



Available online at www.sciencedirect.com



C. R. Geoscience xxx (2008) xxx–xxx

<http://france.elsevier.com/direct/CRAS2A/>

External Geophysics, Climate and Environment

Evidence for a solar signature in 20th-century temperature data from the USA and Europe

Jean-Louis Le Mouél, Vincent Courtillot*, Elena Blanter, Mikhail Shnirman

Geomagnetism and Palaeomagnetism, institut de physique du Globe de Paris, BP 89, 4, place Jussieu, 75252 Paris cedex 05, France

Received 24 October 2007; accepted after revision 2 June 2008

Presented by Claude Jaupart

Abstract

We analyze temperature data from meteorological stations in the USA (six climatic regions, 153 stations), Europe (44 stations, considered as one climatic region) and Australia (preliminary, five stations). We select stations with long, homogeneous series of daily minimum temperatures (covering most of the 20th century, with few or no gaps). We find that station data are well correlated over distances in the order of a thousand kilometres. When an average is calculated for each climatic region, we find well characterized mean curves with strong variability in the 3–15-year period range and a superimposed decadal to centennial (or ‘secular’) trend consisting of a small number of linear segments separated by rather sharp changes in slope. Our overall curve for the USA rises sharply from 1910 to 1940, then decreases until 1980 and rises sharply again since then. The minima around 1920 and 1980 have similar values, and so do the maxima around 1935 and 2000; the range between minima and maxima is 1.3 °C. The European mean curve is quite different, and can be described as a step-like function with zero slope and a ~1 °C jump occurring in less than two years around 1987. Also notable is a strong (cold) minimum in 1940. Both the USA and the European mean curves are rather different from the corresponding curves illustrated in the 2007 IPCC report. We then estimate the long-term behaviour of the higher frequencies (disturbances) of the temperature series by calculating the mean-squared interannual variations or the ‘lifetime’ (i.e. the mean duration of temperature disturbances) of the data series. We find that the resulting curves correlate remarkably well at the longer periods, within and between regions. The secular trend of all of these curves is similar (an S-shaped pattern), with a rise from 1900 to 1950, a decrease from 1950 to 1975, and a subsequent (small) increase. This trend is the same as that found for a number of solar indices, such as sunspot number or magnetic field components in any observatory. We conclude that significant solar forcing is present in temperature disturbances in the areas we analyzed and conjecture that this should be a global feature. **To cite this article:** J.-L. Le Mouél et al., *C. R. Geoscience xxx (2008)*.

© 2008 Académie des sciences. Published by Elsevier Masson SAS. All rights reserved.

Résumé

Sur une signature solaire dans les données de température recueillies au XX^e siècle en Europe et aux États-Unis. Des données de température en provenance de stations météorologiques des États-Unis (six zones climatiques, 153 stations), d’Europe (44 stations considérées comme appartenant à une unique zone climatique) et d’Australie (étude préliminaire, cinq stations) ont été analysées. Les stations disposant de longues séries de températures journalières (recouvrant la plus grande partie du XX^e siècle, avec peu ou pas d’interruptions) ont été sélectionnées. Il a été trouvé que les données de stations sont bien corrélées sur des distances de l’ordre du millier de kilomètres. Quand une moyenne est calculée pour chaque région climatique, on observe des courbes

* Corresponding author.

E-mail address: courtill@ipgp.jussieu.fr (V. Courtillot).

moyennes bien caractérisées, avec une variabilité prononcée dans la fourchette 3–15 ans, et une tendance superposée avec des constantes de temps de l'ordre de la décennie au siècle, qui consiste en un petit nombre de segments linéaires séparés par des changements de pente assez aigus. La courbe d'ensemble pour les États-Unis croît nettement de 1910 à 1940, puis décroît jusqu'en 1980, et ensuite croît à nouveau nettement. Les minima autour de 1920 et 1980 présentent des valeurs similaires, de même que les maxima autour de 1935 et 2000 ; l'écart entre minima et maxima est de 1,3 °C. La courbe moyenne pour l'Europe est très différente, et peut être décrite comme une fonction en escalier, avec une pente nulle et un saut d'environ 1 °C en moins de deux ans autour de 1987. Un minimum (froid) prononcé est aussi observable en 1940. Les courbes moyennes pour les États-Unis et l'Europe sont assez différentes des courbes correspondantes fournies par le rapport GIEC de 2007. Nous estimons alors le comportement à long terme des fréquences plus hautes (perturbations) des séries de température, en calculant les variations quadratiques moyennes interannuelles ou « durée de vie » (c'est-à-dire la durée moyenne des perturbations de température) des séries de données. Les courbes résultantes sont remarquablement bien corrélées sur de longues périodes entre régions et à l'intérieur des régions et entre régions. La tendance séculaire de toutes ces courbes est similaire (allure en S), avec une croissance de 1900 à 1950, une décroissance de 1950 à 1975 et une augmentation (faible) ensuite. Cette tendance est la même que celle trouvée pour différents indices solaires, tels que le nombre de taches solaires ou les composantes du champ magnétique dans un observatoire. Nous concluons à un forçage solaire significatif dans les perturbations de température pour les zones analysées ici et avançons que cette situation pourrait avoir un caractère global. **Pour citer cet article : J.-L. Le Mouél et al., C. R. Geoscience xxx (2008).**

© 2008 Académie des sciences. Published by Elsevier Masson SAS. All rights reserved.

