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Article Title: The climate of the past millennium and online public engagement in a scientific debate

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I have no conflict of interest

ABSTRACT

After the publication in 1999 of the reconstruction of the Northern Hemisphere temperature popularly known as the hockey-stick, climate scientist and internet bloggers engaged in a heated and often stalemated public debate on the validity of paleoclimate reconstructions and on their implications for the wider question of anthropogenic climate change. The internet emerged as an important factor channeling the direct participation of the public almost at the same level as professional scientist. It also allowed dissemination of largely unfiltered information.

I argue that, although paleoclimate research did benefit in some technical aspects, the public debate around the hockey-stick focused on issues that were not scientifically central, like the existence of the Medieval Warm Period or the characterization of 1998 as the warmest year of the millennium. In contrast, much more relevant points, such as constraining the value of climate sensitivity using reconstructions of past climate, remained restricted within purely academic circles.

The public resonance of the hockey-stick debate was also clearly framed by the politicization of climate science and the impacts of the series of IPCC reports, in particular the Third Assessment Report. This resonance was amplified by the expanding use of the internet. The internet represented a new bidirectional channel through which the public and academia could interact to achieve a transparent, democratic and participative evaluation of science. I argue that, although we could have hoped for a positive outcome of the hockey-stick controversy, this opportunity for a new public engagement in scientific debates was missed.
INTRODUCTION

The ‘hockey-stick’ graph is a reconstruction of the North Hemisphere temperature over the past millennium. It was included in a prominent spot in The Third Assessment Report of the Intergovernmental Panel on Climate Change (TAR) (1) and it was accompanied by considerable attention by public media. This graph was about to set the stage of the public debate on climate change for the following decade. In parallel, the internet was emerging as a source of information for the public and, in contrast to the traditional printed and television information channels, also allowed for a two-way channel of interaction between the readers and the publishers. The role of the internet turned to be double edged: on the one hand, it allowed for a widespread distribution of information on the risks of anthropogenic climate change; on the other hand, the decentralized and mainly uncontrolled character of the internet also provided very powerful channels to individuals and groups that were critical with the message of the IPCC and that challenged not only the results of the assessment reports, but also questioned the foundations of the climate science as a whole. They represented, in their own view, a ‘popular uprising’ against the established ivory-tower science of academia.

In this opinion piece, which results from my participation in the workshop ‘Towards a History of Palaeoclimatology’ at the University of Hamburg, I will try to present my personal perspective as a climatologist involved in the controversy on the climate of the past millennium. This piece is, however, not an assessment about which camp of the controversy was right. Nor it does attempt to provide a comprehensive historical account of this controversy. For such an analysis, a historian not directly engaged in the controversy would be far more adequate than me. The main purpose of this piece is to highlight that, in my opinion, the public controversy was misplaced, mostly around points that probably were presented to the public in a simplistic manner. In contrast, the academic discussion did address the most important scientific issues, but these did not reach the public discourse.

The period between 1998 and 2013 witnessed the publication of three IPCC reports and one assessment report on the past-millennium climate by the National Research Council in the US (2). It also witnessed the appearance of many internet blogs focused mainly or exclusively on climate topics, of which perhaps the more active or better known were Realclimate, Climate Audit, Whats up with that?, Climate etc. Tamino, Bishop Hill, , Primaklima, James Empty blog, Stoat, DotEarth, Roger Pielke Jr. blog, and our own Die Klimazwiebel. Some of these internet blogs were generally supportive of the IPCC reports, and others were clearly critical to them.

Realclimate made the first appearance in the blogosphere in January 2005. Its sole author, Steve McIntyre, is a retired mining consultant, which is reflected in the name of the blog. Its main stated motivation is to scrutinize (audit) the claims made in climate research publications as carefully as as mining companies scrutinize costly mining projects. This blog provided rather detailed and a higher-level analysis of the statistics and data issues surrounding climate reconstructions. The web blog Bishop Hill was published, with the last active post in October 2017, by Andrew Montfort, also author of the book ‘The Hockey Stick Illusion’ published in 2009 (3). The blog often linked to Climate Audit and provided thereby a non-technical and strongly opinionated summary. Realclimate was launched in December 2004 by a group of professional climate scientist including the main author of the hockey-stick graph, Michael Mann. The name of the blog suggests the authority claimed by
authentic climate scientist, in contrast to the inaccurate information spread by lay persons. The blog, still active, mainly deals with physical climate science, often providing popular-science versions of the technical literature. Climate etc. was created by Judith Curry in September 2010. She is also a professional climate scientist, but she very often provides a critical, sometimes totally opposed, view to the mainstream climate science represented by the IPCC. This blog mostly includes critical reviews of published papers, occasionally also by the mathematician Nick Lewis, one of the very few outsiders that has since then regularly published in peer-reviewed climate science journal and that also posts occasional blog entries in Climate Audit. Dot Earth was created by the New York Times environmental reporter Andrew Revkin, and it occasionally covered some aspects of paleoclimate of the past millennium.

