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Using Oscillatory Processes in Northern Hemisphere Proxy Temperature Records to Forecast Industrial-era Temperatures

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Abstract: The validity and interpretation of differing representations of proxy temperature profiles from the past 2,000 years for the northern hemisphere remains controversial. One perspective of temperatures over the past 1,000 years embodies a major oscillation with a peak corresponding with the Medieval Warm Period (MWP), a trough representing the Little Ice Age (LIA) and subsequent increasing temperatures to the present. An alternate temperature perspective, known as the "hockey stick" exhibits a slow long-term cooling trend downward from about 1000 AD to about 1900 AD, followed by relatively rapid warming in the 20th century and is a prominent feature in describing the apparent climate crisis. The present study, using spectral analysis, shows that both types of profile have a dominant millennial oscillation and a set of lower power centennial and decadal oscillations. The key difference in determination of development of the proxy temperature profile into either a hockey stick or MWP_LIA cycle is the phase alignments of centennial and decadal oscillations with respect to the millennial oscillation. In both cases, the resultant sine waves from spectral analysis up to 1880 AD can be used to train a an artificial neural network using oscillatory data corresponding to the pre-industrial era, then forecasting temperatures into the 20th century, enabling an estimation of natural and anthropogenic contributions to recent warming. The limitations of highly complex general circulation models that do not to adequately incorporate oscillatory patterns in temperatures may be a compelling reason to promote more extensive use of forecasting with established machine learning techniques such as ANNs.

Keywords: Climate Change, Temperature, Oscillation, Natural, Anthropogenic, Forecast, Artificial Neural Network

1. Introduction

1.1. Literature Review

Instrumental temperature records are, at best, limited to about the past 200 years, and are available for only a few European locations [1-3]. Various proxies have been used to extend temperature records back throughout the Holocene (the past 12,000 years), based on information from a range of different sources including tree rings, ice cores, spleothems (stalagmites and stalactites found in caves), corals, marine sediments, lake sediments and historical documents [4]. Proxy temperature records have been reported at local, regional, continental, hemispheric and global scales [5, 6].

Much emphasis has been placed on composite northern hemisphere proxy temperature reconstructions for the past 2,000 years during the past two decades, when considering climate change. These temperature records have been central to the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports since 1990. Development of proxy temperature profiles has been, and continues to be, very controversial both in the scientific domain and within the wider community. Broadly viewed, there are two apparently divergent paradigms.

One perspective is represented by temperature profiles that are clearly cyclical, with maxima and minima corresponding to a distinct Medieval Warm Period (MWP) peak and a Little Ice Age (LIA) trough in the past 1,000 years, and also a Roman Warm Period (RWP) and a Dark Age (DA) if the temperature record is extended back 2,000 years. Figure 1 shows the northern hemisphere temperature profile presented in the IPCC First Assessment Report in 1990 [7]. This shows the temperature oscillating over the past 1,000 years, with highest temperatures reached during the MWP at about 1200 AD, the lowest temperatures during the LIA at around 1600 AD, followed by increasing temperatures moving towards the current warm period (CWP). Temperatures of the 20^{th} century are shown as lower than the maximum reached during the MWP.

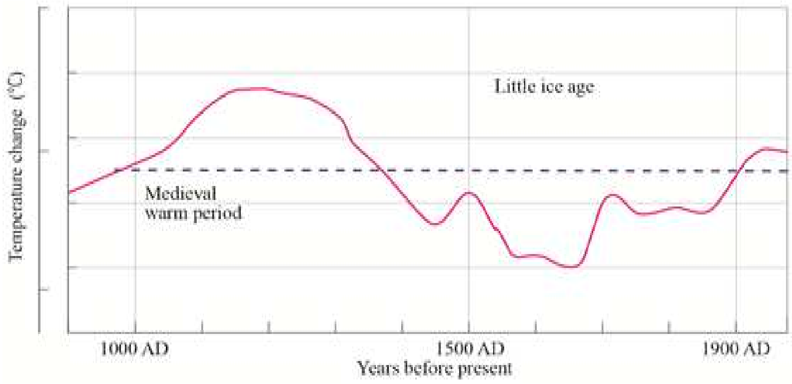


Figure 1. *Temperature variation in the northern hemisphere over the past 1000 years illustrating the MWP_LIA cycle. IPCC First Assessment Report (Figure 7.1c) [7].*

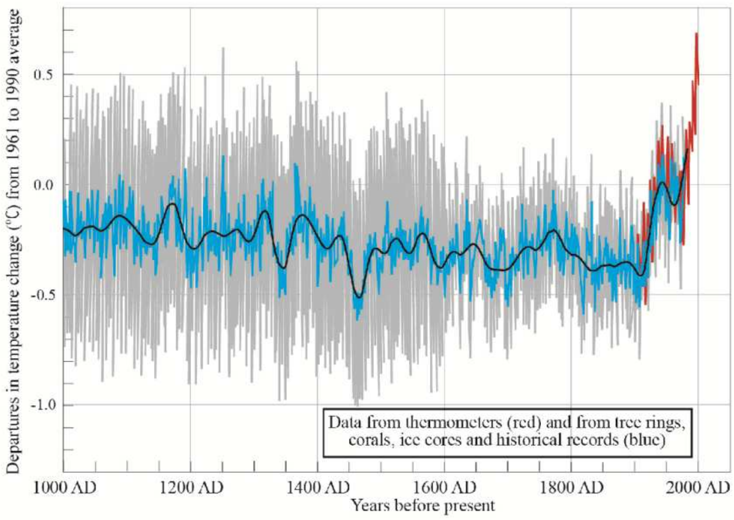


Figure 2. *Temperature variation in the northern hemisphere over the past 1000 years illustrating the "hockey stick". IPCC Third Assessment Report (Figure 1) in Summary for policymakers 2001, [10].*

Studies by Mann, Bradley and Hughes [8, 9] - often referred to as MBH98 and MBH99 respectively, and others during the past two decades have generated an alternative representation of global and northern hemisphere temperatures that have been widely publicised and colloquially often referred to as "the hockey stick". These reconstructions exhibit a slow long-term cooling trend downward trend from about 1000 AD (the ice hockey stick) to about 1900 AD, followed by relatively rapid warming in the 20th century (the blade), with the instrumental temperature record by 2000 AD exceeding earlier temperatures during the previous 1,000 years. While the IPCC Third Assessment Report in 2001 [10] drew on five reconstructions to support its conclusion that recent northern hemisphere temperatures were the warmest in the past 1,000 years, it gave particular prominence to an illustration shown in Figure 2 based on the MBH99 paper The hockey stick graph was subsequently seen by mass media and the public as central to the IPCC case for unprecedented global warming and the developing climate crisis.

The IPCC Fifth Assessment Report 2013 (Chapter 5, Information from Paleoclimate Archives, [11] shows a set of temperature reconstructions that include both types, without drawing significant attention to the ongoing debate. The commentary states that the timing of warm and cold periods is mostly consistent across reconstructions (in some cases this is because they use similar proxy compilations), but the magnitude of the changes is clearly sensitive to the statistical method applied and to the target domain (land or land and sea; the full hemisphere or only the extra-tropics).

Nevertheless, the validity of the hockey stick graph has been intensely debated in the scientific literature over the past two decades [12-16]. This debate includes methodologies used for construction of multi-proxy temperature, the occurrence of the MWP and LIA, whether present temperatures are indeed unprecedented in the past 1,000 years and the causation of current warming trends. Resolution of the debate is important from the perspective of having confidence in forecasts of temperature into the future.

The importance of the implications of the temperature reconstructions is reflected in responses from the political sector. In the United States, the North Report [17] evaluated reconstructions of the temperature record of the past two millennia, providing an overview of the state of the science and the implications for understanding of global warming. It was produced by a National Research Council committee, chaired by Gerald North, at the request of the U.S. House of Representatives Committee on Science. The NRC committee stated that "The basic conclusion of Mann et al. (1998, 1999) was that the late 20th century warmth in the northern hemisphere was unprecedented during at least the last 1,000 years. This conclusion has subsequently been supported by an array of evidence that includes both additional large-scale surface temperature reconstructions and pronounced changes in a variety of local proxy indicators".

One aspect of the temperature reconstructions that has received some attention in the scientific literature is the occurrence of oscillatory patterns within the temperature profiles, although not prominently discussed in IPCC Assessment Reports. Identification of continuing oscillatory patterns can potentially be valuable in forecasting temperatures. A number of studies have found evidence for oscillations in proxy records at millennial, centennial and decadal time scales by applying spectral analysis [18-20]. It has been suggested that some proxy records may not include low frequency oscillations because certain types of proxy (particularly tree rings) do not capture this compared to others proxies such as ice cores. The occurrence of oscillatory processes in past temperature records is important because it potentially provides a method of projecting temperature patterns based on pre-industrial influences forward into the industrial era. The availability of this forecasting capability potentially enables separation of natural and anthropogenic influences on temperature during the industrial era [19]. Identification of oscillatory patterns in temperature records are also useful in understanding potential linkages with solar activity that are known to exhibit oscillatory behaviour on similar time scales.

There is evidence that multi-decadal oscillations have an influence on recent temperature variations. For example, it was concluded [21] that for Canada up to 0.5°C of the current observed warming trend may be associated with decadal variability of the climate such as that represented by the Pacific Decadal Oscillation (PDO) and North Atlantic Oscillation (NAO). However, the presence and utility of oscillatory behaviour is a contentious issue. Mann et al. recently published an article [22] claiming that such decadal and multi-decadal oscillations are merely “noise” and questioning the validity of using oscillations in forecasting.

The significance of decadal oscillations throughout the Holocene has been reviewed [4] including the (El Nino Southern Oscillation) ENSO, (Pacific Decadal Variability) PDV, NAO, the Southern Annular Mode (SAM), Atlantic Multi-decadal Variability (AMV), and the Indian Ocean Dipole (IOD). In citing Mann (2020), this report stated that that “the debate still rages” concerning decadal oscillations. Thus the distinction between hockey stick and MWP_LIA cyclical profiles appears to include the accepted validity and utility of oscillatory patterns in temperature records.

A focus of many proxy temperature reconstructions has been whether temperatures reached in the industrial era are unprecedented when compared to temperatures attained during the Holocene, particularly during the past 2,000 years. For example, a reported temperature reconstruction for 2000 years in China [23] found that the warming during the 20th century is not unprecedented, as similar warming occurred during 981-1100 and 1201-1270 AD. A study of the Arctic [24] spanning 12,000 years found early Holocene temperature oscillations exceeded the amplitude of the current observed and projected warming in Svalbard lakes, with temperatures up to 7°C higher than current.

A number of studies have expressed concerns on the reliability of conclusions and forecasts from General Circulation Models (GCMs). These are complex physical models relied upon by the IPCC and questioned because of apparent failures of these models to simulate oscillatory patterns that are clearly present in both recent and paleo temperature records. One study [25] reported that very important physical mechanisms necessary for reproducing multiple climatic oscillations, which are responsible for about half of the 1850-2010 AD warming, appear to be missing in simulations generated by GCMs. A later investigation [26] concluded that GCMs fail to properly reconstruct the natural variability of the climate throughout the entire Holocene. This shortcoming was evident at multiple time scales including the large millennial oscillations observed throughout the Holocene that were responsible for the MWP and shorter climatic decadal oscillations with periods of 10-60 years. Another study [27] examined the limitations of GCMs and questioned IPCC conclusions because studies considered do not look beyond the industrial era, and are inadequate regarding influences of internal oscillations. This study emphasised the exclusion by the IPCC of the millennial paleo-climatic data, and that natural contributions associated with solar activity and internal variability could in fact be predominant in the observed recent warming.

Many studies have concluded that the presence of oscillations that may affect earth’s climate are closely related to changes in solar activity over a wide range of time scales. Relationships between solar activity and the earth’s climate have been comprehensively reviewed [28-30]. A study of European lake sediments [31] reported the influences of 80, 120, 208, 500, 1,000 and 1,500 year cycles, and related these to solar activity. A multiproxy study of the western Mediterranean region [32] extending over 12,000 years of the entire Holocene showed the presence of millennial cycles attributed to external solar forcing, with a periodicity of 1,430 years. Periodicities of 208, 521, and ~ 1,000 years were found [33] in Antarctic ice-core records which they related to solar activity, particularly sunspot number. Another investigation [34] reported a clear ~200 year cycle for climate variations from Central Asia and related it to the solar De Vries/Suess cycle [35, 36].

1.2. Aims and Scope of Present Study

The present study examines a set of eight published proxy temperature records for the northern hemisphere including examples of both the hockey stick and MWP_LIA cycle profiles. These proxy records are first decomposed into sets of sine waves that when recombined give the best simulation of the original temperature profile. This enables comparison of the periodicities of the main contributing sine waves. This can elucidate whether an examination of oscillatory behaviour can further explain differences between the hockey stick and the MWP_LIA cyclical representations.

The results from decomposition into sets of oscillations can then be used to forecast temperatures into the industrial era, based on oscillatory patterns up to 1880 AD as input data. The accuracy of fitting the data and simulating the natural patterns present can generally be improved by using the sine wave components as input to train an artificial neural network (ANN) [19]. This allows forecasts to be made beyond 1880 AD into the 20th century, extending up to the present. This can potentially enable attribution of temperature increases during the industrial era to natural or anthropogenic influences by comparing the ANN temperature forecasts for the industrial era with the observations.

2. Materials and Methods

There are hundreds of proxy temperature records reported in the scientific literature, the majority corresponding to the Holocene period. For this investigation, eight multi-proxy records for the northern hemisphere were selected for further analysis each extending back over a period of at least 1,000 years. These are a subset of the 17 northern hemisphere records previously considered [37], and includes examples of both hockey stick and MWP_LIA cycle profiles.

The data for eight published northern hemisphere temperature proxy reconstructions were obtained from the NOAA database (National Oceanic and Oceanic Administration, National Centres for Environmental Information. Paleoclimatology Data) [38]. Table 1 gives a summary of the proxy temperature reconstructions used for this analysis. The digital time-series were then examined by spectral analysis using AutoSignal software, applying the Parametric Interpretation and Prediction tools with Fourier Transform analysis.

In each case, the number of sine curves applied to reconstruct the total temperature signal was increased until the improvement in fitting, estimated by correlation coefficient, showed only marginal improvement. By adjustment of periodicities, phase and power of the identified sine wave components, the software optimizes simulations of the original proxy signal, using a defined number of component sine waves. In each case, the optimizations were undertaken from the proxy record start date through to 1880 AD. This can be regarded as a pre-industrial period, with only natural influences on climate that is without anthropogenic (human-caused) contributions. The set of component sine waves obtained by spectral analysis can then be reconstructed into a composite signal and compared with the corresponding original temperature profile.