Keywords: 20th-century temperature data (USA, Europe, Australia); Disturbances; Mean-squared interannual variations; Solar indices; Solar forcing; Geomagnetic field

Mots clés : Données de température pour le XX^e siècle (États-Unis, Europe, Australie) ; Perturbations ; Variations quadratiques moyennes interannuelles ; Indices solaires ; Forçage solaire ; Champ géomagnétique

1. Introduction

Although a proper description of climate change cannot be based on temperature alone, temperature is often considered a useful index and is readily grasped by the general public. As a result, temperature curves are often the main data displayed in papers or reports readily accessible to the public and to policymakers. To give just a few recent examples, a special issue of *Pour la Science* dedicated to global warming featured a paper by Moisselin and Dubuisson [15] on warming in France that started with a figure displaying the mean variations in temperature in metropolitan France from 1901 to 2005, whereas a paper by Le Treut [14] on modelling “certainties and uncertainties” displayed the famous hockey-stick curve (basically the version from Mann, see for instance Jones and Mann, [11]) over the past 1000 years. The *Summary for policymakers* of Working Group 1 (part of its contribution to the IPCC Fourth Assessment Report, [10]) displays variations of the global average temperature from 1850 to 2005. One of the concluding figures (SPM-4) displays changes in the continental and global-scale decadal surface air-temperature anomalies for 1906–2005, measured relative to the corresponding averages for the 1901–1950 period, and compared with model simulations. Observations diverge from model simulations, starting around the mid-1970s, when greenhouse gases are not included.

An item for discussion, which we wish to emphasize, rests with actual temperature measurements and the way global average temperatures are derived. Whereas there are a rather large number of groups around the world studying the physical and chemical processes that affect climate and testing and inter-comparing numerical models (GCMs), the number of independent analyses of mean temperature data is not so large. Two main groups are involved in assembling a global data base of mean temperatures, one in the UK and one in the USA. A new data set from 1850 to the present day has been assembled by the Hadley Research Centre and is described in Brohan et al. [4]. The paper focuses usefully on uncertainty estimates and provides curves for mean temperature change from 1850 to 2005. Uncertainties in recent decades are claimed to be in the order of ± 0.15 °C for the global land average, ± 0.10 °C for the marine average. Corresponding values in the second half of the 19th century are ± 0.40 °C and less than 0.15 °C. Because the surface covered by the oceans is two-thirds of the globe, the marine data dominate the final global average, which has an uncertainty of less than 0.10 °C in recent decades and less than 0.15 °C in the last half of the 19th century. This is the curve used in IPCC WG1 ([10], Figure SPM-3).

Global averages, which are derived from raw data in the Hadley Research Centre database, are faced with the problems of large temporal changes in data distribution, and to a lesser extent quality. The marine data in

particular have been obtained using various bucket and thermometer techniques and automated engine cooling-water observations made from ships. Moreover, measurements are not made at the same instants, of course. Marine data are assigned their local time, whereas for land data the mean of the maximum and minimum daily temperatures is used. These mean daily values (in the case of continental measurements) or instantaneous values (in the case of marine data) are averaged over one month in a 5° square spherical cap, and the 1961–1990 mean is subtracted to define the temperature anomaly. Finally, adjustments are made to reduce the effects of land-use changes, changes in instruments, measurement site and missing data. Clearly, the amount of work involved in acquiring, collecting, analyzing, reducing these 3.7 million data is enormous and cannot easily be redone or checked independently.

We find it quite remarkable that the claimed uncertainties can be so small back to 1850. The marine data are the focus of a specific paper by Rayner et al. [16]. Both Rayner et al. [16] and Brohan et al. [4] discuss in detail the changes in the measurement techniques over these 150 years. Prior to 1900, the total number of observations was less than 5% of the number of data after 2000 and less than 15% of the number of data after 1950. Moreover, the number of 5° square boxes with any data (yielding monthly averages) prior to 1900 was less than 50% of the number of data after 1950. Before 1900, two thirds of the total oceanic surface had no data. It is quite remarkable that this enormous under-sampling hardly affects the uncertainties of the global temperature curves. P. Jones (pers. comm., 2007) informed us that attempting to reconstruct the global temperature means using post-1950 data, under-sampled in the way the pre-1900 data were distributed, hardly changed the global means. This would imply that the marine mean air surface temperature is a remarkably uniform field on the global scale.

We have not been able so far to obtain the files of data used by Brohan et al. [4], i.e. the actual monthly data in each 5° box prior to any processing, including computation of the ‘temperature anomaly’. P. Jones (pers. comm., 2007) writes, quite understandably, that “the aim with the global temperature grids and time series is to make the data easy for scientists to use”, but that “the monthly station data are not available. They have been routinely obtained from the Global Telecommunication System between national meteorological services (NMSs). They have been augmented over the years using data received from NMSs around the world and from scientists working in the climate field.

To get much of the NMS data, the centre has signed agreements with NMSs saying they would not pass the raw data onto third parties.” Also, there is apparently no access to daily data (only monthly means). Being used to collecting and processing worldwide magnetic data, we are quite sympathetic with these difficulties. The database would therefore have to be reconstructed step by step from original observatory publications or partial databases and websites.

