring and the first half of summer, and June is the month with the most positive trend (Figure 11).

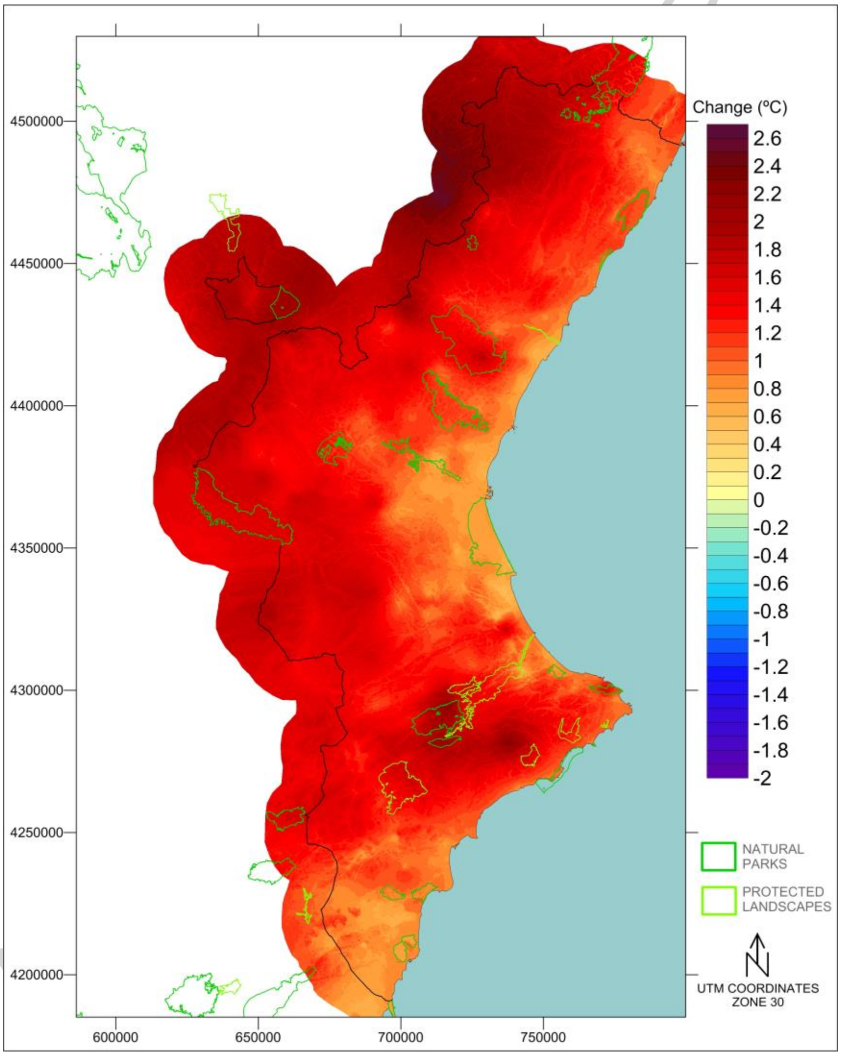


Figure 11: The change magnitude (ºC) of the mean temperature for June during the test period (1997-2011) vs. the reference period (1948-1979) according to SDSITVC (Miró *et al.*, 2015).

Therefore, for those cases in which high temperatures (or their temporal extension) are the limiting bioclimatic factor, the impact would be greater than any of those inferred by the Itc change displayed herein.

A similar fine-scale instrument to SDSITVC for precipitation is not currently available for the region. Yet if we take into account the results made available by studies conducted in the area on the observed series and precipitation types, a worrying scenario emerges in light of the results presented herein. They precisely indicate negative trends in precipitation toward the inland and hilly parts of the region (the Iberian System), which match the areas with the highest rise in temperature (SDSITVC), as opposed to littoral areas (Millán, *et al.*, 2005; Estrela *et al.*, 2010; Miró *et al.*, 2010; Miró *et al.*, 2015). In fact, the total area occupied by the temperate macrobioclimate in the Iberian System section also could be in regression according to the additional data to Itc presented here. Although this last fact is precipitation dependent so it can not yet be well inferred at fine-scale, unlike the Itc. This implies considering future studies into a change in bioclimatic horizons by means of an index that also weights precipitation in order to better assess the role of increased water stress as a marker of change. To do this, obtaining a fine-scale data source for precipitation that complements SDSITVC is currently pending.

