AN ASSESSMENT OF THE ROLE OF HOMOGENIZATION PROTOCOLS IN THE PERFORMANCE OF DAILY TEMPERATURE SERIES AND TRENDS: APPLICATION TO NORTHEASTERN SPAIN

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ABSTRACT

This paper details a full protocol applied to develop high resolution daily temperature dataset. Our methodology has been tested from a dataset of 1583 temperature observatories over the NE Spain. The raw dataset was initially tested for internal and external consistency and an algorithm was utilized to reconstruct the daily temperature series for selected candidate observatories. Discontinuities in the reconstructed series were determined by combining the results obtained by three homogeneity tests: the Standard Normal Homogeneity Test (SNHT), the Easterling and Peterson two-phased regression method and the Vincent test. To assess the role of data homogenization, a set of selected tests was applied to the temperature trends and the spatial and frequency properties of the series. Results show significant improvement in the spatial dependence of temperature trends at seasonal and annual scales after application of homogeneity correction. However, frequency statistics of the series evidenced no significant impact of the homogenization procedure. From the temporal and spatial perspectives, the new compiled dataset seems to be outstanding in a variety of meteorological, ecological, hydrological and agricultural research applications at local, regional and continental scales.

Key words: daily temperature, trends, quality control, reconstruction, homogenization, Spain.

INTRODUCTION

Complete, reliable and spatially dense climatic datasets are mandatory for climatic analyses (EISCHEID *et al.,* 2000). At present, the usefulness of various daily datasets is still degraded as a consequence of gaps that distribute at random in space and time (EISCHEID *et al.,* 2000). Other datasets are still constrained as a consequence of lack of quality assurance or sparse network of stations over a spatial domain.

Developing complete and homogenous climatic datasets has recently been of considerable interest given priority to temperature (e.g. ALLEN and DEGAETANO, 2001, BRUNETTI *et al.,* 2006) and precipitation (e.g. RAMOS-CALZADO *et al.,* 2008, VICENTE-SERRANO *et al.,* 2010). The Mediterranean climate has recently been the main focus of intensive research on climate change and variability. This mainly attributed to the fact that it is one of the most sensitive regions to climate change (BOLLE, 2003). The Mediterranean region has long archives of instrumental climate records that dated back to mid of the 19th century in much of the Mediterranean countries. This promising amount of data can allow potential reconstruction of very useful climate data. However, an important feature is that many daily climate datasets are characterized by short and fragmented series as a consequence of relocations of the observatories. Given that many datasets have already been developed for precipitation in the Mediterranean basin (e.g. RAMOS-CALZADO *et al*., 2008, VICENTE-SERRANO *et al.,* 2010), there are still emphasizing needs to reconstruct temperature series, particularly at the daily time resolution.

This paper describes the full protocol used for the development of this dataset using a very dense network of 1583 stations. Also, this paper aims to assess the influences of this protocol on the identified trends, the spatial coherence and the statistical properties of the series.

1. DATA AND METHODS

2.1. DATASET DESCRIPTION

The original database is composed of the 1583 available daily maximum and minimum temperature series for the period 1900-2006 run by the *Agencia Estatal de Meteorologia.* The dataset is located in Northeastern Spain. The study area is heterogeneous in terms of terrain complexity and climatic regimes. The network of stations is shown in Fig. 1.

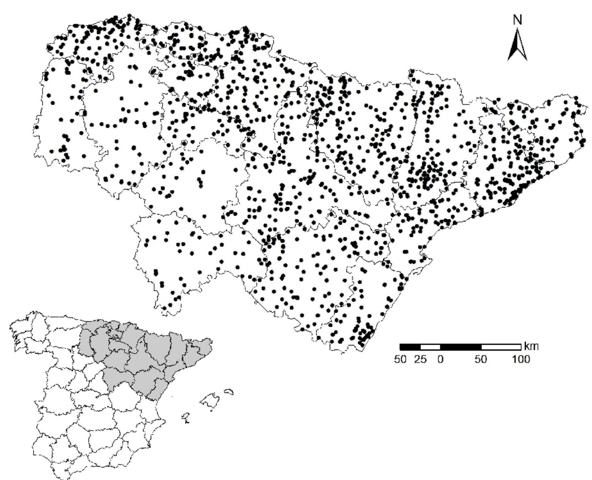

FIG. 1. LOCATION OF THE STUDY AREA AND GEOGRAPHICAL DISTRIBUTION OF TEMPERATURE OBSERVATORIES IN THE ORIGINAL DATASET.