We have given ourselves the more modest objective to use regional data bases, starting with 153 US and 44 European observatories, where we could obtain essentially a century of daily (rather than monthly; this may be quite important, as will be seen below) data (minimum, mean and maximum temperatures). We have analyzed individual station data and averages at the regional and continental scales. We focused on long-term variations evidenced after 3-year averaging of the data, in order to eliminate the large annual cycle. We then looked for an index that would allow us to estimate long-term variations of the characteristics of higher frequencies (disturbances) in the signal, attempting to diminish the otherwise large effect of the annual variation. We have used both a rather classical tool, the mean-squared interannual variation, and a more novel nonlinear filtering technique involving the ‘lifetime’ of temperature curves (which is described in more detail in Le Mouél et al., 2008, a description not needed at the stage of this paper).

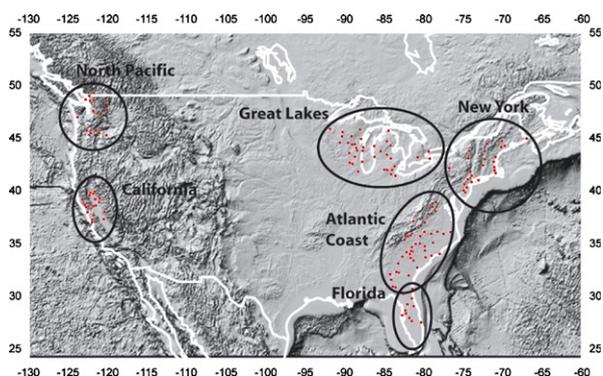


Fig. 1. Climatological stations and climatic regions of the USA used for calculating regional averages. The numbers of stations used are 17 for the North Pacific, 37 for the Great Lakes, 25 for the North Atlantic (New York), 20 for California, 45 for the Atlantic Coast and 9 for Florida.

Stations climatologiques et régions climatiques des États-Unis utilisées pour calculer les moyennes régionales ; nombre de stations : 17 pour le Pacifique Nord, 37 pour les Grands Lacs, 25 pour l'Atlantique Nord (New-York), 20 pour la Californie, 45 pour la côte atlantique et 9 pour la Floride.

We first discuss the results for North America, where we illustrate changes in minimum temperature and temperature disturbances over six climate zones centred on the North Atlantic coast, the Great Lakes, the central US Atlantic coast, Florida, California and the North Pacific coast. We show that there is a quite significant correlation between long-term variations in temperature disturbances and indices related to long-term changes in solar activity. We then repeat the analysis for European stations, the detailed results being described elsewhere (Le Mouël et al., [13]). We also present some

preliminary results from five Australian stations. In a final section, we discuss implications of our findings with respect to potential driving forces of climate change.

2. North American temperatures

The data from 153 stations in North America (Fig. 1) were analyzed. The data are extracted from the ECA&ECD database (available via <http://eca.knmi.nl/>). They consist in series of daily minimum, mean and

