

## Climate of the Last Millennium

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### Climate in Medieval Time

It is often stated that climate in Medieval time was warm, or warmer than “today”. Such a statement might seem innocuous – a mere scientific curiosity -- but it has wider significance. For those opposed to action on global warming, the climate in Medieval time has become a *cause célèbre*. If it was warmer than today in Medieval Time, it could not have been due to fossil fuel consumption, and therefore (the argument goes) this demonstrates that warming in the last century may have been just another natural fluctuation that does not warrant political action on curbing fossil fuel use. Although this is a logically inconsistent argument, it has achieved remarkable traction in political circles, requiring that the issue be carefully re-examined. Actually three issues are involved: the timing of any unusual temperature anomaly, its magnitude relative to “today” and its geographical extent. The latter is especially important because advocates of a warm episode in Medieval time commonly attribute it to solar forcing, arguing that total solar irradiance was as high in Medieval time as in the 20<sup>th</sup> century, with the implication that 20<sup>th</sup> century global warming was largely driven by solar forcing, not greenhouse gases.

The concept of a “Medieval Warm Epoch” (MWE) was first articulated by H.H. Lamb in 1965. Lamb based his argument almost exclusively on a subjective interpretation of historical anecdotes and paleoclimatic data from western Europe, which he used to construct indices of “summer wetness” and “winter severity”. From these he found evidence for warm, dry summers and mild winters centered around A.D. 1100-1200<sup>1</sup>. In European terms, such conditions would have been associated with a prevailing anticyclonic circulation in summer and persistent westerly airflow in winter. Lamb’s studies pre-dated modern quantitative paleoclimatology so the values of temperature change that he attributed to this period (1-2°C above “average”) are essentially anecdotal, and based largely on his own estimates and personal perspective. Lamb never made estimates of the magnitude of a Medieval temperature anomaly on a global, or even hemispheric-scale; his estimates are for the region where most of his data came from—western Europe. Furthermore, since his work was published in 1965, his comparison of temperatures in the past with “today” was based on mean temperatures for the period 1931-60, which was accepted at that time as the climatological norm. Lamb alluded to a few studies in other parts of the world where conditions appeared to have been warm at this time, but he presented no analysis of globally extensive data. In spite of this limited geographical and temporal basis for the concept of a MWE, numerous studies have used the term to frame whatever climatic anomaly might have occurred at some time within the more broadly defined Medieval period (A.D. 500-1500)—even if the record is unrelated to temperature. This has led to a classic reinforcement syndrome, in which ill-defined evidence for a diverse range of climatic anomalies – occurring over a wide range of time intervals –

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<sup>1</sup> To historians, the term Medieval refers to the period from the Fall of Rome (A.D. 476) to the Renaissance (~A.D. 1500), but Lamb’s “Medieval” Warm Epoch was more restricted in time and centered around A.D. 1100-1200 (sometimes referred to as “High Medieval” time).

has created the notion that the MWE was a definitive global phenomenon. However, a careful examination of long-term paleoclimatic data shows that this is not the case. Lamb was correct in his assessment that western Europe was warm in the 12<sup>th</sup> century, and subsequent studies have revealed warm conditions extended to Greenland and as far as the northern Ural mountains. But there are as yet few definitive paleotemperature studies from North America, the Tropics or from the southern hemisphere (which make up ~85% of the surface area of the Earth) that these regions were anomalously warm *at the same time*. As one might expect, it is not hard to find evidence for warm episodes falling at some time within the thousand year span from A.D. 500-1500, but there is no evidence that such episodes were synchronous (Figure 1). Thus, hemispheric mean temperature anomalies in Medieval time were not exceptional, as regions with both positive and negative temperature anomalies tend to cancel out.