2.3. QUALITY CONTROL METHOD

The original series were subjected to several quality control procedures to identify systematic errors resulting from archiving, transcription and other sources of error. The internal consistency was utilized to screen for the within-station data inconsistencies by checking the observed value against other values following the procedures described by REEK ET AL. (1992). The external consistency aimed to eliminate the worst data by identifying potential outliers that differ greatly from the neighbors. Similar to other studies (e.g. EISCHEID *et al.,* 1995, PETERSON *et al.,* 1998, GONZALEZ-ROUCO *et al.,* 2001), the preference was given to trim outliers and keep the valuable extremes. A similar approach was recently used by STEPANEK *et al.,* (2009) and VICENTE-SERRANO *et al.,* (2010).

2.4. THE RECONSTRUCTION PROCEDURE

Many approaches have been adopted to address the problem of split series (RAMOS-CALZADO *et al.,* 2008). These approaches differ in their applicability according to terrain complexity and spatial density of stations (ALLEN AND DEGAETANO, 2001). The regression-based methods taking into account data from adjacent stations with the best temporal correlation and spatial dependence can be superior due to its least sensitivity to outliers (ALLEN AND DEGAETANO, 2001).

We aimed to comprise nearby series of short time span to rebuild long series based on the assumption that the information introduced from nearby stations identically reflects uniform climatic conditions of the target station. The daily series of the original dataset were firstly divided into two broad groups. The first included 668 target observatories still in operation (2004 or more recently). The remaining data (915 observatories) were served as a pool for the reconstruction process. Distance and correlation are considered to rebuild the target series. The pre-selection of the adequate neighbors includes only stations which have: a) a minimum common observing period of 1500 daily values shared by the target station, b) a positive correlation coefficient exceeding 0.90, and c) location within a radius of 15 km.

2.5. HOMOGENITY TESTING

Numerous methods have been developed to detect and correct inhomogenities at low temporal resolution (i.e. monthly and annual) (e.g. ALEXANDERSSON, 1986, JONES *et al.,* 1986, PETROVIC, 2004). However, less attention has been devoted toward daily and sub-daily time resolution (e.g. VINCENT *et al.,* 2002, AGUILAR *et al.,* 2003, WIJNGAARD *et al.,* 2003). A comprehensive review of homogenization approaches is given by PETERSON *et al.,* (1998). Three tests were chosen to check homogeneity of the monthly series at a 5% significance level: the Standard Normal Homogeneity Test (SHNT) for a single break (ALEXANDERSSON, 1986), the Easterling and Peterson test (EASTERLING AND PETERSON, 1995) and the Vincent method (VINCENT *et al.,* 2002). A reference series was objectively built for each target series following the procedure of PETERSON AND EASTERLING (1994) from the neighboring stations lying within a maximum distance of 100 km with correlation greater than 0.7 with the candidate series. All these procedures were run automatically using the PROCLIM software (STEPANEK, 2008). Homogeneity tests were performed at monthly, seasonal and annual scales to avoid problems released from nonlinear weather events introduced in daily version of the data (FENG *et al.,* 2004). Once the assessments were made, the outcomes of significant breaks resulted from the three tests were grouped together. This procedure enables not only identify the same break in one series, but also track down inhomogenities not identified by any of the other two tests. When a statistically significant abrupt change is identified, a correction factor is computed to account for this discontinuity on a monthly base. Based on the pre-defined monthly corrections, the adjustment factors were interpolated into the daily adjustments using the approach described by SHENG AND ZWIERS (1998) and recommended by VINCENT *et al.,* (2002).

2.6. INFLUENCES OF THE APPLIED PROTOCOL ON THE TRENDS AND THE STATISTICAL PROPERTIES OF THE SERIES

An evaluation of the reliability of the developed dataset was accomplished to assess the possible impacts of daily adjustment on statistical parameters of the final series. All the assessment tests were applied exclusively to the stations with coverage from 1950 ($n = 98$).