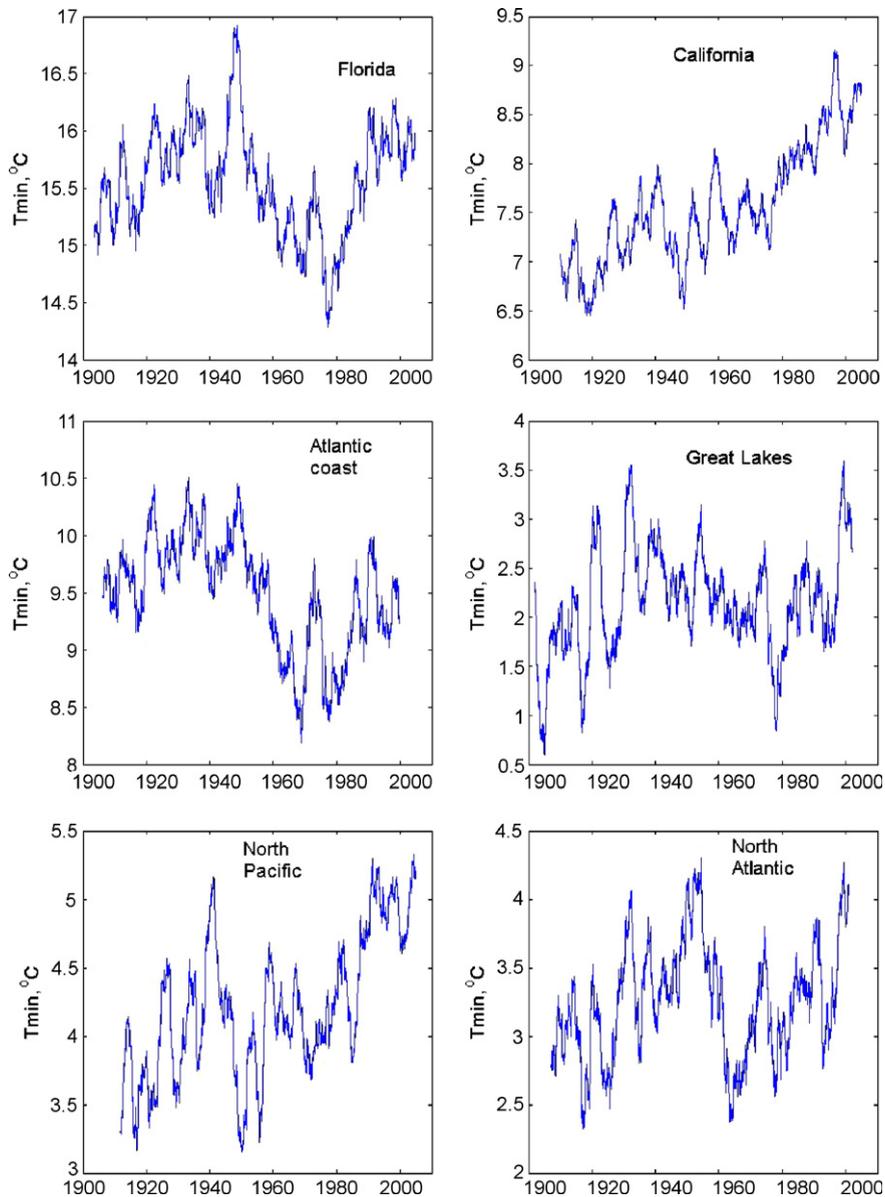


Fig. 2. Three-year running mean minimum temperature curves for the six USA climatic zones shown in Fig. 1. *Courbes moyennes de température minimale journalière moyennée sur trois ans pour les six zones climatiques des États-Unis, indiquées sur la Fig. 1.*

maximum temperature values. In the present paper, we only show results for minimum temperatures in stations with the shortest possible gaps; the other two yield rather similar results. Based on analysis of individual station data and previous definitions of climate zones on the continent (e.g., Groisman and Easterling, [8]), we have used six distinct zones, for which the time evolutions of (3-year-averaged) temperatures are shown in Fig. 2. Whereas the spectral content of all series in the 3–15-year period range is similar and some correlations can be noticed between adjoining climate zones, the longer-term (decadal to secular) trends are clearly very different from one zone to the other. California displays a continuously increasing temperature trend, which can be broken down in three periods, two with a faster rise (1910–1940 and 1980 to the present) and one with a smaller average slope (1940–1980). The North Pacific has similar features with larger amplitude and a significant decrease after 1940. The Great Lakes display a jagged, zigzag-like trend, rising until 1935, decreasing to 1975 and rising since. The North Atlantic coastal area displays a sharp rise until the early 1950s, a strong cooling between 1950 and 1960. On the other hand, in the Central Atlantic coast and Florida regions, the zigzag-shaped curves and their most recent warming segments yield to a plateau when temperatures stabilize, as of ~1985.

The overall mean curve for 153 stations is shown in Fig. 3. It displays three main periods, two with a sharp rise between 1910 and 1935, and between the late 1970s and the present. This is interrupted by a long cooling period from 1930 to the late 1970s. Note that the slope and value reached in the most recent episode are no larger than in the one preceding 1940, and that the warmest temperatures may have been around 1930, as recently noted by the US weather service. There is therefore great similarity in the US (taken as an average)

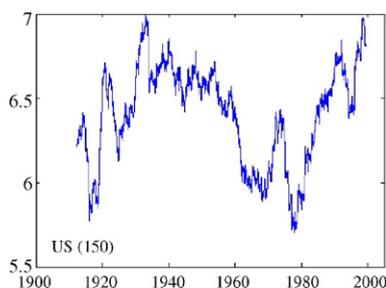


Fig. 3. Overall mean curve (three-year running mean minimum temperature in °C) for the 153 USA stations shown in Fig. 1.

Courbe moyenne d'ensemble (température minimale moyenne sur trois ans en °C) pour les 153 stations des États-Unis indiquées sur la Fig. 1.

between the situation in the 1930s and at present. A North American mean temperature curve is given in Figure SPM-4 of the Working Group 1, part of the IPCC Fourth Assessment Report [10]. We note that this curve and ours are quite different. The overall increase from the beginning to the end of the 20th century is very significant in Figure SPM-4, but is found only in our western US regional curves (Fig. 2), not in the overall mean (Fig. 3). The two curves are based on somewhat different sets of data with very different resolution: one data point every ten years based on monthly averages for Figure SPM-4, vs. daily data with 3-year running mean filtering in our case. Yet, we do not see how these can be so different and wonder about the resolution and significance of the curves in the IPCC report [10].

3. Secular evolution of temperature disturbances in North America

When attempting to find long-term correlations, and possibly causal connections between observables linked to the climate system (here temperature) and potential driving factors (anthropogenic GHG, Sun, cosmic rays...), only the longer periods are relevant if the system is a linear one. But if it is nonlinear and moreover turbulent, cascades from the higher to the lower frequencies or the reverse can occur. In that sense, it is important to estimate the long-term behaviour of the higher frequencies (disturbances), a delicate task with many time series spanning several orders of magnitude in characteristic frequencies. In previous papers, we have used a nonlinear technique of analysis developed for time series whose complexity arises from interactions between different sources over different time scales. We have applied this technique to several geophysical time series [1,2,6]. In Le Mouél et al. [13], we apply it to European temperature time series and to several indicators of solar activity. The technique allows us to extract the ‘lifetime’ of (higher frequency) features from a time series (i.e. roughly the mean duration of temperature disturbances), and then to follow the time evolution of this higher-frequency component on the longer time scales. A more classical technique consists in computing simply the mean squared interannual variation, which is:

$$(1/T) \sum (F(t + d\Delta t) - F(t))^2 \quad (1)$$

with an offset $d\Delta t = 365$ days, in order to suppress the overwhelming effect of Earth’s annual orbit around the Sun, and an averaging interval $T = 22 \times 365$ days, in order to eliminate signals directly related to the solar