The blogs Tamino, James Empty Blog, Stoot, Roger Pielke Jr's and the German blog Primaklima enjoy or enjoyed a smaller readership (some of them are no loner active). They were created by active or former climate scientist and are usually, though not always, aligned with the IPCC consensus. The bilingual blog Die Klimazwiebel (German for the climate onion, alluding to the multilayered structure of the climate debate) was started - now inactive- in December 2009 by one anthropologist, one social scientist and two professional climate scientist, including myself. This blog had probably a more interdisciplinary focus than the other blogs, and it only occasionally dealt with paleoclimate issues. Its stated aim as 'honest broker' was to foster the communication between both camps of the debate. Its discontinuation in 2017 was partly due to the lack of a perceptible progress in this regard.

The conflict between the 'official' science, represented by the IPCC, and some of the critical voices in the blogosphere, which sometimes saw themselves as representatives of 'grass-root' movement¹, were to a large extent focused on the climate of the past millennium. The conflict between these two camps intensified after after the publications of stolen emails from the University of East Anglia in December 2009 in the so-called Climategate (4,5). Climategate and other earlier, but less relevant, episodes had an undeniable and negative personal impact on some the leading scientist, who found themselves embroiled in a battle with clear political ramifications.

This piece will only discuss the scientific aspects on the area of paleoclimatology that this clash brought about, I argue that, broadly speaking, the scientific impact of the critical blogosphere was not as large as the fierce debate may have led to initially suspect. On the other hand, I also think that academic paleoclimatology did benefit on the longer term in some particular methodological aspects, especially related to statistics, data sharing, and the interpretation of proxy records.

The public discussion on the climate of the last millennium showed some characteristics that were novel and that set it apart from other scientific debates, both past and present. Certainly, the appearance of the internet allowed the participation of a very large part of the public outside academia. Previously, these debates had largely been restricted to the technical scientific literature

¹ For instance, the preface in the revised edition of The Hockey-Stick Illusion (5) includes the following paragraph:“...the main stream media have maintained a determined silence about the book, but in the end this may have mattered little because of impact of the blogs and word of mouth. There have been many champions of the Hockey Stick Illusion - readers who lent it to family members and others who bought bundles of copies to distribute to friends and colleagues".
or, at most, to printed media. Traditional channels of communication were mostly unidirectional and exerted a strong filter on all the voiced opinions. However, present scientific debates that are sometimes pursued very lively in some scientific quarters, such as string theory, have not percolated to the mass media and are nowadays limited to remote corners in the internet. Discussions about climate and climate dynamics may be certainly technical but they can be cast in terms that are more accessible to the general public (weather, ocean currents, tree-rings, historical climate, etc.) than it is the case for other debates in theoretical physics or biology, which require a more advanced technical background. The debate on the climate of the past millennium, therefore, also represented an interesting experiment on to what extent ‘grass-roots’ science and open non-expert review could significantly challenge, and finally transform, the established scientific procedures, which are based on more restricted expert-review by scientific peers and ultimately by the scientific community.

In my view, however, the debate adopted a well-known structure, leading to a generally disappointing outcome. For example, it is not unusual to witness political debates focused on a few arguments that are easy to convey and that deliver a powerful emotional picture, but that actually are irrelevant to the grand underlying question. This also happened in the climate debate. Similarly to other current and previous political debates, each camp of the controversy portrayed itself as the desperate and unjustly treated David in a purported fight against a powerful Goliath, these being represented, depending on the point of view, by either the established climate science and its obscure corporative interests (3), or by a greedy and inhumane industrial lobby (6). A desperate confrontation against a powerful adversary also justifies to silence critical voices in one’s own camp and gloss over own contradictions. The paleoclimate debate also shared some of these characteristics, with a narrative in each camp that tended to favor ‘dumbed’ down messages, and that presented their own efforts as the desperate struggle against a powerful adversary.

