Accommodated high-resolution historical temperatures in the Mediterranean area

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Abstract – Numerous documentary collections are available in the Mediterranean countries, which hold potential to build and rearrange climatic reconstructions. These data are vital for obtaining reliable temperature estimates in pre-instrumental age but, in general, they have not been fully explored or analyzed. Past temperature reconstructions showed a wide range of variability, raising questions about the reliability of currently available reconstruction techniques and the uniqueness of late 20th century warming. Taking this challenge up, the present paper has attempted to exploit an historical documentation for the temperature modelling in pre-instrumental time. Combining information derived from proxy-information and large-scale simulation data, a regression-based downscaling mixed model was developed to accommodate the regional temperature field to a location of the Southern Italy (Catanzaro station). The statistical methodology used and the results of winter temperature modelling are discussed. A final exhortation on the robustness of this approach recalls on the accuracy of the model itself, but also on the overall ability to extract the right information to replicate coherently the temperature series.

1. INTRODUCTION

Climate documentary proxy investigations are an attractive approach to accommodate large-scale temperature modeling, because their vivid and resolute narrative can trace back before the instrumental time (Brázdil et al., 2005; Jones et al., 2009). Several authors such as Gershunov and Barnett (1998), Luterbacher and Xoplaki (2003), Pauling et al. (2003), and Ge et al. (2005) suggested that pre-modern instrumental weather indices are promising for enriching climate reconstructions at regional or local scales. Different sets of proxy-variables have indeed been used to find simplified relationships in high-resolution climate time reconstruction (e.g., Wang et al., 1991; Briffa et al. 2002; Larocque and Smith, 2005; Moberg et al., 2005; Diodato, 2007; Davi et al., 2008). Many of these reconstructions rely on empirical relationships between proxy records and temperature data. Comparing linear algorithms and neural networks, Helama et al. (2009) have shown reliable reconstruction capabilities by both approaches.

Although regression-based techniques have been extremely successful, they can engender bias in the estimates if not used with care (Robertson et al., 1999; Moberg et al., 2005; von Storch et al., 2005).These relationship are seldom based on a training process capable to capture all the possible data combinations that occur when extrapolation is performed (e.g., reconstruction period). With specific regard to dendroclimatology, correlation between proxy and temperature data explains about 50% of the variance (Liang et al., 2008; Helama et al., 2009; Tan et al., 2009). Documentary data series correlate better, with an explained variance of about 70% (Leijonhufvud et al., 2008; Dobrovolný et al., 2010). However, there are few statistically derived estimates of uncertainty in documentary based climate reconstructions (Moberg et al., 2009).

To show how the combination of proxy-documentary and modern data can be useful for improving the spatial resolution of past climate, an alternative approach was employed in this paper both by interpolation/training and extrapolation/generalization via documentary-based, statistical downscaling technique. The model developed, COnstrained MIxed Regression (COMIR)–model, combines local weather anomalies documentary proxy-based with large-scale winter temperature data (monthly resolution) to accommodate the regional temperature field. The goal was to produce a simplified mixed model, acceptable and verifiable by scientists as well as knowledgeable people. Catanzaro station, in Southern Italy, was used as test site because it provides a well-documented, close interaction between man and the environment. The model was also validated against data from other Italian sites.

2. ENVIRONMENTAL SETTING, DATA AND METHODS

The study is based on a set of monthly documentary proxy data and modelled seasonal temperatures at regional scale for Catanzaro station, located in a typical valley of Southern Italy (Fig. 1a). The Catanzaro station is located in the Ionian part of the Calabrian region at 38° 54’ North latitude, 16° 26’ East longitude, 320 a.s.l elevation (Fig. 1b).

This region is frequently crossed by depressions generating over the Mediterranean Sea (Wigley, 1992) that, reinforced by continental north-easterly airflows, produce important fluctuations in temperature and precipitation (Barriendos Vallve and Martin-Vide, 1998). Regional temperature data were derived from Luterbacher et al. (2004) who upscaled data, at 0.25 x 0.25 degree grid resolution over European domain (http://www.ncdc.noaa.gov/cgi-bin/paleo/eurotemp.pl), from historical instrumental series and multi-proxy data (Fig. 1a). From this map it is also possible to observe the limited temperature datasets on Southern Europe (including Central and Southern Italy).