ACKNOWLEDGMENTS

This work has been funded by the Regional Government of Valencia through the project PROMETEOII/2014/086. We also thank Helen Warburton for improving our English.

REFERENCES

Angell, J.K. 2006. Changes in the 300-mb North Circumpolar Vortex, 1963–2001. *J. Clim.*, **19**, pp. 2984–2994, doi: 10.1175/JCLI3778.1

Azorín, D. and Jover, N. 2010. Aproximación metodológica para la caracterización del piso supramediterráneo en la provincial de Alicante. *In*: "Biogeografía, una ciencia para la conservación del medio", pp. 335-343. Edited by Giménez, P, Marco, JA, Matarredona, E, Padilla, A. and Sánchez, A., Universidad de Alicante.

Azorín-Molina C., Vicente-Serrano S. M., McVicar T. R., Jerez S., Sanchez-Lorenzo A., López-Moreno Juan-I., Revuelto J., Trigo R. M., Lopez-Bustins J. A. and Espírito-Santo F. 2014. Homogenization and Assessment of Observed Near-Surface Wind Speed Trends over Spain and Portugal, 1961–2011. *J. Clim.*, **27**, 3692-3712, doi: dx.doi.org/10.1175/JCLI-D-13-00652.1

Bourne, S.M., Bhatt, U.S., Zhang, J. and Thoman, R. 2010. Surface-based temperature inversions in Alaska from a climate perspective, *Atmos. Res*., **95**, 353–366, doi:10.1016/j.atmosres.2009.09.013

Brunet, M., *et al*. 2007. Temporal and spatial temperature variability and change over Spain during 1850–2005. *J. Geophys. Res. D: Atmos.*, **112**, D12117, doi: 10.1029/2006JD008249

Costa, J.C., *et al*. 2012. Vascular plant communities in Portugal (Continental, the Azores and Madeira). *Global Geobotany*. **2**, 1–180, doi: 10.5616/gg120001.

Daly, C., Conklin, D.R. and Unsworth, M.H. 2010. Local atmospheric decoupling in complex topography alters climate change impacts. *Int. J. Clim.*, **30**, 1857–1864, doi: 10.1002/joc.2007.

Del-Río S., Penas, A. and Fraile, R. 2005. Analysis of recent climatic variations in Castile and Leon (Spain). *Atmos. Res*. **73**, 69-85. doi:10.1016/j.atmosres.2004.06.005

Del-Río, S., Cano-Ortiz, A., Herrero, L. and Penas, A. 2012. Recent trends in mean maximum and minimum air temperatures over Spain (1921-2006). *Theor. Appl. Climatol.*, **109**, 605-626, doi: 10.1007/s00704-012-0593-2.

Dirnböck, T., Essl, F. and Rabitsch, W. 2011. Disproportional risk for habitat loss of high-altitude endemic species under climate change. *Global Change Biol.*, **17,** 990–996, doi:10.1111/j.1365-2486.2010.02266.x

Dobrowski, S.Z. 2011. A climatic basis for microrefugia: the influence of terrain on climate. *Global Change Biol.*, **17**, 1022-1035, doi: 10.1111/j.1365-2486.2010.02263.x

El Kenawy, A., López-Moreno, J.I. and Vicente-Serrano, S.M. 2012. Trend and variability of surface air temperature in northeastern Spain (1920–2006): Linkage to atmospheric circulation. *Atmos. Res*. **106**, 159–180, doi:10.1016/j.atmosres.2011.12.006

El Kenawy, A., Lopez-Moreno, J.I., McCabe, M.F., Brunsell, N.A. and Vicente-Serrano, S.M. 2015. Daily Temperature Changes and Variability in ENSEMBLES Regional Models Predictions: Evaluation and Intercomparison for the Ebro Valley (NE Iberia). *Atmos. Res*., **155**, 141-157, doi:10.1016/j.atmosres.2014.12.007

Esteban-Parra, M.J., Rodrigo, F.S. and Castro-Díez, Y., 1998. Spatial and temporal patterns of precipitation in Spain for the period 1880-1992. *Int. J. Clim.*, **18**, 1557-1574, doi: 10.1002/(SICI)1097-0088(19981130)18:14<1557::AID-JOC328>3.3.CO;2-A

Estrela, M.J., Miró, J.J., Pastor, F. and Millán, M. 2010. Frontal Atlantic rainfall component in the Western Mediterranean Basin. Variability and spatial distribution. ESF-MedCLIVAR Workshop on

"Hydrological, socioeconomic and ecological impacts of the North Atlantic Oscillation in the Mediterranean region". Zaragoza (Spain), 24-27 May 2010.

