RECONSTRUCTION OF THERMAL LOCAL SIGNAL FROM STATISTICAL DOWNSCALING (SD) THROUGH ARTIFICIAL NEURONAL NETWORK: DETECTION OF LOCAL PATTERNS OF CHANGE IN VALENCIA REGION (SPAIN) (1948-2011)

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I. INTRODUCTION

It has noted the need for more precise knowledge in relation of processes of regional and local manifestations of climate change, where most uncertainties reside (Pita, 2009). The tools of *statistical downscaling* (SD) are very useful since they allow us to model local climate signals and extrapolate them in space-time, in line with real observed data and with less computational cost than dynamic downscaling process. But stationary relations obtained in local models may vary over time, particularly by forcings caused by climate change (Hewitson & Crane , 1996; Wilby et al, 1998; Wilby et al, 2004).

The present paper focuses on the implementation of a SD for the period 1948-2011 (counting with the availability of NCEP-NCAR reanalysis) in Valencia region, with three objectives. First one is to reconstruct daily thermal signal for 300 series available in the study area between 1948-2011, in a homogeneous context without any gaps. The second objective is to validate SD in extrapolated data and to study if it maintains cohesion and temporal stationarity throughout the period. And the last objective is to establish happened local patterns of change and go through their spatial cohesion.

In relation to data coverage, we should note that among all available series in study area only three of them completely cover the period from 1948 to 2011, and a majority of them cover less than half of this period. Moreover they are inhomogeneous series, temporarily inconsistent with each other, and concentrated in more urbanized areas. The application of SD will permit us to have more than 300 valid series for the region in order to assess local patterns of temperature change.

II. DATA AND METHODS

SD were applied to the series of daily maximum temperatures (Tmax) and minimum (Tmin) for 326 stations belonging to government agencies or relevant research institutions in the region, following strict quality control rules. The key criterion for selection of these stations was to dispose of a minimum continuous period of, at least, 10 years within the study period. This criterion was relaxed to 8 years in the case of highlands, where the density of meteorological stations is lower.

SD analysis was performed through an Artificial Neural Network (ANN), resulting of an innovative development made by the authors that crosses traditional MLP with a layer of Hebbian weights (Miró et al, 2012). This is equivalent to previously undertake an Analysis of Principal Components, in parallel disposition, at the beginning of the neural network. This hybrid configuration has greatly declined risk of overfitting.

In relation with the source of explanatory variables or *inputs* for SD analysis we selected reanalysis NCEP / NCAR (grid 2.5 ° x2.5 ° Latitude/Longitude), taking into account its homogeneity for the whole period (1948 to 2011) in the study area. Although it can not be excluded that the reanalysis, as ' homogeneous ' reference in the process, can introduce some inhomogeneity, there are many authors that reduce this possibility for the latitudes and specific geopotential altitudes used in this SD analysis (Kalnay et al., 1996; Kistler et al, 2001; Sterl, 2004; Bengtsson et al, 2004; Rubinstein et al, 2004; Simmons et al, 2004; CCSP, 2008). Nevertheless, it has been avoided the use of data in the layer boundary.

A total of 89 explanatory variables, derived from the reanalysis of those closet four grid points to each station and at different geopotential altitudes from low- middle troposphere (three-dimensional character of the explanatory atmospheric patterns), were used. These variables are those that after multiple tests gave better results in the SD analysis, according to its setting in validation data not used to train the ANN validation as well as lower *overfitting*.

SD analysis was performed for each series by different time lengths of ± 10 years, using an absolute homogeneity test (RHTest) as indicator for making the sections' division. Thus, it is prevented that a jumping type inhomogeneity could be within the section. This fact could reduce the SD analysis performance, but without prejudice that any jump detected by test can be a false positive.

Sectorial SD obtained for each of the sections in each series (SDs) were validated and extrapolated to the entire period from 1948 to 2011. Thereby they could be compared each other and to check as long they maintain mutual cohesion on extrapolation as well as to show if stationary relations are maintained over time.

A weighted average of the SDs was taken as SD final of each series, which also resulted in a better estimation of the probability range regarding sectoral SDs. Final SD places the

entire series fluctuation over time in an intermediate position between all the different observational contexts that caused inhomogeneities (jumps or trends) in the original observed data series. Therefore the problem has been solved. Moreover, with this procedure we gain some more progress. Firstly, it is removed another important problem in the region, the signal of the probable urban thermal heating (Quereda et al, 2000 and 2009). Secondly, we may reconstruct, filling gaps and have higher homogeneity, based on direct interactions between atmospheric patterns and thermal behavior at each point. As a result, it is possible to avoid circularity and possible loss of local variability components.

After obtaining and validating the SD, it´s made an analysis of temperature trends corresponding to the whole study period, using Mann- Kendall Test and Sen calculation of annual / decadal slope of change for all rebuilt series obtained from SD analysis. These trends are grouped into clusters, according to an analysis of spatial patterns of temperature change which included the analysis of physical-geographical factors, those which are modulating different responses of thermal change at local scale. This was performed by multiple correlation (Etxeberría, 1999) and application of Kohonen o SOM maps (Kohonen, 2001). Moreover they were took into account different physical- geographical factors as potential local modulators, such as altitude, latitude, exposure to solar radiation (North-South), continentality and potentiality to temperature inversions and night cooling by radiation.

On the other hand the use of a digital terrain model (DTM, 90 x 90 m.) has also permitted to incorporate altitude, but mainly to derive models expressing differential exposure to solar radiation or the possibility of developing thermal inversions, according to the topographic configuration. In order to do that, we applied Laplacian operators, absolute slope and direction of slope according with the DTM.

Finally , we has made a fine-scale spatial interpolation for the results of thermal change, taking advantage of the physical-geographical factors took into account derived of the original DTM resolution (90 x 90 m.).