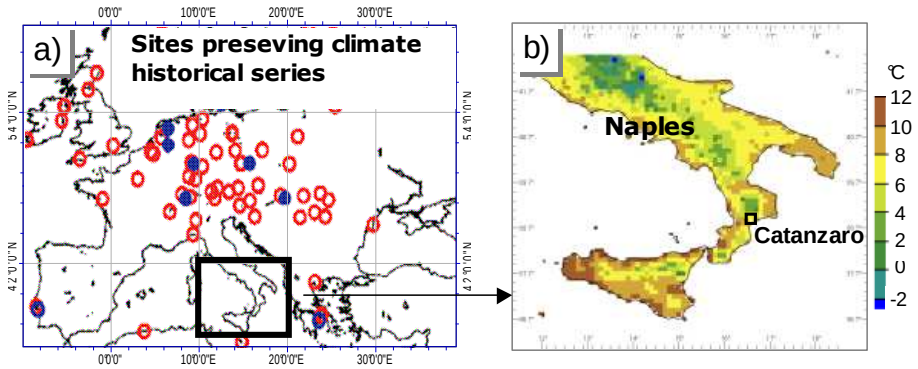

Fig. 1 – **a**): Location of temperature sites (red circles), and documentary monthly-resolved data (blue dots) used by Luterbacher et al. (2004) to reconstruct the regional seasonal temperatures over Europe since 1500 AD; **b**): winter temperature pattern averaged over 1961-1990 in Southern Italy, with indicated the Catanzaro station (arranged by LocClim FAO software at 10 km resolution).

In Fig. 1b, the Italian locations are contextualized based on winter temperature pattern, and the site of Catanzaro placed where documentary data were available at local and sub-regional scales. Such documentary-data were derived from chronicles found in two main sources. The Italian scientist Alfonso Corradi (1833-1892) collected the Christian Age historical documents from 5 to 1850 related to meteorology and epidemics into a 5-volume book (Corradi, 1865-1892). More recently, the historian Umberto Ferrari has published chronicles that report climate extremes and famines for Calabrian region from 1710 to 1769, which also include weather information for the 16th and 17th centuries (Ferrari, 1977).

2.1 Monthly temperature anomaly scaled index

Written documentary sources can be proficiently used to transfer information for deriving temperature related indices. Based on previous papers where different types of indices were proposed in historical climatology studies (Pfister, 1999, 2001; Brázdil et al, 2005), a seven-point scale ranging from –3 for 'extreme coldness' to +3 for 'extreme hotness' (with 0 indicating 'normal' conditions) was taken as a reference. However, it was observed that this ordinal scale bears the limitation of a concise differentiation of the full range of extremes as it assignes the same extreme class to all events above a certain threshold (Glasier and Riemann, 2009). To obtain a realistic level of variability in the temperature modelling, a simplified scaled-index was employed to capture very extreme anomalies that may have been recorded only during the Little Ice Age (e.g., rivers freezing).
Monthly-based indices were calculated that keep variability that is similar to the natural variability over a period longer than the calibration interval. These classes were allocated to climate events via an asymmetric matrix that takes into account the inequality between proxy and actual anomalies in different seasons of the year. As a matter of fact, a river freezing in March or April leads us to consider it as a negative anomaly greater than the same event occurring in December or January. In so doing, it is even more amplified the shift from warmth to coldness during summer than any other season. Based on these new classification principles, temperature anomalies were codified by a monthly Temperature Anomaly Scaled Index (*TASI*) according to the following asymmetric matrix with indices varying by month (Tab. 1).

	Freezing	Very cold	Cold	**Normal**	Warm	Very warm
Dec	-4	-2	-1	0	1	2
Jan	-4	-2	-1	0	1	2
Feb	-4	-2	-1	0	1	2

Tab. 1 – Monthly scaled index for decoding winter temperature anomalies from documentary proxy data.

2.2 Temperature Constrained MIxed Regression (COMIR)–model

Once defined the magnitude of the indices array, the proxies were transformed into a time series with a clearly defined temporal resolution. The statistical transformation of the proxy data into ordinal data in the form of a time series of temperature indices is challenging as it requires both broad statistical and climate dynamics understandings (Brázdil et al., 2005). Air temperature, in particular, depends on regional-synoptic forcing and local weather conditions. In our model, the regional component was derived from the gridded temperature

series (T_R hereafter) by Luterbacher et al. (2004). The model was iteratively arranged towards a robust solution, using the following mixed form:

$$y(T_{\mathrm{COMIR}})_t = a + \left(\varphi \cdot T_{\mathrm{R}}\right)_t + \nu \cdot \left(f(\Omega)_{\mathrm{S}} + TASI_{\mathrm{S}}\right)_t^{\eta} + \varepsilon_t \qquad (1)$$