(and magnetic solar) cycle(s). Our experience with the two methods is that they often generate similar results, even though in some cases the more elaborate technique of lifetimes yields sharper results. We have used the mean squared interannual variation for US stations (although we do show results with the lifetime in the case of European stations in the next section). Results are given in Fig. 4. We have selected as a proxy for solar activity the mean squared daily variation (in that

case $d\Delta t = 1$ day in Eq. (1)) of the vertical component Z of the magnetic field at Eskdalemuir (shown in blue in all sections of the figure). The overall S shape of the curves, with an increase up to 1950, then a decrease until the 1970s, followed by (rather small) growth since then, is common to most curves. This overall correlation fails prior to ~ 1930 in the North Atlantic and Great Lakes regions, and prior to 1945 in the North Pacific.

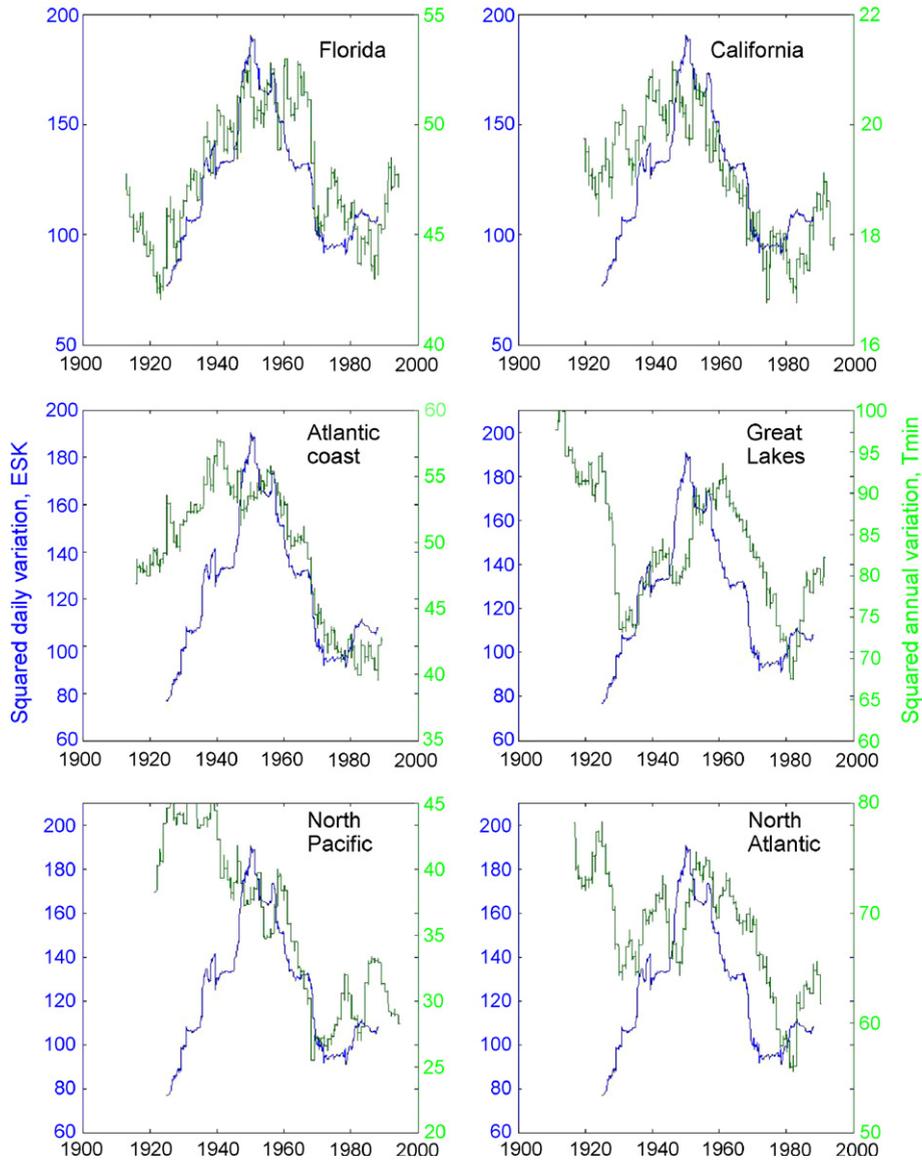


Fig. 4. Mean-squared interannual variations (22-year averaged) of minimum temperature for the six USA climatic zones shown in Fig. 1 (green curves), compared to a magnetic index representing solar activity (the squared daily variation of the vertical component Z of the geomagnetic field at Eskdalemuir; blue curve).

Variations quadratiques moyennées interannuelles (moyennées sur 22 ans) de la température minimale pour les six zones climatiques des États-Unis indiquées sur la Fig. 1 (courbes vertes) comparées à un indice magnétique représentant l'activité solaire (variation quadratique interjournalière de la composante verticale Z du champ géomagnétique à Eskdalemuir : courbe bleue).