Based on the magnitude adopted by each factor in the group of more than 300 stations, it has been made a model of linear regression between observed temperatures and the value derived from physical geographic factors which modulate those temperatures. In this way we may properly weight the spatial distribution of magnitudes for each of these terrain models. All this will permit us to extrapolate the effect of these factors on detected climate change patterns. And similarly we have adjusted the thermal gradient in the vertical, using the information provided by the DTM.

The spatial interpolation method used is ordinary Kriging (Journel, 1989; Keckler, 1995). We proceeded taking care to do cross-validation, taking out of the test interpolation a total of 40 stations randomly distributed in the study area, some of them located in the highlands.

III. SD VALIDATION

Multiple validation criteria were applied:

- Evaluation through a validation set of the average absolute error (MAE) and the average Euclidean error (AEE) of sectorial SDs (derived from the observed daily values).

- Difference between the previous results and the same obtained using the training set (overfitting).
- R correlation coefficient (Pearson) between observed daily series and the final SD.
- R Correlation between sectoral SDs for the whole period 1948-2011 (daily).
- Average SD bias in relation with daily observed data for percentile ranges.
- MAE and R of SD for monthly data.
- Coherence of long-term trends in sectoral SDs.

In summary, we can conclude the following conclusions from the validation exercise:

- Monthly, annual and average data: MAE approximate 0.25 ° C.
- Daily data (90 %) in non-extreme percentiles: MAE approximate 1 ° C.
- Daily data (10 %) in extreme percentiles: MAE approximate 2 ° C.
- Possibility of low *overfitting*, without significant differences between the validation set and training set.
- The differences in obtained error by series are not due to a spatial factor but rather to the original quality of observed series.
- There is not significant loss of performance between SDs in pre-satellite and the satellite phases.
- It remains high the correlations in extrapolated period between sectoral SDs, which are temporally farthest from each other (according with their training period), almost the same than those temporarily neighbors.
- Similarly, coherence of temperature trends in extrapolated period does not differ significantly depending on whether SDs temporarily away in its original lenght of training, respect on temporarily neighbors.

IV. RESULTS: PATTERNS OF CHANGE DETECTED

For Tmax and Tmin it is reflected, firstly, that variability of referred geographical factors has a significant relationship with distribution of trends (multiple correlation around 0.7 and SOM maps indicate clear relationships forming clusters). However not all of them have relevant paper, being only two or three true explanatory factors.

In the case of Tmax, the altitude is an important factor. However, continentality is far away the most relevant. This allow us to group all tendencies into two clusters, the first one related to inland and higher altitude locations, with the most marked trends to global warming, versus de second one, related to coastal areas and low altitude, with more moderate tendencies.

In the case of Tmin, determinants factors in the distribution of trends are again altitude and continentality, and the nightly inversion as a new explanatory factor. Certainly a higher nightly inversion correlates with less positive temperature trends. Meanwhile with a higher altitude those trends tend to be more positive. However in this case continentality exacerbate both negative and positive trends with its increase, while attenuates with its decline. This involves grouping the trends into 5 clusters.

Three subperiods were also detected in the process of heat exchange, the first one arriving until 1979, the second one a sharp is characterized by a significant change between 1980 and 1998, and the third one, during the last 15 years, is a period of consolidation of change. Taking as base period the one from 1948 to 1979, and the final one the years 1997 to 2011 (when the detected change goes to its consolidation), spatial interpolation (kriging) of maximum and minimum temperature averages for both periods was applied, taking into account the geographic factors above mentioned. And then, it was made an estimation of magnitude of change between two periods, creating maps of thermal changes occurred in high resolution (90 x 90 m.).

In summary, the results obtained point to a rise of temperature, very evident in the Tmax, and much nuanced in Tmin by local factors. It has been detected temperature rises of 0.3° C to 1.8° C (1° C on average) in the studied period. In the interior and upland areas this increase has rates three times higher than in the coastal areas. The Tmin recorded rises over 1° C in highlands and mountain slopes, while on valley floors and major depressions (in the inland) it cooled about 0.7 ° C, leaving other areas in weak trends.

V. CONCLUSIONS

First, it is emphasized the highest resolution and detail achieved with the method used in this paper, with respect to previous studies that have analyzed the thermal heating in the region. This is possible thanks to the density of information provided by the SD and the inclusion of topographic factors that modulate temperatures in local level. Thus, the SD is confirmed as a tool of considerable value for the study of the impacts of climate change at local level. Therefore thermal characterization in finer scale allowed us to detect a novel thermal climate behavior at regional and local levels.

Nevertheless, the most important conclusion of the study is related to the detection of a change of spatial patterns in the thermal behavior, permanent over time and space in the region. These patterns are modulated by local factors that seem to be of a great importance and have had very little considered in previous studies.

These patterns indicate particularly greater warming trend in the highlands, and lower in the bottom of valleys. In some high inland points (Iberian sector) heating is truly important, in contrast to the coastal areas. For Tmax there are more gradual differences between littoral and pre-littoral, on the one hand, and inland and highland areas, on the other hand, with more general temperature increases. However, in the case of Tmin, an abrupt decoupling of trends is done for the tandem mountain-valley, even in neighboring areas, involving an increase in the frequency of stable situations likely to nightly inversions in the study area. This coincides with other studies that have detected the same trend in other regions at similar latitudes (Daly et al, 2010; Pepin et al, 2011; Dobrowski et al, 2011).

To finish with, it should be noted that although this study is useful determining a global magnitude of temperature change in Valencia region, in relation with the strengths and weaknesses of SD process, nevertheless, its usefulness primarily lies in the detection of potentially more vulnerable areas to global warming and the different local patterns of response to this change.