THE ‘UNPRECEDENTED-EVENT’ ARGUMENT

Until to the publication of the hockey-stick graph (7,8), a whistle-stop tour the past-millennium climate would have shown show a period of relatively warm temperatures at the beginning of this period (the ‘Medieval Warm Period), followed by several centuries of colder temperatures (the Little Ice Age), which was terminated by the present warm(ing) period in around 1850. An interested reader can find a good summary of the present state of knowledge in Chapter 6 of the Fourth Assessment Report of the IPCC (9).

The hockey-stick graph (Figure 1), in contrast to this prior image, presented a flatter temperature evolutions. The graph displays a very-long, multi-centennial cooling trend from year 1000 until 1900, with only small superposed deviations around this trend. It does not show a period around year 1000 clearly warmer than the rest, or a period in the central centuries of the millennium clearly colder than the rest. In year 1900 the curve displays an abrupt onset of a clear warming trend until the end of the record in 1998. This year would have been, according to the hockey-stick temperature reconstruction, the warmest in the whole past millennium. It was prominently highlighted on page 3 of the Summary for Policy Makers of the Working Group 1 Report of the TAR (1). Later IPCC reports offered a more nuanced view, with the hockey-stick graph presented as a possible temperature evolution among other reconstructions (Chapter 6 of the Fourth Assessment Report of the IPCC (9)).
The reconstructed temperature evolution represented by the hockey-stick graph opened several interesting scientific questions, as I discuss later. The finding that 1998 has been unprecedented in terms of global or North Hemisphere) temperatures is meant to suggest that recent times are 'different from the past'. Since the publication of the TAR, this argument has been often used in other contexts, in which some recent level of temperature, precipitation or extreme event appears as the maximum over a past record. I denote this argument the 'unprecedented-event argument' (UA).

Figure 1. Original figure of the hockey-stick graph as a reconstruction of the Northern Hemisphere temperature anomalies over the past millennium, as published in 1999 in Geophysical Research Letters (8). The year 1998 is highlighted as the warmest year in the past millennium. The shading represents the uncertainty in the estimated temperature. This figure was almost exactly reproduced in 2001 in the Summary for Policy makers of the IPCC Third Assessment Report (1), Working Group 1, but without highlighting the year 1998. The figure caption there, however, ended with the sentence: 'Nevertheless the rate and duration of warming of the 20th century has been much greater than in any of the previous nine centuries. Similarly, it is likely that the 1990s have been the warmest decade and 1998 the warmest year of the millennium.'

The UA offers several advantages to construct an attractive narrative. It is simple to understand by the general public and conveys a powerful sense of uncontroversial evidence. This can be used to support other accompanying messages, for instance the urgency to adopt climate mitigation measures. However, presented in isolation without the proper context, it is neither logically nor tactically very strong. It is logically weak because the attribution of climate change to anthropogenic activities does not depend upon the absolute level of record temperatures, but rather on the occurrence of 'unexpected' warming in a climate driven by only natural factors. The argument is also tactically weak because it is relatively easy to find periods in the paleoclimate record that were at least as warm as the present. The UA, therefore, also offered an easy target for those interested in
falsifying it. Later in this article, I will illustrate that the UA is in some way derived from the climate change detection and attribution framework. However, to properly set the UA in this framework would have been technically much more demanding, thereby losing some of its potency as a simple and straightforward argument.

The UA can be easily counteracted if the climate proxy records indicated periods in the past with temperatures warmer that 1998 or warmer than, more loosely, present time. The skeptical blogosphere thus focused on showing that, in fact, there have been other past periods that were warmer. A very lively debate arose around the existence of the Medieval Warm Period (MWP) as a period with globally warmer temperatures (10). This period, approximately around year 1000 A.D, had been identified in several dendroclimatological and other types of proxy records, but due to the inherent uncertainty in those records and the relative poor spatial coverage of data from that period, the issue of whether or not the MWP was warmer then present remained elusive. It firmly remained in the center of the discussion though. Climategate in 2009 put it in the headlines of almost all internet discussions (Figure 2).