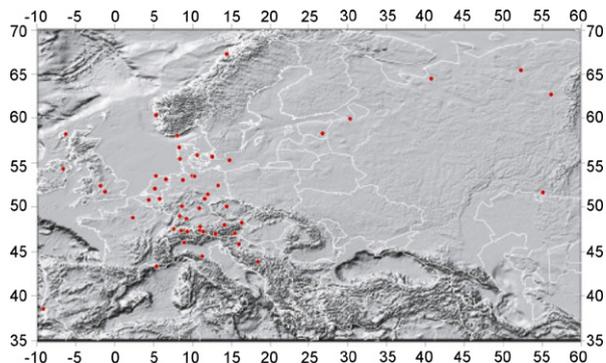


Fig. 5. Geographical distribution of 44 European climatological stations used in this study (see also [13]).

Répartition géographique des 44 stations climatologiques européennes utilisées dans cette étude (voir aussi [13]).

4. European temperatures

We have next analyzed (3-year running average) daily minimum temperature curves from 44 European climatological stations (Fig. 5) covering most of the past century. All individual station curves again display significant energy in the 3–15-year period range and correlate quite well, and so do country averages and the overall European average. So, much of the spectral content of the temperature curves is highly correlated at the continental scale (~3000-km scale). This is discussed in more detail in Le Mouél et al. [13], but for the purpose of the present paper, it is sufficient to show this overall European average (Fig. 6).

The ‘European’ trend that emerges would be positive if simple (first-order) least-squares linear fit over the entire time interval were used. But two particularly striking and sharp features emerge (Fig. 6), which are a brief and intense temperature drop (~1.5 °C) with a minimum in 1940–1941 and a sharp

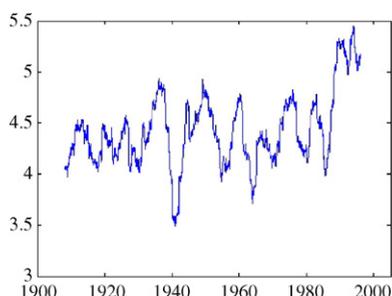


Fig. 6. Overall mean curve (three-year running mean minimum temperature in °C) for 44 European stations shown in Fig. 5.

Courbe moyenne d'ensemble (température minimale moyennée sur trois ans en °C) pour les 44 stations européennes de la Fig. 5.

temperature rise by almost 1 °C in ~1987. Going back to the original station data, these two features are indeed found almost ubiquitously, though they become more pronounced with increasing averaging over the continent. We conclude from this curve that there was indeed warming in the 20th century in Europe, but that the characteristics of this warming are different from those shown again in Figure SPM-4 of Working Group 1, part of the IPCC Fourth Assessment Report [10]. There was almost no regional change in temperature between 1900 and 1987 and since then (although the series is a bit short to evaluate significantly the post-1987 trend; this is confirmed by the most recent and complete station data sets). Most temperature extremes of the 20th century have been reached in the past 20 years, due to the superimposition of the ~±0.5 °C amplitude higher frequency changes (5–15-year period range) and the ~1 °C step-like jump in 1987. The trend in the mean temperature in Europe has been essentially flat before and after 1987. The change occurred in an astonishingly short time and the situation appears to be stable since. That short intense events correlated at the continental scale can occur is well illustrated by the extreme cold event of 1940, which has no other equivalent in the 20th century.

A similar situation has been described for 17 Alaskan meteorological stations over the period 1951–2001 by Hartmann and Wendler [9], their Fig. 5): when a linear trend is calculated over the 50-year period, it is found to be a warming one. But Hartmann and Wendler [9] show that this is a misrepresentation of the observations, which actually consist of two rather quiet, actually cooling periods separated by a quick positive jump in 1976 (that is ten years before the one we observe in Europe): “examining a trend in temperatures that straddles that 1976 shift generally yields an artificially high rate of warming over Alaska.”

5. Secular evolution of temperature disturbances in Europe

In the case of European data, we display both the mean-squared annual variation and the lifetime (see Section 3) for the mean minimum temperature curve of the 44 European stations (Fig. 7, lower row). These are all computed with a 22-year sliding window. Results are clearly similar using both methods. All curves display the same S-shaped variation with values rising from ~1920 to ~1950, then decreasing to a sharp minimum around 1975, and rising more or less since. The same analysis applied to solar indices (here again the mean squared daily variation of the vertical component of the