Firstly, trends of maximum and minimum temperatures were calculated at seasonal and annual scales before and after applying adjustment using the nonparametric Spearman (*Rho*) at a significance level of 95% (p value < 0.05). Seasonal averages were obtained from monthly data for each year and defined as winter (December-February), spring (March-May), summer (June-August), and autumn (September-November). To assess the spatial continuity of the seasonal and annual trends against distance, the semivariance of the magnitude of change was computed.

Secondly, given that adjustment of the series may alter probability distribution of extreme temperature (e.g. frequency and intensity), two extreme temperature indices (annual count of hot and cold days) were computed for the series before and after adjustment. Using these indices could help assessing possible impacts of adjustment on extreme values of the series. The hot (cold) day was defined as the day of maximum (minimum) temperature exceeding (below) the 90th (10th) percentile of the average maximum (minimum) temperature for the period 1950-2006. The spatial continuity of the extreme temperature trends before and after homogenization was also tested using the semivariance of the magnitude of change.

Thirdly, we analyzed some statistical indicators of the series before and after homogenization. We calculated L-moments statistics for each series, which provide information of the scale [L-coefficient of variance (τ_2)], shape [the L-coefficient of skewness (τ_3)] and peakedness of the series [L-coefficient of kurtosis (τ_4)]. More details on the L-moment theory is given by ASQUITH (2003) and the calculation procedure can be found in HOSKING (1990) and HOSKING AND WALLIS (1997). To get a spatial picture of the L-moment coefficients, the values of the statistics were plotted against distance between the observatories using the semivariance models.

3. RESULTS AND DISCUSSION

3.1 THE RESULTING DATASET

The temporal coverage of the new dataset has clearly improved in terms of series completeness. The final serially complete and homogenous observatories dated back to the 1920s (*n=19*), 1950s (*n=98*), 1960s (*n=128*) and 1970s (*n=189*) are shown in Fig. 2a. It seems that the spatial coverage is reasonable so that spatial variability of temperature can effectively be represented at regional scale. The spatial density of these series is globally satisfactory. However, the majority of the observatories are located in the northern and the eastern portions and sparsely distributed in the south and the southwest. Fig. 2b illustrates the temporal evolution of available complete and homogenous series in the new compiled dataset.

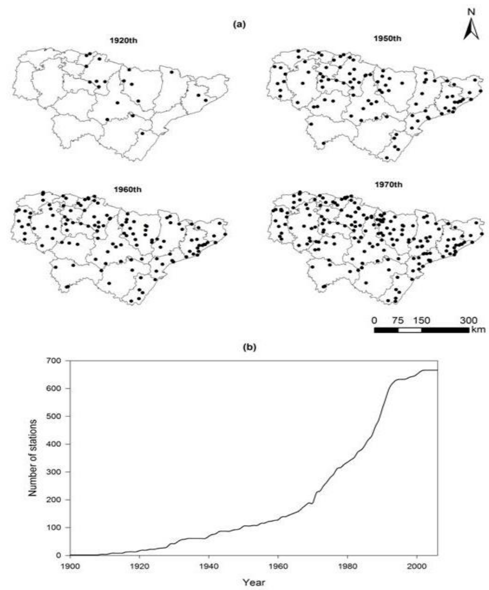

FIG.2. SPATIAL AND TEMPORAL DISTRIBUTION OF THE FINAL COMPLETE AND HOMOGENOUS TEMPERATURE SERIES.

3.2. HOMOGENEITY RESULTS

A summary of homogeneity testing results is given in Table 1. The number of inconsistencies was encountered larger in maximum temperature (n = 969) compared with minimum temperature (n = 865). This can be attributed to high spatial correlation among maximum temperature series which makes it easier to detect even small shifts in the series through relative homogeneity tests (BOHM *et al.,* 2001). It was found that 307 (46 %) and 302 (45.2 %) of minimum and maximum observatories respectively passed the tests successfully.82 % (79%) of the minimum (maximum) temperature series classified as homogenous are of relatively short periods of records (< 30 years).

The SHNT test was found efficient in detecting the most significant break in the series. However, the regression-based methods (e.g. the Easterling and Peterson method, the Vincent method) were proven to have more power in defining multiple breaks. The average value of the correction factor applied to daily monthly maximum and minimum temperature was low (- 0.04º C and - 0.01º C) respectively and very few series needed coefficients of correction higher than 1 ºC. Fig. 3 illustrates one example of T statistics of summer maximum temperature in Fuenterrabia aeropuerto [Guipuzoca] before and after homogenization.