The term Medieval Warm Period precisely subliminally suggested the existence of periods in the past above the present temperature levels. Around year 2003 the scientific community recovered another denomination for this period, the Medieval Climate Anomaly, that had been put forward in 1994 to better describe a climatological period that displayed higher regional temperatures and also anomalous hydroclimate. In 2003, however, its use intended to highlight the uncertainty in the ranking of medieval temperatures against present temperatures (11). The skeptical blogosphere set to scrutinize the validity of proxy records and tried to resolve temperature differences between the MWP and the present period of a few tenths of degree - as indeed the difference between the MWP and the mean 20th century temperature is probably rather small. The critical blogosphere claimed to have uncovered an Orwellian conspiracy by the IPCC to re-write 'climate' history and erase the MWP from climate science.
Figure 2. Time series of the frequency of occurrence in the internet of the expressions 'Medieval Warm Period' and 'Climate sensitivity', obtained with Google Trends. Climategate e-mails (4,5) were released in December 2009.

To some extent this debate resembled older scholastic debates, for there have been many other warmer-than-present periods in the climate history of the Earth. But this has no implication on the question of whether or not human activities have or will have an impact on climate. For instance, it is generally understood that the Mid-Holocene period, around 6000 years before present, was at least in the Northern Hemisphere warmer than the 20\textsuperscript{th} century climate, primely as a result of a different configuration of the Earth’s orbit. This configuration directly favored warmer summer temperatures in the Northern Hemisphere (12) and, due to feedbacks in the climate system, also annual mean temperatures. Also, the Arctic sea-ice cover has also been found in this epoch to be smaller than present, even with ice-free summers in most of the Arctic Ocean (13). Consistently, the northern limit of tree-line in Eurasia was also located northwards of its present position. Looking back at more remote periods, which admittedly are geologically much more dissimilar to the present Earth, the last few million years are known to have been the coldest period since the Jurassic, a period dominated by dinosaurs and with tropical climate at latitudes as north as Alaska (14). Some periods within the last few million years have been considered as potential analogues for a future 2 degrees warming (15). There is not much novelty in warmer-than-present periods. As explained later, the unique character of anthropogenic climate change is the pace of warming, not the temperature level.
Two basic concepts are needed to introduce this framework: internal climate variations and externally forced climate variations. External climate variability is caused by changes in factors that are external to the climate dynamics and which are not influenced by climate itself. A paramount example is solar variations or volcanic eruptions. Internal climate variations, in contrast, are the result of internal climate dynamics, which are non-linear and therefore display turbulent, chaotic and largely unpredictable dynamics. The concept of Internal variability encapsulates the fact that each day, each year, each decade, and even each century are climatically different, although the external drivers may have themselves not changed. Internal variations can be viewed as the ‘climate weather’ that occur at all time scales. In a loose sense, they can be considered as long-term weather fluctuations. A popular example of a pattern of internal climate variability is the El Niño phenomenon.

When facing one unusual (unprecedented) observation, we ask ourselves whether it can be the result of random climate fluctuations that would not require invoking a change in the external driver, or whether its explanation would require a very unusual climate fluctuation. This is the ‘detection step’. The ‘detection’, however, requires an a priori estimate of the amplitude of the internal random climate fluctuations. One immediate problem is that it is impossible to empirically obtain such estimate from observations, because climate observations are affected by both types of variability, external and internal. The amplitude of internal variations can only be derived from the output of climate simulations that have been run artificially keeping the external drivers constant. However,
climate models are known to be imperfect and incomplete - as all computer models of nature. For instance, it is suspected that climate models underestimate the amplitude of internal multidecadal climate variations, with more clear disagreement between simulations and climate reconstructions prior to year 1400 (18). These aspects of climate models, crucial for the detection of 'anomalous' climate variations, were mostly absent in the debate around purportedly unprecedented events and the UA.

The detection of anomalous climate requires some sort of aggregate statistical measure, in contrast to the occurrence of one single unprecedented event that has always some probability to occur at random. Usual aggregate statistical measures are trends in global near-surface temperatures and other variables or changes in the frequency of extremes, for which more powerful statistical tests can be designed (17). In those tests, the level of temperatures relative to some past period does not play a role. Relevant is only the value of that aggregate statistic relative to its expected range of variations in an unperturbed climate. Unfortunately, these aspects were barely touched upon in the blogosphere, perhaps due to its technical subtleties that are difficult to accommodate in a polarized environment.