Fernández-Montes, S., Rodrigo, F.S., Seubert, S. and Sousa, P.M. 2013. Spring and summer extreme temperatures in Iberia during last century in relation to circulation types. *Atmos. Res.*, **127**, 154-177, doi:10.1016/j.atmosres.2012.07.013

Frauenfeld, O.W. and Davis, R.E. 2003. Northern Hemisphere circumpolar vortex trends and climate change implications. *J. Geophys. Res. D: Atmos.*, **108** (D14), 7-1–7-13 Art. No. 4423, doi: 10.1029/2002JD002958, D14.

Gallego, M. C., R. M. Trigo, J. M. Vaquero, M. Brunet, J. A. García, J. Sigró, and Valente, M.A. 2011. Trends in frequency indices of daily precipitation over the Iberian Peninsula during the last century. *J. Geophys. Res. D: Atmos.*, **116**, D02109, doi:10.1029/2010JD014255

Gavilán R. 2005. The use of climatic parameters and indices in vegetation distribution. A case study in the Spanish Sistema Central. *Int. J. Biometeorol.*, **50**, 111–120, doi: 10.1007/s00484-005-0271-5

Gil-Romera, G., J.S. Carrión, J.G. Pausas, M. Sevilla-Callejo, H.F. Lamb, S. Fernández and Burjachs, F. 2010. Holocene fire activity and vegetation response in South-Eastern Iberia. *Quat. Sci. Rev.*, **29** (9-10), 1082-1092, doi:10.1016/j.quascirev.2010.01.006

Gómez, I., Caselles, V. and Estrela, M.J. 2014a. Real-time weather forecasting in the Western Mediterranean basin: An application of the RAMS model. *Atmos. Res.*, **139**, 71-89, doi: 10.1016/j.atmosres.2014.01.011

Gómez, I., Caselles, V., Estrela, M.J. and Niclòs, R. 2014b. RAMS-forecasts comparison of typical summer atmospheric conditions over the Western Mediterranean coast. *Atmos. Res.*, **145-146**, 130-151, doi: 10.1016/j.atmosres.2014.03.018

Gómez, I., Estrela, M.J. and Caselles, V. 2015a. Verification of the RAMS-based operational weather forecast system in the Valencia Region: a seasonal comparison. *Nat. Hazards*, **75**, 1941-1958, doi: 10.1007/s11069-014-1408-9

Gómez, I., Caselles, V. and Estrela, M.J. 2015b. Impacts of soil moisture content on simulated mesoscale circulations during the summer over eastern Spain. *Atmos. Res.*, **164-165**, 9-26, doi:10.1016/j.atmosres.2015.04.015

Gonzalez-Hidalgo, J.C., Brunetti, M. and de Luis, M. 2010. Precipitation trends in Spanish hydrological divisions, 1946–2005. *Climate Res.*, **43**, 215-228, doi: 10.3354/cr00937

Graff, L.S., and LaCasce, J.H., 2012. Changes in the Extratropical Storm Tracks in Response to Changes in SST in an AGCM. *J. Clim*, **25**, 1854–1870, doi: 10.1175/JCLI-D-11-00174.1

Graff, L.S., and LaCasce, J.H. 2014. Changes in Cyclone Characteristics in Response to Modified SSTs. *J. Clim*, **27**, 4273–4295, doi: 10.1175/JCLI-D-13-00353.1

Ighbareyeh, J., Cano-Ortiz, A., Carmona, E., Ighbareyeh, M. and Suliemieh, A. 2015. Assessing Crop Yield Sustainability under the Climatic and Bioclimatic Change in the Area of Palestine. *American Journal of Climate Change*, **4**, 48-56, doi: 10.4236/ajcc.2015.41005

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge. United Kingdom and New York, NY, USA, 1535 pp, doi: 10.1017/CBO9781107415324

Jerez, S., Montavez, J.P., Gomez-Navarro, J.J., Jimenez, P.A., Jimenez-Guerrero, P., Lorente, R. and Gonzalez-Rouco, J.F. 2012.The role of the land-surface model for climate change projections over the Iberian Peninsula. *J. Geophys. Res. Atmos*. **117** (D1), D01109, doi:10.1029/2011JD016576