In each case, this data based on the sinusoidal analysis, was used as the input data for subsequent machine learning. In particular, the data was provided as input to Neurosolutions Infinity software [19]. Many different ANN architectures have been used to make forecasts of climatic variables [39-43]. A common approach in the selection of an optimal ANN architecture is through simple trial and error of candidate models [42, 43]. Using Neurosolutions Infinity software, the process is automated. This offers a great advantage in terms of arriving at an optimum forecast model for every data set of interest without a prohibitive time outlay. The Neurosolutions Infinity program uses a pre-set formula incorporating Root Mean Square Error (RMSE), mean absolute error (MAE) and correlation coefficient (R) to evaluate the accuracy of different machine learning topologies and configurations for each set of selected inputs tested. Based on this formula, the program determines which model and set of inputs is optimal.

For the datasets used in this investigation, the optimal machine learning model automatically selected by Neurosolutions Infinity was a general regression neural network (GRNN) [44]. This has the topology of a feedforward network that “learns” in one pass through the data and can generalize from examples as soon as they are stored. During training, the estimate converges to the conditional mean regression surfaces as more and more examples are observed. It forms very reasonable regression surfaces based on only a few samples, and the estimate is bounded by the minimum and maximum of the observations.

Table 1. *Descriptions for the 8 northern hemisphere multi-proxy temperature reconstructions used in this study.*

Proxy series	Date range (AD)	Proxy types	Number of records
Ljungqvist [6]	800-1999	Extra-tropical historical documentary records, seafloor sediment records, lake sediment records, speleothem records, ice-core records, varved thickness sediment records, tree-ring width and maximum latewood density records.	30
Moberg et al. [45]	1-1979	Tree rings, lake and ocean sediments	11
Christiansen and Ljungqvist [46]	1-1973	Extra-tropical proxies that reach back to at least 300CE	32
Crowley and Lowery [47]	1000-1993	Tree rings, ice cores, pollen, historical documents	12
Mann et al. [9]	1000-1980	Tree rings	28
Jones et al. [48]	1000-1991	Tree rings, ice cores, corals, historical documents	17
Esper et al. [49]	831-1992	Tree-ring chronologies	14
Schneider et al. [50]	600-2002	Mid-latitude summer temperatures based on a wood density network.	15

3. Results

3.1. Decomposition of Proxy Temperature Records into Sets of Component Sine Waves

Table 2 shows the results of spectral analysis for the eight proxy temperature records for the northern hemisphere. Each of the individual temperature proxy records can be decomposed into a set comprising between 4 and 10 sine waves, with periodic oscillations in the millennial, centennial and decadal ranges. For each sine wave, the periodicity is given in years and the power as a percentage. The power factor is proportional to the square of the amplitude of the sine wave.

Table 2. *Component sine wave periodicities and power (%) for northern hemisphere proxy temperature records obtained using spectral analysis of data up to 1880 AD.*

	Millennial and centennial oscillations	Decadal oscillations
Ljungqvist [6]	1230 (72%), 383 (11%). 149 (3%), 128 (4%), 106 (4%)	81 (2%), 76 (4%)
Moberg et al. [45]	1223 (70%), 380 (10%), 183 (2%), 126 (3%), 106 (4%)	82 (2%), 75 (4%). 63 (2%), 55 (2%), 49 (2%)
Christiansen and Ljungqvist [46]	978 (58%), 485 (26%), 438 (4%), 190 (9%)	
Crowley and Lowery [47]	1027 (72%), 538 (5%), 194 (6%), 171 (4%)	97 (2%), 83 (3%), 69 (5%)
Mann et al. [9]	1306 (44%), 211 (10%), 119 (16%)	80 (4%), 66 (13%), 59 (4%), 40 (4%), 29 (5%)
Jones et al. [48]	990 (59%), 143 (13%),	70 (5%), 51 (5%), 36 (3%), 31 (2%), 29 (4%), 27 (4%)
Esper et al. [49]	1173 (28%), 460 (30%), 192 (13%), 113 (5%)	69 (6%), 49 (5%)
Schneider et al. [50]	1172 (19%), 537 (34%), 271 (4%), 187 (13%), 175 (14%)	56 (4%), 53 (5%), 49 (7%)

Table 2 shows the low frequency components (millennial and centennial) make the major contribution to each composite proxy record, with decadal components making relatively minor contributions. In each case, there is a millennial frequency component falling in the range 978-1,306 years. In six cases, this millennial component is the dominant component (power range 44% to 72%). Seven proxy records exhibit centennial oscillations in the range 380-553 years, and six records in the range 183-271 years.

These results are in good agreement with a study [18] reporting a harmonic analysis of worldwide temperature proxies for 2,000 years incorporating six previous global proxy temperature records. This showed the strongest components as sine waves with periodicities of ~1,000 years, ~460 years, and ~190 years, whereas other oscillations of the individual proxies are considerably weaker

Another investigation [51] undertook wavelet analysis showing the dominant periodic variations of 1,130, 790-770, 560 and 390-360 years for Greenland ice core records extending over a period of 4,000 years. Periodicities of ~1,000, 521 and 208 years have been found in Antarctic ice-core records [33]. Studies of European lake sediments [31] reported the influences of millennial (1,500, 1,000 years), centennial (500, 208, 120 years) and decadal (80 years) cycles.

It is instructive to examine the northern hemisphere proxy reconstructions with regard to the dominant low frequency oscillation (Table 2), and the subsequent development of either a hockey stick profile or MWP_LIA cycle. Figure 3 shows the dominant millennial sine wave component from spectral analysis of a hockey stick profile from Crowley and Lowery [47] (red) and a MWP_LIA cycle from Lungqvist [6] (blue). It is evident that these two sine waves have similar periodicities (1,027 and 1,230 years respectively), equivalent amplitude or power (72%), and closely corresponding phase.

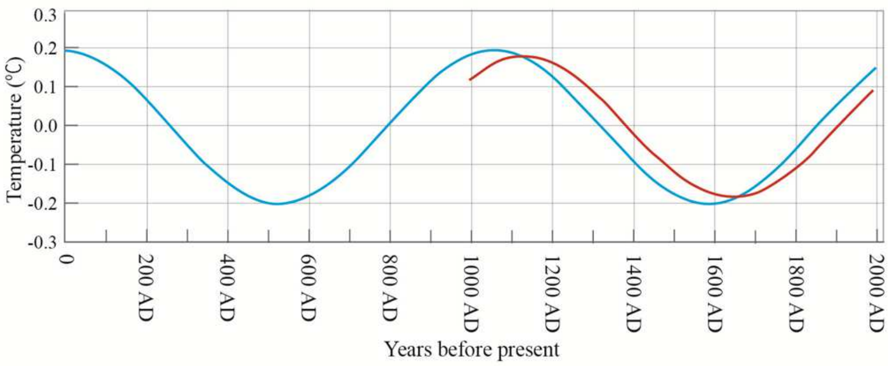


Figure 3. *Lowest frequency (millennial) sine wave component from decomposition of proxy temperature records from Crowley and Lowery [47] (red) and Lungqvist [6] ((blue).*

Figure 4A shows the millennial sine wave from Crowley and Lowery [47], as well as the individual centennial and decadal sine waves from spectral analysis. Figure 4B shows the millennial sine wave and the composite of the centennial and decadal sine waves, and Figure 4C shows the result of combining these.

Figure 5A shows the millennial sine wave from Ljungqvist [6], as well as the individual centennial and decadal sine waves from spectral analysis. Figure 5B shows the millennial sine wave and the composite of the centennial and decadal sine waves, and Figure 5C shows the result of combining these.

It can be concluded that starting from a similar millennial sine wave, through combination with an appropriate set of centennial and decadal sine waves, it is possible to generate either a hockey stick profile as illustrated by Crowley and Lowery [47], or a MWP_LIA cyclic profile, as illustrated by Ljungqvist [6]. The composite temperature profiles for centennial and decadal oscillations are shown together in Figure 6. The key difference in determining whether the profile develops into a hockey stick profile or MWP_LIA cycle appears to be the phase alignments, particularly of centennial cycles, with respect to the dominant millennial cycle.

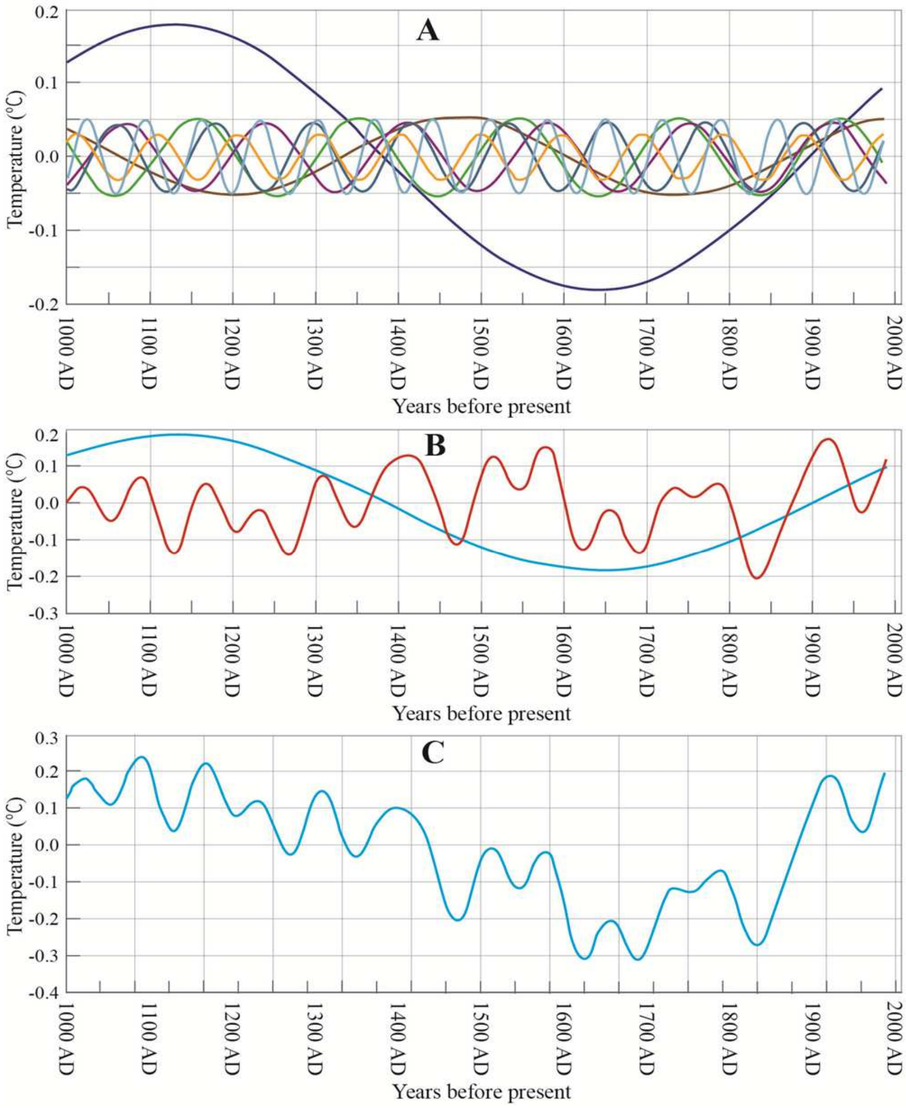
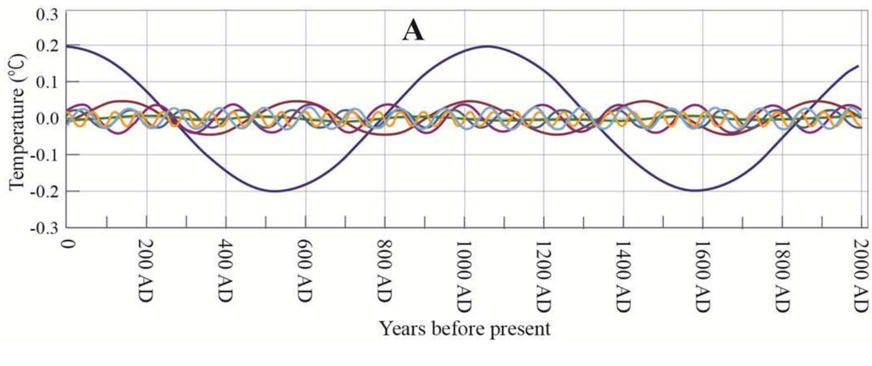


Figure 4. *Sine wave components for Crowley and Lowery [47]. A: Millennial sine wave (blue) with individual centennial and decadal sine waves; B: Millennial sine wave (blue) with composite of centennial and decadal sine waves; C: Composite of millennial, centennial and decadal sine waves.*



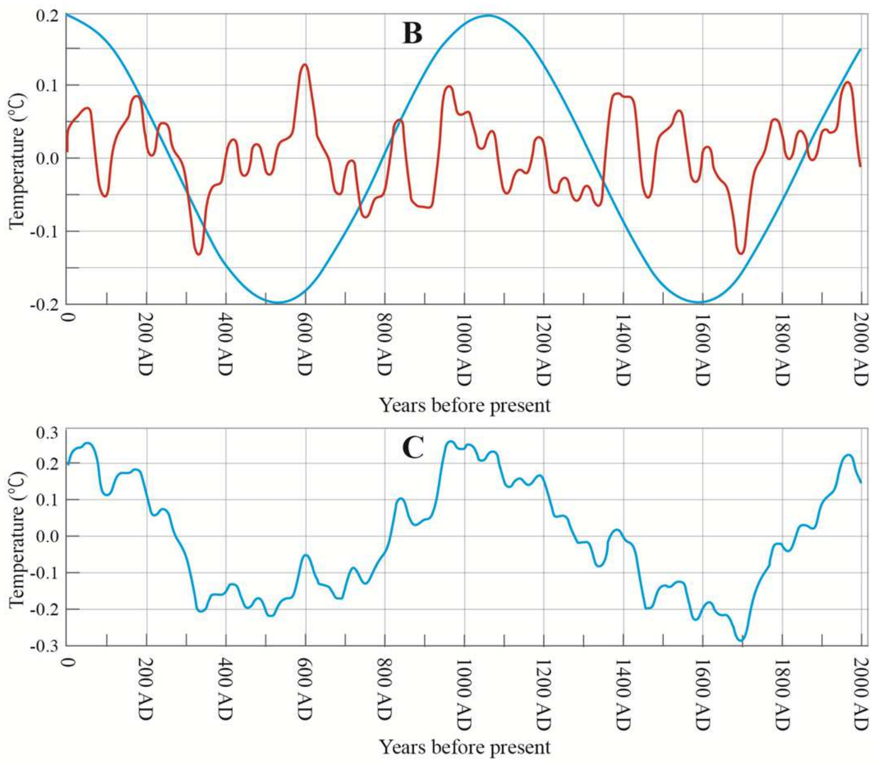


Figure 5. *Sine wave components for Ljungqvist [6]. A: Millennial sine wave (blue) with individual centennial and decadal sine waves; B: Millennial sine wave (blue) with composite of centennial and decadal sine waves; C: Composite of millennial, centennial and decadal sine waves.*