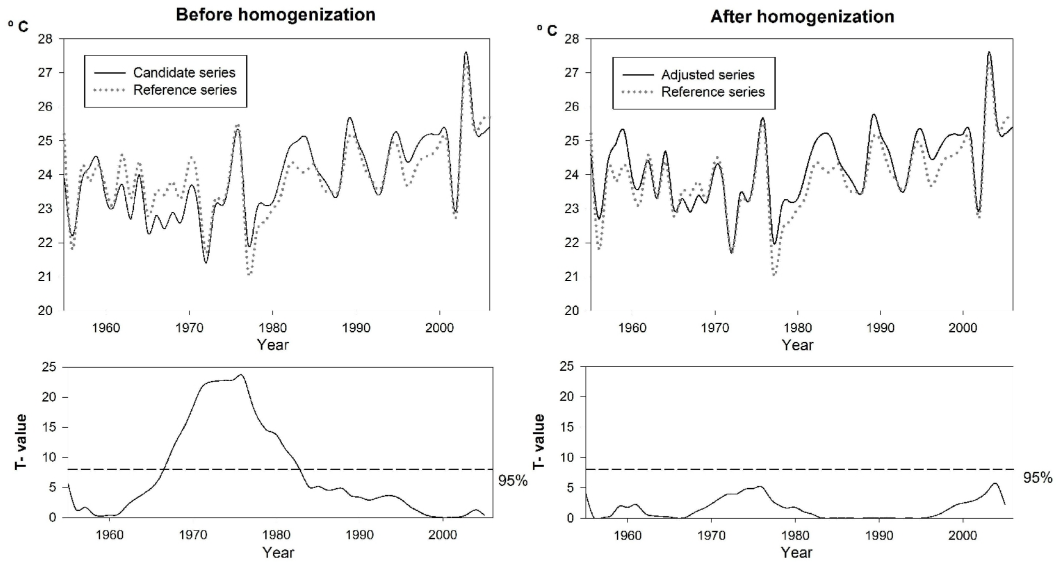

FIG. 3. RESULTS OF THE HOMOGENEITY TEST FOR THE SUMMER MAXIMUM TEMPERATURE IN FUENTERRABIA AEROPUERTO, [GUIPUZOCA] (A) BEFORE AND (B) AFTER HOMOGENEITY CORRECTION. THE TEST STATISTIC (T) IS PLOTTED AGAINST THE C.

Minimum temperature

Maximum temperature

TABLE 1. SUMMARY OF THE RESULTS OF HOMOGENEITY PROCEDURE

3.3. THE INFLUENCE OF THE PROCESSING PROTOCOL ON THE TRENDS AND THE STATISTICAL PROPERTIES OF THE SERIES

The results of the cross-tabulation analysis based on the trends assessment are given in Table 2. In general, the results do not reflect significant difference in the sign of the trends after homogeneity correction. The difference between the linear trends for the homogenized (adjusted) and non-homogenized (unadjusted) average annual temperature is illustrated in Fig. 4. A warming trend in annual maximum and minimum temperature seems to prevail in the region both before and after correcting inhomogenities, particularly in coastal areas.