Laguna, E. *et al*., 1998. Flora endémica, rara o amenazada de la Comunidad Valenciana. Generalitat Valenciana. Valencia, ISBN: 978-84-482-1879-9

Loidi, J., Biurrun, I., Campos, J.A., García-Mijangos, I. and Herrera, M. 2007. A survey of heath vegetation of the Iberian Peninsula and Northern Morocco: a biogeographic and bioclimatic approach. *Phytocoenologia* **37**, 341–370, doi: 10.1127/0340-269X/2007/ 0037-0341

López, M.L., Marco, R., Piñas, S. and López, M.S. 2015. Mapa de Isobioclimas de Aragón. *In*: "Análisis espacial y representación geográfica: innovación y aplicación", pp. 1735-1744. Edited by De la Riva, J., Ibarra, P., Montorio, R., Rodrigues, M. Universidad de Zaragoza-AGE. ISBN: 978-84-92522-95-8

López-Moreno, J.I., Goyette, S. and Beniston, M., 2008. Climate change prediction over complex areas: spatial variability of uncertainties and predictions over the Pyrenees from a set of regional climate models. *Int. J. Climatol*. **28**,1535–1550, doi:10.1002/joc.1645

López-Moreno, J.I., El-Kenawy, A., Revuelto, J., Azorín-Molina, C., Morán-Tejeda, E., Lorenzo-Lacruz, J., Zabalza, J. and Vicente-Serrano, S.M. 2014. Observed trends and future projections for winter warm events in the Ebro basin, northeast Iberian Peninsula. *Int. J. Climatol*., **34**: 49–60. doi:10.1002/joc.3665

Marco, J.A., Padilla, A. and Sánchez, A. 2006. Cartografía corológica mediante el uso de GPS de especies vegetales endémicas, raras o amenazadas en el sector oriental de Aitana (Alacant). In "Serie Geográfica, Biogeografía: distribuciones, dinámicas y diversidad", **13**, 11-24.

Millán, M., Estrela, M.J. and Conrado Badenas. 1998. Meteorological processes relevant to forest fire dynamics on the spanish mediterranean coast. *J. Appl. Meteorol.*, **37**, 83-100, doi: 10.1175/1520-0450(1998)037<0083:MPRTFF>2.0.CO

Millán, M., Estrela, M.J. and Miró, J.J. 2005. Rainfall components: variability and spatial distribution in a mediterranean area (Valencia Region). *J. Clim*, **18** (14), 2682-2705, doi:10.1175/JCLI3426.1

Miró, J.J., Estrela, M.J. and Millán, M. 2006. Summer Temperature Trends in a Mediterranean Area (Valencia Region). *Int. J. Clim.*, **26**, 1051-1073, doi: 10.1002/joc.1297

Miró, J.J., Estrela, M.J., Pastor, F. and Millán, M. 2010. Análisis comparativo de tendencias en la precipitación, por distintos inputs, entre los dominios hidrológicos del Segura y del Júcar (1958-2008). *Investigaciones Geográficas*, **49**, 129-157, doi: 10.14198/INGEO2009.49.07

Miró J.J. 2014. *Downscaling estadístico de series climáticas mediante redes neuronales: Reconstrucción en alta resolución de la temperatura diaria para la Comunidad Valenciana. Interpolación espacial y análisis de tendencias (1948-2011)*. Ph. D. Thesis. University of Alicante, Fundación Centro de Estudios Ambientales del Mediterráneo, and University of Valencia. 523p., doi: 10.13140/RG.2.1.2059.1523

Miró, J.J., Estrela, M.J. and Olcina-Cantos, J. 2015. Statistical downscaling and attribution of air temperature change patterns in the Valencia region (1948–2011). *Atmos. Res.*, **156**: 189-212, doi:10.1016/j.atmosres.2015.01.003

Miró, J.J., Estrela, M.J. and Olcina-Cantos, J. 2016. Reconstrucción de la señal térmica local en la Comunidad Valenciana entre 1948 y 2011 a partir de un downscaling estadístico mediante una red neuronal artificial: Detección de patrones locales de cambio. *Boletín de la Asociación de Geógrafos Españoles*, **70**, 113-147 (eng:471-475), doi:10.21138/bage.2165