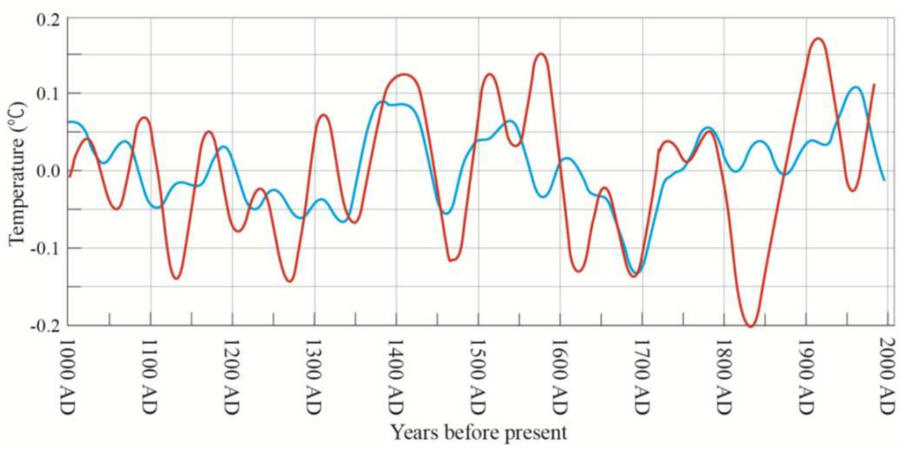


Figure 6. *Composite frequency (centennial and decadal) sine wave component from decomposition of proxy temperature records from Crowley and Lowery [47] (red) and Lungqvist [6] (blue).*

3.2. Reconstruction of Composite Temperature Signals

A composite temperature signal can be constructed from the respective set of component sine waves through simple addition of the respective sinusoidal components, taking account of the phase relationships revealed in the spectral analysis. This composite sine wave signal can itself be used as the basis of making forecasts of temperature. Figures 7A to 14A show the results of combining sine waves from spectral analysis up to 1880 AD, and then projecting the results forward into the 20th century to the end of the corresponding proxy record.

As demonstrated previously [19] superior fitting to the original temperature proxies are generally obtained by using the individual sine wave components and the composite as input data for an ANN. This data from the start of the proxy record up to 1880 AD serves as the training data for the ANN, enables more complex mathematical utilisation of the input data than a simple addition of the component sine wave oscillations. Application of the ANN to the input data generates better fitting to the training data set and this will generally lead to improved forecasting, assuming the relationships learned from the temperature data prior to 1880 AD are maintained into the industrial era.

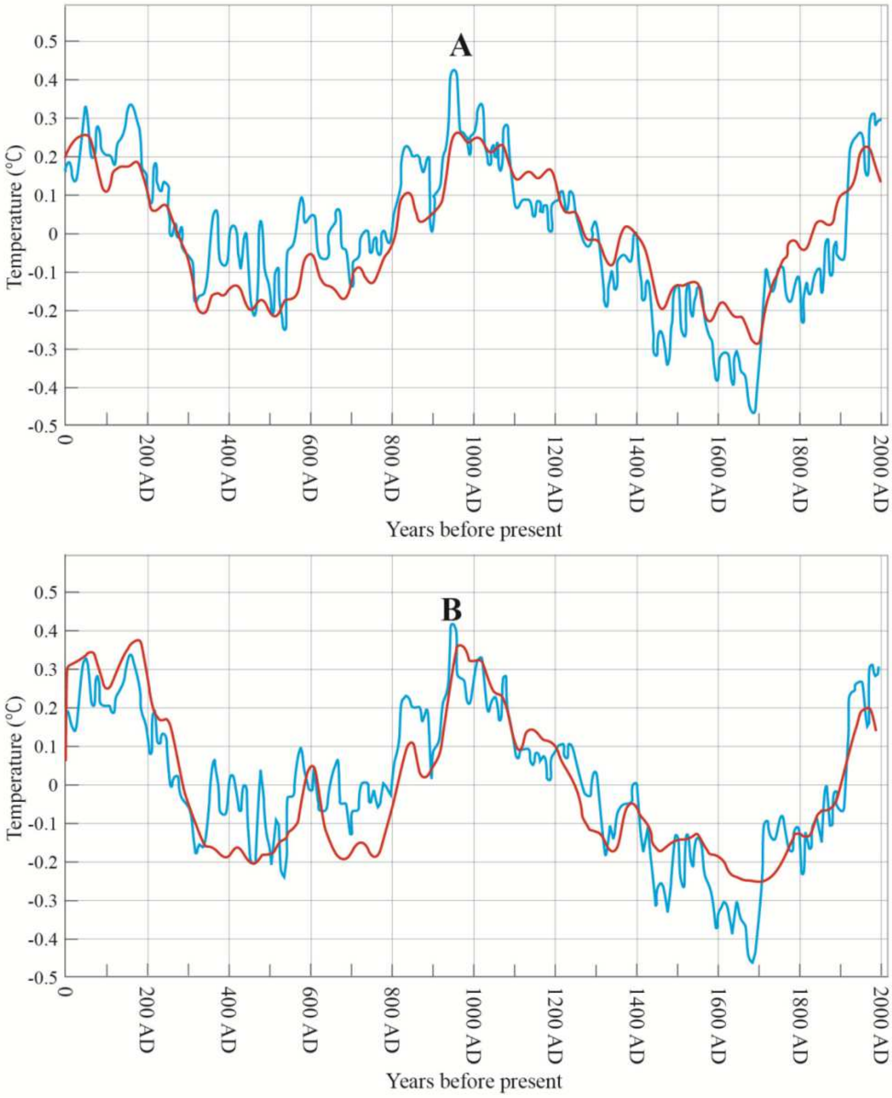
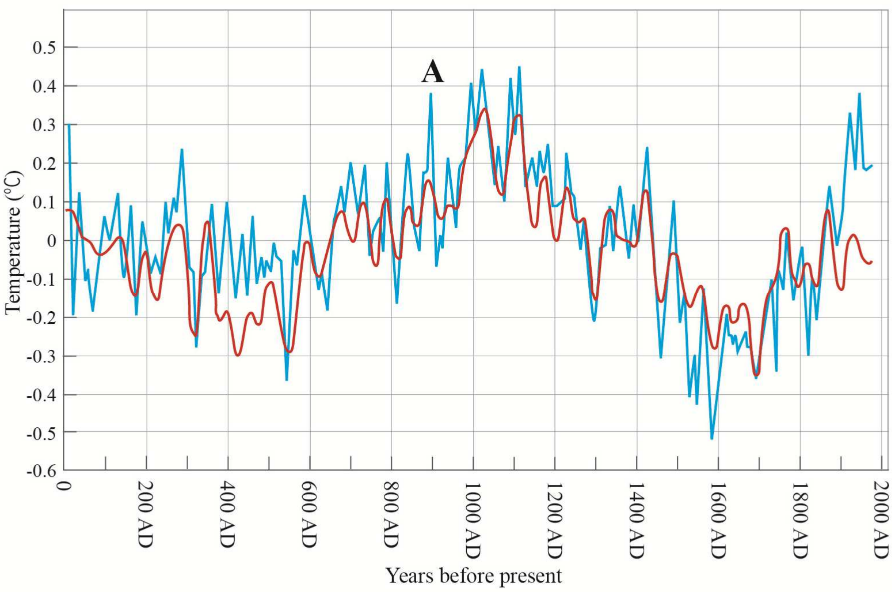


Figure 7. *Proxy temperature profile using results from Ljungqvist [6]. A: composite reconstruction using spectral analysis to generate a sine wave set from data prior to 1880 AD, and forecasting thereafter. B: ANN output using sine wave set from spectral analysis as input to ANN, with data prior to 1880 AD used for training and validation, and after 1880 AD for forecasting.*



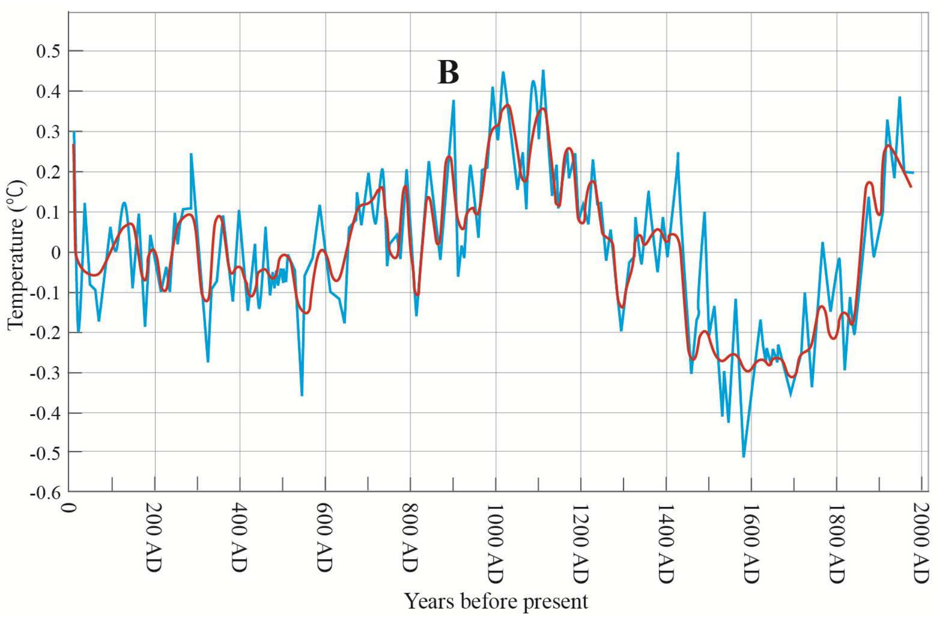


Figure 8. *Proxy temperature profiles using results from Moberg et al [45]. A: composite reconstruction using spectral analysis to generate a sine wave set from data prior to 1880 AD, and forecasting thereafter. B: ANN output using sine wave set from spectral analysis as input to ANN, with data prior to 1880 AD used for training and validation, and after 1880 AD for forecasting.*

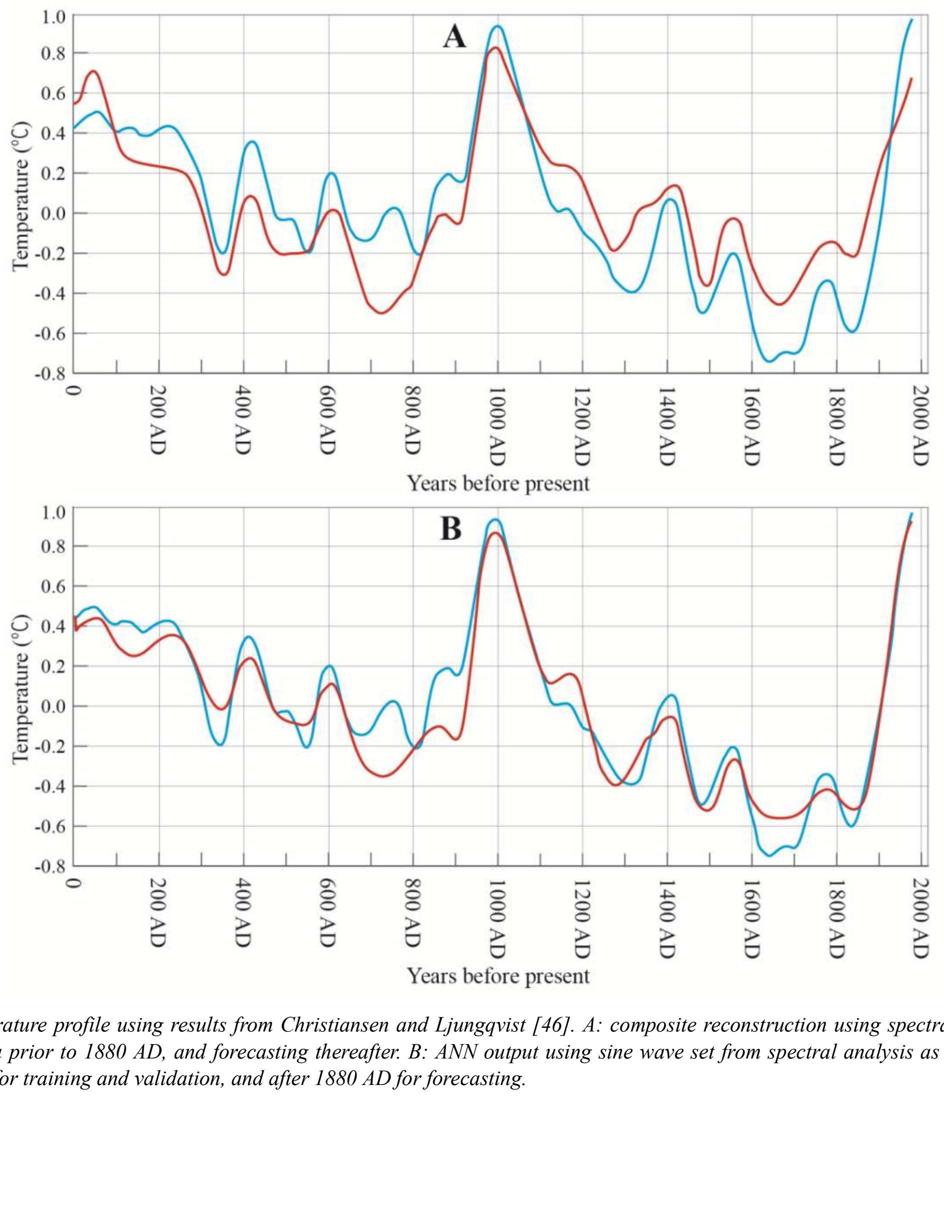


Figure 9. *Proxy temperature profile using results from Christiansen and Ljungqvist [46]. A: composite reconstruction using spectral analysis to generate a sine wave set from data prior to 1880 AD, and forecasting thereafter. B: ANN output using sine wave set from spectral analysis as input to ANN, with data prior to 1880 AD used for training and validation, and after 1880 AD for forecasting.*