How warm was it in “High Medieval” time? It is important to note that the rate of global temperature change has been extremely fast in the last two decades so any discussion of warm periods in the past relative to “today” must clearly articulate what periods are being compared. For example, mean annual northern hemisphere temperature during Lamb’s “climatological normal” of 1931-60 was 0.17°C lower than in the period 1971-2000. Large-scale studies of past temperature variations, which reconstruct mean annual or summer temperatures for the northern hemisphere from a variety of paleoclimatic data, are consistent in showing a decline in temperatures from A.D.1000 (when such studies generally start) to the late 19<sup>th</sup> century, followed by an abrupt and unprecedented rise in temperature to levels higher than at any time in the last millennium (Figure 1). Such analyses, when scaled to the same base of reference, show that temperatures from A.D.1000-1200 (or A.D.1100-1200) were similar to the 1902-1980 mean (-0.04°C), but ~0.35°C below the late 20<sup>th</sup> century (1971-2000) average (Figure 2). Thus there is no evidence that overall northern hemispheric temperatures were warmer than in recent decades during the so-called Medieval Warm Epoch, and the very limited data from the southern hemisphere provide no reason to think that this conclusion is not applicable to the earth as a whole.

Why was western Europe warm in High Medieval time? Recent studies of the effect of solar irradiance forcing point to a possible explanation for the anomalously warm conditions in western Europe during High Medieval time, that Lamb described. High levels of total solar irradiance that characterized the period (Figure 3) tend to be associated with warm conditions in northern and western Europe. These are related to circulation anomalies in the region, possibly involving a shift in the mode of the North Atlantic or Arctic Oscillation. The circulation anomalies are forced from the stratosphere, as a result of anomalous warming in that part of the atmosphere, due to absorption of excess ultra-violet radiation by ozone. Other factors may have reinforced these circulation changes. The period from A.D.1100-1260 had a high level of explosive volcanism (as recorded by ice cores in both Antarctica and Greenland). In the 20<sup>th</sup> century, such events commonly led to exceptionally warm winters in northern Europe and northwestern Russia, and this may have also been a factor influencing the frequency of mild winters in this region during High Medieval time.

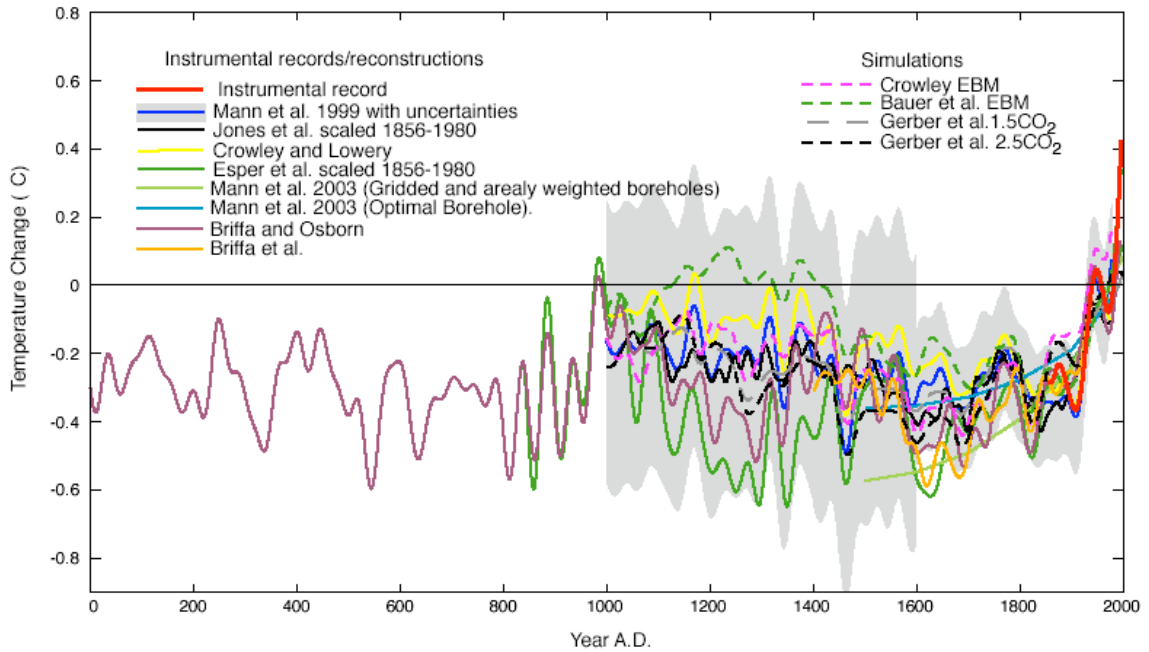
Careful analysis, unfettered by pre-conceived ideas, reveals no *prima facie* case for a globally extensive, synchronous warm period in Medieval time. It is a will-o'-the-wisp that distracts from understanding the true nature of climate variability and climate forcing over the past two millennia. Of more significance is evidence for widespread *hydrological* anomalies in the interval from ~A.D.900 to A.D.1300. For example, Stine (1994) described compelling evidence that prolonged drought affected many parts of the western United States (especially eastern California and the western Great Basin) from (at least) A.D.910 to ~A.D.1110, and from (at least) A.D.1210 to ~A.D.1350. Other parts of the world also experienced persistent hydrological anomalies during this period. This led Stine to argue that a better term for the overall period was the “*Medieval Climatic Anomaly*” (MCA), which removes the emphasis on temperature as its defining characteristic. Prolonged droughts in some areas, and exceptional rains elsewhere, suggest that widespread changes in the frequency or persistence of circulation regimes may account for the unusual nature of this period in many regions, but the causes of such persistent anomalies remain unknown. Pursuing this matter is much more important to our understanding of how anthropogenic forcing may interact with underlying climate variability than continuing to promote an irrelevant paradigm.