The first term, $y(T_{COMIR})_t$, is the seasonal temperature output (°C) of the (COMIR)–model; $\varphi \cdot T_R$ is the regional component of actual temperature (°C); the second term between brackets is the corresponding local temperature component (°C); a is the intercept (°C); parameters φ, ν and η define the order of magnitude of the process involved in the downscaling process (ν and η are meant as switch-off parameters for site-specific climate conditions); $TASI_S$ is the seasonal Temperature Anomaly Scaled Index (sum of monthly indices); $f(\Omega)_S$ is a parametric function varying with the season; the term ε_t is the residual; t indicates the tth year.
For estimating of the parameters of Eq. (1), a procedure for the recursive least-squares algorithm was adopted under the following restrictions:

$$\begin{cases} a = 0 \\ \dfrac{1}{n}\displaystyle\sum_{t=1}^{n} \varepsilon_t \approx 0 \\ \mathrm{NSC} = \max \left| 1 - \dfrac{\displaystyle\sum_{t=1}^{n} \left(y(T)_t - T_t\right)^2}{\displaystyle\sum_{t=1}^{n} \left(y(T)_t - \overline{y(T)}_t\right)^2} \right| \end{cases} \qquad (2)$$

The first condition is to set null intercept, the second is to approximate the residuals (ε_t, with n indicating the number of years) to zero, and the third is to maximize the NSC, the Nash and Sutcliffe (1970) coefficient. In the NSC equation, the term $y(T)$ is the predicted temperature, T is the observed temperature, and $\overline{y(T)}$ is the average temperature of the series analysed. Essentially, the closer NSC is to 1, the more accurate the model is. NSC ranges from $-\infty$ to 1. An efficiency of 1 corresponds to a perfect match of modelled temperatures to the observed data. An efficiency of 0 indicates that the model estimates are as accurate as the mean of the observed data, whereas an efficiency less than zero occurs when the observed mean is a better estimator than the model or, in other words, when the residual variance (described by the nominator in the expression above), is larger than the data variance (described by the denominator). The mixed approach of Eq. (1), where the smoothed trend is derived separately through linear regional component and then coupled to nonlinear-and-local component, results in a descriptive model capable of making extrapolations, i.e. producing values outside the range of values in the calibration sample.
Graphical and statistical analyses were executed interactively using *Solver add-in* Microsoft® Office Excel 2003, with the support of Statistics Library – $\mathcal{R}$ modules (Wessa, 2009).

3. RESULTS AND DISCUSSIONS

In order to have a visual and analytical inspection of the quality of the results, a set of comparative results are hereafter presented and discussed, aiming at evaluating how the (COMIR)–model simulates winter temperatures of Catanzaro station. Results are compared between the (COMIR)-model and the Temperature Regional model by Luterbacher et al. (2004). Performances of the (COMIR)-model are also assessed at other sites than that of the model development.

3.1 Model evaluation and parameterization

For 1950-2002, sufficient proxy–and–instrumental data were available for modelling winter temperatures at Catanzaro. Basically, parameter values (Eq. 4) were obtained against observations by using a recursive procedure as illustrated above, and reported in Table 2.

(COMIR)–model (winter temperatures)						
Parameters / Statistical indices	ϕ	ν	η	$f(\Omega)_s$	R^2	*NSC*
Values	0.20	1.0	0.79	12.0	0.90	0.90

Tab. 2 – (COMIR)-model (Eq. 4) parameters: **φ, ν** and **η** are the scale-factors, $f(\Omega)_S$ is the seasonal function. Evaluation statistics are also reported as computed over the calibration dataset: R^2 is the determination coefficient, and NSC is the Nush-and-Sutcliff model efficiency coefficient.

A good agreement is immediately apparent between observed winter temperatures and (COMIR)–model distributional estimates (Fig. 2a). The Nash-Sutcliffe index of 0.90 reflects indeed negligible departures of the data points from the 1:1 lines in the scatterplots, as well as the alignment of values around the 1:1 lines, indicating an absence of drift in the residuals. Even the frequency histograms reproduce a good approximation of estimates to the actual distribution of temperature values (histograms on the sidelines of Fig. 2a, and Q-Q plot of Fig. 2a$_1$).