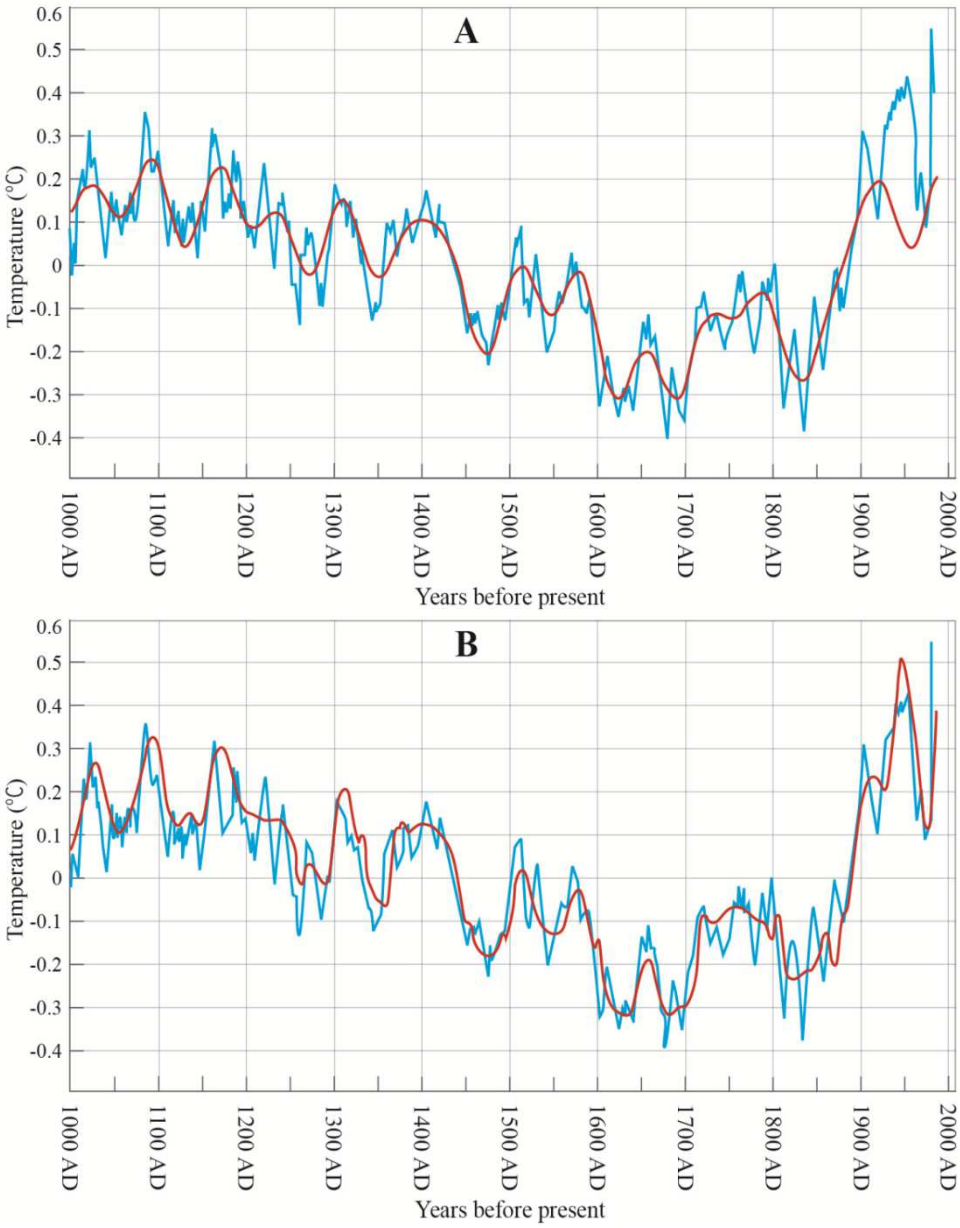
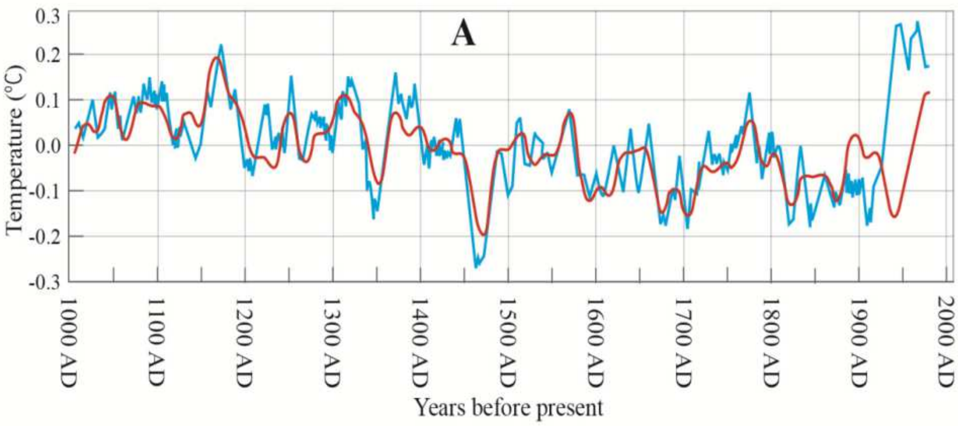


Figure 10. *Proxy temperature profile using results from Crowley and Lowery [47]. A: composite reconstruction using spectral analysis to generate a sine wave set from data prior to 1880 AD, and forecasting thereafter. B: ANN output using sine wave set from spectral analysis as input to ANN, with data prior to 1880 AD used for training and validation, and after 1880 AD for forecasting.*



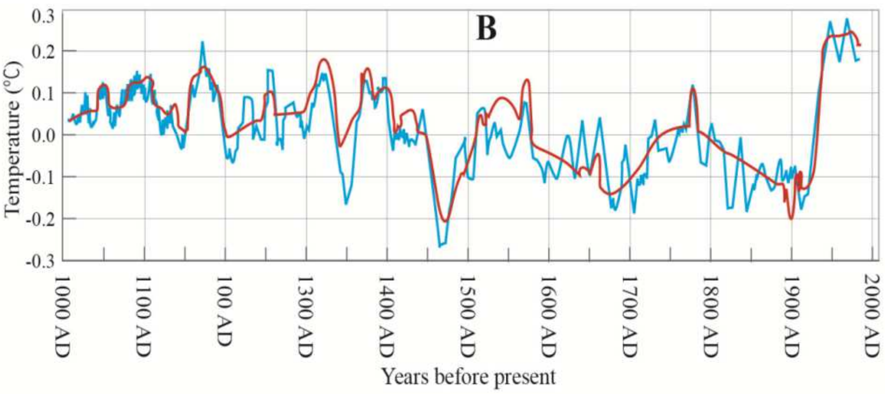


Figure 11. *Proxy temperature profile generated using results from Mann et al [9]. A: composite reconstruction using spectral analysis to generate a sine wave set from data prior to 1880 AD, and forecasting thereafter. B: ANN output using sine wave set from spectral analysis as input to ANN, with data prior to 1880 AD used for training and validation, and after 1880 AD for forecasting.*

Figures 7B to 14B show the results of using sine waves from spectral analysis up to 1880 AD as input for training an ANN, enabling projecting the results forward into the 20th century to the end of the respective proxy records. In each example, the upward warming trend beyond 1880 AD is present in the temperature forecasts. The temperature profiles based on oscillatory patterns learned by the ANN in the training process closely approximate to the actual proxy temperature records. Most of the warming can be explained in terms of a continuation of the natural oscillatory patterns present in the preceding 1,000-2,000 years.

It is also apparent that the predicted temperatures reached in the industrial era for the hockey stick profiles in Figure 10 (Crowley and Lowery, [47]) and in Figure 11 (Mann et al., [9]) are higher than those in the proxy records of the previous 1000 years.

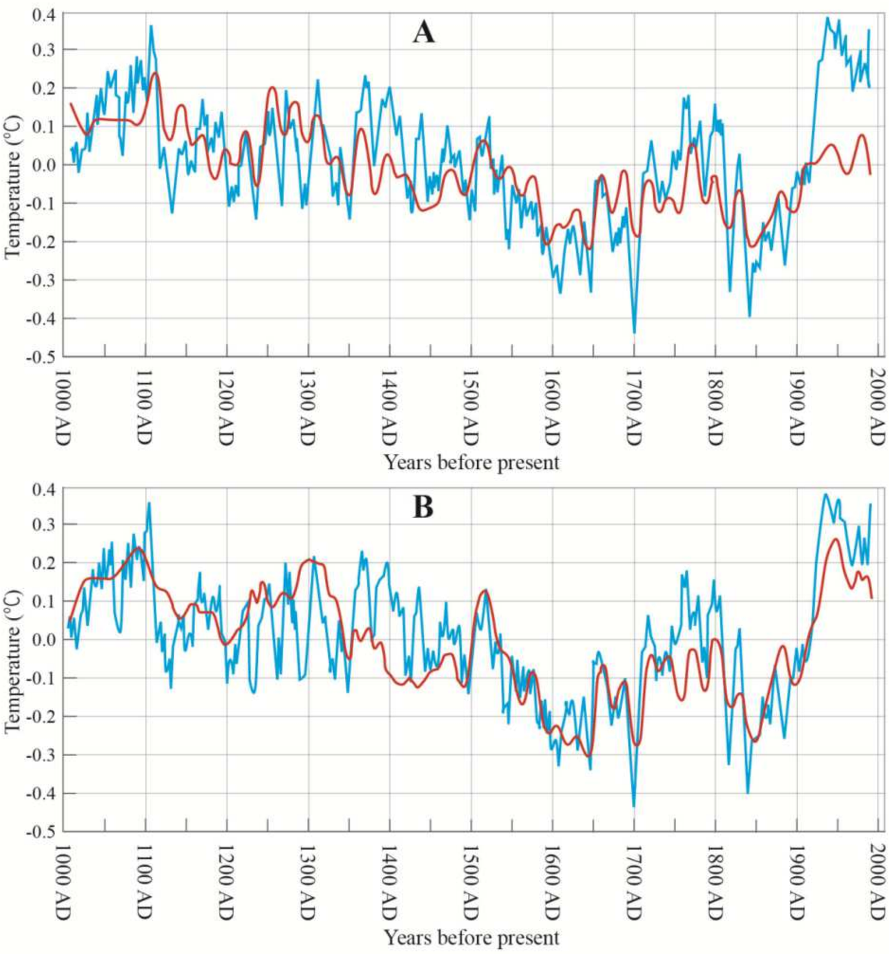


Figure 12. *Proxy temperature profile using results from Jones et al. [48]. A: composite reconstruction using spectral analysis to generate a sine wave set from data prior to 1880 AD, and forecasting thereafter. B: ANN output using sine wave set from spectral analysis as input to ANN, with data prior to 1880 AD used for training and validation, and after 1880 AD for forecasting.*

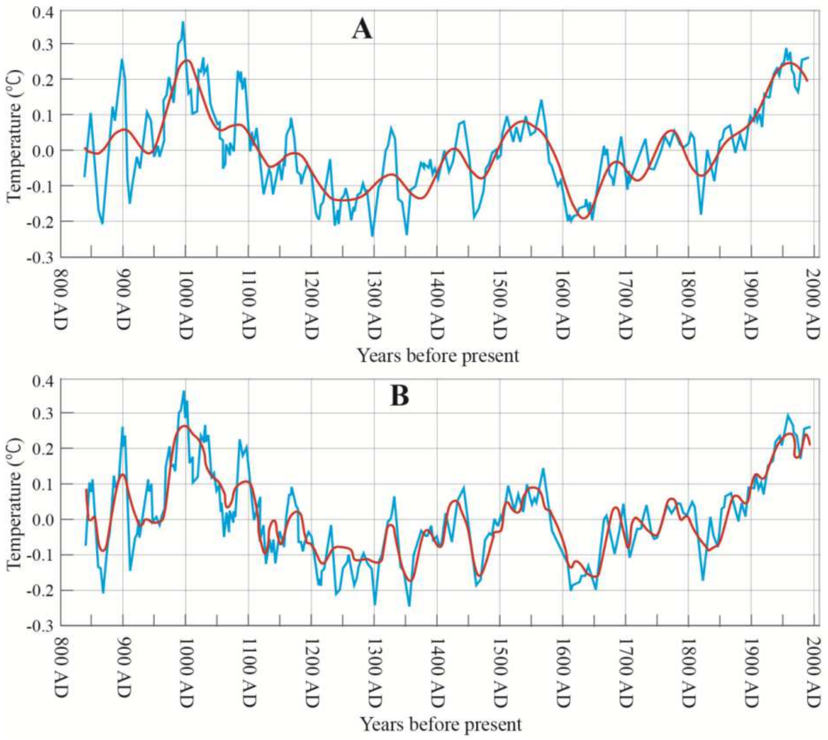


Figure 13. *Proxy temperature profile using results from Esper et al. [49]. A: composite reconstruction using spectral analysis to generate a sine wave set from data prior to 1880 AD, and forecasting thereafter. B: ANN output using sine wave set from spectral analysis as input to ANN, with data prior to 1880 AD used for training and validation, and after 1880 AD for forecasting.*

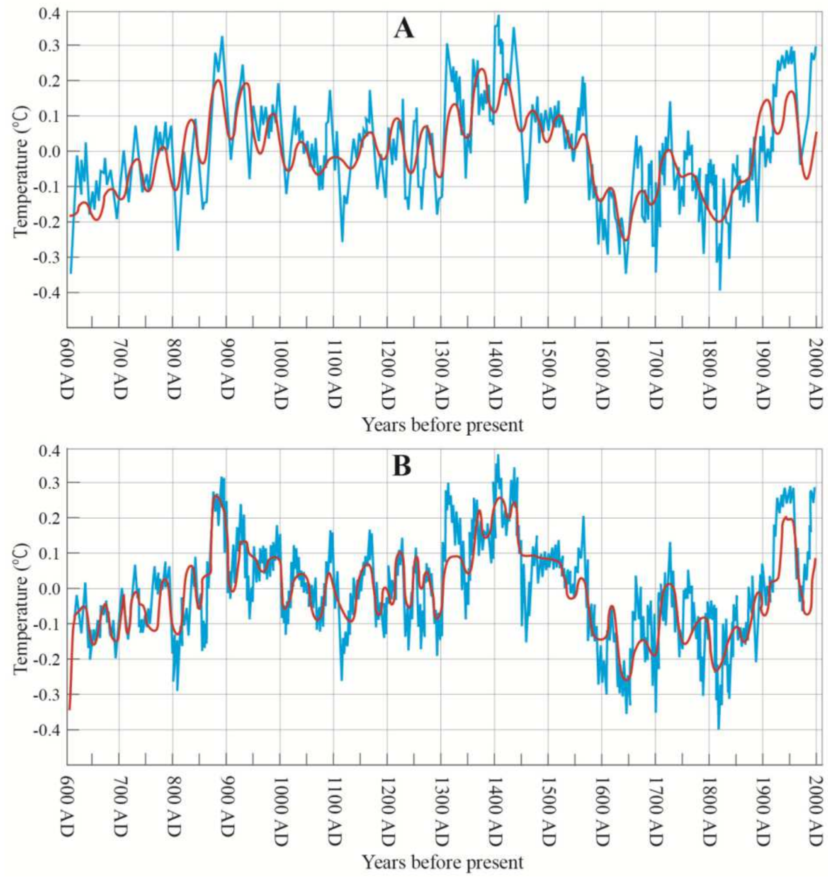


Figure 14. *Proxy temperature profile using results from Schneider et al. [50]. A: composite reconstruction using spectral analysis to generate a sine wave set from data prior to 1880 AD, and forecasting thereafter. B: ANN output using sine wave set from spectral analysis as input to ANN, with data prior to 1880 AD used for training and validation, and after 1880 AD for forecasting.*

3.3. Forecasting Temperatures for the Industrial Era Using Identified Oscillatory Patterns

There have been comparatively few reported studies in which oscillatory patterns identified in proxy temperature records have been extended to make forecasts. One approach to temperature forecasting using oscillations is to use identified natural cycles such as the PDO to make forecasts [52]. An alternative approach is to mathematically examine the profiles of oscillatory behaviour in a temporal record such as a typical proxy temperature record in order to identify patterns that may continue into the future and therefore allow prediction of future temperatures.