Monteiro-Henriques, T. and Espírito-Santo, M.D. 2011. Climate change and the outdoor regional living plant collections: an example from mainland Portugal. *Biodivers. Conserv.*, **20**, 335–343, doi: 10.1007/s10531-010-9864-3

Monteiro-Henriques, T., Martins, M. J., Cerdeira, J. O., Silva, P., Arsénio, P., Silva, Á., Bellu, A. and Costa, J. C. 2015. Bioclimatological mapping tackling uncertainty propagation: application to mainland Portugal. *Int. J. Clim.*, **29** (14)**,** 2156-2170, doi: 10.1002/joc.4357

Muñoz-Díaz, D. and Rodrigo, F.S.. 2006. Seasonal rainfall variations in Spain (1912–2000) and their links to atmospheric circulation. *Atmos. Res*., **81** (1), 94–110, doi:10.1016/j.atmosres.2005.11.005

Ohlemueller, R., Anderson, B.J., Araujo, M.B., Butchart, S.H.M., Kudrna, O., Ridgely, R.S. and Thomas, C. D. 2008. The coincidence of climatic and species rarity: high risk to small-range species from climate change. *Biol. Letters*, **4** (5), 568-572, doi: 10.1098/rsbl.2008.0097

Pastor, F., Valiente, J. A., and Estrela, M. J. 2015. Sea surface temperature and torrential rains in the Valencia region: modelling the role of recharge areas, *Nat. Hazard. Earth Sys.*, **15**, 1677-1693, doi:10.5194/nhess-15-1677-2015

Pearson, R.G. and Dawson, T.P. 2003. Predicting the impacts of climate change on the distribution of species: Are bioclimate envelope models useful?. *Global Ecol. Biogeogr.*, **12**, 361–371, doi: 10.1046/j.1466-822X.2003.00042.x

Peña-Angulo, D., Trigo, R.M., Cortesi, N. and González-Hidalgo, J.C. 2016. The influence of weather types on the monthly average maximum and minimum temperatures in the Iberian Peninsula. *Atmos. Res*., **178-179**, 217–230, doi:10.1016/j.atmosres.2016.03.022

Peñas, J., Pérez-García, F.J., and Mota, J.F. 2005. Patterns of endemic plants and biogeography of the Baetic high mountains (south Spain), *Acta Bot. Gallica*, **152**(3), 347-360, doi: 10.1080/12538078.2005.10515494

Pepin, N.C., Daly, C. and Lundquist, J. 2011. The influence of surface versus free-air decoupling on temperature trend patterns in the western United States. *J. Geophys. Res. D: Atmos*, **116**, D10109, doi: 10.1029/2010JD014769.

Piñas, S., López-Fernández, M. S. and López, M. L. 2008. Termotipos de la España Peninsular y Balear, y su cartografía. *Serie Botánica*, **17**, 237-242. Publicaciones de Biología de la Universidad de Navarra.

Quézel, P. 1985. Definition of the Mediterranean region and the origins of the flora. *In* "Plant Conservation in the Mediterranean Area" pp 9-24. Edited by C.Gomez-Campo, Dr Junk Dordrecht.