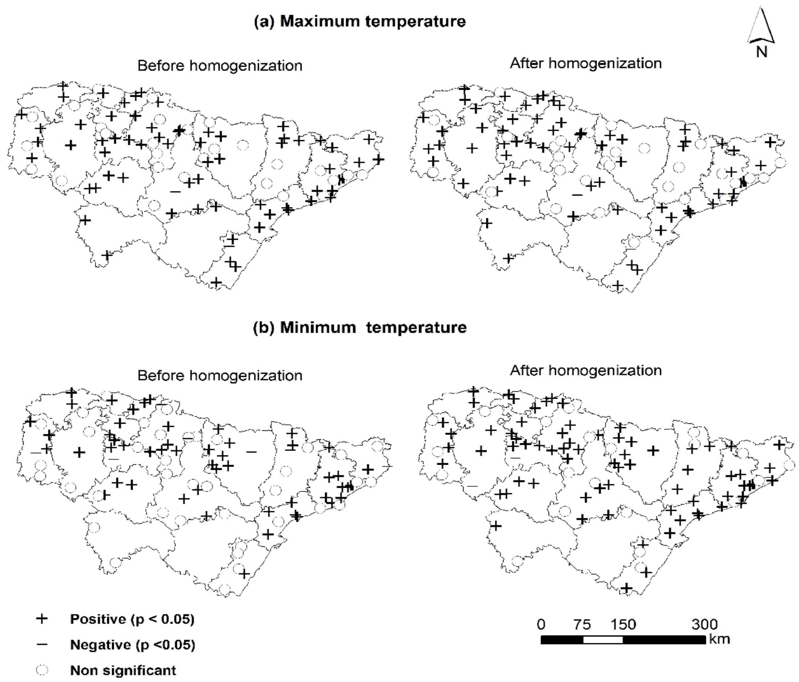

FIG.4. TRENDS OF ANNUAL-AVERAGE MAXIMUM AND MINIMUM TEMPERATURE BEFORE AND AFTER THE HOMOGENEITY CORRECTION.

A visual comparison between the direction of the trends of adjusted and the unadjusted series as seen from Fig. 4 showed that in most cases the adjustment has no discernible effect on the time trends analysis. As illustrated in Fig. 5, scatter plots indicate that the trends are not linearly consistent for most seasons which suggest a considerable impact of this procedure on the magnitudes of the seasonal and annual trends. The semivariance of annual and seasonal trends of maximum and minimum temperature before and after adjustment is illustrated in Fig. 6. The behavior of the temporal trends of the adjusted series as predicted by the model is spatially more dependent compared with those of the series prior to the adjustment.

Similarly, a quick visual inspection of the semivariance of the trends of annual total of hot and cold days indicates a markedly decrease in spatial heterogeneity after applying the homogenization procedure (Fig. 7).

			Before homogenization			
	#	$	%	#		%
After homogenization	&			&		
& '	*62.24*(61)%	)% *0*(0	)% *6.12*(6	)% *48.98*(48	)% *3.06*(3	*23.47*(23)%
'	)% *0*(0	)% *2.04*(2	)% 0(0	)% *0*(0	)% *1.02*(1	)% *1.02*(1
	)% *7.14*(7	)% *0*(0 "	)% *22.45*(22	)% *5.10*(5	)*3.06%*(3 "	*14.29*(14)%
Significance level = 0.05						

Table 2. Results of cross-tabulation analysis for the annual-average trends of maximum and minimum temperature before and after homogenization.

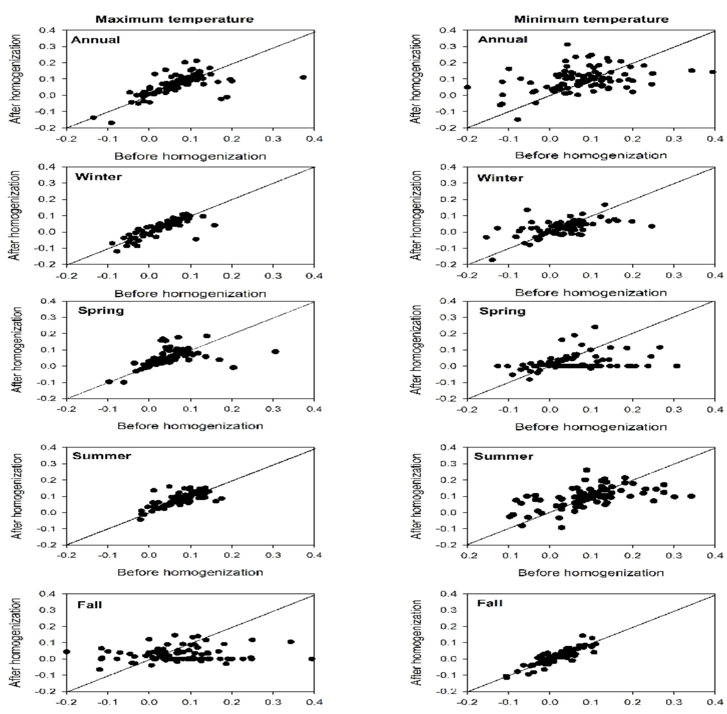

FIG. 5. SLOPES OF THE SEASONAL AND ANNUAL TRENDS BEFORE AND AFTER THE HOMOGENEITY CORRECTION (EXPRESSED IN º C PER DECADE).