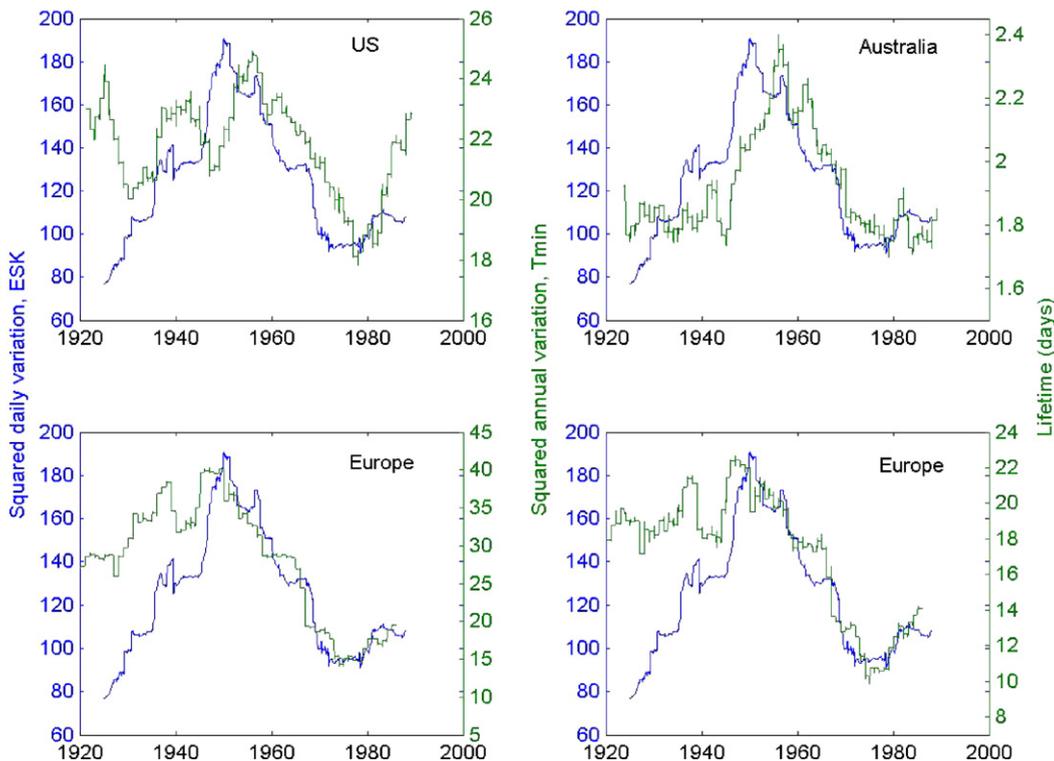


Fig. 7. Comparison of the mean squared interannual variation (left column) and lifetime (right column) of the overall minimum temperature data from the US (153 stations), Australia (preliminary, 5 stations) and Europe (44 stations). Europe (bottom row) is shown for the two types of calculation for quick comparison (green curves), and also the magnetic index representing solar activity as in Fig. 4 (blue curve). *Comparaison de la variation quadratique moyenne interannuelle (colonne de gauche) et de la durée de vie (colonne de droite) pour les données de température minimale d'ensemble provenant des États-Unis (153 stations), d'Australie (étude préliminaire, cinq stations) et d'Europe (44 stations) (courbes vertes). Pour l'Europe (ligne du bas) les deux types de calculs sont comparés. Sur toutes les figures, un index magnétique représentant l'activité solaire est figuré en bleu comme sur la Fig. 4.*

geomagnetic field at Eskdalemuir observatory, an excellent solar indicator) yields a similar result. This S-shaped curve is indeed found to be the same for all components of all magnetic observatories [12]. We have analyzed a number of other indicators, such as long-term changes in the intensity of the 6-month spectral peak in magnetic observatories, or the energy content of the global temperature spectrum at periods less than 10 yr, and always found a similar overall shape.

Fig. 7 also displays the overall curves for the 153 US stations (shown by region in Fig. 4). A preliminary study of five Australian meteorological station data (using the 'lifetime' approach), also displayed in Fig. 7, confirms that the patterns that emerge from the analysis of European and North American data are likely to be global (there are three stations in the North and Northwest of Australia, including Darwin, and two in the Southwest, including Perth). The figure emphasizes the fact that the general features, sign of slopes of decadal trends and times of extremums of all lifetime

and squared annual variation curves are very similar, though they may differ in amplitudes, slope values or higher-frequency details. The correlation of the Australian curve is actually the best. We point out that temperature variations in this subset of west-coast Australian stations are much smaller than in Europe or North America.

6. Discussion and conclusion

In geomagnetism, it is commonplace to use the adjective 'secular' to identify temporal trends in the range from decades to centuries. We use the term in the same way in the following. Figs. 2, 3 and 6 illustrate some similarities, but mainly the large differences between secular temperature trends. This naturally leads one to wonder about the significance of averaging them as part of building an even more global average. The various trends in the USA (Fig. 2) confirm the well-known fact that climate is strongly structured and

organized in neighbouring areas with strong contrasts. Climate is easier to define at a regional rather than at a more global scale. The secular trend has been one of warming since 1950 in California and the North Pacific, since 1960–1970 in the US North Atlantic and Atlantic coast, since 1980 in Florida and the Great Lakes. But we note that recent decades do not appear to be as extreme or unusual in several regions (Great Lakes, North Atlantic, Atlantic coast, Florida) as is sometimes thought. As far as the regions we have examined are concerned, only in California and in Europe are temperatures significantly higher in recent decades than in the early 20th century; the signatures in both regions are very different. Europe, Florida and the Atlantic coast of the USA, and possibly the North Pacific, share the occurrence of a plateau in the last decade of the 20th century (too short to be considered a robust climatic trend?). In much of the USA, the secular trend was a significant cooling from 1930–1940 to 1960–1970, whereas there was already warming in California and a stable state in Europe.