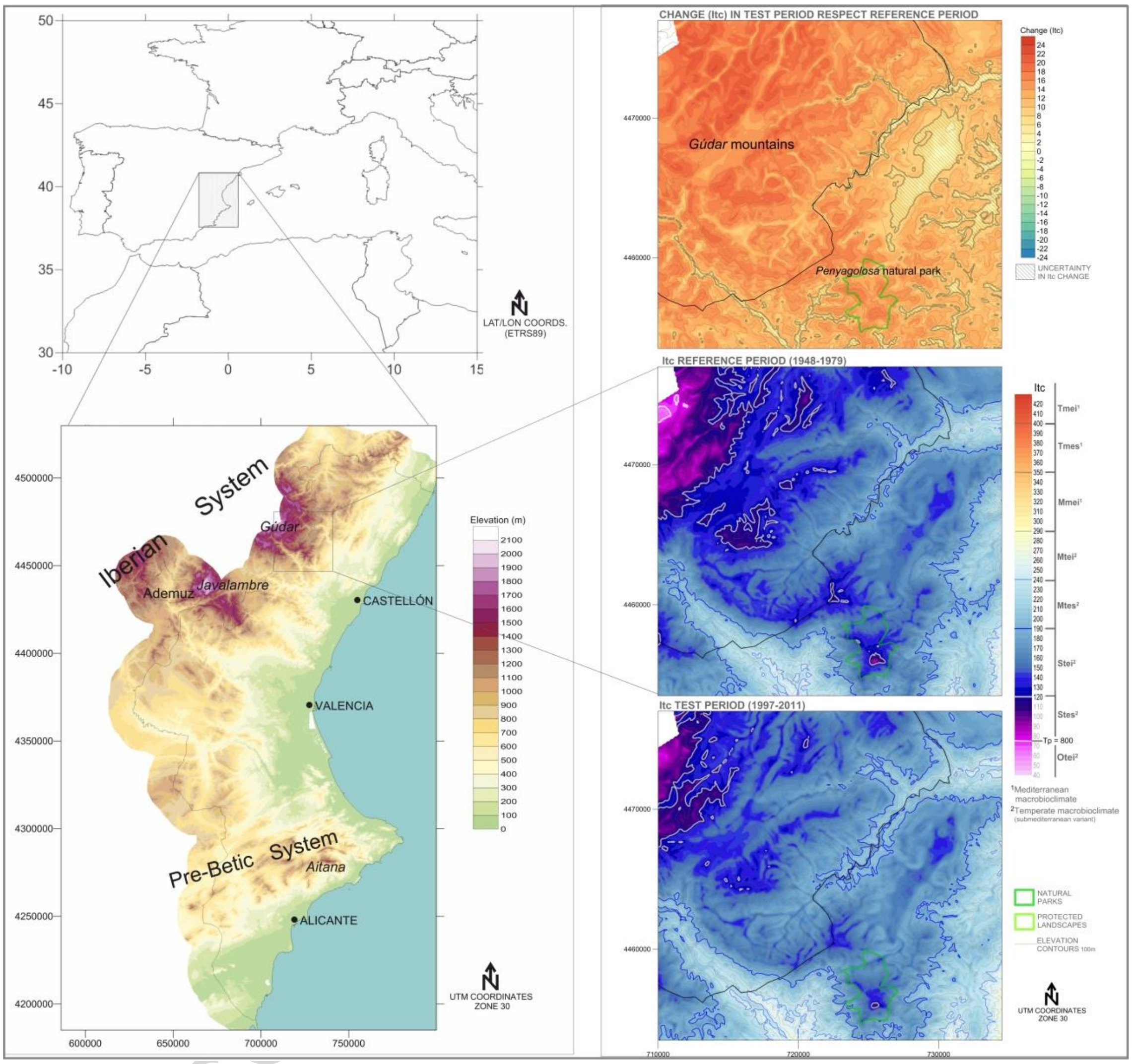
Rivas-Martínez, S. 1987. Memoria del mapa de series de vegetación de España. Ministerio de Agricultura, Pesca y Alimentación, ICONA. Madrid. 268p.

Rivas-Martínez, S., Rivas Sáenz, S. and Penas, A. 2011. Worldwide Bioclimatic Classification System. *Global Geobotany*, **1,** 1-634, doi: 10.5616/gg110001

Sanz-Elorza, M., Dana, E.D., González, A. and Sobrino, E. 2003. Changes in the highmountain vegetation of the central Iberian Peninsula as a probable sign of global warming. *Ann. Bot.-London,* **92**, 273–280, doi: 10.1093/aob/mcg130

Serra, L., Pérez-Rovira, P., Deltoro V.I., Fabregat, C., Laguna, E. and Pérez-Botella, J. 2004. Distribution, status and conservation of rare relict plant species in the Valencian Community. *Bocconea* **16**(2): 857-863.

HIGHLIGHTS



Change for the thermicity index of Rivas-Martínez (It) between a reference period (1948-1979) and a test period (1997-2011). The It (Itc) was calculated from average temperature of the maximum and minimum of the coldest month and annual mean temperature, obtained from statistical downscaling and temperatures interpolation performed in Miró *et al.* (2014). The results show a greater regression for the thermotypes in a finicolous position, e.g. Orotemperate (Otei) and Supratemperate (Stes-Stei) horizons, as well as Supramediterranean Itc equivalents (Smes, Smei). This indicates greater potential vulnerability in climate change for biotopes and taxa located over the highest mountains. Location and elevation is included (left) for reference.