An investigation [51] examined proxy records for surface temperatures of Greenland extending back 4,000 years. Most of the dominant variations identified by the wavelet analysis are persistent with respect to strength and magnitude. Three oscillations (2,804, 1,186 and 556 years) out of 10 identified by wavelet and Fourier analysis of surface temperatures of the Greenland ice sheet to project temperatures forward from 1855 AD and the results were found to closely replicate the warm period over past 150 years. The simple cyclic model was able to forecast the main features of this recorded warming until 2010, showing that a significant part of the 20th century warming may be interpreted as the result of natural climatic variations, characterising at least the previous 4,000 years. Some of the cycles appear to correspond to known cyclic variations in the Moons' orbit around Earth, while others may correspond to solar variations.

In the present study, using northern hemisphere proxy temperatures, the spectral analysis was applied in each case from the start of the temperature record to 1880 AD. A composite signal can be constructed from the sets of component sine waves through simple addition of the sinusoidal components. This composite signal can itself be used as the basis of making projections of temperature. The extended profiles shown in Figures 3A to 10A from 1880 AD onwards are generated by projecting the composite sine wave into the industrial era and are therefore forecasts.

As demonstrated previously [19], it is possible to improve the approximation of the proxy temperature profiles prior to 1880 AD by application of machine leaning techniques, in particular ANNs. This was established by comparing the spectral analysis composite method versus the ANN method for the training periods. The application of ANNs for time series forecasting is a well-established technique that has used in many areas including scientific and financial [53-55]. ANNs have been successfully used for forecasting of climatic variables including temperatures [19] and rainfall [42, 43, 56, 57].

Figures 15 and 16 show the proxy temperature records and the ANN predictions for the period between 1880 AD and the end of the proxy record for examples representing both the hockey stick and the MWP_LIA cyclic profiles respectively. In each case the forecasts show upward trends from 1880 AD onwards and are a good representation of the actual proxy temperature records.

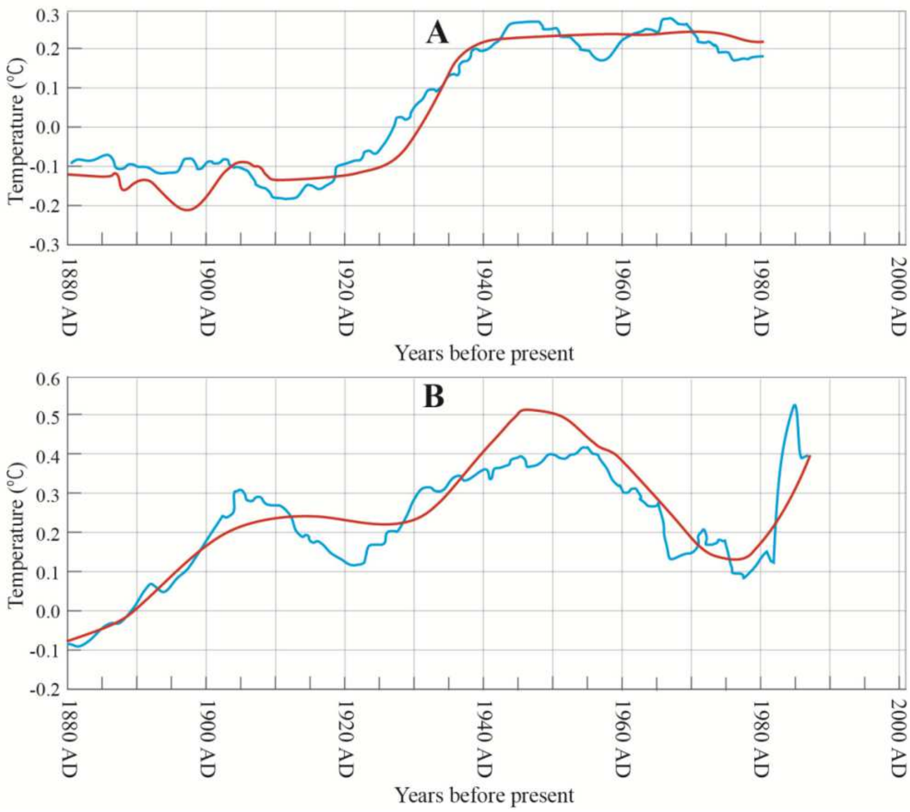


Figure 15. *Proxy temperature profile and forecast temperature profile using an ANN and sine wave data as input for A: Mann et al. [9]; B: Crowley and Lowery [47].*

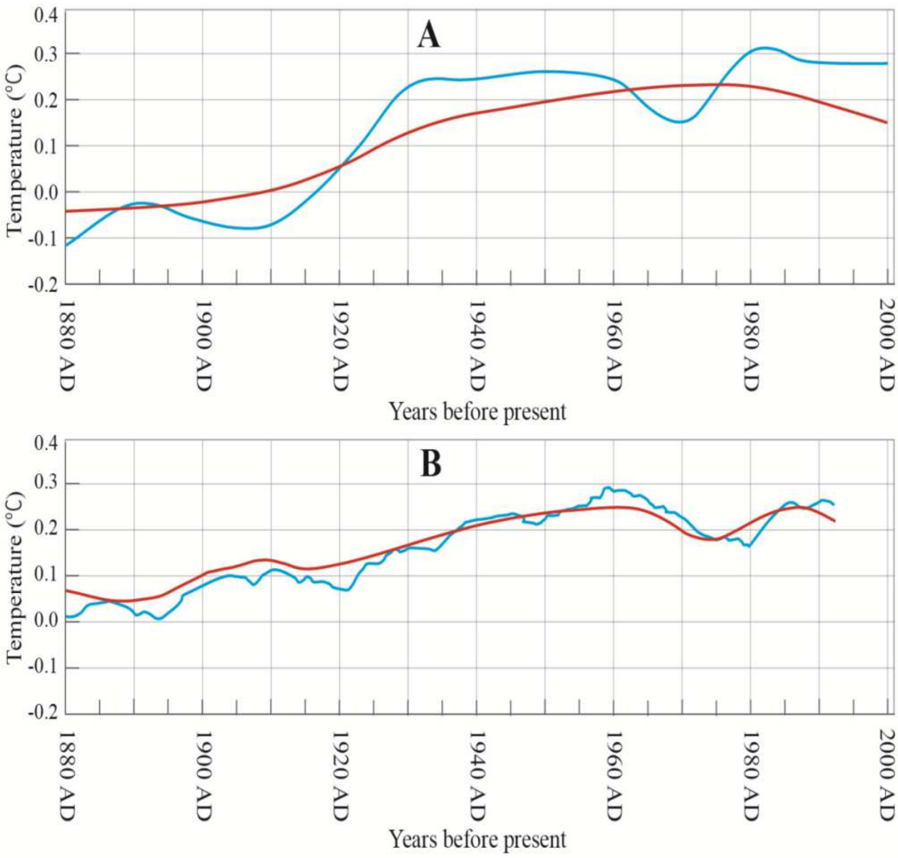


Figure 16. *Proxy temperature profile and forecast temperature profile using an ANN and sine wave data as input for A: Ljungqvist [6]; B: Esper et al. [49].*

4. Discussion

4.1. Oscillatory Cycles in Temperature Records

Oscillatory processes are an important feature of the earth's climate on a range of time frames including annual, decadal, centennial and millennial [58]. The presence of oscillatory processes is clearly evident from visual inspection of most proxy and instrumental temperature records. However, it may not be evident whether these are random oscillations or the combined effects of underlying sets of oscillations with persistent periodicities, amplitudes and phase relationships. The presence of persistent, defined oscillations has been found in both instrumental and proxy temperature records using spectral analysis [18]. For example, in an examination of tree-ring records over 1,300 years for the Gulf of Alaska [20] several multi-decadal oscillations were identified applying spectral analysis. Proxy records for surface temperatures of Greenland, extending back 4,000 years [51] and wavelet analysis showed the dominant periodic oscillations at millennial (1,130 years) and centennial (790-770 years, 560 years and 390-360 years) time frames. Most of the dominant oscillations identified by the wavelet analysis were found to be persistent with respect to strength and magnitude.

4.2. Millennial Scale Periodicities

Table 3 shows examples of millennial scale periodicities reported from studies of proxy temperature records. These can be compared with the range of millennial periodicities (978 - 1,306 years) identified in the present study.

Table 3. *Millennial scale periodicities in temperature proxy-records.*

Proxy	Periodicity (years)	Reference
Greenland ice sheet	1486, 1571	[59]
Multiproxy (non-tree-ring)	1681	[60]
Multiproxy	1152	[45]
Sea surface temperature	1408	[61]
Spleothem	1479	[62]
Japanese cedar tree rings	1230	[63]
Surface subpolar North Atlantic.	1527	[64]
Subpolar North Atlantic	1200	[65]
Indo-Pacific sea-surface temperature	1067	[66]
Antarctic ice cores	~1000	[33]
Greenland ice cores	1130	[51]
European lake sediment	~1000	[31]
Multiproxy study of the western Mediterranean	1430	[32]
Global	~1000	[18]

Millennial-scale climatic oscillations of ~1,470 years are evident in numerous palaeo-climatic records in the North Atlantic and Pacific [67 -71]. A study [72] discussed the existence of a ~ 1,470 year cycle in the context of climate change. Another [67] concluded from studies of the ratio of iron-stained to clean grains in ice-rafted debris in North Atlantic sediments, that climatic conditions have oscillated with an average period ~1,500 years over the past 100,000 years of the Holocene

4.3. Centennial Scale Periodicities

The present study shows the occurrence of centennial and multi-centennial oscillations for all eight proxy records examined in the range 106 to 538 years (Table 2). Many other studies have also reported centennial scale periodicities in temperature records. For example, periodicities of 208 and 521 years have been identified in Antarctic ice-core records [33]. European lake sediments [31] show the influences of 120, 208 and 500 year cycles, while the influence of ~200-year cycle on climate variations has been identified using results from the Central Asian Mountains [34] and cycles of 800, 199, and 110 years have been found in tree-rings of the Tibetan Plateau for the past 2,485 years [73].

Application of Fourier- and wavelet transforms as well as nonlinear optimization to sine functions showed the dominance of a ~200 year cycle considering northern hemispheric proxy data sets [74, 75]. There is evidence for centennial cycles in proxy temperature records worldwide ranging from Antarctica to Central Europe [76]. A harmonic analysis of worldwide temperature proxies for 2,000 years incorporating six previous global proxy temperature records reported centennial periodicities at ~460 years, and ~190 years [18].

For the southern hemisphere, a spectral analysis of a Tasmanian tree ring record of 3,592 years [77] found the reconstruction was dominated by oscillatory patterns of variability with centennial periods of 588 and 210-260 years.

4.4. Decadal Scale Periodicities

Many studies have shown the significance of decadal and multi-decadal oscillations on temperature. For example, one described the impact of North Atlantic-Arctic multi-decadal variability on northern hemisphere surface air temperatures [78]. The results stressed the potential importance of natural internal multi-decadal variability originating in the North Atlantic-Arctic sector in generating inter-decadal climate changes, not only on a regional scale, but also possibly on a hemispheric and even a global scale Another investigation [79] showed the need to incorporate natural oscillations such as the IPO to understand temperature variations in recent decades. Proxy reconstructions indicate substantial multi-decadal variability of the NAO over the past 1,000 years and longer [80] leading to the conclusion concluded that such NAO variations are likely to have altered the AMOC (Atlantic Meridional Overturning Circulation) and thereby influenced hemispheric-scale climate, in addition to the direct effect of NAO variations on atmospheric circulation and climate. Another study showed variations in NAO reconstructions for the past millennium using 48 proxy records [81]. The significance of decadal oscillations throughout the Holocene has been reviewed [4], including ENSO, PDV, AMV, the NAO, the SAM and the IOD. Temperature changes in Maine USA have been attributed to variations in the NAO and AMO over past 900 years [82].

For the Southern Hemisphere, a Tasmanian tree ring record of 3592 years has been studied [77] and spectral analysis of the temperature construction indicated that it is dominant by multi-decadal oscillatory patterns of variability with periods of 68-80 and 31 years.

4.5. Identifiable LIA, MWP, DA and RWP Features in Proxy Temperature Records and Geographical Distribution

A major point of contention that has arisen in considering whether Figure 1 or Figure 2 is a better representation of northern hemisphere temperatures is whether there are clearly identifiable MWP and LIA features in temperature records during the past 1000 years [83]. A review in 2003 of proxy climatic and environmental changes of the past 1000 years [84] examined more than 120 examples published between 1975 and 2002. These included regional and worldwide proxy records for both northern and southern hemispheres. A total of 107 studies indicated there was a discernible climatic anomaly during the MWP (800 AD-1300 AD) in the proxy record, whereas only 6 indicated this was absent. 123 studies indicated there an objectively discernible climatic anomaly during the LIA interval (1300 AD-1900 AD) in the proxy record, whereas only 1 reported this was absent.

