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The Little Ice Age in the North Atlantic Region

Part I: Introduction to Paleoclimatology

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Abstract

It is widely held by both evolutionists and creationists that earth history includes periods of glacial advance known as "ice ages." In most cases, the extent, causes, and effects of an ice age are speculative excursions into undocumented natural history. The salient exception is the Little Ice Age, which extended into the beginning of the modern age of weather instrumentation and measurement. While evidence indicates the Little Ice Age was global, it was particularly well documented in the North Atlantic Region. This is particularly fortuitous for diluvialists, as this region provides an especially useful set of conditions for testing predictions of the rapid, postdiluvial Ice Age model. The first paper in this series reviews the methods used to study climates of the past, particularly their application to the Little Ice Age.

Introduction

Tremendous political pressure is now being exerted worldwide in the name of averting catastrophe from anthropogenic global warming. This often clouds scientific discussion of climate change. While predictions of soaring temperatures, coastal inundation, and desertification take the headlines, the preceding several centuries witnessed notable human suffering and even the demise of whole peoples due to the opposite problem, the Little Ice Age. Evolutionists largely believe that there have been many ice ages that have come and gone over thousands and millions of years. Most creationists believe there was a single, relatively brief ice age after the Biblical Deluge. Both of these positions are speculations without the aid of historiography. Their models need "calibration" from similar phenomena that can be or have been observed. The Little Ice Age, particularly as witnessed in the North Atlantic region, provides a singular means of evaluating ice age models and geologic features inferred to be glacial, as well as postdiluvial climatology in general. This paper presents the historical and scientific methods used to research climatology and glaciation, with particular reference to the North Atlantic region and the Little Ice Age.

Climatology—A Hot Topic

The winds of opinion regarding climate change have reached such strength that it is often difficult for scientists to venture into meaningful, fact-based discussions. Popular magazines such as *Time* (Kluger, 2006) hype global warming and make it seem that every disaster can be blamed on global warming, or "climate change" as it is now being called. The public is becoming carried away with the fear of global warming, so much so that one woman claims to have aborted her baby to reduce her "carbon footprint." Practically every issue related to global warming has been distorted (Lomborg, 2007). Those scientists who have become skeptical that man has caused all

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the global warming are often labelled as "working for the energy companies" (Gore, 2006, pp. 284–287).

Is *Little Ice Age* Hyperbole?

Global warming or even *climate change* is a meaningless term, scientifically, without a datum for comparison. Similarly, whether the term *Little Ice Age* is overdrawn depends on how it is defined. What was the Little Ice Age? We employ the definition of Grove (Ogilvie and Jónsson, 2001): the Little Ice Age was a period of widespread glacial advance on a global scale during the past millennium. While colder temperature is generally linked with glacial advance, it is not the only climatic factor. The Little Ice Age did not appear or disappear overnight, of course, but is generally agreed to have occurred from about the middle of the 1300s to the middle of the 1880s.

The Little Ice Age was a disputed concept even before it was over. Such leading lights as Thoroddsen in Iceland and Fridtjof Nansen in Norway held to the school of "uniformitarians," who believed the range of weather of the 1800s was typical and denied the existence of the Medieval Warm Period or significant, century-scale climate change. This skepticism was soundly dispelled as the Little Ice Age ended, especially by the notable warming from the 1920s to 1950s (Ogilvie and Jónsson, 2001).

Some have objected to the term "Little Ice Age," claiming it is a misnomer, ambiguous, not a worldwide phenomenon, lacking continental glaciation, or disproven by a lack of sustained low global temperature (Grove, 1988; Mann, 2002). Some use the term (or the synonyms *Fernau* and *Kleine Eiszeit*) grudgingly (Ogilvie and Jónsson, 2001). A tendency among global warming advocates is to downplay the Little Ice Age and to give it a more regional extent (Mann, 2002).

While popular computer-generated temperature curves, particularly the Mann et al. (1999) "hockey stick" popularized by the Intergovernmental Panel on Climate Change (IPCC) publications, have "smoothed out" much of the Little Ice Age temperature record, there is no smoothing out history. As will be documented in later parts of this paper, ice advanced in Iceland, Norway, Greenland, Switzerland, and other lands, overrunning farms and villages.

> On several occasions between 1695 and 1728, inhabitants of the Orkney Islands off northern Scotland were startled to see an Inuit in his kayak paddling off their coasts. On one memorable occasion, a kayaker came as far south as the River Don near Aberdeen (Fagan, 2000, p.116).

The Kattegat (strait between the North and Baltic Seas) froze over, and the Swedish army crossed the ice to defeat the Danes in 1658 (Rian, 1994). Crops failed frequently throughout Europe, and particular crops could no longer be grown as far north as they had been previously (Fagan, 2000). The Russians turned their deadliest weapon—winter—on Napoleon in the great French defeat of 1812. These were tangible—all too tangible—effects of significant, century-scale climate change.

Our focus on the North Atlantic region is not based on belief that the Little Ice Age was limited to this area. It was global, as will be shown in Part II of this series. However, we also recognize the validity of some of the criticisms by those who take issue with the term "Little Ice Age." Some of these objections are based on differences from the inferred Great Ice Age (or ice ages) that will be the focus of Part VII in this series.

While large continental ice sheets outside of Greenland and Antarctica have never been observed, we will not dispute that they have existed in North America, Northern Europe, and Russia. Instead, in Part VII of this series we will compare what was observed in the Little Ice Age to what would be necessary for such large continental ice sheets to form.

Importance of the Little Ice Age

Without the Little Ice Age, natural history speculations about climate change, particularly ice ages, would remain poorly constrained. The Little Ice Age provides an invaluable means of applying more science to our speculations.

Importance to Climatology

The present time provides an unparalleled emphasis on climatology in general and climate change in particular. Fears of global catastrophe caused by global warming have induced many to propose significant, restrictive legislation (Conant et al., 2007; Gore, 2006). Whether present and proposed actions are too little or too much cannot be known without defensible data regarding climate change. While the present state of climatology, particularly in regard to climate models, may be inadequate to reach an informed conclusion anytime soon (Posmentier and Soon, 2005), the Little Ice Age provides an adequately documented period of climate change significant enough to reach preliminary conclusions. Although the modern perception of increased natural disasters is largely baseless (Austin, 1998; Cerveny, 2005), the profound effects of the Medieval Warm Period and Little Ice Age were real.

Importance to Glaciology

Since the work of early creationist glaciologist Louis Agassiz in the 1800s (Imbrie and Imbrie, 1979), most glaciological investigations have proceeded on relatively steady state conditions on alpine glaciers. Fluctuations in glaciers, particularly the large-scale recession since the Little Ice Age and also surging glaciers, have provided opportunities to expand our knowledge of the physics and climatology of glaciers.

Importance to Geology

Much of glacial geology has been natural history speculation rather than geologic science (Klevberg, unpublished data). Glacial landforms and deposits have been largely inferred rather than observed. The Little Ice Age provided a large-scale opportunity to redeem glacial geology by observing geologic effects of known historic events.

Importance to Understanding Natural History

Earth history is not the primary theme of the Bible or of the better books of history written in more recent times. Earth history lacks the detailed historiography of political history, yet it is important to humanity in a fundamental way, both reflecting and undergirding one's worldview. The Little Ice Age provides data for testing some of the conclusions one may draw from the disparate natural histories of traditional naturalism and Biblical Christianity.

Methods in Climatology and Paleoclimatology

Weather fluctuates constantly and differs markedly in time and space. It is a fascinating field of study, filled with complexities and many mysteries yet to be solved (Oard, 1997a). Climate is the long-term environmental average of weather and thus more predictable; however, climate too varies greatly in time and space. Paleoclimatology is the study of past climate, in particular climate before the advent of instrumental records.

Instrumental Data

Instrumental data and observations provide the only *direct* means of studying climate. Were instrumental data available for the entirety of the past millennium, the need for proxy data would be slight. Since instrumental records are available for only approximately the past century, proxy data are necessary. The spatial distribution of instruments, while much better than it was previously, remains less than ideal. The length of each instrumental record usually differs from the next, creating additional statistical problems (Juckes et al., 2007). Changes in instruments, recording stations, and surrounding land use have all affected instrumental data and must be compensated for in a careful paleoclimatologic analysis.