### **The Little Ice Age**

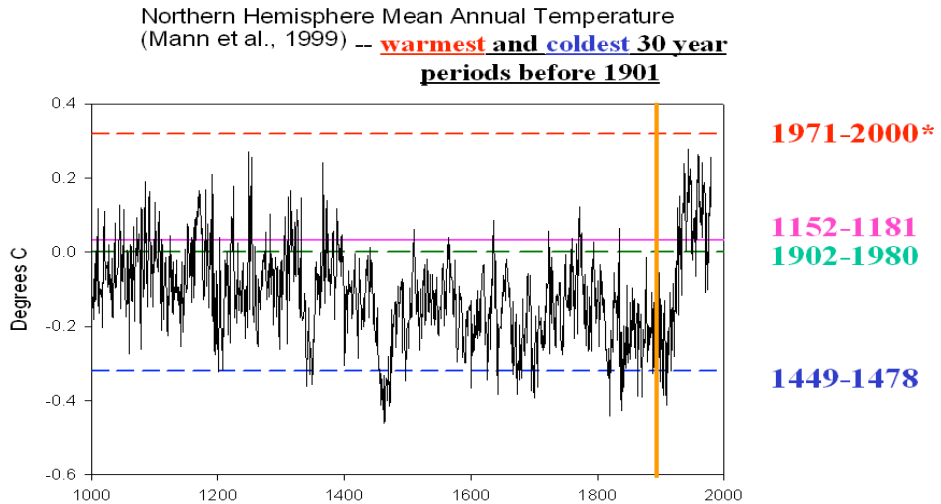
Evidence for a “Little Ice Age” (LIA) is far less controversial than for the Medieval Warm Epoch. Numerous studies provide strong evidence that cooler conditions characterized the period that followed High Medieval time. Since there were regional variations to this cooling episode, it is difficult to define a universally applicable date for the “onset” and “end” of the period, but commonly ~A.D. 1550-1850 is used to bracket the onset and termination of the LIA. However, there is evidence that prolonged cold episodes were experienced much earlier in some regions, and glacier advances were common by the late 13th century in many alpine areas around the North Atlantic and in western Canada. The definitional problem is illustrated in Figure 1 which shows temperatures gradually declining over the first half of the last millennium, rather than a sudden “onset” of a “LIA”. If these reconstructions are accurate, they might explain why different mountain areas registered the onset of this neoglacial episode at different times. As temperatures cooled the threshold temperature for positive mass balance and glacier advances may have been reached in some areas sooner than others, leading to seemingly heterogeneous regional responses. However, by the late 16th century almost all regions had registered glacier advances, and these conditions generally persisted until the mid- to late 19th century making the term “Little Ice Age” ubiquitous and meaningful for this interval. Nevertheless, even within the period 1550-1850 there was a great deal of temperature variation both in time and space. Some areas were warm at times when others were cold and *vice versa*, and some seasons may have been relatively warm while other seasons in the same region were anomalously cold. But whatever date one selects for the “onset” of the LIA, there is little doubt that it was firmly at an end by the beginning of the 20th century. The reduction in ice masses that had accumulated over preceding centuries has continued to the present (in fact, the rate has accelerated) in almost all regions of the world.