Since 2003, there have been many additional proxy records published. For example, an examination of borehole data for Europe for the past 1000 years [85, 86] concluded this clearly showed MWP and LIA features, in contrast to findings of Mann et al. Another study [87] examined 59 individual proxy records including tree rings, lake sediments, marine sediments, glacier ice and spleothems extending back 2000 years for Alaska, Russia, Canada, Scandinavia and Greenland. These showed well-defined MWP, LIA, DA, and RWP features. A study reported reconstructions for Arctic Canada over past 2000 years showing MWP and LIA and RWP features [88]. Another [89] reported proxy-based temperature reconstruction for China during the Holocene exhibiting LIA, MWP and RWP features. Examination of sea surface temperatures from corals in the South China Sea over the past 1,000 years showed distinct MWP and LIA periods [90]. A study of temperatures from the Greenland Ice Sheet [91] showed a MWP and another warmer period 4,000-5,000 years ago

An investigation of the climate evolution of the last 2,700 years in the central - western Mediterranean Sea generated a reconstruction from marine sediment records by integrating planktonic foraminifera and geochemical signals [92]. The results provide the characterization of climatic phases including the RWP, DA, MWP and LIA. Evidence for the MWP and LIA is provided by a study of the Urals from 800 AD [93].

An extensive study [94] of the Mediterranean region with regard to the MWP examined trends from 79 published Mediterranean land and marine sites. It concluded that different regions have undergone warming or cooling during the past 150 years and attributed this to oscillatory patterns associated with AMO and NAO. They found that similar trends seem to have been developed during the MWP 1000-

1200 AD, when conditions in the Western Mediterranean are generally warm (and dry), while large parts of the Central and Eastern Mediterranean were cold.

A study of European summer land temperature anomalies since 800 AD and showed evidence for the MWP and LIA [2]. The results show that subcontinental regions may undergo multi-decadal (and longer) periods of sustained temperature deviations from the continental average, indicating that internal variability of the climate system is particularly prominent at subcontinental scales.

A study examined the MWP in Africa and Arabia and found evidence for both warming and cooling [95] based on temperature records from 44 published localities. The vast majority of available Afro-Arabian onshore sites suggest a warm MWP, with the exception of the southern Levant (Israel, Palestine, and Jordan) where the MWP appears to have been cold. MWP cooling has also been documented in many segments of the circum-Africa-Arabian upwelling systems. Another study [96] reported complimentary paleoclimate proxy data suggesting that the western North Atlantic region remained cool, whereas the eastern North Atlantic region was comparatively warmer during the MWP—a dipole pattern compatible with a persistent positive phase of the NAO.

4.6. Current Temperatures Compared to Proxy Records

Considering the eight proxy temperature records of the northern hemisphere in the present study, in Figures 7-14 only in the case of the Crowley and Lowery [47] in Figure 10 and Mann et al.[9] in Figure 11, representing hockey sticks, are temperatures during the current warm period the maximum reached. Considering Figures 10B and 11B it is significant that the maximum temperatures attained in the forecast exceed maximum temperatures between 1000 AD and 1900 AD. This implies that it may be an intrinsic property of the hockey stick profile, and the underlying properties generated by respective phase alignments that current temperature may exceed those of the past 1,000 years. As these forecasts are made on the basis of extension of natural cycles and relationships between them it is possible that the occurrence of maximum temperatures during the industrial era is natural and to be expected based on the oscillations incorporated.

4.7. Solar Origin of Oscillations

Some studies have concluded that the occurrence of the MWP and LIA are closely associated with the solar activity over the past 1,000 years through the effects of cosmic rays [97]. Other studies [98, 99] have discussed the connection of climate with cosmic rays and effects on cloud cover on time scales ranging from decadal to millennial.

Solar activity and its impact on the earth's climate are often related to Total Solar Irradiance (TSI), a measure of the total energy received from the sun at the top of the atmosphere [100, 101]. The absolute radiometers carried by satellites since the late 1970s have produced indisputable evidence that TSI varies systematically over the 11-year sunspot cycle [29], but it is difficult to explain how the apparent response to the sun, seen in many climate records, is directly attributable to these rather small changes in radiation. Evidence for a solar influence on the lower atmosphere has been reviewed [29] including consideration of mechanisms whereby the sun may produce more significant impacts than might be surmised from a simplistic consideration only of direct variations in the magnitude of TSI.

Studies [102] have found evidence for significant influence of decadal and multi-decadal oscillations particularly the AMO and the NAO changes on European temperatures during the past century. It was concluded that these oscillations are related to solar activity particular direct correlation with the solar 11-year Schwabe cycle. Relationships between solar activity and decadal oscillations such as PDO and NAO have been discussed [103].

Cross-wavelet correlations between the millennium-cycle components of sunspot number and the Earth's climate change remains both strong and stable during the past 8,640 years (6755 BC- 1885 AD) [104]. The Earth's climate indices exhibit the 1,000-year oscillation corresponding to solar activity which can be associated with the Eddy cycle [105]. Other studies [72] have discussed the existence of a ~1,470 year cycle of associated with climate change and the possible origins of the cycle, incorporating orbital, solar and lunar forcing.

4.8. Attribution of Warming to Natural and Anthropogenic Influences

The extent of relative attribution of warming during the industrial era to natural or anthropogenic influences is a complex issue that remains unresolved [106, 107]. It has been recognised that the inclusion of oscillatory processes is important when considering attribution [17, 108]. Some studies report that conclusions regarding the robustness of the finding that anthropogenic factors dominate are not affected by inclusion of oscillatory processes in climate models. However, these studies are often characterised by the limited selection of the short-term oscillatory processes that are included, often only decadal. For example some have included both the ENSO and the AMO [109], while others included only a single oscillation, the AMO [110].

Some investigations [111] have questioned the occurrence of dangerous anthropogenic warming upon recognition of the large amplitude of the natural 60-year cyclic component found to be at most 0.6 °C once the natural component has been removed. One study [112] found that half of the simulated global warming is caused by the increase of greenhouse gases (GHGs), while the increase of the weakly absorbed solar irradiance is responsible for approximately one third of the total warming and did not directly account for oscillatory processes. Another study [113] concluded that, contrary to what has become common place, there are mechanisms other than atmospheric carbon dioxide concentration, so that solar radiation and cosmic rays that may be largely responsible for the observed change in temperature.

A study [114] concluded that most of the temperature trends since at least 1881 AD can be explained in terms of solar variability, with atmospheric greenhouse gas concentrations providing at most a minor contribution. The IPCC 5th Assessment Report [11] concluded that solar activity related to TSI explains only a minor part of the temperature changes during the industrial era. However, others consider that direct changes in TSI may not fully represent impact of solar influences [29].

Figures 15 and 16 enable comparison between the actual proxy temperature and the corresponding temperatures forecast using sine wave decomposition up to 1880 AD followed by neural network forecasting. The forecast profiles generated in this way therefore represent the temperatures by extension of the patterns present prior to 1880 AD into the industrial era. This can be interpreted as the expected temperature profile in the absence of anthropogenic factors such as increasing greenhouse gases (GHGs). In each case, upward trajectory is apparent and does not suggest an increasing departure between forecast and actual proxy temperature with steadily increasing atmospheric GHG concentrations.

4.9. General Circulation Models and Oscillations

General circulation models (GCMs) are mathematical models extensively used to represent physical processes of the atmosphere and ocean and have been used to generate a response of global climate to increasing greenhouse gas emissions [115-122]. GCMs have been extensively used in attempts to differentiate between natural and anthropogenic global warming, for example in Eastern China [123]. GCMs have been used [124] to show that GHG forcing is the primary driver of the surface warming over land in arid and semi-arid regions of the globe between 1946 and 2005, and the contribution from natural influences is negligible. Studies using GCMs [125] concluded that the observed warming over northern South America 1983-2012 has an anthropogenic origin. In another investigation with GCMs [126] it was concluded that anthropogenic influences are responsible for 0.3-0.5°C per century warming during the 20th century.

Several recent GCM studies have attempted to address perceived shortcomings by incorporating natural oscillations. However, these studies are usually limited to consideration of one or several identified natural oscillations such as the AMO, NAO and PDO that operate on decadal or multi-decadal time scales. Studies have been carried out [127] using GCMs and oscillatory processes to evaluate the relative contributions natural and anthropogenic influences on temperatures during the period 1970-2005. Natural influences were represented by AMO contributed warming between 0.13 and 0.20°C compared to the GHG contribution of 0.49-0.58°C. Another study [21] found that up to 0.5°C of the observed warming trend may be associated with low frequency variability of the climate such as that represented by the PDO and NAO. Overall, the influence of both anthropogenic and natural external forcing is clearly evident in Canada-wide mean and extreme temperatures. An examination of instrumental temperatures during the past century [128] found that GCMs are limited in not incorporating oscillatory modes over the past 100 years. New models were developed based on GCMs incorporating known oscillatory patterns including AMO, IPO, and ENSO. It was concluded that both GHGs and natural oscillation important, but the effects of GHGs dominate.

The present analysis shows that. in considering natural oscillations, decadal oscillations probably play a minor role compared to millennial and centennial oscillations, so that GCMs probably continue to underestimate of the contribution of natural oscillations that are apparent when considering time-scales of 1,000-2,000 years.

4.10. Ongoing Debate and Possible Resolution

Following the publication of MBH 1998 and 1999 there has been intense and ongoing debate, both within the scientific community and outside, regarding the validity of the hockey stick, and the implications that would follow from its general acceptance. Several investigations [12-15] have concluded that the methods applied would produce biased reconstructions with underestimated variability particularly in regard to lower frequencies. It has been concluded [129] that the "hockey stick" shape derived in the MBH98 proxy construction was primarily an artefact of poor data handling, obsolete data and incorrect calculation of principal components, although these criticisms have been comprehensively refuted [16].

Mann et al. have produced updated reconstructions of Earth's surface temperature for the past two millennia using a more diverse dataset that was significantly larger than the original tree-ring study, with more than 1,200 proxy records [130]. They used two complementary methods, both of which resulted in a similar "hockey stick" graph, with recent increases in northern hemisphere surface temperatures anomalous relative to at least the past 1,300 years. Mann is quoted as saying, "Ten years ago, the availability of data became quite sparse by the time you got back to 1,000 AD, and what we had then was weighted towards tree-ring data; but now you can go back 1,300 years without using tree-ring data at all and still get a verifiable conclusion." [131].

It has been noted [132] that over two dozen large-scale climate reconstructions had been published, showing a broad consensus that there had been exceptional 20th century warming after earlier climatic phases, notably the MWP and LIA. However, there were still issues of large-scale natural variability to be resolved, especially for the lowest frequency variations, stressing the need for further research [132]. The study concluded that there is now broad recognition of the importance of preserving all possible climatic frequencies in proxy data and reconstructions, and that this is a step forward to simply using data that have likely not preserved low-frequency signals.

An extensive review [37] of large-scale temperature reconstructions of the past two millennia has been presented particularly relating to the variations in the methodologies for generating the types of proxy records reported in the literature, including those used in the present study. The different types of proxy records (historical documentary records, tree rings, ice cores, spleothems, terrestrial sediments, marine sediments, pollen, boreholes) were reviewed with particular emphasis on the possible limitations in their ability to capture low-frequency temperature information. The inherent complexity of the task is discussed with regard to many different factors that can influence the form of the resultant multi-proxy record including: influence of number and positions of proxies; reconstruction methods; temperature proxy records and their limitations; influence of noisy proxies.

The apparent dichotomy between the types of multi-proxy temperature record may be a result of differences in reconstruction methods and selection of proxy records to be included [37]. It may also be explained in terms of the results of spectral analysis as shown in the present study.

Both the MWP_LIA cycle and hockey stick profiles ca be interpreted as being based on a dominant millennial oscillation in the range 978-1,306 years. Superimposed on this millennial oscillation are sets of centennial and decadal oscillations. The resultant effect of the centennial and decadal oscillations is significantly characterised by the phase shifts with respect to the millennial oscillation. In some cases, this reinforces the shape of millennial oscillation so that the distinctive MWP peak and trough of the LIA remain clearly apparent, are shown as in Figure 13C. In other cases, the resultant tends to counteract the peak and trough of the millennial oscillation, thereby flattening the appearance of downward trajectory between 1000 AD and 1850 AD and then reinforcing the rate of rapid warming from 1850 AD onwards, as illustrated in Figure 12C. Different regions can experience warming or cooling at a particular time as found for the Mediterranean during the MWP [95]. In a review of proxy temperature reconstructions over the past two millennia, [37] it was concluded that correlations between local temperatures and the northern hemisphere mean temperature are strongly geographically dependent. In particular, they found that the eastern Pacific and the northern North Atlantic show weak correlations with the northern hemisphere mean while the interior of the continents show strong correlations. This may result in differences in phase alignment between the dominant millennial oscillation and centennial /decadal oscillations in different geographical locations. Therefore selection of proxy records weighted towards particular regions could introduce a bias towards a hockey stick or MWP_LIA cycle, enabling both to co-exist.

5. Conclusions

The presence of oscillatory characteristics within proxy-temperature reconstructions across a range of time-scales, including millennial, centennial and decadal, has been reported in many investigations. The present study examines oscillations from spectral analysis applied to eight published multi-proxy temperature records, including examples representing both hockey stick and MWP_LIA cycles. The analysis shows that each record can be represented by a set of 4-11 sine curves from spectral analysis that include a dominant millennial oscillation and several centennial and decadal oscillations. The apparent divergence into either a hockey stick or MWP_LIA cycles can be derived from the phase alignment of the centennial and decadal oscillations with respect to the millennial oscillation. The maximum temperature of the dominant oscillation at around 1000 AD is increased by superimposing the centennial/decadal oscillations for MWP-LIA cycles, whereas it is reduced and the profile flattened for the hockey stick. This may explain why current temperatures may exceed any in past 1,000 years with hockey stick profile.

Forecasting through projection of pre-industrial temperature oscillatory patterns beyond 1880 AD by applying spectral analysis to generate input to train ANNs show that current atmospheric temperatures can be largely explained on basis of continuation of natural oscillations. This is the case irrespective of whether the hockey stick or MWP_LIA cycles are operative. This process could give rise to temperatures higher that past 1000 years without major contribution from anthropogenic influences.

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References

[1] Jones, P. D., Early European Instrumental Records, in: Jones, P. D., Ogilvie, A. E. J., Davies, T. D., Briffa, K. R. (Eds.), History and Climate: Memories of the Future? Springer US, Boston, MA, 2001, 55-77.

[2] Luterbacher, J., Werner, J. P., Smerdon, J. E., Fernández-Donado, L., González-Rouco, F. J., Barriopedro, D., Ljungqvist, F. C., Büntgen, U., Zorita, E., Wagner, S., Esper, J., McCarroll, D., Toreti, A., Frank, D., Jungclaus, J. H., Barriendos, M., Bertolin, C., Bothe, O., Brázdil, R., Camuffo, D., Dobrovolný, P., Gagen, M., García-Bustamante, E., Ge, Q., Gómez-Navarro, J. J., Guiot, J., Hao, Z., Hegerl, G. C., Holmgren, K., Klimenko, V. V., Martín-Chivelet, J., Pfister, C., Roberts, N., Schindler, A., Schurer, A., Solomina, O., Gunten, L., von, Wahl, E., Wanner, H., Wetter, O., Xoplaki, E., Yuan, N., Zanchettin, D., Zhang, H., Zerefos, C., European summer temperatures since Roman times. Environ. Res. Lett. 2016, 11.