Proxy Data

Proxy data fill voids in the instrumental record. They fill voids in the historical record also and provide a level of specificity lacking in early historiography. Proxy data are used to develop transfer functions to infer temperature or other climatic variables, and these transfer functions are then used to develop climate models (see Figure 1).

Why Proxy Data Are Needed

Instrumental data for most regions stretch back only a century or so. One exception is Iceland, where the first instrumental records date from the 1700s and are continuous starting in the 1800s (Jónsson and Garðarsson, 2001). In many parts of the world, the instrumental record is much younger, and spatial coverage is greatly lacking, especially over oceans. Thus, both in time and space, proxy data are essential for inferring the paleoclimate.

Types of Proxy Data

Types of proxy data, with instrumental measurements for comparison, are summarized in Table I. Instrumental records are the only *direct* records of climate, but they are very limited both temporally and spatially in the past millennium, the time of the Medieval Warm Period and Little Ice Age. The minority of proxy methods are *historical* records, records compiled by contemporary observers or directly linked to them. The majority of proxy methods are indirect methods that rely on natural history presuppositions—radiocarbon dating, dendrochronology, paleomagnetism, etc. These methods are often combined in practice, which potentially increases their precision and reduces their accuracy (by multiplying the errors in the different methods).

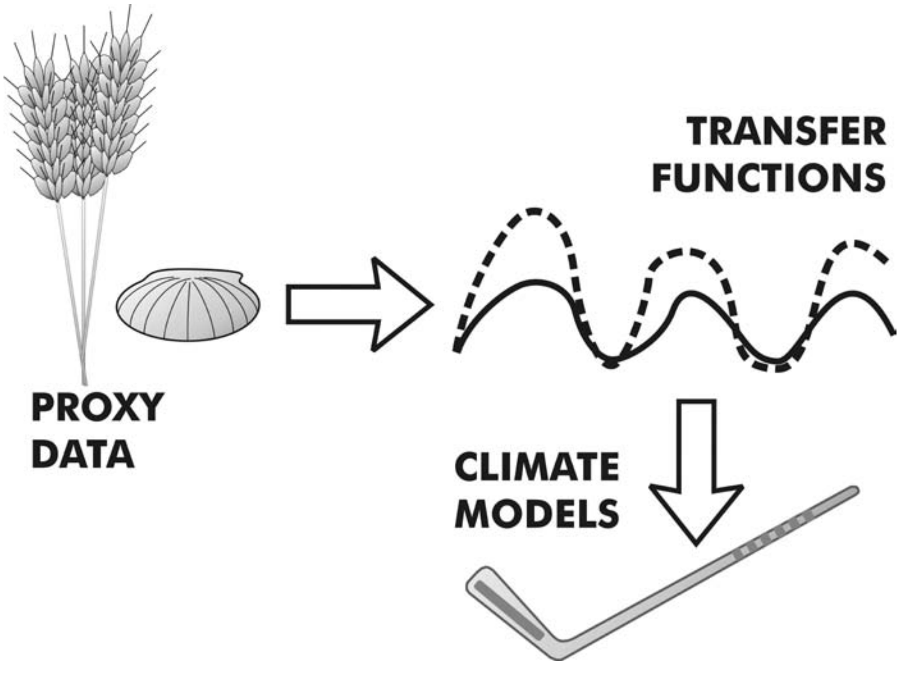

Figure 1. Illustration of how proxy data are used to generate a model.

Table I

Data Type	Direct?	Historical?	Dependencies	Limitations	Interferences
Instrumental	Yes	Yes	Spatial	Records begin after peak of L.I.A.	Urban heat island, station moves
Weather diaries	No	Yes	Observer bias	Few available, short periods of time, largely qualitative, little overlap	Changes in observers, hiatuses
Crop records	No	Yes	Must be same varieties	Must have been grown in same area over prolonged period.	War, disease, changes in crops and crop practices.
Datable organic remains	No	Yes	Accuracy of dates	Very few historically dated materials available	Historic reuse may result in false assumption of first date
Ice in harbors, rivers	No	Yes	Favorable climatic conditions	Continuous historical records must be available	Stream diversion, land use changes, or other major anthropogenic influences
Art work, narratives	No	Yes	Historical realism	Accuracy of original work, dating of work, availability	"Artistic license," artistic ability, accuracy of dates
Lichenometry	No	No	Observer bias, species present, preservation of individual organisms	Need for recognizable moraines or other extent indicators; significant variation in quality of work between observers	Erosion or other factors removing largest lichens, differences between species, climatic or other changes impacting calibration curves
Benthic organisms	No	No	Knowledge of taxonomy and habitat; typically anchored to ^{14}C	Must have adequate sample population and representative sampling	Erosion, sampling problems, any ecologic changes unrelated to climate
Ice cores ($\delta^{18}O$, etc.)	No	No	Dating largely subjective interpretation assuming annual fluctuations	Layers too thin for accurate distinction beyond several centuries	Isotopic mixing may blur signal or shift it.
Sea sediment cores ($\delta^{18}O$)	No	No	Dating largely subjective interpretation assuming annual fluctuations	Thinness of layers, sampling methods, methods of distinguishing layers	Isotopic mixing may blur signal or shift it.
Speleothems ($\delta^{18}O$, etc.)	No	No	Dating largely subjective interpretation assuming annual fluctuations; requires steady supply of mineral-rich water (no interruption)	Not many speleothems of adequate age available	Interruption of water supply may produce multiple layers in one year or missing years

Table I (continued)

Data Type	Direct?	Historical?	Dependencies	Limitations	Interferences
Dendrochronology	No	No	Depends largely on subjective ring matching; relation of tree to moraine important	Must have adequate quality sample from stump or other means of identifying it with glacial event	Reworked wood, decay, mismatching of rings between specimens, microclimatic effects during wood formation
^{14}C dating of wood in moraines	No	No	^{14}C rife with problems, wrong assumptions; wood must be recognizably buried by glacial action at time of death	Same as above plus lack of processes affecting carbon isotope ratios	Reworked wood, ground water and other "old carbon" effects
^{14}C dating of soils, peat, etc.	No	No	Same as above plus problematic nature of dating soil carbon	Soil horizon or organic layer must show evidence of having been buried by glacier at time of death/preservation	"Old" carbon may produce errant results, soil chemistry may interfere
Paleolimnology	No	No	Must have lake with relatively closed-basin conditions for accumulation of sediments; typically dependent on ^{14}C dating	Suitable only for some lakes; requires relatively undisturbed sample, effective means of accurately distinguishing layers	Isotopic mixing, changes in land use or other factors impacting sedimentation that are unrelated to climate
Palynology	No	No	Above but also must have consistent and adequate contribution of pollen	Preservation of pollen grains must be adequate in quality to permit identification and adequate in quantity to permit estimation of ecologic balances	Same as above, plus disease, land use changes, other impacts to plants unrelated to climate
Paleomagnetism and mineralogy	No	No	Similar to sea and lake sediment dependencies plus climate - mineralogy relationships	Same as sea sediment cores and paleolimnology plus ability to accurately measure magnetic susceptibility and paleomagnetic orientation.	Changes in mineralogy unrelated to climate (e.g. sediment sources); paleomagnetic interpretations typically based on uniformitarian assumptions

Ice cores have been relied upon greatly for paleoclimatologic research. The best known are the ice cores from Greenland, though Svalbard, Antarctica, Quelccaya in the Andes, and other locations have also contributed ice core data (e.g. Grove, 1988; Kekonen et al., 2005). In recent years, huge quantities of ice core data have been amassed (cf., Kjøllmoen, 2007; NORPAST, 2001; Oard, 2005). While some studies appear to put great weight on interpretations of ice core data (Mann and Jones, 2003), others indicate this is misplaced confidence (Juckes et al., 2007; Oard, 2005).

Dendrochronology is one of the most important proxies for the past millennium. Historically documented glacial advance and retreat in Switzerland correspond remarkably well with tree ring density curves (*Picea*), with notable glacial advances when summer temperatures were on average 1°C cooler than the long-term average (Grove, 1988; Paulsen et al., 2000). Trees respond primarily to accumulated summer temperature (Stötter et al., 1999).