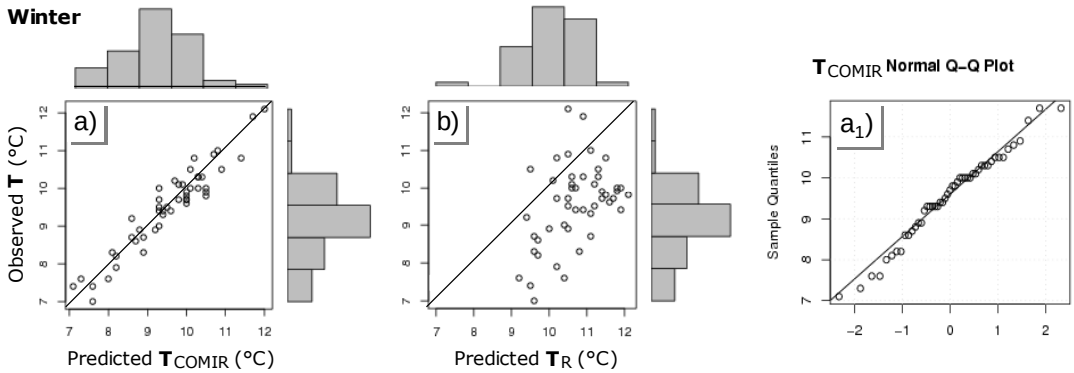

Fig. 2. Scatterplots between observed and predicted winter temperatures (°C) by (COMIR)–model (a) Eq. (4), and by regional model (b) (Luterbacher et al., 2004), with the respective 1:1 drawn lines; (COMIR)–model normal-Q-Q plot was also shown (a$_1$).

The contrary was observed to happen with the Temperature Regional model. The scatterplots of Fig. 2b show a poor agreement between observed and predicted data. A strong bias was observed with temperature overestimated on average of about 1.5 °C.

3.2 Model validation

Beyond checking the quality and accuracy of data being used by the model, validation runs were were performed to ensure that model outputs are representative of winter temperatures outside the range of values included in the calibration sample.
Model validation against independent data taken at Catanzaro in the period 1871-1930 is presented in Figure 3. In general, the performances are similar to the calibration dataset.

Taking still into account the Nash-Sutcliffe index, (COMIR)-model have values equal to 0.76 against Temperature Regional model with –1.46.

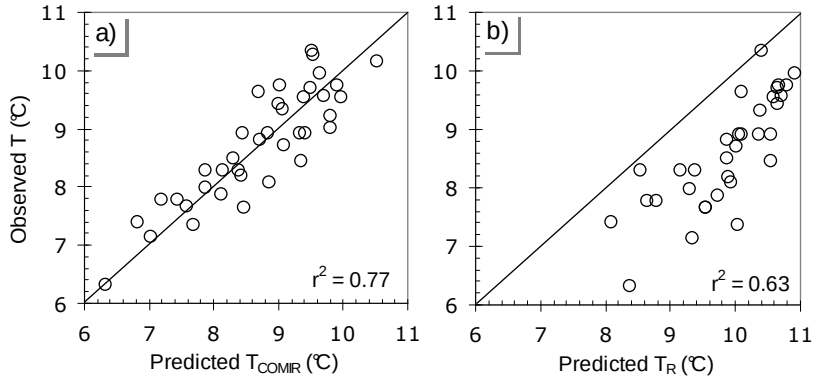

Fig. 3. Scatterplots between observed and predicted winter temperatures (°C) by (COMIR)–model (a) Eq. (1), and by regional model of Luterbacher et al. (2004) (b), at validation stage. Respective 1:1 lines are drawn.

CONCLUSIONS

We have introduced a relatively simple method to reconstruct past climate variability that applies a constrained mixed regression approach in the calibration step to overcome the inherent loss of variance in regional large-scale temperature pattern. This method has been successfully validated with historical temperature data. This merged analysis is also suitable to help defining temperature signals over different temporal scales, and to indicate when and where the analyzed temperature variations are significant. However, the accuracy of these signals depends not only on the intrinsic properties of the (CORIM)-model itself, but also on the overall ability to recover a sufficiently homogeneous documentary series to transfer the right information to a model that must ultimately replicate the actual temperature series.
The authors are engaged to extend the same conceptual and numerical modelling capabilities here published to more complete predictive models with focus on summer season and on composite areas.

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