[3] Parker, D. E., Legg, T. P., Folland, C. K., A new daily central England temperature series, 1772-1991. International Journal of Climatology 1992, 12, 317-342.

[4] Hernández, A., Martin-Puertas, C., Moffa-Sánchez, P., Moreno-Chamarro, E., Ortega, P., Blockley, S., Cobb, K. M., Comas-Bru, L., Giralt, S., Goosse, H., Luterbacher, J., Martrat, B., Muscheler, R., Parnell, A., Pla-Rabes, S., Sjolte, J, Scaife, A. A., Swingedouw, D., Wise, E., Xu, G., Modes of climate variability: Synthesis and review of proxy-based reconstructions through the Holocene. Earth-Science Reviews 2020, 209, 103286.

[5] Trachsel, M.. Grosjean, M., Larocque-Tobler, I., Schwikowski, M., Blass, A., Sturm, M., Quantitative summer temperature reconstruction derived from a combined biogenic Si and chironomid record from varved sediments of Lake Silvaplana (south-eastern Swiss Alps) back to AD 1177. Quaternary Science Reviews 2010, 29, 2719-2730.

[6] Ljungqvist, F. C., A new reconstruction of temperature variability in the extra-tropical Northern Hemisphere during the last two millennia. Geografiska Annaler: Physical Geography 2010, 92 A (3), 339-351.

[7] Folland, C. K., Karl, T., Vinnikov, K. YA., IPCC First Assessment Report. Chapter 7. Observed Climate Variations and Change, 1990, 195-238.

[8] Mann, M. E., Bradley, R S., Hughes, M. K., Global-scale temperature patterns and climate forcing over the past six centuries. Nature 1998, 392 (6678), 779-787.

[9] Mann, M. E., Bradley, R S., Hughes, M. K., Northern hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations. Geophysical Research Letters 1999, 26 (6), 759-762.

[10] IPCC Third Assessment Report, Summary for policymakers 2001.

[11] Masson-Delmotte, V., Schulz, M. Abe-Ouchi, A., Beer, J., Ganopolski, A., González Rouco J. F., Jansen, E., Lambeck, K., Luterbacher, J., Naish,. T., Osborn, T., Otto-Bliesner, B., Quinn, T., Ramesh, R., Rojas, M., Shao X., Timmermann, A., 2013. Information from Paleoclimate Archives. In: 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., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex V., Midgley P. M. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[12] Zorita, E., González-Rouco, F., Legutke, S., Testing the Mann et al. (1998) approach to paleoclimate reconstructions in the contextof a 1000-year control simulation with the ECHO-G coupled climate model, Journal of Climate 2003, 16, 1378-1390.

[13] von Storch, H., Zorita, E., Jones, J. M., Dimitriev, Y., González-Rouco, F., Tett, S. F. B., Reconstructing Past Climate from Noisy Data", Science 2004, 306, 679-882.

[14] Bürger, G., Fast, I., Cubasch U., Climate reconstruction by regression—32 variations on a theme, Tellus A 2006, 58, 227-235.

[15] Zorita, E., González-Rouco, F., von Storch, H., Comments on "Testing the fidelity of methods used in proxy-base reconstructions of past climate". Journal of Climate 2007, 20, 3693-3698.

[16] Wahl, E. R., Ammann, C. M., Robustness of the Mann, Bradley, Hughes reconstruction of Northern Hemisphere surface temperatures: Examination of criticisms based on the nature and processing of proxy climate evidence. Climatic Change 2007, 85 (1-2), 33-69.

[17] North, G. R., Apportioning natural and forced components in climate change. Proceedings of the National Academy of Sciences of the United States of America, 2012, 109 (36), 14285-14286.

[18] Lüdecke, H. J., Weiss, C. O., Harmonic Analysis of Worldwide Temperature Proxies for 2000 Years. The Open Atmospheric Science Journal 2017, 11, 44-53.

[19] Abbot, J., Marohasy, J., The application of machine learning for evaluating anthropogenic versus natural climate change, GeoResJ, 2017, 14, 36-46.

[20] Wilson, R., Wiles, G., D'Arrigo, R., Zweck, C., Cycles and shifts: 1,300 years of multi-decadal temperature variability in the Gulf of Alaska. Climate Dynamics 2007, 28, 425-440.

[21] Wan, H., Zhang, X., Zwiers, F., Human influence on Canadian temperatures, Climate Dynamics 2019, 52, 479-494.

[22] Mann, M. E., Steinman, B. A., Miller, S. K., Absence of internal multidecadal and interdecadal oscillations in climate model simulations. Nature Communications 2020, 11, 49.

[23] Ge, Q., Hao, Z., Zheng, J., Shao, X., Temperature changes over the past 2000 years in China and comparison with the Northern Hemisphere. Climate of the Past 2013, 9, 1153-1160.

[24] van der Bilt, W. G. M., D'Andrea, W. J., Werner, J. P., Bakke, J., Early Holocene temperature oscillations exceed amplitude of observed and projected warming in Svalbard lakes. Geophysical Research Letters 2019, 46, 14,732-14,741.

[25] Scafetta, N., Discussion on climate oscillations: CMIP5 general circulation models versus a semi-empirical harmonic model based on astronomical cycles. Earth-Science Reviews 2013, 126, 321-357.

[26] Scafetta, N., On the reliability of computer-based climate models. Italian Journal of Engineering Geology and Environment 2019, 1, 49-70.

[27] de Larminat. P., Earth climate identification vs. anthropic global warming attribution. Annual Reviews in Control 2016, 42, 114-125.

[28] Haigh, J. D., The impact of solar variability on climate. Science 1996, 272, 981-985.

[29] Haigh, J. D., The Sun and the Earth's Climate. Living Reviews in Solar Physics 2007, 4, 1-63.

[30] Gray, L. J., Beer, J., Geller, M., Geller, M., Haigh, J. D., Lockwood, M., Matthes, K., Cubasch, U., Fleitmann, D., Harrison, G., et al.. Solar influences on climate. Reviews of Geophysics 2010, 48, RG4001.

[31] Kern, A. K., Harzhauser, M., Piller, W. E., Mandic, O., Soliman, A., Strong evidence for the influence of solar cycles on a Late Miocene lake system revealed by biotic and abiotic proxies, Palaeogeography. Palaeoclimatology, Palaeoecology 2012, 329-330, 124-136.

[32] Ramos-Román, M, J., Jiménez-Moreno G., Camuera J., García-Alix, A,, Anderson R. S., Jiménez-Espejo, F. J., Sachse, D., Toney, J., Carrión, J. S., Webster, C. Y., Yanes, C., Millennial-scale cyclical environment and climate variability during the Holocene in the western Mediterranean region deduced from a new multiproxy analysis from the Padul record (Sierra Nevada, Spain). Global and Planetary Change 2018, 168, 35-53.

[33] Zhao, X. H., Feng, X. S., Correlation between solar activity and the local temperature of Antarctica during the past 11,000 years. Journal of Atmospheric and Solar-Terrestrial Physics 2015, 122, 26-33.

[34] Raspopov, O. M., Dergachev V. A., Esper J., Kozyreva, O. V., Frank, D., Ogurtsov, M., Kolström, T., Shao, X., The influence of the de Vries (~200-year) solar cycle on climate variations: Results from the Central Asian Mountains and their global link. Palaeogeography, Palaeoclimatology, Palaeoecology 2008, 259, 6-16.

[35] De Vries, H., Variation in concentration of radiocarbon with time and location on Earth, K. Ned. Akad. Van. Wet.-B, 1958, 61, 94-102.

[36] Suess, H. E., The radiocarbon record in tree rings of the last 8000 years. Radiocarbon 1980, 22, 200-209, 280.

[37] Christiansen, B., Ljungqvist, F. C., Challenges and perspectives for large-scale temperature reconstructions of the past two millennia. Reviews of Geophysics 2017, 55, 40-96.

[38] National Oceanic and Oceanic Administration, National Centres for Environmental Information. Paleoclimatology Data https://www.ncdc.noaa.gov/data-access/paleoclimatology-data

[39] Darji, M. P., Dabhi, V., Harshadkumar B. P. Rainfall forecasting using neural network: a survey. International conference on advances in computer engineering and applications (ICACEA). 2015.

[40] Nayak, D. R., Mahapatra, A., Mishra, P., A survey on rainfall prediction using artificial neural network. International Journal of Computer Applications 2013, 72 (16), 32-40.

[41] Yadu, A. K., Shrivastava, G., Application of Neural Network in Drought Forecasting; An Intense Literature Review, International Journal of Computer Engineering and Technology 2019, 10 (2), 180-195.

[42] Abbot, J, Marohasy J., Application of artificial neural networks to rainfall forecasting in Queensland, Australia. Advances in Atmospheric Science 2012, 29 (4), 717-730.

[43] Abbot, J., Marohasy J., Input selection and optimisation for monthly rainfall forecasting in Queensland, Australia, using artificial neural networks. Atmospheric Research 2014, 138, 166-178.

[44] Specht, D. F., A general regression neural network. IEEE Transactions on Neural Networks and Learning Systems 1991, 2 (6), 568-76.

[45] Moberg, A., Sonechkin, D. M., Holmgren, K., Datsenko, N. M., Karlen, W., Lauritzen, S. E., Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data. Nature 2005, 433 (7026), 613-617.

[46] Christiansen, B., Ljungqvist F. C., The extra-tropical Northern Hemisphere temperature in the last two millennia: reconstructions of low-frequency variability. Climate of the Past 2012, 8, 765-786.

[47] Crowley, T. J., Lowery T., How warm was the Medieval Warm Period? Ambio 2000, 29, 51-54.

[48] Jones, P. D., Briffa, K. R., Barnett, T. P., Tett, S. F. B., High-resolution Palaeoclimatic Records for the last Millennium: Interpretation, Integration and Comparison with General Circulation Model Control-run Temperatures. The Holocene 1998, 8, 455-471.

[49] Esper, J., Cook, E. R., Schweingruber, F. H., Low-Frequency Signals in Long Tree-Ring Chronologies for Reconstructing Past Temperature Variability. Science 2002, 295, 5563.

[50] Schneider, L, Smerdon, J. E., Buntgen, U., Wilson, R. J. S., Myglan, V. S., Kirdyanov, A. V., Esper, J., Revising mid-latitude summer temperatures back to A. D. 600 based on a wood density network. Geophysical Research Letters 2015, 42, 4556-4562.

[51] Humlum, O, Solheim, J-E, Stordahl, K., Identifying natural contributions to late Holocene climate change. Global and Planetary Change 2011, 79, 145-156.

[52] Easterbrook, D. J.,. in Evidence-Based Climate Science (Second Edition), Using Patterns of Recurring Climate Cycles to Predict Future Climate Changes 2016.

[53] Jain A., Kumar A. M., Hybrid neural network models for hydrologic time series forecasting. Applied Soft Computing 2007, 7, 585-592.

[54] Zhang G. P., Neural Networks for Time-Series Forecasting. In: Rozenberg G., Bäck T., Kok J. N. (eds) Handbook of Natural Computing. Springer, Berlin, Heidelberg, 2012.

[55] Remus, W., O'Connor M., Neural networks for time series forecasting. In: Armstrong, J. S. (ed) Principles of forecasting: a handbook for researchers and practitioners. International Series in Operations Research & Management Science, vol 30. Springer, Boston, MA. 2001.

[56] Abbot, J., Marohasy J., Skilful rainfall forecasts from artificial neural networks with long duration series and single-month optimization. Atmospheric Research 2017, 197, 289-299.

[57] Abbot, J., Marohasy J., Forecasting Monthly Rainfall in the Western Australian Wheat-belt up to 18 months in Advance Using Artificial Neural networks. Lecture Notes in Artificial Intelligence 2016, 9992, 71-87.

[58] Bathiany, S., Scheffer, M., van Nes, E. H., Williamson M. S., T. M. Lenton, T. M.. Abrupt Climate Change in an Oscillating World. Scientific Reports 2018, 8, 5040.

[59] Loehle, C., Singer F., Holocene temperature records show millennial-scale periodicity. Canadian Journal of Earth Sciences 2010, 47, 1327-1336.

[60] Loehle, C., A 2000-year global temperature reconstruction on non-tree ring proxies. Energy and Environment 2007, 18 (7), 1049-1058.

[61] Sicre, M.-A., Jacob, J., Ezat, U., Rousse, S., Kissel, C., Yiou, P., Eiríksson, J., Knudsen, K. L., Jansen E., Turon J. L., Decadal variability of sea surface temperatures off North Iceland over the last 2000 years. Earth and Planetary Science Letters 2008, 268 (1-2), 137-142.

[62] Mangini, A., Verdes, P., Spotl, C., Scholz, D., Vollweiler, N., Kromer, B., Persistent influence of the North Atlantic hydrography on central European winter temperature during the last 9000 years. Geophysical Research Letters 2007, 34 (2), L02704.

[63] Kitagawa, H., Matsumoto, E. Climatic implication of d13C variations in a Japanese cedar (*Cryptomeria japonica*) during the last two millennia. Geophysical Research Letters 1995, 22 (16), 2155-2158.

[64] Thornalley, D. J. R., Elderfield, H., McCave, I. N., Holocene oscillations in temperature and salinity of the surface subpolar North Atlantic. Nature 2009, 457 (7230), 711-714.

[65] Came, R. E., Oppo, D. W., McManus, J. F., Amplitude and timing of temperature and salinity variability in the subpolar North Atlantic over the past 10 ky. Geology 2007, 35 (4), 315-318.

[66] Oppo, D. W., Rosenthal, Y., Linsley, B. K., 2,000-year long temperature and hydrology reconstructions from the Indo-Pacific warm pool. Nature 2009, 460 (7259), 1113-1116.

[67] Bond, G. C., Showers, W., Elliot, M., Evans, M., Lotti, R., Hajdas, I., Bonani, G., Johnson, S., The north atlantic's 1-2 kyr climate rhythm: relation to Heinrich events, Dansgaard/Oeschger cycles and the little ice age, in: Mechanisms of Global Climate Change at Millennial Time Scales, American Geophysical Union, 2013.

[68] Braun, H., Christl, M., Rahmstorf, S., Ganopolski, A., Mangini, A., Kubatzki, C., Roth, K., Kromer, B., Possible solar origin of the 1470 year glacial climate cycle demonstrated in a coupled model. Nature 2005, 438, 208-211.