Difficulties with Proxy Data

As shown in Table I, virtually any proxy data set is accompanied with minor or major problems. In addition to natural limitations of these various methods, such as lack of temporal or spatial coverage, serious methodological problems may be present too. These are largely related to assumptions that must be made about the past, with the result that error may increase significantly the further back in time the data are projected (Bradley and Jones, 1993; D'Arrigo et al., 2006; Rutherford et al., 2005; Schmutz et al., 2000).

A common problem with proxy data is comparability. Proxies such as tree rings, crop records, and pollen may give an idea of the average summer temperature, the peak summer temperature, or the length of the growing season, but they will not provide information on the severity of winters. Ice in harbors or rivers may provide an idea of the severity of a winter or the length of the winter, but without necessarily being able to differentiate between them. Written records are usually necessary to differentiate between such input variables, potentially producing some rather unusual but usable proxies (Vasey, 2001).

Many proxies respond to a variety of variables, not just temperature (or precipitation, or another variable of interest). Proxies can be as diverse as borehole temperatures and beetle species (Buckland and Wagner, 2001), but they can respond to variables as diverse as deforestation and detergent, and care must be exercised in interpreting each one.

Transfer Functions

Transfer functions provide a mathematical relationship between proxy data (e.g., duration of ice on a lake, length of growing season, oxygen isotope ratios) and the variable of interest (e.g., average annual temperature, average winter temperature, minimum summer temperature). Transfer functions by definition are intended to extend the relationships observed historically between environmental variables into the unobserved past. They are therefore forensic by nature and enter the realm of *natural history*, in which scientific methods are adjuncts, subservient to the methods of historical study (Adler, 1965; Reed et al., 2006). The assumptions that are employed in that historical study—whether uniformitarianism, catastrophism, or diluvialism—may significantly influence the way the transfer functions are formulated and applied. The further back in time one speculates, the greater the potential error in the inferences.

Some of the most important potential sources of systematic error are radioisotope dating (especially carbon 14) and dendrochronology, as these are heavily dependent on uniformitarian presuppositions and widely used to "calibrate" various transfer functions. Transfer functions are generally calibrated to the instrumental record, but many transfer functions derived from various proxies are "calibrated" to radiocarbon dates or tree rings due to the limited instrumental record (see nearly any paper on medieval or earlier paleoclimatology). Creationists have done significant research on the validity of radiocarbon dating, and documentation of the flaws of the method is beyond the scope of this paper. Note that errors in dating will result in errors in derived transfer functions, and these errors will be propagated in climate models based on these transfer functions. Appendix A presents a more detailed presentation of the effects of ^{14}C dating and dendrochronology on transfer functions. Another method used to "calibrate" transfer functions is varve chronologies. That these are likely to be highly inflated and may well represent non-annual rhythmites (at least in the vast majority of cases) has been demonstrated elsewhere (Oard, 1997b; 2009). Paleolimnology (lake sediment) studies have produced problems by attempting to evaluate sediment cores stratigraphically and based on paleomagnetic correlation. These problems are acknowledged by establishment researchers (NORPAST, 2001, ss. 2.2.1, 4.3, 5.1).

Data are typically "smoothed" to make them more comparable to other data and to make trends easier to observe. "Smoothing" often consists of generating running averages (Figure 2) and graphing them (Figure 3) to remove the wild short-term swings typical of weather. Other statistical methods may be applied; some of these are less self-evident and could be prone to bias (Esper et al., 2005). "The results of calibrating any proxy data depend on whether raw or smoothed records are used and on the chosen seasonal temperature predictand" (Briffa and Osborn, 2002, p. 2228). Varying approaches in calibrating proxy data to temperature records (i.e. transfer functions) can produce very different climate models (Esper et al., 2005; Juckes et al., 2007).

Principal Component Analysis

To create a climate model that can be programmed into a computer and used to infer the past or predict the future requires a means of effectively combining transfer functions. These functions are evaluated for "predictive skill," i.e., how well they match observed data. A combination of transfer functions, often from diverse proxies assembled in the form of a "neural network," can be compared with data from the instrumental

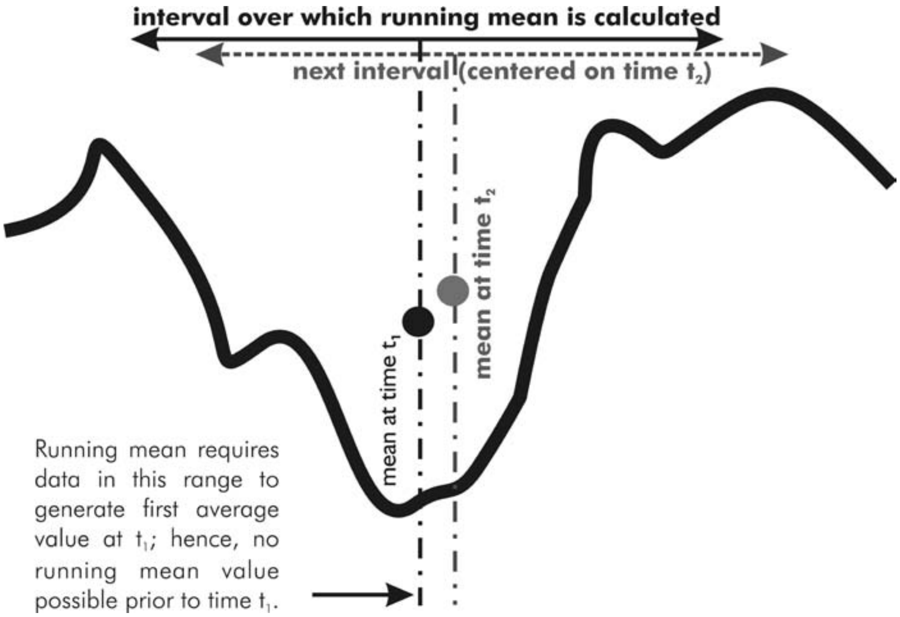

Figure 2. Generating a running mean.

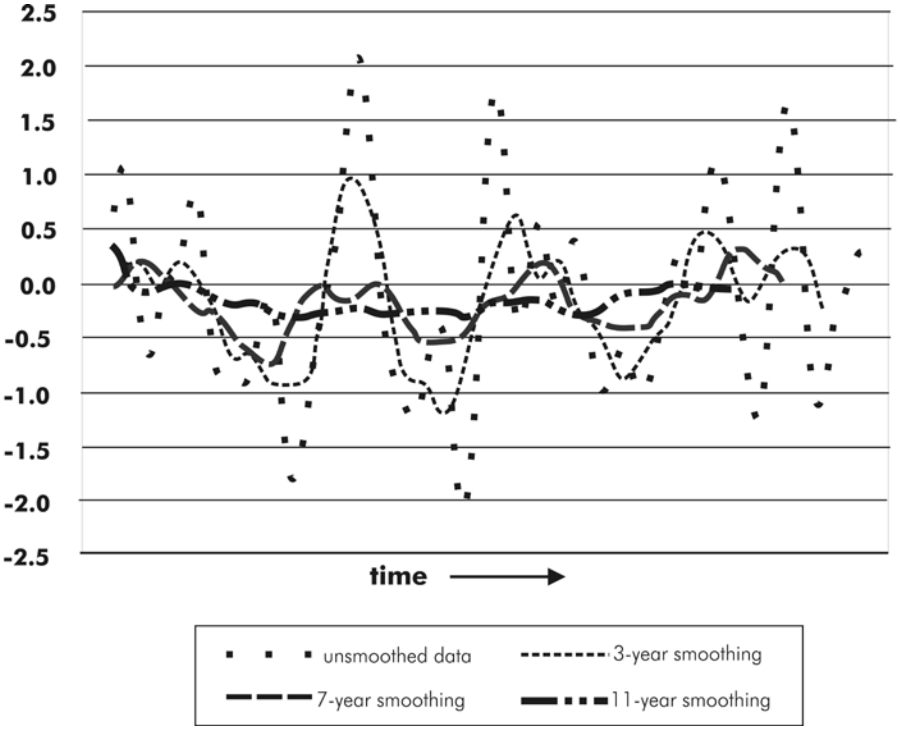

Figure 3. Smoothing data using running means.

record for a calibration period and an eigenvector analysis performed (similar to geologic applications; e.g., Klevberg and Oard, 2005). The empirical eigenvectors, often referred to as "principal components," provide the strongest "signal" amidst the ubiquitous "noise" of the highly complex data representing weather and climate patterns. They are heavily influenced by the choice of proxy data and the weighting given the different data sets. Principal component analysis is a necessary step in developing and optimizing transfer functions. Readers not familiar with principal component or eigenvector analysis may wish to read Appendix B.