No doubt the complexity, or structure that we see in the climate of the LIA is a reflection of the (relative) wealth of information that paleoclimate archives have provided for this period. Nevertheless, when viewed over the long term this overall

interval was undoubtedly one of the coldest in the entire Holocene. If we had similar data for the last 1000 years, our somewhat simplistic concepts of Medieval climatic conditions would certainly be revised and strong efforts are needed to produced a comprehensive paleoclimatic perspective on this time period. Only with such data will we be able to explain the likely causes for climate variations over the last millennium.



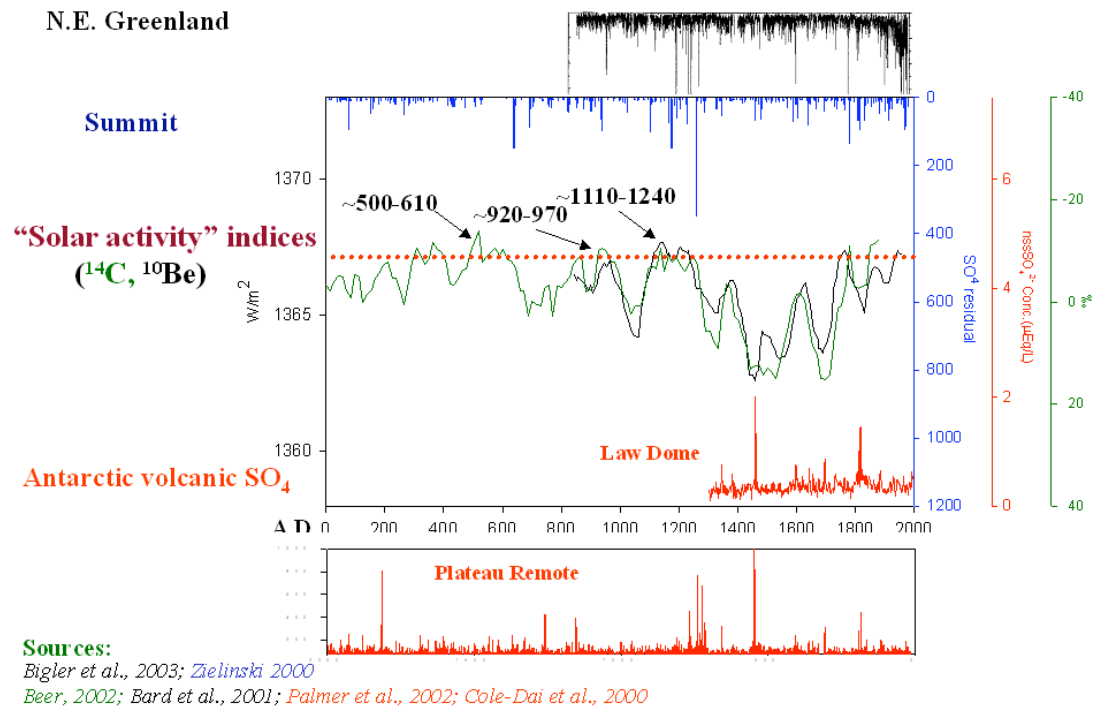
**Figure 1.** Various reconstructions of temperature over the last 1000-2000 years, relative to the reference period 1961-90. All reconstructions have been scaled to the annual, full Northern Hemisphere mean, over an overlapping period (1856-1980), using the NH instrumental record [Jones *et al.*, 1999] for comparison, and have been smoothed on time scales of >40 years to highlight the long-term variations. The smoothed instrumental record (1856-2000) is also shown (from Mann *et al.*, 2003).



*\*Instrumental data*

**Figure 2.** Mean annual northern hemisphere temperatures for various periods over the last millennium, relative to recent instrumental means. In this analysis (Mann et al., 1999) the warmest 30-year period prior to 1901 was 1152-1181, and the coldest was 1449-1478.

### Greenland volcanic SO<sub>4</sub>



**Figure 3.** Some indices of volcanic and solar forcing over the last 2000 years