Relationships between L-moment ratios before and after homogenization are shown in Fig. 8. A comparison of the parent distribution of L-moments (i.e. variance, skewness and kurtosis) permits the assumption that the frequency distribution of temperature series before and after adjustment is generally coincided with a clear linear well-fit for both maximum and minimum temperature. However, the observed bias in the frequency distribution of temperature series in few cases is negligible

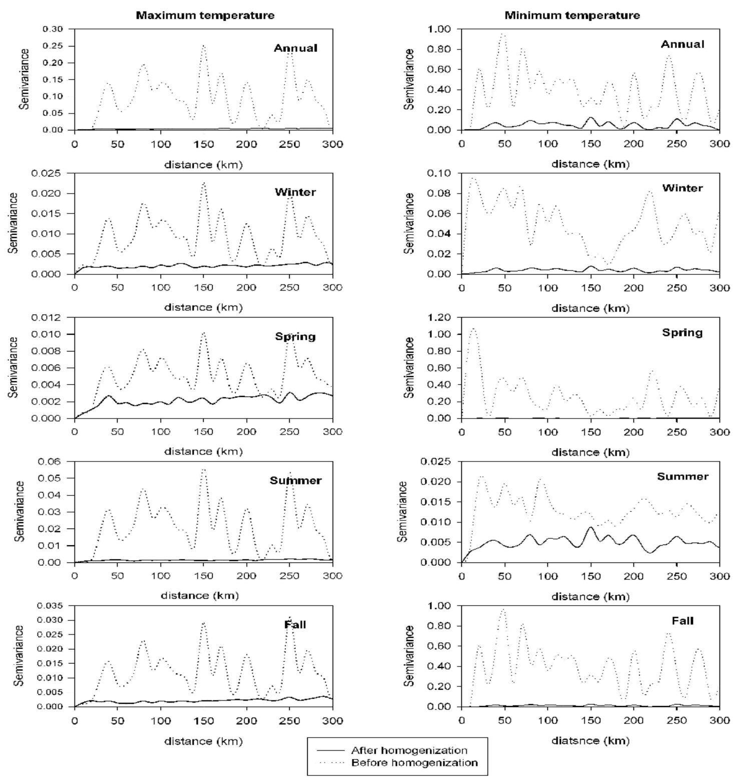

FIG. 6. SEMIVARIANCE OF MAGNITUDE OF THE ANNUAL AND SEASONAL TRENDS OF MAXIMUM AND MINIMUM TEMPERATURE BEFORE AND AFTER HOMOGENEITY CORRECTION.

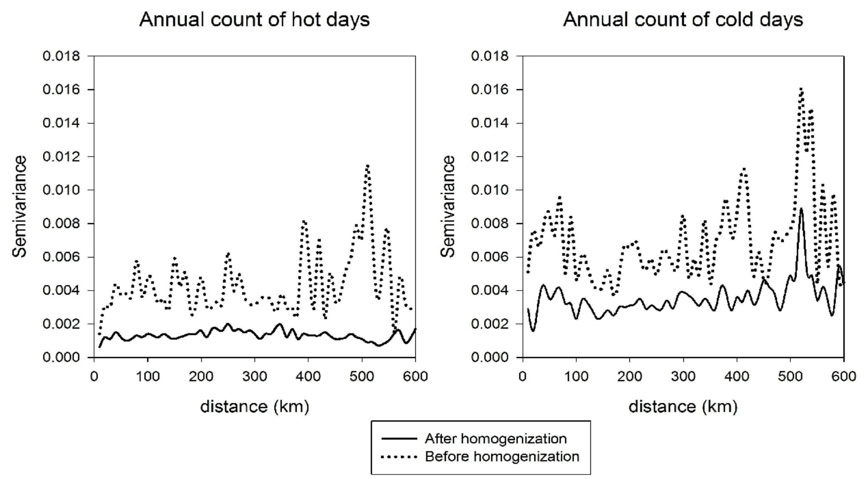

FIG. 7. SEMIVARIANCE OF THE TRENDS OF THE ANNUAL TOTAL COUNT OF HOT AND COLD DAYS BEFORE AND AFTER HOMOGENEITY CORRECTION.