Modeling

Once the eigenvectors have been derived from the overall data set, they can be assembled into a model. A model might be represented thus:

$$F = P_1 + P_2 + P_3 + P_4 + P_5 + R$$

Where the overall function is a combination of five (or some other number) principal components (i.e., empirical eigenvectors) and some remainder or "noise" term. The success of the model is judged on the basis of the correspondence between these principal components and observations and is evaluated against a verification period of the instrumental record that differs from the calibration period (otherwise, it would be tautologous). Thus, the longer the calibration period, the better should be the resulting model, but at the expense of the verification period and vice versa.

Figure 4 shows some of the most prominent climate models for the past millennium. To a large extent, these models have been derived from the same data. Of course, the models are only as good as the transfer functions upon which they are based and the proxy data from which the transfer functions are derived.

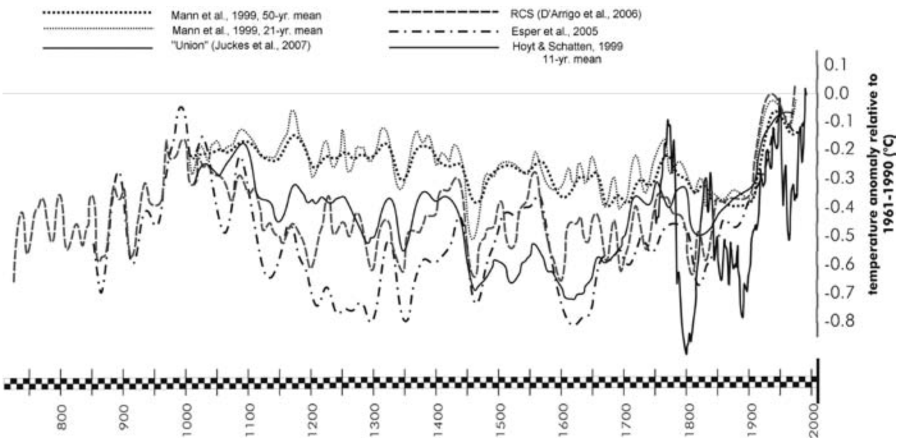

Figure 4. Graph comparing notable models for Northern Hemisphere average land surface temperature.

To Each His Own: History Versus Science

As has been presented elsewhere (Klevberg, 1999; Reed, 2001; Reed et al., 2004), the battle over natural history is not a battle between science and religion but a battle between two incompatible worldviews (Morris, 1989; Ham, 1987; Mortenson, 2004; Reed, 2005). Disagreements over paleoclimatology are a subset of this larger incompatibility.

Essential Philosophic Distinction

Evidence is not all cut from the same cloth; there are different types of evidence (Tyvand, 2009). History is not science, yet paleoclimatological studies must partake of both. There are different methods that must be combined, each method in its own sphere, to properly evaluate "mixed questions" (Adler, 1965) such as we shall investigate in this series. This essential philosophic distinction is typically ignored, glossed over, or outright denied by evolutionists and all too often overlooked or misunderstood by creationists (Reed and Klevberg, in press).

Models Versus Historiography

As we have attempted to make clear in this paper, we believe there has been too much emphasis on sophisticated expression of opinion—models—and too little careful historical analysis. Paleoclimatology is the study of history using the tools of modern climatology and atmospheric science; it is a branch of history, not science. In historical study, the most import must be placed in the testimony of eyewitnesses (Deut. 17:6, 19:15–19; Ruth 4:9–11; 1 Sam. 12:5; Isa. 43:9; Jer. 32:10; Matt. 18:16; John 1:7, 5:31–39; Acts 1:21–22, 2:32, 10:39; 2 Cor. 13:1; 1 Tim. 5:19; 1 John 5:7–8) rather than speculations, even if the speculations are our own. If historical accounts that appear to be well attested and consistent seem to indicate certain conditions prevailed at a given time, and one's climatic model suggests otherwise, the burden of proof is on the model. None of us was there at the time.

Which Bias Is the Best Bias to Be Biased With?

Since paleoclimatology must inevitably move from the realm of science into the realm of history, it will inevitably be affected by the natural history worldview held by the researcher. Bias is inevitable, but the bias and the potential effects of the bias should be recognized openly.

As creationist speaker Ken Ham is well known for saying, "Which bias is the best bias to be biased with anyway?" Differences in conclusions regarding past climate may well result from these different biases.

Data Selection

Diluvialists will want to place the heaviest possible emphasis on historical records. This is not to deny the potential for errant historiography or that light may be cast on the veracity of a historical account by the use of other proxy data. We have junk historiography aplenty today, just as we have junk science, but this is nothing new. Historians have always varied in their reliability; we have Tacitus, James Ussher, and Arnold J. Toynbee, but we also have Michel Foucault, Hayden White, and Joan W. Scott. Nonetheless, when it comes to the unique and unrepeatable phenomena of history, the methods of historical research must govern, and good historical records can be found. The level of confidence exhibited by some in speculative transfer functions and models, sometimes contrary to historical records, is not justified and should not be emulated.

All proxy data sources require the kind of careful review that should typify a historian, whether they are data more familiar to scientists or traditionally the realm of historians. For example, economic results are sure to be recognizable from a major climatic deterioration (Vasey, 2001), but climate change may be only one factor (Rian, 1994).

Transfer Functions

Diluvialists will be much less inclined to extrapolate transfer functions or calibrate them to dubious dating methods. Instrument measurements over the past 100 years and historical records should be given greatest weight when developing transfer functions. These should be used to evaluate the veracity or applicability of statistical methods (cf., Esper et al., 2005).

Eigenvector Analysis

The mathematics of eigenvector analysis or principal component analysis are not a matter of controversy. What is a potential source of disagreement is the rigor with which statistical methods are applied, especially to individual data sets, and the weighting given to different data sets. Many proxy data sets have "holes" that may require careful analysis to "bridge" before an eigenvector analysis can be performed, a step that has not always been properly performed in climate modeling (McKitrick, 2005). Differences that may result from bias during such "hole filling" are illustrated in Figure 5.

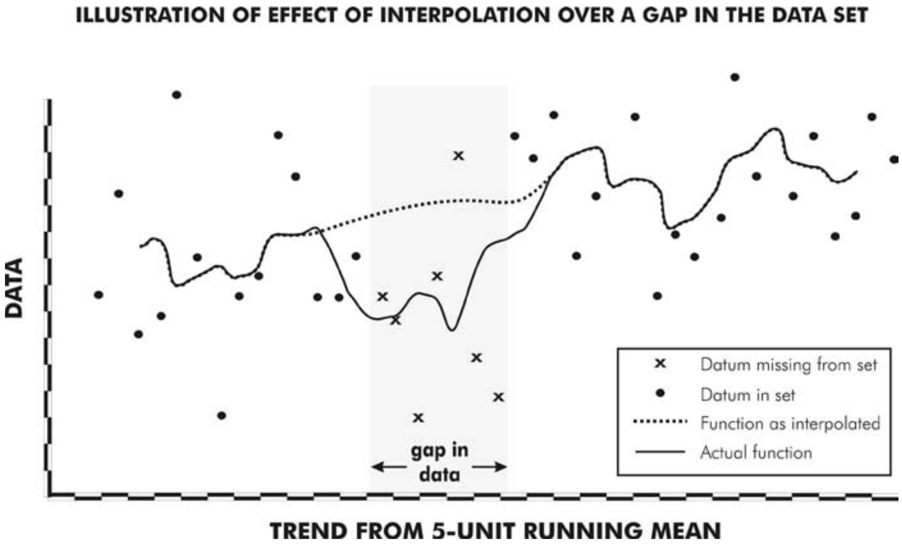

Figure 5. Comparison of curve inferred across data gap with actual data. (Data are hypothetical for illustrative purposes only.)

Modeling

The predictive skill of currently popular climate models is quite low (Posmentier and Soon, 2005). Models developed to reflect land surface temperatures fail to reflect the actual observations in the troposphere (Michaels, 2005). These models are merely sophisticated tools to help us better understand climate change, and none of them truly represents the history of climate. Diluvialists, free from blind commitment to uniformitarianism and its predicted gradualism, will be less inclined to trust in computer models and inclined to put more confidence in historical records.