CLIMATE SENSITIVITY

One important justification for the study of the climate of the past millennium was a potentially better estimation of the sensitivity of the Earth's climate to external radiative perturbations. The European Union has so far funded only one Integrated Research Project on the climate of the past millennium (19). The main objectives of this project were the estimation of the amplitude of natural climate variations over the past millennium and the reduction of the uncertainties of the climate sensitivity. Also two prominent publications from those years presented the link between climate sensitivity and temperature reconstructions (20,21).

Climate sensitivity describes the change in global temperature caused by a change in the external radiative forcing. It is customary expressed as the equilibrium temperature change caused by a doubling of atmospheric CO₂ concentrations. Its value likely lies within the range 1.5 K - 4.5 K (22). It should be kept in mind that this parameter also approximately describes the temperature change due to changes in other external forcings, like solar irradiance or volcanoes, and it can also be expressed in Kelvin per watts/m^2. The precise value of this important climate parameter has proved elusive, and it is still burdened by large uncertainties, that have barely been reduced in the last 30 years. The difficulty of estimating this number from present observations lies in the limited length of the temperature record and the uncertain impact of the different external climate drivers. Apart from the increase in atmospheric CO₂, other external drivers such as tropospheric aerosols from industrial activities blur the direct impact of anthropogenic greenhouse gases on temperatures (20).

Assuming that the sensitivity of climate (per watt/m²) is relatively independent of the type of perturbations - e.g. variations in the solar irradiance or variations in the atmospheric CO₂ concentrations - it would be in principle possible to estimate climate sensitivity from the past evolution of past temperatures and of past solar irradiance and other natural drivers (21,24). It would be a matter of estimating the change in Earth's temperature expressed in degrees per change in external natural forcing expressed in w/m².
A lot of effort was put in the reconstruction of past global temperatures and solar activity and volcanism over the past millennium. These reconstructions are mostly based on the analysis of polar ice-cores. Past variations of solar output are linked to the intensity of the solar magnetic field. This field partially shields the Earth from cosmic rays, and in particular from alpha particles, which react with nitrogen carbon to produce the so called cosmogenic isotopes of Beryllium and Carbon, $^{10}$Be and $^{14}$C. Beryllium is then dissolved in precipitation and is stored in the polar ice-cores. Radiocarbon is adsorbed by living forms and stored in dead or fossilized biological rests. The concentrations of these cosmogenic isotopes can be processed to infer past solar activity. The uncertainties are, however, large, because the Earth's own magnetic field, much stronger the then sun's at the Earth's surface, masks the solar signal, and because the link between the solar magnetic field and solar output of energy is not precisely known. Reconstructions of past solar irradiance based on the same raw data, therefore, still differ in the estimated amplitude of the swings of solar irradiance (24).

Past volcanic activity can also be inferred from the acidity of ice in ice-cores. Volcanic eruptions produce a certain amount of acids that later form atmospheric aerosols. If the eruption is strong enough, they are transported by the atmospheric circulation into the stratosphere and later return to the troposphere and dissolve in precipitation. This process changes the acidity of polar snow. Due to the long path from the eruption site to the polar regions and to the different processes involved, it is not straightforward to infer the intensity and the climate impact of a particular eruptions from measurements in polar ice.

After the publication of the hockey-stick graph, other temperature reconstructions followed (9). They displayed some agreements, but also clear disagreements with the hockey-stick, as they showed larger temperature swings (Figure 3). Generally speaking, wider temperature variations in the past, in contrast to a flatter temperature curve, would hint at a climate that is more sensitive to external perturbations. Several reconstructions had been put forward in the last decades, as shown in Figure 3. Some have been very recently published. Their differences are caused by the different data sets and the diverse statistical methodologies to translate the sparse proxy records (e.g. tree-ring widths) into numerical values of the global (or Northern Hemisphere) mean temperature expressed in degrees (25). Here, it suffices to say here that the hockey-stick reconstruction was one that indicated a rather small temperature variability in the centuries prior to industrialization. Precisely, this flat evolution of past temperatures contrasted with the strong increase in the 20th century and lead to the 'unprecedented-event argument' based on the year 1998.
Figure 3. Reconstructions of the Northern Hemisphere temperature deviations from the mean over the past millennium as published by the IPCC Fourth Assessment Report (9) in year 2007, thus summarizing the state-of-the art during the controversy. The reconstructions are derived mainly from dendroclimatological records and have been smoothed to highlight timescale variability of 30 years and longer. The record labeled PS2004 is exceptionally derived from borehole temperature data; the hockey-stick graph (labeled MBH99) displays smaller temperature variations than most other reconstructions.