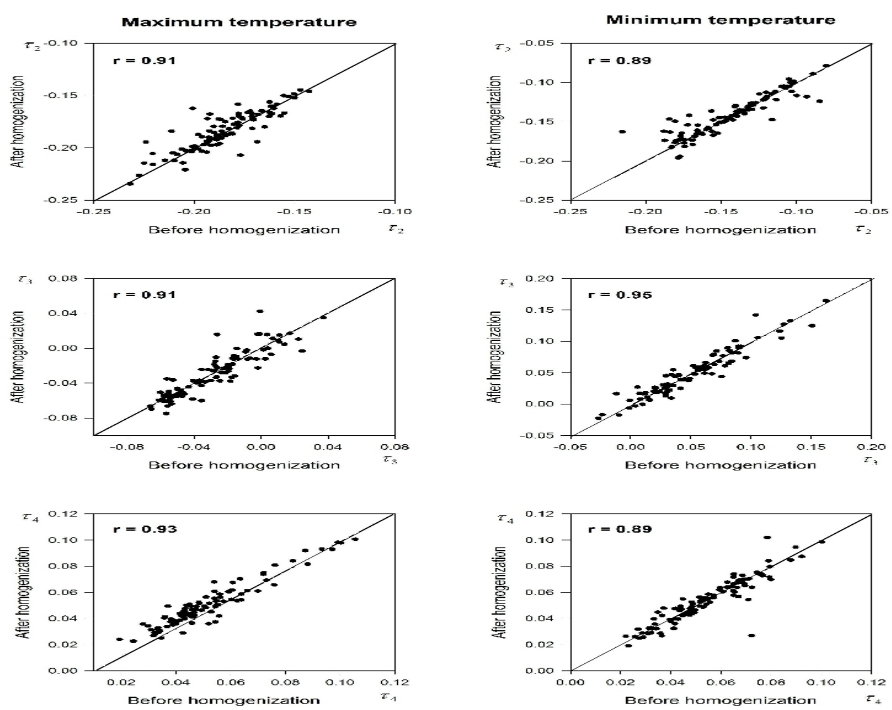

FIG. 8. L-MOMENT COEFFICIENTS OF MAXIMUM AND MINIMUM TEMPERATURE SERIES BEFORE AND AFTER HOMOGENEITY CORRECTION.

4. SUMMARY AND CONCLUSION

The applied methodology made a good use of all available information in the original dataset. One important feature is that all the steps gave more consideration to spatial dependency and temporal characteristics of the nearby observatories. The quality control analysis was proved to be sensitive to trim outliers and keep valuable extremes. Also, the linear regression model used for gap completion is simple, applicable and robust when dealing with extreme values. The homogeneity testing was performed combining the results of three statistical tests which have different sensitivities to define temporal discontinuity in the series. The semivariance was employed to quantify spatial randomness of the series before and after applying the homogeneity correction. The homogeneity adjustment significantly improved the spatial structure of the seasonal and annual trends of maximum and minimum temperature. Similarly, the trends of extreme temperature events exhibited better structured spatial behavior for the series after adjustment. It was also visible that the characteristics of the statistical distributions of the series remain after adjusting the series.

The new dataset is unique in its spatial and temporal resolution and, thereby, has more potential in a variety of hydrological, meteorological and ecological applications. The new dataset can represent different macro climates through capturing features of climate variability. This spatial and temporal improvement can enhance the grid resolution of any climatic study in future.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

AGUILAR E, AUER I, BRUNET M, PETERSON TC, WERINGA J. (2003). *Guidelines on climate metadata and homogenization. World Climate Programme Data and Monitoring WMO-TD No. 1186. World Meteorological Organization*: Geneva 51 pp.

ALEXANDERSSON H. (1986). A homogeneity test to precipitation data. *International Journal of Climatology* **6**: 661-675.

ALLEN RJ, DEGAETANO AT. (2001). Estimating missing daily temperature extremes using an optimized regression approach. *International Journal of Climatology* **21**: 1305 –1319.

ASQUITH WH. (2003). *Modeling of runoff-producing rainfall hyetographs in Texas using L-moment statistics*: Austin, Texas, University of Texas at Austin, Ph.D. dissertation, 386 p.

BOLLE HI. (2003). *Mediterranean Climate: Variability and Trend.* Springer Verlag, Berlin.PP 372..