Summary

The specter of climate change has taken center stage in recent years, yet no meaningful study of climate change is possible without a datum for comparison. This requires historical study of climate, and the most notable climatic phenomenon of recent centuries was the Little Ice Age, which lasted from roughly the mid 1300s to the mid 1800s. While proxy data are necessary to infer the state of climate over most of the past millennium, the latter part of the time period is covered by instrumental records, and the best proxy

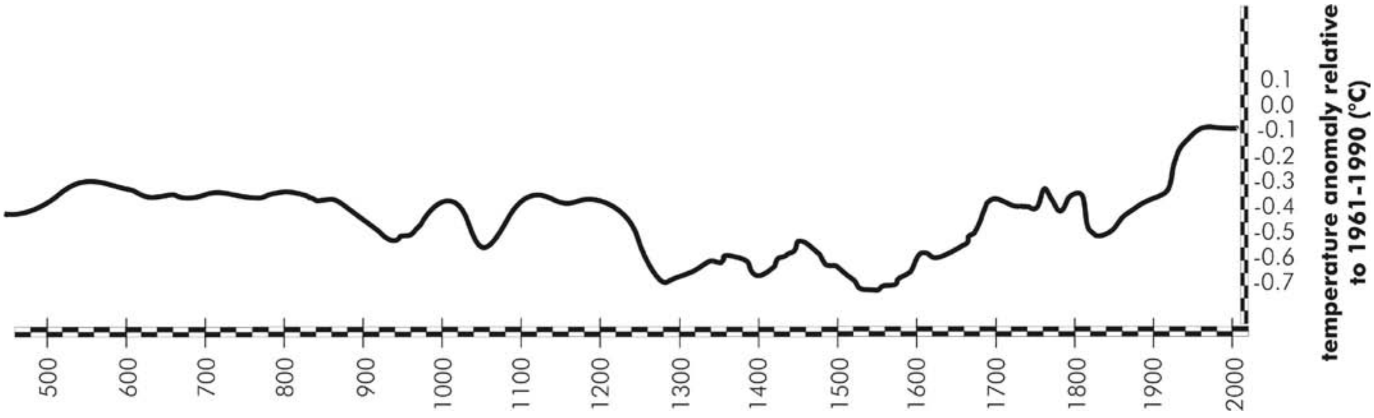

Figure 6. Illustration of "stretching effect" back in time due to uniformitarian bias in transfer function. The curve is hypothetical, for illustrative purposes only, but is based on common Northern Hemisphere land surface temperature curves for the past millennium progressively stretched. This results in what appears to be "anomalously erratic behavior" in recent centuries while in reality it is not.

data for all paleoclimatologic research are—naturally—from the most recent centuries. This provides a great means of tempering earth history speculation with fact. Paleoclimatology is a branch of history, addressing the "mixed question" of past climate with the tools of both historical and scientific study. Biases strongly affect the collection, interpretation, and application of proxy and other data. Models are not neutral. The Little Ice Age has great relevance to questions of natural history, to the study of climate, glaciers, and geology, not only in the North Atlantic region but also in many other parts of the world.

Outline of the Series

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References

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TJ: formerly *Creation Ex Nihilo Technical Journal*, now *Journal of Creation*

Aardsma, G.E. 1991. *Radiocarbon and the Genesis Flood*. Institute for Creation Research, Dallas, TX.

Aardsma, G.E. 1993. Tree-ring dating and multiple ring growth per year. *CRSQ* 29:184–189.

Adler, M.J. 1965. *The Conditions of Philosophy*. Atheneum Books, New York, NY.

Austin, S.A. 1998. Twentieth-century earthquakes: confronting an urban legend. Institute for Creation Research *Impact* 295:i-iv.

Bakke, J., S.O. Dahl, Ø. Paasche, R. Løvlie, and A. Nesje. 2005. Glacier fluctuations, equilibrium-line altitudes and paleoclimate in Lyngen, northern Norway, during the Lateglacial and Holocene. *The Holocene* 15(4):518–540.

Baliunas, S. 2005. Possible effects of solar variability on earth's ecosystems. In Michaels, P.J. (editor), *Shattered Consensus*, pp.210–240. Rowman & Littlefield Publishers, Lanham, MD.

Bradley, R.S., and P.D. Jones. 1993. "Little Ice Age" summer temperature variations: their nature and relevance to recent global warming trends. *The Holocene* 3:367–376.

Briffa, K.R., and T.J. Osborn. 2002. Blowing hot and cold. *Science* 295:2227–2228.

Brown, R.H. 1990. Correlation of C-14 age with the biblical time scale. *Origins* 17:56–65.

Brown, R.H. 1995. Can tree rings be used to calibrate radiocarbon dates? *Origins* 22:47–52.

Brown, R.H. 2006. Update on C-14 age calibration. *CRSQ* 43:54.

Buckland, P.C., and P.E. Wagner. 2001. Is there an insect signal for the "Little Ice Age"? In Ogilvie, A.E.J., and T. Jónsson (editors), *The Iceberg in the Mist: Northern Research in Pursuit of a "Little Ice Age,"* pp. 137–149. Kluwer Academic Publishers, Boston, MA.

Cerveny, R.S. 2005. Severe weather, natural disasters, and global change. In Michaels, P.J. (editor), *Shattered consensus*, pp.106–120. Rowman & Littlefield Publishers, Lanham, MD.

Conant, E., S. Stein, E. Clift, M. Philips. 2007. The truth about denial. *Newsweek*, August 13, pp. 20–29.

Cook, M.A. 1970. Carbon-14 and the "age" of the atmosphere. *CRSQ* 7:53–56.

D'Arrigo, R., R. Wilson, and G. Jacoby. 2006. On the long-term context for late twentieth century warming. *Journal of Geophysical Research* 111:D03103.

Eiríksson, J., K.L. Knudsen, H. Haflíðason, and J. Heinemeier. 2000. Chronology of late Holocene climatic events in the northern North Atlantic based on AMS ^{14}C cates and tephra markers from the volcano Hekla, Iceland. *Journal of Quaternary Science* 15(6):573–580.

Esper, J., D.C. Frank, R.J.S. Wilson, and K.R. Briffa. 2005. Effect of scaling and regression on reconstructed temperature amplitude for the past millennium. *Geophysical Research Letters* 32:L07711-L07711.

Fagan, B. 2000. *The Little Ice Age: How Climate Made History 1300–1850*. Basic Books, New York, NY.

Fischer, A., and J. Heinemeier. 2003. Freshwater reservoir effects in ^{14}C dates of food residue on pottery. *Radiocarbon* 45:449–466.

Fisher, D.A. 2002. High-resolution multiproxy climatic records from ice cores, tree-rings, corals and documentary sources using eigenvector techniques and maps: assessment of recovered signal and errors. *The Holocene* 12:401–419.

Gobet, E., W. Tinner, C. Bigler, P.A. Hochuli, and B. Ammann. 2005. Early-Holocene afforestation processes in the lower subalpine belt of the Central Swiss Alps as inferred from macrofossil and pollen records. *The Holocene* 15:672–686.

Gore, A. 2006. *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It*. Rodale, New York, NY.

Grove, J.M. 1988. *The Little Ice Age*. Metheun & Co., Ltd. New York, NY.

Grove, J.M. 2001. The initiation of the "Little Ice Age" in regions round the North Atlantic.

In Ogilvie, A.E.J., and T. Jónsson (editors), *The Iceberg in the Mist: Northern Research in Pursuit of a "Little Ice Age,"* pp. 53–82. Kluwer Academic Publishers, Boston, MA.

Guiot, J., A. Nicault, C. Rathgeber, J.L. Edouard, F. Guibal, G. Pichard, and C. Till. 2005. Last-millennium summer-temperature variations in western Europe based on proxy data. *The Holocene* 15:489–500.

Ham, K.A. 1987. *The Lie: Evolution*. Master Books, El Cajon, CA.

Heier-Nielsen, S., J. Heinemeier, H.L. Nielsen, and N. Rud. 1995. Recent reservoir ages for Danish fjords and marine waters. *Radiocarbon* 37:875–882.