Thus, somewhat ironically, the flat handle in the hockey-stick record implis a smaller value of the climate sensitivity, whereas the other, more variable, reconstructions indirectly implied larger values of climate sensitivity. Significantly, the title of paper presenting one of the post-hockey-stick reconstructions started with 'Highly variable temperature...' (26). However, this implication for climate sensitivity remained largely ignored by the critical blogosphere. The blogosphere tended to support reconstructions with large temperature variations mainly because those reconstructions suggested that the 20th century was not that unusual in terms of temperature levels, in contrast to the hockey-stick reconstruction. The link between reconstructions with wider variations and implied larger climate sensitivities was largely ignored. By the same token, the political actors closer to the IPCC tended to support the hockey-stick reconstruction, thereby glossing over that this reconstruction actually suggested a smaller climate sensitivity. The late Thomas Crowley, one of the most widely known and respected paleoclimatologist, described in a public talk around 2006 this ironic situation with the words: 'Climate skeptics will have to learn how to love Mann'.

Unfortunately, the hope of paleoclimate research regarding the estimation of the climate sensitivity was not entirely fulfilled, despite the efforts put into climate and forcing reconstructions. The uncertainty in climate sensitivity has remained thereafter barely unchanged (21,23). The debate on the climate reconstructions of the past millennium, however, illustrates well how a polarized atmosphere can mislead an a priori legitimate public debate towards mostly irrelevant discussion.
targets. In this case, the much more relevant issue of the climate sensitivity was largely glossed over by most actors at that time, who tended to focus on the less relevant, but politically much more useful, issue of the occurrence of unprecedented events.

Closing this section, however, I would like to mention the unusual example of Nick Lewis, a mathematician that privately (27) contributed in several internet blogs and also published in peer-reviewed climate journals, alone and also alongside professional climatologist(23,27,28). It is perhaps not by chance that his main contributions were precisely in the field of climate sensitivity.

**DID PALEOCLIMATE RESEARCH NEVERTHELESS BENEFIT ?**

In my opinion, the controversy regrettably focused on less relevant issues - and was perhaps a lost opportunity to explore new ways of substantial contributions to research progress by non-professionals - The criticism raised by the critical blogosphere, however, triggered an exchange on more technical aspects that did contribute to the overall goal of improving the scientific practice. This exchange was broadly divided up in three main fields: (a) the application of more modern statistical methods, (b) a more careful interpretation of existing proxy records, and (c) to a more transparent and more open data-sharing policies.

The progress in the application of statistical methods applied in climate research has traditionally lagged other fields, like econometrics. The number of text books on statistical climatology was at the end of 20th century rather limited. An example is the publication as late as 1998 of a general text book on statistical climatology (29). To my knowledge, only one other book with a similar scope had previously been published (30). A paragraph in Wilk’s preface to the first edition of his book is illustrative of the slow progress in the application of statistics in climatology: ‘...In addition to serving as a textbook, I hope this will be a useful reference both for researchers and for more operationally oriented practitioners. Much has changed in this field since the 1958 publication of the classic Some Applications of Statistics to Meteorology, by Hans A. Panofsky and Glenn W. Brier, and no really suitable replacement has since appeared ’. Even so, these two books (29,30) still do not include relevant statistical fields, like Bayesian statistics, which had barely found any recognition in climatology to that date but that were already being widely applied in other areas.

The debate on the climate of the past past millennium did bring to the surface statistical issues that may had been addressed within smaller paleoclimate communities, but that had not been fully appreciated by the broader climate research community, and in this sense it was indeed beneficial. Examples include: more sophisticated test of hypothesis and statistical significance (29) in the presence of statistically non-independent, or per-processed data (31) data - a topic barely touched upon in previous years ; the caveats posed by serial and long-term correlation when estimating trends in time series and correlation between time series (32); the impact on statistical significance of subjectively pre-screening the data sets prior to the application of a test of hypothesis; the influence of non-stationarity on estimated correlation between time series and the consideration of unit-root processes (33,34); testing statistical methods with synthetic data provided by climate simulations (35).

The exchange between critics and mainstream paleoclimate researchers on these technical issues was not always smooth, and the criticism itself was not always totally fair, as it did not fully acknowledge the particular characteristics of climate data sets. However, it is generally fair to say...
that paleoclimate research did take into account that criticism. Another positive outcome was the attention raised in the statistical community that lead to incursion in the area of climatology by a few professional statisticians.