Another point we wish to make on secular trends is that, however nonunique, a model consisting in no more than three or four rather linear segments would provide most mean temperature curves with a good fit. In the case of Europe, this even reduces to two flat segments separated by a step-like jump. These segments are often interrupted by rather sharp regime changes, giving an impression that in each region climate could be described as a succession of slowly, linearly evolving temperatures separated by sharp and short events of as little as 1- to 2-year duration. To the authors of this paper, this is of course reminiscent of the discovery that geomagnetic secular variation could be described in a similar way (e.g., [5]). This observation does not imply that mechanisms are the same, but emphasizes features that could be characteristic of chaotic nonlinear loosely coupled systems (see also [3]). It is not illegitimate to wonder about the significance and robustness of calculating a worldwide average for a disparate collection of trends. This question is of course addressed in the IPCC reports, in which regional averages are computed and compared to one another.

We have also shown that solar activity, as characterized by the mean-squared daily variation of a geomagnetic component (but equally by sunspot numbers or sunspot surface) modulates major features of climate. And this modulation is strong, much stronger than the one per mil variation in total solar irradiance in the 1- to 11-year range [7]: the interannual variation, which does amount to energy content, varies

by a factor of two in Europe, the USA and Australia. This result could well be valid at the full continental scale if not worldwide.

We have calculated the evolution of temperature disturbances, using either the mean-squared annual variation or the lifetime. When 22-year averaged variations are compared, the same features emerge (Fig. 7), particularly a characteristic centennial trend (an S-shaped curve) consisting of a rise from 1920 to 1950, a decrease from 1950 to 1975 and a rise since. A very similar trend is found for solar indices (see also [5,12]). Both these longer-term variations, and decadal and sub-decadal, well-correlated features in lifetime (see [13]) result from the persistence of higher frequency phenomena that appear to be influenced by the Sun. The present preliminary study of course needs confirmation by including regions that have not yet been analyzed.

References

- [1] E.M. Blanter, M.G. Shnirman, J.-L. Le Mouél, Solar variability: evolution of correlation properties, *J. Atmos. Sol. -Terr. Phys.* 67 (2005) 521.
- [2] E. Blanter, J.-L. Le Mouél, F. Perrier, M.G. Shnirman, Short-term correlation of solar activity and sunspots: evidence of lifetime increase, *Sol. Phys. Phys. Astron.* 237 (2006) 329–350, doi:10.1007/s11207-006-0162-x.
- [3] E. Blanter, J.-L. Le Mouél, M.G. Shnirman, V. Courtillot, The Madden-Julian oscillation as a possible origin of solar signatures in European winter temperatures, *Clim. Dynam.* (submitted).
- [4] P. Brohan, J.J. Kennedy, I. Harris, S.F.B. Tett, P.D. Jones, Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850, *J. Geophys. Res.* 111 (2006) D12106, doi:10.1029/2005JD006548.
- [5] V. Courtillot, J.-L. Le Mouél, Geomagnetic secular variation impulses, *Nature* 311 (1984) 709–716.
- [6] C. Crouzeix, J.-L. Le Mouél, F. Perrier, M.G. Shnirman, E.M. Blanter, Long-term persistence of the spatial organization of temperature fluctuation lifetime in turbulent air avalanches, *Phys. Rev. E* 74 (2006) 036308.
- [7] C. Fröhlich, Solar irradiance variability since 1978: revision of the PMOD composite during solar cycle 21, *Space Sci. Rev.* 125 (1–4) (2006) 53–65.
- [8] P.Y. Groisman, D.R. Easterling, Variability and trends of total precipitation and snowfall over the United States and Canada, *J. Clim.* 7 (1994) 184–205.
- [9] B. Hartmann, G. Wendler, The significance of the 1976 Pacific climate shift in the climatology of Alaska, *J. Clim.* 18 (2005) 4824–4839.
- [10] IPCC Working Group 1, Climate change 2007: the physical science basis, Summary for policymakers, Fourth Assessment Report, 2007 (14 p.).
- [11] P.D. Jones, M.E. Mann, Climate over the past millennia, *Rev. Geophys.* 42 (2) (2004) 1–42, doi:10.1029/2003RG000143, RG2002.
- [12] J.-L. Le Mouél, V. Kossobokov, V. Courtillot, On long-term variations of simple geomagnetic indices and slow changes in

- magnetospheric currents, The emergence of anthropogenic global warming after 1990? *Earth Planet. Sci. Lett.* 232 (2004) 273–286.
- [13] J.-L. Le Mouél, E. Blanter, M. Shnirman, V. Courtillot, Evidence for solar forcing in variability of temperatures and pressures in Europe, *J. Clim.* (submitted).
- [14] H. Le Treut, Certitudes et incertitudes des modèles, *Pour la Science* (dossier 54) (2007) 10–15.
- [15] J.-M. Moisselin, B. Dubuisson, Coup de chaud sur la France, *Pour la Science* (dossier 54), (2007) 30–33.
- [16] N.A. Rayner, P. Brohan, D.E. Parker, C.K. Folland, J.J. Kennedy, M. Vanicek, T.J. Ansell, S.F.B. Tett, Improved analyses of changes and uncertainties in sea surface temperature measured in situ since the mid-nineteenth century: the HadSST2 dataset, *J. Clim.* 19 (2006) 446–469.