Hoyt, D.V., and Schatten, K.H. 1997. *The Role of the Sun in Climate Change*. Oxford University Press, New York, NY.

Ice Core Working Group. 1998. Ice core contributions to global change research: past successes and future directions. National Ice Core Laboratory, University of New Hampshire, Durham, NH.

Imbrie, J., and K.P. Imbrie. 1979. *Ice Ages: Solving the Mystery*. Enslow Publishers. Short Hills, NJ.

Jónsson, T., and H. Garðarsson. 2001. Early instrumental meteorological observations in Iceland. In Ogilvie, A.E.J., and T. Jónsson (editors), *The Iceberg in the Mist: Northern Research in Pursuit of a "Little Ice Age,"* pp. 169–187. Kluwer Academic Publishers, Boston, MA.

Juckes, M.N., M.R. Allen, K.R. Briffa, J. Esper, G.C. Hegerl, A. Moberg, T.J. Osborn, and S.L. Weber. 2007. Millennial temperature reconstruction intercomparison and evaluation. *Climate of the Past* 3:591–609.

Kalela-Brundin, M. 1999. Climatic information from tree-rings of *Pinus sylvestris L.* and a reconstruction of summer temperatures back to AD 1500 in Femundsmarka, eastern Norway, using partial least squares regression (PLS) analysis. *The Holocene* 9:59–77.

Kekonen, T., J. Moore, P. Perämäki, R. Mulvaney, E. Isaksson, V. Pohjola, and R. S.W. van de Wal. 2005. The 800 year long ion record from the Lomonosovfonna (Svalbard) ice core. *Journal of Geophysical Research* 110, D07304, doi:10.10929/2004JD005223.

Kjøllmoen, B. (editor). 2007. *Glaciological Investigations in Norway in 2006*. Norsk Vassdrags og Energi Direktoratet, Oslo, Norway.

Klevberg, P. 1999. The philosophy of sequence stratigraphy–part I: philosophic background. *CRSQ* 36:72–80.

Klevberg, P., and M.J. Oard. 2005. Drifting interpretations of the Kennedy gravel. *CRSQ* 41:289–315.

Klevberg, P., R. Bandy, and M.J. Oard. 2009. Do paleosols represent long ages? In Oard, M.J., and J.K. Reed (editors), *Rock Solid Answers: The Biblical Truth Behind 14 Geological Questions*, pp. 93–110. Master Books, Green Forest, AR, and Creation Research Society Books, Chino Valley, AZ.

Kluger, J., 2006. Global warming. *Time* 167(14):28–62.

Lammerts, W.E. 1983. Are the bristlecone pine trees really so old? *CRSQ* 20:108–115.

Lillehammer, A. 1994. *Fra jeger til bonde–inntil 800 e.Kr.* Volume 1 of *Aschehougs norges historie* (in Norwegian). Aschehoug & Co. (W. Nygaard), Oslo, Norway.

Linderholm, H.W. 2001. Climatic influence on scots pine growth on dry and wet soils in the central Scandinavian mountains, interpreted from tree-ring widths. *Silva Fennica* 35:415–424.

Lomborg, B., 2007. *Cool It: The Skeptical Environmentalist's Guide to Global Warming*. Alfred A. Knopf, New York, NY.

MacDonald, G.M., A.A. Velichko, C.V. Kremenetski, O.K. Borisova, A.A. Goleva, A.A. Andreev, L.C. Cwynar, R.T. Riding, S.L. Forman, T.W.D. Edwards, R. Aravena, D. Hammarlund, J.M. Szeicz, andValery N. Gattaulin. 2000. Holocene treeline history and climate change across Northern Eurasia. *Quaternary Research* 53:302–311.

Mann, M.E. 2002. Little Ice Age. In MacCracken, M.C., and J.S. Perry (editors), *The Earth System: Physical and Chemical Dimensions of Global Environmental Change*, pp.505–509. Volume I in Munn, T. (editor-in-chief). *Encyclopedia of Global Environmental Change*. John Wiley & Sons, Ltd., Chichester, UK.

Mann, M.E., R.S. Bradley, and M.K. Hughes. 1998. Global-scale temperature patterns and climate forcing over the past six centuries. *Nature* 392:779–787.

Mann, M.E., R.S. Bradley, and M.K. Hughes. 1999. Northern Hemisphere temperatures during the past millennium: inferences, uncertainties, and limitations. *Geophysical Research Letters* 26:759.

Mann, M.E., R.S. Bradley, and M.K. Hughes. 2004. Corrigendum: global-scale temperature patterns and climate forcing over the past six centuries. *Nature* 430:105.

Mann, M.E., and P.D. Jones. 2003. Global surface temperatures over the past two millennia. *Geophysical Research Letters* 30(15):CLM 5–1 – CLM 5–4.

Matthews, M. 2006. Evidence for multiple ring growth per year in bristlecone pines. *Journal of Creation* 20(3):95–103.

McIntyre, S., and R. McKitrick, 2005. Reply to comment by Huybers on "Hockey sticks, principal components, and spurious significance." *Geophysical Research Letters* 32:L20713.

McKitrick, R. 2005. The Mann *et al.* Northern Hemisphere "hockey stick2 climate index: a tale of due diligence." In Michaels, P.J. (editor), *Shattered Consensus*, pp. 20–49. Rowman & Litlefield Publishers, Lanham, MD.

Menounos, B., J.J. Clague, R. Gilbert, and O. Slaymaker. 2005. Environmental reconstruction from a varve network in the southern Coast Mountains, British Columbia, Canada. *The Holocene* 15:1163–1171.

Michaels, P.J. 2005. False impressions: misleading statements, glaring omissions, and erroneous conclusions in the I.P.C.C.'s *Summary for Policymakers*. In Michaels, P.J. (editor), *Shattered Consensus*, pp. 1–19. Rowman & Littlefield Publishers, Lanham, MD.

Morris, H.M. 1989. *The Long War against God*. Baker Book House, Grand Rapids, MI.

Mortenson, T. 2004. *The Great Turning*

Point: The Church's Catastrophic Mistake on Geology -- Before Darwin. Master Books, Green Forest, AR.

NORPAST. 2001. Third report, NORPAST–past climates of the Norwegian region. Norges Geologiske Undersøkelse (the geological survey of Norway, with the Norwegian research council, environment and development, research program on climate and ozone layer change, the national meteorological institute, and the universities in Bergen, Tromsø, and Ås).

Oard, M.J. 1992a. Varves–the first "absolute" chronology: part I–historical development and the question of annual deposition. *CRSQ* 29:72–80.

Oard, M.J. 1992b. Varves–the first "absolute" chronology: part II–varve correlation and the post-glacial time scale. *CRSQ* 29:120–125.

Oard, M.J. 1997a. *The Weather Book*. Master Books, Green Forest, AR.

Oard, M.J. 1997b. *Ancient Ice Ages or Gigantic Submarine Landslides?* Monograph 6. Creation Research Society Books, Chino Valley, AZ.

Oard, M.J. 2005. *The Frozen Record: Examining the Ice Core History of the Greenland and Antarctic Ice Sheets*. Institute for Creation Research, Dallas, TX.

Oard, M.J. 2009. Do varves contradict biblical history? In Oard, M.J., and J.K Reed (editors), *Rock Solid Answers: The Biblical Truth Behind 14 Geological Questions*, pp. 125–148. Master Books, Green Forest, AR, and Creation Research Society Books, Chino Valley, AZ.

Ogilvie, A.E.J., and T. Jónsson. 2001. "Little Ice Age" research: a perspective from Iceland. In Ogilvie, A.E.J., and T. Jónsson (editors), *The Iceberg in the Mist: Northern Research in Pursuit of a "Little Ice Age,"* pp. 9–52. Kluwer Academic Publishers, Boston, MA.

Paulsen, J., U.M. Weber, and C. Körner. 2000. Tree growth near treeline: abrupt or gradual reduction with altitude? *Arctic, Antarctic, and Alpine Research* 32:14–20.

Posmentier, E.S. and W. Soon. 2005. Limitations of computer predictions of the effects of carbon dioxide on global temperature. In Michaels, P.J. (editor). *Shattered Consensus*, pp. 241–281. Rowman & Littlefield Publishers, Lanham, MD.

Reed, J.K. 2001. *Natural History in the Christian Worldview*. Creation Research Society Books (Monograph 11), Chino Valley, AZ.