[69] Schulz, M., On the 1470 year pacing of Dansgaard-Oeschger warm events, Paleoceanography, 2002, 17 (2), 1014.

[70] Turney, C S. M., Kershaw, A. P., Clemens, S. C., Branch, N., Moss, P. T., Keith Fifield, L., Millennial and orbital variations of El Nino/Southern Oscillation and high-latitude climate in the last glacial period. Nature, 2004, 428, 306-310.

[71] De Menocal, P., Ortiz, J., Guilderson, T., Sarnthein, M., Coherent high- and low-latitude climate variability during the Holocene warm period, Science 2000, 288, 2198-2202.

[72] Kelsey, A. M., Menk, F. W., Moss P. T., An astronomical correspondence to the 1470 year cycle of abrupt climate change. Climate of the Past Discussions 2015, 11, 4895-4915.

[73] Liu, Y., Cai, Q., Song, H., An, Z., Linderholm, H. W., Amplitudes, rates, periodicities and causes of temperature variations in the past 2485 years and future trends over the central eastern Tibetan Plateau, Chinese Science Bulletin 2011, 56, 2986-2994.

[74] Lüdecke, H. J, Weiss, C. O., Hempelmann, A., Paleoclimate forcing by the solar de Vries / Suess cycle. Climate of the Past Discussions 2015, 11, 279-305.

[75] Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D., Trouet, V., Kaplan, J. O., Herzig, F., Heussner, K.-U., Wanner, H., Luterbacher, J., Esper, J.,. 2500 years of European climate variability and human susceptibility. Science 2011, 331, 578-582.

[76] Lüdecke, J. J., Weiss, C. O., Zhao X., Feng X. Centennial Cycles Observed in Temperature Data from Antarctica to Central Europe. Polarforschung 2015, 85 (2), 179-181.

[77] Cook, E. R., Buckley, B. M., D'Arrigo, R. D., Peterson, M. J., Warm-season temperatures since 1600 BC reconstructed from Tasmanian tree rings and their relationship to large-scale sea surface temperature anomalies. Climate Dynamics 2000, 16, 79-91.

[78] Semenov, V. A., Latif, M., Dommenget, D., Keenlyside, N. S., Strehz, A., Martin, T, Park W., The impact of North Atlantic-Arctic multidecadal variability on Northern Hemisphere surface air temperature. Journal of Climate 2010, 23, 5668-5677.

[79] Dai, A., Fyfe, J. C., Xie, S. P., Dai, X., Decadal modulation of global surface temperature by internal climate variability. Nature Climate Change 2015, 5, 555-559.

[80] Delworth, T. L., Zeng, F., Vecchi, G. A., Yang, X., Zhang L., Zhang, R., The North Atlantic Oscillation as a driver of rapid climate change in the Northern Hemisphere. Nature Geoscience 2016, 9, 509-513.

[81] Ortega, P. et al. Swingedouw, D., Masson-Delmotte, V., Raible, C. C., Casado, M., Yiou, P., A model-tested North Atlantic Oscillation reconstruction for the past millennium. Nature 2015, 523, 71-74.

[82] Miller, D. R., Habicht, M. H., Keisling, B. A., Castañeda I. S., Bradley, R. S.,. A 900-year New England temperature reconstruction from in situ seasonally produced branched glycerol dialkyl glycerol tetraethers (brGDGTs). Climate of the Past 2018, 14, 1653-1667.

[83] Broecker, W. S.,. Paleoclimate: Was the Medieval Warm Period Global? Science 2001, 291 (5508), 1497-1499.

[84] Soon, W., Baliunas, S.,. Proxy climatic and environmental changes of the past 1000 years, Climate Research 2003, 23, 89-110.

[85] Dergachev, V. A., Raspopov. O. M., Reconstruction of the Earth's Surface Temperature Based on Data of Deep Boreholes, Global Warming in the Last Millennium, and Long Term Solar Cyclicity. Part 2. Experimental Data Analysis. Geomagnetism and Aeronomy 2010, 50 (3), 393-402.

[86] Dergachev, V. A., Raspopov, O. M., Reconstruction of the Earth's Surface Temperature Based on Data of Deep Boreholes, Global Warming in the Last Millennium, and Long Term Solar Cyclicity. Part 1. Experimental Data. Geomagnetism and Aeronomy 2010, 50 (3), 383-392.

[87] McKay, N. P., Kaufman, D. S., An extended Arctic proxy temperature database for the past 2,000 years. Scientific Data 2014, 1, 140026.

[88] Auger, J. D., Mayewski, P. A., Maasch, K. A., Schuenemann, K. C., Carleton, A. M,, Birkel, S. D., Saros, J. E., 2000 years of North Atlantic-Arctic climate. Quaternary Science Reviews 2019, 216, 1-17.

[89] Pei, Q., Zhang, D. D., Li J., Fei, J., Proxy-based temperature reconstruction in China for the Holocene. Quaternary International 2019, 521, 168-174.

[90] Deng, W., Liu, X., Chen, X., Wei, G., Zeng, T., Xie, L., Zhao, J. X.,. A comparison of the climates of the Medieval Climate Anomaly, Little Ice Age, and Current Warm Period reconstructed using coral records from the northern South China Sea. Journal of Geophysical Research: Oceans 2017, 122, 264-275.

[91] Dahl-Jensen, D., Mosegaard, K., Gundestrup, N., Clow, G D., Johnsen, S J., Hansen A. W., Balling, N., Past Temperatures Directly from the Greenland Ice Sheet, Science 1998, 282, 268-271.

[92] Margaritelli, G., Cisneros M., Cacho I., Capotondi L., Vallefuoco M., Rettori R., Lirer F., Climatic variability over the last 3000 years in the central - western Mediterranean Sea (Menorca Basin) detected by planktonic foraminifera and stable isotope records. Global and Planetary Change 2018, 169, 179-187.

[93] Demezhko, Y. D., Golovanova, I. V., Climatic Changes in the Urals over the Past Millennium—an Analysis of Geothermal and Meteorological Data. Climate of the Past 2007, 3, 237-242.

[94] Lüning, S., Schulte, L., Garcés-Pastor, S., Danladi, I. B., Gałka, M., The Medieval Climate Anomaly in the Mediterranean region. Paleoceanography and Paleoclimatology 2019, 34 (10), 1625-1649.

[95] Lüning, S., Gałka, M., Vahrenholt, F., Warming and cooling: The Medieval Climate Anomaly in Africa and Arabia. Paleoceanography 2017, 32, 1219-1235.

[96] Young, N E., Schweinsberg, A D., Briner, J P., Schaefer, J M., Glacier maxima in Baffin Bay during the Medieval Warm Period coeval with Norse settlement. Science Advances 2015, 1: e1500806.

[97] Huang, J. B., Wang, S. W., Luo, Y., Zhao Z. C., Wen, X-Y,, Debates on the causes of global warming. Advances in Climate Change Research 2012, 3 (1), 38-44.

[98] Usoskin, I. G., Kovaltsov, G. A., Cosmic rays and climate of the Earth: Possible connection. Comptes Rendus Geoscience 2008, 340, 441-450.

[99] Kikby, J., Cosmic rays and climate. Surveys in Geophysics 2007, 28, 333-375.

[100] Dergachev, V. A., Volobuev D. M., Solar Radiation Change and Climatic Effects on Decennial-Centennial Scales Geomagnetism and Aeronomy 2018, 58 (8), 1042-1049.

[101] Georgieva, K., Nagovitsyn, Yu, Kirov. B., Reconstruction of the Long Term Variations of the Total Solar Irradiance from Geomagnetic Data. Geomagnetism and Aeronomy 2015, 55 (8), 1026-1032.

[102] Lüdecke, H. J., Cina, R., Dammschneider, H-J., Lüning, S., Decadal and multidecadal natural variability in European temperature. Journal of Atmospheric and Solar-Terrestrial Physics 2020, 205, 105294.

[103] van Geel B., Ziegler P. A., 2013. IPCC Underestimates the Sun's role in Climate Change. Energy & Environment 24 (3&4), 432-453.

[104] Zhao, X., Soon W., Velasco Herrera, V. M., Evidence for Solar Modulation on the Millennial-Scale Climate Change of Earth. Universe 2020, 6, 153.

[105] Eddy, J. A., The Maunder minimum. Science 1976, 192, 1189-1202.

[106] Vitale D., Bilancia, M., Role of the natural and anthropogenic radiative forcings on global warming: evidence from cointegration-VECM analysis. Environmental and Ecological Statistics 2013, 20, 413-444.

[107] Joos, F. and Spahni. R., Rates of Change in Natural and Anthropogenic Radiative Forcing over the Past 20,000 Years. Proceedings of the National Academy of Sciences of the United States of America 2008, 105, 1425-1430.

[108] Swanson, K. L., Sugihara, G., Tsonis A. A., May. R., Long-Term Natural Variability and 20th Century Climate Change. Proceedings of the National Academy of Sciences of the United States of America 2009, 106 (38), 16120-16123.

[109] Imbers, J., Lopez, A., Huntingford, C., Allen, M. R., Testing the robustness of the anthropogenic climate change detection statements using different empirical models. Journal of Geophysical Research: Atmospheres 2013, 118, 3192-3199.

[110] Mokhova I. I., Smirnov D. A., Estimating the Contributions of the Atlantic Multidecadal Oscillation and Variations in the Atmospheric Concentration of Greenhouse Gases to Surface Air Temperature Trends from Observations. Doklady Earth Sciences 2018, 480 (1), 602-606.

[111] Gervais F., Anthropogenic CO_2 warming challenged by 60-year cycle. Earth-Science Reviews, Earth-Science Reviews 2016, 155, 129-135.

[112] Egorova, T., Rozanov, E., Arsenovic, P., Peter, T. and Schmutz, W., Contributions of Natural and Anthropogenic Forcing Agents to the Early 20th Century Warming, Frontiers in Earth Science, 2018, 6, Article 206.

[113] Florides, G., Christodoulides P., Messaritis V., Global Warming: CO_2 vs Sun, Global Warming, Stuart Arthur Harris (Ed.), 2010, ISBN: 978-953-307-149-7, InTech, http://www.intechopen.com/books/global-warming/global-warming-co2-vs-sun

[114] Soon, W., Connolly, R., Connolly, M., Re-evaluating the role of solar variability on Northern Hemisphere temperature trends since the 19th Century. Earth Science Reviews 2015, 150, 409-452.

[115] Nozawa, T., Nagashima, T., Shiogama, H., Crooks, S. A., Detecting natural influence on surface air temperature change in the early twentieth century. Geophysical Research Letters 2005, 32, L20719.

[116] Wen, Q. H., Zhang, X., Xu, Y., Wang B., Detecting human influence on extreme temperatures in China Geophysical Research Letters 2013, 40, 1171-1176.

[117] Tett, S. F. B., Betts, R., Crowley, T. J. Gregory, J., Johns, T. C., Jones, A., Osborn, T. J., Ostrom, E., Roberts, D. L., Woodage, M. J., The impact of natural and anthropogenic forcings on climate and hydrology since 1550. Climate Dynamics 2007, 28, 3-34.

[118] Hegerl, G., Luterbacher, J., González-Rouco, F., Tett, S. F. B., Crowley, T., Xoplaki, E., Influence of human and natural forcing on European seasonal temperatures. Nature Geoscience 2011, 4, 99-103.

[119] Santer, B. D., Painter, J. F., Bonfils, C., Mears, C. A., Solomon, S., Wigley, T. M. L., Gleckler, P. J., Schmidt, G. A,. Doutriaux, C., Gillett, N. P., Taylor, K. E., Thorne, P. W., Wentz, F. J., Human and natural influences on the changing thermal structure of the atmosphere. Proceedings of the National Academy of Sciences of the United States of America 2013, 110 (43), 17235-17240.

[120] Zorita, E., Gonzalez-Rouco, J. F., von Storch, H., Montavez, J. P., Valero. F., Natural and anthropogenic modes of surface temperature variations in the last thousand years Geophysical Research Letters 2005, 32, L08707.

[121] Shiogama, H., Nagashima, T., Yokohata, T., Crooks, S. A., Nozawa, T., Influence of volcanic activity and changes in solar irradiance on surface air temperatures in the early twentieth century. Geophysical Research Letters 2006, 33, L09702.

[122] Zhou, L., Dickinson, R. E., Dai, A., Dirmeyer, P., Detection and attribution of anthropogenic forcing to diurnal temperature range changes from 1950 to 1999: comparing multi-model simulations with observations. Climate Dynamics 2010, 35, 1289-130.

[123] Li, L., Wang B., Zhou T., Contributions of natural and anthropogenic forcings to the summer cooling over eastern China: An AGCM study Geophysical Research Letters 2007, 34, L18807.

[124] Li, C., Zhao, T., Ying, K., Quantifying the contributions of anthropogenic and natural forcings to climate changes over arid-semiarid areas during 1946-2005. Climatic Change 2017, 144, 505-517.

[125] Barkhordaria, A., von Storch, H., Zorita, E., Loikith, P. C., Mechoso, C. R., Observed warming over northern South America has an anthropogenic origin. Climate Dynamics 2018, 51, 1901-1914.

[126] Allen M. R., Gillett, N. P., Kettleborough, J. A., Hegerl, G., Schnur, R., Stott P. A., Boer, G, Covey, C., Delworth, T. L., Jones, G. S., Mitchell, J. F. B., Barnett, T. P., Quantifying anthropogenic influence on recent near-surface temperature change. Surveys in Geophysics 2006, 27, 491-544.

[127] Chylek, P., Klett, J. D., Dubey, M. K, Hengartner, N., The role of Atlantic Multi-decadal Oscillation in the global mean temperature variability. Climate Dynamics 2016, 47, 3271-3279.

[128] Folland, C. K., Boucher, O., Colman, A., Parker, D. E. Causes of irregularities in trends of global mean surface temperature since the late 19th century. Science Advances 2018, 4 (6), 5297.

[129] McIntyre, S., McKitrick, R., Corrections to the Mann et. al. (1998) Proxy Data Base and Northern Hemispheric Average Temperature Series. Energy & Environment 2003, 14 (6), 751-771.

[130] Mann, M. E., Zhang, Z. H., Hughes, M. K., Bradley, R. S., Miller, S. K., Rutherford, S., Ni, F. B., Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia. Proceedings of the National Academy of Sciences of the United States of America 2008, 105, 13252-13257.

[131] Black, R., Environment correspondent, BBC News. Climate 'hockey stick' is revived websitehttp://news.bbc.co.uk/2/hi/science/nature/7592575.stm

[132] Esper, F, D., Zorita, J., Wilson, R, "A noodle, hockey stick, and spaghetti plate: A perspective on high-resolution paleoclimatology", Wiley Interdisciplinary Reviews: Climate Change 2010, 1 (4), 507-516.