BRUNETTI M, MAUGERI M, MONTI F, NANNI T. (2006). Temperature and precipitation variability in Italy in the last two centuries from homogenized instrumental time series. *International Journal of Climatology* **26**: 345–381.

COSTA AC, SOARES A. (2009). Homogenization of climate data: review and new perspectives using Geostatistics. *Mathematical Geosciences* **413**: 291–305.

EASTERLING DR, PETERSON TC. (1995). A new method of detecting undocumented discontinuities in climatological time series. *International Journal of Climatology* **15**: 369-377.

EISCHEID JK, BAKER CB, KARL T, DIAZ HF. (1995). The quality control of long-term climatological data using objective data analysis. *Journal of Applied Meteorology* **34**: 2787-2795.

EISCHEID JK, PASTERIS PA, DIAZ HF, PLANTICO MS, LOTT NJ. (2000). Creating a serially complete national daily time series of temperature and precipitation for the western United States. *Journal of Applied Meteorology* **39**: 1580–1591.

FENG S, HU Q, QIAN Q. (2004). Quality control of daily meteorological data in China 1951-2000: a new dataset. *International Journal of Climatology* **24**: 853-870.

GONZALEZ-ROUCA JF, JIMENEZ JL, QUESADA V, VALERO F. (2001). Quality control and homogeneity of precipitation data in the Southwest of Europe. *Journal of Climate*, **14**(5): 964-978.

HOSKING JRM. (1990). L-moments: Analysis and estimation of distributions using linear combinations of order statistics. *Journal of Royal Statistical Society, B series*, **52**: 105-124.

HOSKING JRM AND WALLIS JR. (1997). *Regional frequency analysis: an approach based on L-moments*. Cambridge University Press, Cambridge, U.K, 224pp.

JONES PD, RAPER SCB, BRADLEY RS, DIAZ HF, KELLY PM, WIGLEY TML. (1986). Northern Hemispheric surface air temperature variations 1851–1984. *Journal of Climatology and Applied Meteorology* **25**: 161–179.

PETERSON TC, EASTERLING DR. (1994). Creation of homogeneous composite climatological reference series. *International Journal of Climatology* **14**: 671-680.

PETERSON TC AND OTHERS. (1998). Homogeneity adjustments of in situ atmospheric climate data: a review. *International Journal of Climatology* **18**: 1493-1517.

PETROVIC P. (2004). *Detecting of inhomogeneities in time series using Real Precision Method in: Fourth seminar for homogenization and quality control in climatological databases*. Budapest: Hungary. 6–10 October 2003 WCDMP-No 56 WMO Geneva 79–88.

RAMOS-CALZADO P, GÓMEZ-CAMACHO J, PÉREZ-BERNAL F, PITA-LOPEZ MF. (2008). A novel approach to precipitation series completion in climatological datasets: application to Andalusia. *International Journal of Climatology* **28**: 1525–1534.

REEK T, DOTY SR, OWEN TWA. (1992). Deterministic approach to the validation of historical daily temperature and precipitation data from the cooperative network. *Bull Am. Meteorol. Soc.* **73**: 753–762.

SHENG J, ZWIERS F. (1998). An improved scheme for time-dependent boundary conditions in atmospheric general circulation models. *Climate Dynamics* **14**: 609 –613.

STEPANEK P. (2008). *ProClimDB – software for processing climatological datasets,* CHMI regional office Brno: http://wwwclimahomeu/ ProcData/html.

STEPANEK P, ZAHRADNÍČEK P, SKALÁK P. (2009). Data quality control and homogenization of the air temperature and precipitation series in the Czech Republic in the period 1961-2007. *Adv.Sci.Res*. **3**: 23-26.

VICENTE-SERRANO SM, BEGUERÍA S, LÓPEZ-MORENO J, GARCIA-VERA M, STEPANEK P. (2010) A complete daily precipitation database for North-East Spain: reconstruction, quality control and homogeneity. *International Journal of Climatology* (in press).

VINCENT LA, ZHANG B, BONSAL R, HOGG WD. (2002). Homogenization of daily temperatures over Canada. *Journal of Climate* **15**: 1322–1334.
WIJNGAARD JB, KLEIN TANK AMG, KÖNNEN GP. (2003). Homogeneity of 20th century European daily temperature and precipitation series. *International Journal of Climatology* **23**: 679–692.