Reed, J.K. 2005. *Crucial Questions about Creation*. Mabbul Publishing, Evans, GA.

Reed, J.K., and P. Klevberg. "Geotheory": past and present. *CRSQ* (in press)

Reed, J.K., P. Klevberg, C. Bennett, J. Akridge, C.R. Froede, Jr., and T. Lott. 2004. Beyond scientific creationism. *CRSQ* 41:216–230.

Reed, J.K., P. Klevberg, and C.R. Froede, Jr. 2006. Toward a diluvial stratigraphy. In Reed, J.K., and M.J. Oard (editors), *The Geologic Column: Perspectives Within Diluvial Geology*, pp. 31–48. Creation Research Society Books, Chino Valley, AZ.

Rian, Ø. 1994. *Den nye begynnelsen 1520–1660*. (Volume 5 of *Aschehougs norges historie*) [in Norwegian]. Aschehoug & Co. (W. Nygaard), Oslo, Norway.

Rose, J., C.A. Whiteman, J. Lee, N.P. Branch, D.D. Harkness, and J. Walden. 1997. Mid- and late-Holocene vegetation, surface weathering and glaciation, Fjallsjökull, southeast Iceland. *The Holocene* 7:457–471.

Rutherford, S., M.E. Mann, T.J. Osborn, R.S. Bradley, K.R. Briffa, M.K. Hughes, and P.D. Jones. 2005. Proxy-based Northern Hemisphere surface temperature reconstructions: sensitivity to method, predictor network, target season, and target domain. *Journal of Climate* 18:2308–2329.

Schmutz, J., J. Luterbacher, D. Gyalistras, E. Xoplaki, and H. Wanner. 2000. Can we trust proxy-based NAO index reconstructions? *Geophysical Research Letters* 27:1135–1138.

Smittenberg, R.H., E.C. Hopmans, S. Schouten, J.M. Hayes, T.I. Eglinton, and J.S. Sinninghe Damsté. 2004. Compound-specific radiocarbon dating of the varved Holocene sedimentary record of Saanich Inlet, Canada. *Paleoceanography* 19:PA2012.

Stötter, J., M. Wastl, C. Caseldine, and T. Häberle. 1999. Holocene paleoclimatic reconstruction in northern Iceland: approaches and results. *Quaternary Science Reviews* 18:457–474.

Tyvand, P. 2009. *Darwin 200 år, en festbrems* [in Norwegian]. Origo, Copenhagen, Denmark.

Vasey, D.E. 2001. A quantitative assessment of buffers among temperature variations, livestock, and the human population of Iceland, 1784 to 1900. In Ogilvie, A.E.J., and T. Jónsson (editors), *The Iceberg in the Mist: Northern Research in Pursuit of a "Little Ice Age,"* pp. 243–263. Kluwer Academic Publishers, Boston, MA.

Whitelaw, R.L. 1970. Time, life, and history in the light of 15,000 radiocarbon dates. *CRSQ* 7:56–71,83.

Whitelaw, R.L. 1993. Radiocarbon dating after forty years: do creationists see it as supporting the biblical creation and flood? A review and critique of pertinent creationist writing, 1950–1990. *CRSQ* 29:170–183.

Woodmorappe, J. 2001. Much-inflated carbon-14 dates from subfossil trees: a new mechanism. *TJ* 15(3):43–44.

Woodmorappe, J. 2003a. Field studies in the ancient bristlecone pine forest. *TJ* 17(3)119–127.

Woodmorappe, J. 2003b. Large and systematic regional-scale errors in Middle Eastern carbon-14 dating. *TJ* 17(1):13–15.

Woodmorappe, J. 2004. Bristlecone pine growth rings. *TJ* 18(1):60–61.

Appendix A: Calibration of Transfer Functions

Two common methods of attempting to calibrate transfer functions for long-term proxy data are radiocarbon dating and dendrochronology. Both of these methods have received attention from creationist researchers for quite some time. Changes of frequency of natural events or cycles are often spoken of in the literature and may simply reflect the stretched-out uniformitarian chronology (Eiríksson et al., 2000; Rose et al., 1997; NORPAST, 2001, Appendix 1).

Carbon 14

That radiocarbon dating is beset by problems is well known to creationists, though some find it overwhelmingly convincing (Aardsma, 1991). Many creationists have long found it somewhat useful, especially if corrected for atmospheric disequilibrium (Whitelaw, 1970). Some of the factors affecting the ratios of ^{14}C to ^{12}C include:

- Atmospheric disequilibrium (production exceeds decay)
- Carbon reservoir effects (exchange with "old" carbon)
- Fluctuations in strength of the earth's magnetic field
- Sunspots or other fluctuations in incident solar radiation
- Introduction of errors by "calibrating" ^{14}C to errant dendrochronological or tephrochronological markers (i.e., errors in one of these methods are then imported into the ^{14}C chronology)
- Potentially very significant changes between the antediluvian and postdiluvian ^{14}C:^{12}C ratio.

Dendrochronology

Dendrochronology may be pursued based on ring width or ring wood density. Calibration curves must be developed for the local growth conditions (Guiot et al., 2005), since as trees age, rings become narrower (for constant wood volume). Rings matched between different trees believed to have overlapping lifetimes must also be corrected for individual growing conditions since, for example, a given tree may have slowed in growth due to shading by other trees even as growing conditions improved. An individual tree may have suffered from attack by insects or disease while another individual may have remained unaffected. Removal of an overtowering tree may have released light for a shorter tree, with resulting accelerated growth.

Some of the factors affecting long-time reconstructions using tree rings include:

- Subjective elements in matching tree rings from specimen to specimen
- Microclimatic differences in growth conditions for different specimens
- Individual differences in growth histories (e.g., loss of a shading tree resulting in increased growth rate)
- Possible multiple annual rings (e.g., *Pinus longæva*)
- Matching ring sets inferred to be noncontemporary due to use of errant ^{14}C "dates" (i.e., the ring sets between two specimens actually do overlap but are placed at different times due to reliance on ^{14}C dates that are incorrect)

When dendrochronology is used as a proxy for growing-season temperature, it is needful that the forest chosen is one that is temperature limited. This appears to be true in general of the high-elevation Scandinavian forests (Kalela-Brundin, 1999) and high-latitude Russian forests (MacDonald et al., 2000), where snow provides excess moisture each year (Linderholm, 2001) but not of the Bristlecone Pine (*Pinus longæva*; also *P. aristata* and *P. balfouricana*) stands, which appear to respond more to moisture and carbon dioxide than temperature (McIntyre and McKitrick, 2005; Woodmorappe, 2003a). The *Pinus longæva* chronology may well be a significant factor in development of the controversial Mann et al. (1998) "hockey-stick" model (see also, Mann, 2002; Mann et al., 1998; 1999; 2004; McKitrick, 2005; and McIntyre and McKitrick, 2005), demonstrating the care that needs to be exercised in applying dendrochronology to paleoclimatology.

Selected ^{14}C and Dendrochronology Bibliography

General problems with ^{14}C: Lillehammer (1994, p. 25); Whitelaw (1993).

Atmospheric disequilibrium in ^{14}C: Brown (1990; 2006); Cook (1970).

Carbon reservoir effects: Bakke et al. (2005, p. 530); Fischer and Heinemeier (2003); Woodmorappe, 2003b.

Hard water effects: Heier-Nielsen et al. (1995); Smittenberg et al. (2004).

Terrestrial magnetic field effects: Grove (1988, p. 367).

Solar irradiance or other radiative effects: Grove (1988, pp. 366–367); Baliunas (2005).

Problems dating soils: Grove (2001, p. 55); Klevberg et al. (2009, pp. 88–89).

Necessity of correcting ^{14}C dates for moraines, etc.: Bakke et al. (2005); Rose et al. (1997).

Out-of-order ^{14}C "dates": Bakke et al. (2005, p. 525); Gobet et al. (2005, p. 674).

Multiple rings in bristlecone pine: Aardsma (1993); Lammerts (1983); Matthews (2006); Woodmorappe (2004).

The "segment length curse" and calibration curves in ring matching: Juckes et al. (2007).

Ring-matching problems in bristlecone pine and other species: Woodmorappe (2003b); Klevberg, unpublished data.