Proxy records, such as tree-rings, may or may not be indicative of past climate conditions, depending on their particular characteristics, such as location, tree species, and others. In addition, it is a priori not always clear which climate variable they may encode, temperature, precipitation, or a mixture of both. The selection of proxy records suitable for climate reconstructions is performed as a combination of expert -subjective- knowledge and by statistical comparison with modern instrumental data. A wrong attribution of a proxy record to a particular climate variable may of course be behind deficient climate reconstructions. The critical review by the blogosphere did lead to a closer scrutiny of these false attribution, and did identify wrongly attributed proxy records (36).

Data-sharing practices in science in general began to clearly change in the 2000s (37), and paleoclimate research was no exception (38). Scientific practices are now in clear contrast to the practices that were usual in the 1990's. At that time, it was very rare to share data among researchers, let alone with outsiders of the field. In the paleoclimate context, in particular, this stance was partially justified by the shear amount of work underlying the compilation and analysis of climate proxy records. This involves long and cumbersome field campaigns, and makes the obtained data very valuable from the researcher's perspective. In addition, researchers are under pressure to complete as many publications as possible from a given data set to justify the funding of their research projects and legitimately advance their own careers. This being a comprehensible human stance, it does hinder the scientific scrutiny by peers, the replication of scientific results. and thus scientific progress. For this reason, and partly as a response to the public climate debate, many open data banks were set up in the last decade. Funding agencies now usually prescribe data-sharing policies as a pre-condition for funding. Also, high-profile scientific journals have become more strict in the implementation of their own data-sharing policies (37). The Pages-2K paleoclimate initiative is a clear example of this improvement in climate data-sharing policies (39).

CONCLUSIONS

From an optimistic point of view, several factors had converged at the turn of the century to enable, perhaps for the first time, a widespread public engagement in a scientific discussion: the rise of the internet and the appearance of internet blogs - a new channel of interaction between publisher and reader - with considerable number of readers and commentators; the overall presence of climate and climate change, a relevant and interdisciplinary scientific field of discussion that offered several levels of complexity, ranging from numerical simulation of turbulence to the climate of historical times; and the obvious impact of climate variability and climate changes on society. Indeed, climate change turned to be a scientific topic that even filled elevator conversations.

In my opinion, this contrasted with other relevant scientific fields that were expanding at a hectic pace, such as genetics, or that were also the subject of heated discussions within the scientific ivory tower, such as superstrings (40). These two other examples, however, could not occupy the public area as comprehensively as climate change currently does and the hockey-stick controversy did a few years ago. The reasons for this difference, in my view, can be related to the visibility of the
Intergovernmental Panel on Climate Change, a body that has no parallel in other scientific areas. But an important factor is also the immediate contact that every person has with weather and climate, and with their impacts on the environment and society. In some sense, the climate controversies in the public arena bear some similarities to discussions on food security and food-related health. However, the debate in these areas, though still controversial have not reached the breadth and intensity of the debate on climate change.

The threat of anthropogenic climate change has enormous economic, societal and even political implications. The preferred adaptation and mitigation measures are dictated not only by the scientific corpus but also by our individual view of the world and of society. The rise of the internet, which had made possible some sort of democratization of scientific research, actually resulted in an even fiercer polarization. Many participants in the climate debates would agree that it also lead to disinfomed rather than to more informed citizens. Although this negative impact of the internet in societal debates is by now recognized (41), it is disappointing that even an initially more restricted scientific debate, in which all actors presumably enjoyed a higher level of education than the average population, did not lead to more constructive exchanges. As shown in later social studies, it seems to be very difficult for an individual to accept scientific evidence that conflicts with their own previous beliefs (42).

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Further reading


Time series of the frequency of occurrence in the internet of the expressions 'Medieval Warm Period' and 'Climate sensitivity', obtained with Google Trends. Climategate e-mails (4,5) were released in December 2009.
Reconstructions of the Northern Hemisphere temperature deviations from the mean over the past millennium as published by the IPCC Fourth Assessment Report (9) in year 2007, thus summarizing the state-of-the-art during the controversy. The reconstructions are derived mainly from dendroclimatological records and have been smoothed to highlight timescale variability of 30 years and longer. The record labeled PS2004 is exceptionally derived from borehole temperature data). The hockey-stick graph (labeled MBH99) displays smaller temperature variations than most other reconstructions.