CO_2 fertilization of bristlecone pine: Juckes et al. (2007); McIntyre and McKitrick (2005).

^{14}C dating of trees: Woodmorappe (2001).

Calibrating radiocarbon using dendrochronology: Brown (1995).

Other calibration methods in common use are "varves" (assumed annual silt-clay couplets in proglacial lakes) and ice cores (Gobet et al., 2005, p. 673; Ice Core Working Group, 1998; Smittenberg et al., 2004). Significant calibration problems have arisen in efforts to apply "varves" to dating sediments (Menounos et al., 2005), and radiocarbon has proven superior. This is not surprising, as these methods are fraught with uniformitarian tautologies, as has been shown (Oard 1992a; 1992b; 1997b; 2009).

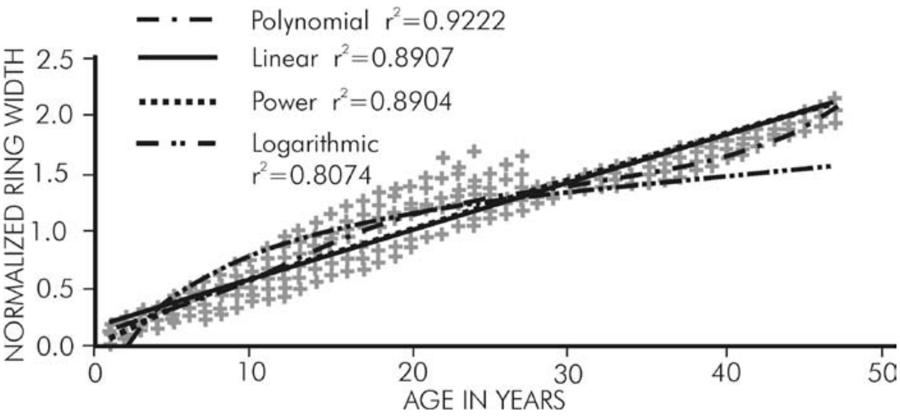

Figure 7. Example of four curves fit to set of actual tree ring data (from Klevberg, unpublished data). The higher the r^2 value, the better the fit.

Appendix B: Introduction to Principal Component Analysis

Anyone who has worked with curve-fitting routines knows some of the limitations of these methods. Many natural decay processes are readily solved with exponential functions because they are related through first-order linear differential equations. "Noisy" data sets are not so tractable, and the common solution is to use a "brute force" approach with polynomial functions and let the computer "crunch" through the numbers using infinite series with a test criterion to determine what fit is "good enough." A rather neat grouping of data is shown in Figure 7 along with four types of curves: linear, polynomial, power, and exponential. The r^2 value provides an indication of how well a given curve fits these data. This is an entirely "instrumentalist" approach to the data–the resulting curve does not necessarily represent a "true" relationship between a given proxy data set and the temperature or other variable one is attempting to infer from those data.

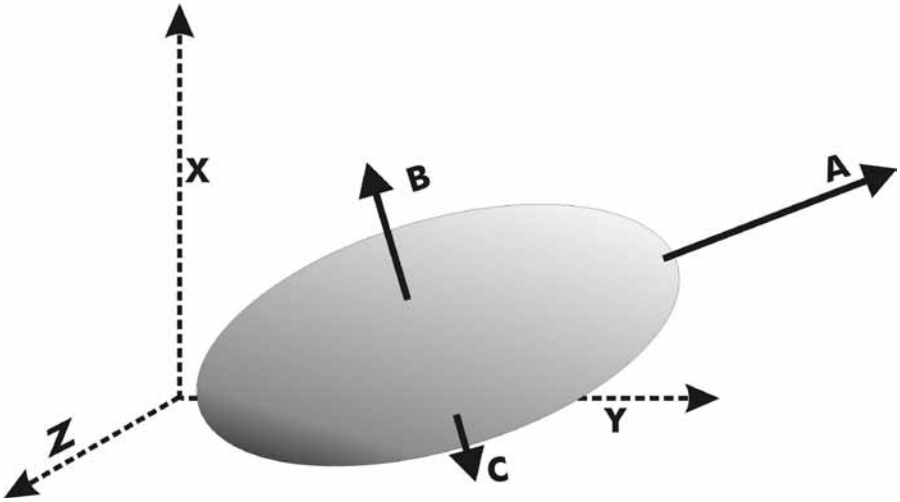

Figure 8. Simple illustration of application of eigenvector analysis: orientation of clasts (individual rocks) in Cartesian coordinates (x,y,z) can be described by three vectors aligned with the A-, B-, and C-axes (longest to shortest dimensions, respectively, of the clast). Eigenvector analysis provides a computational method to find which possible combination of orthogonal vectors produces the maximum and minimum axes (and thus mutually perpendicular third axis) of the rock. This same method can be used for many other types of data.

Since there are many proxies to draw from and many variables that affect climate, no one transfer function will fit them all. There may be as many transfer functions as data sets. To obtain the fewest equations with the most explanatory power, there must be some means of determining how huge sets of often disparate data may be reduced to the smallest number of most "efficient" equations. This is a common objective in linear algebra and is reached through eigenvector analysis, which is explained

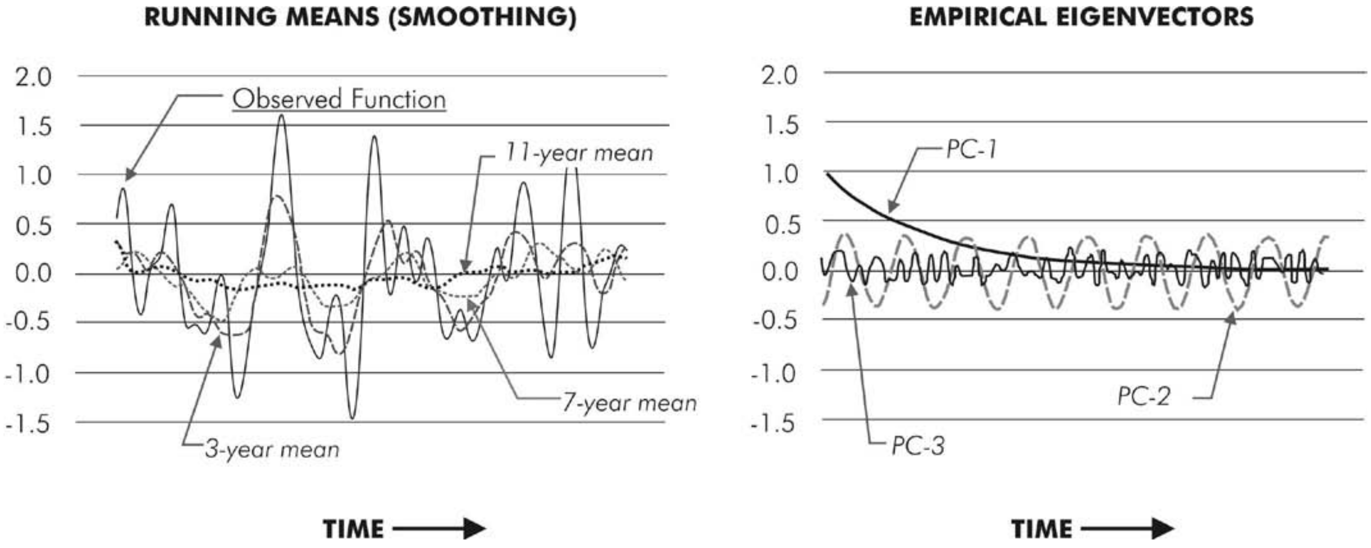

Figure 9. Deriving principal components (empirical eigenvectors) from smoothed data. Principal components and the "observed function" are hypothetical for illustrative purposes only. This made it artificially easy: the "observed function" was assembled from a linear combination of PC1, PC2, and PC3—a perfect fit! In actual practice, deriving the principal components may be much more difficult and much less successful.

theoretically in many linear algebra and other mathematical texts and in application in some scientific papers (e.g. Fisher, 2002). A very simplified example is provided in Figure 8.

Figure 9 shows a hypothetical function and the curves that result from smoothing. A perfect eigenvector analysis would produce principal components PC-1 through PC-3. In reality, the function on the left results from the combination of the three arbitrarily chosen functions (hence the perfect fit). Real data sets, especially climate data, are thick with noise terms that make the process more difficult.